A Booklet for External Review

Center for Nuclear Study
Graduate School of Science, the University of Tokyo

March, 2013

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Contents

Chapter 1

Purpose of External Review

The Center for Nuclear Study (CNS) is in the 15th year since its foundation in April 1997 as a research institute within the Graduate School of Science, the University of Tokyo. It has two primary purposes; to pursue advanced studies in nuclear physics and to provide students of the University of Tokyo with high-quality education on nuclear physics and related science/technology.

After the previous (also first) external review held in February 2005, there has been a major change in the administrative basis of the CNS. When the CNS was established in 1997, it was given a term of 10 years. The first term was to be completed in March 2007, and the main issue of the first external review was whether the renewal of the term should be recommended to the Graduate School of Science or not. The renewal was to be determined formally by the Dean of the Graduate School.

The university system has been changed drastically in the meantime. The rule of 10-year term has disappeared. The new idea of the mid-term plan has been introduced to every part of all universities in Japan. This mid-term consists of 6 years. The first mid-term was from April 2004 till March 2010.

The report of the first external review has been received by the Graduate School early 2005 with much appreciation. The present external review is the second one, and is supposed to cover the 8 years (2005-12) of CNS activities and outcome since the first review. This review is a part of the review of the Graduate School of Science as a whole taking place in 2012-13.

The present review committee is expected to evaluate following items.

1. Scientific activities of primary research groups.
    - Soundness and creativity of research subjects
    - Balance between investments and output
2. Administration.
    - Overall healthiness of CNS
    - Efficiencies in management and operation
    - Allocation of human resources and budgets
3. Education.
    - Supervision to graduate students belonging to CNS
    - Contributions to undergraduate education

4. Future plans.
    - Individual research group including competitiveness and feasibility
    - Possible future plans for CNS from world-wide perspectives

It is noted that the report of this review should be directed to the Dean of Graduate School of Science.

Chapter 2

History and developments of CNS

The CNS was established at the Tanashi campus of the University of Tokyo (UT) in 1997 as a research center within the Graduate School of Science, as stated in the previous section. The primary purposes of the foundation were to maintain and enhance research and educational activities on nuclear science at the University of Tokyo, after the Institute for Nuclear Study (INS), which was one of the members of the University of Tokyo, was terminated according to the restructuring policy of the government to reorganize INS and National Laboratory of High Energy Physics (KEK).

The development of CNS is listed very briefly in this section. Some additional descriptions are provided for several selected topics.

2.1 Major Development of CNS up to 2004

1997.4 CNS was established at the Tanashi campus.
Prof. Masayasu Ishihara of the Department of Physics was appointed to the first Director.

1998.4 "Agreement on Research in the Field of Heavy Ion Science" with a five-year term was concluded between CNS and RIKEN.

1999.12 "Agreement on Joint Research" was concluded between the University of Tokyo and RIKEN.

2000.3 CNS Wako-branch was established on RIKEN Wako campus, and the major part of the CNS members moved there according to the campus plan of the University of Tokyo. Dismantling work of the SF cyclotron facility at the Tanashi campus, which was one of the leftovers from INS, was carried out. It took us the next year to clean up the Tanashi campus, including radioactivities.

2000.4 Prof. Hideyuki Sakai of the Department of Physics succeeded Prof. Masayasu Ishihara as the second Director.

2001.4 Major equipments of CNS such, PA, ECR, and CRIB, have been successfully transported from the Tanashi campus and have been installed in the RIKEN cyclotron facility.

2001.8 The CNS Research and Development Building (Jikken Jyunbi Tou) was constructed on the RIKEN Wako Campus. It has three floors, and the total area is 1200 m^2. The building belongs to the University of Tokyo, while the land fee is paid to RIKEN annually.

2002.4 Theory research group was created.

2003.4 "Agreement on Research in the Field of Heavy Ion Science" between CNS and RIKEN was renewed for another five-year term.

2004.3 "Agreement on the Joint Research of Nuclear Spin Structure" was concluded between the Graduate School of Science, University of Tokyo and the Joint Institute for Nuclear Research, Dubna, Russia.

2.2 Major CNS facilities in Wako at 2004

We list major facilities of CNS present in 2004.

- CRIB
  A low-energy secondary beam analyzer system, called CRIB[1], was built by utilizing some components of the DUMAS spectrometer at the Research Center of Nuclear Physics, Osaka University. It is operated with the beams provided by RIKEN AVF cyclotron.

- GRAPE
  A position-sensitive segmented Ge array system, called GRAPE[2] was designed and built, so that high-energy resolution in gamma-ray measurements can be obtained with Doppler-shift correction.

- ECR
  Several improvements of AVF cyclotron performance have been made. The HyperECR ion source was added to the AVF cyclotron, and a beam acceleration scheme with flat-top dee voltage was established at this cyclotron to improve beam emittance, energy resolution and intensity.

2.3 Major improvements of CNS activities

We present major efforts of CNS for improving its research capability fulfilled between 2005 and 2012. We show administrative and operational aspects here. Scientific accounts will be presented in Chap. 5.

- SHARAQ
  The SHARAQ spectrometer has been constructed jointly by the group of Prof. Sakai in Department of Physics, the CNS and RIKEN. While it was financed largely by a grant money of Prof. Sakai, the collaboration was intended from the beginning. The SHARAQ is a high-resolution magnetic spectrometer installed in RIBF (Radioactive-Ion Beam Facility) of RIKEN, which enables us to carry out high-resolution missing-mass spectroscopy with RI beams. The SHARAQ spectrometer has become one of the major experimental equipments of RIBF, and is open to wider collaborative use.

- GRAPE upgrade
  Since the construction of the first stage of GRAPE, its operation was somewhat complicated. We eliminated this problem by shifting from analog to digital processing. This

[1] The CNS Radioactive Ion Beam separator
[2] The Gamma-Ray detector Array with Position and Energy sensitivity

work is very close to the end, and the GRAPE has become open for wider collaborative use as well.

- CRIB
  The CRIB facility has been used for many facets of physics and science. Proposals of experiments were evaluated by the CNS advisory committee until 2006, while all experiments should have been carried out in the form of some collaboration with CNS. Since February 2007, the evaluation of experiment proposals of CRIB has been assigned to the program advisory committee (NP-PAC) jointly administered by CNS and RIKEN (see Sec. 2.5).

  Prof. Kubono was responsible for CRIB operation, but has retired in March 2012. Due to the lack of human power needed for its operation, even the shutdown of CRIB was considered. The CNS organized a special meeting, in June 2011, to clarify problems of CRIB operation, assess the outcome of CRIB and discuss future options of CRIB. Based on the recommendation of the CNS advisory committee, the CNS decided to continue the CRIB operation and appointed Dr. Yamaguchi to a lecturer position asking him to keep CRIB activities. While this has been done successfully, the shrink of the group size resulted in a downgrade of CRIB activities. We first suspended any new proposal from outside, but later started to accept direct collaborations with Dr. Yamaguchi.

- Polarized target
  The polarized target has been developed as stated in Sec. 5.5. This project had been conducted by Prof. Uesaka. After he has moved to RIKEN, the project is fading out in CNS.

- Active target
  The active target has been developed as stated in Sec. 5.7. This project has been initiated by younger members across different subfields in CNS.

- RHIC/LHC
  There have been considerable contributions in RHIC and LHC due to CNS efforts. They are shown in Sec. 5.8.

- Theory
  There have been considerable new developments in theoretical nuclear structure physics. They are shown in Sec. 5.10.

2.4 Collaboration with RIKEN

The CNS-RIKEN Collaboration Supervisors Meeting (Tantousha Kaigi) is held on a monthly basis. All problems/issues are discussed, and some ideas are exchanged.

In addition to this general meeting, some meetings were held for specific topics: The SHARAQ establishment meeting was held until 2008, and the international program meeting was held until March 2011. Recently, Mass Ring establishment (which is a RIKEN project) meeting is held because the beam line to Mass Ring goes through SHARAQ.

There are several agreements and memoranda between CNS (or the University of Tokyo) and RIKEN, as listed below. These were discussed in the meetings mentioned above.

Heavy-Ion agreement between CNS and RIKEN

The CNS and RIKEN concluded the "Agreement on Research in the Field of Heavy Ion Science" in 1998 with a term of 5 years in order to develop cooperation in research. This agreement has been renewed twice and both parties agreed to renew it for the next period starting in April 2013. The intent of this agreement is for CNS and RIKEN to leverage their respective specialties and promote the development of key facilities and accelerators, leading to a further expansion of the field of heavy ion physics.

Comprehensive agreement between the University of Tokyo and RIKEN

In 2004, the University of Tokyo and RIKEN concluded the "Basic Agreement on Promotion of Collaboration and Cooperation". This is a comprehensive agreement between the University of Tokyo and RIKEN. Although it was made after the agreement stated above, it has become the most underlying scheme for any agreement and memorandum between the two.

Memoranda for SHARAQ and GRAPE

The Graduate School of Science, the University of Tokyo and RIKEN Nishina Center concluded Memorandum on "Collaboration on High-resolution RI-beam analyzer SHARAQ" in 2006 and it was revised in 2010 with a term till March 2013. A similar memorandum on "Collaboration on high-resolution gamma-ray analyzer GRAPE" was concluded in 2012 with a term till March 2013. Both parties agreed to renew the terms of these two memoranda for the next 5 years starting in April 2013.

2.5 NP-PAC

One of the most important administrative changes during 2005-2012 is the creation of the joint program advisory committee. Based on the understanding for more collaborations by Nishina Center Director Y. Yano and CNS Director T. Otsuka, as of February 2007, the CNS and RIKEN Nishina Center has started the joint program advisory committee for nuclear physics, abbreviated as NP-PAC. This committee is comprised of 15-20 international members with a chair from abroad so far. The NP-PAC has been held twice a year since then, except that the one planned for December 2012 was canceled due to the low accelerator performance due to budget problem in RIKEN in the second half of 2012.

The evaluation of proposals for CRIB experiments have been moved from CNS advisory committee to this NP-PAC since then, meaning that CRIB proposals are assessed on the same scientific judgement as all other RIBF proposals. SHARAQ, which was completed in 2009, and GRAPE, for which increased functionality is near completion, have been positioned as apparatuses of RIBF and the proposals are reviewed by the NP-PAC too.

Normal proposal to CRIB experiment is suspended presently as stated above. Currently CNS accepts proposals using CRIB in the form of direct collaboration with CNS, and NP-PAC gives advises on the proposed experiments rather than approval on them.

2.6 International activities

Although CNS members are pursuing a wide variety of international collaborations, we describe some activities conducted by the CNS as a whole.

CNS summer school

The CNS summer school has been organized every summer since 2002, as Otsuka and

Sakai have initiated its organization. The number of participants have been nearly 100, and the duration has been five lecture days excluding weekend break.

The summer school has received regular financial support from the Graduate School of Science as a project for international exchange. More details of the CNS summer school are summarized in Appendix. C.

Todai-RIKEN Joint International Program for Nuclear Physics
The Todai-RIKEN Joint International program for Nuclear physics (TORIJIN) was established in 2006 in order to internationally develop nuclear physics at RIBF jointly with RIKEN, based on a comprehensive agreement between the University of Tokyo (Todai) and RIKEN (see above).

One of the principal activities of the program is support for the Japan-US Theory Institute for Physics with Exotic Nuclei (JUSTIPEN), which is a DoE project for the dispatch of researchers in nuclear physics from US to Japan. The support includes lodging, office, seminars, travel arrangements, etc. TORIJIN organized several workshops jointly with JUSTIPEN.

EFES project
CNS has gained, for international cooperation activities, a grant called the International Research Network for Exotic Femto Systems (EFES[3]), one of the Core-to-Core Programs of the Japan Society for the Promotion of Science (JSPS). EFES sent graduate students and young researchers abroad for attending schools and meetings or participating collaborations, organized joint workshops with US (JUSTIPEN), France (LIA), Germany (EMMI), Finland and Italy. It supported some collaborations with France, Norway and US. Another function of EFES project was support to the CNS-EFES summer school.

After EFES project is complete in March 2011, the number of graduate students attending summer schools abroad was maintained, and partial financial assistance was continued by the CNS effort. CNS hopes to continue these independently in the future and is currently searching for an appropriate source of external funding.

2.7 Theory project with K super computer

High Performance Computing Infrastructure (HPCI) project has been started by MEXT, in order to maximize the usage of the K super computer. One of the major fields of HPCI project is particle, nuclear and astrophysics, and the CNS accepted a project on nuclear physics headed by Otsuka. This project lasts from 2011 till 2015 with the employment of five researchers at maximum.

2.8 Fukushima radioactivity

CNS played a major initiative to measure the radioactive contamination of the environment by the Fukushima Daiichi Nuclear Power Plant damaged in the Great East Japan Earthquake. See details in Sec. 3.7.2.

[3]118,360 kyen in total, 2006–2010. See Sec. 3.4 for allotment for each fiscal year.

2.9 A short chronology: 2005 ∼ 2012

2005.4 “Fundamental agreement on promotion of cooperation and coordination between the university of Tokyo and the RIKEN” was signed off.

2005.6 Prof. Takaharu Otsuka of the Department of Physics succeeded Prof. Hideyuki Sakai as Director, and has been running the CNS since then.

2005.8 The 4th CNS Summer School

2005.11 International Symposium on “Origin of Matter and Evolution of the Galaxies (OMEG05)” (co-hosted by CNS, RIKEN, Dept of Astronomy, UT, and NAOJ)

2005.11 RIBF Technical Advisory Committee (RIBF-TAC)

2005.11 Workshop on technical aspects of SHARAQ spectrometer (CNS, Dept of Physics UT, RIKEN)

2005.11 11th International Workshop on Polarized Sources and Targets (PST05) (CNS, RIKEN)

2005.12 6th CNS-PAC

2005.12 RIKEN-CNS RIBF International Workshop on “Correlation and Condensation: New Features in Loosely Bound and Unbound Nuclear State”

2006.2 Workshop on “Physics of Quark-Gluon Plasma at RHIC” (CNS, RIKEN)

2006.3 International Workshop on “Nuclear Physics with RIBF” (CNS, RIKEN)

2006.4 RIKEN Nishina Accelerator Research Center was created.

2006.4 EFES started.

2006.6 TORIJIN started.

2006.7 JUSTIPEN started.

2006.8 5th CNS Summer School

2006.10 2nd German-Japanese Workshop on Nuclear Structure and Astrophysics (CNS, RIKEN)

2006.12 “Collaboration on High-resolution RI-beam analyzer SHARAQ” was signed off.

2006.12 1st beam at RIBF

2007.2 1st NP-PAC

2007.5-6 International Workshop on “Direct Reaction with Exotic Beams” (CNS, RIKEN, Kyushu-U)

2007.6 6th Liaison Council

2007.8 6th CNS Summer School

2007.9 2nd NP-PAC

2007.12 OMEG07 (Hokkaido, CNS, RIKEN, NAOJ, RCNP, KEK, Astro UT, Science Council of Japan, JPS)

2008.2 3rd NP-PAC

2008.3 renewal of "Agreement on Research in the Field of Heavy Ion Science"

2008.4 Core-to-core program of "EFES" was expanded as a Strategic Research Networks

2008.4 CNS-RIKEN Join Symposium on "Frontier of gamma-ray spectroscopy and Perspectives for Nuclear Structure Studies (gamma08)" (CNS, RIKEN)

2008.8 7th CNS-EFES International Summer School (CNS-EFES08)

2008.10 6th Liaison Council, Ceremony of the 10th anniversary of CNS-RIKEN collaboration.

2008.10 2nd Asian Triangle Heavy Ion Conference (ATHIC 2008) (CNS, RIKEN, Center for Computing Sciences, University of Tsukuba)

2008.11 4th NP-PAC

2009.3 renewal of the international exchanges agreement with JINR(Russia)

2009.3 Completion of SHARAQ, commissioning

2009.6 CNS advisory committee

2009.6 5th NP-PAC

2009.6 Commemoration of completion of SHARAQ

2009.8 8th CNS-EFES International Summer School (CNS-EFES09)

2009.11 first physics experiment at SHARAQ

2009.12 6th NP-PAC

2010.3 OMEG10 (CNS, RCNP, NAOJ, KEK, JAEA, Konan, RIKEN Nishina Center)

2010.5 renewal of Memorandum on "Collaboration on High-resolution RI-beam analyzer SHARAQ"

2010.6 7th NP-PAC

2010.8 9th CNS-EFES International Summer School (CNS-EFES10)

2010.9 7th Liaison Council

2010.12 8th NP-PAC

2010.12 International Symposium "Halo2010"

2011.1 French-Japanese Symposium on "Nuclear Structure Problems –organized in the framework of FJNSP LIA and EFES–"

2011.3 Great East Japan Earthquake

2011.3 Conclusion of EFES

2011.6 CRIB Review Meeting, CNS advisory committee

2011.6 9th NP-PAC

2011.9 10th CNS-EFES International Summer School (CNSSS11)

2011.11 OMEG11 (CNS, RIKEN Nishina Center, NAOJ, KEK, RCNP, Konan)

2011.12 8th Liaison Council

2011.12 10th NP-PAC

2012.5 Memorandum on “Collaboration on high-resolution gamma-ray analyzer GRAPE” was concluded.

2012.6 11th NP-PAC

2012.8 11th CNS-EFES International Summer School (CNSSS12)

2012.10 4th International Conference on “Collective Motion in Nuclei under Extreme Conditions” (COMEX4) (co-hosted by CNS, RCNP, sponsored by RIKEN Nishina Center)

Chapter 3

Organization and Operation

3.1 Members (As of February 28, 2013)

Director	Takaharu Otsuka
Professors	Susumu Shimoura, Hideki Hamagaki
Associate Professors	Kentaro Yako
Lecturers	Hidetoshi Yamaguchi
Associate Professors	Shinichiro Michimasa, Taku Gunji, Shinsuke Ota
Guest Professors	Hiroaki Utsunomiya
Guest Associate Professors	Yutaka Utsuno
Project Associate Professors	Shimizu Noritaka
Project Assistant Professors	Hisayuki Torii, Tooru Yoshida, Yoritaka Iwata
Technical Staff	Yukimitsu Ohshiro, Norio Yamazaki
Administrative Chief	Hiroshi Yoshimura
Technical Assistants	5
Administrative Assistants	5
Project Researchers	4
Research Assistants	2
Graduate Students	Master course; M1 2, M2 5
	Doctor course; D1 3, D2 3, D3 6

A complete list of current CNS members is provided in Appendix A. Abbreviated curriculum vitae of Academic staffs is listed in Appendix D.

3.2 Organization Management

The Director is responsible for managing the CNS. The Director is appointed by the Dean of the Graduate School of Science, with approval in a faculty-staff meeting of the Graduate School of Science. The term of the Director is two years, and reappointment is allowed.

CNS had two committees, the Council and the Steering Committee, with the CNS Council, chaired by the Dean of School of Science, being the supreme committee of CNS. In 2009, the Council and the Committee were integrated into the Steering Committee, which consisted of 10 or 11 members. The Steering Committee supervises CNS, and makes advises on the management and scientific policies to CNS. Appointment of professors and the budget policy are the two important functions of this committee. Appointment of associate professors and lecturers, and approval of research associates is among other important functions. The Committee is usually held once every year. The current members of the Steering Committee are listed in Table 3.1.

The staff members have CNS Management Meetings on a monthly basis to share the progress of each research group as well as to discuss various issues concerning the management of CNS. Also, Technical Coordination Meeting is held for the purpose of ensuring fairness and transparency on job assignments to the technical staffs.

Table 3.1: Members of CNS Steering Committee

AIHARA, Hiroaki	Department of Physics, Graduate School of Science, UT
HOSHINO, Masahiro	Department of Earth and Planetary Science, Graduate School of Science, UT
MIYASHITA, Seiji	Department of Physics, Graduate School of Science, UT
OTSUKA, Takaharu	Department of Physics, Graduate School of Science, UT
SHIMOURA, Susumu	Center for Nuclear Study, Graduate School of Science, UT
HAMAGAKI, Hideki	Center for Nuclear Study, Graduate School of Science, UT
GONOKAMI, Makoto	Department of Physics, Graduate School of Science, UT
SAKURAI, Hiroyoshi	Department of Physics, Graduate School of Science, UT
NAGAMIYA, Shoji	J-PARC Center, KEK and JAEA
SAKURAI, Hiroyoshi	Department of Physics, Graduate School of Science, UT
KOBAYASHI, Tomio	International Center of Elementary Particle physics, UT
TAKAHASHI, Hiroyuki	Department of Nuclear Engineering and Management, Graduate School of Engineering, UT

3.3 Employment of Scientific Members

3.3.1 Employment Procedures

Employment opportunity for vacant positions, not only faculty staffs but also postdoctoral associates, shall be widely advertised so that applications are invited from all of the relevant community. For staff position openings, advertisement is arranged to appear in a BUTSURI, a monthly Japanese magazine of the Physical Society of Japan, physics community, and is also distributed to the related community members through the mailing lists for nuclear physics community (ml-np), theoretical nuclear physics community (ntj-l) and experimental high-energy community (hecforum). Registration to the database of Japan Research Career Information Network (JREC-IN) is also usually made. For postdoctoral position openings, only these mailing lists were used. Depending upon the positions in question, definite and appropriate, but different selection procedures are employed.

3.3.2 Service Period of Scientific Staff Members

The service periods of the faculty and research associates since FY2005 are shown in Fig 3.1. Figure 3.2 shows the same information sorted out in accordance with the research group.

The Nuclear Astrophysics group was lead by Prof. Kubono, who also looked after the Accelerator / Ion source group, and taken over by Lecturer Yamaguchi after the retirement. The successor of Accelerator / Ion source group is Prof. Shimoura.

The NUSPEQ group, whose primary apparatus is GRAPE, was initiated by Prof. Shimoura. He and Associate Prof. Uesaka completed the SHARAQ spectrometer and recently Associate Prof. Yako became the contact person of SHARAQ.

Associate Prof. Uesaka lead the Spin group, introducing a system of the polarized proton target. The activity of polarized proton target at CNS is dissipating after he moved to RIKEN. Meanwhile Assistant Prof. Ota started the Active Target project.

The Quark Physics group is lead by Prof. Hamagaki. The Nuclear Theory group is lead by Prof. Otsuka, who is a Professor in the Department of Physics. TORIJIN had its Project Associate Professors during the period from 2007 to 2010 with a financial backup by EFES.

Figure 3.1: Service years of the CNS faculty and research associates since FY2005.

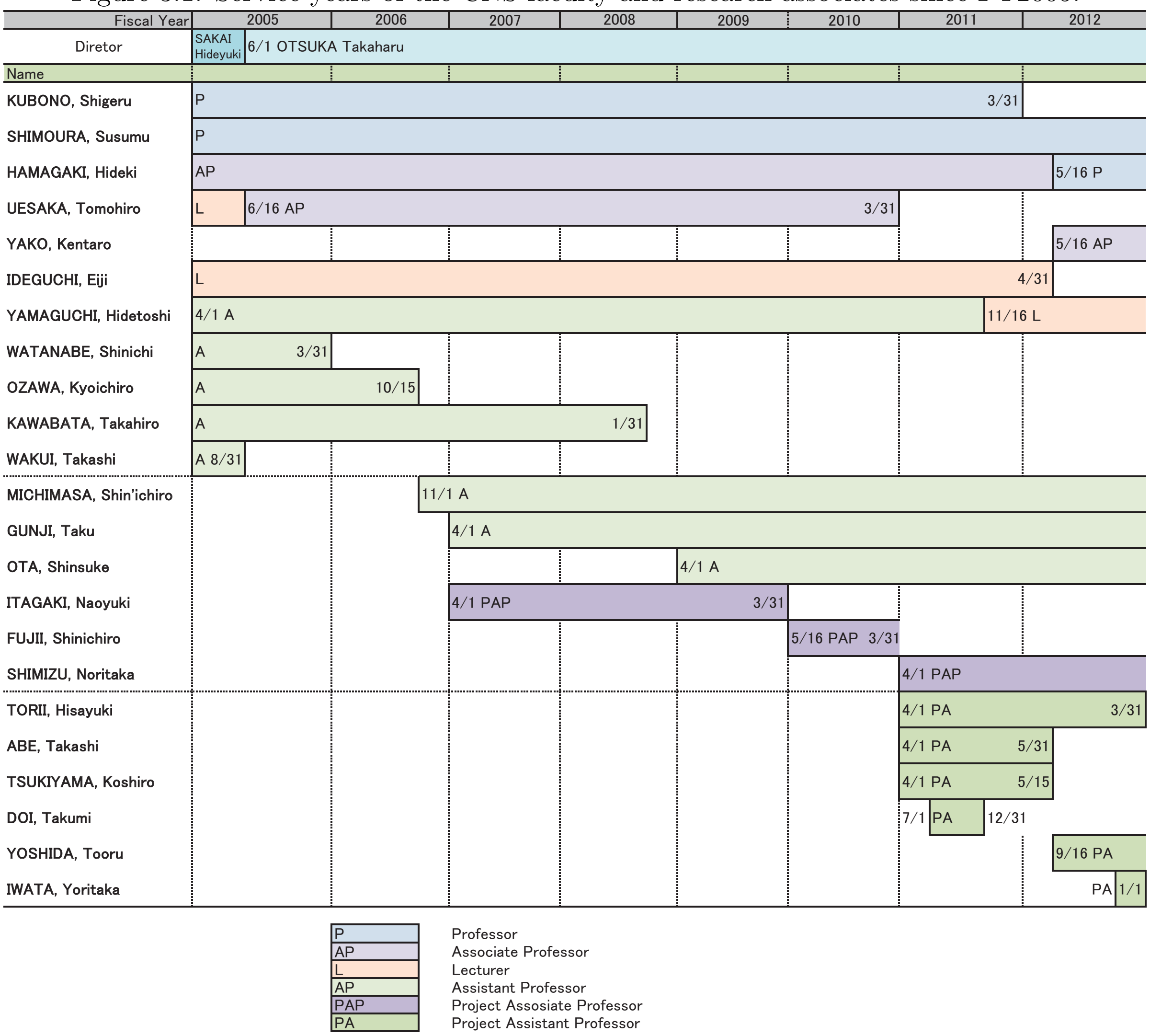
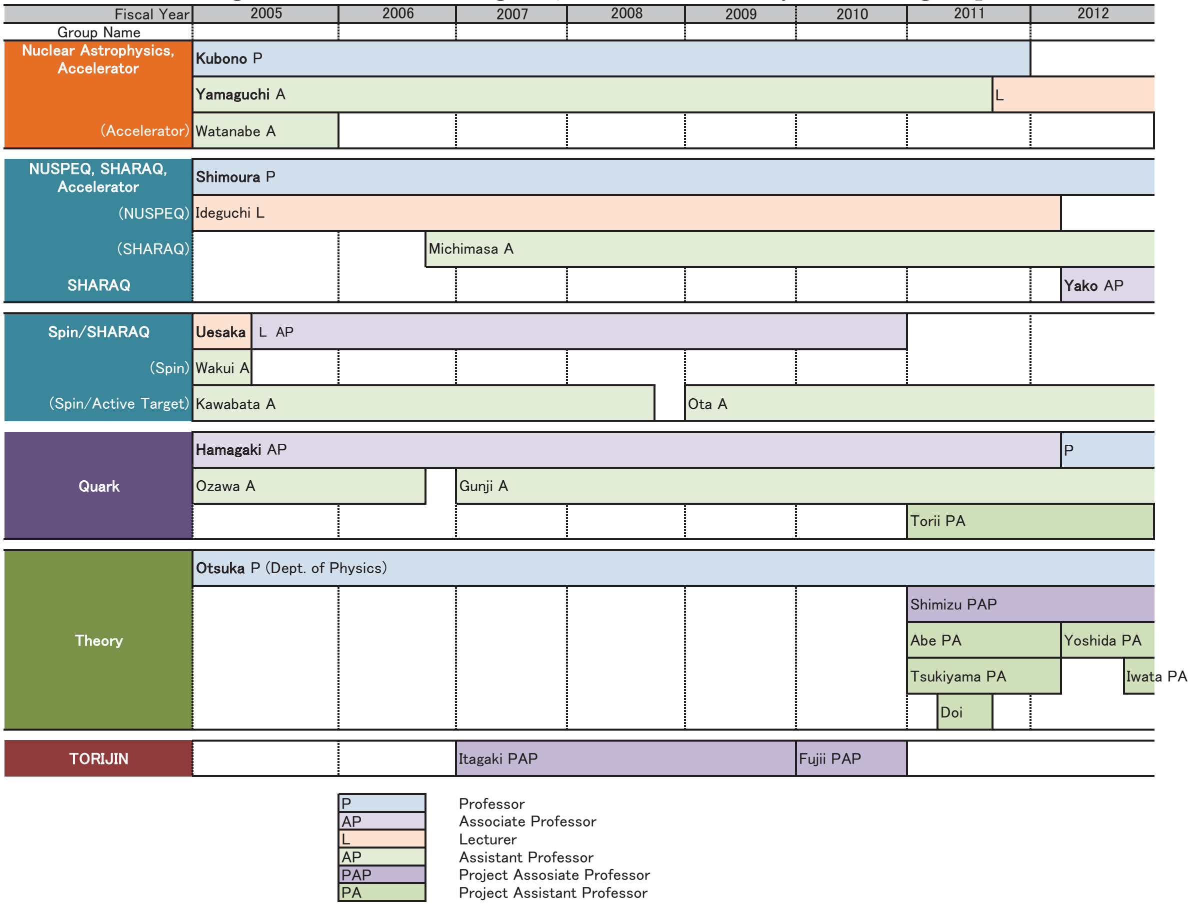


Figure 3.2: Same as Fig 3.1, but sorted out by research group.



3.4 Financial Situation

The major financial source of CNS is the management expenses grant (MEG), called Un-eihi Koufukin in Japanese. The MEG is spent to employ non-permanent members including post-docs and to maintain and develop scientific apparatuses. Table 3.4 shows its variation for the period of 2005–2012 fiscal years. The budget has remained fairly constant till 2008, and has begun to decrease as scheduled due to the expiration of several maintenance budgets. The budget of 2012 has been reduced due to special situation after the Great East Japan Earthquake in 2011. The portion of the employment cost over the MEG is about a quarter. The management and operation cost includes building operation and management expenses, utility costs, communications and transportation expenses, cleaning expenses, and other expenses of both offices in the Hongo and Wako campuses.

The major part of MEG goes to research activities. It is used for maintaining and improving some equipments like CRIB and those related to AVF cyclotron. The MEG is also used for development of new equipments like GRAPE and SHARAQ as well as challenges like Active Target. The chronological variation of MEG allocated to each research group is shown in Fig. 3.3. Dynamical changes of the financial allocations can be seen.

In addition to the MEG, the CNS has gained external fundings. The major grants are shown below.

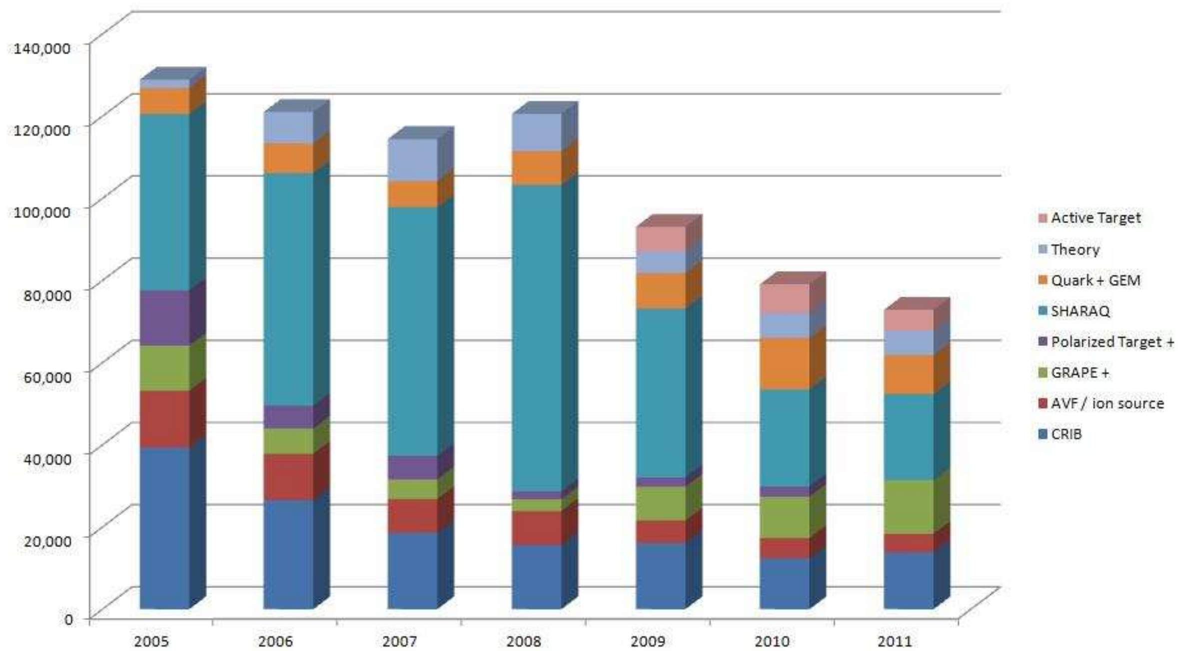


Figure 3.3: Chronological variation of MEG allocations to each group.

Table 3.2: The amount of management expenses grant (MEG) from 2005 to 2012. The budgets are shown in kyen (1000 yen).

Fiscal Year	2005	2006	2007	2008	2009	2010	2011	2012
ME Grants	198,332	201,451	192,821	191,461	187,766	168,206	159,355	155,548
Employment cost	28,971	35,658	37,294	42,227	41,653	39,690	38,924	36,689
ratio (%)	14.6	17.7	19.3	22.1	22.2	23.6	24.4	23.6
Maintenance & Operation cost	11,569	14,035	13,323	14,603	13,350	13,650	12,725	13,042
ratio (%)	5.8	7.0	6.9	7.6	7.1	8.1	8.0	8.4

- EFES: International Research Network of Exotic Femto System (JSPS Core-to-core Program)

Table 3.3: The amount of grants on EFES (in kyen).

Fiscal Year	2006	2007	2008	2009	2010
Grants	15,000	18,820	33,000	33,000	26,250

- Strategic Young Researcher Overseas Visits Program for Accelerating Brain Circulation (MEXT)

Table 3.4: The amount of grants on Strategic Young Researcher Overseas Visits Program for Accelerating Brain Circulation.

Fiscal Year	2010	2011	2012
Grants	17,800	23,737	22,003
Employment cost	0	4,533	4,598
ratio (%)	0.0	19.1	20.9

- HPCI: High Performance Computing Infrastructure Program (NEXT)

Table 3.5: The amount of grants on High Performance Computing Infrastructure Program (MEXT).

Fiscal Year	2011	2012
Grants	60,080	45,445
Employment cost	31,144	33,035
ratio (%)	51.8	72.7

- Strategic Funds for the Promotion of Science and Technology (MEXT)

Table 3.6: The amount of grants on Strategic Funds for the Promotion of Science and Technology.

Stage	#1	#2	#3
Period	2011.6–10	2011.11–2012.5	2012.7–2013.2
Grants	22,843	1,311	3,326
Employment cost	3,027	789	2,054
ratio (%)	13.3	60.2	61.8

Other grants are listed in Appendix B.

3.5 Administrative Support Members

There are a large amount of administrative work in CNS, as about 50 people belong to CNS and the annual budget is large. The administrative work of CNS is fulfilled by a chief administrator, three members in Wako and one in Hongo. Only the chief is a regular permanent employee of the university. The others are employed through contracts on yearly bases. Considering the large budget and the geological isolation, one permanently employed chief administrator is the minimum requirement for the stable and secure management of CNS. Currently, four other administrative members are of high skill and ample experiences. It is one of the highest priorities to keep them in CNS.

3.6 Technical Support Members

There are two technical staff members who were permanently employed but have retired recently. They are still working in CNS in the so-called re-employment program. This re-employment is for five years after the formal retirement.

One of them is playing the major indispensable role in the operation and development of the ion source for heavy-ion beam from AVF cyclotron. This beam is used not only for nuclear physics experiments but also for interdisciplinary activities including applications to industries. The other one has been taking essential parts of the CRIB and SHARAQ operations. The CRIB is used for nuclear physics experiments with astrophysical implications but also for other purposes including educational and industrial usages.

In addition to these core technicians, there are five technical support members who are employed on yearly basis.

3.7 Public Relations and Community Services

3.7.1 Public Relations

CNS Home Page

CNS home page (`http://www.cns.s.u-tokyo.ac.jp/index.html`), written in English and Japanese, has news in the front page where information on scientific activities and open jobs are posted. Several categorized pages include information on the CNS research activities, main facilities and instruments as well as the geological information of CNS.

Open house

The CNS has been having a one-day open house every year. After settling at RIKEN Wako campus, the CNS open house has been made on the same day with that of RIKEN.

Open campus

CNS has been participating in the open campus of School of Science, the University of Tokyo held every year since 2006. Two staffs give talks for the public (the audience is mostly high school students) and students of CNS display some of the experimental apparatus.

3.7.2 Fukushima survey

For the accidents at the Fukushima Daiichi Nuclear Power Plant in March 2011, the nuclear physics community in Japan performed various kinds of contributions relating to radiation measurements. Members of the CNS participated to the radiation screening of evacuated people in Fukushima just after the accidents. Because of importance of the survey of the distribution of radioactivities over the wide-area, scientists proposed measurements of the gamma-rays from soils in order to making radiation maps. Based on the discussions, the government started the radiation survey project[1] from June 2011.

Soil samples from the 5-cm surface layer were collected for about 2,200 locations in Fukushima and nearby prefectures within approximately 100 km from the Fukushima Daiichi Nuclear Power Plant (NPP) from June 6 to 14 and from June 27 to July 8, 2011. The sampling points were on 2×2 km^2 meshes for the 80-km region from the NPP and 10×10 km^2 meshes for the outer region.

Some 10,000 samples in total, corresponding to five or three different points for each location, were analyzed by a collaboration (60%) among universities and institutes, including CNS, RIKEN Nishina Center (RNC), Research Center for Nuclear Physics (RCNP), and other 20 academic organizations as well as by the Japan Chemical Analysis Center (JCAC) (40%).

CNS acted as a hub of the collaboration, where tasks such as receiving and checking about 6000 samples from Fukushima; sending them to 22 analysis groups depending on their capacities; and collecting, checking, and summarizing the results were performed. About 120 samples, collected from within 20 km of NPP, were analyzed by CNS and RNC.

Preceding to the large-scale measurements, a pilot study for sampling and measurement was performed in May, where five or more samples were collected at 10×10 km^2 meshes (57 points) in the 80-km region. The activities of Cs-134, Cs-137, and I-131 were analyzed by measuring γ-rays emitted by all the samples using the germanium detector(s) by analysis groups (TMU, JAEA, RCNP, Osaka Univ., CNS). Activities of other substances such as Te-129m, Ag-110m were also analyzed. Inhomogeneous distribution of activities in a sample was found by the measurements of a Ge detector viewing a sample from different directions (top/bottom), which shows that a stirring procedure is important for sampling. Substantial amount of variation in total activities of the five samples from a same point is also found, which indicates that the average of the samples is to be the typical magnitude of a certain point. Based on the pilot study, protocols for samplings and for measurements were determined.

The same $\sim$300 samples were analyzed by multiple groups, one of which is either CNS or JCAC, for the purpose of a cross checking. Results from these different groups were consistent within 30% for each sample and within 15% for an average of five samples for each location. The deviation is considered to be due to the inhomogeneity of the activities in soil samples, since it was found that for some samples, counting rates depended on the direction of the sample relative to the detector.

The maps based on the resultant activities (Cs-137, Cs-134, I-131, Te-129m, and Ag-110m) are found from the Web pages of MEX, JAEA, and RCNP[2]. Database of all the measured activities is also able to access from the Web page(http://radb.jaea.go.jp/).

The results are expected to be used as a basis for assessing the radiation dose in the concerned areas, further investigations in the environmental research works, and other such purposes.

The projects of the MEXT have continued for long-term survey, where the CNS has been measuring soil samples for studying the diffusion of the radioactivities as a function of depth.

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[1] The 2011 Strategic Funds for the Promotion of Science and Technology, entitled "Establishment of the Base for Taking Measures for Environmental Impact of Radioactive Substances – Study on Distribution of Radioactive Substances" of MEXT

[2] `http://radioactivity.mext.go.jp/`, `http://ramap.jaea.go.jp/map/`, `http://www.rcnp.osaka-u.ac.jp/dojo/`

3.7.3 Community Services

CNS International Summer School

The CNS has been hosting a series of international summer schools. The summer school aimed at providing basic knowledge and perspectives on nuclear physics for graduate students and post-docs. It consisted of lectures by leading scientists in the world in the field of both experimental and theoretical nuclear physics. Each lecture started with an introductory talk from the fundamental point of view and ended with up-to-date topics in the relevant field.

Every year, we receive about one hundred attendances from several countries.

All the information concerning the summer school, including time tables and lecture notes, is open for access at the following URL:

`http://www.cns.s.u-tokyo.ac.jp/summerschool/`,

and a short summary of 11-years of the summer school is given in Appendix C.

Community Services by Individuals

Staff members of CNS are serving to the community in various ways, which includes editorial service for journals, members of advisory boards and steering committees of other institutes and organizations. These information will appear in the curriculum vitae of the staff members in Appendix D.

Chapter 4

Education

Education is one of the main aims for which CNS was founded. Main scope of the education is to provide updated information on the nuclear physics and related technologies to the graduate students, and to train doctor-course students through research. The CNS has also been active in participating in the educational programs for undergraduate students.

4.1 Education through Research

The CNS has been participating to the education program of the Physics, the Graduate School of Science, as an associate institute. CNS faculty members have been entitled to participate in the education programs for the graduate students of the Physics Course, the Graduate School of Science.

Master-course students are guided to learn basic concept of nuclear physics and to master a wide variety of basic techniques, which includes computer programing, data and error analysis, gas and vacuum handling, data taking and handling, fast and slow electronics, gaseous detectors and scintillation counters. Development of a prototype detector and/or readout electronics has been strongly recommended, which usually provide an ideal circumstance to learn about the basic techniques. Master-course students are rather busy, since they have to take several classes for various fields in physics.

Doctor-course students are guided to choose and challenge a subject which is forefront in nuclear physics, and are expected to complete a doctoral thesis. Through the researches, it is intended that a student would master many high-graded skills which are needed to be able to perform research in the forefront of nuclear physics by themselves.

Table 4.1 shows the number of master-course and doctor-course students of the CNS as well as the number of students from the collaborating organizations as a function of fiscal year.

CNS produced 27 masters and 20 doctors in the period of 2005–2012. Master and doctor theses of the CNS students are listed in Appendix E. A summary of career paths of the graduates is shown in Appendix F.

4.2 Lectures and Seminars

The CNS faculty staffs have been participating in the lecture program of the Graduate School of Science, by having series of lectures on Nuclear Physics and other subjects. The lectures are

Table 4.1: Number of master-course and doctor-course students of the CNS and the students from the outside collaborating institutes in the last fiscal years. Numbers shown in parentheses are the numbers of students from abroad.

	Year	2005	2006	2007	2008	2009	2010	2011	2012
CNS	Master	8(1)	6(1)	5(1)	7	7	8	10(1)	7(1)
	Doctor	7	8	8	10(2)	8(2)	12(3)	12(2)	12(1)
Outside	Bachelor	5	2	1	2	1	2	2	2
	Master	0	0	1	1	0	1	1	0
	Doctor	2	1	1	1	2	1	1	0

listed in Appendix G. In 2012, Three series of lectures were given by CNS staffs. The staffs also make special lectures and seminars for the graduate students in other universities.

4.3 Training of undergraduates using an accelerator

The CNS has been actively participating in the execution of nuclear scattering experiments at RIKEN since 2002 which are a part of curriculum of experimental physics for undergraduate students of the Department of Physics.

In total 30 students participated in one of the four beam times in this acacdemic year. α beams at $E_\alpha = 6.5$ MeV were provided from the AVF cyclotron. In the experiments before 2010, the beam was transported via E7A course to the primary target position of the CRIB, where there were a lot of activities also from the researchers working for CRIB experiments. Therefore, we switched to the other beam line in E7, namely E7B, by introducing a newly developed scattering chambers in the E7B course.

In each experimental run, the students were divided into two groups and took one of the following two subjects.

- Measurement of elastic scattering of α particles from ^{197}Au.
- Measurement of gamma-rays emitted in the cascade decay of the rotational bands of ^{154}Gd or ^{184}Os.

The current scattering chamber has two target ports (upstream and downstream) allowing both groups to work on the experimental setups simultaneously.

Before the experiment, they received radiation safety course. The course at RIKEN consisted of two days. Brief description of RIKEN accelerator facility and a guided tour of the RIKEN Accelerator Facility were provided, and the preparation of the experimental setup was made on the first day. Actual data taking using the apparatus prepared in the previous day was made on the second day.

4.4 Experience seminar for Freshmen and Sophomore

The CNS has been participating in an educational program called experience seminar for Komaba students since 2006, which is a compulsory subject in the regular curriculum for Freshmen and Sophomore at Komaba. It is aimed to provide the inexperienced students with occasions to learn how to see unseen subatomic particles, through constructing a cloud chamber and a TPC detector with GEM readout, and using them to detect particles. The experience seminar is usually performed in the middle of February, for four days from Tuesday to Friday. Figure 4.1 shows a snapshot of the seminar held last year.

Figure 4.1: A snapshot of the seminar held in February, 2011. The 11 students participated in the seminar are watching signals from the GEM-based TPC, and trying to understand what they are seeing.

Chapter 5

Research Activities

In this chapter, research activities of CNS in the past eight years are presented, with emphasis on the achievement. Since rather wide variety of research activities has been performed, brief overview is provided before going into the descriptions of individual activities.

5.1 Overview of CNS Research Activities

"Heavy Ion" is a key word which characterizes the activities of CNS, and the research activity of CNS is covering a wide range of "heavy ion" related science. From the viewpoint of research field or subfield, the activities may be categorized as follows.

- Nuclear astrophysics (Astro)
- Study of structure of nuclei far from the stability line (Structure)
- Heavy ion spin physics (Spin)
- Spin-isospin responces in nuclei (Spin-isospin)
- Study of hot and dense matter with high energy heavy ion collisions (QGP)
- Beam and accelerator science and engineering (Accelerator)
- Nuclear theory (Theory)

Abbreviation used in this section is shown in the parenthesis. Explanation of the research activities are provided according to the above order. The listed items correspond to the research groups inside CNS, which are conducting the actual researches.

5.1.1 Joint research programs

Activities of CNS have been centered at RIKEN accelerator facility, RI beam factory (RIBF) as described in Chapter 2. There are, however, the research activities in the various places other than RIBF, as listed in Table 5.1.
In order to carry out researches at RIBF and various other places, CNS has agreed on various joint research programs with many institutes and universities in Japan as well as in foreign countries, as illustrated in Fig. 5.1.

Table 5.1: Facilities CNS has been utilizing for research.

Research Category	facilities where research is performed
Astro	RIBF (RIKEN)
Structure	RIBF (RIKEN), JAEA, CYRIC (Tohoku), IPN (Orsay)
Spin	RIBF (RIKEN), RCNP (Osaka), JINR (Dubna, Russia)
QGP	RHIC (BNL, USA), LHC (CERN)
Accelerator	RIBF (RIKEN)

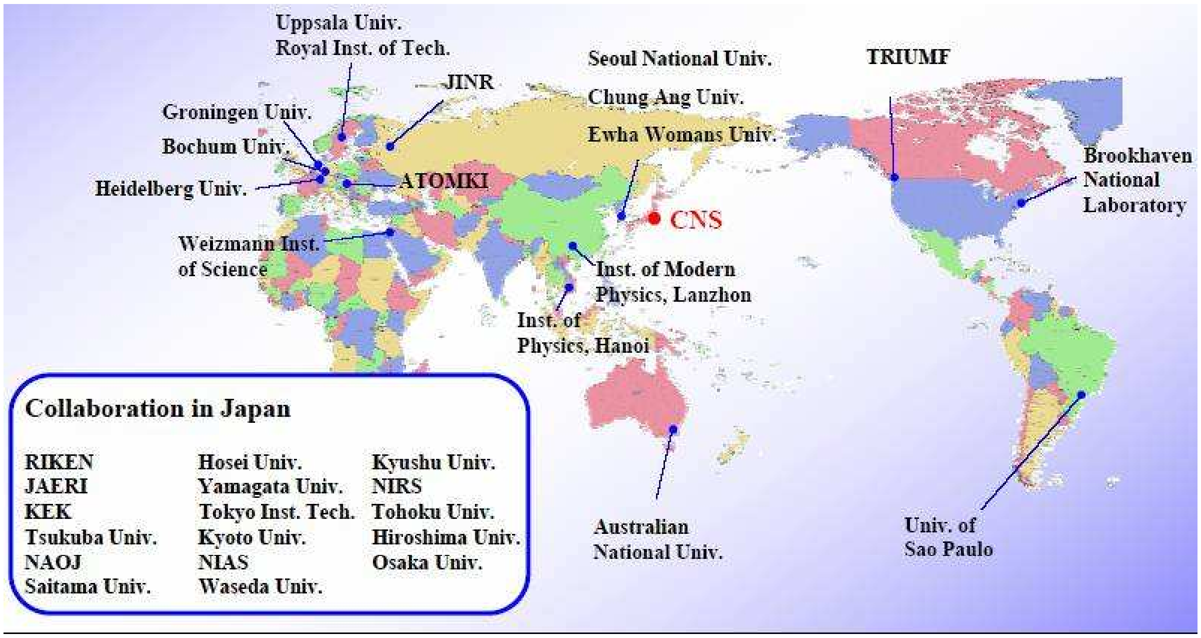


Figure 5.1: Collaborating Institutions

International collaboration

h The major international collaborations CNS is currently tied to include:

- **QGP:** collaboration in high energy heavy ion collisions has been carried out at Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory (BNL), USA and Large Hadron Collider (LHC) at CERN.
- **SPIN physics at JINR:** spin physics programs using polarized deuteron beams of several GeV are in progress at Joint Institute for Nuclear Research (JINR) in Russia.

Specific type of collaborations may be mentioned as needed in the description of individual research programs.

5.1.2 Publications, reports, and organizing workshops...

Articles published in the last seven and half years after the birth of CNS are listed in Appendix H. While having been maintaining research activities at a high level, CNS has also been very active in organizing workshops and symposia. The list is provided in Appendix I.

5.2 CNS Facilities in the Joint Venture with RIKEN

CNS facilities located in Wako campus of RIKEN are outlined in this section, and the details of the development and the related research activities are described in the corresponding subsections.

5.2.1 Research and Development Facilities in the CNS Research Building

Layout of the CNS Research and Development Building (Jiiken Junbi Tou) is shown in Fig. 5.2. R & D and maintenance of detectors and instruments have been performed on the first floor of this building, which include **Hi-ECR ion source for the AVF cyclotron**, **Gamma-ray counters**, **Active gas target** and other counters.

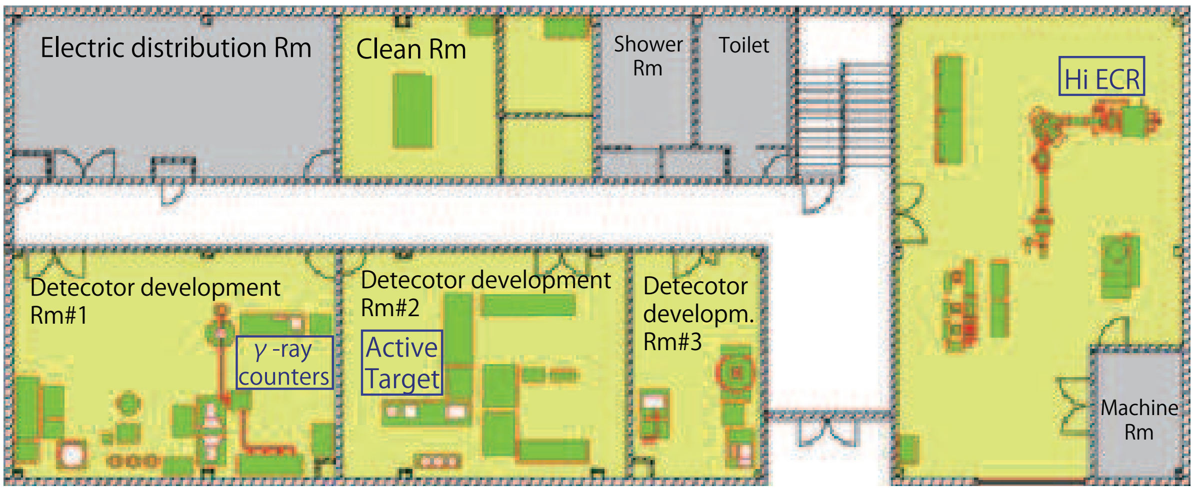


Figure 5.2: The layout of the ground floor of the CNS Research and Development building.

5.2.2 Accelerator and Experimental Facilities of CNS in RIBF

Figure 5.3 shows the CNS facilities, which are indicated by the red color, in the RIKEN RI beam factory (RIBF). Here, the symbol E is a beam line for interdisciplinary line and the symbol I is the linear accelerator that adds 2 MeV/u for heavy ion beams.

Low-energy heavy ion physics including nuclear astrophysics and nuclear physics at low energies is one of the major programs of CNS. To perform clean measurements on processes for astrophysical problems improvement of the AVF cyclotron, and development of the related facilities such as CRIB and Hyper ECR source were performed.

Another important research activity is experimental researches of unstable nuclei using the intermediate heavy ion beams from RRC or SRC. The high-resolution gamma-ray detector GRAPE and polarized targets were developed and used successfully for the experiments. The major activity on the polarized targets moved to RIKEN after Associate Prof. Uesaka moved to RIKEN in 2011. The most notable progress of CNS at RIBF in the term of 2005-2012 is completion of SHARAQ in 2009 capable of high-resolution missing-mass spectroscopy of RI-induced reactions.

Followings are some characteristics of each facility.

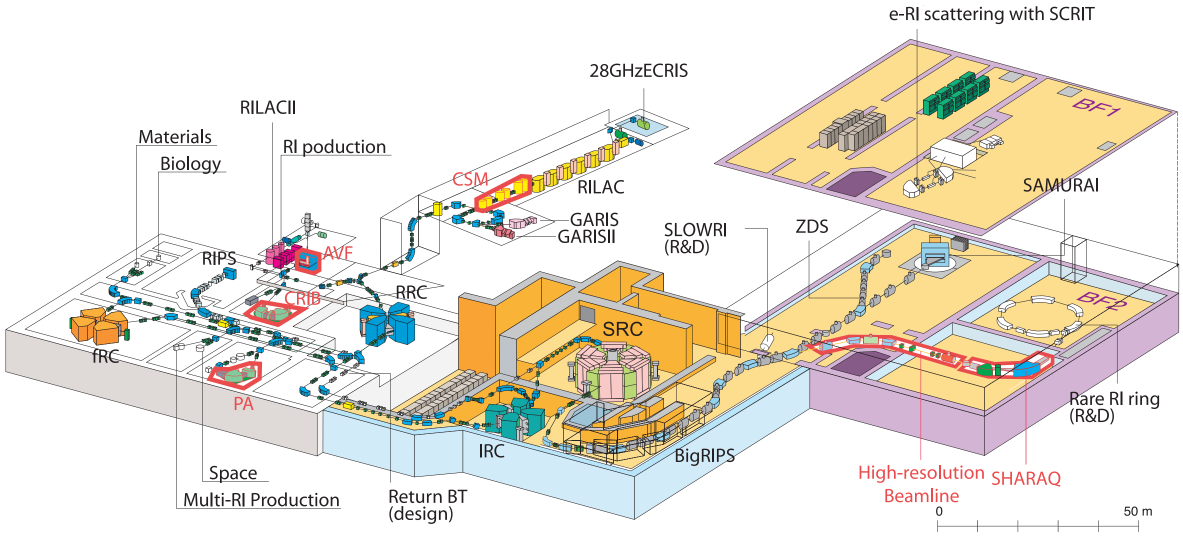


Figure 5.3: Birds-eye view of RIBF. The CNS facilities is colored by red.

Hyper ECR Ion Source for the AVF Cyclotron

The 14-GHz ECR heavy ion source, called Hyper-ECR, was installed for the AVF cyclotron of RIKEN as the second ion source. The beam line and the switching magnet were also installed by the CNS effort as well. This ion source has strengthened the operation of the AVF cyclotron and the subsequent RIKEN Ring Cyclotron. Following the continuous development, this source is now providing various heavy ion beams not only for nuclear and nuclear astrophysics but also for applications such as biology, material sciences, etc. The detail of the technological achievement is described later in Sec. 5.9.

Flattop Acceleration System for the AVF Cyclotron

As one of the major developments in the AVF Upgrade Project, the flattop acceleration system was designed and installed successfully for the first time in Japan to the AVF cyclotron. This has resulted in a much better quality for the accelerated ion beams, and thus made it possible to extract the beams with a single-turn extraction mode. It also gives better beam quality for the beams from the Ring Cyclotron subsequently.

The Energy Booster (CSM)

A linac, which is called the Energy Booster (CSM), was installed after the RIKEN linac so that all the beams can be accelerated from 4 MeV/u to 6 MeV/u, which is high enough to study various aspects of nuclear physics, and also gives a better condition for acceleration to higher energies at RRC. A typical accomplishment is a successful synthesis of super heavy element of $Z = 113$ with cold heavy ion fusion reactions, measured with GARIS.

CNS Low-Energy In-Flight RI Beam Separator CRIB

To open new research fields, a low-energy in-flight RI beam separator, called CRIB, was designed and installed in 2000, in the occasion of starting the joint venture with RARF. It should be noted that an old spectrometer, called DUMAS, was used as the main part of the in-flight separator. CRIB is equipped with window-less gas target system, high-power Faraday cup, and a Wien filter system which provides better separation of the RI beams.

GRAPE for RI Beam Gamma-Ray Spectroscopy

The fragment separators RIPS and BigRIPS of RIKEN at intermediate energies provide many kinds of unstable nuclei far from the line of stability. Since the nuclei of interest are flying with high velocity, one needs to correct for the Doppler shift in order to deduce spectra of high resolution. For this purpose, CNS has developed a Ge crystal array that has a detection capability of γ-ray incidence positions on the Ge crystals. A position-sensitive readout method for Doppler-shift correction was developed with segmented Ge detectors which form a detector array called GRAPE. This method has been successfully used for investigation of nuclear structure of unstable nuclei that are far from the line of stability.

Polarized Proton Target

A spin-polarized solid proton target is developed at CNS. This target specializes in RI beam experiments; for ease of detection of low-energy recoiled protons under inverse kinematics condition, the target operates under a modest environment with a low magnetic field of $\sim$0.1 T and a high temperature of $\sim$ 100 K. This property exhibits a sharp contrast to usual dynamic-nuclear-polarization targets requiring a magnetic field of $>$2.5 T and a temperature of $<$0.1 K.

SHARAQ Spectrometer

The SHARAQ project was started in 2004 aiming at high-resolution missing-mass spectroscopy of RI-induced reactions at 100–350 MeV. In March 2009, the construction of high-resolution beamline and SHARAQ spectrometer in RIBF were completed by the collaboration with RIKEN Nishina Center and ICHOR project team of the University of Tokyo (See Fig. 5.3 for location). The experimental devices were designed to satisfy the lateral-and-angular dispersion-matching condition. The momentum resolution and angular resolution of the total system were evaluated to be $p/\Delta p = 15000$ and 1 mrad, respectively, by a first-order ion-optical calculation.

5.3 Nuclear Astrophysics and CRIB

CRIB is a radio-isotope (RI) beam separator operated by CNS, installed in the RIBF facility of RIKEN Nishina Center. CRIB can produce low-energy ($<$ 10 MeV/u) RI beams in flight, using primary heavy-ion beams from the AVF cyclotron of RIKEN ($K = 70$). It has been providing various RI beams for many experiments since its first operation in 2001. The installation and operation of CRIB were carried out as a joint project of CNS and RIKEN.

Figure 5.4 shows the structure of CRIB. Specifications of the system are provided in Table 5.2.

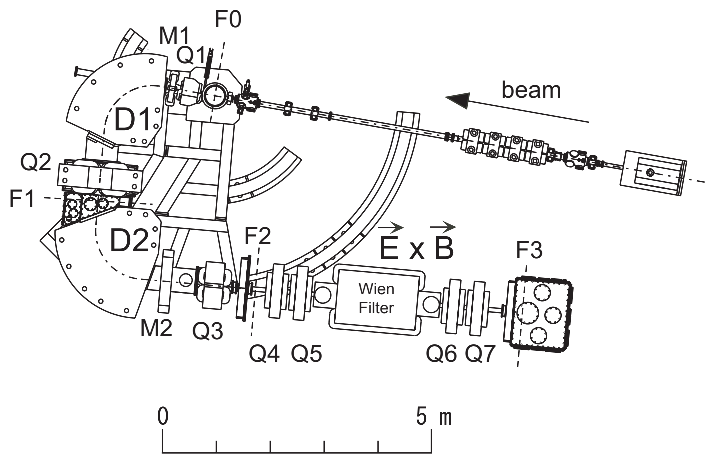


Figure 5.4: Plane view of CRIB. The primary beam is accelerated by the AVF cyclotron of RIKEN. D, Q, and F represent a dipole magnet, a quadrupole magnet, and a focal plane, respectively.

Table 5.2: Specification of CRIB dipole section

Orbit Radius	84 - 98 cm
Maximum Energy	110 Z^2/A MeV
Energy Range	30 %
Solid Angle	5.6 msr
Momentum Resolution	1/850
Momentum Dispersion(F2)	$\sim$0

Most of the RI beams are produced via direct reactions such as (p, n), (d, p), and (^{3}He, n), taking place at an 8-cm-long gas target with a maximum pressure of 760 Torr. A cryogenic target system, in which the target gas can be cooled down to about 90 K, was built in 2006. The cryogenic temperature makes the gas target nearly 4 times thicker, and also a better cooling efficiency against the heat deposited by the beam is obtained. We succeeded in producing an intense ^{7}Be beam of 2×10^8 pps using the system. One main feature of the target system is forced circulation of the target gas. We have found that the circulation of the target gas at a rate of 55 standard liters per minute (slm) was effective in eliminating the density reduction, caused by heat deposition of the beam. An improvement of metallic ion production at Hyper ECR ion source was also essential for the intense ^{7}Be beam production. Solid targets such as beryllium foil can also be used as the production target, instead of the gas target.

The secondary beam is purified with an magnetic analysis using dipole magnets, and with a Wien filter, which can separate the beams according to their velocities. For relatively light RI beams such as ^{7}Be, we can obtain a good purity of almost 100% after the Wien filter. The Wien filter is operated with high voltages of $\pm$50–100 kV, supplied for a pair of 1.5-m long electrodes with a gap of 8 cm. For a stable operation at a higher voltage, we are making improvements on the insulators and other parts of the system. As for the insulators, we have replaced the original plastic ones with ceramic ones, tested several cleaning method including a water-jet cleaning, and redesigned their geometrical shape based on an electric field calculation.

RI beams which have been produced at CRIB are listed in Table 5.3, with typical parameters. The RI-beam energy is optimized for each measurement, and can be changed according to the primary beam energy, the thickness of the production target, and other conditions. The intensity also varies depending on the conditions. The number of available RI beams has been increasing, and the most recently developed beams are ^{16}N, ^{22}Na, and ^{44}Ti. As for the ^{8}B beam, we spent a special effort to increase its energy and intensity. As a result, we satisfied all the requirements to obtain a ^{8}B beam with an energy around 9 MeV/u, and an intensity of 1 $\times$ 10^4 pps, which is needed for a reaction mechanism study of ^{8}B + Pb. For the moment, the ^{8}B beam at 9 MeV/u is a unique beam which cannot be produced in any other facility in the world.

Developments for detectors are also on going for a better performance in experiments with low-energy RI beams. PPAC has been used as a beam monitoring detector, and we started to use another beam monitor with a micro-channel plate (MCP). It has an advantage over PPAC that we can reduce the thickness of the material in which the beam has to traverse. An active target system was also built for a complete identification of reaction products, as described later in Sec. 5.7.2, and used for several experiments.

We owe much to the technical staff for the stable operation of CRIB. There are two technical staff who are essenial for CRIB. One (Y. Ohshiro) is an expert of the ion source, and the RI beam intensity is much improved by his development of the ion source. The other (N. Yamazaki) is taking care of the whole system of CRIB, and maintains the Wien filter. Although they are skillful and have much experiences, they both have retired and being hired as temporary staff. We cannot expect them to work for more than a few years. How to maintain our facility without them remains a big issue for us.

5.3.1 Performed experiments using CRIB

The RI beams available at CRIB have been applied for various studies, mainly focused on nuclear astrophysics and nuclear structure study. An experimental method extensively used is the thick-target method in inverse kinematics. In that method, the beam energy is degraded in a thick reaction target, and reactions occur at various center-of-mass energies. We detect light particles emitted after reactions, and reconstruct the kinematics. This method has several advantages, namely, (a) we can study reactions with short-lived RI which cannot be used as the target, (b) we can perform simultaneous measurements of cross section of various excitation energies without varying the incoming RI beam energy, and (c) we can perform measurements at 180° in center-of-mass angle, where the Coulomb scattering is minimal. Many fruitful results have been obtained at CRIB with this method.

Table 5.3: RI beams produced at CRIB, with typical parameters of beam production. "Position" shows the name of the focal plane where the RI beam was measured. F2 is located before the Wien filter, and F3 is after that.

Primary Beam			Target	Secondary (RI) Beam				
Ion	Energy (MeV/u)	Current (pnA)		Ion	Energy (MeV/u)	Intensity (pps)	purity (%)	Position
^{7}Li	5.0	500	H_2	^{7}Be	3.8	5.0×10^{6}	100	F3
^{7}Li	5.6	1350	H_2	^{7}Be	3.6	2.7×10^{8}	75	F2
^{7}Li	6.5	333	D_2	^{8}Li	5.0	2.0×10^{5}	100	F3
^{6}Li	9.5	500	^{3}He	^{8}B	5.2	1.0×10^{4}	30	F3
^{10}B	7.8	200	CH_4	^{10}C	6.1	1.6×10^{5}	90	F2
^{11}B	4.6	1000	H_2	^{11}C	0.9	8.8×10^{5}	97	F3
^{10}B	7.9	420	^{3}He	^{12}N	5.8	6.0×10^{2}	30	F3
^{13}C	6.0	500	H_2	^{13}N	3.7	2.0×10^{5}	98	F3
^{18}O	6.1	200	Be	^{14}C	6.2	2.8×10^{5}	19	F2
^{14}N	8.4	500	H_2	^{14}O	2.4	5.0×10^{5}	93	F3
^{15}N	5.0	0.1	D_2	^{16}N	0.9	2.5×10^{1} †	89	F3
^{16}O	6.6	83	D_2	^{17}F	4.7	5.0×10^{5}	98	F3
^{18}O	6.1	200	Be	^{17}N	5.6	3.5×10^{5}	24	F2
^{16}O	10.4	86	^{3}He	^{17}Ne	4.9	2.4×10^{2}	0.3	F2
^{18}O	6.1	200	Be	^{17}O	5.4	1.2×10^{5}	8	F2
^{18}O	5.9	35	H_2	^{18}F	3.2	6.2×10^{5}	73	F3
^{18}O	7.0	400	Be	^{18}N	5.7	3.4×10^{5}	6.1	F2
^{16}O	6.8	560	^{3}He	^{18}Ne	3.7	5.1×10^{5}	81	F3
^{20}Ne	6.2	56	D_2	^{21}Na	1.9	5.0×10^{5}	96	F3
^{20}Ne	6.1	100	^{3}He	^{22}Mg	3.7	3.5×10^{3}	18	F3
^{22}Ne	6.1	520	H_2	^{22}Na	3.0	5.2×10^{5}	90	F3
^{24}Mg	7.4	60	D_2	^{23}Mg	4.0	3.2×10^{4}	12	F2
^{24}Mg	7.5	42	D_2	^{25}Al	3.5	1.2×10^{6}	50	F3
^{24}Mg	7.5	200	^{3}He	^{26}Si	3.0	6.0×10^{4}	23	F3
^{28}Si	5.9	37	D_2	^{30}P	1.0	2.6×10^{3}	30	F3
^{28}Si	7.3	77	^{3}He	^{30}S	0.5	1.5×10^{4}	45	F3
^{40}Ar	4.5	118	^{3}He	^{39}Ar	3.7	7.0×10^{2}	4	F3
^{42}Ca	5.9	7	^{3}He	^{44}Ti	2.3	1.0×10^{3} ‡	15	F3
^{36}Ar	3.6	80	^{12}C	^{46}Cr	1.2	5.6×10^{0}	1.8	F3

† 2×10^{4} pps is expected when a 100-pnA primary beam is available.
‡ 1×10^{4} pps is expected when a 70-pnA primary beam is available.

The experiments at CRIB have been performed after an approval by the CNS-PAC (until 2006) or the NP-PAC, co-hosted by CNS and RIKEN (2007–2010). We did not accept new proposals during 2010–2011 due to the retirement of Prof. Kubono, however, a new procedure to propose CRIB experiments by the discretion of CNS director was newly defined in 2012.

Many experiments under international collaborations have been performed at CRIB. During 2004–2012, there have been experiments proposed by foreign collaborators in Italy, Hungary, U.K., Korea, China, Vietnam, Australia, Canada, and Brazil, listed in Table. 5.4. Domestic collaborators in Kyushu Univ., TiTech, Tohoku Univ., and Osaka Univ. also proposed and performed experiments at CRIB.

Table 5.5 summarizes the annual statistics of the beamtime for each country. We have been performing 30–50 days of experiments per year at CRIB during 2006–2011. The number of experiments has been reduced since 2011, because of the retirement of Prof. Kubono and the great earthquake. The number of publications of peer-reviewed original papers, also shown in Table 5.5, has been increasing in turn. After the retirement of Prof. Kubono, the manpower dedicated to CRIB experiments has been reduced, but we want to keep performing experiments around 20 days per year. The beamtime for experiments during 2006–2012 which was mainly carried out by CNS members amounted 45% of the total beamtime. The beamtime for experiments proposed by foreign groups was 40% of the total beamtime. Among all the countries, China and Korea have taken the beamtime most, and provided much manpower. Thus they are expected to be productive partners in the near future as well. We would like to enhance the international collaborations more widely, with groups who have interests in our facility.

Table 5.4: List of foreign groups proposed and performed experiments at CRIB. Number of maximum participants gathered by each group in a experiment is also shown.

Country	Institution	Max. part.
Hungary (HN)	ATOMKI	2
Italy (IT)	INFN (Catania)	6
	INFN (Legnaro)	3
Canada (CA)	McMaster Univ.	4
Australia (AU)	ANU	2
Republic of Korea (KR)	Ewha Womans Univ.	4
	Chung-Ang Univ.	8
Vietnam (VN)	IOP	3
China (CN)	CIAE	7
	IMP (Lanzhou)	5
Brazil (BR)	Sao Paolo	2
U.K. (UK)	Edinburg	3

Proton resonant scattering and (p, γ) reaction

Hydrogen burning is one of the most important and basic process in the nucleosynthesis, as hydrogen is the most abundant element in the universe. In high-temperature hydrogen burning, taking place at first generation stars, X-ray bursters, novae, supernovae (ν-process and νp-process), and other astrophysical sites, some of (p, γ) reactions on proton-rich nuclei become very relevant. However, we have quite limited information on astrophysical reactions with

Table 5.5: Annual beamtime statistics (in days) used at CRIB by each country under our international collaboration. The rightmost two columns (# o.p. and # p.p.) shows the number of peer-reviewed original papers and proceeding papers published, respectively

Year	Japan	HN	IT	CA	AU	KR	VN	CN	BR	UK	Sum	# o.p.	# p.p.
2001 to 2004	83.5	2									85.5	1	13
2005	14		1	6							21	1	2
2006	23	3		2	8	10					46	0	2
2007	13		7	9			2	10	10		51	1	2
2008	11		8	4		6	9			1.5	39.5	2	2
2009	19.5					6		4			29.5	2	3
2010	28		2					2			32	1	7
2011	0		2			6	17	9			34	2	2
2012	6							19			25	3	16
Total	198	5	20	21	8	28	28	44	10	1.5	363.5	13	49

unstable nuclei, due to the experimental difficulties. Nevertheless, the reaction rates involving unstable nuclei are also essential for understanding how the observed astrophysical phenomena are initiated and evolve by time.

We can study resonances in compound nuclei contributing to (p, γ) reactions via proton resonant scattering with "thick-target in inverse kinematics" method using the RI beams at CRIB. Measurements of proton resonant scattering has been performed for many RI since CRIB was built.

The followings are the recent major achievements:

- ^{13}N+p
  Single particle resonances in ^{14}O were studied. A clear assignment of $J^\pi = 2^-$ has been made for the level at $E_{\rm ex}$ = 6.767(11) MeV in ^{14}O for the first time. The excitation functions showed a signature of a new 0^- level at $E_{\rm ex}$ = 5.71(2) MeV.

- ^{22}Mg+p
  A new state at 3.95 MeV was found and its spin-parity was assigned as $J^\pi = 7/2^+$. The core-excited structure of ^{23}Al is discussed within a shell-model picture. The stellar reaction rate of the ^{22}Mg(p, γ)^{23}Al reaction has been reevaluated, and the revised total reaction rate is about 40% greater than the previous result for temperatures beyond T_9 = 0.3.

- ^{7}Be+p for solar neutrino production
  This is related to a very responsible reaction to the solar neutrino production, ^{7}Be(p, γ). A broad negative parity state around $E_{\rm ex}$ = 3 MeV in ^8B was previously reported and its implication to the neutrino production had been discussed. We determined the energy and width of the resonance with much better precisions, and confirmed its resonant contribution at solar temperature is negligible compared to the direct reaction.

- ^{25}Al+p,^{26}Si+p, ^{22}Na+p, and cosmic γ-rays
  In relation with the production of ^{26}Al nucleus, which is relevant as a cosmic γ-ray source,

we performed measurements of ^{25}Al+p and ^{26}Si+p. The production rate of ^{26}Al could be greatly varied according to the ^{25}Al/^{26}Si(p,γ) reaction rates. We obtained new resonance information in each measurement. We also performed a measurement of ^{22}Na+p, which is related to the puzzle of unobserved cosmic γ-ray from ^{22}Na decay.

- ^{21}Na+p, ^{17}F+p for evaluation of (p, α) reaction rates
  The proton resonant elastic scattering can be applied to studies of (p, α) reaction, or its inverse, (α, p) reaction. Measurements of ^{21}Na+p and ^{17}F+p were performed to study astrophysically important ^{18}Ne(α, p) and ^{14}O(α, p) reactions from their exit channels.

Besides the proton resonant scattering, we also performed an indirect measurement of ^{12}N(p, γ), an important reaction in the hydrogen burning, by the asymptotic normalization coefficient (ANC) method. We measured the angular distribution of ^{12}N(d, n) reaction cross section at CRIB and determined the optical potential. Using the ANC method, we evaluated ^{12}N(p,γ) reaction rate,and it revised the previous evaluation by 2 orders of magnitude.

5.3.2 Systematic study of (α, p) reactions

In hot hydrogen burning processes, (α, p) reactions also play important roles. In particular, the ^{14}O(α, p) reaction is considered as the break-out reaction from hot-CNO cycle to a higher temperature process, which is followed by the *rp*-process. In a process called αp-process, a sequential chain of (α, p), (p, γ) reactions accelerates nucleosynthesis of proton-rich nuclei, faster than the normal *rp*-process. The rates of these reactions are considered to be very crucial to understand astrophysical phenomena such as X-ray bursters.

We performed a systematic study of (α, p) reactions for 2006–2011. The reactions we measured were ^{11}C(α, p), ^{14}O(α, p), and ^{21}Na(α, p) with a standard (gas filled in a small chamber) helium gas target, and ^{18}Ne(α, p), ^{30}S(α, p), and ^{22}Mg(α, p), with the newly built active target, described in Sec. 5.7.2. CRIB is a particularly suitable facility for these measurements, as there we can obtain proton-rich and low-energy RI beams. Experimental data for these reactions have scarcely been obtained previously, and we obtained valuable information to determine reaction rates more precisely.

5.3.3 Studies on (α, γ) reaction and α-cluster structure via α resonant scattering

As written above, proton resonant scattering has been measured many times at CRIB and the experimental method has been established well. However, α resonant scattering, in which the target is helium instead of hydrogen, had been recognized as a by-product of (α, p) reaction measurement, but not as a main motivation of the experiment.

The first study at CRIB in which the α resonant scattering was the main subject was the ^{7}Li/^{7}Be+α resonant scattering experiment, performed in 2009 and 2010. It resulted in an interesting study in both respects of astrophysical ^{7}Li/^{7}Be(α, γ) reactions at high temperature and exotic α-cluster structures in ^{11}B/^{11}C. As shown in Fig. 5.5, we successfully observed many strong α resonances. In ^{11}B nucleus, we proposed a negative-parity band which is similar to a rotational band. In a later theoretical calculation with asymmetrized molecular dynamics (AMD), the experimental moment of inertia was reproduced well, and the band was explained as levels with a 2α-t structure, rather than a simple rotational band. α resonant scattering is expected to produce more unique results, taking advantage of the low-energy RI beams of CRIB.

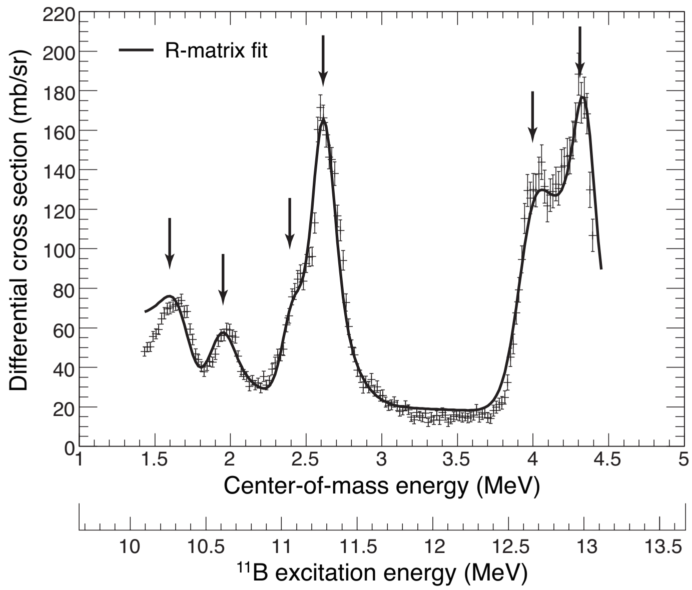


Figure 5.5: Excitation function of ^{7}Li+α resonant elastic scattering. Many resonances were observed as indicated, and an R-matrix analysis was performed for them.

5.3.4 β-decay half life of ^{46}Cr

On interests of Gamow-Teller transition strength, we performed a measurement of β-decay half life of ^{46}Cr. The ^{46}Cr beam was the heaviest among the RI beams ever produced at CRIB, and was produced via fusion reaction with a ^{36}Ar beam and a carbon target. The ^{46}Cr beam was stopped in a target and β and γ rays from decays were measured by silicon and germanium detectors, respectively. We determined the β-decay half life with a much better precision ($T_{1/2} = 232 \pm 9$ ms) compared to previous measurements.

5.3.5 Application of ^{7}Be

The intense ^{7}Be beam we developed at CRIB has appeared to be useful not only for nuclear reaction studies but also for other applications. Because the decay of ^{7}Be is through electron capture, the lifetime could be affected by the surrounding atoms in solid materials. To measure the lifetime shift in metals, the ^{7}Be beam at CRIB was used. We implanted ^{7}Be in niobium, and a signature of small shift of half life ($T_{1/2} = 53.25$ days to 53.18 days) was observed by a offline measurement. It is also proposed to use a relatively long-lived RI for a wear diagnostics test of industrial material such as engine parts. So far we performed an irradiation test with Industrial Cooperation Team at RIKEN, and a sufficient number of ^{7}Be were successfully implanted into the sample material.

5.3.6 Future prospects of Nuclear Astrophysics Group and CRIB

The low-energy RI beam separator CRIB should continue to be a productive facility to perform unique studies also in the near future. Standard procedure of the RI beam production and the thick-target method has been established during the 10 years' operation, and CRIB has entered on a productive phase, as indicated by the gradually increasing number of publications.

The situation of the beamtime allocation in Nishina Center is basically desirable for CRIB. Running with the AVF accelerator alone, the operation cost of CRIB is much lower than other beamlines in RIBF. The operation of CRIB does not conflict with RIPS or BigRIPS, when the AVF cyclotron is not used for them. Therefore, we have a prospect to perform experiments almost as much as we can carry out with our manpower, around 20 days per year.

Physics

In the first years of CRIB, a main topic was the study of proton resonances via the resonant scattering, to evaluate the cross section of hydrogen burning processes. Now the main topic is shifted to α-induced reactions, but only recently we could obtain good physics results. We will continue the studies for direct measurements of astrophysical (α, p) reactions, evaluation of (α, γ) reaction rates by measuring resonances, and search for α-cluster levels. We still have quite limited experimental information on the (α, p) reactions in the αp-process. There are several other (α, p) reactions which should make significant contribution in X-ray bursters, supernovae and other phenomena, such as ^{26}Si(α, p). The temperature of the αp-process is quite close to the typical RI beam energy at CRIB, and our experimental data would surely contribute to the systematic understanding of the high-temperature phenomena.

The resonance study via the α resonant elastic scattering has been proven to be useful for nuclear cluster study by our ^{7}Li/^{7}Be+α experiments. The α width, which can be determined almost directly from our elastic scattering spectra, should provide valuable information on the cluster structure, as shown for the ^{11}B nucleus. There is a strong demand from nuclear-cluster theorists for such experimental data, especially for unstable nuclei near the stability line.

We can also evaluate the resonant contributions for (α, γ) reactions using the resonant parameters measured by the α resonant elastic scattering. However, not in many cases we can study resonances critically affect for astrophysical reaction rates, because elastic scattering is dominated by Coulomb scattering at the lowest energy region. A possible measurement to study reaction rate at astrophysical temperature more directly is by transfer reaction. An experiment by transfer reaction was first performed at CRIB for the ^{12}N(d, n) reaction. Using the experimental result, the astrophysical ^{12}N(p, γ) reaction rate was indirectly determined by the ANC method. We would like to perform measurements of transfer reactions, including α-transfer reaction (^{6}Li, d), for other unstable nuclei.

Developments for higher intensity beams

If we will perform measurements of low-cross section reactions, such as cluster transfer or direct capture reaction, an RI beam with higher intensity might be necessary. Improvements on several parts of the system can be considered.

The cryogenic target has a sufficient thickness in respect of the acceptance of the beam energy dispersion, produced in the production target. The limiting factor for a high current beam can be the heat deposited by the primary beam, which may break the window foils. An improvement is necessary to obtain a better heat conductance, or to use a window-less target.

In developments of heavier-mass RI beams, the energy loss problem is more crucial than lighter ions, and the beam particle identification from neighboring-mass nuclei becomes more difficult. ^{44}Ti is one of such heavy-ion beam recently developed, but more tests of beam production are still necessary. An ionization chamber is used for the beam particle identification, and usage of a thin charge stripper foil may help us to obtain a better purity.

The Wien filter was initially designed as with the maximum high voltages of ±200 kV, however, we cannot operate it stably at voltages of ±100 kV or higher, due to frequent discharges. We will continue to work for a better stability at higher voltages. When the stability is lost, we found it is effective to exchange the insulators for the high voltage feedthrough or supporting electrodes. We are working for improving the insulators, by trying several methods for cleaning and making a redesign based on a simulation of the electric field. Another improvement could be made on its transmission. Currently, a typical transmission of the Wien filter is 30%. The low transmission is because the optics calculation was not performed with a realistic dispersion, and we need a new design and optics calculation to improve the transmission. A minimum upgrade would be enlarging the duct size, but a modification of the poles of quadrupole magnets is also necessary.

Collaboration

Currently, CRIB is mainly operated by 3 members (1 lecturer and 2 postdocs) in CNS, forming collaborations with external groups. 3 persons are minimum for the whole operation of CRIB but not sufficient for extra development works. The manpower from external group is quite essential to maintain CRIB as a productive facility. There are many researchers in Japan and abroad showing interests for making a proposal at CRIB, and some of them have much experience of CRIB operation. We would like to keep performing experiments with worldwide collaborations and producing good physics results.

The importance of the technical staff should also be emphasized. We strongly need to have alternative persons who can take care of the ion source and CRIB hardware, to maintain CRIB as a reliable and attractive facility in the near future.

Other facilities and future prospects

In the late 2010s', next-generation facilities such as FAIR and SPIRAL2, will be built, and they should be able to produce low-energy RI beams with high intensities. There are also plans for RI beam facilities similar to CRIB, such as RISP at IBS, Korea, and at Legnaro, Italy. Nevertheless, we can expect CRIB can be a still unique facility for 5 years or more, since we may have advantages in low-energy RI beam production with low cost, or production of RI beams having specific lifetimes suitable for in-flight production with dirct reactions.

A possible plan is that we will fully make use of CRIB for the coming 5 years, and then give the role to other facilities. After that we may start a new project, which should be planned during the 5 years.

5.4 Structure of nuclei far from the stability

Varieties in the properties of nuclei far from the stability give rich information on nuclear system in a wide area of the nuclear chart. Experiments using radioactive isotope (RI) beams in the last few decades have shown exotic phenomena such as neutron halos, soft collective excitations, changes of the magic numbers and so on. We are realizing that the nuclear structure should be studies as functions of the protons and neutron numbers (Z and A) as well as of the excitation energies (E_{x}). The NUSPEQ[1] group has been performing in-beam spectroscopy of (1) in-flight exotic nuclei produced by direct reactions of RI beams at more than several tens of MeV per nucleon. (2) high-spin states in nuclei produced by low-energy fusion reactions of stable and unstable nuclei. In addition to the above studies, we devoted on the SHARAQ project from FY2005 with other groups in the CNS, which is described in the separate section.

The above mentioned activities of the group will be continued to study nuclear structures in a wide area of nuclear chart by using possible combinations of the high-resolution γ-ray detector array GRAPE and the SHARAQ with upgrading plans of them.

The following subsections describe the highlights of the results in these 8 years.

5.4.1 Studies of exotic structures in neutron-rich nuclei using RI beams

Structure of $N = 8$ neutron-rich nucleus ^{12}Be

It is well known that the shell gap between p- and sd- shells disappears in the $N = 7$ nucleus ^{11}Be which has the ground state of $1/2^+$ 0.34 MeV below the normal $1/2^-$. For ^{12}Be, recent experimental results of a large spectroscopic factor of the n+^{11}Be($1/2^+$) for the ground state of ^{12}Be, and a large cross section in the proton inelastic scattering to the first 2^+ state, finding of a low-lying intruder 1^- state at $E_{\mathrm{x}} = 2.7$ MeV indicate the loss of the $N = 8$ magicity due to the quenching in the shell gap.

Experimental efforts for finding of the low lying excited 0^+ state have been continued for about 25 years, since it is a natural consequence of the degeneracy of the $1\mathrm{p}_{1/2}$ and $2\mathrm{s}_{1/2}$ orbitals. We found the 0_2^+ state at $E_{\mathrm{x}} = 2251 \pm 1$ keV as an isomeric state produced by fragmentation reactions of the ^{18}O projectile. From the observed mean life of 331 ± 12 ns and the branching ratios $W(\mathrm{E2})/W(\mathrm{E0}) = 0.215 \pm 0.018$, the reduced transition probability $B(\mathrm{E2};0_2^+ \rightarrow 2_1^+)$ is deduced to be 6.7 ± 0.8 $\mathrm{e}^2\mathrm{fm}^4$ $= 0.83 \pm 0.20$ $B_{\mathrm{sp}}(\mathrm{E2})$. The E0 matrix element $\langle 0_2^+ | r^2 | 0_{\mathrm{g.s.}}^+ \rangle$ are deduced to be 0.88 ± 0.04 fm^2. These magnitudes are predicted well by a simple model where the both the 0^+ states have a mixing of the normal and intruder configurations of loosely bound two neutrons by a deformed well.

Cluster structures in neutron-rich nuclei

Cluster structures in the neutron-rich nucleus ^{12}Be were experimentally investigated via α-inelastic scattering. Excited states in the ^{12}Be nucleus were populated by a ^{12}Be(α,α') reaction at 60 A MeV in the inverse kinematics, and identified by measuring a ^{6}He+^{6}He and α+^{8}He breakup channels in coincidence. The differential cross section and the angular correlations between the decay particles were obtained for each excitation energy at 10–20 MeV for ^{6}He+^{6}He and at 9–19 MeV for α+^{8}He, respectively, reconstructed by the measured momentum vectors of the two helium isotopes. A multipole decomposition analysis based on the distorted-wave Born approximation was applied for the angular distribution of the inelastic scattering together with the angular correlation between the decay particles with respect to the directions of the

[1] **NU**clear **SP**ectroscopy for **E**xtreme **Q**uantum system

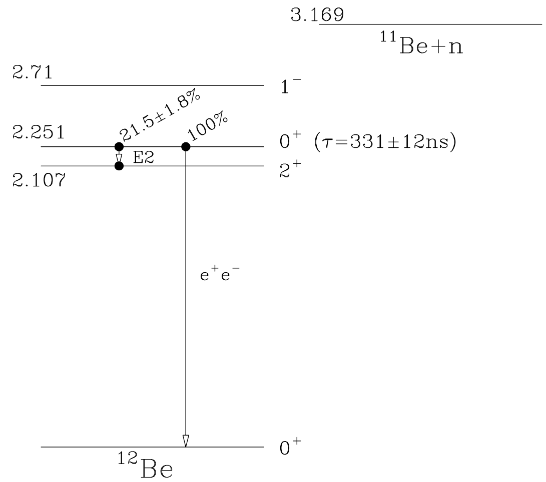


Figure 5.6: Low lying states and transition strengths in ^{12}Be

incident beam and to the momentum transfer simultaneously. From the decomposed excitation energy spectra for $J = 0$ to 4, several new excited states were identified. Comparison between the two channels with help of theoretical predictions, it is suggested that several kinds of the bands characterized by the molecular orbitals and atomic orbitals of the valence neutrons exist in the excitation energies above 10 MeV.

Proton single particle states in neutron-rich nuclei

The single particle states in a nuclear mean-field have been studied through nucleon transfer reactions such as (d,p) and (d,n) around 10 MeV per nucleon because of the kinematical matching conditions. We found that for the higher incident energies, the cross sections of the (α,t) and (α,^{3}He) reactions are rather large, because of a large Q-value and a wide momentum distribution of a nucleon in the α particle.

We have studied the proton single particle states in neutron-rich nuclei via γ-ray spectroscopy of the ^{13}B* and the ^{23}F* nuclei populated by the (α,t) reactions on the ^{12}Be and the ^{22}O nuclei, respectively. For the measurement of the ^{13}B*, we introduced an array of position-sensitive Ge detectors for Doppler-shifted γ rays to distinguish decays from nearly degenerate excited states. We have found that the strongly populated 4.8-MeV state has spin and parity of $1/2^+$ by a DWBA analysis of the angular distribution. This state is suggested to be a candidate of of the proton single particle state of $\Omega^\pi = 1/2^+$ in a deformed well of the ^{12}Be core.

For spectroscopy of ^{23}F*, we measured the ^{4}He(^{22}O,^{23}Fγ) (proton transfer), the ^{4}He(^{23}F,^{23}Fγ) (inelastic excitation), and the ^{4}He(^{24}F,^{23}Fγ) (neutron knockout), simultaneously, because of the cocktail RI beams. We have found several new excited states by analyzing the γ and γ-γ spectra. Comparison among the population probabilities for three kinds of reactions we identified proton single-particle states, especially for the $d_{3/2}$ and the $s_{1/2}$ orbitals. The reduction of the excitation energy of the identified $3/2^+$ state is consistent with the monopole migration of the tensor correlation in the neutron-rich nuclei.

Nuclei in the border of the island of inversion

The nuclei in the region around the ^{32}Mg in the nuclear chart, which is called as the island of inversion, have attracted much attention, since a small excitation energy of the 2_1^+ state (0.89 MeV) and a large transition probability between the ground and the 2_1^+ state were found in the ^{32}Mg nucleus in spite of the neutron number is 20. Recent findings of the second 0^+ states in ^{32}Mg and ^{34}Si make it interested to study the structure of ^{33}Al considered to be on the border of the island of inversion. We have found the γ-ray of 746(4) keV in the α inelastic scattering on ^{33}Al, which is considered to be the deexcitation γ-ray from the first excited state. The strength of the γ-ray and the angular distribution of the scattered α-particle suggests that the admixture of the monopole excitation as well as quadrupole excitation, which lead to a possible $J^\pi = 5/2^+$ assignment of the first excited state.

Beta Decay Study of C, N, O Isotopes Close to the Neutron-Drip Line

The nuclei with Z≈8 provide an opportunity to investigate the effects of neutron excess on the p-sd shell gap of the proton side. In particular, the β-decay of the neutron-rich C, N isotopes is an excellent probe. In these nuclei, the valence neutrons belong to the sd shell, while the valence protons belong to the p shell. Therefore, intruder states are populated selectively through the β-decay because of the selectivity of the β-decay. To clarify them an experiment of $\beta - \gamma$ measurements for ^{19,20}C, $^{20-22}$N, and ^{24}O was performed.

The γ-ray detection system consisted of two clover-type Ge detectors and the CNS Ge array (GRAPE) was employed. The photopeak efficiency of this system was 4.3 % for 1 MeV γ rays. Each clover-type Ge detectors was surrounded by anti-Compton shield, which consisted of eight BGO scintillators. Each BGO scintillator had a size of 80×250×25 mm^3. For a veto of a β-ray to the Ge detectors, each Ge detector had an plastic scintillator at the front end. The plastic scintillators with a thickness of 1 mm were used for the clover-type Ge detectors and a plastic scintillators with the thickness of 5 mm for GRAPE.

By using this setup, we have carried out an experiment of $\beta - \gamma$ spectroscopy for ^{19,20}C, $^{20-22}$N, ^{24}O. After the careful analysis, β-delayed γ-rays originated from these nuclei were successfully observed.

Lifetime Measurement of ^{32}Mg First 2^+ State

Lifetime of excited states of nuclei provides us with important information of the nuclear structure. To extend the measurement to nuclei far from stability, it is necessary to develop new methods fit for unstable nuclei by fragmentation reactions at intermediate energies. We started to apply the Recoil Distance Method (RDM) for the lifetime measurements of excited states of unstable nuclei in the 10ps range.

Among the unstable nuclei, ^{32}Mg is a typical nucleus of the 'Island of Inversion'. The energy of the first excited state and the value of B(E2;$2_1^+ \rightarrow 0^+$) implies the break of closed shell structures. The B(E2) values of ^{32}Mg were previously obtained from the intermediate-energy Coulomb excitation of ^{32}Mg and the $\beta-\gamma$ spectroscopy of ^{32}Na. However, uncertainties of B(E2) values are large and somewhat inconsistent among the measurements. Therefore, high-precision measurement of B(E2) was desired. In order to achieve it, we applied the RDM to intermediate-energy RI beams of ^{32}Mg for the first time.

In the RDM, RI beams excited by any reactions at the secondary target fly to the plunger at ∼1 mm downstream of the target, and then they are decelerated by the plunger. De-excitation γ rays emitted before and after deceleration will have different energies because of their different

Doppler shifts. The lifetime of the excited state is deduced by comparing the counts of the two peaks.

De-excitation γ rays were detected by the position sensitive Ge detector array GRAPE which composed of 12 Ge crystals surrounding the target around 120 degrees with respect to the beam axis. Each crystal was placed at a distance of 135 mm from the target. To decrease backgrounds originated from environmental γ rays and neutrons, seven BGO crystals with a size of $80\times250\times25$ mm^3 were arranged at the upstream and downstream of the GRAPE. Doppler-corrected γ-ray energy spectra using the target system-2, which was obtained in coincidence with inelastically scattered ^{32}Mg isotopes. A γ-ray peak at 895(10) keV was observed, which is attributed to $2^+_1 \rightarrow 0^+_{g.s.}$ transition in ^{32}Mg. As expected, it really has a double-peaked structure and life time of the 2^+ level was successfully extracted by the RDM.

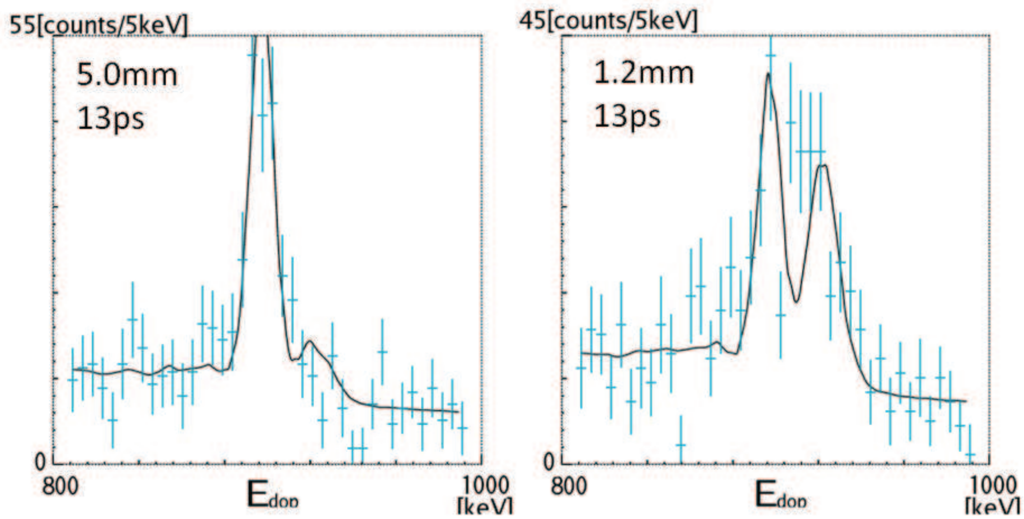


Figure 5.7: Doppler corrected γ-ray energy spectrum of ^{32}Mg obtained in the RDM measurement. Left panel corresponds the distance between the target and degrader is 5 mm while right panel is that for 1.2 mm.

5.4.2 High-spin states in neutron-rich nuclei

Development of low-energy RI beams

In-beam gamma-ray spectroscopy by fusion-evaporation reactions is one of the most efficient methods for the study of nuclear structure at high spin, since large amounts of angular momentum can be brought into the system. However, nuclei produced via fusion-evaporation reactions using stable isotope beams are limited, in many cases, to the proton-rich side relative to the β-stability line. In order to investigate high-spin states of neutron-rich nuclei by the fusion-evaporation reaction, it is necessary to use neutron-rich secondary beams. In the region closed to the doubly magic nucleus ^{48}Ca, the onset of deformed collective states due to the presence of deformed shell gaps in Z = 20, 22 and N = 28 are expected at high-spin. In order to actualize the high-spin studies of these neutron-rich nuclei, we have developed a low-energy RI beam, ^{46}Ar, which can be utilized for the fusion-evaporation reaction ^{46}Ar+^{9}Be to populate high-spin states of neutron-rich Ca and Ti isotopes.

The following experiment was performed at RIKEN Projectile fragment Separator (RIPS) in RIKEN Accelerator Research Facility. A neutron-rich ^{46}Ar beam was produced by projectile fragmentation of a primary beam of ^{48}Ca at 64 MeV/nucleon bombarding the primary target of 1.625 mm-thick ^{9}Be and separated by RIPS. An aluminum curved degrader with thickness of 0.6 mm placed at the momentum dispersive focal plane (F1) was used to achieve a clear isotope separation as well as to lower the energy of the secondary beam to $\sim$24 MeV/nucleon. The particle identification of the fragments was performed by measuring time-offlight (TOF) and energy loss (ΔE). The TOF was obtained from the timing information between plastic scintillator of 0.1-mm thickness placed at the achromatic focal plane (F2) and two PPACs (Parallel-Plate Avalanche Counter) at the third focal plane (F3). A purity of ^{46}Ar beam was 99The ^{46}Ar beam was further lowered in energy using a rotatable aluminum degrader of 0.3-mm thickness placed at F2. The energy of the secondary beam was adjusted by changing the rotation angle of the degrader relative to the beam direction and the TOF between F2 and F3 was measured on an event by event level. The energy was optimized to produce ^{50}Ti at the maximum cross section by a measured and calculated excitation function. The low-energy beam was transported to F3, where a thin ^{9}Be of 10-μm thick secondary target was placed for the fusion-evaporation reaction. A typical intensity of 1.0×10^{6} particle per second was obtained at the secondary target.

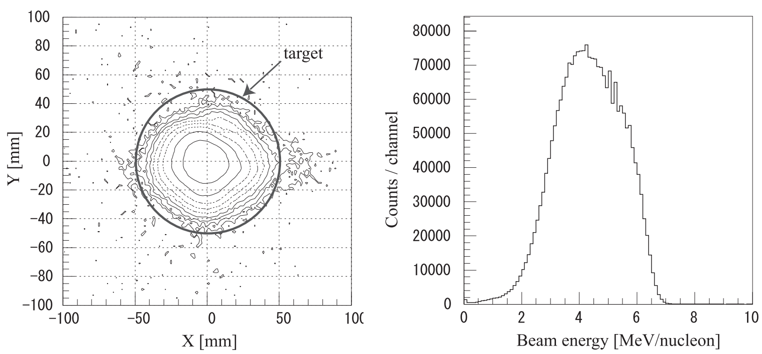


Figure 5.8: Profile(left panel) and energy distribution (right panel) of ^{46}Ar beam at the secondary target position.

This method can also be applied to the other mass regions in neutron rich as well as proton rich. Since the fusion reaction is suitable to access to the proton rich region, it will enable to study excited states near $N = Z$ nuclei. Low-energy RI beam is also useful for the experiment of multiple Coulomb excitation of RI beam itself. We intend to apply the secondary fusion as well as Coulomb excitation by means of low-energy RI beams to expand the region of high-spin studies which were not accessible with stable isotope beam experiments at the most advanced RI-beam facility (RIBF).

Spectroscopy of high-spin states in $^{49-51}$Ti by using fusion reaction of low-energy RI beams

In neutron-rich A$\sim$50 isotopes, studies of the shell structure are recently gaining much attention from both the theoretical and experimental point of view. One example is the appearance of N = 32 and/or 34 sub-shell closures by changing the single-particle orbits in this mass region. A spectroscopic study of the yrast high-spin states provides important information on the presence of shell gaps, since large jumps in transition energies at high-spin values are often assessed as an indicator of excitations that involve breaking of the core; states with higher angular momentum are generated from excitations across a shell gap. In the yrast levels of ^{50}Ti, a large gap in the excitation energy between 6^+ and 7^+ states is understood as a one-particle one-hole (1p1h) excitation across the N = 28 shell gap, and many shell model calculations predict that the N = 28 gap persists in neighboring nuclei of ^{50}Ti.

In order to populate high-spin states of neutron-rich Ti isotopes, $^{49-51}$Ti, we employed a new method using a low-energy neutron-rich radioisotope (RI) beam. Since ^{50}Ti is most neutron rich in Ti isotopes, high-spin states in this region is not accessible through conventional fusion reaction using stable isotope beam and the usage of secondary fusion reaction induced by the neutron-rich RI beams is necessary for such studies. In-beam γ-ray spectroscopy was performed to study the shell structure at high spin in $^{49-51}$Ti via the fusion-evaporation reaction using a secondary ^{46}Ar beam by the ^{9}Be(^{46}Ar, xn)$^{55-x}$Ti reaction.

Gamma rays emitted from evaporation residues were detected by an array of germanium detectors: Gamma-Ray detector Array with Position and Energy sensitivity (GRAPE) together with two clover and one coaxial germanium detectors. The GRAPE consists of 18 high-purity germanium detectors, and each detector contains two crystals of 6 cm in diameter and 2 cm thick sharing a common anode between them. Each cathode is segmented into a 3×3 matrix. The GRAPE provides position information of the interaction point of the γ-rays, which is extracted from a pulse shape analysis of output signals from the cathode. The opening angle of each γ-ray was deduced from the position of the incident and outgoing particles of the target as well as the detection points of the γ-rays, and used for the Doppler-shift correction. These γ-ray detectors were placed around the secondary target to cover the angular range between 30° and 120° relative to the beam direction.

Events associated with the fusion-evaporation reactions were identified based on the velocity difference between the beam and reaction products. By gating on a relatively low-velocity region in the energy spectrum of the outgoing particles, accidental coincidence background mainly from the β-decay of ^{46}Ar was significantly reduced. The evaporation channel was further separated based on a cross-section dependence of the incident beam energy. The energy of the ^{46}Ar beam was distributed between 2 and 8MeV/nucleon at the secondary target due to the energy straggling after passing through the degraders and the beam line detectors. By gating on a different region of the beam energy spectrum, excitation functions of each γ-ray were obtained and used for the identification of the evaporation channel. Based on this excitation-function analysis and $\gamma - \gamma$ coincidence relations, level schemes of $^{49-51}$Ti were constructed and the high-spin levels at 7050 keV in ^{49}Ti and at 4406 and 5246 keV in ^{51}Ti were newly identified. The observed levels were compared with full-pf-shell model calculations, and the yrast level structure indicates the persistency of N=28 shell gaps in $^{49-51}$Ti.

5.4.3 High-spin states studied using stable beams

Study of Superdeformation in ^{40}Ar

After a systematic investigation of superdeformations in various mass regions, a new 'island' of superdeformed (SD) nuclei was found in the nuclear chart around A $\sim$ 40 (i.e., ^{36}Ar, ^{40}Ca, and ^{44}Ti). SD shell structure in this mass region plays an important role in forming such large deformed structures. In this mass region, presences of SD shell gaps at N=Z=18, 20, 22 are predicted and another SD structure associated with Z=18 and N=22 SD shell gaps is expected in high-spin states of ^{40}Ar. In order to investigate such SD band in ^{40}Ar, we have performed an in-beam γ-ray spectroscopy using a ^{26}Mg(^{18}O, 2p2n)^{40}Ar reaction.

The experiment was performed at the tandem accelerator facility of the Japan Atomic

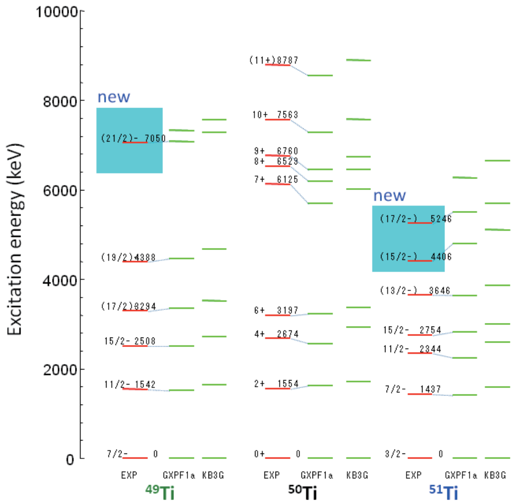


Figure 5.9: Experimentally obtained excited energy levels of $^{49-51}$Ti and comparison with the shell model calculations.

Energy Agency. An ^{18}O beam of 70 MeV was used to irradiate the two stacked ^{26}Mg target foils of 0.47 and 0.43 mg/cm^2 thickness. High-spin states in ^{40}Ar were populated via the ^{26}Mg(^{18}O, 2p2n)^{40}Ar reaction. Gamma rays were detected by the GEMINI-II array comprised of 16 HPGe detectors with BGO Compton suppressor shields, in coincidence with charged particles detected by the Si-Ball, a 4π array consisting of 11 ΔE Si detectors.

After examining the $\gamma - \gamma$ coincidence relations by gating on the low-lying known γ-ray transitions, a rotational band consisting of five γ-ray transitions ranging from 2^+ to 12^+ states was newly identified.

To determine the deformation of the band, the transition quadrupole moment Q_t was deduced from the residual Doppler shift analysis to be ~1.45 eb. This result indicates the superdeformed shape of the band with the deformation parameter $\beta_2 \sim 0.5$.

This is a first example to find SD band in Japanese accelerator facility.

Study of High-Spin States in ^{35}S

We have been systematically studying high-spin states in A=30~40 nuclei to clarify the superdeformed (SD) shell structure and to investigate the spherical and SD shape coexistences in this mass region. Recently, we have found a SD rotational band in ^{40}Ar and the SD region in A=30~40 nuclei is extended from N=Z (i.e., ^{36}Ar, ^{40}Ca and ^{44}Ti) to neutron-rich side. Another SD shell structure is predicted in Z=16 and the onset of SD bands in sulfer isotopes is expected. Cranked Skyrme-Hartree-Fock calculations predict the SD structure in ^{32}S and ^{36}S isotopes. However, spectroscopic studies of sulfer isotopes are not well explored and only low-lying levels near the ground state are studied. In order to clarify high-spin levels and to investigate collective structure in ^{35}S, we have performed an in-beam γ-ray spectroscopy experiment.

The experiment was performed at the tandem accelerator facility of the Japan Atomic Energy Agency and the Cyclotron and Radioisotope Center, Tohoku University. A ^{26}Mg(^{18}O, 2p2n)^{40}Ar fusion-evaporation reaction was employed to populate high-spin states in ^{35}S. Same setup as

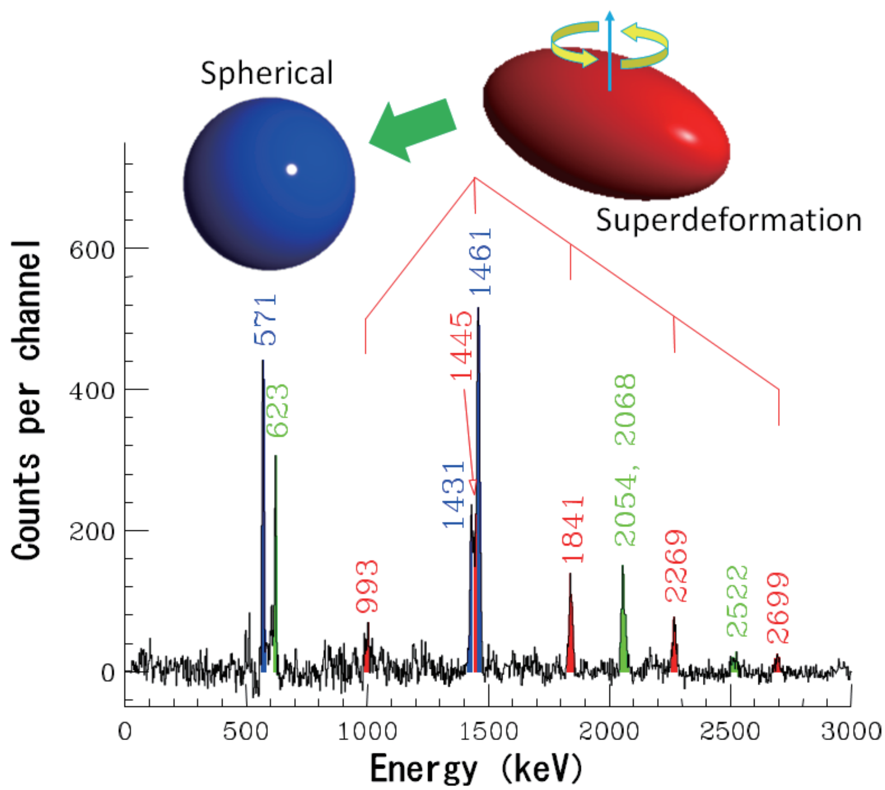


Figure 5.10: Gamma-ray spectrum from ^{40}Ar.

the case of ^{40}Ar study was used for γ-ray measurements.

In ^{35}S, spin-parity of ground state is $3/2^+$ and at 1.991 MeV, the $7/2^-$ isomeric state with a half-life of 1.02(5) ns is known, but higher-spin levels have not been identified. In our measurement, several γ-ray transitions are found in coincidence with the 1991 keV transition and excited levels were newly identified. In order to assign spins and parities of these levels, DCO analysis was performed. In addition, linear polarization measurements of γ rays have been performed in order to fix the spins and parities of high-spin levels.

Search for Superdeformed Band in A$\sim$110 Region

Study of superdeformed (SD) nuclei provides unique testing ground for the shell structure at extreme deformation. Recent experimental work of Clark et al in ^{108}Cd suggests a new SD region in A$\sim$110 nuclei. It was discussed that the ^{108}Cd is most deformed among the SD nuclei. Theoretical calculations using a cranked Strutinsky method also predict that a new region of SD states in A$\sim$110 nuclei with $45 < Z < 49$ and 57<N<65. However, discovery of SD states was limited to ^{108}Cd so far. Systematic investigation of high-spin states in A$\sim$110 nuclei will be useful to understand how such extremely deformed structure emerges in this mass region.

In order to find new SD nuclei in A$\sim$110 region with 45<Z<49 and 57<N<65 systematically, we have performed in-beam γ-ray measurements using a ^{20}Ne + ^{96}Zr reaction to investigate high-spin states of ^{107}Cd next to the ^{108}Cd, where a presence of SD structure is expected at high-spin levels. The experiment was performed at the Cyclotron and Radioisotope Center, Tohoku University. The ^{20}Ne ions, accelerated by the 930 cyclotron to an energy of 131 MeV, were used to bombard a stack of two self-supporting ^{96}Zr targets of 0.5 mg/cm^2 thickness.

High-spin states in ^{107}Cd were populated by ^{96}Zr(^{20}Ne,1α5n)^{107}Cd reaction.

Prompt γ rays were detected by Hyperball-2 array composed of 12 coaxial Ge detectors and 6 Clover Ge detectors in this experiment. Clover detectors were placed at 90° and coaxial detectors were placed at ~46° and at ~134° (6 detectors each) relative to the beam direction. Each Ge detector was shielded with BGO counters for Compton background suppression. Evaporated charged particles in the reaction were detected by the Si-Ball charged particle filter which consists of 30 Si detectors mounted on the truncated icosahedron shaped frame.

High-spin states in ^{107}Cd were previously studied up to the $(51/2^+)$ state at 11.852 MeV via ^{94}Zr(^{17}O,4n) reaction. Several negative- and positive-parity bands were observed and two of positive-parity bands (band 1 and band 2) were interpreted as being signature partners of a three-quasiparticle $\nu g_{7/2} h^2_{11/2}$ configuration. Based on single and double gating, coincidence relations between observed γ rays were examined. Previously reported γ transitions up to the $47/2^+$ state were confirmed. In addition, new γ-ray cascade transitions (band 3) connecting to band 1 and 2 were identified. However, excitation energy and the spin are not determined since linking transitions were not observed. Multipolarities of the transitions were checked by the angular distribution analysis and it is consistent with the E2 character of the transitions.

In order to estimate the size of deformation of the band 3, dynamical moment of inertia ($J^{(2)} \equiv \hbar^2 \frac{dI}{d\omega}$) is compared with those of band 1 and 2 and with that of SD band in ^{108}Cd. Although the number of transitions of band 3 is not large, $J^{(2)}$ values of band 3 is larger than those of band 1 and 2 and comparable with those of SD band in ^{108}Cd. This may indicate the large deformation of the band 3.

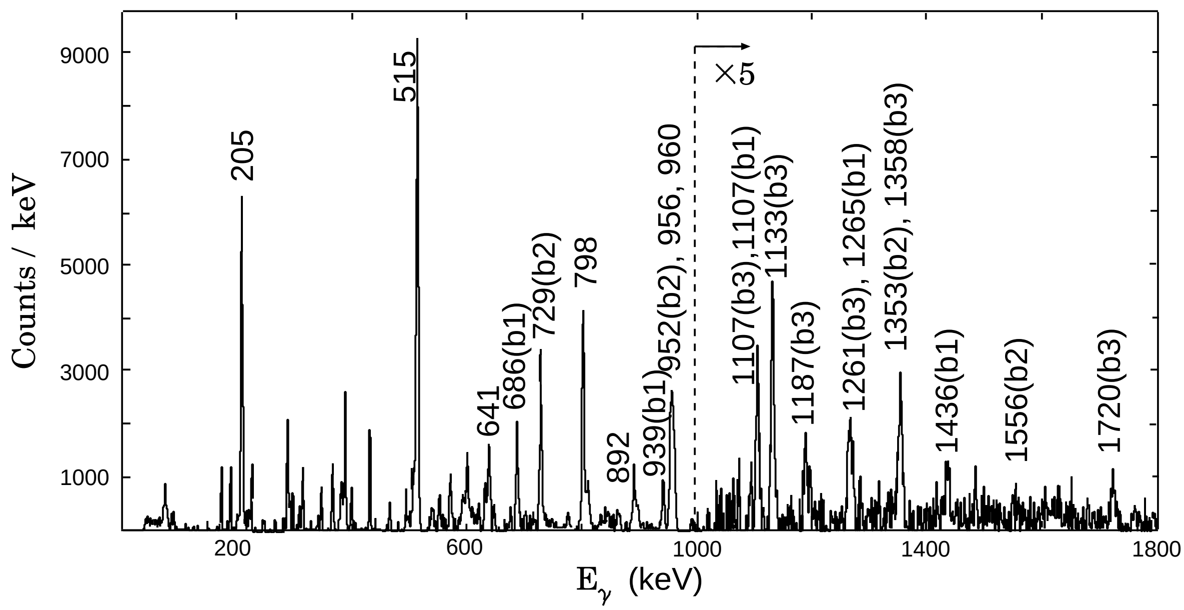


Figure 5.11: Gamma-ray energy spectrum gated by 1076 and 493 keV transitions. Assigned γ peaks are labeled with their transition energy in keV. In-band transitions of band 1, 2, 3 are also labeled with (b1), (b2), and (b3), respectively.

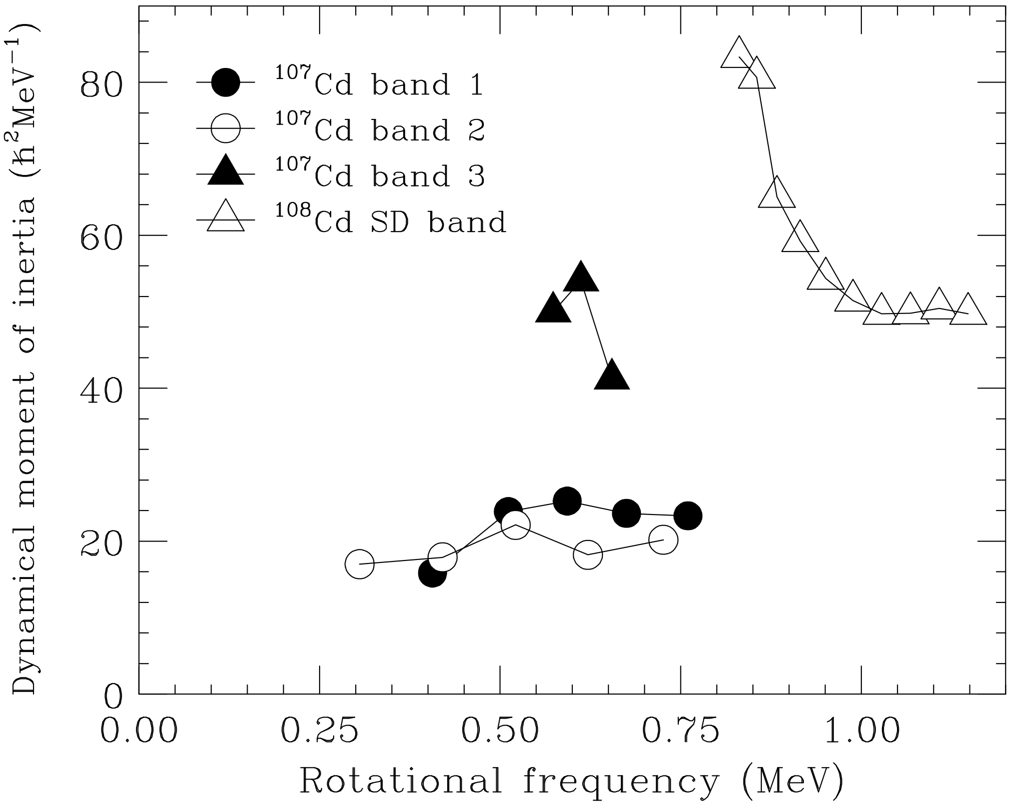


Figure 5.12: Dynamical moments of inertia for band 1,2,3 of ^{107}Cd and that of superdeformed band in ^{108}Cd.

5.4.4 Experiments at BigRIPS

Gamma-ray spectroscopy around ^{54}Ca

The neutron-rich nucleus ^{54}Ca is a key nucleus for the shell evolution in fp-shell nuclei. The ^{56}Ti and ^{55}Sc nuclei from projectile fragmentation reaction of ^{70}Zn at 345 A MeV were used for production of ^{53,54}Ca via nucleon knockout reactions. Gamma rays were detected by the DALI2 array and at least three transitions were identified.

Isomers in neutron-rich deformed region around $Z \sim 60$ and $N \sim 100$

Neutron-rich $Z \sim 60$ isotopes produced at the BigRIPS at RIKEN RIBF by in-flight fission of ^{238}U at 345 A MeV. By analyzing delayed γ-rays 19 new isomers were identified (Fig. 5.13) and evolution of deformation in the nuclei in the neutron-rich deformed region.

5.4.5 GRAPE (Gamma-Ray detector Array with Position and Energy sensitivity)

The GRAPE array was developed for high resolution γ-ray spectroscopy for in-flight excited nuclei of more than 25% of the light velocity. The array consists of 18 detectors, each of which has two 3×3-segmented Ge crystals of planar type.

We established a simulation of the pulse shape as a function of the interaction position and developed circuits for analog shaping and timing pickup which corresponds to the depth of

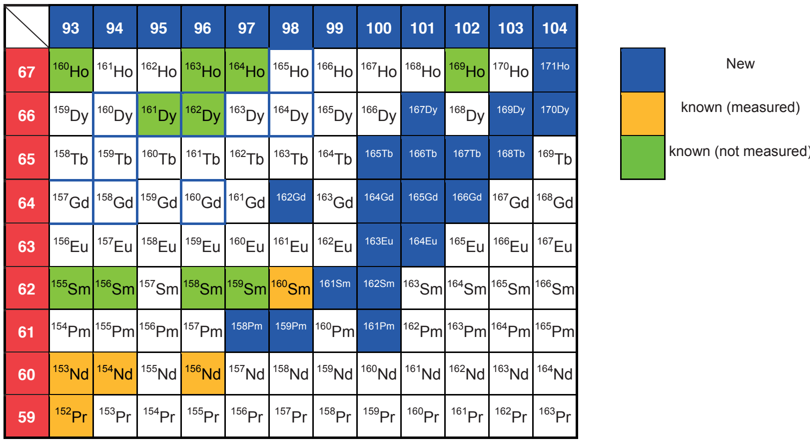


Figure 5.13: Isomers in the $Z \sim 60$ region. The label of 'New' denotes new isomer.

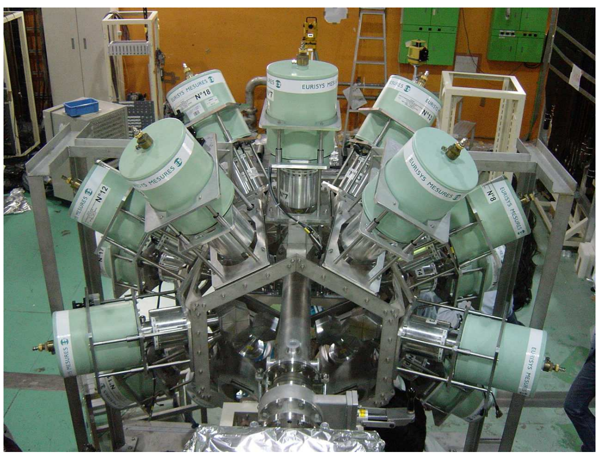


Figure 5.14: Photograph of GRAPE

the interaction (one dimensional). Overall performance of the GRAPE was demonstrated by a measurement of ^{4}He(^{32}Mg,^{32}Mg γ) reaction at 40 A MeV as shown in Fig. 5.15. It is noted that by using

In order to obtain three dimensional position sensitivity and for easier tuning, we started upgrade of acquisition system based on digital pulse-shape processing. We developed VME modules as dedicated digitizing system by using sampling ADC, FPGA, ethernet interface, etc. This upgrade is expected to enhance in-beam spectroscopy experiments, as well as other applications such as γ-ray imaging.

Table 5.6: Specification of GRAPE

Efficiency ($\epsilon\Omega$) for 1 MeV γ	$\sim$ 5 %
Position Resolution	< 2 mm (FWHM)
Resolution of Doppler Correction for v/c=0.3 emitter	< 1.4 %

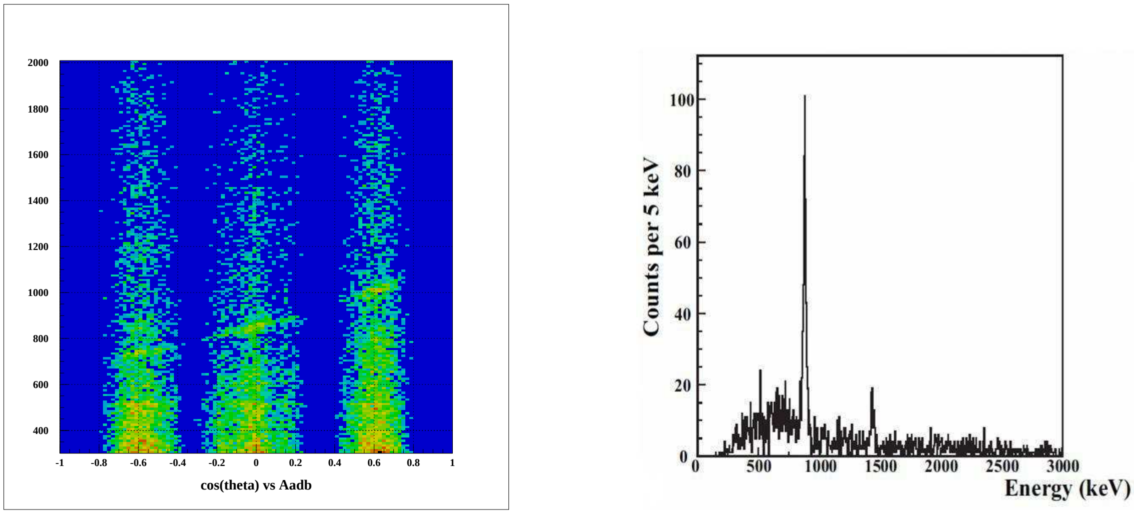


Figure 5.15: Left: Two dimensional histogram as a function of the emission angle and the laboratory energy of γ-rays from $^{4}He(^{32}Mg,^{32}Mg\ \gamma)$. Right: Energy spectrum of γ-ray from ^{32}Mg after correction of Doppler shift, which is obtained by selecting events under the condition that two or more segments in a detector give energy signals.

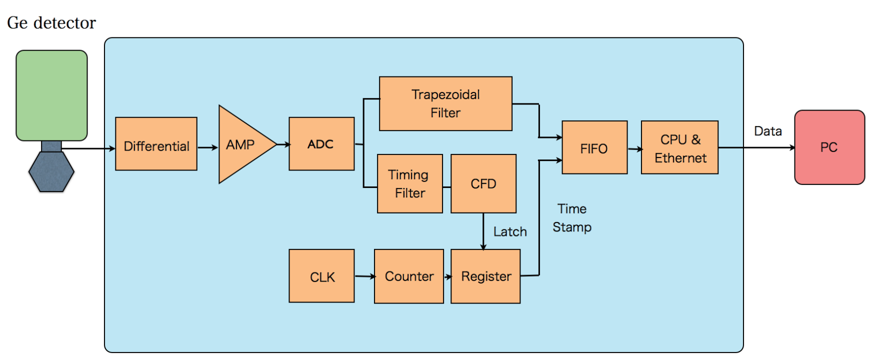


Figure 5.16: Dedicate VME modules for GRAPE (Left) and block diagram implemented in the module (Right).

5.5 Polarized target and heavy ion spin physics

Research in nuclear physics is being advanced using a spin polarization probe. Emphasis is being placed on research primarily using a polarized target in the investigation of unstable nuclides. In addition, research on spin-isospin responces using heavy ion charge exchange reactions induced by unstable nuclei (refer to the section on the SHARAQ Project) is being carried out along with the investigation of forward-angle scattering using an active target (refer to the section on the Active Target Project).

5.5.1 Development of polarized-proton solid-state target and polarized-proton scattering on neutron-rich nuclei

The establishment of the first polarized-proton solid-state target in the world for an unstable beam experiment was carried out. The most significant characteristic of this polarized target is that it operates at a temperature of 100 K and in a low magnetic field of 0.1 T, in contrast to existing polarized-proton solid-state targets, which operate at only ultralow temperatures (<1 K) and in high magnetic fields (>>1.5 T). Due to this, the detection of low energy recoil protons has become possible for the first time, facilitating polarized proton and unstable nucleus beam scattering experiments.

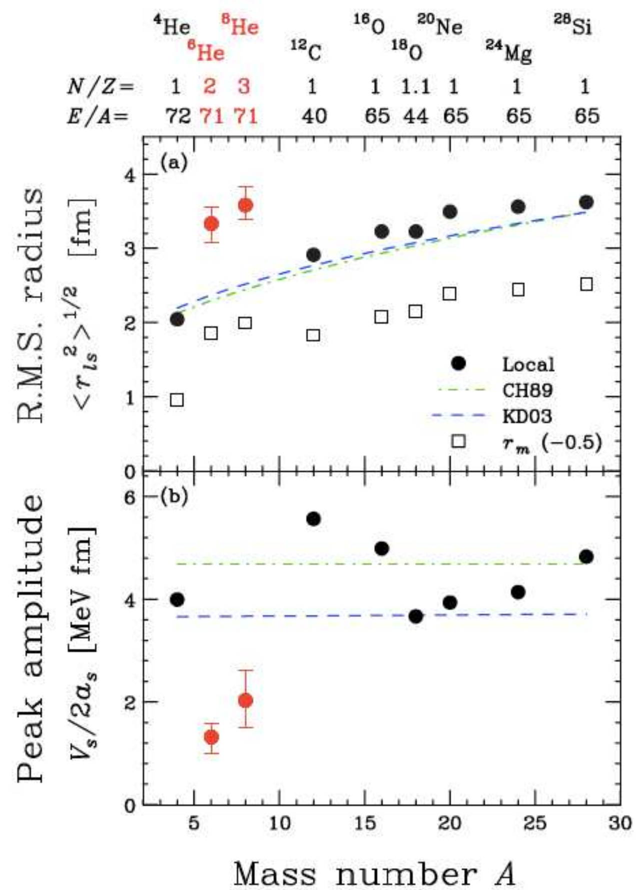


Figure 5.17: The depth of the LS potential and the root mean square radius for ^{6}He and ^{8}He.

The results of p-^{6}He nucleus elastic scattering carried out at the RIKEN RIPS facility using a polarized-proton target at an incident energy of 71 MeV/u were published in Physical Review C (PRC): "T. Uesaka, S. Sakaguchi et al., PRC 82, 021602R (2010) and S. Sakaguchi et al., PRC 84, 024604 (2011)." This was the first report in the world on spin polarization quantity measurements in an unstable nucleus scattering experiment. From the results on the analyzing power measurement for the above ^{6}He and for the p-^{8}He nucleus elastic scattering carried out in 2007 at 71 MeV/u, it became evident that the depth of the spin orbit potential for these wakly-bound nuclei was shallow at under half in comparison to stable light nuclei and that the root mean square radius increased 30-40%. The doctoral dissertation summarizing these results (Sakaguchi) was highly evaluated, and won the 17th Award for Outstanding Young Physicists –Experimental Nuclear Physics– in 2011

Spectroscopic studies on single vacancy states by (p, pN) reaction

The nucleon knockout (p,pN) reaction is the most effective method of single particle state spectroscopy in the energy range of 200-300 MeV/u acquired at RIBF. By incorporating a spin-asymmetry measurement using polarized protons into this method, it is possible to determine the total angular momentum J for the orbit the knocked-out nucleon occupied without uncertainty. A ^{18}O$(p,2p)$ reaction experiment was carried out using a 200 MeV polarized proton beam at the Osaka University RCNP in 2010 as a pilot experiment for oxygen isotope research at RIBF. This research demonstrated the following: 1) the spin orbit splitting energy for the 1p orbit of ^{18}O ($S_{s1/2}$-$S_{p3/2}$) is small in comparison to ^{16}O at 500 keV, 2) it is necessary to evaluate the fragmented single particle strengths in determining this spin orbit splitting energy, and 3) in particular, the states at 10.1 MeV and 11.1 MeV which were first spin-parity identified in this experiment provides a non-negligible contribution. Based on these results, an experiment design was decided and an ^{14,22,24}O$(p, 2p)$ reaction experiment was carried out at RIBF in 2011. The data analysis for this experiment is currently underway.

Basic research and development for polarized targets

Basic research and development for polarized target is also proceeding in parallel with experiments. The following has been carried out to date: 1) study of correlation of laser pulse time structure and polarization rate, 2) basic research for the buildup of normal temperature proton polarization, 3) tests for the buildup of 13C nucleus polarization focusing on medical/biological research applications, and 4) the development of new excitation light sources. These developments will be continued hereafter, leading up to experiments at the RIBF.

5.5.2 Development of a high position-resolution neutron detector

The development of a neutron detector with a high position resolution of around 3.7 mm has been started in order to apply the knockout reaction described in the previous section to the investigation of neutron single particle states. A protopype neutron detector consisting of 100 fiber scintillators was produced in 2012. The cross-section and the length of each fiber scintillator were 3.7-mm square and 1 m, respectively. The light outputs from scintillators were amplified by using multi-anode photomultiplier. Its basic performance was measured at the Cyclotron and Radioisotope Center (CYRIC), Tohoku University. The data analysis for this experiment is currently underway.

5.5.3 Research on light neutron-rich nuclei using a heavy ion double charge exchange (^{18}O, ^{18}Ne) reaction

Research on a four-neutron system double Gamow-Teller state using an unstable nucleus-induced double charge exchange reaction is being planned at SHARAQ. Meanwhile, there have been a few instances of spectroscopic research using a heavy ion double charge exchange reaction to date and a detailed verification of the reaction analysis methods has yet to be carried out. Accordingly, systematic research on heavy ion double charge exchange reactions at from several tens to a few hundred MeV/u was started with a double charge exchange (^{18}O, ^{18}Ne) using a 80 MeV/u ^{18}O beam provided by the Research Centre for Nuclear Physics, Osaka University. The (^{18}O, ^{18}Ne) reaction is expected to has a high transition probability because of the mirror symmetry between the incident and scattering particles and then to has a large cross-section in contract to other heavy-ion double-charge exchage reactions.

An experiment studying ^{9}He and ^{12}Be using ^{9}Be and ^{12}C targets, respectively, was carried out. As a result, three strong peaks were observed in the ^{12}C(^{18}O,^{18}Ne)^{12}Be reaction. Whilst the results of reaction analysis by means of coupled channel reproduced the angular distribution well, it showed discrepancies of a few times to around 10 times in the absolute scattering cross-section. In the future it will be necessary to carry out a more detailed investigation of the reaction analysis from the point of view of the uncertainty in the optical potential. Meanwhile, the ratio of the cross-section of the 0^+_1 ground state and that of the 0^+_2 excited state acquired in this experiment implies that the $2p_{1/2}$ occupancy in the 0^+_2 is twice as large as that in the ground state, which is consistent with current knowledge. This signifies that the research on the structure of the nucleus using the heavy ion double charge exchange reaction is promising. [H. Matsubara, M. Takaki et al., to be published in Few Body Systems]

5.5.4 Development of a mid- to high-energy deuteron polarization analysis reaction

The polarized deuteron beam of maximum energy 880 MeV (440 MeV per nucleon) is a characteristic beam to rival the unstable nuclei at RIBF. Research on few-nucleon systems has been proposed using this beam. The development of the polarization analysis reaction necessary for performing experiments with a polarization beam was carried out at the Russian Joint Institute for Nuclear Research (JINR). In addition, the following research has been jointly advanced with the group led by Dr. Ladygin of JINR, based on an international exchange agreement concluded between the University of Tokyo School of Science and JINR in 2004. In 2005, a deuteron polarization gage was established inside the target section of JINR's superconductive synchrotron. [P.K. Kurilkin, T. Uesaka et al., NIM A 642, 45 (2011)] Using this target, polarization resolution Ay, Ayy and Axx of the proton-deuteron elastic scattering was measured at Ed = 270, 880, 2000 MeV. The results of experiments at 880 MeV showed that the vector polarization resolution (Ay) has a value of -0.2 for a scattering angle in the centre-of-gravity system greater than 60° to the rear, and that the tensor polarization resolution has a large value of around +0.6 by the same angle to the front. [P.K. Kurilkin, T. Uesaka et al., Physics Letters B 715, 61 (2012)] This research was highly evaluated by JINR and was given the Second Award in the technical development section at the JINR Scientific Council held in debris 2012 (the Japanese awardees were Suda, Maeda, Sakaguchi, Sasamoto, and Uesaka–all affiliated with CNS at the time of the experiment).

5.5.5 Research on the cluster state of carbon-proximate nuclei by α inelastic scattering

Research on cluster states is being carried out by α inelastic scattering. Inelastic scattering measurements were carried out on ^{11}B and ^{12}C using 400 MeV α beam at the Research Centre for Nuclear Physics, Osaka University, with the objective of demonstrating the effect of valence nucleons or holes in the cluster state. The excited state of a ^{11}B nucleus and a ^{13}C nucleus, which can be considered to be neutron or proton holes added to the second 0+ state of a ^{12}C nucleus (a well-known cluster state), was achieved by α inelastic scattering with the objective of extracting information relating to the acquired transition strength from the nucleus structure. The states having strong monopole intensity in the vicinity of Ex = 8.56 MeV ($3/2_3^-$) in the ^{11}B nucleus and at Ex = 8.86 MeV ($1/2_2^-$), 11.08 MeV ($1/2_3^-$), and 12.5 MeV in the ^{13}C nucleus. This result suggests the possibility that the states have a cluster structure similar to 0^+ of ^{12}C.Recently, a method using α elastic scattering has been developed for^{24}Mg. [T. Kawabata et al., Journal of Physics: Conference Series 321 (2011) 012012]

5.6 SHARAQ Project

The SHARAQ[2] Project was started in 2004. In March 2009, the High-resolution beamline and SHARAQ spectrometer were completed in RIBF by the collaboration with RIKEN Nishina Center and ICHOR project team of the University of Tokyo. The SHARAQ is aiming at high-resolution spectroscopy of RI-induced reactions at 100–350 MeV by the missing-mass method, and at extending a variety of research tools in the field of nuclear physics.

5.6.1 Experimental Devices

SHARAQ spectrometer and High-resolution beamline

The SHARAQ spectrometer and High-resolution beamline were in operation since March 2009. The devices were designed to satisfy the lateral-and-angular dispersion-matching condition. The momentum resolution and angular resolution of the total system were respectively evaluated to be $p/\Delta p = 15000$ and 1 mrad by a first-order ion-optical calculation. The commissioning runs were done in March and May 2009 to measure the transport matrix elements of the beamline and spectrometer by using ^{14}N beam at 250A MeV. Consequently we confirmed agreements between the measurement and the computational evaluation.

Figure 5.18: Photograph of SHARAQ spectrometer and High-resolution Beamline

Ion optics

We developed two ion-optical transport modes of the SHARAQ spectrometer and High-resolution beamline, the Dispersion-matching mode and the High-resolution achromatic mode, for fitting to each experimental requirement. The Dispersion-matching mode ion-optically achieved the momentum resolution of $p/\delta p = 3000$ (FWHM), and finally achieved 8100 (FWHM) by event-by-event correction of the beam vectors at BigRIPS-F3, where is the starting achromatic focus of the dispersion-matching.

Detectors

We are developing radiation detectors for beam particles and reaction products focusing low physical thickness, high detection efficiency, high position resolution and/or high timing reso-

[2]**S**pectrocopy of **H**igh-resolution **A**nalyzer of **R**adio**A**ctive **Q**uantum beams

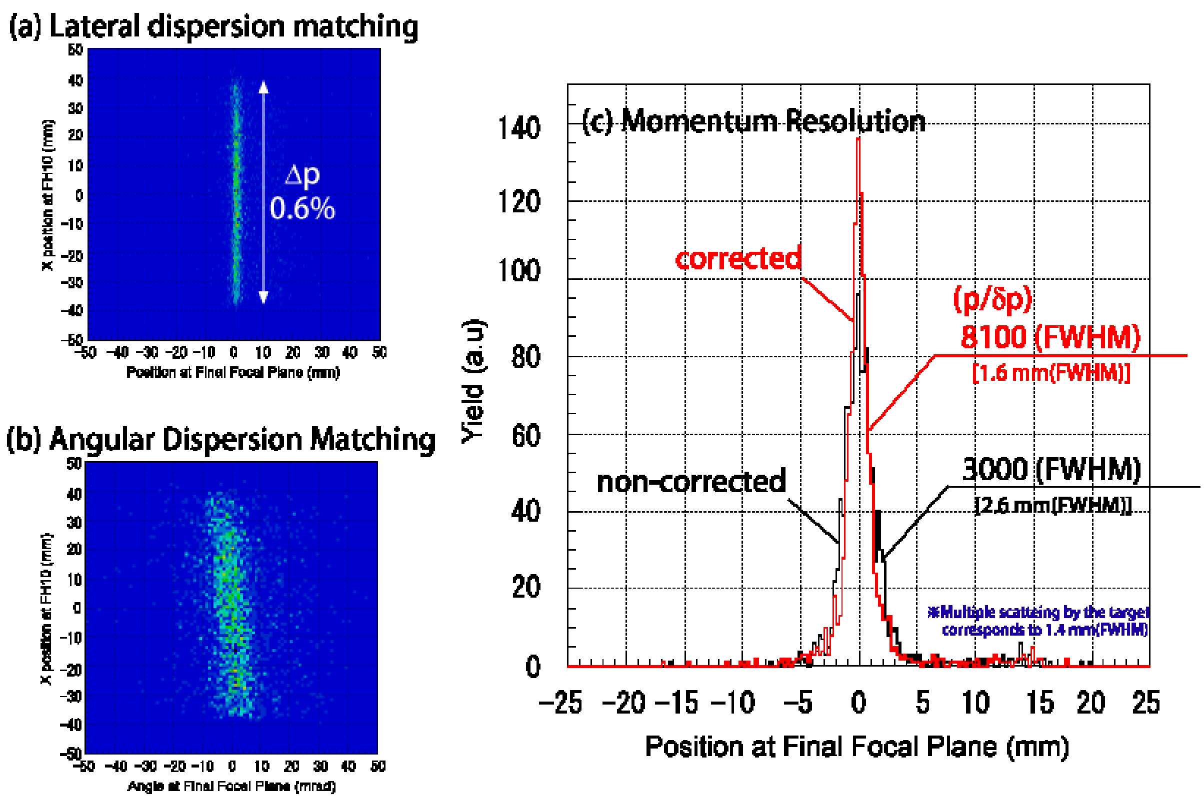


Figure 5.19: Performance of the Dispersion-matching Transport mode. (a) Lateral dispersion matching condition. (b) Angular dispersion matching condition. (c) Momentum resolution.

lution.

1. **Low-Pressure Multi-Wire Drift Chamber**
   We installed eight low-pressure multi-wire drift chamber (LPMWDC) in physics experiments for diagnosis, tuning of beam optics and correction for reaction products' momenta. The detectors achieved efficiencies of almost 100% even for light ions (Z = 1–7) by an operation with 8-kPa isobutane gas. The position resolution of the detectors was successfully 300 μm (FWHM). Furthermore the LPMWDCs are demonstrated to have good high-rate performance that the LPMWDCs stably operated during a 7-days measurement suffering from the ^{10}C beam of an intensity of 2×10^6 cps.

2. **Low-pressure Cathode-Readout Drift Chamber**
   We manufactured Low-pressure Cathode-Readout Drift Chambers (CRDCs) as tracking detectors for the final focal plane of the SHARAQ spectrometer. The detector was developed by an collaboration with CNS and GANIL, France. The detectors achieved efficiencies of almost 100% and position resolution of 500 μm (250 μm) in FWHM for 300A-MeV ^{3}He (200A-MeV ^{12}C) ions by an operation with 2-kPa isobutane gas.

3. **Plastic Hodoscope for Beam Tracking**
   We developed a plastic hodoscope for beam tracking at high-rate achromatic focus such as BigRIPS-F3. The hodoscope consists of 30 plastic scintillator bars of $1.0 \times 1.0 \times 30.0$ cm^3 arranged side by side, and has an active area 30 mm2. The readout is made by an multi-anode photomultiplier and the hit position determine a hit pattern. The detector achieved a detection efficiency of 80% for 2-MHz beam of the spot size of 3mmϕ.

4. **Diamond Detector**
   We are developing a timing detector made by CVD polycrystalline diamond to measure precisely the time of flight of the High-resolution beamline and SHARAQ spectrometer. The detector has a thickness of 200 μm and an active area of 28 mm^2. We manufactured 2 diamond detectors and examined the time-of-flight measurement of the dispersion-matching beam. The timing resolution of a diamond detector was estimated to be 26.8 ps (σ) for 8.8A-MeV ^{4}He and to be 30.0 ps (σ) for 200A-MeV ^{14}N.

5.6.2 Physics Program

The primary physics program of SHARAQ is study of collective excitation of nuclei by using charge exchange reactions. The most characteristic subject is the use of RI-beam induced reactions as probes. RI beams have a variety of isospin (T), spin (S), and internal energy (mass excess), while light stable beams such as proton, deuteron, and ^{3,4}He have $T, S \leq 1$ and the minimum internal energies among isobars. Due to the properties, RI-beam induced charge exchange reactions (RICE) have unique potentials which are missing in stable-beam induced reactions and can be used to reach the yet-to-be-discovered states.

RI beams produced at the RI Beam Factory at RIKEN have an energy ranging 150–300 MeV/nucleon which is most appropriate for spectroscopic purposes. At these energies, the nucleon-nucleon interaction is weakest and thus a nucleus is most transparent. Therefore one can expect that absorption or distortion effects is smaller than at other energies. It should be noted that at these energies the spin-isospin modes are most strongly excited relative to the spin-isospin independent ones. Thus the spin-isospin excited states are most clearly seen in this energy region.

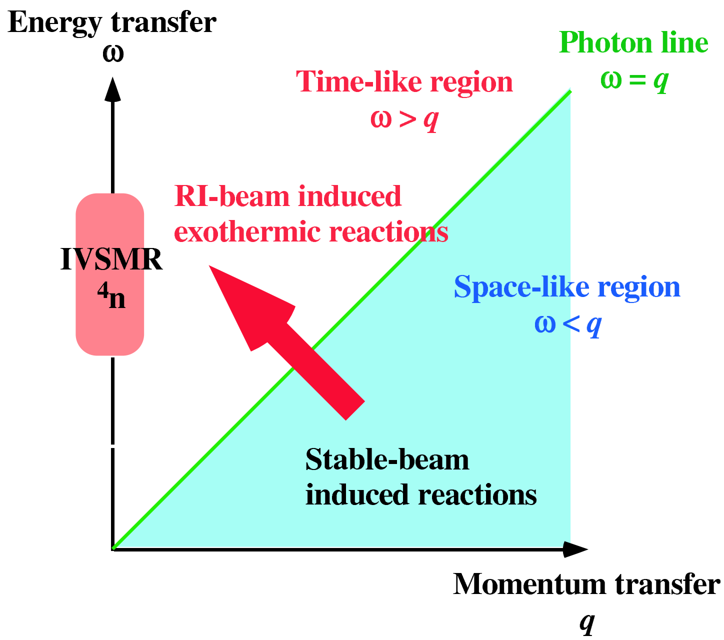


Figure 5.20: Momentum transfer q and energy transfer ω regions achievable with stable-beam induced and RI-beam induced reactions.

In some of the RI-induced charge exchange reactions, a large mass excess of unstable nuclei results in a large positive Q-value in the projectile. The Reaction of this kind is called exothermic charge exchange reaction and the internal energy of the projectile can be transferred to the target while the momentum transfer is kept small. With this capability, the exothermic reactions can be efficient in populating highly excited states in a recoilless manner. This allows us to study the nuclear excitations in the time-like ($\omega > q$) region[3] (See Fig. 5.20).

Taking advantage of this exothermic charge exchange reactions, we carried out the study of isovector spin monopole resonances in nuclei and tetra-neutron states as describe in the following.

Search of new resonance modes by charge exchange reactions

1. **Seach for isovector spin monopole resonance of the β^+-type**
   The first experiments with the SHARAQ spectrometer was performed to search for β^+-type isovector spin monopole resonances. The isovector spin monopole excitations are characterized by the same isospin and angular momentum transfer as the GT excitations ($\Delta T = \Delta S = 1$, $\Delta L = 0$), but with a radial node in the transition density ($\Delta n = 1$)[4]. The $(t, {}^3\text{He})$ reaction at 300 MeV/nucleon was used to extract β^+ strengths selectively. An intense triton beam of 10^7 Hz was produced by the projectile fragmentation of a primary 320-MeV/nucleon α beam and the scattered ^{3}He ions were momentum-analyzed by the SHARAQ spectrometer.

   Monopole cross sections of the $^{90}\text{Zr},^{208}\text{Pb}(t, {}^3\text{He})$ reaction were obtained through use

[3] This is the core idea of the ICHOR (= **I**spspin-Spin responses in **CH**arge-exchange ex**O**thermic **R**eations) project, which also gave the financial basis (Grant-in-Aid for Specially Promoted Research (MEXT): 2005-2009) of the kickoff of the SHARAQ project.

[4] This mode is related to the spin-isospin compressibility while α-inelastic scatterings is related to compressibility of nuclear matter

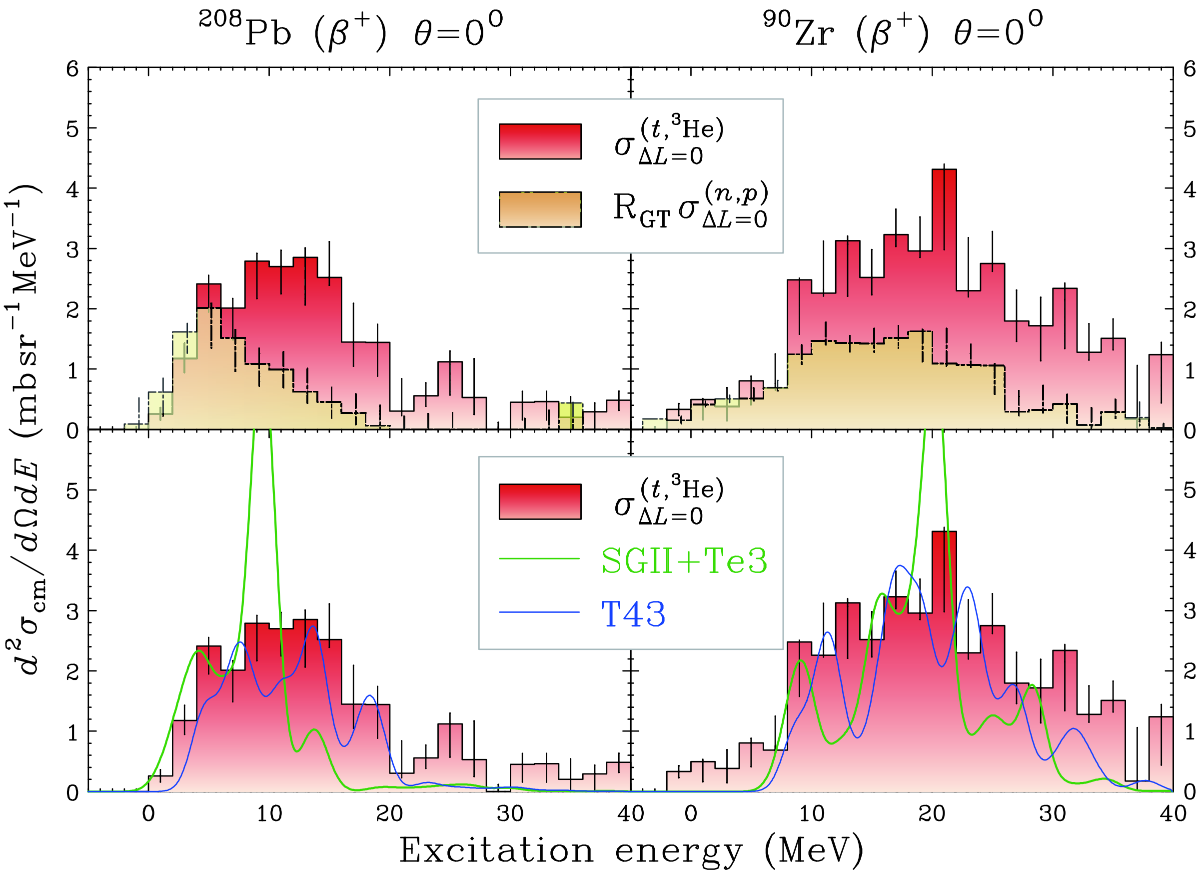


Figure 5.21: Monopole cross sections of the ^{90}Zr,^{208}Pb(t,^{3}He) reaction (red), together with those of the (n, p) reactions (yellow).

of the multipole decomposition analysis. The obtained monopole cross sections (red) are shown in Fig. 5.21, together with those of the (n, p) reactions for the same target (yellow). It is known that the (n, p) reaction is weakly sensitive to the IVSMR because of its transparent nature. Apparent enhancement from the (n, p) cross sections are observed, which are manifestations of IVSMR [Miki et al., PRL108(2012)262503.]

2. **Search of isovector spin monpole resonance of β^- type by exothermic charge exchange reaction**

   An experiment to prove the effectiveness of the exothermic charge exchange reaction was conducted by using the ^{90}Zr(^{12}N, ^{12}C) reaction at 200 MeV/nucleon with the SHARAQ spectrometer[S. Noji, doctoral dissertation]. The reaction has a large positive Q-value of +16.8 MeV in the projectile. We have applied this method to populate β^--type IVSMR for the ^{90}Zr target. Preliminary results clearly show that the cross section ratio of IVSMR to GT is largely enhanced in the (^{12}N, ^{12}C) reaction compared to the (p, n) reaction.

3. **Super-allowed Fermi type charge exchange reactions**

   RI-beam induced reactions provide us with a variety of spin-parity selectivities which are missing in stable-beam induced reactions. An interesting example is the (^{10}C,^{10}B(0^+; IAS)) reaction which selectively populates isovector ($\Delta T = 1$) non-spin-flip ($\Delta S = 0$) modes in nuclei. Here the super-allowed Fermi transition in a *projectile* is used to populate isovector

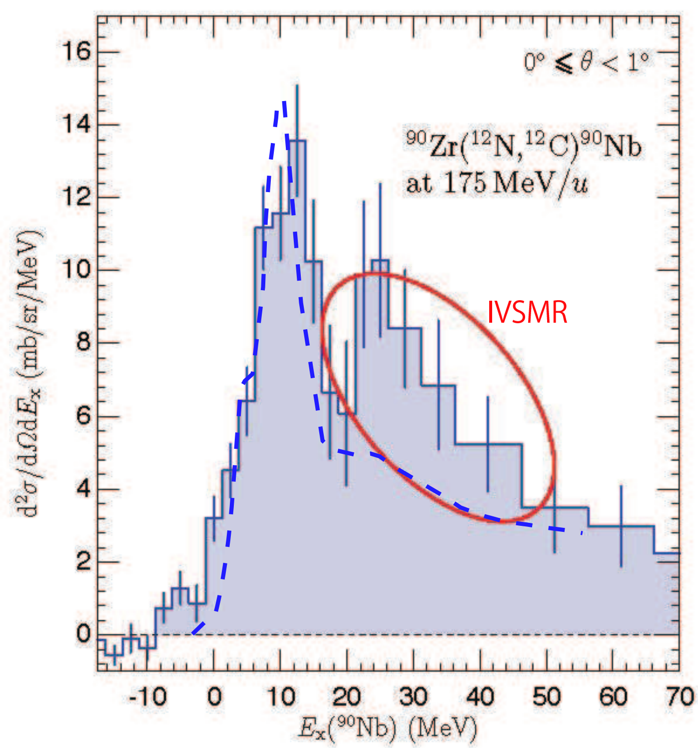


Figure 5.22: The $^{90}Zr(^{12}N, ^{12}C)$ spectrum at the forward angles. Overlaid dashed spectrum is the (p, n) data at 200 MeV for comparison[Prout et al., PRC63(2000)014603]

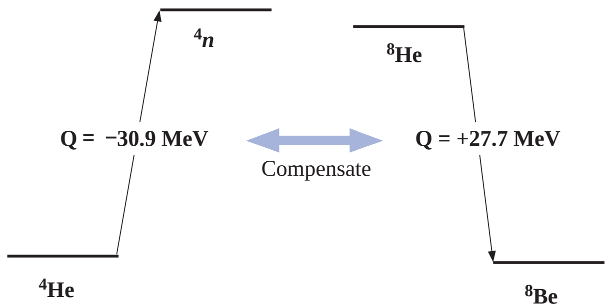


Figure 5.23: Energy balance in the exothermic ^{4}He(^{8}He,^{8} Be)^{4}n reaction.

non-spin-flip modes in a *target* nucleus. It should be noted that there is no stable-beam induced reaction which has the $\Delta T = 1$ and $\Delta S = 0$ selectivity with a reasonably large transition strength. The isobaric analogue state of the ^{10}C ground state is located at 1.740 MeV in ^{10}B. The transition to the 1.740-MeV state in the projectile can be tagged experimentally by detecting the de-excitation gamma-ray with an energy of 1.022 MeV.

The ^{7}Li, ^{90}Zr(^{10}C,^{10} B(0^+; IAS)) experiment to search for isovector non-spin-flip monopole resonances was performed with the SHARAQ spectrometer in 2010.The 200-MeV/nucleon ^{10}C beam with an intensity of $2{\times}10^6$ sec^{-1} bombarded the secondary ^{7}Li and ^{90}Zr targets. Scattered ^{10}B particles were analyzed by the SHARAQ spectrometer and de-excitation gamma-rays were detected with the NaI(Tl) detector array DALI2surrounding the target. In the Doppler-corrected gamma-ray spectrum, the 1.022-MeV peak which is a signature of $\Delta S = 0$ transitions has been clearly observed.

4. **Study of tetra-neutron system by exothermic double charge exchange reaction** He(^{8}He, ^{8}Be)4n

   In spite of previous experimental efforts, existence of the tetra-neutron states is still controversial. An experiment to search for tetra-neutron states via the ^{4}He(^{8}He, ^{8}Be) reaction has been conducted in 2012. The exothermicity of the (^{8}He, ^{8}Be) reaction is advantageous in populating the fragile tetra-neutron states from the ^{4}He target. The energy needed in the target excitation is almost completely compensated by the positive Q-value in the projectile (See Fig. 5.23). The missing mass was obtained by detecting two α particles produced by the decay of residual ^{8}Be nucleus. The energy of the secondary ^{8}He beam was analyzed at the same time by the hi-resolution beamline to correct for the missing mass. The experiment at SHARAQ is expected to present more decisive information on the nature of tetra-neutron system.

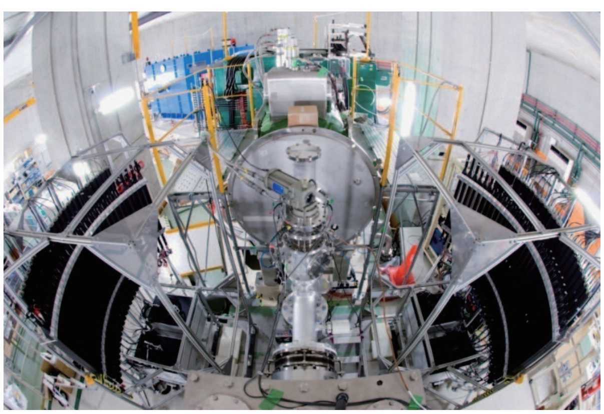
5. (p, n) **reaction in inverse kinematics**

   The spin-isospin excitations in nuclei provide a good basis for studying a nuclear structure. Although charge-exchange reactions, such as (p, n) and (^{3}He, t) reactions at intermediate energies, are established probes used to study these excitations in stable nuclei, the charge-exchange study of unstable nuclei is currently only in its early stage. Experiments in inverse kinematics are challenging mainly because the recoils on the probe particle are small. Generally, the detection of recoil particles with kinetic energies below ∼3 MeV is required for the study of Gamow-Teller excitations.

   We constructed a facility at SHARAQ where the (p, n) reactions on unstable nuclei can be studied. It consists of a liquid-H_2 (LH_2) target in a scattering chamber made with 1.6 mm-thick aluminum, the magnetic spectrometer SHARAQ, and the wide-angle inverse-kinematics neutron detectors for SHARAQ (WINDS). A photo of WINDS is shown in Fig. 5.24(left) WINDS is a set of neutron counters on each (left and right) side of the target, covering the angular region $60^\circ < \theta_{\mathrm{lab}} < 120^\circ$. The distance between the target and the counter wall is 180 cm. The left (right) counter wall consists of 30 (29) plastic scintillators (BC408) of $60 \times 10 \times 3$ cm^3. These scintillators are placed such that the 3-cm-wide planes face the target. The missing mass spectra of the (p,n) reaction are derived from the scattering angle of the neutron (θ_{lab}) and its kinetic energy (T_n) which is measured by the time-of-flight (TOF) method.

In June 2011, we performed the measurement of the ^{12}Be(p,n) reaction as the first (p,n) measurement in inverse kinematics at RIBF. A primary beam of ^{18}O was accelerated up to 250A MeV, and it was focused on the production target of 20-mm-thick Be at BigRIPS-F0, yielding a secondary ^{12}Be beam of 200A MeV a purity of 95%. It was transported to a liquid hydrogen target at the pivot position of SHARAQ (S0). SHARAQ and the detectors at its focal plane (S2) were used to tag the residual nucleus (^{12}B) or its decay products (^{11}B or ^{10}B).

Figure5.24(right) shows the spectrum of the ^{12}Be$(p,n)^{12}$B reaction with tagging of ^{12}B at S2, covering the excitation energy region of 0 to 3.4 MeV. Here, the angular distributions of Gamow-Teller (GT) and spin-dipole components are expected to have peaks at $\theta_{\mathrm{cm}} = 0^\circ$ ($T_n \sim 0$ MeV) and 8–12° ($T_n = 4.5$–8.0 MeV), respectively. The observed locus is due to the GT transition to the ground state of ^{12}B. We observed the GT giant resonance of unstable nucleus for the first time in the spectrum where ^{11}B is tagged.



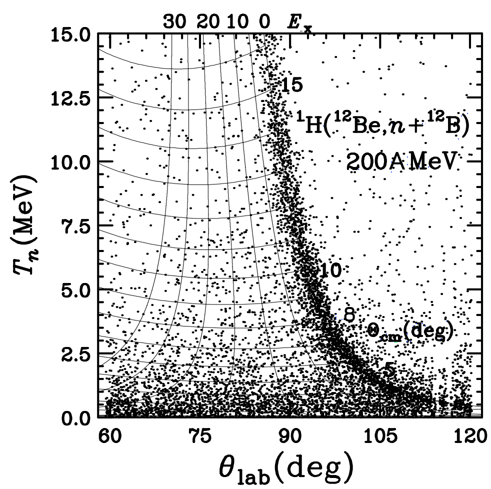


Figure 5.24: (left) A photo of WINDS. (right) ^{12}Be(p,n) spectra with tagging of residual ^{12}B nucleus at SHARAQ.

Measurement of $(p,2p)$, (p,pn) reactions by using the polarized proton target

The polarized proton target gives a new perspective on the study of unstable nuclei. See Sec. 5.5.1.

The followings are the experiments in preparation. We hope we have the beamtime in FY2013.

Mass Measurement Experiment by the Bρ-TOF method

We are promoting experiments to measure unstable nuclear masses by combining high momentum resolution of the SHARAQ system and the high timing resolution of the diamond detectors. By the above-mentioned developments of the High-resolution beamline, the SHARAQ spectrometer and the diamond detector, the present system has a performance of 300-keV mass resolution in the mass range of $A \sim 50$. Accordingly experiments for pf-shell nuclei are available when RIBF delivers proper primary beams.

Development of Parity-transfer probe: the $(^{16}\mathrm{O}, ^{16}\mathrm{F}(\mathrm{g.s.}))$ reaction

Among the isovector spin-dipole transitions 0^- excitations are of particular interest since they carry the simplest pion-like quantum number and thus they reflect pion-like correlations in nuclei. Also, recent calculations of nuclear structure such as self-consistent HF+RPA predict a characteristic behavior of collective 0^- resonance where the peak energy is strongly shifted toward high excitation energy due to tensor correlations. For the purpose of meeting the growing interest on 0^- excitations we propose a parity-transfer probe of $(^{16}\mathrm{O}(0^+), ^{16}\mathrm{F}(\mathrm{g.s}; 0^-))$ reaction.

The first experiment is the measurement of $^{12}\mathrm{C}(^{16}\mathrm{O}(0^+), ^{16}\mathrm{F}(\mathrm{g.s}; 0^-))$ reaction at $250A$ MeV to establish the effectiveness by observing the known 0^- state in (^{12}B) ($E_x = 9.3$ MeV) and another one at $E_x \sim 15$ MeV predicted by shell model. Since the scattered ^{16}F(g.s.) nucleus decays instantaneously into $^{15}\mathrm{O} + p$, we are preparing a multi-wire drift chambers to track the proton in coincidence with ^{15}O at the focal plane of SHARAQ.

We note that this measurement is currently feasible only at RIBF-SHARAQ because a high resolution is requied to isolate ^{16}F(g.s.) from other states.

5.6.3 Perspectives

Apart from the experiment already proposed, there are some ideas to extend the field of spin-isospin study by using SHARAQ.

- RI-beam induced double charge exchange reactions to study two-phonon resonances such as double Gamow-Teller resonance. Understanding of such resonance would better understanding of the nuclear matrix element of the double beta decay.
- Measurement of (p, n) reaction on various types of isomers. Technically, isolation of isomers by means of TOF from secondary beam is the key. The detectors developed for the mass measurement (Sec. 5.6.2) can be utilized.
- (n, p)-type reactions in inverse kinematics. By installing the active target filled by deuterium gas, one can measure the $(d, ^2\mathrm{He})$ reaction on unstable nuclei. Such a facility allows one to study the β^+ GT excitations of *fp* shell nuclei, which are important in understanding the processes related to supernova.
- Combining SHARAQ with gamma detectors surrounding the target.

5.7 Active Target Project

5.7.1 Active target for an intermediate energy high-intensity unstable nucleus beam

The equation of state for nuclear matter do not just characterize the bulk properties of nuclei, but also determine the characteristics of neutron stars. The derivation of the modulus of incompressibility, which is one of the parameters of the equation, is performed through the monopole and dipole resonance measurements. Furthermore, in the determination of the electron capture probability of chemical elements neighboring iron, which is a parameter that determines the lifespan of the initial stage of supernova explosions, the measurement of the Gamow-Teller transition intensity distribution is sought, and so naturally the measurement of monopolar excitation modes is necessary. Measurements of the forward angle scattering are essential for the derivation of monopole and dipole strengths, and the development of a deuterium CNS Active Target (CAT) (Fig. 5.25) has been promoted by Center for Nuclear Study, the University of Tokyo with the cooperations of RIKEN, Physics Department, the University of Tokyo, Kyoto University, and Miyazaki University in order to realize this.

The CAT consists of the GEM-TPC and two arrays of NaI detectors located at the both side of GEM-TPC. The vertex of reaction is determined using the GEM-TPC. The total energy of low-energy particle which stops in the active area of GEM-TPC is extracted from the range measured by the GEM-TPC and that of relatively high-energy particle which reaches at the NaI detector is measured by NaI. This system enables us to measure the reactions up to the 10-degrees scattering angles in the center-of-mass frame. There are a gap in the sensitivity for total energy deu to the spacial gap and the thick materials between the active area of the GEM-TPC and the NaI crystal. This problem should be solved in the future.

Figure 5.25: Schematic view of the CAT for intermediate-energy high-intensity unstable beam.

For GEM-TPC flight path reconstruction, one dimension (the z direction) is derived from the drift time, and the remaining two dimensions (the XY surface) are derived using the ratio of charges collected by equilateral trianglar shape pads. By using charge division, it is possible to acquire resolution sufficient even for a low pad number. So far, the basic properties for the case CNS-GEM (100 μm) He+CO2 (10%) gas and deuterium gas were used as an amplification gas at atmospheric pressure and the basic properties for the case Thick-GEM (400 μm) low pressure hydrogen and deuterium gas were used as an amplification gas have been investigated as basic research. In 2009, a prototype was manufactured and an evaluation of its performance was carried out using a 30-MeV helium beam at the Tsukuba University tandem accelerator facility. At this time, the position resolution in the Z direction and the XY plane using He+ CO2 (10%) was 70 μm and 700 μm, respectively. In 2010 and 2011, an operational test using deuterium gas was carried out at the HIMAC of the National Institute of Radiological Sciences using a 250 MeV/u 56Fe beam. The institute has succeeded in confirming behavior under a beam exposure of up to 300 kHz and the detection of the recoil particle flight path. The data analysis for this experiment is currently underway. In 2012, an experiment to measure giant resonance was executed using an oxygen beam. The advancement of giant resonance measurements with regard to intermediate unstable nuclei is planned for the future at RIBF.

5.7.2 Active target system at CRIB for nuclear astrophysics

To perform a complete identification of reaction products, we have been developing an active target system as shown in Fig. 5.26, since 2008. Is was manufactured based on the active target system previously built at KEK, which is referred to as GEM-MSTPC. Basically it consists of a time projection chamber (TPC), which measures 3-dimensional trajectories of the particles inside the chamber. Using GEM as the readout, the TPC correctly works against beams with a relatively high rate of 10^6 pps. Our GEM-MSTPC was designed for (α, p) reaction measurements using RI beams, and it has low-gain GEMs to measure RI beams, and high-gain GEMs to measure protons, separated in regions. He+CO_2(10%) gas is filled in the chamber, and the helium gas serves as the detector gas and the reaction target simultaneously.

The GEM-MSTPC has been used for actual reaction measurements of ^{18}Ne(α, p), ^{30}S(α, p), ^{22}Mg(α, p) at CRIB in 2010–2011.

Usage of the active target (GEM-MSTPC) at CRIB enables us a new type of measurement which was not possible with previous targets. GEM-MSTPC has been used for several (α, p) reaction measurements, however, none of them yielded an excitation function of the reaction cross section as a final result yet. One major reason is that the complexity of the system is making the analysis extremely time-consuming. Currently an analysis framework is being made for the analysis of ^{30}S(α, p) reaction measurement, and the analysis environment should be much improved in future experiments.

A proposed experiment using the active target is for ^{16}N decay. The ^{12}C(α, γ) is a main reaction of the helium burning, but its cross section at low-energy is difficult to measure by direct method. We are planning to measure β-delayed α decay of ^{16}N, $^{16}\mathrm{N} \rightarrow {}^{16}\mathrm{O}^* \rightarrow {}^{12}\mathrm{C}+\alpha$. This is an inverse process of ^{12}C(α, γ), and we can derive the reaction rate indirectly. The active target is particularly suitable for such types of measurement, as we need to measure low energy α particles, which can be emitted to any direction from stopped ^{16}N. We are making an upgrade for the GEM-MSTPC for this stopped beam experiment. A gating grid to cope with pulsed-beam experiments has been manufactured. A new data acquisition capable of self-triggering is being prepared, with a flexible online data monitor.

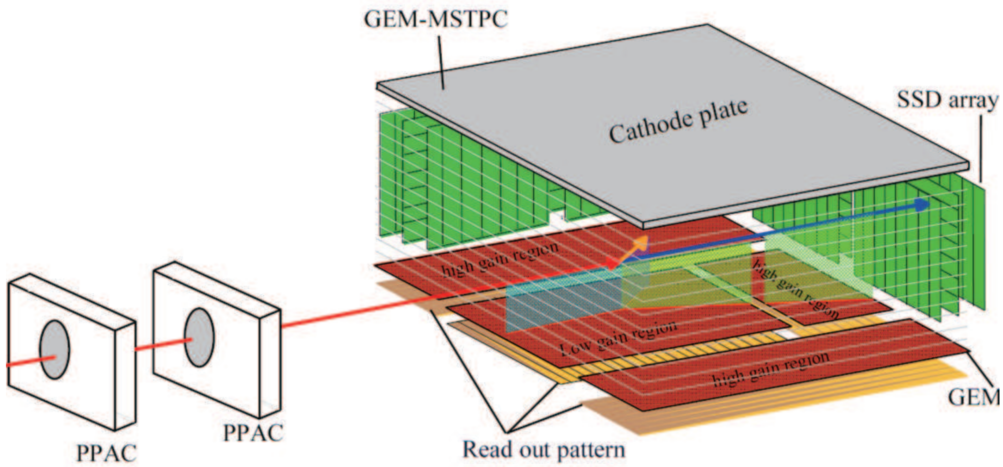


Figure 5.26: Design view of the active target system for nuclear astrophysics studies (GEM-MSTPC).

5.8 Experimental studies of QCD matter under extreme conditions

5.8.1 Scope of the research

Properties of hadronic matter under extreme conditions such as high density and/or high temperature have drawn strong attention in the last few decades. Hadrons, which are the main source of mass in the universe, are composite particles consists of (anti-)quarks, while quarks are confined inside hadrons in the normal conditions. Lattice-QCD simulation, thanks to the recent development of computers, predicts the existence of a new phase of hadronic matter called quark-gluon plasma (QGP) at high temperature, where quarks and gluons are liberated from confinement. It is believed that QGP has existed in the early universe for $\sim 10\mu$sec after the Big Bang. Recent theoretical works also suggest very rich structure at high baryon density region, which may have relevance to the inner core of neutron stars. Since confinement is a basic property of QCD and QGP is believed to be the basic form of matter in the early universe, the research field is intimately connected to particle physics and cosmology as well as nuclear physics.

High-energy heavy-ion collision is a unique tool to realize high density matter and to study its properties in a laboratory. Studies have started in 1970's. A new era began when Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory (BNL) started operation in 2000. RHIC provides Au-Au head-on collisions at 200 GeV per nucleon-pair. Yet another big set forward is the start of heavy ion program at Large Hadron Collider (LHC) at CERN in 2010, which provides Pb-Pb collisions at 2.76 TeV per nucleon-pair at present and 5.5 TeV in near future.

The CNS group has been participating in the PHENIX experiment at RHIC, and the ALICE experiment at LHC. In this report, the activities of the CNS group in PHENIX and ALICE during 2005 and 2012 are briefly summarized.

5.8.2 The PHENIX experiment at RHIC

Historically, a group at INS (Institute for Nuclear Study), predecessor of CNS, was an original member of the PHENIX experiment when the PHENIX collaboration was formed in 1994, and the activities were taken over to the CNS group.

RHIC

The RHIC at BNL is the first heavy-ion collider ever built, dedicated to the studies of nuclear matter at extreme conditions of high temperature and density. A plain view of RHIC accelerator complex is shown in Fig. 5.27. It has two independent rings with circumference of 3.87 km, and is capable of making collisions between different nuclear species. Maximum c.m.s colliding energy is 500 Z/A GeV per nucleon pair. Construction of RHIC started in 1991 and was finally completed in 1999.

Currently, there are two experimental programs, STAR and PHENIX at RHIC.

The PHENIX experiment

A schematic view of the the PHENIX experimental setup is shown in Fig. 5.28. It consists of two central arms (East and West), two muon arms (North and South) and inner detectors for event trigger and event characterization. The PHENIX has excellent capability to measure

Figure 5.27: Perspective view of the RHIC accelerator complex at Brookhaven National Laboratory, USA.

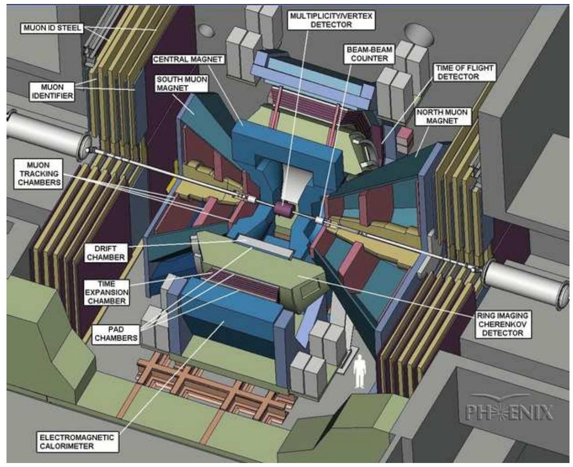


Figure 5.28: A schematic view of the PHENIX experimental setup.

photons, electrons and muons as well as hadrons. With this capability, the PHENIX experiment intends to address as many signatures as possible for QGP formation.

US-Japan Collaboration

The CNS group, together with several other Japanese institutes, has been participating in the PHENIX experiment at RHIC, with support from the US-Japan Collaboration in the field of High Energy Physics in the last 20 years, funded by MEXT and operated by KEK.

The SPIN project is also an important program at RHIC, which aims to study spin structure of a nucleon. The project has been led by the radiation laboratory at RIKEN.

RHIC runs

Since the first collisions between Au nuclei in June 2000, RHIC runs have been performed basically once in every year, which lasted for several months. The RHIC physics runs are summarized in Table 5.7.

Contributions of the CNS group to the PHENIX experiment

Main contributions of the CNS group to the PHENIX experiment is listed below.

- RICH operation: H. Hamagaki has been a DC (Detector Council) member for RICH, and the CNS group is responsible for its operation and calibration.
- Physics analysis: The CNS group members, in particular PhD students, have played leading roles in the physics analysis, and are a chair-person or a core member of the paper preparation groups (PPG), formed for each journal paper.
- H. Hamagaki was the project head of the US-Japan heavy-ion project in the term from 2000 to 2007.
- Kyoichiro Ozawa was a convenor of Light Vector Meson Physics Working Group in 2006 – 2008.

RUN	Period	nuclear species	$\sqrt{s_{NN}}$ (GeV)
Year-1 RUN	June 15 – Sep. 5, 2000	Au + Au	56, 130
Year-2 RUN	Aug. 17 – Nov. 25, 2001	Au + Au	200
	end of Dec. – Jan. 24, 2002	p + p	200
Year-3 RUN	beg. of Jan. – Mar. 23, 2003	d + Au,	200
	one month of May, 2003	p + p	200
Year-4 RUN	beg. of Jan. – end of Mar., 2004	Au + Au	63, 200
	beg. of April – May 14, 2004	p + p	200
Year-5 RUN	beg. of Jan. – Jun 24, 2005	Cu + Cu	63, 200
		p + p	200, 400
Year-6 RUN	beg. of Feb. – Jun, 26, 2006	p + p	63, 200
Year-7 RUN	beg. of Mar.27 – Jun. 26, 2007	Au + Au	200
Year-8 RUN	Nov. 26, 2007 – Mar. 12, 2008	d + Au	200
		p + p	200
Year-9 RUN	Mar. 17 – Apr, 13, 2009	p + p	500
	Apr. 14 – Jun. 29, 2009	p + p	200
Year-10 RUN	Jan. 9 – Jun. 10, 2010	Au + Au	200, 62, 39, 7.7
Year-11 RUN	Feb. 13 – Apr. 18, 2011	p + p	500
	Apr. 24 – Jun. 20, 2011	Au + Au	19.6, 200
Year-12 RUN	Feb. 10 – Apr. 19, 2012	p + p	200, 510
	Apr. 25 – May 15, 2012	U + U	193
	May 19 – Jun. 25, 2012	Cu + Au	193

Table 5.7: Summary of RUNs at RHIC

5.8.3 Physics analysis efforts in the PHENIX experiment

There have been many interesting results achieved by the PHENIX experiment in the last decade. The two major discoveries at RHIC are the realization of high-density matter in heavy ion collisions and creation of matter behaving as near-perfect liquid.

The strategy of the CNS group has been to investigate the properties of the QCD matter using the penetrating or hard probes, with emphasis in the measurement of leptons and photons. Main physics subjects the CNS group has been working on in the last 8 years is listed in the following. The main task forces, mostly PhD students, are indicated, and shown also is when PhD was obtained.

- Systematic measurement of J/ψ yields in p + p, d + Au, Cu + Cu, and Au + Au collisions: S. Kametani (07/2007), T. Gunji (03/2007, S. Oda (03/2008)
- Study of heavy flavor production with single electron measurements: F. Kajihara (03/2007), Y. Morino (03/2009), R. Akimoto (D3)
- Study of jet quenching effect with neutral pion measurement in Au + Au collisions: T. Isobe (07/2007), Y. Aramaki (03/2011)
- High p_{T} single photon production in Au + Au collisions: T. Isobe (07/2007)
- Low p_{T} photon production in in p + p, d + Au, and Au + Au collisions: Y. Yamaguchi (03/2011)
- Production of J/ψ in ultra-peripheral Au + Au collisions: A. Takahara (D3)

Only a few results are presented below.

Study of energy loss of heavy quarks

Strong suppression was observed in central Au-Au collisions in the π^0 yield at high p_{T}, compared to the scaled yield from p-p collisions. The cause of this effect was concluded to be the energy loss of partons, from the results in d-Au collisions and distinctly difference in the behavior between π^0 and direct photon in central Au-Au collisions. This conclusion supports the postulation that extremely high density is formed in heavy ion collisions.

If radiative energy-loss process is dominant, energy loss of heavy quarks is predicted to be strongly hindered. Charm and bottom quarks have large branching ratio for semi-leptonic decay, and the contribution from the decay is dominant in the electron spectrum in the p_{T} range from 1 to 10 GeV/c.

Nuclear modification factor R_{AA} (yield in A-A divided by the yield in p-p and number of NN collisions) of single electrons was measured as a function of collision centrality. Contrary to the expectation, strong suppression of single electron yield was observed in central Au-Au collisions, as shown in the upper panel of Fig. 5.29. This finding is considered as an evidence of strongly coupled QGP, which is a necessary condition of near-perfect liquid with a small η/s.

Systematic study of J/ψ production in p-p, d-Au, Cu-Cu and Au-Au collisions

Heavy quarkonia have been considered to be a promising probe to inspect the QGP formation. In the de-confined phase, long-range confining potential vanishes due to the color Debye screening, which leads to the suppression of heavy quarkonium yields. Theorists also claim that J/ψ yield may be enhanced due to $c-\bar{c}$ coalescence in QGP and at hadronization stage at RHIC energies, where c and $\bar{c}$ production is abundant. Systematic measurement of J/ψ yield in p-p, d-Au, Cu-Cu and Au-Au collisions has been made to clarify the situation.

Figure 5.30 shows: (a) R_{AA} of J/ψ yield in Cu-Cu and Au-Au collisions as a function of N_{part} in central rapidity region, and (b) in forward rapidity region, and (c) R_{AA} divided by the expected R_{AA} for cold nuclear matter effect in Cu-Cu collisions. Figure 5.30 (c) indicates that yield suppression in Cu-Cu can be totally explained by the cold nuclear matter effect, which includes the modified parton distribution functions plus $J/\psi-N$ breakup cross section obtained from d-Au data. R_{AA}s for Au-Au behave similarly with those for Cu-Cu at comparable N_{part}, while R_{AA}s in Au-Au decrease further at larger N_{part}.

Thermal photons in heavy ion collisions

Positive low-p_{T} photon signals have long been awaited. According to a theoretical prediction, there is a window in p_{T} from 1 to 3 GeV/c, where photon yield from thermal QGP radiation is dominant. However, since the $\gamma_{meas}/(\pi^0 \to \gamma\gamma)$ ratio is estimated to be $\sim 10\,\%$ even in the region, we need to measure the yield with the systematic uncertainty better than $10\,\%$. Thus, the evaluations of π^0 and η contribution are really important.

A virtual photon method was applied to the measurement of low-p_{T} photons successfully, where the low-mass electron pairs are measured and the huge contributions from π^0 Dalitz decay was avoided by setting the mass window appropriately, and the obtained yield is extrapolated to the real photon.

Figure 5.31 shows the nuclear modification factor R_{AA} for direct photon yield in d-Au and Au-Au collisions, obtained using the virtual photon method. Clear difference is seen in the behavior of R_{AA} between d-Au and Au-Au collisions.

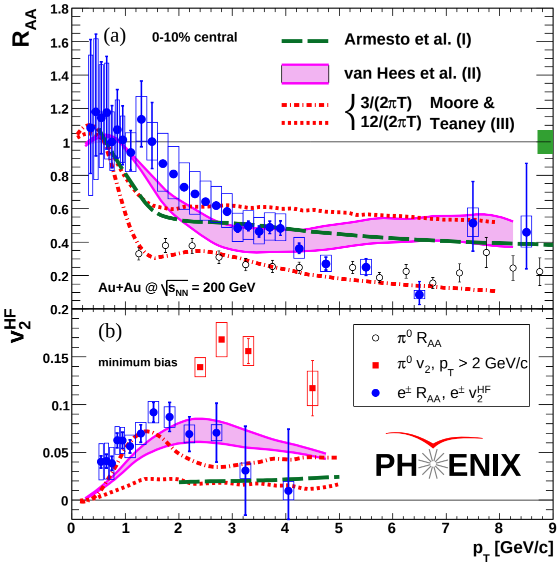


Figure 5.29: (a) Nuclear modification factor R_{AA} of heavy-flavor electrons in 0–10% central Au-Au collisions with π^0 data and model calculations. The box at $R_{AA} = 1$ shows the uncertainty in T_{AA}. (b) v_2 of heavy-flavor electron in minimum bias collisions compared with π^0 data and the same models.

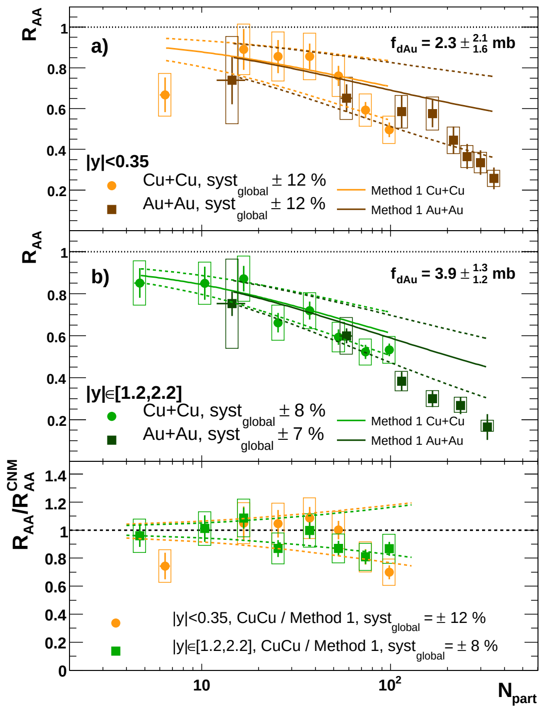


Figure 5.30: (a,b) R_{AA} vs N_{part} for J/ψ production in Cu+Cu and Au+Au collisions. The curves are predictions from ad hoc fits to d+Au data. (c) Ratios of the measured R_{AA} values to the predicted cold nuclear matter R_{AA}. The dashed lines show the 1 σ uncertainties from the d+Au fits.

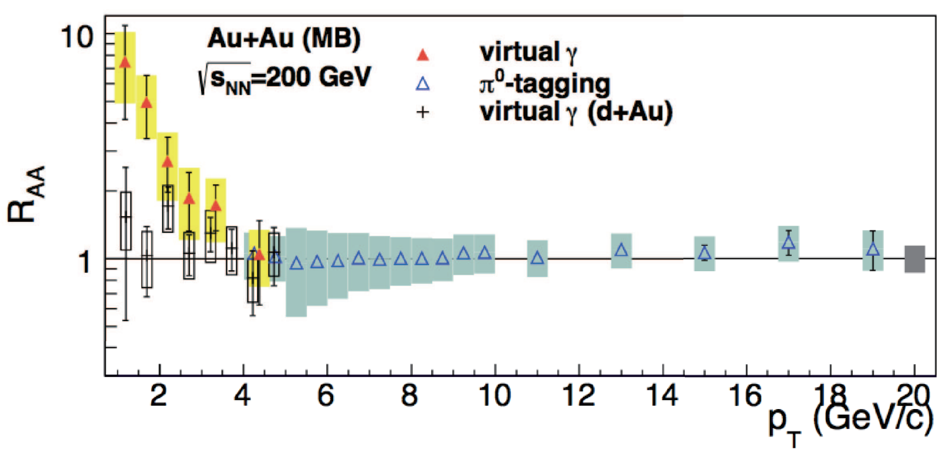


Figure 5.31: Nuclear modification factors for Au-Au (MB) and d-Au are shown as a function of p_{T}. The triangle symbols show results from the (closed) virtual and (open) real photon measurements, respectively. The (+) symbols are for R_{dA} for $p_{\mathrm{T}} < 5$ GeV/c.

5.8.4 The ALICE experiment at LHC

The CNS group has been in the ALICE collaboration since 2006. Current status of the ALICE experiment and our activities are briefly described in the following.

LHC: Large Hadron Collider

Large Hadron Collider (LHC) is a large-scale colliding-type hadron accelerator with circumference of 27 km built at CERN. Although primary purpose of LHC is to find Higgz and search for SUSY partners, CERN has decided to allocate a part of the beam time (about 10 %) of LHC to heavy-ion experiments.

A first p-p collision, after the recovery from the incident, was realized in November 2009, and the collisions at $\sqrt{s} = 7$ TeV (half the maximum energy) was achieved in March 29, 2010. Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV was realized in Nov. 4, 2010, and the two heavy-ion runs were performed so far in 2010 and 2011. In January 2013, p-Pb run was also performed successfully.

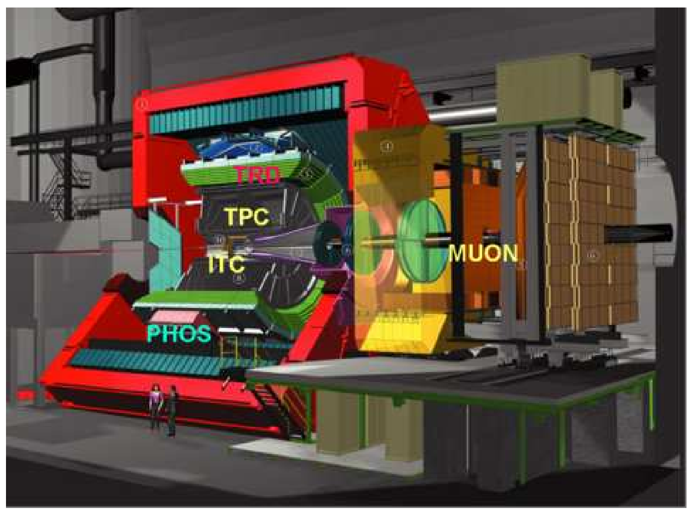


Figure 5.32: A layout of the ALICE experiment at LHC. It consists of two major parts; central part and forward muon part. The central part is designed to be capable of tracking all the charged particle in central Pb + Pb collisions which two subsystems; ITC (inner tracking chambers) and TPC (time projection chambers). It has electron identification capability with TRD (transition radiation detector), and photon spectrometer (PHOS) with $PbWO_4$ crystals.

ALICE experiment

The ALICE experiment is dedicated to heavy ion studies, and is unique among the LHC experiments. ATLAS and CMS, however, have been participating in the heavy-ion runs. The ALICE experimental setup is shown in Fig. 5.32. It looks compact if compared with ATLAS and CMS.

The ALICE experiment aims to cover as many observables as possible with maximum possible aperture. The setup is divided into two parts; central part and forward muon part. The heart of the central part of the setup is the TPC (Time Projection Chamber) and ITC (Inner Tracking Chamber) made of silicons, installed in a large air-core solenoidal magnet, which was converted from the one used in the L3 experiment at LEP.

The ALICE experiment has started producing interesting results. Two topical results are mentioned here.

- J/ψ production in Pb-Pb collisions: The R_{AA} values for J/ψ (covering down to $p_{\mathrm{T}}-0$) are larger compared to those at RHIC, and also the v_2, representing the elliptical anisotropy in azimuth, is non-zero in contrast to the results at RHIC. These results strongly suggest that the contribution from the recombination process is sizable at LHC energies, which is not clearly observed at RHIC.

- Exclusive reconstruction of D mesons are successfully performed, thanks to the powerful 3D tracking capability, and preliminary results on the energy loss are obtained. Extensive study of the energy loss and thermalization of heavy quarks will be one of the key driving issues for promoting the ALICE upgrade, which is explained later.

Contribution of the CNS group to the ALICE experiment

The CNS group have been participating in the several operation/construction and service tasks, as listed below.

- R&D of TRD: Primary purpose of TRD (transition radiation detector), which utilizes the transition radiation, is to strengthen the electron identification capability of the ALICE experiment. The CNS group joined in the TRD R & D effort as early as in 2003, and three master students participated in the performance study of TRD, and wrote master theses based on the study: T. Gunji (2004), Y. Morino (2006), A. Takahara (2007). Contribution was also made in the construction and installation stages.
- Installation and operation of TRD: The CNS group has been participating in the installation, commissioning and operation of TRD.
- TPC calibrations: Two PhD students contributed to the studies of TPC calibrations: S. Sano and Y. Hori. One was on the acceptance correction in the boundary region of the TPC sectors. Another was on the distortions of drift due to the imperfectness of the electric and magnetic field.
- T. Gunji is a convener in the physics analysis group on low-mass electron-pairs (PWG-DQ-LMee) since April 2012.
- H. Hamagaki is serving as a member of editorial board since April 2012.
- There are outstanding efforts for ALICE upgrade, which are explained later.

5.8.5 Physics analysis efforts in the ALICE experiment

The physics topics we have been working are listed in the following. Two PhD students successfully defended the PhD theses, and two PhD students are currently working on the analysis.

- Strange particle production in p-p collisions at LHC: S Sano (03/2012)
- Multi-particle azimuthal correlations in Pb-Pb collisions at LHC: Y. Hori (03/2013)
- Jet quenching effect probed with high-p_T π^0: T. Tsuji (D2)
- Production of low-mass pairs in p-Pb collisions: S. Hayashi (D1)

Brief descriptions on the top two subjects are provided below.

Strange particle production in p-p collisions at LHC

Study of particle production is a first things to do when a new beam or collision energy becomes available. Particle production was studied with emphasis on the strange baryons in $\sqrt{s} = 7$ TeV p-p collisions. Thanks to the powerful 3D tracking capability, clean samples of Λ, Ξ and Ω were obtained.

Particle yields and spectra were obtained as a function of particle multiplicity, aiming to see a hint of thermalization process. From the hadron spectra, radial flow velocity and freeze-out temperature were deduced. Clear increase of flow velocity with increase of particle multiplicity was observed.

Figure 5.33 shows the results of the chemical fit to the observed particle yield ratios. The yields of multi-strange baryons, Λ, Ξ, and Ω, are significantly larger compared to the expected values obtained using the chemical model. It is noted that this is a new finding and is not reproducible with PYTHIA.

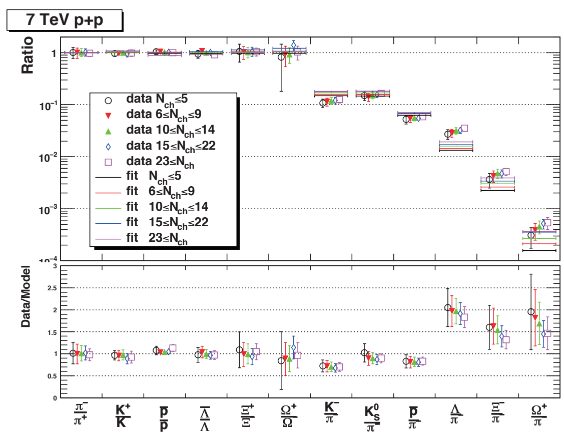


Figure 5.33: Dots and lines show the particle yield ratio and the result of chemical fitting, respectively.

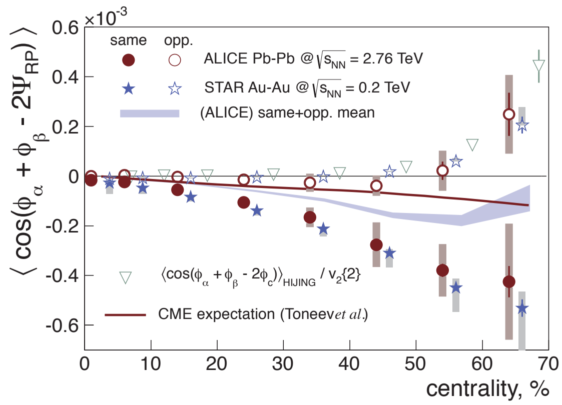


Figure 5.34: Centrality dependence of the correlation, $\langle \cos(\phi_\alpha + \phi_\beta - 2\Psi_{RP}) \rangle$, measured by the ALICE experiment. The results by the STAR collaboration are also shown for comparison.

Study of azimuthal charged-particle correlations in Pb-Pb collisions

Chiral magnetic effect (CME) has been a hot topic. CME is an occurrence of charge dependent flow with respect to the reaction axis, due to the combination of the two factors; possible local parity violation and strong magnetic field in the heavy-ion collisions.

The particle correlation, $\langle \cos(\phi_\alpha + \phi_\beta - 2\Psi_{RP}) \rangle$, has been proposed as an possible observable, where α and β represents the sign of the charge of emitted particles. The STAR collaboration reported a positive result consistent with the theoretical predictions.

The correlation measurement was performed for Pb-Pb collisions, and the obtained results, as shown in Fig. 5.34 are very similar to those by the STAR collaboration.

Study was performed utilizing a simple model based on a blast wave model, and the tendency was well reproduced if a degree of local charge conservation is included. This suggests that the trivial dynamical effects other than the CME effect have to be carefully evaluated before drawing a conclusion.

5.8.6 Efforts for the ALICE upgrades

Efforts for the future ALICE upgrades have been performed. There are two major subjects:

- Development of FoCal (Forward Calorimeter) as an ALICE upgrade option (2009 –).
- GEM TPC upgrade in the ALICE experiment (2012 –)

Brief descriptions are provided in the following.

Development of FoCal for ALICE upgrade

It is known from the DIS measurements that gluon density increases with decrease of Bjorken x. It has been argued that the gluon density eventually saturates, because the gluon merging process becomes effective with increase of gluon density. It is stressed here that the cause of density increase (gluon splitting) and saturation (gluon merging) are both the intrinsic non-linear properties of QCD.

Theoretically, the gluon saturation scale $Q_s^2(x)$, which represents the boundary of gluon saturation, is expressed as,

$$Q_s^2(x) \sim x^{-\lambda}, \tag{5.1}$$

with $\lambda \sim 0.3$. $Q_s^2(x)$ has an A-dependence ($A^{1/3}$), that is, the gluon saturation scale for a certain x is extended in case of nucleus compared to a proton. Comparison of the data between p-p and p-A collisions is the practical way to investigate the effect. It is noted here that $Q_s^2(x)$ should be large enough for the pQCD calculations to be predictable.

In the high-energy hadron colliders such as RHIC and LHC, the x region with sizable $Q_s^2(x)$ is reachable. Compared to RHIC, LHC provides better kinematical condition to study the effect. In order to access smaller x, measurement at forward rapidity region is needed, and this is exactly the reason why the forward calorimeter (FoCal) is proposed as an upgrade of the ALICE experiment.

The main goal of the FoCal is to measure single photon and π^0 in the forward rapidity region; $\eta > 3$. The electro-magnetic calorimeter to measure photons need to fulfill several requirements. In the forward region, particle density is relatively high even in p-p and p-Pb collisions. Therefore, materials with small Morier radius is to be chosen, and readout with reasonably high segmentation is needed, in the order to 1×1 cm^2. In order to separate the two photons from π^0 decay, capability of two-hit separation down to a few millimeters is required.

Our choice is a stack of W with thickness of 3.5 mm ($\sim X_0$) and Si layers. Total of ~ 20 layers will be needed. Most of the Si layers are pad-type readout with pad size of $\sim 1 \times 1$ cm^2, and several layers with fine grained pixel-type or strip-type readout are inserted to attain the fine two-hit separation capability.

The contributions of the CNS group is summarized below.

- Proposal of forward measurement was initially proposed by the CNS group.
- Simulation works have been done to understand the basic detector properties and to optimize the performances.
- A detector prototype with W and Si pad-type layers was constructed, and was tested with the beam from CERN PS.
- A wide dynamic range of $\sim 10,000$ is needed to cover comfortably the p_{T} up to $\sim$ 10 GeV/c in the forward rapidity range; $\eta = 3 \sim 4$. A readout ASIC prototype with

4-gain current conveyors with attenuation gain of 256/512, 64/512, 8/512 and 1/512, was developed with help from Dr. H. Ikeda (JAXA, Open-It) and Prof. M. Tanaka (KEK, Open-It).

Development of the detector prototype and readout ASIC was performed with the support from the JSPS Grants-in-Aid for Scientific Research (A)(General) from FY2010 to FY2012.

GEM TPC upgrade in the ALICE experiment

Discussion on the upgrade plan of the ALICE experiment has started several years ago, even before the real physics runs. Various ideas have been proposed, and one of the surviving ones is the FoCal. However, a general consensus on the upgrade of the whole detector system was reached only last year.

Interaction rate of Pb-Pb collisions at current is several kHz, and the ALICE DAQ system can accept 0.5 kHz at this moment. Current bottle neck is ITS (Inner Tracking System), and the next one is TPC. According to the luminosity upgrade plan of LHC, Pb-Pb interaction rate will eventually reach 50 kHz, and the ratio between the delivered luminosity and accepted one can be as large as 100.

Since the event topology in heavy ion collisions is so complex, reduction of event rate with triggers, hardware or software with simple algorithm, is not so effective in many observables. In particular, it is true for low-mass lepton-pairs, mesons and baryons with charm or bottom and so on, which are considered to be key measurements in the future. From this consideration, the ALICE collaboration decided to pursue the speedup of DAQ system and front-end electronics, with the goal to have capability to record 50 kHz of Pb-Pb collisions. It is to be stressed here that accessibility to many interesting physics currently not possible due to poor statistics will be greatly enhanced with this ambitious upgrade.

In case of TPC, more than replacement of electronics is required to achieve the goal. Current TPC utilizes the gating grid to prevent back flow of ions (IBF) from the electron multiplication region into the drift region, which distorts the electric drift field. With the gating grid, the maximum data taking rate is limited to 3.5 kHz. In order to overcome this difficulty, an idea of continuous readout without gating was proposed, by replacing MWPC (Multi-wire Proportional Chamber) with GEMs, since the IBF (Ion back flow) could be reduced significantly with GEMs.

A simulation result suggests that IBF needs to be kept as low as $\sim 2 \times 10^{-3}$ to maintain the moderate field distortion. This is not a trivial task, and R&D has started last year at CNS, CERN and TMU, in order to find the solution(s) to realize the required IBF. At CNS, strong dependence of IBF on the intensity of irradiated X-rays was found. It was unexpected, and the cause is still not well understood. Currently, the CNS group has been trying to test COBRA GEM, which has divided electrodes to gain more control of the electric field to absorb ions more efficiently.

In addition to the IBF issue, there are several remaining issues to go with the GEM solution.

- Production of large-size GEMs with reasonable cost.
- Gain stability of GEM in a long term
- Durability of GEM under real circumstances.

5.8.7 Detector R&D efforts on GEM

Several detector R&D efforts have been performed on GEM in the last years. GEM, invented in 1997 by F. Sauli at CERN, has a very simple structure of thin plastic (typically $\sim 50\mu m$

thick) with metal-plated at both sides, and periodically pieced through holes (with typical hole diameter of $\sim 70\mu m$ and a pitch of $\sim 140\mu m$). Electron multiplication occurs in the strong electric field inside the holes. It has drawn strong attention as a most promising gas chamber, partly because of high expectation for a wide variety of applications to other fields such as biomedical.

In 2003 when the CNS group started R & D, we could not imagine that GEM would be used in a large-scale experiment in near future. Actually, GEM was already used for HBD (Hadron Blind Detector) in the PHENIX experiment, and is considered to be a strong candidate used in the upgrade of LHC detectors, CMS and ALICE.

The CNS group has had close collaboration with the Tamagawa group at RIKEN Nishina Center to develop and study new types of GEM, as listed in the following.

- GEM with laser etching technology: It is common to use wet-etching technology to piece holes to the insulator, which somehow puts limit to the thickness of insulator. With laser etching, GEM with thickness of $100\mu m$ became possible. Basic performances were tested, and it was found out that the GEM has an impressive long-term gain stability, which seems to due to the cylindrical hole shape.

- Resistive GEM: One serious problem in the MPGD (micro pattern gas detector) in common is the fragility against sparks. In order to improve this, usage of resistive electrodes instead of metallic electrodes was proposed. GEM with resistive Kapton electrodes was made, and performance was tested.

- Development of glass GEM: Normal GEM uses an organic material, such as Kapton and LCD, as the insulator. In neutron measurement, hydrogen atoms in the insulator is the serious background source. In case of gaseous photomultiplier, organic material is the source of outgas, which damages the photocathode. In order to overcome these difficulties, GEM using glass as insulator was tried, utilizing the technology developed by HOYA. The prototype had difficulty in holding voltage in case of Ar-based gases, while it worked reasonably well in case of Ne-based gases. Further studies are being planned.

In parallel to the basic GEM development, efforts were made to use GEM for applications, as listed below.

- Basic study of TPC performance: a prototype TPC with GEM readout was developed and tested with the secondary beams at KEK PS. Position resolution for several gases were tested.

- Development of GEM Cherenkov counter with CsI photocathode: basic study was made to develop GEM-based Cherenkov counter with CsI photocathode.

- Development of ASIC for coarse pixel readout: One of the plausible application of GEM is the 2D imaging device, and a prototype ASIC chip for pixel readout was designed and made. It is aimed to read the stored charge in the integrators with refresh rate of 1 kHz.

- Development of GEM-based 2D imaging device for gamma-rays: Efforts were made to develop 2D imaging for gamma-rays with a fund from JST. To detect gamma-rays, a special gamma convertor was developed. Basic studies were successfully made to prove the working principle.

5.8.8 Future plans of the QGP studies

In the coming 5 years, more emphasis will be placed on the ALICE experiment rather than the PHENIX experiment.

We have considered several possible strategies. One possible direction is to go down the energy. The primary purpose is to search for the critical point in the QCD phase diagram, which is a charming option. It is unfortunate that the limited acceptance in the current PHENIX experiment is not suited to pursue this direction, since the luminosity is low at low collision energy at RHIC and competing with the STAR experiment seemed to be not a wise choice. The PHENIX experiment has a plan of upgrade, named as sPHENIX, which is not a simple addition or modification of the current PHENIX setup but rather a new detector system with emphasis on the compact-size 4π calorimetry.

Another choice is to go to higher energy collisions available at LHC. It is expected that matter with higher temperature, higher density, and longer duration time is created with collisions at higher energies. Combined with the knowledge obtained at RHIC, deeper understanding of the properties of QGP can be expected.

Since it is practically very difficult to make significant contributions to the two projects, the CNS group is inclined to choose the ALICE upgrades. The CNS group has already committed to the two upgrade plans in the ALICE experiment; GEM TPC upgrade and FoCal forward upgrade. It is anticipated that carrying these projects, with a higher priority in the TPC upgrade at present, will provide add excellent physics opportunities.

LOI (Letter of Intent) for the ALICE upgrade was submitted to LHCC in last August, and was acknowledged to go to the next step in the LHCC last November. As a next step, TDR (Technical design report) on TPC upgrade has to be prepared.

The other issues

Let me mention on the organization issue. The success of the Japanese group in the PHENIX collaboration strongly is largely due to the financial support from US-Japan Collaboration which has been covering travel, long stay, detector construction, and detector R&D. Such support is a key to maintain the long-term large-scale international collaborations. It is not available for the ALICE experiment at this moment, and stable operations are difficult. Efforts to establish the base have been made, but no success so far.

One good news is that the proposal of heavy-ion research plan prepared by the people involved in the RHIC and LHC experiments was endorsed as one of the four large-scale research programs by the Nuclear Physics Committee, which is an action taken by the Committee in response to the call for proposals for the master plan of research programs by the Science Council of Japan. A research proposal will be submitted to the Science Council of Japan.

5.9 Accelerator Research and Development

Since 2005 April, a part of the scientific activities of CNS has been directed to the accelerator research and development which can be categorized into following three major parts. The first item is application of the CNS instruments to the AVF cyclotron which are genuinely original to CNS, and their continuous improvement according to the CNS research programs. The second is development of ECR ion sources continued from the birth of CNS. The third is the contribution to the so-called beam instruments of AVF cyclotron and beam transport line.

5.9.1 AVF cyclotron

This machine has been operated as an injector for the ring cyclotron (RRC), CRIB experiments, biophysics, radioisotope production, and so on. Performance of the AVF in 2009, for example, was as follows. In standalone operations of the AVF, a total of 817 h was dedicated to the CRIB experiments managed by CNS, the University of Tokyo, in spite of the total operation time of 3870 h. The CRIB experiments were efficiently performed, however, some of the CRIB experiments involving the use of Li ion beam were canceled. Intense and stable beams were not delivered due to some impediments of RF system of the Hyper-ECR ion source. Trouble due to cooling water leakage at the AVF RF amplifier also occurred. These problems were solved step by step.

The upgrading of the AVF is in progress in cooperation with RIKEN. In this program, the more attractive beam has been pursued, with high energy and strong intensity. It expanded the availability of RI beams at CRIB and strengthen the capability of RI production using an intense and energetic proton beam.

The power supplies for the sector magnets of the AVF were improved to increase the maximum energy of the light ion beam at the beginning of 2005. The maximum current of the main coil was increased from 1100 A to 1200 A. The two sets of power supplies for the trim coils were also improved. As the result, the K-number of the AVF was increased from 70 to 78. The maximum energy of $^{15}N^{5+}$ beam was increased beyond 9 MeV/nucleon, extending the availability of RI beams of CRIB.

The flattop acceleration system was added to the AVF cavities in 2002. The momentum resolution of the accelerated beam was improved from 0.3 % to 0.1 %. A high-power operation with the flattop system was restricted due to the damage of a ceramic insulation part of the RF amplifier. In 2006, the improvement of the ceramic insulation part was performed as a challenge. To clarify this discharge problem, Teflon covers were manufactured and tested in order to suppress the emission of electrons at a high potential. After attaching Teflon covers, the atmospheric discharge hardly occurred in the power test of the flattop acceleration system. The improvement of the ceramic part is now underway.

In 2006, a grazer lens was renovated because the old one has an intrinsic problem due to a coil trouble. The old one was pull out from the center of upper-yoke of the AVF, and the new one was re-installed. Then, the beam focusing power at the AVF beam injection line was improved by two times. Typical effect to the AVF is that the beam acceptance is improved and resultant beam intensities were increased at higher extraction energy of AVF.

In 2007, the following two projects were authorized. First, the beam trajectory in the AVF injection area was investigated to get higher energy efficiently in the single-harmonics mode in cooperation with DSR of Russia. Second, a high RF voltage became available in higher frequency range by adjusting the capacitance of the coupling condenser in the RF amplifier. To establish such research activities, collaboration between CNS and RIKEN was conducted.

The first project was focused on the improvements in beam transmission efficiency and beam quality in the AVF. The computer model of the electromagnetic fields of the AVF was prepared and successfully checked against the measurements. Electric and magnetic field distributions and mechanical structures were transmitted to the beam dynamics code for simulations, and particle losses on the surface of the system elements were estimated. Results of these simulation codes were applied to increase the maximum available energies of AVF. In 2009, the central region of AVF was renovated to increase the maximum available energies of $^{16}O^{7+}$ and $^{6}Li^{3+}$ ion beams to 12 MeV/nucleon. An acceleration test of $^{4}He^{2+}$ at 11.2 MeV/nucleon, which has an A/Q equivalent to $^{6}Li^{3+}$ ion beam, was carried out with the new central region geometry. Injection efficiency (R74/I36) around 50 % was obtained, which was five times higher than that obtained for the old geometry. The second project is now underway. Preliminary test shows that two sets of condensers with different values are necessary in the whole operating frequency of the AVF-dee electrodes. Besides, in 2012, a replacement of the existing AVF-dee electrodes was carried out due to cooling water leakage. High power RF test and vacuum test of the new electrodes are still continued.

5.9.2 ECR Ion Sources

A various applications of AVF are scheduled in RIKEN RIBF facility. In order to supply a variety of gaseous or metallic ions with high charge state to those facilities, a 14 GHz ECR ion source (called HyperECR-IS) and a Superconducting ECR ion source (called SC-ECR-IS) have been operated in a shift. SC-ECR-IS was moved from Tsukuba University in collaboration with CNS, the University of Tokyo. Now development of the SC-ECR-IS is being carried out by RIKEN group, however first beam extraction from SC-ECR-IS was carried out by CNS members in March 2007. HyperECR-IS was moved from Tanashi campus to the RIBF facility collaborating with RIKEN in 2000. We have been improved the Hyper ECR-IS, especially for producing high intensity heavy ion beams from solid materials and supplying them stably. We introduce an inserting-rod-method in the case of high-melting point materials and use a crucible method in the case of low-melting point one.

The Hyper ECR-IS provides a first ECR zone and a second ECR zone. The second ECR zone is formed at the center of plasma chamber. It is a closed ECR zone with the resonance-magnetic field of 4.8 kG. Electron turns at the neighborhood of this magnetic field with the RF of 14.25 GHz. The electron accelerated in the second-ECR zone contributes for both of the vapor formation and the ionization of the vaporized material. The electron removed axially out of this ECR zone bombards the rod or the crucible and induces vaporization, and the vapor moved near the second ECR zone is ionized.

The varieties of the insertion devices are available in the Hyper ECR-IS. If we put the rod much closer to the second ECR zone at the center axis, beam intensity was significantly reduced. In order to improve the movement of energetic electrons, the rod is set near the plasma chamber wall, and remotely controlled so as to increase the beam intensity. This method is named as off-center rod insertion method. Applicable melting temperature is higher than 800 °C whenever the rod insertion method is employed.

Optimization of the crucible vapor has been studied. Materials of low melting temperature are exhausted through the large hole of the crucible, if it is heated at a high temperature. Then the melted materials are dropped on the inner wall of plasma chamber and results in a damage due to bad vacuum pressure. This was improved by adjusting both the number of small holes and the distance from the second ECR zone. A new crucible of stainless steel with five holes of 2 mm in diameter and a hot liner of Ta sheet placed in the plasma chamber, have been employed. A separation of the $^{14}N^{6+}$ beam was successfully performed by the AVF. We succeeded in the extraction of $^{7}Li^{2+}$ and $^{7}Li^{3+}$ with intensities of 200 eμA and 75 eμA, respectively, from the Hyper ECR-IS. Then, $^{40}Ca^{12+}$ and $^{56}Fe^{15+}$ ion beams with intensities of 24 eμA and 7 eμA was obtained by CaO and FeO rods, respectively.

5.9.3 Increased functionality of the AVF cyclotron

The expansion of the range of acceleration energy and the increase of beam intensity is being advanced at the AVF cyclotron, which is used in intensive radiation applications and nuclear research. In the last eight years initiatives were taken to increase the acceleration energy, for better transmission efficiency, and to improve its characteristics.

Specifically, efforts were made in the following areas. First, along with the increased range of beam intensities, non-destructive high-sensitivity beam current monitors were developed in 2008 and 2011 in the E7-CRIB beamline in order to measure the beam current from a few nA to several tens of μA extracted from the AVF cyclotron. The beam intensity is obtained as the height of frequency spectrum which is measured with a spectrum analyzer. Second, improvements were made on the central region RF shield and inflector with the objective of increasing the AVF acceleration energy in 2009. As a result of establishing a flag-type Faraday cup at the electrostatic deflector (ESD) of the AVF extraction system and performing beam-extraction measurements in 2009, an ESD transmission efficiency of 90% became feasible. Third, an emittance measuring instrument was installed on the AVF beam transport section (C01) in 2011. Although an increase in beam intensity was realized with regard to beam production and acceleration, how to suppress the radioactivation of irradiated equipment and to decrease the beam halo were the issues. Concerning the improvement of transmission by the optimization of the beam orbit and emittance control, it was found to be necessary to study the characteristics of the cyclotron beam emittance etc. Measurement with the emittance monitor was commenced to study the beam formation with multipole magnetic field. This study is in progress in cooperation with JAERI Takasaki. Fourth, the operation of the ion source became more sophisticated method and resulted in an increase in the intensity of the ion source and in the variety of ions extracted.

Consequently, it has also been made possible to vary the beam characteristics greatly. For this reason, the technological development for the efficiency of the transport system that introduces the beam into the AVF has become important. From 2011 through 2012, efforts were made in improving the AVF axial injection system, and an online beam monitoring system for the ion source, including computer-controlled beam viewers, beam scanners and beam emittance monitor, was developed. The beam viewer with a KBr plate, installed in the low-energy beam line of AVF, observes a phosphor image due to an irradiation of the injection beam. The phosphor image is taken by a TV camera system. An acquired TV camera image is analyzed to study the beam structure originating from ECR plasma and so on. The beam scanner was installed at the image point of the Hyper ECR-IS analyzer to observe the beam profile of the injection beam. A beam scanning is controlled with a pulse-motor drive system, and a static measurement of an isotope beam (e.g.$^{29}Si^{8+}$ for a $^{28}Si^{8+}$ beam injection) allows us to tune the intensity of the main beam without disturbing the beam injection. The emittance monitor was installed in the axial beam injection line of the AVF (I36) to evaluate the injection efficiency of the AVF.

5.10 Nuclear structure calculations

5.10.1 Introduction

The CNS has started theoretical studies since the year 2001. One of the major activities is the large-scale nuclear structure calculation project. This project has been operational since the year 2001 based on the collaboration agreement between CNS and RIKEN Accelerator Research Facility (presently RIKEN Nishina Center), recognizing immense importance, apparent relevance and high urgency of the project. In this project, PC clusters are provided by Grants-in-Aids by the Ministry of Education, Science, Technology, Culture and Sport (MEXT) [5] for the representative personnel, Takaharu Otsuka, while infrastructures (e.g. electricity, cooling, etc.) and running costs are supported primarily by CNS and RIKEN Nishina Center. The PC clusters are located at the computer room of the RI-Beam Factory building, Wako campus, RIKEN Nishina Center. We, theory group of the CNS, mainly performed parallel computations of the Monte Carlo shell model (MCSM) to study nuclear structure of exotic nuclei and its related topics. Based on this experience, we participate the High Performance Computing Infrastructure (HPCI) program of strategic field No. 5 "The origin of Matter and the Universe" by the MEXT for five years since FY2011. Since then we focus on the massive parallel computation of the MCSM on T2K supercomputers and K computer in order to open a new frontier of large-scale computer science and to investigate novel structure of exotic nuclei.

On the other hand, we introduced a PC server equipped with large capacity of the main memory (600GB main memory, 40 CPU cores) by a new research grant [6], won by T. Otsuka in 2011. Utilizing this server, we performed large-scale shell model calculations with conventional Lanczos diagonalization method to obtain high-precision wave functions aiming at the study of beta spectroscopy of forbidden transition and double beta decay. On the other hand, utilizing a massive parallel computer the MCSM can treat much larger systems than the Lanczos method while the MCSM only provides us with several low-lying states for a given spin/parity. Thus, there are complementary advantages in both conventional Lanczos method and the MCSM, and we use both of them.

5.10.2 Microscopic study on nuclear force and exotic nuclear structures

The scientific aspect of the project is to obtain theoretical predictions and analyses of a huge variety of nuclei, stable and unstable, by means of the shell model calculations. We studied importance of tensor force and three-body force in the understanding of the shell evolution of exotic nuclei. Especially, the paper in which we discussed the essential role of the tensor force in the description of shell evolution was selected as "viewpoint" of Physical Review Letters. [7]

In this paper, we also proposed "Monopole-based Universal interaction" (V_{MU}), which is expected to be useful for shell-model calculations. Subsequently, we performed shell-model calculations using the V_{MU} and ascertained its validity in various mass region resulting in the further understanding of the shell evolution. Among these studies, we succeeded in reproducing the experimental results of the distribution of the one-neutron-separation spectroscopic factors of ^{48}Ca by shell-model calculations with *sd*-*pf* shell as a model space, and studied the evolution of spin-orbit spitting energy due to tensor force. In addition, we showed that the disappearance

[5] Grant-in-Aids for Specially Promoted Research (13002001) and for Scientific Research (20244022) by MEXT, Japan

[6] Grant-in-Aid for Scientific Research (23244049) by MEXT, Japan

[7] T. Otsuka, T. Suzuki, M. Honma, Y. Utsuno, N. Tsunoda, K. Tsukiyama, and M. H.-Jensen, Phys. Rev. Lett. **104**, 012501 (2010)

of the $N = 28$ magic number and large oblate deformation at ^{42}Si are caused by the tensor force and its accompanied shell evolution (tensor-driven Jahn-Teller effect). [8] Yutaka Utsuno, guest associate professor of CNS, contributed to a major part of this work, and is now studying the single particle energy of $0g_{9/2}$ orbit in neutron-rich nuclei and the single-particle behavior of low-lying energy levels of Sb isotopes. The achievement as for the Ca isotopes leads to the ongoing shell-model calculations of the pygmy and giant dipole resonance. The code of this shell-model calculations was developed by Noritaka Shimizu, project associate professor of CNS.

Based on shell-model structure calculations, we study the neutrino-nucleus reaction in supernovae and the nuclear matrix elements related to double-beta decay. These issues are mainly conducted by Toshio Suzuki, former guest professor of CNS. In practice, we studied nuclear structure of neutron-rich carbon isotopes by shell-model calculations and the nuclear force including $\pi + \rho$ meson exchange tensor force, and described the anomalous $M1$ transition of ^{17}C. We also studied nuclear structure including p-shell, p-sd-shell neutron-rich nuclei systematically by utilizing V_{MU} interaction, which led to drastically improved description of the spin-dependent transitions and magnetic moments.

We performed precise study of the Gamow-Teller transition probabilities and neutrino-nucleus reaction of ^{56}Ni. It revealed that the proton emission cross section and the production rate of Mn element are larger than those of the precedence research. It implies the importance of two-peak structure of the Gamow-Teller transition distributions, which were experimentally measured by the (p, n) reaction after our prediction. We also discussed precisely electron capture rates of Ni isotopes under the astrophysical condition, namely under high temperature and high pressure.

5.10.3 Monte Carlo shell model and HPCI program

Based on the long experience of the parallel computation utilizing PC clusters, we step forward to massive parallel computations of the MCSM and shell-model calculations. Since FY2011, we have been in charge of the project "Peta-scale calculations of quantum many-body systems for nuclear properties and its applications" (chief: T. Otsuka, CNS), which is a part of HPCI strategic program field 5 (chief: S. Aoki, Tsukuba Univ.) in order to promote large-scale shell model calculations.

The great progress of the methodology and algorithm of the MCSM was achieved in these few years. N. Shimizu *et al.* renewed the MCSM method by combining the original MCSM with the energy-variance extrapolation, which was originally introduced to nuclear shell-model calculations by T. Mizusaki and M. Imada. This method enables us to overcome largely the limitation of the conventional Lanczos diagonalization method. In this method, we plot the energy and energy variance of the sequence of approximated wave functions, provided by the MCSM. The approximated energy is fitted by a 2nd-order polynomial of the corresponding energy variance, so the exact energy is estimated as a extrapolated value of the fitted line to zero energy variance. As a consequence, few low-lying eigenenergies of huge (10^{14} dimension or more) matrix is estimated in high precision. Figure 5.35 shows the plots for the extrapolation of the energy of the ground state and the first excited state of ^{64}Ge, the m-scheme dimension of which reaches 10^{14} and far beyond the limitation of conventional Lanczos method. It is shown that the exact energies are estimated as y-intercepts of the fitted lines in high precision.

[8] Y. Utsuno, T. Otsuka, B.A. Brown, M. Honma, T. Mizusaki, and N. Shimizu, Phys. Rev. C **86**, 051301(R) (2012)

In the view of the computational science, we proposed a new algorithm to compute efficiently the matrix elements between non-orthogonal Slater determinants, which results in the acceleration of the MCSM code. Consequently, the newly developed MCSM code runs more than five times faster than the old code.

These developments of the MCSM enabled us to discuss neutron-rich Cr, Ni isotopes with $pf + g_{9/2}d_{5/2}$ model space. As an example of the achievements, we show the MCSM results of the level schemes of ^{68}Ni, in which spherical, oblate deformed, prolate deformed shapes co-exist in low-lying excitation energies in Fig. 5.36.

In addition, we performed no-core shell model calculations utilizing the MCSM since 2009, and tested the validity of the JISP16 interaction in p-shell nuclei. We do not only overcome the limitation of the conventional Lanczos method, but produce unique achievements such as the analysis of the density profile of the intrinsic states. The recent activities concerning the MCSM were summarized in Ref [9].

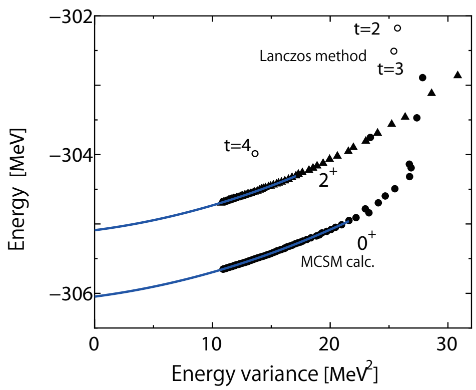


Figure 5.35: Energy-variance plot of ^{64}Ge. The black filled symbols denote the approximated energies and energy variances of the MCSM wave functions. The blue lines are drawn by the chi-square fit.

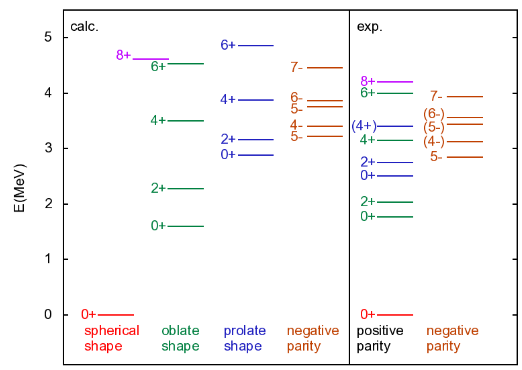


Figure 5.36: Level schemes of ^{68}Ni. The left panel shows the MCSM results and the right shows the experimental values.

5.10.4 Future perspectives

We participate the HPCI program, which continues until FY2015, and promote large-scale nuclear shell-model calculations with the MCSM utilizing massive parallel computers, e.g. K computer, in order to obtain new insights of nuclear structure. Especially, the contribution of tensor force and three body force in nuclear medium will be investigated. In parallel, we perform the shell-model calculations with Lanczos method in the medium-mass region to obtain high-precision wave functions towards the understanding the r-process and its applications, e.g. the precise esitmation of the nuclear matrix elements of double-beta decay.

[9] N. Shimizu, T. Abe, Y. Tsunoda, Y. Utsuno, T. Yoshida, T. Mizusaki, M. Honma, and T. Otsuka, Prog. Theor. Exp. Phys. **2012(1)**, 01A205 (2012).

Appendix A

CNS Member List

as of Feb. 28, 2013

Name	Position
OTSUKA, Takaharu	Director, Professor
SHIMOURA, Susumu	Professor
HAMAGAKI, Hideki	Professor
YAKO, Kentaro	Associate Professor
YAMAGUCHI, Hidetoshi	Lecturer
MICHIMASA, Shin'ichiro	Assistant Professor
GUNJI, Taku	Assistant Professor
OTA, Shinsuke	Assistant Professor
SHIMIZU, Noritaka	Project Associate Professor
TORII, Hisayuki	Project Assistant Professor
YOSHIDA, Toru	Project Assistant Professor
IWATA, Yoritaka	Project Assistant Professor
UTSUNOMIYA, Hiroaki	Guest Professor, Konan University
UTSUNO, Yutaka	Guest Professor, Japan Atomic Energy Research Institute
OHSHIRO, Yukimitsu	Technical Staff
YAMAZAKI, Norio	Technical Staff
YAMAKA, Shoichi	Technical Assistant
YOSHIMURA, Kazuyuki	Technical Assistant
KUREI, Hiroshi	Technical Assistant
WATANABE, Shinichi	Technical Assistant
SENO, Takehiko	Technical Assistant
YOSHIMURA, Hiroshi	Administrative Chief
YAMAMOTO, Ikuko	Administrative Assistant
ENDO, Takako	Administrative Assistant
KISHI, Yukino	Administrative Assistant
ITAGAKI, Toshiko	Administrative Assistant
SOMA, Yuko	Administrative Assistant

continued to the next page

CNS member list, continued from the previous page

Name	Position
YAMAGUCHI, Yorito	Project Researcher
STEPPENBECK, David	Project Researcher
NAKAO, Taro	Project Researcher
EBATA, Shuichiro	Project Researcher
KAHL, David	Research Assistant
MATSUSHITA, Masafumi	Research Assistant
TAKAHARA, Akihisa	Graduate Student (D3)
MIYA, Hiroyuki	Graduate Student (D3), RIKEN Junior Research Associate
TOKIEDA, Hiroshi	Graduate Student (D3), JSPS DC Fellow
AKIMOTO, Ryoji	Graduate Student (D3), JSPS DC Fellow
HORI, Yasuto	Graduate Student (D3), JSPS DC Fellow
TANG, Tsz Leung	Graduate Student (D2)
GO, Shintaro	Graduate Student (D2), RIKEN Junior Research Associate
KAWASE, Shoichiro	Graduate Student (D2), JSPS DC Fellow
TSUJI, Tomoya	Graduate Student (D2), RIKEN Junior Research Associate
KISAMORI, Keiichi	Graduate Student (D1), RIKEN Junior Research Associate
TAKAKI, Motonobu	Graduate Student (D1), RIKEN Junior Research Associate
HAYASHI, ShinIchi	Graduate Student (D1), RIKEN Junior Research Associate
YOKOYAMA, Rin	Graduate Student (M2)
FUJII, Toshihiko	Graduate Student (M2)
SEKIGUCHI, Yuko	Graduate Student (M2)
KUBOTA, Yuki	Graduate Student (M2)
LEE, CheongSoo	Graduate Student (M2)
KOBAYASHI, Motoki	Graduate Student (M1)
TERASAKI, Kohei	Graduate Student (M1)
KOBAYASHI, Kazuma	Visiting Research Student, Rikkyo University
SHO, Ryo	Visiting Research Student, Rikkyo University

Appendix B

Summary of External Funds

Table B.1–B.6 show the externally funded projects in CNS for each year during 2005–2012. The amount of the budget is shown in kyen (1000 yen), separately for direct and indirect usage for the research project. Table B.7 is a summary of the total amount of external funds for each year, shown for each group.

Table B.1: List of externally funded projects in 2005.

Representative person	Type, Number	Subject	Amount (kyen) direct	indirect
2005:				
S. Shimoura	Scientific Research(A) 15204018	Evolution of shell Structure and Collectivity in Neutron-Rich Nuclei	6,700	0
H. Hamagaki	Scientific Research(A) 14204021	Study of state with high temperature and high density using jets and quarkonia as probes	3,800	0
T. Uesaka	Grant-in-Aid for Young Scientists (A) 17684005	Polarized proton target with a new light source and study on scatterings of proton-unstable nuclei	8,300	0
T. Kawabata	Grant-in-Aid for Young Scientists (B) 17740132	Verification of covalent-bond model in atomic nuclei	1,800	0
H. Yamaguchi	Grant-in-Aid for Young Scientists (B) 17740135	Precise direct measurement of astrophysical nuclear reaction ^{7}Be(p,γ)^{8}B	1,400	0
J.J. He	Grant-in-Aid for Foreign JSPS Fellows 04F04055	Study on astrophysical reactions using unstable nuclei	1,200	0
Y. Zheng	Grant-in-Aid for Foreign JSPS Fellows 17-05053	Study on high-spin structures in neutron-rich nuclei by multiple Coulomb excitation with RI beams	1,200	0
M.L. Liu	Grant-in-Aid for Foreign JSPS Fellows 17-05052	Study on high-spin and large-deformation states in neutron-rich nuclei	1,200	0
Y. Maeda	Grant-in-Aid for JSPS Fellows(PD) 16-10087	Study on spin-dependent term in 3-body force via neutron-deuteron elastic scattering	1,100	0
T. Gunji	Grant-in-Aid for JSPS Fellows (DC1) 16-11332	Investigation of nuclear effects and QGP-phase at the energy of RHIC	900	0
S. Kubono	Bilateral Joint Research Projects (Korea)	Experimental study on explosive nucleosynthesis in the universe	900	0

Table B.2: List of externally funded projects in 2006.

Representative person	Type, Number	Subject	Amount (kyen) direct	indirect
2006:				
S. Shimoura	Scientific Research(A) 15204018	Evolution of shell Structure and Collectivity in Neutron-Rich Nuclei	3,700	1,110
T. Uesaka	Grant-in-Aid for Young Scientists (A) 17684005	Polarized proton target with a new light source and study on scatterings of proton and unstable nuclei	6,200	1,860
T. Kawabata	Grant-in-Aid for Young Scientists (B) 17740132	Verification of covalent-bond model in atomic nuclei	1,400	0
H. Yamaguchi	Grant-in-Aid for Young Scientists (B) 17740135	Precise direct measurement of astrophysical nuclear reaction ^{7}Be(p,γ)^{8}B	1,000	0
S. Fujii	Grant-in-Aid for Young Scientists (B) 18740133	Structures of nuclear shells and unstable nuclei based on modern nuclear forces	700	0
Y. Zheng	Grant-in-Aid for Foreign JSPS Fellows 17-05053	Study on high-spin structures in neutron-rich nuclei by multiple Coulomb excitation with RI beams	1,200	0
M.L. Liu	Grant-in-Aid for Foreign JSPS Fellows 17-05052	Study on high-spin and large-deformation states in neutron-rich nuclei	1,200	0
Y. Maeda	Grant-in-Aid for JSPS Fellows(PD) 16-10087	Study on spin-dependent term in 3-body force via neutron-deuteron elastic scattering	1,100	0
T. Gunji	Grant-in-Aid for JSPS Fellows (DC1) 16-11332	Investigation of nuclear effects and QGP-phase at the energy of RHIC	900	0
S. Oda	Grant-in-Aid for JSPS Fellows (DC2) 18-10719	Strong interaction in states with high temperature and density by measuring vector mesons	1,000	0
S. Sakaguchi	Grant-in-Aid for JSPS Fellows (DC1) 18-11398	Spin-orbit interaction in neutron-rich nuclei using polarized solid proton target	1,000	0
Y. Morino	Grant-in-Aid for JSPS Fellows (DC1) 18-11413	Study on extremely high-temperature and density states in collisions of high-energy heavy ions using jet as a probe	1,000	0
S. Kubono	Bilateral Joint Research Projects (Korea)	Experimental study on explosive nucleosynthesis in the universe	1,200	0
T. Otsuka	JSPS Core-to-Core Program	International Research Network of Exotic Femto System	15,000	0

Table B.3: List of externally funded projects in 2007 and 2008.

Representative person	Type, Number	Subject	Amount (kyen) direct	indirect
2007:				
S. Shimoura	Scientific Research(A) 19204024	Multi-neutron system by secondary reaction of unstable nuclei	11,800	3,540
H. Yamaguchi	Grant-in-Aid for Young Scientists (B) 17740135	Precise direct measurement of astrophysical nuclear reaction ^{7}Be(p,γ)^{8}B	1,000	0
Y. Wakabayashi	Grant-in-Aid for Young Scientists (B) 19740131	Determination of beta-decay half life of 46Cr	1,200	0
S. Fujii	Grant-in-Aid for Young Scientists (B) 18740133	Structures of nuclear shells and unstable nuclei based on modern nuclear forces	500	0
T. Gunji	Grant-in-Aid for Young Scientists (start-up) 19840012	Study on physical property of quark-gluon plasma matter using quarkonium as a probe	1,350	0
S. Oda	Grant-in-Aid for JSPS Fellows (DC2) 18-10719	Strong interaction in states with high temperature and density by measuring vector mesons	900	0
S. Sakaguchi	Grant-in-Aid for JSPS Fellows (DC1) 18-11398	Spin-orbit interaction in neutron-rich nuclei using polarized solid proton target	900	0
Y. Morino	Grant-in-Aid for JSPS Fellows (DC1) 18-11413	Study on extremely high-temperature and density states in collisions of high-energy heavy ions using jet as a probe	900	0
S. Kubono	Bilateral Joint Research Projects (Korea)	Experimental study on explosive nucleosynthesis in the universe	300	0
S. Kubono	Bilateral Joint Research Projects (Korea)	Study on explosive nucleosynthesis processes in supernovae	900	0
T. Otsuka	JSPS Core-to-Core Program	International Research Network of Exotic Femto System	17,110	1,710
2008:				
S. Shimoura	Scientific Research(A) 19204024	Multi-neutron system by secondary reaction of unstable nuclei	13,000	3,900
T. Gunji	Grant-in-Aid for Young Scientists (B) 19840012	Study on physical property of quark-gluon plasma matter using quarkonium as a probe	1,800	540
Y. Wakabayashi	Grant-in-Aid for Young Scientists (B) 19740131	Determination of beta-decay half life of 46Cr	1,400	420
Y. Morino	Grant-in-Aid for JSPS Fellows (DC1) 18-11413	Study on extremely high-temperature and density states in collisions of high-energy heavy ions using jet as a probe	900	0
S. Sakaguchi	Grant-in-Aid for JSPS Fellows (DC1) 18-11398	Spin-orbit interaction in neutron-rich nuclei using polarized solid proton target	900	0
S. Shimoura	Co-Investigator (H. Sakai, Univ. Tokyo, Specially Promoted Research) 17002003	Isospin-spin responses in charge-exchange exothermic reactions	15,000	450
H. Hamagaki	Co-Investigator (Y. Miake, Tsukuba Univ., Scientific Research(S)) 20224014	Study of Jets in Quark Gluon Plasma with Parton. Identification.	500	0
H. Hamagaki	Co-Investigator (T. Sugitate, Hiroshima Univ., Specially Promoted Research) 18002010	Formation of Quark Matter and Photon Physics	1,000	0
S. Kubono	Bilateral Joint Research Projects (Korea)	Study on explosive nucleosynthesis processes in supernovae	1,200	0
T. Otsuka	JSPS Core-to-Core Program	International Research Network of Exotic Femto System	30,000	3,000

Table B.4: List of externally funded projects in 2009 and 2010.

Representative person	Type, Number	Subject	Amount (kyen) direct	indirect
2009				
S. Shimoura	Scientific Research (A) 19204024	Multi-neutron system by secondary reaction of unstable nuclei	5,700	1,710
S. Kubono	Scientific Research (B) 21340053	Study on alpha-cluster structure in astrophysical nuclear reactions	8,000	2,400
T. Gunji	Grant-in-Aid for Young Scientists (B) 19840012	Study on physical property of quark-gluon plasma matter using quarkonium as a probe	1,600	480
H. Hamagaki	Co-Investigator (T. Sugitate, Hiroshima Univ., Specially Promoted Research) 18002010	Formation of Quark Matter and Photon Physics	2,000	600
H. Hamagaki	Co-Investigator (Y. Miake, Tsukuba Univ., Scientific Research(S)) 20224014	Study of Jets in Quark Gluon Plasma with Parton. Identification.	500	150
H. Hamagaki	JST, Development of Advanced Measurement and Analysis Systems	Ultra high sensitive and large-area gamma-ray image sensor using GEM	3,000	0
S. Kubono	Bilateral Joint Research Projects (Korea)	Study on explosive nucleosynthesis processes in supernovae	300	0
S. Kubono	Bilateral Joint Research Projects (Korea)	Nucleosynthesis in novae and X-ray bursts	900	0
T. Otsuka	JSPS Core-to-Core Program	International Research Network of Exotic Femto System	30,000	3,000
2010:				
S. Shimoura	Scientific Research(A) 19204024	Multi-neutron system by secondary reaction of unstable nuclei	4,100	1,230
S. Kubono	Scientific Research(B) 21340053	Study on alpha-cluster structure in astrophysical nuclear reactions	4,500	1,350
H. Hamagaki	Scientific Research(A) 22244022	Development of electromagnetic calorimeter for measuring photons from ultra high energy hadron collisions	23,800	7,140
S. Michimasa	Grant-in-Aid for Young Scientists (B) 22740150	Investigation for the mechanism of magic-number emergence in unstable nuclei	2,000	600
H. Hamagaki	Co-Investigator (T. Sugitate, Hiroshima Univ., Specially Promoted Research) 18002010	Formation of Quark Matter and Photon Physics	1,000	300
H. Hamagaki	Co-Investigator (Y. Miake, Tsukuba Univ., Scientific Research(S)) 20224014	Study of Jets in Quark Gluon Plasma with Parton. Identification.	500	150
Y. Hori	Grant-in-Aid for JSPS Fellows (DC1) 22-8478	Generation process of quarkonium in high-energy extra peripheral collisions	700	0
T. Otsuka	JSPS Core-to-Core Program	International Research Network of Exotic Femto System	26,250	2,625
S. Kubono	Bilateral Joint Research Projects (Korea)	Nucleosynthesis in novae and X-ray bursts	1,200	0
H. Hamagaki	JST, Development of Advanced Measurement and Analysis Systems	Ultra high sensitive and large-area gamma-ray image sensor using GEM	3,780	1,134
H. Hamagaki	Strategic Young Researcher Overseas Visits Program for Accelerating Brain Circulation R2206	Enhancing international research network in nuclear-collision experiment at the world's highest energy and education for young researchers	17,611+189	0
M. Dozono	Grant-in-Aid for JSPS Fellows (PD) 21-4349	Investigation of behaviour of pions in atomic nuclei by a complete measurement of spin	700	0

Table B.5: List of externally funded projects in 2011.

Representative person	Type, Number	Subject	Amount (kyen) direct	indirect
2011:				
H. Hamagaki	Scientific Research(A) 22244022	Development of electromagnetic calorimeter for measuring photons from ultra high energy hadron collisions	7,800	2,340
H. Hamagaki	Scientific Research(A) 22244022 (carry over)	Development of electromagnetic calorimeter for measuring photons from ultra high energy hadron collisions	5,600	0
S. Kubono	Scientific Research(B) 21340053	Study on alpha-cluster structure in astrophysical nuclear reactions	1,600	480
S. Kubono	Scientific Research(B) 21340053 (carry over)	Study on alpha-cluster structure in astrophysical nuclear reactions	107	0
N. Shimizu	Grant-in-Aid for Young Scientists (B) 20740127	Theoretical investigation of new collective motion in neutron-rich nuclei	400	120
S. Michimasa	Grant-in-Aid for Young Scientists (B) 22740150	Investigation for the mechanism of magic-number emergence in unstable nuclei	800	240
S. Ota	Grant-in-Aid for Young Scientists (B) 23740174	Gamow-Teller transition probability distribution for unstable nuclei near iron by missing-mass spectroscopy in inverse kinematics	3,300	990
Y. Hori	Grant-in-Aid for JSPS Fellows (DC1) 22-8478	Generation process of quarkonium in high-energy extra peripheral collisions	700	0
H. Tokieda	Grant-in-Aid for JSPS Fellows (DC2) 23-3895	Study on electron-capture rates in massive stars using an active target system	700	0
S. Kawase	Grant-in-Aid for JSPS Fellows (DC1) 23-6202	Study on spin-orbit interaction in oxygen isotopes via proton-knockout reaction	700	0
R. Akimoto	Grant-in-Aid for JSPS Fellows (DC2) 23-8004	Study on phase of quark-gluon plasma using heavy quark as a probe	700	0
T. Doi	Grant-in-Aid for JSPS Fellows(PD)21-5985	Study on atomic nuclei and nuclear force with lattice QCD	210	0
H. Hamagaki	Co-Investigator (Y. Miake, Tsukuba Univ., Scientific Research(S)) 20224014	Study of Jets in Quark Gluon Plasma with Parton. Identification	500	150
N. Shimizu	Co-Investigator (T. Otsuka, Univ. of Tokyo., Scientific Research(A)) 23244049	New shell-model and mean-field calculations for unstable nuclei and their social application	325	0
S. Kubono	Bilateral Joint Research Projects (Korea)	Nucleosynthesis in novae and X-ray bursts	300	0
H. Hamagaki	JST, Development of Advanced Measurement and Analysis Systems	Ultra high sensitive and large-area gamma-ray image sensor using GEM	460	138
H. Hamagaki	Strategic Young Researcher Overseas Visits Program for Accelerating Brain Circulation R2206	Enhancing international research network in nuclear-collision experiment at the world's highest energy and education for young researchers	23,737	0
T. Otsuka	Tsukuba Univ., High Performance Computing strategic program	elucidation of nuclear properties using ultra large-scale simulations of quantum many-body systems and its applications	60,080	0
T. Otsuka	JAEA, governmental project, soil investigation (#1)	Investigation of distribution of radioactive material	22,843	0
T. Otsuka	JAEA, governmental project, soil investigation (#2)	Second investigation of distribution of radioactive material by the accident in Fukushima Daiichi Nuclear Power Station	2,680	0

Table B.6: List of externally funded projects in 2012.

Representative person	Type, Number	Subject	Amount (kyen) direct	indirect
2012				
H. Hamagaki	Scientific Research(A) 22244022	Development of electromagnetic calorimeter for measuring photons from ultra high energy hadron collisions	5,000	1,500
S. Michimasa	Grant-in-Aid for Young Scientists (B) 22740150	Investigation for the mechanism of magic-number emergence in unstable nuclei	500	150
S. Ota	Grant-in-Aid for Young Scientists (B) 23740174	Gamow-Teller transition probability distribution for unstable nuclei near iron by missing-mass spectroscopy in inverse kinematics	400	120
H. Tokieda	Grant-in-Aid for JSPS Fellows (DC2) 23-3895 (carry over)	Study on electron-capture rates in massive stars using an active target system	85	0
H. Tokieda	Grant-in-Aid for JSPS Fellows (DC2) 23-3895	Study on electron-capture rates in massive stars using an active target system	600	0
Y. Hori	Grant-in-Aid for JSPS Fellows (DC1) 22-8478	Generation process of quarkonium in high-energy extra peripheral collisions	700	0
R. Akimoto	Grant-in-Aid for JSPS Fellows (DC2) 23-8004	Study on phase of quark-gluon plasma using heavy quark as a probe	600	0
S. Kawase	Grant-in-Aid for JSPS Fellows (DC1) 23-6202	Study on spin-orbit interaction in oxygen isotopes via proton-knockout reaction	600	0
N. Shimizu	Co-Investigator (T. Otsuka, Univ. of Tokyo., Scientific Research(A)) 23244049	New shell-model and mean-field calculations for unstable nuclei and their social application	1,000	300
K. Yako	Co-Investigator (H. Sakai, RIKEN., Scientific Research(B)) 22340049	Isospin-spin responses in charge-exchange exothermic reactions in inverse kinematics for unstable nuclei	300	90
H. Hamagaki	Co-Investigator (Y. Miake, Tsukuba Univ., Scientific Research(S)) 20224014	Study of Jets in Quark Gluon Plasma with Parton. Identification.	500	150
S. Shimoura	Co-Investigator (T. Nakamura, TiTech, Grant-in-Aid for Scientific Research on Innovative Areas) 24105005	Properties of neutron-rich and middle- or low-density nuclear matter	6,920	2,076
H. Hamagaki	Strategic Young Researcher Overseas Visits Program for Accelerating Brain Circulation R2206	Enhancing international research network in nuclear-collision experiment at the world's highest energy and education for young researchers	22,003	0
T. Otsuka	Tsukuba Univ., High Performance Computing strategic program	Elucidation of nuclear properties using ultra large-scale simulations of quantum many-body systems and its applications	45,445	0
T. Otsuka	JAEA, governmental project, soil investigation (#2, carry over)	Second investigation of distribution of radioactive material by the accident in Fukushima Daiichi Nuclear Power Station	1,380	0
T. Otsuka	JAEA, governmental project	Establishment of the method to survey long-term effect caused by the radioactive material by the accident in Fukushima Daiichi Nuclear Power Station	3,326	333

Table B.7: Total amount of the external budget for each group (kyen).

	Quark Physics	Nuspec,Spin, SHARAQ	Nuclear Astro.	Theory
2005	4700	20300	2600	0
2006	2900	15800	2200	15700
2007	3150	12700	3400	17610
2008	4200	28900	2600	30000
2009	7100	5700	9200	30000
2010	47580	6800	5700	26250
2011	39707	5500	2007	86328
2012	28803	9404	0	51150

Appendix C

Summary of the CNS International Summer School

In 2011 the CNS International Summer School marked its 10th milestone. We invited approximately eight lecturers in summer season every year since 2002 to held the CNS summer school for a term of 1 week. Here we list the invited lecturers to our summer school, and look at the 11-year trend of participants.

Lecturers who participated in the summer school so far is as follows.

The 1st CNS International Summer School (CISS02):
S.M. Austin (Michigan, USA), C. Baktash (Oak Ridge, USA), I. Hamamoto (Lund, Sweden), Y. Koike (Hosei), T. Otsuka (Tokyo), S. Shimoura (Tokyo), J.A. Tostevin (Surrey, UK), N. Itagaki (Tokyo), S. Kubono (Tokyo), A. Ozawa (RIKEN), K. Tanida (RIKEN), I. Tanihata (RIKEN)

The 2nd CNS International Summer School (CISS03):
Y. Akaishi (KEK), K. Amos (Melbourne, Australia), H. Hamagaki (Tokyo), T. Hatsuda (Tokyo), M. Honma (Aizu), S. Kubono (Tokyo), T. Motobayashi (RIKEN), T. Nilsson (CERN), V.R. Pandharipande (Illinois, USA), H. Sakai (Tokyo)

The 3rd CNS International Summer School (CISS04):
D. Frekers (Muenster, Germany), Y. Fujita (Osaka), K. Hagino (Tohoku), T. Nakano (RCNP), P. Navratil (LLNL, USA), W. Nazarewicz (Tennessee/ORNL, USA), M. Oka (TITech), T. Otsuka (Tokyo), H. Sakurai (Tokyo)

The 4th CNS International Summer School (CISS05):
G.F. Bertsch (Washington, USA), M. Harakeh (KVI, Netherlands), R. Machleidt (Idaho, USA), T. Kajino (NAOJ), K. Yabana (Tsukuba), N. Aoi (RIKEN), E. Ideguchi (Tokyo), T. Mizusaki (Senshu), T. Teranishi (Kyushu), T. Uesaka (Tokyo)

The 5th CNS International Summer School (CISS06):
I. Hamamoto (Lund, Sweden), B. Sherrill (MSU, USA), T. Neff (MSU, USA), W. Mittig (GANIL, France), M. Kohno (Kyushu dent.), T. Takatsuka (Iwate), K. Sumiyoshi (Numazu), H. Ueno (RIKEN), Y. Utsuno (JAEA)

The 6th CNS International Summer School (CISS07):
W.H. Dickhoff (Washington, USA), T. Aumann (GSI, Germany), R. Hix (Oak Ridge, USA), H. Sakaguchi (Miyazaki), T. Suzuki (Nihon), M. Matsuo (Niigata), T. Hirano (Tokyo), T. Kubo (RIKEN)

The 7th CNS-EFES International Summer School (CNE-EFES08):
P. Van Isacker (GANIL, France), U.-G. Meissner (Bonn, Germany), T. Nakamura (TITech), T. Nakatsukasa (RIKEN), A. Ohnishi (Yukawa Institute), T. Otsuka (Tokyo), A. Richter (Darm-

stadt, Germany), J.P. Schiffer (Argonne, USA), M. Wakasugi (RIKEN)

The 8th CNS-EFES International Summer School (CNS-EFES09):

M.H. Jensen (Oslo, Norway), C. Bertulani (Texas A&M Commerce, USA), P. Van Duppen (Leuven, Belgium), S. Shimoura (Tokyo), H. Horiuchi (RCNP, Osaka), N. Ishii (Tokyo), H. Sakai (RIKEN), K. Makishima (Tokyo/RIKEN), T. Kawabata (Kyoto), T. Gunji (Tokyo)

The 9th CNS-EFES International Summer School (CNS-EFES10):

K. Langanke (GSI, Germany), A. Vitturi (Padova, Italy), W. Lynch (MSU, USA), J. Dobaczewski (Warsaw, Poland), J. Meng (Peking, China), S. Chiba (JAEA), K. Yoneda (RIKEN), H. Yamaguchi (Tokyo)

The 10th CNS International Summer School (CNSSS11):

R. Johnson (Surrey, UK), A.O. Macchiavelli (LBNL, USA), S. Wanajo (TUM/MPA, Germany), I. Tanihata (RCNP, Osaka), T. Shimoda (Osaka) T. Kishimoto (Osaka), Y. Aritomo (JAEA), S. Nishimura (RIKEN)

The 11th CNS International Summer School (CNSSS12):

P. Navratil (TRIUMF, Canada), T.K. Dao (INST, Vietnam), P. Descouvemont (Univ. Libre de Bruxelles, Belgium), G. de France (GANIL, Frace), K. Sekiguchi (Tohoku) T. Fukushima (Keio), H. Sagawa (Aizu), K. Yako (CNS), T. Otsuka (UT/CNS)

The number of participants in each summer school was 100 persons on average. The histogram in Fig. C.1 shows the trend of participants. In respect of the steering of the summer

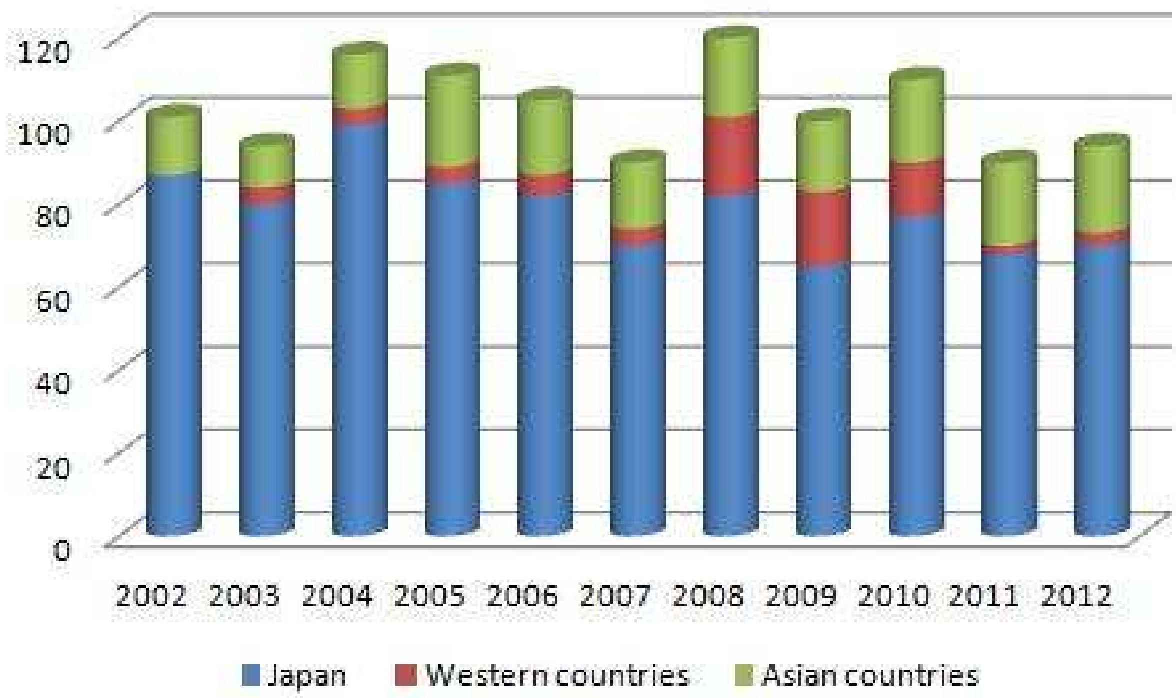


Figure C.1: Eleven-year trend of participants in the CNS international summer school. The blue, green and red in each bar show the numbers of participants from Japan, Western and Asian countries, respectively.

school, we have conducted stimulating lectures as well as provided plenty of opportunities for simultaneous discussion and exchange of opinions. We have set oral presentation sessions and poster sessions by young scientists in its timetable. Especially education for students and posdocs from Asian countries has been seriously regarded to promote continuous progress of nuclear physics in Asia. In series of CNS summer school , 188 students or postdocs attended from Asian countries except Japan, which was 17% of all participans. Their nationalities were widely spread in Asia, such as China, Korea, India, Vietnam, Bangladesh, Taiwan, Myanmar, Malaysia, Uzbekistan, and Turkey. This is one of evidences that CNS international summer school are widely known and CNS is appreciated as a research center of excellence in Asia.

Right at this moment, we have a golden opportunity in nuclear physics due to innovative experiments performed with new generation accelerator facilities and to drastic progress of nuclear theory coupled with developing large-scale computers. Research collaboration in Asia region becomes more and more important. From now on also we will try to hold the series of CNS international summer school to provide fulfilling opportunities for international research exchange.

Appendix D

Curriculum Vitae of Current Staff

SHIMOURA, Susumu
(Professor)

Career
1979.03: graduate Faculty of Science, Kyoto University
1981.03: graduate Master course of Department of Physics, Kyoto University
1984.03: leave Doctor course of Department of Physics, Kyoto University, before completion
1984.04: Research fellow of Japan Society for the Promotion of Science
1984.06: Research Associate of Department of Physics, Kyoto University
1988.04: Research Associate of Physics Department, University of Tokyo
1992.04: Lecturer of Physics Department, Rikkyo University
1994.04: Associate Professor of Physics Department, Rikkyo University
2000.05∼: Professor of Center for Nuclear Study (CNS), Graduate School of Science, University of Tokyo

Doctoral Degree: 1986.03 Doctor of Science (Kyoto University)
Awards:
Society: Physical Society of Japan, Atomic Energy Society of Japan

Community service and social activities:
1998∼2000: Associate editor of Butsuri (JPS)
1999∼2000: B-PAC member of RCNP, Osaka University
2001∼2003: P-PAC member of RCNP, Osaka University (2002∼ Chair)
2005∼2009: Council member of the Physical Society of Japan
2006∼2008: P-PAC member of RCNP, Osaka University
2006∼2009: Organizing Committee of US-Japan Joint meeting at Hawaii (HAW09)
2006∼2007: Vice chair of DREB2007 (Direct Reactions with Exotic Beams)
2008∼ : Steering Committee member of RCNP, Osaka University
2008∼2010: Board member of the Nuclear Physics Executive Committee of Japan
2010∼2010: Chair of Halo2010 symposium
2010∼ : Associate editor of JPSJ and PTP
2011∼2012: Co-chair of 4th Conference on Collective Motion in Nuclei under Extreme Conditions (COMEX4)
2012∼ : Board member of the Nuclear Physics Executive Committee of Japan
2012∼ : Supervising editor of PTEP

Main research activities: My main interest is in the nuclear properties in a wide area of the nuclear chart, in particular, understanding of nuclei far from the stability as typical many-body quantum systems of two kinds of fermions (proton and neutron). Exotic phenomena have been found in structures of neutron-rich and proton-rich nuclei by using RI-beams and the technique of in-beam spectroscopy mainly at accelerator facility at RIKEN. A Ge array with position sensitivity called GRAPE has been developed for high resolution in-beam γ-ray spectroscopy, which is now upgrading using digital signal processing technology. For new aspects in RI-beam experiments, namely investigation of new modes of nuclear system, the SHARAQ project in RIKEN RIBF was started, where high-resolution magnetic spectrometer was constructed as well as a high-resolution beam line for RI beams.

Recent publications

(1) Tomohiro Uesaka, Susumu Shimoura, Hideyuki Sakai, and for the SHARAQ Collaboration: "The SHARAQ spectrometer", Prog. Theor. Exp. Phys. **2012** (2012) 03C007 (11 pages).

(2) H. Baba, T. Ichihara, T. Ohnishi, S. Takeuchi, K. Yoshida, Y. Watanabe, S. Ota, S. Shimoura: "New data acquisition system for the RIKEN Radioactive Isotope Beam Factory", Nucl. Instr. Meth. A **616** (2010) 65–68.

(3) A. Saito, S. Shimoura et al.: "The ^{6}He+^{6}He and α+^{8}He Cluster States in ^{12}Be via α-Inelastic Scattering", Mod. Phys. Lett. A **25** (2010) 1858–1861.

(4) M. Niikura, E. Ideguchi, N. Aoi, H. Baba, T. Fukuchi, Y. Ichikawa, H. Iwasaki, T. Kubo, M. Kurokawa, M. Liu, S. Michimasa, T. Ohnishi, T.K. Onishi, S. Ota, S. Shimoura, H. Suzuki, D. Suzuki, Y. Wakabayashi, K. Yoshida, Y. Zheng: "Yrast spectroscopy in $^{49-51}$Ti via fusion-evaporation reaction induced by a radioactive beam", Eur. Phys. J. A **42** (2009) 471–475.

(5) "Two-particle correlations in continuum dipole transitions in Borromean nuclei", Phys. Rev. C **80** (2009) 031301 (4 pages).

(6) S. Ota, S. Shimoura et al.: "Low-lying proton intruder state in ^{13}B", Phys. Lett. B **666** (2008) 311–314.

(7) S. Shimoura et al.: "Lifetime of the isomeric 0_2^+ state in ^{12}Be", Phys. Lett. B **654** (2007) 87–91.

(8) I. Hamamoto, S. Shimoura: "Properties of ^{12}Be and ^{11}Be in terms of single-particle motion in deformed potential", J. Phys. G **34** (2007) 2715–2725.

(9) S. Michimasa, S. Shimoura et al.: "Proton single-particle states in the neutron-rich ^{23}F nucleus", Phys. Lett. B **638** (2006) 146–152.

(10) H. Ryuto, M. Kunibu, T. Minemura, T. Motobayashi, K. Sagara, S. Shimoura, M. Tamaki, Y. Yanagisawa, Y. Yano: "Liquid hydrogen and helium targets for radioisotope beams at RIKEN", Nucl. Instr. Meth. A **555** (2005) 1–5.

HAMAGAKI, Hideki
(Professor)

Career
1973.03: ḡraduate Physics Department, Hokkaido University
1975.03: ḡraduate Master course of Physics Department, University of Tokyo
1977.03: l̄eave Doctor course of Physics Department, University of Tokyo, before completion
1977.04: R̄esearch Associate of Institute for Nuclear Study, University of Tokyo
1997.04: Research Associate of Center for Nuclear Study (CNS), Graduate School of Science, University of Tokyo
1998.06: Associate Professor
2012.04∼: Professor

Doctoral Degree: 1978.12 Doctor of Science (University of Tokyo)
Awards:
Society: Physical Society of Japan

Comminity service and social activities:
2003.∼: Associate editor of Nuclear Physics A
2003∼2009: International Advisory Committee of the 17th through 21th International Conference of Ultra-Relativistic Nucleus-Nucleus Collisions (QM04 – QM09)
2012∼2015: Co-chairperson of the 25th International Conference of Ultra-Relativistic Nucleus-Nucleus Collisions (QM15)

Main research activities:
(1) Investigation of the properties of the quark gluon plasma (QGP), a new state of matter using the ultra-relativistic heavy ion collisions at the PHENIX experiment at the Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory in USA, and the ALICE experiment at at the Large Hadron Collider (LHC) at CERN. (2) Detector R&D on GEM.

Recent publications:
(1) H. Hamagaki and M. Asakawa: "Strongly Interacting Quark Gluon Plasma Discovered at RHIC", BUTSURI **67** (2012) 616-624.
(2) Hideki Hamagaki: "High energy density QCD: Experimental overview", Prog. Theor. Phys. Suppl. 193 (2012) 79-88.
(3) A. Adare et al. (PHENIX collaboration): "Azimuthal anisotropy of neutral pion production in Au+Au collisions at $\sqrt(s_{NN}) = 200$ GeV: Path-length dependence of jet quenching and the role of initial geometry", Phys. Rev. Lett. 105, 142301 (2010).
(4) T. Tamagawa, H. Hamagaki et al.:"Development of Thick-foil and Fine-pitch GEMs with a Laser Etching Technique", Nucl. Instrum. Meth. 608 (2009) 390-396.
(5) A. Adare et al. (PHENIX Collaboration): "Energy Loss and Flow of Heavy Quarks in Au+Au Collisions at s(NN)**(1/2) = 200-GeV", Phys. Rev. Lett. 98 (2007) 172301.

YAKO, Kentaro
(Associate Professor)

Career
1997.03: ḡraduate Department of Physics, University of Tokyo
1999.03: ḡraduate Master course of Department of Physics, University of Tokyo
2002.03: l̄eave Doctor course of Physics Department, University of Tokyo, before completion
2002.04: R̄esearch Assistant of Center for Nuclear Study, Graduate School of Science, University of Tokyo (CNS)
2002.10: P̄roject Researcher of CNS
2004.06: R̄esearch Associate of Department of Physics, University of Tokyo
2012.05∼: Associate Professor of CNS

Doctoral Degree: 2002.9 Doctor of Science (University of Tokyo)
Awards:
Society: Physical Society of Japan

Comminity service and social activities:
2011∼: Book-review Subcommittee of BUTSURI (JPS)
2012: Local Organizing Committee of the 4th international conference on "Collective Motion in Nuclei under Extreme Conditions (COMEX4)"
2012: Japan Organizing Committee of The 6th LACM-TORIJIN-JUSTIPEN Workshop
2012∼: Users Executive Committe of RIBF
2012∼: Physics Program Advisory Committee (P-PAC) of Research Center of Nuclear Physics (RCNP)

Main research activities:
My main research subject is the spin-isospin responses in nuclei by using charge-exchange reactions at intermediate energies. Current interest is on the Gamow-Teller and spin-dipole resonances of neutron-rich nuclei, which can be studied by (p,n) reactions in inverse kinematics at RIBF.

Recent publications:
(1) K. Yako, H. Sakai: "Looking into the Nuclear Matrix Elements of Double Beta Decay", BUTSURI **67** (2012) 389.
(2) K. Yako et al.: "Gamow-Teller Strength Distributions in ^{48}Sc by the ^{48}Ca(p,n) and ^{48}Ti(n,p) Reactions and Two-Neutrino Double-β Decay Nuclear Matrix Elements", Phys. Rev. Lett. **103** (2009) 012503.
(3) K. Yako et al.:"RCNP (n,p) facility", Nucl. Instrum. and Meth. in Phys. Res. A **592** (2008) 88.
(4) K. Yako, H. Sagawa, H. Sakai:"Neutron skin thickness of 90Zr determined by charge exchange reactions", Phys. Rev. C **74** (2006) 051303(R).
(5) K. Yako et al.:"Determination of the Gamow-Teller quenching factor from charge exchange reactions on ^{90}Zr", Phys. Lett. B **615** (2005) 193.

YAMAGUCHI, Hidetoshi
(Lecturer)

Career
1999.03: ḡraduate Physics Department, University of Tokyo
2001.03: ḡraduate Master course of Physics Department, Graduate School of Science, University of Tokyo
2004.03: ḡraduate Doctor course of Physics Department, Graduate School of Science, University of Tokyo
2004.04∼: Research Associate of Center for Nuclear Study (CNS), University of Tokyo
2007.04∼: Assistant Professor of CNS, University of Tokyo
2011.11∼: Lecturer of CNS, University of Tokyo

Doctoral Degree: 2004.3 Doctor of Science (University of Tokyo)
Awards: 2004.3 President's award of University of Tokyo
Society: Physical Society of Japan
Community service and social activities:
2010: Program Advisory Committee of the 10th International Symposium on Origin of Matter and Evolution of Galaxies (OMEG10).
2011: Organizing Committee of the 11th International Symposium on Origin of Matter and Evolution of Galaxies (OMEG11).

Main research activities:

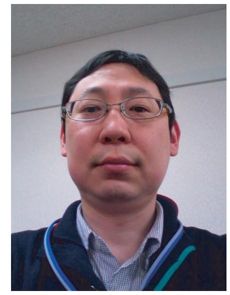
My main research subject is nuclear experimental physics using low-energy RI beam. I am leading the nuclear astrophysics group in CNS and responsible for the operation of CRIB (CNS RI-beam separator). CRIB can produce pure and relatively low-energy RI beam (less than 10 MeV per nucleon) by the in-flight separation method, and unique experiments can be performed with it.

I am particularly interested in studying astrophysical reactions which play important roles. We need precise nuclear reaction rates to completely understand the whole process of the nuclear synthesis and energy generation in the universe, occurring in various environments, big bang, stars, X-ray bursters, novae, supernovae, and so on. However, our knowledge is limited, especially of reactions involving unstable nuclei, and there are still puzzles remaining unsolved. The nucleosynthesis in hot environment running through proton-rich nuclei is the current major interest, and I will challenge to determine the astrophysical reaction rates of key break reactions such as ^{15}O(p, γ).

The exotic structures of unstable nuclei is also an interesting subject. Using proton- or α-resonant scattering method, we can study exotic nuclear structures through resonances. An example is the low-lying negative-parity states in ^{8}B, which are related to the proton-halo structure. The states were observed by using low-energy ^{7}Be beam at CRIB with a proton target. I also observed many strong alpha resonances in ^{11}B and ^{11}C and discussed on their spin-parities. The strong resonances are due to the α-cluster structure in these nuclei, and we found some of them had 3-body cluster structure. I would like to perform more extensive studies for such exotic structures in various unstable nuclei.

Recent publications

(1) H. Yamaguchi et al. : "Alpha-resonance structure in ^{11}C studied via resonant scattering of ^{7}Be+α and ^{7}Be(α, p) reaction", Phys. Rev. C, to be published (2013) / arXiv:1212.5991.
(2) H. Yamaguchi et al. : "α resonance structure in ^{11}B studied via resonant scattering of ^{7}Li+α", Phys. Rev. C **83**, (2011) 034306.
(3) H. Yamaguchi et al. : "Low-lying non-normal parity states in ^{8}B measured by proton elastic scattering on ^{7}Be", Phys. Lett. B **672** (2009) 230–234.
(4) H. Yamaguchi et al. : "Nuclear astrophysics studies using low-energy 7Be beams at CRIB", Nucl. Phys. A. **805** (2008) 546–548.
(5) H. Yamaguchi et al. : "Development of a cryogenic gas target system for intense radioisotope beam production at CRIB", Nucl. Instr. and Meth. in Phys. Res. A **589** (2008) 150–156.



MICHIMASA, Shin'ichiro
(Assistant Professor)

Career
1995.04 – 1999.03: Department of Physics, Rikkyo University
1999.04 – 2001.03: Master course of Physics Department, University of Tokyo
2001.04 – 2004.03: Doctor course of Physics Department, University of Tokyo
2004.04 – 2006.10: RIKEN special doctoral researcher
2006.11 – : Assistant professor of Center for Nuclear Study (CNS), University of Tokyo
Doctoral Degree: 2006.12 Doctor of Science (University of Tokyo)
Society: Physical Society of Japan
Main research activities: Nuclear experimental physics probed by direct reactions of short-lived nuclei.

I am primarily interested in underlying nuclear structure characterizing the properties of short-lived nuclei, such as occurrences of magicity loss/creation or shape coexistence. I am promoting to measure the nuclear reaction, especially direct reactions, of radioactive ion beams at intermediate energy to reveal shell structure in unstable nuclei. The direct reactions have varieties in how it affects a target nucleus, and their reaction mechanism is relatively well-understood because they are single- or a few-step processes. We aim at investigating characteristic features of a radioactive isotope by exploiting the sensitivity of direct reactions.

Another topic of my interest is a challenge of nuclear reaction studies involving radioactive isotopes as a reaction probe. Some short-lived nuclei and their isomers which are able to be used as a secondary beam have large internal energies and/or large angular momenta. They may have capability to occur an exotic excitation such as a extremely large angular momentum transfer. We will develop new reaction probes coupled with the exotic structure of radioactive nuclei and try to studying unknown features in stable nuclei.

To realizing those reaction studies, we completed the High-resolution beamline and the SHARAQ spectrometer for high-resolution and high-efficiency measurement of nuclear reactions in RIBF. We are developing detectors for high-rate capability and high position resolution for use by combining with those apparatus.

Recent publications
(1) K. Miki et al.: "Identification of the β^+ Isovector Spin Monopole Resonance via the ^{208}Pb and ^{90}Zr(t,^{3}He) Reactions at 300 MeV/u", Phys. Rev. Lett. **108** (2012) 262503.
(2) S. Takeuchi et al.: "Well Developed Deformation in ^{42}Si", Phys. Rev. Lett. **109** (2012) 182501.
(3) D. Suzuki et al.: "Breakdown of the $Z = 8$ Shell Closure in Unbound ^{12}O and its Mirror Symmetry", Phys. Rev. Lett. **103** (2009) 152503.
(4) T. Uesaka et al.: "The high resolution SHARAQ spectrometer", Nucl. Instru. Methods Res. B **266** (2008) 4218.
(5) S. Michimasa et al: "Proton single-particle states in the neutron-rich ^{23}F nucleus", Phys. Lett. B **638** (2006) 146.

GUNJI, Taku
(Assistant Professor)

Career
2002.03: ḡraduate Department of Physics, Kyoto University
2004.03: ḡraduate Master course of Physics Department, University of Tokyo
2007.03: ḡraduate Doctor course of Physics Department, University of Tokyo
2007.04∼: Research Associate of Center for Nuclear Study (CNS), University of Tokyo

Doctoral Degree: 2007.3 Doctor of Science (University of Tokyo)
Awards: 2009.3 Award for Outstanding Young Physicists (Experimental Nuclear Physics)
Society: Physical Society of Japan
Comminity service and social activities:
2008∼2008: Local Organising Committee of the 2nd Asian Triangle Heavy Ion Conference
2008∼2008: Local Organising Committee of the 5th micro-pattern gaseous detector workshop

Main research activities:

Nuclear experimental physics and study of the properties of hot and dense QCD medium (quark-gluon-plasma) using relativistic high energy heavy ion collisions. It is believed that the ordinal hadronic medium undergoes the phase transition to Quark-Gluon-Plasma (QGP), which is composed of quarks and gluons, under extreme high temperature and high energy density. This form of matter is considered to have existed in the early Universe after approx. 10 micro-seconds after the Big Bang. My research is to study the properties of this form of matter and the early Universe using relativistic high-energy heavy-ion collisions at RHIC-PHENIX experiment at BNL (Brookhaven National Laboratory) in USA and LHC-ALICE experiment at CERN (European Organization for Nuclear Research) in Europe.

Recent publications
(1) B. Abelev, T. Gunji et al. (for the ALICE Collaboration): "Pion, Kaon, and Proton Production in Central Pb–Pb Collisions at $\sqrt{s_{NN}}$=2.76 TeV", Phys. Rev. Lett. **109** (2012) 252301
(2) B. Abelev, T. Gunji et al. (for the ALICE Collaboration): "Inclusive J/ψ production in p-p collisions at $\sqrt{s}$ =2.76 TeV", Phys. Lett. B **718** (2012) 295-306
(3) S. Afanasiev, T. Gunji et al. (for the PHENIX Collaboration): "Measurement of Direct Photons in Au+Au Collisions at $\sqrt{s_{NN}}$ =200 GeV", Phys. Rev. Lett. **109** (2012) 152302
(4) K. Aamodt, T. Gunji et al. (for the ALICE Collaboration): "Higher harmonic anisotropic flow measurements of charged particles in Pb-Pb collisions at $\sqrt{s_{NN}}$=2.77 TeV", Phys. Rev. Lett. **107** (2011) 032301
(5) K. Aamodt, T. Gunji et al. (for the ALICE Collaboration): "Centrality dependence of the charged-particle multiplicity density at mid-rapidity in Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV" Phys. Rev. Lett. **106** (2011) 032301

OTA, Shinsuke
(Assistant Professor)

Career
2001.03: graduate Department of Physics, Kyoto University
2003.03: graduate Master course of Department of Physics, Kyoto University
2006.03: graduate Doctor course of Department of Physics, Kyoto University
2006.04∼2009.03: Research Associate of Center for Nuclear Study (CNS), University of Tokyo
2009.04∼: Assistant Professor of Center for Nuclear Study (CNS), University of Tokyo
Doctoral Degree: 2009.3 Doctor of Science (Kyoto University)
Awards: 2009.9 Award for Outstanding Young Physicists –Experimental Nuclear Physics–
Society: Physical Society of Japan
Comminity service and social activities:
2010.4-2011.3: Secretary of Nuclear Experimental Physics Forum (Kakudan)
Main research activities:

Nuclear experimental physics using intermediate energy unstable nuclei beam.

I am especially interested in the nuclear correlation which is thought to be an essential feature of the many body problem in the nuclei and also interested in the bulk property of nuclei represented by the giant resonances such as giant monopole resonances and Gamow-Teller resonances. Expanding the playing field on these topic from stable nuclei to unstable nuclei gives the new point of view.

The measurement of the forward angle scatterings on proton, deuteron and helium is promissing tool to study these properties if we can measure the very low energy recoiled light particles. I'm responsible for the development of a gaseous active target which enables us to measure such low energy recoiled particles. I and colleagues performed a pilot experiment using ^{14}O beam.

Recent publications

1. S. Ota et al.: "Low-lying proton intruder state in 13B", Phys. Lett. B**666** (2008) 311–314

2. S. Shimoura, S. Ota et al "Lifetime of the Isomeric 0_2^+ State in ^{12}Be", Phys. Lett. B, Elsevier, 654, (2007))pp.87-91

3. E. Ideguchi, S. Ota, T. Morikawa, M. Oshima, M. Koizumi, Y. Toh, A. Kimura, H. Harada, K. Furutaka, S. Nakamura, F. Kitatani, Y. Hatsukawa, T. Shizuma, M. Sugawara, H. Miyatake, Y.X. Watanabe, Y. Hirayama, M. Oi: "Superdeformation in asymmetric $N > Z$ nucleus ^{40}Ar", Phys. Lett. B **686** (2010) 18–22.

4. S. Takeuchi, N. Aoi, T. Motobayashi, S. Ota et al., "Low-lying states in ^{32}Mg studied by proton inelastic scattering", Phys. Rev. C 79, 054319 (2009)

5. N. Aoi, E. Takeshita, H. Suzuki, S. Takeuchi, S. Ota et al., "Development of Large Deformation in ^{62}Cr", Phys. Rev. Lett. 102, 012502 (2009)

SHIMIZU, Noritaka
(Project Associate Professor)

Career
1996.03: ḡraduate Department of Physics, University of Tokyo
1998.03: ḡraduate Master course of Department of Physics, University of Tokyo
2001.03: ḡraduate Doctor course of Department of Physics, University of Tokyo
2001.04∼2004.03: Special Postdoctral Researcher, RI-Beam Science laboratory, RIKEN
2004.04∼2005.08: Postdoctoral Researcher, Departmenf of Physics, University of Tokyo
2005.09∼2011.03: Research Associate, Departmenf of Physics, University of Tokyo
2011.04∼: Project Associate Professor, Center for Nuclear Study, University of Tokyo

Doctoral Degree: 2001.3 Doctor of Science (University of Tokyo)
Awards:
Society: Physical Society of Japan
Comminity service and social activities:

Main research activities:

My major activities are the theoretical study on nuclear structure in medium heavy mass region and the developments of numerical methods for quanutm many-body systems. Based on nuclear shell-model caclulations, the quadrupole collectivity of Xe, Ba isotopes are discussed microscopically. I combined the Monte Carlo Shell Model method with the energy-variance extrapolation to estimate the energy expectation values precisely where the conventinal Lanczos method is not feasible. The computational aspect of the code developments for massive parallel computers is also my concern.

Recent publications

(1) N. Shimizu et al.: "New generation of the Monte Carlo shell model for the K computer era", Prog. Theor. Exp. Phys. **2012(1)** (2012) 01A205

(2) Y. Utsuno et al.: "Efficient computation of Hamiltonian matrix elements between non-orthogonal Slater determinants", Comp. Phys. Comm. **184** (2013) 102

(3) C. Bauer et al.: "Prolate shape of ^{140}Ba from a first combined Doppler-shift and Coulomb-excitation measurement at the REX-ISOLDE facility", Phys. Rev. C **86** (2012) 034310

(4) N. Shimizu et al.: "Variational procedure for nuclear shell-model calculations and energy-variance extrapolation", Phys. Rev. C **85** (2012) 054301

(5) T. Mizusaki and N. Shimizu, "New variational Monte Carlo method with energy variance extrapolation for large-scale shell-model calculations", Phys. Rev. C **85** (2012) 021301(R)

TORII, Hisayuki
(Project Assistant Professor)

Career
1996.03: ḡraduate Physics Department, Kyoto University
1998.03: ḡraduate Master course of Physics Department, Kyoto University
2003.06: l̄eave Doctor course of Physics Department, Kyoto University
2003.04: Special Postdoctoral Researcher of RIKEN
2006.04: Research Fellowship for Young Scientists of JSPS
2009.04: Special Assistant Professor of Hiroshima University
2011.04: Project Assistant Professor of Center for Nuclear Study (CNS), University of Tokyo

Doctoral Degree: 2004.11 Doctor of Science (Kyoto University)
Society: Physical Society of Japan

Community service and social activities:

Main research activities: My research activities focus on experimental studies for properties of Quantum Chromo Dynamics (QCD) in hot and/or dense medium. The properties of hadrons in high energy nucleus collision or nuclear matter are measured using neutral pion and photon radiation. Current main activity is to perform the ALICE experiment at the Large Hadron Collider (LHC) project and PHENIX experiment at the Relativistic Heavy Ion Collider (RHIC) project which are aiming to research an exotic state of matter, such as quark gluon plasma (QGP). In addition to such physics activities, I'm maintaining an electromagnetic calorimeter (PHOS) of the ALICE experimental apparatus, which was constructed by an international collaboration with Japanese group and foreign countries and installed from the beginning of the first year of LHC.

Recent publications
(1) H. Torii for the ALICE-PHOS collaboration "The ALICE PHOS calorimeter" J. Phys. Conf. Ser. **160** (2009) 012045.
(2) K. Aamodt et al.(ALICE Collaboration): "Charged-Particle Multiplicity Density at Midrapidity in Central Pb-Pb Collisions at $sqrts_{NN}$=2.76TeV." Phys. Rev. Lett. **105** (2010) 252301.
(3) B. Abelev et al. (ALICE Collaboration): "Neutral pion and η meson production in proton-proton collisions $sqrts$=0.9TeV and $sqrts$=7TeV" Phys. Lett. B**717** (2012) 162-172.
(4) A. Adare et al.: "Direct photon production in d+Au collisions at $sqrts_{NN}$=200GeV" 1208.1234v1, 6 Aug 2012., under publication.

YOSHIDA, TOORU
(Project Assistant Professor)

Career
2002.03: ḡraduate Physics Department, Hokkaido University
2004.03: ḡraduate Master course of Physics Department, University of Tokyo
2007.03: ḡraduate Doctor course of Physics Department, University of Tokyo
2012.09∼: Project Assistant Proffessor of Center for Nuclear Study (CNS), University of Tokyo

Doctoral Degree: 2007.3 Doctor of Science (University of Tokyo)
Society: Physical Society of Japan

Main research activities: Nuclear theoretical physics using shell model and cluster model.

My interests are in cluster structure of light nuclei. Cluster structure is important for light nuclei especially in the excited states around the α breakup threshold. The cluster model calculation is one of the natural methodology for them. How cluster structure is manifested can be revealed by more microscopic calculations.

The microscopic calculation of light nuclei without assuming core nucleus by using Monte Carlo shell-model calculation is now possible due to the recent progress of super computer such as K computer. Wavefunctions of many light nuclei are under calculation. I am investigating the properties of these state.

Recent publications
(1) N. Shimizu et al.: "New-generation Monte Carlo shell model for K computer era", Prog. Theor. Exp. Phys. **2012** 01A205.
(2) T. Yoshida et al.: "Symplectic structure and monopole strength in ^{12}C", Phys. Rev. C **83** (2011) 024301.
(3) T. Yoshida et al.: "Appearance of cluster structure in ^{13}C", Phys. Rev. C **79** (2009) 034308.

IWATA, Yoritaka
(Project Assistant Professor)

Career
2000.03: ḡraduate Department of Applied Science, Osaka University
2002.03: ḡraduate Master course of Department of Applied Science (Applied Math.), Osaka University
2005.03: c̄ourse work completed Doctor course of Information Science and Technology, Osaka University (received degree in 2006.03)
2008.03: ḡraduate Doctor course of Physics Department, University of Tokyo

2006.04∼ 2007.03: 21st COE Research Assistant of Physics Department, University of Tokyo
2007.04∼ 2009.03: JSPS Fellow of Physics Department, University of Tokyo
2009.04∼ 2012.12: EMMI Fellow of Extreme Matter Institute, GSI Helmholtz Centre for Heavy-Ion Research
2013.01∼: Project Assistant Professor of Center for Nuclear Study, University of Tokyo

Doctoral Degree: 2006.3 Doctor of Information Science and Technology (Osaka University)
Doctoral Degree: 2008.3 Doctor of Science (University of Tokyo)
Society: Mathematical Society of Japan, Physical Society of Japan

Theoretical research on many-nucleon systems.

I have been working on heavy-ion reaction research based on the time-dependent density functional theory. In particular, the mechanisms of low-energy reactions such as fusion reactions, deep inelastic reactions, and (fusion-/quasi-) fission reactions have been studied in a self-consistent way. The synthesis of exotic nuclei and superheavy nuclei is the main issue.

I enter into nuclear structure business. The research is definitely based on large-scale shell model calculations. This project would be my main subject as a CNS (Center for Nuclear Study, University of Tokyo) member.

Recent publications
(1) Y. Iwata, K. Iida and N. Itagaki: "Synthesis of thin, long heavy nuclei in ternary collisions", Phys. Rev. C **84** (2013) 01416.
(2) Y. Iwata, and J. A. Maruhn: "Energy density functional in nuclear physics", in Book "Density Functional Theory: Principles, Applications and Analysis", Nova Publishers (2013).
(3) Y. Iwata: "Zero Sound Propagation in Femto-Scale Quantum Liquids', J. Mod. Phys. **3** 6 (2012) 476.
(4) Y. Iwata, and J. A. Maruhn: "Enhanced spin-current tensor contribution in collision dynamics", Phys. Rev. C **84** (2011) 014616.
(5) Y. Iwata, T. Otsuka, J. A. Maruhn and N. Itagaki: "Suppression of charge equilibration leading to the synthesis of exotic nuclei", Phys. Rev. Lett. (2010) 252501.
(6) Y. Iwata, T. Otsuka, J. A. Maruhn and N. Itagaki: "Geometric classification of nucleon transfer at moderate low-energies", Nucl. Phys. A **836** (2010) 108.
(7) Y. Iwata, T. Otsuka, J. A. Maruhn and N. Itagaki: "Synthesis of exotic nuclei in heavy-ion collisions at higher energies", Eur. Phys. J A **43** (2009) 613.

Appendix E

Master and Doctor Theses

Master Theses

Name	Title	Supervisor	Date
Y. Morino	“Study of Electron Identification Capability of ALICE TRD”	H. Hamagaki	Mar. 2006
Y. Sasamoto	“Study of cluster states in ^{11}B and ^{13}C via alpha inelastic scattering”	T. Uesaka	Mar. 2006
S. Sakaguchi	“Analyzing Power Measurement for the $\vec{p}$+^{6}He Elastic Scattering at 71 MeV/u with Upgraded Solid Polarized Proton Target”	T. Uesaka	Mar. 2006
Y.L. Yamaguchi	“Research and Development of Gas Electron Multiplier (GEM) with a dry etching technique”	H. Hamagaki	Mar. 2007
Y. Aramaki	“Development of a Gas Cherenkov Counter Using Gas Electron Multipliers (GEMs)”	H. Hamagaki	Mar. 2007
S, Saito	“Study of Minimum Bias Trigger Efficiency in Heavy Ion Collisions at RHIC-PHENIX”	H. Hamagaki	Mar. 2007
G. Amadio	“Study of the Resonant Scattering of ^{7}Be+p”	S. Kubono	Mar. 2007
D.H. Kahl	“^{30}S Beam Development and the ^{30}S Wating Point in Type I X-Ray Bursts”	(S. Kubono)	2008, McMaster Univ. (Canada)
T. Kawahara	“Process of proton polarization under low magnetic field at high temperature”	(T. Uesaka)	Mar. 2008, Toho Univ.
Y. Kurihara	“Development of High-Energy Resolution Ion Chamber for Low-Energy Heavy Ions”	S. Kubono	Mar. 2009
A. Takahara	“Performance Evaluation of TRD in LHC-ALICE Experiment”	H. Hamagaki	Mar. 2009

continued to the next page

Name	Title	Supervisor	Date
R. Akimoto	"Development of Time Projection Chamber using Gas Electron Multiplier, for Use as an Active Target"	H. Hamagaki	Mar. 2010
Y. Hori	"Simulation Study for Foward Tracking Calorimeter in LHC-ALICE experiment"	H. Hamagaki	Mar. 2010
H. Miya	"Development of Tracking Chamber for High-resolution Nuclear Spectroscopy with RI beam"	S. Shimoura	Mar. 2010
H. Tokieda	"Cathode Readout Drift Chambers for the SHARAQ Spectrometer"	T. Uesaka	Mar. 2010
T. Tsuji	"Simulation Study of the Forward Calorimeter for LHC-ALICE"	H. Hamagaki	Mar. 2011
S. Kawase	"Spin-orbit Separation of proton orbit in ^{18}O by the ($\vec{p}$, 2p) reaction 200 MeV"	T. Uesaka	Mar. 2011
S. Go	"Development of 3-D position sensitive Ge detectors for highly-sensitive in-beam gamma-ray spectroscopy"	S. Shimoura	Mar. 2011
K. Kisamori	"Development of two-alpha detection system for exothermic double-charge exchange reaction (^{8}He, ^{8}Be)"	S. Shimoura	Mar. 2012
M. Takaki	"Study of ^{12}Be nucleus via heavy-ion double charge exchange reaction"	S. Shimoura	Mar. 2012
Y. Kikuchi	"Development of hodoscope consisting of 1-mm square plastic scintillators for the experiments with high-rate unstable-nuclei beam"	E. Ideguchi	Mar. 2012
A. Nukariya	"Development of a Readout System for the GEM-based X-ray Imaging Detector"	H. Hamagaki	Mar. 2012
S. Hayashi	"Development of a Readout Circuit for Forward Calorimeter in LHC-ALICE experiment"	H. Hamagaki	Mar. 2012
T. Fujii	"Spectroscopy of ^{32}Mg via α-inelastic Scattering"	S. Shimoura	(Mar. 2013)
R. Yokoyama	"Isomers of Deformed Neutron-rich Nuclei"	S. Shimoura	(Mar. 2013)
Y. Kubota	"Development of a tracking-type neutron detector with high granularity for studying unstable nuclei"	H. Yamaguchi	(Mar. 2013)
C.S. Lee	"Properties of Thick GEM in Low-Pressure Deuterium for Low-Pressure Gaseous Active Target"	H. Yamaguchi	(Mar. 2013)
Y. Sekiguchi	"Development of SOI pixel detector for radiation monitor"	H. Hamagaki	(Mar. 2013)

Doctor Theses

Name	Title	Supervisor	Date
A. Saito	"Exotic Cluster States in ^{12}Be *via* α-inelastic Scattering"	S. Shimoura	Mar. 2006
S. Michimasa	"Proton Shell Structure in Neutron-rich Nucleus ^{23}F"	S. Shimoura	Dec. 2006
T. Gunji	"J/ψ Production in High Energy Heavy Ion Collisions at RHIC"	H. Hamagaki	Mar. 2007
S. Kajihara	"Measurement of Single Electrons from Semi-Leptonic Decay of Heavy Quarks in Au + Au Collisions at 200 A GeV"	H. Hamagaki	Mar. 2007
T. Isobe	"Production of Direct Photons and Neutral Pions in Relativistic Au+Au Collisions"	H. Hamagaki	Jul. 2007
S. Kametani	"Measurement of J/ψ Yield in d+Au Collisions at $\sqrt{s_{NN}} = 200$ GeV"	H. Hamagaki	Jul. 2007
S. Oda	"Production of Charmonia in Cu+Cu and p+p collisions at $\sqrt{s_{NN}} = 200$ GeV"	H. Hamagaki	Mar. 2008
Y. Morino	"Production of charm and bottom quarks in $p+p$ collisions at 200 GeV"	H. Hamagaki	Mar. 2009
M. Niikura	"High-spin Spectroscopy of $^{49-51}$Ti by Fusion Reaction of RI Beam"	S. Shimoura	Mar. 2009
S. Ota	"Low-lying proton intruder state in ^{13}B via ^{4}He(^{12}Be,^{13}Bγ) reaction"	(S. Shimoura)	Mar. 2009, Kyoto Univ.
S. Sakaguchi	"Elastic Scattering of Polarized Protons from Neutron-rich Helium Isotopes at 71 MeV/A"	T. Uesaka	Mar. 2009
Jun-young Moon	"Study of astrophysically important nuclear states of ^{27}P using radioactive ion beam"	(S. Kubono)	Mar. 2009, Chung-Ang Univ (Korea)
Dam Ngyen Binh	"Study of the ^{21}Na(α,p)^{24}Mg Stellar Reaction by α-scattering and (α,p) Measurements in Inverse Kinematics"	S. Kubono	Oct. 2011
Y. Aramaki	"Measurement of Neutral Pion with Respect to the Azimuthal Angle in Au+Au Collisions at $\sqrt{s_{NN}} = 200$ GeV"	H. Hamagaki	Mar. 2011
Y. Yamaguchi	"Direct photon measurement with virtual photon method in d+Au collisions at $\sqrt{s_{NN}} = 200$ GeV"	H. Hamagaki	Mar. 2011
K. Miki	"Study of the isovector spin monopole resonance via the (t, ^{3}He) reactions at 300 MeV/u"	H. Sakai	Mar. 2011
S. Noji	"A New Spectroscopic Tool by the Radioactive-Isotope-Beam Induced Exothermic Charge-Exchange Reaction"	T. Uesaka	Mar. 2012

continued to the next page

Name	Title	Supervisor	Date
S. Sano	"Multi-strange Particle Production in Proton+Proton Collisions at $\sqrt{s}$=7 TeV"	H. Hamagaki	Mar. 2012
Y. Sasamoto	"Study of the isovector non-spin-flip monopole resonance via the super-allowed Fermi type charge exchange (^{10}C,^{10}B) reaction"	T. Uesaka	Apr. 2012
S. Hayakawa	"Direct Measurement of the Break-out Reaction ^{11}C(α,p)^{14}N in Explosive Hydrogen-Burning Process"	S. Kubono	Nov. 2012
Y. Hori	"Mixed harmonic azimuthal correlations in $\sqrt{s_{NN}}$ = 2.76 TeV Pb-Pb collisions measured by ALICE at LHC"	H. Hamagaki	Mar. 2013

Appendix F

Career paths of the CNS graduates

Graduates of CNS go on their career paths using their experiences as scientific researchers. Their careers after CNS in 2005–2012 are summarized in Tables F.1 and F.2. In this period CNS produced 27 masters and 20 doctors. More than 80% of the master-course gradates went on to the doctor course. Graduates of the doctor-course often remain in CNS for one or two years and then move on. Currently 6 graduates are post-doctoral researchers elsewhere. Typical career path of the doctors of CNS is to become an assistant professor.

Eight graduates have found their new paths in private companies, which include manufacture companies like Mitsubishi Electric, Nippon Electric (NEC), Fujitsu, and Shimadzu Corp. as well as an investment company.

Master course students

Table F.1: Career path of master-course students.

Master	27
Doctor course	22
Private company	5

Doctor course students and Postdocs

Table F.2: Current careers of graduates of the doctor-course.

Ph.D		20
Public research institute		3
University		6
Public-interest company		1
Private company		3
Post-doctoral researchers	CNS	1
	domestic, non-CNS	4
	abroad	2

Appendix G

List of Lectures

Table G.1: List of lectures at the Graduate School of Science given by the CNS faculty staffs.

Fiscal Year	Term	Title	Lecturer
2006	Summer	Nuclear Physics IV	Kubono, Uesaka
2007	Summer	Nuclear Physics V	Shimoura (with H. Sakurai)
	Summer	Quantum Structure of Matter at Extreme Conditions II	Hamagaki (with T. Hatsuda)
2008	Summer	Nuclear Physics IV	Kubono, Uesaka
	Summer	Quantum Structure of Matter at Extreme Conditions II	Hamagaki (with T. Hatsuda)
2009	Summer	Nuclear Physics III	Kubono, Uesaka
	Summer	Quantum Structure of Matter at Extreme Conditions II	Hamagaki (with T. Hirano)
2010	Summer	Nuclear Physics III	Kubono, Uesaka
	Summer	Quantum Structure of Matter at Extreme Conditions II	Hamagaki (with T. Hatsuda)
2011	Summer	Nuclear Physics III	Shimoura, Kubono
	Summer	Quantum Structure of Matter at Extreme Conditions II	Hamagaki (with T. Hirano)
	Winter	Experimental Techniques in Particle and Nuclear Physics	Ideguchi (with H. Sakamoto)
2012	Summer	Nuclear Physics III	Shimoura, Yamaguchi
	Summer	Hadron Physics	Hamagaki (with T. Hatsuda)
	Winter	Basic Numerical Calculation	Shimizu (with N. Yoshida)

Appendix H

References

H.1 Original Papers

1. G. Neyens, M. Kowalska, D. Yordanov, K. Blaum, P. Himpe, P. Lievens, S. Mallion, R. Neugart, N. Vermeulen, Y. Utsuno and T. Otsuka: "Measurement of the Spin and Magnetic Moment of ^{31}Mg: Evidence for a Strongly Deformed Intruder Ground State", Phys. Rev. Lett. **94** (2005) 022501 (4 pages).

2. Y. Yanagisawa, S. Kubono, T. Teranishi, K. Ue, S. Michimasa, M. Notani, J. J. He, Y. Ohshiro, S. Shimoura, S. Watanabe, N. Yamazaki, H. Iwasaki, S. Kato, T. Kishida, T. Morikawa and Y. Mizoi: "Low-energy radioisotope beam separator CRIB", Nucl. Instrum. Methods A **539** (2005) 74–83.

3. K. Adcox *et al.* (PHENIX Collaboration): "Formation of dense partonic matter in relativistic nucleus nucleus collisions at RHIC: Experimental evaluation by the PHENIX collaboration", Nucl. Phys. A **757** (2005) 184–283.

4. S. S. Adler *et al.* (PHENIX Collaboration): "Deuteron and antideuteron production in Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV", Phys. Rev. Lett. **94** (2005) 122302 (6 pages).

5. S. S. Adler *et al.* (PHENIX Collaboration): "Jet structure of baryon excess in Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV", Phys. Rev. C **71** (2005) 051902 (6 pages).

6. S. S. Adler *et al.* (PHENIX Collaboration): "Systematic studies of the centrality and $\sqrt{s_{NN}}$ dependence of $dE_T/d\eta$ and d $d\mathrm{N}_{\mathrm{ch}}/d\eta$ in heavy ion collisions at mid-rapidity", Phys. Rev. C **71** (2005) 034908 (25 pages) [Erratum-ibid. C **71** (2005) 049901 (1 page)].

7. S. S. Adler *et al.* (PHENIX Collaboration): "Production of ϕ mesons at mid-rapidity in $\sqrt{s_{NN}}$ = 200 GeV Au+Au collisions at RHIC", Phys. Rev. C **72** (2005) 014903 (23 pages).

8. S. S. Adler *et al.* (PHENIX Collaboration): "Saturation of azimuthal anisotropy in Au+Au collisions at $\sqrt{s_{NN}}$ = 62-200 GeV", Phys. Rev. Lett. **94** (2005) 232302 (6 pages).

9. S. S. Adler *et al.* (PHENIX Collaboration): "Mid-rapidity direct-photon production in $p + p$ collisions at sqrt(s) = 200 GeV", Phys. Rev. D **71** (2005) 071102 (7pages).

10. S. S. Adler *et al.* (PHENIX Collaboration): "Measurement of single electron event anisotropy in Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV", Phys. Rev. C **72** (2005) 024901 (10 pages).

11. S. S. Adler *et al.* (PHENIX Collaboration): "Centrality dependence of direct photon production in = $\sqrt{s_{NN}}$ 200 GeV Au+Au collisions", Phys. Rev. Lett. **94** (2005) 232301 (6 pages).

12. S. S. Adler *et al.* (PHENIX Collaboration): "Measurement of transverse single-spin asymmetries for mid-rapidity production of neutral pions and charged hadrons in polarized $p+p$ collisions at $\sqrt{s} = 200$ GeV", Phys. Rev. Lett. **95** (2005) 202001 (6 pages).

13. S. S. Adler *et al.* (PHENIX Collaboration): "J/ψ production and nuclear effects for d+Au and $p+p$ collisions at $\sqrt{s_{NN}} = 200$ GeV", Phys. Rev. Lett. **96** (2006) 012304 (6 pages).

14. S. S. Adler *et al.* (PHENIX Collaboration): "Single electrons from heavy flavor decays in $p+p$ collisions at $\sqrt{s} = 200$ GeV", Phys. Rev. Lett. **96** (2006) 032001 (6 pages).

15. S. S. Adler *et al.* (PHENIX Collaboration): "Measurement of identified π^0 and inclusive photon second-harmonic parameter v_2 and implication for direct photon production in $\sqrt{s_{NN}}$ 200 GeV Au+Au", Phys. Rev. Lett. **96** (2006) 032302 (6 pages).

16. S. S. Adler *et al.* (PHENIX Collaboration): "Nuclear modification of electron spectra and implications for heavy quark energy loss in Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV", Phys. Rev. Lett. **96** (2006) 032301 (6 pages).

17. Z. Fraenkel, T. Gunji, H. Hamagaki, M. Inuzuka, T. Isobe, Y. Morino, S.X. Oda, K. Ozawa, S. Saito, T. Sakaguchi *et al.*: "A hadron blind detector for the PHENIX experiment at RHIC", Nucl. Instrum. Methods A **546** (2005) 466–480.

18. C. Adler, T. Gunji, H. Hamagaki, M. Inuzuka *et al.* (ALICE Collaboration): "Electron/pion identification with ALICE TRD prototypes using a neural network algorithm", Nucl. Instrum. Methods A **552** (2005) 364–371.

19. C. Adler, T. Gunji, H. Hamagaki *et al.* (ALICE Collaboration): "Position reconstruction in drift chambers operated with Xe, CO_2 (15%).", Nucl. Instrum. Methods A **540** (2005) 140–157.

20. A. Andronic, T. Gunji, H. Hamagaki, Y. Morino, S. Saito *et al.* (ALICE Collaboration): "Transition radiation spectra of electrons from 1 GeV/c to 10 GeV/c in regular and irregular radiators", Nucl. Instrum. Methods A **558** (2006) 516–525.

21. M. Naruki, H. Hamagaki, K. Ozawa *et al.*: "Experimental signature of the medium modification for ρ and ω mesons in 12GeV p+A reactions", Phys. Rev. Lett. **96** (2006) 092301 (4 pages).

22. J.K. Ahn, K. Ozawa *et al.*: "$\Sigma^+ p$ elastic scattering cross setion in the region of $350 \leq P_{\Sigma^+} \geq 750$ MeV/c with a scintillating fiber active target, Nucl. Phys. A **761** (2005) 41–66.

23. Y. Kondo, T. Nakamura, N. Aoi, H. Baba, D. Bazin, N. Fukuda, T. Gomi, H. Hasegawa, N. Imai, M. Ishihara, T. Kobayashi, T. Kubo, M. Miura, T. Motobayashi, A. Saito, H. Sakurai, S. Shimoura, T. Sugimoto, K. Watanabe, Y.X. Watanabe, T. Yakushiji, Y. Yanagisawa, and K. Yoneda: "In-beam γ-ray spectroscopy of neutron-rich boron isotopes ^{15,17}B via inelastic scattering on ^{12}C", Phys. Rev. C **71** (2005) 044611 (9 pages).

24. Z. Elekes, Zs. Dombrádi, R. Kanungo, H. Baba, Zs. Fülöp, J. Gibelin, Á. Horváth, E. Ideguchi, Y. Ichikawa, N. Iwasa, H. Iwasaki, S. Kanno, S. Kawai, Y. Kondo, T. Motobayashi, M. Notani, T. Ohnishi, A. Ozawa, H. Sakurai, S. Shimoura, E. Takeshita, S. Takeuchi, I. Tanihata, Y. Togano, C. Wu, Y. Yamaguchi, Y. Yanagisawa, A. Yoshida, and K. Yoshida: "Low-lying excited states in ^{17,19}C", Phys. Lett. B **614** (2005) 174–180.

25. H. Iwasaki, T. Motobayashi, H. Sakurai, K. Yoneda, T. Gomi, N. Aoi, N. Fukuda, Zs. Fülöp, U. Futakami, Z. Gacsi, Y. Higurashi, N. Imai, N. Iwasa, T. Kubo, M. Kunibu, M. Kurokawa, Z. Liu, T. Minemura, A. Saito, M. Serata, S. Shimoura, S. Takeuchi, Y.X. Watanabe, K. Yamada, Y. Yanagisawa, and M. Ishihara: "Quadrupole collectivity of ^{28}Ne and the boundary of the island of inversion", Phys. Lett. B **620** (2005) 118–124.

26. R. Kanungo, Z. Elekesa, H. Baba, Zs. Dombrádi, Zs. Fülöp, J. Gibelin, Á. Horváth, Y. Ichikawa, E. Ideguchi, N. Iwasa, H. Iwasaki, S. Kawai, Y. Kondo, T. Motobayashi, M. Notani, T. Ohnishi, A. Ozawa, H. Sakurai, S. Shimoura, E. Takeshita, and S. Takeuchi, I. Tanihata, Y. Togano, C. Wu, Y. Yamaguchi, Y. Yanagisawa, A. Yoshida, K. Yoshida: "Search for an isomeric state in ^{19}C", Nucl. Phys. A **757** (2005) 315–328.

27. Zs. Dombrádi, Z. Elekes, R. Kanungo, H. Baba, Zs. Fülöp, J. Gibelin, Á. Horváth, E. Ideguchi, Y. Ichikawa, N. Iwasa, H. Iwasaki, S. Kanno, S. Kawai, Y. Kondo, T. Motobayashi, M. Notani, T. Ohnishi, A. Ozawa, H. Sakurai, S. Shimoura, E. Takeshita, S. Takeuchi, I. Tanihata, Y. Togano, C. Wu, Y. Yamaguchi, Y. Yanagisawa, A. Yoshida, and K. Yoshida: "Decoupling of valence neutrons from the core in ^{17}B", Phys. Lett. B **621** (2005) 81–88.

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Appendix I

Symposia and Workshops

I.1 Symposia

1. 21st Century COE International Symposium on ”Neutrino Processes and Stellar Evolution” (NEPSE07)

   Feb. 7–9, 2007, Sanjo Kaikan, University of Tokyo, Japan.

   The purpose of the NPSE07 symposium was to discuss various problems and issues on neutrino-nucleus reactions and their implications in stellar evolutions as well as recent developments of physics of neutrinos. It was timely to discuss such problems and issues at the time of the 20th anniversary of the supernovae 1987A.

   The organizing committee consisted of K. Sato(Univ. of Tokyo), K. Nomoto(Univ. of Tokyo), T. Kajita(ICRR, Univ. of Tokyo), K. Kubono(CNS, Univ. of Tokyo), T. Otsuka(Univ. of Tokyo, Chair of NEPSE07), H. Sakai (Univ. of Tokyo), S. Shimoura (CNS, Univ. of Tokyo), T. Kajino(NAO), A. Suzuki(KEK)

2. The CNS-RIKEN Joint International Symposium on “Frontier of gamma-ray spectroscopy and Perspectives for Nuclear Structure Studies” (gamma08)

   Apr. 3–5 2008, Wako campus of RIKEN, Japan.

   Recent progress and future perspectives of gamma-ray spectroscopy and recent development of advanced gammaray detectors were discussed.

   The organizers were, E. Ideguchi (CNS), N. Aoi (RIKEN), S. Michimasa (CNS), H. Scheit (RIKEN), A. Odahara (Osaka), T. Koike (Tohoku), T. Ishii (JAEA), T. Nakatsukasa (RIKEN), S. Shimoura (CNS), T. Motobayashi (RIKEN), T. Otsuka (CNS/Tokyo). The symposium was hosted by CNS University of Tokyo and RIKEN.

3. Japanese-French conference “New Paradigms in Nuclear Physics”

   Sep. 29–Oct. 2, 2008, Paris, France.

   The year 2008 was the 150th anniversary year of Japan-France relationship, and the present symposium was regarded as a part of the 150th anniversary project of the Ministry of Foreign Affairs of Japan. About 100 participants discussed the new paradigms in nuclear physics. EFES was one of the co-hosts. The conference was organized by Hiroshi Toki (RCNP: Co-chair), Sydney Gales (GANIL: Co-chair), Mamoru Fujiwara (RCNP: scientific secretary), David Boilley (GANIL: scientific secretary), Kouichi Hagino (Tohoku: scientific secretary), Marcella Grasso (IPN Orsay: scientific secretary), Toru

Motobayashi (RIKEN), Nguyen Van Giai (IPN Orsay), Takaharu Otsuka (Tokyo), Valerie Frois (IPN Orsay: Symposium secretary), Hiroaki Utsunomiya (Konan), Christine Lemaitre (GANIL: Symposium secretary)

4. The ICHOR-EFES International Symposium on "New Facet of Spin-Isospin Responses"

   Oct. 29–31, 2008, RIBF Conference Hall, RIKEN, Japan.

   At RIKEN the Radio-Isotope Beam Factory (RIBF) has started working. The University of Tokyo has taken an initiative to construct the magnetic spectrometer called SHARAQ dedicated to the high energy-resolution measurements in the experimental hall of RIBF under the Isospin-spin responses in CHarge-exchange exOthermic Reactions (ICHOR) program. Commissioning of SHARAQ was planned to start at March 2009. Thus this was a good opportunity to discuss physics which will be opened up by SHARAQ, placing particular emphasis on the spin-isospin responses. The symposium was organized by H. Sakai (UT) Chair, H. Sakurai (RIKEN), T. Otsuka (CNS,UT), S. Shimoura (CNS,UT, Secretary), R. G. T. Zegers (NSCL), and K. Langanke (GSI). and was hosted by RIKEN, ICHOR program, EFES, RIKEN, and CNS University of Tokyo.

5. The 6th Japan-Italy symposium on Heavy Ion Physics

   Nov. 11–15, 2008. Tokai, Japan.

   The aim of this symposium was to discuss the recent studies in nuclear and hadron physics and future projects. The topics of this symposium were Nuclear structure (shell structure, nuclear mass, symmetry energy, hyper nuclei), Nuclear dynamics (Superheavy element, nuclear fusion, direct reaction, nuclear fission), Innovative instrumentation and future facilities (RNB-development, detectors and electronics, J-PARC, RIBF, TRIAC, SPES), and Applications of nuclear physics (life science, material science, nuclear energy). EFES was one of the co-hosts. The symposium was organized by H. Ikezoe (JAEA, Chair), T. Kajino (NAOJ/Tokyo), H. Miyatake (KEK, Scientific secretary), T. Motobayashi (RIKEN, Vice Chair), T. Nakatsukasa (RIKEN), T. Otsuka (Tokyo/CNS/RIKEN), A. Bracco (Milano), G. Fortuna (INFN Headquarters), M. Lattuada (LNS), C. Signorini (Padova), A. Vitturi (Padova).

6. The International Symposium on "Origin of Matter and Evolution of Galaxies 2010" (OMEG2010)

   Mar. 8–10, 2010, Osaka, Japan

   This is the 10th international symposium of nuclear astrophysics, which started in 1988 by INS (predecessor of CNS) together with RIKEN. It was hosted this time by seven institutions; Research Center for Nuclear Physics, Osaka University (RCNP), RIKEN Nishina Center (RNC), Center for Nuclear Study, University of Tokyo (CNS), Division of Theoretical Astrophysics, National Astronomical Observatory of Japan (NAO), High Energy Accelerator Research Organization (KEK), Japan Atomic Energy Agency (JAEA), Konan University. The symposium was participated by 120 researchers, including 28 people from outside of Japan. Special emphasis was placed this time on the weak interaction as well as the electro-magnetic interaction for astrophysics. The symposium proceedings will be published in a book of AIP conference series.

   Organizing committee was compromised of I. Tanihata (RCNP, chair), T. Kishimoto (RCNP, Co-chair), T. Kajino (NAOJ, Co-chair), S. Kubono (CNS, Co-chair), W. Aoki (NAOJ), S. Chiba (JAEA), K. Kato (Hokkaido), Y. Fujita (Osaka), H. Miyatake (KEK),

T. Motobayashi (RIKEN), S. Nishimura (RIKEN), K. Nomoto (IPMU), A. Tamii (RCNP), H. Toki (RCNP), and H. Utsunomiya (Konan), T. Hayakawa (JAEA, scientific secretary), H. J. Ong (RCNP, scientific secretary), and T. Shima (RCNP, scientific secretary)

7. 25th Annivrsary of the Discovery of Halo Nuclei (Halo2010)

   Dec. 6–10, 2010, Hayama, Japan

   The Halo2010 Symposium was devoted to review various experimental and theoretical progresses in the fields of physics of drip-line nuclei and to discuss future perspectives initiated by 3rd generation RI beam facilities. 64 researchers, including 18 persons from outside of Japan participated to the symposium. The symposium was hosted by CNS.

   Local Organizers: S. Shimoura (Chair), H. Hamagaki (CNS), T. Nakatsukasa (RNC), T. Otsuka (Tokyo/CNS), H. Sakurai (RNC), S. Michimasa (CNS, Secretary)

8. French-Japanese Symposium on Nuclear Structure Problems – organized in the framework of FJNSP LIA and EFES –

   Jan. 5–8, 2011, RIKEN, Japan

   This symposium covered the topics of structure of exotic nuclei, nuclear reactions of stable and unstable nuclei, nuclear astrophysics, superheavy elements, new facilities and equipment, on-going and planned collaboration, and the related topics.

   The Symposium was organized on the basis of FJNSP LIA (French Japanese Nuclear Structure Problems International Associated Laboratory) in collaboration with EFES. The Organizers were B. Blank (CENBG Bordeaux), K. Hagino (Tohoku), T. Kishimoto (RCNP), W. Korten (SPhN, Saclay), T. Motobayashi (RNC), T. Osuka (CNS/Tokyo) M. Rousseau (IPHC Strasbourg), P. Roussel-Chomaz (DSM, Saclay), H. Sakurai (RNC), and H. Otsu (RNC, Secretary)

9. RIBF ULIC and CNS Symposium on Frontier of gamma-ray spectroscopy (gamma11)

   Jun. 30–Jul. 2, 2011, RIKEN, Japan

   The purpose of the symposium was to discuss recent progress and future perspectives of gamma-ray spectroscopy as well as the recent developments of advanced gamma-ray detectors. It is hoped that the symposium will encourage international cooperation and stimulate physicists in the field of nuclear structure studies.

   The Organizers were E. Ideguchi (CNS, co-chair), N. Aoi (RCNP/RIKEN, co-chair), S. Michimasa (CNS), H. Scheit (RIKEN), A. Odahara (Osaka), T. Koike (Tohoku), Y. Utsuno (JAEA), T. Nakatsukasa (RIKEN), S. Shimoura (CNS), T. Motobayashi (RIKEN), and T. Otsuka (CNS/Tokyo)

10. The 11th International Symposium on "Origin of Matter and Evolution of Galaxies" (OMEG11)

    Nov. 14–17, 2011, RIKEN, Japan

    Origin of Matter and Evolution of Galaxies (OMEG11) was the 11th symposium of a series started 1988, to discuss the subjects of nuclear astrophysics and related fields. In this symposium the following two topics were emphasized : RI beam experiments for explosive astrophysical phenomena, and first-generation stars and the evolution in the early universe.

CNS hosted the symposium with co-hosts of RNC, NAO, KEK, RCNP, Konan Univ., and JaFNA.

Chairs: S. Kubono (Chair), T. Kajino (Co-chair), T. Motobayashi (Co-chair) H. Miyaktake (Co-chair), and K. Nomoto (Co-chair).

11. International Symposium "Exotic Nuclear Structure From Nucleons" (ENSFN2012)

    Oct. 10–12, 2012, University of Tokyo, Japan

    Recent achievement and perspectives in the structure of Exotic nuclei were discussed from the viewpoint of the nuclear force. This symposium was supported by Riken Nishina Center and CNS.

    Organizes: T. Abe (Univ. Tokyo), M. Honma (Aizu, chair), N. Itagaki (YITP, Kyoto) T. Mizusaki (Senshu), T. Nakatsukasa (RNC), H. Sakurai (Tokyo/RNC), N. Shimizu (CNS, scientific secretary), S. Shimoura (CNS), Y. Utsuno (JAEA/CNS; scientific secretary)

12. 4th International Conference on "Collective Motion in Nuclei under Extreme Conditions" (COMEX4)

    Oct. 22–26, 2012, Hayama, Japan

    The COMEX conferences are a continuation of the series of topocal conferences on Giant Resonances, started in 1979. The scope of COMEX4 includes the related topics of collective excitations in stable and unstable nuclei. Decay studies from highly excited states, cluster and exotic shapes of nuclei, and applications in astrophysics are also the scope of this conference.

    Local Organizers: Y. Fujita (RCNP, Co-chair), S. Shimoura (CNS, Co-chair), N. Aoi (RCNP), T. Nakamura (TIT), A. Tamii (RCNP), K. Yako (CNS), M. Yamagami (Aizu), H. Otsu (RIKEN), S. Ota(CNS)

I.2 Workshops

1. 11th International Workshop on "Polarized Sources and Targets" (PST05)

    Nov. 14–17, 2005, Yayoi Auditorium Ichijo Hall, the University of Tokyo, Japan.

    The workshop is a traditional one to discuss physics and technologies related to the polarized gas/solid targets, polarized electron/ion/neutron sources, and polarimetry. Its 11th meeting was co-hosted by CNS and RIKEN. 82 scientists including 29 from abroad participated and joined active discussions on various aspects of polarization techniques and its applications.

    The organizers are K. Asahi (co-chair, RIKEN/TITech), H. En'yo (RIKEN), K. Hatanaka (RCNP), N. Horikawa (Chubu), K. Imai (Kyoto), T. Iwata (Yamagata), T. Kawabata (CNS), Y. Miyachi (TITech), Y. Mori (Kyoto), T. Nakanishi (Nagoya), H. Okamura (CYRIC), H. Sakai (co-chair, Tokyo), N. Sakamoto (RIKEN), Y. Sakemi (RCNP), T. Shibata (TITech), T. Shimoda (Osaka), T. Tamae (LNS, Tohoku), A. Tamii (RCNP), M. Uchida (TITech), T. Uesaka (CNS, secretary), K. Yako (Tokyo), and A. Yoshimi (RIKEN, secretary).

2. Workshop on "Technical Aspects of SHARAQ Spectrometer"

Nov. 20, 2005, CNS Wako Campus, Saitama, Japan

The purpose of this workshop was to discuss technical aspects of the design and construction of the SHARAQ spectrometer, the beamline with a large dispersion, and the detector system. Three professors. J.A. Nolen (ANL), H. Geissel (GSI) and W. Mittig (GANIL), were invited and made valuable suggestion and discussion with about 20 participant.

The organizers are S. Shimoura (CNS), T. Uesaka (CNS), and H. Sakai (Tokyo).

3. RIKEN-CNS RIBF International Workshop: "Correlation and Condensation: New Features in Loosely Bound and Unbound Nuclear States"

   Dec. 8-10, 2005, Conference room, RIBF Building 2F, RIKEN

   The scope of the workshop covered new features in loosely bound and unbound nuclear states such as di-neutron correlation and clustering phenomena. Recent theoretical and experimental results were presented and discussed with the 50 participants including the 5 speakers from abroad.

   The organizers are S. Aoyama (Niigata), Y. Funaki (Kyoto), H. Horiuchi (Kyoto), T. Kawabata (CNS), M. Matsuo (Niigata), T. Motobayashi (RIKEN), T. Nakamura (TIT), and M. Takashina (RIKEN).

4. CNS Workshop on "Past, Present and Future of Shell Model (with a course of shell model code)"

   Jan. 26–28, 2006, CNS Wako Campus, Saitama, Japan.

   In this workshop, experimental and theoretical studies related to the shell model were presented, including some reviews and histories. Current problems and future directions were also indicated. The major discussions were on the issues such as recent progress on the Monte Carlo shell model, nuclear structure calculations from the first principle, properties of chiral band, recent results on random interactions, roles of nuclear shell model for astrophysics, and recent experimental developments. In addition to the ordinary talks and discussions, one-hour training course was offered so that participants can master how to run a state-of-the-art shell-model code. The presentation file of each talk is now accessible on-line at the CNS WEB cite.

   The organizers are T. Mizusaki (Senshu, CNS), S. Kubono (CNS), T. Shimoura (CNS), and S. Fujii (CNS).

5. International Workshop on "Physics of Quark Gluon Plasma"

   Feb. 16–17, 2006, RIKEN, Saitama, Japan

   The purpose of this workshop was to achieve further understanding for the property of QGP. We discussed on the hot results from RHIC with enough time slots. The RHIC operation was started to study Quark-Gluon-Plasma and we obtained various new results from RHIC data in 5 years. We realized that the hadronic matter with high 100 temperature and density has very rich phases, such as color glass condensate. Three professors, G. Baym(Illinois), J. Ruppert(Duke), and S. Midouszewski (Texas A&M) were invited and gave valuable talks. About 60 scientists participated and 17 talks were presented. The presentation file of each talk is now accessible on-line at http://phenix.cns.s.u-tokyo.ac.jp/ws06/index e.html

   The organizers are H. Hamagaki(CNS), T. Hatsuda(Tokyo), H. Enyo(RIKEN), M. Asakawa(Osaka), S. Yokkaichi(RIKEN), K. Ozawa(CNS), and H, Torii(RIKEN).

6. International Workshop on “Nulear Physics with RIBF”

   Mar. 13–17, 2006, RIKEN, Saitama, Japan

   This workshop organized by RIKEN and CNS on the occasion that the RI Beam Facto ry (RIBF) will be constructed in 2006. The aim of this workshop was to discuss various research programs in RIBF and to point out problems to be solved by exchanging ideas and interests. This workshop also gave a trigger to form collaborations and networks for both coming experimental and theoretical works. About 150 scientists including 30 from abroad participated and 90 talks were presented. Workshop web site: http://rarfaxp.riken.go.jp/RIBF2006/

   The organizers are T. Kubo (RIKEN), N. Aoi (RIKEN), H. Ueno(RIKEN), S. Shimoura (CNS), K. Asahi (RIKEN), T. Kobayashi (Tohoku), M. Wada (RIKEN), A. Ozawa (Tsukuba), M. Wakasugi (RIKEN), K. Morita (RIKEN), T. Kubono (CNS), T. Otsuka (Tokyo), A. Ono (Tohoku), K. Hagino (Tohoku), M. Matsuo (Niigata), T. Motobayashi (RIKEN), Y. Enyo (YIFP), H. Sagawa (Aizu), K. Ogata (Kyushu), A. Kohama (RIKEN), K. Yabana (Tsukuba), and H.Sakurai (RIKEN).

7. 2nd German-Japanese Workshop on “Nuclear Structure and Astrophysics”

   Oct. 4–7, 2006, RIKEN, Japan

   Second German-Japanese Workshop on Nuclear Structure and Astrophysics has been held during 4-7/Oct. 2006 at the conference room, RIBF building, RIKEN, which is a cooperative workshop between German and Japanese scientists, and many talks and discussion have been given. This workshop was the second time of the series after the first one held at GSI in December 2004. This time, not only from GSI, 20 scientists came to Japan from many districts of Germany and all of them gave presentations. From Japanese side, 71 persons registered and 49 presentation were given. To promote the collaborations between German and Japanese scientists, the collaboration meeting and facility tour to RIBF, which was near completion, were organized. The workshop was supported by University of Tokyo-RIKEN Joint International Program for Nuclear Physics (TORIJIN), and also from the German side, DFG and GSI have supported. The workshop corresponds to the activity of core-to-core program, JSPS. P. Ring (TU Munich), H. Emling (GSI), K. Langanke (GSI), T. Otsuka (Tokyo), T. Motobayashi (RIKEN), T. Kobayashi (Tohoku), and K. Yabana (Tsukuba)

8. Japanese-French Workshop on “Exotic Femto Systems”

   Mar. 13–16, 2007, GANIL, Caen, France

   This should be the first of a new serie of workshops aimed was to strengthen the links between theory and experiments, and collaborations between Japan and France. The workshop was supported by the core-to-core project “Exotic Femto Systems” by the JSPS and by GANIL.

   Organizers were T. Otsuka(Tokyo), T. Motobayashi(Tokyo), H. Utsunomiya(Kobe), A. Odahara(Osaka), G. Marcella(Orsay), M. Iolanda(Bordeaux), M. Wolfgang(Caen), and B. David(Caen).

9. International Workshop “Joint JUSTIPEN-LACM” Meeting

   Mar. 5–8, 2007, Oak Ridge National Laboratory, USA

The meeting is a merger of two workshops: (i) the US-Japan theory meeting under the auspices of the Japan-US Theory Institute for Physics with Exoctic Nuclei (JUSTIPEN) and (ii) the annual NNSA-JIHIR meeting on the nuclear large amplitude collective motion (LACM) with an emphasis on fission. The purpose of the meeting, jointly organized by the JUSTIPEN Governing Board, by the UT/ORNL theory group, and by the JSPS Core-to-Core program "Exotic Femto Systems" is to bring together scientists (theorists and experimentalists) with interests in physics of radioactive nuclei, LACM, and theoretical approaches related to the SciDAC-2 UNEDF project. One emphasis of the meeting will be on topics related to future collaborations betwen US and Japanese groups (under JUSTIPEN).We are looking forward to an exiting meeting with stimulating discussions. The meeting is supported by the National Nuclear Security Administration under the Stewardship Science Academic Alliance program, JIHIR, JSPS, Todai-RIKEN Joint International Program for Nuclear Physics, and UNEDF.

The organizers are T. Otsuka (Tokyo), T. Motobayashi (RIKEN), H. Sakai (Tokyo), H. Horiuchi (RCNP/Osaka), M. Matsuo (Niigata), T. Noro (Kyushu), C. Bertulani(ORNL), D. Dean (ORNL), W. Nazarewicz (ORNL), and T. Papenbrock (ORNL).

10. International Workshop on "Direct reactions with Exotic Beams" (DREB2007)

    May 30–Jun. 2, 2007, RIKEN, Japan

    DREB2007 was the fifth InternationalWorkshop in a series of workshops initialized by researchers from MSU, Florida, Saclay and Orsay. DREB2007 intends to discuss the extraction of nuclear structure and astrophysical information from direct reactions with exotic beams as well as the understanding of reaction mechanisms. It also included the latest theoretical and experimental topics on varieties of reaction studies. DREB2007 was hosted by Faculty of Science at Kyushu University), RIKEN Nishina Center for Accelerator-Based Science) and CNS.

11. The third Japanese-German workshop on "Nuclear structure and astrophysics"

    Sep. 29–Oct. 2, 2007, Frauenwoerth im Chiemsee, Germany

    This was the third joint workshop between German and Japanese nuclear physicists. About 60 people joined including 19 Japanese participants. This workshop was organized by K. Langanke (GSI), P. Ring (Munich), T. Otsuka (Tokyo).

12. The first FIDIPRO-JSPS meeting on "Energy density functionals on nuclei"

    Oct. 25–27, 2007, Jyvaskyla, Finland.

    This was a workshop to discuss the development of the density functional theory to calculate the wide mass range of nuclear systems. Also, this workshop was a good opportunity to celebrate the new theory group in Jyvaskla.

13. Correlations in Nuclei: From Di-nucleons to Clusters

    Nov. 26–29, 2007, Institute for Nuclear Theory,Washington University, USA.

    This was a small workshop to discuss the many-body correlation in nuclear systems. The main issue was to include such correlations in the so called ab initio calculations. There were only 13 talks and much time was used for the discussions. The workshop was organized by B.R. Barrett (Arizona) and T. Otsuka (Tokyo).

14. The International Symposium on “Origin of Matter and Evolution of Galaxies 2007: From Dawn of Universe to the Formation of Solar System”

    Sapporo, Japan, Dec. 4–7, 2007

    This is the 10th international symposium of nuclear astrophysics, which started in 1988 by INS (predecessor of CNS) together with RIKEN. It was hosted this time by seven institutions; Hokkaido University, Center for Nuclear Study, University of Tokyo (CNS), National Astronomical Observatory (NAO), RIKEN, Department of Astronomy (University of Tokyo), RCNP (Osaka), and KEK. The symposium was participated by 123 researchers, including 26 people from outside of Japan. Special emphasis was placed this time on evolution of first stars and nuclear astrophysics with RI beams. The symposium proceedings was published in a book of AIP conferences series (No. 1016).

    Organizing committee was comprised of M.Y. Fujimoto (Hokkaido, Chair), S. Kubono (CNS, Tokyo, Co-chair), T. Kajino (NAOJ, Co-chair), K. Kato (Hakkaido, Co-chair), W. Aoki (NAOJ), T. Suda (RIKEN), H. Miyatake (KEK), T. Nozawa (Hokkaido), K. Ishikawa (Hokkaido), T. Suda (Hokkaido, scientific secretary), T. Motobayashi (RIKEN), T. Kishimoto (RCNP), K. Nomoto (Tokyo), S.Watanabe (Hokkaido), A. Ohnishi (Hokkaido), T. Nozawa (Hokkaido).

15. The 2nd LACM-EFES-JUSTIPEN Workshop

    Jan. 23–25, 2008, Oak Ridge National Laboratory, USA

    The purpose of the present meeting was to bring together scientists (theorists and experimentalists) with interests in physics of radioactive nuclei, large amplitude collective motion, and theoretical approaches. One emphasis of the meeting was on topics related to future collaborations between US and Japanese groups (under JUSTIPEN). JUSTIPEN is the DOE project in USA to send nuclear physicists to Japan to promote the nuclear theory collaborations. About 70 scientists (20 were from Japan) have participated in.

    This workshop was organized by Hisashi Horiuchi (RCNP), Tetsuro Ishii (JAEA), Yoshiko Kanada-En’yo (YITP), Hiroari Miyatake (KEK), Tohru Motobayashi (RIKEN), Takashi Nakatsukasa (RIKEN), Takaharu Otsuka (CNS/Tokyo), Hideyuki Sakai (Tokyo), Tomohiro Uesaka (CNS), David Dean (Oak Ridge), Witek Nazarewicz (Oak Ridge), Thomas Papenbrock (Oak Ridge, Lead Organizer) Nicolas Schunck (Oak Ridge), Mario Stoitsov (Oak Ridge), Sherry Lamb (Oak Ridge, Secretary).

16. Future Prospects for Spectroscopy and Direct Reactions 2008

    Feb. 26–28, 2008, Michigan State University, USA.

    The purpose of the workshop was to initiate and develop physics cases with upcoming heavy-ion spectrometers (for instance SHARAQ) in the field of structure of exotic nuclei and related problems.

    This workshop was organized by Alex Brown, Alexandra Gade, Thomas Glasmacher, Tohru Motobayashi, Tomohiro Uesaka, Taka Otsuka, Yutaka Utsuno, Remco Zegers, and Shari Conroy (secretary).

17. The CNS-RIKEN Joint International Symposium on “Frontier of gamma-ray spectroscopy and Perspectives for Nuclear Structure Studies” (gamma08)

    Apr. 3–5 2008, Wako campus of RIKEN, Japan. Recent progress and future perspectives of gamma-ray spectroscopy and recent development of advanced gammaray detectors were discussed. The organizers were, E. Ideguchi (CNS), N. Aoi (RIKEN), S. Michimasa (CNS), H. Scheit (RIKEN), A. Odahara (Osaka), T. Koike (Tohoku), T. Ishii (JAEA), T. Nakatsukasa (RIKEN), S. Shimoura (CNS), T. Motobayashi (RIKEN), T. Otsuka (CNS/Tokyo). The symposium was hosted by CNS University of Tokyo and RIKEN.

18. Hokudai-TORIJIN JUSTIPEN-EFES workshop "Perspective in Resonances and Continua on nuclei" & "JUSTIPEN-EFES-Hokkaido-UNEDF meeting"

    Jul. 21–25 2008, Onuma, Japan.

    The workshop was under the activities of JUSTIPEN and EFES. JUSTIPEN is the DOE project in USA to send nuclear physicists to Japan to promote the nuclear theory collaborations. This time 20 scientists have visited Japan from USA and discussed with 50 Japanese participants. The main focus was on resonance behavior of unstable nuclei, large scale calculation etc. "Hokudai-EFES-TORIJIN-JUSTIPEN meeting on Resonances and Continua" was organized by K. Kato (Hokkaido), M. Kimura(Hokkaido), T. Otsuka (Tokyo), N. Itagaki (Tokyo), S. Shimoura (CNS, Tokyo), T. Motobayashi (RIKEN), T. Nakatsukasa (RIKEN), and "JUSTIPEN-EFES-Hokudai-UNEDF meeting" was organized by B. Balantekin (Wisconsin), B. Barrett (Arizona), W. Nazarewicz (Oak Ridge), J. Vary (Iowa), N. Itagaki (Tokyo), T. Otsuka (Tokyo), K. Kato (Hokkaido), M. Kimura (Hokkaido).

19. The Joint ANL-EFES Workshop for a Compton-Suppressed Ge Clover Array for Stopped and Energy Degraded Exotic Beams

    Dec. 4–5, 2008, Argonne National Laboratory, USA.

    The workshop was hosted by Argonne National Lab., USA, EFES, and Argonne National Lab.

20. First EMMI-EFES workshop on neutron-rich exotic nuclei "Realistic effective nuclear forces for neutron-rich nuclei"

    Feb. 9–11 2009, GSI Darmstadt, Germany.

    The workshop focused on the transformation of realistic forces to realistic effective forces that retain the phase-shifts and deuteron properties (realistic) but are adapted (effective) to low-momentum many-body Hilbert spaces that cannot represent short-range correlations. About 50 people have participated (15 from Japan). The workshop was organized by H. Feldmeier (GSI) and T. Otsuka (Tokyo).

21. The Workshop on "Competition of hydrogen burning with n p-process and r-process in explosive nucleosynthesis"

    Feb. 19–20, 2009, Nishina Hall, RIKEN, Japan.

    43 persons were attended. High-temperature hydrogen burning, in relation with recent hot topics such as n p-process in supernovae, p-nuclei and metal-poor stars were extensively discussed from experimental and theoretical points of view. The organizers were, S. Kubono (CNS), T. Kajino (NAO), S. Nishimura (RIKEN), H. Yamaguchi (CNS), T. Yoshida (NAO), T. Teranishi (Kyushu), N. Iwasa (Tohoku), S. Wanajo (Tokyo), K. Maeda (Tokyo), H. Ishiyama (KEK) and K. Yoneda (RIKEN). The workshop was financially supported by CNS, RIKEN and JSPS.

22. The 3rd LACM-EFES-JUSTIPEN workshop

Feb. 23–25 2008, Oak Ridge National Laboratory, USA.

The purpose of the meeting was to bring together scientists (theorists and experimentalists) with interests in physics of radioactive nuclei, large amplitude collective motion, and theoretical approaches related to the SciDAC-2 UNEDF project. As in the preceding Joint JUSTIPEN-LACM Meetings (2007, 2008), one emphasis of the meeting was on topics related to future collaborations between US and Japanese groups (under JUSTIPEN). About 70 scientists (20 were from Japan) have participated in. This workshop was organized by Takaharu Otsuka (Tokyo), Takashi Nakatsukasa (RIKEN), Susumu Shimoura (CNS, Tokyo), David Dean (Oak Ridge), Witek Nazarewicz (Oak Ridge), Thomas Papenbrock (Oak Ridge, Lead Organizer) Nicolas Schunck (Oak Ridge).

23. Fist LIA-EFES workshop "Low-energy collective motion of exotic nuclei"

    Mar. 2–4 2009, GANIL, Cean, France.

    There were 30 participants and the workshop was organized in order to conduct informal discussions. The aim of the workshop was to discuss possible developments of various models and theories on the structure of heavier exotic nuclei, which will become a frontier of the next generation of radioactive-ion beams. The workshop was organized by Takaharu Otsuka (Tokyo), Nori Aoi (RIKEN), Navin Alahari (GANIL), Piet Van Isacker (GANIL).

24. Arctic FIDIPRO-EFES workshop

    Apr. 20–24, 2009, Saariselka, Finland

    Topics of the workshop covered nuclear structure theory and experimentswith special focus on future developments. On the theoretical side, new developments in describing nucleiwithin the energy-density-functional and shell-model methods were discussed, with a particular emphasis on structure of exotic nuclei. On the experimental side, the physics opportunities of the upgraded facilities at JYFL and emerging opportunities at other facilities like ISOLDE, SPIRAL2, RIKEN and FAIR were discussed. The upgrades at JYFL consists of the new recoil separator MARA in the present laboratory and the upgraded IGISOL facility to be located in the extension building of the experimental hall served also by the high-intensity proton beams from the new MC30 cyclotron. The symposium was hosted by University of Jyvaskyla and TORIJIN.

25. EFES workshop for "ab-initio calculations and nuclear forces",

    Oct. 12, Hilton Waikoloa Village, Hawaii, USA

    The workshop was hosted by JUSTIPEN and TORIJIN.

26. JUSTIPEN-EFES workshop on unstable nuclei,

    Dec. 7–9, 2009, RIKEN, Japan

    The workshop was hosted by JUSTIPEN and TORIJIN.

27. 2nd Meeting of OMEG Institute on R-process nucleotynthesis

    Jul. 15, 2010, RIKEN, Japan

28. 3rd Meeting of OMEG Insttitue on the $^{12}C(\alpha, \gamma)^{16}O$ reaction

    Nov. 1, 2010, RIKEN, Japan

29. 6th LACM-TORIJIN-JUSTIPEN workshop

    Oct.31–Nov. 2, 2012, Oak Ridge National Laboratory, USA.

    15 researchers participated from Japan. The workshop was hosted by JUSTIPEN and TORIJIN.