Research Programs at CNS

Shigeru KUBONO

Center for Nuclear Study, University of Tokyo

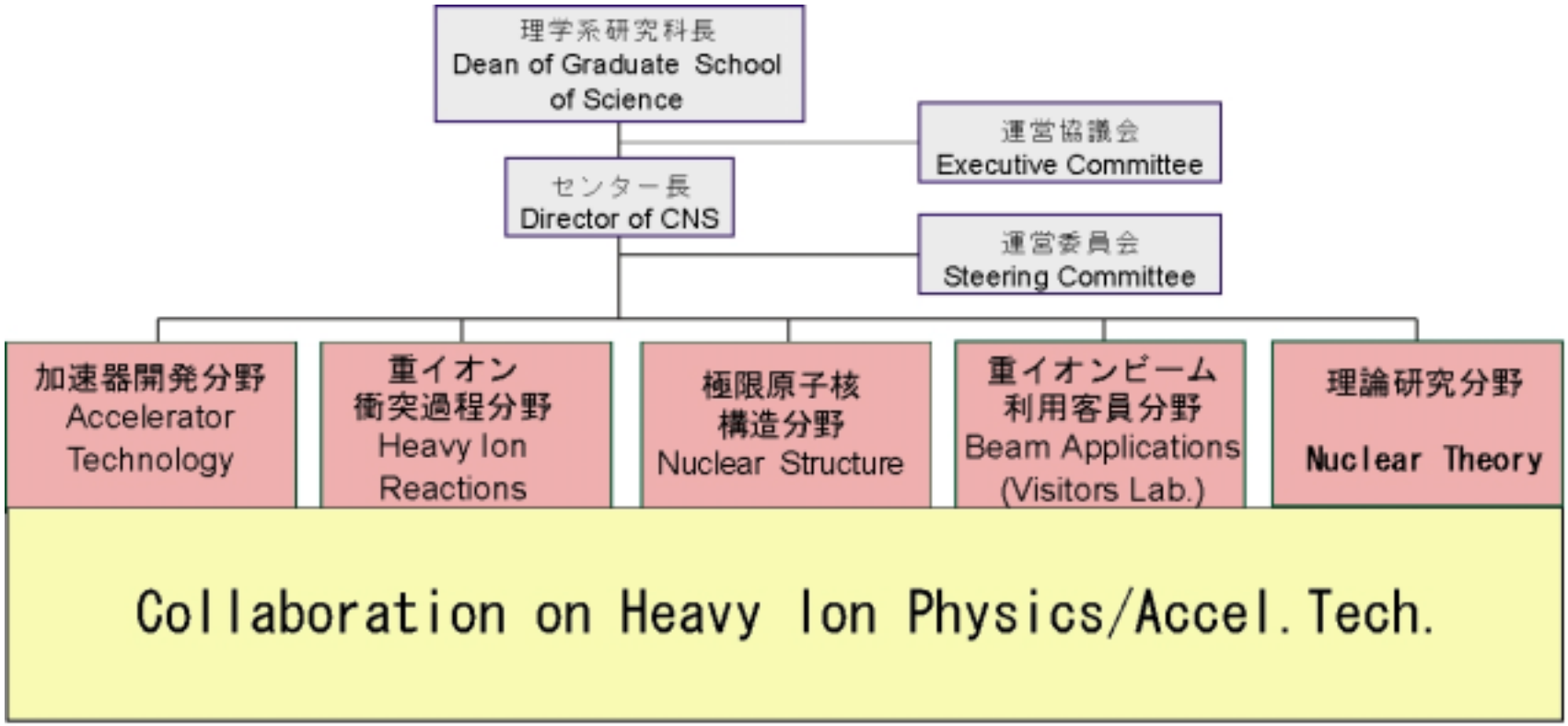
1. **Outline of CNS**
2. **Research Opportunities and the Scope**
3. **Nuclear Astrophysics**

   - Hot pp-chain

   - Neutron source for the s-process

   - ANC method for the (n,γ) reaction

CNS Organization



- Dev.of AVF
- ECR
  Accel.design
- Heavy ion fusion

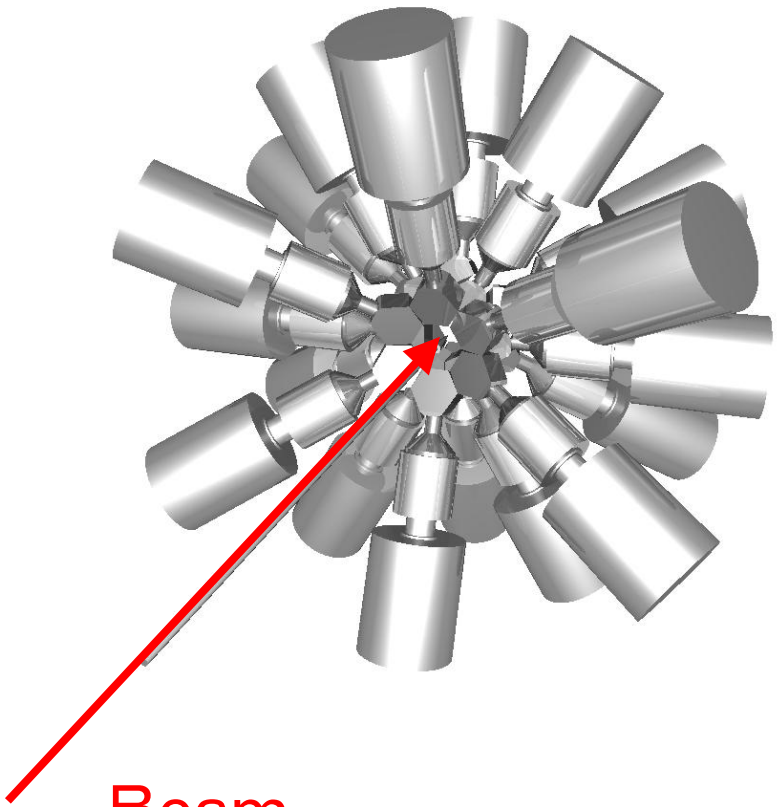
- Nuclear Astrophysics
- High Energy Heavy Ion
  (RHIC)

- Shell Model
- Three body

- Dev.of AVF
  Cluster IS
  Laser IS

- Nuclear structure/ reactions of exotic nuclei
- Polarization / Primary beams

CNS Ge Detector Array

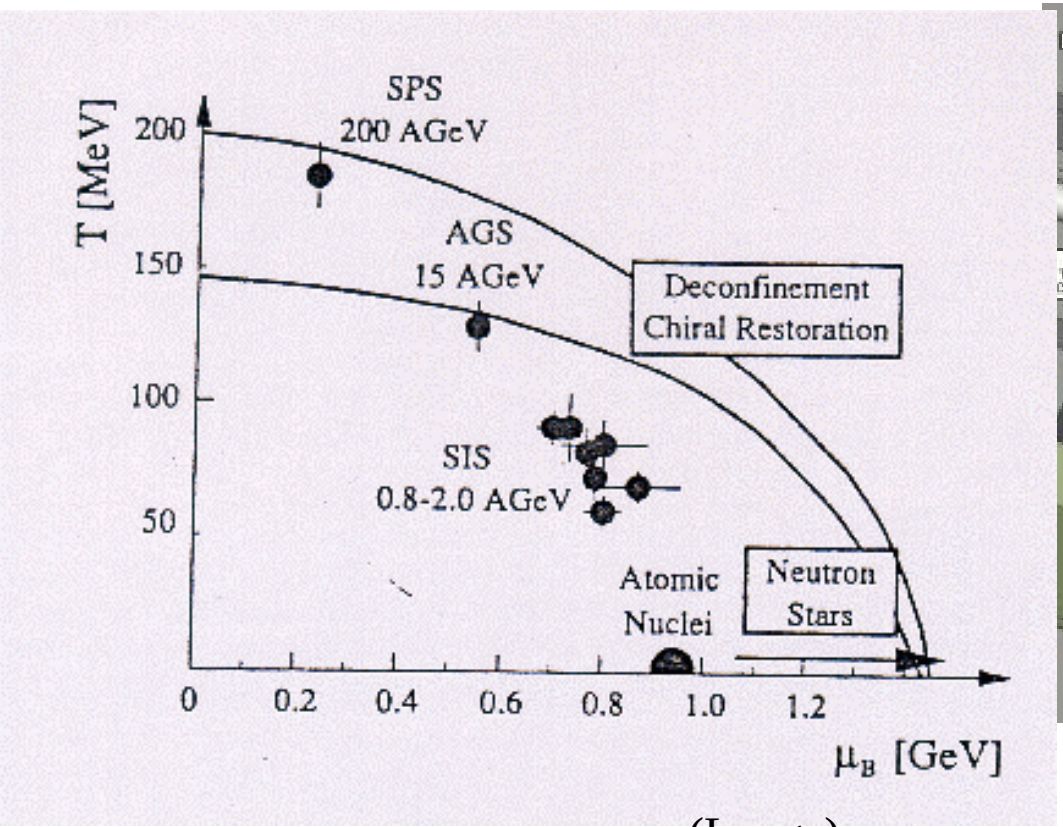


18 position-sensitive Ge detectors

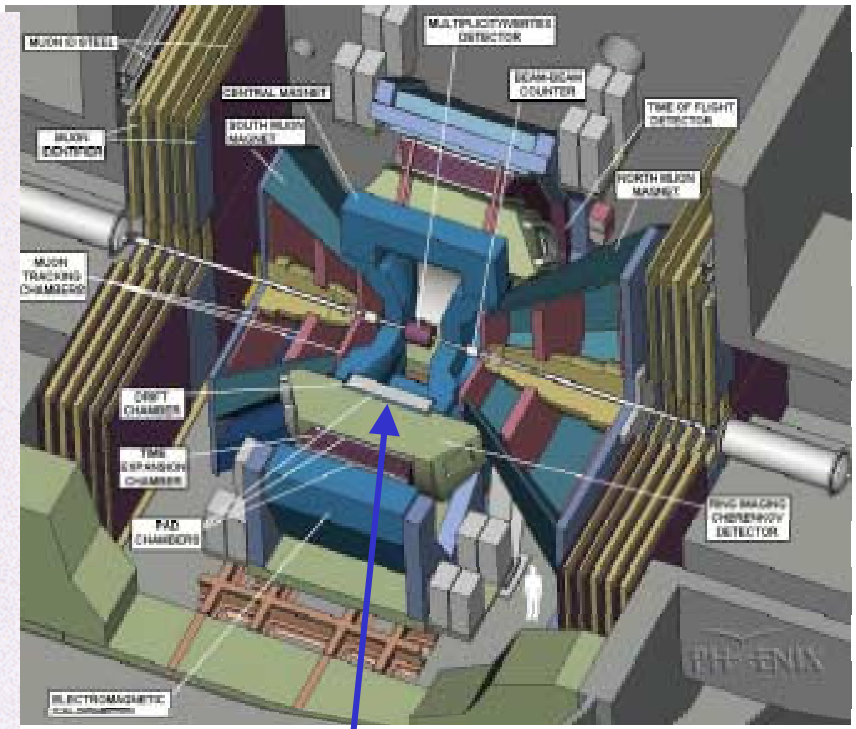
- Position resolution ≈ 1mm FWHM
  → Doppler Shift Correction
- Total detection efficiency = 5 %
  for 1 MeV gamma rays

Physics of Unstable Nuclei
cluster, magicity, halo, G.R.,

PHENIX Experiment at RHIC(@BNL)



(Lange)



PHENIX実験装置

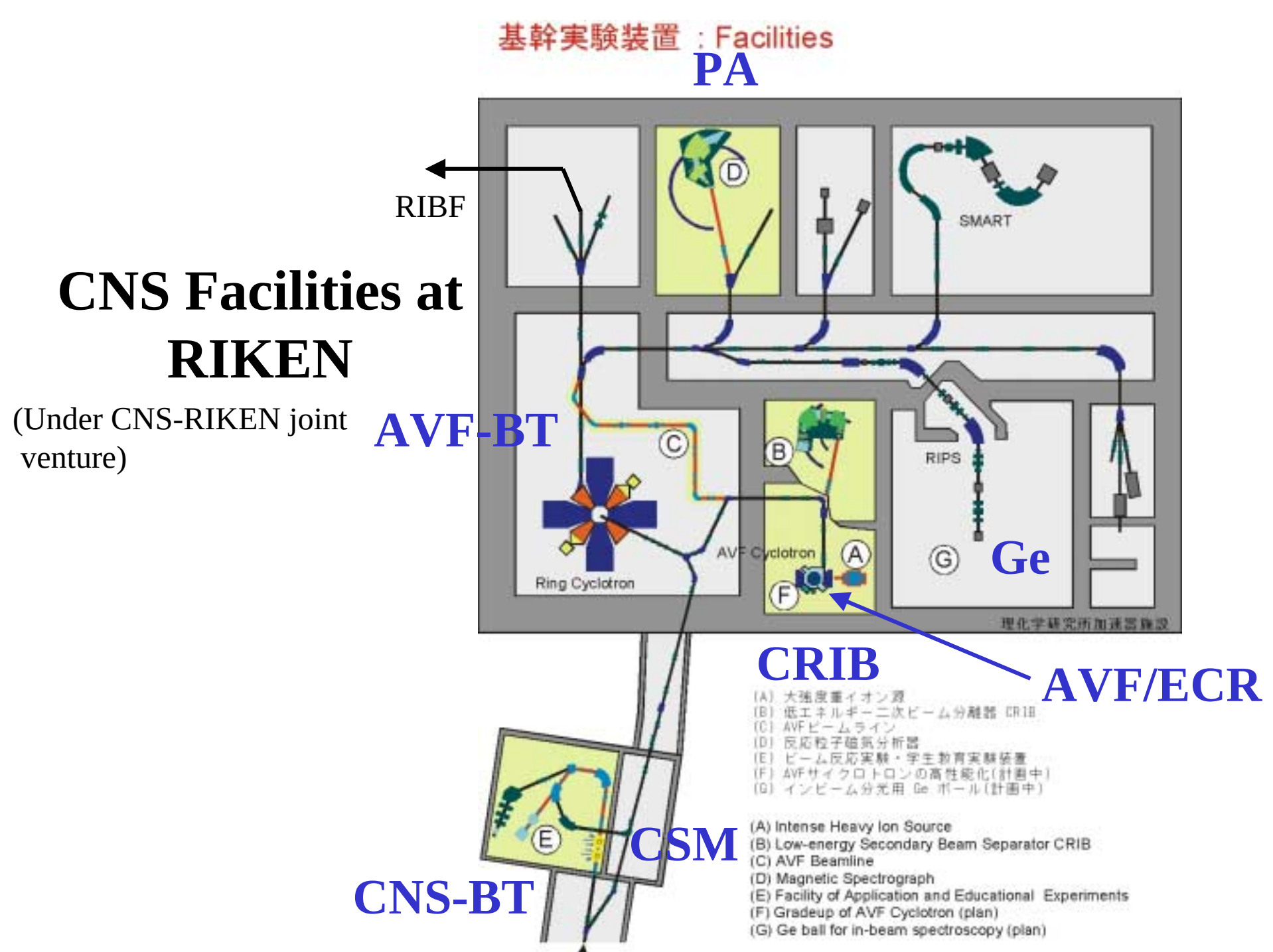
RICH detector / CNS

High density matter ?

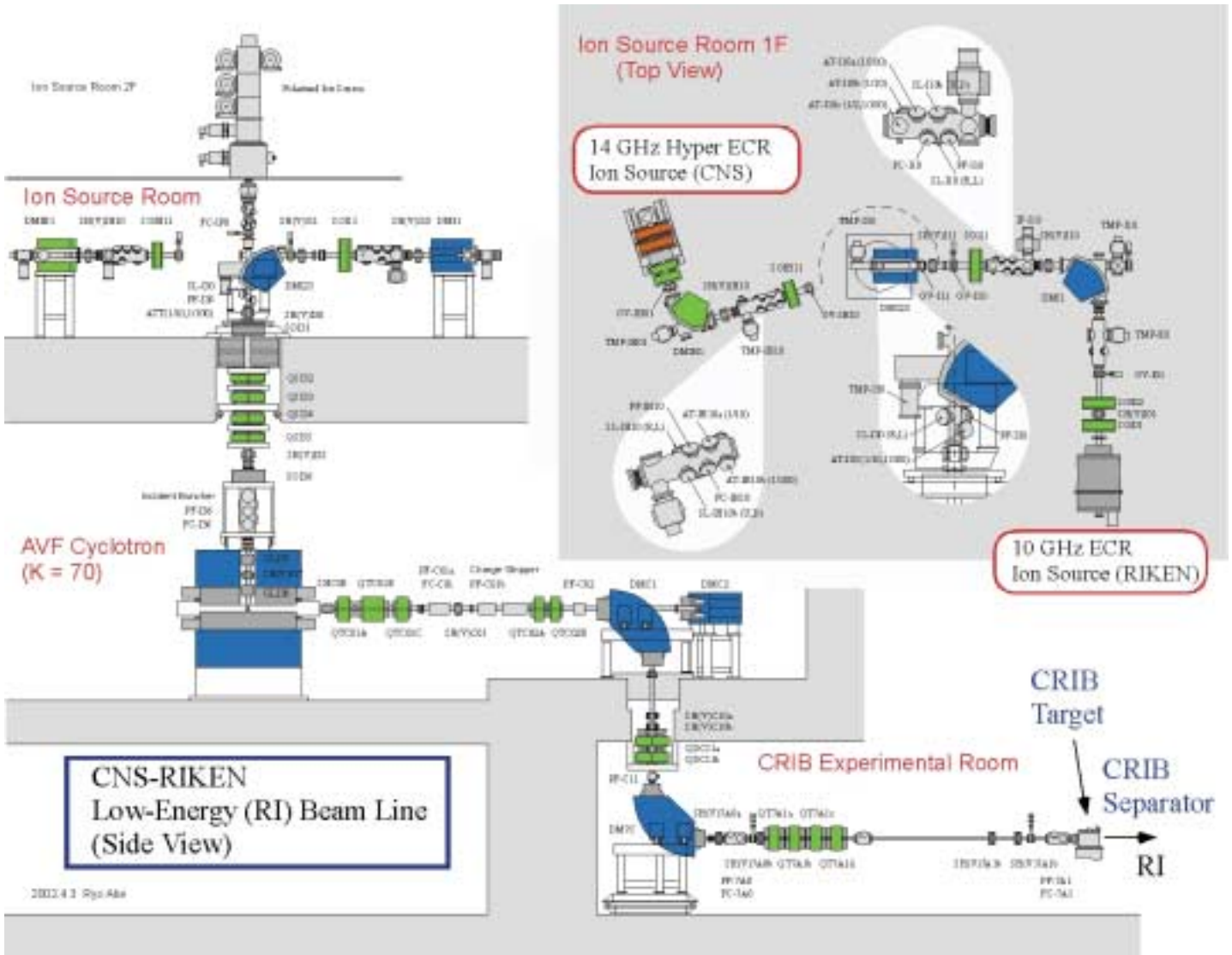
Quak-gluon plasma ?

CNS Facilities at RIKEN

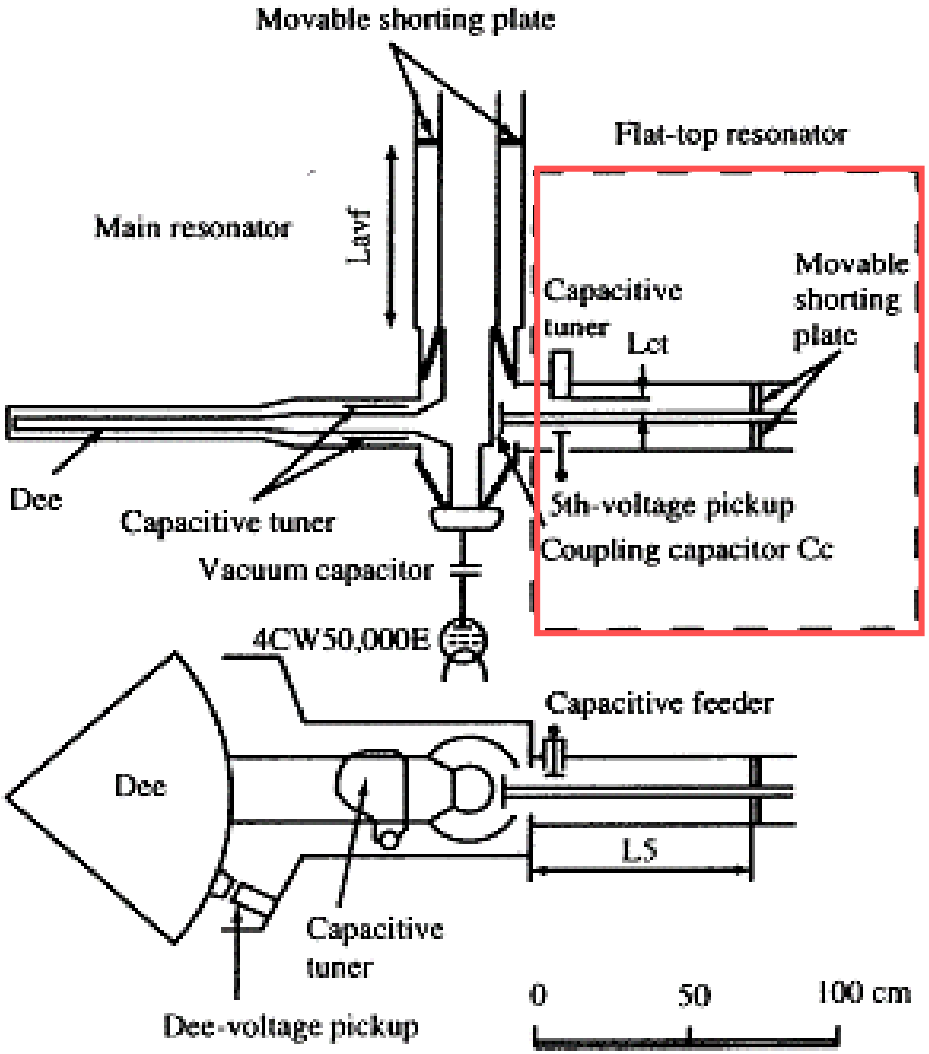
(Under CNS-RIKEN joint venture)



AVF Cyclotron and the ECRs’



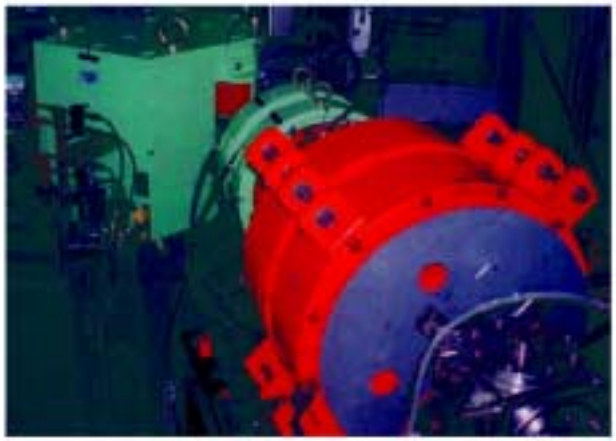
Flat-top Acceleration with AVF

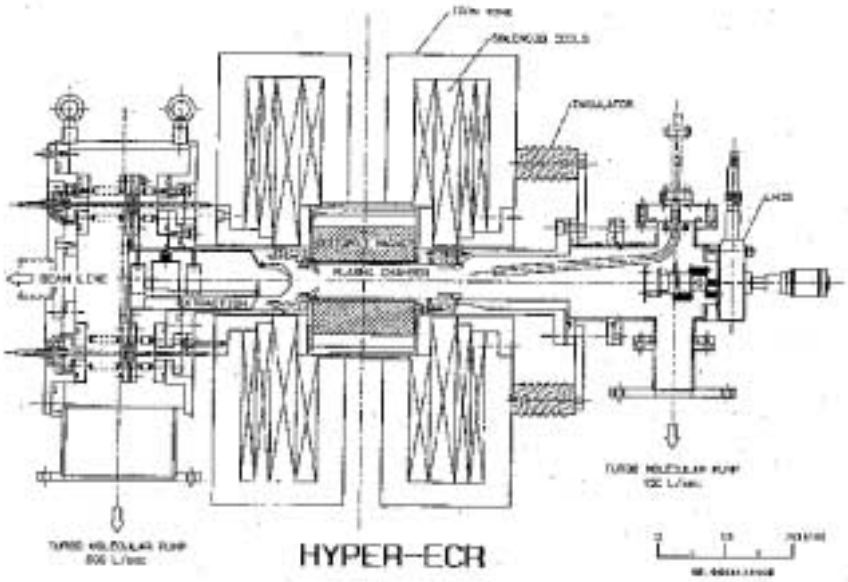


By fundamental + third hamonic

Hyper-ECR

CNS ECR Ion Source (14 GHz)





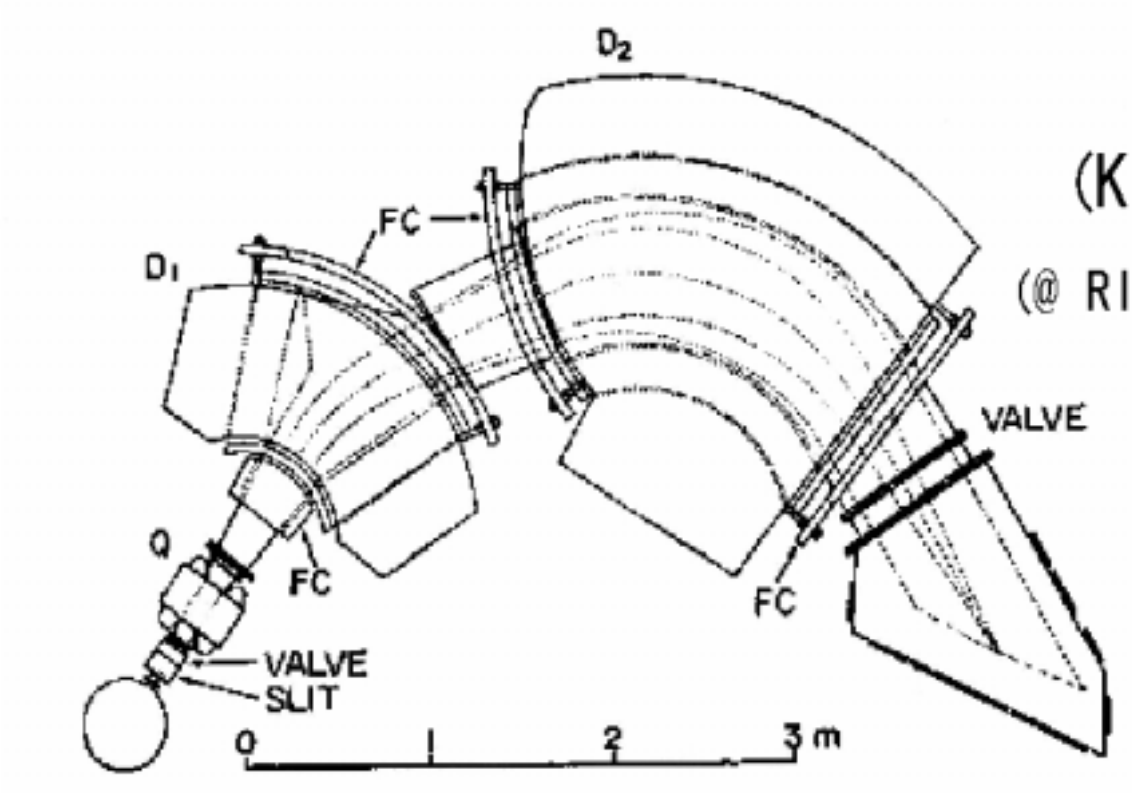
HyperECR の主なパラメター

Microwave power source	
frequency	14.25 GHz
max.power	2.0 kW
Plasma chamber	
diameter	50 mm
length	190 mm
Multipole magnet	
multipolarity	Sextupole
Field strength on the surface	10.6 kG
material	Nd-Fe-B
inner diameter	57 mm
length	150 mm
Mirror field	
Max.field strength on axis	12 kG
max.Current	600 A
max.Power	72 kW
Turbomolecular pumps	500 l/sec
	150 l/sec

Ion Intensities (eμA)

	^{14}N	^{16}O	^{20}Ne	^{40}Ar
4+	315 eμA		240	
5+	300	500 eμA		
6+	57	490	115	
7+		60	65	
8+			32	480
9+			1.5	220
11+				43
12+				15
13+				11
14+				2.2

High-resolution Magnetic Spectrograph **PA**



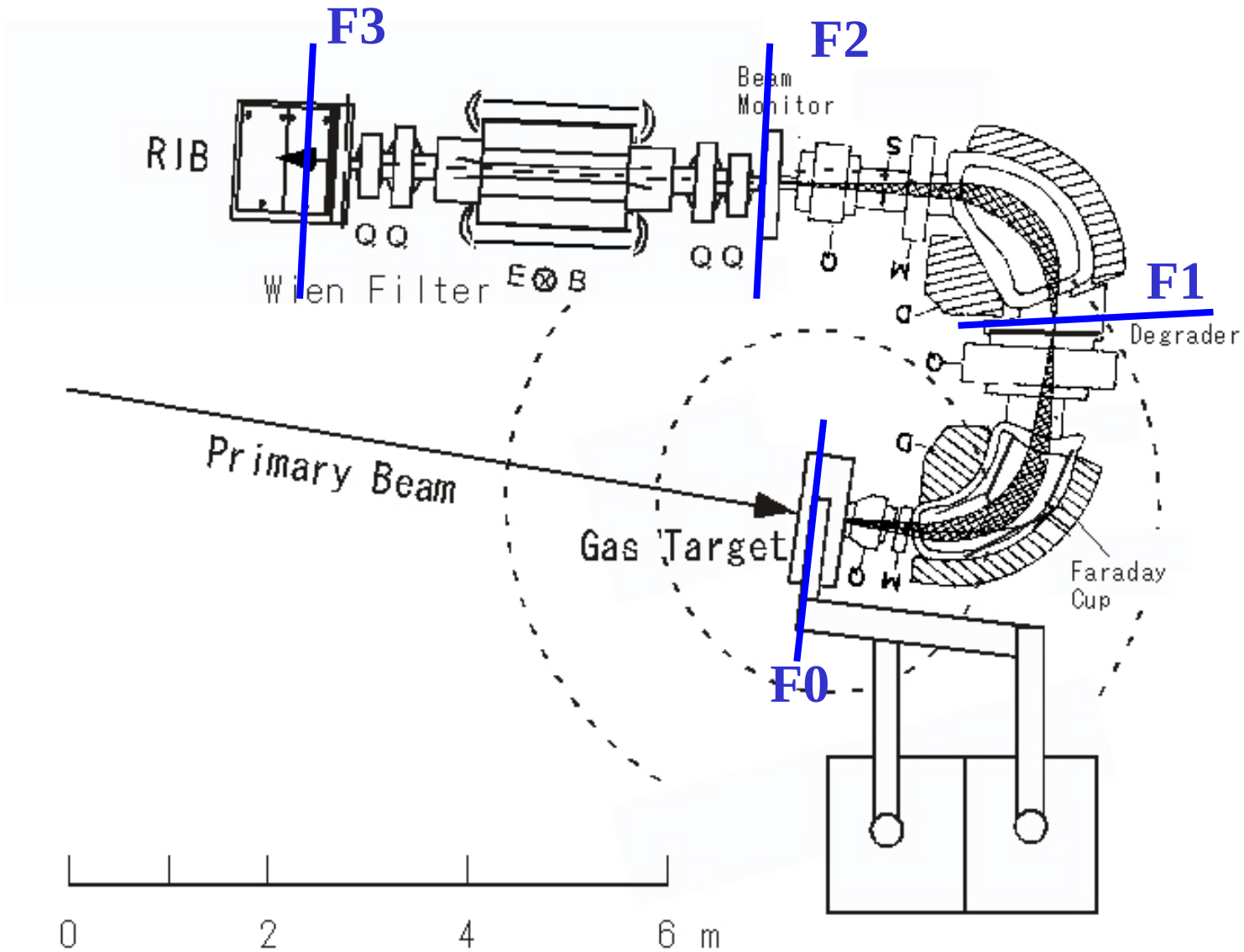
(K = 160)

(@ RIKEN E2 hall)

性能表 Specifications

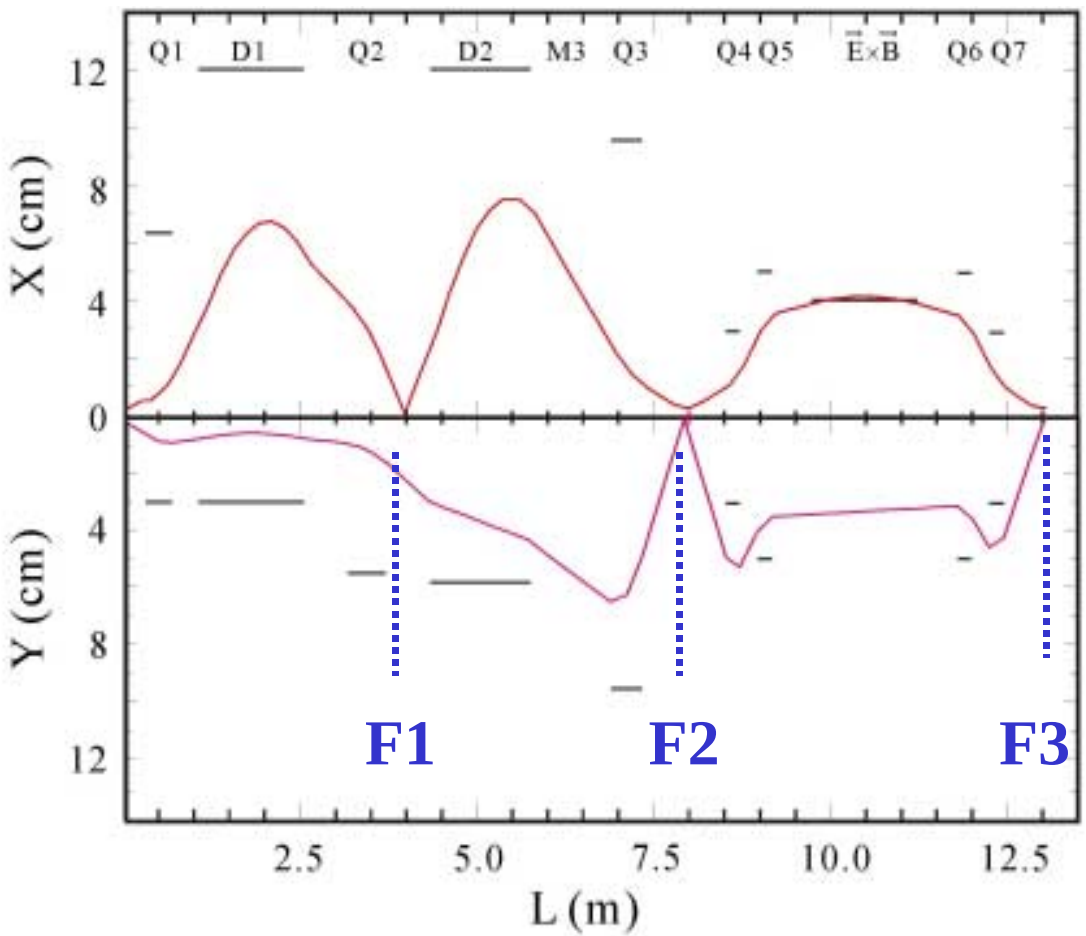
軌道半径 Radius	130 - 150	cm
分析エネルギー範囲 Energy range	30	%
測定角度範囲 Angular range	-20 ~ +135	度
立体角 Solid angle	6.4	msr
横倍率 Horiz. magnification	- 0.37	
縦倍率 Vertical magnification	- 4.44	
運動量分解能 Momentum resolution	0.01	%
最大電流（双極電磁石） Max. current (Dipole)	880	A
（四極電磁石） Max. current (quadrupole)	570	A
総重量 Weight	55	tons

CNS RIB Separator (CRIB)



Beam Property of CRIB

ΔX=ΔY=2mm
Δθ=Δϕ=20 mrad



Specifications

Solid Angle 5.6 msr(75x75 mr^2)
Max. Mag. Rigidity 1.28 Tm
Radius of Central Orbit 0.9 m

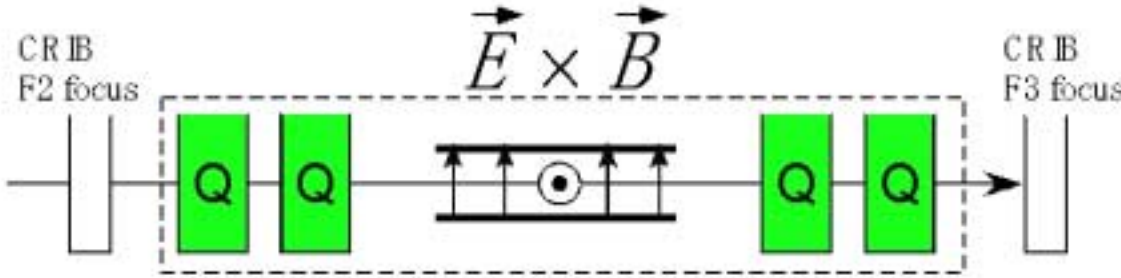
F0→F1 (dispersive Focal Plane)
- **Magnification of X** 0.3
- **Momentum dispersion** 1.6 m
- **Momentum acceptance** ±7.5 %
- **Momentum resolution** P/Δp=800

F0 →F2 (achromatic focal plane)
- **Magnification of X** 1.2
- **Magnification of Y** 0.5
- **Momentum dispersion** 0.0 m

Wien Filter

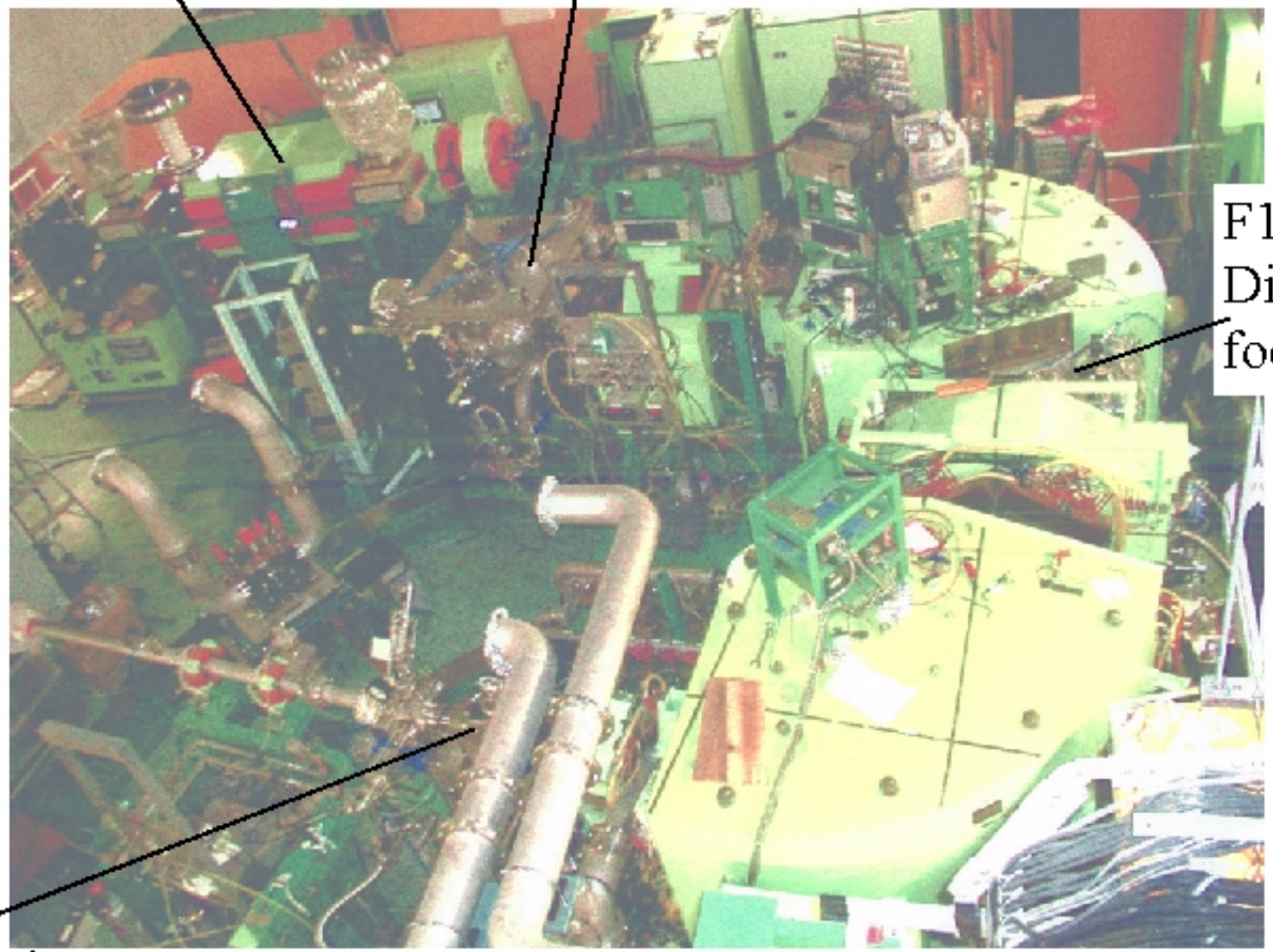
Construction finished
H V test in progress

The last section of CR IB
Velocity filter by $E \times B$

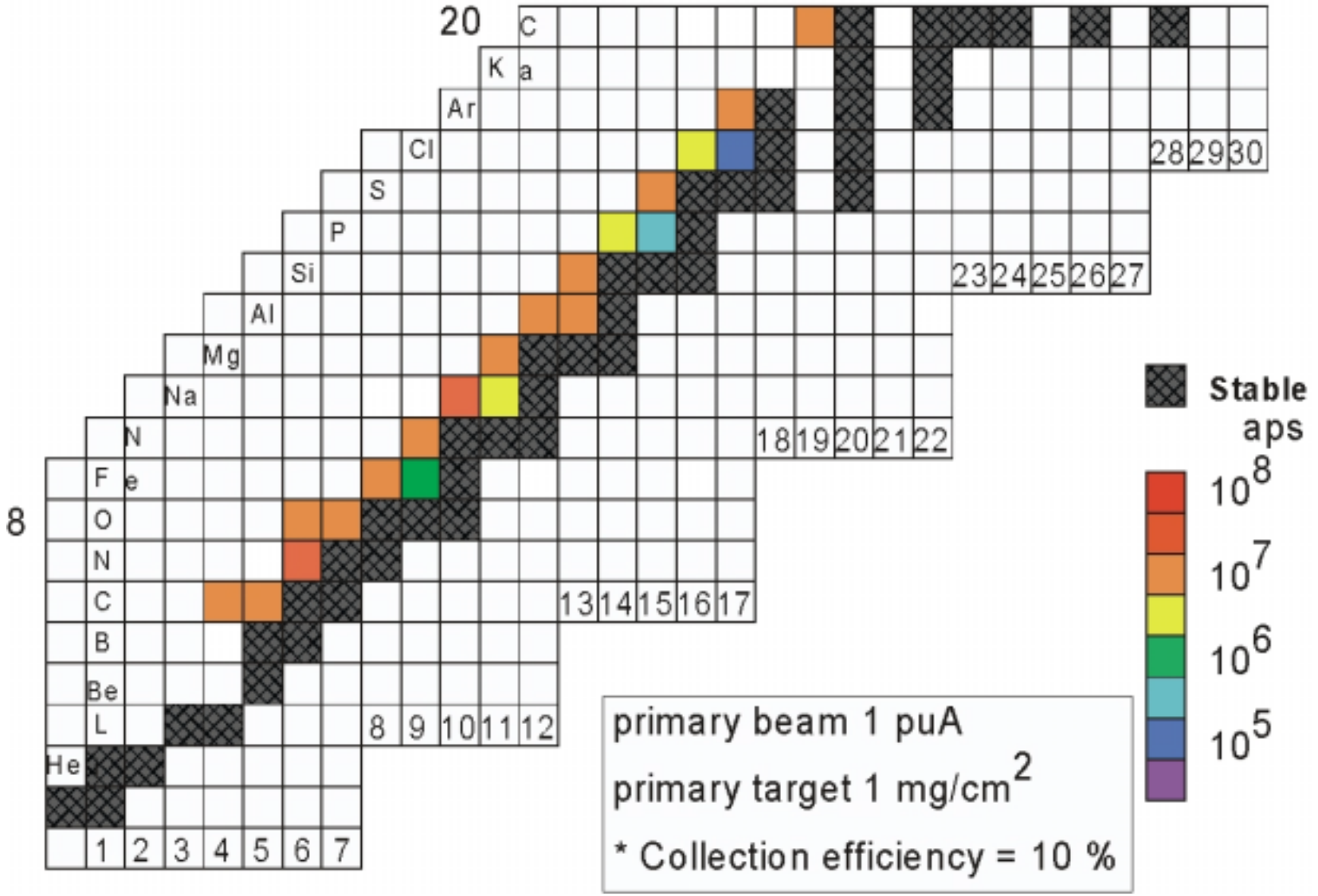


Total length: 5 m
Length ($E \times B$ part): 1.5 m
E_{max}: 50 kV/cm (gap 8 cm)
B_{max}: 3 kGauss
Magnification: 1 (both H & V)
Velocity resolving power:
$\Delta V/V = 2\%$ for $A/Q = 2$, $E/A = 10$ MeV

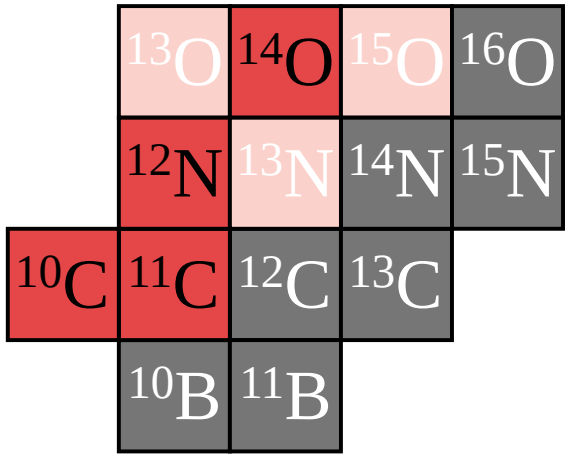
CNS RIB Separator (CRIB)



Estimated RIB Production Rates with CRIB



Test result of Low-Energy RIB Productions



Used the (p,n) & (^{3}He,n) reactions in inverse kinematics.
Measured at F2.

RI beam	Primary beam	Reaction	Cross section	Target	Collection efficiency	Intensity	Purity with degrader
^{10}C 6.1 *A* MeV	^{10}B(4+) 7.8 *A* MeV (200 pnA)	**p(^{10}B,^{10}C)n**	2 mb	CH_4 gas 1.3 mg/cm^2	30 %	**(1.6×10^5 cps)**	90 %
^{14}O 6.7 *A* MeV	^{14}N(6+) 8.4 *A* MeV (500 pnA)	**p(^{14}N,^{14}O)n**	8 mb	CH_4 gas 1.3 mg/cm^2	50 %	**(1.7×10^6 cps)**	80 %
^{12}N 3.9 *A* MeV	^{10}B(4+) 7.8 *A* MeV 200 pnA	**^{3}He(^{10}B,^{12}N)n**	5 mb	^{3}He gas 0.25 mg/cm^2	1 %	**2.5×10^3 cps**	3 %
^{11}C 3.4 *A* MeV	^{10}B(4+) 7.8 *A* MeV 200 pnA	**^{3} He(^{10}B,^{12}N*) n** ^{12}N* → **^{11}C**+p	≈20 mb	^{3}He gas 0.25 mg/cm^2	≈ 2 %	**1.6×10^4 cps**	15 %

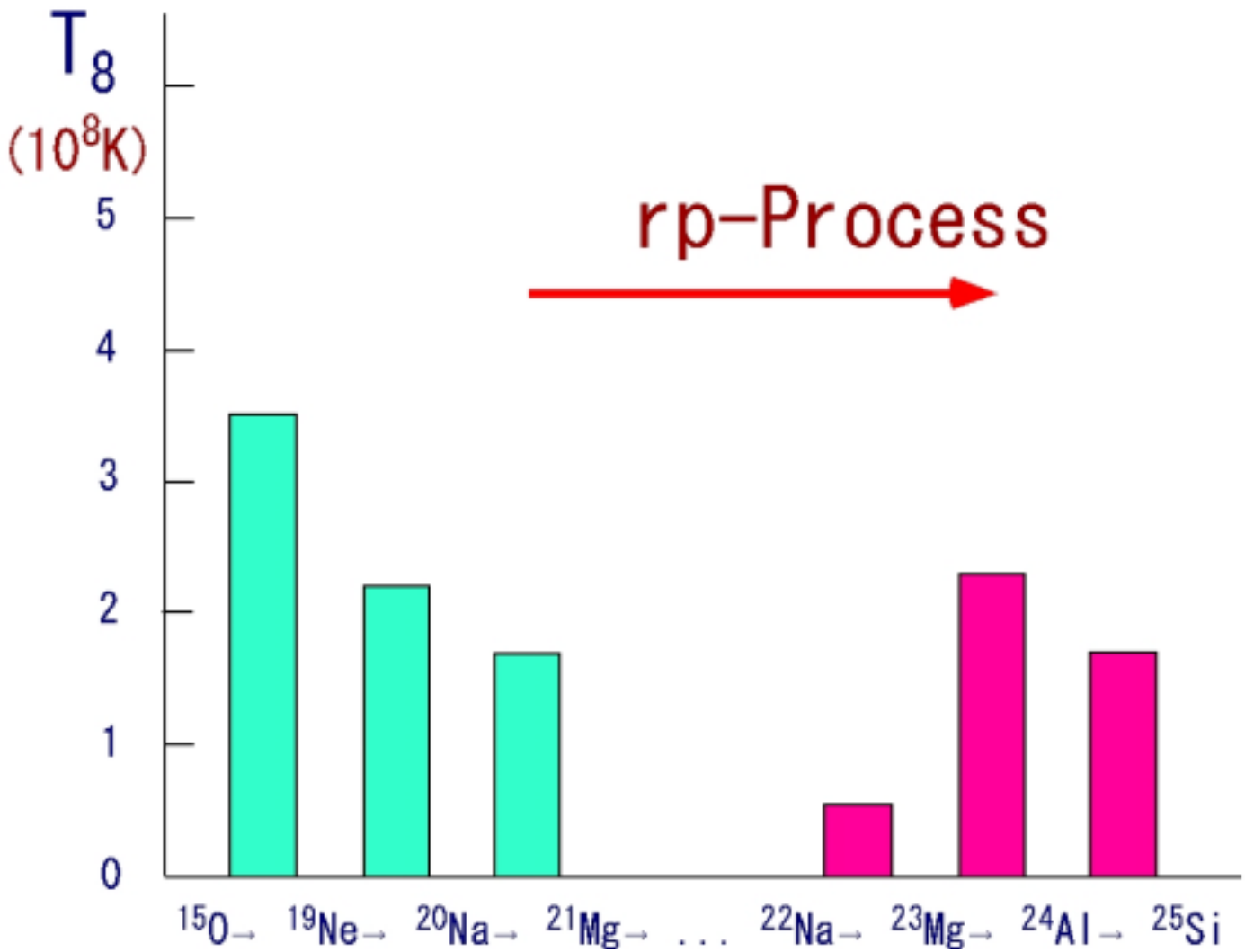
^{17}N, ^{22}Mg > 10^4 aps, ~ 10%

* ( ); Actual production tests of ^{10}C & ^{14}O were performed at lower intensities.
* Cross-section values are taken from other exp. results.

Nuclear Astrophysics Programs at CNS

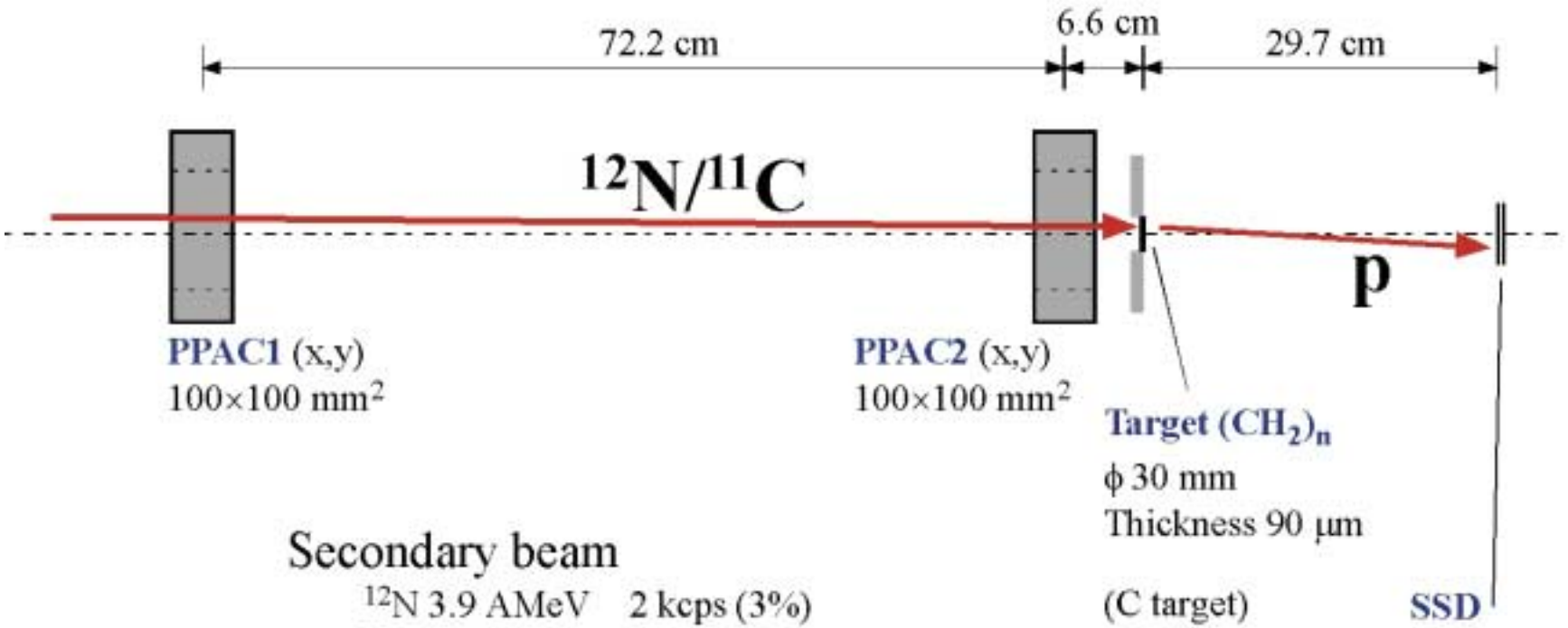
- Primordial Nucleosynthesis
- Hydrogen Burning
  - pp-chain
  - CNO cycle
  - rp-process
- (n,γ) Reaction Study

Ignition Temperature



Setup for ^{12}N+p & ^{11}C+p elastic resonance scattering

at CRIB F2



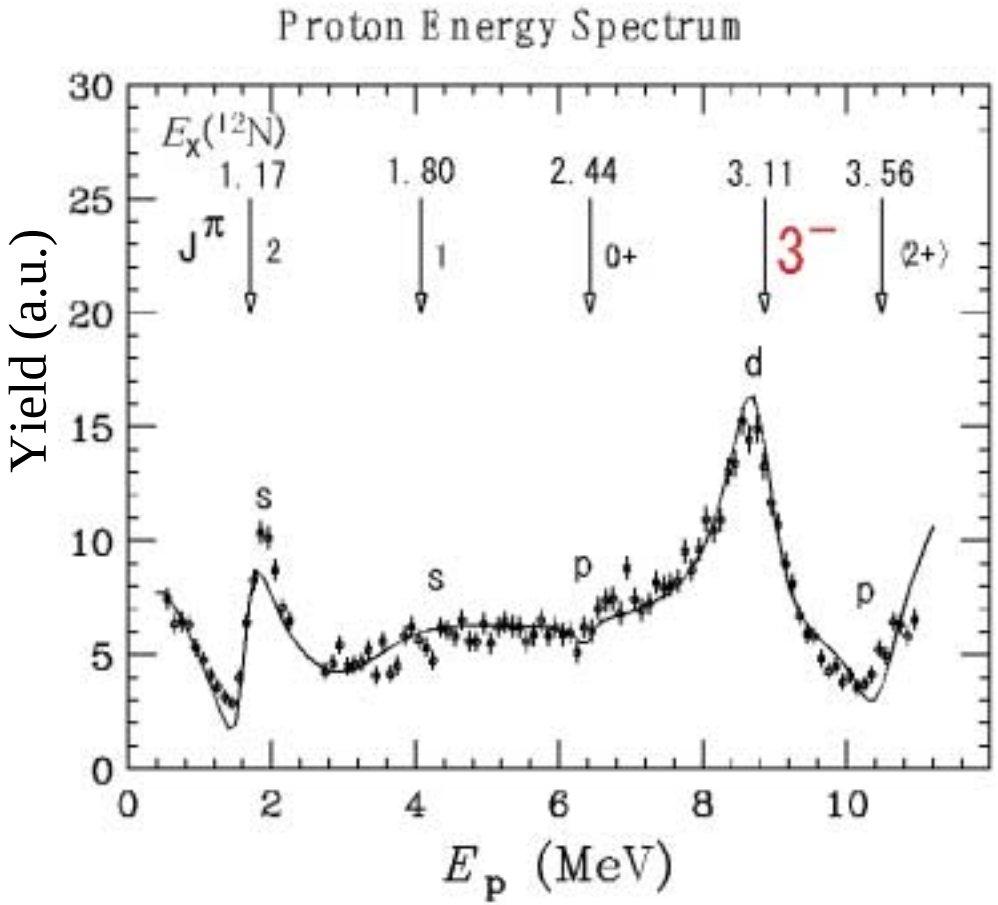
Secondary beam

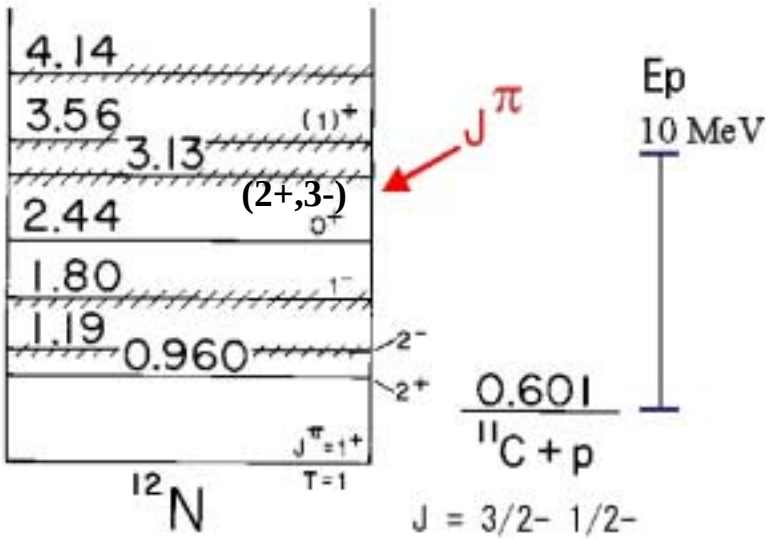
^{12}N 3.9 AMeV 2 kcps (3%)

^{11}C 3.4 A MeV 10 kcps (15%)

(background: ^{10}B & light particles)

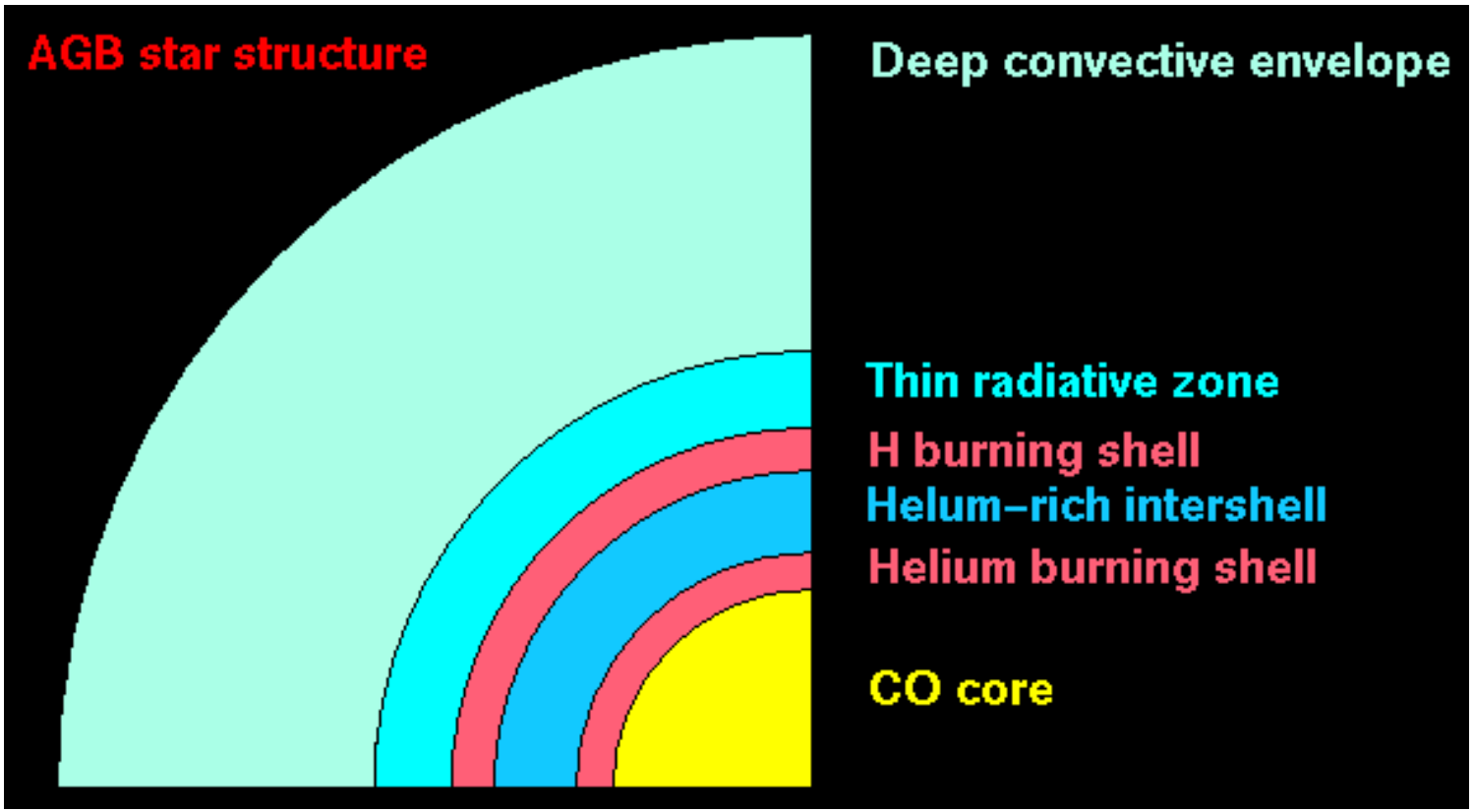
Low-Energy Resonant Elastic Scattering of $^{11}C + p$





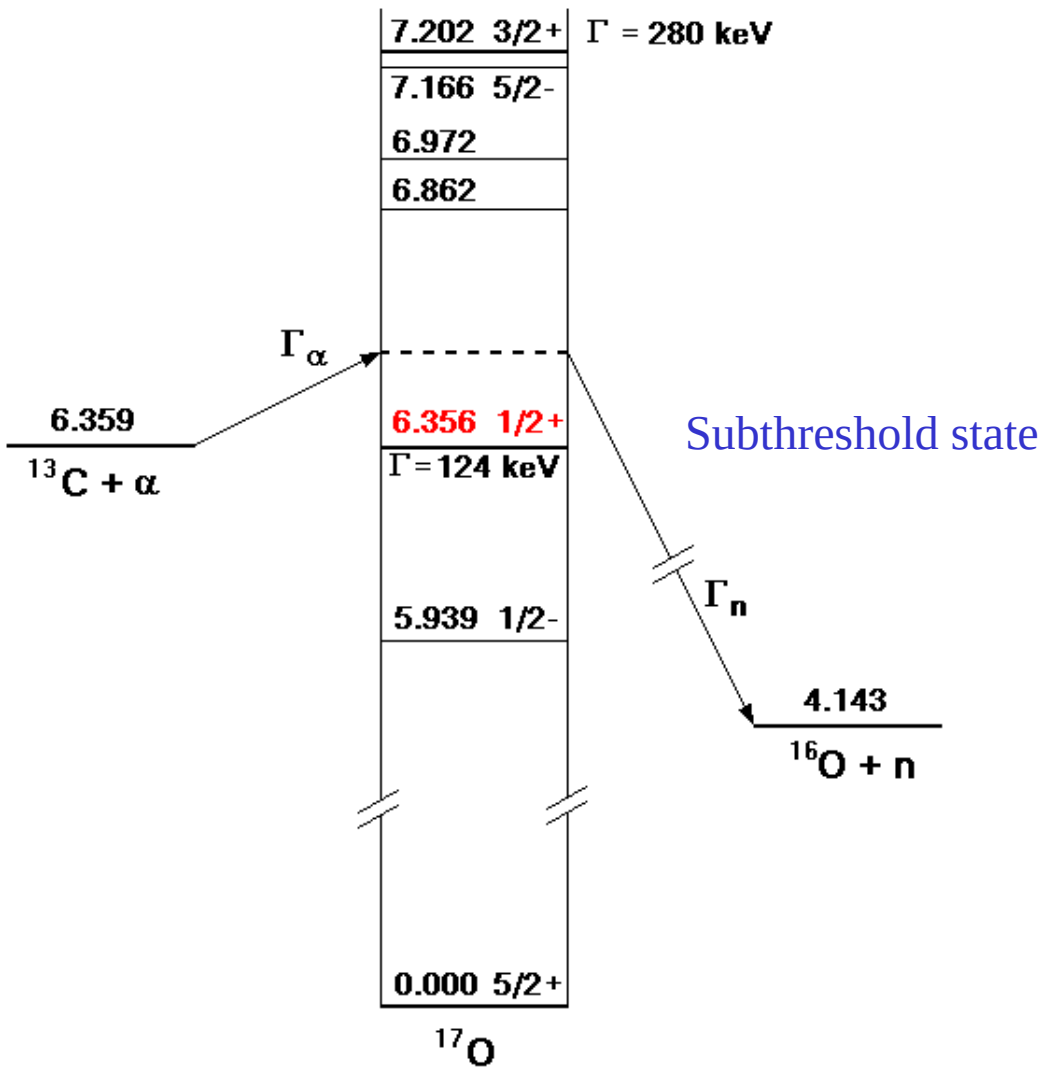
$^{13}C(\alpha,n)^{16}O$ Reaction is the Main Neutron Source for the s-Process ?

- The $^{13}C(\alpha,n)^{16}O$ reaction on He-burning shell (~0.1 GK)
- The $^{12}C(p,\gamma)^{13}N(\beta^{+})^{13}C$ reaction on H burning shell
- Low/intermediate-mass AGB stars



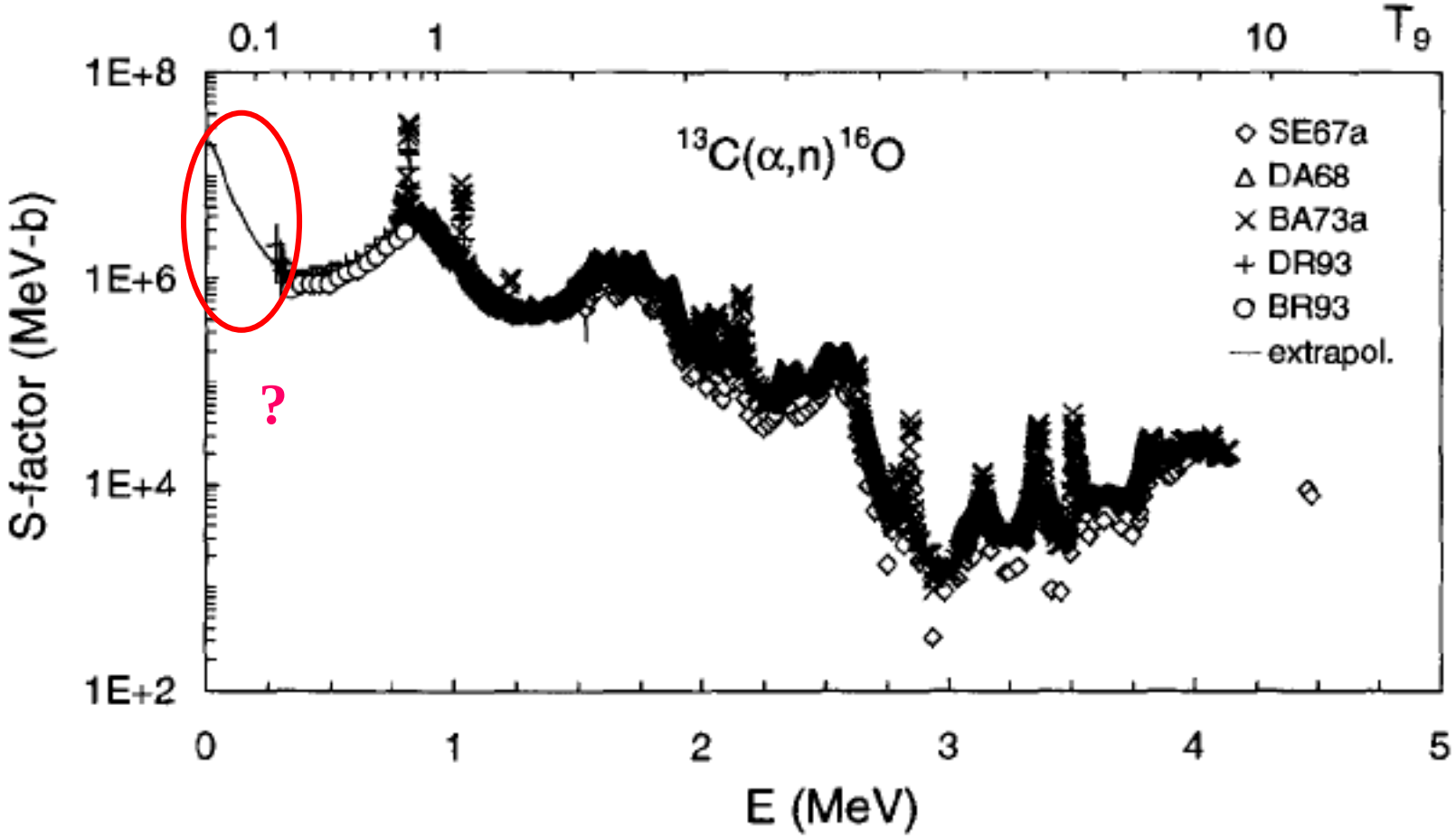
(http://www.supersci.org)

Levels in ^{17}O

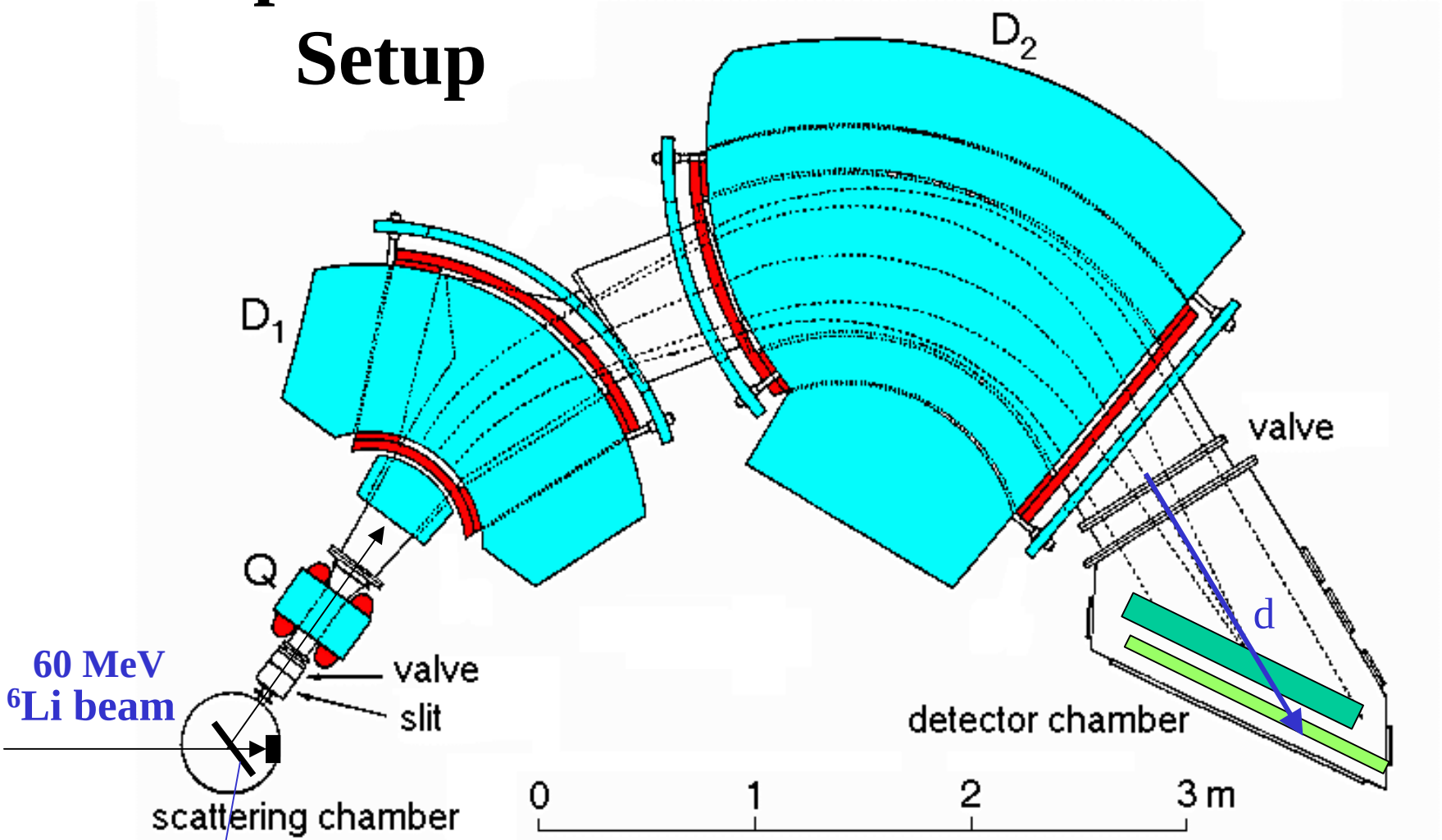


Subthreshold state

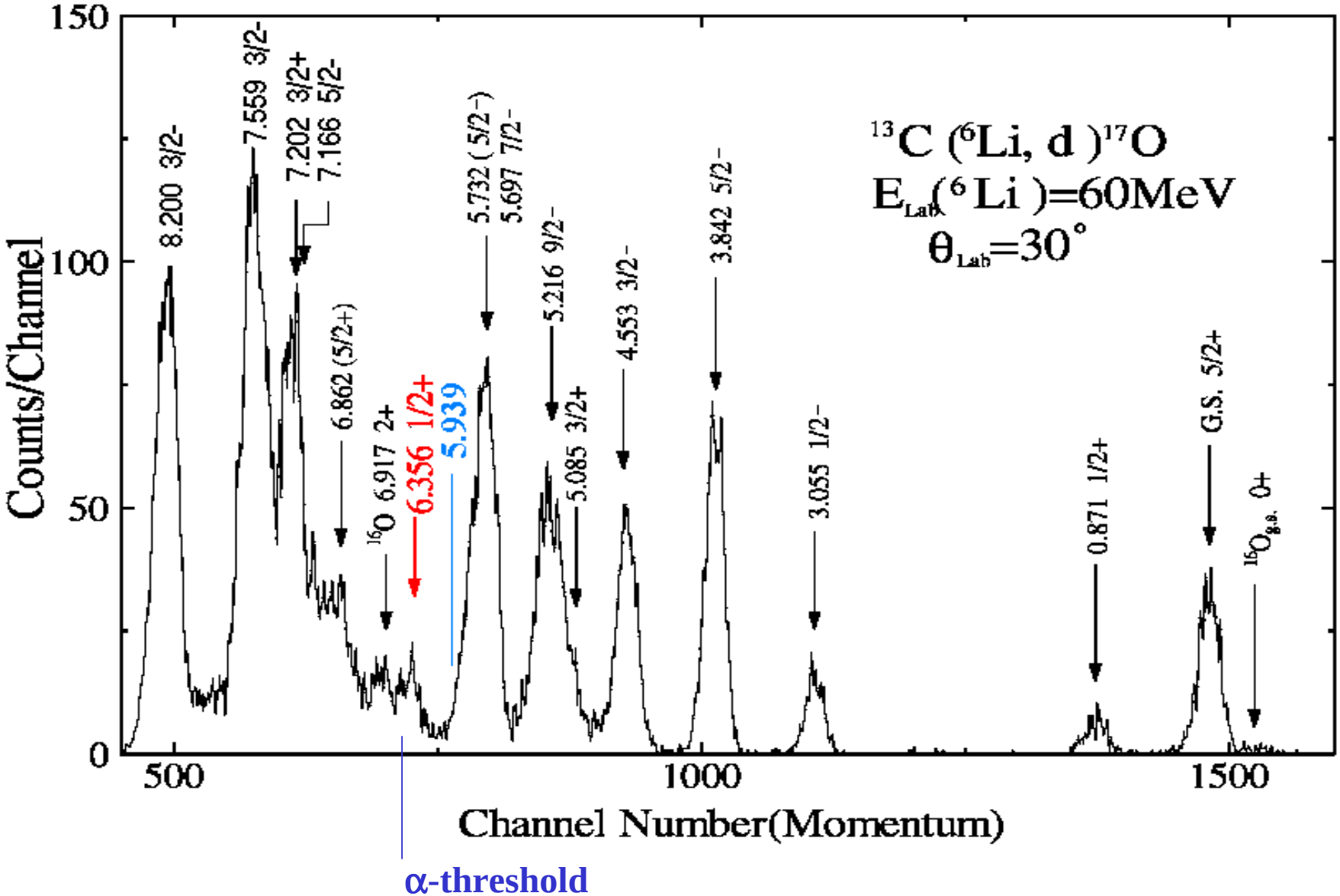
NACRE collaboration (Angulo *et al*, Nucl. Phys. **A656**(1999)3)



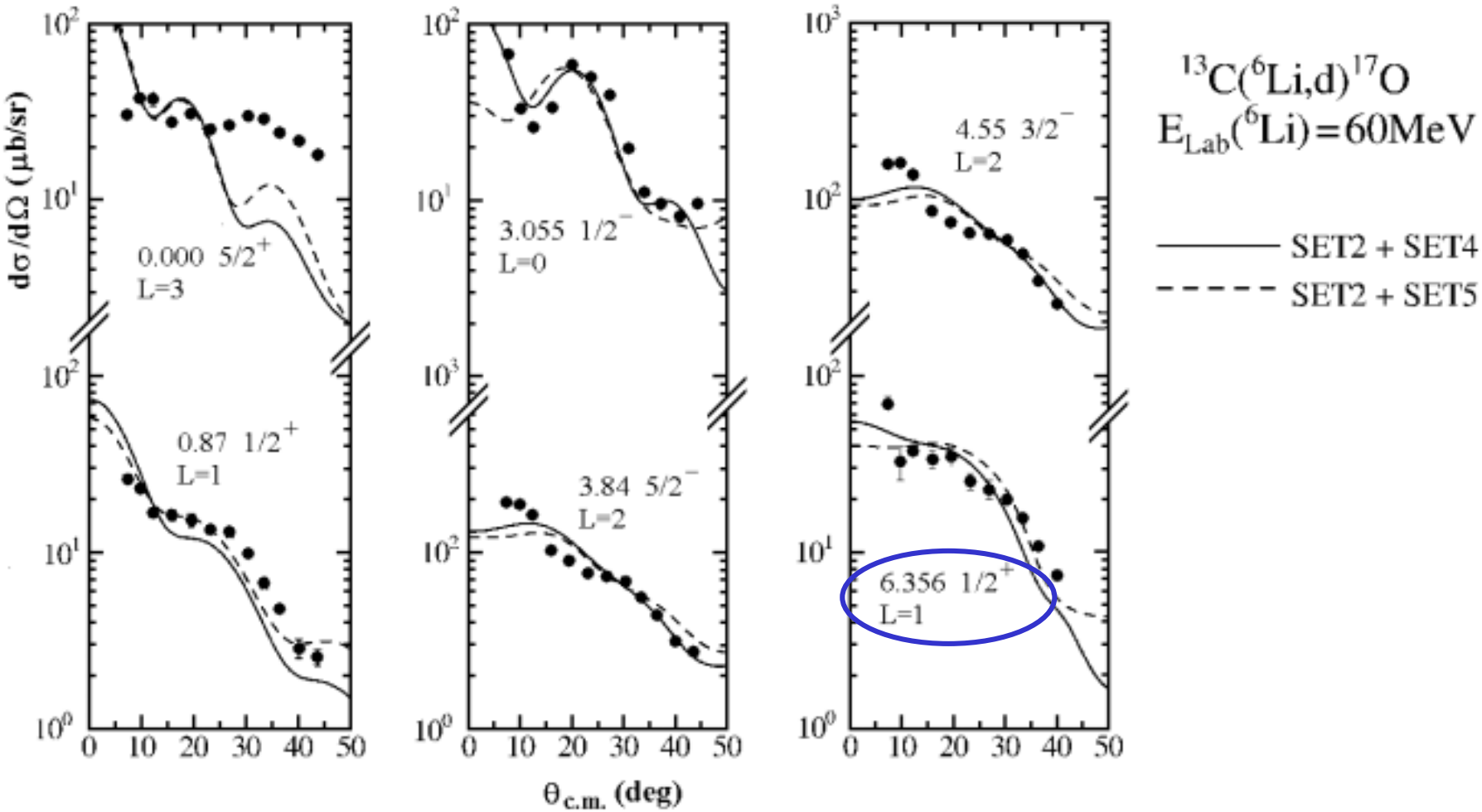
Experimental Setup



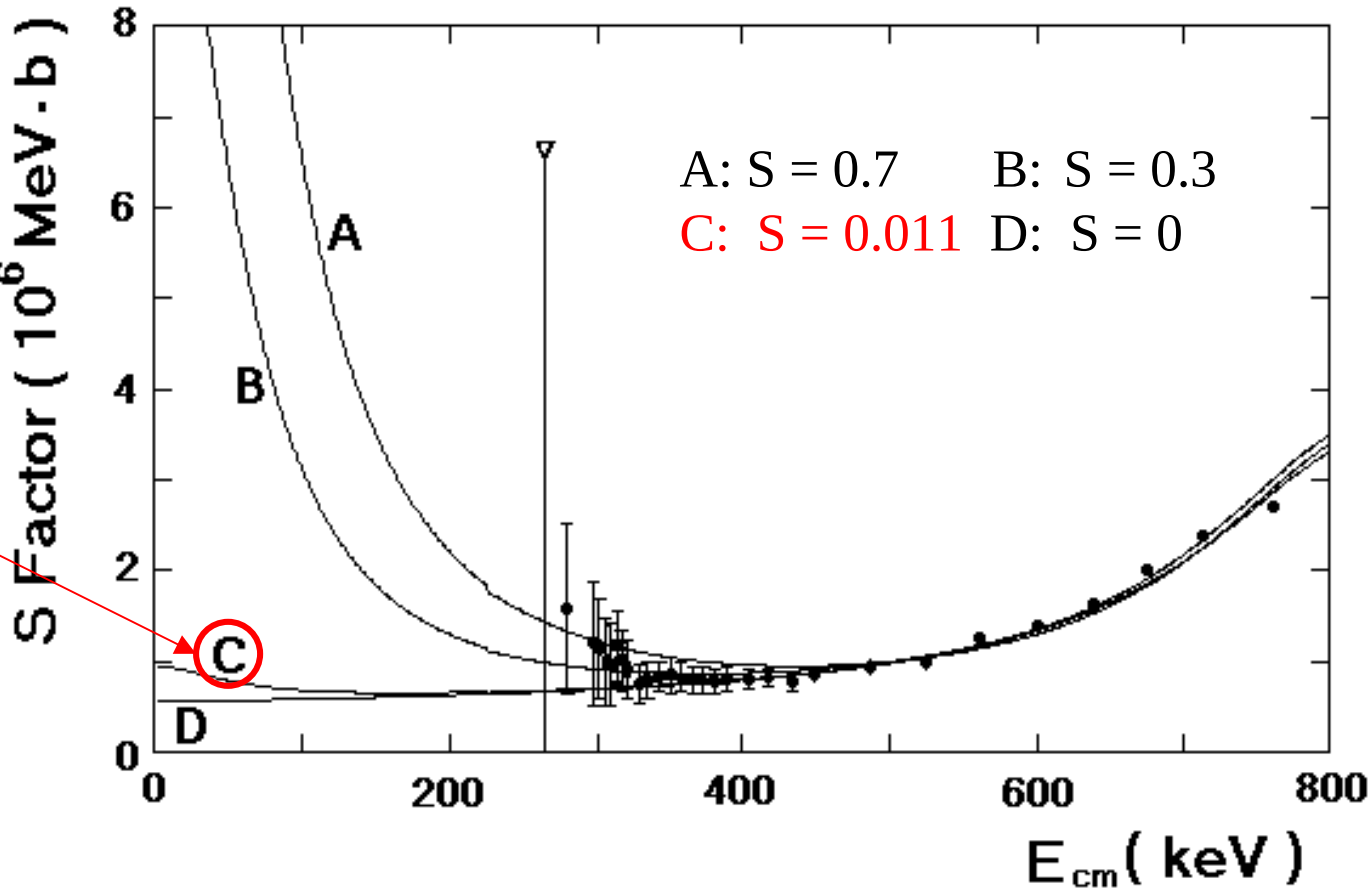
$^{13}C(^{6}Li,d)^{17}O$


Counts/Channel
Channel Number(Momentum)
150
100
50
0
500
1000
1500
$^{13}C\ (^{6}Li,\ d\ )^{17}O$
$E_{Lab}(^{6}Li\ )$=60MeV
θ_{Lab}=30°
8.200 3/2-
7.559 3/2-
7.202 3/2+
7.166 5/2-
6.862 (5/2+)
^{16}O 6.917 2+
6.356 1/2+
5.939
5.732 (5/2-)
5.697 7/2-
5.216 9/2-
5.085 3/2+
4.553 3/2-
3.842 5/2-
3.055 1/2-
0.871 1/2+
G.S. 5/2+
$^{16}O_{g.s.}$ 0+
α-threshold

Angular Distributions of $^{13}C(^{6}Li,d)^{17}O$



$^{13}C(\alpha,n)^{16}O$ Reaction



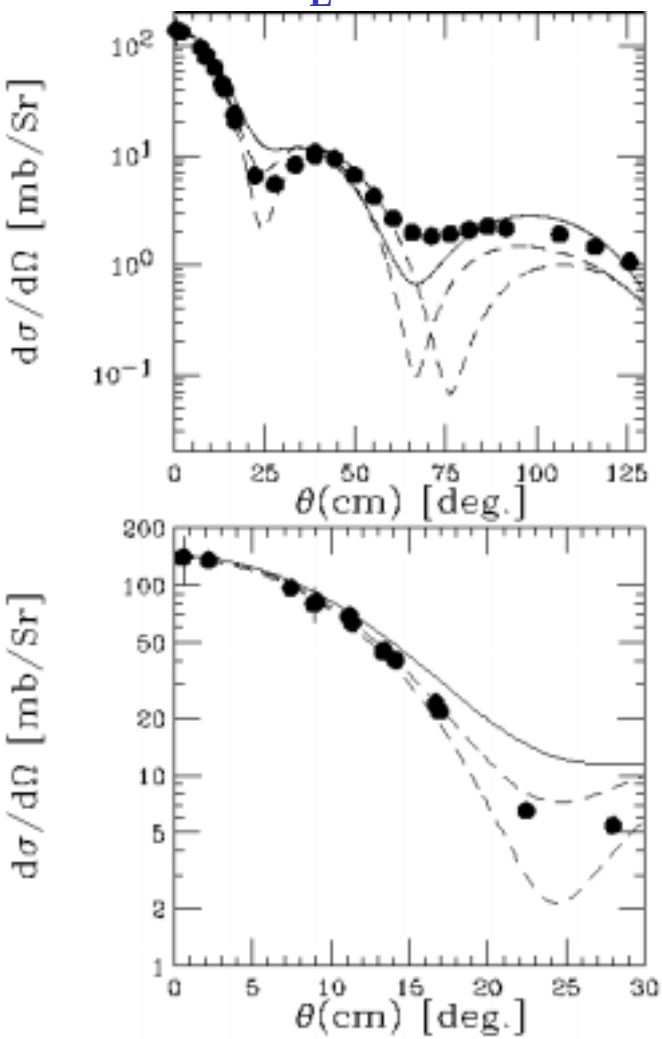
Present Result

→ The role of the sub-threshold state was found to be very small in the s-process nucleosynthesis !

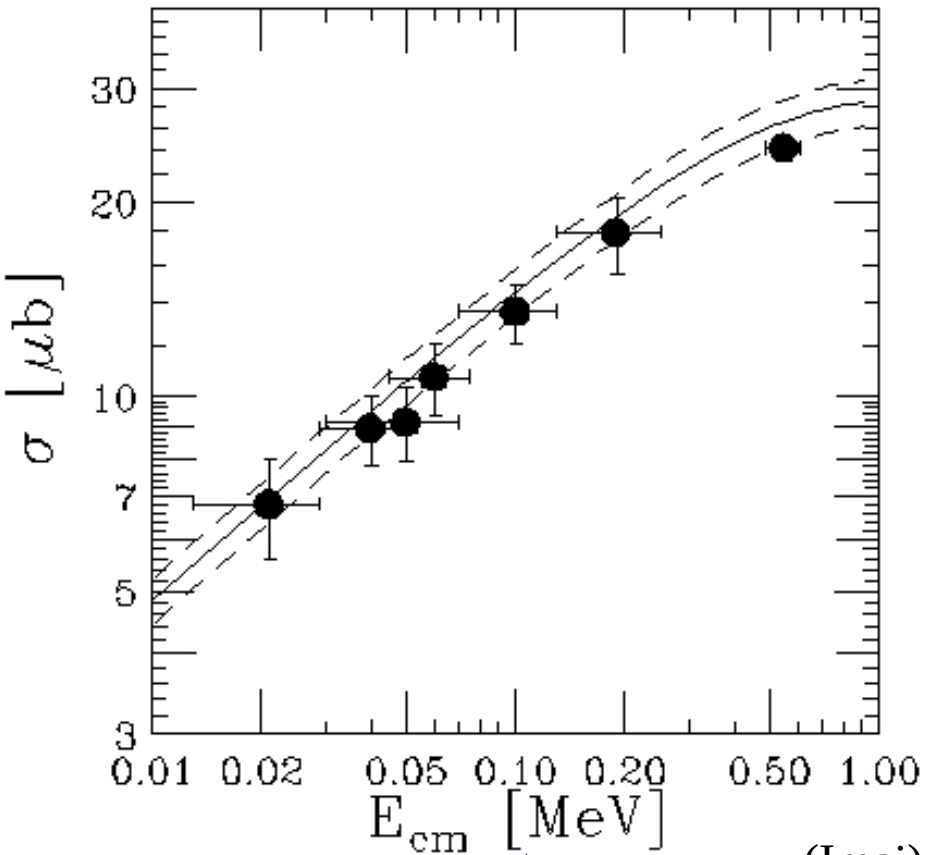
The ^{12}C(d,p) reaction for the ^{12}C(n,γ)^{13}C stellar reaction

^{12}C(d,p)^{13}C(1/2$^+$)

E_L=11.8 MeV



^{12}C(n,γ)^{13}C(1/2$^+$)



(Imai)

→ ANC = 3.20 ± 0.29 ±0.13 fm^{-1}

Uncertainties of ANC Method with (d,p) reactions for (n,γ) reactions

1. Choice of optical potential ~ 10 %
   ** Potentials that fit a large angular range give less.
2. Choice of bound state potential ~ 2 %
3. Interior contribution ~ 6 %
4. Breakup effect ~ 4 %

5. Need transfer data of small uncertainty at very forward angles. ~ exp %

total > 12 %

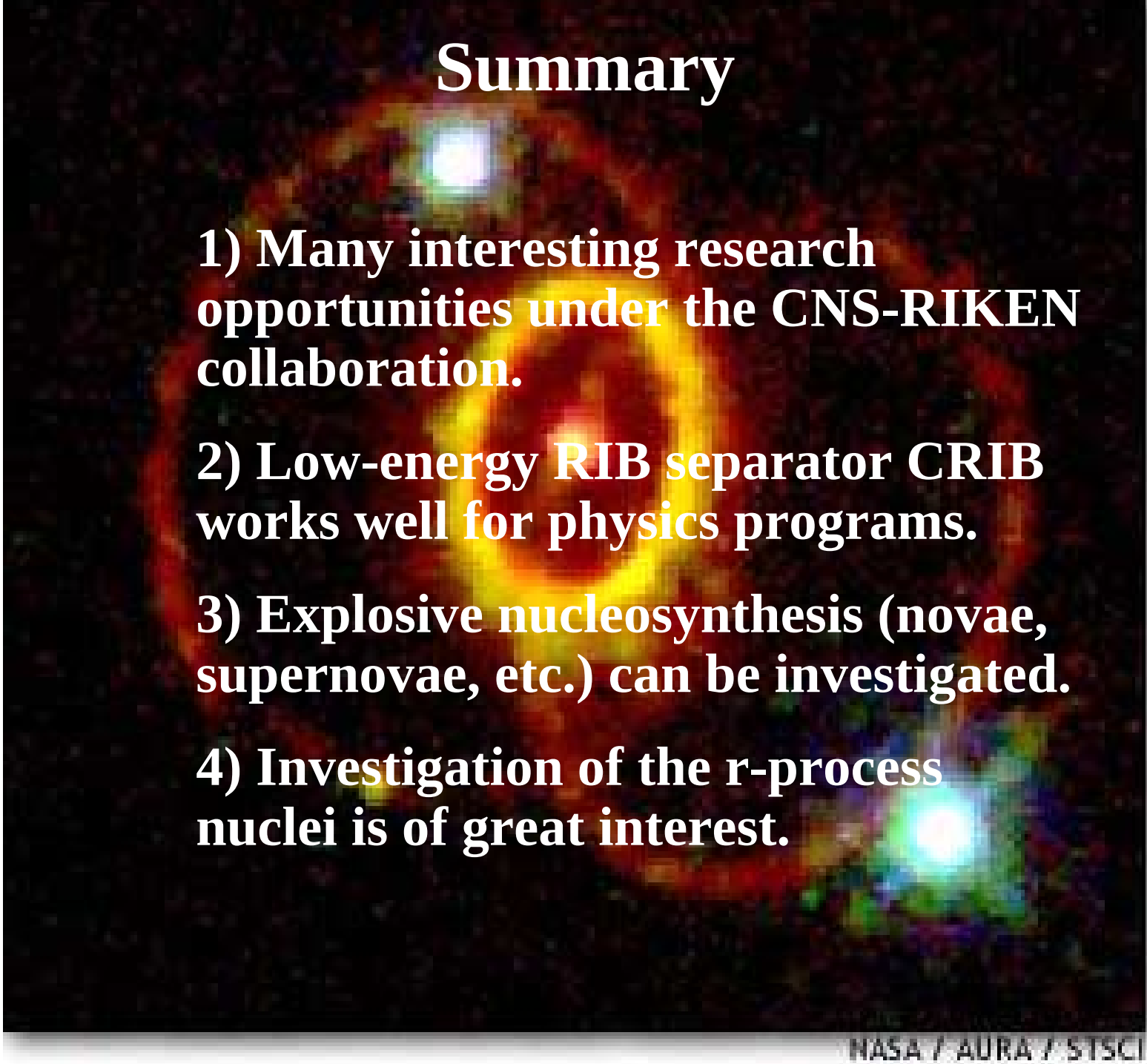
Summary

1) Many interesting research opportunities under the CNS-RIKEN collaboration.

2) Low-energy RIB separator CRIB works well for physics programs.

3) Explosive nucleosynthesis (novae, supernovae, etc.) can be investigated.

4) Investigation of the r-process nuclei is of great interest.



Please come to CNS for collaboration

- We welcome all of you to come back to CNS for collaboration works.
- We encourage especially young people to come to study a new idea on Physics.