RCNPでの励起状態精密測定:現状と計画

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「宇宙核物理実験の現状と将来」研究会

August 7-8, 2014 at RCNP

Outline

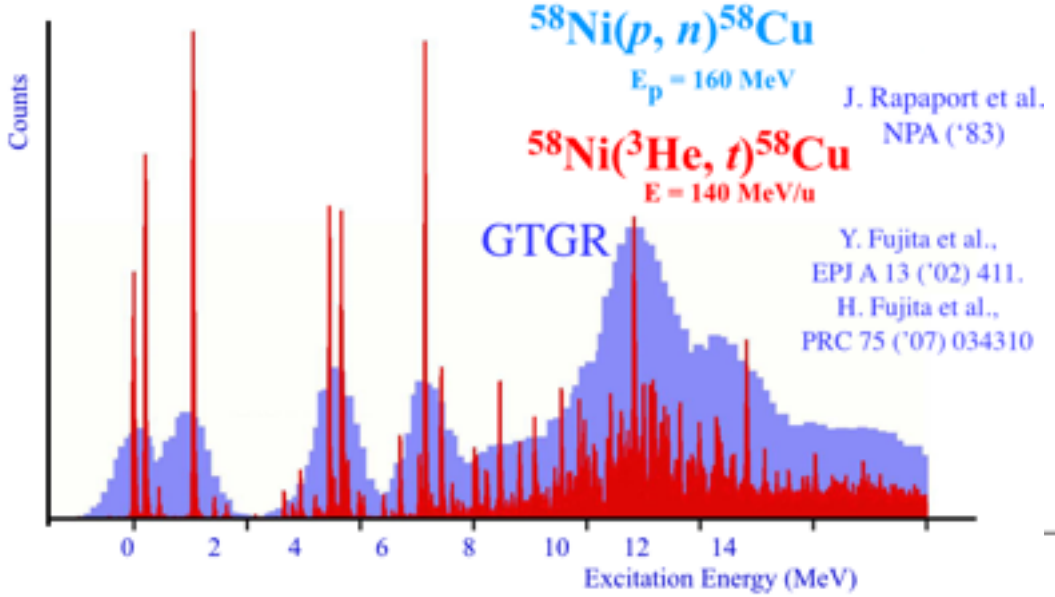
1. Overview of Spectrometer Experiments at RCNP

2. E1 response, PDR, Dipole Polarizability, Neutron Skin

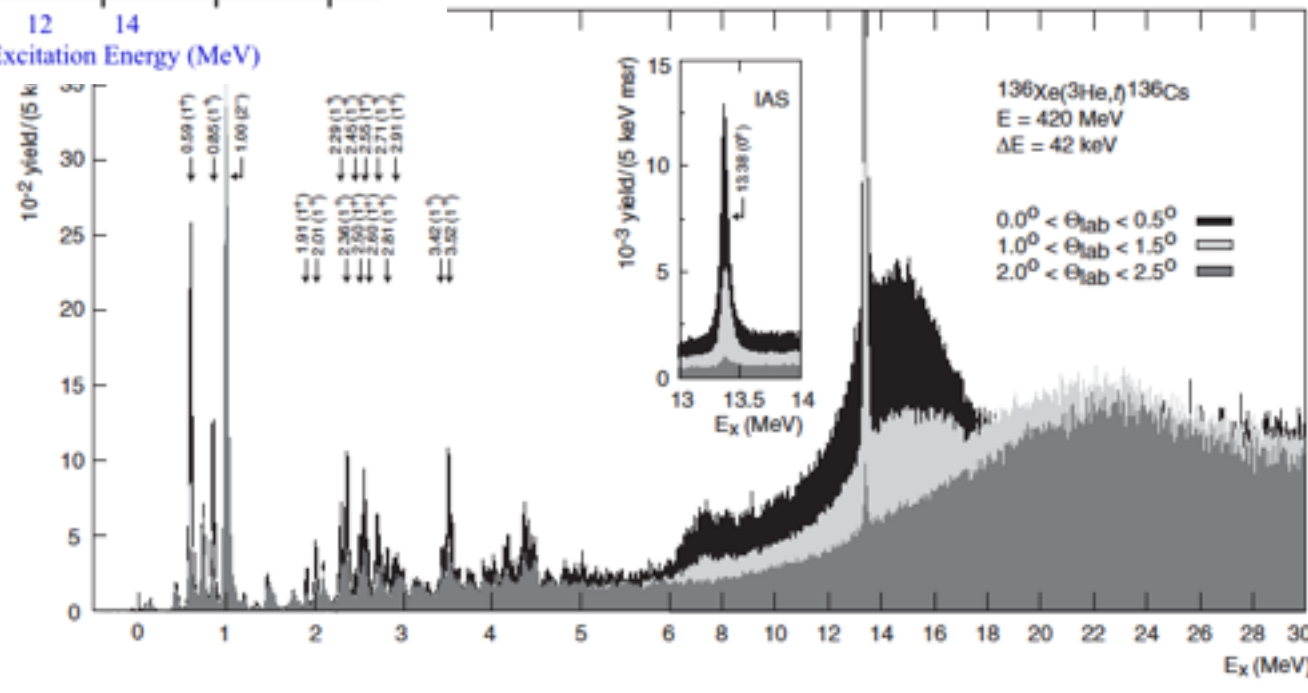
3. Non-Resonant Triple Alpha Reaction Rate at Low Temperature

1. Overview of Spectrometer Experiments at RCNP

Gamow-Teller and spin-isospin Responses



P. Puppe et al., PRC 84, 051305(R) (2011)



GMR and Nuclear Incompressibility

U. Garg, M. Fujiwara, et al.,

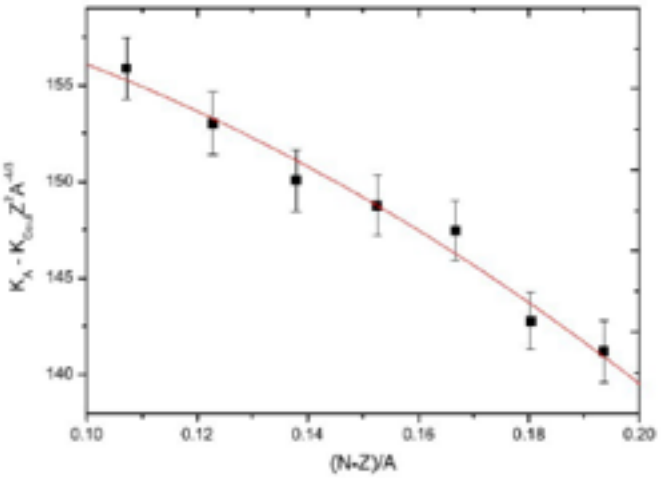


図 2.2.14: GMR の有効平均励起エネルギーと Sn 同位体における非対称度 $[= (N - Z)/A]$ の比較。

$$K_\tau = -550 \pm 100 \text{ MeV}$$

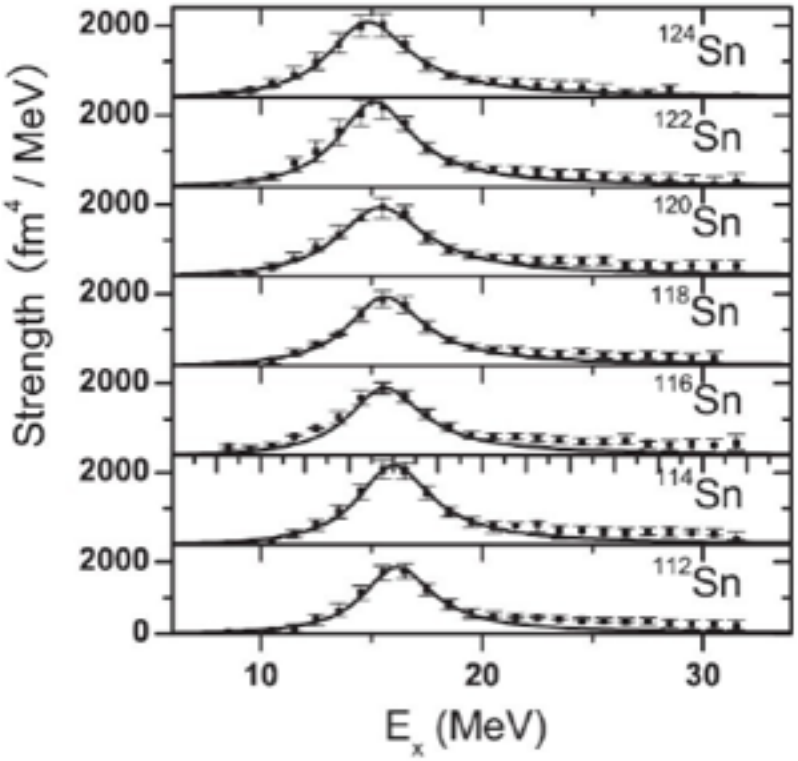


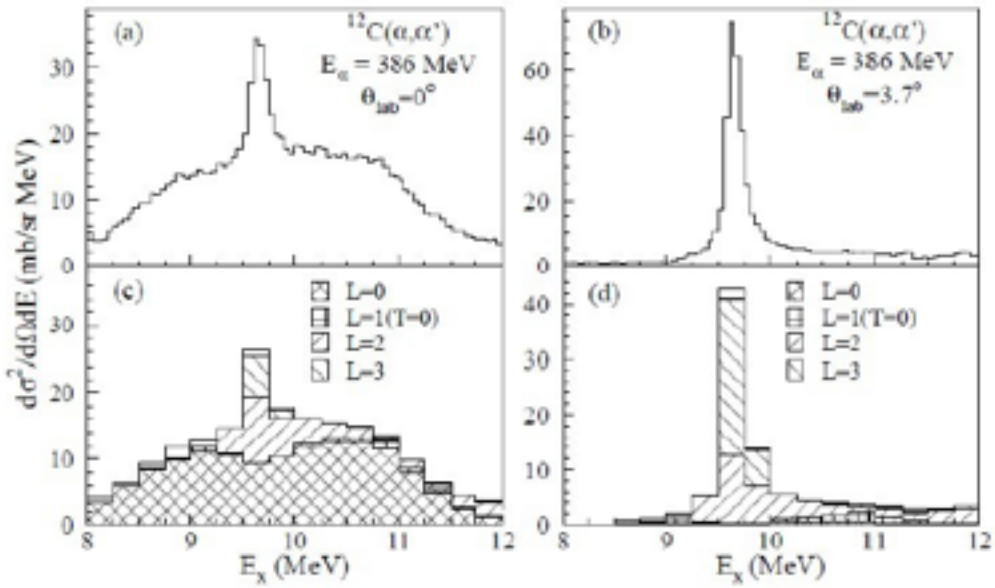
図 2.2.13: Sn 同位体の GMR 励起強度分布。

From GMR data on ^{208}Pb and ^{90}Zr,

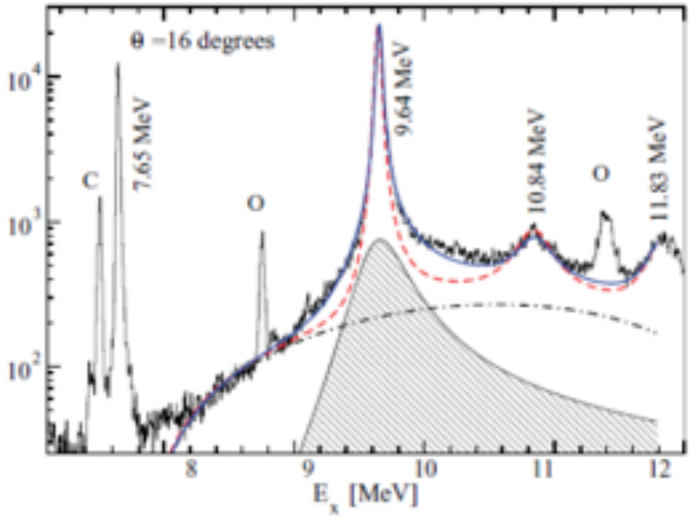
$K_\infty = 240 \pm 10$ MeV

[See, *e.g.*, G. Colò *et al.*, Phys. Rev. C 70 (2004) 024307]

2nd 2^+ States in ^{12}C and Carbon Synthesis at High Temperature



M. Itoh et al., NPA**738**, 268 (2004)
M. Itoh et al., PRC 84, 054308 (2011)

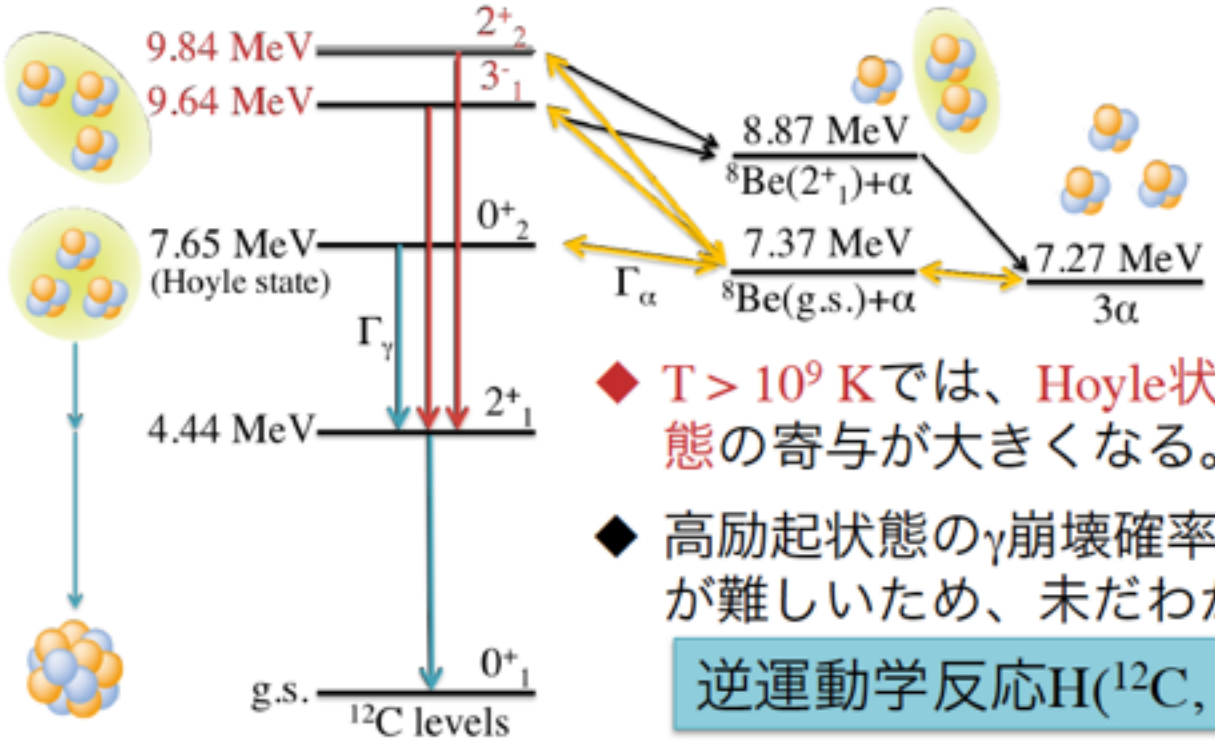


M. Freer et al. PRC**86**, 034320 (2012)
M. Freer *et al.*, PRC**80**, 041303(R) (2009)

(Exp. at iThembaLABS)

Talk by M. Tsumura

^{12}C原子核における稀ガンマ崩壊モードの探索



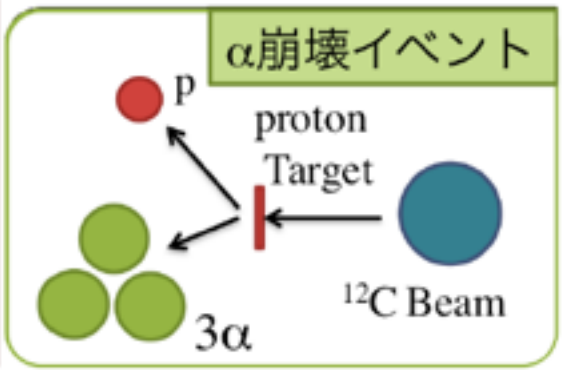
^{12}Cなどの重い元素の合成では、トリプルα反応が重要な役割を担っている。

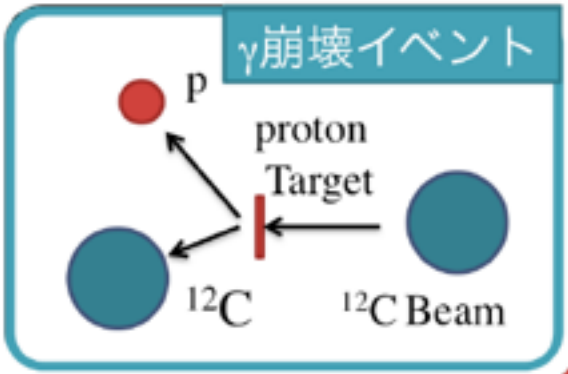
- $T > 10^9$ Kでは、Hoyle状態よりも高い励起状態の寄与が大きくなる。
- 高励起状態のγ崩壊確率は非常に小さく測定が難しいため、未だわかっていない。

[1] F. Hoyle and W. A. Fowler, Astrophys. J **132**, 565 (1960).

逆運動学反応H(^{12}C, ^{12}C p)による測定を計画

全励起イベント





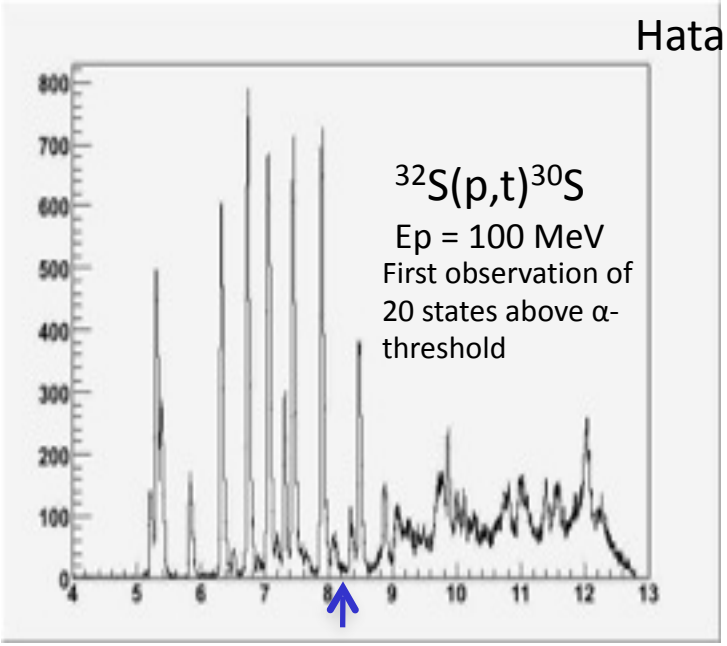
γ 崩壊確率 Γ_γ / Γ

$$\frac{\Gamma_\gamma}{\Gamma} = \frac{\text{γ崩壊イベント数}}{\text{全励起イベント数}}$$

pと^{12}Cの同時計測により、γ線を測定することなくγ崩壊確率を決定!!

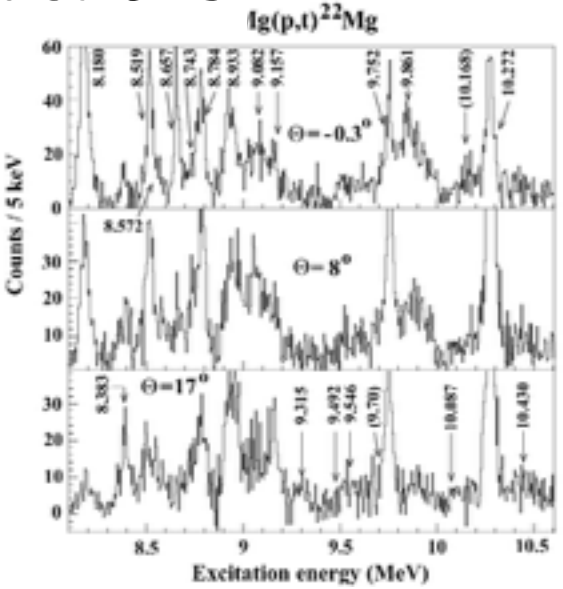
Resonance States Measured by (p,t) Reactions

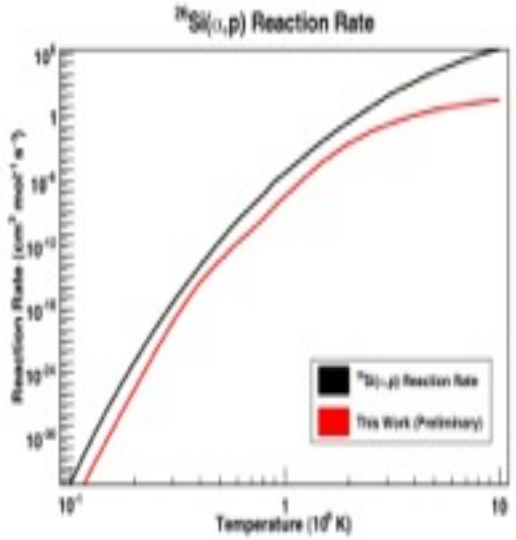
PhD thesis S. O'Brien

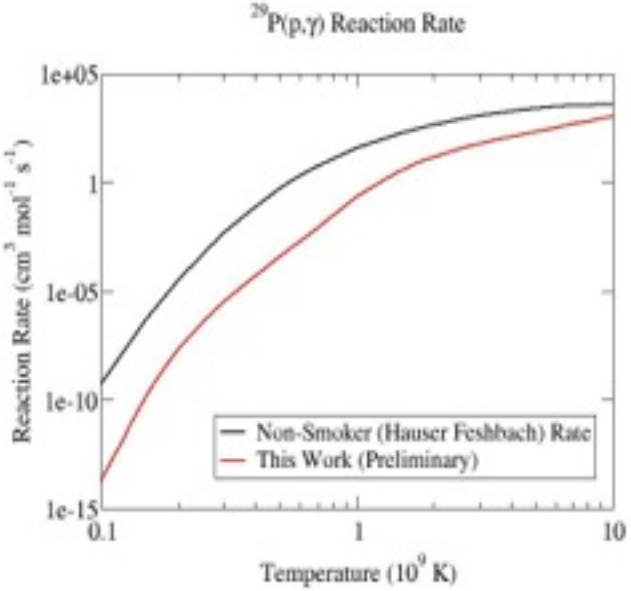


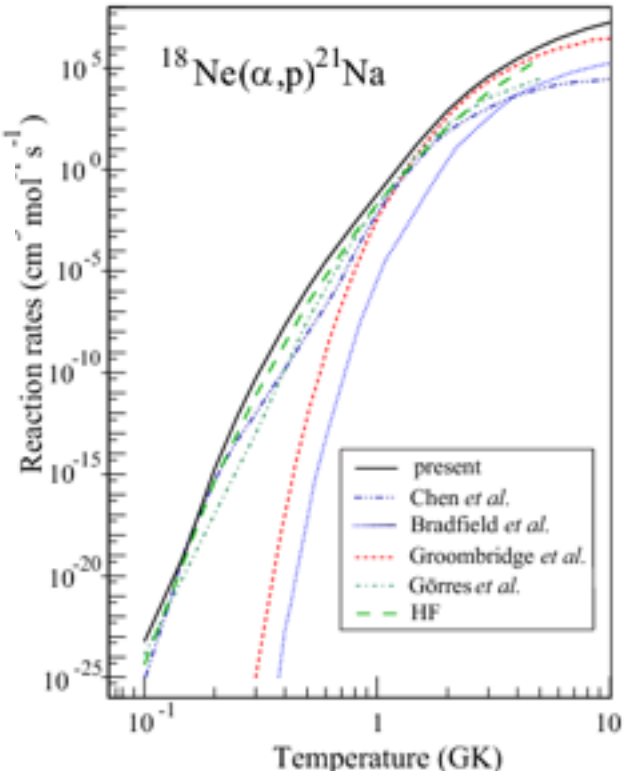
G.P.A. Berg, J. Goerees, K. Hatanaka, et al.,

Rapid reaction chain of radiative capture (p,γ),(α, γ) and (α,p) reactions in proton-rich nuclei after breakout of hot CNO stellar burning.









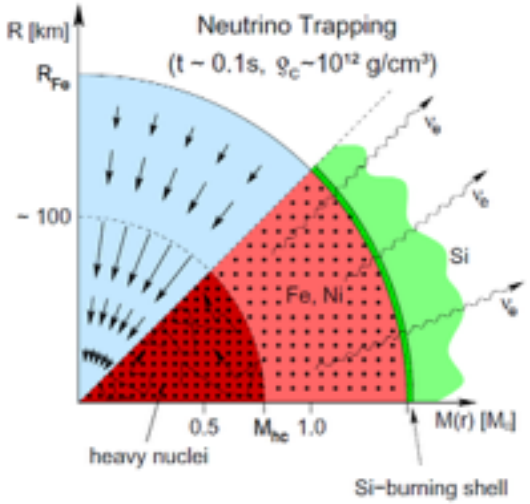
2. E1 Response, PDR, Dipole Polarizability, Neutron Skin

Nuclear Equation of State

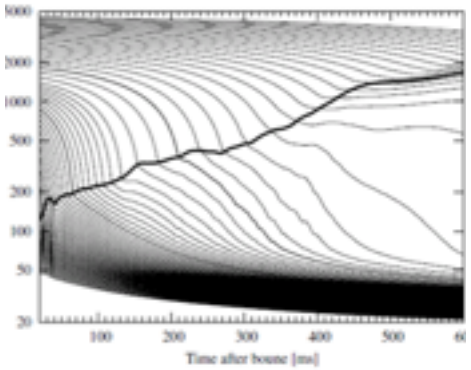
Symmetry Energy of Nuclear EOS

is important in nuclear physics and nuclear-astrophysics

Core-collapse supernova



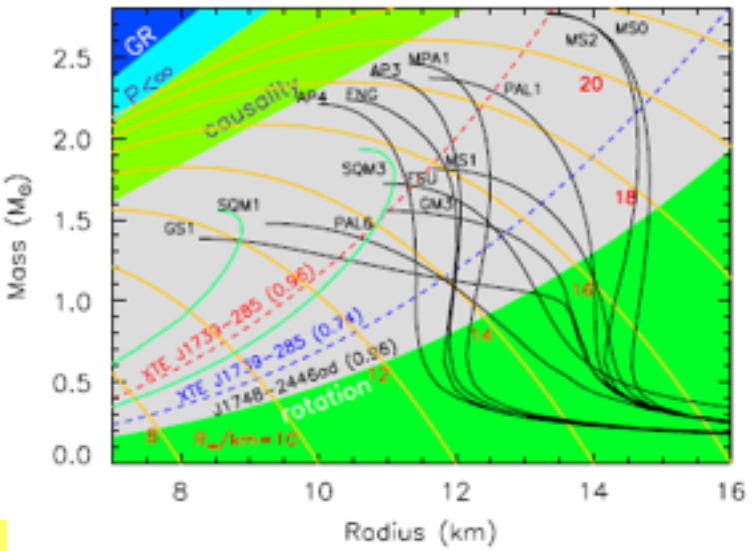
Langanke and Martinez-Pinedo



Y. Suwa et al., ApJ764, 99 (2013).

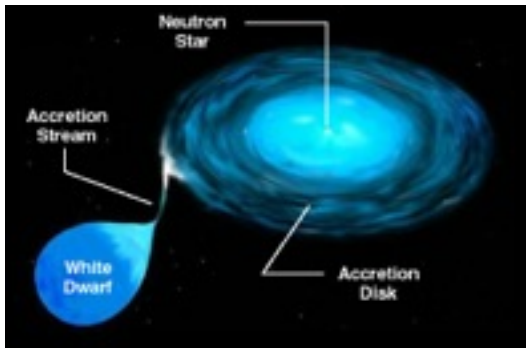
Nucleosynthesis

Neutron star mass vs radius

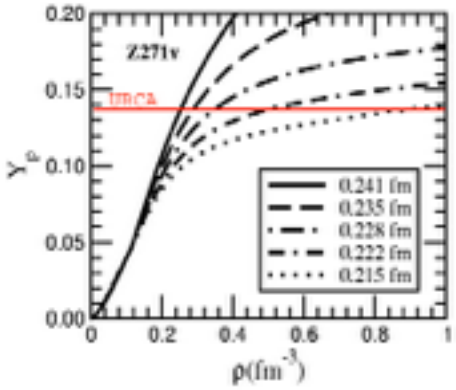


Lattimer et al., Phys. Rep. 442, 109(2007)

Accreting neutron star X-ray burst

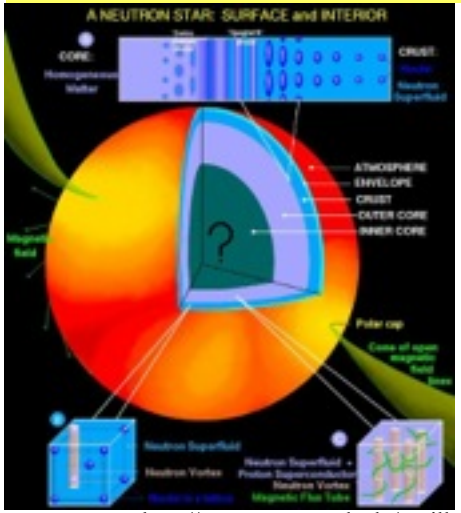


Neutron star cooling



Lattimer and Prakash, Science 304, 536 (2004).

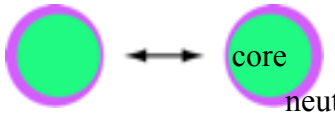
Neutron star structure

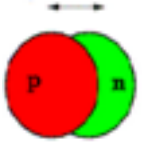


http://www.astro.umd.edu/~miller/nstar.html

Electric Dipole Response of Nuclei

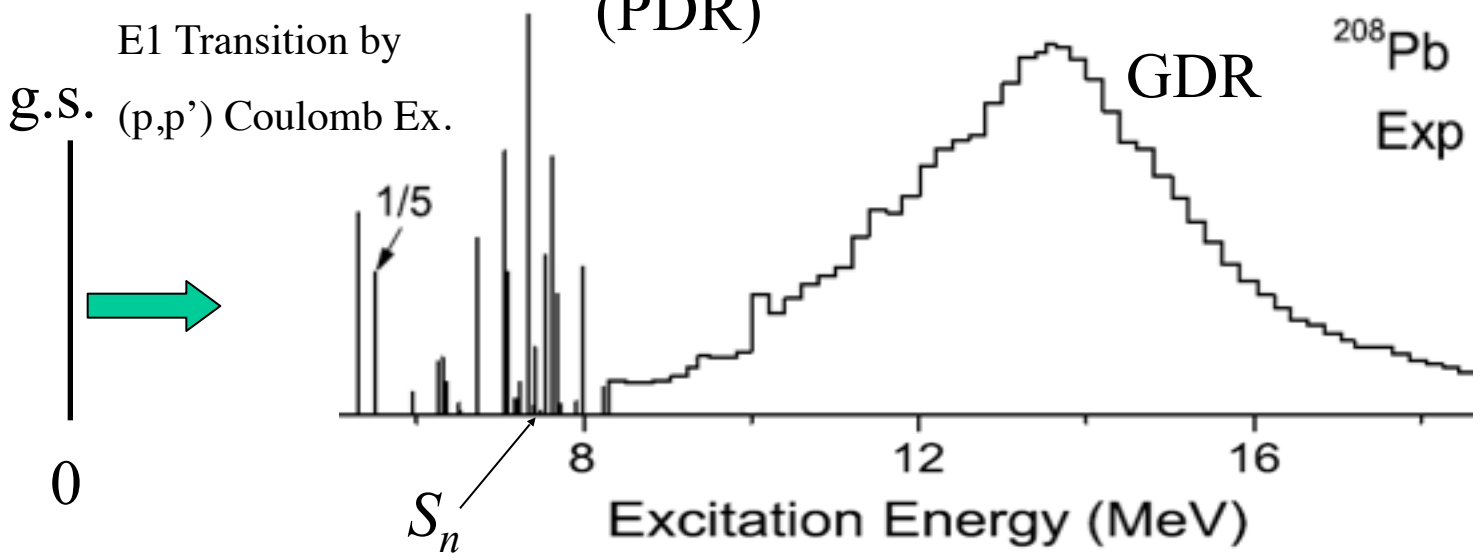
Low-Lying
Dipole Strength



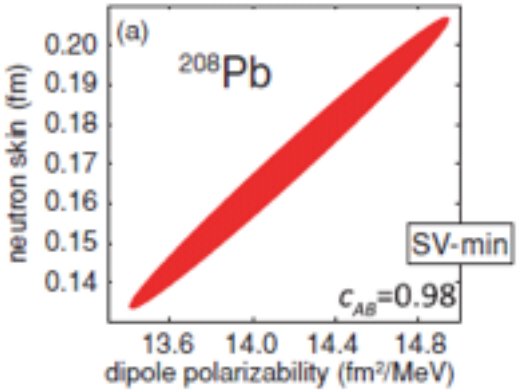


(PDR)

E1 Transition by
(p,p') Coulomb Ex.



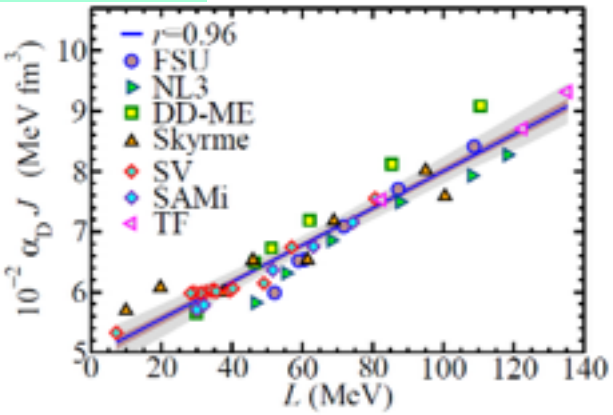
中性子スキン



P.-G. Reinhard and W. Nazarewicz, PRC 81, 051303(R) (2010).

Symmetry Energy

$$\alpha_D = \frac{\hbar c}{2\pi^2}\int \frac{\sigma_{\rm abs}^{E1}}{\omega^2} d\omega = \frac{8\pi}{9}\int \frac{dB(E1)}{\omega}$$

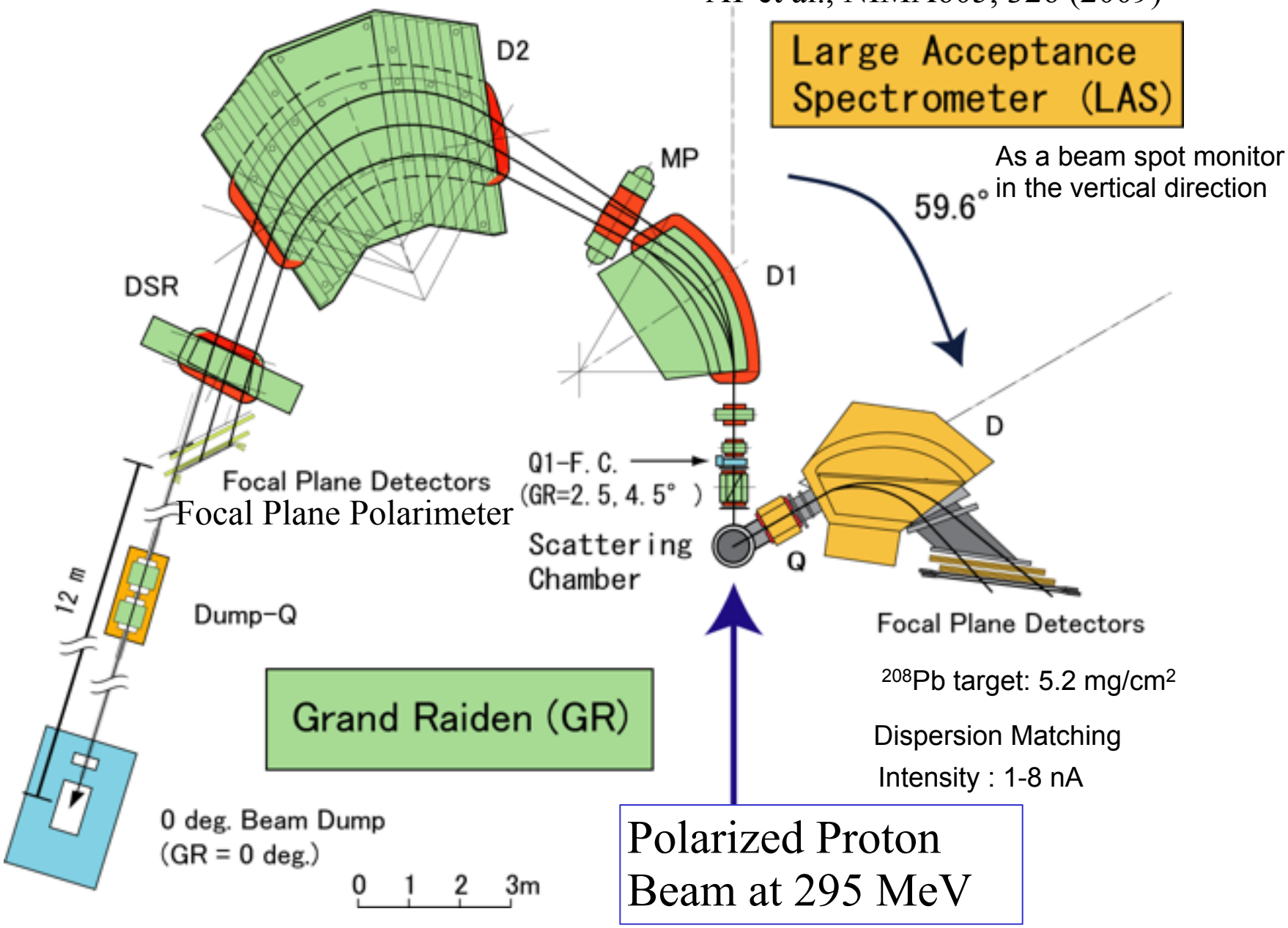


※Inakura et al, の計算では、平均場計算による相関の幅はもう少し大きい(2つにスプリット?)

X. Roca-Maza *et al*., PRC**88**, 024316(2013)

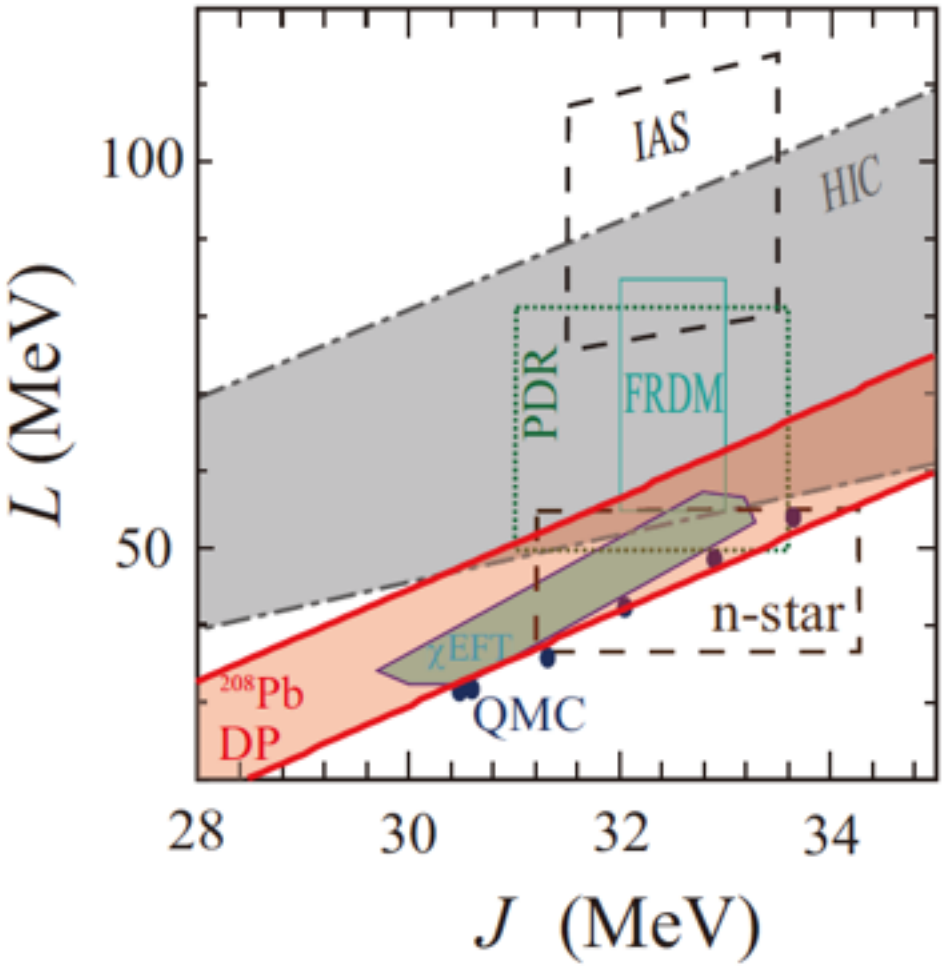
Spectrometers in the 0-deg. experiment setup

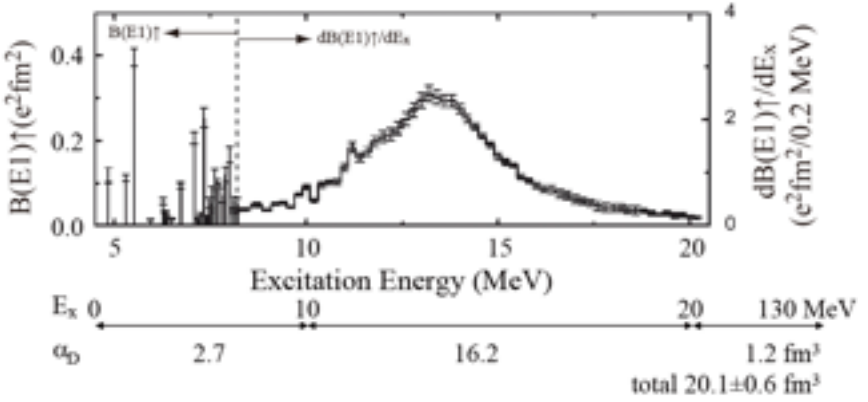
AT et al., NIMA605, 326 (2009)

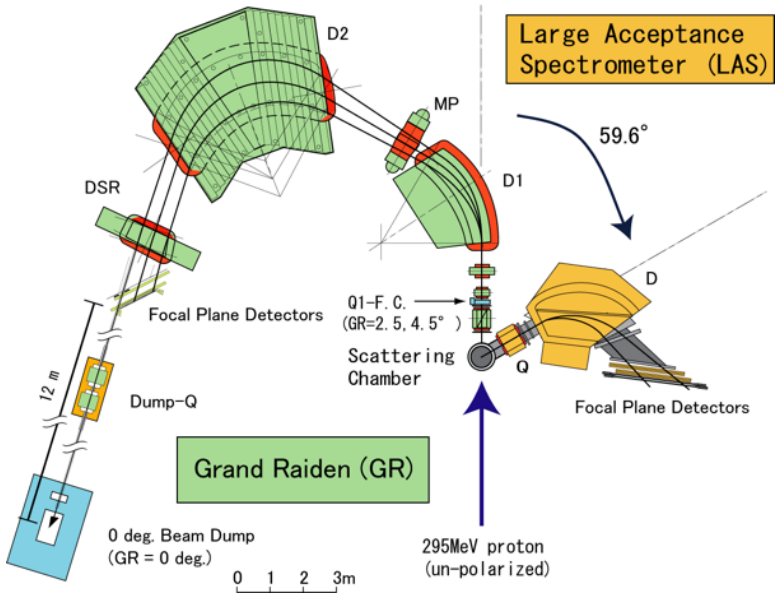


Constraints on J and L

AT et al., EPJA**50**, 28 (2014).



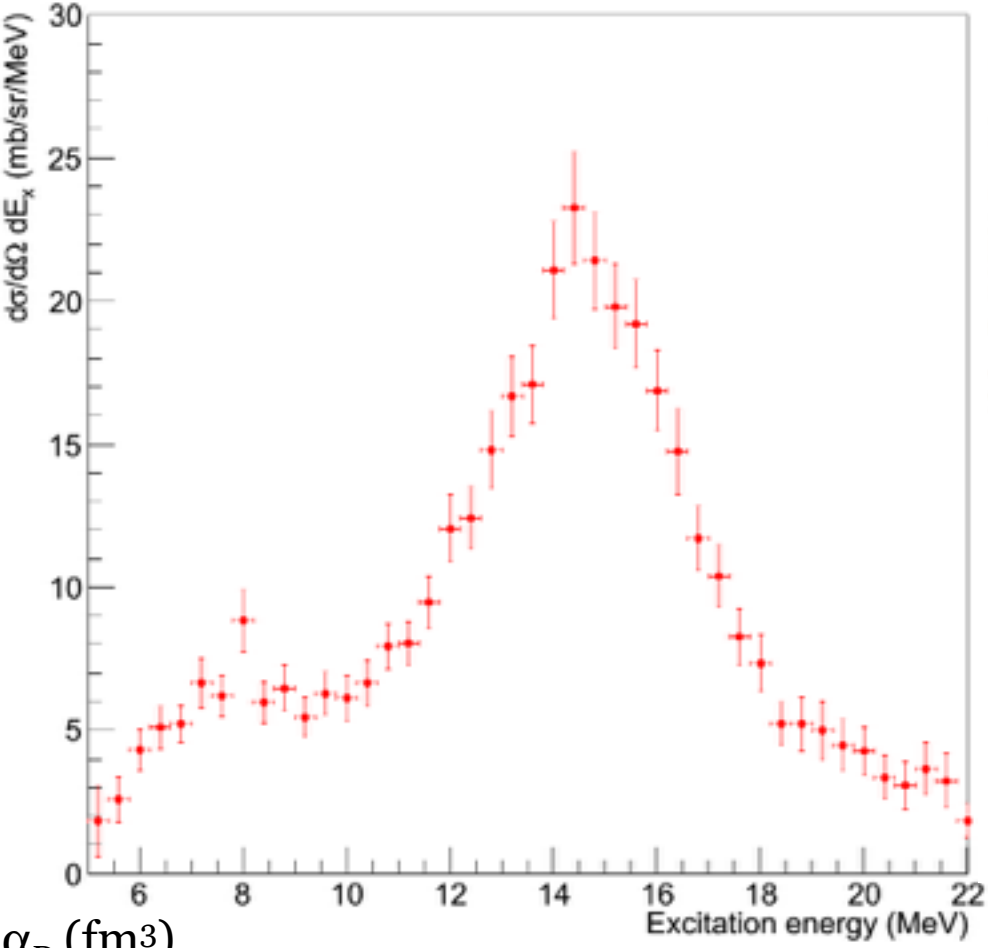


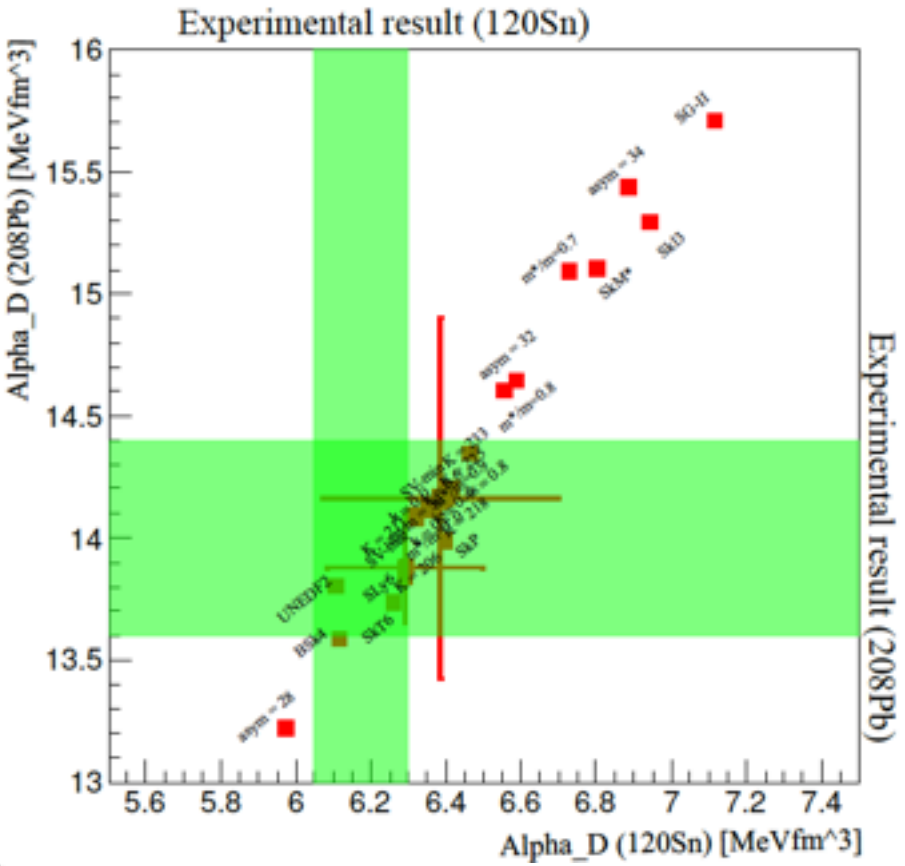


Dipole Polarizability of ^{120}Sn

T. Hashimoto, A.M. Krumbholtz et al.

calc. by P.-G. Reinhard





α_D (fm^3)

0.181 from (γ, γ')

8.07 from (p, p')

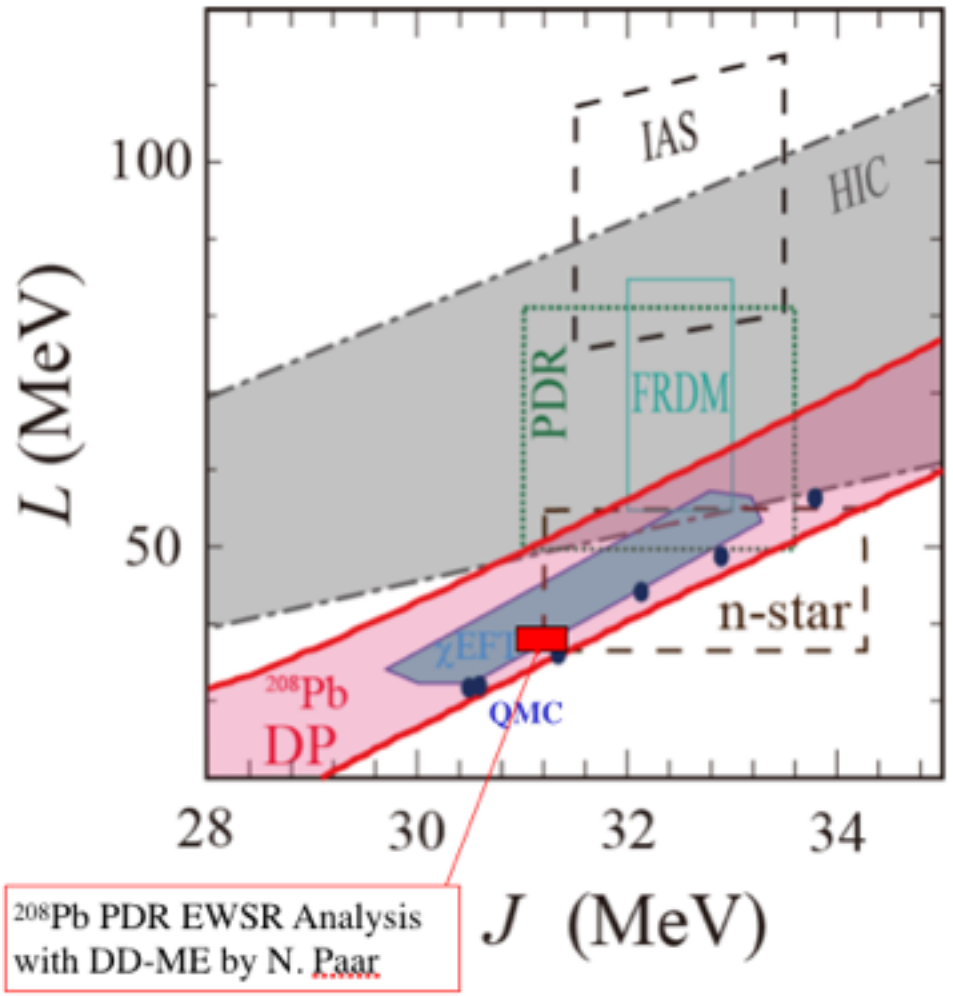
135 MeV

8.89 Form (γ, xn)

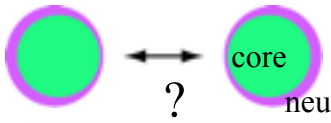
$\alpha_D = 8.89 \pm 0.18$ fm^3 (Preliminary) Measurement on tin isotopes is approved.

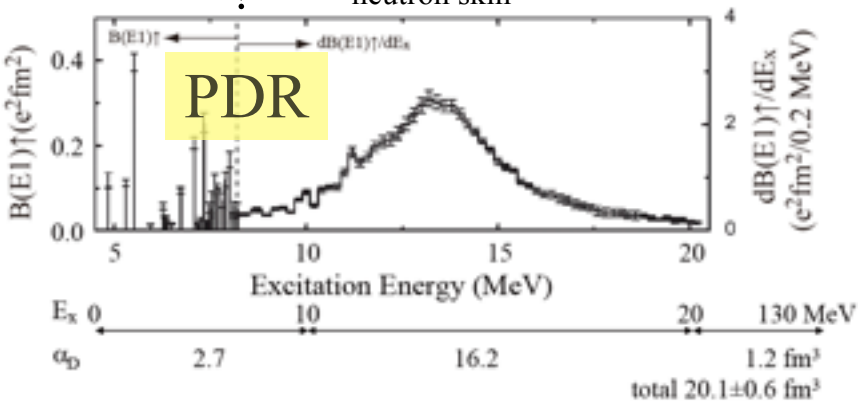
Constraints on J and L

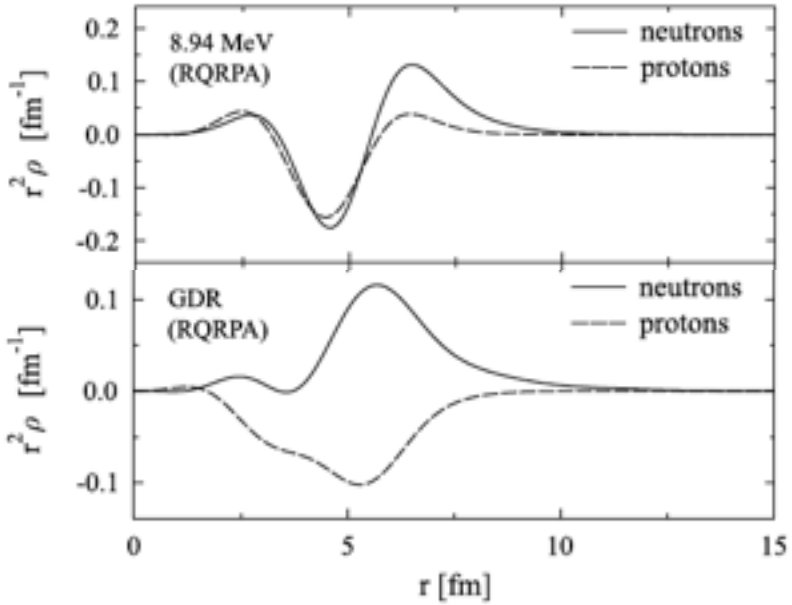
AT et al., EPJA**50**, 28 (2014).



208Pb PDR EWSR Analysis with DD-ME by N. Paar



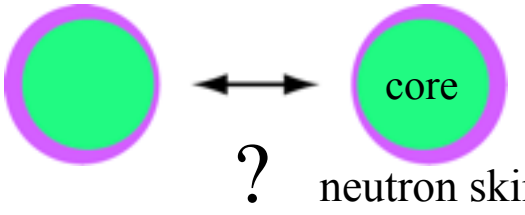




Cluster Dipole Sum-Rule of PDR

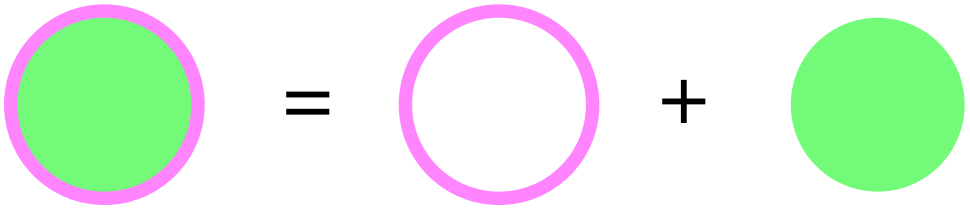
Assuming that the PDR is formed by the dipole oscillation of the neutron skin against the other part (core),

PDR



Y. Alhassid, M. Gai and G.F. Bertsch, PRL49, 1482(1982)
H. Sagawa and M. Honma, PLB251,17(1990)
R. de Diego, E. Garrido et al., PRC77, 024001 (2008)

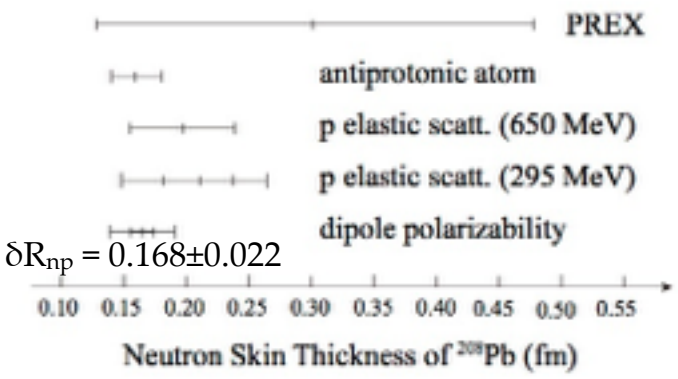
Cluster Dipole Sum-Rule



A, N, Z = $A_s, N_s, (Z_s = 0)$ + $A_c, N_c, (Z_c = Z)$

$$60\frac{(Z_s A_c - Z_c A_s)^2}{A A_s A_c}$$

TRK: $60\frac{NZ}{A}$



Number of neutrons in the skin: N_s

2% TRK $\rightarrow N_s$ (skin) ~ 12

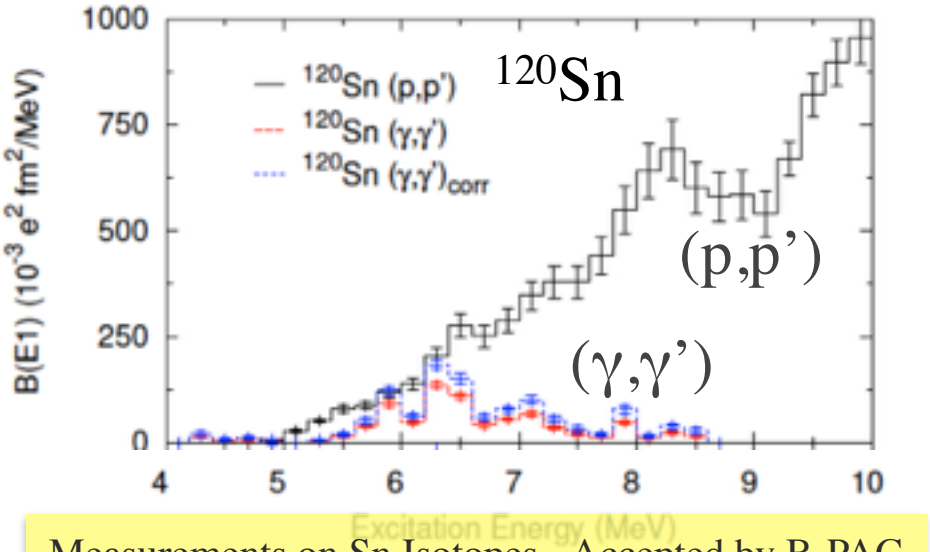
R_n=5.66 and δR_{np} = 0.168±0.022

$\rightarrow N_s$ = 10.9±1.4

The numbers are consistent to each other.

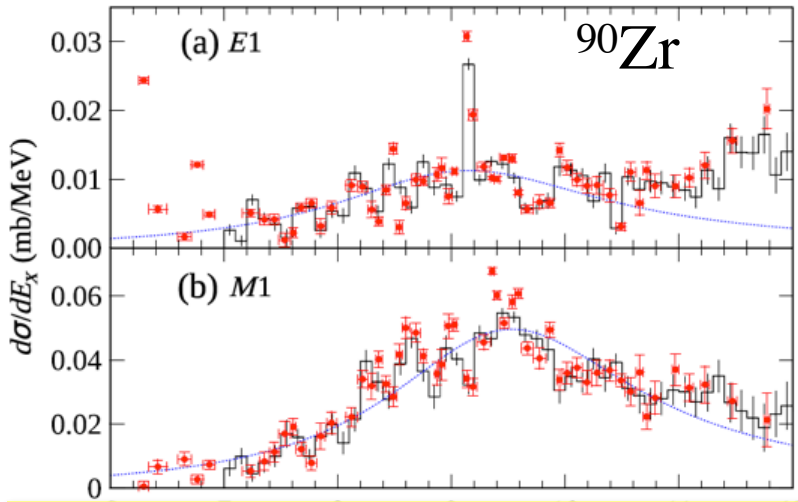
PDR in ^{120}Sn and ^{90}Zr

T. Hashimoto, A.M. Krumbholtz et al.

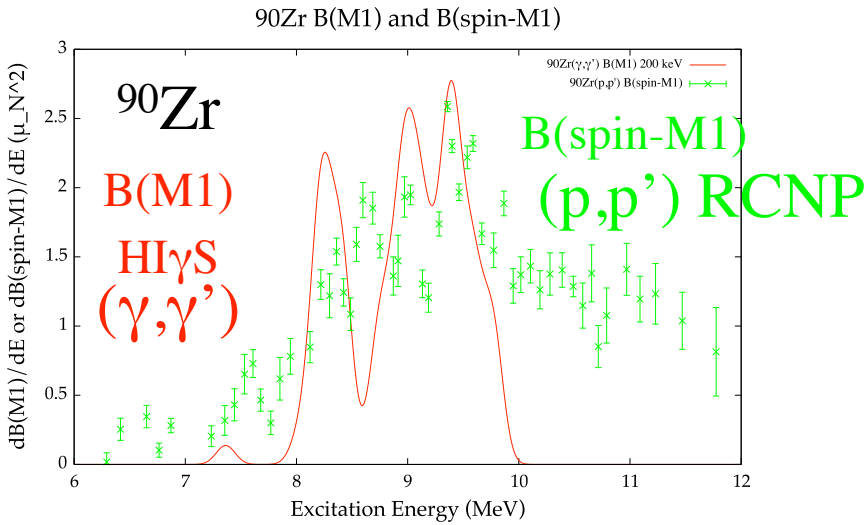


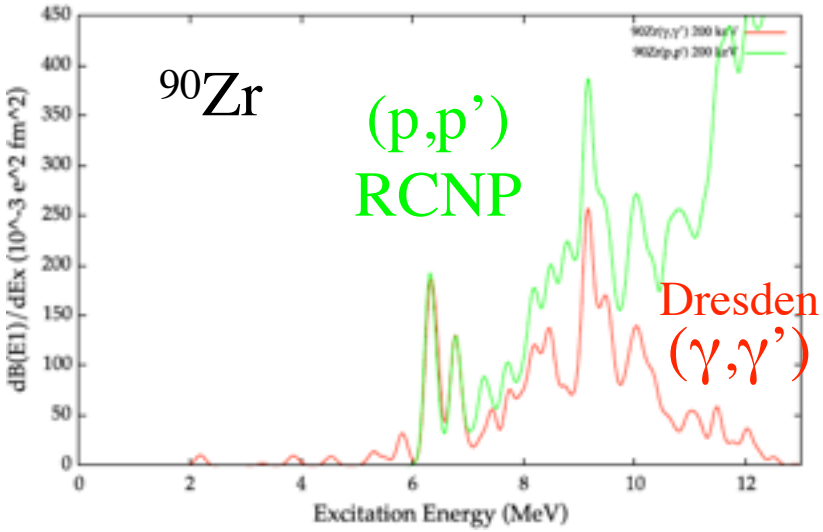
Measurements on Sn Isotopes - Accepted by B-PAC

C. Iwamoto, H. Utsunomiya, AT et al.



Measurements on Zr Isotopes - Submitted to B-PAC

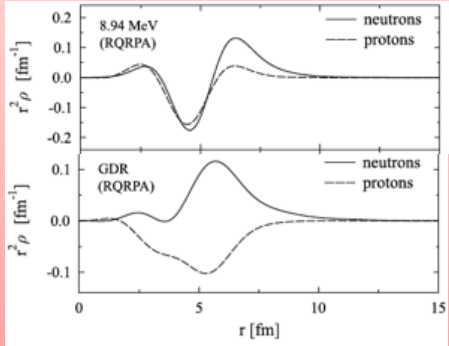




Coin. measurements of high-resolution light-ion reactions and decay γ

Spectrometer

PDR structure
transition density,
isospin-structure



Rare γ

12

rare γ
giant resonances

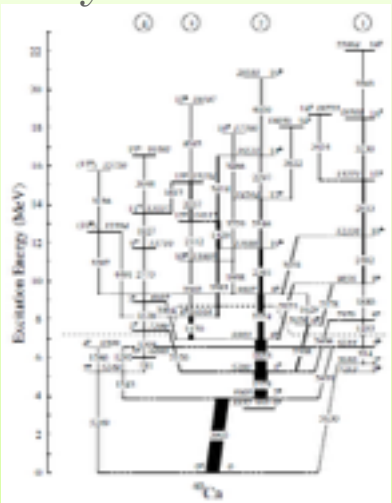
New Probes of Excitation Modes

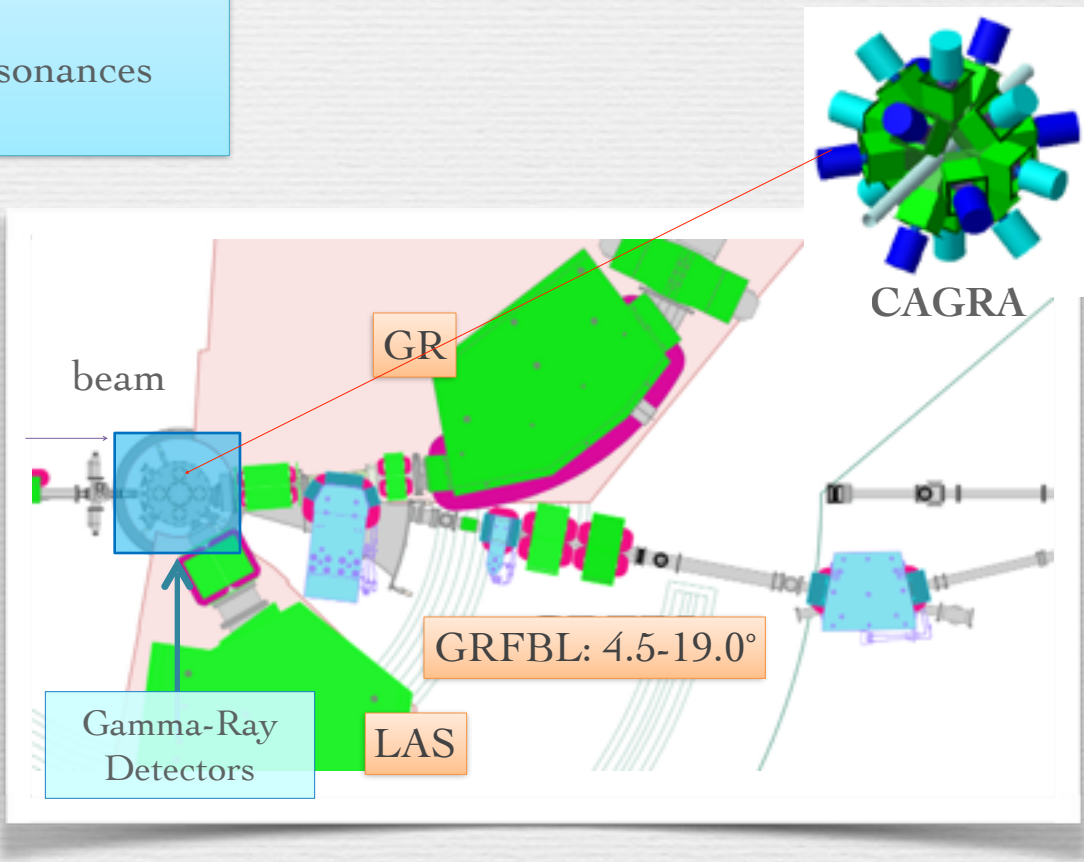
(^{6}Li,^{6}Li'γ): IV spin-flip inelastic scattering

(^{14}C,^{14}C'γ) : parity transfer inelastic scattering

Excitation of high-spin states by nuclear interaction and γ-decay detections

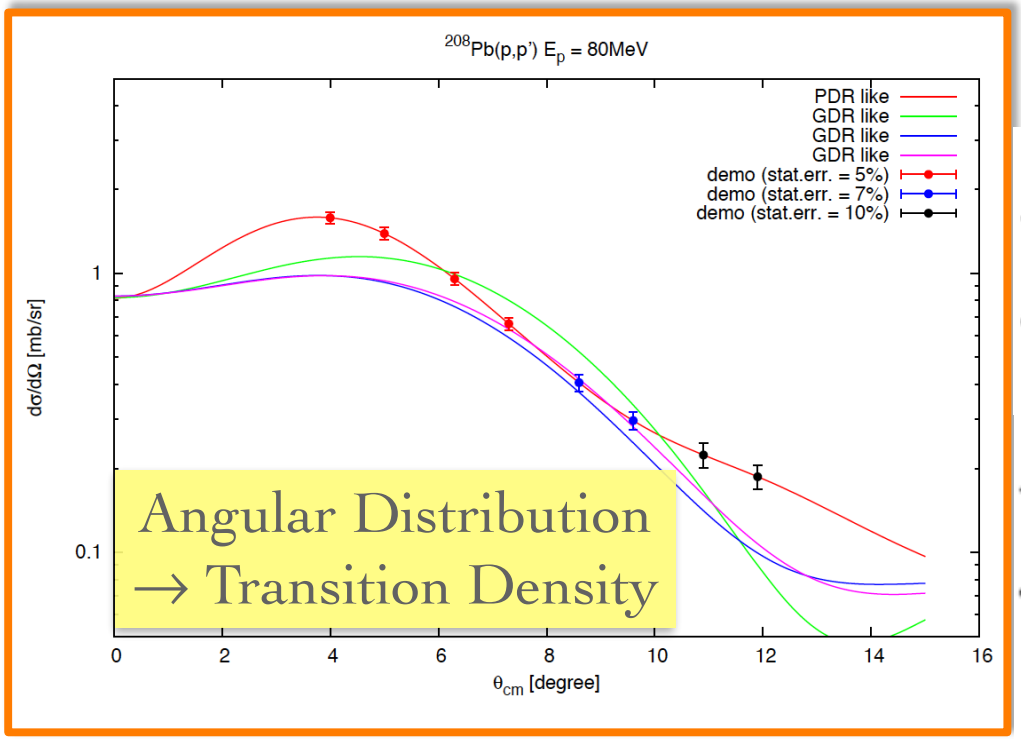
excitation mechanism, excitation on high-spin states, high-spin frontier

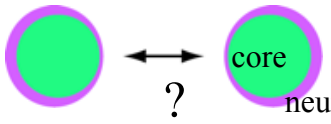


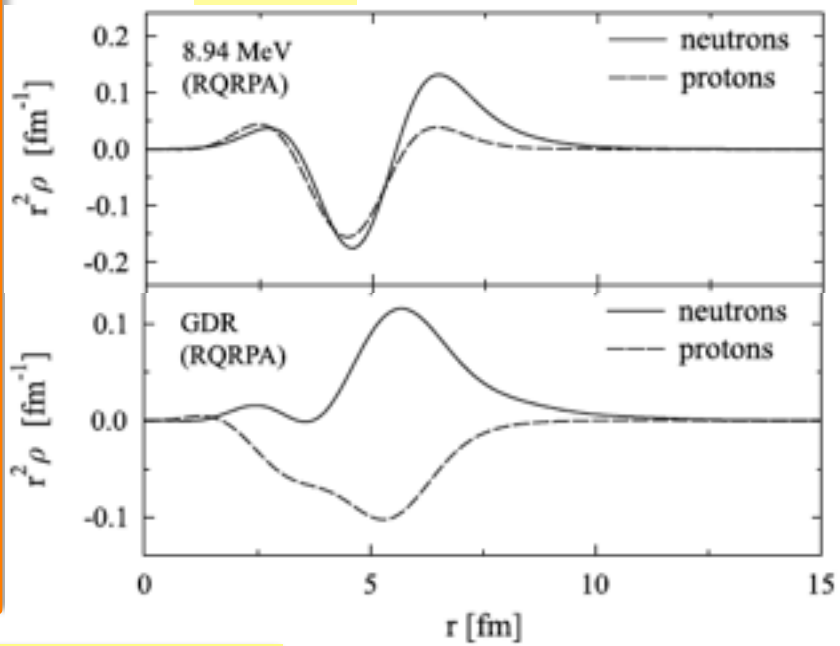


Study of the PDR Structure by (p,p'γ) and (α,α'γ

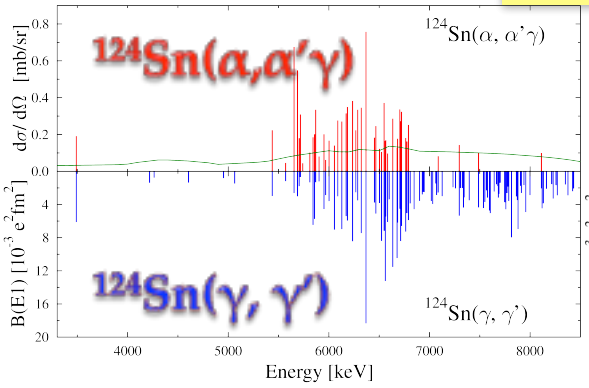
Proposal Submitted to RCNP-BPAC

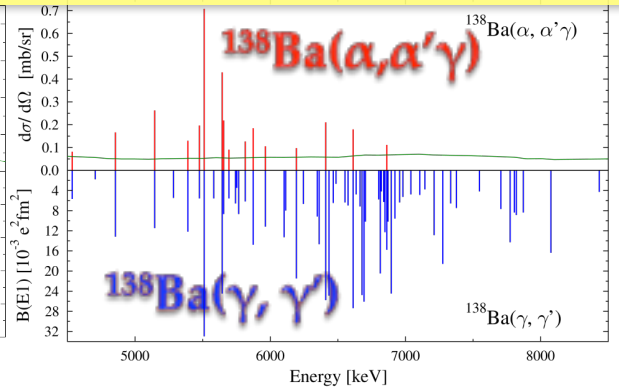


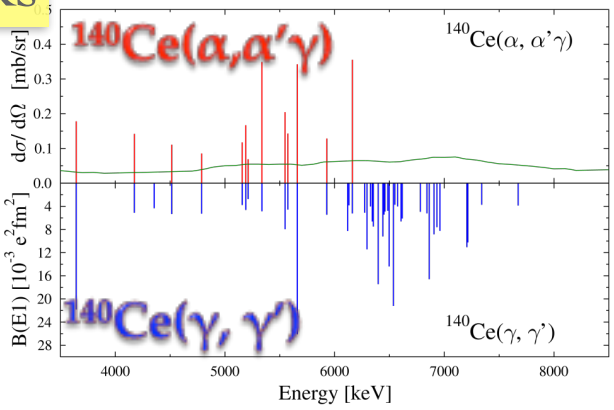




Isospin Property of the PDRs

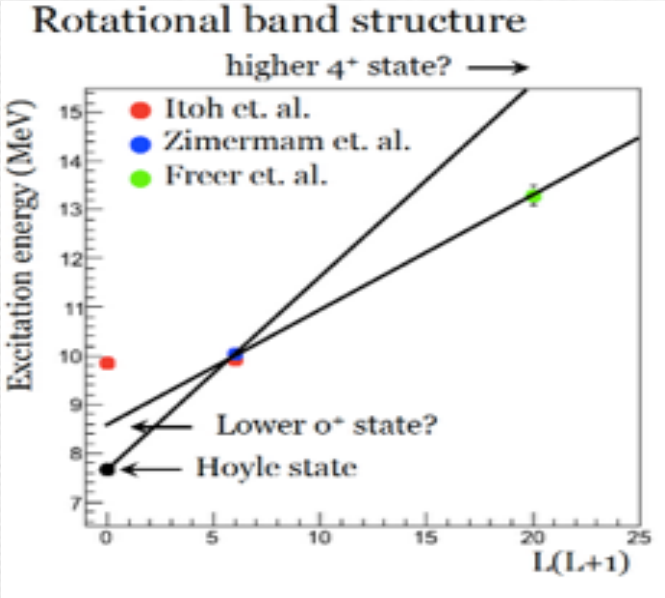




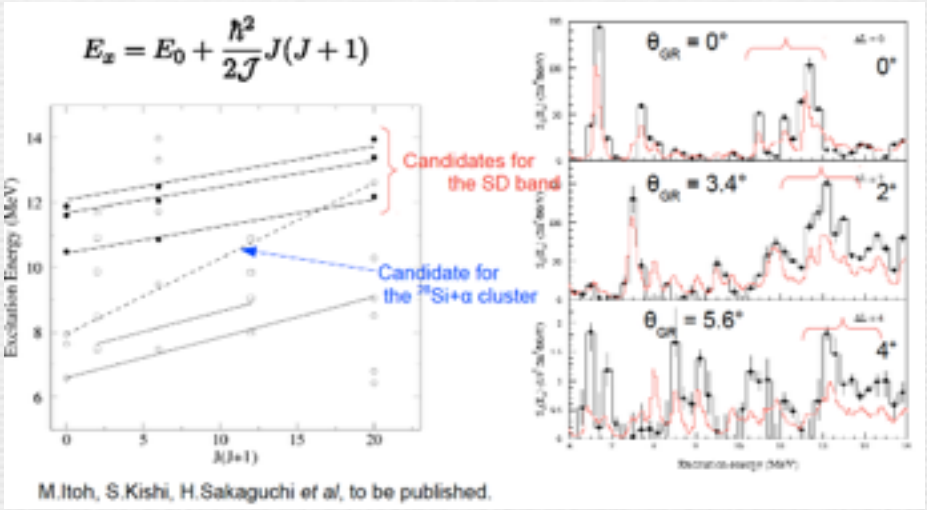


稀

Rotational Band of the Hoyle State



Super-deformed Band in



回転バンド決定的な証拠

γγでは稀γ遷移測定は困難

- 初期励起エネルギーのタグ、スキャン
- 高分解能励起+高分解能崩壊

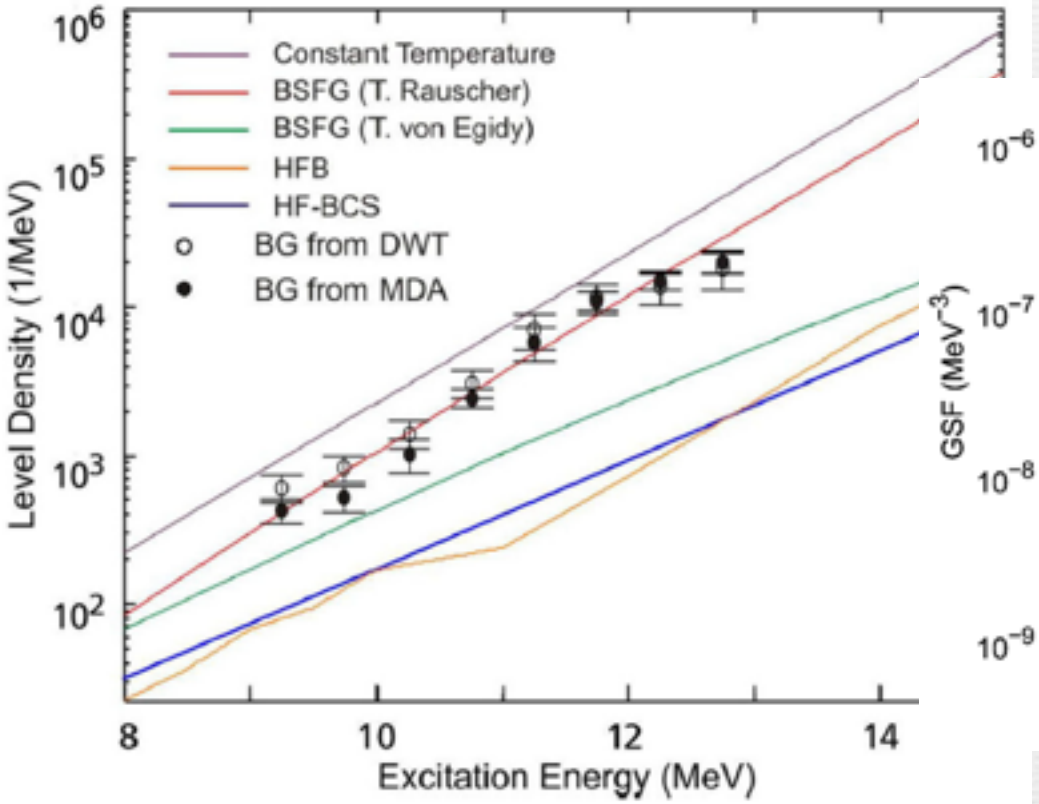
  S/Nの圧倒的向上

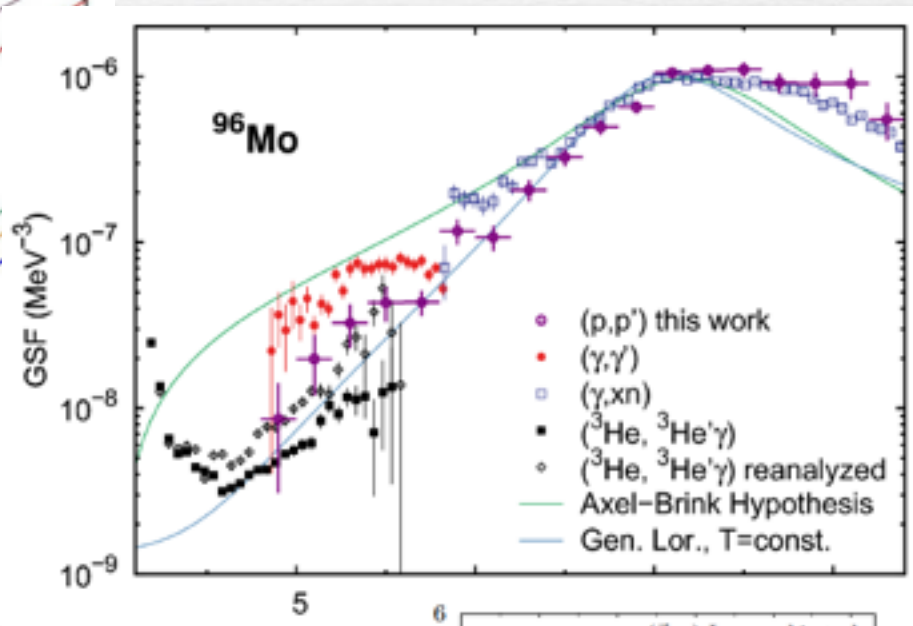
T. Hashimoto, M. Itoh

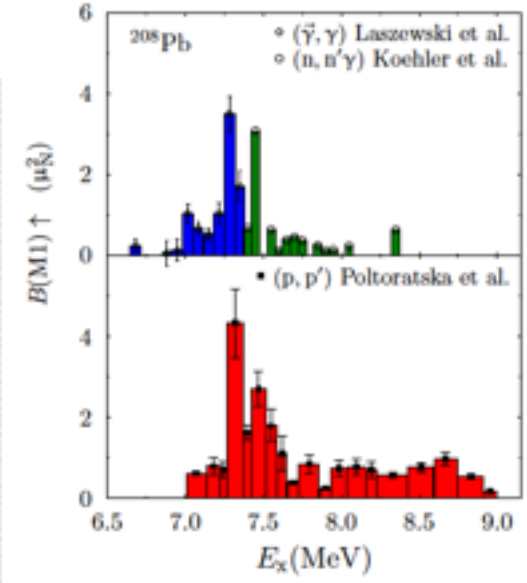
1-

Gamma Strength Function

D. Martin et al.,







I. Poltoratska, R.W. Fearick et al.,
PRC89,054322 (2014)

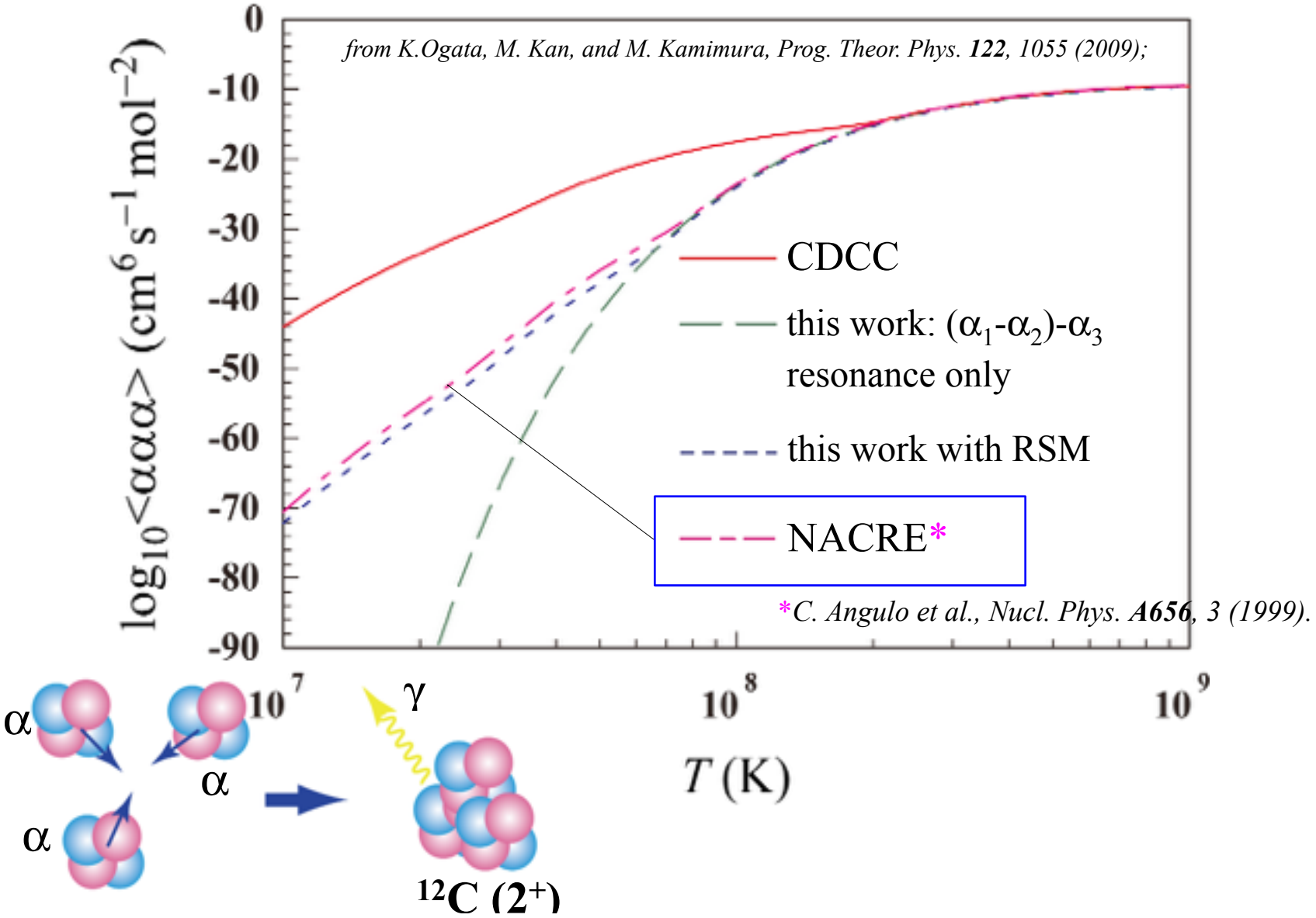
J. Birkhan et al., M1 strength, for re-submission
H. Matsubara et al., M1 quenching draft
R.W. Fearick et al., Fine Structure of GDR in sd-shell draft

Non-resonant Triple-Alpha Reaction at Low Temperature

T. Ito, A. Tamii

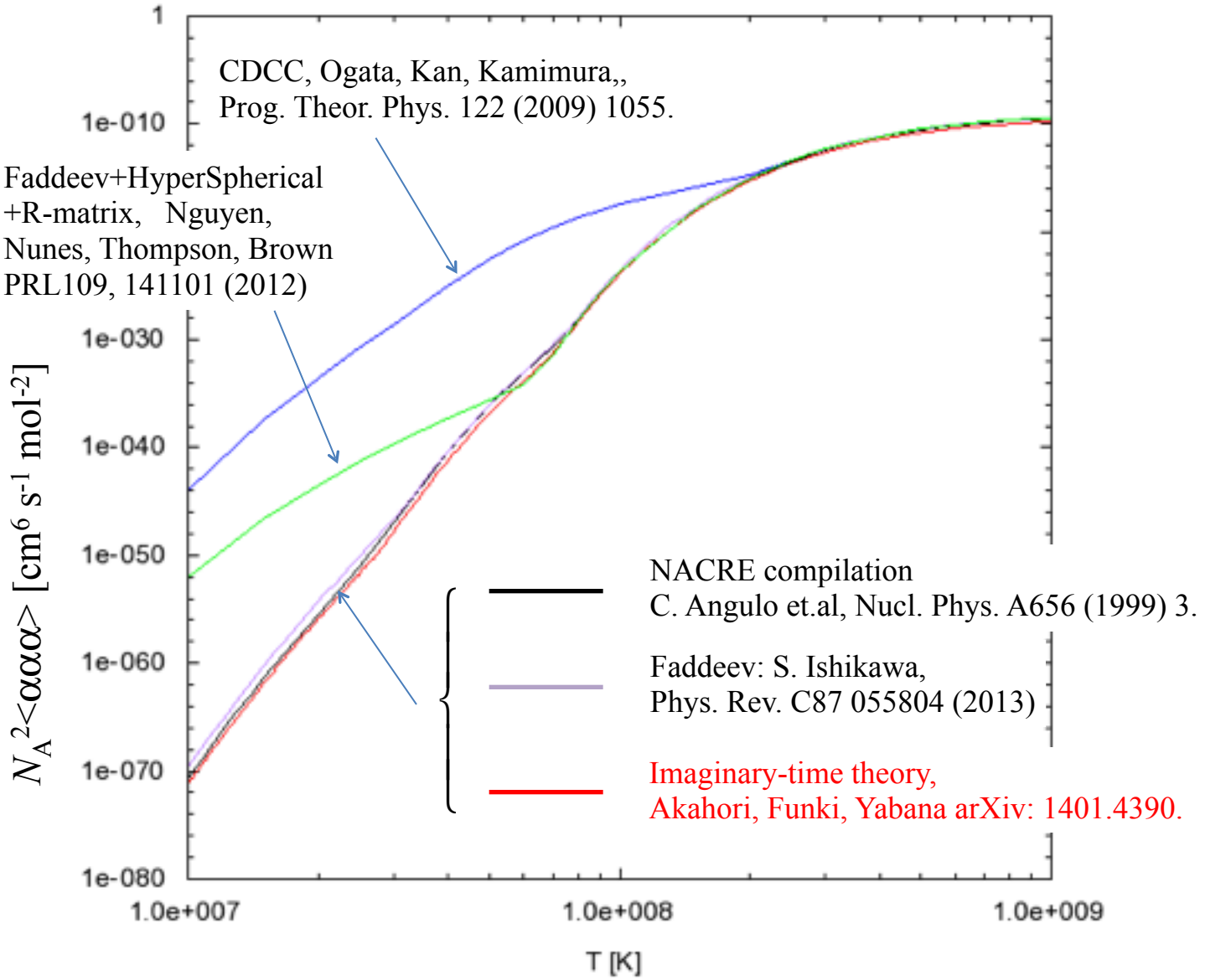
Research Center for Nuclear Physics, Osaka University
RCNP-E387 Collaboration

The Triple-α Reaction Rate



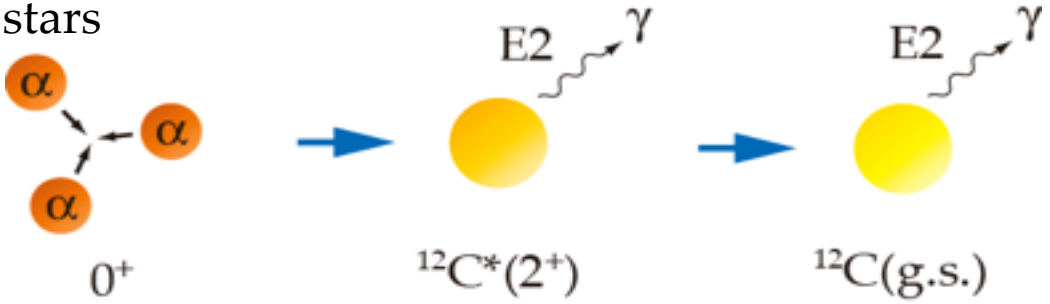
Triple-alpha reaction rate: theoretical controversy

10^{26} order of magnitude difference at 10^7 K

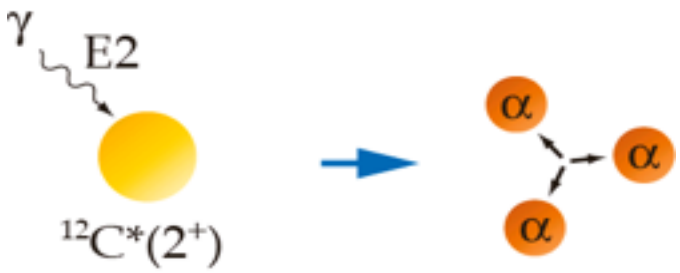


Probing the Triple-α Fusion Reaction Rate at Low Temperature

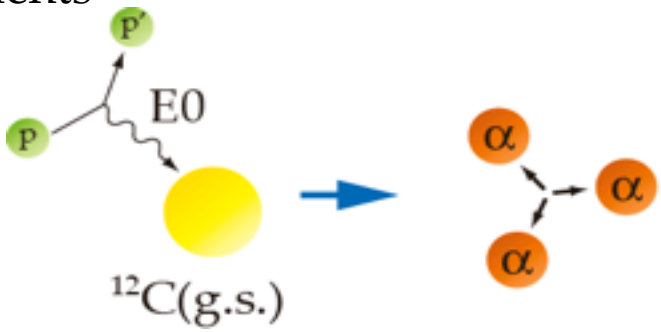
Reaction in stars



Inverse reaction

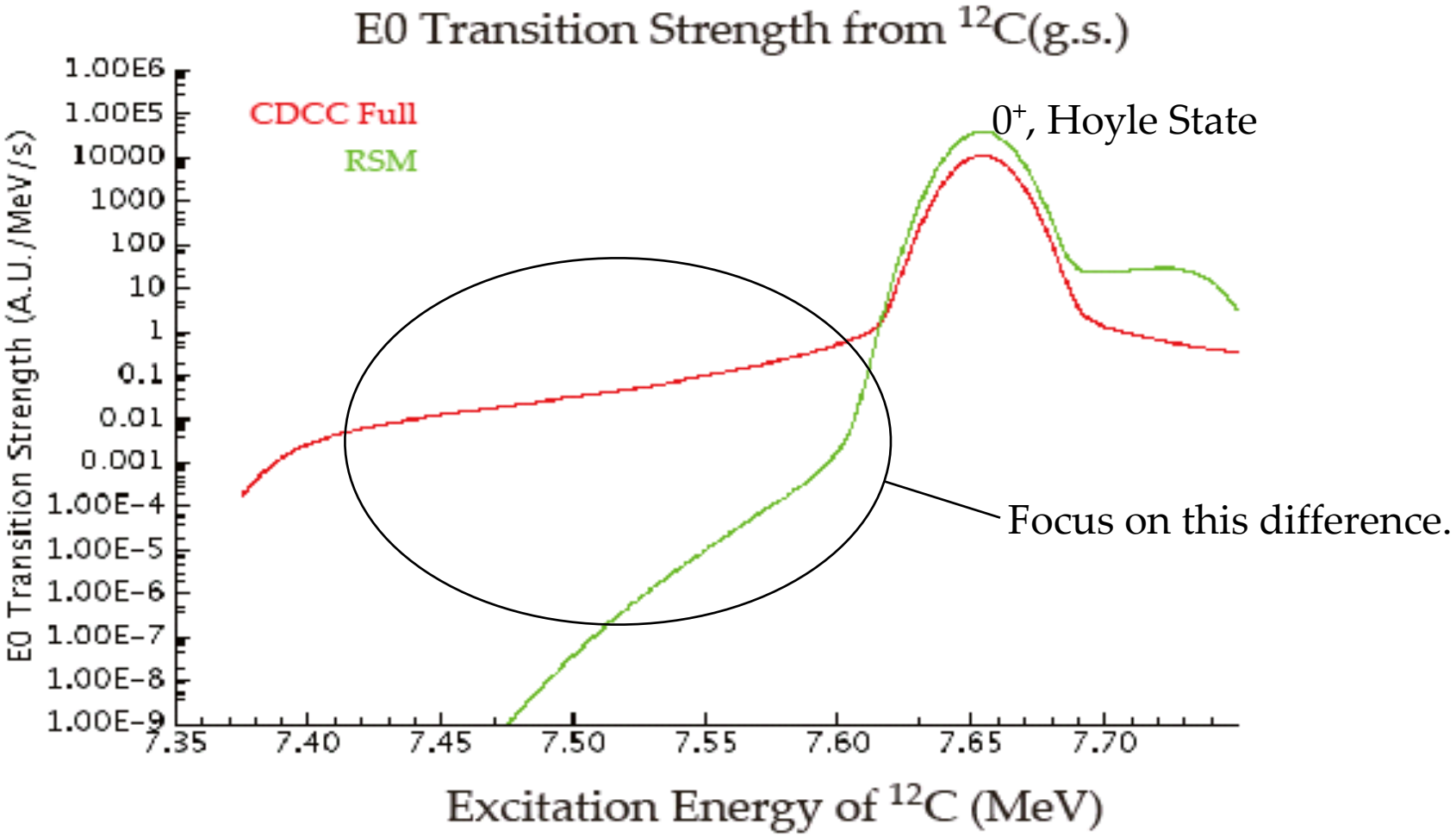


Proposed measurements



by $^{12}C(p,p)$ and $^{13}C(p,d)$

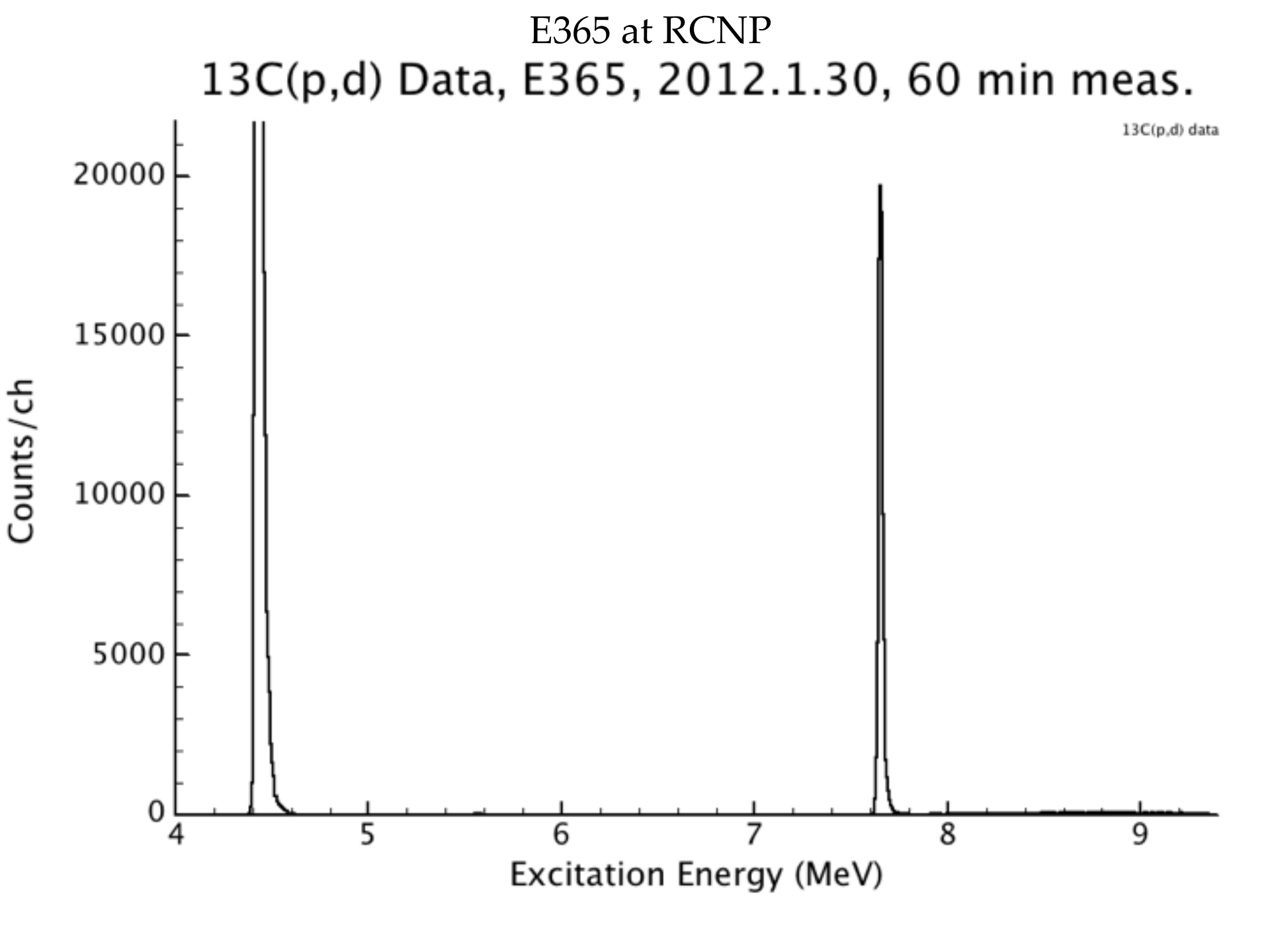
E0 Transition Strength to the Three-α Continuum



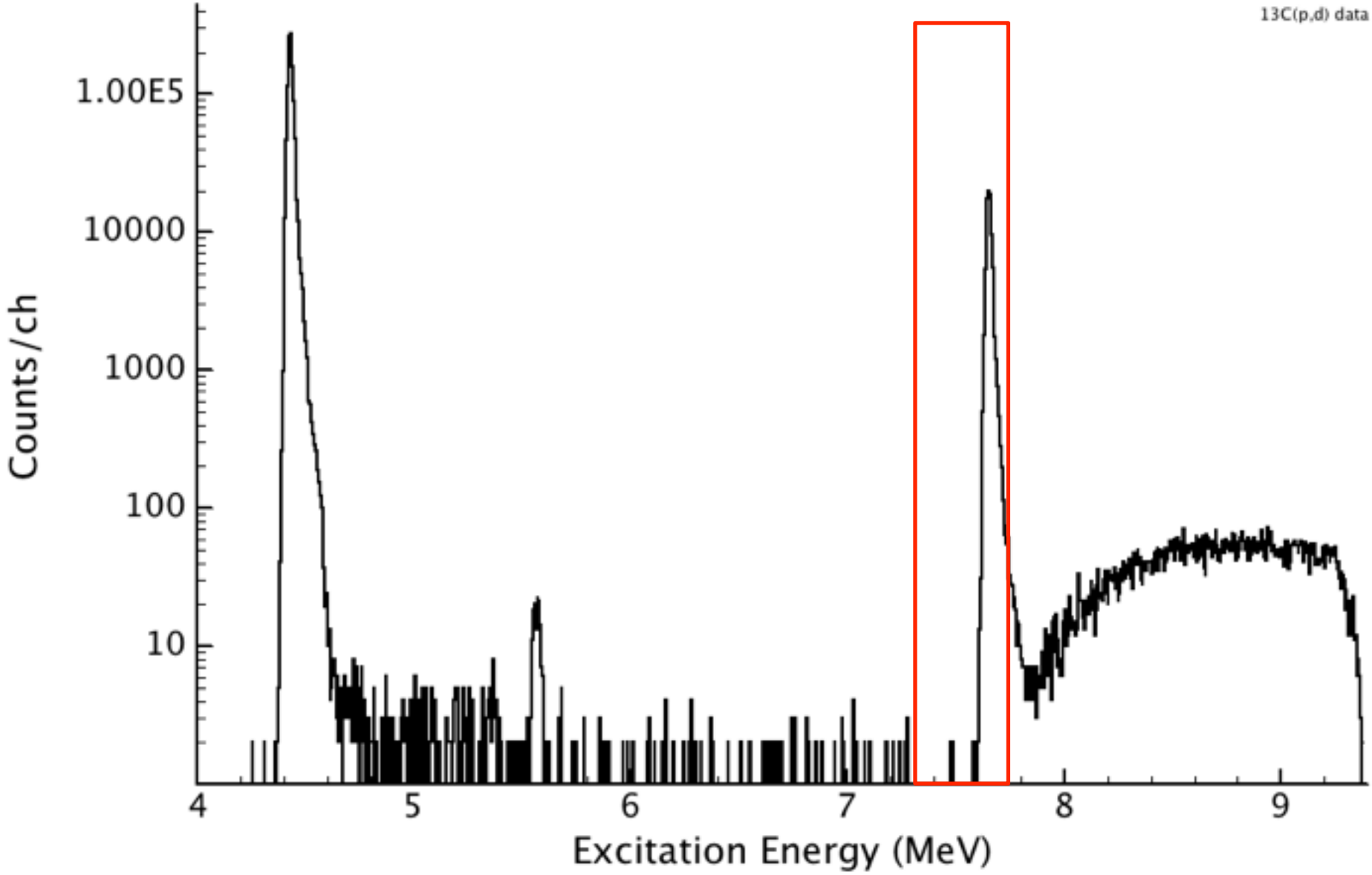
^{12}C g.s. wave function from M. Kamimura et al.,

The ααα threshold is at 7.275 MeV.

E365 at RCNP


13C(p,d) Data, E365, 2012.1.30, 60 min meas.
13C(p,d) data
Counts/ch
20000
15000
10000
5000
0
4
5
6
7
8
9
Excitation Energy (MeV)

13C(p,d) Data, E365, 2012.1.30, 60 min meas.

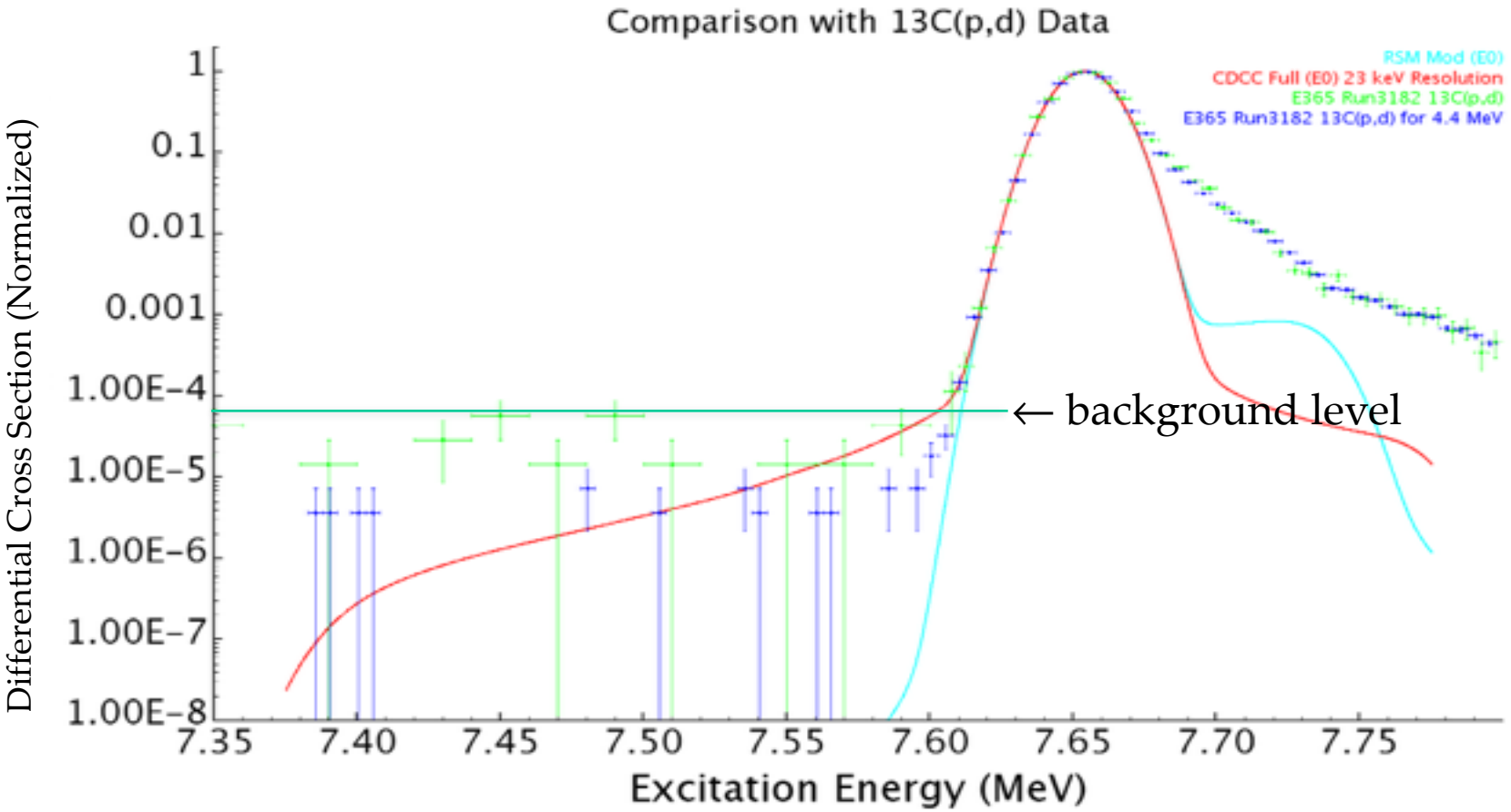


Data: ^{13}C(p,d) at 0 degree

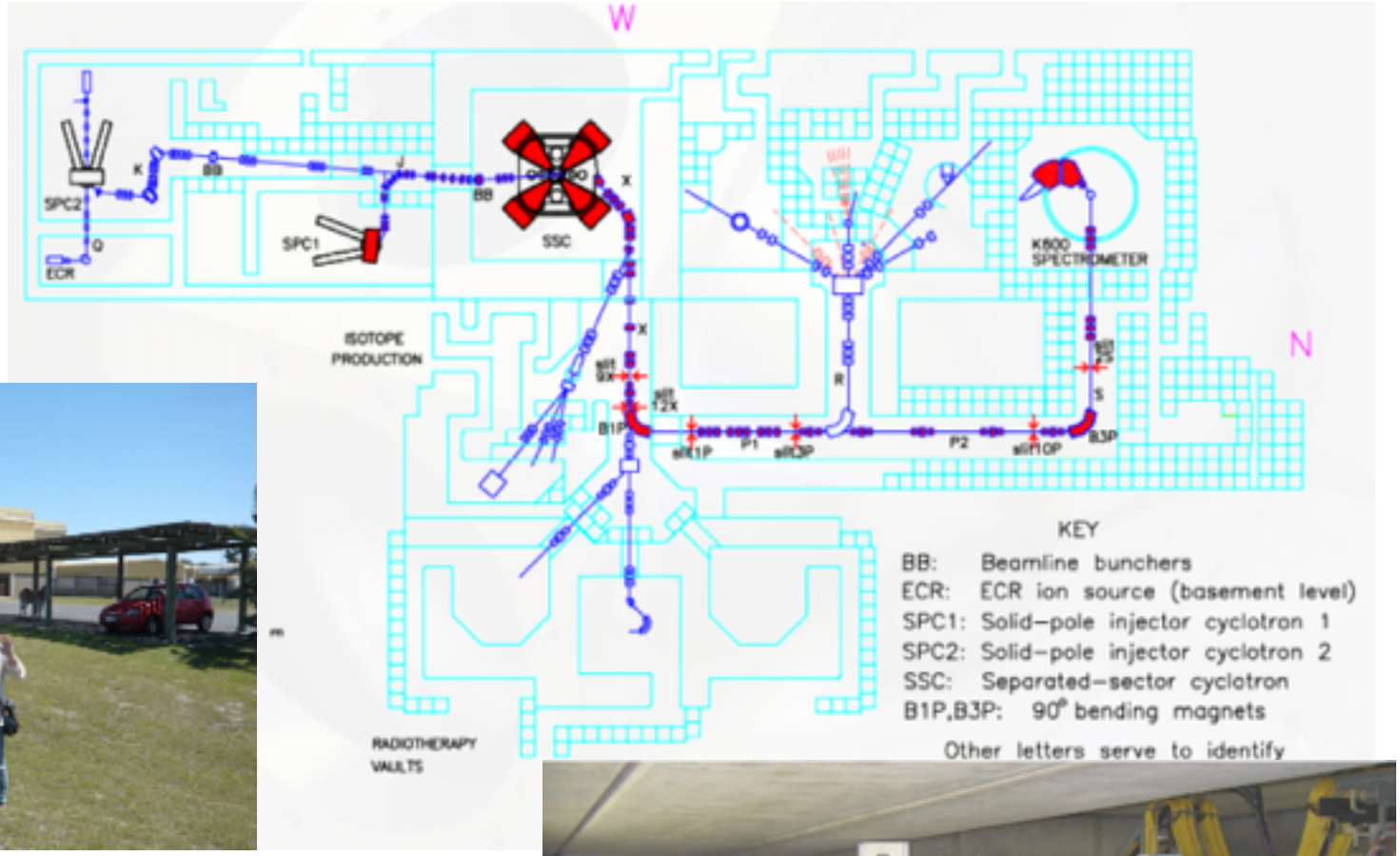
2012.1.30 in RCNP-E365

Achromatic Mode, 23 keV

60 minutes at 150 nA



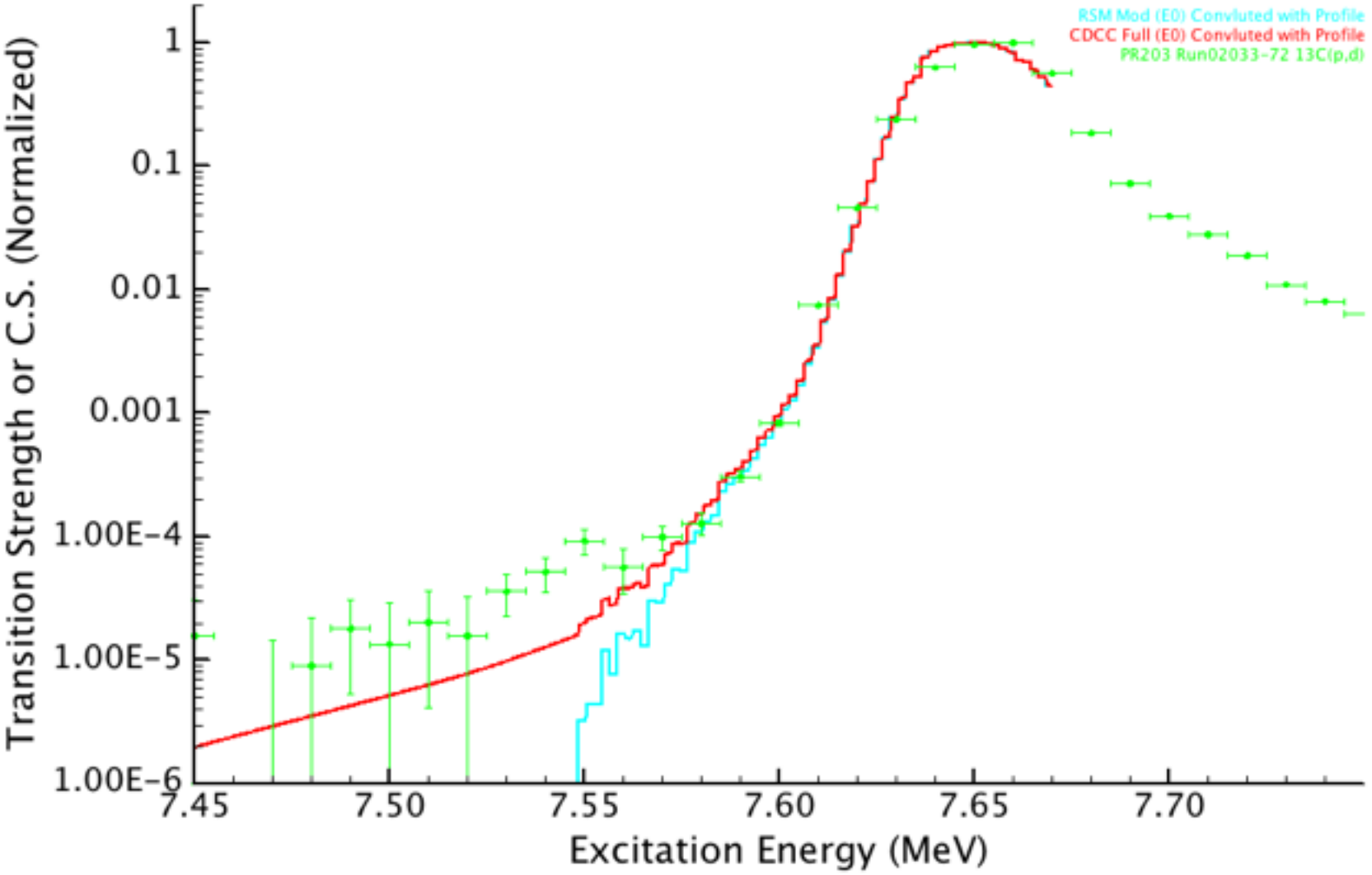
PR203 at iThemba, Mar 2013



^{13}C(p,d) at 0 degree

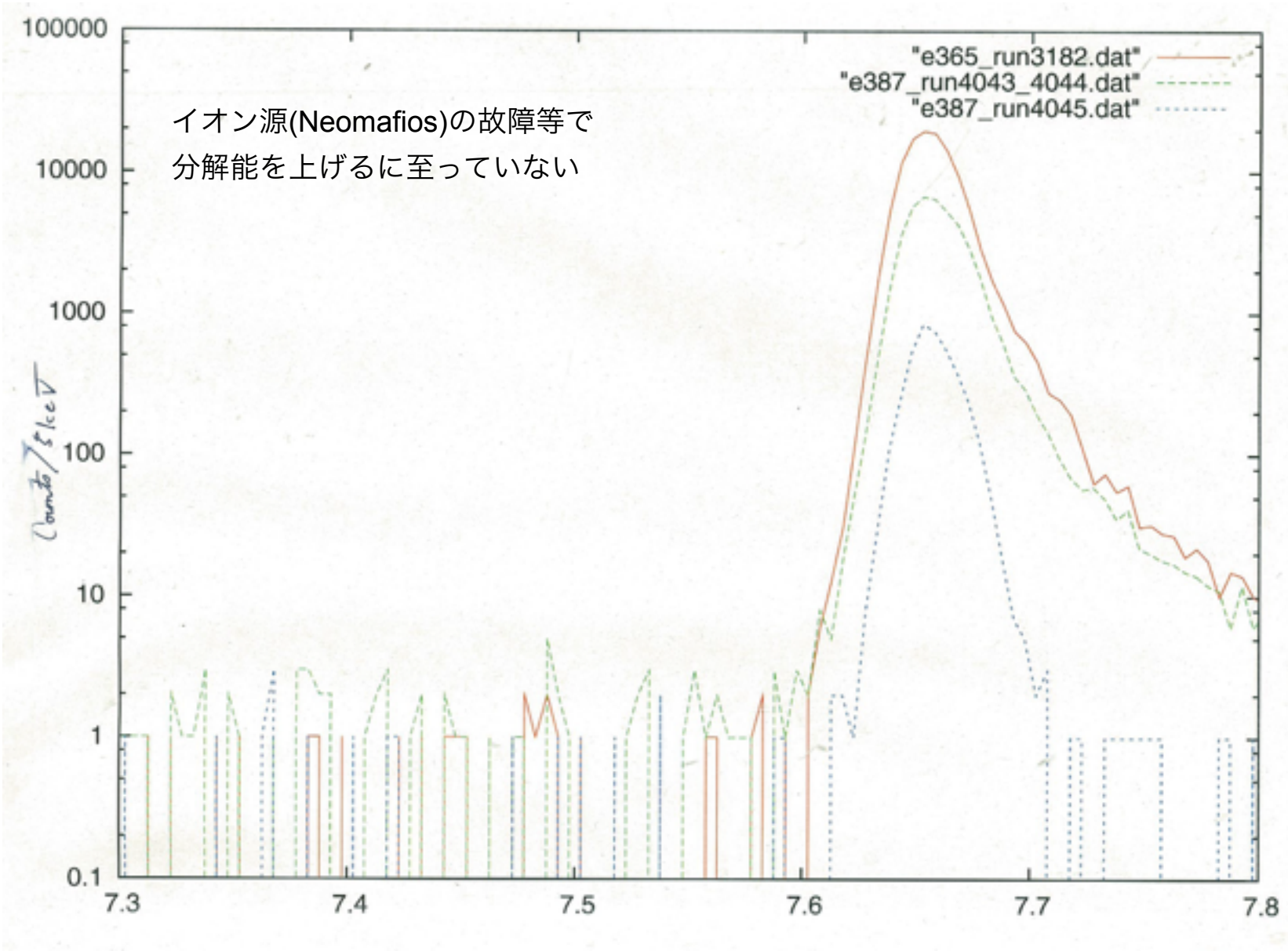
PR203 at iThemba, Mar 2013

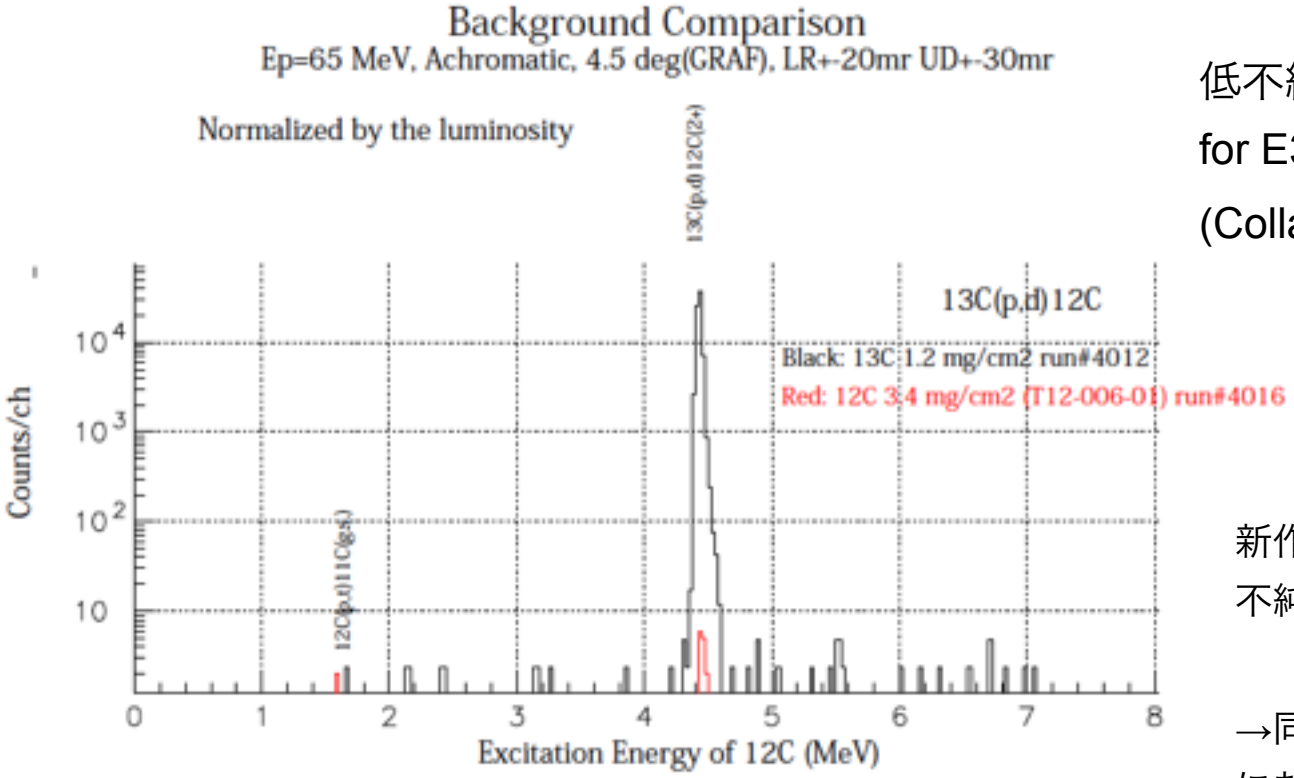
Dispersion Matching

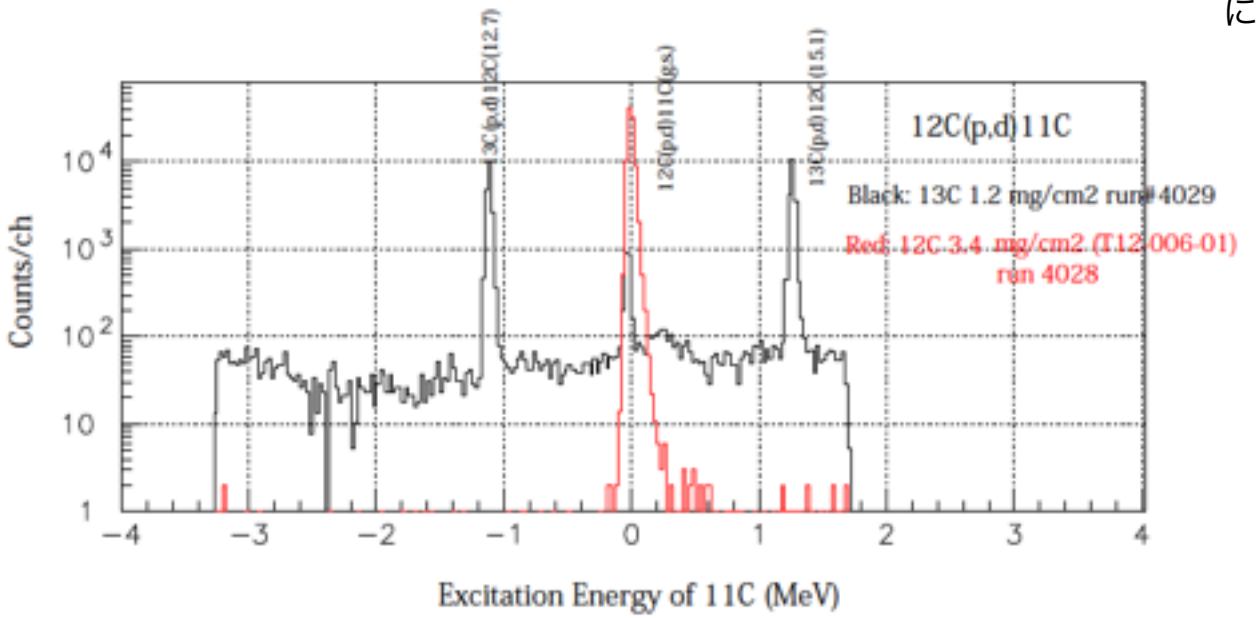


^{13}C(p,d) at 0 degree

E387 at RCNP, July 2014
Dispersion Matching, 25 keV







低不純物高濃縮12C標的の開発
for E387 and BRILLIANT
(Collaboration with 菅井氏)

新作の12C濃縮(99.995%)標的の不純物は極めて少ない。

→同じ手法での13C標的の再作製にむけて議論中

Future

励起状態の精密測定: 高分解能、低B.G.、ガンマ同時計測

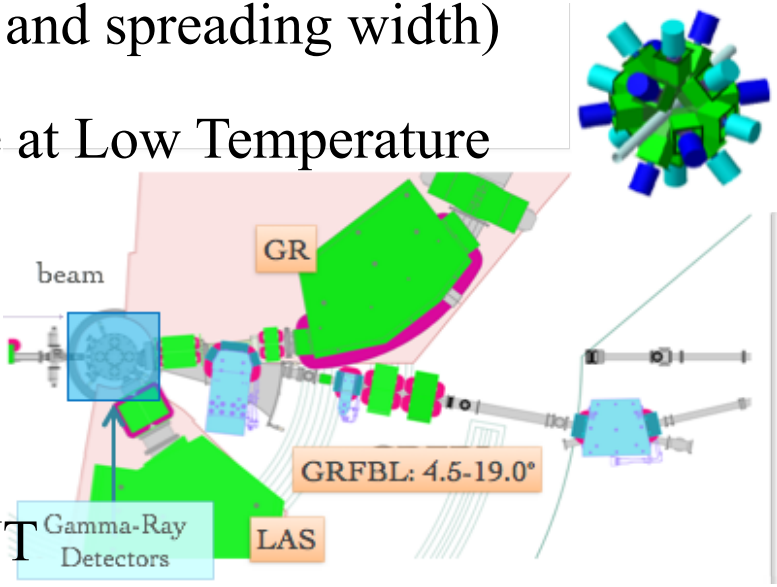
1. PDR の機構を解明する
   - Transition Density, アイススピン構造、,Isotope/Mass 依存性
   - 中性子スキン、EOS、(n,γ)反応への寄与

2. ガンマ同時計測、稀崩壊イベントの測定
   → 回転バンド、超変形、
   Giant Resonance Decay (fine structure and spreading width)

3. Non-Resonant Triple Alpha Reaction Rate at Low Temperature
   実験により決着する
   (alpha非束縛連続状態の測定)

4. SDR、NC IV Spin Response, ..

5. 不安定核インプラント標的: BRILLIANT



Thank you