SAMURAI International Workshop 2011, March 9-10, 2011, Tokyo, RIKEN

(p,n) reactions on light neutron-rich nuclei, ^{14}Be,^{16}C, and ^{17}N

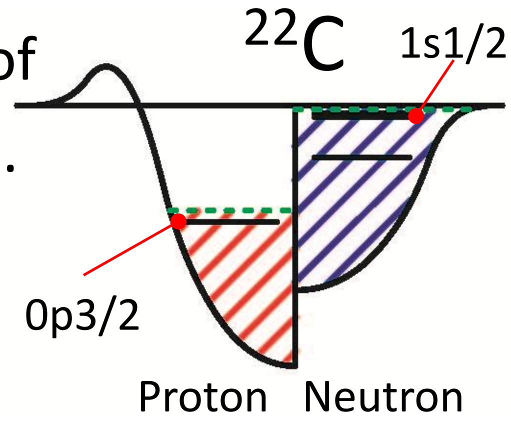
Y.Satou, Seoul National University

Contents

1. Introduction
2. (p,n) reaction in inverse kinematics as a probe of weak transition strengths
3. A proof-of-principle study
4. Three expansible directions
5. Summary

1. Introduction

- The **Gamow-Teller transition** represents one of the fundamental modes of nuclear excitations.



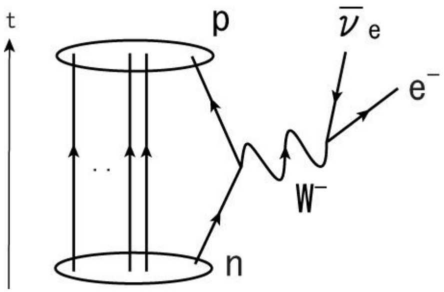
$$T_{fi} = \left\langle \Psi_f \left| \sum_k \boldsymbol{\sigma}_k \cdot \boldsymbol{\tau}_k \right| \Psi_i \right\rangle$$

- The properties are important not only for understanding **spin-isospin correlations** in nuclei, but also for their implications for a variety of **astrophysical phenomena** where weak processes play a key role, e.g., late stages of stellar evolution and neutrino nucleosynthesis.

K.Langanke, G.Martinez-Pinedo, Rev. Mod. Phys. 75 (2003) 819.

2. (p,n) reaction in inverse kinematics as a probe of weak transition strengths

β-decay



- β-decay rates and reduced transition probabilities B(F) and B(GT).

$$ft = 6147/\left[B(\mathrm{F}) + \left(\frac{g_A}{g_V}\right)^2 B(\mathrm{GT})\right]$$

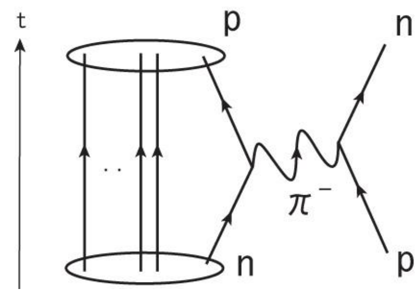
Fermi

$$B(\mathrm{F}) = \frac{1}{2I_i + 1}\left|\left\langle f \left\| \sum_k \tau^k \right\| i \right\rangle\right|^2$$

Gamow-Teller

$$B(\mathrm{GT}) = \frac{1}{2I_i + 1}\left|\left\langle f \left\| \sum_k \sigma^k \tau^k \right\| i \right\rangle\right|^2$$

(p,n) charge exchange (CE) reaction



- Proportionality relationship between (p,n) cross sections and B(F) and B(GT).

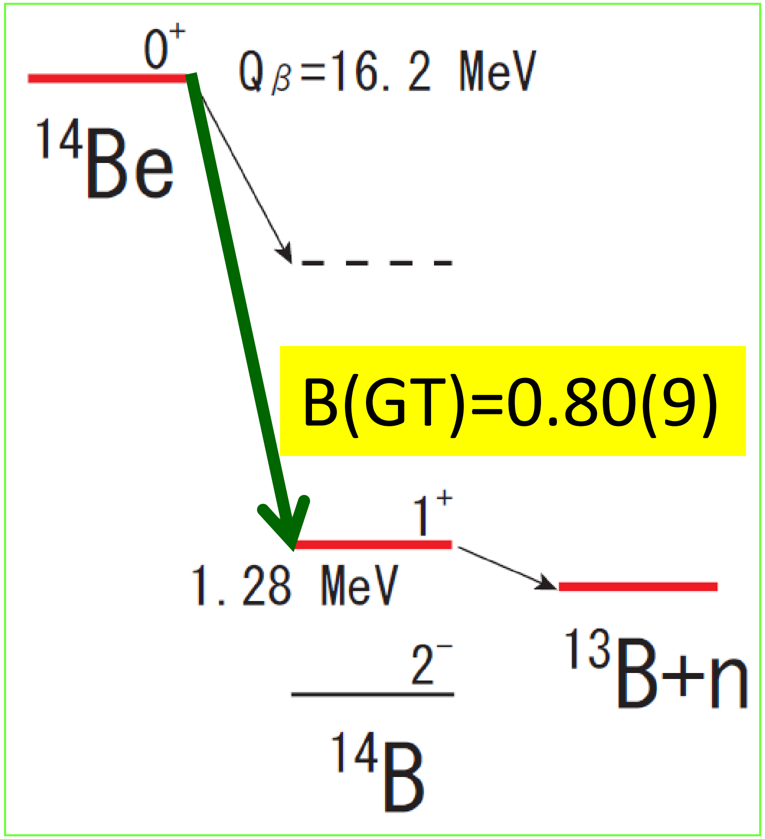
$$\left(\frac{d\sigma}{d\Omega}\right)_{\substack{L=0\\q=0}} = \left[\frac{E_i E_f}{(\hbar^2 c^2 \pi)^2}\right] N_D |J_{\sigma\tau}|^2 B(\mathrm{GT})$$

C.D.Goodman et al.,PRL44(1980)1755.
T.N.Taddeucci et al., NPA469(1987)125.

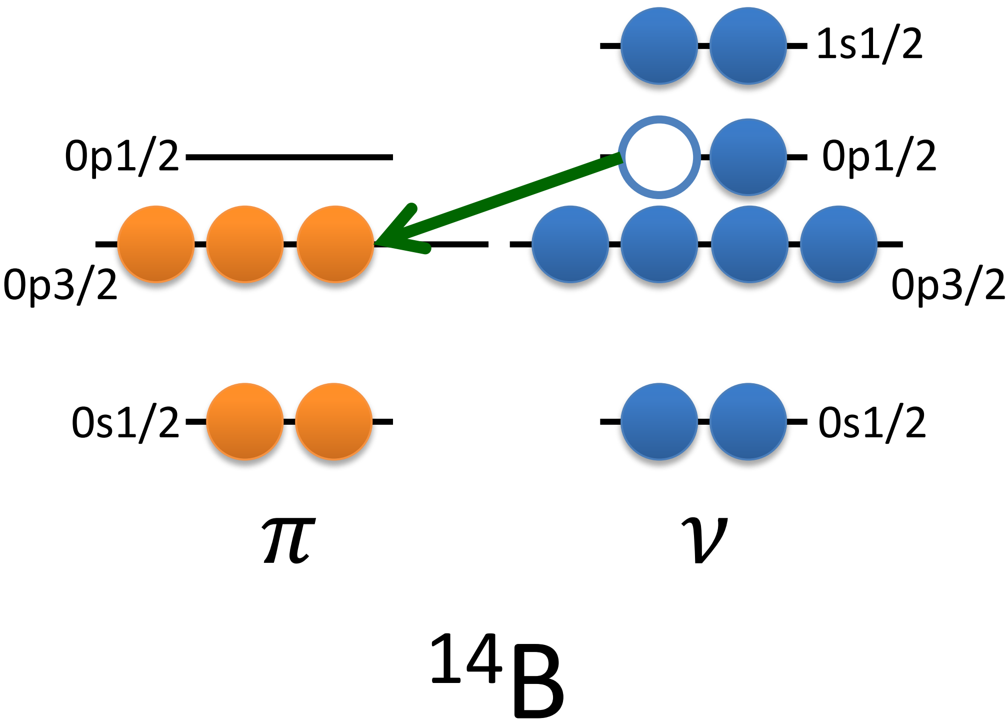
- **Unconstrained by any Q_β limitations**
- **Rarely been explored in inverse kinematics**

3. A proof-of-principle study

- ^{14}Be(p,n)^{14}B(1$^+$) @ 69 MeV
  - ✓ B(GT) known from β–delayed neutron spectroscopy
    N.Aoi, K.Yoneda et al., PRC66(2002)01430.

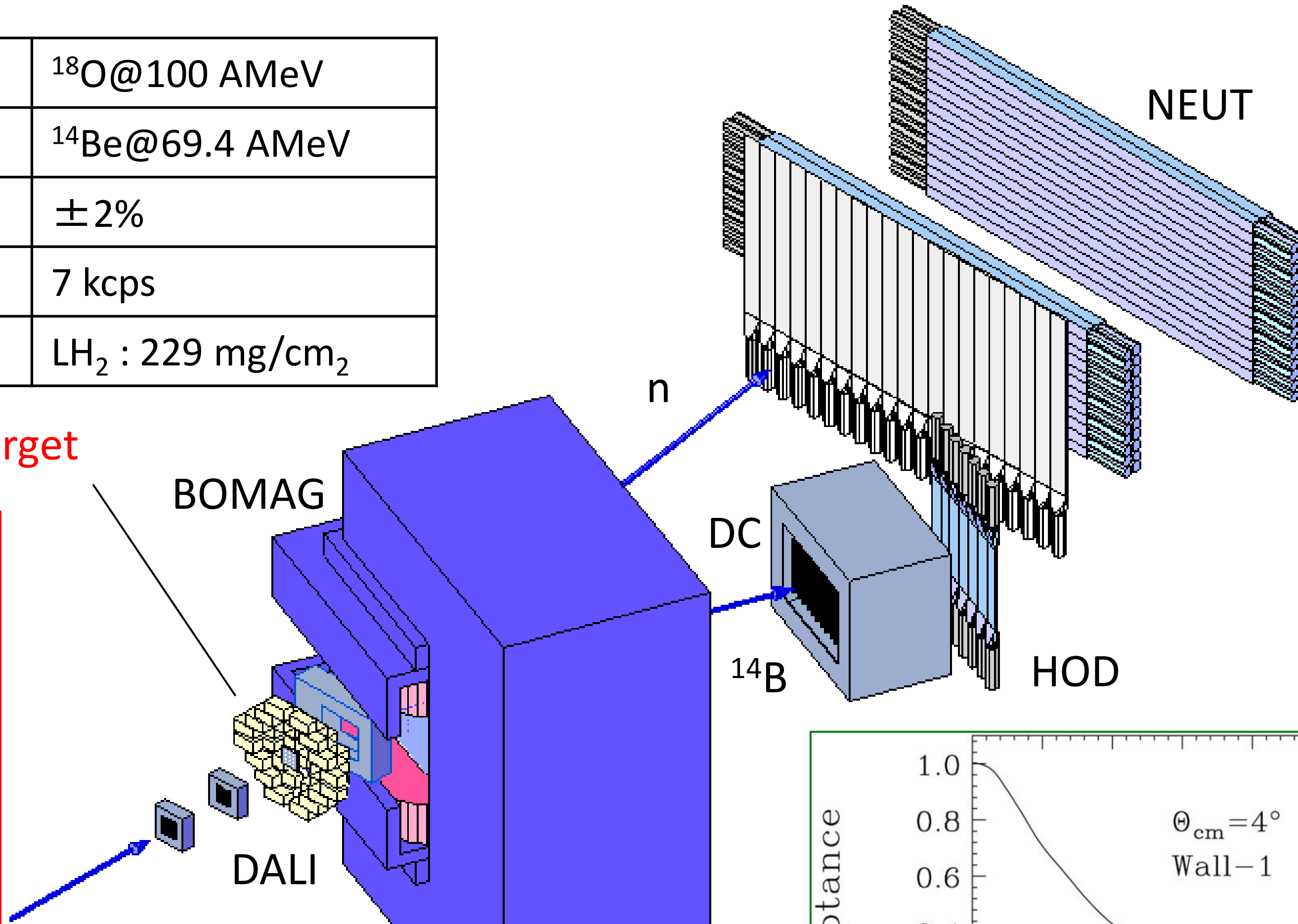


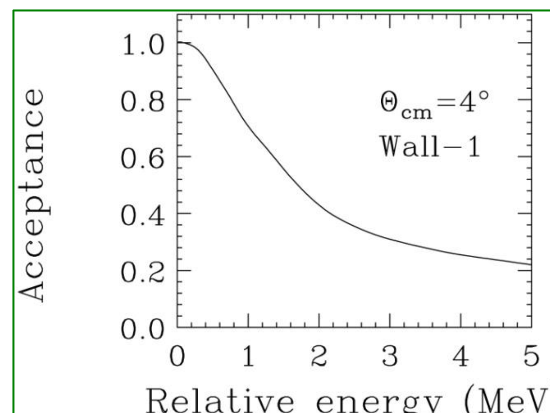
Intruder configuration of the first 1$^+$ state in ^{14}B



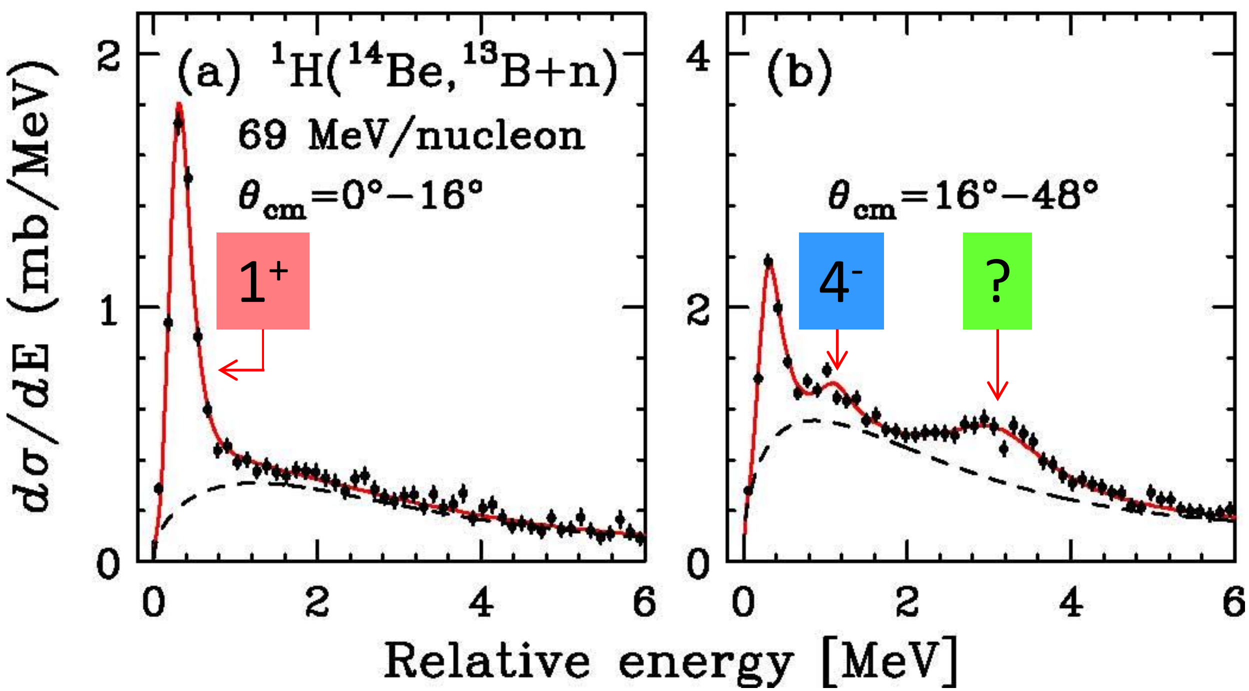
Experimental setup

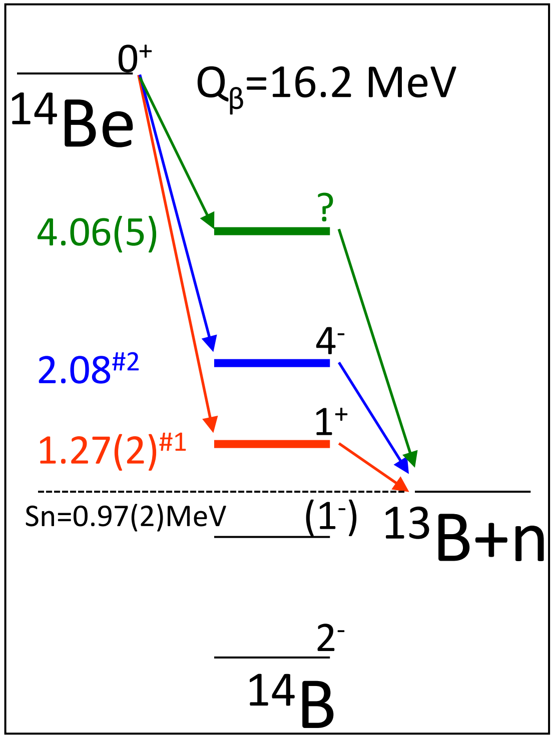
Primary beam	^{18}O@100 AMeV
Secondary beam	^{14}Be@69.4 AMeV
⊿P/P	±2%
Intensity	7 kcps
Secondary Target	LH_2 : 229 mg/cm$_2$





Invariant mass spectra



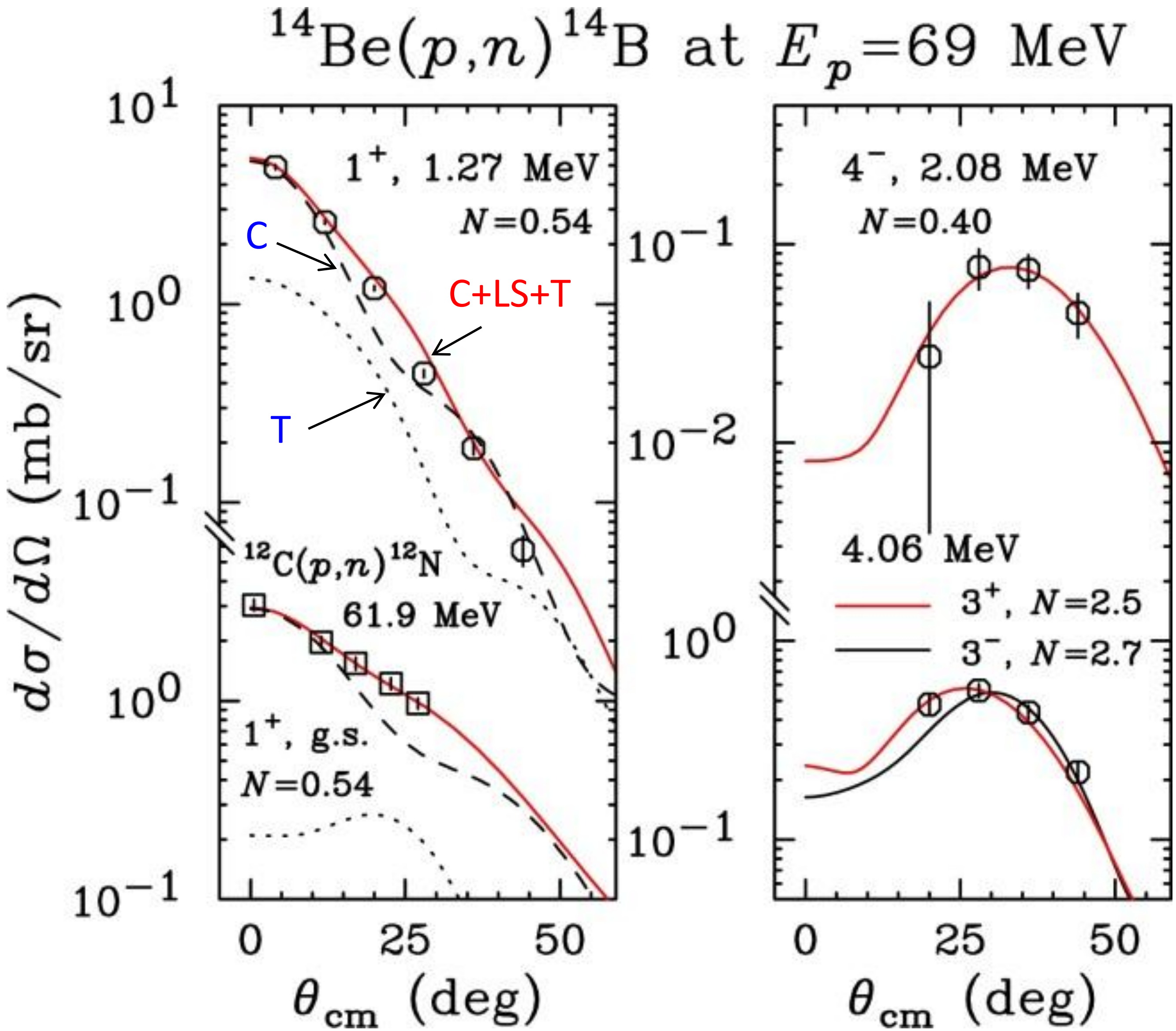


Er (MeV)	Ex (MeV)	Γr (MeV)	ℓ (ħ)	J^{π}
0.304(4)	1.27(2)	0.16(2)	1	1^{+}
1.11	2.08	---	2	4^{-}
3.09(5)	4.06(5)	[1.0(3),1.2(5)]	(1,2)	$(3^{+},3^{-})$

#1: Reported to be 1.28(2) MeV in Refs.
M.Belbot et al., PRC56(1997)3038.
Aoi et al., PRC66(2002)014301.

#2: Taken from Refs.
R.Kalpakchieva et al., EPJA7(2000)451.
G.C.Ball et al, PRL31(1973)395.

Differential cross sections

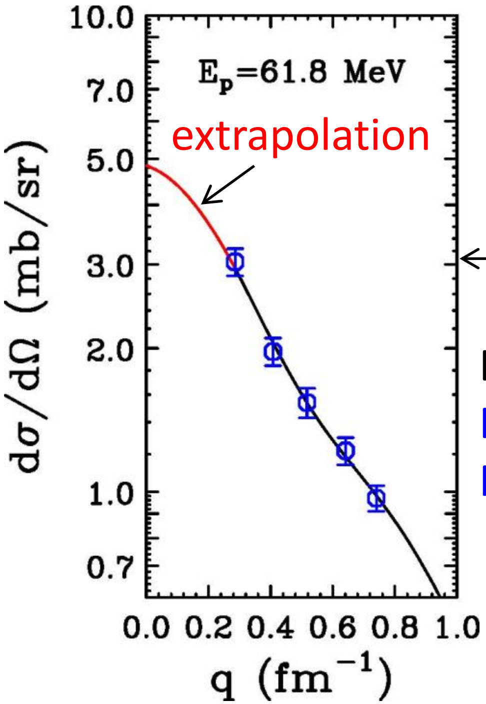


Momentum extrapolation and $B(GT)_{(p,n)}$

$$\left(\frac{d\sigma}{d\Omega}\right)_{\substack{L=0\\q=0}} = \left[\frac{E_i E_f}{(\hbar^2 c^2 \pi)^2}\right] N_D |J_{\sigma\tau}|^2 B(\mathrm{GT})$$

$^{12}\mathrm{C}(p,n)^{12}\mathrm{N}(1^+,\mathrm{gnd.})$

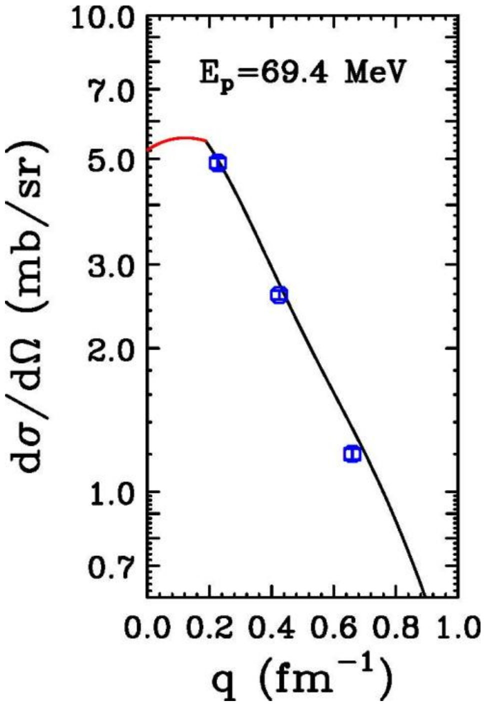
$|J_{\sigma\tau}| = 212.1 \pm 3.1(\mathrm{stat}) \pm 9.3(\mathrm{syst})$



Deta from B.D.Anderson et al., NIM169(1980)153.

$^{14}\mathrm{Be}(p,n)^{14}\mathrm{B}(1^+ 1.27\ \mathrm{MeV})$

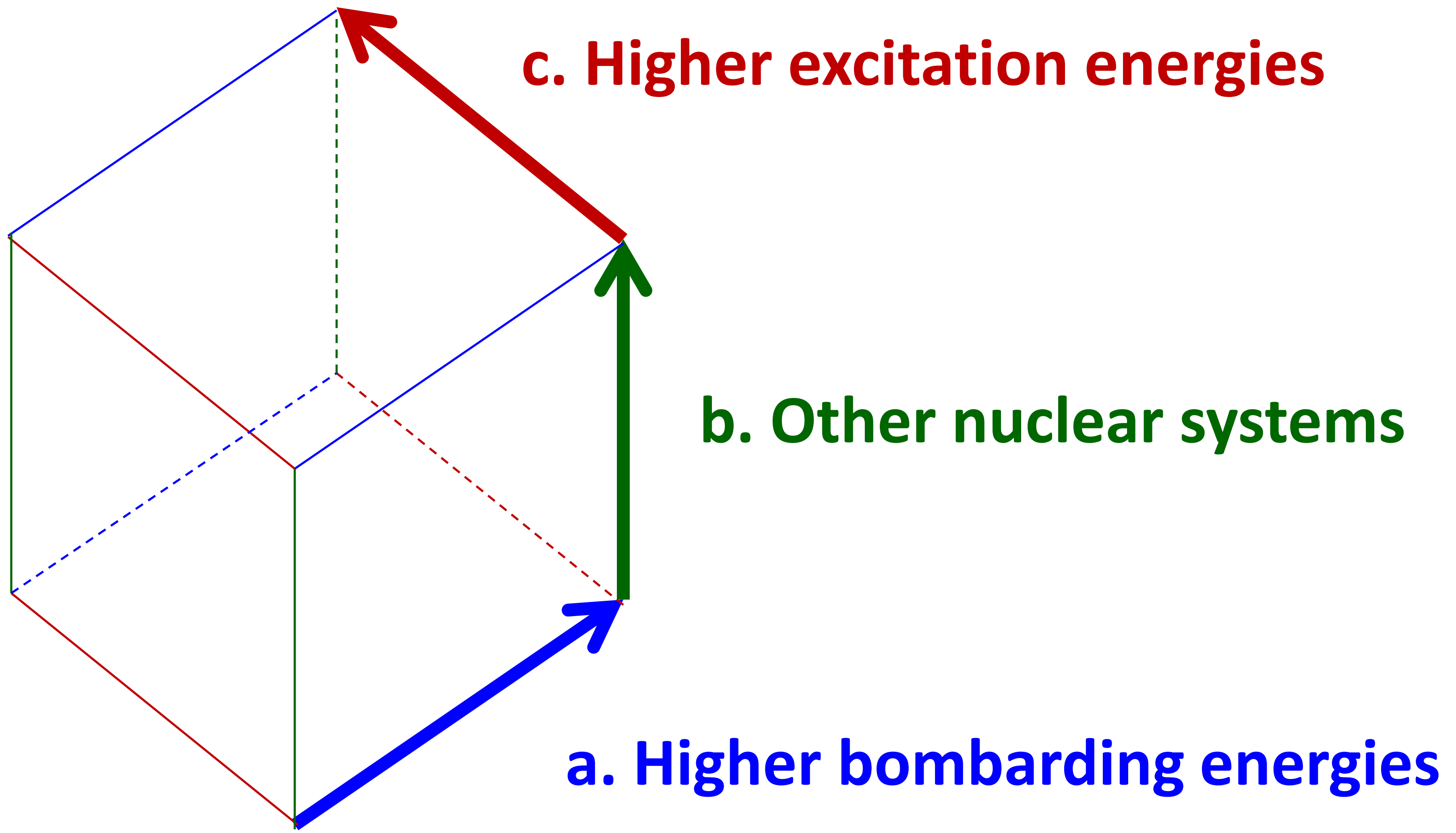
$B(GT)_{(p,n)} = 0.79 \pm 0.03(\mathrm{stat}) \pm 0.09(\mathrm{syst})$



$B(GT)_{\beta-\mathrm{decay}} = 0.80 \pm 0.09$

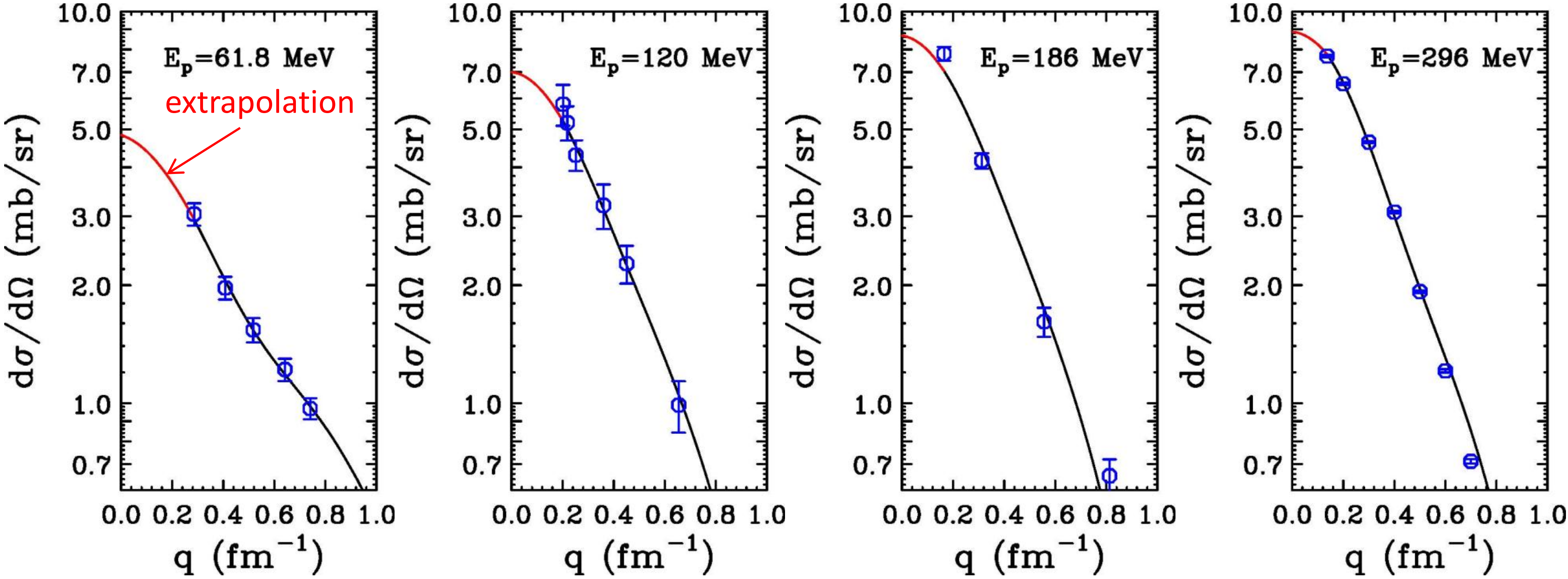
Consistent B(GT) values for (p,n) and β-decay studies

4. Three expansible directions



a. Higher bombarding energies

$^{12}\mathrm{C}(p,n)^{12}\mathrm{N}(1^+,\mathrm{gnd.})$

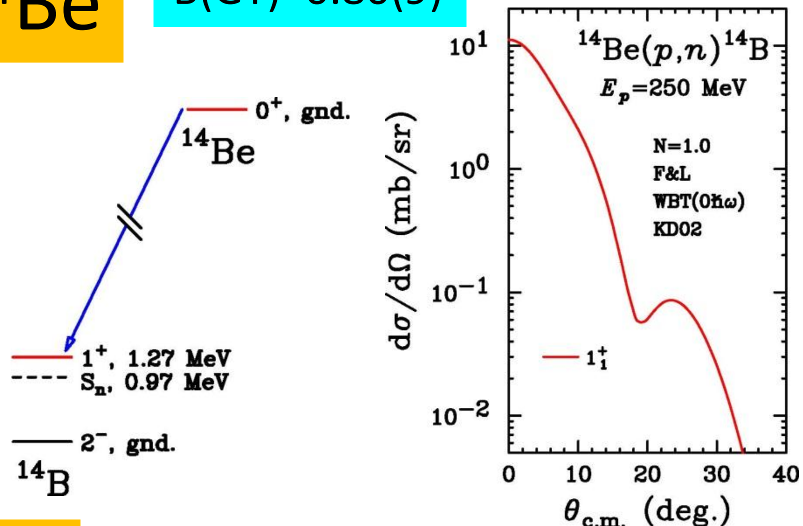


Higher the incident energy,
(1) smaller the distortion effects and
(2) the forward most point approaches nearer to q=0.

b. Other nuclear systems

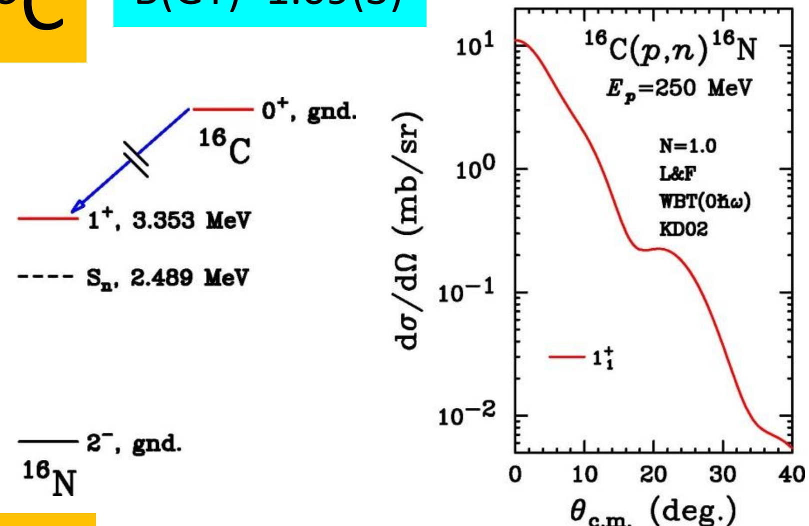
^{14}Be

B(GT)=0.80(9)



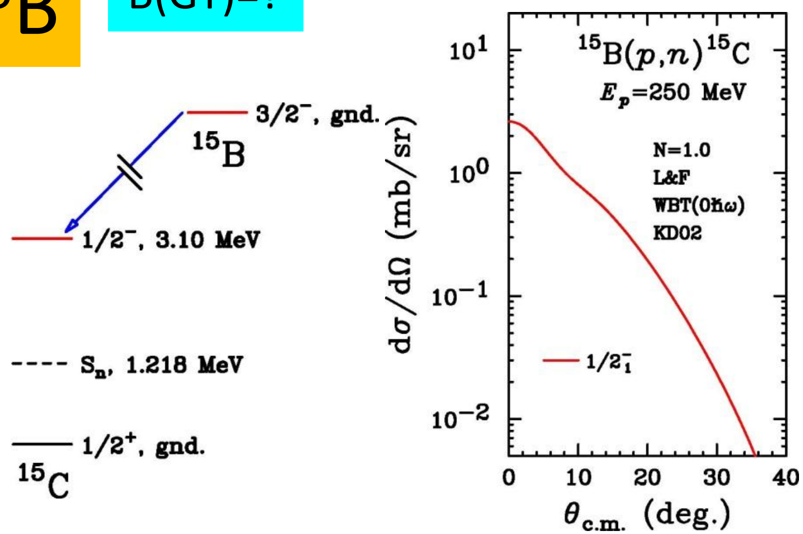
^{16}C

B(GT)=1.09(3)



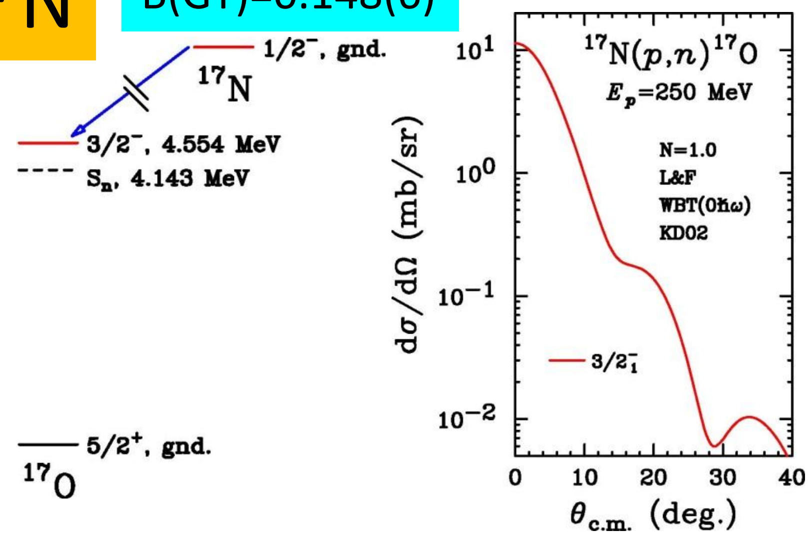
^{15}B

B(GT)=?



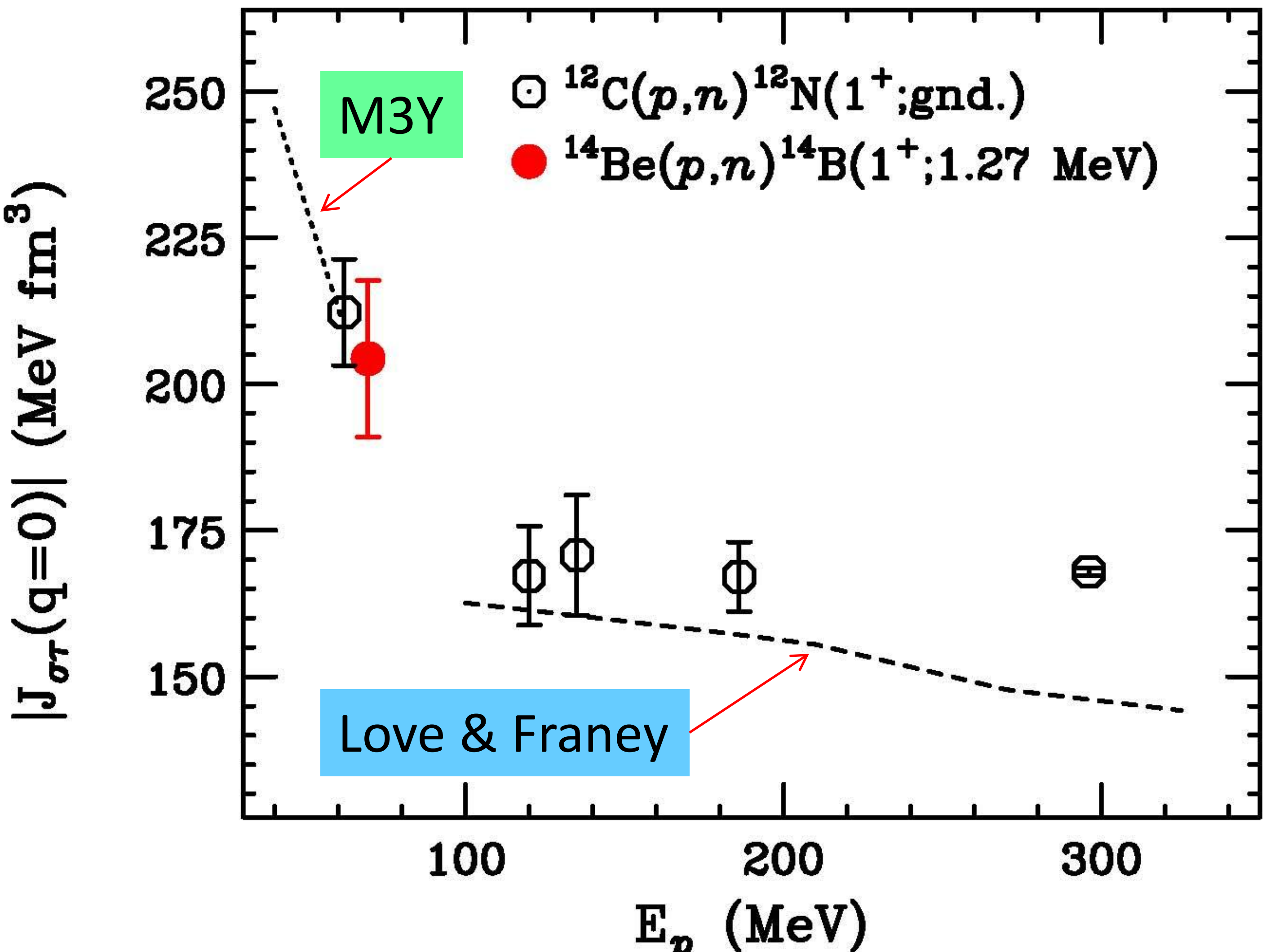
^{17}N

B(GT)=0.148(6)



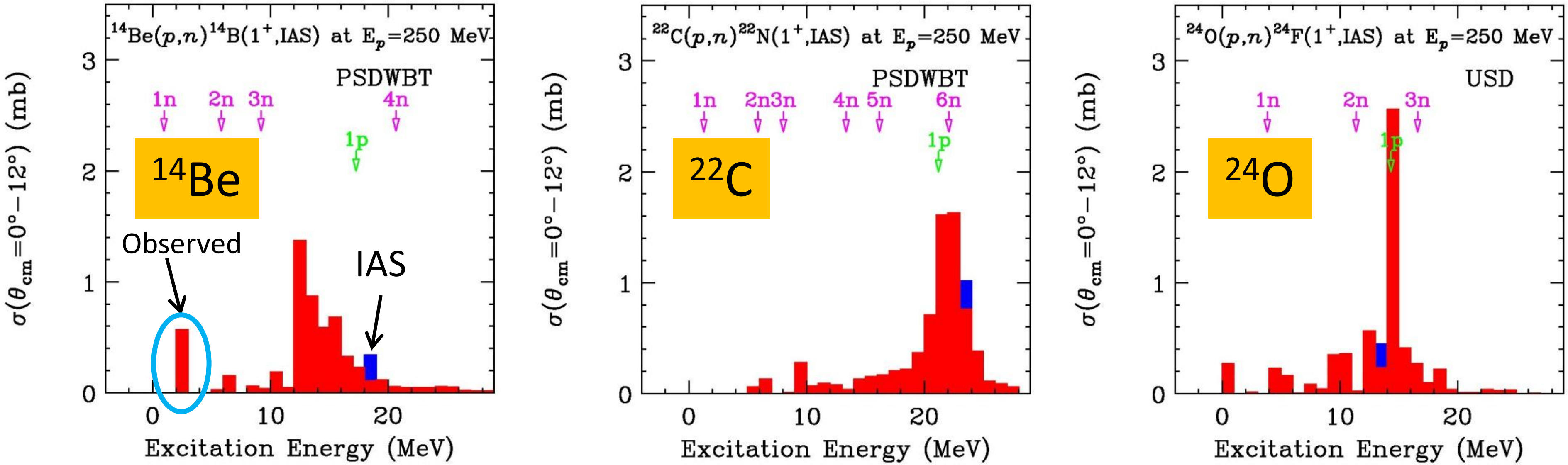
Energy dependence of $|J_{\sigma\tau}(q=0)|$

Could we have universal values for $|J_{\sigma\tau}(q=0)|$?



c. Higher excitation energies

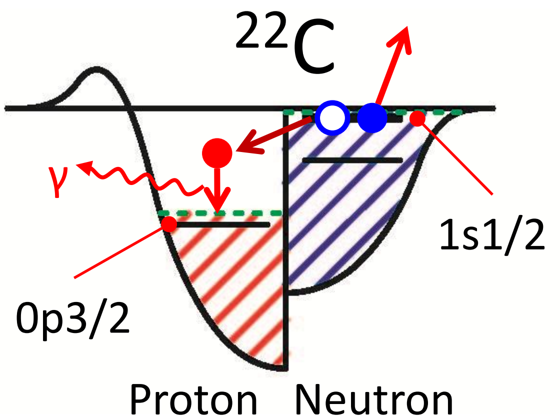
(p,n) Gamow-Teller responses calculated by shell-model



Giant resonance-like structures are predicted to exist.

1. Do they really exist ?
2. What properties they have ?

Location, strength, width



Summary

- The (p,n) reaction on ^{14}Be was measured at 69 MeV/nucleon in inverse kinematics.
- By extrapolating the cross section to q=0, the B(GT) leading to the 1^+ state was deduced, which compared well with the β-decay value.
- Future possible extensions of the (p,n) reaction study in three directions are mentioned.

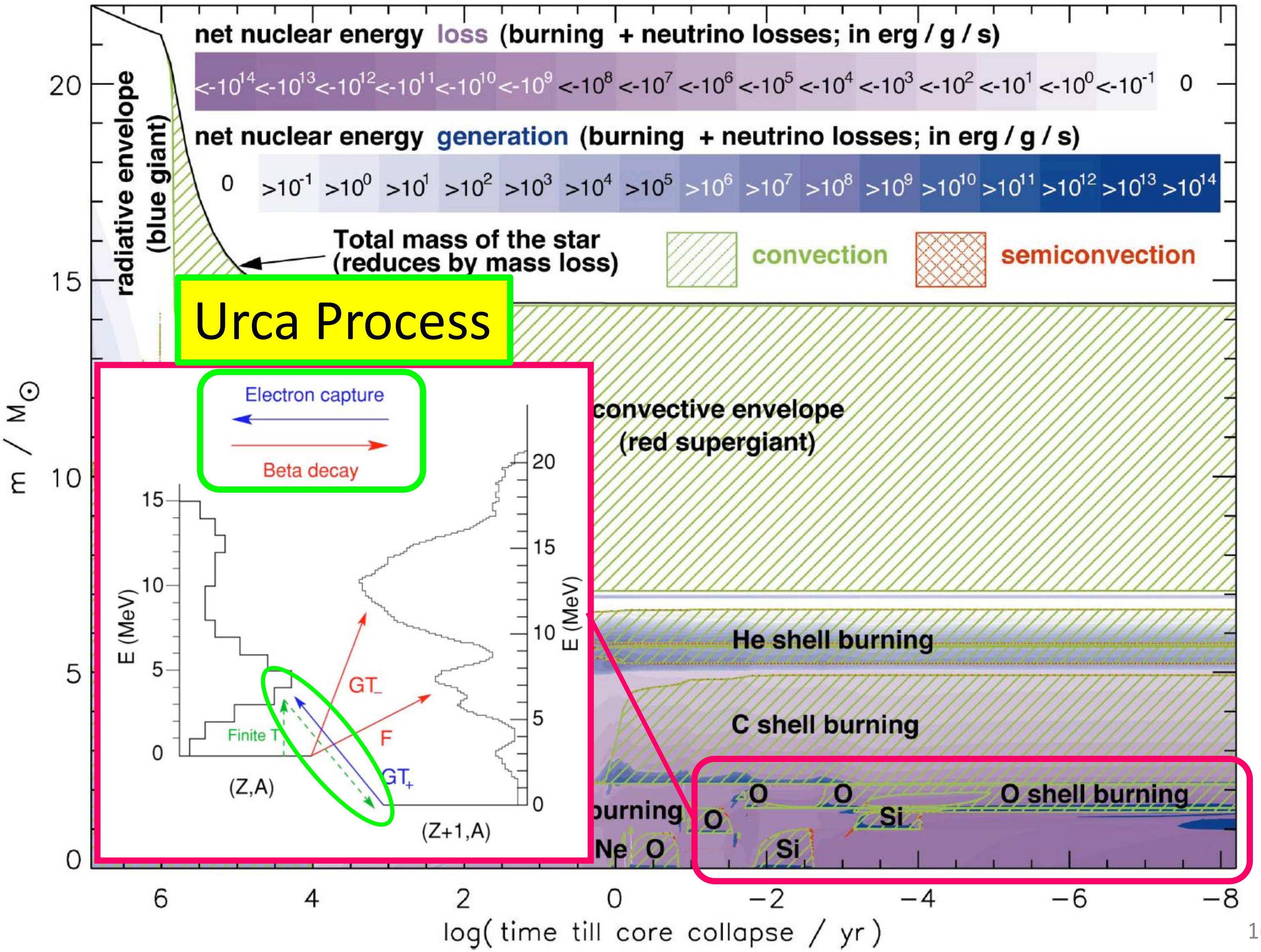
Collaboration: — RIKEN, R364n —

Physics Letters B 697 (2011) 459.

- Seoul National University
  - Y.Satou
- Tokyo Institute of Technology
  - T.Nakamura, T.Sugimoto, Y.Kondo, N.Matsui, Y.Hashimoto, T.Nakabayashi, T.Okumura, M.Shinohara
- RIKEN
  - N.Fukuda, T.Motobayashi, Y.Yanagisawa, N.Aoi, S.Takeuchi, T.Gomi, H.Sakurai, H.Otsu, M.Ishihara
- Rikkyo University
  - Y.Togano, S.Kawai
- Tokyo University
  - H.J.Ong, T.K.Onishi
- Center of Study (CNS) Tokyo University
  - S.Shimoura, M.Tamaki
- Tohoku University
  - T.Kobayashi, Y.Matsuda, N.Endo, M.Kitayama

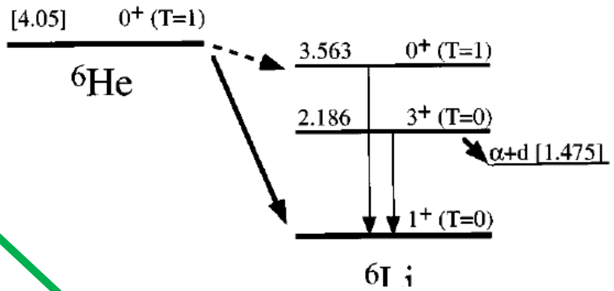
Energy history of a 22M⊙ star as a function of time until core collapse

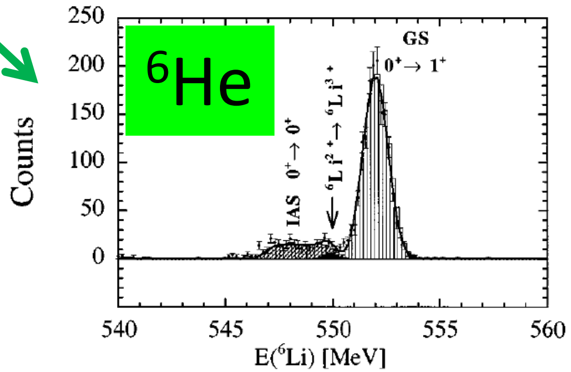
K.Langanke and G. Martines-Pinedo, RMP 75 (2003) 819.



Existing CE studies in inverse kinematics

1. Missing mass method
   - ^{6}He(p,n)^{6}Li(IAS & 1$^+$)
     J.A.Brown et al., PRC54(1996)2105. @93 AMeV
     M.D.Cortina-Gil et al., PLB371(1996)14. @41.6 AMeV
     Zhihong Li et al., PLB527(2002)50. @4.17 AMeV
   - ^{34}P(^{7}Li,^{7}Be+γ)^{34}Si
     R.G.T.Zegers et al., PRL104(2010)212504. @100 AMeV





2. Invariant mass method
   - ^{11}Li(p,n)^{11}Be(IAS)
     T.Teranishi et al., PLB407(1997)110. @64 AMeV
   - ^{14}Be(p,n)^{14}B(IAS)
     S.Takeuchi et al., PLB515(2001)255. @74 AMeV

➢ ^{14}Be(p,n)^{14}B*(1$^+$,1.27 MeV)
Present study @ 69 AMeV