Gamow-Teller strengths in p-, sd- and pf-shell nuclei as a test case of shell-model calculations

-Comparison of B(GT): Exp. & SM-

Y. Fujita, Osaka Univ.
at SM workshop, Tokyo, 2006. Jan.26-28

Vibration Modes in Nuclei (Operators)

Microscopic classification of giant resonances

	$\Delta S = 0$, $\Delta T = 0$	$\Delta S = 0$, $\Delta T = 1$	$\Delta S = 1$, $\Delta T = 0$	$\Delta S = 1$, $\Delta T = 1$
$L = 0$		$\sum \tau_i$ IAS		$\sum \vec{\sigma}_i \tau_i$ GTR
2^{nd} order	$\sum r_i^2$ ISGMR	$\sum r_i^2 \tau_i$ IVGMR	$\sum r_i^2 \vec{\sigma}_i$ ISSMR	$\sum r_i^2 \vec{\sigma}_i \tau_i$ IVSMR
$L = 1$		$\sum r_i Y_m^1 \tau_i$ IVGDR	$\sum r_i Y_m^1 \vec{\sigma}_i$ ISSDR	$\sum r_i Y_m^1 \vec{\sigma}_i \tau_i$ IVSDR
2^{nd} order	$\sum r_i^3 Y_m^1$ ISGDR			
$L = 2$	$\sum r_i^2 Y_m^2$ ISGQR	$\sum r_i^2 Y_m^2 \tau_i$ IVGQR	$\sum r_i^2 Y_m^2 \vec{\sigma}_i$ ISSQR	$\sum r_i^2 Y_m^2 \vec{\sigma}_i \tau_i$ IVSQR
$L = 3$	$\sum r_i^3 Y_m^3$ ISGOR	$\sum r_i^3 Y_m^3 \tau_i$ IVGOR	$\sum r_i^3 Y_m^3 \vec{\sigma}_i$ ISSOR	$\sum r_i^3 Y_m^3 \vec{\sigma}_i \tau_i$ IVSOR

B(GT) derivation

★β decay :fundamental, but E_x range :limited "Q-window limitation"

★(*p*, *n*) reaction at intermediate energies (E = 100-500 MeV)

"proportionality" : B(GT) and σ(0°)

$$\sigma(0^\circ) = K N_{\sigma\tau} \, | J_{\sigma\tau}(0^\circ) |^2 \, B(\mathrm{GT})$$

⇒Breakthrough against "Q-window limitation"

but resolution : rather poor (ΔE = 200-400 keV)

★(^{3}He, *t*) reaction at intermediate energies (E = 130-150 MeV/u)

"high resolution" (ΔE < 50 keV)

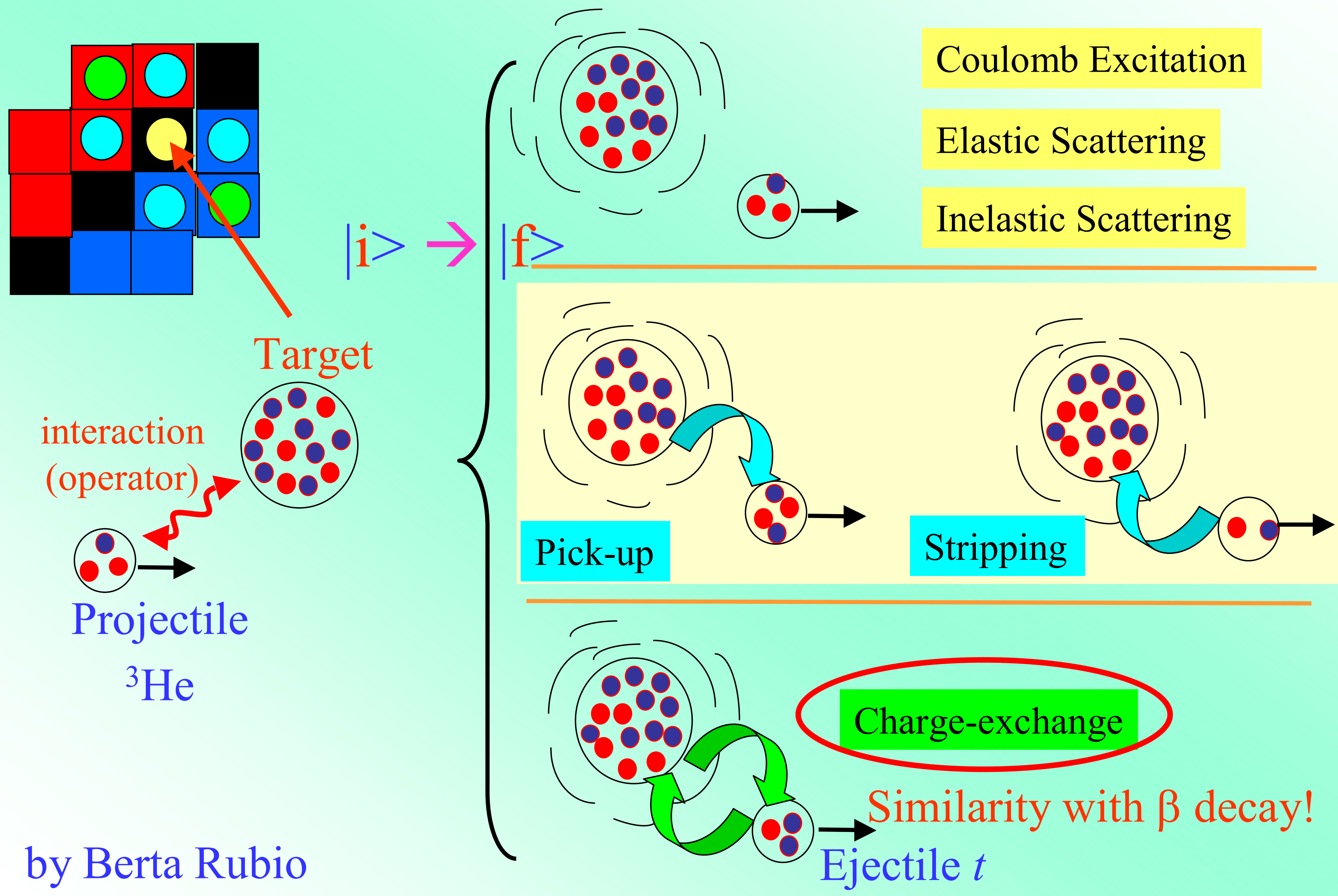
☆magnetic spectromerter, matching techniques

"proportionality" : good (B(GT) > 0.03)

⇒Breakthrough against "Energy resolution limitation"

⇒Reliable B(GT) values for individual transitions

Direct Reactions with Light Projectiles



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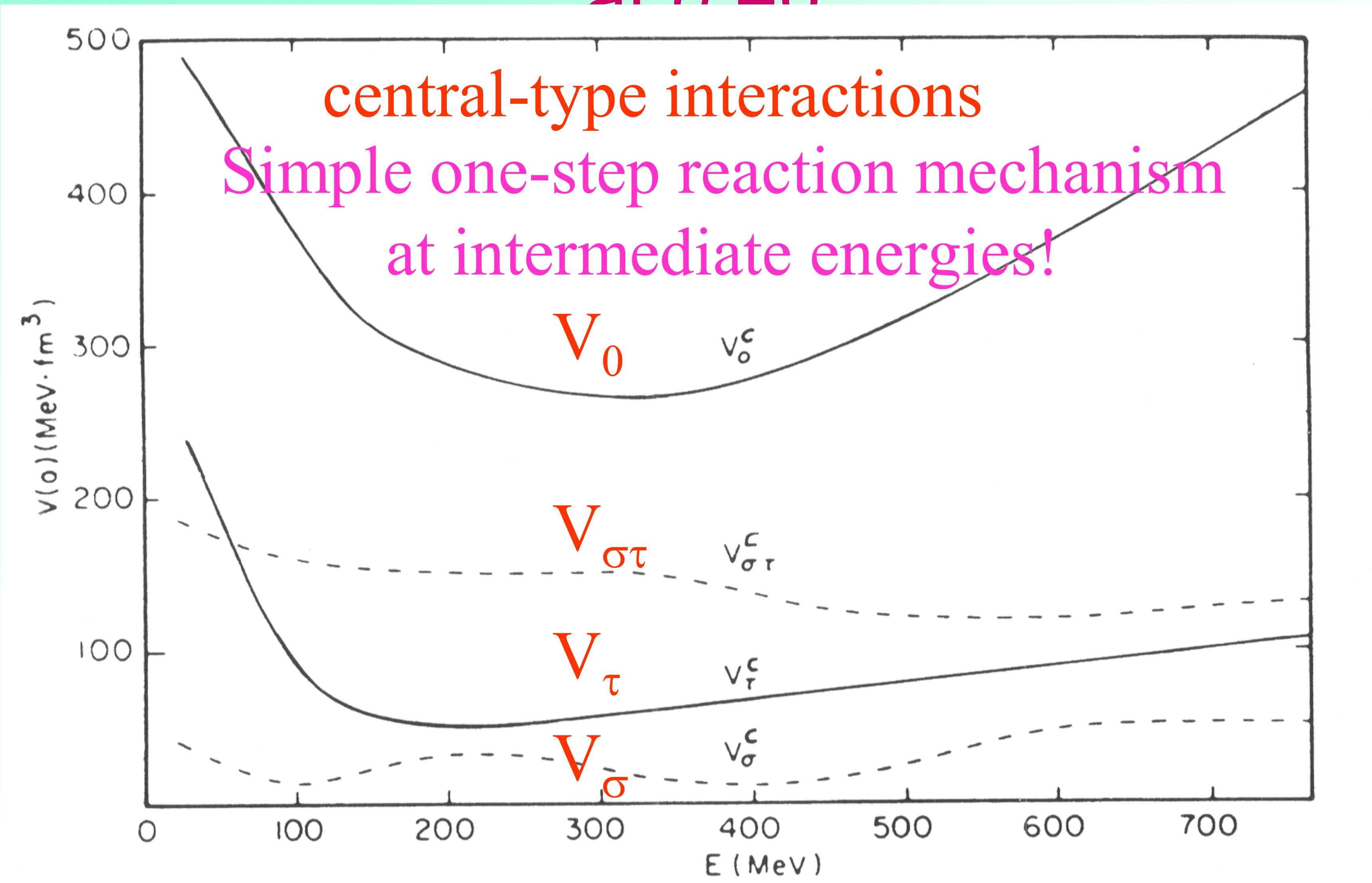
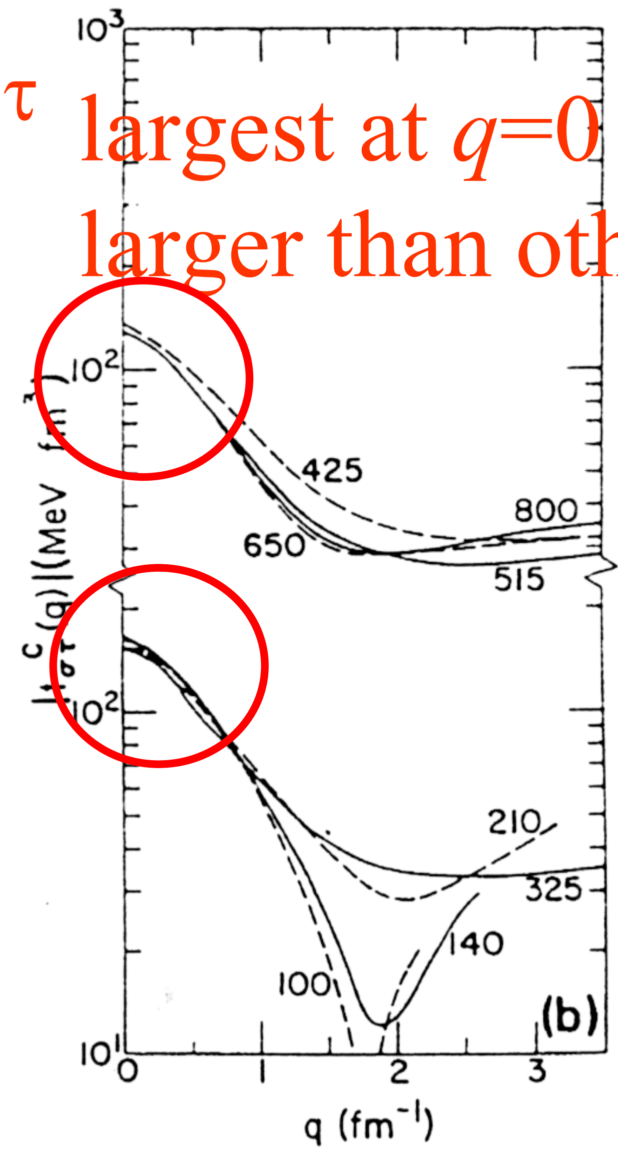
Nucleon-Nucleon Int. : E_{in} dependence at q =0



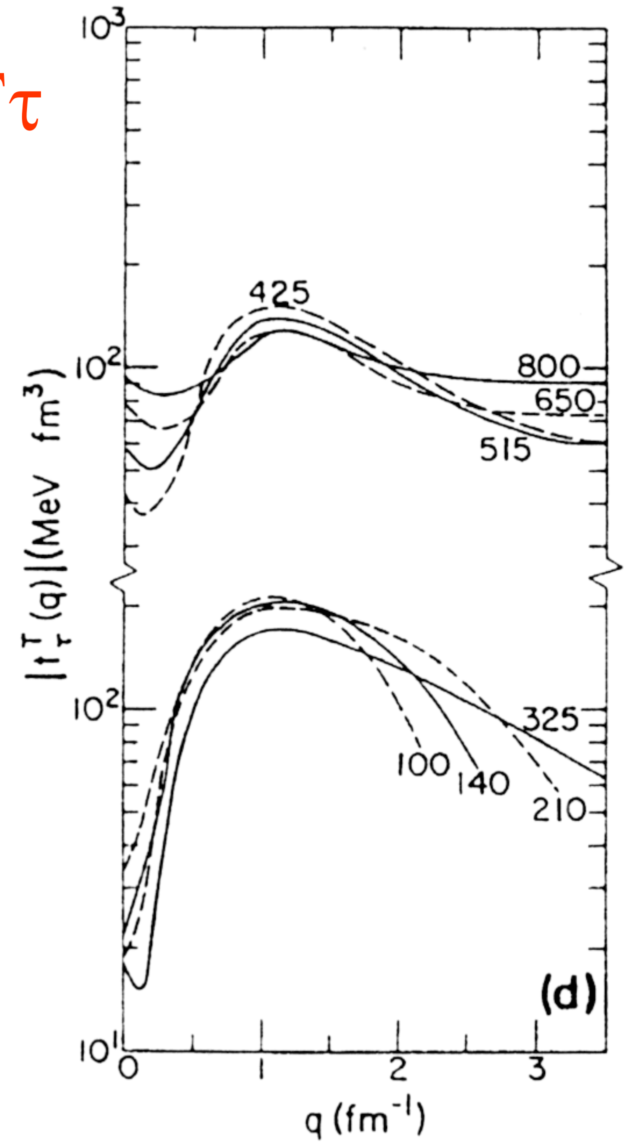
N.-N. Int. : στ & Tensor-τ *q*-dependence

στ largest at *q*=0 !

larger than others !

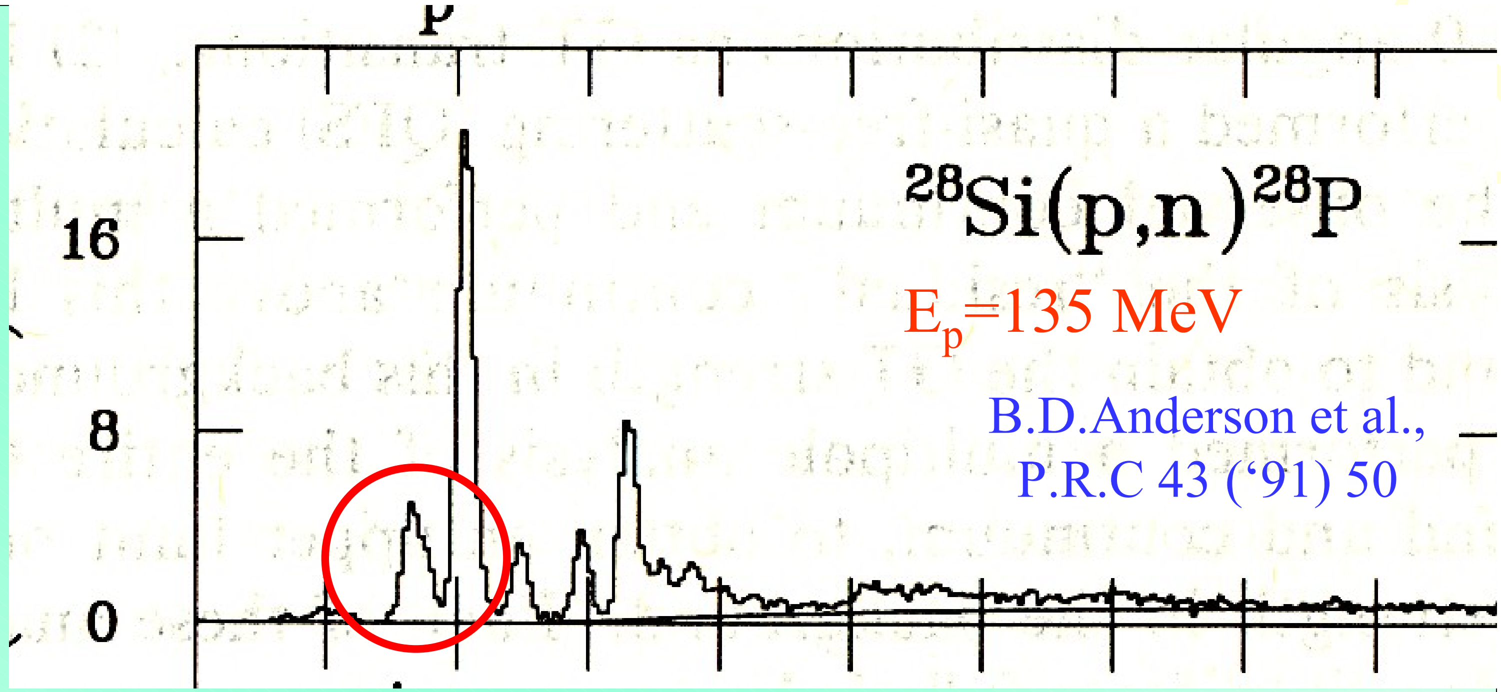


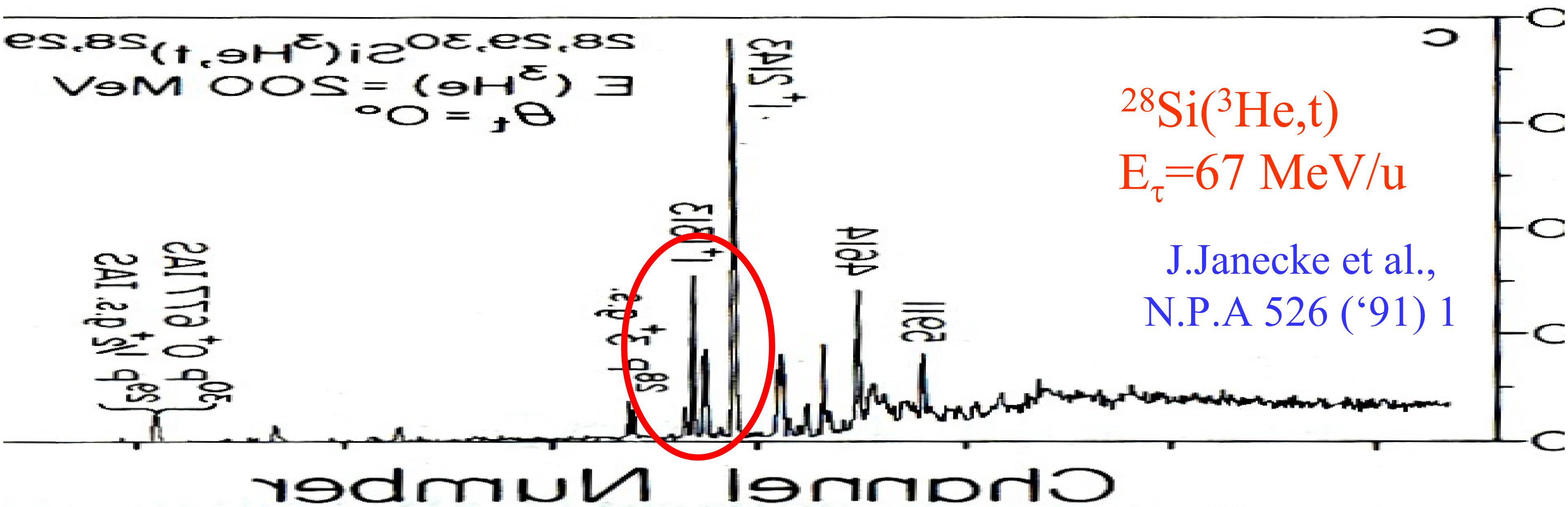
Tτ



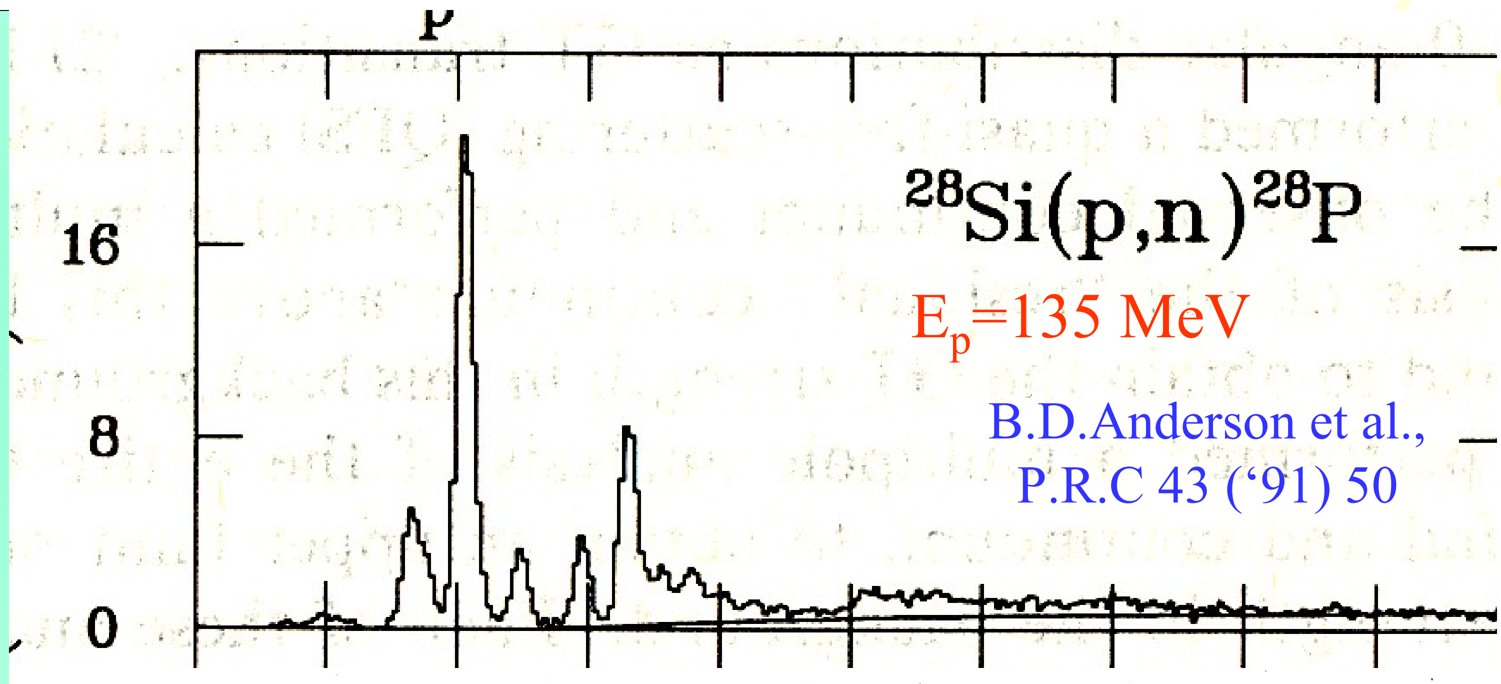
Love & Franey PRC 24 ('81) 1073

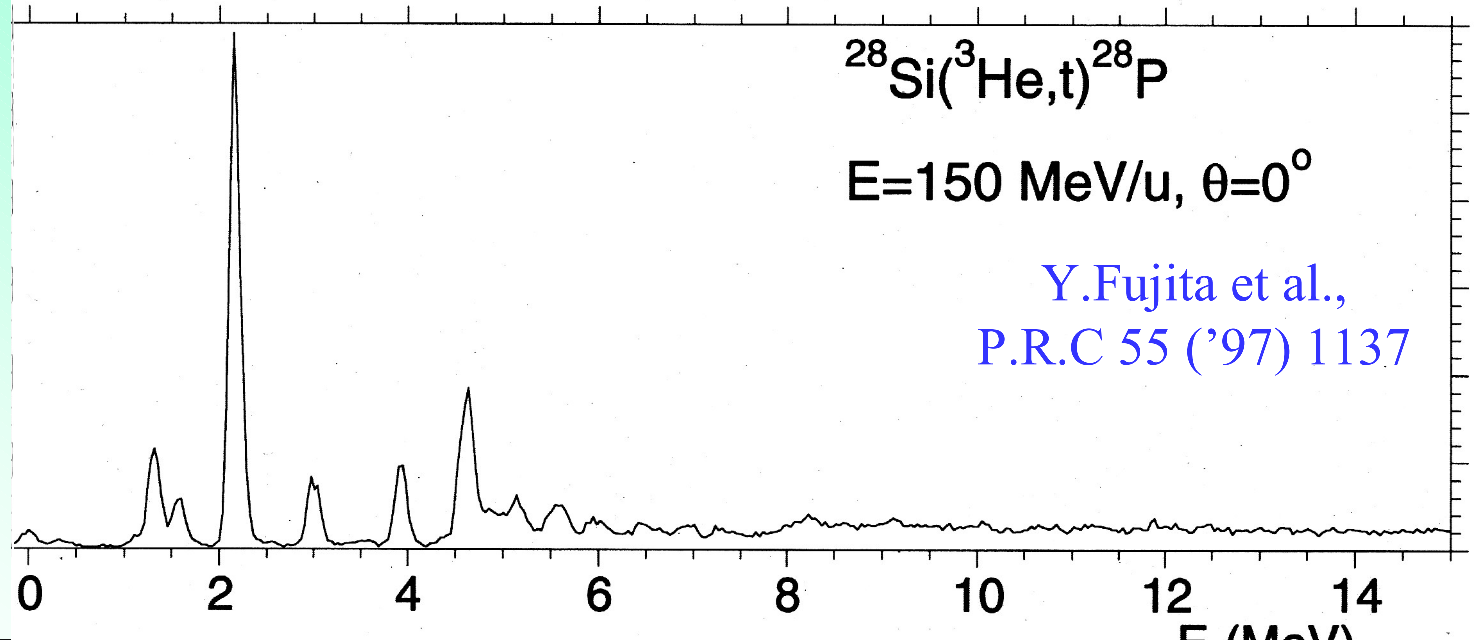
^{28}Si: CE Reactions (I)



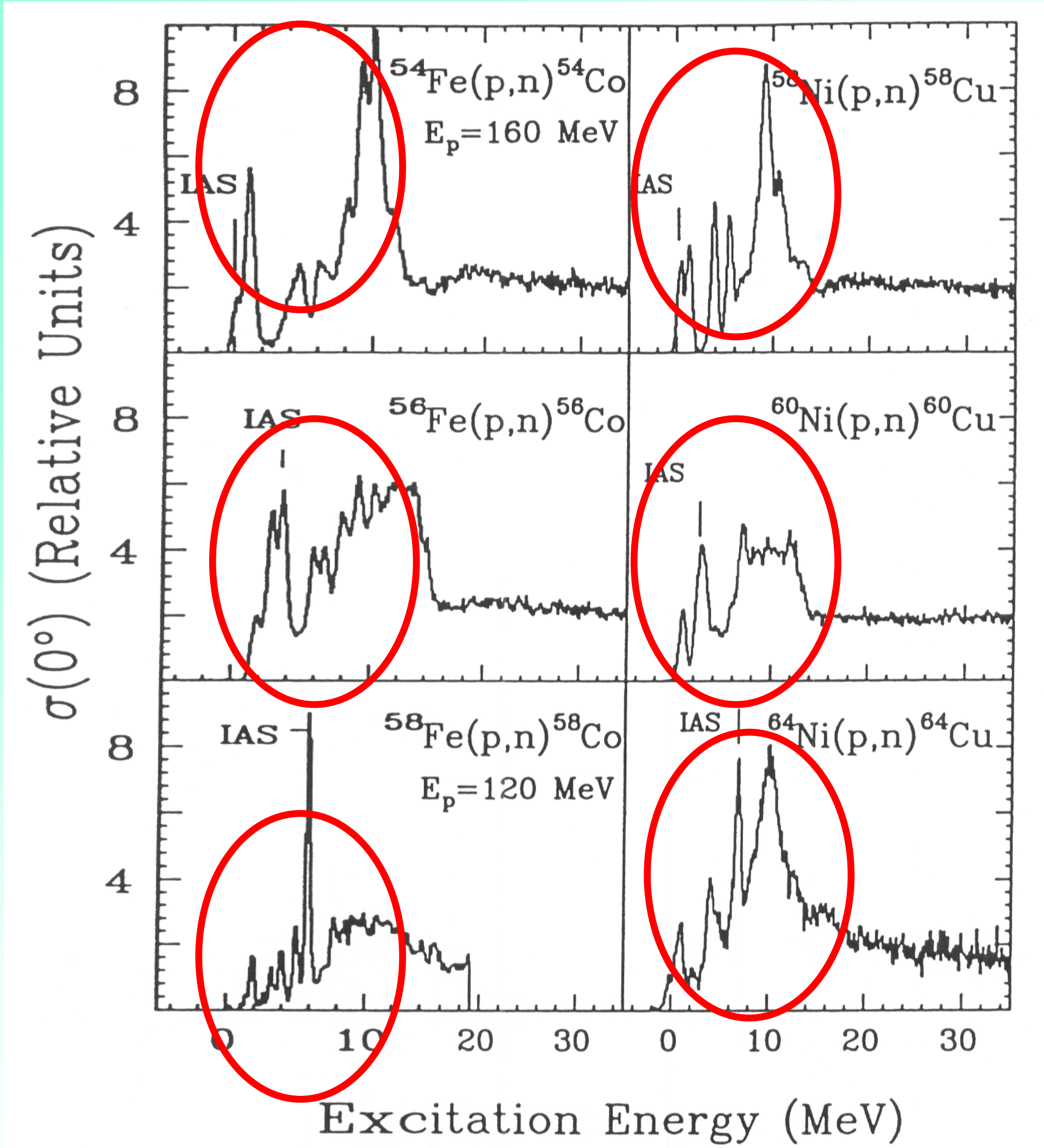


^{28}Si: CE Reactions (II)





(*p*, *n*) spectra for Fe and Ni Isotopes



(*p*, *n*) spectra for A>90 Nuclei

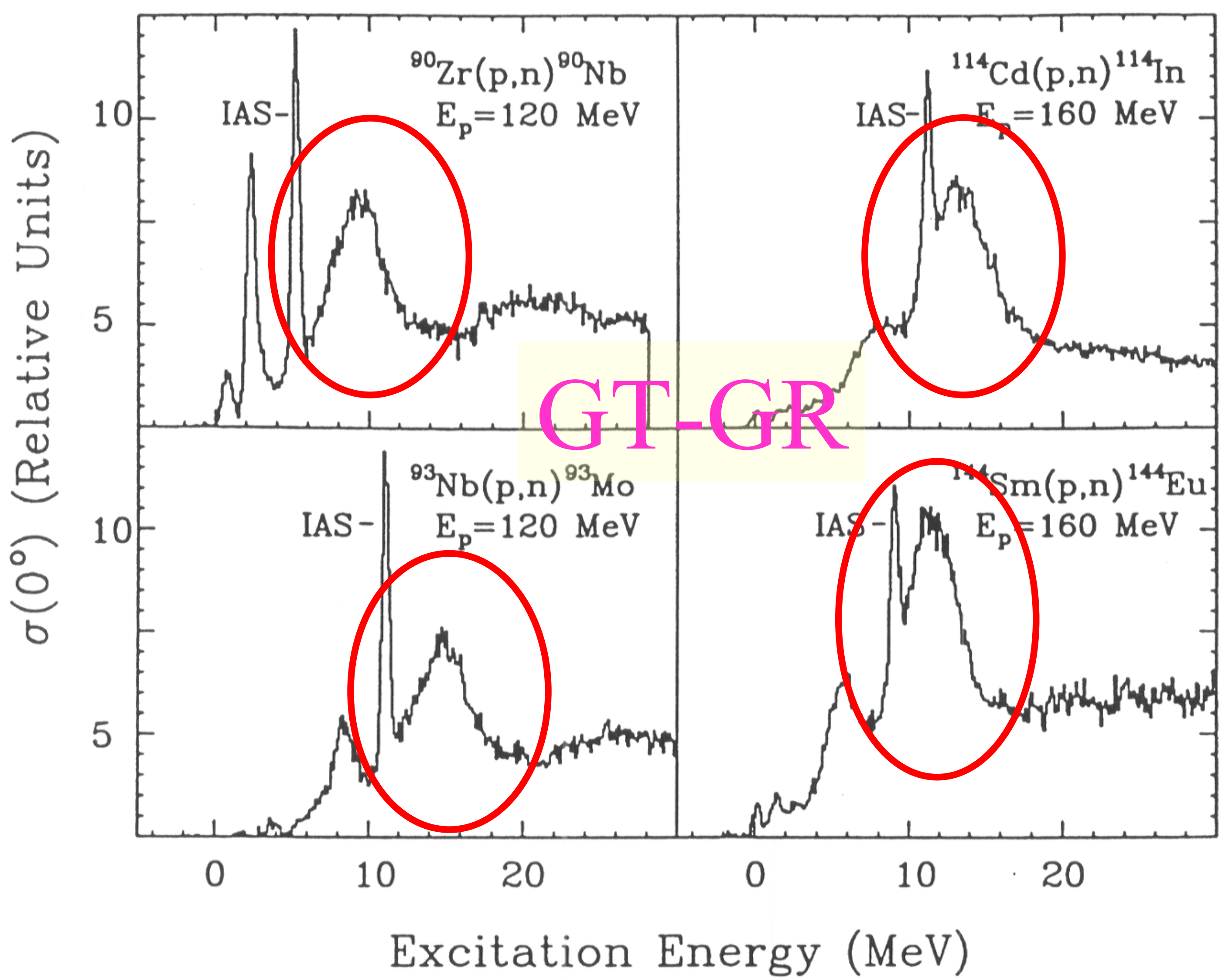


Figure 10 Zero-degree (p,n) spectra for medium A-mass nuclei at the indicated incident energies.

B(GT) derivation

★β decay :fundamental, but E_X range :limited "Q-window limitation"

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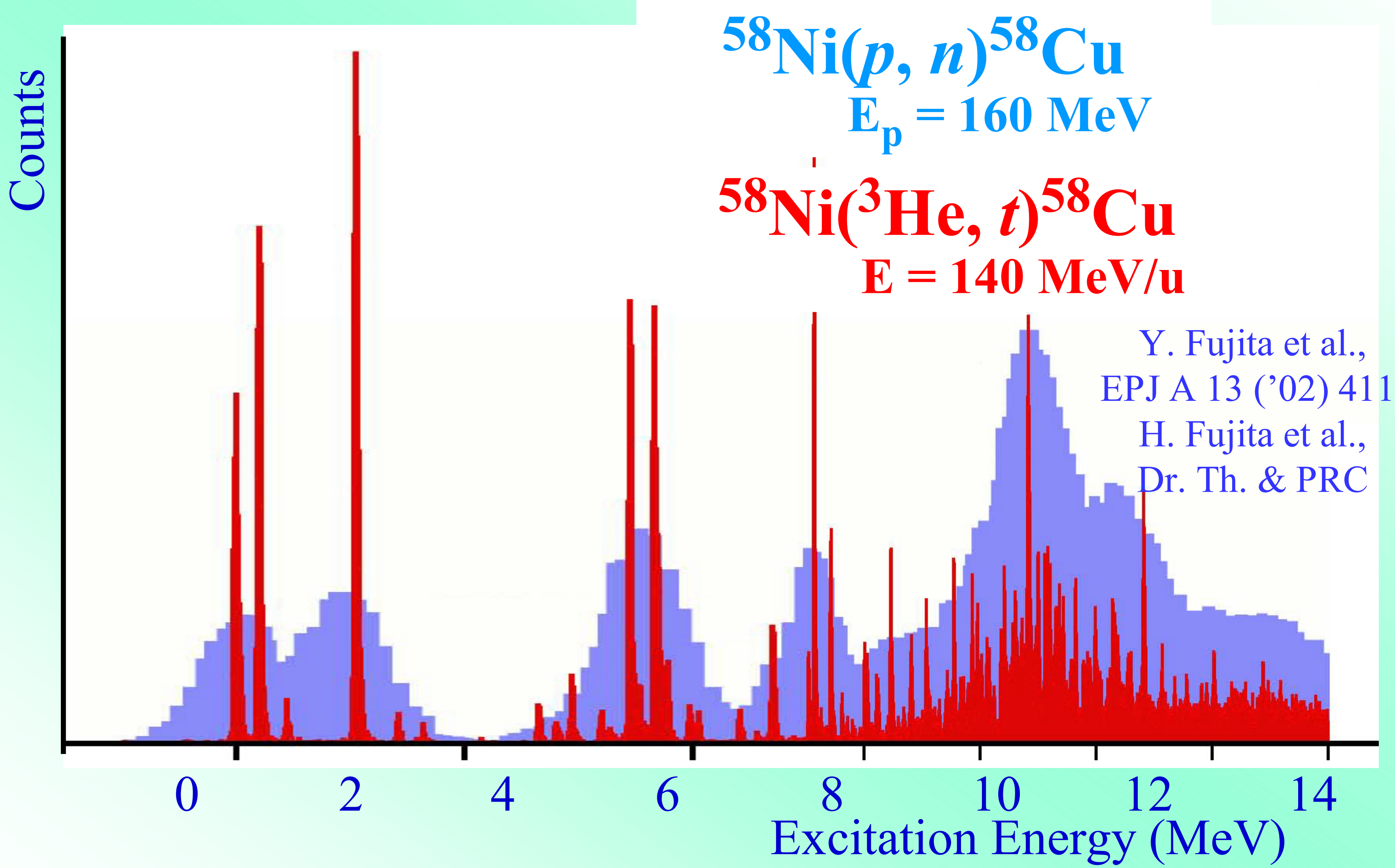
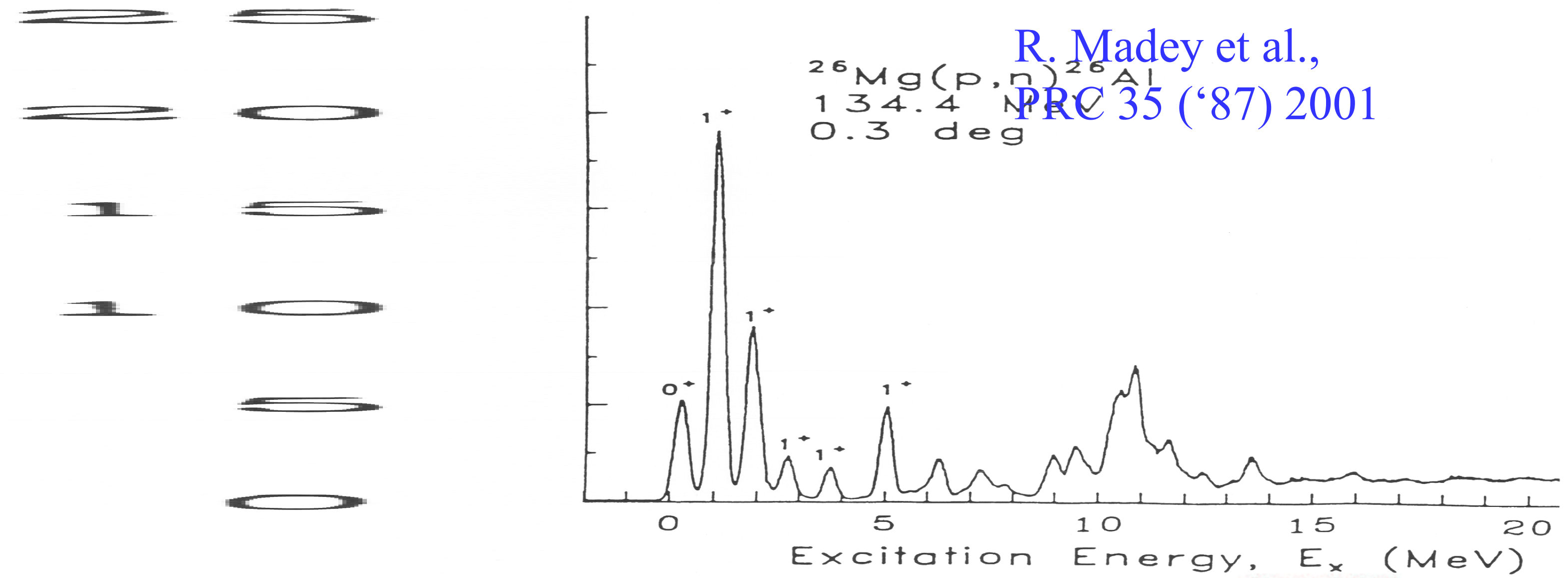
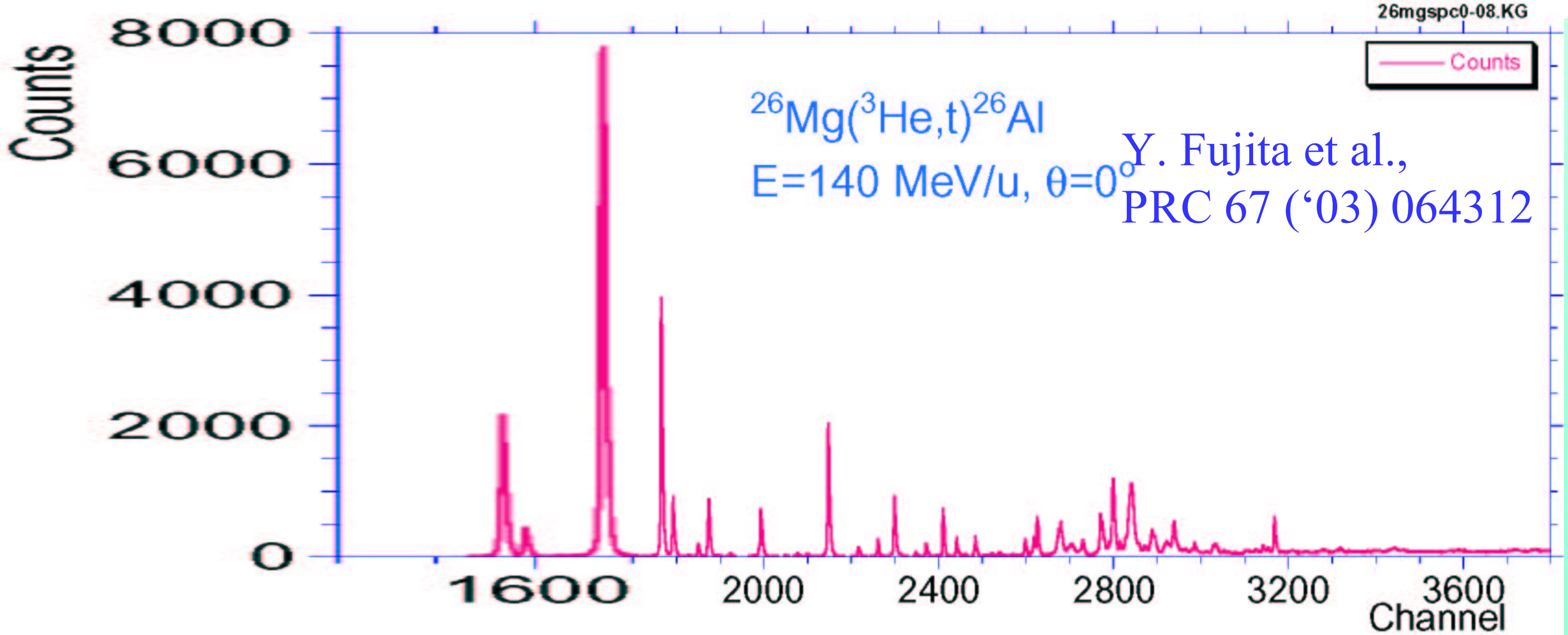
Comparison of (p, n) and (^{3}He,t) spectra



$^{26}Mg(p,n)^{26}Al$ & $^{26}Mg(^3He,t)^{26}Al$ spectra



R. Madey et al.,
PRC 35 ('87) 2001

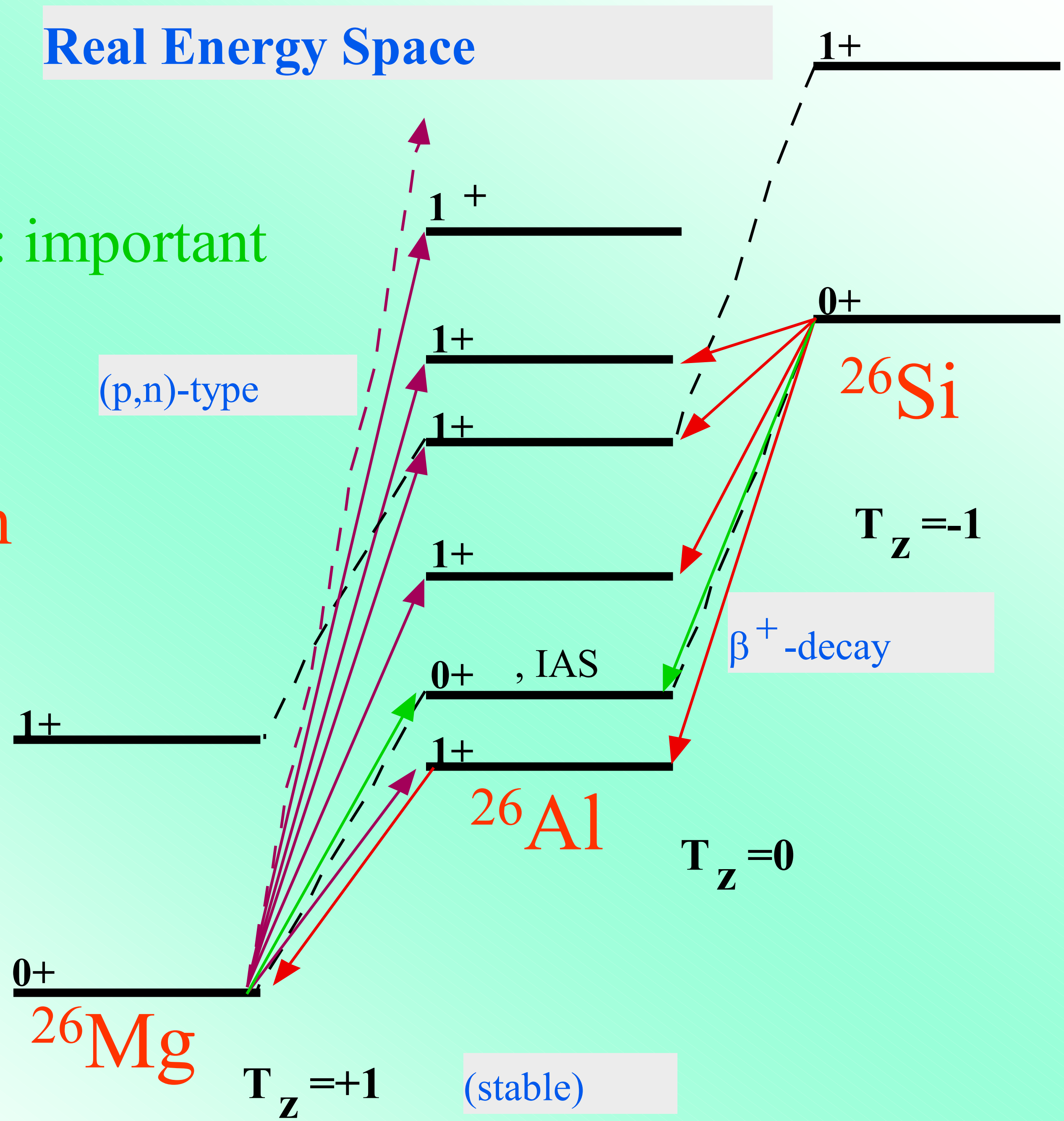


Y. Fujita et al.,
PRC 67 ('03) 064312

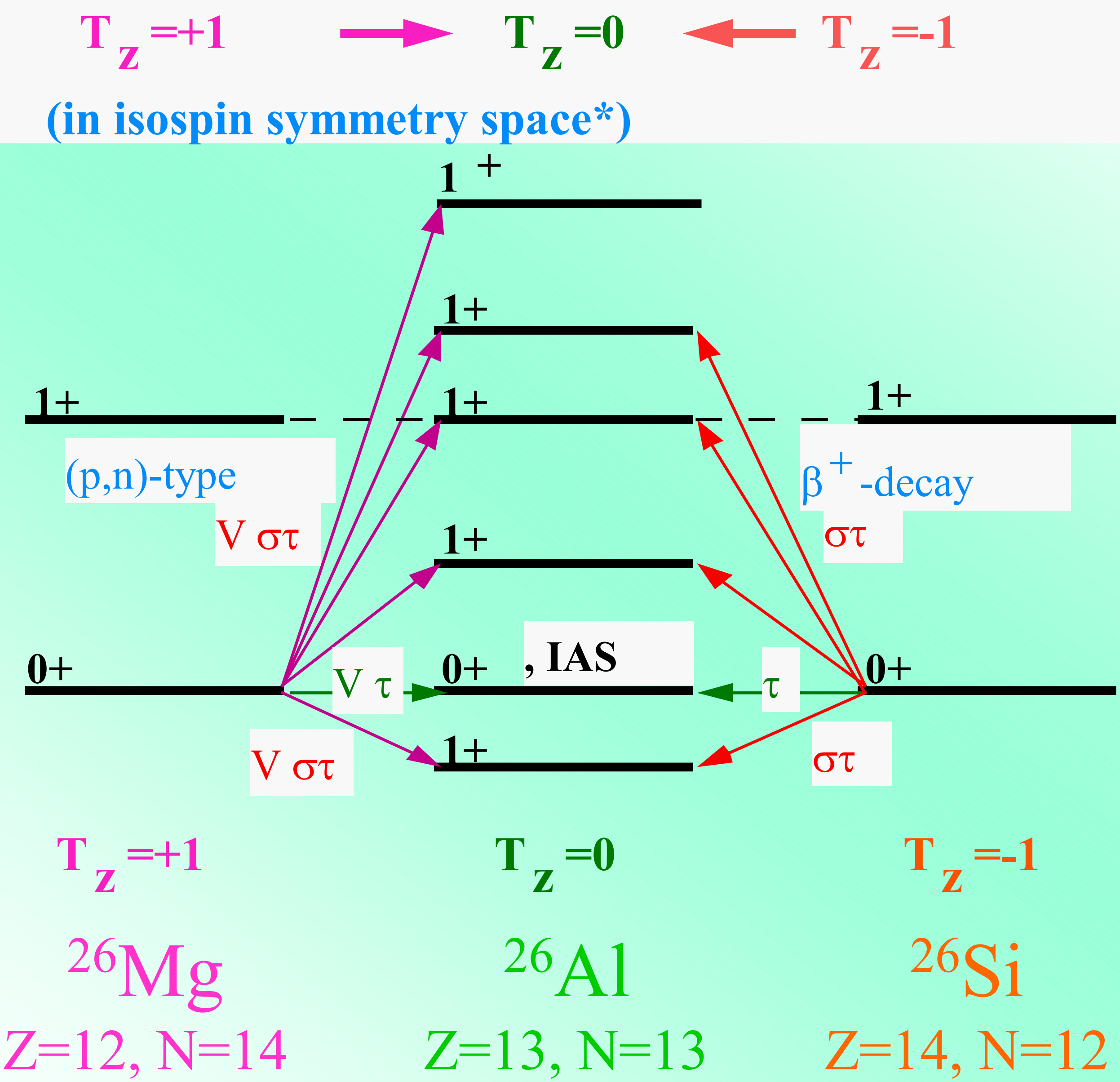
T=1 system

Coulomb Energy: important

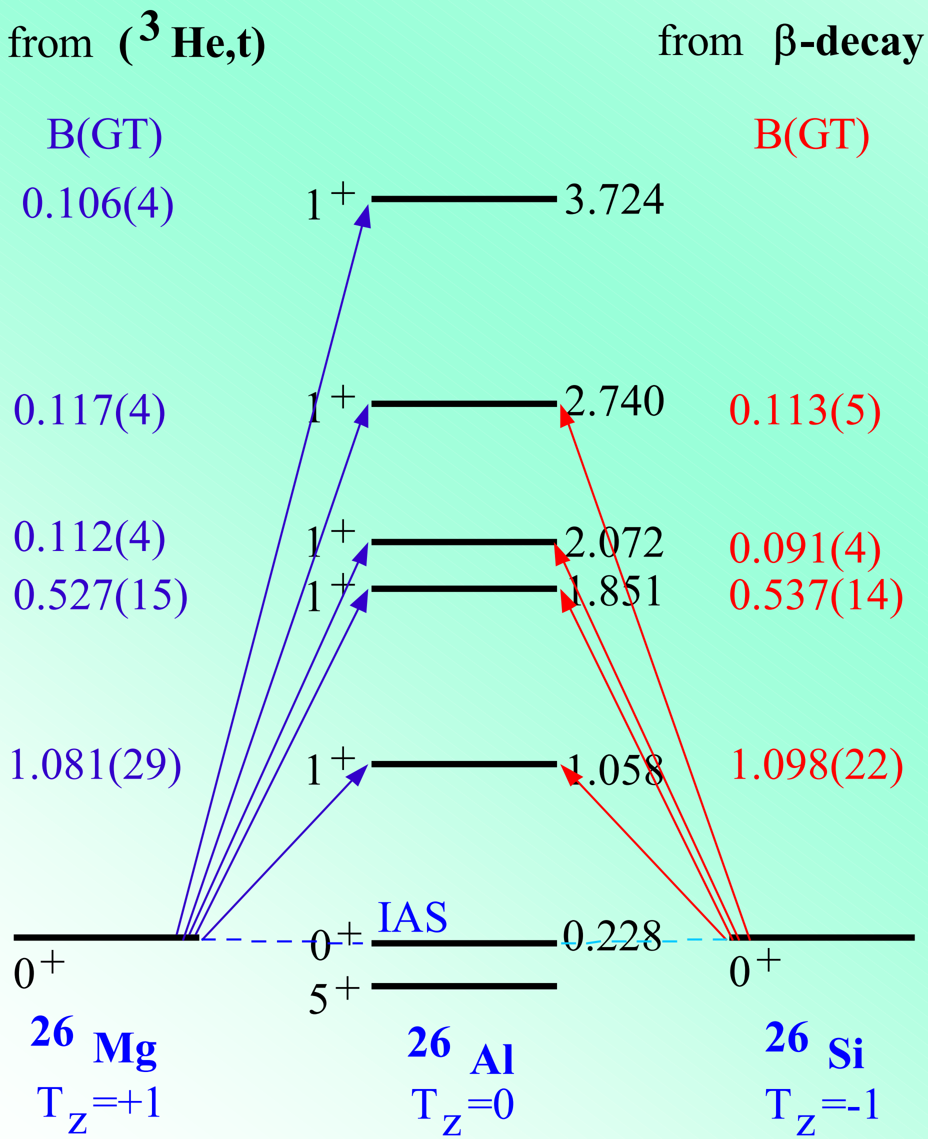
A=26 system

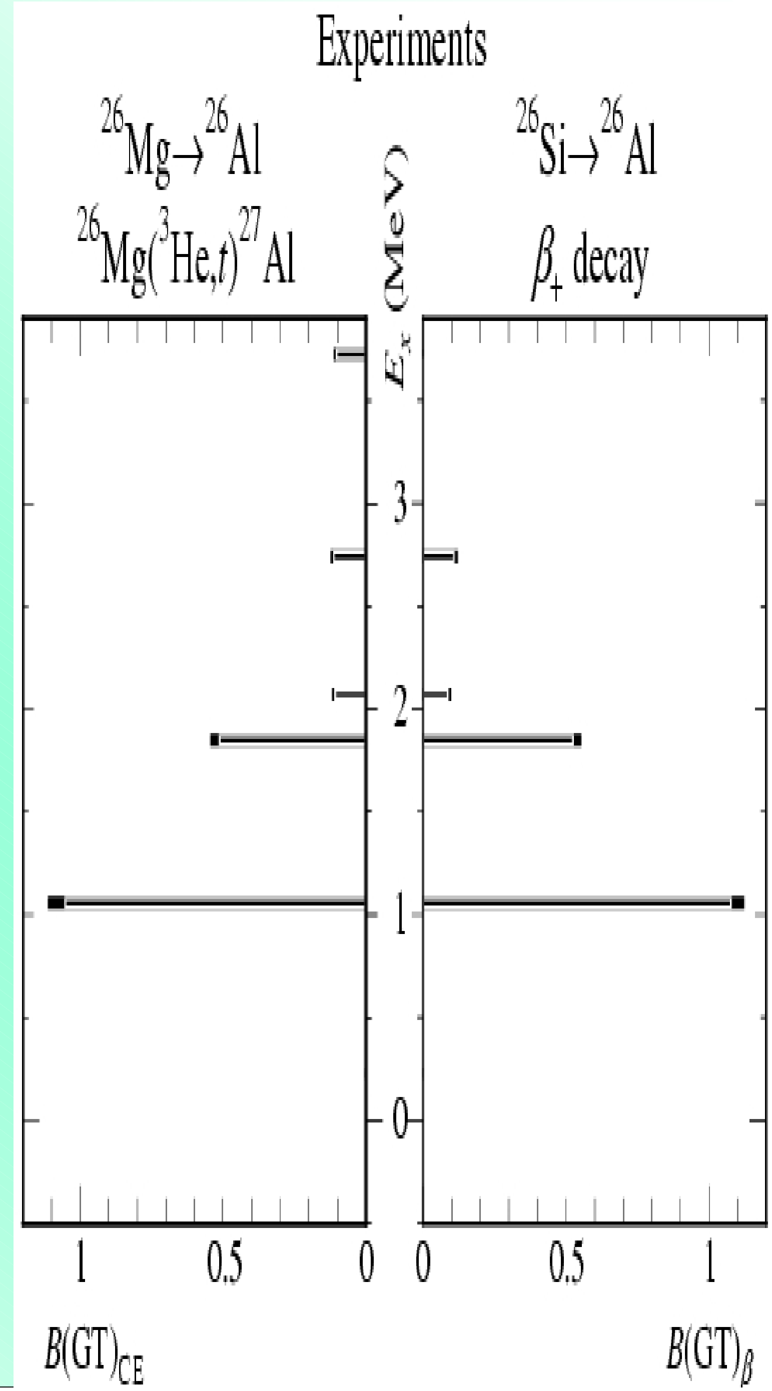


T=1 symmetry : Structures & Transitions

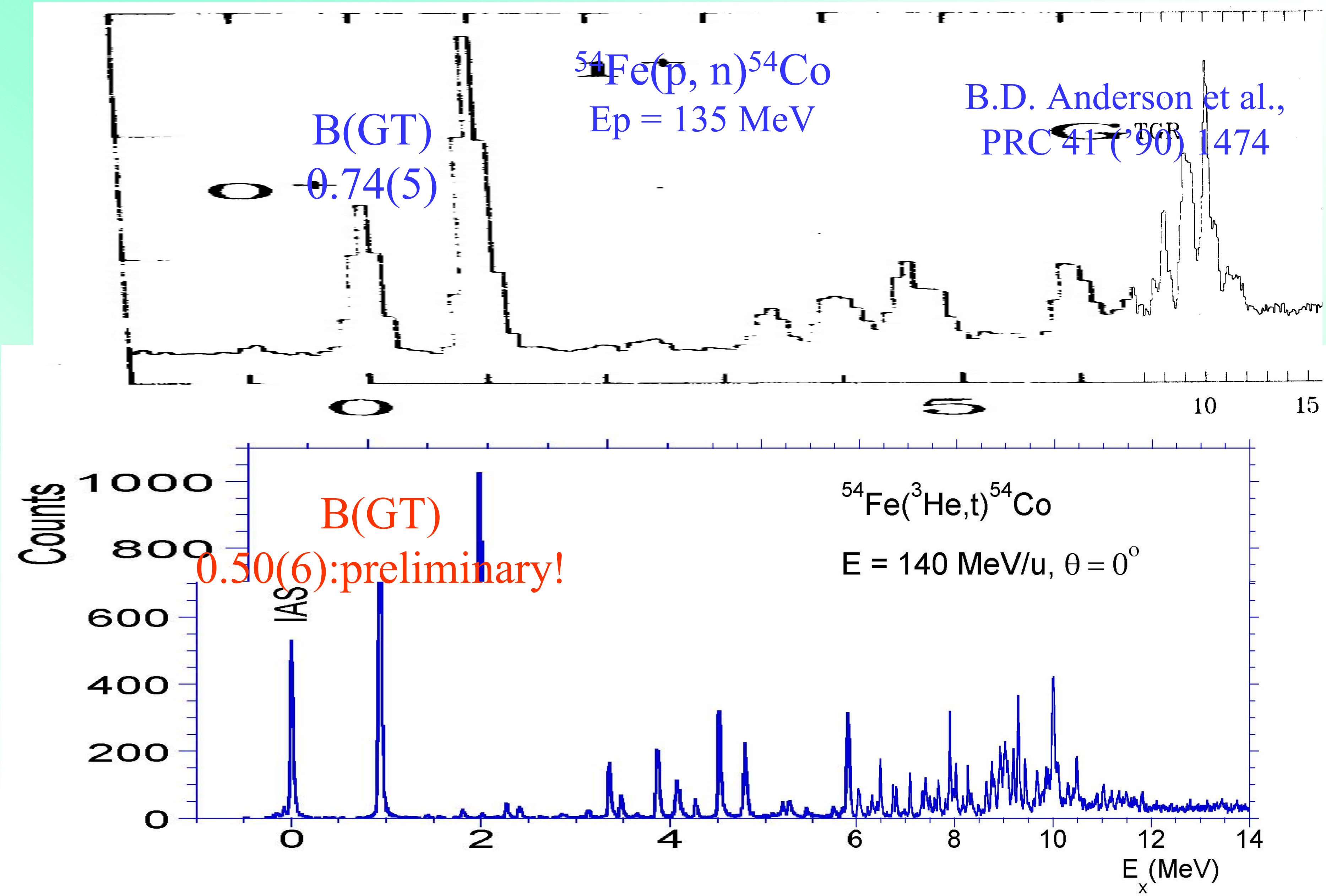


B(GT) values from Symmetry Transitions (A=26)

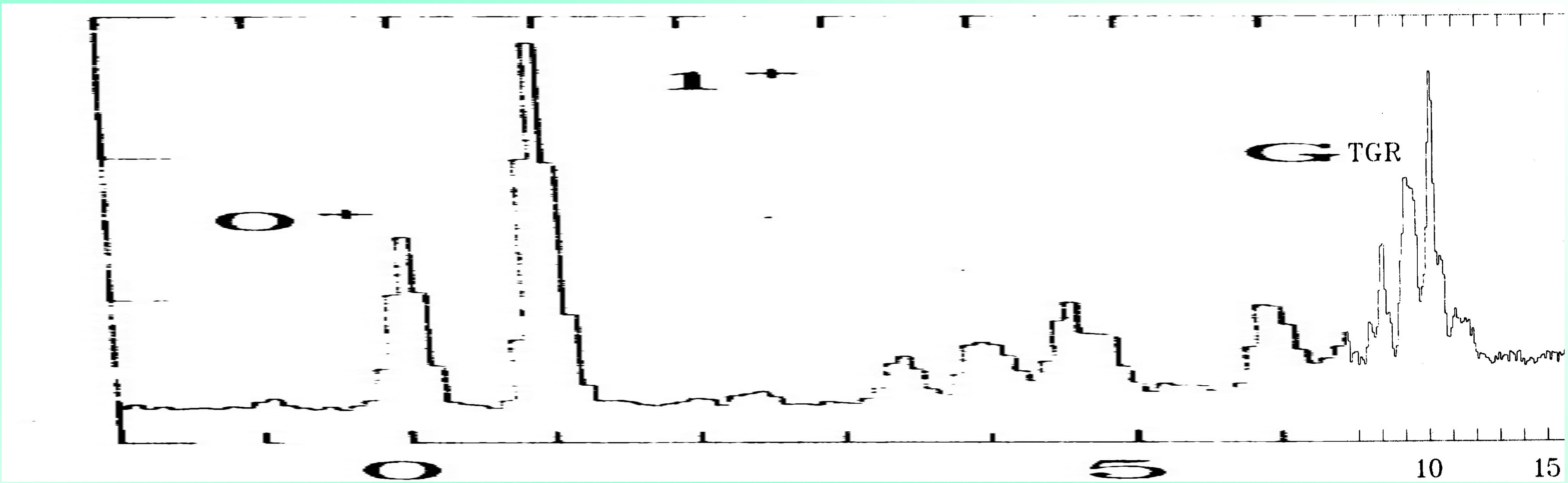




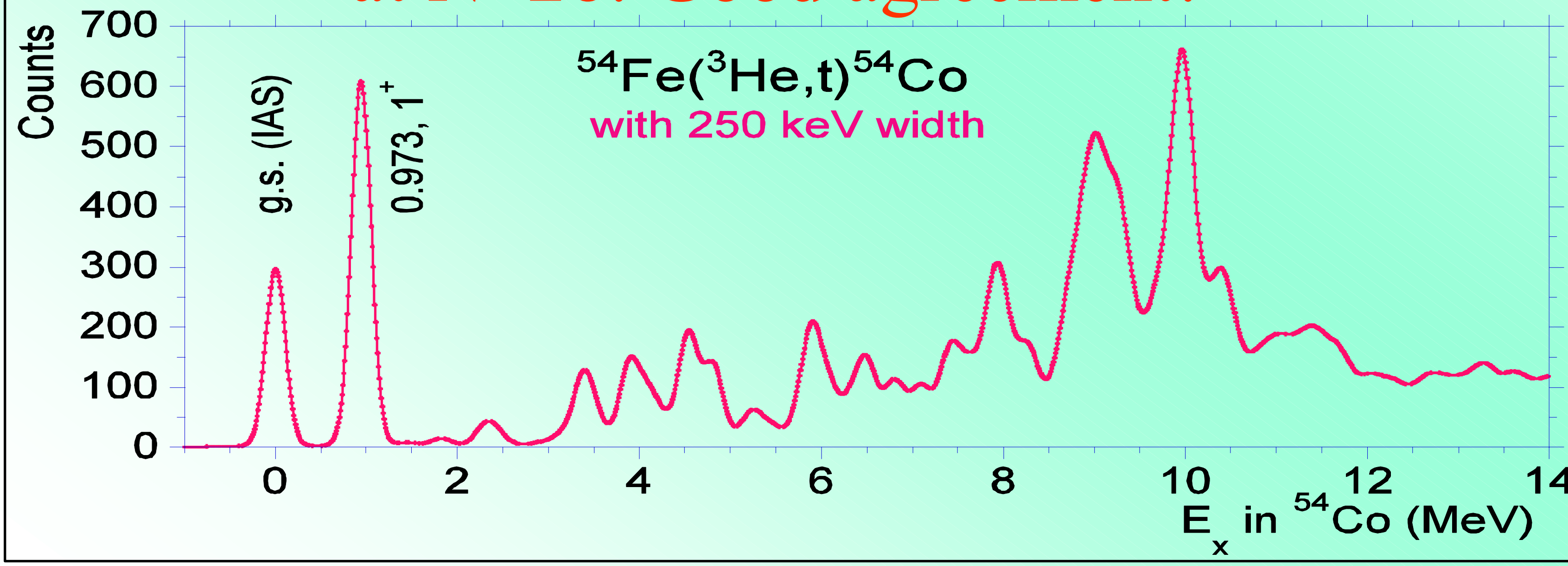
^{54}Fe(p,n) & ^{54}Fe(^{3}He,t)



$^{54}Fe(p,n)$ & $^{54}Fe(^3He,t)$+width



at N=28: Good agreement!



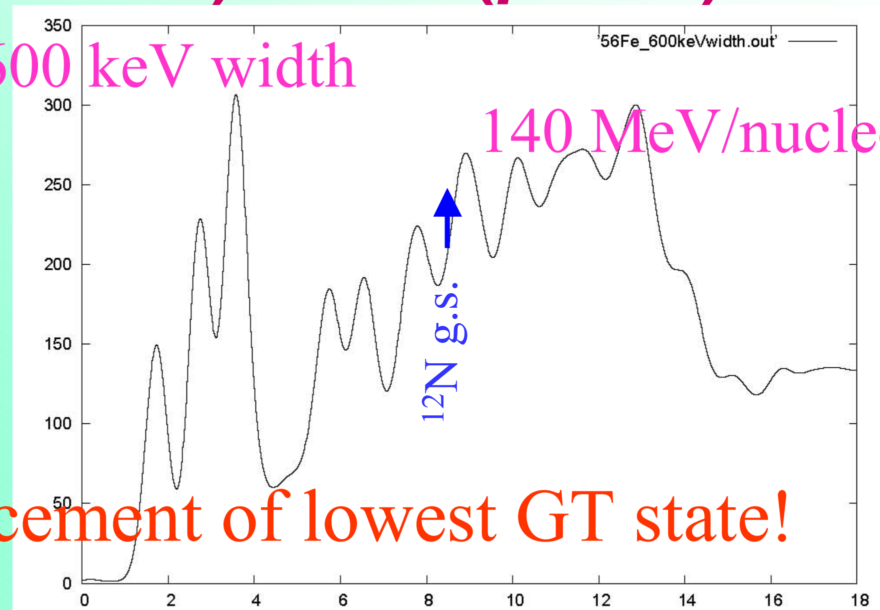
^{56}Fe target: (^{3}He,*t*) vs. (*p*, *n*)

(^{3}He,t)

1.7 MeV GT state enhanced!

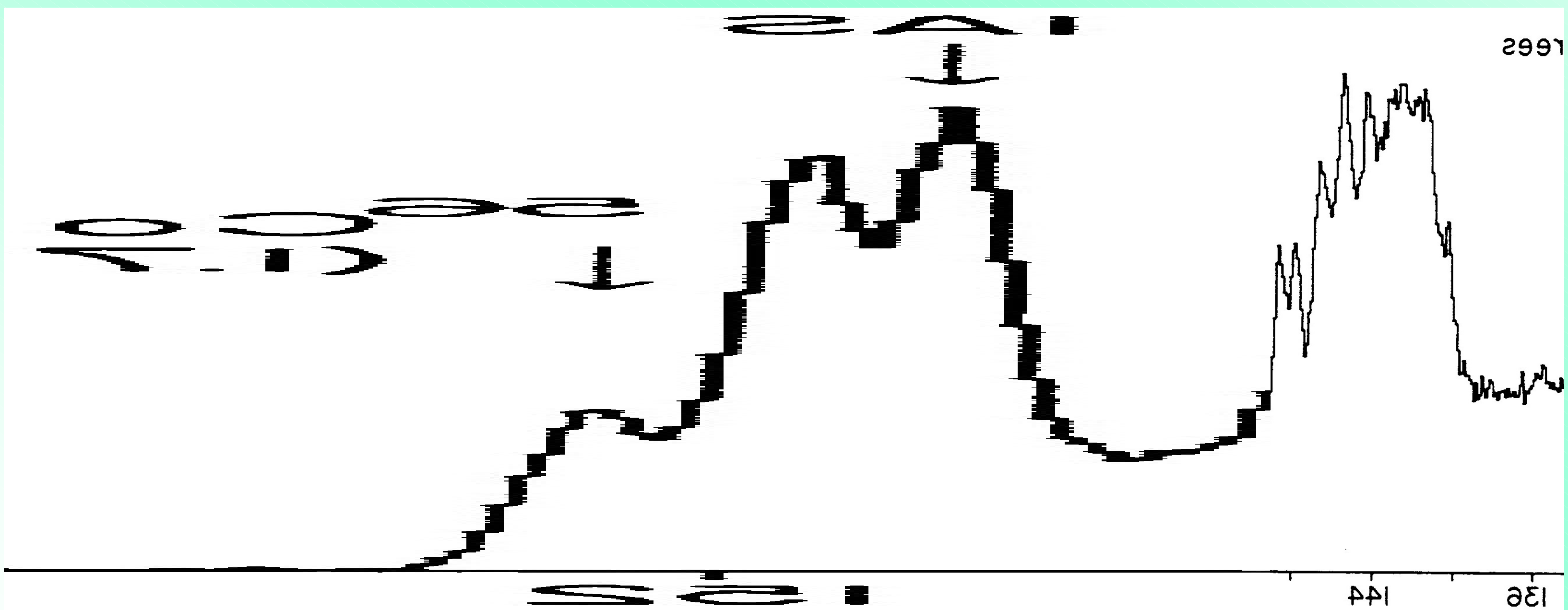
with 600 keV width

140 MeV/nucleon

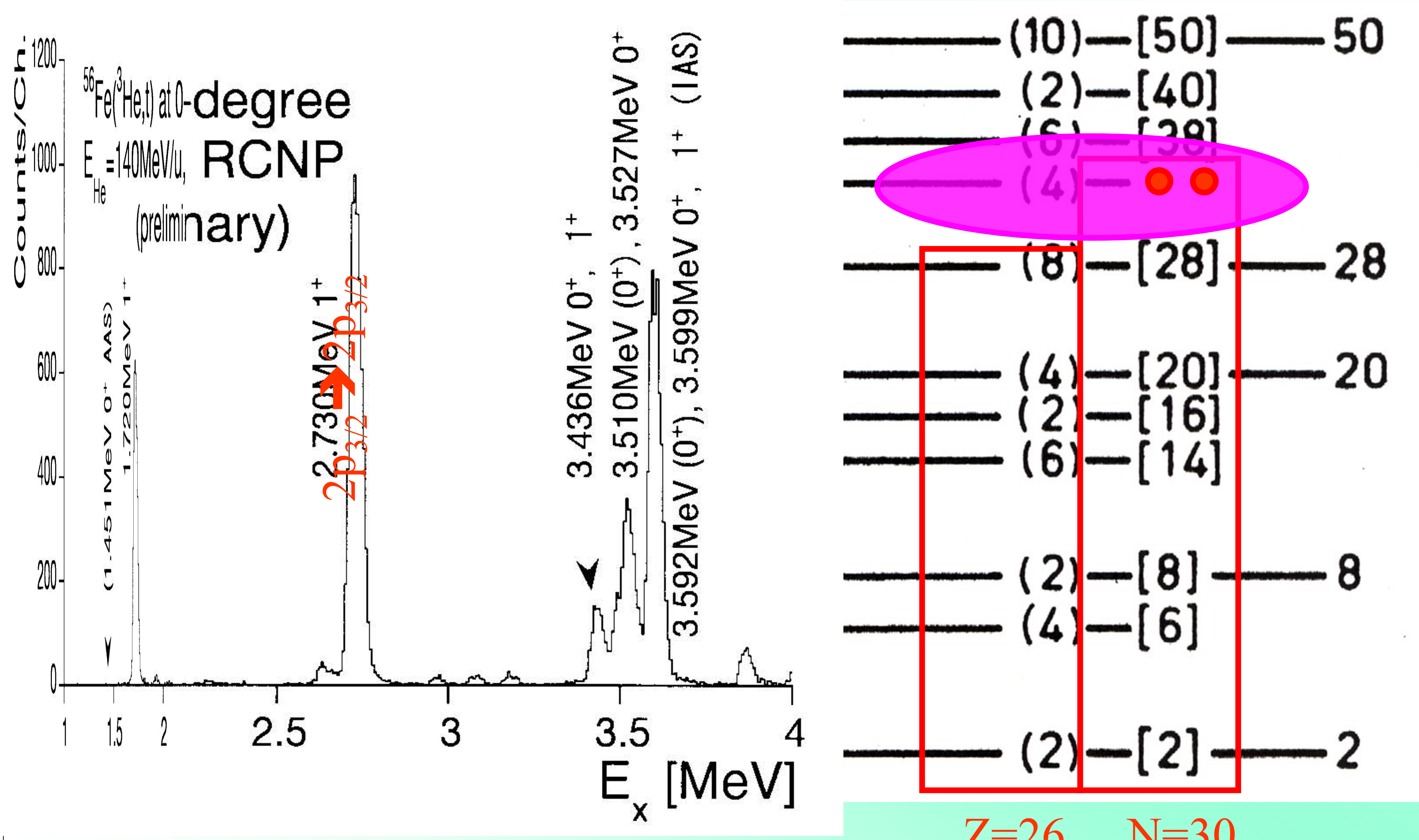


at N=30, exceptional enhancement of lowest GT state!

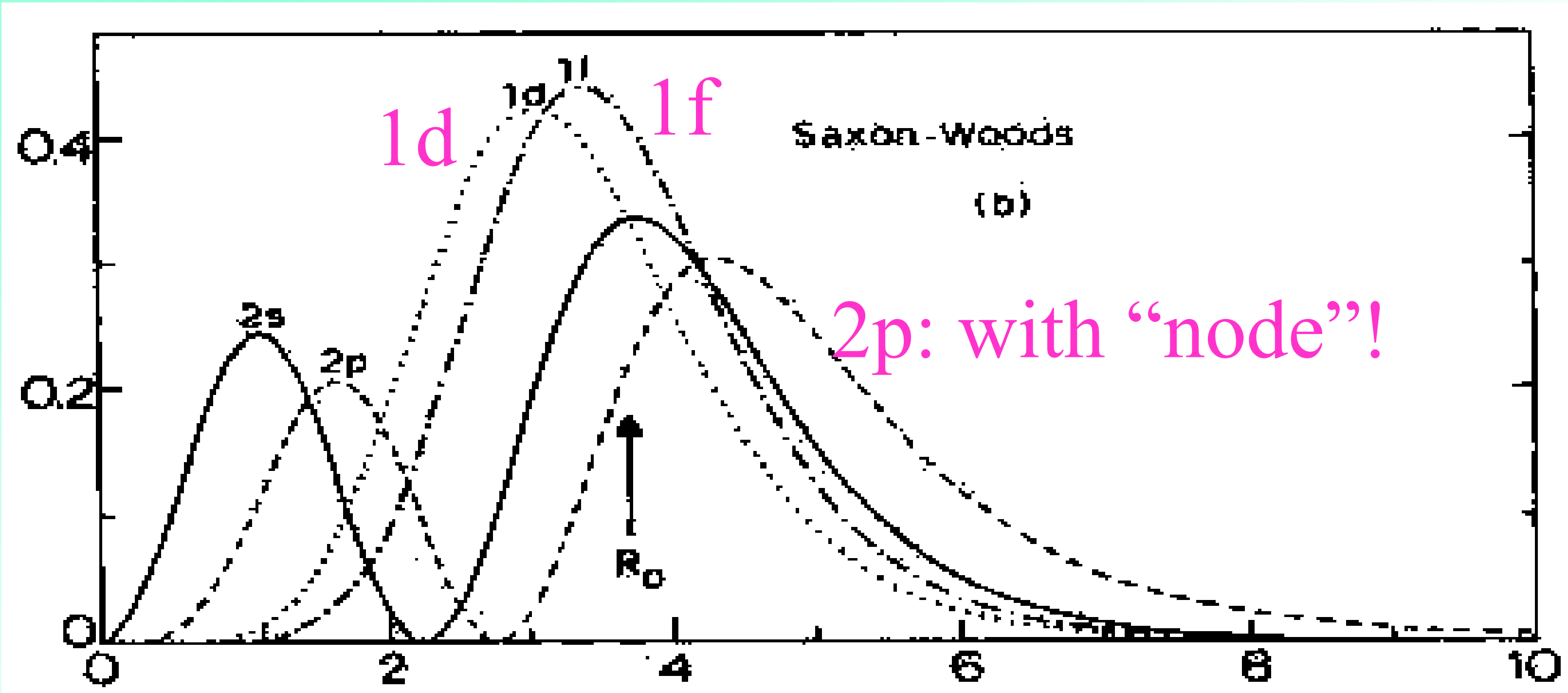
(p, n)



$^{56}Fe(^3He,t)$: low-lying GT states



Wave function (radial direction)



$^{56}Fe \rightarrow {}^{56}Co$
GT transition

lowest	$2p_{3/2} \rightarrow 2p_{3/2}$
low-lying	$2p_{3/2} \rightarrow 2p_{1/2}$
higher Ex	$1f_{7/2} \rightarrow 1f_{5/2}$

Due to "surface nature" of (^3He,t), reaction strength may be affected by the presence of the node.

?? Proportionality ??

*proportionality has been most well studied in (^{3}He,t)

Universal proportionality X ← for all mass A

Specific proportionality O ← for each A

(of the order of a few - 10%)

Larger uncertainties of the proportionality:

1) for the $j_< \rightarrow j_<$ transitions (weak!)

(ex. $p_{1/2} \rightarrow p_{1/2}$, $d_{3/2} \rightarrow d_{3/2}$)

2) when a w.f. has a node

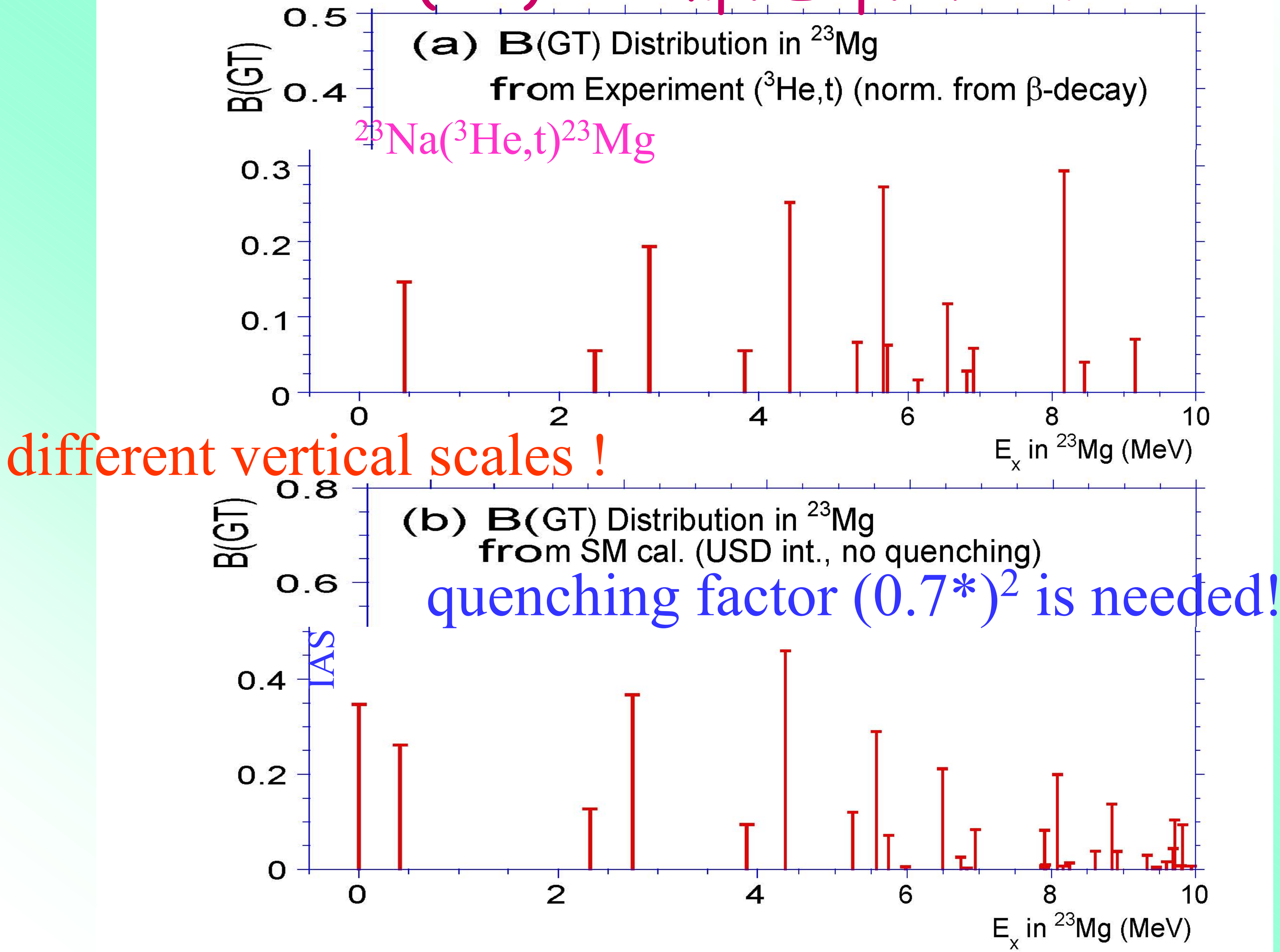
(ex. $2s_{1/2} \rightarrow 2s_{1/2}$, $2p_{3/2} \rightarrow 2p_{3/2}$)

at N=18 at N=30

at the *sd* -shell region

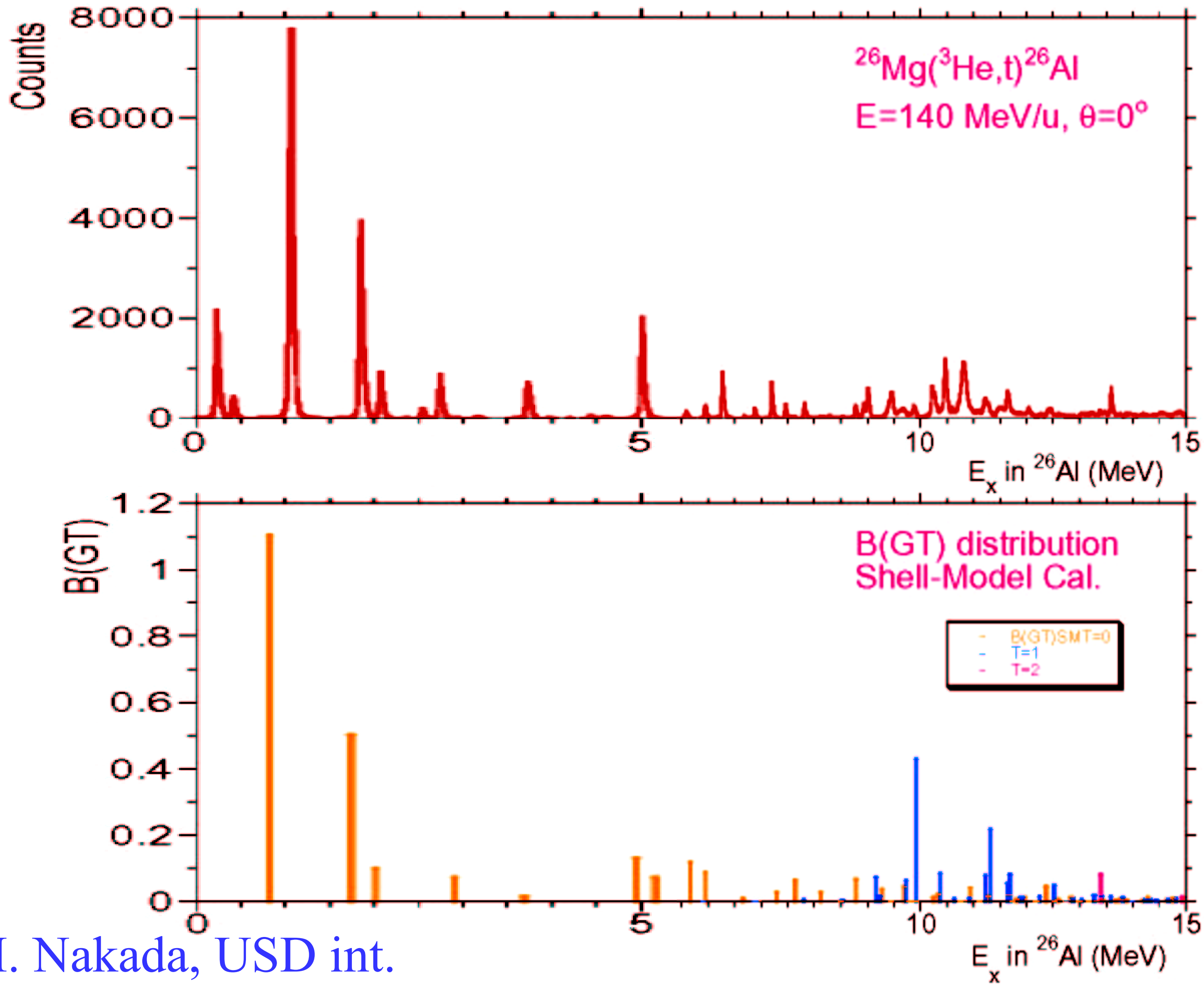
**A=23 T=1/2 → 1/2 transitions

A=23 B(GT) : Comp. Exp. & SM



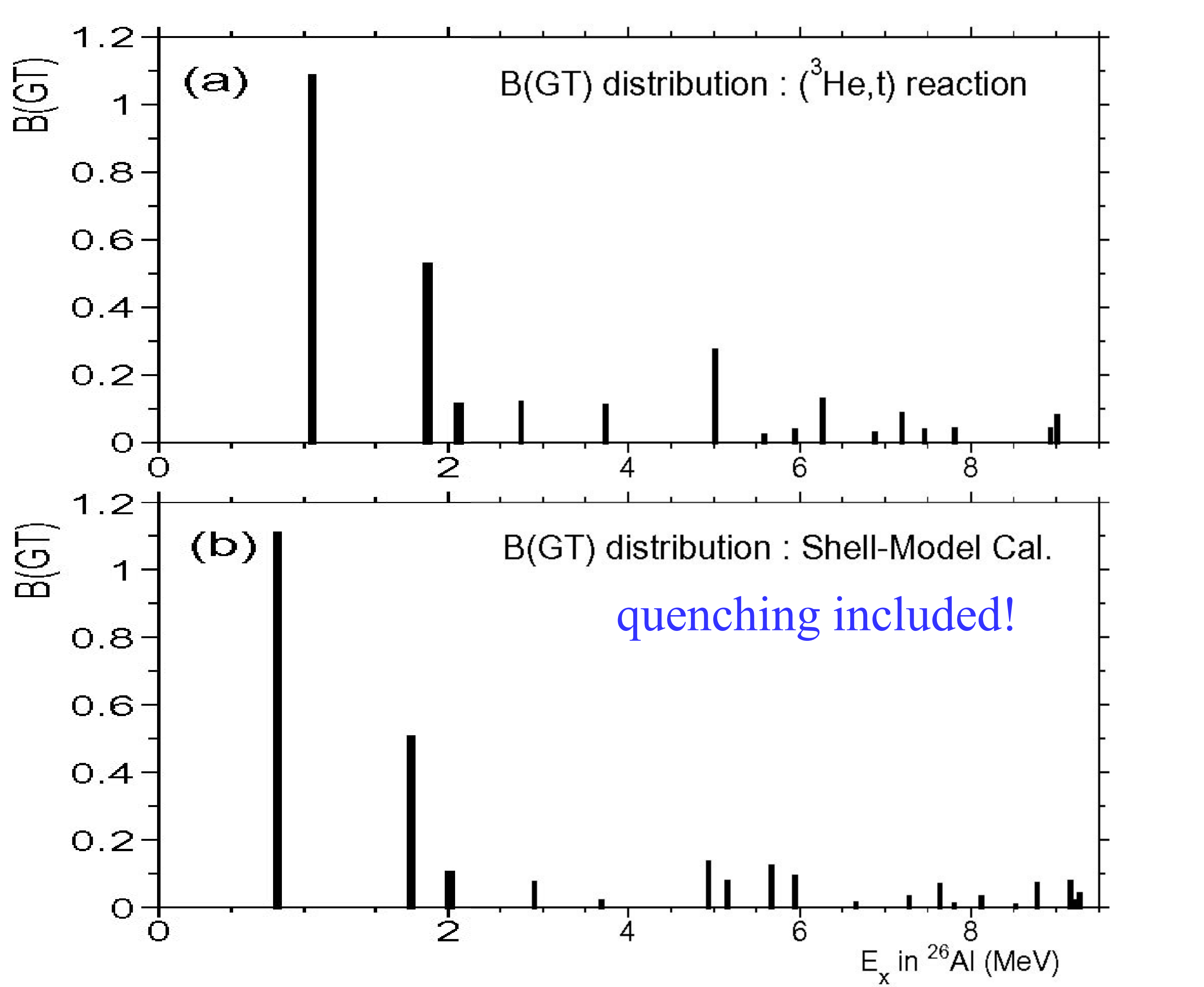
**A=26 T=1 → 0 transitions

$^{26}Mg(^{3}He,t)$ spectrum and SM cal. B(GT)



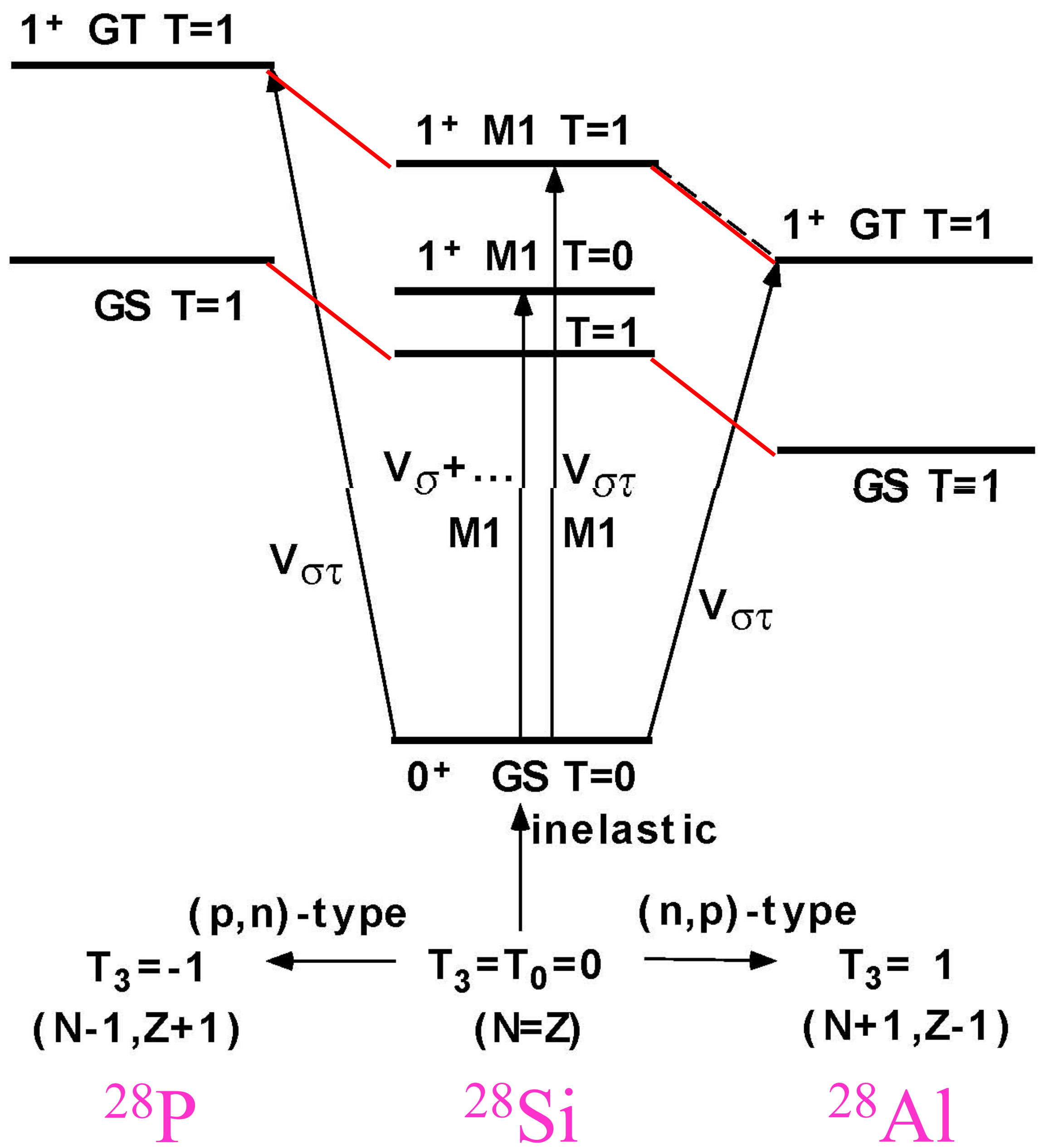
by H. Nakada, USD int.

B(GT) distributions (low-lying): Exp. & SM

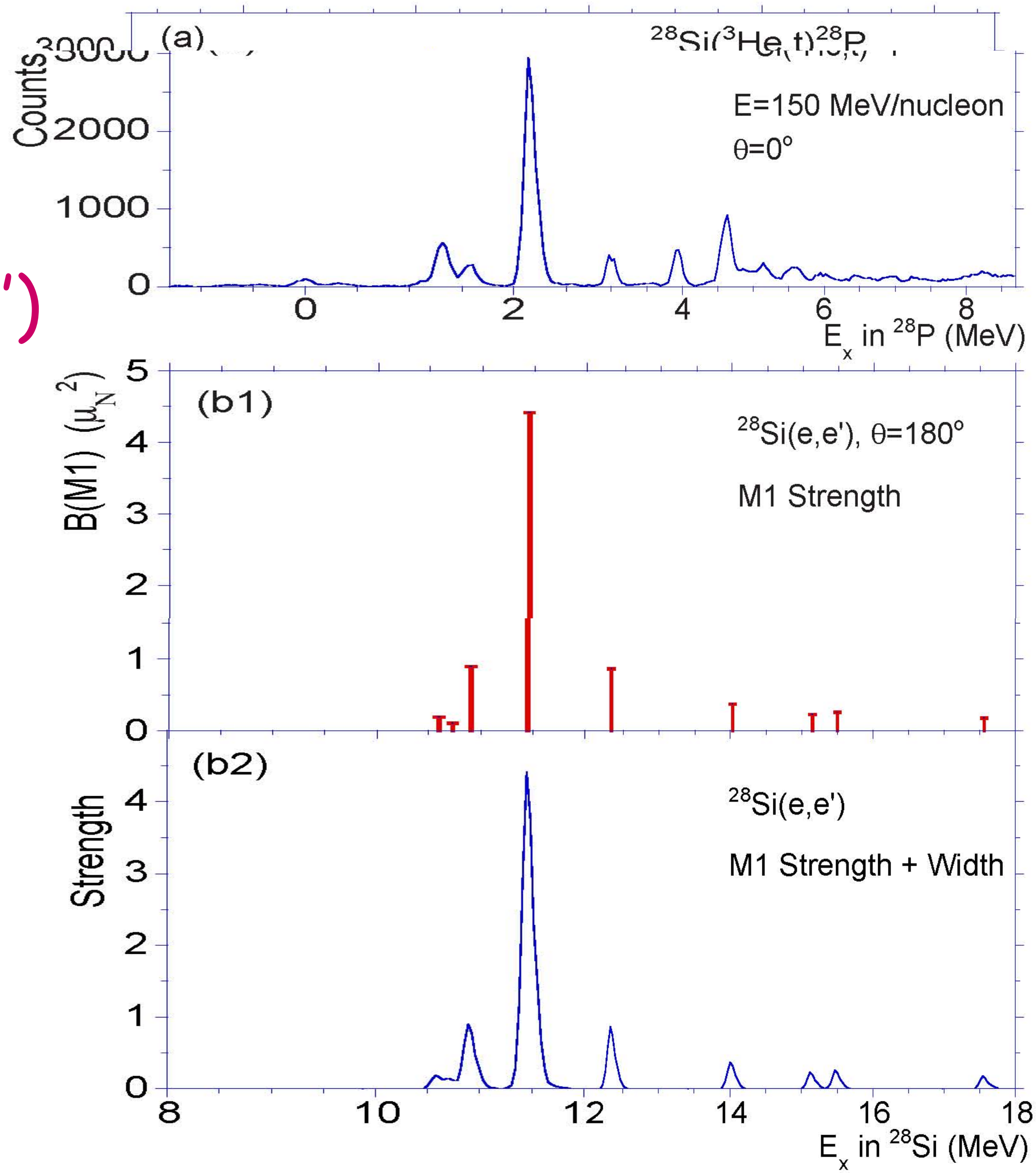


**A=28 T=0 → 1 transitions

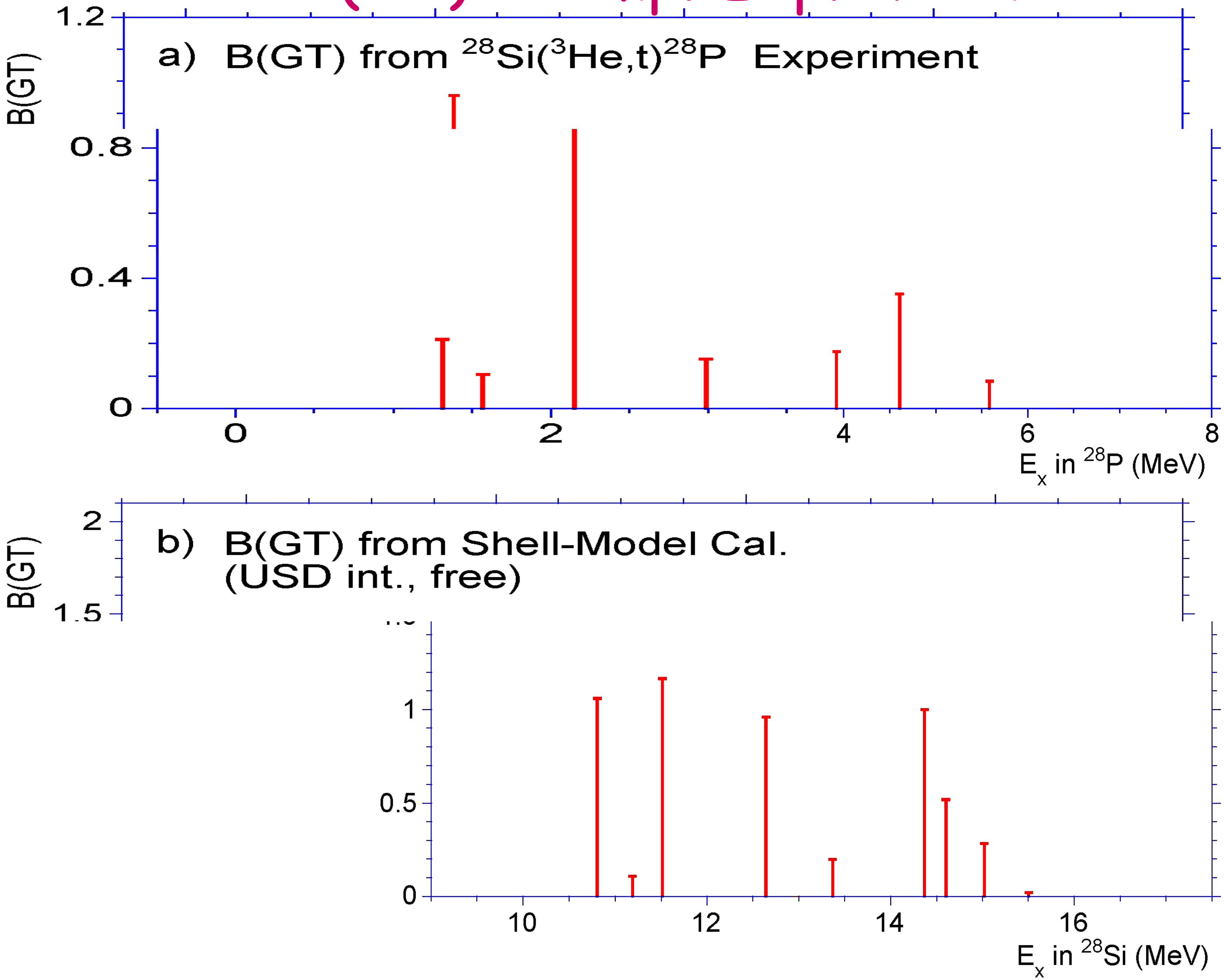
Isospin Structure of T=0 Nucleus ^{28}Si



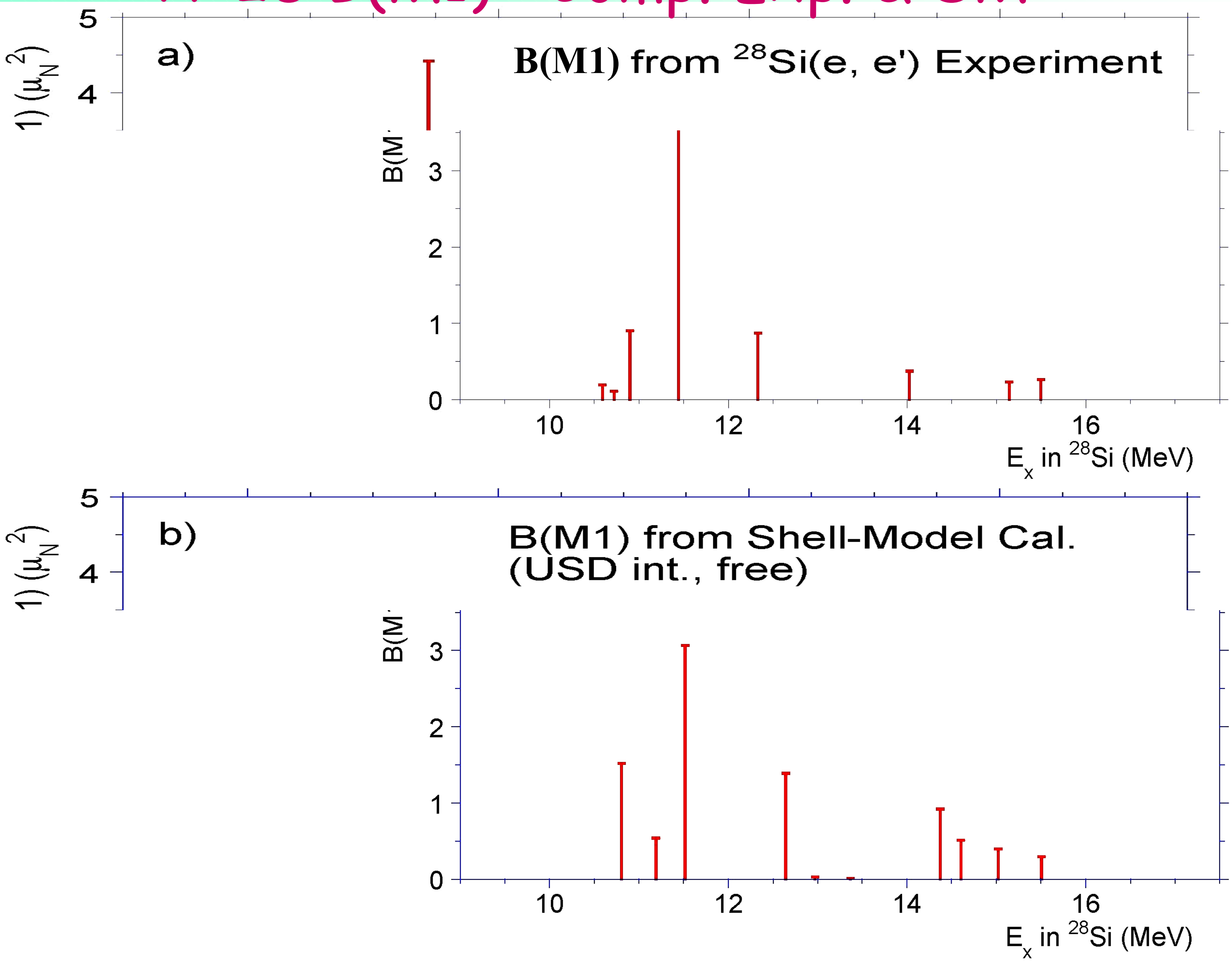
^{28}Si Comp: (^{3}He,t) & (e, e')



A=28 B(GT) : Comp. Exp. & SM

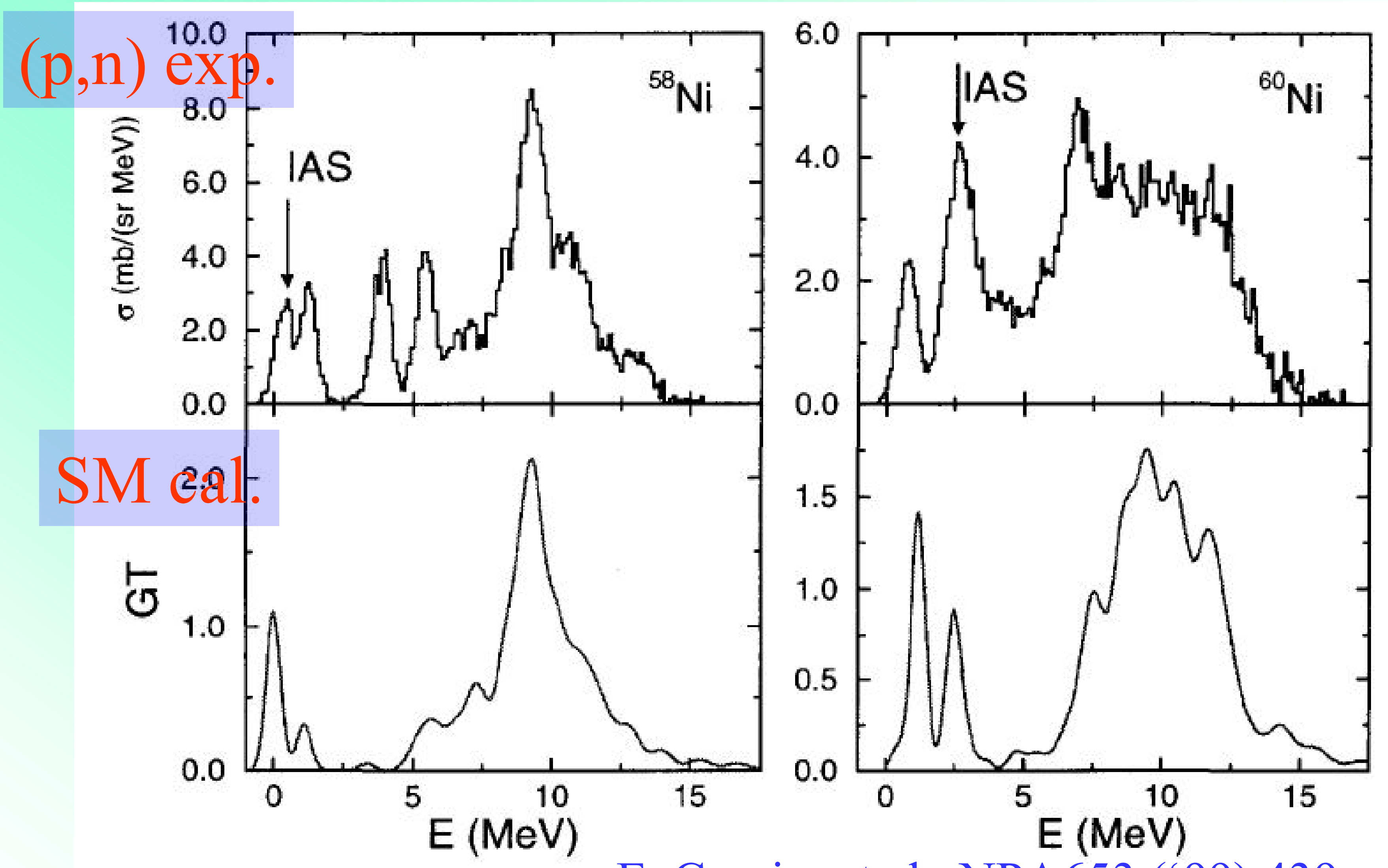


A=28 B(M1) : Comp. Exp. & SM



at the Ni region of *fp* -shell

SM-cal: GT- from Ni isotopes

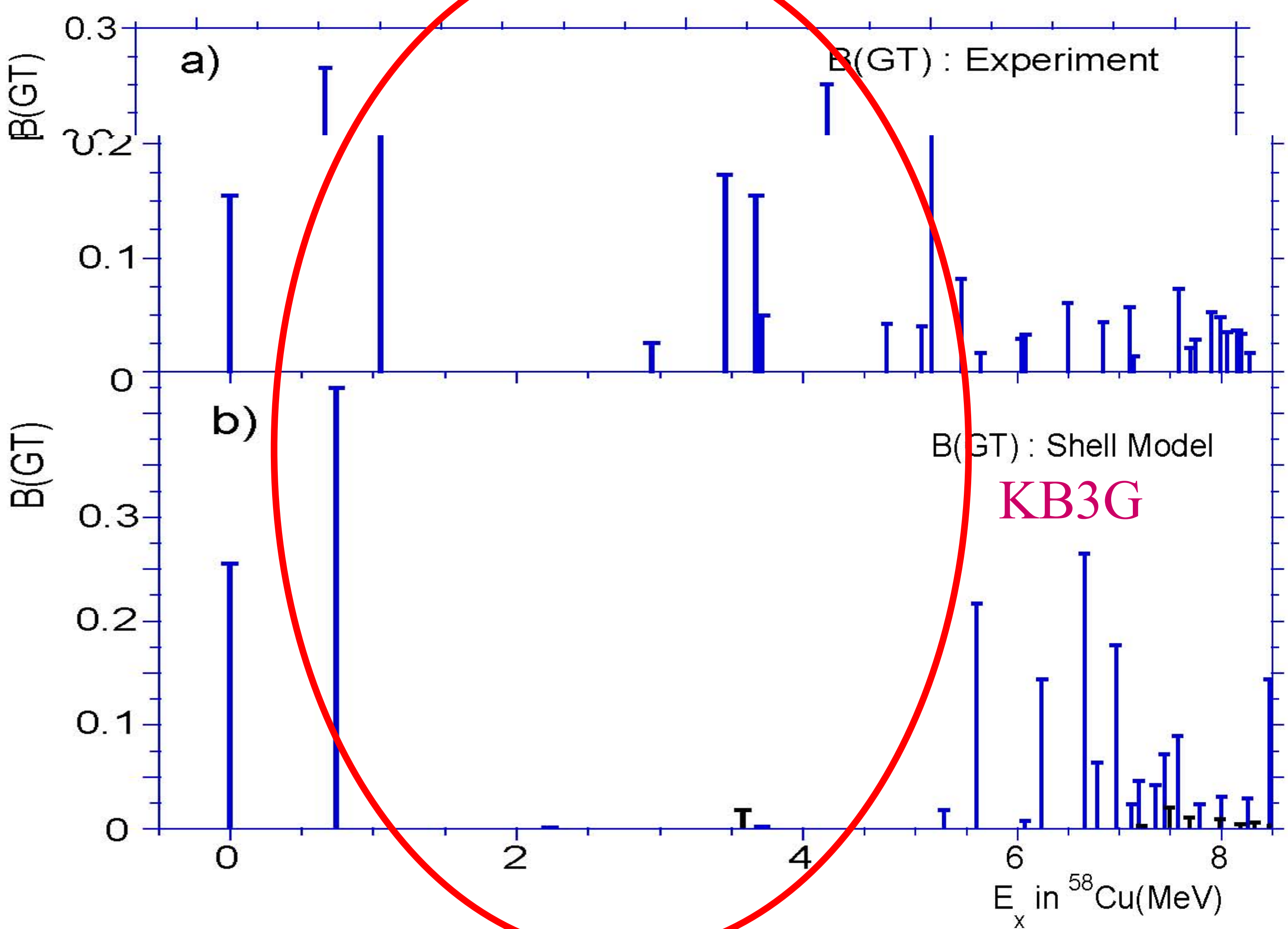


E. Caurier et al., NPA653 ('99) 439

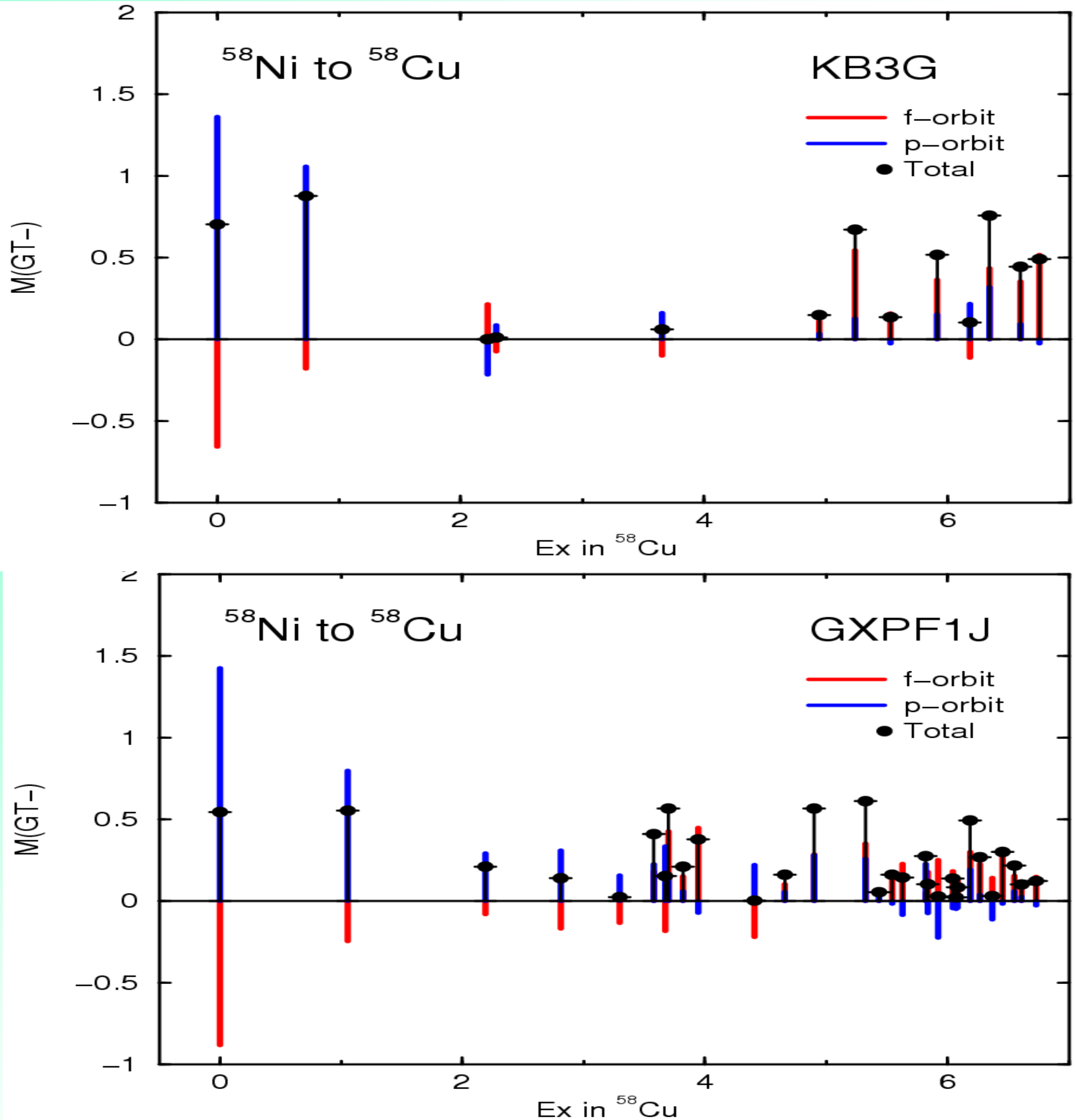
KB3G int.

Comparison of B(GT): Exp. & Theory

Y. Fujita et al.,
Eur. Phys. J 13 ('02) 411

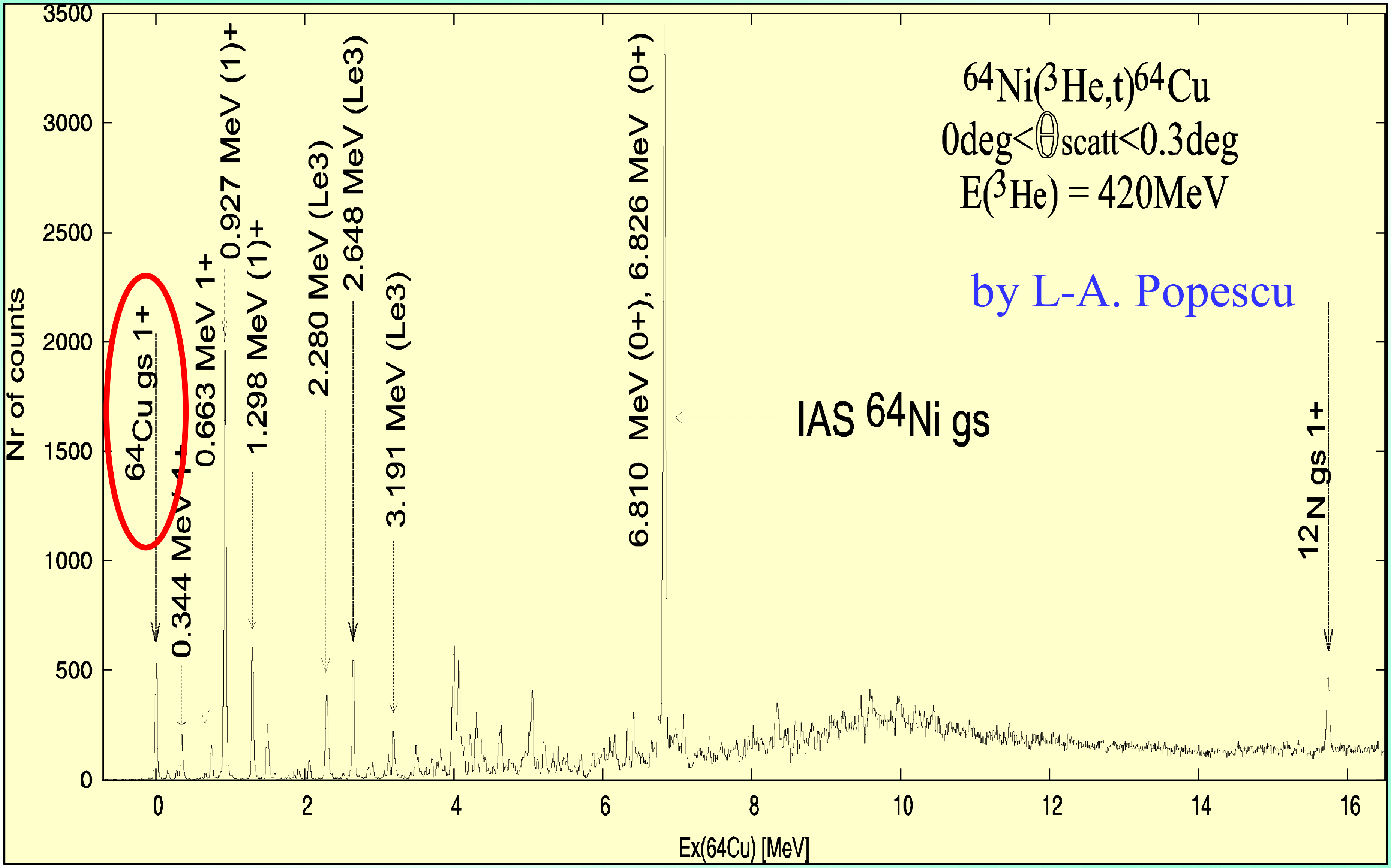


Interaction Dependence

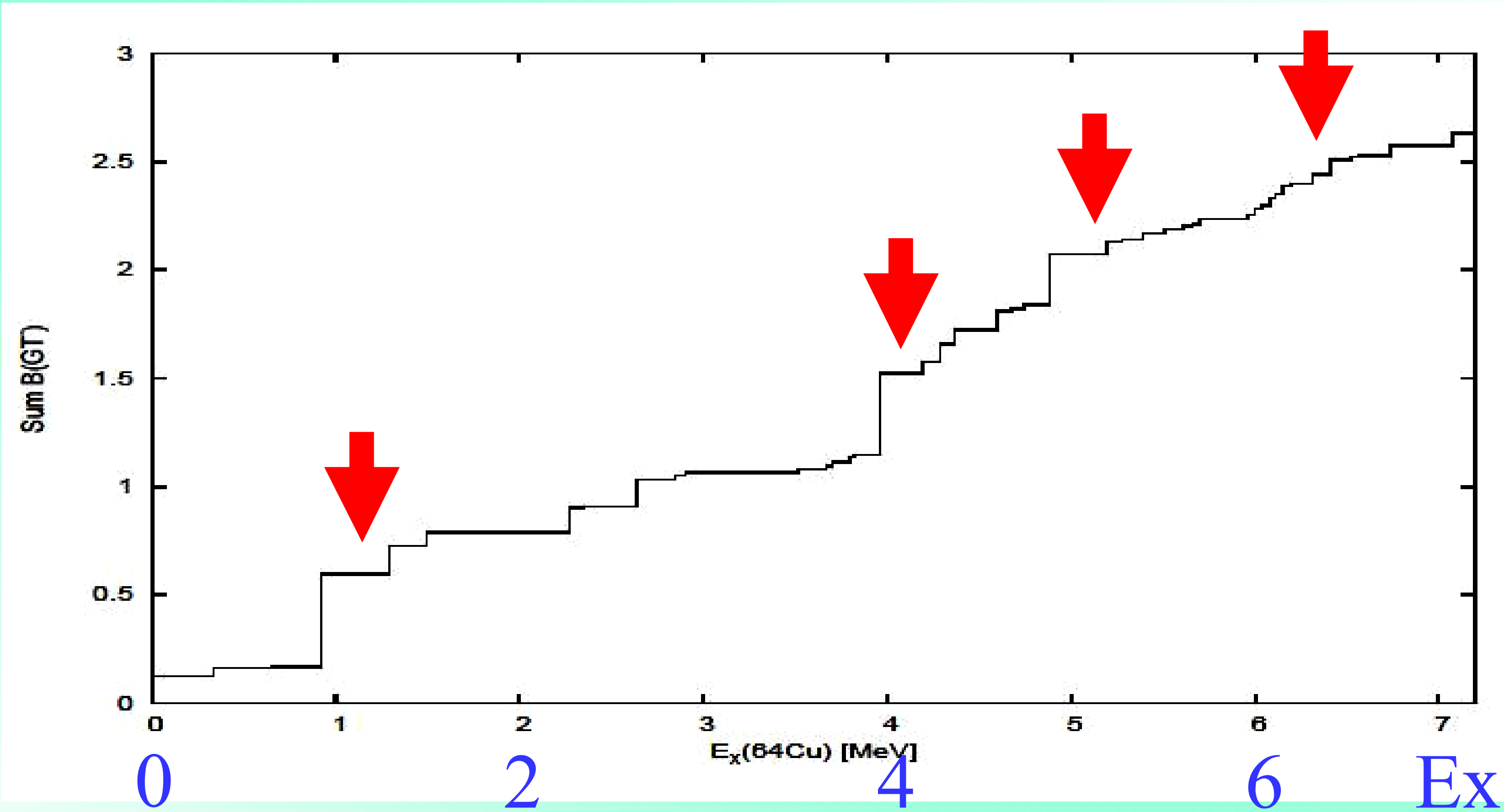


by
M. Honma

$^{64}Ni(^{3}He,t)^{64}Cu$ spectrum



B(GT) Running Sum



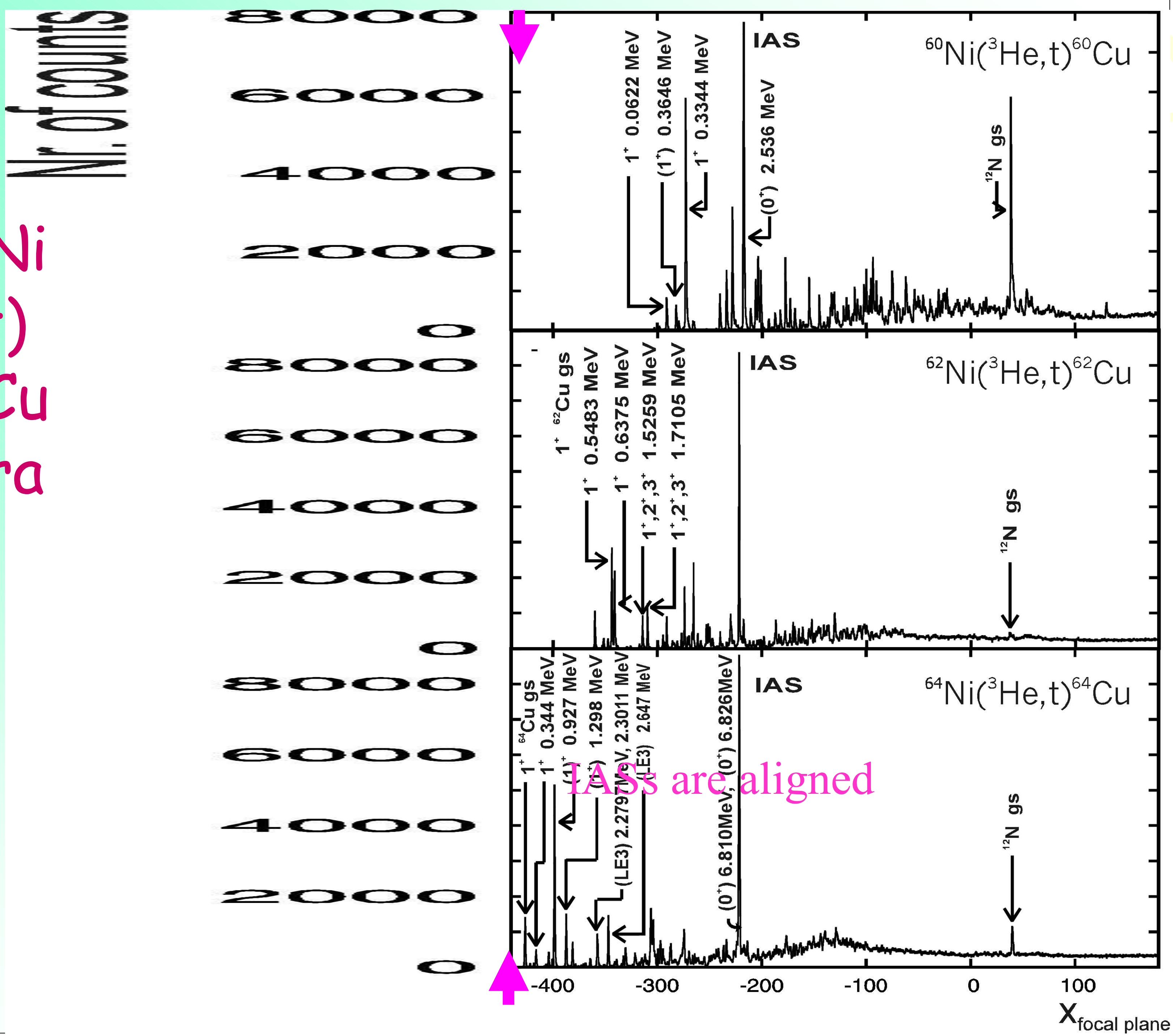
$p_{3/2} \rightarrow p_{3/2}$

$p_{3/2} \rightarrow p_{1/2}$

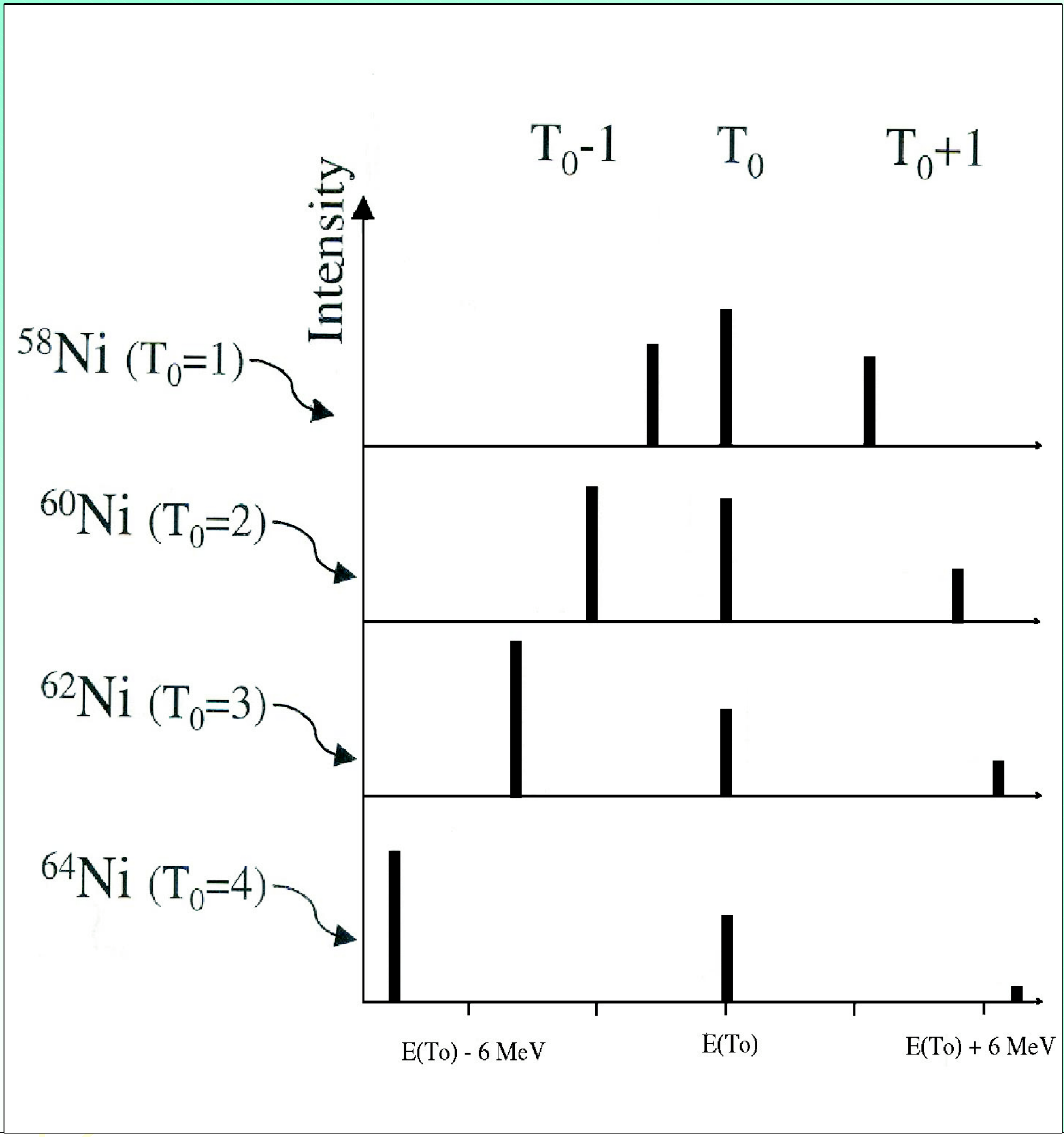
$f_{5/2} \rightarrow f_{5/2}$

$f_{7/2} \rightarrow f_{5/2}$

^{60,62,64}Ni (^{3}He,t) ^{60,62,64}Cu Spectra

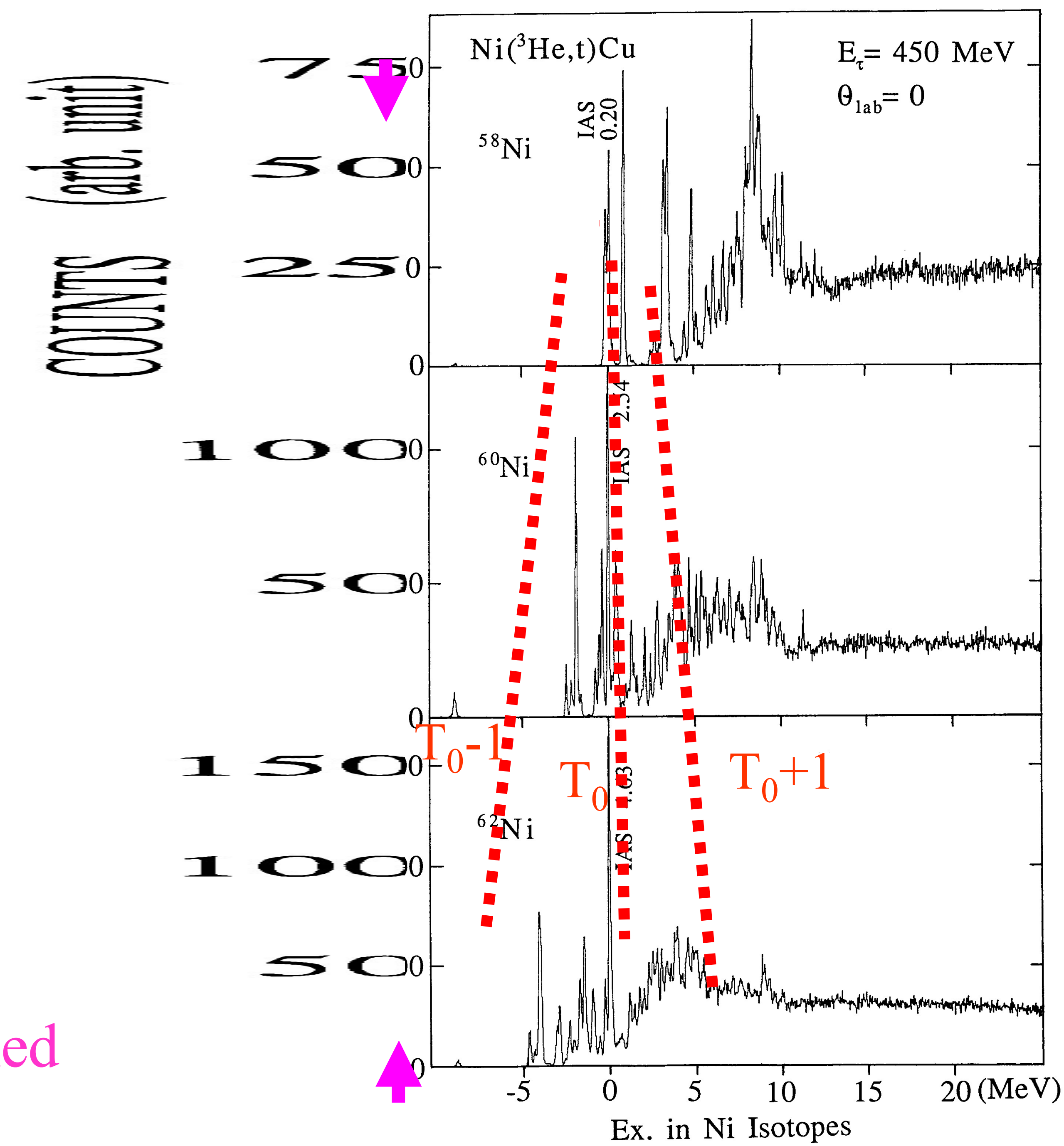


GT transitions from Ni isotopes



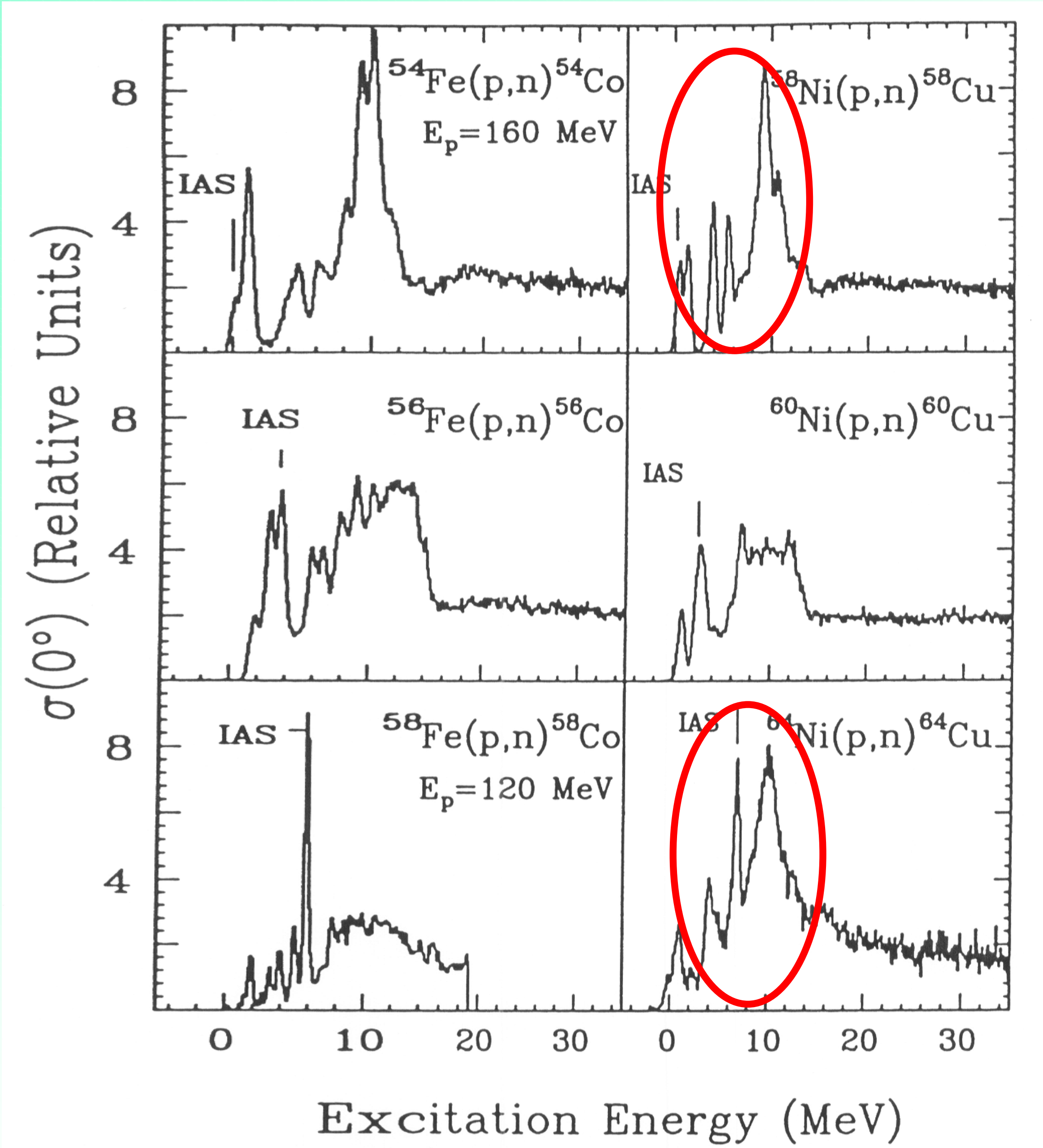
Isospin symmetry energy & Ratio of isospin CG coefficients

Ni isotopes



IASs are aligned

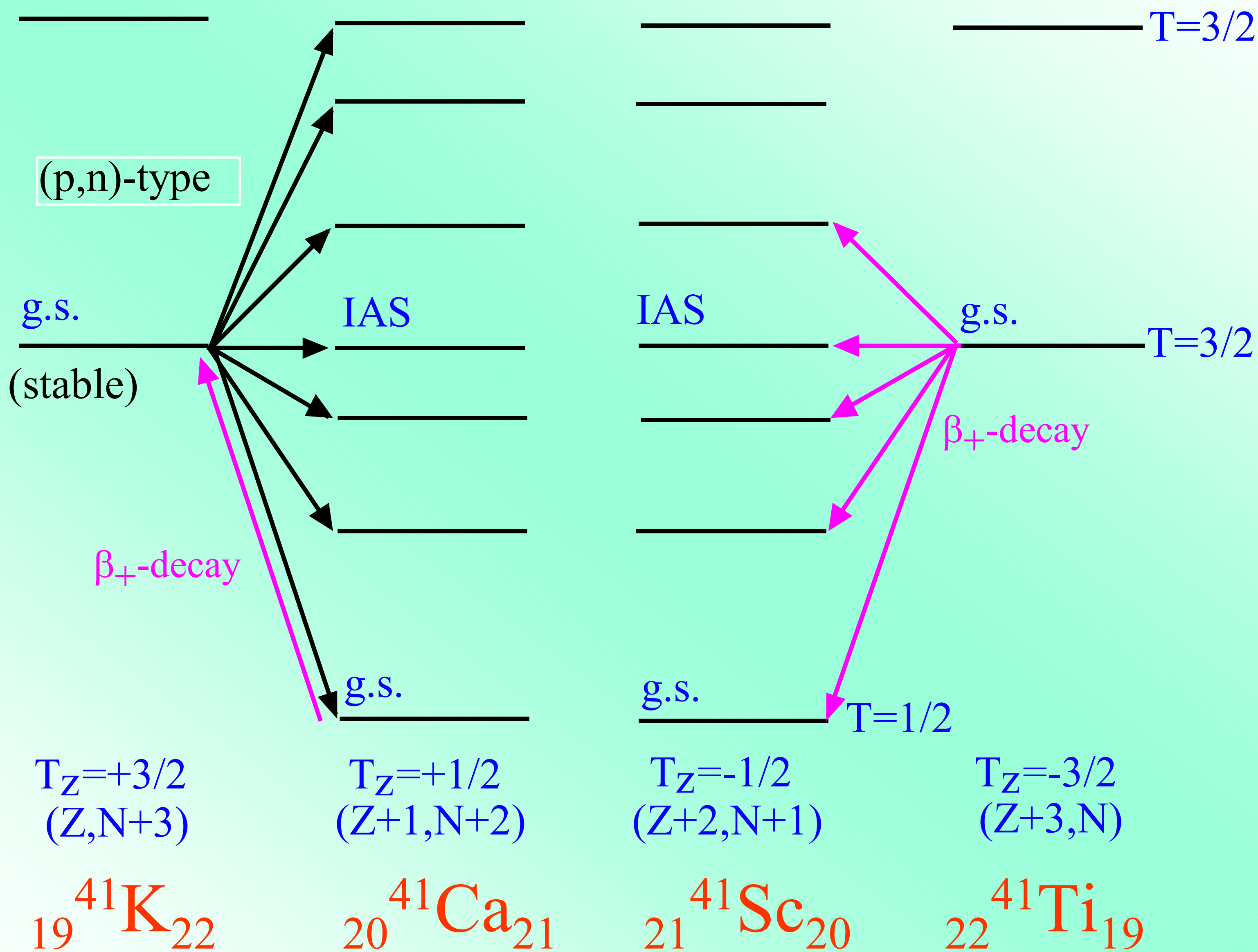
(*p*, *n*) spectra for Fe and Ni Isotopes



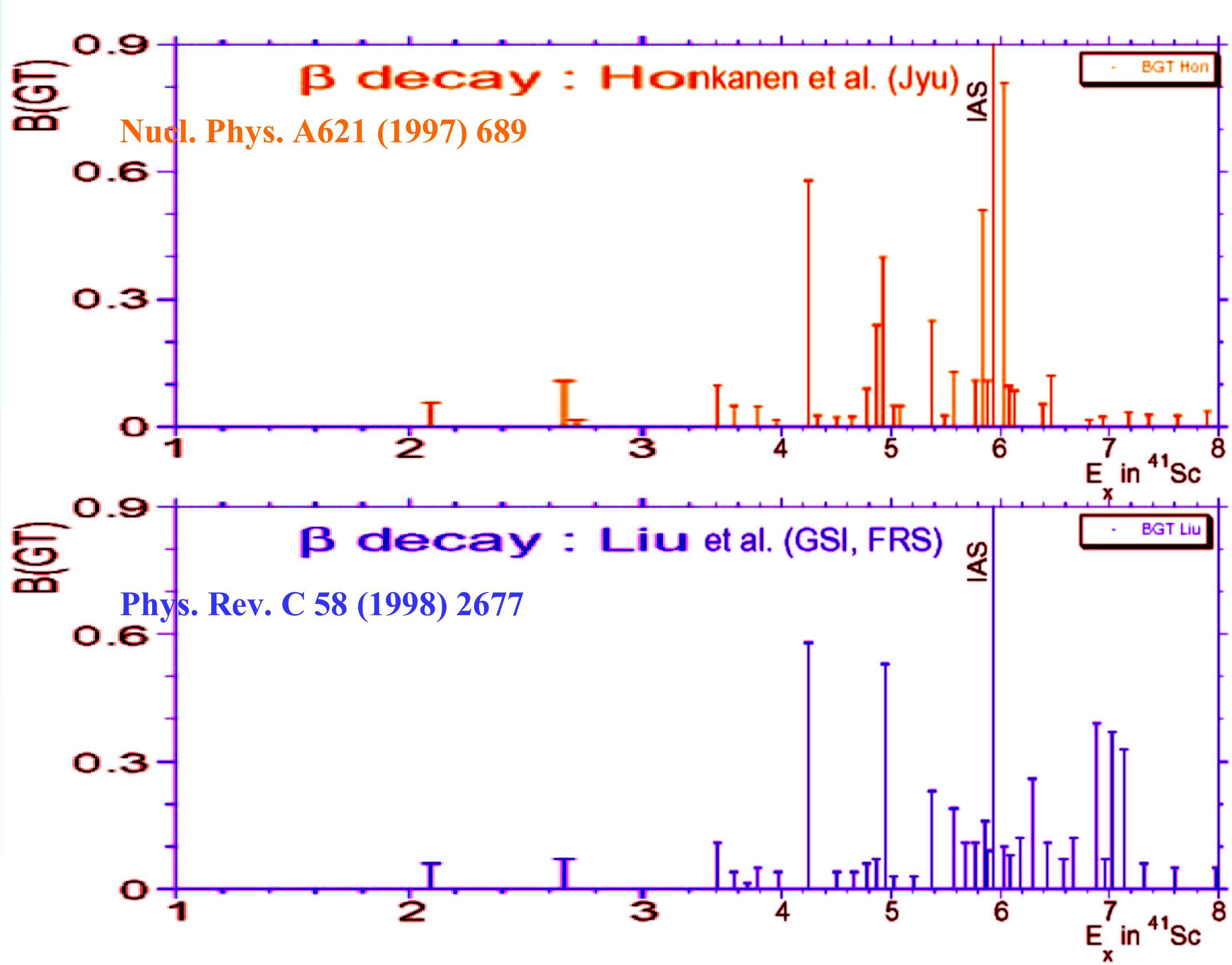
at the lower part of *fp* -shell region

**Critical case: A=41, T_z=3/2→1/2 transitions

T=3/2 system: structures & transitions

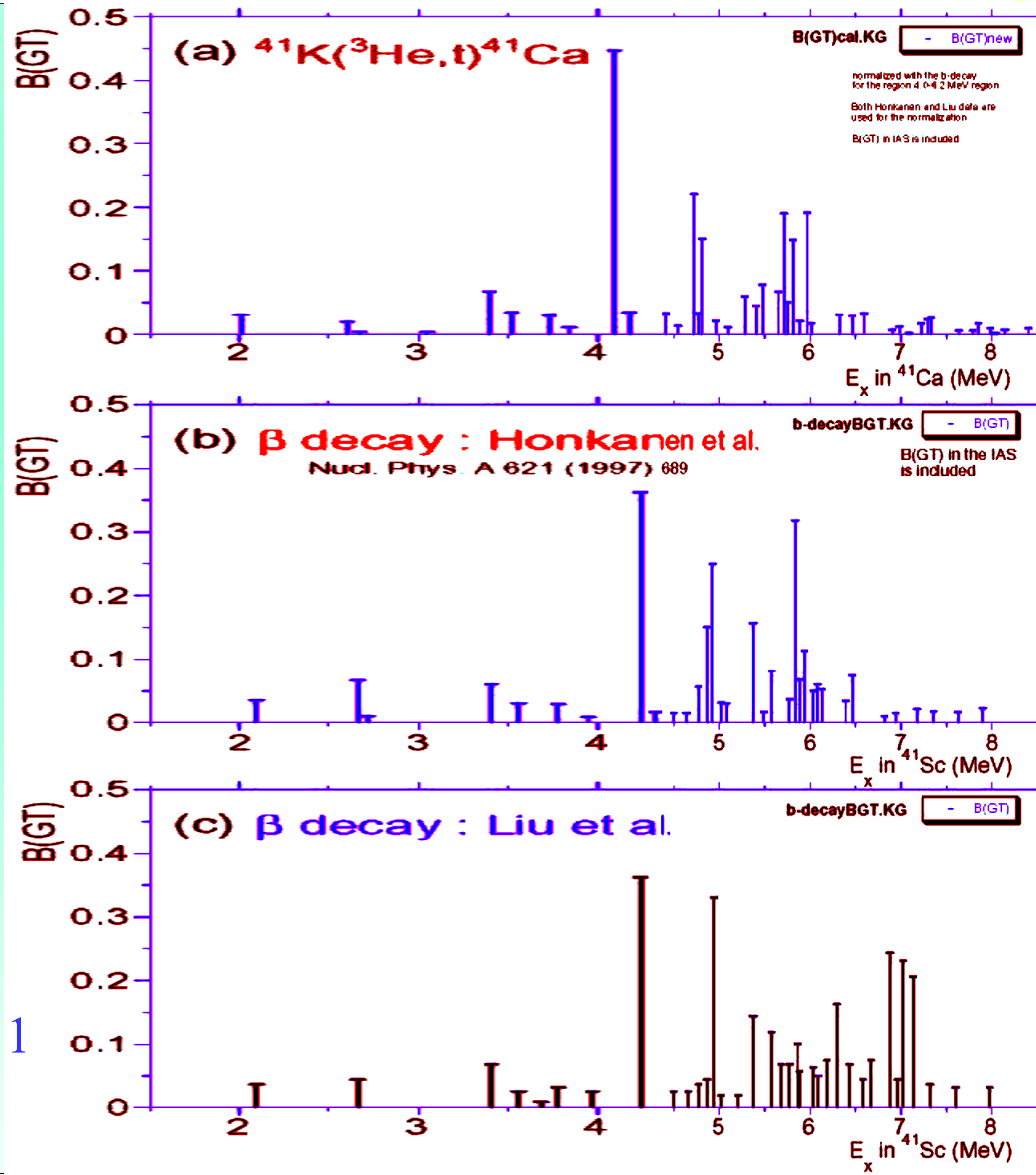


Comparison of two β-decay results

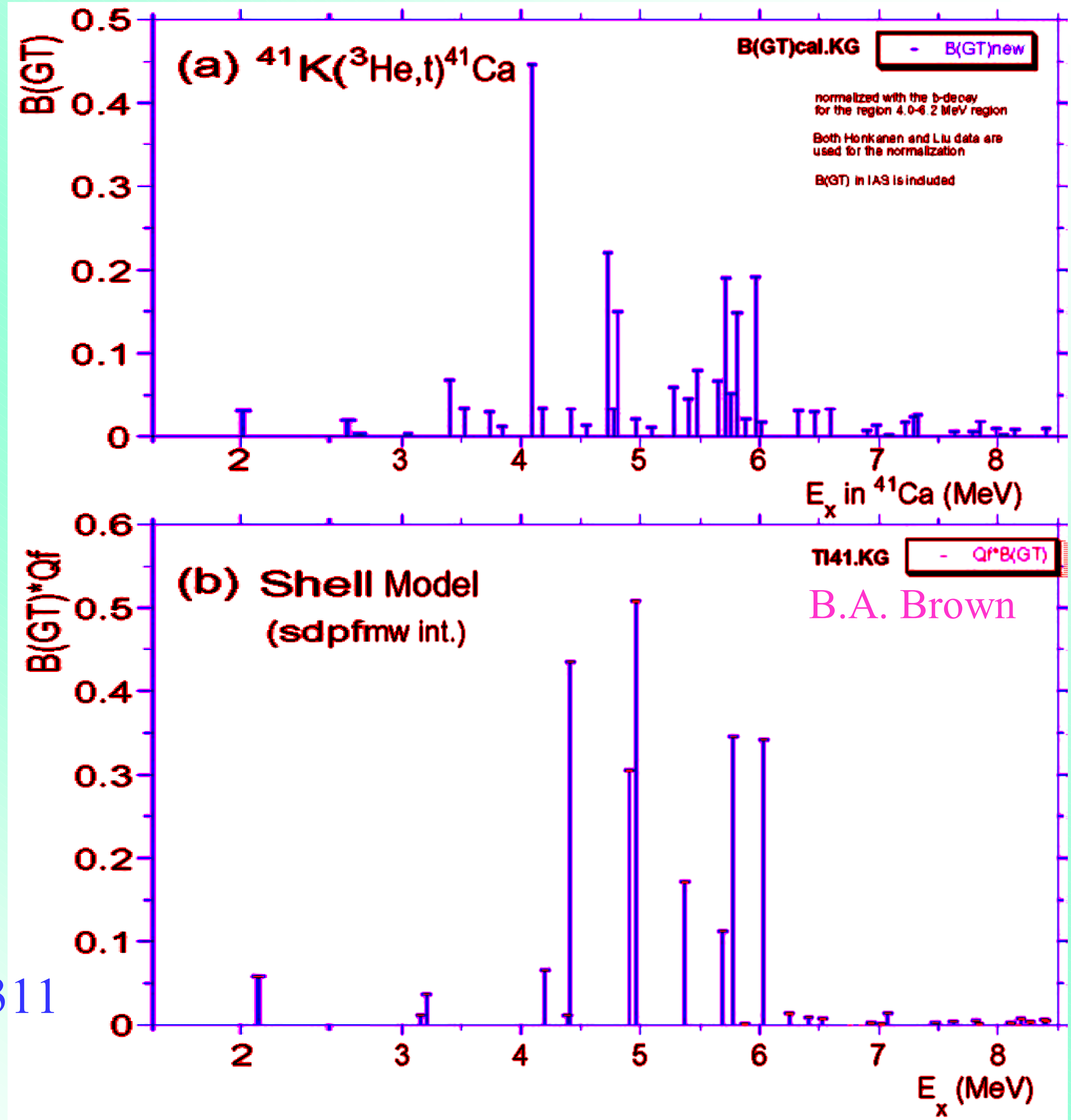


Comparison:
$^{41}K(^{3}He,t)^{41}Ca$
&
^{41}Ti β-decay

Y. Fujita et al.,
PRC 70 ('04) 054311

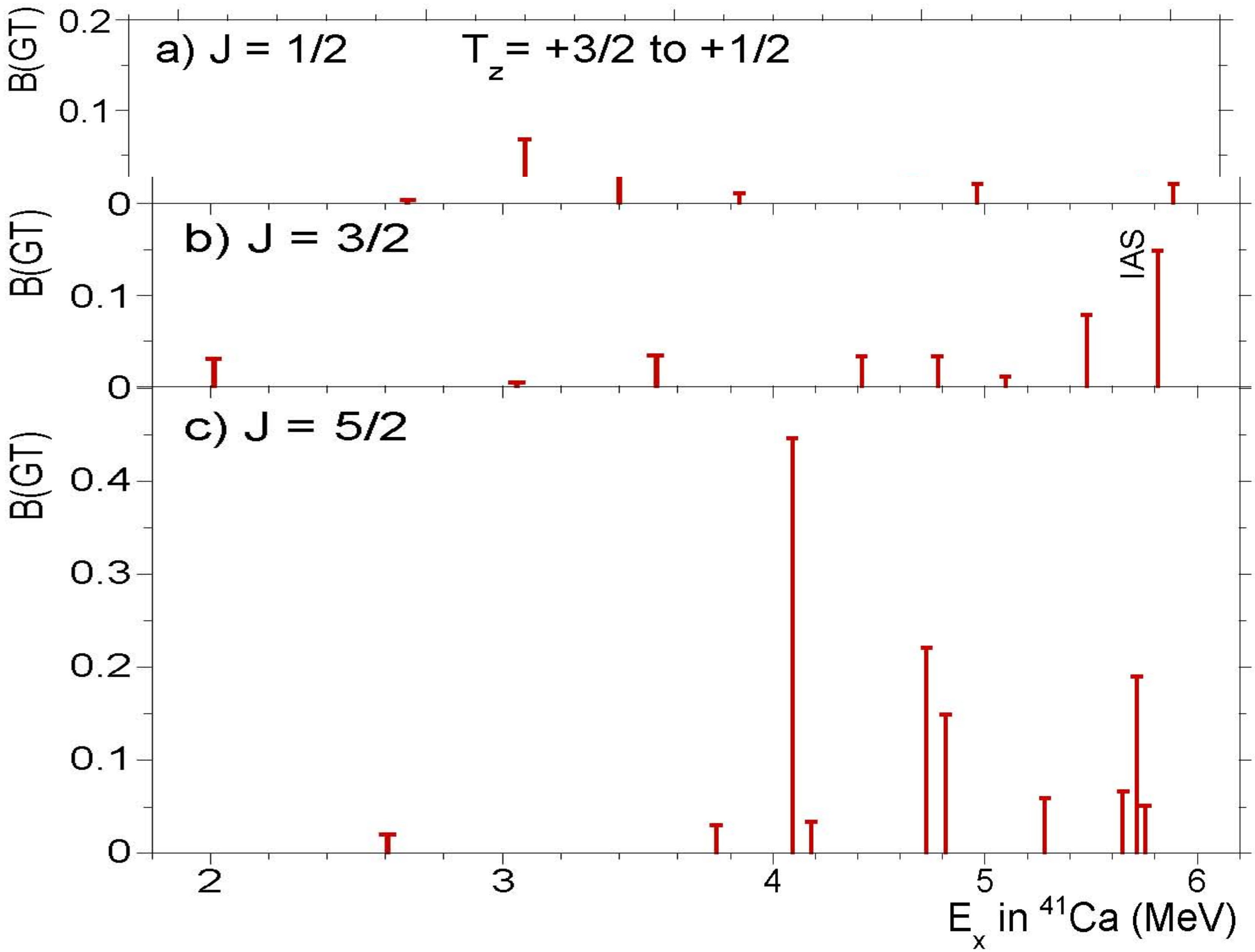


Comparison: $^{41}K(^{3}He,t)^{41}Ca$ & Shell Model



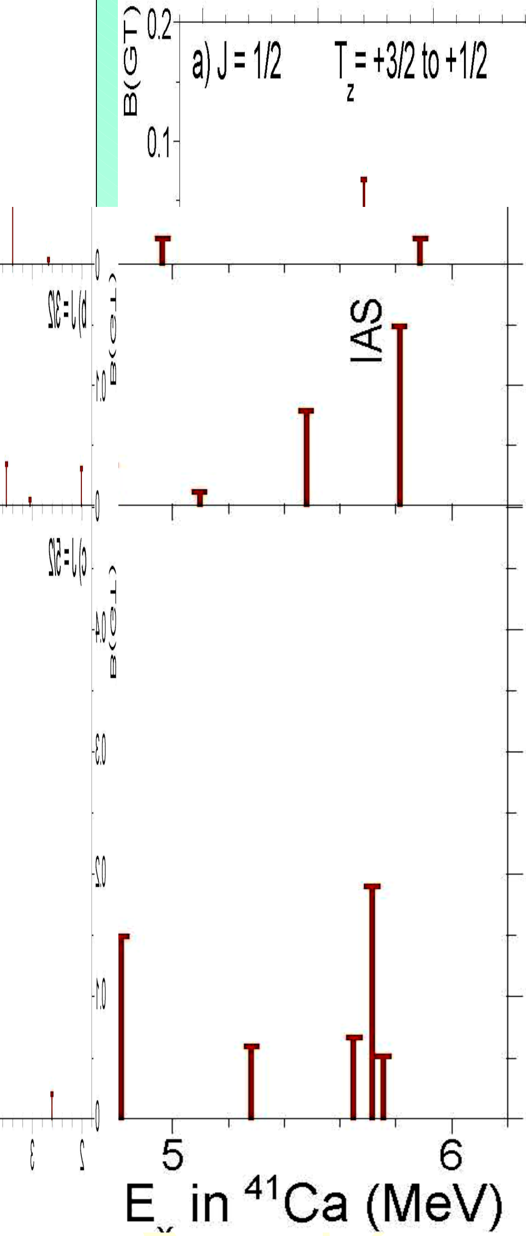
Y. Fujita et al., PRC 70 ('04) 054311

(^{3}He,t) B(GT) : *J* = 1/2, 3/2, 5/2

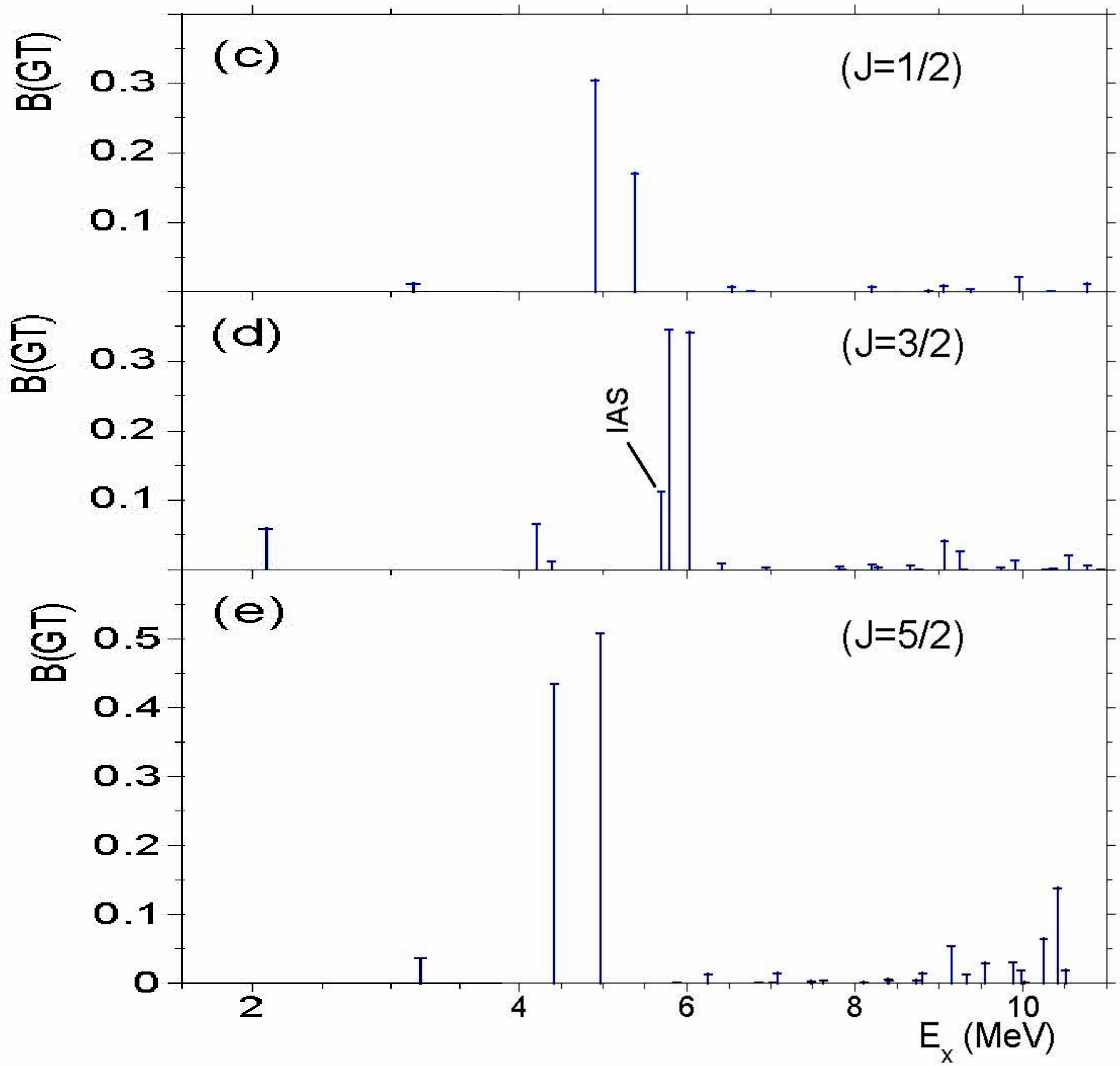


Exp. & SM B(GT) : *J* = 1/2, 3/2, 5/2

Exp.



SM cal.

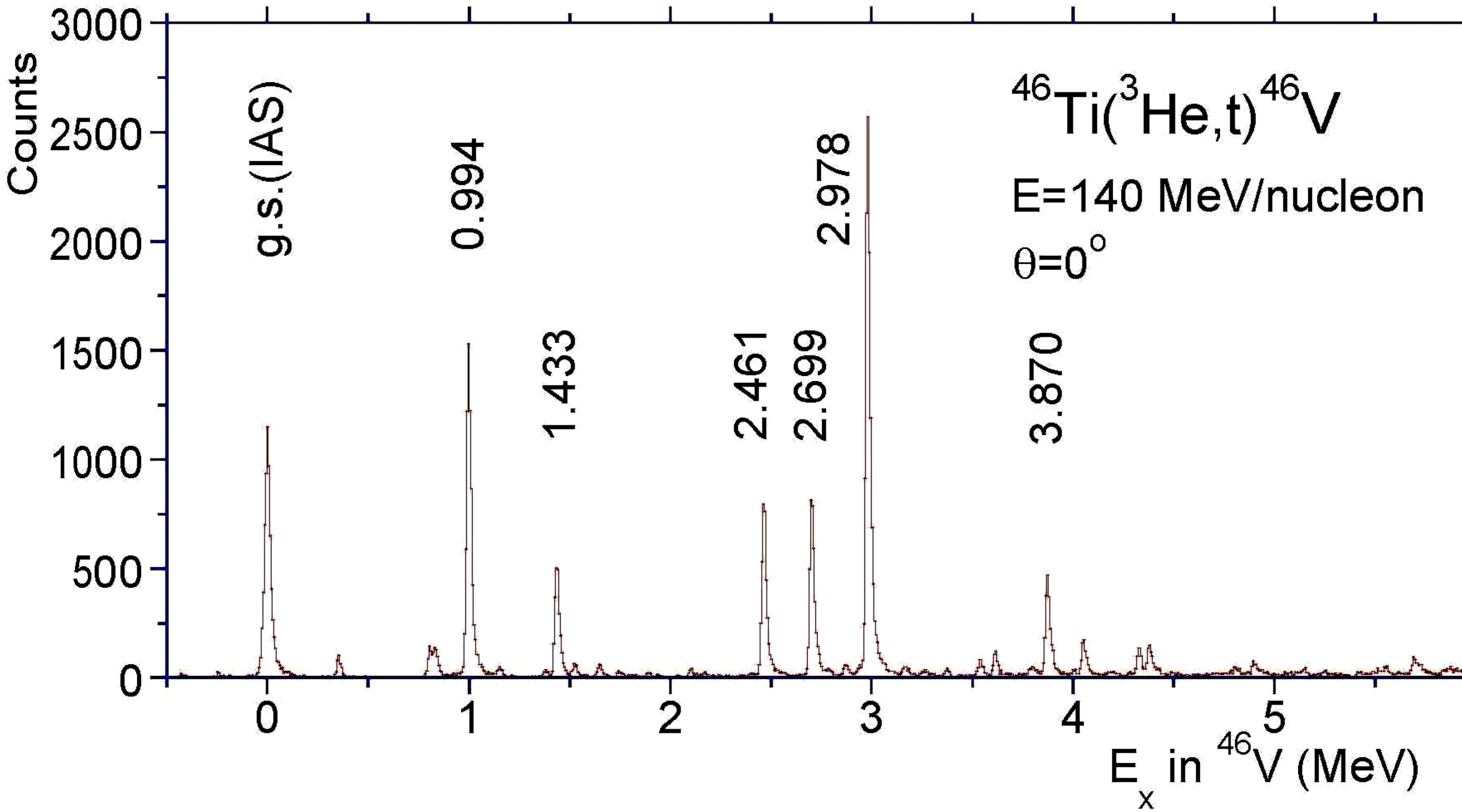


**A=46, T=0, 1 system

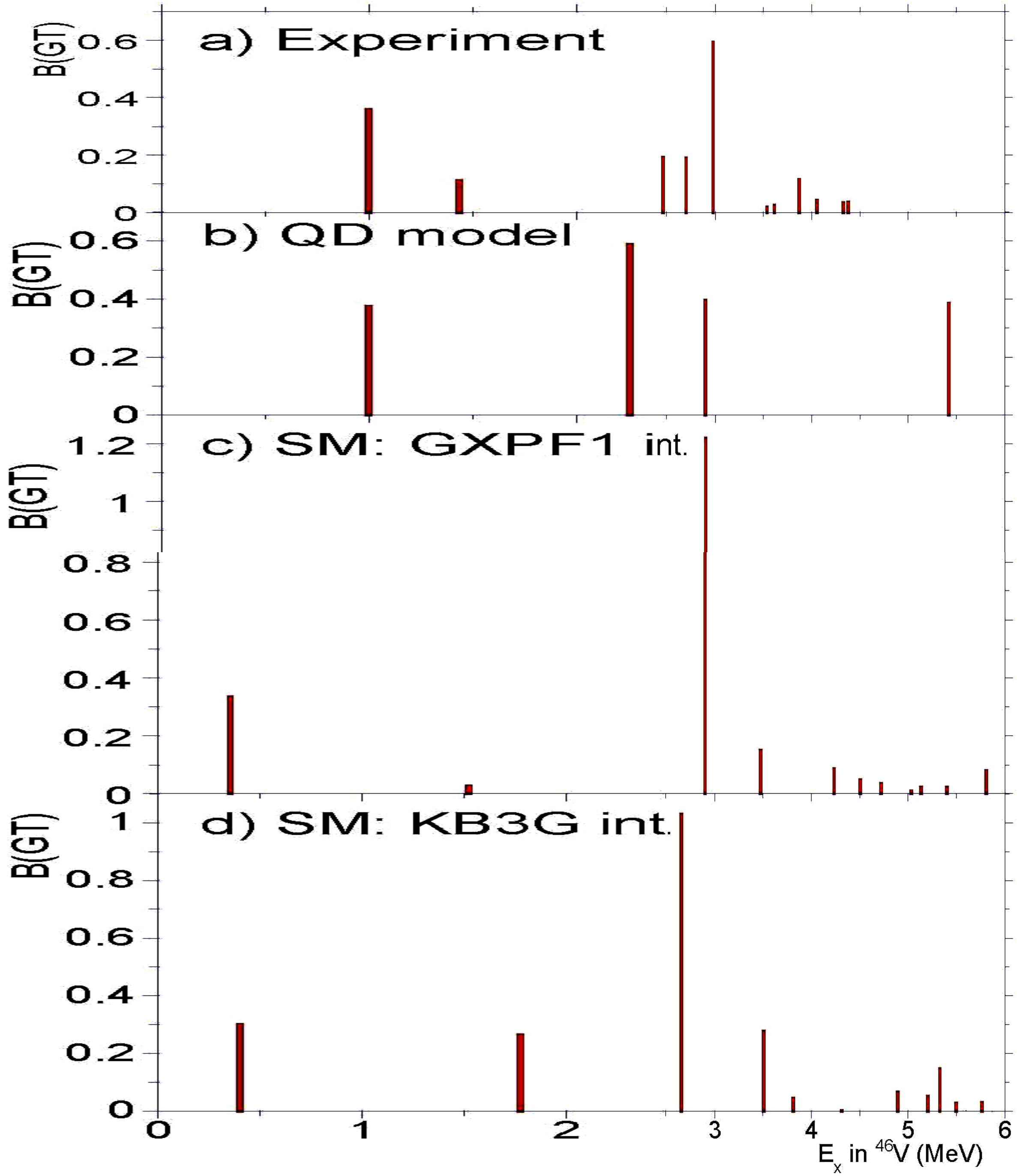
$^{46}Ti(^{3}He,t)$

T. Adachi et al.

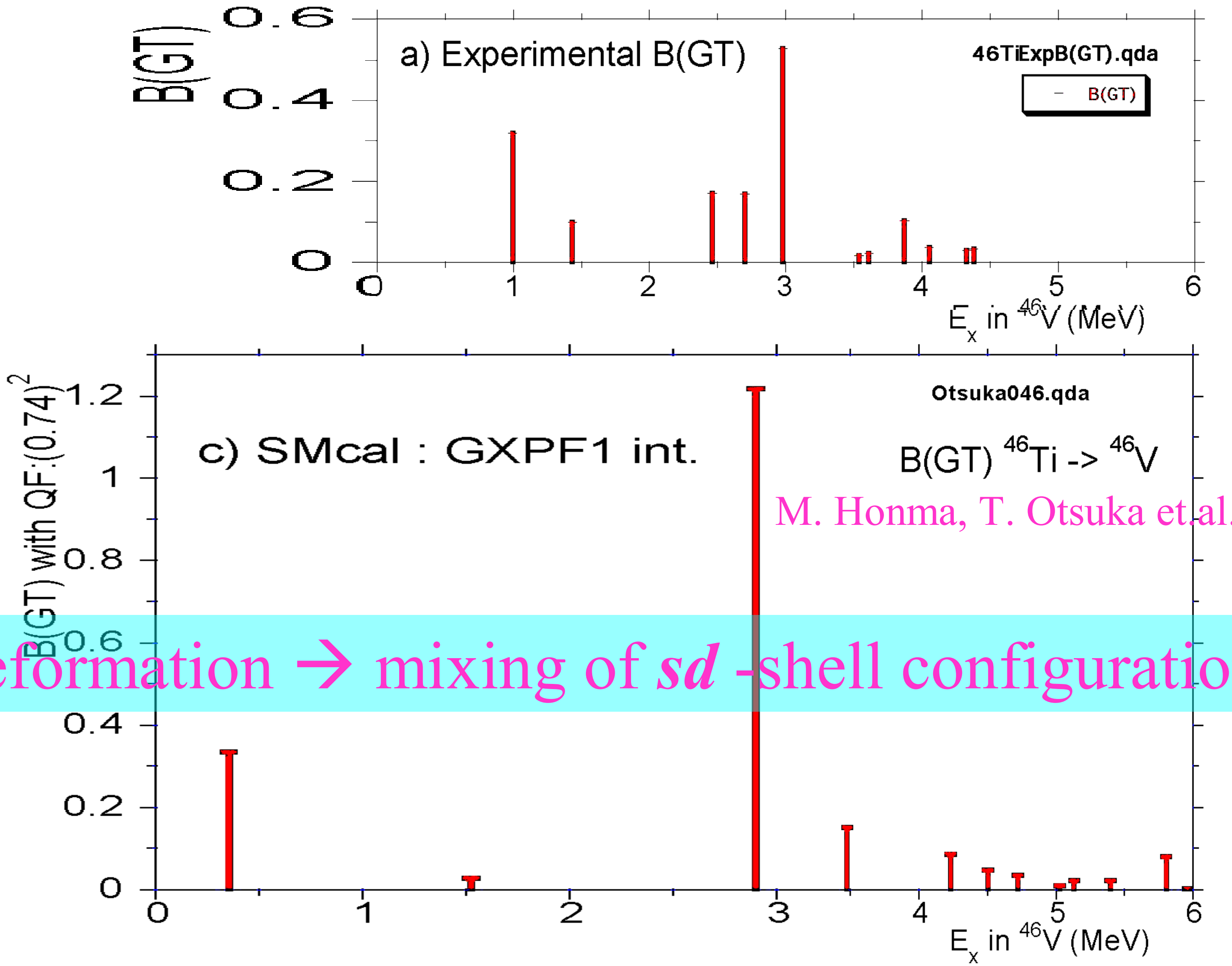
PRC in press



B(GT) Experiment vs Calculations



B(GT) : Exp. vs. SM

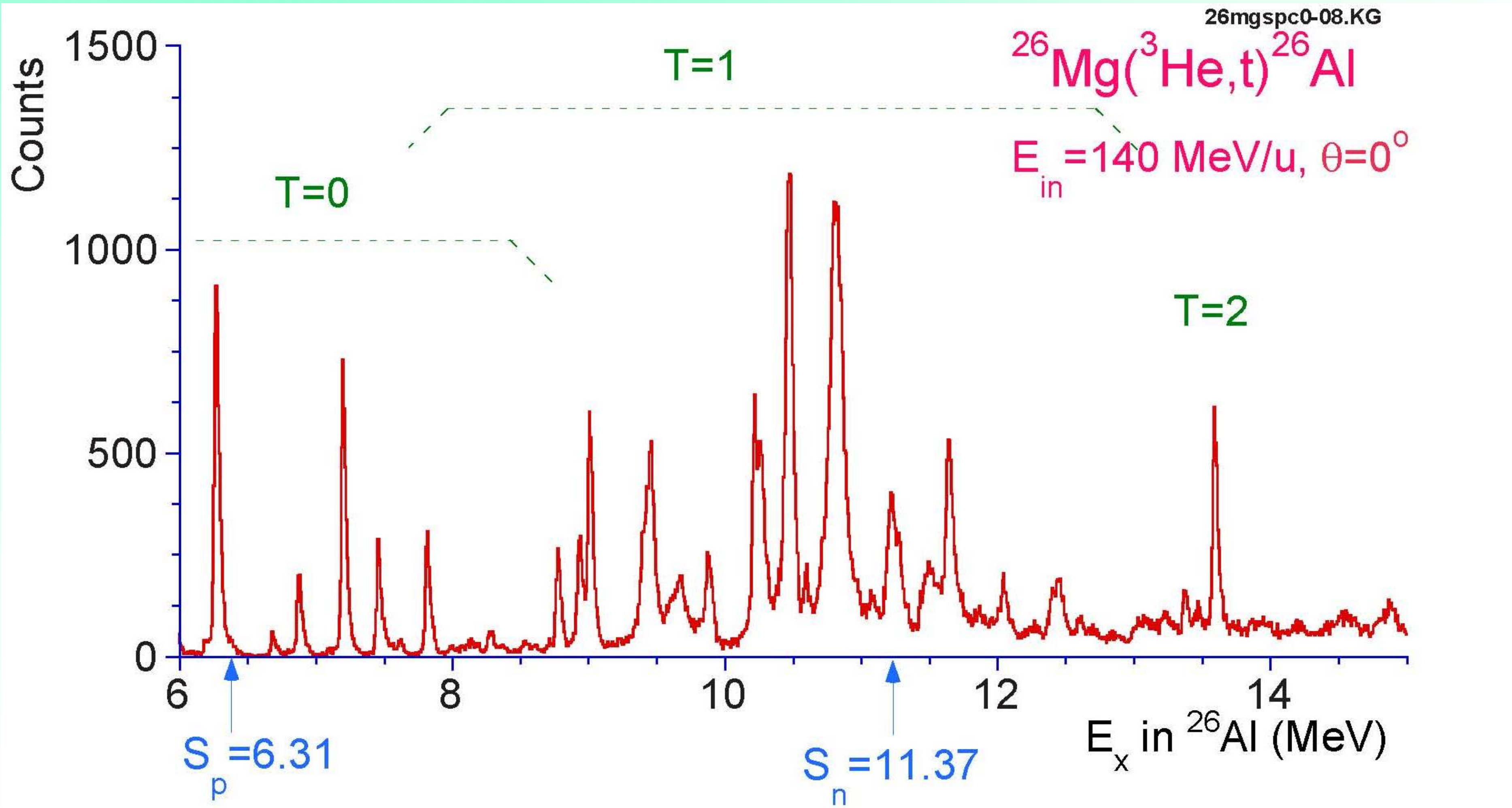


M. Honma, T. Otsuka et.al.

deformation → mixing of *sd* -shell configurations

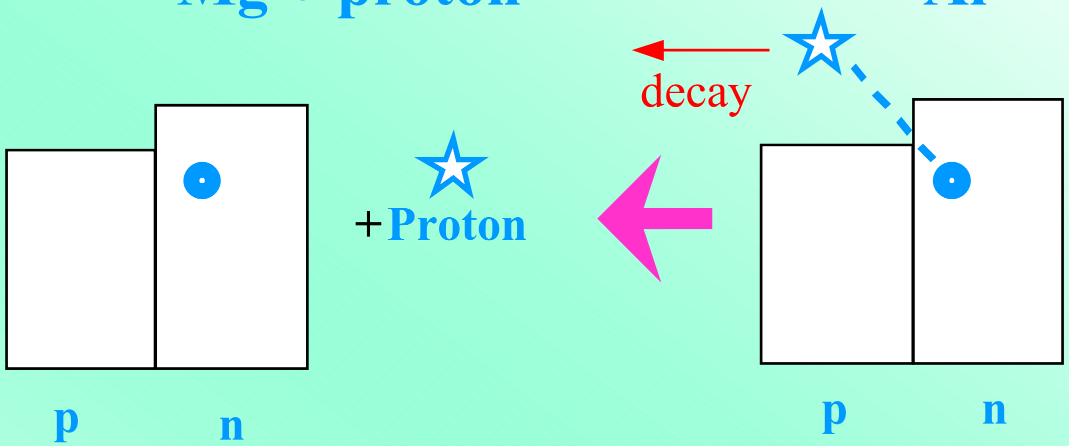
**"Width" represents a lot !

$^{26}Mg(^{3}He,t)$ spectra



Importance of Isospin : *p*-decay of ^{26}Al

^{25}Mg + proton ^{26}Al



T_z : 1/2 + (-1/2) = 0

T : 1/2 + 1/2 = 0 or 1

3/2 + 1/2 = 1 or 2

#S_p (p-sep. energy) in ^{26}Al : 6.31 MeV

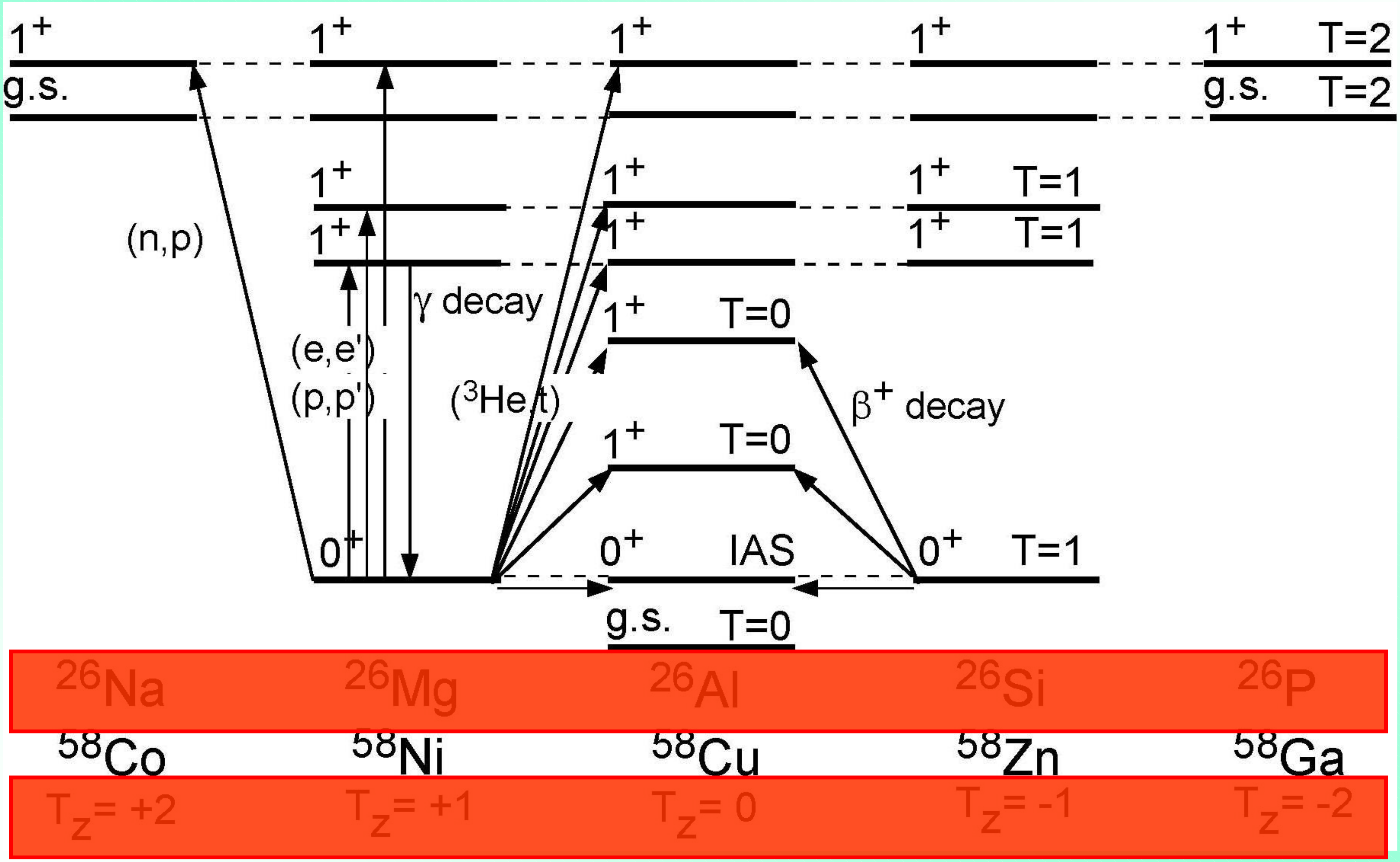
#T=3/2 state in ^{25}Mg : E_x > 7.79 MeV

→ effective S_p in ^{26}Al

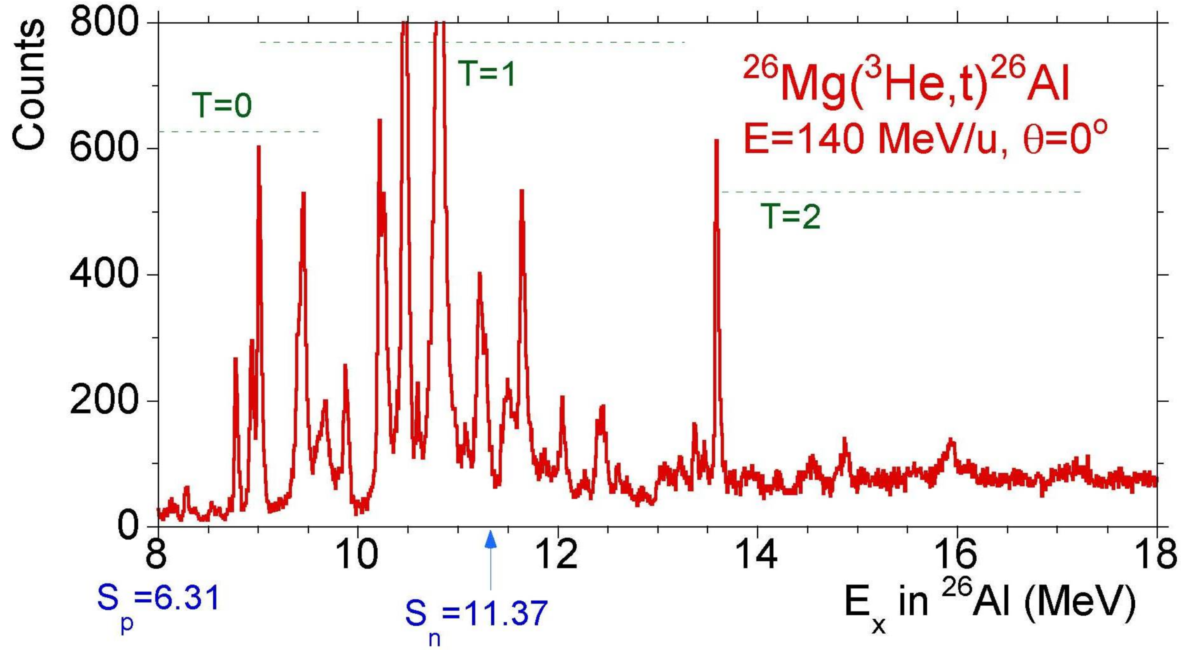
for T = 0, 1 states : E_x = 6.31 MeV

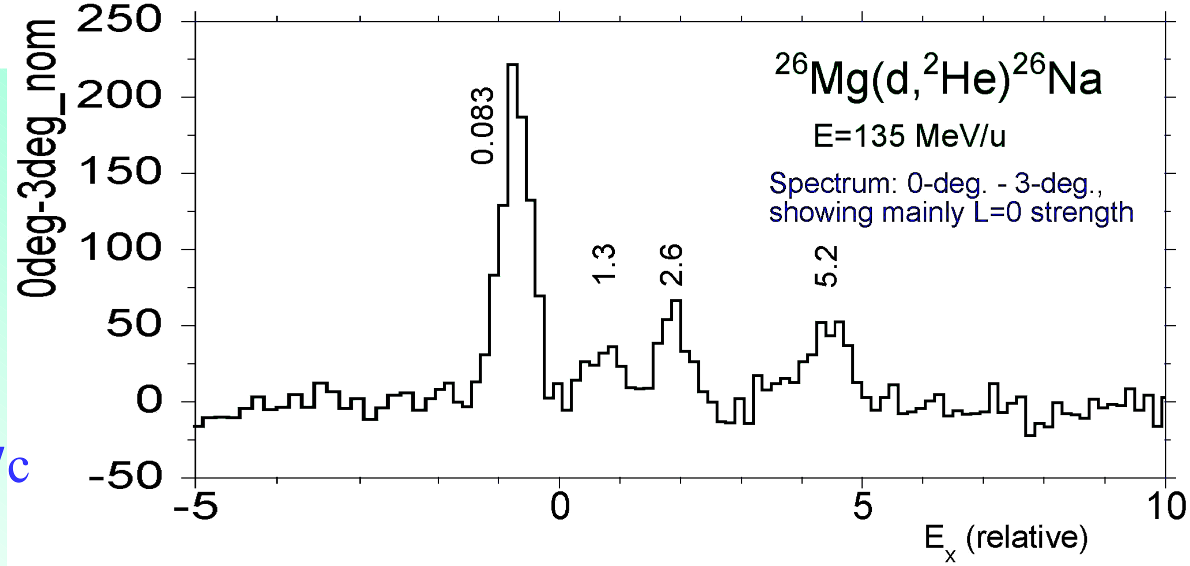
for T = 2 states : E_x = 14.1 MeV

Analog Relationship (T=0,1,2)



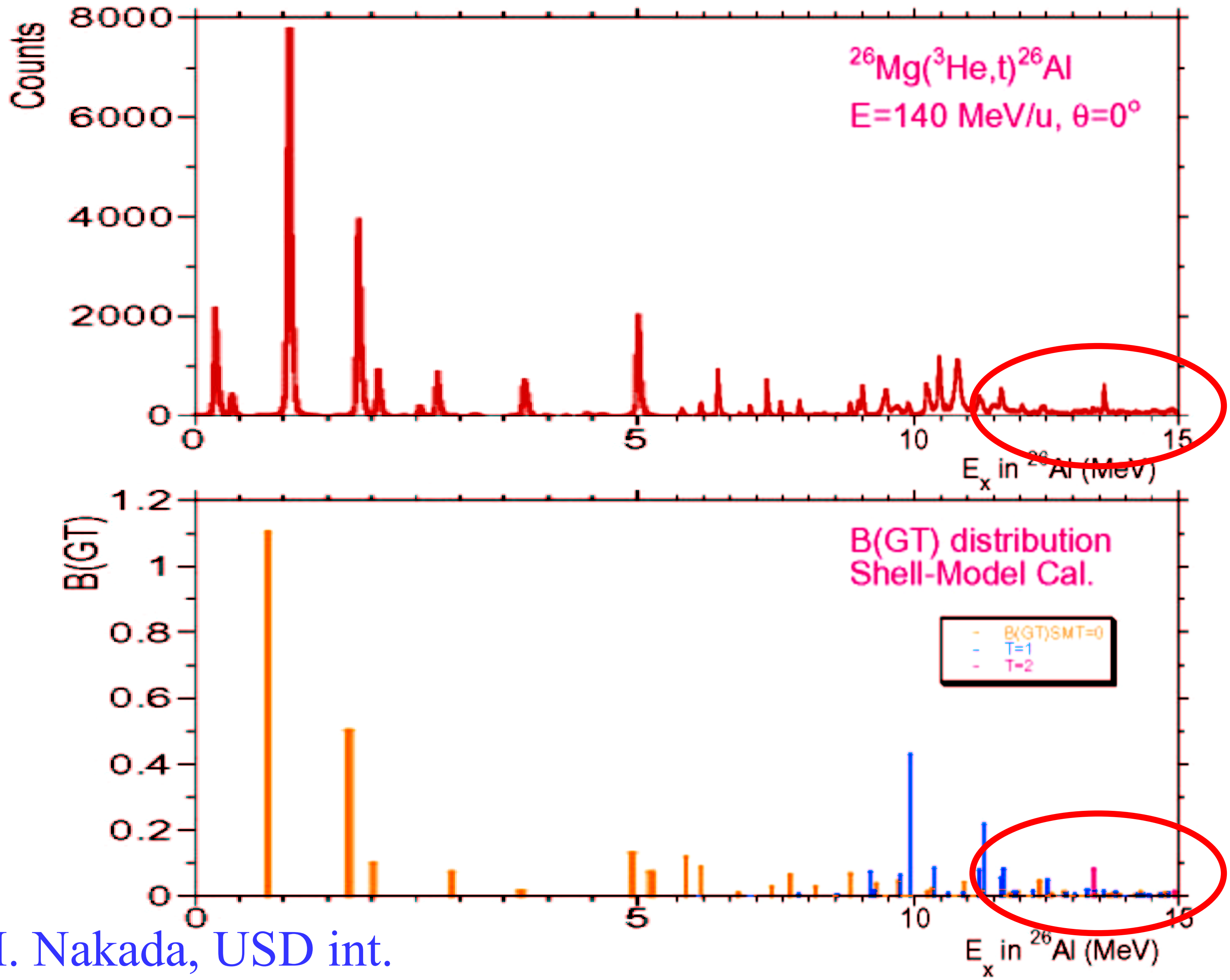
Comparison: $^{26}Mg(^{3}He,t)^{26}Al$ and $^{26}Mg(d,^{2}He)^{26}Na$





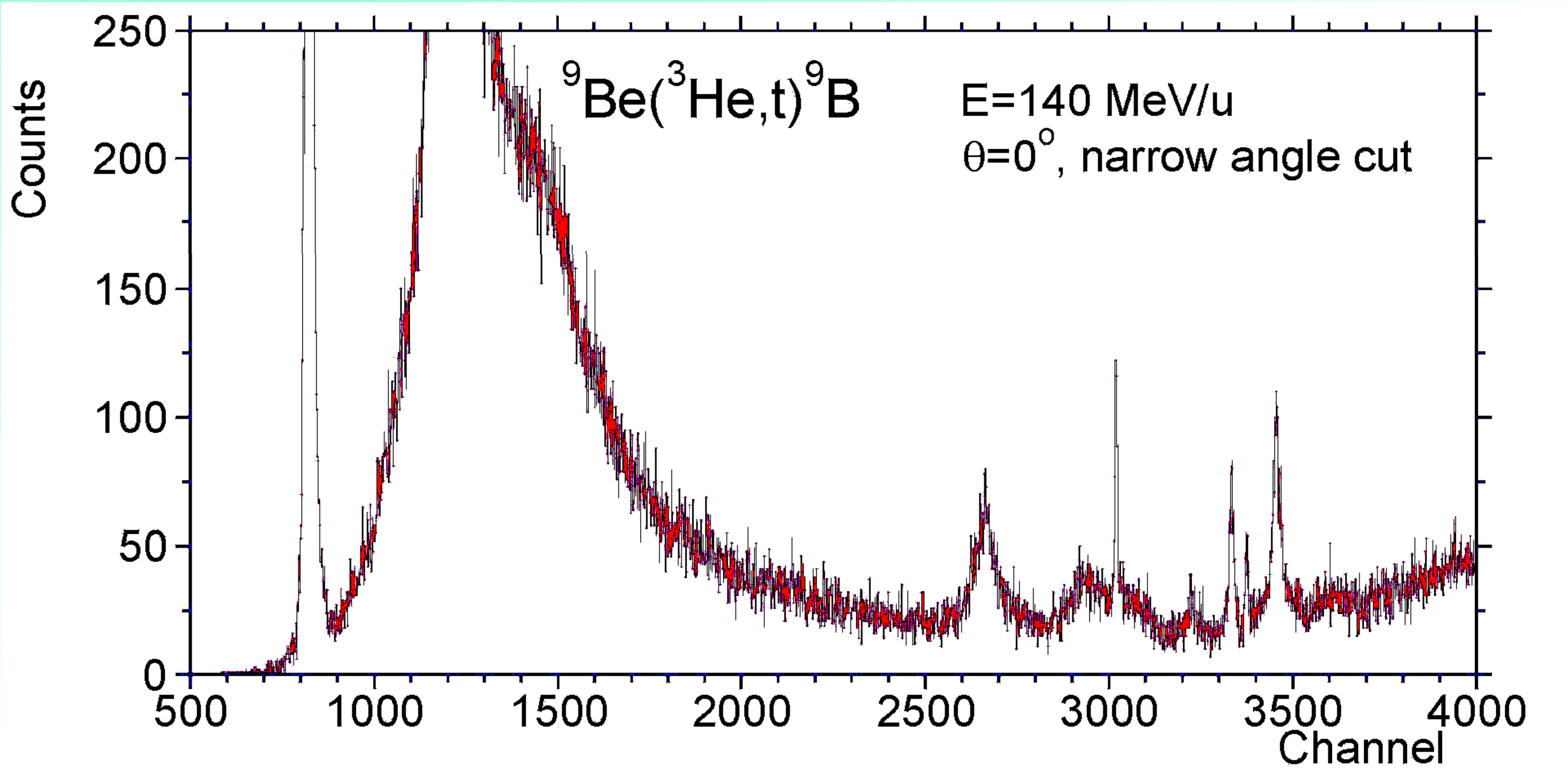
T. Niizeki et al.,
N.P. A577 (1994) 37c

$^{26}Mg(^{3}He,t)$ spectrum and SM cal. B(GT)

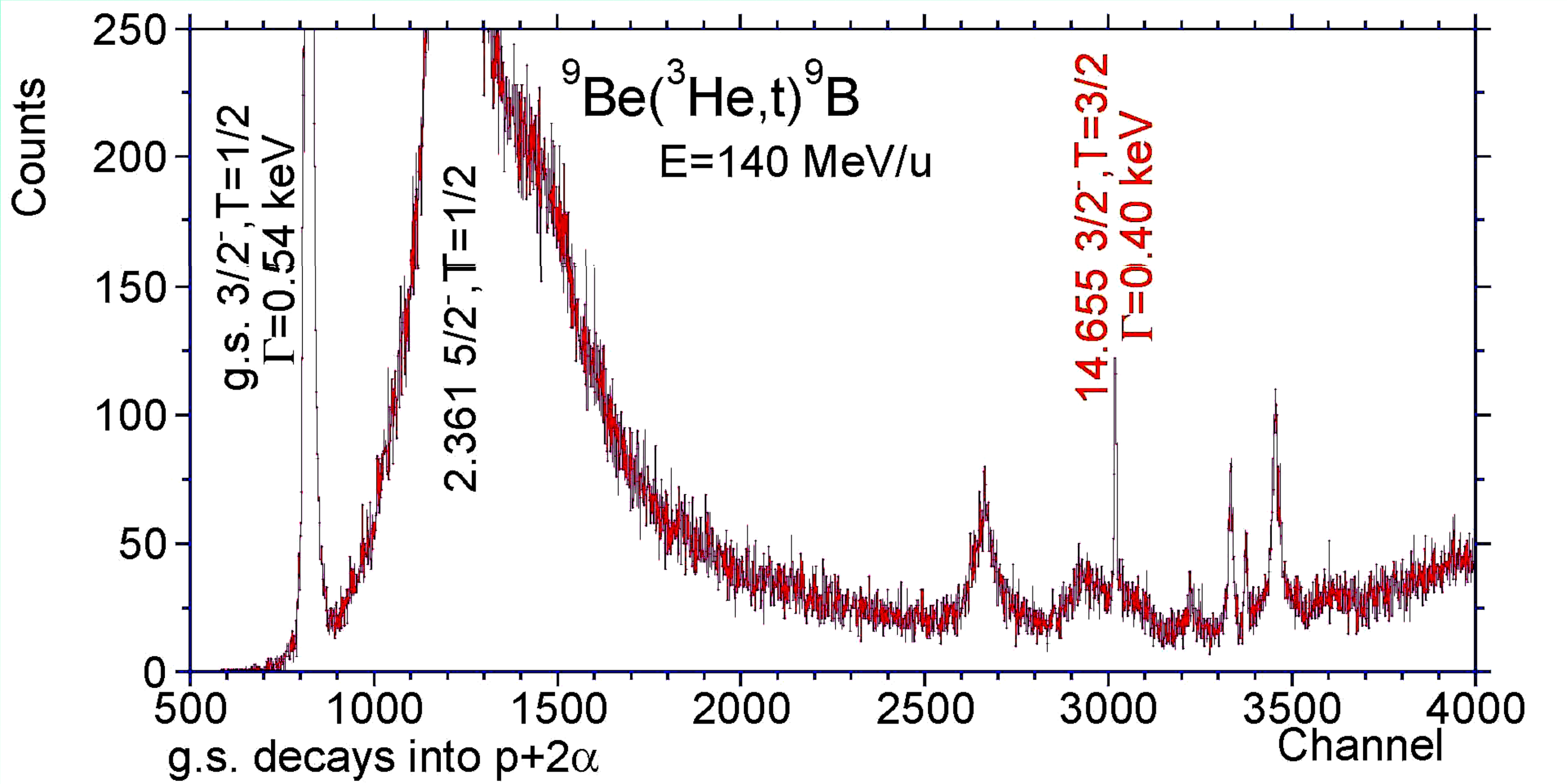


by H. Nakada, USD int.

$^9Be(^3He,t)^9B$ spectrum (at various scales)



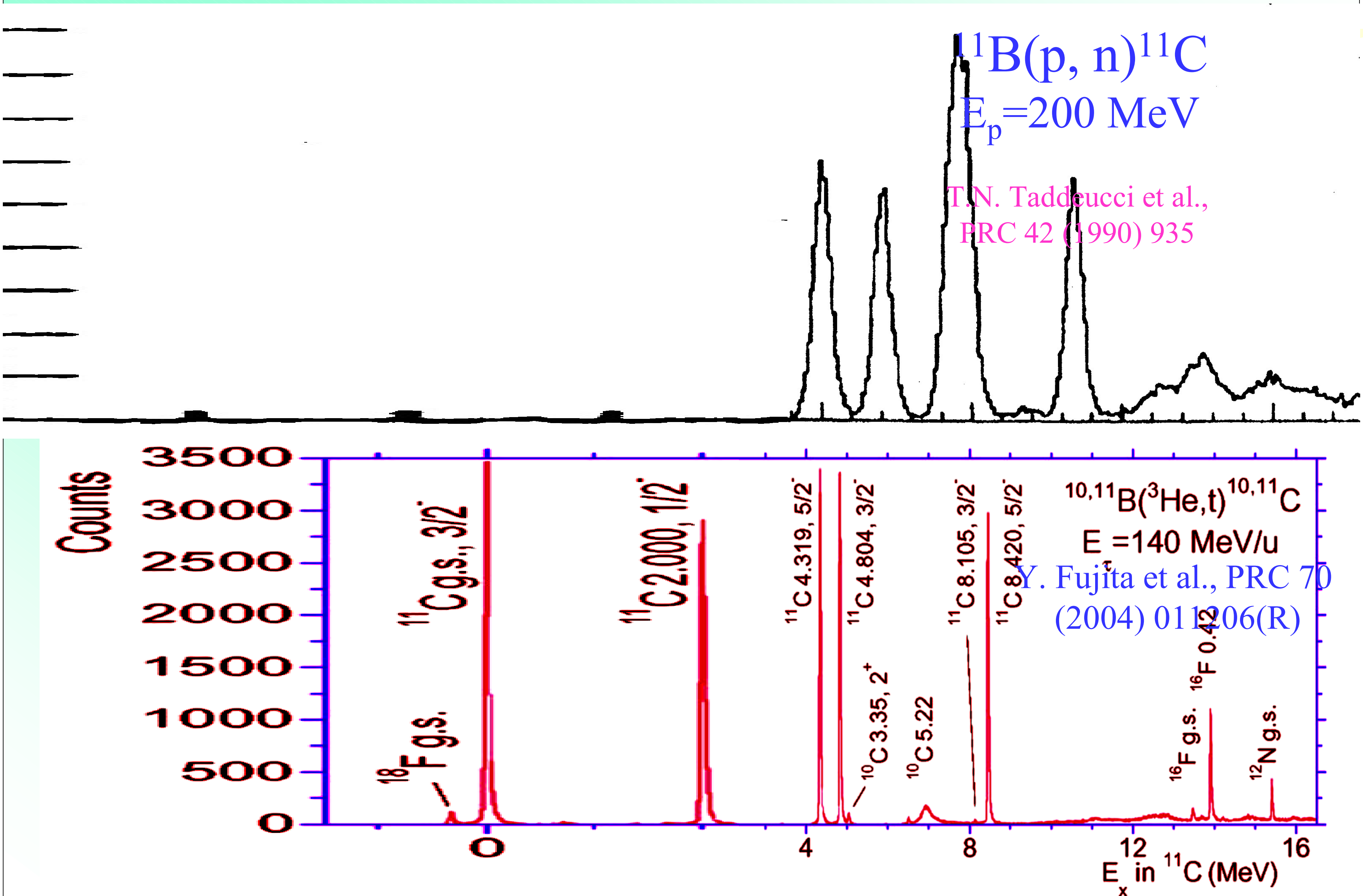
$^{9}Be(^{3}He,t)^{9}B$ spectrum (II)



Isospin selection rule prohibits
proton decay of **T=3/2** state!

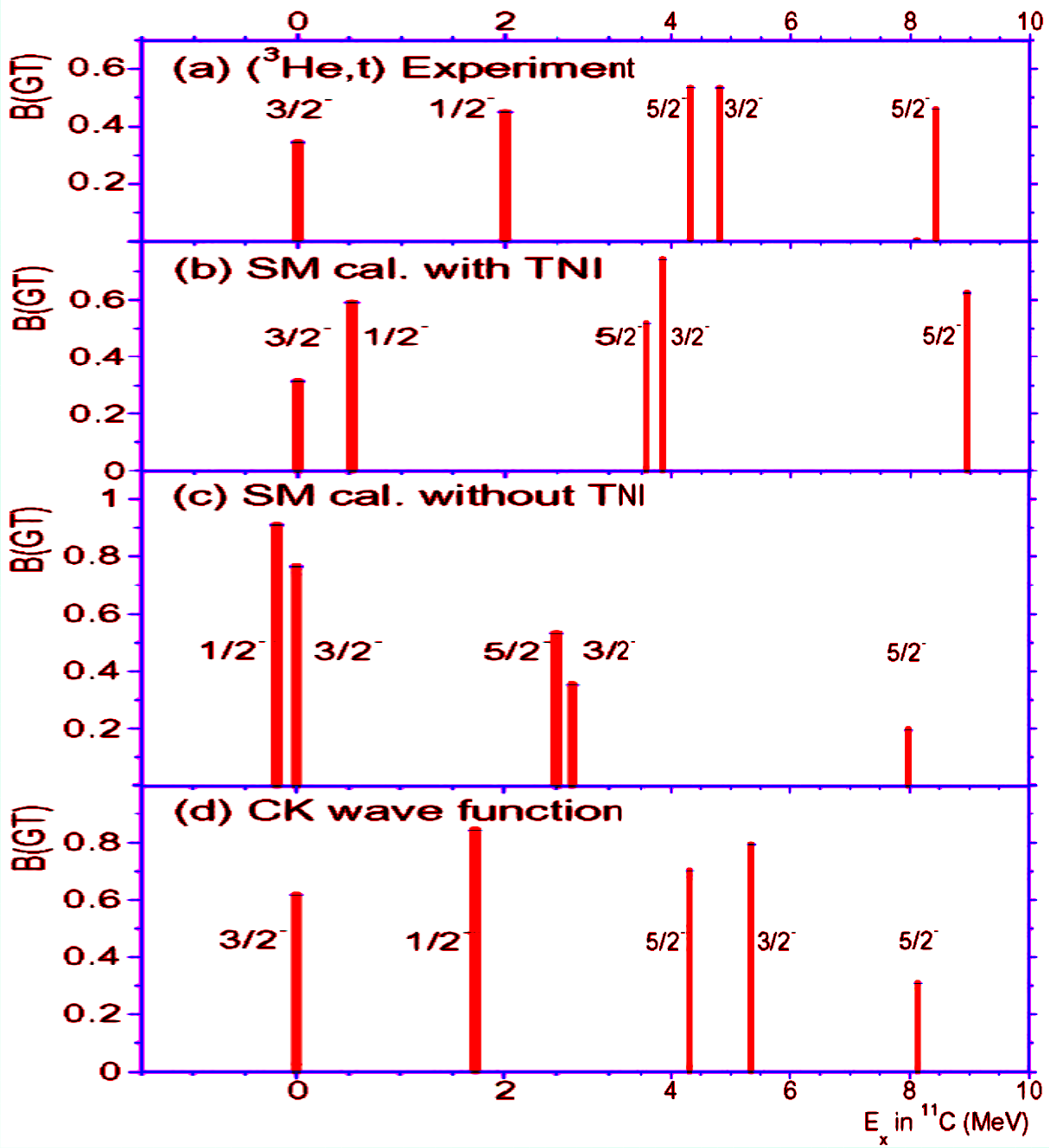
**Limitation of the Space

(p,n) and (^{3}He,t) Spectra on ^{11}B



Comparison: $^{11}B(^{3}He,t)^{11}C$ & Shell Models

non-core SMcal:
By Navratil & Ormand
Phys. Rev. C 68 ('03)034305



Y. Fujita et al., PRC 70 (2004) 011206(R)

Summary

*Observed strengths are well reproduced

(by including the recommended

"quenching factor")

*Fragmentation of strengths:

A=23, 26	very good !
A=28	not so well
A=41	sd & f should be included
A=46	deformed: fp and sd are needed
A=58	GXPF1 reproduced well !

*Widths of states: more sophisticated !?