High-resolution Study of Gamow-Teller Transitions in the ^{46,47,48}Ti(^{3}He,t)^{46,47,48}V Reactions

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Outline

- The importance of Gamow-Teller (GT) transitions
- Main features of Gamow-Teller (GT) / Fermi (F) transitions
- Transition probabilities: B(GT), B(F)
- Measuring B(GT)s : beta-decay and charge exchange reactions
- High resolution (3He,t) experiments at RCNP : ^{46,47,48}Ti(3He,t)^{46,47,48}V
- Results
- Conclusions

Why are GT transitions important?

Gamow-Teller (GT) transitions are the most common weak interaction processes.

Good Probe to Study some Key questions in Nuclear Structure.

-Because of their simple character

Astrophysical Interest

- At the core collapse stage of type II supernovae, Gamow-Teller (GT) transitions in pf-shell nuclei play an important role *

* K. Langanke et al, Rev. Mod. Phys. **75, 819 (2003).**

The main features of GT transitions

GT transitions are governed by the $\sigma\tau$ operator.

The $\sigma\tau$ operator has no spatial component -> transitions between states with similar spatial shapes are favoured.

They are of isovector (IV) nature.

Allowed GT transitions $\Delta T = 1$, $\Delta S = 1$ and $\Delta L = 0$,

they also have $\Delta J = 1$ and no parity change.

Isospin quantum number T plays an important role:

$T=T_0$ states are connected with T_{0-1}, T_0 and T_{0+1} states

They can be studied either in β decay (weak interaction) or in Charge Exchange (strong interaction) reactions.

The main features of F transitions

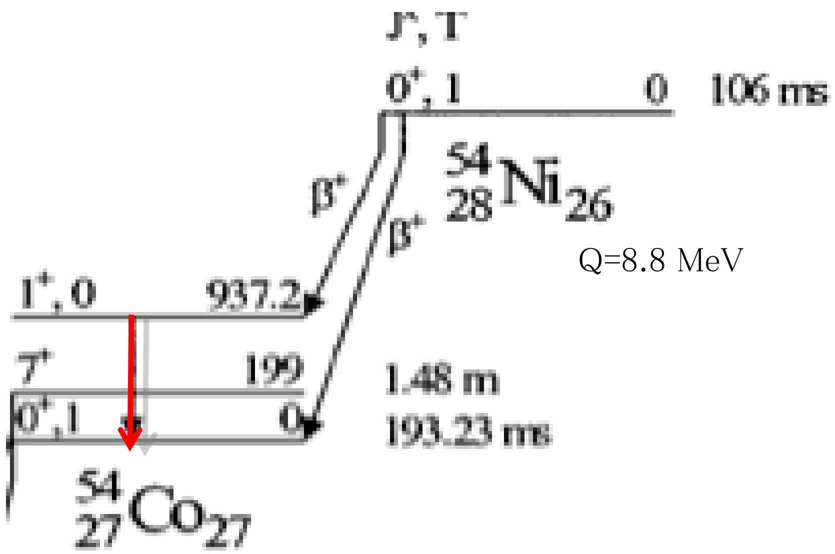
Fermi transitions are due to the τ operator. Hence only a single state (Isobaric Analog State, IAS) is populated in the final nucleus.

They are of isoscalar (IS) nature with $\Delta T = 1$, $\Delta S = 0$ and $\Delta L = 0$, they also have $\Delta J = 0$ and no parity change.

They can be studied either in β decay (weak interaction) or in Charge Exchange (strong interaction) reactions.

Measuring B(GT)s-(I)

β-decay studies:



The most direct information on B(GT)
A weak interaction process,

The accessible excitation energy is limited by the decay Q-value.

Measuring B(GT)s-(II)

Charge-exchange Reactions:

Strong interaction process

GT strengths B(GT) can reliably be mapped up to higher excitations if a "standard B(GT) value" from decay is available.

An approximate proportionality between measured cross sections and

B(GT) values has been established in (p,n) reactions.

at incident beam energies > 100 MeV/u at the scattering angle 0 °

$$\frac{d\sigma(0^\circ)_{GT}}{d\Omega} \approx \hat{\sigma}_{GT} \cdot B(GT)$$

*T.N. Taddeucci et. al., NPA469 (1987) 125

(^{3}He,t) type CE reactions

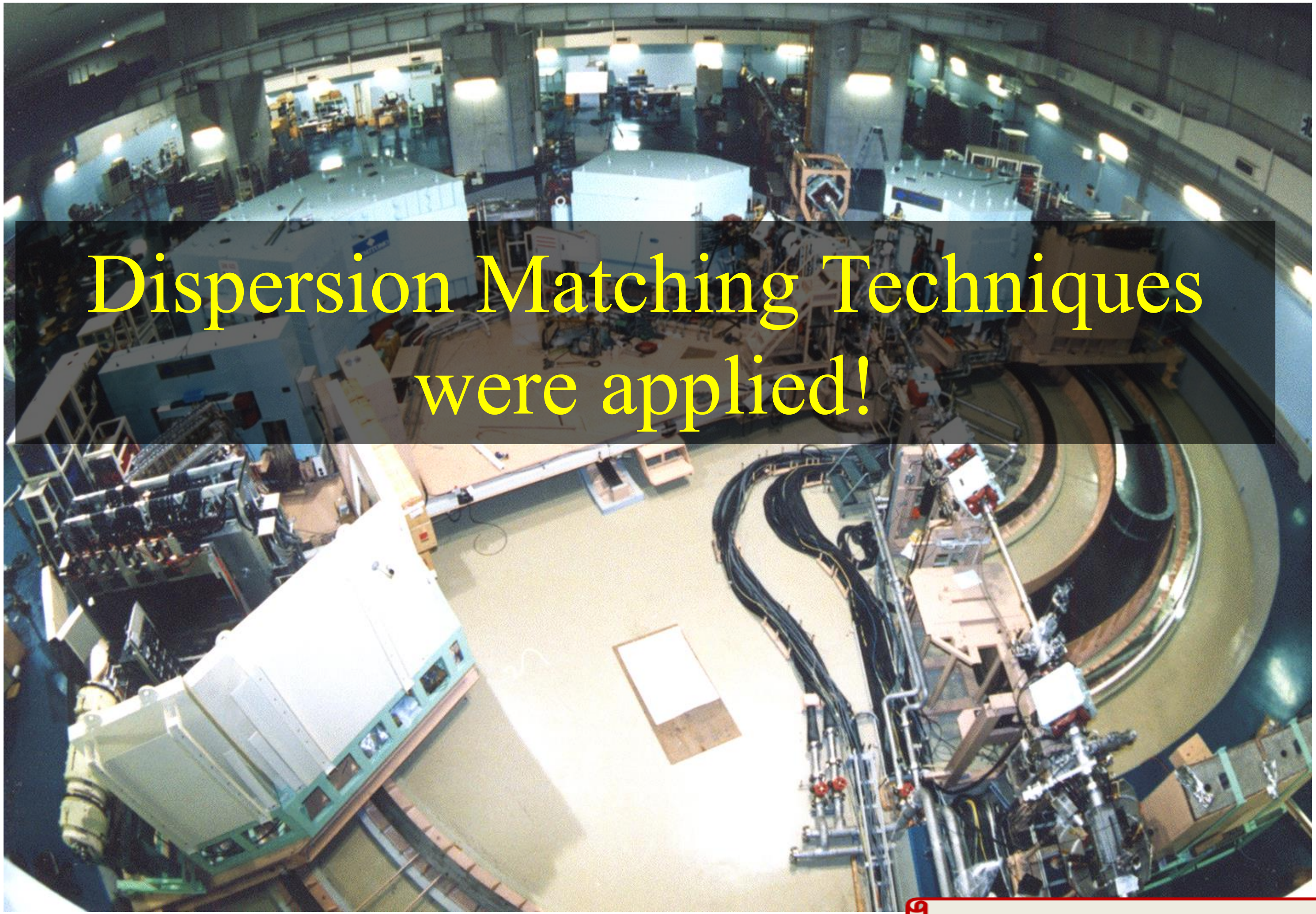
^{46}Ti → 0.92 mg/cm^2

^{47}Ti → 0.85 mg/cm^2

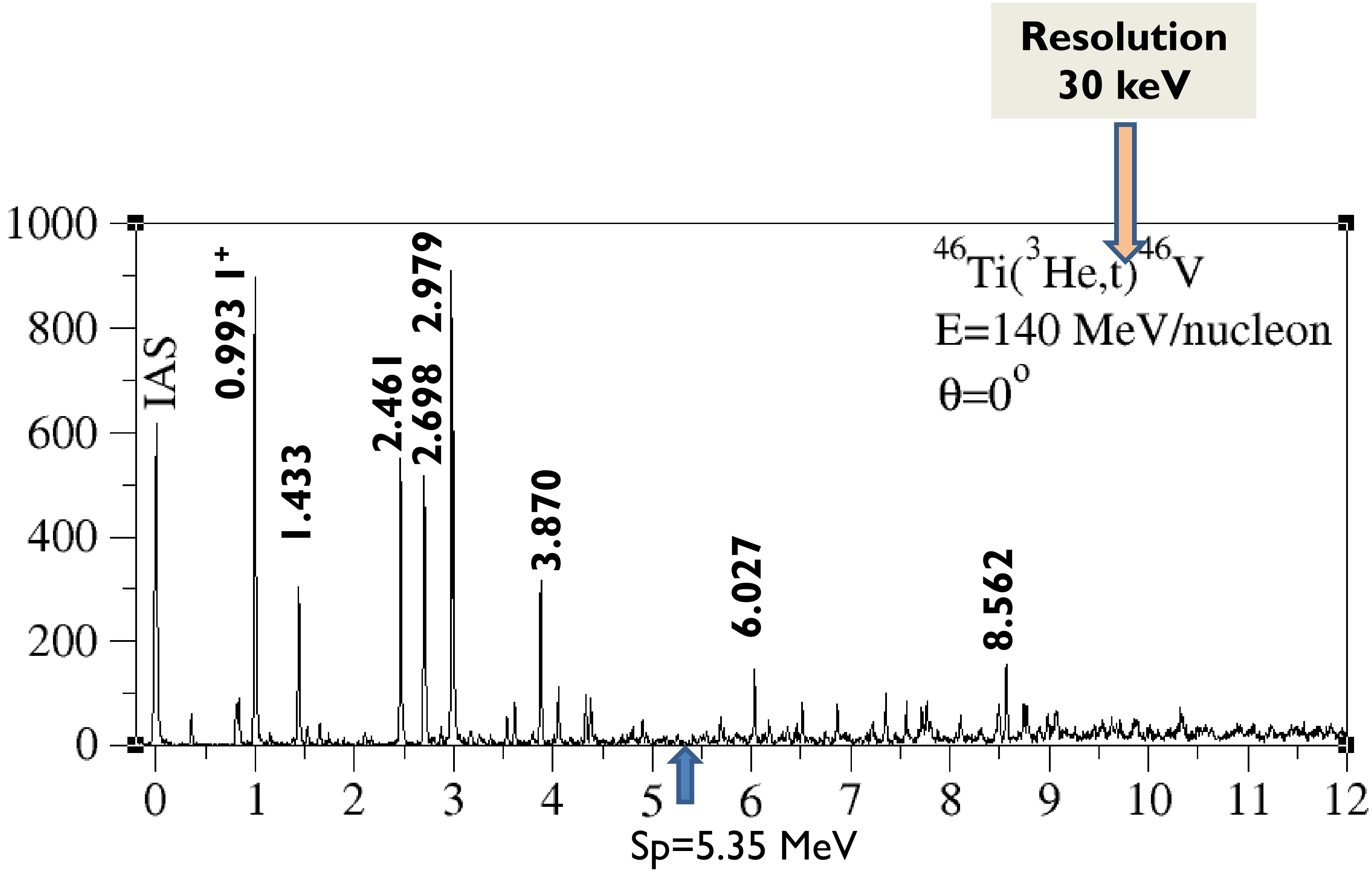
^{48}Ti → 0.50 mg/cm^2

@ 140 MeV/n

Research Center for Nuclear Physics (RCNP)

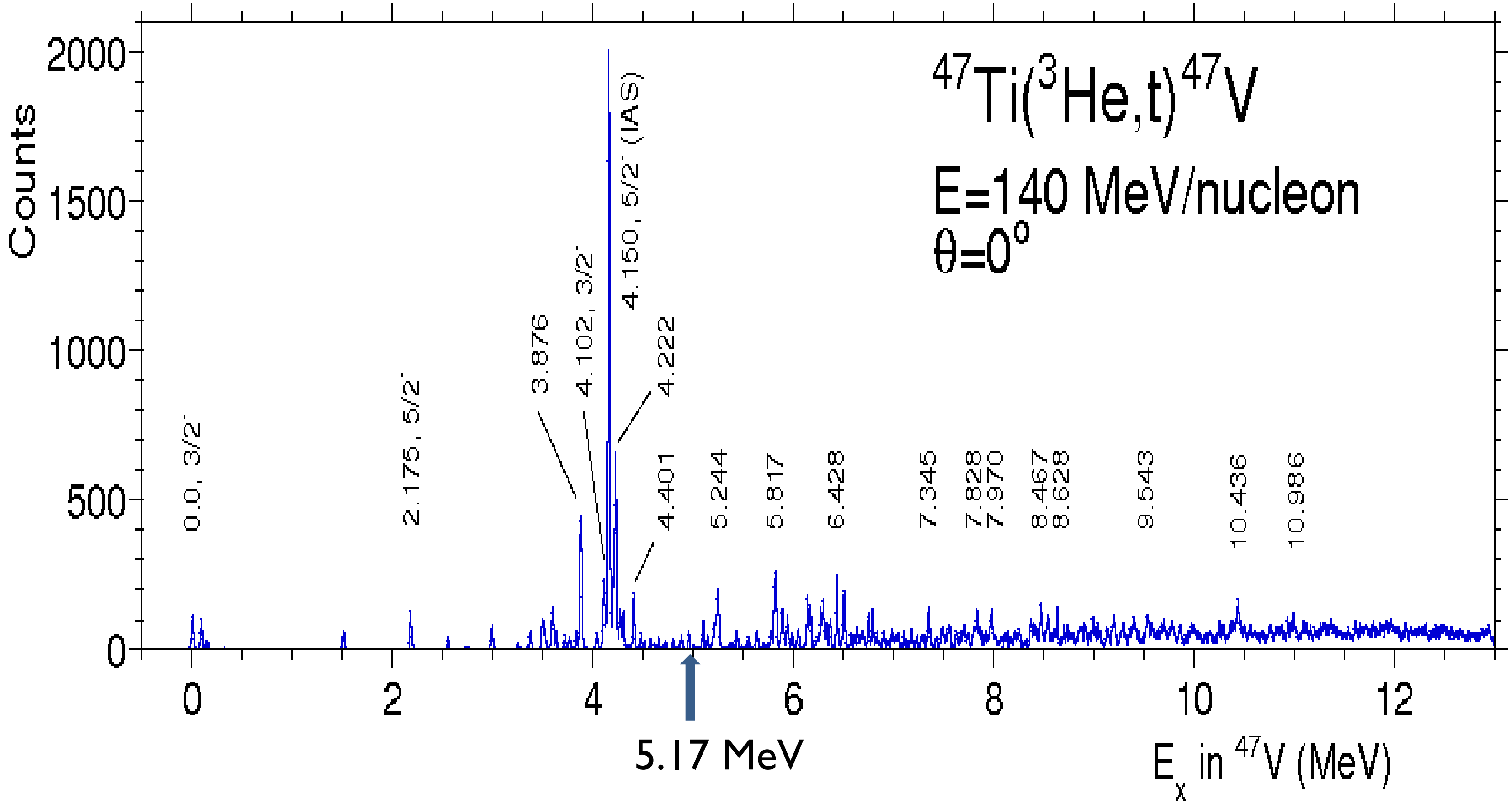


T. Wakasa et al., NIM A482 ('02) 79.



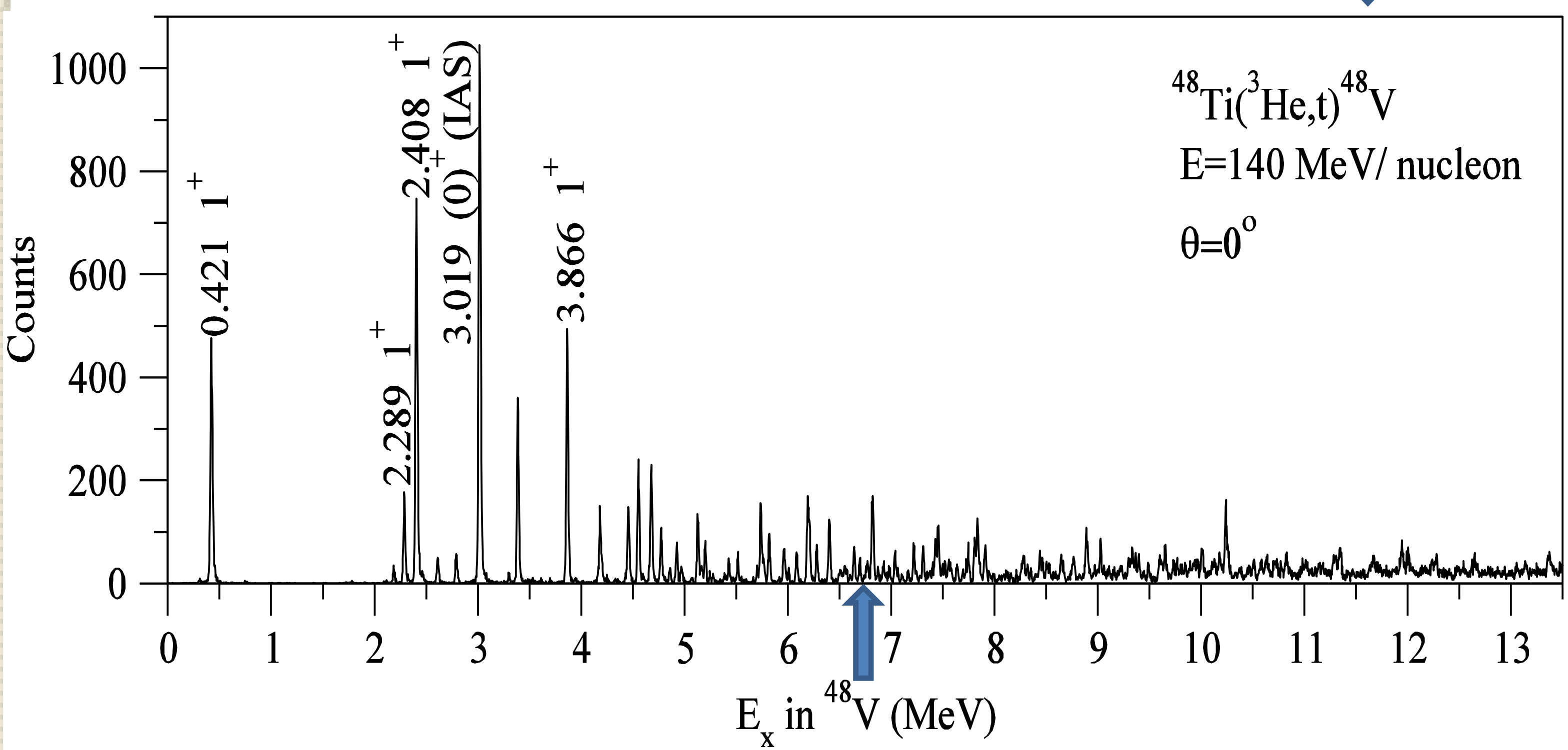
- Adachi T. et. al., Physical Review C 73, 02431 (2006). (Up to 6 MeV)
- Dogan M. et al., MSc Thesis, Istanbul University, 2014, publication – in preparation

Resolution 20 keV



E. Ganioğlu et al., Phy. Rev. C 87, 014321 (2013)

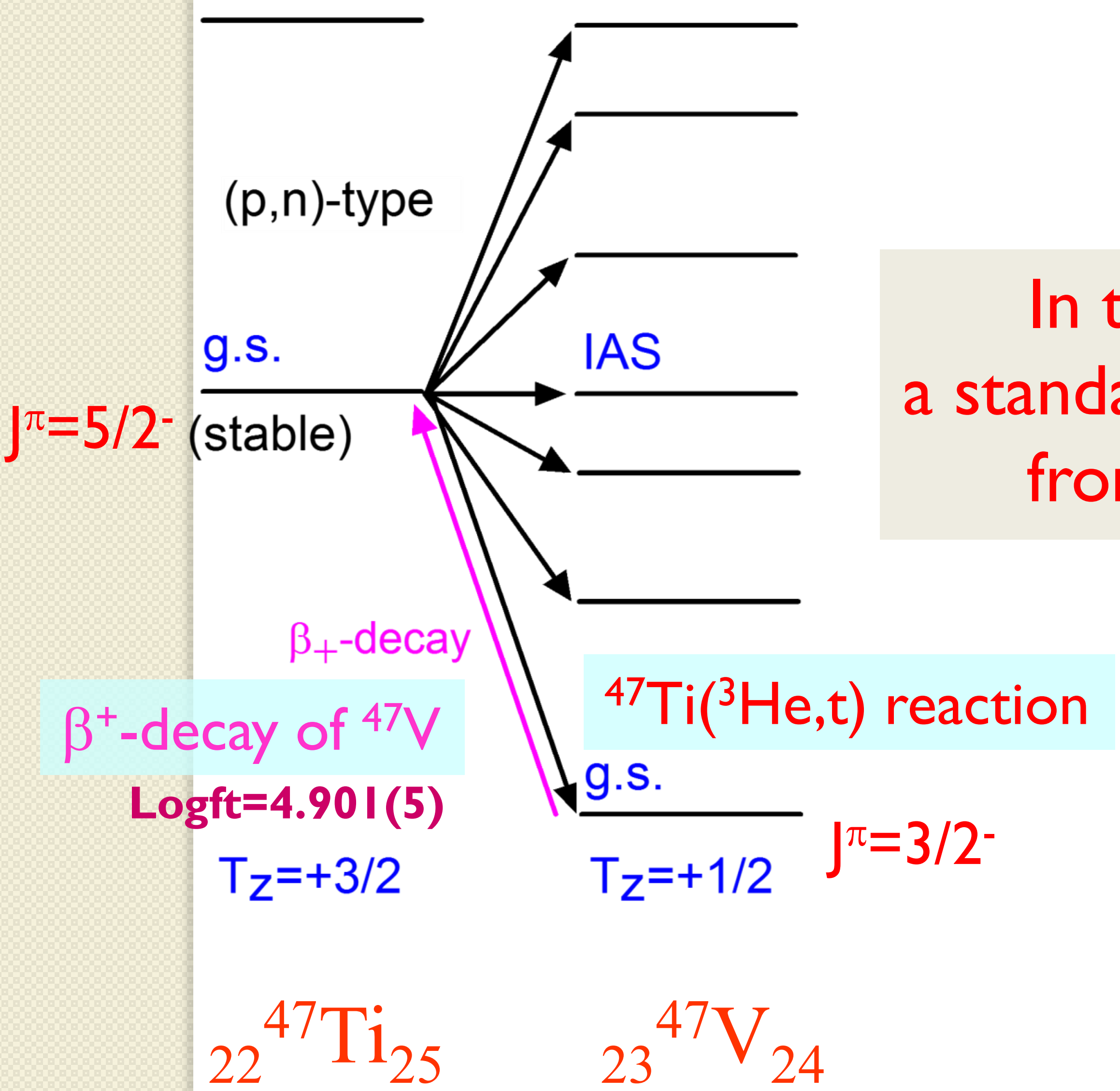
Resolution
21 keV



6.83 MeV

E. Ganioğlu et al., in preparation

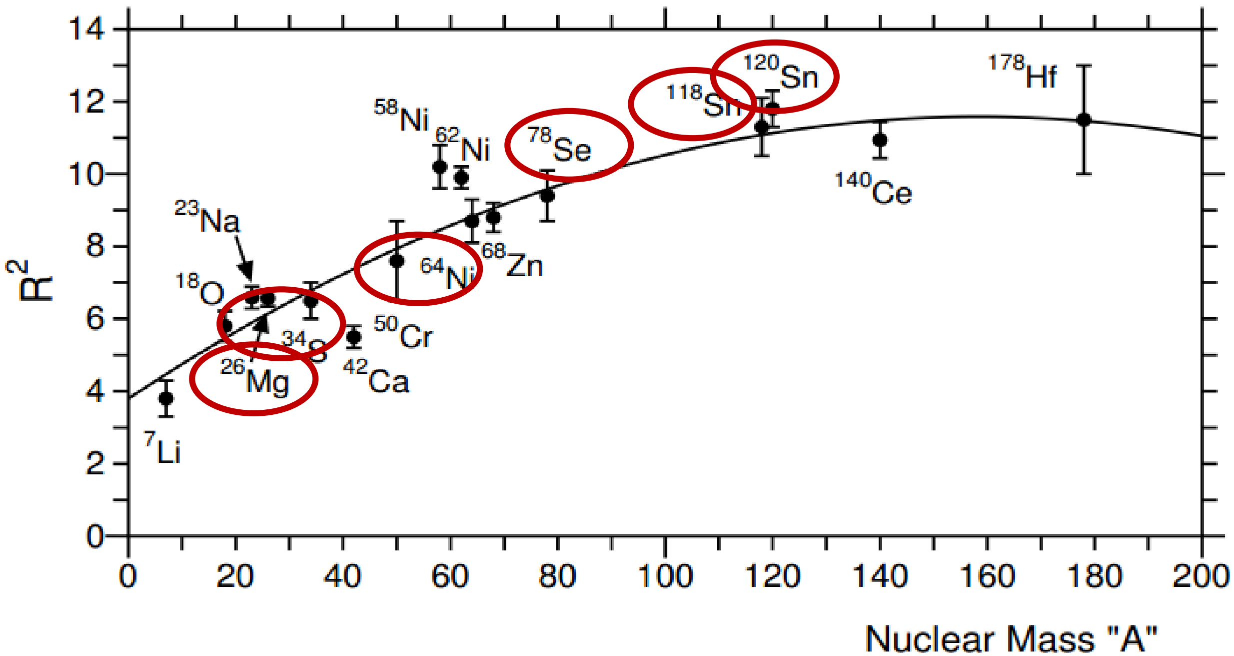
Deriving B(GT)s I:



In the A=47 system,
a standard B(GT) is obtained
from β-decay of ^{47}V

Y. Fujita et al., Prog. In Part. And Nucl. Phys. 66, (2011)

Deriving B(GT)s II:
Nuclear Mass Dependence of R2



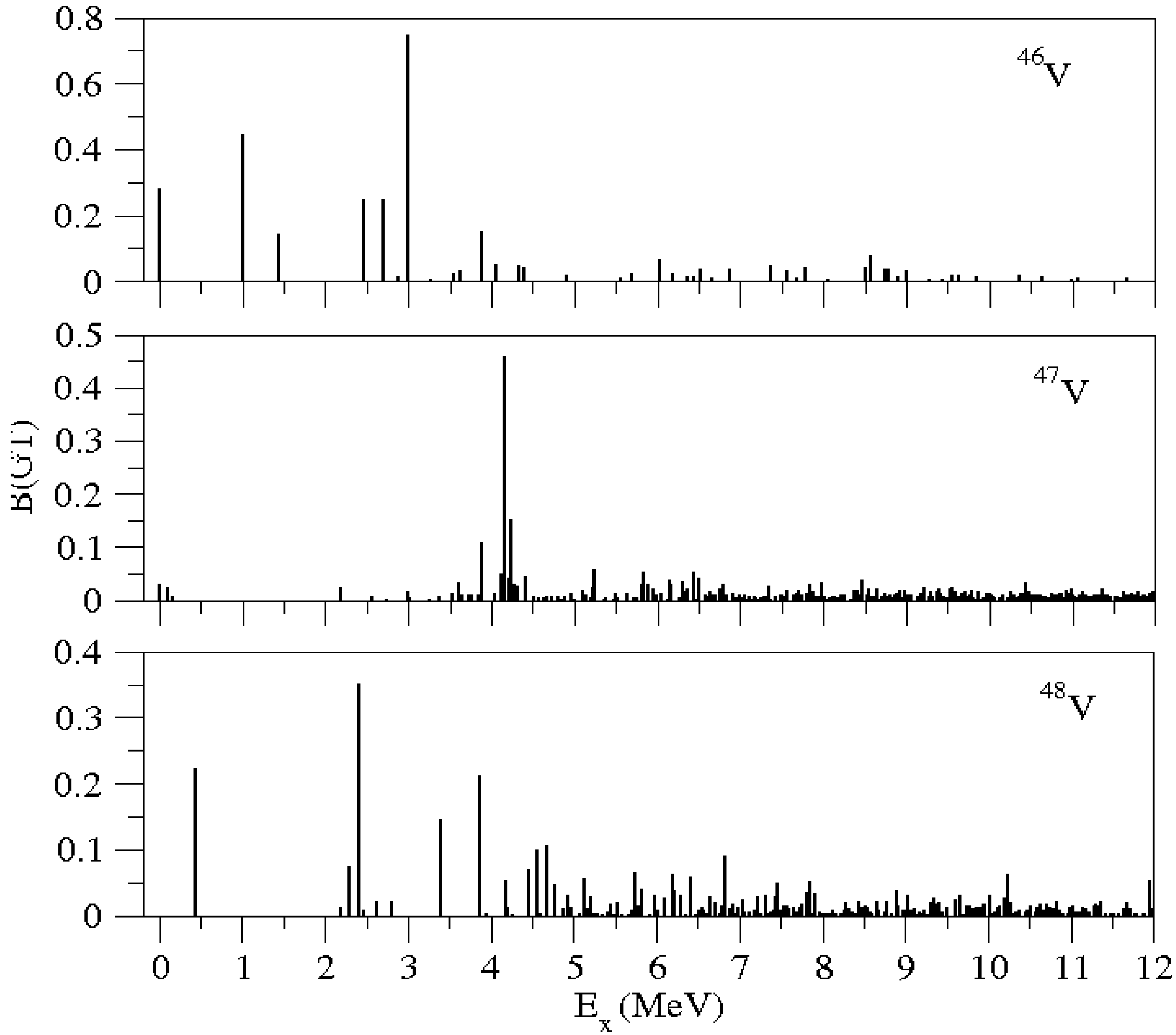
R^2 for ^{46}V = 7.7±0.9

R^2 for ^{48}V = 8.2±0.4

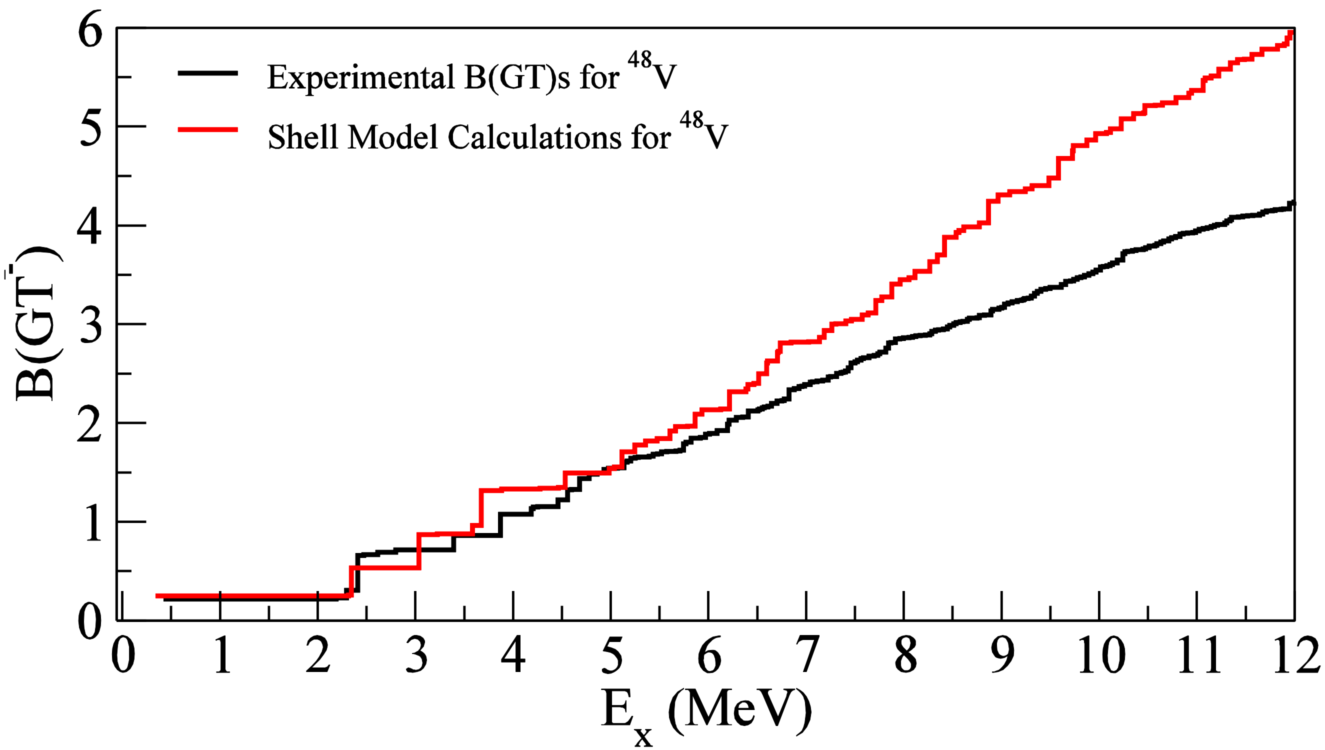
$$R^2 = \frac{\hat{\sigma}_{\rm GT}(0^\circ)}{\hat{\sigma}_{\rm F}(0^\circ)} = \frac{\sigma_{\rm GT}(0^\circ)}{B({\rm GT})} \Big/ \frac{\sigma_{\rm F}(0^\circ)}{B({\rm F})}$$

T. Adachi et al., Nucl. Phys. A 788 (2007) 70c,
and H. Fujita, Y. Fujita, private communication

B(GT) Distributions



Cumulative Sum of B(GT)



SM calculations by M. Honma, Aizu Un, Japan

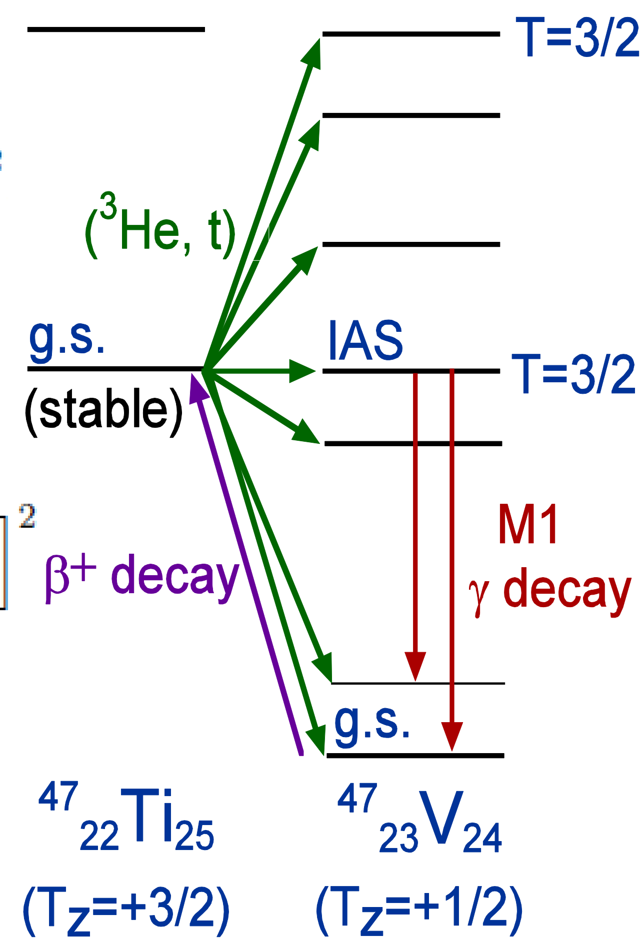
B(M1) [γ-transitions in 47V] v.s. B(GT)

$$B(\mathrm{GT}) = \frac{1}{(2J_i+1)}\frac{1}{2}\frac{C_{\mathrm{GT}}^2}{(2T_f+1)}\left[M_{\mathrm{GT}}(\sigma\tau)\right]^2$$

$$B(M1) = \frac{1}{(2J_i+1)}\frac{3}{4\pi}\mu_N^2\frac{C_{M1}^2}{(2T_f+1)} \times\left[g_\ell^{\mathrm{IV}} M_{M1}(\ell\tau) + g_s^{\mathrm{IV}}\frac{1}{2}M_{M1}(\sigma\tau)\right]^2$$

Under the assumption that the E2/M1 mixing ratios are small :

$$B(M1) \propto \frac{1}{E_\gamma^3} I_\gamma$$



Comparison of analogous B(M1) and B(GT)

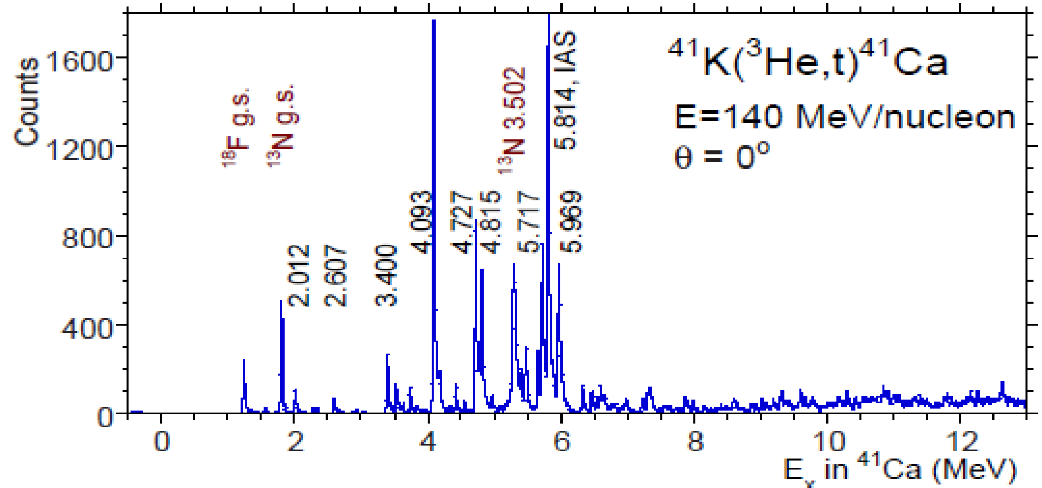
States in ^{47}V		g transitions in ^{47}V		GT transitions to ^{47}V
Ex (MeV)	Jπ	Eg (MeV)	B(M1) ratio	B(GT) ratio
0.0	$3/2^-$	4.150	1.00(2)	1.00(1)
0.0088	$5/2^-$	4.063	0.79(3)	0.81(13)
0.146	$7/2^-$	4.004	0.29(2)	0.22(6)

!Strongest M1 and GT strengths to the g.s of 47V are normalized to unity!

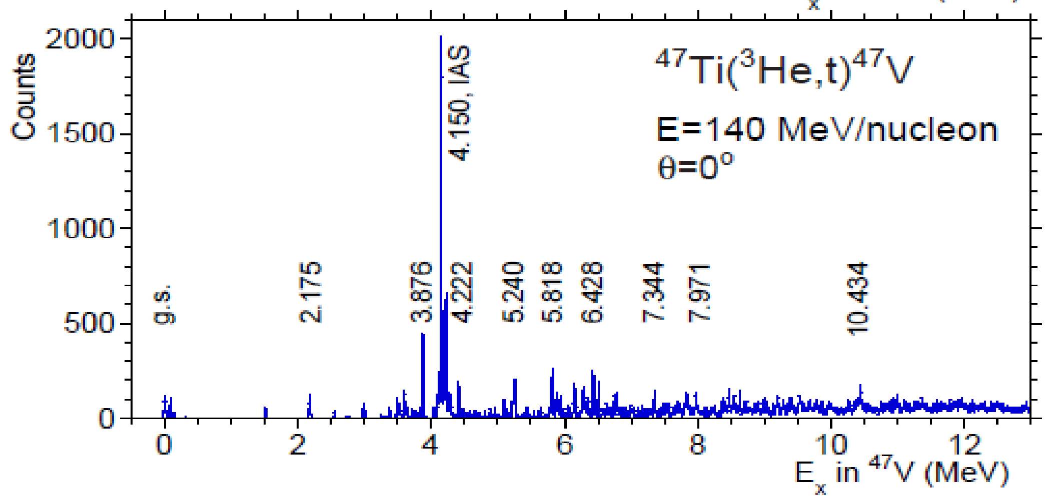
*T.W. Burrows, Nuclear Data Sheets, **108, 923 (2007)**

Tz=+3/2 to Tz=+1/2 GT transitions

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

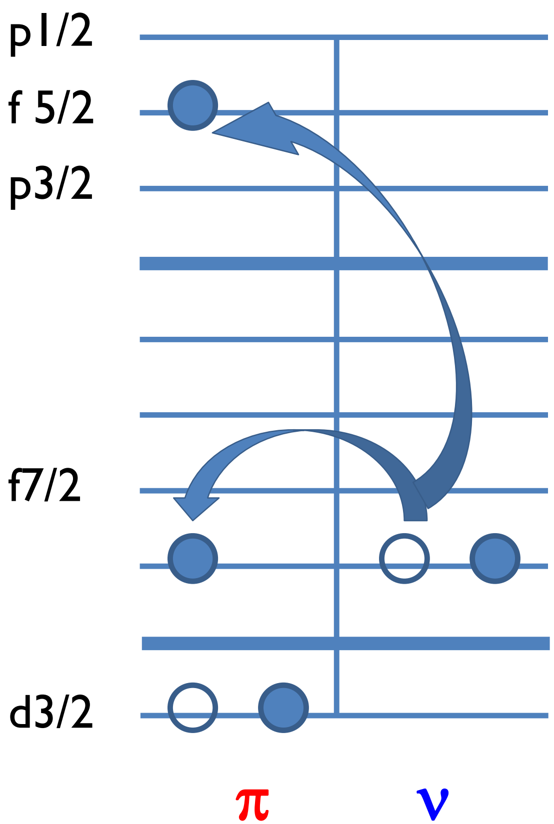


p–p character !
States lie at relatively low excitation energy.



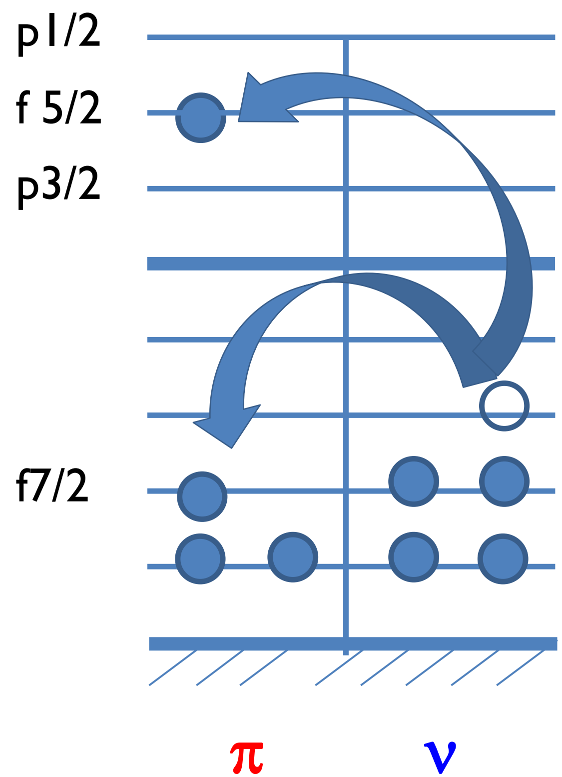
p–h character !
States are pushed up in excitation energy.

41K → 41Ca



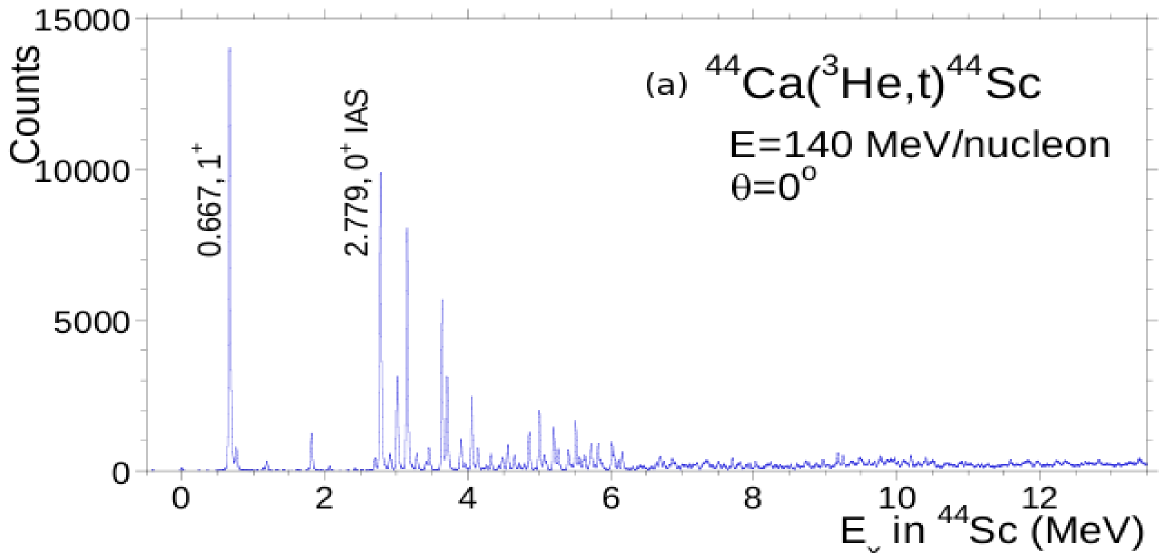
p- p character atractive

47Ti → 47V

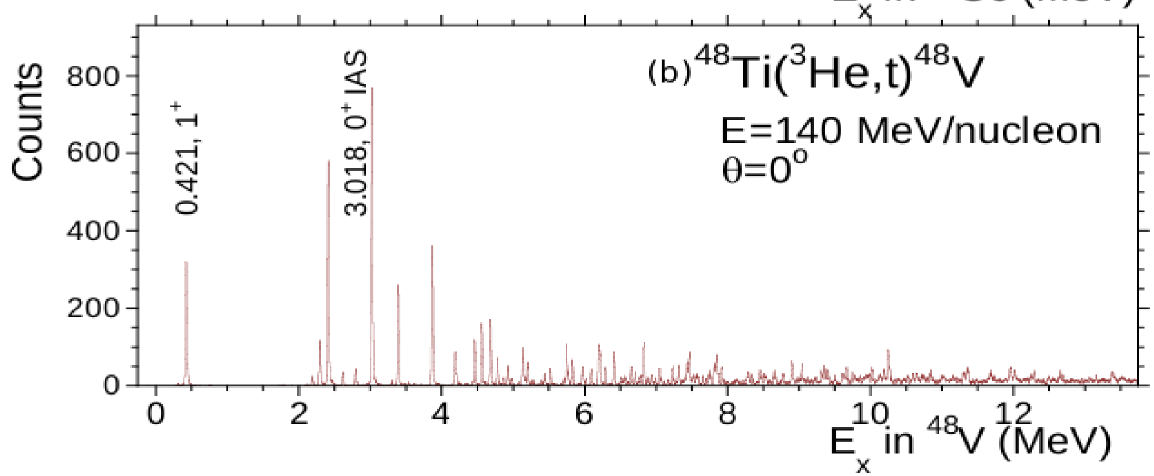


p- h character repulsive

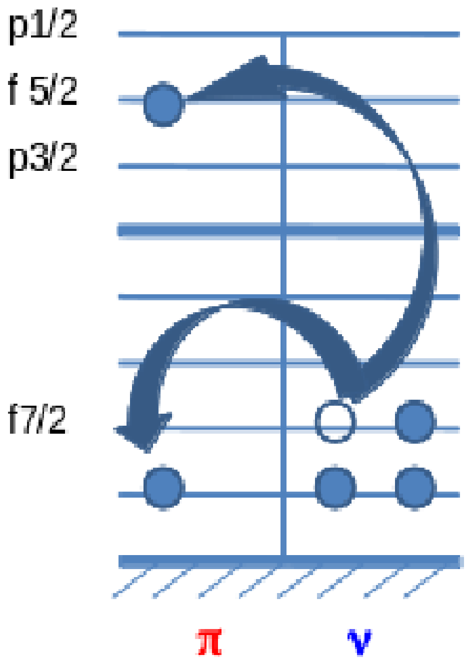
Tz=+2 to Tz=+1 GT transitions



p–p character !
States lie at relatively low excitation energy.

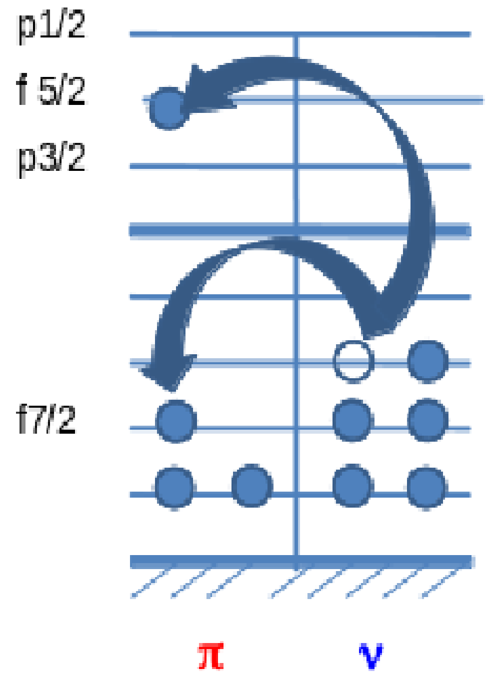


p–h character !
States are pushed up in excitation energy.



^{44}Ca -> ^{44}Sc

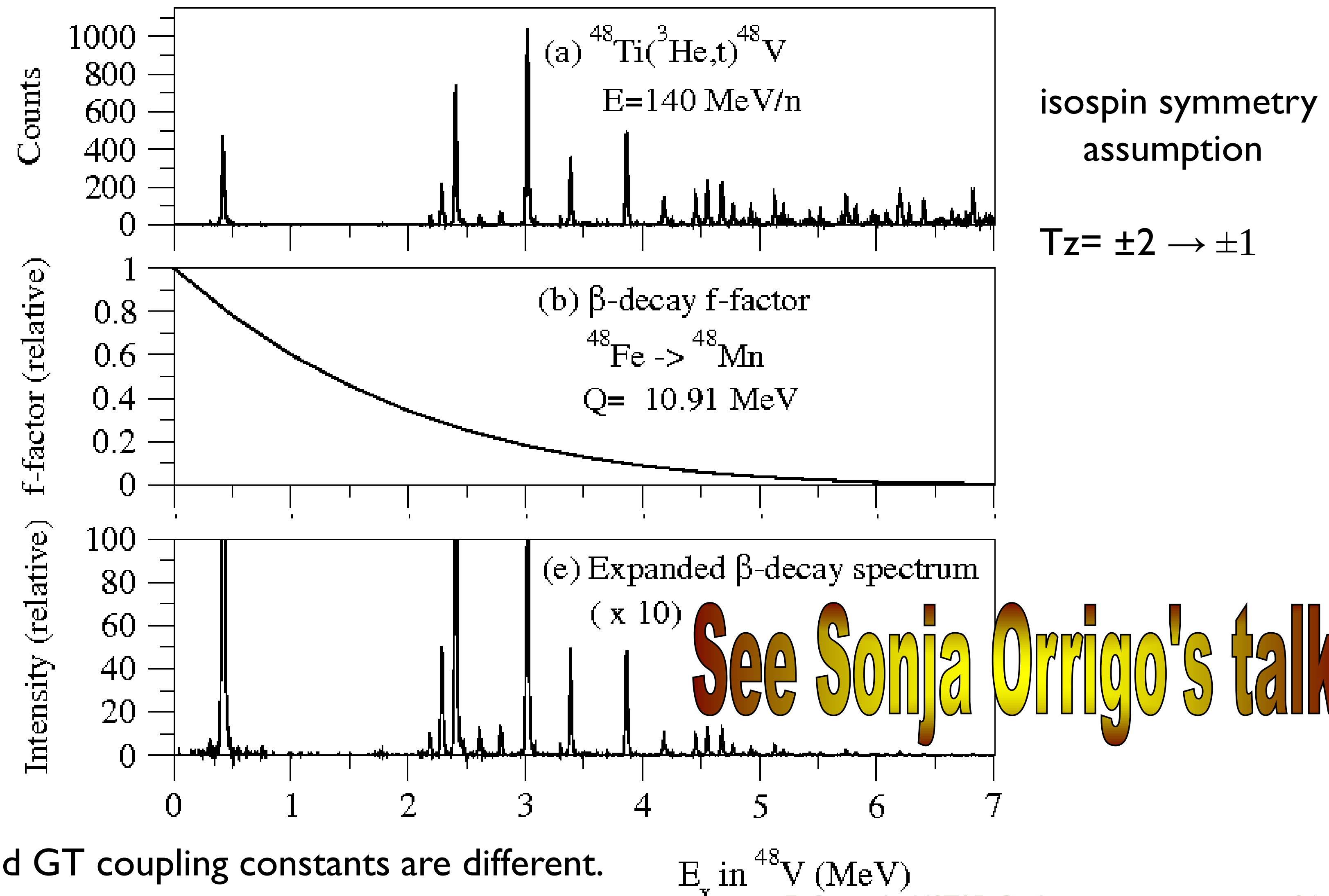
p- p character
atractive



^{48}Ti -> ^{48}V

p- h character
repulsive

Mirror Beta-decay



isospin symmetry assumption

$T_z = \pm 2 \rightarrow \pm 1$

! F and GT coupling constants are different.

Conclusion

•In this work the studies of the (^{3}He,t) reaction on Tz=1/2 and 1, have been extended to the Tz = +3/2 and Tz=+2 nuclei and excitation energies of previously known states were reproduced to 5 keV up to 12 MeV.

•Relative intensities of the analogous M1 and GT transitions in the A=47 system are in good agreement.

•Shell model calculations were performed using the GXPF1 interaction. The experimental B(GT) distribution was well reproduced up to 5 MeV.

•A comparison was made of the $T_z = 3/2 \rightarrow 1/2$ GT transitions for ^{41}K and ^{47}Ti nuclei and $T_z = 2 \rightarrow 1$ GT transitions for ^{44}Ca and ^{48}Ti nuclei. In the ^{41}K, ^{44}Ca (^{3}He,t)^{41}Ca,^{44}Sc spectrum, the GT strengths are concentrated in the region between 4-6 MeV, while in the ^{47}Ti(^{3}He,t)^{47}V spectrum, they are spread out in energy.

•A comparison was made of the $T_z = 2 \rightarrow 1$ GT transitions for ^{44}Ca and ^{48}Ti nuclei. In the ^{44}Ca(^{3}He,t)^{44}Sc spectrum, the GT strengths are concentrated in the region between 2-6 MeV, while in the ^{48}Ti(^{3}He,t)^{48}V spectrum, they are spread out in energy.

•(^{3}He,t) type reactions with the other stable Ti targets (^{49,50}Ti) are being analysed.


46Fe
47Fe
48Fe
49Fe
50Fe
51Fe
52Fe
53Fe
54Fe
45Mn
46Mn
47Mn
48Mn
49Mn
50Mn
51Mn
52Mn
53Mn
44Cr
45Cr
46Cr
47Cr
49Cr
50Cr
51Cr
52Cr
43V
48V
49V
50V
51V
42Ti
43Ti
44Ti
45Ti
46Ti
47Ti
48Ti
49Ti
50Ti
41Sc
42Sc
43Sc
44Sc
45Sc
46Sc
47Sc
48Sc
49Sc
40Ca
41Ca
42Ca
43Ca
44Ca
45Ca
46Ca
47Ca
48Ca
39K
40K
41K
42K
43K
44K
45K
46K
47K
N=Z

Collaborators

H. Fujita[2], Y. Fujita[2] ,T. Adachi[3], , A. Algora[4], M. Csatlos[5], J. Deaven[6], M. Doğan[1], E. Estevez[4],C. Guess[6], J. Gulyas[5], K. Hatanaka[3], K. Hirota[3], D. Ishikawa[3], A. Krasznahorkay[5], H. Matsubara[3],R. Meharchand[6], F. Molina[4], H. Okamura[3], H.J. Ong[3], G. Perdikakis[6], B. Rubio[4], C. Scholl[7], G. Susoy[1], T. Suzuki[3],A. Tamii[3], J. Thies[8], R.G.T. Zegers[6], J. Zenihiro[3]

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