

High Resolution ($^3\text{He},t$) Study of Gamow-Teller Transition Strengths of $T_z=0$ fp-shell nuclei

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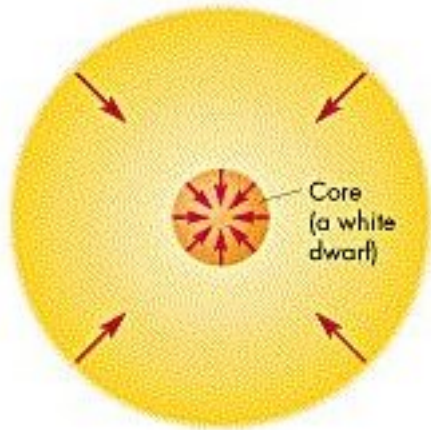
Research Center for Nuclear Physics, Osaka University

Department of Physics, Kyoto University

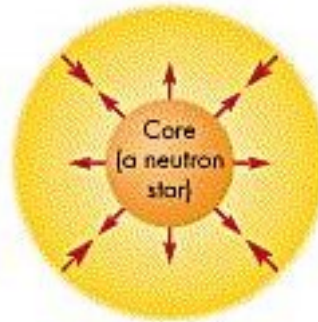
Institute für KernPhysik, Technische Universität Darmstadt, Germany

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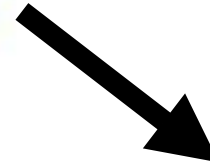
© Type II supernova



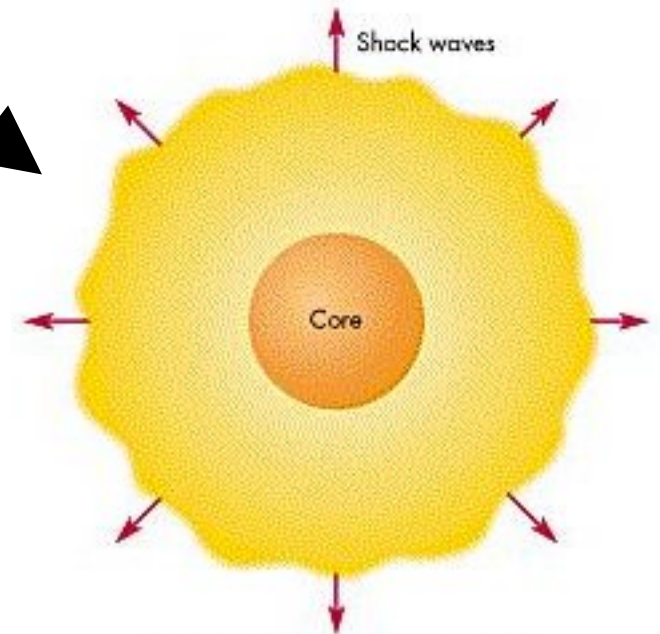
Iron Core
Collapse



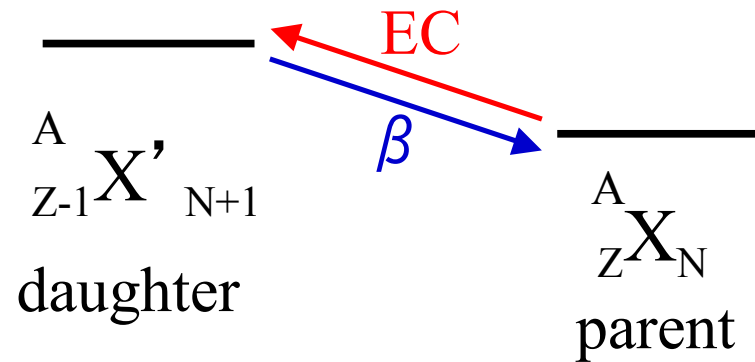
Neutron Rich
Core Rebound



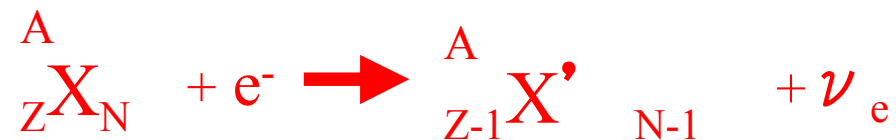
Shockwave moves
Outward through
the Star



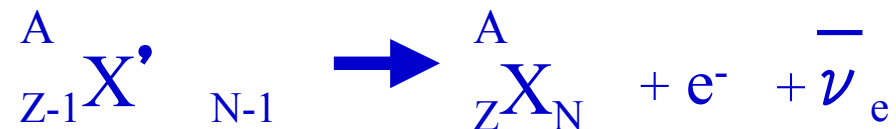
© Roles of Electron Capture & β decay in Core Collapse



☆ Electron Capture (EC)



☆ β decay



© Reaction Rates and Transition Strengths B(GT)

Reaction Rates λ (s^{-1}) for EC or β decay

K. Langanke and G. Martinez-Pinedo, NPA 673 (2000) 481.

$$\lambda = \frac{\ln 2}{K} \sum_i \frac{(2J_i+1) e^{-E_i/(kT)}}{\sum_i e^{-E_i/(kT)}} \sum_j B_{ij} \Phi$$

i: initial states

j: final states

$K=6145(6)s$

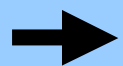
k: Boltzman Constant

T: Temperature

Reduced Transition Strengths

Phase Space Factor (Excitation Energy Dependent)

Fermi (τ)



(Concentrate to IAS)
 $B(F) = N-Z$

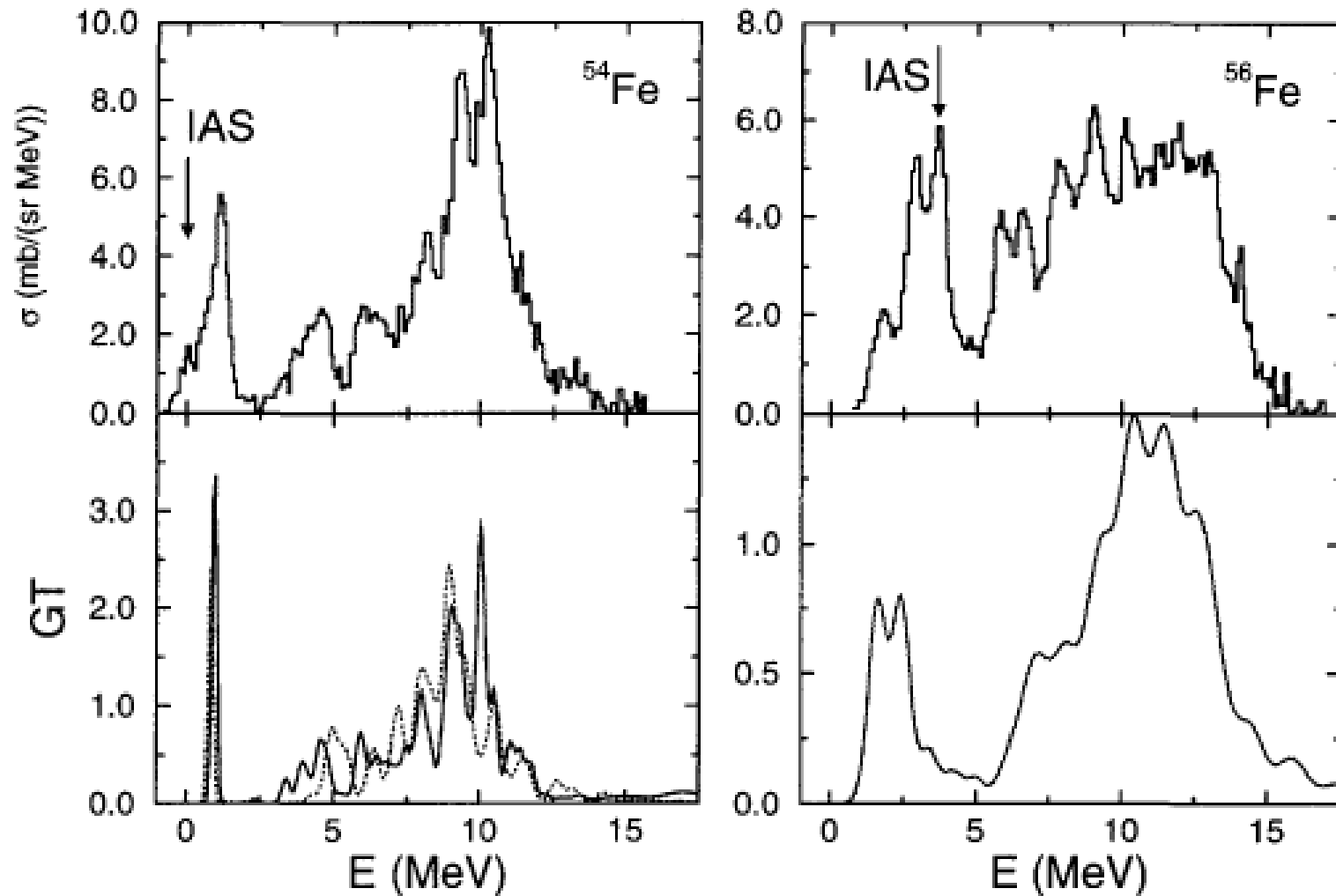
Gamow-Teller (GT)

($\sigma \tau_{\pm}$)



$$B(GT_{\pm}) = \frac{\langle f | \sigma \tau_{\pm} | i \rangle^2}{(2J_i+1)}$$

© Comparison between Experimental Spectra & Shell Model Calculation



E. Caurier et. al., NPA 653 (1999) 439.

© B(GT) Measurement in Charge Exchange Reactions

☆ β decay (Q-value limitation)



☆ Charge Exchange Reactions (p,n), (d,²He), (³He,t) etc.

☆ At 0 deg. (q → 0)	• Cross Section for L=0 • $\sigma \tau$	→ Max → Dominant
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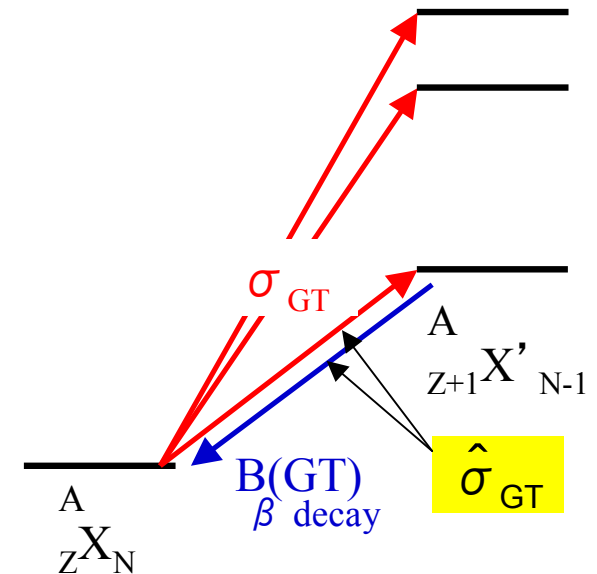
☆ An incident beam energy $E_i > 100 \text{ MeV/u}$	• $\sigma \tau$ • One-Step Reaction	→ Dominant → Dominant
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$$\sigma(0^\circ) = \frac{K N_{\sigma \tau} |J_{\sigma \tau}|^2}{\sigma \tau} B(\text{GT})$$

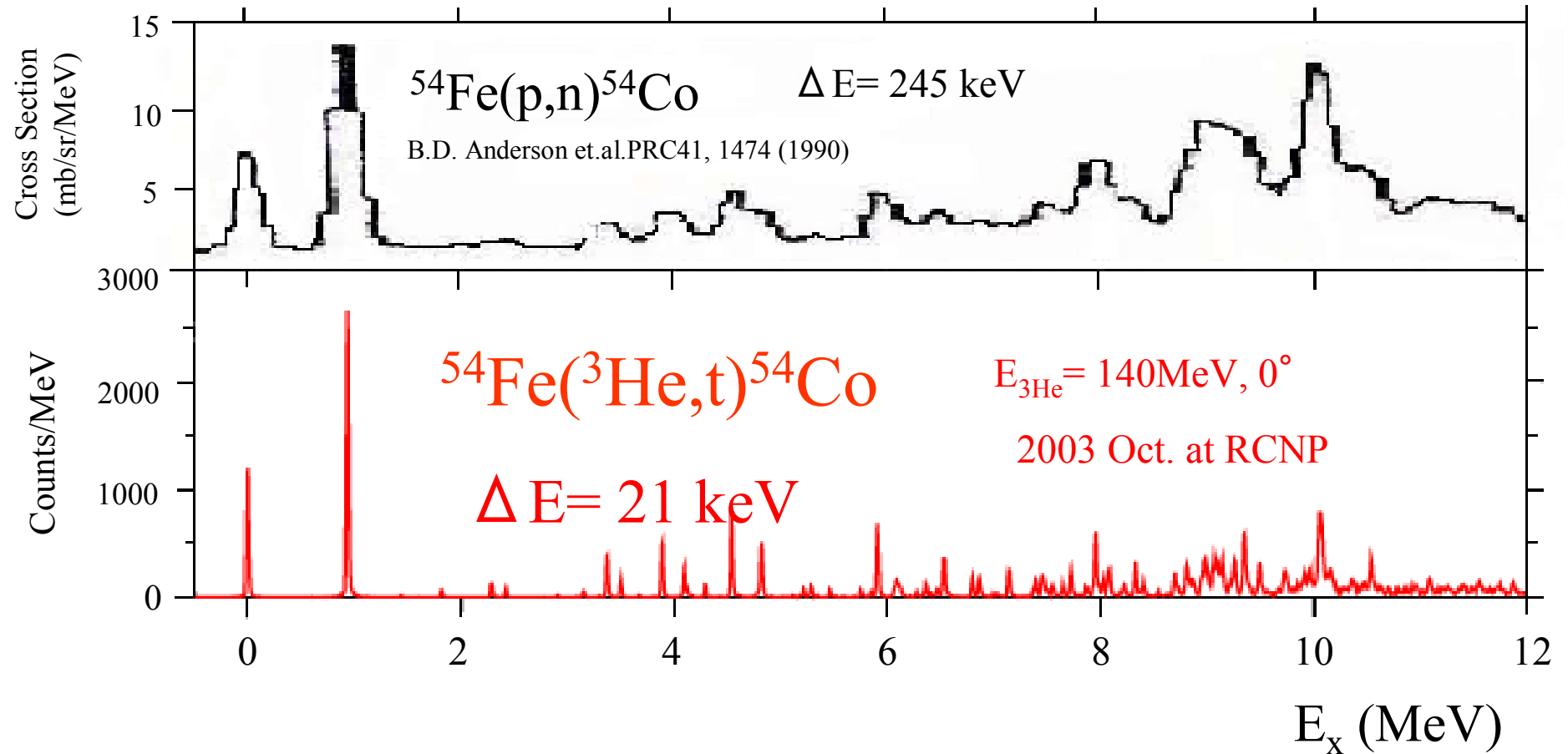


σ_{GT} : Unit Cross Section

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



© Improvement in Energy Resolution with ($^3\text{He},t$) Experiment



© Confirmation of Proportionality Between ($^3\text{He},t$) and β decay

Y.Fujita et. al., PRC 67 (064312) 2003

($^3\text{He},t$)

B(GT)

0.106(4)

0.117(4)

0.112(4)

0.527(15)

1.081(29)

β decay

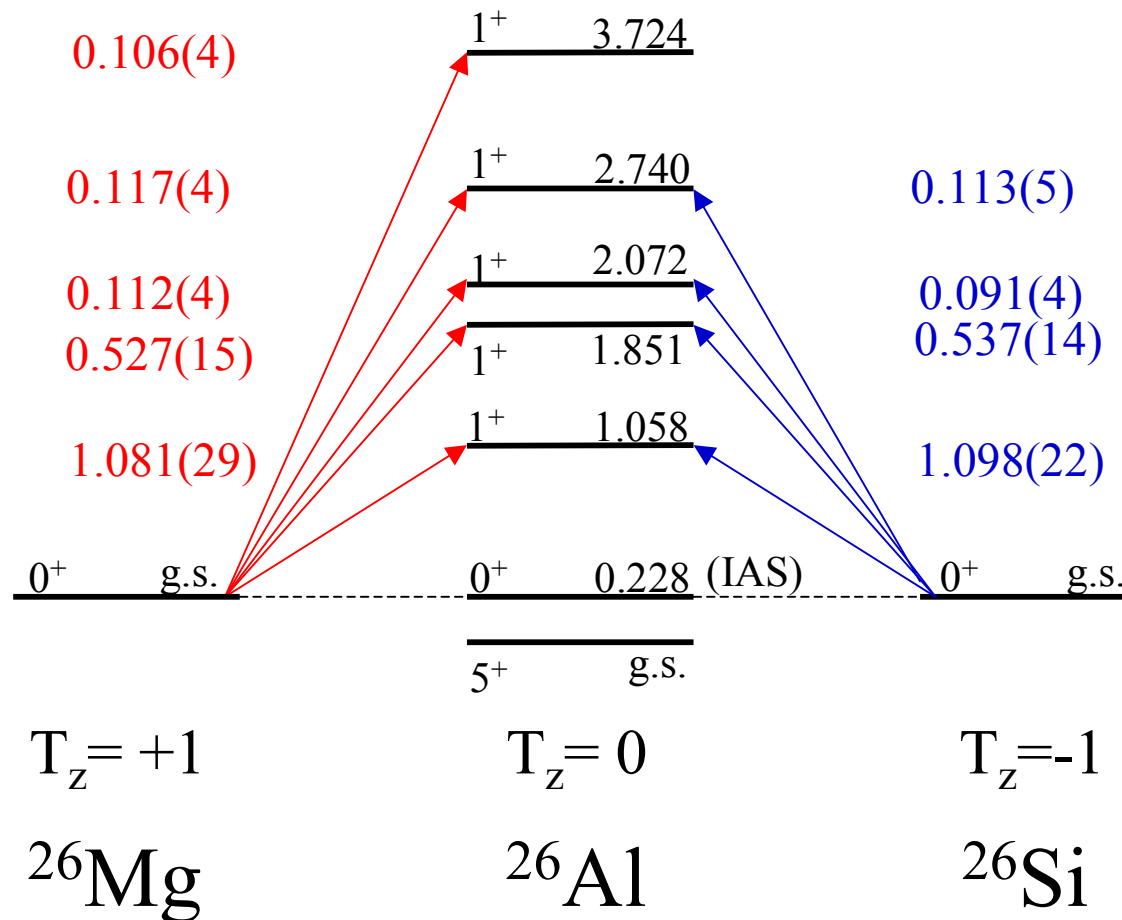
B(GT)

0.113(5)

0.091(4)

0.537(14)

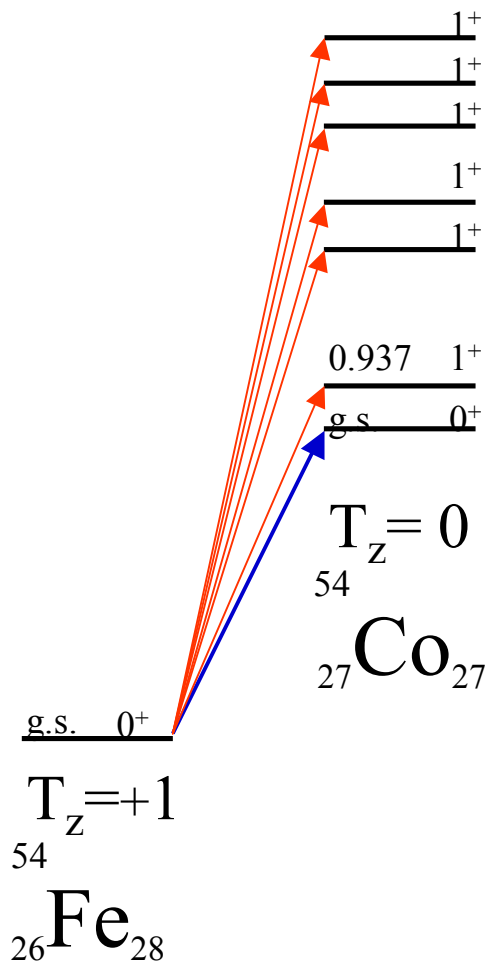
1.098(22)



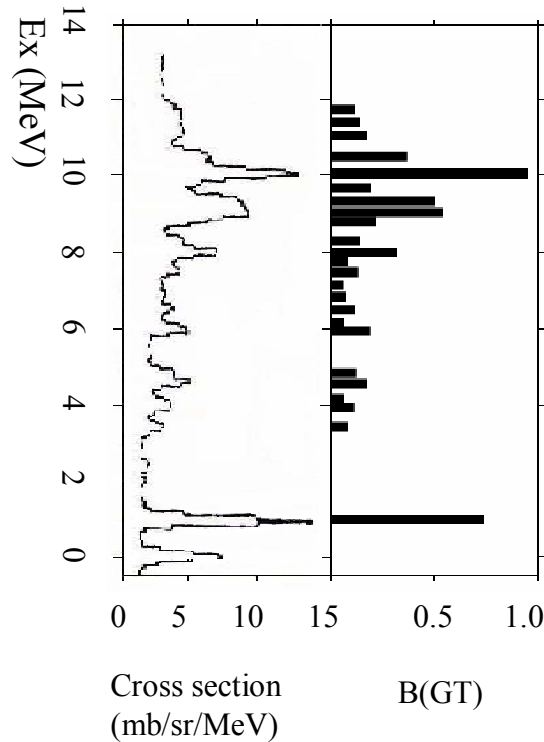
© Previous B(GT) Measurements in ^{54}Co

$^{54}\text{Fe}(p,n)^{54}\text{Co}$

B.D. Anderson et.al.
PRC41, 1474 (1990)

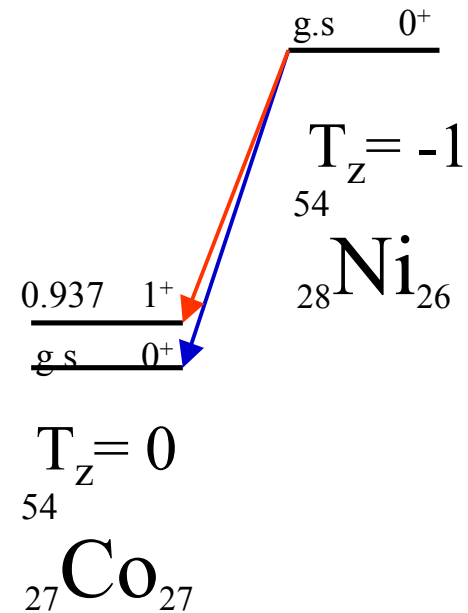


$\Delta E = 245 \text{ keV}$



$^{54}\text{Ni} \beta \text{ decay}$

I.Reusen et. al.,
PRC59 (1999) 2416

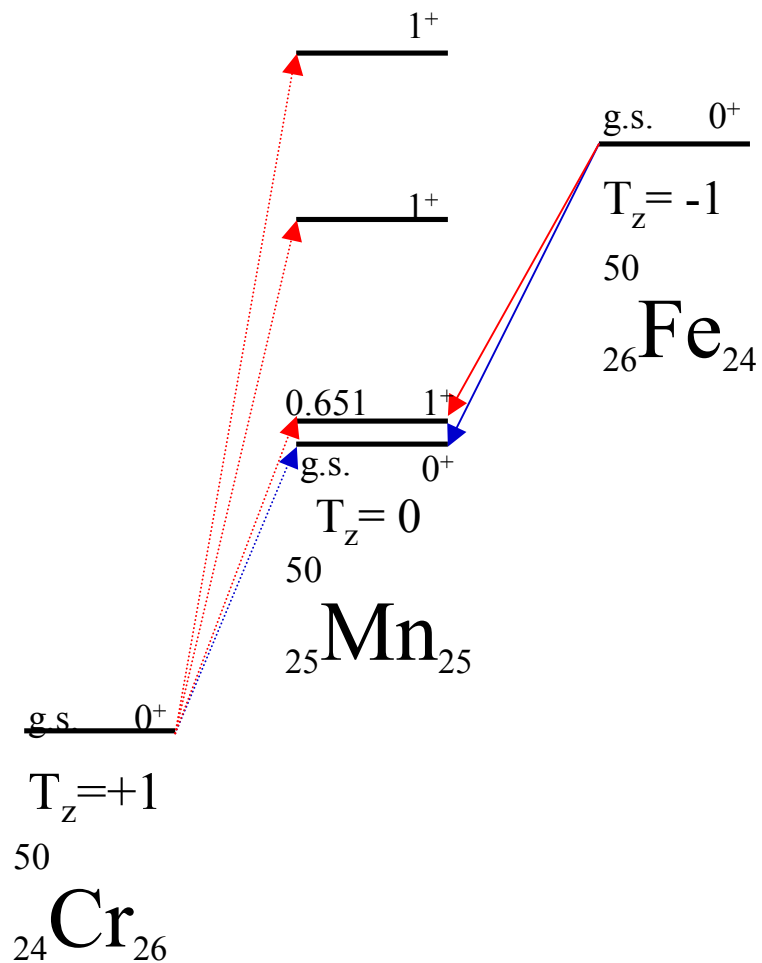


→ Fermi
→ GT

© Previous B(GT) Measurements in ^{50}Mn and ^{46}V

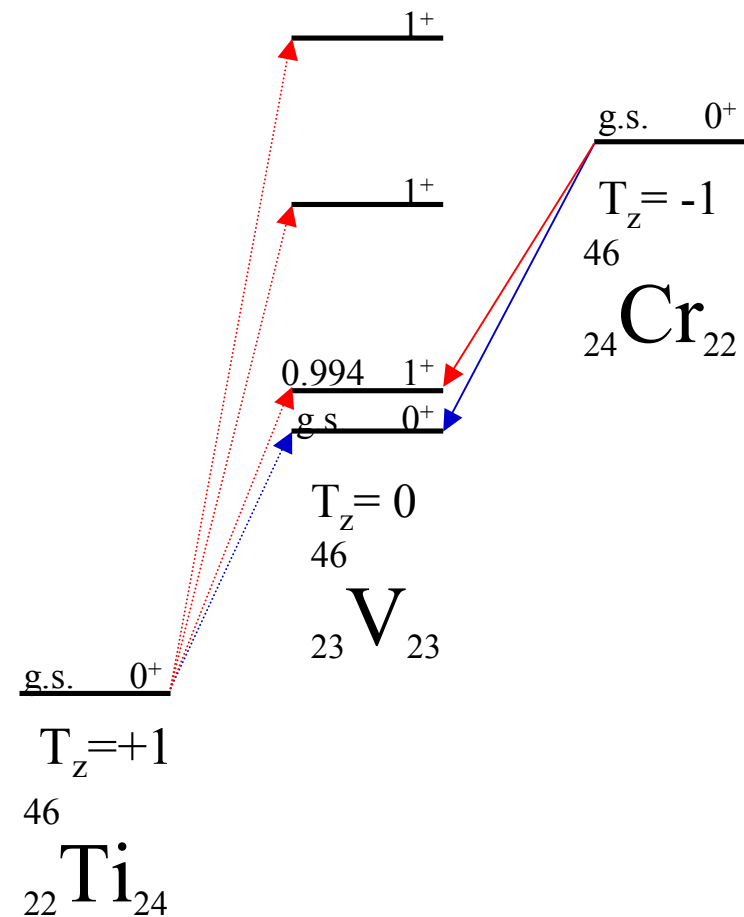
^{50}Fe β decay

V.T. Koalowsky et. al.,
NPA624 (1997) 293.



^{46}Cr β decay

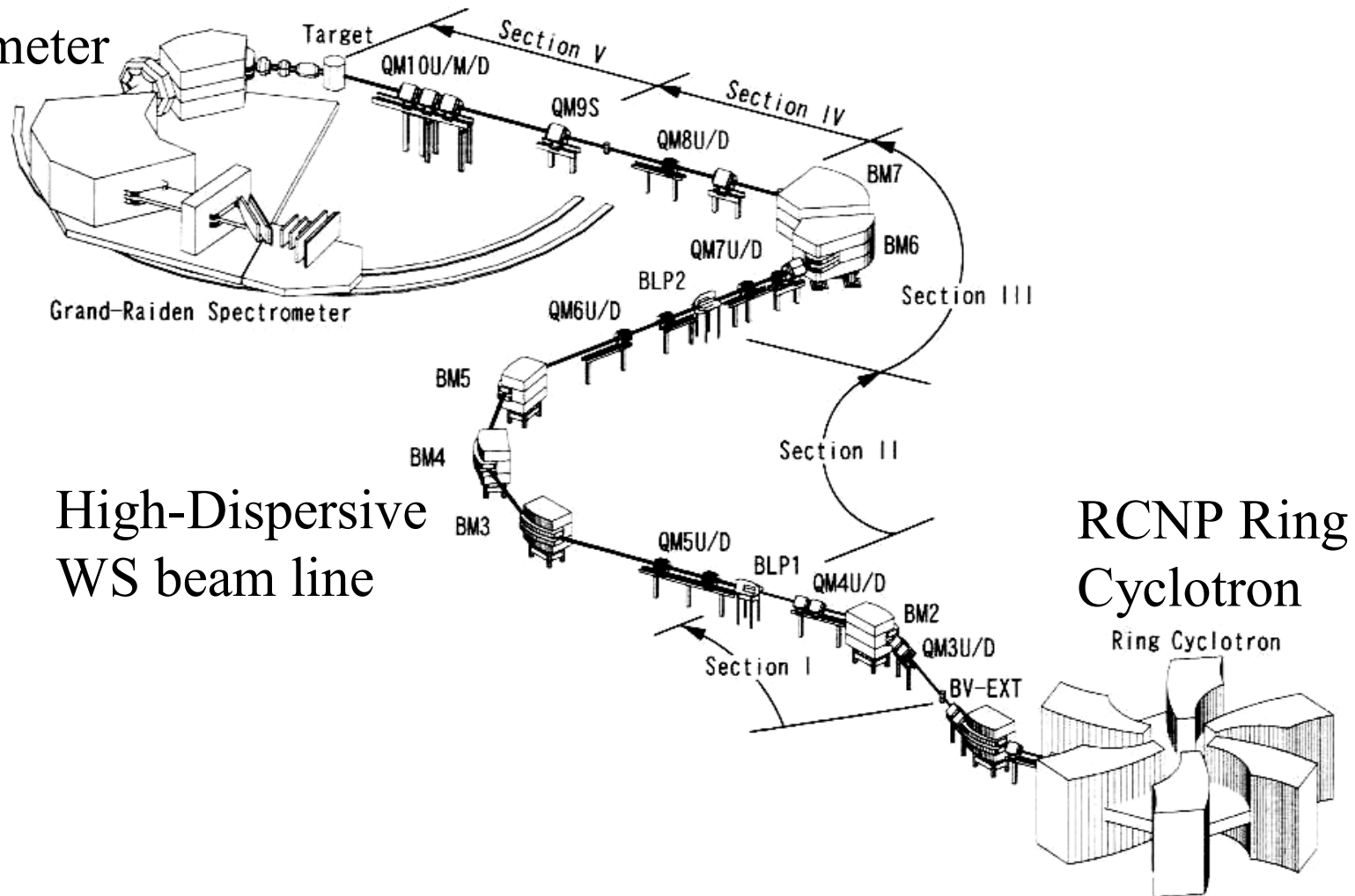
T.K. Onishi et. al.,
PRC72,024308 (2005).



© WS Beam Line Course at RCNP

T. Wakasa et al., NIM A482 (2002) 79.

Grand-Raiden
Spectrometer

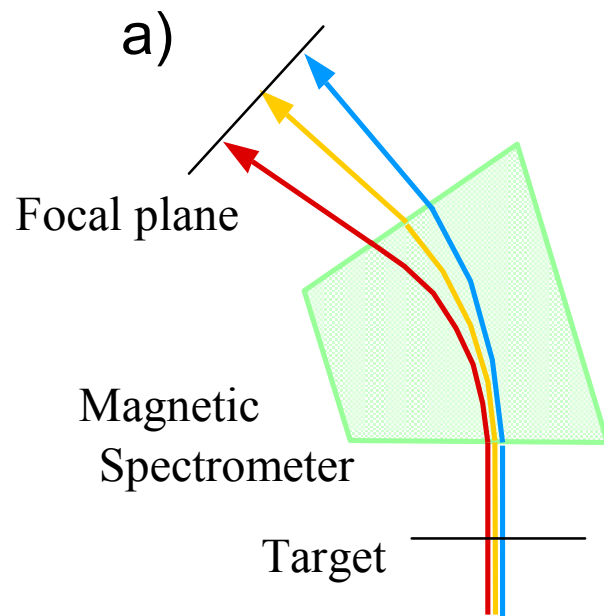


High-Dispersive
WS beam line

RCNP Ring
Cyclotron
Ring Cyclotron

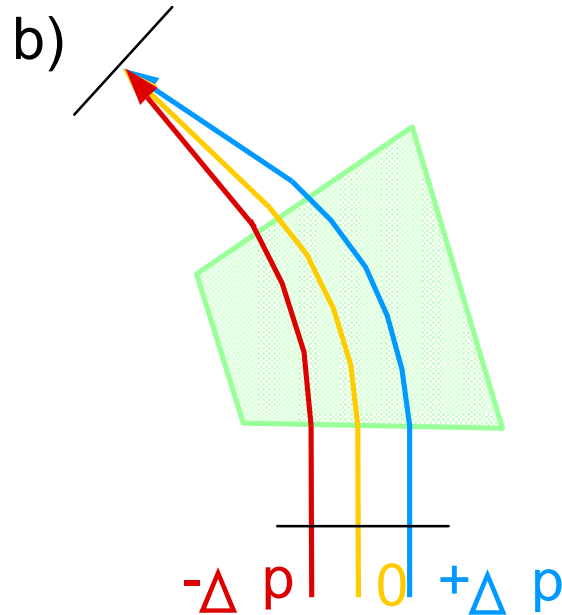
© Dispersion Matching Techniques

Y. Fujita et. al., NIM B126 (1997) 274. & H. Fujita et. al., NIM A484 (2002) 17.



Achromatic beam
transportation

$\Delta E \sim 200 \text{ keV}$
for $140 \text{ MeV/u } ^3\text{He beam}$

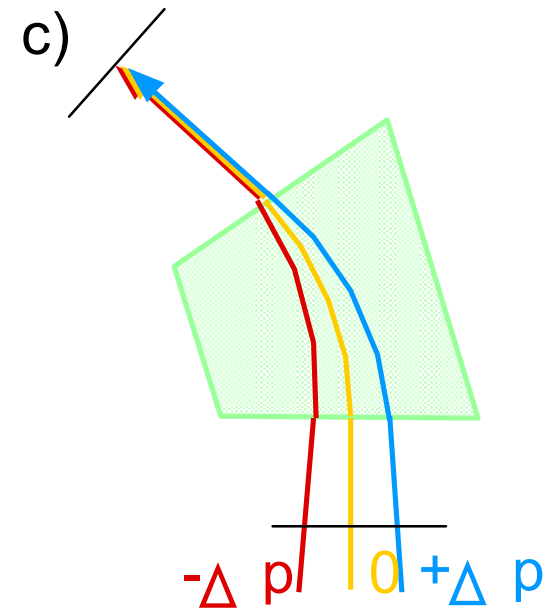


Lateral dispersion
matching

$\Delta E \sim 35 \text{ keV}$

Horiz. angle resolution

$\Delta\theta_{sc} > 15 \text{ mrad}$



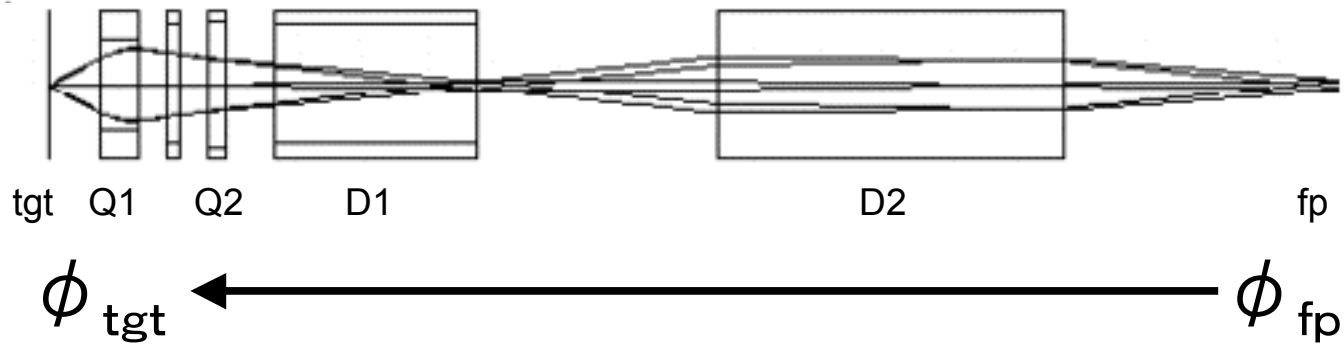
Angular dispersion
matching

$\Delta\theta_{sc} \sim 5 \text{ mrad}$

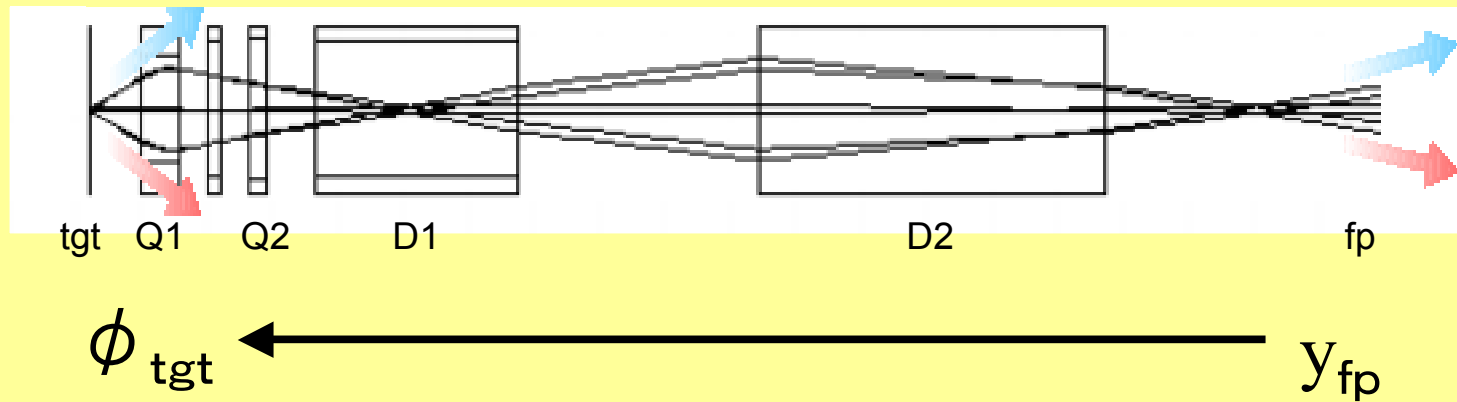
Over focus mode (Precise Vertical angle measurement)

H.Fujita et. al., NIM A 469 (2001) 55.

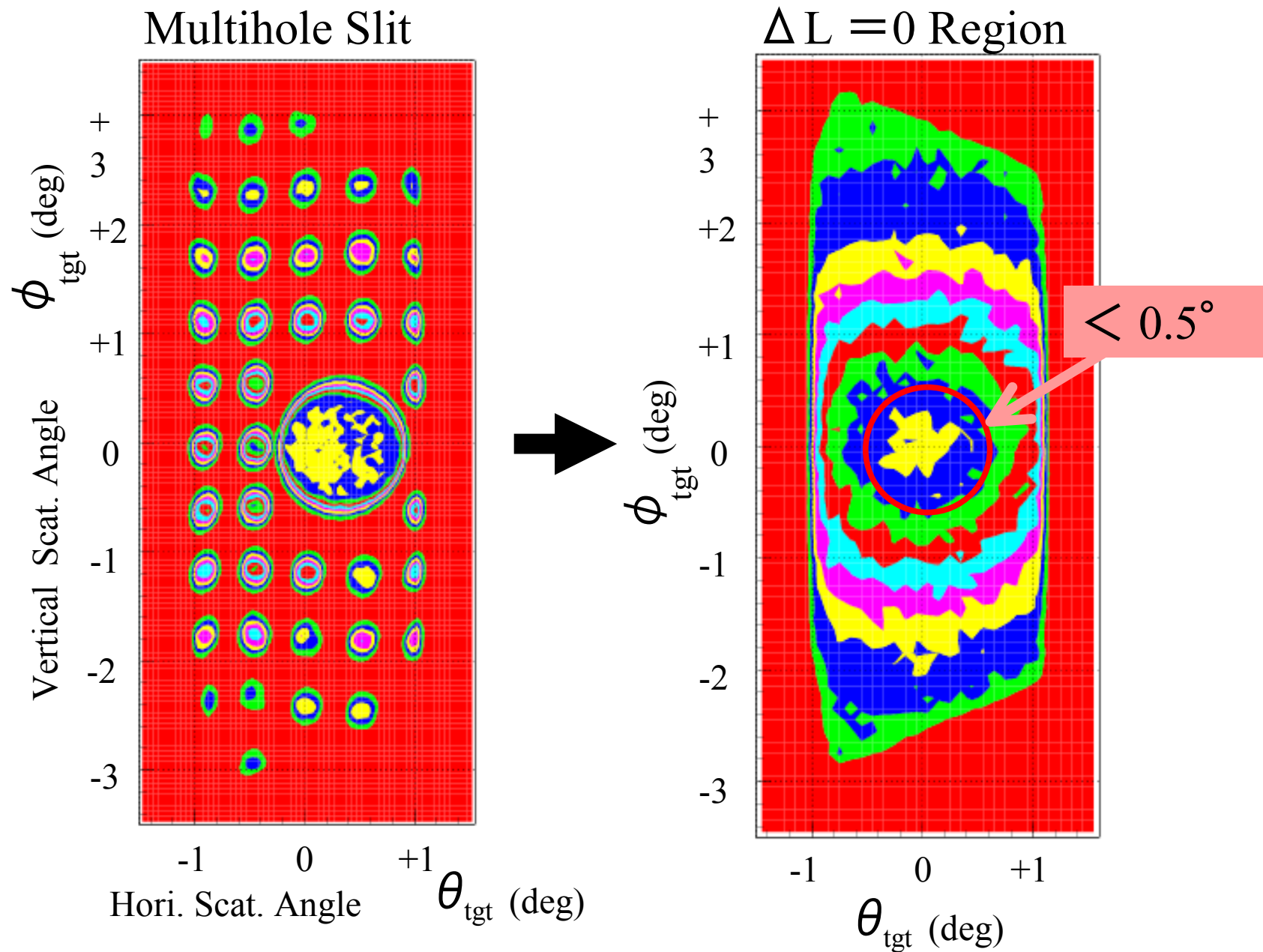
(a) Normal Vertical Point-to-Point Mode



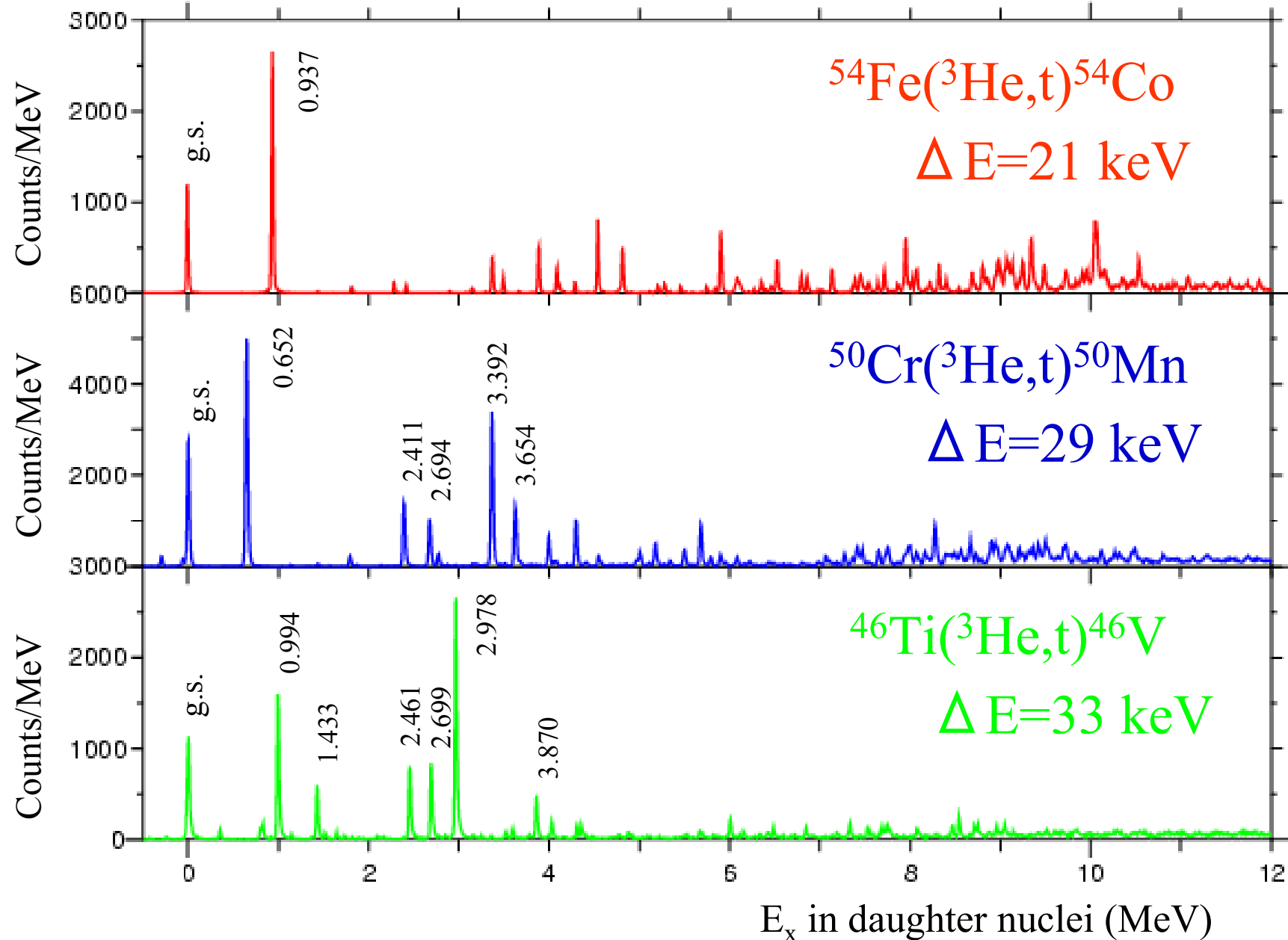
(b) Over focus mode (defocused at focal plane)



© Angle Calibration Measurements

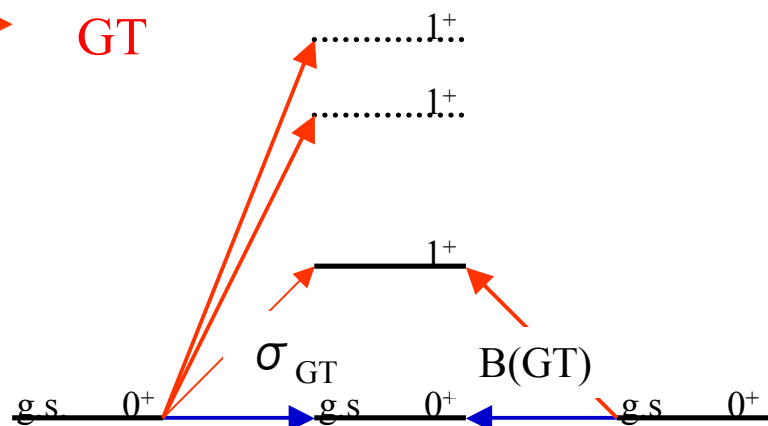


© High Resolution Spectra of ^{54}Co , ^{50}Mn and ^{46}V



© β decay Result from ^{54}Ni , ^{50}Fe and ^{46}Cr

 Fermi
 GT



β decay GT transition
 $T_z = -1 \rightarrow T_z = 0, 1\text{st } 1^+$ state

$T_z = +1$	$T_z = 0$	$T_z = -1$
$^{54}_{26}\text{Fe}_{28}$	$^{54}_{27}\text{Co}_{27}$	$^{54}_{28}\text{Ni}_{26}$
$^{50}_{24}\text{Cr}_{26}$	$^{50}_{25}\text{Mn}_{25}$	$^{50}_{26}\text{Fe}_{24}$
$^{46}_{22}\text{Ti}_{24}$	$^{46}_{23}\text{V}_{23}$	$^{46}_{24}\text{Cr}_{22}$

$T_{1/2}$ (ms)	BR (%)	B(GT)
106(12)	22(4)	0.69(16)
I.Reusen et. al., PRC59 (1999) 2416		
155(11)	23(6)	0.59(15)
V.T. Koalowsky et. al., NPA624 (1997) 293.		
240(140)	21.6(50)	0.64(20)
T.K. Onishi et. al., PRC72,024308 (2005).		

© Ratio of the GT and Fermi Unit Cross Section

Proportionality for GT and Fermi

$$\begin{aligned}\sigma_{\text{GT}}(0^\circ) &= K N_{\sigma\tau} |J_{\sigma\tau}|^2 B(\text{GT}) = \hat{\sigma}_{\text{GT}} B(\text{GT}) \\ \sigma_{\text{F}}(0^\circ) &= K N_{\tau} |J_{\tau}|^2 B(\text{F}) = \hat{\sigma}_{\text{F}} B(\text{F})\end{aligned}$$

Definition of R^2 value

$$R^2 = \frac{\hat{\sigma}_{\text{GT}}}{\hat{\sigma}_{\text{F}}}$$

Fermi Unit Cross Section

$$\hat{\sigma}_{\text{F}} = \sigma_{\text{F}} / B(\text{F})$$

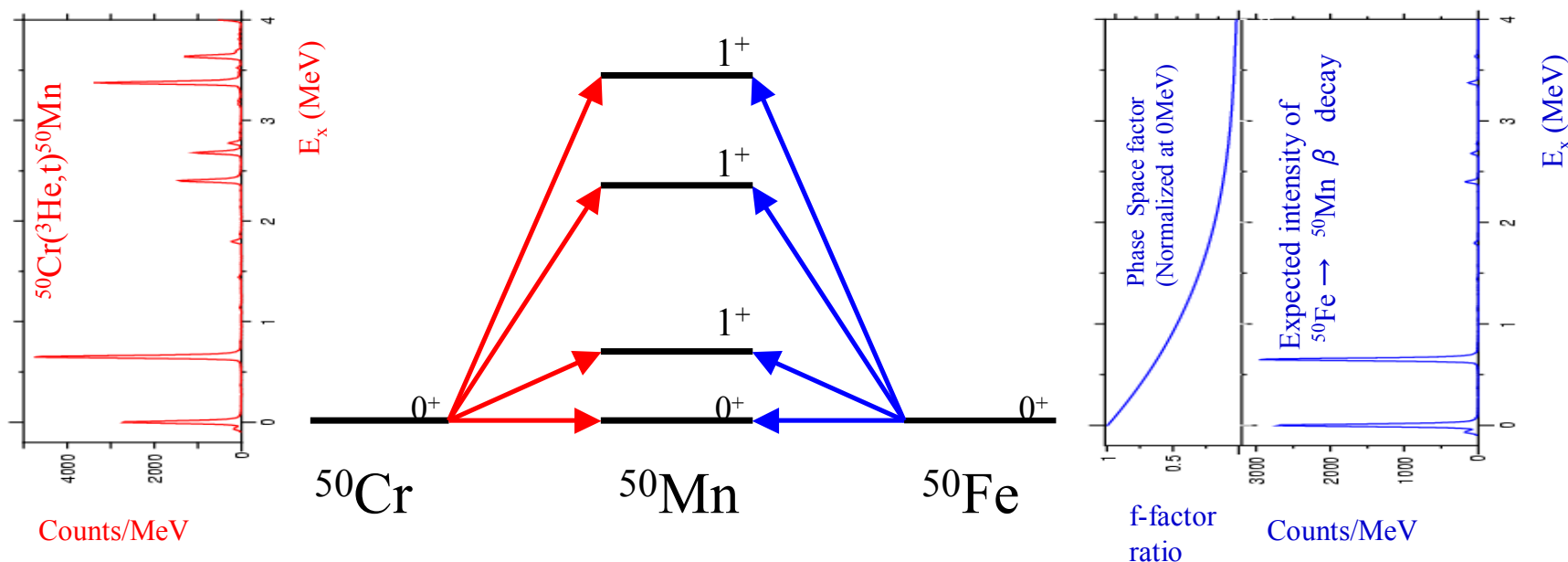
All Fermi Strengths Concentrate to IAS : $B(\text{F}) = N-Z$

σ_{F} : IAS is certainly observed in ($^3\text{He}, t$)

If R^2 is calculated, $\hat{\sigma}_{\text{GT}}$ is calculated. $\hat{\sigma}_{\text{GT}} = R^2 \hat{\sigma}_{\text{F}}$

© B(GT) Derivation in ^{50}Mn

Y. Fujita et. al., PRL 95 212501 (2005)



$$\frac{1}{T_{1/2}} = \frac{1}{t_F} + \sum_{i=GT} \frac{1}{t_i}$$

$$B(F) + (g_v/g_A)^2 B(GT) = \frac{K}{ft}$$

$$R^2 = \frac{\hat{\sigma}_{GT}}{\hat{\sigma}_F} = \frac{\sigma_{GT}/B(GT)}{\sigma_F/B(F)}$$



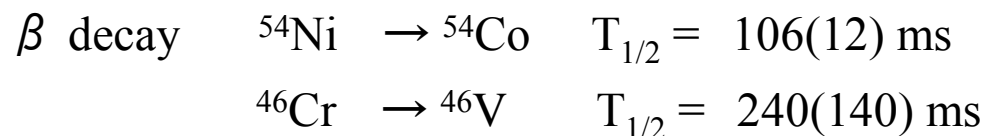
$$\frac{1}{T_{1/2}} = \frac{B(F)}{K \sigma_F} \left[\sigma_F f_F + \frac{(g_v/g_A)^2}{R^2} \sum_{i=GT} f_i \sigma_i \right]$$

$$R^2 (A=50) = 7.6 \pm 2.0$$

$^{50}\text{Fe} \beta$ decay measurement

$$T_{1/2} = 155(12) \text{ ms}$$

© B(GT) Derivation in ^{54}Co & ^{46}V



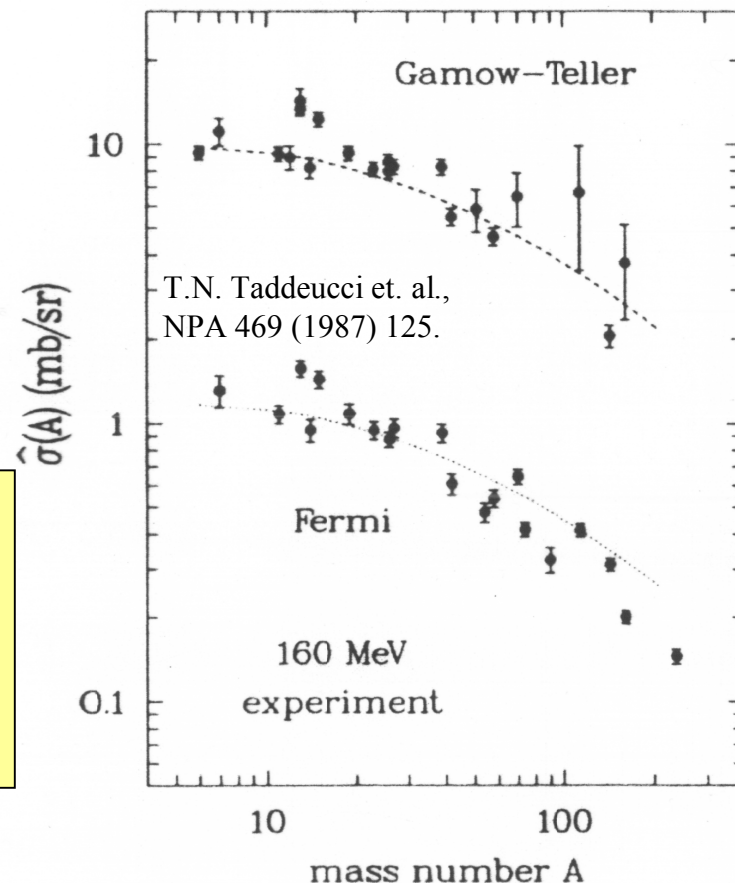
$R^2(E_i, A)$ depends on E_i (incident energy) \rightarrow For $(^3\text{He}, t)$, 140 MeV/u fixed.
 A (nuclear mass) \rightarrow ?

In (p,n) $\hat{\sigma}_{\text{GT}}$ $\hat{\sigma}_{\text{F}}$ Uneven for mass A
 $R^2 = \frac{\hat{\sigma}_{\text{GT}}}{\hat{\sigma}_{\text{F}}}$ Moderate change for mass "A"

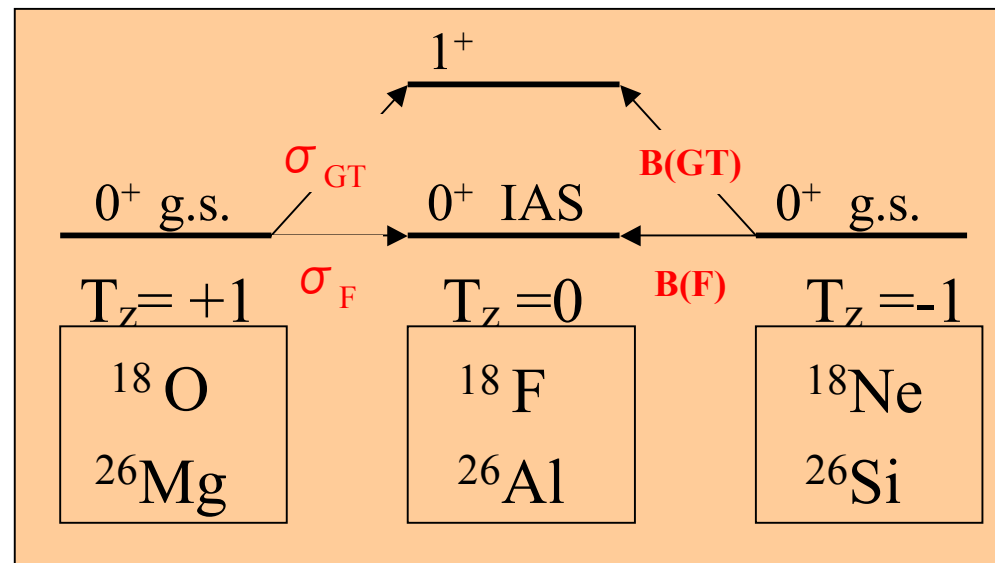
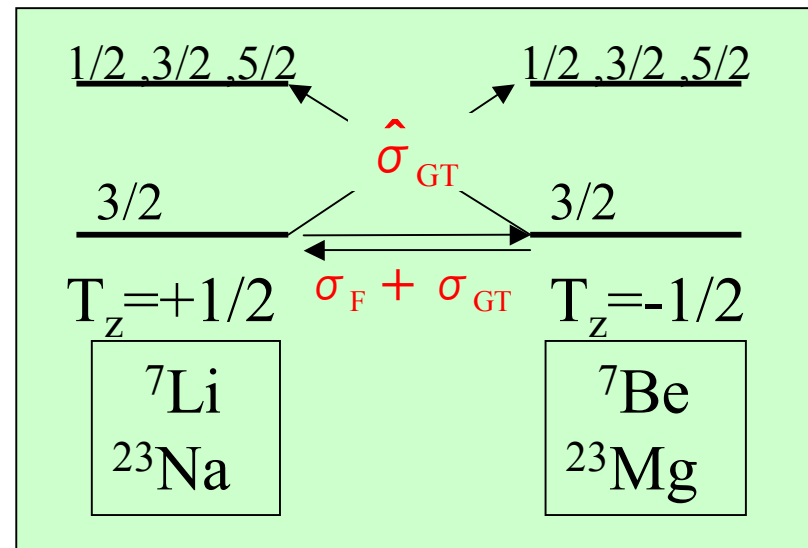
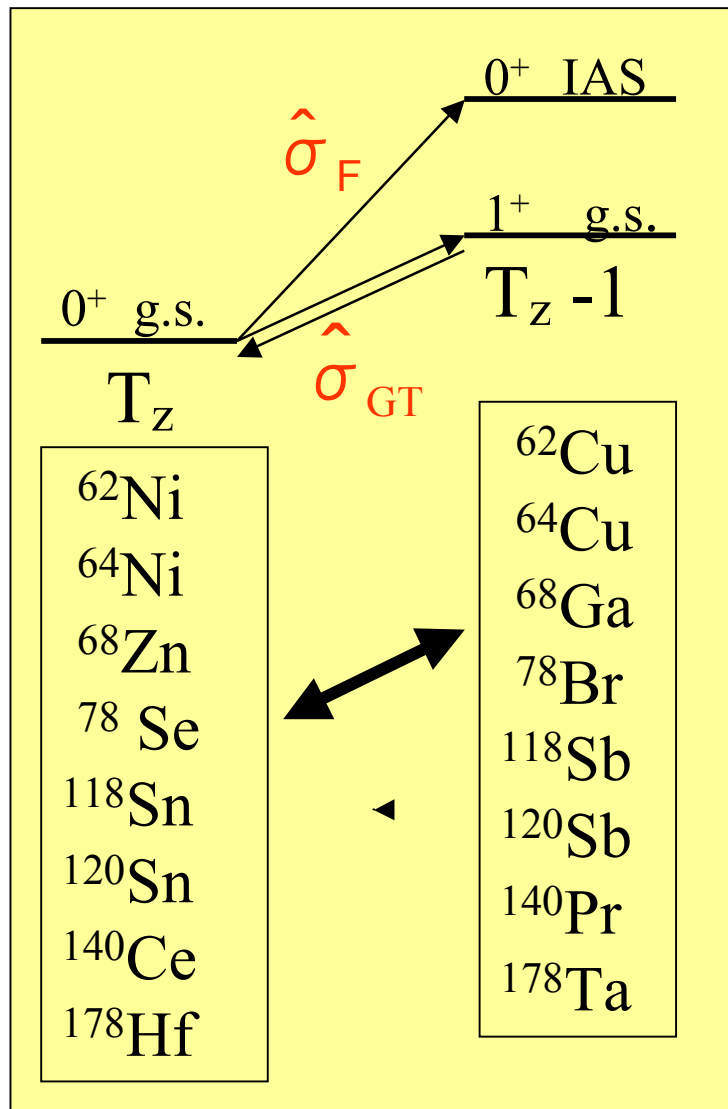
$$\hat{\sigma}_{\text{GT}} (A=54, 46) = R^2 \times \hat{\sigma}_{\text{F}} (A=54, 46)$$

\uparrow
interpolated

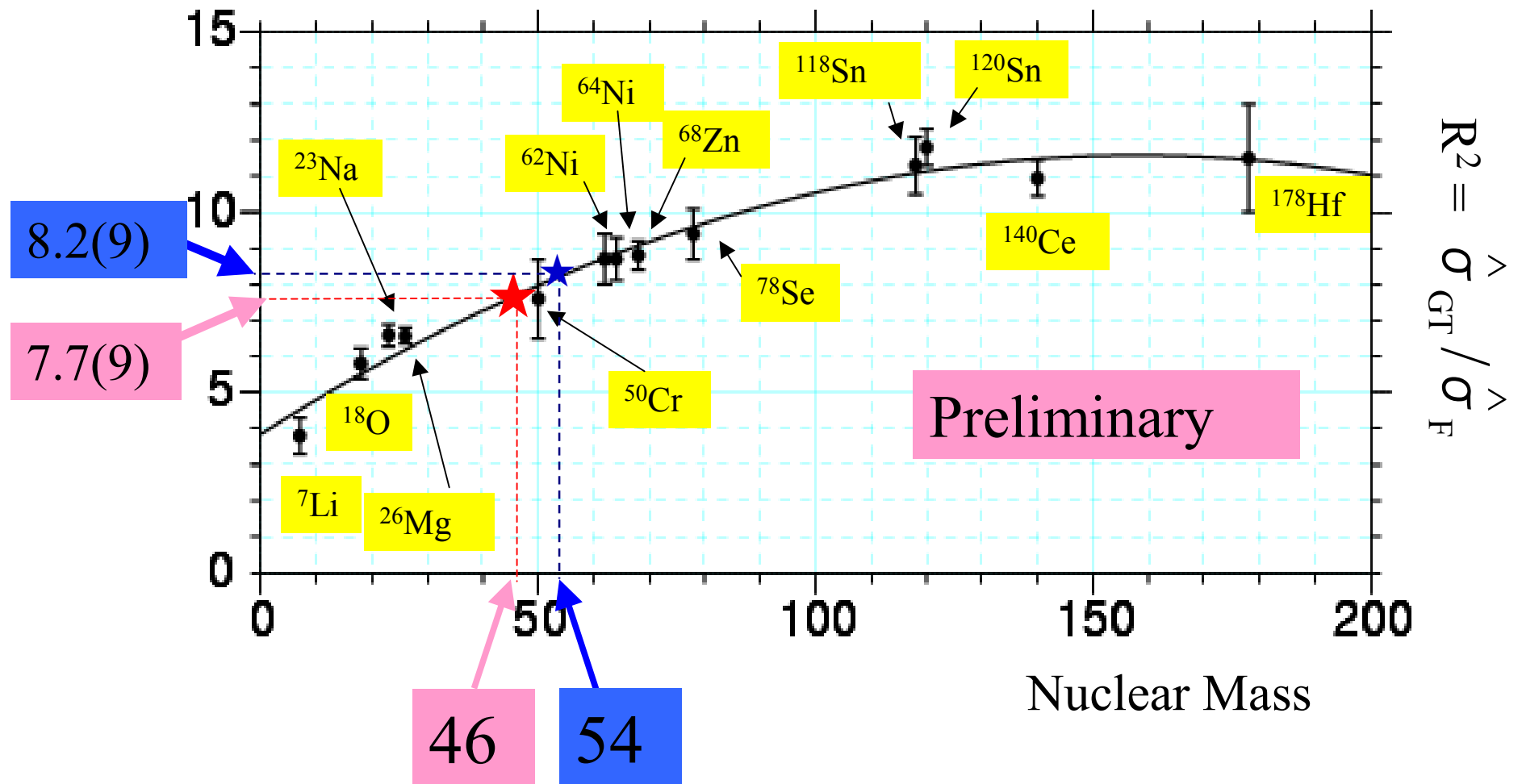
Mass Dependence of R^2 ?



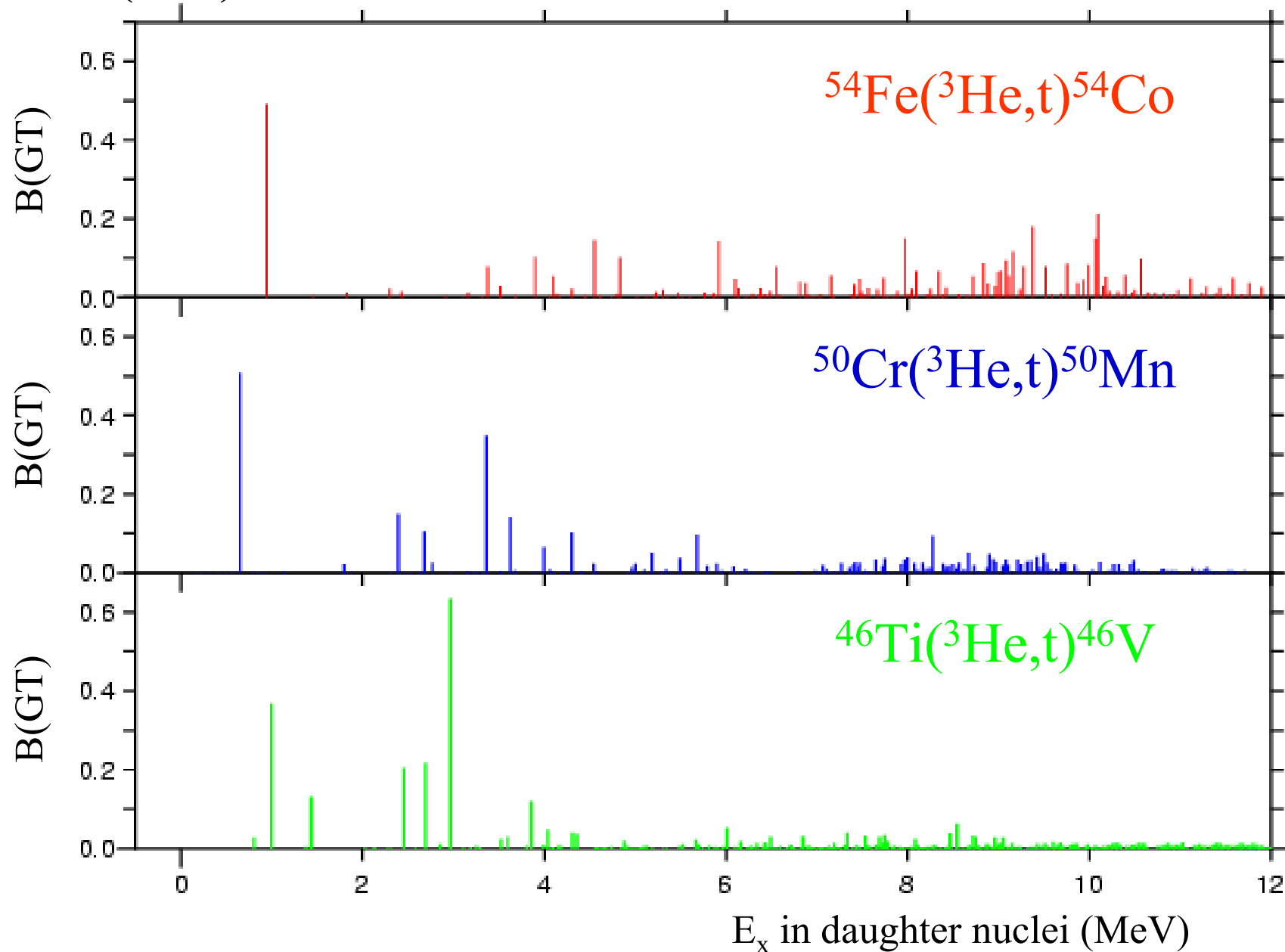
© Derivations of R^2 Values for Various Nuclei



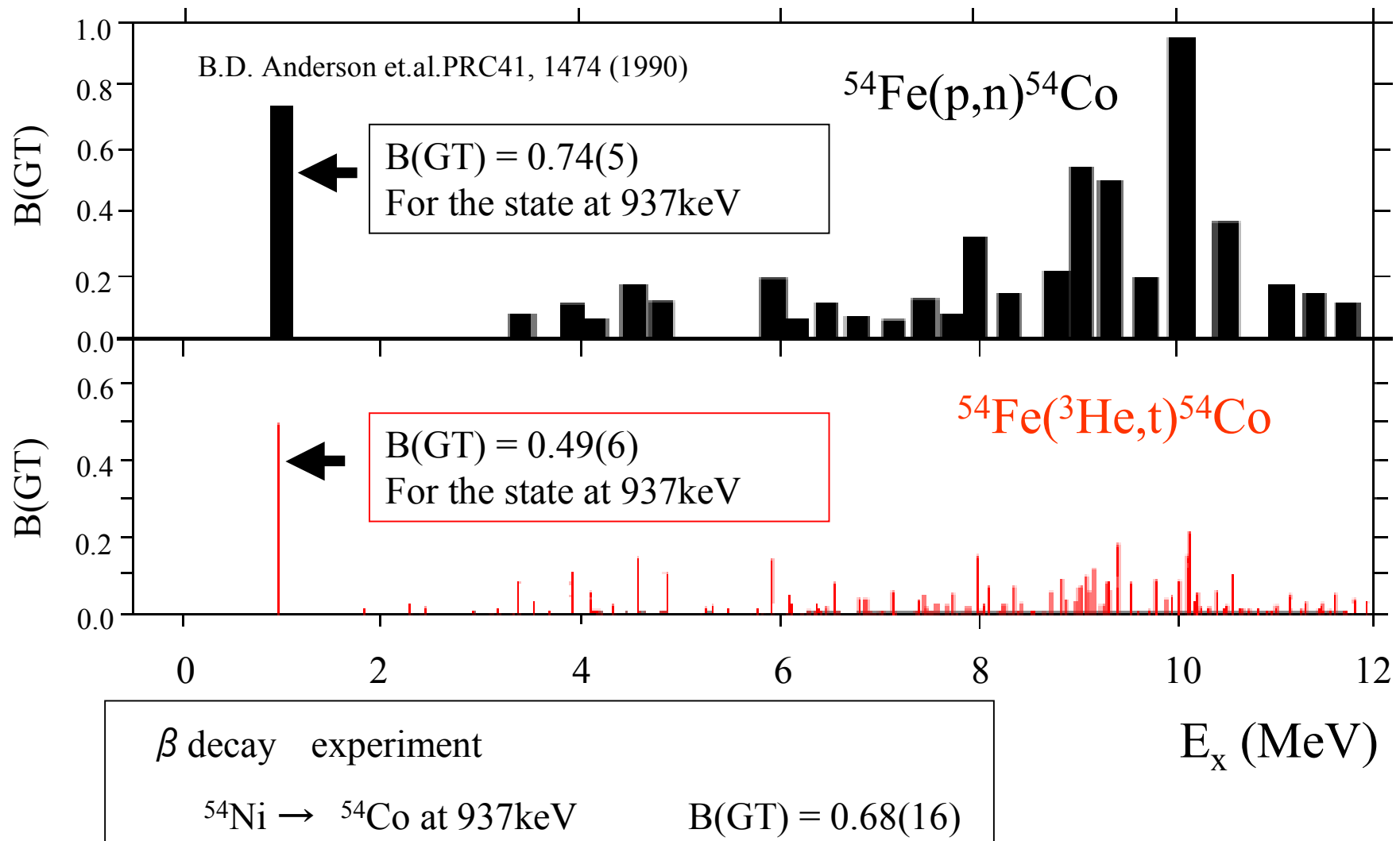
© Nuclear Mass Dependence of R^2



© B(GT) distributions in ^{54}Co , ^{50}Mn and ^{46}V



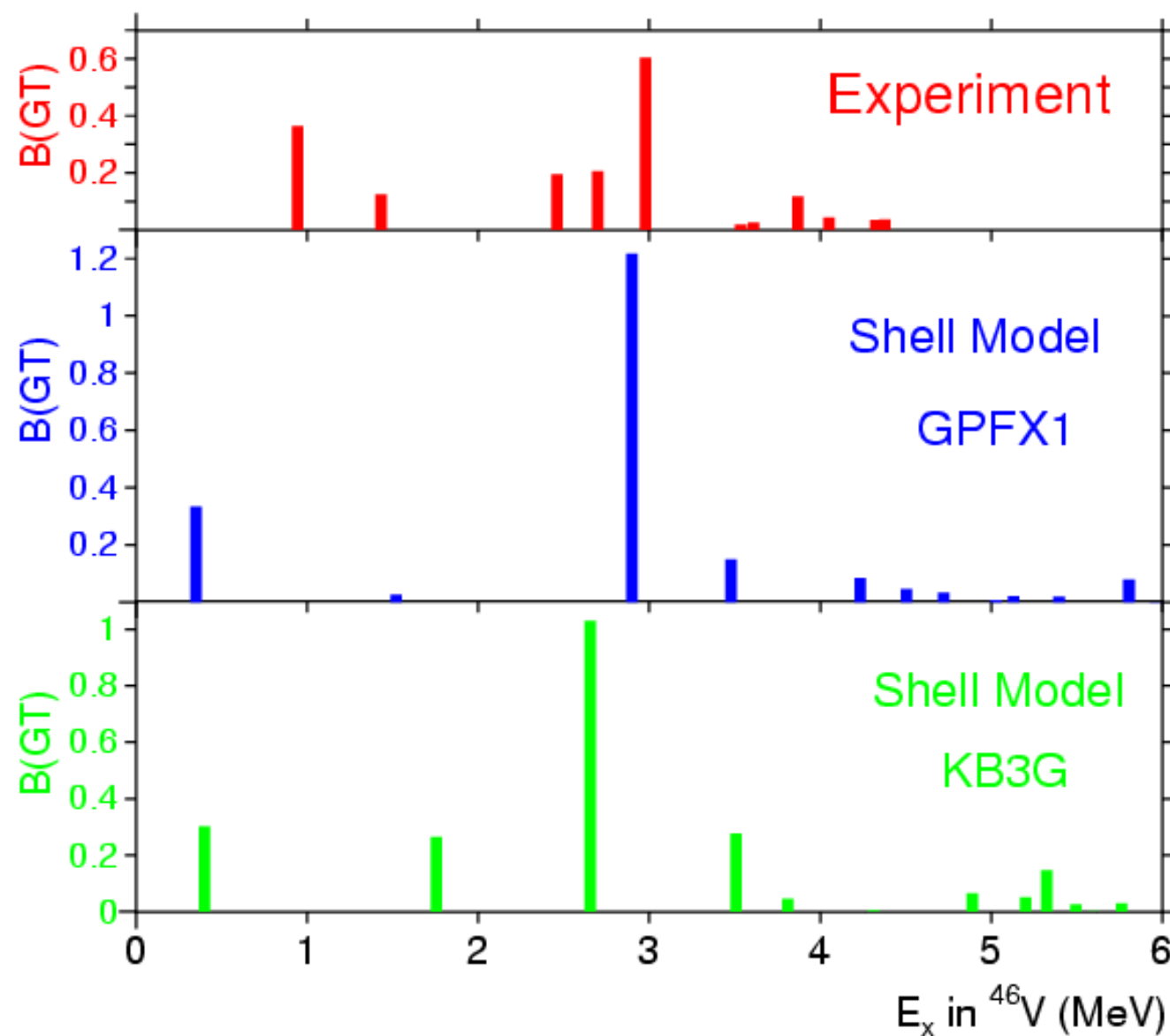
© Comparison of B(GT) distributions between (p,n) & (³He,t) in ⁵⁴Co



© Comparison between Exp. and Shell Model

^{46}V below 6MeV

T.Adachi et. al., PRC in press.



© Summary

High Resolution ($^3\text{He},t$) Experiment

^{54}Fe	$(^3\text{He},t)$	^{54}Co	21 keV
^{50}Cr		^{50}Mn	29 keV
^{46}Ti		^{46}V	33 keV

Derivation of B(GT) value \rightarrow unit cross section $\hat{\sigma}_{\text{GT}}$

$$\hat{\sigma}_{\text{GT}} = R^2 \hat{\sigma}_{\text{F}}$$



Derivation of R^2 value

For ^{50}Mn Estimate yield from ^{50}Fe β decay

Half life of ^{50}Fe β decay

For ^{54}Co & ^{46}Ti “ R^2 ” is smooth function of “A”

Systematic Derivation for Various Mass Nuclei

B(GT) distributions $E_x < 12\text{MeV}$ were calculated.