高分解能測定における高品質ビームへの期待

Yoshitaka FUJITA (Osaka Univ.)

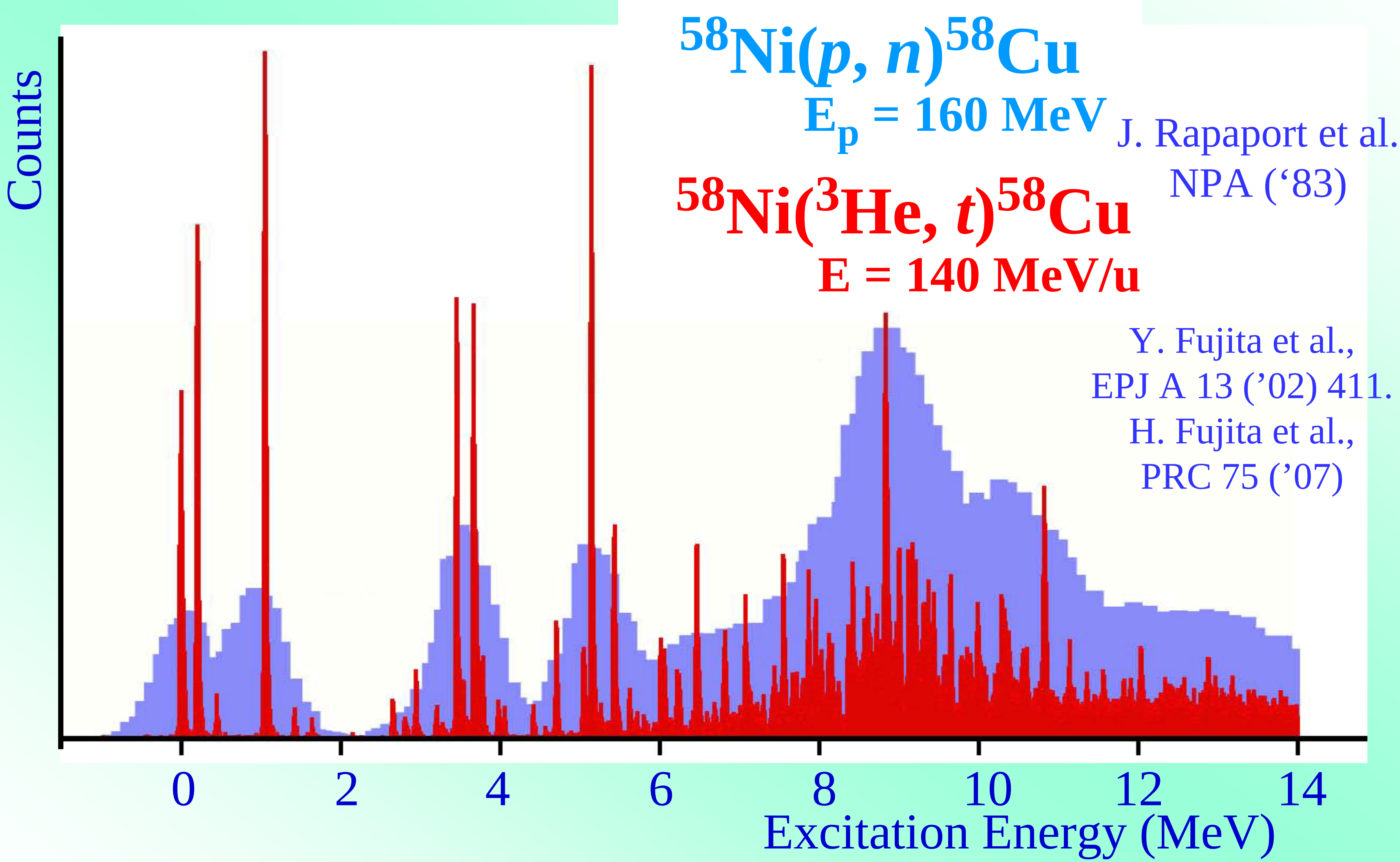
RCNP 入射サイクロトロン更新で展開される新しい研究

2007 Feb. 19-20

RCNPでの高分解能研究と関連して

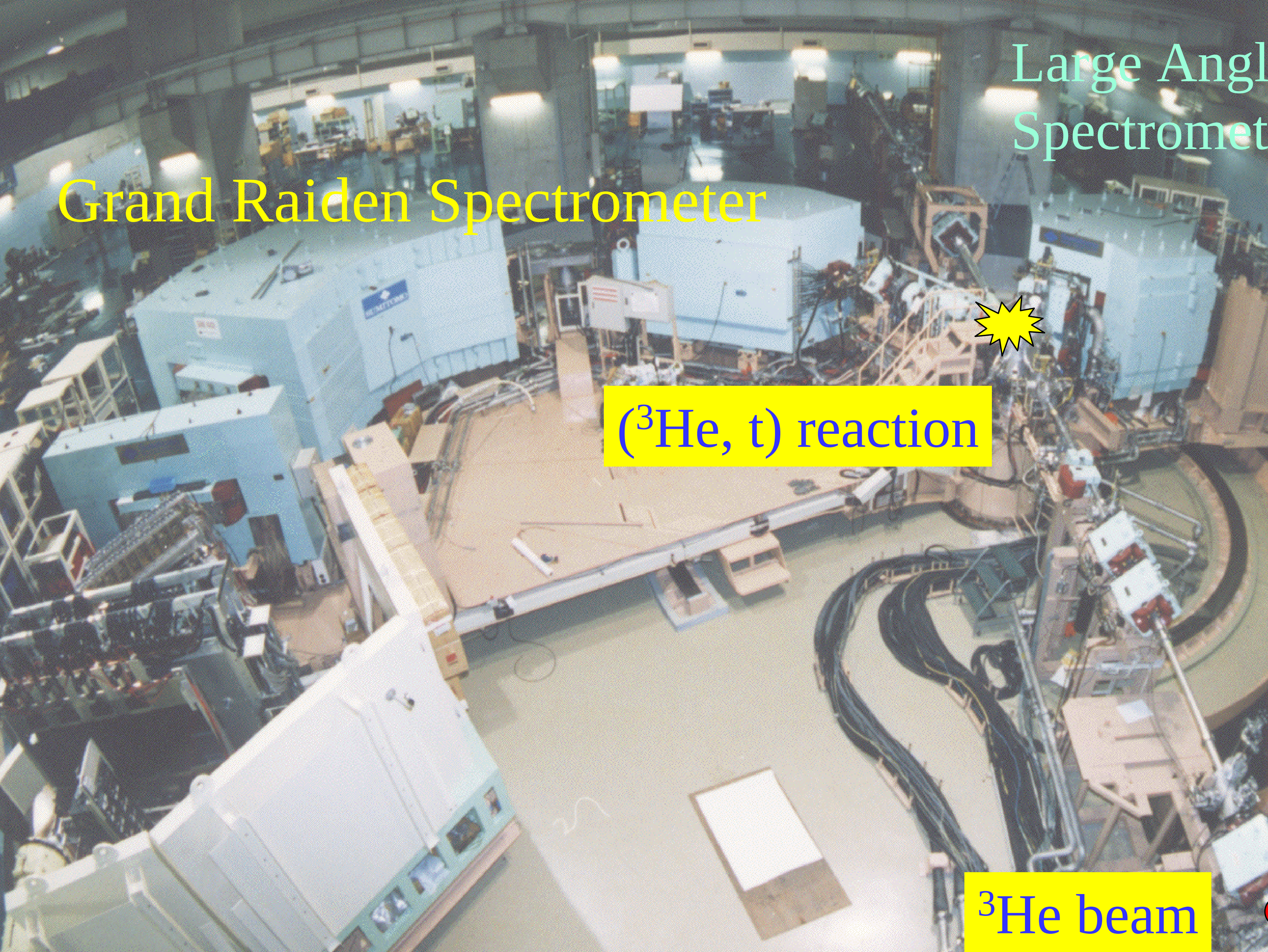
***High Resolution Experiment

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



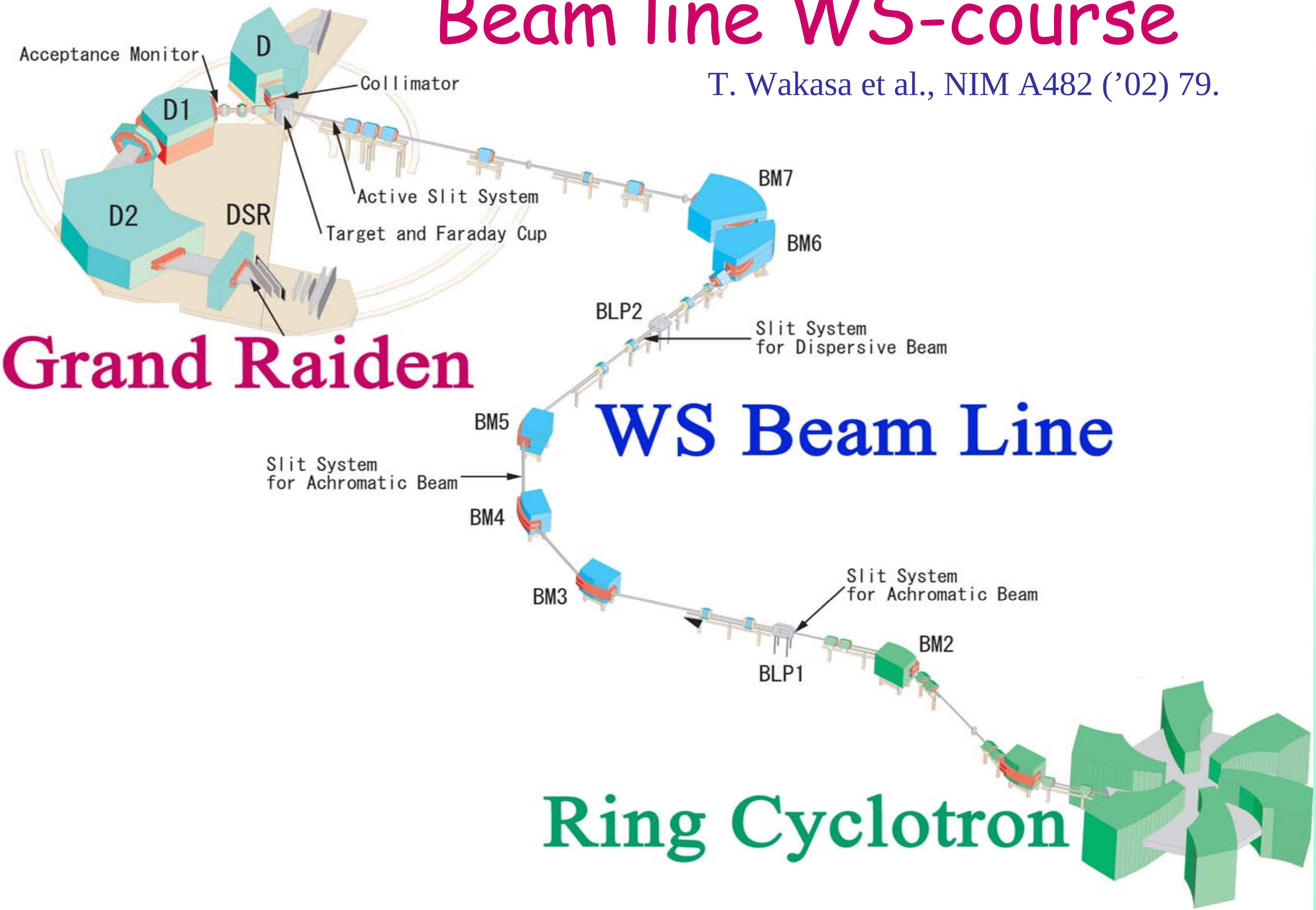
RCNP Ring Cyclotron

Good quality ^{3}He beam (140 MeV/nucleon)


Large Angl
Spectromet
Grand Raiden Spectrometer
(^{3}He, t) reaction
^{3}He beam

Beam line WS-course

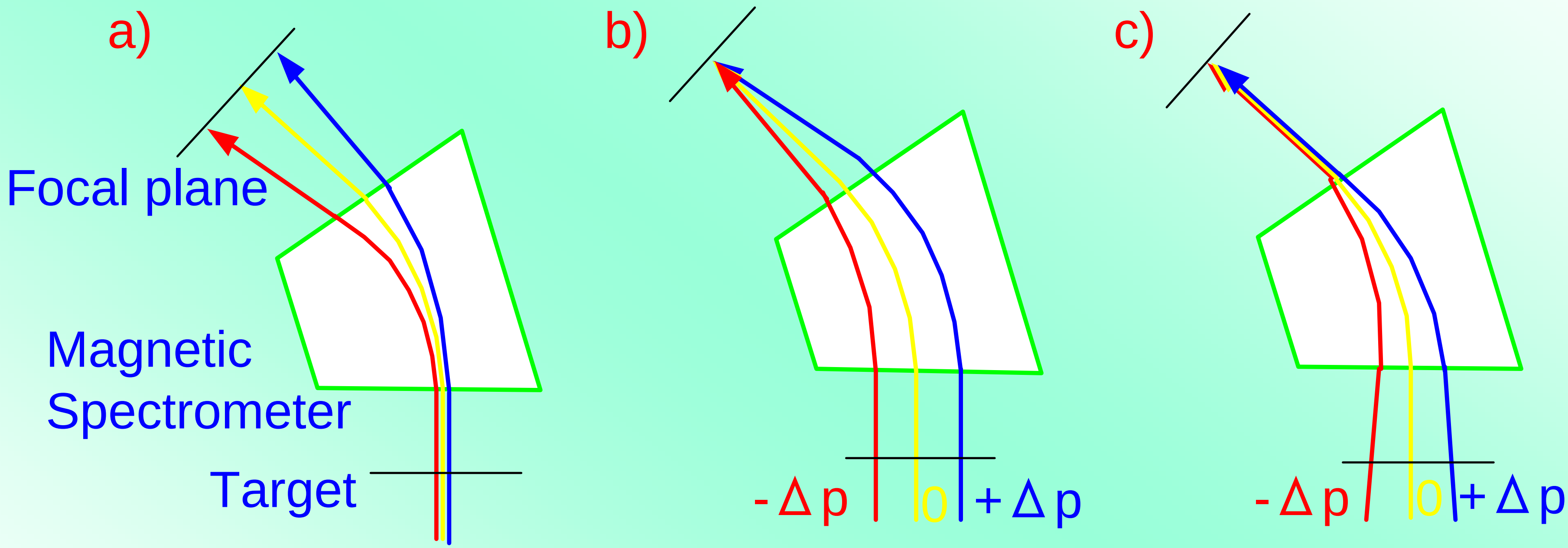
T. Wakasa et al., NIM A482 ('02) 79.



Matching Techniques

Y. Fujita et al., N.I.M. B 126 (1997) 274.

H. Fujita et al., N.I.M. A 484 (2002) 17.



Achromatic beam transportation

$\Delta E \sim$ 200 keV

for 140MeV/u ^{3}He beam

Lateral dispersion matching

$\Delta E \sim$ 35 keV

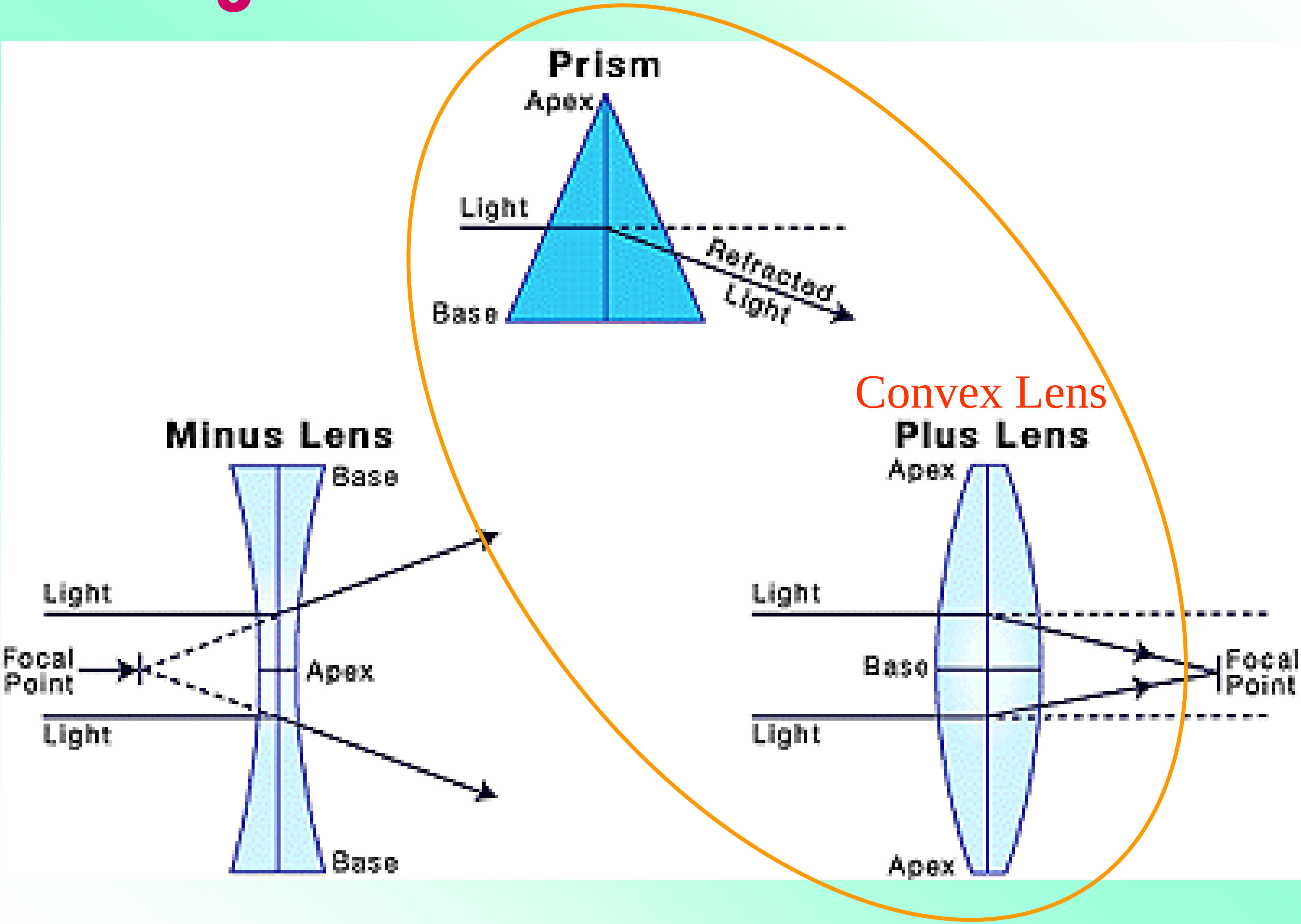
Horiz. angle resolution

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

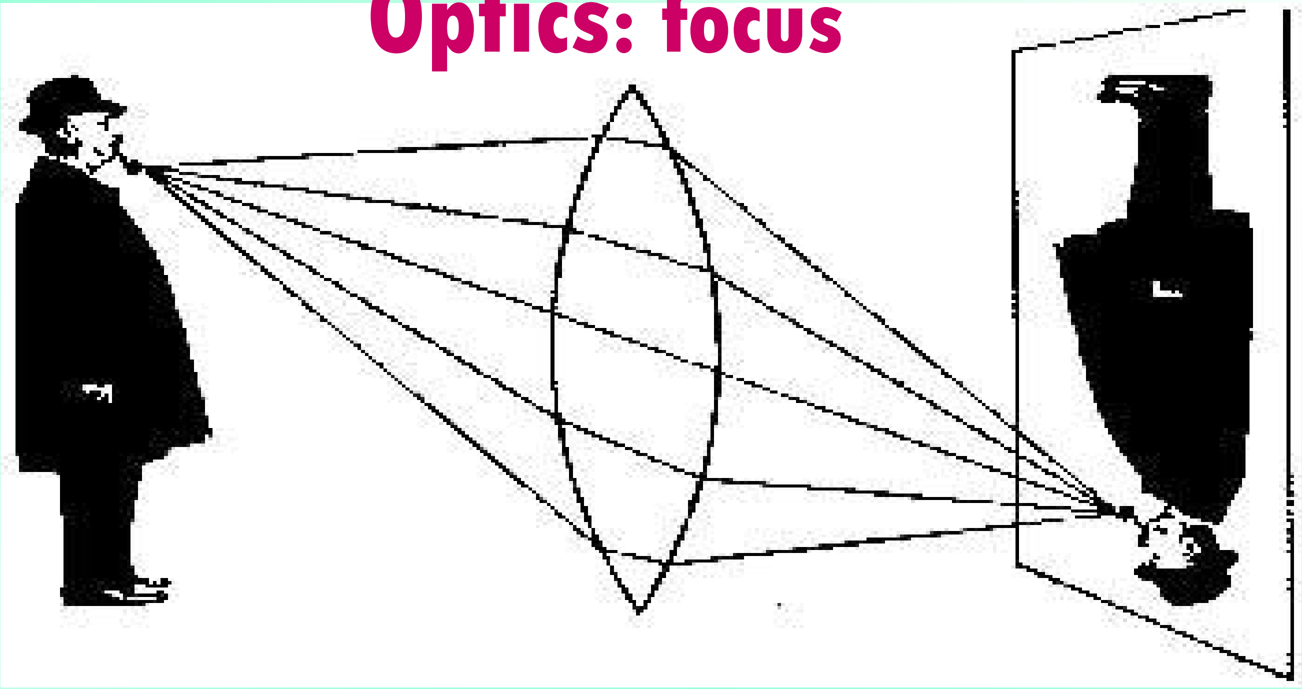
Angular dispersion matching

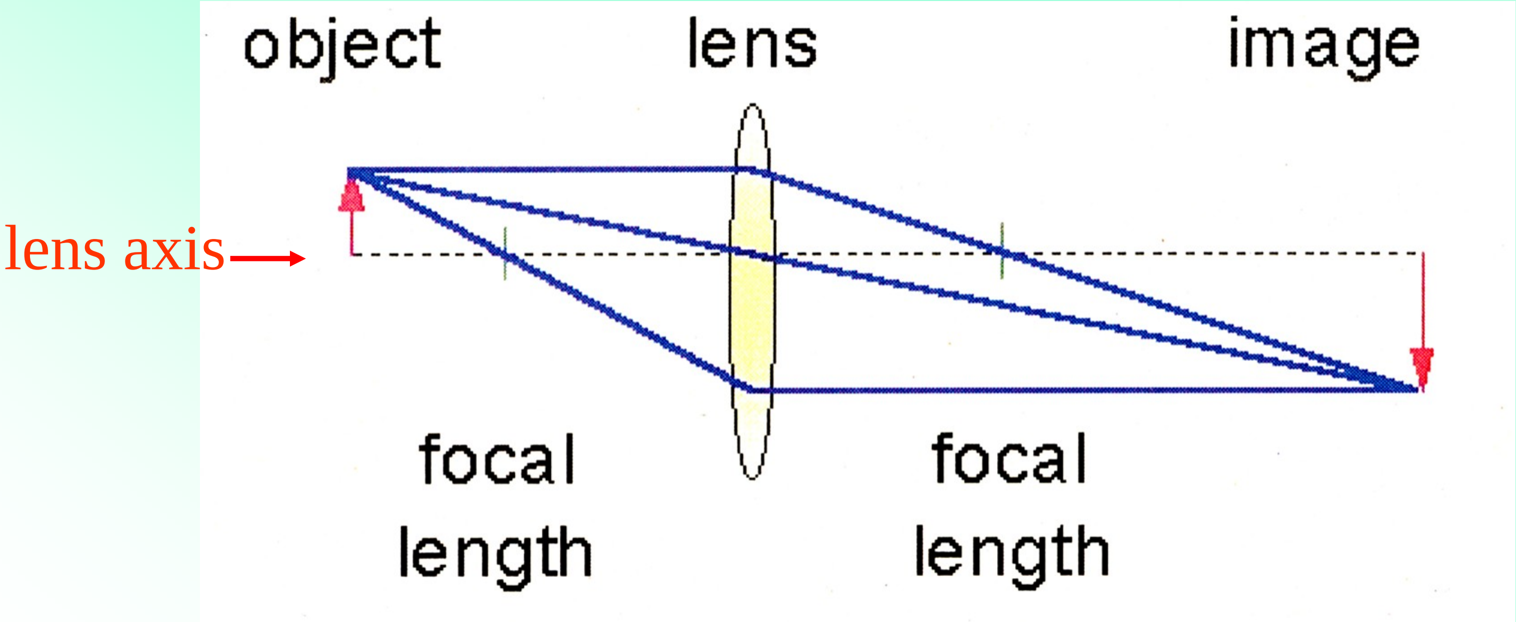
$\Delta\theta_{sc} \sim$ 5mrad

Magnet= convex Lens + Prism

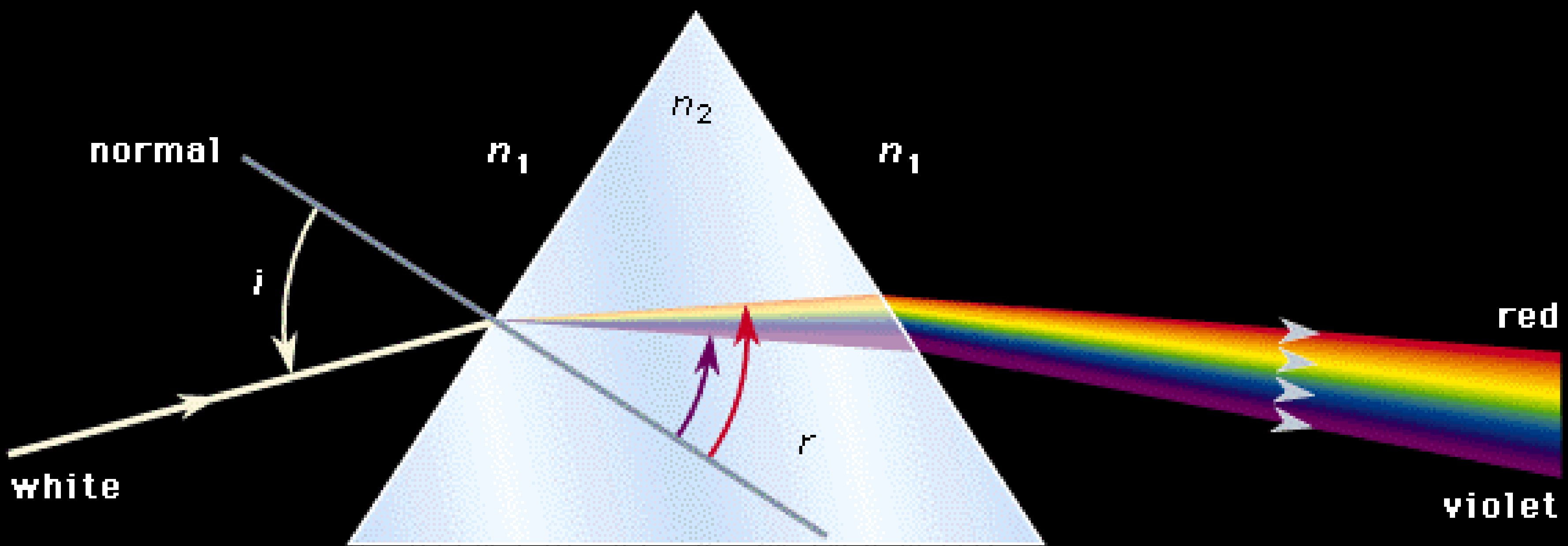


Optics: focus





Prism



The angles *i* and *r* that the rays make with the normal are the angles of incidence and refraction. Because n_2 depends upon wavelength, the incident white ray separates into its constituent colours upon refraction, with deviation of the red ray the least and the violet ray the most.

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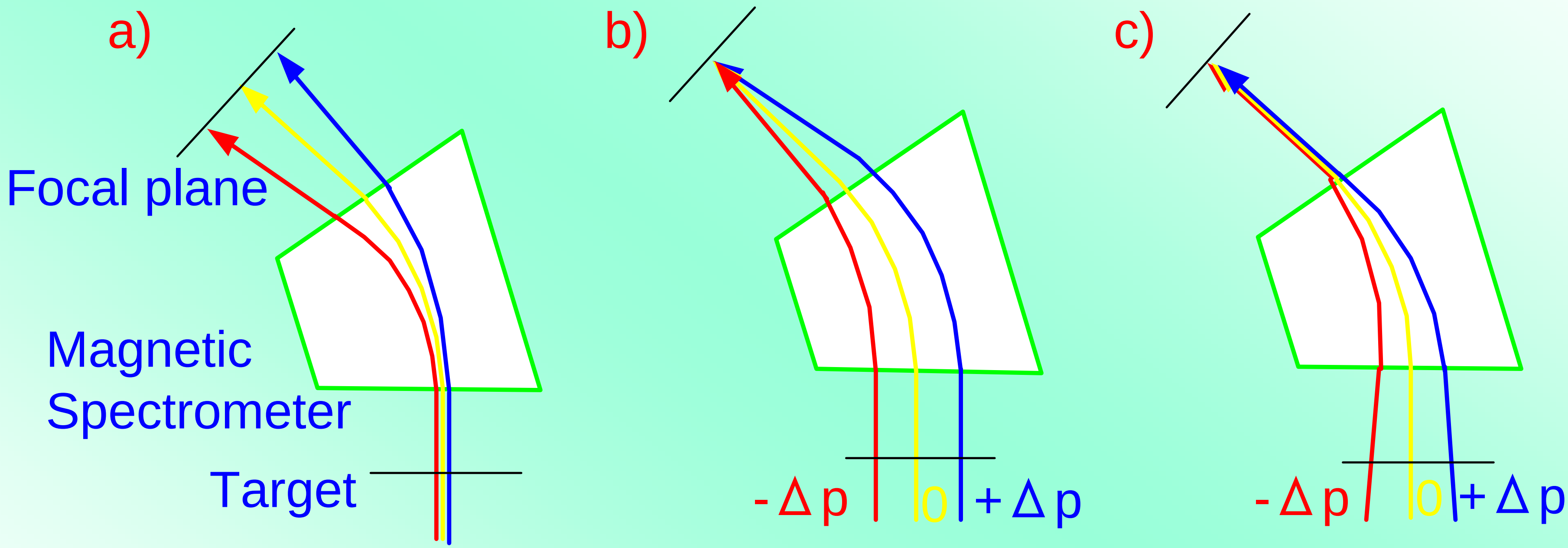

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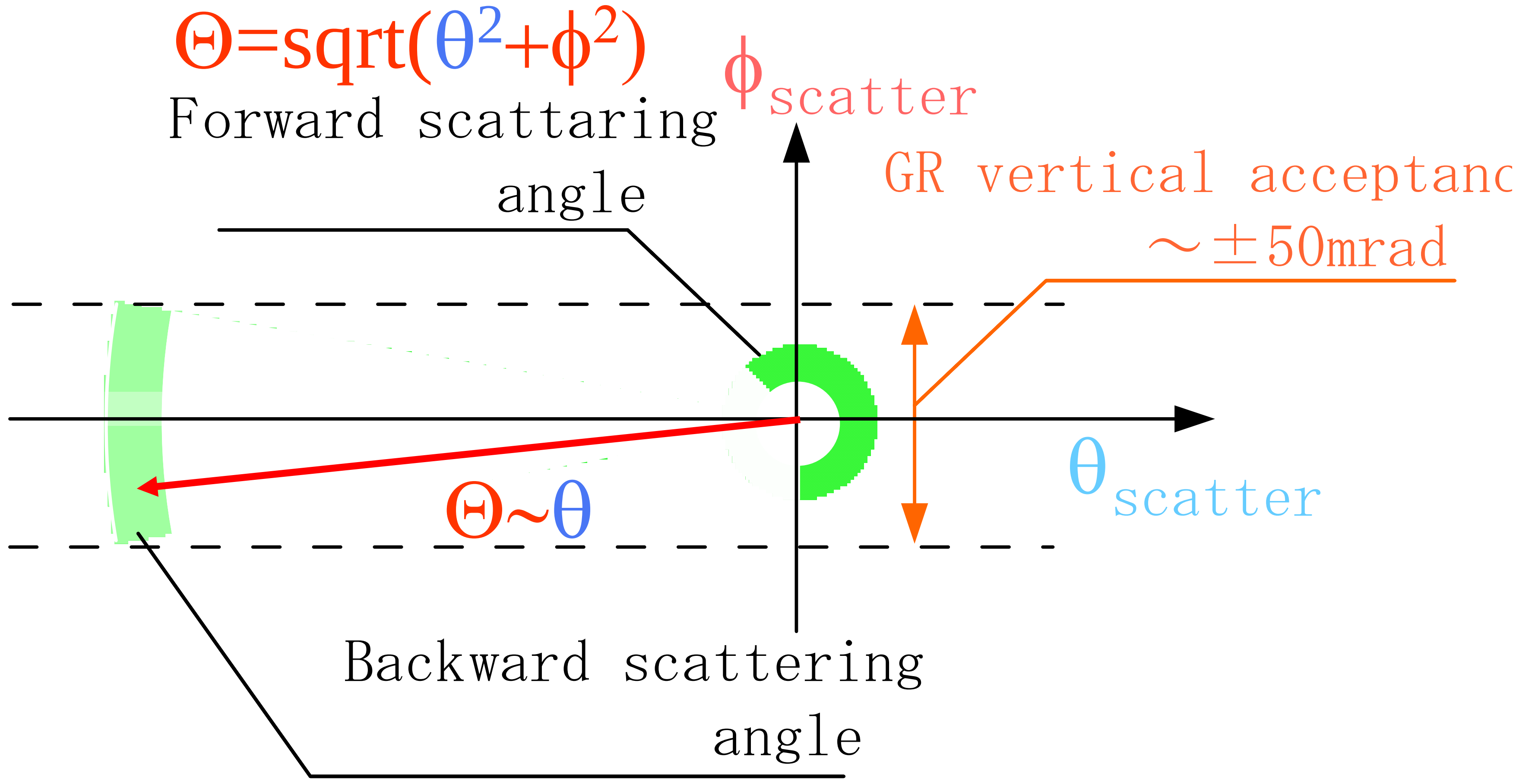
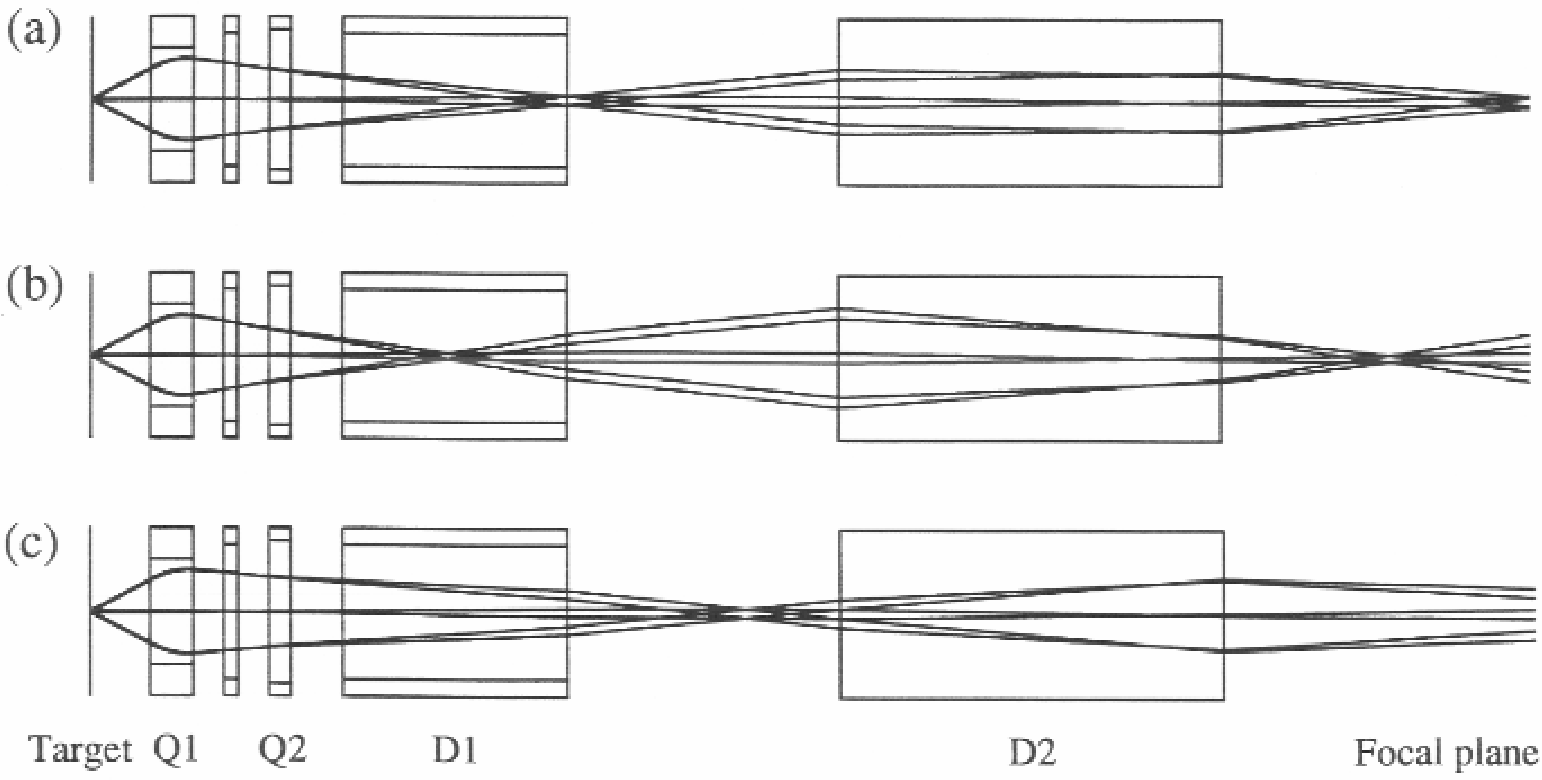
Importance of Vertical Scattering Angle at 0°



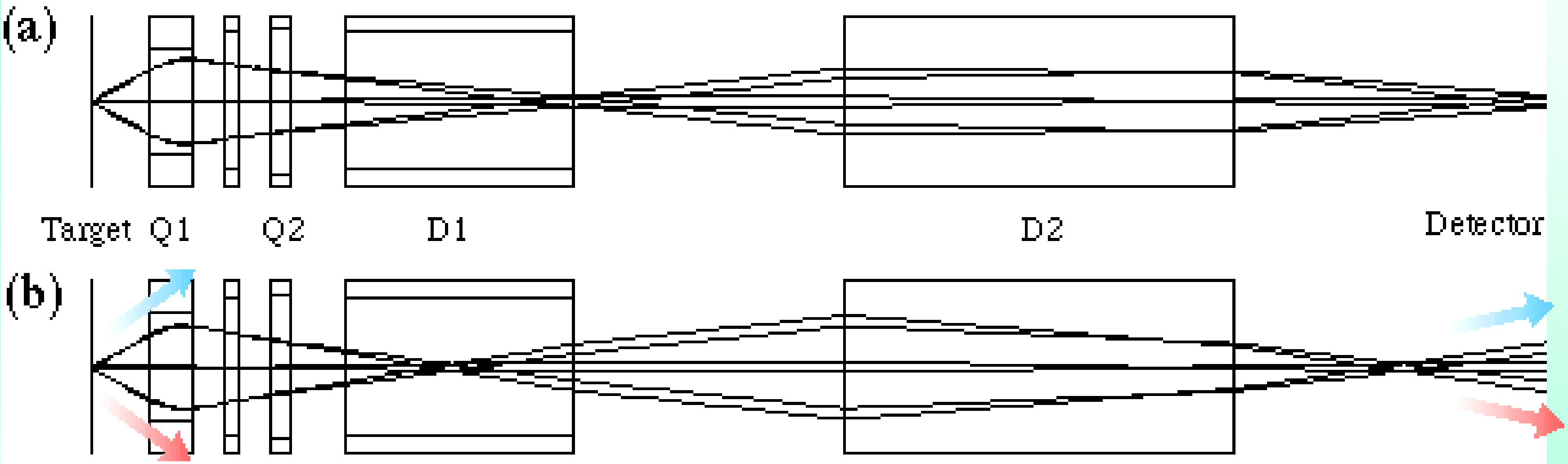
Off-focus Mode in Vertical Direction



Over-focus Mode of Grand Raiden

H.Fujita et al., Nucl. Instr. Meth. A 469 (2001) 55.

Vertical orbits of scattered particles in Grand Raiden

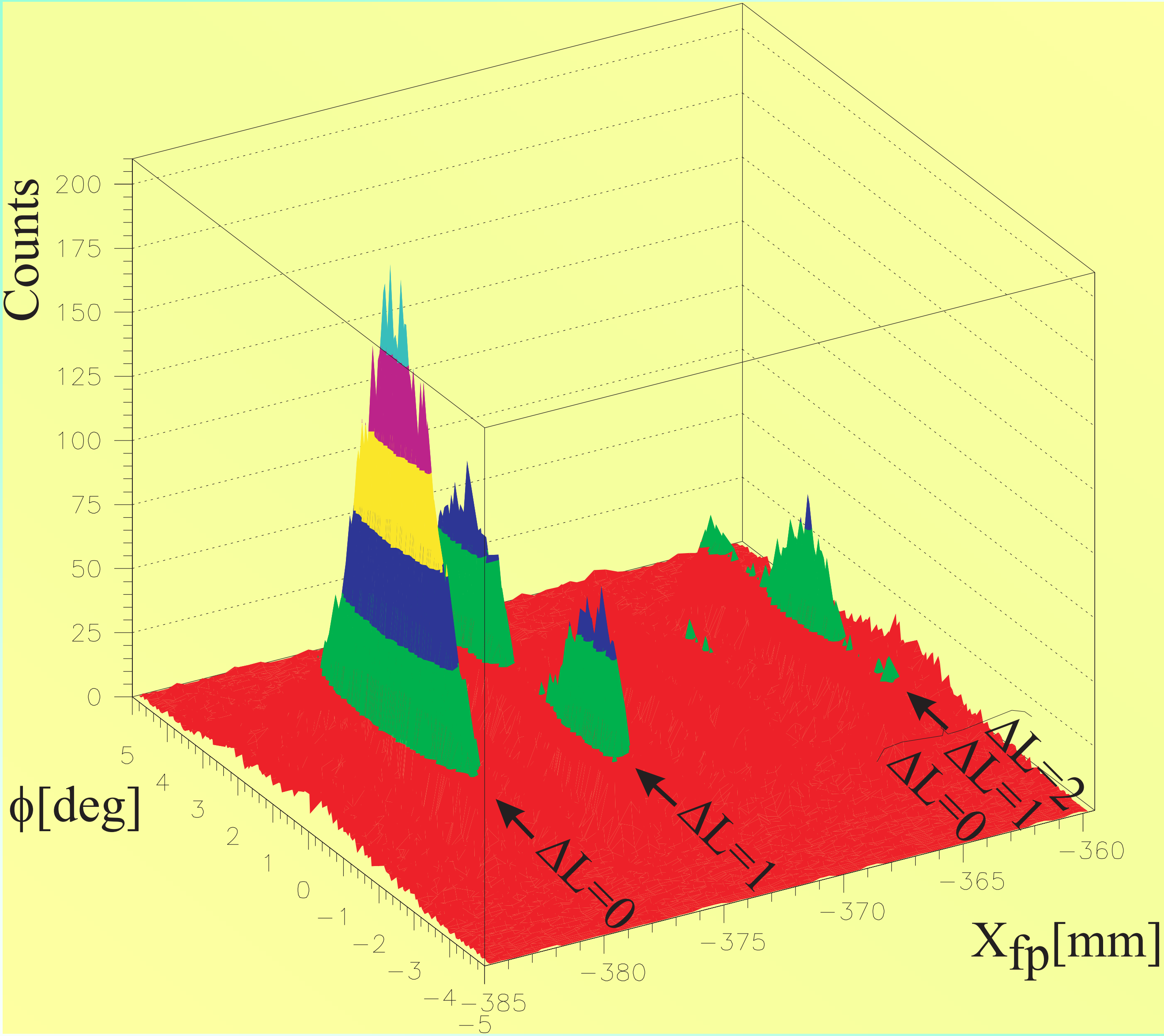


(a) ... Normal vertical point-to-point mode

(b) ... "Over-focus mode" for precise vertical scattering angle measurement

*Vertical scattering angle is measured from vertical position at the focal plane y_{fp} (not from ϕ_{fp})

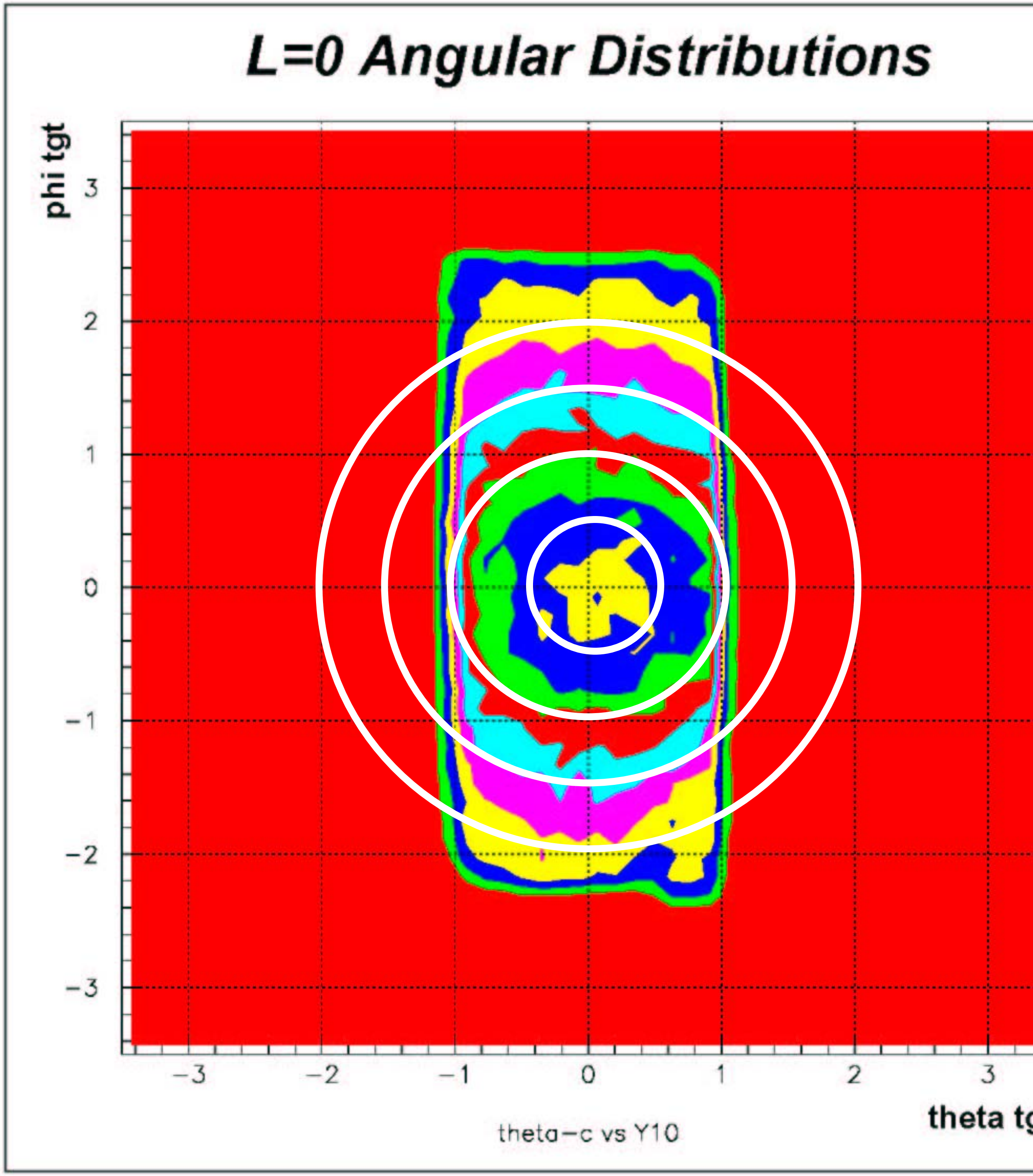
Identification of GT transitions
-Angular distributions for different ΔL-



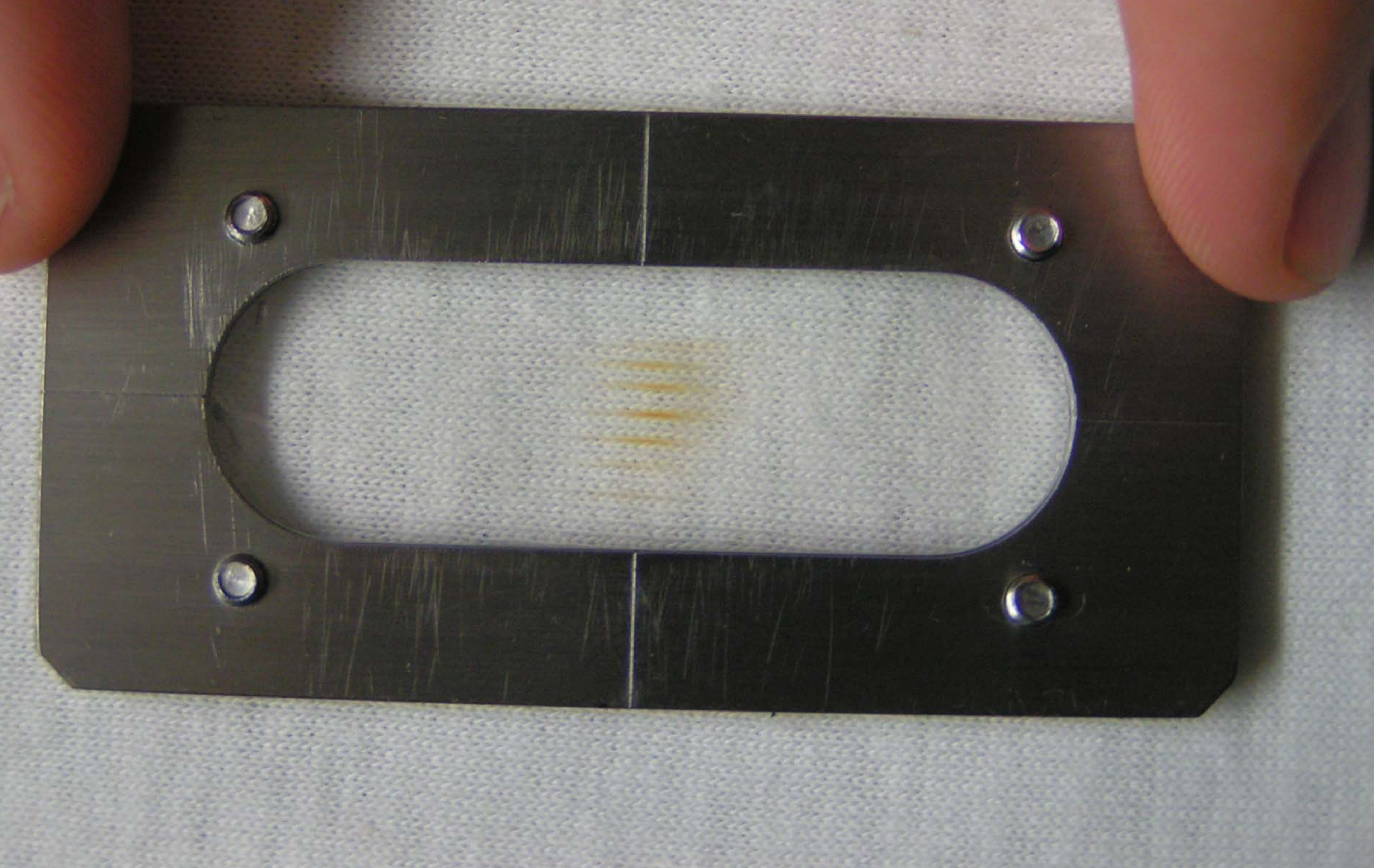
Contour Map within the Acceptance

Concentric L=0 angular distribution around 0°

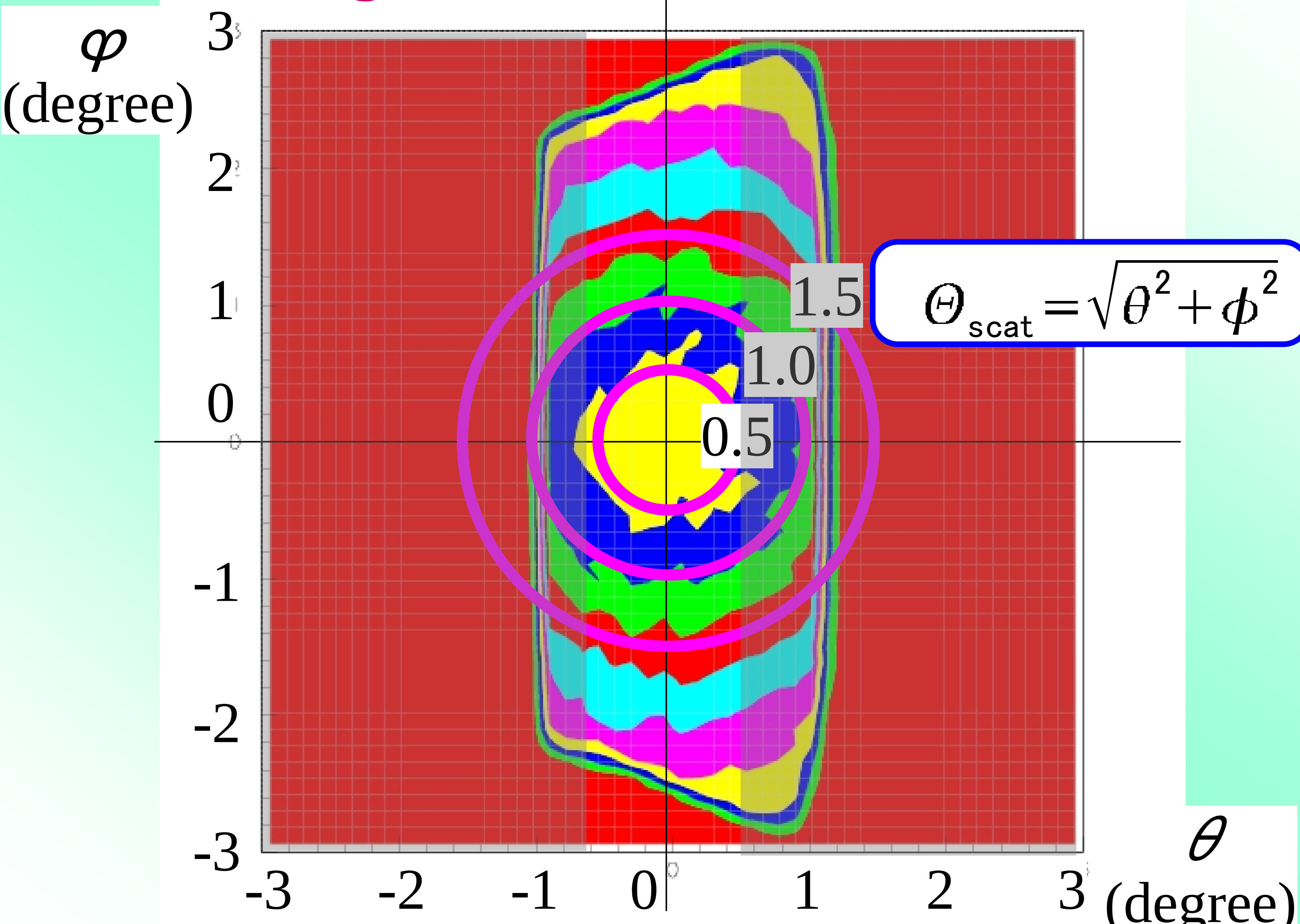
$\Theta = \mathrm{sqrt}(\theta^2 + \phi^2)$



Beam spot size under Dispersion Matching



Angular distribution



Dispersion Matching is possible …

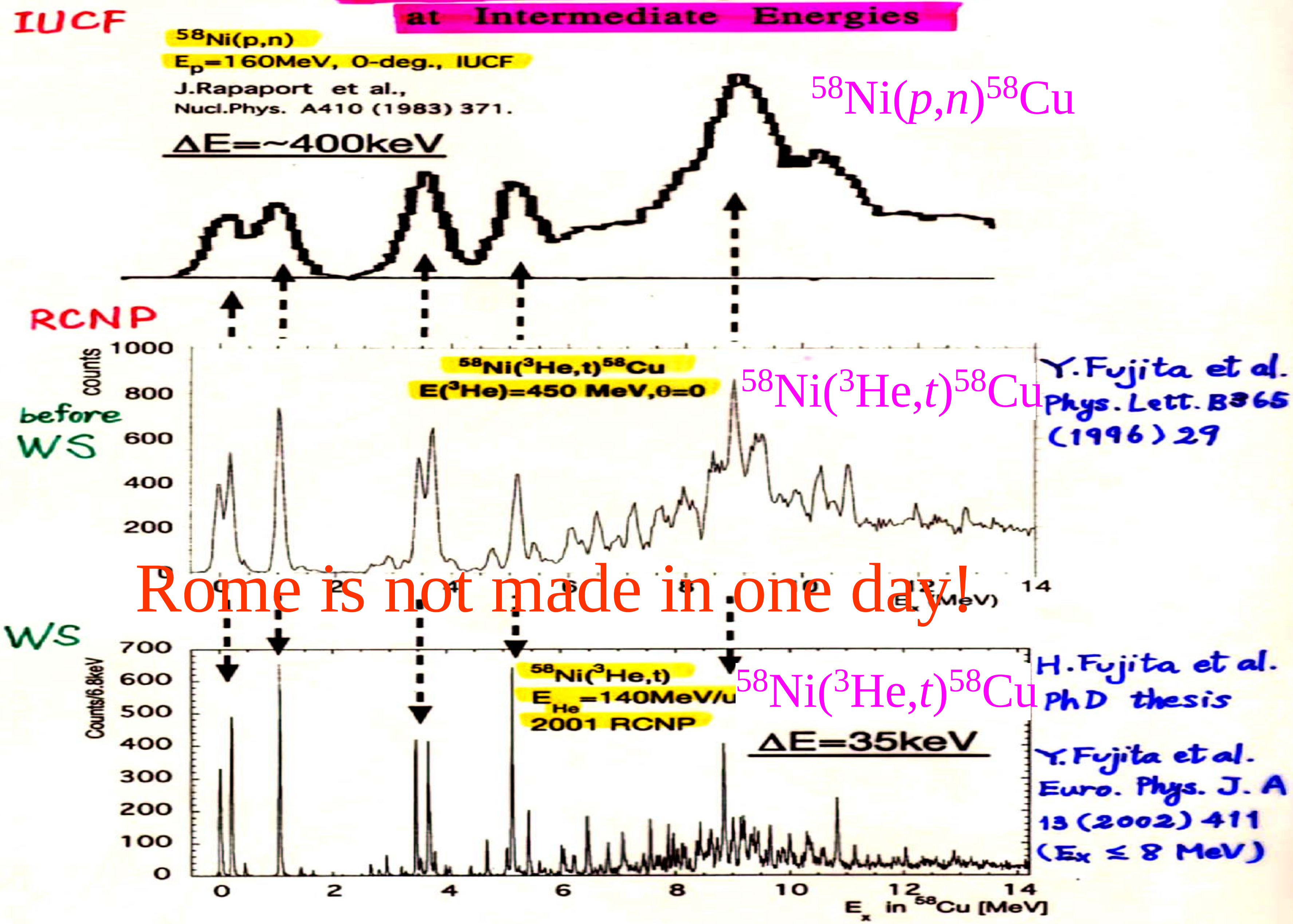
Dispersion matching is the idea of 1st order

* Only when the beam emittance is “moderate”
  - multi-component beam is not allowed
  - multi-turn beam is not allowed
* Only when the beam energy spread is “moderate”
  - energy reduction factor ~5
  - distortion of angular distribution in relation to the acceptance of the Spectrometer

↓

Beam Quality of the Injector is Crucial !
(RING is a “Booster”)

Evolution of Resolution in Charge-Exchange Reactions at Intermediate Energies



RIKEN vs. RCNP

Facility

RIKEN	RCNP
RI beam facility	Stable beam facility
Various short-lived nuclei	-smaller chance-
cocktail beam	single beam
Dirty beam (high intensity!)	High quality beam (lower intensity)
large emittance	small emittance
large energy spread	small energy spread

Experiment

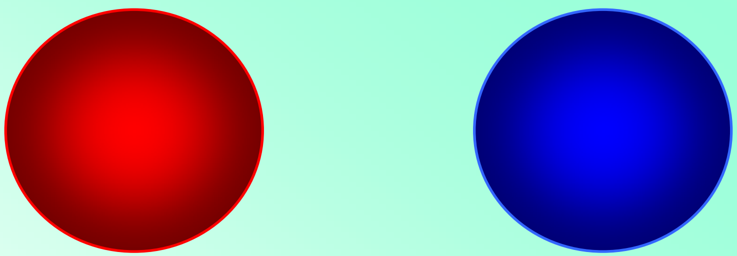
RIKEN	RCNP
Inverse kinematics	Normal kinematics
Invariant-mass Spectroscopy	Singles measurement
Partial decay measurements	Total decay width + partial
γ: Doppler shift	no effect from Doppler shift
particle decay	
Extension in T_z axis	Extension to higher T (higher Ex)

***Isospin Symmetry

Nucleon & Coin

back front

= Coin



= Nucleon

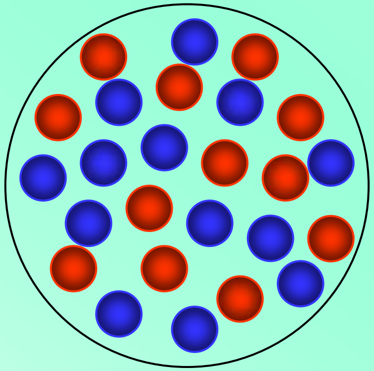
proton neutron

similar mass

nearly the same interaction

T_z=-1/2 T_z= 1/2 isospin T=1/2

Isospin of a Nucleus



$^{A}{}_{N}Z$

$$T_z = (1/2)N + (-1/2)Z$$

*z-component: conserved

The size of a vector should be larger than its z-component!

$$T = \text{or} > |T_z|$$

ex. ^{26}Mg (Z=12, N=14) : T_z= +1, T= 1, 2, …

^{26}Al (Z=13, N=13) : T_z= 0, T= 0, 1, 2, …

^{27}Si (Z=14, N=12) : T_z= -1, T= 1, 2, …

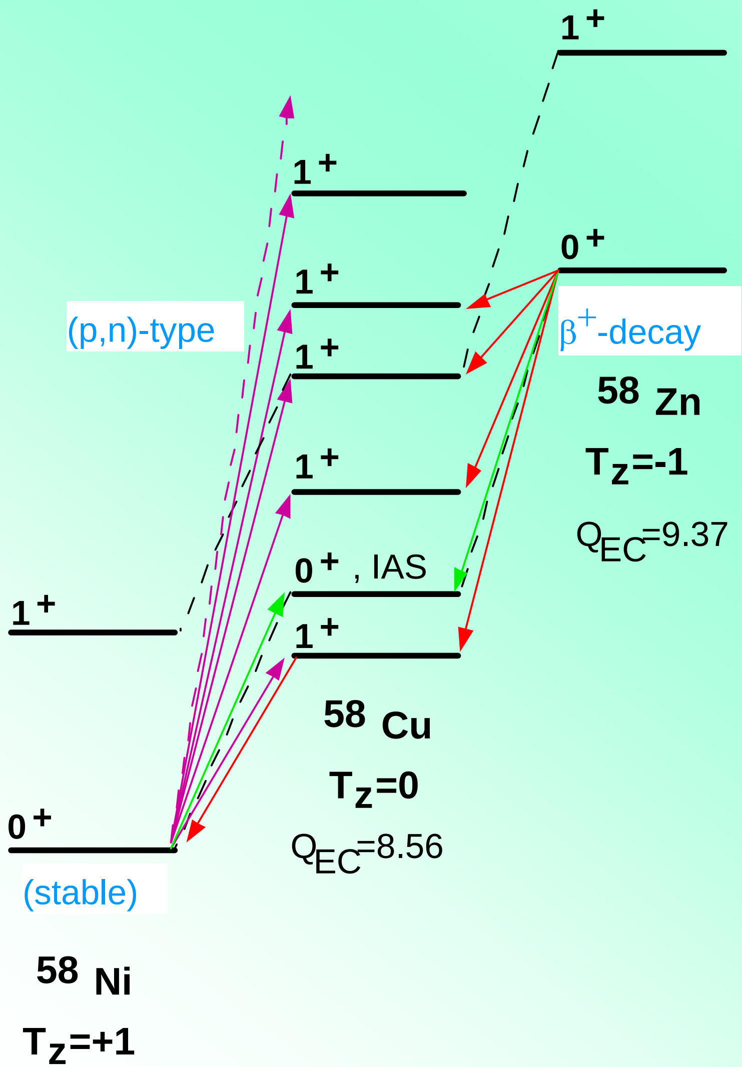
Isospin Analogous Structure is expected over same mass A nuclei (isobars)!

Transitions in real & isospin space (T=1)

Symmetry Transitions from T=1 Nuclei

$T_z=+1$ → $T_z=0$ ← $T_z=-1$

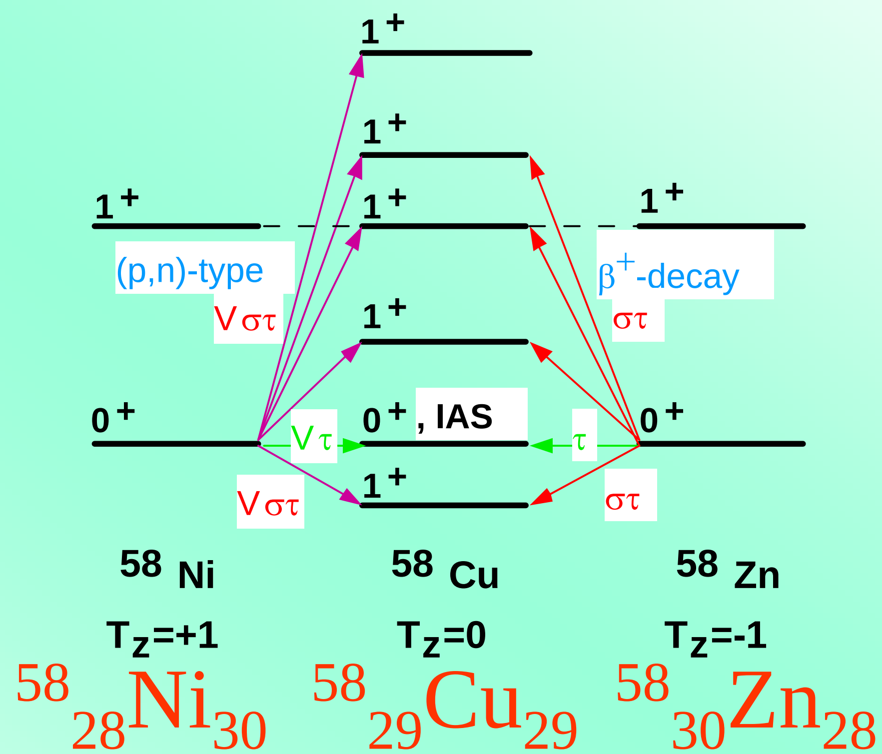
(in real energy space)



Symmetry Transitions from T=1 Nuclei

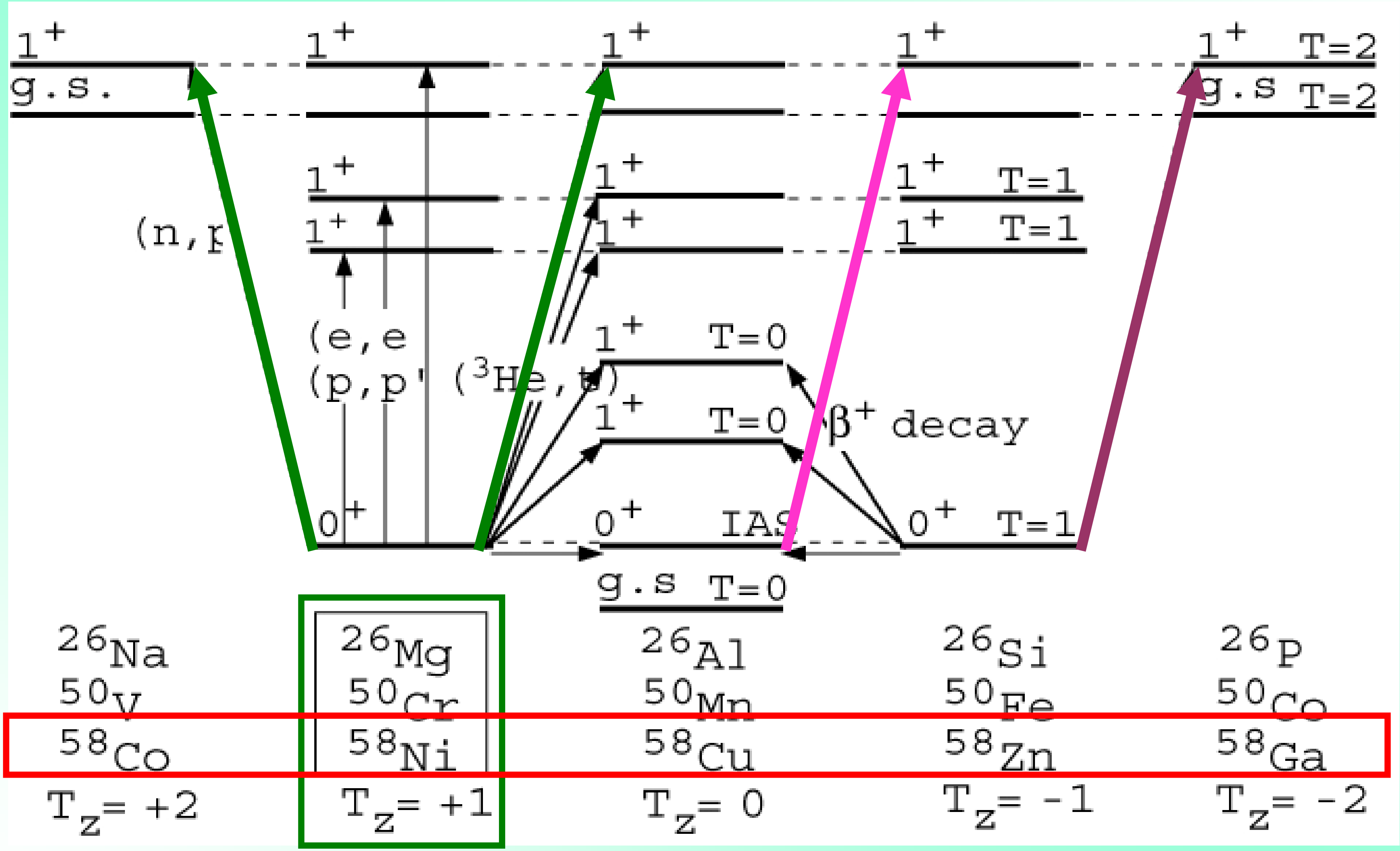
$T_z=+1$ → $T_z=0$ ← $T_z=-1$

(in isospin symmetry space*)



*after the correction of
Coulomb displacement energy

T=1 and T=2 Symmetry



stable

Comparison of CE and IE reactions

T identification
on the basis of Isospin Symmetry

B(GT) & B(M1) : Similarity & Difference

GT operator

$$O_{GT\pm} = \mp \frac{1}{\sqrt{2}} \sum_{j=1}^{A} (\boldsymbol{\sigma}_j \tau_j^{\pm})$$

GT transition strength

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

IV Spin

M1 operator

0.5 0.88 0.5 4.7

$$\boldsymbol{\mu} = \left\{ \sum_{j=1}^{A} (g_l^{\mathrm{IS}} \boldsymbol{l}_j + g_s^{\mathrm{IS}} \boldsymbol{s}_j) - \sum_{j=1}^{A} (g_l^{\mathrm{IV}} \boldsymbol{l}_j + g_s^{\mathrm{IV}} \boldsymbol{s}_j) \tau_{zj} \right\} \mu_N$$

M1 transition strength

$$B(M1) = \frac{1}{2J_i+1} \frac{3}{4\pi} \mu_N^2 \left[\left(g_l^{\mathrm{IS}} M_{M1}(l) + g_s^{\mathrm{IS}} \frac{1}{2} M_{M1}(\sigma) \right) - \frac{C_{M1}}{\sqrt{2T_f+1}} \left(g_l^{\mathrm{IV}} M_{M1}(l\tau) + g_s^{\mathrm{IV}} \frac{1}{2} M_{M1}(\sigma\tau) \right) \right]^2$$

IS

IV

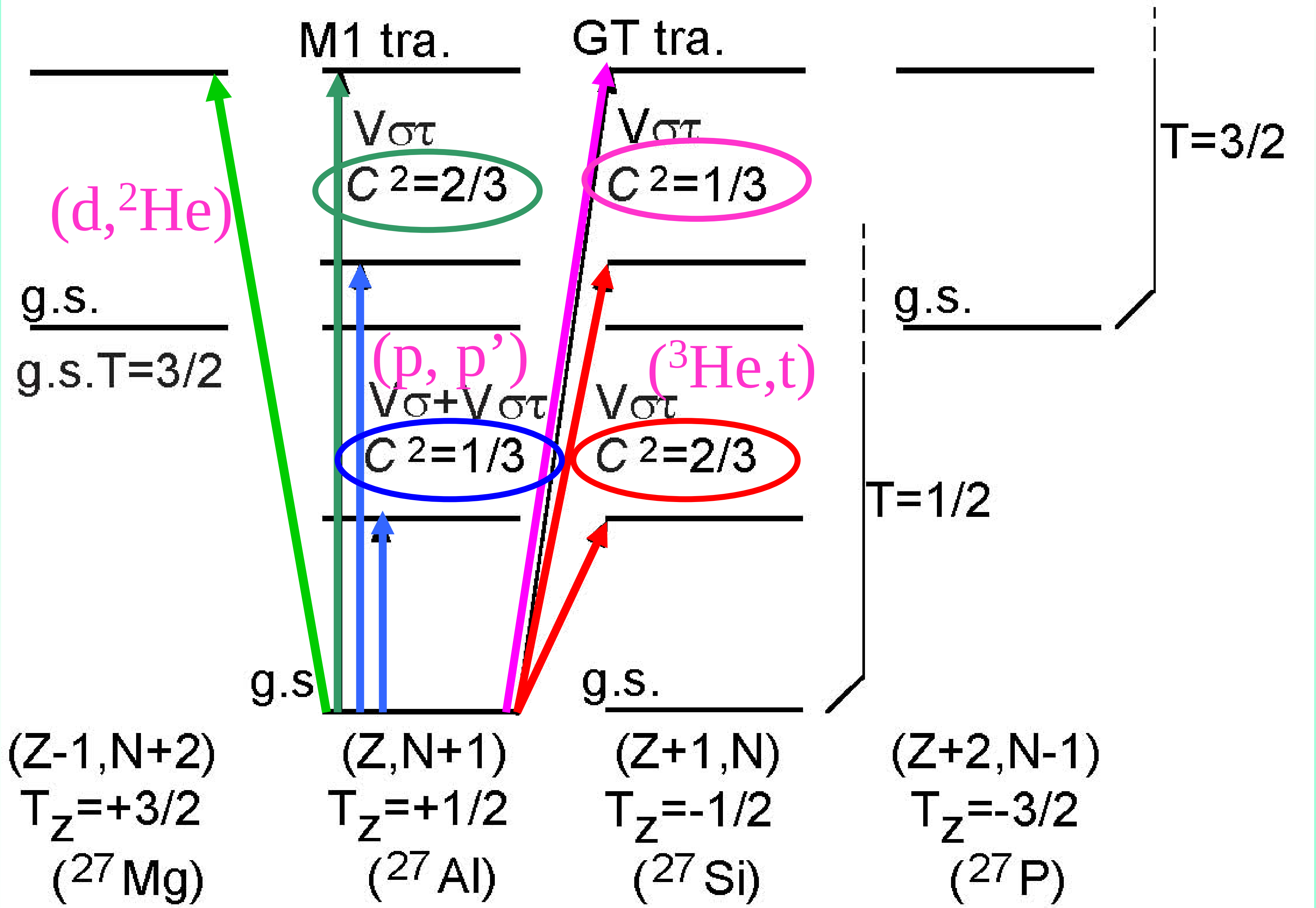
Orbital Spin (main term)

Meson Exchange Currents

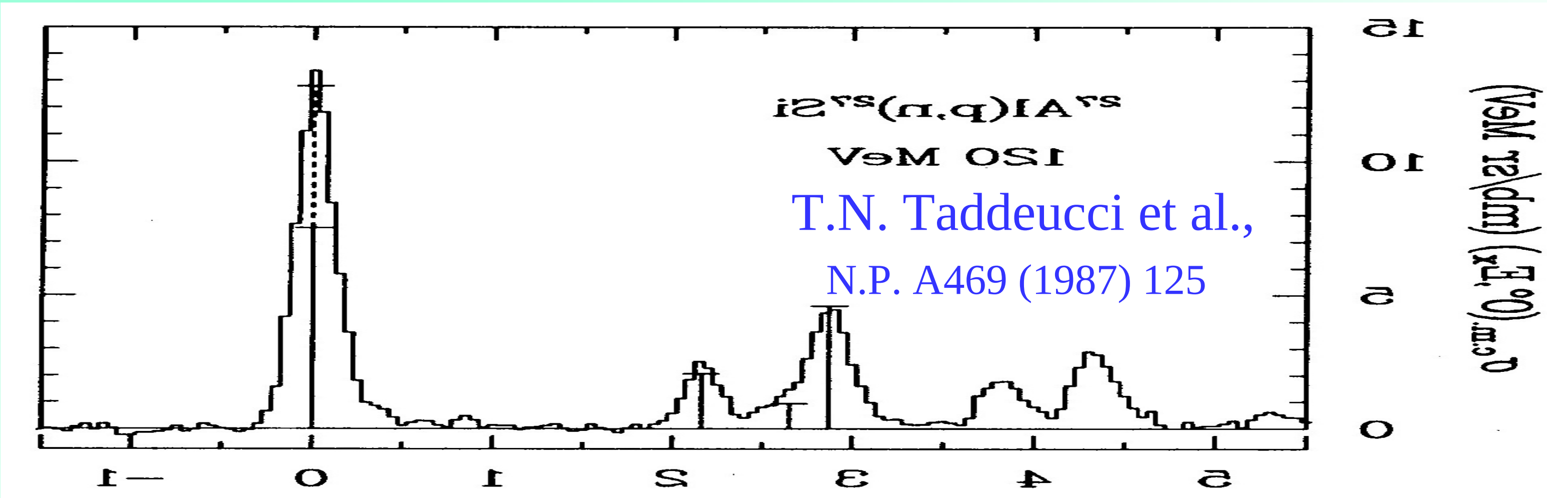
$$[M_{M1}(\sigma\tau)]^2 = R_{\mathrm{MEC}} [M_{\mathrm{GT}}(\sigma\tau)]^2$$

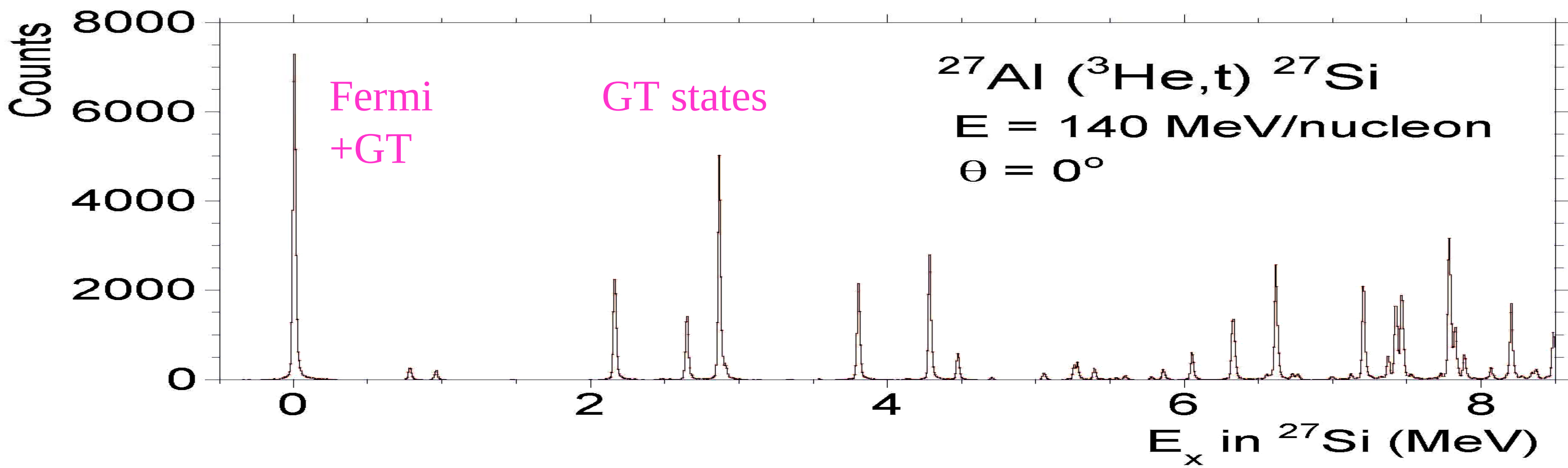
$R_{\mathrm{MEC}} \sim 1.25$

T=1/2 & 3/2 Symmetry

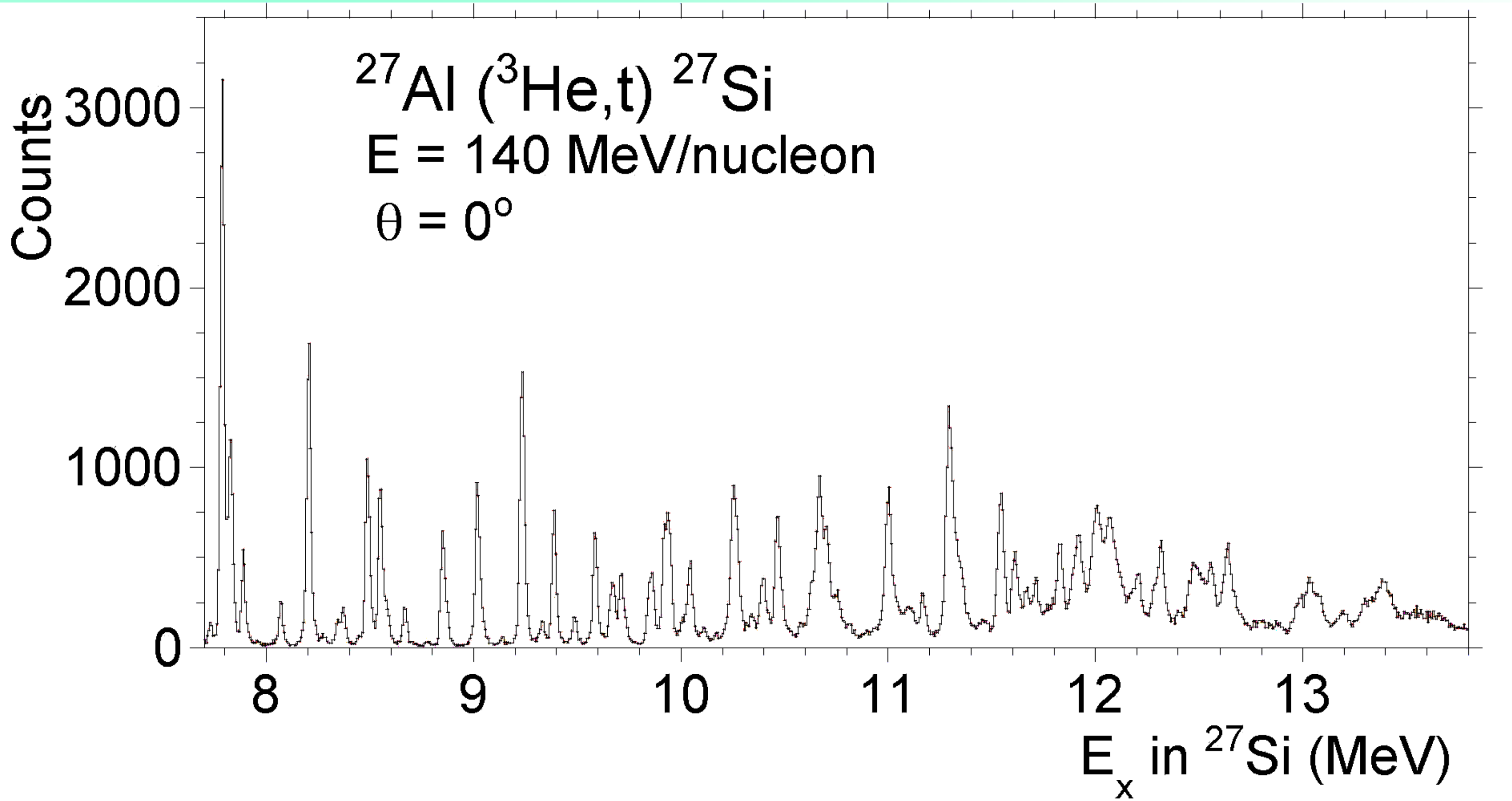


Comparison: ^{27}Al(p,n) and ^{27}Al(^{3}He,t)

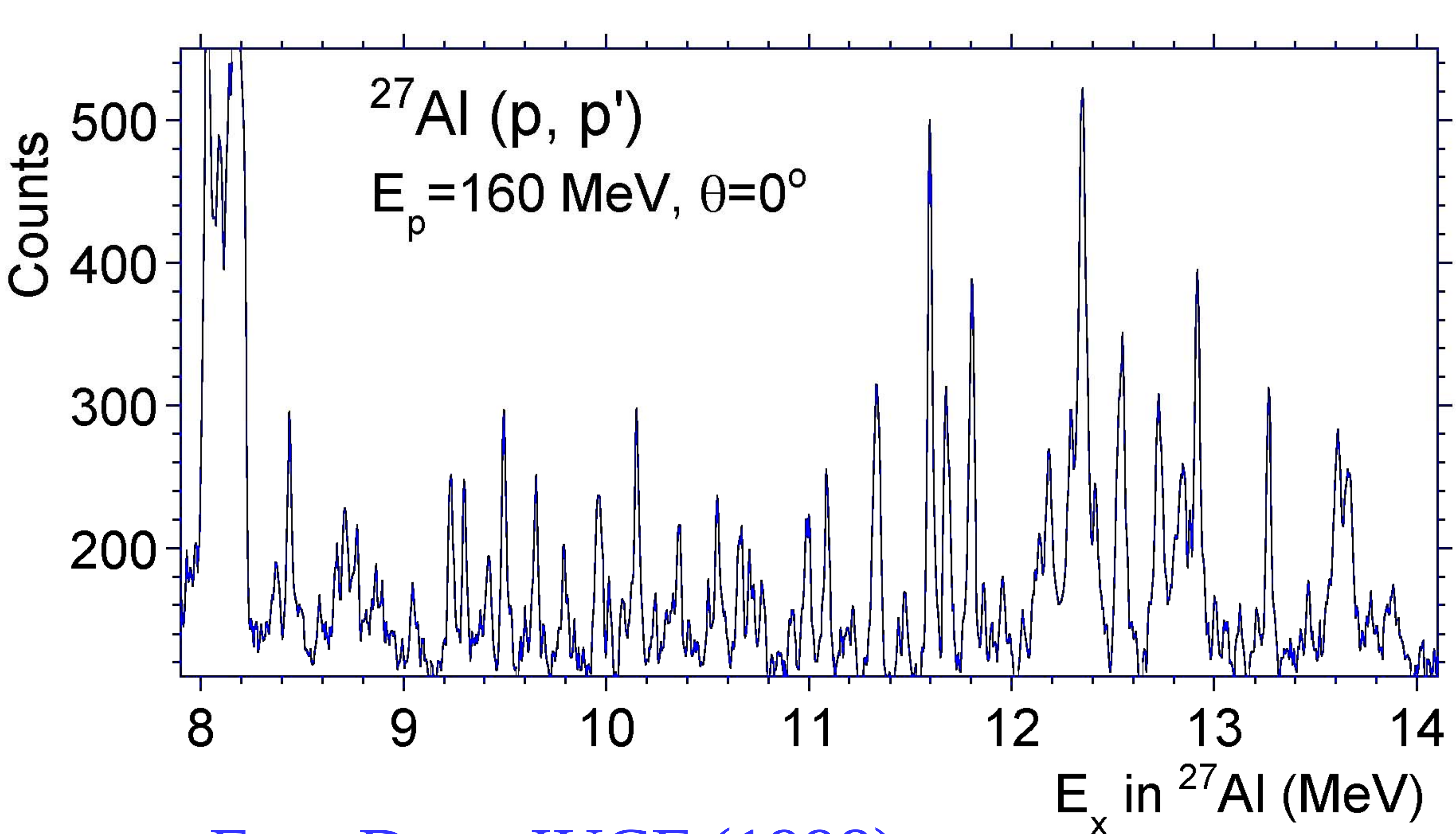




$^{27}Al(^{3}He,t)$ spectrum (E_x>8 MeV)

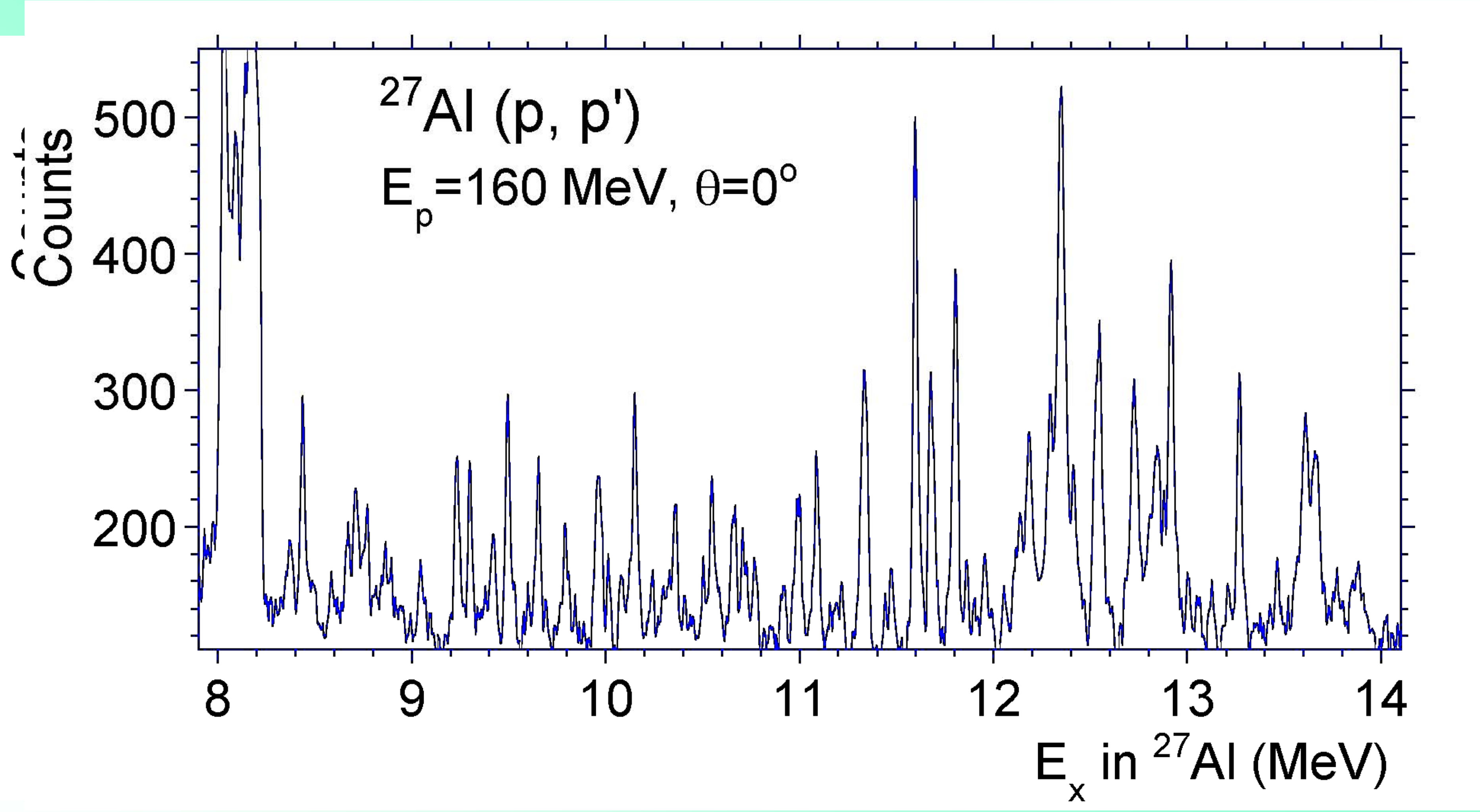


$^{27}Al(p, p')$ spectrum (E_x>8 MeV)

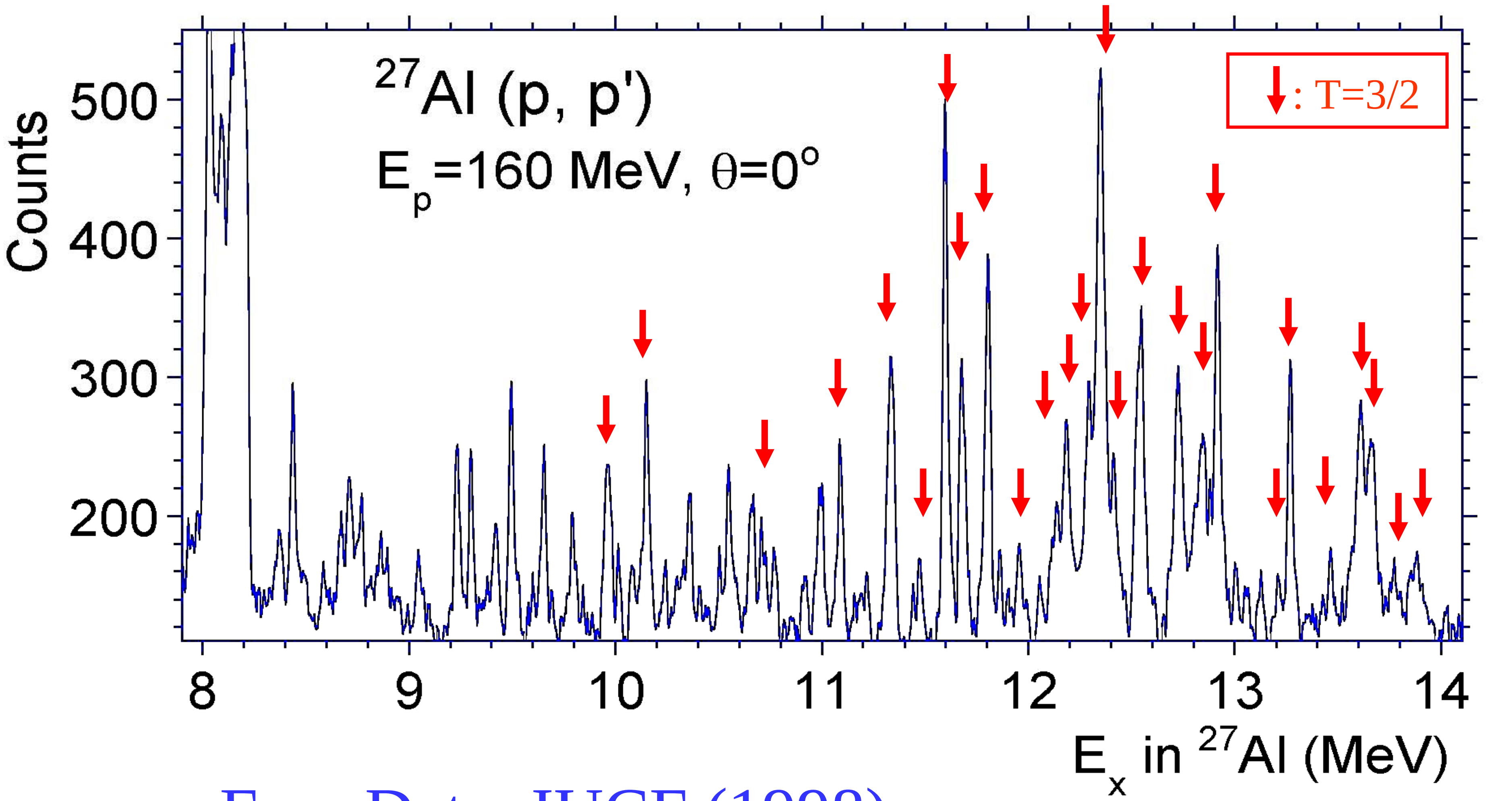


Exp. Data: IUCF (1998)

Comp.: ^{27}Al(^{3}He,t) and ^{27}Al(p, p') spectra

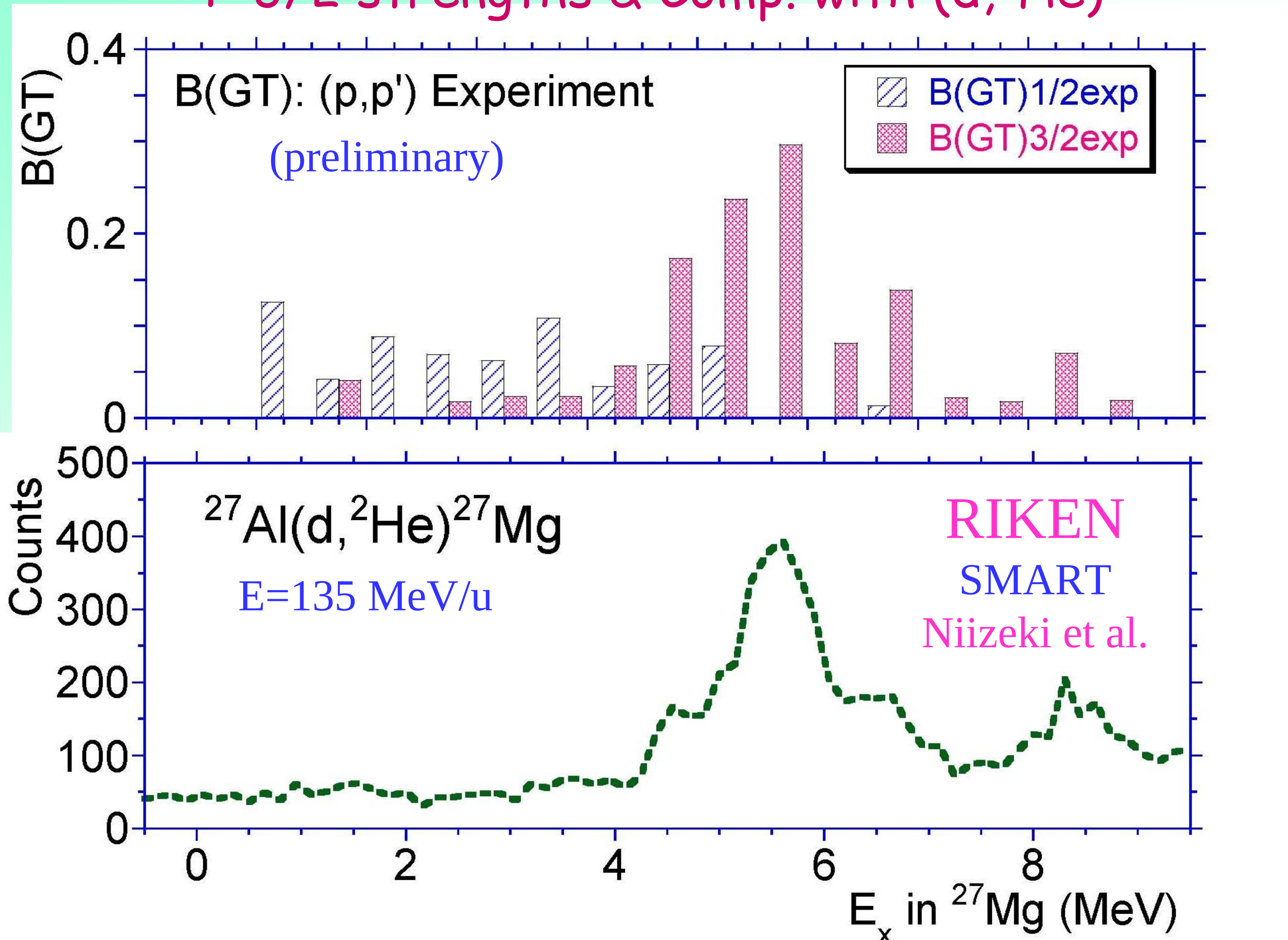


$^{27}Al(p, p')$ spectrum (E_x>8 MeV)



Exp. Data: IUCF (1998)

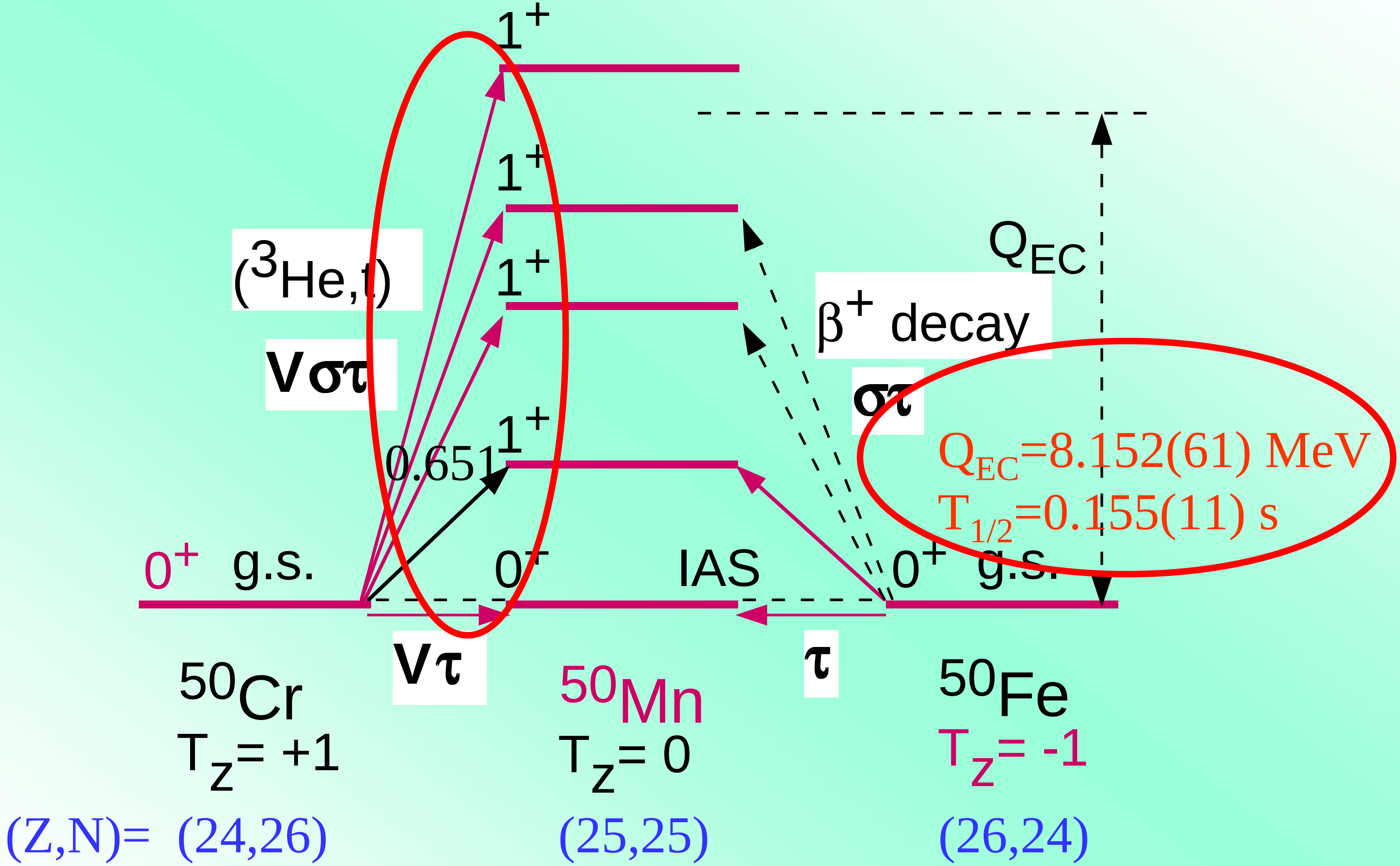
T=3/2 strengths & Comp. with (d,^{2}He)



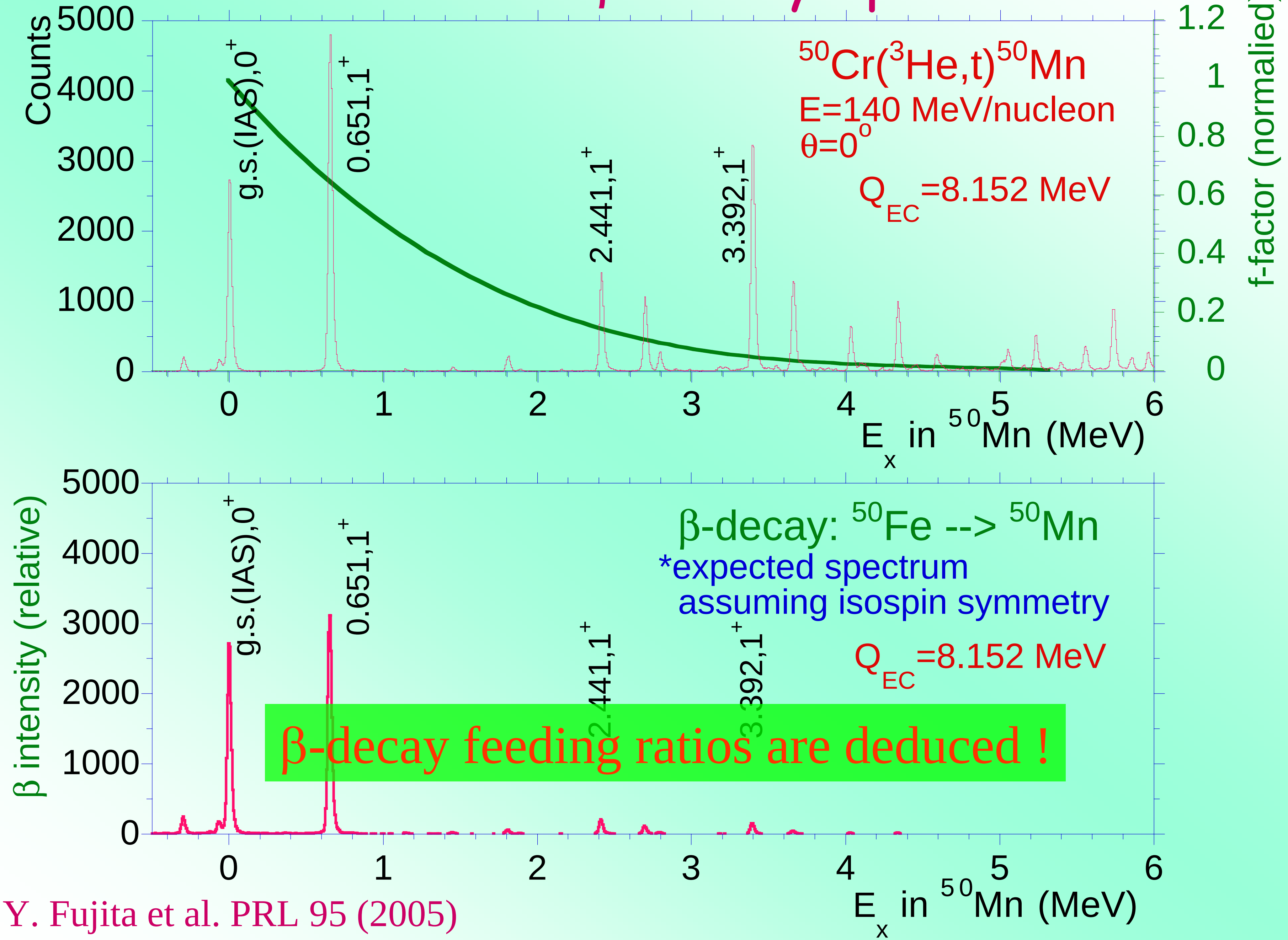
**Reconstruction of β decay from (^{3}He,t)

---assuming isospin symmetry ---

Isospin Symmetry Transitions:
$^{50}Cr(^3He,t) \rightarrow$ ^{50}Mn $\leftarrow$ β-decay ^{50}Fe



Simulation of β-decay spectrum

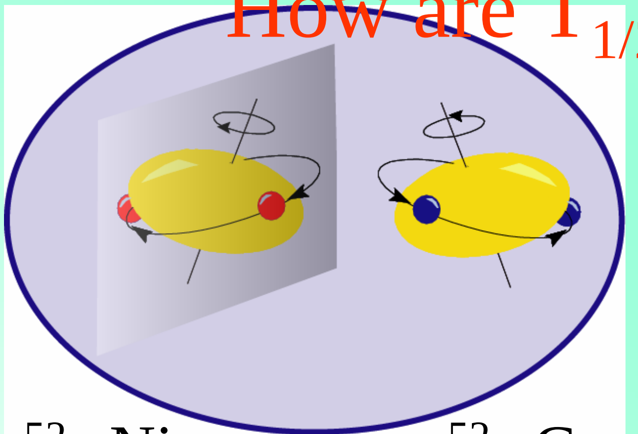


Y. Fujita et al. PRL 95 (2005)

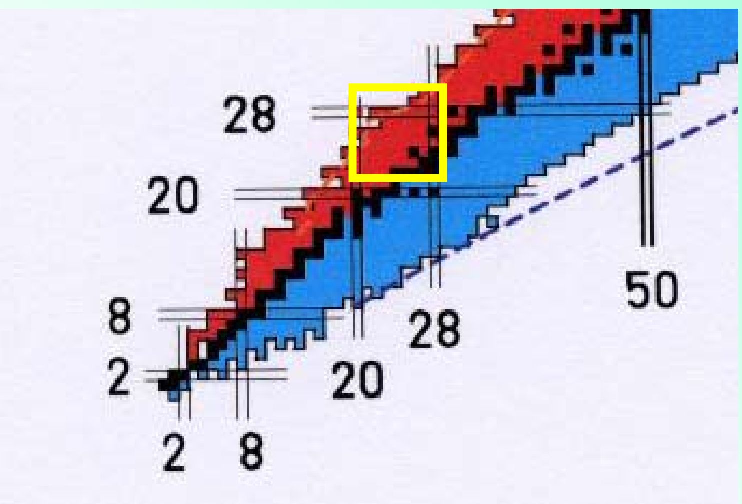
T = 2 Isospin Symmetry in *pf*-shell Nuclei

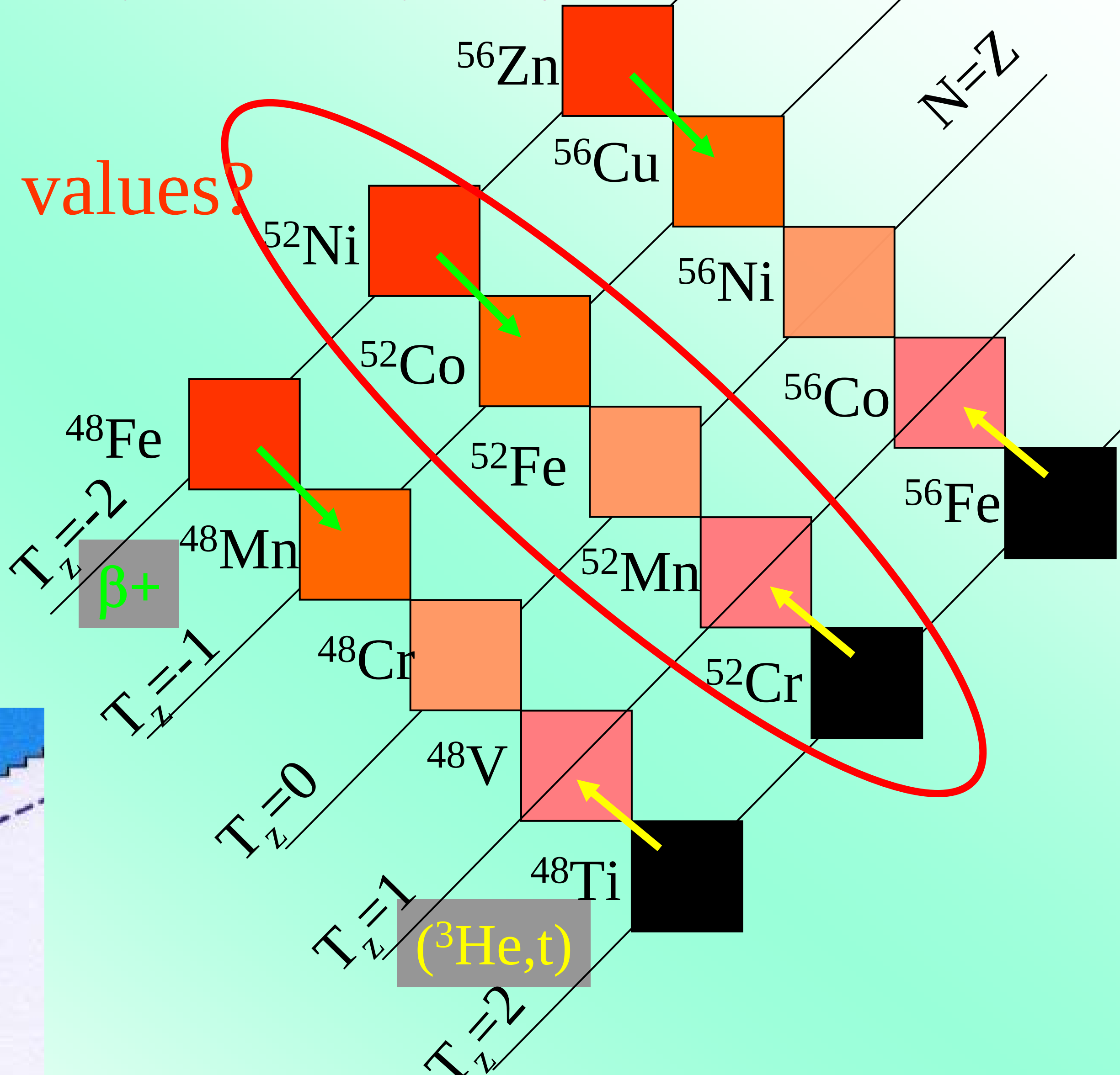
Mirror nuclei

How are $T_{1/2}$ values?



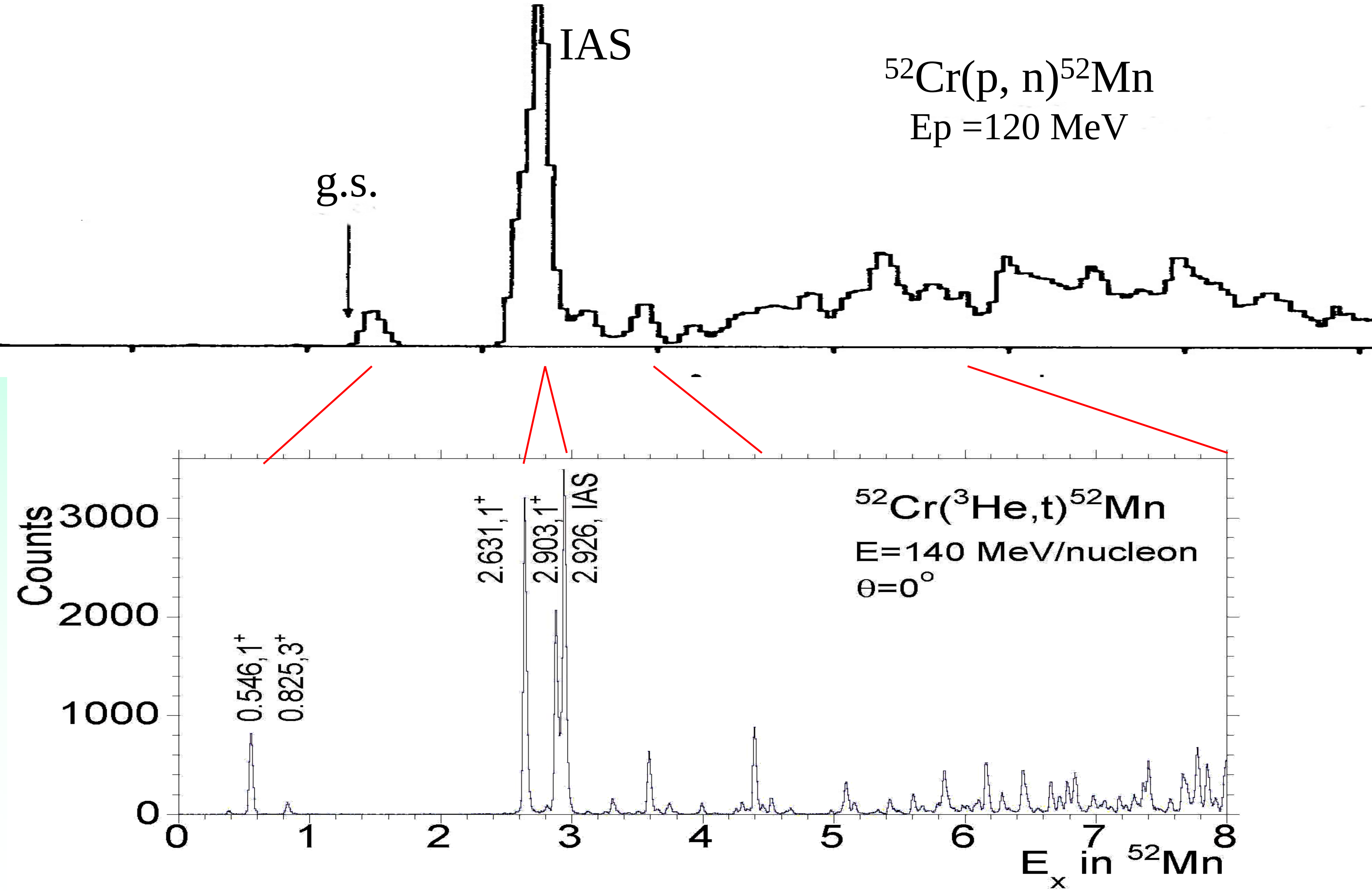
$^{52}_{28}Ni_{24}$ $^{52}_{24}Cr_{28}$





by Y. Fujita, B. Rubio

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



β-decay Half-life $T_{1/2}$
-via reconstruction of β-decay spectrum-

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

B(F)=N-Z

$$Feedings \propto 1/t_i$$

abs. B(GT) distribution
from (^{3}He,t)

^{52}Ni β-decay Half-life T1/2

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

B(F)=N-Z

Isospin symmetry estimation

$T_{1/2}$~ 38 (4) ms (preliminary)

β-decay exp. (GANIL '06 B. Blank et al.)

$T_{1/2}$= 40.8 (30) ms

SM cal. (PRC 57, 2316, '98)

$T_{1/2}$= 50 ms

Mass formula (T. Tachibana et al.)

$T_{1/2}$= 35 ms

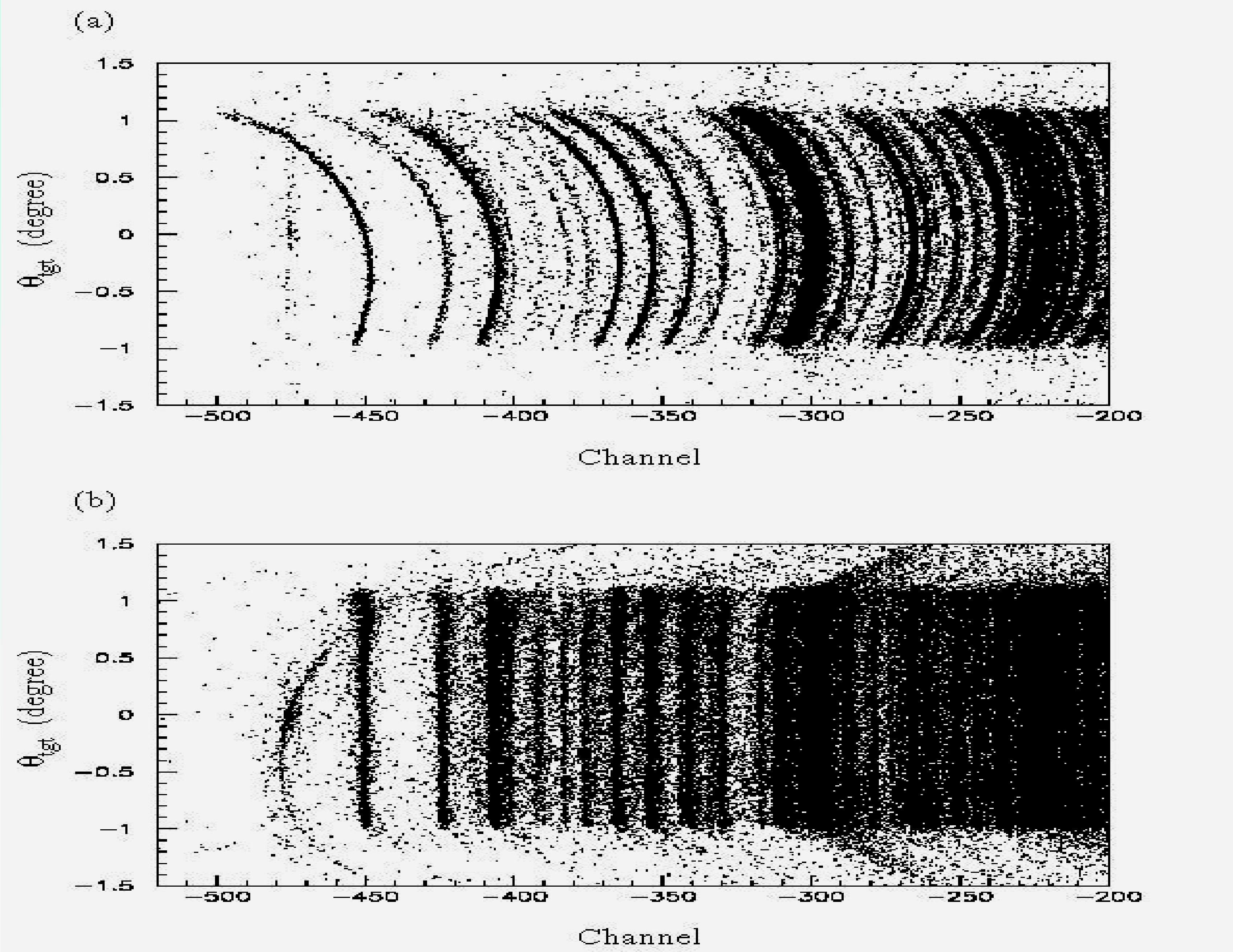
$$Feedings \propto 1/t_i$$

abs. B(GT) distribution from ^{52}Cr(^{3}He,t)

Q_{EC}=11.898(44) MeV

Uncertainty of the Q-value should still be reduced !

Effect of 2nd order aberrations



Summary Words

★ High Resolution

(^{3}He,t) reaction : one order better resolution than in a (p,n) reaction

Inelastic Scatterings (p,p'), (3He,3He') : less back ground

➔RCNP is "THE" leading facility in the world

★ Angular Distribution Measurement in Dispersive Mode

★ Polarization Related Measurements in Dispersive Mode (using pol. p, pol. ^{3}He, …)

➔Various New Steps toward the "Higher Quality Measurements and Physics" are foreseen !