Determination of the Gamow-Teller quenching factor via the $^{90}Zr(n,p)$ reaction at 293 MeV

RCNP E149 collaboration

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1. Introduction

Motivation: Quenching problem of the Gamow-Teller Strength

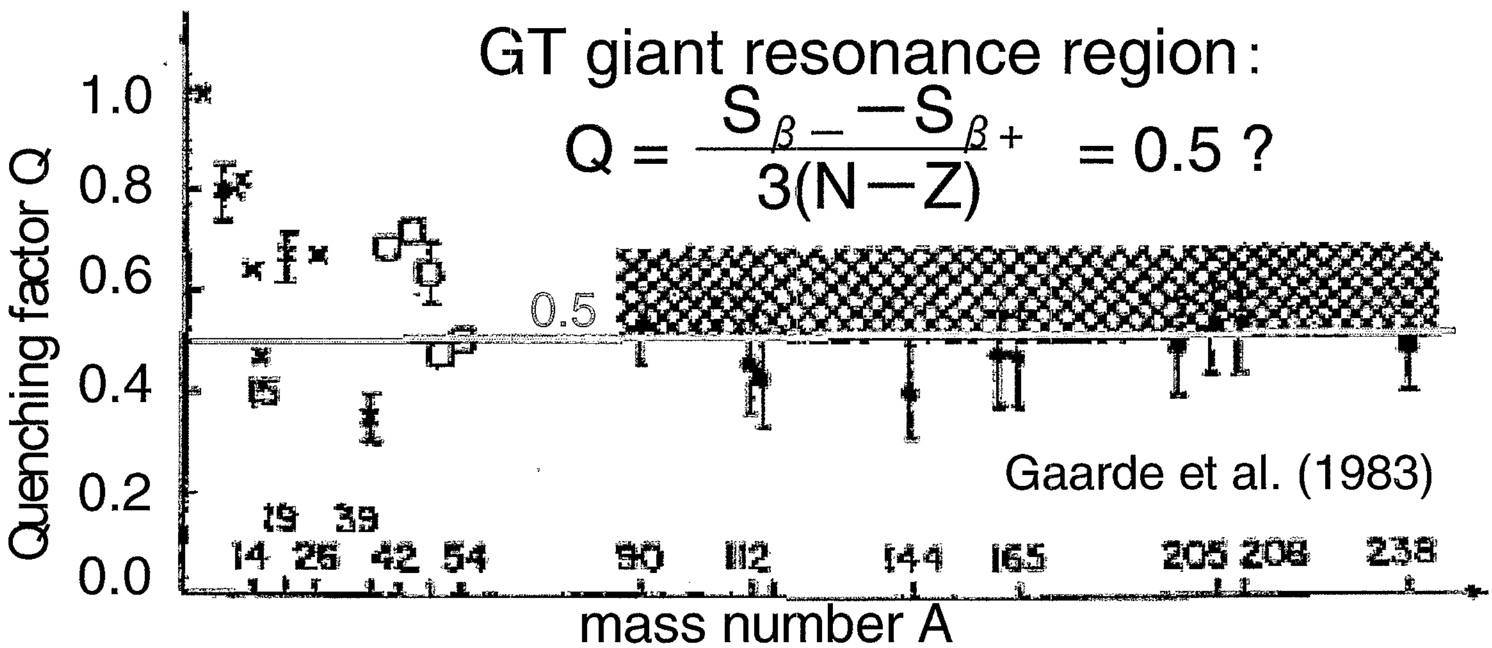
■ Gamow-Teller (GT) Excitation

$$\sigma t_{\pm}, \quad \Delta S = \Delta T = 1, \; \Delta L = 0$$

■ Ikeda's sum rule

$$S_{\beta-} - S_{\beta+} = 3(N-Z)$$

■ Quenching problem



■ Two interpretations

1. [1p1h GT state]+[ΔN^{-1}]… E_x = 300 MeV
2. [1p1h GT state]+[2p2h] … E_x = 20〜50 MeV
   GT strengths in the continuum

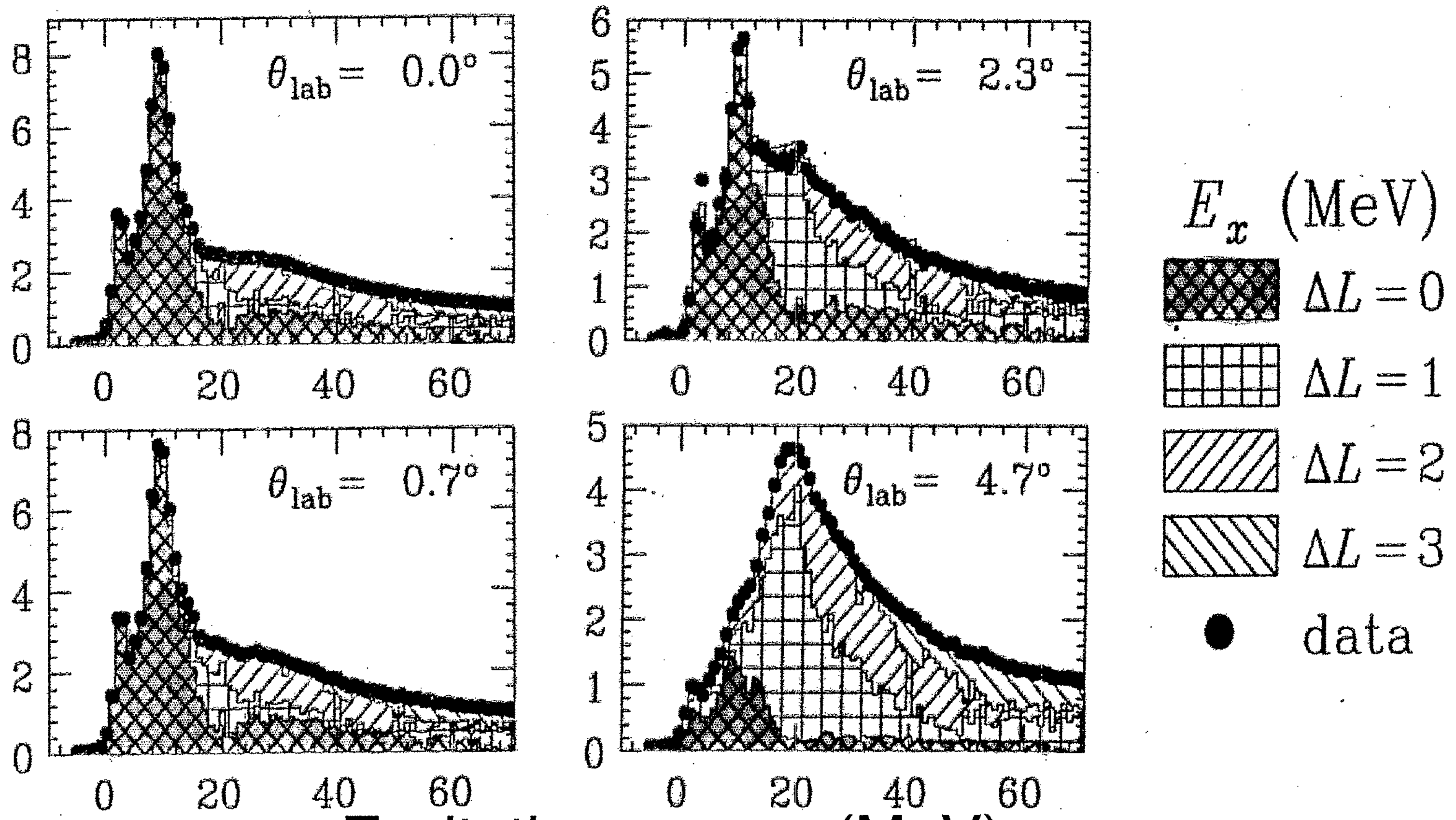
β^- strengths in continuum obtained from the ^{90}Zr(p,n) spectra

(Wakasa et al. PRC55,2909 (1997))

■ 300MeV

- $V_{\sigma\tau}/V_{\tau}$ is largest
- distortion effect is smallest

■ Extraction of the $\Delta L = 0$ component by multipole decomposition analysis (MDA)



Excitation energy (MeV)

■ β^- strengths (at $E_x < 50$ MeV)

$$\sigma_{\Delta L=0}(q,\omega) = \hat{\sigma}_{GT} F(q,\omega) B(GT)$$

- $\hat{\sigma}_{GT}$: GT unit cross section
- $F(q,\omega)$: kinematical factor

$$S_{\beta-;MDA} = 34.2 \pm 1.6$$

■ Subtraction of the contribution from isovector spin monopole (IVSM) excitation

IVSM: $2\hbar\omega$, $\Delta J^{\pi}=1^{+}$, $\Delta L = 0$, $\hat{O} = r^2 \sigma t_-$

DWIA calculation: assuming …

all the IVSM strengths at $E_x < 50$ MeV

→ 6.2 units

$$S_{\beta -} = 28.0 \pm 1.6$$

$$^{90}Zr \ldots 3(N-Z) = 30$$

■ β^+ strengths obtained from other $^{90}Zr(n,p)$ measurements

E_n (MeV)	$S_{\beta +}$	E_{max} (MeV)	
98	1.7 ± 0.2	10	(Uppsala)
198	1.0 ± 0.3	7.8	(TRIUMF)

- E_{max} is small
- lower energy

} insufficient to obtain Q

■ Aim

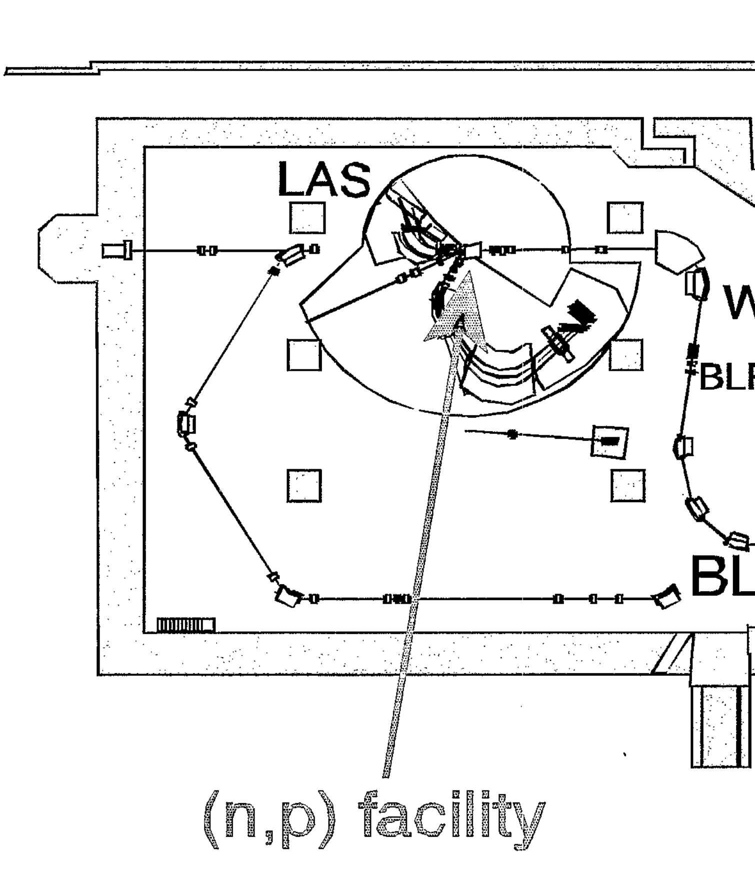
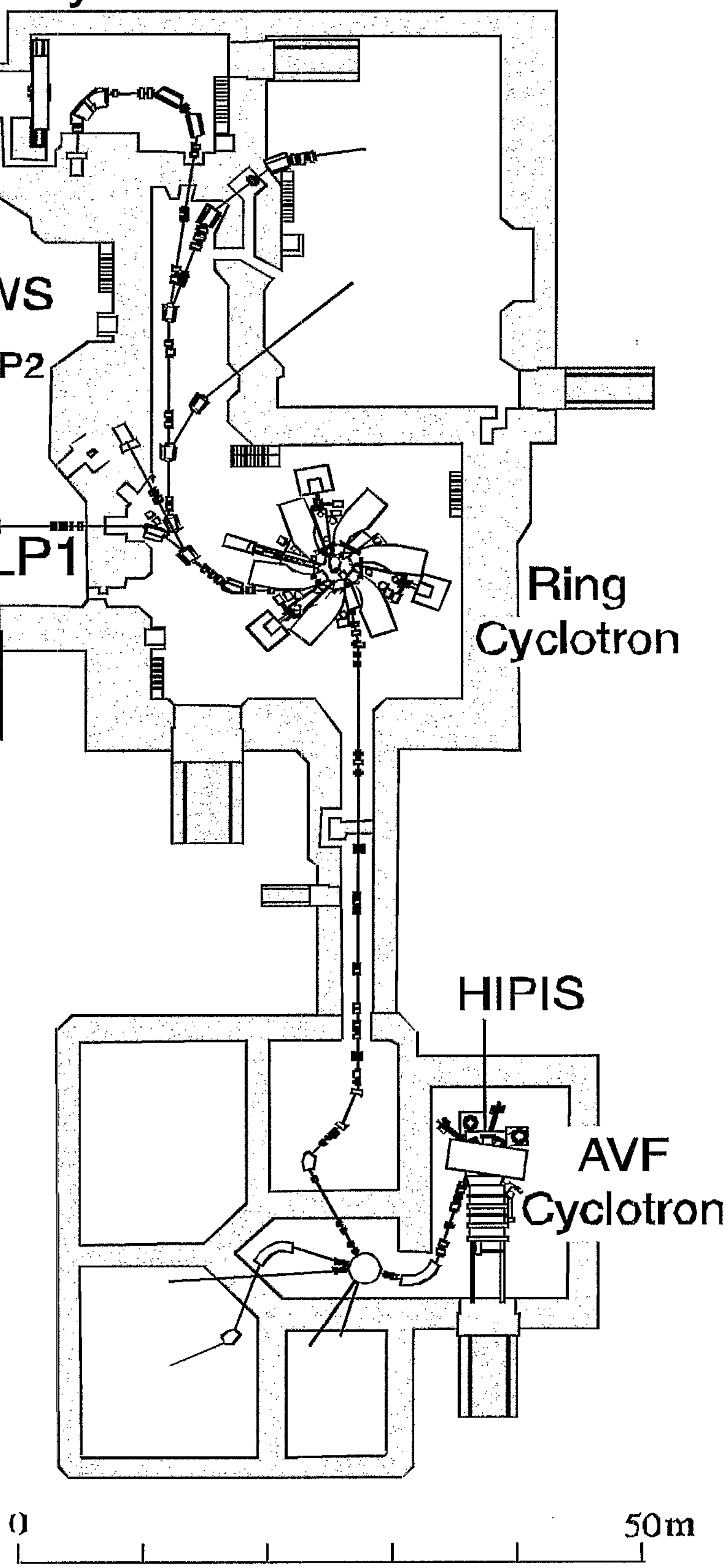
$^{90}Zr(n,p)$ spectra at 300 MeV + MDA

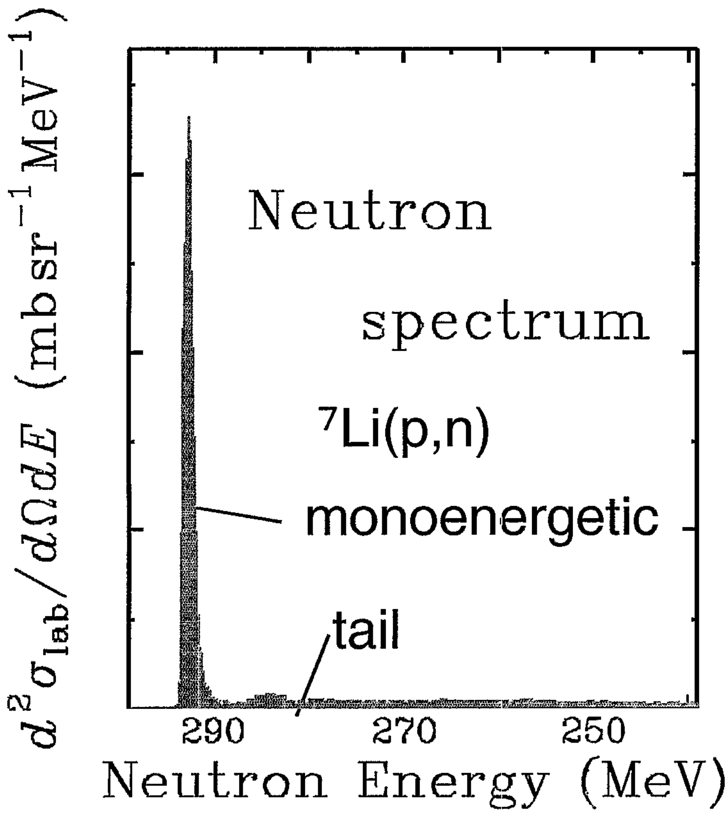
→ $S_{\beta +}$ in the continuum

→ Q (with $^{90}Zr(p,n)$ result)

2. Experiment

■RCNP, Osaka University

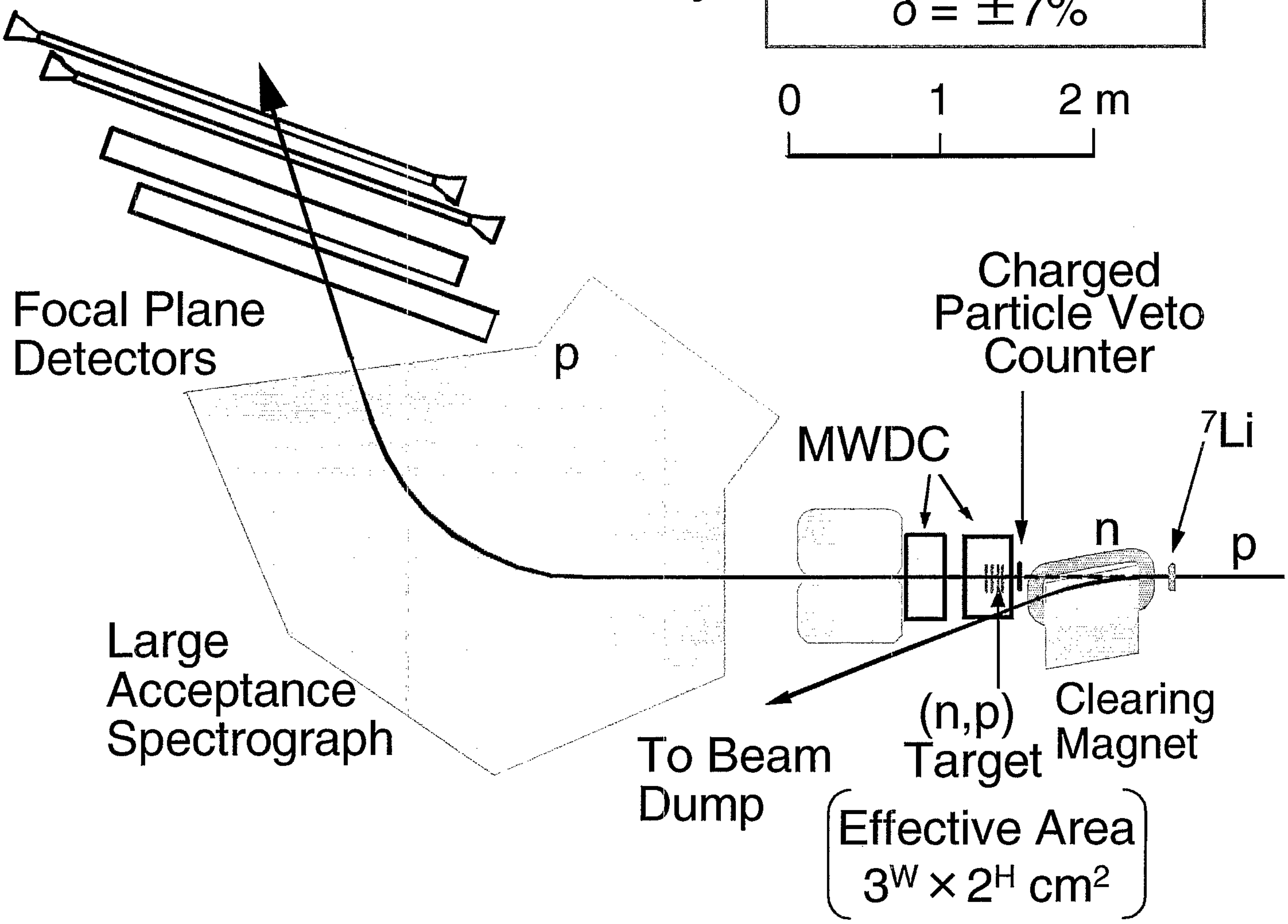





$D_{NN} = 0.28 \rightarrow P_n = 0.20$ if $P_p = 0.70$

■(n,p) facility @RCNP, Osaka university

Large Acceptance:
$\Delta\Omega = 11$ msr,
$\delta = \pm 7\%$



<u>(n,p) targets:</u>

$3\times$ Zr 200～400 mg/cm^2

$1\times CH_2$ 50 mg/cm^2

n+p scattering cross sections are known

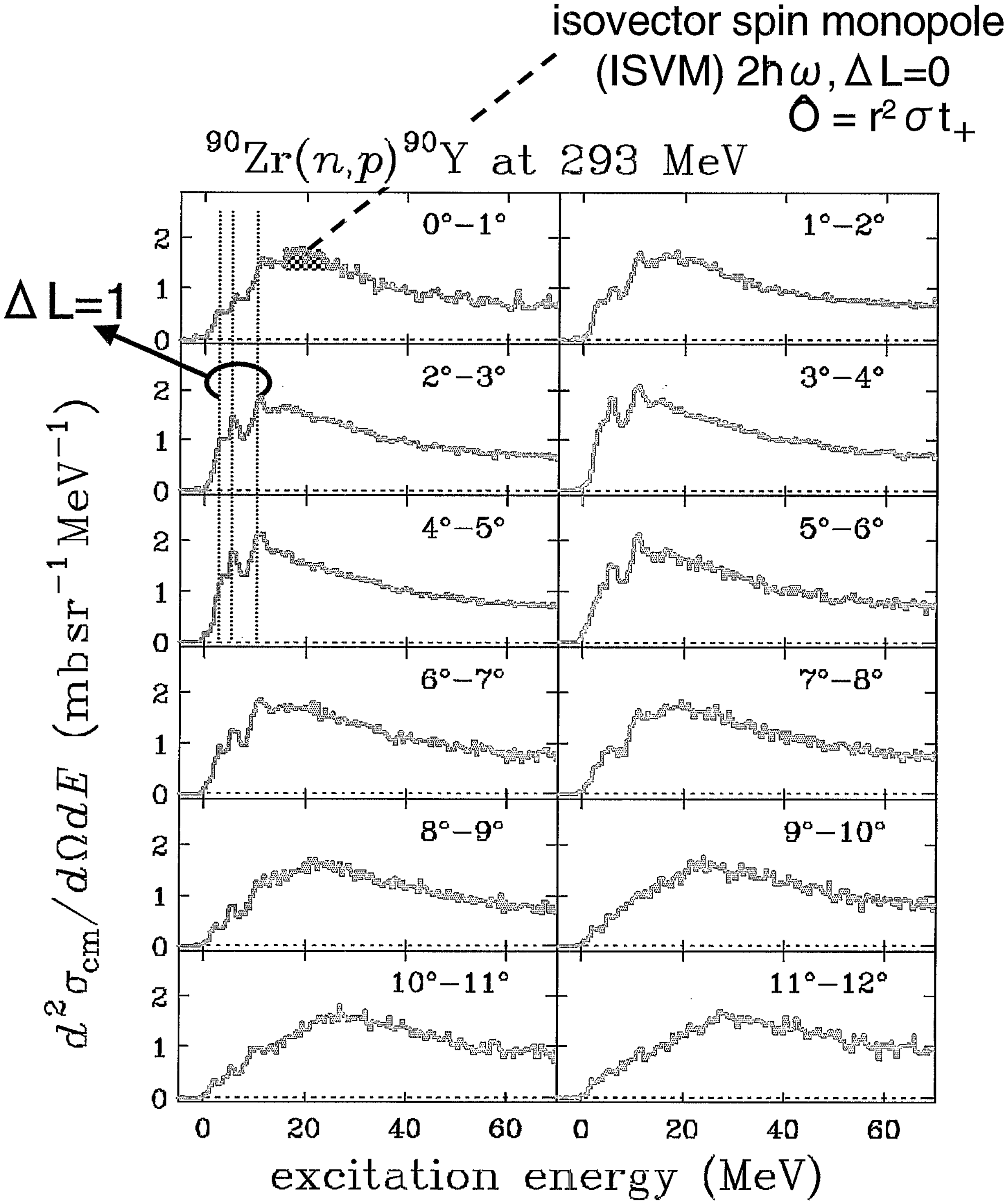
… no. of n+p events → no. of neutrons

<u>Measured quantities</u>

$$\frac{d\sigma^2}{d\Omega dE} \text{ and } A_y \text{ at } \begin{cases} \theta = 0\sim 12^\circ \\ E_x = 0\sim 70 \text{ MeV} \end{cases}$$

3. Result

■ Double differential cross sections

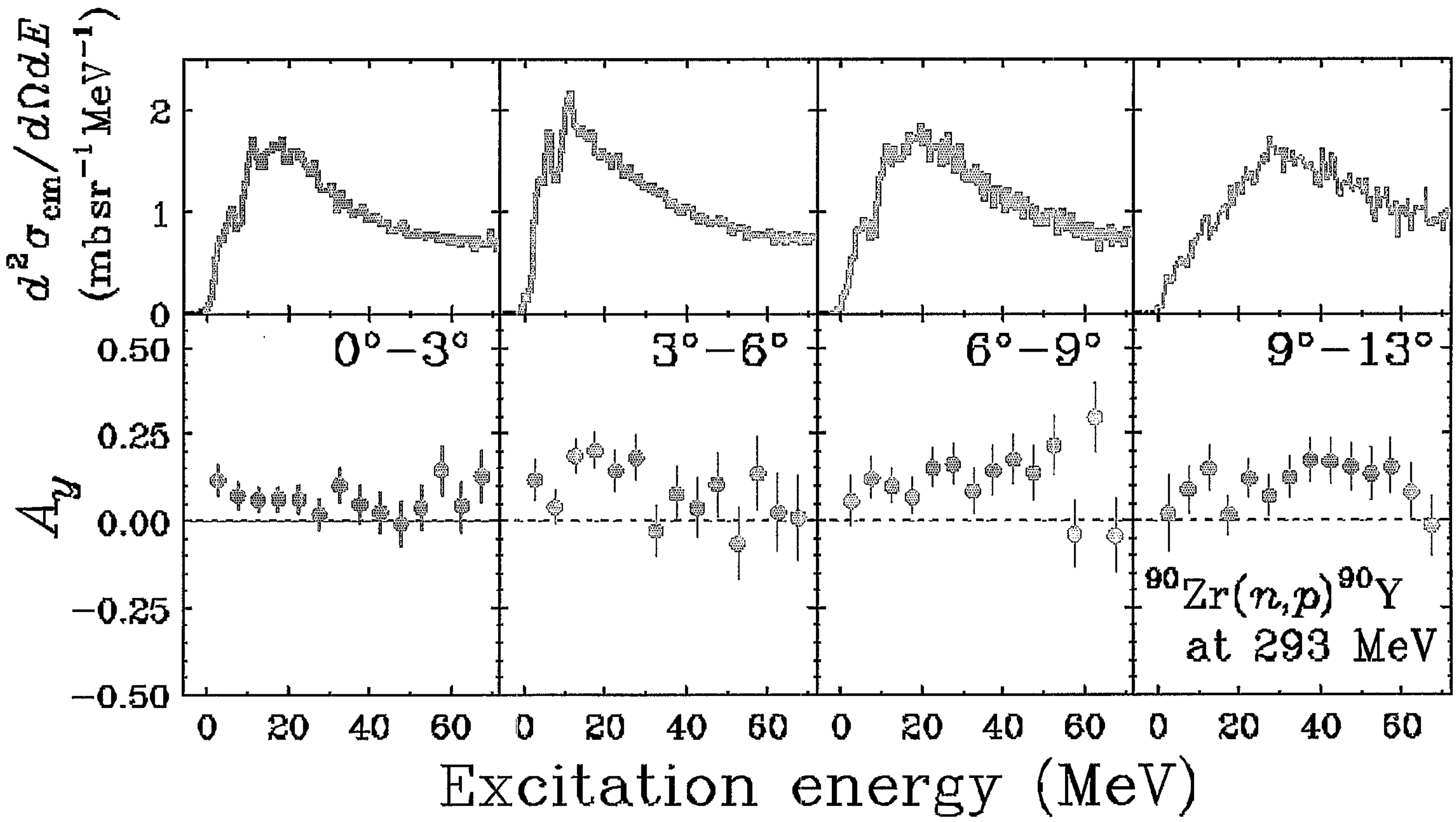


statistical uncertainty:

±3% / 0.5 MeV ・1° @1−2° E_x = 20 MeV

systematic uncertainty: ±6%

■Analyzing powers



statistical uncertainty:

±0.05 / 0.5 MeV ･3° @0−3° E_x = 30 MeV

systematic uncertainty: ±35%

A_y ≈0.1 @ 0∼3°

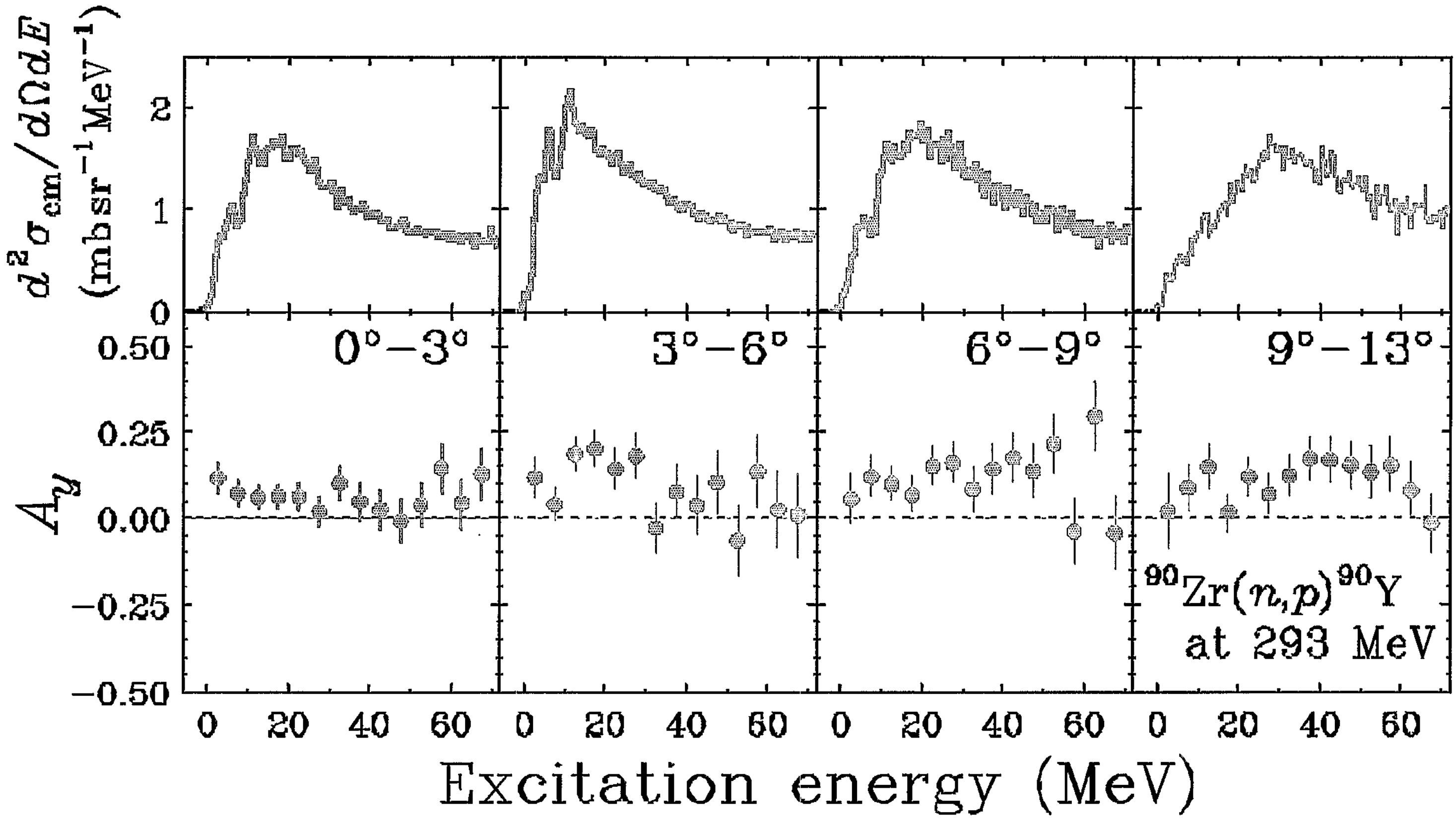
… due to ΔL=1 component

Analyzing powers…

- have no information at 0° (A_y=0).
- depend heavily on optical potential.

⇒ A_y data were not included in the MDA

■Analyzing powers



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4. Analysis

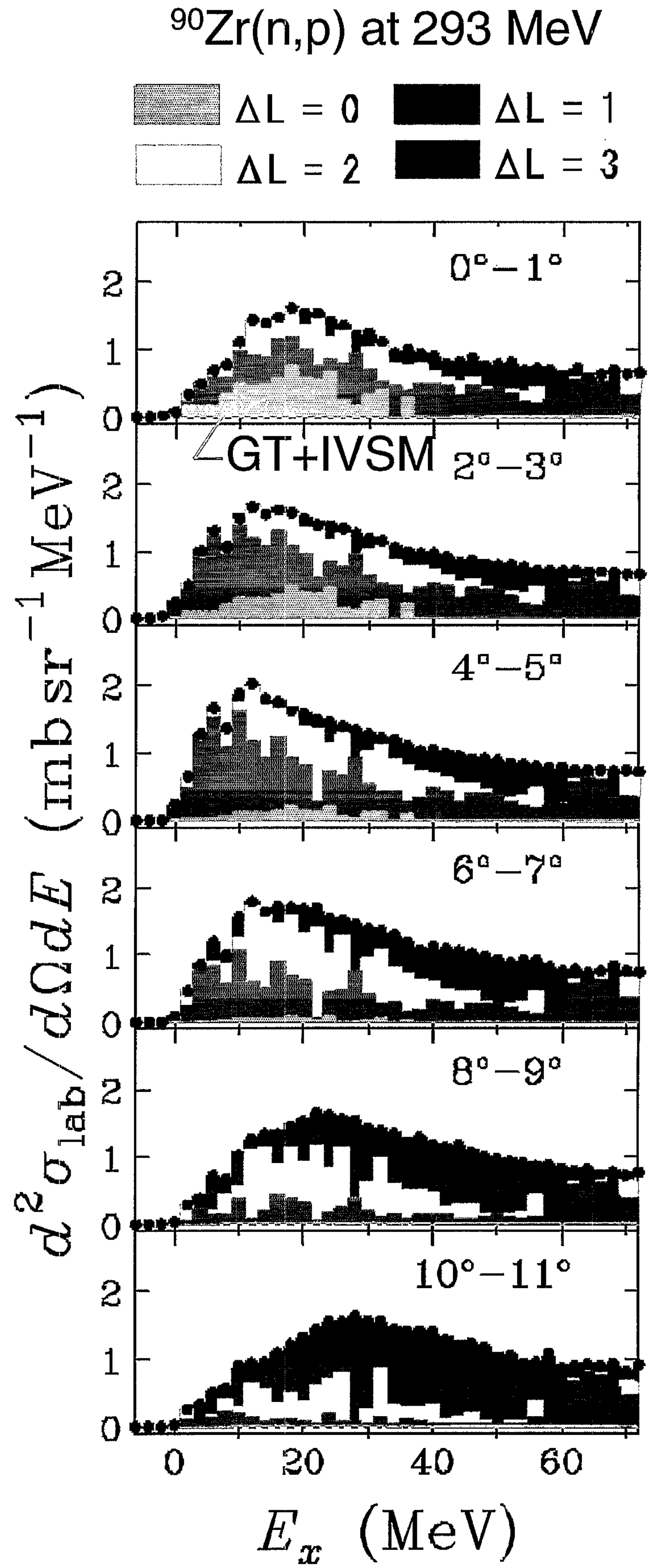
■Extraction of $\sigma_{\Delta L=0}$ by MDA

MDA

χ^2 – fit:

$$\sigma_{exp}(\theta, E_x) = \sum_{\Delta L} a_{\Delta L} \sigma^{DWIA}_{\Delta L}(\theta, E_x)$$

$J^\pi = 1^+(\Delta L = 0)$,
$0^-, 1^-, 2^-(\Delta L = 1)$,
$3^+(\Delta L = 2)$,
$4^-(\Delta L = 3)$



DWIA inputs:

- NN interaction
  Franey & Love @325 MeV

- optical potential
  n … Shen et al.
  p … Cooper et al.
- transition density
  pure 1p1h configuration
  n-particle (N=51～82)
  $1g_{7/2}$, $2d_{5/2}$, $2d_{3/2}$, $1h_{11/2}$, $3s_{1/2}$
  p-hole (Z=21～50)
  $1g_{9/2}$, $2p_{1/2}$, $2p_{3/2}$, $1f_{5/2}$, $1f_{7/2}$
  radial wave functions
  Woods-Saxon (WS)、
  harmonic oscillator (HO)

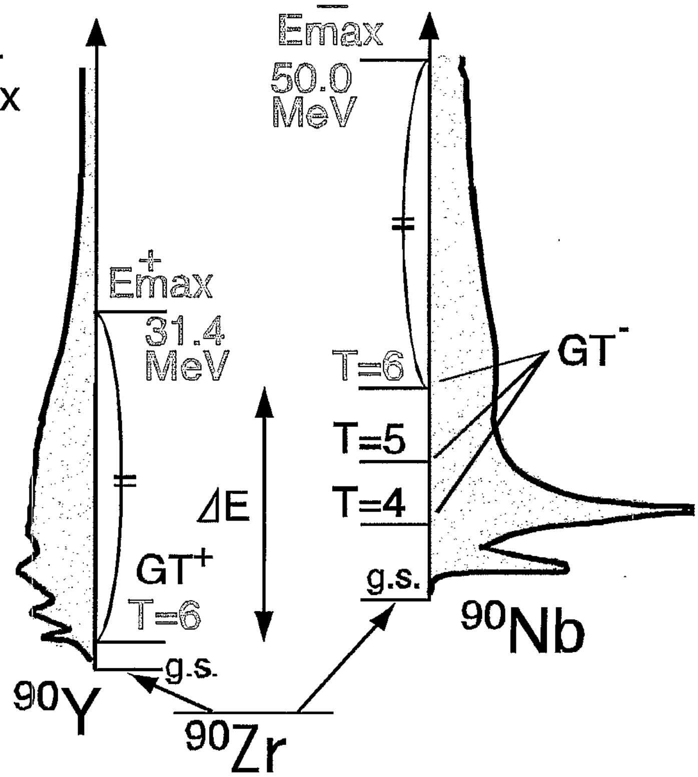
■B(GT)

$$\sigma_{\Delta L=0} = \hat{\sigma}_{GT} F(q,\omega)\, B(GT)$$

$\hat{\sigma}_{GT}$: GT unit cross section 3.6±0.6 mb/sr

$F(q,\omega)$: kinematical factor

■Determination of E^{+}_{max}



(p,n) … E^{-}_{max} = 50 MeV

preserving

$E_{max} - E(GT, T=6)$,

$$E^{+}_{max} = 50.0 - 18.6 = 31.4 \text{ MeV}$$

$$S_{\beta+;\,MDA} = \int^{31.4\text{ MeV}} B(GT)\,dE_x = 5.4 \pm 0.3$$

■IVSM contribution ⇒ DWIA

TDA calc. by Hamamoto & Sagawa

- Whole transition density at ω = 20.8 MeV
- Radial wave functions:
  - HO
  - WS + shallow binding (s.b.)

→ IVSM contribution: 2.4±0.8 units

$$S_{\beta+} = (5.4 \pm 0.4) - (2.4 \pm 0.8) = 3.0 \pm 0.3 \pm 0.8 \pm 0.5$$

(±0.3: MDA; ±0.8: IVSM; ±0.5: $\hat{\sigma}_{GT}$)

■GT quenching factor Q

estimation of the IVSM contribution is different.

$$S_{\beta-} - S_{\beta+} = (28.0 \pm 1.6 \pm 5.4) - (3.0 \pm 0.3 \pm 0.5)$$
$$= 25.0 \pm 1.7 \pm 4.9$$

(1.7: MDA; 4.9: $\hat{\sigma}_{GT}$)

$Q = 0.83 \pm 0.06$ (MDA) in {1p1h, 2p2h} region

… Larger than

Q ~0.5 : obtained at the GT giant resonance (1p1h) region

⇒ 2p2h contribution is important.
contribution of Δ isobar is small.

■Landau Migdal Parameter $g'_{N\Delta}$

spin-isospin part of the LM interaction:

g'_{NN}	ph-ph
$g'_{N\Delta}$	ph-ΔN^{-1}
$g'_{\Delta\Delta}$	ΔN^{-1}-ΔN^{-1}

universality ansatz:
$g'_{NN} = g'_{N\Delta} = g'_{\Delta\Delta} = 0.6$

calculation by Suzuki&Sakai

[Suzuki & Sakai PLB455, 25 (1999)]

$Q = 0.83 \pm 0.06$ ⇒ $g'_{N\Delta} = 0.16 \sim 0.35$
(Chew-Low model)
if $g'_{\Delta\Delta} = 0.6$

NB) $\pi + \rho$ exchange…
$g'_{N\Delta}$ value increases by 0.1 (Arima et al.)

⇒ universality ansatz does not hold.

5. Summary

- New (n,p) facility at RCNP.
- Measurement of $\frac{d\sigma^2}{d\Omega dE}$ and A_y

  for the $^{90}Zr(n,p)$ reaction at 300 MeV
  to derive β^+ strengths in the continuum.
  θ_{lab} : 0∼12°, E_x: 0∼70 MeV

- MDA
  … $S_{\beta+}$ = 3.0±0.3 ±0.8 ±0.5
  at E_x < 31.4 MeV
  (±0.3: MDA; ±0.8: IVSM; ±0.5: $\hat{\sigma}_{GT}$)

- Q = 0.83±0.06
  by using $S_{\beta-}$ obtained
  from $^{90}Zr(p,n)$ spectra
  …larger than Q∼0.5
  → contribution of Δ excitation is small
  compared with the 2p2h contribution.

- Q → Landau Migdal parameter $g'_{N\Delta}$
  $g'_{N\Delta}$=0.16∼0.35 (Chew-Low model)
  if $g'_{\Delta\Delta}$=0.6