Gamow-Teller and Spin-Dipole Transitions Studied by (p,n) Polarization Measurements

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Outline

- Quenching of spin-isospin responses
  - GT strength
  - SD strength
- New data/analysis of $^{208}Pb(p,n)$
  - SD strength
  - GT strength
  - IVSM strength
- Summary

Quenching of GT Strength

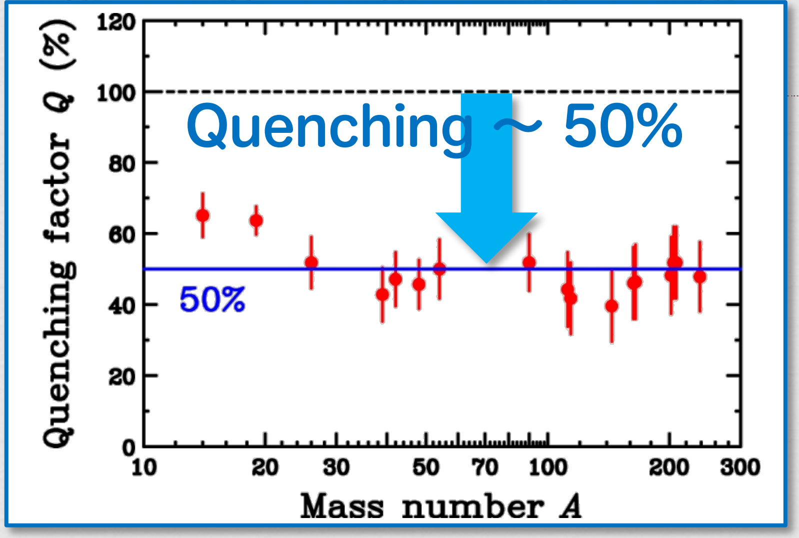
- GT quenching problem

$$Q \equiv \frac{S_{\beta-} - S_{\beta+}}{3(N-Z)} \approx 50\%$$

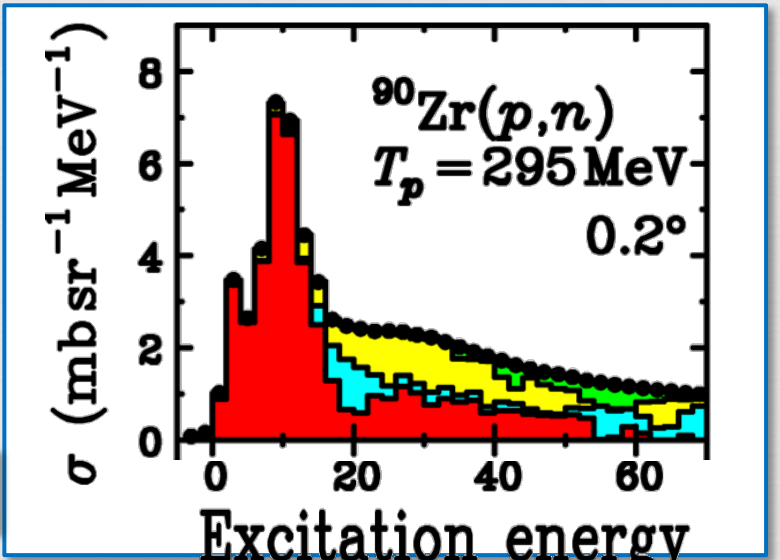
  - Nuclear config. mixing ?
  - Δh admixture ?

- GT(L=0) in MDA
  - No B.G.(L≠0) in GTR
  - Significant up to ~50 MeV
    - 2p2h effects(+IVSM)

- GT Quenching factor
  - Q_{GT} = 0.86±0.07
    - Δh quenching ~ 0.1



C. Gaarde, NP A396, 127c(1983).



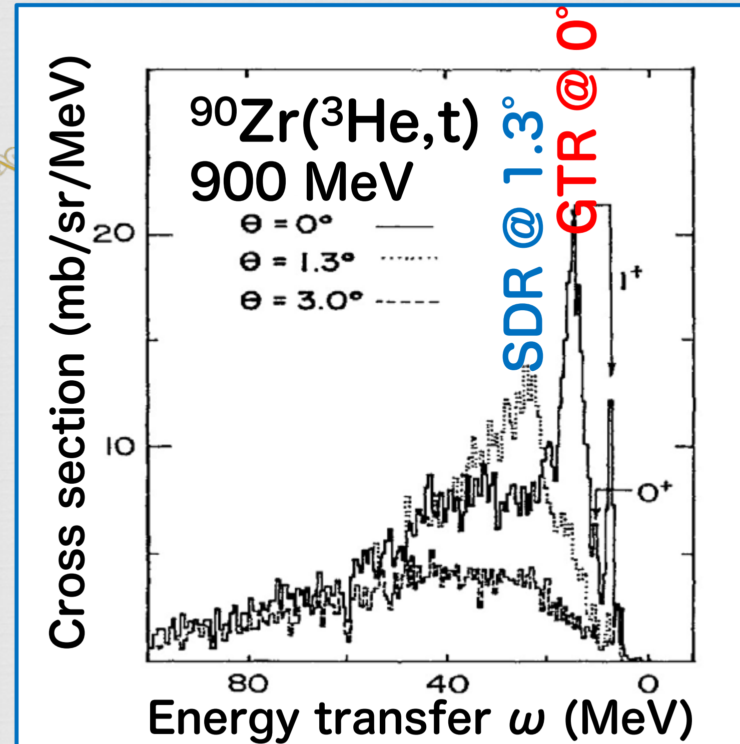
K. Yako et al., PL B615, 193 (2005).

How about quenching on other multipoles ?

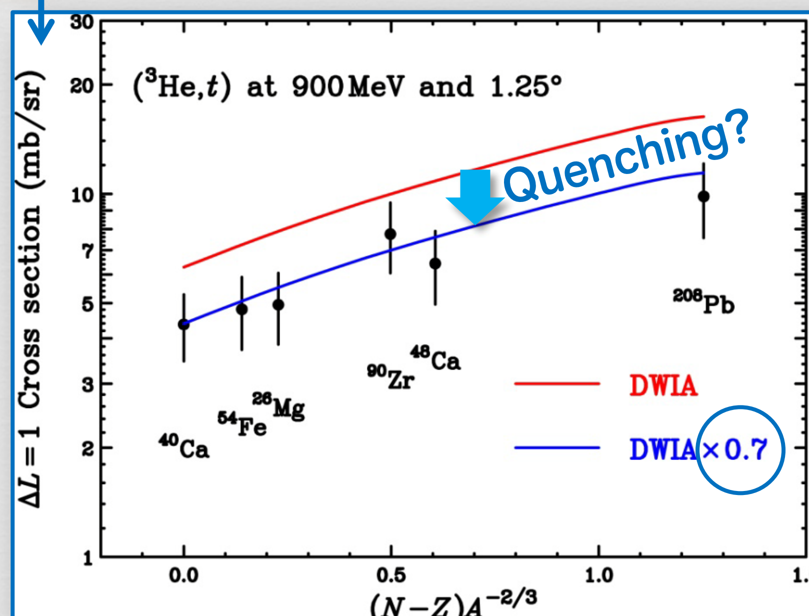
MDA for (^{3}He,t)

- Assumption

$$\sigma^{\exp}(\theta,\omega) = a_{L=0}(\omega)\sigma^{\mathrm{calc}}_{L=0}(\theta) \quad \text{GT(L=0)}$$
$$+a_{L=1}(\omega)\sigma^{\mathrm{calc}}_{L=1}(\theta) \quad \text{SD(L=1)}$$
$$+a_{L=2}(\omega)\sigma^{\mathrm{calc}}_{L=2}(\theta) \quad \text{SQ(L=2)}$$
$$+a_{L=3}(\omega)c \quad \text{Const(L≧3)}$$



- Comparison with DWIA
  - RPA with δ-type ph int.
  - Reproduce (N-Z)$A^{-2/3}$ dep.
  - Syst. large by～1.4

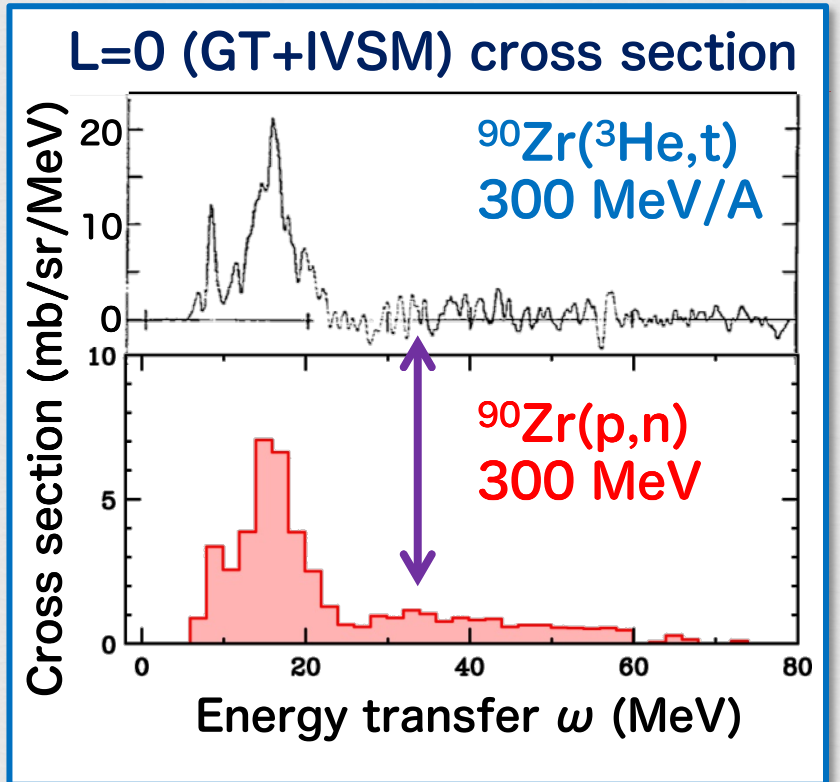


- **SD strength is quenched by Q_{SD}～0.7 ? (c.f. Q_{GT}～0.9)**

A. Brockstedt et al., NP A530, 571 (1991).

SD Strength is quenched?

- Inconsistent with (p,n)
  - (^{3}He,t)
    - Negligible at ω>25 MeV
  - (p,n)
    - Strength up to ~60 MeV
- (p,n) strength in continuum
  - GT due to config. mixing
  - IVSM
    - **IVSM should be more pronounced in (^{3}He,t)**



A. Brockstedt et al., NP A530, 571 (1991).
K. Yako et al., PL B615, 193 (2005).
T.W. et al., PRC 55, 2909 (1997).

- Large syst. uncertainty in (^{3}He,t)?
  - (Complicated) reaction mechanism in (^{3}He,t)?
    - Projectile form factor: $\rho_p(q) \neq \exp(-0.42q^2)$
    - Large distortion effects
    - …

How about (p,n) data ?

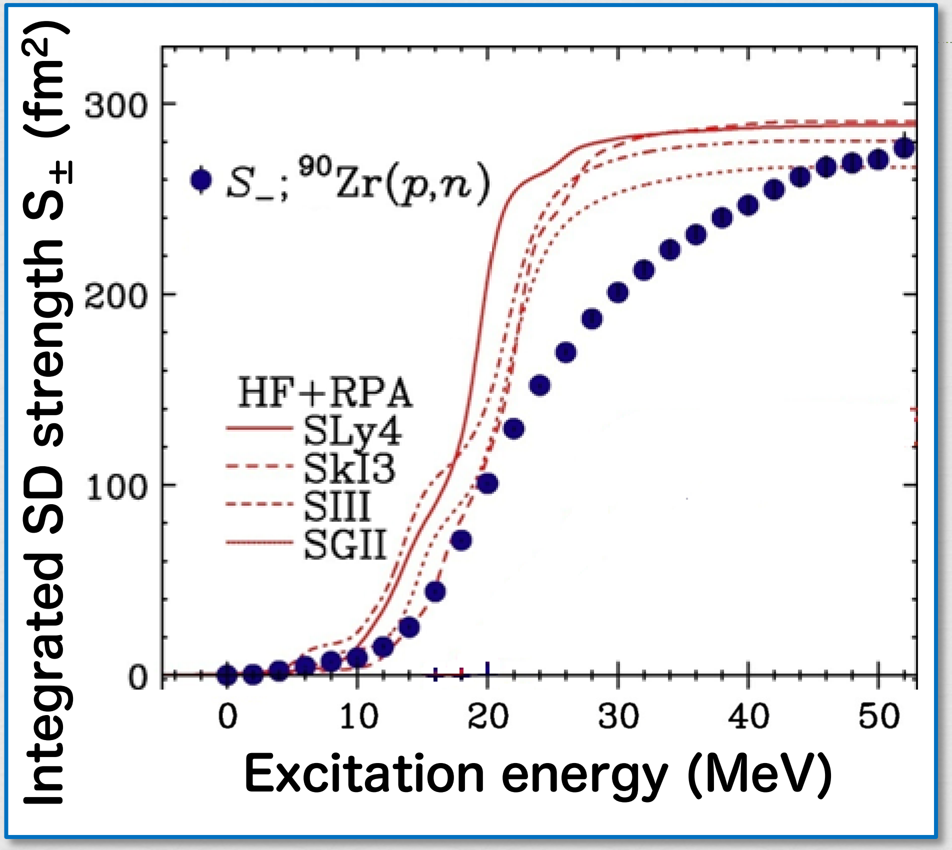
Integrated SD strengths

- Integrated SD strength

$$S_{\pm} = \int_0^{E_x} \frac{dB(\mathrm{SD}_{\pm})}{dE} dE$$

- Comparison with theory
  - HF+RPA
    - Skyrme int.
  - Gradual increase
    - Theory: 1p1h
    - Exp: 2p2h is important
  - Exp. values approach HF+RPA values at ∼50 MeV
    - (p,n) : ≧95% of theoretical values → **Almost NO quenching**

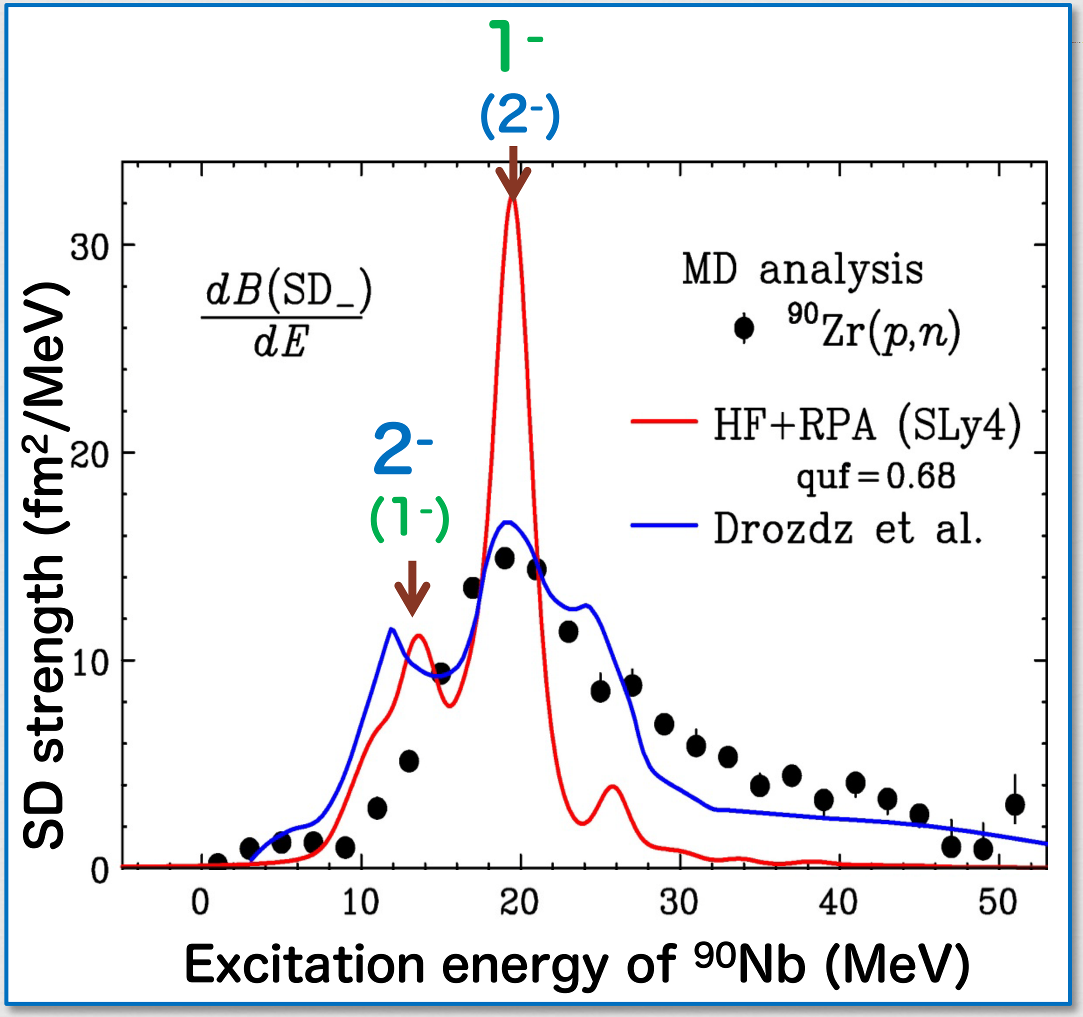
K. Yako et al., PRC 74, 051303(R) (2006).



SD Strength Distributions

- Exp. strength
  - Extends to ~50 MeV
    - Configuration mix.
  - Single bump
- HF+RPA (1p1h)
  - Underestimation at E_x > 25 MeV
    - 2p2h is important
  - Three peaks
    - $E_x(2^-) < E_x(1^-)$
- Second-Order RPA
  - Reasonably reproduce in the whole region
  - Three bumps

K. Yako et al., PRC 74, 051303(R) (2006).



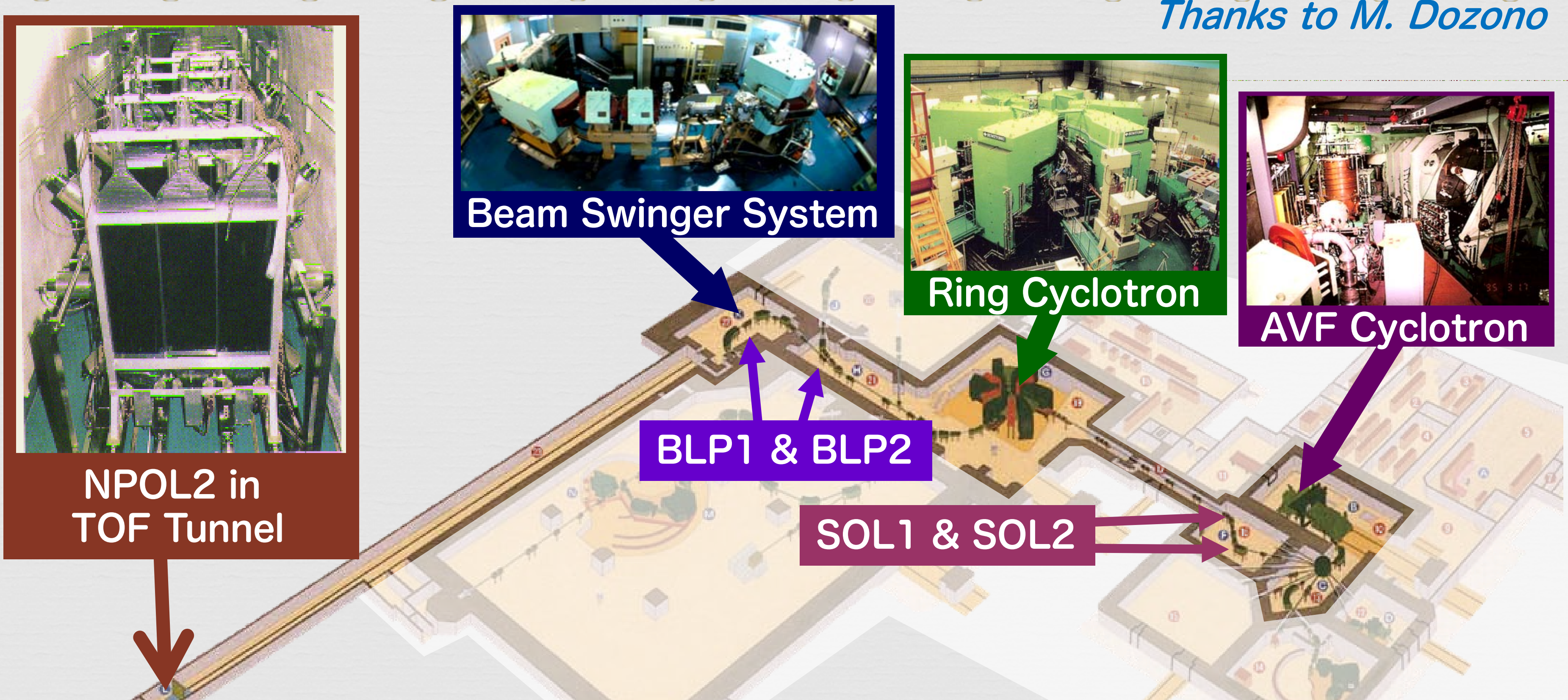
- Each $\Delta J^{\pi}(0^-, 1^-, 2^-)$ distribution → Inconsistent (Missing corr.?)

This "Experimental" Work for ^{208}Pb(p,n)

- New data and analysis for ^{208}Pb(p,n)
  - Cross section and analyzing power in θ=0.0° ～13.4°
  - Complete polarization transfer D_{NN} and D_{LL} at 0.0°
  - Polarization transfer D_{NN} at 4°, 7°, 10°
- Goal
  - Total and separated SD strengths of ^{208}Pb(p,n)
    - Quenching/distribution of total/separated SD strengths
  - GT/IVSM strengths of ^{208}Pb(p,n)
    - First trial to separate GT from IVSM in MDA
    - Quenching/distribution of GT/IVSM strengths
- Tool
  - Polarization transfer D_{ij}
    - Sensitive to ΔJ^{π}(0^-, 1^-, 2^-) and modes (GT, IVSM)
  - Multipole Decomposition analysis (MDA) with D_{ij}
    - Based on reliable DWIA+RPA calculations

Research Center for Nuclear Physics
Ring Cyclotron Facility

Thanks to M. Dozono



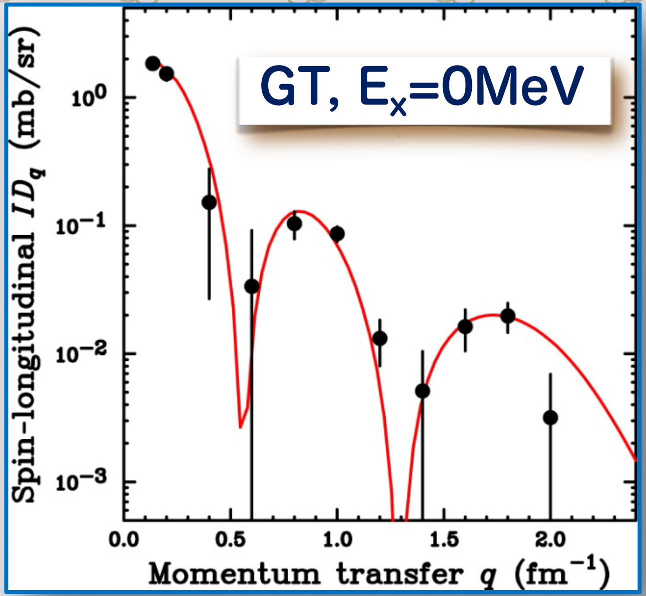
- 300MeV polarized protons
  - Smallest distortion
- Beam Polarization
  - Controlled by two solenoids
  - Measured by two BLPs (p+p)
- Beam Swinger
  - $\theta = 0^\circ \sim 13^\circ$
- Neutron measurement
  - NPOL2 with 100m TOF
  - D_{ij} measurement with NSR

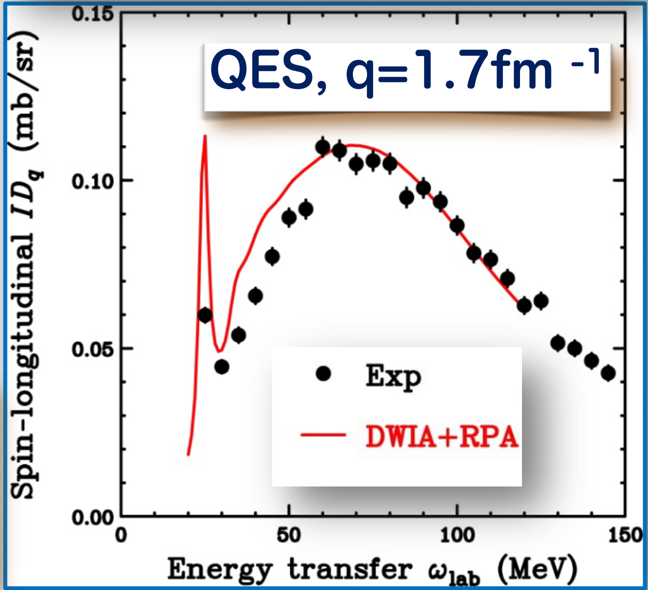
DWIA+RPA Calculations

- Computer code : crdw
  - Developed by Ichimura group
- DWIA
  - Global optical potentials for ^{208}Pb
    - Proton : Hama *et al.*
    - Neutron : Shen *et al.*
  - NN t-matrix
    - Franey and Love t-matrix
- RPA
  - $\pi + \rho$ +g' p-h interaction
    - $g'_{NN} = 0.60$
    - $g'_{N\Delta} = 0.35$

← ^{90}Zr data

- **No free parameter**
- **Well reproduce pionic modes for $^{12}C(p,n)$**
- **Absolute values are reliable**

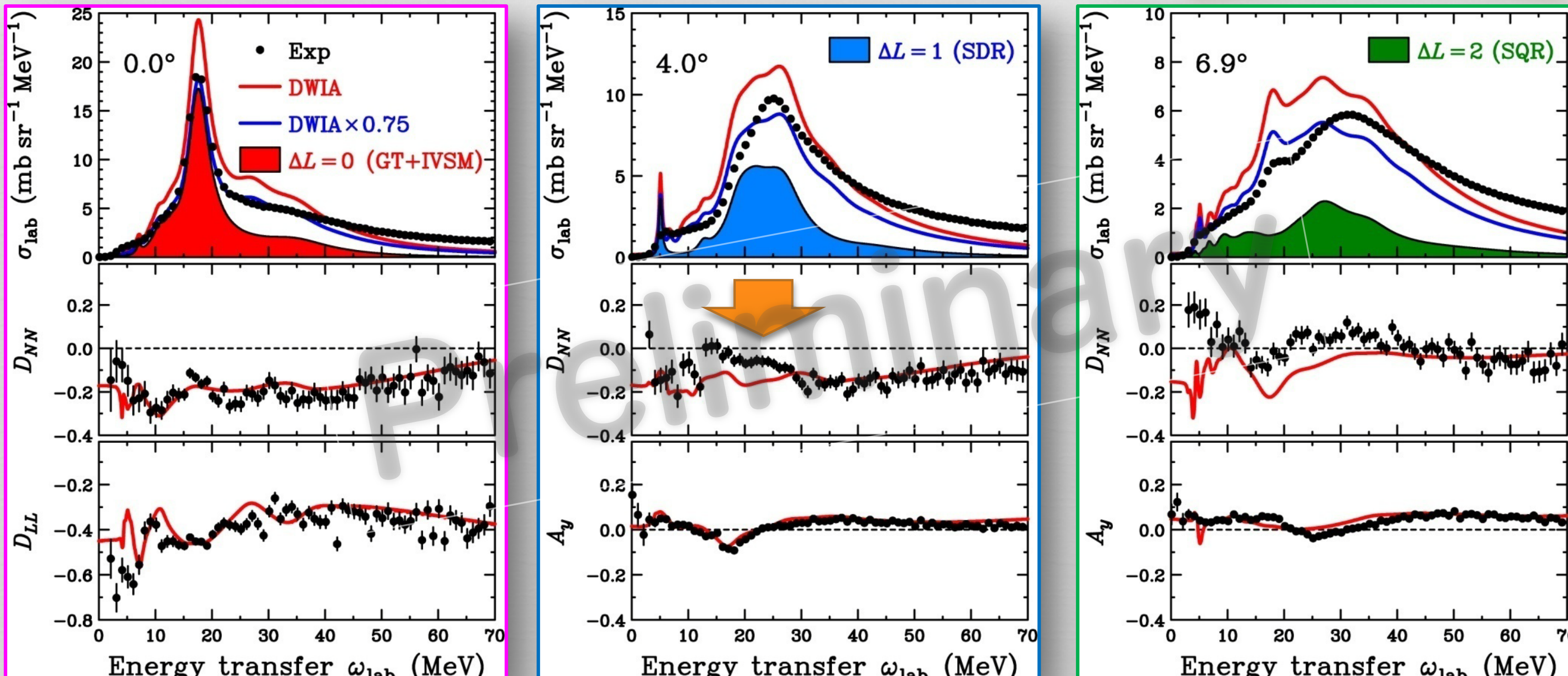




Experimental Results

- DWIA+RPA (−) → Overestimation in GR region
  - Quenching by 2p2h : ~0.7 (← $^{90}Zr(p,n)$)
    - Reasonably reproduce the GR region (−)
    - Should be re-distributed into the continuum
  - Significant difference in D_{NN} at 4.0°
    - 0^-, 1^-, 2^- distributions seem to be different

MDA should be performed



SD Strength Separation into Each ΔJ^π

- Cross sections
  - GT(L=0) : Maximum at ~0°
  - SD(L=1) : Maximum at ~3.5°
    - SD(L=1) can be extracted
  - ΔJ^π dependence is weak
    - 0^-, 1^-, 2^- could NOT be separated

Linearly dependent

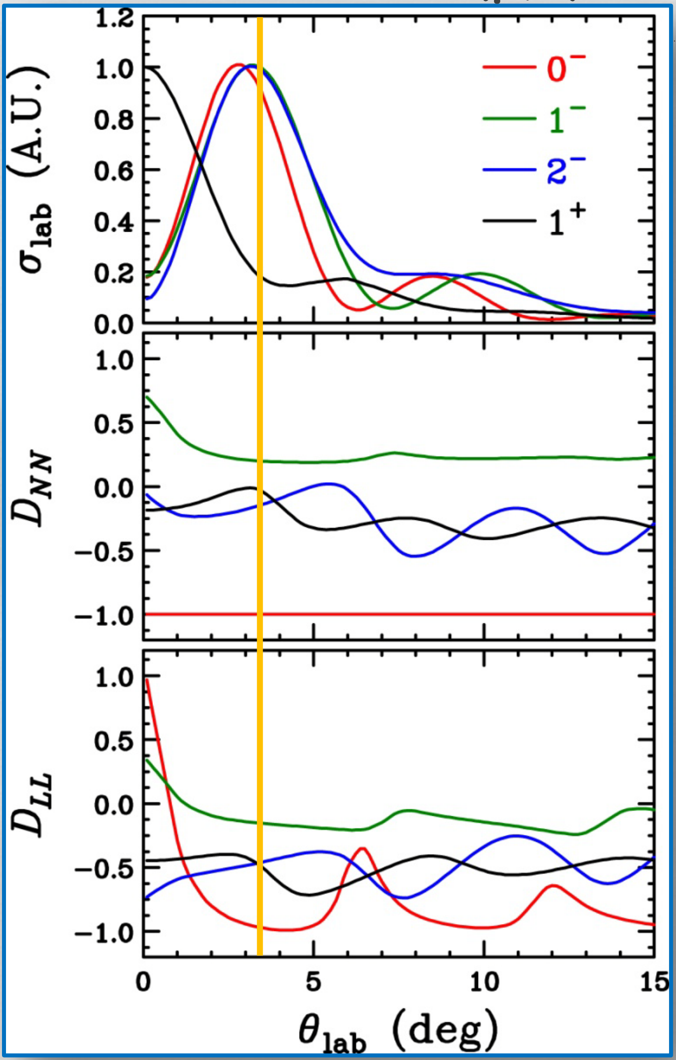
$$\sigma^{\rm exp}_{L=1} = a_{0-}\sigma^{\rm calc}_{0^-} + a_{1-}\sigma^{\rm calc}_{1^-} + a_{2-}\sigma^{\rm calc}_{2^-}$$

- Polarization transfer D_{ij} → *Into MDA*
  - Sensitive to ΔJ^π
    - 0^-, 1^-, 2^- could be separated

Linearly independent

$$D^{\rm exp}_{L=1} = \frac{a_{0-}D^{\rm calc}_{0^-} + a_{1-}D^{\rm calc}_{1^-} + a_{2-}D^{\rm calc}_{2^-}}{\sigma^{\rm calc}_{L=1}}$$

DWIA for ^{208}Pb(p,n)



Separation between GT and IVSM

- IVSM
  - $O_{\mathrm{IVSM}} = \sum_i r_i^2 \sigma_i \tau_i$
  - Similar angular distributions in σ
  - MDA → Could not be separated

Linearly dependent

$$\sigma_{1+}^{\mathrm{exp}} = a_{\mathrm{GT}} \sigma_{\mathrm{GT}}^{\mathrm{calc}} + a_{\mathrm{IVSM}} \sigma_{\mathrm{IVSM}}^{\mathrm{calc}}$$

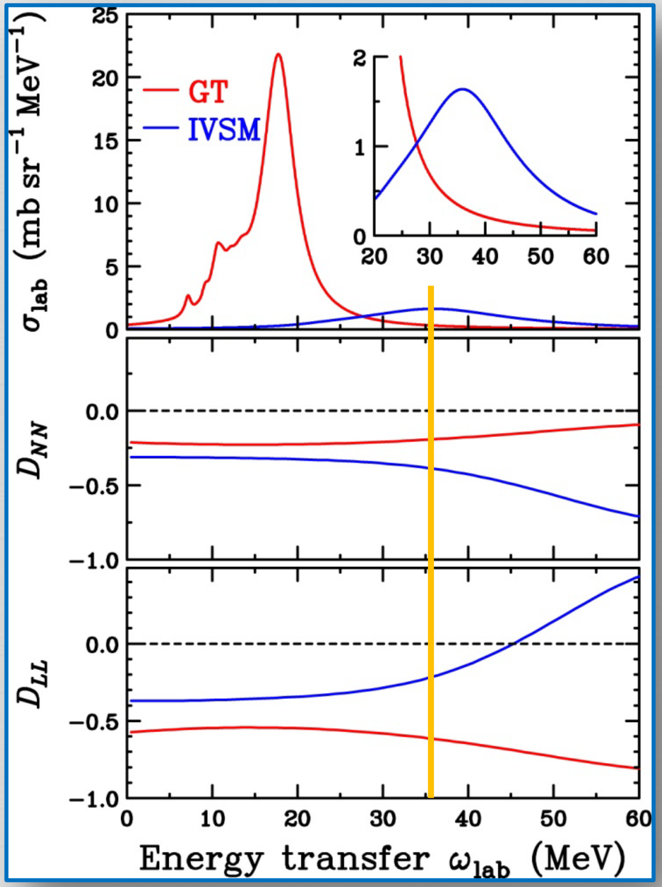
  - Interference between IVSM and GT → 10〜20% (Neglected)

- DWIA+RPA prediction for D_{ij}
  - Significant difference in D_{ij}
    - Different l=2 contributions
    - IVSM and GT could be separated

Linearly independent

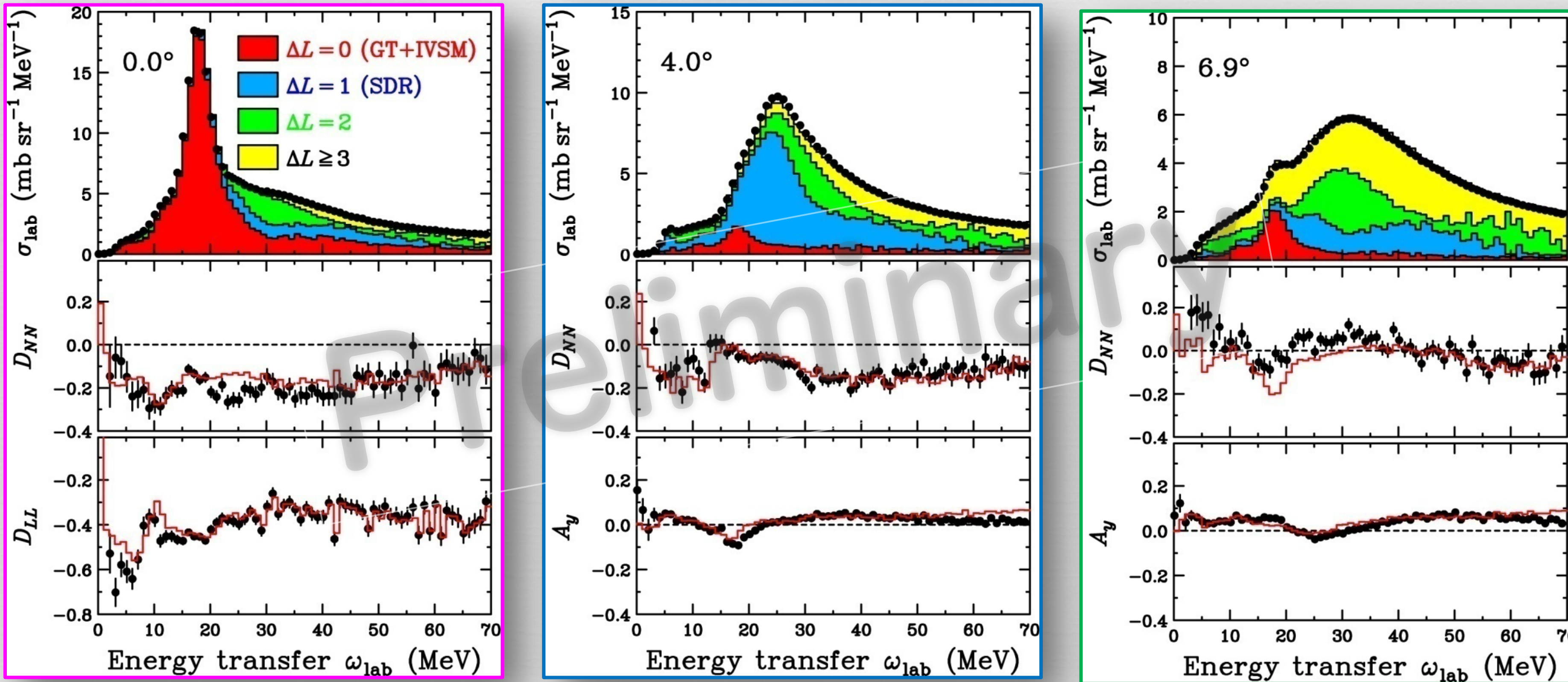
$$D_{1+}^{\mathrm{exp}} = \frac{a_{\mathrm{GT}} D_{\mathrm{GT}}^{\mathrm{calc}} + a_{\mathrm{IVSM}} D_{\mathrm{IVSM}}^{\mathrm{calc}}}{D_{1+}^{\mathrm{calc}}}$$

DWIA for ^{208}Pb(p,n) at 0°



I. Hamamoto and H. Sagawa, PRC 62, 024319 (2000).

Results of MDA

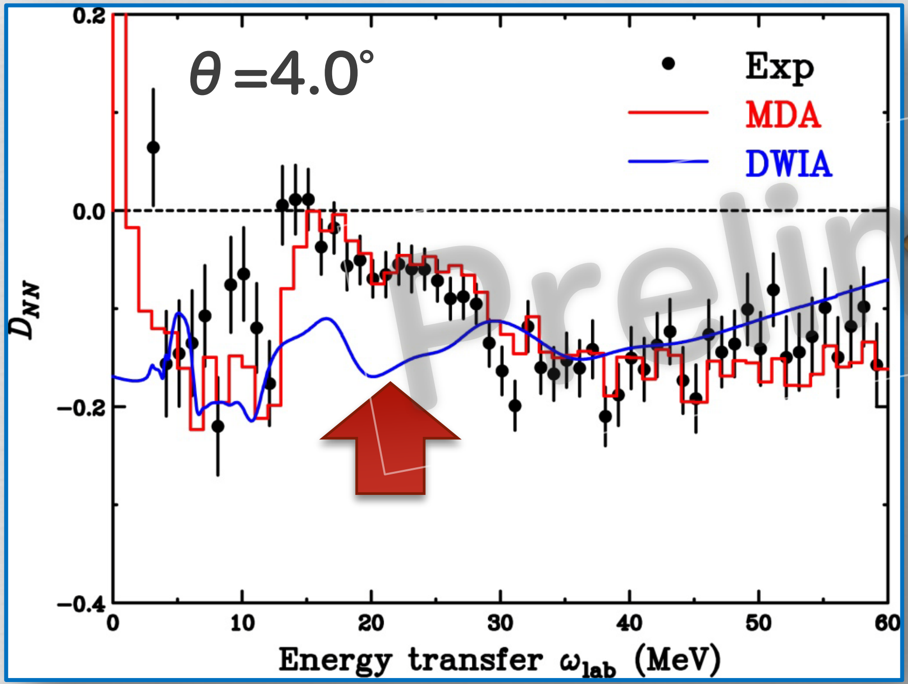


Successful description for both c.s. and polarization (D_{ij}, Ay) data

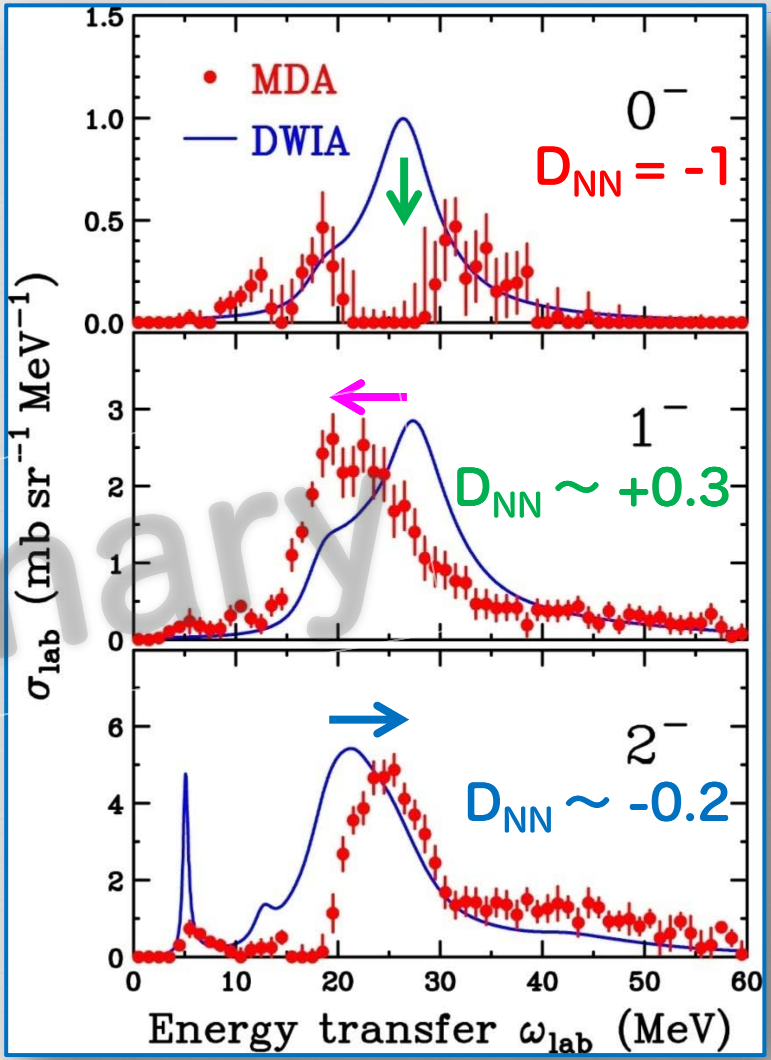
- Significant L=0(GT+IVSM) contritbuion up to 70 MeV
- Fairly large L=1(SDR) contribution up to 60 MeV

Comparison between DWIA and MDA

ΔJ^π	MDA (compared with theory)
0-	Quenching
1-	Softening (shift to lower ω)
2-	Hardening (shift to higher ω)



SD Cross Sections



SD unit cross section

- SD unit cross section
  - Maximum cross section at ∼4°
  - Proportionality relation

$$\sigma_{\mathrm{SD}}(4^\circ) \simeq \hat{\sigma}_{\mathrm{SD}} B(\mathrm{SD})$$

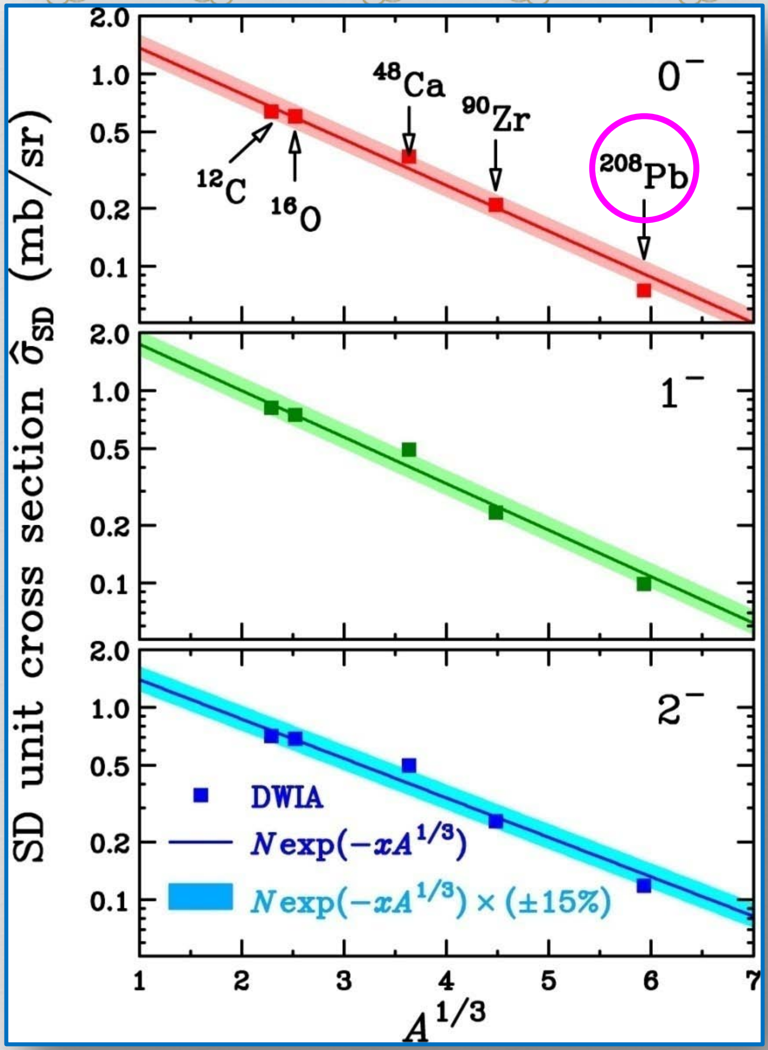
- DWIA (■)
  - ^{12}C, ^{16}O, ^{48}Ca, ^{90}Zr, ^{208}Pb
  - SD resonance at ω∼20 MeV

- A-dependence

C. Gaarde et al., NPA 369, 258 (1981).

$$\hat{\sigma}_{\mathrm{SD}}(A) = N \exp(-x A^{1/3})$$

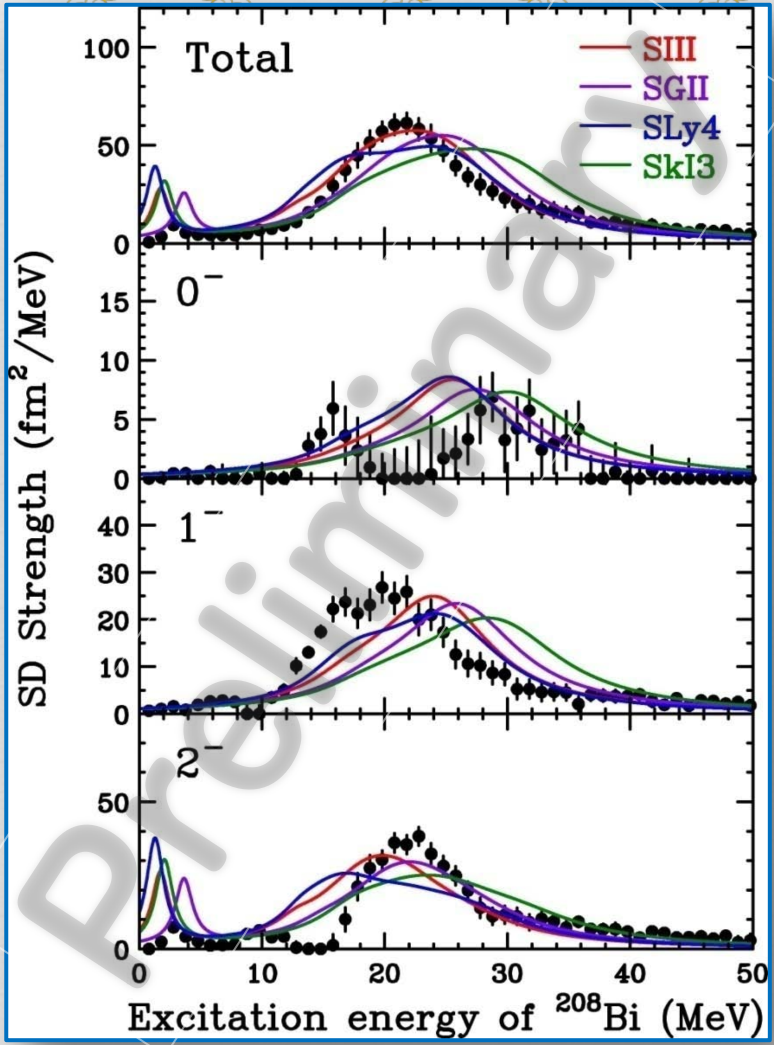
  - Proper description for A-dep.
  - Reproduce DWIA results within ∼15% → syst. uncertainty



SD Strength Distributions

H. Sagawa et al., PRC 76, 024301 (2007).

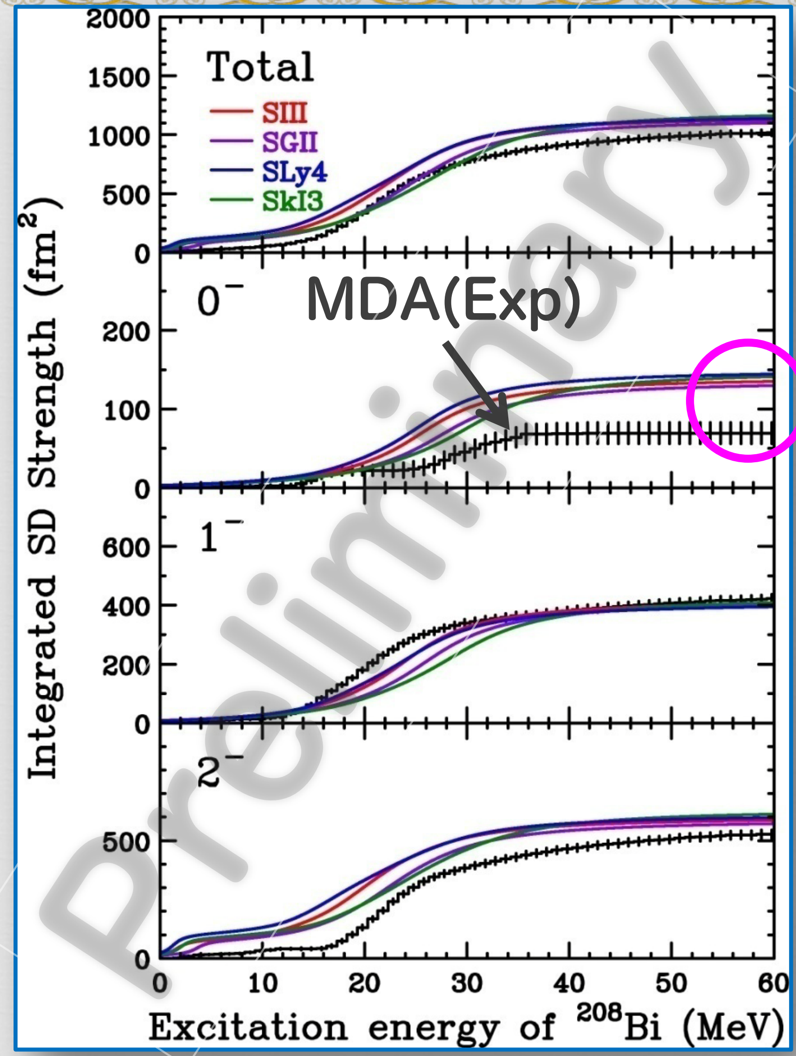
- Total strength
  - Asymmetric single bump
    - Extend up to ~50 MeV
    - Same as ^{90}Zr(p,n)results
  - SIII provides better description
- 0^- strength
  - Quenched
    - Seems to be fragmented
- 1^- strength
  - Softened compared with theory
    - Peak shift to lower E_x
- 2^- strength
  - Hardened compared with theory
    - Peak shift to higher E_x



- No Skyrme int. which reproduces both total and separated strengths
- ΔJ^{π}-dependent correlation ? → Require further investigations

Integrated SD Strengths

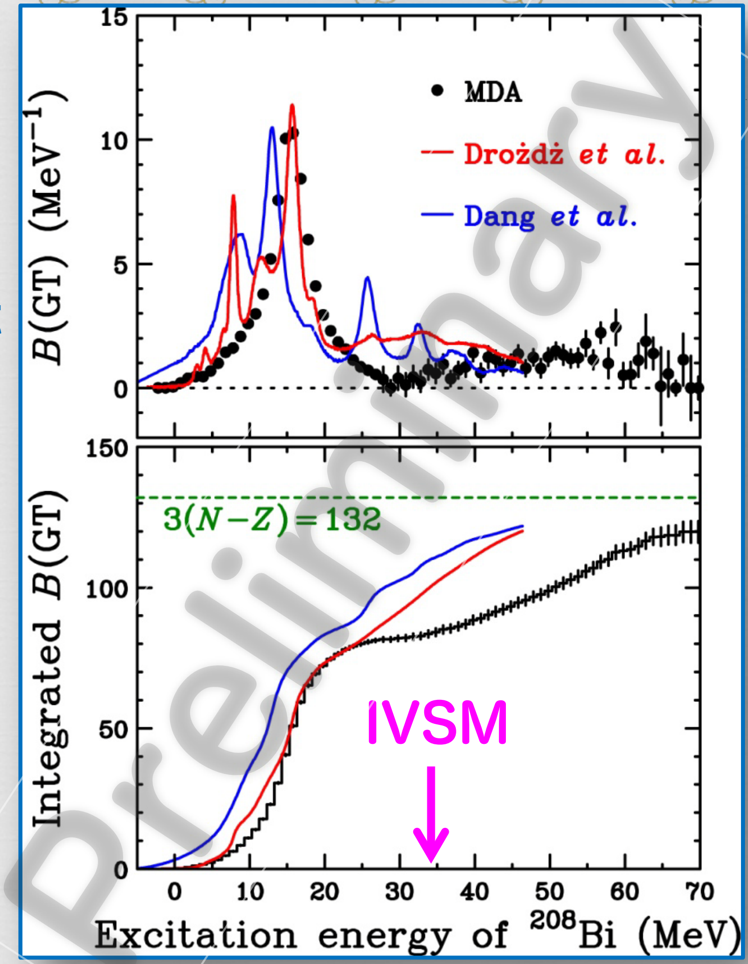
- Total strength ($E_x \leqq 60$ MeV)
  - MDA : $(1.02 \pm 0.03) \times 10^3$ fm^2
  - Theory: $(1.10 \sim 1.16) \times 10^3$ fm^2
  - Quenching fac. : 0.88~0.93
    - Similar to GT quenching
  - Systematic uncertainty~15%
- 0^- strength
  - Significant quenching by ~0.5
- 1^- strength
  - Consistent with theory
- 2^- strength
  - Small quenching by ~ 0.9



- Total SD strength up to 60 MeV is quenched by ~0.9
- Quenching effects (factors) might depend on spin-parity

Gamow-Teller Strength

- Experimental B(GT)
  - B(GT) in GTGR ~ 60% of 3(N-Z)
    - Similar to ^{90}Zr(p,n) result
  - Significant strength up to 70 MeV
    - Configuration mixing is important
  - Total strength = 120±4
    - Q_{GT}=0.91±0.03 of 3(N-Z)
    - Consistent with ^{90}Zr result
    - Systematic uncertainty~15%

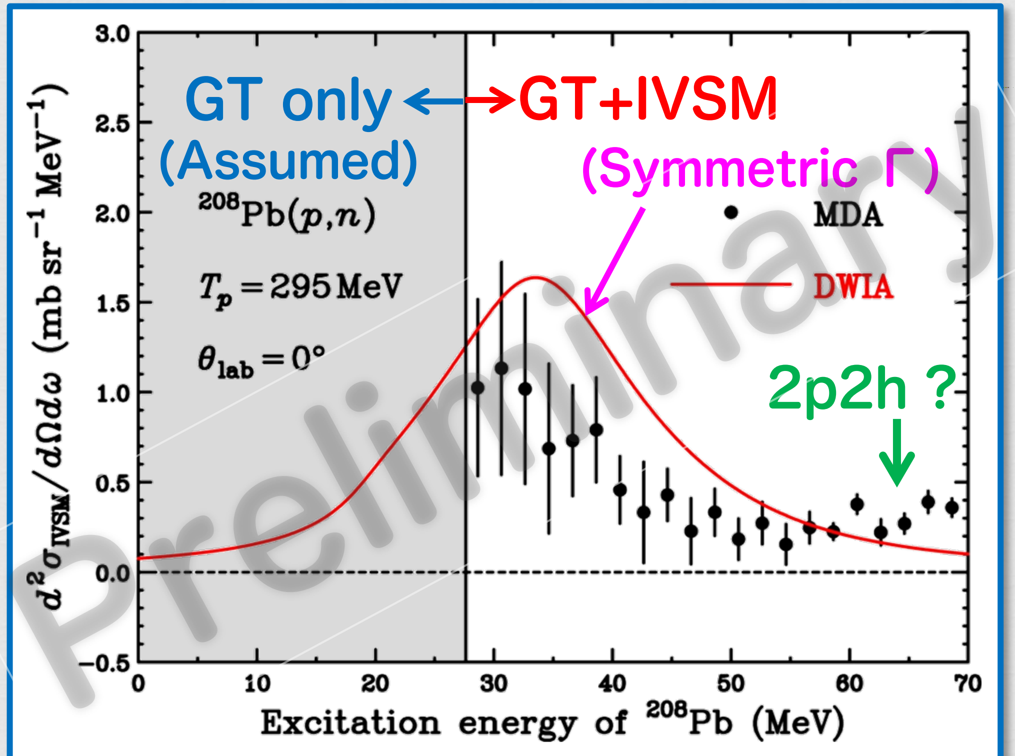


- Comparison with theory
  - Two calc. with 2p2h config. mixing
  - Quenching in GTGR by ~0.6
    - Consistent with MDA result
  - Significant strength in the continuum
    - Consistent with MDA results
    - Lower ω → Interference effects between GT and IVSM ?

S. Drozdz et al., PR 197, 1 ('87)
N. D. Dang et al., PRL 79, 1638 ('97)

IVSM Distribution

- IVSM cross section
  - Peak at ∼30 MeV
    - Consistent with theory
  - Fairly large uncertainty
    - Correlation with GT



- Comparison with DWIA+RPA
  - Systematically small by ∼0.6
    - Configuration mixing ? → Excess at large ω?
    - Interference effect ?

Investigation for interference effects in DWIA is required

Summary

- SD strength
  - SD quenching Q_{SD}～0.9 of theoretical values (E_x≦60 MeV)
    - Quenching effects might depend on ΔJ^{π} (Not Conclusive)
    - Consistent with ^{90}Zr result (～15% uncertainty)
  - Softening (hardening) of 1^- (2^-) strength → Correlation ?
- GT strength
  - IVSM is separated with D_{ij} (No interference is assumed)
  - GT quenching Q_{GT}=0.91±0.03 of 3(N-Z)
    - Configuration mixing is important
    - Consistent with ^{90}Zr result (～15% uncertainty)
- IVSM strength
  - Peak at ～30 MeV → Consistent with theory
  - Small exp. values/Significant strength up to 70 MeV
    - Configuration mixing ? Interference effects ?

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