Momentum Transfer Dependence of Spin Isospin Modes in Quasielastic Region (RCNP E131 Collaboration)

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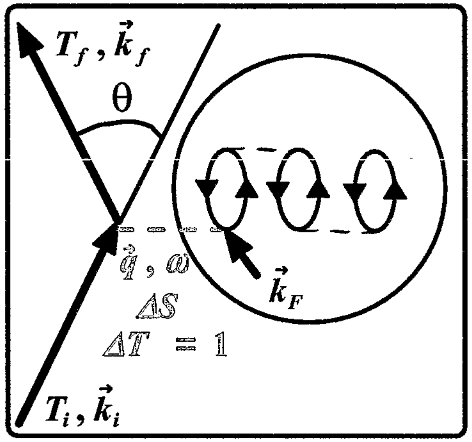
Overview

- Motivations
- Experiment
- Definition of Experimental Spin Responses
- Experimental Spin Responses
  - ^{2}H data
  - ^{12}C data
    - *R_L/R_T ratio*
    - *Comparison with (e,e') Results*
    - *Comparison with RPA Responses*
- Spin-Direction Dependence of N_{eff}
- 2-Step Contribution
- Summary

Quasi-Elastic Scattering

- **QES Process**
  - Momentum and energy transfers: q and ω
  - Spin Transfer: ΔS
    - ***Longitudinal* (π) *vs Transverse* (ρ)**
  - Isospin Transfer: ΔT

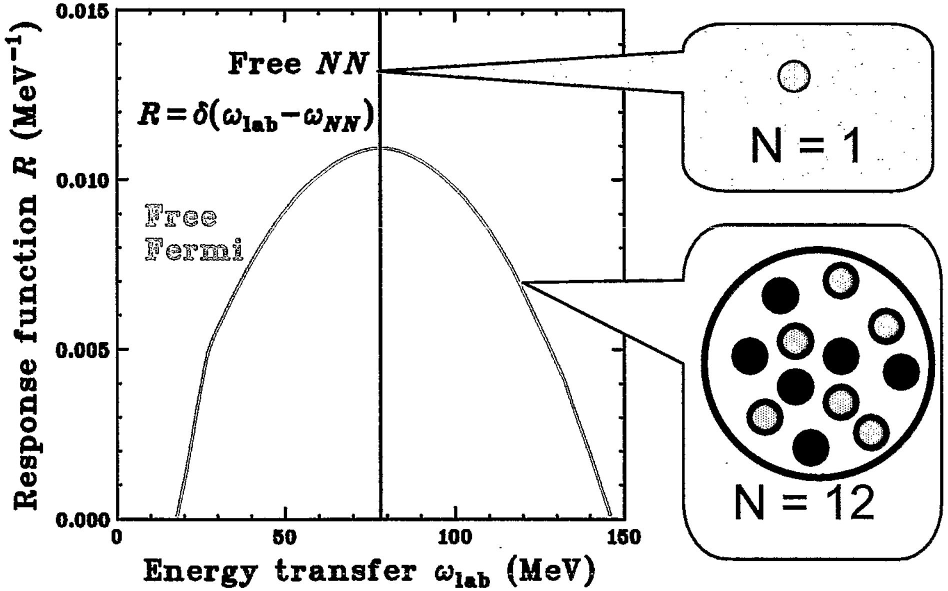


- **Kinematics**

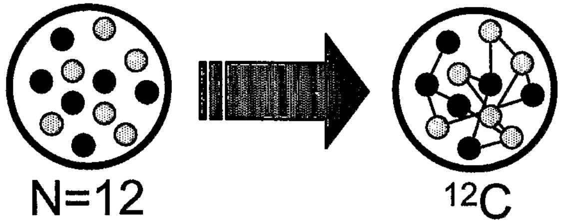
$$\omega = \frac{\left(\vec{q} + \vec{k}_F\right)^2}{2m} - \frac{\left(\vec{k}_F\right)^2}{2m}$$

$$= \frac{q^2}{2m} + \frac{\vec{q} \cdot \overrightarrow{k_F}}{m}$$

↑ peak (first term) ↑ width (second term)



- **Nuclear Correlations**



  - Response functions ?

Pionic Correlations in Nuclei

- π+ρ+g' Model Interaction
  - Spin-longitudinal (π) interaction
    - *Attractive at $q > 0.8\ fm^{-1}$*
  - Spin-transverse (ρ) interaction
    - ***Repulsive***
- Nuclear Spin Response
  - Longitudinal Response

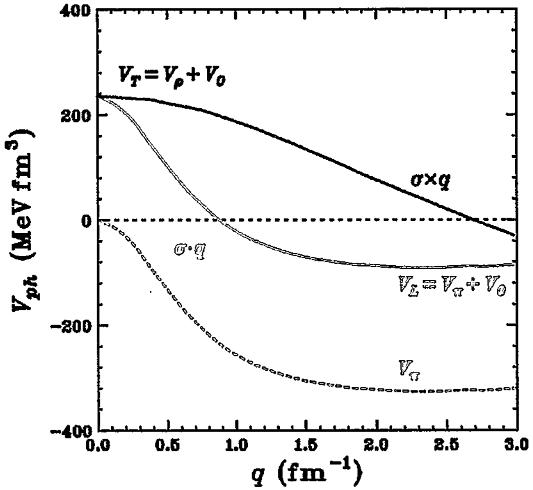
$$R_L \propto \left| \langle n | \sigma \cdot \mathbf{q} | 0 \rangle \right|^2$$

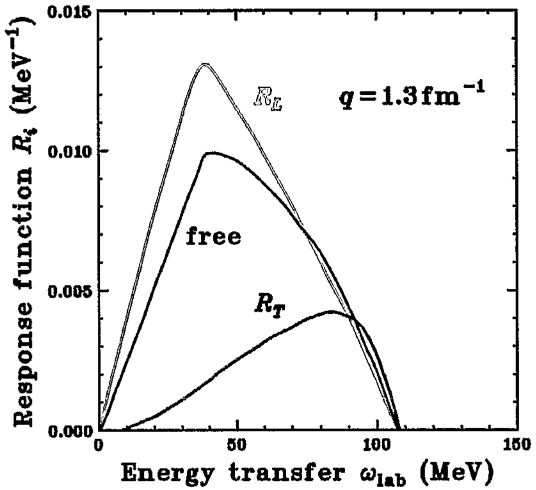
    - *Enhancement and Softening*
  - Transverse Response

$$R_T \propto \left| \langle n | \sigma \times \mathbf{q} | 0 \rangle \right|^2$$

    - ***Quenching and Hardening***

$$\Rightarrow \text{enhancement of } \frac{R_L}{R_T}$$

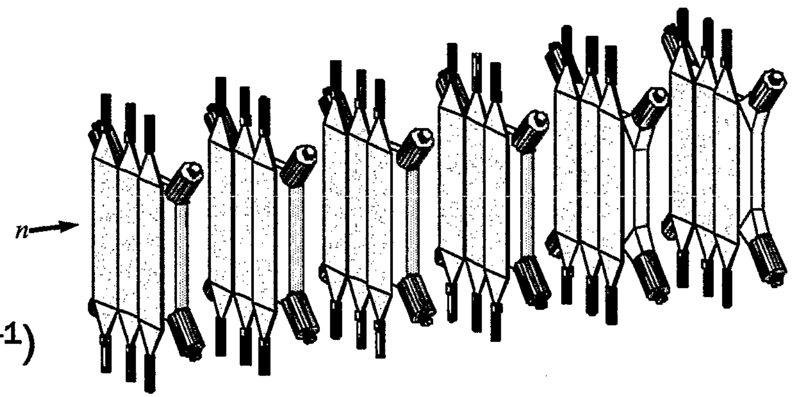




W.M. Alberico et al., NP A379, 429 (1982)

Experiment

- Measure complete sets of polarization transfers
  - ^{2}H(Free response)
  - ^{12}C (Nuclear response)
- Beam
  - 345 MeV polarized protons
  - Beam polarization:0.70±0.01
  - Beam current: 10-50 nA
- Neutron Detector/Polarimeter NPOL2
  - High Performance of Neutron Polarimetry (FOM)
    - *4.9×10^{-4} @ 300 MeV*
      (c.f. 2.3×10^{-4} @ LAMPF)
  - High Efficiency of Neutron Detection
    - *0.15 @ 150- 400 MeV*
  - TOF flight path length: 100m
- Observables
  - θ_{lab}: 16deg.,22deg.,27deg.(q=1.2-2.0fm^{-1})
  - Complete measurement
    - *Cross section*
    - *Analyzing power and induced polarization*
    - *A Compete set of polarization transfers*



Neutron Polarimeter NPOL2

Definition of Experimental Responses

- **Factorized Form for Quasielastic Scattering**

$$I = \tilde{C}\,N_{\rm eff}\left(\left|t_0^\eta\right|^2 R_0 + \left|t_q^\eta\right|^2 R_q + \left|t_n^\eta\right|^2 R_n + \left|t_p^\eta\right|^2 R_p\right)$$

R_0 : non – spin

R_q : spin – longitudinal

R_n, R_p : spin – transverse

$$\tilde{C} = 8\left[\frac{\mu_i \mu_f}{(2\pi)^2}\frac{k_f}{k_i}\frac{1}{2(2J_A+1)}\right]\left[\frac{\sin(\theta_{\rm cm})}{\sin(\theta_{\rm lab})}\frac{\sqrt{s_{NA}}}{M_T^*}\right](2J_A+1)$$

- **NN t-Matrix in the Optimal Frame**

$$t^\eta = \Big[\left(A^\eta + C_2^\eta \sigma_{1n}\right)1 + \left(B^\eta \sigma_{1n} + C_1^\eta\right)\sigma_{0n} + \left(E^\eta \sigma_{1q} + D_1^\eta \sigma_{1p}\right)\sigma_{0q} + \left(F^\eta \sigma_{1p} + D_2^\eta \sigma_{1q}\right)\sigma_{0p}\Big]\tau_0 \cdot \tau_1$$

- **Transform polarization observables from laboratory to c.m. frame**

$$\left\{D_{S'S}, D_{NN}, D_{L'L}, D_{S'L}, D_{L'S}\right\} \Longrightarrow \left\{D_{nn}, D_{qq}, D_{pp}, D_{qp}, D_{pq}\right\}$$

- **Polarized Cross Sections and Experimental Spin-Responses:R_i**

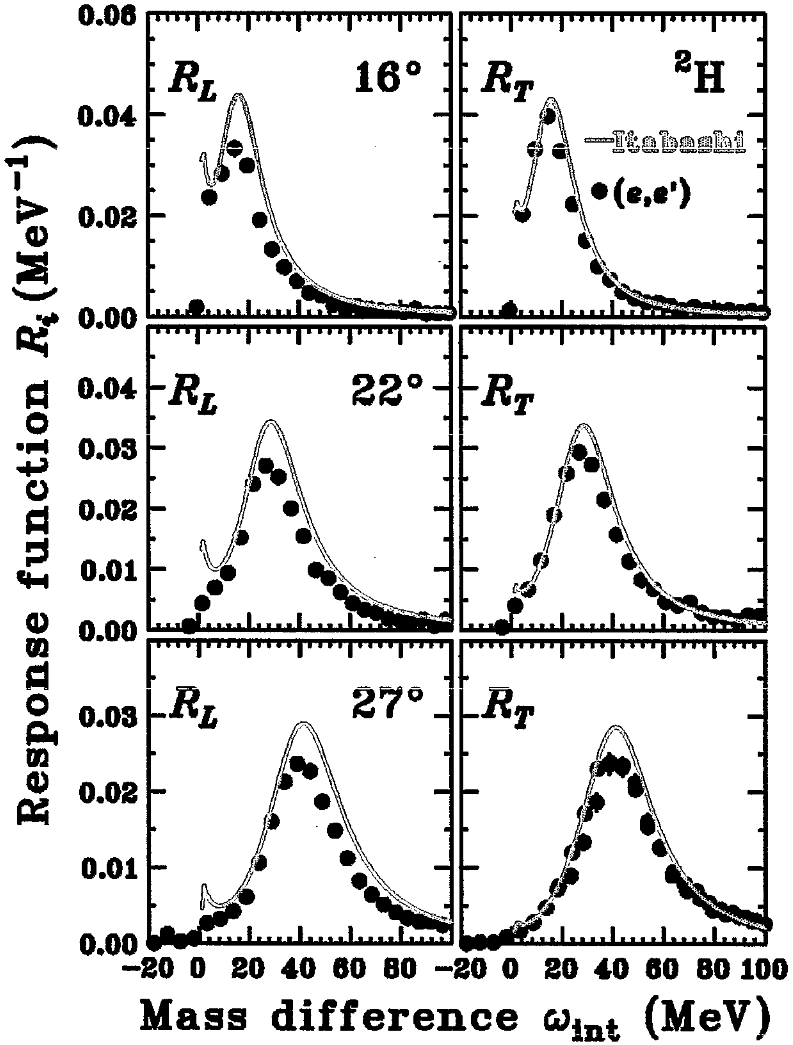
$$I\,D_q = \frac{I}{4}\left[1 - D_{nn} + D_{qq} - D_{pp}\right] = \tilde{C}\,N_{\rm eff}\left|E^\eta\right|^2 R_q$$

$$I\,D_p = \frac{I}{4}\left[1 - D_{nn} - D_{qq} + D_{pp}\right] = \tilde{C}\,N_{\rm eff}\left|F^\eta\right|^2 R_p$$

RCNP E131 Collaboration

Response Functions for ^2H

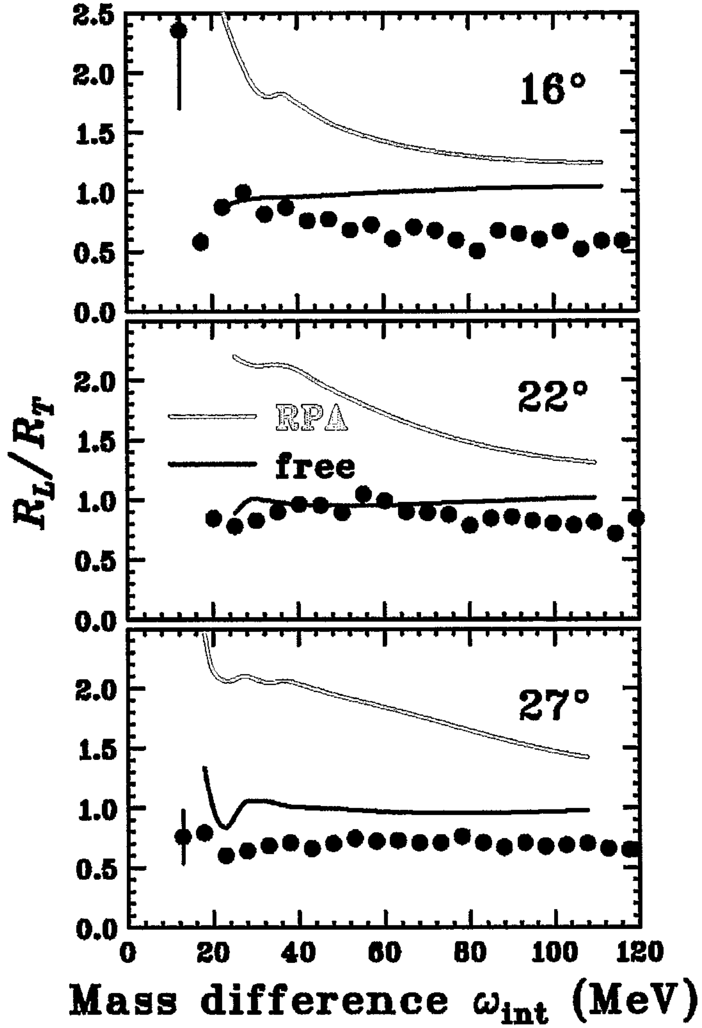
- **Simplest nuclear system**
  - Benchmark reaction
  - Check the formalism to deduce response functions
- **Data**
  - ● : (p,n) data at RCNP
  - ● : (e,e') data at MIT-Bates
  - — : Itabashi et al.
- **Comparison with (e,e')**
  - Good agreement with (e,e')
  - Formalism is appropriate
  - Exp. Data (absolute values) are reliable
- **Comparison with calculations**
  - Overestimate the experimental results ((p,n) and (e,e'))
  - MEC effects are not included in the calculations



A. Itabashi et al., Prog. Theor. Phys. 91, 69 (1994)

Ratios of Response Functions for ^{12}C

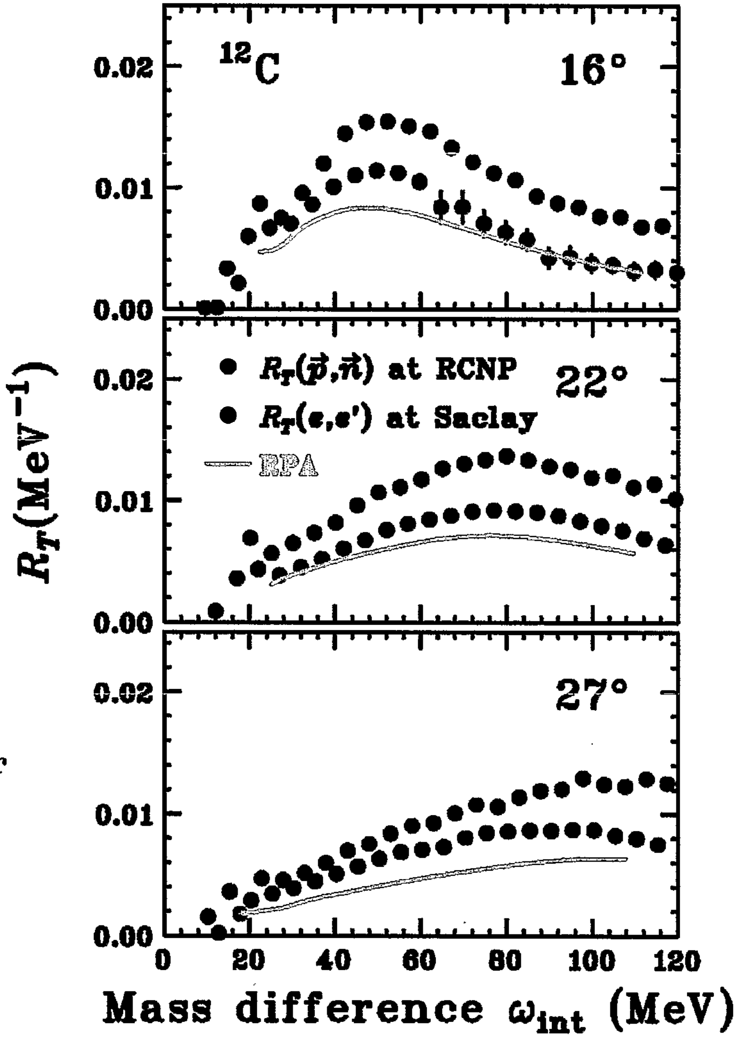
- Response Ratio
  - Less than 1 at all momentum transfers
- No-evidence of enhancement of R_L relative to R_T
  - Consistent with the results of (p,p') and (p,n) at LAMPF
- No-enhancement of R_L ?
  - No-enhancement of R_L
  - No-quenching of R_T
  - Both



K. Kawahigashi et al. PRC 63, 044609 (2001)

Comparison to (e,e') Results

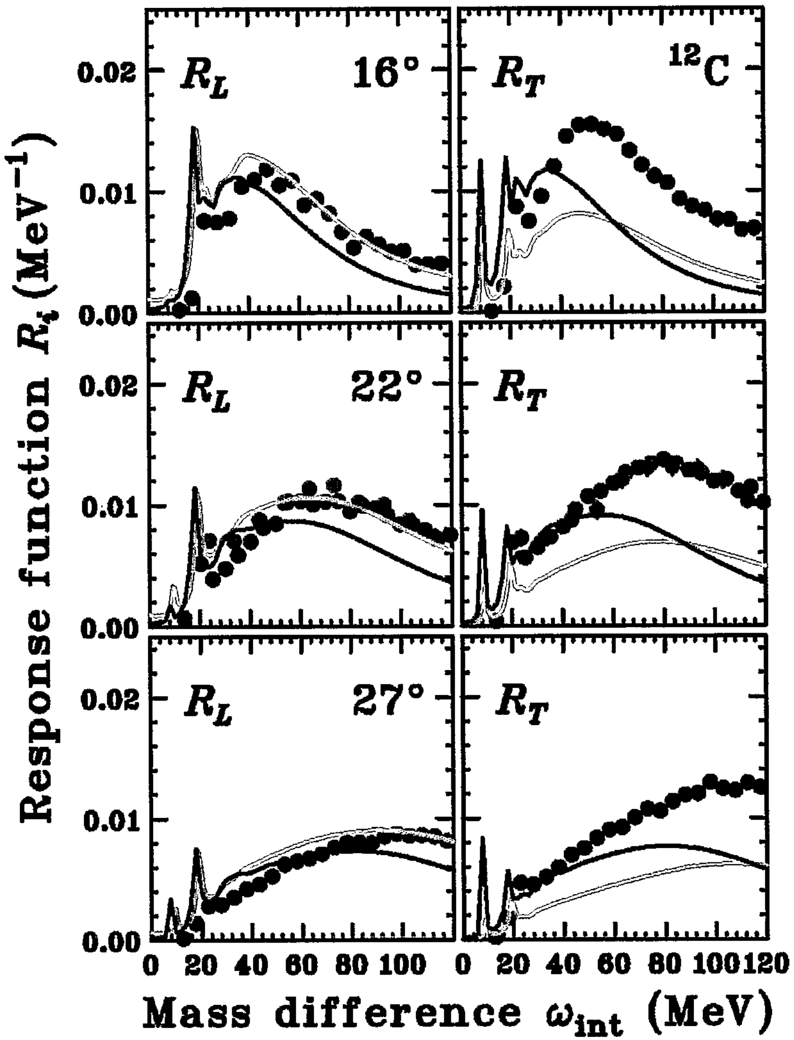
- Comparison to (e,e')
  - $R_T(p,n) = R_T(e,e')$
    if we ignore the MEC contributions
- (e,e') vs. RPA
  - $R_T(e,e') > R_T(RPA)$
  - 2p2h and MEC contributions
- (p,n) vs. (e,e)
  - $R_T(p,n) > R_T(e,e')$
  - $R_T(p,n) >> R_T(RPA)$
  - Mask the pionic enhancement in R_L/R_T
    - *Spin-direction dependence of N_{eff} ?*
    - *2-step contribution ?*



K. Kawahigashi et al. PRC 63, 044609 (2001)

Comparison to RPA Responses

- **RPA responses**
  - π + ρ + g' model
- **Data**
  - ● : RCNP data
  - ● : LAMPF data
  - — : RPA responses
  - — : Free response
- **Spin-Longitudinal R_L**
  - Enhancement : ◯
    - *Signature of pionic enhancement*
- **Spin-Transverse R_T**
  - Hardening : ◯
    - *Standard ρ-exchange model* : ◯
  - Quenching : ×
    - ***Spin-dependent N_{eff} ?***
    - ***2-step contribution ?***



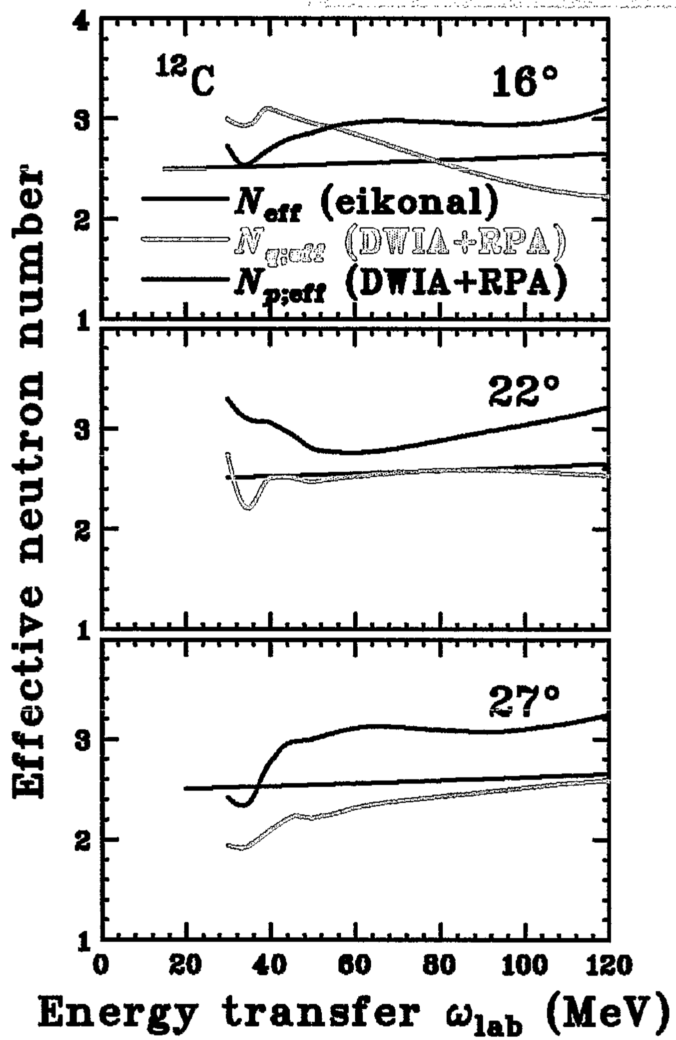
K. Kawahigashi et al. PRC 63, 044609 (2001)

Spin-Direction Dependence of N_{eff}

- Spin-Direction Dependence of N_{eff}
  - ID_i^{DW}: DWIA+RPA
  - ID_i^{PW}: PWIA+RPA
  - $N_{i;eff}$ is defined as

$$N_{i;eff}(\omega) = N \frac{ID_i^{DW}(\omega)}{ID_i^{PW}(\omega)}$$

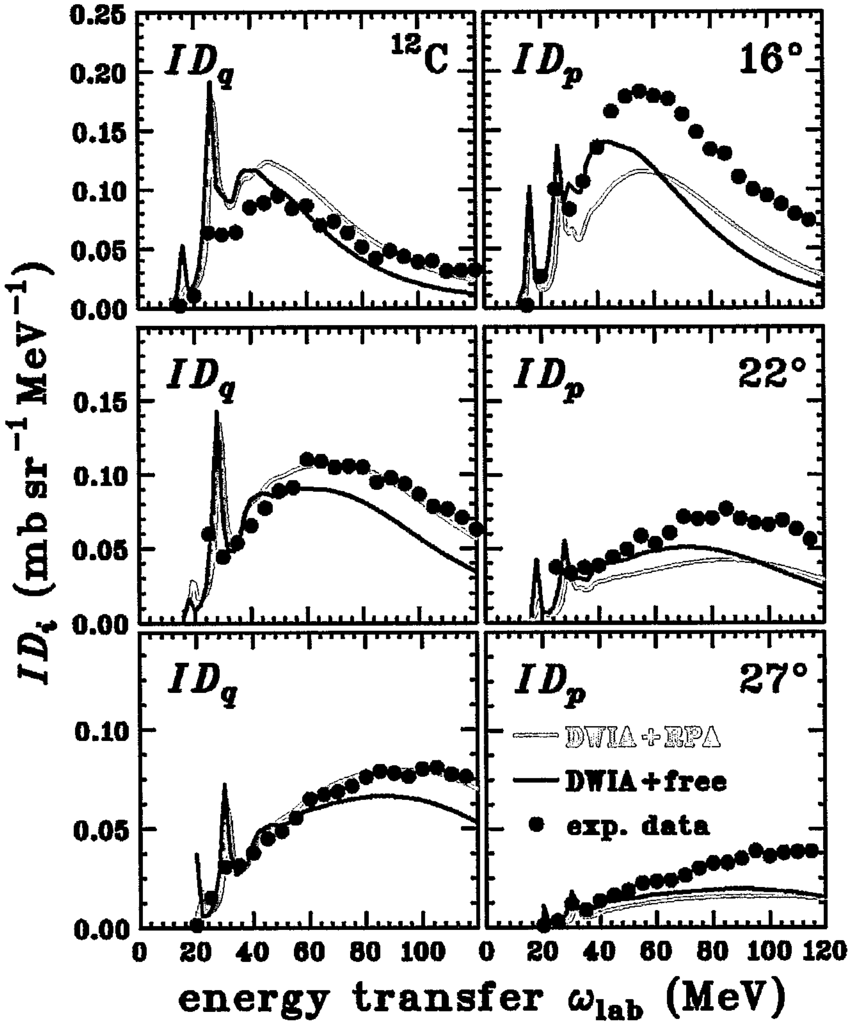
- Spin-Longitudinal $N_{q;eff}$ (Small effects)
  - $N_{q;eff} > N_{eff}$ at 16°
    - *Enhance the enhancement of R_L*
  - $N_{q;eff} < N_{eff}$ at 27°
    - ***Mask the enhancement of R_L***
- Spin-Transverse $N_{p;eff}$ (Large Effects)
  - $N_{p;eff} >> N_{eff}$ at all angles
    - ***Mask the quenching of R_T***
- N_{eff} description in eikonal approximation is not appropriate especially for spin-transverse mode



K. Kawahigashi et al. PRC 63, 044609 (2001)

Comparison to DWIA+RPA

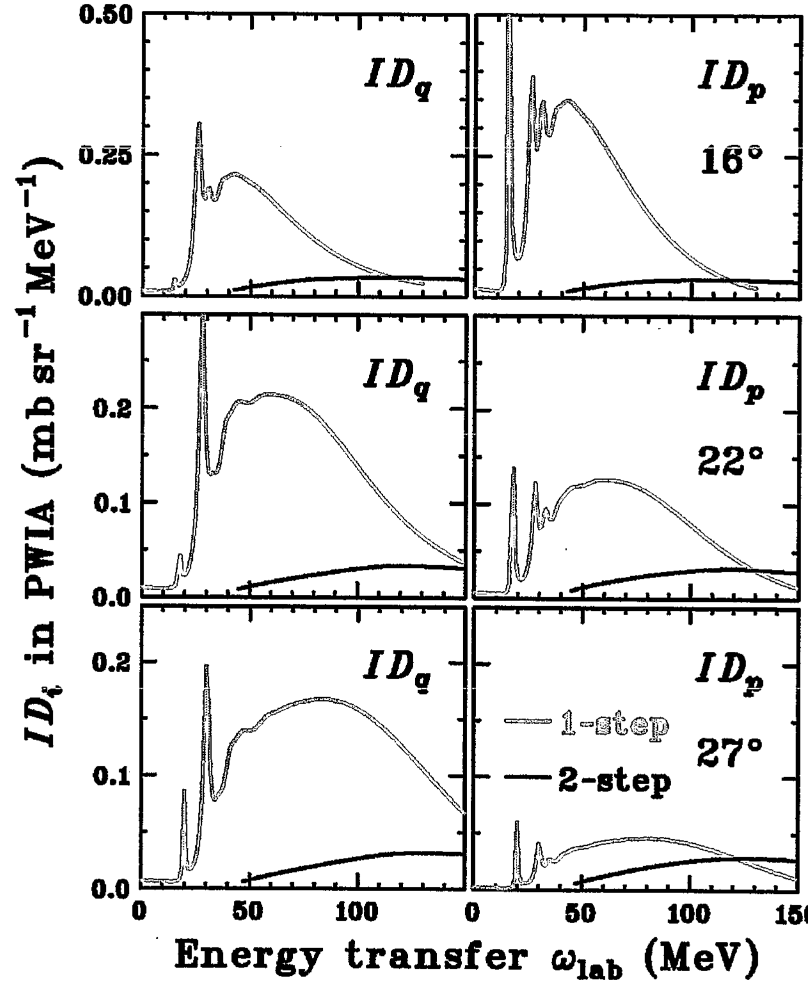
- **DWIA+RPA by Ichimura Group**
- **Spin-Longitudinal ID_q**
  - Fairly good agreement with data at whole region
  - Signature of pionic correlations
- **Spin-Transverse ID_p**
  - Discrepancy becomes small compared with R_l
  - **Underestimate at whole region**
  - **Spin-direction dependence of N_{eff} is not sufficient to explain the enhancement of R_T**
  - 2-step contribution?
    - ***Spin-direction dependent?***



K. Kawahigashi et al. PRC 63, 044609 (2001)

2-Step Contributions in ID_q and ID_p

- **Plane Wave Calculations**
  - Full spin-direction dependence in both 1-step and 2-step processes
  - Contribution to each ID_i
    - ***2-step contribution to ID_q***
    - ***2-step contribution to ID_p***
  - Plane Wave Approximation
    - ***2-step relative to 1-step***
- **Results**
  - 2-step of ID_p > 2-step of ID_q
  - 2-step contribution in ID_q
    - *Small*
    - *becomes small at large q*
  - 2-step contribution in ID_p
    - *Fairly large*
    - *becomes large at large q*



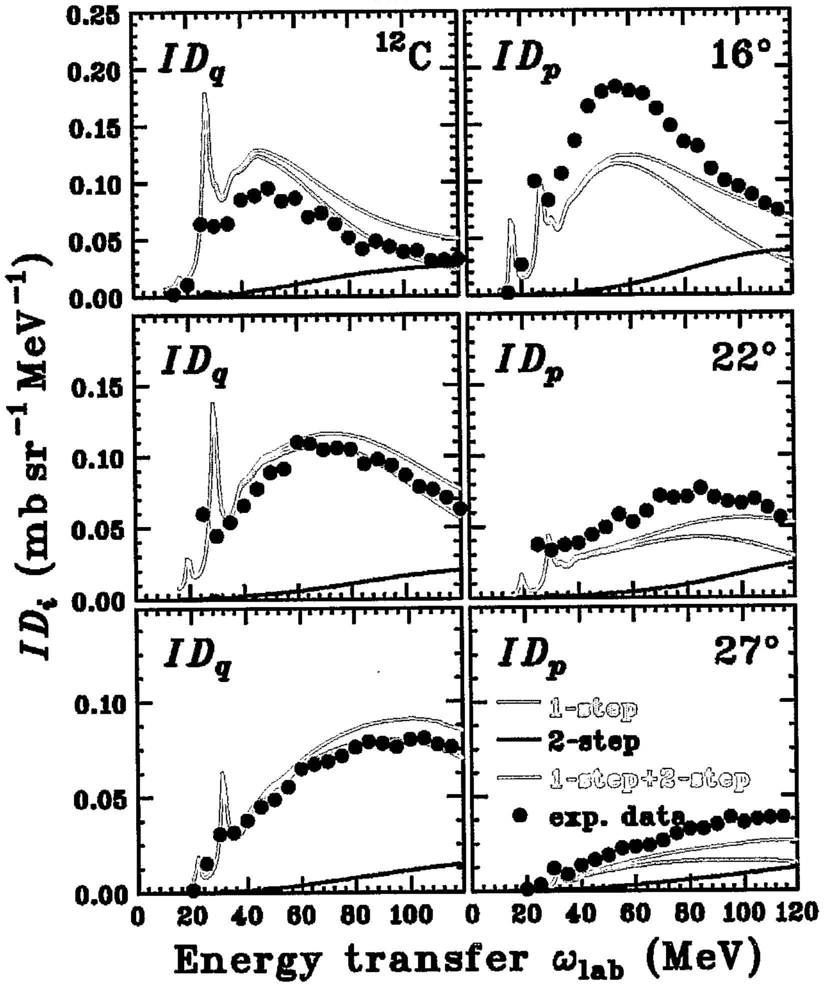
Y. Nakaoka, PRC 65, 064616 (2002)

DWIA+RPA and 2-Step Contribution

- 1-Step Contribution
  - DWIA+RPA Calculation
- 2-Step Contribution
  - PW approximation with full spin-direction dependence
  - 2-step contribution is calculated as

$$2step = 1step(DWIA + RPA) \times \frac{2step(PW)}{1step(PW)}$$

- ID_q: Small effect
  - Not disturb the agreement at low ω
  - Slightly overestimate at large ω
- ID_p: Better description
  - Well reproduce the exp. data at large ω
  - Discrepancy around the peak
  - 2p2h configurations ?



K. Kawahigashi et al. PRC 63, 044609 (2001)

Y. Nakaoka, PRC 65, 064616 (2002)

Summary

- Complete sets of polarization observables for quasi (p,n) reactions
  - ^2H (Free Response) and ^{12}C (Nuclear Response) at $q = 1.2 - 2.0\ fm^{-1}$
- Results for ^2H
  - Fairly good agreement with theory
- Results for ^{12}C
  - R_i : $R_L/R_T < 1$ (No enhancement)
- Comparison to (e,e') and RPA
  - Enhancement of R_L
    - ***Evidence of pionic correlations in nuclei***
  - Enhancement of R_T (Not quenching)
    - ***Mask the signature of pionic enhancement in R_L/R_T***
    - ***Spin-direction dependence of N_{eff} / 2-step contribution***
- Comparison to DWIA+RPA (Spin-Direction Dependence of N_{eff})
  - Spin-direction dependence of N_{eff} is important for the spin-transverse mode
  - Enhancement in the spin-transverse mode
- 2-Step contribution
  - 2-step contribution is important for the spin-transverse mode
  - Discrepancy in the spin-transverse mode becomes small significantly
  - Enhancement in the spin-transverse mode (2p2h configuration ?)

SESSION 5

SPIN PHYSICS WITH NUCLEI

Hideyuki Sakai, Tokyo

Few-Body Physics and Nuclear Properties Chair: Hideyuki Sakai, Tokyo

Tuesday 14:00 – 16:30 ***Berkner, Room B***

14:00 – 14:30 Complete set of proton spin observables in pd elastic scattering at 250 MeV, (K. Hatanaka)
Anomaly in Tensor Analyzing Powers of pd Radiative Capture, (K. Sagara)

14:30 – 14:50 Polarization Transfer Measurement for d-p Elastic Scattering - A Probe For Three Nucleon Force Properties, (K. Sekiguchi)

14:50 – 15:10 Measurement of the Analyzing Powers For The $d\bar{d} \rightarrow {}^3He\ n$ and $d\bar{d} \rightarrow {}^3Hp$ Reactions at Intermediate Energies, (T. Saito)

15:10 – 15:30 Extraction of Neutron Density Distributions from Proton Elastic Scattering at Intermediate Energies, (H. Takeda)

15:30 – 15:50 T_{20} for ${}^7Li$ Induced Transfer Breakup Reactions, (P. Ward)

15:50 – 16:10 Polarizations For ${}^{12}C(p,2p)$ Reactions at 1 GeV, (H. Yoshida)

16:10 – 16:30 Momentum Transfer Dependence of Spin Isospin Modes in Quasielastic Region, (T. Wakasa)