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

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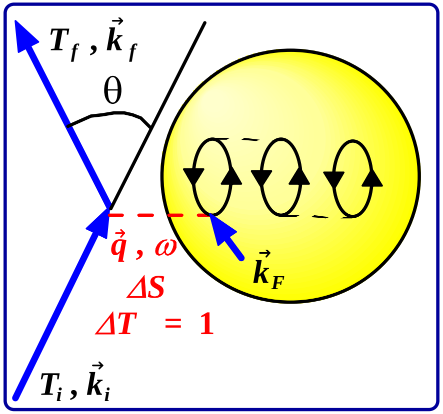
Overview

- **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

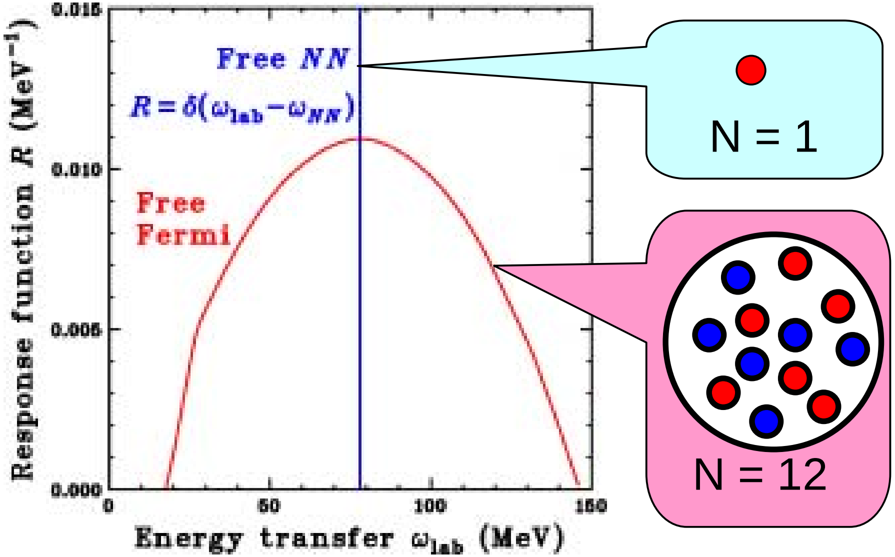
- **QES Process**
  - Momentum and energy transfers: q and ω
  - Spin Transfer: ΔS
    - ***Longitudinal (π) vs Transverse (ρ)***
  - Isospin Transfer: ΔT



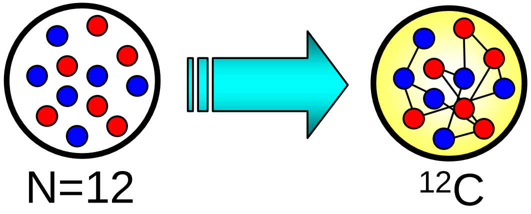
- **Kinematics**

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

$$= \underset{\substack{\uparrow \\ \text{peak}}}{\frac{q^2}{2m}} + \underset{\substack{\uparrow \\ \text{width}}}{\frac{\vec{q}\cdot\overrightarrow{k_F}}{m}}$$



- **Nuclear Correlations**



  - Response functions ?

Pionic Correlations in Nuclei

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

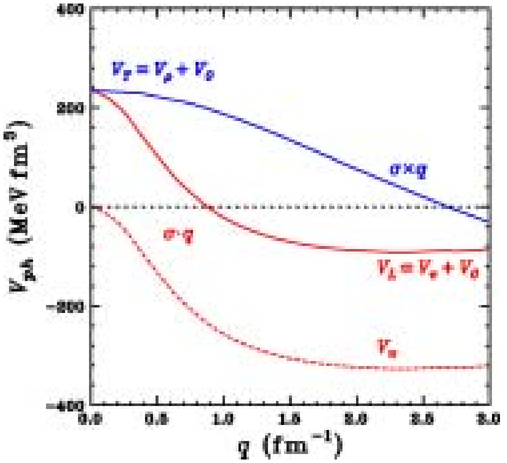
$$R_L \propto \left| \langle n | \sigma \cdot \mathbf{q} | 0 \rangle \right|^2$$

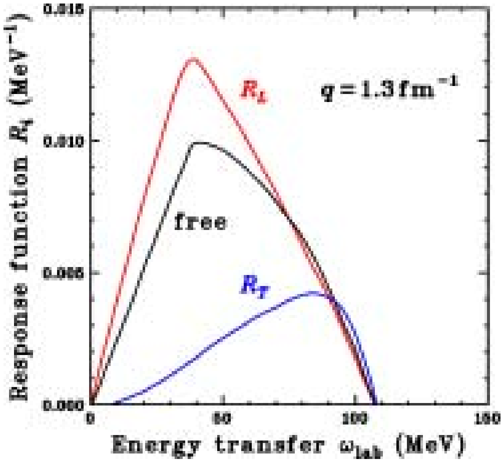
    - ***Enhancement and Softening***
  - Transverse Response

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

    - ***Quenching and Hardening***

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

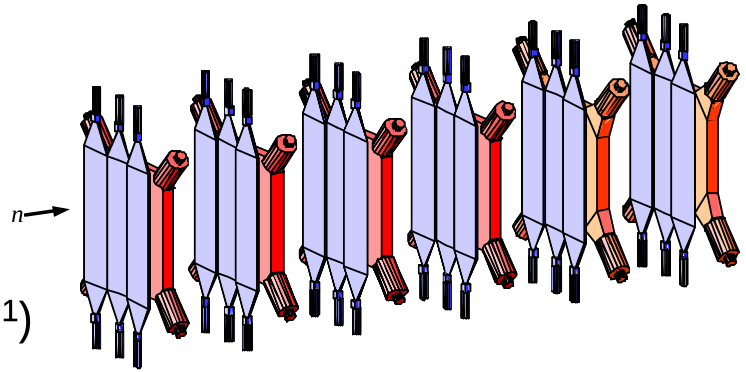




W.M. Alberico et al., NP A379, 429 (1982)

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 X 10^{-4} @ 300 MeV***
(c.f. 2.3 X 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

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

R_0 : non – spin

R_q : spin – longitudinal

R_n, R_p : spin – transverse

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

- 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

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

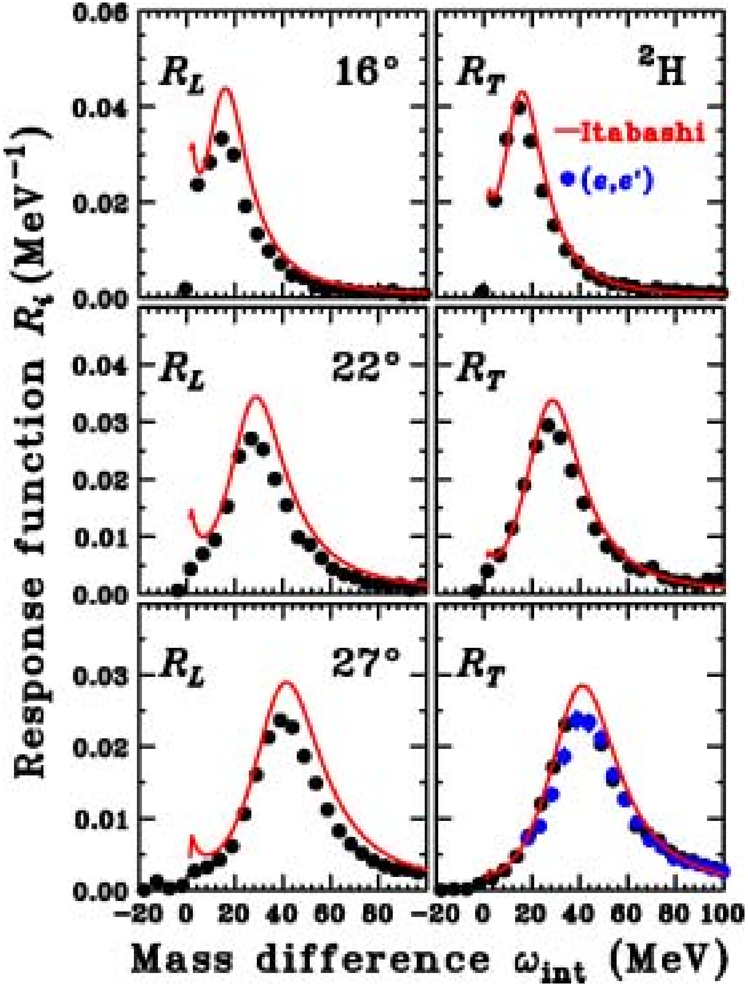
- Polarized Cross Sections and Experimental Spin-Responses:R_i

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

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

Response Functions for ^{2}H

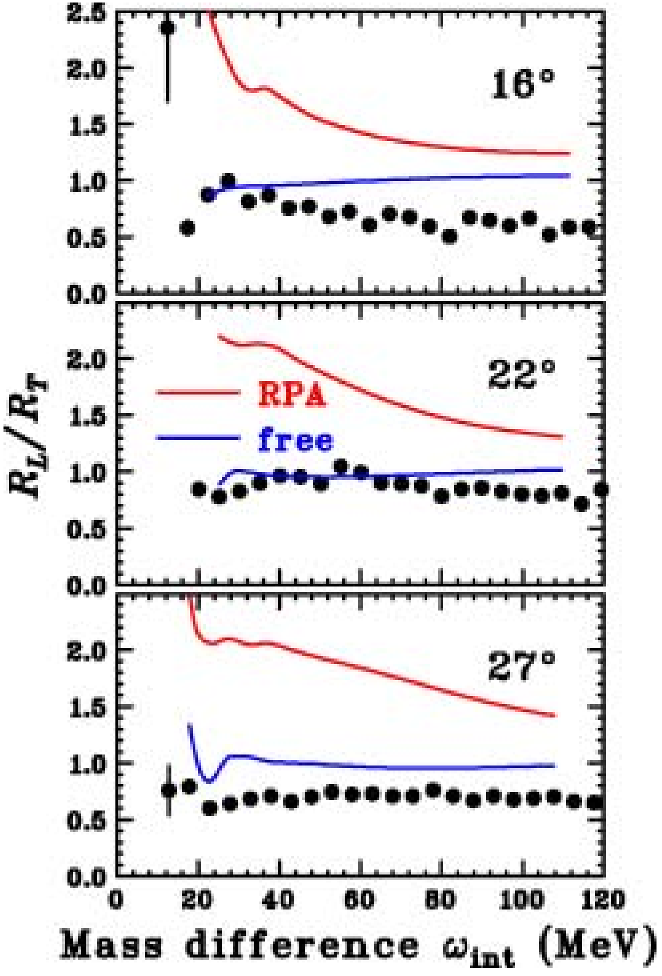
- **Simplest nuclear system**
  - Benchmark reaction
  - Check the formalism to deduce response functions
- **Data**
  - ● : (p,n) data at RCNP
  - ● : (e,e’) data at MIT-Bates
  - — : Itabashi et al.
- **Comparison with (e,e’)**
  - Good agreement with (e,e’)
  - Formalism is appropriate
  - Exp. Data (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

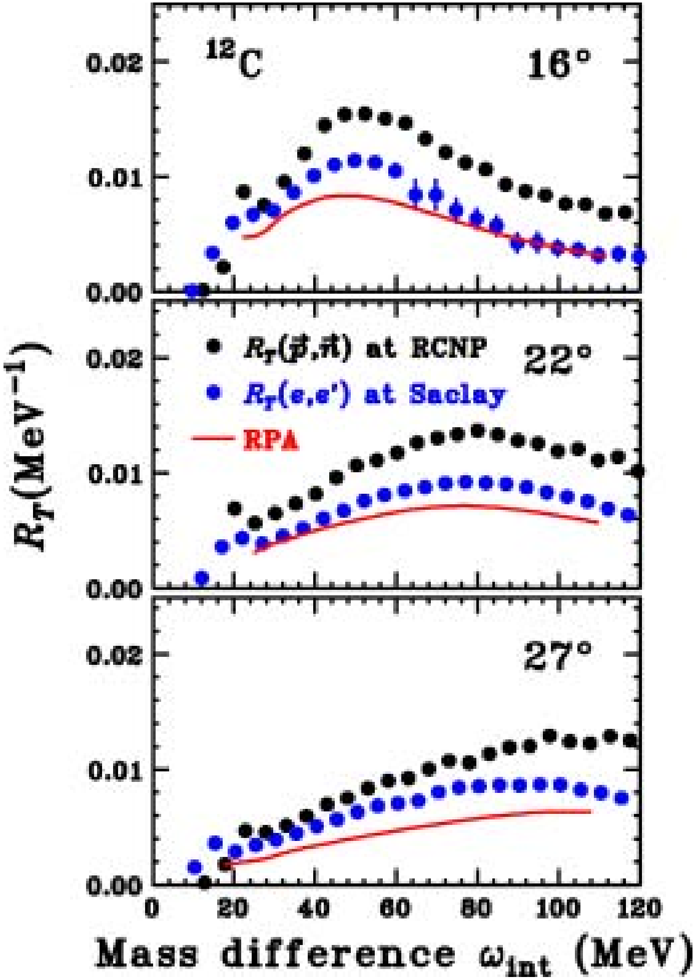
- **Response Ratio**
  - Less than 1 at all momentum transfers
- **No-evidence of enhancement of R_L relative to R_T**
  - Consistent with the results of (p,p’) and (p,n) at LAMPF
- **No-enhancement of R_L ?**
  - No-enhancement of R_L
  - No-quenching of R_T
  - Both



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

Comparison to (e,e’) Results

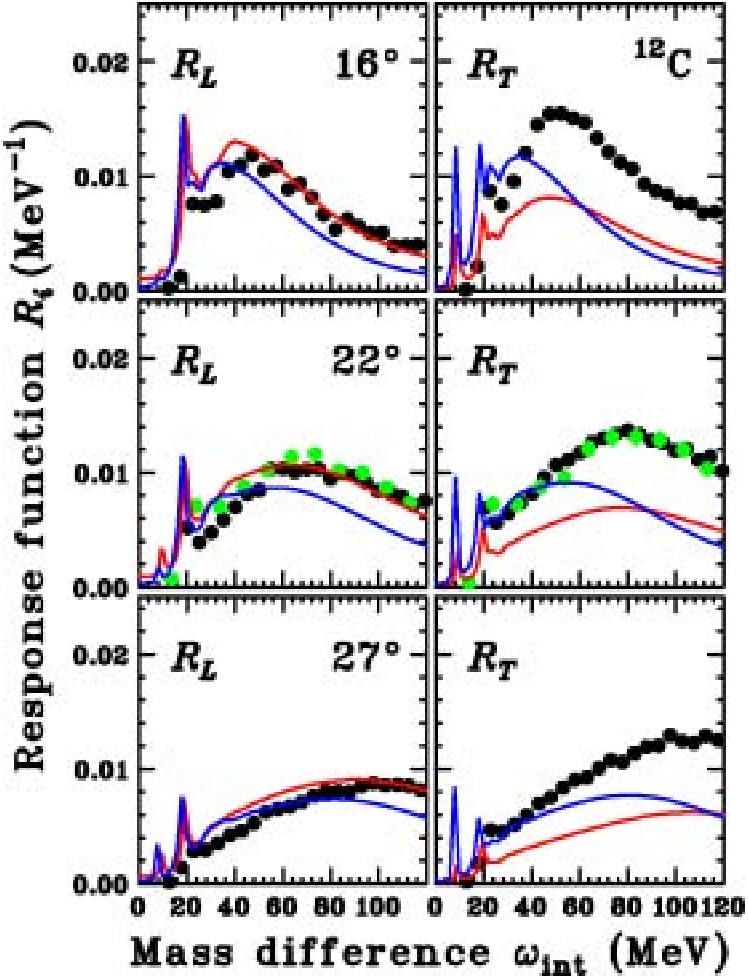
- **Comparison to (e,e’)**
  - R_T(p,n) = R_T(e,e’)
    if we ignore the MEC contributions
- **(e,e’) vs. RPA**
  - R_T(e,e’) > R_T(RPA)
  - 2p2h and MEC contributions
- **(p,n) vs. (e,e)**
  - R_T(p,n) > R_T(e,e’)
  - R_T(p,n) >> R_T(RPA)
  - Mask the pionic enhancement in R_L/R_T
    - ***Spin-direction 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 ?***



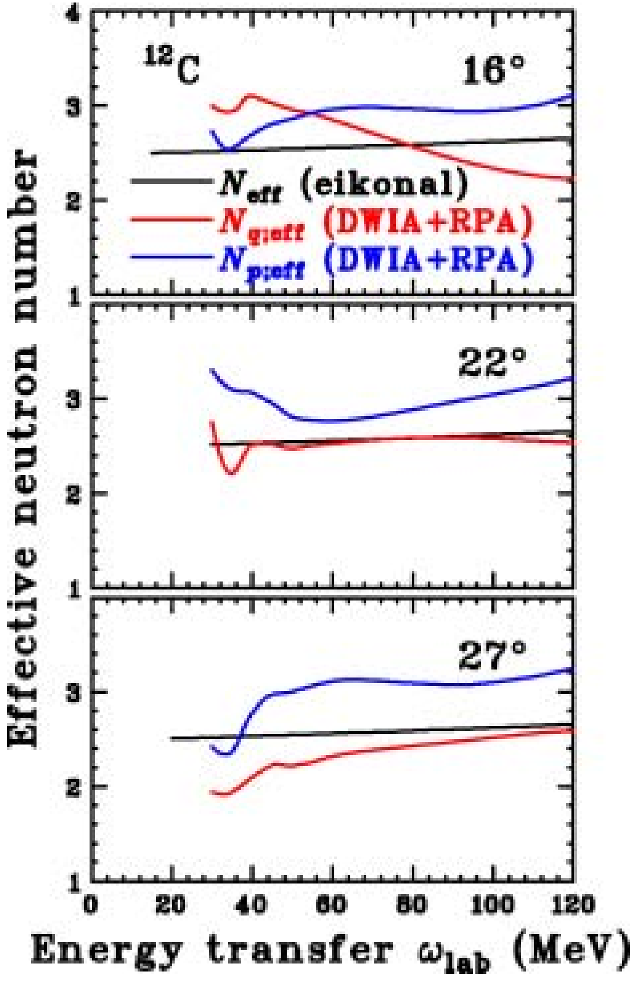
K. Kawahigashi et al. PRC 63, 044609 (2001)

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

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

- **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**



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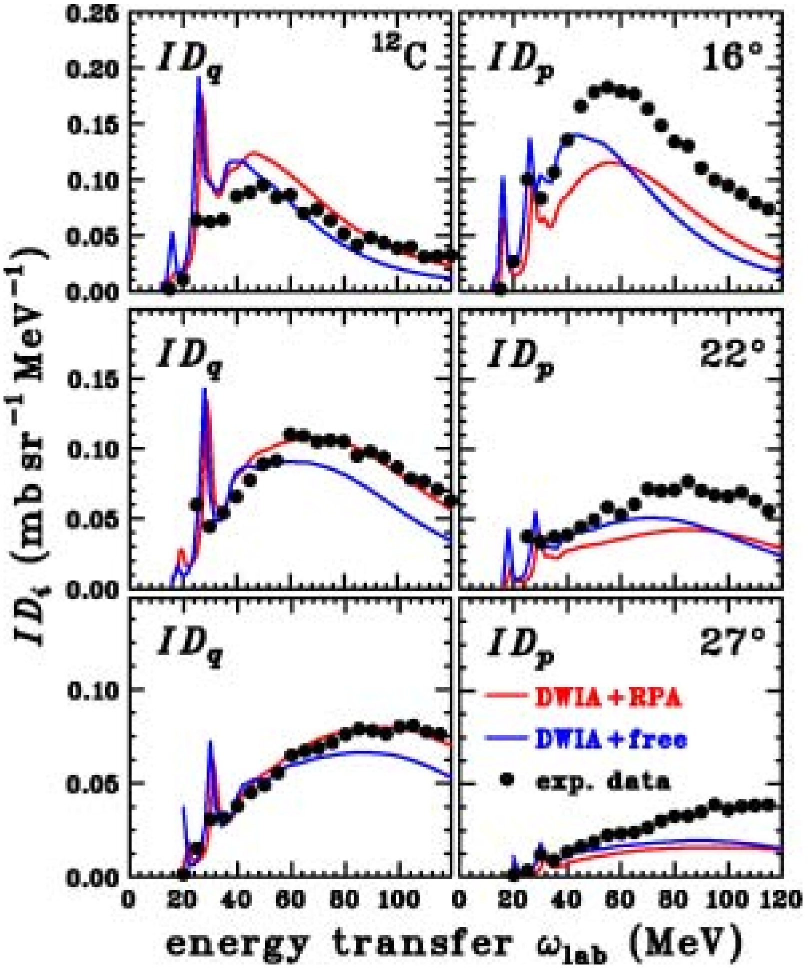
Comparison to DWIA+RPA

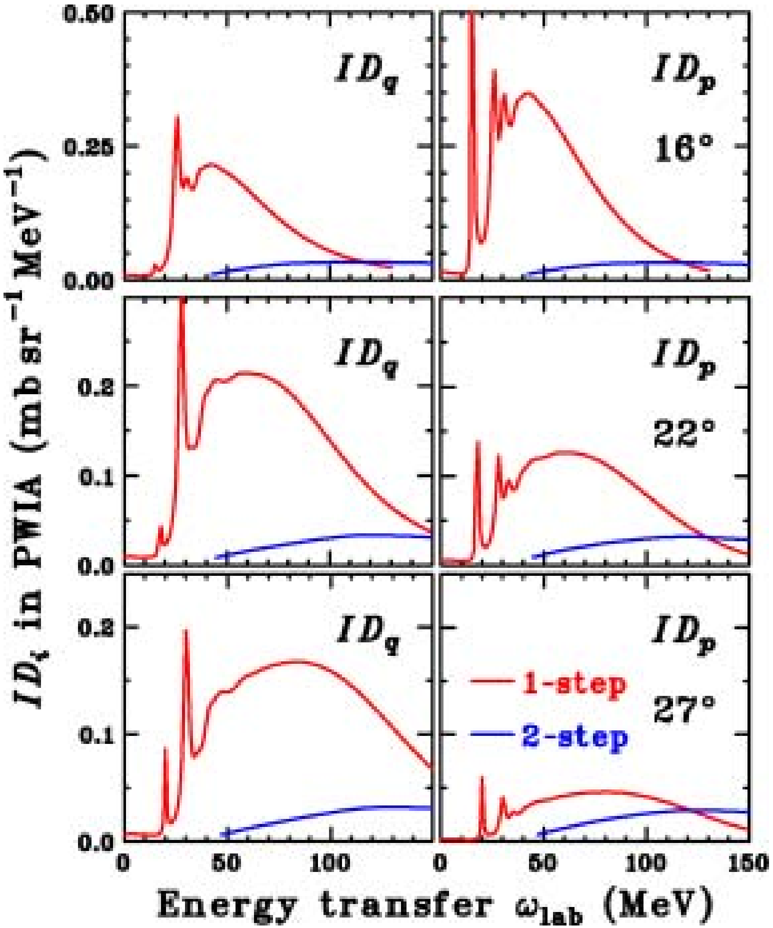
- **DWIA+RPA by Ichimura Group**
- **Spin-Longitudinal ID_q**
  - Fairly good agreement with data at whole region
  - Signature of pionic correlations
- **Spin-Transverse ID_p**
  - Discrepancy becomes small compared with R_i
  - Underestimate at whole region
  - Spin-direction dependence of N_{eff} 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***



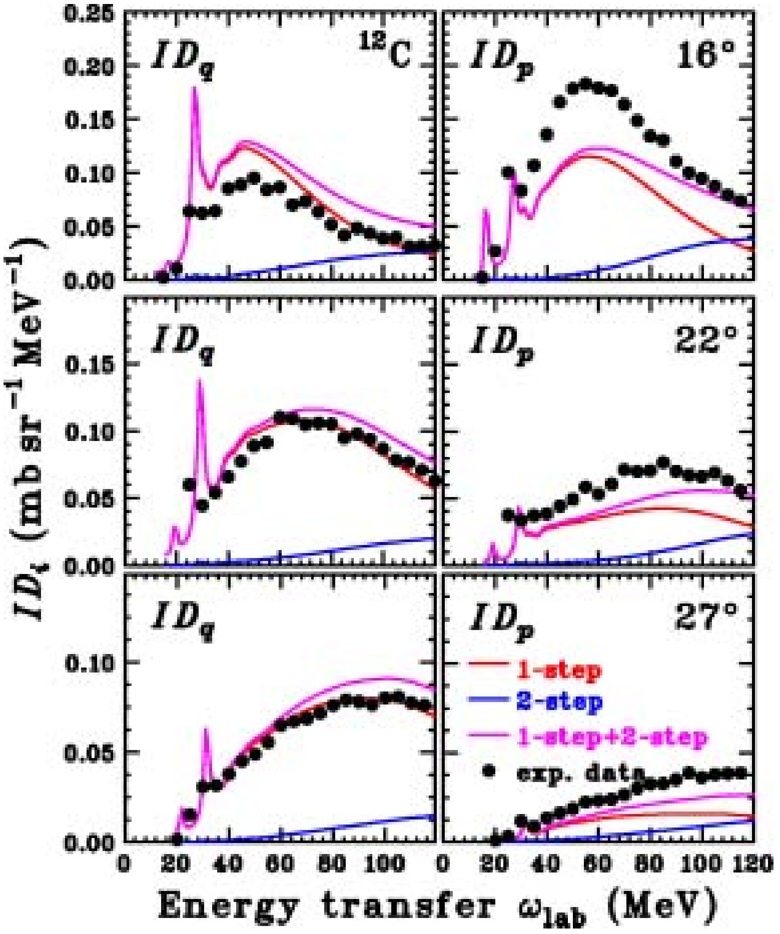
Y. Nakaoka, PRC 65, 064616 (2002)

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 ?



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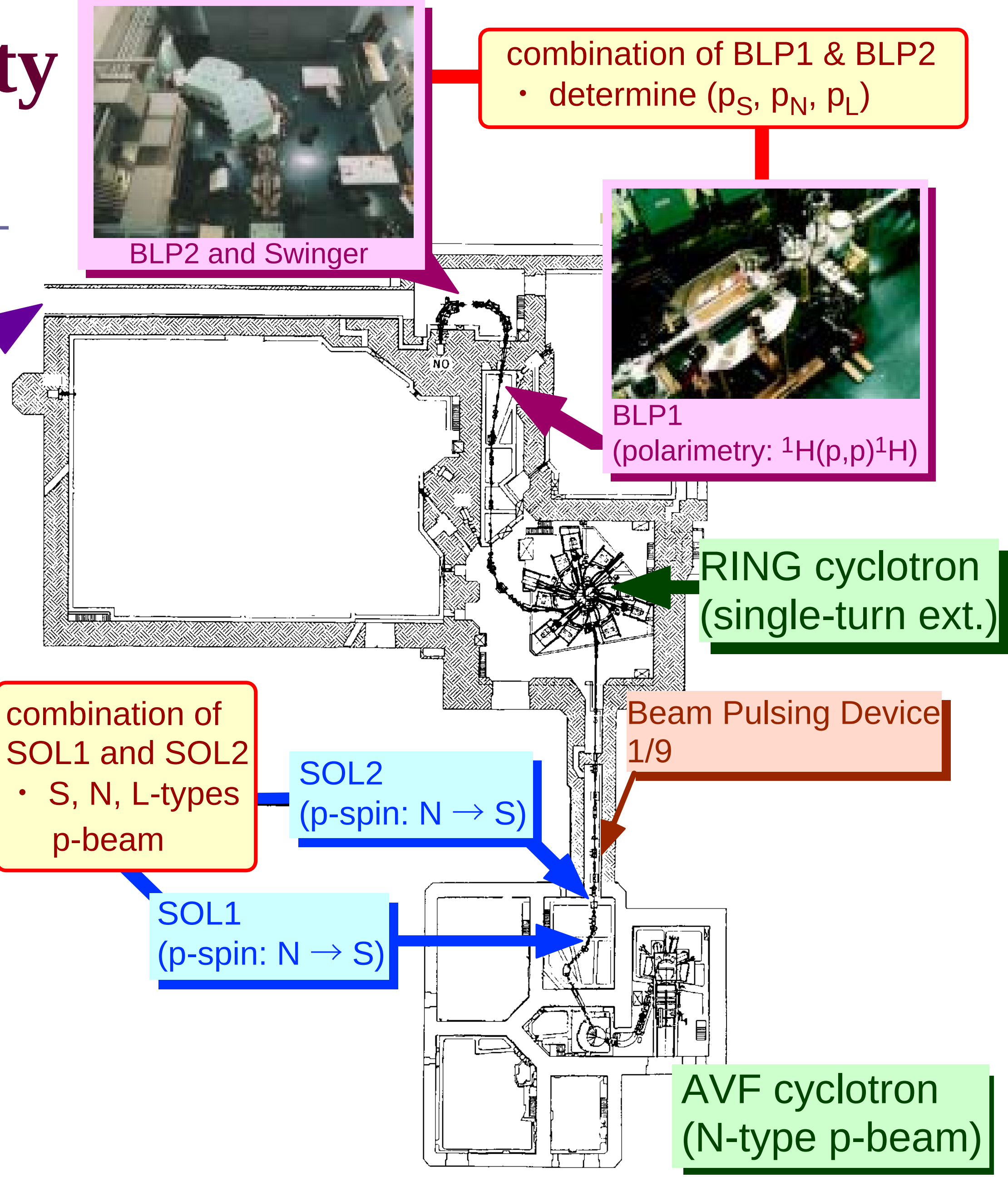
Summary

- **Complete sets of polarization observables for quasi (p,n) reactions**
  - ^{2}H (Free Response) and ^{12}C (Nuclear Response) at $q = 1.2 – 2.0\ \mathrm{fm}^{-1}$
- **Results for ^{2}H**
  - 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 ?)

NTOF Facility and NPOL2

n-Polarimeter NPOL II



BLP2 and Swinger

combination of BLP1 & BLP2
- determine (p_S, p_N, p_L)

BLP1
(polarimetry: $^1H(p,p)^1H$)

RING cyclotron
(single-turn ext.)

Beam Pulsing Device
1/9

combination of SOL1 and SOL2
- S, N, L-types p-beam

SOL2
(p-spin: N → S)

SOL1
(p-spin: N → S)

AVF cyclotron
(N-type p-beam)

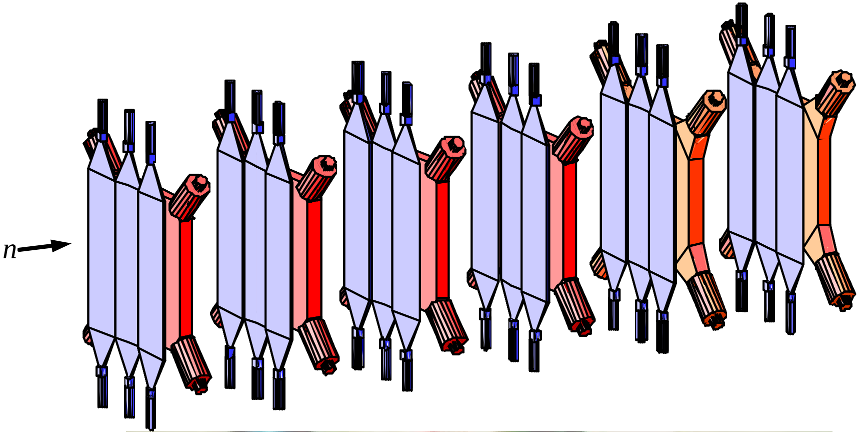
Neutron Polarimenter NPOL2

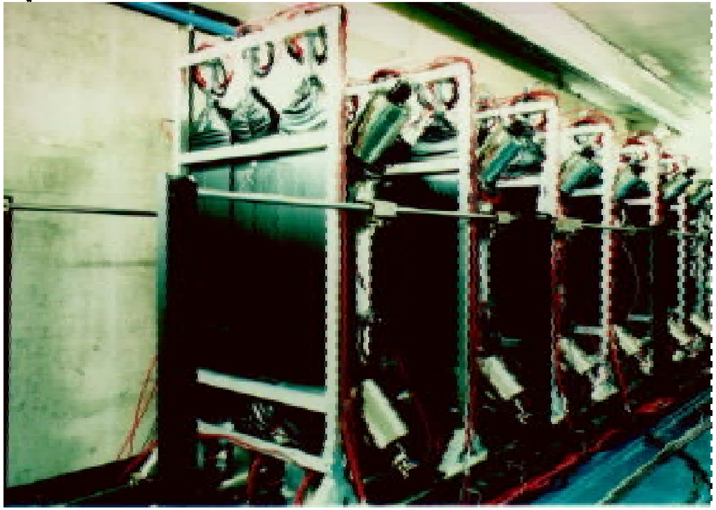
- **Position Sensitive 2D Neutron Detectors**
  - 6 layers
  - 1 m x 1 m x 0.1 m
  - 4 layers: Liquid sci. BC519
  - 2 layers: Plastic sci. BC408
- **High Performance of Neutron Polarimetry (FOM)**

IUCF	4.6 X 10^{-5} @ 160 MeV
LAMPF	2.3 X 10^{-4} @ 500 MeV
RCNP	4.9 X 10^{-4} @ 300 MeV

- **High Efficiency of Neutron Detection**

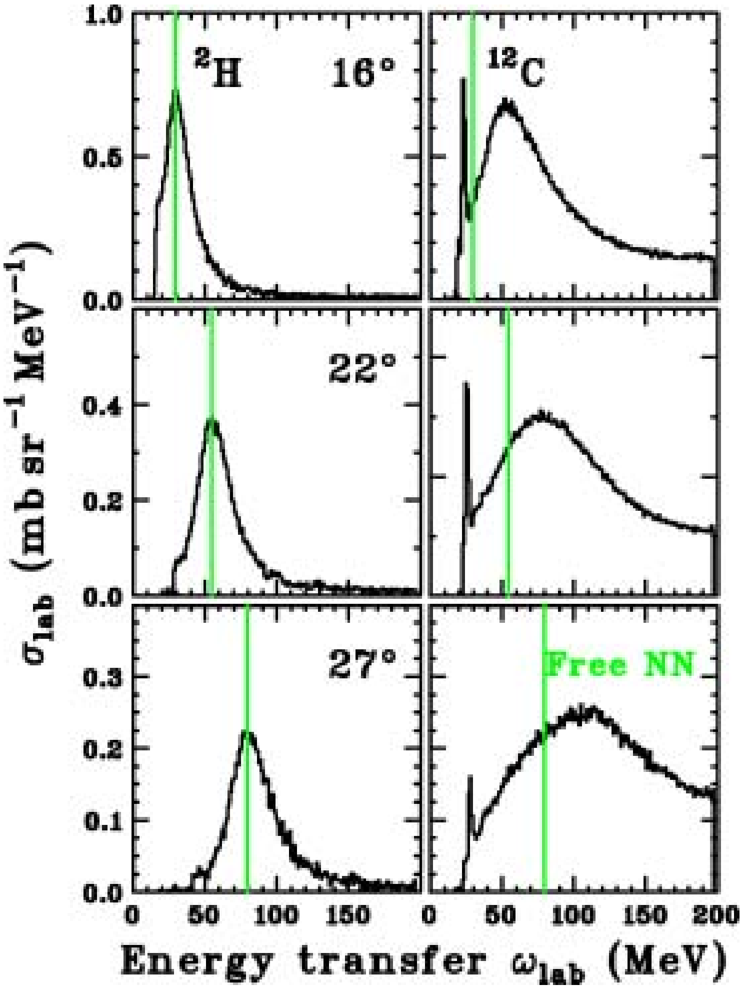
RCNP	0.15 @ 150- 400 MeV



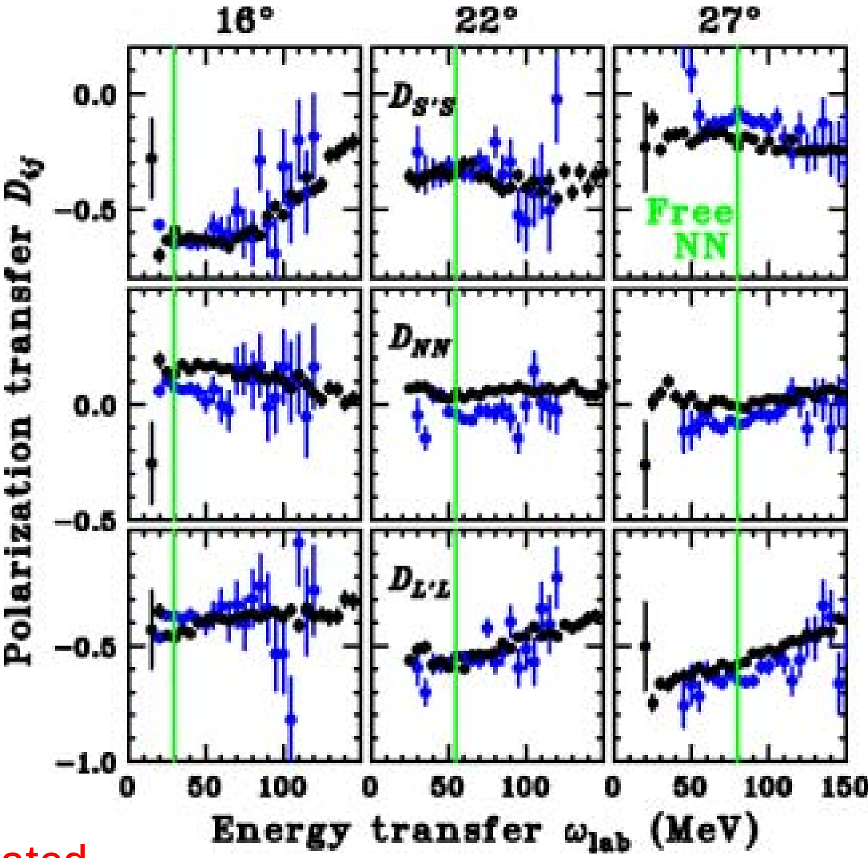


Cross sections of (p,n) QES

- ^{2}H Target
  - Almost no-shift
  - Free response
- ^{12}C Target
  - Large shift (more than 20 MeV)
- Large shift observed in nuclear targets
  - Signature of hardening of R_T?



Polarization Transfer Coefficients



- **Experimental data**
  - ● : 12C data
  - ● : 2H data
- **Statistical uncertainties**
  - ΔD_{ij} = 0.014/5-MeV
    (cf. 0.028/10-MeV at LAMPF)
  - Highly accurate responses can be extracted
- **Target dependence**
  - ^{2}H data = ^{12}C data
  - Nuclear correlation effects are not observed clearly in D_{ij} data
- **Search for pionic correlations**
  - Cross sections should be separated into spin-longitudinal and spin-transverse modes

DWIA+RPA and 2-Step Contribution

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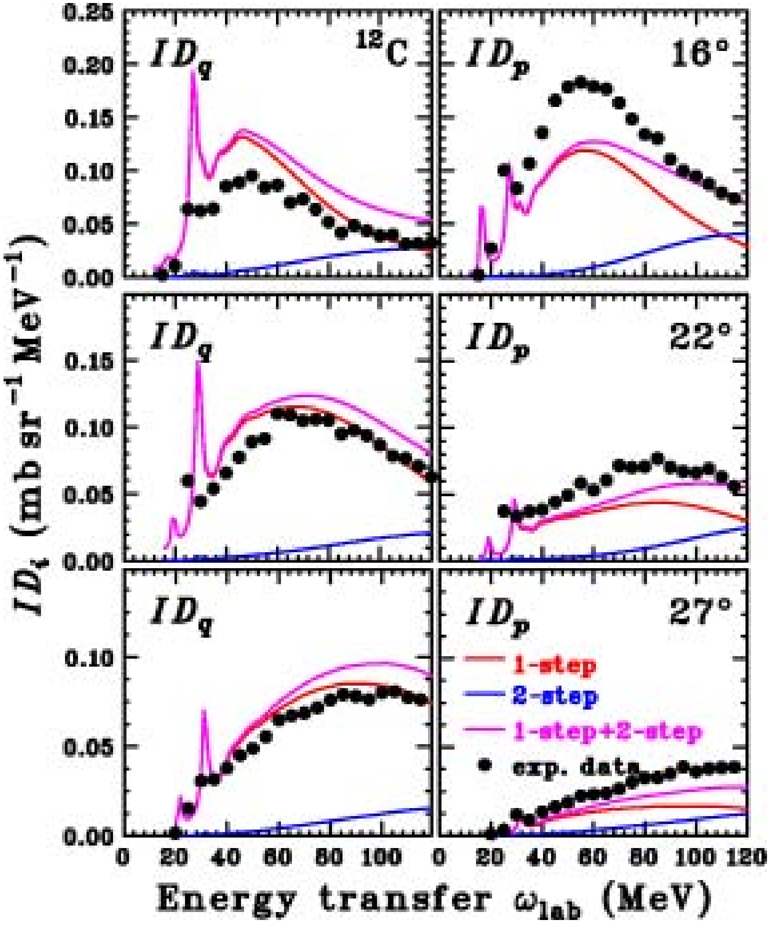

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