

*Isovector effective NN interaction  
in  
 $^{28}\text{Si}(p,n)^{28}\text{P}(6^-)$  at 198 MeV*

**Tomotsugu WAKASA**

**for the RCNP-E236 collaboration**

*Department of Physics, Kyushu University*

# Motivation

## - Medium modification of NN interaction -

### • Nuclear medium effects on NN interaction in nuclei

#### – Conventional medium effects

- Nuclear binding / Pauli blocking
- Relativistic mean field effects

#### – Non-conventional medium effects

- Medium modifications of
  - Meson / Nucleon masses
  - Coupling constant

$\rho$ -meson mass scaling

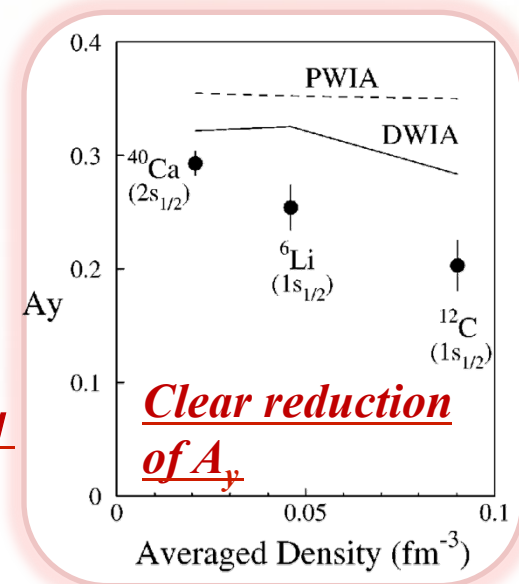
### • Experimental efforts to investigate these effects

#### – Exclusive (p,2p) reaction from s-shell

- Direct comparison of NN in free space with NN in nuclear medium
- Distortion effects of recoil nucleon are large ( $T_p < 100$  MeV)
  - Difficult to obtain absolute values of effective NN interaction

#### – Stretched states via (p,p') and (p,n)

- Reliable treatment for distortions ( $T_p = T_n$ )
- Transition form factor is known from (e,e') scattering data



Enable us to assess the absolute size of NN interaction in nuclei



# How to measure absolute size of medium effects

- *Factorize impulse approximation (FIA)*

$$\sigma_{\text{FIA}}(q, \omega) = N_D \cdot \sigma_{\text{NN}}(q, \omega) \cdot R(q, \omega)$$

$$D_{ij} = (\text{Distortion}) \otimes (\text{NN interaction}) \otimes (\text{Response})$$

- *Polarized cross sections and KMT NN amplitudes*

- NN scattering amplitude M in KMT notation

$$M = A + B\sigma_{0n}\sigma_{1n} + C(\sigma_{0n} + \sigma_{1n}) + E\sigma_{0q}\sigma_{1q} + F\sigma_{0p}\sigma_{1p}$$

- Experimental I and  $D_{ij} \Rightarrow ID_0, ID_n, ID_q, ID_p$

$$ID_q = \frac{I}{4} [1 - D_{nn} + D_{qq} - D_{pp}] = N_D \cdot |E|^2 \cdot R_q$$

$$ID_p = \frac{I}{4} [1 - D_{nn} - D_{qq} + D_{pp}] = N_D \cdot |F|^2 \cdot R_p$$

If R is known

→ NN amplitudes (E, F, etc) can be studied separately

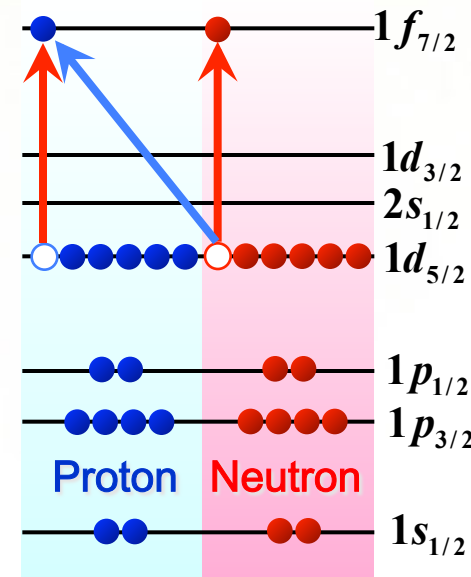
# Stretched state

- R is known from (e,e') scattering-

- *Stretched states (ex.  $^{28}\text{Si}$ )*
  - $^{28}\text{Si}(p,p')^{28}\text{Si}$   $1d_{5/2}$  p/n-hole and  $1f_{7/2}$  p/n-particle
  - $^{28}\text{Si}(p,n)^{28}\text{P}$   $1d_{5/2}$  n-hole and  $1f_{7/2}$  p-particle

- *Spin-transverse form factor (response) :  $R_p$*

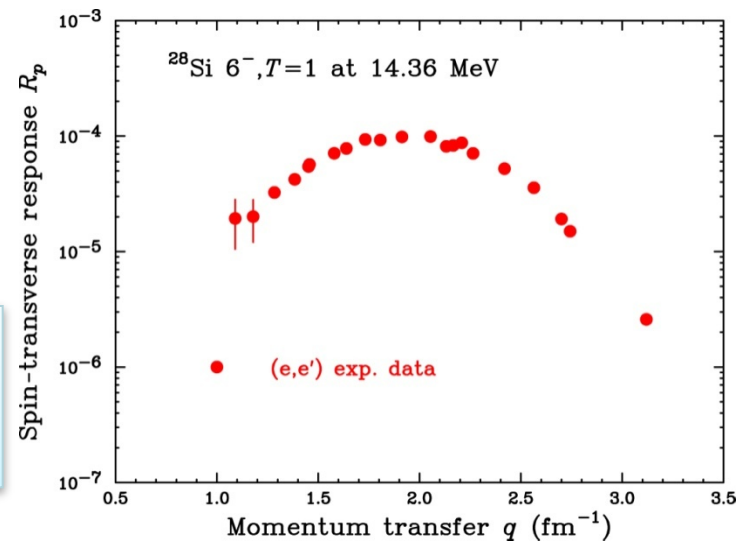
$R_p$  is given by the (e,e') data  
 → Less ambiguity in theoretical calculations  
 → **Reliable information on effective NN interaction**



- *Spin-longitudinal :  $R_q$* 
  - Nuclear correlation effects are small for stretched state transitions

- Transition probability=nuclear surface

$$\frac{R_q}{R_p} = \frac{2J}{J+1} = 1.71 \quad \rightarrow \quad \text{Also less ambiguity in } R_q$$



# Results of $^{28}\text{Si}(p,p')$ at IUCF

## - Motivation of this experiment -

*E. J. Stephenson et al., PRL 78, 1636 (1997)*

- *Two controversial explanation*

- **Medium modifications in nuclei**

- Reduction of  $\rho$ -meson mass  
 $\Rightarrow 20\%$  (*Density independent calc.*)

- **Isospin mixing**

- Mixing angle between  $T=0$  and  $T=1$   
 $\Rightarrow 13$  degrees

Later "density-dependent" DWIA

$\rightarrow$  The effect is too small to explain data  
 (Surface peak of transition density)

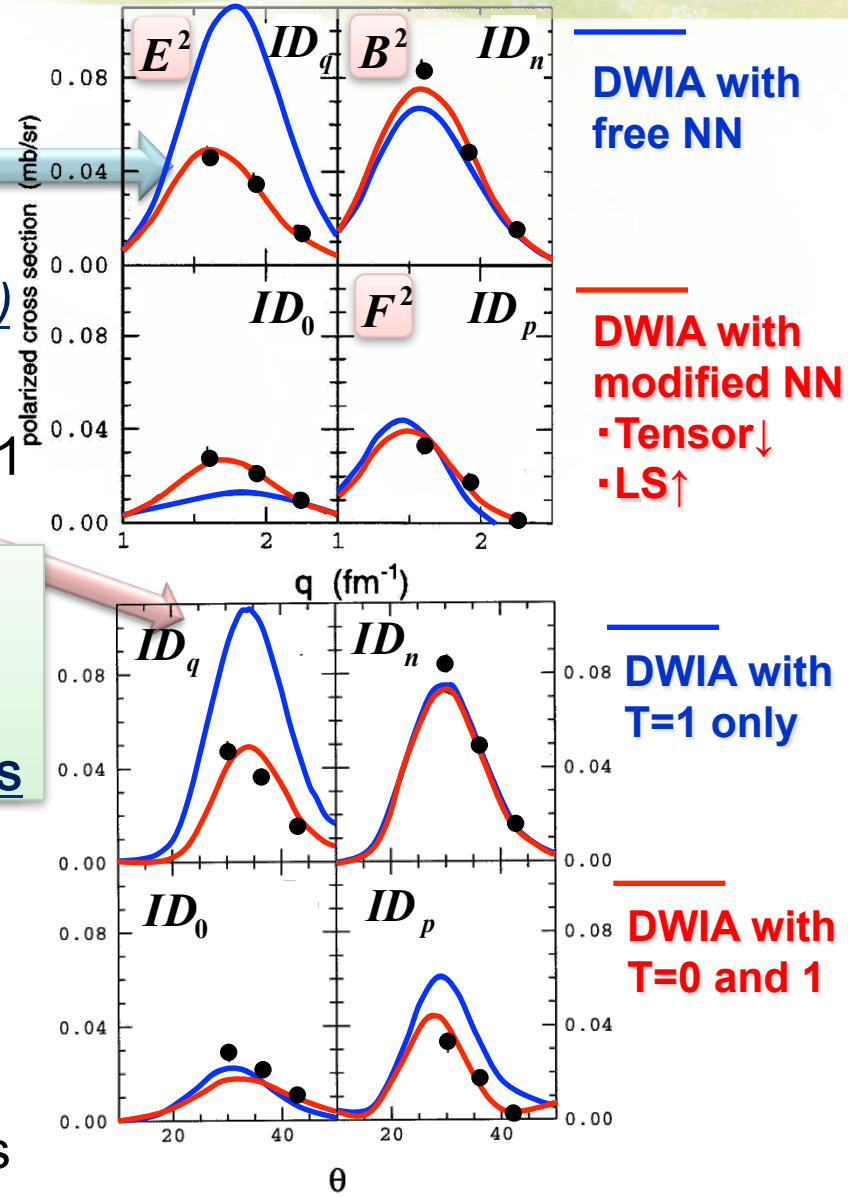
$\Rightarrow$  **Important to study isospin mixing effects**

- *Advantage of the  $(p,n)$  reaction*

- **Pure isovector probe**

- *Excite only  $T=1$  states*
    - *Exclude isospin mixing effects*

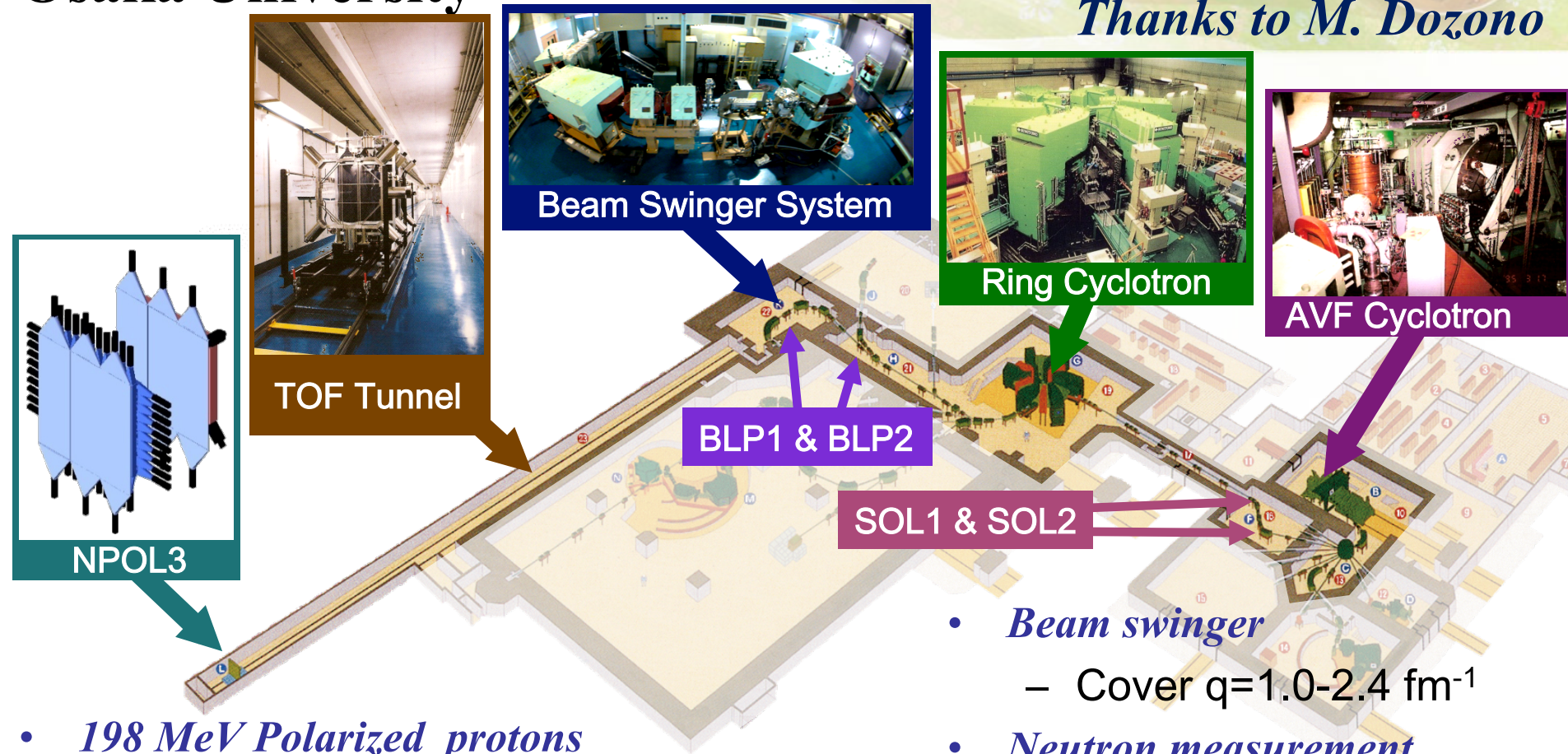
- Ideal probe to observe medium effects



# Research Center for Nuclear Physics

Osaka University

*Thanks to M. Dozono*



- *198 MeV Polarized protons*
  - Same as (p,p') at IUCF (reliable DWIA)
- *Beam polarization*
  - Control with 2-sets of solenoids
  - Measure with 2-sets of BLP by p-p

- *Beam swinger*
  - Cover  $q=1.0-2.4 \text{ fm}^{-1}$
- *Neutron measurement*
  - NPOL3 with 100 m TOF
  - Complete measurement of neutron polarization with NSR

# Neutron detector/polarimeter NPOL3

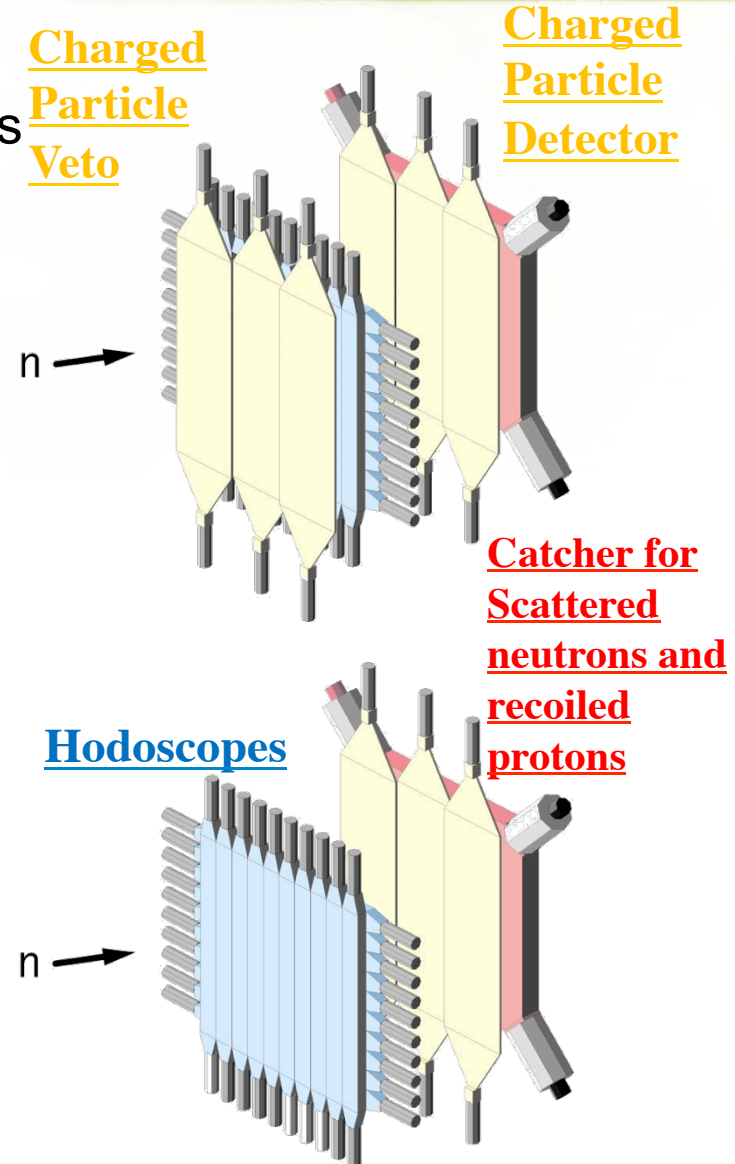
Thanks to E. Ihara

- *Neutron detector*

- 20 sets of 100cm×10cm×5cm hodoscopes
  - Fast response PMT(rise time < 2ns)
- Large solid angle : 0.1 msr at 100m
  - Efficiency :  $\epsilon \sim 0.03$
- Energy resolution
  - 300 keV for 200 MeV neutrons

- *Neutron polarimeter*

- Polarimetry
  - n+p scattering in hodoscopes
- Scattered neutrons/recoiled protons are detected with catcher
- Performance
  - $A_{y;eff} = 0.13$  for 200 MeV neutrons
  - $FOM = 1.0 \times 10^{-4}$



# Energy spectrum and peak fitting

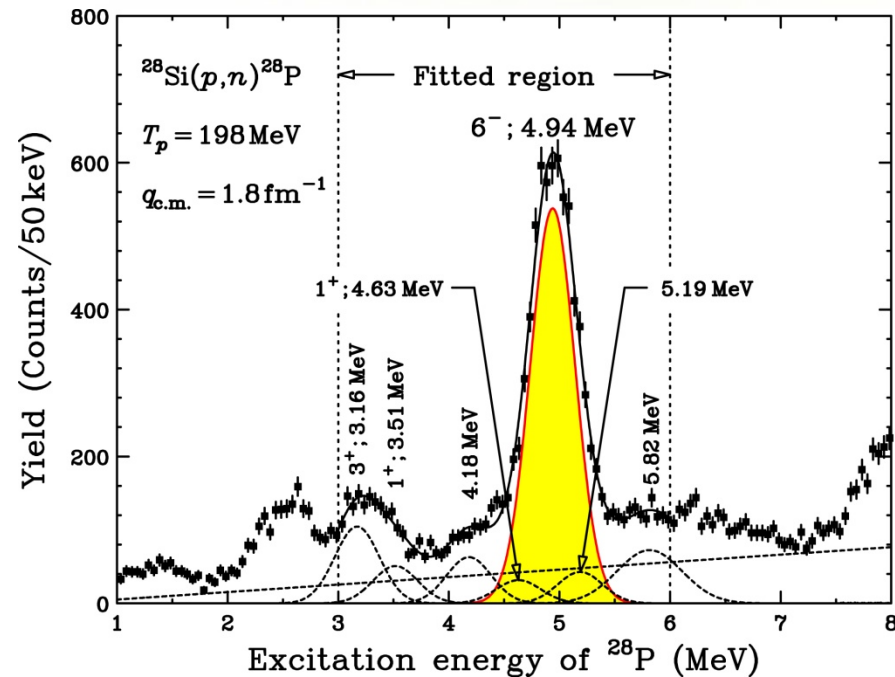


- *Energy spectrum*

- Prominent  $6^-$  peak at 4.94 MeV
- 480 keV FWHM
  - With thick  $123 \text{ mg/cm}^2$  target

- *Peak fitting*

- With known 7 states in 3-6 MeV
  - 3.16, 3.51, 4.18 4.63
  - **4.94( $6^-$ )**, 5.19, 5.82 MeV
- Good reproduction of exp. data
  - Reliable  $6^-$  yield for  $q=1.0\text{-}2.4 \text{ fm}^{-1}$

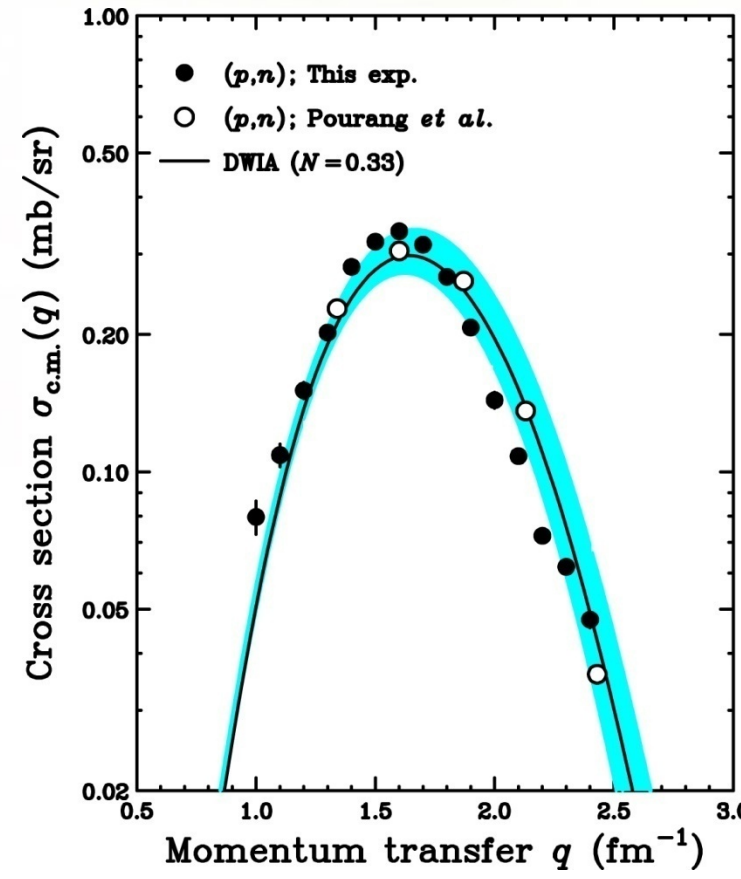




# Cross Section and DWIA Calculation

- *Smooth q-dependence specified by  $L=6$* 
  - Clear separation of  $6^-$  from neighboring states with  $\Delta E=500\text{keV}$
  - Consistent with previous work
- *DWIA calculations*
  - Slightly sensitive to OMP (shown by band)
  - DWIA reproduces our data
    - q-dependence
    - Absolute values
      - OMP (Distortions)
      - S-Factor (Form factor)

} *Reliable*



Comparison with DWIA enables us to obtain the information on absolute values of NN interaction

# Results

## - Comparison with $(p,p')$ and DWIA-

- **Comparison with  $(p,p')$**

- $(p,p')$  data multiplied by 2 (Isospin C.G.)
- $(p,n)$  data are consistent with  $(p,p')$

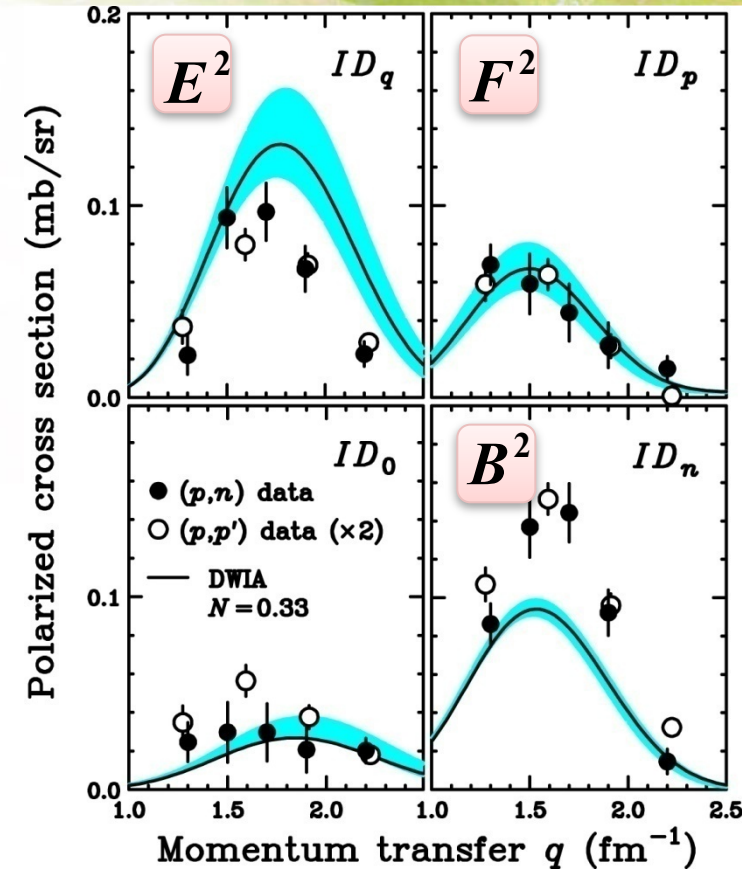
Experimentally exclude the possibility of isospin-mixing effects for the discrepancy in  $(p,p')$  case

- **Comparison with DWIA**

- $ID_q$ : Over-prediction
- $ID_n$ : Under-prediction
- $ID_q$  and  $ID_0$ : Reasonable reproduction

Modification of NN amplitude in KMT

- Spin-longitudinal E : Reduction
- Normal spin-transverse B : Enhancement
- Other amplitudes A,C, and F : No modification





# Energy half-off-shell effects

- *Conventional medium effects*
  - Nuclear binding, Pauli blocking etc.

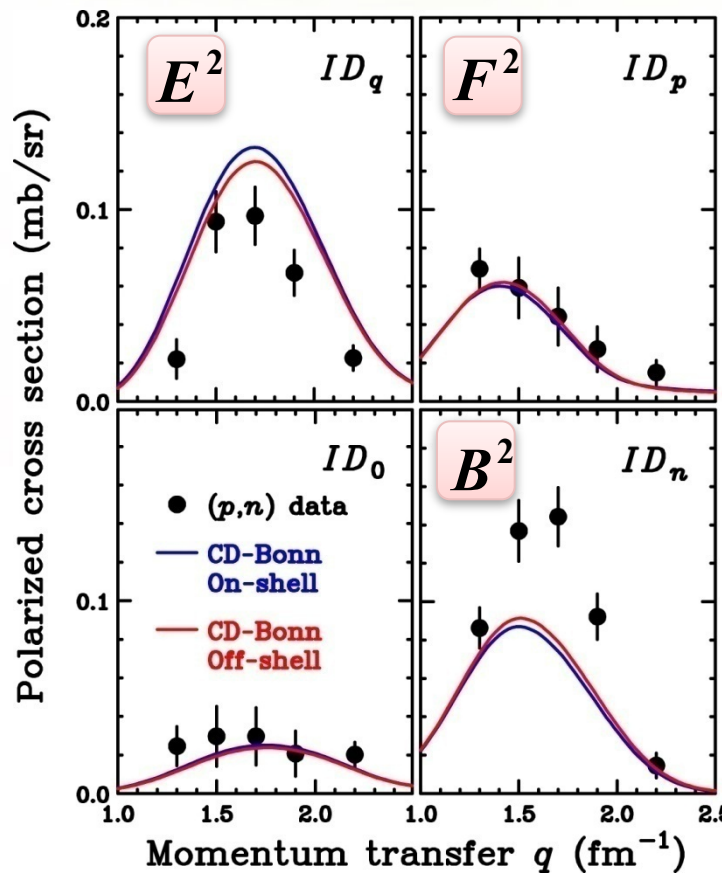
Sammarruca et al. show that these effects are too small to explain (p,p') data

- *Non-conventional medium effects*
  - $\rho$ -meson mass modification

◆ *Density independent DWIA*  
→ Qualitatively: ○, Quantitatively: ×  
◆ *Density dependent DWIA*  
→ Effective is too small (Surface peak)

- *Energy half-off-shell effects*
  - Reaction Q-value = -20.6 MeV  $\gg$  0
  - Energy on-shell / half-off-shell t-matrixes are deduced from CD-Bonn

Partly explain the discrepancy in  $ID_q$  and  $ID_n$  → **Effect is too small**  
*More comprehensive and detailed theoretical analyses are required*



# Summary



- *High resolution measurement of  $^{28}\text{Si}(p,n)^{28}\text{P}(6^-)$  at 198 MeV*
  - 500 keV FWHM → Clear separation from neighboring states
  - Good statistics for investigation of effective NN interaction
- *Comparison with theoretical calculations and (p,p')*
  - Consistent with (p,p') data
    - Isospin-mixing is NOT responsible for discrepancy in (p,p')
  - Reliable calculations with responses normalized to (e,e')
    - $\text{ID}_q (\propto E)$  : Small quenching
    - $\text{ID}_n (\propto B)$  : Significant enhancement
  - Enhancement of B is also observed in QES data
- *Comparison with energy half-off-shell calculations*
  - Effects are too small to explain the data

# Thanks



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# DWIA calculations

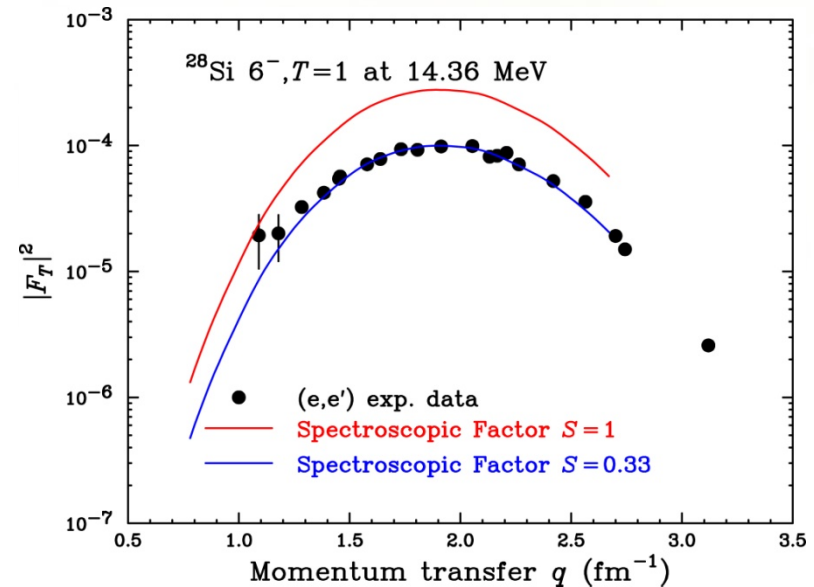
## - Normalization for form factor -

- *DWIA calculations*

- Code: dw81
- t-matrix: Franey and Love 210 MeV based on free NN t-matrix
- OMP: Several parameter sets
  - For elastic scattering on  $^{28}\text{Si}$
  - OMP dependence is considered as theoretical uncertainty

- *Transition form factor*

- $6^-$  configuration:
  - Pure '1f<sub>7/2</sub> proton particle' and '1d<sub>5/2</sub><sup>-1</sup> neutron hole'
- Spectroscopic factor (absolute value of form factor)
  - Normalized to experimental (e,e') data for analog state (S=0.33)



# Enhancement of $ID_n$

- Common feature at large  $q$ -



- *Two spin-transverse  $ID_i$*

$$ID_p \approx N_D \cdot F^2 \cdot R_p \quad ID_n \approx N_D \cdot B^2 \cdot R_n$$

Spin - transverse response is common ( $R_p = R_n$ )

$$\Rightarrow \frac{ID_n}{ID_p} = \frac{B^2}{F^2}$$

*“Insensitive to response/distortion”*

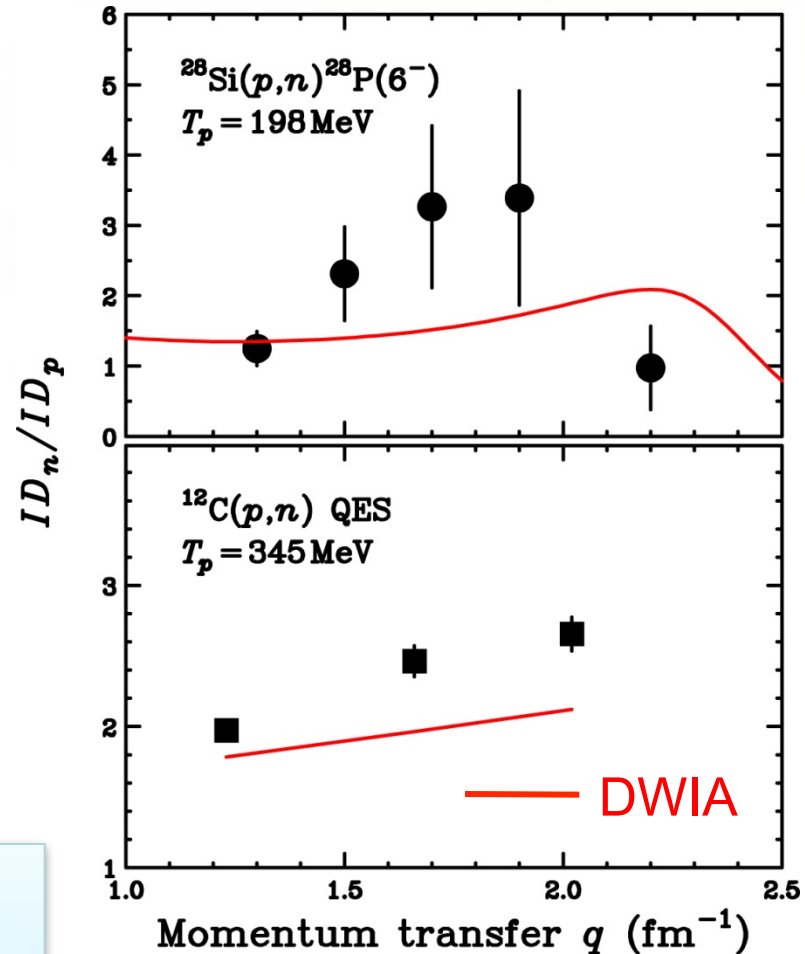
- *Momentum-transfer dependence*

- Enhancement of  $ID_n/ID_p$ 
  - Stretched state in  $^{28}\text{Si}(p,n)$
  - QE scattering in  $^{12}\text{C}(p,n)$

Enhancement of B at large  $q$  (1.5 - 2.0  $\text{fm}^{-1}$ )

◆ Common to (p,n) reaction

◆ Common to intermediate energies



*T. Wakasa et al.,  
Phys. Rev. C 69, 054609 (2004).*