# Study of the Spin Dependent $^{3}$He-Nucleus Interaction at 450MeV

J.Kamiya, K.Hatanaka, Y.Sakemi, T.Wakasa, H.P.Yoshida, E.Obayash, K.Hara, Y.Kitamura, Y.Shimizu, K.Fujita, N.Sakamoto

*RCNP, Osaka University*

Y.Shimbara, T.Adachi

*Department of Physics, Osaka University*

H.Sakaguchi,M.Yosoi, M.Uchida, Y.Yasuda

*Department of Physics, Kyoto University*

T.Kawabata

*RIKEN, BNL*

T.Noro

*Department of Physics, Kyusyu University*

## Contents

1. Scientific Motivation
2. Experiment
   - calibration of the FPP
   - $d\sigma/d\Omega, A_y$ measurement
3. Optical Model Analysis
4. Summary

# Spin dependent interaction between $^3$He-Nucleus Interaction

- How it is related to the spin dependent part of the n-n interaction?
- $^3$He-Nucleus elastic scattering
  - Determination of the optical potential parameters

    Important for other reactions ($^3$He,$t$) etc.
  - reaction mechanism is simple

    small break up effect

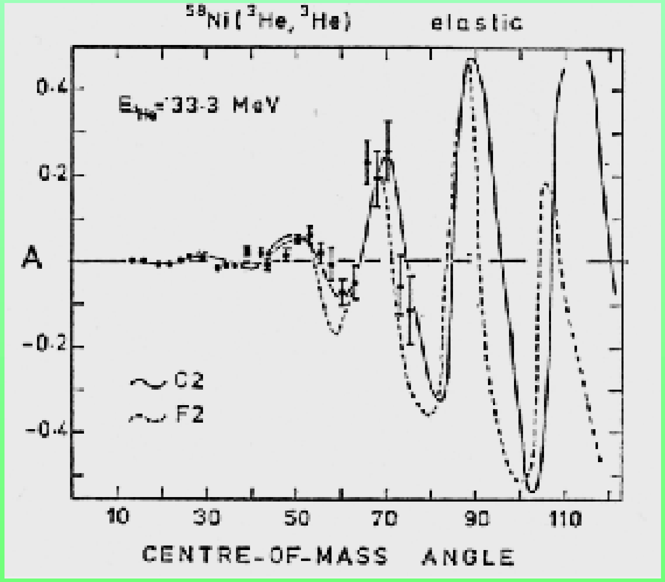
    d => n + p, $^6$Li => α + d

    Full CDCC is needed

$$\Psi^{CDCC}=\phi_0(r)\chi_0+\Sigma\Sigma\phi(i,r)\chi(i,R)$$

- Experimental data are limited to low energy (33MeV)

  $V_{S.O.}=4$ MeV, $a_{S.O.}=0.2-0.3$ fm

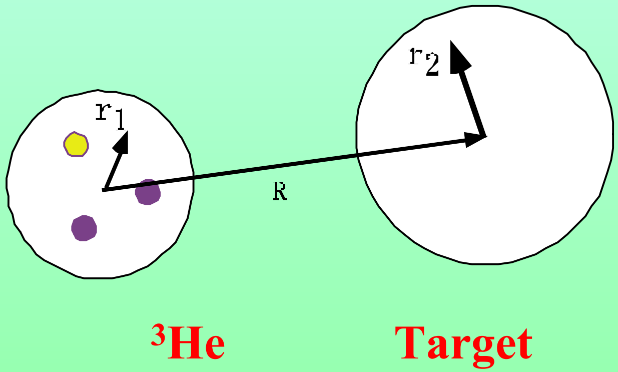



$^3$He+$^{58}$Ni $T_{^3He}$=33MeV

*S.Roman et al. NP A284(1977)365*

# Microscopic Optical Models

- Double folding model




Folding potential

$$V^N(\mathrm{r}) = \int \rho_{^3\mathrm{He}}(\mathrm{r}_1)\rho_\mathrm{T}(\mathrm{r}_2)v_{NN}(\mathrm{s})\mathrm{dr}_1\mathrm{dr}_2$$

Effective Nucleon-Nucleon interaction (FR-DDM3Y)

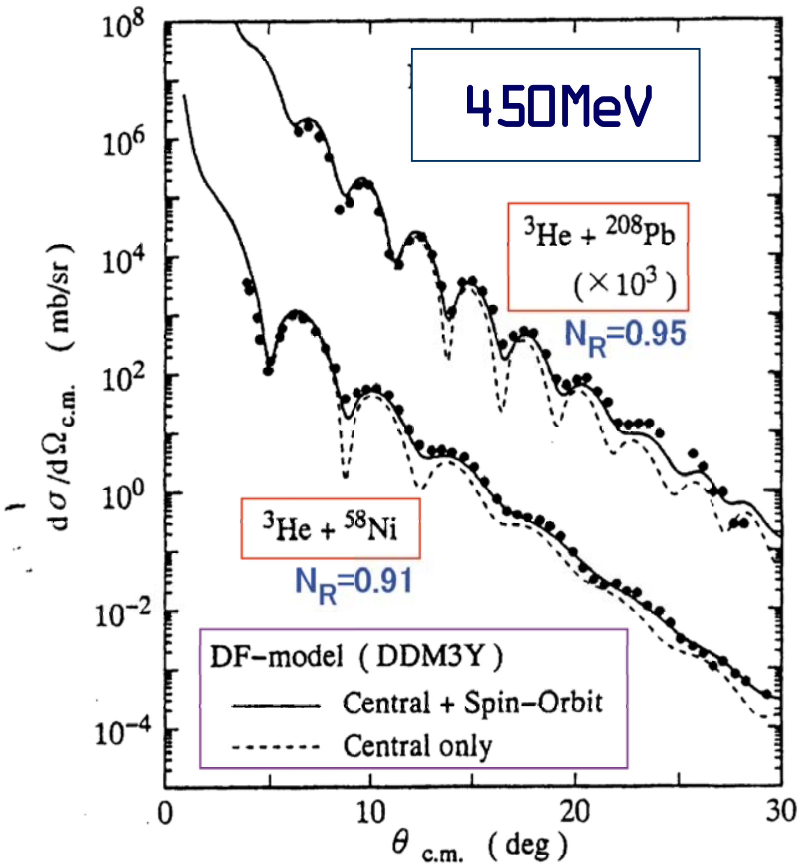
$$v_\mathrm{NN} = v_\mathrm{C}(\mathrm{s}) + v_\mathrm{s.o.}(\mathrm{s})L \cdot \sigma$$

Optical Potential

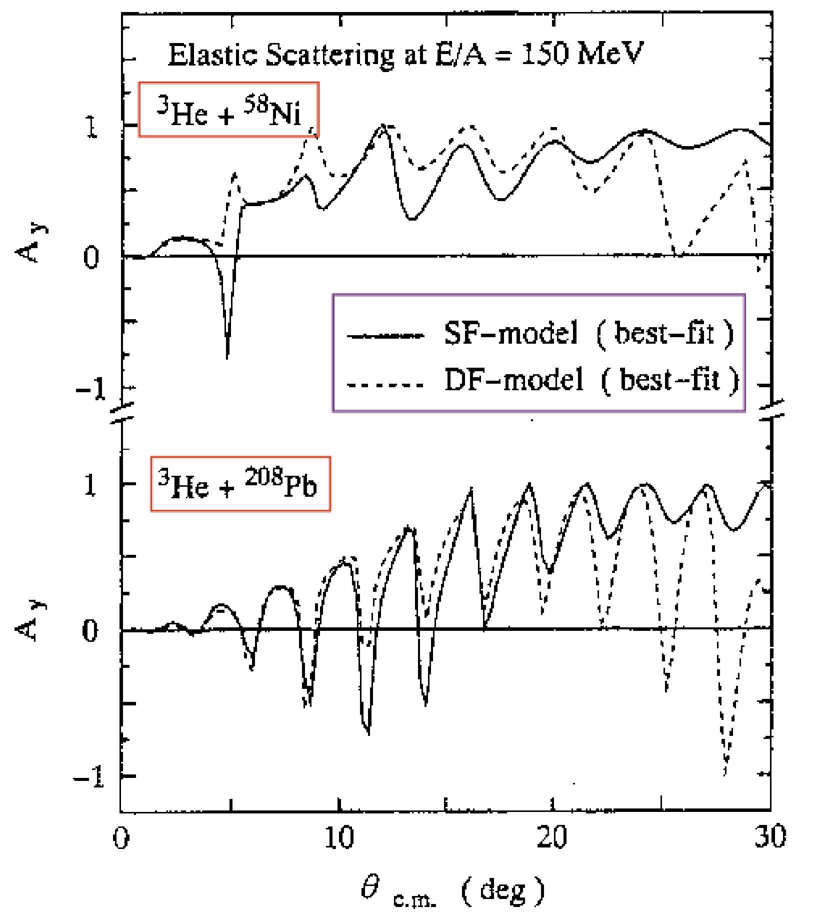
$$V_{NN} = \underline{N_R} V^N{}_C(\mathrm{s}) + \underline{N_{LS}} V_{s.o.}(\mathrm{s})L \cdot \sigma + V^\mathrm{c}(\mathrm{r}) + iW_\mathrm{ws}(\mathrm{r})$$

**renormalization factor**

# Folding Model Calculations




*Y.Sakuragi et al. N.I.M.A402(1998)347*




The Spin-Orbit interaction has a large effect on $d\sigma/d\Omega$ and $A_y$

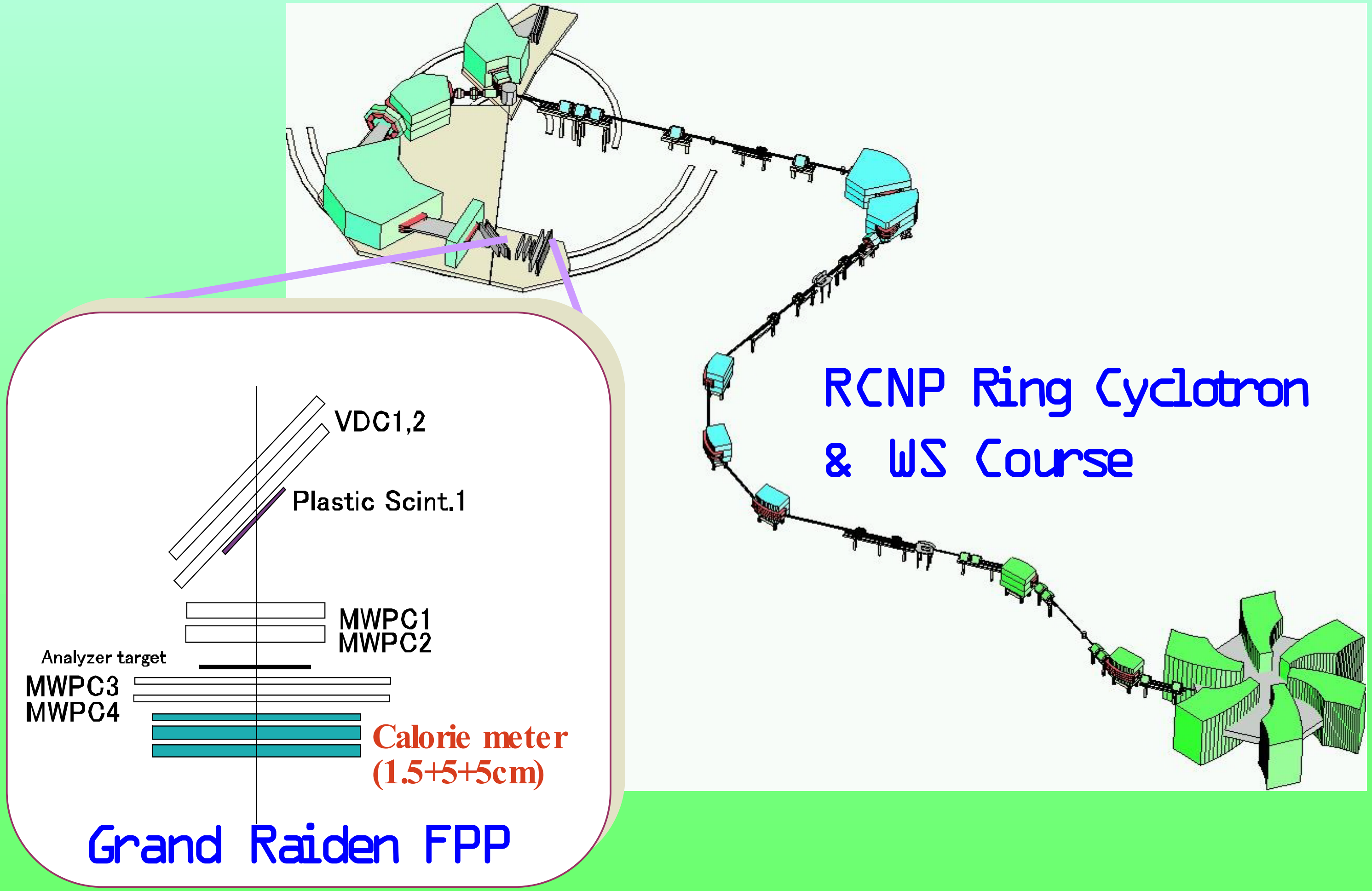
# Experimental Parameters

- Beam : $^{3}$He
- Beam energy : $T_{^{3}He}$=450MeV
- Reactions : $^{3}$He+$^{12}$C, $^{58}$Ni, $^{90}$Zr elastic scattering
- Beam intensity : 10 – 40 enA
- Measured

  Observable : dσ/dΩ, $p$ (= $A_y$ for ½+0 ½+0)
- Angular range : 5-30deg for dσ/dΩ,

  5-20deg for polarization

# Experimental Setup



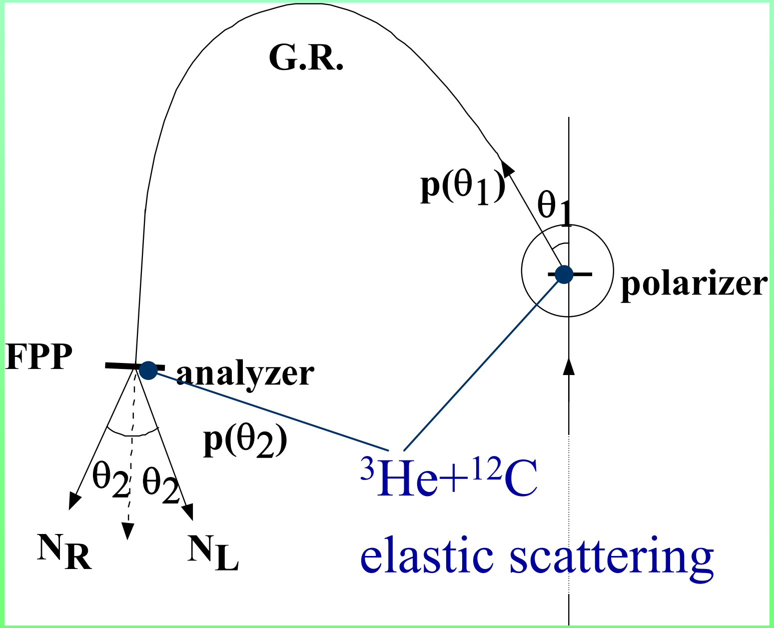
# Calibration of the FPP

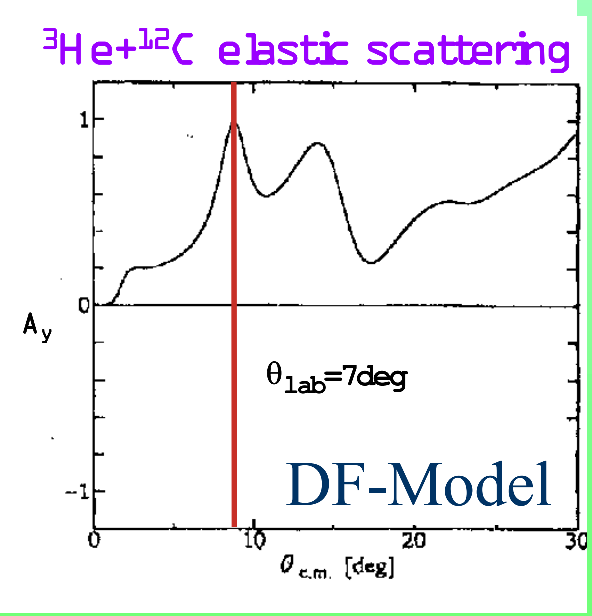
## Absolute Value of the Polarization

- Double scattering method

**When $\theta_1=\theta_2$ for spin ½+0 → ½+0 reaction**

**$p=A_y$ , L-R Asymmetry=$(N_L-N_R)/(N_L+N_R)=p^2$**

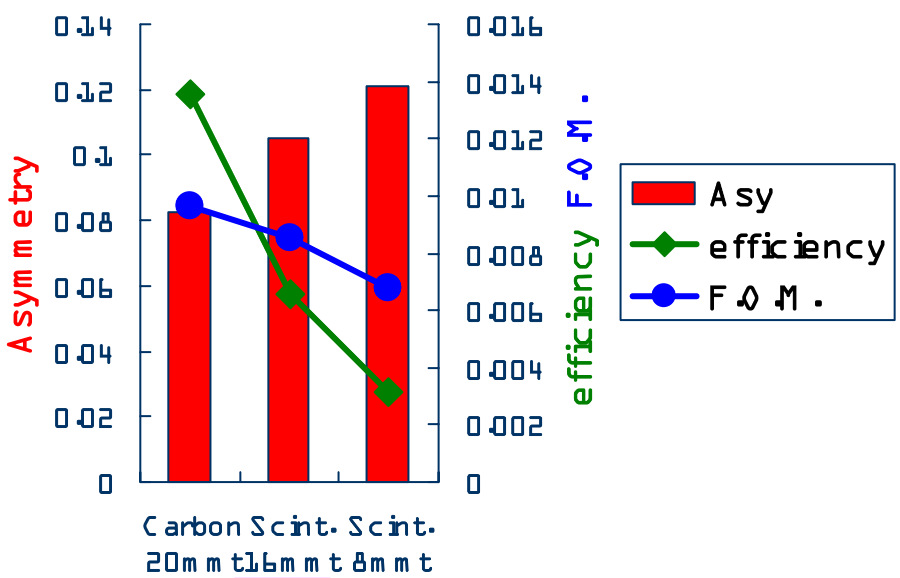


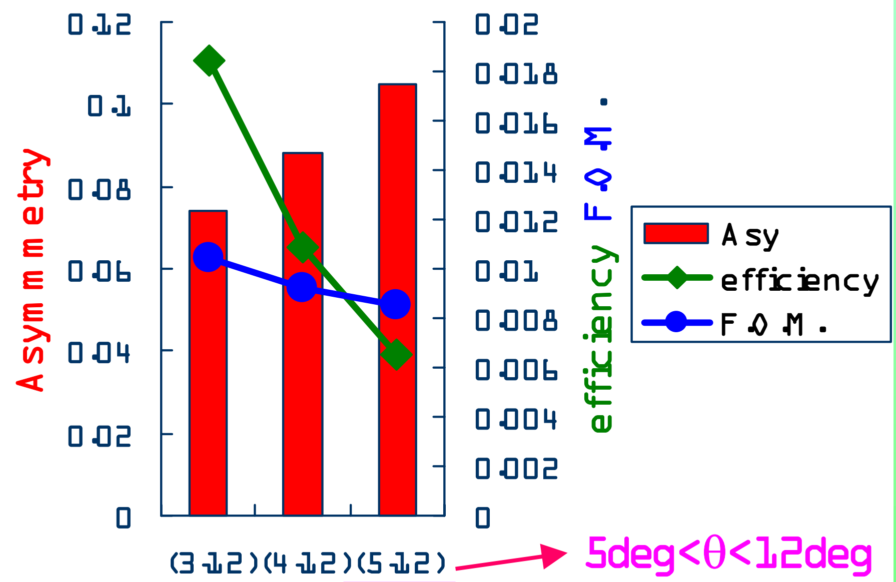

$P = 0.547 \pm 0.018$

# Effective Analyzing Power

Target dependence
(5deg<θ<12deg)




Angular Integral Range
Dependence (Scint. 16mm)



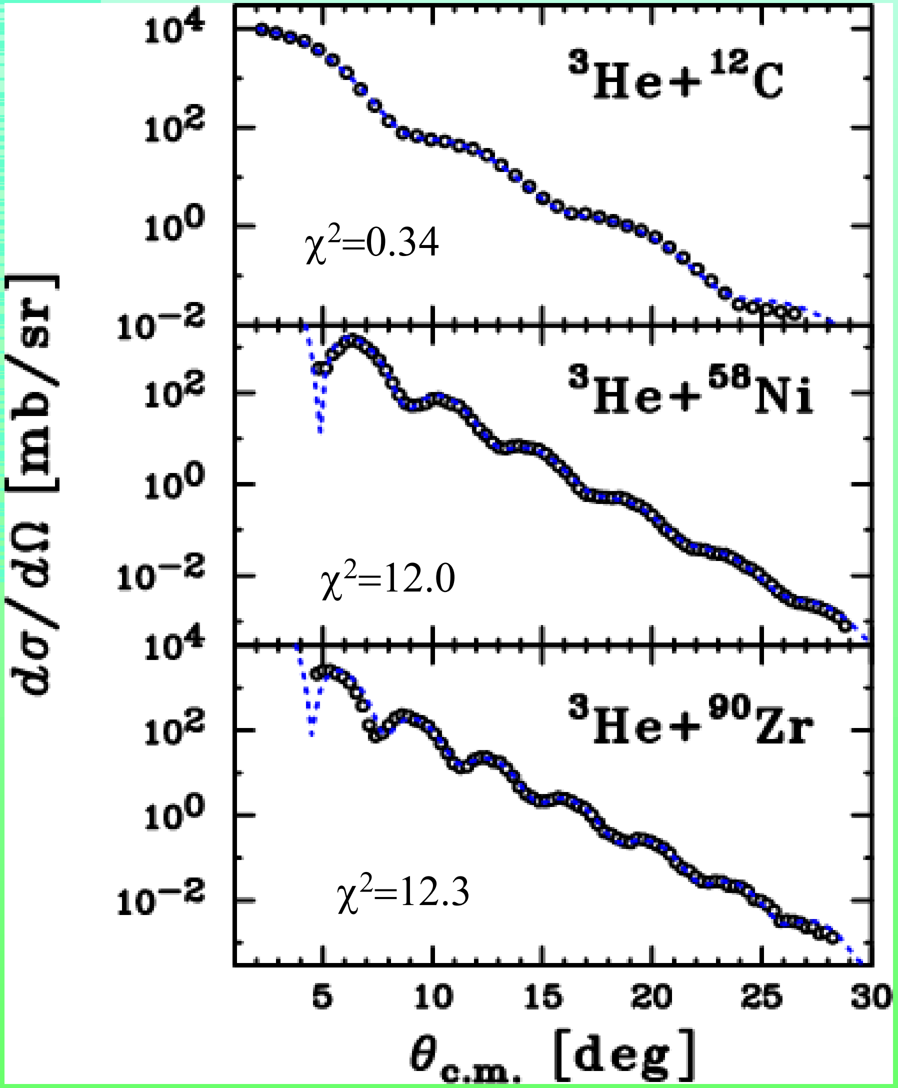

Analyzer target : Scintillator 16mm$^t$

Angular Integral Range : 5deg<θ<12deg

$$A_y^{eff} = 0.232 \pm 0.010$$

# Phenomenological Optical Potentials

## Central potentials




- Woods-Saxon optical potential

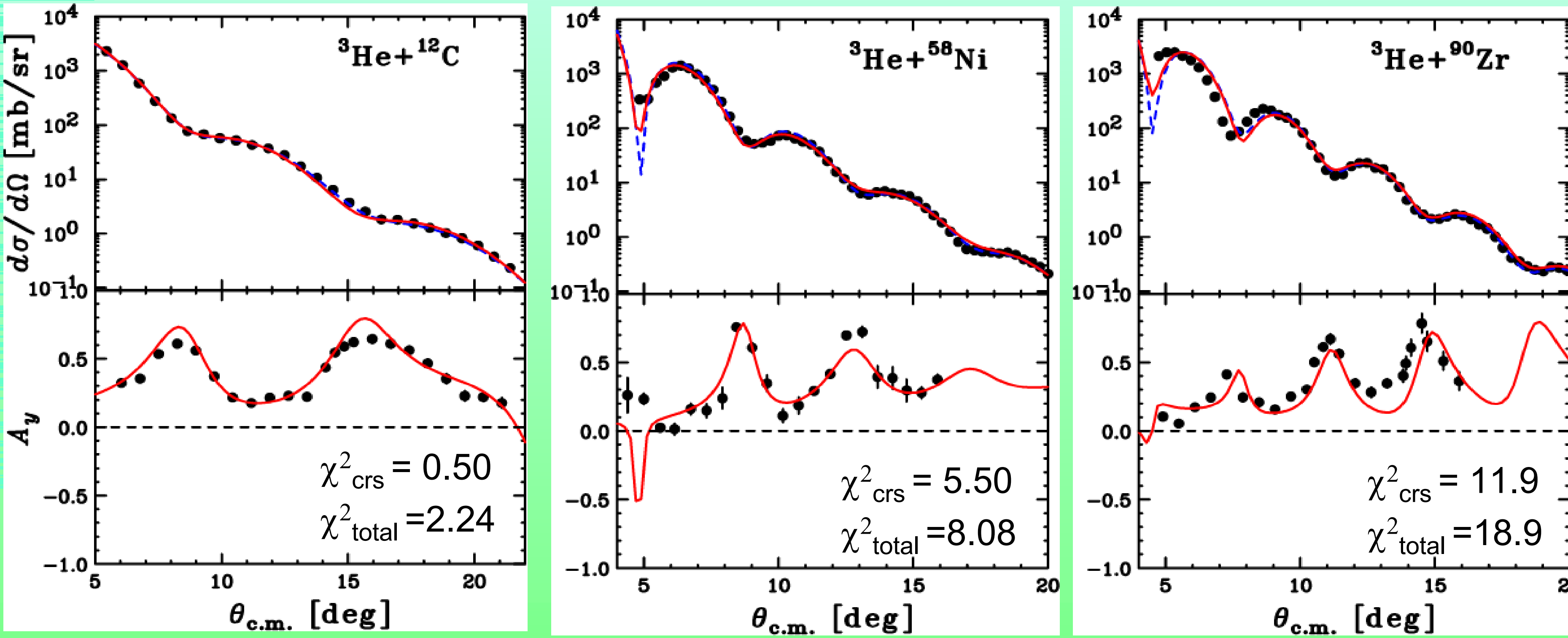
  Central potentials

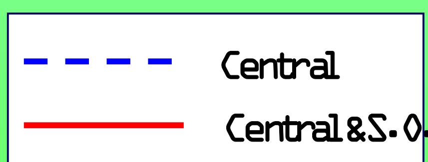
$$U_{cent} = V_c - V[1+\exp(x_R)]^{-1} - iW[1+\exp(x_I)]^{-1}$$

$$x_R = (r - r_R A^{\frac{1}{3}})/a_R, x_I = (r - r_I A^{\frac{1}{3}})/a_I$$

- Systematic search for the minimum $\chi^2$ ~code ecis88

# Phenomenological Optical Potentials Spin-Orbit Potentials

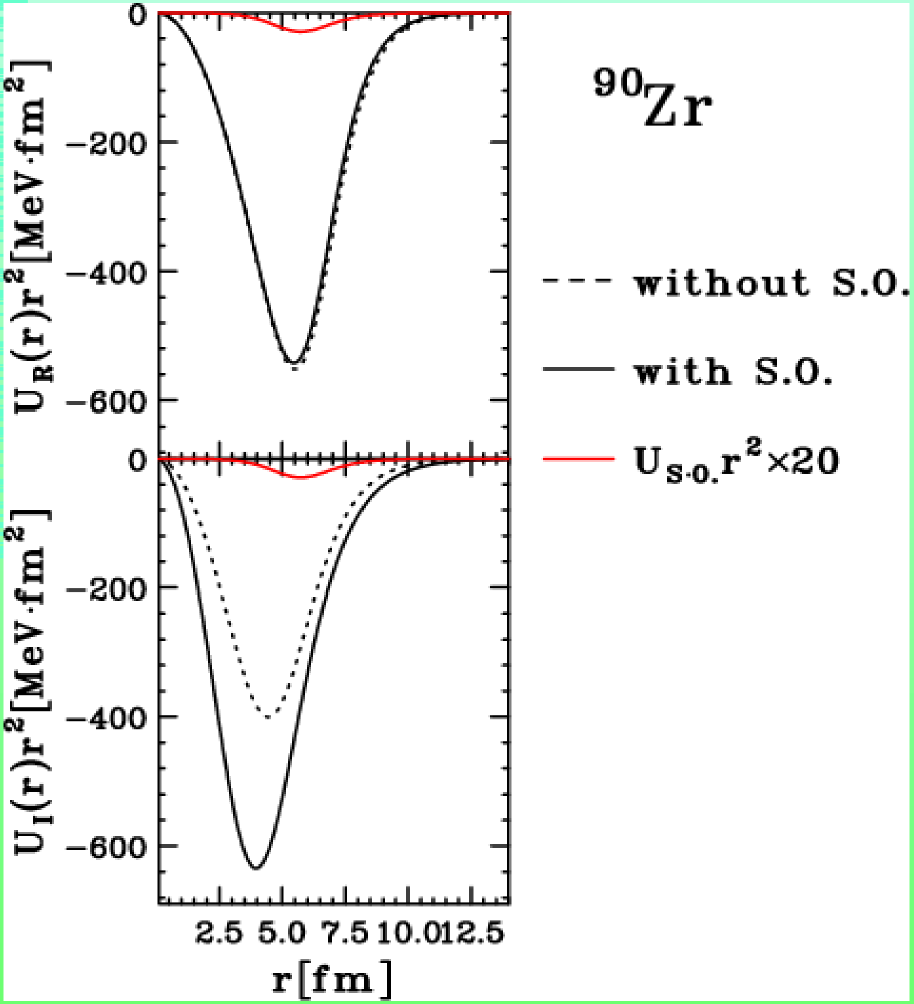



$$U_{s.o} = \left(\frac{\hbar}{m_\pi c}\right) V_{s.o} \frac{1}{r}\frac{d}{dr} f(r, r_{s.o.}, a_{s.o.})\, \sigma \cdot l$$

$$f(r, r', a') = [1 + \exp(r - r' A^{\frac{1}{3}} / a')]^{-1}$$

# Effect of the Spin-Orbit potentials

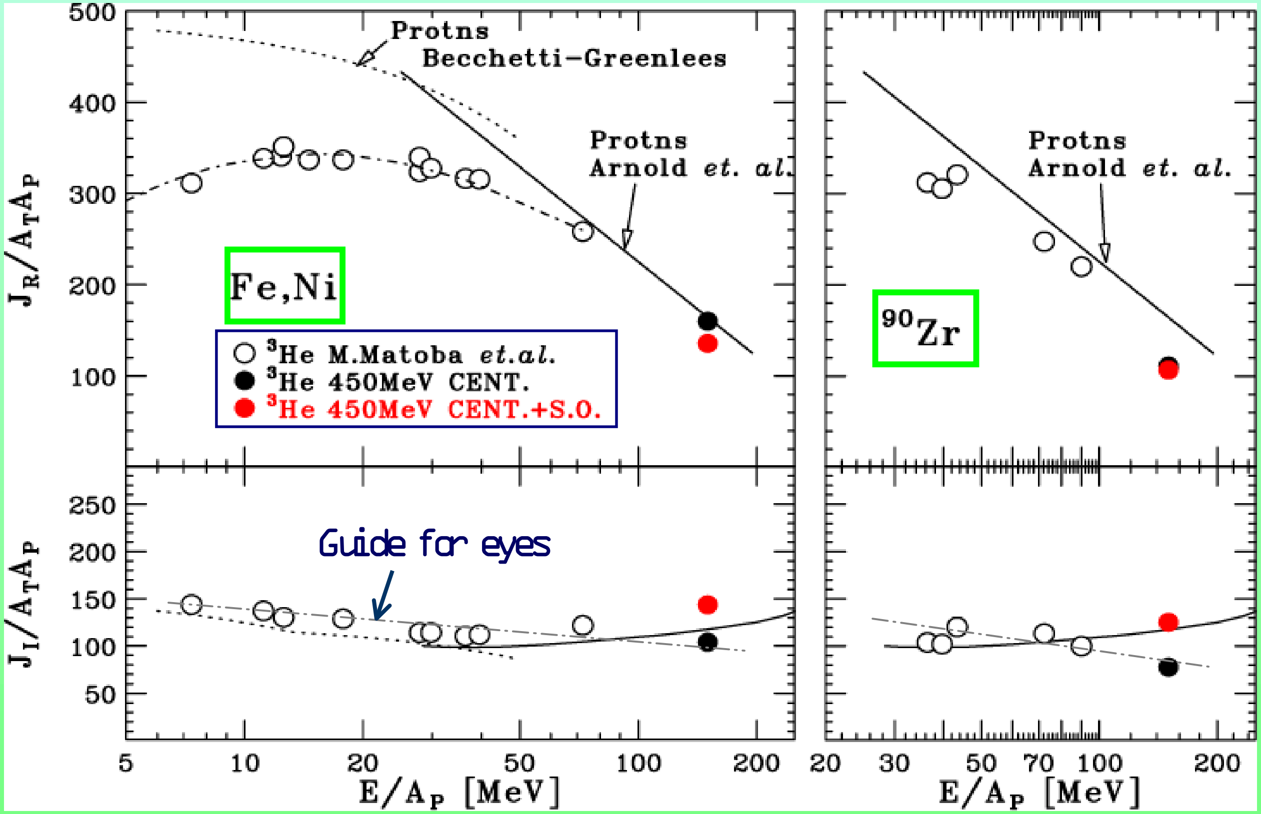



- Spin-Orbit potential

Small effect on the real central potential $U_R(r)$

Large effect on the imaginary central potential $U_I(r)$

# Energy dependence for volume integrals of optical potentials




$J_R$: similar behavior to proton @E/A>70MeV/u

$J_I$ :similar behavior to proton if Spin-Orbit potentials are included

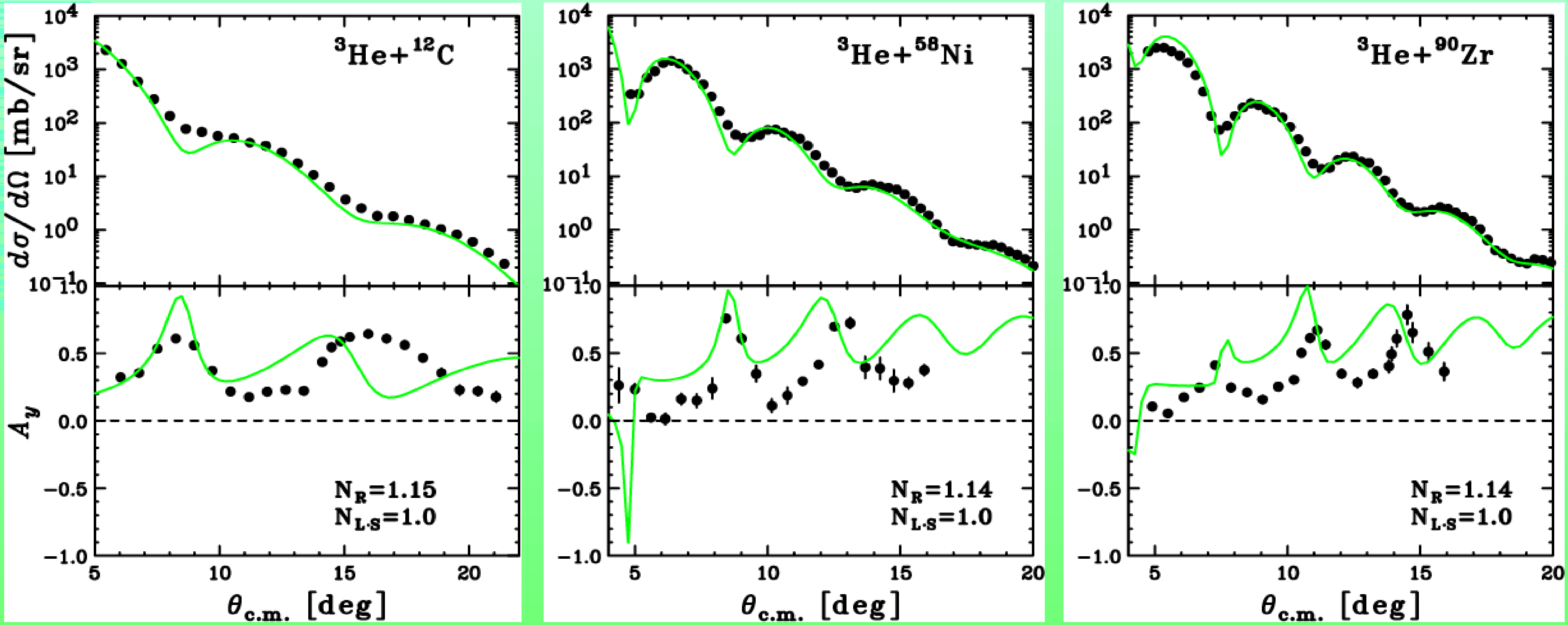
→ $^3$He-Nucleus interaction is dominated by the n-N interactions

# Double-Folding Model

*preliminary calculations*

$$V_{DF}^{(C)}(\mathrm{r}) = \int \rho_{^3\mathrm{He}}(\mathrm{r}_1)\rho_{\mathrm{T}}(\mathrm{r}_2)v^{(c)}{}_{NN}(\mathrm{s})d\mathrm{r}_1 d\mathrm{r}_2$$

$$U_{DF}(r) = N_R V_{DF}^{(C)}(r) + iW_I(r; W_0, r_I, a_I) + N_{L\cdot S} F_{DF}^{(S.O.)}(r) L\cdot S$$




*Calculations*

# Summary

- Angular distribution of $d\sigma/d\Omega$ & $A_y$ were measured at 150MeV/u
- $A_y$ has large values even at the forward angles
- Spin-Orbit potential gives the large effect on the Imaginary Central potential
- Energy dependence of Volume Integrals per nucleon shows the similar behavior to protons
- Microscopic model calculation is now progressing

Present experimental data contribute to study the S.O. part of the folding potentials

# Absolute Value of the Polarization

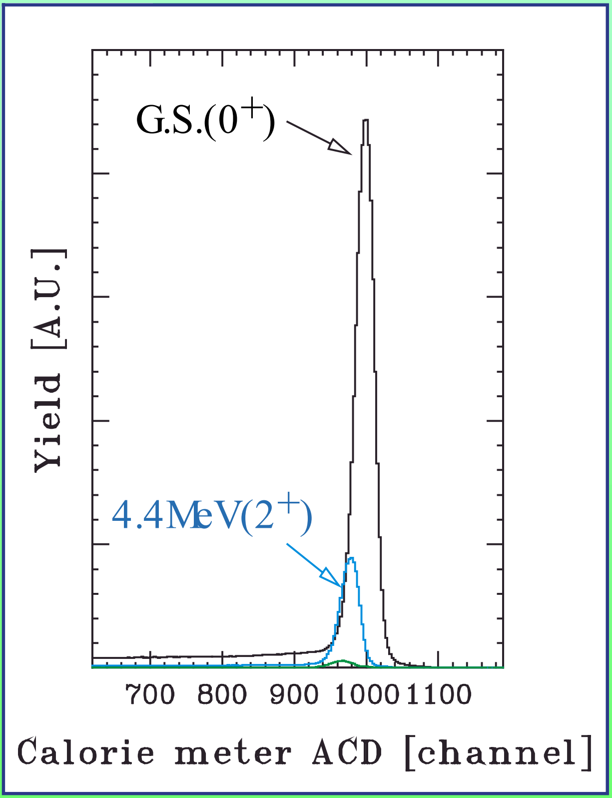
| | Thickness [mg/cm²] | Energy Loss [MeV] | Counting rate [1/pnA·sec] |
|---|---|---|---|
| 1st target | 30.0 | 590keV | 7.3E03 |
| 2nd target | 375(2mm) | 4.8MeV | 2.3E-01 |

Energy resolution is not good enough

↓

The first excitation was included in the analysis

$$P = 0.547 \pm 0.018$$



# Optical Potential Parameters

## Central Potential : $d\sigma/d\Omega$

| | $V$ | $r_R$ | $a_R$ | $W$ | $r_I$ | $a_I$ | $J_R$ | $J_I$ |
|---|---|---|---|---|---|---|---|---|
| $^{12}$C | 20.0 | 1.58 | 0.71 | 38.9 | 0.96 | 0.88 | 153 | 124 |
| $^{58}$Ni | 41.3 | 1.30 | 0.83 | 29.9 | 1.19 | 1.01 | 160 | 104 |
| $^{90}$Zr | 25.5 | 1.39 | 0.79 | 34.0 | 1.07 | 0.90 | 111 | 77.8 |

## Central & Spin-Orbit Potential : $d\sigma/d\Omega$, $P$

| | $V$ | $r_R$ | $a_R$ | $W$ | $r_I$ | $a_I$ | $V_{S.O.}$ | $r_{S.O.}$ | $a_{S.O.}$ | $J_R$ | $J_I$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $^{12}$C | 19.8 | 1.57 | 0.75 | 12.7 | 1.67 | 0.67 | 2.00 | 0.98 | 0.62 | 152 | 108 |
| $^{58}$Ni | 31.4 | 1.33 | 0.92 | 42.6 | 1.25 | 0.76 | 2.40 | 0.91 | 0.64 | 136 | 144 |
| $^{90}$Zr | 25.3 | 1.38 | 0.77 | 81.6 | 0.88 | 1.00 | 0.41 | 1.23 | 0.79 | 107 | 125 |