Analyzing Power Measurement for Proton Elastic Scattering on ^{6}He

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Satoshi Sakaguchi

Center for Nuclear Study, Univ. of Tokyo

Collaborators

CNS, Univ. of Tokyo

T. Uesaka, T. Kawabata, K. Suda, Y. Maeda, Y. Sasamoto

Univ. of Tokyo

H. Sakai, K. Yako, H. Kuboki, M. Sasano, Y. Takahashi, H. Iwasaki, Y. Ichikawa, D. Suzuki, T. Nakao

Toho Univ.

T. Kawahara

Saitama Univ.

K. Itoh

RIKEN

K. Sekiguchi, N. Aoi, M. Yamaguchi, N. Sakamoto

Tokyo Institute of Technology

Y. Satou, Y. Hashimoto, M. Shinohara

CYRIC, Tohoku Univ.

T. Wakui, H. Okamura, M. Itoh, R. Matsuo, M. Ichikawa

RCNP, Osaka Univ.

A. Tamii

Polarized Proton + RI-Beam

- Direct reactions with polarized protons
  - Proton induced direct reactions

    Simple reaction → Radii, Matter distribution, …
  - + "Spin Polarization"
    - (p,p'), (p,n) — spin-isospin response
    - (p,d), (d,p), (p,pN) — J^{π} of single particle/hole states
    - (p,p), (d,d) — spin-orbit potential
  - Polarized proton: one of most powerful probes

    ⇔ No study of unstable nuclei with polarized proton

To explore new aspects of unstable nuclei via polarization observables.

CNS Polarized Proton Target

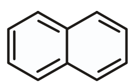
- **Strong point**
  - **Operation in modest conditions**
    - **Low magnetic field: 0.1 T**
    - **High temperature: 100 K**

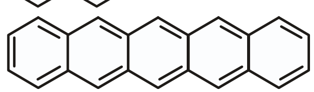
Unique pol. p target for RI-beam exp. !

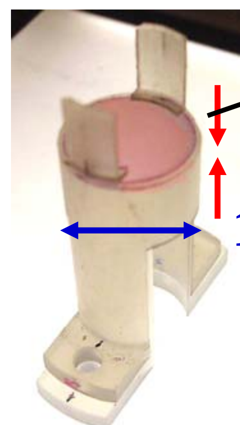
⇔ Conventional pol. p target (2.5 T, 0.5 K)

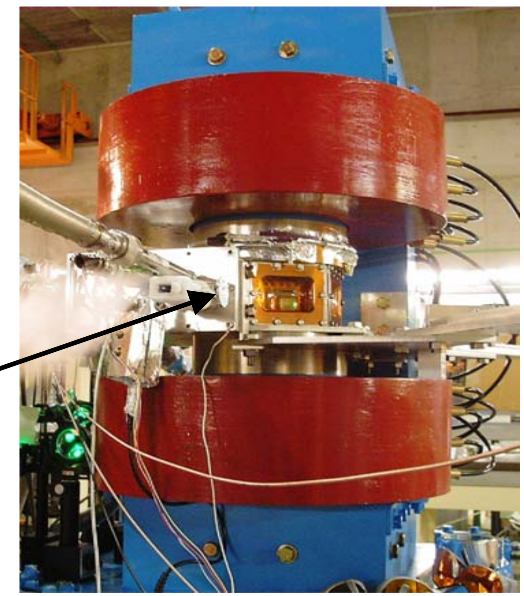
- **Target material**

  Single crystal of

  naphthalene 

  + pentacene 





- **Polarizing method**
  - **Laser excitation**

    → Electron pol. in aromatic molecules

A. Henstra et al.,
Phys. Lett. A **134** (1988) 134.
T. Wakui et al.,
NIM A **526** (2004) 182.

Study of unstable nuclei with polarized proton

Spin-orbit Potential in *n*-rich Nuclei

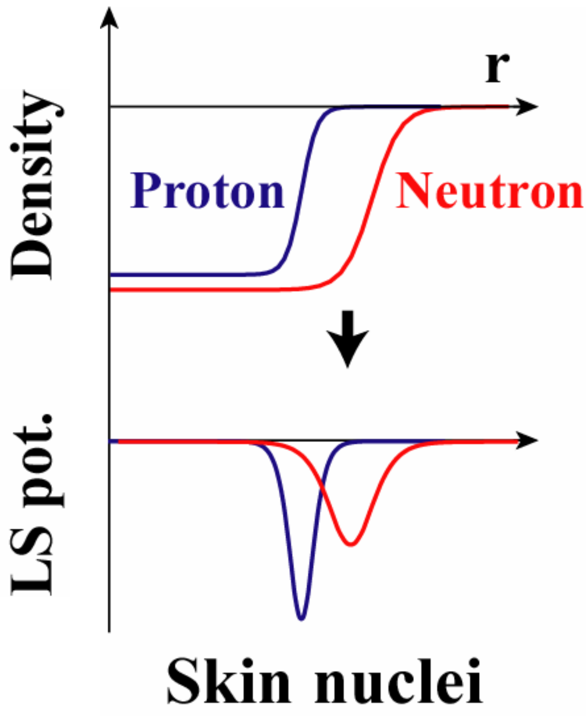
- **Spin-orbit interaction in unstable nuclei**
  - **Introduction of spin-orbit int. by Mayer & Jensen**
    → shell structure, magic number

- **Spin-orbit potential**
  - **Localized on nuclear surface**

$$V_{LS} \sim \frac{1}{r}\frac{d}{dr}\rho$$

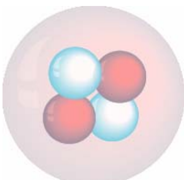
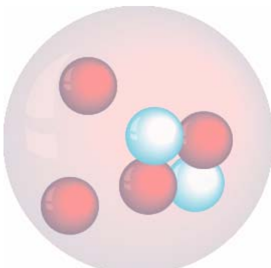
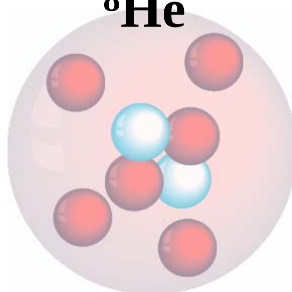
  - **Neutron skin/halo nuclei**:
    Different surface of proton/neutron

→ **How does spin-orbit potential behave in neutron skin/halo nuclei ?**



Proton Elastic Scattering on He Isotopes

- $\vec{p}$ + He isotopes

^{4}He	^{6}He	^{8}He
		
N/Z=1	N/Z=2	N/Z=3
r_m =1.49 fm	r_m=2.30 fm	r_m=2.45 fm
S_{2n}=28.3 MeV	S_{2n}=1.86 MeV	S_{2n}=2.58 MeV
	halo/skin	skin

  - dσ/dΩ:

    p+^{6}He   71 MeV/u @RIKEN

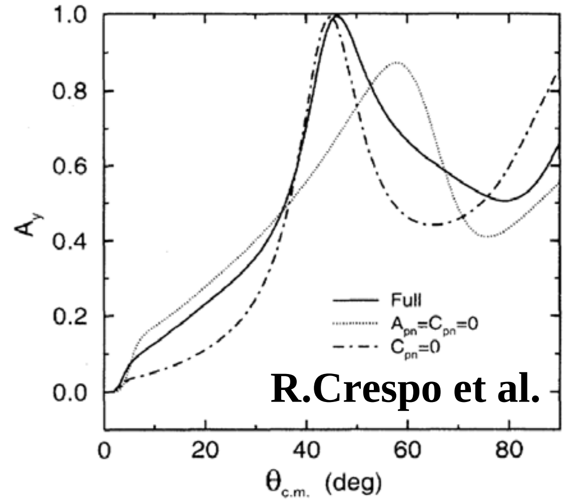
    41.6 MeV/u @GANIL

    25.3 MeV/u @Dubna

    p+^{8}He   71 MeV/u @RIKEN

  - **A$_y$: No data exists!**

- A_y calculation
  - p+^{6,8}He: S.P.Weppner et al., Phys. Rev. C 61 (2000) 044601.
  - p+^{8}He: R.Crespo et al., Phys. Rev. C 51 (1995) 3283.



Effects of excess neutrons on analyzing power

Experiment

- **Facility, Beam**
  - RIKEN, RIPS

    ^{6}He beam (71 MeV/u)

    - Intensity : 250 kcps
    - Δx : 10 mmϕ

      $\Delta\theta$: 20 mrad

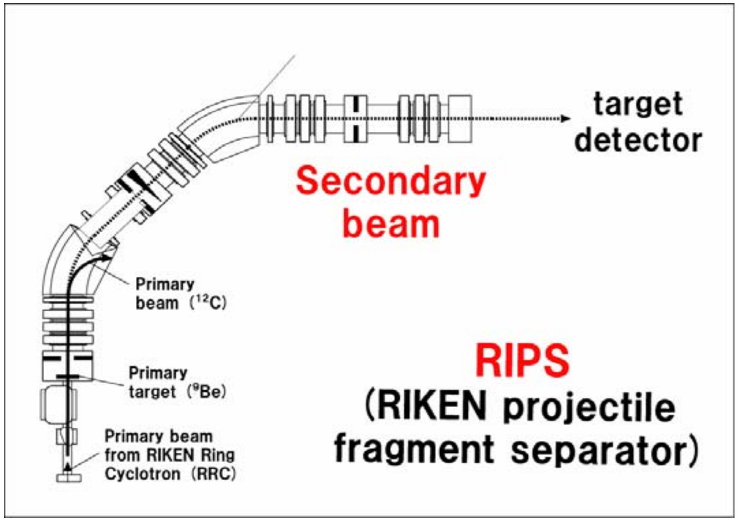
- **Target**
  - Solid polarized proton target

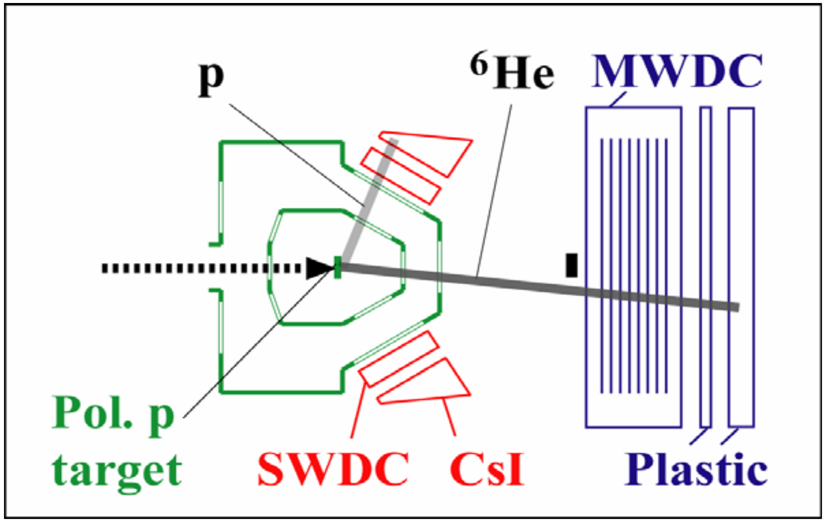
    14mmϕ, 1mm^{t} ($4.3\times10^{21}/cm^{2}$)

    Average polarization : 13.8%

- **Detector**
  - Forward: Scattered ^{6}He
  - Backward: Recoil proton

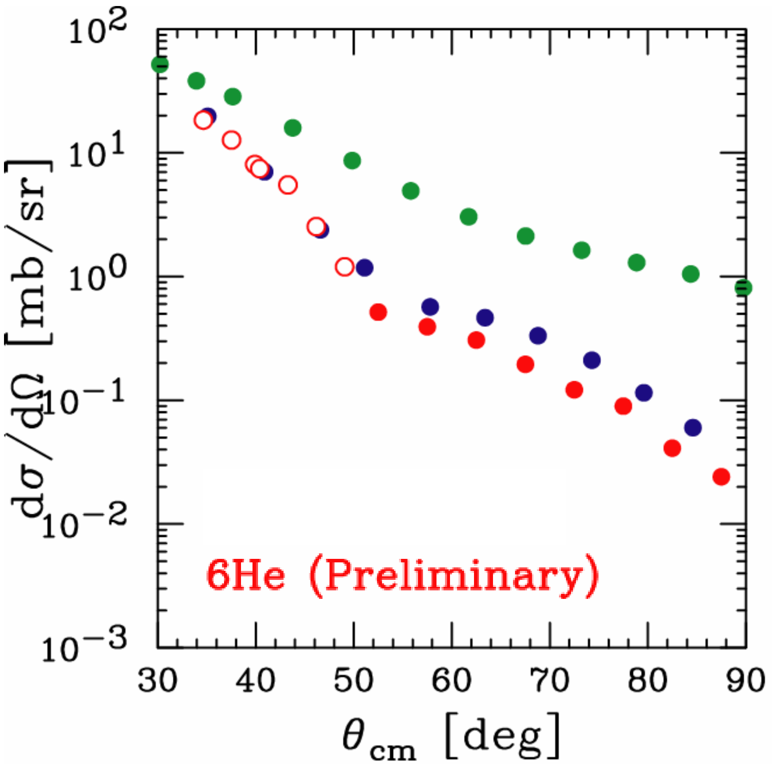
  → Scattering angle, ΔE, E





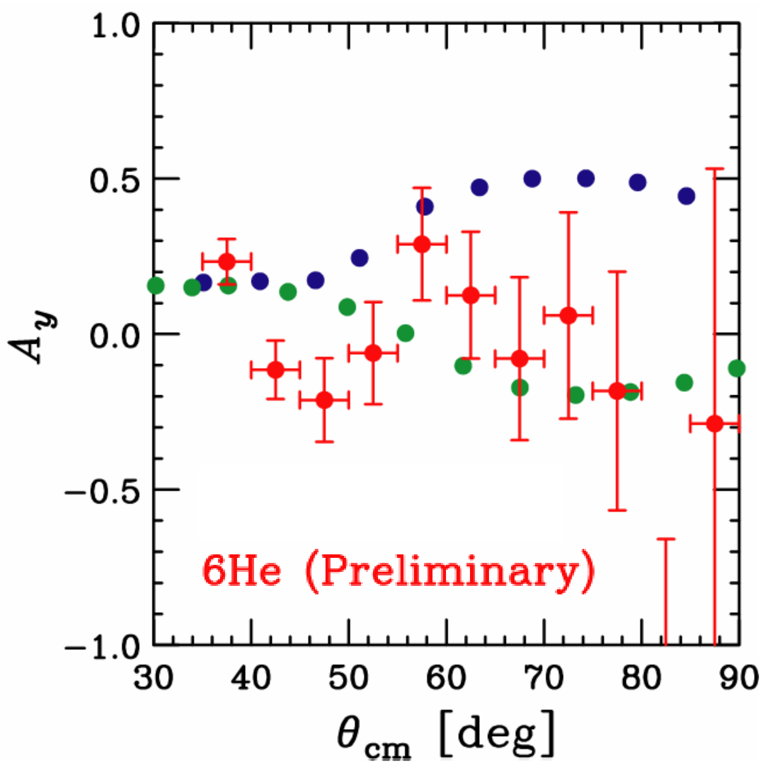
Experimental data

- **Differential cross section**
  - **Compared with ^{6}Li, ^{4}He**
  - **^{6}He ~ ^{6}Li → similar radii**



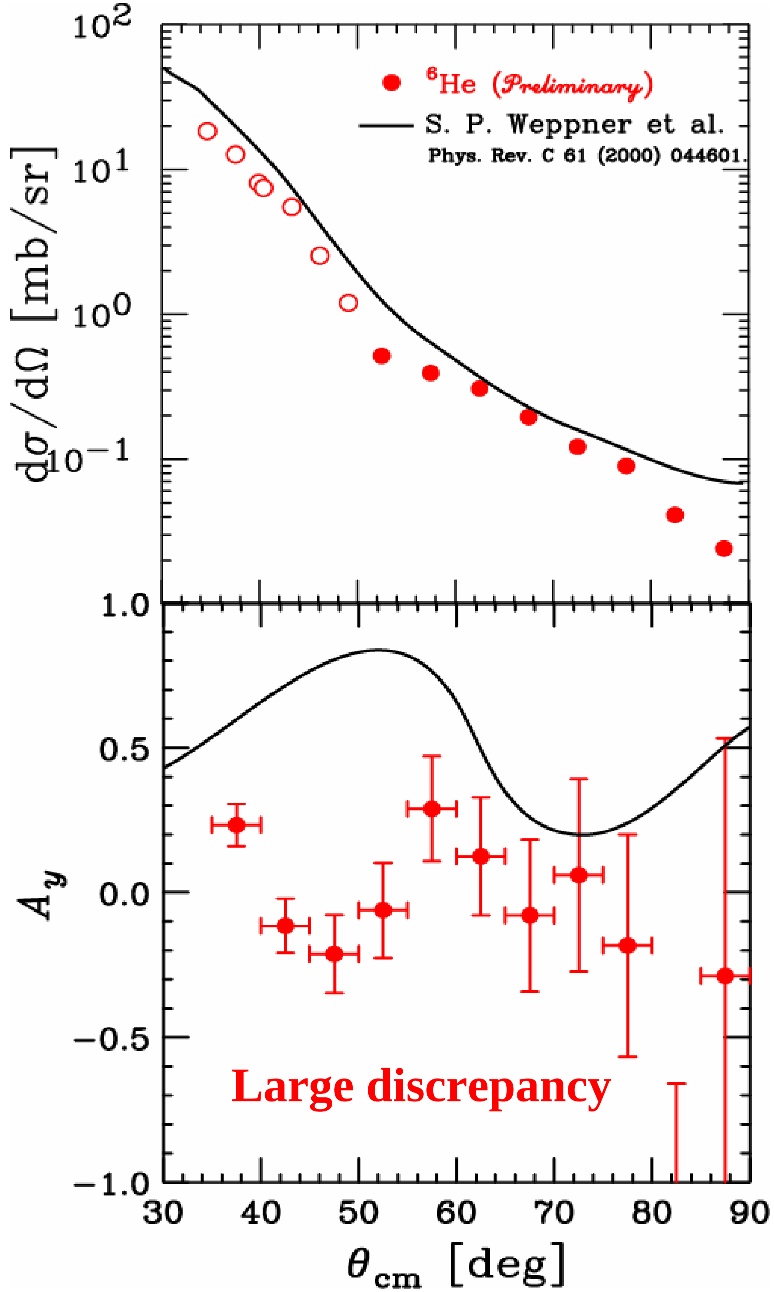
○: **A. Korsheninnikov NPA 616** (1997) 45.

- **Analyzing power**
  - **Interesting behavior much different from stable nuclei**



Microscopic Calculation

- **Optical potential**
  1. Phenomenological OP
  2. Microscopic OP
- **G-matrix folding calculation**
  - Folding calculation of
    - Effective NN interaction:
      Melbourne-G, CEG, JLM, NM I, …
    - Density distribution:
  - Successful in stable nuclei
- **Analyzing power in p+^{6}He**
  - Large discrepancy in pol. observable
    Something is missed…

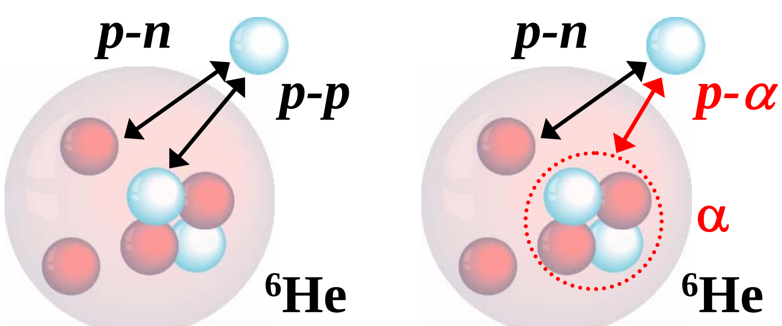


Cluster-folding Calculation

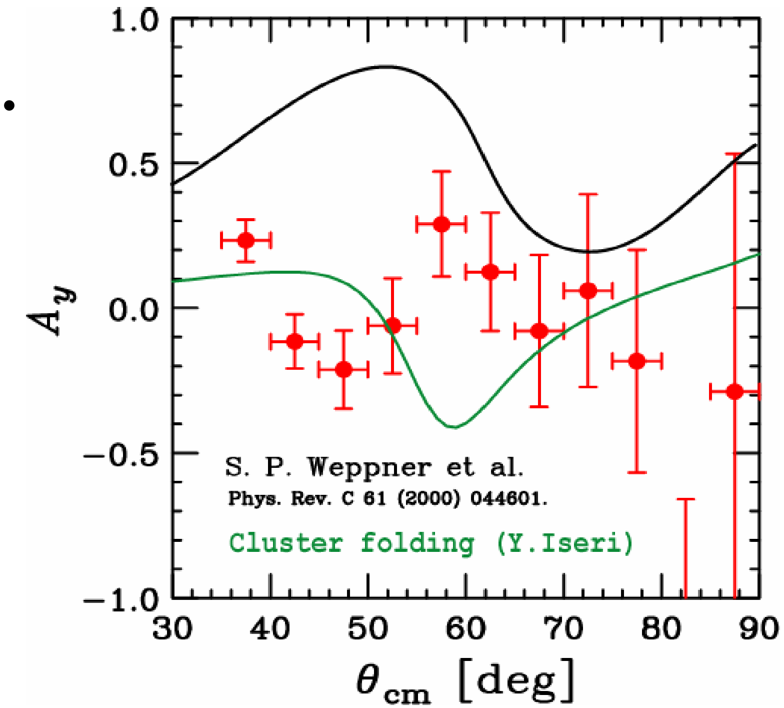
- Current "6-body" folding calc.
  - p-p int. / p-n int.
  - 2p/4n density in ^{6}He

  Fails to reproduce A_y in p+α

- α+2n cluster folding calc.
  - p-α int. / p-n int.
  - α/2n density in ^{6}He



Talk by Iseri-san on Jun. 1

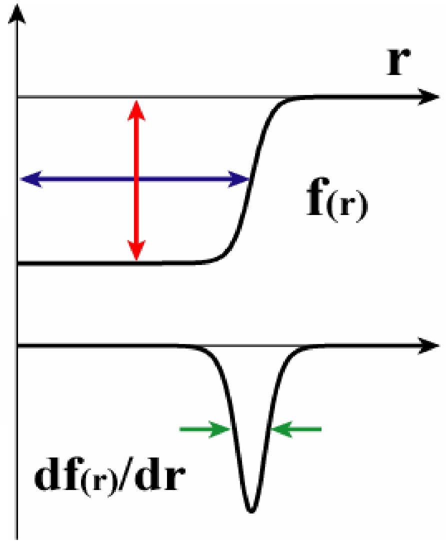


- Negative values: reproduced.
  → p+α is an important starting point to understand p+^{6}He
- Phase: should move to forward
  → Is LS potential extended?

Phen. Optical Model Analysis

- **Phenomenological optical potential**
  - **Woods-Saxon type：depth, radius, diffuseness**

$$f(r;r_0,a_0) = \left[1+\exp\left(\frac{r-r_0A^{1/3}}{a_0}\right)\right]^{-1}$$



  - **Central (real/imaginary), Spin-orbit terms (Coulomb, Surface imaginary terms： fixed)**

$$\begin{aligned} U(r) &= V_{Coul}(r) + V_R f(r;r_R,a_R) + iW_{wv} f(r;r_{wv},a_{wv}) \\ &\quad -4a_{ws}W_{ws}i\frac{d}{dr}f(r;r_{ws},a_{ws}) \\ &\quad + V_{ls}\left(\frac{\hbar}{m_\pi c}\right)^2 \frac{1}{r}\frac{d}{dr}f(r;r_{ls},a_{ls})(\overrightarrow{\sigma}\cdot\overrightarrow{L}) \end{aligned}$$

Spin-orbit potential

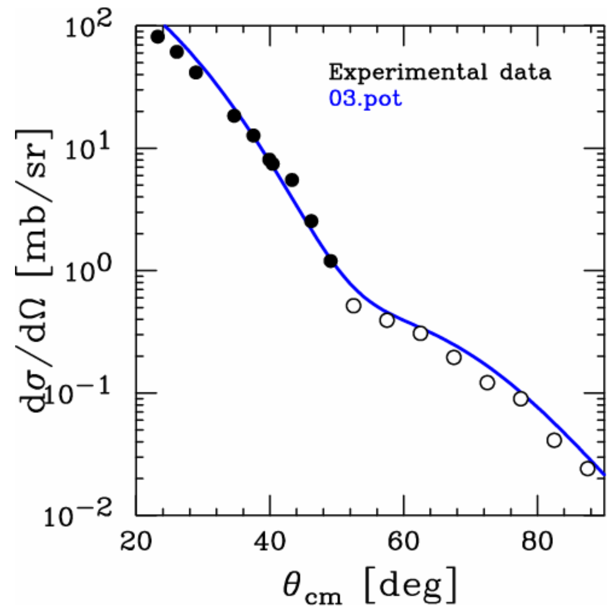
Phen. Optical Model Pot.

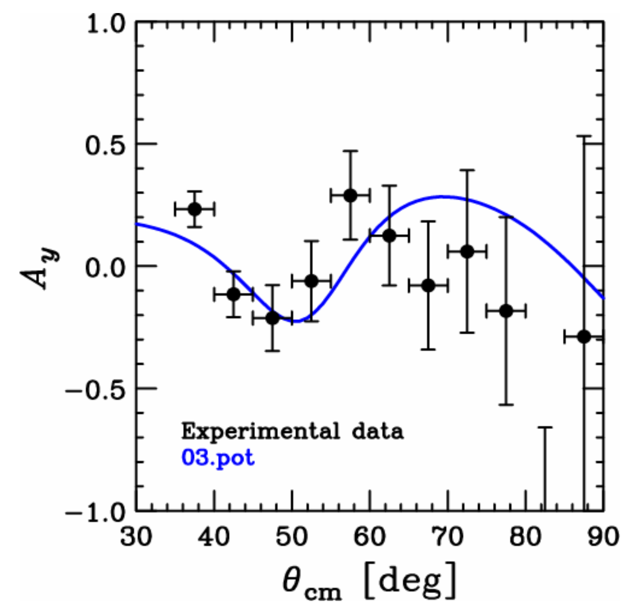
- **Fitting results**

	Depth (MeV)	Radius (fm)	Diffus. (fm)
Real	24.6	1.21	0.74
Imaginary	7.9	1.26	0.58
Spin-orbit	2.3	1.44	0.88

⇔ **Typical values:**

r_{ls} ∼1.2 fm, a_{ls} ∼0.6 fm





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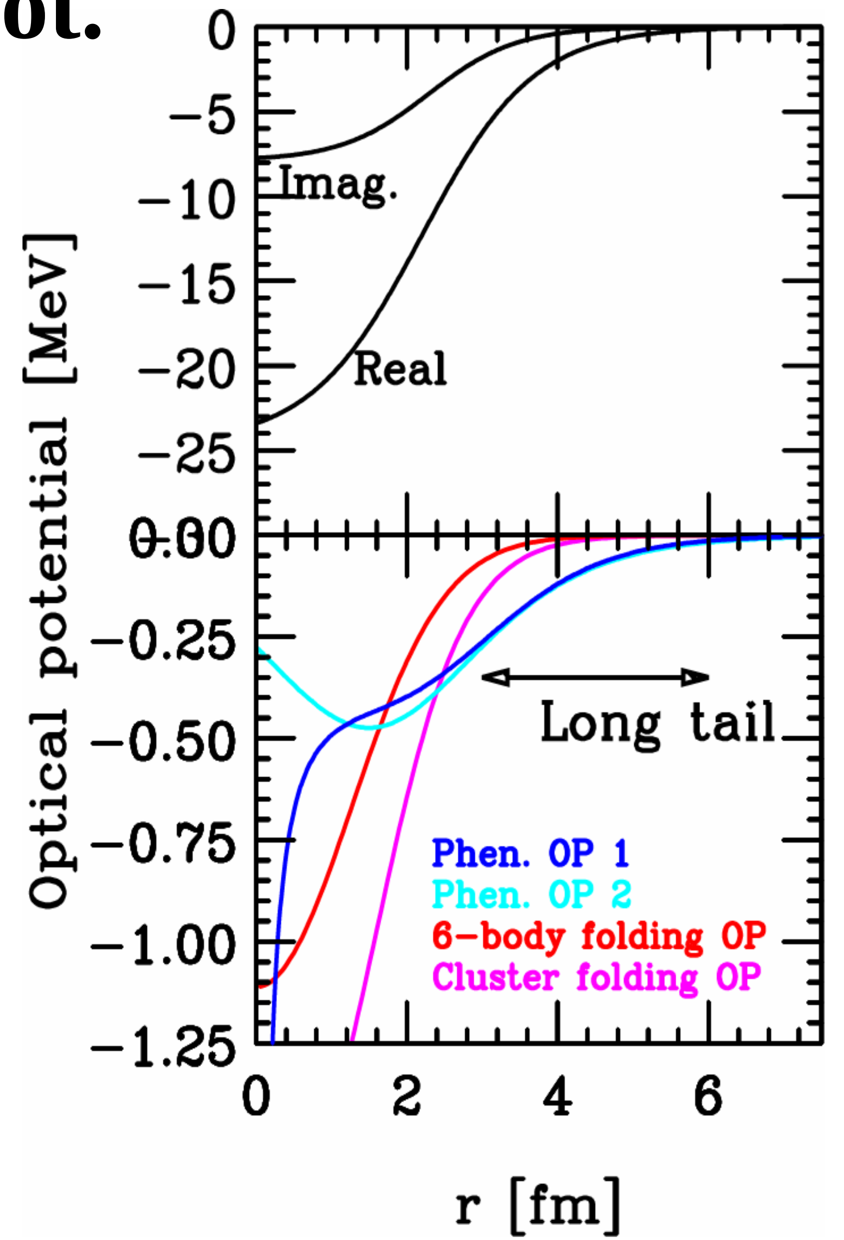
- Comparison with microscopic OP

NN int.: CEG, Density: GEM

Analysis indicates LS pot. in ^{6}He has a “long tail”.



Summary

- **Spin-orbit potential in neutron skin/halo nuclei**

  Analyzing power measurement for $\vec{p}$+^{6}He @71MeV/u

- **Comparison with G-matrix folding calculation**

  A_y data cannot be reproduced

  Cluster folding calculation: p+α is a good point to start

- **Phenomenological optical model analysis**

  Long-tail shape of spin-orbit potential in ^{6}He is indicated.

  r_{ls}, a_{ls} ~ 1.44, 0.88 fm ⇔ 1.1, 0.6 fm (typical values)

- **Proton elastic scattering on ^{8}He**

  First polarization data was obtained!