Studies of Few-Nucleon Systems via $^2\text{H}(p,pn)p$ Deuteron Breakup Reaction

Bogusław Włoch

Institute of Nuclear Physics, Polish Academy of Science
Neutron Detection in Deuteron Breakup Reaction

Bogusław Włoch

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Outlook

- Short Introduction
- Neutron detection
- Cross-section results
- Summary
Important role of the 3NF in Few-Nucleon systems

\[ V_{12} + V_{23} + V_{31} = V_{\text{theory}} \]

\[ 3NF = V_{123} \]

3N System

\[
\begin{align*}
\text{d} \sigma / \text{d} \Omega \text{ [mb/sr]} & \quad 108 \text{ MeV/nucleon} \\
\theta_{\text{cm}} \text{ [deg]} & \quad \theta_{\text{cm}} \text{ [deg]}
\end{align*}
\]

High precision data from Los Alamos W. P. Abfalterer et al., PRL 81, 57 (1998)
Aim of the analysis

- Development of the method for neutron detection in BINA experiment
- Determination of differential cross-sections for deuteron breakup reactions:
  - $dp \rightarrow (pn)p$
  - $dd \rightarrow (dn)p$

At 80 MeV/nucleon deuteron beam
Why neutron?

- Low energy detection threshold, different phase-space regions
- Comparing (pp) and (pn) cross-sections, access to Coulomb interaction
Case 1: $dp \rightarrow (pn)p$

- Simplest 3N system
- Strict calculation
- Large experimental data set from 2011
- Suitable for neutron detection development
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- Simplest 3N system
- Strict calculation
- Large experimental data set from 2011
- Suitable for neutron detection development

- $(pn)p$ and $(pp)n$ cross-sections can differ significantly
- Studying Coulomb interactions
Case 2: \( dd \rightarrow (dn)p \)

- More complex 4N system
- Only aprox. Calculation (SSA)
Case 2: $dd \rightarrow (dn)p$

- More complex 4N system
- Only aprox. Calculation (SSA)
- Direct comparison $dd \rightarrow (dn)p$ And $dd \rightarrow (dp)n$
- Coulomb in 4N
- Possible in the future: exclusive $dd \rightarrow (ppn)n$
Neutron Detection in BINA
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Neutron Detection in BINA

2\textsuperscript{nd} PROTON Out of Detector!
Configurational Efficiency

$\Delta \phi = 80^\circ$

$\Delta \phi = 100^\circ$

$\Delta \phi = 120^\circ$

$\Delta \phi = 140^\circ$

$\Delta \phi = 160^\circ$

$\Delta \phi = 180^\circ$
Neutron Detection in BINA

- Neutron interact with E scint.
- MWPC & ΔE as Veto
- Efficiency estimated on complete exclusive dp→(ppn)
- Efficiency ~10-15%
Position reconstruction

- X position based on asymmetry of ADC and TDC signal
- Resolution $\sigma \approx 12$ mm

ADC asym.  
\[ \sigma = 12 \text{ mm} \]

TDC asym.  
\[ \sigma = 12.6 \text{ mm} \]

Combined information  
\[ \sigma = 11.6 \text{ mm} \]
Energy reconstruction

- Based on Time-of-Flight method
- Charged particle needed to calculate reaction time
- Calibrated on events with two protons

σ=13 MeV
Results: En-Ep Histograms

\[ \theta_N=19 \quad \theta_P=19 \quad \phi=80 \]
Results: En-Ep Histograms

θ_N=19  θ_P=19  φ=80
Results: En-Ep Histograms

$\theta_n=19 \quad \theta_p=19 \quad \phi=80$

$\theta_n=19, \ \theta_p=19, \ \phi=80, \ S=104$
Results: En-Ep Histograms
Results: \( dp \to (pn)p \)

Differential cross-section for configuration of \( Th_{\text{proton}} = 23^\circ \) \( Th_{\text{neutron}} = 23^\circ \)

\[
\frac{d^3 \sigma}{d \Omega d S} [\text{mb sr}^{-2} \text{MeV}^{-1}]
\]

\( d\phi = \{80, 100, 120, 140, 160, 180\} \)

\( S [\text{MeV}] \)
Results: \( dp \rightarrow (pn)p \)

Differential cross-section for configuration of Th\_proton =19° Th\_neutron =19°
Results: $dp \to (pn)p$

Differential cross-section for configuration of $\text{Th}_{\text{proton}} = 27^\circ$ $\text{Th}_{\text{neutron}} = 21^\circ$
Results: \( dp \rightarrow (pn)p \)

Differential cross-section for configuration of \( \text{Th}_{\text{proton}} = 27^\circ \), \( \text{Th}_{\text{neutron}} = 25^\circ \)

\[
\sigma(\theta) = \frac{d^2 \sigma}{d\Omega d\theta} = \frac{d \sigma}{d \Omega d \theta} \quad \text{(mb sr}^{-2} \text{MeV}^{-1})
\]

Graphs show the differential cross-section for different angles and energies.
Comparison with theory: chi-squared test

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\[ \frac{\chi^2}{d.o.f.} \]

\[
\begin{align*}
\text{Th}_{\text{proton}} & = 23^\circ & \text{Th}_{\text{neutron}} & = 23^\circ \\
\text{Th}_{\text{proton}} & = 19^\circ & \text{Th}_{\text{neutron}} & = 19^\circ \\
\text{Th}_{\text{proton}} & = 27^\circ & \text{Th}_{\text{neutron}} & = 21^\circ \\
\text{Th}_{\text{proton}} & = 27^\circ & \text{Th}_{\text{neutron}} & = 25^\circ
\end{align*}
\]
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\[ \Delta \phi_{12} [^\circ] \]
Comparision with theory

- The quality of the agreement was studied with A-deviation factor:

\[ A = \frac{1}{N} \sum_{i=1}^{N} \frac{|\sigma_i^{\text{exp}} - \sigma_i^{\text{theory}}|}{\sigma_i^{\text{exp}} + \sigma_i^{\text{theory}}} \]

- \( A \) belongs to \([0,1]\)
- Good for larger discrepancies
Comparison with theory

\[ \text{Th}_{\text{proton}} = 23^\circ, \text{Th}_{\text{neutron}} = 23^\circ \]

\[ \text{Th}_{\text{proton}} = 19^\circ, \text{Th}_{\text{neutron}} = 19^\circ \]

\[ \Delta \phi_{12} [^\circ] \]

\[ \Delta \phi_{12} [^\circ] \]
Summary

- The neutron detection methods in BINA experiment are developed
- First results of $dp \rightarrow (pn)p$ cross-section
- **NOW: Systematic errors studies**
- The $dd \rightarrow (dn)p$ reaction analysis is still in progress