Measurement of the analyzing powers in pd elastic and pn quasi-elastic scattering at small angles at ANKE-COSY

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MOTIVATION: Nucleon-Nucleon (NN) interaction

Understand nuclear force in GeV region
  → pp and np-amplitudes
  → Phase Shift Analysis*

ANKE

→ Small angle pp-elastic: $A_y$ and $\delta$
→ Charge-exchange deuteron breakup: $\delta$, $A_y$, $A_{yy}$, $C_{yy}$, $C_{xx}$
→ Small angle pn, pd-elastic: $A_y$

MOTIVATION: Where are we in pp elastic?

- Wealth of data ($35^\circ < \theta_p < 90^\circ$)  
  $0.5 < T_p \leq 2.5$ GeV

- EDDA’s large impact on PSA: significantly reduced ambiguities in phase shifts ($l=1$)

  \[ \text{Source: } \text{http://nn-online.org/NN} \]

- No experimental data at smaller angles ($\theta_p < 35^\circ$) above $T_p = 1.0$ GeV

\[ \text{Source: } \text{http://nn-online.org/NN} \]
MOTIVATION: Where are we in pn?

R. Arndt: *Gross misconception within the community that np amplitudes are known up to a couple of GeV. np data above 800 MeV is a DESERT for experimentalists.*

ANKE is able to provide the experimental data for both: pp and np systems and improve our understanding of NN interaction.

Source: [http://nn-online.org/NN](http://nn-online.org/NN)
**Experiment: ANKE at COSY**

**Polarized proton beam:** \( T_p = 0.8, 1.6, 1.8, 2.0, 2.2, 2.4 \text{ GeV} \),

**Beam polarization:** \( P_y \approx 50\%, \) spin flipped every cycle (5 min)

**\( D_2 \) cluster jet target:** \( d = 5 \cdot 10^{14} \text{ cm}^{-2} \)

**Polarimetry:** EDDA detector

**Forward detector (FD):**
  fast proton @ 0-15°

**Silicon Tracking Telescope (STT):**
  low energy proton (spectator)
  \( (5^\circ < \Theta_{cm} < 30^\circ) \)

**Triggers:**
- Self-triggering STT L2
- FD*STT coincidence

**Ideal for small angle elastic scattering studies**
Silicon tracking telescope at ANKE

Identification of stopped protons of 2.5 - 30 MeV, deuterons of 3.5 – 40 MeV

*I. Lehmann et al., NIM A 530 (2004) 275*
## Beam polarization measurement by EDDA

- Carbon fibre target (pC)
- Known effective pC analyzing power
- Scintillator semi-rings (φ asymmetry)

<table>
<thead>
<tr>
<th>Beam Energy T&lt;sub&gt;_kin&lt;/sub&gt; [MeV]</th>
<th>Av. Polarisation P [%]</th>
<th>Statistical Error P&lt;sub&gt;_er&lt;/sub&gt; [%]</th>
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</thead>
<tbody>
<tr>
<td>796</td>
<td>55.4</td>
<td>0.8</td>
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<tr>
<td>1600</td>
<td>50.4</td>
<td>0.3</td>
</tr>
<tr>
<td>1800</td>
<td>-50.8</td>
<td>1.1</td>
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<td>1965</td>
<td>-42.9</td>
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<td>2157</td>
<td>-50.1</td>
<td>1.0</td>
</tr>
<tr>
<td>2368</td>
<td>43.5</td>
<td>1.5</td>
</tr>
</tbody>
</table>

- LEP: P~90% at injection
- EDDA: P~50% at experiment energy
- ~1% statistic and 3% systematic error
Analyzing power in $\bar{p}d$ elastic

Cross ratio method: \( S \)yst. errors suppressed in first order

\[
\varepsilon = \frac{L - R}{L + R} = P_A \quad L = \sqrt{L_1L_2} = \sqrt{L\uparrow R\downarrow} \quad R = \sqrt{R_1R_2} = \sqrt{L\downarrow R\uparrow}
\]

Deuteron detected in STT (STT trigger)

Angle defined from deuteron energy \( \sigma \theta < 0.2^0, \quad \sigma E_d < 2\% \)

Missing mass \( M_x \) in \( pd \to dX, \) STT

\[
A_y^{pd} = 0.4714q - 0.0987q^3 + 0.0077q^5.
\]

* LAMPF F.Irom, PRC 28, (1983) 2380

S.Dymov Measurement of the analyzing powers in pd elastic and pn quasi-elastic scattering at small angles
Analyzing power in pn quasi-free elastic (1)

- Fast proton in FD in coincidence with spectator proton in STT
- No detector Left-Right symmetry – cross ratio not applicable
- Must define ratio of luminosity with beam spin up and down: use ratio of deuterons from pd-elastic taken with STT-trigger
  \[
  \frac{(L_d^\uparrow \cdot R_d^\uparrow)}{(L_d^\downarrow \cdot R_d^\downarrow)}
  \]
- Very low and unpolarized background in Mx spectra, except 800 MeV, where deuterons from pd → dπ^0+p_{spec} in FD suppressed by dE/dX
- Only the right STT was used to suppress quasi-free pp-elastic

Simulation: pn-quasi (empty histogram) and pp-quasi elastic counts. Left STT in coincidence with FD

Missing mass Mx in pd → pX+p_{spec}
Analyzing power in pn quasi-free elastic (2):
Results at 800 MeV

800 Mev is a test energy:
compare with SAID SP07, data

Quasi-free kinematics: $p_T > p_{\text{spec}}$

Smallest $p_T$ are at 800 MeV $100 < p_T < 260$ MeV/c

Cuts for quasi-free scenario:

$p_{\text{spec}}/p_T < 0.5$, $p_T > 190$ MeV/c

$\Theta_{cm} > 17^0$ at 800 MeV,
full acceptance at higher energies

SAID SP07
ANKE
Bartlett, PRC 27(1983),682
Analyzing power in pn quasi-free elastic (3): 
Results at 1600 and 2200 MeV

SAID SP07:

based on data < 1.5 GeV, 
fails at $T_p=1.6-2.4$ GeV

SAID AD14:

Includes WASA data at ~1.1 GeV  
(Adlarson, PRL 112, 202301 (2014)) 
Expected to work only up to 1.5 GeV, 
But fits ANKE data at 1.6 GeV

$A_y^p$ decreasing with energy same as in pd-elastic
Summary

- Analyzing power $A_y^p$ was measured in pd-elastic and pn quasi-elastic scattering in the forward angles at $T_p = 0.8$ - 2.4 GeV.
- In pd-elastic $A_y^p$ at 800 MeV consistent with LAMPF data. At 1.6 GeV $A_y^p$ is about 2 times smaller than at 800 MeV, and decreases with energy.
- Results on pn quasi-elastic coincide well with available data at 800 MeV and 2200 MeV, and with SAID SP07 solution at 800 MeV. Data at 1600 MeV agree with SAID AD14 solution.
- The energy dependence in pn quasi-elastic scattering is similar to that in pd-elastic.
- The results obtained will be used in the PSA.

Thank you!
Measurement of the analyzing powers in pd elastic and pn quasi-elastic scattering at small angles
**np program: quasi-elastic pn**

\[ pd \rightarrow ppn \]

\[ T_p = 0.8, 1.6, 1.8, 2.0, 2.2, 2.4 \text{ GeV} \]

Polarization with EDDA

- Fast proton in **FD**
- Slow proton in **STT**

Compatible with existing data

**SAID SP07 describes well at 796 MeV.** Dedicated SAID solution at 1.6 GeV