Polarimetry for the polarized deuterium target at ANKE/COSY

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for the ANKE-Collaboration

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Motivation – Investigate np system at higher energies

Deuteron is used as source for quasi free polarized neutron for np program at ANKE

**np forward**

dp observables: $d\sigma/d\Omega$, $T_{20}$, $T_{22}$, $A_{yy}$, ... leads to measurements of

np observables: $d\sigma/d\Omega$, $A_{xx}$, $A_{yy}$, $A_{xy,y}$, ...

**np charge exchange**

With deuteron beam, experiments have been done at COSY up to $T_n=1.135$GeV

With deuteron target, study can be extended up to $T_n = 2.8$GeV
Polarized Internal Gas Target at ANKE

PIT main components:

- Atomic Beam Source (ABS)
  - H or D
  - H beam intensity (2 HFS)
    \[ I = 8.2 \cdot 10^{16} \text{ atoms/s} \]
  - Beam size at the IP
    \[ \sigma = 2.85 \pm 0.42 \text{ mm} \]
- Polarization for deuterium
  - \( Q_y \approx 70\% \)
  - \( Q_{yy} \approx 70\% \)
- Lamb-Shift Polarimeter (LSP)
- Target Chamber with Storage Cell (SC) (15x20x370 mm³) to increase the target density
Setup of the experiment

June 2012

- **Beam:** Unpolarized proton beam ($T_p = 600$MeV)
- **Target:**

<table>
<thead>
<tr>
<th>Deuterium</th>
<th>$Q_y$</th>
<th>$Q_{yy}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vector</td>
<td>+1</td>
<td>+1</td>
</tr>
<tr>
<td></td>
<td>-1</td>
<td>+1</td>
</tr>
<tr>
<td>Tensor</td>
<td>0</td>
<td>-2</td>
</tr>
<tr>
<td></td>
<td>0</td>
<td>+1</td>
</tr>
<tr>
<td>Unpol.</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

- **Detectors**
  - **Fd:** Forward detector
  - **Pd:** Positive detector
  - **STT:** Silicon Tracking Telescope

$N_2$: background simulation of cell wall
Empty cell: generate background
Polarimetry reactions

Polarization is measured with **nuclear reactions** with high cross section and analyzing power which fall in ANKE acceptance.

**Vector polarization measurement:**
\[
p \hat{d} \rightarrow d \pi^+ n_{sp} \quad p \hat{d} \rightarrow pd
\]
\[
p \hat{d} \rightarrow d \pi^0 p_{sp}
\]

**Tensor polarization measurement:**
\[
p \hat{d} \rightarrow pd
\]
\[
p \hat{d} \rightarrow ^3H \pi^+
\]
Reaction identification for $p\vec{d} \to pd$

Deuterons are identified by energy deposit in different layers of STT.

Reaction $pd \to pd$ is selected by missing mass method, there is very low background under the peak.
$\vec{p}d \rightarrow pd$ used as a polarimetry

Cross section is large, and detector acceptance covers the region where $A_y$ and $A_{yy}$ are known.

Both vector and tensor analyzing powers large and well-known.
Polarimetry principle \((p\vec{d} \rightarrow pd)\)

\[
\frac{d\sigma}{d\Omega}(\theta, \phi) = \left(\frac{d\sigma}{d\Omega}\right)_0(\theta) \left\{1 + \frac{3}{2}Q_yA_y(\theta)\cos\phi + \frac{1}{4}Q_{yy}[A_{yy}(\theta)(1 + \cos 2\phi) + A_{xx}(\theta)(1 - \cos 2\phi)]\right\}
\]

\[
\mathcal{A}_V \quad \mathcal{A}_T
\]

\[
CR = \frac{\frac{N_L^p \cdot N_R^0 - N_R^p \cdot N_L^0}{N_L^p \cdot N_R^0 + N_R^p \cdot N_L^0}}
\]

\[
\begin{align*}
\frac{\left(\frac{\varepsilon_L^p}{\varepsilon_R^p}\right)}{\left(\frac{\varepsilon_L^0}{\varepsilon_R^0}\right)} \cdot \left(1 - \mathcal{A}_V + \mathcal{A}_T\right) - \left(1 + \mathcal{A}_V + \mathcal{A}_T\right)
\end{align*}
\]

\[
= \frac{-\frac{3}{2}Q_yA_y(\theta)}{1 + \frac{1}{4}Q_{yy}[A_{yy}(\theta)(1 + \cos 2\phi) + A_{xx}(\theta)(1 - \cos 2\phi)]}
\]

\[
\approx \frac{-\frac{3}{2}Q_yA_y(\theta)}{1 + \frac{1}{2}Q_{yy}A_{yy}(\theta)} \quad \phi \rightarrow 0^\circ, 180^\circ
\]

If the ratio of the left and right detector efficiency \(\frac{\varepsilon_L}{\varepsilon_R}\) does not change, \(Q_y\) and \(Q_{yy}\) can be determined by fitting the CR obtained from the measurement.
Check consistency of $\frac{\varepsilon_L}{\varepsilon_R}$

Efficiency ratio is almost the same for unpolarized and nitrogen data, which means that it was not changing significantly during the experiment.

$$\frac{\varepsilon_L^0 / \varepsilon_R^0}{\varepsilon_L^{N_2} / \varepsilon_L^{N_2}} \approx 0.975 \pm 0.005$$
Result of polarization measurement ($p\bar{d} \rightarrow pd$)

1\textsuperscript{st} State ($1, 1$)

- Measured polarization:
  - $Q_y = 0.719+/-0.005$
  - $Q_{yy} = 0.951+/-0.054$

2\textsuperscript{nd} State ($-1, 1$)

- Measured polarization:
  - $Q_y = 0.716+/-0.007$
  - $Q_{yy} = 0.738+/-0.068$

Preliminary
Result of polarization measurement \((\vec{p} \bar{d} \rightarrow p d)\)

**3\textsuperscript{rd} State \((0, -2)\)**

Measured polarization:

\[Q_y = -0.101 \pm 0.003\]

**4\textsuperscript{th} State \((0, 1)\)**

Measured polarization:

\[Q_y = -0.014 \pm 0.003\]

Tensor polarization \(Q_{yy}\) cannot be determined due to reduced signal caused by small value of \(Q_y\).

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**Graphs**

- Left graph: CR vs. \(\theta_{cm}^d\) [Deg]
- Right graph: CR vs. \(\theta_{cm}^d\) [Deg]

*Preliminary*
Result of polarization measurement \((p\bar{d} \rightarrow pd)\)

If vector polarization \(Q_y\) is closed to 0, luminosity ratio \(R_{Lu}\) and tensor polarization \(Q_{yy}\) can be determined by fitting

\[
\frac{N^p(\theta, \phi)}{N^0(\theta)} = R_{Lu} \left[ 1 + \frac{1}{4} Q_{yy} A_{yy}(\theta) (1 + < \cos 2\phi >) \right]
\]

**3rd State (0, -2)**

- \(R_{Lu} = 0.697 +/- 0.003\)
- \(Q_{yy} = -1.24 +/- 0.023\)

**4th State (0, 1)**

- \(R_{Lu} = 0.702 +/- 0.004\)
- \(Q_{yy} = 0.3032 +/- 0.026\)
Identification of $p\bar{d} \rightarrow \{pp\}n$ reaction.

Fewer deuterons in 2-track events

$p\bar{d} \rightarrow pd$ is isolated by building missing mass spectrum for 2-track events in STT

Shape of the background from the storage cell is simulated by nitrogen gas.
Preliminary result of $A_{yy}$ measurement for $p\vec{d} \rightarrow \{pp\}n$

CE reaction is not sensitive to deuteron vector polarization if $\{pp\}$ is in $^1S_0$ ($E_{\{pp\}} < 3\text{MeV}$)

$$\frac{N^p(\theta, q)}{N^0(q)} = R_{Lu} \left[1 + \frac{1}{4} Q_{yy} A_{yy}(q)(1+ < \cos 2\phi >)\right]$$

Ayy of CE reaction is measured using the tensor polarization extracted from $p\vec{d} \rightarrow p\vec{d}$, which is in a good agreement with the theoretical prediction.
Summary and Outlook

- Target commissioning experiment was successful.
- High performance of the target was achieved.
- Preliminary measurements of CE analysis powers are in good agreement with the theory.
- Production experiment was approved by COSY-PAC.
- Good physics results are expected.

Thank you