Polarized beam experiments with polarized internal storage cell targets at COSY/Jülich

26.September 2016, Bernd Lorentz
IKP4-FZJ and PAX collaboration
SPIN 2016
Outline

- Polarized beams at COSY
- Polarized target
- Low beta insertion
- PAX and TRIC experiment
- Summary and Outlook
Cooler Synchrotron (COSY)

- COSY accelerates and stores (polarized) protons / deuterons between 300/600 and 3700 MeV/c
- 4 internal and 3 external experimental areas
- Electron cooling at low momenta
- Stochastic cooling at high momenta
COSY CBS: Polarized H⁻/D⁻ Ion Source
EDDA Polarimeter

- two-layered cylindrical scintillator structure
  - Outer Layer (→ trigger!)
    - D: 32 overlapping slabs of triangular cross-section \((\Delta \phi = 11.25^\circ)\)
    - F,R: 2x29 semirings \((\Delta \theta_{\text{lab}} = 2.5^\circ)\)
      - left semirings \(\phi \in [-90^\circ, 90^\circ]\)
      - right semirings \(\phi \in [90^\circ, 270^\circ]\)
  - Inner Layer (H): 640 scintillating fibers
    → vertex reconstruction \((\sigma \approx 1\text{mm})\)
- Acceptance: \(\theta_{\text{lab}} \in [10^\circ, 72^\circ]\)
- Targets: CH\(_2\) and C fiber targets, polarized H and D atomic beam target.
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extension of polarimetry to lower energies
Spin Motion

Thomas-BMT equation (Thomas [1927], Bargmann, Michel, Telegdi [1959]):

\[
\frac{d\vec{S}}{dt} = \frac{e}{\gamma m} \vec{S} \times [(1 + \gamma G)\vec{B}_\perp + (1 + G)\vec{B}_\parallel ]
\]

Precession Equation in Laboratory Frame

Number of spin rotation per turn: \( \nu_p = \gamma G \)

\( G = \frac{g - 2}{2}, \ G_p = 1.7928473, \ G_p = 1.800, \ G_d = -0.142987 \)

Imperfection resonance:

\( \gamma G = k \)

Field and positioning errors of magnets

Resonance strength \( \sim y_{rms} \)

\( \rightarrow \) adiabatic spin flip (partial snake)
\( \rightarrow \) vertical orbit correction (reduce strength)
\( \rightarrow \) increase \( y_{rms} \) (increase strength – flip)

Intrinsic resonance:

\( \gamma G = (kP \pm Q_y) \)

\( P: \) super-periodicity
\( Q_y: \) vertical tune

\( \rightarrow \) vertical tune jumps
\( \rightarrow \) vertical coherent betatron oscillations

Spin 2016, B.Lorentz
Spin Motion

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Precession Equation in Laboratory Frame

Number of spin rotation per turn:

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v_p = \gamma G
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Field and positioning errors of magnets

Resonance strength ~ \(y_{rms}\)

→ adiabatic spin flip (partial snake)

Intrinsic resonance:

\[
\gamma G = (kP \pm Q_y)
\]

P: super-periodicity

Q_y: vertical tune

Vertical focusing fields

Resonance strength \(\sim \sqrt{\varepsilon_y}\)

→ vertical tune jumps

→ vertical orbit correction (reduce strength)

→ vertical coherent betatron oscillations

→ increase \(y_{rms}\) (increase strength – flip)
# Spin Resonances in Cosy

## Protons

<table>
<thead>
<tr>
<th>Momentum (GeV/c)</th>
<th>Kinetic Energy (GeV)</th>
<th>Imperfection Resonance</th>
<th>Intrinsic Resonance</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.464</td>
<td>0.108</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>0.835</td>
<td>0.318</td>
<td>6-</td>
<td></td>
</tr>
<tr>
<td>0.986</td>
<td>0.422</td>
<td>-1+</td>
<td></td>
</tr>
<tr>
<td>1.259</td>
<td>0.632</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>1.512</td>
<td>0.841</td>
<td>7-</td>
<td></td>
</tr>
<tr>
<td>1.634</td>
<td>0.946</td>
<td>0+</td>
<td></td>
</tr>
<tr>
<td>1.871</td>
<td>1.155</td>
<td>4</td>
<td></td>
</tr>
</tbody>
</table>

## Deuterons

### Depolarizing resonances for deuterons

- **Operation range**: 0.6 ≤ Fractional Tune ≤ 0.7
- **Momentum / MeV/c**: 0 ≤ 4000

<table>
<thead>
<tr>
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<th>Intrinsic Resonance</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.103</td>
<td>1.364</td>
<td>8-</td>
<td></td>
</tr>
<tr>
<td>2.217</td>
<td>1.469</td>
<td>1+</td>
<td></td>
</tr>
<tr>
<td>2.443</td>
<td>1.678</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>2.666</td>
<td>1.888</td>
<td>9-</td>
<td></td>
</tr>
<tr>
<td>2.776</td>
<td>1.992</td>
<td>2+</td>
<td></td>
</tr>
<tr>
<td>2.997</td>
<td>2.202</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>3.215</td>
<td>2.411</td>
<td>10-</td>
<td></td>
</tr>
<tr>
<td>3.324</td>
<td>2.516</td>
<td>3+</td>
<td></td>
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</tbody>
</table>
Polarized Proton Beam

Methods to preserve polarization

→ tune jumps
→ vertical orbit excitation

Achieved: $10^{10}$ protons with $P > 75\%$ at 3.3 GeV/c
Spin Flipping

Reversal of the polarization of the stored beam by crossing an artificial depolarizing resonance created by transverse RF-fields.

\[ f_{\text{res}} = (k + \gamma G) f_0 \]

Extensive studies carried out by Spin@Cosy collaboration (A.D.Krisch et.al, COSY crew …)

In use today: water cooled air core RF-solenoid (rf-power: \(~\text{kW}, \text{B-fields: } \sim\text{mT}\))

Example of application

\( \eta \)-mass determination in \( \text{d p} \rightarrow ^3\text{He } \eta \) at Anke

Use depolarizing resonance for accurate determination of beam momentum

\[ f_{\text{res}} = (1 + \gamma G) f_0 \]

\( \Delta p/p < 6 \times 10^{-5} \) at 13 momenta between 3100 and 3200 MeV/c

P.Goslawski et al., Physical Review Special Topics - Accelerators and Beams (Vol.13, No.2)
Spin Filtering Experiment
Polarized Antiproton Experiment (PAX)
Principle of Spin Filter Method

\[ \sigma_{\text{tot}} = \sigma_0 + \sigma_\perp \cdot \vec{P} \cdot \vec{Q} + \sigma_\parallel \cdot (\vec{P} \cdot \vec{k})(\vec{Q} \cdot \vec{k}) \]

P beam polarization
Q target polarization
k || beam direction

For initially equally populated spin states: \( \uparrow (m=+\frac{1}{2}) \) and \( \downarrow (m=-\frac{1}{2}) \)

**transverse case:**
\[ \sigma_{\text{tot}} = \sigma_0 \pm \sigma_\perp \cdot Q \]

**longitudinal case:**
\[ \sigma_{\text{tot}} = \sigma_0 \pm (\sigma_\perp + \sigma_\parallel) \cdot Q \]
**Principle of Spin Filter Method**

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- **Q target polarization**
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*Polarized H target*
**Principle of Spin Filter Method**

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- **P beam polarization**
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Polarized p (d) target using atomic beam source and storage cell

More details about target: G. Ciullo: contribution to this conference: 27 Sep 2016, 14:30
Low-\(\beta\) section

\[
\mu \frac{2}{\alpha \gamma c} \mu \frac{1}{2}
\]

- Significant reduction of the machine acceptance due to storage cell (\(d = 9.6\) mm, \(l = 400\) mm)
- Solution: low-\(\beta\) section

Regular Cosy optics

low beta optics
- The low-$\beta$ section allows one to use a storage cell of small diameter.
- The storage cell and the detector are placed inside the PAX target chamber.
- The magnetic holding field system allows one to control (flip/reorient) the direction of the polarized $\vec{d}$ inside the target.
Spin-filtering cycle

- Spin-flipper
- Cluster target + STT (beam polarimetry)
- COSY ring
- Polarized target

Graphs showing polarization buildup with filter time and deuteron asymmetry vs $\theta_2$.
Spin-filtering: result

- Milestone for the field

  - Confirms understanding of spin-filtering as a viable method to polarize a stored beam.
  - Confirms complete control of the systematics of the experiment.

Time Reversal Invariance Experiment at COSY (TRIC)

Polarized proton beam and polarized deuterium storage cell target

With the Pax installation possible at Cosy

Details tomorrow, 12:45
Yuri Valdau:
Preparation for the Time Reversal Invariance experiment at COSY (TRIC)
Ongoing developments
Openable Storage Cell

- At the PAX IP one can either install a closed or an openable cell.
- The latter, under preparation by the Ferrara group (2017), offers higher beam current for the TRIC experiment.
Breit Rabi Polarimeter

- During a test experiment in June 2016, the PAX atomic beam source and the Breit-Rabi polarimeter were commissioned with deuterium gas at COSY.
- Deuterium vector ($p_z$) and tensor ($p_{zz}$) polarizations of more than 0.75 were obtained.
PAX Detector

- $\varphi$-symmetric detection system
- 24 double-sided silicon strip detectors (300 $\mu$m, 300 $\mu$m, 1500 $\mu$m)
- Strip pitch of 0.7 mm results in a vertex resolution of $\leq$ 1 mm
- All spin observables measurable with $\varphi$-dependence ($\cos(\varphi)$, $\cos(2\varphi)$)

Setup and commissioning by COSY-PAX collaboration in 2017

Courtesy: PAX detector group
Siberian Snake

For longitudinal beam polarization a siberian snake solenoid was acquired
- 4.7 Tm superconducting solenoid
- on site at Jülich
- lab test ongoing
- preparation for installation in progress
- 2 weeks of commissioning beamtime recomended by Cosy Beam Advisory Committee (CBAC)

Longitudinal spin filtering possible
Conclusion and Outlook

COSY has all tools needed for the proposed polarized beam experiment
- Polarized protons and deuterons from ion source
- Methods for compensating depolarizing resonances during acceleration
- Fast beam polarimeter
- Spin manipulation tools (flipper)

PAX installation polarized internal p and d target, already operated for PAX
- Low beta section
- Storage cell
- Polarized target and polarimeter

Outlook
Priority of COSY operation shifted to the study of electric dipole moment of deuteron
(-> parallel session 'beam' Tuesday afternoon)

TRIC could be carried through in the near future
PAX longitudinal spin filter tests still on list of things to do