Towards Polarized Antiprotons at FAIR

http://www.fz-juelich.de/ikp/pax

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Outline

- PAX physics program
- Accelerator configuration for FAIR
- Towards polarized antiprotons
QCD Physics at FAIR (CDR): **unpolarized Antiprotons in HESR**

**PAX → Polarized Antiprotons**

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**Central PAX Physics Case:**

Transversity distribution of the nucleon in Drell-Yan:

- FAIR as successor of DIS physics
- last leading-twist missing piece of the QCD description of the partonic structure of the nucleon
- observation of $h_1^q(x,Q^2)$ of the proton for valence quarks ($A_{TT}$ in Drell-Yan $>0.2$)
  - transversely polarized proton beam or target (√)
  - transversely polarized antiproton beam (×)
PAX Physics Program

- Transversity
- Electromagnetic Form Factors
- Hard Scattering Effects
- SSA in DY, origin of Sivers function
- Soft Scattering
  - Low-\(t\) Physics
  - Total Cross Section
  - \(\bar{p}p\) interaction
Leading Twist Distribution Functions

Probabilistic interpretation in helicity base:

- $f_1(x)$
- $g_1(x)$
- $h_1(x)$

No probabilistic interpretation in the helicity base (off diagonal)

Transversity base

- $u^\uparrow = \frac{1}{\sqrt{2}} (u_R + u_L)$
- $u^\downarrow = \frac{1}{\sqrt{2}} (u_R - u_L)$

Probabilistic interpretation in helicity base:

- $q(x)$ spin averaged (well known)
- $\Delta q(x)$ helicity diff. (known)
- $\delta q(x)$ helicity flip (unknown)
Transversity

Properties:
- Probes relativistic nature of quarks
- No gluon analog for spin-1/2 nucleon
- Different $Q^2$ evolution than $\Delta q$
- Sensitive to valence quark polarization

Chiral-odd: requires another chiral-odd partner

Impossible in DIS

Direct Measurement

Indirect Measurement: Convolution of with unknown fragment. fct.
Transversity in Drell-Yan processes

Polarized antiproton beam $\rightarrow$ Polarized proton target (both transverse)

\[
A_{TT} \equiv \frac{d\sigma^{\uparrow\uparrow} - d\sigma^{\uparrow\downarrow}}{d\sigma^{\uparrow\uparrow} + d\sigma^{\uparrow\downarrow}} = \hat{a}_{TT} \frac{\sum_{q} e_{q}^{2} h_{1}^{q}(x_{1},M^{2})h_{1}^{\bar{q}}(x_{2},M^{2})}{\sum_{q} e_{q}^{2} q(x_{1},M^{2})\bar{q}(x_{2},M^{2})}
\]

$\sum_{q} e_{q}^{2} q(x_{1},M^{2})\bar{q}(x_{2},M^{2})$

$M$ invariant Mass of lepton pair
Proton Electromagnetic Formfactors

- Measurement of relative phases of magnetic and electric FF in the time-like region
  - Possible only via SSA in the annihilation $pp \rightarrow e^+e^-$

- Double-spin asymmetry
  - independent $G_E-G_m$ separation
  - test of Rosenbluth separation in the time-like region

\[ A_y = \frac{\sin(2\theta) \cdot \text{Im}(G_E^* G_M)}{\left[ (1 + \cos^2(\theta)) |G_M|^2 + \sin^2(\theta) |G_E|^2 \right]} / \tau \]

\[ \tau = q^2 / 4m_p^2 \]
Facility for Antiproton and Ion Research (GSI, Darmstadt, Germany)

- Proton linac (injector)
- 2 synchrotrons (30 GeV p)
- A number of storage rings
  → Parallel beams operation
PAX Collider Setup

Luminosity $> 10^{31}$ cm$^{-2}$s$^{-1}$
Intense beam of polarized antiprotons was never produced:

• Conventional methods (ABS) not applicable

• Polarized antiprotons from antilambda decay
  • $I < 1.5 \cdot 10^5 \text{ s}^{-1}$ ($P \approx 0.35$)

• Antiproton scattering off liquid $H_2$ target
  • $I < 2 \cdot 10^3 \text{ s}^{-1}$ ($P \approx 0.2$)

• Stern-Gerlach spin separation in a beam (never tested)

• 5/2006 (Th. Walcher et al.) polarized electron beam

Spin filtering is the only successfully tested technique
Principle of spin-filtering

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

- \( \sigma_{\text{beam}} \) beam polarization
- \( \sigma_{\text{target}} \) target polarization
- \( \vec{k} \parallel \) beam direction

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

**Transverse case:**

\[ \sigma_{\text{tot} \pm} = \sigma_0 \pm \sigma_{\perp} \cdot Q \]

**Longitudinal case:**

\[ \sigma_{\text{tot} \pm} = \sigma_0 \pm (\sigma_{\perp} + \sigma_{\parallel}) \cdot Q \]
Principle of spin-filtering

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

- P beam polarization
- Q target polarization
- k \parallel beam direction

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

**transverse case:**

\[ \sigma_{tot}^{\pm} = \sigma_0 \pm \sigma_\perp \cdot Q \]

**longitudinal case:**

\[ \sigma_{tot}^{\pm} = \sigma_0 \pm (\sigma_\perp + \sigma_\parallel) \cdot Q \]

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1992 Filter Test at TSR with protons

Experimental Setup

- Dissociator
- Beam Formation
- Sextupole
- HF-Transition
- Guide Field
- Storage Cell
- Circulating Beam
- p, α

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1992 Spin Filter Test at TSR with protons

Experimental Setup

Results

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Two interpretations of FILTEX result

Observed polarization build-up: \( \frac{dP}{dt} = \pm (1.24 \pm 0.06) \times 10^{-2} \text{ h}^{-1} \)
\[
P(t) = \tanh\left(\frac{t}{\tau_1}\right), \quad \frac{1}{\tau_1} = \sigma_1 Q dt
\]
\[
\sigma_1 = 72.5 \pm 5.8 \text{ mb}
\]

Spin filtering works! But how?

1994. Meyer and Horowitz: three distinct effects
1. Selective removal through scattering beyond \( \theta_{\text{acc}} = 4.4 \text{ mrad} \) \( \sigma_{R\perp} = 83 \text{ mb} \)
2. Small angle scattering of target prot. into ring acceptance \( \sigma_{S\perp} = 52 \text{ mb} \)
3. Spin-transfer from pol. el. of target atoms to stored prot. \( \sigma_{E\perp} = 70 \text{ mb} \)
\[
\sigma_1 = \sigma_{R\perp} + \sigma_{S\perp} + \sigma_{E\perp} = 65 \text{ mb}
\]

2005. Milstein & Strakhovenko + Nikolaev & Pavlov: only one effect
1. Selective removal through scattering beyond \( \theta_{\text{acc}} = 4.4 \text{ mrad} \) \( \sigma_{R\perp} = 85.6 \text{ mb} \)
No contribution from other two effects
\[
\sigma_1 = 85.6 \text{ mb}
\]

(\( \rightarrow \) more in next talk by N.N. Nikolaev)
Spin Filtering: Present Status

Spin filtering works, but:

1. Controversial interpretations of FILTEX experiment
   • Further experimental tests necessary
   • How does spin filtering work?
   • Which role do electrons play?
   → Tests with protons at COSY

2. No data to predict polarization from filtering with antiprotons
   → Measurements with antiprotons at AD/CERN
Spin Filtering studies at COSY

Goal:
- Understanding the spin filtering mechanism:
- Disentangle electromagnetic and hadronic contributions to the polarizing cross section
Polarizing cross sections from the two models

A measurement of $\sigma_{\text{eff}}$ to 10% precision requires polarization measurement with $\Delta P/P = 10\%$. 

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How to disentangle hadronic and electromagnetic contributions to $\sigma_{\text{eff}}$?

### Method 1: Polarization build-up experiments

**Injection of different combinations of hyperfine states**

- Different electron and nuclear polarizations
- Null experiments possible:
  - Pure electron polarized target ($P_z = 0$), and
  - Pure nuclear polarized target ($P_e=0$)

<table>
<thead>
<tr>
<th>Inj. states</th>
<th>$P_e$</th>
<th>$P_z$</th>
<th>Interaction</th>
<th>Holding field</th>
</tr>
</thead>
<tbody>
<tr>
<td>$</td>
<td>1\rangle$</td>
<td>+1</td>
<td>+1</td>
<td>Elm. + had.</td>
</tr>
<tr>
<td>$</td>
<td>1\rangle +</td>
<td>4\rangle$</td>
<td>0</td>
<td>+1</td>
</tr>
<tr>
<td>$</td>
<td>1\rangle +</td>
<td>2\rangle$</td>
<td>+1</td>
<td>0</td>
</tr>
</tbody>
</table>

**Strong fields can be applied only longitudinally (minimal beam interference)**

- Snake necessary

**AD Experiments require both transverse and longitudinal (weak) fields.**

**AD Experiments will be performed also with D target.**

**Target polarimetry requires BRP for pure electron and D polarization.**
Experimental setup

- Low-beta section
- Polarized target (former HERMES target)
- Detector
- Snake
- Commissioning of AD setup
Low beta section

$\beta_{x,y}^{\text{new}} = 0.3 \text{ m} \to \text{increase in density with respect to ANKE: factor 30}$

- Shorter buildup time, higher rates
- Larger polarization buildup rate due to larger acceptance
- Use of former HERMES target (more details in A. Nass’ 9A, Fr)

S.C. quadrupoles necessary for AD experiment
**ANKE vs new IP: Acceptance and Lifetime**

**Cross sections**

- **... only hadronic**
- **- electromagnetic + hadronic**

**Lifetimes**

- **COSY average** $\psi_{acc} = 1$ mrad
- **...** $\psi_{acc} = 2$ mrad
Figure of Merit at new IP

Calculation based on Budker-Jülich

$T^{\text{opt}} \sim 55$ MeV
ANKE vs new IP: Polarization

Expectations based on Budker-Jülich:

- $T = 40$ MeV
- $N_{\text{inj}} = 1.5 \times 10^{10}$ protons

<table>
<thead>
<tr>
<th>PIT</th>
<th>Filter. time</th>
<th>Polar.</th>
<th>Total rate</th>
<th>Meas. Time ($\Delta P/P = 10%$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ANKE</td>
<td>$2\tau = 16$ h</td>
<td>1.2 %</td>
<td>$7.5 \times 10^2$ s$^{-1}$</td>
<td>44 min</td>
</tr>
<tr>
<td></td>
<td>$5\tau = 42$ h</td>
<td>3.5 %</td>
<td>$5 \times 10$ s$^{-1}$</td>
<td>26 min</td>
</tr>
<tr>
<td>New IP</td>
<td>$2\tau = 5$ h</td>
<td>16 %</td>
<td>$2.2 \times 10^4$ s$^{-1}$</td>
<td>1 s</td>
</tr>
<tr>
<td></td>
<td>$5\tau = 13$ h</td>
<td>42 %</td>
<td>$1.5 \times 10^3$ s$^{-1}$</td>
<td>$&lt; 1$ s</td>
</tr>
</tbody>
</table>
Detector concept

- Will measure beam polarization by using the polarization observables:
  - p-p elastic (COSY)
  - pbar-p elastic (AD)
- Good azimuthal resolution (up/down asymmetries)
- Low energy recoil (<8 MeV)
  - Silicon telescopes
  - Thin 5µm Teflon cell needed
- Angular resolution for the forward particle for p-pbar at AD
- AD experiment will require an openable cell
Hans-Otto Meyer’s idea

“If polarized electrons polarize an initially unpolarized beam, then, unpolarized electrons should depolarize an initially polarized beam!”

Method 2: Depolarization experiments

Electrons in $^{4}\text{He}$ storage cell target:
- Large analyzing power
- Large counting rates

- Distinguish electron effect from normal depolarization in COSY
- Prerequisites:
  - Large beam lifetime
  - Large polarization lifetime

New Proposal for COSY turned in this week

Prediction for ANKE/COSY (4 weeks)
AD ring at CERN

Study of spin filtering in pbar-p (pbar-d) scattering

Measurement of effective polarization cross-section
  Both transverse and longitudinal
  Variable acceptance at target
  Polarized D target

First measurement for spin correlations in pbar-p (and pbar-D)

T = 5 - 2.8 GeV
N_p = 3 \cdot 10^7
Antiproton Beam Polarization
(Hadronic Interaction: Longitudinal Case)

Model A: T. Hippchen et al.,

Model D: V. Mull, K. Holinde,

3 beam lifetimes
Ψ_{acc}=20 mrad

2 beam lifetimes
Ψ_{acc}=10-50 mrad
<table>
<thead>
<tr>
<th>Year</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fall 2006</td>
<td>Submission of proposal to COSY-PAC</td>
</tr>
<tr>
<td></td>
<td>Beam depolarization studies</td>
</tr>
<tr>
<td></td>
<td>(Beam lifetime studies)</td>
</tr>
<tr>
<td>Spring 2007</td>
<td>Submission of FP 7 application</td>
</tr>
<tr>
<td>Fall 2007</td>
<td>Technical proposal to COSY-PAC for spin filtering</td>
</tr>
<tr>
<td></td>
<td>Technical proposal to SPSC for spin filtering at AD</td>
</tr>
<tr>
<td>2006-2007</td>
<td>Design and construction phase</td>
</tr>
<tr>
<td>2008-2009</td>
<td>Spin-filtering studies at COSY</td>
</tr>
<tr>
<td></td>
<td>Commissioning of AD experiment</td>
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<tr>
<td>2009</td>
<td>Installation at AD</td>
</tr>
<tr>
<td>2009-2010</td>
<td>Spin-filtering studies at AD</td>
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</tbody>
</table>

Quite a challenge in front of us:

Young (and less young) polarization enthusiasts are welcome!