Do unpolarized electrons affect the polarization of a stored proton beam?

Proposal # 13²

Dieter Oellers
Institut für Kernphysik
Forschungszentrum Jülich

for the ANKE and PAX Collaborations
QCD Physics at FAIR (CDR): \textit{unpolarized} Antiprotons in HESR

PAX $\rightarrow$ Polarized Antiprotons

\textbf{Central PAX Physics Case:}

Transversity distribution of the nucleon in Drell-Yan:
$\rightarrow$ FAIR as successor of DIS physics

\textit{requirements:}
- transversely polarized proton beam or target (✓)
- transversely polarized antiproton beam (✗)
Outline

• Physics Case

• Experimental Setup

& Required Machine Performance

• Beam Request
How to Polarize Antiprotons?

Only one experimentally tested method to make a beam:

**Spin-dependent attenuation of a stored beam**
(any spin-dependent loss filters spin of the stored beam)

contributing effects (qualitatively)

- **Nucleon-Nucleon:** scattering outside ring acceptance spin flip
- **Nucleon-Electron:** scattering outside ring acceptance spin flip
How to Polarize Antiprotons?

Only one experimentally tested method to make a beam:

**Spin-dependent attenuation of a stored beam**
(any spin-dependent loss *filters* spin of the stored beam)

**contributing effects (qualitatively)**

- **Nucleon-Nucleon:** scattering outside ring acceptance, spin flip
- **Nucleon-Electron:** scattering outside ring acceptance, spin flip

$$\Theta_{max} = \frac{m_e}{m_p} \approx 0.5 \text{ mrad}$$
FILTEX at TSR (1992)

Observed polarization build-up:

\[ \frac{dP}{dt} = \pm (1.24 \pm 0.06) \times 10^{-2} \text{ h}^{-1} \]

\[ P(t) = \tanh\left(\frac{t}{\tau_1}\right) \]

\[ \frac{1}{\tau_1} = \sigma_1 \cdot Q \cdot d_t \cdot f_{\text{rev}} \]

\[ \sigma_1 = 72.5 \pm 5.8 \text{ mb} \]

Spin filtering works! But how?

F. Rathmann. et al., PRL 71, 1379 (1993)
Two Interpretations

1994 Meyer and Horowitz: three distinct effects
1. Selective removal through scattering beyond $\theta_{acc} = 4.4$ mrad ($\sigma_{R\perp} = 83$ mb)
2. Small angle scattering of target proton into ring acceptance ($\sigma_{S\perp} = 52$ mb)
3. Spin-transfer from polarized electrons of target atoms to stored protons ($\sigma_{E\perp} = -70$ mb)

$$\sigma_1 = \sigma_{R\perp} + \sigma_{S\perp} + \sigma_{E\perp} = 65 \text{ mb}$$

2005 Milstein & Strakhovenko + Nikolaev & Pavlov:
only pp scattering contributes to polarization buildup
$$\sigma_1 = 85.6 \text{ mb}$$

Goal: Distinguish between this two interpretations
→ Do unpolarized electrons affect the polarization of a stored proton beam?
Basic Idea

If polarized electrons polarize an unpolarized proton beam then unpolarized electrons depolarize a polarized proton beam (H.O.Meyer)

Depolarization Experiment at $T_p=45$ MeV:
- $\rightarrow ^4\text{He}$ as unpolarized electron target
- $(d_t^e \approx 4 \cdot 10^{14} \text{ cm}^{-2})$

$P(t) = P_0 e^{-\frac{t}{\tau_p}}$

$\tau_p = \frac{1}{\sigma_{ep} \cdot f \cdot d_t \cdot Q^e}$

$\sigma_{ep}(45 \text{ MeV}) \sim 33 \text{ mb}$
Why first Depolarization Measurement, and not Polarization Buildup?

- Nikolaev: Spin-flip cross section limit:
  \[ \Delta \sigma_1(\theta < \theta_{acc}) \leq \Delta \sigma_0(\theta < \theta_{acc}) \]

- no low beta section available
- no strong guide field at ANKE PIT possible
  \[ \Rightarrow \text{new setup required (TP1)} \]
- Measurement possible with existing equipment
Outline

- Physics Case
- Experimental Setup & Required Machine Performance
- Beam Request
Beam Polarimetry

Efficient Analyzer required: p-\(^4\)He elastic scattering

Other advantages:
- \(^4\)He nucleus has spin 0
- High analyzing power (~0.9)
- Dense target via storage cell

\[ \theta_{\text{Lab}} = 140^\circ \]

\[ \text{FOM} = A_y^2 \cdot \frac{d\sigma}{d\Omega} \]
Experimental Setup (top view)

- Target cell: 20 x 200mm
- Proton beam
- Target density
- Silicon detectors measure $E, \phi, \Theta$
- $p$: $T = 17.8\text{ MeV}$, $\Theta = 140^\circ$
- $\alpha$: $T = 27.2\text{ MeV}$, $\Theta = 15^\circ$
General Requirements

- $>2 \cdot 10^{10}$ stack-injected protons
- $P > 0.7$
- Target density $> 2 \cdot 10^{14}$ cm$^{-2}$
- Electron cooling to compensate multiple scattering
Machine Tunes

Machine Resonances (upto 3\textsuperscript{rd} order)

- 1\textsuperscript{st} order
- 2\textsuperscript{nd} order
- 3\textsuperscript{rd} order

Depolarizing Resonances (upto 3\textsuperscript{rd} order)

- 2-Q\_x + 2Q\_y
- 2+Q\_x - Q\_y
- 9+2Q\_x + Q\_y
- 9-Q\_x - Q\_y
- 9-2Q\_x
- 9-2Q\_y
- 2-2Q\_x - Q\_y
- -2.Q\_x + 2Q\_y
- 2-Q\_x + Q\_y
- -2+2Q\_x - Q\_y

Dieter Oellers
Polarization Lifetime

\[ P(t) = P_0 e^{-\frac{t}{\tau_{p,\text{total}}}} \]

\[ \frac{1}{\tau_{p,\text{total}}} = \frac{1}{\tau_{p,\text{COSY}}} + \frac{1}{\tau_{p,\text{MH}}} \]

1. Polarization Lifetime of COSY is finite
2. Depolarizing target effect is about 100 times larger than residual gas effect

Special COSY cycle needed to obtain individual polarization lifetimes
COSY Cycle Setup

- Target-On time: $T_1$ and $T_3$
- Target-Off time: $T_2$

\[ \tau_{\text{total}} \]
\[ \tau_{\text{COSY}} \]

Significance:
\[ \sigma = \frac{\tau_{\text{MH}}}{\Delta \tau_{\text{Target}}} \]

Expected Significance:
4 – 5 $\sigma$ of target effect in 4 weeks of data taking
Required Machine Performance

\[ \sigma = \frac{\tau_{MH}^p}{\Delta \tau_{p}^{\text{Target}}} \]

- Dependence on polarization of beam:
  \[ \tau > 0.7 \]

- Dependence on beam lifetime with \( 2 \times 10^{12} / \text{cm}^2 \) \( ^4 \text{He} \) target:
  \[ \tau > 600 \text{ s} \]

- Dependence on beam lifetime without target:
  \[ \tau > 4000 \text{ s} \]

- Dependence on polarization lifetime without target:
  \[ \tau > 10000 \text{ s} \]

- Dependence on number of protons in beam:
  \[ # > 2 \times 10^0 \]

- Dependence on target density:
  \[ d_t > 2 \times 10^4 / \text{cm}^2 \]

Dieter Oellers
Summary of Requirements

- number of protons in beam $> 2 \cdot 10^{10}$
- initial beam polarization $P > 0.7$
- $\tau_{\text{beam\ target}} > 600$ s
- $\tau_{\text{beam\ notarget}} > 4000$ s
- $\tau_{\text{COSY}} > 10000$ s
- $d_t \sim 2 \cdot 10^{14}$ He/cm$^2$
- $\tau_{P\ MH} = 170000$ s

Dieter Oellers
Beam Request

- 3 weeks of machine development
  1st half of 2007 (ASAP) to provide:
  - required beam conditions
  - test of diagnostic systems and other tools

- 4 weeks of data taking
  2nd half of 2007
  - achieve 4–5 σ significance of target effect
1st Week:
maximize lifetime of beam
a) vacuum improvements (mass spectra in ring sections)
   - closed orbit corrections (Beam Position Monitors)
   - adjust betatron tunes
   - measure beam current and target density dependence
b) measure precisely $\beta$-functions using shunts

2nd Week
a) determine upper limit target density & optimize electron current
b) use barrier bucket cavity to increase target density
c) measure $\Theta_{\text{acc}}$, make it symmetrical
d) measure always beam emittance by $H^0$ diagnosis

3rd Week
a) operate and adjust spin flipper
   measure flip efficiency

maximize polarization lifetime
b) asymmetric acceptance studies using scrapers
   - optimize betatron tunes
   - improve beam polarization at injection
   - measure polarization lifetime

Spare Slides
More Requirements

- >2 \times 10^{10} \text{ stack-injected protons}
- \text{P} > 0.7
- \text{target density} > 2 \times 10^{14} \text{ cm}^{-2}
- \text{Electron cooling to compensate multiple scattering}

Beam Emittance Calculation

A. Smirnov (Dubna) using BetaCool

Horizontal and vertical beam emittance with \(2 \times 10^{14} \text{ He/cm}^2\) and \(I_e = 250 \text{ mA}\):
- \(t = 8\text{s}: \) the target is switched off
- \(t = 16\text{s}: \) reduced to \(I_e = 40 \text{ mA}\)
Fundamental equation

\[ \sigma^e_l (> \theta_{acc}) = \frac{1}{2} \int_{\theta_{acc}}^{\theta_{acc}} d\Omega \left( \frac{d\sigma}{d\Omega} \right) \left( A_{00nn} + A_{00ss} \right) \]

\[ \Delta \sigma_0 = \left[ \sigma^e_l (\leq \theta_{acc}) - \sigma^E_0 (\leq \theta_{acc}) \right] \]

\[ = \int_{\theta_{min}}^{\theta_{acc}} d\Omega \frac{d\sigma}{d\Omega} \left( 1 - \frac{1}{2} D_{n0n0} - \frac{1}{2} D_{s's0s0} \cos(\theta_{lab}) \right) \]

\[ \Delta \sigma_1 = \sigma^e_l (\leq \theta_{acc}) - \sigma^E_1 (\leq \theta_{acc}) \]

\[ = \frac{1}{2} \int_{\theta_{min}}^{\theta_{acc}} d\Omega \frac{d\sigma}{d\Omega} \left( A_{00nn} + A_{00ss} - K_{n00n} - K_{s's0s0} \cos(\theta_{lab}) \right) \]

Evolution of Beam Polarization \((z \sim t)\):

\[ P(z) = P(0) \exp(-N\Delta \sigma_0 z) + Q \frac{\Delta \sigma_1}{\Delta \sigma_0} \left\{ 1 - \exp(-N\Delta \sigma_0 z) \right\} \]

\(\Delta \sigma_0 = \text{spin-flip on unpolarized target}, \quad \Delta \sigma_1 = \text{spin-flip on polarized target}, \quad |\Delta \sigma_1| \leq |\Delta \sigma_0| \)
**Fundamental equation**

\[
d\sigma = d\sigma_0 \left\{ \frac{1}{2} \left( 1 + \frac{1}{2} PQ \left( A_{0onn} + A_{0oss} \right) \right) \right. \\
+ \left. \frac{1}{2} SP \left( D_{s'0s0} \cos \theta + D_{k'0s0} \sin \theta + D_{n0n0} \right) \right. \\
+ \left. \frac{1}{2} SQ \left( K_{s'00s} \cos \theta + K_{k'00s} \sin \theta + K_{n00n} \right) \right\} \\
\equiv \frac{1}{2} \left( 1 + SP \right) d\Sigma_{0,T} + \frac{1}{2} \left( 1 - SP \right) 2d\Delta\Sigma_{0,T} \\
+ \frac{1}{2} Q \left( P + S \right) d\Sigma_{1,T} + \frac{1}{2} \left( P - S \right) dQ \Delta\Sigma_{1,T}.
\]

**P:** Polarization of beam  
**S:** Polarization of scattered particle  
**Q:** Polarization of target
Detectors

double sided Silicon Detectors (one missing)

preamplifier electronics
Depolarizing Measurements at 500MeV

Data from July 2003

proton beam depolarization. 0.5 GeV

\[ \frac{\varepsilon(t)}{\varepsilon(0)} \]

\[ \chi^2 = 1.3 / 3 \quad C_L = 0.83 \]

\[ \tau = (28.5 \pm 1.8) \text{ min} \]

G. Macharashvili, Pax Note 5/2006

Dieter Oellers
Depolarizing Measurements at 800MeV

Data from July 2003
proton beam depolarization. 0.8 GeV

\[ \tau = (407 \pm 164) \text{ min} \]
\[ \chi^2 / \nu = 1.1 / 3, \text{ CL } = 0.90 \]

COSY working point

G. Macharashvili, Pax Note 5/2006

Dieter Oellers