Polarisation of antiprotons by means of spin-flip interaction with positrons

Why it probably does not work.

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POLARISED ANTIPROTON BEAMS - HOW?
Daresbury, 29. 08. 2007

Publications

- A surprising method for polarising antiprotons.
  Th. Walcher, H. Arenhövel, K. Aulenbacher, R. Barday, and A. Jankowiak
  arXiv:0706.3765, accepted by EPJ A
- Coulomb effects in polarisation transfer in elastic antiproton and proton electron scattering at low energies.
  H. Arenhövel
  arXiv:0706.3576, accepted by EPJ A

Outline

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1. Physics motivation and basic idea
2. Polarisation transfer probability $\langle P_{zz}\sigma \rangle$
   for electron/positrons to proton/antiprotons
3. Intense source of polarised positrons
4. Realisation in storage rings: two design examples
5. Discussion

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- $\bar{p}p$ scattering and annihilation at very low energies, $N\bar{N}$ potential from s- and p-wave interaction: study of QCD at low Q^2 $\curvearrowright$ effective degrees of freedom in QCD
- spectroscopy in $\bar{p}p$ annihilation: meson spectroscopy $\curvearrowright$ effective quark models
- GPDs, transversity, Sivers and all that: spin degrees of freedom $\curvearrowright$ non-perturbative QCD

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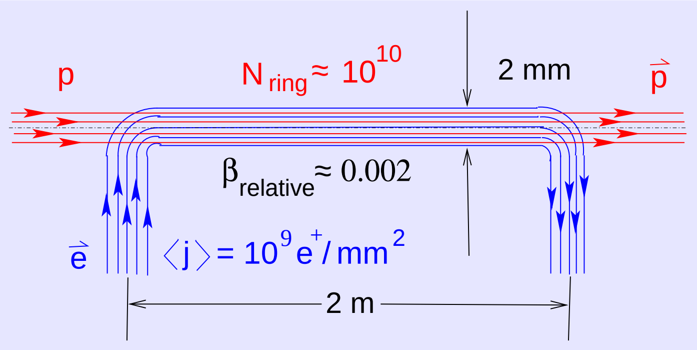
Basic idea

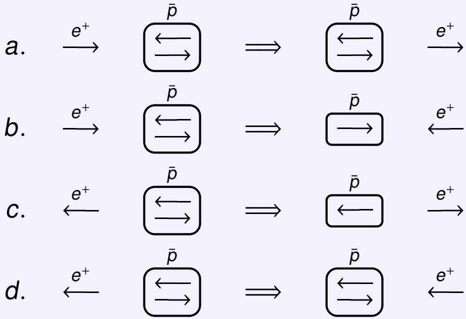


needed:

- probability for spin-transfer $\vec{e} + \bar{p} \rightarrow \vec{\bar{p}} + e$
  more precisely: “cross section” for spin-flip
  i.e. probablity for spin-flip hyperfine interaction of positrons with antiprotons
- intense source of polarised positrons

Realisation in a storage ring
spin-flip details

four possibilites of polarisation transfer interactions:



Polarisation transfer cross section

probability for polarisation transfer (sometimes "spin transfer") in

$$\vec{e}^{\pm} + \vec{N} \rightarrow \vec{N} + e^{\pm}$$

classical problem of application of QED

$$\sigma(\lambda_{h_f}, \lambda_{h_i}, \lambda_{l_i}) = (1 + \lambda_{h_f}\lambda_{h_i})\sigma_0 + \lambda_{l_i}(\lambda_{h_i} + \lambda_{h_f})\langle P_{zz}\sigma\rangle + \lambda_{l_i}(\lambda_{h_i} - \lambda_{h_f})\langle P_{zzz}\sigma\rangle$$

transfer of polarisation of charged leptons (l) to unpolarised hadrons (h):
$\lambda_{h_i} = 0,\ \lambda_{h_f} = \pm 1,\ \lambda_{l_i} = 1$, i.e. case a. and d.:

$$\sigma(\pm 1, 0, 1) = \sigma_0 + (\pm 1)\langle P_{zz}\sigma\rangle = \sigma_0 \pm \langle P_{zz}\sigma\rangle$$

transfer of polarisation of charged leptons (l) to polarised hadrons (h):
$\lambda_{h_i} = \mp,\ \lambda_{h_f} = \pm 1,\ \lambda_{l_i} = 1$, i.e. case b. and c.:

$$\sigma(\mp 1, \pm 1, 1) = \sigma_0 \pm \langle P_{zz}\sigma\rangle \left\{ \begin{array}{ll} 2 : & \lambda_{h_i} = \lambda_{h_f} \\ 0 : & \lambda_{h_i} = -\lambda_{h_f} \end{array} \right\} \pm \langle P_{zzz}\sigma\rangle \left\{ \begin{array}{ll} 0 : & \lambda_{h_i} = \lambda_{h_f} \\ 2 : & \lambda_{h_i} = -\lambda_{h_f} \end{array} \right.$$

Polarisation transfer cross section

calculation of $\langle P_{kl}\sigma\rangle$ three stages of approximation:

1. high energies: plane wave approximation
   used for determination of electric form factor of G_E^p and G_E^n
   (Arnold, Carlson, and Gross, 1981)
2. medium energies: global correction of wave distortions by taking the value of Coulomb wave function at origin
   (Horowitz and Meyer, 1994)
3. low energies: exact integration of Coulomb wave functions
   (Arenhövel, 2007)

result in plane wave Born approximation:

$$P_{kl}\frac{d\sigma^0}{d\Omega_h} = \frac{4\,c_s}{q^2}(\hat{q}_k\hat{q}_l - \delta_{kl}) = \frac{4\,c_s}{q^2}\begin{cases} 0 & : \quad \hat{q}_k = \hat{q}_l \ \text{ or } \ k \neq l \\ -2 & : \quad \hat{q}_k = -\hat{q}_l \ \text{ and } \ k = l \end{cases}$$

Polarisation transfer cross section
with exact Coulomb corrections

- T matrix

$$T_{fi}^{DW} = T_{fi}^{C} + T_{fi}^{ss,DW}$$

- nonrelativistic Coulomb amplitude

$$T_{fi}^{C} = -\frac{4\pi\alpha Z_h}{\vec{q}^2}\, e^{i\phi_c(\theta)}$$

- distorted wave hyperfine amplitude

$$T_{fi}^{ss,DW} = \langle \psi_f^{C(-)} | V^{ss} | \psi_i^{C(+)} \rangle$$

- hyperfine interaction

$$V^{ss} = -\frac{\pi\alpha Z_h \mu_h}{mM}\Big(\vec{\sigma}_e \cdot \vec{\sigma}_h \Delta - (\vec{\sigma}_e \cdot \vec{\nabla})(\vec{\sigma}_h \cdot \vec{\nabla})\Big)\frac{1}{r}\,.$$

Polarisation transfer cross section
Coulomb-hyperfine interaction interference

$$P_{kl}\frac{d\sigma^0}{d\Omega_h} = \frac{1}{16\pi^2}\frac{M_e^2 M_h^2}{W^2} \times \mathrm{Trace}(T_{fi}^{\dagger}\gamma_5 \not{S}_h(k) T_{fi}\gamma_5 \not{S}_e(l)),$$

- only even rank tensors contribute in the Trace
- lowest order contribution to spin dependent scattering (no spin flip): interference of Coulomb and hyperfine interaction
- central Coulomb and spin-orbit interaction do not contribute

Polarisation transfer cross section
the difficulties

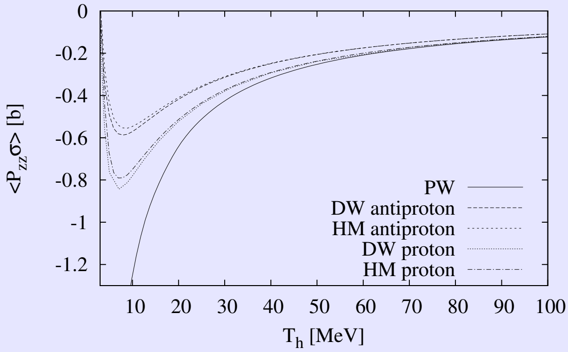
- essential problem: integration over the rapidly oscillating Coulomb wave functions
- solution: S.B. Levin, E.O. Alt, and S.L. Yakovlev, *Real-axis integral representation for the two-body Coulomb scattering wave function*, preprint MZ-TH/01-30 (unpublished).
- needed total cross sections: integration over solid angle down to θ_{min}

$$\theta_{min} = 2\arctan\left(\frac{\eta_c}{p}\frac{1}{b}\right)$$

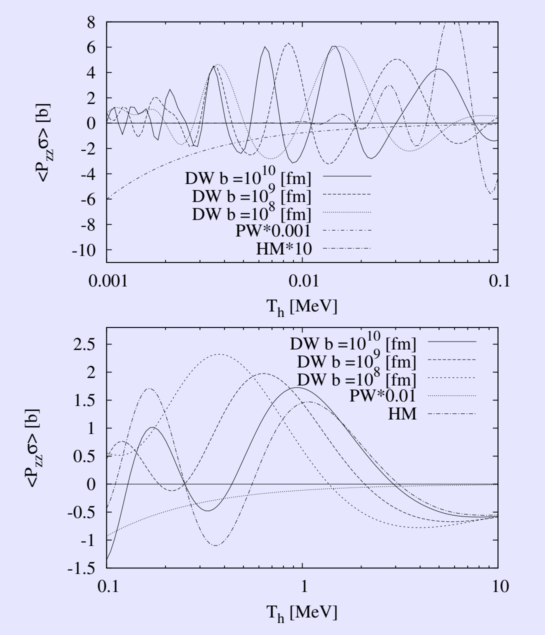
- estimate of impact parameter b:

$$b \gtrsim \frac{1}{2}\sqrt[3]{n_e/e} \approx 10^{11}\,\text{fm}$$

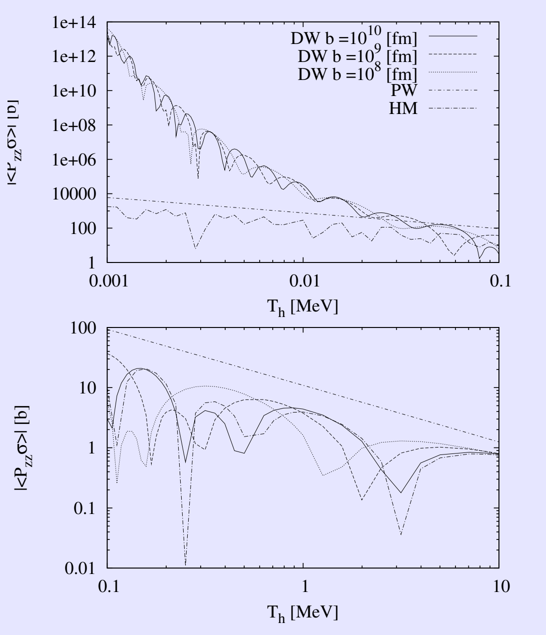
Polarisation transfer cross section
results



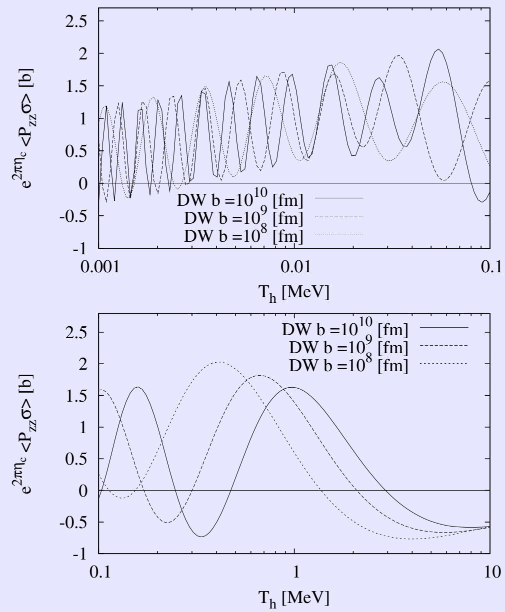
proton- and antiproton-electron interaction



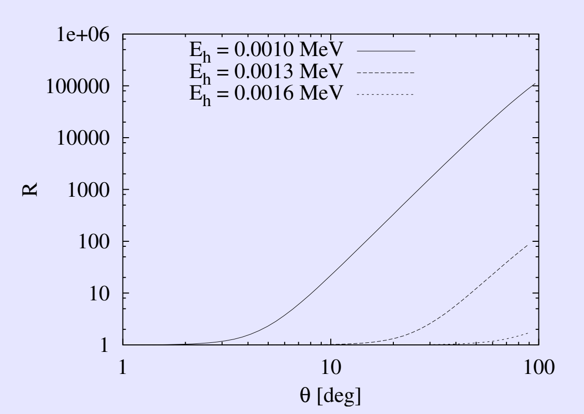
antiproton-electron interaction: like charge signs $\curvearrowright$ repulsion



proton-electron interaction: unlike charge signs $\curvearrowright$ attraction



proton-electron interaction: divided by $e^{-2\pi\eta_c}$



ratio of unpolarized differential cross section with spin contribution (i.e. Arenhövels DW calculation) over Rutherford cross section

Conclusion

We did not get ready with a final conclusion for this workshop.
The hope that the spin flip method works is low.