About stored, polarized particles

ANKE/PAX Workshop on Spin Physics
May 30 – June 1, 2007, Ferrara, Italy

H.O. Meyer, Indiana University

…physics with polarized anti-protons?

Our dream of useful polarized anti-proton beams is >20 y old:

Bodega Bay, 1985 (Krisch, Chamberlain, organizers)

interaction with external fields

Synchrotron radiation

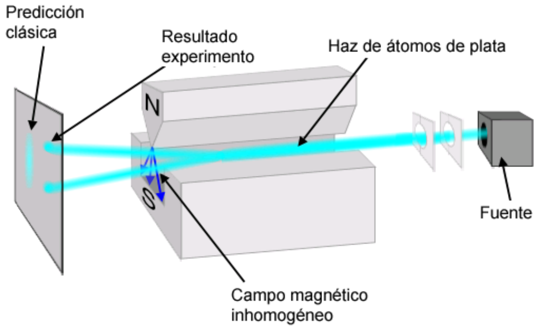
HE electron ring: P_e~0.8 in 1 h !
but effect goes with $\mu \cdot (\gamma^4 / R)$
In 20 TeV $\bar{p}$ ring, $\tau_{pol} \approx 10^7\, y$
(stimulation by circularly polarized EM radiation? Needs X-ray laser)

Stern-Gerlach effect

B field gradient (e.g., in a quadrupole) separates magnetic substates. Effect averages out in 1 betatron oscillation. Needs snake beteen quadrupoles. Effect never demonstrated in 20 y of trying.

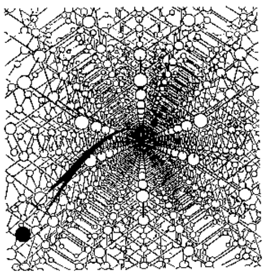
Stochastic polarization

Analogous to stochastic cooling
Sense magnetic moment at one location; kick at another
Van der Meer: signal to noise ~ 10^{-42}



atomic interactions

Polarization during channeling
Magnetized single-crystal Fe foil



Atomic beam source
Make anti-hydrogen atoms and treat as in conventional ABS. Supply problem.

Dynamic nuclear polarization
$\bar{p}$ immersed in co-moving polarized e beam.
Microwave radiation to stimulate spin exchange.

Kleppner: $\frac{1}{P}\frac{dP}{dt} \approx 10^{-5}\ s^{-1}$

Can we make polarized e with sufficient density?

scattering and reactions

Polarization at $\bar{p}$ production

Polarization is large where cross section is small. Unfavorable phase space.

Spin filter

If $\sigma_{tot}(\uparrow\uparrow) \neq \sigma_{tot}(\uparrow\downarrow)$

Depopulate one spin state faster than the other.

Spin transfer in strong interaction

Small-angle scattering (within ring acceptance) from polarized target (p or d) in Coulomb-nuclear interference region.

Spin transfer in $\bar{p} + e$ scattering

Electrons either in a trap, co-moving beam or in polarized target atoms

some observations:

1. all methods that are not clearly crazy need a storage ring

2. demonstrated methods to polarize nuclei involve discarding unwanted spin states.

3. lossless methods would require a selective spin flip (or spin exchange with a polarized target of some sort)

4. proposed methods involve long processing times. Need long beam lifetimes, long polarization lifetimes.

5. stringent control and thorough understanding of ring will be required. Need help from accelerator physicists.

beam depolarization

PHYSICAL REVIEW D VOLUME 33, NUMBER 7 1 APRIL 1986

Spin depolarization of a polarized antiproton beam by electron cooling

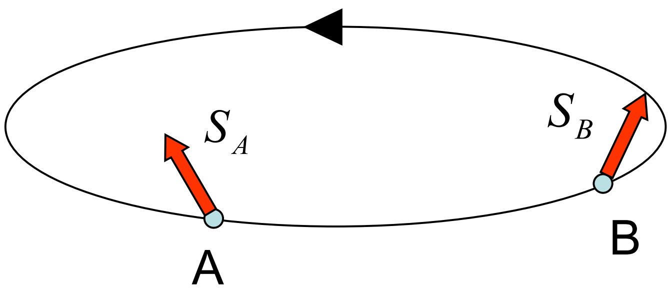
L. W. Anderson
Department of Physics, University of Wisconsin, Madison, Wisconsin 53706
(Received 16 October 1985; revised manuscript received 7 January 1986)

A polarized beam of antiprotons can be depolarized by the random collisions with electrons that occur in electron-beam cooling. An estimate shows that the depolarization rate is very small so that electron-beam cooling can be used with polarized antiprotons with negligible loss of polarization.

!

Why does a stored beam depolarize?

spin motion in a ring (S = 1/2)



$$S_B = T(\vartheta_B, \vartheta_A) \cdot S_A$$

"spin transfer matrix"

one full turn: $T(\vartheta_A + 2\pi, \vartheta_A) = OTM$ = rotation by $2\pi\nu_s$ around axis $\hat{n}_{CO}$

"one-turn map" "spin tune" "spin closed orbit"

⇨ if $S \parallel \hat{n}_{CO}$ then S is stable

⇨ if $S \perp \hat{n}_{CO}$ then S precesses ν_s times per turn around $\hat{n}_{CO}$

⇨ in a perfect machine (only vertical B fields):

$\hat{n}_{CO}$ is vertical, and $\nu_s = G\gamma$ (protons: $G = 1.79285$)

non-vertical fields

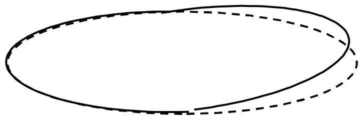
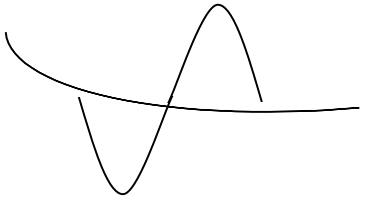
…cause periodic spin kicks

K kicks per turn → resonance condition $G\gamma = K$

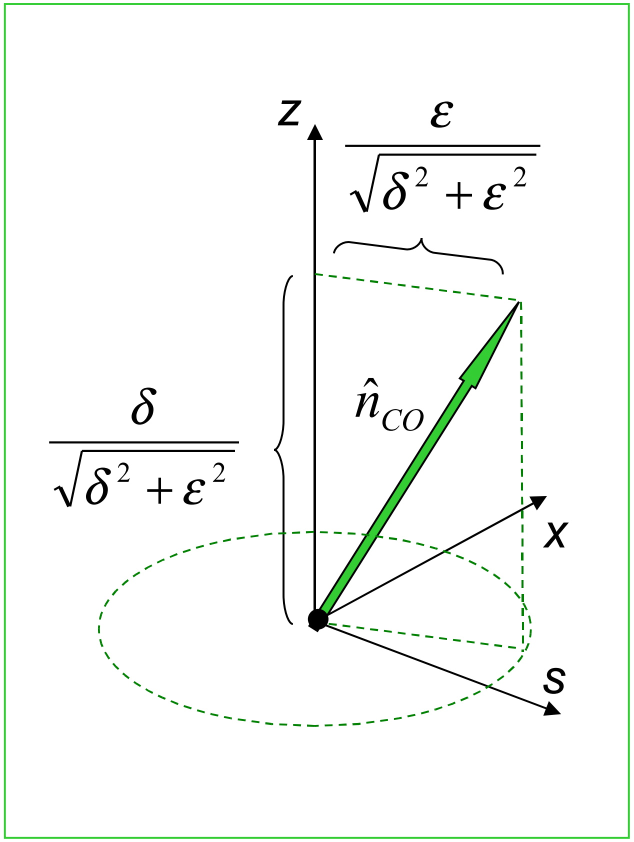
ε = resonance strength

(depends on non-vertical field value)

examples of resonances:

	orbit error	"imperfection" resonance	*K* = integer
	focusing fields	"intrinsic" resonance	*K* = integer $\pm\nu_v$ "vertical tune"

spin closed orbit near a resonance



$\hat{n}_{CO}$ is no longer vertical

ε = resonance strength

$\delta = K - G\gamma$ distance from resonance

⇨ when energy changes slowly, $\hat{n}_{CO}$ changes, but S follows and vertical polarization decreases, but *beam stays polarized*

⇨ on top of intrinsic resonance, $\hat{n}_{CO}$ is in *s*-*x* plane, rotates around *z* (→ spin flipper)

S precesses around $\hat{n}_{CO}$

⇨ so far no loss of polarization !

spin dispersion

particle beam has momentum spread and betatron amplitude spread

leads to spread of δ spread of ε

⇨ individual particles now have different $\hat{n}_{CO}$ which precesses at a different rate,
thus ensemble decoheres and polarization is lost

⇨ any mechanism that affects the $\hat{n}_{CO}$ of individual particles contributes to depolarization

depolarization by scattering ?

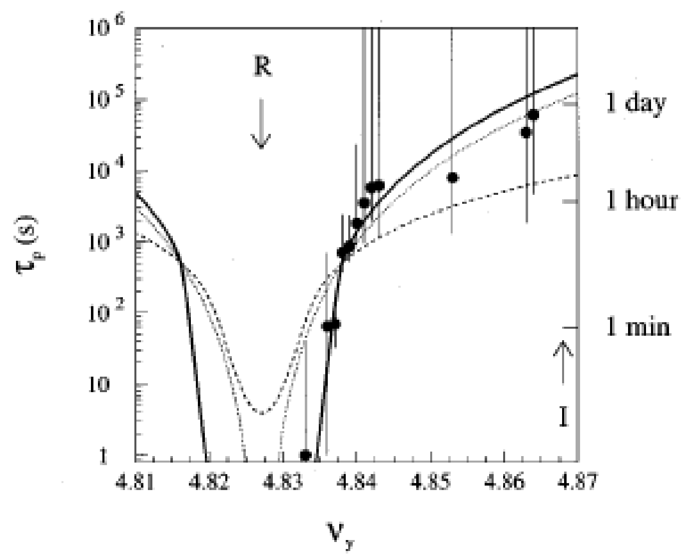
PHYSICAL REVIEW E VOLUME 56, NUMBER 3 SEPTEMBER 1997

Polarization lifetime near an intrinsic depolarizing resonance

H. O. Meyer,[1] B. Lorentz,[2] M. Dzemidzic,[3] J. Doskow,[3] W. Haeberli,[2] P. V. Pancella,[4] R. E. Pollock,[1] B. v. Przewoski,[3]
F. Rathmann,[2] T. Rinckel,[3] F. Sperisen,[3] and T. Wise[2]
[1]*Department of Physics, Indiana University, Bloomington, Indiana 47405*
[2] *University of Wisconsin–Madison, Madison, Wisconsin 53706*
[3]*Indiana University Cyclotron Facility, Bloomington, Indiana 47405*
[4]*Western Michigan University, Kalamazoo, Michigan 49008*
(Received 8 April 1997)

200 MeV proton beam near
$G\gamma = 7 - \nu_{y}$ intrinsic resonance

N_2 target of ~ 10^{14} molecules/cm^2



target effect

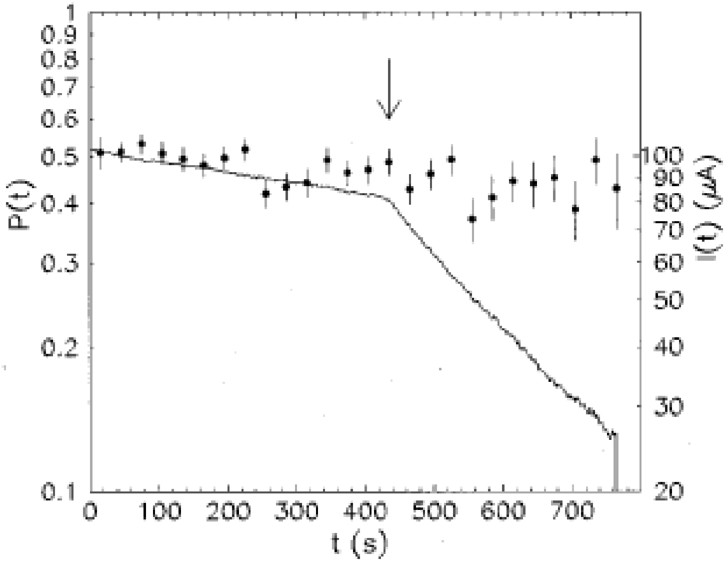


FIG. 4. Beam current (solid line, right-hand scale) and polarization (points, left-hand scale) as a function of time during a run for which $\nu_y = 4.842$. The arrow indicates the time at which the additional nitrogen target was turned on.

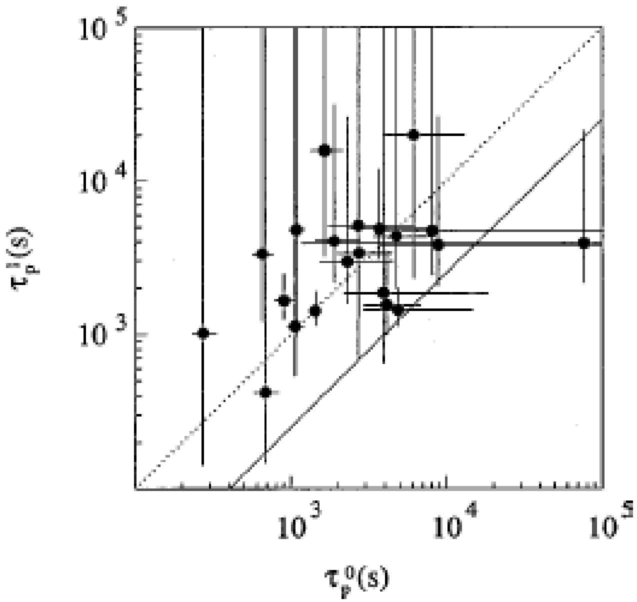


FIG. 5. Comparison of the polarization lifetimes τ_p^1 and τ_p^0 with and without an additional nitrogen target. The N_2 target lowers the beam lifetime by about a factor of 4. The data are expected to lie on the solid line if the polarization lifetime were proportional to the beam lifetime, as required by the mechanism discussed in Sec. II C. The dashed line shows the locus which is expected if there is no effect of the target on the polarization lifetime.

target effect expected but not seen, not clear why…

conclusion

better understanding and control
of stored polarization
is needed for future COSY test of
spin transfer in $\overline{p} + e$ scattering.