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INTERNAL HYDROGEN OR SOLID TARGETS AND POLARIZATION EXPERIMENTS

AT LEAR

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INTRODUCTION

The complicated partial wave structure together with the strong inelasticity of the $\bar{p}$ -p system starting right at threshold holds the promise to make polarization experiments at LEAR interesting and rich in information^{1,2,3}. Double scattering experiments or hyperon decay techniques will be powerful tools in this field. Experiments at present foresee to use the external beam to pin down spin effects. In the present note we want to sketch the advantages of an internal target⁴ for the purpose to control the spin degrees of freedom in the $\bar{p}$ -p entrance channel.

In section 1. we compare the problems and merits of $\bar{p}$ interactions on an internal polarized atomic hydrogen target similar to the jet target foreseen for the SPS⁵. In section 2, we discuss the possibilities to obtain polarized antiprotons via scattering on internal targets. Finally, in section 3, we indicate conditions needed to obtain a stored polarized antiproton beam in LEAR which could then be used for experiments on an internal or external polarized target.

It is worthwhile to recall here the general advantages of an internal target in conjunction with phase-space cooling of the circulating beam as first discussed by Budker et al.¹⁰.

- (a) "Recirculation" of all particles after each traversal of the target except for those who undergo reactions or scattering by an angle which cannot be corrected by the cooling system;

- (b) Extremely sharp energy resolution, limited only by the cooling strength and/or Landau broadening in $\bar{p}$ target interactions;
- (c) High angular resolution by having a thin beam (low beta optics) or a thick beam (high beta) and a narrow target;
- (d) Absence of multiple interactions in the target (which can be extremely thin because of (a) above without loss of efficiency). Hence, conservation of all kinematical correlations.

The price to pay for these advantages is the interference with the ultra-high vacuum of the ring and the problems of particle detection inside or close to the machine.

1. ANTIPROTON SCATTERING ON AN INTERNAL POLARIZED PROTON TARGET

A polarized atomic beam H^0 source has been developed and is proposed as an internal target for an SPS experiment⁵. The same type of target can be used at LEAR.

This source provides a proton polarization of $\sim 90\%$ in a thermal H^0 beam which has no other contamination. The polarization can be guided and freely oriented in a weak magnetic field. It is possible to flip the proton spin and/or to orient it transversely or longitudinally with respect to the $\bar{p}$ beam. A target thickness of $5 \times 10^{-12} \text{ g/cm}^2$ (i.e. $\sim 3 \times 10^{12} \text{ protons/cm}^3$ assuming 1 cm thickness) seems feasible⁵.

The emittance growth induced by multiple scattering on such a target corresponds to the growth induced by a LEAR vacuum of $\sim 1.4 \times 10^{-9} \text{ mbar}$ (H_2 equivalent) all around the ring. This emittance growth can be compensated by stochastic cooling for momenta $< 500 \text{ MeV/c}$ and it is negligible for higher momenta.

With $10^{10} \bar{p}$ stored at 1 GeV/c such a polarized target leads to $> 10^4 \bar{p}$ - $p^\uparrow$ interactions per second while using up just the interacting $\bar{p}$. The same $\bar{p}$ - $p^\uparrow$ interaction rate is reached on an external target which has 150 mg/cm^2 protons when it is illuminated with the full $\bar{p}$ current of $10^6 \bar{p}$ per s. This proton density corresponds to about 0.8 g/cm^2 of a standard polarized target which contains $> 0.6 \text{ g/cm}^2$ heavy nuclei, with a correspondingly important degradation of energy resolution and correspondingly strong background reactions.

The advantages of the internal target in antiproton economy, target purity, ease of spin orientation, polarization at low energy and angular resolution are thus evident.

2. POLARIZED EXTERNAL ANTIPROTON BEAMS AFTER SCATTERING ON AN INTERNAL HYDROGEN OR CARBON TARGET

Hadronic scattering in general is a source of polarized outgoing particles. Bradamante⁶ has studied $\bar{p}$ scattering on Carbon and found that there might be a useful degree of polarization which, however, remains to be measured. Antiproton scattering on unpolarized protons may be attractive. It produces quite pronounced $\bar{p}$ polarizations at forward angles where the cross-section is large. This can be inferred from $\bar{p}$ scattering data on polarized protons. An example is shown in Fig. 1 for 910 MeV/c⁷.

Fig. 1: Analysing power of antiprotons scattered on polarized protons (from reference 7).

Into a solid angle $\Delta\Omega(\theta)$ we can get from a $\bar{p}$ consumption I_0 a scattered $\bar{p}$ flux of

$$\Delta I(\theta) = \frac{(d\sigma_{\text{elast}}/d\Omega)}{\sigma_{\text{total}}^{\text{hadronic}}} I_0 \cdot \epsilon \Delta\Omega \quad (\sigma_{\text{total}}^{\text{hadronic}} \text{ at } 910 \text{ MeV/c amounts to about } 130 \text{ mb})$$

Here ϵ is the target efficiency shown in Fig. 2a and 2b for external and internal unpolarized hydrogen targets. The internal target is more economic (Fig. 2b) and it provides the best obtainable brilliance and rate if we operate it such that it "eats up" the available average flux of $\bar{p}$ ($\sim 10^6 \bar{p}/s$ from PS+AA). For this case, and a solid angle of 10 msr we show in Table 1 the quantity $P^2(\theta) \cdot \Delta I(\theta) / I_0$ which is a figure of merit for a polarized beam and for the economic use of the available $\bar{p}$.

Fig. 2: Strong interaction efficiency for (a) external hydrogen target which allows for a certain cm resolution $\Delta\sqrt{s}$; (b) for an internal hydrogen target

We also show in Table 1 how the energy of elastically scattered antiprotons varies with angle θ .

Table 1

Example of $\bar{p}$ polarization by scattering on an internal proton target at 910 MeV/c into 10 msr

(Note that on an external scatterer the figure of merit has to be multiplied by the corresponding efficiency $\epsilon \lesssim 1$ which is shown in figure 2a).

Scattering angle (degrees)		Differential cross-sections (mb/sr)		Polariz. from the theoretical curve	Figure of merit ($\epsilon \approx 1$)	kinematic momentum shift
θ^*	θ_{lab}	$\frac{d\sigma}{d\Omega^*}$	$\frac{d\sigma}{d\Omega_{lab}}$	P (experim. points are higher)	$\frac{P^2 \Delta I(\theta)}{I_0}$	$\frac{scat. mom.}{beam mom.}$
0	0			0	0	1
36.9	17.0	13	58	0.2	$178 \cdot 10^{-6}$	0.94
45.6	21.0	7.3	31	0.24	$137 \cdot 10^{-6}$	0.911
53.1	24.6	4.2	17	0.28	$103 \cdot 10^{-6}$	0.88
60.0	27.8	1.7	6.6	0.3	$46 \cdot 10^{-6}$	0.85

This kinematic effect is a drawback for the light proton targets and becomes important if one wants to accept large $\Delta\theta$. A polarizer with larger atomic number e.g. ^{12}C looks more favourable in this respect but it has the disadvantage that Coulomb scattering which increases with Z^2 , will provoke more important losses.

In fact, ^{12}C e.g. can be used as an internal scatterer and polarizer in LEAR in an exciting and attractive way: a Carbon fiber of, say, 1μ diameter which crosses vertically oriented (the low density tail of) the circulating $\bar{p}$ current acts as a scatterer of extremely high brilliance. The "source" is $\sim 1 \mu$ wide and has a vertical size equal to the beam height. This eventually allows to extract a scattered polarized $\bar{p}$ beam of unbeatable low overall emittances. One could even dream to put the fiber into straight section 1 of LEAR and scatter into the usual extraction channel.

If the $\bar{p}$ beam has a horizontal width $W \approx 1 \text{ cm}$ then the 1μ fiber sees only a fraction $f < \frac{1\mu}{W} = \frac{1\mu}{1\text{cm}} = 10^{-4}$ of the circulating current. The overall effective target thickness is the fiber thickness (1μ ^{12}C layer corresponds to $\sim 10^{-4} \text{ g/cm}^2$) multiplied by f and we find in our example an effective ^{12}C target of $\sim 10^{-8} \text{ g/cm}^2$.

This would produce 10^6 $\bar{p}$ scattered per second at ~ 1 GeV/c if we store $\sim 10^8$ $\bar{p}$ in LEAR. It is worthwhile to note that all stored $\bar{p}$ will have a chance to hit the fiber after some time, as they perform betatron oscillations. In fact, by putting the fiber near the edge of the beam and inducing a particle diffusion towards it the rate of interactions can be varied in a controlled manner. Rf noise can be used much like in the stochastic extraction process⁸, to induce particle migration over a given range of aperture and to control the beam density at the target position. By working in a low density tail relatively thick (10 μ) fibers are still acceptable.

Note also that filament targets are compatible with UHV conditions and that they are of unbeatable simplicity. They look thus very interesting for antiproton nuclear physics studies.

3. THE FILTER METHOD TO OBTAIN A POLARIZED STORED ANTIPROTON BEAM

The idea is to pass an initially unpolarized antiproton beam stored in LEAR through a transversally polarized internal (proton) target e.g. with polarization up ($\uparrow$). Assume that the singlet and triplet cross-sections are different (e.g. $\sigma_{\downarrow\downarrow} > \sigma_{\uparrow\uparrow}$). After a while, polarization ($\uparrow$) will be enriched in the stack of $\bar{p}$ that remain in the machine (the sample of particles which have not interacted). Polarization goes therefore on the expense of circulating antiproton density. The idea has already been discussed in 1968 for protons in the ISR⁹. But only with the availability of phase-space cooling there might be a chance to realize it especially at LEAR energies^{10,11} since one needs quite long filtering times and, in addition, compensation of multiple Coulomb scattering.

With beam and filter target polarization vectors $\vec{P}_b$ and $\vec{P}_T$ and beam direction $\vec{k}$, the polarized total cross-section for $\bar{p}p\uparrow$ can be written as

$$\sigma_t = \sigma_o + \frac{\sigma_T}{2} \vec{P}_b \cdot \vec{P}_T + \sigma_2 (\vec{P}_b \cdot \vec{k}) (\vec{P}_T \cdot \vec{k})$$

The last term vanishes if we have transverse target polarization $\vec{P}_T \cdot \vec{k} = 0$ and we have

$$\sigma_t = \sigma_o + \frac{\sigma_T}{2} \vec{P}_b \cdot \vec{P}_T$$

We can integrate over the spin directions in the antiproton stack and get as a function of time t the polarization $P(t)$ of the stack and its remaining intensity $I(t)$

$$P(t) = \coth \left(\frac{\sigma_T}{2} \frac{dvt}{\sigma_T} \right) - \frac{2}{\sigma_T} \frac{dvt}{dt}$$

$$\frac{I(t)}{I_0} = \left(e^{-\sigma_0 d \nu t} \right) \frac{2 \sinh \left(\frac{\sigma_T}{2} d \nu t \right)}{\sigma_T d \nu t}$$

where d is the thickness of the ($\sim 100\%$) polarized filter target in protons per cm^2 , and ν is the revolution frequency of the stored antiprotons.

There appears a typical time constant $\tau_0 = 1/\sigma_0 \nu d$ which governs the process. In Table 2 we give the relevant quantities $P(t)$, $I(t)/I_0$ and the figure of merit $P^2 I/I_0$ as function of time $\tau = t/\tau_0$ with different assumptions for the transverse cross-section σ_T/σ_0 . For large ratios σ_T/σ_0 we find attractive intensities and polarizations. If we have, for example, $\sigma_T/\sigma_0 = 2/3$ and $t/\tau_0 \approx 3$, then an initial stack of 10^{11} unpolarized antiprotons would be converted to $6 \cdot 10^9$ $\bar{p}$ with 31% polarization.

Table 2

Time development of stored $\bar{p}$ intensity I/I_0 , polarization P and figure of merit $P^2(I/I_0)$ for various polarization dependence of the total cross-section

t/τ_0	$\frac{\sigma_T}{\sigma_0} = 0.2$			$\frac{\sigma_T}{\sigma_0} = 2/3$			$\frac{\sigma_T}{\sigma_0} = 2$		
	I/I_0	P	$P^2 I/I_0$	I/I_0	P	$P^2 I/I_0$	I/I_0	P	$P^2 I/I_0$
1	0.37	0.03	0.04%	0.38	0.11	0.45%	0.43	0.31	4.2%
1.5	0.22	0.05	0.06%	0.23	0.16	0.61%	0.32	0.44	6.0%
2	0.14	0.07	0.06%	0.15	0.21	0.66%	0.24	0.53	6.9%
2.5	0.8	0.08	0.06%	0.09	0.26	0.64%	0.20	0.61	7.3%
3	0.05	0.10	0.04%	0.06	0.31	0.56%	0.16	0.67	7.3%

The figures of merit in tables 1 and 2 can be directly compared if we think of extracting the polarized stacks and using them on an external target. The "filter method" is potentially much more effective. It could provide more and higher polarized antiprotons per used total $\bar{p}$ flux.

A further improvement might be obtained by using a second internal proton (reaction) target. One would once more gain by the higher efficiency of the internal target (Fig. 2) while still keeping the optimal energy and angular resolution of the cooled beam. This internal target could be of the polarized type. With numbers mentioned above ($6 \cdot 10^9$ stored polarized $\bar{p}$ at 910 MeV/c and a polarized jet with $3 \cdot 10^{12}$ $p^\uparrow$ per cm^2) one could observe momentarily $0.7 \cdot 10^4$

$\bar{p} \uparrow + p \uparrow$ interactions per second. If one could establish equilibrium in the "filtering" action this would need a continuous input of $0.7 \cdot 10^4 / (I/I_0)$ $\bar{p}$ into the storage and filter system (for I/I_0 see Table 2).

However, there are, of course, problems:

- (1) σ_T/σ_0 is not known; it has to be measured.
- (2) The relevant time constant τ is prohibitively long for a filter target of $\sim 5 \cdot 10^{-12}$ g/cm². $\tau_0 = 1/\sigma v d$ for ~ 1 GeV/c is around 10^7 s or ~ 100 days.

If we could increase the "filter" target thickness by a factor 100, it would become feasible. This might be possible by injecting the polarized protons parallel to the circulating antiproton beam over a length of some meters or by development of a target of ~ 100 times the density of the SPS target.

REFERENCES

1. Antiproton-proton cross-sections and spin effects (LEAR experiment PS172), PSCC Report 80-76/PSCC/p. 16, 1980.
2. Study of threshold production of hyperon antihyperon pairs (LEAR experiment PS185), CERN/PSCC 81-69, PSCC/p. 49, 1981.
3. K. Kilian, P. Dalpiaz, Polarization with LEAR, CERN $\bar{p}$ LEAR Note 31.
4. K. Kilian, D. Möhl, Gas jet target in LEAR, CERN $\bar{p}$ LEAR Note 44; 1979; Antineutron production with an internal target in the LEAR magnet, CERN $\bar{p}$ LEAR Note 90, 1981.
5. L. Dick et al., The CERN polarized atomic hydrogen beam target, in: Proc. of 1980 Symposium on High Energy Physics with polarized beams and polarized targets (Lausanne 1980), L. Joseph and J. Soffer, ed., Birkhäuser Verlag (1981) p. 212.
6. F. Bradamante, Polarized $\bar{p}$ beams, This Conference.
7. M.G. Albrow et al., Nucl. Phys. B37 (1972) 349.
8. R. Cappi, W. Hardt, R. Giannini, Ultra-slow extraction from LEAR, This Conference.
9. P. Csonka, Nucl. Instr. Meth. 63 (1968) 247.
P. Csonka et al., Polarized proton storage rings, CERN Int. Report ISR-VAC/69-47; see also PS Machine Study Team: Proposal for a two year study on polarized beam and light ion acceleration in the PS (Part II, Appendix 1), CERN Int. Report MPS/DL 71-1 (1975).
10. G.I. Budker, A.M. Skrinski, Sov. Phy. Usp. 21 (4) 1978 p. 277.
11. K. Kilian, Polarization Physics planned at LEAR, same proceedings as reference 5, p. 219.