# Polarized Antiprotons – How and Why?

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A brief report is given on the ongoing experimental efforts to produce a beam of polarized antiprotons. If successful such beams may be used in a second stage of the FAIR/HESR-facility currently under construction in Darmstadt (Germany). For further information readers are referred to the given references.

## 1. Introduction

The physics case for antiproton beams – if polarized – is enormous, including a first time measurement of double-spin observables in proton-antiproton Drell-Yan reactions [1]. Since these are dominated by annihilations of valence quark – valence antiquark in the proton and in the antiproton, respectively, the double spin asymmetry $A_{TT}$ will give direct access to transversity, the important but largely unknown piece of the nucleon spin structure [2].

Unfortunately, the preparation of polarized antiprotons is very demanding, and in fact has not been achieved with sufficient intensity and/or degree of polarization up to now. Some time ago, it has been proposed to use *spin filtering* for in-situ polarization build-up in a stored beam of antiprotons to achieve the required parameters [3]. Recently, a different method has been suggested, *viz.* exploiting the interaction of antiprotons with polarized positrons at small relative velocity, where, according to one calculation [4], the expected cross sections are gigantic (see, however, refs. [12, 13]).

The PAX-collaboration has taken on these issues and has started a systematic experimental search for the best method and operation parameters for producing a polarized beam of antiprotons, which could be used at FAIR ("Facility for Antiproton and Ion Research"), to be build at GSI (Darmstadt, Germany) [5] in an upgrade of the "High Energy Storage Ring" (HESR) into an asymmetric polarized-proton polarized-antiproton collider.

## 2. Strategies for polarizing antiprotons

For more than two decades, physicists have tried to produce beams of polarized antiprotons. Recent workshops at Daresbury (UK) [6] and Bad Honnef (Germany) [7] have reviewed the different possibilities. In principle the following two approaches can be applied:

1. flipping of the spins in an ensemble of particles to one preferred state, and
2. selective removal of "wrong" particles from the beam.

Conventional methods that work very reliably for protons, like atomic beam sources (ABS), cannot be used for antiprotons due to their annihilation with matter. Polarized antiprotons have been produced in the in-flight decay of antihyperons. At Fermilab, polarizations of $\sim 35\%$ and intensities up to $1.5 \cdot 10^5\,\mathrm{s}^{-1}$ have been achieved [8]. Scattering of energetic antiprotons off liquid hydrogen yielded $P \sim 0.2$ and $I \sim 2 \cdot 10^3\,\mathrm{s}^{-1}$ [9]. It must be stated, however, that both approaches cannot be used for an efficient accumulation in a storage ring, which would greatly increase the luminosity.

The spacial separation by the Stern-Gerlach effect ("Spin splitting") in an inhomogeneous magnetic field could also be used, as proposed in 1985 [10], but due to the enormous technological expense this method has never been tested experimentally. Two more methods have been proposed:

1. "spin filtering" and
2. "spin transfer".

In the following, both techniques are described in some detail; much more information can be found in the mentioned references.

### *2.1. Spin-Filtering Method*

The spin-filtering technique is based on a repeated traversal of a beam of particles through a polarized hydrogen gas target: since the scattering cross sections for "spin-up" and "spin-down" are somewhat different, the beam will slowly acquire an increasing degree of polarization, however, at the expense of a reduction in beam intensity – this immediately implies that it makes no sense to filter for too long time, because no beam would be left. The optimum filtering time in a storage ring is about twice the beam lifetime. Therefore it is of utmost importance to design or use a polarizer ring such that it keeps as many as possible scattered particles in the ring acceptance. The proof-of-principle of this method has been conducted with protons in the "FILTEX" (filter experiment) at the TSR (Test Storage Ring) of the Max-Planck Institute for Nuclear Physics in Heidelberg (Germany). Since the TSR was not optimized for acceptance, the achieved polarization build-up was about 1% per hour, resulting in a polarization of the proton beam of a few percent [11].

### *2.2. Spin-Transfer Method*

A different way of polarizing a(n) (anti-)/proton beam was recently put forward by a group from Mainz (Germany) [4]: they propose to use the spin-transfer from a polarized (positron)/electron beam to the (antiproton)/proton, since, according to their calculations, the corresponding cross sections become very large for small relative velocities between leptons and hadrons. It should be mentioned that a scientific dispute has been going on about the size of this cross section – a different group claims that the cross section is much smaller [12], which would make this method impracticable. In fact, more recently the Mainz-group has come up with an erratum [13], reducing their original cross section by many orders of magnitude. Nevertheless, the excitement about this potential technique comes because there would be no dramatic beam intensity loss in a storage ring. However, up to now, no experimental verification whether this method will actually work, has been achieved.

The PAX-collaboration has taken on this proposal and performed an experiment, which provides such a test – in the following section, this experiment is briefly described.

## 3. Spin-Transfer Measurement by Depolarization

The polarization build-up experiment of a hadron beam in a storage ring by interaction with a polarized electron beam is not possible for the time being, since no intense polarized electron beam is available at a hadron storage ring. One might consider use of a polarized hydrogen target, where the electron makes the polarization, but due to the much larger hadronic cross sections, a signal would be very hard to find. Instead, we have looked for the time-reversed process, i.e. the depolarization of an originally polarized proton beam in COSY-Jülich (Germany) [14], which is interacting with the unpolarized electron beam of our electron cooler.

The experiment consists of two parts:

1. Interaction of the polarized proton beam with the electrons of the cooler; this should depolarize the protons, i.e. $\vec{p} + e \rightarrow p + e$, and

2. Analysis of the remaining proton beam polarization; to do this, the ANKE deuteron cluster jet target, located immediately behind the

interaction region, has been used. The reaction exploited was proton-deuteron elastic scattering, using two silicon tracking telescopes left and right of the beam.

These measurements were conducted for different relative velocities between electrons and protons. Actually, the measurement scheme is more complicated, because electron cooling tends to remove the necessary velocity mismatch [15, 16].

The experiment was carried out in February 2008, and after a careful analysis, the final results of the measurement have been published recently [16]. They show that no proton beam depolarization is observed, which indicates that the spin-transfer cross section must be much smaller than originally expected by the Mainz-group [4], and thus makes this method inapplicable for achieving our goal, the effective polarization of a beam of antiprotons.

Still, we have the spin-filtering method, and corresponding investigations are foreseen for the near future at COSY (with proton beams) and at CERN/AD (with antiprotons). During the summer shutdown of COSY, a "low-$\beta$ section" has been installed in the ring, and during 2010, spin-filtering tests with protons to commission all the equipment will be conducted. In parallel, a proposal has been submitted to CERN SPSC for a spin filtering measurement with antiprotons at the AD-ring [17].

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