Do unpolarized electrons affect the polarization of a stored beam?[1]

Frank Rathmann

Institut für Kernphysik and Jülich Center for Hadron Physics, Forschungszentrum Jülich, Germany

Abstract. We present a short overview of the PAX physics case for polarized antiprotons. In order to progress towards a stored polarized antiproton beam, it is crucial to understand the interaction of polarized protons with unpolarized electrons. Therefore investigations that address in particular the contributions of electrons to the polarization buildup of a stored proton beam are presented here in more detail. The measurement of the depolarizing $\vec{p}e$ cross section settled a long–standing controversy about the role of electrons in the polarization buildup of a stored beam by spin–filtering. Instead of studying the buildup of polarization in an initially unpolarized beam, here the inverse situation was investigated by observation of the depolarization of an initially polarized beam. For the first time, electrons in the electron cooler have been used as a target to study their depolarizing effect on a 49.3 MeV proton beam orbiting in COSY. The foreseen spin–filtering experiments at COSY–Jülich and at the AD of CERN are briefly discussed as well.

Keywords: Polarization, antiprotons, *ep* interaction, polarized targets
PACS: 24.70.+s, 25.43.+t, 13.88.+e

THE PAX EXPERIMENT

The QCD physics potential of experiments with high energy polarized antiprotons is enormous, but up to now high–luminosity experiments have been impossible. The situation would change dramatically with the production of stored polarized antiproton beams, and the subsequent realization of a double–polarized high–luminosity antiproton–proton collider. The list of fundamental physics issues to be addressed with such a collider includes the measurement of transversity, the quark transverse polarization inside a transversely polarized proton, which constitutes the last missing leading twist piece of the QCD description of the partonic structure of the nucleon. The transversity can be directly accessed only via double–polarized antiproton–proton Drell–Yan production. It should be noted, that without a measurement of the transversity, the spin tomography of the proton will remain incomplete. Other items of interest are the measurement of the phases of the timelike form factors of the proton, and double–polarized hard antiproton–proton scattering.

The PAX collaboration (**P**olarized **A**ntiproton e**X**periments) has formulated its ambitious physics program [1] and a Technical Proposal [2] has recently been submitted for the new Facility for Antiproton and Ion Research (FAIR) to be built at GSI in Darmstadt, Germany. The uniqueness and the strong scientific merits that would become available with the advent of stored beams of polarized antiprotons have been well received [3],

[1] for the ANKE and PAX collaborations

and there is now an urgency to convincingly demonstrate experimentally that a high degree of antiproton beam polarization can be reached. The suggested collider aims at luminosities in excess of 10^{31} cm^{-2}s^{-1}. An integral part of such a machine is a dedicated large–acceptance Antiproton Polarizer Ring (APR) [4], for which a basic design has been developed [5].

TOWARDS POLARIZED ANTIPROTONS

For more than two decades, physicists have tried to produce beams of polarized antiprotons [6], generally without success. Conventional methods like atomic beam sources, appropriate for the production of polarized protons and heavy ions cannot be applied, since antiprotons annihilate with matter. Polarized antiprotons have been produced from the decay in flight of $\bar{\Lambda}$ hyperons at Fermilab. The intensities achieved with antiproton polarizations $P > 0.35$ never exceeded $1.5 \cdot 10^5$ s^{-1} [7]. Scattering of antiprotons off a liquid hydrogen target could yield polarizations of $P \approx 0.2$, with beam intensities of up to $2 \cdot 10^3$ s^{-1} [8]. Small angle $\bar{p}C$ scattering has been studied at LEAR, but the observed antiproton polarizations are negligibly small [9, 10]. Unfortunately, all the above mentioned approaches do not allow efficient accumulation in a storage ring, which would greatly enhance the luminosity. Spin splitting using the Stern–Gerlach separation of the given magnetic substates in a stored antiproton beam was proposed in 1985 [11]. Although the theoretical understanding has much improved since then [12], spin splitting using a stored beam has yet to be observed experimentally. In contrast to that, a convincing proof of the spin–filtering principle was provided by the FILTEX experiment at the TSR–ring in Heidelberg [13].

DO UNPOLARIZED ELECTRONS AFFECT THE POLARIZATION OF A STORED BEAM?

The original idea of PAX to use polarized electrons to produce a polarized beam of antiprotons [4] has triggered further theoretical work on the subject, which led to a new suggestion by a group from Mainz [14, 15] to use co–moving electrons (or positrons) at slightly different velocities than the orbiting protons (or antiprotons) as a means to polarize the stored beam. The cross section for $e\vec{p}$ spin–flip predicted by the Mainz group in a *numerical* calculation is as large as about $2 \cdot 10^{13}$ barn, if the relative velocities between proton (antiproton) and electron (positron) are adjusted to $v/c \approx 0.002$. At the same time, *analytical* predictions for the same quantity by a group from Novosibirsk [16] range well below a mbarn. Thus prior to the experiment, the two theoretical estimates differed by about 16 orders of magnitude. It should be also emphasized, that the practical use of the $\vec{e}p$ or $\vec{e^+}\bar{p}$ processes to polarize anything is excluded if the spin–flip cross sections are smaller than about 10^7 barn.

In order to provide an experimental answer for this puzzle, the ANKE and PAX collaborations joined forces at COSY and mounted an experiment, where for the first time, electrons in the electron cooler have been used as a target, and in which the effect of electrons on the polarization of a 49.3 MeV proton beam orbiting in COSY was

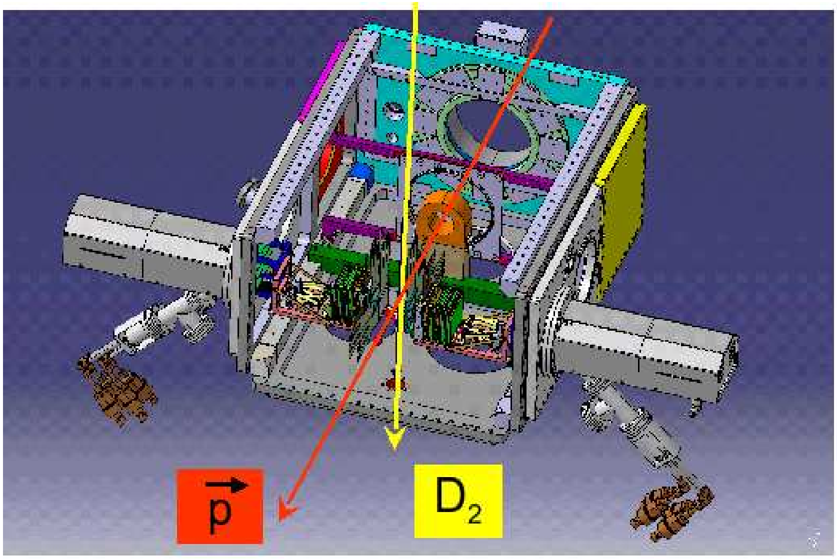

FIGURE 1. Using events from elastic $\vec{p}d$ scattering, two Silicon detector telescopes mounted near the deuterium beam (D_2) of the ANKE cluster jet target measure the change of the proton ($\vec{p}$) beam polarization induced by the depolarizing $e\vec{p}$ spin–flips in the COSY electron cooler.

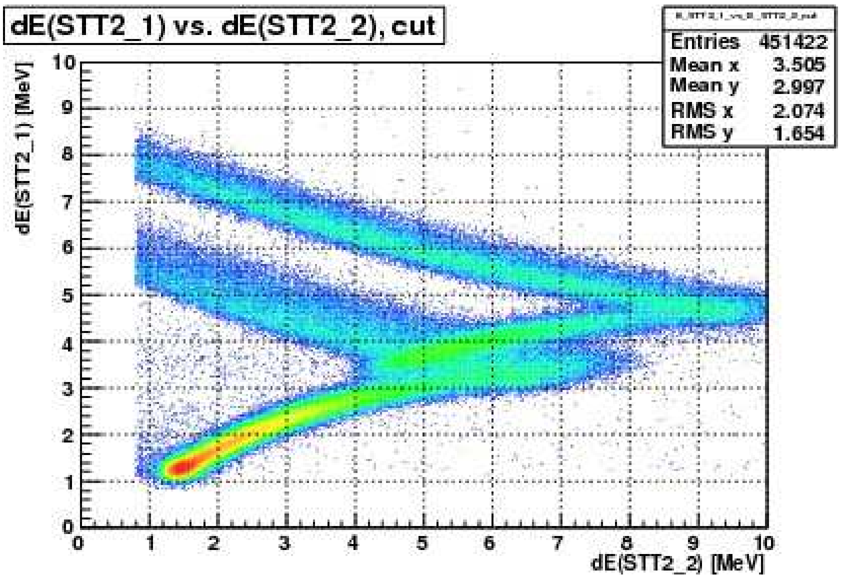

FIGURE 2. Identification of *pd* elastic scattering in the detector system.

determined. Instead of studying the buildup of polarization in an initially unpolarized beam, here the inverse situation was investigated by observation of the depolarization of an initially polarized beam. The proton beam polarization has been measured by making use of the analyzing power of $\vec{p}d$ elastic scattering on a deuterium cluster jet target. The experimental setup of the polarimeter consisting of two telescopes, each of them containing two 300 μm thick layers of Silicon, is depicted in Fig. 1.

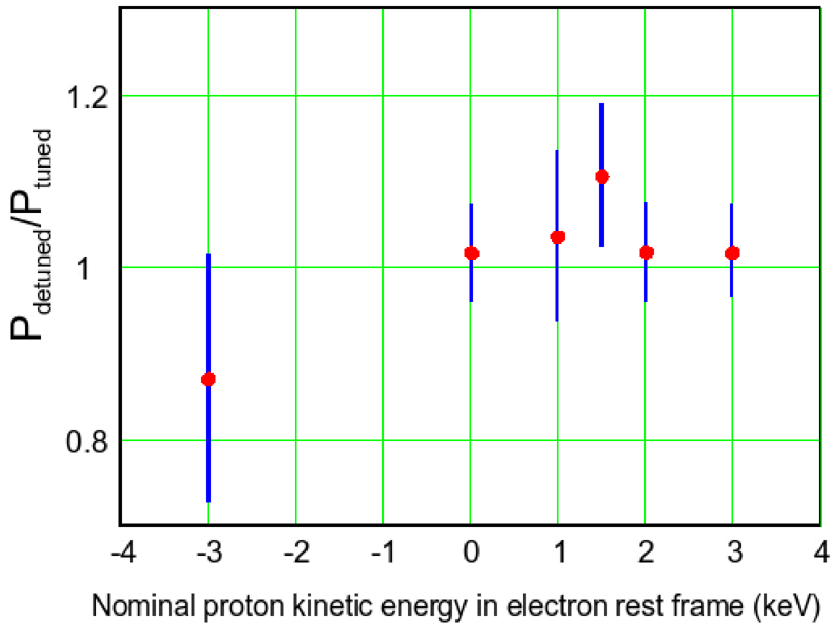

FIGURE 3. Ratio of the measured polarizations $\frac{P_{\text{detuned}}}{P_{\text{tuned}}}$ as function of the proton kinetic energy in the electron rest frame.

The energy deposit in the first detector layer is plotted as a function of the energy deposit in the second layer in Fig. 2. The upper band corresponds to deuterons and the lower one to protons from *pd* elastic scattering.

The depolarizing cross section is determined from the ratio of the measured beam polarizations P_{detuned} and P_{tuned} (Fig. 3). These polarizations correspond to well–defined changes of the electron velocity with respect to the protons, which were achieved by detuning the accelerating voltage in the electron cooler by a specific amount.

The depolarizing cross section is plotted in Fig. 4 as a function of the magnitude of the electron velocity in the proton rest frame.

The measurement shows that the predictions by the Mainz group were too large by at least six orders of magnitude. It should be noted that very recently, the Mainz group has submitted two errata to their original publications stating that because of numerical problems in the calculation their theoretical estimates were too large by about 15 orders of magnitude.

SPIN–FILTERING EXPERIMENTS AT COSY AND AD

The depolarization study constitutes the first step of investigations at COSY, shedding light on the *ep* spin–flip cross sections when the target electrons are unpolarized. The experimental finding rules out the practical use of polarized leptons to polarize a beam of antiprotons with present–day technologies. This leaves us with the only proven method to polarize a stored beam in situ, namely *spin filtering* by the strong interaction. At present, we are lacking a complete quantitative understanding of all underlying

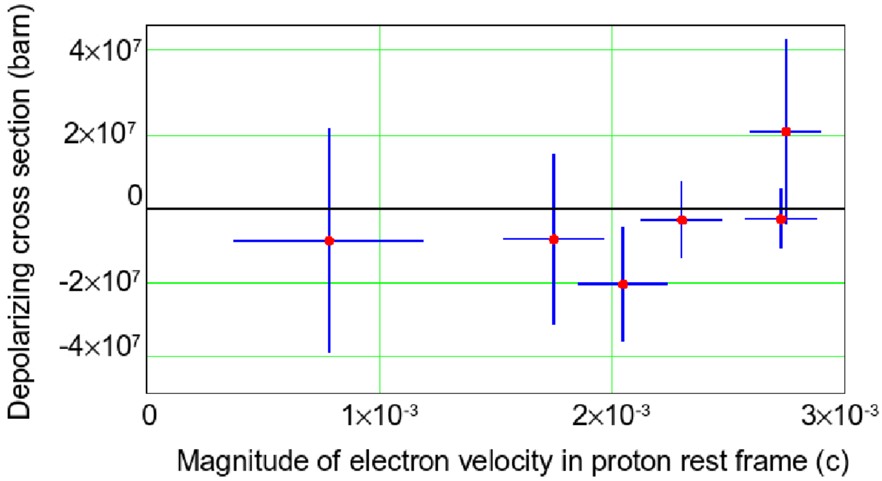

FIGURE 4. The depolarizing cross section is plotted as a function of the magnitude of the electron velocity in the proton rest frame, indicating an upper limit of a few 10^7 b. Prior to the experiment, the two theoretical estimates of this cross section differed by about 16 orders of magnitude at a relative velocity of $v/c = 2 \cdot 10^{-3}$ [15, 16]. The experiment ruled out the higher estimate.

processes, therefore the PAX collaboration is aiming at high–precision polarization buildup studies with transverse and longitudinal polarization using stored protons in COSY [17]. The buildup process itself can be studied in detail, because in this situation the spin–dependence of the pp interaction is completely known. The polarized internal target required for these investigations was previously used at the HERMES experiment at HERA/DESY. Including the target polarimeter, it has meanwhile been relocated to Jülich [18], where it is presently set up to be installed together with a large–acceptance detector system for the determination of target and beam polarizations in a dedicated low–β section at COSY.

In contrast to the pp system, the experimental basis for predicting the polarization buildup in a stored antiproton beam by spin filtering is practically non–existent. Therefore, it is of high priority to perform, subsequently to the COSY experiments, a series of dedicated spin–filtering experiments using stored antiprotons. The AD–ring at CERN is a unique facility at which stored antiprotons in the appropriate energy range are available with characteristics that meet the requirements for the first–ever antiproton polarization buildup studies. At the same time, the equipment required for the dedicated spin–filtering experiments at the AD, i.e. the polarized internal target and the new low–β section, an efficient polarimeter to determine target and beam polarizations, and a Siberian snake to maintain the longitudinal beam polarization, must be extensively commissioned and tested at COSY, prior to the experimental investigations at CERN. Already in 2005, the PAX collaboration suggested in a Letter–of–Intent [19] to the SPS committee of CERN to study the polarization buildup via spin filtering of stored antiprotons by multiple passage through a polarized internal hydrogen gas target, because only through these investigations, one can obtain direct access to the spin dependence of the total $\bar{p}p$ cross sections. Apart from the obvious interest for the general theory of $\bar{p}p$ interactions, the knowledge of these cross sections is necessary for the interpretation of unexpected features of the $\bar{p}p$, and other antibaryon–baryon pairs, contained in final states in J/Ψ and *B*–decays. Once these experiments have provided an experimental data base, the design of a dedicated APR can be targeted, as the next major milestone.

REFERENCES

1. F. Rathmann [PAX Collaboration], *Proceedings of the 17th International Spin Physics Symposium*, Kyoto, Japan, 2006, Eds. Kenichi Imai, Tetsuya Murakami, Naohito Saito, Kiyoshi Tanida, AIP Conf. Proc. **915**, 924 (2007).
2. Technical Proposal for *Antiproton–Proton Scattering Experiments with Polarization*, PAX Collaboration, spokespersons: P. Lenisa (Ferrara University, Italy) and F. Rathmann (Forschungszentrum Jülich, Germany), available from `http://arXiv:hep-ex/0505054` (2005). An update of this proposal can be found at the PAX website `http://www.fz-juelich.de/ikp/pax`.
3. The reports from the various committees can be found at the PAX collaboration website at `http://www.fz-juelich.de/ikp/pax`.
4. F. Rathmann *et al.*, Phys. Rev. Lett. **94**, 014801 (2005).
5. A. Garishvili *et al.*, *Proc. of the EPAC 2006*, Edinbough, Scotland, 2006, Eds. C. Biscari, H. Owen, Ch. Petit-Jean-Genaz, J. Poole, and J. Thomason, ISBN 92-9083-278-9 and ISBN 978-92-9083-278-2. Available from `http://accelconf.web.cern.ch/AccelConf/e06/` MOPCH083, p. 223.
6. *Proc. of the Workshop on Polarized Antiprotons*, Bodega Bay, CA, 1985, Eds. A. D. Krisch, A. M. T. Lin, and O. Chamberlain, AIP Conf. Proc. **145** (AIP, New York, 1986).
7. D.P. Grosnick *et al.*, Nucl. Instrum. Methods **A 290**, 269 (1990).
8. H. Spinka *et al.*, *Proc. of the 8th Int. Symp. on Polarization Phenomena in Nuclear Physics*, Bloomington, Indiana, 1994, Eds. E.J. Stephenson and S.E. Vigdor, AIP Conf. Proc. **339** (AIP, Woodbury, NY, 1995), p. 713.
9. A. Martin *et al.*, Nucl. Phys. A 487, 563 (1988).
10. R. Birsa *et al.*, Phys. Lett. B **155**, 437 (1985).
11. T. O. Niinikoski and R. Rossmanith, Nucl. Instrum. Methods **A 255**, 460 (1987).
12. P. Cameron *et al.*, *Proc. of the 15th Int. Spin Physics Symp.*, Upton, New York, 2002, Eds. Y. I. Makdisi, A. U. Luccio, and W. W. MacKay, AIP Conf. Proc. **675** (AIP, Melville, NY, 2003), p. 781.
13. F. Rathmann *et al.*, Phys. Rev. Lett. **71**, 1379 (1993).
14. H. Arenhövel, Eur. Phys. J. A, **34**, 303 (2007).
15. T. Walcher *et al.*, Eur. Phys. J. A, **34**, 447 (2007).
16. I. Milstein, S.G. Salnikov, and V.M. Strakhovenko, Nucl. Instrum. Methods **B 266**, 3453 (2008).
17. Letter–of–Intent for Spin Filtering Studies at COSY, PAX Collaboration, spokespersons: P. Lenisa (Ferrara University, Italy) and F. Rathmann (Forschungszentrum Jülich, Germany), available from the PAX website `http://www.fz-juelich.de/ikp/pax/`.
18. A. Nass *et al.* [PAX Collaboration], *Proceedings of the 17th International Spin Physics Symposium*, Kyoto, Japan, 2006, Eds. Kenichi Imai, Tetsuya Murakami, Naohito Saito, Kiyoshi Tanida, AIP Conf. Proc. **915**, 1002 (2007).
19. Letter–of–Intent for *Measurement of the Spin–Dependence of the $\bar{p}p$ Interaction at the AD–Ring*, PAX Collaboration, spokespersons: P. Lenisa (Ferrara University, Italy) and F. Rathmann (Forschungszentrum Jülich, Germany), available from `http://arXiv:hep-ex/0512021`, (2005).