

# QCD physics with polarized antiprotons at GSI

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## Abstract

A polarized antiproton beam at the Facility for Antiproton and Ion Research, proposed by the PAX collaboration, will open a window to new physics uniquely accessible at the new High Energy Storage Ring. Our proposal to realize an asymmetric collider, in which polarized protons with momenta of about 3.5 GeV/c collide with polarized antiprotons with momenta up to 15 GeV/c, is well-suited to perform a direct measurement of the transversity distribution function  $h_1$ . In this report we summarize the outcome of various working group meetings within the PAX collaboration. The overall machine setup at the HESR, proposed by the PAX collaboration, is described along with the associated PAX experimental program.

The possibility to test the nucleon structure via double spin asymmetries in polarized proton–antiproton reactions at the HESR ring of FAIR at GSI has been suggested by the PAX collaboration last year in Ref. [1]. Since then, there has been much progress, both in understanding the physics potential of such an experiment [2, 3, 4, 5] and in studying the feasibility of efficiently producing polarized antiprotons [6]. The physics program of such a facility would extend to a new domain the exceptionally fruitful studies of the nucleon structure performed in unpolarized and polarized deep inelastic scattering (DIS), which have been at the center of high energy physics during the past four decades. It suffices to mention the unique possibility of a direct measurement of the transversity distribution function  $h_1$ , one of the last missing fundamental pieces in the QCD description of the nucleon. In the available kinematic domain of the proposed experiment, which covers the valence region, the Drell–Yan double transverse spin asymmetry was recently predicted to be as large as 30% [2, 3]. Other novel tests of QCD at such a facility include the polarized elastic hard scattering of antiprotons on protons and the measurement of the phases of the time-like form factors of the proton (see [1]). A viable practical scheme<sup>1</sup> which allows us to reach a polarization of the stored antiprotons at HESR–FAIR of  $\simeq 30\%$  has been

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<sup>1</sup>The basic approach to polarizing and storing antiprotons at HESR–FAIR is based on solid QED calculations of the spin transfer from electrons to antiprotons [7], which is being routinely used at Jefferson Laboratory for the electromagnetic form factor separation [8], and which has been tested and confirmed experimentally in the FILTEX experiment [9].

worked out and published in Ref. [6].

In this brief report we summarize the outcome of various working group meetings of the PAX Collaboration, the results of which have been presented in 2004 at several workshops and conferences [10]. The PAX collaboration proposes an approach that is composed of two phases. During these the major milestones of the project can be tested and optimized before the final goal is approached: A polarized proton–antiproton asymmetric collider, in which polarized protons with momenta of about 3.5 GeV/c collide with polarized antiprotons with momenta up to 15 GeV/c. These circulate in the HESR, which has already been approved and will serve the PANDA experiment. In the following, we will briefly describe the overall machine setup at the HESR, schematically depicted in Fig. 1, as proposed by the PAX collaboration.

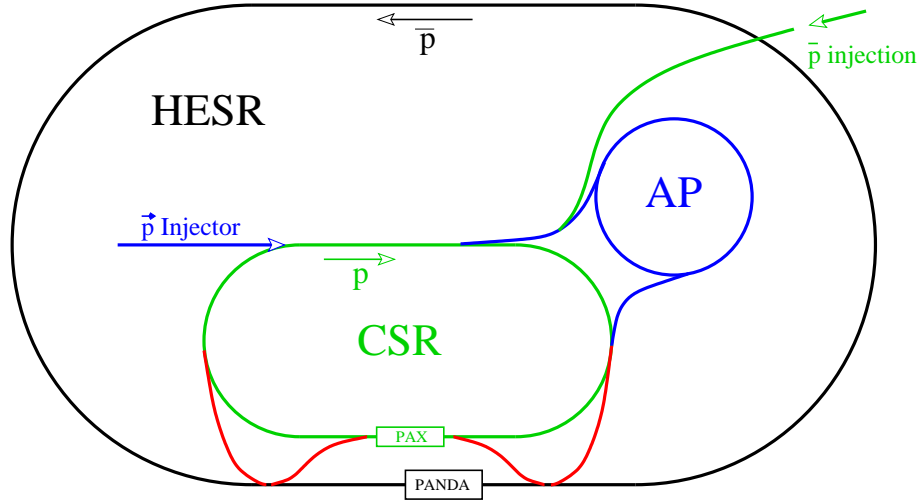


Figure 1: The proposed accelerator set-up at the HESR (black), with the equipment used by the PAX collaboration in Phase I: CSR (green), AP, beam transfer lines and polarized proton injector (all blue). In Phase II, by adding two transfer lines (red), an asymmetric collider is set up. It should be noted that, in this phase, also fixed target operation at PAX is possible.

Let us summarize the main features of the accelerator setup:

1. An Antiproton Polarizer (AP) built inside the HESR area with the crucial goal of polarizing antiprotons at kinetic energies around  $\approx 50$  MeV ( $p \approx 300$  MeV/c), to be accelerated and injected into the other rings.
2. A second Cooler Synchrotron Ring (CSR, COSY-like) in which protons or antiprotons can be stored with a momentum up to 3.5 GeV/c. This ring shall have a straight section, where a PAX detector could be installed, running parallel to the experimental straight section of HESR.
3. By deflection of the HESR beam into the straight section of the CSR, both the collider or the fixed-target mode become feasible.

It is worthwhile to stress that, through the employment of the CSR, effectively a second interaction point is formed with minimum interference with PANDA. The proposed solution opens the possibility to run two different experiments at the same time.

The physics program should be pursued in two different phases.

- (I) A beam of unpolarized or polarized antiprotons with momentum up to 3.5 GeV/c in the CSR ring, colliding on a polarized hydrogen target in the PAX detector. This phase is independent of the HESR performance.

This first phase, at moderately high energy, will allow for the first time the measurement of the time-like proton form factors in single and double polarized  $\bar{p}p$  interactions in a wide kinematical range, from close to threshold up to  $Q^2 = 8.5 \text{ GeV}^2$ . It would enable to determine several double spin asymmetries in elastic  $\bar{p}^\uparrow p^\uparrow$  scattering. By detecting back scattered antiprotons one can also explore hard scattering regions of large  $t$ : In proton-proton scattering the same region of  $t$  requires twice the energy. There are no competing facilities at which these topical issues can be addressed. For the theoretical background, see the PAX LoI [1] and the recent review paper [4].

- (II) This phase will allow the first ever direct measurement of the quark transversity distribution  $h_1$ , by measuring the double transverse spin asymmetry  $A_{TT}$  in Drell-Yan processes  $p^\uparrow \bar{p}^\uparrow \rightarrow e^+ e^- X$  as a function of Bjorken  $x$  and  $Q^2$  ( $= M^2$ )

$$A_{TT} \equiv \frac{d\sigma^{\uparrow\uparrow} - d\sigma^{\uparrow\downarrow}}{d\sigma^{\uparrow\uparrow} + d\sigma^{\uparrow\downarrow}} = \hat{a}_{TT} \frac{\sum_q e_q^2 h_1^q(x_1, M^2) h_1^{\bar{q}}(x_2, M^2)}{\sum_q e_q^2 q(x_1, M^2) \bar{q}(x_2, M^2)},$$

where  $q = u, \bar{u}, d, \bar{d} \dots$ ,  $M$  is the invariant mass of the lepton pair and  $\hat{a}_{TT}$ , of the order of one, is the calculable double-spin asymmetry of the QED elementary process  $q\bar{q} \rightarrow e^+ e^-$ . Two possible scenarios might be foreseen to perform the measurement.

- (a) **Asymmetric Collider:** A beam of polarized antiprotons from 1.5 GeV/c up to 15 GeV/c circulating in the HESR, colliding on a beam of polarized protons with momenta up to 3.5 GeV/c circulating in the CSR. This scenario however requires to demonstrate that a suitable luminosity is reachable. Deflection of the HESR beam to the PAX detector in the CSR is necessary (see Fig. 1).

By proper variation of the energy of the two colliding beams, this setup would allow a measurement of the transversity distribution  $h_1$  in the valence region of  $x > 0.05$ , with corresponding  $Q^2 = 4 \dots 100 \text{ GeV}^2$  (see Fig. 2).  $A_{TT}$  is predicted to be larger than 20 % over the full kinematic range, up to the highest reachable center-of-mass energy of  $\sqrt{s} \sim \sqrt{200}$ . The cross section is large as well: With a luminosity of  $5 \cdot 10^{30} \text{ cm}^{-2} \text{ s}^{-1}$  about 2000 events per day can be expected<sup>2</sup>. For the transversity distribution  $h_1$ , such an experiment can be considered as the analogue of polarized DIS for the determination of the helicity structure function  $g_1$ , i.e. of the helicity distribution  $\Delta q(x, Q^2)$ ; the kinematical coverage  $(x, Q^2)$  will be similar to that of the HERMES experiment.

- (b) **High luminosity fixed target experiment:** If the required luminosity in the collider mode is not achievable, a fixed target experiment can be conducted. A beam of 22 GeV/c (15 GeV/c) polarized antiprotons circulating in the HESR is used to collide with a polarized internal hydrogen target. Also this scenario requires the deflection of the HESR beam to the PAX detector in the CSR (see Fig. 1).

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<sup>2</sup>A first estimate indicates that in the collider mode luminosities in excess of  $10^{30} \text{ cm}^{-2} \text{ s}^{-1}$  could be reached. We are presently evaluating the influence of intra-beam scattering, which seems to be one of the limiting factors.

A theoretical discussion of the significance of the measurement of  $A_{TT}$  for a 22 GeV/c (15 GeV/c) beam impinging on a fixed target is given in Refs. [2, 3, 5] and the recent review paper [4]. The theoretical work on the  $K$ -factors for the transversity determination is in progress [11, 12]. This measurement will explore the valence region of  $x > 0.2$ , with corresponding  $Q^2 = 4 \dots 16 \text{ GeV}^2$  (see Fig. 2). In this region  $A_{TT}$  is predicted to be large (of the order of 30 %, or more) and the expected number of events can be of the order of 2000 per day.

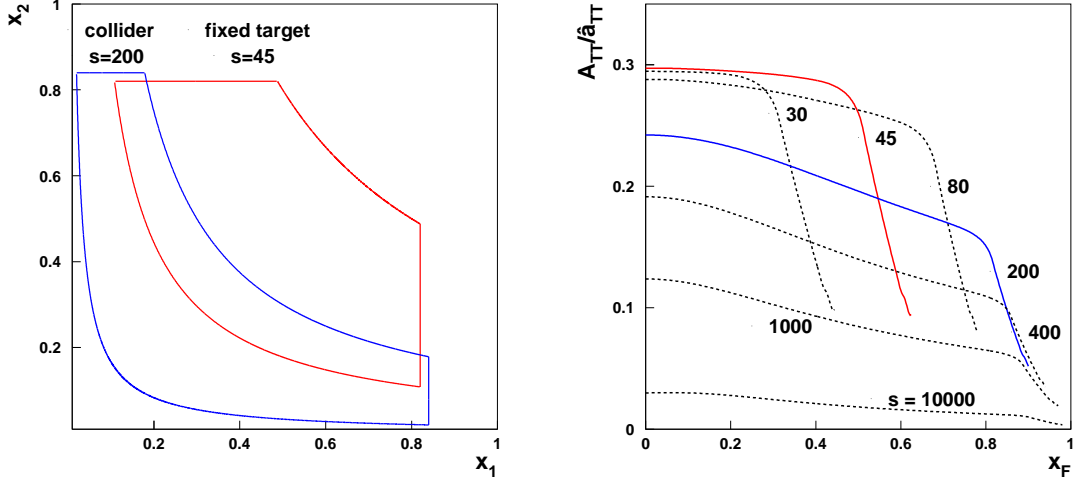


Figure 2: Left: The kinematic region covered by the  $h_1$  measurement at PAX in phase II. In the asymmetric collider scenario (blue) antiprotons of 15 GeV/c impinge on protons of 3.5 GeV/c at c.m. energies of  $\sqrt{s} \sim \sqrt{200} \text{ GeV}$  and  $Q^2 > 4 \text{ GeV}^2$ . The fixed target case (red) represents antiprotons of 22 GeV/c colliding with a fixed polarized target ( $\sqrt{s} \sim \sqrt{45} \text{ GeV}$ ). Right: The expected asymmetry as a function of Feynman  $x_F$  for different values of  $s$  and  $Q^2 = 16 \text{ GeV}^2$ .

We would like to mention, that we are also investigating whether the PANDA detector, properly modified, is compatible with the transversity measurements in the collider mode, where an efficient identification of the Drell–Yan pairs is required. At the interaction point, the spins of the colliding protons and antiprotons should be vertical, with no significant component along the beam direction.

To summarize, we note that the storage of polarized antiprotons at HESR will open unique possibilities to test QCD in hitherto unexplored domains. This will provide another cornerstone to the antiproton program at FAIR.

## References

- [1] PAX LoI, <http://www.fz-juelich.de/ikp/pax>
- [2] M. Anselmino, V. Barone, A. Drago and N. Nikolaev, "Accessing transversity via J/PSI production in polarized proton-antiproton interactions", *Phys. Lett. B* **594**, 97 (2004)

- [3] A. Efremov, K. Goecke and P. Schweitzer, "Transversity distribution function in hard scattering of polarized protons and antiprotons in the PAX experiment", *Eur. Phys. J* **35**, 207 (2004)
- [4] S. Brodsky, "Testing Quantum ChromoDynamics with antiprotons", e-Print Archive: hep-ph/0411046
- [5] P. Zavada, "Proton transversity and intrinsic motion of the quarks," arXiv:hep-ph/0412206.
- [6] F. Rathmann et al., "A method to polarize stored antiprotons to a high degree", e-Print Archive: physics/0410067, accepted for publication in *Phys. Rev. Lett.*
- [7] H.O. Meyer, *Phys. Rev. E* **50**, 1485 (1994); C.J. Horowitz and H.O. Meyer, *Phys. Rev. Lett.* **72**, 3981 (1994).
- [8] R. Madey *et al.*, *Phys. Rev. Lett.* **91**, 122002 (2003); S. Strauch *et al.*, *Phys. Rev. Lett.* **91**, 052301 (2003); O. Gayou *et al.*, *Phys. Rev. Lett.* **88**, 092301 (2002).
- [9] F. Rathmann et al., *Phys. Rev. Lett.* **71**, 1379 (1993).
- [10] For a list of PAX collaboration meetings and conference presentations, please visit the PAX web-site at <http://www.fz-juelich.de/ikp/pax/talks>
- [11] P. G. Ratcliffe, "Transversity  $K$  Factors for Drell-Yan," arXiv:hep-ph/0412157.
- [12] V. Barone, C. Corianò and P. Ratcliffe, in preparation.