An Absolute Polarimeter for the Measurement of the Proton Beam Polarization at HERA

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Abstract: It is proposed to build an absolute Coulomb-Nuclear Interference (CNI) polarimeter for measuring the proton beam polarization at HERA. An alternative use of a polarized (unpolarized) proton beam with an unpolarized (polarized) jet target would allow to determine the beam polarization with about 5% accuracy free of theoretical uncertainties. Consistency checks of polarization measurements would be done by using different combinations of beam and target polarization. Several realization schemes of such a polarimeter are discussed.

The beam polarization in a polarized HERA proton ring should be measured and monitored either continuously or frequently during the experimental runs. There are three stages to be considered during acceleration [1]:
- Filling the HERA ring by polarized protons of 38 GeV
- Acceleration from injection energy of 38 GeV up to the final energy of $E_{fin} = 820$ GeV
- Colliding regime. This is the main regime for running experiments.

The proton beam filling time is about 120' including 30' for accumulation at 38 GeV. We have to be able to check the beam polarization at this stage before ramping up the energy. The acceleration from 38 GeV to 820 GeV passes several steps and takes about 40'$\div$50'. This stage is crucial for initial tuning of the beam polarization, since the strongest depolarization resonances are to be crossed. From the polarimetry point of view it is desirable to maintain the intermediate plateau in the magnetic field during about 30' or more to reach the necessary precision in beam polarization measurements. A point of interest is at 200 GeV, where the E704 experiment discovered a large analyzing power in inclusive pion production [$2 \div 4$]. A relative pion polarimeter might be used for rapidly checking the polarization of the internal beam at this specific point (or at 820 GeV, if a dedicated nucleon-nucleon polarization experiment, like HERA-$\overrightarrow{N}$ [5], would have delivered calibration data, already). Another important feature desirable to be implemented at HERA is the possibility to decelerate the beam, say from 820 GeV to 200 GeV, in order to check the consistency of the spin depolarization theory. For example, the correct siberian snake function presumes the conservation of beam polarization in acceleration and deceleration processes, which might be checked directly by this method.

Possible polarimeters, both absolute and relative ones, and their figures of merit have been discussed elsewhere [$6 \div 8$]. As concerns HERA, we discuss in the following several scenarios for an absolute CNI polarimeter [9]:

Scenario 1: CNI polarimeter with detection of only recoil protons.

Scenario 2: CNI polarimeter with detection of only forward particles. It appears to be very attractive since this approach may allow to gain one or even two orders of magnitude in the azimuthal acceptance, $\Delta\,\phi\,/(2\,\pi)$, compared to the previous case.

Scenario 3: CNI polarimeter with detection of both protons. Evidently, in this case the time of polarization measurements will be of the same order as for scenario 1, but the events will be cleaner due to smaller background.

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In fact, all three scenarios might be operated in parallel if three separate triggers were realized. In order to avoid any theoretical uncertainty we intend to perform the polarization measurement in two steps: In the first step we measure (calibrate) the analyzing power by using the unpolarized beam and a polarized target. In the second step, knowing the analyzing power from the previous experiment, we determine the beam polarization by measuring the left-right asymmetry with the polarized beam and an unpolarized target.
If, instead, both beam *and* target are polarized such a measurement constitutes an independent way of measuring the beam polarization gaining an additional factor 2 in running time. Simultaneously the observable A_{NN} may be measured in this case, too.
Scenario 1 has several advantages:
- It is simple and occupies little space around the polarimeter target, only. Several solid state detectors would be used for measuring the coordinate and energy of the recoil particle
- It is a fast and reliable detector as it was demonstrated in an experiment [10]
- It is not sensitive to the initial energy
- No severe constraints are imposed on the beam parameters

To calculate the statistical accuracy for scenario 1 we consider two versions: i) *Realistic version* [5]: Unpolarized beam of I = 80 mA, polarized jet target of density $n = 3 \cdot 10^{13}\ atoms/cm^2$. The luminosity is $L = 1.5 \cdot 10^{31}\ cm^{-2} \cdot s^{-1}$. In the region of interest $t = 10^{-3} \div 10^{-2}\ GeV^2$, the average differential cross-section is $d\sigma/dt = 80\ mb/GeV^2$ and the mean value of the analyzing power is $A_N = 3\%$. The geometrical acceptance for a one arm apparatus is $\Delta\ t = 10^{-2}(GeV/c)^2$, $\Delta\ \phi\ /(2\pi) = 4.5 \cdot 10^{-3}$. The anticipated combined trigger and reconstruction efficiency is assumed to be 50%. Then the counting rate is expected to be N = 27 ev/s and the CNI analyzing power of $\Delta A_N/A_N = \pm 5\%$ precision may be reached during 7 hours of data taking assuming $P_T = 0.8$ as target polarization. ii) *Optimistic version*: Unpolarized proton beam of I=160 mA (which is one goal of the HERA upgrade program), polarized jet target of density $n = 10^{14}\ atoms/cm^2$ (which is acceptable according to [11]), and addition of a second recoil arm. Finally we gain a factor $\kappa = 2 \cdot 3 \cdot 2 = 12$. With all above parameters the counting rate is expected to be N = 324 ev/s leading to $\Delta\ A_N/A_N = \pm\ 5\%$ precision after a T = 0.6 hour measurement.
The second step consists in measuring the beam polarization by using the polarized proton beam and an unpolarized target. The beam polarization, P_B, is defined through the relation $\epsilon = P_B \cdot A_N$, where A_N is taken from the previous measurement. The factor ϵ is measured in this second step. Then $\Delta\ P_B/P_B = \sqrt{(\Delta\epsilon/\epsilon)^2 + (\Delta\ A_N/A_N)^2}$ is the precision of the beam polarization P_B. Assuming for simplicity the same error bars in both steps we get: $\Delta P_B/P_B \approx \sqrt{2} \cdot \Delta A_N/A_N$. The ideal case will occur when the luminosity of the polarized beam with an unpolarized target is the same as above or better (since we can use the unpolarized target with higher density). If the beam polarization is also $P_B = 0.8$ the 5% precision might be reached in the same time as above, i.e. for T= 0.6 h. Then the final precision of the beam polarization will be $\Delta\ P_B/P_B = \sqrt{2} \cdot 5 = \simeq 7\%$.
The technique of **Scenario 2** (forward arm polarimeter) was demonstrated to work reliably in colliders [12]. This polarimeter detects the forward scattered particles moving very close (several *mm*) to the main internal circulating proton beam. The detectors sit in Roman Pots. The measured particle position transforms directly to the scattering angle if one puts some restrictions on the lattice function (see below). The accelerator lattice serves as a powerful magnetic spectrometer suppressing strongly the background. The synchrotron radiation from the nearby electron ring has to be taken into account. The following features of internal beam dynamics are to be fully exploited:
- The jet target must be positioned in a region of a large β-function (target position "TP"); the

beam particles are essentially parallel to each other in this region
- The parallel particles coming from the TP region should be focused in the focal plane. The Roman Pots with strip or pixel detectors will be installed at this position (detector position "DP")
- The difference between advanced phases at these two positions, ψ_{TP} and ψ_{DP}, must be $\Delta\ \psi\ =\ (2k+1)\ \cdot\ \pi/2$, where k is any integer number
- the betatron parameter $\alpha\ =\ -1/2\ \cdot\ d\beta/ds$ should be zero in the TP region.
In general, if the proton was scattered at the TP region under the angle $\theta\ =\ \sqrt{t}/E_{fin}$, it will be detected in the DP region at the position $d\ =\ L_{eff}\ \cdot\ \theta$, where L_{eff} is the effective length in the lattice. For the following calculations we selected the $s\ \simeq$ 1500 m region in HERA and interpolated into the TP region to get the condition $\alpha\ \simeq 0$. In order to fix the detector position we looked for phase advance differences $\Delta\ \psi$ under the above condition. For $k\ =\ 0$ the calculated parameters at TP and DP show a small difference between X- and Y-planes, preferring slightly X. In order to calculate the size and the angular divergence of the beam at both positions we used the standard formulae assuming the normalized emittance $\epsilon_N = 4\pi$ mm $\cdot$ mrad. The calculations show that to reach the point $t\ =\ 10^{-3}\ GeV^2$ the detector should be positioned at 4.0 mm from the beam axis in the X-plane. This is about 20 times bigger than the beam dimension. Background problems must be carefully studied together with the radiation level. If no spin rotator will be foreseen for polarimetry, we must stick to the horizontal plane. For the forward detector alone, the azimuthal acceptance might be 10 or 100 times bigger (for a 4x4 cm^2 detector), compared to the recoil detector. Hence one can expect counting rates of $10^3\ \div\ 10^4$ ev/s. Therefore a 5% precision might be reached in several minutes.
We conclude that the CNI polarimeter may become a useful tool in the process of acceleration and storage of a polarized proton beam at HERA. It was shown that a recoil polarimeter or a forward polarimeter, or a combination of both of them may fit to the requirements: fast and absolute measurements of beam polarization of HERA . Additionally, new information can be obtained from such measurements (e.g. A_{NN}).

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