A Possible Inclusive Neutral Pion Polarimeter for a Polarized HERA Proton Ring

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Abstract

A sketch of an inclusive π^0 polarimeter for the possibly later polarized HERA-p ring is discussed. The specific features of such a polarimeter are a high counting rate, a high analyzing power and a complete azimuthal coverage. This polarimeter could be used from the injection energy of 40 GeV up to the top energy of 820 GeV assuming that the analyzing power is the same or its variation with energy will be known. Running time estimates are given for these two energies.

1 Introduction

The HERA Spin Programme foresees the acceleration of a polarized proton beam up to 820 GeV after injection from PETRA at 40 GeV. For measuring the beam polarization while passing through several strong depolarizing resonances (during the acceleration) and in the physics runs one needs to utilize a polarimeter with a high figure of merit (FoM) [1], $A_N^2 \cdot \sigma$, where the analyzing power, A_N, and the cross-section, σ, of the used process incorporate the acceptance of the polarimeter. According to the classification of polarimeters [2] the best choice would be an absolute, local, and on-line polarimeter with high FoM. However, such a polarimeter has not been established yet. In any practical case, like the polarized HERA-p ring, we have to consider not only a high FoM but also costs and reliability of such a device. In exactly this spirit the inclusive charged pion polarimeter (ICPP) was recently proposed for RHIC [3]; this proposal is based on the high analyzing power, $A_N^{\pm}$, discovered by the E704 Collaboration at Fermilab in inclusive charged pion production at large x_F, at 200 GeV/c incoming beam momentum [4]. Such process has also a sufficiently large cross-section, allowing to determine the beam polarization rather quickly.

In the current paper we propose to apply the idea of an inclusive neutral pion polarimeter (INPP) to the polarized HERA-p environment (the RHIC case was discussed in ref. [5]), i.e. we propose to measure the value of the single spin asymmetry in π^0 production and to determine the beam polarization by comparison with the known value of the analyzing power. Due to the lack of experimental data on the analyzing power at 820 GeV we have to assume in first approximation that the E704 results can be used directly at 820 GeV in the same domain of kinematics.

A new measurement of the π^0 analyzing power at an appropriate initial proton energy is highly desirable. This could be accomplished by a dedicated experiment like HERA-$\vec{N}$ [6]. We argue that a high analyzing power, a large cross-section and flexibility would be very attractive features of such a polarimeter. Some additional advantages like full azimuthal coverage (which is useful in checking any parasitic transverse component of beam polarization), easy coexistence with the accelerator environment (adaptation to varying the initial energy) etc. will be discussed later.

2 The Polarimeter

The results of the E704 measurements of the analyzing power, A_N^0, for inclusive π^0 production in singly polarized pp interactions at 200 GeV/c are well known [7]. The analyzing power in the kinematical region

$$0.4 < x_F < 0.8; \qquad 0.6 < p_T(GeV/c) < 2.0 \tag{1}$$

appears to be higher than 5%. In the following we consider π^0's produced in this kinematical region as useful signal for the application of the INPP, while all others π^0's are treated as background. The size of the error bars in the E704 results [7] allows to estimate the projected normalization precision in the beam polarization measurement to be $\pm 9\%$. If a new measurement of the analyzing power with better accuracy should once be performed the expected precision would be correspondingly better.

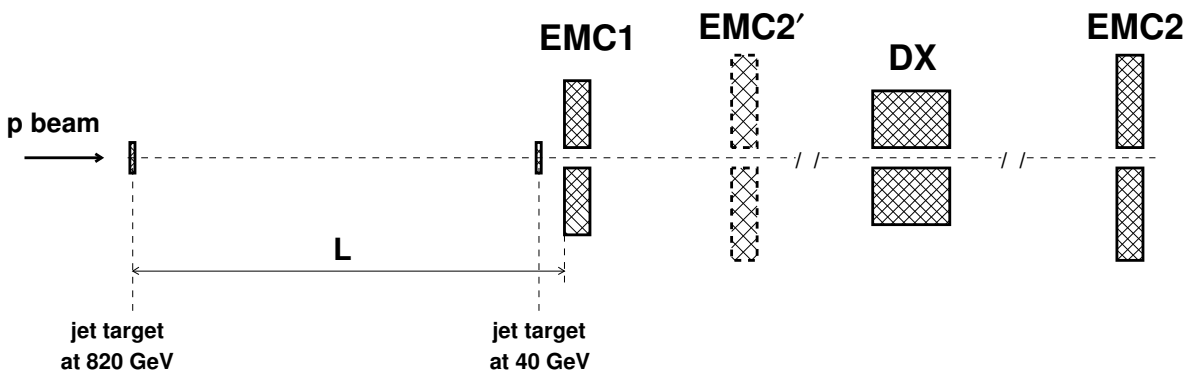

Figure 1: *Sketch of the inclusive neutral pion polarimeter for HERA. EMC1 and EMC2 are the electromagnetic calorimeters. DX is a sweeping magnet. The dashed EMC2' shows the calorimeter position for polarimetry at the injection energy of 40 GeV.*

A sketch of the proposed detectors is shown in Fig. 1; note that this is not connected yet to the HERA lattice structure. The INPP would consist of two electromagnetic calorimeters, EMC1 and EMC2. EMC1 has an internal hole of 60 mm diameter defined by the vacuum pipe. It is installed at a distance L from the target and this distance as well as its outer diameter are variables, depending on the initial energy. EMC2 is placed behind the DX magnet (this in fact is a series of magnetic elements) at a distance of about 100 m to the target and covers completely the hole in EMC1. In this way EMC1 and EMC2 present together one integrated EMC covering the whole azimuthal angle and keeping with high efficiency the useful kinematical interval (1). The combination of two calorimeters offers some flexibility for the polarimeter. Requiring that

both decay photons from the π^0 strike separately EMC1 and EMC2 we hope to be able to establish a coincidence of these two signals, which would present a first step towards an on-line INPP. The second step will be to maximize the value of the FoM and the significance of the signal, S/(S+B), that is the number of registered π^0's from kinematical region (1) over the total number of registered π^0's. This can be done by adjusting the distance, L, of EMC1 with respect to the target position and by selecting the threshold energy for the detection of decay photons which can be chosen differently for both calorimeters, if necessary. After selecting the optimum conditions we must check two conditions: 1) the signal is not dominated by background and noise and 2) the analyzing power is not washed out significantly.
For separation of gammas from charged particles both EMC1 and EMC2 could be supplied with scintillating hodoscopes H1 and H2 installed in front of them.

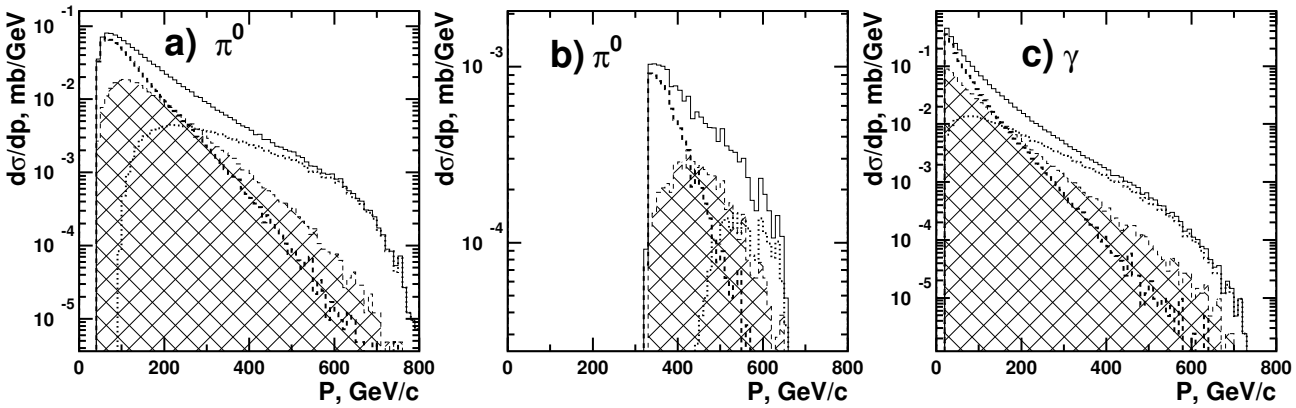

Figure 2: *Cross section of inclusive π^0 production in pp interactions at 820 GeV/c. Both decay photons are registered in some combination of EMC1 and EMC2. a) versus momentum of produced π^0; b) the same as a) but π^0's produced in the kinematical region (1) only; c) decay photon momentum spectrum corresponding to π^0's shown in a). See text for further explanations.*

In order to generate the inclusive π^0 production in the reaction

$$p + p \to \pi^0 + X, \tag{2}$$

PYTHIA 5.7 and JETSET 7.4 programs [8] were used. As an illustration the cross-sections for reaction (2) are presented in Fig. 2 for a position of EMC1 at L= 16m and a threshold energy for photon registration of $E_\gamma^{min} = 20$ GeV. Four different distributions are shown in each of these figures:

- solid line - both photons are in the acceptance of either EMC1 or EMC2;
- dashed line - both photons are in the acceptance of EMC1;
- dotted line - both photons are in the acceptance of EMC2;
- hatched area - one of the photons is in the acceptance of EMC1, while the second one is in the acceptance of EMC2.

All distributions fall steeply in the region of interest. It is seen from fig. 2a that the average momentum of π^0's is much higher in EMC2 than in EMC1. The momentum spectrum is almost flat in EMC2 and steeply decreasing in EMC1. Fig. 2b is obtained after having applied kinematical

conditions (1). Unfortunately only a small portion of all events is useful for polarimetry.
The hatched area represents a coincidence of signals S1 from EMC1 and S2 from EMC2 on the base of which an on-line INPP could possibly be built.
In the following we consider only production of those π^0's which give rise to a coincidence between signals $S1$ from EMC1 and $S2$ from EMC2. In order to design a feasible scheme for an INPP we studied how the distance, L, between the target and the EMC1 influences the polarimeter characteristics. The dependence of $A_N^2 \cdot \sigma$ on L is shown in Fig. 3a. The different curves are labeled by the threshold energy, E_γ^{min}, which was taken to be the same for both calorimeters.
As it is seen from Fig. 3a, the optimum position for EMC1 is close to 22.5m. The next requirement follows from the necessity to have a good signal significance, S/(S+B). It means (see Fig. 3b) that for S/(S+B)$\geq$ 0.8 we have to select the EMC1 position at L$\simeq 10 \div 18$ m at the photon threshold energy $E_\gamma^{min}(GeV) \sim 170$ GeV. Optimizing between both figures 3a and 3b we fixed L=17.5m.

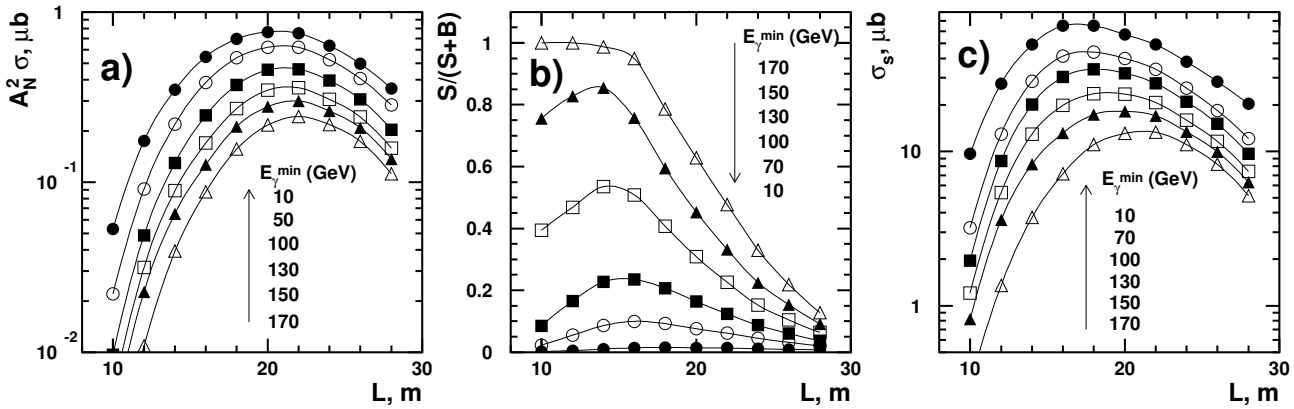

Figure 3: *Shown as a function of EMC1 position, L, are: a) figure of merit, $A_N^2 \cdot \sigma$, b) the signal significance, $S/(S+B)$, c) the integrated useful cross section for inclusive π^0 production. The initial protons energy is 820 GeV. The curves are labeled by the threshold energy, E_γ^{min}, for detection of decay photons in EMC1 and EMC2.*

An estimate was made of the expected counting rates with EMC1 and EMC2 in coincidence.
We assumed a hydrogen jet target with a moderate density $n_t = 3 \cdot 10^{13} atoms/cm^2$ [6], a realistic beam currrent I = 80 mA for HERA-p at 820 GeV, and a beam polarization $P_B = 70\%$, leading to a luminosity of $L = 1.5 \cdot 10^{31} cm^{-2} \cdot s^{-1}$. Taking then the cross-section values for the useful signal, σ_s, from Fig. 3c we obtained the counting rates per second as shown in the Table.
To reach a certain precision $\Delta P_B/P_B$ in measuring the beam polarization, say 5%, one needs to know the average analyzing power for the accepted sample of π^0's. This analyzing power depends on L and is shown in the Table, as well. The choice of the EMC1 position at L=17.5m is justified by the sufficiently high S/(S+B) ratio, the high analyzing power and a minimum running time, $T_{5\%}$, in comparison to neighbouring positions (see the Table). It means that one can accumulate $N_{5\%} = 10^5$ events, which is sufficient to achieve $\Delta P_B/P_B = 5\%$ in about 12 minutes.
For this optimized case, the gross dimensions of EMC1 and EMC2 were estimated with an MC program by requiring that 99% of the γ's needed for the INPP are falling into the acceptance. These dimensions are presented in the Table, too.

Since HERA's injection energy is 40 GeV we checked the possibility to measure with the INPP the proton beam polarization also at this energy. Not having yet experimental data on pion asymmetries at this energy (a measurement at BNL at 23 GeV is envisaged to be realized soon) we assume for the time being that the E704 results can be used directly at 40 GeV in the same kinematical domain as we have it assumed for 820 GeV. Fig. 4a presents the FoM of the INPP at 40 GeV versus distance L. It is seen, that there is a FoM maximum in a region of $1 \div 1.2$ m depending on the selected photon threshold energy, E_γ^{min}. Another important information is the signal significance presented in Fig. 4b. We see also a maximum around $L = 0.8 \div 1.0$ m. Figure 4c shows the cross-section of the useful signal. Applying the same approach as above for the 820 GeV INPP we obtained the corresponding parameters for the 40 GeV INPP (see the Table).

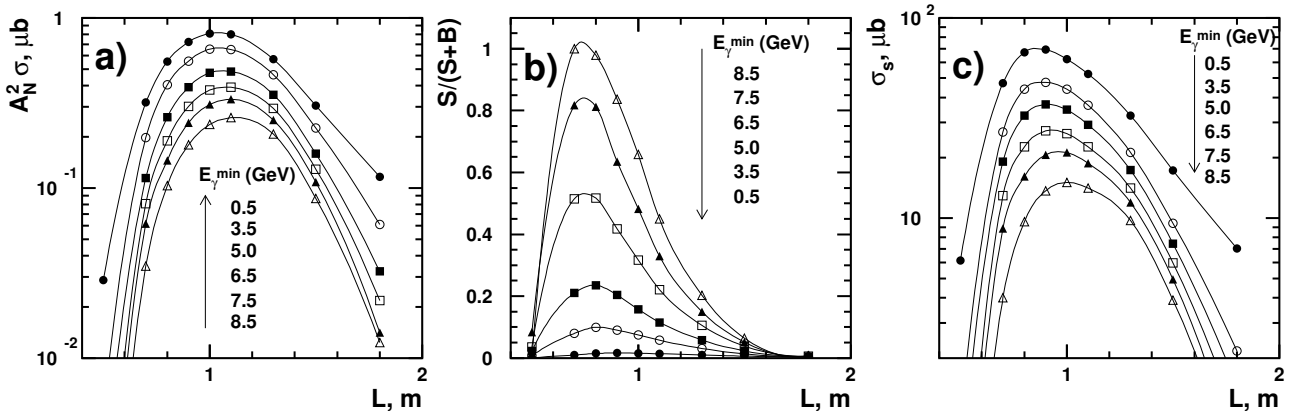

Figure 4: *The same as in Fig. 3, but for the initial protons energy of 40 GeV.*

The results summarized in the Table show that the optimum distance between the target and the EMC1 at 40 GeV is equal to 1 m, while the EMC2' should be placed at a distance of about 5.6 m. The running time, $T_{5\%} \simeq 10$ minutes, is comparable to that for a 820 GeV INPP.

Table: *Expected rate of the useful signal and other INPP parameters for 820 and 40 GeV.*

E_p, GeV	820			40		
L(m)	15	17.5	20	0.8	1.0	1.2
S/(S+B)	0.98	0.84	0.63	1.0	0.68	0.3
$\sigma_s, \mu b$	5	10	12	9.5	13	12
$N(counts/sec)$	75	150	180	142.5	195	180
$A_N, \%$	9.6	9.0	8.0	9.1	8.0	4.1
$N_{5\%}, 10^4$	8.9	10.1	12.8	9.9	12.	48.5
$T_{5\%}, min$	20	12	12	11	10.3	44
outer diam., mm						
EMC1		200			200	
EMC2		400			400	

3 Conclusions

We propose to build an inclusive neutral pion polarimeter (INPP) to measure the polarization in the later possibly polarized HERA-p ring, during injection at 40 GeV and during routinely running at 820 GeV. It is robust, reliable, and might fit into the existing accelerator environment. An INPP has the following advantages over a charged pion polarimeter (ICPP):

- full azimuthal coverage. This allows to measure any transverse component of the beam polarization in the same run;
- practically full coverage of the useful x_F, p_T region with high analyzing power;
- high factor of merit;
- it does not disrupt the main experiments;
- it is less sensitive to background due to the high energy threshold for photons;
- no necessity for a magnetic spectrometer and extra particle identification detectors.

An important problem to be solved is to demonstrate that an INPP may be operated as an on-line polarimeter. Another problem is the absence of experimental data on the analyzing power at 820 GeV; this problem can best be solved at HERA by dedicated measurements as proposed elsewhere [6].

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