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SPIN EFFECTS IN THE INCLUSIVE REACTIONS $\pi^{\pm} + p(\uparrow) \to \pi^{\pm}$ + ANYTHING AT 8 GeV/c

L. DICK, A. GONIDEC, A. GSPONER and M. WERLEN
CERN, Geneva, Switzerland

C. CAVERZASIO, K. KURODA, A. MICHALOWICZ and M. POULET
IPN, Orsay, France

and

D. ASCHMAN, K. GREEN, P. PHIZACKLEA and G.L. SALMON
Oxford University, Oxford, England

The asymmetry in inclusive reactions of the type a + p(↑) → a + anything at 8 GeV/c (a = π^+, π^-, or p) have been measured at the CERN Proton Synchrotron using a polarized proton target. In the πp reactions and over a limited range of p_T ($0.17 \leqslant p_T \leqslant 0.36$) GeV/c the results indicate i) an asymmetry for $x = p_{\parallel}^*/p_{max}^* > 0.7$ which is mirror symmetric for the π^+ and π^- reactions; ii) an asymmetry compatible with zero for $0.3 < x < 0.7$.

In this letter we present the results of an experiment performed at the CERN Proton Synchrotron (PS) to measure the asymmetry ϵ of inclusive reactions on a polarized proton target:

$$\pi^{\pm} + p(\uparrow) \to \pi^{\pm} + \text{anything}. \tag{1}$$

Measurements were made at an incident momentum of 8 GeV/c, a transverse momentum $p_T = 0.265 \pm 0.095$ GeV/c, and for different values of $x = p_{\parallel}^*/p_{max}^*$, in the "fragmentation region" of the incoming particle from $x = 0.3$ up to 0.9.

Although many phenomenological models have been used in the field of inclusive reactions during recent years, ideas concerning spin-dependent effects of inclusive processes are slowly emerging [1–4]. One reason is the complexity of the problem; another is the lack of experimental results. Recently, generalization of the Mueller-Regge ideas to polarized hadrons and formalism have been carried out by several authors [5–9].

A zero asymmetry was predicted by Abarbanel and Gross [1], in the region of beam fragmentation, arising from the constraints of s-channel helicity conservation with the factorization of Regge residues at zero degree. Salin and Soffer [8] have also shown that exchange of mixed naturalities are necessary to explain a non-zero asymmetry in this kinematic region. Spin effects in inclusive reactions have already been studied experimentally in inelastic electron-proton scattering [10], photoproduction of π^- by polarized γ on protons [11], and also in some strong interactions [12, 13], However, the present experiment is a first check of the factorization argument of Abarbanel and Gross in strong interactions.

Another important motivation is based on the fact that, as emphasized by many authors, the asymmetry

$$\epsilon \sim \frac{\langle\lambda(+)|M|\lambda(-)\rangle}{\langle\lambda(+)|M|\lambda(+)\rangle} \tag{2}$$

is directly proportional to the helicity flip amplitude, $|\lambda(+)\rangle$ and $|\lambda(-)\rangle$ being the proton (particle b) helicities [4, 5, 8]. That is to say, asymmetry measurements in the beam fragmentation region will provide a sensitive tool for the study of non-factorizing cut contributions.

Fig. 1 shows the experimental set-up. A secondary beam (intensity 10^6 to 2×10^6) hits a polarized proton target (propanediol $C_3H_8O_2$; dimensions $\Phi = 1.5$ cm, $L = 4.2$ cm). The scattered pion is momentum analysed by a CERN 1 m standard magnet and the hodoscopes H_3 (2 mm spacing) and H_4, H_5, H_6 (3 mm spacing) give all the kinematical information.

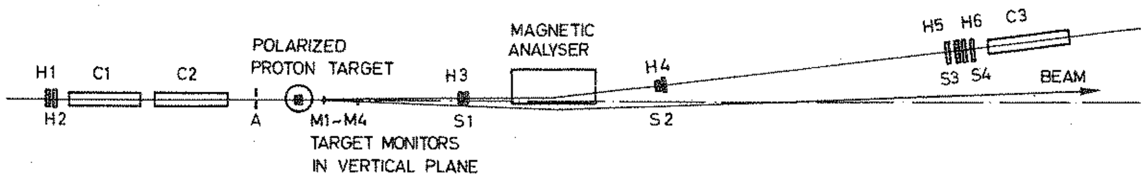

Fig. 1. Experimental set-up for the asymmetry measurement in $\pi^{\pm}p \to \pi^{\pm}$ + anything inclusive process at 8 GeV/*c*.

Changes in the position of the hodoscopes or the current in the magnet allow different regions (x, p_T) of the phase space to be reached. The signature of the event is given by three threshold Čerenkov counters C_1, C_2, C_3, and the trigger was $T = C_1(\pi)C_2(\pi)C_3(\pi)S_1S_2S_3S_4$ where S_{1-4} are the scintillation trigger counters. The rate of multiple particles going through the detectors, which cannot be resolved with this very simple system of detection, was always less than 3%.

Two telescopes $(M_1M_3$ and $M_2M_4)$ symmetrically mounted in the vertical plane at zero degrees horizontally, are used as two monitors. These give information proportional to the product of the beam intensity and the number of nuclei in the target.

The parameter ϵ_H is defined as follows:

$$\epsilon_H = \frac{1}{P_T}\frac{n(+)-n(-)}{n(+)+n(-)}, \tag{3}$$

where P_T is the target polarization, and $n(+)$ and $n(-)$ are the normalized numbers of $\pi + p \to \pi$ + anything events observed with the direction of target polarization positive (spin up) and negative (spin down).

Although the set-up is quite simple, the experiment presents two main difficulties in that it is a zero constraint experiment and that the stability of the experiment must be very good.

Because it is a zero constraint experiment, we have to extract the asymmetry ϵ_H due to free hydrogen from the total asymmetry ϵ_T given by all the material of the target through a dilution factor R:

$$\epsilon_H = R \cdot \epsilon_T = R\,\frac{1}{P_T}\frac{N(+)-N(-)}{N(+)+N(-)}. \tag{4}$$

$N(+), N(-)$ are the normalized (by $M_1M_3 + M_2M_4$ rates) numbers of events of the type π + target $\to \pi$ for positive and negative polarization.

The dilution factor R is the ratio $\{N(+)+N(-)\}/\{n(+)+n(-)\}$ which is close to the chemical ratio of all the nucleons over free protons contained in the target (~8 in case of the propanediol). Consequently, the tolerance of error on ϵ_T becomes so severe that the precise measurement of ϵ_H needs not only high statistics but also very good stability of the counting rates

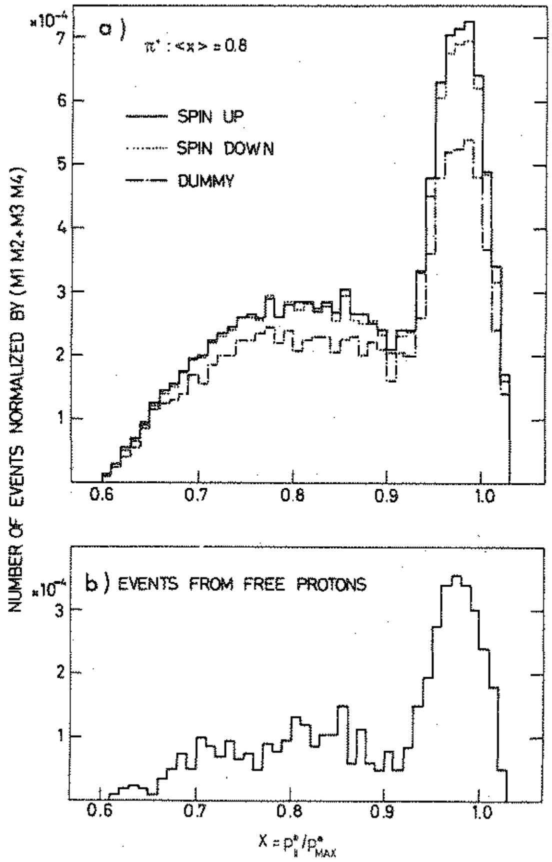

Fig. 2 a) Distributions of the normalized events, as a function of x, for a particular setting around $\langle x \rangle = 0.8$. b) Deduced distribution from free protons.

In order to obtain the factor R which may vary slightly following the kinematical conditions, we made special runs with a carbon dummy-target localized inside the cryostat itself.

Fig. 2a shows an example of spectra as function of x compared with the polarized target spectra, for a particular setting of measurement at $\langle x \rangle = 0.8$. From the fact that the denominator of R, $n(+) + n(-)$, is given as a small difference of large two numbers, $N(+) + N(-)$ and the normalized number of dummy target events, we see immediately that a sufficient precision on R requires a prohibitive precision on the dummy target simulation. To avoid this difficulty, we have normalized the dummy spectrum such that the number of events $n(+)$ and $n(-)$ under the peak at $x \approx 1.0$ give the known experimental value of the polarization in the elastic πp scattering. For this purpose, we have used an interpolated value of the polarization in the elastic πp scattering at 6 [14] and 10 GeV/c [15], and obtained the factor R as function of x. The average value of R was found to be 7 ± 0.7 in fairly good agreement with the chemical ratio.

Fig. 2b shows a spectrum of free hydrogen events after subtraction of the dummy spectrum thus normalized. For $x < 0.9$ contamination, elastic or quasi-elastic contribution in the inclusive events is negligible. But for $x > 0.9$, no inclusive result can be extracted from the data.

The stability of the asymmetry measurement was controlled by reversing the sign of the target polarization as frequently as possible. During the acquisition we tried to obtain the best conditions of stability, and the analysis was considered in two steps:

i) We verified separately the internal stability of the monitors (M_1M_3 and M_2M_4) and the events (trigger rate and processed events' rate). This stability generally is within the statistical limit. For example, we required the ratio M_1M_3/M_2M_4 of the target monitors to be equal for all runs (+) and runs (−) within a precision of 0.002.

ii) A time-dependent analysis method was developed. We know very well that in polarized target experiments the bias on the measured asymmetry would be very small if we had the possibility of reversing the target polarization every minute, for example. Unfortunately this is not the case, and in practice we accumulate data for about two hours with the same sign of target polarization. In this case the conditions of the experiment are not exactly the same for a series of runs (+) and the following series of runs (−). In fact small variations exist which can be compensated for as follows:

If $N(t_i)$ is the appropriate normalized number[‡] of total events corresponding to the target polarization P_i (algebraic value) in a run i taken in a series of runs,

Table 1
Experimental results of the asymmetry in $\pi^\pm + p(\uparrow) \to \pi^\pm$ + anything inclusive reactions at 8 GeV/c for $0.17 \leqslant p_T \leqslant 0.36$ GeV/c

x	$\epsilon(\pi^+)$	$\epsilon(\pi^-)$
0.35 ± 0.05	1.9 ± 2.3%	−3.0 ± 3.4%
0.45 ± 0.05	−0.9 ± 2.0%	−1.3 ± 2.2%
0.55 ± 0.05	−2.8 ± 3.0%	−2.6 ± 3.5%
0.65 ± 0.05	3.4 ± 2.3%	−1.9 ± 3.2%
0.75 ± 0.05	3.5 ± 1.9%	−1.6 ± 2.3%
0.85 ± 0.05	8.8 ± 1.8%	−9.1 ± 2.7%

‡ For the reason of simplicity, we suppose here $N(i)$ absolutely normalized number by an ideal monitor. However, as shown in ref. [16], the time dependent approach allows to recognize only sudden variations of the counting rates as a consequence of the target-polarity change, that means, any slow fluctuation of the monitor is automatically incorporated in the drift function, releasing the above condition on the absolute normalization.

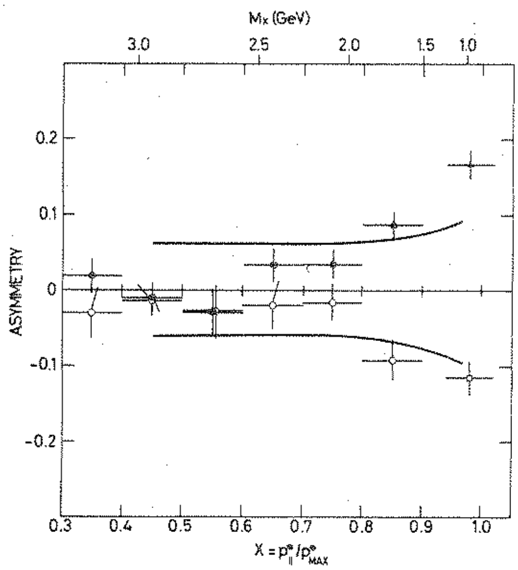

Fig. 3. Asymmetry data from this experiment. (●): $\pi^+p \to \pi^+$; (○): $\pi^-p \to \pi^-$; (▲) and (□) "elastic points" in π^+, π^-.

at time t_i (average value), then

$$N(t_i) = (1 + \epsilon_T P_i) \cdot F(t_i), \qquad (5)$$

where $F(t_i)$ is a drift function which reduces to a constant if there is no time fluctuation of the apparatus. The problem is now reduced to a determination of ϵ_T and $F(t_i)$ by a least squares fit, and for a series of n runs $F(t_i)$ is approximated by a polynomial. The solution for such non-linear normal equations can be obtained in the first order and it gives the parameter ϵ_T and its error, which includes the statistical error but also the non-reducible bias.

The method is described in detail elsewhere [16] and the results we obtain on $\Delta\epsilon_T$ vary from 0.25% to 0.5%, depending on the statistics and the quality of the data.

Table 1 gives the results of the asymmetry ϵ of the inclusive processes $\pi^\pm + p(\uparrow) \to \pi^\pm$ at 8 GeV/c and for $0.17 \leqslant p_T \leqslant 0.36$ GeV/c and different x-values. These results are displayed in fig. 3 as a function of x and of the missing mass M_X.

The two points measured in this experiment [at $x = 0.97$ and $t \approx 0.17 \pm 0.04$ (GeV/c)^2] corresponding to the elastic scattering polarization were used for an absolute normalization of the dummy-target data as mentioned above. The missing-mass resolution ($\approx \pm 200$ MeV) does not allow a detailed study to be made of the resonance region.

The results can be summarized as follows: The asymmetries in π^+ and π^- induced reactions show a mirror symmetry *as in the elastic reactions, with the same sign.* The asymmetry is found to be positive in π^+, negative in π^- for $x > 0.7$. Its magnitude decreases rapidly as x decreases (or M_X increases). For $0.3 < x < 0.7$, asymmetry is found to be flat and almost compatible with zero: $\langle\epsilon\rangle_{\pi^+} = 0.6 \pm 1.2\%$, $\langle\epsilon\rangle_{\pi^-} = -2.0 \pm 1.5\%$.

In our restricted kinematical conditions [$s = 16$ GeV^2; $t \sim$ fixed: -0.1 to -0.2 (GeV/c)^2; M_X^2/s variable: $0.13 \to 0.7$ corresponding to p_T fixed and x variable on a large scale] our data show a very fast decrease of the asymmetry as a function of only one parameter. As M_X corresponds to the total centre-of-mass energy of the three-body system $ab\bar{c}$ in the Mueller-Regge picture, we can say that the asymmetry is very close to zero above an energy of 2.25 GeV. The prediction of Soffer and Wray [17] using a triple Regge cut model reproduces well the flatness of the data in this region, but with a slight disagreement in magnitude.

The non-zero asymmetry we found is well localized in a region of small M_X. In this region it might be expected that two-body exchange diagrams of "elastic-like" reactions dominate the production process; this idea would lead naturally to an asymmetry that is *a priori* different from zero when averaged over the different exclusive reactions.

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