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SPIN DEPENDENCE OF INCLUSIVE REACTIONS FROM PROTON-PROTON COLLISIONS AT 7.9 GeV/c

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The spin dependence of inclusive proton and pion production by 7.9 GeV/c protons has been measured using a polarized proton target, for nominal values of $x = p_L^{cm}/p_{max}^{cm} = 0.7$ in the transverse momentum range 0.4 GeV/$c < p_t <$ 1.2 GeV/c, and for $p_t = 0.4$ GeV/c in the range $0.1 < x < 0.96$. The results indicate a positive asymmetry of +5% over this kinematic region, which corresponds to fragmentation of the unpolarized proton.

1. Introduction

In a previous paper [1] we described the first experiment to use a polarized target for measuring scattering asymmetries in inclusive reactions. This experiment gave evidence for a mirror symmetry in the scattering asymmetries between the two

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reactions $\pi^+ p\uparrow \to \pi^+ + X$ and $\pi^- p\uparrow \to \pi^- + X$ at 8 GeV/c, and an indication that in $p + p\uparrow \to p + X$ the asymmetry was non-zero. Since then several experiments have measured inclusive scattering asymmetries with polarized beams [2] or measured the polarization of the final state particle [3,4] to show that substantial spin effects exist up to 300 GeV/c.

The present experiment studies the scattering asymmetries from a polarized target of reactions

$$p + p\uparrow \to p + X\,,$$

$$p + p\uparrow \to \pi^{\pm} + X\,,$$

at 7.9 GeV/c incident momentum.

2. Experimental details

The apparatus used in these inclusive scattering asymmetry measurements was a slightly modified version of that used to measure the polarization parameter in pp elastic scattering at 7.9 GeV/c described in a previous paper [5]. The beam, magnetic spectrometer, monitor system and polarized target were discussed in detail and so only those points of relevance to the inclusive measurement will be described here.

2.1. The spectrometers

The experimental layout is shown in fig. 1. A high intensity 7.9 GeV/c extracted proton beam of 10^9 protons per pulse from Nimrod at the Rutherford Laboratory was incident on a polarized proton target. Scattered particles were detected by a spectrometer which was the forward scattering arm from the elastic experiment [5] with some minor modifications and additions. Numerous settings in the Feynman longitudinal variable $x = p_L^{cm}/p_{max}^{cm}$, and the transverse momentum, p_t, for this spectrometer allowed particles in the kinematic range $0.125 < x < 0.96$ and $0.3 < p_t < 1.2$ GeV/c to be detected.

The spectrometer consists of a magnet 1 m long (M_{402}), scintillation counters

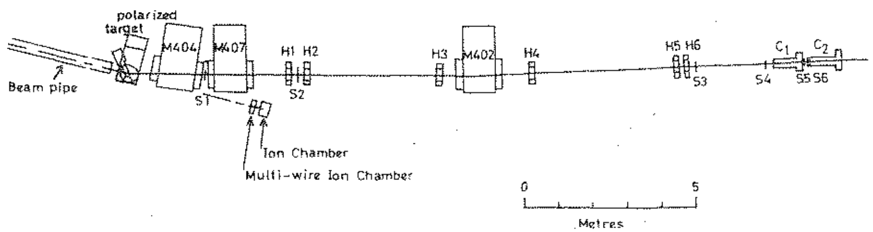

Fig. 1. The apparatus.

$S_1 - S_6$, and two threshold Čerenkov counters C_1 and C_2 (to identify the particles as protons or pions). Counter S_1 defined the angular acceptance $\Delta\theta < \pm 1.5$ mrad, and S_5 or S_6 defined the acceptance in laboratory momentum $\Delta p_{lab} = \pm 0.5$ GeV/c to ± 1.1 GeV/c (depending on the particle and kinematic region). To cover the wide kinematic range without moving the spectrometer, two further magnets (M_{404} and M_{407}) were used to steer particles into the spectrometer. For each setting of the steering magnets, the analysing magnet was adjusted so that the outgoing central ray was along the axis of the Čerenkov counters which were fixed in position. The magnet settings were calculated for each point and checked at some settings by wire orbit measurements.

The acceptances in x and p_t defined by the counters S_1 and S_6 were typically $\Delta x = \pm 0.06$ and $\Delta p_t = \pm 0.14$ GeV/c, and were sufficiently small for it to be unnecessary to subdivide the acceptance further using the hodoscopes. Data from the hodoscopes were used to check the x and p_t acceptance, make estimates of background and to show that at all points we were excluding elastic scattering events.

2.2. *The polarized target*

The polarized target was a standard CERN cryostat using propanediol at 0.5°K in a cavity 14 mm in diameter and 43 mm long. The average polarization of the material was measured by an NMR coil surrounding the target. Because of radiation damage to the central region of the target which was traversed by the beam, a correction was applied to the NMR measurement to give the correct polarization of this central part. The correction, which was a function of the total particle flux through the target material, was obtained from measurements of the elastic pp scattering in which the recoil proton was also detected, at $|t| = 1.7$ (GeV/c)^2 where the polarization parameter in elastic scattering is known to be large. Again this is described in detail in ref. [5].

The target material was changed after 0.8×10^{14} protons had passed through it, by which time the polarization of the target core had dropped by a factor of two.

2.3. *The monitors*

Two three-scintillation counter telescopes viewed the target in the plane of target polarization; M_{135} above the scattering plane and M_{246} below. These two telescopes were sensitive to the number of interactions in the target but insensitive to the polarization direction.

It was important for the beam position on the target to be stable, so as not to cause a variation in the relative acceptance of the spectrometer to the monitors. The beam's vertical and horizontal position was monitored continuously by multiwire ionization chambers with 1 mm wire spacing which, for this experiment, were positioned downstream of the target so as not to scatter background particles into the spectrometer. The beam position was stable to better than 0.5 mm during the

entire data taking. The absolute beam intensity of 10^9 protons per pulse, was monitored by a thin plate ionization chamber. The whole region containing the beam and the polarized target, from the end window of the beam vacuum pipe to beyond S_2, was enclosed in a helium bag to minimize the background particles scattered into the spectrometer.

As an additional check on the stability of the beam on the target and on the absence of a false asymmetry in the monitors, we monitored the ratio (M_{135} + M_{246})/(Ion Chamber) and found asymmetries statistically consistent with zero.

3. The dilution factor

There is a severe limitation in performing an inclusive scattering experiment with a polarized target. Since one particle only is detected from each interaction, there is no way of distinguishing between scattering from the free (polarized) protons in the target and the more numerous (unpolarized) nucleons in the heavier nuclei both in the target and its surroundings (cryostat, and microwave cavity). In particular the ratio of bound to free nucleons in propanediol ($C_3H_8O_2$) is 8.5: 1.0.

The measurement one is trying to make is ϵ_H, the inclusive scattering asymmetry from free polarized protons given by

$$\epsilon_H = \frac{1}{P_T}\left[\frac{N_H^+ - N_H^-}{N_H^+ + N_H^-}\right] ,$$

where P_T is the value of the proton polarization and $N_H^+(N_H^-)$ is the scattering rate when the polarization is up (down).

In fact one observes the asymmetry ϵ_{obs} given by

$$\epsilon_{obs} = \frac{1}{P_T}\left[\frac{N_T^+ - N_T^-}{N_T^+ + N_T^-}\right] = \frac{1}{P_T}\left[\frac{N_H^+ - N_H^-}{N_H^+ + N_H^- + 2(N_A + N_B)}\right] ,$$

where $N_T^{+(-)} = N_H^{+(-)} + N_A + N_B$ is the total scattering rate, N_A is the scattering rate from the nucleons in the heavy nuclei of the target and N_B is the scattering rate from the nucleons in the background material (cryostat walls, etc). ϵ_H and ϵ_{obs} are defined to be positive when more particles are scattered to the left of the beam direction when the target polarization is up.

Thus $|\epsilon_{obs}| < |\epsilon_H|$ because of the diluting effect of the term $2(N_A + N_B)$ in ϵ_{obs}, and for propanediol $\epsilon_{obs} \simeq 0.2\ \epsilon_H$. Generally it is not possible to make material of the correct chemical composition necessary for a direct measurement of N_A, so an indirect method has to be employed. We have made use of the fact the ϵ_H and ϵ_{obs} are related to what we have called the dilution factor D such that

$$\epsilon_H = \epsilon_{obs} D ,$$

where

$$D = [1 + b/f][1 + N_B/N_S] ,$$

$$N_S = N_A + N_H = N_T - N_B ,$$

$$N_H = \frac{1}{2}(N_H^+ + N_H^-) ,$$

$$N_T = \frac{1}{2}(N_T^+ + N_T^-) .$$

N_S is the total scattering rate from the target material and $b/f = N_A/N_H$ is the bound nucleon/free proton scattering ratio. The term $[1 + N_B/N_S]$ can be evaluated by a direct measurement of the scattering rate with the target material removed.

The term $[1 + b/f]$ can be calculated by measuring the b/f ratio with material not unlike the target material. We perfomed this subsidiary experiment by measuring the b/f ratio in polythene (CH_2) at every spectrometer setting. Assuming that nuclear shielding causes a dependence on the atomic mass of the form A^α we find that α varies over the range $\frac{2}{3}$ to 1 according to x and p_T. Details of this measurement will be published separately. Using these values of α we compute the b/f ratios for the propanediol molecule using the relation

$$(b/f)_{C_3H_8O_2} = \frac{1}{8}[3 \times (12)^\alpha + 2 \times (16)^\alpha] .$$

These values are shown in table 1.

Table 1
Measured asymmetries, dilution-factors and hydrogen asymmetries

x	p_t	ϵ_{obs} %	$1 + b/f$	$1 + N_B/N_S$	D	ϵ_H %
(a) p + p → p + X						
0.62	0.4	0.39 ± 0.46	4.77 ± 0.04	1.50 ± 0.10	7.1 ± 0.5	2.8 ± 3.3
0.62	0.6	0.93 ± 0.34	5.21 ± 0.12	1.06 ± 0.01	5.5 ± 0.2	5.1 ± 1.9
0.62	0.8	1.01 ± 0.28	6.04 ± 0.24	1.08 ± 0.01	6.5 ± 0.3	6.6 ± 1.8
0.62	1.10	1.13 ± 0.22	7.44 ± 0.38	1.09 ± 0.01	8.1 ± 0.4	9.2 ± 1.8
0.60	1.15	0.60 ± 0.60	7.35 ± 0.40	1.11 ± 0.01	8.2 ± 0.5	4.9 ± 4.9
0.39	0.4	1.33 ± 0.57	5.51 ± 0.13	1.06 ± 0.01	6.2 ± 0.2	8.2 ± 3.6
0.73	0.4	0.42 ± 0.43	4.43 ± 0.04	1.66 ± 0.10	7.3 ± 0.5	3.1 ± 3.2
0.84	0.5	0.33 ± 0.67	4.92 ± 0.06	1.60 ± 0.25	7.9 ± 1.2	2.6 ± 5.3
0.82	0.75	0.19 ± 0.91	5.02 ± 0.09	1.60 ± 0.25	8.0 ± 1.2	1.5 ± 7.3
(b) p + p → π^+ + X						
0.79	0.4	0.88 ± 0.34	4.55 ± 0.18	1.32 ± 0.05	6.0 ± 0.31	5.3 ± 2.1
0.79	0.6	1.31 ± 0.94	4.31 ± 0.30	1.07 ± 0.01	4.6 ± 0.3	6.0 ± 4.3
0.79	0.8	1.52 ± 0.61	4.93 ± 0.99	1.12 ± 0.01	5.5 ± 1.1	8.4 ± 3.4
0.75	0.9	0.44 ± 3.2	4.74 ± 1.5	1.16 ± 0.02	5.5 ± 1.7	2.4 ± 18
0.70	1.02	2.93 ± 1.48	10.2 ± 7.5	1.20 ± 0.03	12.2 ± 9.0	36 ± 20
0.57	0.4	1.66 ± 0.32	5.76 ± 0.33	1.12 ± 0.02	6.9 ± 0.4	11.5 ± 2.3
0.90	0.4	1.04 ± 0.32	3.60 ± 0.15	1.35 ± 0.10	4.9 ± 0.4	5.1 ± 1.6
0.94	0.4	0.17 ± 0.5	3.9 ± 0.3	1.35 ± 0.15	5.3 ± 0.7	0.9 ± 2.6
0.91	0.62	−0.02 ± 0.95	3.62 ± 0.55	1.35 ± 0.15	4.8 ± 0.9	−0.1 ± 4.6
(c) p + p → π^- + X						
0.79	0.6	0.57 ± 0.36	4.31 ± 0.30	1.07 ± 0.02	4.6 ± 0.3	2.6 ± 1.7

4. Analysis and data

For each x and p_T setting a series of runs with polarization sign reversals of the form +−−++−−+; up to 20 reversals were made in order to maximise the number of +/− pairs and reduce the errors from systematic effects. The asymmetry was calculated for each run pair, and the mean of these asymmetries calculated. For most settings the counting rates were so large that fluctuations in the ratio of spectrometer counts to the monitors due, for example, to fluctuations in the beam intensity, exceeded that expected on the basis of the number of counts recorded, typically 10^5. The resultant χ^2 of the average asymmetry was thus larger than expected, and the computed error on the mean experimental asymmetry was therefore increased accordingly.

The alternative analysis procedure of fitting the function $(1 - P_T(t))f(t)$ to the counting rate [6], where $f(t)$ was taken to be a series of Legendre polynomials in the time of measurement, t, resulted in essentially the same value for the asymmetry ϵ_{obs}, and for its error.

The observed asymmetries are tabulated in table 1, together with the values of the dilution factor and the contributing terms. The values of the asymmetry for scattering from polarized protons are tabulated in the final column of table 1 and plotted in fig. 2.

The main feature of the data is that the asymmetry in the region $x > 0$ is positive and of the order of 5% both for proton and for π^+ production, with no strong variation with x or p_t. The point measured for π^- shows an asymmetry of the same sign as that found for π^+, and of a comparable magnitude. The proton data agrees with the results reported by Gonidec [1] and by Aschman [1], both in sign and magnitude. These results are also plotted in fig. 2.

The results presented here for the inclusive pion production asymmetry are in the unpolarized particle fragmentation region. They contrast sharply with the results of ref. [2] for the polarized particle fragmentation region, in which larger asymmetries are found and which vary rapidly with transverse momentum. On the other hand the proton production results show a similar small positive asymmetry for both fragmentation regions.

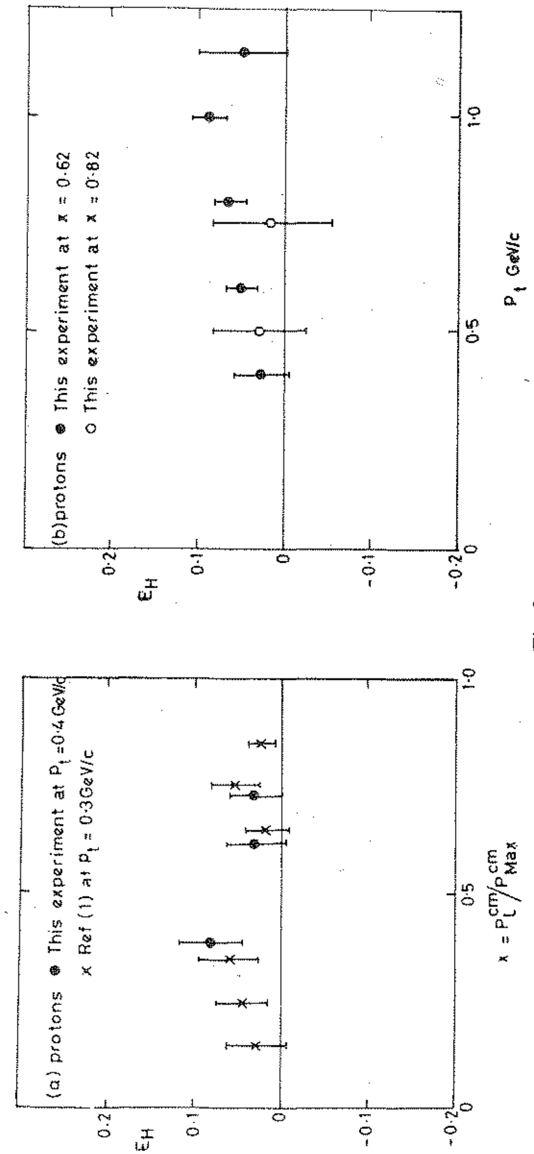

Fig. 2.

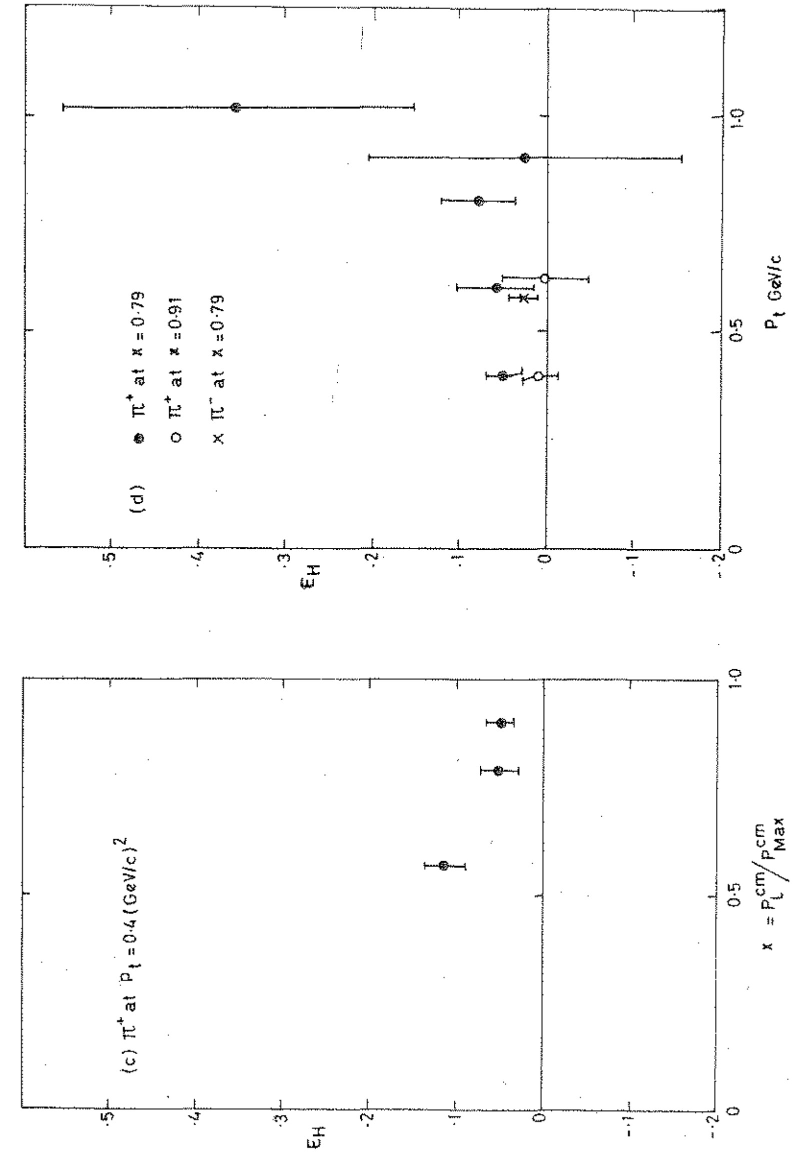

Fig. 2. Inclusive asymmetries, ϵ_H. (a) and (b) for $p + p \to p + X$; (c) and (d) for $p + p \to \pi^{\pm} + X$.

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