Hadron Azimuthal Distributions and Transverse Spin Asymmetries in DIS of Leptons off Transversely Polarized Targets from SMC

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Azimuthal distributions of hadrons (mainly π^+ and π^-) produced in DIS off transversely polarized targets (proton and deuteron) are studied for the first time in SMC. From these azimuthal distributions, transverse single-spin asymmetries are derived. According to Collins ('Collins effect'), the azimuthal distribution of the leading hadron might exhibit an symmetry which originates from the transverse polarization of the final quark.

1. INTRODUCTION

While transverse spin effects have been known in hadronic interactions since a few decades, investigations with leptonic probes have started very recently. For instance, in inclusive pion production by transversely polarized proton beams π^+ (π^-) are produced preferentially to the beam-left (beam-right) with A_N values in excess of 30 % at large x_F (the proton spin points upward). For a recent review see [1].

It is natural to search for such effects also in deep inelastic scattering (DIS) of (unpolarized) leptons off transversely polarized targets. If the observed asymmetries in pion production are induced by the transverse polarization of the recombining quark at large x_F, large azimuthal dependencies are expected also in lepton induced processes for the leading hadron. A detailed experimental program to investigate transverse spin effects in DIS has been proposed recently by the COMPASS collaboration at CERN [2].

In the meanwhile, first, preliminary results on the transverse spin dependence in semi-inclusive hadron production are presented by the Spin Muon Collaboration. SMC took some data also with a transversely polarized proton target (butanol) at 100 GeV and a deuteron target (deuterated butanol) at 190 GeV muon beam energy. Although the main goal of these measurements have been the g_2 structure function [3], enough events with hadrons have been collected to give a first look at these phenomena.

2. PHENOMENOLOGY

Following Collins [4], the fragmentation function for transversely polarized quarks $\mathcal{D}_q^h$ is built up from two pieces, a spin-independent part D_q^h, and a spin-dependent part ΔD_q^h:

$$\mathcal{D}_q^h(z,\vec{p}_q^{\,h}) = D_q^h(z,p_q^h) + \Delta D_q^h(z,p_q^h)\cdot \sin\,\phi_c \quad (1)$$

The angle ϕ_c, known as 'Collins angle', is the azimuthal angle between the outgoing hadron ϕ_h and the final quark spin $\phi_{S'}$ around the virtual photon momentum, and at leading twist it is given by

$$\phi_c = \phi_h \,-\, \phi_{S'} = \phi_h \,+\, \phi_S - \pi \quad (2)$$

where ϕ_S is the initial quark spin azimuthal angle. Note that $\sin\,\phi_c$ is the spin component of the final quark normal to the production plane defined by the virtual photon and outgoing hadron. This is the only single-spin asymmetry allowed by the symmetries conserved in strong interactions. The various angles and the $\gamma^* + q\uparrow\rightarrow q'$ process are illustrated in fig. 1.

This spin dependence of the fragmentation function leads to a specific azimuthal dependence for the outgoing leading hadron

$$\mathrm{d}\sigma(\phi_c) \sim Const\cdot(1 + A_N \sin\,\phi_c)\,\mathrm{d}\phi_c\ . \quad (3)$$

The amplitude A_N of the azimuthal modulation

$$A_N = H(x)\cdot a_c(z,p_T) \quad (4)$$

is proportional to both the transversity distribution, $H(x)$, and the *analyzing power* in the polarized quark fragmentation, a_c, known also as

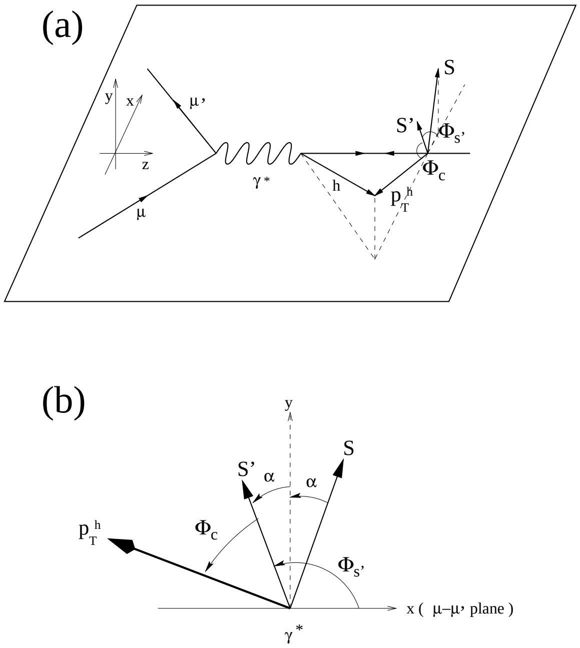

Figure 1. Definition of the 'Collins angle' $\phi_c = \phi_h - \phi_{S'}$ in the Breit frame: (a) perspective view, (b) front view (the γ^* points out of the page).

quark polarimeter. At present, both quantities are unknown, and experimentally one measures their product A_N. Note that $a_c(z, p_T)$ depends strongly on the selected hadron kinematics, and it will vary from experiment to experiment because of different selection criteria and acceptance effects.

3. RESULTS

Experimentally, one access these effects by selecting the leading (fastest) hadron produced in DIS off a transversely polarized target in the event, and by studying its azimuthal dependence with respect to the ϕ_c angle. This is equivalent to look for asymmetries in the yields of hadrons produced opposite in azimuth (weighted by sin ϕ_c)

$$\varepsilon_N = \frac{1}{< \sin\phi_c >} \cdot \frac{N(\phi_c) - N(\phi_c + \pi)}{N(\phi_c) + N(\phi_c + \pi)} \qquad (5)$$

The largest effects appear for sin $\phi_c = \pm\,\pi$ (therefore *left-right* asymmetry w.r.t. final quark spin). The transverse single-spin asymmetry A_N is derived from the measured asymmetry ε_N as

$$A_N = \frac{1}{P_T\, f\, D_{NN}} \cdot \varepsilon_N \qquad (6)$$

where P_T and f are the target transverse polarization and dilution factor, respectively. D_{NN} is the transverse spin transfer coefficient (or depolarization factor) in $\gamma^* + q \uparrow \to q'$:

$$D_{NN} = 2\,(1-y)\,/\,\left(1 + (1-y)^2\right) \qquad (7)$$

D_{NN} is large at low y and decreases with increasing y. The low y region corresponds also to the large x region, where quarks polarization is expected to be higher. Thus larger asymmetries are expected at lower y.

Events have been selected requiring (only the most relevant cuts are listed)

- $Q^2 > 1$ GeV^2
- $y < 0.7$
- $\nu > 10\,(15)$ GeV for proton (deuteron) data

and, for the fastest hadron in the event

- $z > 0.25$
- $p_T > 0.1$ GeV$/c$ and $p_T > 0.5$ GeV$/c$.

The fastest detected hadron is usually the leading hadron for large enough z. About 120 K events on proton and about 250 K events on deuteron has passed these selections and have been used in the analysis. Average values of the kinematical variables for the selected sample are: $< z > \sim 0.45$, $< p_T > \sim 0.5$ GeV$/c$ for the $p_T > 0.1$ GeV$/c$ data and $< p_T > \sim 0.8$ GeV$/c$ for the $p_T > 0.5$ GeV$/c$ data, both for the proton and the deuteron target.

The SMC target consisted of two cells with opposite polarizations, and the target polarization itself was reversed several times during the data taking, in order to minimize systematic effects related to the apparatus acceptance and changes in efficiencies.

Figure 2 shows the ϕ_c azimuthal distribution for positive hadrons (mainly π^+'s) produced off the polarized proton target. This ϕ_c distribution has been obtained from the measured one (*raw* distribution) after weiting it with $P_T\, f\, D_{NN}$ and subtracting the *unpolarized* part. The superimposed sinusoidal line is a fit to the data of the form $(Const + A_N \sin\phi_c)$.

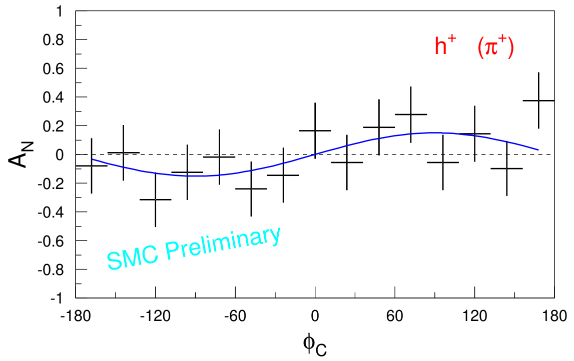

Figure 2. ϕ_c azimuthal distributions for positive hadrons produced off transversely polarized protons with a $(Const + A_N \sin\phi_c)$ fit superimposed.

Figure 3 shows the transverse single-spin A_N results for proton and deuteron data separately. In figure 3a the A_N data are also separated for positive (mainly π^+'s) and negative (mainly π^-'s) hadrons. $A_N = 0.11 \pm 0.06$ for π^+'s, and $A_N = -0.02 \pm 0.06$ for π^-'s on the proton target at $< x > \sim 0.08$ and $< Q^2 > \sim 5$ GeV^2. On deuteron, A_N is small for both π^+'s and π^-'s. Figures 3b and 3c show the p_T dependence of A_N for positive and negative hadrons, respectively. The data indicate that A_N increases in magnitude with increasing p_T.

In summary, these are the first, preliminary, results on the azimuthal dependence of hadron production in semi-inclusive DIS off transversely polarized targets. Although the statistical precision is limited, mainly because of the large target dilution factor f, indications of possible transverse spin effects are observed in the data, with an almost $2\,\sigma$ positive effect for π^+'s produced on protons.

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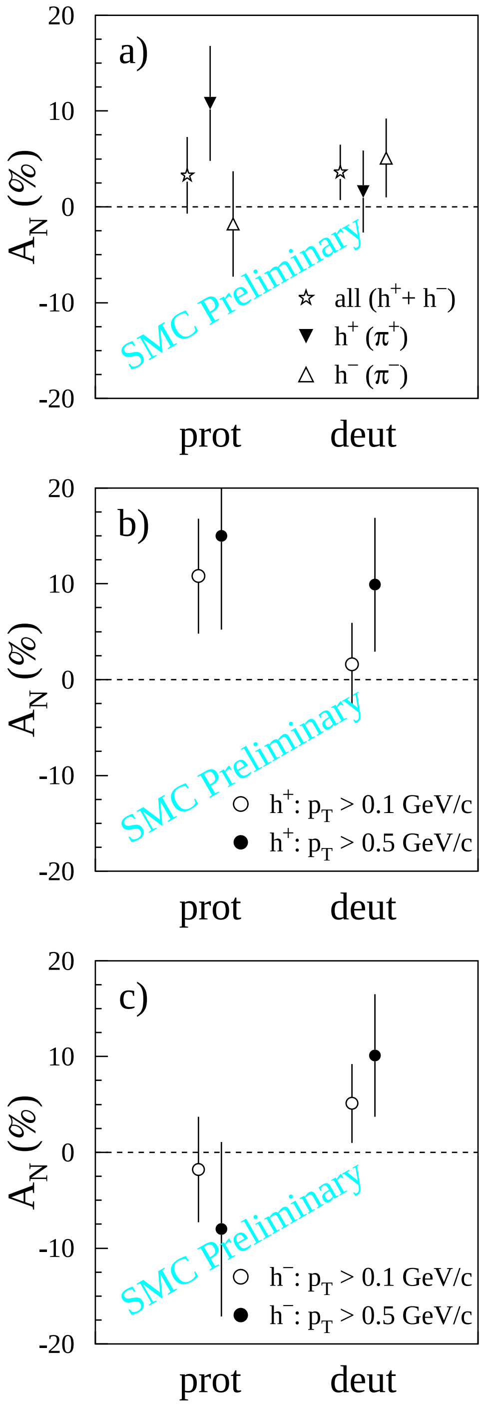

Figure 3. The transverse spin asymmetry A_N for proton and deuteron data. The errors shown are statistical only.