Eur. Phys. J. C 24, 407–412 (2002)
Digital Object Identifier (DOI) 10.1007/s100520200918

THE EUROPEAN
PHYSICAL JOURNAL C

Predictions for azimuthal asymmetries in pion and kaon production in SIDIS off a longitudinally polarized deuterium target at HERMES

A.V. Efremov[1,a], K. Goeke[2], P. Schweitzer[3]

[1] Joint Institute for Nuclear Research, Dubna, 141980 Russia
[2] Institut für Theoretische Physik II, Ruhr-Universität Bochum, 44780 Bochum, Germany
[3] Dipartimento di Fisica Nucleare e Teorica, Universitá degli Studi di Pavia, 27100 Pavia, Italy

Received: 8 January 2002 / Revised version: 25 January 2002 /
Published online: 26 April 2002 – © Springer-Verlag / Società Italiana di Fisica 2002

Abstract. Predictions are made for azimuthal asymmetries in pion and kaon production from SIDIS off a *longitudinally polarized deuterium* target for HERMES kinematics, based on information on the "Collins fragmentation function" from DELPHI data and on predictions for the transversity distribution function from non-perturbative calculations in the chiral quark-soliton model. There are no free parameters in the approach, which has already been successfully applied to explain the azimuthal asymmetries from SIDIS off polarized *proton* targets observed by HERMES and SMC.

1 Introduction

Recently noticeable azimuthal asymmetries have been observed by HERMES in pion electro-production in semi-inclusive deep-inelastic scattering (SIDIS) of an unpolarized lepton beam off a longitudinally polarized proton target [1,2]. Azimuthal asymmetries were also observed in SIDIS off transversely polarized protons at SMC [3]. These asymmetries are due to the so-called *Collins effect* [4] and contain information on $h_1^a(x)$ and $H_1^\perp(z)$. The transversity distribution function $h_1^a(x)$ describes the distribution of transversely polarized quarks of flavor a in the nucleon [5]. The T-odd fragmentation function $H_1^\perp(z)$ describes the fragmentation of transversely polarized quarks of flavor a into a hadron [4,6–8]. Both, $H_1^\perp(z)$ and $h_1^a(x)$, are twist-2 and chirally odd. First experimental information to $H_1^\perp(z)$ has been extracted from DELPHI data on e^+e^- annihilation [9,10]. HERMES and SMC data [1–3] provide first information on $h_1^a(x)$ (and further information on $H_1^\perp(z)$).

In [12] HERMES and SMC data on azimuthal asymmetries from SIDIS off a, respectively, longitudinally and transversely polarized *proton* target [1–3] have been well explained. In the approach of [12] there are no free parameters: for $H_1^\perp$ information from DELPHI [9,10] was used, for $h_1^a(x)$ predictions from the chiral quark-soliton model were taken [13]. In this note we apply this approach to predict azimuthal asymmetries in pion and kaon production from SIDIS off *a longitudinally polarized deuterium* target, which are under current study at HERMES.

Similar work has been done in [14–16] however making use of certain assumptions on $H_1^\perp$ and h_1^a and/or considering only twist-2 contributions for target polarization transversal with respect to the virtual photon momentum component. We take into account all $1/Q$ contributions.

2 Ingredients for prediction: $H_1^\perp$ and $h_1^a(x)$

2.1 The T-odd fragmentation function $H_1^\perp$

The fragmentation function $H_1^\perp(z, \boldsymbol{k}_\perp^2)$ describes a left–right asymmetry in the fragmentation of a transversely polarized quark with spin $\boldsymbol{\sigma}$ and momentum $\boldsymbol{k}$ into a hadron with momentum $\boldsymbol{P}_h = -z\boldsymbol{k}$. The relevant structure is $H_1^\perp(z, \boldsymbol{k}_\perp^2)\boldsymbol{\sigma}(\boldsymbol{k} \times \boldsymbol{P}_{\perp h})/|\boldsymbol{k}|\langle P_{\perp h}\rangle$, where $\langle P_{\perp h}\rangle$ is the average transverse momentum of the final hadron. Note the different normalization factor compared to [6,7]: $\langle P_{h\perp}\rangle$ instead of M_h. This normalization is of advantage for studying $H_1^\perp$ in the chiral limit.

$H_1^\perp$ is responsible for a specific azimuthal asymmetry of a hadron in a jet around the axis in the direction of the second hadron in the opposite jet. This asymmetry was measured using the DELPHI data collection [9,10]. For the leading particles in each jet of two-jet events, summed over z and averaged over quark flavors (assuming $H_1^\perp = \sum_h H_1^{\perp q/h}$ is flavor independent), the most reliable value of the analyzing power is given by $(6.3 \pm 2.0)\%$, however

[a] Supported by RFBR Grant No. 00-02-16696 and INTAS Project 587 and the Heisenberg-Landau program

a larger "optimistic" value is not excluded

$$\left|\frac{\langle H_1^\perp\rangle}{\langle D_1\rangle}\right| = (12.5 \pm 1.4)\%, \tag{1}$$

with presumably large systematic errors. The result (1) refers to the scale M_Z^2 and to an average z of $\langle z\rangle \simeq 0.4$ [9, 10]. A close value was also obtained from the pion asymmetry in inclusive pp scattering [17].

When applying the DELPHI result (1) to explain the HERMES data a weak scale dependence of $\langle H_1^\perp\rangle/\langle D_1\rangle$ is assumed. In [12] – taking the chiral quark-soliton model prediction for $h_1^a(x)$ – both $H_1^\perp(z)/D_1(z)$ and $\langle H_1^\perp\rangle/\langle D_1\rangle$ have been extracted from the HERMES and SMC data [1–3]. The value for $\langle H_1^\perp\rangle/\langle D_1\rangle$ obtained from that analysis is very close to the DELPHI result (1), but of course model dependent. (The theoretical uncertainty of $h_1^a(x)$ from the chiral quark-soliton model is around (10–20)%.) This indicates a weak scale dependence of the analyzing power and supports the above assumption. Here we take $\langle H_1^\perp\rangle/\langle D_1\rangle = (12.5 \pm 1.4)\%$, i.e. the DELPHI result, (1), with positive sign for which the analysis of [12] gave evidence.

2.2 $h_1^a(x)$ in the nucleon

For the transversity distribution function $h_1^a(x)$ we take predictions from the chiral quark-soliton model (χQSM) [13]. The χQSM is a relativistic quantum field-theoretical model with explicit quark and antiquark degrees of freedom. This allows one to unambiguously identify quark as well as antiquark nucleon distribution functions. The χQSM has been derived from the instanton model of the QCD vacuum [18]. Due to the field-theoretical nature of the χQSM, the quark and antiquark distribution functions computed in the model satisfy all general QCD requirements (positivity, sum rules, inequalities) [19]. The model results for the known distribution functions – $f_1^q(x)$, $f_1^{\bar q}(x)$ and $g_1^q(x)$ – agree within (10–30)% with phenomenological parameterizations [20]. This encourages confidence in the model predictions for $h_1^a(x)$. Figure 1 shows the model results for the proton transversity distribution, $h_1^{a/p}(x)$ with $a = u, \bar u, d, \bar d$, at $Q^2 = 4\,\mathrm{GeV}^2$.

2.3 $h_1^s(x)$ and $h_1^{\bar s}(x)$ in the nucleon

We assume strange transversity distributions to be zero

$$h_1^s(x) \simeq 0, \quad h_1^{\bar s}(x) \simeq 0. \tag{2}$$

This is supported by calculations of the tensor charge in the SU(3) version of χQSM [21]

$$g_T^s := \int_0^1 \mathrm{d}x (h_1^s - h_1^{\bar s})(x) = -0.008$$
$$\text{vs.} \quad g_T^u = 1.12, \quad g_T^d = -0.42 \tag{3}$$

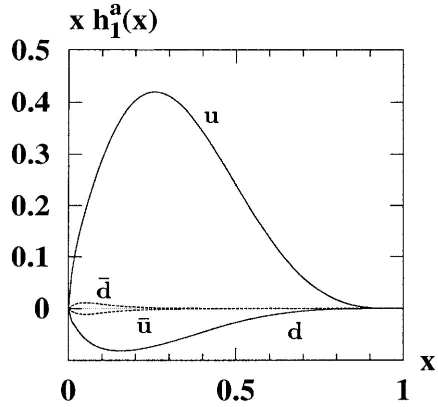

Fig. 1. The chiral quark-soliton model prediction for the proton $xh_1^a(x)$ versus x at the scale $Q^2 = 4\,\mathrm{GeV}^2$

at the low scale of $\mu \simeq 0.6\,\mathrm{GeV}$. (These numbers should be confronted with the very realistic χQSM results for the axial charge $g_A^u = 0.902$, $g_A^d = -0.478$, $g_A^s = -0.054$ [22].)

The result, (3), does not necessarily mean that $h_1^s(x)$ and $h_1^{\bar s}(x)$ are small per se. But it makes plausible the assumption, see (2), in the sense that the strange quark transversity distributions in the nucleon can be neglected with respect to the light quark ones.

2.4 $h_L^a(x)$ in the nucleon

The "twist-3" distribution function $h_L^a(x)$ can be decomposed as [7]

$$h_L^a(x) = 2x \int_x^1 \mathrm{d}x' \frac{h_1^a(x')}{x'^2} + \tilde h_L^a(x), \tag{4}$$

where $\tilde h_L^a(x)$ is a pure interaction dependent twist-3 contribution. According to calculations performed in the instanton model of the QCD vacuum the contribution of $\tilde h_L^a(x)$ in (4) is negligible [23,24]. So when using the χQSM predictions for $h_1^a(x)$ we consequently use (4) with $\tilde h_L^a(x) \simeq 0$.

3 Azimuthal asymmetries from the deuteron

In the HERMES experiment the cross sections $\sigma_D^\pm$ for the process $lD^\pm \to l'hX$, see Fig. 2, will be measured in dependence of the azimuthal angle ϕ between the lepton scattering plane and the plane defined by the momentum $\boldsymbol{q}$ of the virtual photon and momentum $\boldsymbol{P}_h$ of the produced hadron. ($^\pm$ denotes the polarization of the deuteron target, $^+$ means polarization opposite to the beam direction.)

Let P be the momentum of the target proton, and l (l') the momentum of the incoming (outgoing) lepton. The relevant kinematical variables are the center of mass energy squared $s := (P+l)^2$, the four momentum transfer $q := l - l'$ with $Q^2 := -q^2$, the invariant mass of the

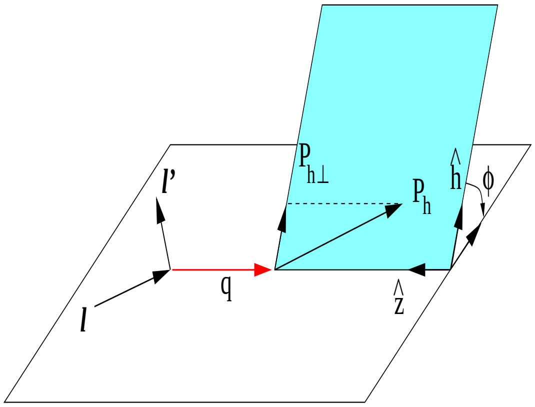

Fig. 2. Kinematics of the process $lD \to l'hX$ in the lab frame

photon–proton system $W^2 := (P+q)^2$, and x, y and z defined by

$$x := \frac{Q^2}{2Pq}, \quad y := \frac{2Pq}{s}, \quad z := \frac{PP_h}{Pq};$$
$$\cos\theta_\gamma := 1 - \frac{2M_{\rm N}^2 x(1-y)}{sy}, \tag{5}$$

with θ_γ denoting the angle between the target spin and the direction of motion of the virtual photon. The observables measured at HERMES are the azimuthal asymmetries $A_{\rm UL,D}^{\sin\phi}(x,z,h)$ and $A_{\rm UL,D}^{\sin 2\phi}(x,z,h)$ in SIDIS electroproduction of the hadron h. The subscript $_{\rm U}$ reminds one of the unpolarized beam, and $_{\rm L}$ reminds one of the longitudinally polarized deuterium (D) target (with respect to the beam direction). The azimuthal asymmetries are defined by

$$A_{\rm UL,D}^{W(\phi)}(x,z,h) = \tag{6}$$
$$\frac{\int {\rm d}y{\rm d}\phi W(\phi)\left(\frac{1}{S^+}\frac{{\rm d}^4\sigma_{\rm D}^+}{{\rm d}x{\rm d}y{\rm d}z{\rm d}\phi} - \frac{1}{S^-}\frac{{\rm d}^4\sigma_{\rm D}^+}{{\rm d}x{\rm d}y{\rm d}z{\rm d}\phi}\right)}{\frac{1}{2}\int {\rm d}y{\rm d}\phi\left(\frac{{\rm d}^4\sigma_{\rm D}^+}{{\rm d}x{\rm d}y{\rm d}z{\rm d}\phi} + \frac{{\rm d}^4\sigma_{\rm D}^-}{{\rm d}x{\rm d}y{\rm d}z{\rm d}\phi}\right)},$$

where $W(\phi) = \sin\phi$ or $\sin 2\phi$ and $S^\pm$ denotes the deuteron spin. For our purposes the deuteron cross sections can be sufficiently well approximated by

$$\sigma_{\rm D}^\pm = \sigma_p^\pm + \sigma_n^\pm. \tag{7}$$

(We do not consider corrections due to deuteron D-state admixture which are smaller than other expected experimental and theoretical errors.) The proton and neutron semi-inclusive cross sections $\sigma^{p\pm}$ and $\sigma^{n\pm}$ (7) have been computed[1] in [7] at tree-level up to order $1/Q$. Using the results of [7] (see [12] for an explicit derivation) we obtain

$$A_{\rm UL,D}^{\sin\phi}(x,z,h) = B_h\left(P_{\rm L}(x)\frac{\sum_a^h e_a^2 x h_{\rm L}^{a/{\rm D}}(x)H_1^{\perp a}(z)}{\sum_{a'}^h e_{a'}^2 f_1^{a'/{\rm D}}(x)D_1^{a'}(z)}\right.$$
$$\left. + P_1(x)\frac{\sum_a^h e_a^2 h_1^{a/{\rm D}}(x)H_1^{\perp a}(z)}{\sum_{a'}^h e_{a'}^2 f_1^{a'/{\rm D}}(x)D_1^{a'}(z)}\right). \tag{8}$$

Here, e.g. $h_1^{u/{\rm D}}(x) = (h_1^{u/p} + h_1^{u/n})(x) = (h_1^u + h_1^d)(x)$, where as usual $h_1^a(x) \equiv h_1^{a/p}(x)$. B_h and the x dependent prefactors $P_{\rm L}(x)$, $P_1(x)$ are defined by

$$B_h = \frac{1}{\langle z\rangle\sqrt{1+\langle z^2\rangle\langle \boldsymbol{P}_{\perp{\rm N}}^2\rangle/\langle \boldsymbol{P}_{\perp h}^2\rangle}},$$
$$P_{\rm L}(x) = \frac{\int {\rm d}y 4(2-y)\sqrt{1-y}\cos\theta_\gamma M_{\rm N}/Q^5}{\int {\rm d}y(1+(1-y)^2)/Q^4},$$
$$P_1(x) = -\frac{\int {\rm d}y 2(1-y)\sin\theta_\gamma/Q^4}{\int {\rm d}y(1+(1-y)^2)/Q^4}. \tag{9}$$

The distribution of transverse momenta has been assumed to be Gaussian which is supported by the data [1,2]. $\langle \boldsymbol{P}_{\perp{\rm N}}^2\rangle$ and $\langle \boldsymbol{P}_{\perp h}^2\rangle$ denote the average transverse momentum squared of the struck quark from the target and of the produced hadron, respectively. An explicit expression for $A_{\rm UL}^{\sin 2\phi}$ can be found in Eq. (11) of [11], which, however, must be corrected by adding an overall minus-sign.

When integrating over y in (9) (and over z and x in the following) one has to consider experimental cuts. Thereby we neglect the implicit dependence of the distribution and fragmentation functions on y through the scale $Q^2 = xys$, and evaluate them instead at $Q^2 = 4\,{\rm GeV}^2$, the typical scale in the HERMES experiment. Most cuts used in the data selection are the same as in the proton target experiment [1,2]

$$1\,{\rm GeV}^2 < Q^2 < 15\,{\rm GeV}^2, \quad 2\,{\rm GeV} < W,$$
$$0.2 < y < 0.85, \quad 0.023 < x < 0.4 \tag{10}$$

and $0.2 < z < 0.7$ with $\langle z\rangle = 0.41$. Only the cuts for the momentum of the produced hadron $2\,{\rm GeV} < |\boldsymbol{P}_h| < 15\,{\rm GeV}$ changed (to be compared with proton target experiments [1,2]: $4.5\,{\rm GeV} < |\boldsymbol{P}_h| < 13.5\,{\rm GeV}$). The only quantity relevant for our calculation and possibly altered by these changes is $\langle \boldsymbol{P}_{\perp h}^2\rangle$. We assume this change to be marginal – since upper and lower cut have been enlarged "symmetrically" – and use the value from [1,2].

3.1 Pion production

Due to charge conjugation and isospin symmetry the following relations hold:

$$D_1^\pi := D_1^{u/\pi^+} = D_1^{\bar d/\pi^+} = D_1^{d/\pi^-} = D_1^{\bar u/\pi^-}$$
$$= 2D_1^{u/\pi^0} = 2D_1^{\bar u/\pi^0} = 2D_1^{d/\pi^0} = 2D_1^{\bar d/\pi^0}, \tag{11}$$

where the arguments z are omitted for brevity. Analog relations are assumed for $H_1^{\perp\pi}$. Other "unfavored" fragmentation functions are neglected[2]. Then $H_1^{\perp\pi}(z)$ and $D_1^\pi(z)$

[1] Notice a misprint in the sign of twist-3 term in (115) of [7]. For the correct sign see [8]. Notice also our different definition of the azimuthal angle, ϕ, see [12] for details

[2] In [16] the effect of unfavored fragmentation has been studied. The authors conclude that the "favored fragmentation approximation" works very well, possibly except for $A_{\rm UL}(\pi^-)$ from a *proton* target

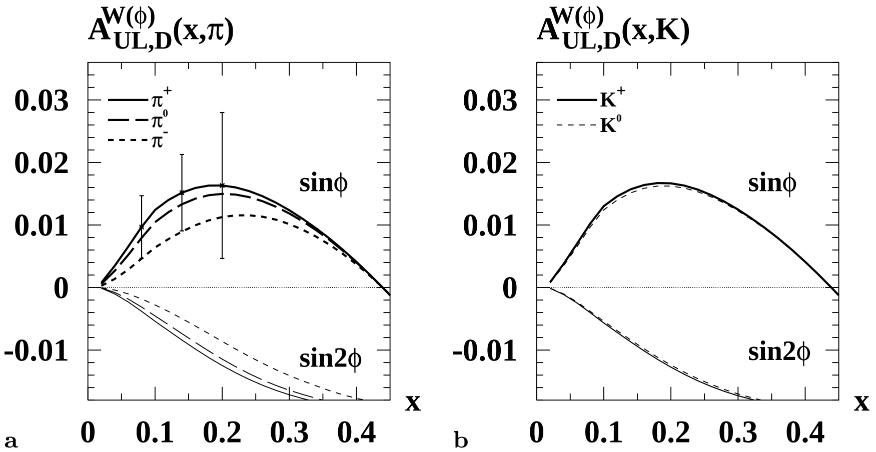

Fig. 3a,b. Predictions for azimuthal asymmetries $A^{W(\phi)}_{\mathrm{UL,D}}(x,h)$ versus x from a longitudinally polarized deuteron target for HERMES kinematics. The results refer to the central value of the analyzing power $\langle H_1^\perp\rangle/\langle D_1\rangle = (12.5 \pm 1.4)\%$; see (1) **a** For pions the "data points" do not anticipate the experiment but correspond merely to a simple estimate of the expected error bars (see text). **b** For kaons, based on the assumption (18)

factorize out in (8) such that

$$A^{\sin\phi}_{\mathrm{UL,D}}(x,z,\pi) = B_\pi \frac{H_1^{\perp\pi}(z)}{D_1^\pi(z)} \times \left(P_{\mathrm{L}}(x)\frac{\sum_a^\pi e_a^2 x h_{\mathrm{L}}^{a/\mathrm{D}}(x)}{\sum_{a'}^\pi e_{a'}^2 f_1^{a'/\mathrm{D}}(x)} + P_1(x)\frac{\sum_a^\pi e_a^2 h_1^{a/\mathrm{D}}(x)}{\sum_{a'}^\pi e_{a'}^2 f_1^{a'/\mathrm{D}}(x)}\right). \tag{12}$$

Here the summation $\sum_a^\pi$ over those flavors is implied which contribute to the favored fragmentation of the pion π. So the deuteron azimuthal asymmetries in SIDIS pion production are given (symbolically) by

$$A^{\sin\phi}_{\mathrm{UL,D}}(\pi^+) \propto \frac{4h^{u+d} + h^{\bar u+\bar d}}{4f_1^{u+d} + f_1^{\bar u+\bar d}},$$
$$A^{\sin\phi}_{\mathrm{UL,D}}(\pi^0) \propto \frac{h^{u+d} + h^{\bar u+\bar d}}{f_1^{u+d} + f_1^{\bar u+\bar d}},$$
$$A^{\sin\phi}_{\mathrm{UL,D}}(\pi^-) \propto \frac{h^{u+d} + 4h^{\bar u+\bar d}}{f_1^{u+d} + 4f_1^{\bar u+\bar d}}, \tag{13}$$

where $h^{u+d} \equiv P_{\mathrm{L}}(h_{\mathrm{L}}^u + h_{\mathrm{L}}^d)(x) + P_1(h_1^u + h_1^d)(x)$ and f_1^{u+d} is an abbreviation for $(f_1^u + f_1^d)(x)$, etc. Since the χQSM predicts $(h_1^{\bar u} + h_1^{\bar d})(x) \simeq 0$ [13], we see from the symbolic (13) that the only differences between the asymmetries for different pions are different weights of the unpolarized antiquark distributions in the denominator. As $(f_1^u + f_1^d)(x) \gg (f_1^{\bar u} + f_1^{\bar d})(x) > 0$, we see that

$$A^{\sin\phi}_{\mathrm{UL,D}}(\pi^+) \gtrsim A^{\sin\phi}_{\mathrm{UL,D}}(\pi^0) \gtrsim A^{\sin\phi}_{\mathrm{UL,D}}(\pi^-). \tag{14}$$

Averaging over z in (12) (numerator and denominator separately), using the *central value* for $\langle H_1^{\perp\pi}\rangle/\langle D_1^\pi\rangle$, see (1), and the parameterization of [25] for $f_1^a(x)$ we obtain the results for $A^{\sin\phi}_{\mathrm{UL,D}}(x,\pi)$ shown in Fig. 3a.

For $A^{\sin\phi}_{\mathrm{UL,D}}(x,\pi^+)$ the statistical error of the HERMES data is estimated[3]. The small differences between azimuthal symmetries for different pions from the deuteron target will be difficult to observe.

We remark that in (8) the contribution to $A^{\sin\phi}_{\mathrm{UL,D}}$ containing $h_{\mathrm{L}}^a(x)$ is "twist- 3" and the contribution containing $h_1^a(x)$ is "twist-2". The "twist-2" contribution enters the asymmetry with the factor $\sin\theta_\gamma \sim M_{\mathrm{N}}/Q$; see (5) and (9). So the "twist-2" and "twist-3" part are equally power suppressed. For HERMES kinematics the "twist-3" contribution to $A^{\sin\phi}_{\mathrm{UL,D}}$ is roughly a factor of three larger than the "twist-2" contribution and of opposite sign. However for larger values of $x > 0.4$ the latter becomes dominant, see erratum of [12].

For completeness also the $A^{\sin 2\phi}_{\mathrm{UL,D}}(x,\pi)$ asymmetries are shown in Fig. 3a.

3.2 Kaon production

The RICH detector of the HERMES experiment is capable to detect kaons. For kaons

$$D_1^K := D_1^{u/K^+} = D_1^{d/K^0} = D_1^{\bar d/\bar K^0} = D_1^{\bar u/K^-} \overset{\mathrm{SU(3)}}{\simeq} D_1^{\bar s/K^+} = D_1^{\bar s/K^0} = D_1^{s/\bar K^0} = D_1^{s/K^-}. \tag{15}$$

Analogous relations are assumed for $H_1^{\perp K}$. The exact relations in (15) follow from charge conjugation and isospin symmetry. The approximate relation follows from SU(3) flavor symmetry[4]. As we did for pions, we neglect unfavored fragmentation into kaons. So we obtain

$$A^{\sin\phi}_{\mathrm{UL,D}}(x,z,K) = B_K \frac{H_1^{\perp K}(z)}{D_1^K(z)} \times \left(P_{\mathrm{L}}(x)\frac{\sum_a^K e_a^2 x h_{\mathrm{L}}^{a/\mathrm{D}}(x)}{\sum_{a'}^K e_{a'}^2 f_1^{a'/\mathrm{D}}(x)} + P_1(x)\frac{\sum_a^K e_a^2 h_1^{a/\mathrm{D}}(x)}{\sum_{a'}^K e_{a'}^2 f_1^{a'/\mathrm{D}}(x)}\right). \tag{16}$$

[3] The statistical error of $A^{\sin\phi}_{\mathrm{UL,D}}(x,\pi^+)$ is estimated by dividing the statistical error of $A^{\sin\phi}_{\mathrm{UL},p}(x,\pi^+)$, [2], by $N^{1/2}$, which considers the roughly $N \simeq 3$ times larger statistics of the deuteron target experiment as compared to the proton target experiments [26]

[4] There might be considerable corrections to the approximate SU(3) flavor symmetry relation in (15). But they have no practical consequences. As for $H_1^{\perp K}$ such corrections do not contribute due to (2). As for D_1^K we have, e.g. for $A_{\mathrm{UL}}(K^+)$, in the denominator $e_u^2 f_1^{u/\mathrm{D}}(x) = (4/9)(f_1^u + f_1^d)(x) \gg e_s^2 f_1^{\bar s/\mathrm{D}}(x) = (2/9)f_1^{\bar s}(x)$

We assume that $\langle \boldsymbol{P}^2_{\perp K}\rangle$ and $\langle z\rangle$, which enter the factor B_K, (9), are the same as for pions. The summation $\sum_a^K$ goes over "favored flavors", i.e. (symbolically)

$$\begin{aligned} A_{\rm UL,D}^{\sin\phi}(K^+) &\propto \frac{4h^{u+d}}{4f_1^{u+d}+2f_1^{\bar s}}, \\ A_{\rm UL,D}^{\sin\phi}(K^0) &\propto \frac{h^{u+d}}{f_1^{u+d}+2f_1^{\bar s}}, \\ A_{\rm UL,D}^{\sin\phi}(\bar K^0) &\simeq A_{\rm UL,D}^{\sin\phi}(K^-) \simeq 0. \end{aligned} \tag{17}$$

Recall that $(h_1^{\bar u}+h_1^{\bar d})(x) \simeq h_1^s(x) \simeq h_1^{\bar s}(x) \simeq 0$ according to the predictions from χQSM.

We obtain $A_{\rm UL,D}^{\sin\phi}(x,K) \propto \langle H_1^{\perp K}\rangle/\langle D_1^K\rangle$ after averaging over z in (16). How large is the analyzing power for kaons? We know that the unpolarized kaon fragmentation function $D_1^K(z)$ is roughly five times smaller than the unpolarized pion fragmentation function $D_1^\pi(z)$ [27]. Is also $H_1^{\perp K}(z)$ five times smaller than $H_1^{\perp\pi}(z)$? If we assume this, i.e. if

$$\frac{\langle H_1^{\perp K}\rangle}{\langle D_1^K\rangle} \simeq \frac{\langle H_1^{\perp\pi}\rangle}{\langle D_1^\pi\rangle} \tag{18}$$

holds, we obtain – with the central value of $\langle H_1^\perp\rangle/\langle D_1\rangle$ in (1) – azimuthal asymmetries for K^+ and K^0 as large as for pions, see Fig. 3b. (Keep in mind the different normalization for $H_1^\perp$ used here.) Figure 3b shows also $A_{\rm UL,D}^{\sin 2\phi}(x,K)$ obtained under the assumption (18).

HERMES data will answer the question whether the assumption (18) is reasonable. In the chiral limit $D_1^\pi = D_1^K$ and $H_1^{\perp\pi} = H_1^{\perp K}$ and the relation (18) is exact. In nature the kaon is "far more off the chiral limit" than the pion; indeed $D_1^\pi \gg D_1^K$ [27]. In a sense the assumption (18) formulates the naive expectation that the "way off the chiral limit to the real world" proceeds analogously for spin dependent quantities, $H_1^\perp$, and for quantities containing no spin information, D_1.

3.3 Comparison to $A_{\rm UL}$ from the proton target

The $A_{\rm UL,D}^{W(\phi)}(x,\pi^+)$ will be roughly half the magnitude of the $A_{{\rm UL},p}^{W(\phi)}(x,\pi^+)$ which was computed in our approach and confronted with HERMES data [2] in [12]. However, the deuteron data will have a smaller statistical error due to more statistics. So $A_{\rm UL,D}^{\sin\phi}(x)$ for pions and – upon validity of the assumption (18) – K^+ and K^0 will be clearly seen in the HERMES experiment and perhaps also $A_{\rm UL,D}^{\sin 2\phi}(x,h)$.

In Table 1, finally, we present the totally integrated azimuthal asymmetries $A_{\rm UL}^{\sin\phi}(h)$ for pions from proton target – from [12] – and for pions and kaons from deuteron target – computed here. The HERMES data on $A_{{\rm UL},p}^{\sin\phi}(\pi)$ [1,2] are shown in Table 1 for comparison. The fields with "?" will be filled by HERMES data in the near future.

Table 1. Comparison of theoretical numbers and (as far as already measured) experimental data for the totally integrated azimuthal asymmetries $A_{\rm UL}^{\sin\phi}(h)$ observable in SIDIS production of hadron h from *longitudinally polarized proton* and *deuteron* targets, respectively. For the proton the HERMES data are from [1,2]. Theoretical numbers based on the DELPHI result (1) and predictions from χQSM for the HERMES kinematics from [12]. For the deuteron predictions are from this work for HERMES kinematics. HERMES has already finished data taking and is currently analyzing

Asymmetry $A_{\rm UL}^{\sin\phi}(h)$		DELPHI + χQSM ± stat of (1) in %	HERMES ± stat ± syst in %
proton:	π^+	2.1	$2.2 \pm 0.5 \pm 0.3$
	π^0	1.5	$1.9 \pm 0.7 \pm 0.3$
	π^-	-0.3	$-0.2 \pm 0.6 \pm 0.4$
deuteron:	π^+	1.0	
	π^0	0.9	?
	π^-	0.5	
deuteron:	K^+	1.1	
	K^0	1.0	?
	$\bar K^0$, K^-	~ 0	

4 Conclusions

The approach based on experimental information from DELPHI on $H_1^\perp$ [9] and on theoretical predictions from the chiral quark-soliton model for $h_1^a(x)$ [13] has been shown [12] to describe well the HERMES and SMC data on azimuthal asymmetries from a polarized proton target [1–3]. Here we computed azimuthal asymmetries in pion and kaon production from a *longitudinally polarized deuteron* target for HERMES kinematics.

Our approach predicts azimuthal asymmetries $A_{\rm UL,D}^{W(\phi)}$ comparably large for all pions and roughly half the magnitude of $A_{{\rm UL},p}^{W(\phi)}(\pi^+)$ measured at HERMES [1,2].

Under the assumption that the kaon analyzing power $\langle H_1^{\perp K}\rangle/\langle D_1^K\rangle$ is as large as the analyzing power for pions $\langle H_1^{\perp\pi}\rangle/\langle D_1^\pi\rangle$ we predicted also azimuthal asymmetries for kaons. If the assumption holds, HERMES will observe $A_{\rm UL,D}^{\sin\phi}(K)$ and $A_{{\rm UL},D}^{\sin 2\phi}(K)$ for K^+ and K^0 as large as for pions. The asymmetries for $\bar K^0$ and K^- are zero in our approach. It will be exciting to see whether HERMES data will confirm the assumption $\langle H_1^{\perp K}\rangle/\langle D_1^K\rangle \stackrel{!?}{\simeq} \langle H_1^{\perp\pi}\rangle/\langle D_1^\pi\rangle$.

It will be very interesting to study HERMES data on the z dependence: $A_{\rm UL,D}^{\sin\phi}(z,h)$. The HERMES data on the z dependence of the azimuthal asymmetries from a *proton* target [1,2] have been shown [12] to be compatible with the fit $H_1^{\perp\pi}(z)/D_1^\pi(z) = az$ for $0.2 < z < 0.7$ with a constant $a = (0.33 \pm 0.06 \pm 0.04)$ (statistical and systematical error of the data [1,2]). This result has a further uncertainty of (10–20)% due to model dependence. Based on this observation we could have predicted here $A_{\rm UL,D}^{\sin\phi}(z,h) = c_h z$, with c_h some constant depending on the particular hadron. It will be exciting to see whether HERMES deuterium data will also exhibit a (roughly) linear dependence on z, or whether it will allow one to make a more sophisticated parameterization than $H_1^{\perp\pi}(z)/D_1^{\pi}(z) \propto z$ as concluded to in [12].

Acknowledgements. We would like to thank D. Urbano and M.V. Polyakov for fruitful discussions, B. Dressler for providing the evolution code, and C. Schill from the HERMES Collaboration for clarifying questions on experimental cuts. This work has partly been performed under the contract HPRN-CT-2000-00130 of the European Commission and the DFG and BMBF of Germany.

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