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AZIMUTHAL ASYMMETRIES IN PRODUCTION OF CHARGED HADRONS BY HIGH ENERGY MUONS OFF POLARIZED DEUTERIUM TARGETS AT COMPASS

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OUTLINE

1. Introduction: theoretical summary & motivations.
2. Method of the analysis.
3. Data selection.
4. Results.
5. Conclusions and prospects.

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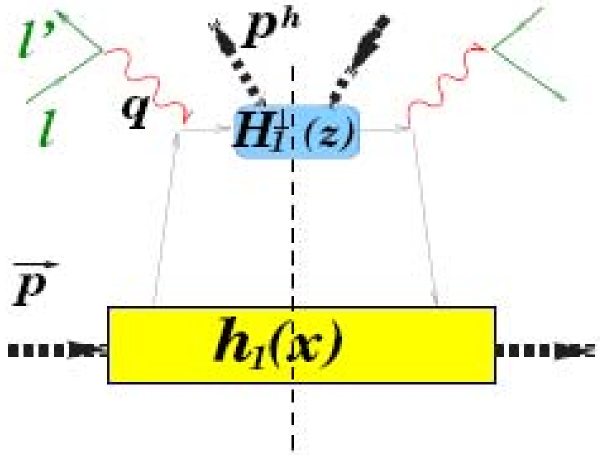
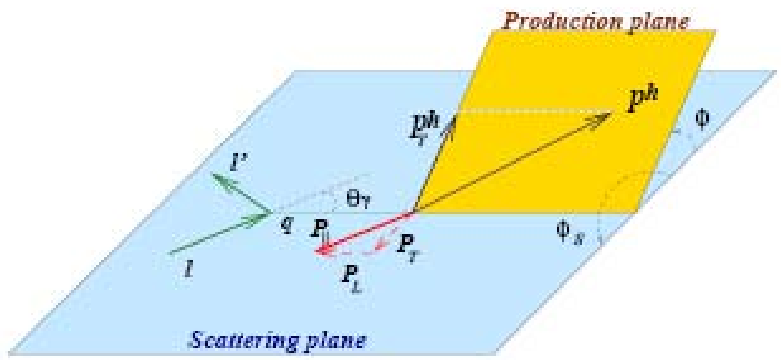
INTRODUCTION (1)

The azimuthal distributions of hadrons in SIDIS of leptons on T-and L-targets are sources of information on new PDFs and PFFs, characterizing the longitudinal and transverse spin structure of nucleons, e.g.:

$$d\sigma_h / d\phi \sim h_1(x) \otimes H_1^{\perp}(z) \cdot \sin\phi + \ldots$$

$$\ell + \overline{N} \to \ell' + X + h$$





A number of PDF's and PFF's enter in total SIDIS cross section

INTRODUCTION (2)

The cross section and asymmetry of the h production in SIDIS:

$$d\sigma = d\sigma_{00} + P_\mu d\sigma_{L0} + P_L\left(d\sigma_{0L} + P_\mu d\sigma_{LL}\right) + \left|P_T\right|\left(d\sigma_{0T} + P_\mu d\sigma_{LT}\right),$$

$$a(\phi) = \frac{d\sigma^{\leftarrow\Rightarrow} - d\sigma^{\leftarrow\Leftarrow}}{d\sigma^{\leftarrow\Rightarrow} + d\sigma^{\leftarrow\Leftarrow}} \sim \left|P_L\right|\left(d\sigma_{0L} + P_\mu d\sigma_{LL}\right) + \left|P_L\right| tg(\theta_\gamma)(d\sigma_{0T} + P_\mu d\sigma_{LT}) \ ,$$

where contributions to σ_{ij} (i=beam, j= target polarizations) from each quark and antiquark (up to the order of (M/Q)) have forms:

Twist 3

$$d\sigma_{0L} \propto \ \in x h_{1L}^{\perp}(x) \otimes H_1^{\perp}(z)\sin(2\phi) + \sqrt{2\in(1-\in)}\frac{M}{Q}x^2\left[h_L(x)\otimes H_1^{\perp}(z) + f_L^{\perp}(x)\otimes D_1(z)\right]\sin(\phi),$$

helicity — Twist 3

$$d\sigma_{LL} \propto \sqrt{1-\in^2} \quad x g_{1L}(x)\otimes D_1(z) + \sqrt{2\in(1-\in)}\frac{M}{Q}x^2\left[g_L^{\perp}(x)\otimes D_1(z) + e_L(x)\otimes H_1^{\perp}(z)\right]\cos(\phi),$$

transversity — pretzelosity

$$d\sigma_{0T} \propto \quad \in[x h_1(x)\otimes H_1^{\perp}(z)\sin(\phi+\phi_S) + x h_{1T}^{\perp}(x)\otimes H_1^{\perp}(z)\sin(3\phi-\phi_S)$$

Sivers

$$-x f_{1T}^{\perp}(x)\otimes D_1(z)\sin(\phi-\phi_S)]\ ,$$

Mulders&Tangerman
Boer&Mulders
Bucchetta et al.

$\otimes$=convolution in k_T

$$d\sigma_{LT} \propto \quad \sqrt{1-\in^2}\, x g_{1T}(x)\otimes D_1(z)\cos(\phi-\phi_S).\ ,$$

ϕ_S = 0 for L-target

INTRODUCTION (3)

Summary:

–Quark t- and ℓ- spin effects contribute to the asymmetries $a(\phi)$ in hadron production from longitudinally polarized target.

–Several asymmetry modulations should be seen in $a(\phi)$.

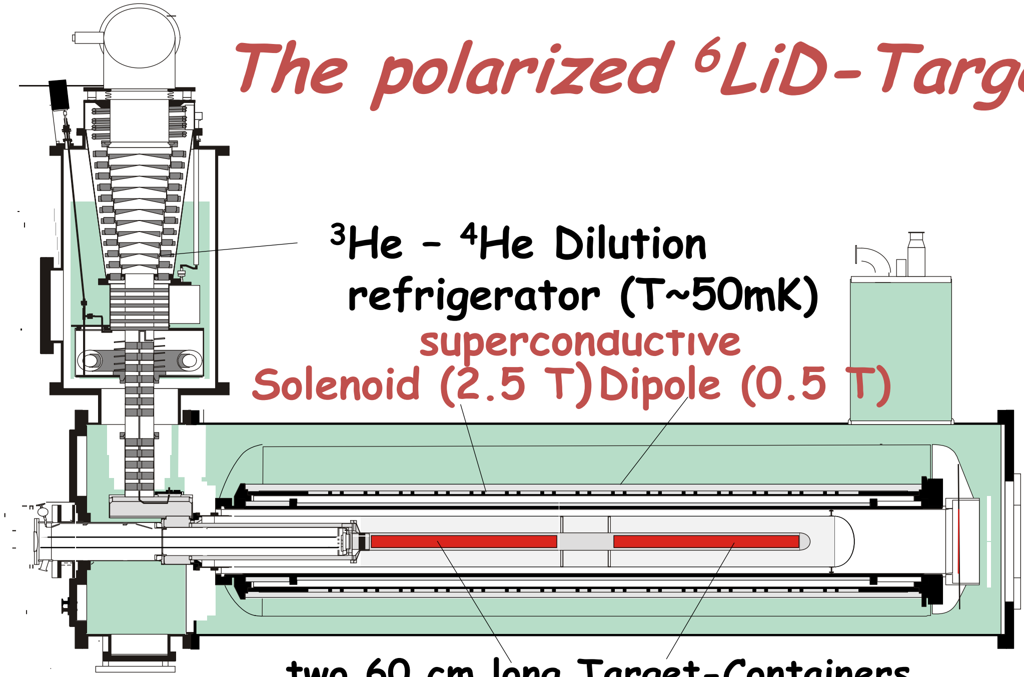
–Aims: search for $a(\phi)$, its possible sin(ϕ) (Sivers + Transversity), sin(2ϕ), sin(3ϕ) (Pretzelosity) and cos(ϕ) (Twist 3) modulations and x, z, p_h^T -dependence of corresponding amplitudes.

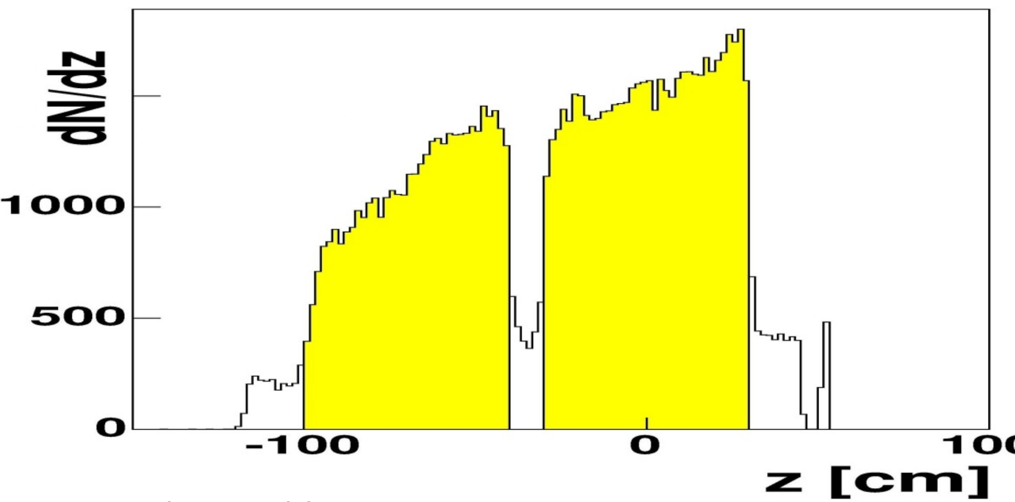
– $a(\phi)$ expected to be small, ≤1%.

– Methods of analysis should be adequate.

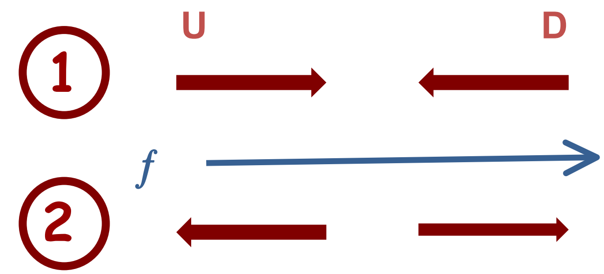
METHOD OF ANALYSIS (1)

The polarized ^{6}LiD-Target



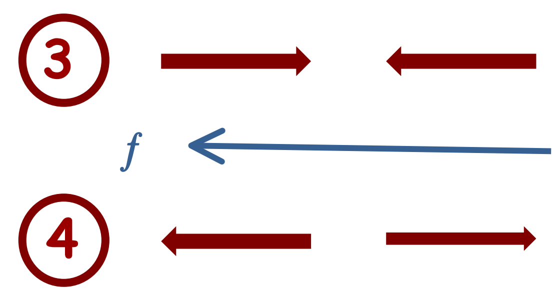


4 target polarizations:



reversed every 8 hours

After few weeks



reversed every 8 hours

Polarization: ~ 50%

METHOD OF ANALYSIS: (2)

$$R_f(\phi) = \frac{N^U_{+f}(\phi)}{N^D_{-f}(\phi)} \cdot \frac{N^D_{+f}(\phi)}{N^U_{-f}(\phi)} = \frac{C^U_f(\phi) L^U_{+f} \sigma_+(\phi)}{C^D_f(\phi) L^D_{-f} \sigma_-(\phi)} \cdot \frac{C^D_f(\phi) L^D_{+f} \sigma_+(\phi)}{C^U_f(\phi) L^U_{-f} \sigma_-(\phi)} = \frac{\sigma_+(\phi)^2}{\sigma_-(\phi)^2},$$

where

$N^t_{pf}(\phi)$ is a number of events,

t = U or D for Upper or Down cell,

p = + or – polarization (along or opposite to the beam),

f = + or – solenoid field direction (along or opposite to beam),

$C^t_f(\phi)$ target acceptance factor (source of false asymmetries),

$L^t_{pf} = \Phi^t_{pf} n^t$ product of beam flux and target density,

σ_p spin dependent cross sections.

$L^t_{\pm f}$ and $C^t_f(\phi)$ cancel if beam crosses both cells and if one combines periods with the same *f*.

$$R_f(\phi) = \frac{\left(1 + P^U_{+,f} a_f(\phi)\right)\left(1 + P^D_{+,f} a_f(\phi)\right)}{\left(1 - P^D_{-,f} a_f(\phi)\right)\left(1 - P^U_{-,f} a_f(\phi)\right)},$$

$$a_f(\phi) \approx \frac{R_f(\phi) - 1}{P^U_{+,f} + P^D_{+,f} + P^U_{-,f} + P^D_{-,f}}$$

$$a_+(\phi) \approx a_-(\phi)$$

$$a(\phi) = a_+(\phi) \otimes a_-(\phi) \rightarrow \textit{final results}$$

METHOD OF ANALYSIS: (3)

Summary:

– the DR method has been tested using a part of data,

– possible ϕ-dependent false asymmetries, connected with the acceptance, are canceled,

– the DR method can be used for studies of small modulations of ϕ- asymmetries, of order 0.2% or smaller,

– the analysis of the full set of COMPASS L-data is in progress, the data of 2002-2004 from deuterium are presented in a number of talks at the International conferences and the paper is accepted for publication in the EPJ C.

DATA SELECTION (1)

AIM: TO HAVE A CLEAN SAMPLE OF IDENTITYED HADRONS

(1) Selection of "GOOD SIDIS EVENTS" out of preselected SIDIS sample of events with $Q^2>1\ GeV^2$ and $y>0.1$ (=167.5 *M* from 2002, 2003, 2004 data taking)

EXCLUDED EVENTS:

- originated from bad spills,
- with a number of rec.prim.vertex >1,
- χ^2/NDF>2,
- Z vertex outside the fiducial volume U or D- cell,
- 140 GeV >E(muon)> 180 GeV,
- invariant mass W < 5 GeV,
- y > 0.9.

= 58% of initial sample

DATA SELECTION (2)

(2) Selection of “GOOD TRACKS” from “GOOD SIDIS EVENTS”.
Total number of tracks from “GOOD SIDIS EVENTS” = 290 M
Excluded tracks:
- identified as muons,
- with z-variable >1,
- with p_T^h <0.1 GeV -----------→ “GOOD TRACKS” = 157 M

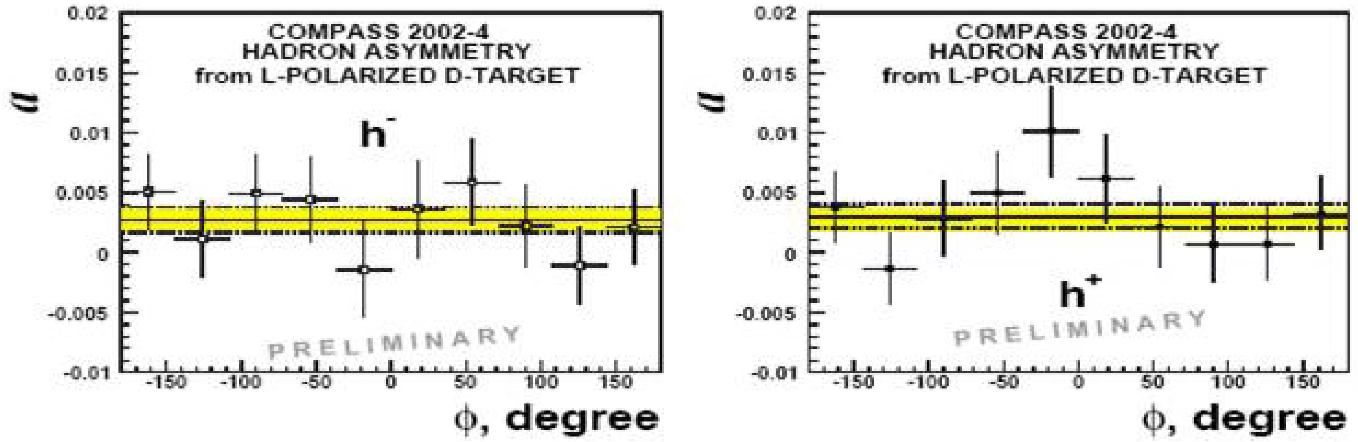
(3) Selection of “GOOD HADRONS” from “GOOD TRACKS”.
Each track should:
- hit one of the hadron calorimeters HCAL1 or HCAL2,
- have an associated energy cluster E_{hcal1}>5 GeV or E_{hcal2} > 7 GeV,
- energy cluster coordinates compatible with the track coordinates,
- energy cluster compatible with the momentum of the track → “GOOD HADRONS” = 53 M (25 M h^- + 28 M h^+)

(4) Each “GOOD HADRON” enters in considerations of asymmetries in restricted region $p_T^h = 0.1 - 1.0\ GeV/c$

x = 0.004 – 0.7, z = 0.2 – 0.9,

RESULTS (1)

The weighted sum of azimuthal asymmetries $a(\phi)=a_{+}(\phi) \otimes a_{-}(\phi)$ **for** h^- **(left) and** h^+ **(right) averaged over all kinematical variables** :



$$a(\phi) = a^{const} + a^{\sin\phi}\sin(\phi) + a^{\sin 2\phi}\sin(2\phi) + a^{\sin 3\phi}\sin(3\phi) + a^{\cos\phi}\cos(\phi) \quad or \quad a(\phi) = a^{const}$$

RESULTS (1)

Fit parameters in units 10^{-4}

	h^-	h^+	h^-	h^+
a^{const}	23 ± 11	35 ± 11	27 ± 11	30 ± 11
$a^{\sin\phi}$	-1 ± 16	-13 ± 15	0	0
$a^{\sin 2\phi}$	20 ± 16	-15 ± 15	0	0
$a^{\sin 3\phi}$	6 ± 16	3 ± 15	0	0
$a^{\cos\phi}$	10 ± 16	24 ± 15	0	0
$\chi^2/n.d.f.$	3.42/5	5.18/5	4.82/9	8.03/9

—Within a stat. precision of about 0.15%, ϕ-dependent amplitudes are compatible with zero; fits by constants: OK,

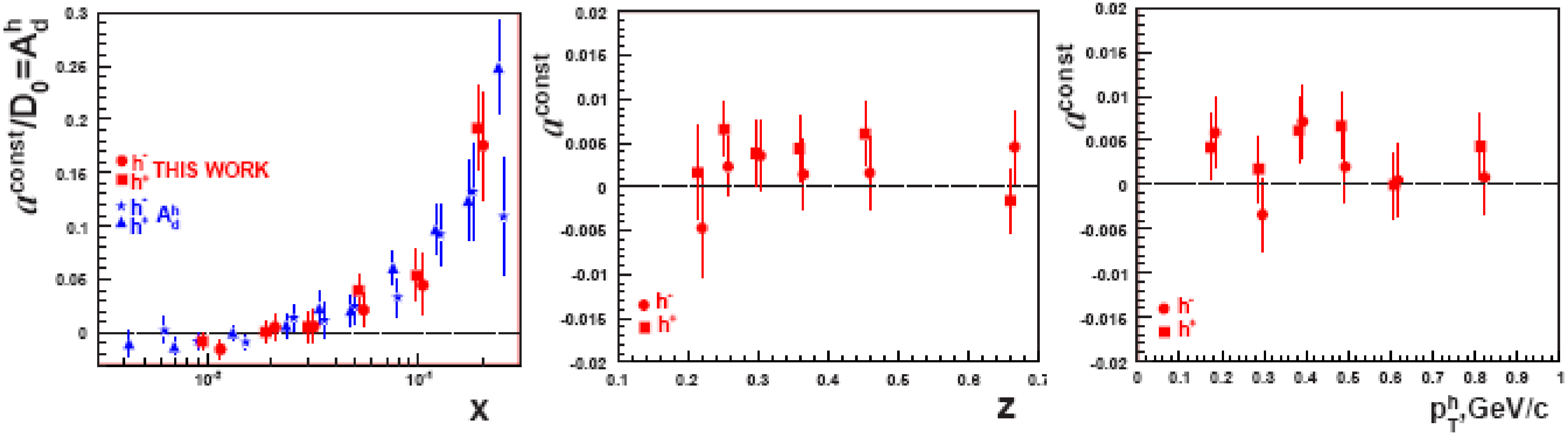
—parameters a^{const} are different from zero and about equal for h^+ and h^-.

REMIND: $a^{const} \propto d\sigma_{LL} \propto g_{1L}(x) \otimes D_1(z)$, where g_{1L} is a helicity PDF of L-polarized quarks in L-polarized target convoluted with PFF of non-polarized quarks in non-polarized hadron. For isoscalar D-target it is expected to be weakly dependent on the hadron charge.

RESULTS (2)

COMPASS

Dependence of the parameter a^{const} for h^+ and h^- on kinematical variables:



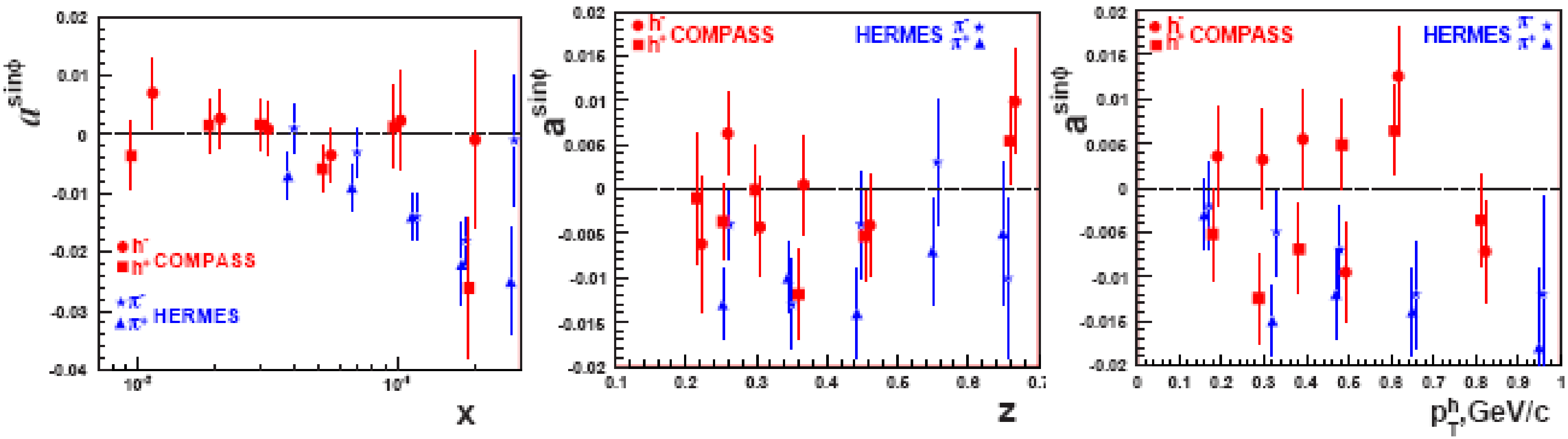
— $A_0(x) = a^{const}(x) / D_0(x) \equiv A_d^h(x)$ (D_0 is a virtual photon depolarization factor) is in agreement with COMPASS published data (PLB660(2008)458),

— $a^{const}(z, p_T^h)$ for h^- and for h^+: small and flat.

— Statistical errors are shown, systematic ones are estimated to be smaller: global systematic multiplicative errors are smaller than 6%.

RESULTS (3)

Dependence of the parameter $a^{\sin\phi}$ for h⁺ and h⁻ on kinematic variables:



— $a^{\sin\phi}(x)$ are less pronounced than the HERMES ones [Phys.Lett. B562 (203)182],

— $a^{\sin\phi}(z, p_T^h)$ is flat and do not confirm the HERMES trends.

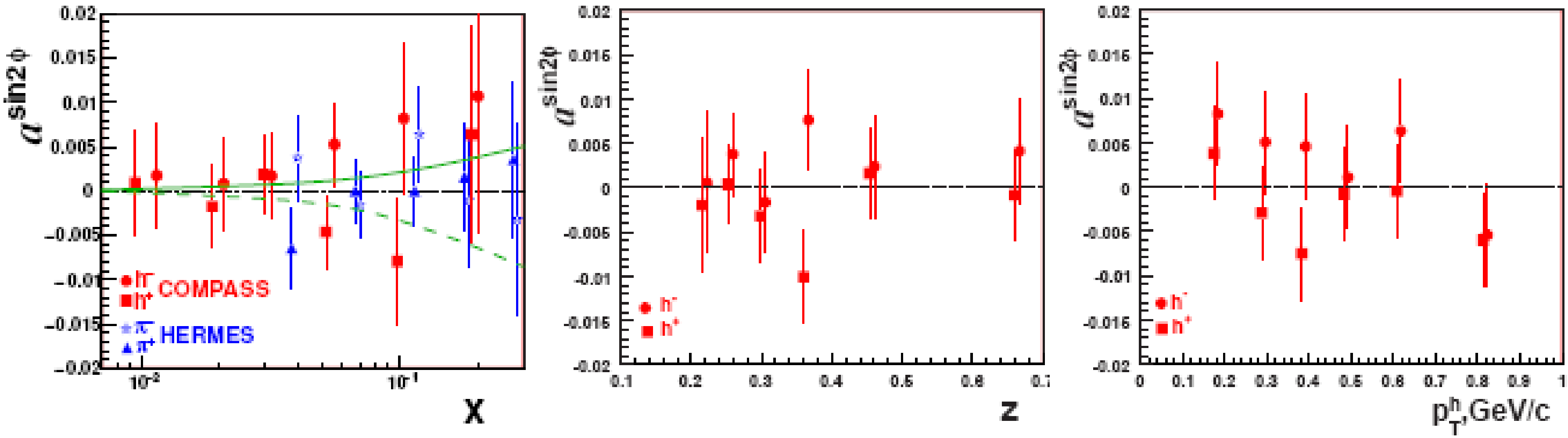
REMIND: $a^{\sin\phi} \propto d\sigma_{0L} \propto \frac{M}{Q} x^2 \left(h_L(x) \otimes H_1^{\perp}(z) + f_L^{\perp}(x) \otimes D_1(z) \right)$

where $h_L(x)$ and $f_L^{\perp}(x)$ are pure twis-3 PDF.

NOTE: HERMES data are for identified π^+ and π^- and at smaller $\langle Q^2 \rangle$.

RESULTS (4)

Dependence of the parameter $a^{\sin 2\phi}(x)$ for h^+ and h^- on kinematic variables:



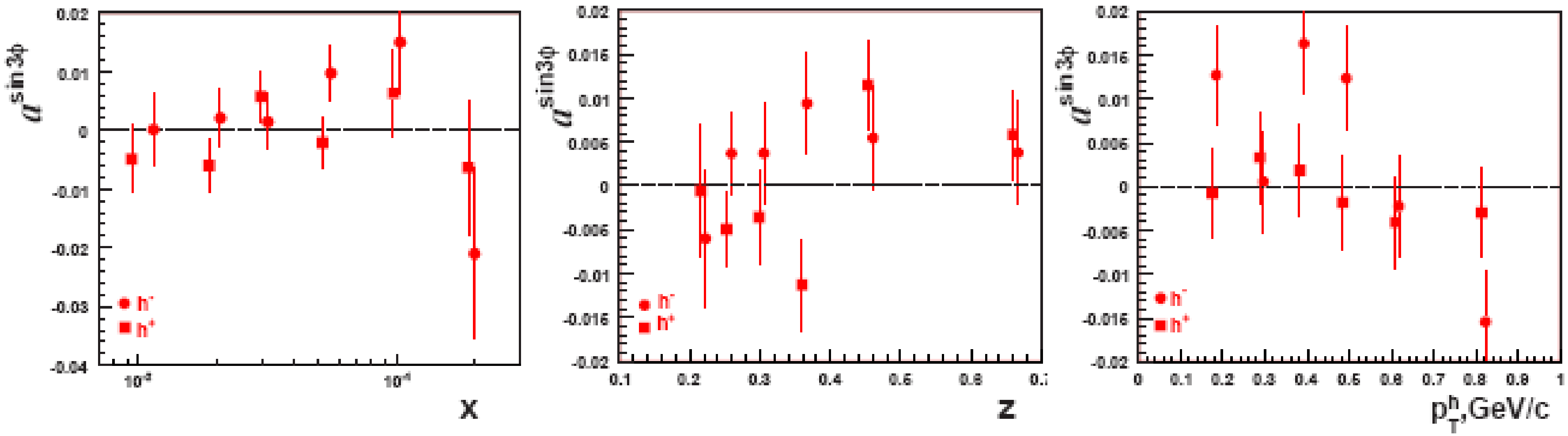
— $a^{\sin 2\phi}(x)$ are small and in general agree with HERMES and theoretical predictions by H.Avakian et al., Phys.Rev. D77 (2008) 014023, dashed – for h-, solid – for h+

— $a^{\sin 2\phi}(z, p_T^h)$ - no other data.

REMIND: $a^{\sin 2\phi} \propto d\sigma_{0L} \propto x h_{lL}^{\perp}(x) \otimes H_1^{\perp}(z)$, where $h_{1L}^{\perp}$ is a PDF not seen yet. It is linked with the transversity PDF h_1 by a relation of the Wandzura-Wilczek type.

RESULTS (5)

Dependence of the parameter $a^{\sin 3\phi}(x)$ **for h+ and h- on kinematic variables:**

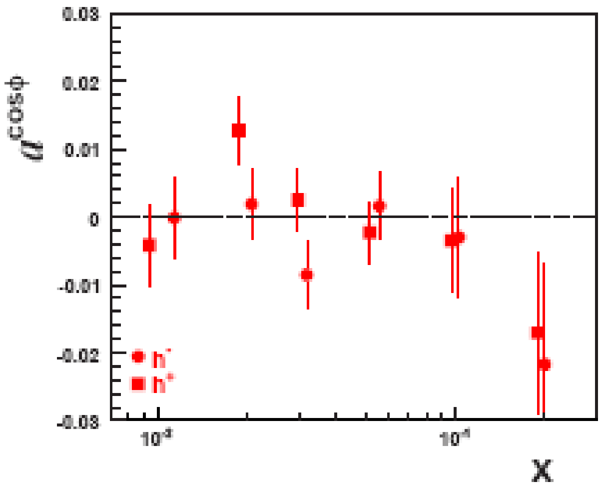


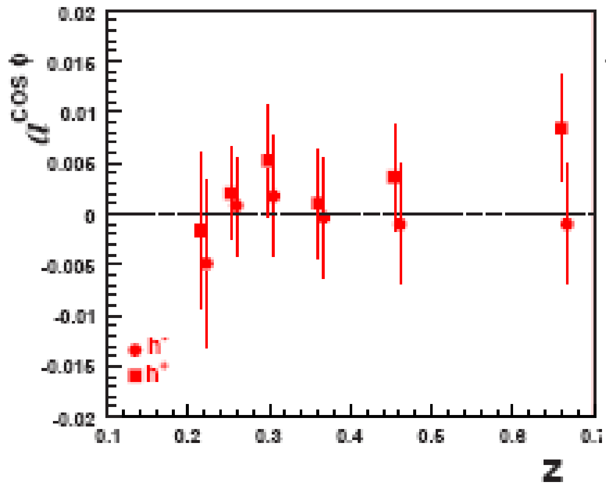
— $a^{\sin 3\phi}(x)$ **are small, compatible with zero. But some peculiarities: points for h- are mostly positive whill these for h+ are mostly negative as for the COMPASS results for the amplitude of the sin(3ϕ- ϕ$_s$) modulation extracted form the data with transversally polarized D-target.**

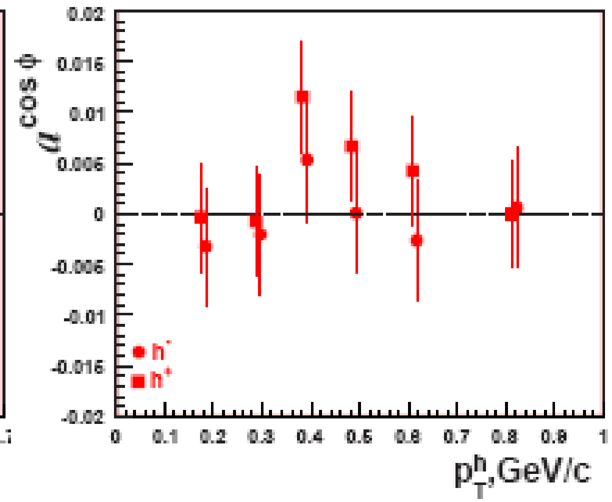
REMIND: $a^{\sin 3\phi} \propto d\sigma_{0T} \propto x h_{1T}^{\perp} \otimes H_1^{\perp}(z)$ **, where** $h_{1T}^{\perp}$ **is pretzelosity PDF additionally suppressed by** $tg(\theta_\gamma) \sim \frac{M}{Q}$.

RESULTS (6)

Dependence of the parameter $a^{\cos\phi}(x)$ for h^+ and h^- on kinematic variables:







- $a^{\cos\phi}(x)$ increasing with *x* in absolute value,
- $a^{\cos\phi}(z)$ and $a^{\cos\phi}\left(p_T^h\right)$ small, flat and consistent with zero,
- $a^{\cos\phi}(x)$, $a^{\cos\phi}(z)$, $a^{\cos\phi}\left(p_T^h\right)$ are studied for the first time.

REMIND: $a^{\cos\phi} \propto d\sigma_{LL} \propto \frac{M}{Q} x^2 \left(g_L^{\perp}(x) \otimes D_1(z)_4 + \ldots\right)$, where $g_L^{\perp}$ is a pure twist-3 PDF (analog to the Cahn effect in unpolarized SIDIS).

CONCLUSIONS & PROSPECTS (1)

1. The azimuthal asymmetries $a(\phi)$ in the SIDIS (Q^2>1 GeV^2, y>0.1) production of negative (h^-) and positive (h^+) hadrons by 160 GeV muons on the longitudinally polarized deuterium target, have been studied with COMPASS data collected in 2002-2004.
2. After integration over *x* , *z* and p_T^h variables, all ϕ -modulation amplitudes of $a(\phi)$ are consistent with zero within errors, while ϕ - independent parts of the $a(\phi)$ differ from zero and are almost equal for h^- and h^+.
3. In the study of the amplitudes over the range 0.0004<*x*<0.7, 0.2<*z*<0.9 and 0.1< p_T^h < 1 GeV/c it was found:
   - the ϕ - independent parts of the $a(\phi)$, $a^{const}(x)/D_0$, where D_0 *is a virtual photon depolarization factor, are in agreement with the COMPASS published data on* A_d^h *, calculated by another method and using different cuts;*
   - *the amplitudes* $a^{\sin\phi}(x,z,p_T^h)$ *are small and in general compatible with the HERMES data, if one takes into account the difference in x and* Q^2 *between the two experiments. One can also note, that in the HERMES experiment the asymmetries are calculated for identified leading pions, while in this analysis every hadron is included in the asymmetry evaluation;*
   - the amplitudes $a^{\sin 2\phi}$, $a^{\sin 3\phi}$ and $a^{\cos\phi}$ are consistent with zero within statistical errors of about 0.5% (only statistical errors are shown in the plots while systematical errors are estimated to be much smaller).

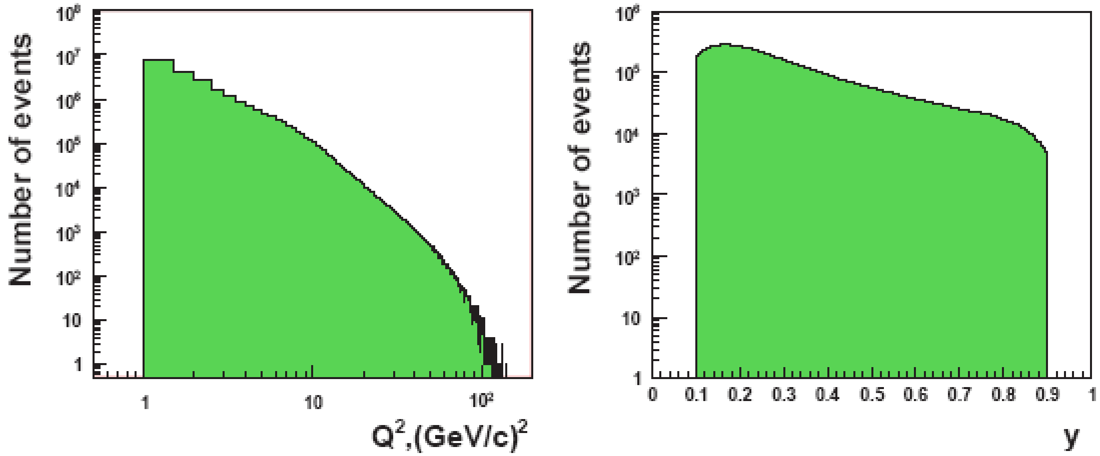
CONCLUSIONS & PROSPECTS (2)

4. The results of this analysis are obtained with restriction z>0.2 of the energy fraction of the hadron in order to assure that it comes from the current fragmentation region. This request removes almost one half of statistics. The tests have shown that with a lower cut , z>0.05 , the results are identical.

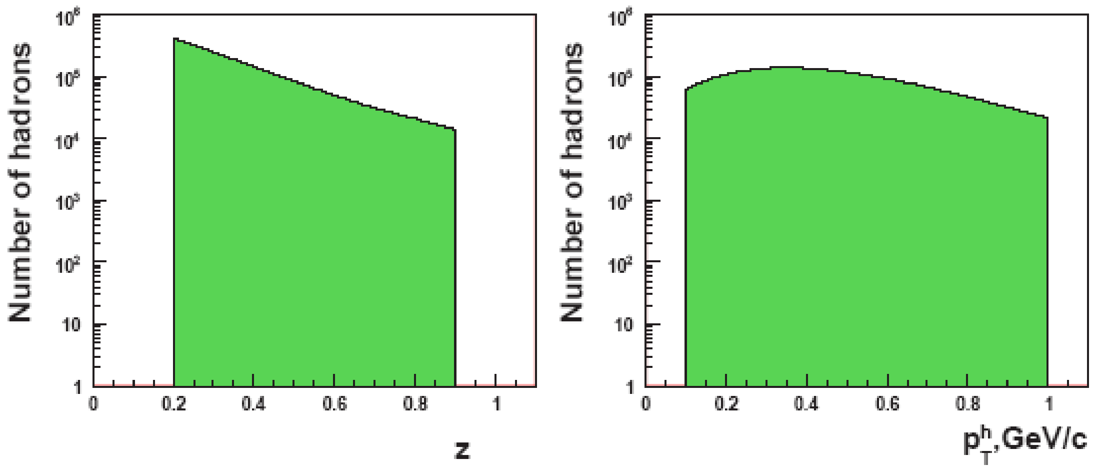
5. These data will be useful to constrain models for PDFs. The present general description of the SIDIS cross-section involves a considerable number PDFs depending on the longitudinal or transversal components of the nucleon spin. Probably, not all of them are on the same footing. Hopefully our data will help to assess which PDFs are important in the description of the nucleon structure .

6.The samples used in the present analysis account only for a part of the COMPASS data. New data of 2006 from the deuterium target will be added. These data will increase the statistics by about a factor of 2. New data of 2007 from the hydrogen target will be interesting in comparison with the effects already observed by the COMPASS and HERMES on the transversally polarized targets.

BACK UP SLIDES.KINEMATICS



The distribution of events, passed all data selection cuts, vs. Q^2 (left) and vs. y(right).



The distribution of identified good charged hadrons vs. z (left) and vs. p_T^h (right).

BACK UP SLIDES.BINNING

x bins	z bins	p_T^h bins (GeV)
	0.05(0.120)0.200	
0.004(0.010)0.012	0.200(0.216)0.234	0.100(0.177)0.239
0.012(0.020)0.022	0.234(0.253)0.275	0.239(0.289)0.337
0.022(0.031)0.035	0.275(0.299)0.327	0.337(0.385)0.433
0.035(0.053)0.076	0.327(0.361)0.400	0.433(0.485)0.542
0.076(0.098)0.132	0.400(0.455)0.523	0.542(0.610)0.689
0.132(0.190)0.700	0.523(0.661)0.900	0.689(0.814)1.000

The size of each bin is optimized to have ≥ 1 M of events
The first z bin (0.05 – 0.2) has been used for tests only