Azimuthal Asymmetries from Unpolarized Data at COMPASS

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on behalf of the COMPASS collaboration

- **Intrinsic k_T of quarks in the nucleon:**
  - **Cahn effect**
- **Transverse momentum dependent distribution functions (TMDs)**
  - **measured with unpolarized nucleons**

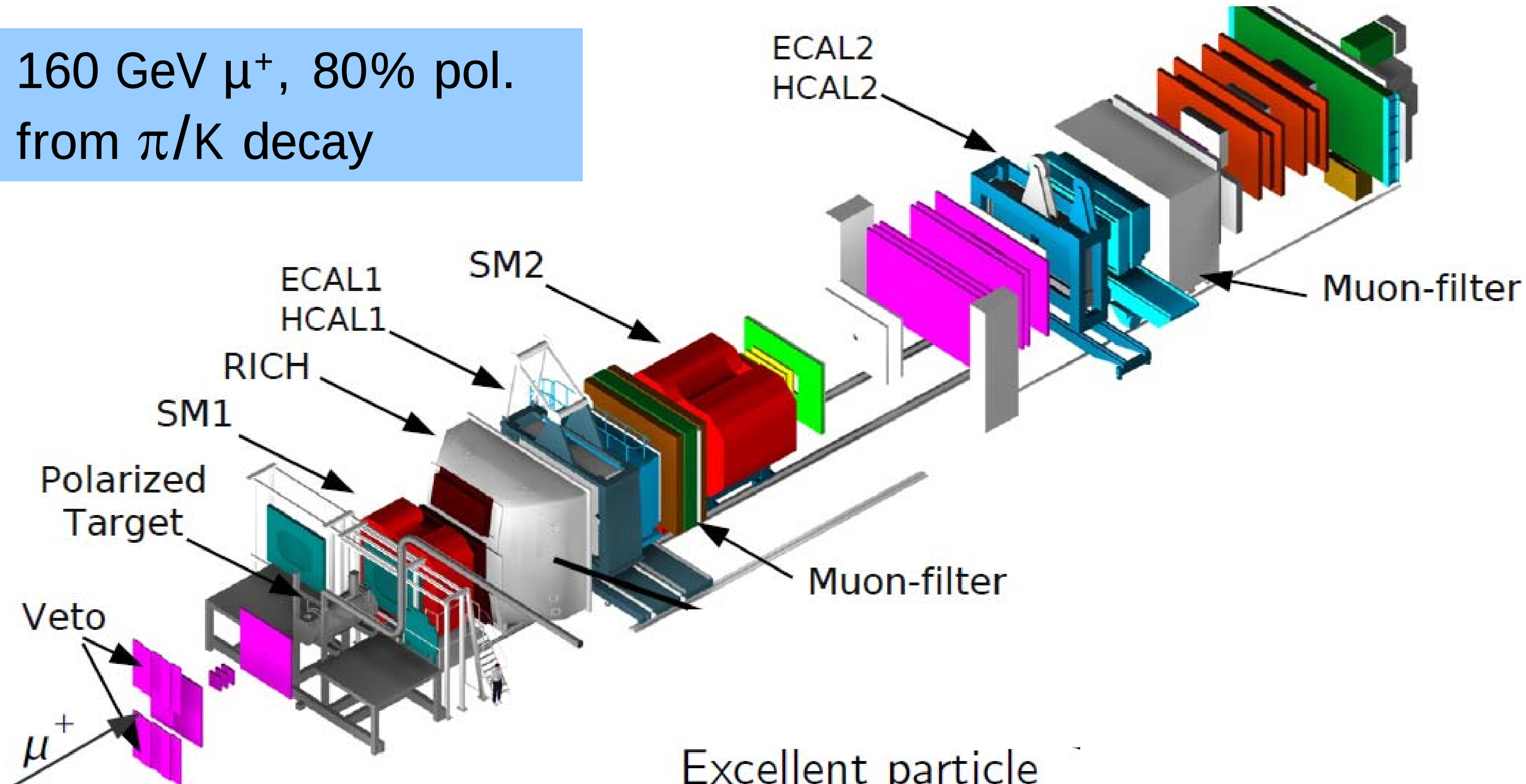
bmb+f - Förderschwerpunkt COMPASS Großgeräte der physikalischen Grundlagenforschung

DIS2011, April 13th 2011, Newport News, USA


Jura mountains
Lac Léman
COMPASS
LHC
SPS
CERN

COMPASS

Beam: 160 GeV μ^+, 80% pol.
from π/K decay

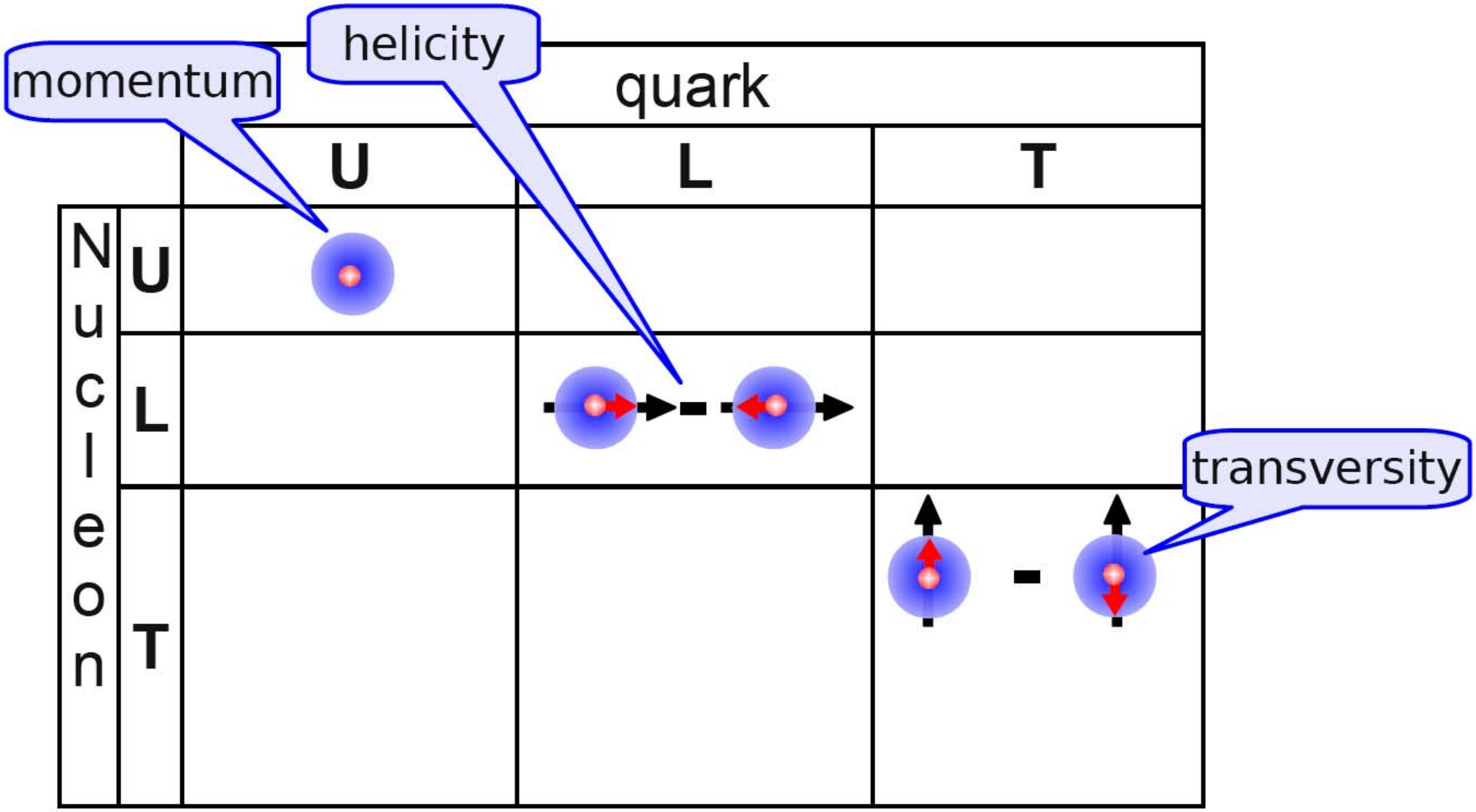


Excellent particle identification

solid NH_3 or ^{6}LiD target
(polarization averaged)

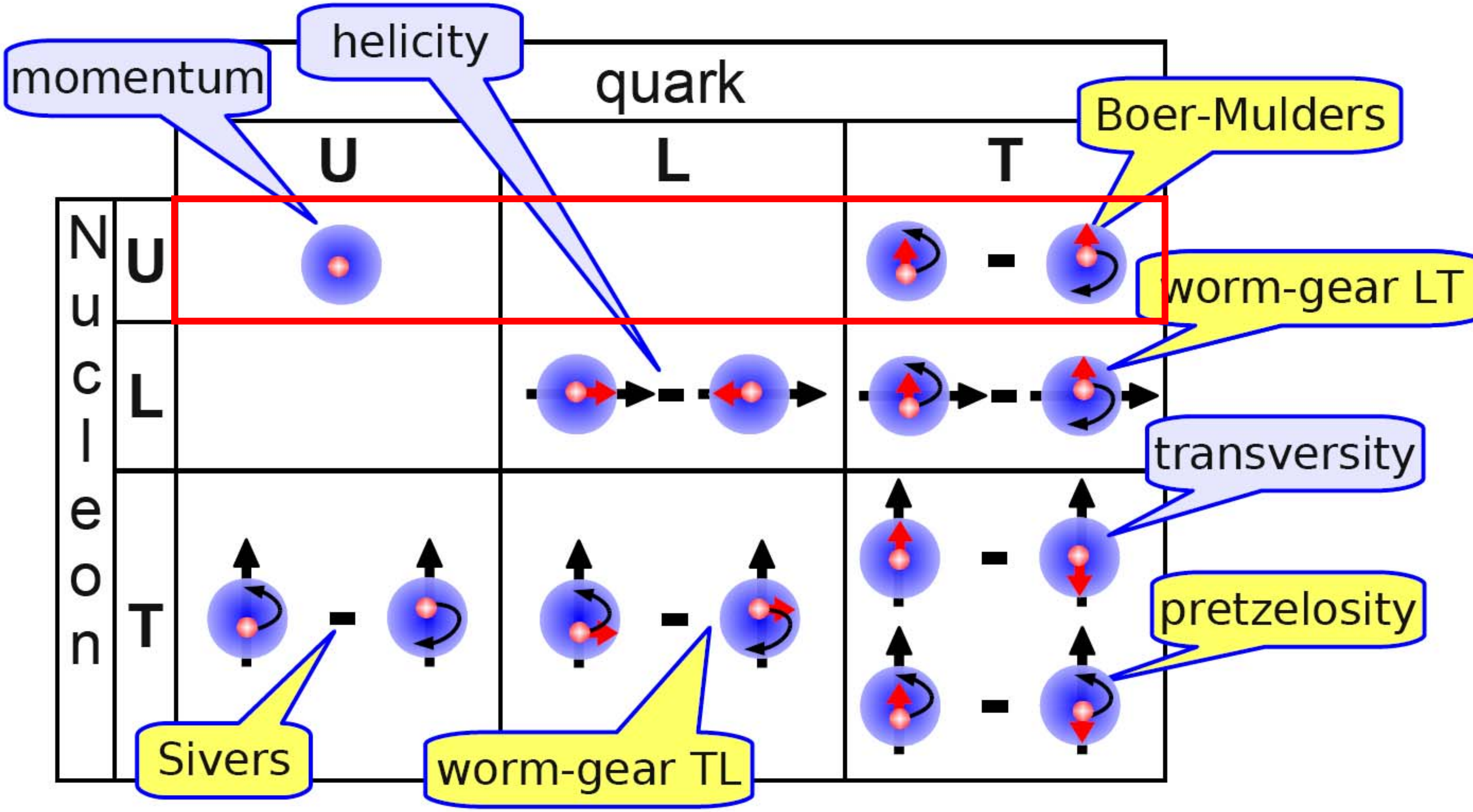
TMDs

Three parton distribution functions when integrating over $k_\perp$



TMDs

Eight parton distribution functions when taking into account $k_\perp$



Unpolarized SIDIS taking into account k_T

$$N(\phi_h) \propto N_0 \cdot \left(1 + \varepsilon_1 A^{UU}_{\cos\phi_h} \cos\phi_h + \varepsilon_2 A^{UU}_{\cos 2\phi_h} \cos 2\phi_h + \lambda_l \varepsilon_3 A^{LU}_{\sin\phi_h} \sin\phi_h\right)$$

$$\sum_q PDF_q(x, k_T) \otimes FF_q(z, k_T)$$

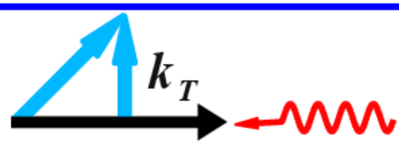
- 3 independent azimuthal modulations of hadrons:

$A^{UU}_{\cos\phi_h}$ $A^{UU}_{\cos 2\phi_h}$ $A^{LU}_{\sin\phi_h}$

Kinematical factors: $\varepsilon_1 = \frac{2(2-y)\sqrt{1-y}}{1+(1-y)^2}$ $\varepsilon_2 = \frac{2(1-y)}{1+(1-y)^2}$ $\varepsilon_3 = \frac{2y\sqrt{1-y}}{1+(1-y)^2}$ λ_l beam polarization

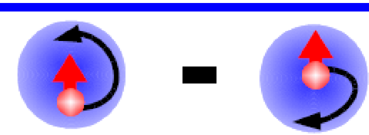
Azimuthal asymmetries in unpolarized SIDIS

- Cahn effect:

Cahn Effect 

kinematical effect due to transv. momentum of partons in the nucleon

- Boer-Mulders effect: Boer-Mulders TMD

Boer-Mulders $h_1^\perp$: 

correlation of parton transv. momentum and transv. polarization in an unpolarized nucleon

- twist-3 effect due to beam polarization

Cahn effect

The unpolarized SIDIS cross section:

$$d\sigma^{lp \to l'hX} = \sum_q f_q\left(x, Q^2\right) \otimes d\sigma^{lp \to l'q} \otimes D_q^h\left(z, Q^2\right)$$

The elementary cross-section:

$$d\sigma^{lp \to l'q} \propto \hat{s}^2 + \hat{u}^2$$

Taking into account the quark transverse momentum:

$$\hat{s} = sx\left[1 - \frac{2k_T}{Q}\sqrt{1-y} \cdot \cos\phi\right] + O\left(\frac{k_T^2}{Q}\right)$$

Boer-Mulders effect

$$A_{\cos\phi}^{UU}, A_{\cos 2\phi}^{UU} \propto h_1^{\perp} \otimes H_1^{\perp}$$

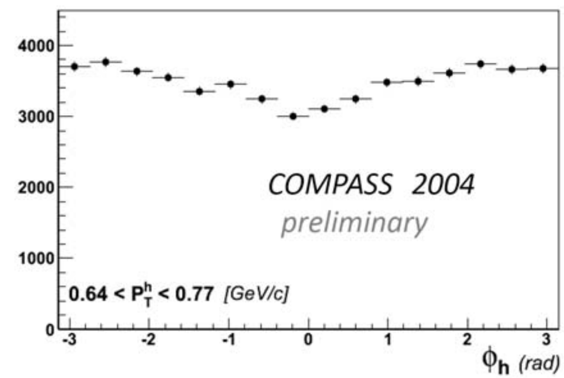
Quark spin can be unevenly distributed in transverse space

A distortion in the distribution of quark spin in transverse space can give rise to a Boer-Mulders function *Burkardt, hep-ph/0510408*

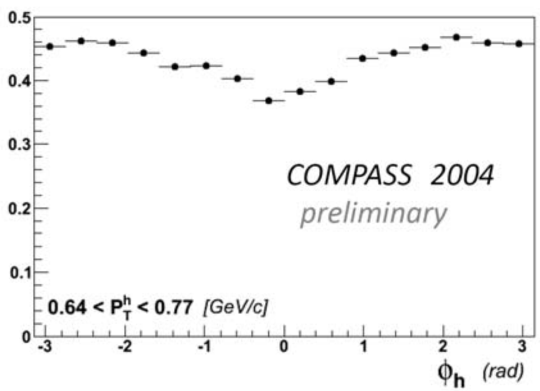
Acceptance correction:

For each bin in x, z and P_T^h, the detector acceptance is corrected by a Monte-Carlo simulation:

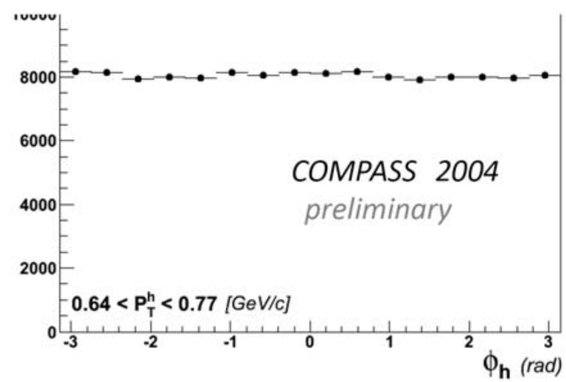
MC rec. azimuthal distribution



azimuthal acceptance

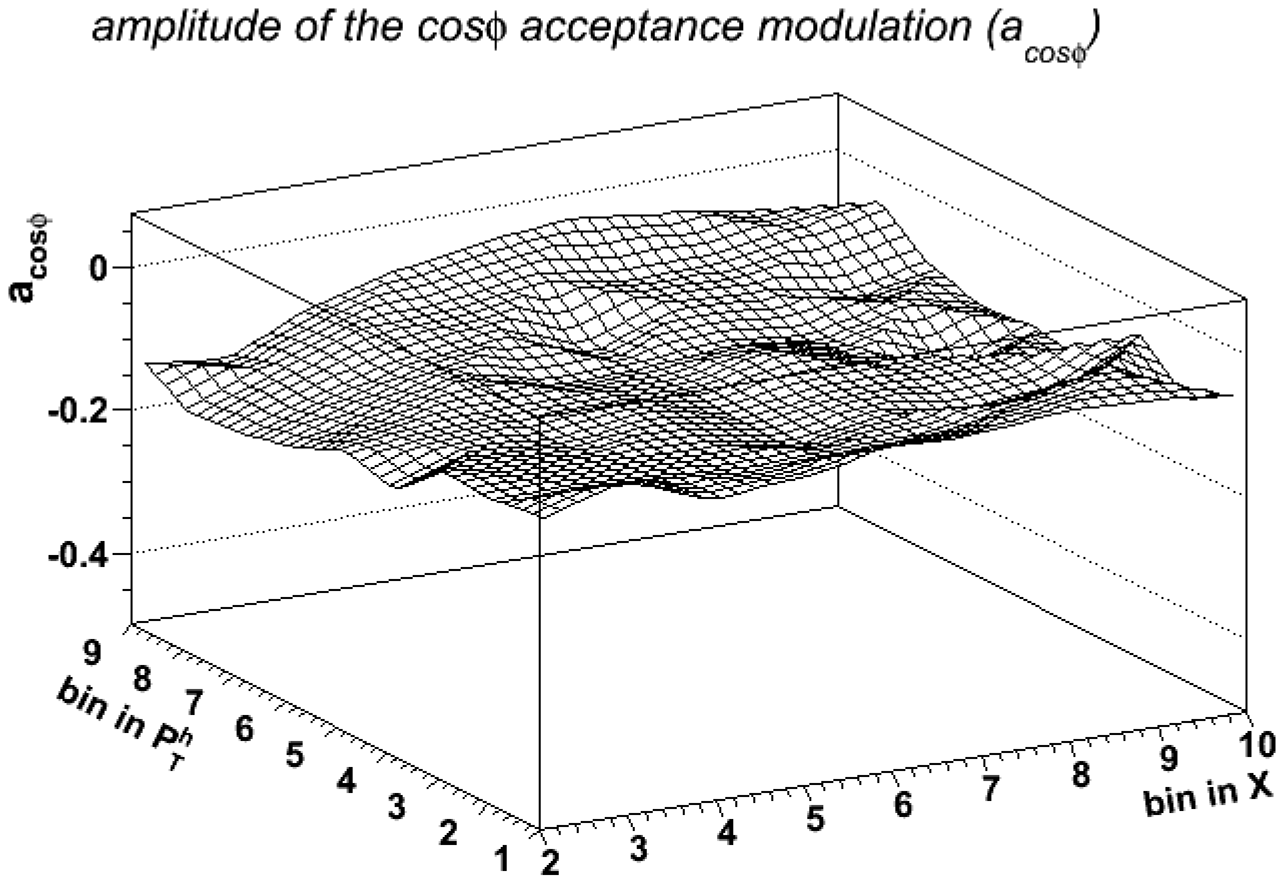


MC gen. azimuthal distribution



Acceptance correction:

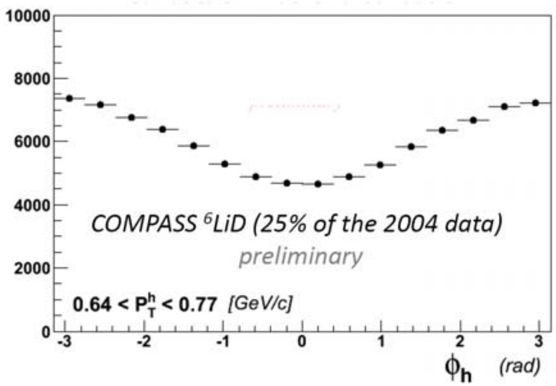
The azimuthal acceptance has been studied in two dimensions:



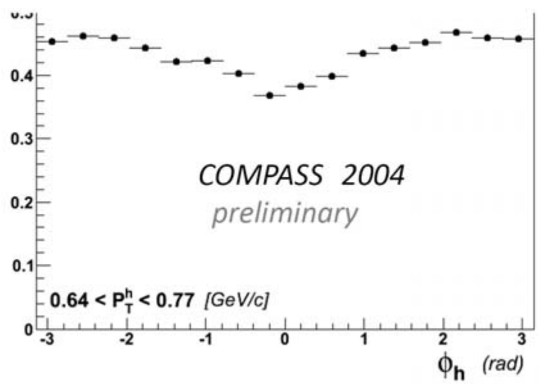
Acceptance correction:

Correction of data for acceptance effects and fitting:

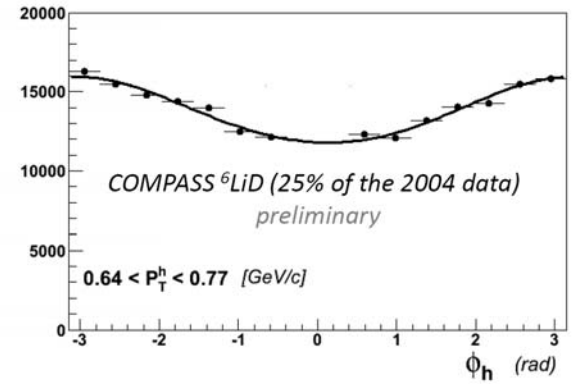
measured azimuthal distribution



azimuthal acceptance



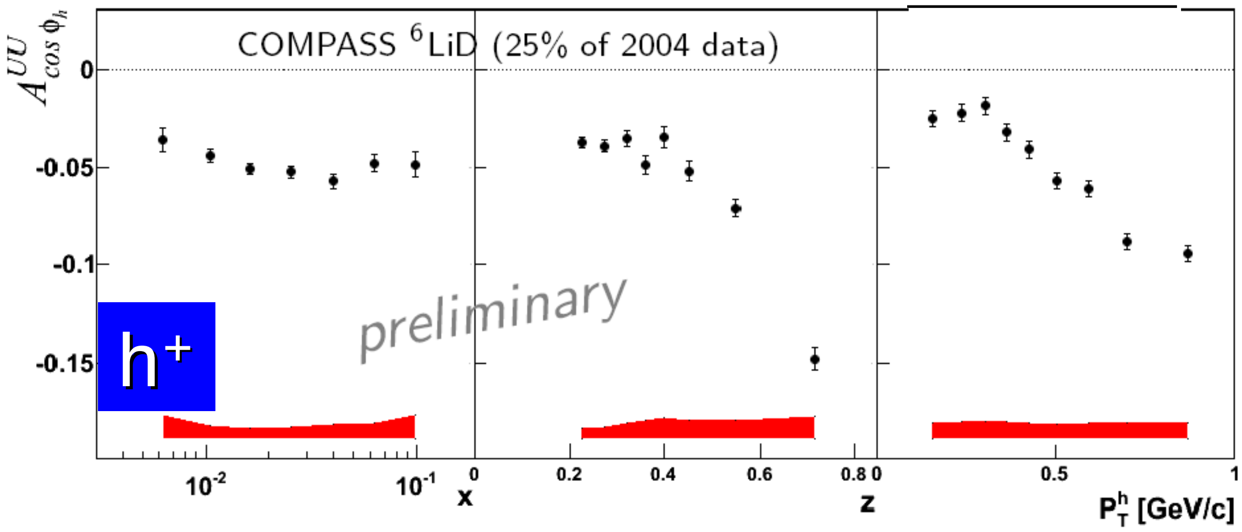
measured azimuthal distributions corrected by the acceptance

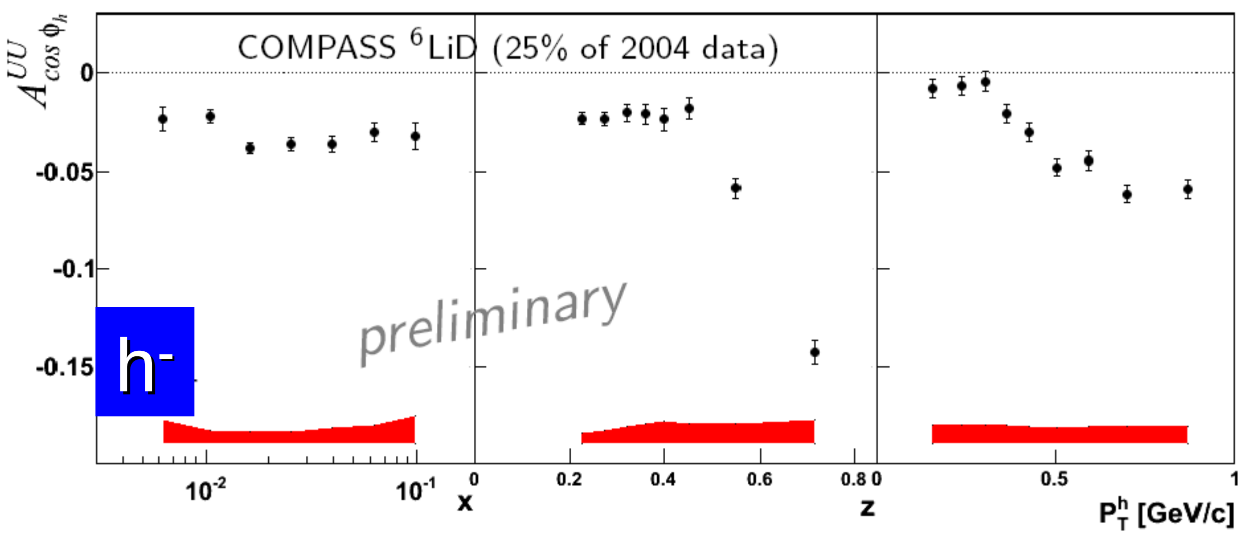


amplitudes extracted with a fit:

$$p_0 \cdot (1 + p_1 \cdot \cos\phi_h + p_2 \cdot \cos 2\phi_h + p_3 \cdot \sin\phi_h)$$

Results: $A^{UU}_{\cos\phi}$

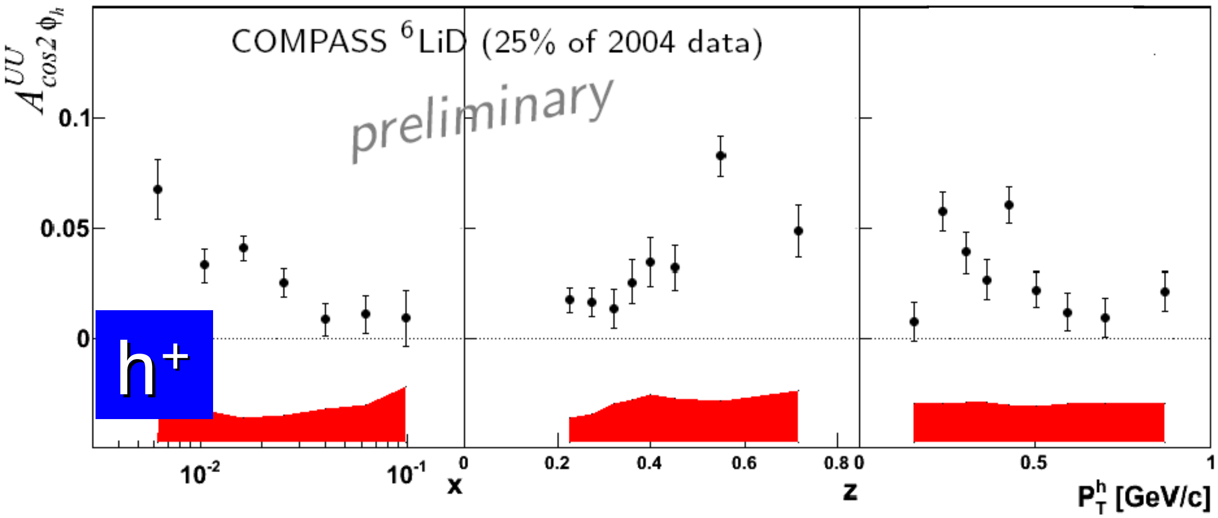


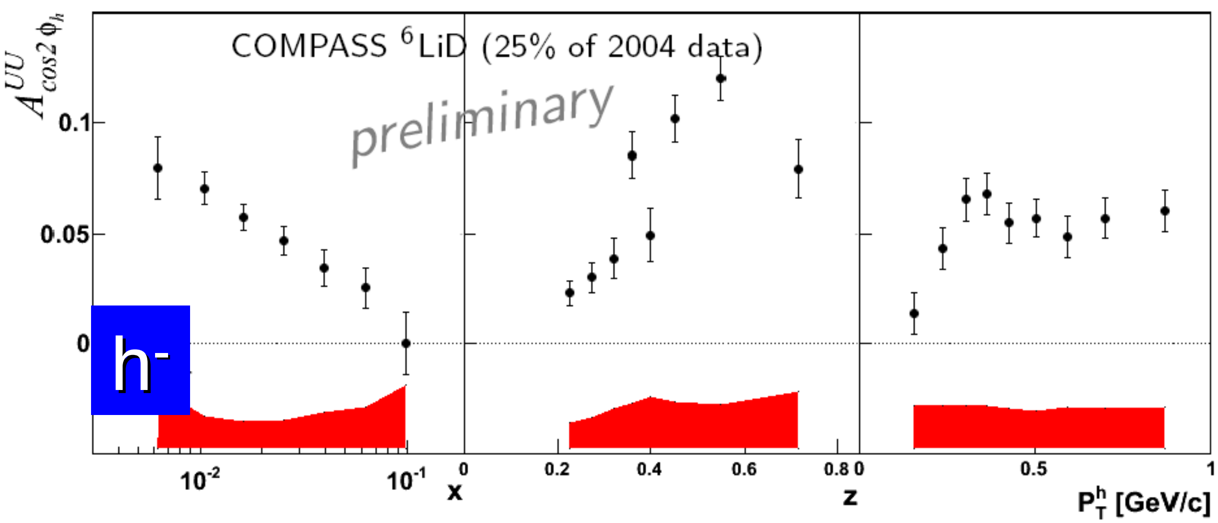


$A^{UU}_{\cos\phi}$: Mainly Cahn effect

- Large negative asymmetries
- Charge dependent

Results: $A^{UU}_{\cos 2\phi}$



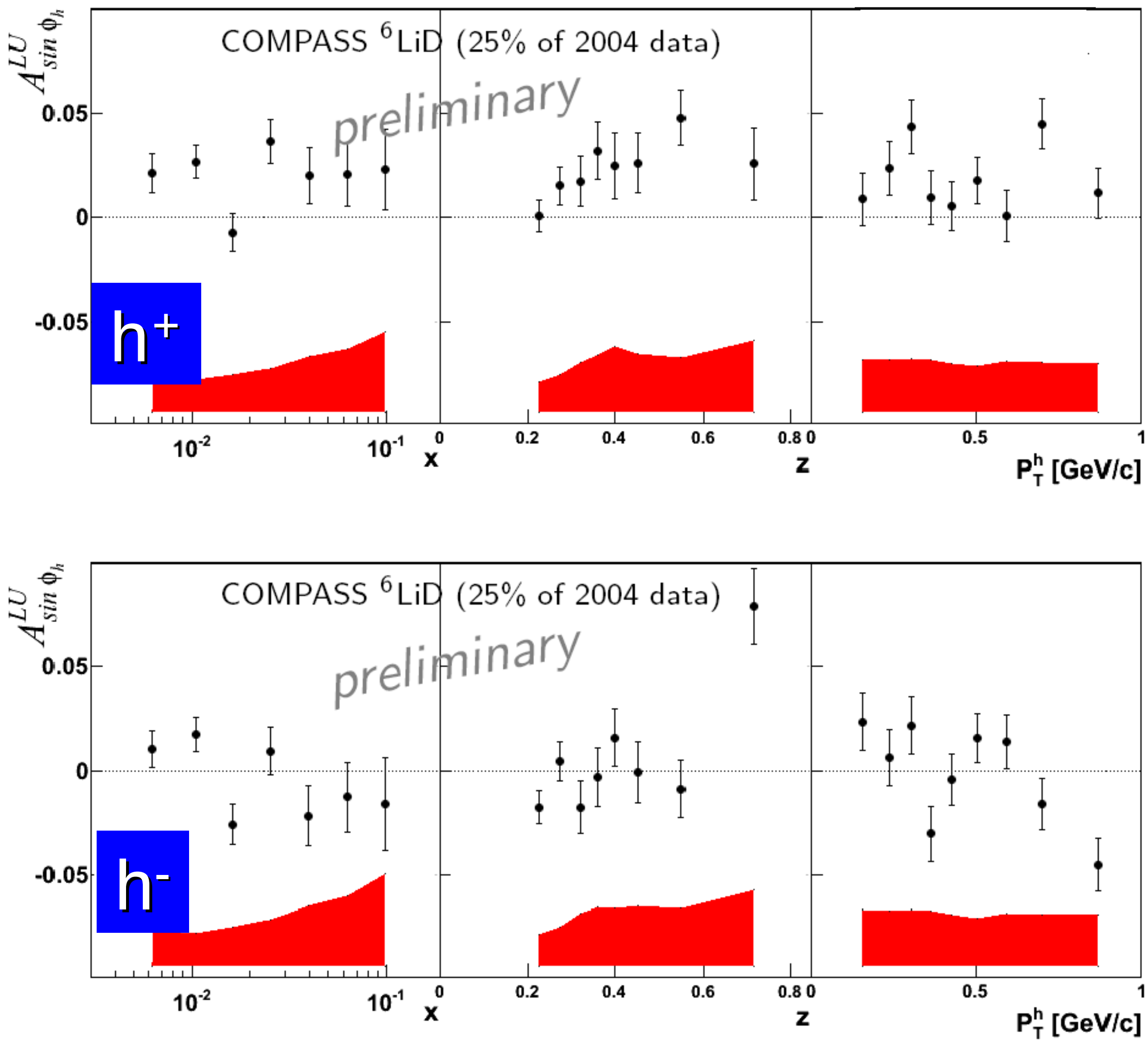


$A^{UU}_{\cos 2\phi}$: Boer-Mulders TMD

$+\text{Cahn} \propto \left(\frac{k_\perp}{Q}\right)^2$

- Large positive asymmetries
- Charge dependent

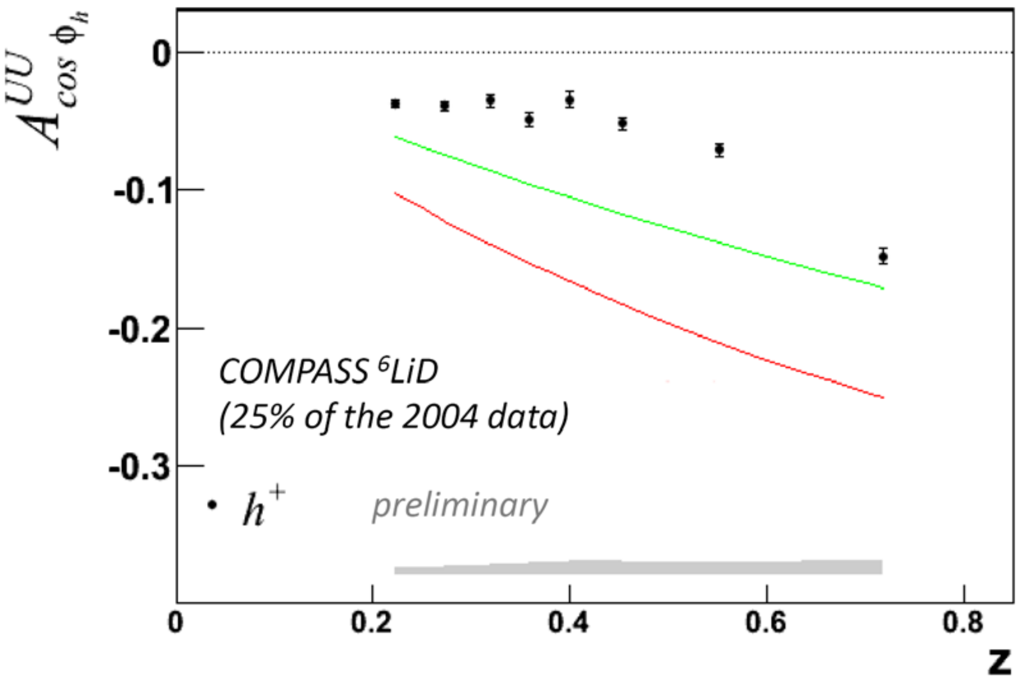
Results: $A^{LU}_{\sin\phi}$



$A^{LU}_{\sin\phi}$: twist-3 effect due to beam polarization

- h^+ positive asymmetry
- h^- small asymmetry, compatible with zero

Comparision with theory



$< k_\perp^2 >$, $< p_\perp^2 >$ (GeV/c)²

0.25, 0.20 *Anselmino et al. (EMC data)*

0.38, 0.16 *Schweitzer et al. (HERMES data)*

$k_\perp$: quark trans. Momentum

$p_\perp$: hadron transv. momentum

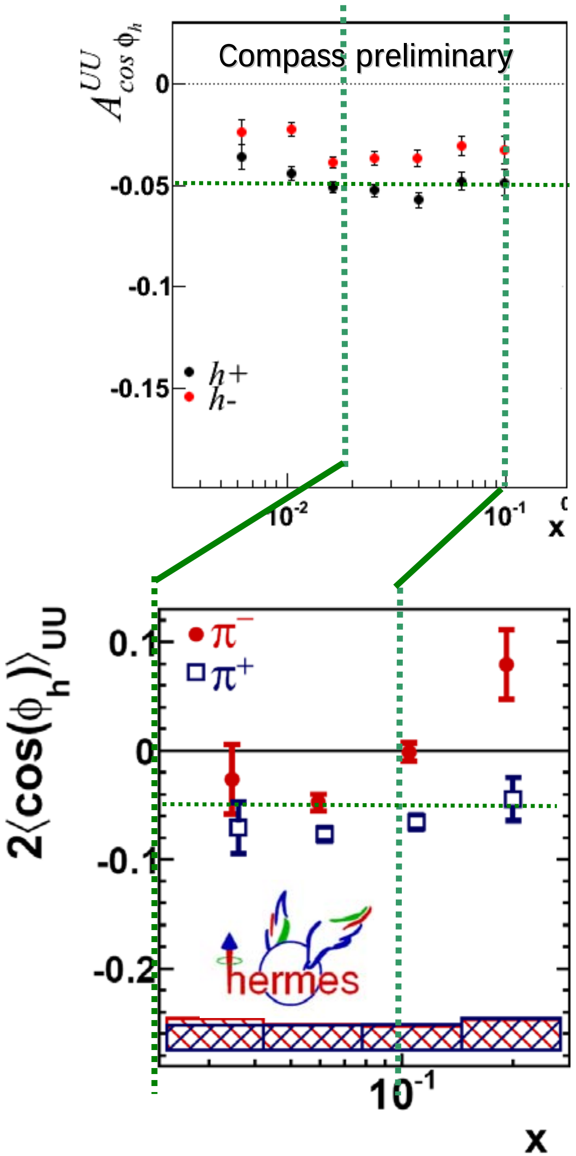
Considering Cahn effect only:

$$A^{UU}_{\cos\phi_h}(z,k_\perp^2,p_\perp^2)=\frac{z\langle k_\perp^2\rangle\sqrt{\pi}}{2\langle Q\rangle\sqrt{z^2\langle k_\perp^2\rangle+\langle p_\perp^2\rangle}}$$

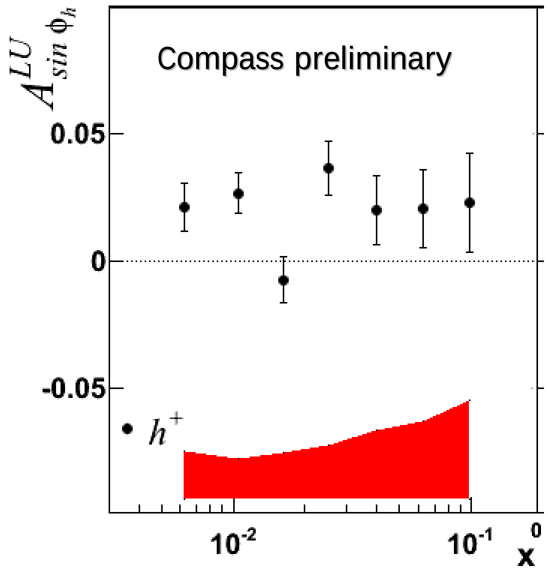
Schweitzer et al.

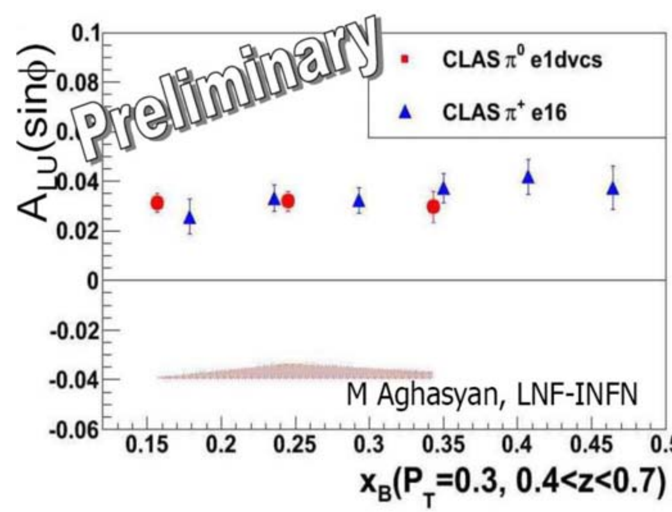
Comparision with HERMES+Clas

cosϕ



sinϕ





Different kinematics:

HERMES+Clas:

Lower Q^2 and W
Larger x

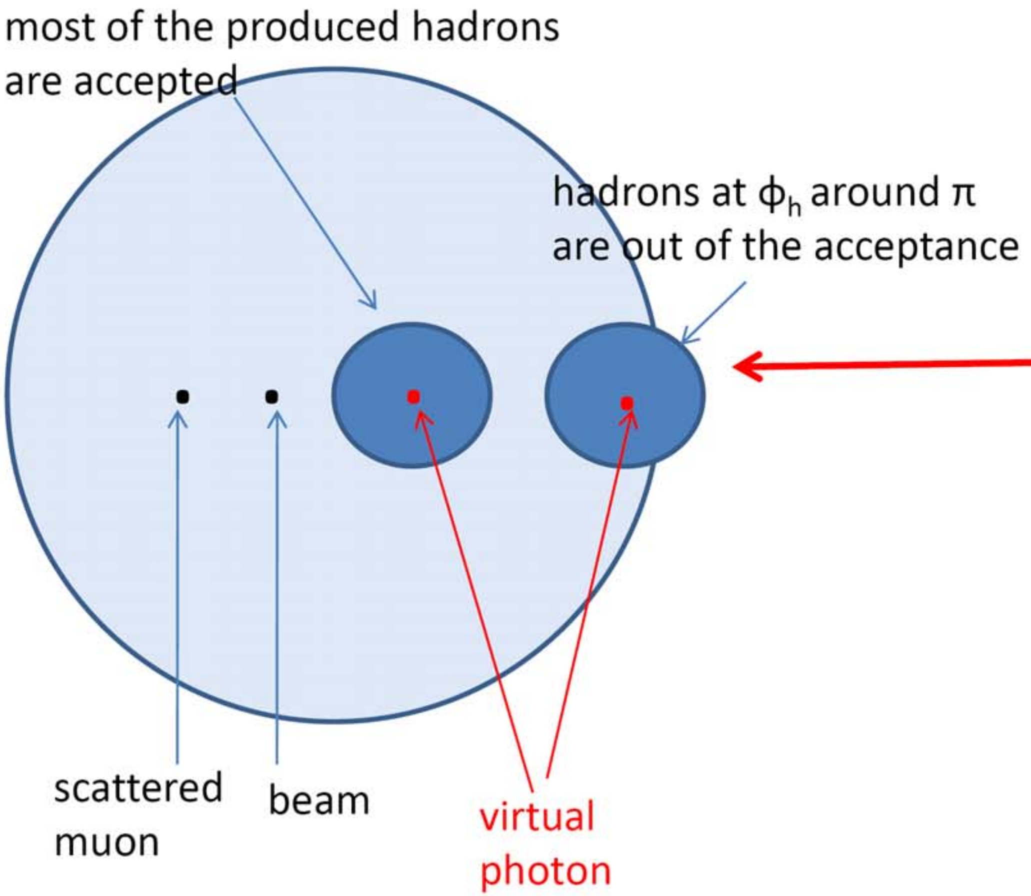
Summary

COMPASS results for unpolarized azimuthal asymmetries on a ^{6}LiD target for pos. and neg. Hadrons:

- The measured $\cos\phi_h$ amplitude is large and negative (up to -0.15)
- The $\cos2\phi_h$ amplitude is positive (0.05)
- There is a clear difference in amplitudes between positive and negative hadrons
  → hint for flavour dependence of Boer-Mulders function

Spares

Acceptance cuts



$Q^2 > 1\ (\text{GeV}/c)^2$

$\theta_\gamma^{lab} < 0.06$

$0.003 < x < 0.13$

$0.2 < y < 0.9$

$W > 5\ \text{GeV}/c^2$

$0.2 < z < 0.85$

$0.1 < P^T_h < 1\ \text{GeV}/c$

Systematic uncertainty

the sources of the systematic error which have been checked and included in the evaluation are the following:

- differences between amplitudes of the azimuthal modulations extracted using the 3 different MC samples

- differences between amplitudes of the azimuthal modulations extracted from transverse and longitudinal data (different apparatus setup → 2 different MC descriptions)

- estimation of possible azimuthal effects from unknown inefficiencies of detectors in low redundancies region

Systematic uncertainty

other studies ...

- a first calculation of the possible effects of radiative corrections have been performed using RADGEN and have been found to be relatively small

- more amplitudes have been added in the fitting function to the ones expected from the unpolarized cross section → compatible with zero

... not included in the systematic errors