# Azimuthal Asymmetries from Unpolarized Data at COMPASS

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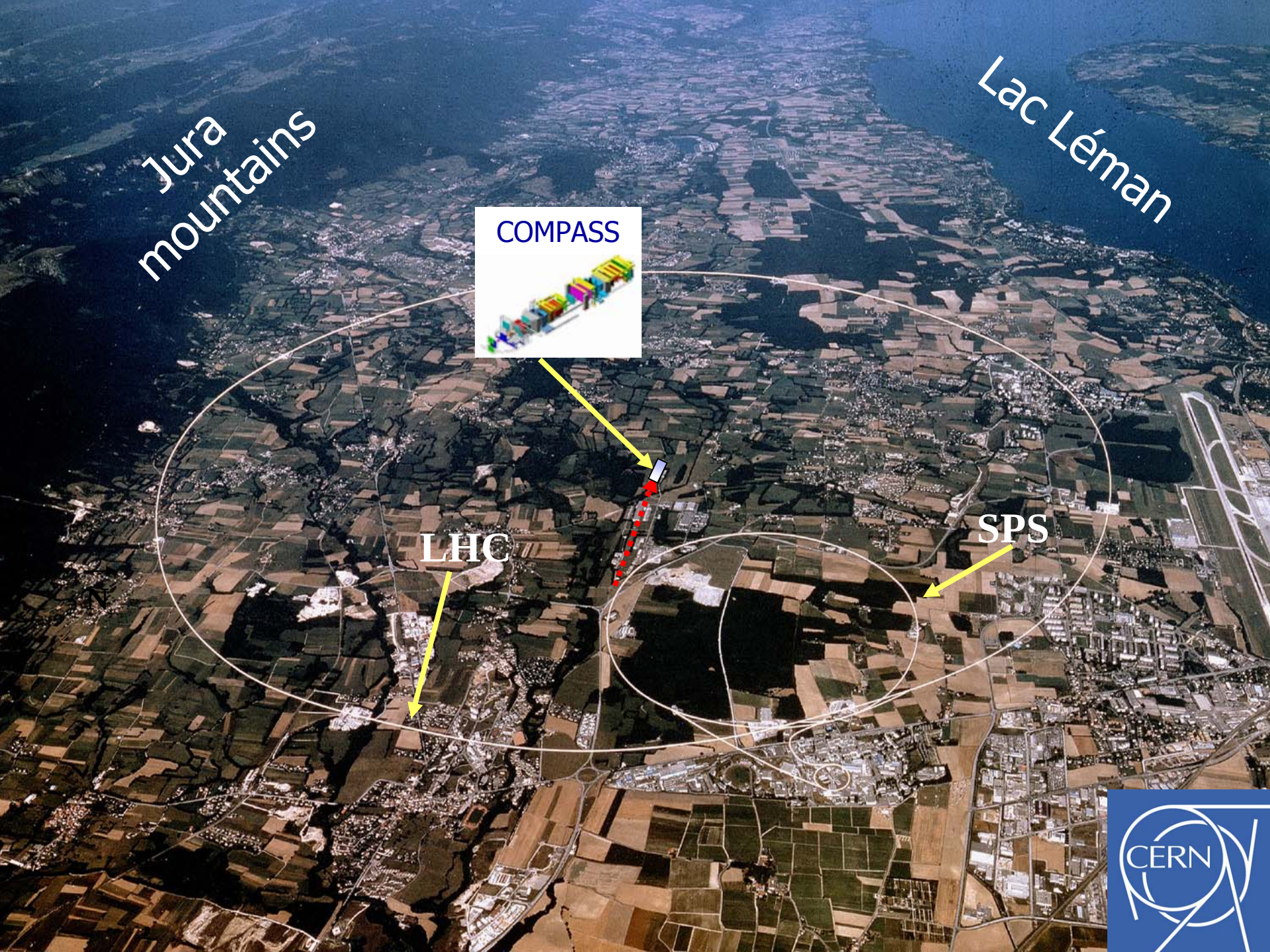
*on behalf of the COMPASS collaboration*

- **Intrinsic $k_T$ of quarks in the nucleon:**
  - **Cahn effect**

- **Transverse momentum dependent distribution functions (TMDs)**
  - **measured with unpolarized nucleons**

DIS2011, April 13th 2011, Newport News, USA


Jura mountains
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COMPASS
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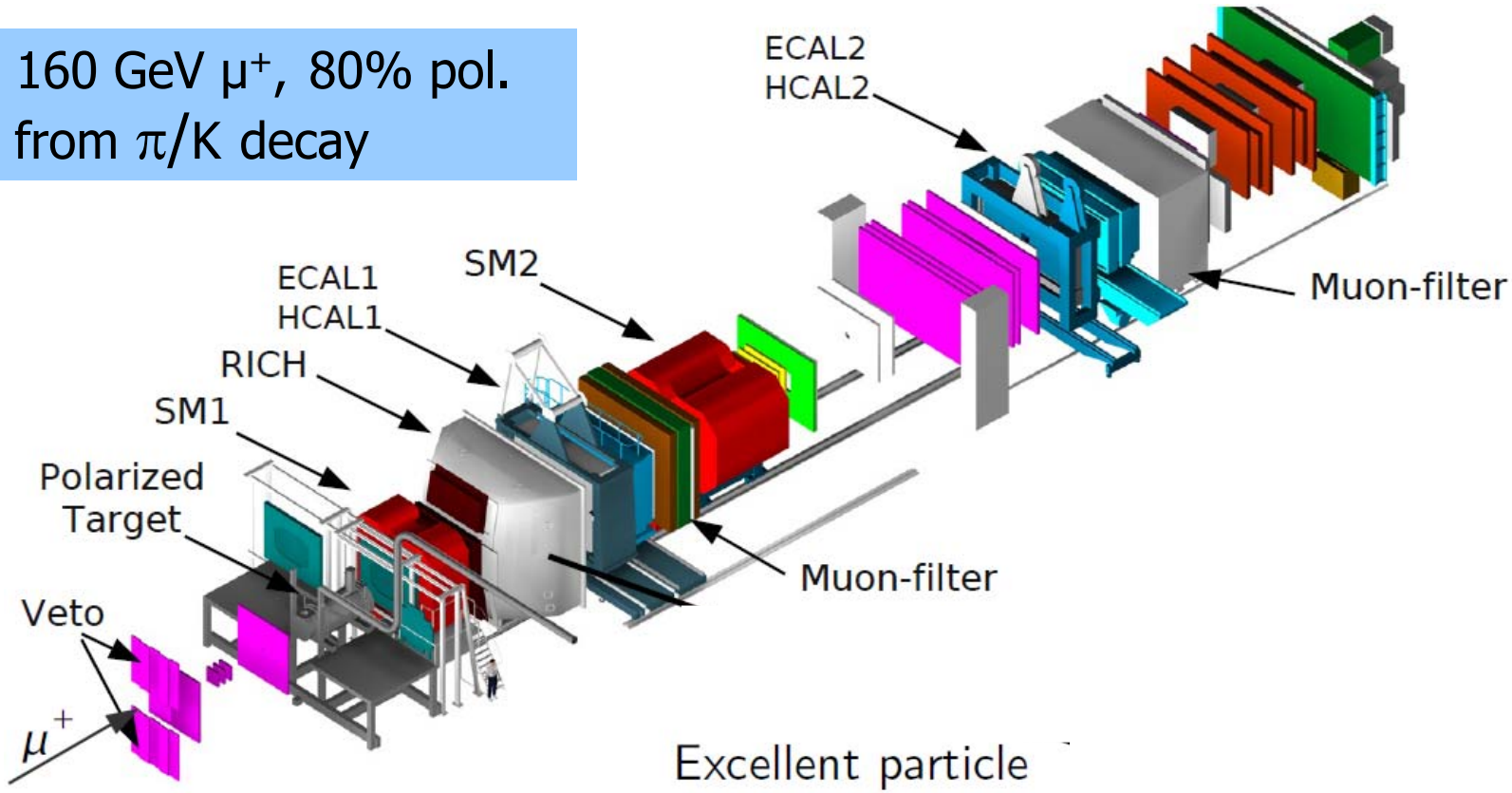
# COMPASS

Beam: 160 GeV $\mu^+$, 80% pol.
from $\pi$/K decay

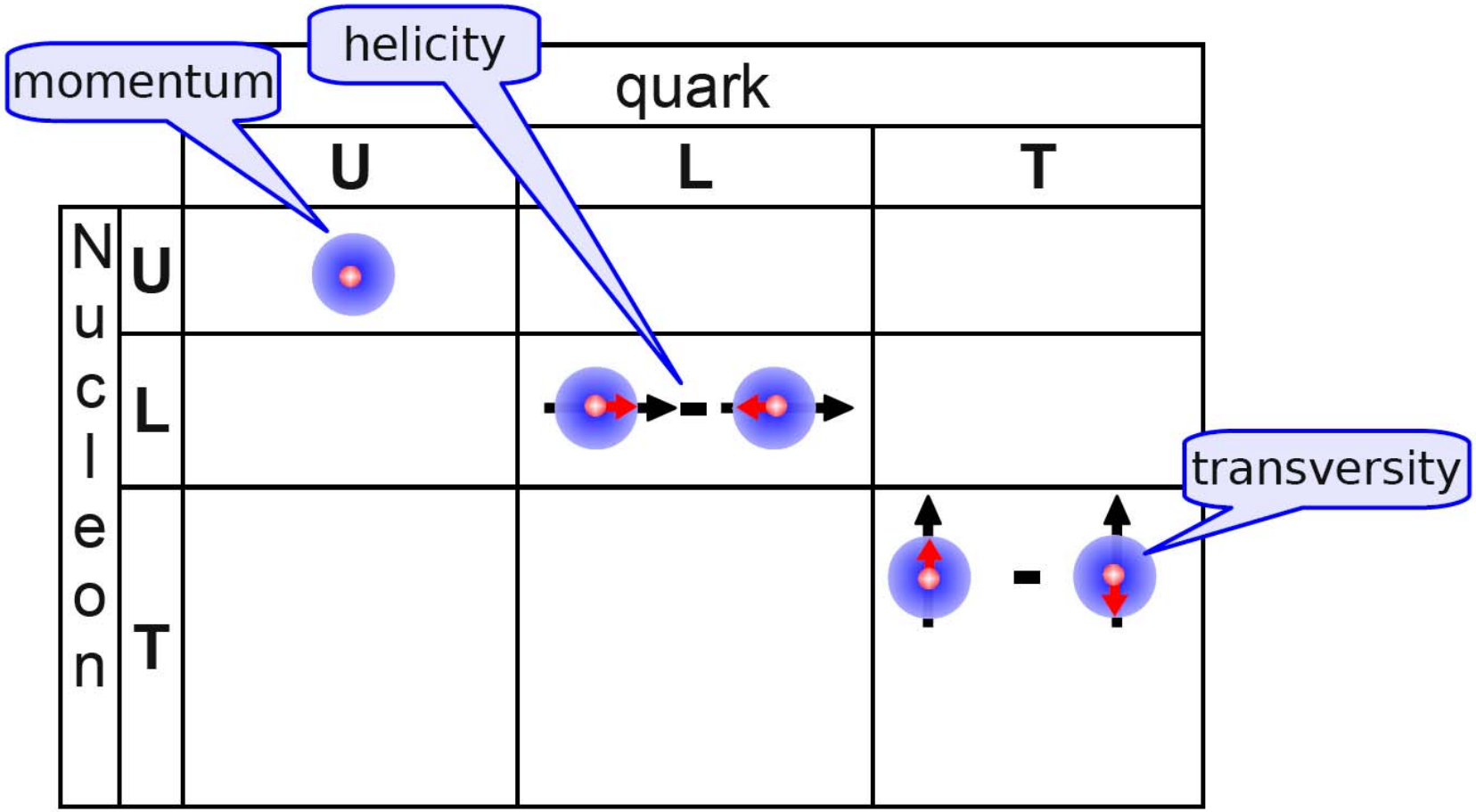



Excellent particle identification

solid $NH_3$ or $^6$LiD target
(polarization averaged)

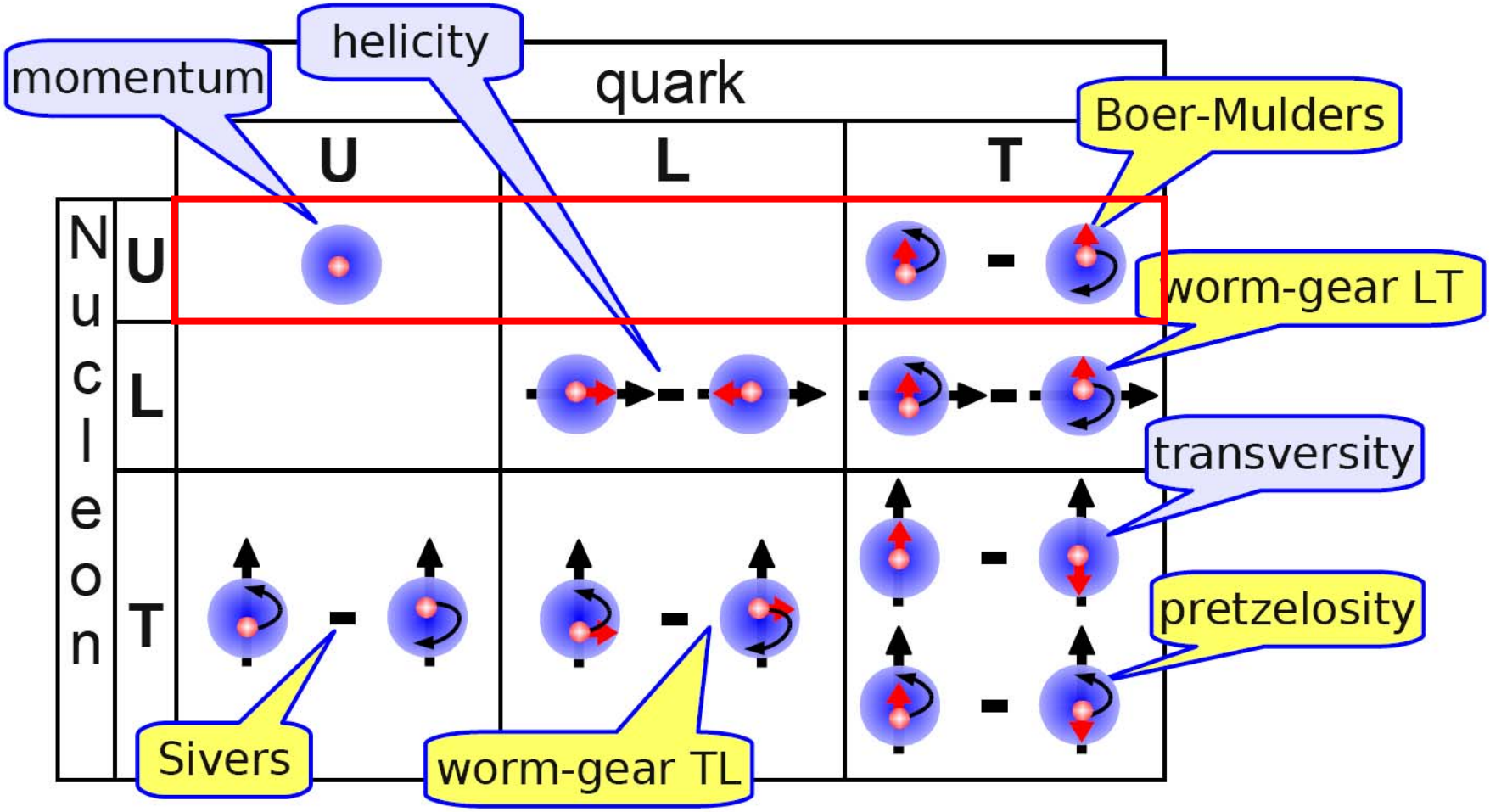
# TMDs

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 $k_T$

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

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

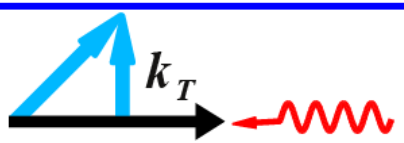
- 3 independent azimuthal modulations of hadrons:

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

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

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

Side view

Front view

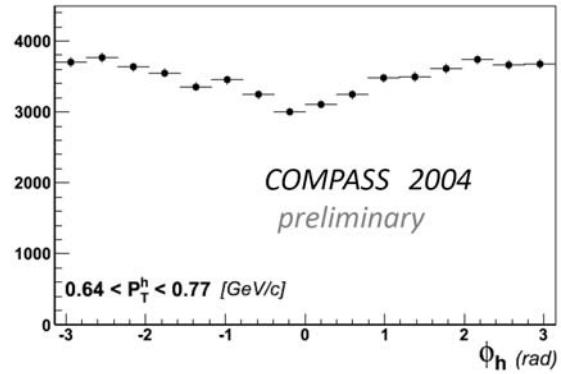
Quark spin can be unevenly distributed in transverse space

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

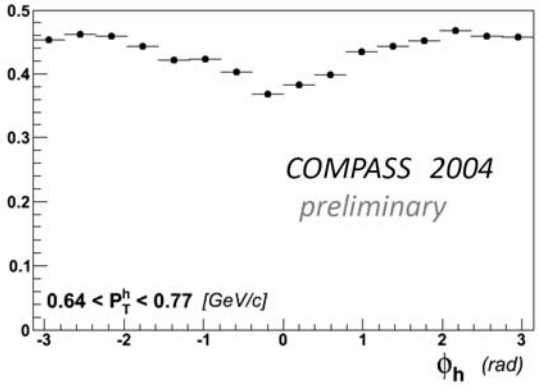
# Acceptance correction:

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

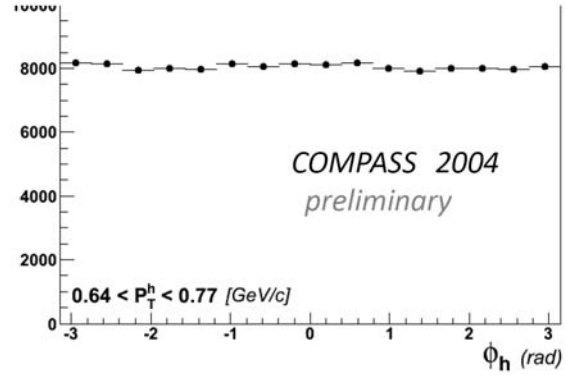
**MC rec. azimuthal distribution**




**azimuthal acceptance**

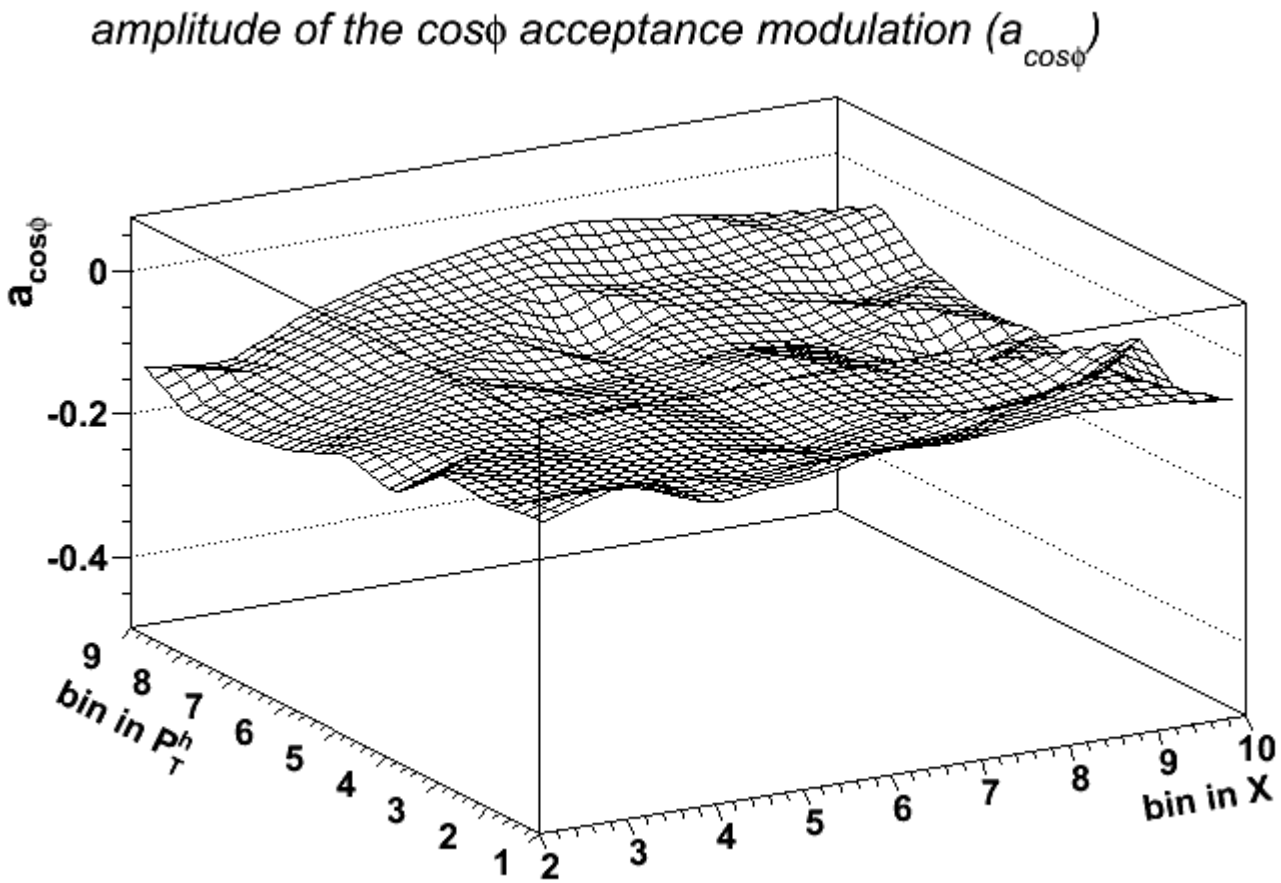



**MC gen. azimuthal distribution**



# Acceptance correction:

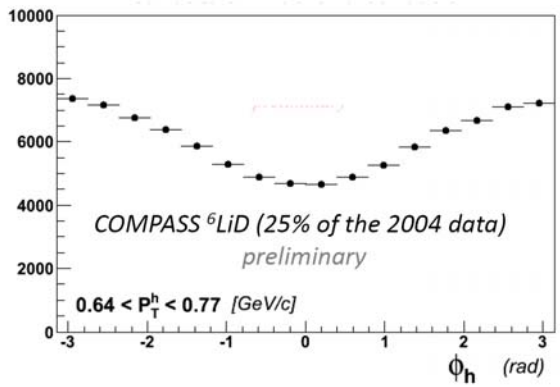
The azimuthal acceptance has been studied in two dimensions:



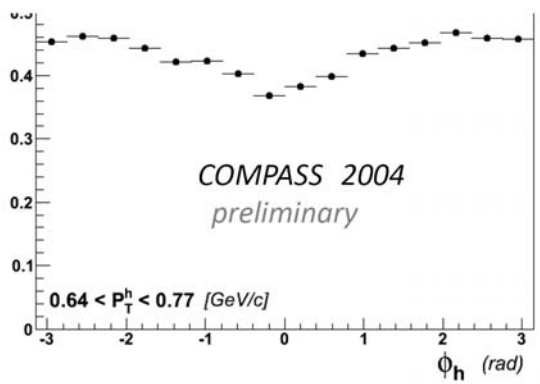
# Acceptance correction:

## Correction of data for acceptance effects and fitting:

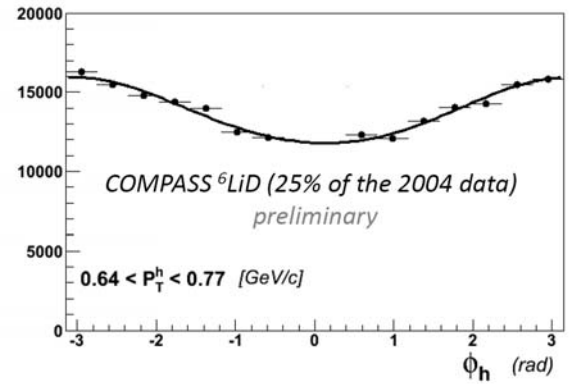
**measured azimuthal distribution**




**azimuthal acceptance**



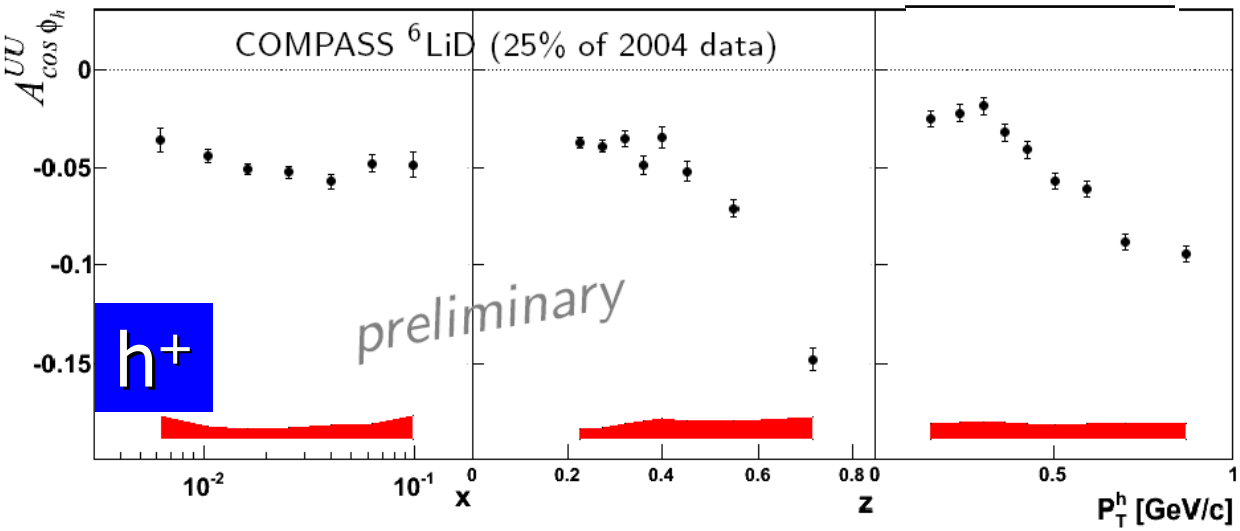

**measured azimuthal distributions corrected by the acceptance**

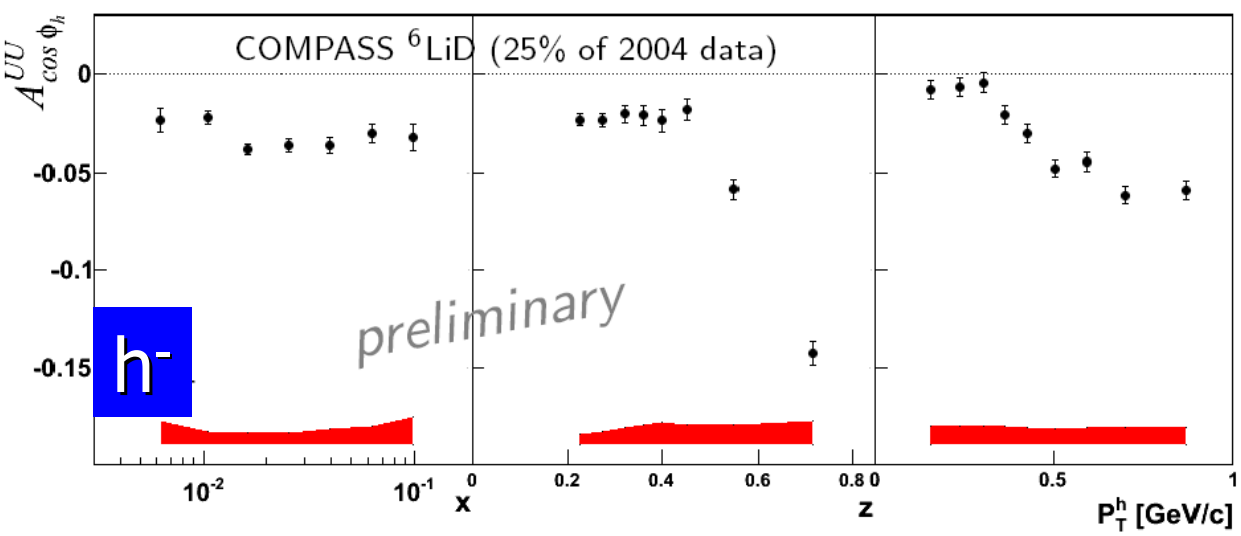



**amplitudes extracted with a fit:**

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

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

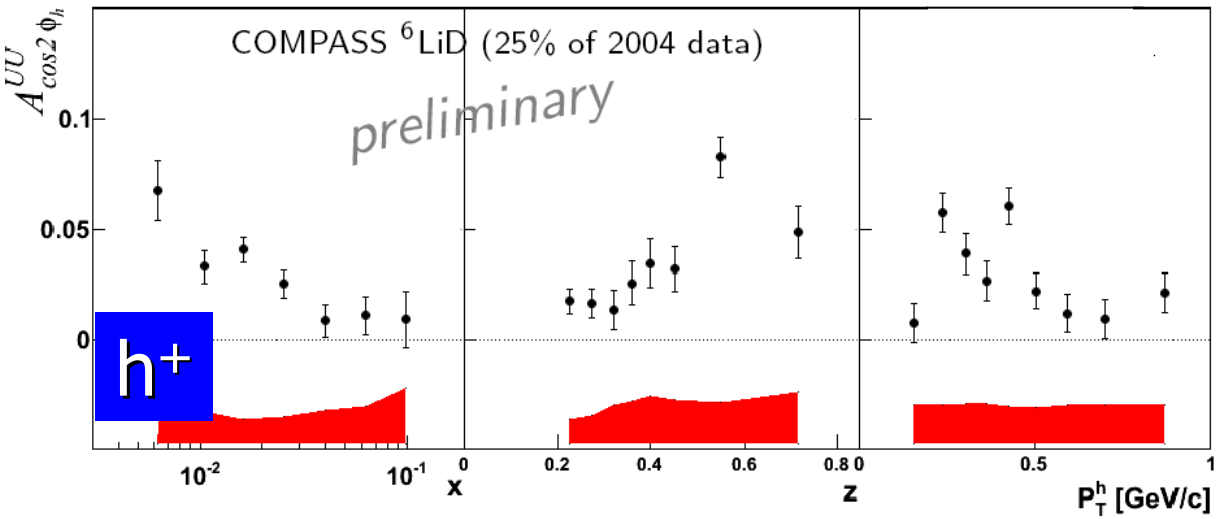


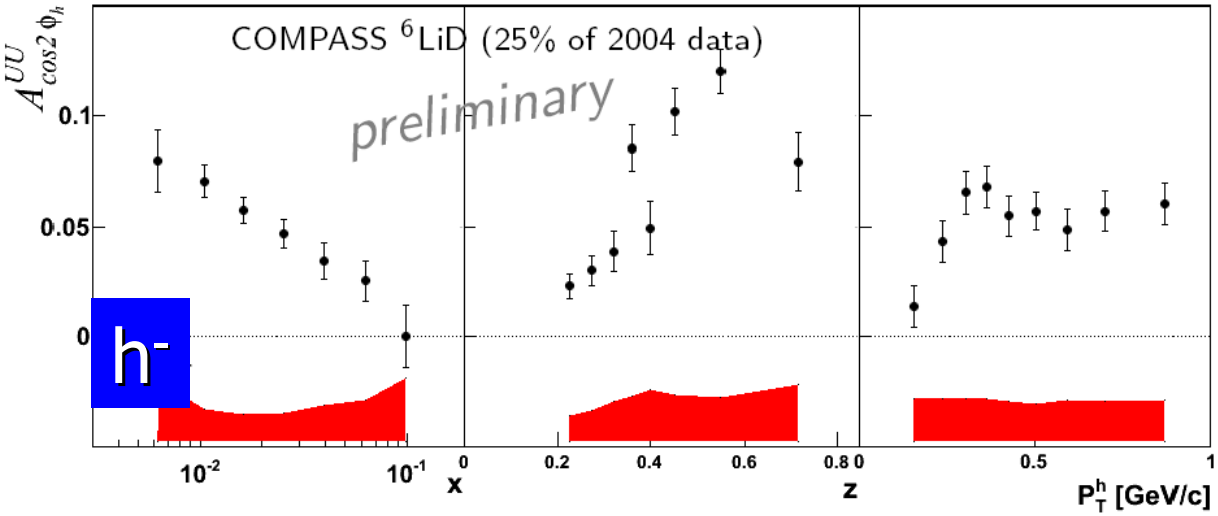




$A^{UU}_{\cos\phi}$: Mainly Cahn effect

- Large negative asymmetries
- Charge dependent

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



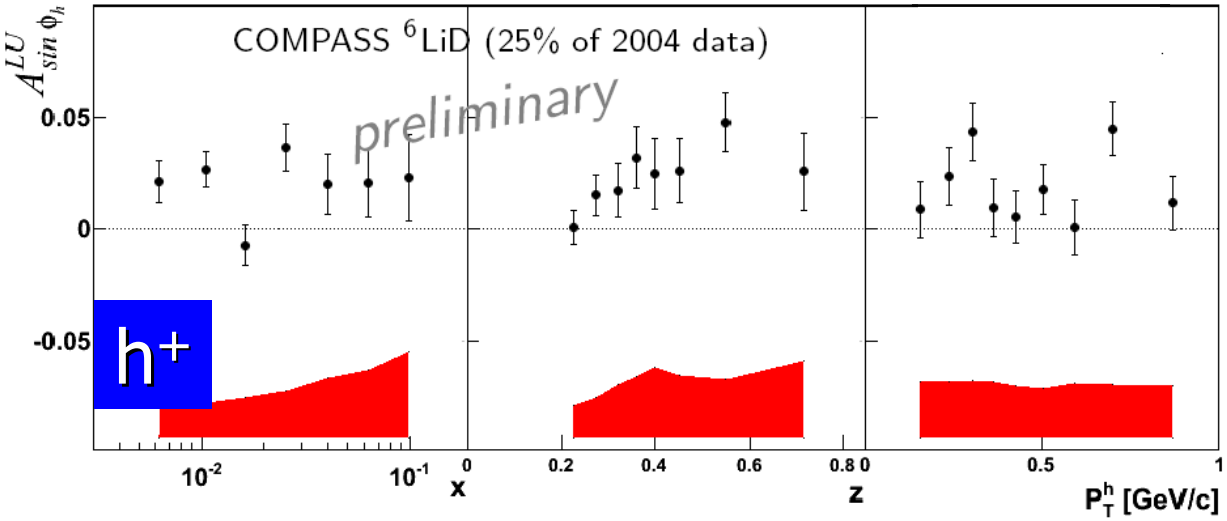



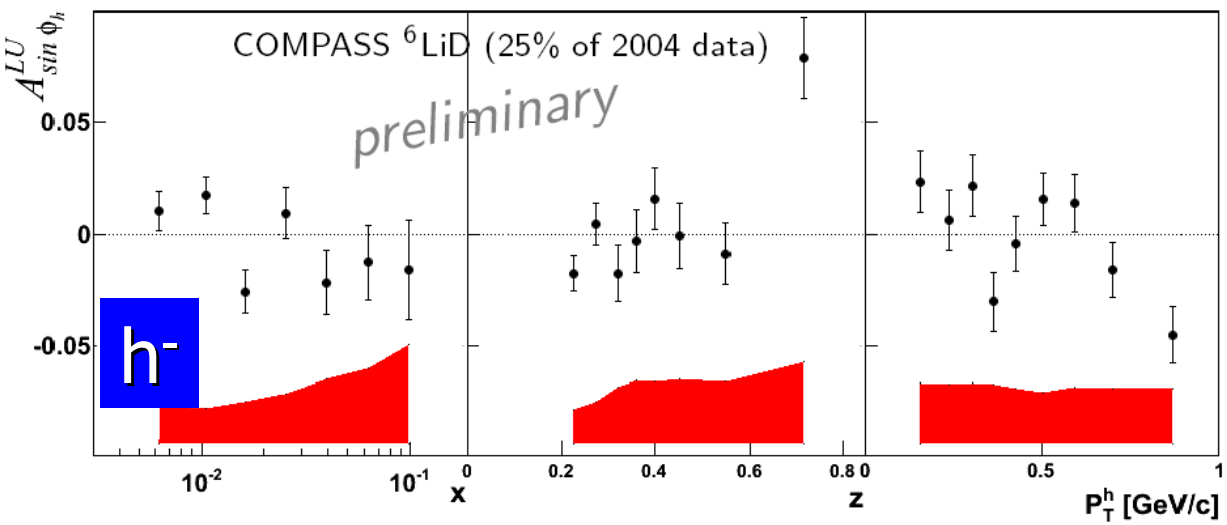

$A^{UU}_{\cos 2\phi}$: Boer-Mulders TMD

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

- Large positive asymmetries
- Charge dependent

# Results: $A^{UU}_{\sin\phi}$

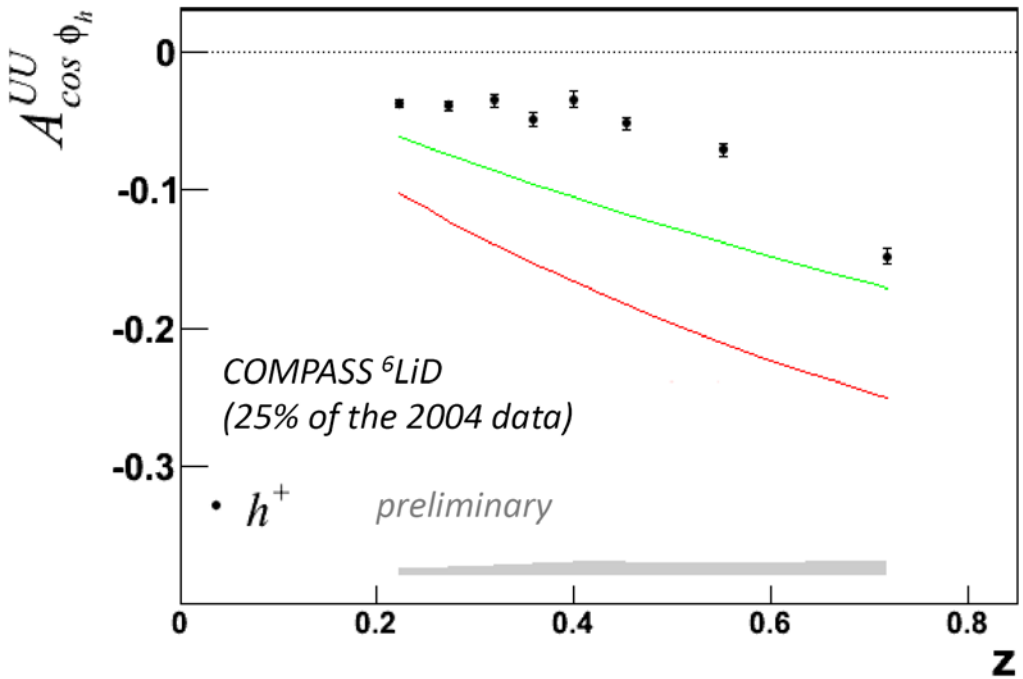



$A^{LU}_{\sin\phi}$: twist-3 effect due to beam polarization

- $h^+$ 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:

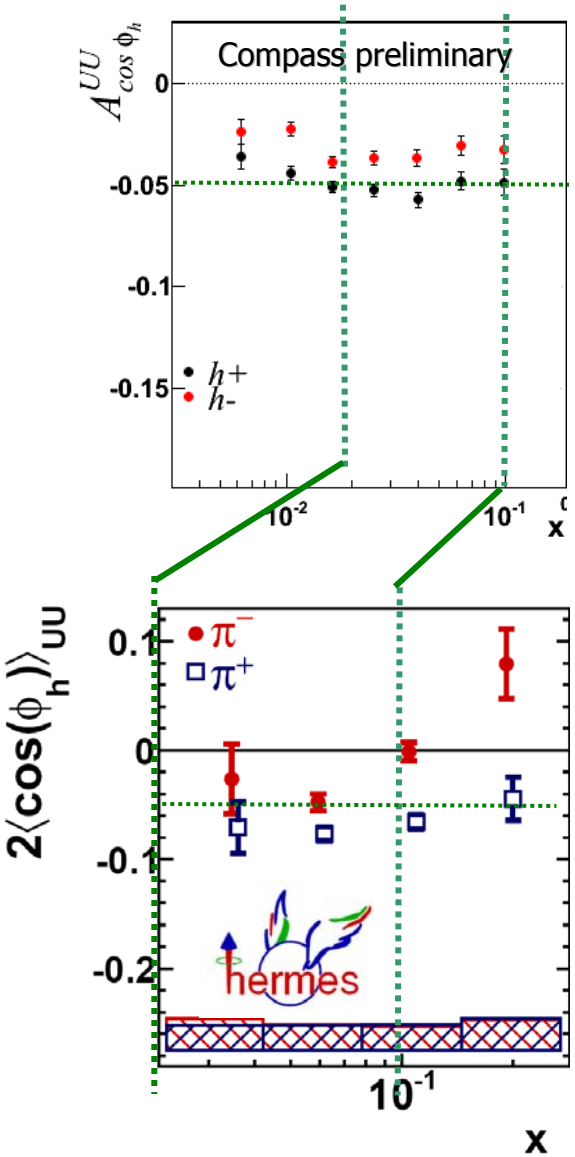
$$A^{UU}_{\cos\phi_h}(z, k_\perp^2, p_\perp^2) = \frac{z\langle k_\perp^2\rangle\sqrt{\pi}}{2\langle Q\rangle\sqrt{z^2\langle k_\perp^2\rangle + \langle p_\perp^2\rangle}}$$

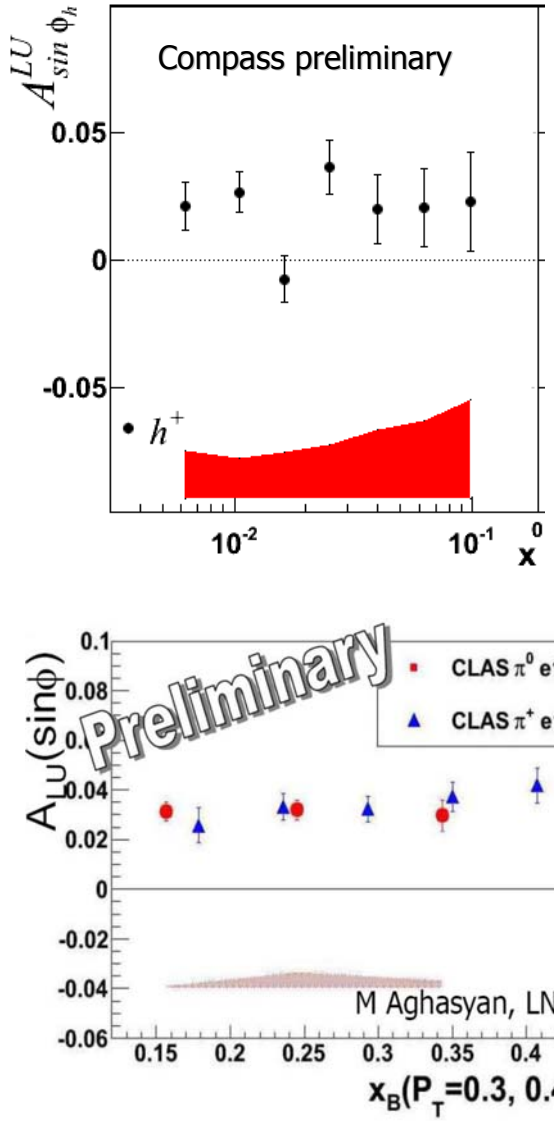
Schweitzer et al.

# Comparision with HERMES+Clas

cosϕ

sinϕ




Different kinematics:

HERMES+Clas:

Lower $Q^2$ and W
Larger x

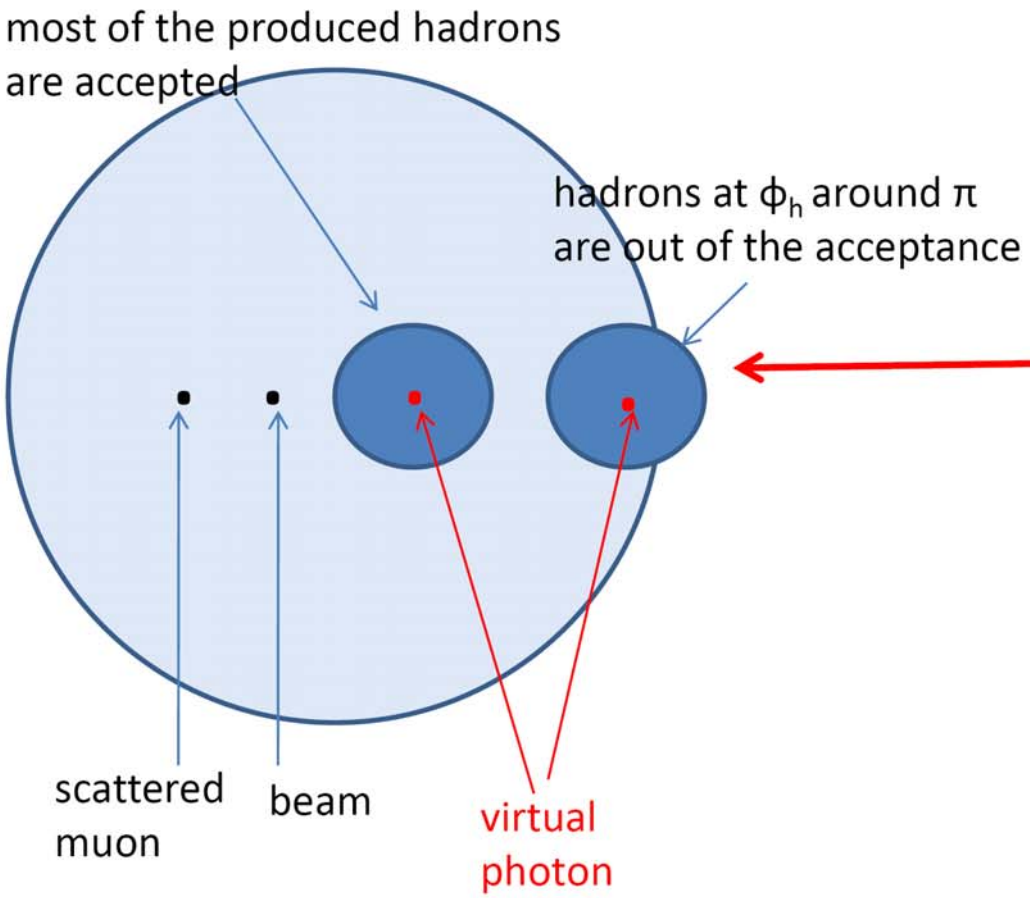
# Summary

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 $\cos 2\phi_h$ 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




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

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

$0.003 < x < 0.13$

$0.2 < y < 0.9$

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

$0.2 < z < 0.85$

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

# 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