Unpolarized azimuthal asymmetries in SIDIS at COMPASS

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on behalf of the COMPASS Collaboration

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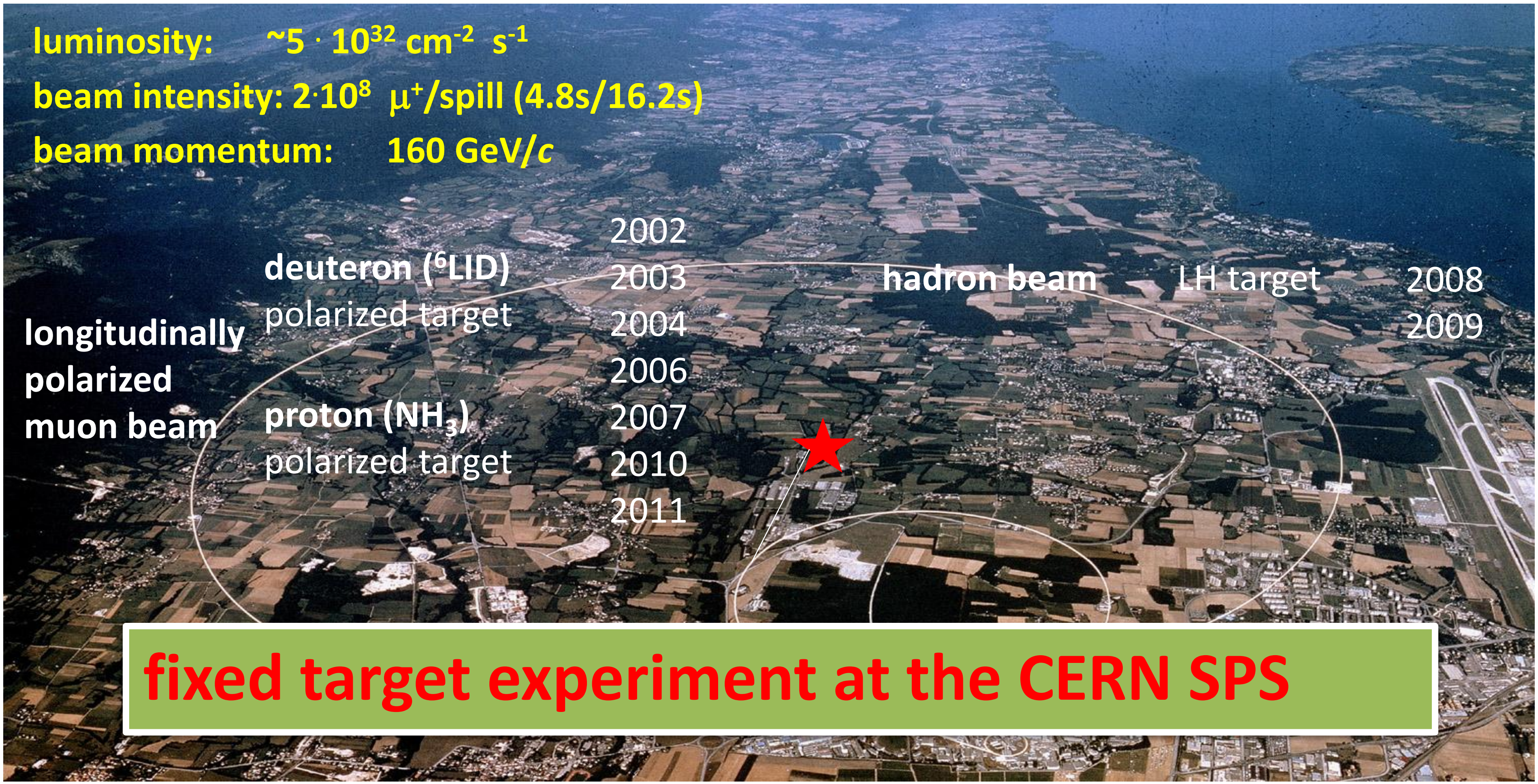
COMPASS

COmmon
Muon and
Proton
Apparatus for
Structure and
Spectroscopy

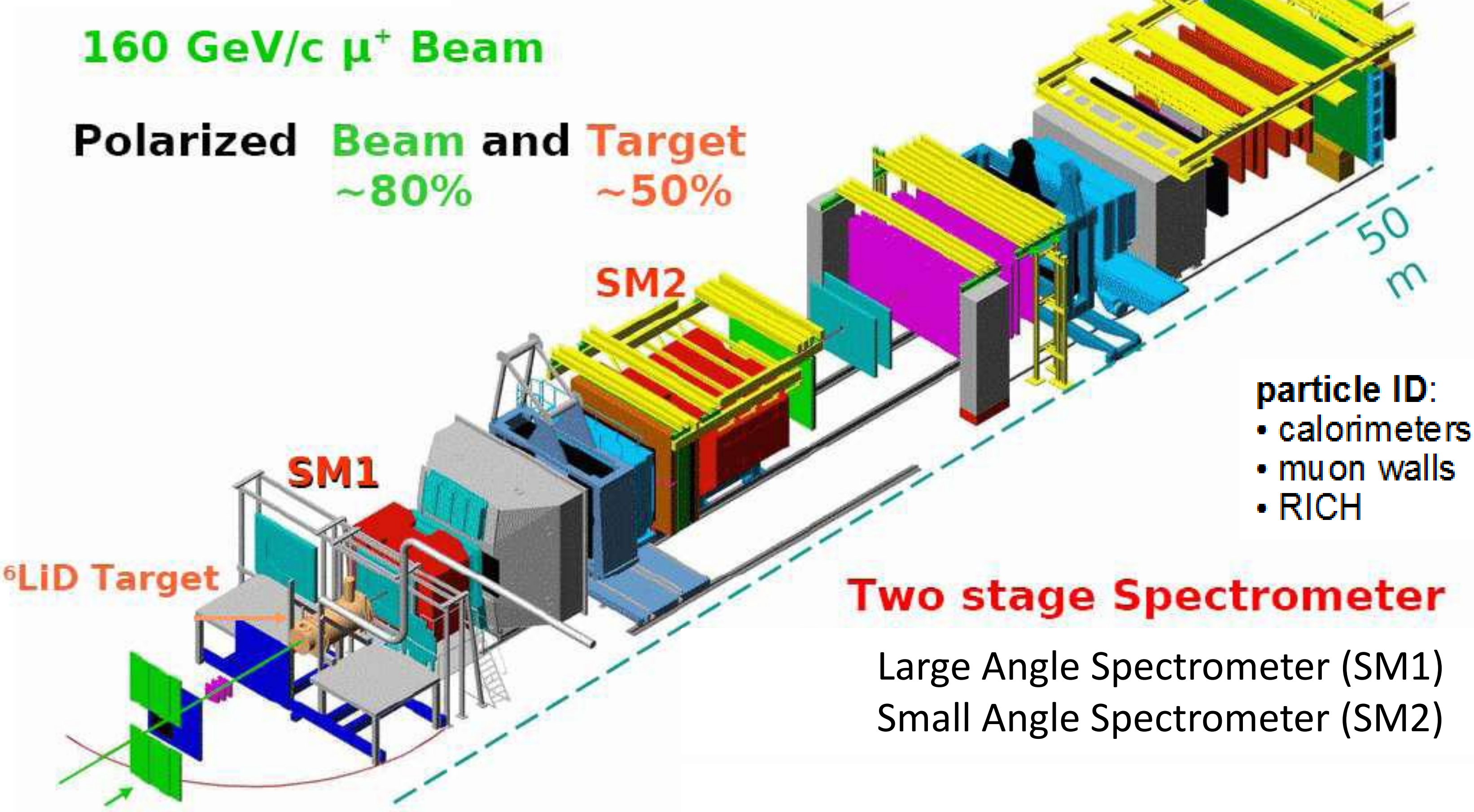
wide physics program carried on using both muon and hadron beam



This talk will focus on the results extracted from the 2004 data (longitudinally pol. muon beam, transversely pol. deuteron target)

The COMPASS experiment (2004 setup)

several tracking detectors of different type
- to cope with **high particle rates**
- to cover a **large angular acceptance** ~ 0-180 mrad



Large Angle Spectrometer (SM1)
Small Angle Spectrometer (SM2)

SIDIS: a key process to investigate the structure of the nucleon

lepton interacts with a **single constituent** of the nucleon (Q^2>1GeV^2/c^2)

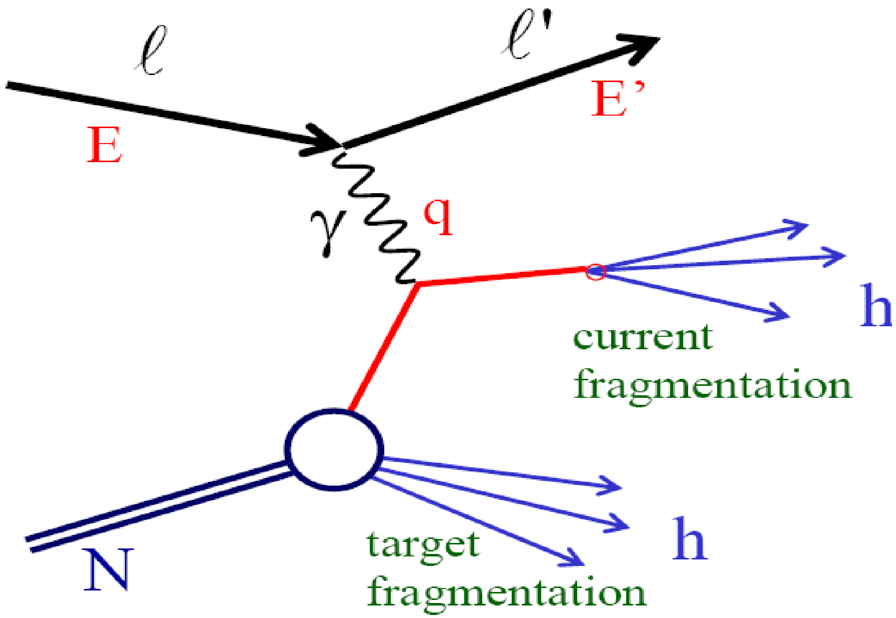
$$q = \ell - \ell'$$

$$Q^2 = -q^2 \qquad W^2 = (P+q)^2$$

$$x = \frac{Q^2}{2P \cdot q}$$ *Bjorken scaling variable*

$$y = \frac{P \cdot q}{P \cdot \ell} =_{LAB} \frac{E - E'}{E}$$

$$z = \frac{P \cdot P_h}{P \cdot q} =_{LAB} \frac{E_h}{E - E'}$$

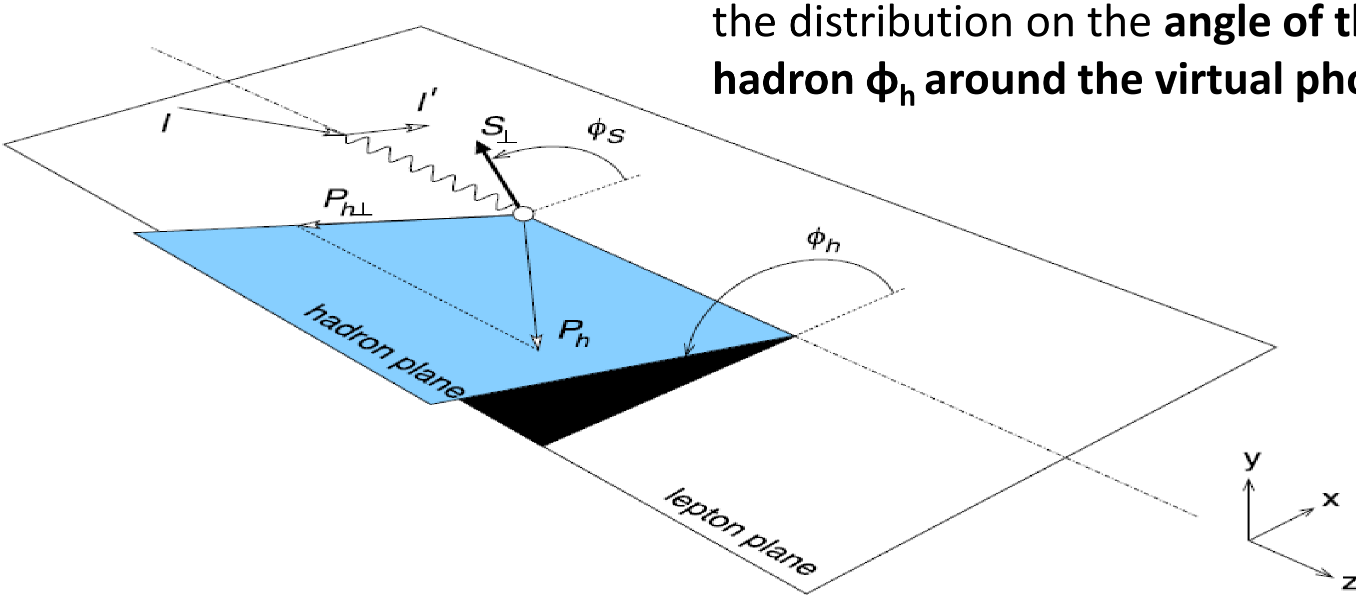


at least one hadron is detected in the final state
(information on the struck quark)

azimuthal asymmetries

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

3 independent azimuthal modulations on the distribution on the **angle of the hadron ϕ_h around the virtual photon direction**

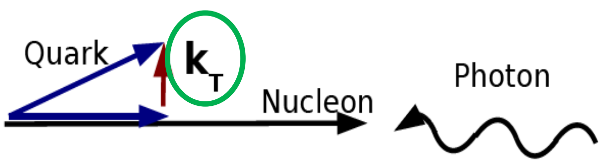


QPM **convolution on the** **TM of the quark** **between different PDFs and a FFs**

$$\sum_q e_q^2 f_q(x, k_\perp) \otimes D_q^h(z, p_\perp)$$

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

mainly **Cahn** effect: **kinematical effect** proportional to the **quark transverse momentum**



$$d\sigma^{lq\to lq} \propto \hat{s}^2 + \hat{u}^2 \propto \left(1 + \varepsilon_1 \frac{k_\perp}{Q} \cos\varphi\right)$$

Boer-Mulders (*T-odd !*) function, one of the most famous **TMD PDF**, convoluted with the **Collins FF**

the **Boer-Mulders function correlates** the **quark transverse momentum** and the **quark spin** in an **unpolarized nucleon**

higher twist effect proportional to beam polarization

no clear interpretation in terms of PM

QPM **convolution on the TM of the quark between different PDFs and a FFs**

$$\sum_q e_q^2 f_q(x, k_\perp) \otimes D_q^h(z, p_\perp)$$

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

$$F^{\cos\phi_h}_{UU,\text{Cahn}} = \frac{2M}{Q} \mathcal{C}\left[-\frac{\hat{\mathbf{h}} \cdot \mathbf{k}_T}{M} f_1 D_1\right]$$

$$F^{\cos\phi_h}_{UU,\text{BM}} = \frac{2M}{Q} \mathcal{C}\left[-\frac{(\hat{\mathbf{h}} \cdot \mathbf{k}'_T)\, \mathbf{k}^2_T}{M_h M^2} h_1^\perp H_1^\perp\right]$$

$$F^{\cos 2\phi_h}_{UU,\text{BM}} = \mathcal{C}\left[-\frac{2(\hat{\mathbf{h}} \cdot \mathbf{k}_T)(\hat{\mathbf{h}} \cdot \mathbf{k}'_T) - \mathbf{k}_T \cdot \mathbf{k}'_T}{M M_h} h_1^\perp H_1^\perp\right]$$

$$F^{\cos 2\phi_h}_{UU,\text{Cahn}} = \frac{M^2}{Q^2} \mathcal{C}\left[\frac{2(\hat{\mathbf{h}} \cdot \mathbf{k}_T)^2 - \mathbf{k}^2_T}{M^2} f_1 D_1\right]$$

$$\langle \cos\phi_h \rangle = \frac{1}{Q}\,\text{Cahn} + \frac{1}{Q}\,\text{BM} \qquad \langle \cos 2\phi_h \rangle = \text{BM} + \frac{1}{Q^2}\,\text{Cahn}$$

different Q^2 dependencies

other higher twist effects ?

The **amplitudes of the 3 azimuthal modulations** have been **measured at COMPASS** separately for **positive and negative hadrons**, as functions of the kinematical variables **x,z** and $\mathbf{P^h_T}$ (transv. mom. of the hadron w.r.t. the virtual photon)

Basic idea of the method

• To measure those amplitudes from experimental data the **apparatus acceptance is needed** (unlike transverse spin asymmetries measurement)

• **for each bin** (k) in **x, z** and $\mathbf{P_T^h}$

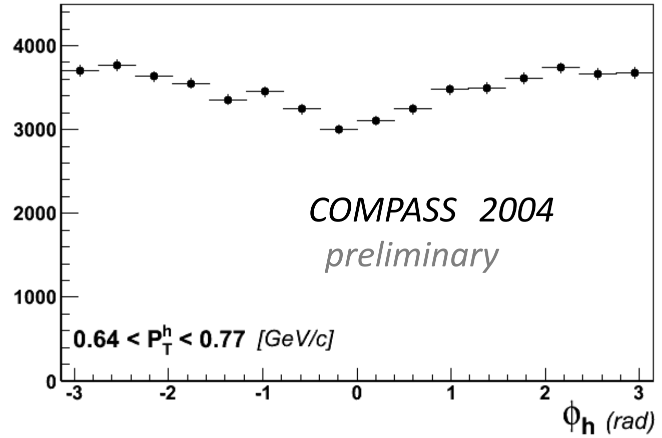
- The **measured azimuthal distributions** need to be **corrected** for the **apparatus acceptance** which may depend on ϕ_h

$$N_k^{corr}(\phi_h) = \frac{N_k(\phi_h)}{Acc_k(\phi_h)}$$

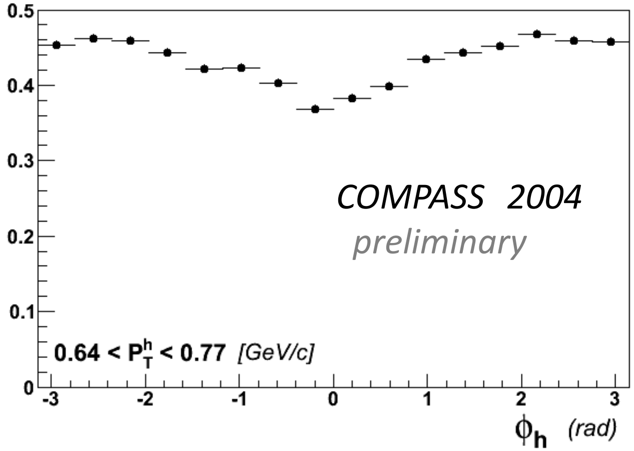
- Azimuthal acceptance calculated from **dedicated MC simulations**

$$Acc_k(\phi_h) = \frac{R_k^{mc}(\phi_h)}{G_k^{mc}(\phi_h)}$$

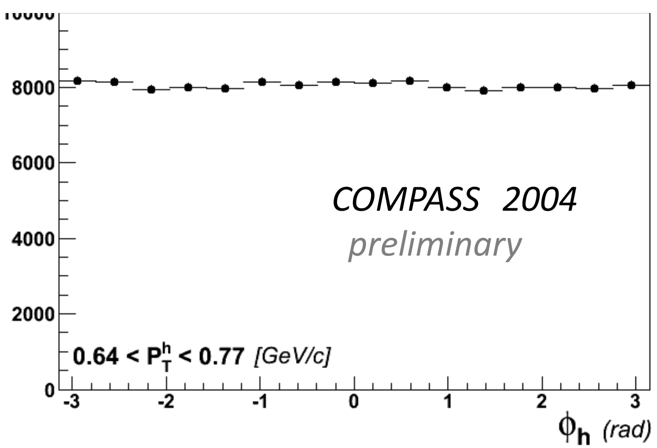
MC rec. azimuthal distribution



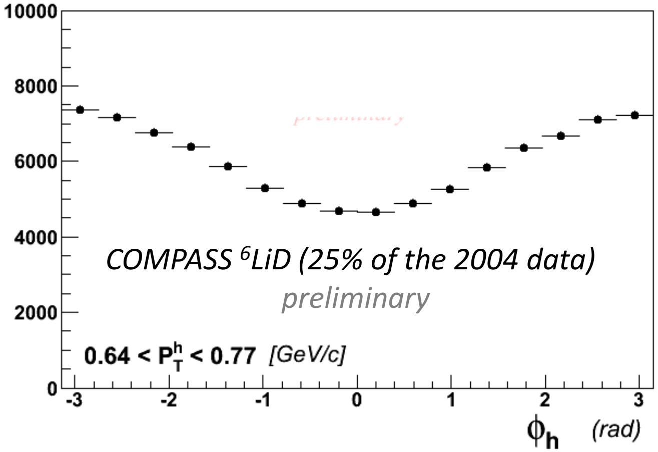
azimuthal acceptance



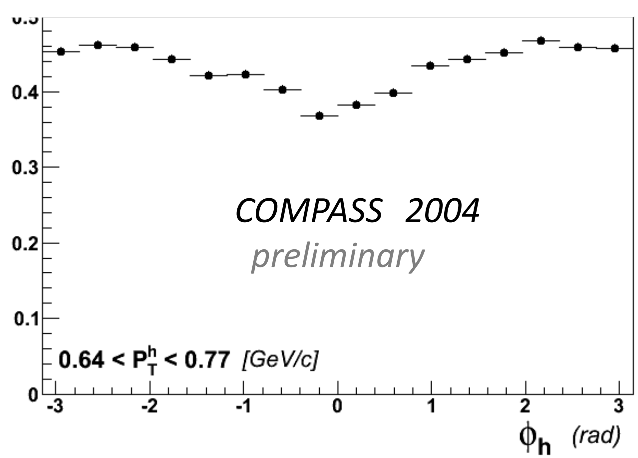
MC gen. azimuthal distribution



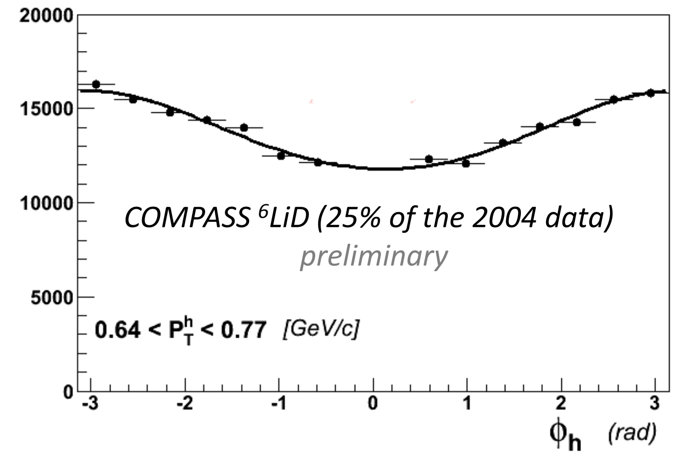
measured azimuthal distribution



azimuthal acceptance



measured azimuthal distributions corrected by the acceptance

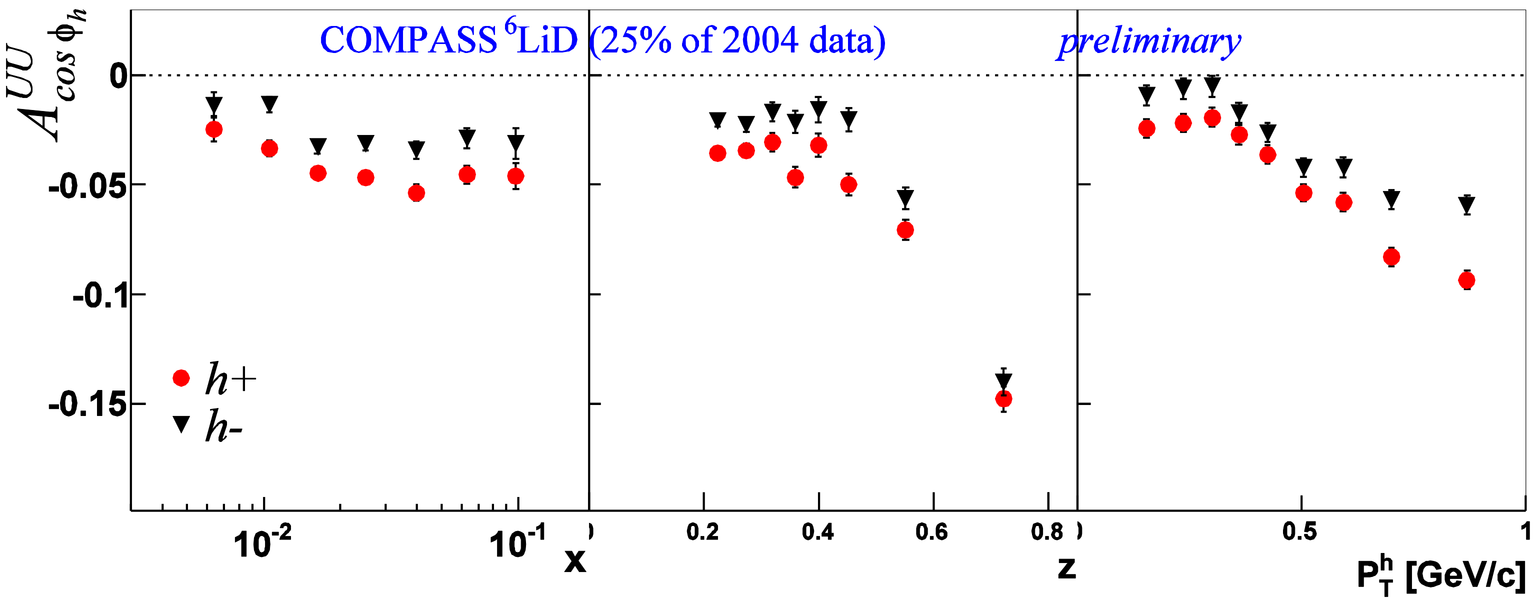


amplitudes extracted with a fit:

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

Results extracted binning alternatively in x, z and P_T^h

shown
at SPIN2010



sys ≈ 2 · stat

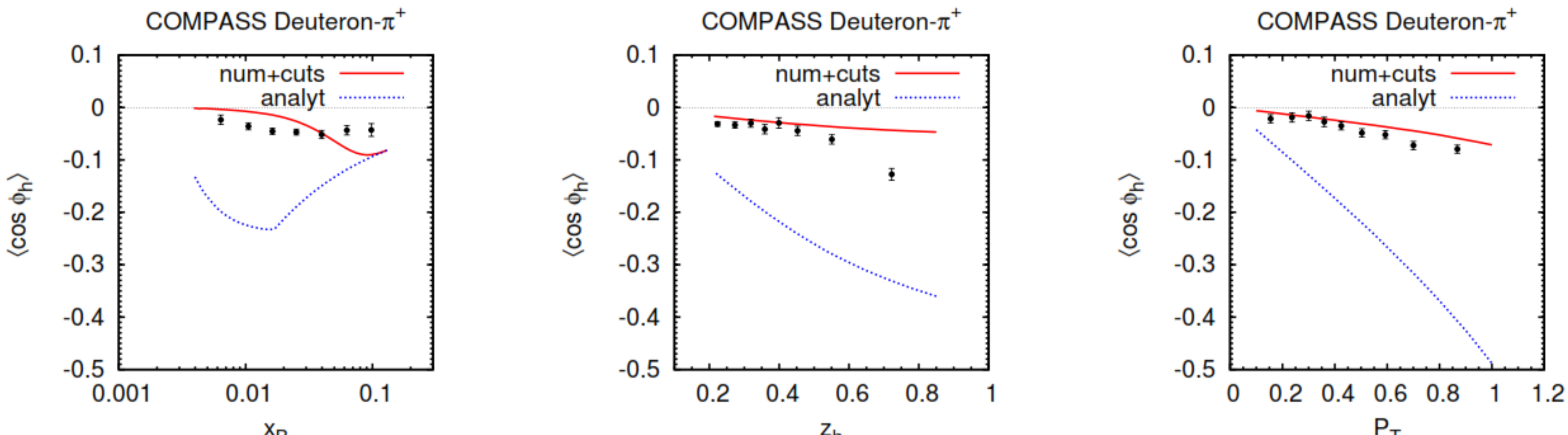
$$\langle \cos\phi_h \rangle = \frac{1}{Q}\,\text{Cahn} + \frac{1}{Q}\,\text{BM}$$

strong z dependence, for z > 0.5

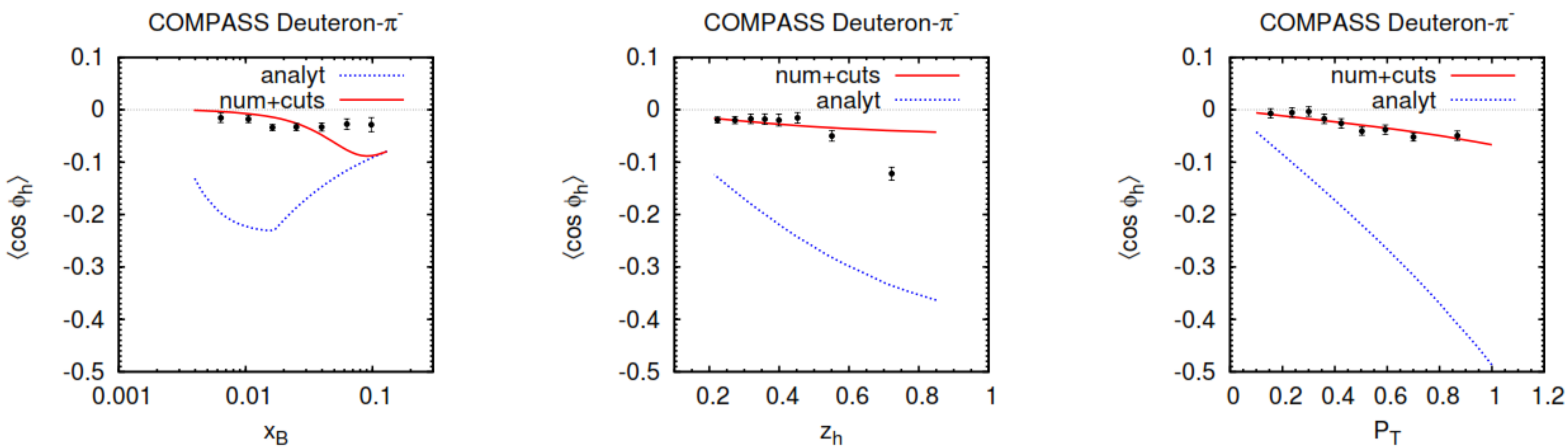
important input to phenomenological predictions

kinematical cuts had to be introduced for the quark intrinsic transverse momentum

$$f_{q/p}(x,k_\perp) = f_{q/p}(x)\,\frac{1}{1-e^{-(k_\perp^{\max})^2/\langle k_\perp^2\rangle}}\,\frac{e^{-k_\perp^2/\langle k_\perp^2\rangle}}{\pi\langle k_\perp^2\rangle}$$

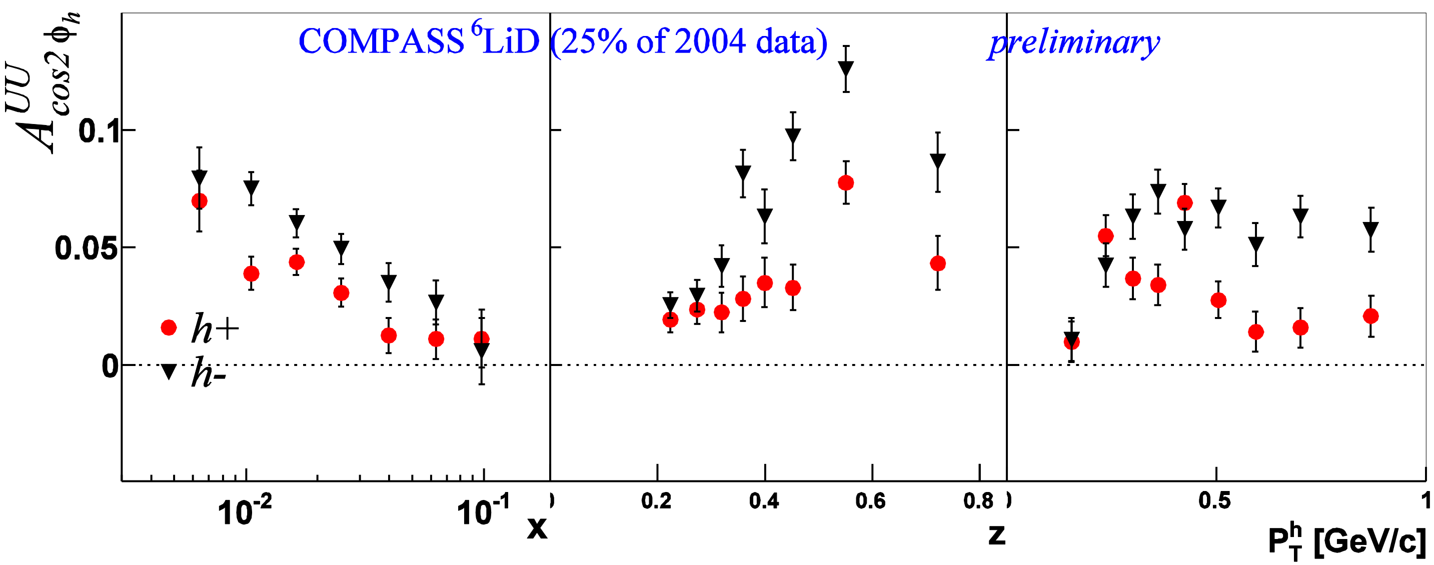


*PRD**84** (Boglione, Melis, Prokudin)*



Results extracted binning alternatively in x, z and P_T^h

shown at SPIN2010



sys ≈ 2 · stat

$$\langle \cos 2\phi_h \rangle = \mathsf{BM} + \frac{1}{Q^2}\,\mathsf{Cahn}$$

P_T^h dependence difficult to reproduce (PRD81, Barone,Melis,Prokudin) waiting for the curve in PT …

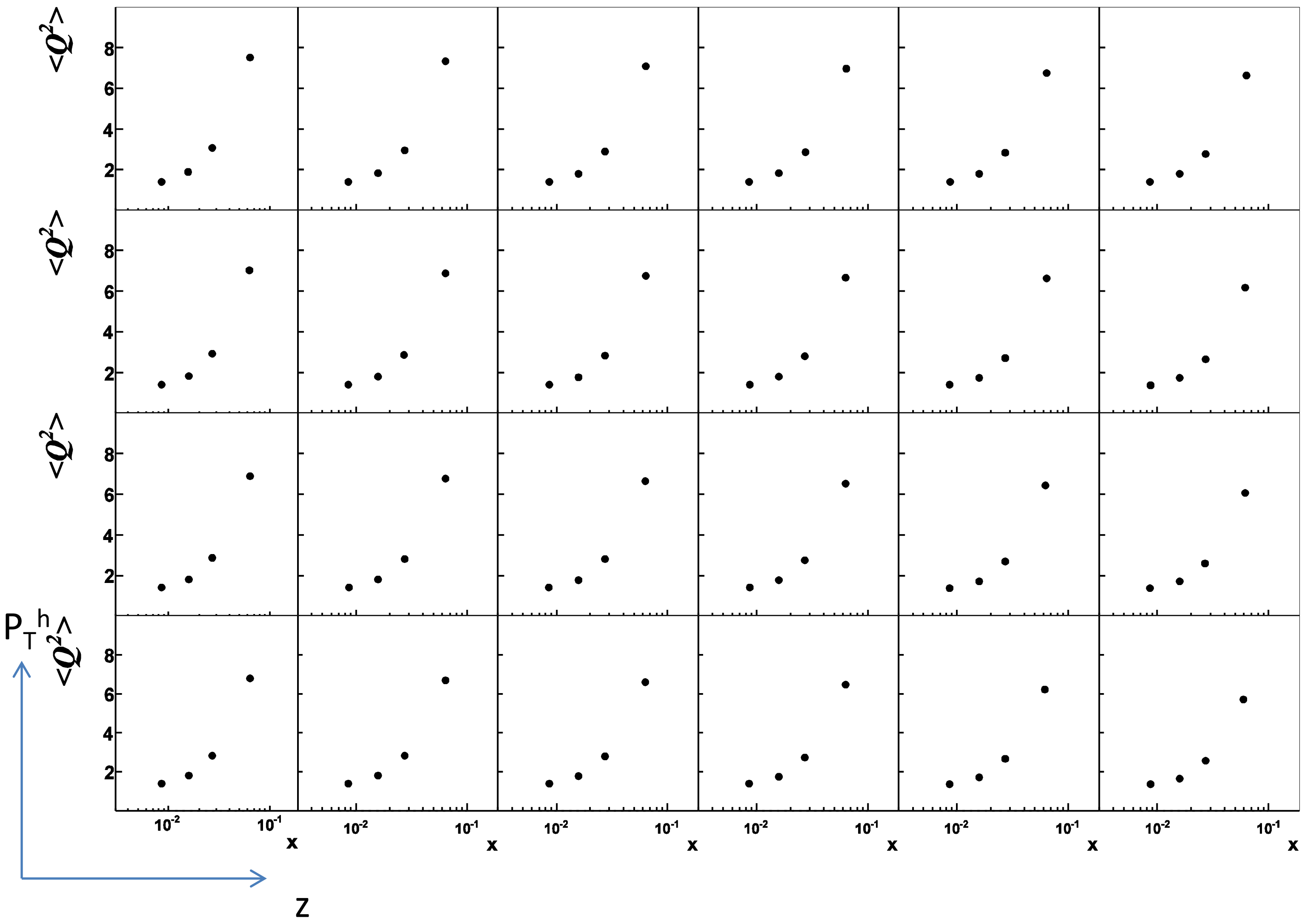
to better understand the interesting and unexpected kinematical dependencies found

a multi dimensional analysis has been done

binning simultaneously in x, z and P_T^h

Multi dimensional extraction:

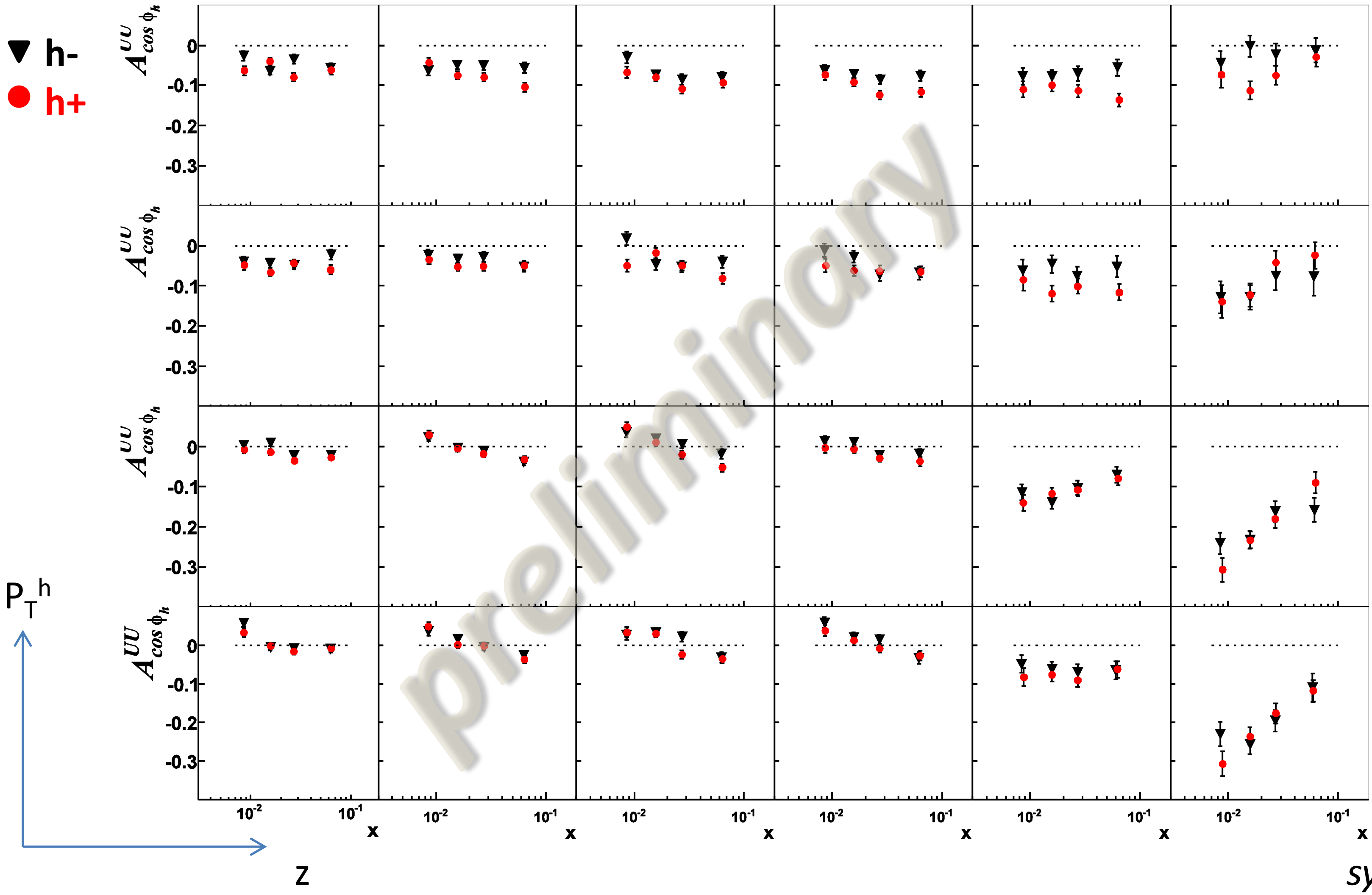
x	P_T^h	z
0.003 - 0.012	0.1 - 0.3	0.2 - 0.25
0.012 - 0.02	0.3 - 0.5	0.25 - 0.32
0.02 - 0.038	0.5 - 0.64	0.32 - 0.40
0.038 - 0.13	0.64 - 1.0	0.40 - 0.55
		0.55 - 0.70
		0.70 - 0.85



Results for

$$A_{\cos\phi_h}^{UU}$$

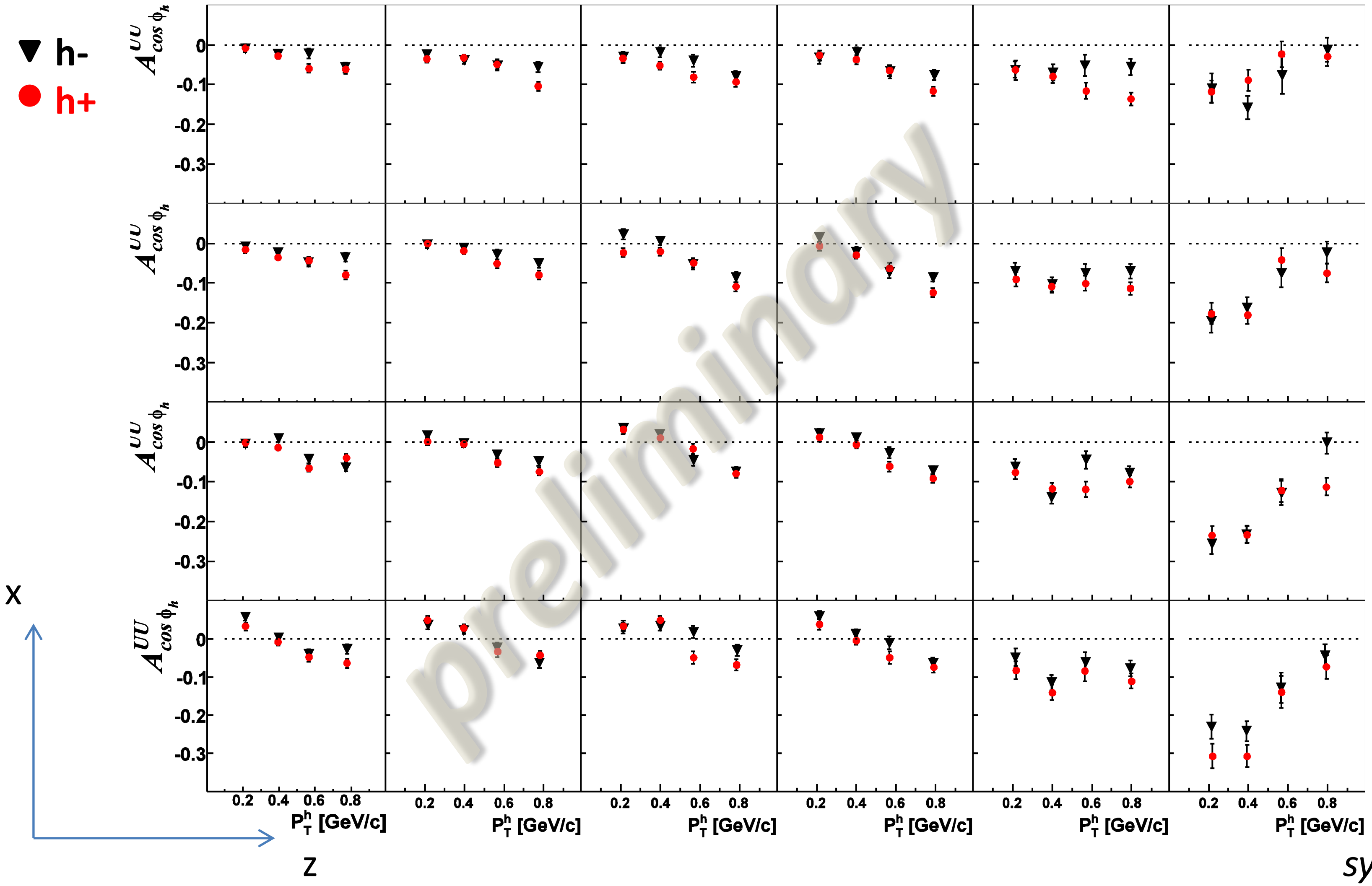
COMPASS ^{6}LiD (25% of 2004 data)



sys ≈ 2 · stat

largest difference between positive and negative hadrons at large P_T^h
x trend changes going from small to large z values

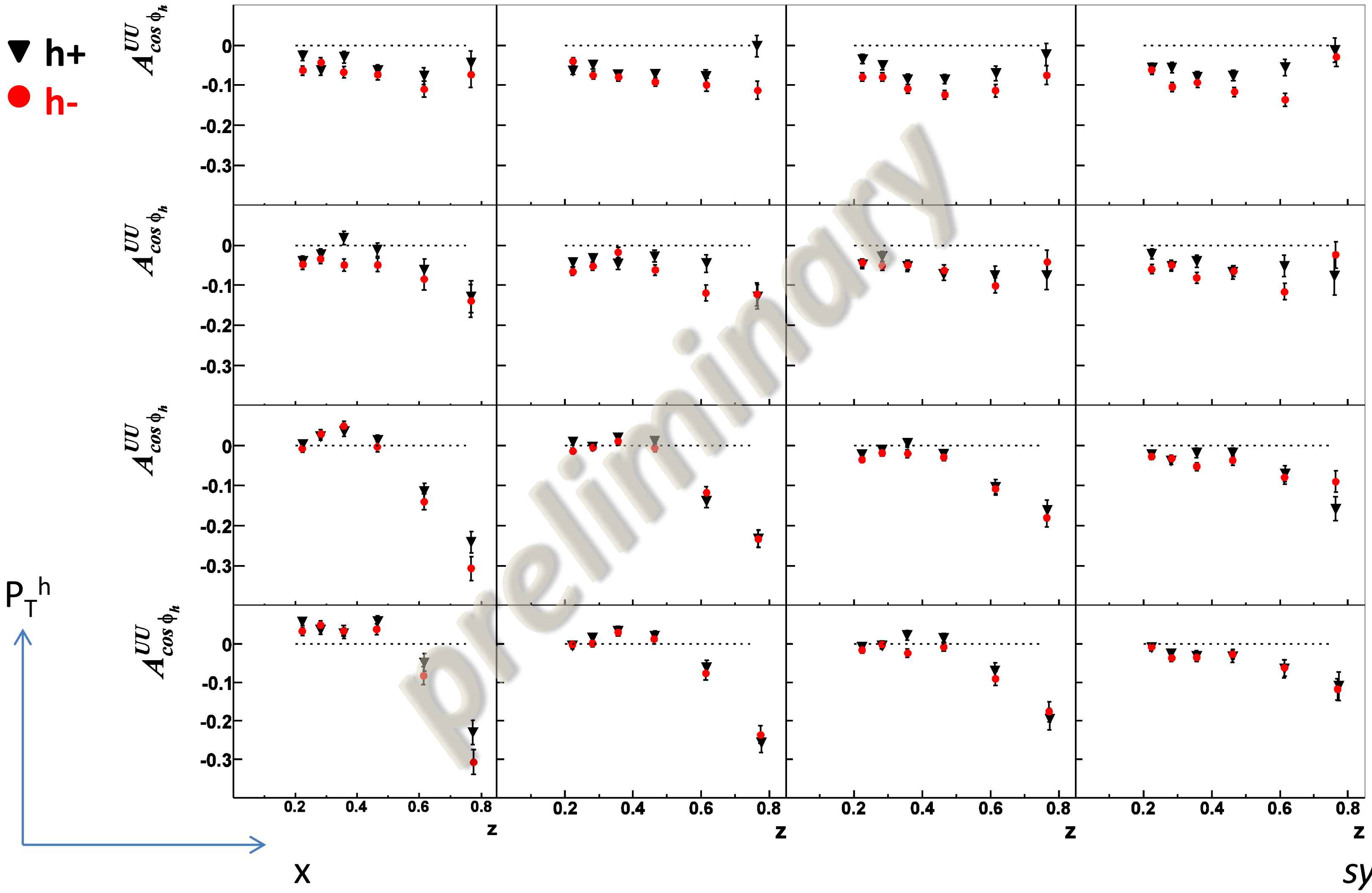
COMPASS ^{6}LiD (25% of 2004 data)



sys ≈ 2 · stat

$P_T{}^h$ trend changes going from small to large z values
and it is roughly the same for all x intervals

COMPASS ^{6}LiD (25% of 2004 data)



sys ≈ 2 · stat

z strong dependence more evident at small x and small P_T^h

Results for

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

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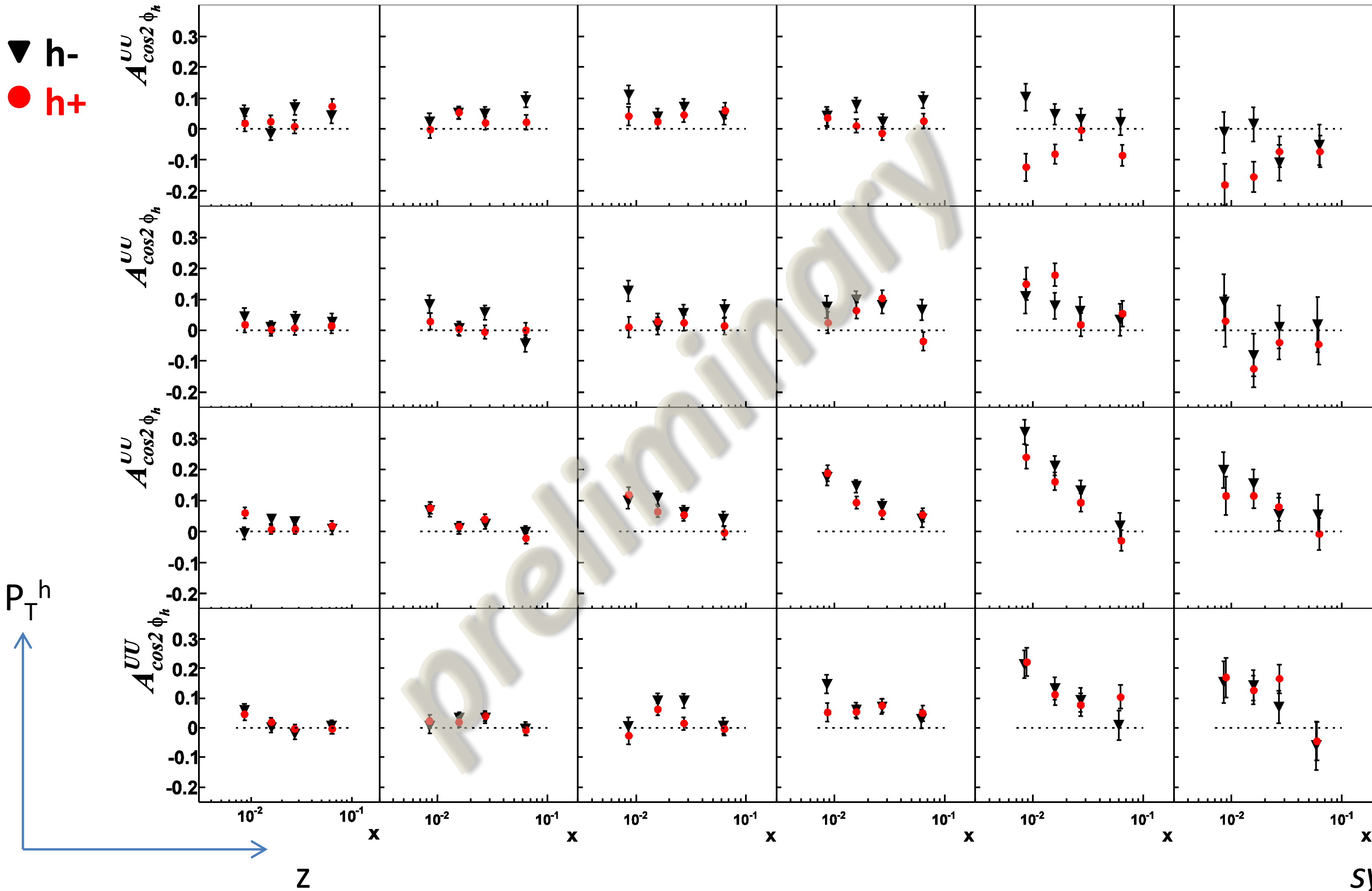
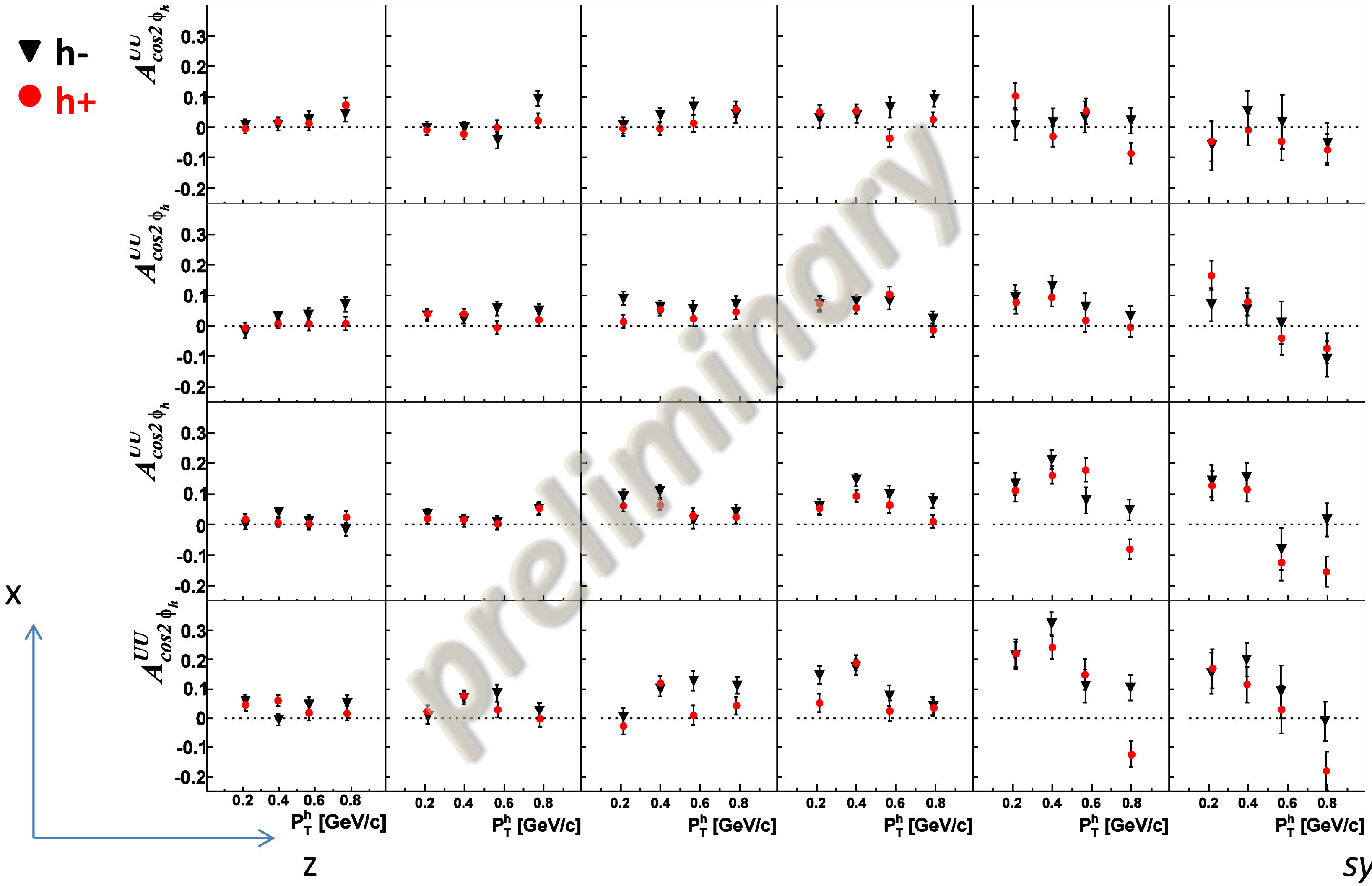


sys ≈ 2 · stat

x trend changes from small to large z values

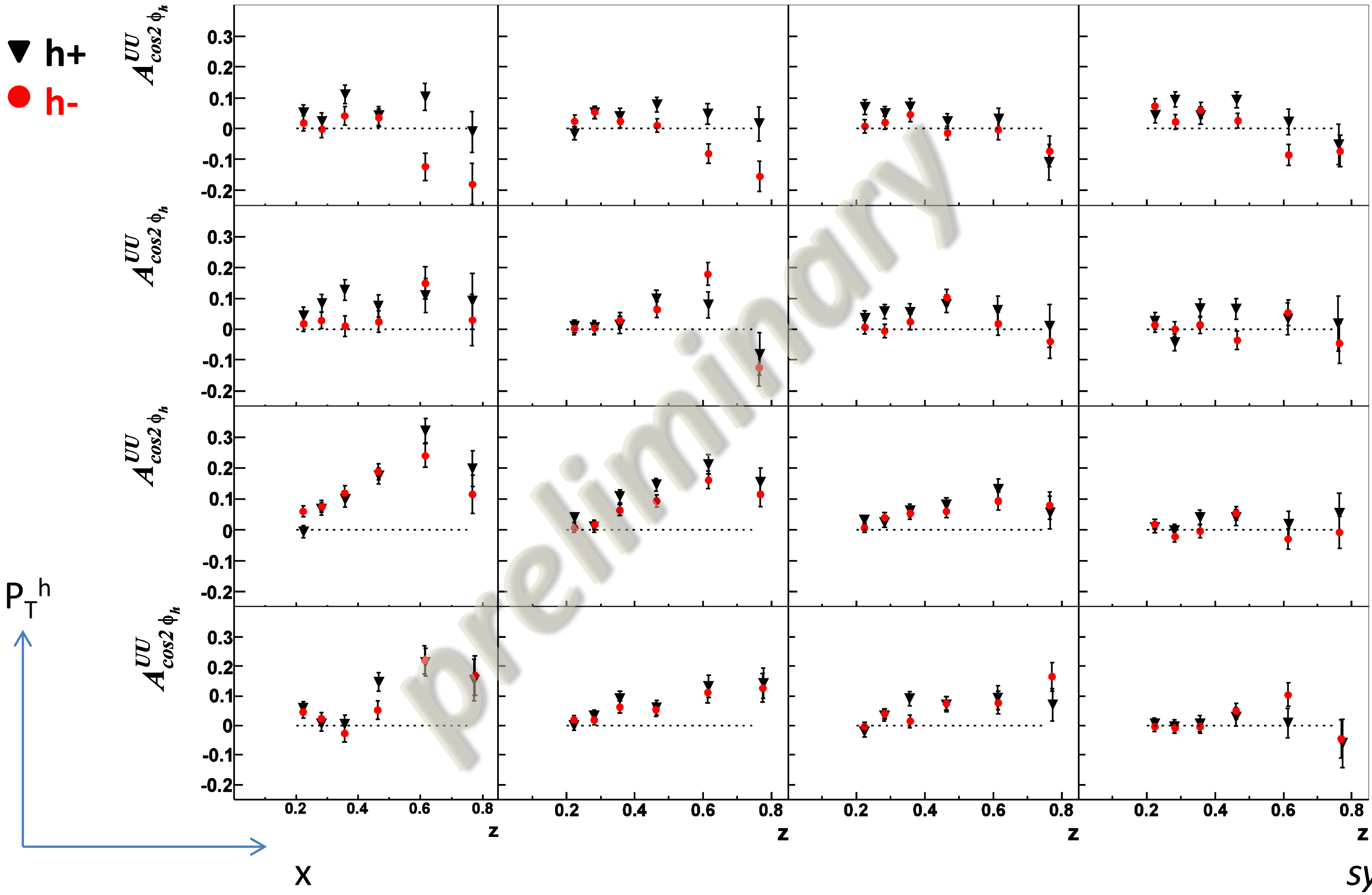
COMPASS ^{6}LiD (25% of 2004 data)



sys ≈ 2 · stat

the $P_T{}^h$ trend difficult to reproduce by models is there for large z and low x

COMPASS ^{6}LiD (25% of 2004 data)



sys ≈ 2 · stat

strongest effect at low x and low P_T^h

Summary and outlook

- kinematical dependencies investigated in the x, z and P_T^h grid

  → complex picture

- the strong z dependence seems to come from the small x and small P_T^h region
- x trends clearly change going at large z values ($z > 0.5$)
- the interpretation of the results must also take into account the correlation between x and Q^2
- interesting inputs for theory
- new measurement of the unpolarized azimuthal asymmetries at COMPASS II in parallel to DVCS, starting from 2015

backup

Full MC chain to reproduce apparatus acceptance:

- LEPTO (generator, CTEQ5L PDF)
- COMGEANT (dedicated software to simulate the spectrometer)
- CORAL (same software used for the event reconstruction)

SIDIS cuts applied

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

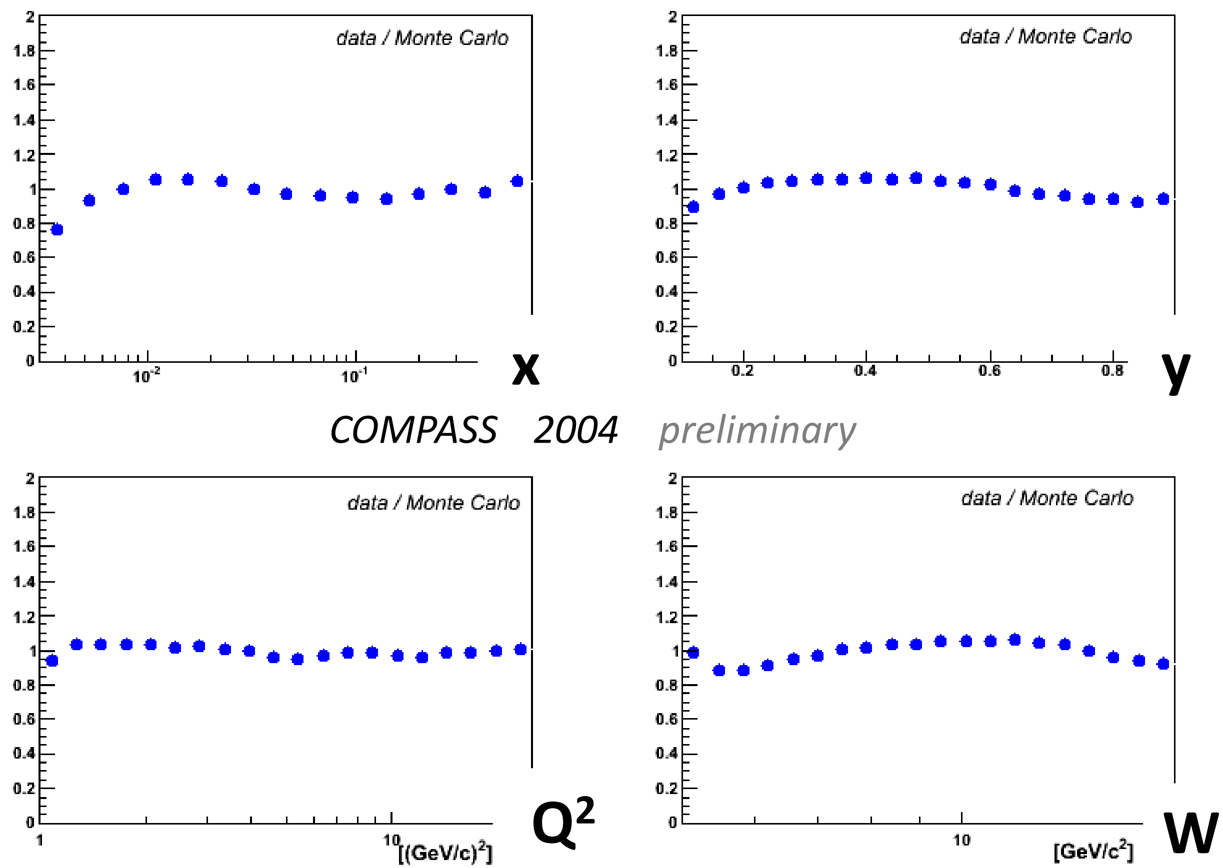
$0.1 < y < 0.9$

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

$0.2 < z < 0.85$

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

DATA / MONTE CARLO DIS variables



overall good agreement between real data and MC is a check on the reliability of the MC description (no absolute normalization needed)

SIDIS cuts applied

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$W > 5\ GeV/c^2$

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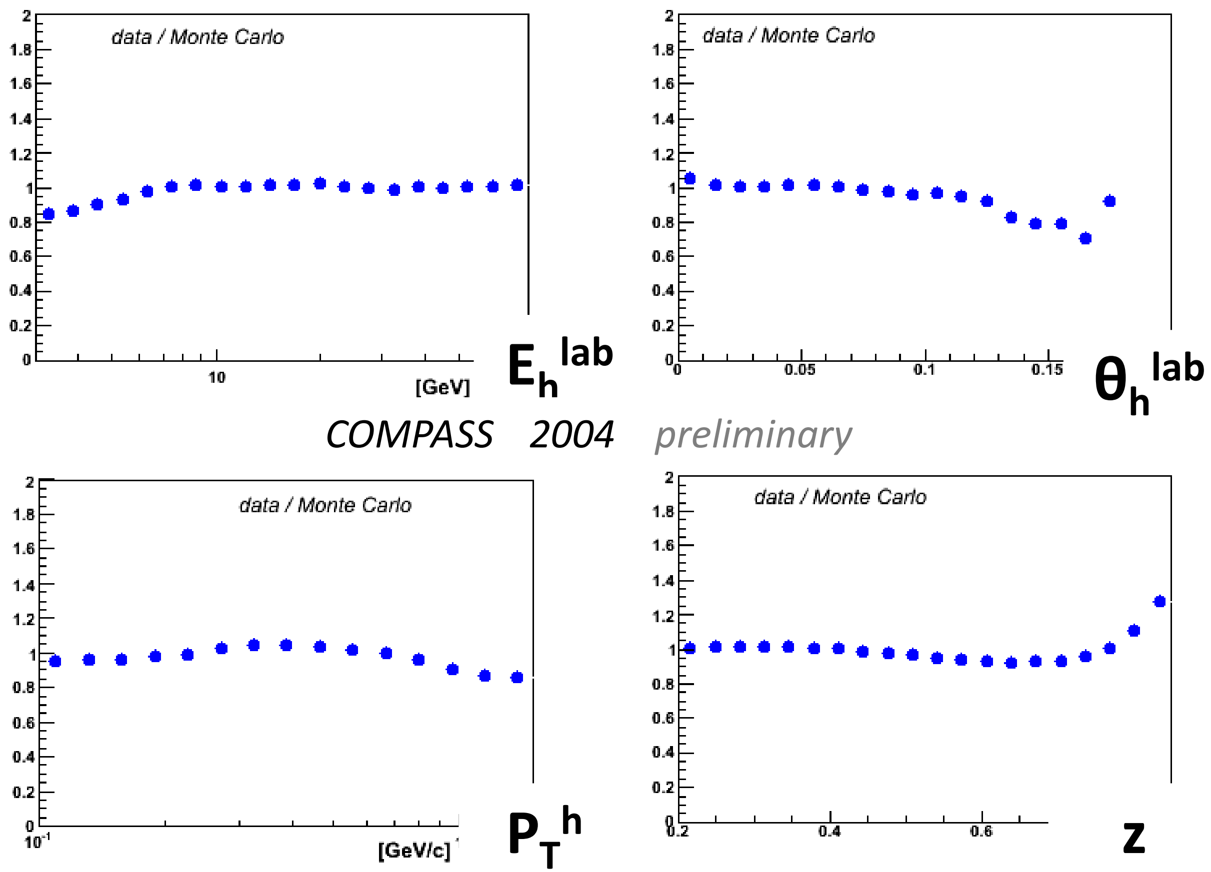
$P^T_h > 0.1\ GeV/c$

DATA / MONTE CARLO

Hadron variables



Many checks done on the reliability of the results and on the systematics

- acceptance corrections < 20%
- compatibility with the 1D results
- study of the possible detectors/triggers acceptance effects
- results obtained using different MC

asymmetries extracted using

different MC (different Lepto tunings)
produced to have different kinematical distributions
describing reasonably well the data
and used to calculate the acceptance

main contribution to the systematic error $sys \approx 2 \cdot stat$

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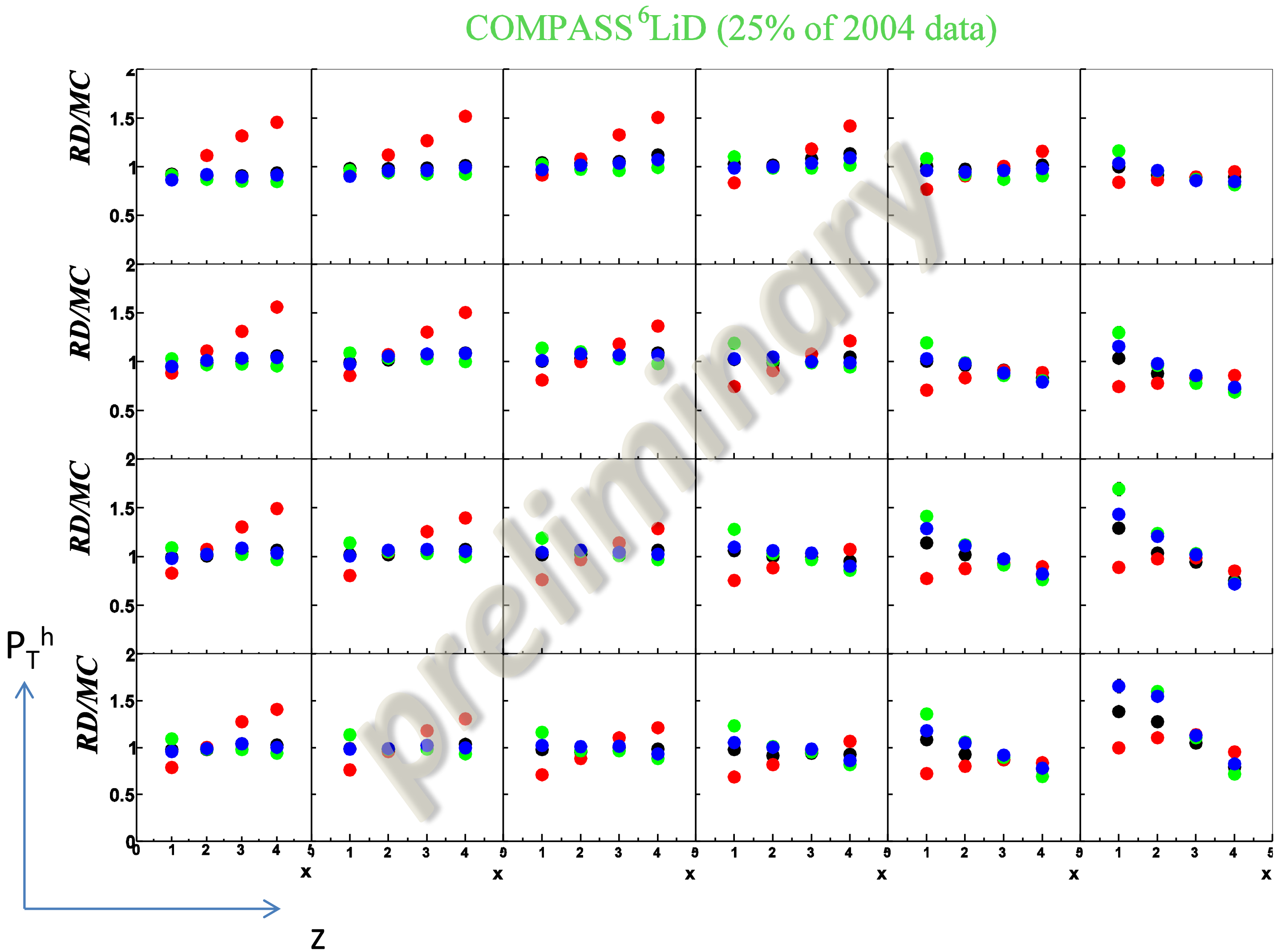

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