Measurements of azimuthal asymmetries in SIDIS on unpolarized protons

Andrea Moretti

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on behalf of the COMPASS Collaboration

Content of this talk

- Unpolarized SIDIS at COMPASS
- Azimuthal asymmetries in SIDIS
- Overview of previous results
- A look at new COMPASS data
- Conclusions and perspectives

Unpolarized SIDIS at COMPASS

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- $\ell N \rightarrow \ell' h X$: one hadron detected in coincidence with the scattered lepton in the final state.

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$M(z, P_T^{h\,2})$

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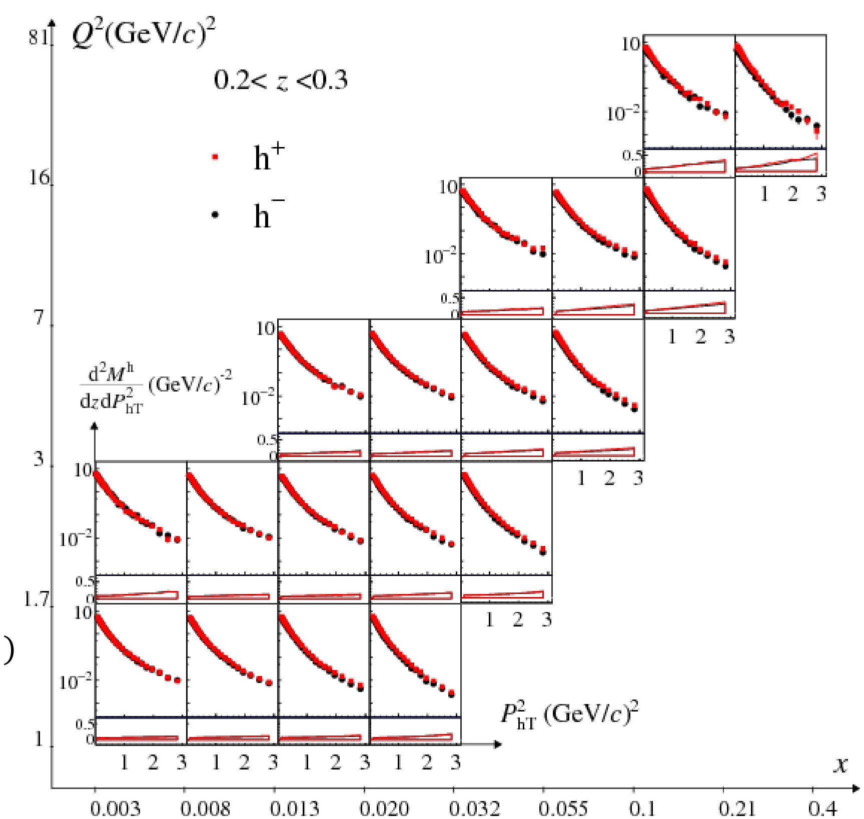
see F. Kunne's talk (focused on K^+ / K^-)

Multiplicities $(z, P_T^{h\,2})$ with deuteron target
[COMPASS Coll., Phys. Rev. D **97**, 032006, 2018]
Here, e.g., multiplicities in a selected z bin, as function of $P_T^{h\,2}$, for different regions of x and Q^2.



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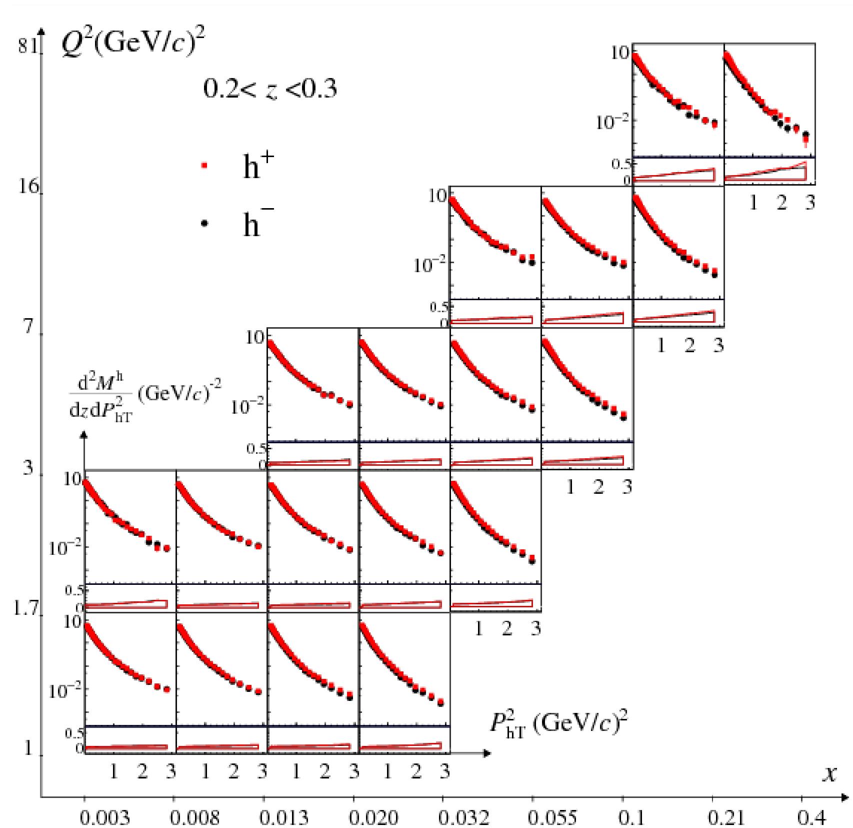


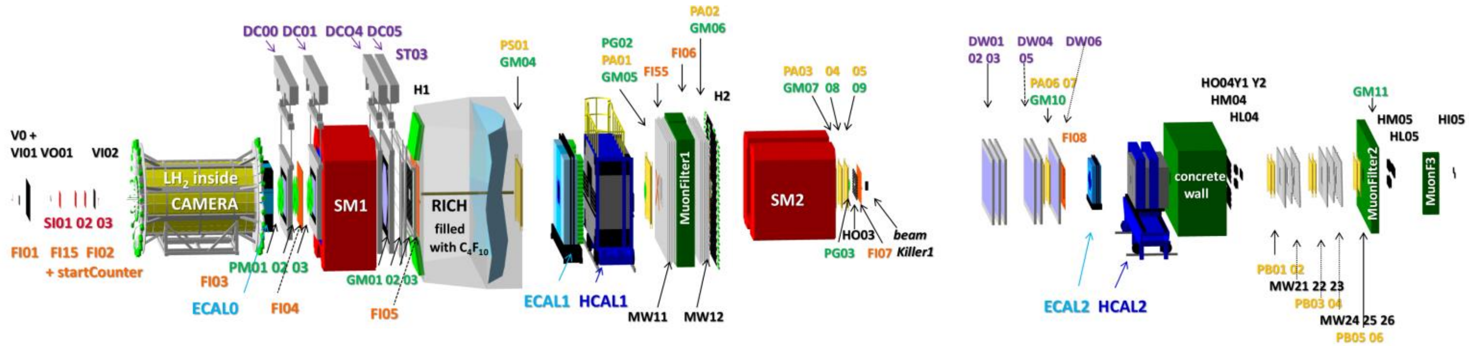
TWO MAIN EXPERIMENTAL OBSERVABLES

MULTIPLICITIES
$M(z, P_T^{h\,2})$

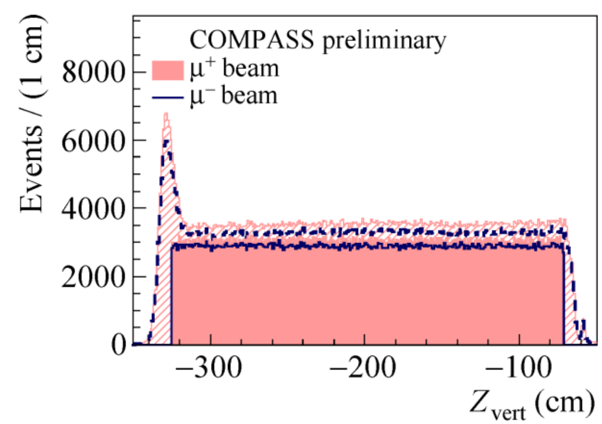
AZIMUTHAL ASYMMETRIES
$A_{XU}^{f(\phi_h)}(x, z, P_T^h)$

this talk

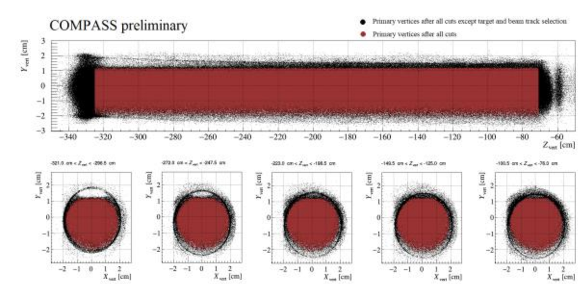
The 2016-2017 COMPASS runs



- Main goal of the 2016 and 2017 runs in COMPASS: access GPDs via the **Deeply Virtual Compton Scattering** (see A. Ferrero's talk).
- 160 GeV/c μ beam (μ^+ and μ^- with balanced statistics)
- In parallel, SIDIS data were collected
  → multiplicities, azimuthal asymmetries



- Target: liquid hydrogen 2.5 m long
- Unpolarized, one cell
- Very good resolution on the position of the primary vertices
- Target holder and exit windows well visible (but removed with proper cuts)



Azimuthal asymmetries in SIDIS

Azimuthal asymmetries

Differential cross section for the production of a hadron h in unpolarized DIS:

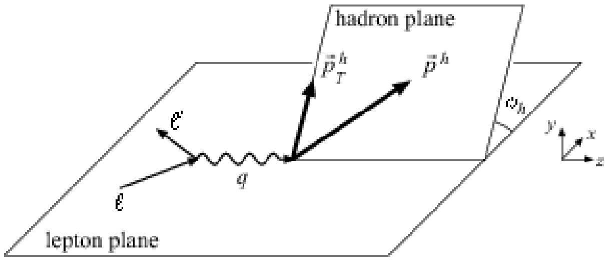
$$\frac{d\sigma}{P_T^h dP_T^h dx\, dy\, dz\, d\phi_h} = \sigma_0 (1 + \epsilon_1 A_{UU}^{\cos\phi_h} \cos\phi_h + \epsilon_2 A_{UU}^{\cos 2\phi_h} \cos 2\phi_h + \lambda \epsilon_3 A_{LU}^{\sin\phi_h} \sin\phi_h)$$

- $A_{UU}^{\cos\phi_h}$, $A_{UU}^{\cos 2\phi_h}$ and $A_{LU}^{\sin\phi_h}$ are ratios of azimuthal angle-dependent structure functions with the unpolarized part of the cross section
- λ is the beam polarization
- ϵ_i are kinematic factors:

$$\epsilon_1 = \frac{2(2-y)\sqrt{1-y}}{1+(1-y)^2},$$

$$\epsilon_2 = \frac{2(1-y)}{1+(1-y)^2},$$

$$\epsilon_3 = \frac{2y\sqrt{1-y}}{1+(1-y)^2}$$



RELEVANCE OF AZIMUTHAL ASYMMETRIES FOR

- THE EXTRACTION OF BOER-MULDERS TMD
- THE EVALUATION OF INTRINSIC QUARK TRANSVERSE MOMENTUM

[Anselmino et al. Phys.Rev. D71 (2005) 074006]
[Barone et al. Phys.Lett. B632 (2006) 277-281]
[Boglione et al., Phys. Rev. D84 (2011) 034033]

Azimuthal asymmetries

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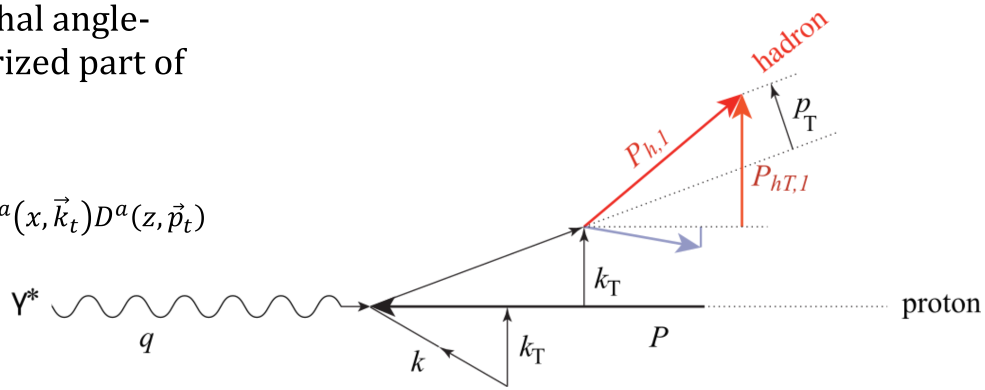
$$C[wfD] = x \sum_a e_a^2 \int d^2 \vec{k}_t \int d^2 \vec{p}_t \delta^2(\vec{k}_t + \vec{q}_t - \vec{p}_t) w(\vec{k}_t, \vec{p}_t) f^a(x, \vec{k}_t) D^a(z, \vec{p}_t)$$

$$\hat{h} = \vec{P}_{hT} \, / \, |\vec{P}_{hT}|$$



Boer-Mulders TMD

$$A_{UU}^{\cos 2\phi_h} = \frac{F_{UU}^{\cos 2\phi_h}}{\mathrm{F}_{\mathrm{UU,T}} + \epsilon F_{UU,L}} \propto C\left[-\frac{2(\hat{h} \cdot \vec{k}_T)(\hat{h} \cdot \vec{p}_T) - \vec{k}_T \cdot \vec{p}_T}{M\, M_h} h_1^\perp H_1^\perp \right]$$

$$A_{UU}^{\cos\phi_h} = \frac{F_{UU}^{\cos\phi_h}}{\mathrm{F}_{\mathrm{UU,T}} + \epsilon F_{UU,L}} \propto \frac{2M}{Q} C\left[-\frac{(\hat{h} \cdot \vec{p}_T) k_T^2}{M^2 M_h} h_1^\perp H_1^\perp - \frac{(\hat{h} \cdot \vec{k}_T)}{M} f_1 D_1 \right]$$

Boer-Mulders TMD

Cahn effect

Overview of previous results

Previous measurements

Azimuthal asymmetries measured at COMPASS, HERMES and CLAS in different kinematic ranges:

- At COMPASS with a 160 GeV/c μ^+ beam and solid LiD (deuterated Lithium) target.
- At HERMES with 27 GeV /c $e^{\pm}$ beam and gaseous hydrogen/deuteron target. PID
- At CLAS, particular attention to $A_{LU}^{\sin\phi_h}$, more coming from CLAS12

[COMPASS Coll., 10.1016/j.nuclphysb.2014.07.019]

[HERMES Coll., 10.1103/PhysRevD.87.012010]

[CLAS Coll., PoS DIS2016 (2016) 215]

Evidence of strong kinematic dependencies, still not well understood.

↓

Possibility to use new COMPASS data to investigate the subject with better statistics and systematics.

COMPASS results for azimuthal asymmetries on deuteron

Azimuthal asymmetries from COMPASS data, collected with **deuteron target**, with two approaches:

- **1D analysis**
  (separately in bins of x, z, P_T^h)

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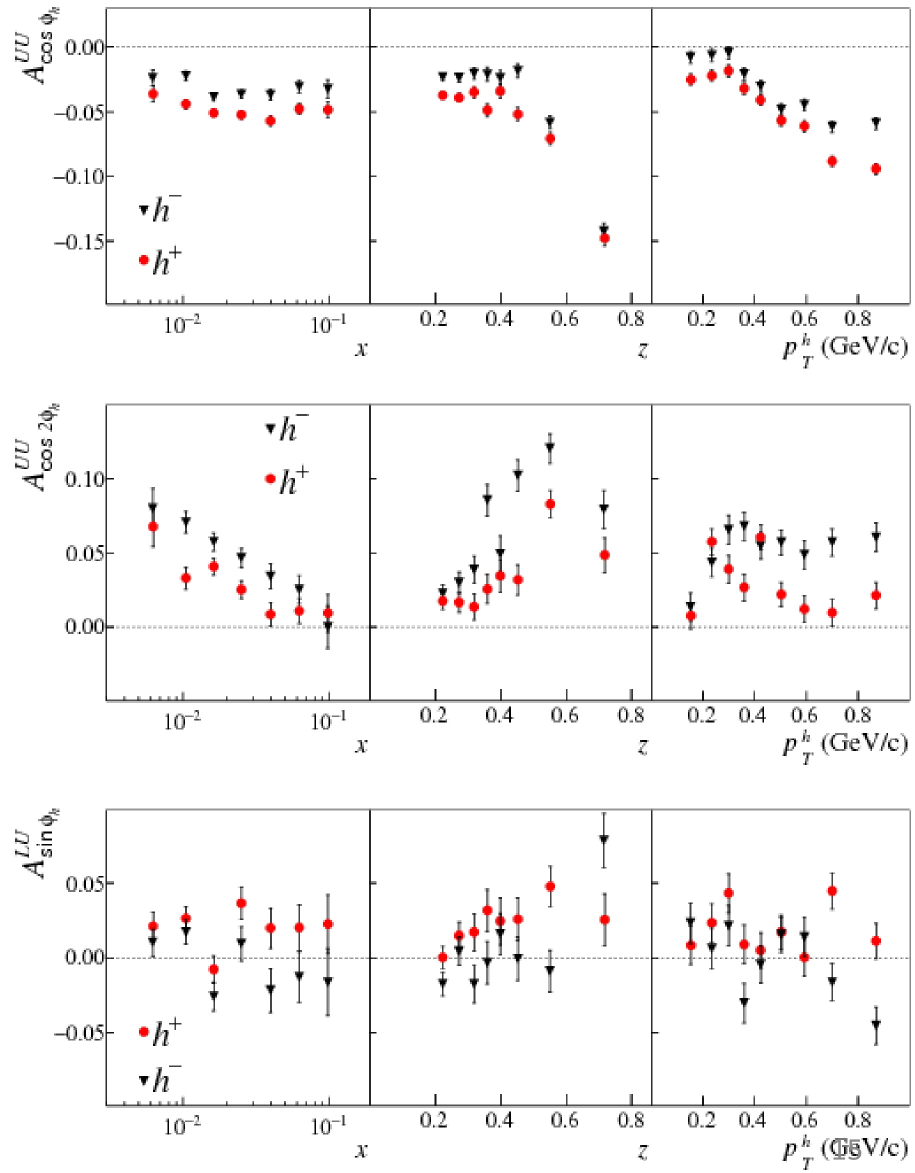

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Azimuthal asymmetries from COMPASS data, collected with **deuteron target**, with two approaches:

- **1D analysis**
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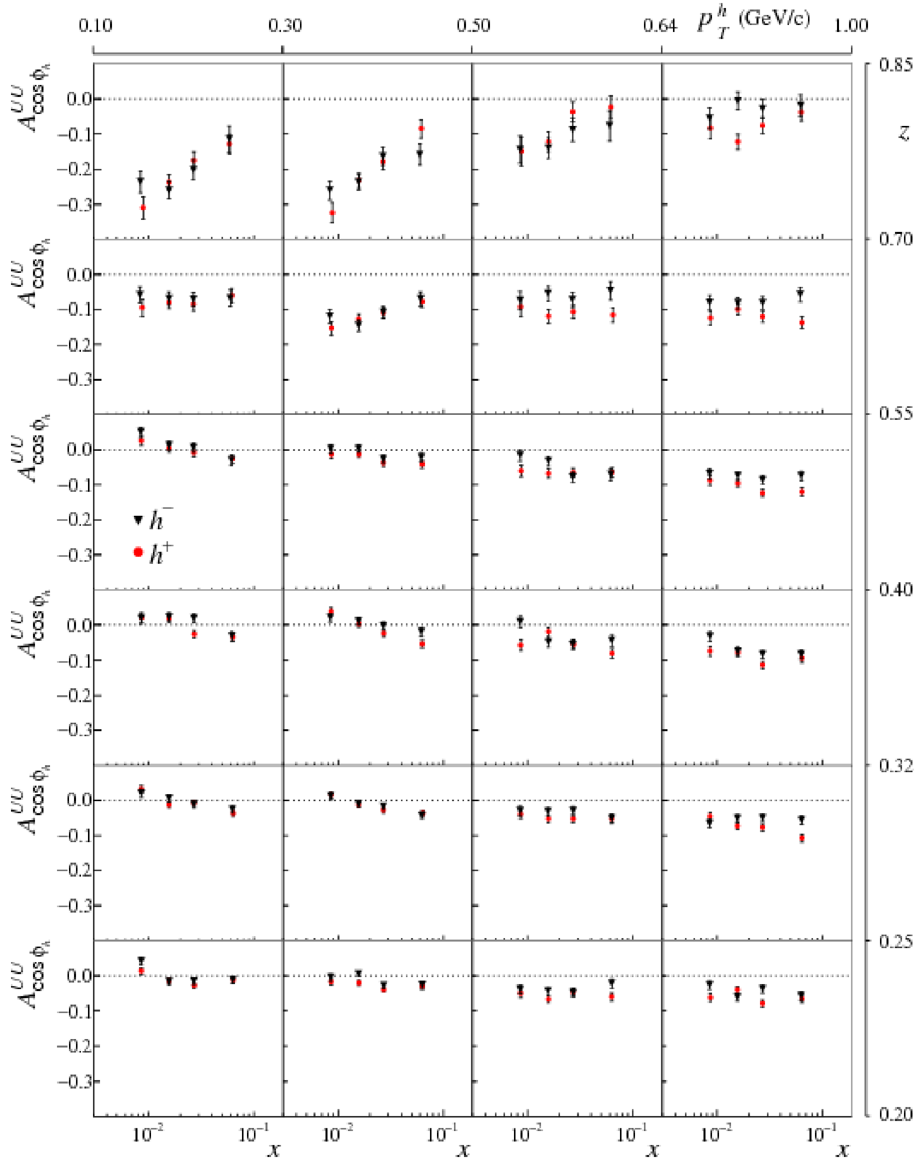
- **3D analysis**
  (simultaneously binning the three variables).

Here $\boldsymbol{\cos\phi_h}$, but also $\cos 2\phi_h$ and $\sin\phi_h$ asymmetries have been measured.

Remarkable kinematic dependencies (e.g. $\cos\phi_h$ at large z) still not well explained.

[COMPASS Coll., 10.1016/j.nuclphysb.2014.07.019]



A look at new COMPASS data

Selection of DIS events and hadrons

Here: Analysis of part of 2016 (1 period out of 12+9) with the same procedure as old analysis.

DIS events selection:

- $Q^2 > 1\ (\mathrm{GeV/c})^2$
- $\mathrm{W} > 5\ (\mathrm{GeV/c^2})$
- $0.2 < y < 0.9$
- $0.003 < x < 0.130$ → 7 bins

Hadron selection:

- $0.2 < z < 0.85$ → 8 bins
- $0.1\ (\mathrm{GeV/c}) < P_T^h < 1.0\ (\mathrm{GeV/c})$ → 9 bins

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Hadrons in the considered period: (approx.)

	μ^+ beam	μ^- beam
h^+	269 000	254 000
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h^+/h^-	1.24	1.27

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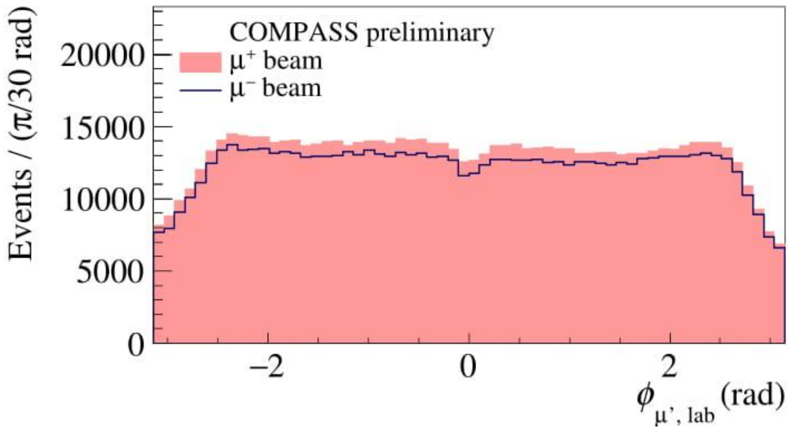

Remarkably good acceptance in $\phi_{\mu'}^{lab}$.

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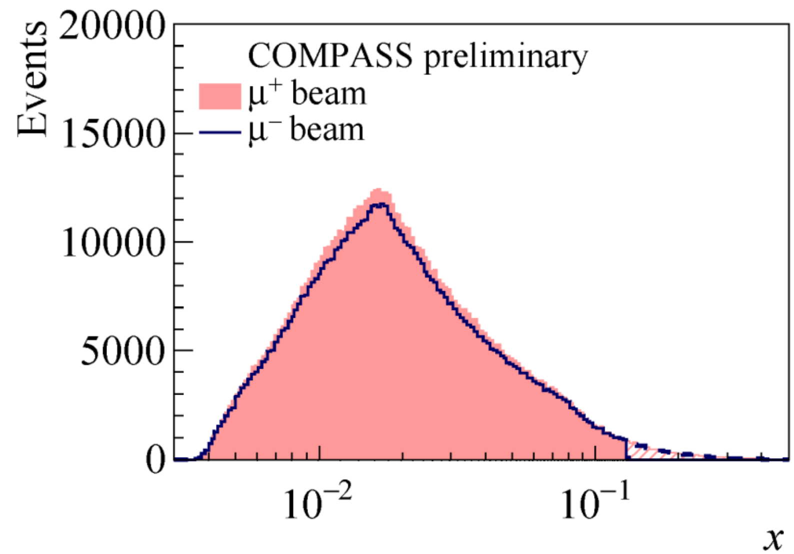

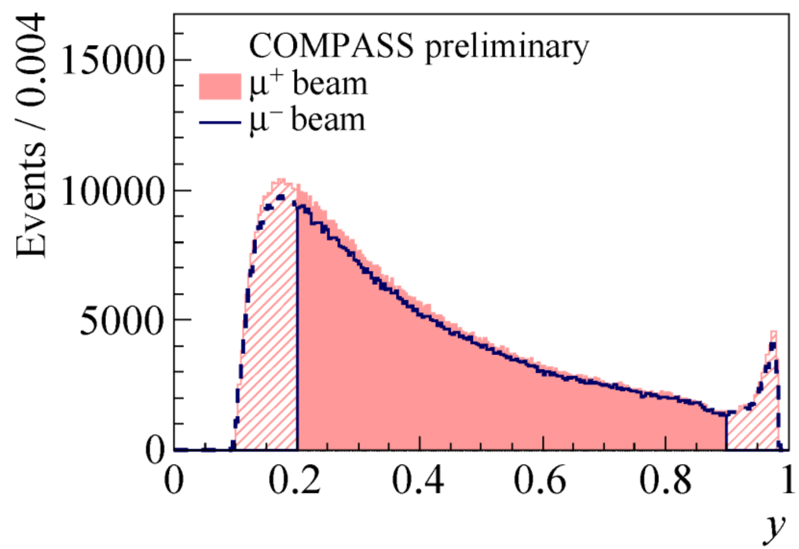

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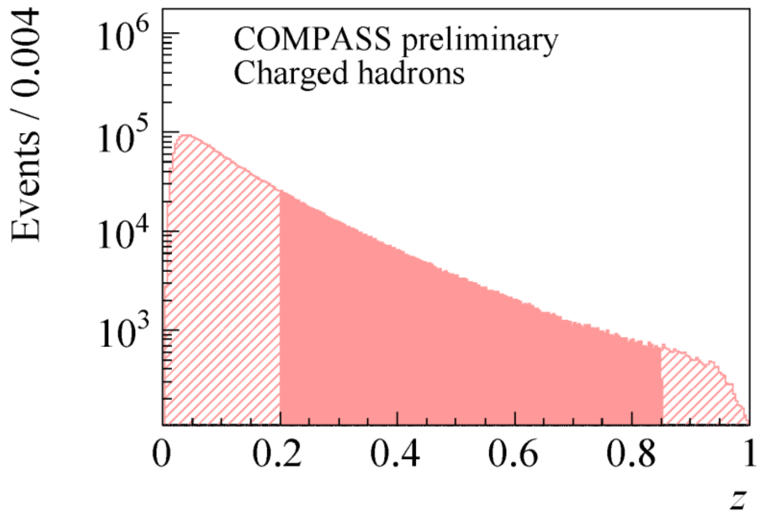
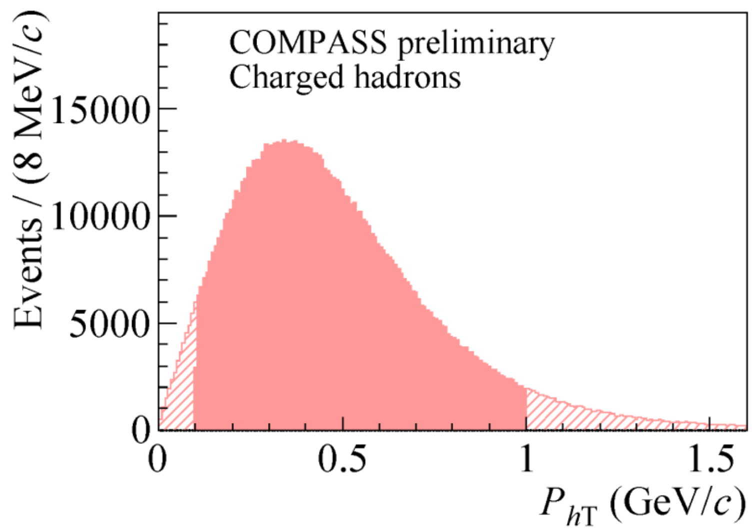




Extraction of asymmetries

Procedure applied for the $\mu^+ - \mu^-$ subperiods and for positive and negative hadrons separately :

Sample divided in kinematic bins $(7\ x, 8\ z, 9\ P_T^h)$

For each kinematic bin, subdivision in 16 ϕ_h bins

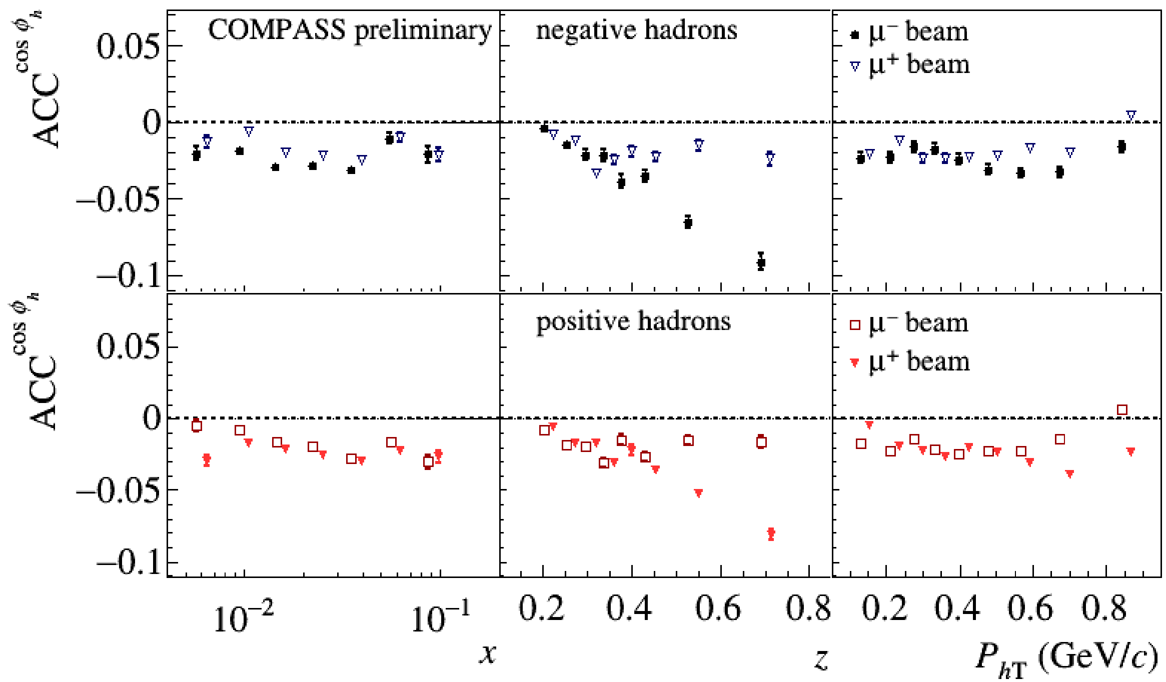
Removal of radiative peak $(-\frac{\pi}{8} < \phi_h < \frac{\pi}{8})$

Correction for acceptance
(from Monte Carlo, next slide)

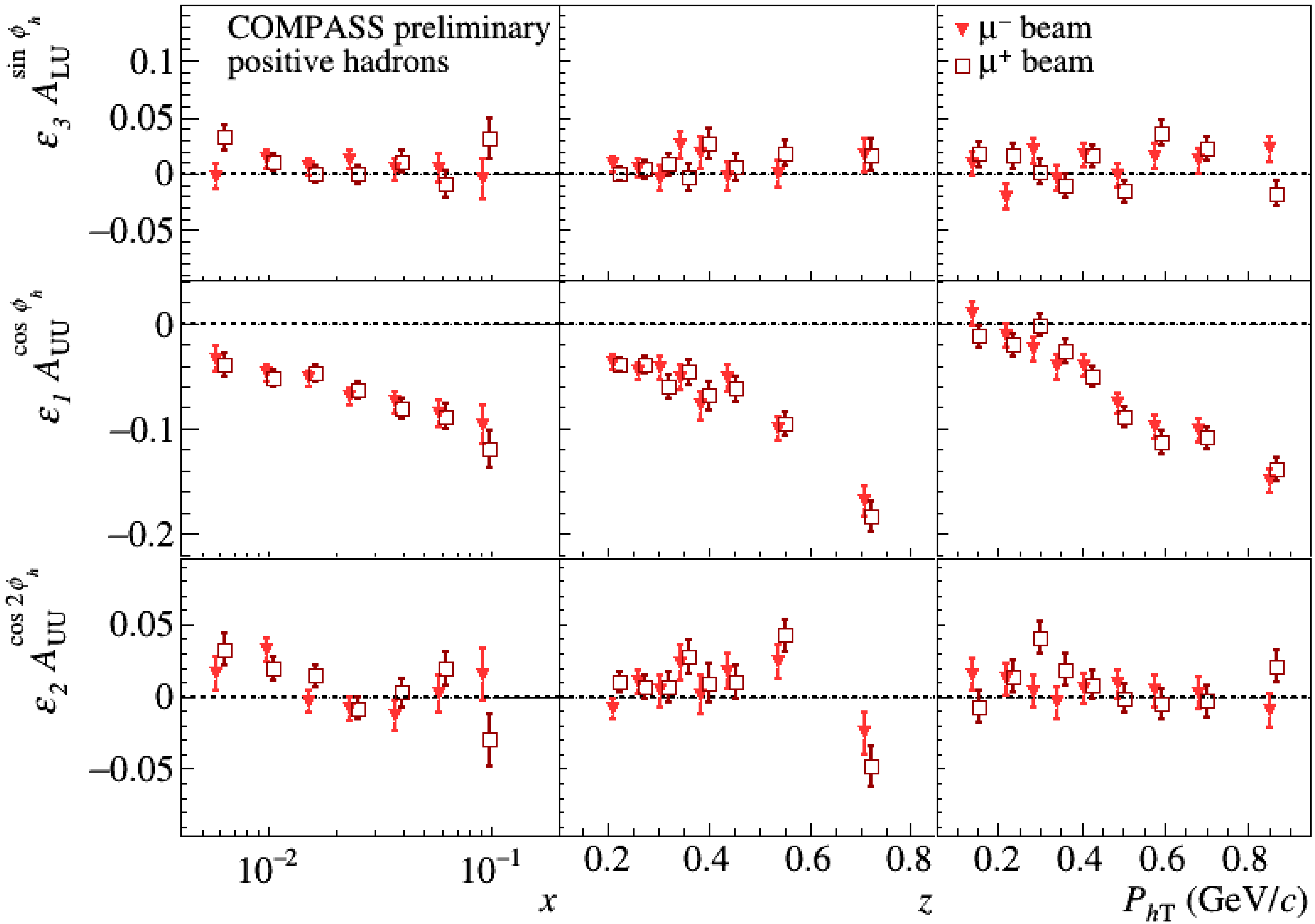
FIT

Acceptance corrections

- Acceptance of the apparatus calculated with a Monte Carlo simulation tailored on the considered period
- LEPTO used as a generator
- Acceptance modulations very small (generally about 2%, always smaller than 10%)
- Effect for the modulation of acceptance in $\cos\phi_h$: mirror symmetry for h^+ and h^- with μ^+ and μ^- beams (and remarkable compatibility of corresponding asymmetries, see next slides)
- Effect at high z (hole in the hadron absorber)

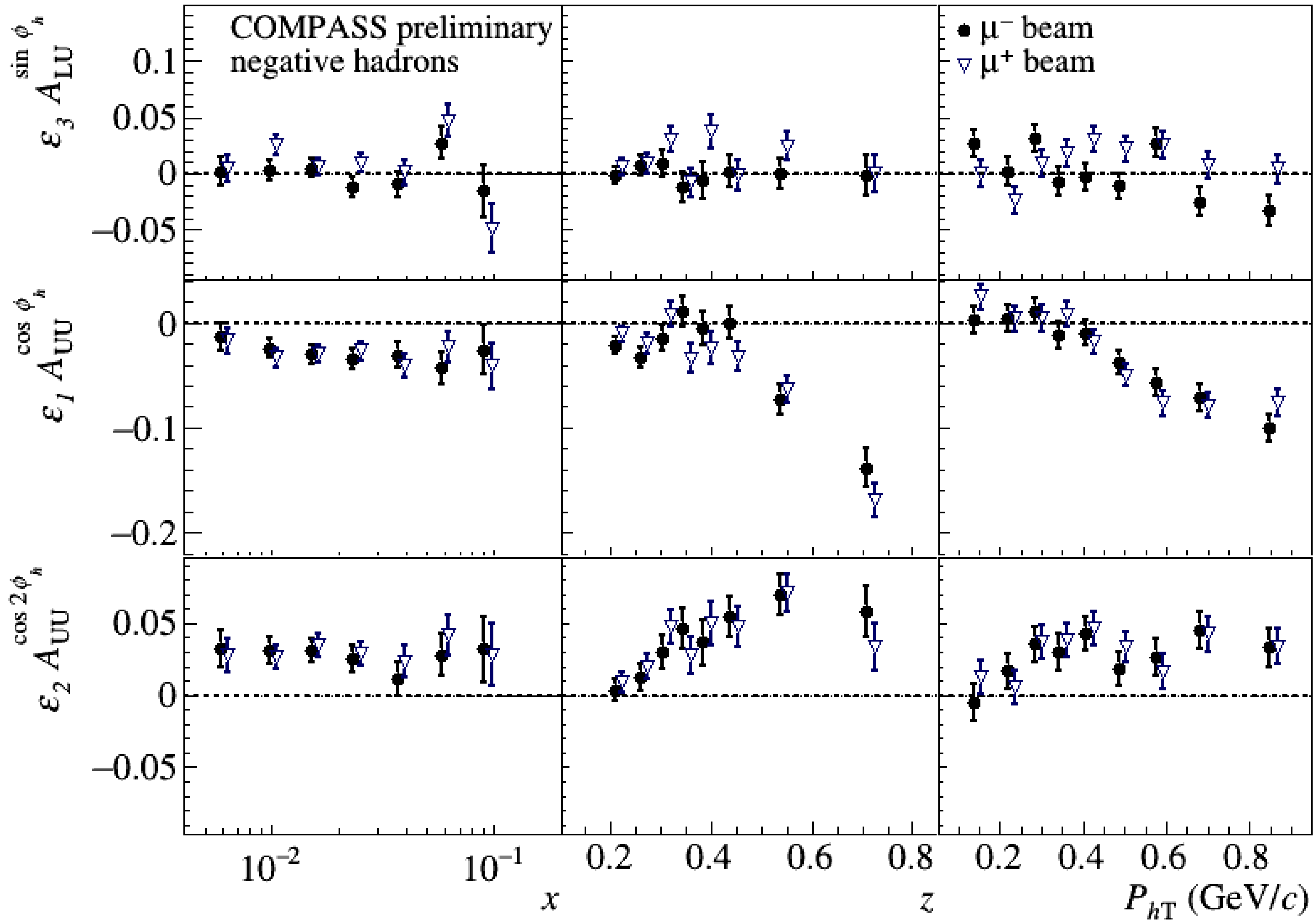


Results – positive hadrons



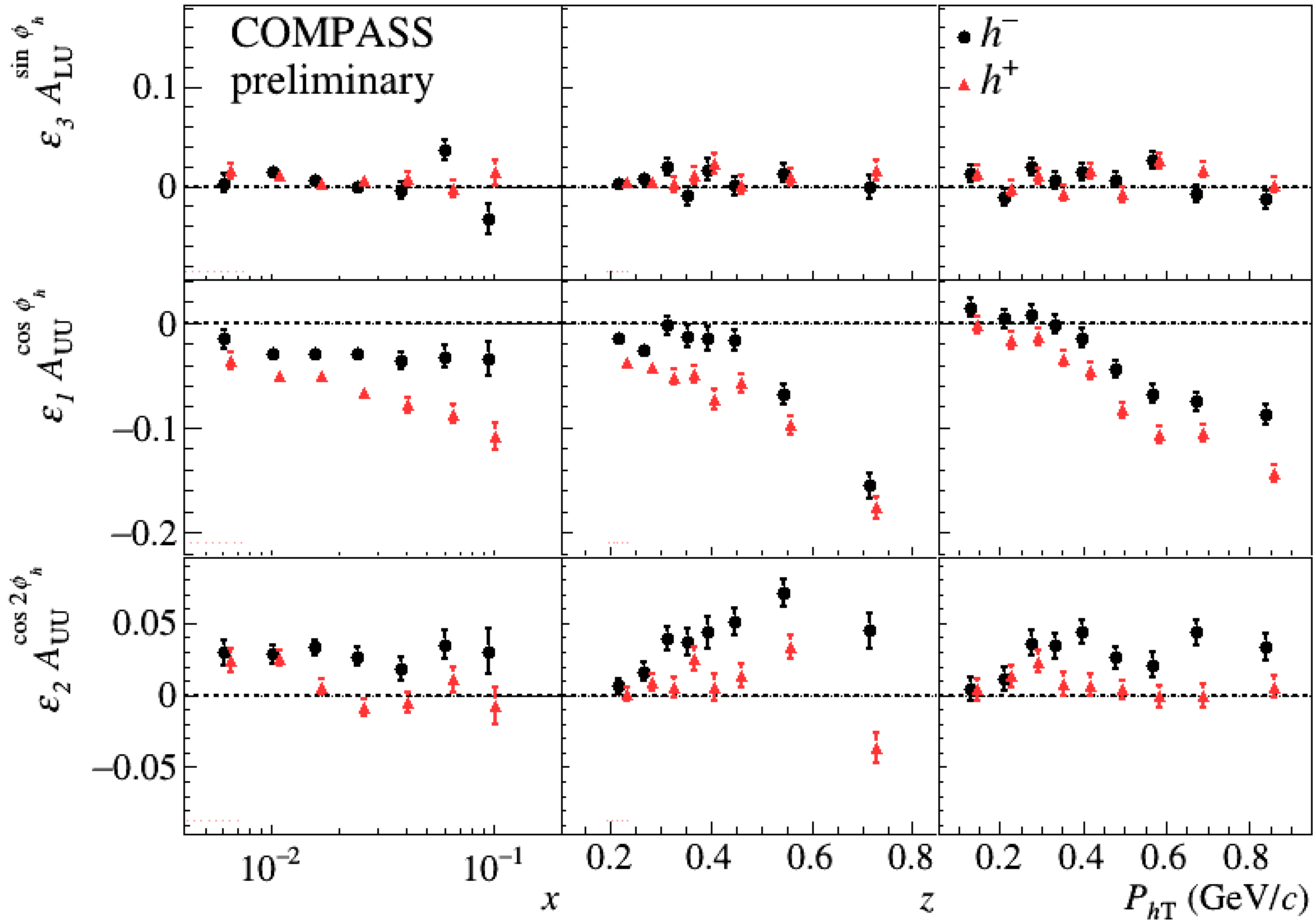
Statistical errors only

Results – negative hadrons



Statistical errors only

Results – combination of μ^+ and μ^- beams

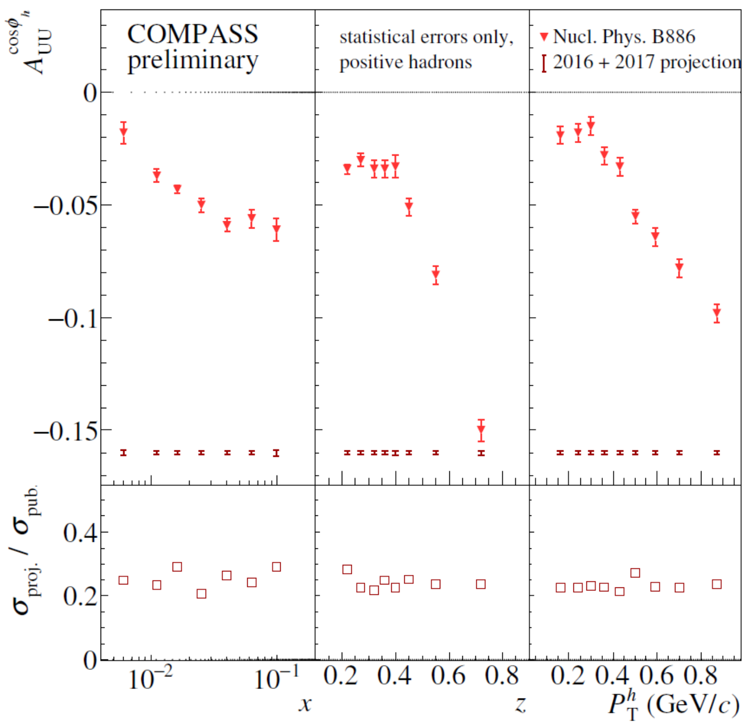


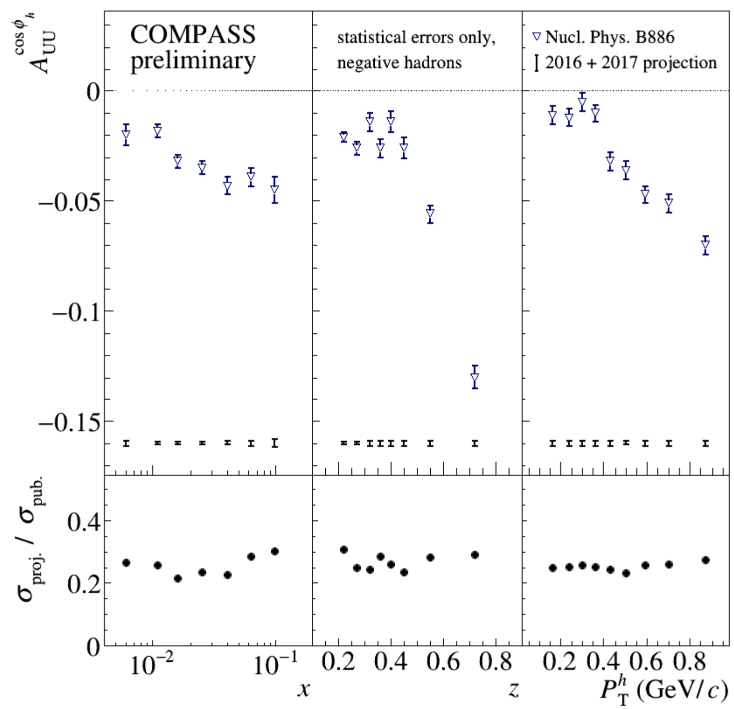
Statistical errors only

Projections for statistical errors

- The amount of data considered in this analysis correspond to **~4%** of the available statistics.
- The estimated reduction in the statistical error is a **factor 5**, almost flat at 0.25.
- Systematic uncertainties will be much smaller than for the published COMPASS deuteron data.

COMPARISON WITH PREVIOUS RESULTS
ratio of estimated error / published





Conclusions and perspectives

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1. The strong kinematic dependencies of the asymmetries are confirmed
2. Considering the whole 2016+2017 sample,
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PERSPECTIVES

- Possibly extend the kinematic range (keeping acceptance correction below 10%)
- Extend from 1D analysis to 3D in x, z and P_T^h (but other variables can be used as well)
- PID to allow flavor separation
- Other measurements: multiplicities (z, P_T^h but also q_T), y vs W ...
- ... And much more... → see A. Kerbizi's talk

thank you