Azimuthal asymmetries of hadrons produced in unpolarized SIDIS at COMPASS

Dubna Spin 2019

Andrea Moretti

on behalf of the COMPASS Collaboration

Content of this talk

- Introduction
- Previous COMPASS measurements
- Preliminary results from 2016/2017 data taking
- Projection of statistical uncertainties
- Diffractive vector mesons contamination
- Conclusions

Azimuthal asymmetries in unpolarized SIDIS

The production of hadrons in the semi-inclusive deep inelastic scattering (SIDIS) is a powerful tool for probing the nucleon structure and assess TMD-PDFs and TMD-FFs.

The fully differential cross section for the production of a hadron h in unpolarized DIS:

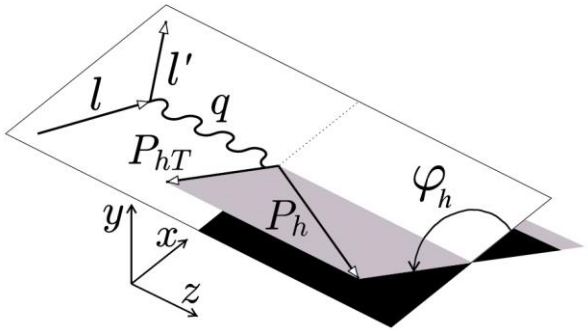
$$\frac{d\sigma}{P_{hT}dP_{hT}dx\,dy\,dz\,d\phi_h} = \sigma_0(1 + \epsilon_1 A_{UU}^{\cos\phi_h} cos\phi_h + \epsilon_2 A_{UU}^{\cos 2\phi_h} cos2\phi_h + \lambda\epsilon_3 A_{LU}^{sin\phi_h} sin\phi_h)$$

- $A_{UU}^{\cos\phi_h}$, $A_{UU}^{\cos 2\phi_h}$ and $A_{LU}^{\sin\phi_h}$ are ratios of azimuthal angle ϕ_h-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 in unpolarized SIDIS

→ extraction of the Boer-Mulders TMD

→ evaluation of the quark intrinsic $\boldsymbol{k_T}$

Azimuthal asymmetries and multiplicities

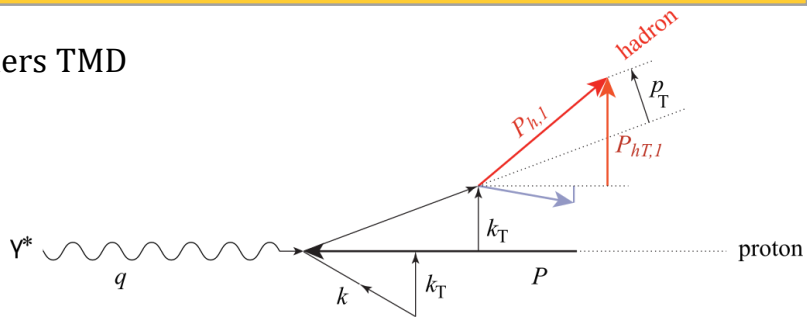
Boer-Mulders TMD

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

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

Boer-Mulders TMD

Cahn effect



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

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

Azimuthal asymmetries and multiplicities

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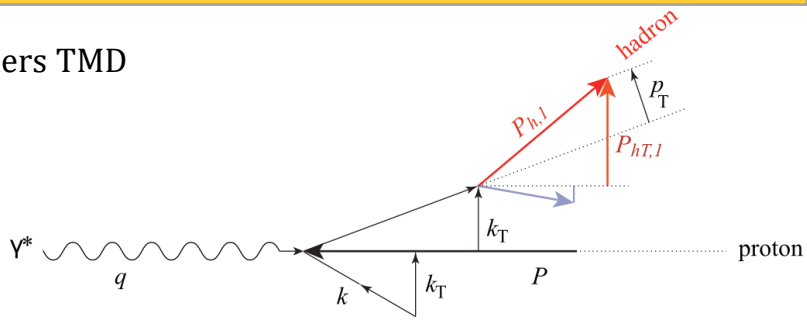
Boer-Mulders TMD Cahn effect



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- Independent information on $\boldsymbol{k_T^2}$ and $\boldsymbol{p_T^2}$ can be obtained from the study of $\boldsymbol{P_{hT}}$ **− dependent multiplicities**, defined as the ratio of the SIDIS cross section and the DIS cross section:

$$\frac{d^2M^h(x,Q^2;z,P_{hT}^2)}{dz\,dP_{hT}^2} = \frac{d^4\sigma^{\ell p\to\ell' h\,X}}{dx\,dQ^2 dz\,dP_{hT}^2} \Big/ \frac{d^2\sigma}{dx\,dQ^2}$$

- In gaussian approximation and for small values of P_{hT}, where $\boldsymbol{\langle P_{hT}^2\rangle = z^2\langle k_T^2\rangle + \langle p_T^2\rangle}$ is expected to hold,

$$\frac{d^2M^h(x,Q^2;z,P_{hT}^2)}{dz\,dP_{hT}^2} = \frac{N}{\langle P_{hT}^2\rangle}\exp\left(-\frac{P_{hT}^2}{\langle P_{hT}^2\rangle}\right)$$

COMPASS published results

Azimuthal asymmetries and transverse momentum dependent multiplicities of hadrons produced in SIDIS: hot topics towards the understanding of the TMD structure of nucleon.

- A lot of work on the experimental side. Results from JLAB, HERMES, COMPASS
- Deep investigation on the theoretical side

COMPASS contribution, so far:
(160 GeV muon beam)

- P_{hT}^2-distributions on deuteron
  [EPJ C73 (2013)]
- P_{hT}^2-multiplicities on deuteron
  [PRD 97 (2018)]
- azimuthal asymmetries on deuteron
  [NPB 886 (2014)]

data collected in 2004 and 2006 with a transversely polarized deuteron target

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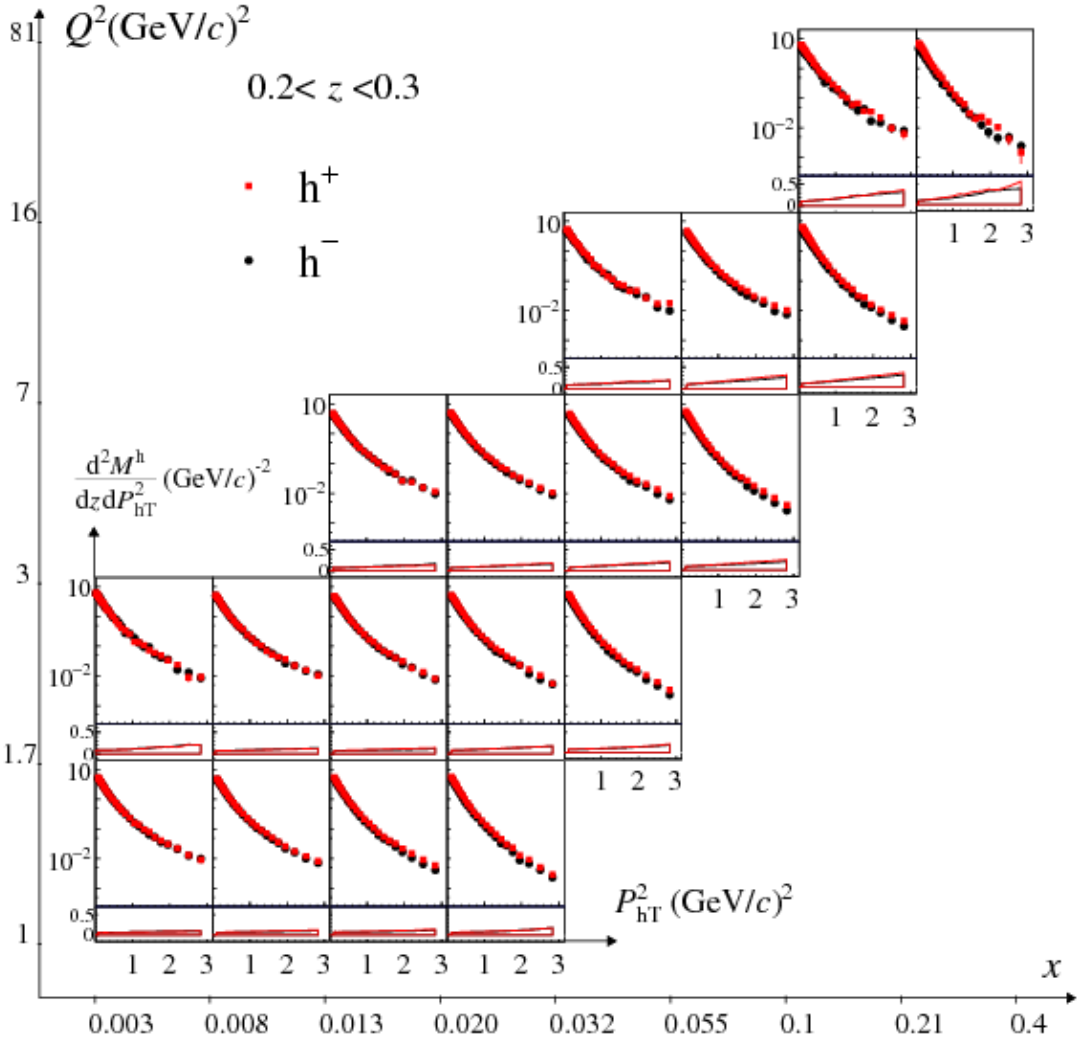

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Azimuthal asymmetries from COMPASS data, collected with a **deuteron target**, **1D analysis** (separately in bins of x, z, P_{hT})

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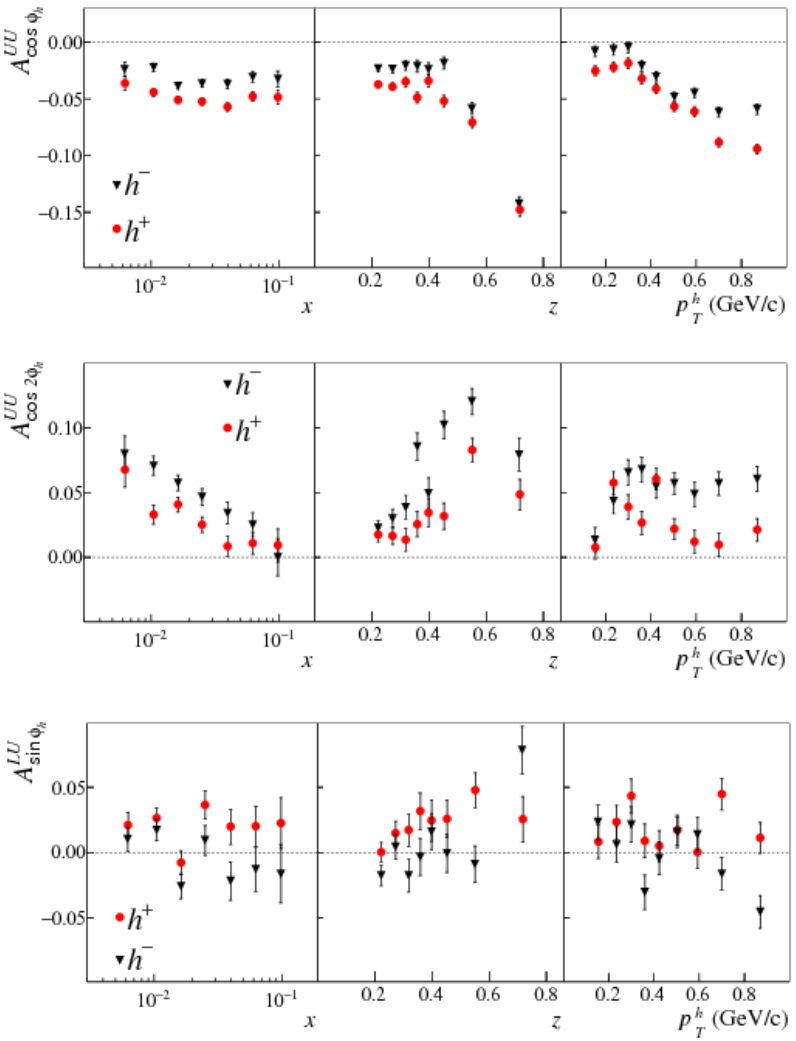

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Azimuthal asymmetries and transverse momentum dependent multiplicities of hadrons produced in SIDIS: hot topics towards the understanding of the TMD structure of nucleon.

Azimuthal asymmetries from COMPASS data, collected with a **deuteron target**, **3D analysis** (simultaneous binning of x, z, P_{hT}). Here **cos ϕ_h**, but also cos $2\phi_h$ and sin ϕ_h asymmetries have been measured.

COMPASS contribution, so far:
(160 GeV muon beam)

- P_{hT}^2-distributions on deuteron
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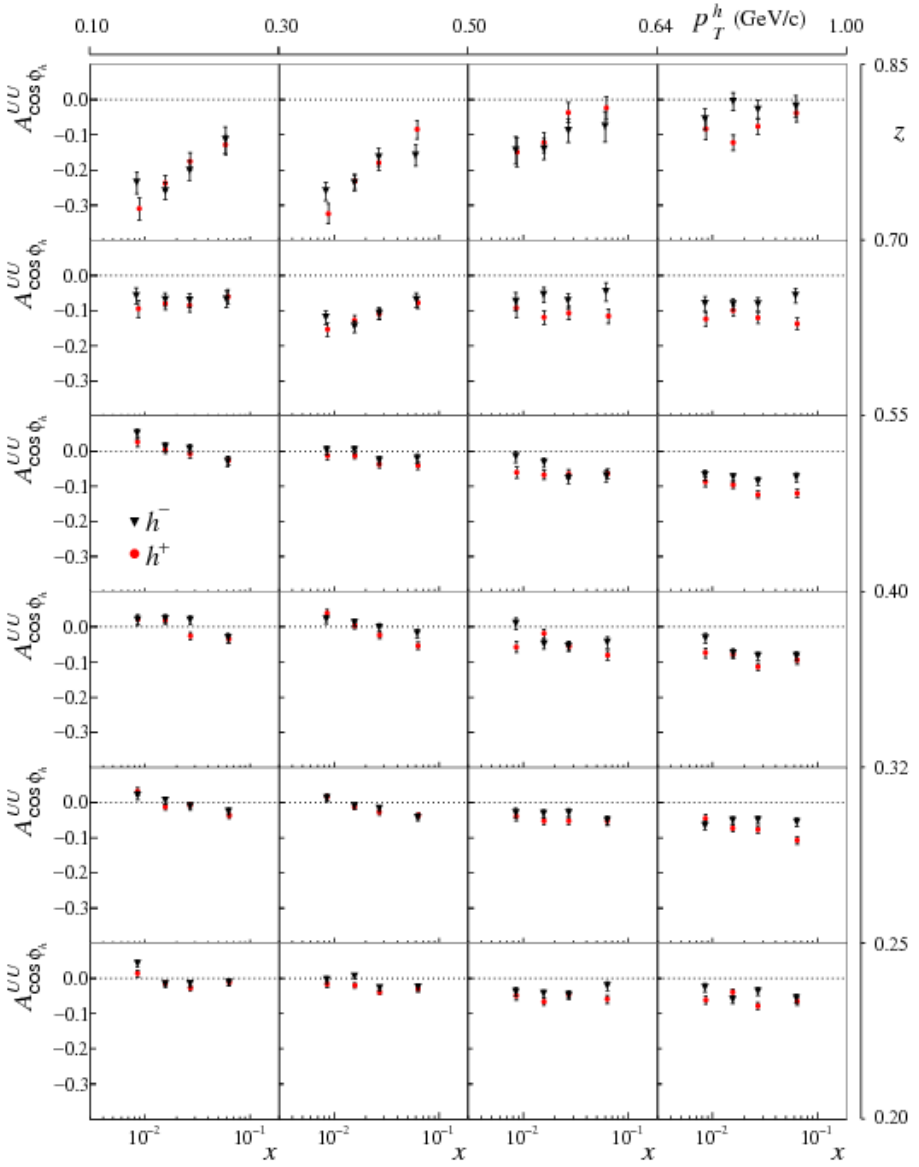
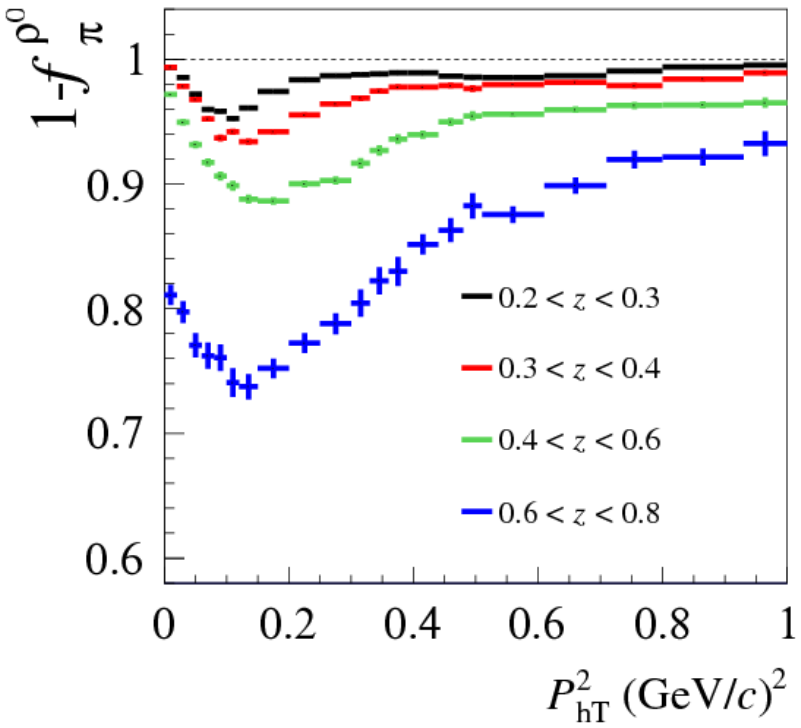


DVM contamination

- Hadrons can be produced in the decay of diffractively produced vector mesons ($\rho \to \pi^+\pi^-, \phi \to K^+K^-, \omega \to \pi^0\pi^+\pi^-$); they are indistinguishable from the ones produced in "true" SIDIS.
- These "exclusive hadrons" can exhibit an azimuthal modulation, inherited from the parent mesons
(modeled via SDMEs - Spin Density Matrix Elements).
- Their percentage and azimuthal modulations are key ingredients.



Fraction of π from the decay of exclusive ρ mesons on deuteron, as estimated in PRD 97 (2018), as a function of P_{hT}^2 and in bins of z.

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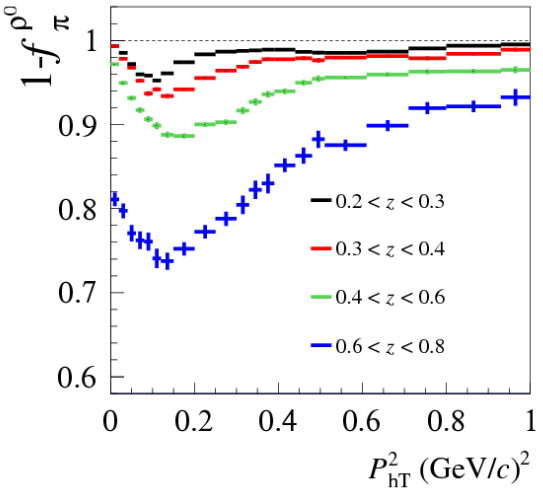
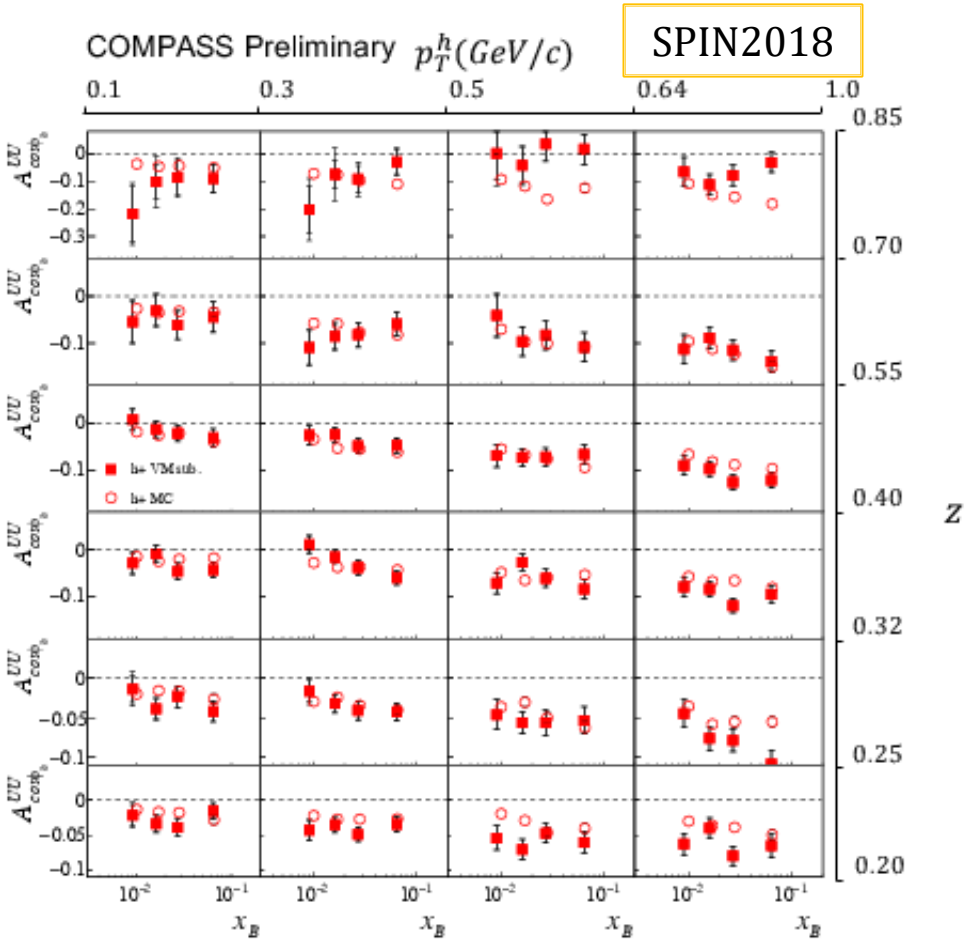
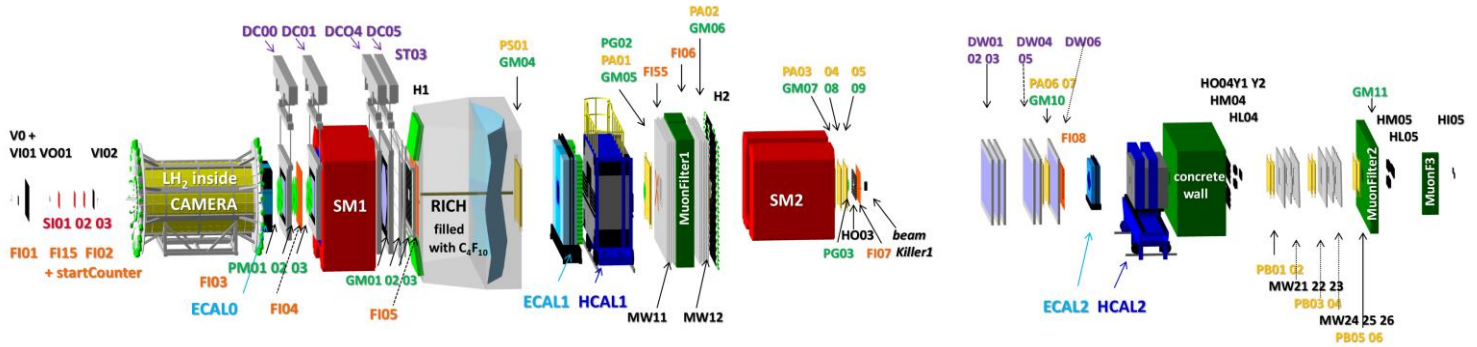


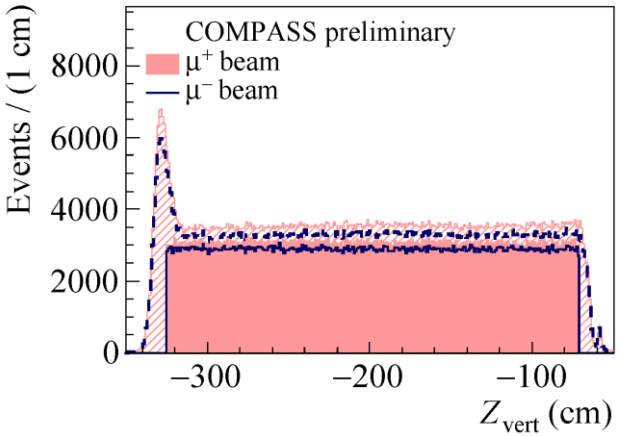
Comparison of the $cos\phi_h$ asymmetry obtained from data after subtracting of DVM contribution with a MC simulation with Cahn effect.



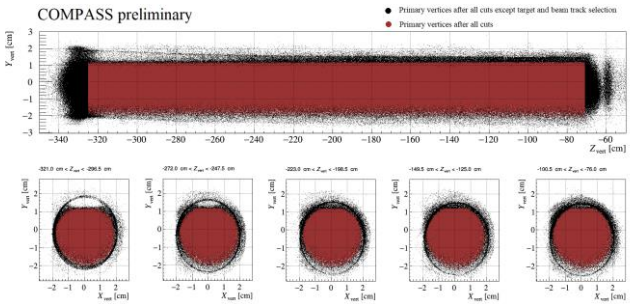
The 2016/2017 COMPASS runs



- Main goal of the 2016 and 2017 runs in COMPASS: access GPDs via the **Deeply Virtual Compton Scattering**
- 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
- Good Monte Carlo is absolutely crucial



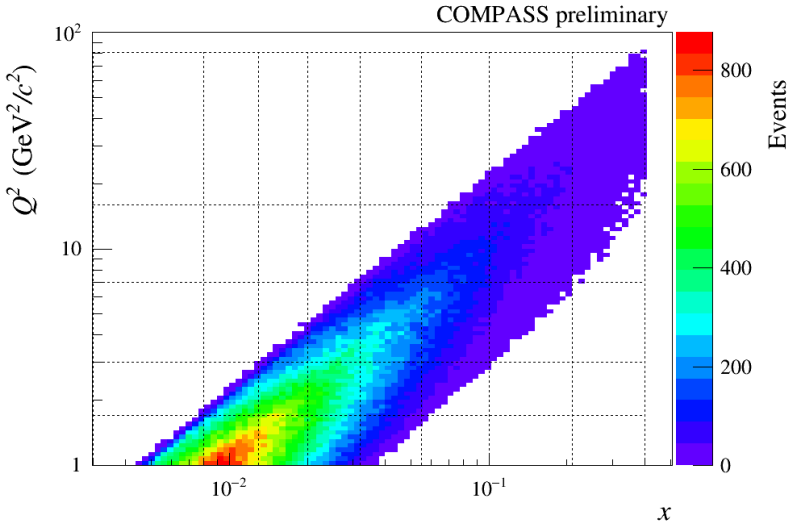
Kinematic distributions

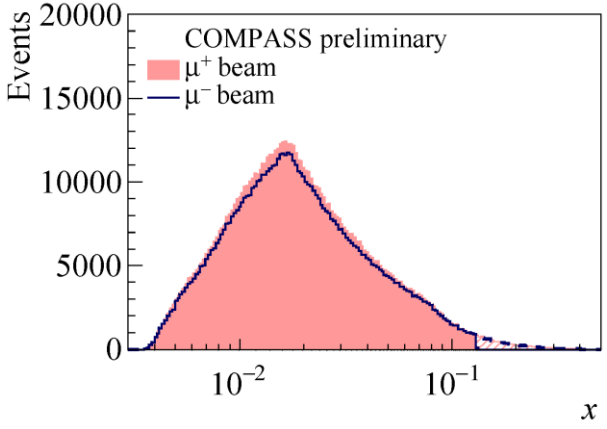
The COMPASS Collaboration is working on the analysis of the data collected on proton.

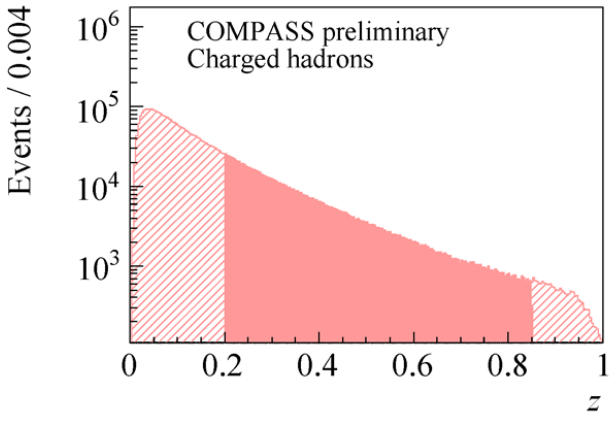
In this talk:

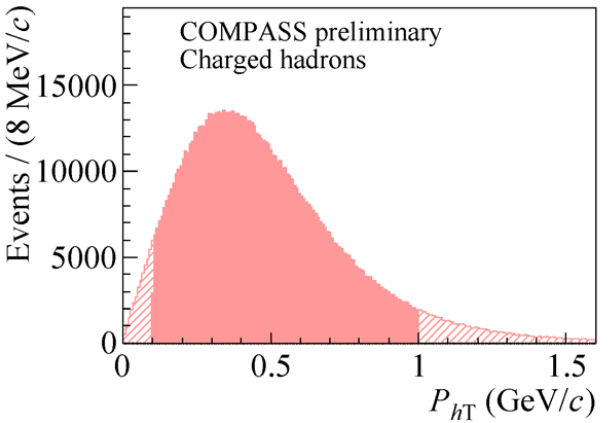
- **preliminary results for multiplicities of charged hadrons** in a restricted kinematic range
- **preliminary results for azimuthal asymmetries of charged hadrons** in 1D, with projections of the statistical uncertainties for the full 2016+2017 sample
- **estimation of the DVM contribution**

Here: a selection of kinematic distributions ($x - Q^2$ coverage, x, z, P_{hT})



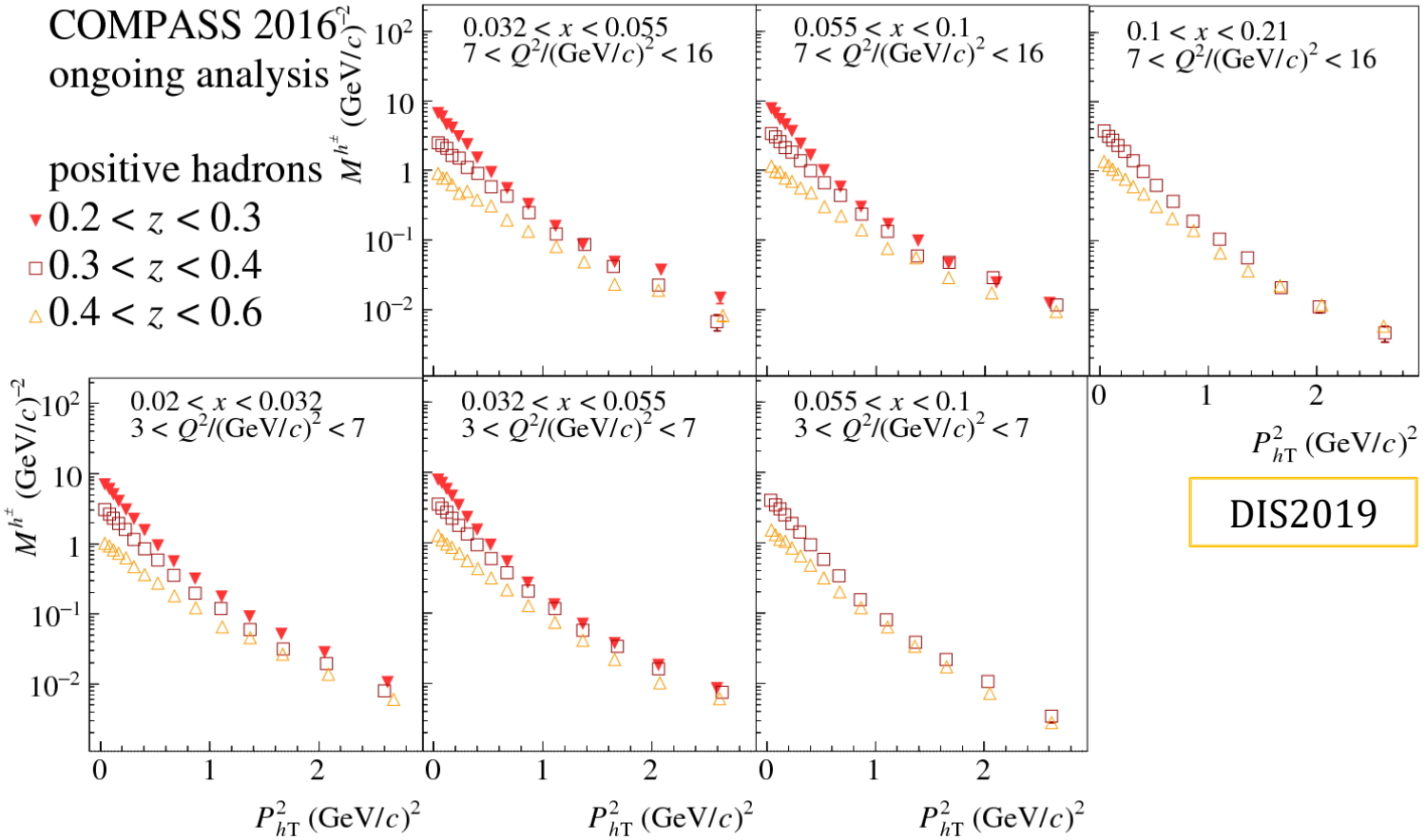






Preliminary results for multiplicities

Here: preliminary results for multiplicities of charged hadrons in a restricted kinematic range, where acceptance is flat and the contamination of DVM is estimated negligible.
These results are not corrected for radiative effects. From **~10%** of the available statistics.



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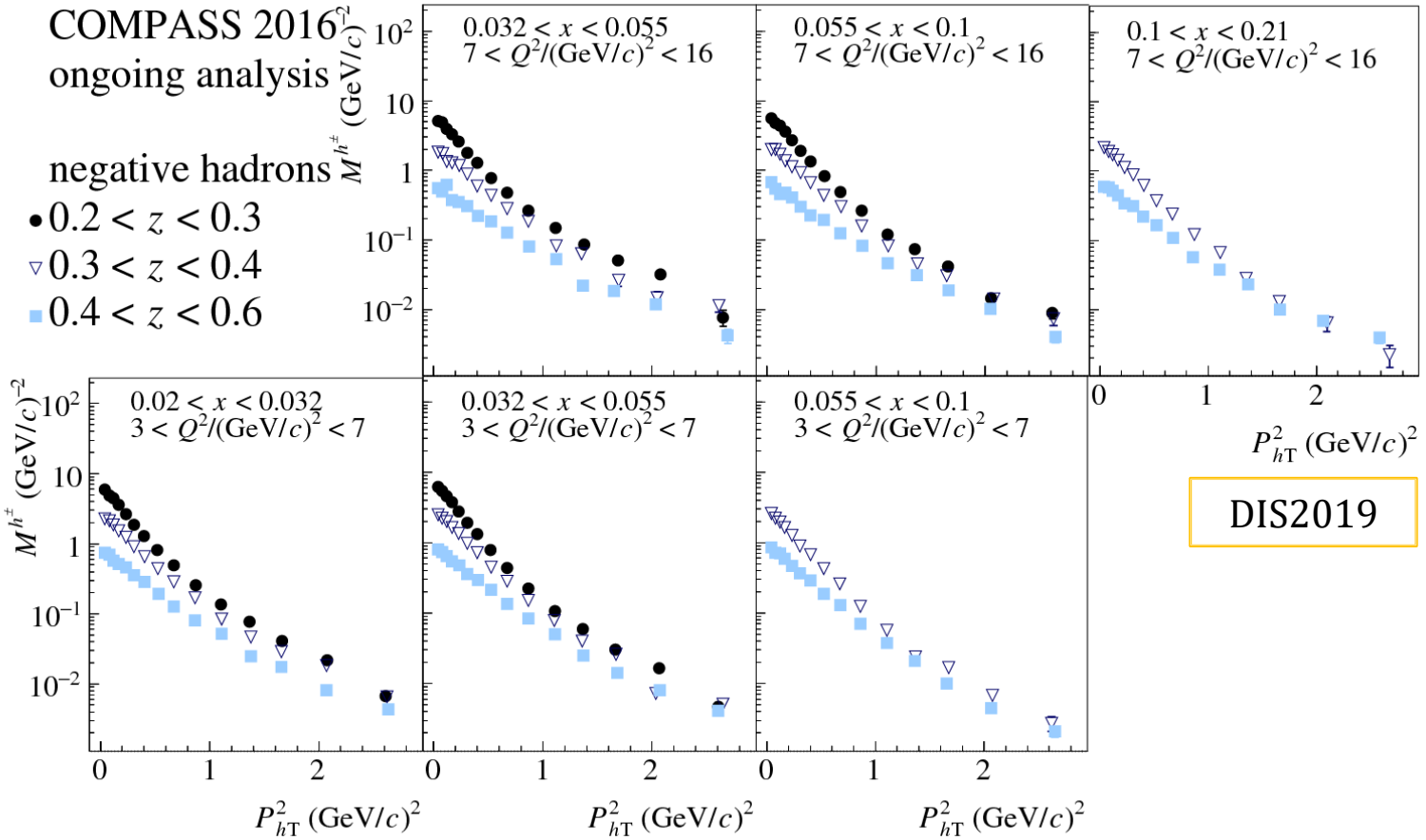


Procedure for the extraction of the asymmetries

Sample divided in kinematic bins ($7\ x, 8\ z, 9\ P_{hT}$)

For each kinematic bin, subdivision in 16 ϕ_h bins

Removal of radiative peak ($-\frac{\pi}{8} < \phi_h < \frac{\pi}{8}$)
[and of DVM contribution]

Correction for acceptance

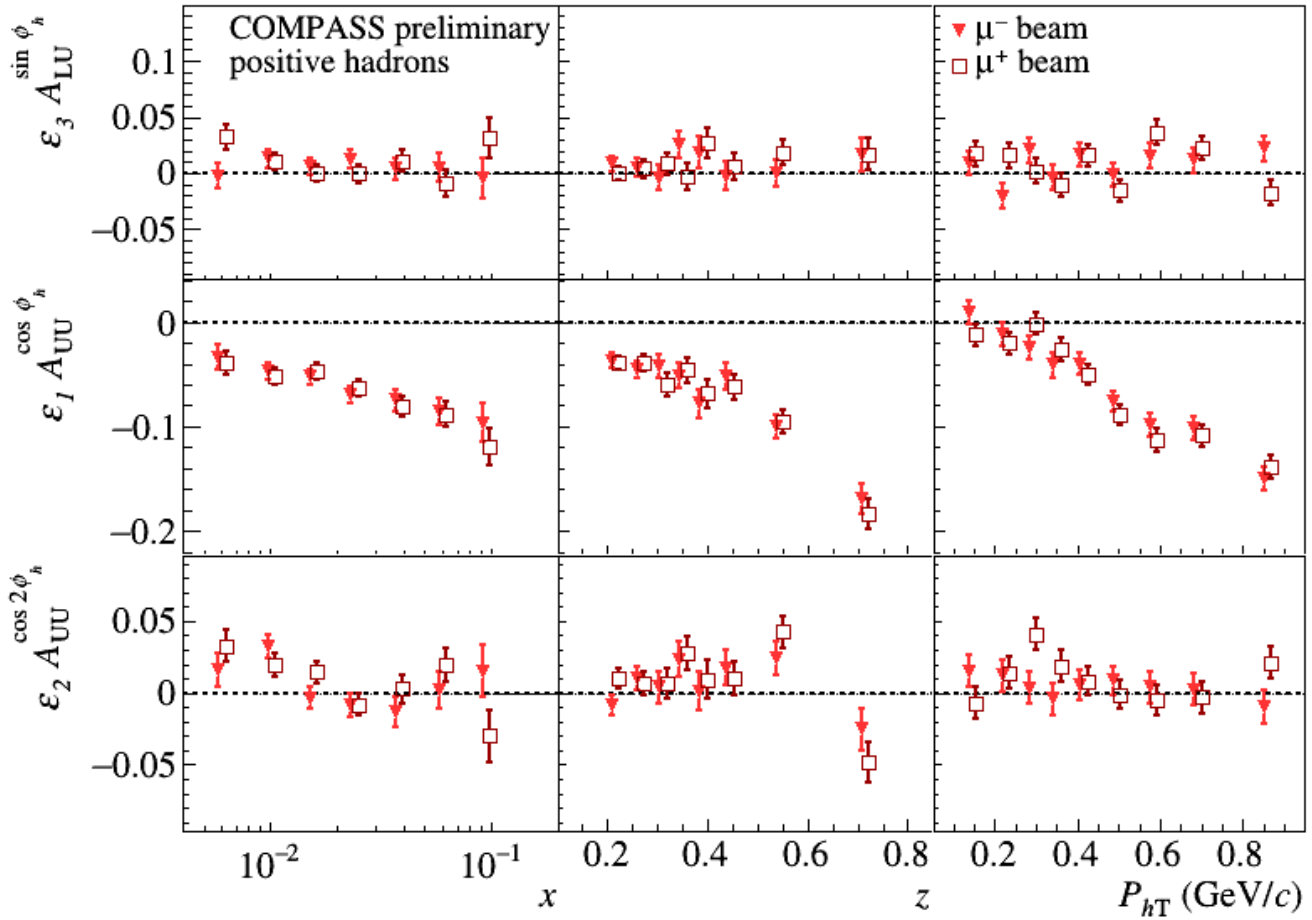
Fit of the azimuthal spectra

The extraction of the azimuthal asymmetries has been performed on **~4%** of the available statistics.

	μ^+ beam	μ^- beam
h^+	269 000	254 000
h^-	216 000	200 000

Preliminary results for azimuthal asymmetries

Here: preliminary results for azimuthal asymmetries of charged hadrons from **~4%** of the available statistics.
Uncertainties are statistical only. The agreement between μ^+ and μ^- results is very good.



SPIN2018

Strong kinematic dependences as observed on deuteron

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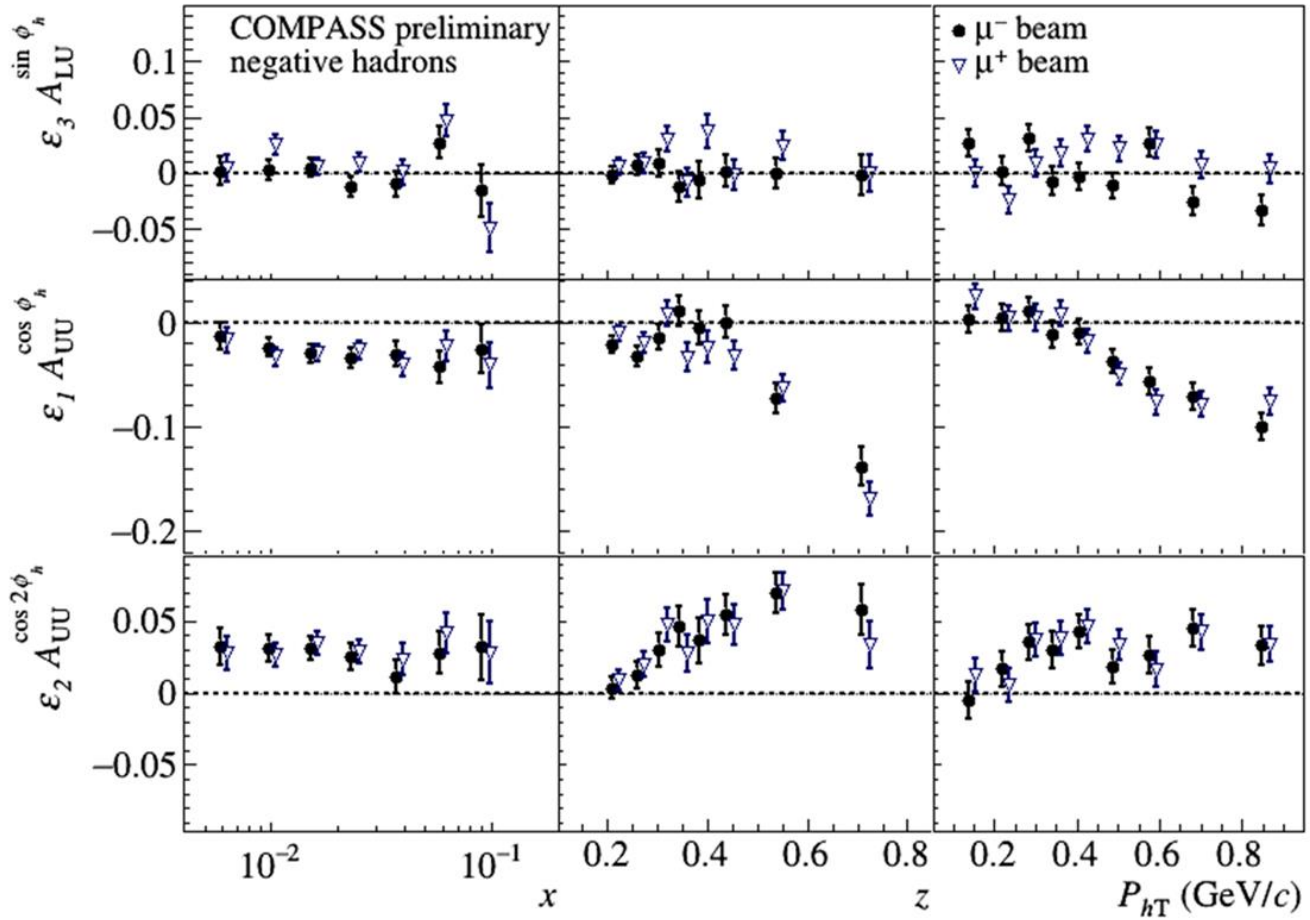

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Preliminary results for azimuthal asymmetries

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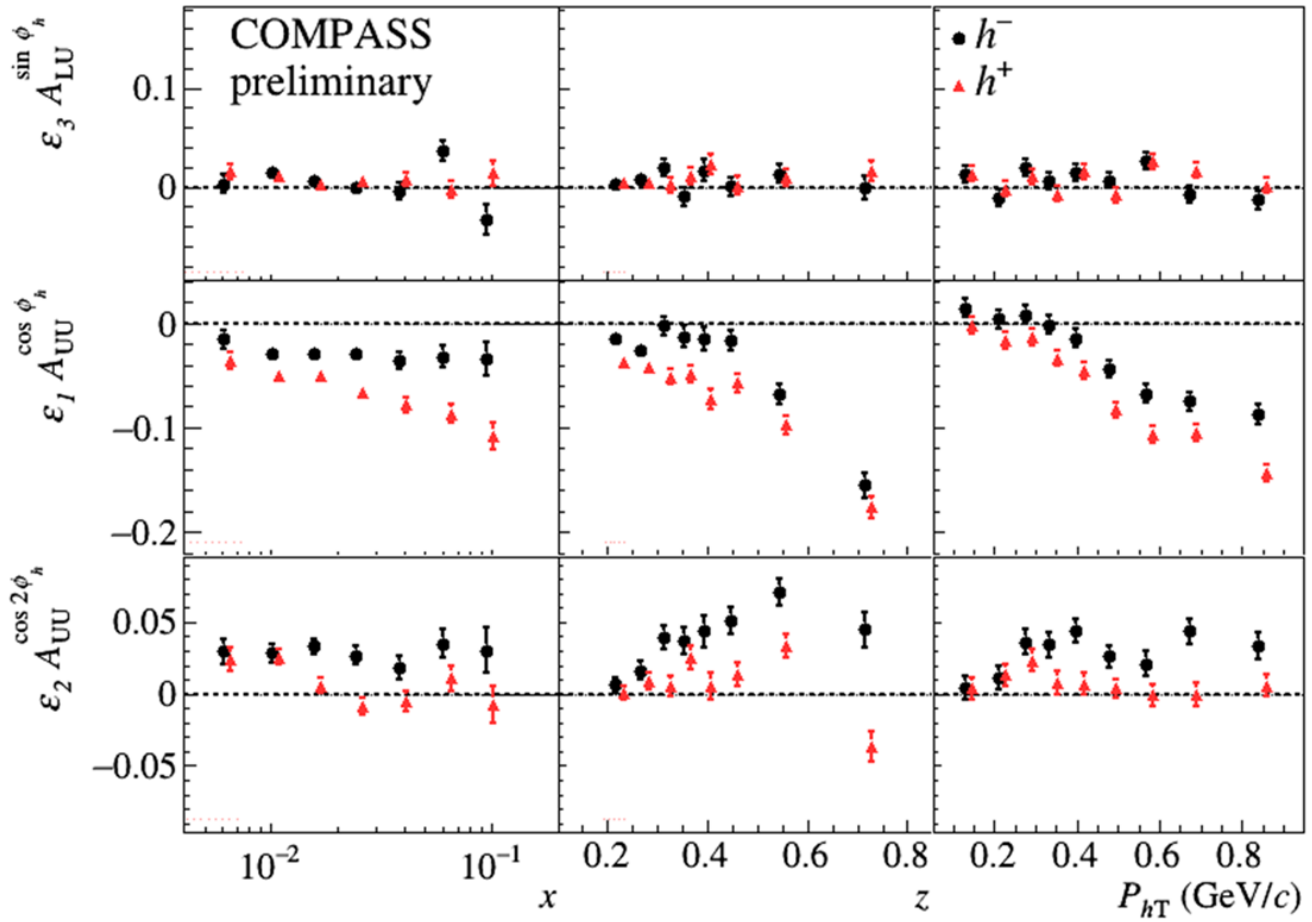
Uncertainties are statistical only. As the agreement between μ^+ and μ^- results is very good, the corresponding results are merged to give the following:

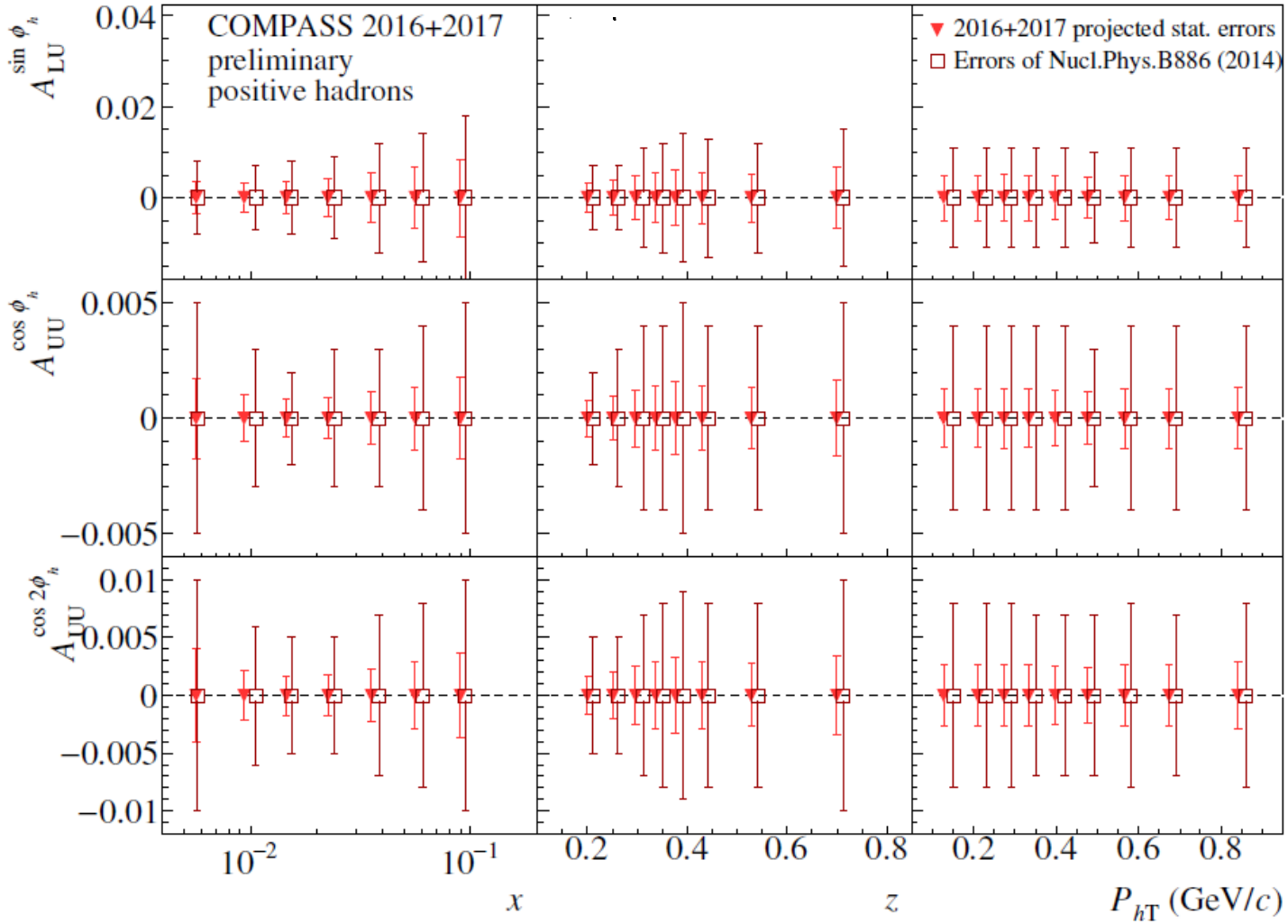


SPIN2018

Strong kinematic dependences as observed on deuteron

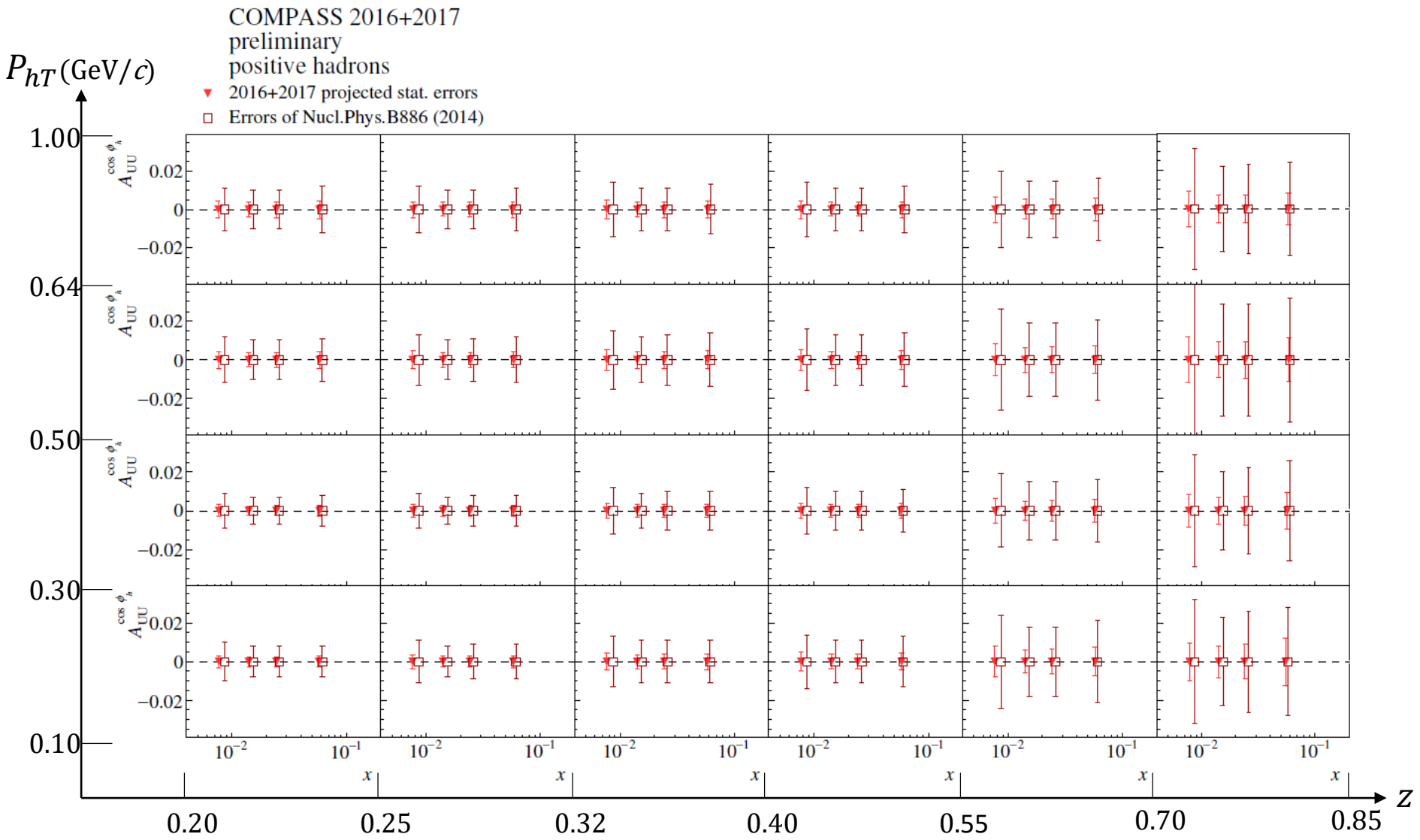
Projection for the 1D asymmetries (full target length)

Systematic uncertainties on the published results: **~2** x statistical uncertainty
expected for the new results: **~1** x statistical uncertainty



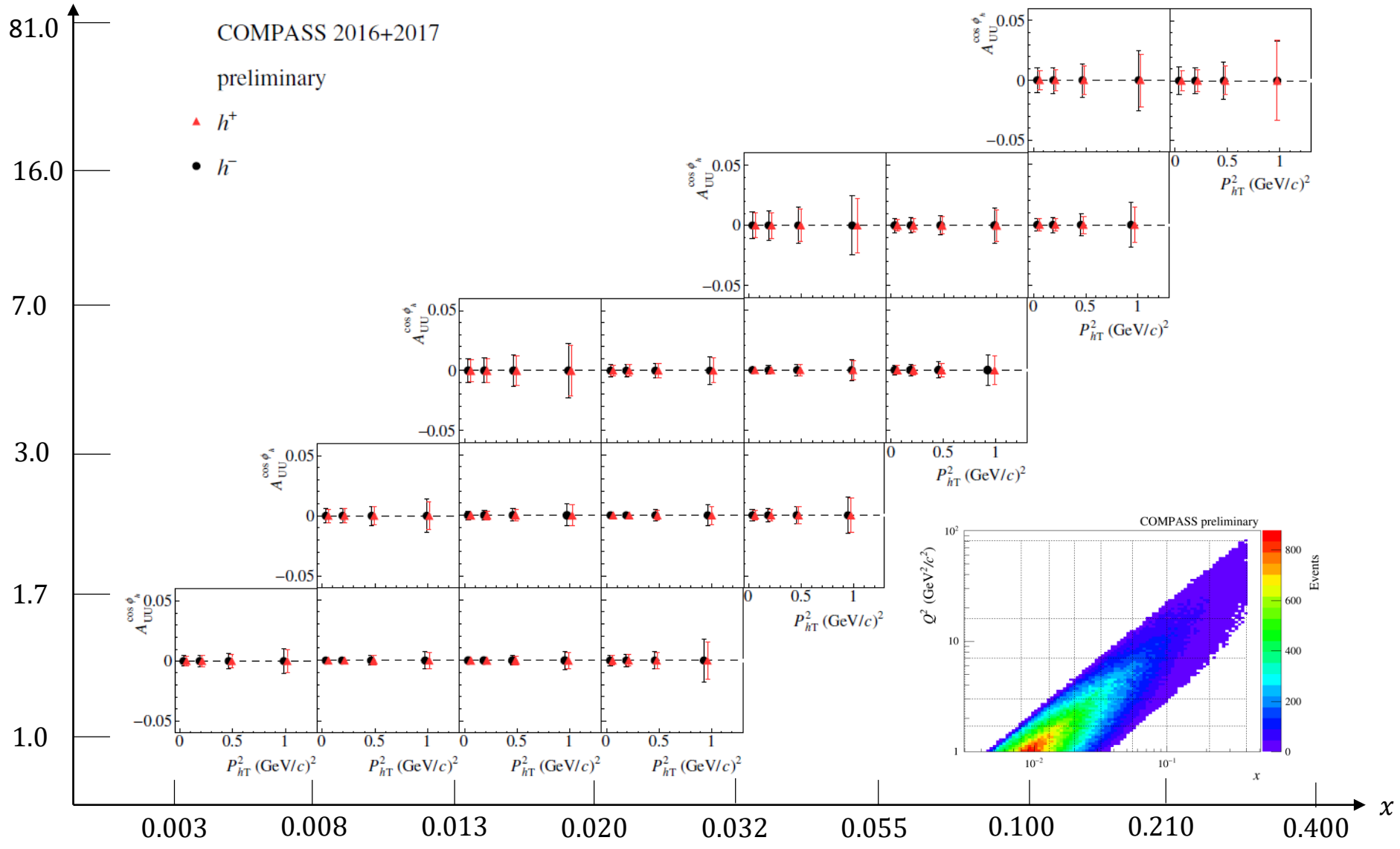
Projection for the 3D asymmetries (full target length)

- COMPARISON WITH PUBLISHED DEUTERON for the $cos\,\phi_h$ asymmetry



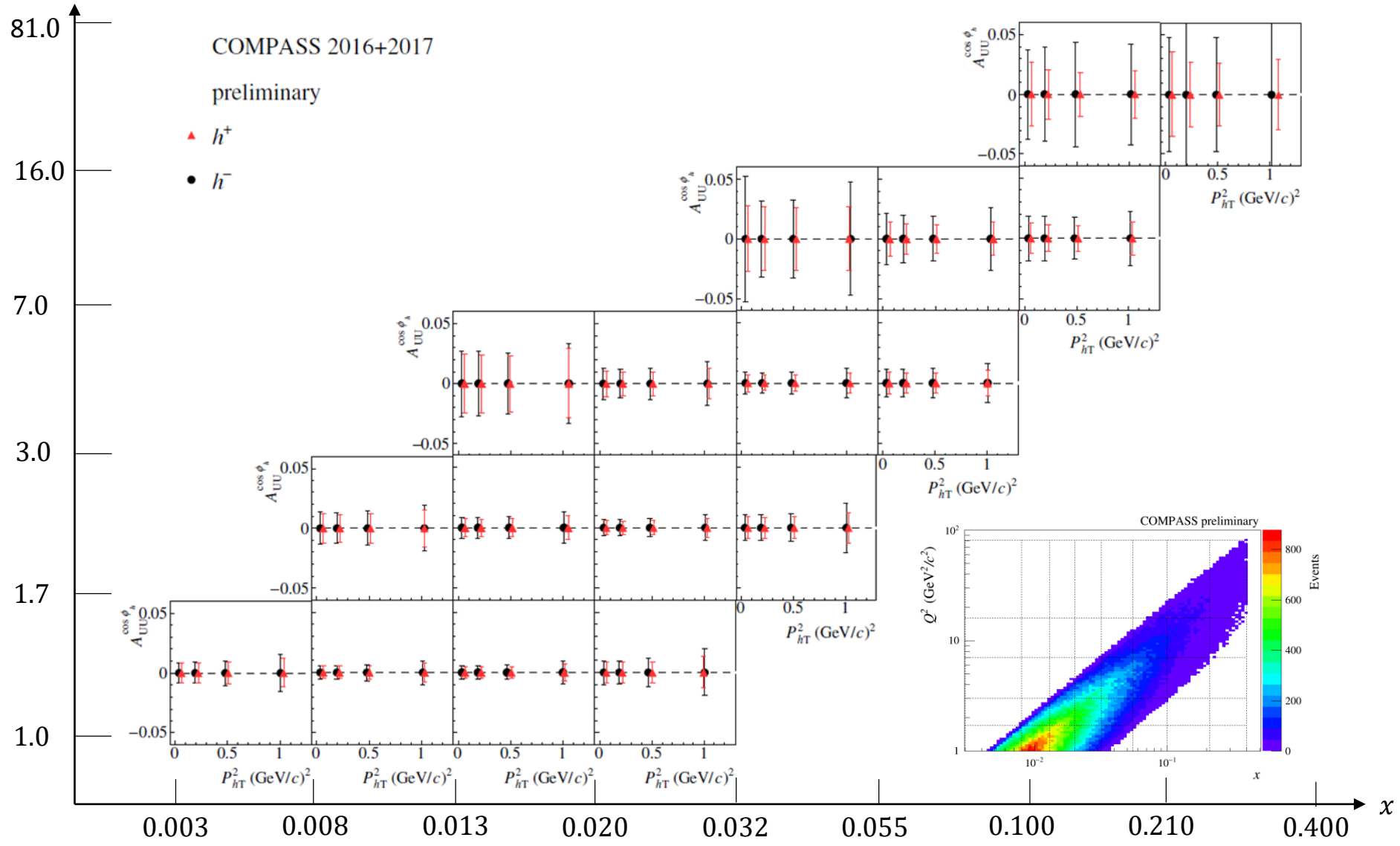
Projection for the 4D asymmetries (full target length)

- $cos\ \phi_h$ asymmetry in the first z bin $(0.2 < z < 0.3)$



Projection for the 4D asymmetries (full target length)

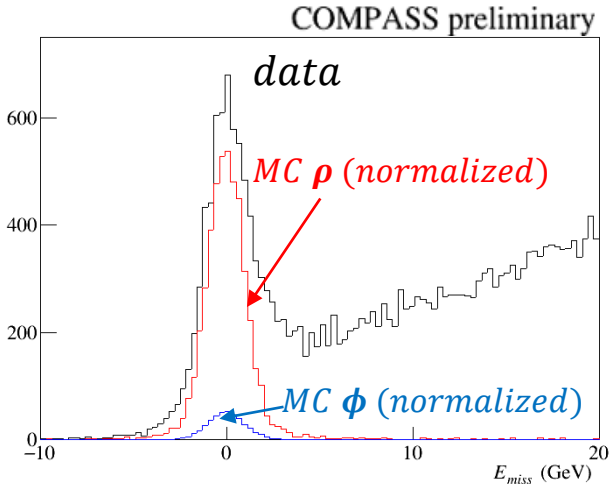
- $cos\,\phi_h$ asymmetry in the last z bin $(0.6 < z < 0.8)$



The method

A new estimation of the DVM contamination, based on the following features:

1. NORMALIZATION
   - a precise knowledge of the diffractive cross section is not required
   - The aim if to reproduce the signal from exclusive vector mesons in the data with the HEPGEN Monte Carlo, based on missing energy, total z and invariant mass spectra **for 2h with opposite charge**
   - A smooth trend is expected once the exclusive component is subtracted



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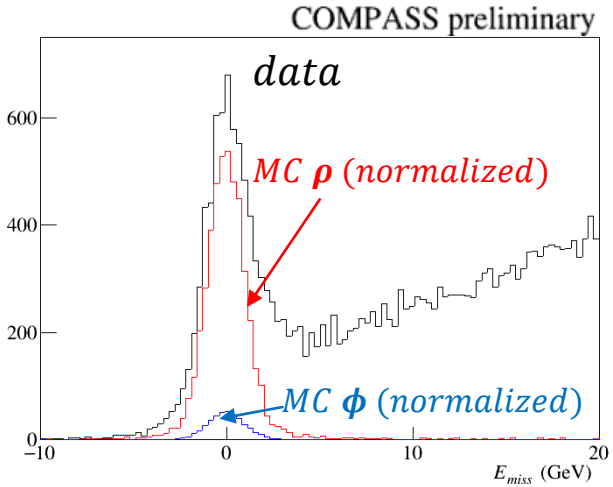
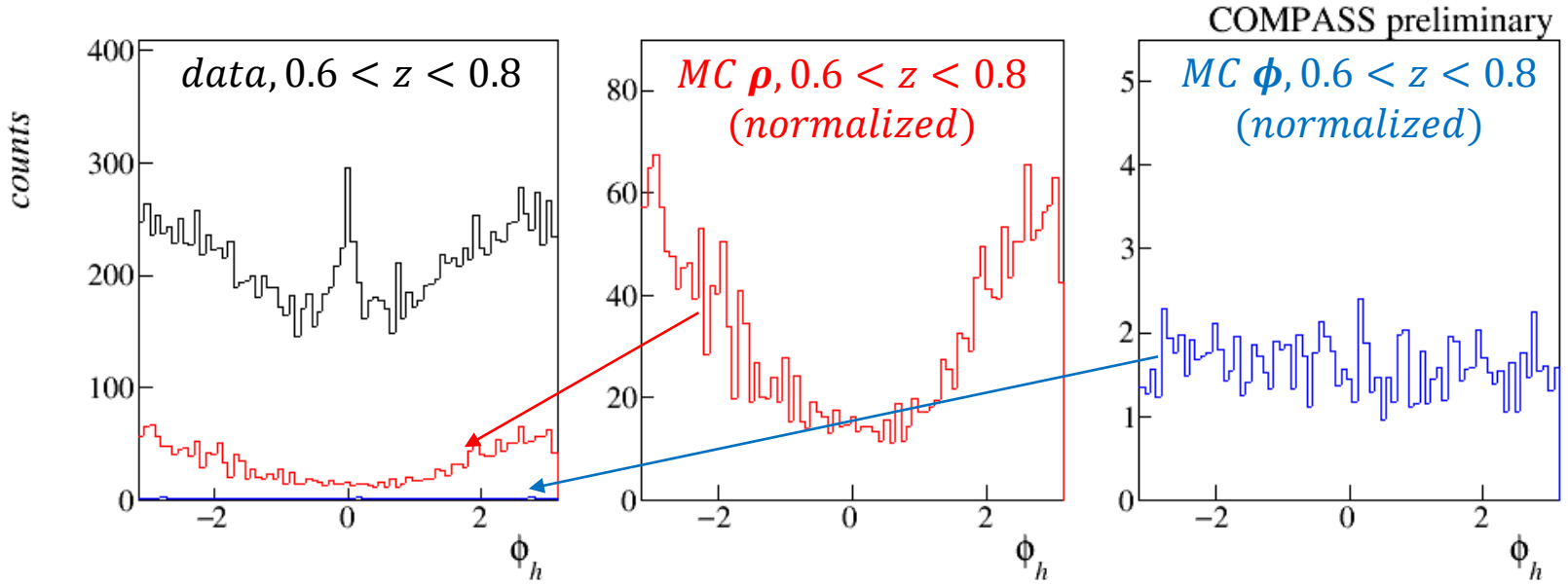


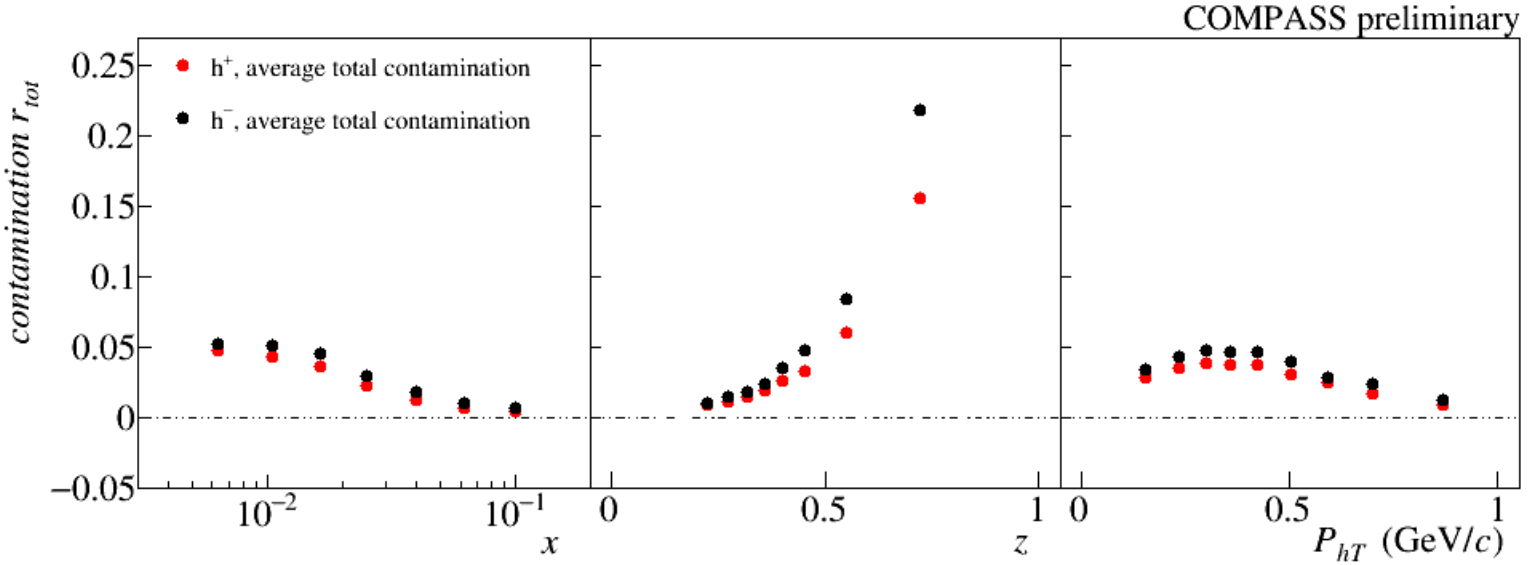
2. MEASUREMENT OF THE ASYMMETRIES
   - Based on the subtraction of the azimuthal spectra from data and from Monte Carlo



Contamination and correction

The method for both **normalization** of the samples and for the **subtraction** of the DVM contamination is fully implemented.

- the contamination $r_{tot} = \frac{N_h^{excl}}{N_h^{tot}} = \frac{N_h^{\rho,excl} + N_h^{\phi,excl} + N_h^{\omega,excl}}{N_h^{tot}}$

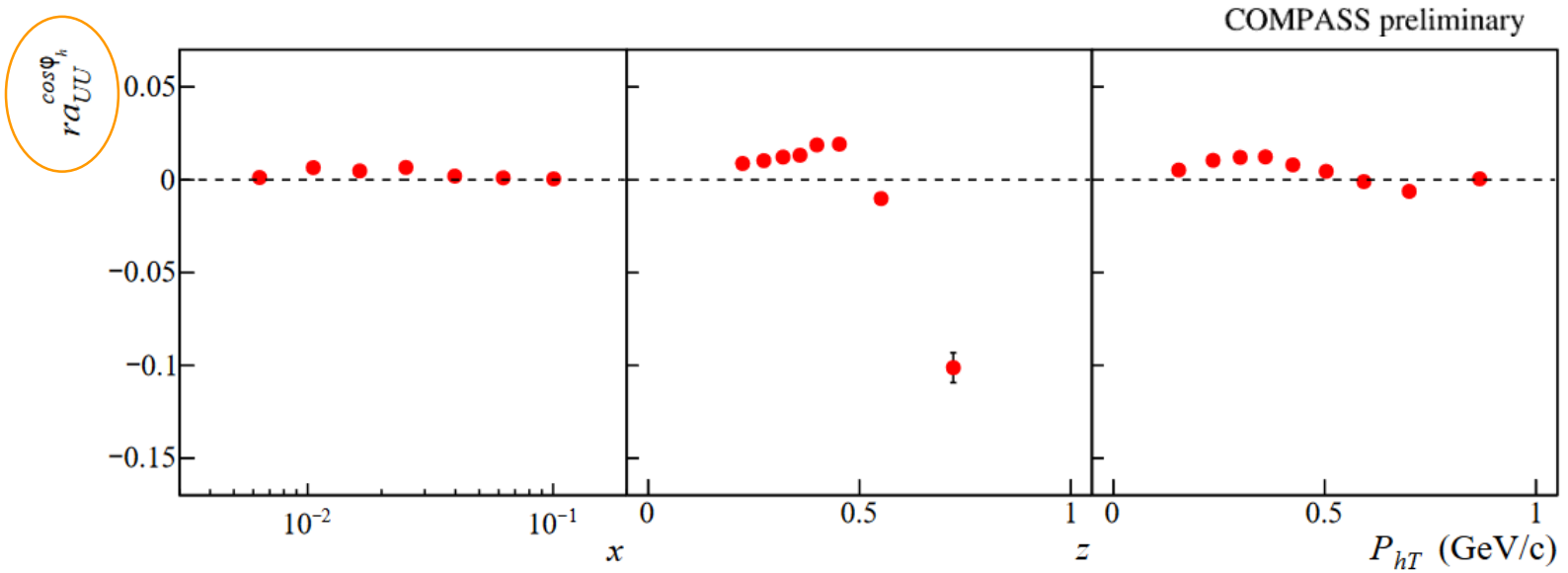


averaged over several subperiods of data taking

Contamination and correction

The method for both **normalization** of the samples and for the **subtraction** of the DVM contamination is fully implemented.

- $A_{corr} \approx \frac{A_{not\ corr} - r a_{excl}}{1-r}$, where a_{excl} is the azimuthal modulation of the "exclusive hadrons".
- Here the size of the correction to the unsubtracted asymmetries:



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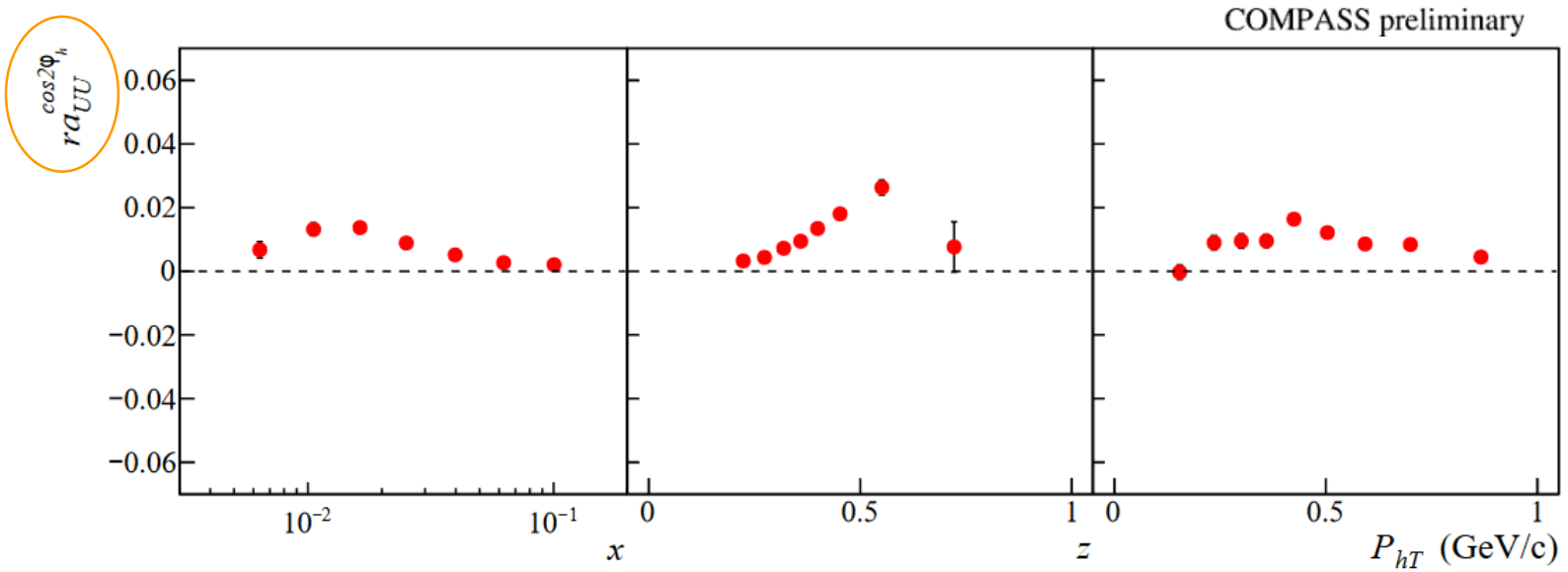
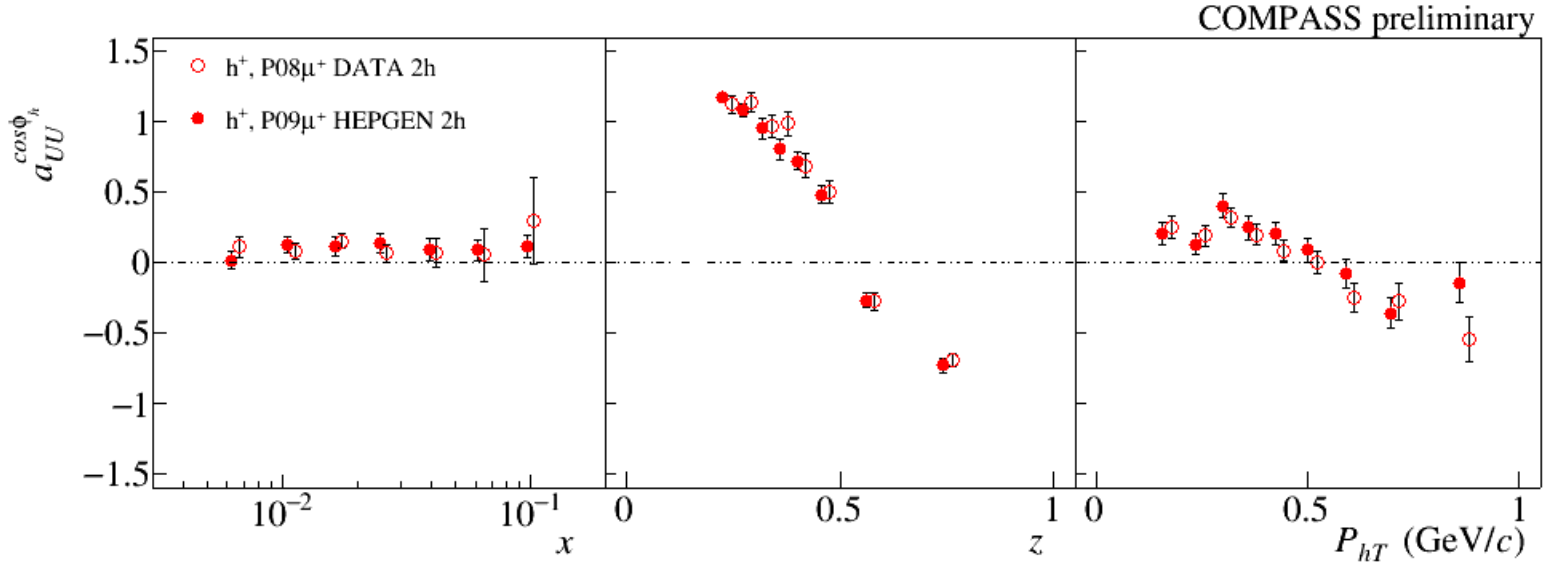
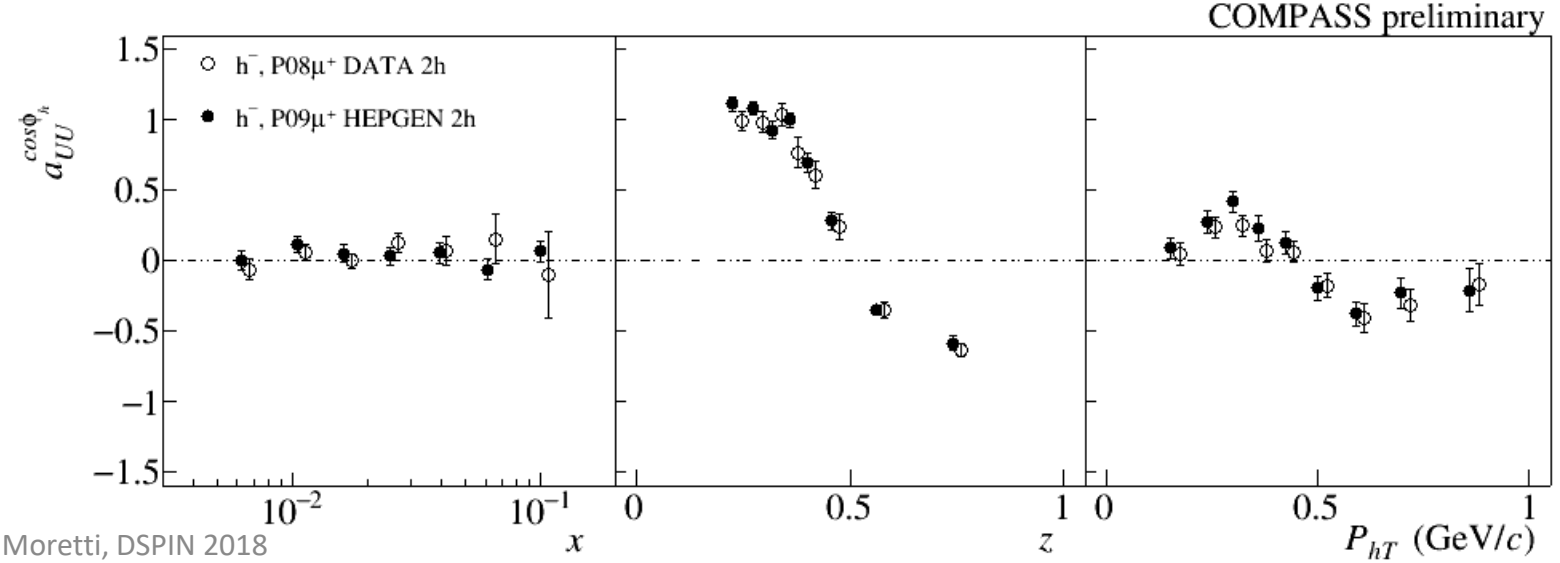


Comparison Data – MC for the 2h case

A check of the good description given by HEPGEN: comparison of 2h raw "asymmetries" in DATA and MC





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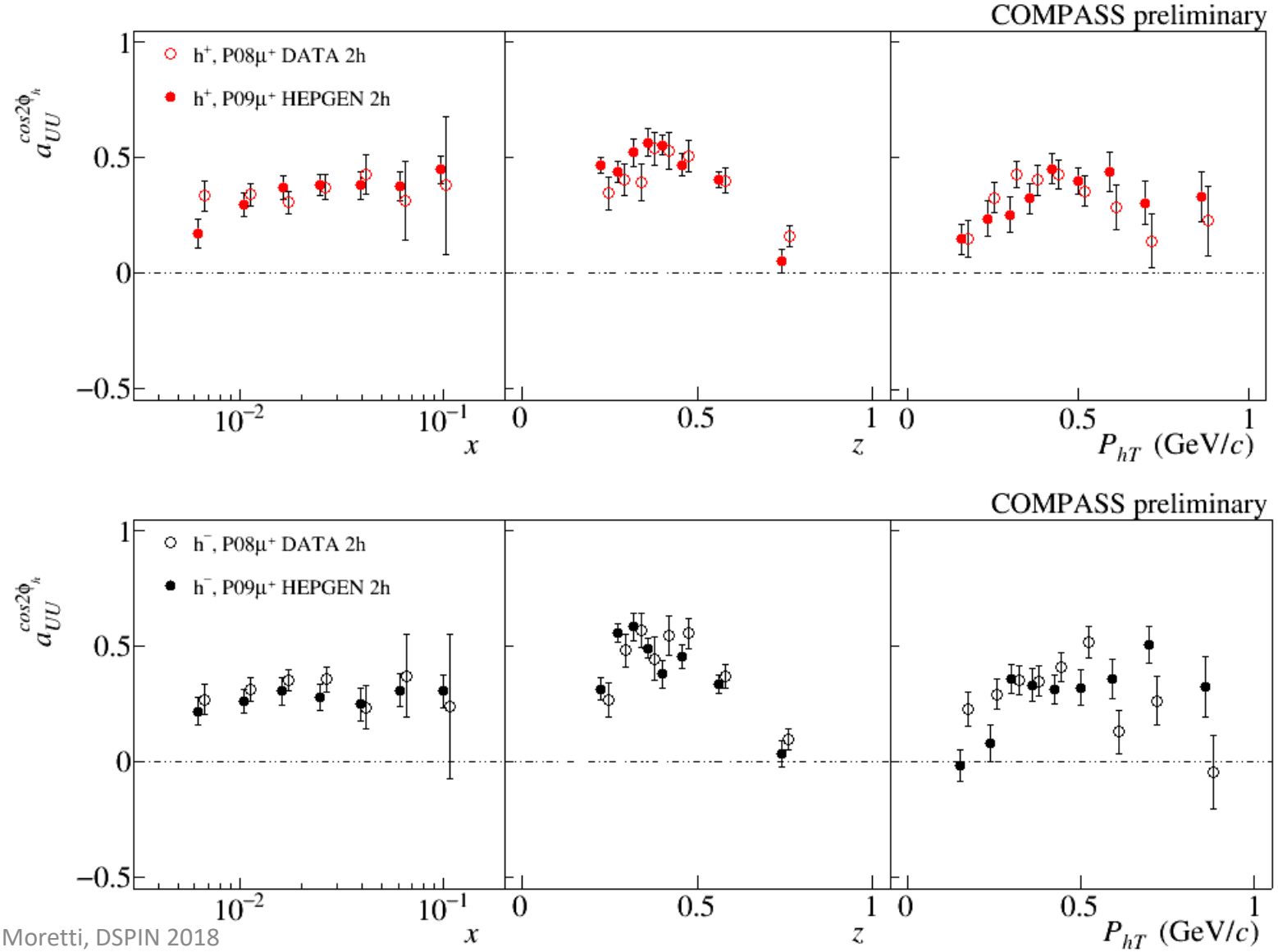


Conclusions

- The COMPASS Collaboration is working on the analysis of the proton data collected in 2016 and 2017.
- Azimuthal asymmetries and TMD-multiplicities are hot topics being addressed.
- Preliminary results have been shown, together with projections for the statistical uncertainty.
- A method for the estimation and subtraction of the DVM contribution has been presented here.
- A challenging analysis, but of great impact for TMD physics.

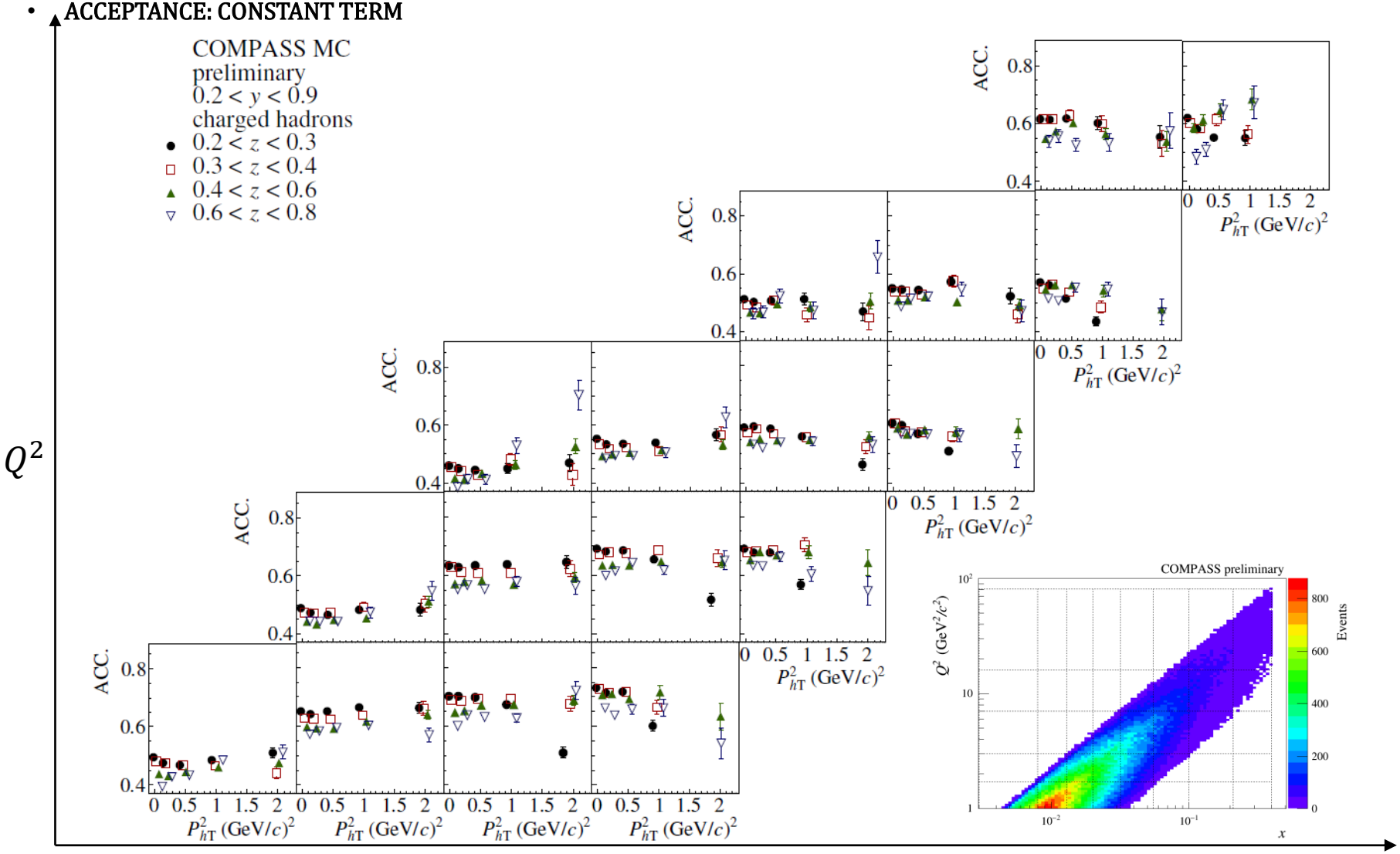
Thank you!

backup

Acceptance study - projection for the 4D asymmetries

The usable range for the 4D extraction of the azimuthal asymmetries is studied looking at acceptance (considering both beam and hadron charges together)

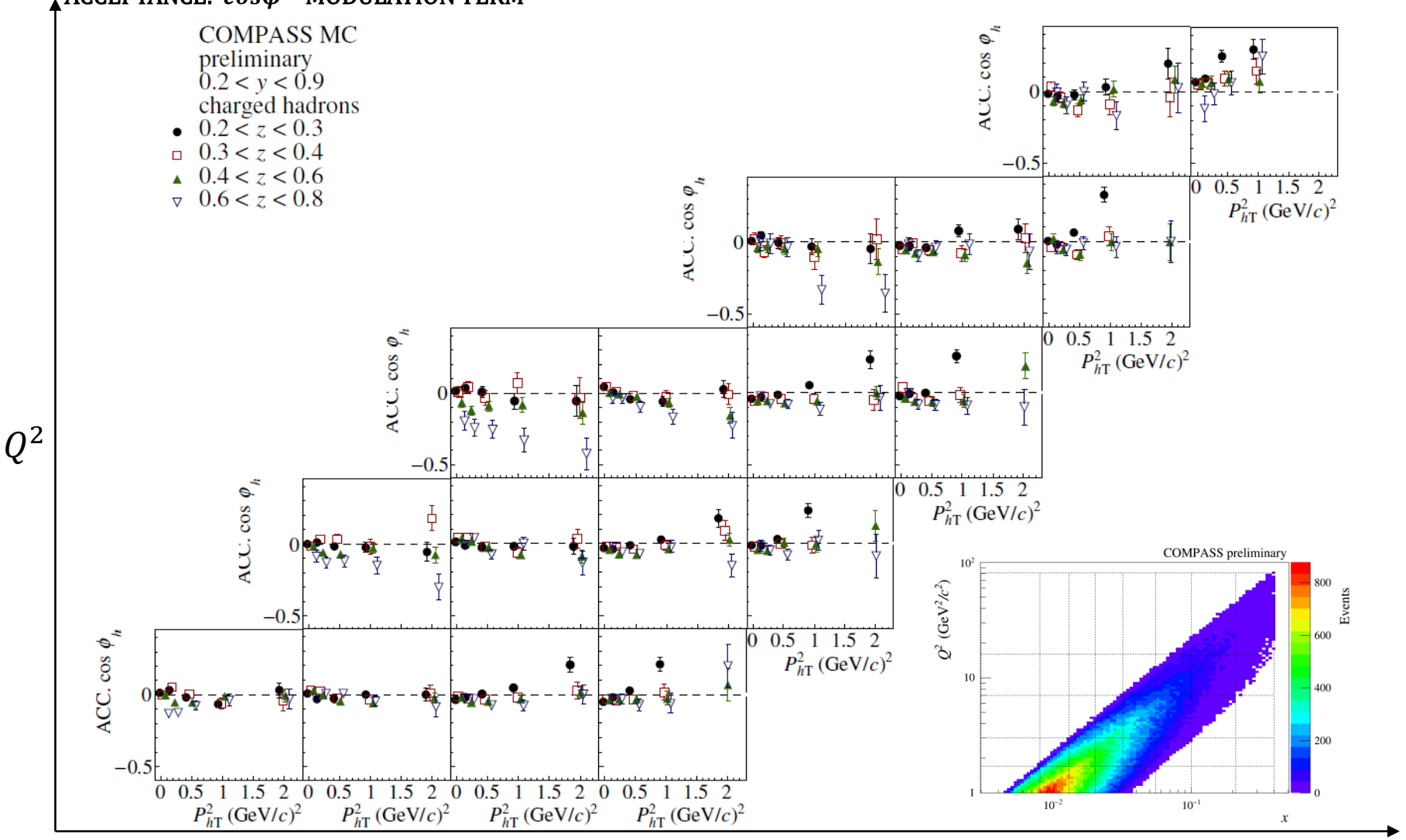
- **ACCEPTANCE: CONSTANT TERM**



Acceptance study - projection for the 4D asymmetries

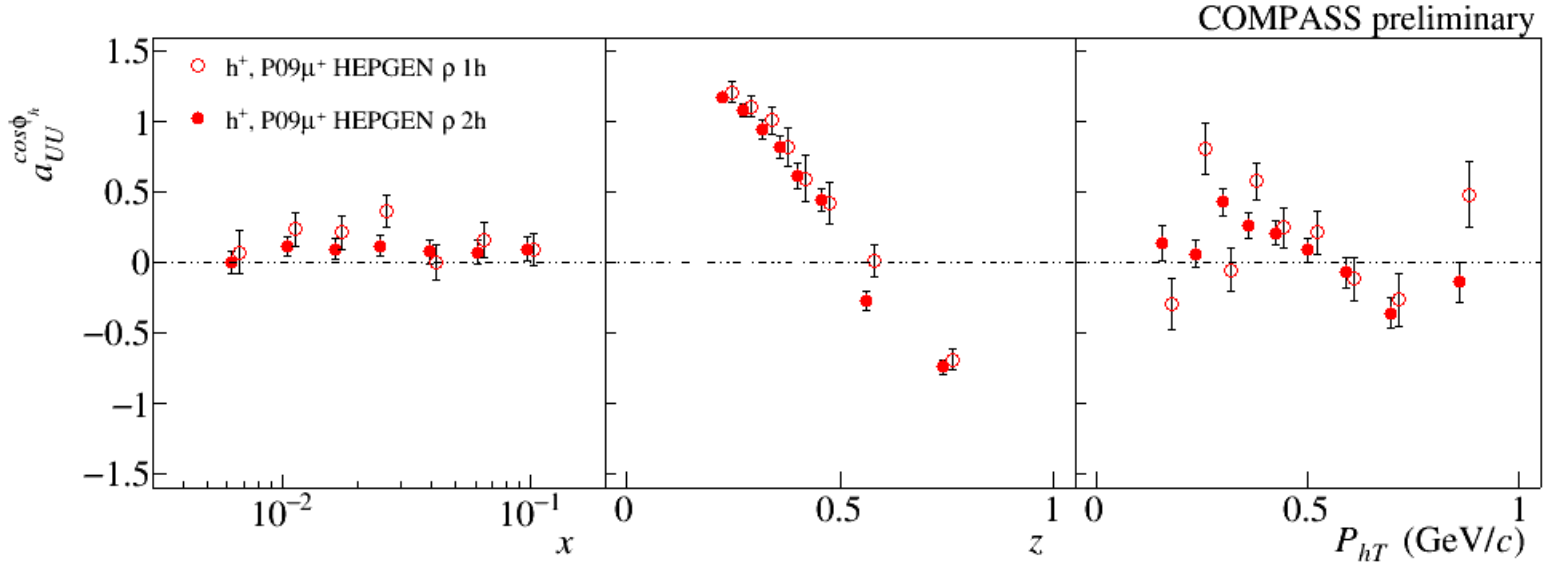
The usable range for the 4D extraction of the azimuthal asymmetries is studied looking at acceptance (considering both beam and hadron charges together)

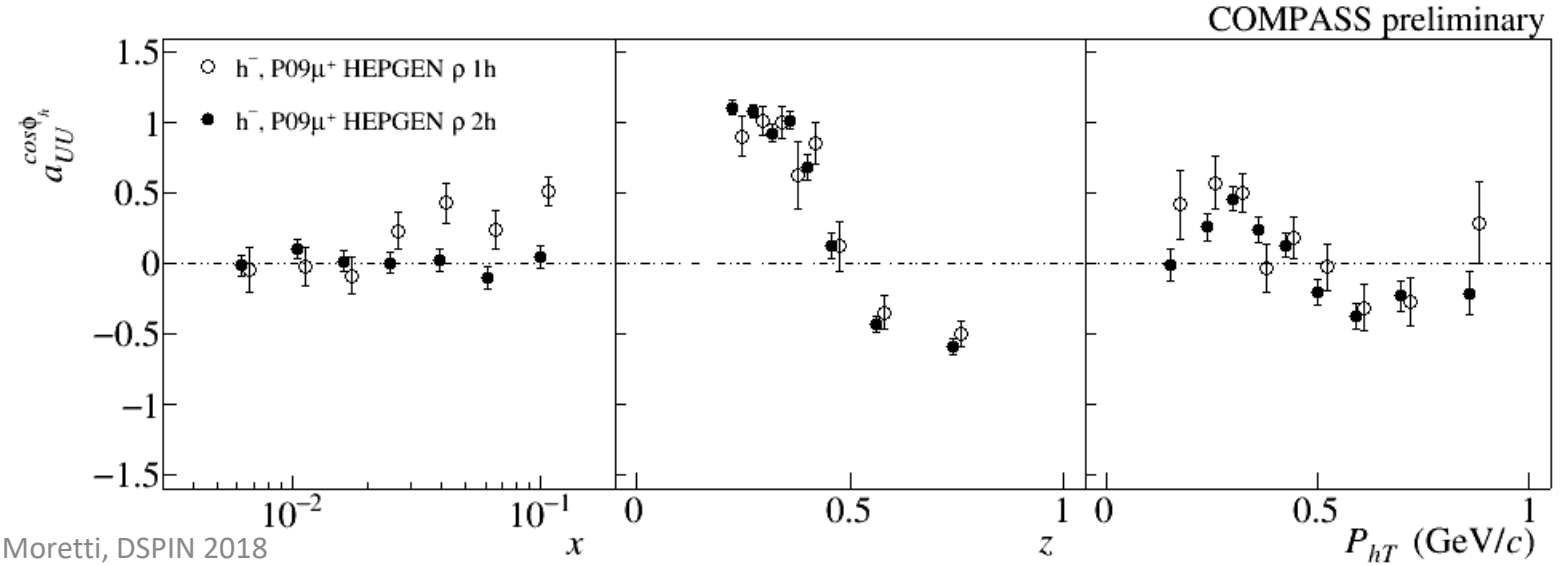
- **ACCEPTANCE: $cos\phi$ - MODULATION TERM**



Comparison 1h-2h in MC

As it has been assumed that 1h and 2h have the same modulations in exclusive events, we checked it in MC





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