Accessing the nucleon structure in unpolarized SIDIS at COMPASS

Andrea Moretti

on behalf of the COMPASS Collaboration

Introduction

Semi-Inclusive Deep Inelastic Scattering (SIDIS) is a powerful tool to access the rich and complex structure of the nucleon.

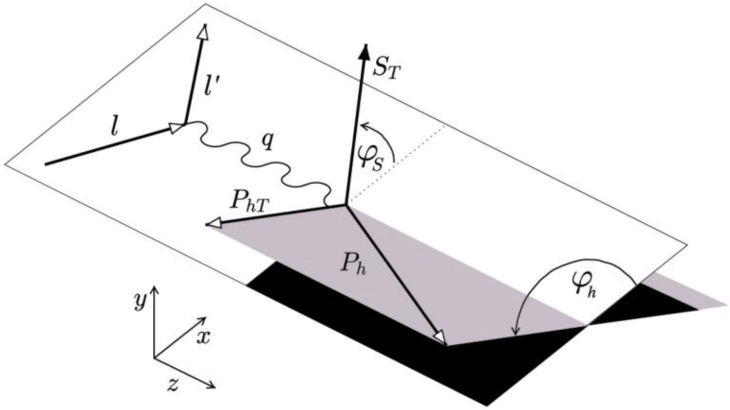
Depending on the nucleon polarization, several (TMD)-PDFs can be accessed

In this talk: focus on the SIDIS off unpolarized nucleons

Nucleon \ Quark	**U** unpolarized	**L** longitudinally polarized	**T** transversely polarized
U unpolarized	$f_1^q(x,k_T^2)$ **number density**		$h_1^{\perp q}(x,k_T^2)$ **Boer-Mulders**
L longitudinally polarized		$g_1^q(x,k_T^2)$ **helicity**	$h_{1L}^{\perp q}(x,k_T^2)$ **Kotzinian-Mulders worm-gear L**
T transversely polarized	$f_{1\perp}^q(x,k_T^2)$ **Sivers**	$g_{1T}^{\perp q}(x,k_T^2)$ **Kotzinian-Mulders worm-gear T**	$h_1^q(x,k_T^2)$ **transversity** $h_{1T}^{\perp q}(x,k_T^2)$ **Pretzelosity**

Cross section for unpolarized SIDIS

In SIDIS, a high energy lepton scatters off a nucleon target and at least one hadron is observed in the final state.



The Gamma Nucleon System (GNS)

For an unpolarized nucleon target, at high Q^2 and in the one-photon exchange approximation **the fully-differential cross-section** reads:

$$\frac{d^5\sigma}{dx\, dy\, dz\, d\varphi_h dP_T^2} = \frac{2\pi\alpha^2}{xyQ^2}\frac{y^2}{2(1-\varepsilon)}\left(1+\frac{\gamma^2}{2x}\right)$$

$$\cdot\left(F_{UU,T} + \varepsilon F_{UU,L} + \sqrt{2\varepsilon(1+\varepsilon)}F_{UU}^{\cos\varphi_h}\cos\varphi_h + \varepsilon F_{UU}^{\cos 2\varphi_h}\cos 2\varphi_h + \lambda_l\sqrt{2\varepsilon(1-\varepsilon)}F_{LU}^{\sin\varphi_h}\sin\varphi_h\right)$$

Bacchetta et al., *JHEP* 02 (2007) 093

- x is the Bjorken variable
- Q^2 the photon virtuality
- $\gamma = \frac{2Mx}{Q}$ (small in COMPASS kinematics)
- $y = 1 - \frac{E_{\ell'}}{E_\ell}$ the inelasticity with $E_{\ell(')}$ the energy of the incoming (scattered) lepton in the target rest frame
- $\varepsilon(y) = \frac{1-y-\frac{1}{4}\gamma^2 y^2}{1-y+\frac{1}{2}y^2+\frac{1}{4}\gamma^2 y^2}$
- λ_l is the beam polarization.
- z is the fraction of photon energy carried by the hadron
- φ_h its azimuthal angle in the Gamma Nucleon System
- P_T its transverse momentum w.r.t. the photon

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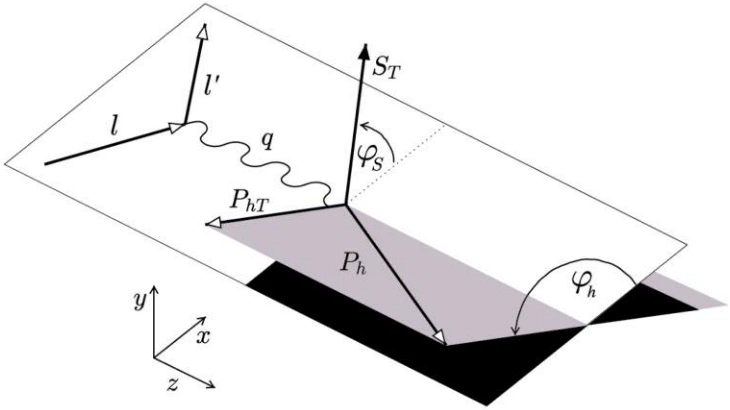

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The structure functions $F_{XY[,Z]}^{[f(\varphi_h)]}$ can be written in terms of

- TMD Parton Distributions Functions (PDFs)
- TMD Fragmentation Functions (FFs).

Unpolarized structure functions

Unpolarized SIDIS → access to the **number density TMD** and to the **Boer-Mulders TMD** $h_1^\perp$

Quark \ Nucleon	**U** unpolarized	**L** longitudinally polarized	**T** transversely polarized
U unpolarized	$f_1^q(x,k_T^2)$ **number density**		$h_1^{\perp q}(x,k_T^2)$ **Boer-Mulders**

The correlation between $\boldsymbol{k_T}$ and $\boldsymbol{s_T}$ *generates* a neat transverse polarization

Boer-Mulders function $\boldsymbol{h_1^\perp}$ couples to the **Collins FF** $\boldsymbol{H_1^\perp}$: fragmentation of a transversely polarized quarks into hadron

Up to order $1/Q$ (i.e. at twist-3) in Wandzura-Wilczek approximation *:

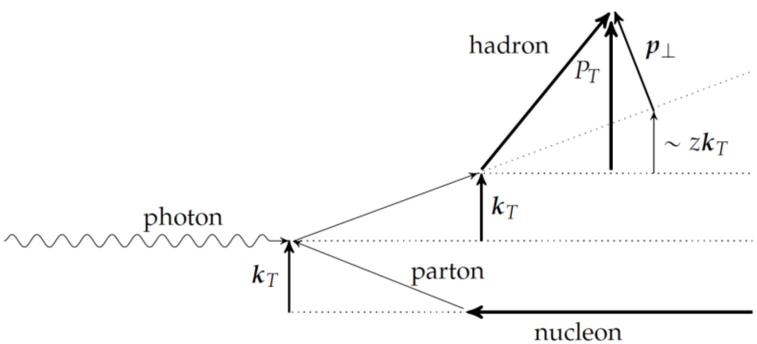
$$F_{UU,T} = \mathcal{C}[f_1 D_1]$$

Cahn effect *Boer-Mulders term*

$$F_{UU}^{\cos\varphi_h} = \frac{2M}{\boldsymbol{Q}}\mathcal{C}\left[-\frac{(\hat{h}\cdot\vec{\boldsymbol{k}}_{\boldsymbol{T}})}{M}\boldsymbol{f_1 D_1} - \frac{(\hat{h}\cdot\vec{\boldsymbol{p}}_\perp)\boldsymbol{k_T^2}}{zM^2 M_h}\boldsymbol{h_1^\perp H_1^\perp} + \cdots\right]$$

$$F_{UU}^{\cos 2\varphi_h} = \mathcal{C}\left[-\frac{2(\hat{h}\cdot\vec{\boldsymbol{k}}_{\boldsymbol{T}})(\hat{h}\cdot\vec{\boldsymbol{p}}_\perp) - \vec{\boldsymbol{k}}_{\boldsymbol{T}}\cdot\vec{\boldsymbol{p}}_\perp}{zM\,M_h}\boldsymbol{h_1^\perp H_1^\perp}\right]$$

Boer-Mulders term



where $\mathcal{C}[wfD]$ is the convolution over the unobservable transverse momenta:

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

$$\hat{h} = \vec{P}_T / |\vec{P}_T|$$

* possible further contributions at high z from the *Berger-Brodsky* mechanism
Brandenburg et al., *Phys.Lett.B* 347 (1995) 413-418

Unpolarized structure functions

Gaussian Ansatz → the TMD PDFs and FFs factorize as:

$$f_1^q(x,k_T^2) = f_1^q(x)\frac{e^{-\frac{k_T^2}{\langle k_{T,q}^2\rangle}}}{\pi\langle k_{T,q}^2\rangle} \qquad D_1^{h/q}(z,p_\perp^2) = D_1^{h/q}(z)\frac{e^{-\frac{p_\perp^2}{\langle p_{\perp,h/q}^2\rangle}}}{\pi\langle p_{\perp,h/q}^2\rangle}$$

from which, assuming flavour independence, it follows that e.g.

$$F_{UU,T} = x\sum_q e_q^2 f_1^q(x) D_1^{h/q}(z)\frac{e^{-\frac{P_T^2}{\langle P_T^2\rangle}}}{\pi\langle P_T^2\rangle}$$

→ $\boldsymbol{P_T^2}$ **distributions**

$$F_{UU\,|\,Cahn}^{\cos\varphi_h} = -\frac{2zP_T\langle k_T^2\rangle}{Q\langle P_T^2\rangle}F_{UU,T}$$

$$F_{UU\,|\,BM}^{\cos\varphi_h} = -\frac{2P_T\langle k_T^2\rangle\langle p_\perp^2\rangle}{zQMM_h\langle P_T^2\rangle^3}\left(\langle p_\perp^2\rangle\langle P_T^2\rangle + z^2\langle k_T^2\rangle(P_T^2-\langle P_T^2\rangle)\right)\frac{\sum_q x h_1^{\perp q}(x)H_1^\perp(z)}{\sum_q x f_1^q(x)D_1(z)}F_{UU,T}$$

$$F_{UU|BM}^{\cos 2\varphi_h} = \frac{P_T^2\langle k_T^2\rangle\langle p_\perp^2\rangle}{MM_h\langle P_T^2\rangle^2}\frac{\sum_q x h_1^{\perp q}(x)H_1^\perp(z)}{\sum_q x f_1^q(x)D_1(z)}F_{UU,T}$$

→ **Azimuthal asymmetries**

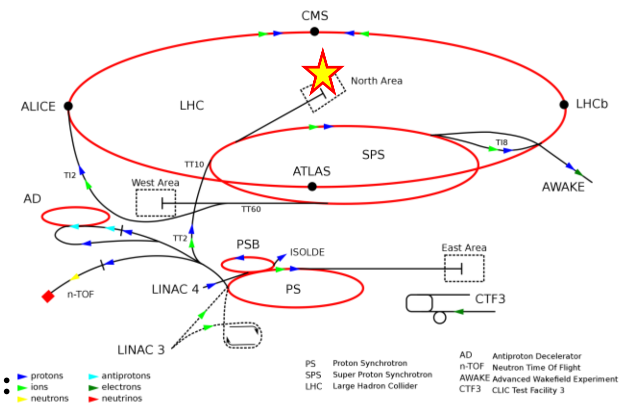
Both sets of observables measured in COMPASS with an unpolarized proton target after similar measurements on deuteron

EPJC 73 (2013) 2531
PRD 97(2018) 032006
NPB 886 (2014) 1046
NPB 956 (2020) 115039

The COMPASS experiment

COMPASS contribution to the understanding of the nucleon structure

- spin asymmetries with transverse and longitudinal spin polarization
  important results on the extraction of transversity and Sivers functions
- SIDIS with unpolarized target
  azimuthal asymmetries and P_T^2-distributions on deuteron



COMPASS (COmmon Muon Proton Apparatus for Structure and Spectroscopy):

- 24 institutions from 13 countries (about 220 physicists)
- a fixed target experiment
- located in the CERN North Area, along the SPS M2 beamline

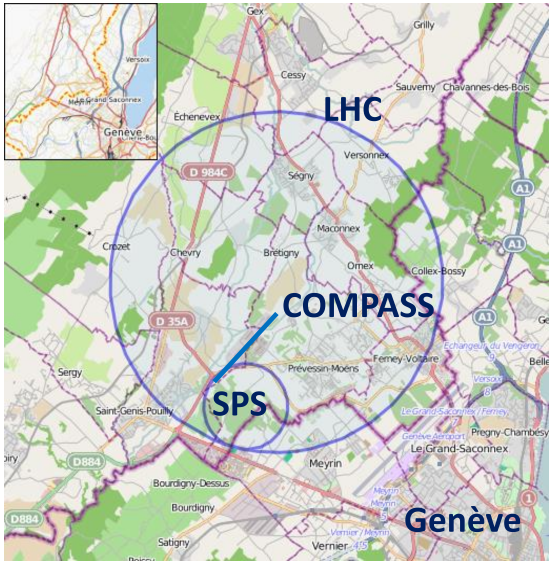
Broad research program:

- SIDIS with μ beam, with (un)polarized deuteron or proton target.
- Hadron spectroscopy with hadron beams and nuclear targets
- Drell-Yan measurement with π^- beam with polarized target
- Deeply Virtual Compton Scattering (DVCS)
- …

Talks by
C. Riedl (GPDs)
and R. Longo (DY)

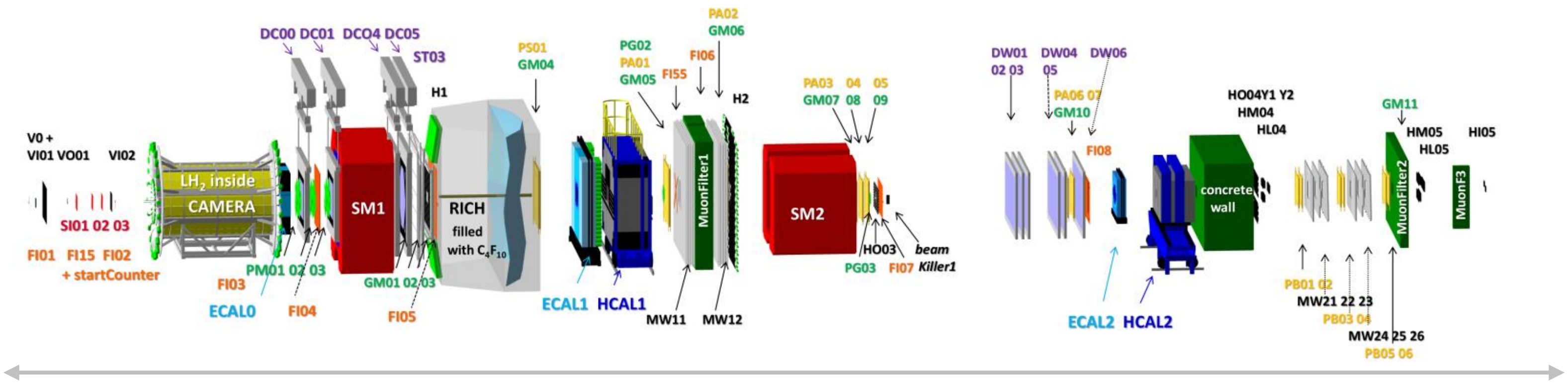
A multipurpose apparatus:

- Two-stage spectrometer, about 330 detector planes
- μ identification, RICH, calorimetry



The COMPASS location at CERN

The 2016 COMPASS run



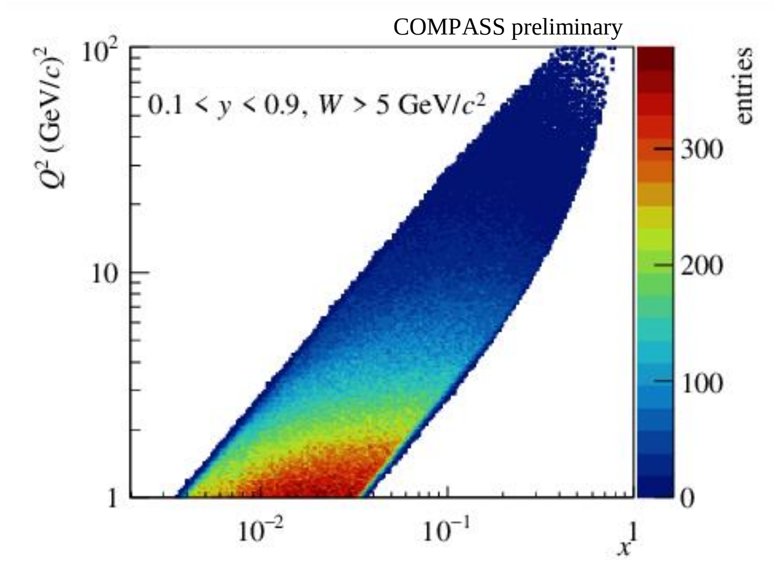
The 2016 COMPASS experimental setup

In 2016 (and 2017) the data-taking was dedicated to the measurement of Deeply Virtual Compton Scattering (DVCS).

In parallel, new SIDIS data have been collected in COMPASS, with:

- 160 GeV/c μ beam (μ^+ and μ^- with balanced statistics)
- Unpolarized, 2.5 m long **liquid hydrogen target**

Part of the data (~11% of the available statistics) have been analyzed to measure unpolarized SIDIS observables → ~ 6.5 million hadrons



The $x - Q^2$ coverage

List of the main results

Large set of results from the proton data: not all shown here!

P_T^2-distributions

- *For positive and negative hadrons in bins of x, Q^2 and z (4,2,4)*
- *Fits with single exponential, double exponential and Tsallis*
- *$\langle P_T^2 \rangle$ vs. z^2 as from the double exponential fit*
- *Fit of $\langle P_T^2 \rangle$ vs. z^2 in bins of x, Q^2 and z*
- *Distributions in q_T and q_T^2*
- *Distributions in 2 W bins + ratio high-over-low Q^2 + ratio high-over-low W*
- *Distributions in 4 Q^2 bins*

Azimuthal asymmetry $A_{UU}^{\cos\phi_h}$, $A_{UU}^{\cos 2\phi_h}$ and $A_{LU}^{sin\phi_h}$

- *1D: standard binning in x, z or P_T*
- *Also: low-z and high-P_T -- for completeness*
- *1D standard + 4 bins in Q^2 --- new: interesting evolution of $A_{UU}^{cos\phi_h}$*
- *1D standard + 2 bins in Q^2 and 2 bins in W*
- *3D: standard binning (simultaneous in x, z and P_T)*
- *In addition to deuteron analysis: low-z bin*

Contribution from exclusive hadrons

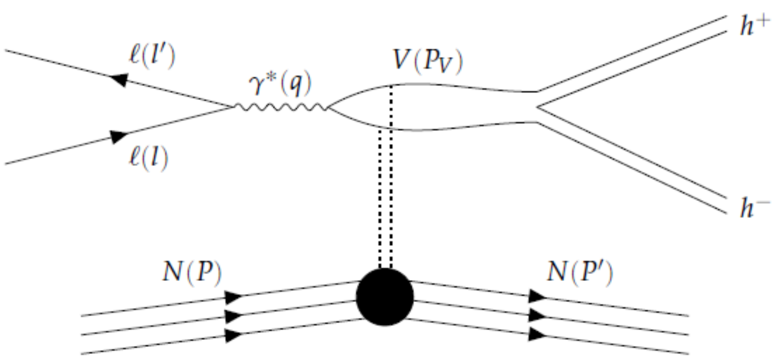
Hadrons from the decay of exclusive diffractive vector mesons *(exclusive hadrons)*, very interesting per se, constitute a relevant source of background for the SIDIS measurement.

The two most important channels: $\rho^0 \to \pi^+\pi^- \; and \; \phi \to K^+K^-$

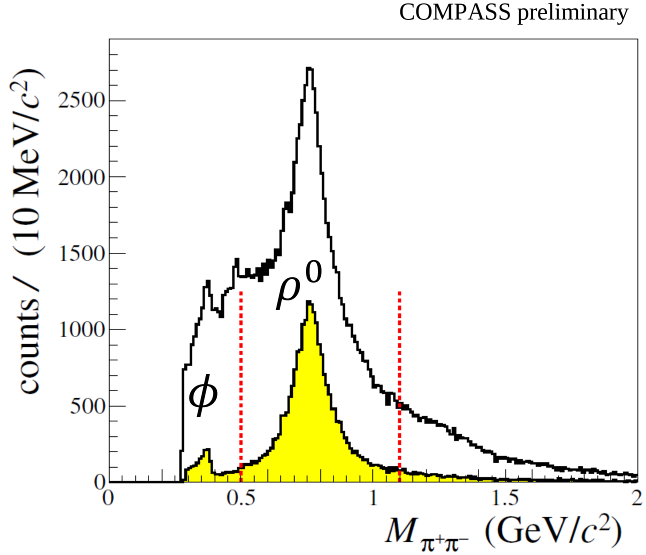
- Well visible in the data at vanishing missing energy

$$E_{miss} = \frac{M_X^2 - M_p^2}{2M_p}$$

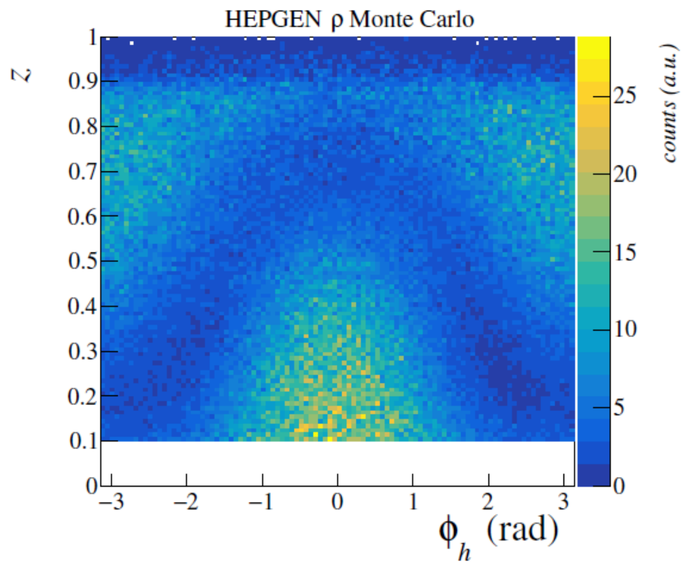
- Strong modulations in the azimuthal angle
- Contamination as high as 30% at high z



The diffractive production of a vector meson V and its decay into a hadron pair



Invariant mass distribution in the data, before and after cutting in missing energy



$\phi_h - z$ correlation for exclusive hadrons

Impact on the azimuthal asymmetries measured on a deuteron target: COMPASS, *Nucl.Phys.B* 956 (2020) 115039

Transverse momentum distributions

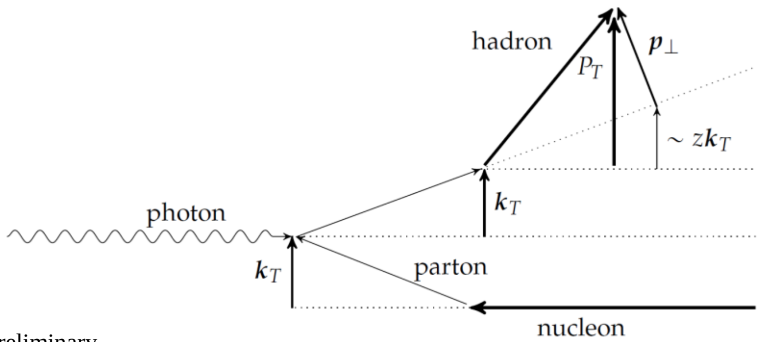
See also the talk by A. Martin TMDs session II

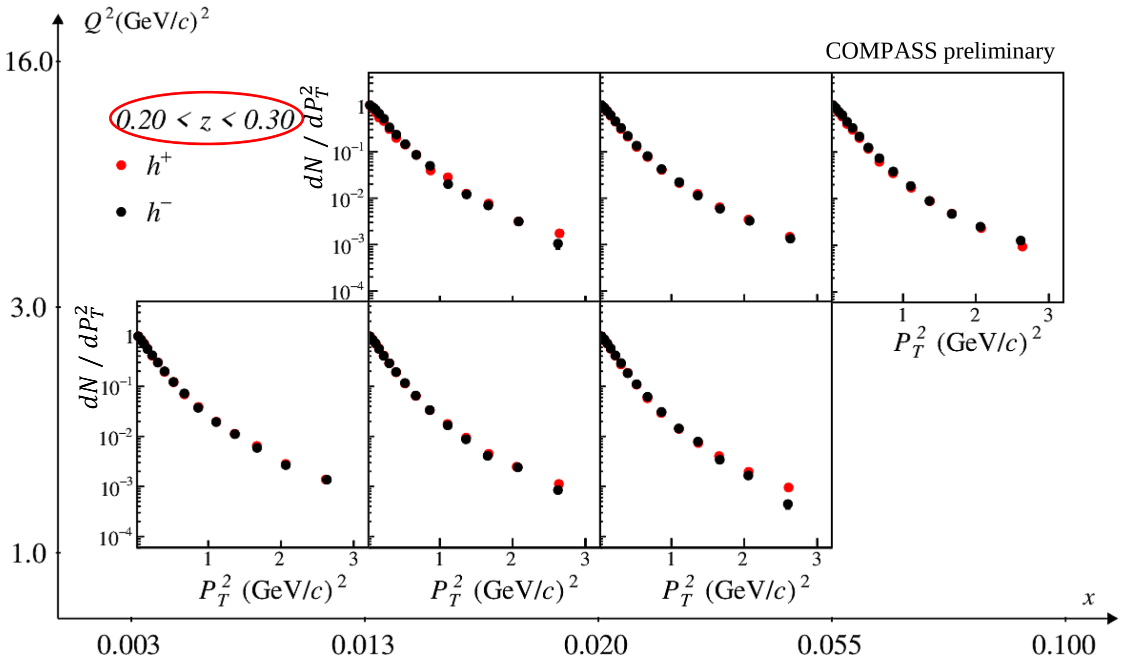
Transverse-momentum distributions
- give relevant information on k_T and $p_\perp$
- are interesting for the TMD evolution studies:
  a lot of theoretical work to reproduce the experimental distributions over a large energy range

In gaussian approximation, at small values of P_T, the number of hadrons is expected to follow:

$$\frac{d^2N^h(x,Q^2;z,P_T^2)}{dz\,dP_T^2} \propto \exp\left(-\frac{P_T^2}{\langle P_T^2\rangle}\right)$$

$$\langle P_T^2\rangle = z^2\langle k_T^2\rangle + \langle p_\perp^2\rangle$$



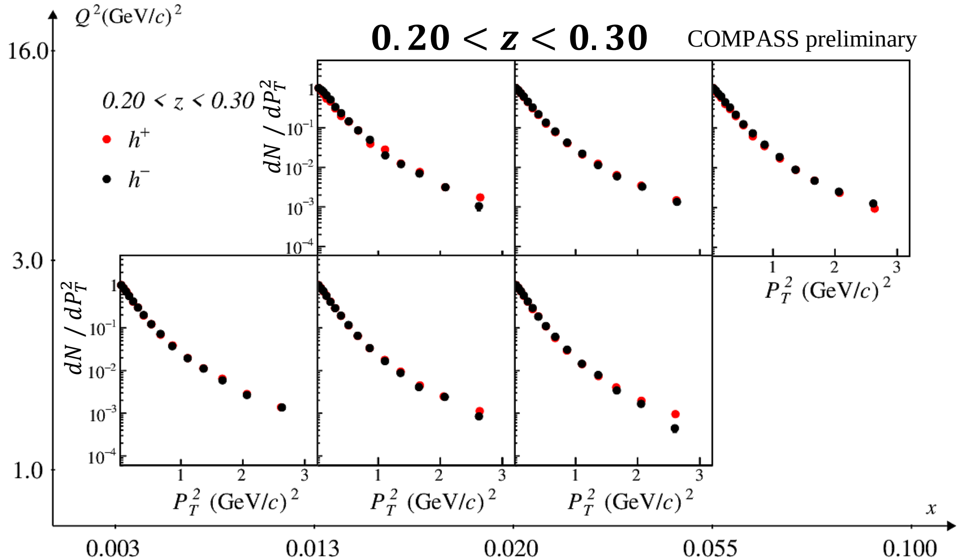


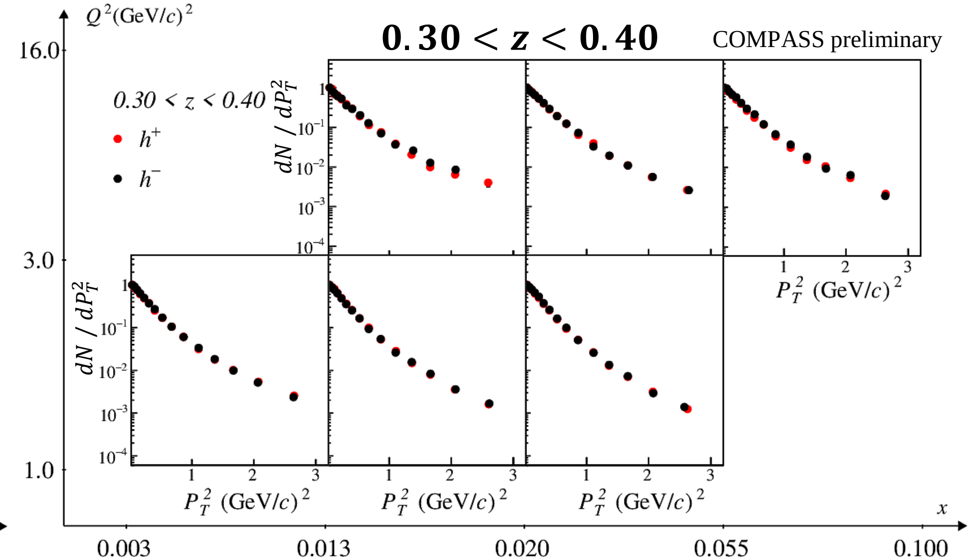
- **Normalization: first P_T^2 bin.**
- Different normalization for each bin and charge
- Two different slopes for P_T above / below 1 GeV/c
- Perturbative effects expected to contribute more there
- Likely not sufficient to explain the high- P_T trend

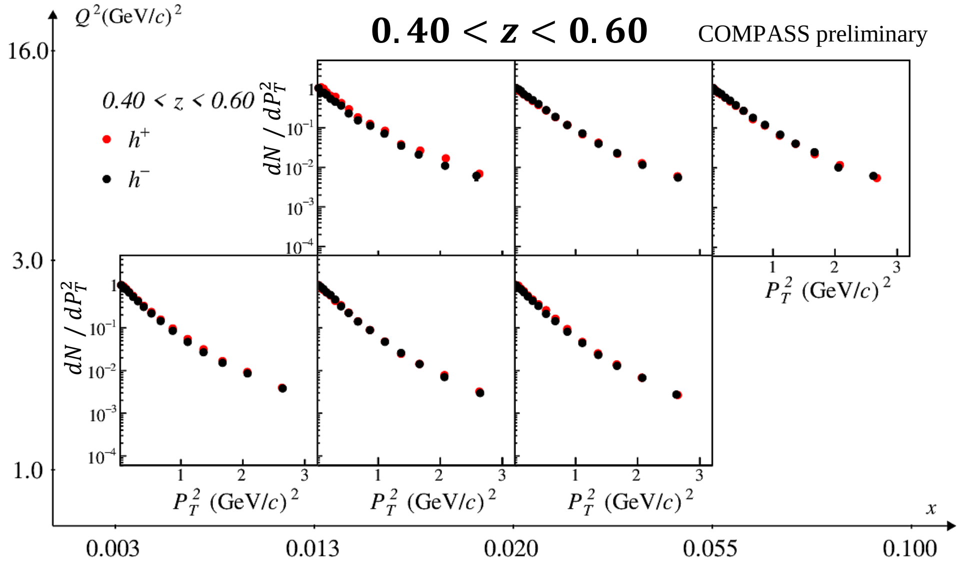
e.g. Gonzales-Hernandez et al., *Phys.Rev.D* 98 (2018) 11, 114005

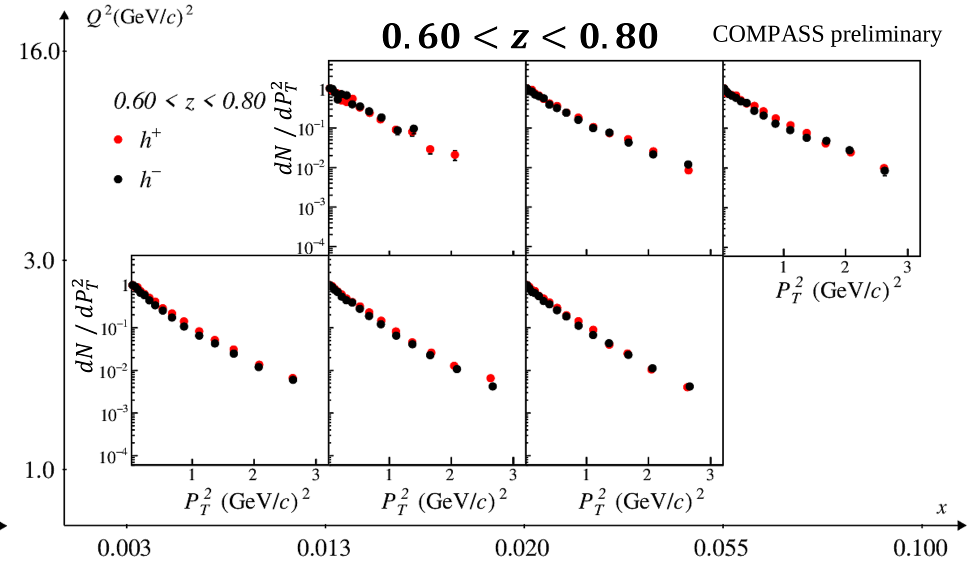
Transverse momentum distributions

The error bars correspond to the statistical uncertainty only. $\sigma_{syst} \sim 0.3\,\sigma_{stat}$







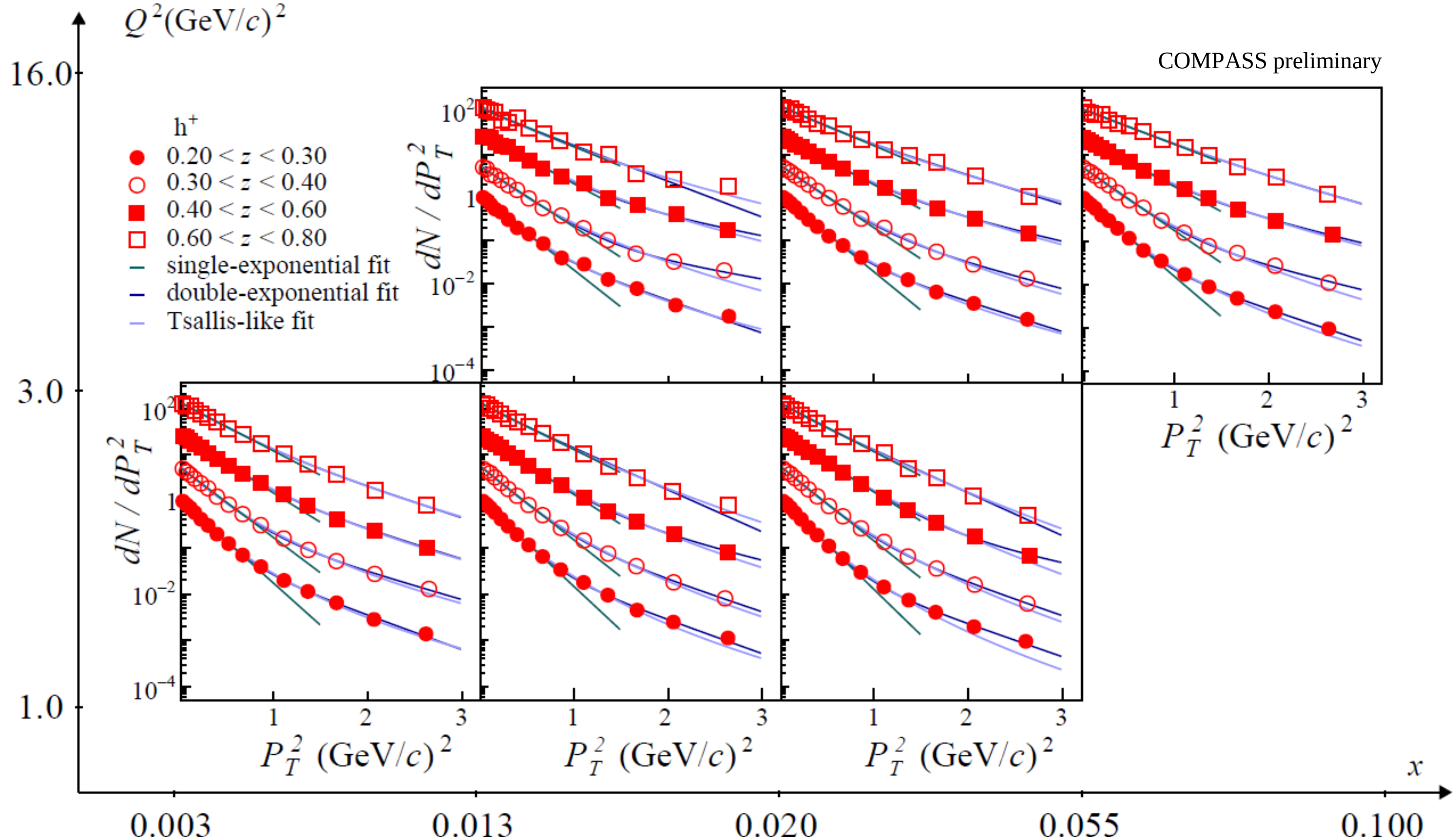


Fit of the P_T^2 - distributions

P_T^2 – distributions fitted with three different functions:

- a single-exponential up to 1 GeV/c : $f(x) = \alpha \exp\left(-\frac{x}{\beta}\right) \Longrightarrow \langle P_T^2 \rangle = \beta$
- a double-exponential up to 3 GeV/c : $g(x) = A \exp\left(-\frac{x}{a}\right) + B \exp\left(-\frac{x}{b}\right) \Longrightarrow \langle P_T^2 \rangle = \frac{Aa^2+Bb^2}{Aa+Bb}$
- a Tsallis-like power law up to 3 GeV/c : $h(x) = c_0(1 + c_1 x)^{-c_2} \Longrightarrow \langle P_T^2 \rangle = \frac{1}{c_1(c_2-2)}$

Very similar results



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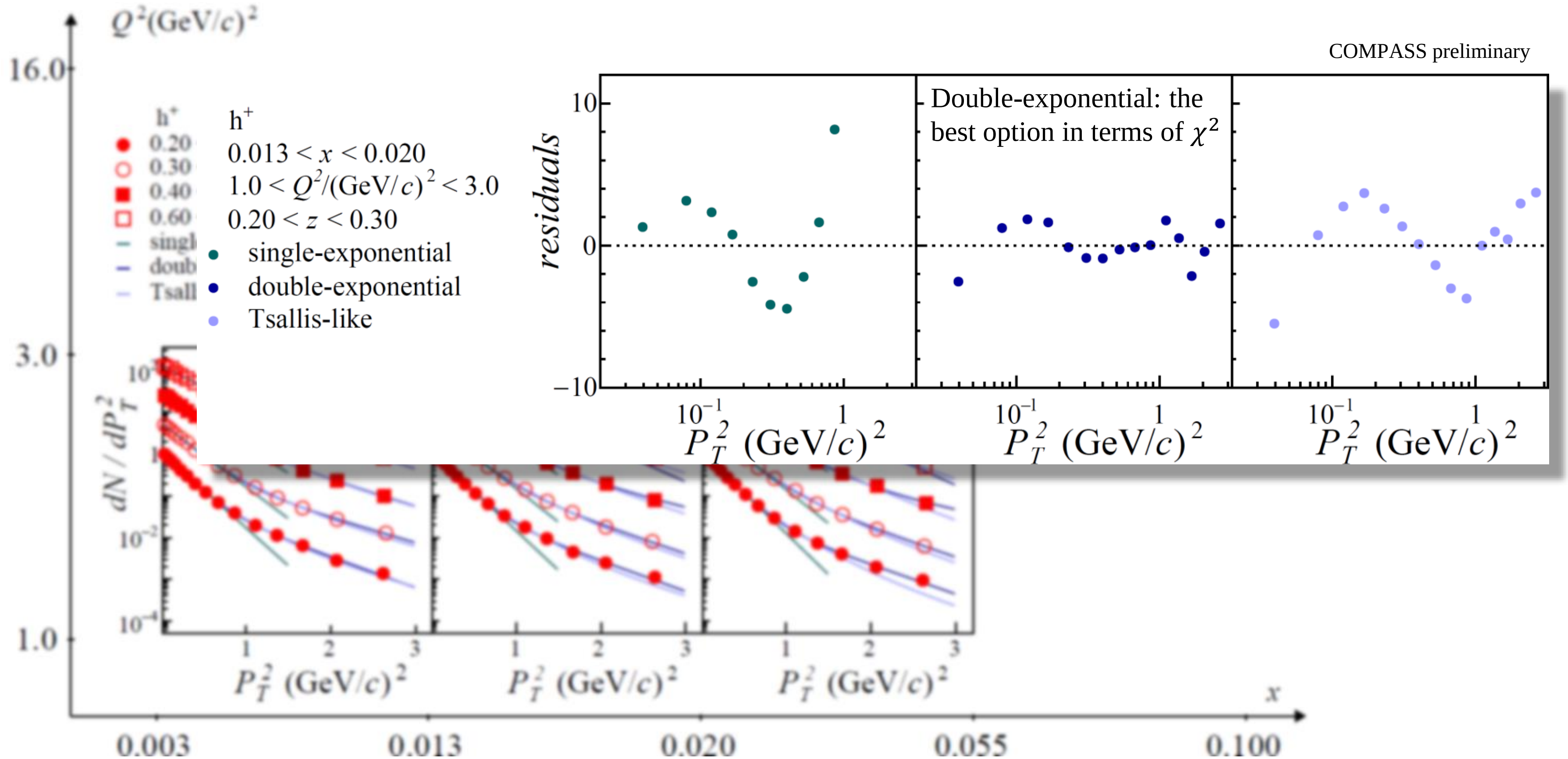
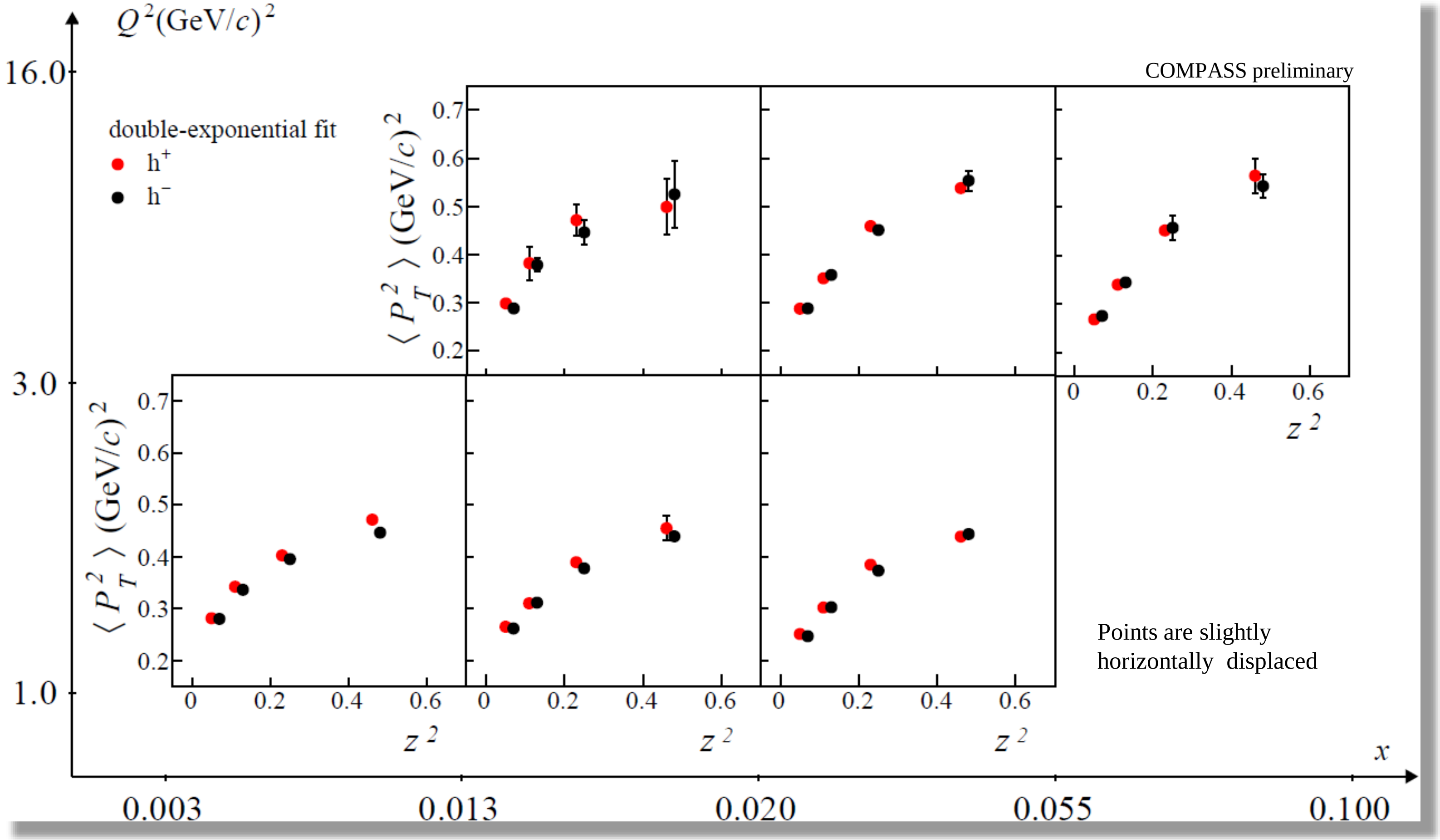


Fit of the P_T^2 - distributions

Leading Order expectation: $\langle P_T^2 \rangle = z^2 \langle k_T^2 \rangle + \langle p_\perp^2 \rangle$
Deviation from linearity: already there with the deuteron multiplicities / distributions



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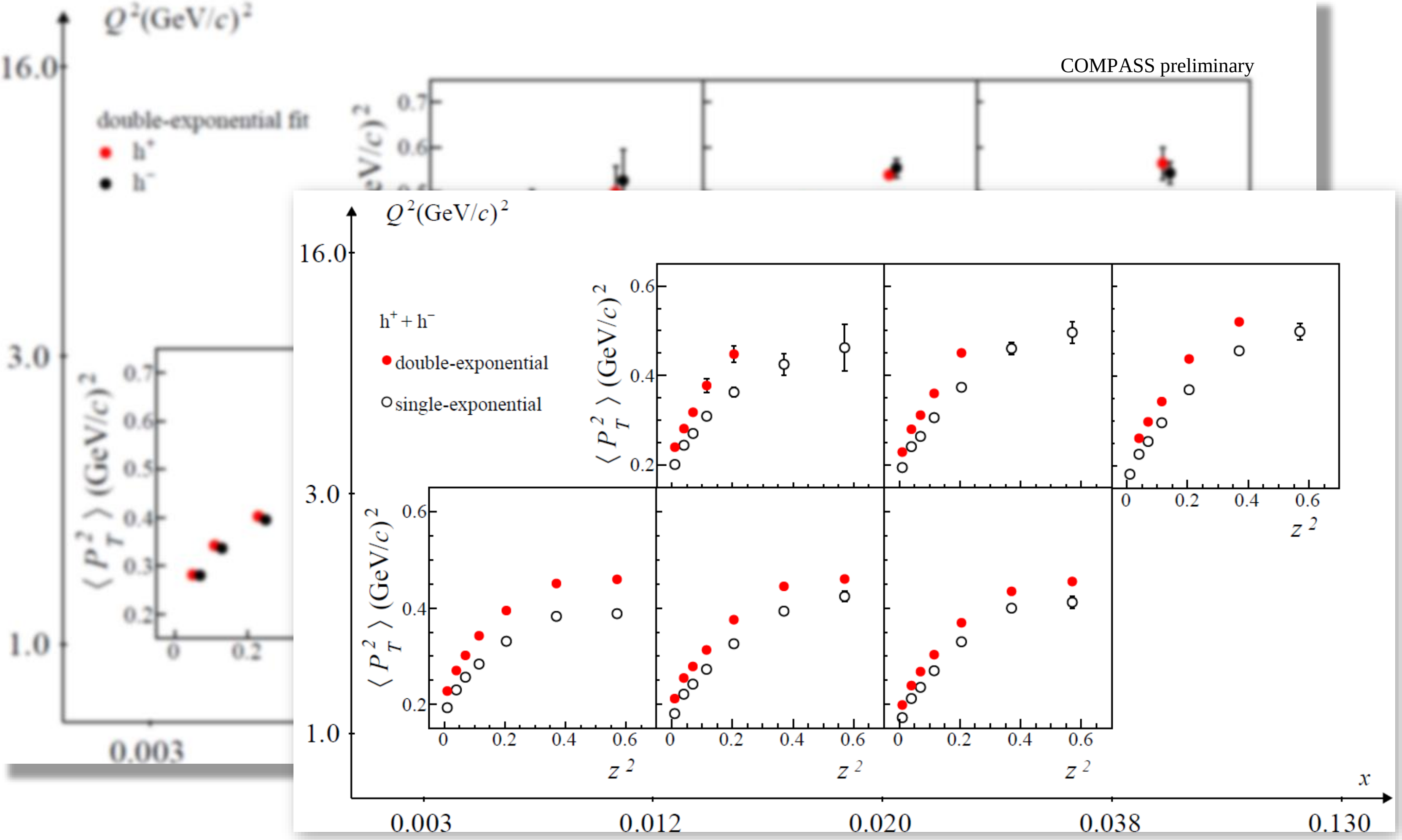

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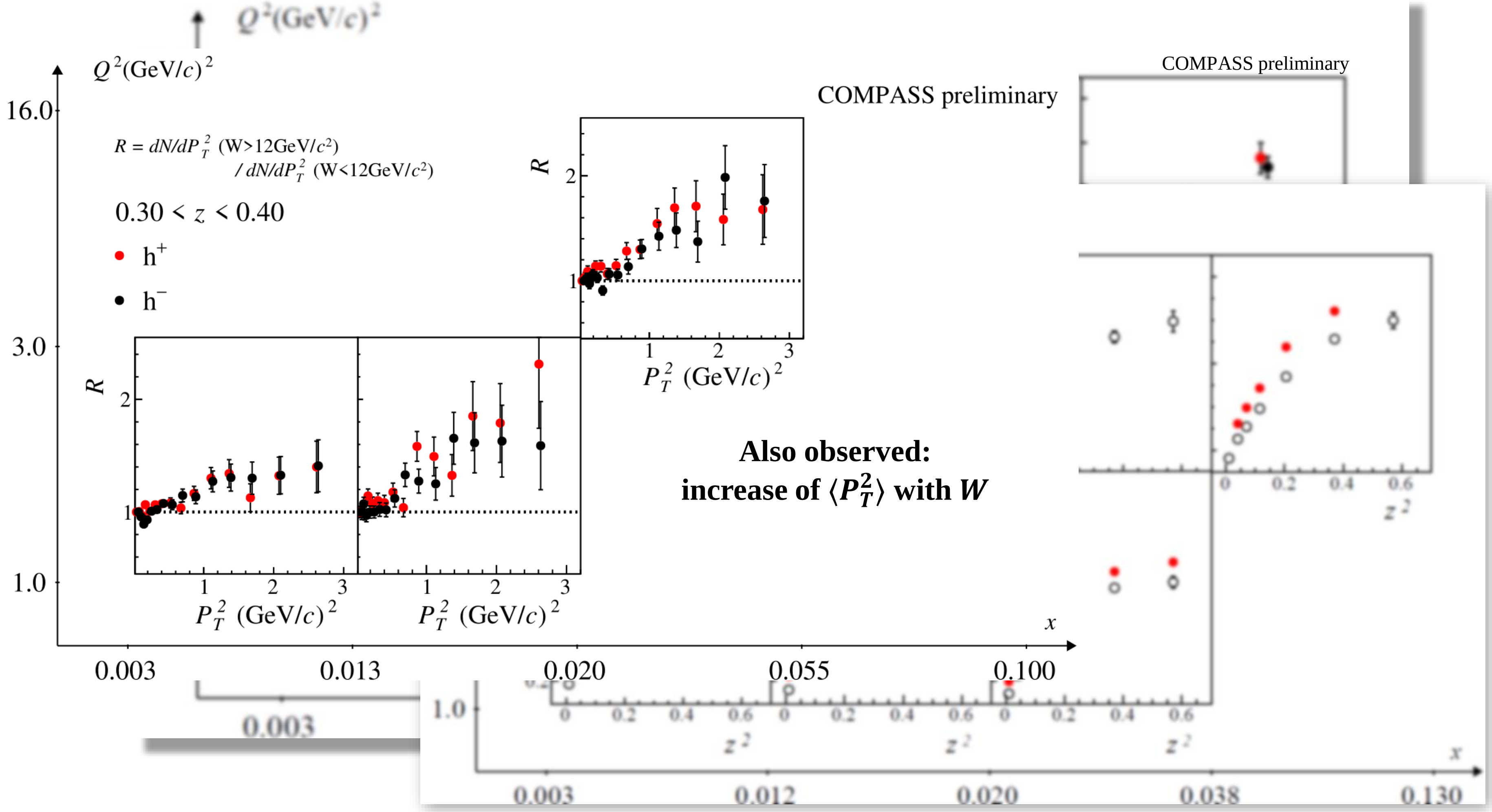


Also observed:
increase of $\langle P_T^2 \rangle$ with W

Azimuthal asymmetries – 1D

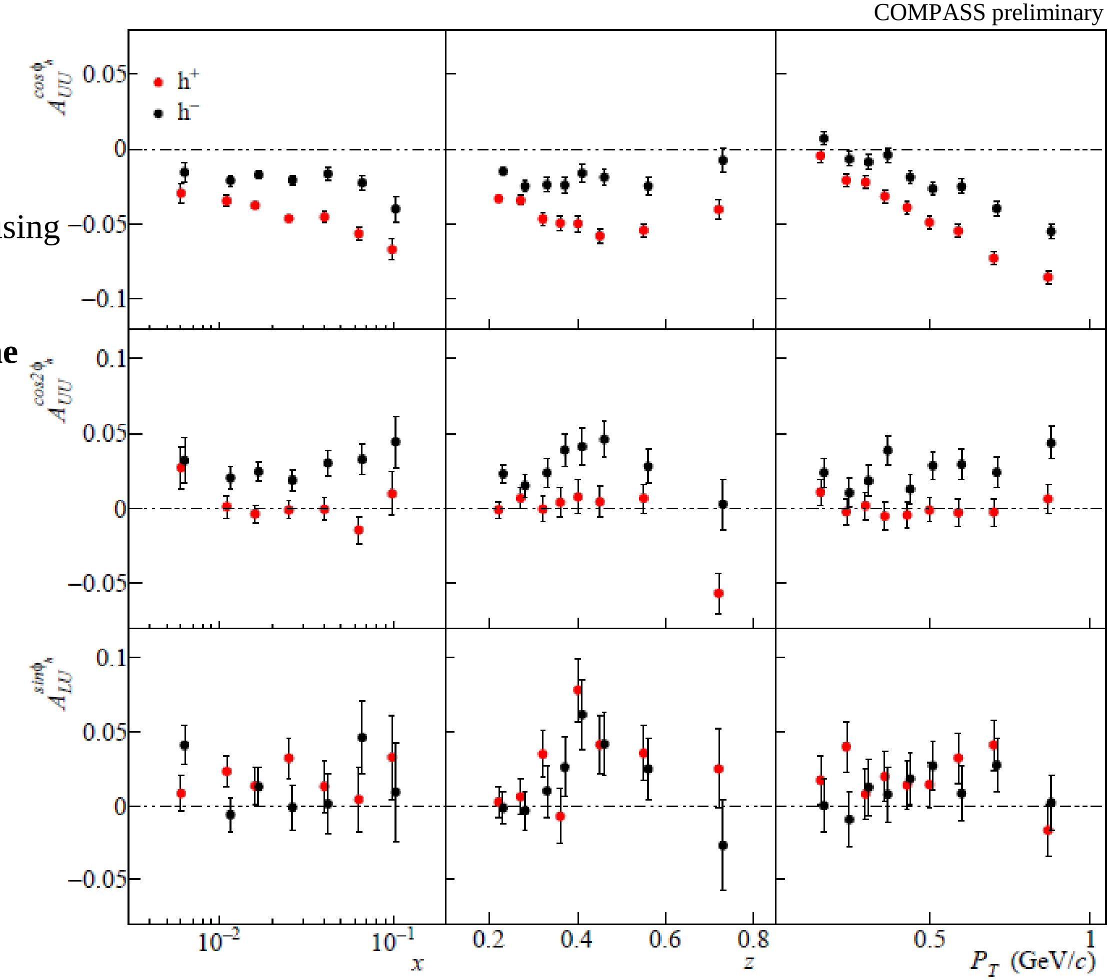
Azimuthal asymmetries: defined as the following ratios

$$A_{UU}^{\cos\phi_h} = \frac{F_{UU}^{\cos\phi_h}}{F_{UU,T}} \qquad A_{UU}^{\cos 2\phi_h} = \frac{F_{UU}^{\cos 2\phi_h}}{F_{UU,T}} \qquad A_{LU}^{\sin\phi_h} = \frac{F_{LU}^{\sin\phi_h}}{F_{UU,T}}$$

Steps in the measurement:

1. Exclusive hadrons:
   - the visible component is *discarded*
   - the non-visible component is *subtracted* using the HEPGEN Monte Carlo
2. Acceptance correction
3. Fit of the **amplitude of the modulation in the azimuthal angle** of the hadrons
   - as a function of x, z or P_T (1D)
   - with a simultaneous binning (3D)

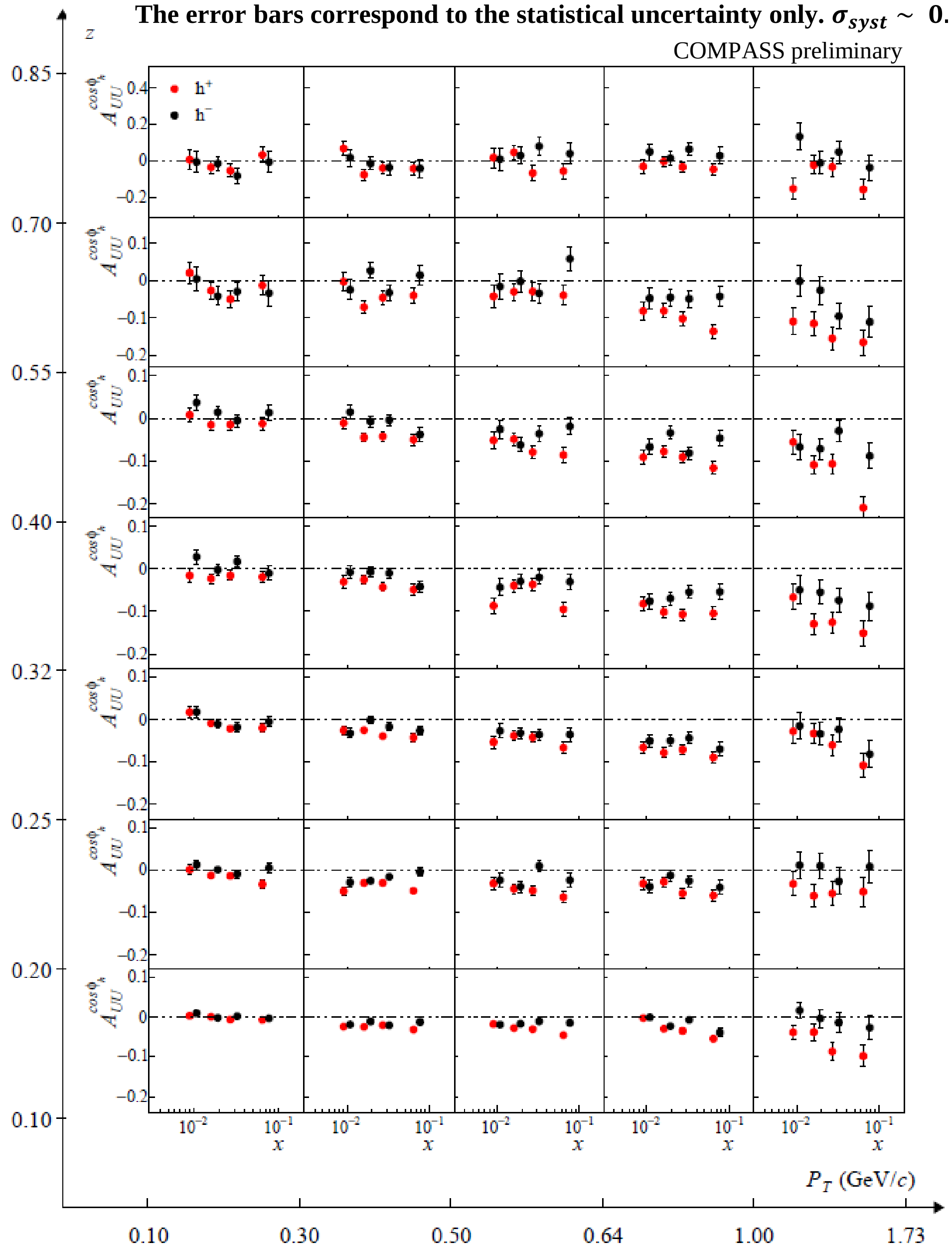
- **Strong kinematic dependences**
- **Interesting differences** between positive and negative hadrons, as observed in previous measurements by COMPASS on deuteron and by HERMES



The error bars correspond to the statistical uncertainty only. $\sigma_{syst} \sim \sigma_{stat}$ (1D)

Azimuthal asymmetries – 3D – $A_{UU}^{cos\phi_h}$

The error bars correspond to the statistical uncertainty only. $\sigma_{syst} \sim 0.5\,\sigma_{stat}$ (3D)



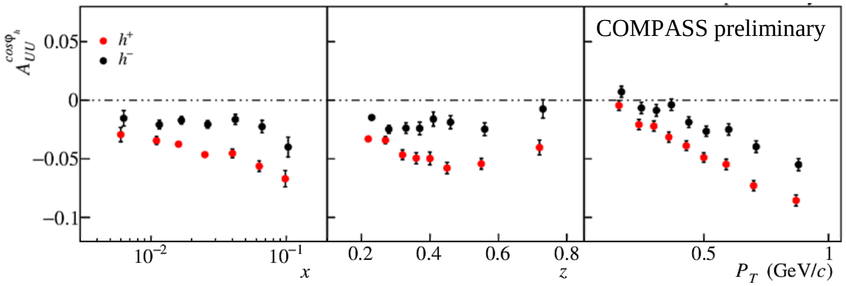
3D azimuthal asymmetries for positive and negative hadrons

Clear signal, strong dependence on P_T;
compatible with zero at high z.
In agreement with COMPASS deuteron results.

Expectation from Cahn effect:

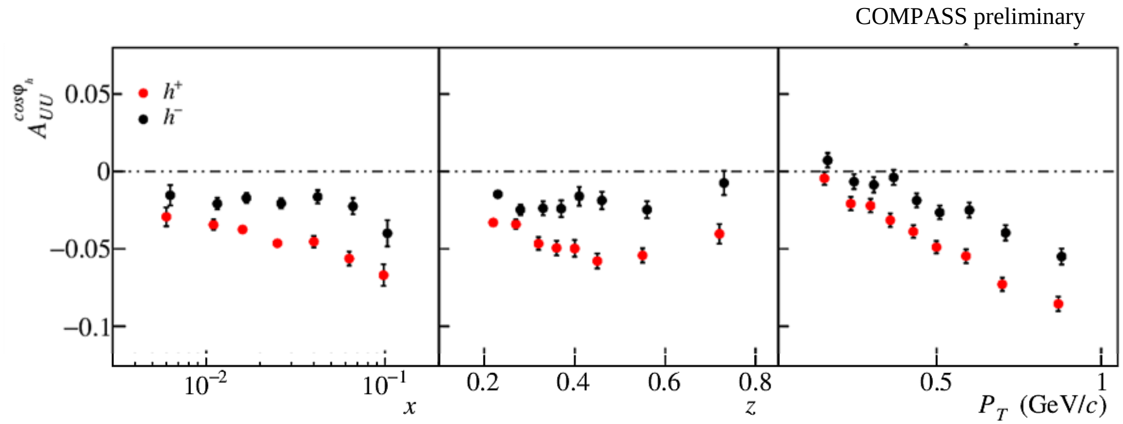
$$A_{UU|Cahn}^{\cos\phi_h} = -\frac{2zP_T\langle k_T^2\rangle}{Q\,\langle P_T^2\rangle}$$

Comparison with the 1D case:
lowest z and highest P_T bin not included in the average



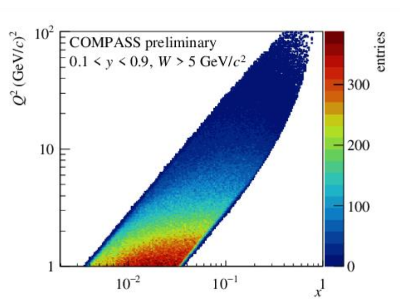
Extraction of $\langle k_T^2 \rangle$ from $A_{UU}^{\cos\phi_h}$

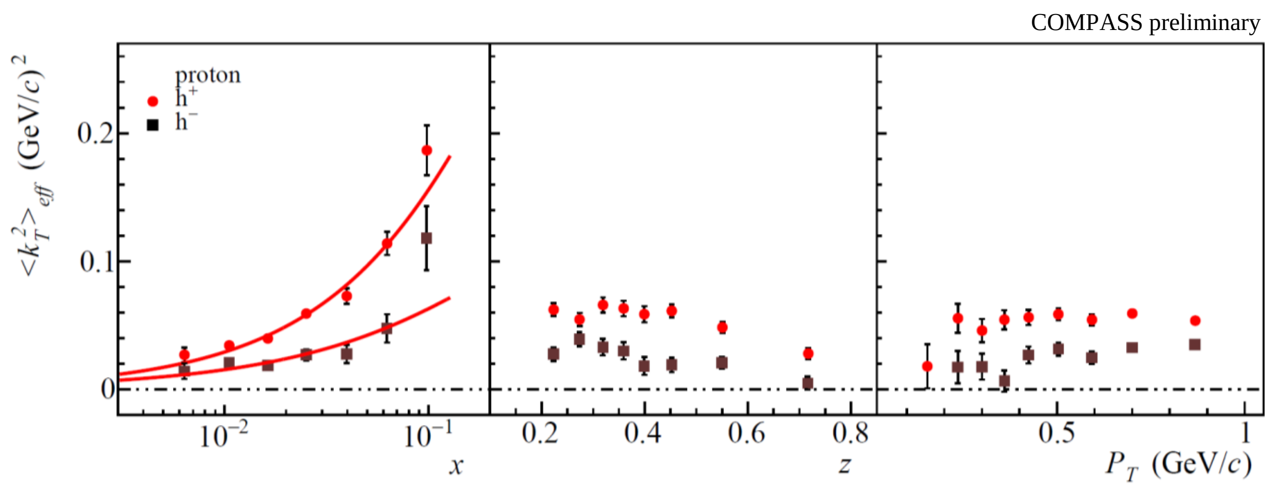
Extraction of $\langle k_T^2 \rangle$
from the 1D – asymmetry
assuming only Cahn effect
at work



$$\langle k_T^2 \rangle_{eff} = -\frac{Q\langle P_T^2 \rangle A_{UU}^{\cos\phi_h}}{2zP_T}$$

Power-law fit of $\langle k_T^2 \rangle(x)$





Is it an x – or Q^2 – dependence (or both)?

Azimuthal asymmetries – 1D – Q^2 dependence

Binning in Q^2

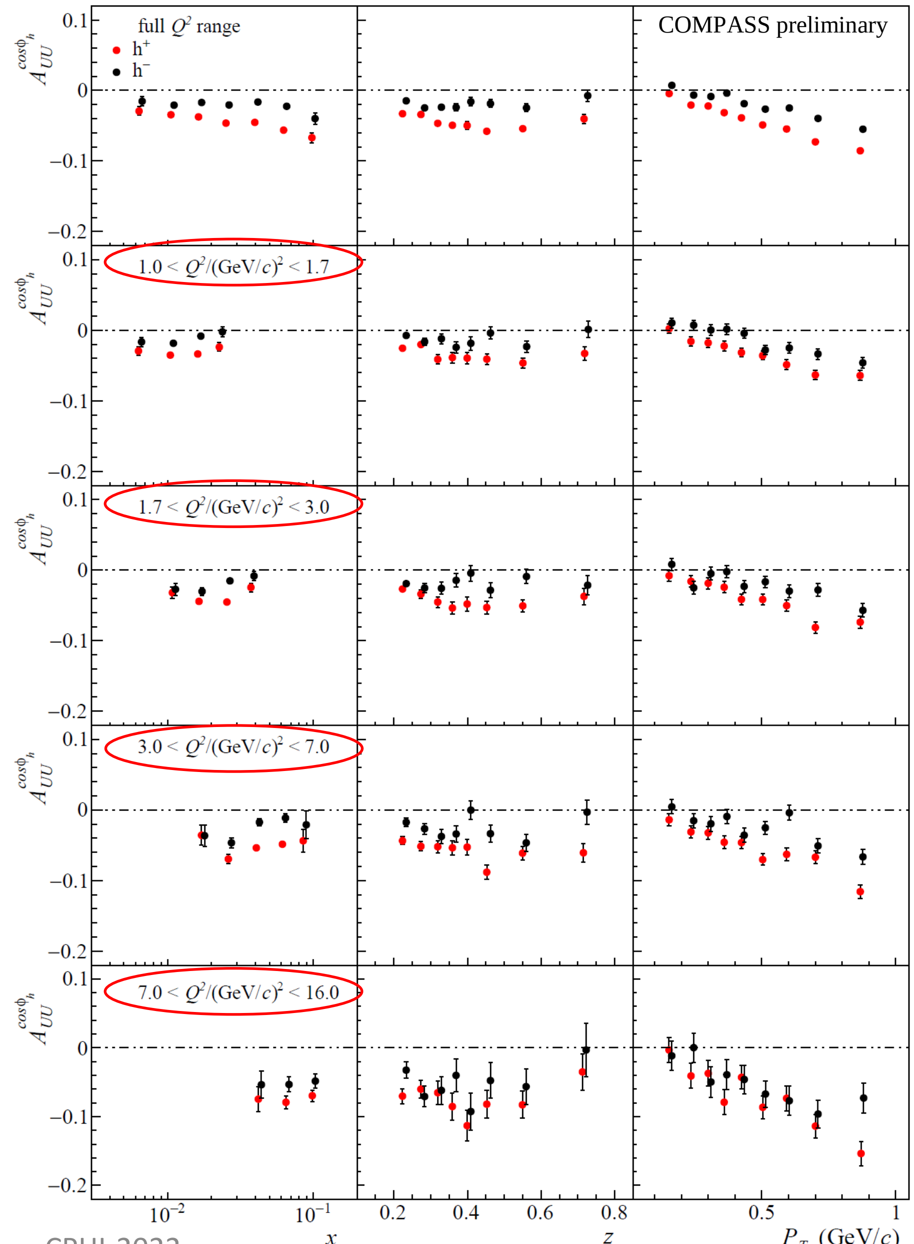
- The $A_{UU}^{cos\phi_h}$ asymmetry is observed to increase with Q^2
- Flavor-independent expectation from the Cahn effect:

$$A_{UU|Cahn}^{\cos\phi_h} = -\frac{2zP_T\langle k_T^2\rangle}{Q\,\langle P_T^2\rangle}$$

- → A strong dependence of $\langle k_T^2\rangle$ on Q^2, the relevance of other terms in the asymmetry, radiative corrections

- The difference between positive and negative hadrons decreases with Q^2.

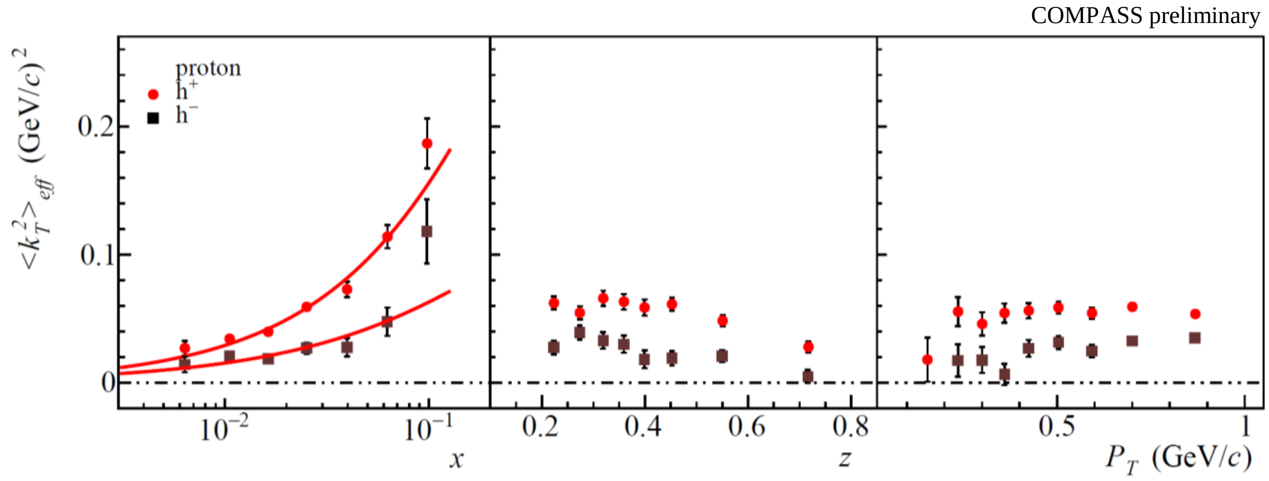
- Almost no Q^2 dependence for $A_{UU}^{cos2\phi_h}$



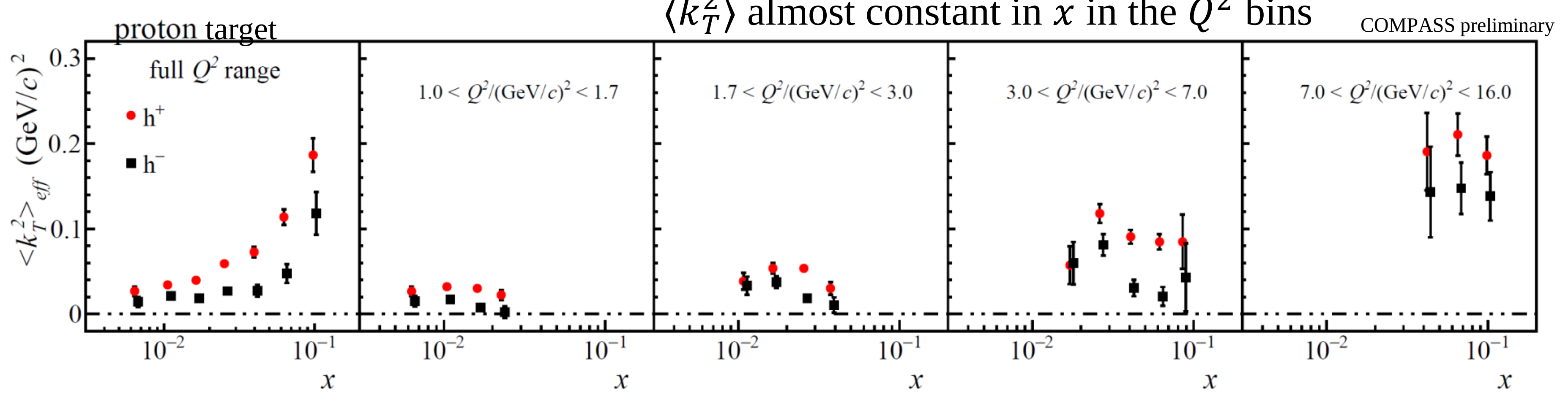
Extraction of $\langle k_T^2 \rangle$ from $A_{UU}^{\cos\phi_h}$

Extraction of $\langle k_T^2 \rangle$ *assuming only Cahn effect at work*

$$\langle k_T^2 \rangle_{eff} = -\frac{Q\langle P_T^2 \rangle A_{UU}^{cos\phi_h}}{2zP_T}$$

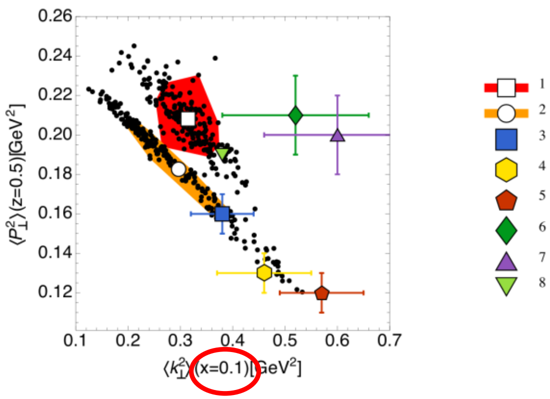


$\langle k_T^2 \rangle$ almost constant in x in the Q^2 bins

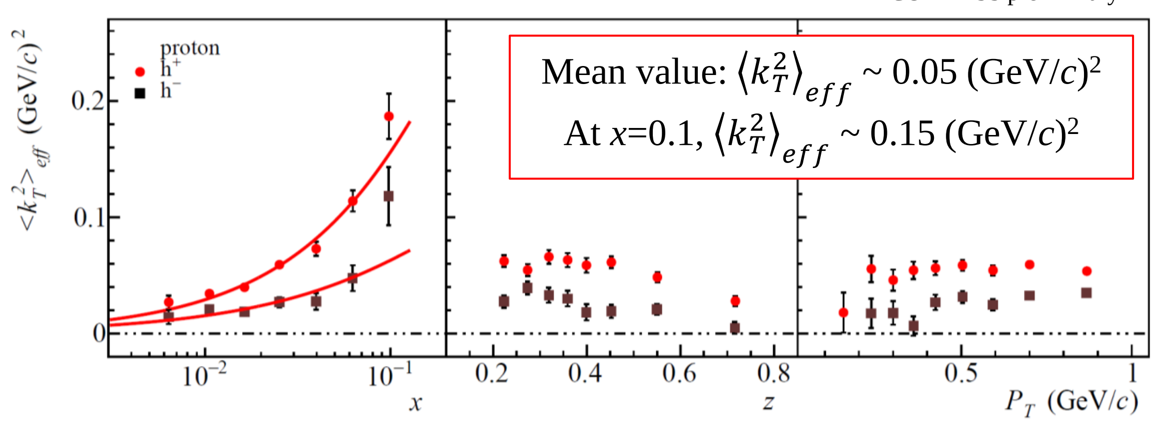


Extraction of $\langle k_T^2 \rangle$ from $A_{UU}^{\cos\phi_h}$

For comparison:
Bacchetta et al JHEP 06 (2017) 081
Analysis of SIDIS d- multiplicities (HERMES, COMPASS)
+ Drell-Yan (E288, E605 Tevatron)
and Z-boson production(CDF, D0)



COMPASS preliminary

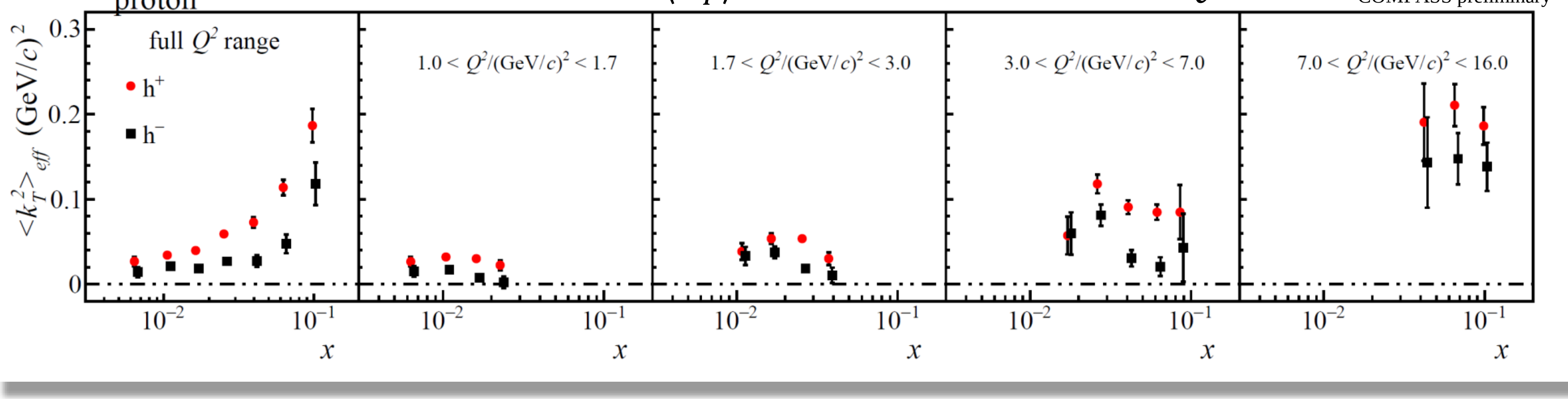


Mean value: $\langle k_T^2 \rangle_{eff} \sim 0.05$ (GeV/c)^2

At x=0.1, $\langle k_T^2 \rangle_{eff} \sim 0.15$ (GeV/c)^2

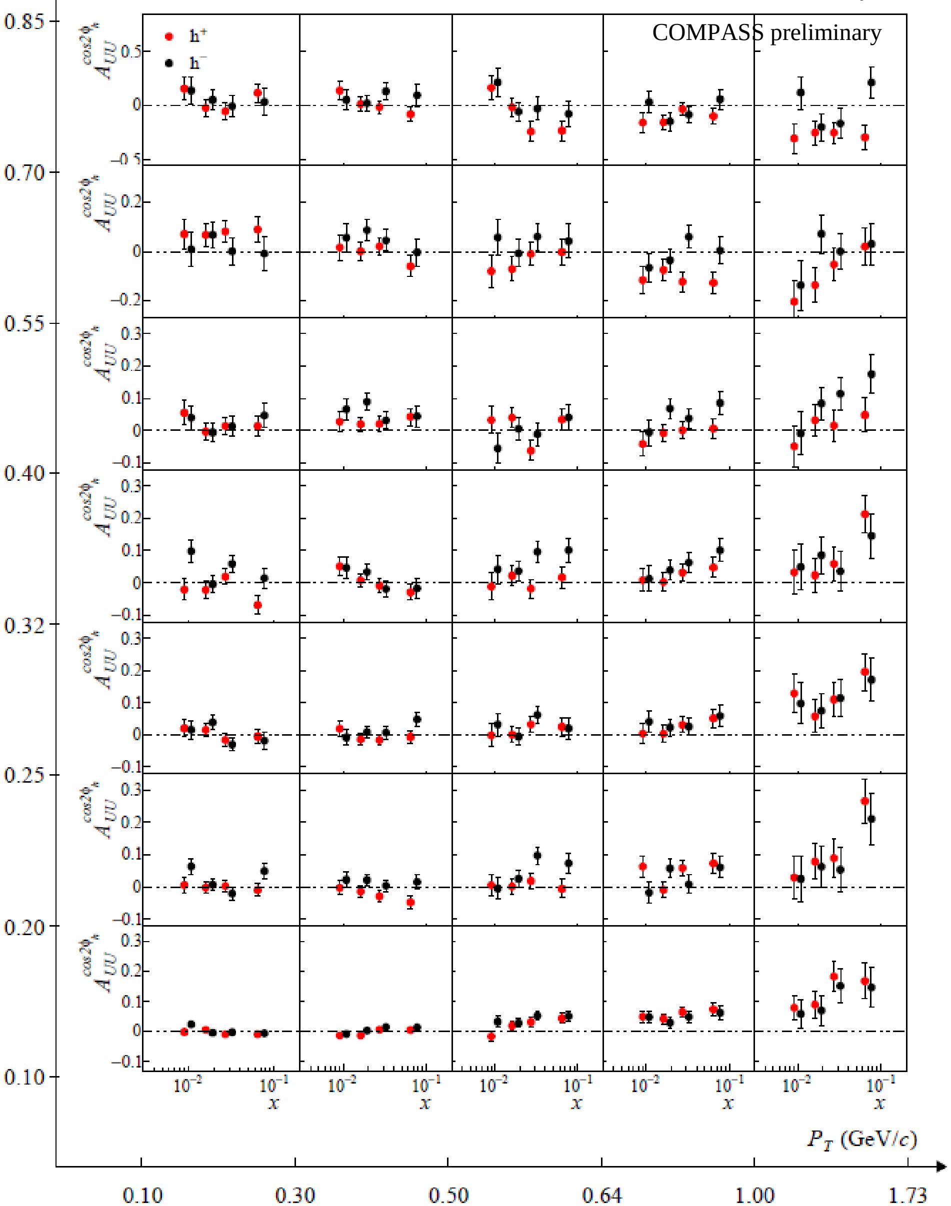
$\langle k_T^2 \rangle$ almost constant in x in the Q^2 bins

COMPASS preliminary



Azimuthal asymmetries – 3D – $A_{UU}^{cos2\phi_h}$

The error bars correspond to the statistical uncertainty only. $\sigma_{syst} \sim 0.5\, \sigma_{stat}$ (3D)

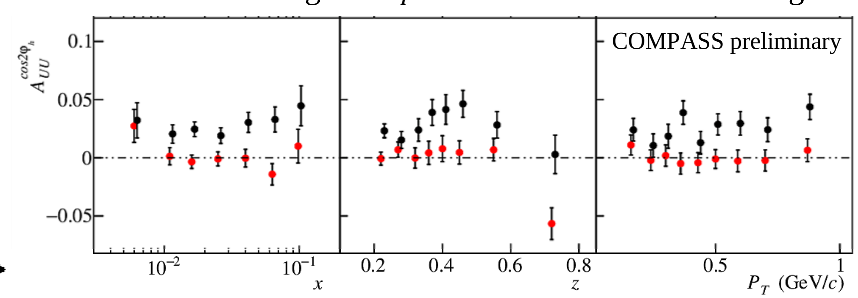


3D azimuthal asymmetries for positive and negative hadrons

Clear signal, strong dependence on x and P_T; interesting change of sign along z at high P_T.

The larger contribution from the $h_1^{\perp} H_1^{\perp}$ convolution $\rightarrow$ direct information on $h_1^{\perp}$ may be extracted

Comparison with the 1D case:
lowest z and highest P_T bin not included in the average



Conclusions and Perspectives

- Two sets of observables in unpolarized SIDIS are particularly interesting for the TMD physics: **azimuthal asymmetries** and **transverse momentum distributions**

- After the first measurements on a deuteron target, **COMPASS** has produced new results for both of them, using a **proton** target

- Intriguing investigations of their properties
  Not all shown here! Q^2 and W dependences, q_T distributions…

- Both sets of observables are interesting,
  rich kinematic dependences,
  difference between positive and negative hadrons
  → they deserve deeper studies.

Non–exhaustive list of interesting open points to be addressed

- Impact of radiative corrections
  may be relevant e.g. for the Q^2 dependence of the azimuthal asymmetries
- Impact of phase-space limitations in the generation of hadrons
- Role of vector mesons inclusively produced in SIDIS
  particularly for their contribution to the P_T^2 - distributions at low P_T

Thank you

backup

The 2016 COMPASS run

Events and hadron selection – standard

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

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

$0.003 < x < 0.130$

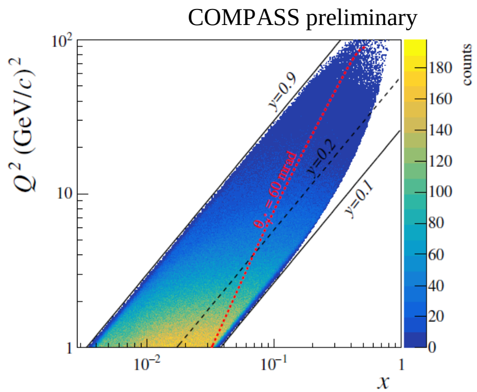
$0.2 < y < 0.9$

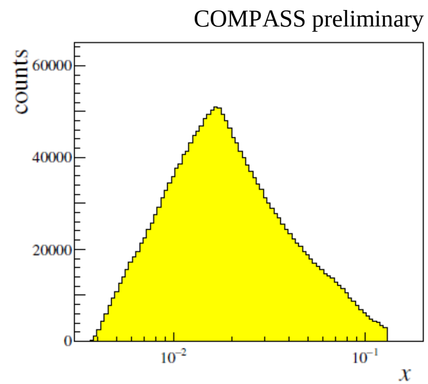
$\theta_\gamma < 60$ mrad

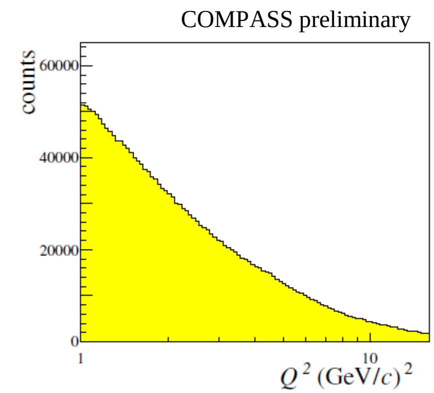
$z > 0.1$

$P_T > 0.1\ \mathrm{GeV}/c$

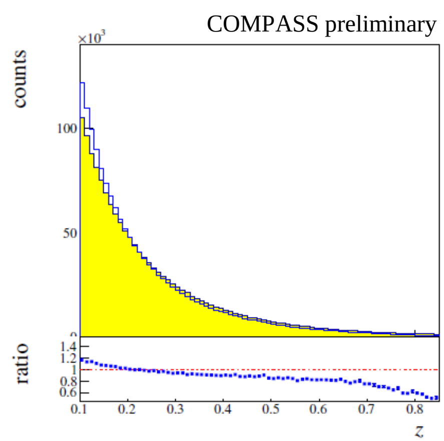
Size of the hadron sample: ~ 6.5 M hadrons

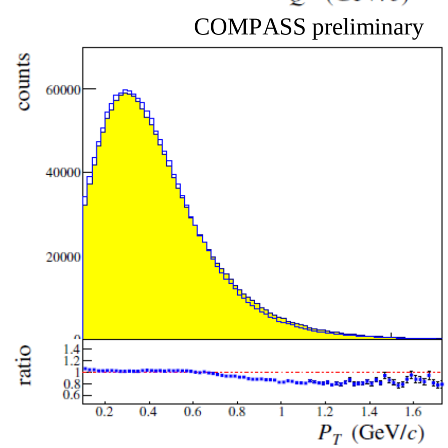






Comparison with the LEPTO Monte Carlo simulation.
Exclusive contribution at high z in the data

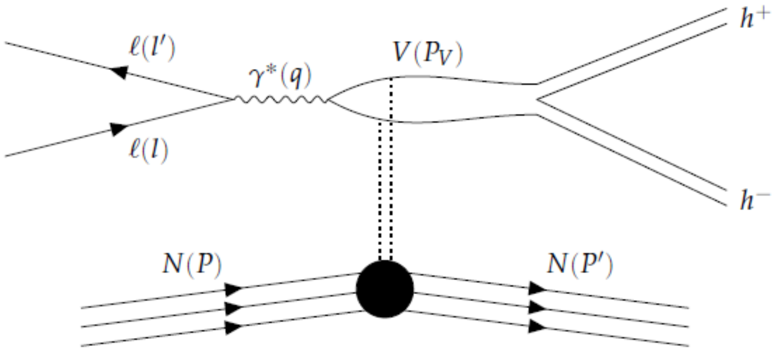




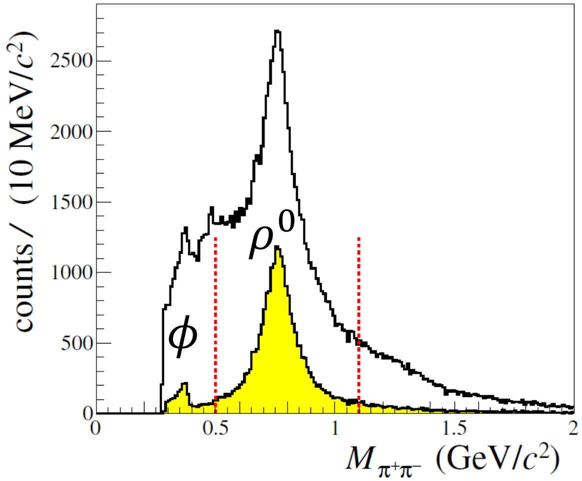
Contribution from exclusive hadrons

- The exclusive events fully reconstructed in the data are
  1) selected by cutting in missing energy E_{miss}
  2) used to normalized the HEPGEN Monte Carlo, needed to take into account the non-reconstructed part
  3) discarded
- The exclusive events non-fully reconstructed are subtracted using the normalized HEPGEN Monte Carlo

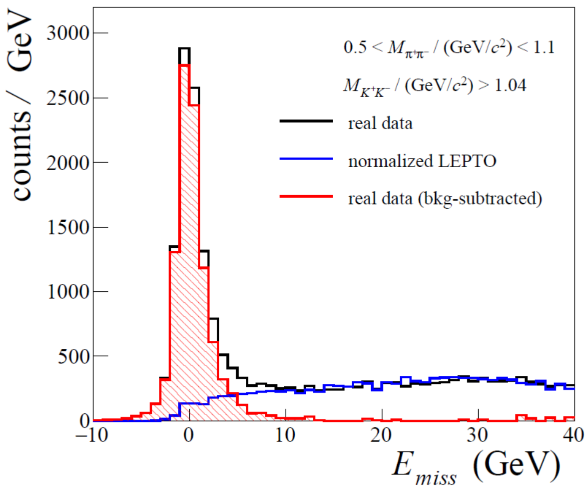
- This procedure does not require the knowledge of the absolute cross-section for the diffractive production, not well known (~ 30% relative uncertainty)



The diffractive production of a vector meson V and its decay into a hadron pair



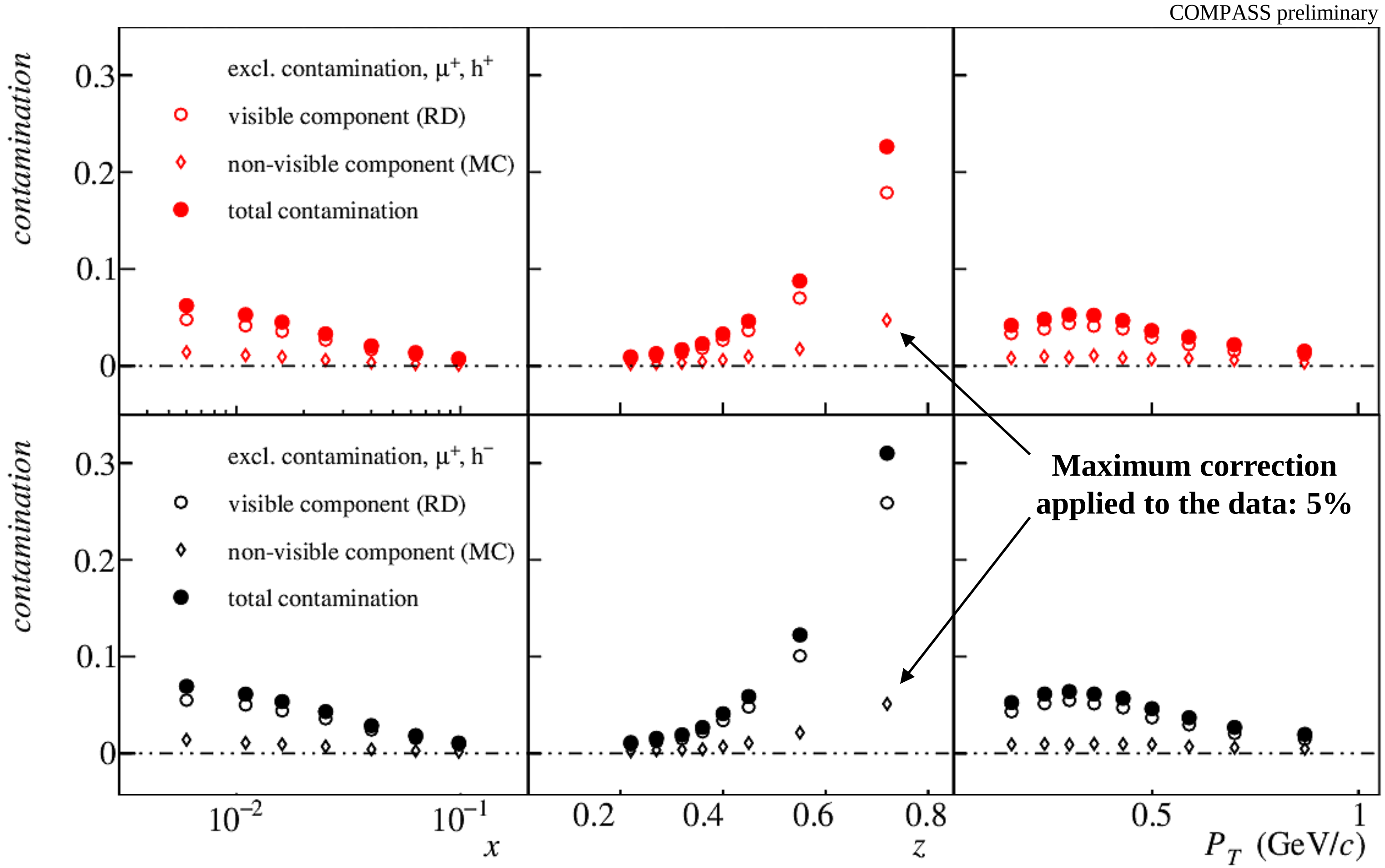
Invariant mass distribution in the data, before and after cutting in missing energy



The exclusive peak as observed in the data

Contribution from exclusive hadrons

Estimated exclusive hadrons contaminations in the data:
~80% is fully reconstructed



Maximum correction applied to the data: 5%

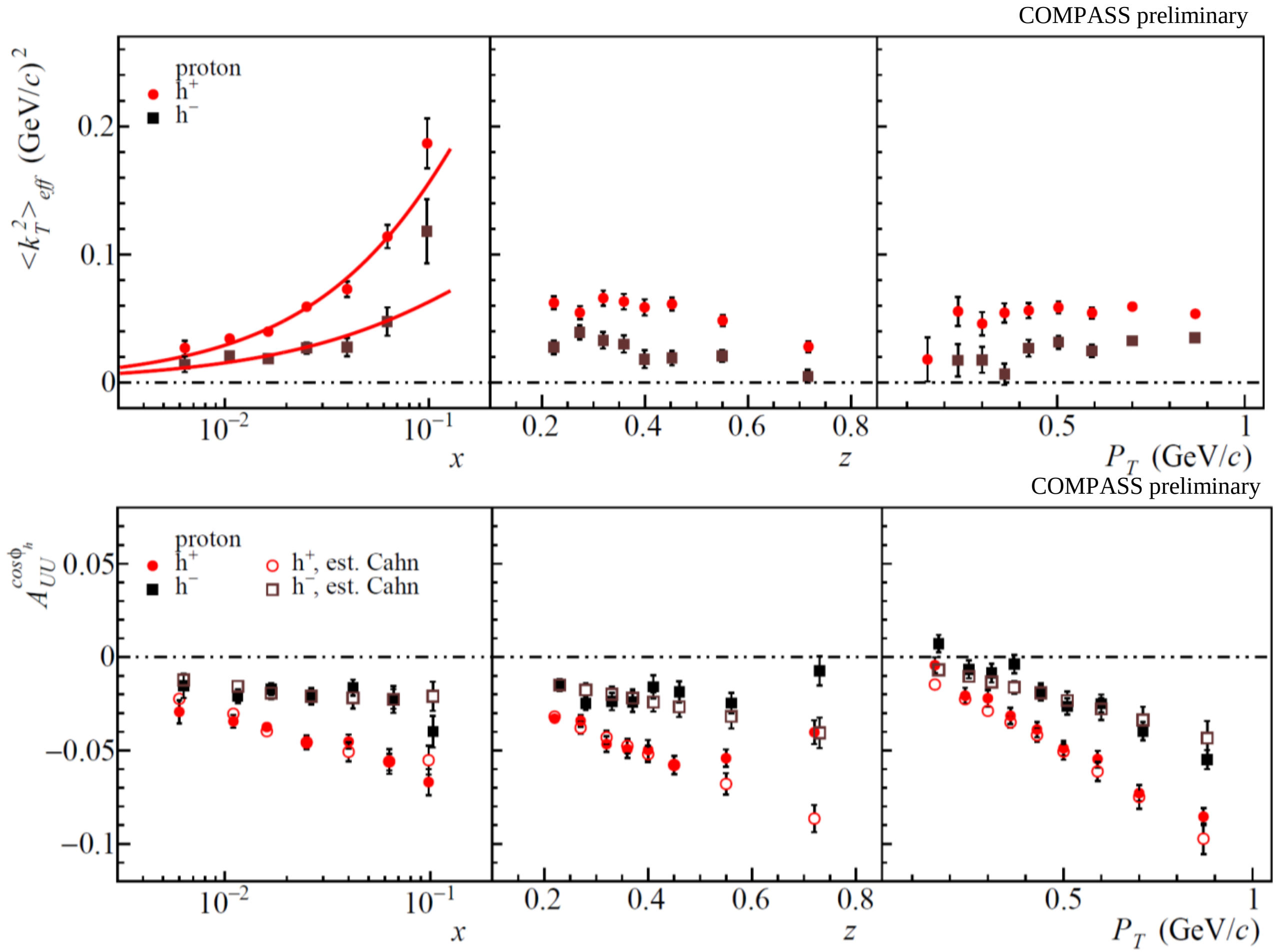
Extraction of $\langle k_T^2 \rangle$ from $A_{UU}^{\cos\phi_h}$

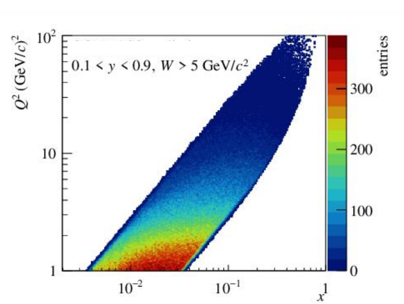
Extraction of $\langle k_T^2 \rangle$ *assuming only Cahn effect at work*

$$\langle k_T^2 \rangle_{eff} = -\frac{Q\langle P_T^2 \rangle A_{UU}^{\cos\phi_h}}{2zP_T}$$

Power-law fit of $\langle k_T^2 \rangle(x)$

Rather satisfactory description also vs z (below 0.5) and P_T



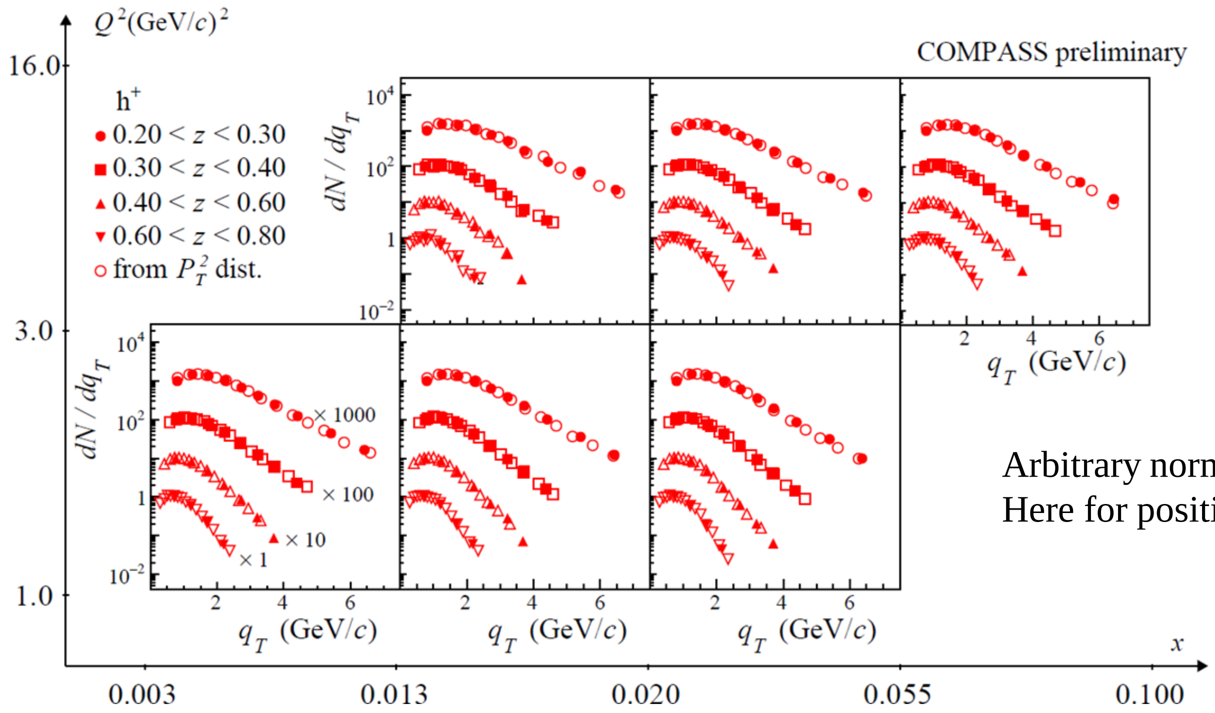


Is it an $x-$ or Q^2- dependence (or both)?

q_T distributions

- $q_T = P_T\,/\,z$, often indicated to set the limits of applicability of the TMD formalism (expected to hold at low q_T/Q)
- q_T distributions measured using the same hadron sample selected for the standard P_T^2 distributions
- Comparison with the approximated formula:

$$\frac{dN_h}{dz\,dP_T^2} = \frac{dN_h}{dz\,2P_T dP_T} = \frac{dN_h}{dz\,dP_T/z}\frac{1}{2zP_T} \approx \frac{dN_h}{dz\,dq_T}\frac{1}{2zP_T}$$



Arbitrary normalization and scaling
Here for positive hadrons, similar for negative

q_T^2 distributions

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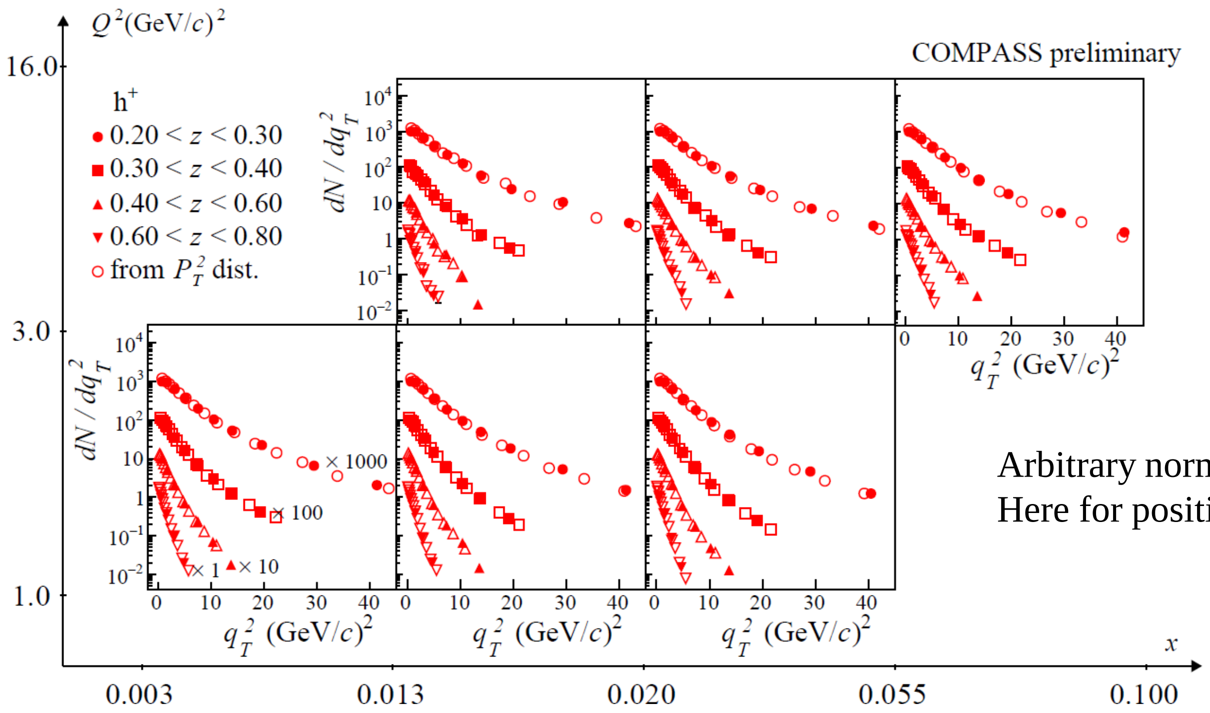
$$\frac{dN_h}{dz\, dq_T^2} = \frac{dN_h}{dz\, 2q_T dq_T} = \frac{dN_h}{dz\, dq_T} \frac{1}{2q_T}$$



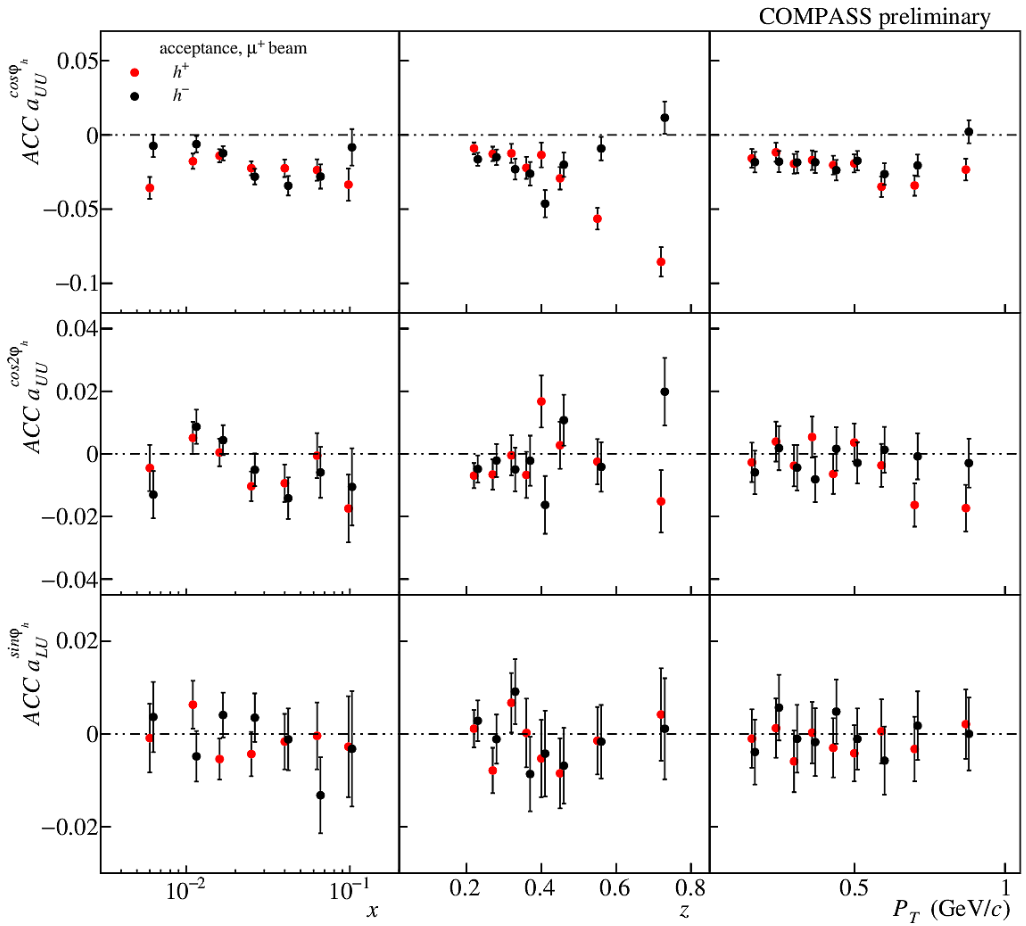
Arbitrary normalization and scaling
Here for positive hadrons, similar for negative

Acceptance modulations

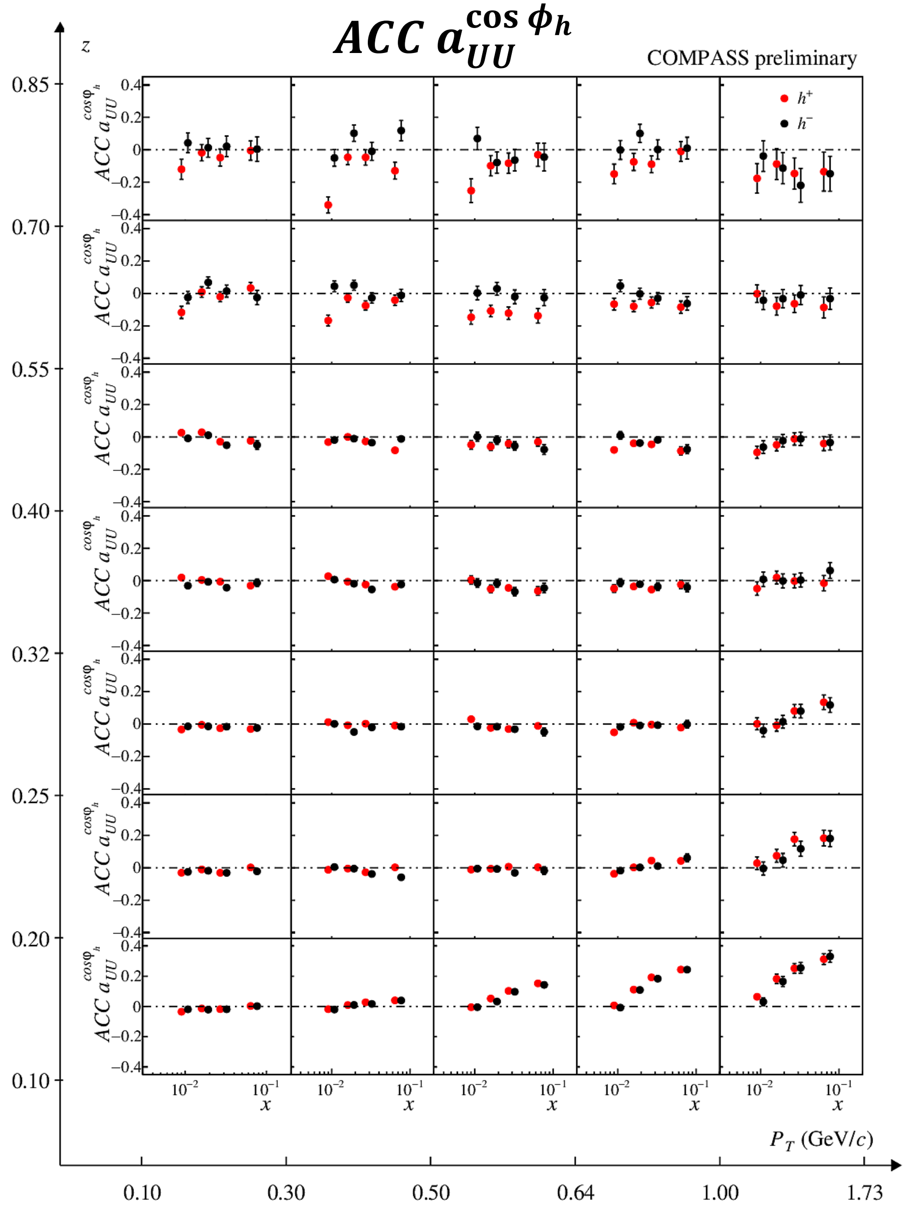
Correction for acceptance applied to each ϕ bin, taken as the ratio of reconstructed and generated hadrons:

$$c_{acc}(\phi) = \frac{N_h^{rec}(\phi^{rec})}{N_h^{gen}(\phi^{gen})}$$

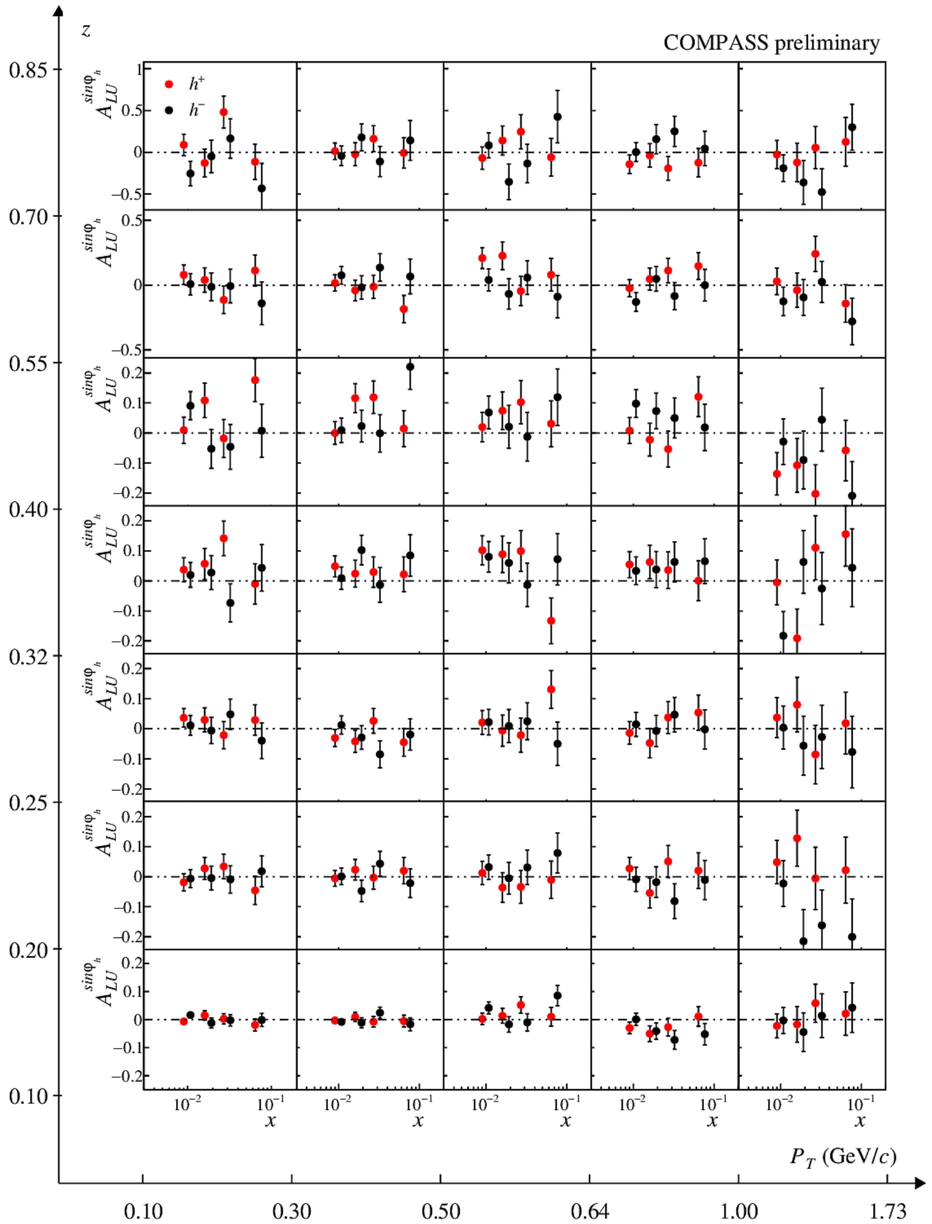
Azimuthal modulations of the acceptance in 1D binning, for μ^+ beam and positive (red) and negative hadrons (black).



Acceptance modulations



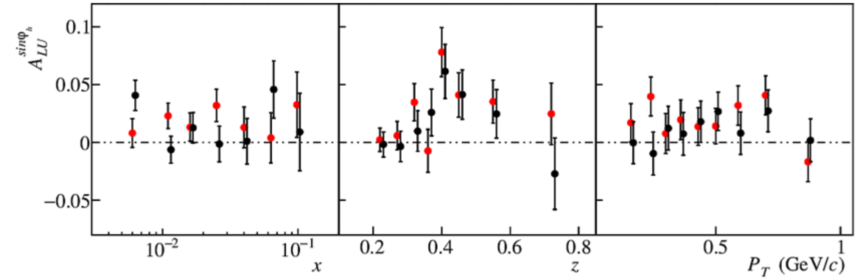
Azimuthal asymmetries – 3D



3D azimuthal asymmetries for positive and negative hadrons

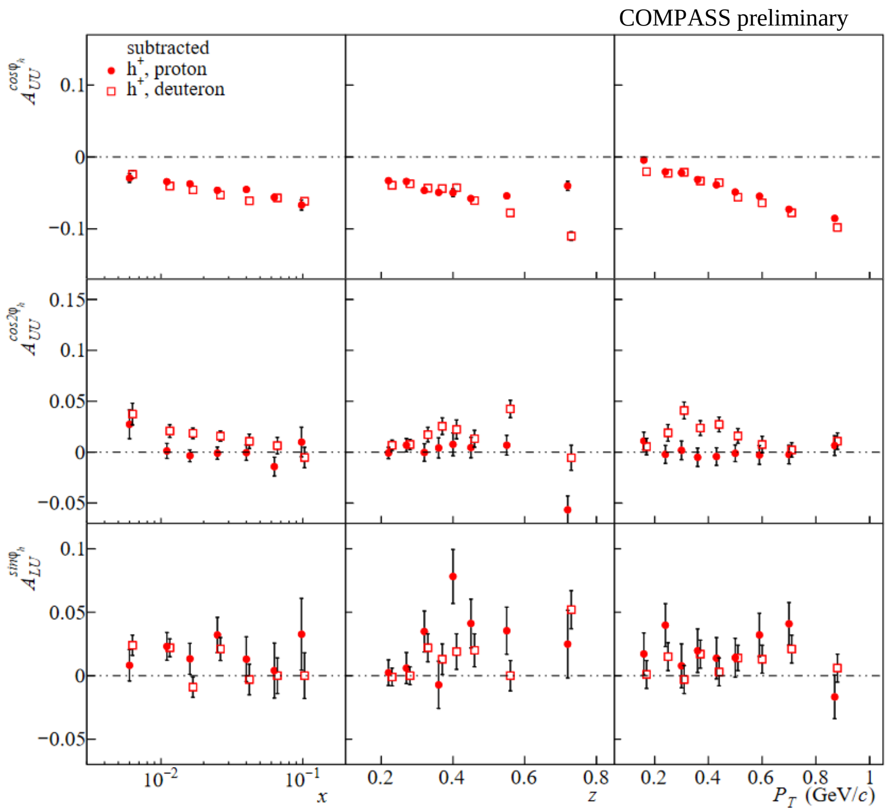
$A_{LU}^{\sin\phi_h}$ as a function of x,
in bins of z (rows) and P_T (columns).

Comparison with the 1D case:
lowest z and highest P_T bin not included in the average

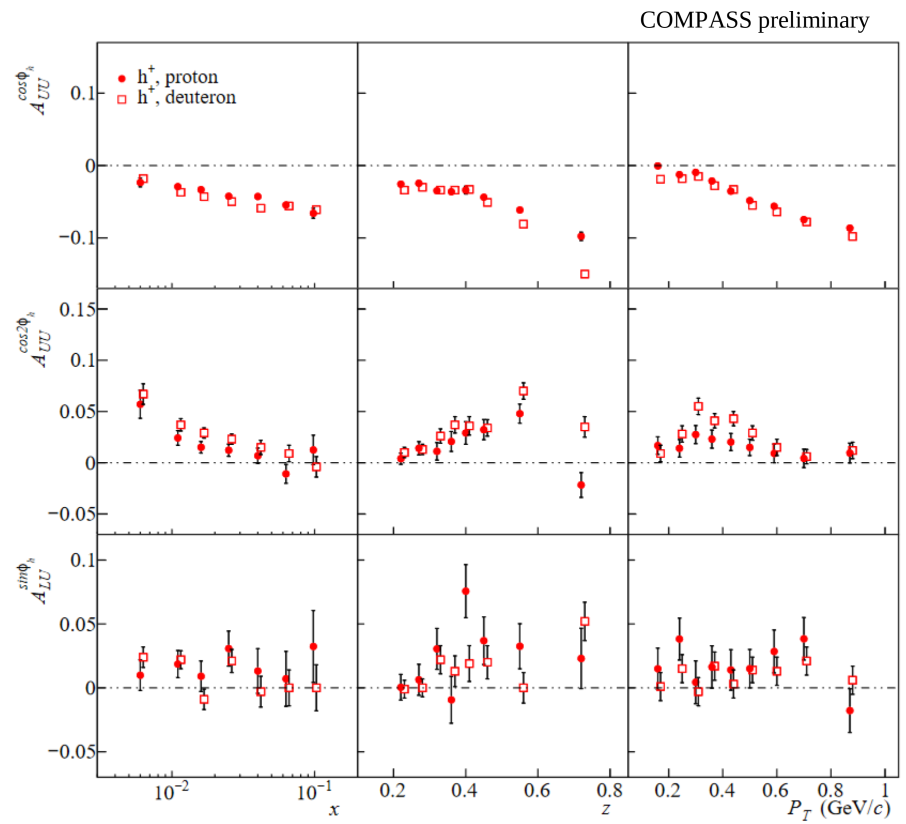


Comparison with deuteron results

Exclusive hadrons discarded / subtracted



*Exclusive hadrons **not** discarded / subtracted*

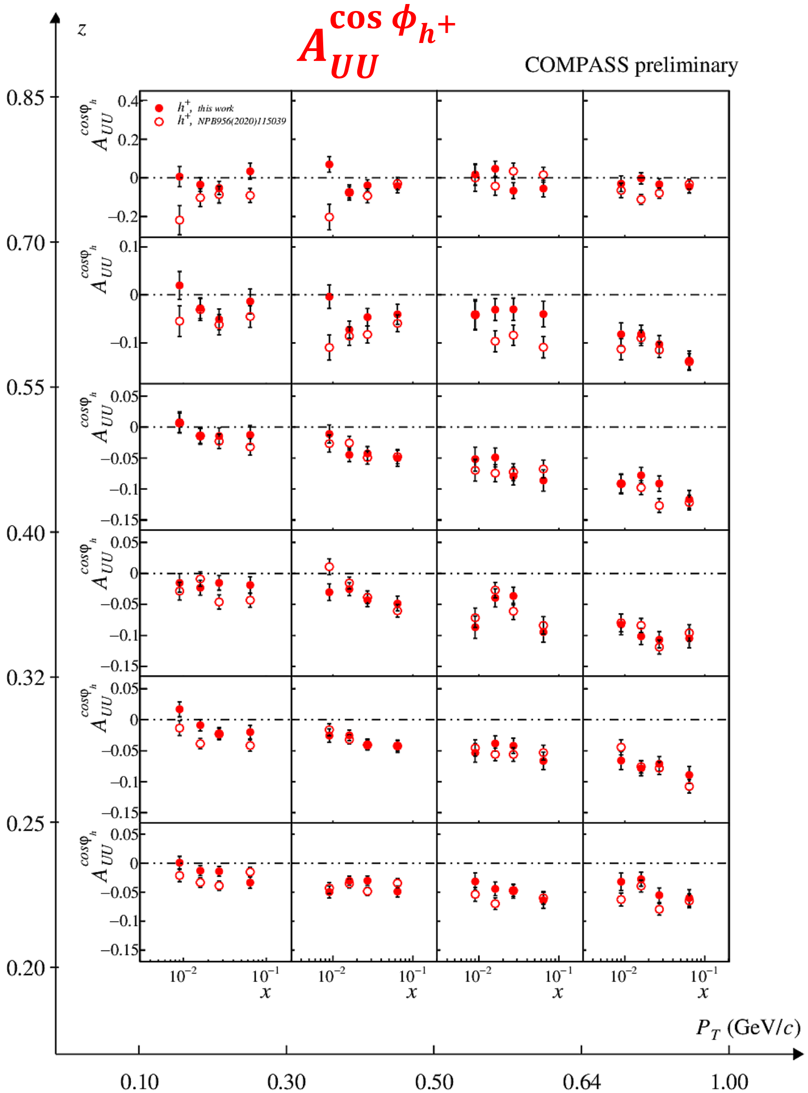


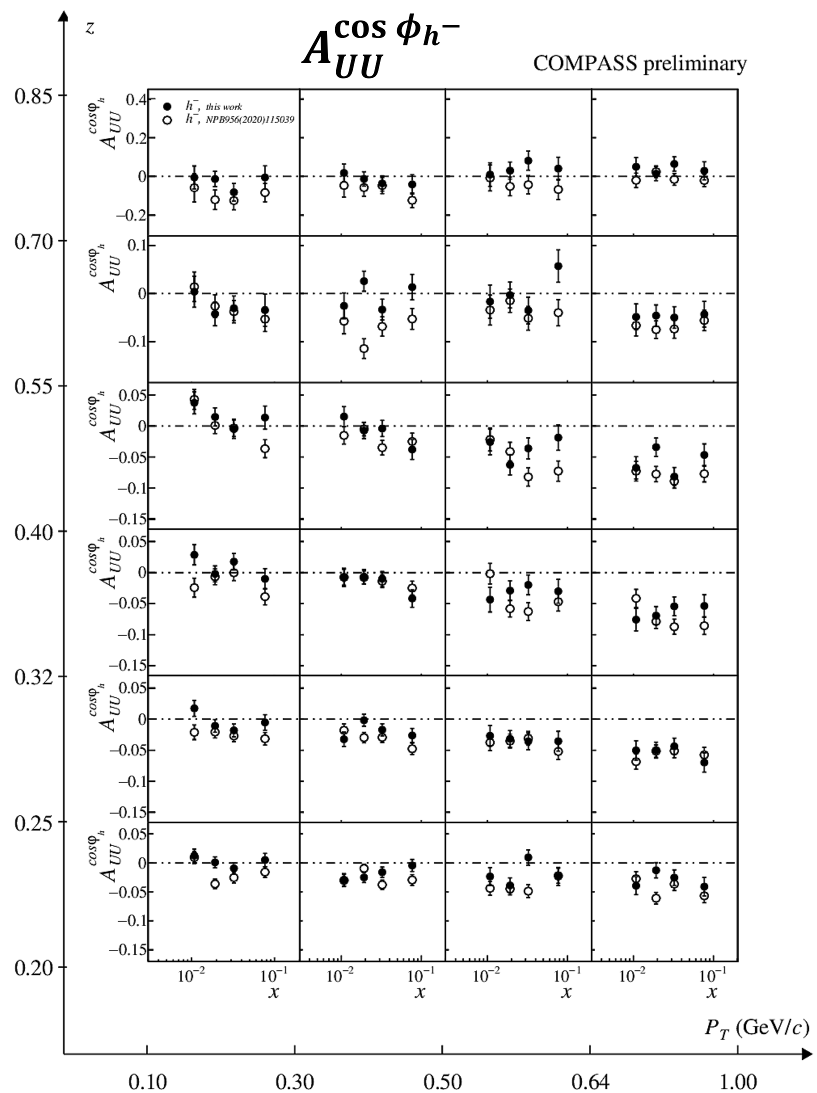
Difference visible also *before* the DVM subtraction / correction

Comparison with deuteron results

Current results (full points) compared to published results on deuteron **[COMPASS, NPB 956 (2020) 115039].**

Proton and deuteron results are in good agreement, as observed in other experiments (HERMES).





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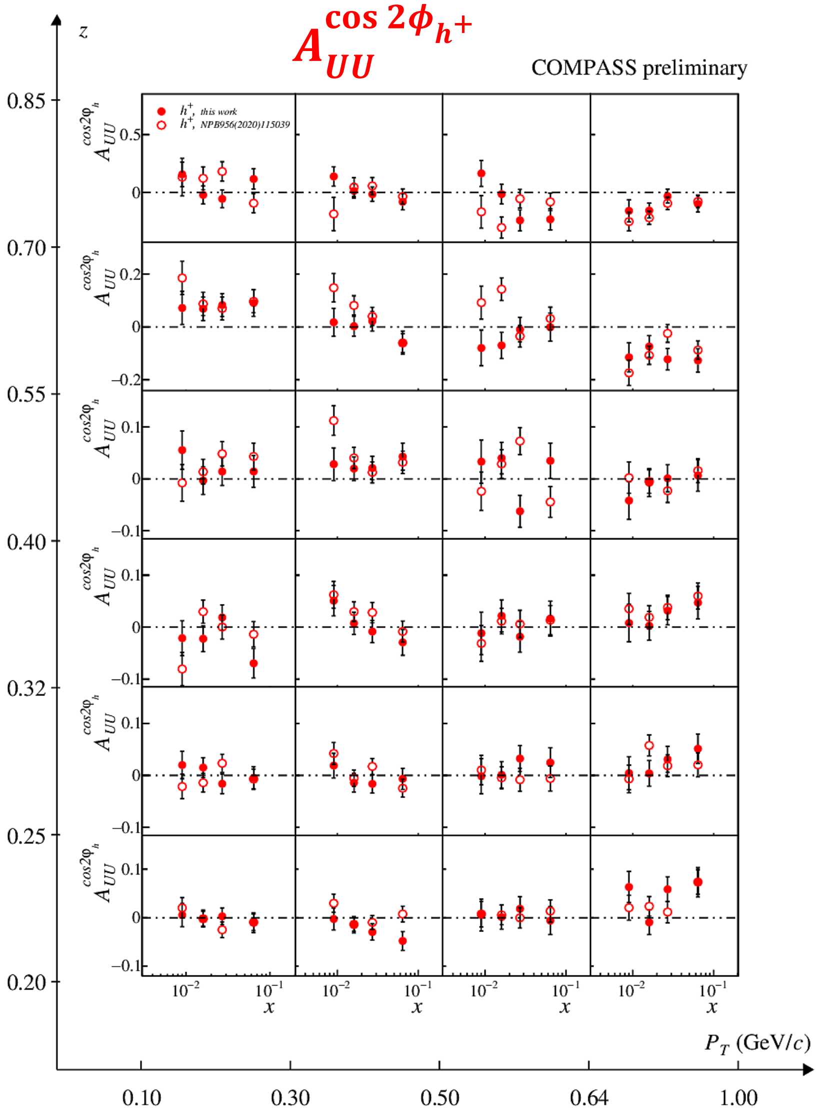
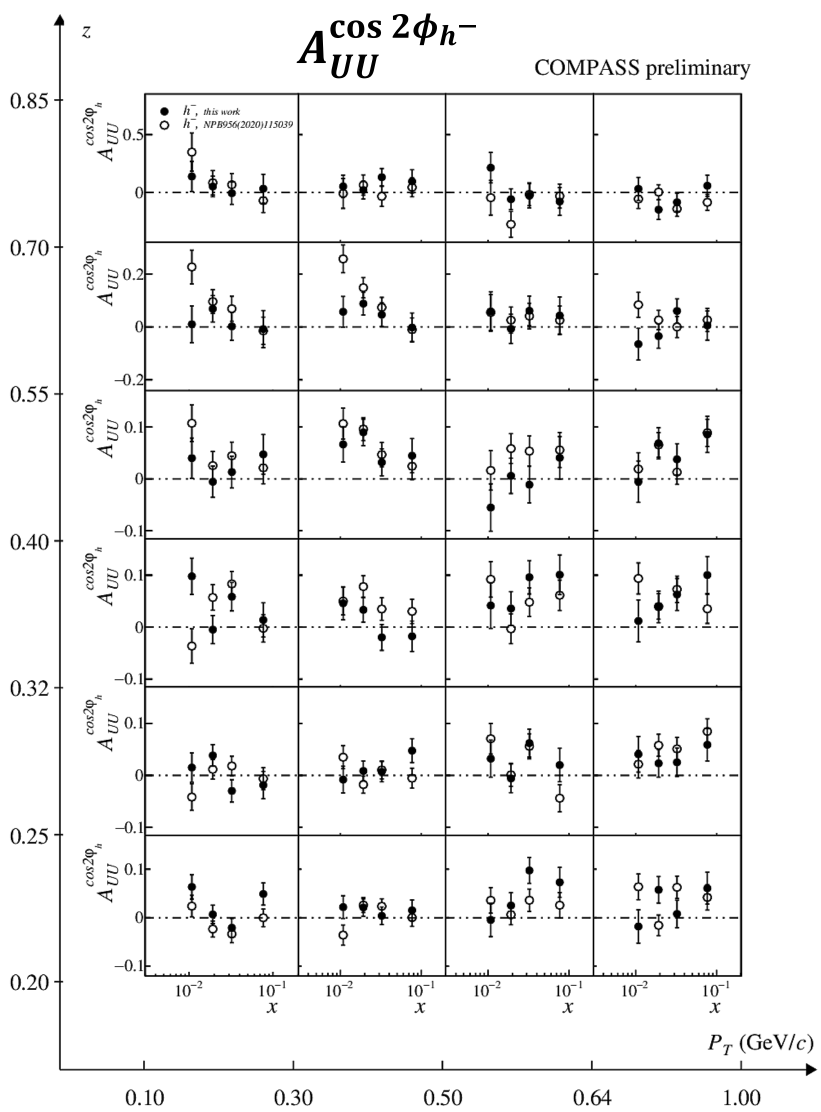
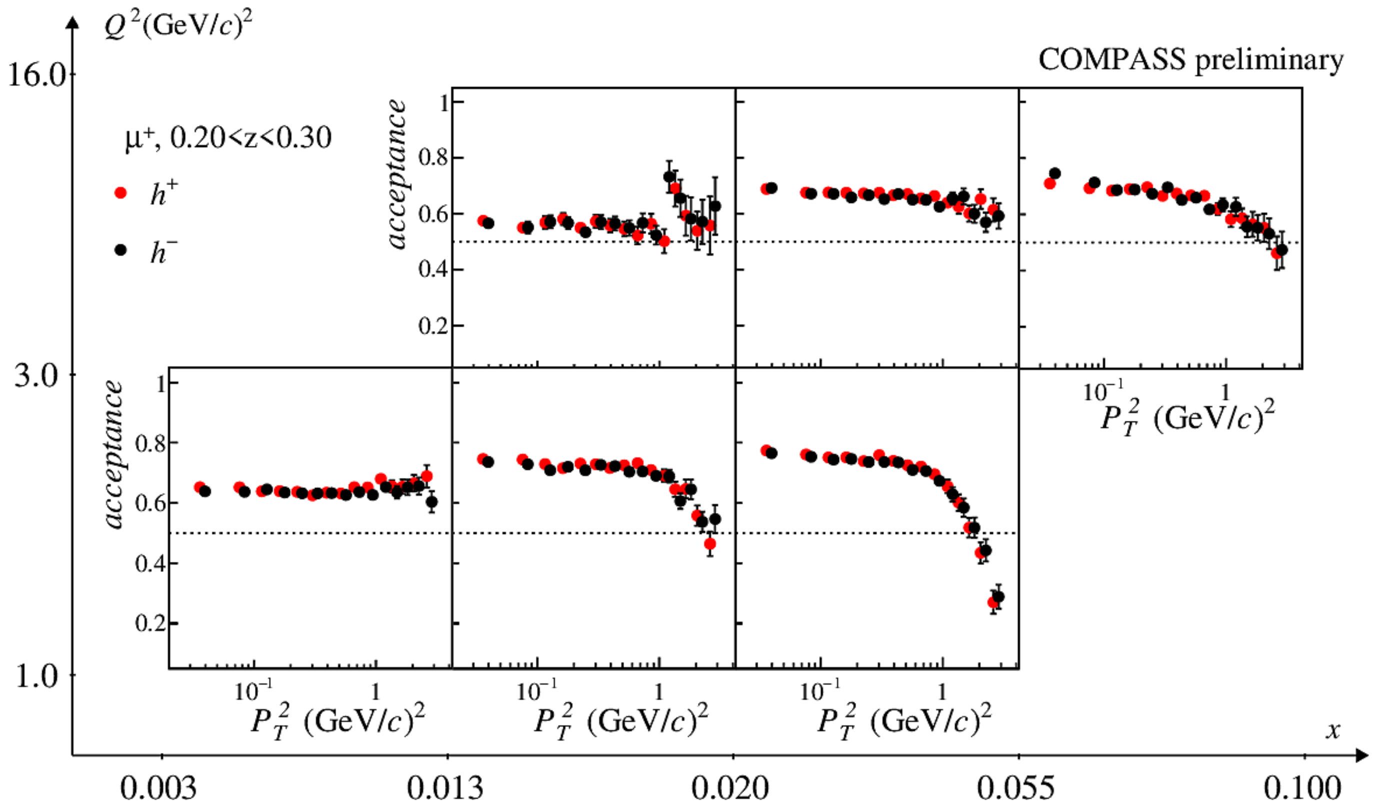




Acceptance

$$c_{acc}(P_T^2) = \frac{N_h^{rec}(P_T^{rec\,2})}{N_h^{gen}(P_T^{gen\,2})}$$

The acceptance is shown here in the first z bin, for positive and negative hadrons.
A flat plateau at values larger than 50% and, in some bins, a decrease at large P_T^2.



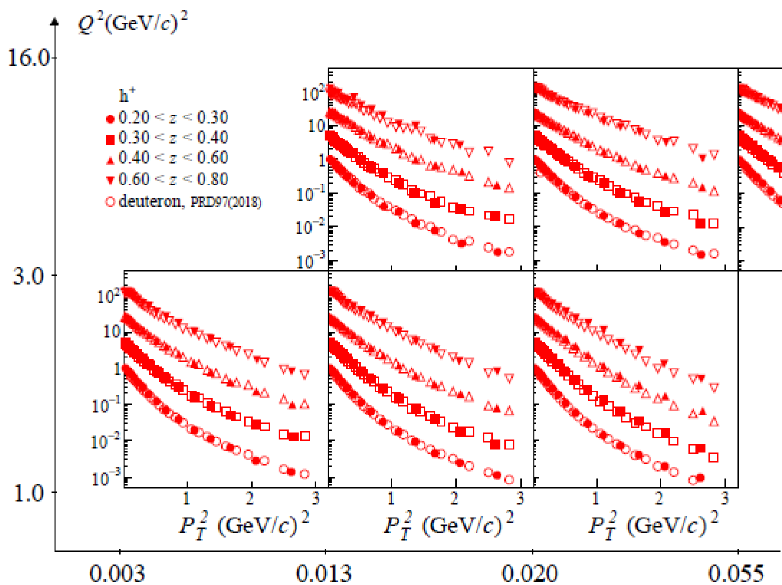
P_T^2 - DISTRIBUTIONS

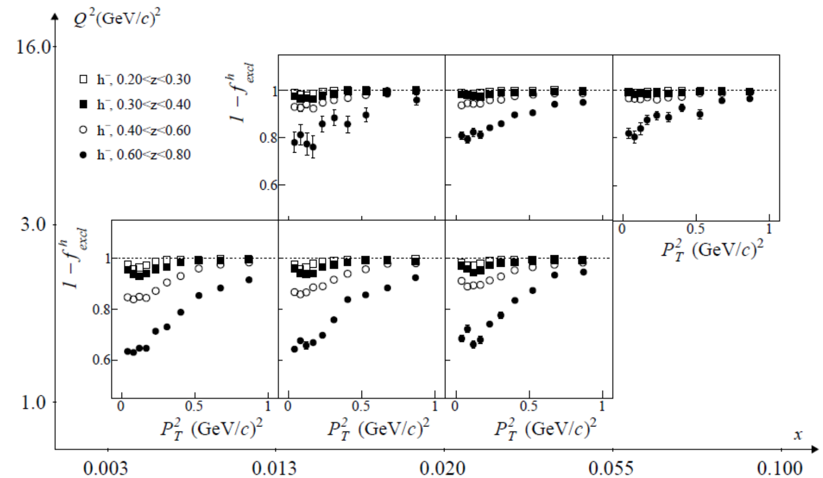
Comparison with deuteron results

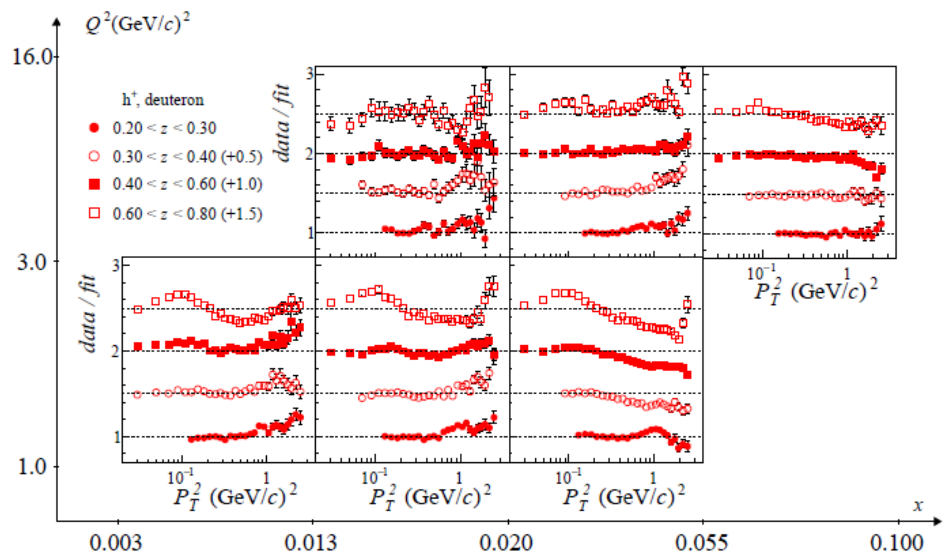
The new results are compared to published results on a deuteron target **[COMPASS, PRD97(2018) 032006]**

The old results have been renormalized over the first point and averaged over x and Q^2 in order to match the current binning, while the z and P_T^2 binning has not been modified.

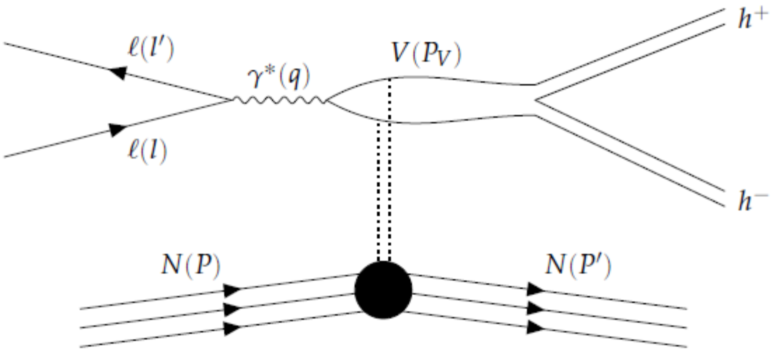
The agreement between new proton results and old deuteron ones is given in the plot on the right



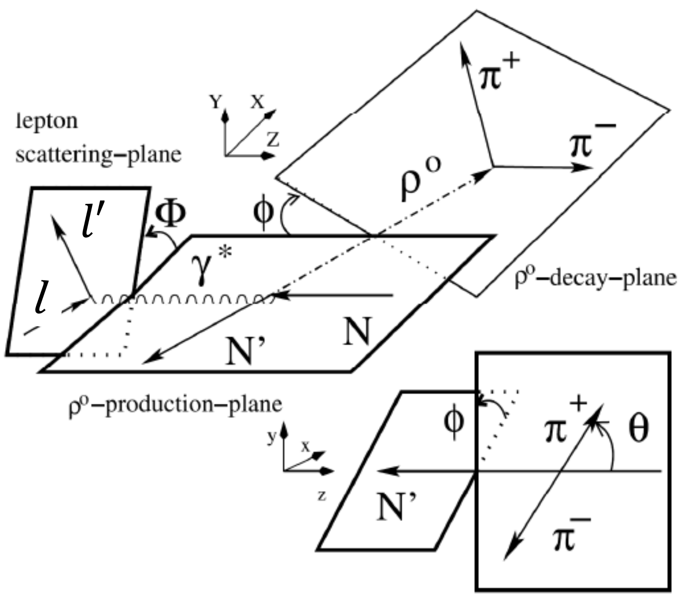




Exclusive ρ^0 Spin Density Matrix Elements



The diffractive production of a vector meson V and its decay into a hadron pair



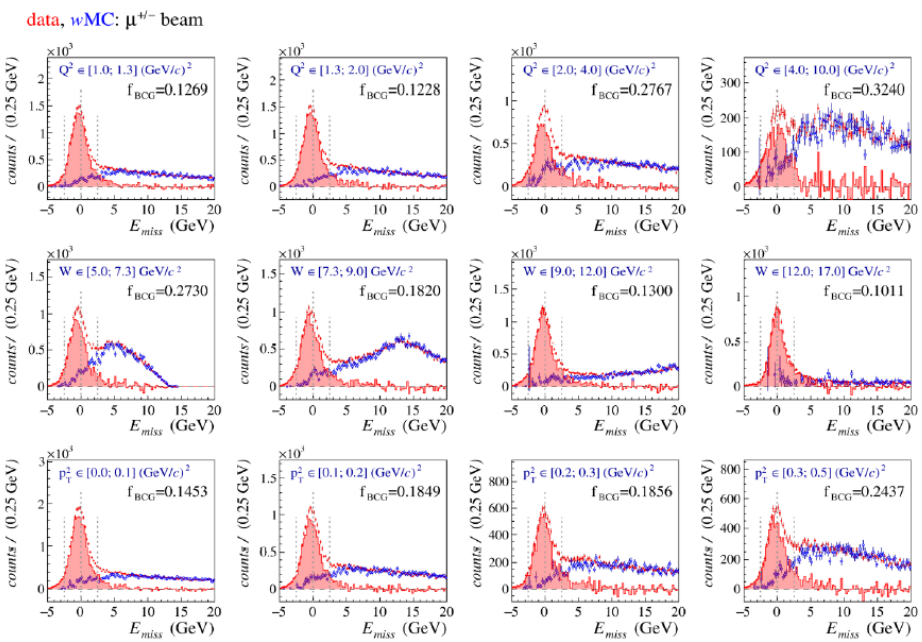
$$\begin{aligned}
W^U(\cos\theta,\Phi,\phi) = \frac{3}{8\pi^2}\Bigg[& \frac{1}{2}\left(1-r^{04}_{00}\right)+\frac{1}{2}\left(3r^{04}_{00}-1\right)\cos^2\theta-\sqrt{2}\mathrm{Re}\left\{r^{04}_{10}\right\}\sin 2\theta\cos\phi-r^{04}_{1-1}\sin^2\theta\cos 2\phi \\
& -\epsilon\cos 2\Phi\left(r^1_{11}\sin^2\theta+r^1_{00}\cos^2\theta-\sqrt{2}\mathrm{Re}\left\{r^1_{10}\right\}\sin^2\theta\cos\phi-r^1_{1-1}\sin^2\theta\cos 2\phi\right) \\
& -\epsilon\sin 2\Phi\left(\sqrt{2}\mathrm{Im}\left\{r^2_{10}\right\}\sin 2\theta\sin\phi+\mathrm{Im}\left\{r^2_{1-1}\right\}\sin^2\theta\sin 2\phi\right) \\
& +\sqrt{2\epsilon\left(1+\epsilon\right)}\cos\Phi\left(r^5_{11}\sin^2\theta+r^5_{00}\cos^2\theta-\sqrt{2}\mathrm{Re}\left\{r^5_{10}\right\}\sin 2\theta\cos\phi-r^5_{1-1}\sin^2\theta\cos 2\phi\right) \\
& +\sqrt{2\epsilon\left(1+\epsilon\right)}\sin\Phi\left(\sqrt{2}\mathrm{Im}\left\{r^6_{10}\right\}\sin 2\theta\sin\phi+\mathrm{Im}\left\{r^6_{1-1}\right\}\sin^2\theta\sin 2\phi\right)\Bigg]
\end{aligned}$$

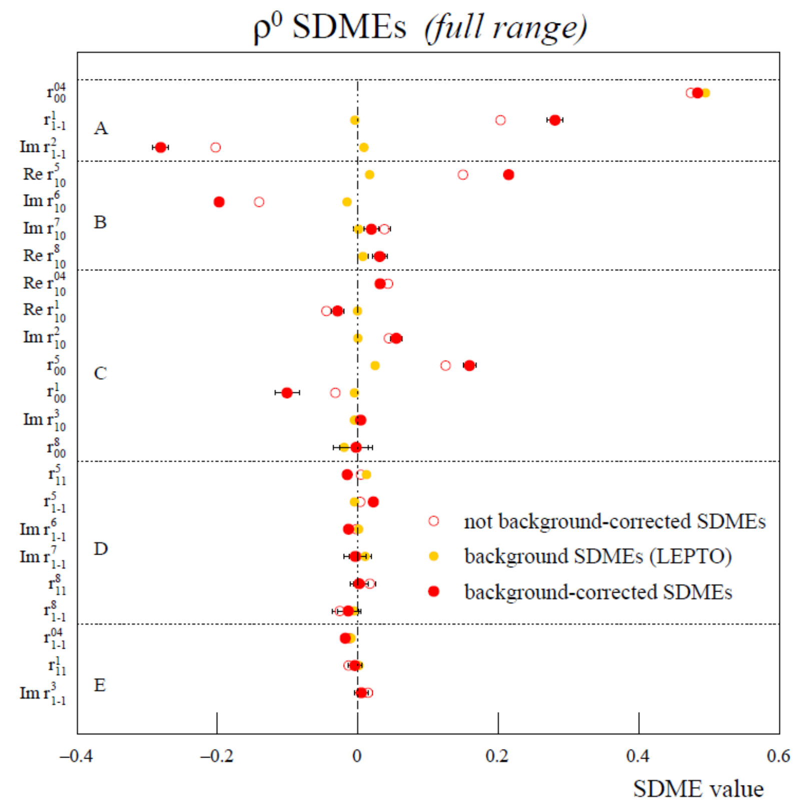
$$\begin{aligned}
W^L(\cos\theta,\Phi,\phi) = \frac{3}{8\pi^2}\Bigg[& \sqrt{1-\epsilon^2}\left(\sqrt{2}\mathrm{Im}\left\{r^3_{10}\right\}\sin 2\theta\sin\phi+\mathrm{Im}\left\{r^3_{1-1}\right\}\sin^2\theta\sin 2\phi\right) \\
& +\sqrt{2\epsilon\left(1-\epsilon\right)}\cos\Phi\left(\sqrt{2}\mathrm{Im}\left\{r^7_{10}\right\}\sin 2\theta\sin\phi+\mathrm{Im}\left\{r^7_{1-1}\right\}\sin^2\theta\sin 2\phi\right) \\
& +\sqrt{2\epsilon\left(1-\epsilon\right)}\sin\Phi\left(r^8_{11}\sin^2\theta+r^8_{00}\cos^2\theta-\sqrt{2}\mathrm{Re}\left\{r^8_{10}\right\}\sin 2\theta\cos\phi-r^8_{1-1}\sin^2\theta\cos 2\phi\right)\Bigg]
\end{aligned}$$

Exclusive ρ^0 Spin Density Matrix Elements

UML fit of the observed pion distributions, correcting for the apparatus acceptance, in three steps:

- SDMEs with no background correction
- SIDIS background fraction estimation and background SDMEs
- SDMEs with SIDIS background correction





Exclusive ρ^0 Spin Density Matrix Elements