Transverse momentum dependent multiplicities of hadrons produced in DIS at COMPASS

Andrea Moretti

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on behalf of the COMPASS Collaboration

P_{hT}^2- dependent multiplicities in SIDIS

Transverse momentum dependent multiplicities of hadrons produced in SIDIS: a hot topic 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 . See e.g. contributions today [WG6], and many others…

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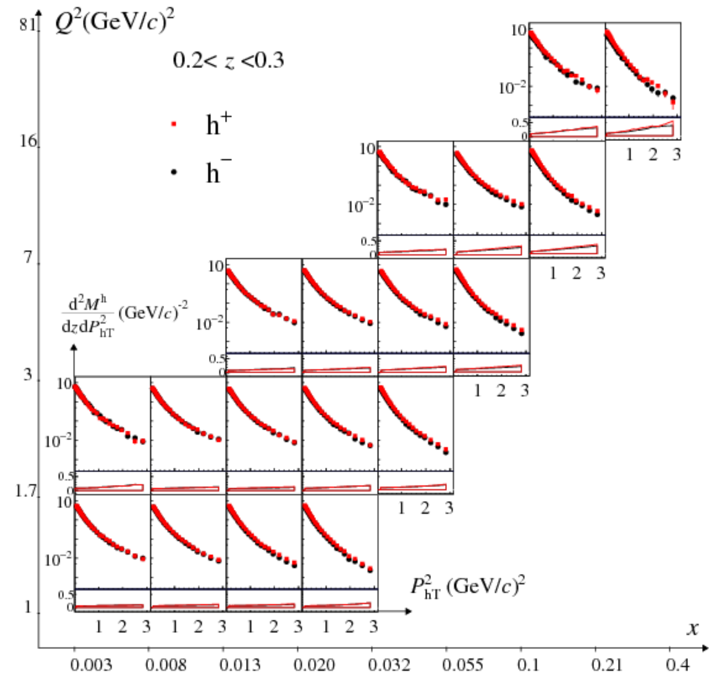
COMPASS contribution, so far:
(160 GeV muon beam)

- 2013: P^2_{hT}-distributions from 2004 deuteron data [Eur.Phys.J. C73 (2013) no.8, 2531]
- 2018: P^2_{hT}-multiplicities from 2006 deuteron data [PRD 97 (2018) 032006]



COMPASS published multiplicities (deuteron 2006)

New COMPASS contribution

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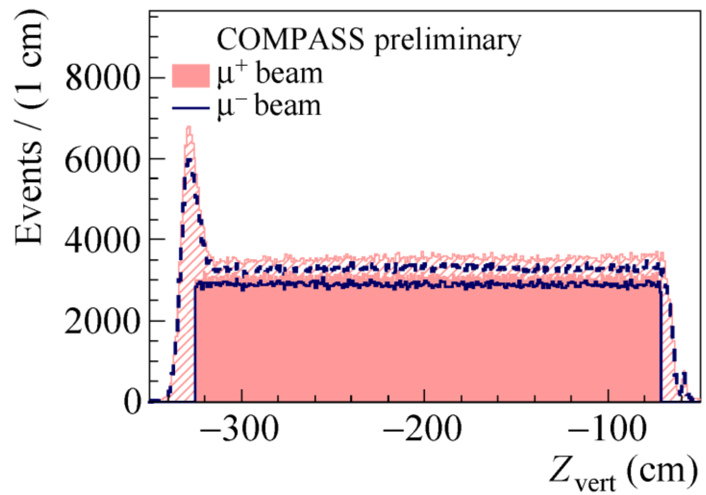
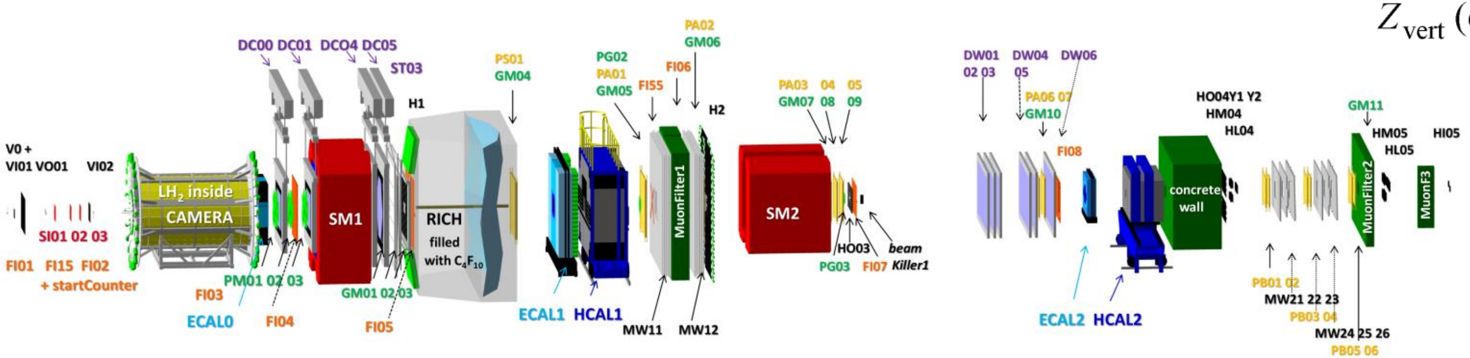
160 GeV muon ($\mu^{\pm}$) beam, proton target

Data collected in 2016 and 2017
Unpolarized liquid hydrogen target
Measurement of DVCS cross section → high precision
SIDIS measurement in parallel





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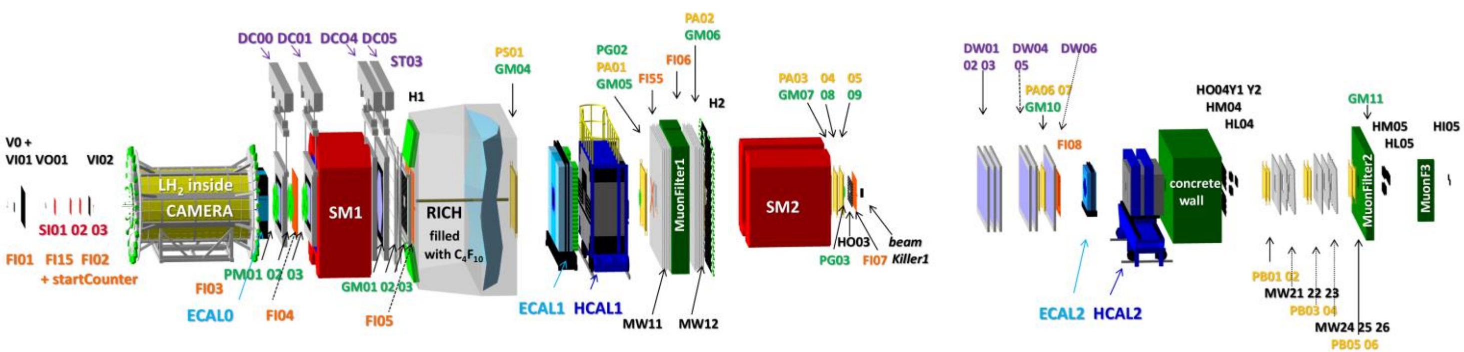
New measurements from this data:
- collinear multiplicities [N.Pierre]
- azimuthal asymmetries [J.Matousek]
- P_{hT}^{2} multiplicities **[this talk]**



Multiplicities – definition(s)

Hadron multiplicities: the ratio of **spin-independent SIDIS cross section**

$$\frac{d^4\sigma^{\ell p\to\ell' h\,X}}{dx\,dQ^2 dz\,dP_{hT}^2} = \frac{2\pi^2\alpha^2}{(xys)^2}\left[1+(1-y)^2\right] F_{UU}(x,Q^2,z,P_{hT}^2)$$

and the **DIS cross section,** being

$$F_{UU}\left(x,Q^2,z,P_{hT}^2\right) = \sum_q e_q^2 \int d^2k_T d^2p_{h\perp}\delta^{(2)}(P_{hT}-zk_T-p_{h\perp}) f_1^q(x,Q^2,k_T) D_q^h(z,Q^2,p_{h\perp})$$

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

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Measured multiplicities M^h_{meas}:

$$\boldsymbol{M^h_{meas}(x, Q^2, z, P_{hT}^2) = \frac{N^h\,(x, Q^2, z, P_{hT}^2)}{N^{DIS}(x, Q^2)\, \Delta z\, \Delta P_{hT}^2} \; \frac{1}{acc(x, Q^2, z, P_{hT}^2)}}$$

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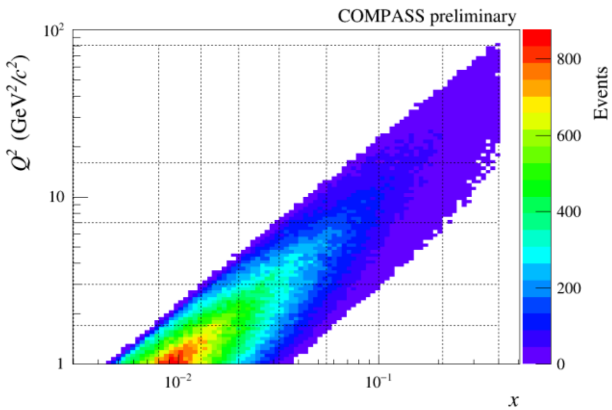
Acceptance calculated via Monte Carlo based on LEPTO as

$$\frac{N^h_{rec}(x,Q^2,z,P_{hT}^2)}{N^h_{gen}(x,Q^2,z,P_{hT}^2)|_{DIS_{rec}}}$$

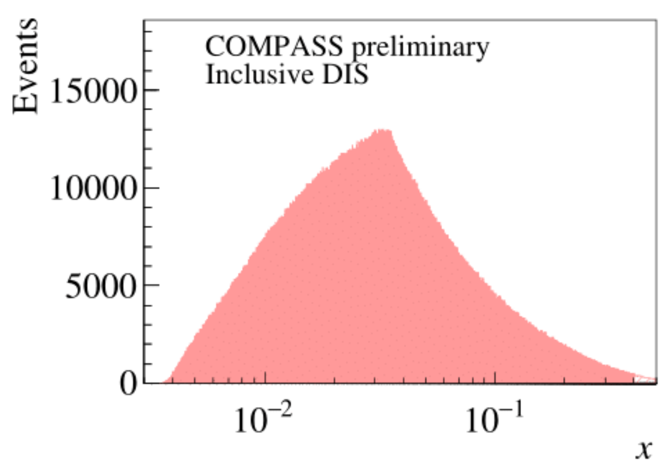
Analysis of 2016 data

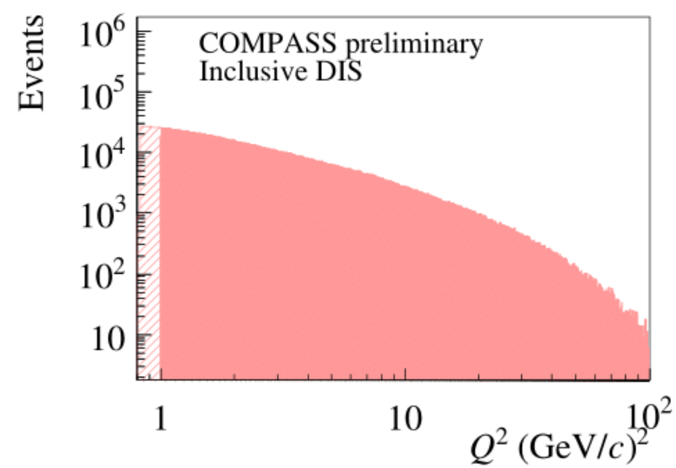
- Current analysis of 2016 data is based on the one performed on COMPASS 2006 data collected on an isoscalar (deuteron) target [PRD 97 (2018) 032006]
- 2 periods analyzed (out of 21) ~ 10% of available statistics



DIS selection

$$Q^2 > 1\ (\mathrm{GeV}/c)^2$$
$$x > 0.003$$
$$0.1 < y < 0.9$$





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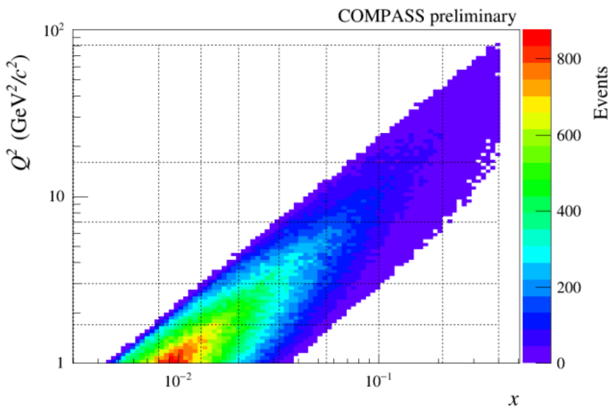

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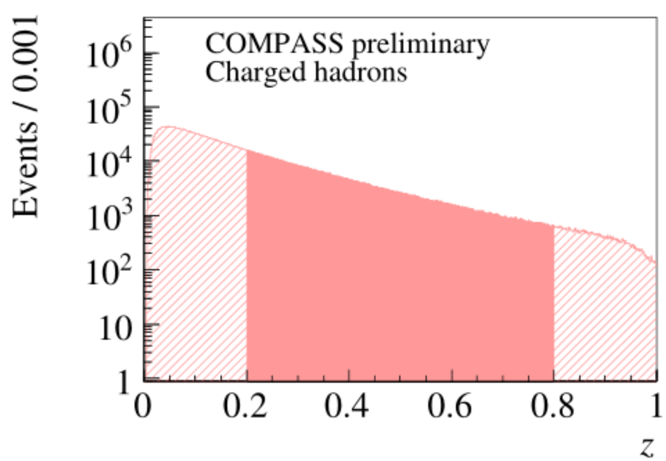
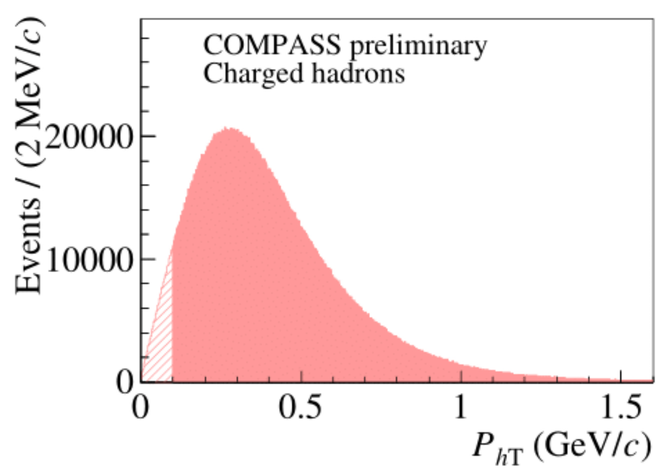
Hadron selection

charged
$0.2 < z < 0.8$
$0.02 < P_{hT}^2/(\mathrm{GeV/c})^2 < 3$





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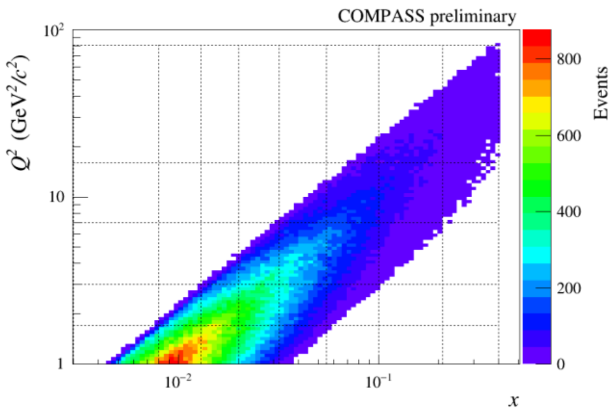

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- Multidimensional analysis: P_{hT}^2 multiplicities are measured in bins of (x, Q^2, z)
  for each (x, Q^2) bin, we divided z range in 4 bins, as in the previous analysis.

	1	2	3	4	5	6	7	8	9	10
$P_{hT}^2/(\mathrm{GeV}/c)^2$	0.02	0.06	0.10	0.14	0.196	0.27	0.35	0.46	0.60	0.76
	1.00	1.24	1.52	1.85	2.35	3.00				
$Q^2/(\mathrm{GeV}/c)^2$	1	1.7	3	7	16	81				
x	0.003	0.008	0.013	0.02	0.032	0.055	0.1	0.21	0.4	
z	0.2	0.3	0.4	0.6	0.8					

15 bins in P_{hT}^2

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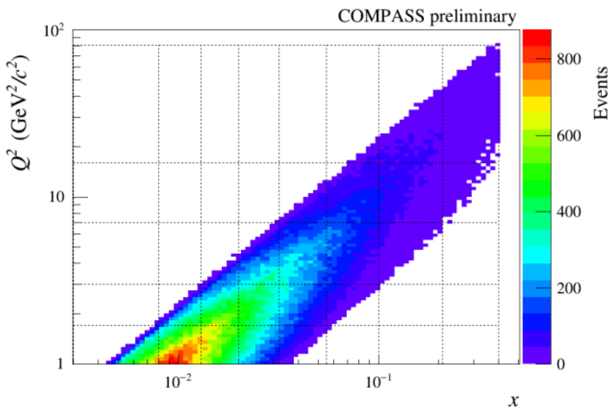

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15 bins in P_{hT}^2

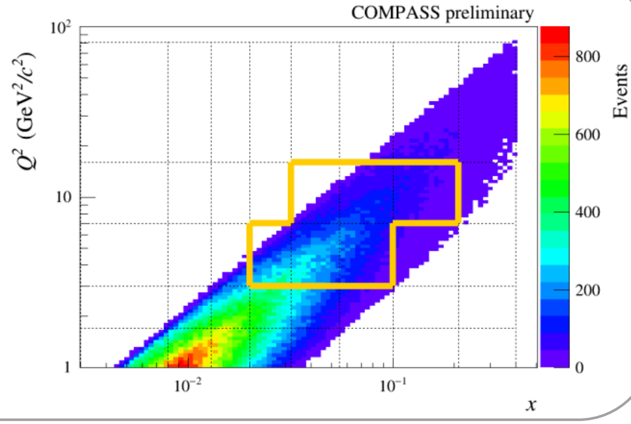
The analysis is in progress. **This talk:**
preliminary results in a selected kinematic range from part of the data.

Acceptance in P_{hT}^2

KINEMATIC RANGE

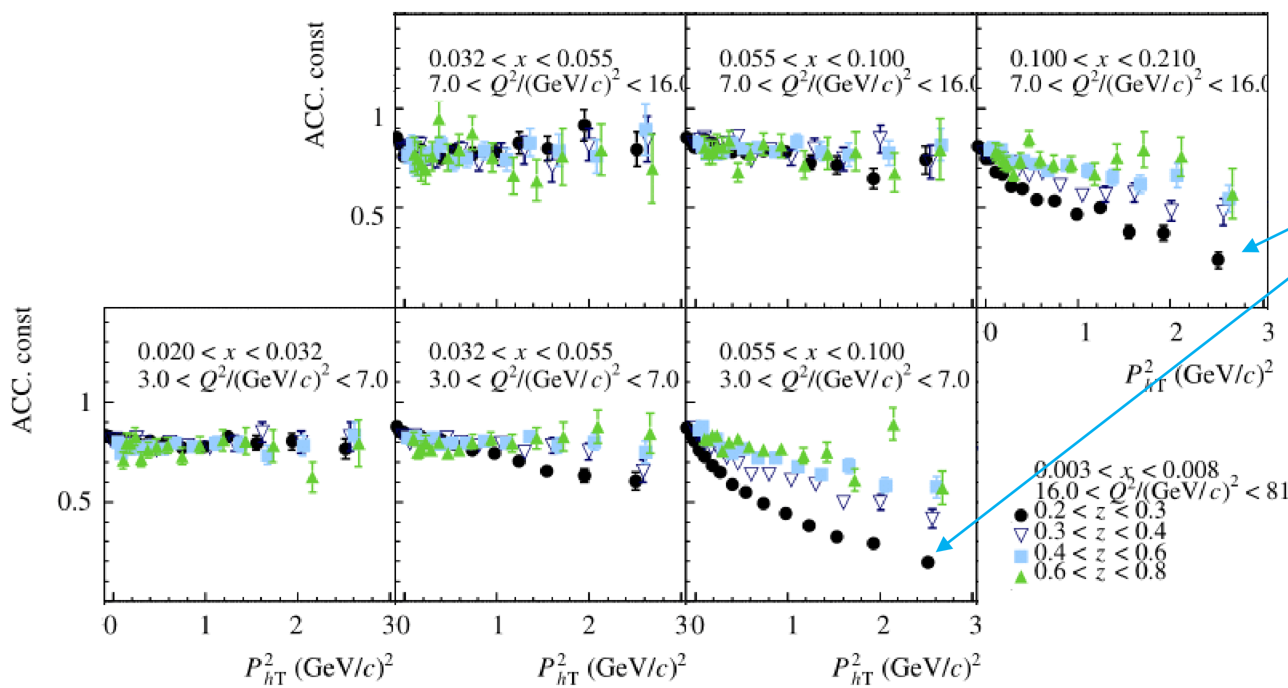
$3 < Q^2 \,/\, (\mathrm{GeV}/c)^2 < 16$
$0.02 < x < 0.21$
$0.1 < y < 0.9$

$0.2 < z < 0.6$
$0.02 < P_{hT}^2 \,/\, (\mathrm{GeV}/c)^2 < 3$



- Acceptance in P_{hT}^2 generally large and flat in the selected (x, Q^2) range
- Small z hadron acceptance has instead a strong dependence on P_{hT}^2

Negative hadrons



These bins are discarded here

Acceptance in P_{hT}^2

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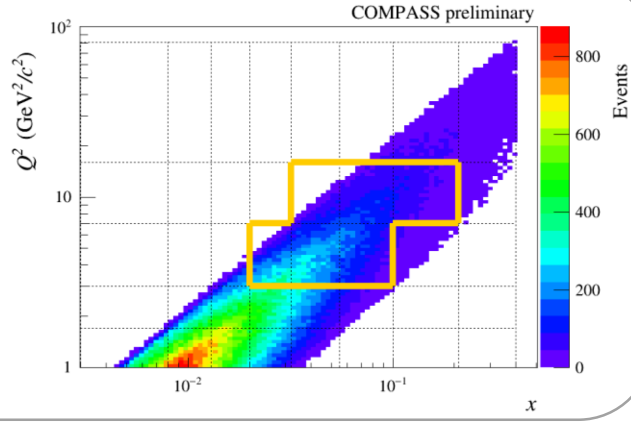
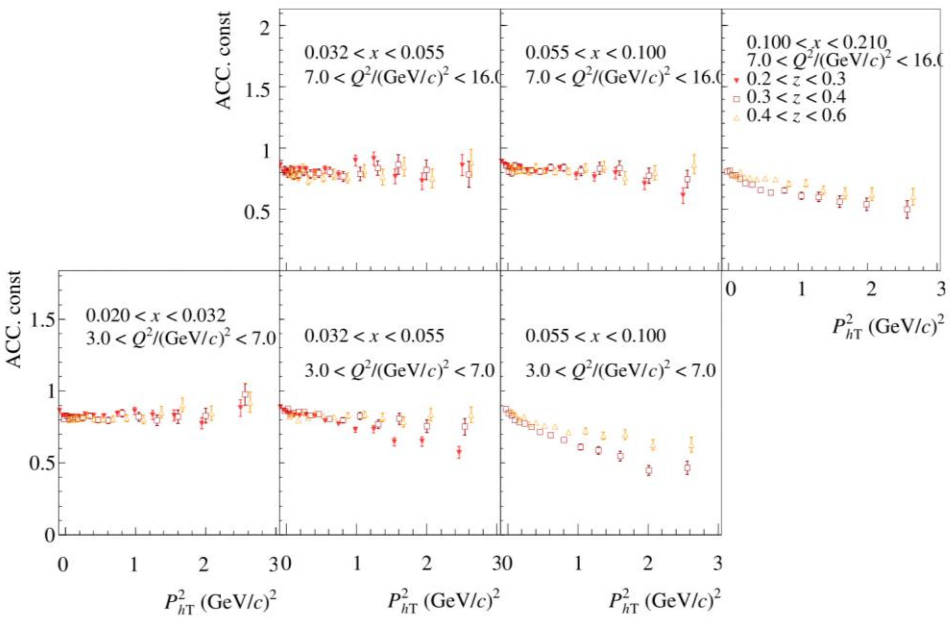
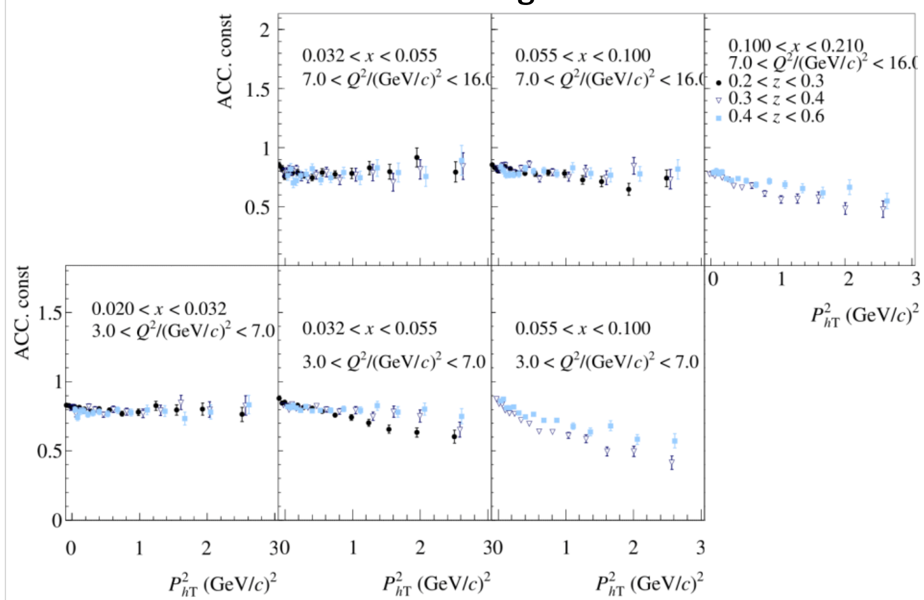


- Acceptance in P_{hT}^2 generally large and flat in the selected (x, Q^2) range
- Small z hadron acceptance has instead a strong dependence on P_{hT}^2
- Acceptance shape is almost independent on the hadron charge

Positive hadrons



Negative hadrons

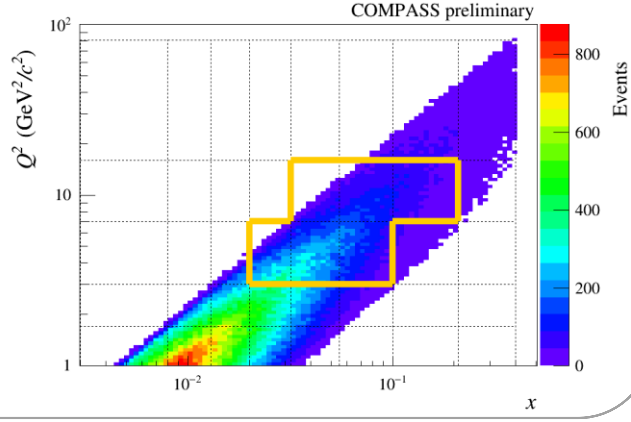


Acceptance in hadron azimuthal angle ϕ_h^{GNS}

KINEMATIC RANGE

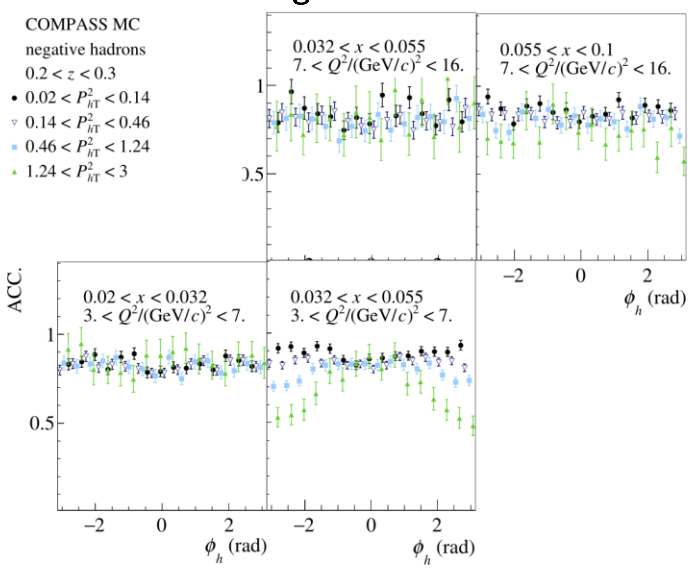
$3 < Q^2\ /\ (\mathrm{GeV}/c)^2 < 16$
$0.02 < x < 0.21$
$0.1 < y < 0.9$

$0.2 < z < 0.6$
$0.02 < P_{hT}^2\ /\ (\mathrm{GeV}/c)^2 < 3$

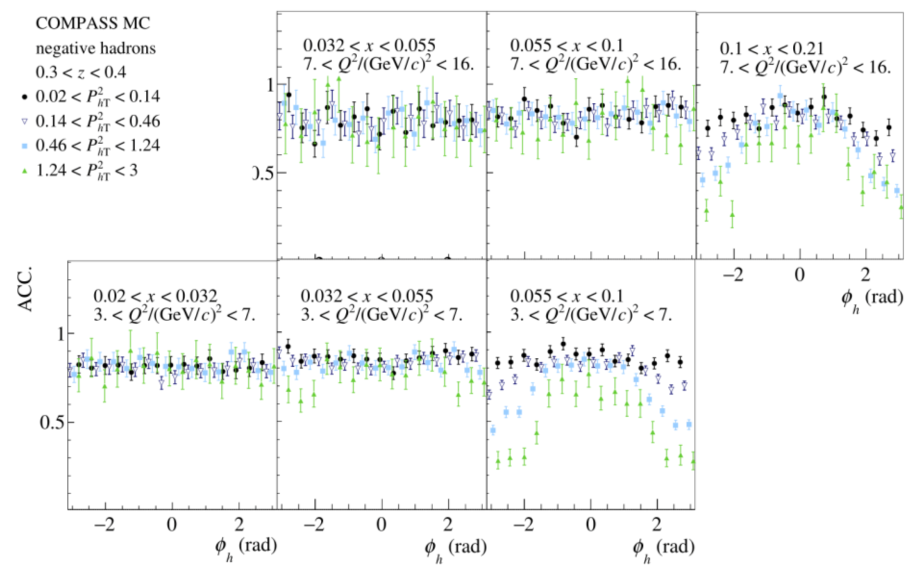


- Acceptance in ϕ_h^{GNS} has been investigated in four P_{hT}^2 bins to spot modulations
- Here examples for negative hadrons in different z bins.

Negative hadrons



Negative hadrons



Contaminations and systematics

In parallel, selection of kinematic range where corrections due to diffractive vector mesons contamination ($\rho \to \pi^+\pi^-, \phi \to K^+K^-, \dots$) are estimated to be small than 2%. Corrections for DVM are **not applied**.

In the fourth z bin ($0.6 < z < 0.8$) the DVM contamination is estimated to be larger than 2%.

Several tests performed to estimate possible **systematic effects:**

- stability of the results in time inside periods
- compatibility of different periods

Moreover, multiplicities have also been measured for different:

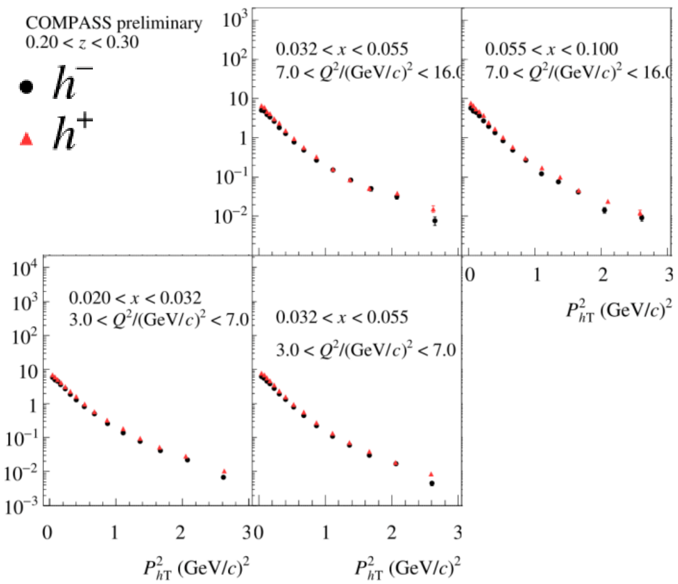
- azimuthal sectors of the spectrometer (ϕ_h^{lab})
- sections of the (long!) target

- The **upper limit** on the systematic error, relative to multiplicity, is

$$\sigma_{syst} \,/\, M^h < 0.1$$

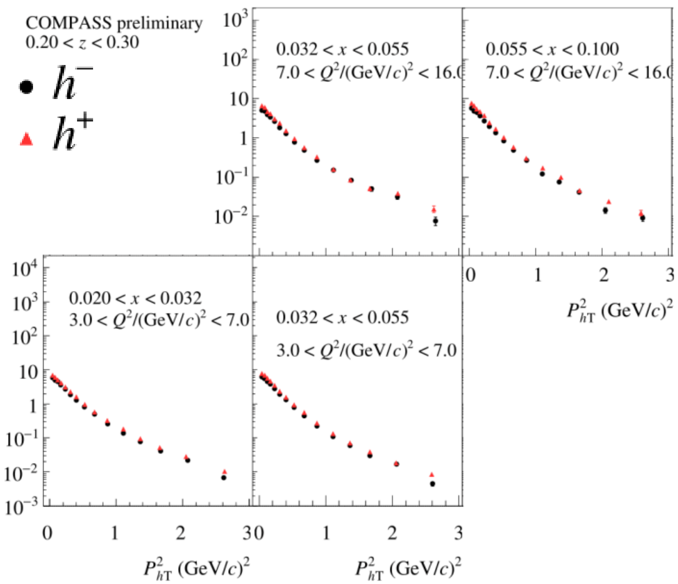
(at large P_{hT}^2)

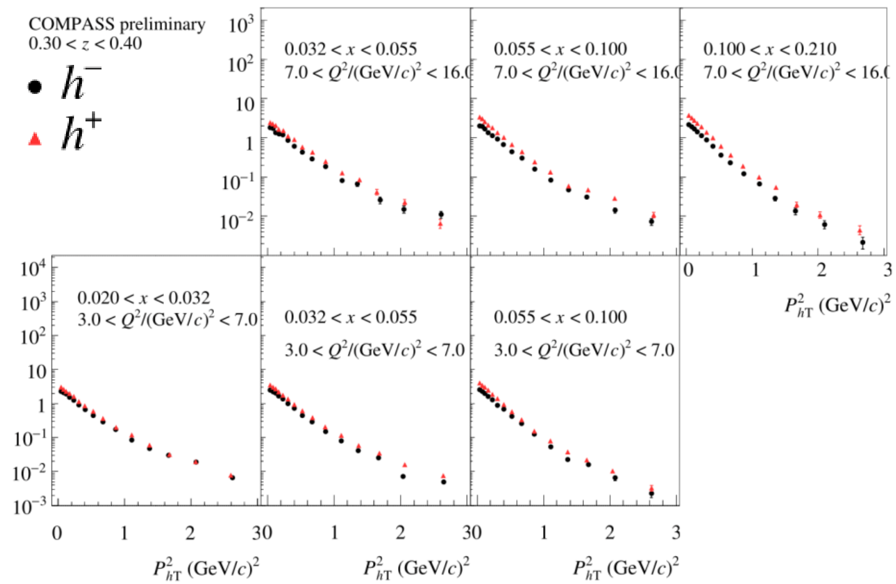
Results (first z bin)



Results not corrected for radiative effects

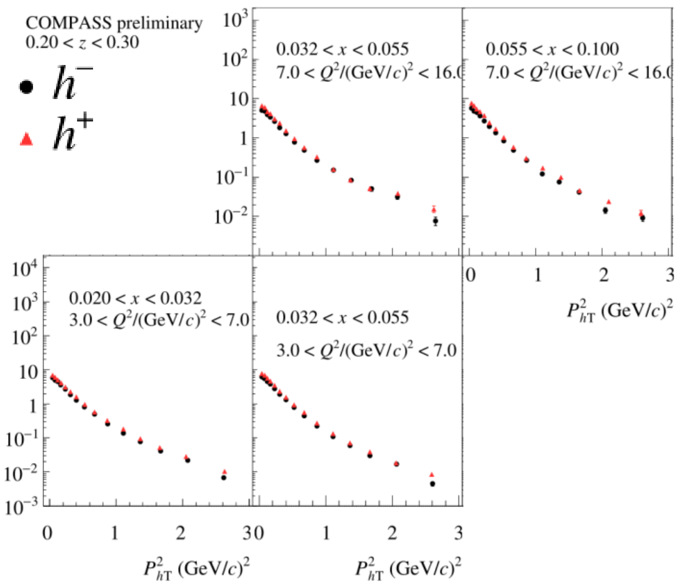
Results (first + second z bin)

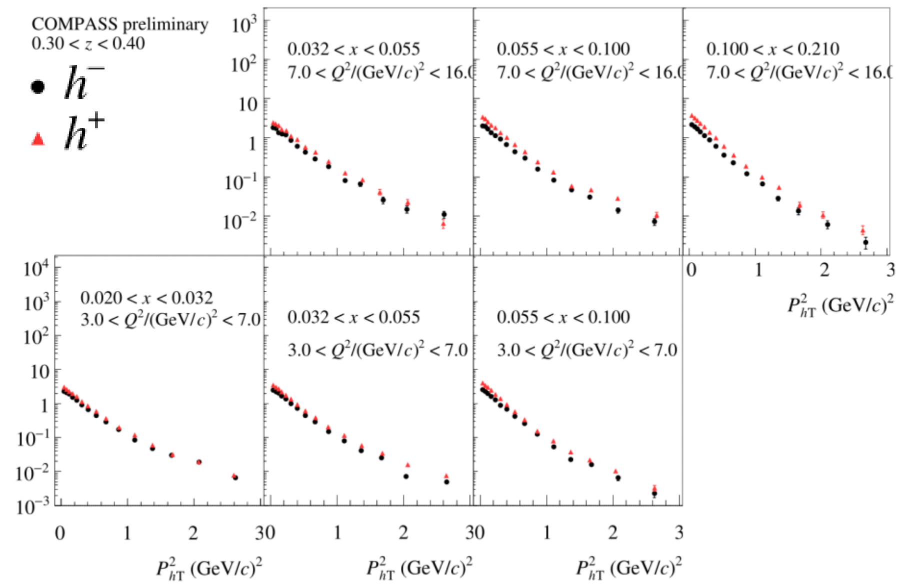


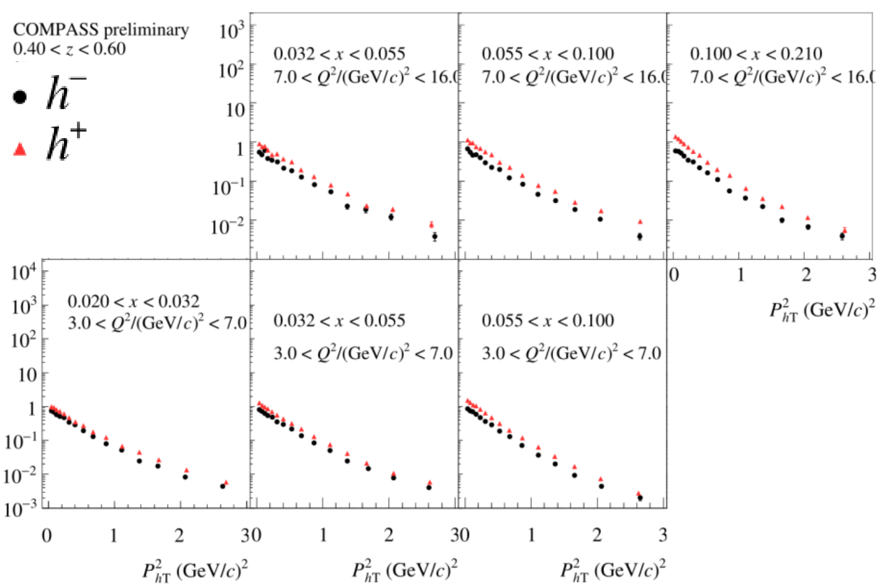


Results not corrected for radiative effects

Results (first + second + third z bin)







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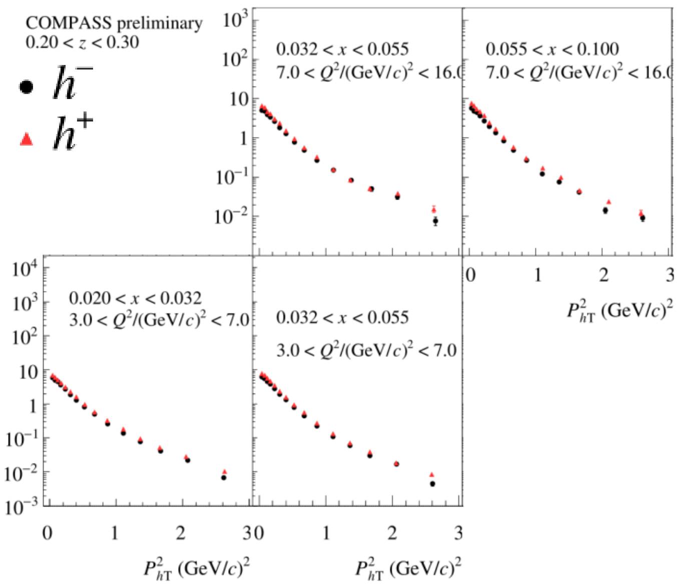
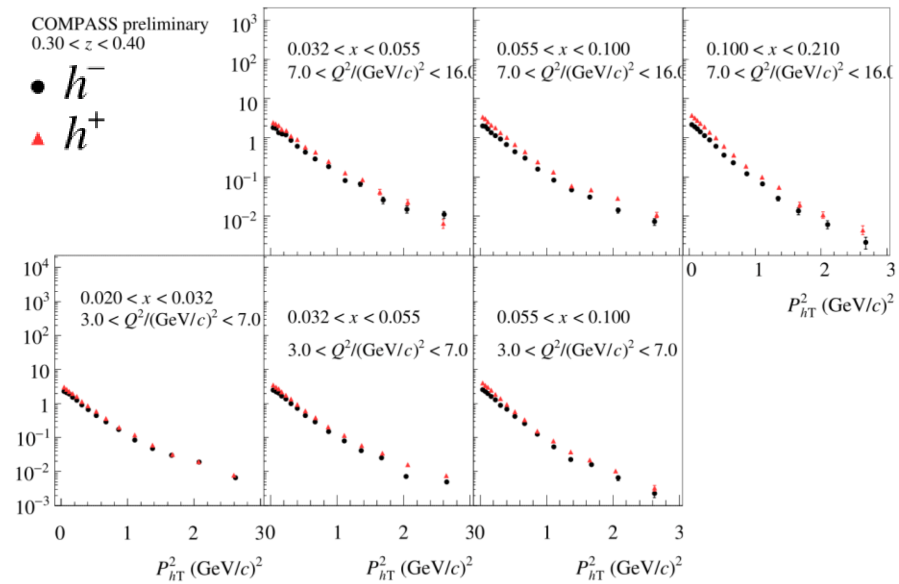
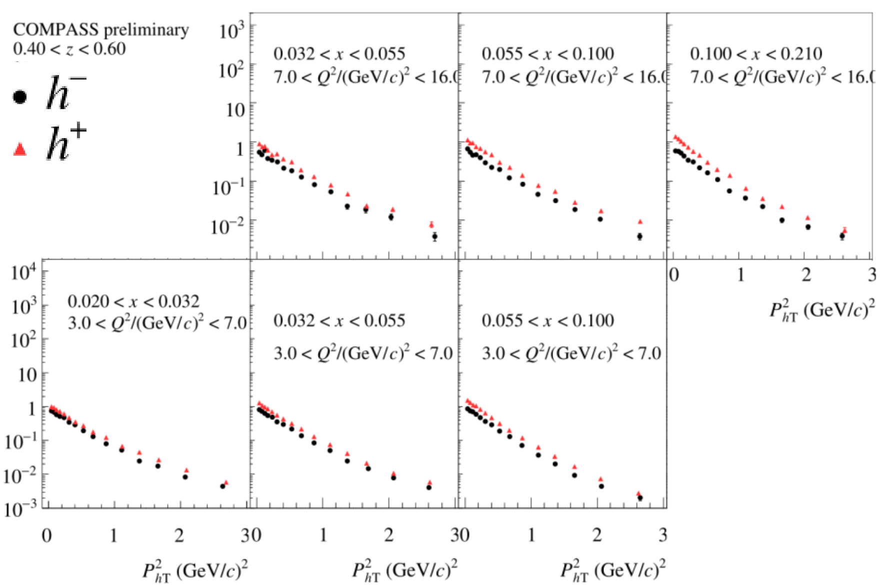






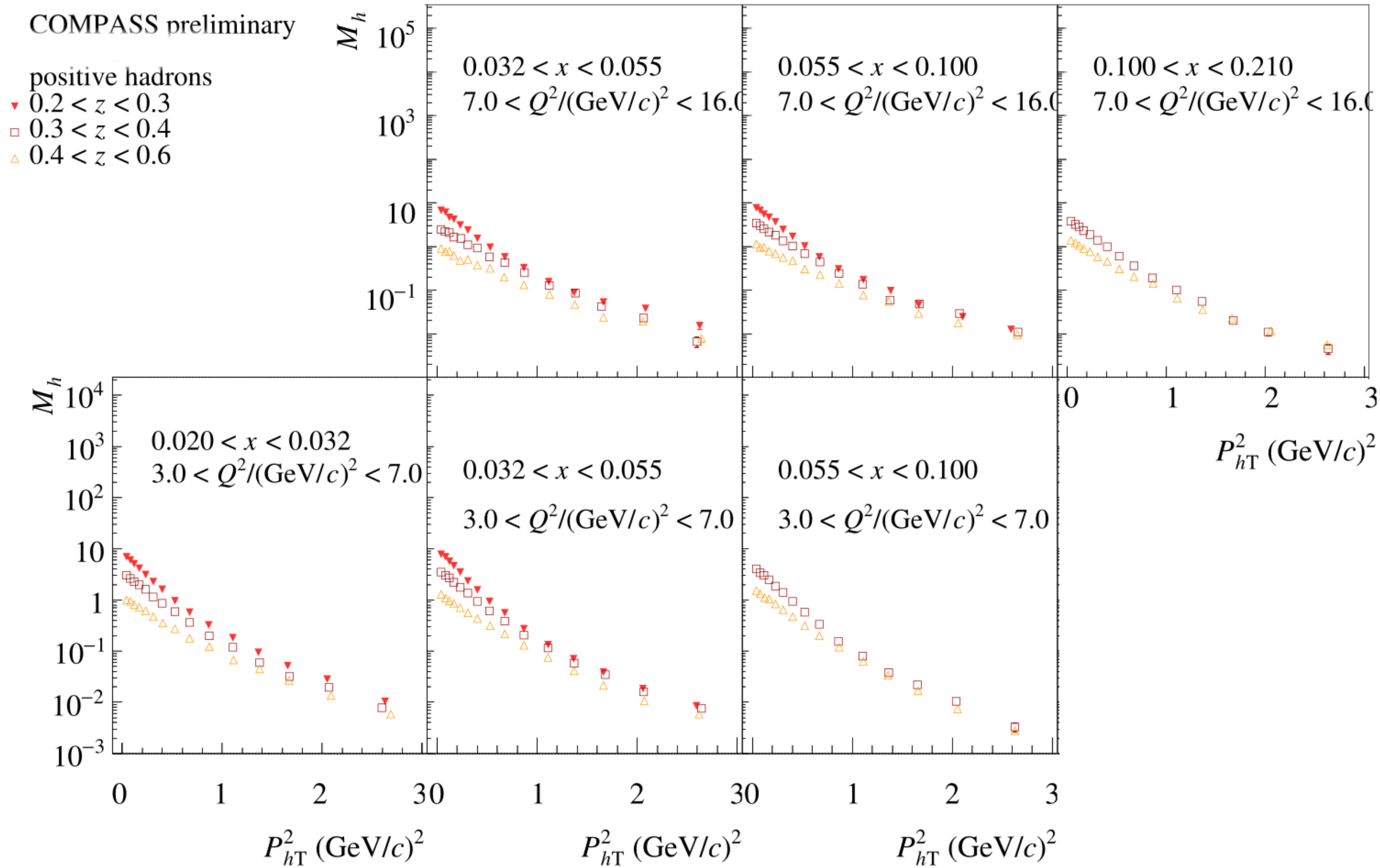
Smooth trend.

Results are consistent with previous COMPASS measurement on isoscalar target.

The difference between positive and negative hadrons increases with z, as expected.

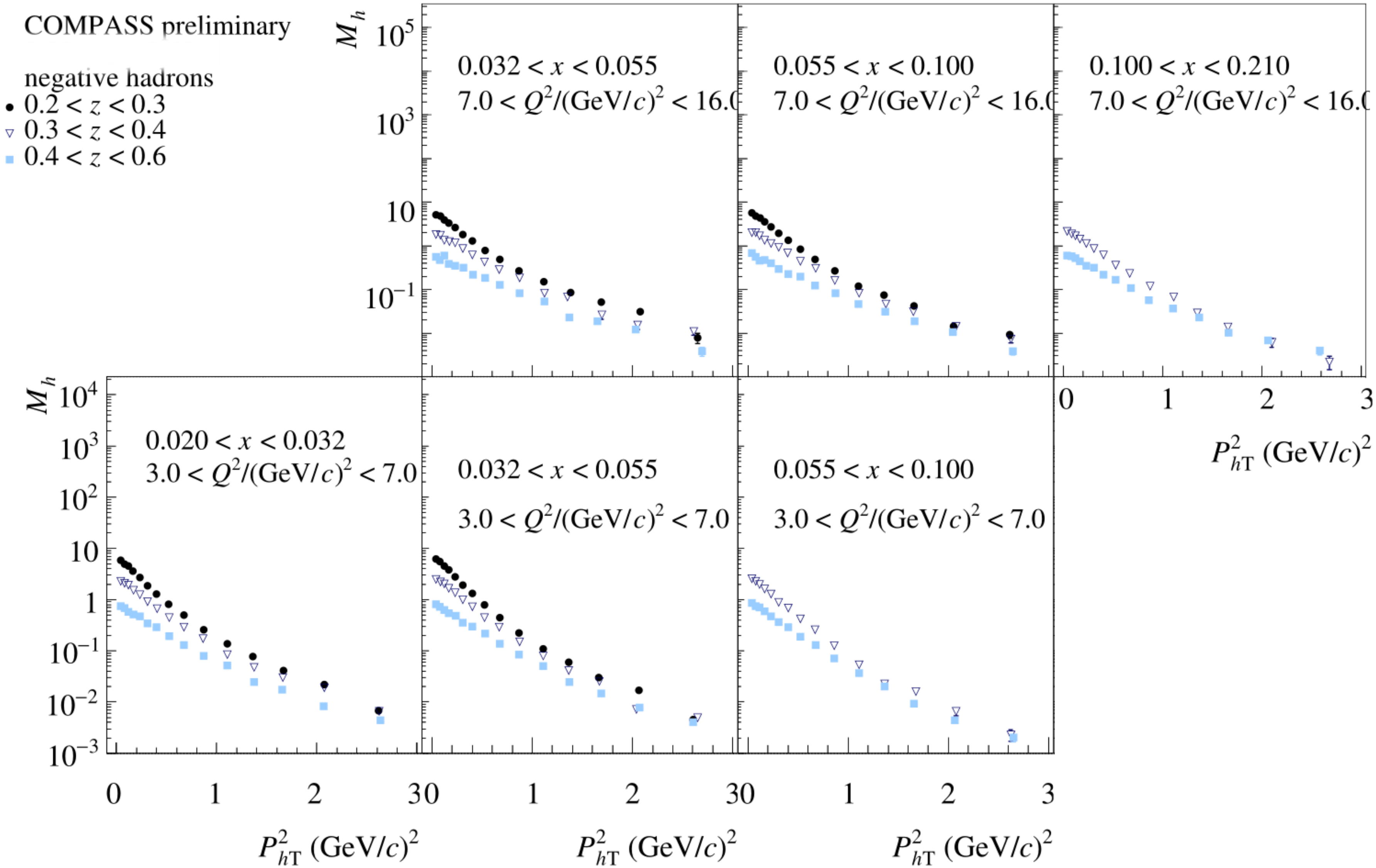
Results not corrected for radiative effects

Results – multiplicities for positive hadrons



Results not corrected for radiative effects

Results – multiplicities for negative hadrons



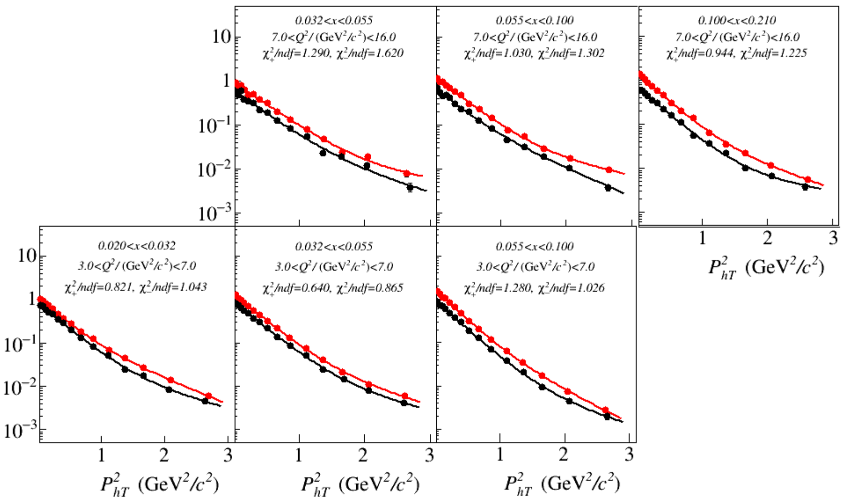
Results not corrected for radiative effects

Fit of multiplicities

The smooth multiplicities trend is well described by

Double exponential

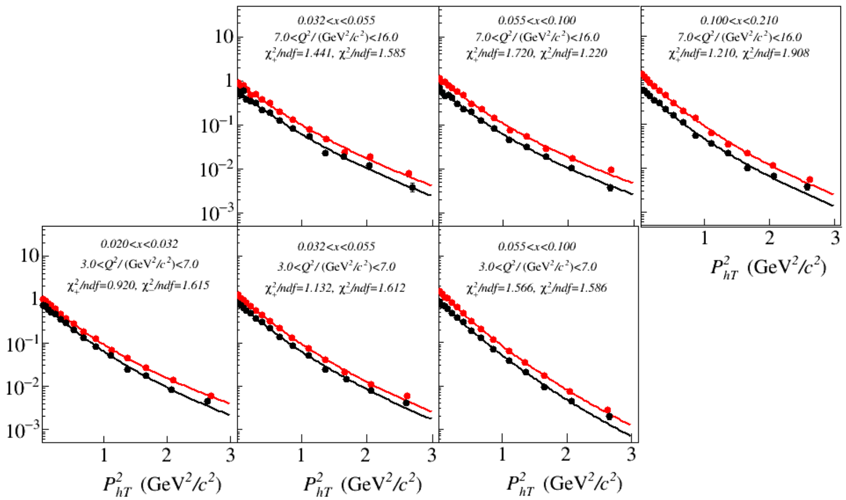
$$f_1 = \frac{N_1}{\alpha_1}\exp\left(-\frac{P_{hT}^2}{\alpha_1}\right) + \frac{N_{1'}}{\alpha_{1'}}\exp\left(-\frac{P_{hT}^2}{\alpha_{1'}}\right)$$



$$P_{hT}^2 < 3\ (\text{GeV}/c)^2$$
$$<\chi^2/ndf> = 0.98$$

Tsallis function

$$f_2 = N_2\left(1-(1-q)\frac{P_{hT}^2}{T}\right)^{\frac{1}{1-q}}$$



$$P_{hT}^2 < 3\ (\text{GeV}/c)^2$$
$$<\chi^2/ndf> = 1.46$$

Fit of multiplicities in the range $0.4 < z < 0.6$

Fit of multiplicities

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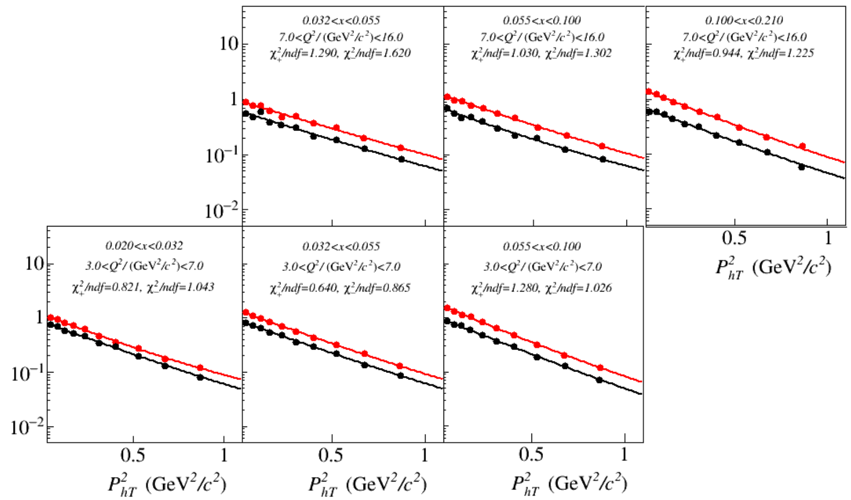

Zoom: $P_{hT}^2 < 1\ (\mathrm{GeV}/c)^2$

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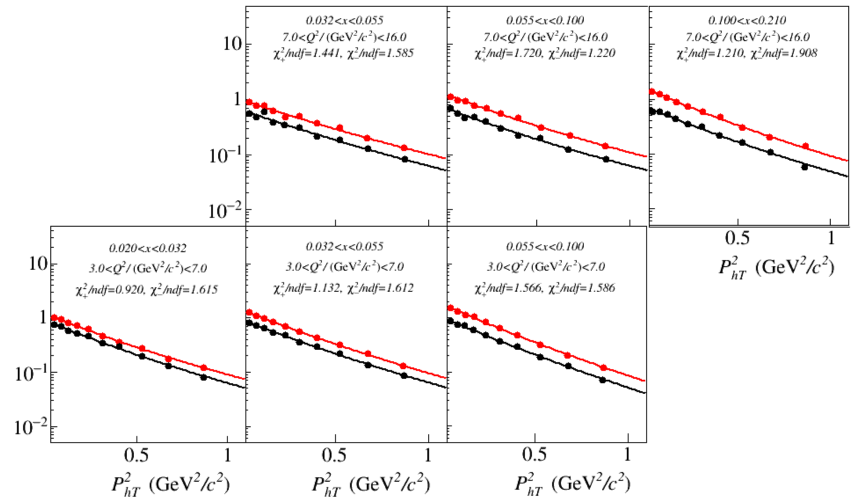

Zoom: $P_{hT}^2 < 1\ (\mathrm{GeV}/c)^2$

$< \chi^2/ndf > = 1.46$

Fit of multiplicities in the range $0.4 < z < 0.6$

Outlook

COMPASS is working on SIDIS data collected with an unpolarized proton target to study TMDs with particular focus on

azimuthal asymmetries and $\boldsymbol{P^2_{hT}}$ **- dependent multiplicities**
in view of a combined analysis with similar binning

$\boldsymbol{P^2_{hT}}$ **- dependent multiplicities**
Preliminary results in a selected kinematic range are encouraging

Next steps

- Use largest kinematic range as possible (even using part of target)
- Multiplicities as function of other variables ($q_t = P_{hT} / z$), in rapidity bins, ...
- Analyze all 2016 and 2017 periods

→ Expected gain in statistics up to a factor of 10
with respect to the current analysis

Thank you!

Backup

Diffractive vector meson contributions

Hadrons can be produced in the decay of diffractively produced vector mesons ($\rho \rightarrow \pi^+\pi^-, \phi \rightarrow K^+K^-, \dots$).
DIS events and final-state hadrons are indistinguishable from the “true” DIS / SIDIS production, but the theoretical description of diffractive production is given in terms of Pomeron exchange (gluon ladder) at variance with single-photon exchange approximation.

Let’s indicate with N_{DIS}^{obs} the number of observed events and with N_{DVM} the estimated number of reconstructed diffractively produced vector mesons (DVM):

$$N_{DIS}^{obs} = N_{DIS} + N_{DVM} \approx N_{DIS} + N_\rho + N_\phi \Rightarrow f_{DVM} = \frac{N_\rho + N_\phi}{N_{DIS} + N_\rho + N_\phi}$$

Analogously, the number of observed hadrons N_h^{obs} is built upon several terms:

$$N_h^{obs} = N_h^{SIDIS} + N_h^{DVM} \approx N_h^{SIDIS} + N_h^\rho + N_h^\phi \Rightarrow f_h^{DVM} = \frac{N_h^\rho + N_h^\phi}{N_h^{SIDIS} + N_h^\rho + N_h^\phi}$$

All quantities have been estimated via Monte Carlo simulations based on LEPTO for the SIDIS part and on HEPGEN for the DVM part. Here: plots for the DIS / pion / Kaon correction term, as from COMPASS paper [PRD 97 (2018) 032006].
New analysis in qualitative agreement (not expected to be identical due to the different target)