COMPASS results on unpolarised azimuthal asymmetries and distributions

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OUTLINE

- COMPASS experiment
- results
    - azimuthal asymmetries
    - hadron multiplicities

COmmon
Muon and
Proton
Apparatus for
Structure and
Spectroscopy

29 Institutes, ~230 physicists

NA58

wide physics program carried on using both muon and hadron beam

muon beam	**deuteron** (^{6}LiD) polarized target	2002	L/T target polarization
		2003	L/T target polarization
		2004	L/T target polarization
	spectrometer upgrade	2005	*SPS shutdown*
	proton (NH_3) polarized target	2006	L target polarization
		2007	L/T target polarization
		2010	T target polarization
		2011	L target polarization
hadron beam	LH target	2008	
		2009	

longitudinally polarised muon beam

beam intensity: $2 \cdot 10^8$ $\mu+$/spill (4.8s/16.2s)

beam momentum: **160 GeV/*c***

luminosity: $\sim 5 \times 10^{32}$ cm^{-2} s^{-1}

- muon beam:
  - **nucleon spin structure**
    - ΔG/G
    - helicity distributions
    - transverse spin effects
    - Λ physics
    - ρ^0 production
    - ...

SIDIS

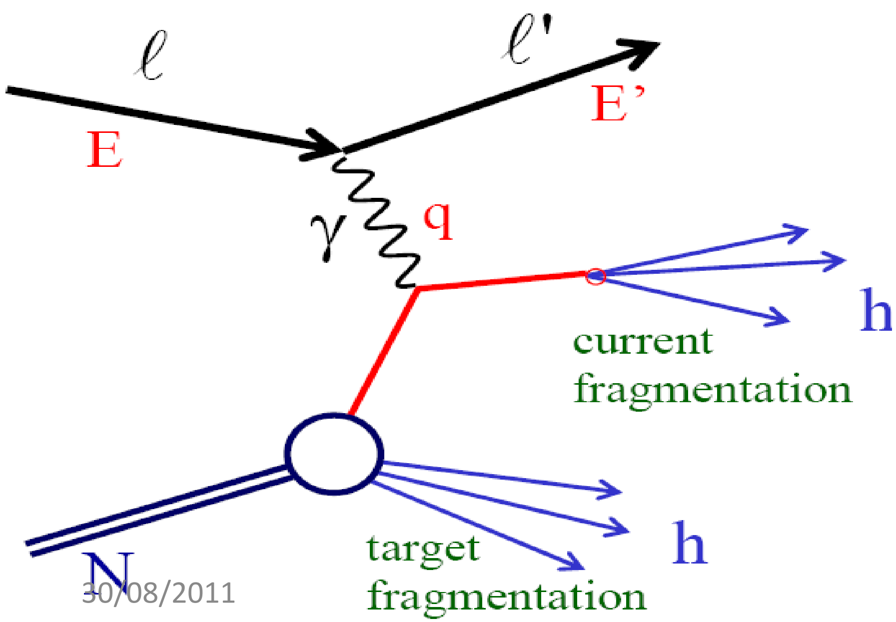
lepton interacts with a **single constituent** of the nucleon (Q^2>1GeV^2/c^2)

$$q = \ell - \ell' \qquad Q^2 = -q^2$$

$$W^2 = (P + q)^2$$

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

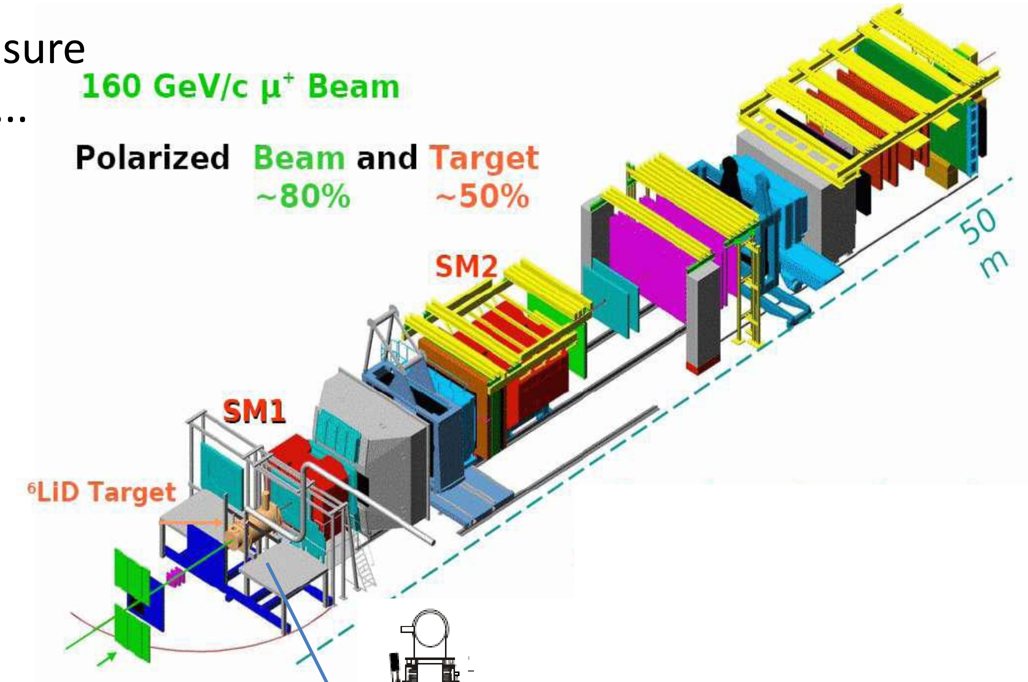
$$y = \frac{P \cdot q}{P \cdot \ell} =_{LAB} \frac{E - E'}{E}$$



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

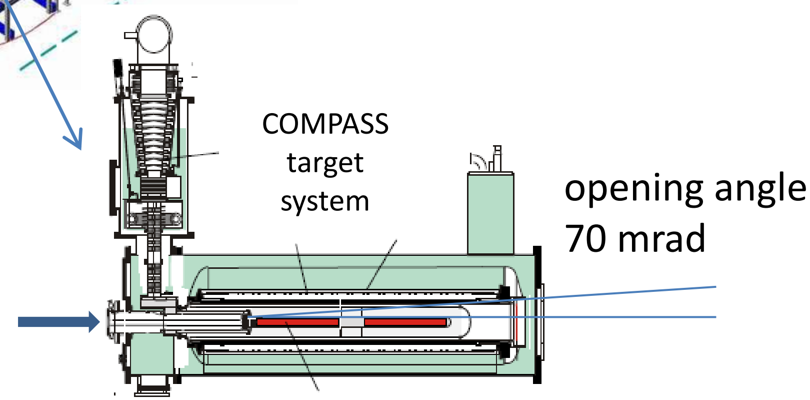
$$z = \frac{P \cdot P_h}{P \cdot q} =_{LAB} \frac{E_h}{E - E'}$$

complex apparatus optimized to measure
spin dependent asymmetries, but also ...



spin averaged physics
combining + and – pol.

MC simulation needed to **correct the real data distributions**
for the acceptance of the apparatus
(geometrical acceptance,
detector and trigger efficiencies,...)



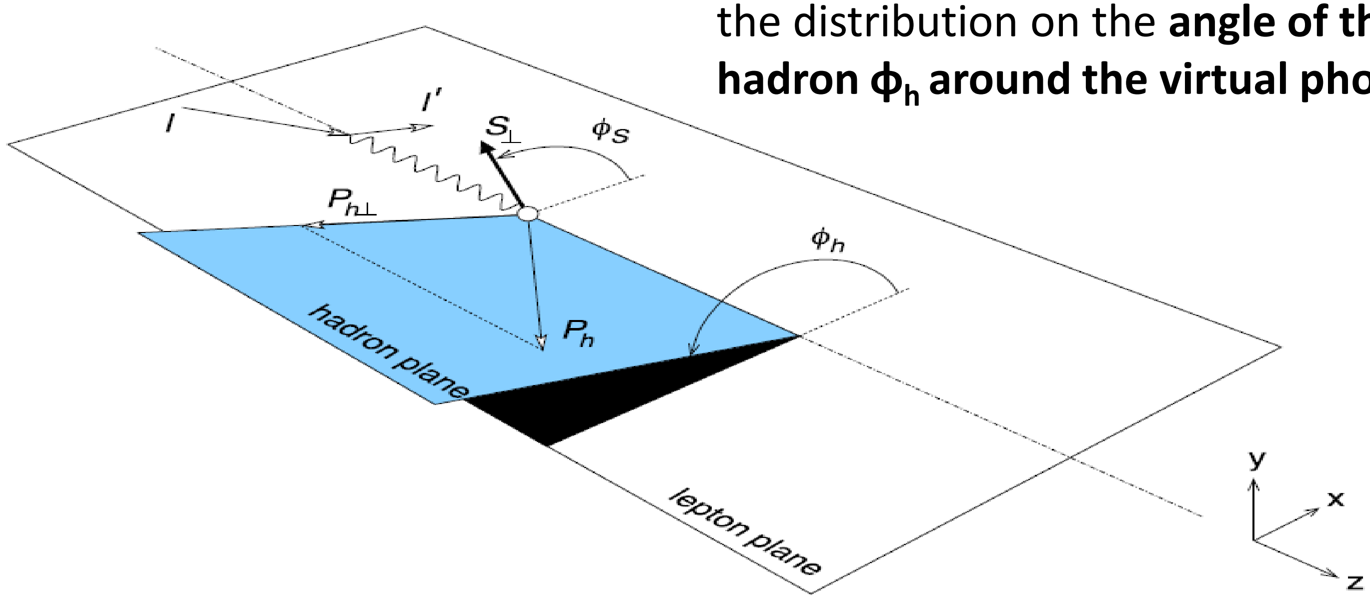
*simulation of the **2004 data taking** widely studied*
and the apparatus behaviour well understood
already a large amount of data to measure unpolarized distributions

Results from the analyses of the **unpolarized distributions** at COMPASS

1. 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**

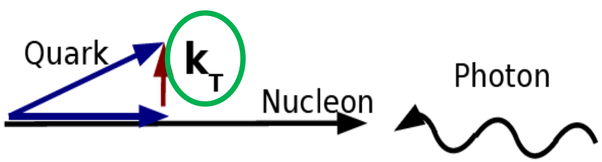


QPM **convolution on the** **TM of the quark** **between different PDFs and a FFs**

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

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

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

Basic idea of the method

for each bin (k) in **x, z** and **P_T^h** (transv. mom. of the hadron w.r.t. the virtual photon)

The **measured azimuthal distributions** have been **corrected** for the **apparatus acceptance** which depends on ϕ_h

Azimuthal acceptance calculated from as the **ratio** between **Reconstructed** and **Generated** distributions from **MC**

acceptance extracted adding one more dimension (x in the example)

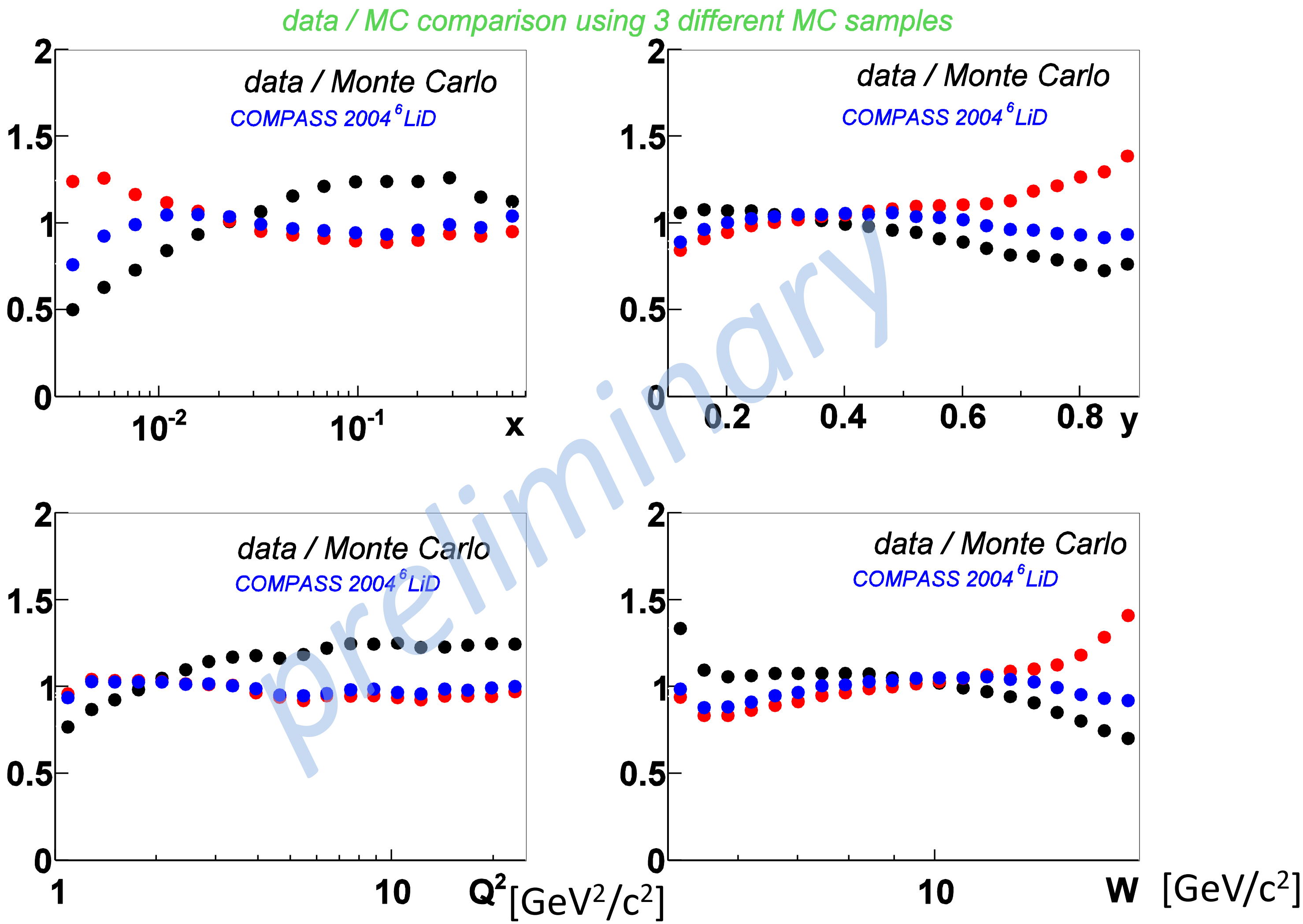
$$N_k^{corr}(\phi_h, x) = \frac{N_k(\phi_h, x)}{Acc_k(\phi_h, x)}$$

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

amplitudes extracted with a fit

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

it has been checked that the extracted **azimuthal amplitudes are ~the same** by **using 3 different MC simulations** describing equally well the apparatus



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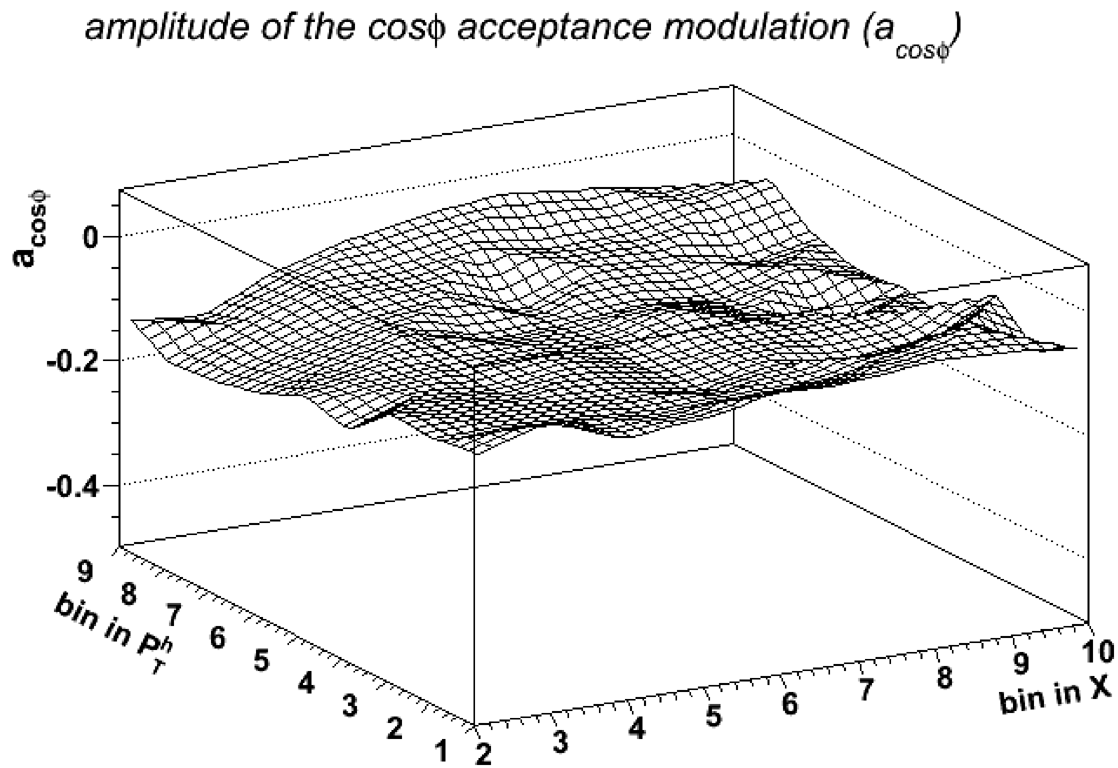
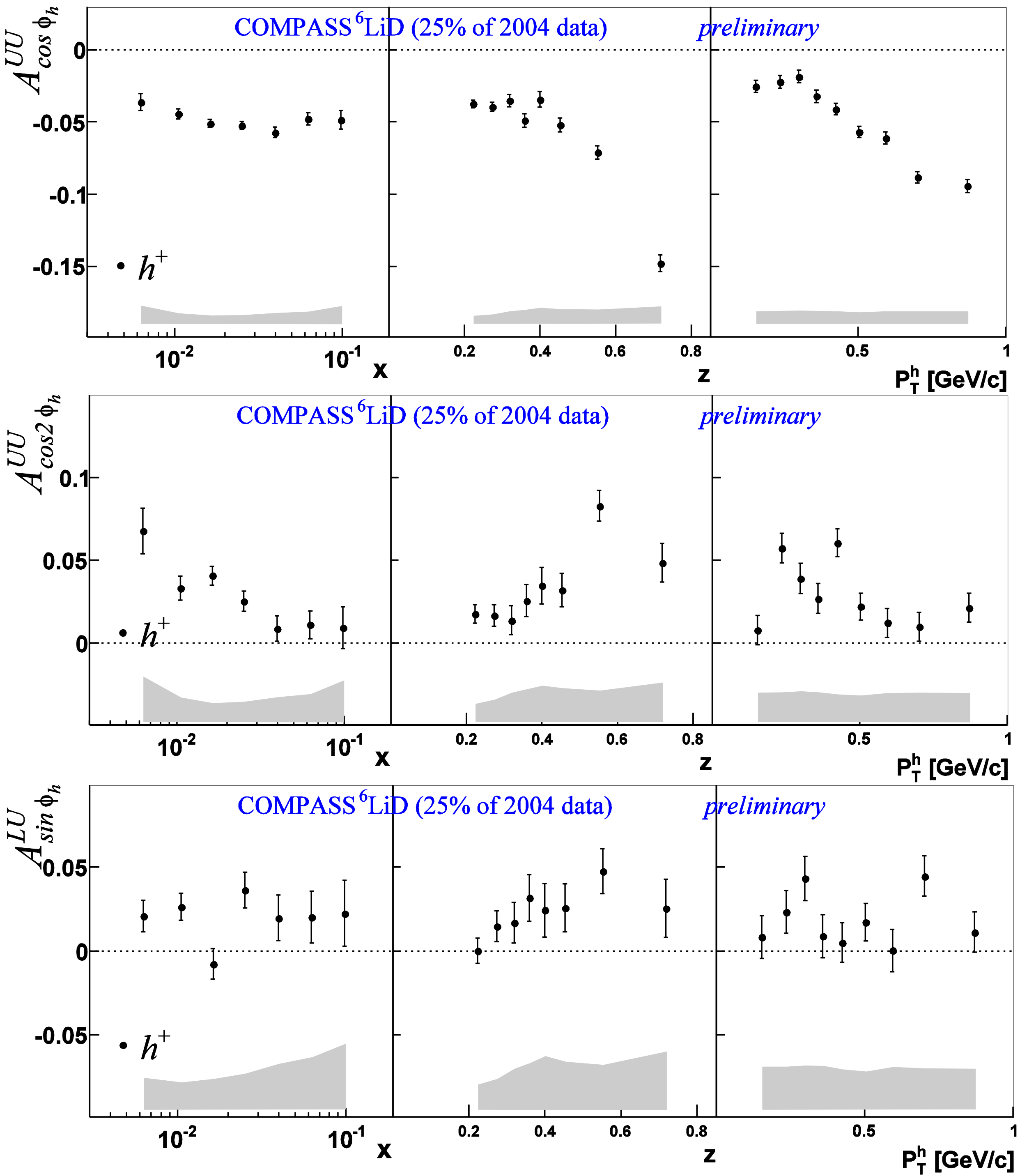
The apparatus azimuthal acceptance *as a function of the event kinematics has been* ***studied*** *at length*

the regions giving rise to
large azimuthal modulations in the acceptance
(above 50% for some bin)
have been ***excluded***

$Q^2 > 1\ (\mathrm{GeV}/c)^2$
$\theta_\gamma^{lab} < 0.06$
$0.003 < x < 0.13$
$0.2 < y < 0.9$
$W > 5\ \mathrm{GeV}/c^2$
$0.2 < z < 0.85$
$0.1 < P^T_h < 1\ \mathrm{GeV}/c$

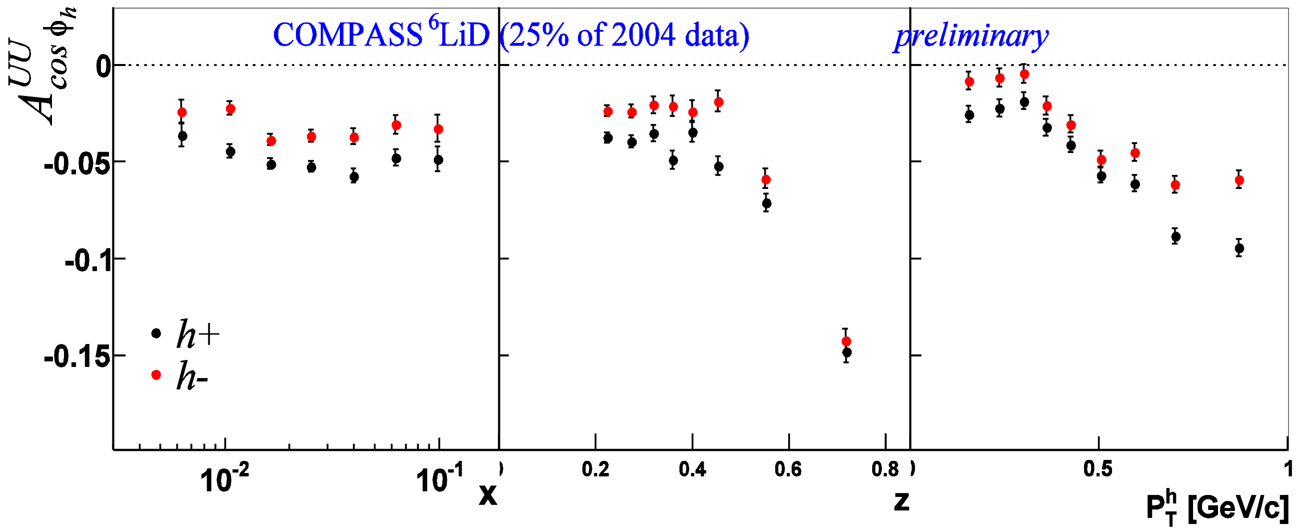


The **amplitudes of the 3 azimuthal modulations** have been **measured** separately for **positive and negative hadrons**, as functions of the kinematical variables **x**,**z** and $\mathbf{P^h_T}$

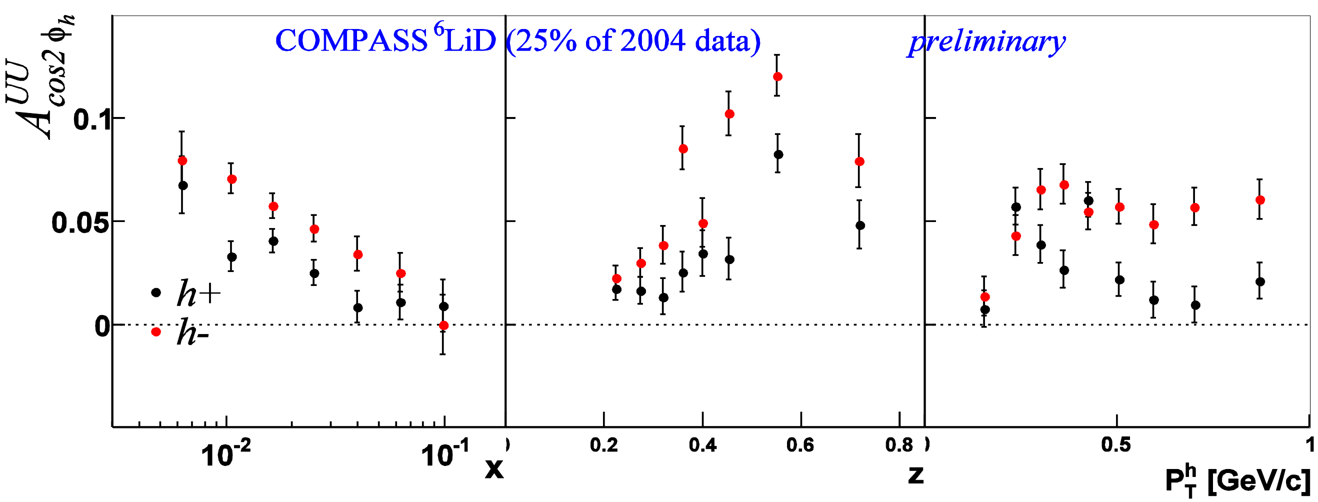


presented at spin2010

comparison between results from positive and negative hadrons



strong kinematical trends in z and P_T^h (difficult to describe)



different results for positive and negative hadrons : possible signature of the Boer-Mulders TMD PDF prediction for the Cahn effect can be calculated assuming

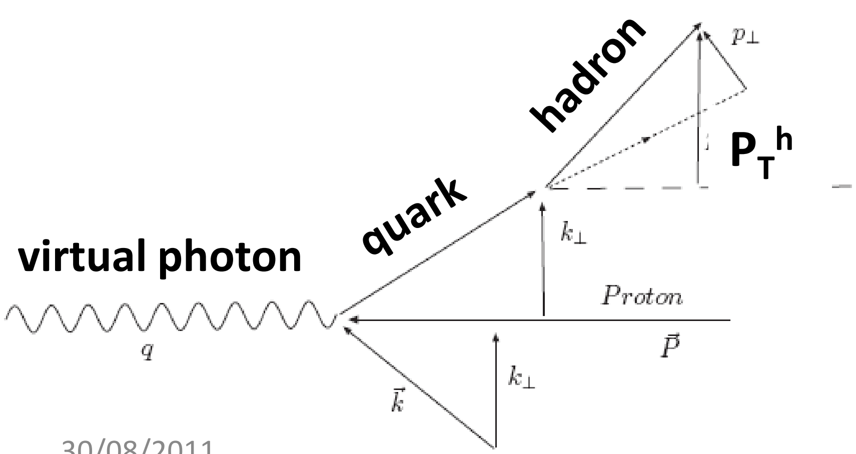
$$f_q(x, k_\perp) = f_q(x)\frac{1}{\pi\langle k_\perp^2\rangle}e^{-k_\perp^2/\langle k_\perp^2\rangle}$$

$$D_q^h(z, \vec{p}_\perp) = D_q^h(z)\frac{1}{\pi\langle p_\perp^2\rangle}e^{-p_\perp^2/\langle p_\perp^2\rangle}$$

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

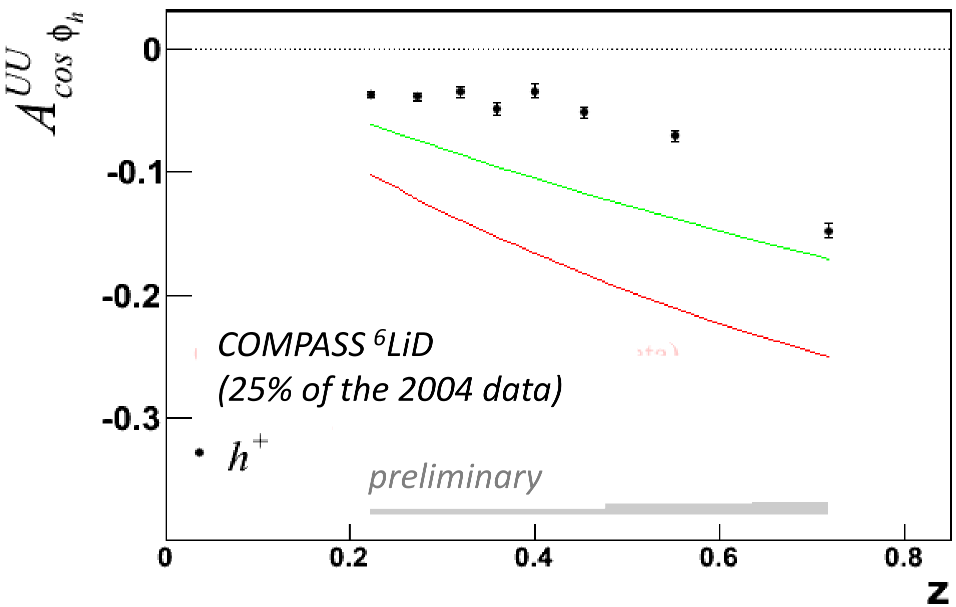
and the **cos ϕ_h** amplitude is expected to be

$$A_{\cos\phi_h}^{UU}(z) = \frac{z < k_\perp^2 > \sqrt{\pi}}{2 < Q > \sqrt{< P_T^{h2} >}}$$



$$< P_T^{h2} > = z^2 < k_\perp^2 > + < p_\perp^2 >$$

$$A_{\cos\phi_h}^{UU}(z) = \frac{z < k_\perp^2 > \sqrt{\pi}}{2 < Q > \sqrt{z^2 < k_\perp^2 > + < p_\perp^2 >}}$$



results are not well reproduced by calculations of this expression using:

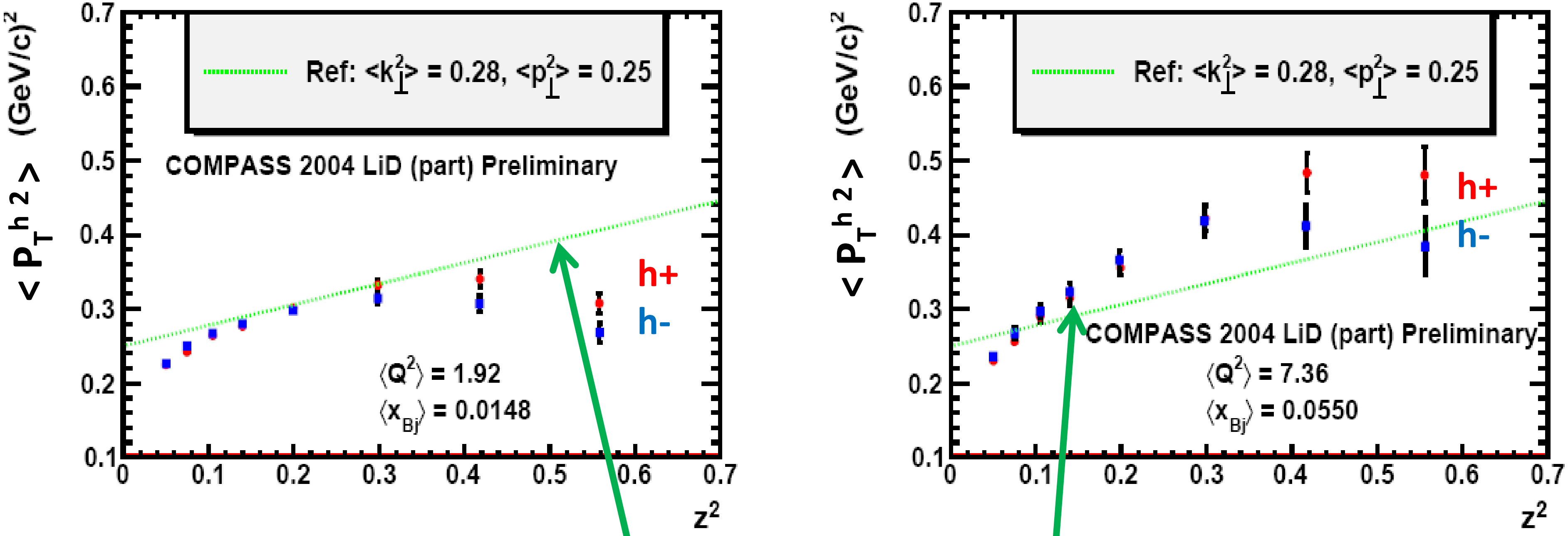
$< k_\perp^2 >, < p_\perp^2 >$ (GeV/c)^2

0.25, 0.20 *Anselmino et al. (PRD71 2005)*

combined analysis of EMC data

0.38, 0.16 *Schweitzer et al. (PRD81 2010)*

from <P_T^{h2} (z)> measured by HERMES



moreover the relation

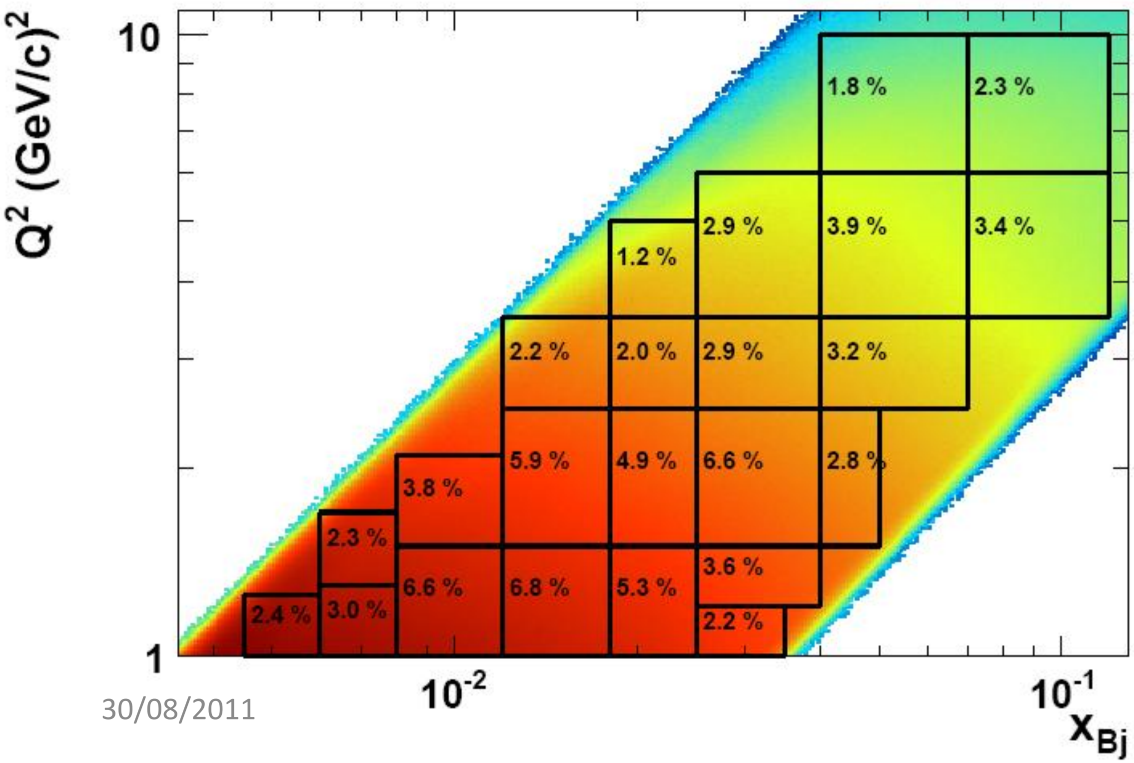
$$< P_T^{h2} > = z^2 < k_\perp^2 > + < p_\perp^2 >$$

seems not to hold for COMPASS data ...

2. transverse momentum dependent hadron multiplicities

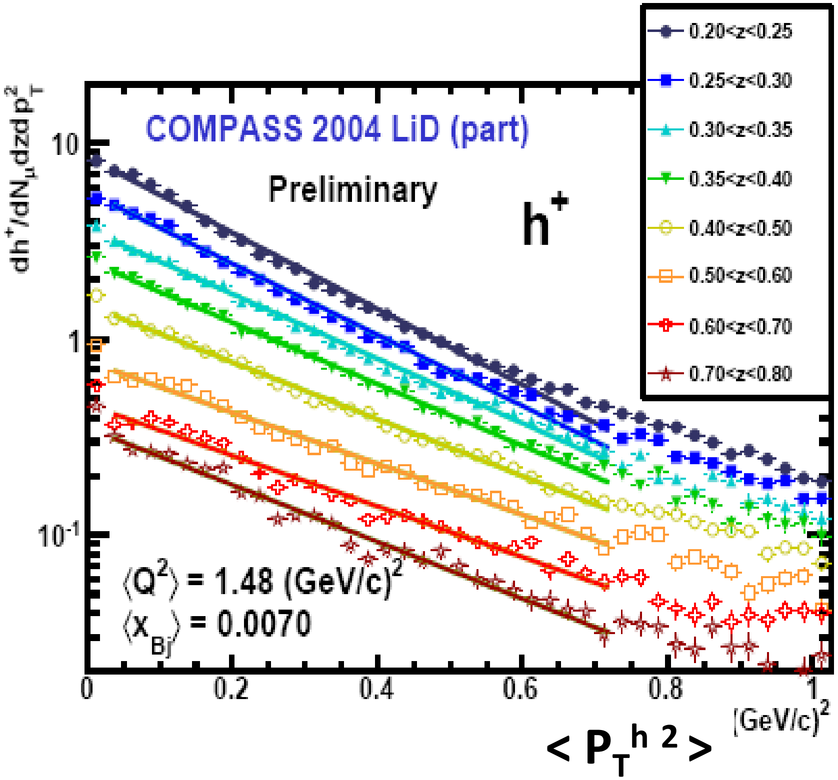
P_T^h dependent distributions measured from the unpolarized hadron multiplicities $\propto e^{-\frac{P_T^{h2}}{<P_T^{h2}>}}$

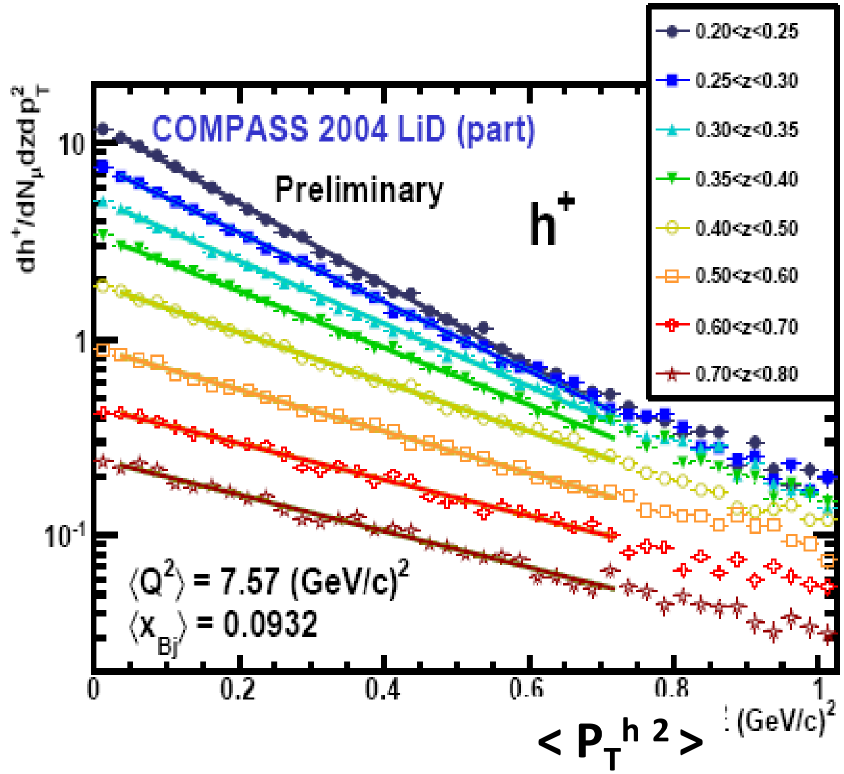
fits to the acceptance corrected hadron multiplicities in **different kinematical bins (Q², x)** to get $< P_T^{h2} >$ as function of z separately for positive and negative hadrons



$Q^2>1$; $0.1<y<0.9$

$0.2<z<0.8$



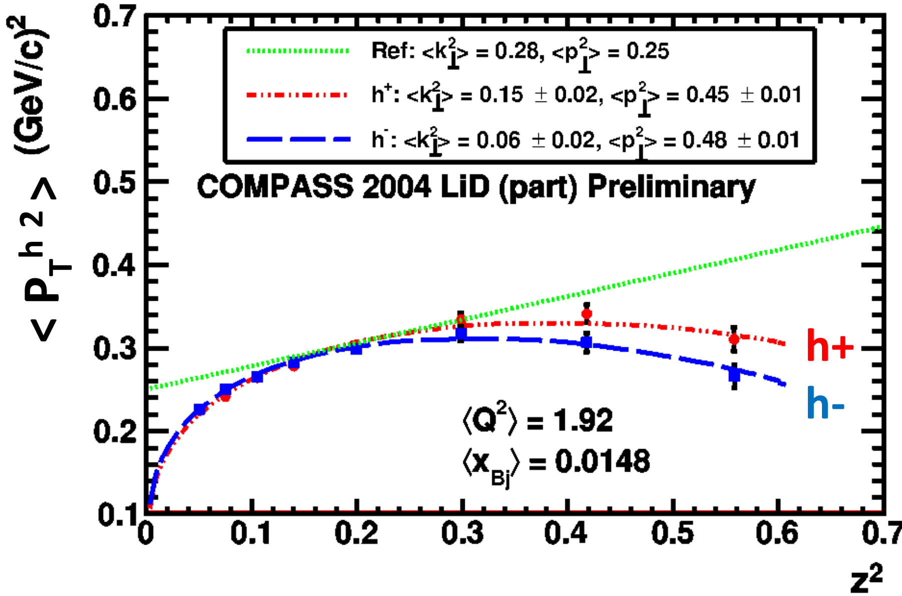


from the fits to the hadron multiplicities it seems that the dependence on z^2 is not linear...

$$< P_T^{h2} > = z^2 < k_\perp^2 > + < p_\perp^2 >$$

⬇

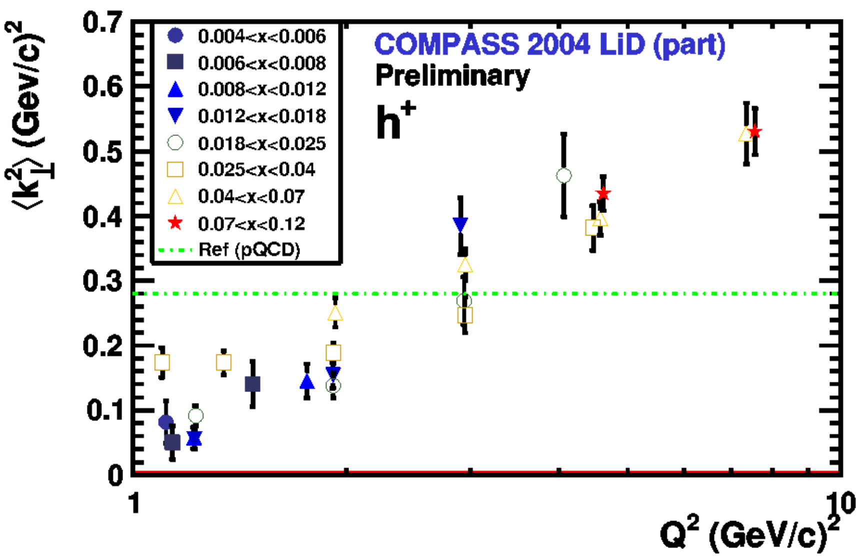
$$< P_T^{h2} > = z^2 < k_\perp^2 > + z^{1/2}(1-z)^{3/2} < p_\perp^2 >$$

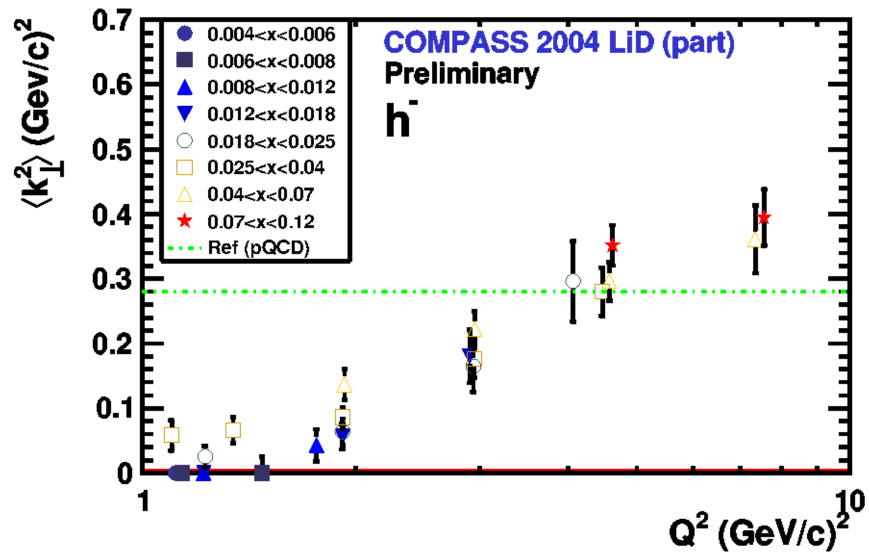


$$< P_T^{h2} > = z^2 < k_\perp^2 > + < p_\perp^2 >$$

$$< P_T^{h2} > = z^2 < k_\perp^2 > + z^{1/2}(1-z)^{3/2} < p_\perp^2 >$$

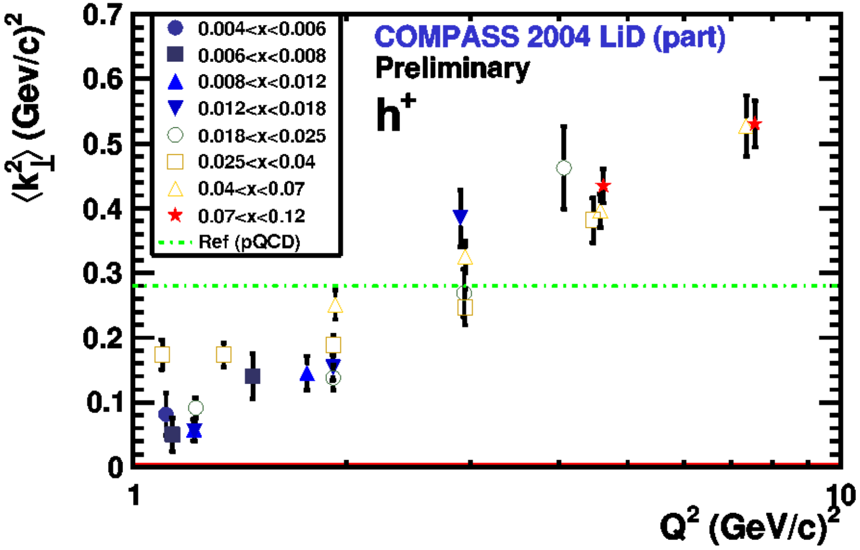
... extracting $k_\perp$ using this parameterization ....

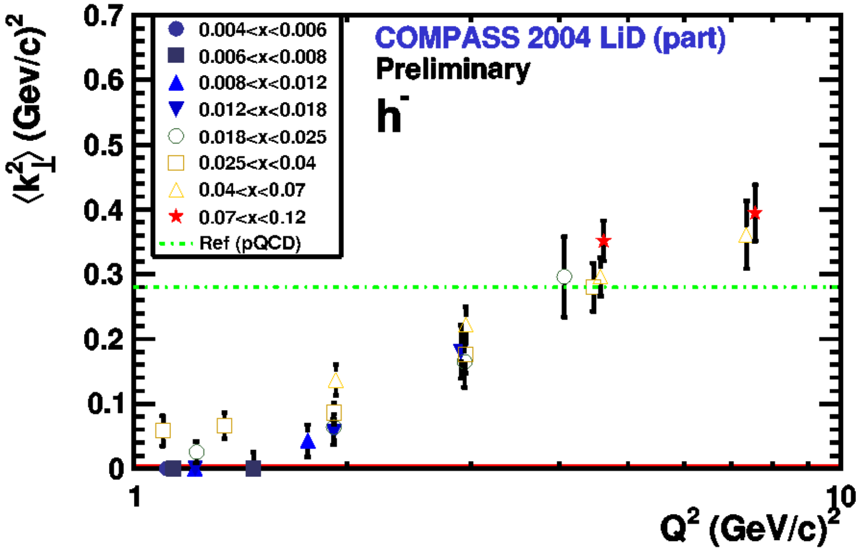




intriguing results !

... extracting $k_\perp$ using this parameterization ....





3. hadron multiplicities vs x and z

QPM collinear

$$\frac{dM^h(x,\ z)}{dz} = \frac{\sum_q e_q^2 f_q(x) \cdot D_q^h(z)}{\sum_q e_q^2 f_q(x)}$$

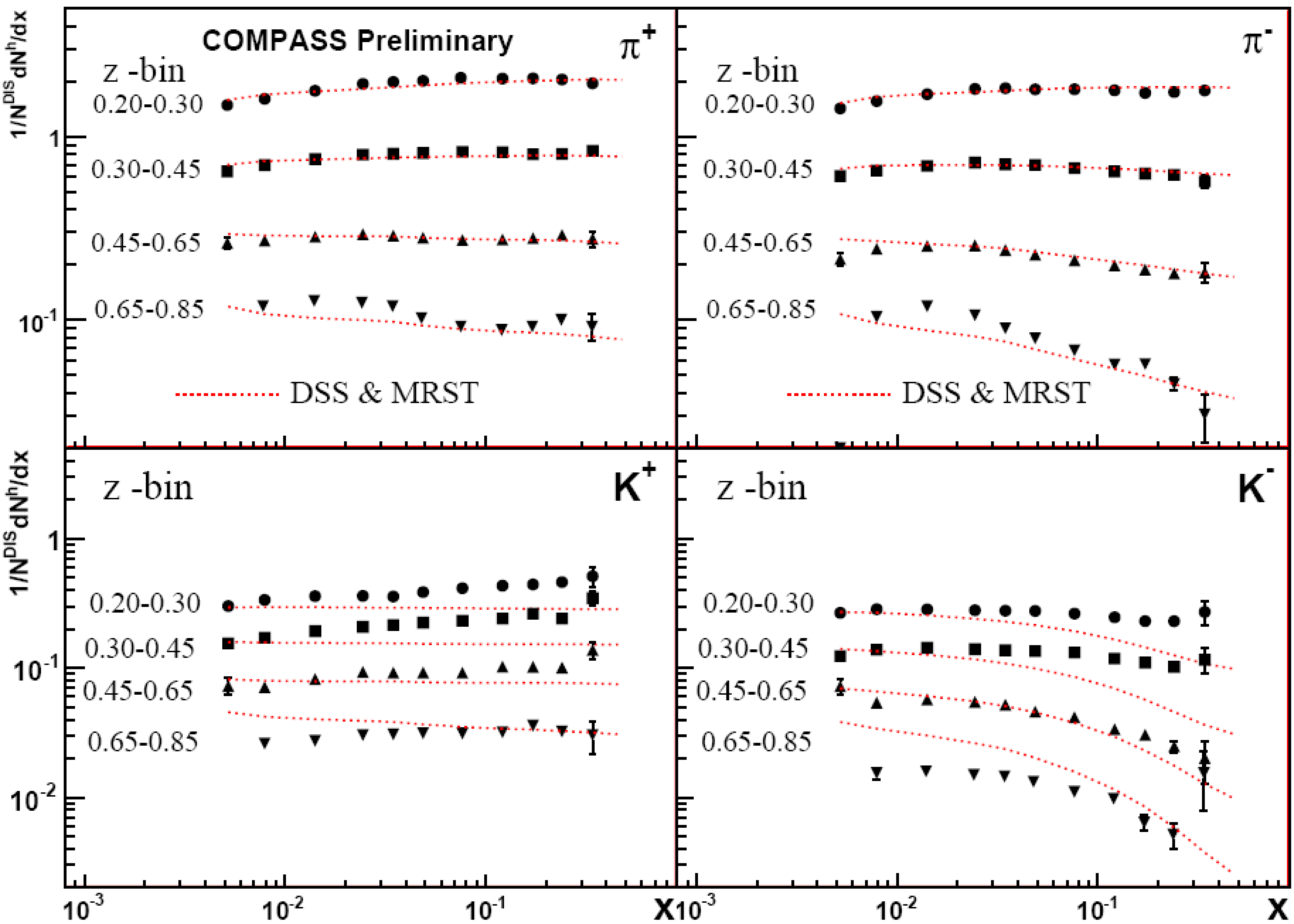
- ***allow to extract FFs***

analysis performed in bins of (x,z) and (Q^2,z)

$Q^2 > 1$; $0.1 < y < 0.9$
$W > 7$ (to avoid large acceptance corrections)
$0.2 < z < 0.85$

real data multiplicities corrected for the acceptance

π^+, π^-, K^+, K^- identification performed



COMPASS Preliminary
π^+
π^-
K^+
K^-
z -bin
0.20-0.30
0.30-0.45
0.45-0.65
0.65-0.85
DSS & MRST
$1/N^{DIS} dN^h/dx$
x

CONCLUSIONS and OUTLOOK

- COMPASS provides interesting results
  from the unpolarized measurements on deuterium

- TM effects have been studied in the COMPASS kinematics both from the azimuthal asymmetries and the hadron multiplicities

- interesting kinematical dependencies in z and P_T^h
  from both azimuthal asymmetries and hadron multiplicities

- interesting inputs for theory and global analyses

CONCLUSIONS and OUTLOOK

- COMPASS2

  SIDIS program in parallel with DVCS
  on proton (LH_2 target)
  apparatus more suitable for
  cross section measurement
  more precise measurements
  on the ***unpolarized distributions***
  and for the ***extraction of FFs***

backup

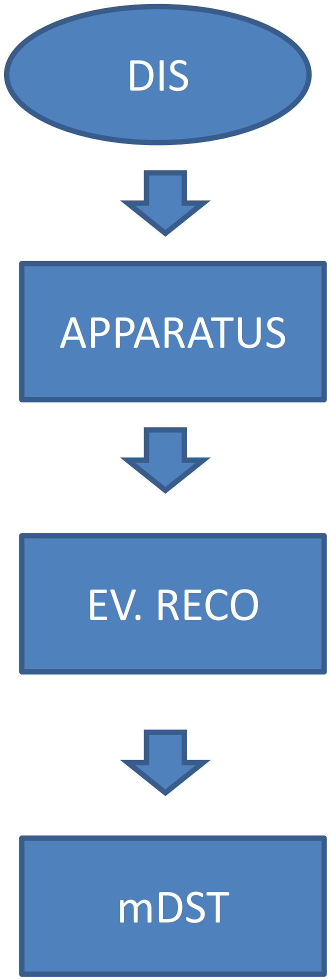
COMPASS MC chain

- **generation**
  Lepto
  DIS events simulation

- **propagation**
  COMGEANT
  simulates the interaction and the propagation
  of the particles inside the spectrometer
  magnets, materials, detectors,triggers, ...
  different setups are individually described

- **reconstruction**
  CORAL (program for the data reconstruction)
  vertices, tracking, momentum,
  the same program used in MC and real data

- files with the reconstructed quantities are produced in the same format as for the real data



COMPASS MC full chain simulation

- **generation**
  Lepto
  DIS events simulation

- **propagation**
  COMGEANT
  simulates the interaction and the propagation
  of the particles inside the spectrometer
  magnets, materials, detectors, triggers, ...
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  tracking , vertices, momentum,
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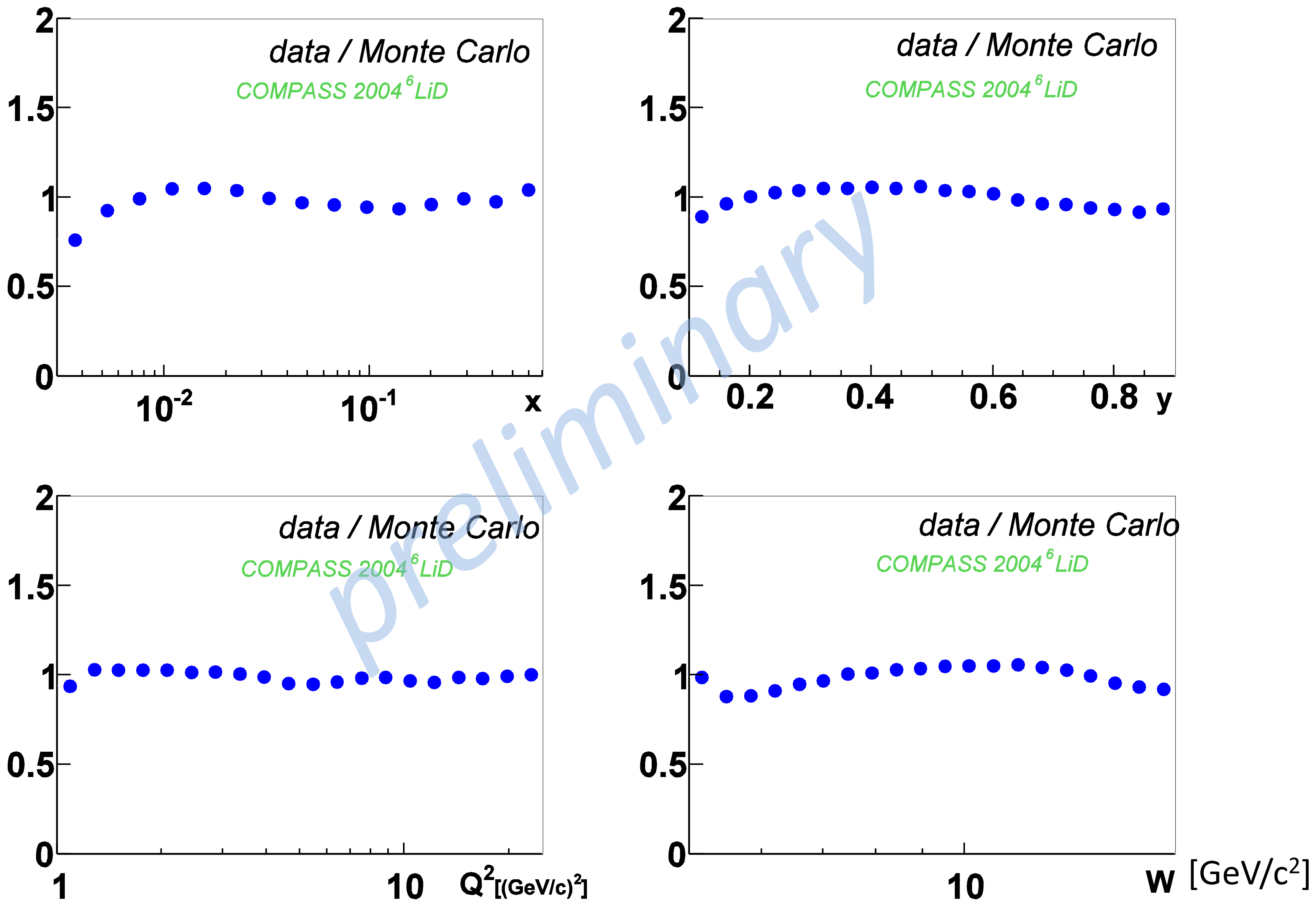
  in the same format as for the real data

***fine tuning** can be*
different** for **each analysis

indeed huge work
has been done in order to
optimize the description
of the real data conditions

*an example of **Monte Carlo – Real Data comparison** in the next 2 slides*

Events RD/MC ratios



Hadrons RD/MC ratios