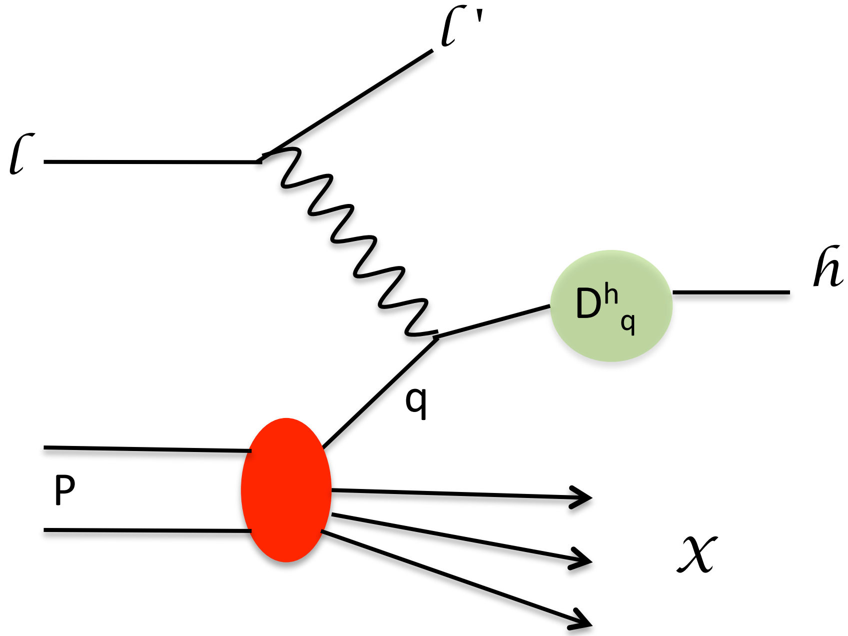
Pion and kaon multiplicities in Semi Inclusive Deep Inelastic Scattering at COMPASS

Nour Makke *on behalf of the COMPASS collaboration*
Trieste University, INFN

Outline

- Deep Inelstic Scattering process
- Single and double hadron fragmentation functions
- Extraction of hadron multiplicities
- Results
- Summary and Conclusions

Deep Inelastic Scattering (DIS)



○ **Relevant kinematics for cross section**

Q^2 photon virtuality ⇔ resolution at which the nucleon is probed

x_B long. momentum fraction of the struck quark in the nucleon

○ **DIS Cross section:**

PDFs FFs

Unpolarized $\sigma^h \sim f_q(x,Q^2) \cdot D^h_q(z,Q^2)$

Polarized $\Delta\sigma^h \sim \Delta f_q(x,Q^2) \cdot D^h_q(z,Q^2)$

○ **Information on PDFs & FFs can be found in other processes:**
hadron-hadron collisions, e^+e^- annihilations, …

○ **Current knowledge of:**
- **PDFs: well known**
- **FFs: poorly known**

What about polarized PDFs Δf_q ?

Polarized parton distributions Δf_q

Polarized parton distributions are extracted from double spin asymmetries

$$A = \frac{\sum_q e_q^2 \Delta q . D_q^h}{\sum_q e_q^2 q . D_q^h}$$

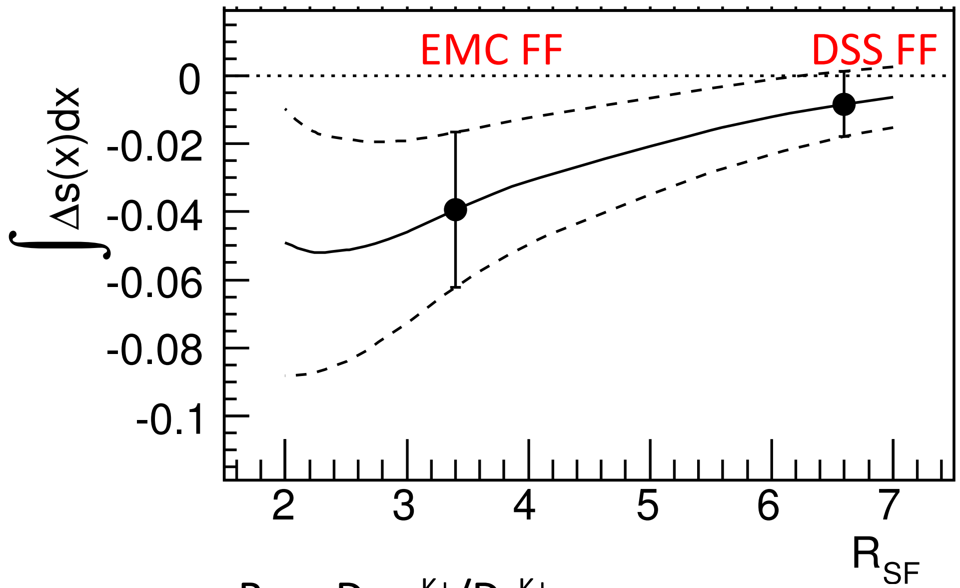
- **A is experimentally measured, q & D_q^h estimated using parametrisations.**
- **Using different D_q^h Δq remains the same except for strange quarks Δs**

Δs Puzzle

Inclusive measurements: Δs < 0
SIDIS measurements: Δs ≥ 0 However depends on

- **kaon FFs**
- **S(x)**

⇒ **need more experimental data on single hadron multiplicities in Semi-inclusive Deep Inelastic Scattering**

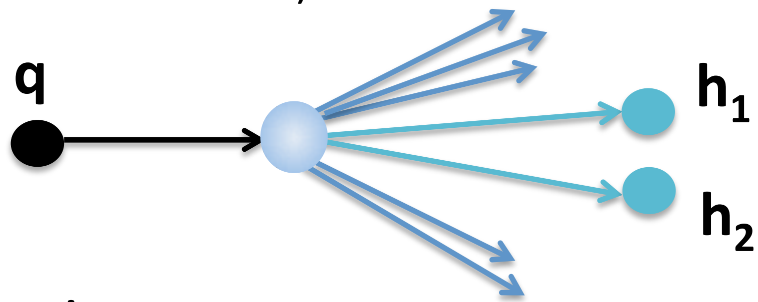


$R_{SF} = D_{sbar}^{K+}/D_u^{K+}$

Dihadron fragmentation functions

- Describe the probabiliy that a quark hadronizes into two hadrons (plus other unobserved fragments in the final state)

$q \rightarrow h_1 h_2 X$:



Dihadron fragmentation functions

- were first introduced in the late 1970's to study the hadron structure of jets (*by Konishi, Ukawa and Veneziano, PLB 78, 243 (1978)*);

- are needed to obtain consistent result for two hadron production in e^+e^- annihilation at NLO in α_S pQCD (needed for absorbing collinear divergence), *PLB 578, 139 (2004);*

- play an important role in heavy ion physics (used as tools to investigate the in-medium effects in heavy ion collisions), PRL 99, 152301 (2007);

- can be used to access transversity distribution of the nucleon (h_1);

DiFFs are needed in several high energy scattering processes with final state hadrons

Why dihadron fragmentation functions needed

- In order to access Transversity distribution in the nucleon $h_{1,q}$
  <u>*needed to give a complete partonic spin structure of the nucleon*</u>

- In the fragmentation $q^{\uparrow} \rightarrow (h^+h^-)\,X$ (*denoted by H_q*), there exist a correlation between the transverse polarization of the parton ($q^{\uparrow}$) and the orientation of the plane given by the momenta of the two hadrons

  - Semi-inclusive DIS, ***lp -> l' (h^+h^-)X***: access to ***$h_q H_q^{2h}$*** via spin asymmetry

$$A_{UT} \propto \frac{\sum_q e_q^2 h_{1,q}(x) H_{1,q}(z, M_h)}{\sum_q e_q^2 f_{1,q}(x) D_{1,q}(z, M_h)}$$

  - e^+e^- annihilation, ***e^+e^- -> (h^+h)(h^+h)X***: access to ***$H_q^{2h}\overline{H_q^{2h}}$*** via azimuthal asymmetry

$$A \propto \frac{\sum_q e_q^2 H_{1,q}(z, M_h) \bar{H}_{1,q}(\bar{z}, \bar{M}_h)}{\sum_q e_q^2 D_{1,q}(z, M_h) \bar{D}_{1,q}(z, M_h)}$$

The transversity h_q can be accessed from *$h_q H_q^{2h}$ and $H_q^{2h}\overline{H_q^{2h}}$ combinations BUT first unpolarized DiFFs $D_q^{2h}(z, M_h)$ need to be known.*

=> Need hadron pairs multiplicities

Properties of single and double fragmentation functions

Single FF: $D_q^h(z,Q^2)$	double FF: $D_{1,q}^{2h}(z,M_h,Q^2)$

- Probability that a quark (q) hadronizes into a hadron (h) with fractional energy (z)
- Satisfy momentum conservation

- Probability that a quark (q) hadronizes into two hadrons (h_1 & h_2) with fractional energies (z_1 & z_2)
- Carry information not accessible to single-hadron FF
- More complex o study and to measure
- **DO NOT** satisfy momentum conservation

- **Universal** and **non perturbative** object
- Satisfy **factorization theorem**
- Satisfy **isospin symmetry** (violated as shown by recent analyses)
- Satisfy **charge conjugation**

Both single and double FFs poorly known, need more experimental data for global fits
In particular hadron multiplicities from SIDIS

Why hadron multiplicities

Assuming Quark Parton Model, Leading Order

PDFs FFs

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

- Gives access to non-perturbative and universal objects that enter cross sections of different processes (pp collisions, SIDIS,…):
  PDFs and FFs

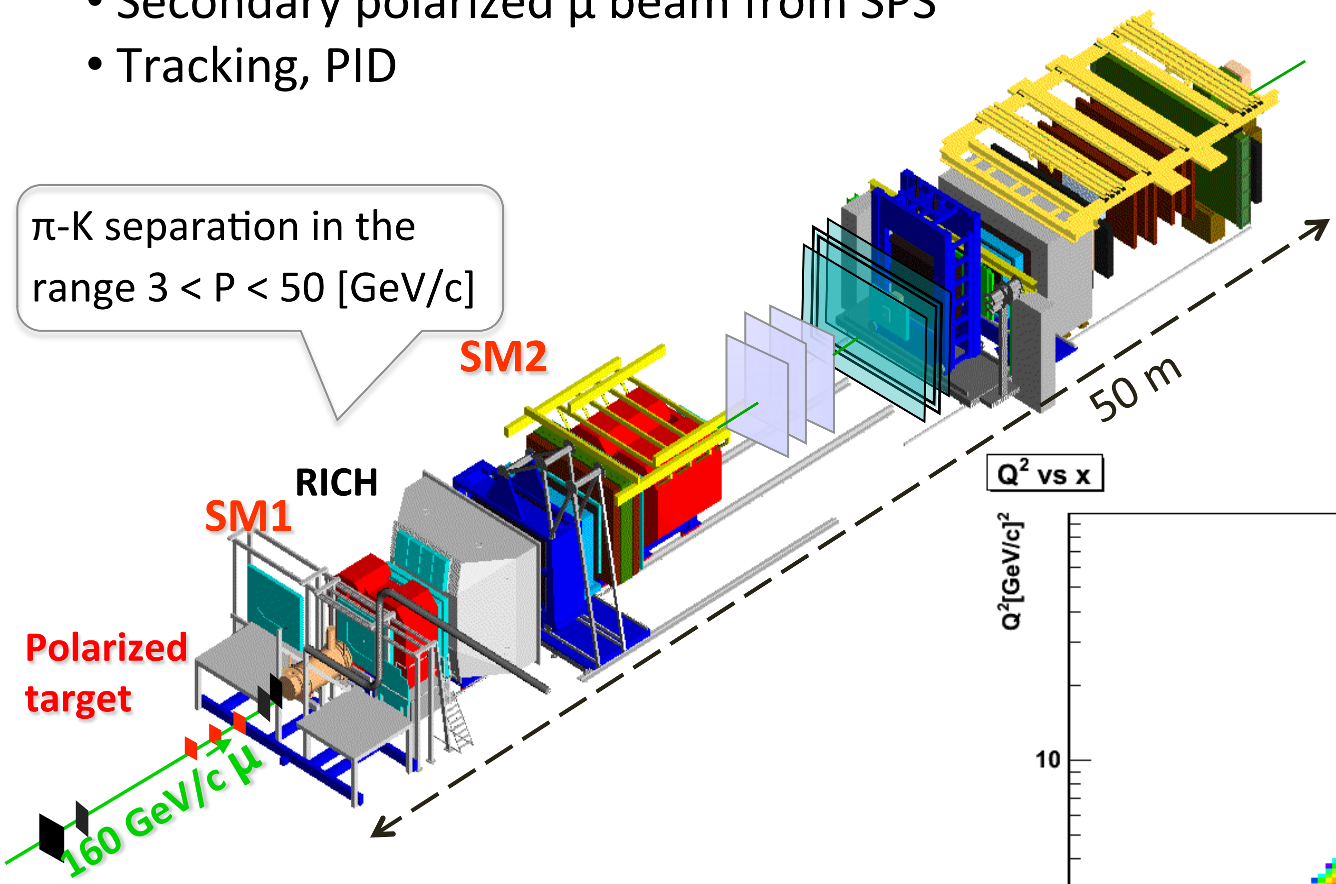
- Disentangle quarks & antiquarks
- Allows flavor/charge separation
- Provides inputs to global analysis

The COMPASS Experiment

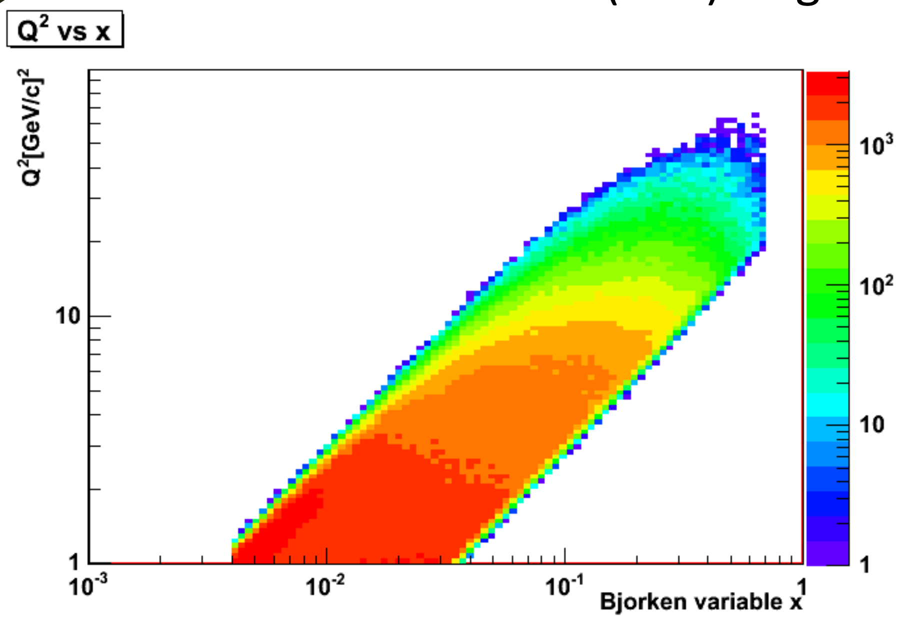
Common Muon and Proton Apparatus for Structure and Spectroscopy

- Fixed target experiment @ CERN
- Secondary polarized μ beam from SPS
- Tracking, PID

π-K separation in the range 3 < P < 50 [GeV/c]



<u>2004 Data set</u>:
160 GeV/c μ^+ beam
Deuteron (^6LiD) target



Experimental definition of hadron multiplicities

- Hadron multiplicity is the averaged number of hadrons per deep inelastic scattering event:

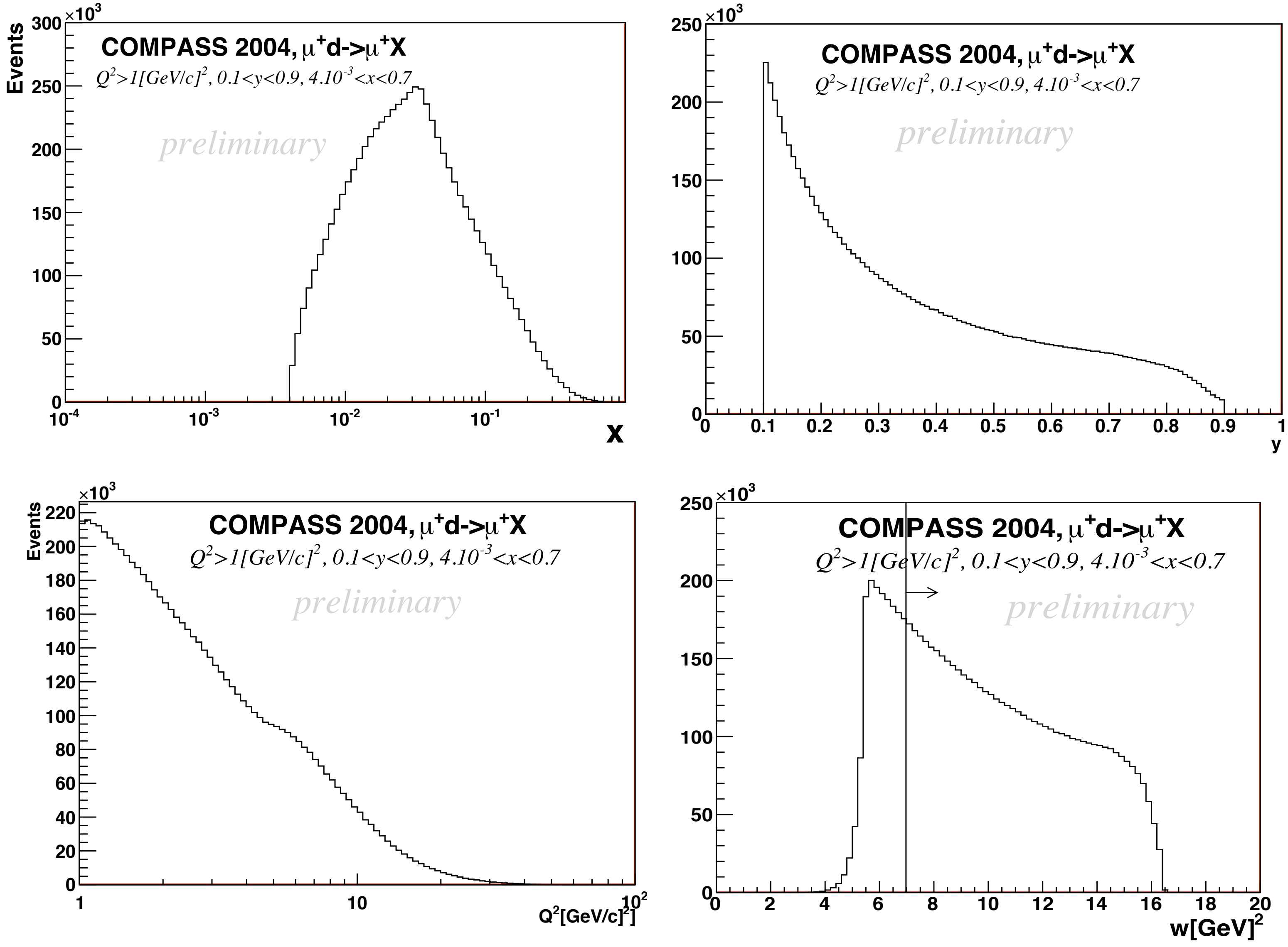
$$\frac{dM^h(x,Q^2,z)}{dz} = \frac{dxdQ^2}{d^2N^{DIS}(x,Q^2)} \cdot \frac{d^3N^h(x,Q^2,z)}{dxdQ^2dz} = \frac{\text{hadron yields}}{\text{DIS events yields}}$$

- Selected kinematic domain:
  - $Q^2 > 1\ [\mathrm{GeV}/c]^2$
  - $0.1 < y < 0.9$
  - $W > 7$ GeV
  - $4.10^{-3} < x < 0.7$
- Hadron candidate cuts:
  - $0.2 < z < 0.85$
  - $P > 10$ GeV/c for kaons and $P > 3$ GeV/c for pions

- Final statistics collected with only 25% of 2004 data

N(DIS)	N(π^+)	N(π^-)	N(K^+)	N(K^-)
$5.3\ 10^6$	10^6	$9.5\ 10^5$	~ 2.10^5	~ $1.3\ 10^5$

Kinematical distributions of selected DIS events



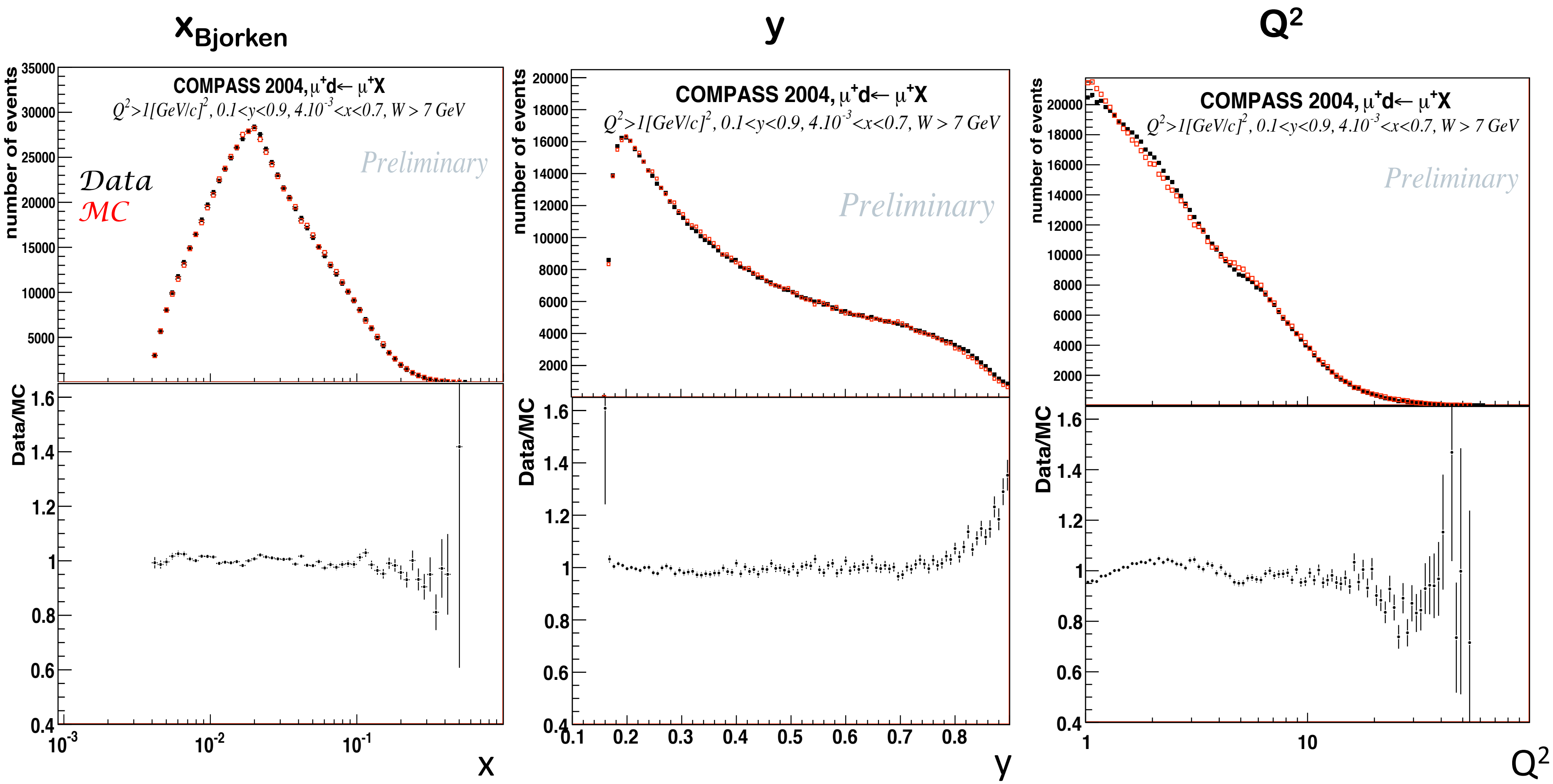
From raw multiplicities to final hadron multiplicities

- **Acceptance of the apparatus:**
  - Estimated by producing large MC sample (~ 10^7 DIS events) and COMPASS tuning of fragmentation parameters in LUND string model
  - DIS events generated using LEPTO with kinematic cuts
    $Q^2>0.7$ (GeV/c)^2, $0.05 < y < 0.95$, $W > 0$ GeV/c
  - Estimated in 2 dimensions (x,z) and (Q^2,z) for charge separated pions, kaons and unidentified hadrons
  - Defined in kinematic bin i [(x_i, x_{i+1}), (Q^2_i,Q^2_{i+1})]

$$\epsilon_i = \frac{M^{rec}_{MC,i}}{M^{gen}_{MC,i}} \quad \Longrightarrow \quad M_{corrected,i} = \frac{M_{data,i}}{\epsilon_i}$$

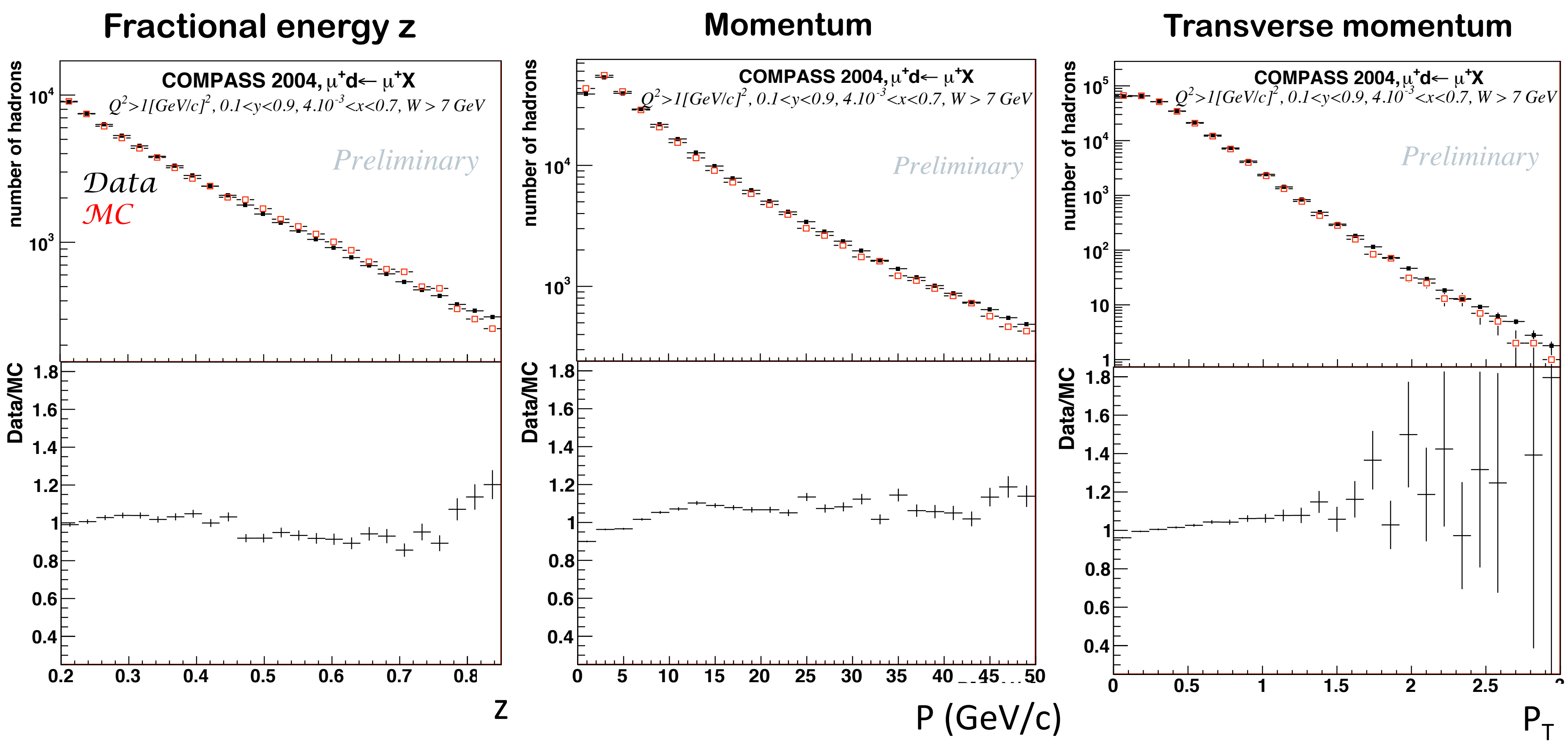
- **Radiative corrections**
  < 15% for x < 0.01 and negligeable for x > 0.01

Monte Carlo description of data for DIS variables



Good decscription of data by Monte Carlo for inclusive variables

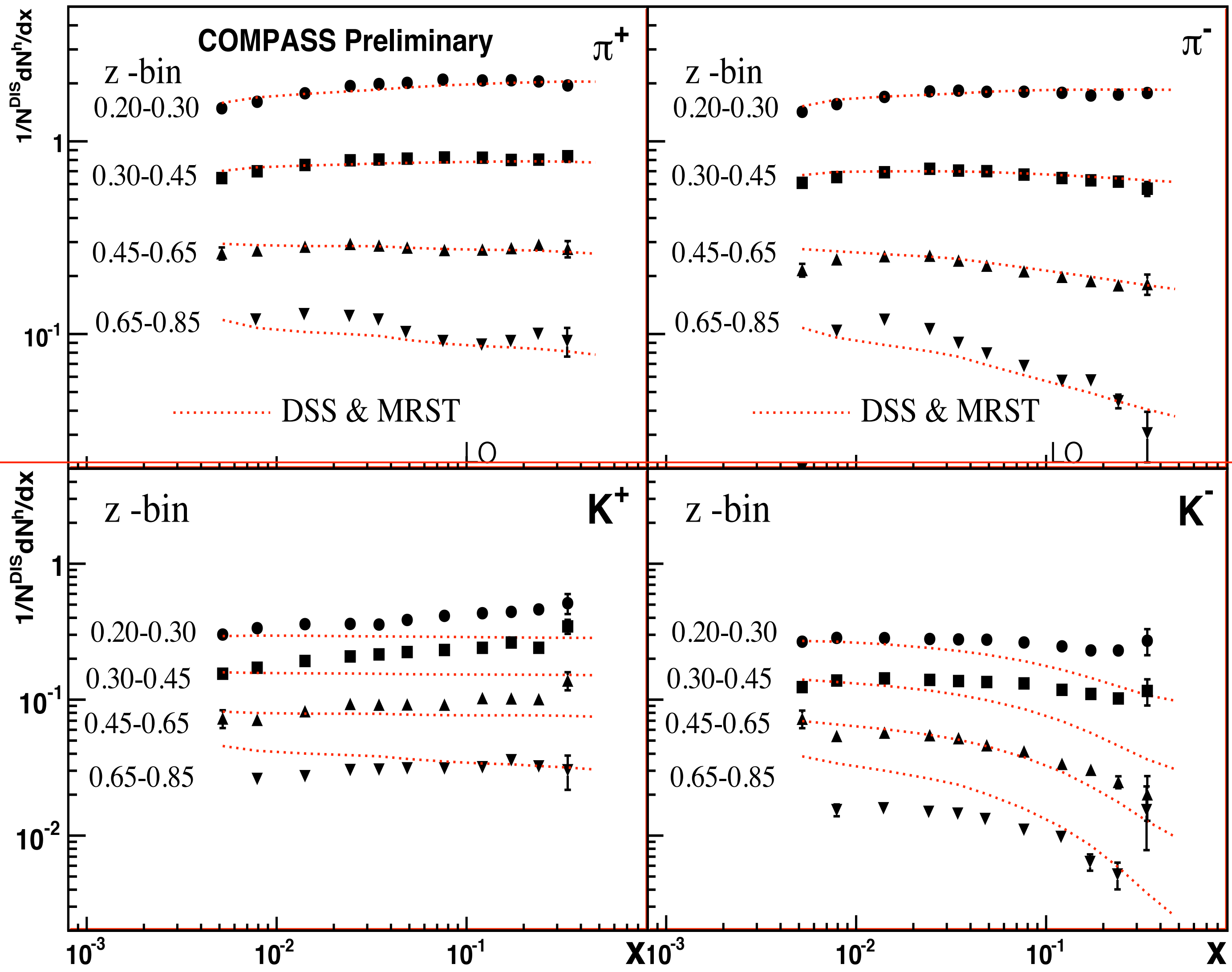
Monte Carlo description of data for SIDIS variables



Good decscription of data by Monte Carlo for semi-inclusive variables, thanks to COMPASS tuning for fragmentation (M. Stolarski talk)

MC simulation <u>used only</u> for acceptance estimation

Comparison with predictions : 2D (x,z) multiplicities

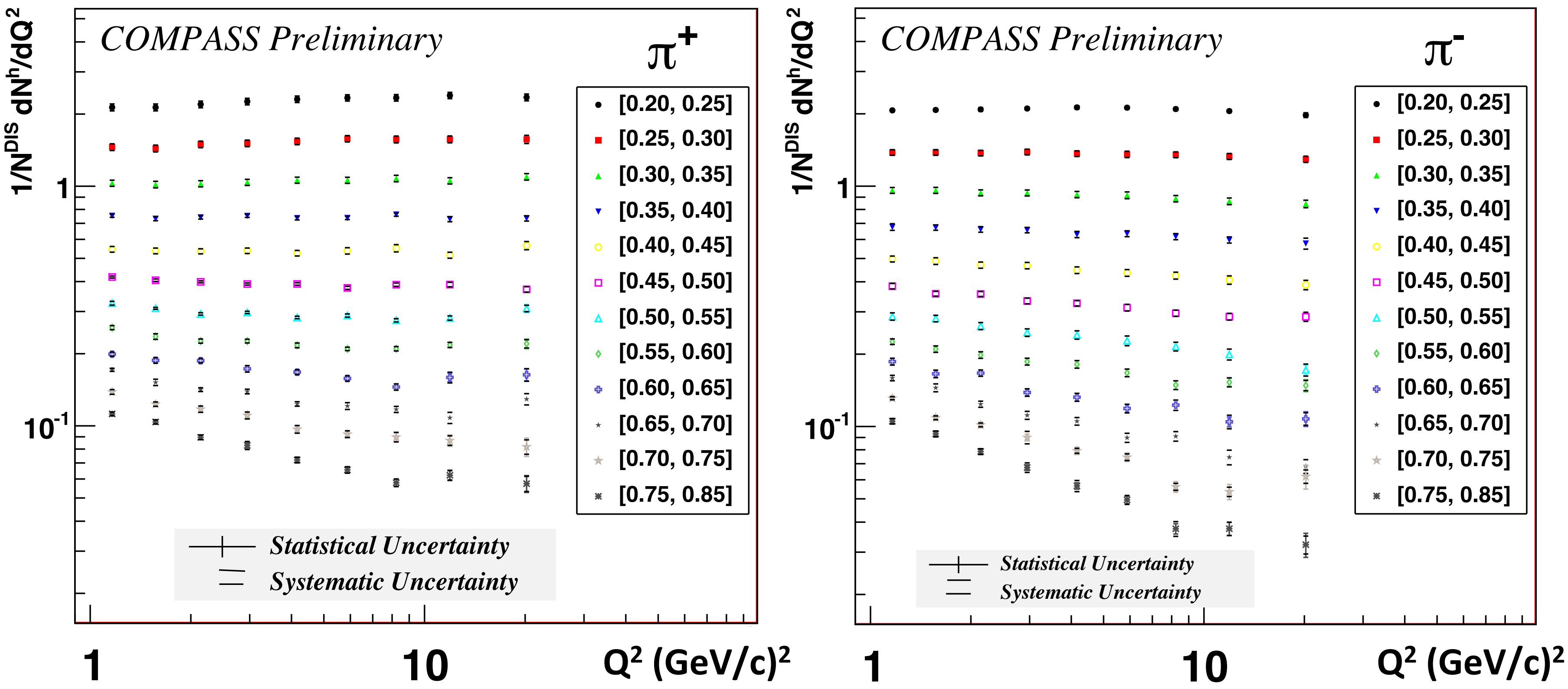


- $\pi^\pm$ multiplicities in **good agreement** with LO predictions up to z<0.65

- **Large** deviations of $K^\pm$ multipicities wrt LO predictions
  - Model uncertainty
  - Unknown s(x) ?
  - Missing higher orders ?
  - COMPASS data favors different FFs than DSS

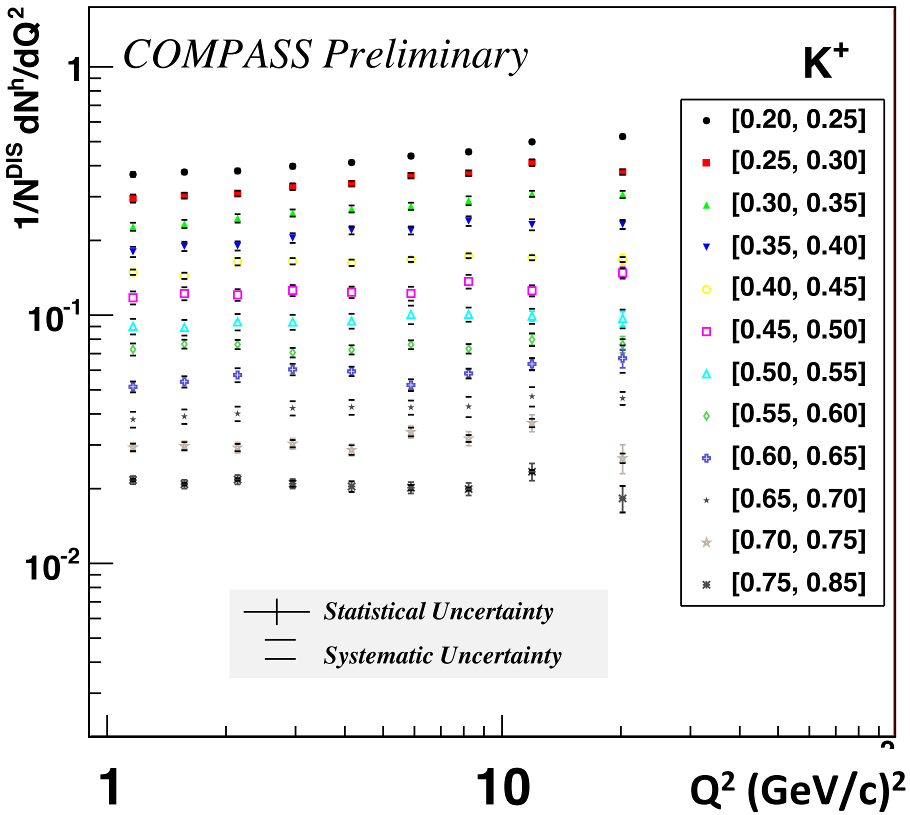
syst. Uncertainties: MC: ~ 1% (2%) for π (K) for x < 0.15
Particle identification 5%(10%) for π (K) for 0.01 < x < 0.15

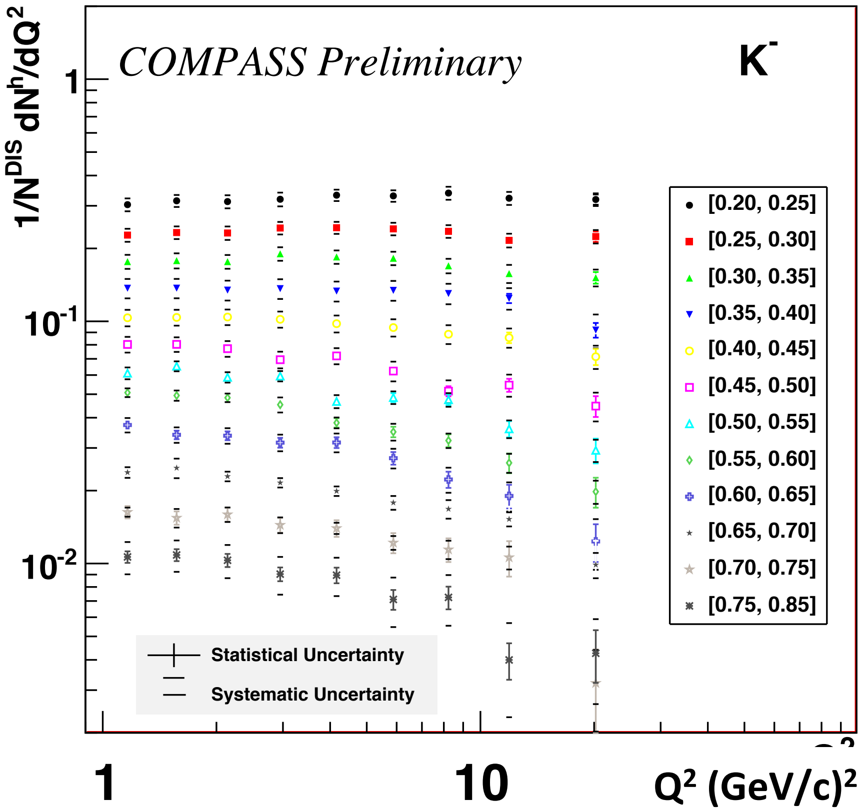
Results : 2D (Q^2,z) Multiplicities for $\pi^{\pm}$



- Strongest Q^2 dependence for negative than for positive pions
- Reasonnably described by LO theoretical calculations

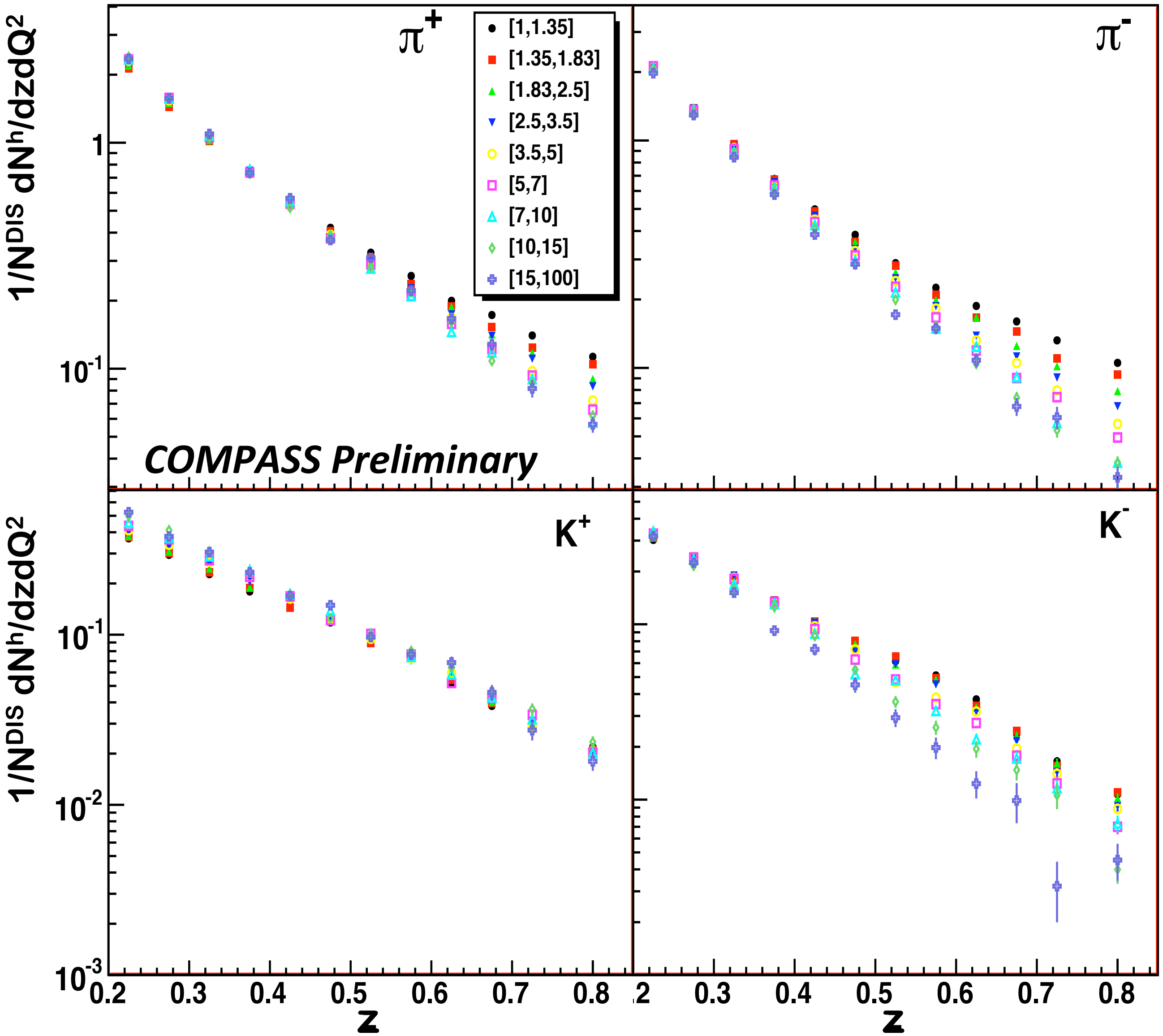
Results : 2D (Q^2,z) Multiplicities for $K^\pm$





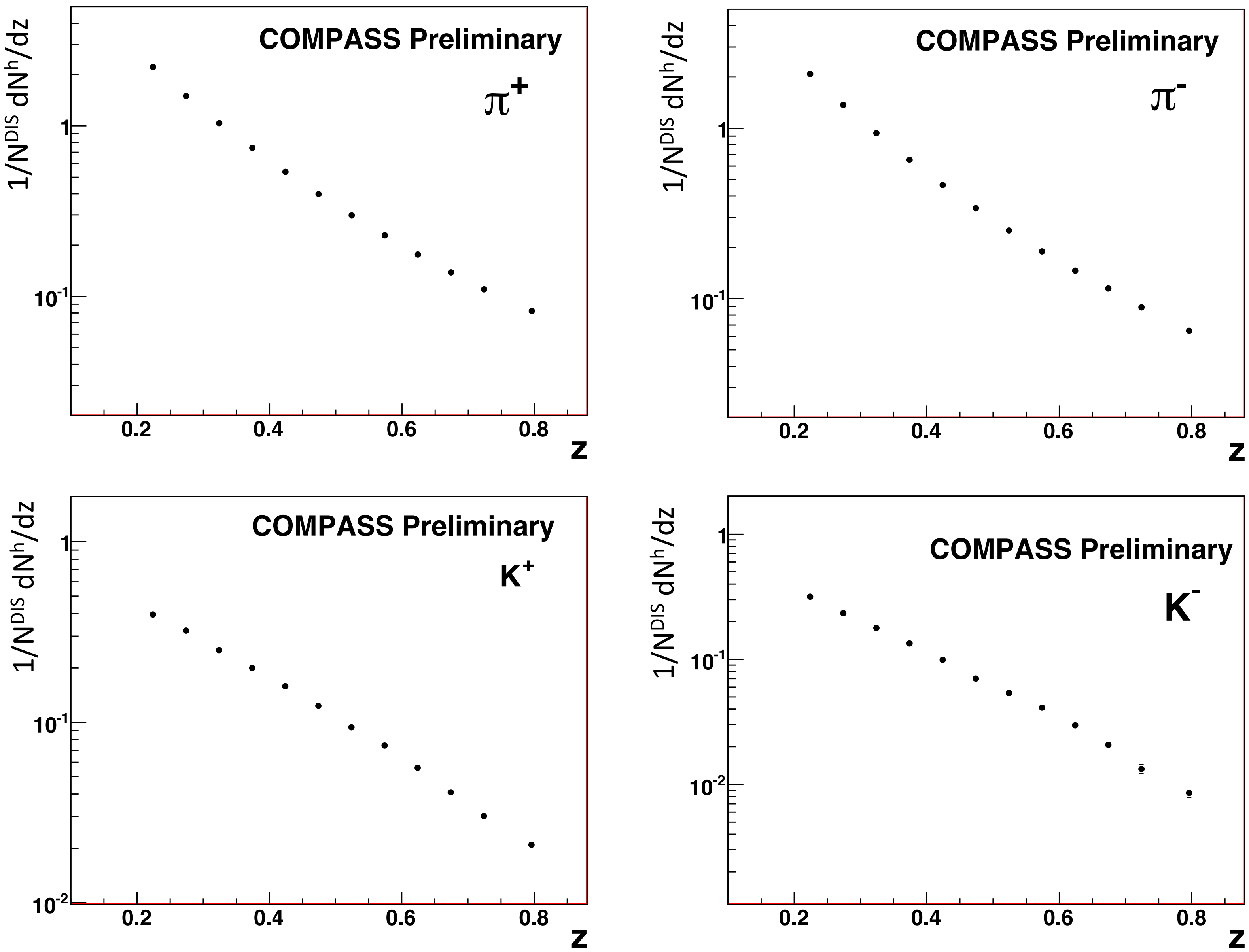
- NOT described by LO theoretical calculations
- Kaon data show tendence for small strange contributions

Results : 2D (z,Q^2) Multiplicities for $\pi^{\pm}$ & $K^{\pm}$

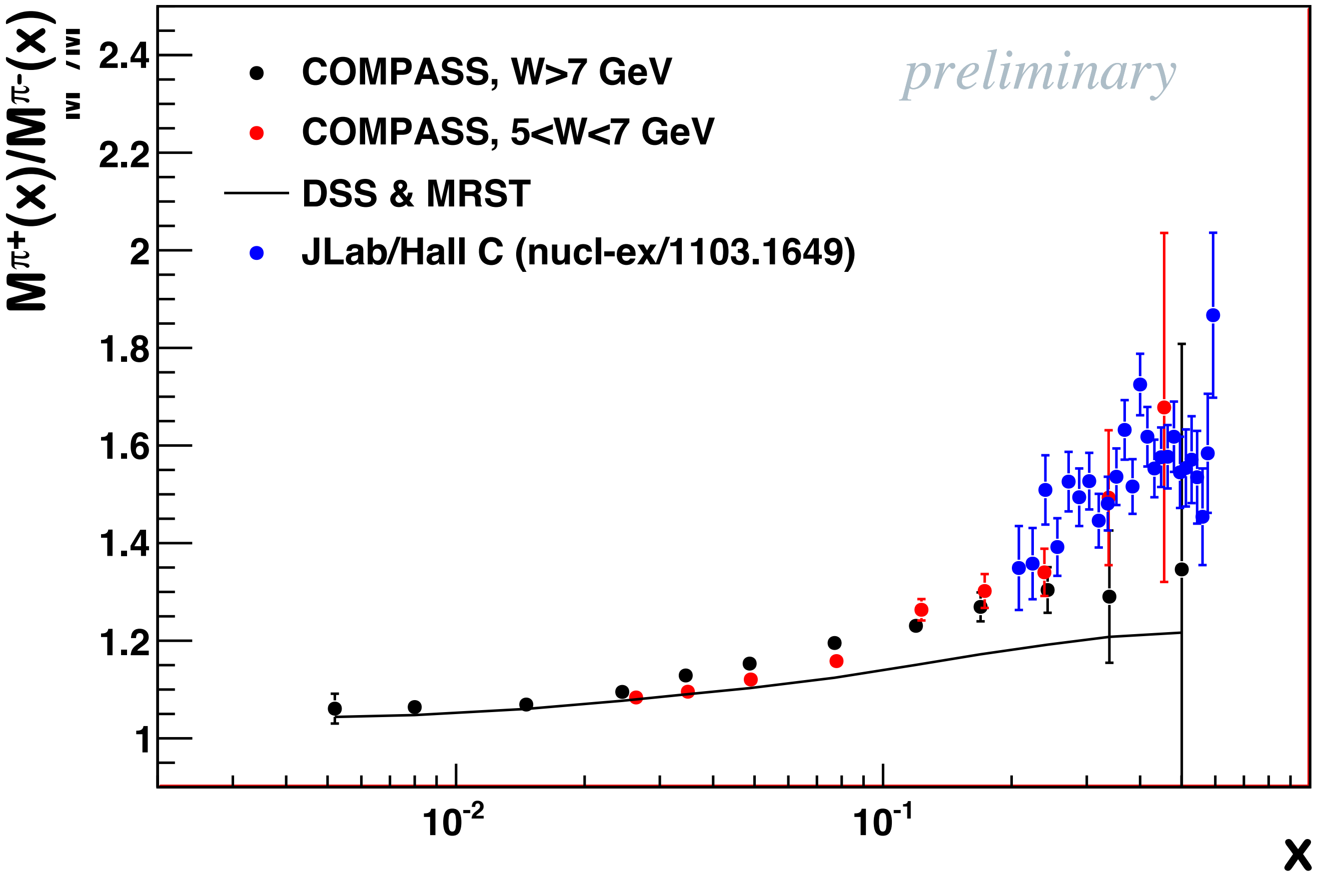


- **Distributions needed for global QCD analysis of single FFs**
- **Strongest Q^2 dependence for negative hadrons at high z and Q^2**
- **Similar effect observed for unidentified hadrons**

Results: 1D z multiplicities for $\pi^{\pm}$ & $K^{\pm}$



Ratio of pion multiplicities ($M^{\pi+}/M^{\pi-}$) versus x



- Systematic effects cancel in the ratio $M^{\pi+}/M^{\pi-}$
- gives access to ratio of fragmentation functions $D_u^{\pi+}/D_d^{\pi+}$
- Wide kinematic domain covered by COMPASS

Summary and conclusions

- $\pi^{\pm}$ and $K^{\pm}$ multiplicities as a function of (x,z) and (Q2,z) from μ-d DIS measured at COMPASS
- π multiplicities described by LO calculations, kaon multiplicities disagree with predictions.
- Data can significantly contribute to knowledge of the hadronization process and useful:
  - for direct LO extraction of quark fragmentation functions
    - pion: results consistent with existing measurements (EMC,..)
    - Kaon: ongoing
  - for direct LO extraction of unpolarized s(x) from kaon's multiplicities
  - To test LO assumption of factorization
  - to be included in global QCD analyses of single hadron FFs
- Measurements of hadron pair multiplicities ongoing
- Measurement of single hadron multiplicities from μ-p DIS on the list.