Study of the hadronisation process from semi-inclusive single hadron and hadron pair production at COMPASS

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

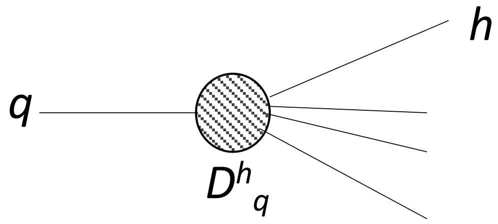
Outline

- Single-hadron fragmentation functions
- Di-hadron fragmentation functions
- Semi-inclusive DIS & Hadron multiplicities
- Results
- Summary and outlook

Single-hadron Fragmentation Functions (FFs)

- Describe the collinear transition of a quark *q* into a final-state hadron *h* carrying momentum fraction *z* (*q -> h X*)

- D^h_q *gives the mean number of hadrons produced in the quark hadronization*



- Relevant in every reaction where a hadron is produced in the final state
- Key role in flavor separation of polarised parton distributions
- Universal and non-perturbative quantities
- Depend on energy fraction of the photon transferred to the hadron:

$$z = \frac{E_h}{E_\gamma}$$

- Depend on Q^2, evolution described by DGLAP equations
- Energy conservation sum rule (used their determination):

$$\sum_h \int_0^1 z D_i^h(z, Q^2) dz = 1$$

The ΔS puzzle

- Strange quark contribution to nucleon spin:

$$\Delta S = \int dx[\Delta s(x) + \Delta \bar{s}(x)]$$

Inclusive measurement

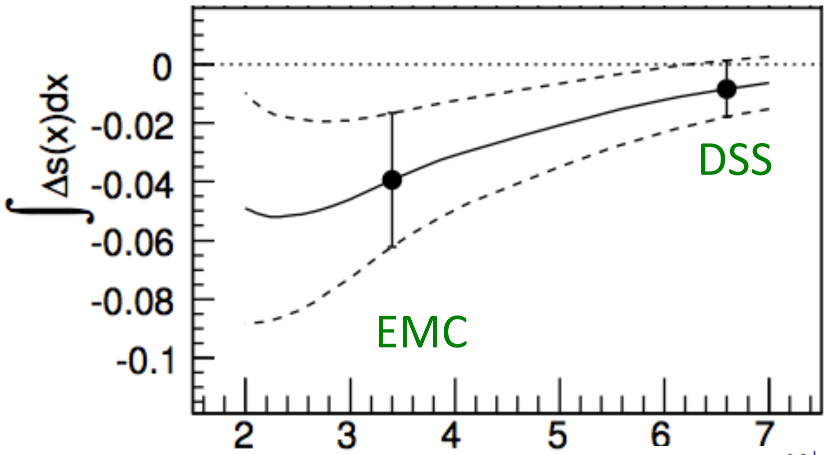
- $\Gamma_1 = g_1(x)$
- SU(3) flavor symmetry & axial charges of baryons

$\Delta S = -0.08 \pm 0.01_{stat.} \pm 0.02_{syst.}$

Semi-Inclusive measurement

- Depending on fragmentation functions
- Strongly dependent on the ratio R_{SF}

$\Delta S = -0.02 \pm 0.02_{stat.} \pm 0.02_{syst.}$

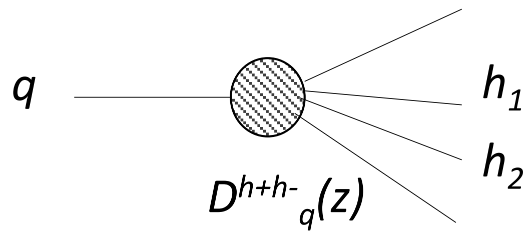


$$R_{SF} = \frac{D_{\bar{s}}^{K^+}}{D_u^{K^+}}$$

Single-hadron FFs remain a key element in the ΔS puzzle

Dihadron Fragmentation Functions (DiFFs)

- Describe the probability that a quark of given flavor (q_f) hadronizes into a final-state hadron pair ($q_f \to h_1^+ h_2^- X$):



- first introduced in the late 1970's to study the hadron structure of jets
  *Konishi, Ukawa and Veneziano, Phys. Lett. B **78**, 243 (1978)*

- needed in NLO calculations in α_S for two hadron production in e^+e^- annihilation
  *Phys. Lett. B **578**, 139 (2004);*

- useful to investigate the in-medium effects in heavy ion collisions
  *Phys. Rett. L **99**, 152301 (2007)*

- key element to access transversity distribution of the nucleon (h_1) in SIDIS

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

Status of unpolarized FFs & DiFFs

- Experimental information available in several hard scattering reactions

- Most experimental data measured at e^+e^- colliders
  - Clean process: depends only on FFs (no dependence on PDFs)
  - Measured at fixed energy scales (far from fixed target scales)
  - Mostly sensitive to singlet combinations
  - Cannot separate Quark from Anti-Quark fragmentation

- FFs accessible in hadron-hadron collisions:
  - most sensitive to gluon FFs
  - Useful for medium modifications

- Accessible in semi-inclusive DIS using hadron yields produced in DIS events
- Several global NLO QCD analyses exist (KRE, KKP, DSS, …)
  - Use different data sets and assumptions
  - Significantly disagree

- No global QCD analyses exist yet for unpolarized DiFFs.

- Available experimental information consists of only invariant mass spectra of hadron pairs, no information on simultaneous (z, Q^2, M_{inv}) dependence

- An extraction of DiFFs done using <u>Monte Carlo simulation </u>of e+e- annihilations
  (*by A. Courtoy, A. Bacchetta, M. Radici and A. Bianconi)*

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Poorly known fragmentation functions, especially kaon's FFs

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  - Use different data sets and assumptions
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Unknown DiFFs

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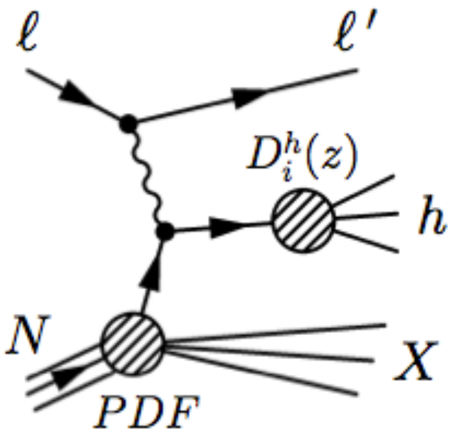
Semi-Inclusive DIS (SIDIS)



- *l N -> l' h X : at least one hadron is detected with the scattered lepton in the final state*
- Allows flavor/charge separation of FFs
- Wide Q^2 coverage (low to high Q^2)

Relevant observable for FF access: **Hadron Multiplicities**

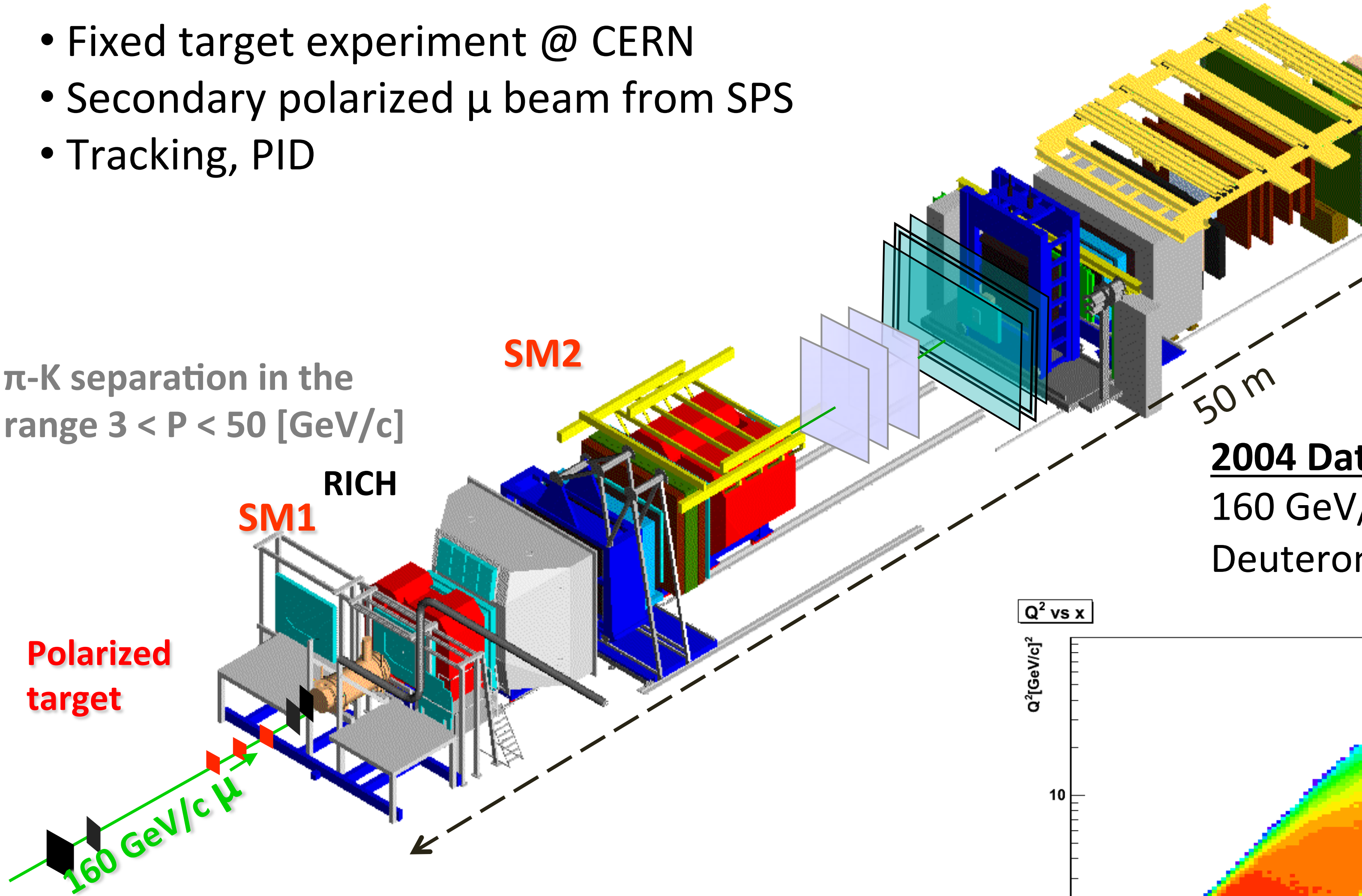
$$M^h(x,z) = \frac{d\sigma_{SIDIS}/dxdz}{\sigma_{DIS}} = \frac{\sum_q e_q^2(q(x)D_q^h(z) + \bar{q}(x)D_{\bar{q}}^h(z))}{\sum_q e_q^2(q(x) + \bar{q}(x))}$$

- ***Disadvantage***: Dependence on unpolarised PDFs:
  - Up, down unpolarized PDFs well known
  - Strange PDF s(x) poorly known => More information from hadron multiplicities
- Useful to study the hadronisation process in nuclear medium (using different targets)

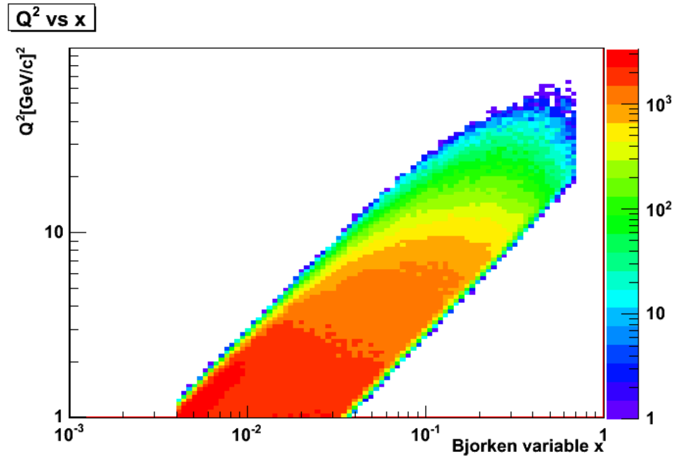
The COMPASS Experiment

Common Muon and Proton Apparatus for Structure and Spectroscopy

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



2004 Data set:
160 GeV/c μ^+ beam
Deuteron (^{6}LiD) target



Multiplicity definition and method of extraction

Definition: averaged number of hadrons produced per DIS event.

Method of extraction: *In a given kinematic bin* ***i***

1. Experimental hadron multiplicity:

$$M_{raw}(i) = N^{h}(i) \,/\, N^{DIS}(i)$$

2. Acceptance estimation using Monte Carlo simulation, acceptance defined as

$$a_i = M_{rec}(i_R) \,/\, M_{gen}(i_G)$$

3. Final multiplicities:

$$M_{cor}(i) = M_{raw}(i) / a_i$$

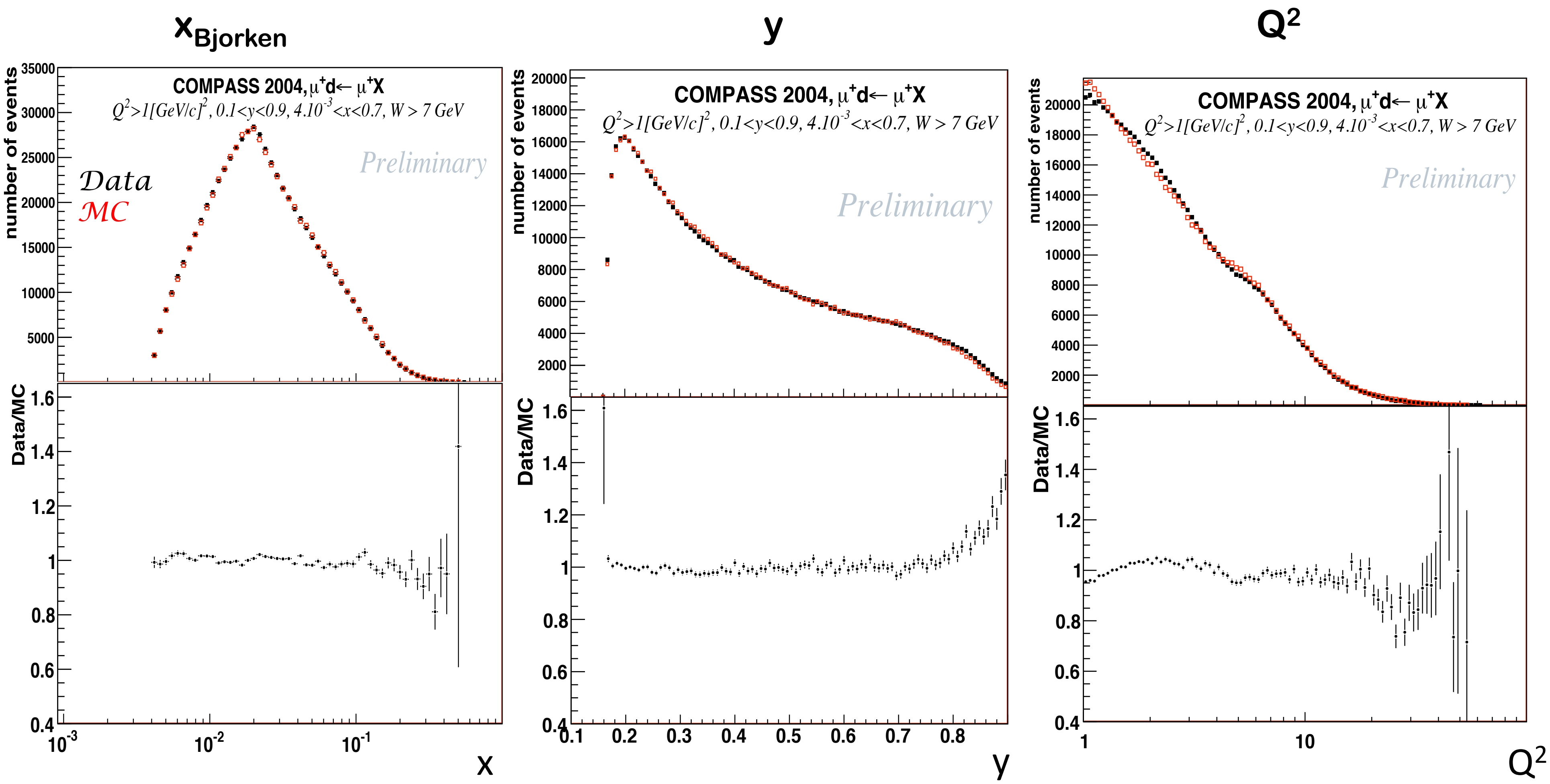
Kinematic domain

$Q^2 > 1$ (GeV/c)^2, $0.1 < y < 0.9$, W . 7 (GeV), $0.003 < x < 0.7$

$0.2 < z < 0.85$

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

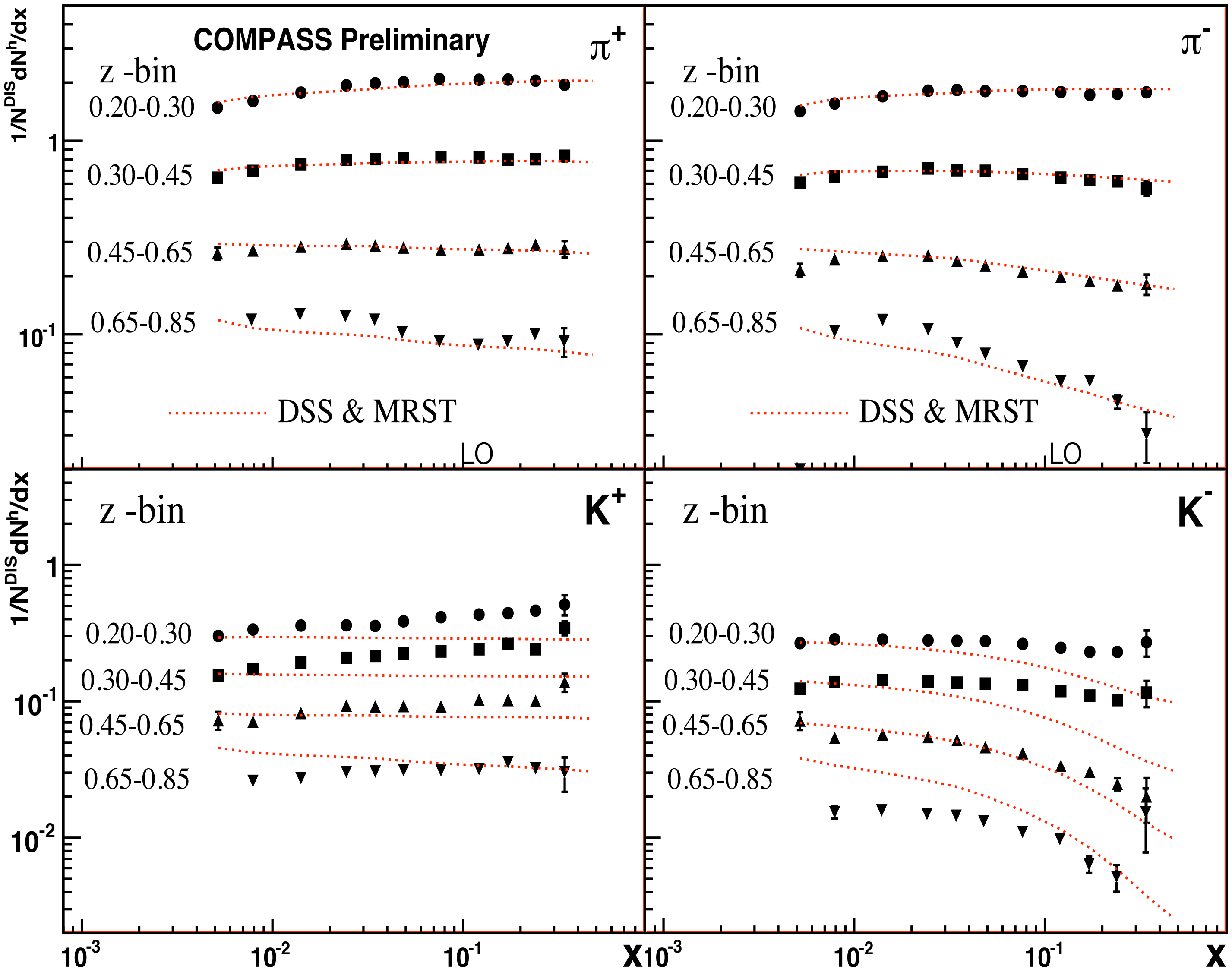
Monte Carlo description of COMPASS data for DIS variables



Good decscription of data by Monte Carlo for inclusive variables

Results on single hadron multiplicities

Results: 2D (x,z) multiplicities

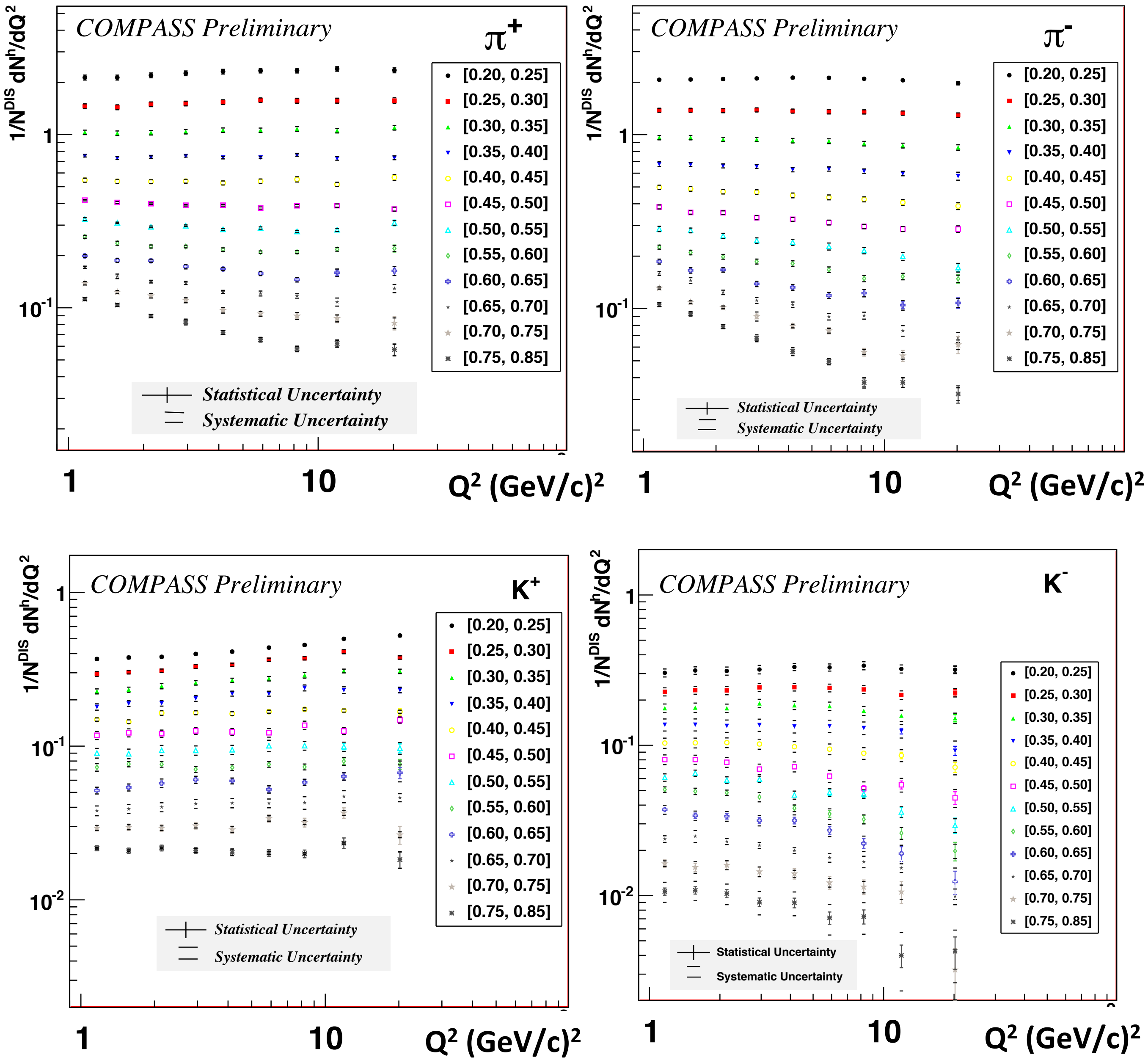


- $\pi^{\pm}$: poor agreement up to z<0.65
- $K^{\pm}$: Significant disagreement in all z bins
  - Unknown s(x) ?
  - Missing higher orders ?
  - COMPASS data favors different FFs than DSS

    Cf. presentation by A. Sidorov
- K^0 under investigation

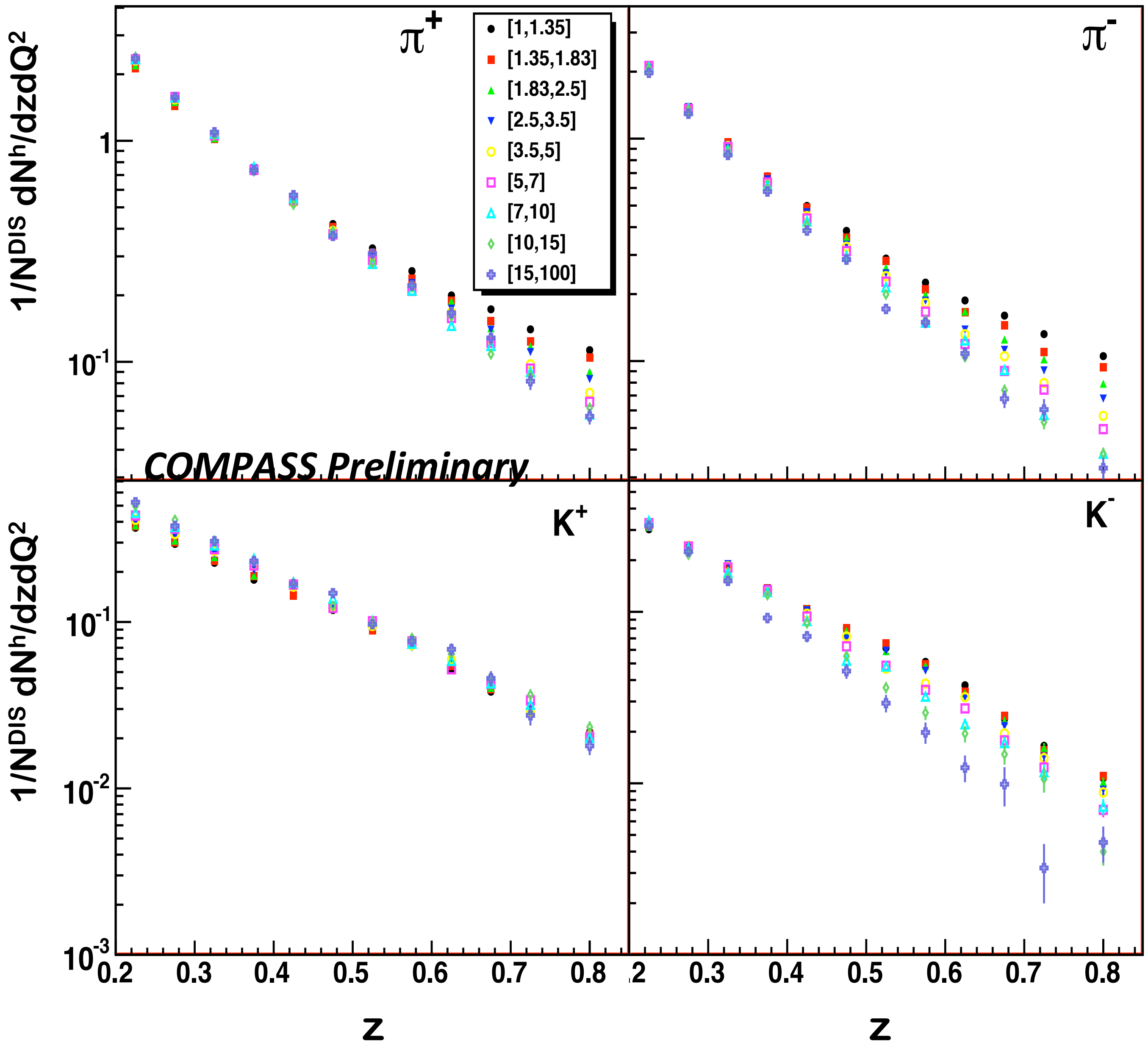
syst. Uncertainties due to: MC: ~ 1% (2%) for π (K) for x < 0.15
Particle identification < 8%(5%) for π (K)

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



- Strongest Q^2 dependence for h^-
- In fair agreement with LO predictions

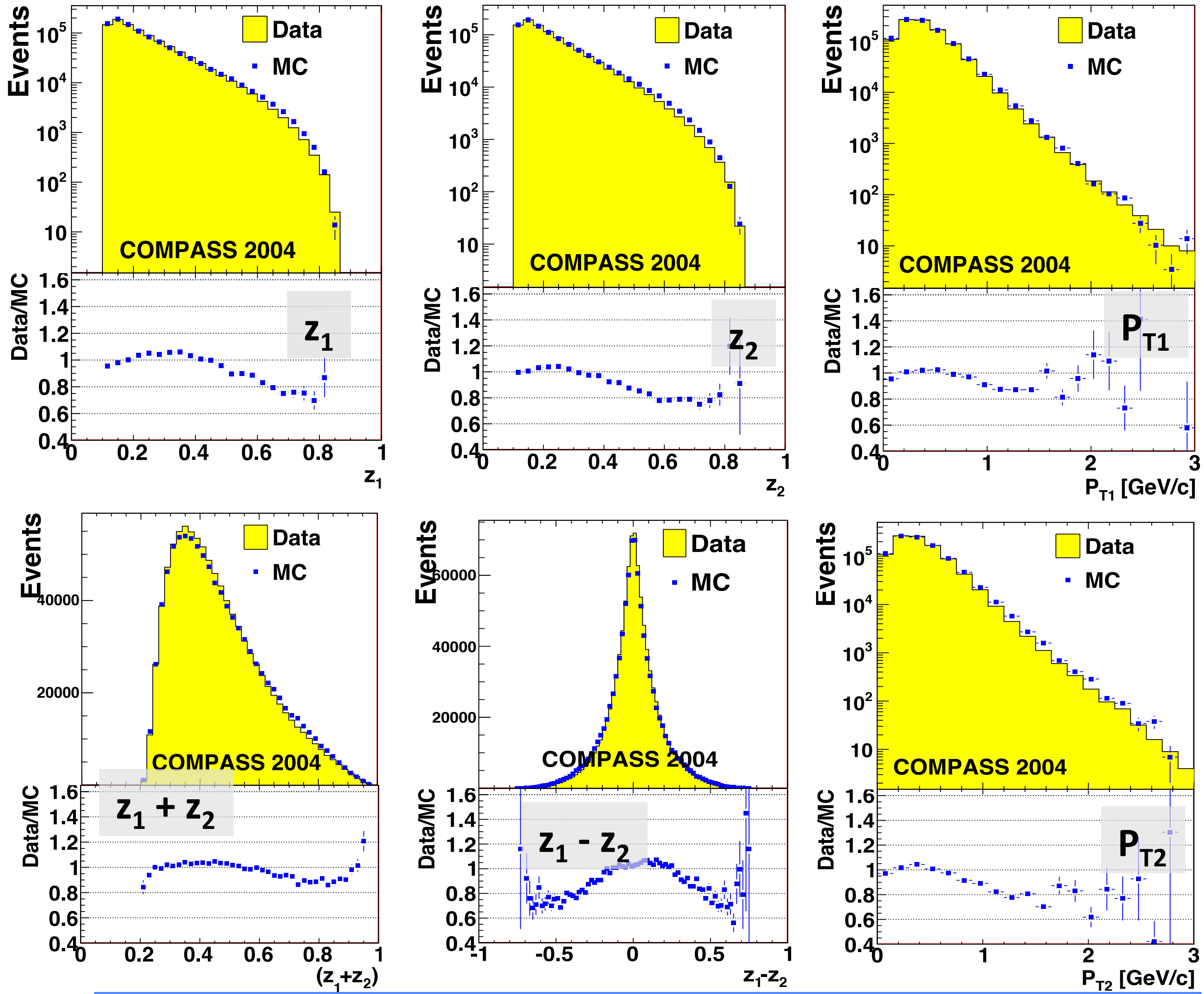
Results: 2D (Q^2,z) Multiplicities for π and K



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

Results on hadron pair multiplicities

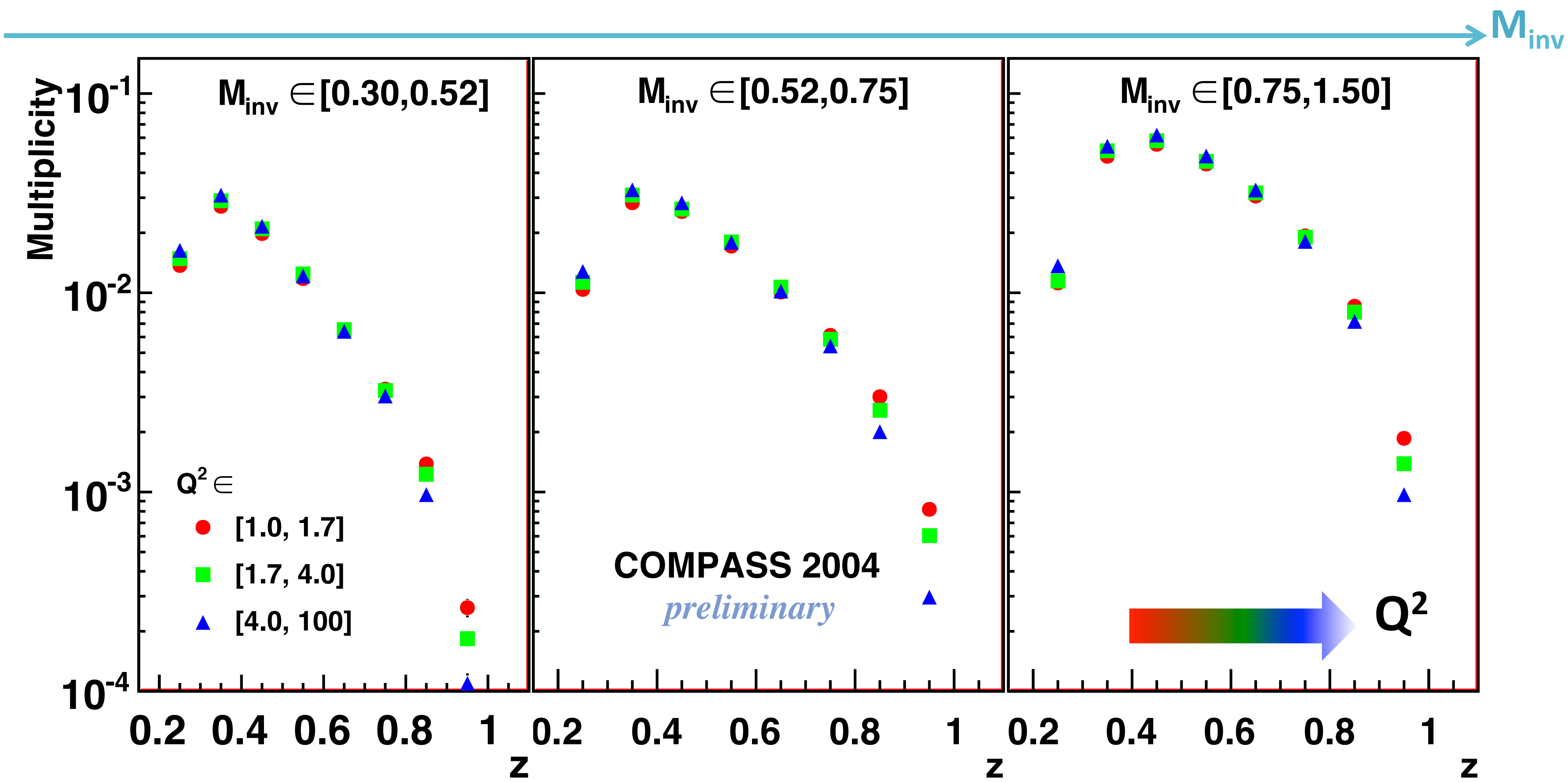
Monte Carlo description of COMPASS data (I)



Reasonable description of COMPASS data by MC simulation

New: 2004 Hadron pair multiplicities versus (z,Q^2,M_{inv})

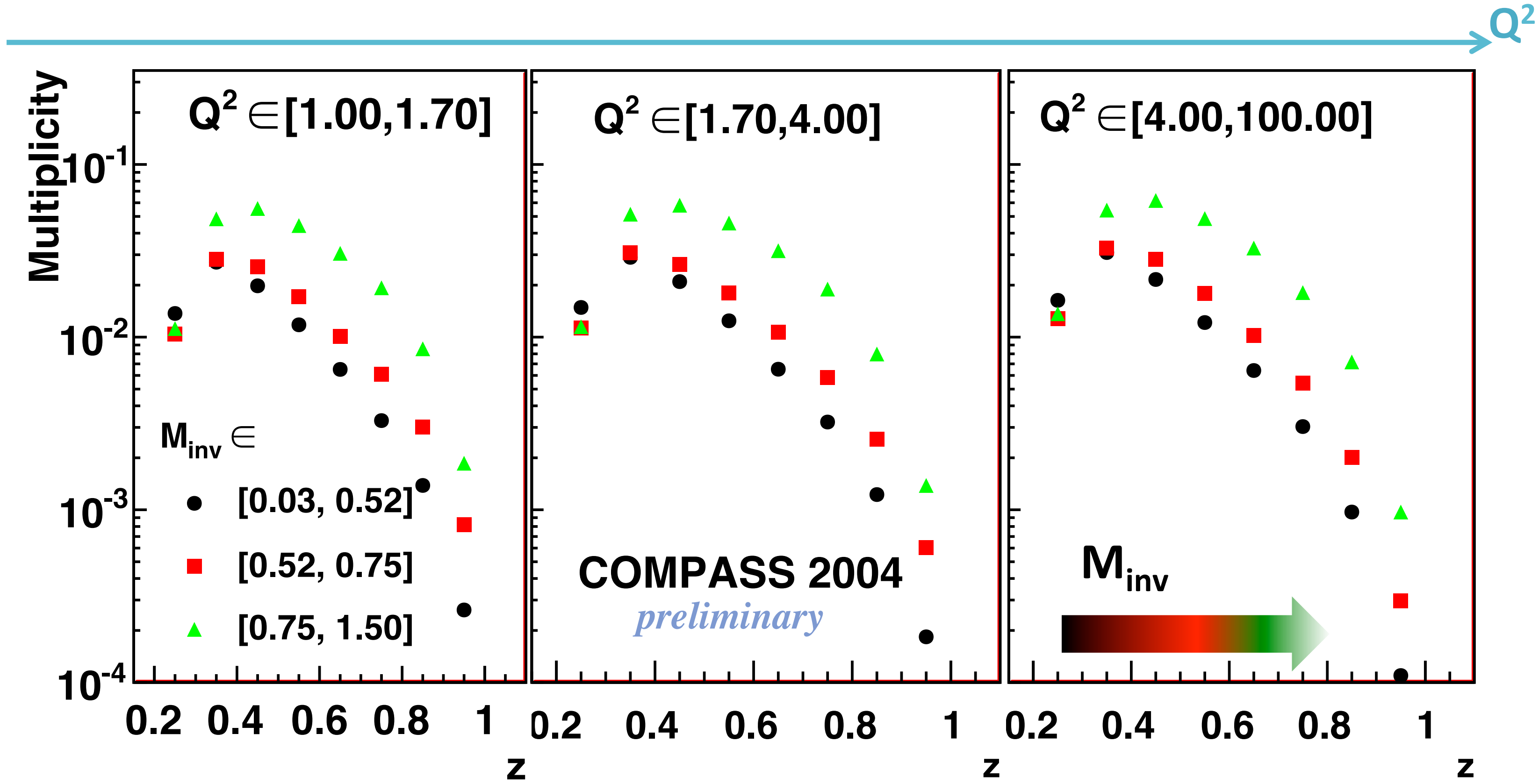
- Goal: measurement of $D_q^{h+,\,h-}(z.\ M_{inv},\ Q^2)$
- Key ingredient to access transversity function



$(z = z_1 + z_2)$

Weak Q^2 dependence as predicted by LEPTO generator

New: 2004 Hadron pair multiplicities versus (z,Q^2,M_{inv})



- Non negligible dependence upon M_{inv} and $z(= z_1 + z_2)$
- (z, M_{inv}) dependence in agreement with LEPTO prediction

First determination of hadron pair multiplicities from SIDIS

Summary

- π/K charged multiplicities versus (x,z) and (Q2,z) from μ-d DIS measured at COMPASS
- **π**: poor agreement with LO predictions, **K**: significant disagreement
- Resulting multiplicities can significantly contribute to global QCD analyses for FFs
- Useful for the determination of strange quark distribution s(x)
- First measurement of unidentified hadron pair multiplicities aiming to determine Dihadron fragmentation functions

Outlook

- Single hadron multiplcities from μ-p DIS
- Measurement of Identified hadron pair multiplicities
- Determination of s(x)