Fragmentation Functions Measurement at COMPASS

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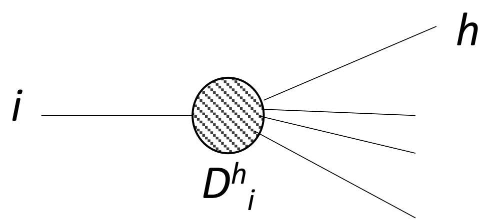
on behalf of the COMPASS collaboration

- Single-hadron fragmentation functions
- Di-hadron fragmentation functions

Single-hadron Fragmentation Functions (FFs)

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

- $D^h_{i(q,g)}$ *gives the mean number of hadrons produced in the parton hadronisation*



- Relevant in every high energy reaction where final-state hadrons are produced
- Play a key role in flavor separation of polarised PDFs
- Universal and non-perturbative quantities

- Depend on energy fraction of the photon transferred to the hadron
- Depend on Q^2, evolution described by DGLAP equations
- Energy conservation sum rule (used in the FF determination):

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

Strange Sea Quark Polarisation Puzzle

Strange Quark Polarisation in the nucleon:

$$\int_0^1 \Delta s(x) + \Delta\bar{s}(x) dx = 2\Delta S$$

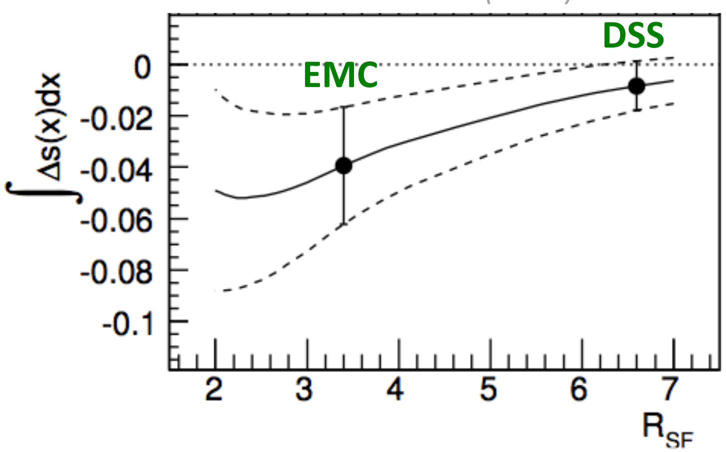
- From Inclusive Asymmetries: $2\Delta S = -0.08 \pm 0.01 \pm 0.02$ *PLB 647(2007) 8-17*
- From Semi-Inclusive Asymmetries: $2\Delta S = -0.02 \pm 0.02 \pm 0.02$ *PLB 693 (2010) 227-235*

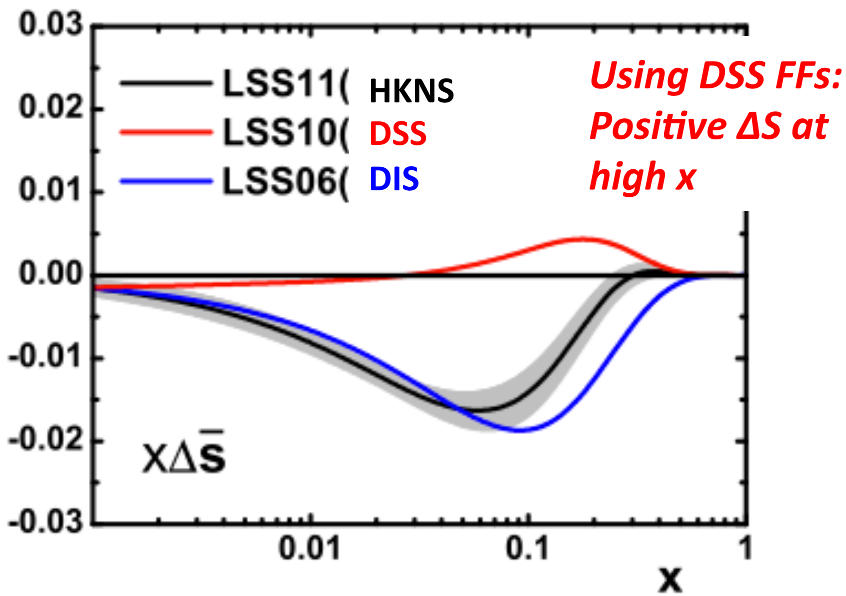
  Strongly depends upon the choice of *poorly known* fragmentation functions

  ⇔ $\Delta S = f(R_{SF})$, $R_{SF} = D_{str}^{K}/D_{u}^{K}$

- Extract R_{SF} (& FFs) from COMPASS data

PLB 693 (2010) 227-235



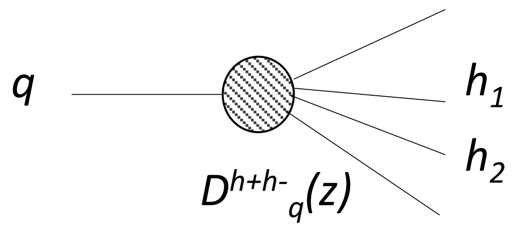


Using DSS FFs: Positive ΔS at high x

Single-hadron FFs are a key ingredient in the ΔS puzzle

Dihadron Fragmentation Functions (DiFFs)

- Describe the probability that a quark of given flavor (q_f) fragments 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 hadron pair production in e^+e^- annihilation
  *Phys. Lett. B **578**, 139 (2004)*

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

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

DiFFs needed in several high energy processes with final state hadrons

Current knowledge of unpolarised FFs & DiFFs

Single-hadron FFs

- Experimental information available in all hard scattering reactions

- Most experimental data measured in e^+e^- colliders
  - Clean process ⇔ depends only on FFs
  - Fixed energy scales (far from fixed target scales)
  - Mostly sensitive to singlet combination (for LEP Data)
  - No separation of quark and anti-quark fragmentation

- Accessible in hadron-hadron collisions:
  - Most sensitive to gluon FFs
  - Useful for medium modifications of FFs

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

Hadron pair FFs

- No global QCD analyses exist.

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

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

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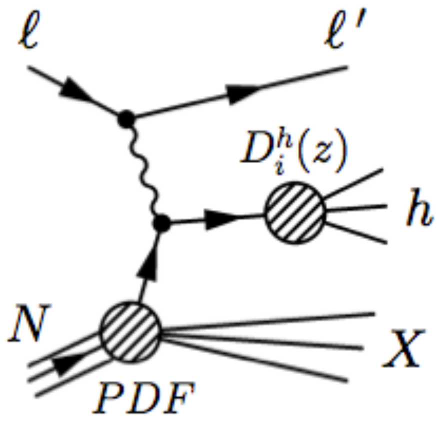
Unknown DiFFs

Semi-Inclusive DIS (SIDIS)



- *l N -> l' h X : at least one hadron is detected in coincidence with the scattered lepton in the final state*
- Allows flavor/charge separation of FFs
- Allows a wide Q^2 coverage

Relevant observable for FF study: LO **Hadron Multiplicities**

$$M^h(x, Q^2, z) = \frac{d^3\sigma^h/dxdQ^2dz}{d^2\sigma^{DIS}/dxdQ^2} = \frac{\sum_q e_q^2(q(x,Q^2)D_q^h(z) + \bar{q}(x,Q^2)D_{\bar{q}}^h(z))}{\sum_q e_q^2(q(x,Q^2) + \bar{q}(x,Q^2))}$$

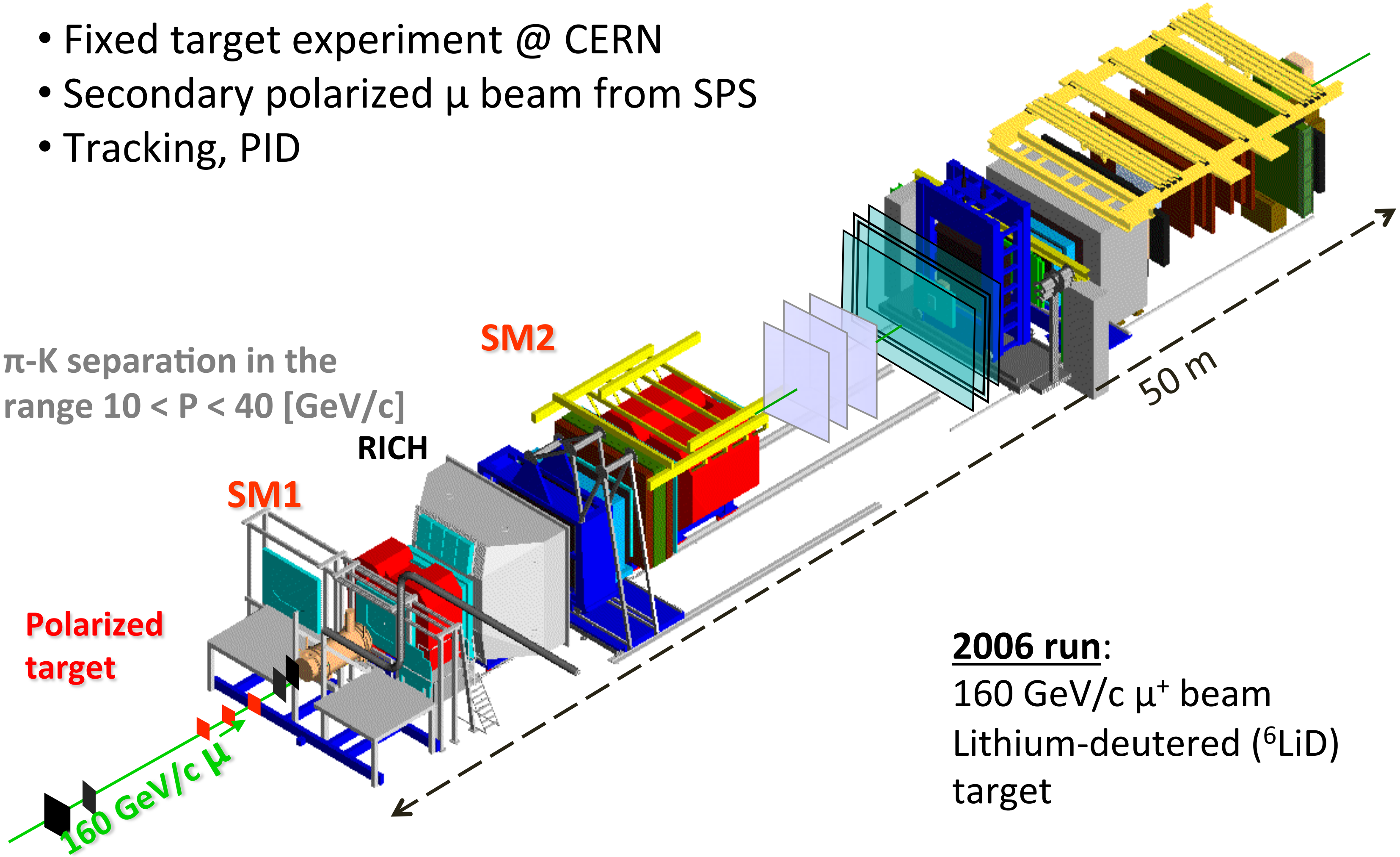
- Depends on unpolarised PDFs:
  - Up, down unpolarised PDFs well known
  - ***Strange PDF s(x) poorly known***

- 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



<u>2006 run</u>:
160 GeV/c μ^+ beam
Lithium-deutered (^{6}LiD)
target

Multiplicity definition and method of extraction

Definition: averaged number of hadron produced per DIS event.

Method of extraction: In a given kinematic bin ***i =(x,y,z)***

1. Experimental hadron multiplicity:

$$M_{exp}(i) = T^h(i) / N^{DIS}(i)$$

T_h Vector of true particles (corrected for RICH inefficiencies)

$$\begin{pmatrix} I_\pi \\ I_K \\ I_p \end{pmatrix} = \begin{pmatrix} P^{\pi\to\pi} & P^{K\to\pi} & P^{p\to\pi} \\ P^{\pi\to K} & P^{K\to K} & P^{p\to K} \\ P^{\pi\to p} & P^{K\to p} & P^{p\to p} \end{pmatrix} \cdot \begin{pmatrix} T_\pi \\ T_K \\ T_p \end{pmatrix}$$

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

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

3. Final multiplicities:

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

Kinematic domain

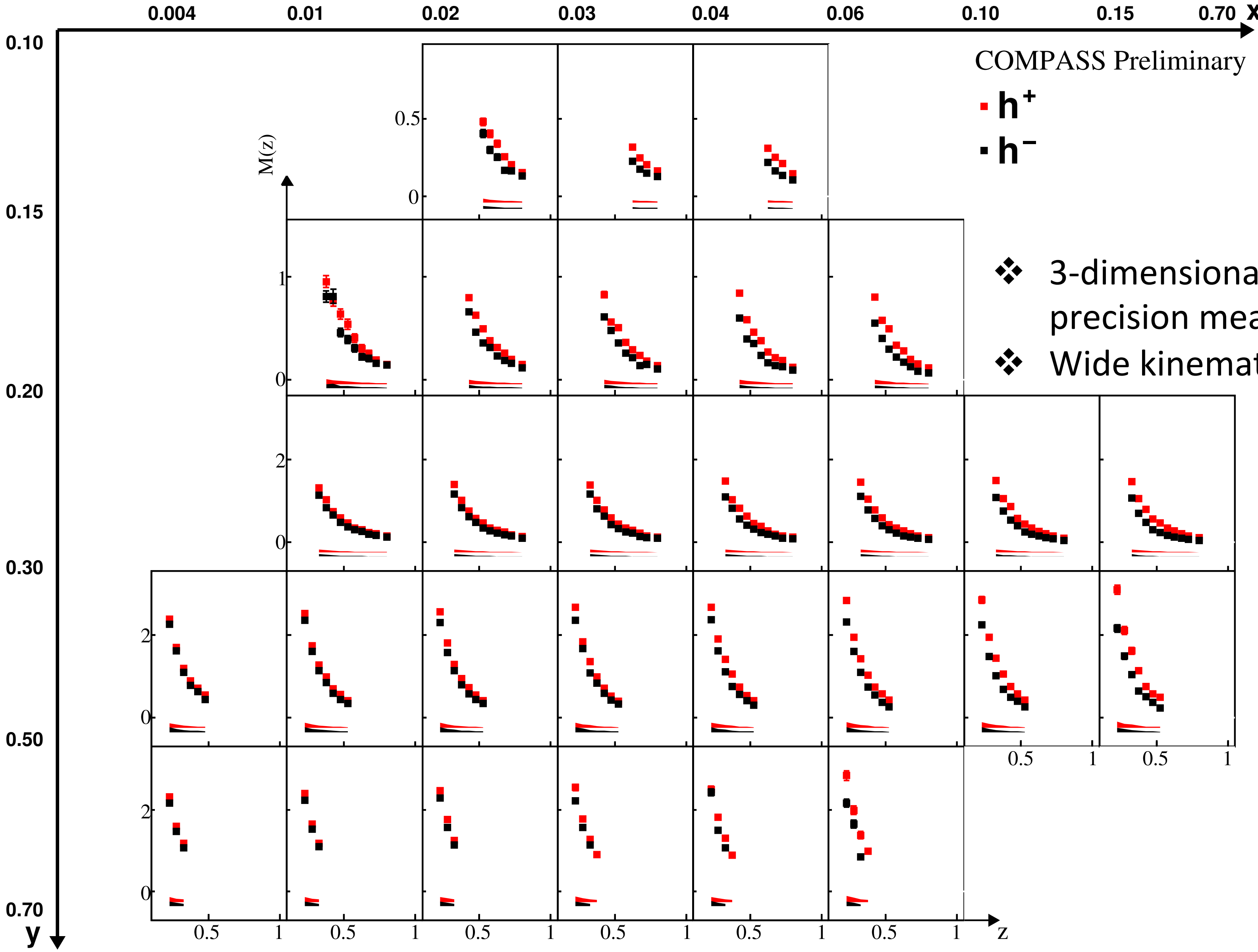
$Q^2 > 1$ (GeV/c)^2, $0.1 < y < 0.9$, $5 < W < 17$ *(GeV)*, $0.003 < x < 0.7$

$0.2 < z < 0.85$

Results on single hadron multiplicity

Unidentified hadron multiplicities vs (x,y,z)

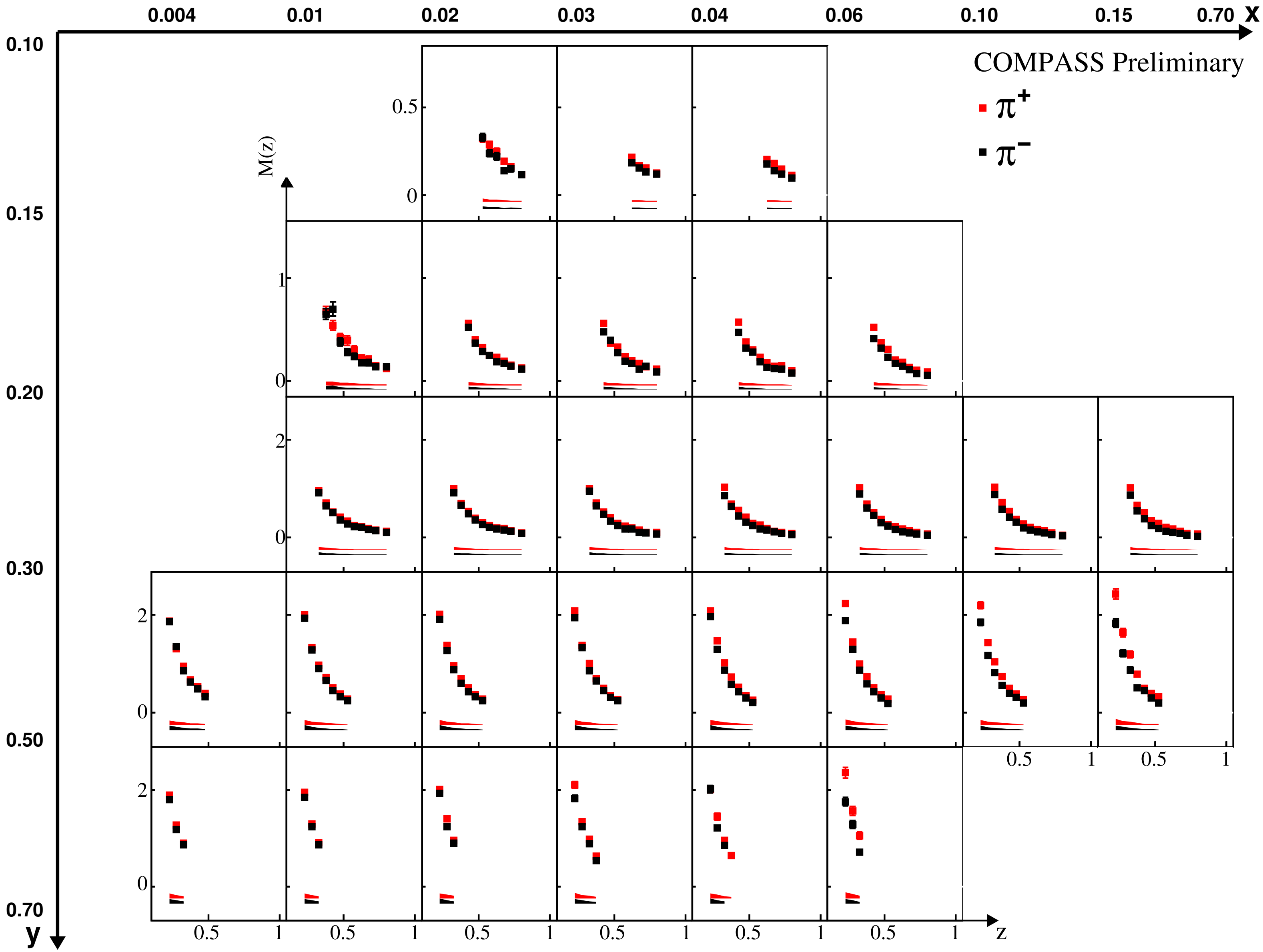
New



- 3-dimensional High precision measurement
- Wide kinematic domain

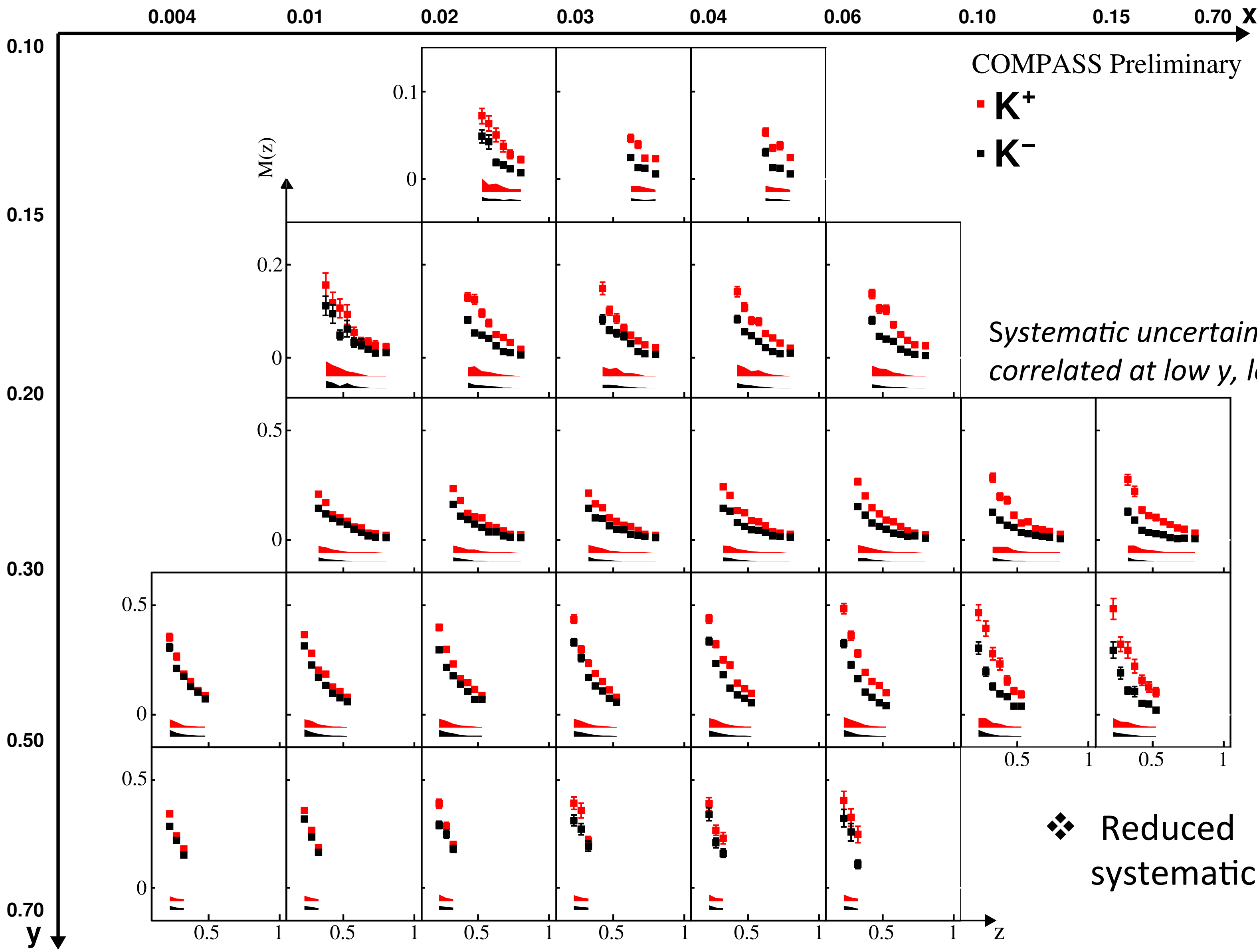
Charged pion multiplicities vs (x,y,z)

New



Charged kaon multiplicities vs (x,y,z)

New



Systematic uncertainty fully correlated at low y, low z

- Reduced systematic errors

Sum of charged kaon multiplicities ($M^{K+ + K-}$) vs x

$$\int_{0.2}^{0.85} M^{K^+ + K^-}(x,z)dz = \frac{Q(x)\int D_Q^K(z)dz + S(x)\int D_S^K(z)dz}{5Q(x)+2S(x)}$$

Non-strange: $Q(x) = u(x) + \bar{u}(x) + d(x) + \bar{d}(x),\quad D_Q(z) = 4D_{fav}^K(z) + 6D_{unf}^K(z)$

Strange: $S(x) = s(x) + \bar{s}(x)\quad D_S^K(z) \simeq 2D_{str}^K(z)$

- *High x* — *Assuming 2S(x) << 5Q(x)*

  S(x) ~ 0 ⇔ $\int_{0.2}^{0.85} M^{K^+ + K^-}(x,z)dz = \frac{1}{5}\int D_Q^K(z)dz$ ⇔ x independent

- *Low x*

$$\int_{0.2}^{0.85} M^{K^+ + K^-}(x,z)dz = \frac{1}{5}\left(\int D_Q^K(z)dz + \frac{S(x)}{Q(x)}\int D_S^K(z)dz\right)$$

Significant increase of M(x) at small x wrt high x suggests significant strange contribution to kaon production

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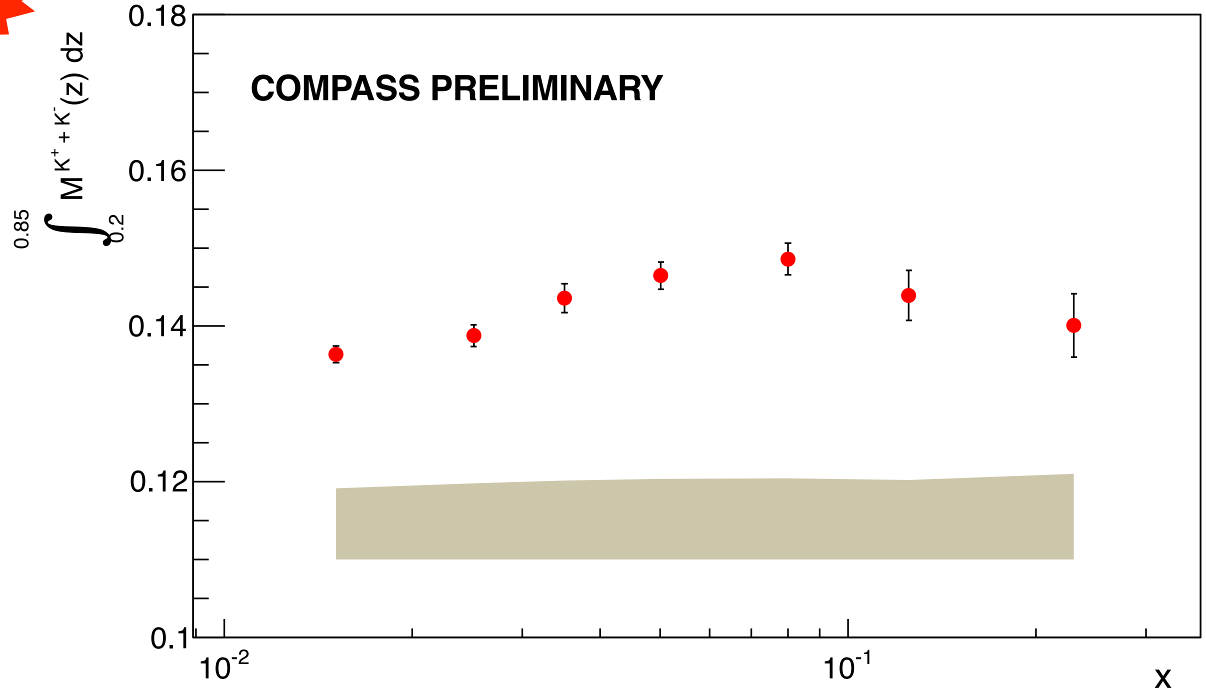


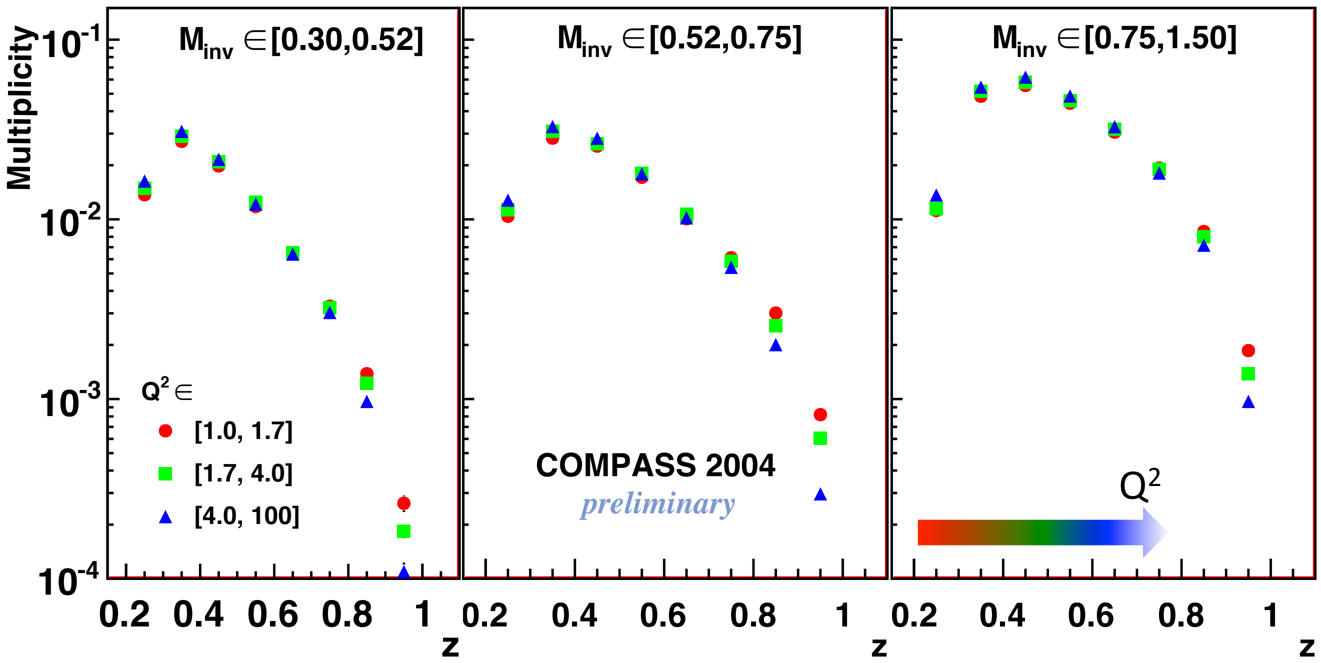
- z integrated $M^{K+ + K-}$ in [0.2, 0.85]
- Directly related to strange PDF s(x) and strange quark FF into kaon $D_S^K(z)$
- Lack of strong growth of $M^{K+ + K-}$ going from high x towards low x suggest rather small values of D_S^K
- Ongoing studies to reduce systematic uncertainties

Results on hadron pair multiplicity

Hadron pair (h^+h^-) multiplicities versus (z,Q^2,M_{inv})

Kinematic domain

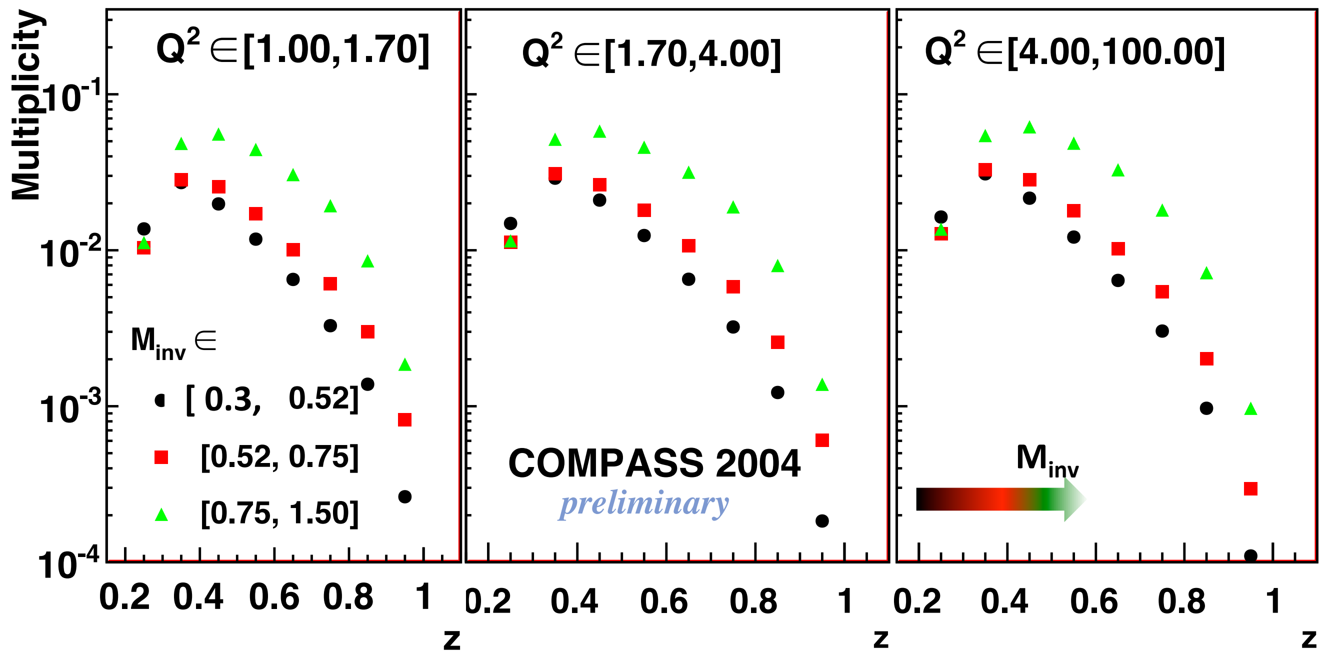
$Q^2 > 1$ (GeV/c)^2, $0.1 < y < 0.9$, $5 < W$ (GeV), $0.003 < x < 0.7$



- Goal: measurement of $D_q^{h+,h-}(z, M_{inv}, Q^2)$, $z = z_{h+} + z_{h-}$
- **Key ingredient to access transversity function** (*C. Braun's talk*)

- **First measurement in simultaneous (x,Q2,M_{inv}) bins**
- Weak Q^2 dependence as predicted by LEPTO generator

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



- Non negligible dependence upon M_{inv} and z
- (z, M_{inv}) dependence in agreement with LEPTO prediction

Summary & Outlook

- (x,y,z) dependent pion and kaon multiplicities from μ-d DIS measured at COMPASS

- Improved kaon identification with reduced systematic errors
  with ongoing studies to reduce systematics

- *New results supersede previous results of pion and kaon multiplicities from 2004 data*

- First measurement of unidentified hadron pair multiplicities for the perspective of extracting Dihadron fragmentation functions

- More high precision measurement on the list
  - P_T^2 dependent pion and kaon multiplicities in (x,Q^2,z) bins
  - Identified hadron pair multiplicities in (z,Q^2,M_{inv}) bins