Hadron Multiplicities from COMPASS

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Motivation

- Strange quark polarisation in the nucelon: $\int(\Delta s + \Delta\bar{s})\mathrm{d}x = \Delta S$
- measured in DIS and SIDIS
- from NLO p QCD fits to world g_1 data (with SU(3) symmetry in hyperon decays)

$$\Delta S = -0.8 \pm 0.01 \pm 0.02 \qquad \text{(PLB 647 (2007) 8)}$$

- from LO fit to $A_1^{\mathrm{p,d}}$, $\mathrm{K}^{\pm}$ and $\pi^{\pm}$ asymmetries (COMPASS data only)

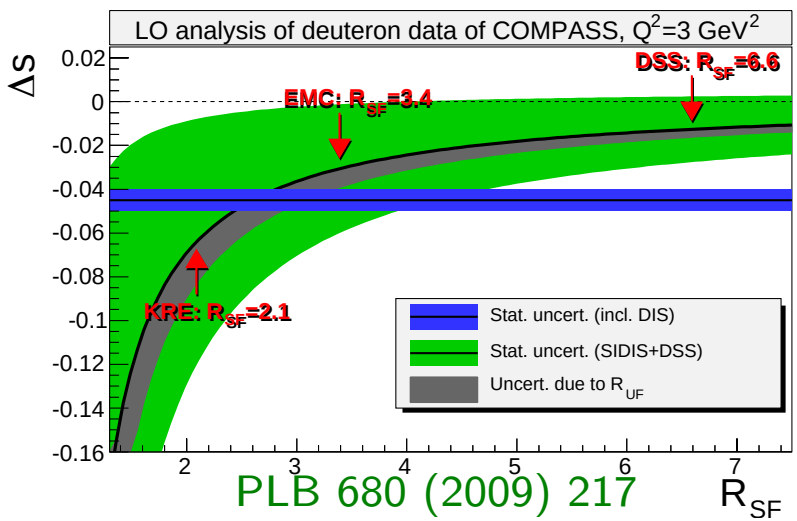
$$\Delta S = -0.01 \pm 0.01 \pm 0.01 \qquad \text{(PLB 693 (2010) 227)}$$

- SIDIS result depends strongly on choice of strange-quark-to-kaon fragmentation functions (FF)

- $R_{UF} = \dfrac{\int D_d^{K^+}(z)\mathrm{d}z}{\int D_u^{K^+}(z)\mathrm{d}z}$

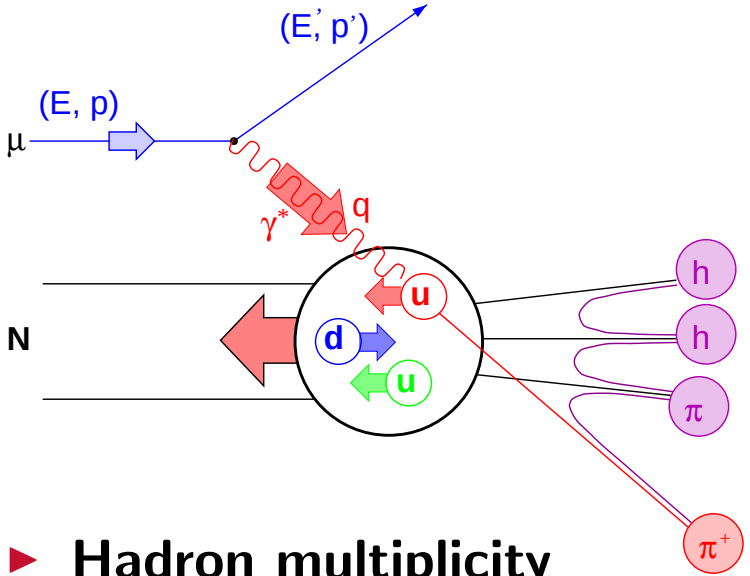
  $R_{SF} = \dfrac{\int D_{\bar{s}}^{K^+}(z)\mathrm{d}z}{\int D_u^{K^+}(z)\mathrm{d}z}$

- strong dependence on R_{SF}



PLB 680 (2009) 217

Deep inelastic scattering



$$Q^2 = -q^2$$
$$y = \frac{E - E'}{E}$$
$$x = Q^2/2MyE$$
$$z = E_h/yE$$

- **Hadron multiplicity**

$$\frac{\mathrm{d}M^{\mathrm{h}}(x,z,Q^2)}{\mathrm{d}z} = \frac{\mathrm{d}\sigma^{\mathrm{h}}(x,z,Q^2)/\mathrm{d}x\mathrm{d}z\mathrm{d}Q^2}{\sigma^{\mathrm{DIS}}(x,Q^2)/\mathrm{d}x\mathrm{d}Q^2}$$

- **Factorsation Ansatz**

$$\sigma^{\mathrm{h}} \sim \sum \sigma_{\mathrm{hard}} \otimes \mathrm{PDF} \otimes \mathrm{FF}$$

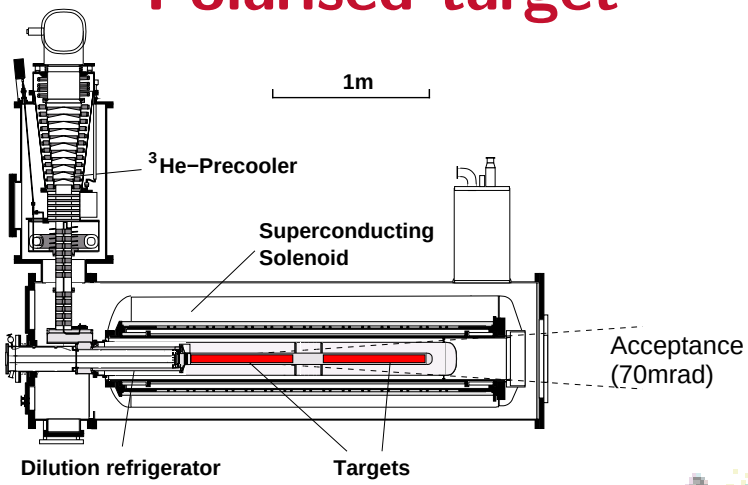
- with PDF: $q(x,Q^2)$ and fragmentation functions (FF): $D_q^{\mathrm{h}}(z,Q^2)$

Multiplicities in LO pQCD:

$$\frac{\mathrm{d}M^{\mathrm{h}}(x,z,Q^2)}{\mathrm{d}z} = \frac{\sum_q e_q^2 q(x,Q^2) D_q^{\mathrm{h}}(z,Q^2)}{\sum_q e_q^2 q(x,Q^2)}$$

COMPASS experiment

Polarised target



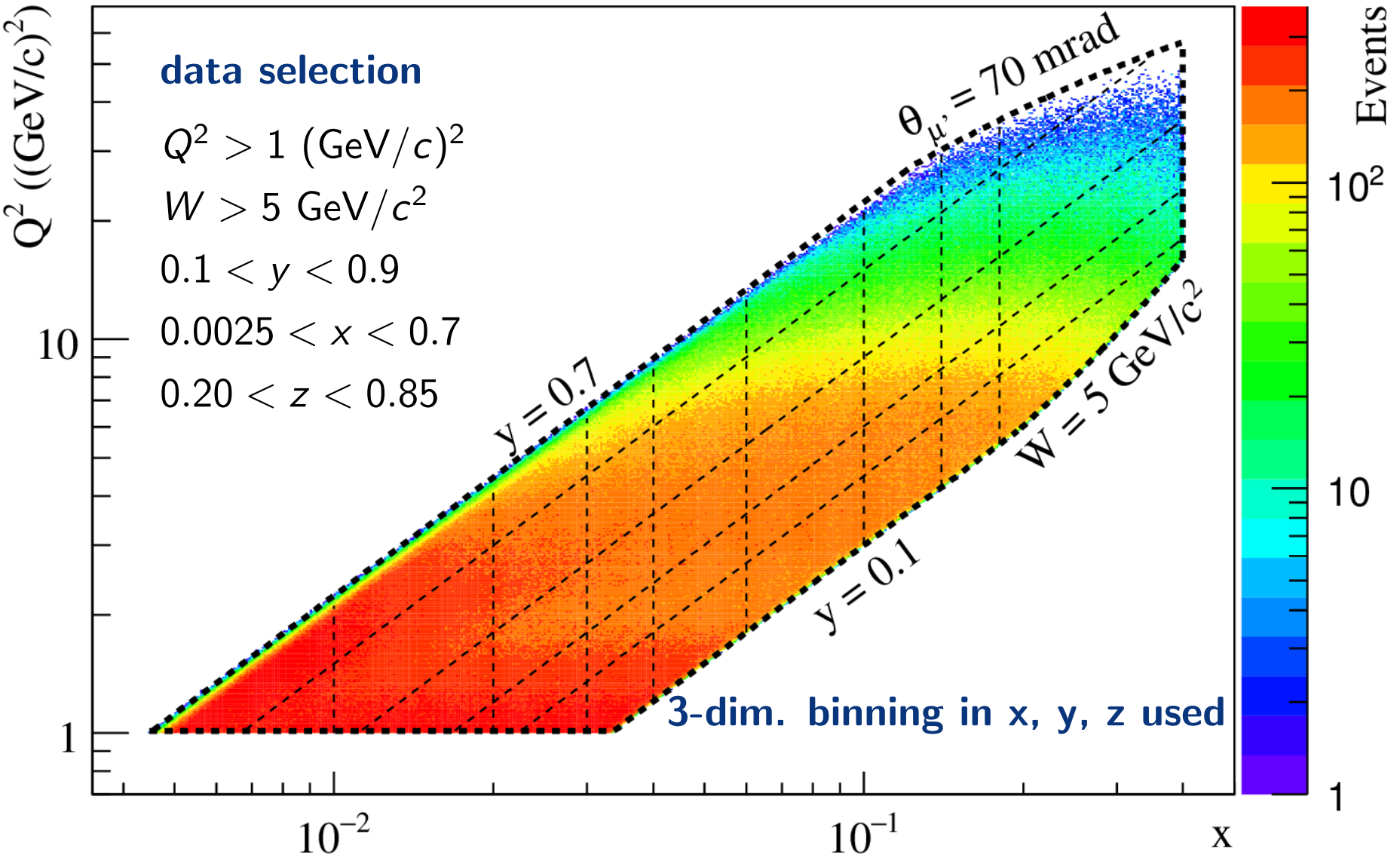
target material: 1.2 m ^{6}LiD, NH_3

polarisation: 50%, 90%

Spectrometer

- Two magnets (1 Tm, 4.5 Tm)
- Tracking ($p > 0.5$ GeV/c)
- PID: π, K, p (RICH)
- ECAL, HCAL, muon filter

COMPASS kinematics



Multiplicity analysis

Analysis steps:

Data from 2006 with isoscalar ^{6}LiD target

Raw multiplicities $N^{\mathrm{h}}/N^{\mathrm{DIS}}\Delta z$

Pion and kaon identification wih COMPASS RICH

Radiative corrections

Unfolding of PID efficiencies

Diffractive vector meson contamination

Electron contamination

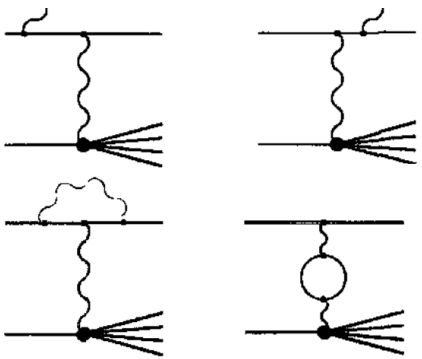
Detector acceptance

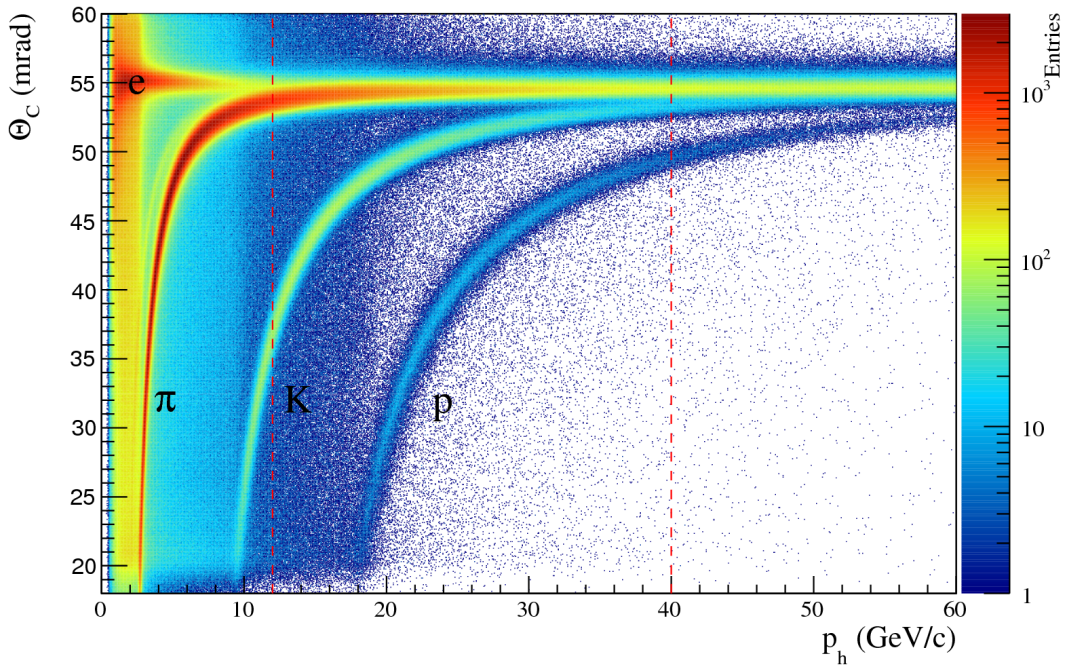
Bin migration

Final Multiplicities

event-by-event, bin-by-bin, included in acc. correction

Radiative corrections and PID





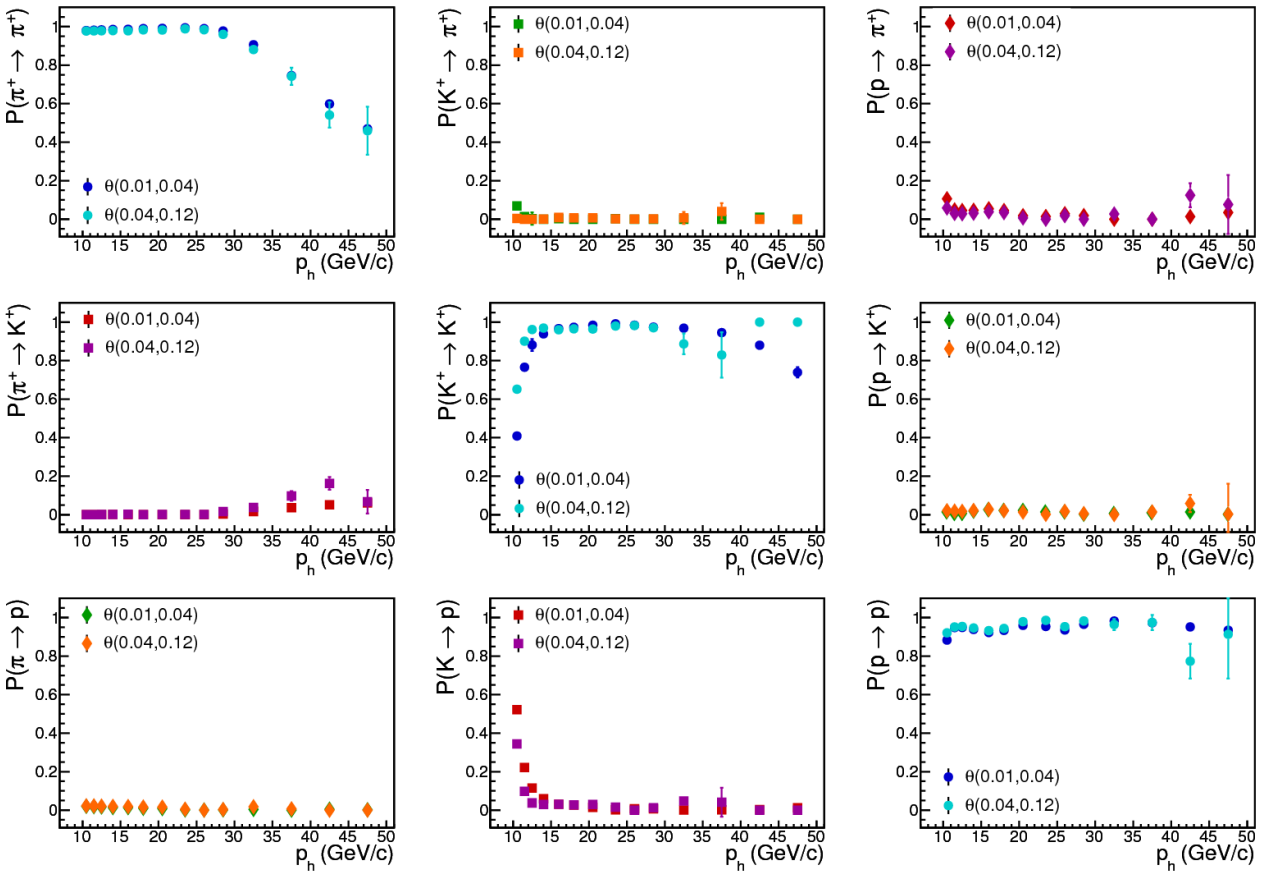
- radiative correction factor

$$\eta(x,y) = \frac{\mathrm{d}\sigma^{1\gamma}/\mathrm{d}x\mathrm{d}y}{\mathrm{d}\sigma^{\mathrm{meas}}/\mathrm{d}x\mathrm{d}y}$$

- separate factor for N^{DIS} and N^{h}
- no z dep taken into account
- total correction to multiplicities: between 5% at low x, high y to less than 1% at high x, low y

- likelihood method used for PID based on radial distribution of photon around track projection
- excellent π, K and p discrimination for 12-40 GeV particle momentum

RICH performance



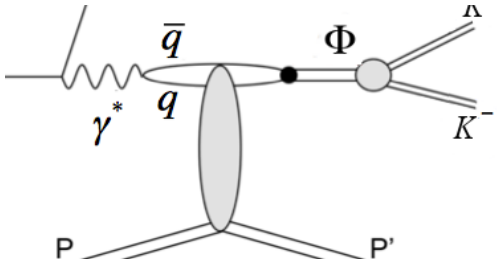
determined from data:

using decays of
K^0, Λ, $\bar{\Lambda}$, ϕ
into π, K and p

- PID efficiencies high, only small misidentification
- used to unfold true numbers from measured ones:

  $N^i_{\text{true}} = \sum_j \left(\mathrm{P}^{-1}\right)_{ij} N^{\mathrm{j}}_{\text{meas}}$ with $i, j = \pi$, K, p
- systematic uncertainties: 1-3% for pions , 5-10% for kaons

Diffractive vector meson production

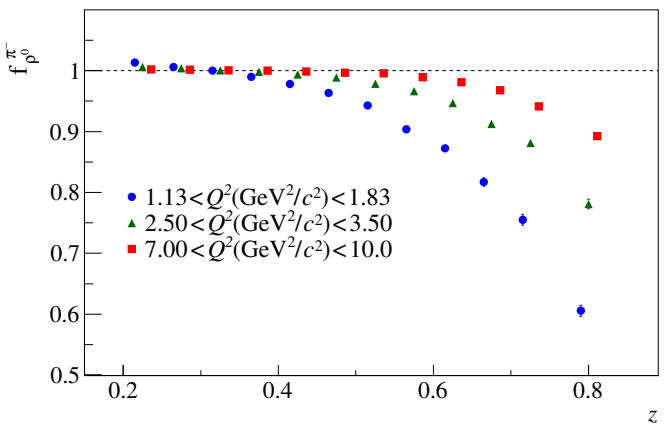


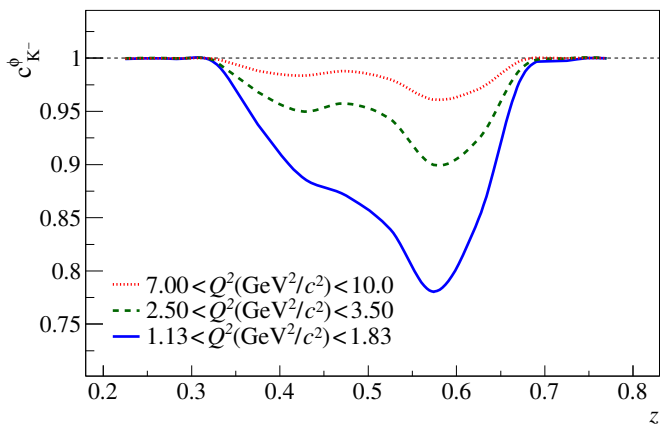
- estimated using MC: HEPGEN (VM) and LEPTO (DIS) generator plus full COMPASS simulation

$$c^{\mathrm{h}}_{\rho^0,\phi} = \frac{N^{\mathrm{h}}_{\mathrm{VN}}(x,y,z)}{N^{\mathrm{h}}_{\mathrm{DIS}}(x,y,z) + N^{\mathrm{h}}_{\mathrm{VM}}(x,y,z)}$$

- similar correction factor for N^{DIS}

Correction for M^{π} from $\rho^0 \to \pi^+\pi^+$ Correction for N^{K} from $\phi \to \mathrm{K}^+\mathrm{K}^-$

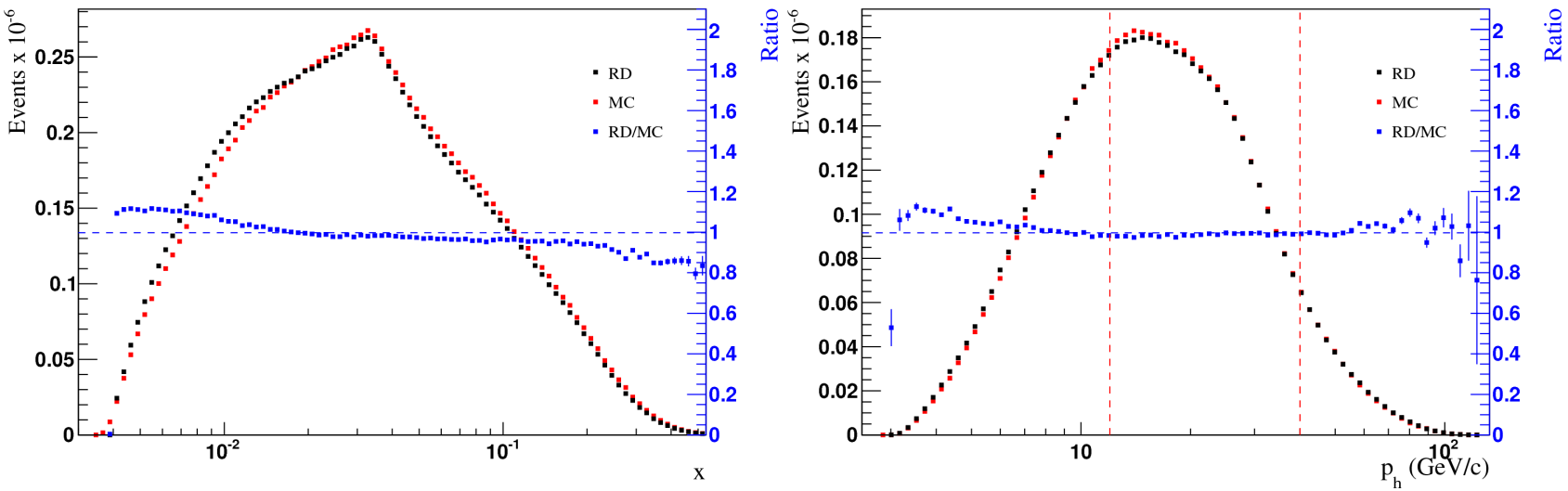




correction $< 10\%$, except:
kaons: low x, mid z up to 25%, pions: low x, high z up to 55%
systematic uncertainty: 30% of the corrections

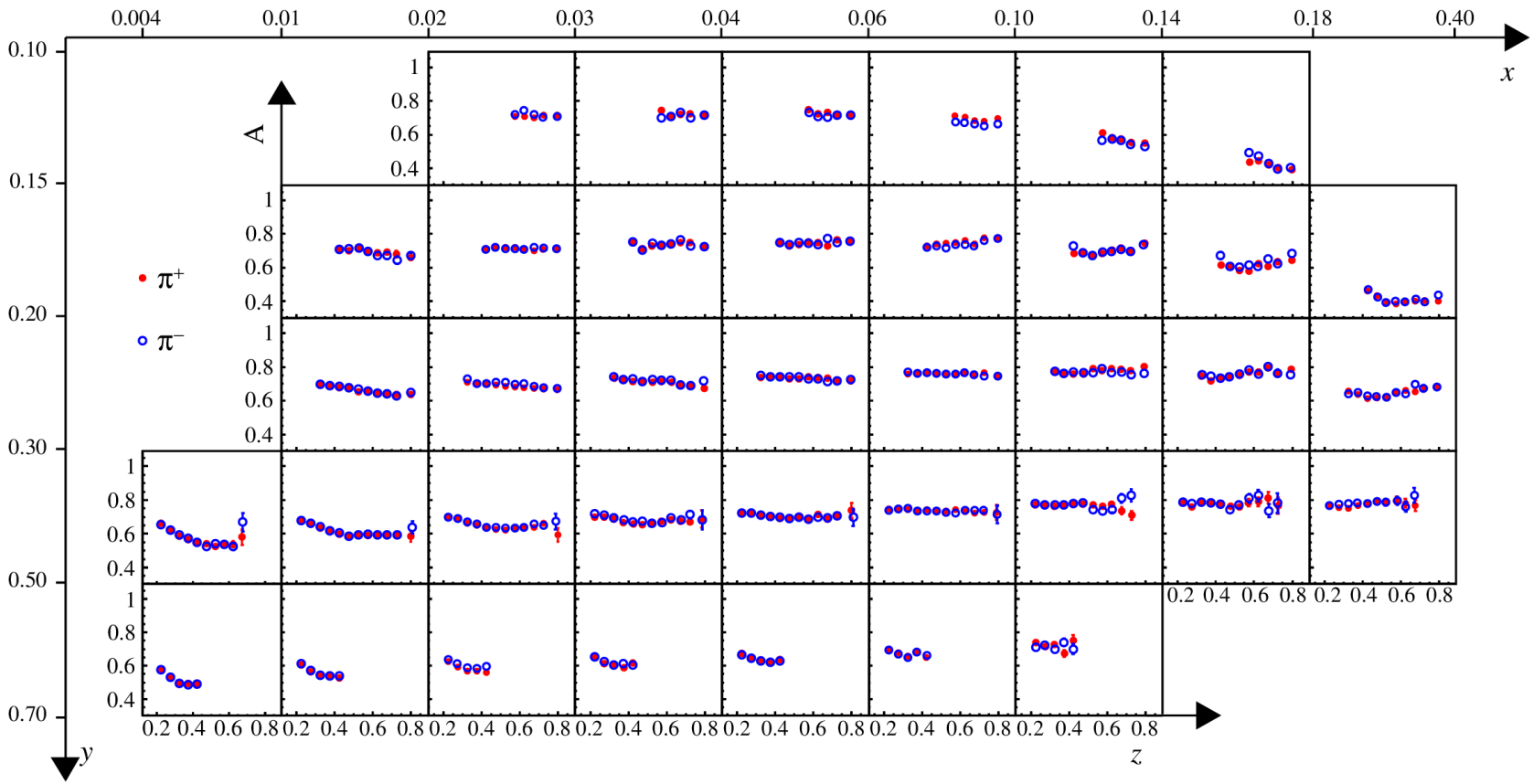
MC simulation

- using LEPTO generator, JETSET, FLUKA, spectrometer description plus reconstruction
- simulation includes detector geometry, efficiencies, kinematic smearing, electron contamination of pion and hadron sample
- example for D/MC distributions:



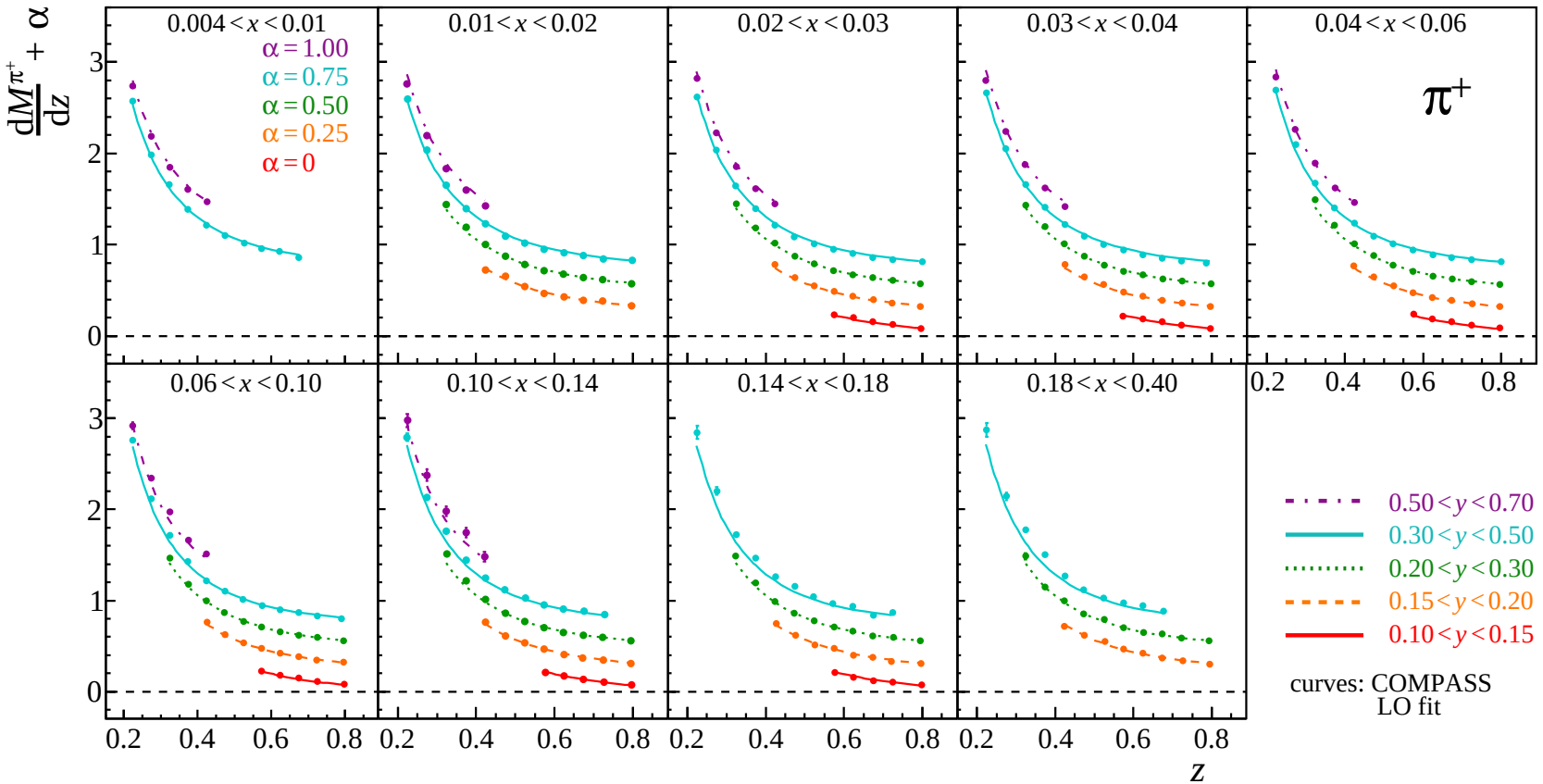
- description of data good enough for use in 3-dim. acceptance calculation
- acceptance uncertainty: exploit independent measurements with 3 target cells

Acceptance



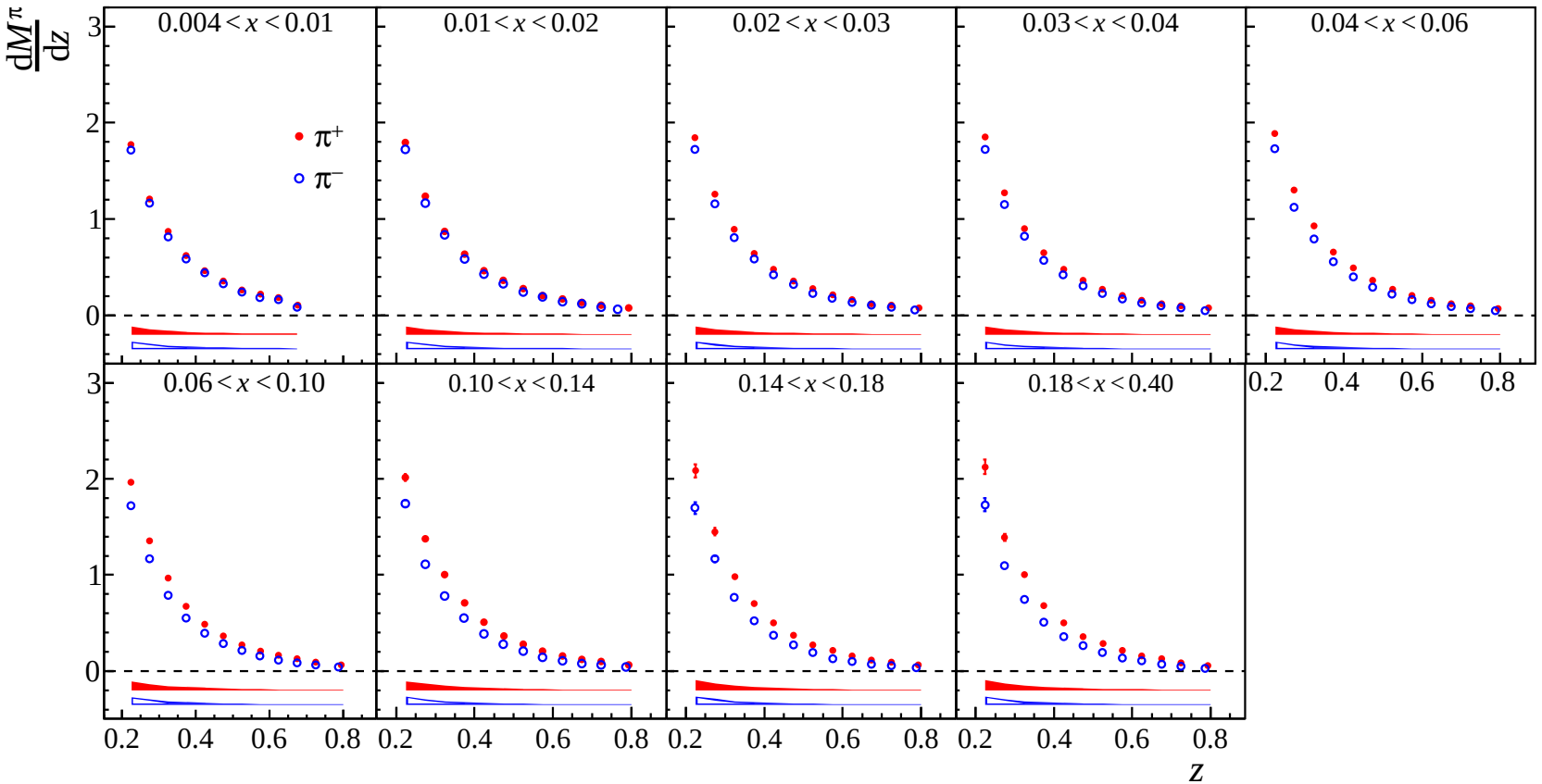
- muon acceptance basically cancels
- hadron acceptance has little kinematic dependence except for high x
- acceptance about 60-80%, uncertainty about 5%
- losses due to secondary interactions in solid state target plus reconstruction efficiency

Results for pion multiplicities



- 317 kinematic bins (arXiv:1604.02695)
- practically no y dependence, strong z dependence
- curves: COMPASS LO pQCD fit

$\pi^{\pm}$ multiplicities



- small charge asymmetry due to u-quark dominance
- systematic errors: bands at bottom
- acceptance 5%, RICH 0.1% - 2%, VM corr. maximum 12%

Extraction of quark FF into pions

- assuming charge and isospin symmetry

$$D^{\pi}_{\text{fav}} = D^{\pi^+}_{u} = D^{\pi^-}_{d} = D^{\pi^+}_{\bar{d}} = D^{\pi^-}_{\bar{u}}$$

$$D^{\pi}_{\text{unf}} = D^{\pi^+}_{d} = D^{\pi^-}_{u} = D^{\pi^+}_{\bar{u}} = D^{\pi^-}_{\bar{d}}$$

- assumed in addition: $D^{\pi}_{\text{unf}} = D^{\pi^\pm}_{s} = D^{\pi^\pm}_{\bar{s}}$

- pion multiplicities

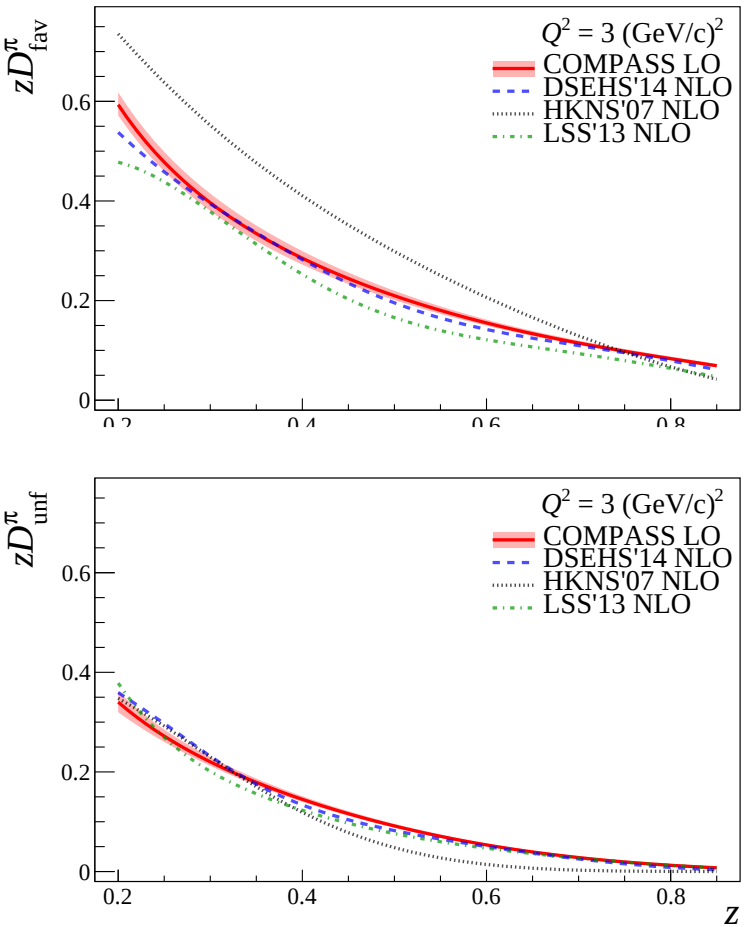
$$M^{\pi^+}(x, Q^2, z) = \frac{(4(u+d)+\bar{u}+\bar{d})D^{\pi}_{\text{fav}} + (u+d+4(\bar{u}+\bar{d})+2(s+\bar{s}))D^{\pi}_{\text{unf}}}{5(u+d+\bar{u}+\bar{d}+2(s+\bar{s}))}$$

$$M^{\pi^-}(x, Q^2, z) = \frac{(u+d+4(\bar{u}+\bar{d}))D^{\pi}_{\text{fav}} + (4(u+d)+\bar{u}+\bar{d}+2(s+\bar{s}))D^{\pi}_{\text{unf}}}{5(u+d+\bar{u}+\bar{d}+2(s+\bar{s}))}$$

- for PDFs MSTW08 LO is used
- two LO extractions: LO QCD fit with parametr. at $Q_0^2 = 1\,(\text{GeV}/c)^2$
  direct extraction in each kinematic bin

Results for Fragmentation Functions

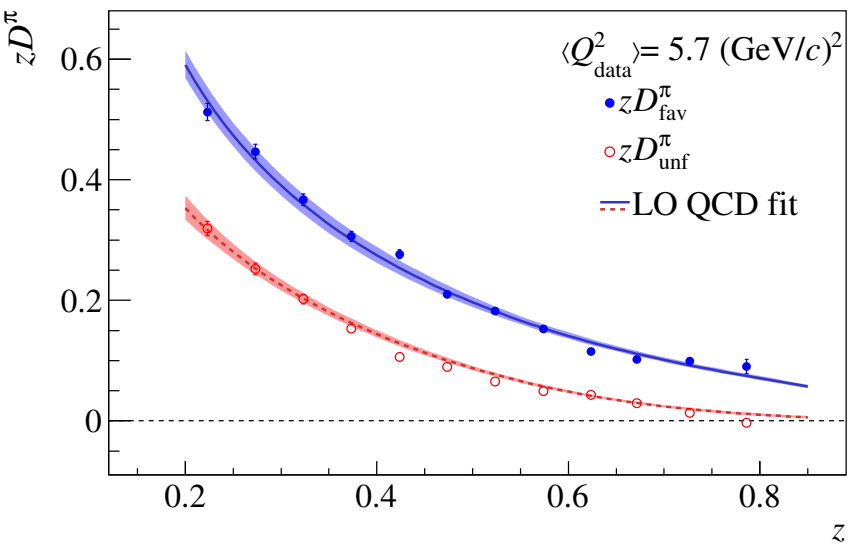
Results from LO fit



- Results agree well with recent fits to world data
- exception:
  HKNS fit to e^+e^- data only

Direct extraction

- good agreement with fit results
- average Q^2 and x of each bin used
- no assumptions on functional form, no Q^2 evolution needed



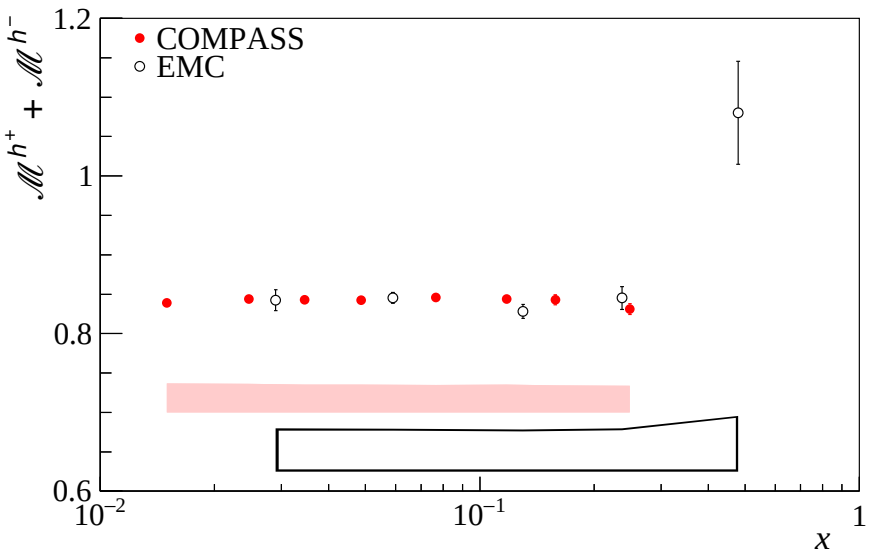
$0.3 < y < 0.5,\ 0.04 < x < 0.06$

Pion multiplicity sum

data averaged over y and integrated over z:

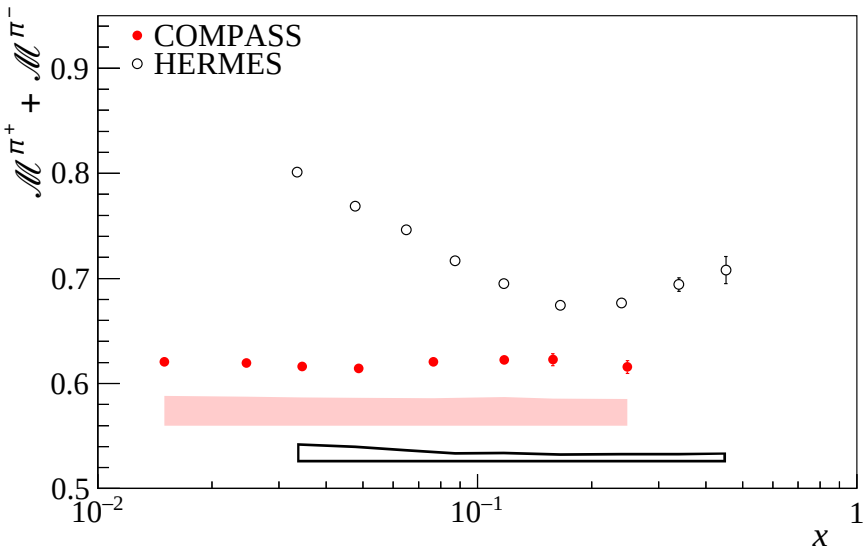
$$\mathscr{M}^{\pi^+} + \mathscr{M}^{\pi^-} = \mathscr{D}^{\pi}_{\text{fav}} + \mathscr{D}^{\pi}_{\text{unf}} - O([s + \bar{s}][\mathscr{D}^{\pi}_{\text{fav}} - \mathscr{D}^{\pi}_{\text{unf}}])$$

Charged hadrons:



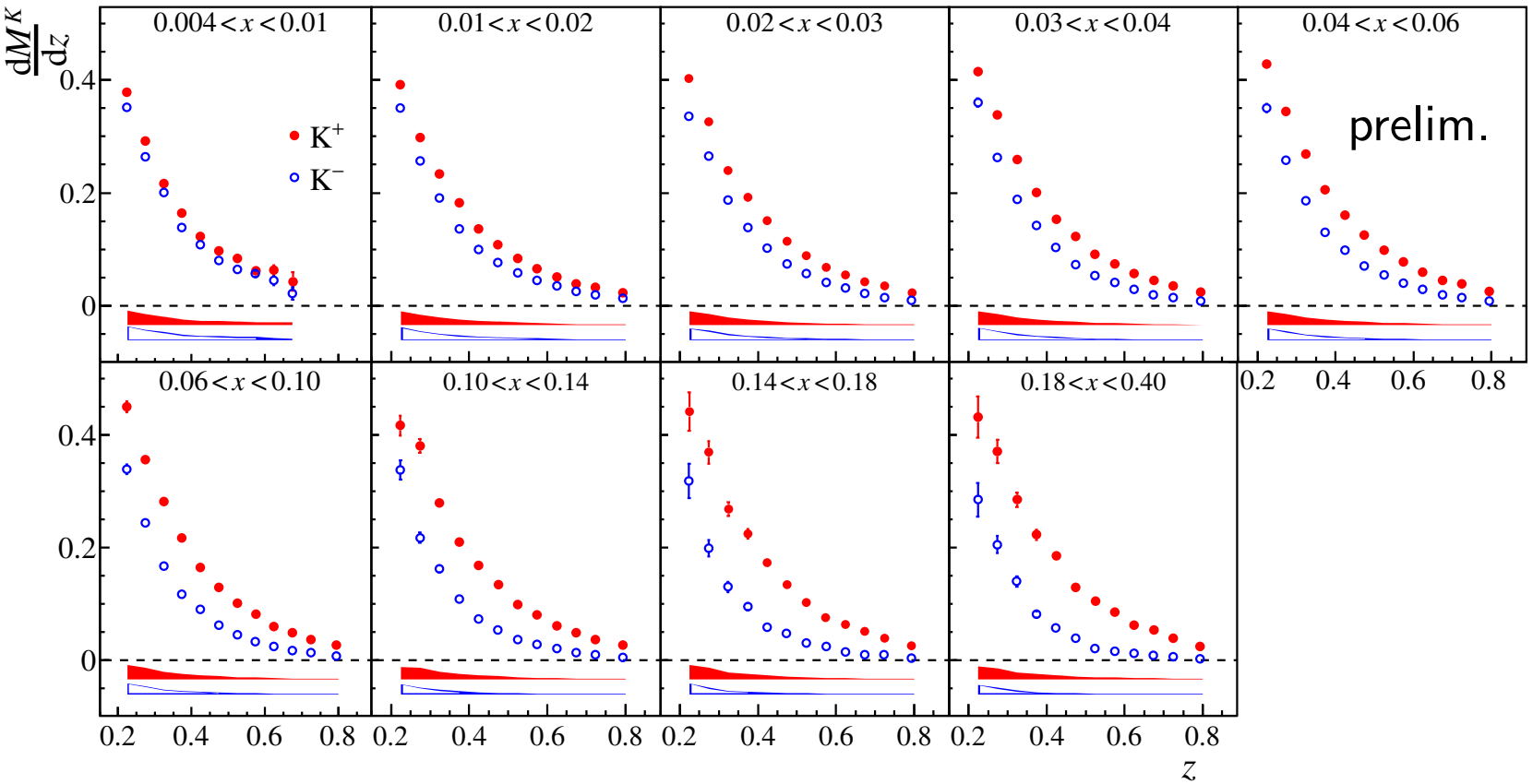
results in good agreement with EMC
Z. Phys. C (1991) 361)

Pions:



disagreement with HERMES (lower energy)
PRD 89 (2014) 097101

$K^{\pm}$ multiplicities



- large charge asymmetry (K^- contains only nucleon sea quarks)
- systematic uncertainties:
- acceptance 5%, RICH 0.2%-15%, VM corr. maximun 6%
- not shown: asymmetric error due to radiative corr.

LO QCD analysis

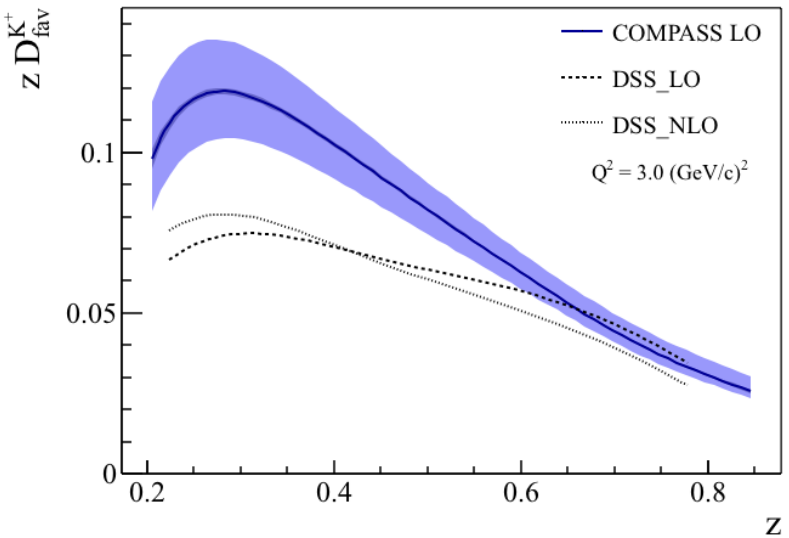
- preliminary results
- using charge and isospin symmetry:

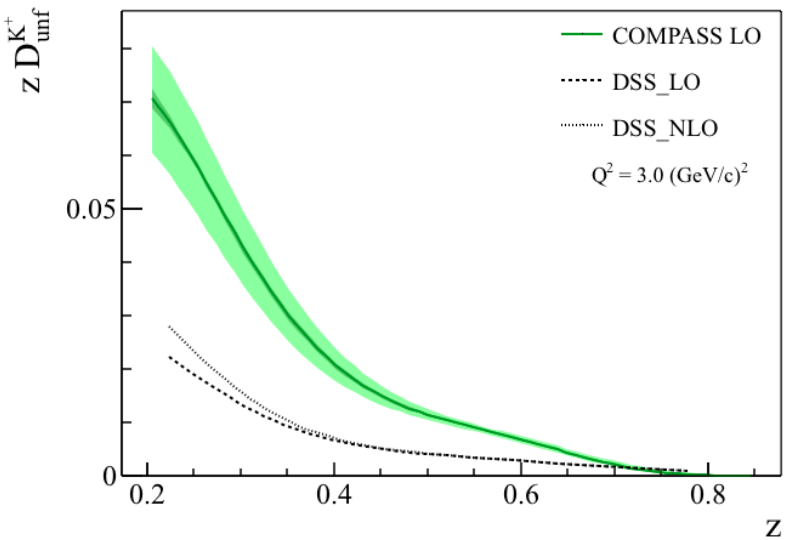
$$D^K_{\mathrm{fav}} = D^{K^+}_u = D^{K^-}_d$$

$$D^K_{\mathrm{unf}} = D^{K^+}_{\bar{u}} = D^{K^-}_{\bar{d}} = D^{K^+}_s = ...$$

$$D^K_{\mathrm{str}} = D^{K^+}_{\bar{s}} = D^{K^-}_s$$

- unpolarised PDFs from MSTW08
- results for favoured and unfavoured FFs very stable, strange FF still under investigation
- favoured and unfavoured FF are considerably larger than DSS parametrisation



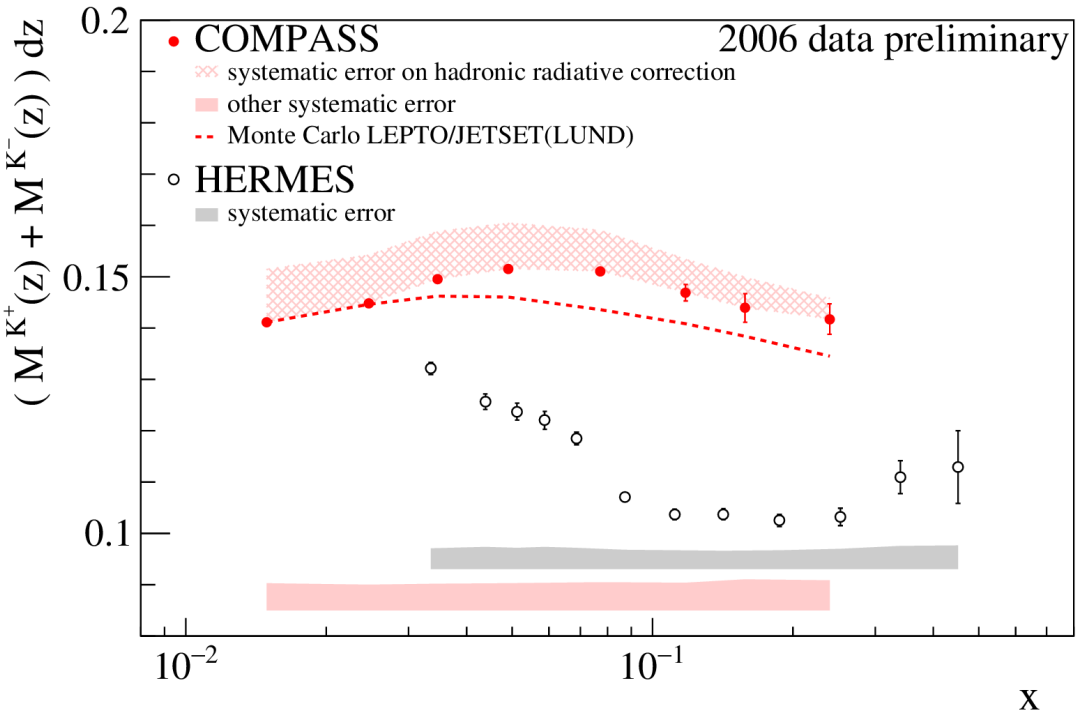


Kaon multiplicity sum

data averaged over y and integrated over z:

$$\mathscr{M}^{\mathrm{K}^+} + \mathscr{M}^{\mathrm{K}^-} = \frac{U\mathscr{D}_U^{\mathrm{K}} + S\mathscr{D}_S^{\mathrm{K}}}{5U + 2S}$$

with $U = u + \bar{u} + d + \bar{d}$, $S = s + \bar{s}$



- at high x $\mathscr{M}^{\mathrm{K}^+} + \mathscr{M}^{\mathrm{K}^-} = \mathscr{D}_U^{\mathrm{K}}/5$
- COMPASS: $\mathscr{D}_U^{\mathrm{K}} \approx 0.7$
  DSS: $\mathscr{D}_U^{\mathrm{K}} \approx 0.34 \pm 0.04$
- points also to larger non-strange FFs than by DSS
- disagreement with HERMES

Summary

Results

- Charged pion multiplicities from scattering 160 GeV muons on isoscalar ^{6}LiD target (arXiv:1604.02695)
- Preliminary data for charged kaon multiplicities
- Will be updated very soon, paper is circulating inside collaboration

Ongoing

- Analysis of K^0 multiplicities (larger momentum range, no PID)
- Analysis of 2012 hydrogen data (much less secondary interactions)
- Data taking with hydrogen target in 2016/7 for deeply virtual Compton scattering
- In parallel:
  SIDIS measurements for multiplicities $M^h(x, Q^2, z, p_T, \phi)$

Multiplicity ratios