Pion Multiplicities in Muon-Nucleon Scattering

DIS2014 Warsaw

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On behalf of the COMPASS collaboration

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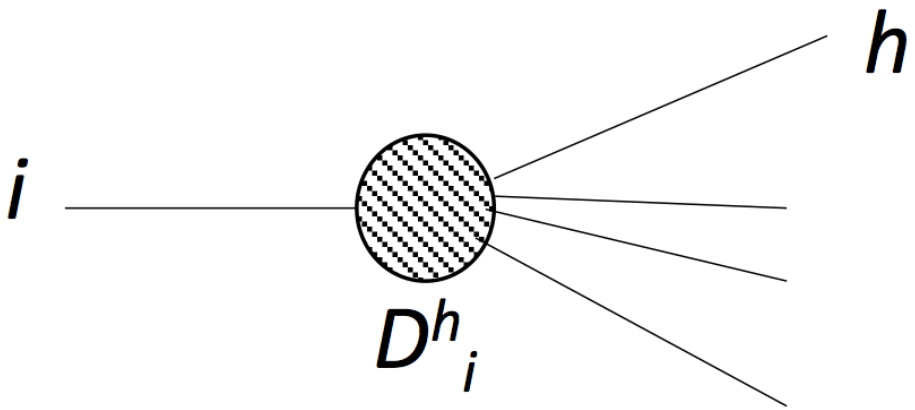
UNIVERSITÄT MAINZ

Fragmentation Functions

- Hadronisation in QCD
- Fragmentation functions D_i^h
- Hadronisation of quark with flavour i to hadron h
- Normalised, universal and process independent
- Favoured and unfavoured FFs
- $D_u^{\pi^+}$ is favoured FF



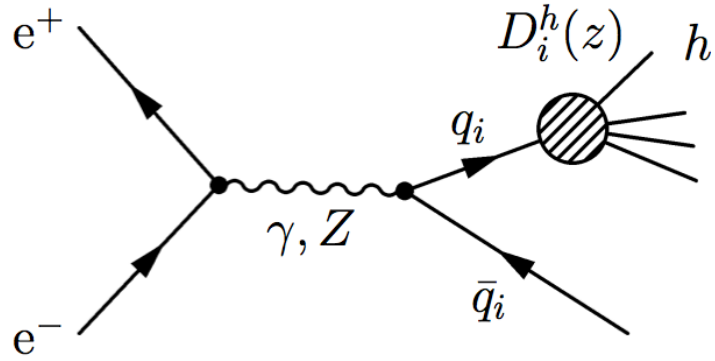
$$\sum_h \int_0^1 z D_i^h(z)\, dz = 1$$

$$D_{fav.} > D_{unfav.}$$

How to Access Fragmentation Functions

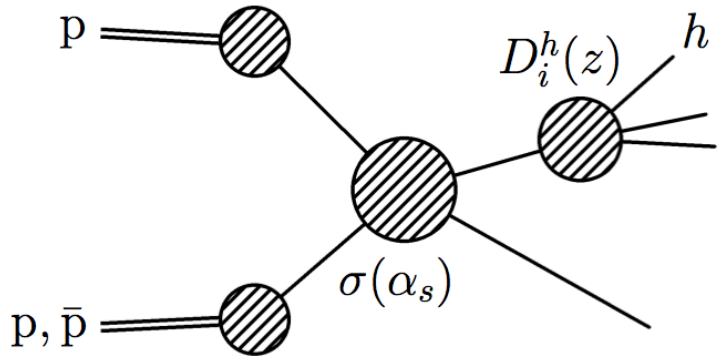
e^+e^- annihilation

Precise and clean data
Only depends on FF
$q\bar{q}$ fragmentation not distinguishable
Charge sum
(LEP, BELLE,...)



pp collision

Gluon FF
Strongly dependant on PDFs
Difficult theoretical description
(RHIC, Fermi Lab., ...)



Fragmentation Functions from SIDIS

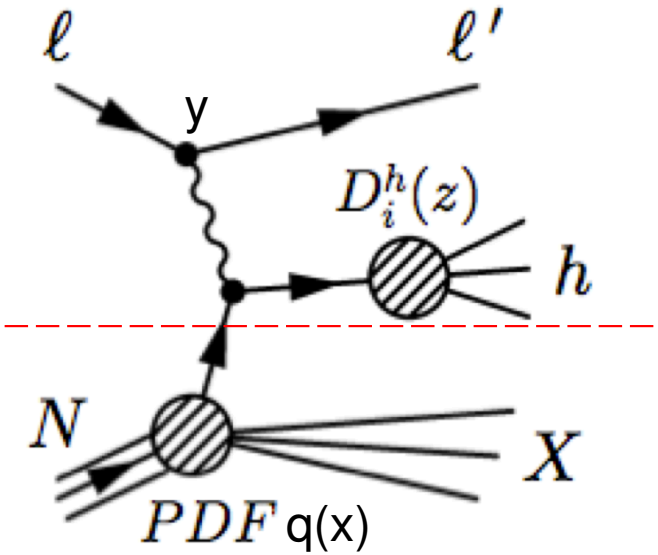
Semi-Inclusive Deep Inelastic Scattering

$$\Rightarrow \ell + N \xrightarrow{\gamma^*} \ell' + h + X$$

Allows flavour separation

Wide coverage in x and Q^2

(COMPASS, HERMES,...)



$$Q^2 \equiv -\mathbf{q}^2 = -(\mathbf{k}-\mathbf{k}') \overset{\text{lab}}{\simeq} 4EE' \sin\frac{\theta}{2}$$

$$x \equiv \frac{Q^2}{2\mathbf{P}\cdot\mathbf{q}} \overset{\text{lab}}{=} \frac{Q^2}{2M\nu}$$

$$y \equiv \frac{\mathbf{P}\cdot\mathbf{q}}{\mathbf{P}\cdot\mathbf{k}} \overset{\text{lab}}{=} \frac{\nu}{E}$$

$$z \equiv \frac{\mathbf{p_h}\cdot\mathbf{P}}{\mathbf{q}\cdot\mathbf{P}} \overset{\text{lab}}{=} \frac{E_h}{\nu}$$

Multiplicities as Observables

- Factorisation theorem
- SIDIS cross section in leading-twist
- in LO pQCD:

Hard scattering cross section
Parton distribution function
Fragmentation functions

$$\sigma^{\mathrm{h}} = \sum_i \sigma^0 \otimes q_i(x) \otimes D_i^h(z)$$

Extraction of FF from hadron multiplicities (LO)

$$M^h(x,z) = \frac{1}{\sigma^{DIS}} \frac{d\sigma^h}{dx\,dz} = \frac{\sum_q e_q^2\, q(x)\, D_q^h(z)}{\sum_q e_q^2\, q(x)}$$

Depends on the unpolarised parton distribution functions q(x)

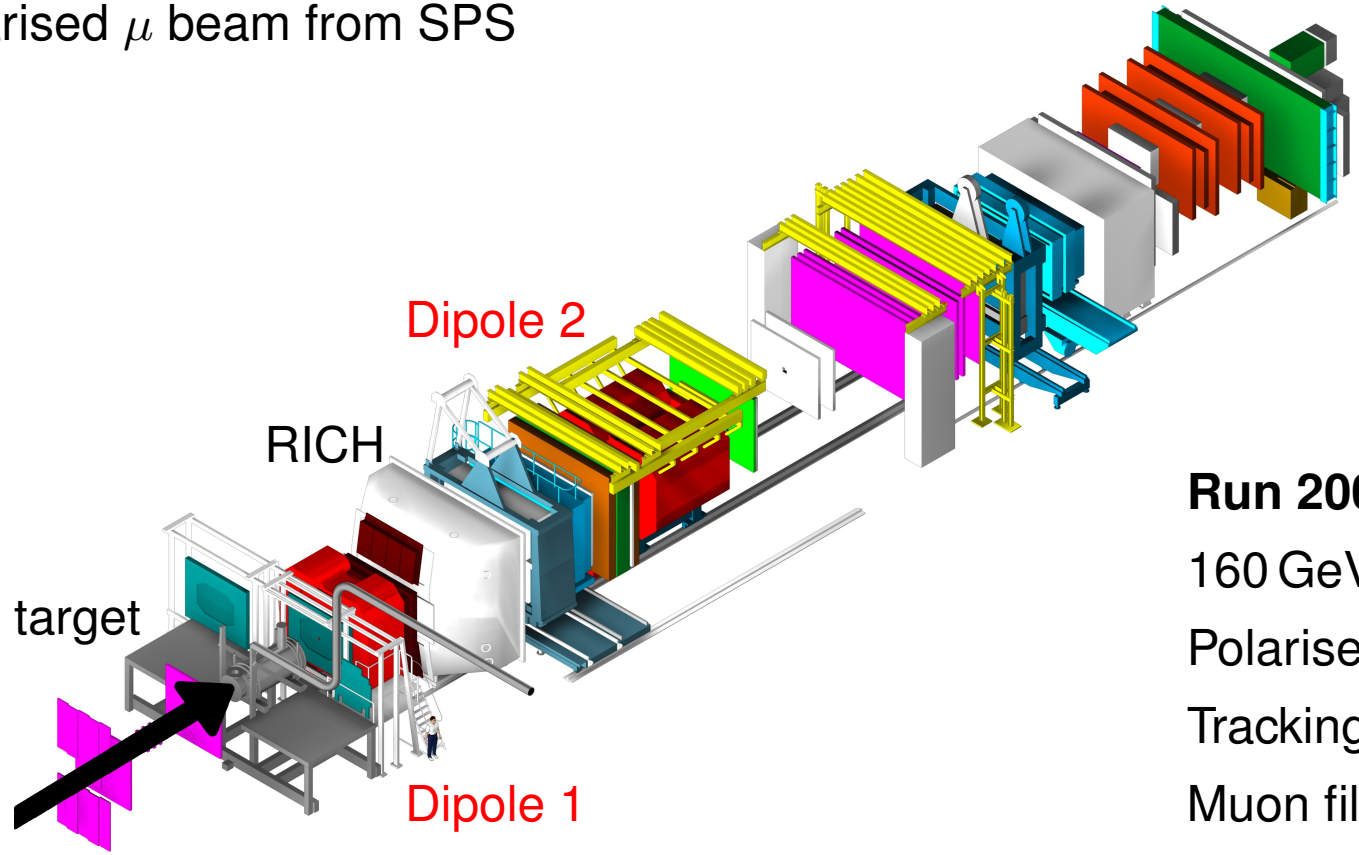
- Unpolarised up/down PDFs well known
- Strange PDFs less well known

The COMPASS Experiment

COmmon **M**uon and **P**roton **A**pparatus for **S**tructure and **S**pectroscopy

Fixed target experiment @CERN

Polarised μ beam from SPS



Run 2006:

160 GeV/c μ^+

Polarised ^{6}LiD target

Tracking

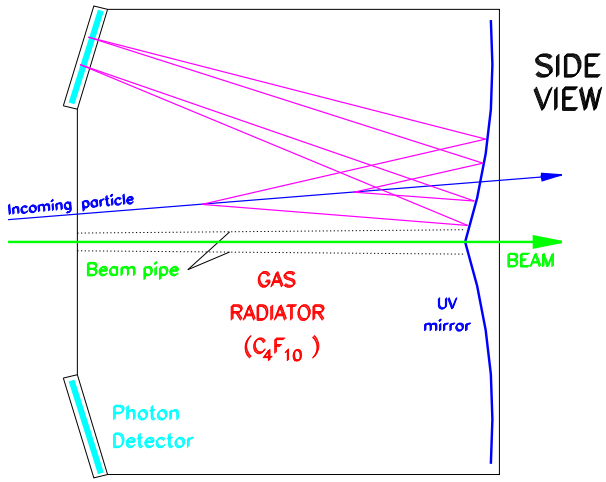
Muon filter for μ' ID

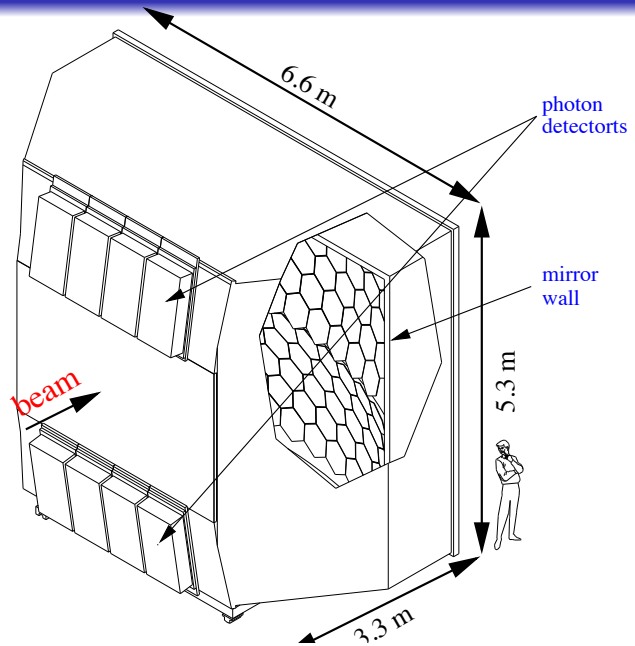
PID with RICH

CERN-PH-EP/2007-001 hep-ex/0703049

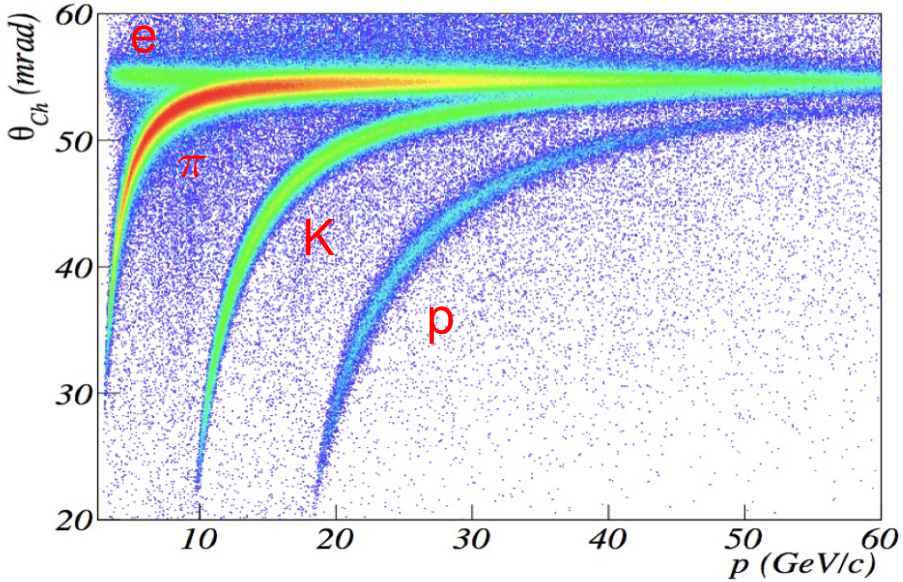
High acceptance, high luminosity and PID

RICH: Kaon and Pion Separation





- C_4F_{10} radiator gas
- 20 m^2 mirror surface with good UV reflectivity
- Photon detection:
  MAPMT and MWPC coated with CsI
- π-K separation from 10 GeV to 40 GeV



Data Set and Multiplicity Extraction

3 weeks of data taking 2006 on ^{6}LiD target
$\approx$ 70M events from "inclusive" triggers

- Inclusive Kinematic cuts:

$Q^2 > 1$ GeV^2
$0.1 < y < 0.7$
$0.004 < x < 0.7$

- Hadron Kinematic cuts:

$0.2 < z < 0.85$
$10 < P_h < 40$ GeV

- Analysis method

3-dimensional binning (x,y,z)
Get raw hadron multiplicities (unidentified and identified)
Correct for apparatus acceptance
Correct for PID efficiencies

Acceptance

Monte Carlo simulation

- Taking into account geometric acceptance of the apparatus
- Detector efficiencies

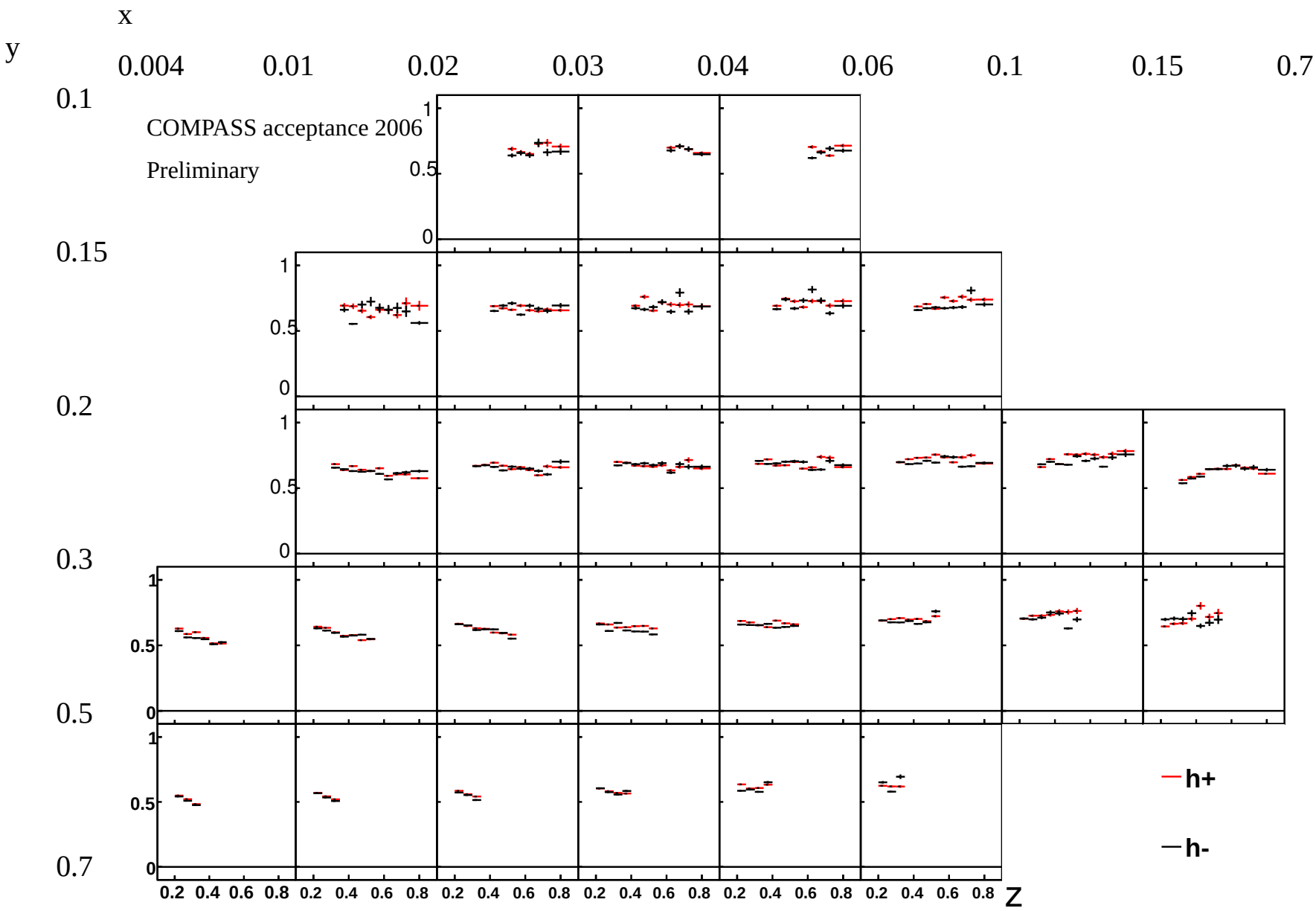
LEPTO generator with PDFs
JETSET for hadronisation
GEANT3 with COMPASS detector models

$$A^h(x, y, z) = \frac{M_r^h(x_r, y_r, z_r)}{M_g^h(x_g, y_g, z_g)}$$

r for reconstructed and g for generated MC
Mult = $\text{Mult}_{\text{obs}}/\text{A}^h$

LEPTO extrapolation:
Not all bins are completly filled (cuts)
Fill up with LEPTO model

Acceptance Correction for Unidentified Hadrons



Correction and Uncertainties

Radiative Corrections
QED radiative effects with TERAD

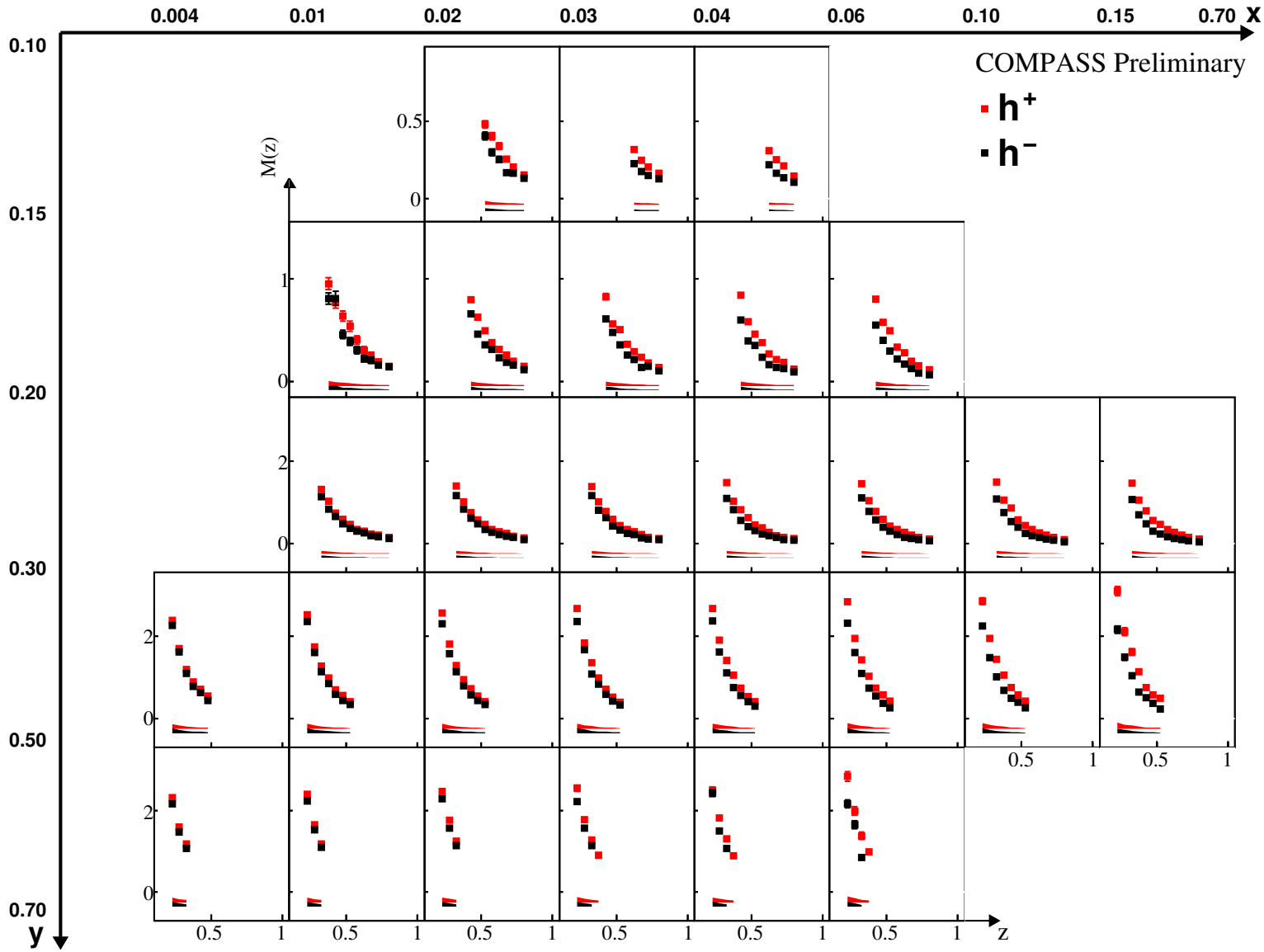
Sov. J. Nucl. Phys **26** (1977) 660

Muon dependent systematics
Muon acceptance and systematic uncertainties cancel out

MC model dependence
Using different quark fragmentation models in JETSET
Different parton distribution functions in LEPTO
$\approx 5\%$

LEPTO dependence
Effects in smaller and larger z region
Only using bins where LEPTO contribution is small (<10%)
Small systematic uncertainty

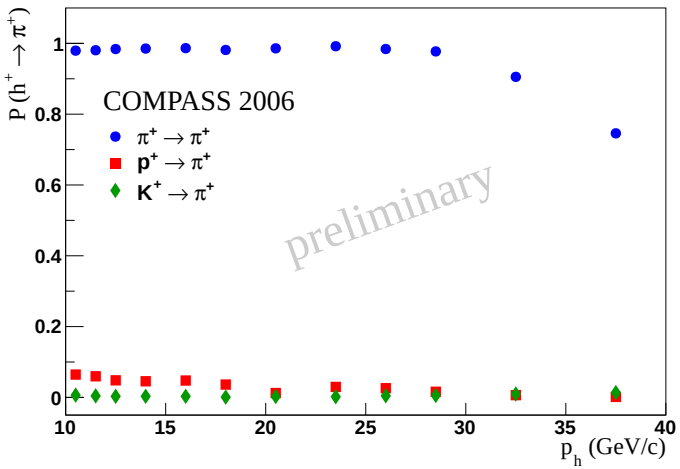
Unidentified Hadron Multiplicities $M^{h^{\pm}}(x, y, z)$



RICH Unfolding

Experimental method to extract RICH efficiencies and missidentification
Tagging hadrons from known decays

$\Lambda^0 \to p + \pi^-$ for protons, $K^0_s \to \pi^+ + \pi^-$ for pions and $\phi \to K^+ + K^-$ for kaons

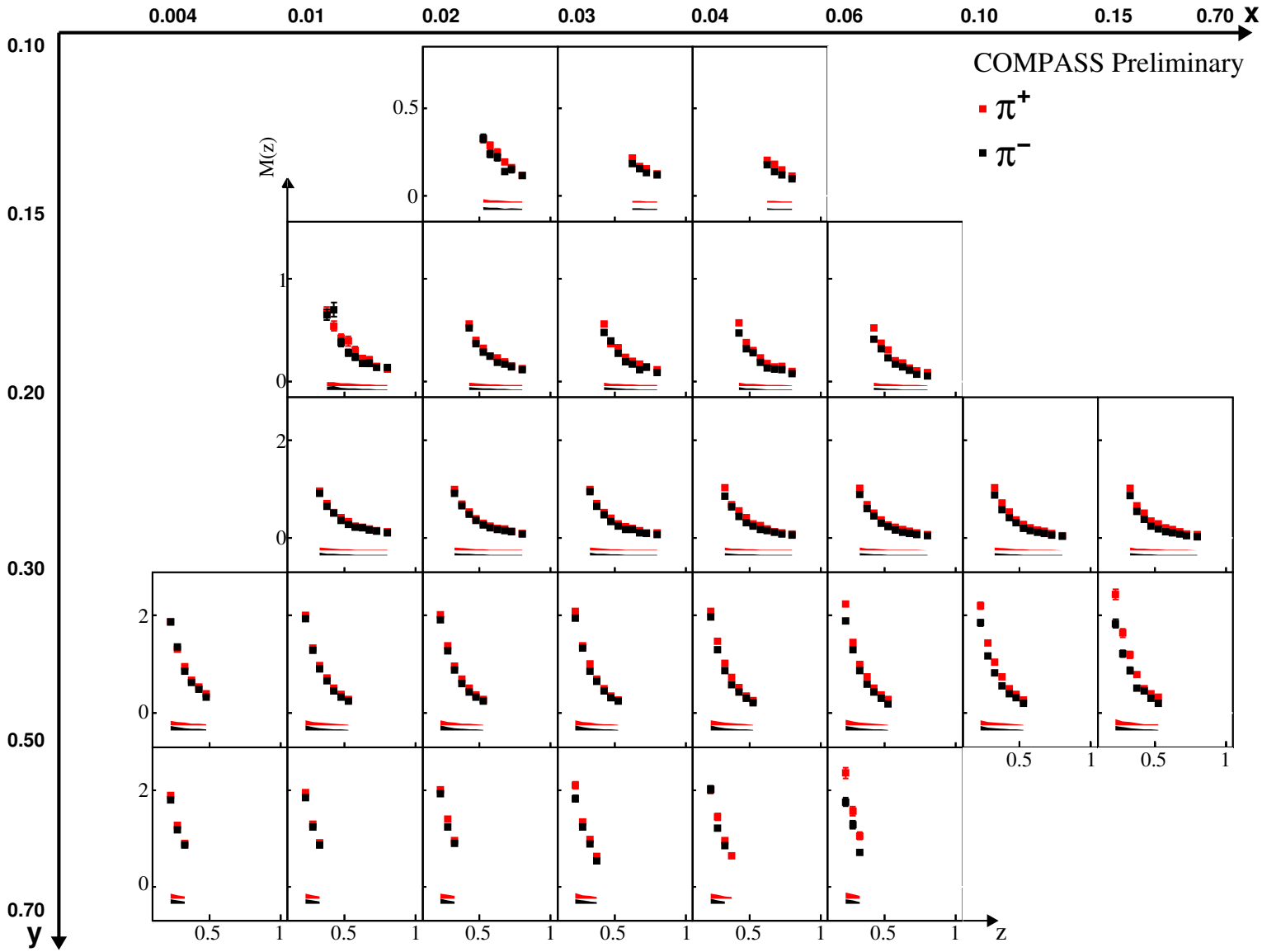


$$\begin{pmatrix} I_\pi \\ I_K \\ I_p \end{pmatrix} = \begin{pmatrix} P^\pi_\pi & P^\pi_K & P^\pi_p \\ P^K_\pi & P^K_K & P^K_p \\ P^p_\pi & P^p_K & P^p_p \end{pmatrix} \begin{pmatrix} T_\pi \\ T_K \\ T_p \end{pmatrix}$$

$$\vec{T} = \vec{I} \cdot P^{-1}$$

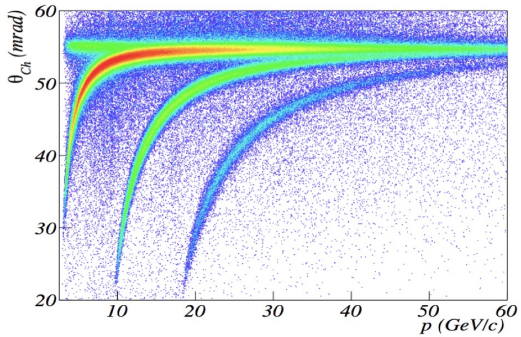
Systematics:
1% - 3% for pions
5% - 10% for kaons

Pion Multiplicities $M^{\pi^{\pm}}(x, y, z)$



Electron Contamination

Electron missidentified as pion
Using RD and LEPTO MC



3-8 GeV/c: electron - pion separation possible

Compare MC/RD for contamination
MC is reasonable
Systematic 25 %

10-40 GeV/c: analysis momentum range

Use MC to extract contamination

5 % for low z and bellow 1 % for high z

Diffractive ρ Contribution

Production of exclusive vector meson $\rightarrow$ production of lighter mesons

$$\gamma^* p \rightarrow \rho^0 p \rightarrow p\pi^+\pi^- \text{ exclusive}$$

$$\gamma^* p \rightarrow \rho^0 N^*(\Delta) \rightarrow \pi^+\pi^- X \text{ diffractive dissociation}$$

Method

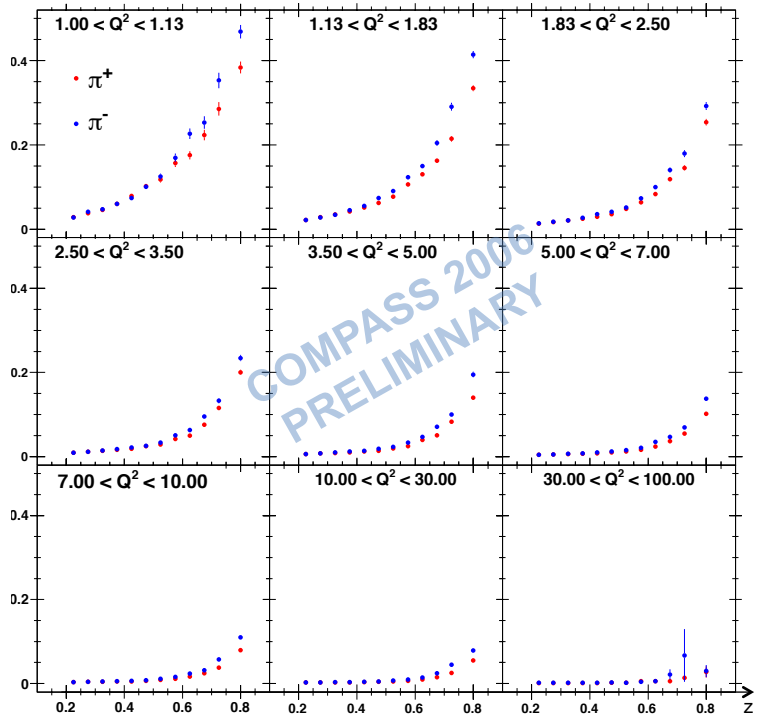
Two MC data sets (LEPTO, HEPGEN)

$\alpha_{\rho^0}^{\pi^\pm}$ fraction of $\pi^\pm$ from ρ^0

$\beta_{DIS}^{\rho^0}$ fraction of ρ^0 event of DIS events

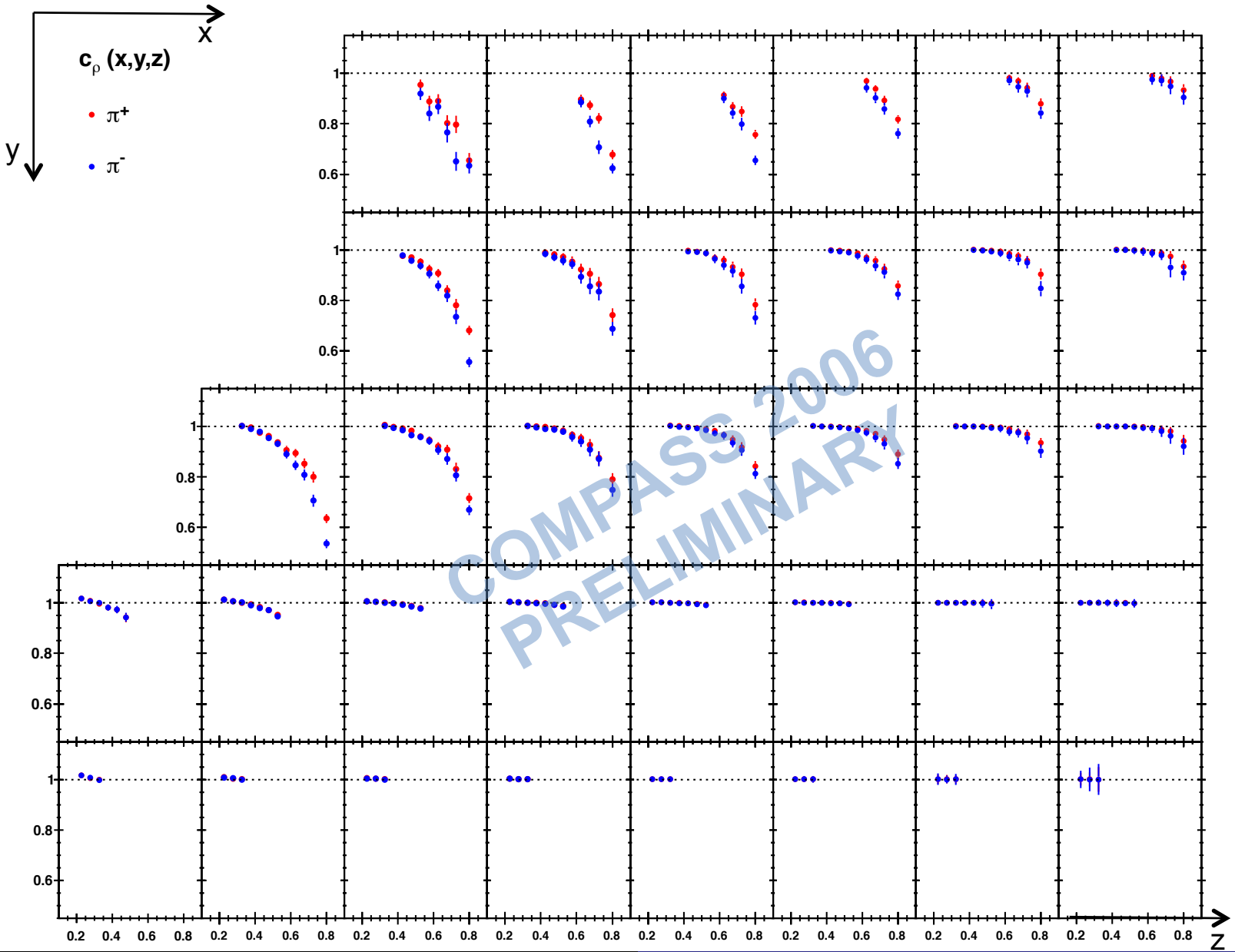
$c_\rho = \frac{1-\alpha}{1-\beta}$ multiplicity correction factor

HEPGEN: A. Sandacz, P. Sznajder, arXiv:1207.0333 [hep-ph]
LEPTO: G. Ingelman, Comput.Phys.Commun. **101** (1997) 108

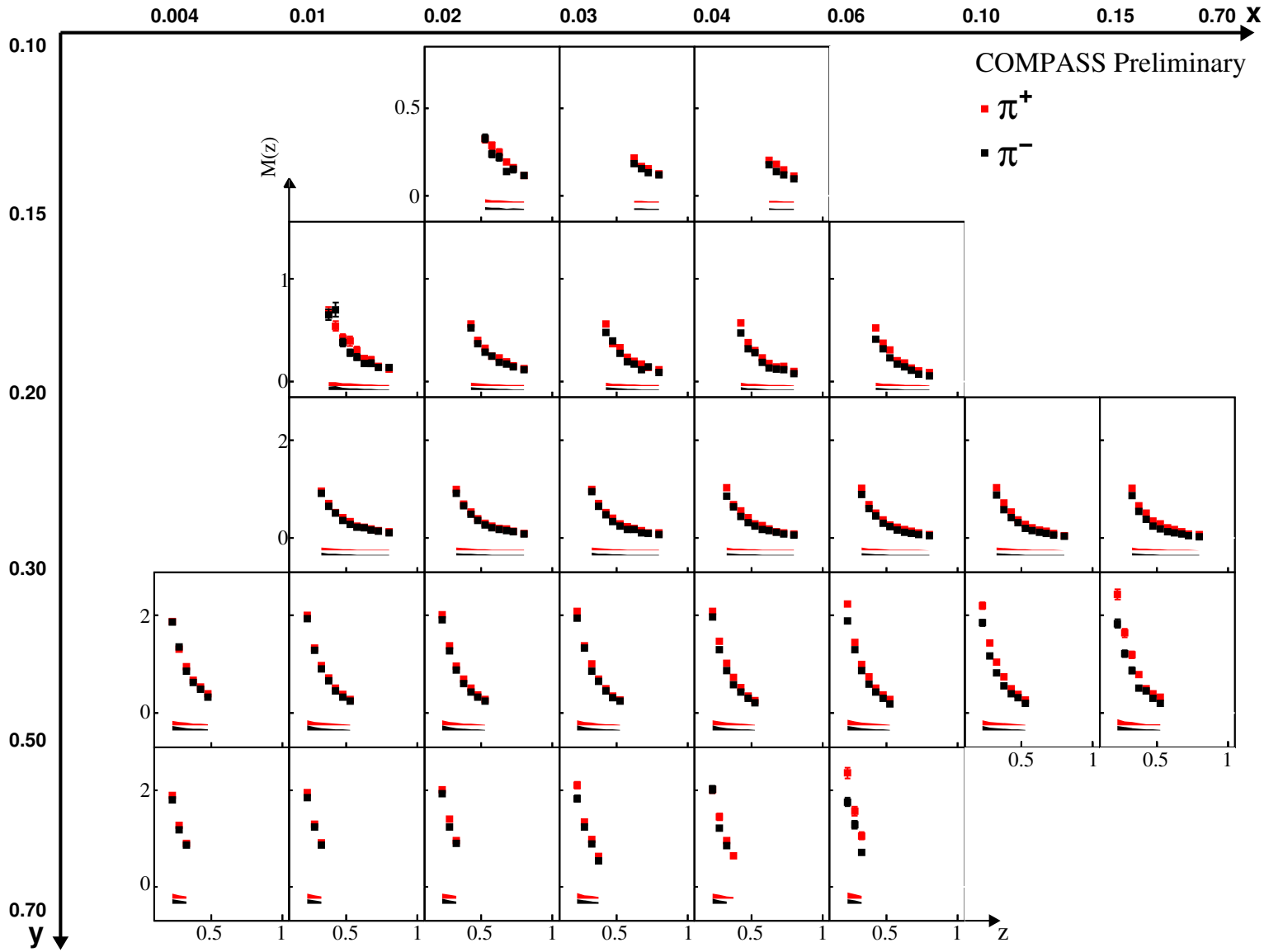


Fraction of $\pi^\pm$ from ρ^0

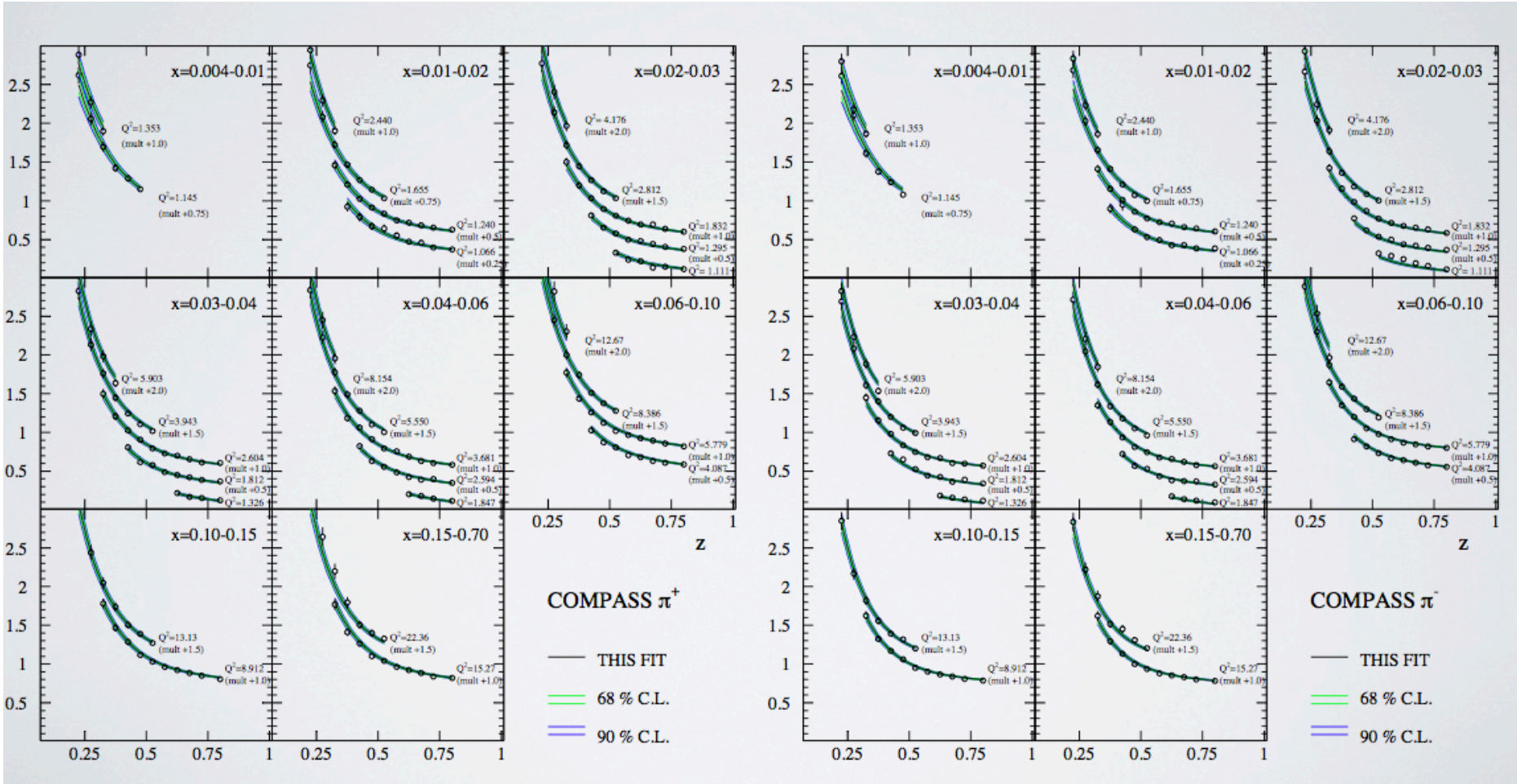
ρ Correction



Reminder: Pion Multiplicites $M^{\pi^{\pm}}(x, y, z)$



COMPASS data vs. DSS



Talk from R. Sassot
Indiana-Illinois Workshop on Fragmentation Functions
Bloomington (December 12-14, 2013)

Extraction of Fragmentation Functions

χ^2 Fit on experimental multiplicities
Fit at Q_0^2 and evolution to all Q^2 with DGLAP
From charge and isospin symmetry of isoscalar target (^{6}LiD):

$$D_{\text{fav}} = D_u^{\pi^+} = D_{\bar{d}}^{\pi^+} = D_d^{\pi^-} = D_{\bar{u}}^{\pi^-}$$

$$D_{\text{unf}} = D_d^{\pi^+} = D_{\bar{u}}^{\pi^+} = D_u^{\pi^-} = D_{\bar{d}}^{\pi^-} = D_s^{\pi^\pm} = D_{\bar{s}}^{\pi^\pm}$$

$$M(\pi^+) = \frac{(4(u+d)+\bar{u}+\bar{d})D_{\text{fav}} + (u+d+4(\bar{u}+\bar{d})+2(s+\bar{s}))D_{\text{unf}}}{5(u+d+\bar{u}+\bar{d})+2(s+\bar{s})}$$

$$M(\pi^-) = \frac{(u+d+4(\bar{u}+\bar{d}))D_{\text{fav}} + (4(u+d)+\bar{u}+\bar{d}+2(s+\bar{s}))D_{\text{unf}}}{5(u+d+\bar{u}+\bar{d})+2(s+\bar{s})}$$

with u, d, $\bar{u}$, $\bar{d}$, s, and $\bar{s}$ as respective parton distribution functions (MSTW08)

Functional Form

$$zD_{\text{fav}} = zD_{\text{unf}} = \mathcal{N} z^\alpha (1-z)^\beta [1+\gamma(1-z)^\delta]$$

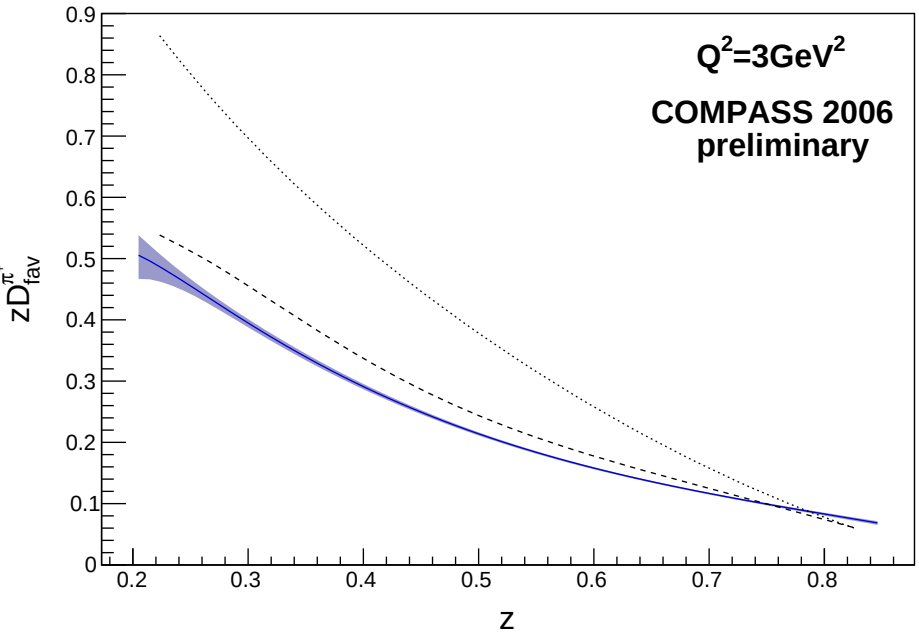
$$zD_{\text{g}} = \mathcal{N} z^\alpha \exp(-\beta z)$$

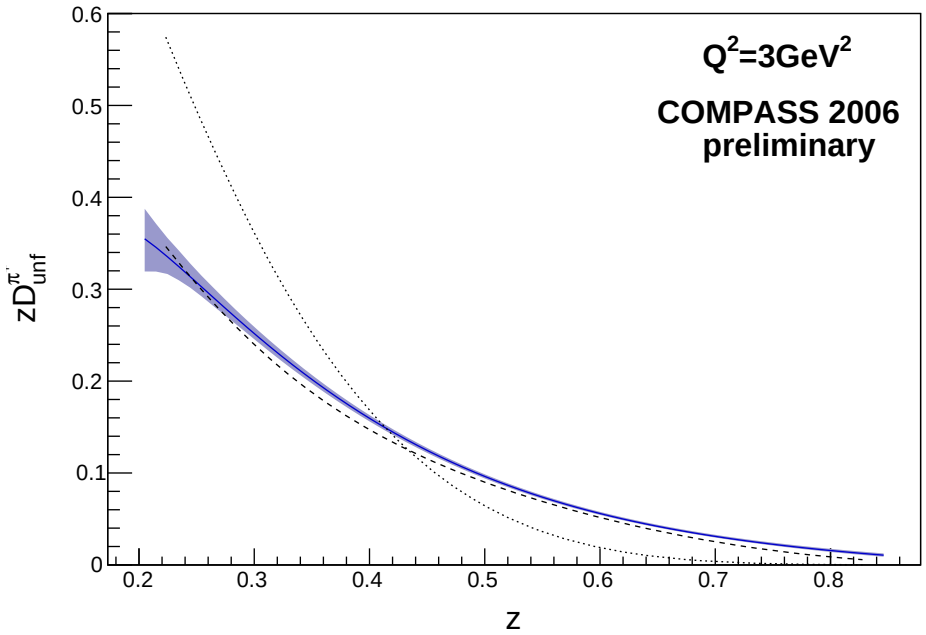
Fit result of FF with ρ Correction

COMPASS fit

DSS D. de Florian, Phys. Rev. **D75** (2007)

HKNS Hirai et al. ,Phys. Rev. **D75** (2007)





- COMPASS data fit with statistical error only
- Poor agreement with HKNS
- Good agreement with DSS
- ρ correction contributes at high z (>0.7)

Summary and Outlook

- 2006 run at COMPASS with ^{6}LiD target and 160 GeV μ^+ beam
- Measured high statistic pion multiplicities in x, z, and y bins
- Correction for electron and diffractive ρ contribution

Outlook: Kaon Multiplicities

Detailed investigation of RICH ongoing
More MC statistic
K^0_s multiplicities soon

Outlook: Proton Target

Short run in 2012
Data on liquid hydrogen
> 2015 long runs

Thanks for your attention

Backup: Kaon Multiplicities $M^{K^{\pm}}(x, y, z)$