Pion and Kaon multiplicities at COMPASS to extract quark Fragmentation Functions

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On behalf of the COMPASS Collaboration

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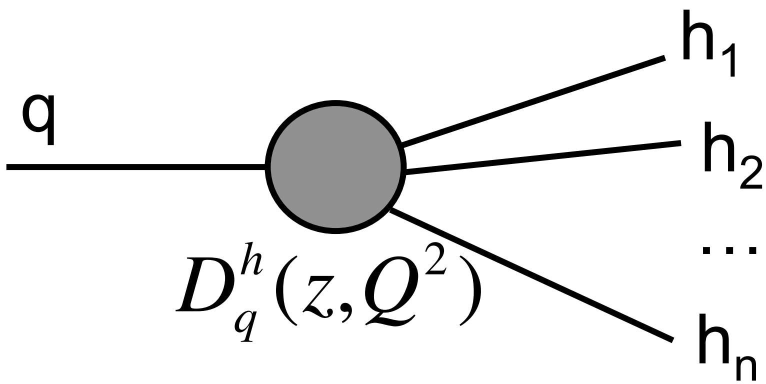
Outline

- Fragmentation Functions
- Semi-inclusive deep inelastic scattering and hadron multiplicities
- The COMPASS experiment at CERN
- Extraction of multiplicities
- LO fits of quark Fragmentation Functions into Pions
- Conclusion and outlook

Fragmentation Functions in pQCD



$$D_q^h(z,Q^2)$$

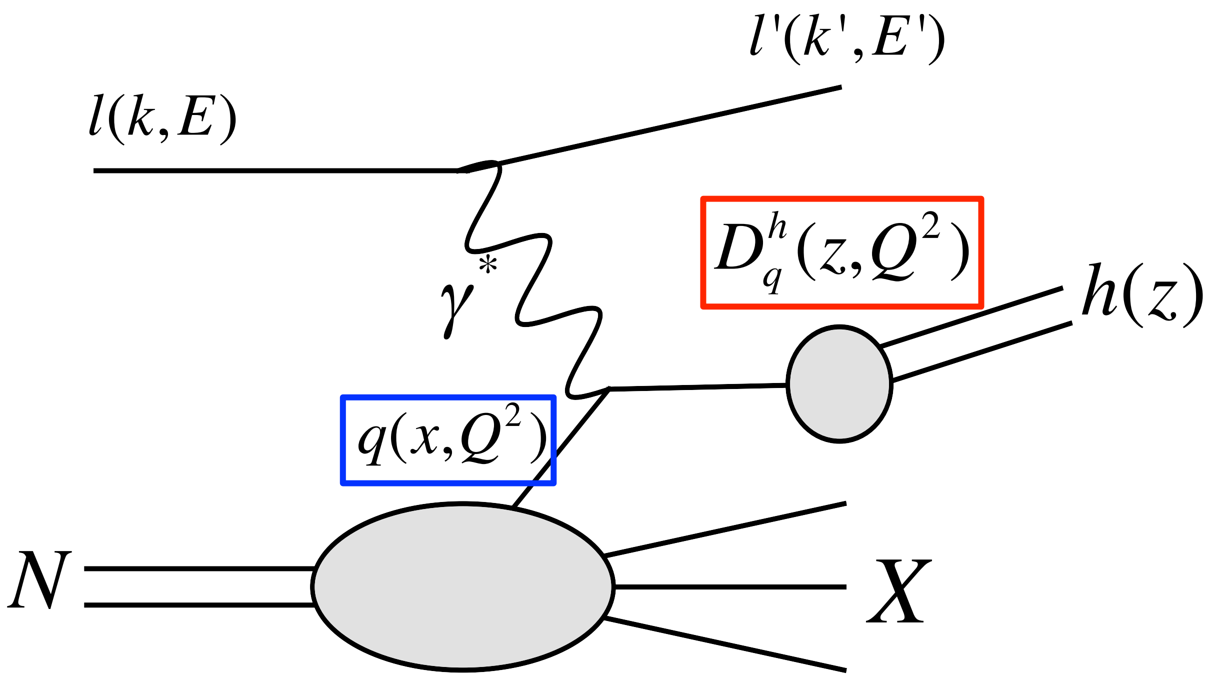
$$z = \frac{E_h}{E_q}$$

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

- Fragmentation Functions (FFs) $D_q^h(z,Q^2)$: describe hadronisation of a parton *q* into a final-state hadron *h* carrying an energy fraction *z*, at a given Q^2
- Universal (process independent)
- Motivations :
  - single hadron production in various processes (p/p, e^+/e^-)
  - flavour dependence of hard processes (direct measurements)

SIDIS to access quark Fragmentation Functions

- Semi-inclusive deep inelastic scattering (SIDIS)



$$Q^2 = -(k-k')^2$$

$$x = \frac{Q^2}{2M(E-E')}$$

$$y = \frac{E-E'}{E}$$

$$z = \frac{E_h}{E-E'}$$

- Advantages for extraction of quark Fragmentation Functions :
  - Flavour separation
  - Charge separation

Hadron multiplicities

- SIDIS cross-section :

$$\sigma^h = \sum_q \sigma^0 \otimes q(x,Q^2) \otimes D_q^h(z,Q^2)$$

hard scattering — PDFs — quark Fragmentation Functions

- PDFs known ⟶ access to Fragmentation Functions

- **Hadron multiplicities** as observable :
  - Average number of hadrons produced per DIS events at a given kinematics

$$M^h(x,Q^2,z) = \frac{1}{\sigma_{DIS}} \frac{d\sigma^h}{dx\, dz\, dQ^2}$$

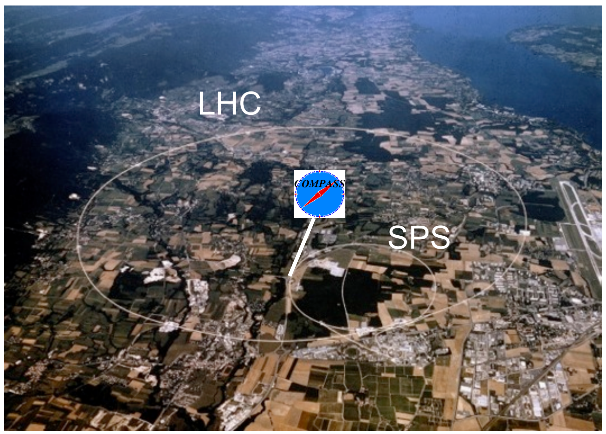
  - LO :

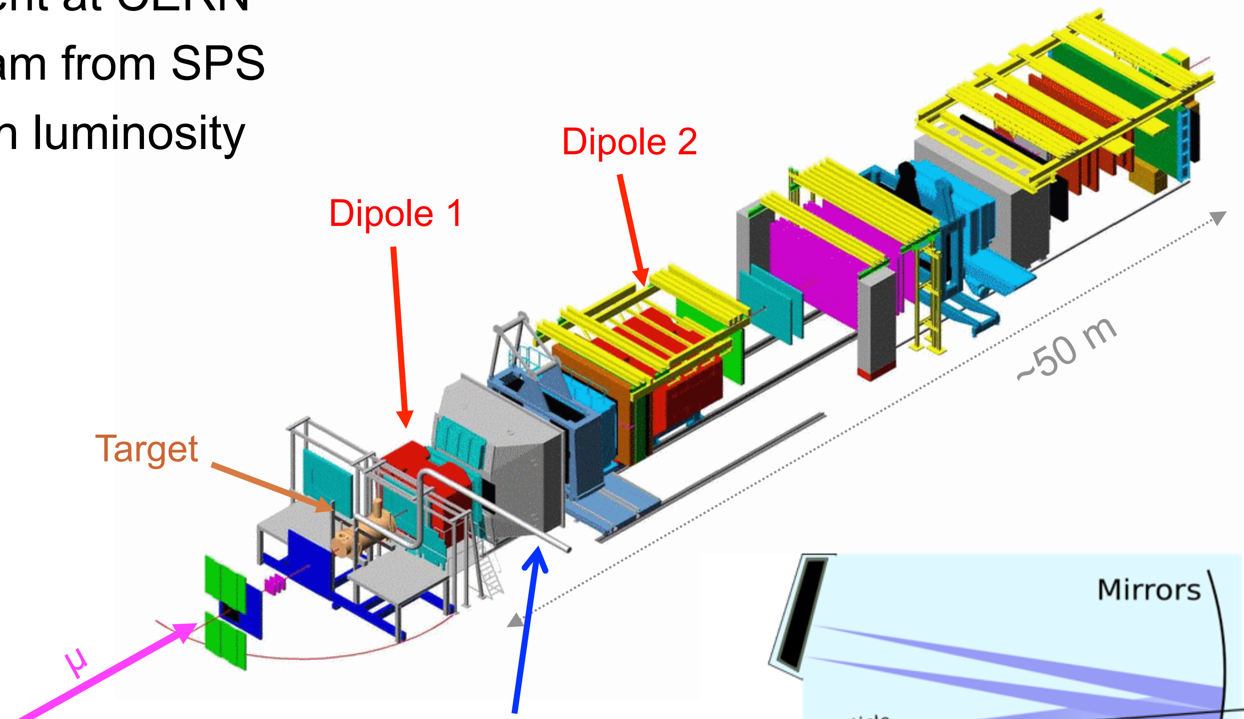
$$M^h(x,Q^2,z) = \frac{\sum_q e_q^2 q(x,Q^2) D_q^h(z,Q^2)}{\sum_q e_q^2 q(x,Q^2)}$$

The COMPASS experiment at CERN

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

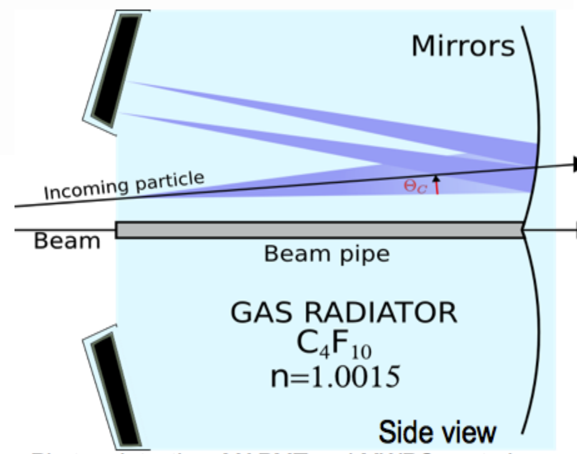
- Fixed target experiment at CERN
- μ (polarised) or π beam from SPS
- High acceptance, high luminosity





RICH

- PID
- K/π separation 10-40 GeV/c



Photon detection: MAPMT and MWPC coated with CsI

2006 run :

- μ^+ 160 GeV/c
- isoscalar target (^{6}LiD)

Data analysis and hadron multiplicity extraction

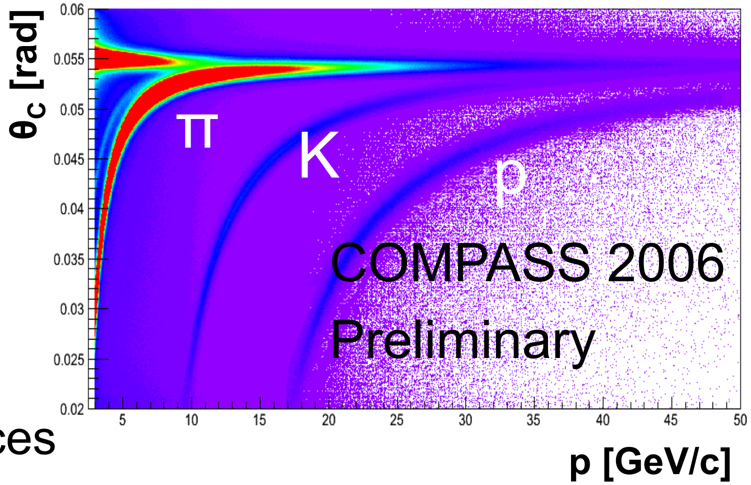
- 3 weeks of data taking on ^{6}LiD target (1/4 of 2006 data)
  - 70 M inclusive triggers

- **Kinematic cuts** :
  - *Inclusive* :
    - $Q^2 > 1$ GeV^2/c^2
    - $0.1 < y < 0.7$
    - $0.004 < x < 0.7$
  - *Hadrons* :
    - $0.2 < z < 0.85$
    - $10 < p_h < 40$ GeV/c

- **Analysis** :
  - 3 dimensional kinematic binning (x, y, z) ($\langle Q^2 \rangle$ evaluated for each bin)
  - Measurement of raw multiplicities (identified and unidentified hadrons)
  - Correction for :
    - RICH particle identification inefficiency
    - Apparatus acceptance
    - Electron contamination (pion multiplicities only)
    - Diffractive ρ^0 and ϕ contamination

RICH PID efficiency

- RICH identification not perfect
- Efficiency determined from data by comparing well identified π, K and p to RICH response :
  - pions : $K_S^0 \rightarrow \pi^+ + \pi^-$
  - kaons : $\Phi \rightarrow K^+ + K^-$
  - protons : $\Lambda^0 \rightarrow p + \pi^-$



- Efficiencies stored in RICH performance matrices (in 12 momentum and 2 angle bins)

$$\begin{pmatrix} I_\pi \\ I_K \\ I_p \end{pmatrix} = \begin{pmatrix} \varepsilon_\pi^\pi & \varepsilon_K^\pi & \varepsilon_p^\pi \\ \varepsilon_\pi^K & \varepsilon_K^K & \varepsilon_p^K \\ \varepsilon_\pi^p & \varepsilon_K^p & \varepsilon_p^p \end{pmatrix} \begin{pmatrix} T_\pi \\ T_K \\ T_p \end{pmatrix}$$

identification probability (green circles)

misidentification probability (red circles)

$\vec{T}$ **true numbers of hadrons**

$\vec{I}$ **numbers of hadrons identified by the RICH**

Correction of data by inverting the matrices : $\vec{T} = \vec{I} \cdot \varepsilon^{-1}$

Acceptance

Correction for apparatus geometric acceptance and detector efficiencies

Monte Carlo Simulation :

LEPTO Event Generation (MSTW08) → **JETSET** Hadronisation → **GEANT3** Apparatus description → Data Reconstruction software

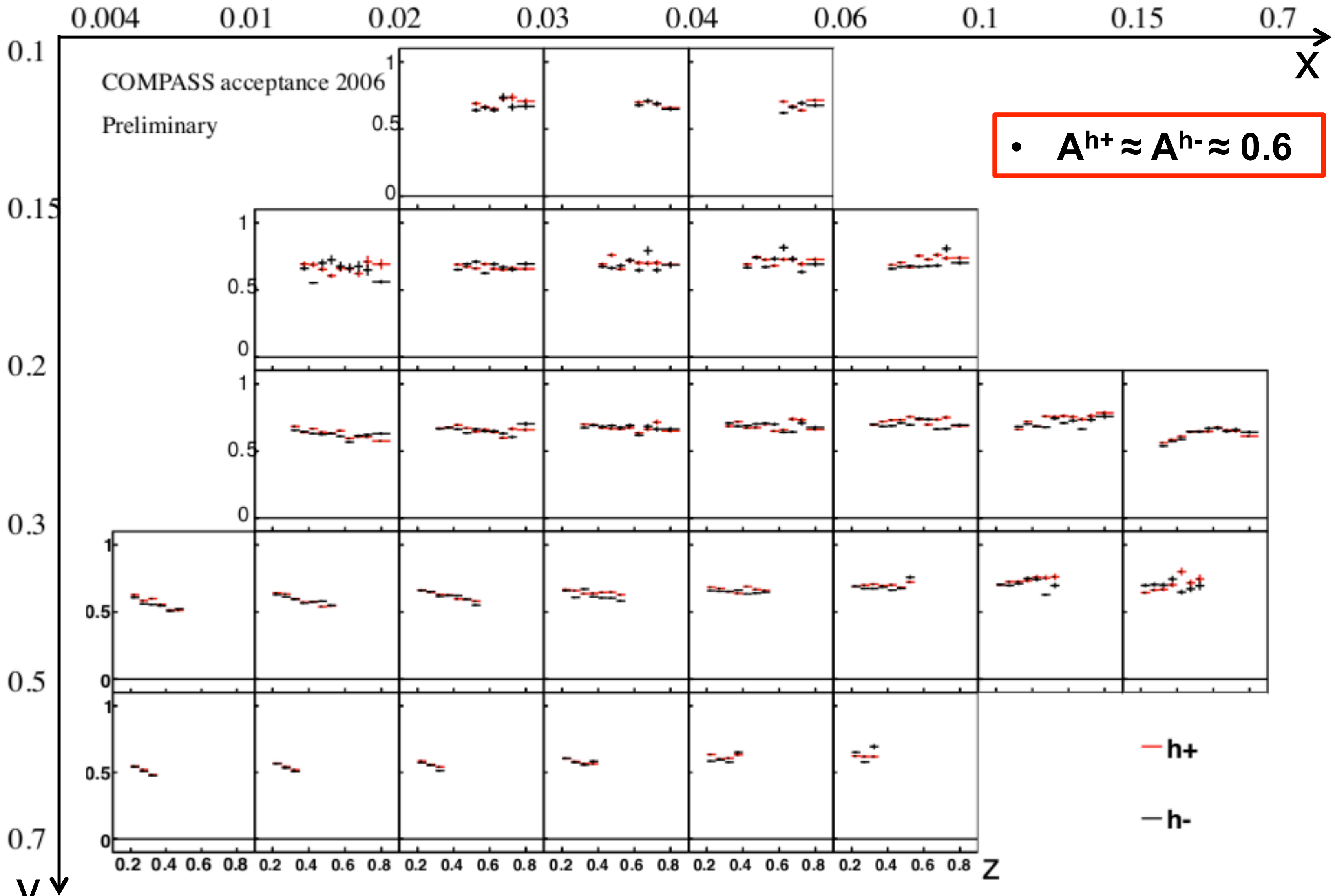
$$A^{h}(x,y,z) = \frac{M_{r}^{h}(x,y,z)}{M_{g}^{h}(x,y,z)}$$

$M_{r}^{h}(x,y,z)$ ← Reconstructed : same geometric and kinematic cuts as real data

$M_{g}^{h}(x,y,z)$ ← Generated : only kinematic cuts

$$h = h^{+}, h^{-}, \pi^{+}, \pi^{-}, K^{+}, K^{-}$$

Acceptance for $h^{+/-}$

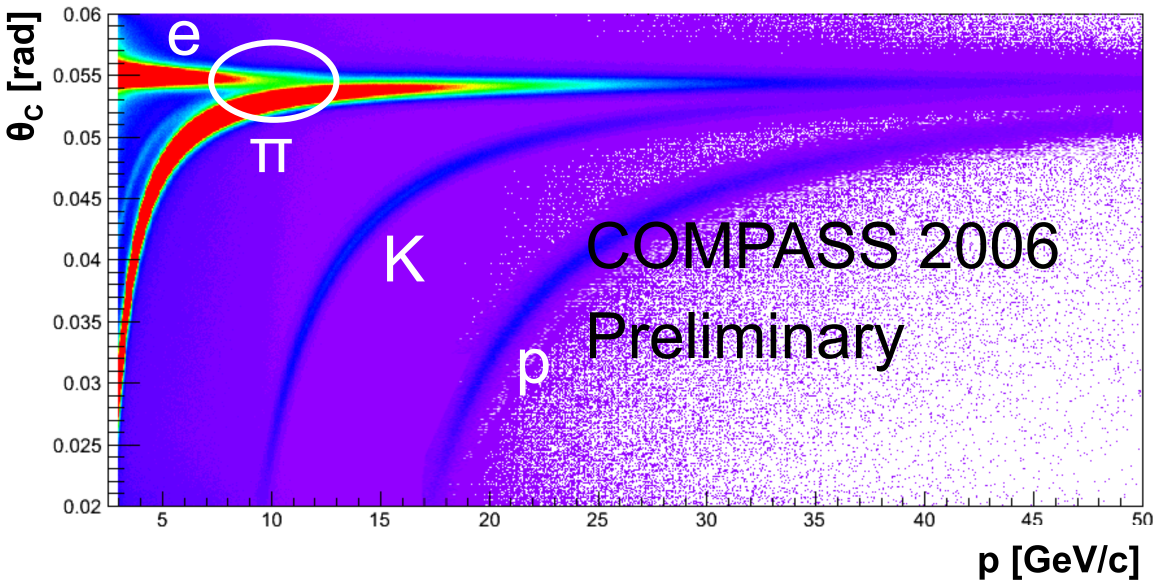


- $A^{h+} \approx A^{h-} \approx 0.6$

Electron contamination of pion sample

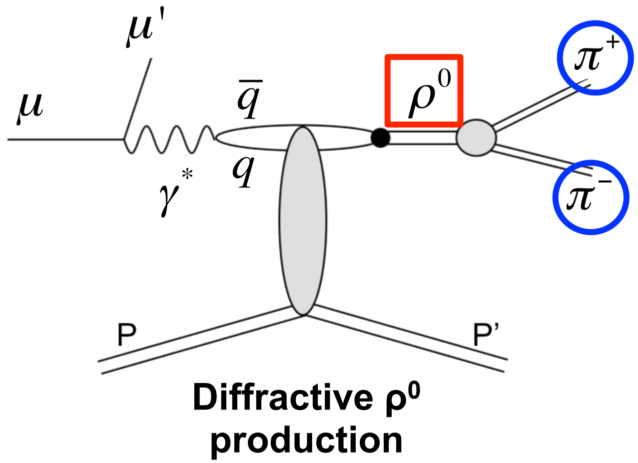
Electrons can be misidentified as pions

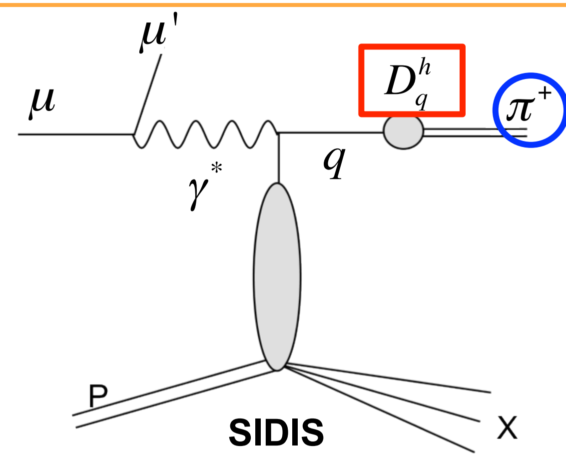
- 3 - 8 GeV/c :
  - e/π separation possible
  - difference MC/data 25 %
- 10 - 40 GeV/c (analysis range) :
  - Contamination evaluated by MC
  - 50 % systematic uncertainty



Correction of pions yields : <1% (high z) to 5% (low z)

Correction for decay of diffractive vector mesons





- Presence of K and π from diffractive vector mesons in the data
- No quark hadronisation ⟶ violation of Fragmentation Function universality if hadron multiplicities include them ?
- Main channels : $\gamma^* N \rightarrow \rho^0 N \rightarrow \pi^+ \pi^- N$

  $\gamma^* N \rightarrow \Phi N \rightarrow K^+ K^- N$
- Single K and π not distinguishable from SIDIS hadrons in the data

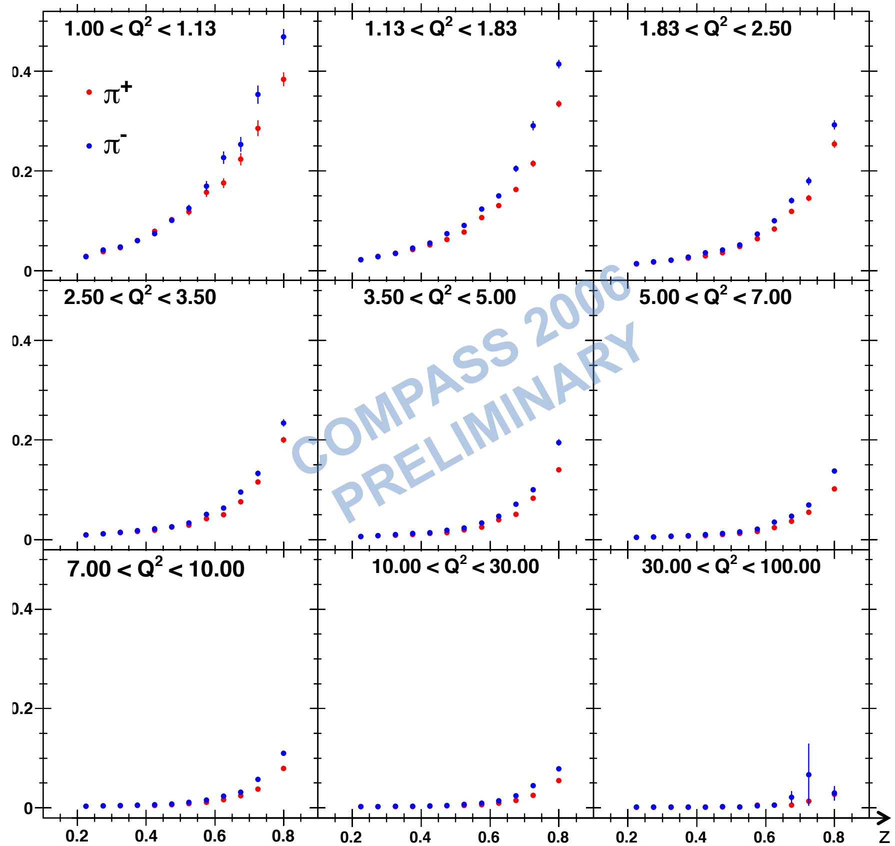
Correction for decay of diffractive vector mesons

- Monte Carlo study using 2 generators :
  - HEPGEN : diff. ρ^0 and ϕ samples
  - LEPTO : SIDIS sample

  - Correction of measured hadron and inclusive event yields :

  - Average contribution is low (few %), but high in certain bins :
    - **max ~40% for π (high z, low Q^2)**
    - **max ~25% for K (z~0.6, low Q^2)**

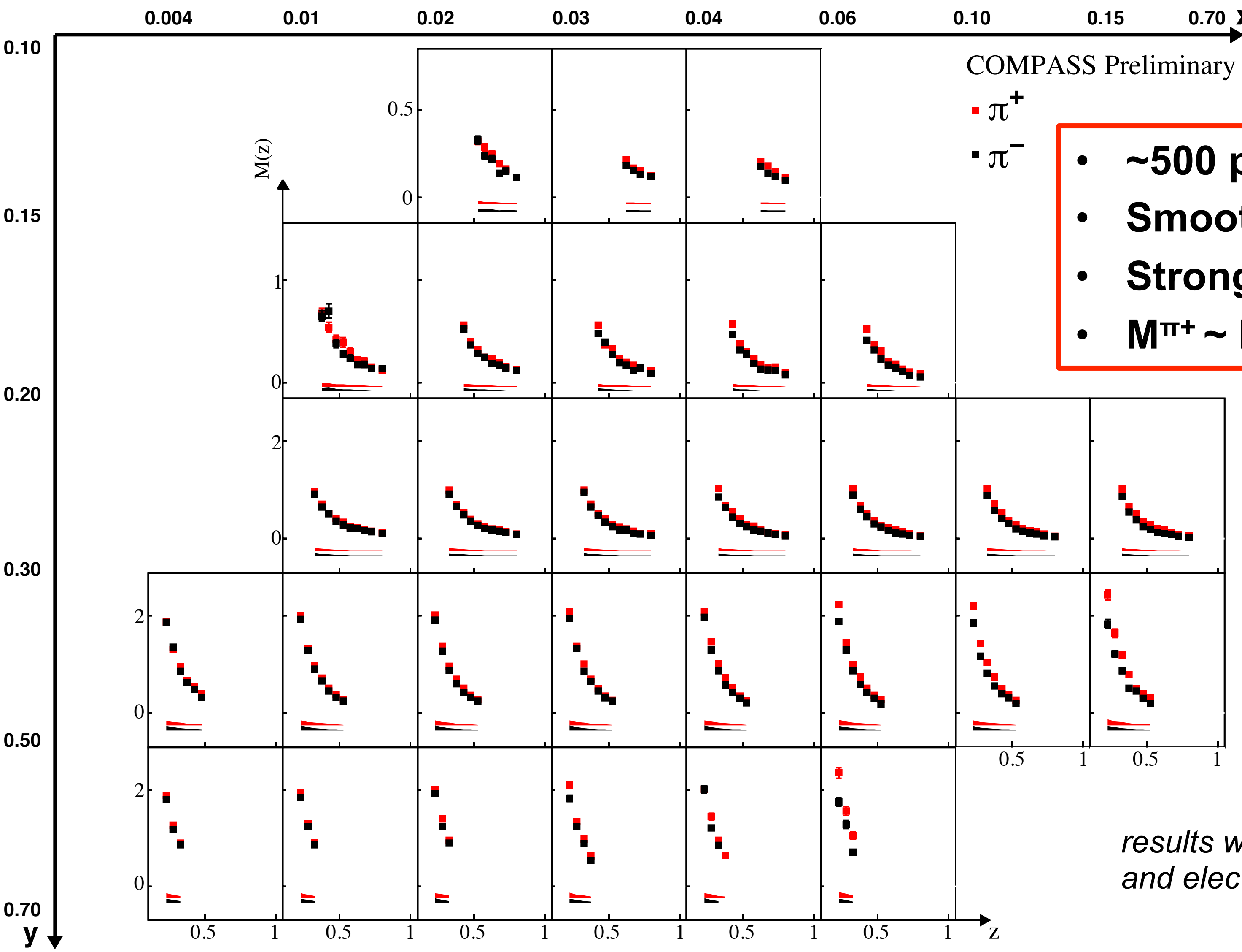
- Data published with and without correction



Fraction of π from diffractive ρ^0

HEPGEN : A. Sandacz and P. Sznajder - *arXiv:1207.0333 [hep-ph]*

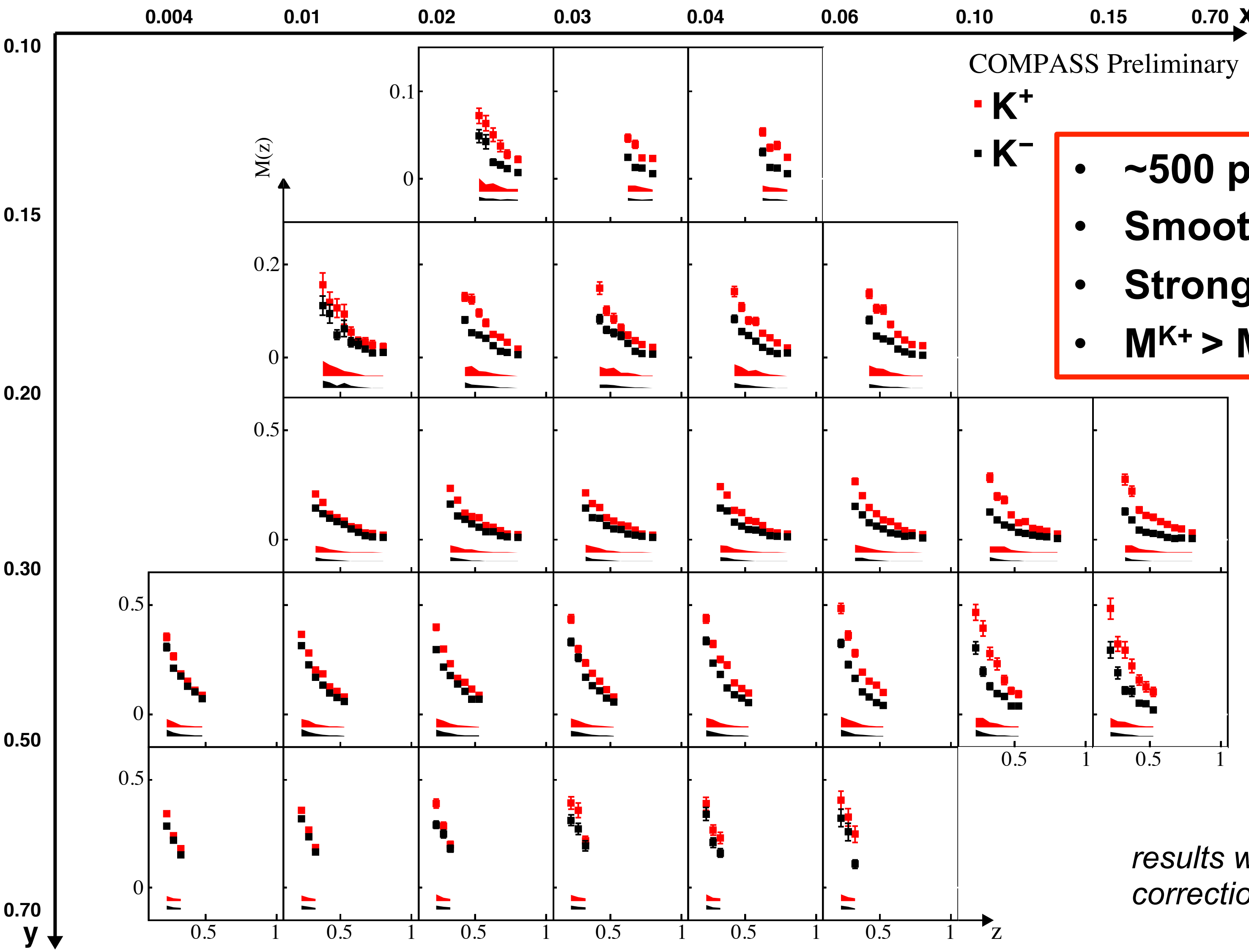
Pion multiplicities



- **~500 points**
- **Smooth**
- **Strong *z* dependence**
- **$M^{\pi^+} \sim M^{\pi^-}$**

results without diff. VM and electron corrections

Kaon multiplicities



- ~500 points
- Smooth
- Strong *z* dependence
- $M^{K+} > M^{K-}$

results without diff. VM correction

Extraction of quark FF into Pions

- Charge and isospin symmetry gives :

$$D_u^{\pi^+} = D_{\bar{d}}^{\pi^+} = D_d^{\pi^-} = D_{\bar{u}}^{\pi^-} = D_{fav}(z,Q^2)$$

$$D_d^{\pi^+} = D_{\bar{u}}^{\pi^+} = D_{\bar{d}}^{\pi^-} = D_u^{\pi^-} = D_{unf}(z,Q^2)$$

$$D_{fav}(z,Q^2) > D_{unf}(z,Q^2)$$

- Strangeness always unfavoured : $D_s^{\pi^\pm} = D_{\bar{s}}^{\pi^\pm} = D_{unf}(z,Q^2)$

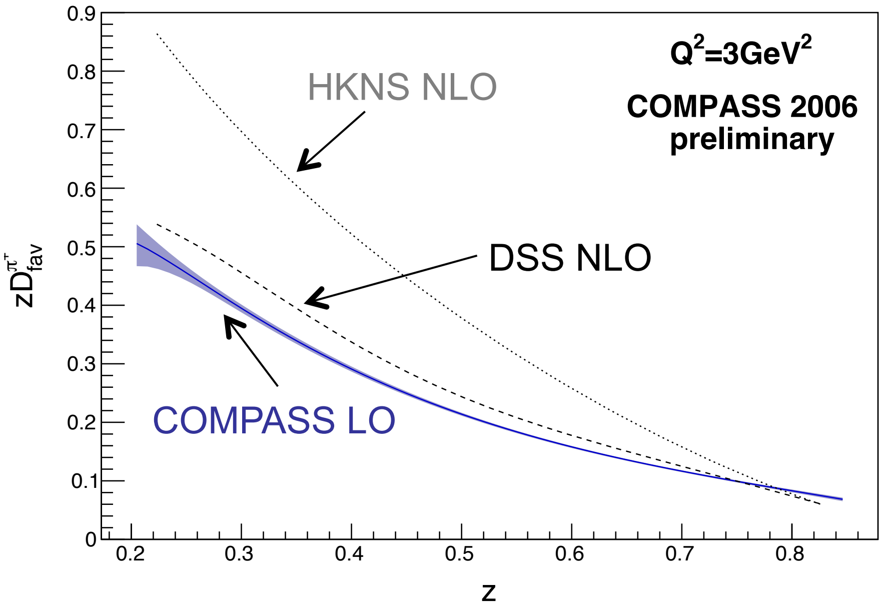
$$M^{\pi^+}(x,Q^2,z) = \frac{(4(u+d)+\bar{u}+\bar{d})D_{fav} + (u+d+4(\bar{u}+\bar{d})+2(s+\bar{s}))D_{unf}}{5(u+d+\bar{u}+\bar{d})+2(s+\bar{s})}$$

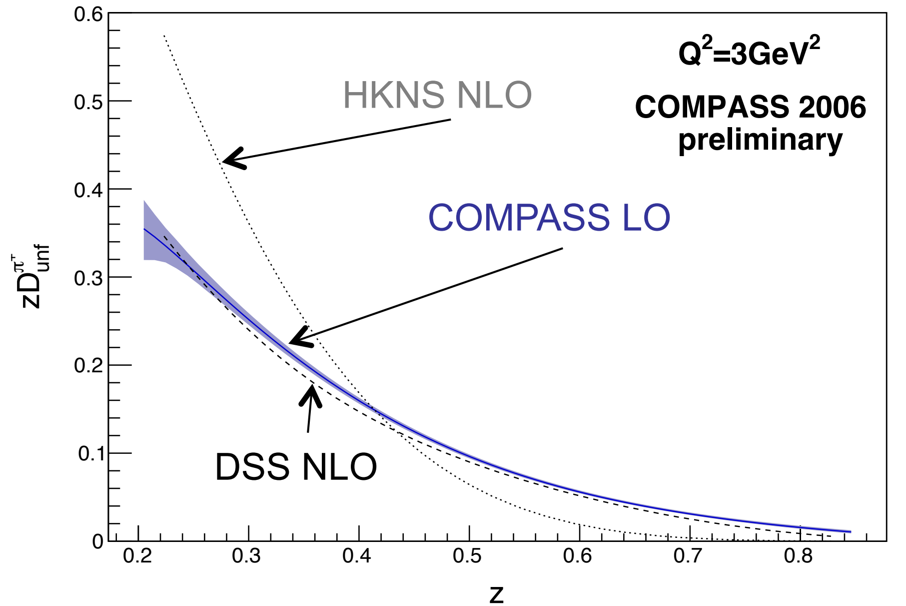
$$M^{\pi^-}(x,Q^2,z) = \frac{(u+d+4(\bar{u}+\bar{d}))D_{fav} + (4(u+d)+\bar{u}+\bar{d}+2(s+\bar{s}))D_{unf}}{5(u+d+\bar{u}+\bar{d})+2(s+\bar{s})}$$

$u,\ d,\bar{u},\bar{d},\ s,\ \bar{s}(x,Q^2) =$ parton distribution functions (MSTW08)

- LO fit of experimental multiplicities :
  - Functional form : $zD_{fav} = zD_{unf} = Nz^{\alpha}(1-z)^{\beta}\left[1+\gamma(1-z)^{\delta}\right]$ at a given Q_0^2
  - Evolution from Q_0^2 to Q^2 of data points with DGLAP

Fit results of pion FF with diff. ρ^0 correction





- COMPASS LO fit to check data consistency
- COMPASS fit with statistical error only
- Good agreement with DSS as expected
- HKNS : significant difference (expected : no SIDIS data)

Conclusion and outlook

- Pion and kaon multiplicities from COMPASS 2006 data with isoscalar ^{6}LiD target and 160 GeV μ^+ beam

- High statistic results in *x*, *y* and *z* bins

- Pion multiplicities :
  - publication submitted soon with twice more statistics
  - results to be included in NLO global fits
  - will constrain quark FFs into pions at fixed target energies

- Kaon multiplicities :
  - Final checks and improvements ongoing

- Measurements with proton target :
  - ongoing analysis (2012 data on H_2 target)
  - 2015 and beyond

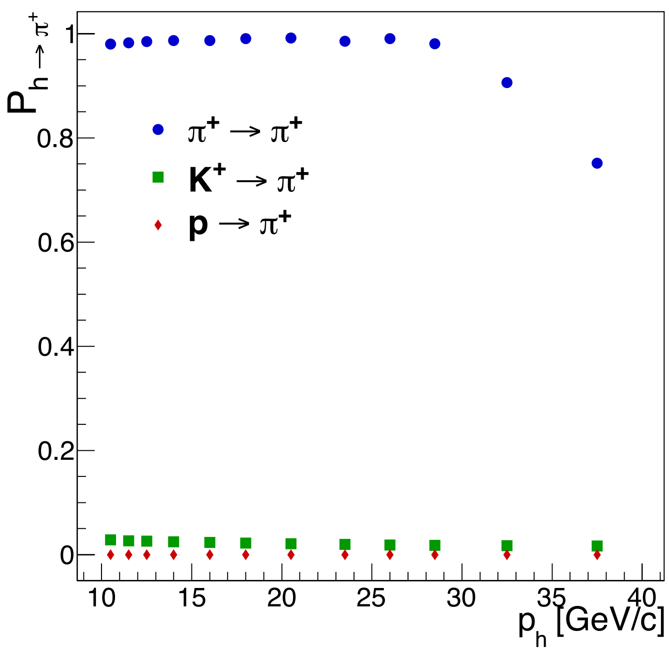
Thank you for your attention

Backup slides

RICH PID efficiency

Determination of RICH identification matrices using known decays :

- pions : $K_S^0 \rightarrow \pi^+ + \pi^-$
- kaons : $\Phi \rightarrow K^+ + K^-$
- protons : $\Lambda^0 \rightarrow p + \pi^-$



Observed number of hadrons (RICH)

RICH identification matrix

True number of hadrons

$$\begin{pmatrix} I_\pi \\ I_K \\ I_p \end{pmatrix} = \begin{pmatrix} \varepsilon_\pi^\pi & \varepsilon_K^\pi & \varepsilon_p^\pi \\ \varepsilon_\pi^K & \varepsilon_K^K & \varepsilon_p^K \\ \varepsilon_\pi^p & \varepsilon_K^p & \varepsilon_p^p \end{pmatrix} \begin{pmatrix} T_\pi \\ T_K \\ T_p \end{pmatrix}$$

identification probability (green circle)

misidentification probability (red circle)

Correction of identified pion and kaon yields : $\vec{T} = \vec{I} \cdot \varepsilon^{-1}$

Acceptance

Momentum extrapolation :

- Multi-dim. acceptance correction cancels generator model dependance if ideal

- In practice, some model dependance remains, particularly due to p < 10 GeV/c cut
  - ➢ Evaluation of LEPTO extrapolation below p cut
  - ➢ Exclusion of bins if model contribution > 10 %

Systematics uncertainties

- Acceptance : (≈ **5 %**)
  - different sets of PDF in Lepto
  - different JETSET tunings

- RICH PID efficiency
  - pions : **1 % - 3 %**
  - kaons : **5 % - 10 %**

- Diff. ρ^0 and ϕ correction
  - 30 % theoretical uncertainty on HEPGEN cross-section
    - **12 %** max uncertainty on correction

- Electron correction
  - 25 % MC/data difference -> **50 %** conservative syst. error

ρ^0 correction