Charged hadron multiplicities and quark fragmentation functions from COMPASS

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On behalf of the COMPASS Collaboration

- **Charged hadron multiplicities**
- **Quark fragmentation functions into pions from LO fit**
- **Outlook**

COMPASS at CERN

Fixed target
160-200 GeV muon beam and190 hadron beams from CERN SPS
→ Multipurpose setup

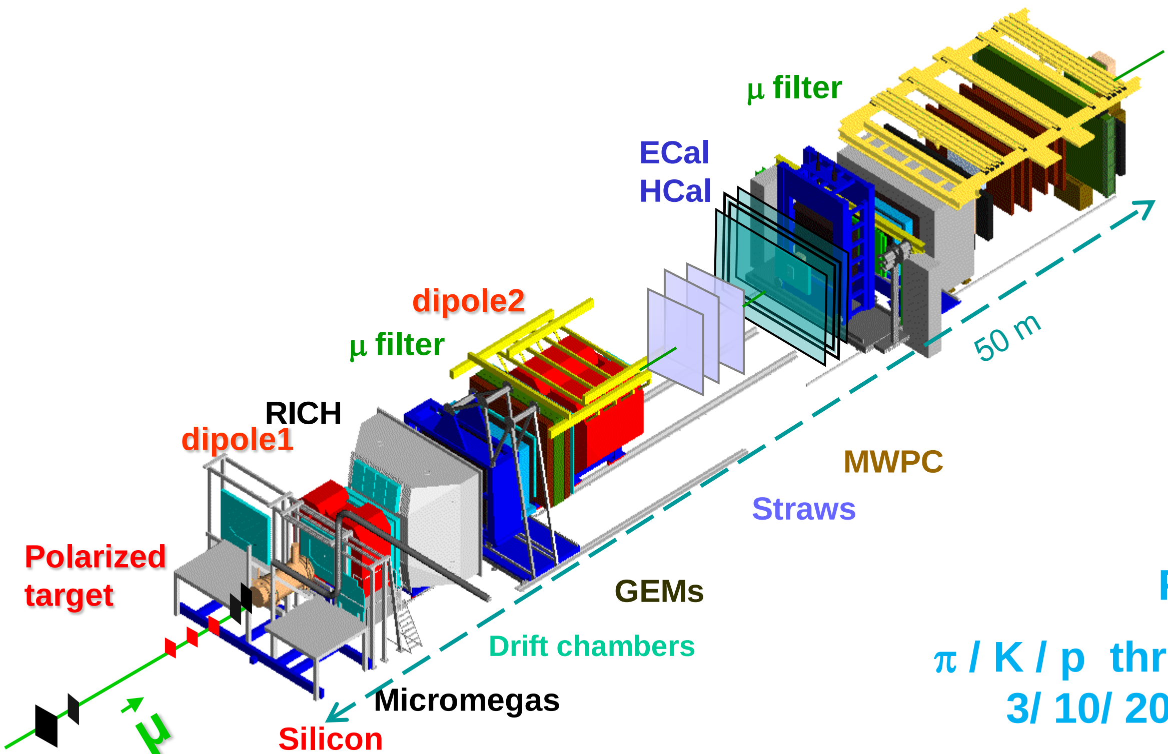
Polarized muon beam & polarized target: d, p

Nucleon spin structure

Hadron beam π / K / p & LH_2 or nuclei

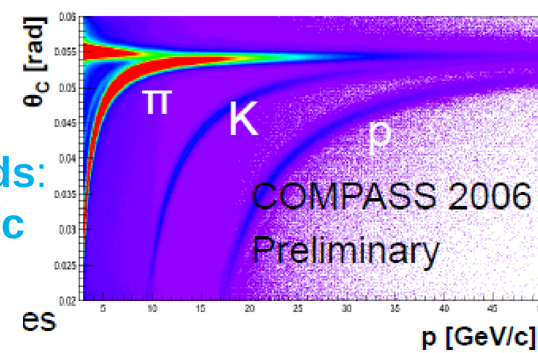
Meson spectroscopy
π, K polarizabilities

Future:
GPDs from DVCS
TMDs from Polarized
Drell-Yan



NIMA 577 (2007) 455

RICH
π / K / p thresholds:
3/ 10/ 20 GeV/c



Quark Fragmentation Functions (FF)

- Non perturbative objects
- Process independent
- Needed to access strange quark polarization Δs from polarized SIDIS.

strange quark FF = largest uncertainty in this extraction.

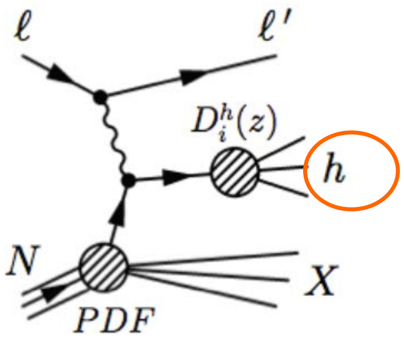
Data sensitive to FFs exist from e^+e^- and pp reactions,
but are unsufficient for good flavour separation and at too high Q^2

→ extract FFs from unpolarized COMPASS SIDIS data

Quark FFs from SIDIS

Measurement of multiplicities of π, K, p in **SIDIS**

$\mu^+ d \rightarrow \mu^+ h^\pm X$



Hadron multiplicitiy = mean number of hadrons h per DIS event

$z = E_h / (E_\mu - E_\mu')$

PDFs FFs

$$\frac{dM^h(x,Q^2,z)}{dz} \underset{\text{at LO}}{=} \frac{\sum_q e_q^2 f_q(x,Q^2) D_q^h(z,Q^2)}{\sum_q e_q^2 f_q(x,Q^2)}$$

PDFs depend on x, while FFs depend on z

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

Data can be obtained in a fine binning in x, z, Q^2

→ Input to global QCD analyses to extract quark FFs

Data analysis - hadron multiplicities

- 3 Weeks of 2006 data (1/4 of total stat.)
  ^{6}LiD target : isoscalar
- **Kinematic cuts** :
  - *Inclusive events:*
    - $Q^2 > 1$ 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

Data cover $5 < W < 17$ GeV

- **Analysis** :
  - Calculate **raw** multiplicities of h^{+-}, π^{+-} and K^{+-}
    - in 3D-binning: (x, y, z), $\langle Q^2 \rangle$ evaluated in each bin
    - RICH likelihood cuts are used for identification
  - Apply corrections:
    - Efficiency/ purity of RICH detector for π/K identification
    - Spectrometer acceptance
      including efficiency of detectors and event reconstruction
    - Electron contamination of π sample
    - Diffractive vector meson production ρ^0 and ϕ

RICH performance matrices

Need to evaluate absolute efficiency / purity of RICH detector

- "pure" π, K and p samples, well identified from parent decays:

pions : $K_S^0 \rightarrow \pi^+ + \pi^-$

kaons : $\Phi \rightarrow K^+ + K^-$

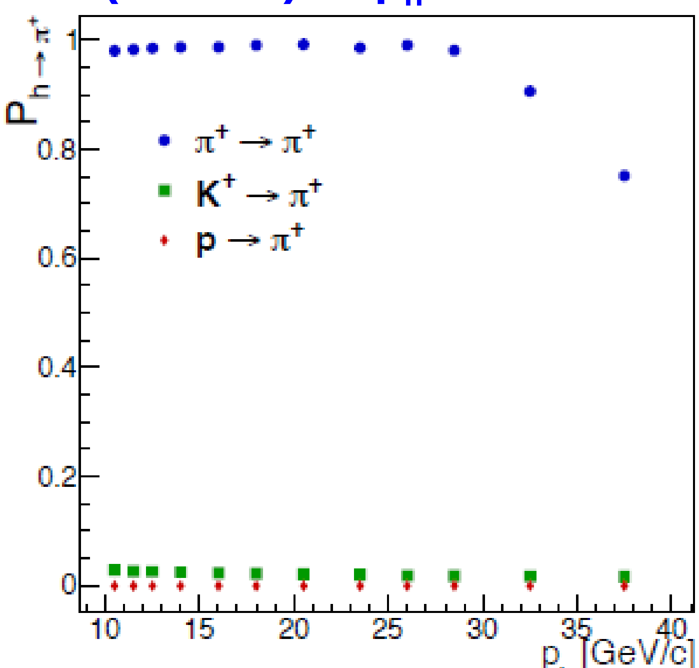
protons : $\Lambda^0 \rightarrow p + \pi^-$

- Look at RICH responses

→ Probabilities $\mathscr{P}$ of identification and misidentification of **$\pi^{+/-}$, $K^{+/-}$ and p**

Example for positive particles

$\mathscr{P}$ ($h^+ \rightarrow \pi^+$) *vs* **p_h** *in one* **θ** *bin:*



Q.Curiel, PhD Thesis 2014

$\mathscr{P}$ in **(p_h, θ)** bins

p_h : momentum of hadron

θ : angle at RICH entrance

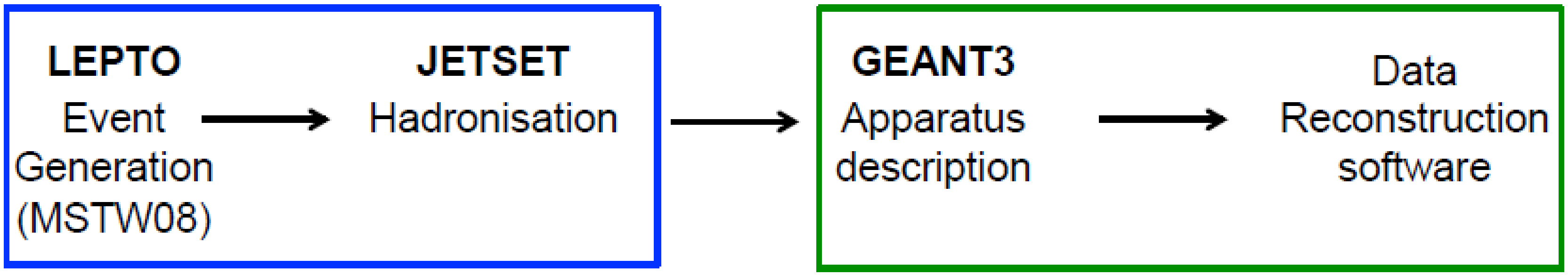
Measured "True"

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

Acceptance calculation

Includes geometric acceptance plus detector and reconstruction efficiency

Monte Carlo Simulation :



$$A^h(x,y,z) = \frac{M_r^h(x,y,z)}{M_g^h(x,y,z)}$$

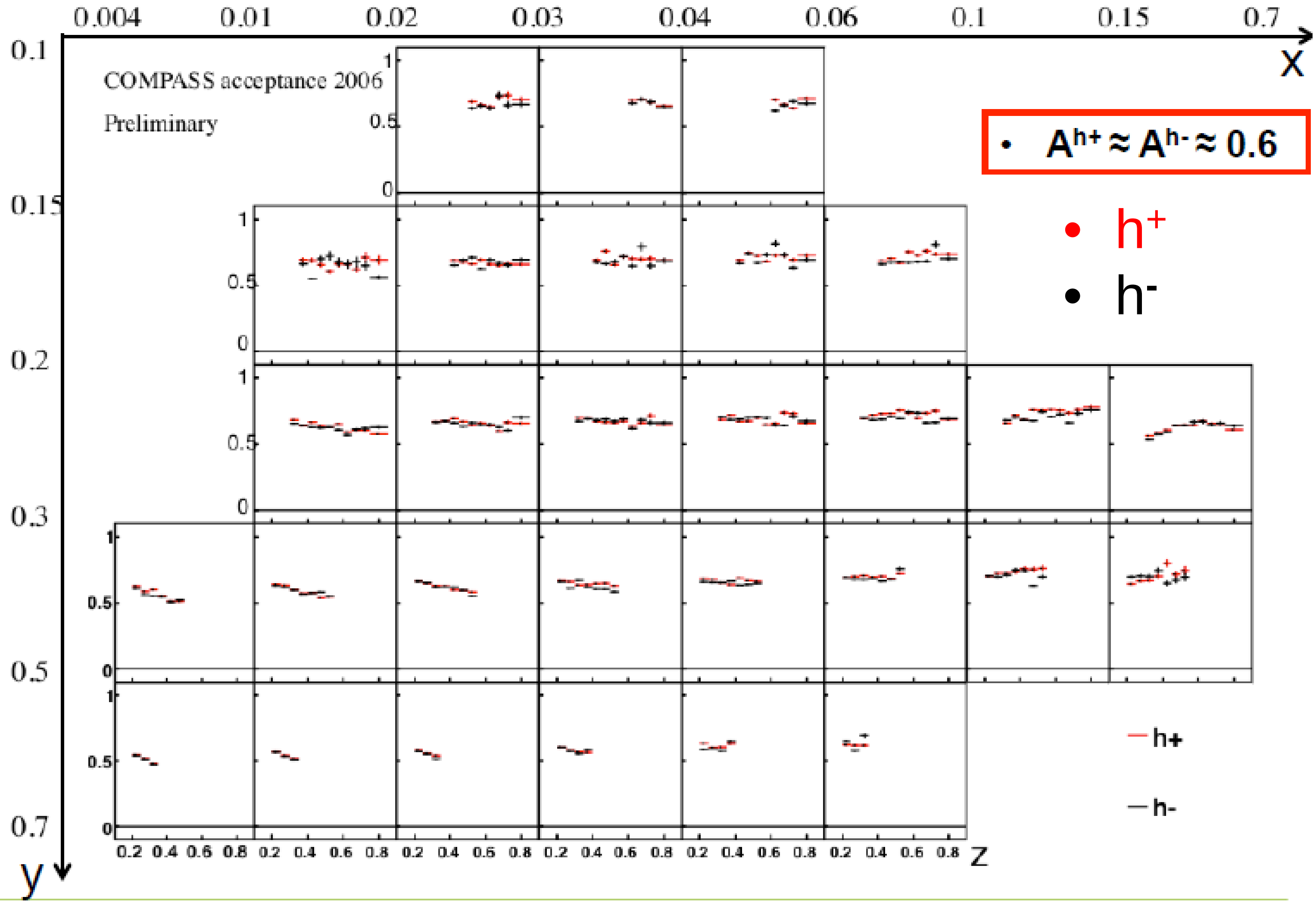
Reconstructed

Generated (kinematical cuts only)

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

Spectrometer acceptance for h^+ and h^-

Prelim. results from MC simulation: A(z) in 29 (x-y) bins

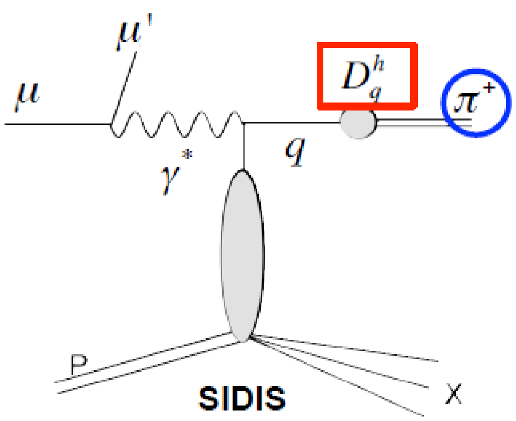


- $A^{h+} \approx A^{h-} \approx 0.6$

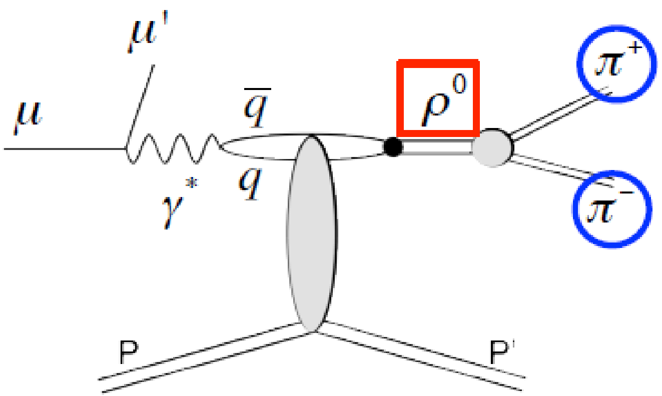
- h^+
- h^-

Contribution from diffractive meson production

The data sample includes SIDIS events but also
π and K from diffractive meson production, without quark hadronization.



SIDIS



Diffractive ρ^0 production

Main VM: ρ^0 and ϕ

$$\gamma^* N \to \rho^0 N \to \pi^+\pi^- N$$

$$\gamma^* N \to \Phi N \to K^+K^- N$$

Contribution from diffractive meson production

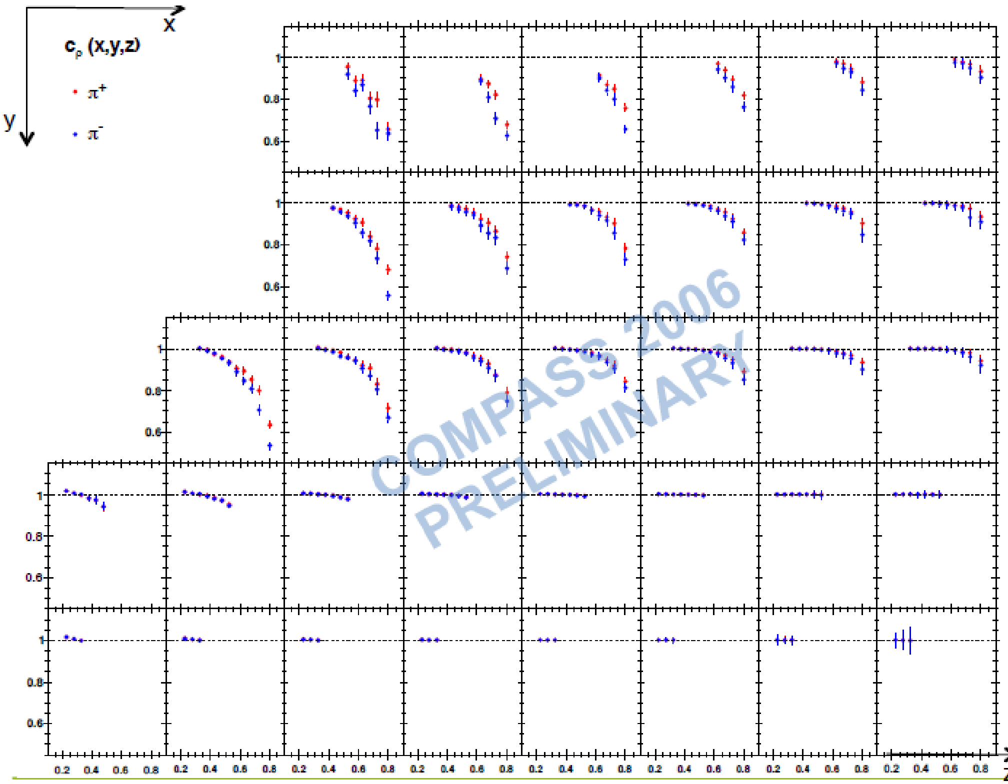
F. Thibaud, QCD Montpellier-2014

- MC simulation,
using LEPTO for SIDIS
and HEPGEN for VM production

- In total, contribution from VM
small : few %

However in some bins, it reaches:
- 40% for π (high z, low Q^2)
there, π multiplicities are very small
- 20% for K (z~0.6, low Q^2)

- Multiplicity data will be published
with and without correction

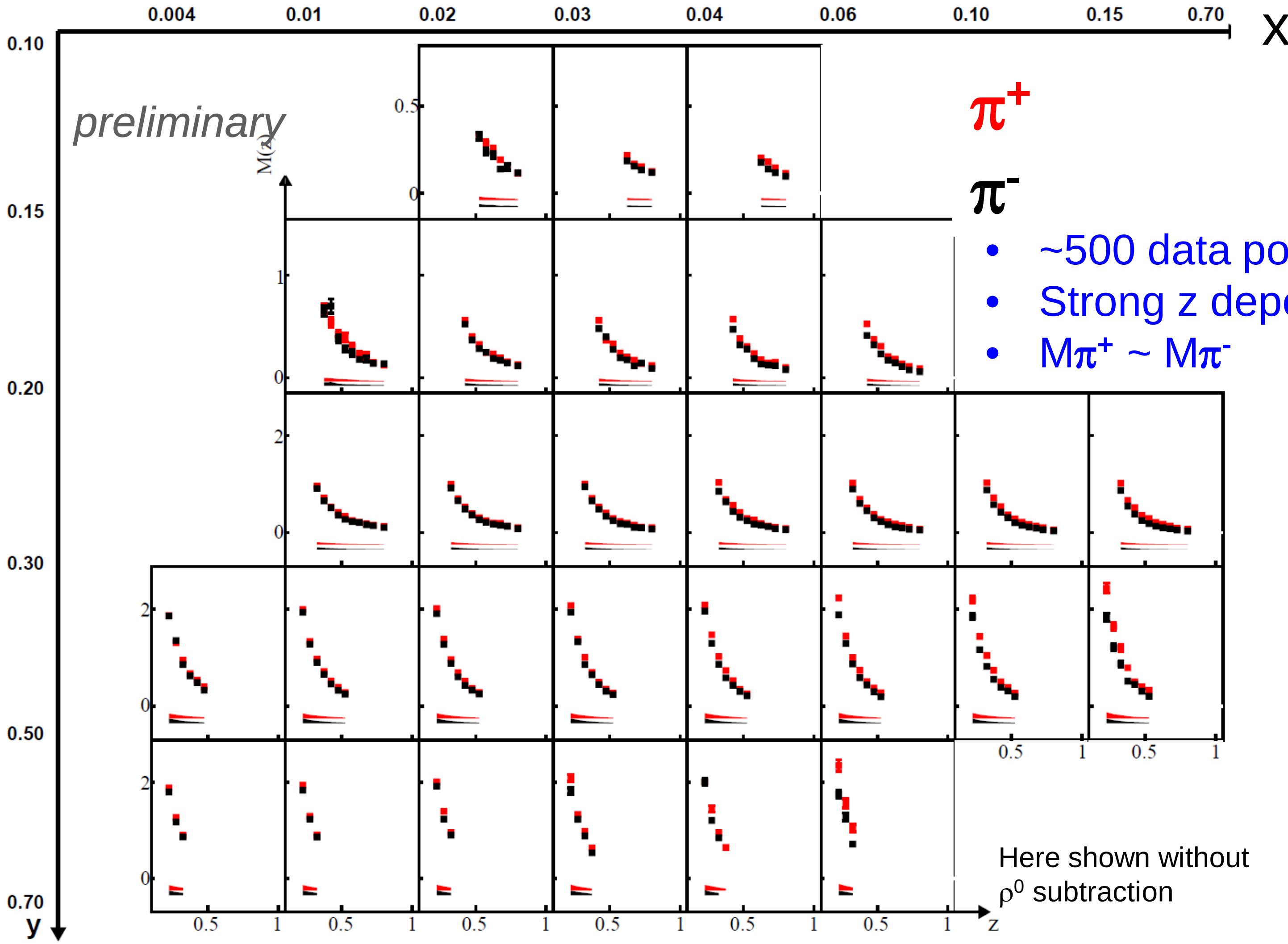


Ex: Correction for contribution of π from ρ^0 in the data sample, vs z, in 35 (x,y) bins

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

π^+ and π^- multiplicities vs z in (x,y) bins

COMPASS prelim. (DIS-2013, N.Makke)



- ~500 data points for π
- Strong z dependence
- $M\pi^+ \sim M\pi^-$

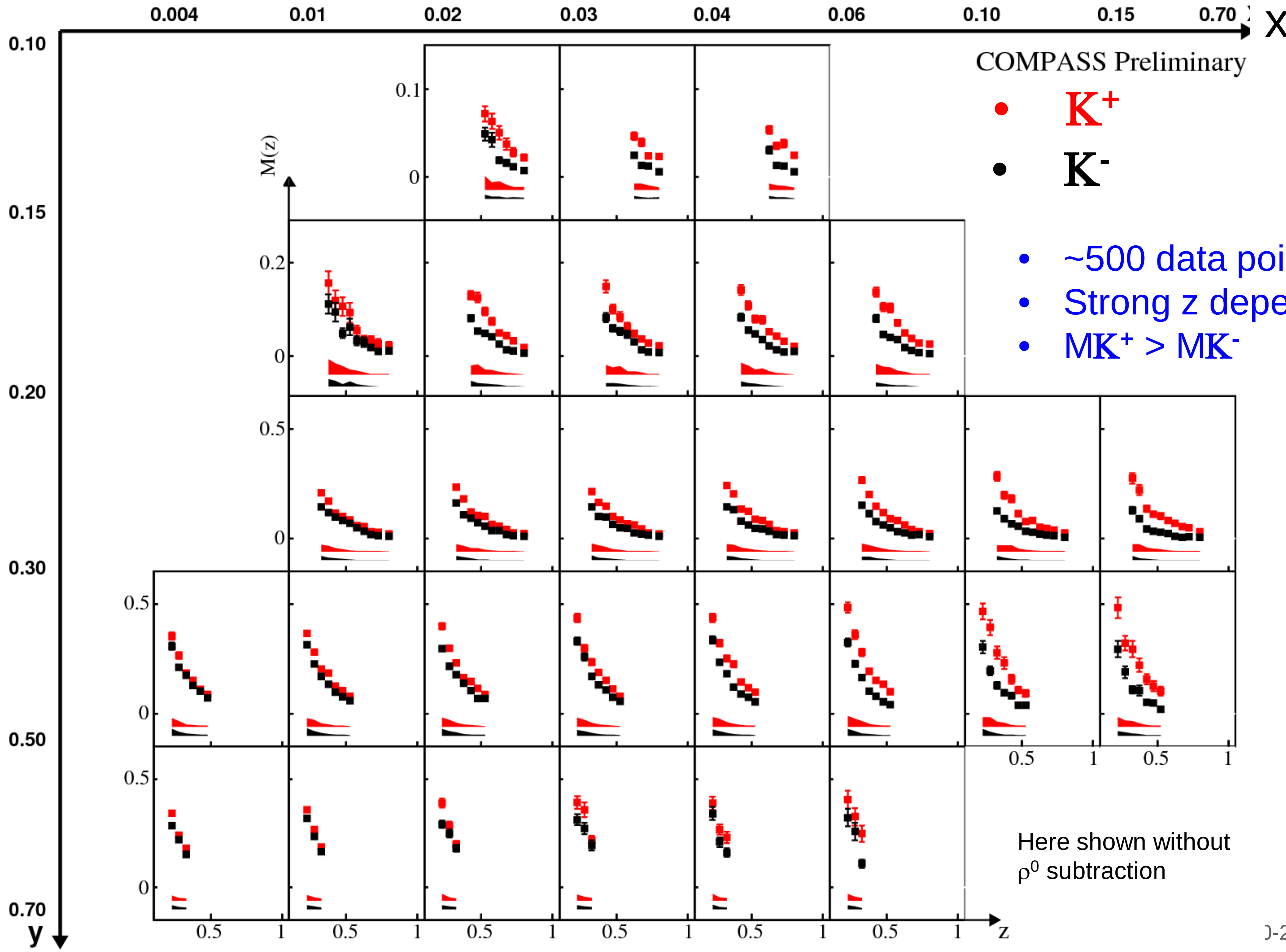
Here shown without ρ^0 subtraction

Systematics dominated by uncertainty on acceptance (5%) and RICH.

NB- Also measured: p_T dependence ***(see talk of N.Makke)*** and 2h multiplicities

K⁺ and K⁻ multiplicities vs z in (x,y) bins

COMPASS prelim. (DIS-2013, N.Makke)



- ~500 data points for K
- Strong z dependance
- MK⁺ > MK⁻

Here shown without ρ^0 subtraction

Quark FFs into π, from COMPASS LO fits

Assume isospin and charge symmetry:

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

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

Assume also $D_s^{\pi+} = D_s^{\pi-} = D_{unf}^{\pi+}$

Choose functional forms for FFs (z); use DGLAP.

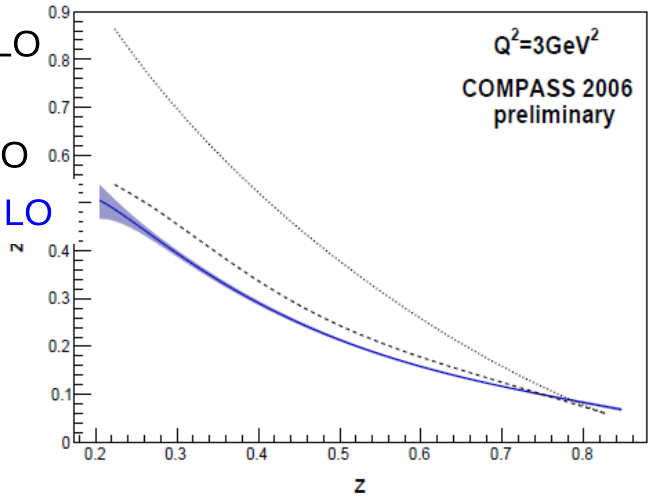
Fit π^+ and π^- multiplicities and extract the 2 independent FFs:

$zD_{fav}^{\pi+}$

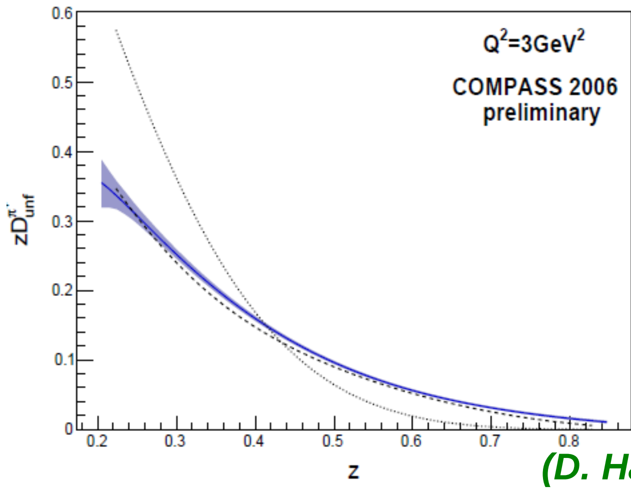
HNKS NLO

DSS NLO

COMPASS LO



$zD_{unfav}^{\pi+}$



—— COMPASS LO

….. DSS NLO

----- HNKS NLO

(D. Hahne DPG-2014 and N. du Fresne von Hohenesche. DIS-2014)

Next step: Fragmentation functions into kaons D_s^{K+} and D_s^{K-} starting from kaon multiplicities

Summary

Multiplicities for **$h^+, h-, \pi^+, \pi^-, K^+, K^-$**

in a fine binning of x,y,z; 5 < W < 17 GeV

Important input to global QCD fit of FFs at NLO

Quark FF into pions from LO fit of $\pi+,\pi-$ multiplicities

D^{π}_{fav} & $D^{\pi}_{unfav}(z,Q^2)$: Promising results already at LO

In progress

Finalize pion and kaon multiplicities with improved MC and RICH treatment

Extract quark FF into kaons

Analyze data on H_2 target (2012) → more input for flavor separation

Future

2016-2017 : large set of proton data

(in parallel to GPD program: μ beam, H_2 target & upgraded RICH detector).

Spares

Systematic 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

Quark FFs into π, from COMPASS fits

N.Dufresnes at DIS-2014 Starting from π multiplicities, extract 2 FFs.

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

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

And assuming $D_{unf}^{\pi+} = D_s^{\pi+} = D_s^{\pi-}$

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

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

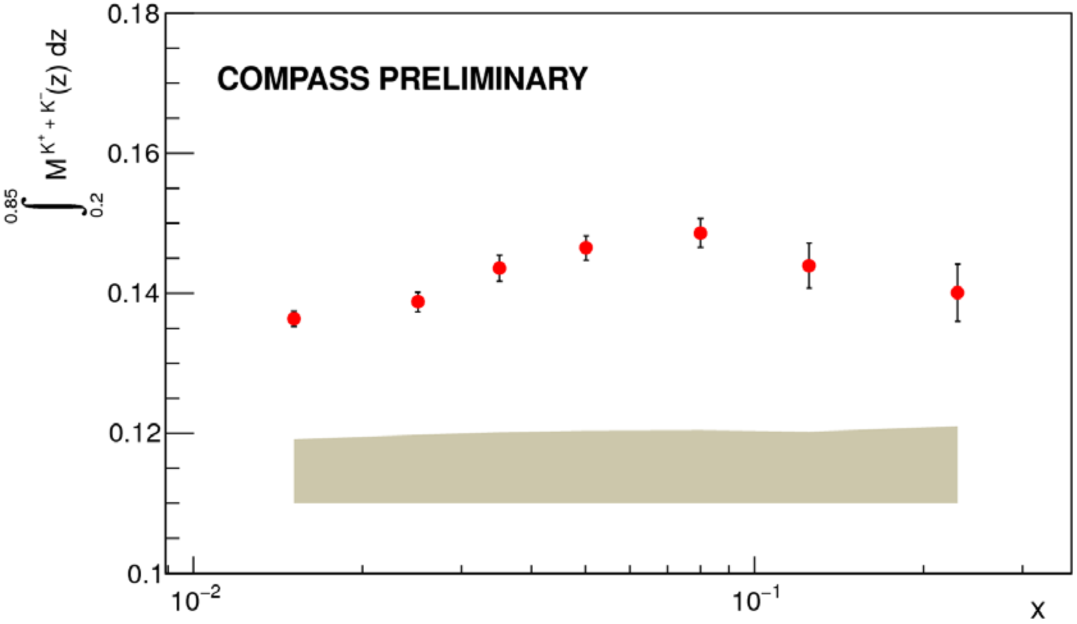
$u, d, \bar{u}, \bar{d}, s, \bar{s}(x,Q^2)$ = parton distribution functions (MSTW08)

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

Sum $M(K^+) + M(K^-)$

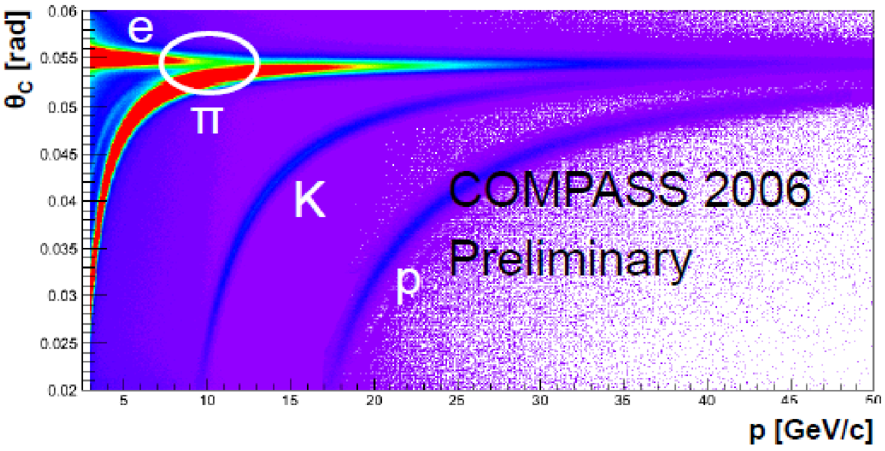
N.Makke, DIS 2013



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)