$K^{\pm}$ multiplicities

in semi-inclusive deep-inelastic scattering from COMPASS

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Motivation: strange sea quark polarization from SIDIS

Strange quark helicity distribution, $\Delta s(x)$,
can be extracted from spin asymmetries of kaon production, however it
strongly depends upon the choice of *poorly known* fragmentation functions ($D_i^h(z,Q^2)$ **)**

The value of the first moment obtained:

$$\int \Delta s(x,Q^2)\,dx = f(R_{SF}),\;\; R_{SF} \equiv \frac{\int D_{\bar{s}}^{K^+}(z,Q^2)\,dz}{\int D_u^{K^+}(z,Q^2)\,dz}$$

Our interest: weigh in on the apparent disagreement in the values obtained from 2 analyses: inclusive(EMC) and semi-inclusive(DSS) by measuring SIDIS kaon multiplicities from COMPASS data for extraction of $D_i^K(z,Q^2)$

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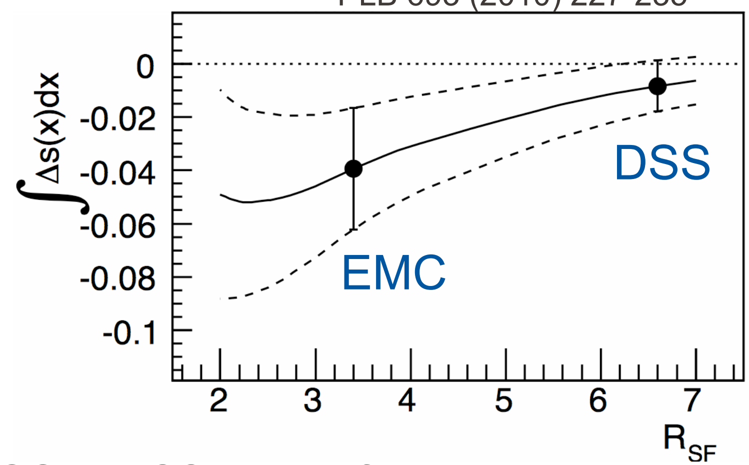
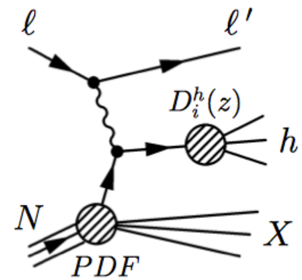


COMPASS results for Δs integrated over x using measured spin asymmetries and 2 sets of fragmentation functions (DSS and EMC)

Kaon multiplicities from SIDIS

What is a SIDIS kaon multiplicity measurement?
The normalized yield of final state kaons

$$M^K(x,y,z) = \frac{N^K(x,y,z)/\Delta z}{N^{DIS}(x,y)}$$



$$Q^2 = -(\mathbf{p}_l - \mathbf{p}_{l'})^2$$

$$x = \frac{Q^2}{2M_N(E_l - E_{l'})}$$

$$z = \frac{E_h}{(E_l - E_{l'})}$$

$$y = \frac{(E_l - E_{l'})}{E_l}$$

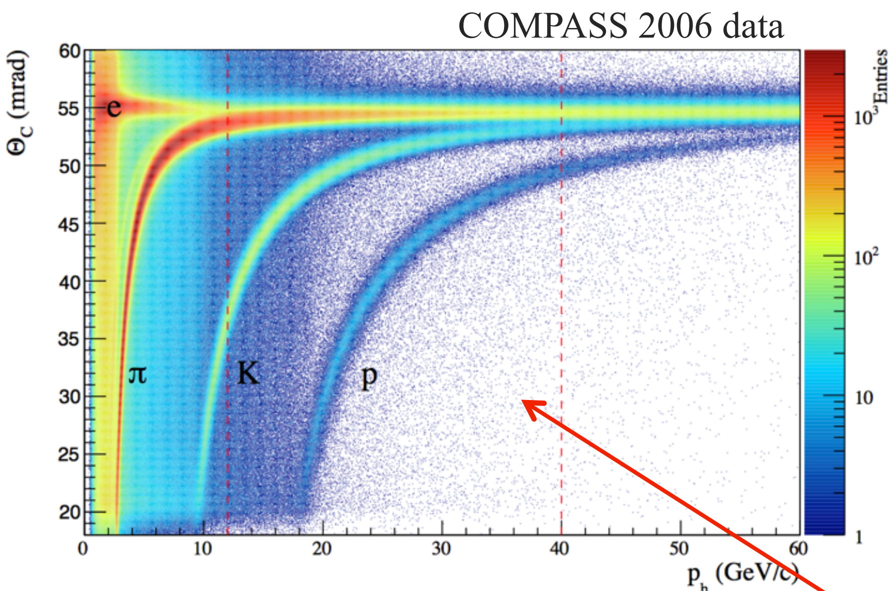
where Δz is the width of the z-bin, $N^{DIS}(x,y)$ is the number of DIS events, $N^K(x,y,z)$ the number of final state kaons

In LO pQCD kaon multiplicities can be expressed in terms of parton distribution functions (pdfs) and fragmentation functions (FFs) as:

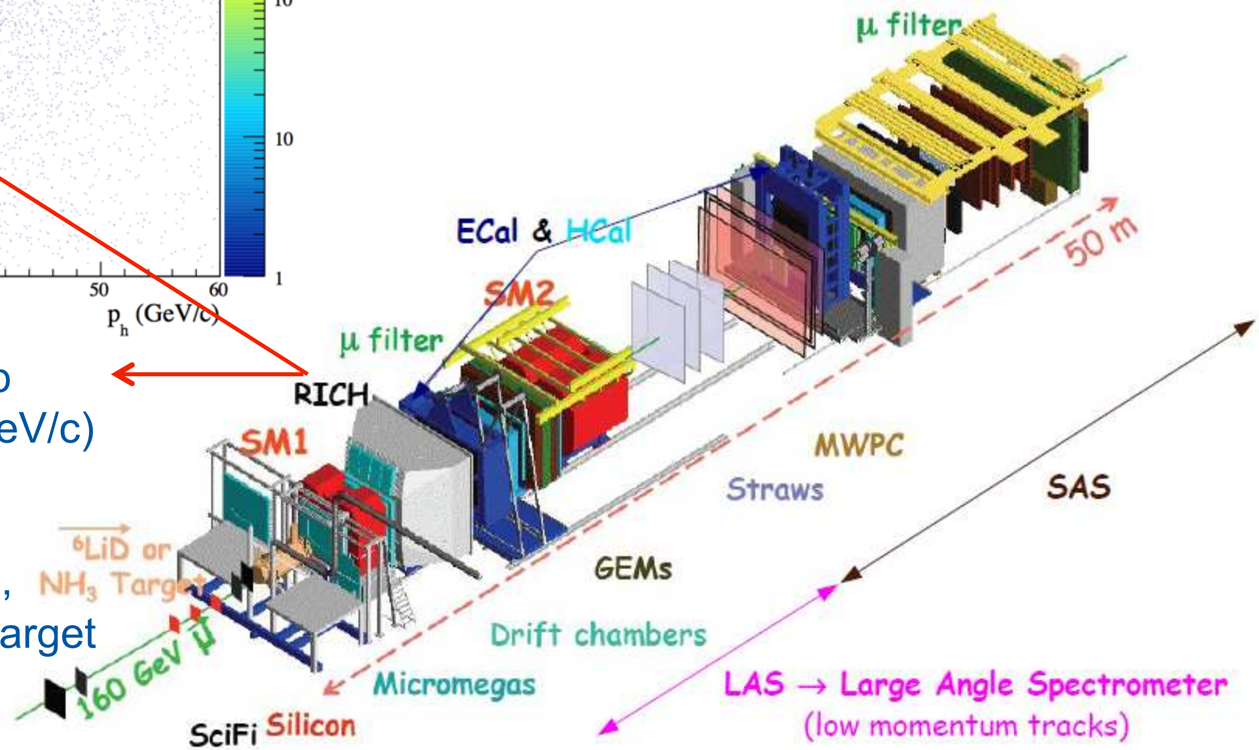
pdfs FFs

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

COMPASS spectrometer



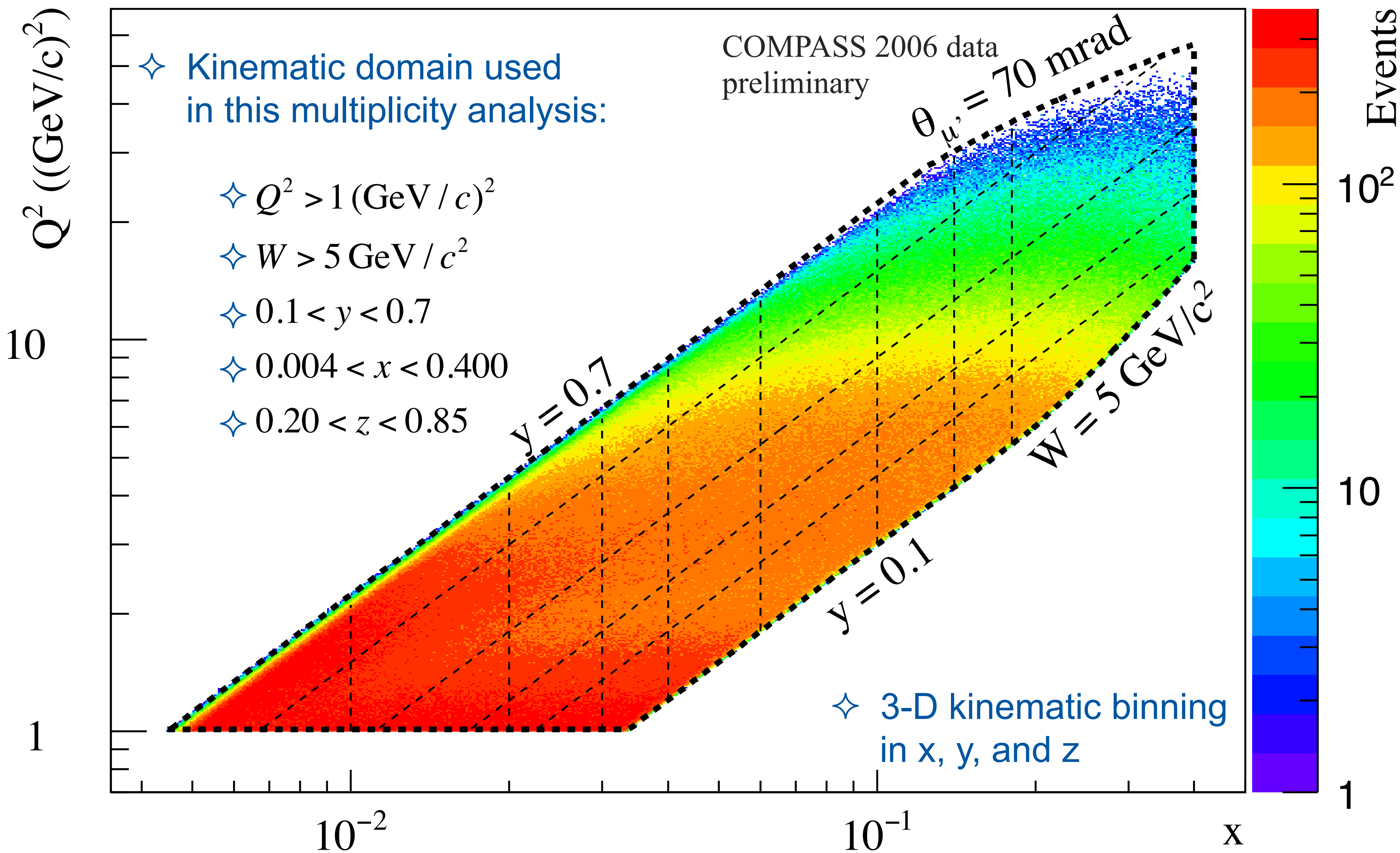
- ✧ Designed for fixed-target experiments at CERN SPS
- ✧ Can operate with muon or hadron beams
- ✧ This analysis: 160 GeV μ^+ beam (2006)



- ✧ Excellent charged π, K, p discrimination (12 - 40 GeV/c) with the RICH
- ✧ This analysis: 1.2 m long, polarized ^{6}LiD isoscalar target (2006)

COMPASS kinematics

- Kinematic domain used in this multiplicity analysis:
  - $Q^2 > 1\,(\mathrm{GeV}/c)^2$
  - $W > 5\,\mathrm{GeV}/c^2$
  - $0.1 < y < 0.7$
  - $0.004 < x < 0.400$
  - $0.20 < z < 0.85$



- 3-D kinematic binning in x, y, and z

Multiplicity analysis

COMPASS Raw Data

- ✧ Event and particle reconstruction
- ✧ Event and particle selection
- ✧ RICH PID and unfolding

Monte Carlo

- ✧ Radiative correction
- ✧ Detector acceptance
- ✧ Kinematic bin smearing
- ✧ Diffractive VM correction

Final Multiplicities

RICH PID and unfolding

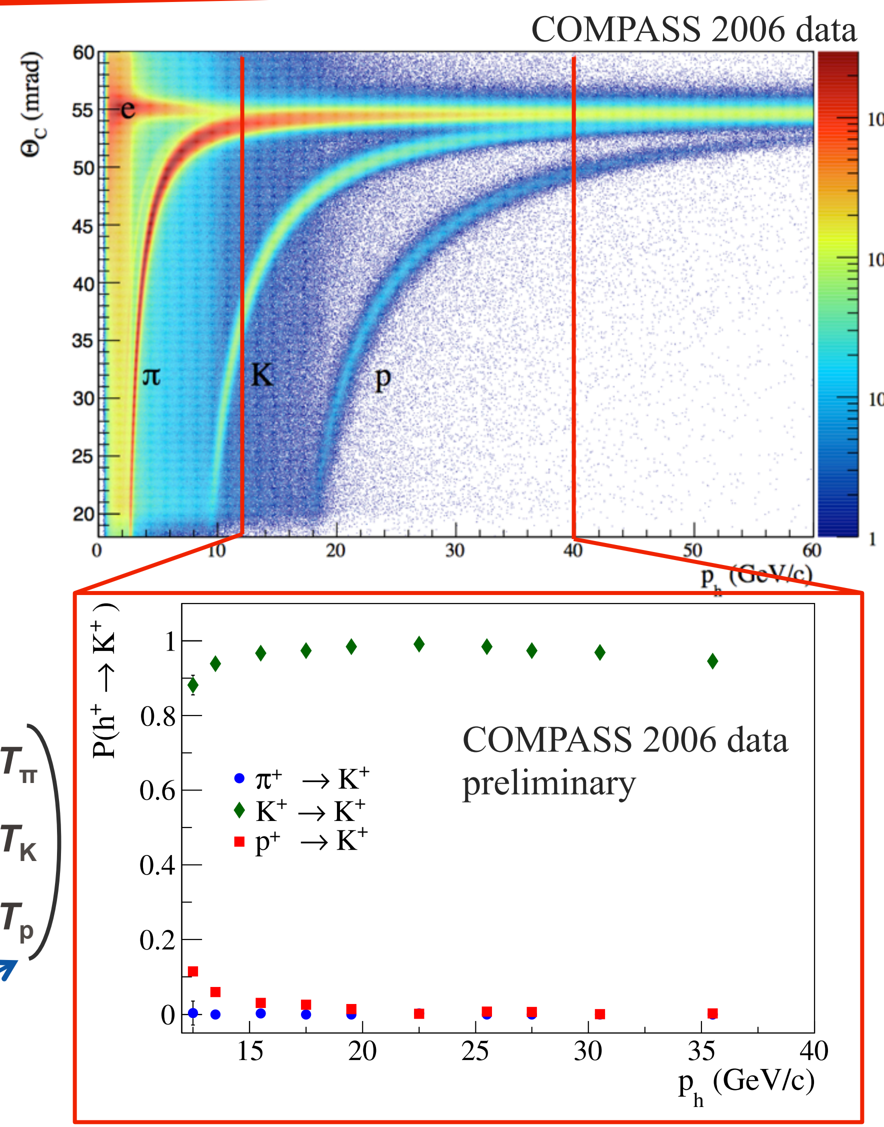
- Particle identification uses likelihoods based on the number and distribution of detected photons in RICH associated to a charged particle
- Purity of the kaon sample depends on the probabilities, P, of correct identification and misidentification
- The kaon yield is corrected using these probabilities by unfolding:

RICH probabilities

$$\begin{pmatrix} I_\pi \\ I_K \\ I_p \end{pmatrix} = \begin{pmatrix} P(\pi^\pm \Rightarrow \pi^\pm) & P(\pi^\pm \Rightarrow K^\pm) & P(\pi^\pm \Rightarrow p^\pm) \\ P(K^\pm \Rightarrow \pi^\pm) & P(K^\pm \Rightarrow K^\pm) & P(K^\pm \Rightarrow p^\pm) \\ P(p^\pm \Rightarrow \pi^\pm) & P(p^\pm \Rightarrow K^\pm) & P(p^\pm \Rightarrow p^\pm) \end{pmatrix} \begin{pmatrix} T_\pi \\ T_K \\ T_p \end{pmatrix}$$

Identified

“True”



Corrections to data:

acceptance and smearing

Correction for the limited geometrical acceptance, reconstruction and detector inefficiencies as well as resolutions

reconstructed multiplicity

kinematic bin determined using reconstructed values

$$A(x,y,z) = \frac{Mrec}{Mgen} = \frac{N^{K}_{rec}(x',y',z')\,/\,N^{DIS}_{rec}(x',y')}{N^{K}_{gen}(x'',y'',z'')\,/\,N^{DIS}_{gen}(x'',y'')}$$

generated multiplicity

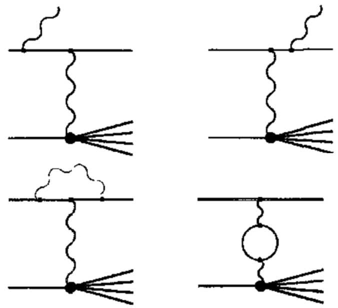
kinematic bin determined using generated values

MC technical features:

- ✧ Events are generated with the LEPTO generator (LUND model)
- ✧ JETSET package for parton hadronisation with COMPASS high p_T tuning
- ✧ FLUKA used to simulate secondary interactions in the target
- ✧ Spectrometer simulated using GEANT3 toolkits

Corrections to data:

radiative



Processes considered: emission of an additional real photon, vertex correction, and vacuum polarization

correction factors are applied on an event by event basis

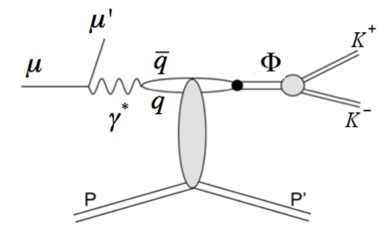
$$\eta(x,y) = \frac{d^2\sigma_{1\gamma} / dxdy}{d^2\sigma_{measured} / dxdy}$$

inclusive (DIS) correction ranges from a ~2% (high x, low y) to 15% (low x, high y) effect

semi-inclusive (hadronic) correction: DIS correction with elastic tail contribution taken out. ***The respective integration of semi-inclusive tails is not implemented (under investigation)***

inclusive correction > semi-inclusive correction

diffractive vector meson



presence of hadrons from diffractive vector mesons in the data

No parton hadronisation

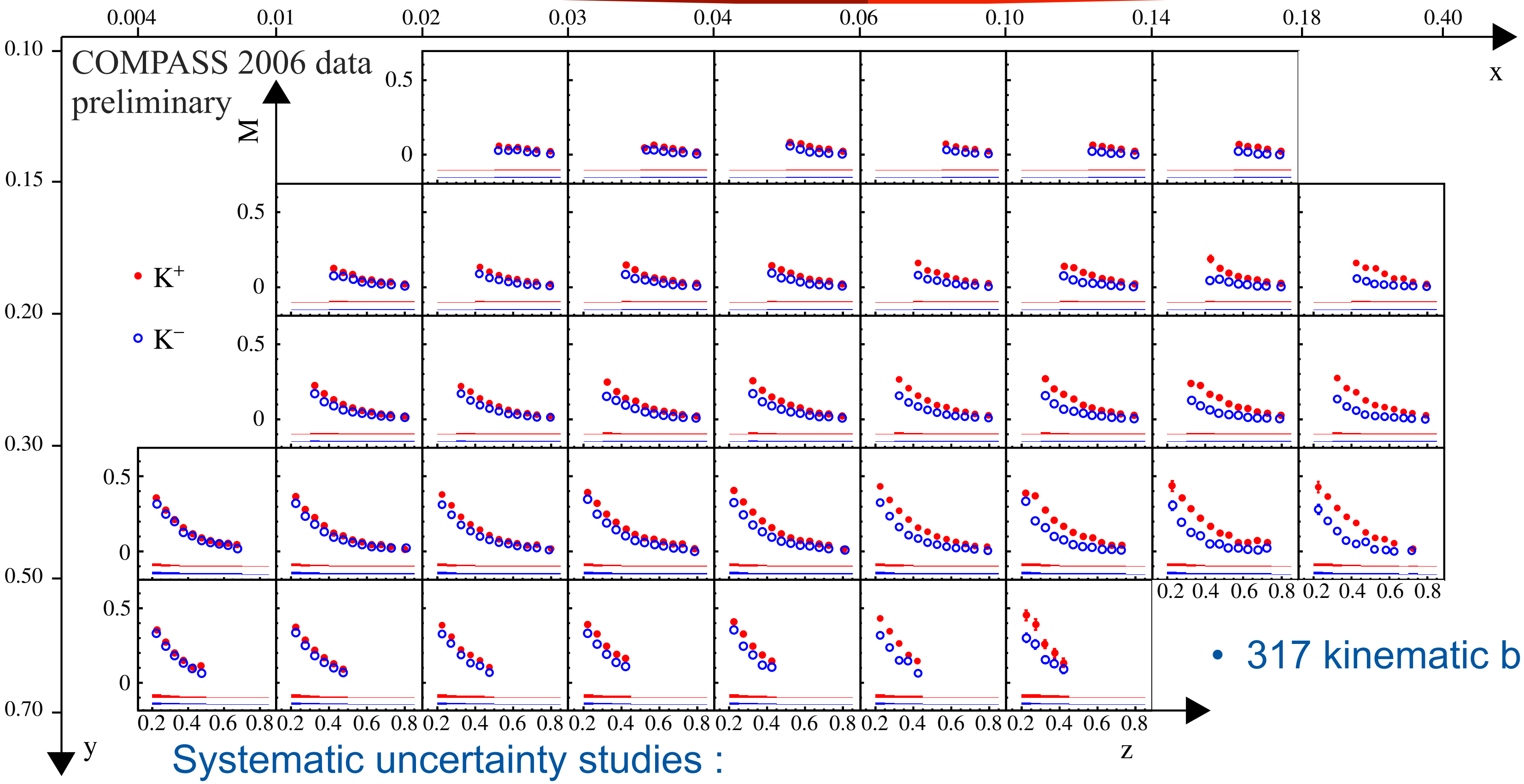
correction factor to the kaon yield determined using LEPTO(SIDIS) and HEPGEN(Diffractive) Monte Carlo, with each sample normalized using the respective luminosities

$$f_{\Phi}^{K}(x,y,z) = \frac{N_{HEPGEN}^{K}(x,y,z)}{N_{LEPTO}^{K}(x,y,z) + N_{HEPGEN}^{K}(x,y,z)}$$

similar correction for the diffractive events in the DIS sample

overall correction is <10% in most bins except low x, mid z where it can reach ~25%

Kaon multiplicity results



- 317 kinematic bins

Systematic uncertainty studies :

Acceptance (studied for the previous release using different JETSET tunings): 5%

RICH PID/efficiency for kaons : 0.2 %(low y) - 15 %(high y, high z)

Diff. Vector Meson correction: 30 % theoretical uncertainty on HEPGEN cross-section

< 6 % maximum uncertainty on VM correction (low x, mid z)

Not shown: asymmetric systematic error of the radiative corrections (later slide)

Leading order extraction of fragmentation functions into kaons

Charge and isospin symmetry gives:

$$D_{fav}^{K} = D_{fav}^{K\pm} = D_{u}^{K+} = D_{\bar{u}}^{K-}$$

$$D_{unf}^{K} = D_{unf}^{K\pm} = D_{\bar{u}}^{K+} = D_{s}^{K+} = D_{u}^{K-} = D_{\bar{s}}^{K-} = D_{d}^{K\pm} = D_{\bar{d}}^{K\pm}$$

$$D_{str}^{K} = D_{str}^{K\pm} = D_{\bar{s}}^{K+} = D_{s}^{K-}$$

For an isoscalar target, in LO:

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

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

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

Fits of experimental multiplicities:

Functional form: $zD_i(z, Q_0^2) = N_i z^{\alpha_i}(1-z)^{\beta_i}(1+\gamma_i(1-z)^{\delta_i})$ $\quad i = fav$

$zD_i(z, Q_0^2) = N_i z^{\alpha_i}(1-z)^{\beta_i}$ $\quad i = str, unf, glu$

Evolution from Q^2_0 to Q^2 of data points with DGLAP

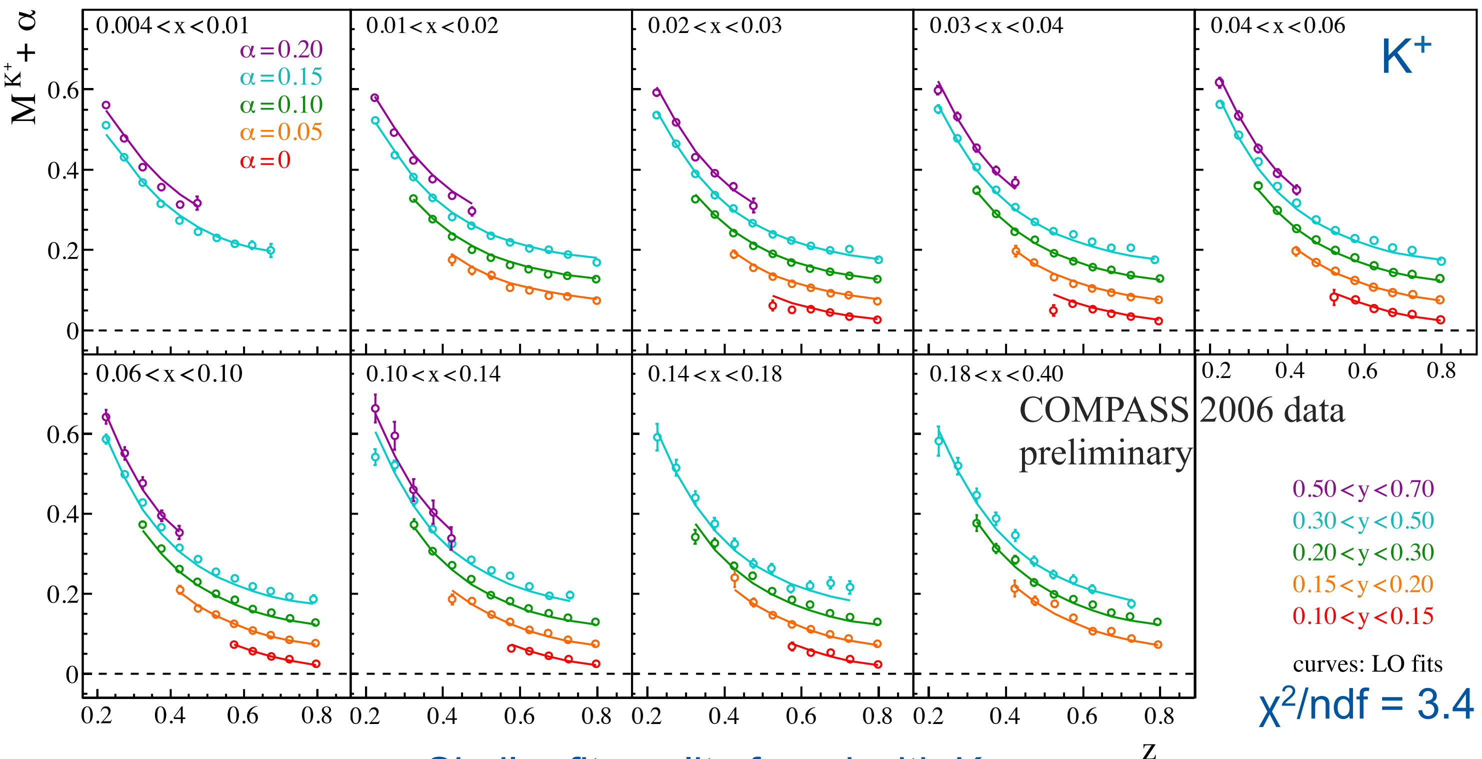
Leading order extraction of fragmentation functions into kaons

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

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

$$zD_i(z, Q_0^2) = N_i z^{\alpha_i}(1-z)^{\beta_i}(1+\gamma_i(1-z)^{\delta_i}) \quad i = fav$$

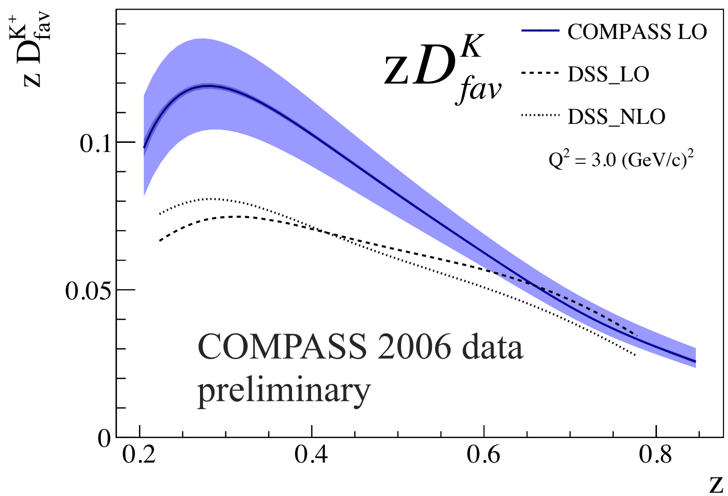
$$zD_i(z, Q_0^2) = N_i z^{\alpha_i}(1-z)^{\beta_i} \quad i = str, unf, glu$$

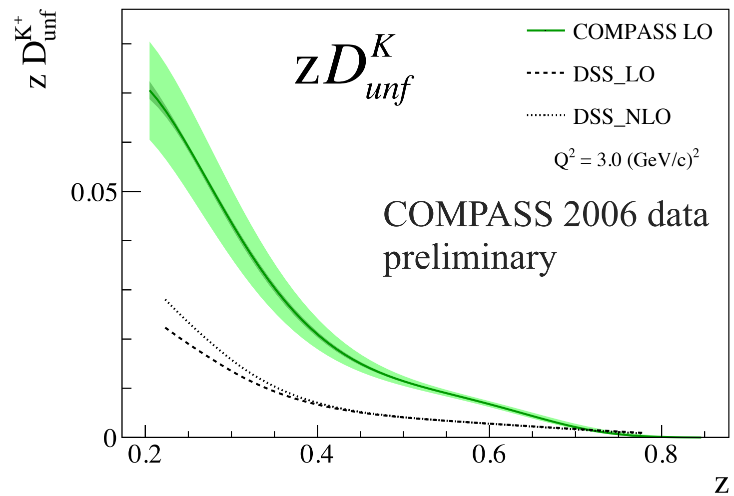


$\chi^2/ndf = 3.4$

Similar fit quality found with K^-

Leading order extraction of fragmentation functions into kaons





The values of zD^K_{fav}, zD^K_{unf} obtained using the **new data** are significantly above the existing DSS results (fits on world data) for both favoured and unfavoured.

$$D^K_{fav} = D^{K\pm}_{fav} = D^{K+}_{u} = D^{K-}_{\bar{u}}$$

$$D^K_{unf} = D^{K\pm}_{unf} = D^{K+}_{\bar{u}} = D^{K+}_{s} = D^{K-}_{u} = D^{K-}_{\bar{s}} = D^{K\pm}_{d} = D^{K\pm}_{\bar{d}}$$

At this stage of analysis, the result for zD^K_{str} is not very stable, however some insight can be gained by looking at the **multiplicity sum**…

Kaon multiplicity sum

For the isoscalar target, when expressed at LO the sum has a simple form:

$$\frac{dN^{K^+ + K^-}}{dN^{DIS}} = \frac{(u+d+\bar{u}+\bar{d})(4D^K_{fav}+6D^K_{unf}) + 2(s+\bar{s})(D^K_{str}+D^K_{unf})}{5(u+d+\bar{u}+\bar{d})+2(s+\bar{s})} = \frac{QD^K_Q + SD^K_S}{5Q+2S}$$

Recall, $u, d, \bar{u}, \bar{d}, s, \bar{s}$ = parton distribution functions
and charge and isospin symmetry gives:

$$D^K_{fav} = D^{K\pm}_{fav} = D^{K+}_{u} = D^{K-}_{\bar{u}}$$

$$D^K_{unf} = D^{K\pm}_{unf} = D^{K+}_{\bar{u}} = D^{K+}_{s} = D^{K-}_{u} = D^{K-}_{\bar{s}} = D^{K\pm}_{d} = D^{K\pm}_{\bar{d}}$$

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

At **high x** the strange can be neglected:

$$\frac{dN^{K^+ + K^-}}{dN^{DIS}} = \frac{(4D^K_{fav}+6D^K_{unf})}{5} = \frac{D^K_Q}{5}$$

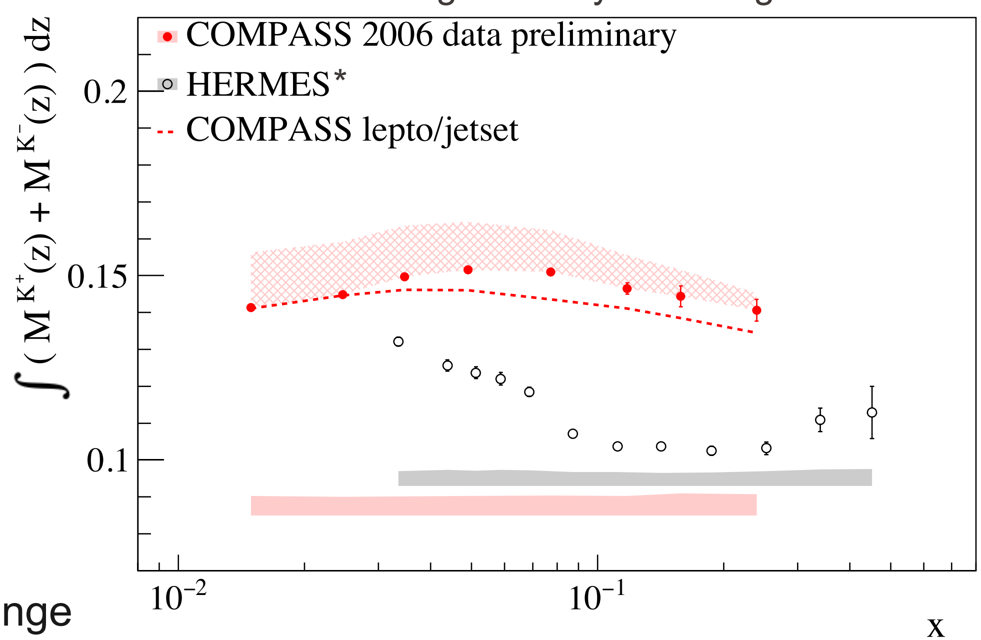
This analysis: $D^K_Q \approx 0.7$

DSS: $D^K_Q \approx 0.43 \pm 0.04$

At **low x**, with $D^K_{str} > D^K_{fav}$

D^K_Q has weak Q^2 dependence (3%) in our range
so one would expect a rise in the kaon multiplicity sum going to low x (DSS ~50% increase) which is not what we observe

Data are averaged over y and integrated over z



*HERMES results: PRD 89 (2014) 097101

Summary

- Charged kaon multiplicities were measured from **COMPASS 2006 data** with an isoscalar ^{6}LiD target and 160 GeV μ+ beam
- Multiplicities were measured in 317 3-D kinematic bins of x, y, and z
- Large discrepancy with respect to HERMES $K^{\pm}$ results
- Stable D_{fav} and D_{unf} results from LO fits to our data that differ from DSS
- Outlook/In progress:
  - Finalizing semi-inclusive radiative corrections