

# Multiplicities of charged pion, kaon and hadrons from COMPASS

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*On behalf of the COMPASS Collaboration*



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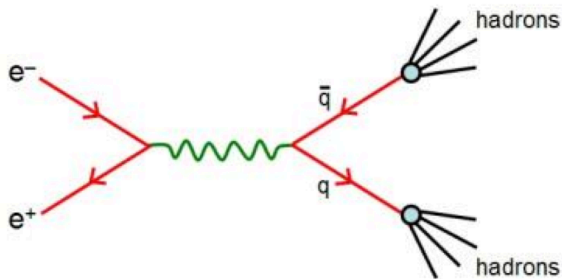
# Motivation: Fragmentation Functions

- ✧ Fragmentation functions (FF) describe parton fragmentation into hadron
- ✧ Relevant any time a final-state hadron is produced in high energy collisions
- ✧ Key ingredient in the flavor-separation of polarised parton distributions  $\Delta q$
- ✧ Fundamental role in understanding single spin asymmetries, transversity ( $h_1$ )...
- ✧ Accessible in different processes

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## $e^+e^-$ annihilation

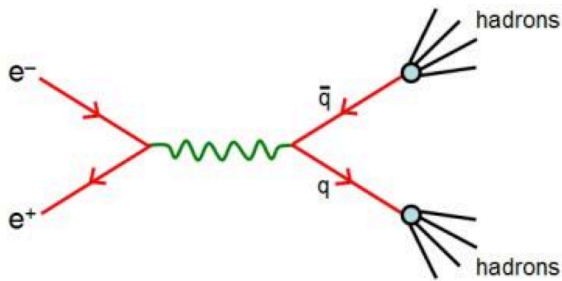


- ✧ Clean process (only FFs enter)
- ✧ Very precise data (LEP/SLD, BELLE, BABAR,...)
- ✧ only sensitive to  $q + \bar{q}$  FF

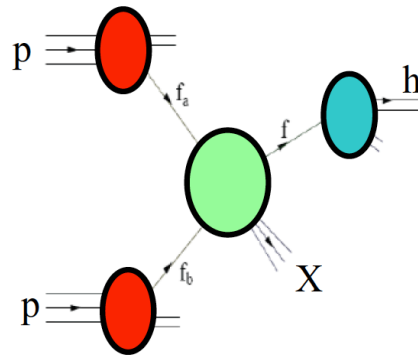
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## $e^+e^-$ annihilation



## pp collisions



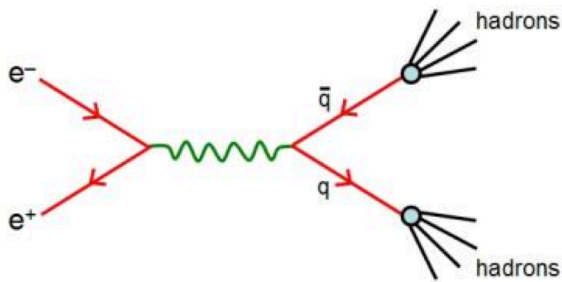
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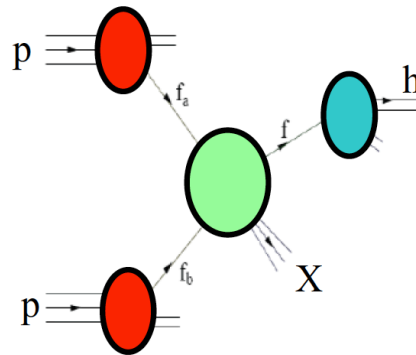
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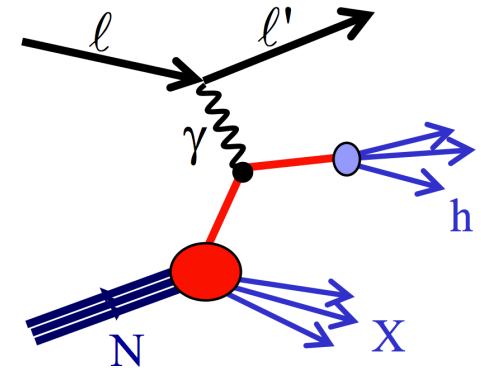
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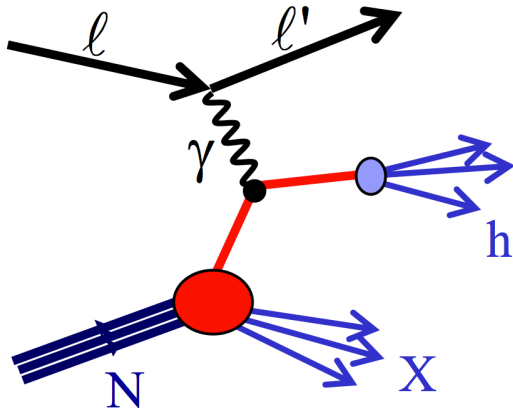
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## SIDIS



# Semi-Inclusive DIS

SIDIS: a powerful tool to study  $q \rightarrow h$  fragmentation



- ✧ Assess PDFs/FFs
- ✧ Flavor/charge separation
- ✧ wide scale coverage
- ✧ Nuclear target provide laboratory for fragmentation in nuclear medium
- ✧ Relevant for spin physics kinematic

$$d\sigma^{\ell p \rightarrow \ell h X} \sim \sum_q e_q^2 f_q(x, Q^2) \cdot d\sigma^{\ell q \rightarrow \ell q} \cdot D_q^h(z, Q^2)$$

# Motivation, cont.

✧ Strange quark polarisation in the nucleon:  $\int (\Delta s + \Delta \bar{s}) dx = \Delta S$

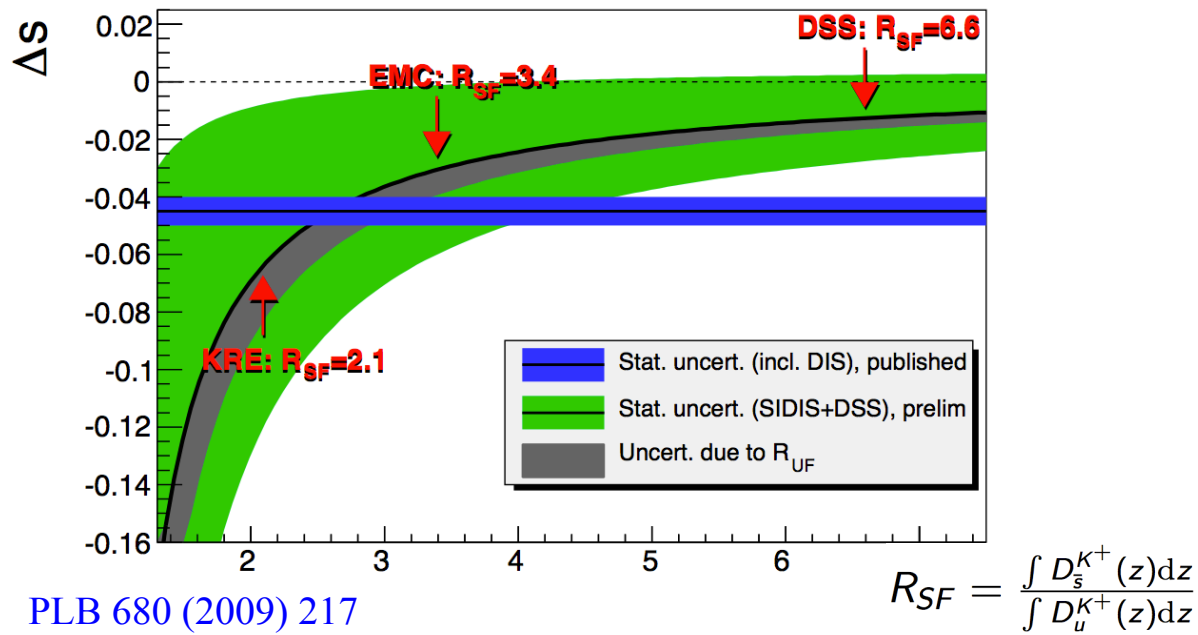
✧  $\Delta S$  obtained from fits to  $g_1$  data and SIDIS  $\pi$  (SU(3) symmetry) is negative

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

✧ SIDIS  $K$  data prefer zero or positive value at moderate  $x$  values

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

✧ However impact of SIDIS  $K$  data strongly depends upon the choice of strange quark FF  $D_S^K$



# Hadron Multiplicity

- ✧ Hadron Multiplicities are defined as observed number of hadrons in a number of DIS events

$$\frac{dM^h(x, Q^2, z)}{dz} = \frac{d^3\sigma^h(x, Q^2, z) / dx dQ^2 dz}{d^2\sigma(x, Q^2) / dx dQ^2}$$

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

quark FFs

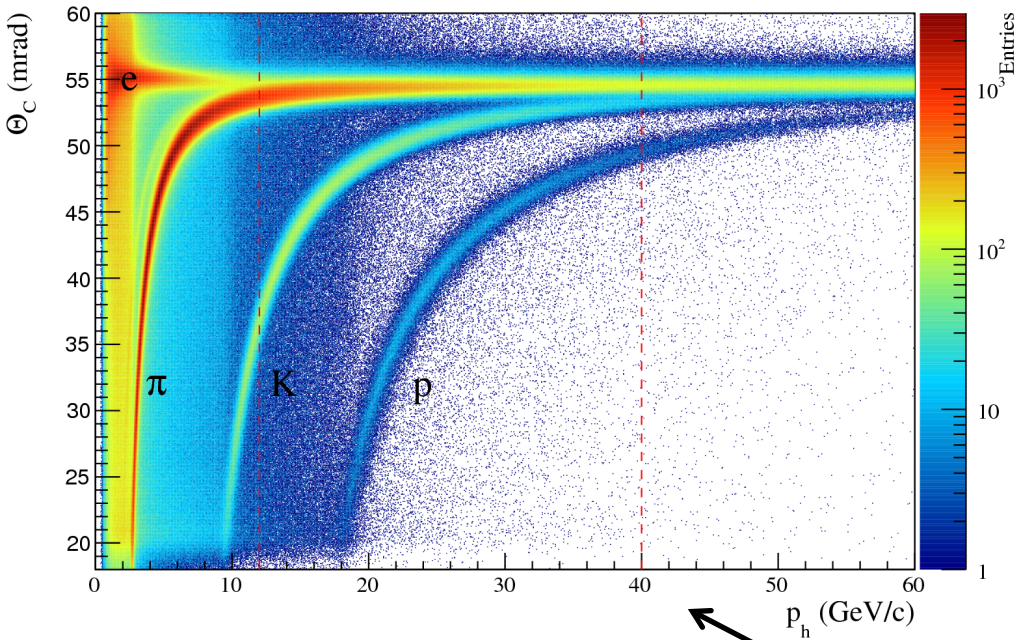
quark PDFs

Experimentally measured multiplicity must be corrected for many effects as

- ✧ Spectrometer acceptance
- ✧ PID efficiency and purity
- ✧ Radiative effects
- ✧ Diffractive vector meson production



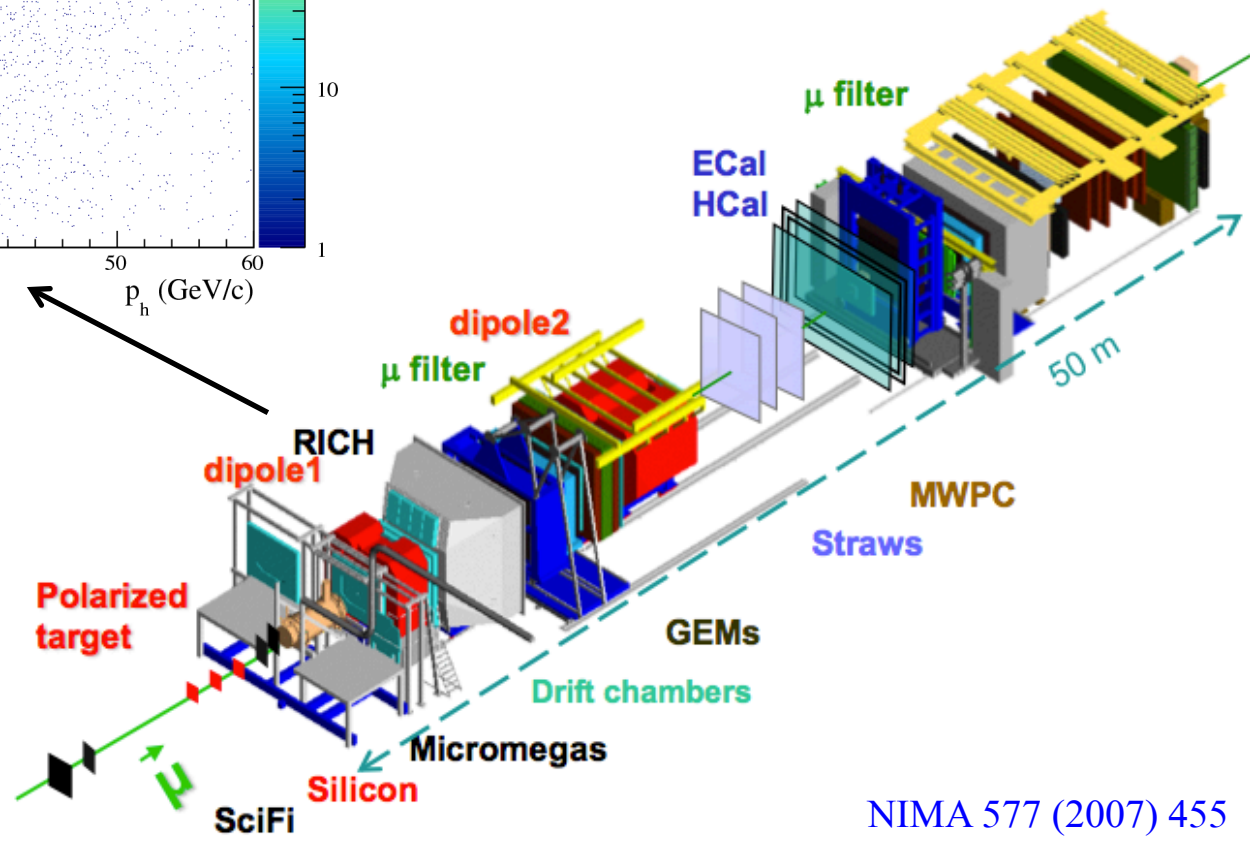
# COMPASS Spectrometer



- Fixed-target
- Polarised muon beam & polarised targets p&d

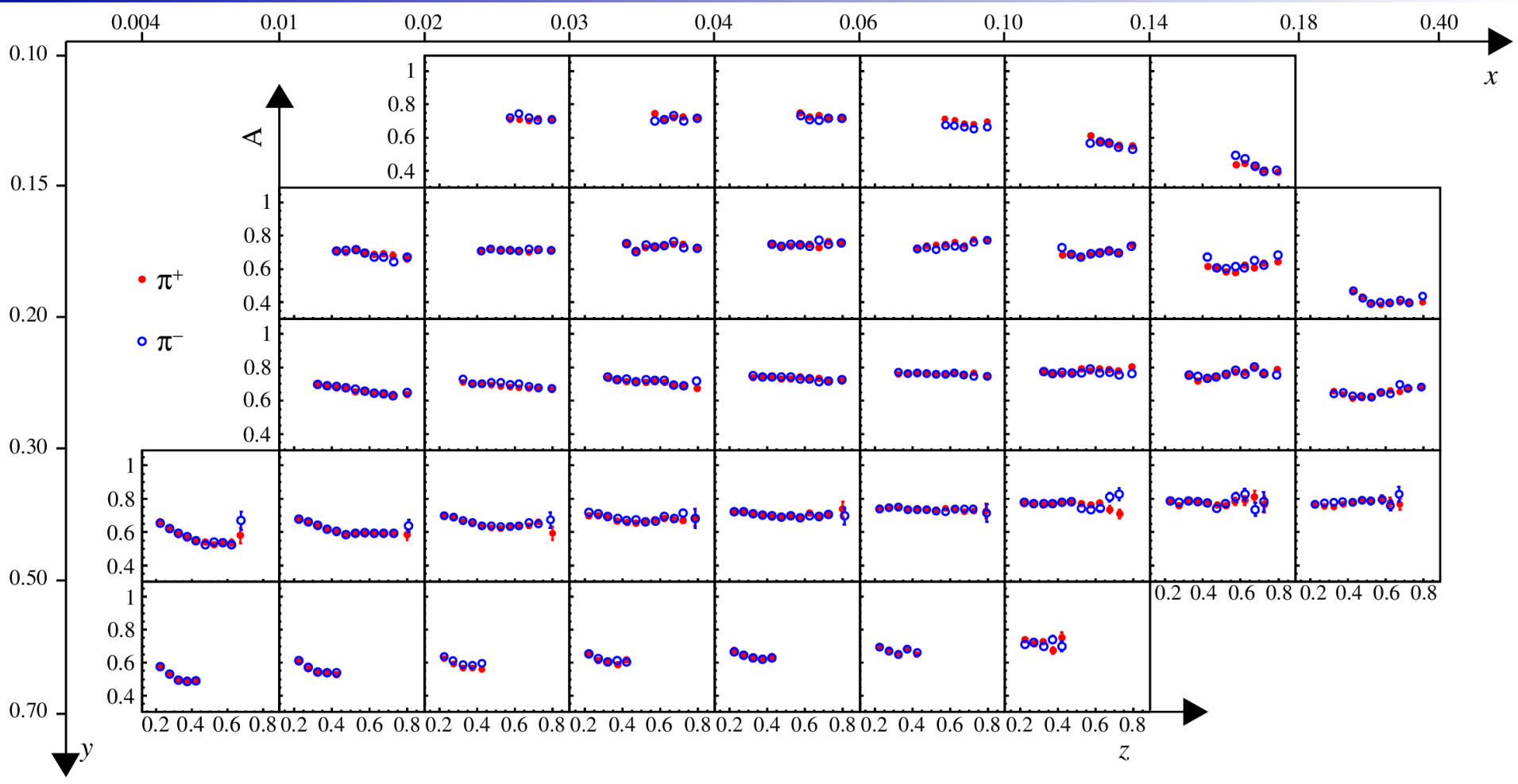
Excellent discrimination between  $\pi$ ,  $K$ ,  $p$  using RICH

This analysis:  
 160 GeV  $\mu^+$  beam  
 1.2 m long polarised  ${}^6\text{LiD}$  isoscalar target (2006)



NIMA 577 (2007) 455

# Acceptance

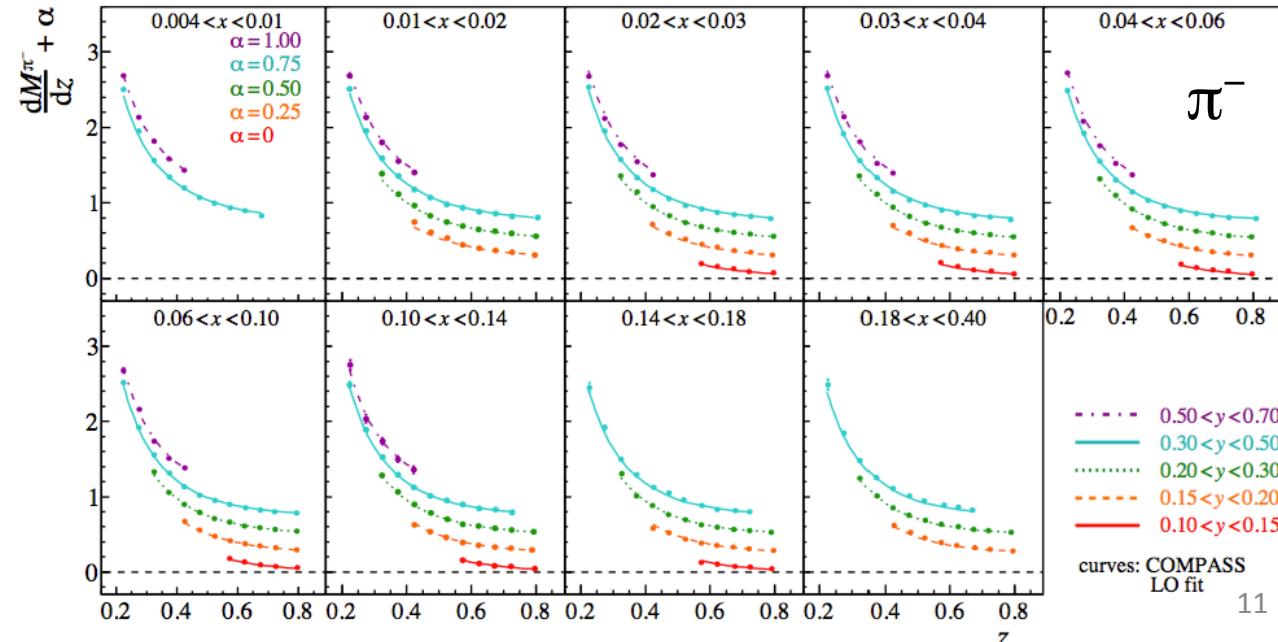
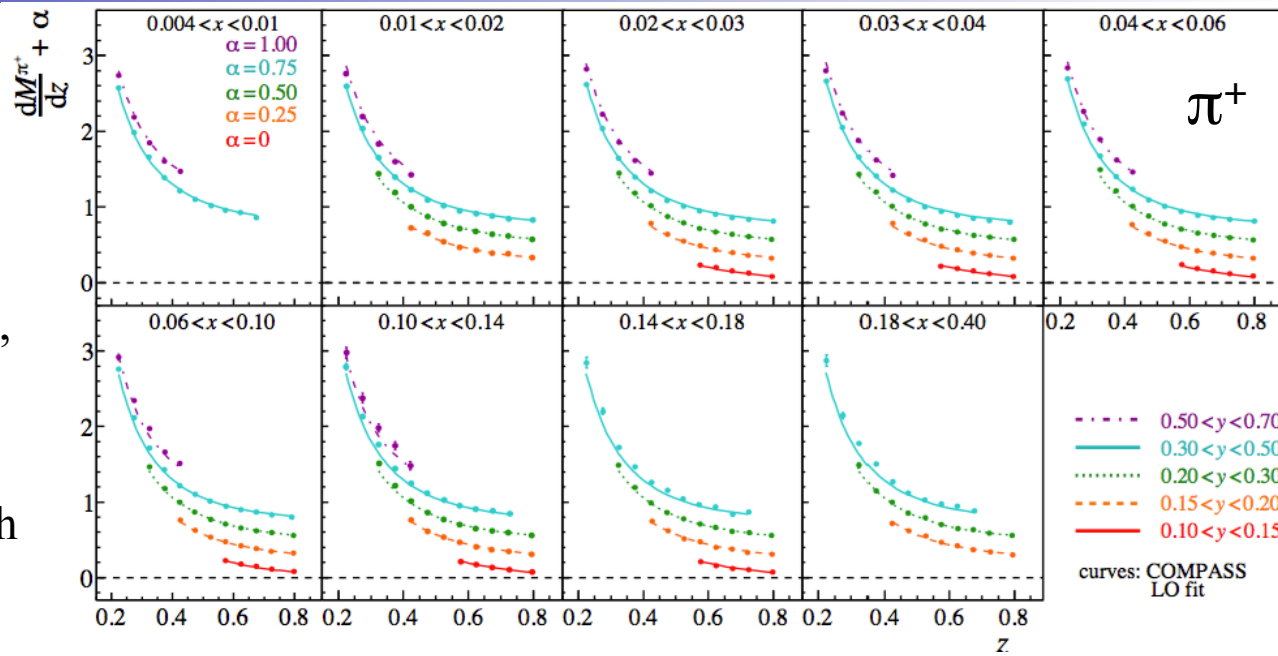


- ✧ Multidimensional evaluation of acceptance to avoid model dependencies
- ✧ High and flat acceptance in all kinematic bins, about 60-80%, uncertainty about 5%
- ✧ Little kinematic dependence except at high  $x$

# Charged pion multiplicity results

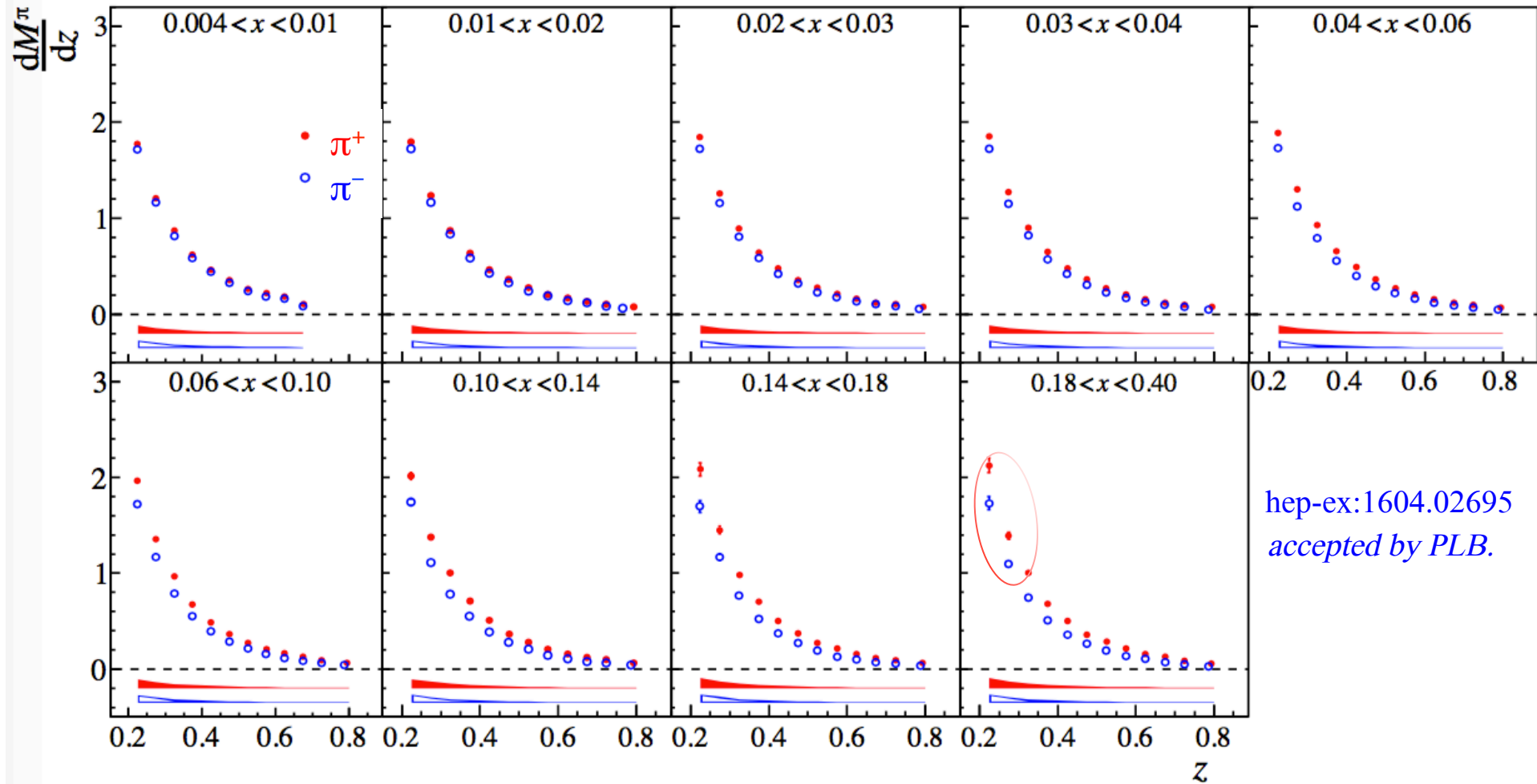
## 3-D kinematic binning in $x$ , $y$ , and $z$

- ✧ 317 kinematic bins
- ✧ Practically no  $y$  dependence, strong  $z$  dependence
- ✧ curves: COMPASS LO pQCD fit: Results agree with world FFs
- ✧ DSS++ fit of FFs used preliminary data (only 189 kinematic bins)
- ✧ Paper accepted by PLB, arXiv:1604.02695



# Charged pion multiplicity results

2-D projection in  $x, z$



✧ Small charge asymmetry due to u-quark dominance

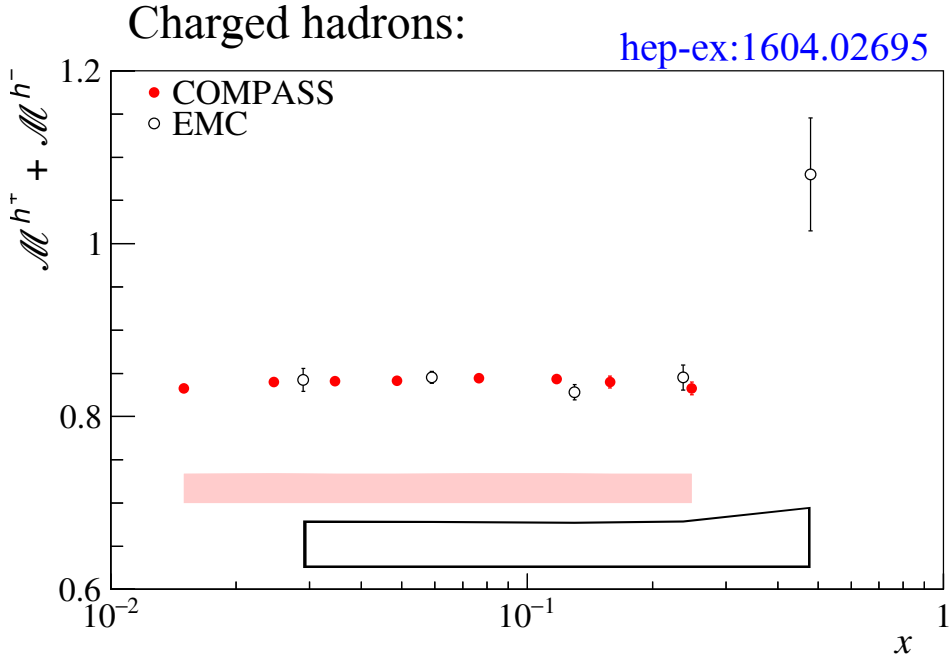
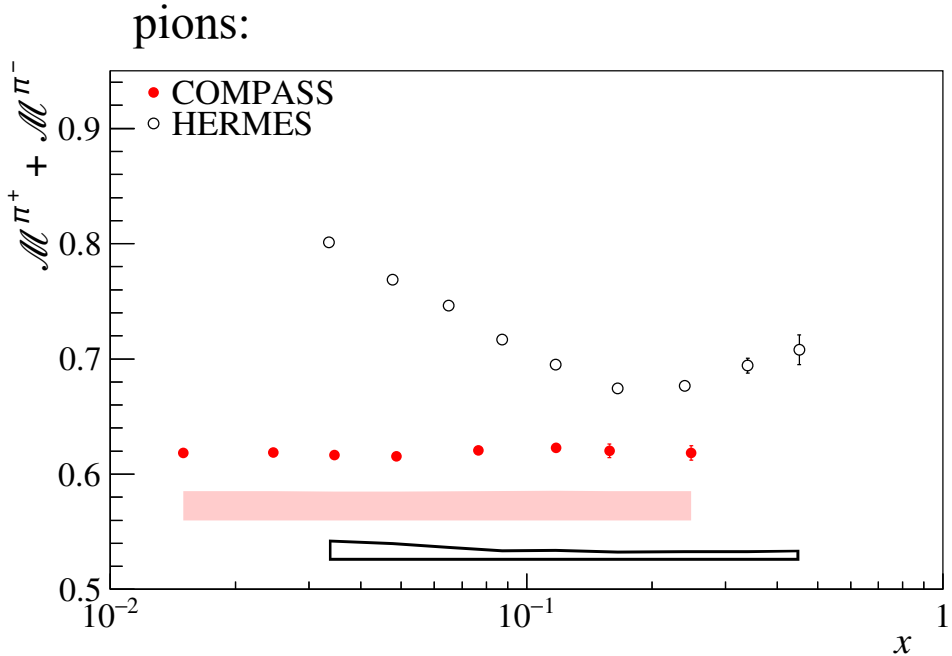
# Pion multiplicity sum

For the isoscalar target, when expressed at LO the sum is:

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

z-dependent term

⇒ z integrated sum is expected to be almost flat vs. x

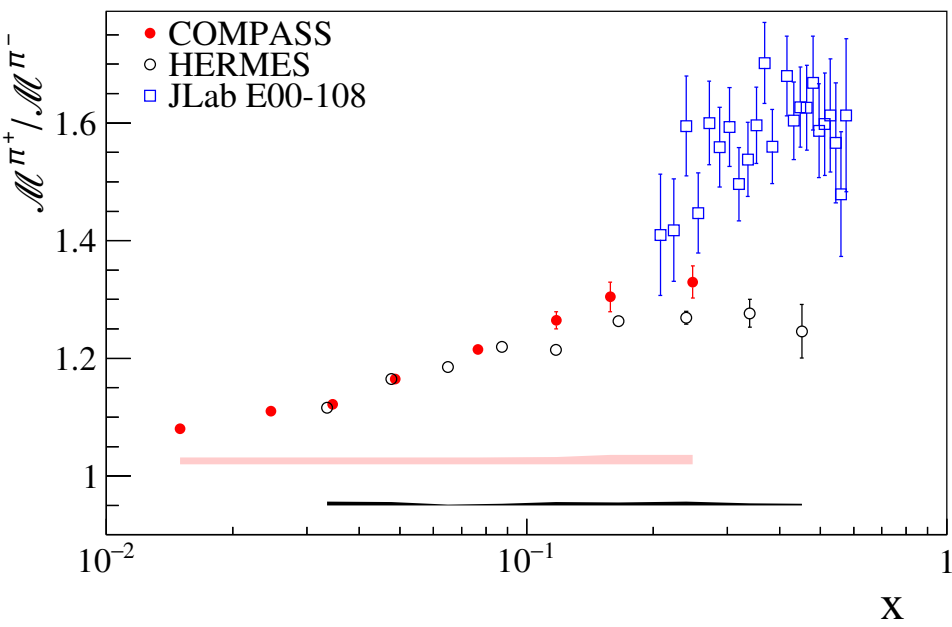


no x-dependence observed neither in COMPASS nor in EMC data as expected from LO predictions, at variance with HERMES data (lower energy)

# $\pi^+/\pi^-$ multiplicity ratio

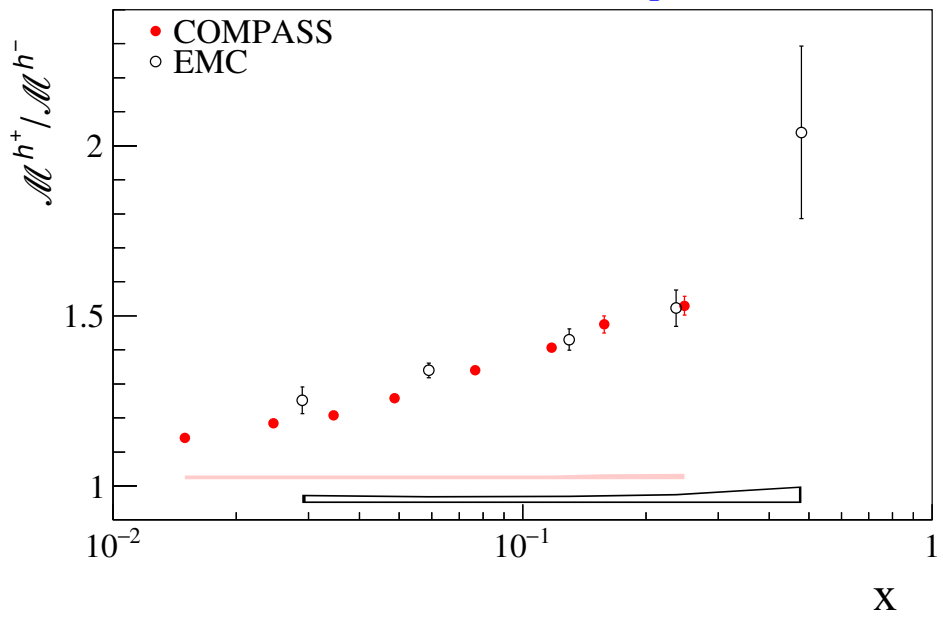
- ✧ Interesting observable ( $\pi^+/\pi^-$ ,  $h^+/h^-$ ) because of cancellation of most of experimental systematic uncertainties
- ✧ Good agreement between COMPASS and EMC for charged hadrons, similar kinematic ranges covered by both experiments
- ✧ Reasonable agreement between COMPASS and HERMES results despite the discrepancy observed in the sum

pions:



Charged hadrons:

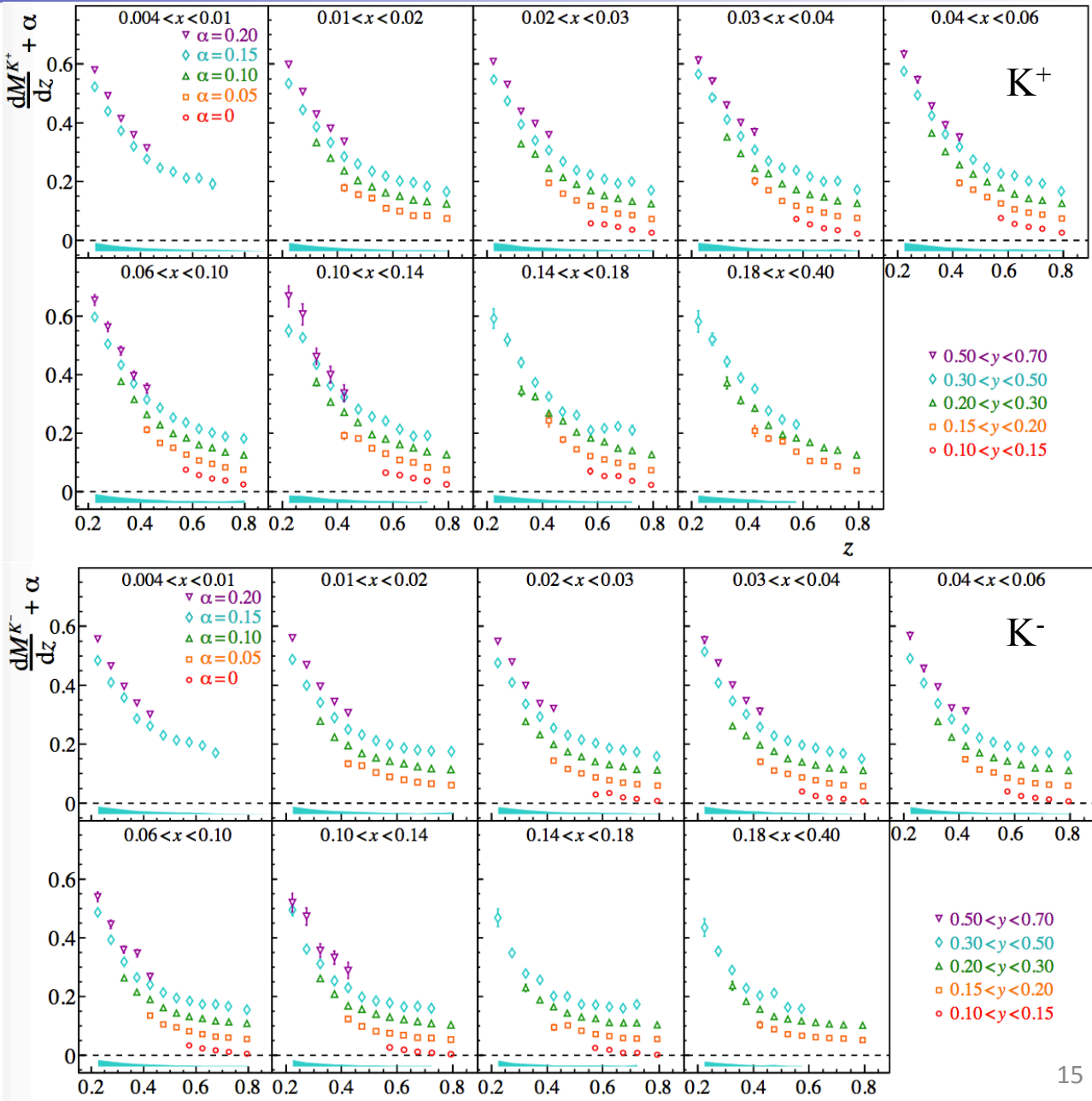
[hep-ex:1604.02695](https://arxiv.org/abs/hep-ex/1604.02695)



# Charged Kaon multiplicity results

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

- ✧ 317 kinematic bins
- ✧ Strong  $z$  dependence as expected
- ✧ Paper submitted to PLB.  
hep-ex:1608.06760
- ✧ Valuable inputs for NLO QCD analyses foreseen in the near future



# Kaon multiplicity sum

For the isoscalar target, when expressed at LO the sum is:

$$M^{K^++K^-} \approx \frac{QD_Q^K + SD_S^K}{5Q + 2S}$$

non-strange:  $Q = u + d + \bar{u} + \bar{d}$   
 $D_Q^K = 4D_{fav}^K + 6D_{unf}^K$

strange:  $S = s + \bar{s}$ ,  $D_S^K$

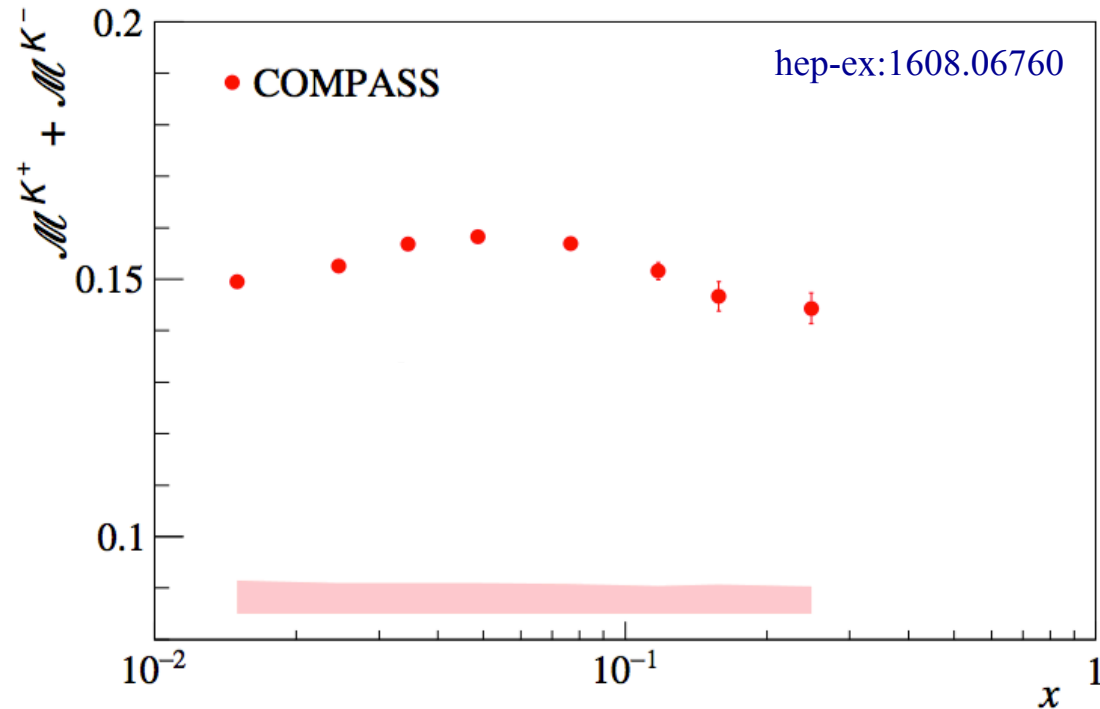
→ Separate strange and non-strange contributions

✧ At high  $x \rightarrow S \approx 0 \rightarrow$  access  $D_Q^K$

✧  $D_Q^K = 5M^{K^++K^-} = 0.7$

✧  $D_Q^K = 0.43$  in DSS analysis

Kaon results suggest larger non-strange than in DSS (PRD 75 114010)





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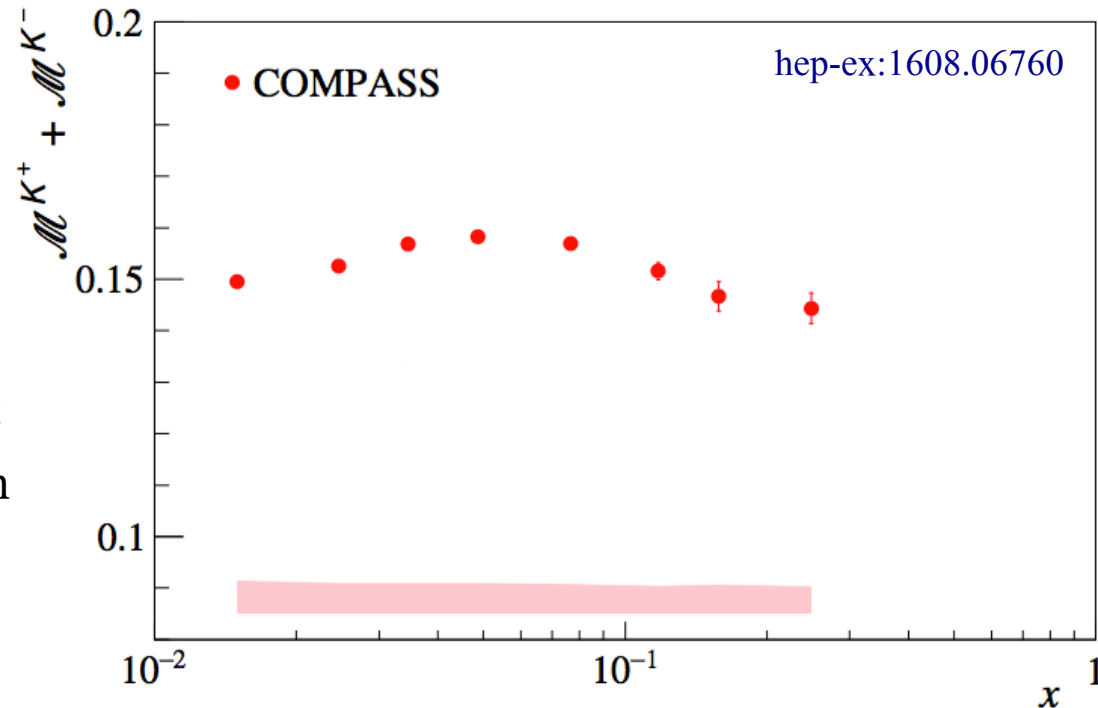
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✧ At low  $x \rightarrow SD_S^K$  may be significant

With DSS  $D_{str}/D_{fav}$ , one expects a rise in the  $M^{K^++K^-}$  towards low  $x$  (DSS  $\sim 50\%$  increase)



✧ Strong increase of  $M^{K^++K^-}$  towards low  $x$  is not observed

✧ Results suggest lower  $D_{str}/D_{fav}$  than in the DSS parameterisation

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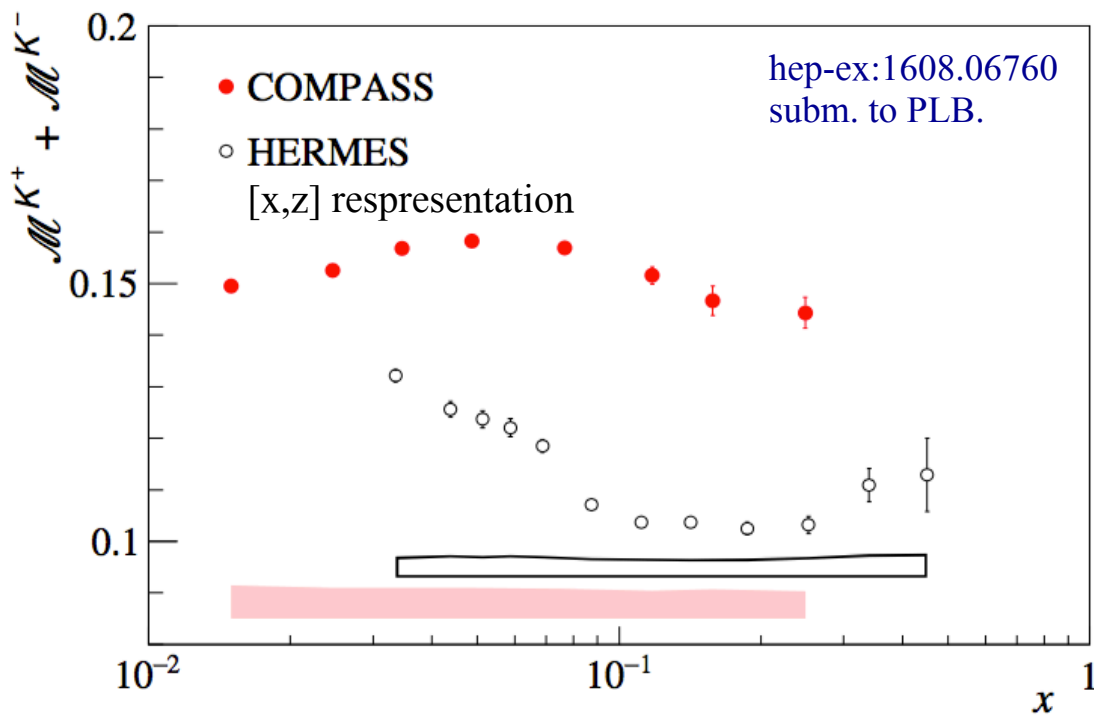
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## COMPASS vs. HERMES

Significant discrepancies observed:

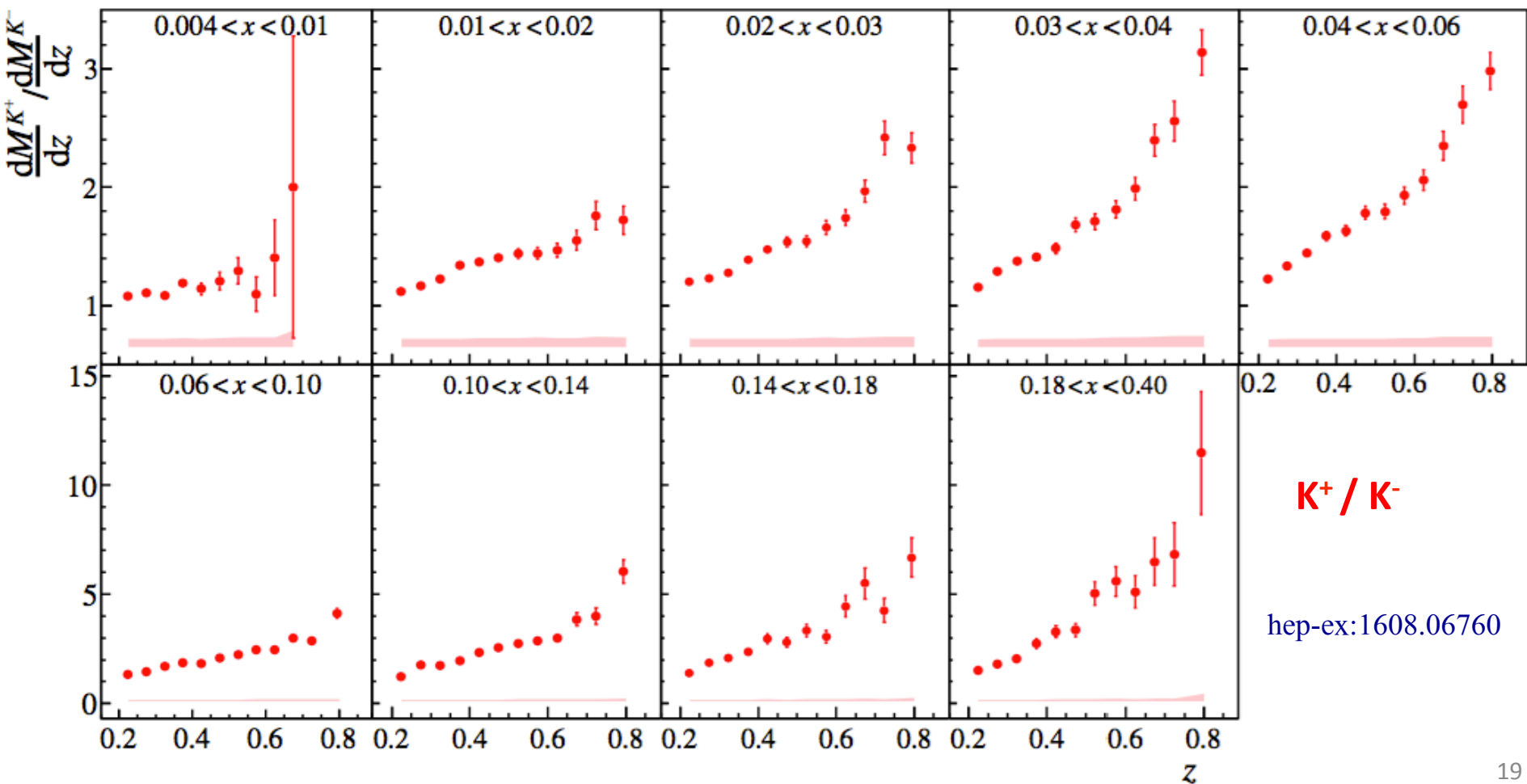
- shape of the sum at low x
- value of the sum at high x



# Kaon multiplicity ratio

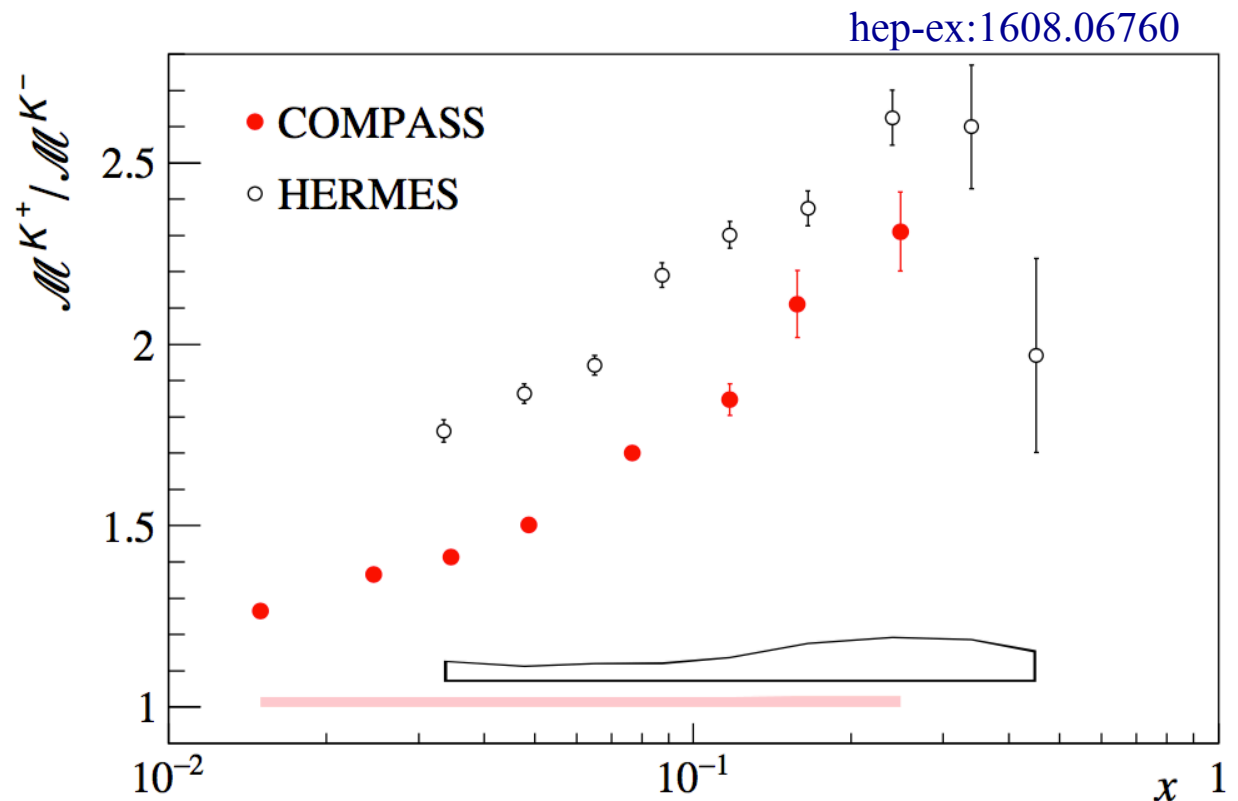
## 2-D projection in $x$ , and $z$

- ✧  $K^+/K^-$  is interesting to study due to significant cancellation of systematic uncertainties
- ✧ Larger ratio at large  $z$  reflects favoured fragmentation dominance in  $K^+$



# Kaon multiplicity ratio, COMPASS vs. HERMES

- ✧ The ratio  $K^+/K^-$  is interesting to study due to significant cancellation of systematic uncertainties
- ✧ Significant discrepancy between COMPASS and HERMES is observed in contrast with the pion case ( $\pi^+/\pi^-$ ) where a good agreement was found
- ✧ NLO QCD fits of FFs will help



# Summary

- ✧ Charged pion, kaon and hadron multiplicities were measured at COMPASS using data collected with an isoscalar  ${}^6\text{LiD}$  target and 160 GeV  $\mu^+$  beam in 2006
  - ✧ in a wide kinematic domain
  - ✧ in 3-D kinematic binning in  $x, y$  and  $z$
  - ✧ Paper on charged pion and hadron multiplicities; *accepted by PLB*  
[CERN-EP-2016-095](#), [hep-ex:1604.02695](#)
  - ✧ Paper on charged kaon multiplicities; *submitted to PLB*  
[CERN-EP-2016-206](#), [hep-ex:1608.06760](#)
- ✧ Visible tensions between COMPASS and HERMES (lower energy) results
- ✧ Favored and unflavored FF extracted from LO fits to COMPASS  $\pi^\pm$  multiplicities only are in good agreement with results from global fits

# Backup

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# RICH efficiency/purity

- ✧ COMPASS RICH detector is able to detect  $\pi$ , K and p starting from 3, 9 and 18 GeV/c respectively, up to about 50 GeV/c
- ✧ A 3x3 efficiency-purity matrix is obtained from data based on decays of  $K^0$ ,  $\Phi$  and  $\Lambda$
- ✧ The analysis region was limited to a momentum range where K identification is stable, namely 13-40 GeV/c
- ✧ In the selected range, efficiency of K id is very high at the same time, miss-identification of  $\pi$  as K is very low.
- ✧ In order to minimize possible systematic effects,  $\pi$  and h multiplicities were extracted in the same momentum range as K

