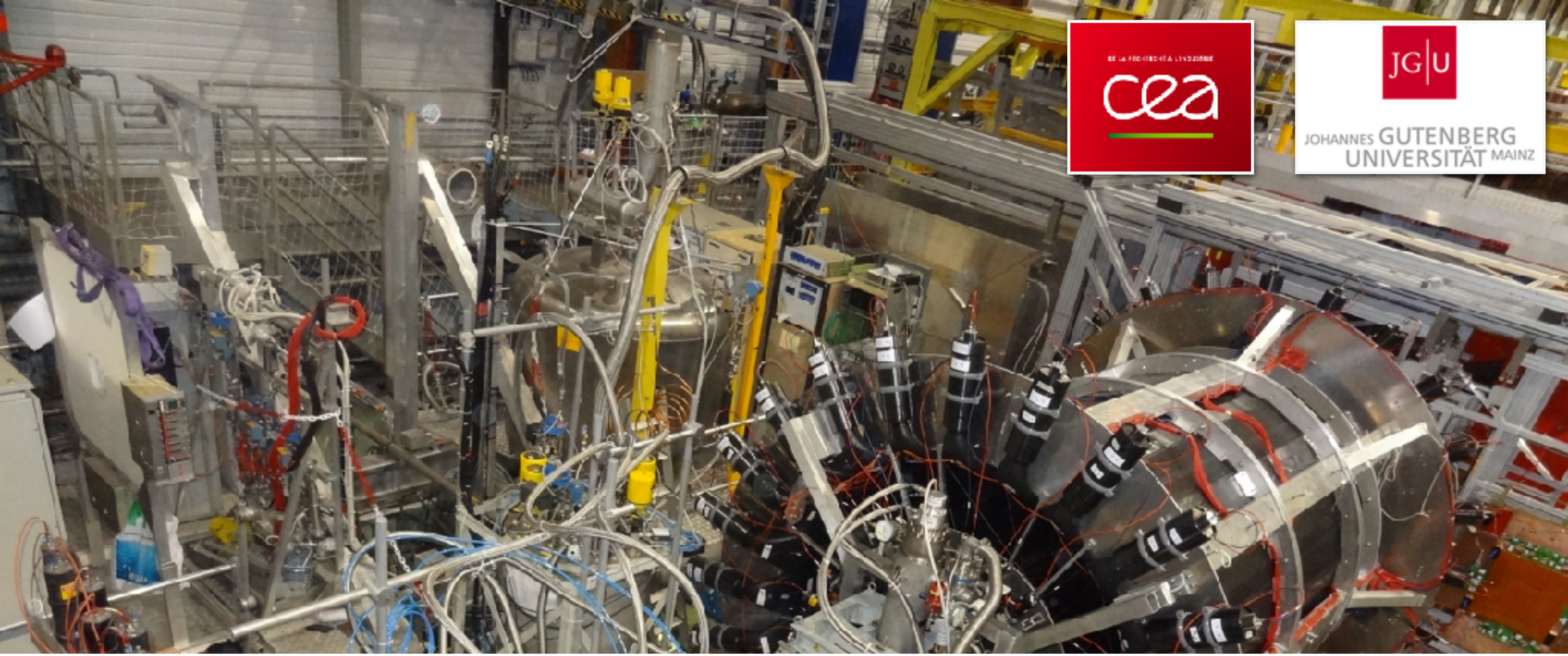
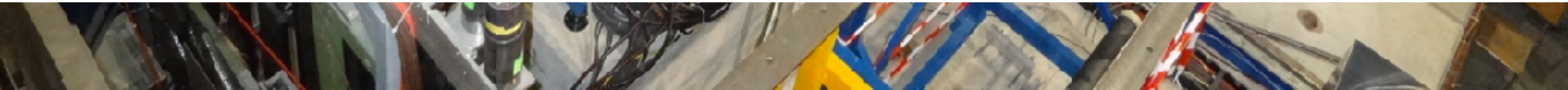


QUARK FRAGMENTATION FUNCTIONS FROM PION AND KAON PRODUCTION

IN DEEP-INELASTIC SCATTERING FROM COMPASS

Nicolas Pierre

November 10, 2016 – GDR QCD 2016



CONTENTS

- Extraction of quark fragmentation functions from pion multiplicities

- Extraction of quark fragmentation functions from kaon multiplicities

- Radiative corrections

MOTIVATION : STRANGE QUARK POLARIZATION

Nucleon spin - Strange quark polarisation is defined by : $\int_0^1 \Delta s(x) + \Delta\bar{s}(x)dx = 2\Delta S$

From NLO QCD fits of g_1 along with a_8 from β decay :

$$2\Delta S = -0.08 \pm 0.01 \pm 0.02$$

(PLB 647(2007) 8-17)

From NLO QCD fits of longitudinal SIDIS $A_1^{K\pm}$, $A_1^{\pi\pm}$ and $A_1^{p,d}$:

$$2\Delta S = -0.01 \pm 0.01 \pm 0.01$$

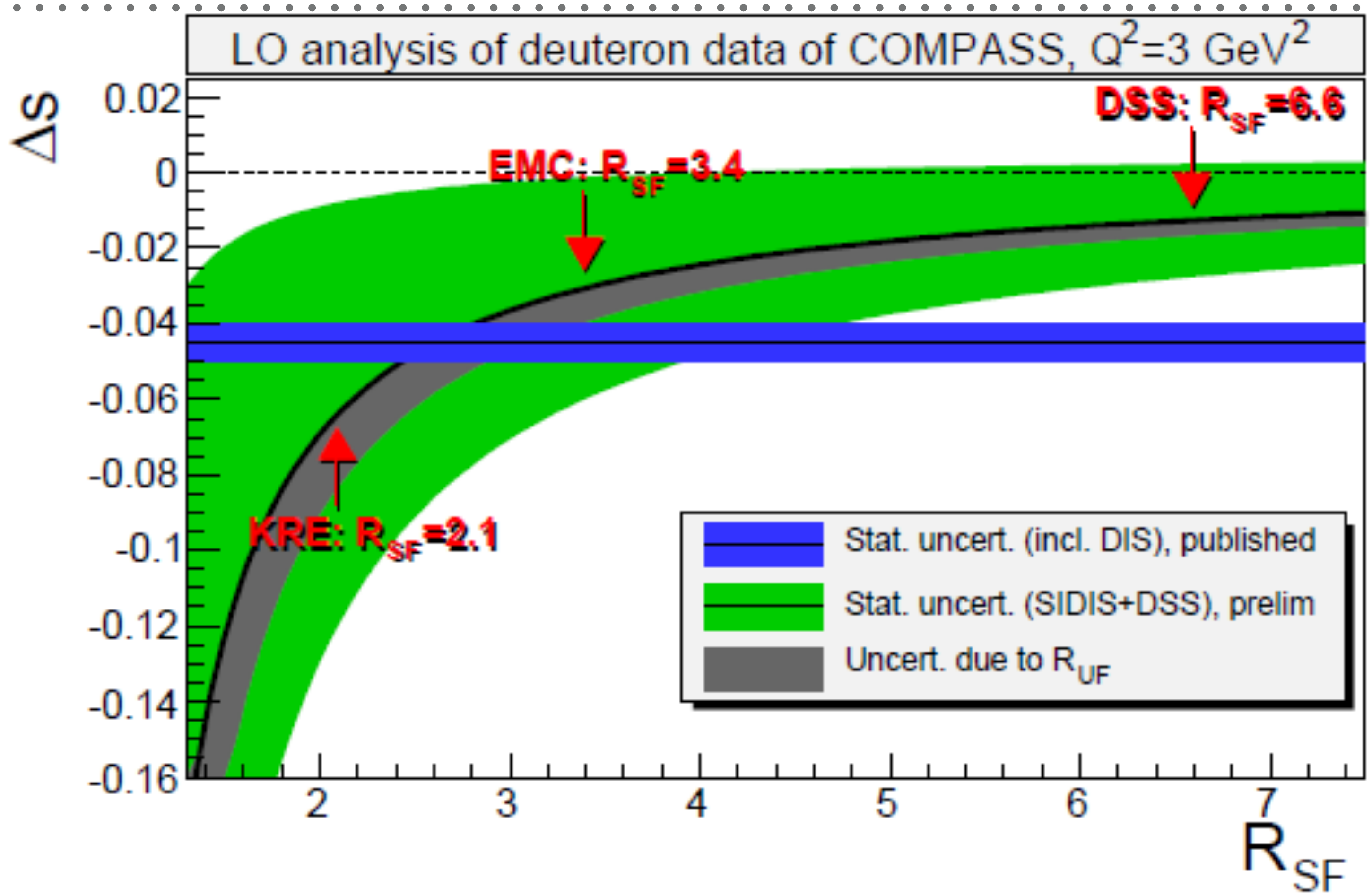
(PLB 693(2010) 227-235)

- ΔS form Semi-Inclusive Asymmetries strongly linked to quark fragmentation, especially the strange one, poorly known :

(PRB 75(2007) 114010) $$2\Delta S = f(R_{SF}),\ R_{SF} = \frac{\int D_{\bar{s}}^{K^+}(z)dz}{\int D_u^{K^+}(z)dz}$$

FFs

MOTIVATION : STRANGE QUARK POLARIZATION



(PLB 680(2009) 217)

- ΔS form Semi-Inclusive Asymmetries strongly linked to quark fragmentation, especially the strange one, poorly known :

(PRB 75(2007) 114010)

$$2\Delta S = f(R_{SF}),\ R_{SF} = \frac{\int D_{\bar{s}}^{K^+}(z)dz}{\int D_{u}^{K^+}(z)dz}$$

FFs

- One goal of the analysis : Extract FFs from COMPASS kaon data and then determine R_{SF}

FRAGMENTATION FUNCTIONS

Fragmentation functions :

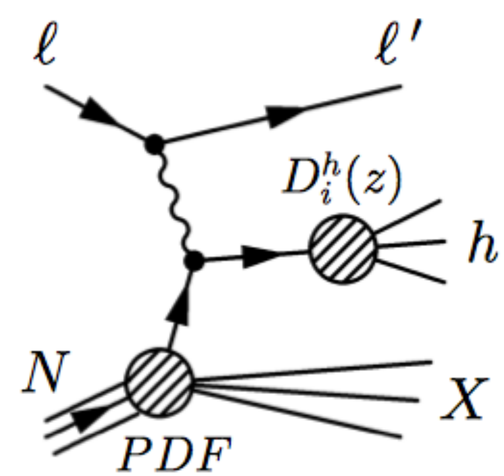
- Quark fragmentation function into hadron D^{h}_{q} : probability density of finding a hadron h with a certain energy fraction z of the struck quark q at given Q^2.
- Can be measured in several processes, including SIDIS.
- Are universal quantities, can describe several processes.

HADRON MULTIPLICITIES FROM SIDIS

What is a SIDIS hadron multiplicity measurement ?

One can express the differential cross section for hadron production normalised to the differential inclusive DIS cross section by :

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



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

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

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

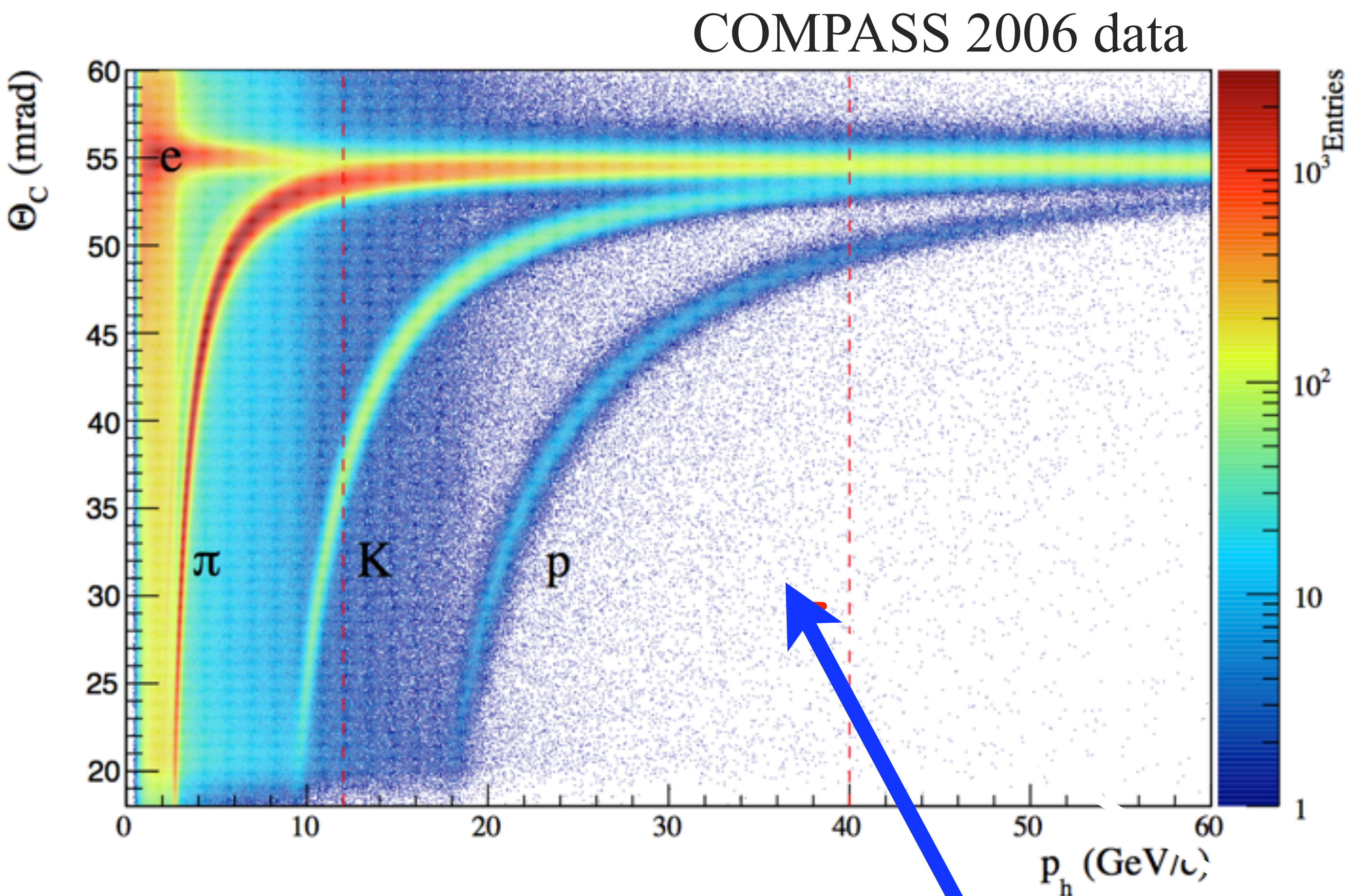
This can also be expressed, in LO pQCD, as a function of Parton Distribution Functions (PDFs) and Fragmentation Functions (FFs) :

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

quark to hadron FFs

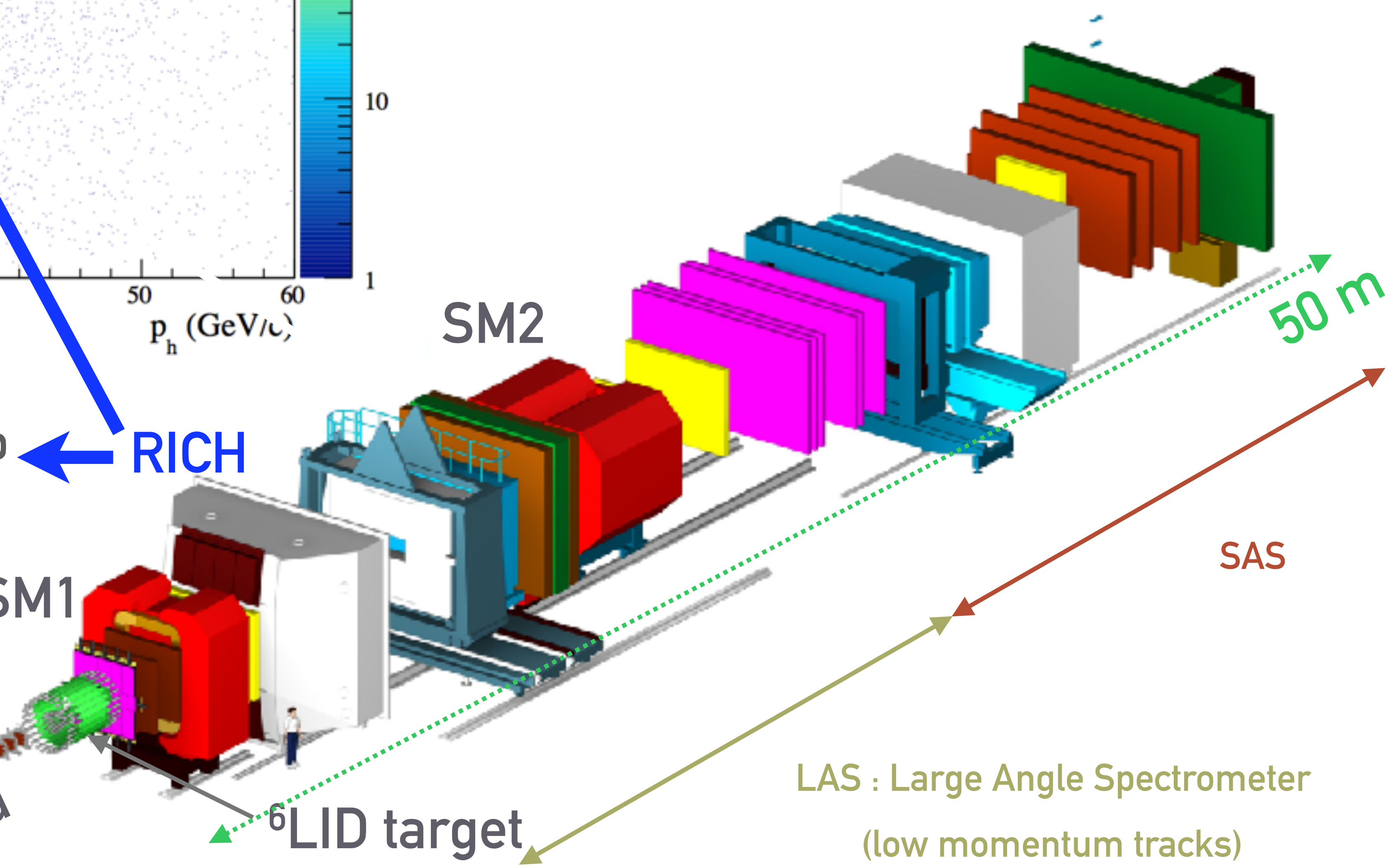
quark PDFs

COMPASS SPECTROMETER



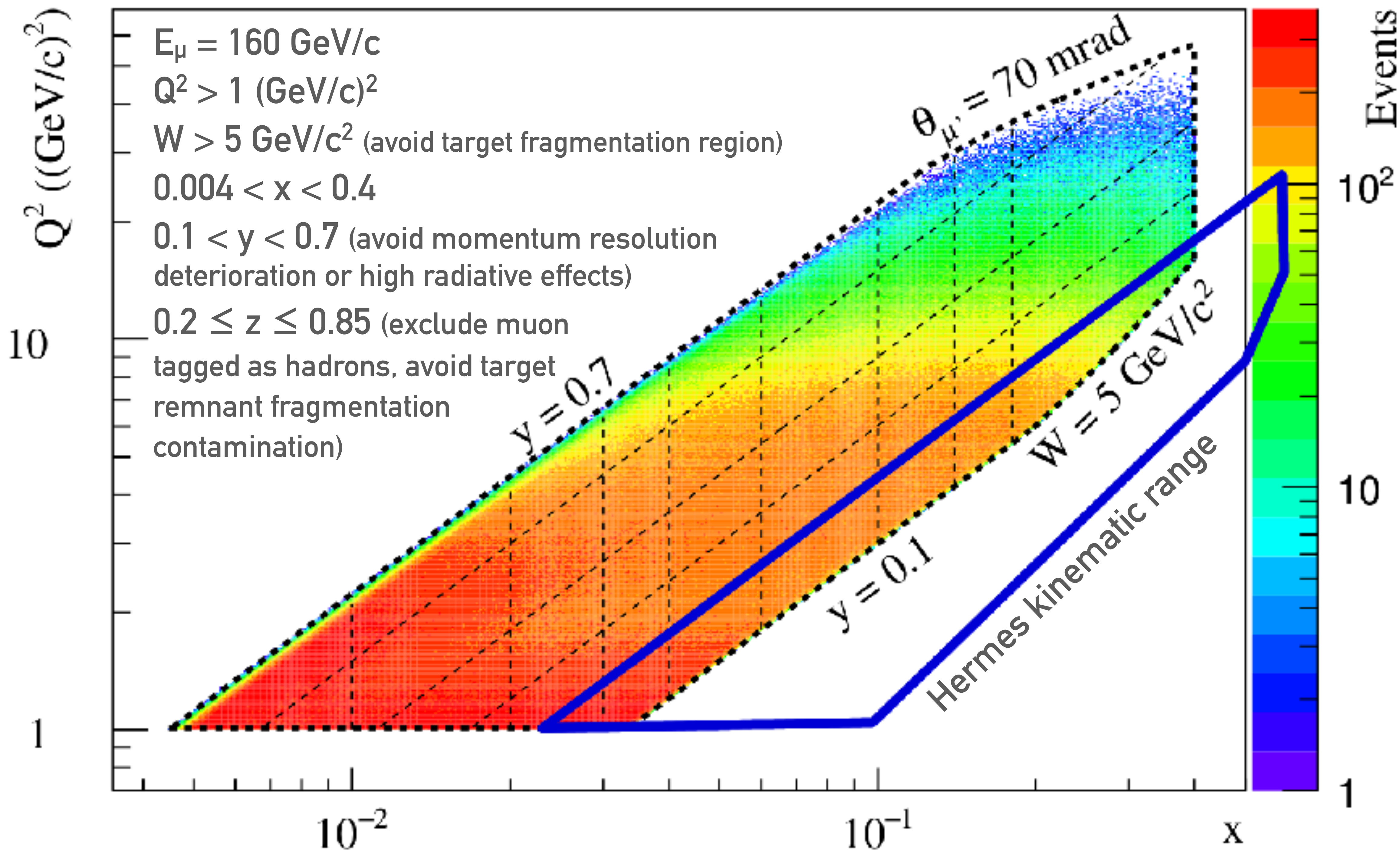
- Fixed target experiment at CERN SPS
- Can operate with muon or hadron beams
- This analysis : 160 GeV μ^+ beam (2006)

- RICH : excellent charged π, K, p discrimination
- This analysis : 1.2 m long, polarized ^{6}LID isoscalar target (2006)

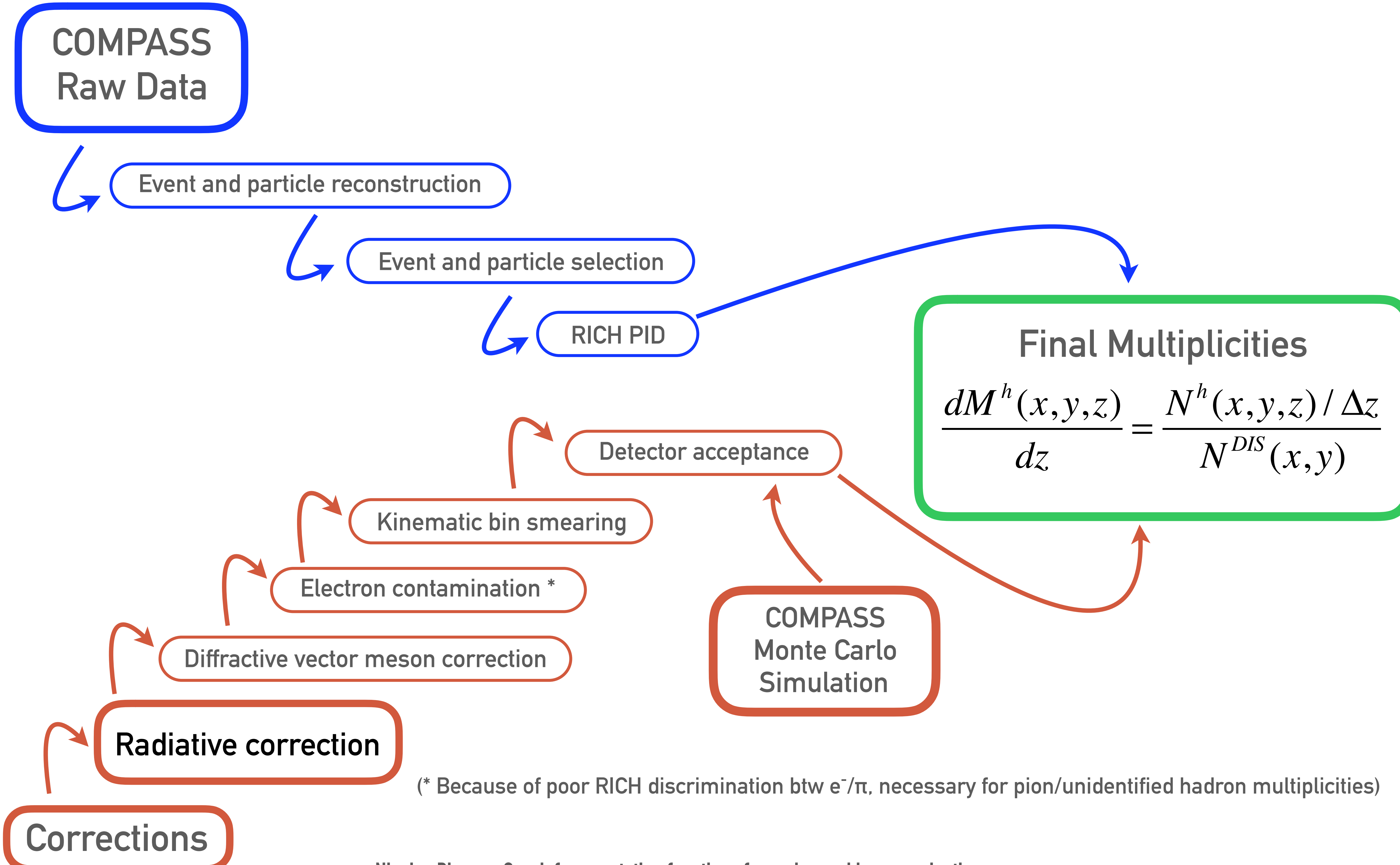


COMPASS KINEMATICS

The COMPASS kinematic range :



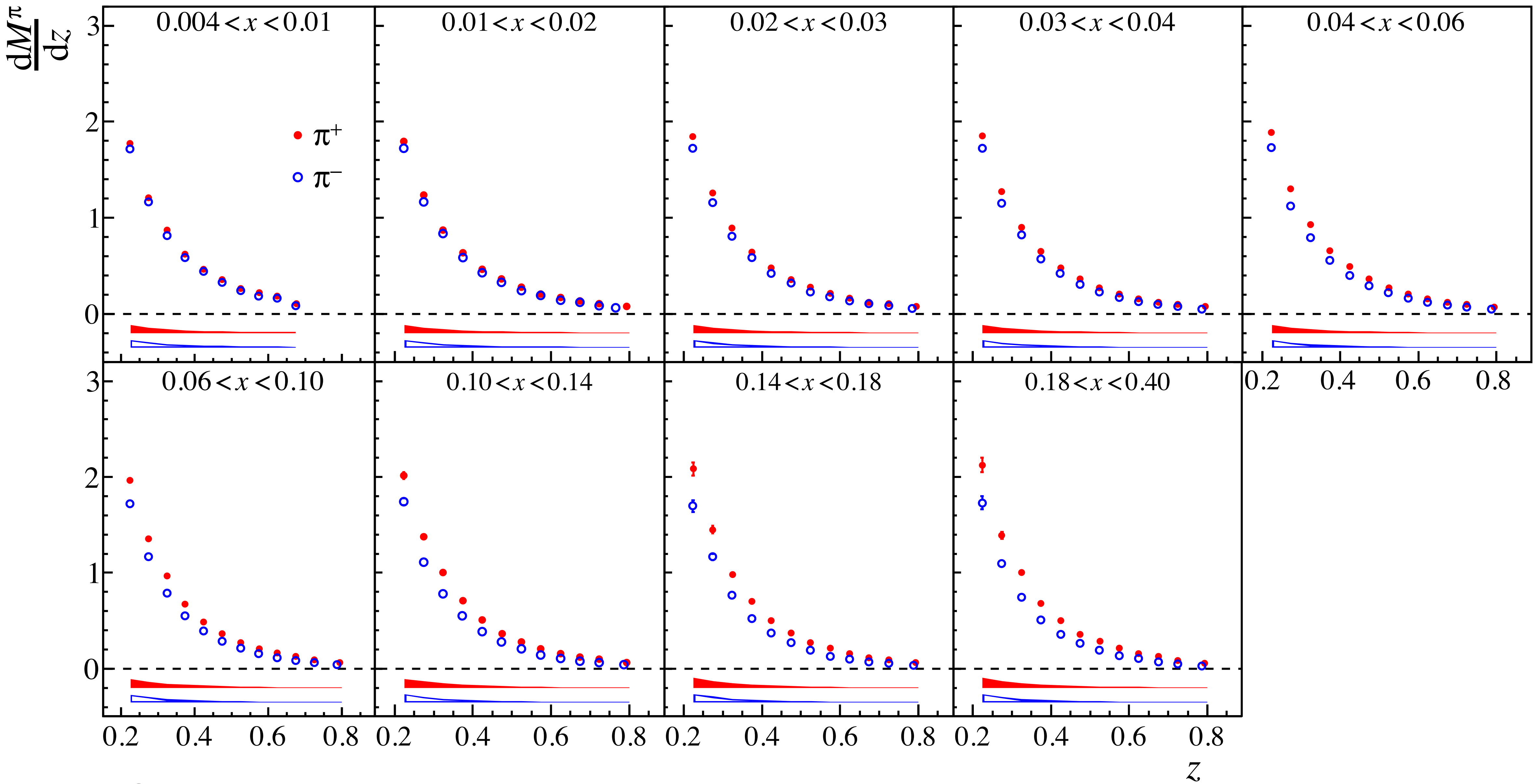
MULTIPLICITY ANALYSIS



(* Because of poor RICH discrimination btw e^-/π, necessary for pion/unidentified hadron multiplicities)

PION MULTIPLICITY RESULTS

arXiv:1604.02695v2
CERN-EP-2016-095
(to be published in PLB)



Systematic studies :

Acceptance : 5%

RICH PID/Efficiency for $\pi^{\pm}$: 0.1% (low y) - 2% (high y)

Diffractive VM correction : 12% max (low x, high z)

Electron correction : 50% conservative sys. error

x, y, z 3D-binning
317 kinematic bins
Strong z-dependance

EXTRACTION OF QUARK FF INTO PIONS

All in all, 12 FFs to extract. But using symmetries and assumptions, reduction to 2 independent FFs :

Charge and Isospin symmetries

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

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

Strangeness = unfavoured assumption

$$D_{unf}^{\pi} = D_{s}^{\pi\pm} = D_{\bar{s}}^{\pi\pm}$$

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

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

where $u, d, \bar{u}, \bar{d}, s, \bar{s}$ are PDFs

Two methods of LO extraction

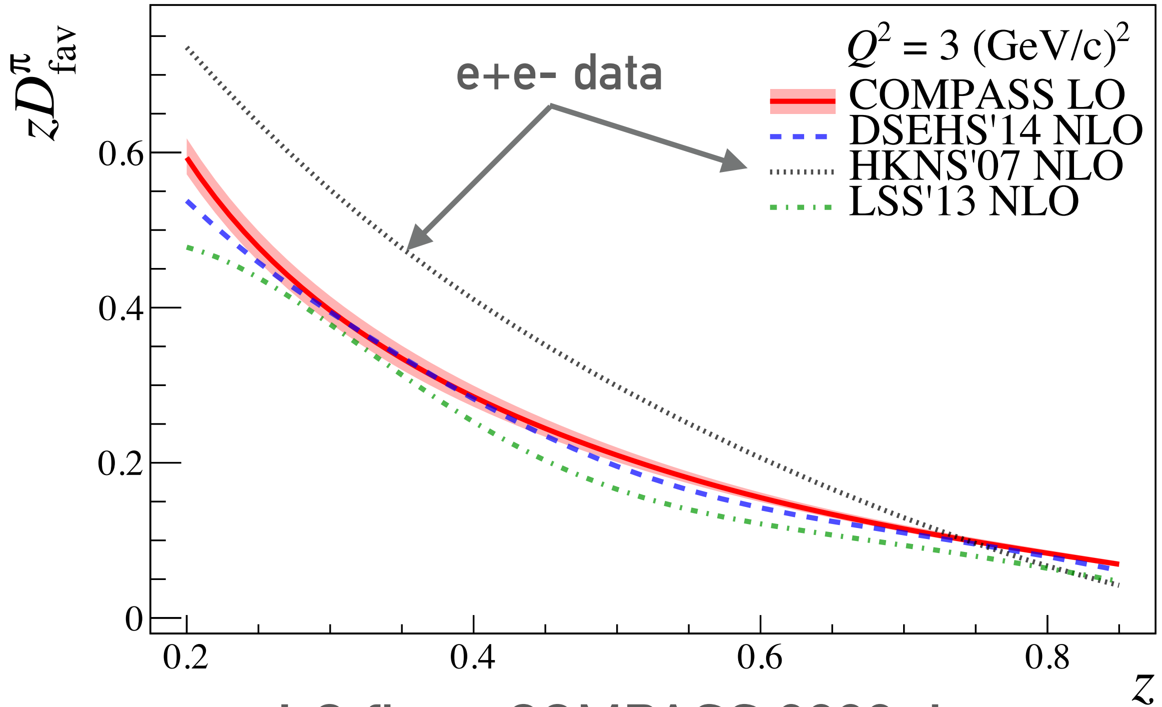
- Direct extraction with above formulas in each kinematic bin (not possible with kaons)
- Fits to data of multiplicities :

  Choice of functional form : $zD_i(z,Q_0^2) = N_i \frac{z^{\alpha_i}(1-z)^{\beta_i}}{\int_{0.2}^{0.85} z^{\alpha_i}(1-z)^{\beta_i}}$

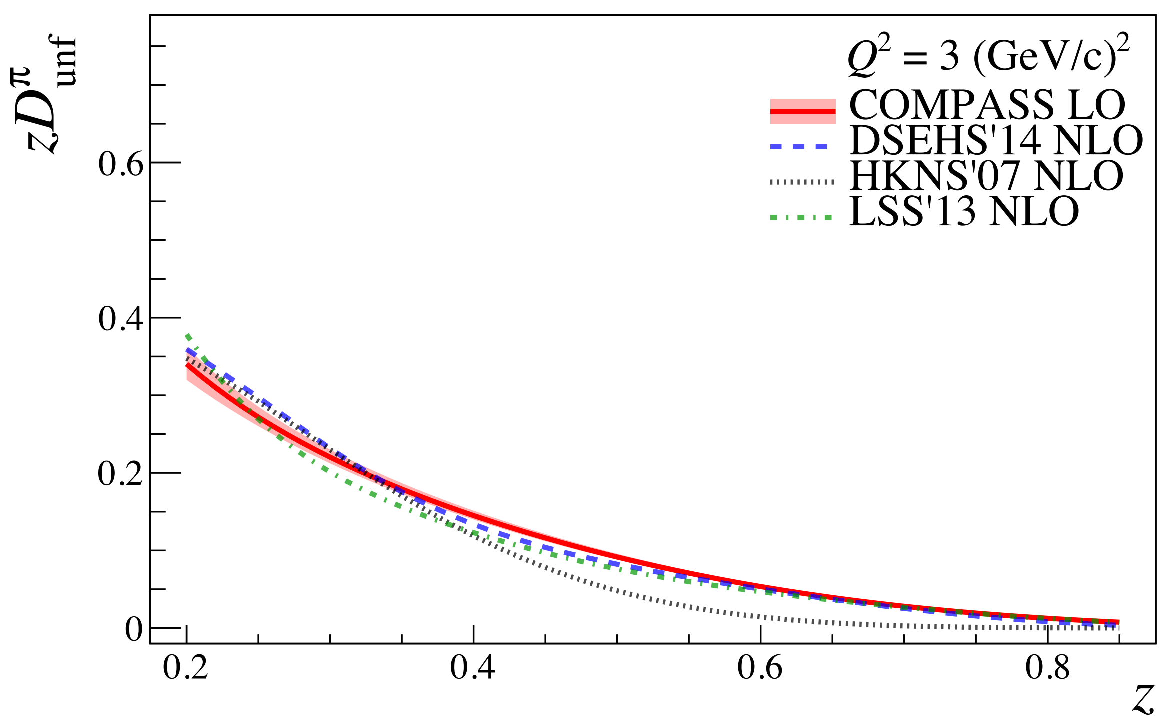
  Evolution of $Q^2 = 1$ $(\mathrm{GeV}/c)^2$ to given Q^2 done with DGLAP equations.

FF FROM COMPASS LO FIT OF $M^{\pi^{\pm}}$

arXiv:1604.02695v2
CERN-EP-2016-095
(to be published in PLB)



LO fit on COMPASS 2006 data



Results from COMPASS LO fit for D^{π}_{fav} and D^{π}_{unf} agree with other NLO fits using SIDIS data.

FF FROM COMPASS LO FIT OF $M^{\pi^\pm}$

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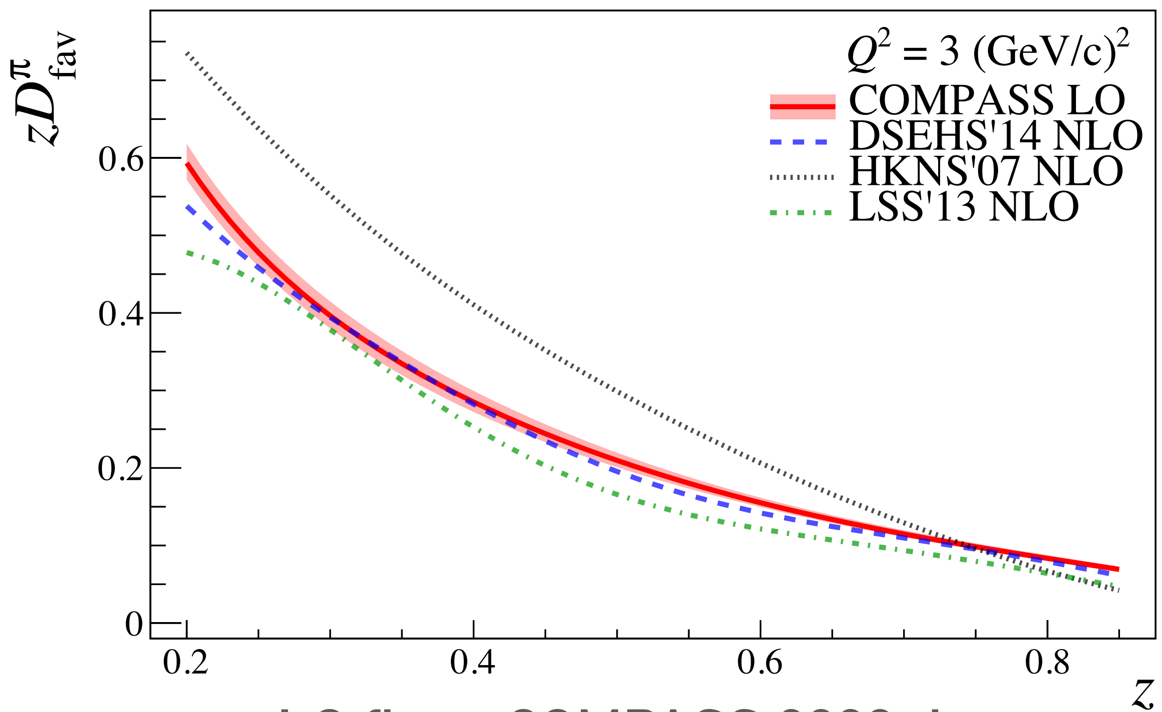
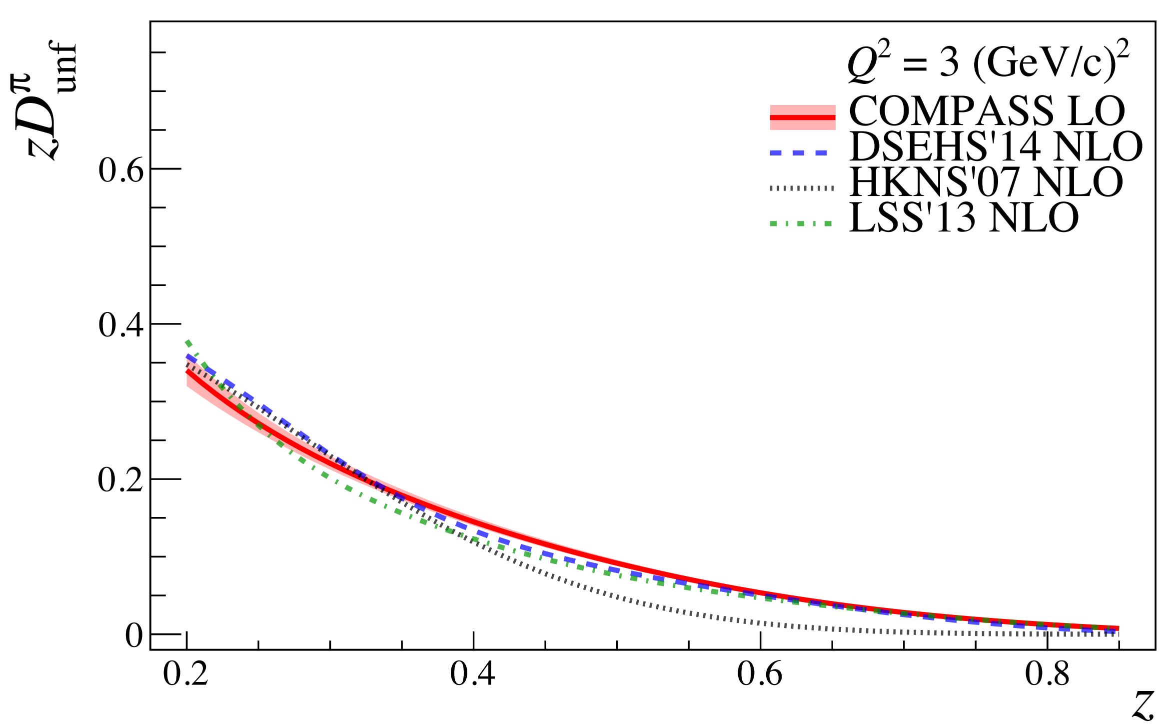


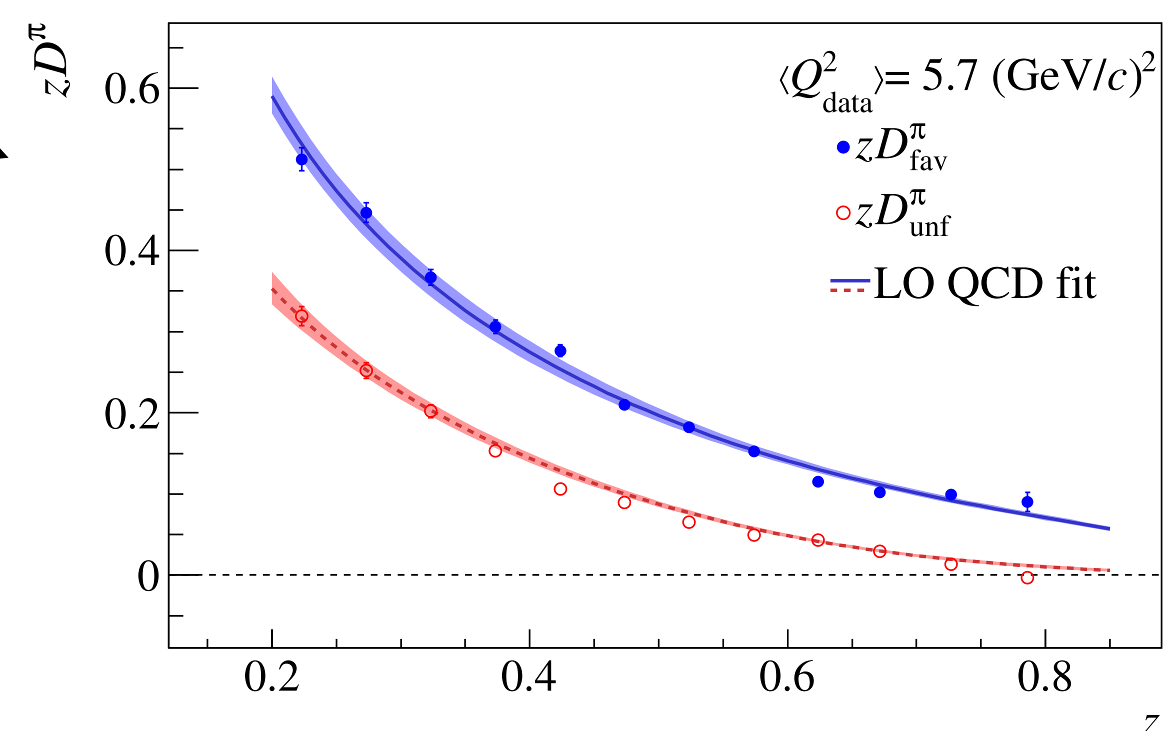
LO fit on COMPASS 2006 data



Results from COMPASS LO fit for D^{π}_{fav} and D^{π}_{unf} agree with other NLO fits using SIDIS data.

Results from direct extraction in individual kinematic (x,y,z) bins agree with extraction from global fit

Direct extraction for 1 x-y bin



MULTIPLICITY SUM

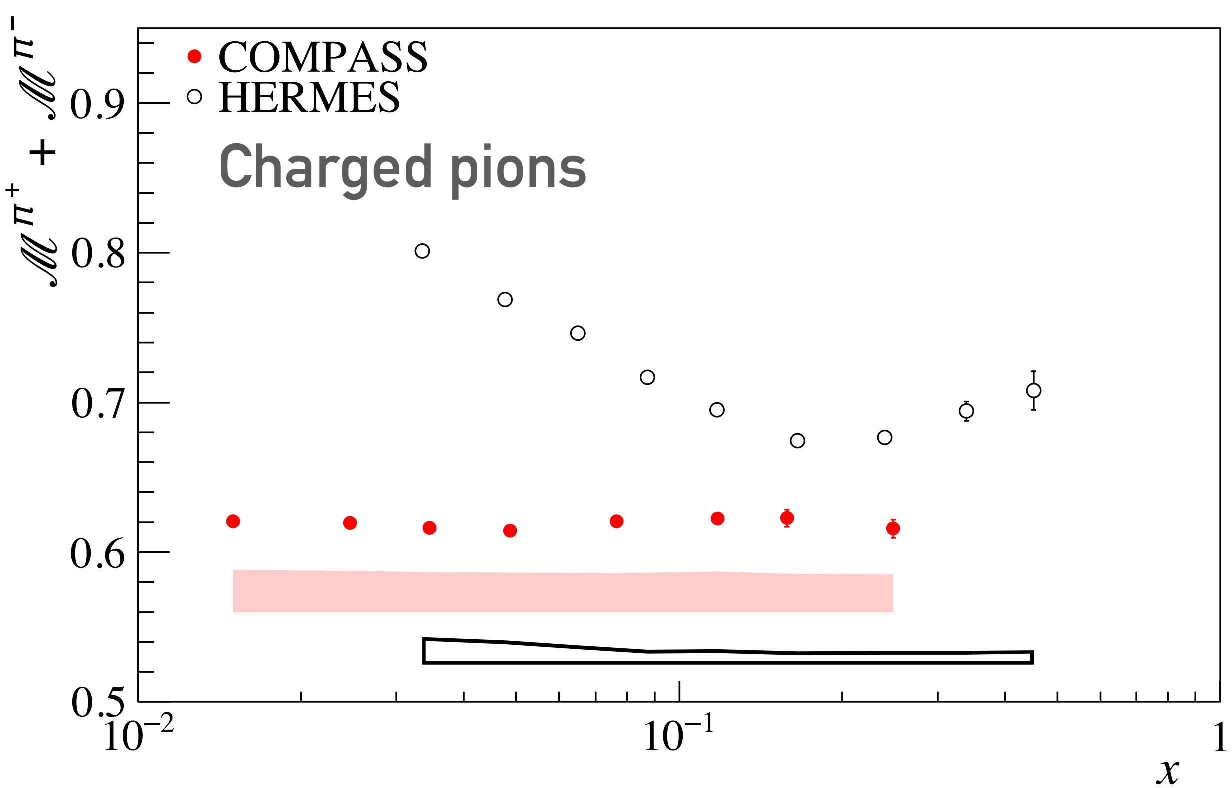
arXiv:1604.02695v2
CERN-EP-2016-095
(to be published in PLB)

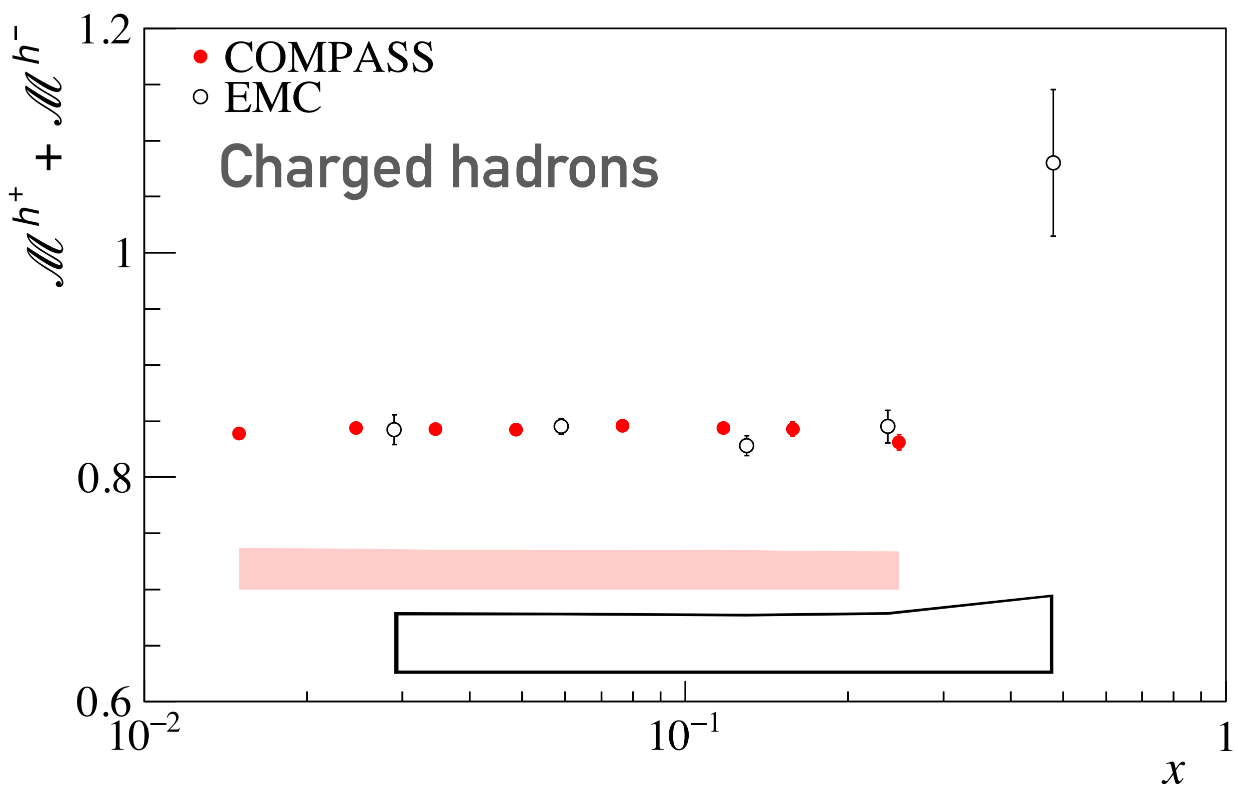
The multiplicity sum has a very simple expression at LO :

$$\mathcal{M}^{\pi+} + \mathcal{M}^{\pi-} = D^{\pi}_{fav} + D^{\pi}_{unf} - \frac{2(s(x)+\bar{s}(x))(D^{\pi}_{fav} - D^{\pi}_{unf})}{5(u(x)+d(x)+\bar{u}(x)+\bar{d}(x))+2(s(x)+\bar{s}(x))}$$

small x-dependent terms

Data are here averaged over y and integrated over z



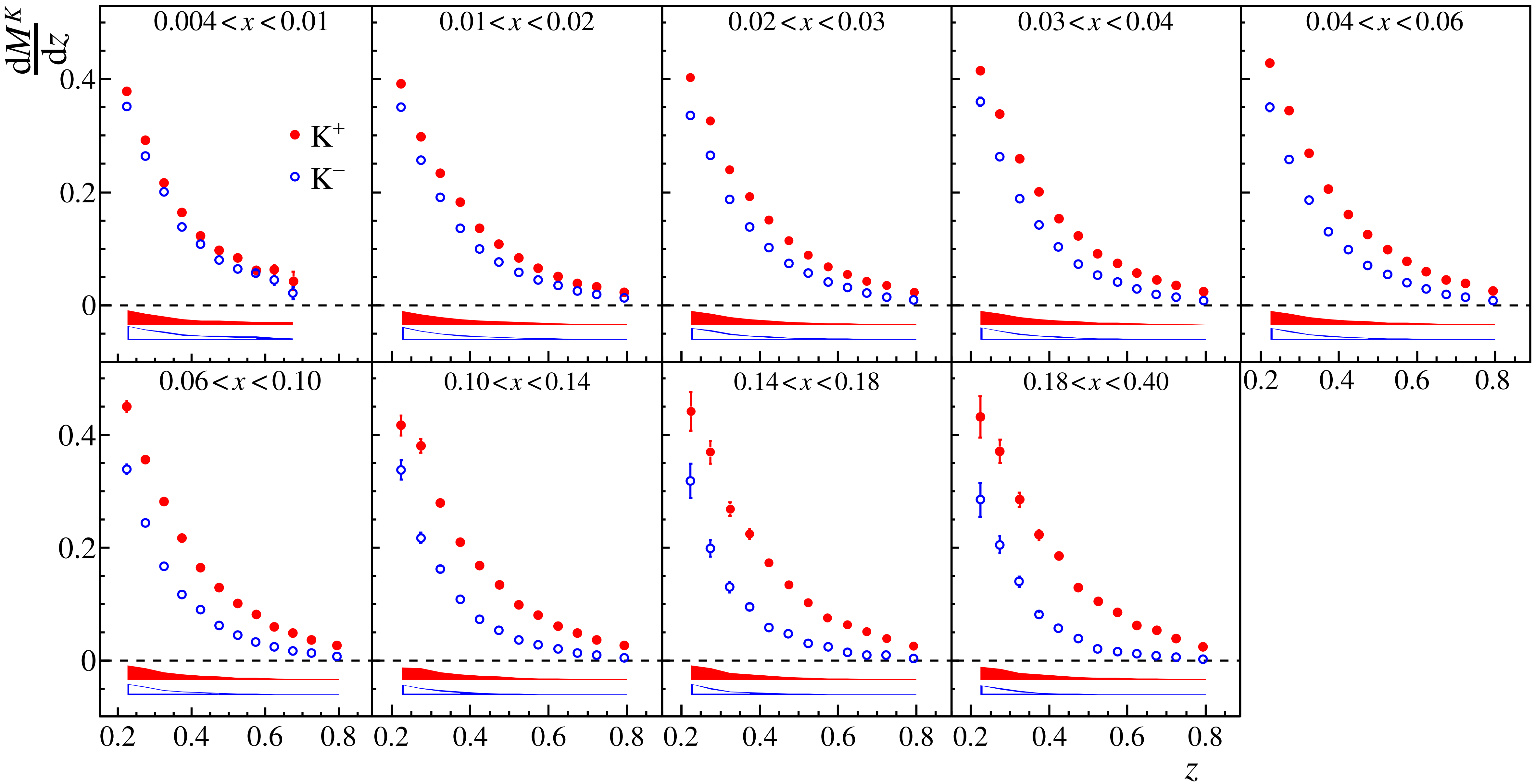


Pion : Flat shape as expected from LO predictions.
Disagreement with HERMES (however taken at lower energy).

Hadron : Results on charged hadrons in good agreement with EMC results (similar kinematic range).

KAON MULTIPLICITY RESULTS

arXiv:1608.06760v1
CERN-EP-2016-206
(submitted to PLB)



Systematic studies :
Acceptance : 5%
RICH PID/Efficiency for $K^{\pm}$: 0.2% (low y) - 15% (high y, high z)
Diffractive VM correction : < 6% max (low x, mid z)

x, y, z 3D-binning
317 kinematic bins
Strong z-dependance

EXTRACTION OF QUARK FF INTO KAONS

All in all, 12 FFs to extract. But using similar symmetries and assumptions, reduction to 3 independent FFs :

For an isoscalar target, in LO :

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

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

Only possibility to extract the quark FFs into kaons is to fit the multiplicities.

These precise data will constitute an important input for global NLO QCD fits and to extract the quark fragmentation functions, in particular D^{K}_{str}.

KAON MULTIPLICITY SUM

arXiv:1608.06760v1
CERN-EP-2016-206
(submitted to PLB)

For an isoscalar target, at LO :

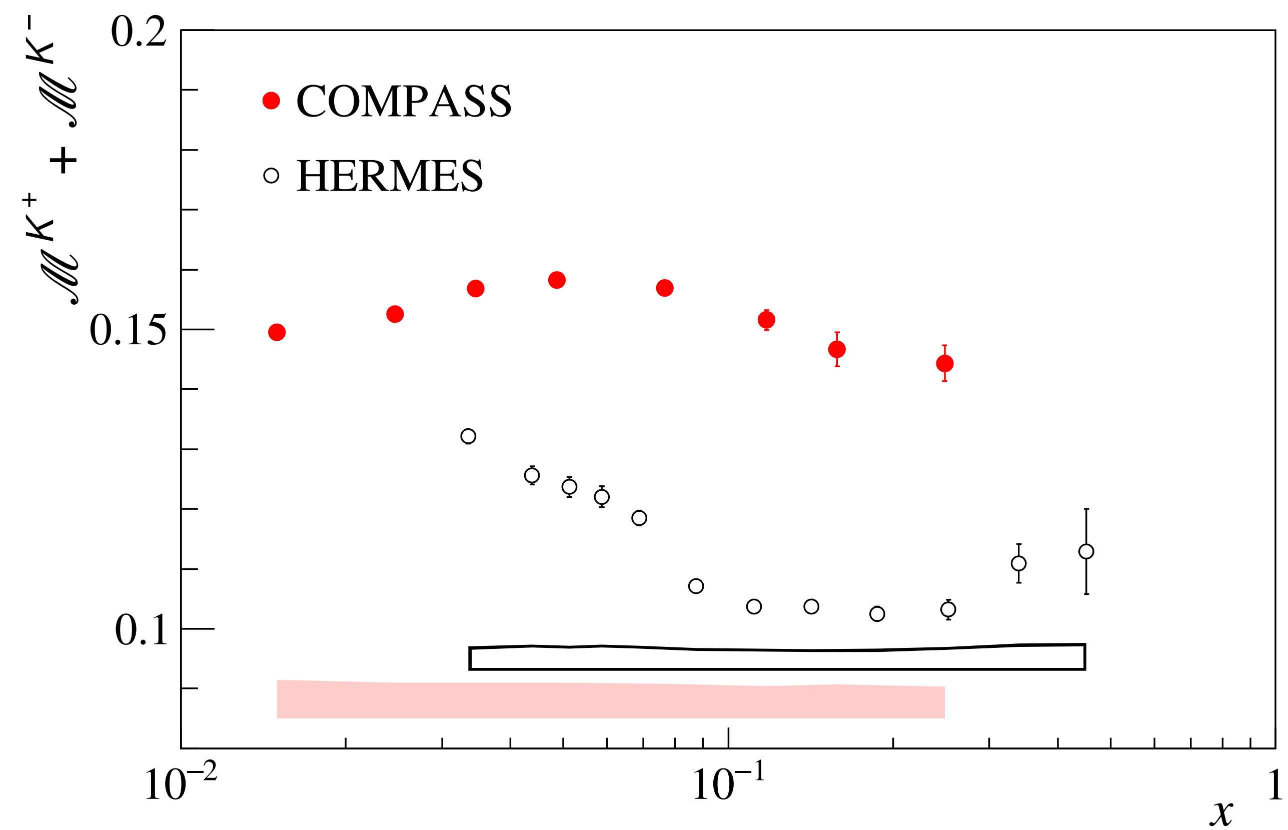
$$\frac{dN^{K^+ + K^-}}{dN^{DIS}} = \frac{(u+d+\bar{u}+\bar{d})(4D^K_{fav}+6D^K_{unf}) + (s+\bar{s})(D^K_{str}+D^K_{unf})}{5(u+d+\bar{u}+\bar{d})+2(s+\bar{s})} = \frac{QD^K_Q + SD^K_S}{5Q+2S}$$

- At high x, S~0 then

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

From COMPASS fit : $D^K_Q \sim 0.7$
From DSS fit : $D^K_Q \sim 0.43 \pm 0.04$

Points to larger non-strange FFs than DSS



- At low x, $D^K_{str} > D^K_{fav}$ then

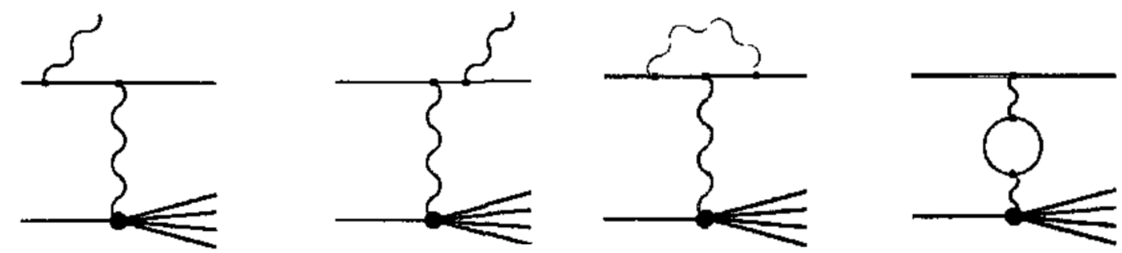
D^K_Q has weak Q^2 dependance in our range, one would expect a rise in the kaon multiplicity sum at low x, which is not the case.

Points to smaller R_{SF} than DSS

$$2\Delta S = f(R_{SF}),$$

$$R_{SF} = \frac{\int D^{K^+}_{\bar{s}}(z)dz}{\int D^{K^+}_{u}(z)dz}$$

RADIATIVE CORRECTIONS



Radiative corrections (RC)

= Emission of a real photon, vertex correction and vacuum polarization.

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

COMPASS uses RADGEN.
OK for inclusive DIS, but not for SIDIS. Does not include the z dependence.

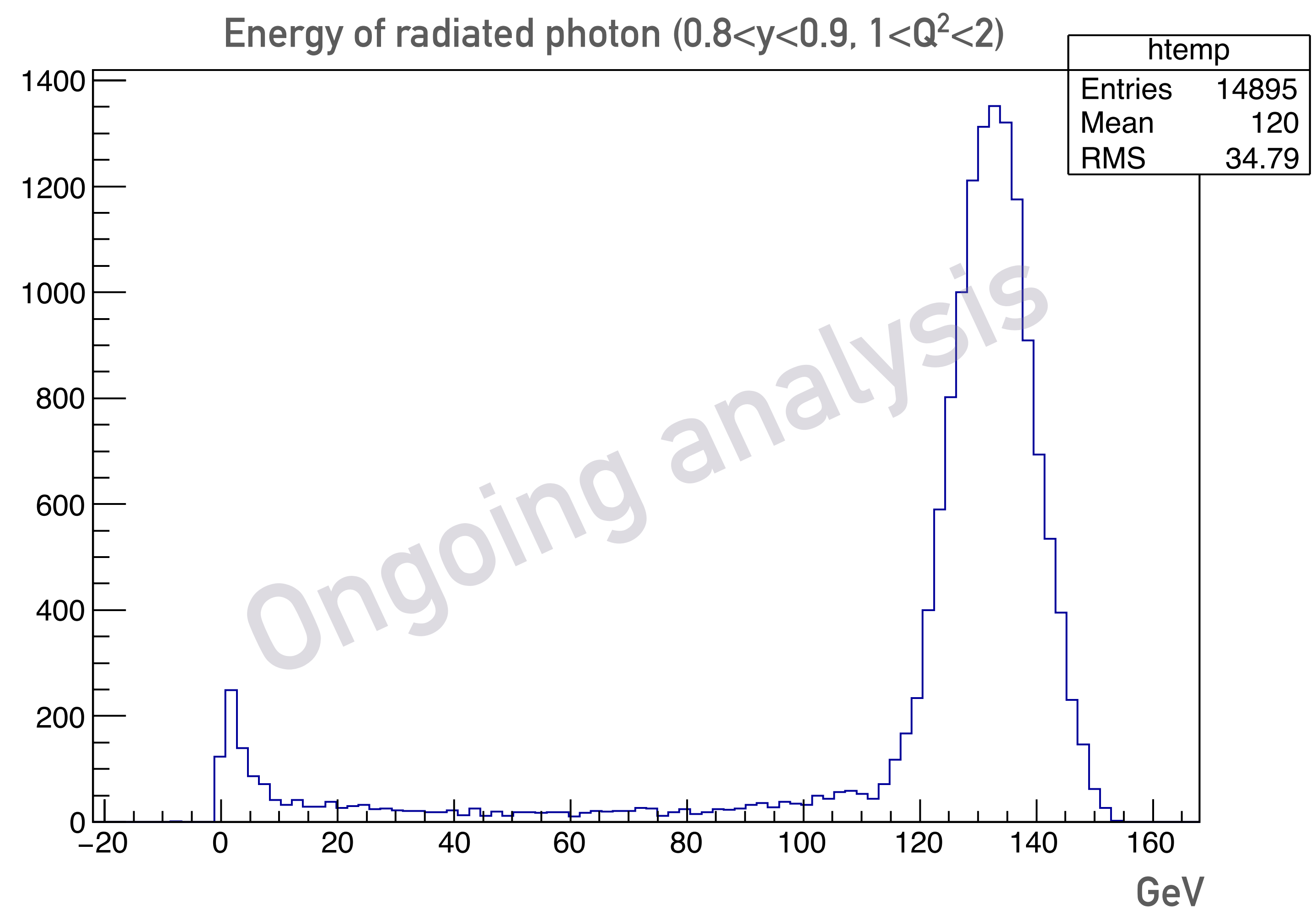
Total RC applied to the multiplicity goes from 5% at low x - high y to <1% at high x - low y.

IMPROVING THE RESULTS

RADGEN : produces more hard photons (high energy photons) than soft photon (low energy photons).

Naïve thinking : in theory, more soft than hard photons.

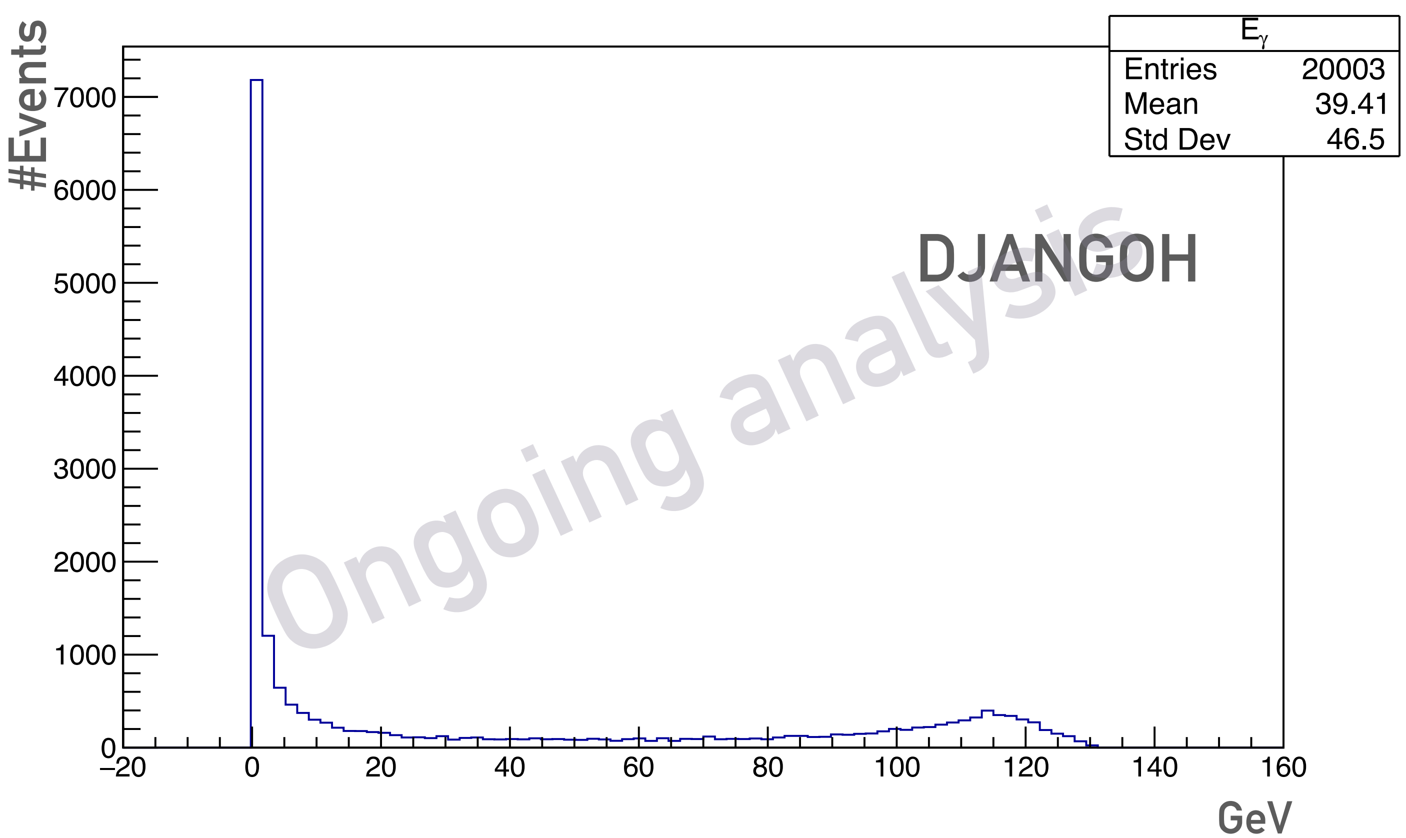
But : MC simulation + RADGEN do not describe well data : too much hard photon.

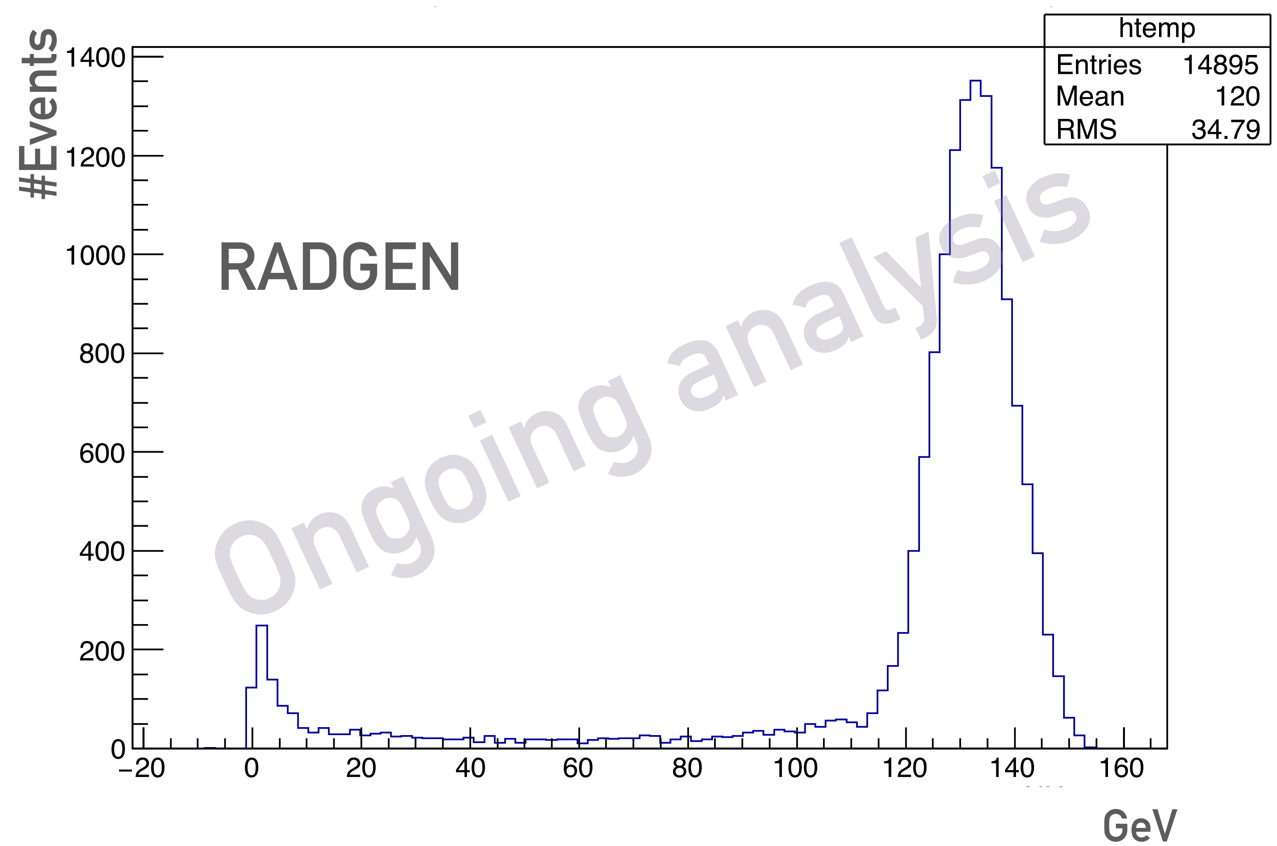


Can we use another MC generator for radiative events and see if it reproduces the results of RADGEN ?

DJANGOH / RADGEN COMPARISON

Energy of radiated photon (0.8<y<0.9, 1<Q²<2)

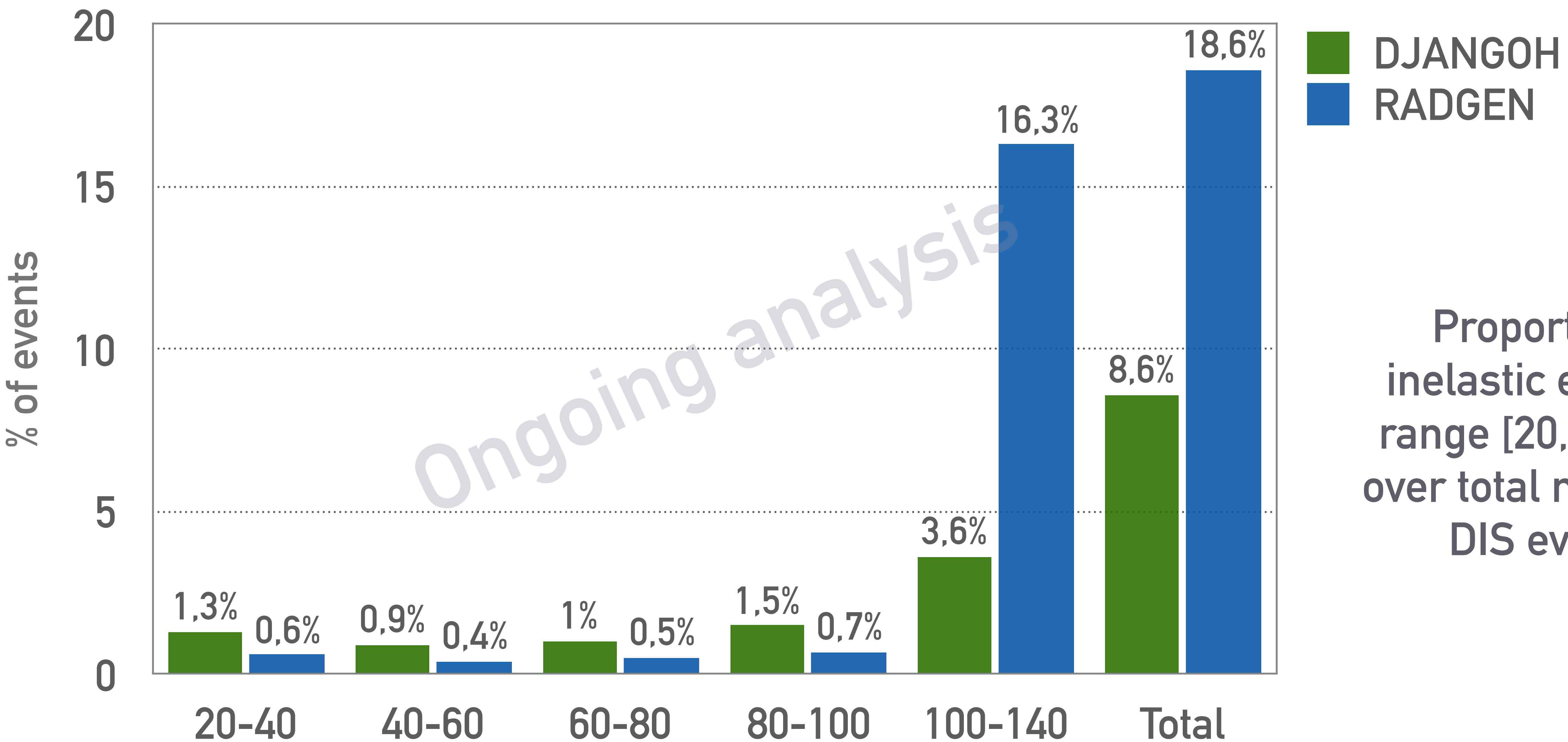




First observation :

- DJANGOH produces more soft photons than hard photons

DJANGOH / RADGEN COMPARISON



Proportion of inelastic events in range [20,140] GeV over total number of DIS events.

DJANGOH produces less hard photons than RADGEN

SUMMARY AND PROSPECTS

Summary

- High precision data on charged pion, kaon and hadron multiplicities measured from COMPASS data taken with an isoscalar ^{6}LiD target and a 160 GeV μ^+ beam.
- Good agreement with EMC results and a discrepancy with respect to HERMES results.
- Pion : D^{π}_{fav} and D^{π}_{unf} extracted from LO fits to COMPASS multiplicities in good agreement with NLO fits of world data.
- Kaon : present results point to potentially larger D^{K}_{fav} than previously thought.
  - Very large set of precise data will constrain FF into kaons.
  - The result is much awaited for the nucleon spin puzzle.

Prospects

- RC results from DJANGOH may have an impact on kaon multiplicities.
- Ongoing work on 2016 COMPASS data taken with a lH_2 target and a 160 GeV μ^+/μ^- beam.

BACKUP

THE DJANGOH GENERATOR

- Event generator for neutral/charged current ep interactions at HERA by H. Spiesberger.
- Simulates DIS using LEPTO including both QED and QCD radiative effect.
- Includes single photon emission from lepton/quark line, self energy corrections and complete set of one-loop weak corrections.
- Includes also the background from $ep \to ep\gamma$
- Capable of obtaining hadronic final state via the use of JETSET.
- Modified to work for μp interactions.

ACCEPTANCE AND SMEARING

Correction for the limited geometrical acceptance, reconstruction and detectors inefficiencies as well as resolutions and electron contamination in the reconstructed sample.

reconstructed multiplicities

kinematic bin determine using reconstructed values

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

~70%

generated multiplicities

kinematic bin determine using generated values

MC technical features :

- Events are generated with the LEPTO generator
- JETSET package for parton harmonization with compass high p_T tuning
- FLUKA used to simulate secondary interactions in the target
- Spectrometer simulated using GEANT3

RICH PID AND UNFOLDING

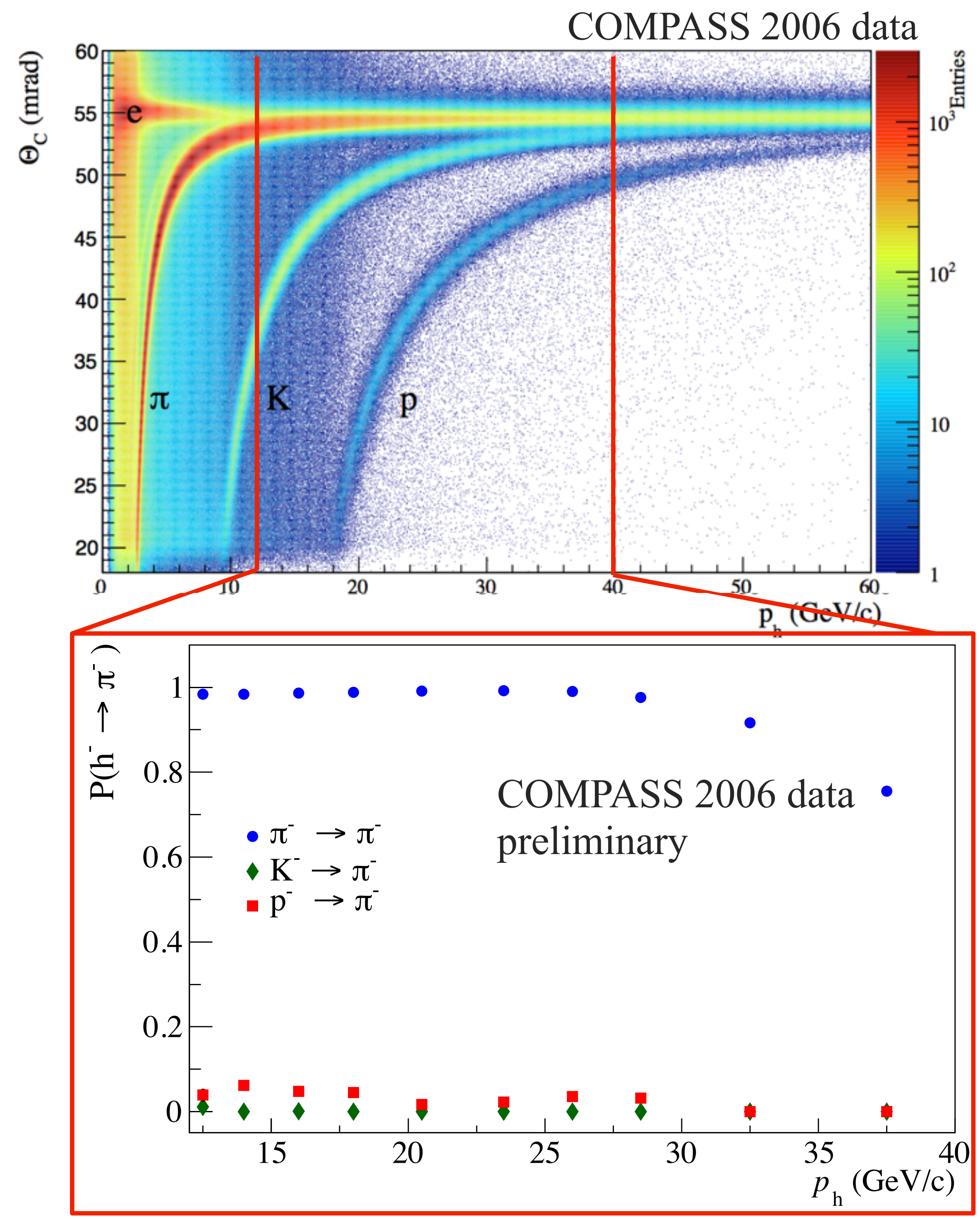
- Particle identification uses likelihoods based on the number and distribution of detected photons in RICH associated to a charged particle
- Purity of the pion and kaon sample depends on the probability of correct identification and misidentification, determined through analysis of known decay chainel in data
- The pion and kaon yields are corrected using the probabilities by unfolding :

RICH probabilities

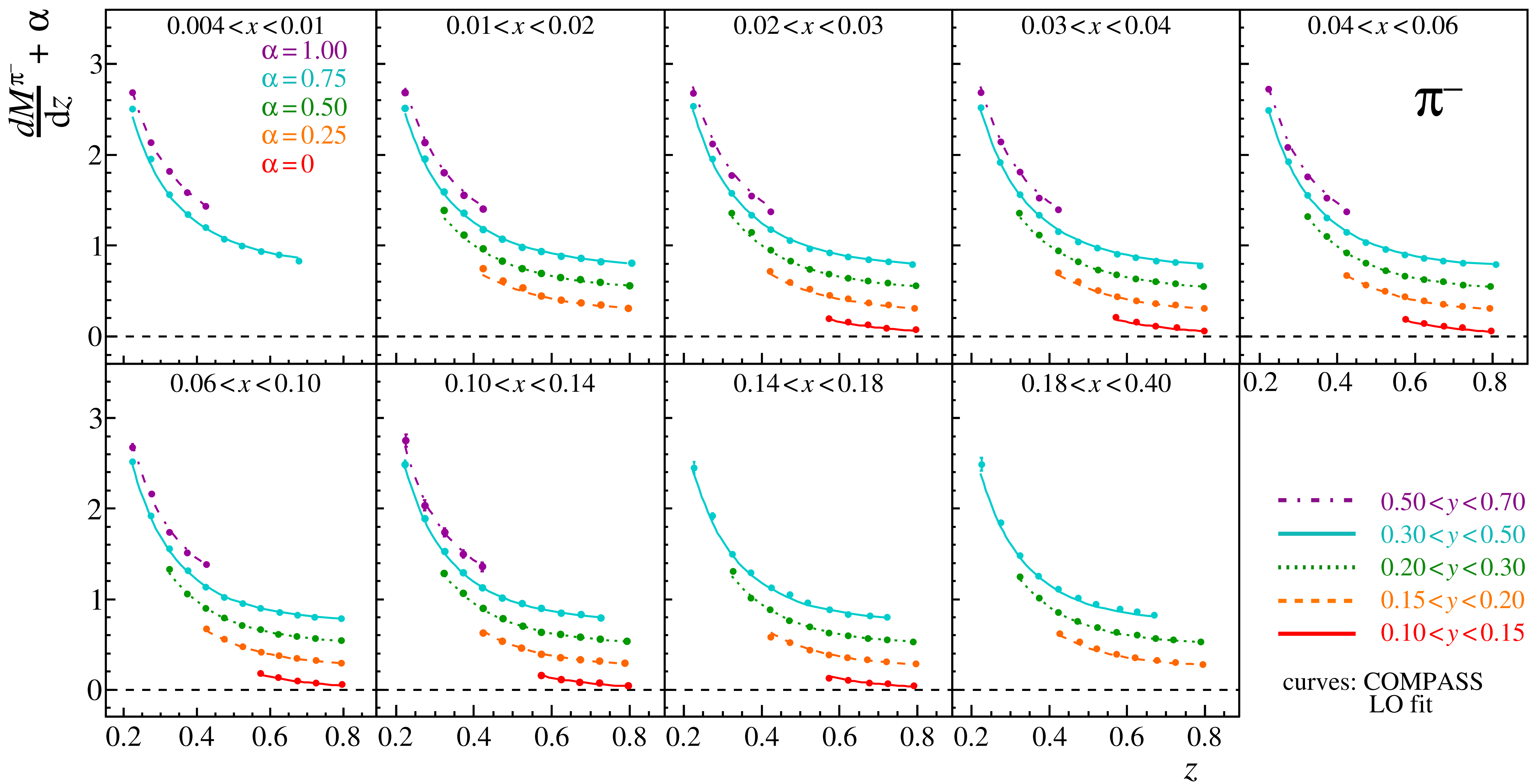
$$\begin{pmatrix} I_\pi \\ I_K \\ I_p \end{pmatrix} = \begin{pmatrix} P(\pi^\pm \Rightarrow \pi^\pm) & P(\pi^\pm \Rightarrow K^\pm) & P(\pi^\pm \Rightarrow p^\pm) \\ P(K^\pm \Rightarrow \pi^\pm) & P(K^\pm \Rightarrow K^\pm) & P(K^\pm \Rightarrow p^\pm) \\ P(p^\pm \Rightarrow \pi^\pm) & P(p^\pm \Rightarrow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

Identified

“True”



MULTIPLICITY FITS



MULTIPLICITY FITS