COMPASS Collinear Multiplicities on Proton and Deuteron Targets

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On behalf of the COMPASS Collaboration

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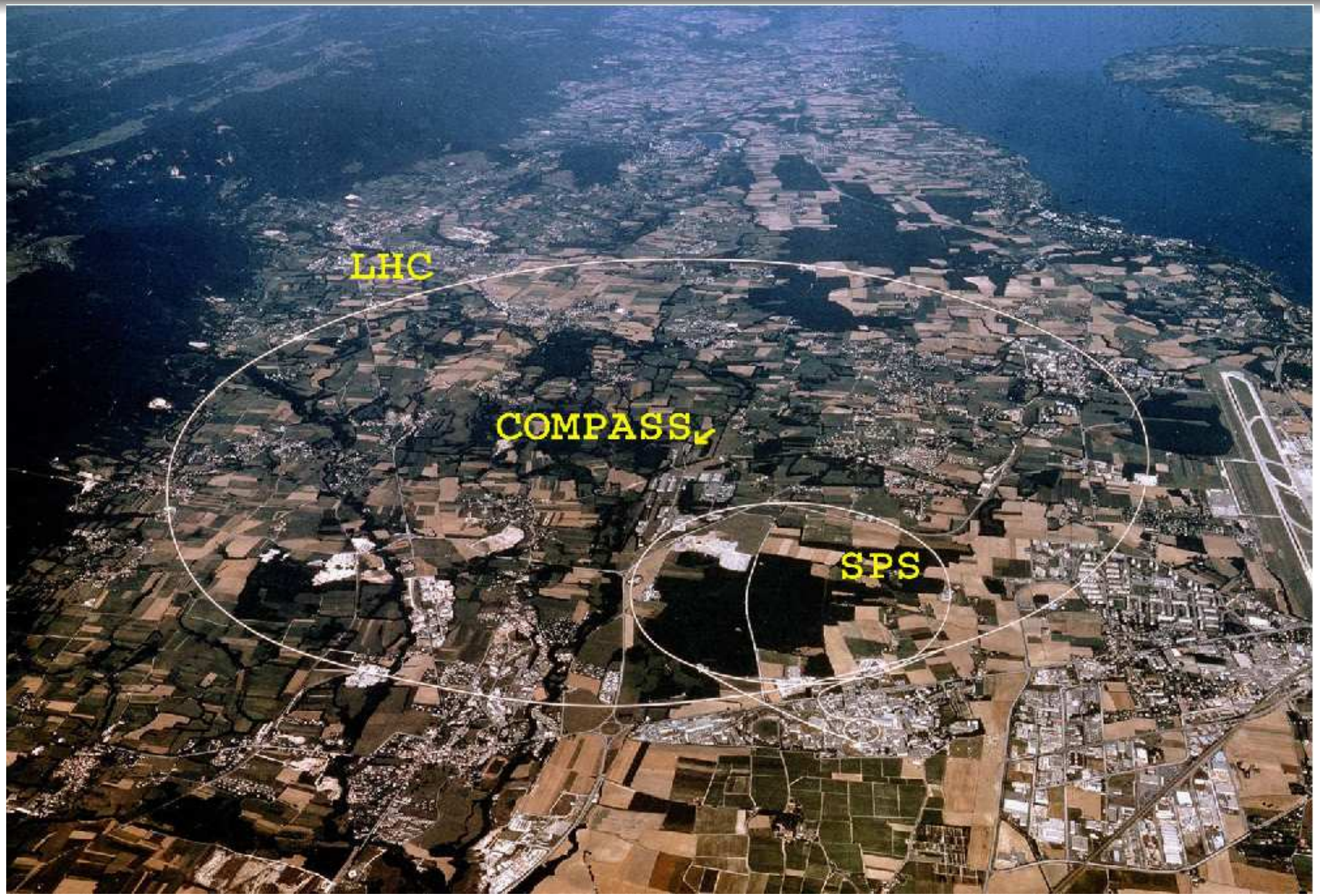
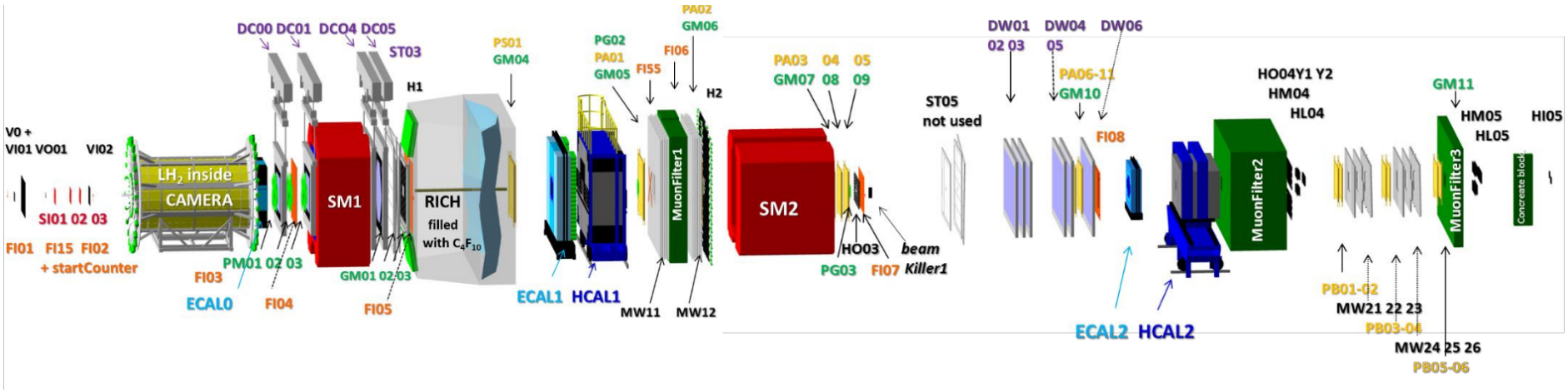
National Centre for Nuclear Research
ŚWIERK

COMPASS at CERN, 2002-2022



COMPASS Spectrometer 2016



- COLLABORATION
  - about 210 physicists
  - 27 institutes
- DETECTOR
  - two stage spectrometer
  - 60 m length
  - about 350 detector planes
- BEAM & TARGET
  - $\mu^{\pm}$ at 160 GeV/c
  - Liquid H target, 250 cm long
- FEATURES
  - angular acceptance: $\pm$180 mrad
  - track reconstruction: $p > 0.5$ GeV/c
  - identification h, e, μ: calorimeters and muon filters
  - identification: π, K, p (RICH) $p > 2$, 9, 18 GeV/c respectively

Motivation

- Fragmentation functions (FF(s), $D_{\mathrm{q}}^{\mathrm{h}}$) describe parton fragmentation into hadrons
- In Leading Order pQCD $D_{\mathrm{q}}^{\mathrm{h}}$ describes probability density for a quark of flavour q to fragment into a hadron of type h
- The cleanest way to access FFs is in $\mathrm{e}^{+}\mathrm{e}^{-}$ annihilation. However,
  - only sensitive to the sum of $\mathrm{q} + \bar{\mathrm{q}}$ fragmentation
  - flavour separation possibilities are limited
- In the SIDIS, $\mu^{\pm} + \mathrm{p(d)} \rightarrow \mu^{\pm'} + \mathrm{h} + X$
  - possibility to separate fragmentation from q and $\bar{\mathrm{q}}$
  - full flavour separation possible
  - FF are convoluted with PDFs
- By studying pp collisions with high p_{T} hadrons $\rightarrow$ access to gluon fragmentation functions
- SIDIS data are crucial to understand quark fragmentation process

COMPASS Published Papers

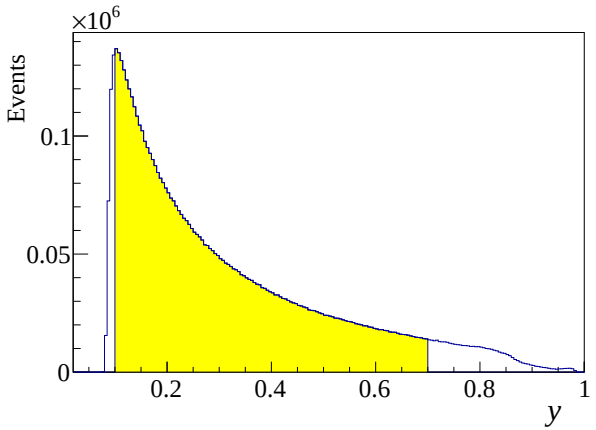
- COMPASS already published several articles based on isoscalar and proton target data
  - PLB 764 (2017) 001
  - PLB 767 (2017) 133
  - PRD 97 (2018) 032006
  - PLB 786 (2018) 390
  - PLB 807 (2020) 135600
  - PRD 112 (2025) 012002 (new *RC*, proton)
  - PLB 875 (2026) 140266 (new *RC*, isoscalar, update of the first two papers)
- Last year's efforts were devoted to improving the QED radiative effects treatment (*RC*)
- Preliminary results for the proton were presented at DIS2024
- Today: Final proton results and updated isoscalar results
- The results published in PLB 875 (2026) 140266 supersede those reported in PLB 764 (2017) 001 and PLB 767 (2017) 133

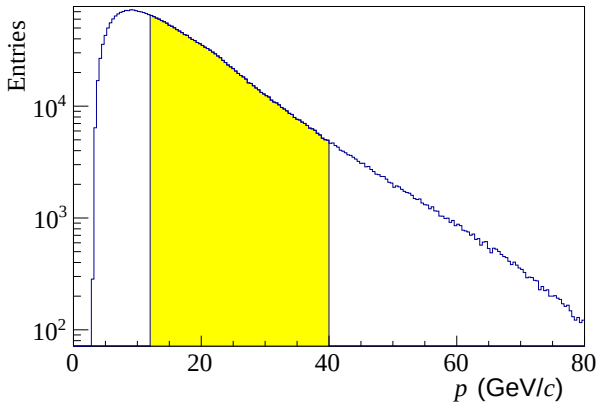
Multiplicity Measurement

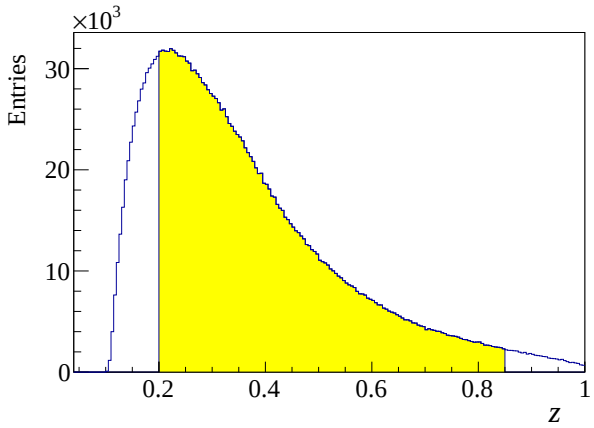
- Fragmentation studies in SIDIS can be done using hadron multiplicity data
- Hadron multiplicities are defined as number of observed hadrons per DIS event
- $$\frac{dM^h(x,z,Q^2)}{dz} = \frac{d^3\sigma^h(x,z,Q^2)/dxdQ^2dz}{d^2\sigma^{DIS}(x,Q^2)/dxdQ^2}$$
- Experimentally measured raw hadron multiplicities need to be corrected for e.g.
  - spectrometer acceptance and reconstruction program efficiency
  - RICH efficiency and purity (for π and K)
  - diffractive vector meson production
  - QED radiative effects

Data Selection and Kinematic Distributions

- DIS selection:
  - Reconstructed μ and μ',
  - $Q^2 > 1$ (GeV/c)^2, $x < 0.4$, $W > 5$ GeV/c^2,
  - $0.1 < y < 0.7$, fraction of beam energy carried by virtual gamma
- Hadron cuts:
  - $0.2 < z < 0.85$, fraction of the virtual photon energy carried by a hadron
  - 12 GeV/c $< p <$ 40 GeV/c, $\theta < 0.12$, $|dy/dz| < 0.08$, PID cuts
- Analysis is performed in 9 bins of Bjorken x, 5 bins of y and 12 bins of z
- Total sample: unidentified hadrons: 1.7M, π: 1.3M, K: 280k

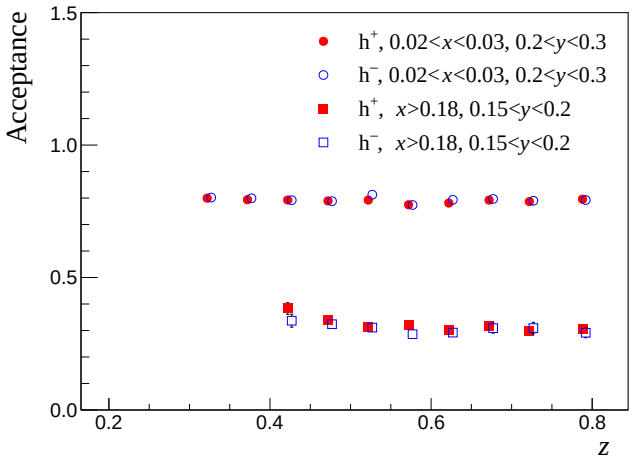


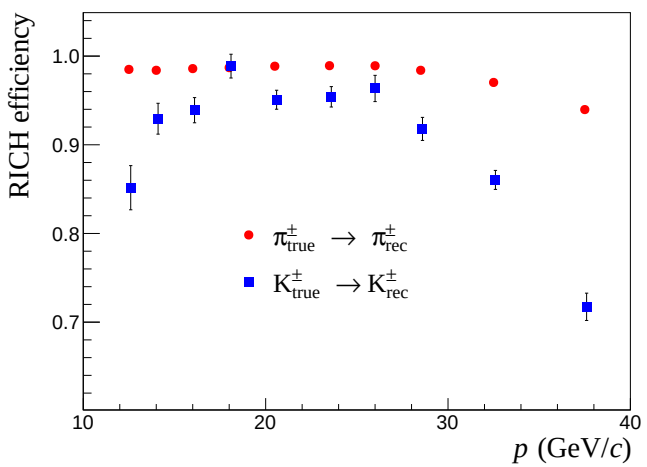


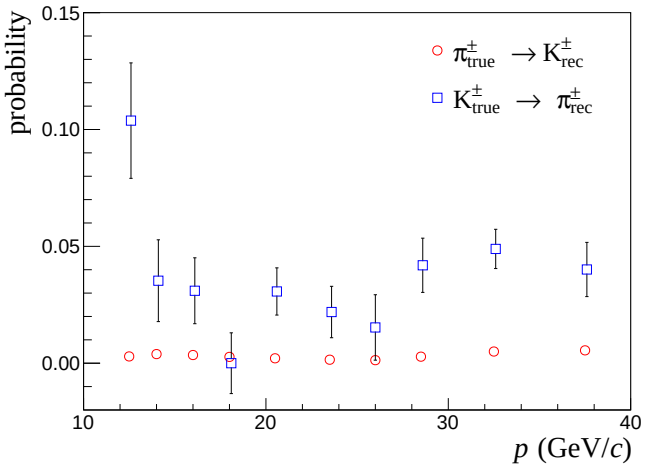


Acceptance and RICH

- COMPASS has a typical acceptance of about 70%, which decreases at the edges of phase space
- The acceptance is generally flat
- The RICH detector shows stable performance, with high efficiency and a relatively low misidentification rate

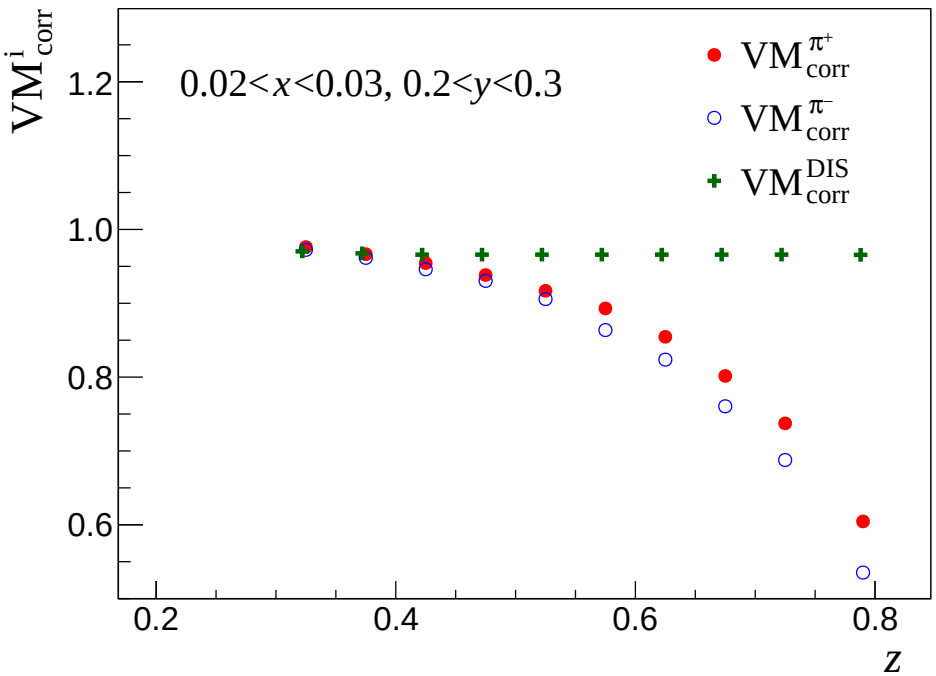


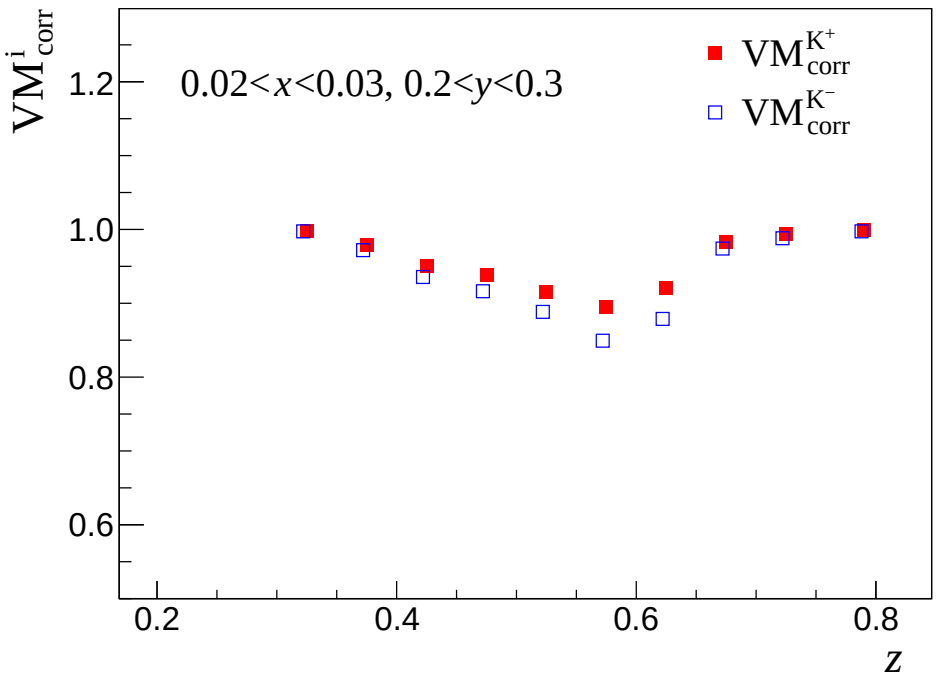




Exclusive Diffractive Vector Meson Corrections

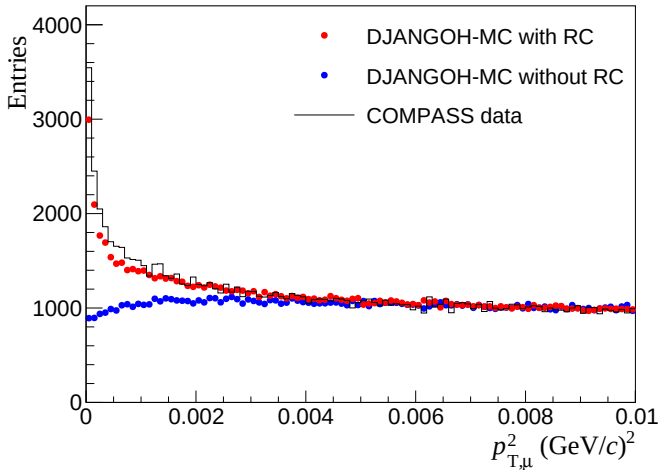
- Exclusive diffractive vector meson production is not part of DIS
- Decay products of vector mesons (ρ, ϕ) contaminate the SIDIS sample
- The HepGen generator was used to correct the data
- These corrections are provided together with the data; therefore, if a better model is developed in the future, the results can be easily updated

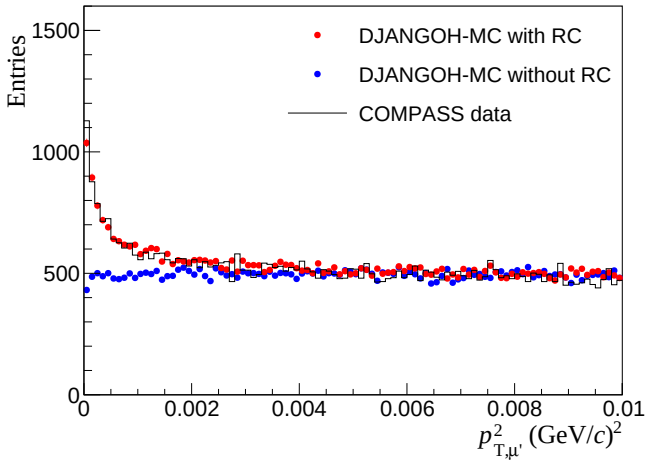


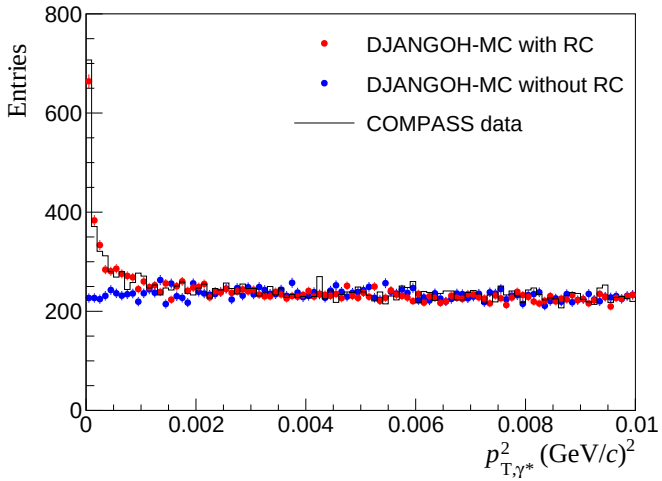


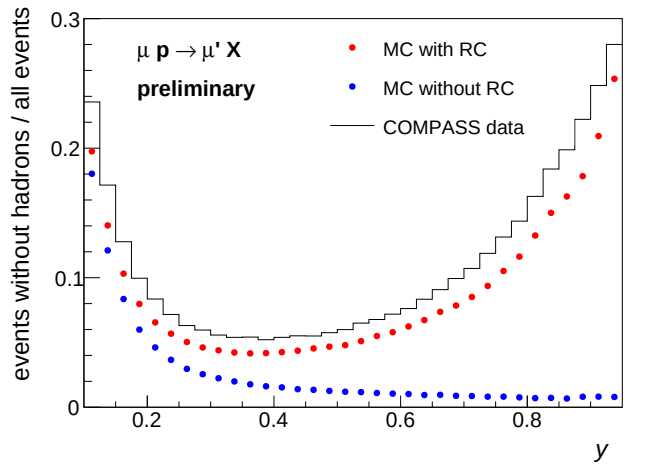
Radiative Corrections

- Correction due to radiative effects is a multiplicative factor to the multiplicity itself, and can be large, especially at low x and high y
- The DJANGOH program is used for *RC* simulations
- It was tested against COMPASS data and the TERAD program

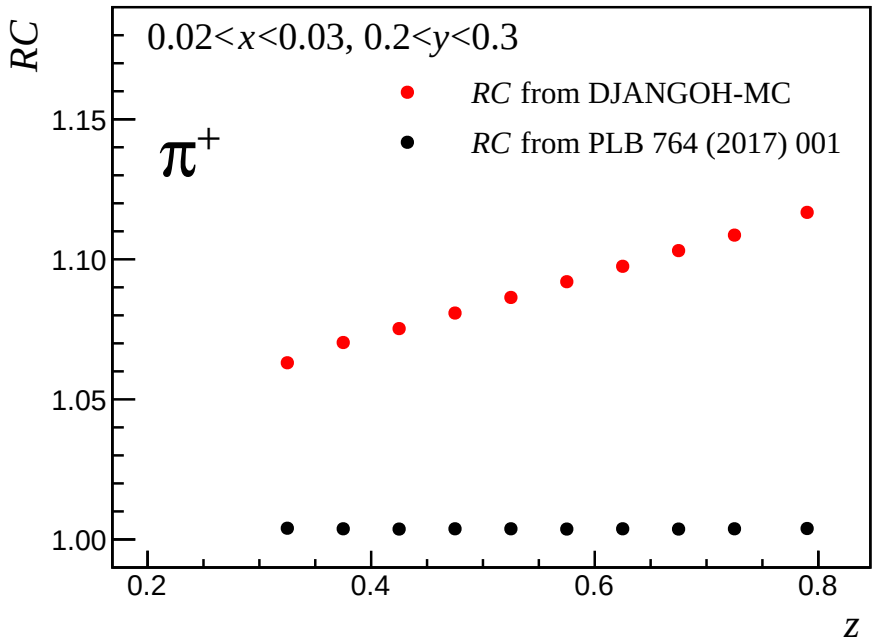


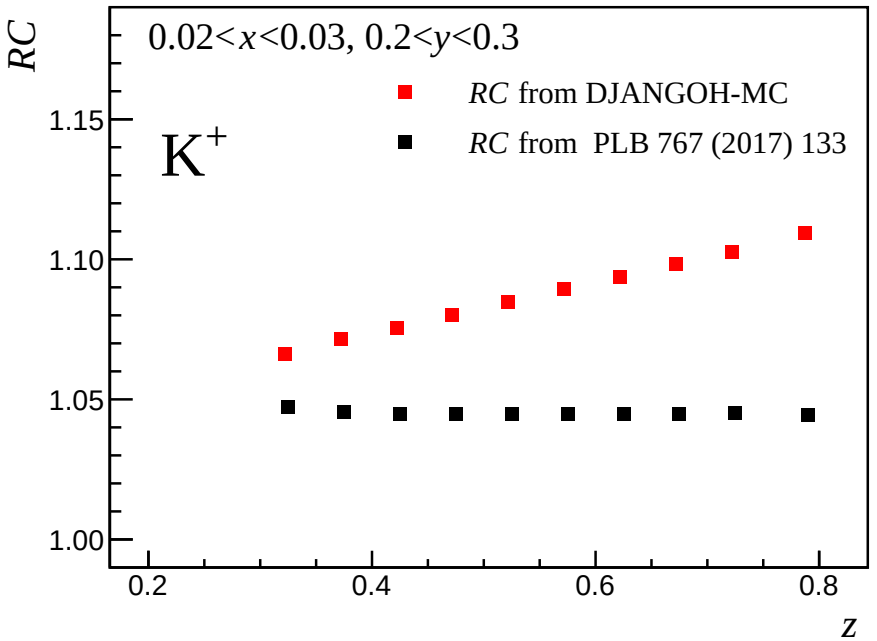






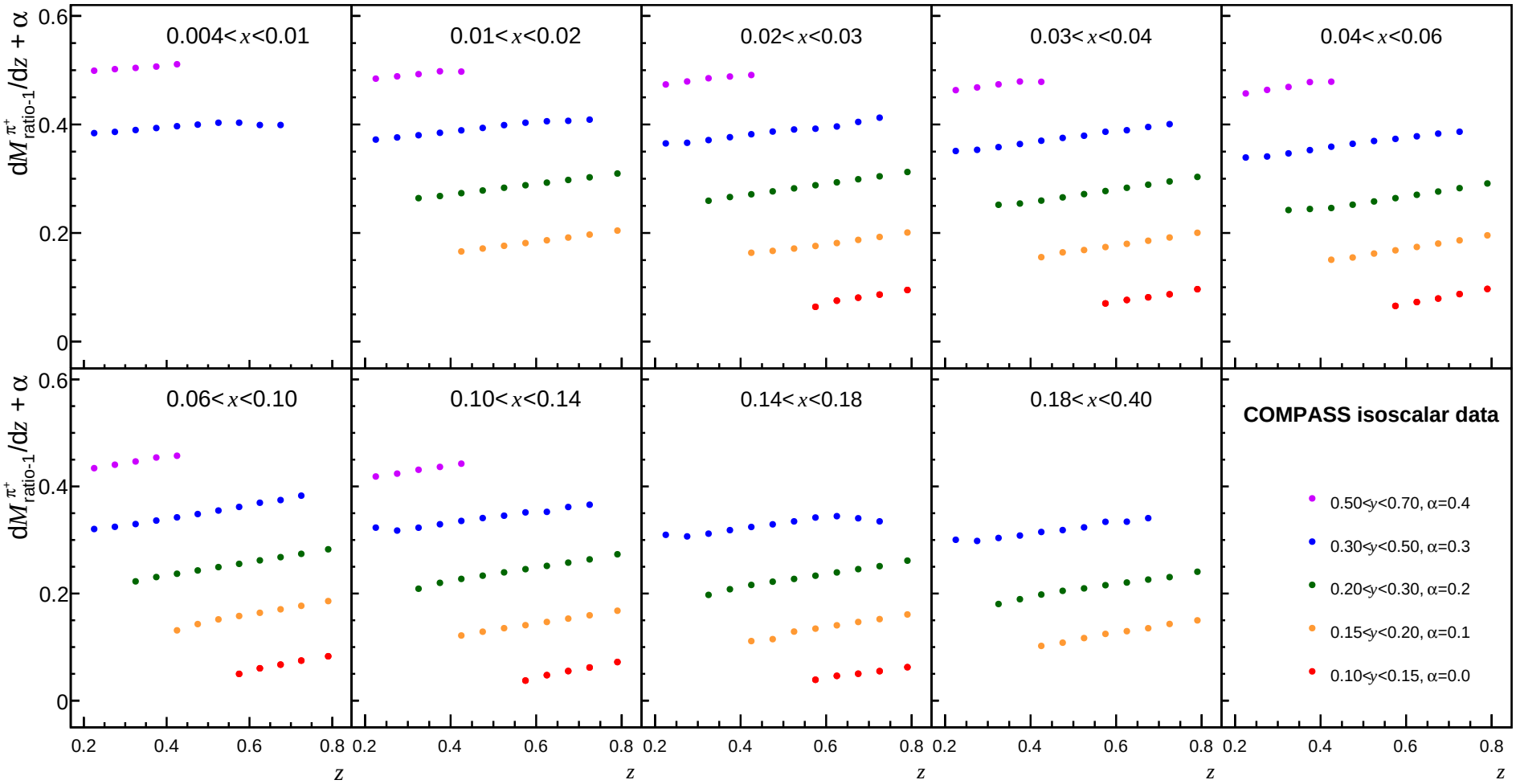
Radiative Corrections Past vs Present



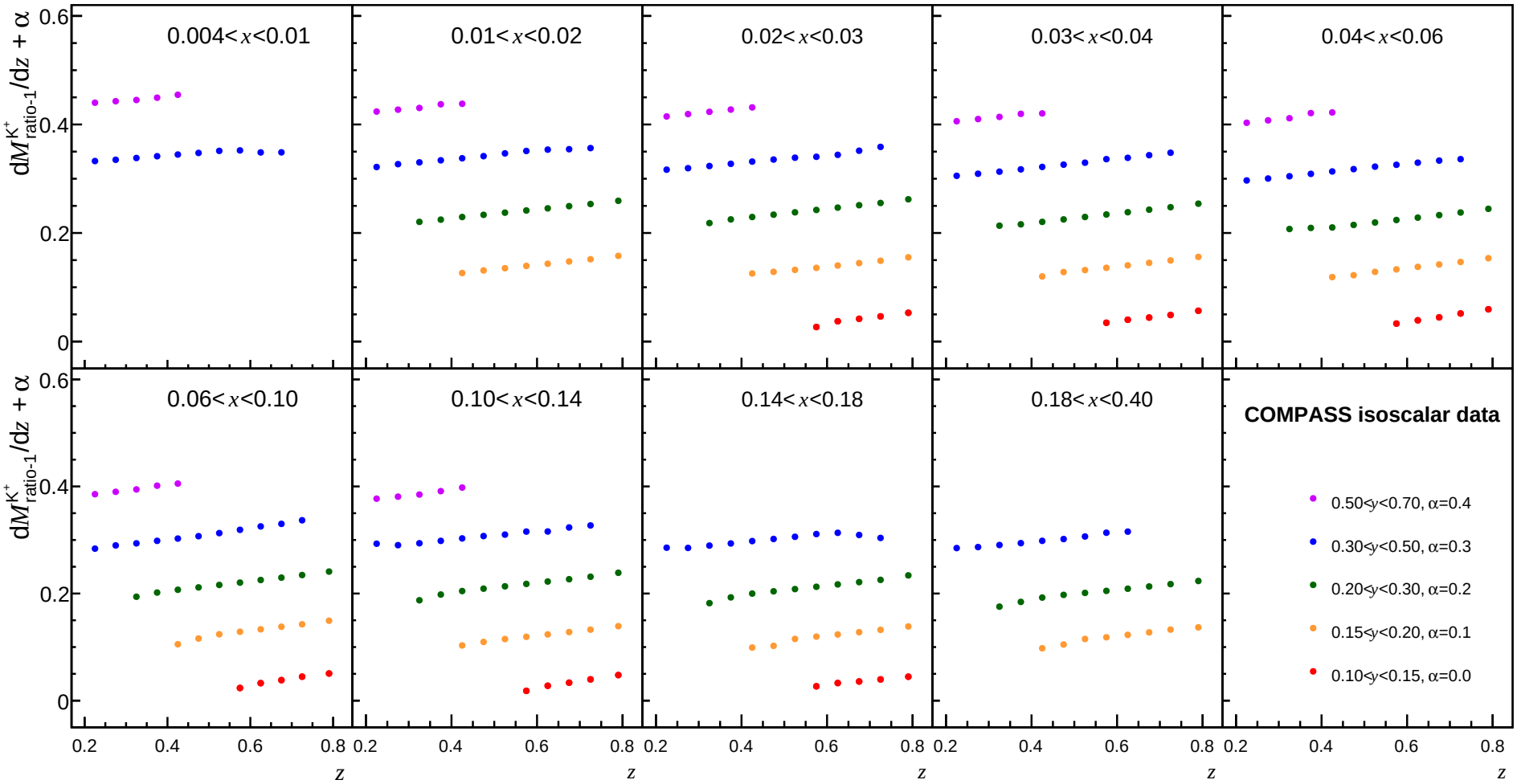


- Significant differences are observed between the previous and the current radiative corrections (RC)
- COMPASS has presented results both with and without its estimates of RC
- Therefore, the new RC results can be easily implemented to correct earlier COMPASS multiplicity papers

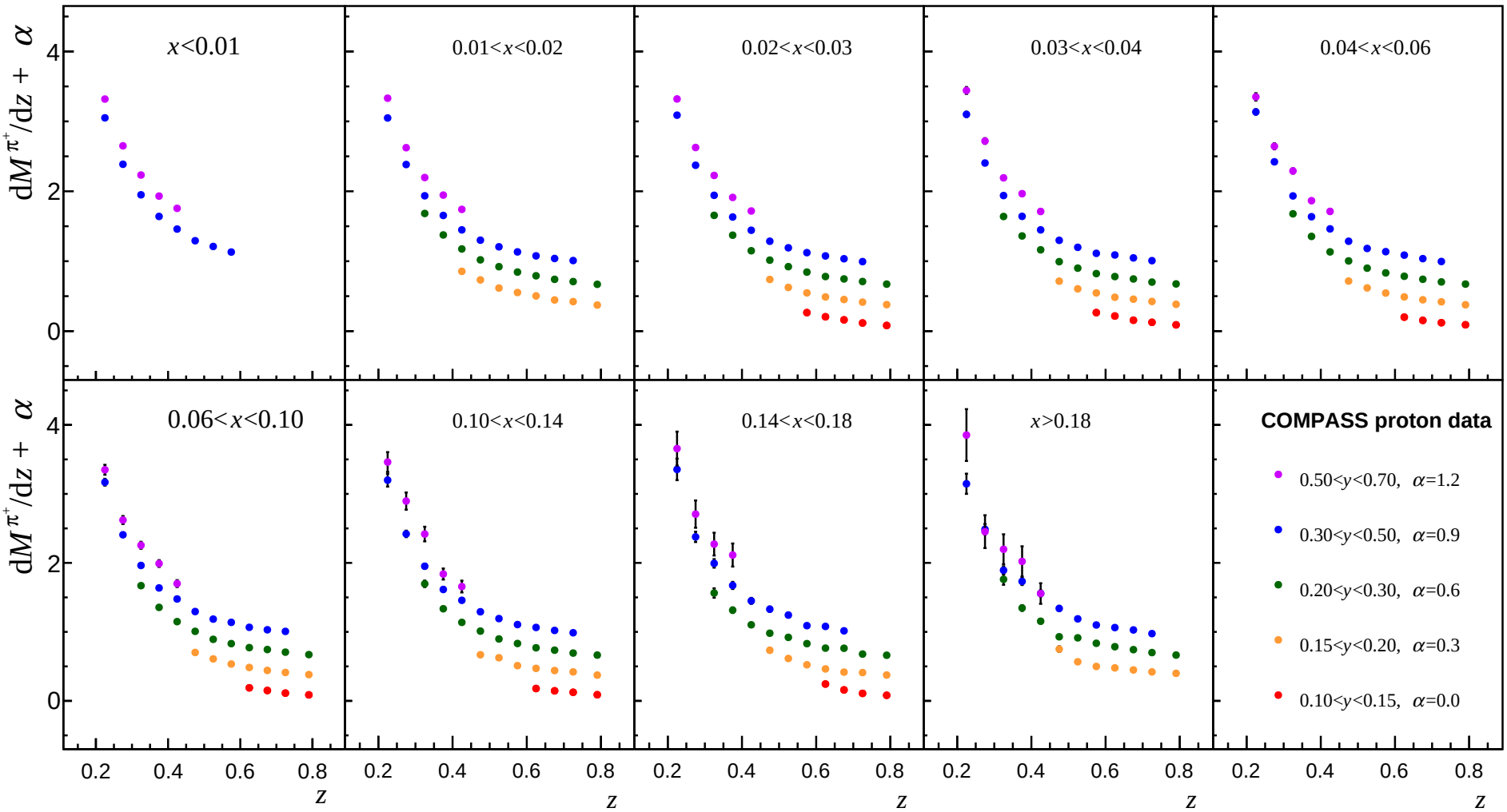
Corrections to π^+ Results, Izoscalar Target



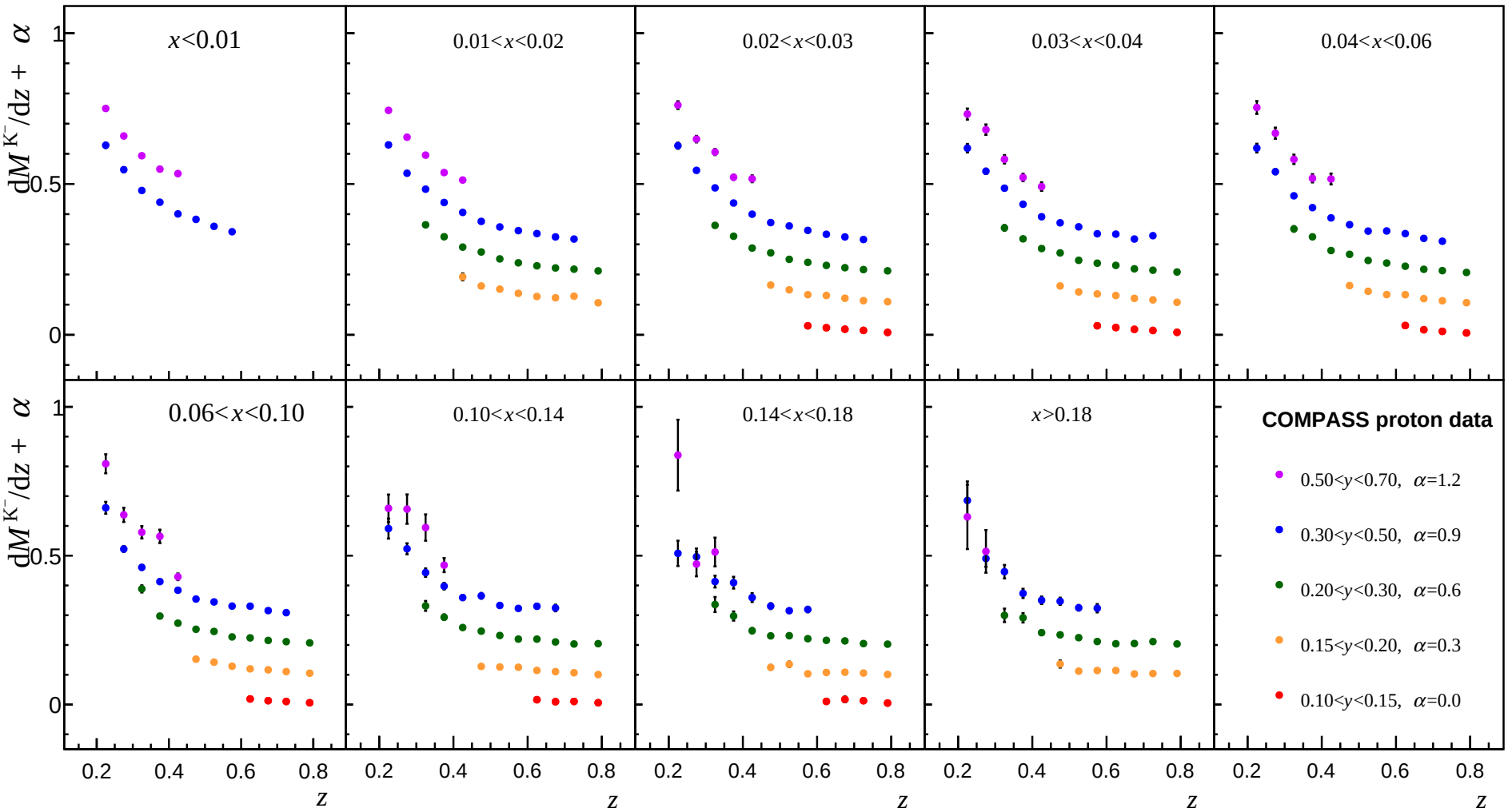
Corrections to K^+ Results, Izoscalar Target



Multiplicities of π^+, Proton Target

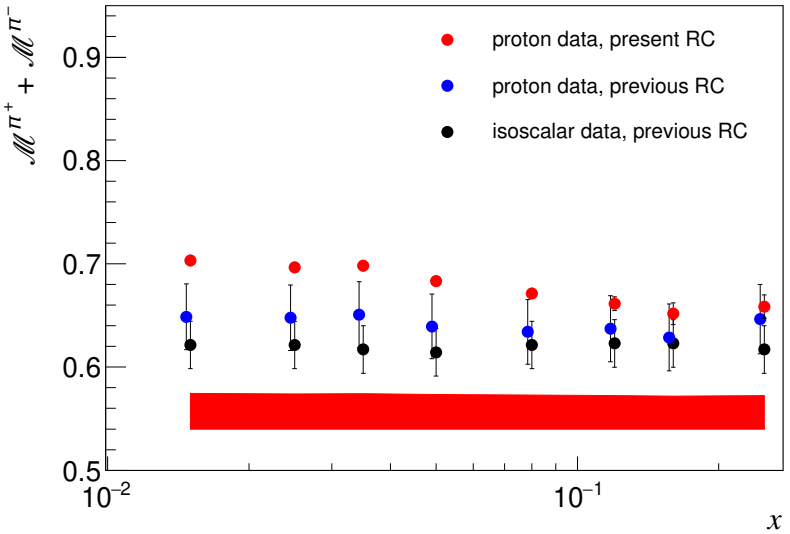


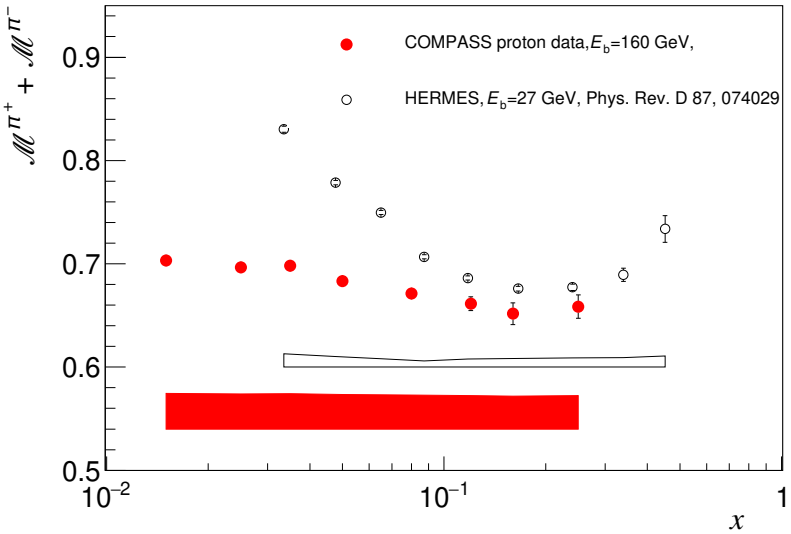
Multiplicities of K^-, Proton Target



Sum of Pion Multiplicities

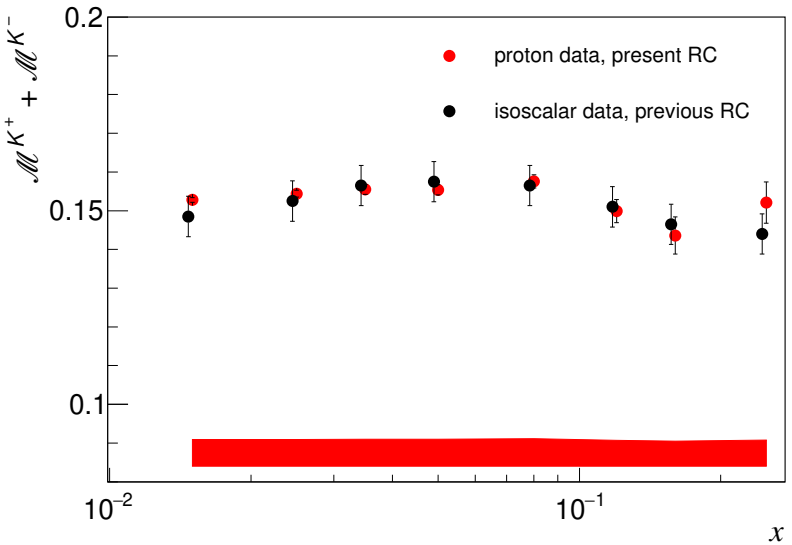
- Let $D_{\mathrm{fav,(unf)}} = D_{\mathrm{q}}^{\mathrm{h}}$ where q is (not) the valence quark of h
- For proton and isoscalar targets in LO pQCD:
- $\frac{dM^{\pi^+}}{dz} + \frac{M^{\pi^-}}{dz} \approx D_{\mathrm{fav}} + D_{\mathrm{unf}}$, i.e. both results are expected to be very similar
- $D(Q^2, z) \rightarrow$ obtained from multiplicity sum is effectively independent of x
- $\mathscr{M}^{\pi^+} + \mathscr{M}^{\pi^-} = \int_{0.2}^{0.85} (\frac{dM^{\pi^+}}{dz} + \frac{dM^{\pi^-}}{dz}) dz$

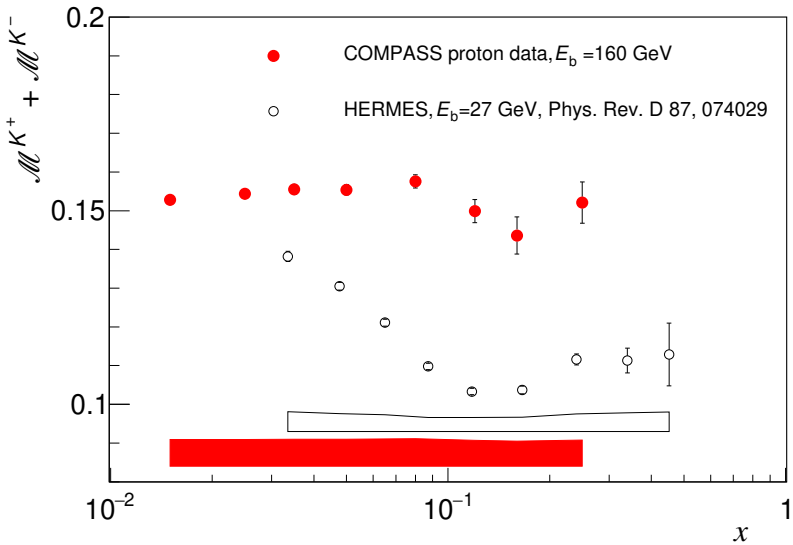




Sum of Kaon Multiplicities

- Contrary to pion case, here $D_s^{\mathrm{K}^-}$, $D_{\bar{s}}^{\mathrm{K}^+}$ are dominant, larger than e.g. $D_u^{\mathrm{K}^+}$
- At high x strange quarks $s, \bar{s}$ should be suppressed w.r.t. light quarks; *i.e.* we should see some turn-on effect related to the increased relative density of strange quarks at lower x
- Perhaps x values accessed by COMPASS are too low to assure low density of $s, \bar{s}$
- $\mathscr{M}^{\mathrm{K}^+} + \mathscr{M}^{\mathrm{K}^-} = \int_{0.2}^{0.85} \left(\frac{dM^{\mathrm{K}^+}}{dz} + \frac{dM^{\mathrm{K}^-}}{dz} \right) dz$





Summary

- SIDIS data are crucial for understanding quark fragmentation into hadrons
- Today, COMPASS results for $\mathrm{h}^{\pm}, \pi^{\pm}, \mathrm{K}^{\pm}$ multiplicities on a proton target were presented, along with updated results for the isoscalar target
- The impact of radiative corrections is larger than originally anticipated in early isoscalar data analyses
- The isoscalar results published in PLB 875 (2026) 140266
  include a new treatment of QED radiative effects and supersede those reported in PLB 764 (2017) 001 and PLB 767 (2017) 133
- For consistency, the aforementioned isoscalar results should be used together with the proton results published in PRD 112 (2025) 012002