COMPASS Results on Pion and Kaon Multiplicities from SIDIS on Proton Target

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On behalf of the COMPASS Collaboration

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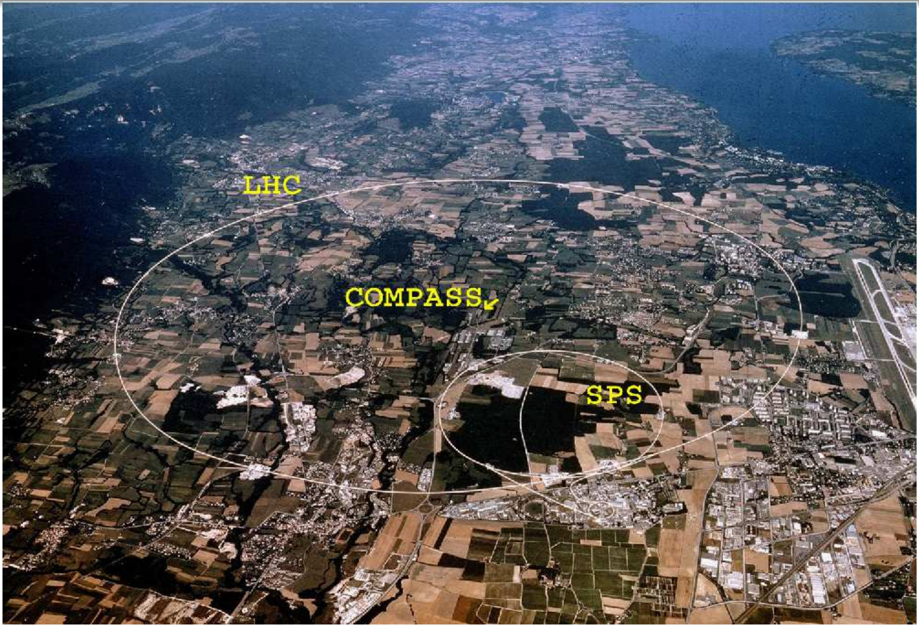
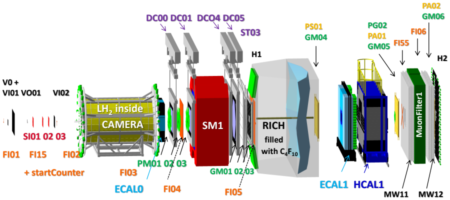
COMPASS at CERN



COMPASS Spectrometer 2016



- COLLABORATION
  - about 210 physicists
  - 27 institutes
- DETECTOR
  - two stage spectrometer
  - 60 m length
  - about 350 detector planes

- TARGET
  - Liquid H target
  - 250 cm - total length
- BEAM
  - $\mu^{\pm}$ at 160 GeV$/c$
- FEATURES
  - angular acceptance: ± 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

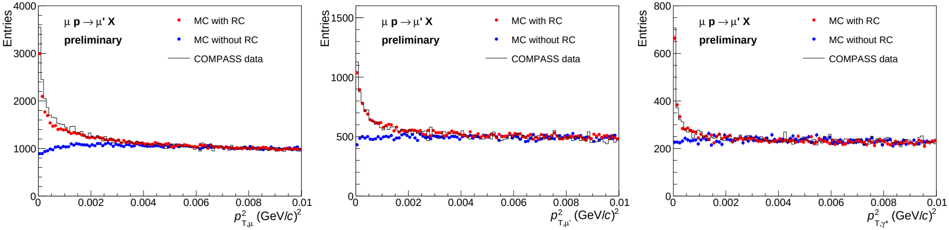
- Fragmentation functions (FF(s), D_q^h) describe parton fragmentation into hadrons
- FFs are needed in analyses which deal with a hadron(s) in the final state
- In Leading Order QCD D_q^h describes probability density for a quark of flavour q to fragment into a hadron of type h
- The cleanest way to access FFs is in e^+e^- annihilation. However,
  - only sensitive to the sum of $q + \bar{q}$ fragmentation
  - flavour separation possibilities are limited
- In the SIDIS ($\mu^\pm + p \rightarrow \mu^{\pm'} + h + X$) data, FF are convoluted with PDFs. However,
  - possibility to separate fragmentation from q and $\bar{q}$
  - full flavour separation possible
- By studying pp collisions with high p_T hadrons, access to gluon fragmentation functions
- SIDIS data are crucial to understand quark fragmentation process

Multiplicity Measurement

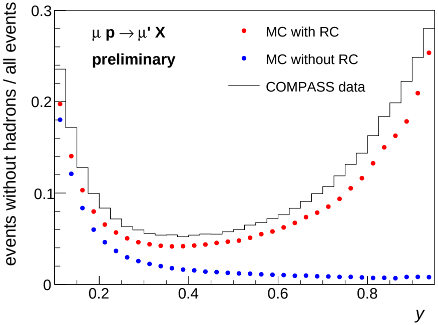
- Fragmentation studies in SIDIS can be done using hadron multiplicity data
- Hadron multiplicities are defined as number of observed hadrons per DIS event
- $\frac{dM^h(x,z,Q^2)}{dz} = \frac{d^3\sigma^h(x,z,Q^2)/dxdQ^2dz}{d^2\sigma^{DIS}(x,Q^2)/dxdQ^2}$
- Experimentally measured hadron multiplicities need to be corrected for various effects e.g.
  - spectrometer acceptance and reconstruction program efficiency
  - RICH efficiency and purity (for π and K)
  - radiative corrections
  - diffractive vector meson production
- COMPASS already published several articles based on isoscalar target data
  - PLB 764 (2017) 001
  - PLB 767 (2017) 133
  - PRD 97 (2018) 032006
  - PLB 786 (2018) 390
  - PLB 807 (2020) 135600
- Today, preliminary results from the proton target are presented

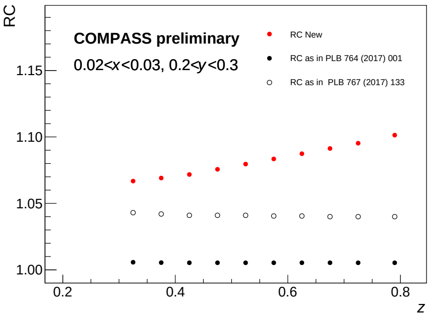
Radiative Corrections

- 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 programme is used for RC simulations
- It was tested against COMPASS data and the TERAD program
- Some early results were shown already in 2019



Radiative Corrections cont.



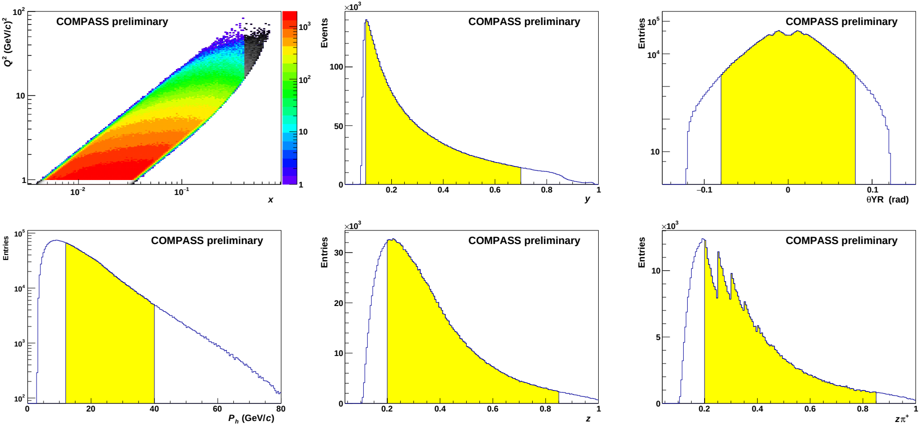


- COMPASS was always showing results with and without our estimate for RC
- Thus, new results can be easily implemented to older COMPASS multiplicity papers
- Note: according to our present knowledge the data from PLB 764 (2017) 001 ($\pi^{\pm}$, $h^{\pm}$) need correction sometimes above 10%

Data Selection - Main Cuts

- DIS selection:
  - Reconstructed μ and μ',
  - $Q^2 > 1$ (GeV$/c)^2$
  - $W > 5$ GeV$/c^2$,
  - $0.1 < y < 0.7$, fraction of beam energy, E, 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$/c$, momentum cut due to RICH PID acceptance,
  - $\theta < 0.12$, $|dy/dz| < 0.08$, RICH acceptance
- Analysis is performed in 9 bins of Bjorken x, 5 bins of y and 12 bins of z
- To avoid the "zero-acceptance" region, DIS sample is bin-by-bin restricted using
  - $\nu_{max} = \frac{\sqrt{p_{max}^2 + m_h^2}}{z_{max}}$,
  - $\nu_{min} = \frac{\sqrt{p_{min}^2 + m_h^2}}{z_{min}}$,
    - where $\nu = E - E'$,
    - $p_{min} = 12$ GeV$/c$ and $p_{max} = 40$ GeV$/c$,
    - z_{min} and z_{max} - correspond to the edges of a given bin in z variable.

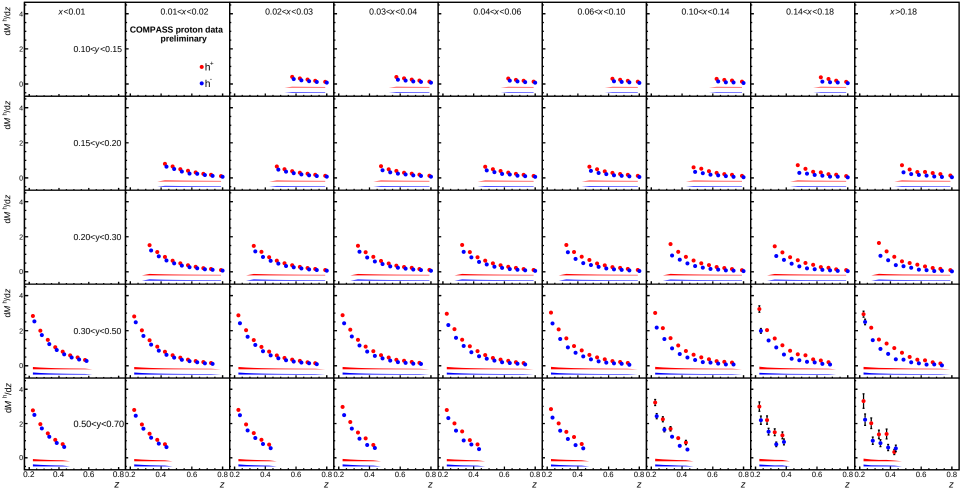
Kinematic Distributions



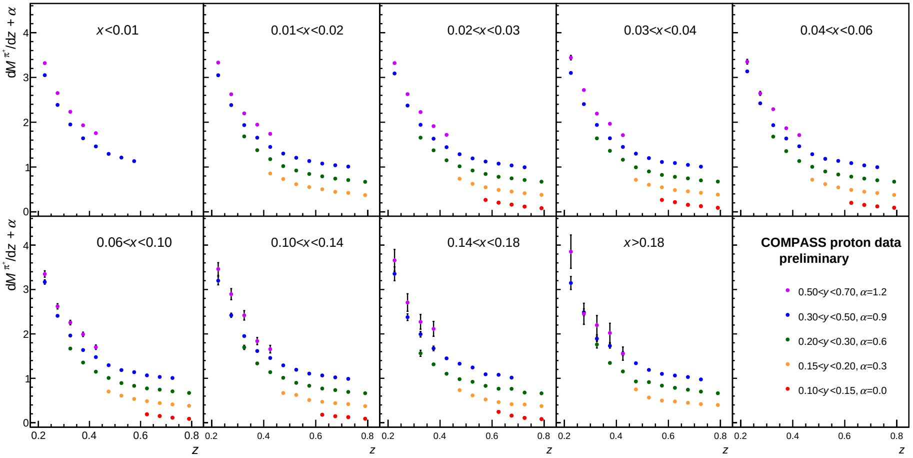
- The bottom right plot shows the impact of the ν cuts on z distribution
- Total sample of events:
  - DIS: 5.5M
  - unidentified hadrons: 1.7M (π: 1.3M, K: 280k)

RESULTS

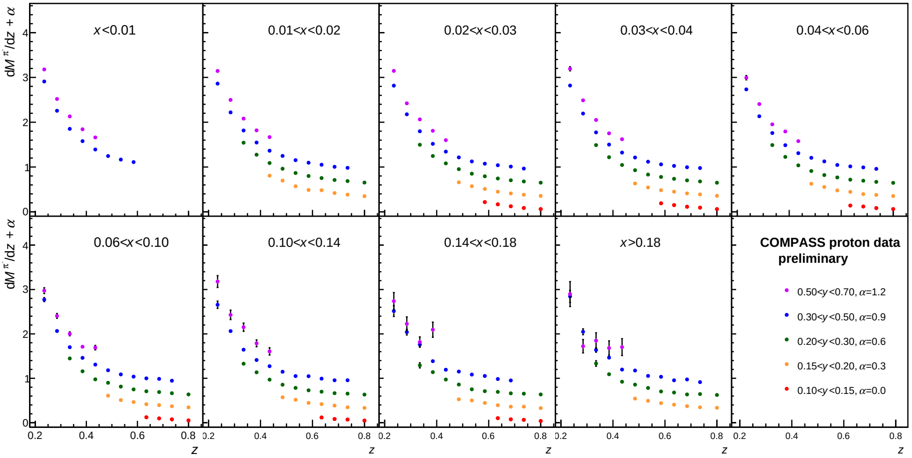
Multiplicities of Unidentified Hadrons



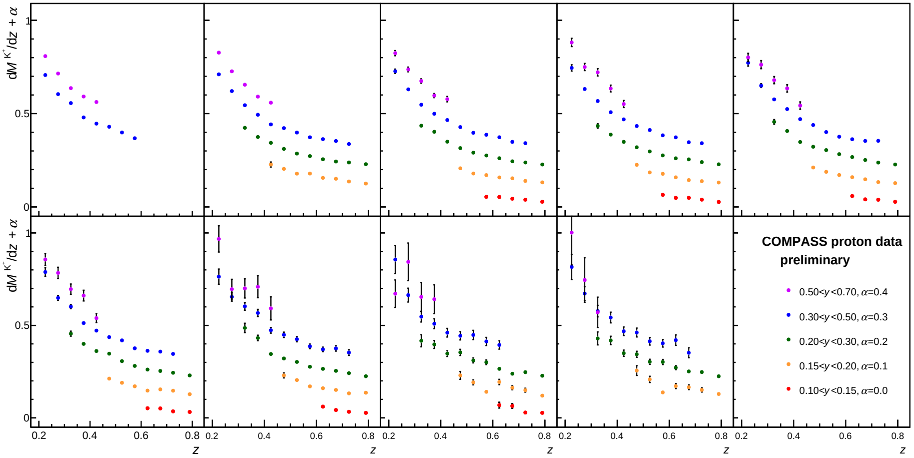
Multiplicities of π^+



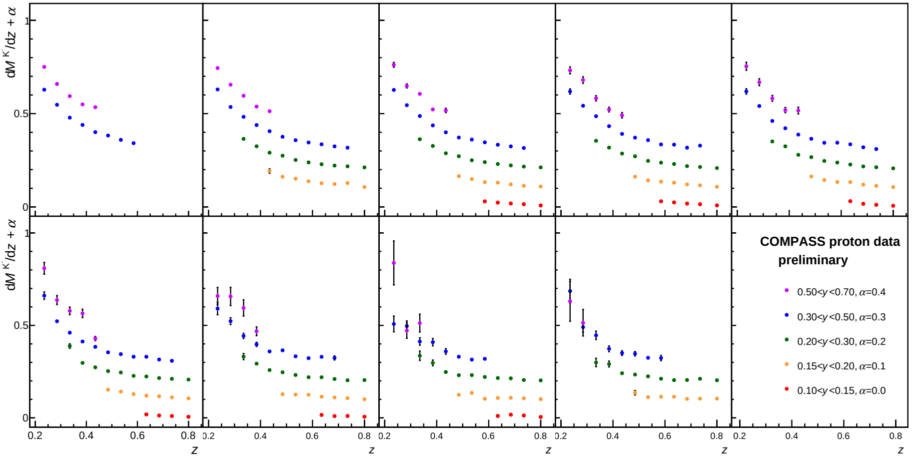
Multiplicities of π^-



Multiplicities of K^+

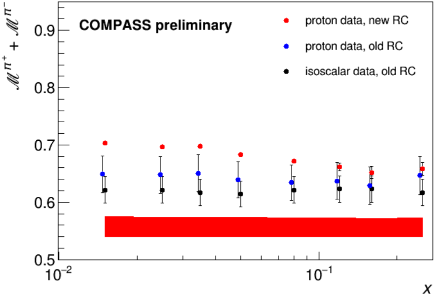


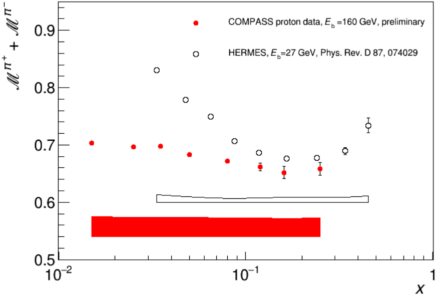
Multiplicities of K^-



Sum of Pion Multiplicities

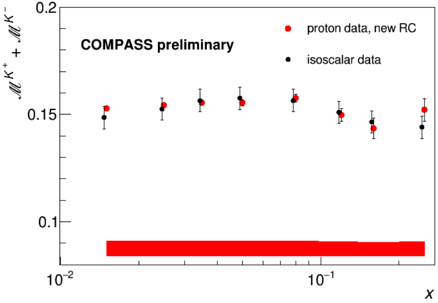
- Let $D_{fav,(unf)} = D_q^h$ where q is (not) the valence quark of h, in LO pQCD:
- For proton target in LO pQCD:
  - $\frac{dM^{\pi^+}}{dz} + \frac{M^{\pi^-}}{dz} = D_{fav} + D_{unf} - \frac{s+\bar{s}}{4u+4\bar{u}+d+\bar{d}+s+\bar{s}}(D_{fav} - D_{unf}) \approx D_{fav} + D_{unf}$
- For isoscalar target in LO pQCD:
  - $\frac{dM^{\pi^+}}{dz} + \frac{M^{\pi^-}}{dz} = D_{fav} + D_{unf} - \frac{2(s+\bar{s})}{5(u+\bar{u}+d+\bar{d})+2(s+\bar{s})}(D_{fav} - D_{unf}) \approx D_{fav} + D_{unf}$
- Results for proton and isoscalar targets are expected to be very similar
- $D(Q^2, z) \rightarrow$ obtained from multiplicity sum is effectively independent of x
- $\mathcal{M}^{\pi^+} + \mathcal{M}^{\pi^-} = \int_{0.2}^{0.85}(\frac{dM^{\pi^+}}{dz} + \frac{dM^{\pi^-}}{dz})dz$

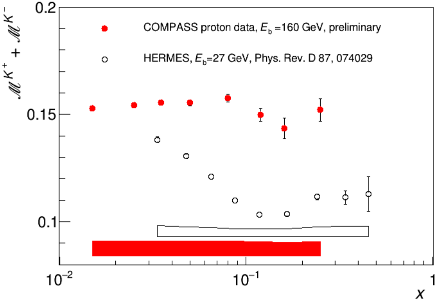




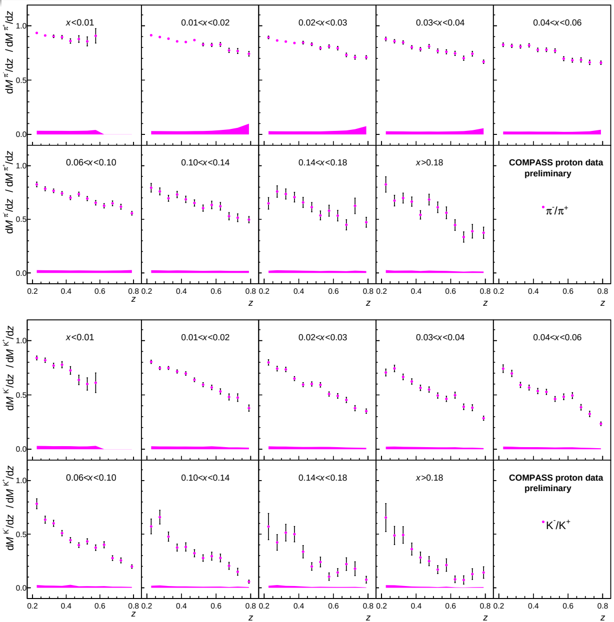
Sum of Kaon Multiplicities

- Contrary to pion case, here $D_s^{K^-}$, $D_{\bar{s}}^{K^+}$ are dominant, larger than e.g. $D_u^{K^+}$
- Since there are not too many $s, \bar{s}$ at high x, we should see some turn-on effect related to the increased density of strange quark PDFs at lower x
- Perhaps x values accessed by COMPASS is too low to assure low density of $s, \bar{s}$
- $\mathcal{M}^{K^+} + \mathcal{M}^{K^-} = \int_{0.2}^{0.85} (\frac{dM^{K^+}}{dz} + \frac{dM^{K^-}}{dz}) dz$





Multiplicity Ratios π^-/π^+ and K^-/K^+

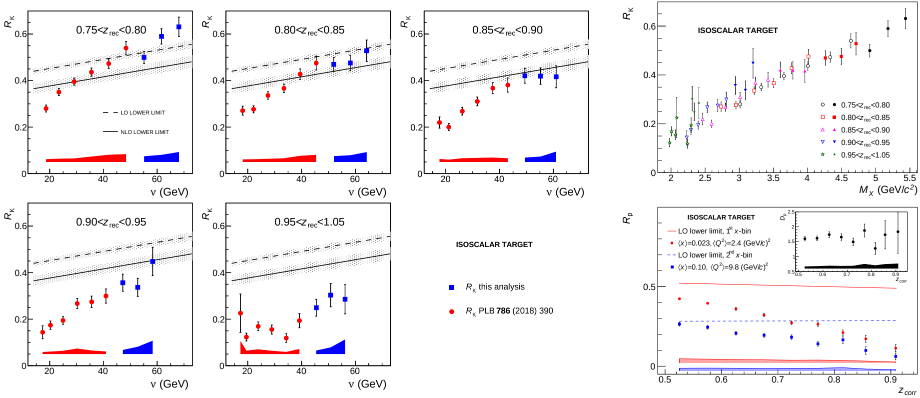


Multiplicity Ratios K^-/K^+ and $\bar{p}/p$ from Isoscalar Target

- In the multiplicity ratio a lot experimental and theoretical uncertainties cancel
- In LO pQCD one can calculate a lower limit for the ratio
  - $R_K(x,Q^2,z) = \frac{\mathrm{d}M^{\mathrm{K}^-}(x,Q^2,z)/\mathrm{d}z}{\mathrm{d}M^{\mathrm{K}^+}(x,Q^2,z)/\mathrm{d}z} = \frac{4(\bar{\mathrm{u}}+\bar{\mathrm{d}})D_{\mathrm{fav}}+(5\mathrm{u}+5\mathrm{d}+\bar{\mathrm{u}}+\bar{\mathrm{d}}+\mathrm{s}+\bar{\mathrm{s}})D_{\mathrm{unf}}+(\mathrm{s}+\bar{\mathrm{s}})D_{\mathrm{str}}}{4(\mathrm{u}+\mathrm{d})D_{\mathrm{fav}}+(5\bar{\mathrm{u}}+5\bar{\mathrm{d}}+\mathrm{u}+\mathrm{d}+\mathrm{s}+\bar{\mathrm{s}})D_{\mathrm{unf}}+(\mathrm{s}+\bar{\mathrm{s}})D_{\mathrm{str}}}$
  - $R_p(x,Q^2,z) = \frac{\mathrm{d}M^{\bar{\mathrm{p}}}(x,Q^2,z)/\mathrm{d}z}{\mathrm{d}M^{\mathrm{p}}(x,Q^2,z)/\mathrm{d}z} = \frac{(5\bar{u}+5\bar{d})D_{fav}+(5u+5d+2s+2\bar{s})D_{unf}}{(5u+5d)D_{fav}+(5\bar{u}+5\bar{d}+2s+2\bar{s})D_{unf}}$
- D_{unf} is expected to be small at large z, thus can be neglected
  - $R_K = \frac{4(\bar{\mathrm{u}}+\mathrm{d})D_{\mathrm{fav}}+(\mathrm{s}+\bar{\mathrm{s}})D_{\mathrm{str}}}{4(\mathrm{u}+\mathrm{d})D_{\mathrm{fav}}+(\mathrm{s}+\bar{\mathrm{s}})D_{\mathrm{str}}}$
  - $R_p = \frac{\bar{u}+\bar{d}}{u+d}$
- since $(\mathrm{s}+\bar{\mathrm{s}})D_{\mathrm{str}}$ is positive, it can also be neglected for the lower limit calculation
  - $R_K > \frac{\bar{\mathrm{u}}+\bar{\mathrm{d}}}{\mathrm{u}+\mathrm{d}}$
  - $R_p > \frac{\bar{\mathrm{u}}+\bar{\mathrm{d}}}{\mathrm{u}+\mathrm{d}}$
- The lower limits predicted by LO pQCD for R_K and R_p are the same
- R_K expected to be 10-15% higher than R_p because of D_{str}
- R_π suffers from large contamination of decay products of diffractive ρ^0

Multiplicity Ratios K^-/K^+ and $\bar{p}/p$ from Isoscalar Target cont.

- Results published PLB 786 (2018) 390 and PLB 807 (2020) 135600
- At high z multiplicity ratio for K^-/K^+ and $\bar{p}/p$ in data are below lower limits expected from pQCD in (N)LO
- Kaon results presented for $x < 0.05$
- Effect more pronounced for $\bar{p}/p$ and starts at lower z



Summary

- SIDIS data are crucial for understanding quark fragmentation into hadrons
- COMPASS already published several papers based on isoscalar data analysis
- Today, results for $h^{\pm}, \pi^{\pm}, K^{\pm}$ multiplicities on proton target were shown
- Impact of Radiative Correction is larger than originally anticipated in early isoscalar data analyses
- Otherwise, there is a good agreement between proton and isoscalar data
- Analysis is considered as finished - paper is in preparation