π and K SIDIS multiplicities, $\bar{p}/p$ and K^-/K^+ ratios at large *z* measured at COMPASS

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On behalf of COMPASS Collaboration

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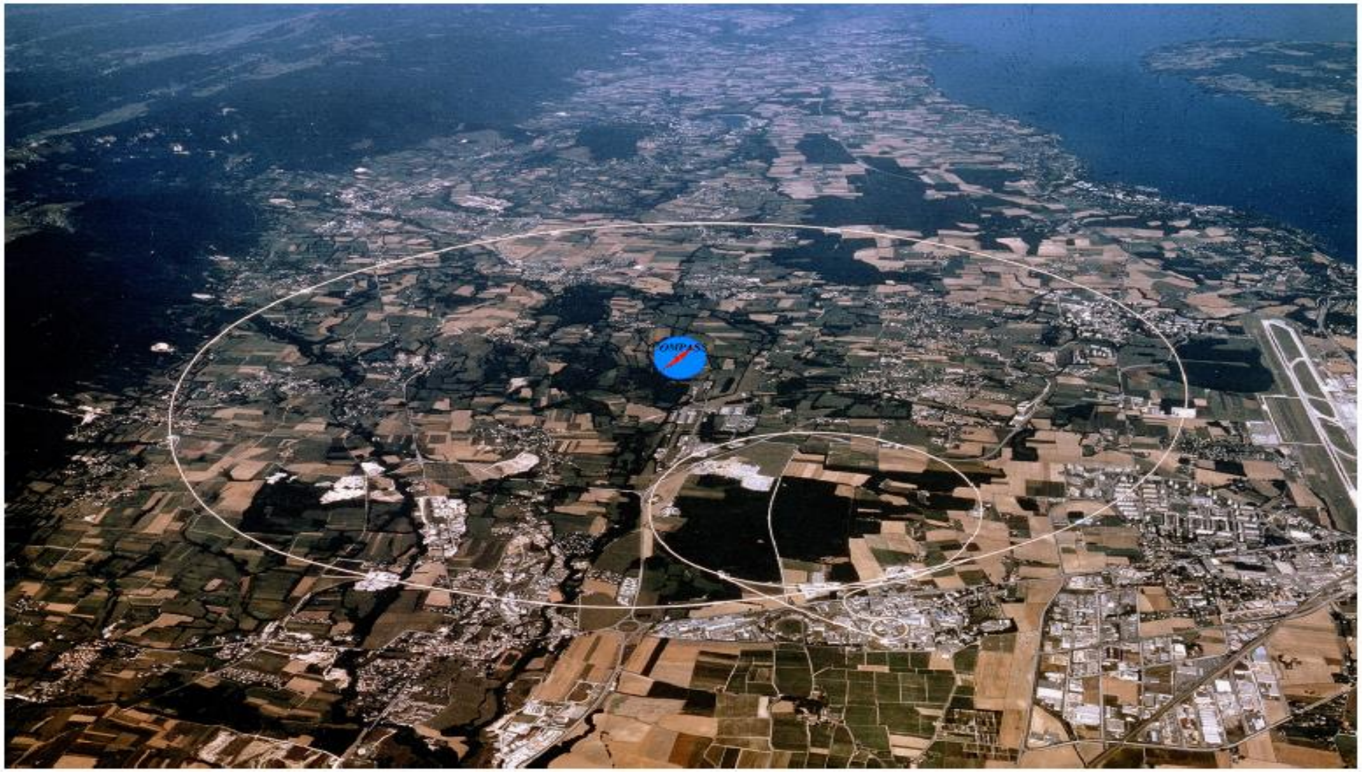
COmmon Muon Proton Apparatus for Structure and Spectroscopy



~240 physicists, 13 countries, 25 institutions

Fixed target experiment, multi-purpose set-up.
Secondary ~200 GeV muon and hadron beams from CERN SPS
Various targets

Motivation

Longitudinal spin- Impact of FF on Δs extraction

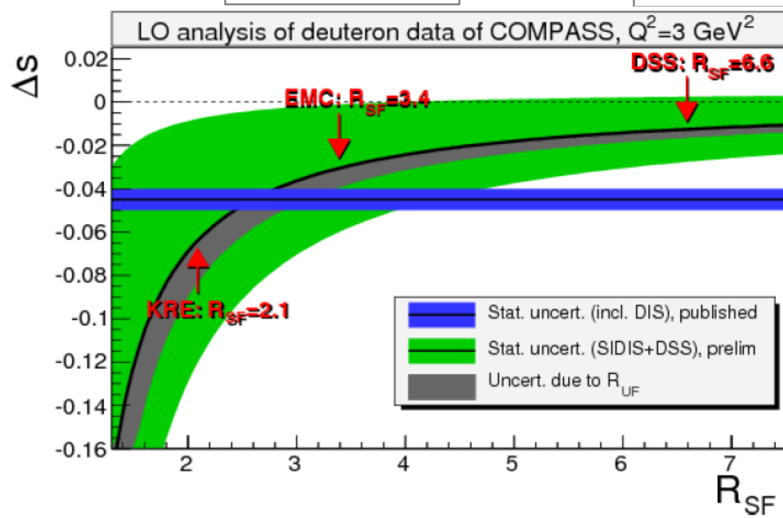
Δs extraction from SIDIS depends on value of D_s^K fragmentation function.

using EMC FF

using DSS FF

Δs vs **R_{SF}**

$R_{SF} = D_s^K / D_u^K$



Inclusive data (assuming SU_3)

COMPASS, PLB 680 (2009) 217

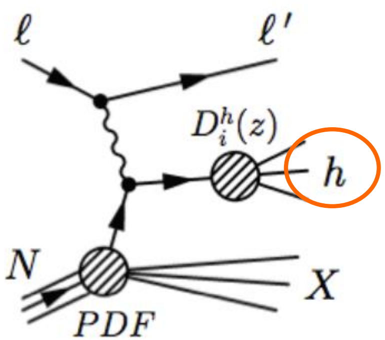
Most Δs extractions from SIDIS used the old DSS value for $\mathbf{R_{SF}}$. Could be revisited.

Quark Fragmentation Functions (FF)

FFs : - Non perturbative object; needed to describe various reactions
- Strange quark FF= **largest uncertainty in Δs extraction** from polarized SIDIS.

Data exist from e^+e^- and pp reactions, but insufficient and at too high Q^2

→ Measure hadron multiplicities in **SIDIS: $\mu^+ d \to \mu^+ h^\pm X$** h= π, K, p



$z = E_h/(E_\mu - E_\mu')$

PDFs FFs

$$\frac{dM^h(x,Q^2,z)}{dz} \underset{\text{at LO}}{=} \frac{\sum_q e_q^2 f_q(x,Q^2) D_q^h(z,Q^2)}{\sum_q e_q^2 f_q(x,Q^2)}$$

PDFs depend on x, while FFs depend on z

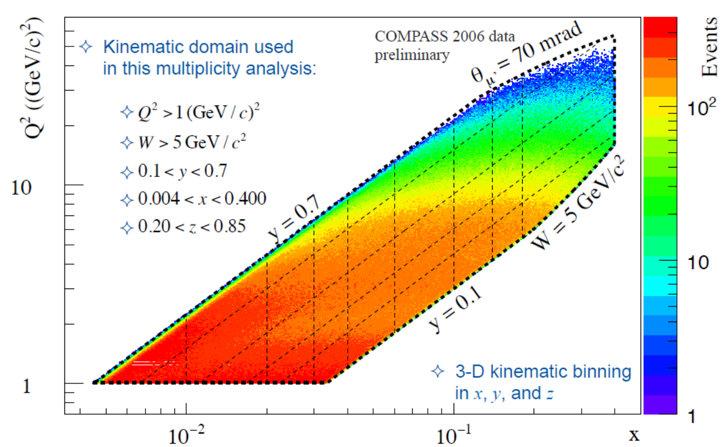
→ With kaons, access typically : $s(x,Q^2).D_s^K(z,Q^2)$

Corrections for : acceptance, RICH purity & efficiency, radiative effects and vector meson contamination

Data obtained in a fine binning in x, z, Q^2

→ **π and K multiplicities constitute an input to global NLO QCD analyses to extract quark FFs,**

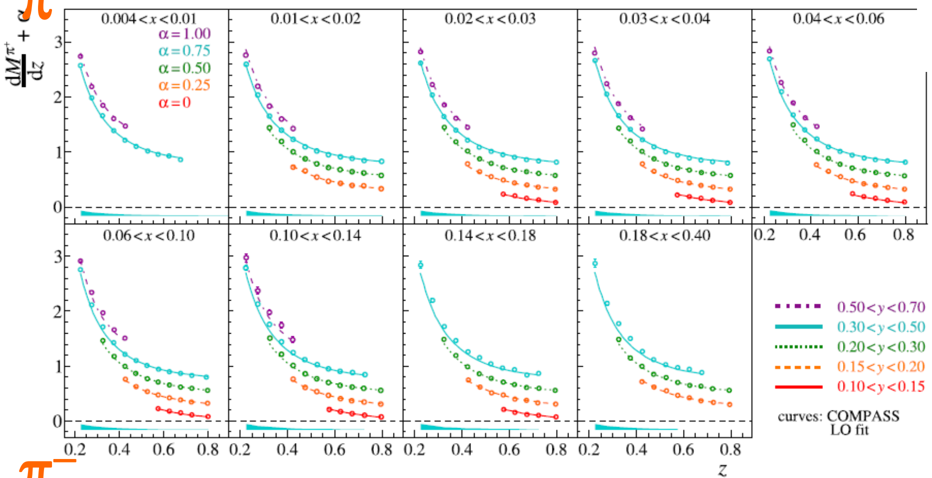
→ **Especially, K will constrain strangeness**



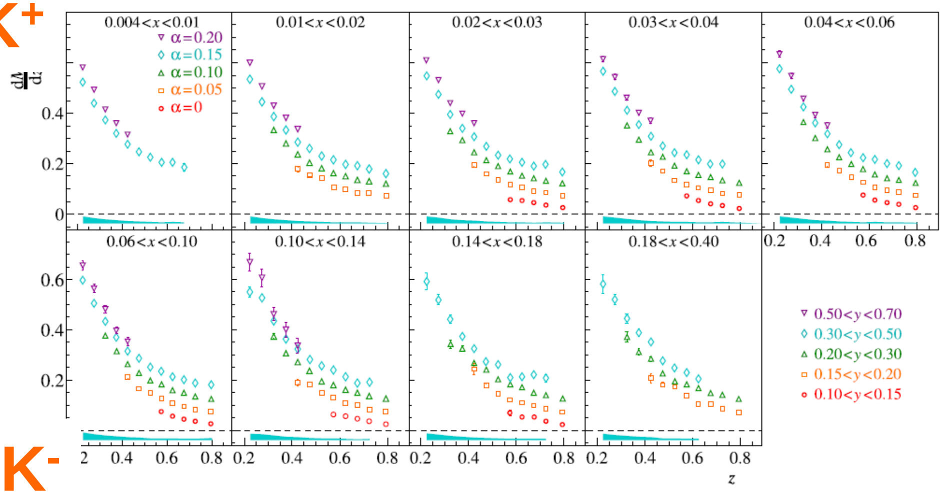
F. Kunne

COMPASS π and K multiplicities vs z in (x,y) bins

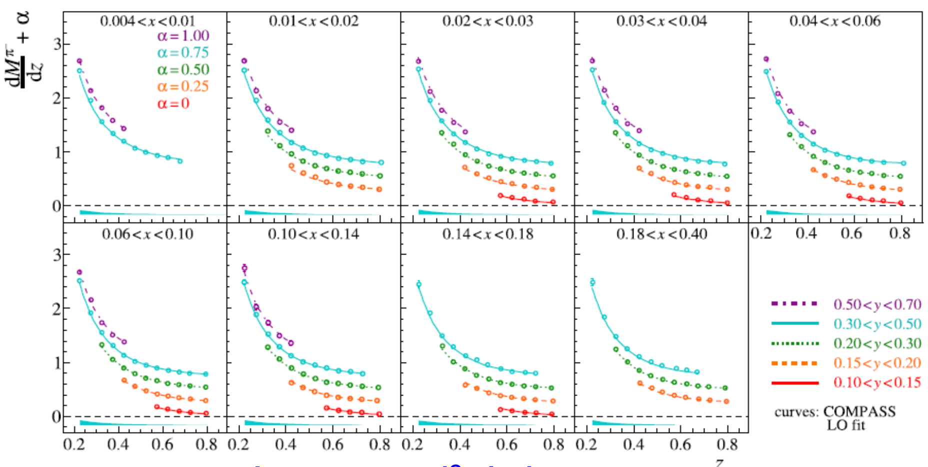
π^+



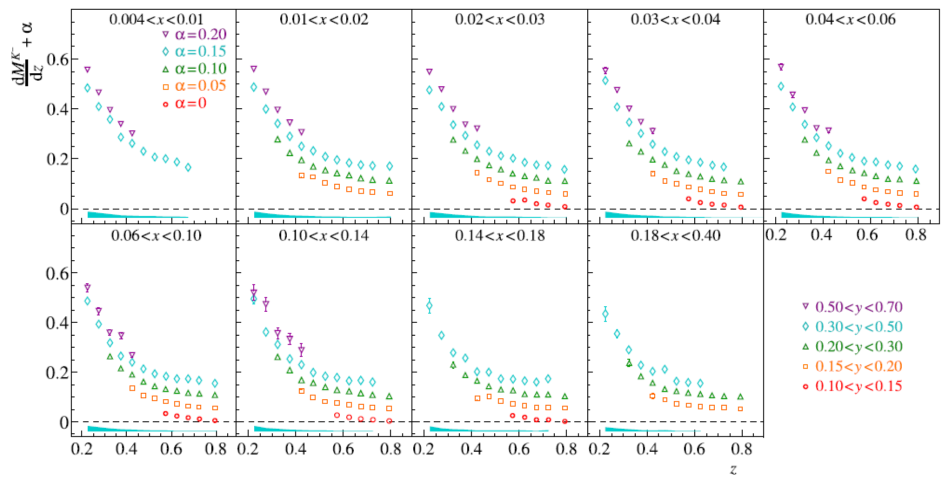
K+



π^-



K-



- Isoscalar target (^{6}LiD)
- More than 1200 points in total, various Q^2 staggered vertically for clarity
- Strong z dependence
- $M(\pi^+) \sim M(\pi^-)$ and $M(K^+) > M(K^-)$

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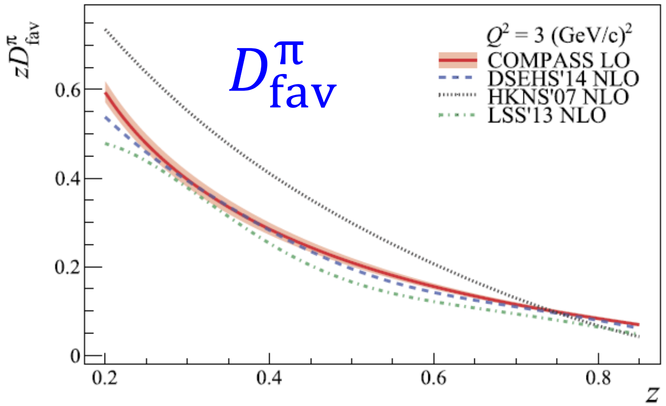
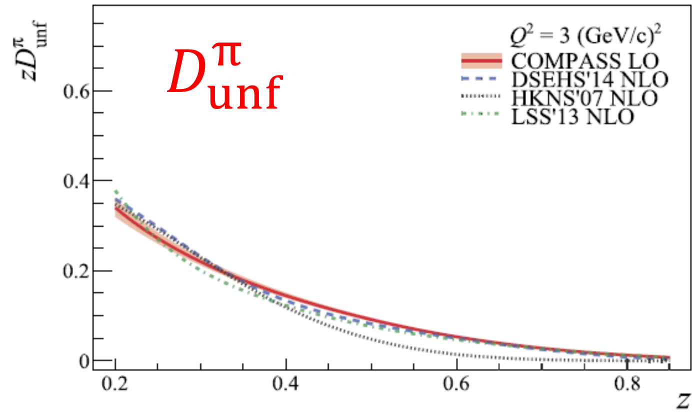
From multiplicities to quark Fragmentation Functions

Pions Results from COMPASS LO fits assuming 2 independent FFs: D^{π}_{fav} D^{π}_{unf}





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- As expected, $D^{\pi}_{\mathrm{fav}} > D^{\pi}_{\mathrm{unf}}$
- COMPASS LO fit results ~agree with DSEHS and LSS NLO.

Kaons Assuming 3 independent FFs: D^{K}_{fav} D^{K}_{str} D^{K}_{unf}

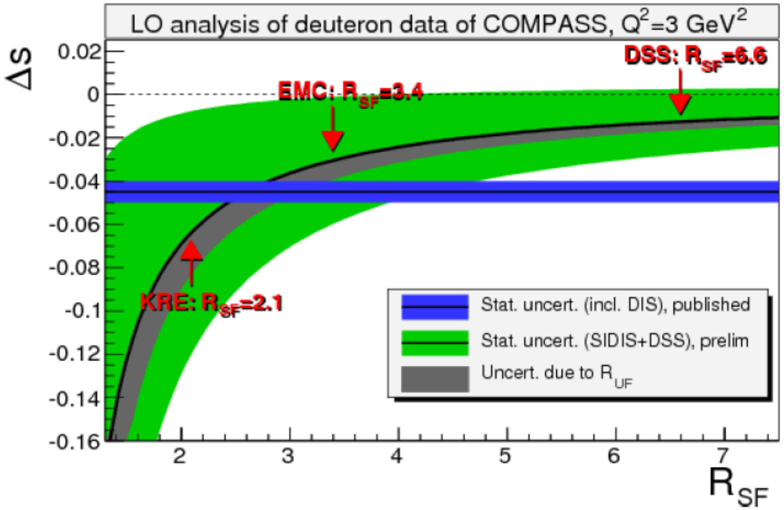
- LO fit not conclusive. Some difficulty in fitting high *z* data, even at NLO.
- Still, get constraints on FFs from sum of K^+ and K^- multiplicities (see later)
- Global NLO fits now give smaller D^{K}_{str} than previously, meaning larger Δs.

(e.g. in ***DSS17*** where half of data come from COMPASS,

and also in combined fit of PDF and FF via iterative study)

Borsa, Sassot, Stratmann, arXiv:1708.01630

Longitudinal spin- Impact of FF on Δs extraction



Sum of z-integrated multiplicities $\pi^+ + \pi^-$ & $K^+ + K^-$

For isoscalar target, simple dependence on FFs:

$$M^{\pi^+ + \pi^-} = (1 - \cancel{2S/(5Q+2S)})\, D_{\mathrm{fav}} + D_{\mathrm{unf}}$$

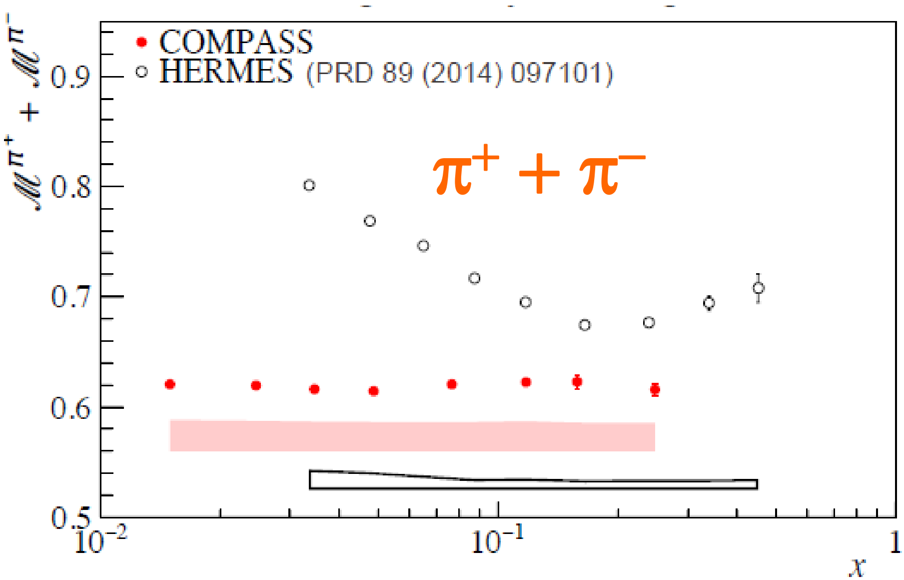
$$5M^{K^+ + K^-} = D_Q^K + S/Q\, D_S^K$$

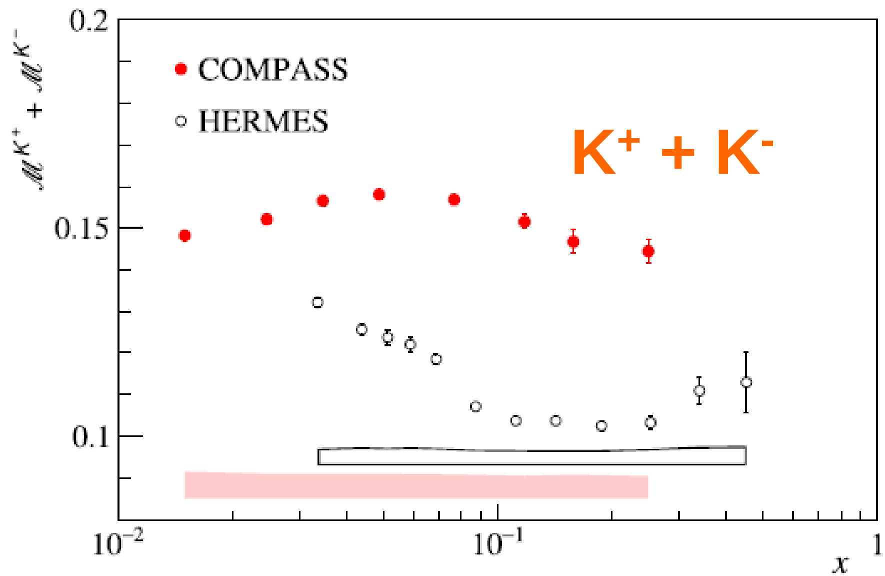
high x data ***low x data***

where:

At high x, ~no x dependence expected

$$\begin{cases} Q = u + \bar{u} + d + \bar{d}, \\ S = s + \bar{s}, \\ D_Q^K = 4D_{fav}^K + 6D_{unf}^K \end{cases}$$





COMPASS pion data:

- **significantly below HERMES ones**
- **no x dependence as expected**

(as in EMC h, but not shown here)

COMPASS kaon data:

- **significantly above HERMES ones**
- **Indicate larger D_Q^K than old NLO fits**

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K Multiplicities on p target

- Preliminary result from 2016 run (2017 to come)
- Radiative corrections using DJANGOH event generator (Spiesberger)
  → reduces systematics

M(K$^-$)+M(K$^+$)

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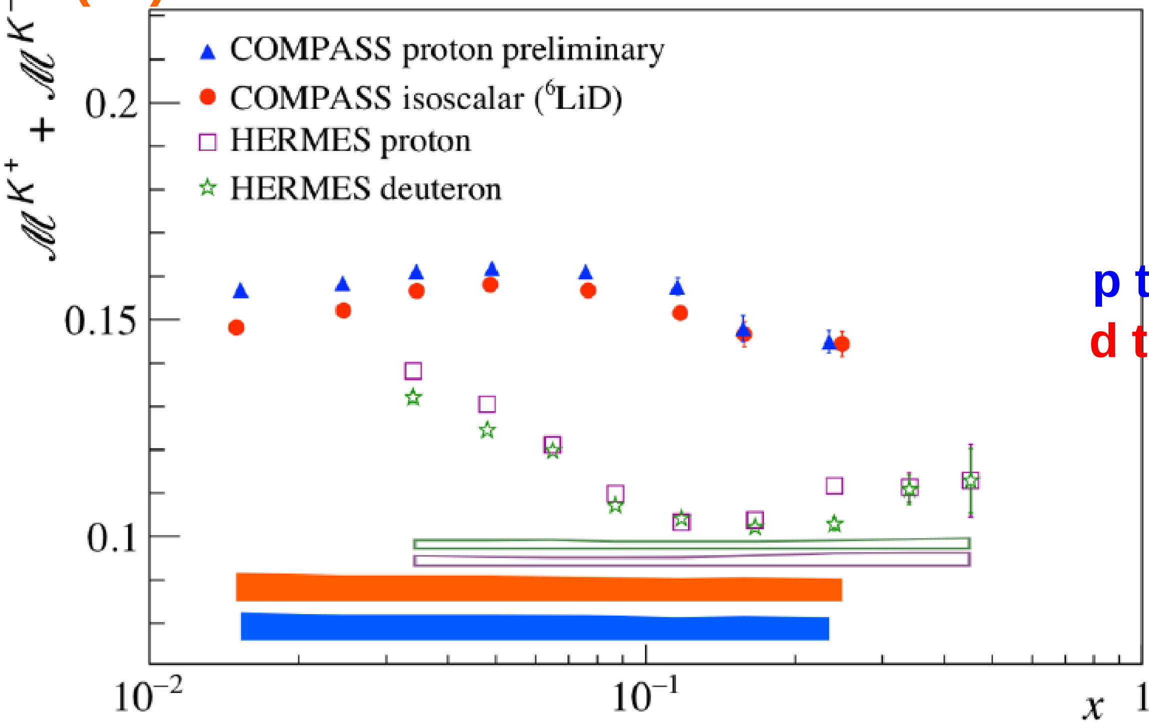


p target
d target

- Results on **p** confirm discrepancy COMPASS vs HERMES (x,z) data set, observed on **d** target
- **p** results 5% above **d** ones, as expected

Some hints on discrepancies HERMES / COMPASS

Kaons:

- Target hadron mass corrections could explain part of discrepancies. ***Guerrero, Accardi, PRD 97 (2018) 114012***
- For the very few points that have exactly the same kinematics in *x,y z* variables, HERMES and COMPASS agree

M(K$^-$)/ M(K$^+$) kaon multiplicity ratio at high z

Motivation: High *z* region not studied so far
Most experimental and theoretical uncertainties cancel in ratio

Some simple estimation at LO, proton target
with assumptions (D_{unf} neglected…) :

$$R_{\mathrm{K}} = \frac{4\bar{\mathrm{u}}D_{\mathrm{fav}} + \mathrm{s}D_{\mathrm{str}}}{4\mathrm{u}D_{\mathrm{fav}} + \bar{\mathrm{s}}D_{\mathrm{str}}}.$$

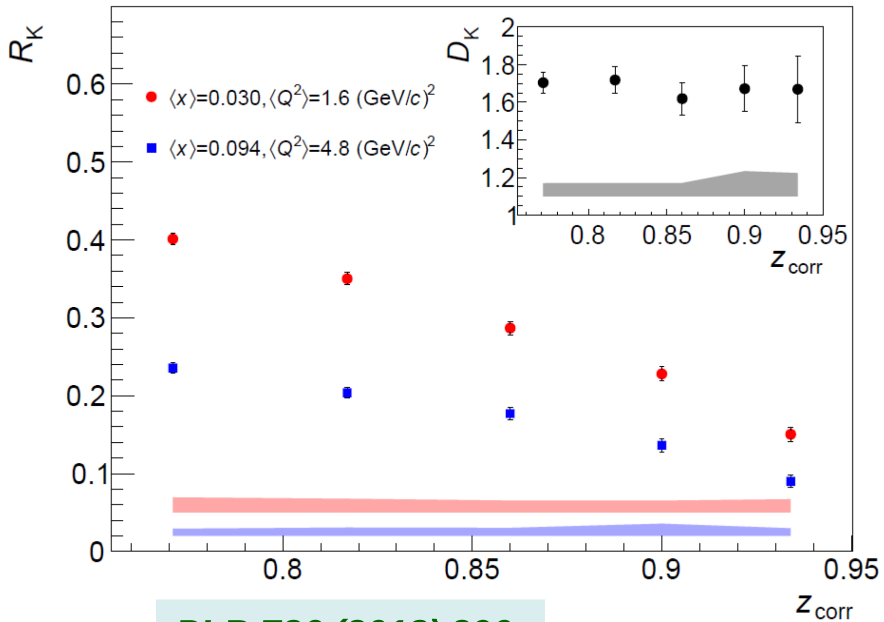
and assuming $\mathrm{s} = \bar{\mathrm{s}},$ gives limits: $R_{\mathrm{K}} > \frac{\bar{\mathrm{u}}}{\mathrm{u}}$ for a proton target

$$\boxed{R_{\mathrm{K}} > \frac{\bar{\mathrm{u}} + \bar{\mathrm{d}}}{\mathrm{u} + \mathrm{d}}}$$ for a deuteron target

M(K⁻)/ M(K⁺) at high *z* – Results vs *z*

Isoscalar target

Ratio measured vs *z* in two *x* bins



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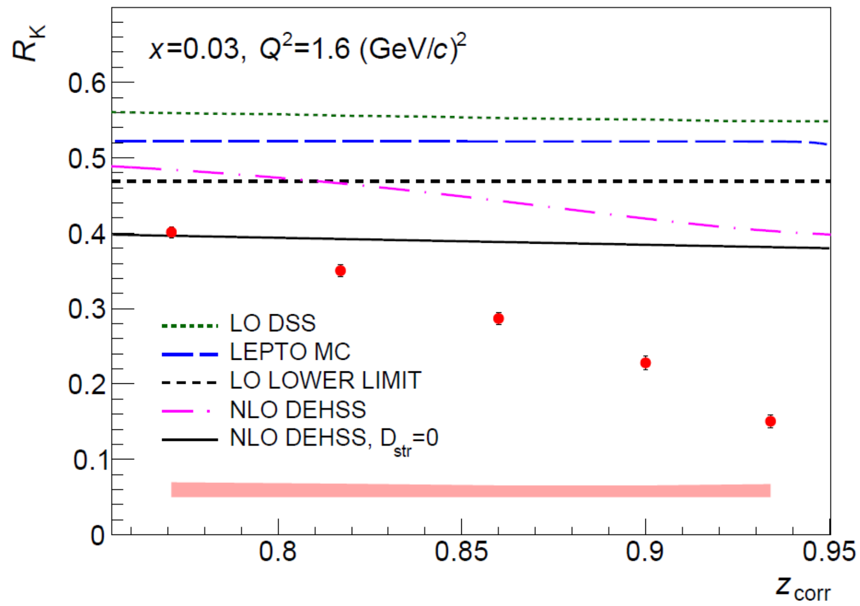
Compare to theory, bin *x*=0.03

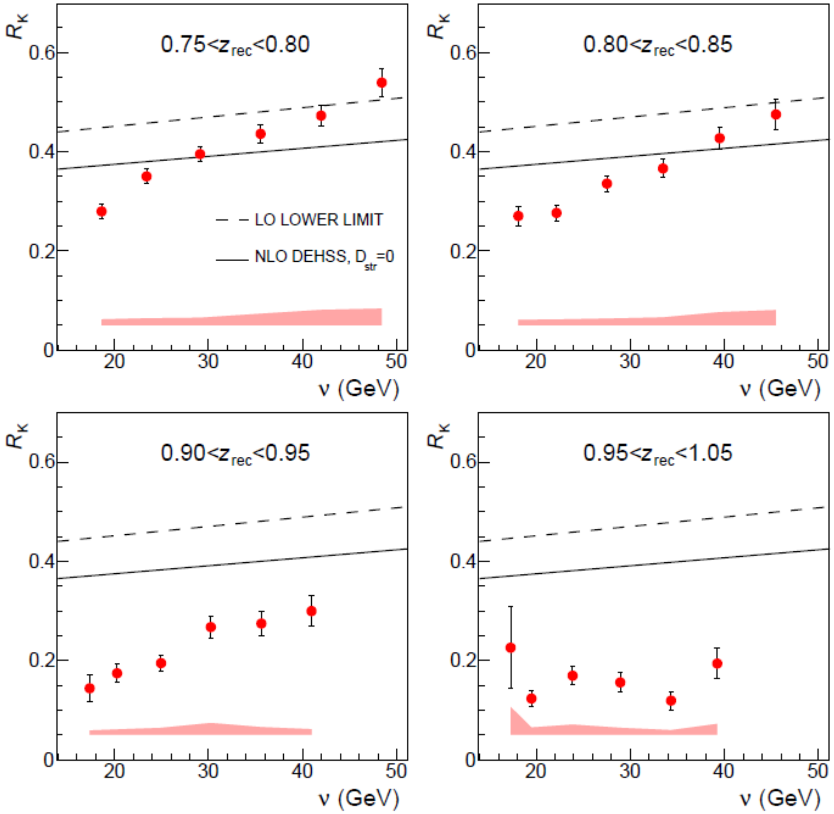


M(K⁻) / M(K⁺) ratio well below expectations at high *z*

$M(K^-)/ M(K^+)$ – Results vs $\nu = E_h/z$ in 5 z bins

Isoscalar target

for bin x=0.03



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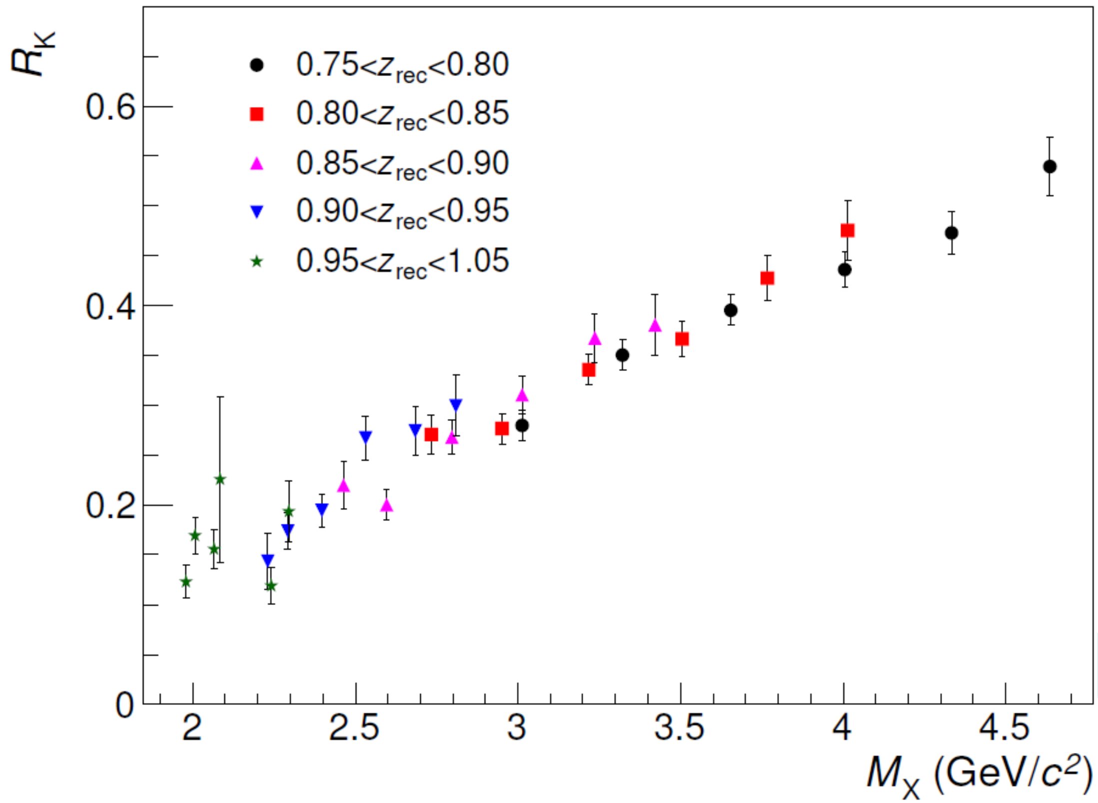
Larger discrepancy with theory for smaller ν

M(K⁻)/ M(K⁺) – Results vs missing mass M_X

High *z* kaon → reduced phase space for other particles
Study missing mass behaviour

$$M_X = \sqrt{M_p^2 + 2M_p\nu(1-z) - Q^2(1-z)^2}$$



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- **M(K⁻)/ M(K⁺) shows unexpected strong rise with M_X**
- **Suggests to take into account the available phase space for hadronization, in the formalism**

Recent developments

K^-/K^+ **Does R_K reaches pQCD expectations at higher ν?**

→ Extend ν range up to 70 GeV
done by improving kaon selection at high momenta 40 → 55 GeV/c

$\bar{p}$ /p **Does R_p show similar unexpected behaviour as R_K?**

→ Study antiproton/ proton case :
R_p vs lower LO limit, dependence on ν, dependence on M_X

Kaons (I): R_K vs ν in 5 z bins

New data with high K momenta cover higher ν range, up to 70 GeV

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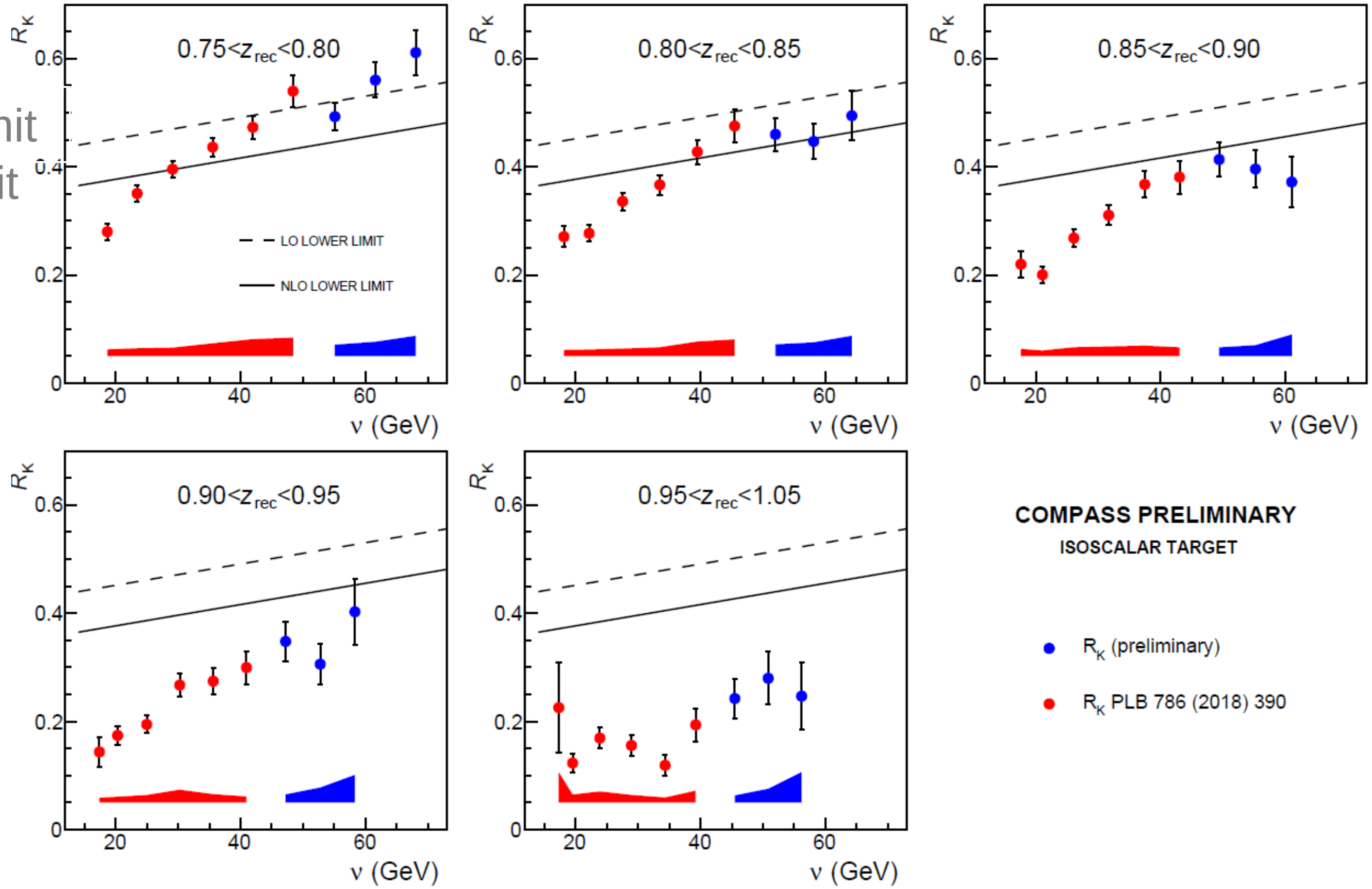
- - NLO limit

— LO limit



- Better compatibility with pQCD expectations at **higher ν**
- … and at lower z ~ 0.75- 0.85
- For lower energy experiments, could lower z regions be affected?

Kaons (II): R_K vs M_X

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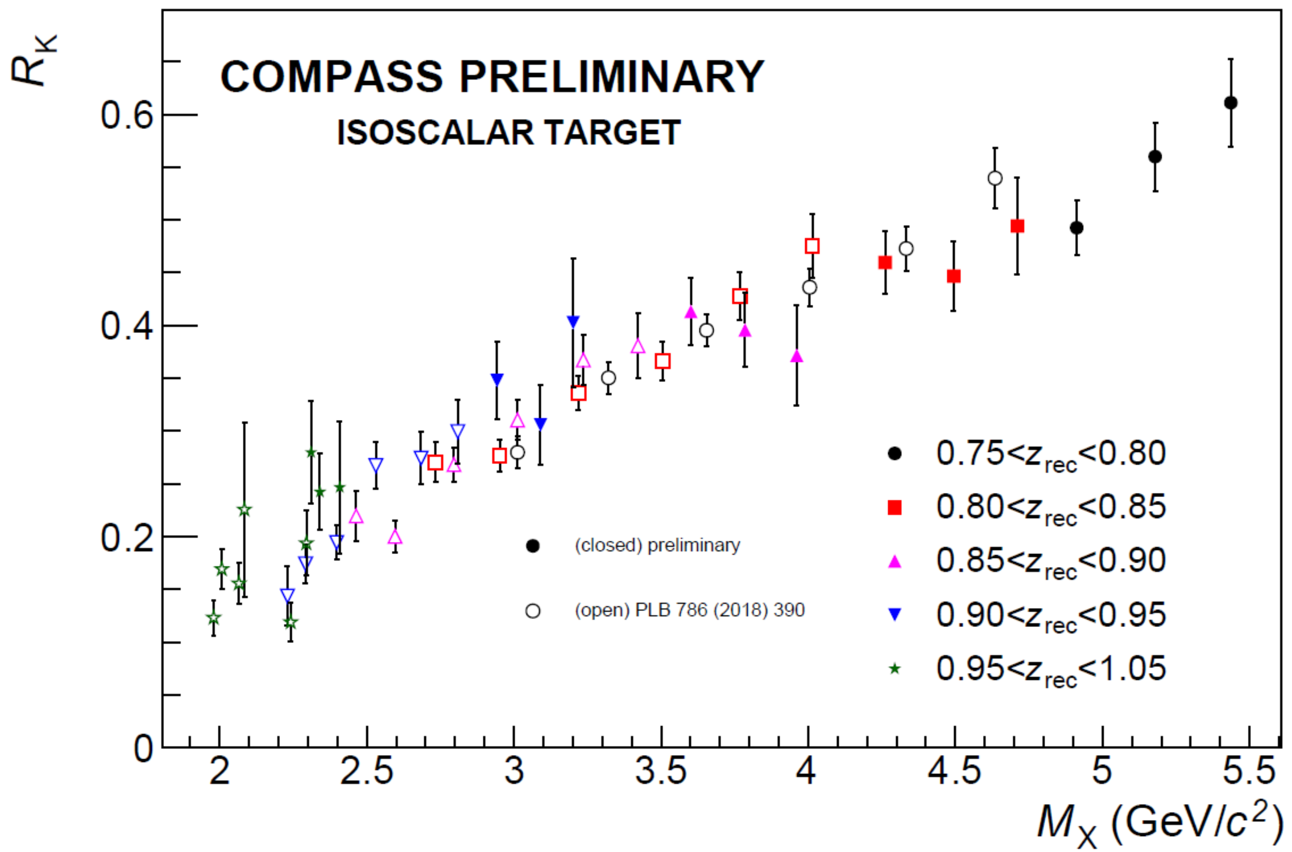
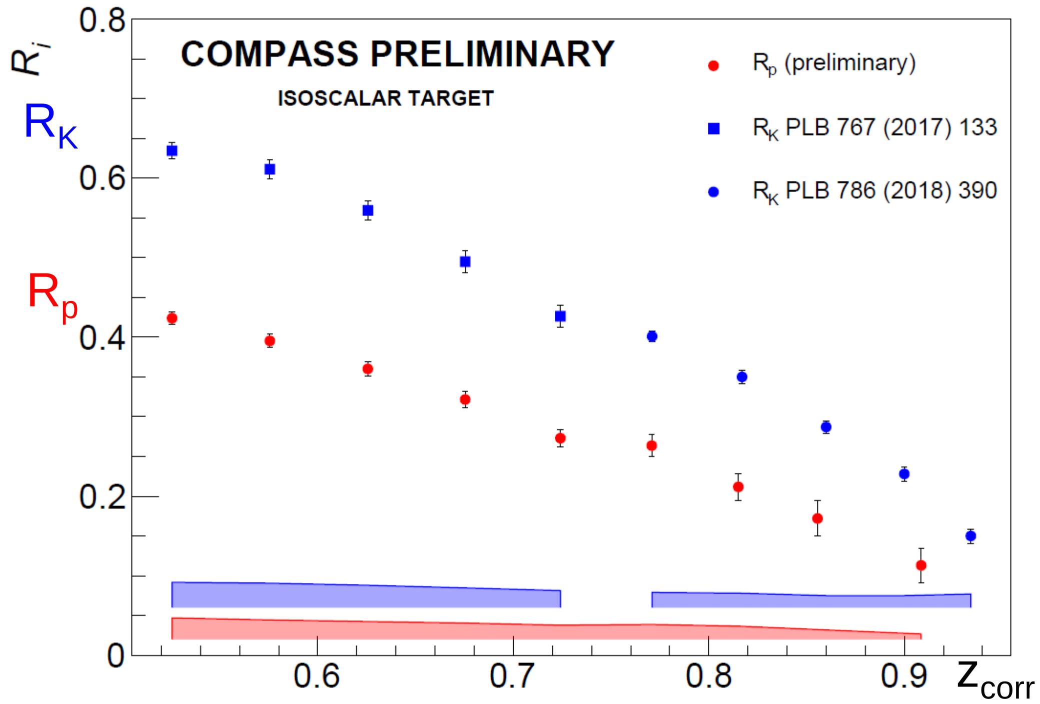


- New data slightly extend M_X range (closed points)
- At fixed M_X, no dependence on ν nor z
  → confirms that **M_X encompasses all dependences**

Kaons and protons: R_K and R_p vs z



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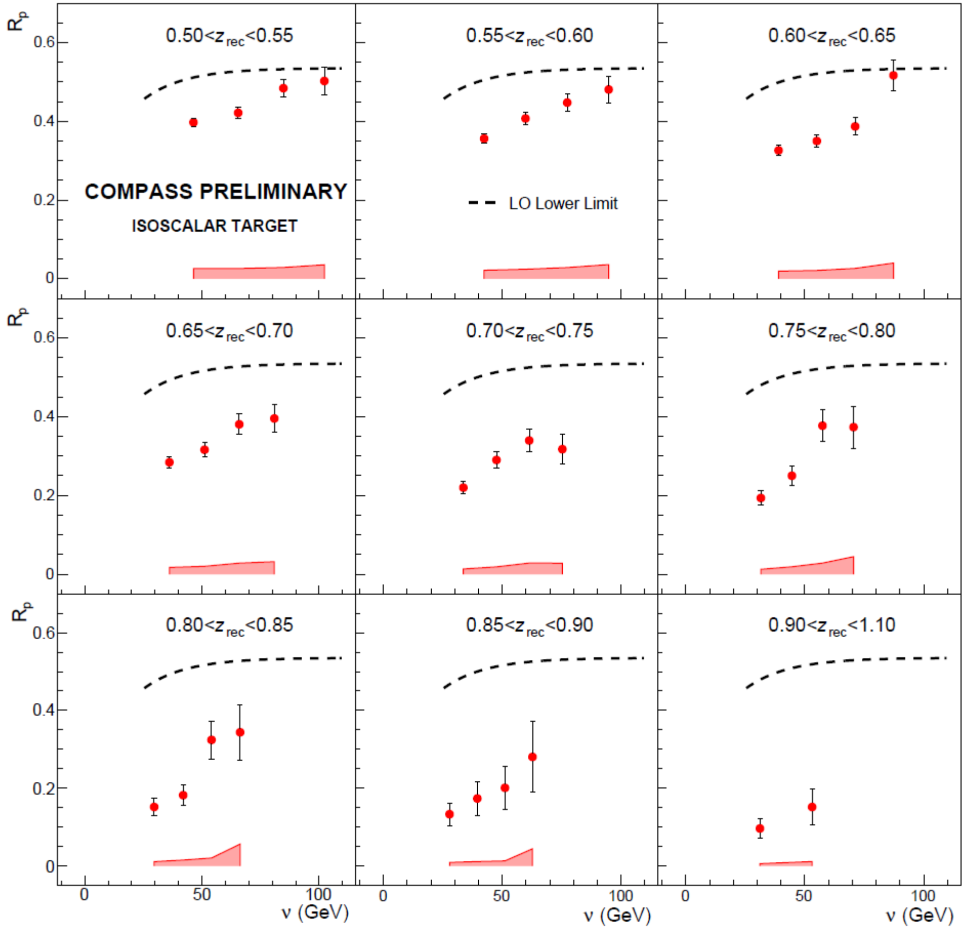
Shown for lower x bin ~0.02

- **R_p** decreases vs z, as **R_K**
- Observe large difference between R_K and R_p, while only 15% expected from LO pQCD

→ **Is discrepancy wrt theory larger for higher mass hadrons?**

Protons (II): R_p vs ν in 9 z bins



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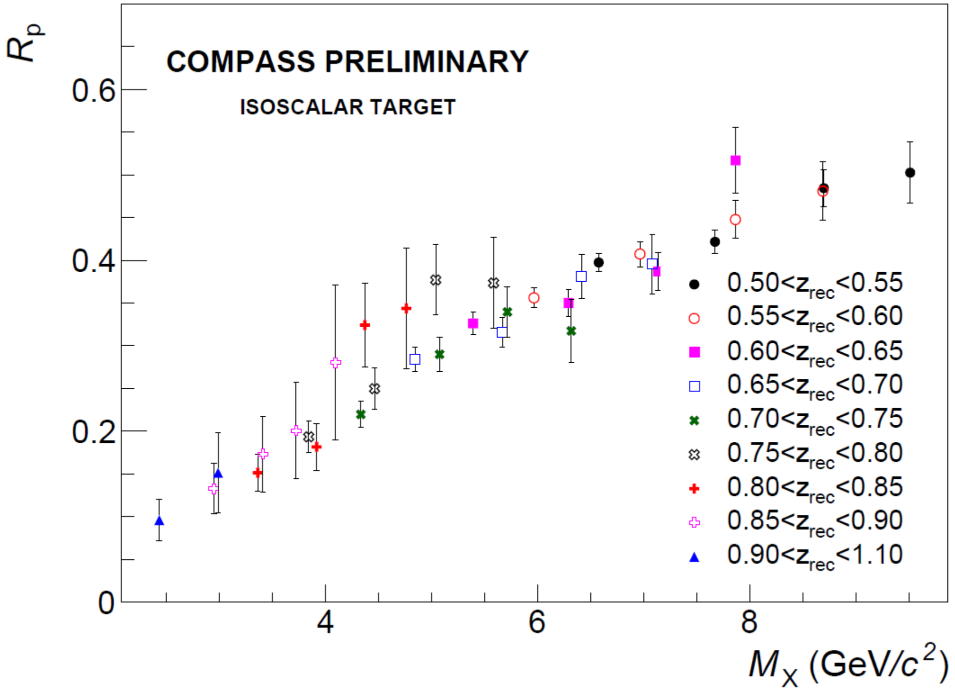
- Observe ν dependence for R_p (as seen for R_K) (beyond expected from $x(\nu)$)
- **R_p closer to pQCD expectations at higher ν values**

Protons (III): R_p vs M_X



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$$M_X = \sqrt{M_p^2 + 2M_p\nu(1-z) - Q^2(1-z)^2}$$

→ For protons also, **M_X encompasses all dependences (ν and z)**

Protons (I): R_p vs z in two x bins

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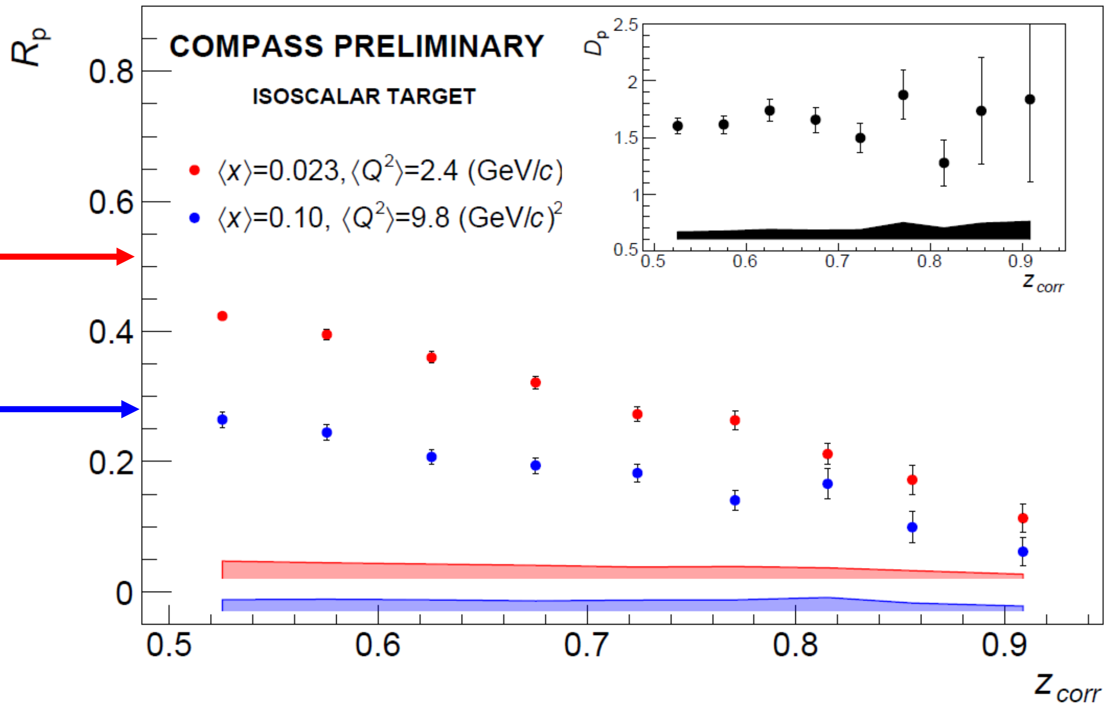
Lower LO limits for:
<x>=0.02
<x>=0.10



R_p ratio below lower limit in whole z range

Summary – SIDIS π, K and p multiplicities

$\bar{p}$/p and K^-/K^+ multiplicity ratios at high z:

- Data **disagree** with current NLO QCD calculations **at high *z* and low ν**
  (At lower energy, larger region in z may be affected)

- Unexpected rise of ratios with missing mass, suggesting to take into account the available phase space for hadronization, in the formalism.

… Paper in preparation

Reminder : π and K SIDIS multiplicities

isoscalar target : PLB 2017

hydrogen target: prelim data DIS-2019

- Largest kaon sample measured, to constrain kaon FFs (D_s^K)

- Some hints on reasons for **large discrepancy** COMPASS vs HERMES

- **Smaller D_s^K and larger D_u^K** than previously leads to **slightly larger Δs from SIDIS**, i.e. no longer strong incompatibility with Δ**s** from inclusive data.