Single hadron multiplicities in SIDIS @ COMPASS

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On behalf of the COMPASS collaboration

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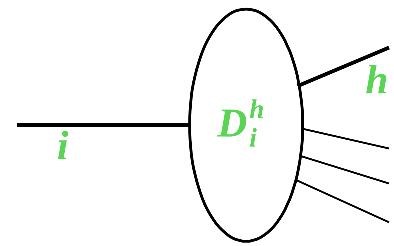
Motivation

- SIDIS $lN \to lhX$ gives access to Fragmentation Functions (FFs)

- **Collinear** FFs $D_i^h(z, Q^2)$ describe the collinear transition
  of a parton i
  into a hadron h carrying energy fraction $z = E_h/E_i$.



  - Non-perturbative but universal objects.
    Factorisation: [PDF $\otimes$] parton-level X-section $\otimes$ FF
  - Scale dependence: $dD_q^h(z, Q^2)/dlnQ^2 = [P_{qq} \otimes D_q^h + P_{gq} \otimes D_g^h](z, Q^2)$

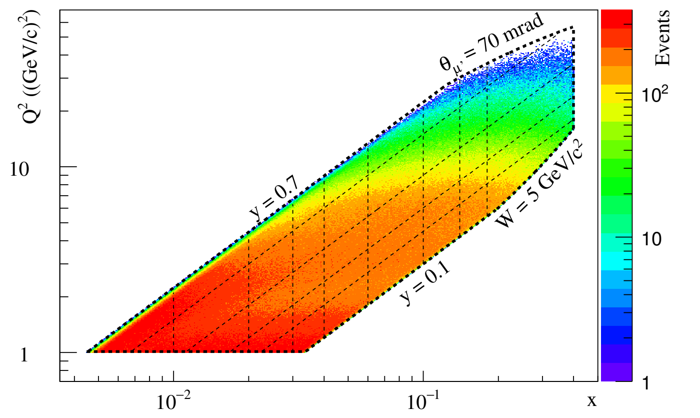
- FFs are needed in analyses with a hadron in the final state
  (*when a hadron is **inclusively** detected in **hard** scattering*)

- Cleanest way to access FFs: e^+e^- annihilation. However. . .
  . . . only sensitive to $q + \bar{q}$, flavour separation limited.
  - In SIDIS, FFs are convoluted with PDFs. However. . .
    . . . $q/\bar{q}$ and flavour separation possible.
  - pp: $pp \to hX$ at high pT: little flavour/charge separation, but with gluon at leading order
    $pp \to (jet\ h)X$, see PRD 92 (2015),
  - SIDIS data are crucial to understand parton fragmentation

Multiplicity Measurement in SIDIS

- Multiplicity is number of hadrons *per* inclusive DIS event

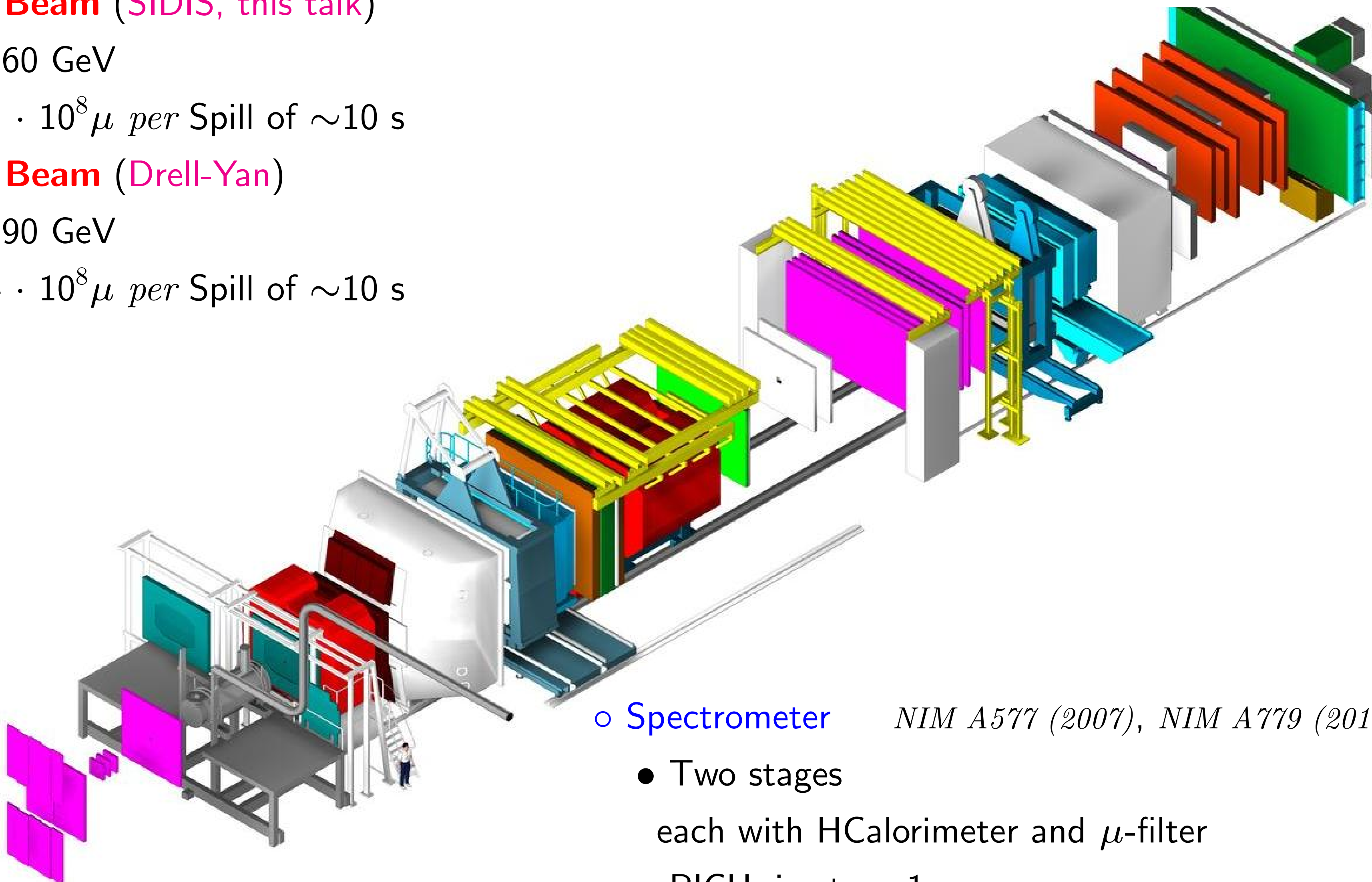
$$\frac{dM^h(x,z,Q^2)}{dz} = \frac{d^3\sigma^h(x,z,Q^2)/dxdzdQ^2}{d^2\sigma^{DIS}/dxdQ^2}$$



- Measurements need to be corrected for various effects:
  - Spectrometer acceptance
  - ParticleID efficiency and purity
  - Radiative effects
  - Diffractive vector meson production (*Subtracted using MC generator HEPGEN based on Handbag Model by Goloskokov and Kroll*)
  - Feed-down from weak decays of charmed hadrons (*Negligible in our measured z range* $(z > 0.2)$)

COMPASS: Spectrometer

- ◦ **$\mu^{\pm}$ Beam** (SIDIS, this talk)
  - 160 GeV
  - $2 \cdot 10^8 \mu$ *per* Spill of ∼10 s
- ◦ **π^- Beam** (Drell-Yan)
  - 190 GeV
  - $4 \cdot 10^8 \mu$ *per* Spill of ∼10 s



- ◦ Spectrometer *NIM A577 (2007)*, *NIM A779 (2015)*
  - Two stages
    each with HCalorimeter and μ-filter
  - RICH: in stage 1
  - ECalorimeters(0,1&2)

Multiplicity of $\pi^{\pm}$ on isoscalar target (^{6}LiD)

- PLB764 (2017) 1
- 3D binning: $x \times y \times z$
- LO QCD Fit,

  using Hirai, Kumano software with:

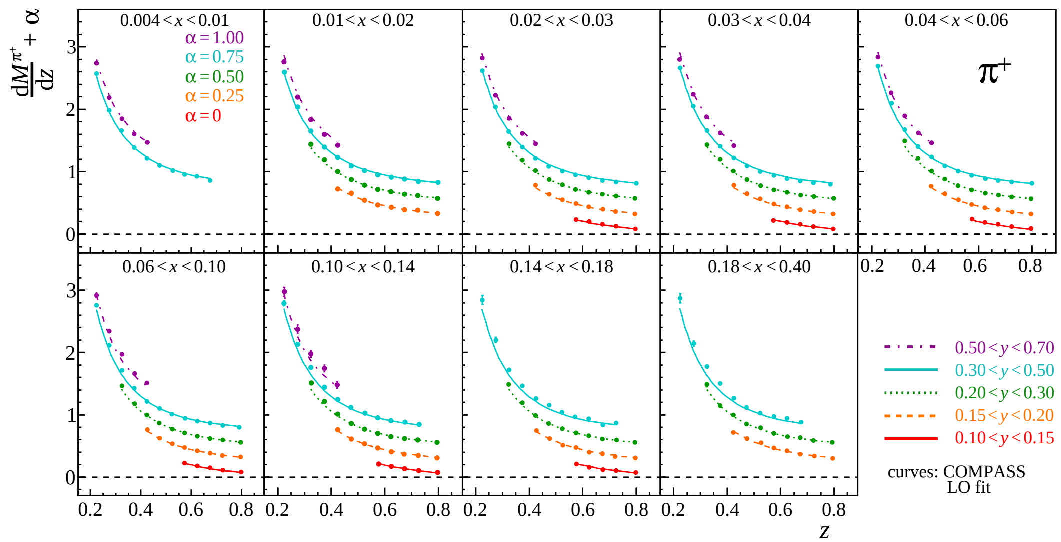
  $D^{\pi}_{fav} = D^{\pi+}_{u} = D^{\pi^+}_{\bar{d}}$ *and c.c.*

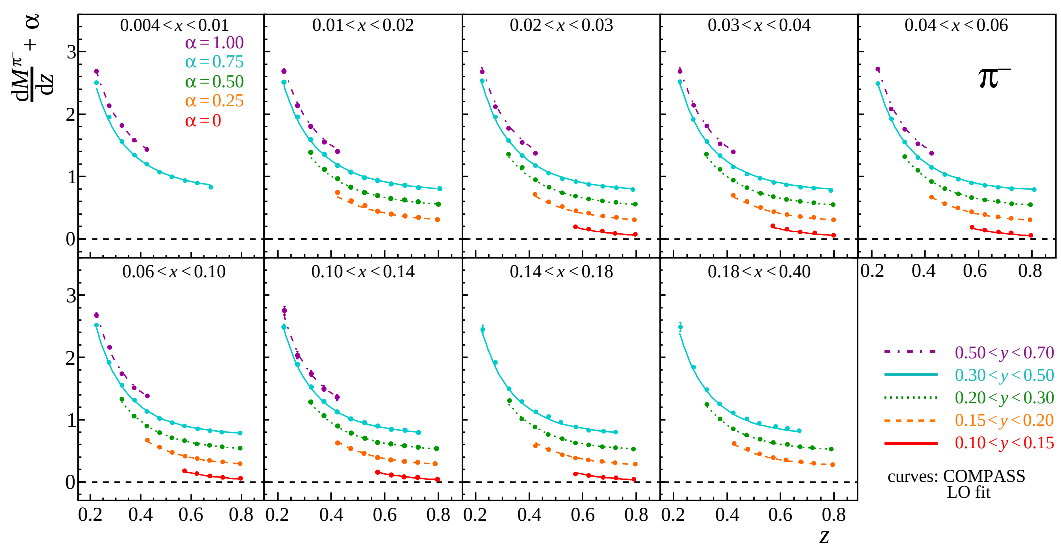
  D^{π}_{g} *(in Q^2 evolution only)*

  Simplification:

  $D^{\pi}_{unf} = D^{\pi^{\pm}}_{q}$, $\forall$ non-valence q

- Also unidentified $h^{\pm}$





Multiplicity of $K^{\pm}$ on isoscalar target (^{6}LiD)

- PLB767 (2017) 133

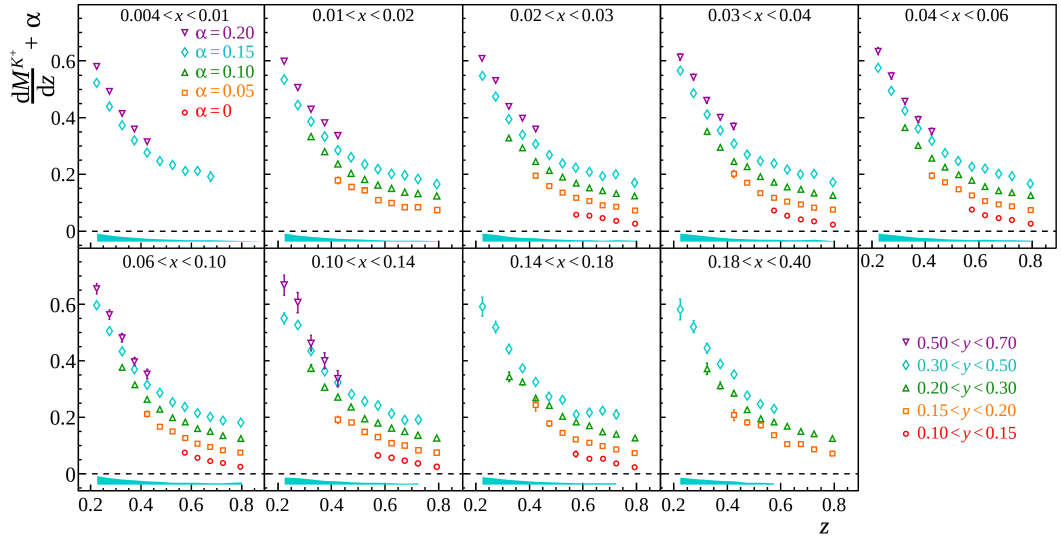
- LO QCD Fit **unstable**

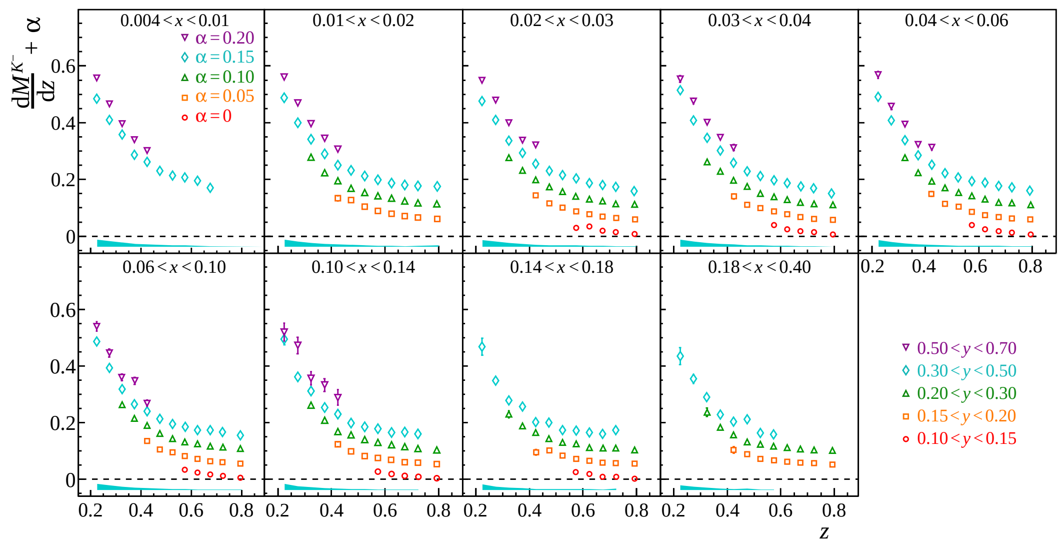
$$D^K_{fav} = D^{K+}_u \ and \ c.c.$$

$$D^K_{str} = D^{K^+}_{\bar{s}} \ and \ c.c.$$

$$D^K_g$$

$$D^K_{unf} = D^{K^{\pm}}_q, \forall \text{ non-valence } q$$





Comparison w/ Other SIDIS Measurements

- **EMC**: $h^{\pm}$ ZPC52 (1991), **HERMES**: $\pi^{\pm}$, $K^{\pm}$ PRD87 (2013), **JLab E00-108**: $\pi^{\pm}$: PRC85 (2012)
- Sum and Ratio of integrals (*over measured range*)

$$\mathscr{M} = \int \frac{dM}{dz} dz \qquad (\mathscr{D} = \int D dz)$$

LO pQCD + **simplifying assumptions** yield simple expressions and provide guidance

(*Shown is the* ***isoscalar target*** *case*)

$$\circ\ \mathscr{M}^{\pi^+} + \mathscr{M}^{\pi^-} \overset{\text{LO}}{=} \mathscr{D}^{\pi}_{fav} + \mathscr{D}_{unf}\pi - \frac{2S}{5Q+2S}(\mathscr{D}^{\pi}_{fav} - \mathscr{D}^{\pi}_{unf}) \simeq \mathscr{D}^{\pi}_{fav} + \mathscr{D}^{\pi}_{unf}$$

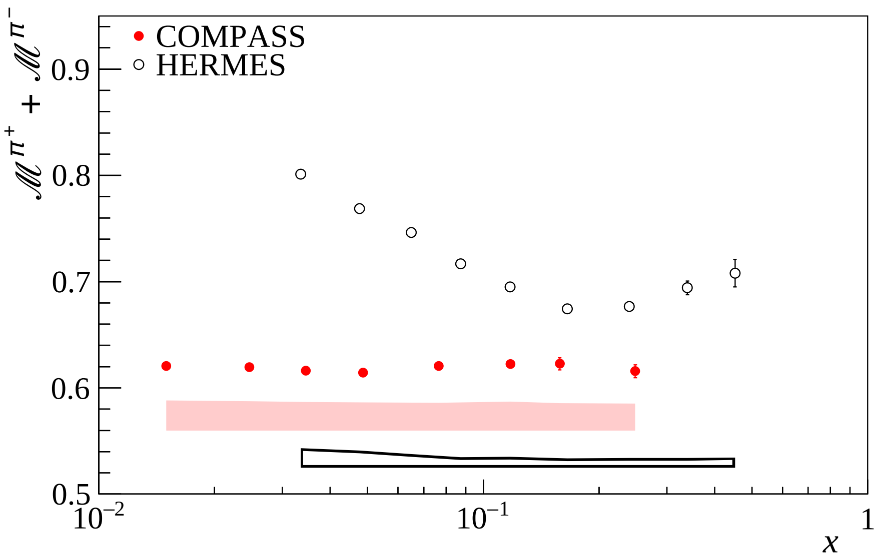
$$Q = u + \bar{u} + d + \bar{d},\ S = s + \bar{s}$$

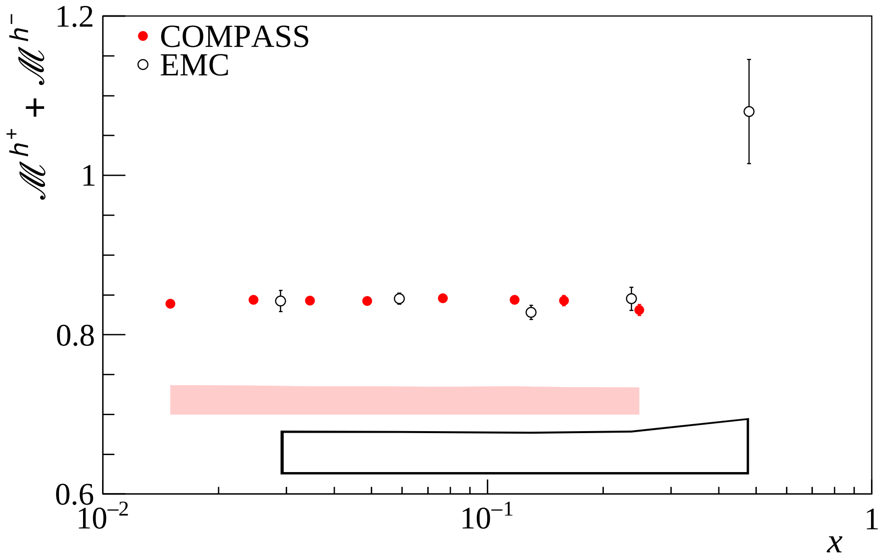
$\Rightarrow$ depends on x only weakly *via* $\mathscr{D}(Q^2)$ evolution and x/Q^2 correlation at fixed target.

$$\circ\ 5(\mathscr{M}^{K^+} + \mathscr{M}^{K^-}) \overset{\text{LO}}{\simeq} 4\mathscr{D}^{K}_{fav} + 6\mathscr{D}^{K}_{unf} + S/Q\ D^{K}_{S}$$

Comparison w/ Other SIDIS Measurements: π Multiplicity Sum

- COMPASS data averaged over y





$\Rightarrow$ Discrepancy w/ HERMES, beyond systematics uncertainty

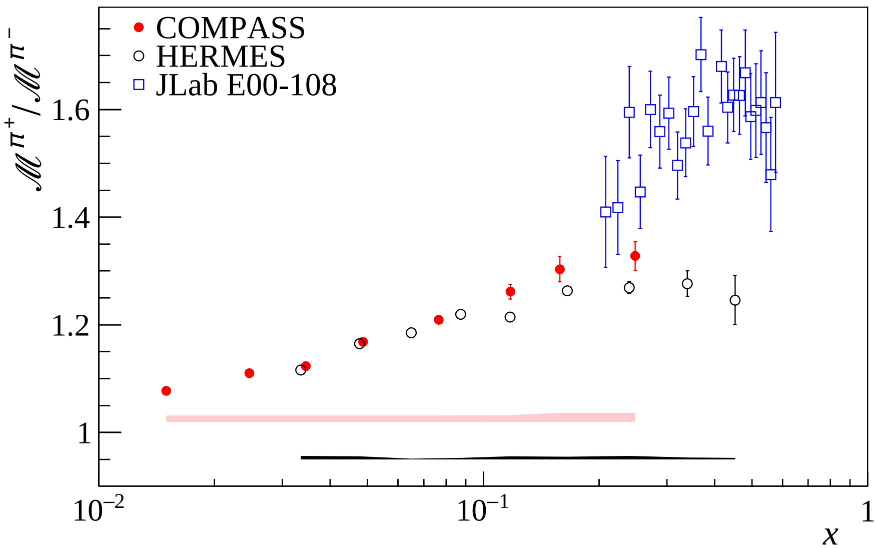
$\Rightarrow$ COMPASS (*averaged over* y) and EMC agree w/ LO pQCD prediction

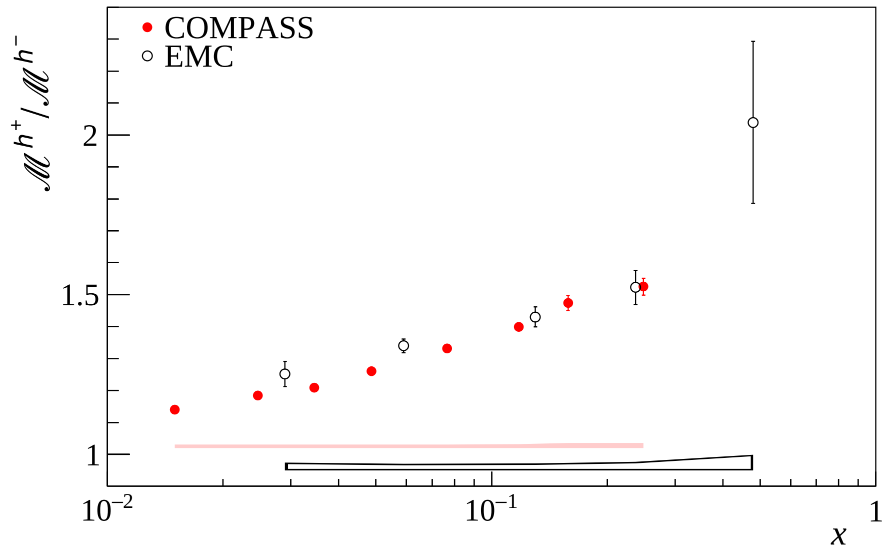
Caveat: Displayed is one of two possible HERMES data sets:

viz. $x \times z$ as opposed to alternative $Q^2 \times z$

π/π^- Multiplicity Ratio

- The ratio π^+/π^- is interesting because of cancellation of many systematic errors.





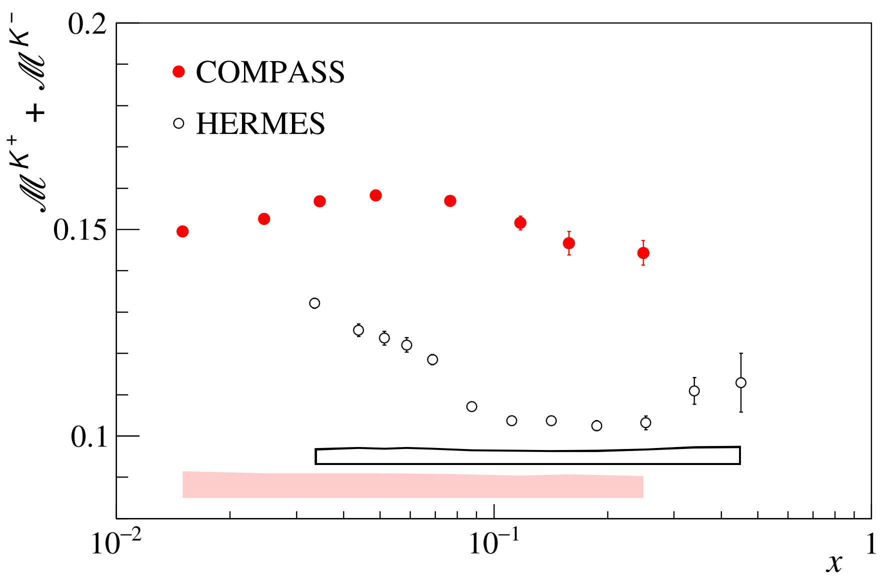
$\Rightarrow$ Agreement with HERMES, w/in systematics

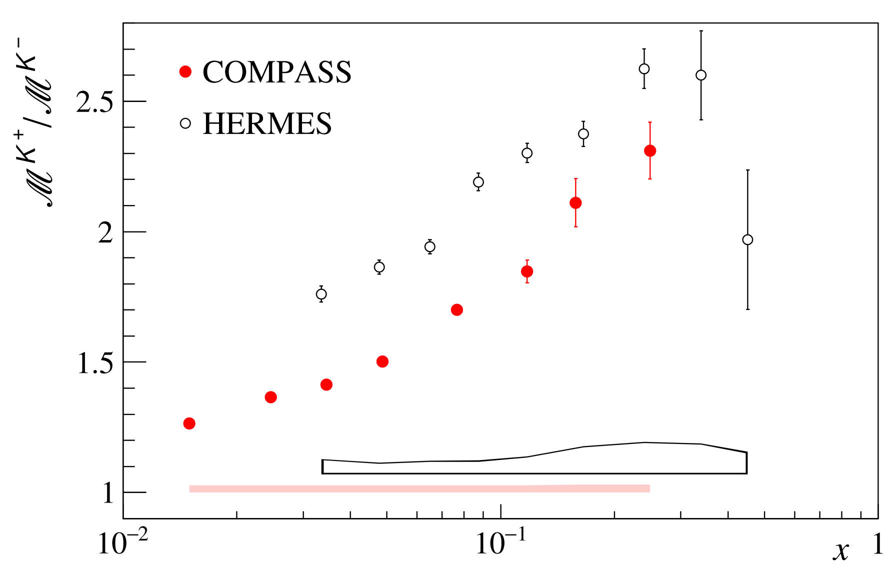
$\Rightarrow$ HERMES vs. JLab discrepancy at high x likely due to different W range

and possible higher twist contribution

K Multiplicity Sum and Ratio

- Comparison w/ **HERMES $x \times z$ data set**





$\Rightarrow$ Significant differences between COMPASS and HERMES

- Shape of $\mathscr{M}^{K^+} + \mathscr{M}^{K^-}$
- Value at high x of $\mathscr{M}^{K^+} + \mathscr{M}^{K^-}$ $\leftrightarrow$ Combination of $\mathscr{D}_q$
- Ratio, whereas there's agreement for pions

- Guerrero and Accardi PRD97 (2018): discrepancy suppressed by hadron mass corrections

Experimental Status of FFs: Global QCD Fits

- Global fits exploit universality by combining data sets from several processes:
  - DEHSS = De Florian, Sassot, Stratmann *et al.*: PRD91 (2015), PRD95 (2017): e^+e^-, pp and SIDIS.
  - NNPDF: Bertone *et al.*: EPJC78 (2018): e^+e^-, $pp(\bar{p})$.
  - HKKS = Hirai, Kawamura, Kumano, Saito PTEP (2016): e^+e^-.
  - LSS = Leader, Sidorov, Stamenov PRD93 (2016): SIDIS.
  - AKK = Albino, Kniehl, Kramer NPB803 (2008): e^+e^-, $pp(\bar{p})$.

- Exploit SIDIS full potential *via* combined fit of FFs, PDFs and/or pPDFs (*polarised PDFs*)
  - JAM17 = Ethier, Sato, Melnitchouk: PRL119 (2017) (e^+e^-, SIDIS = COMPASS only)
  - Borsa, Sassot, Stratmann: PRD96 (2017)

  Help clarify PDFs of strange sea, COMPASS/HERMES disagreement

K^-/K^+ Multiplicity Ratio at high z

- PLB786 (2018) 390

- Ratio?
  - Ratio cancels out many of the systematics

  $\Rightarrow$ Can explore otherwise experimentally difficult SIDIS high z

- Ratio of Kaons, as opposed to pions?
  - Diffractively produced vector meson decays . . .

  . . . dominate at **high z** in pion case ($\rho^o \to \pi^+\pi^-$)

  . . . stay w/in 0.3< z <0.7 in kaon case ($\phi \to K^+K^-$)
  because break-up momentum is small.

- **Domain of validity of pQCD + independent fragmentation in SIDIS?**

  What SIDIS data to consider in global fit?

K^-/K^+ at high z: Predictions

- At LO in pQCD, on a p **target**:
  - $$\frac{dM^{K^-}}{dM^{K^+}} \overset{\text{LO}}{=} \frac{4\bar{u}D_{fav} + (4u + \bar{d} + d + \bar{s})D_{unf} + sD_{str}}{4uD_{fav} + (4\bar{u} + d + \bar{d} + s)D_{unf} + \bar{s}D_{str}}$$

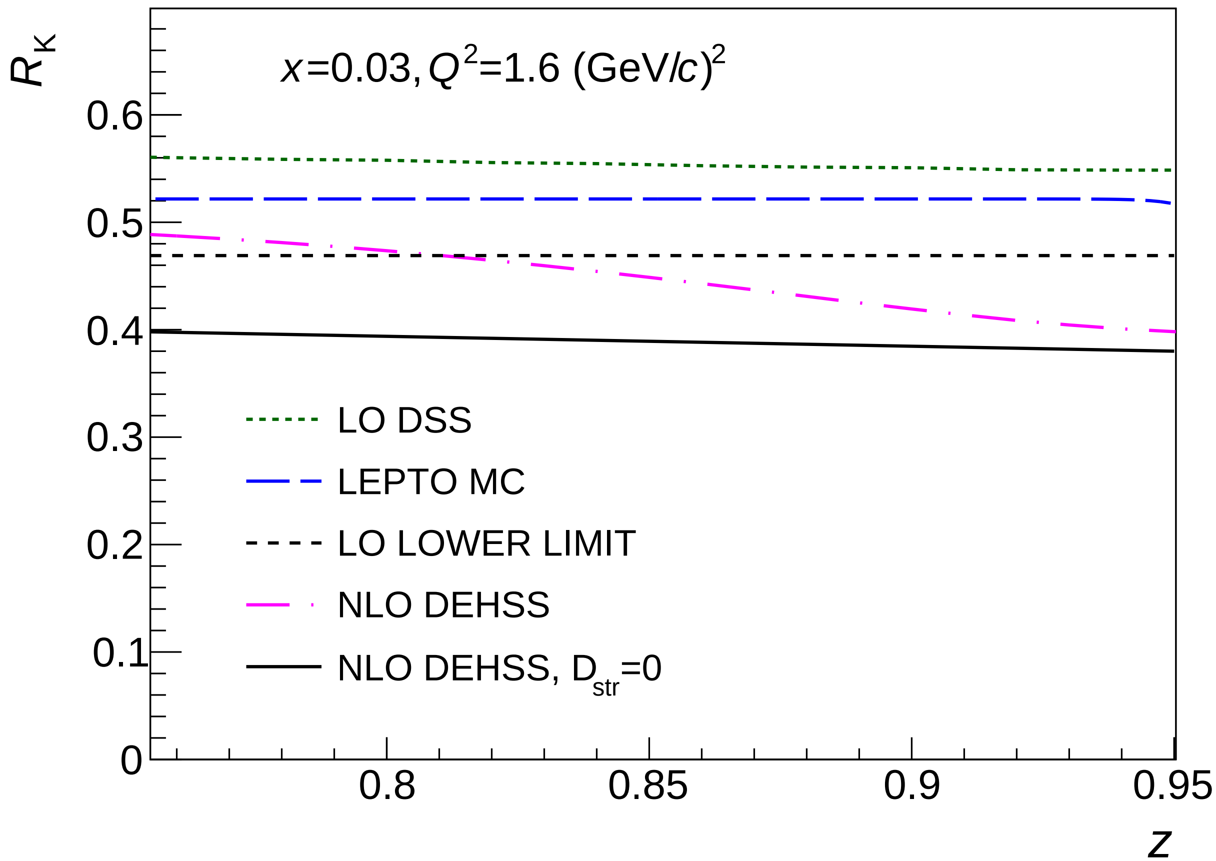
    Neglecting D_{unf} ($since\ high\ z$), and trivial simplifications:

    $$\frac{dM^{K^-}}{dM^{K^+}} \overset{\text{LO}}{\simeq} \frac{4\bar{u}D_{fav} + sD_{str}}{4uD_{fav} + \bar{s}D_{str}} > \frac{\bar{u}}{u}$$
  - On a d **target**:

    $$\boldsymbol{R_K} = \frac{dM^{K^-}}{dM^{K^+}} > \frac{\bar{u} + \bar{d}}{u + d}$$

- At NLO,
  - Reasonably safe lower bound obtained by setting $D_{str} = 0$, working around dispersion among PDF and FF sets.

K^-/K^+ at high z: Predictions

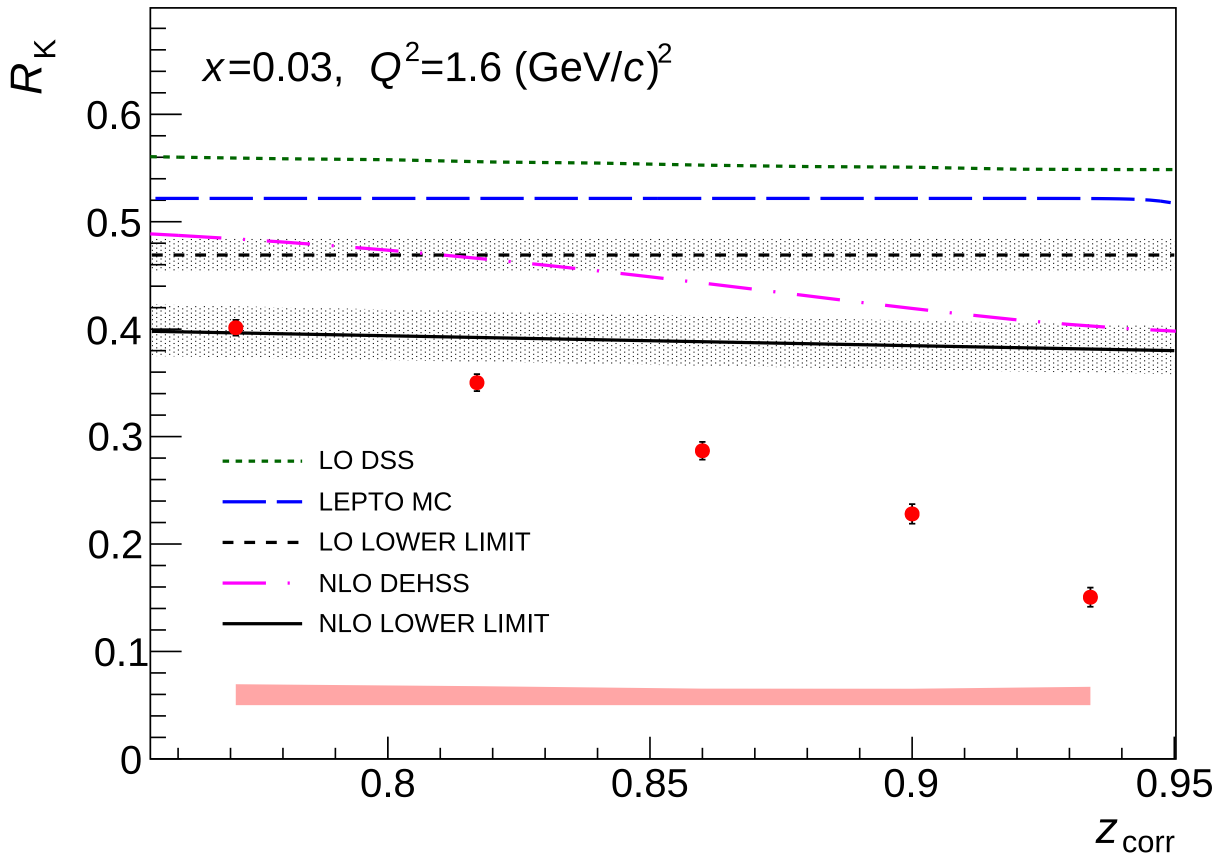


- Model calculations (*in addition to lower limits*)

  LO DSS07, NLO DEHSS

  LEPTO, w/ $H^K_{q/N}(x, z, Q^2)$ fragmentation ansatz

K^-/K^+ at high z: COMPASS Results *vs.* Predictions

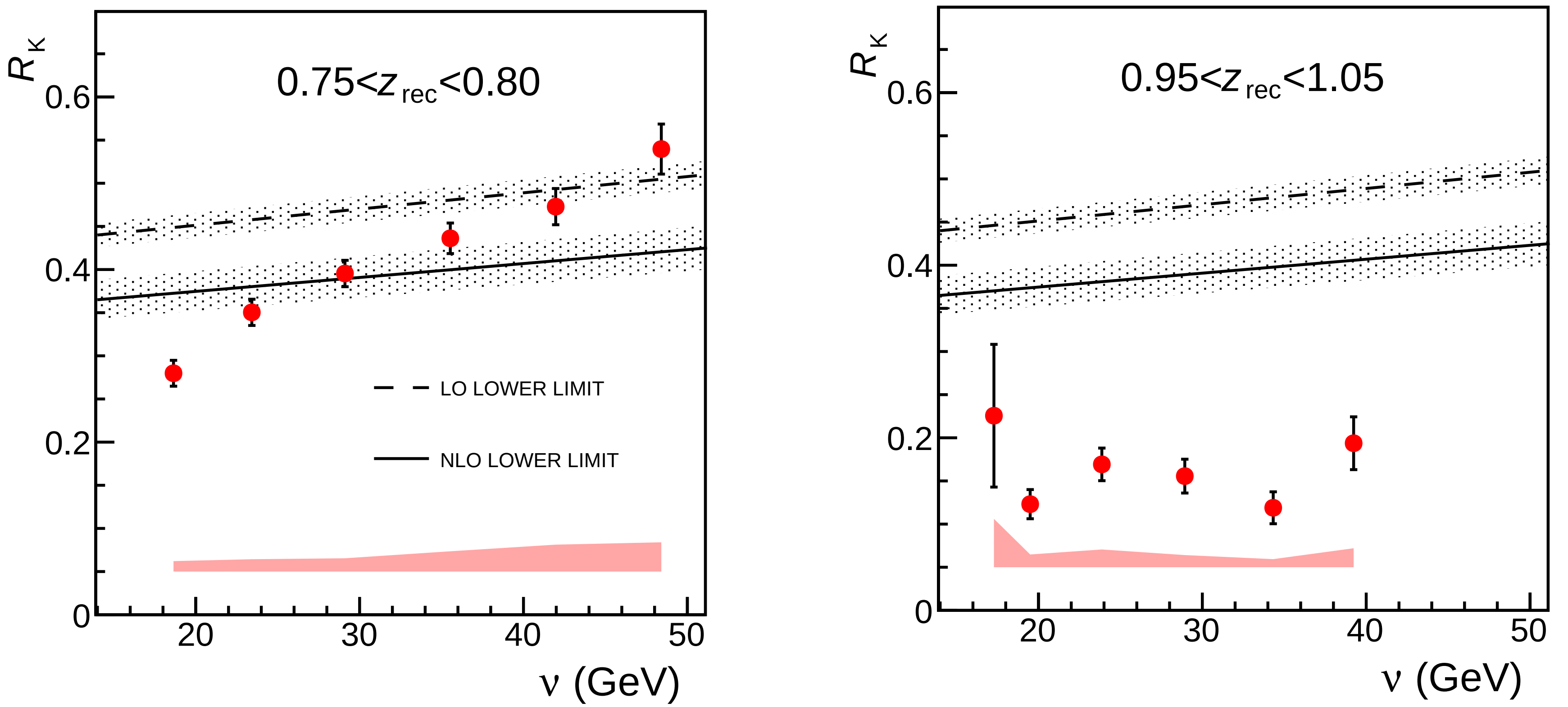


$\Rightarrow$ Clear disagreement w/ models, violation of LO and NLO limits

(*Safe result: all effects, here unaccounted for, in theory,*

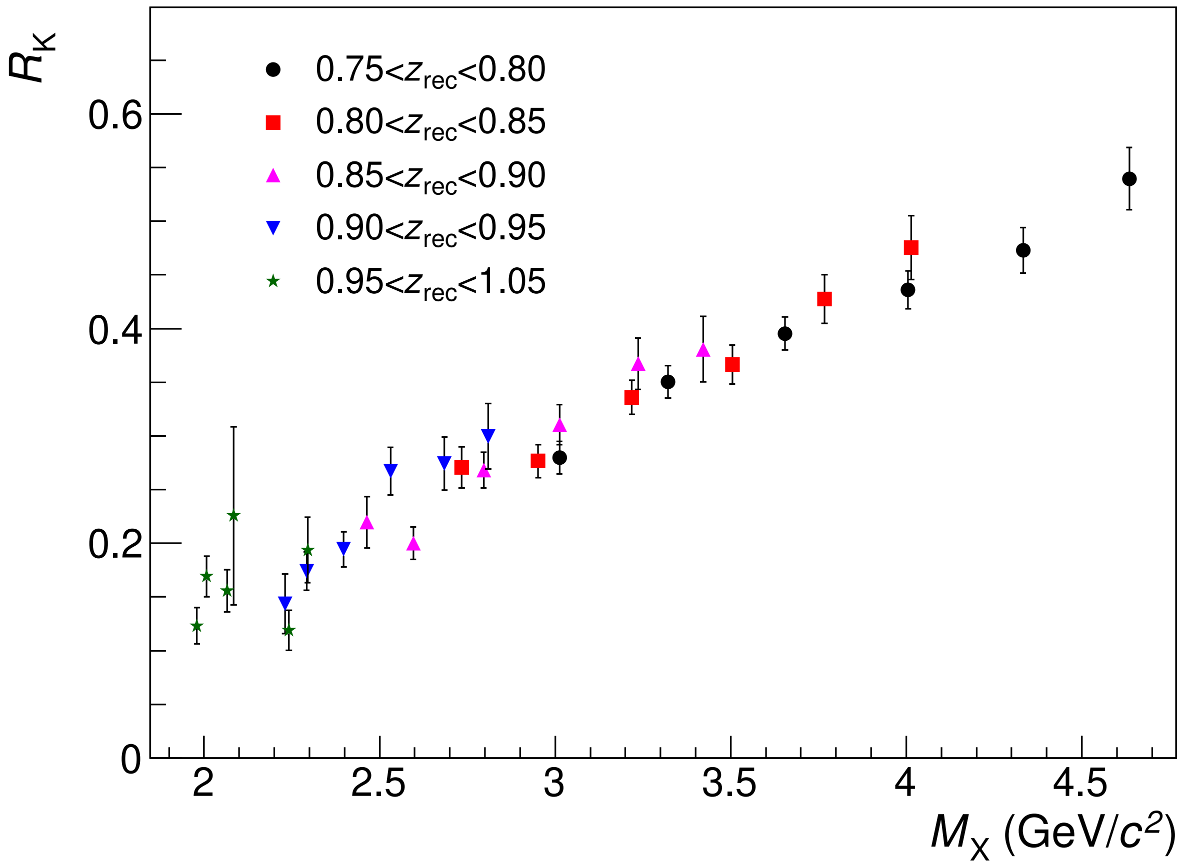
tend to further increase disagreement.)

K^-/K^+ at high z: COMPASS Results *vs.* photon energy ν



⇒ **Low ν high z: applicability of independent fragmentation pQCD questionable**

K^-/K^+ at high z: COMPASS Results *vs.* Missing Mass



⇒ Low ν high z: Independent fragmentation is what becomes invalid

Fragmentation becomes sensitive to phase space for hadron production

Conclusions and Outlook

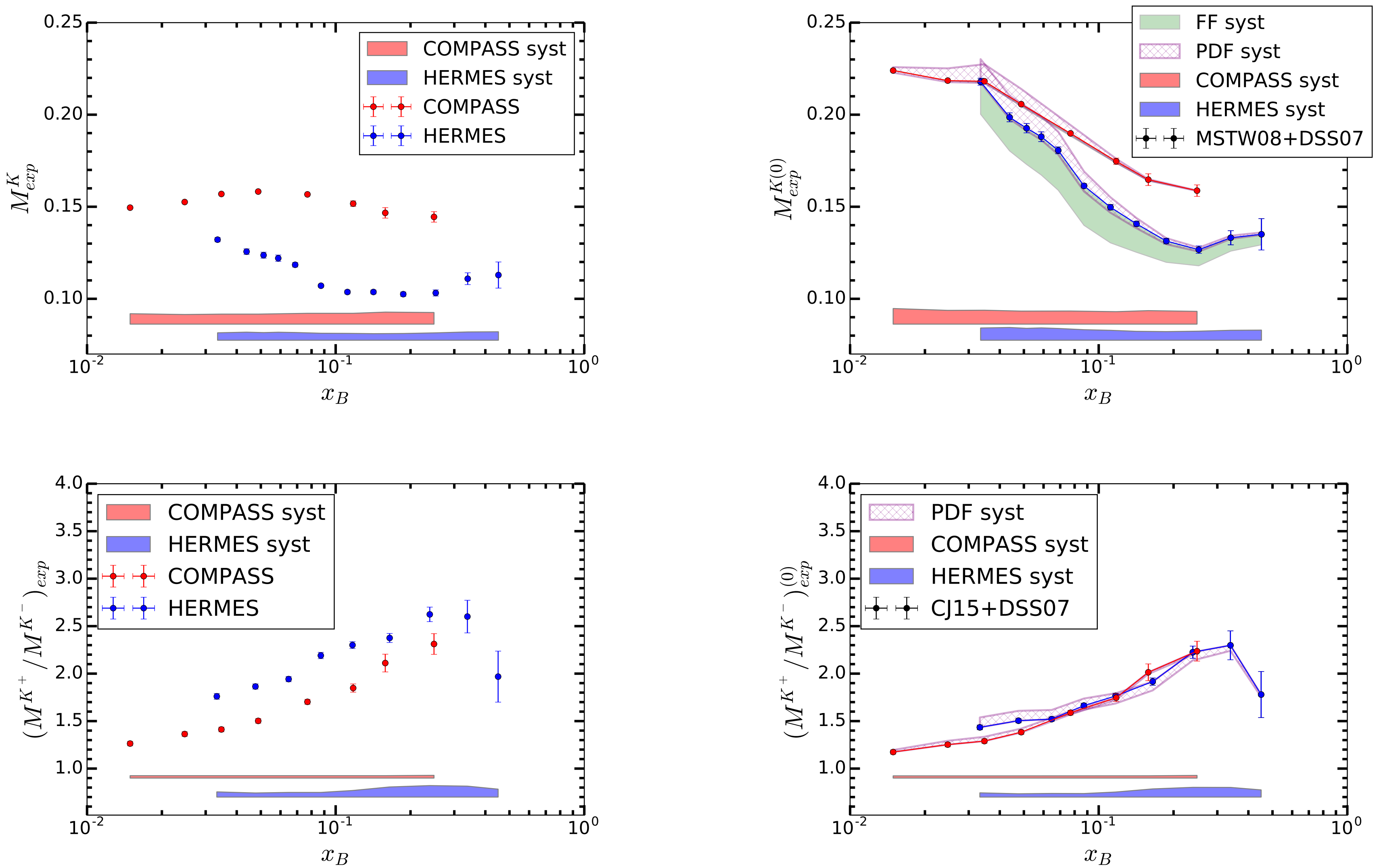
- SIDIS crucial to understand parton fragmentation

  May help to clarify sea PDFs (*via combined FF/PDF fits*)

- COMPASS:
  - $\pi^\pm$ and $K^\pm$ on isoscalar target.
  - $K^-/K+ \Rightarrow$ pQCD w/ independent fragmentation becomes invalid at high z low ν
  - More results from 2016-17 runs: on proton target, $\sim$.5 fb^{-1}
    $\Rightarrow$ Will improve flavour separation potential

Spares

J. V. Guerrero and A. Accardi, PRD97 (2018) 114012



Importance of Inclusive Hadron Production

- High energy hadron collisions:
  - QGP *via* high p_T hadron suppression.
  - Control of Standard Model background processes

- Spin physics: Flavor separation of Polarised Parton Distributions
  - Polarised Gluon Distribution *via* High pT hadron production
    - In quasi-real photoproduction $\vec{\gamma}^*\vec{N}$ @ COMPASS *cf. talk of Astrid Morreale*
    - In $\vec{p}\vec{p}$ @ RHIC
  - Polarised SIDIS @ HERMES, COMPASS, JLab.
    - Presently (*before W production @ RHIC*), only way to disentangle experimentally Δq from $\Delta\bar{q}$.
    - Polarised strangeness puzzle: Inclusive $\neq$ Semi-Inclusive DIS.

- e^+e^- SIA (*Single-Inclusive Annihilation*):
  - Clean process: only non-perturbative piece = D_q^h
  - At M_Z $\Rightarrow$ sensitive to *Singlet* D_Σ^h
  - Some flavor tagging, but no distinguishing *favoured* D_u^h from *unflavoured* $D_{\bar{u}}^h$