HADRON MULTIPLICITY AND FRAGMENTATION IN SIDIS

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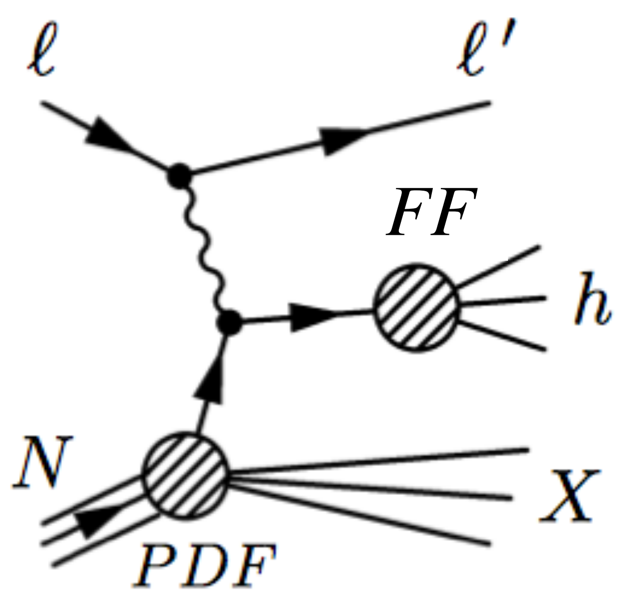
QUARK FRAGMENTATION FUNCTIONS

FFs :
- ✦ Non-perturbative objects, needed to describe several processes
- ✦ Strange quark FF : largest uncertainty in Δs extraction from polarized SIDIS. Data in e^+e^-/pp reaction but insufficient and at too high Q^2.

→ Measure hadron multiplicities in SIDIS : $lN \rightarrow l'hX$, $h=\pi,K,p$



$$\frac{dM^h(x,Q^2,z)}{dz} \overset{LO}{=} \frac{\sum_q e_q^2 \overbrace{\boxed{q(x,Q^2)}}^{\text{PDFs}} \overbrace{\boxed{D_q^h(z,Q^2)}}^{\text{FFs}}}{\sum_q e_q^2 q(x,Q^2)}$$

PDFs depend on x, while FFs depend on z.

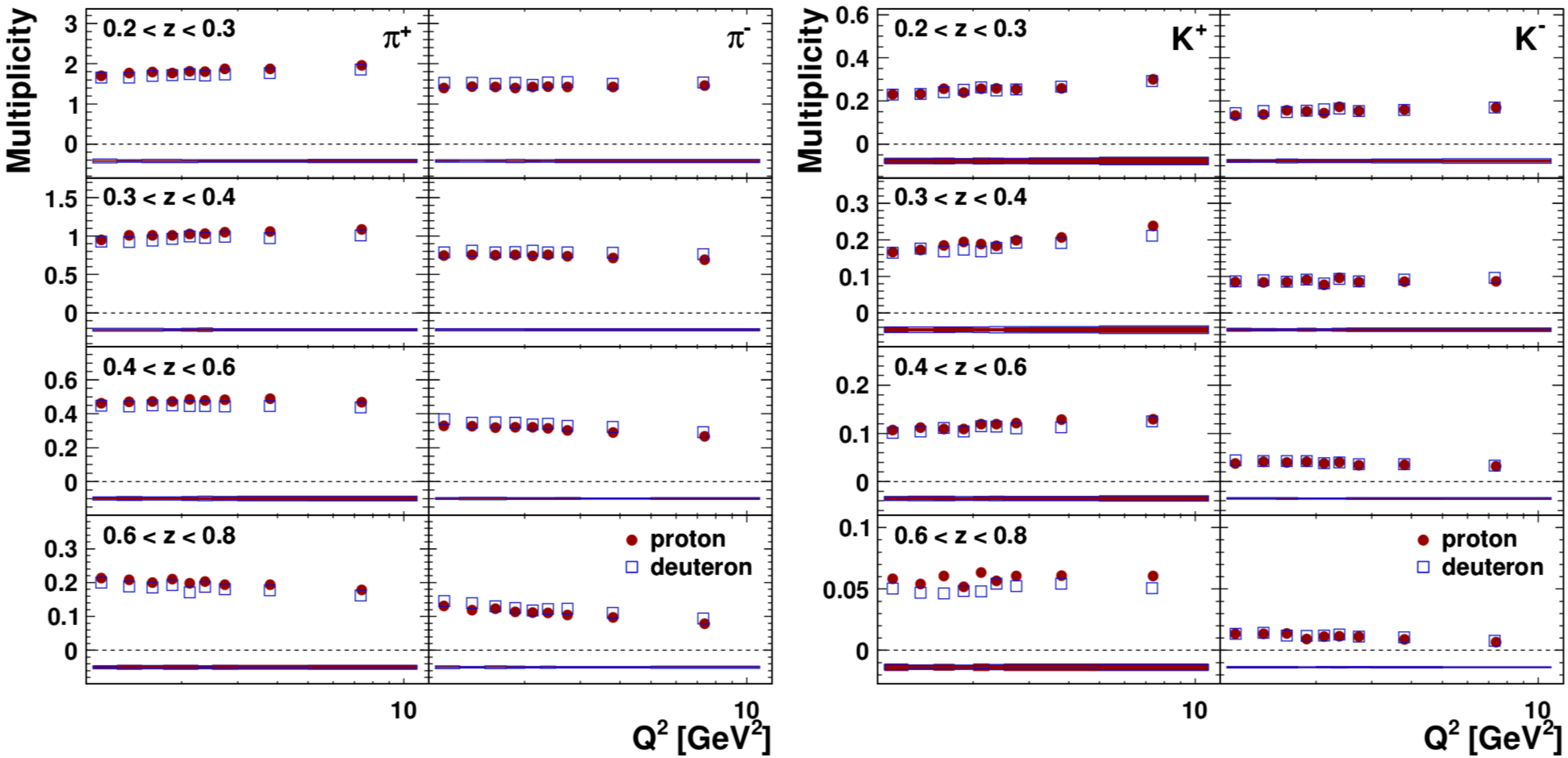
→ With kaons, access typically : $s(x,Q^2).D_s^K(z,Q^2)$

$$z = \frac{E_h}{\nu} = \frac{E_h}{E_\mu - E_{\mu'}}$$

→ π and K multiplicities allow to do global NLO QCD analyses to extract quark FFs.

→ Strangeness is contained in K

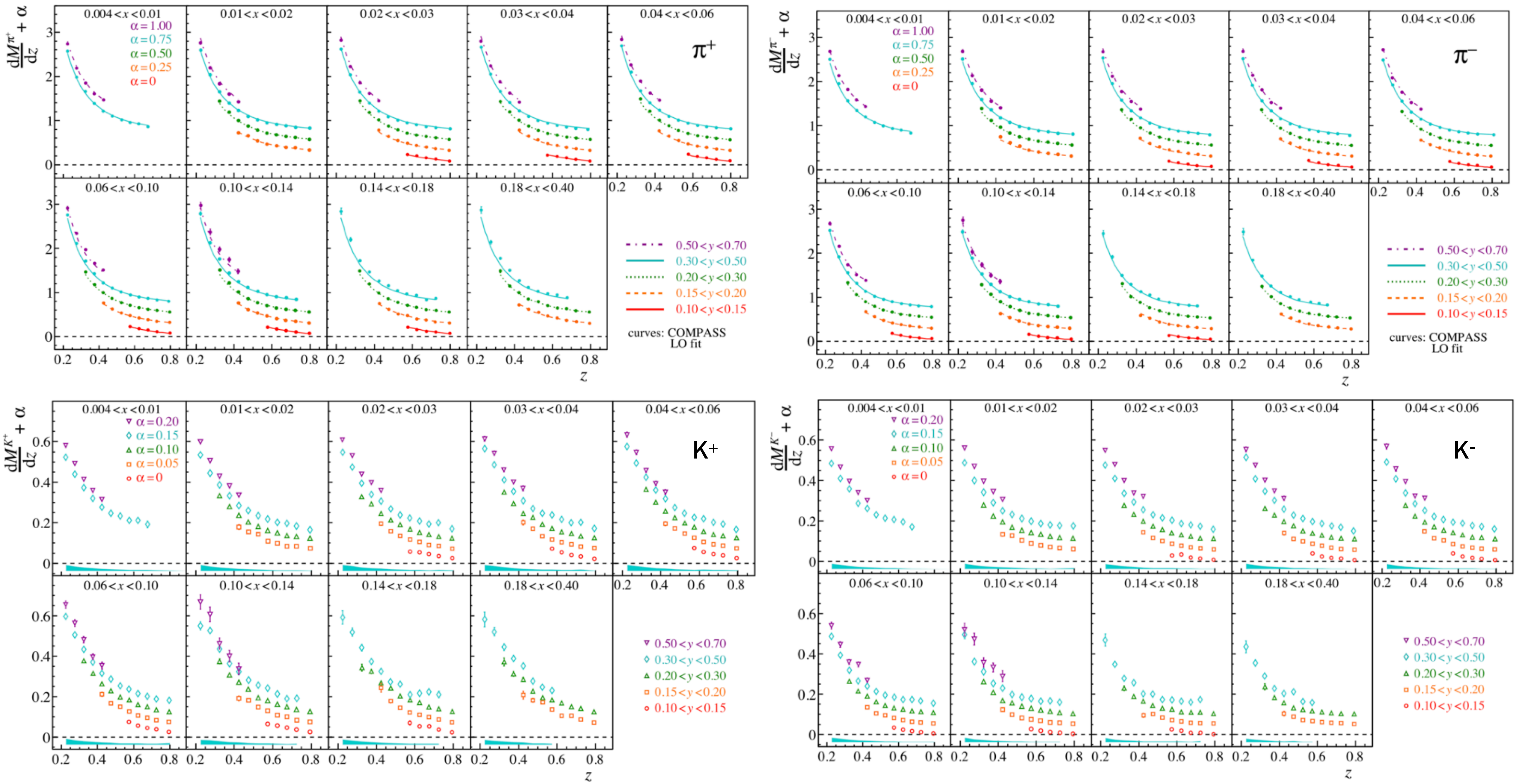
HERMES Π AND K DATA IN (Q^2,Z) BINS



- Q^2 in [1,15] GeV^2

Phys. Rev. D 87, 074029

COMPASS Π AND K DATA IN (X,Y,Z) BINS



- More than 1200 points in total, strong z dependence
- $M^{\pi+} \sim M^{\pi-}$ and $M^{K+} > M^{K-}$

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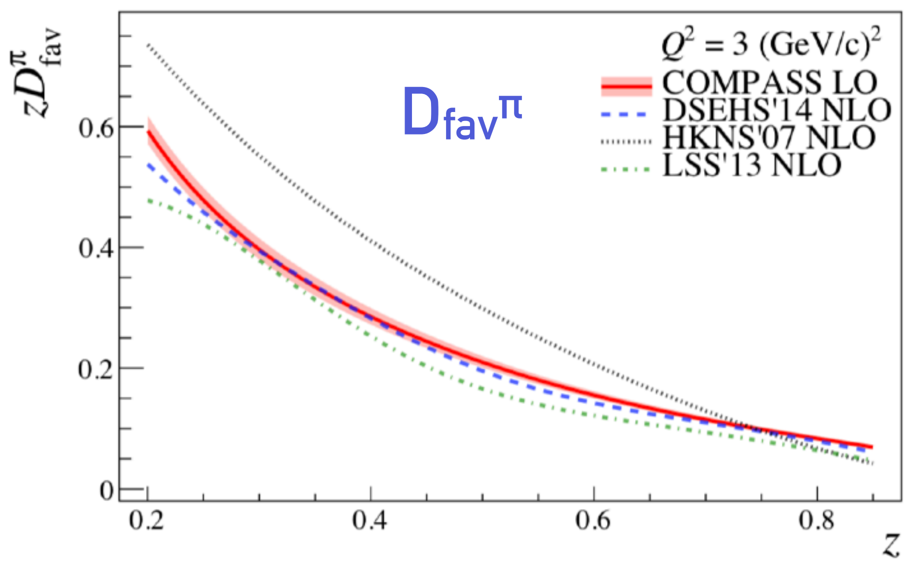
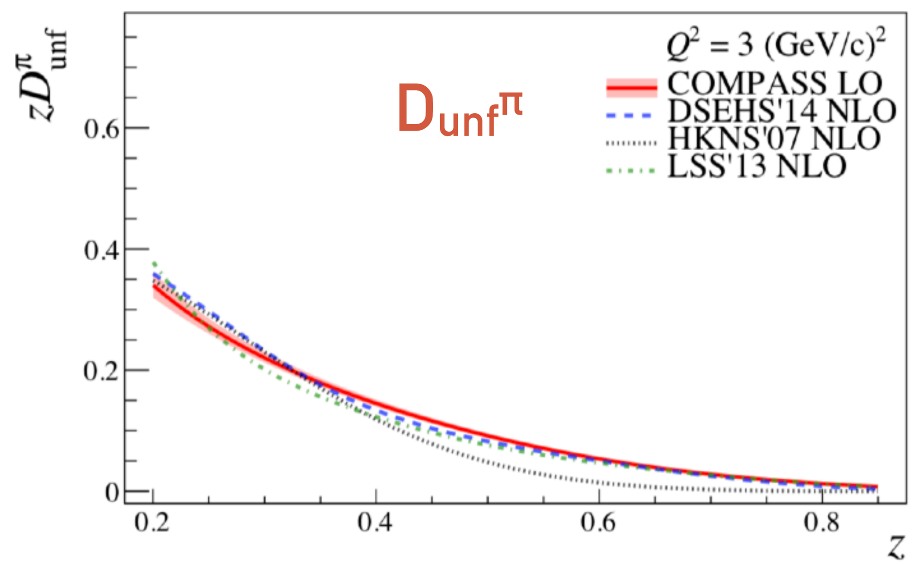
FROM MULTIPLICITIES TO QUARK FFS

↳Pions COMPASS LO fits assuming 2 independent FFs : D_{fav}^{π} and D_{unf}^{π}





- ✦ As expected D_{fav}^{π} > D_{unf}^{π}
- ✦ COMPASS LO fit agrees with DSEHS and LSS LO

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↳Kaons COMPASS LO fits assuming 3 independent FFs : D_{fav}^{K}, D_{unf}^{K} and D_{str}^{K}

- ✦ LO fit not conclusive, difficulties fitting high z data even at NLO (see later)
- ✦ DSS17 NLO fit : half of COMPASS data -> Smaller D_s^K than previously
  - ↳ iterative study of strange PDF and FF : BSS Phys. Rev. D 96 (2017) 094020
- ✦ Some constrains on FFs from K^++K^- multiplicity sum

SUM OF Z-INTEGRATED MULTIPLICITIES (PIONS)

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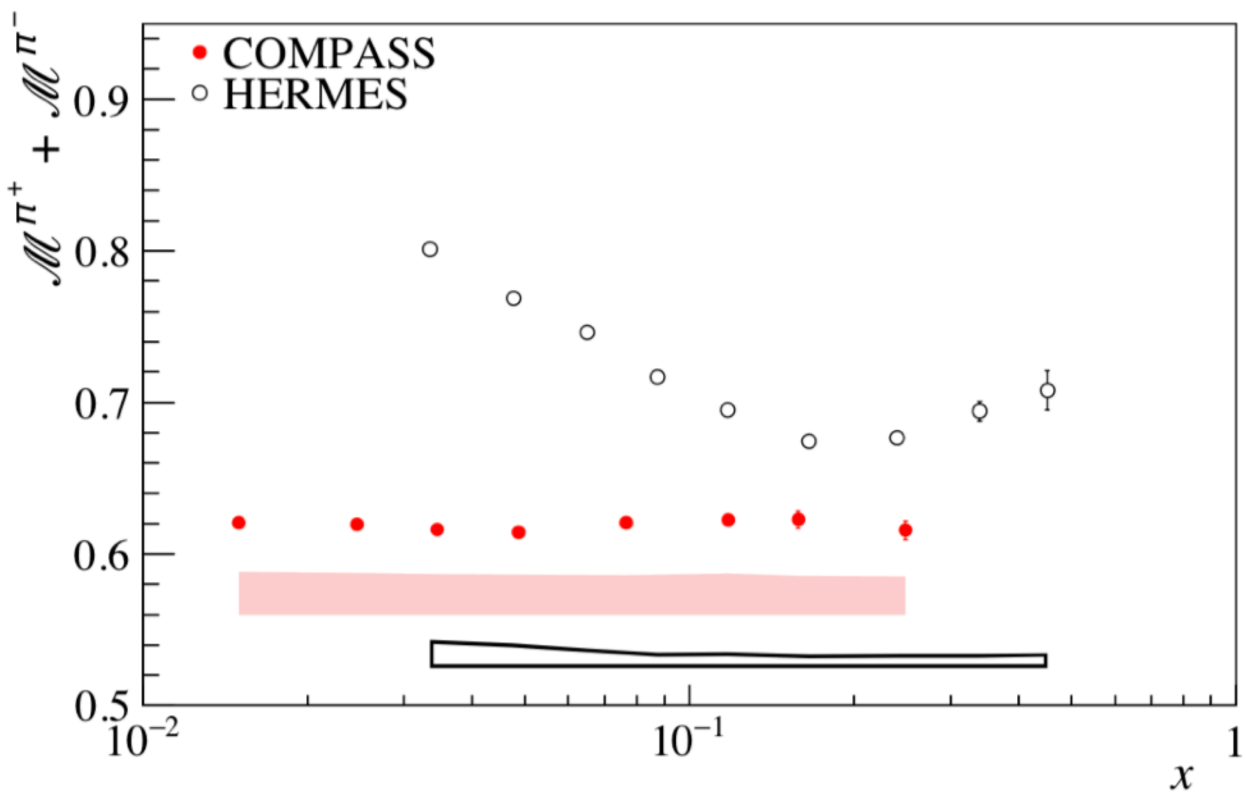
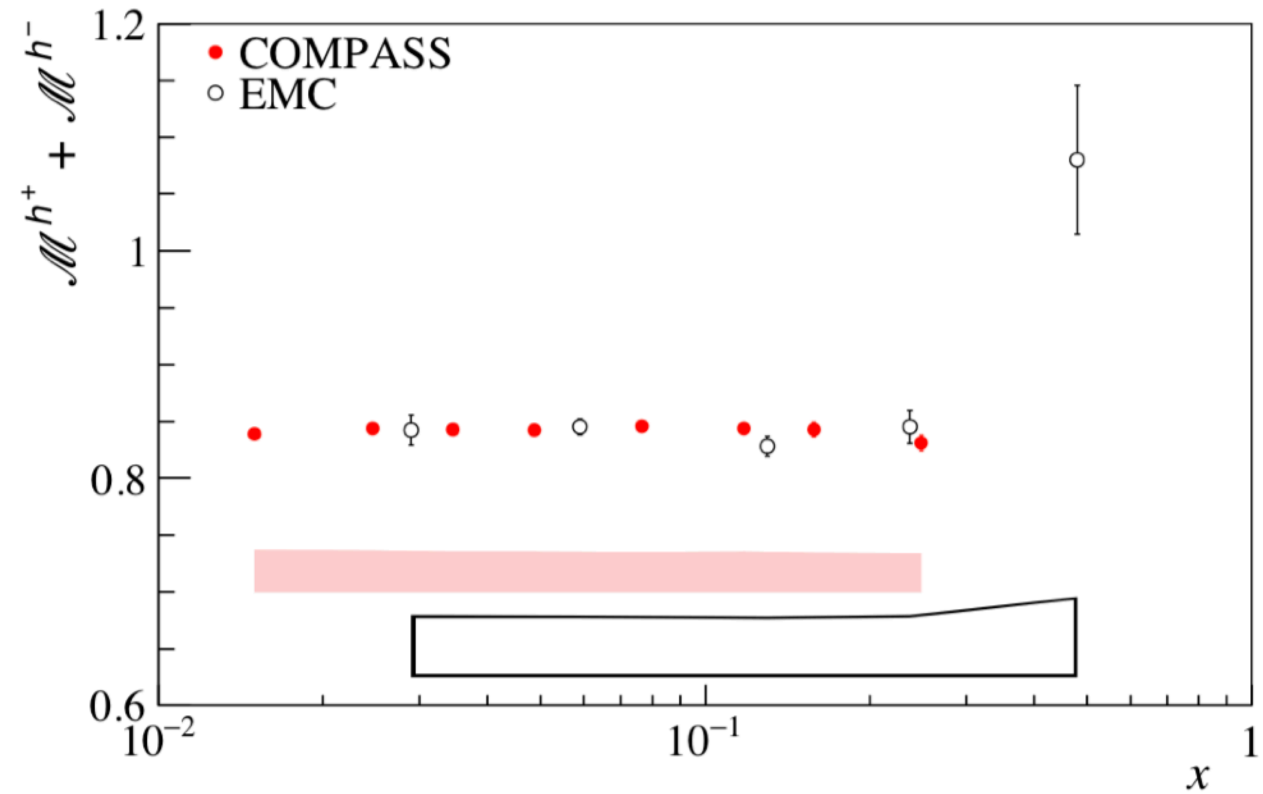
For an isoscalar target :

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





- COMPASS pion data significantly below HERMES ones
- No x dependence for COMPASS pion data as in EMC hadron data

SUM OF Z-INTEGRATED MULTIPLICITIES (KAONS)

For an isoscalar target :

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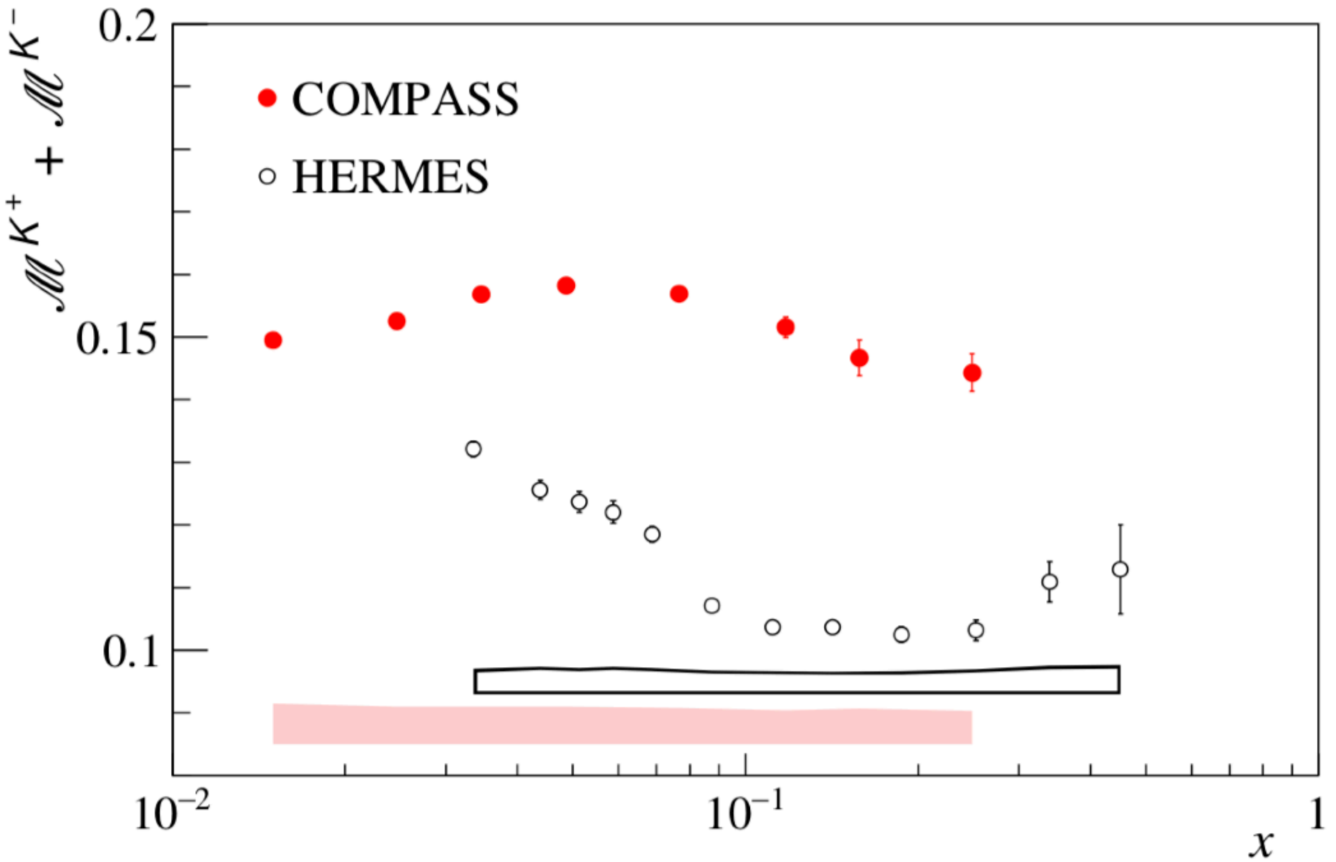
$$M^{K^+ + K^-} = \frac{(u+d+\bar{u}+\bar{d})(4D^K_{fav}+6D^K_{unf})+(s+\bar{s})(D^K_{str}+D^K_{unf})}{5(u+d+\bar{u}+\bar{d})+2(s+\bar{s})} = \frac{QD^K_Q+SD^K_S}{5Q+2S} \overset{\text{high x, } S\sim 0}{=} \frac{D^K_Q}{5}$$



- At high x, S~0 :

  From COMPASS : $D_Q^K \sim 0.7$
  From DSS fit : $D_Q^K \sim 0.43 \pm 0.04$

- At low x, $D_{str}^K > D_{fav}^K$:

  Weak Q^2 dependance for D_Q^K, no rise in kaon multiplicity sum at low x.

- COMPASS kaon data significantly above HERMES ones
- Smaller D_S^K and larger D_Q^K than previous NLO fits

COMMENTS ON QED RADIATIVE CORRECTIONS

In the COMPASS paper of kaon multiplicities :

- ✦ Inclusive corrections (Muon, denominator) : TERAD
- ✦ Semi-Inclusive corrections (Kaon, numerator) : TERAD minus elastic and quasi-elastic tails.

TERAD gives z-integrated semi-inclusive corrections thus overestimates the correction.

↳ Conservative approach : correction calculated from two extreme cases (full and no corrections to the number of kaons) ; half of the correction is applied to multiplicities.

→ Overall correction between 1% and 7% depending on kinematics

Ongoing work in COMPASS : use Djangoh which account for z-dependence

- ✦ For muons, agreement Djangoh / TERAD within 3%
- ✦ For kaons, correction between 0% and 10% depending on kinematics, average at 5%

→ Djangoh corrections within the systematic errors in the publication

K+/K- MULTIPLICITY RATIO

In multiplicity ratio, cancellation of several experimental and theoretical uncertainties.

In LO pQCD, a limit of the ratio is :

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

At large z, D_{unf}^K is expected to be small :

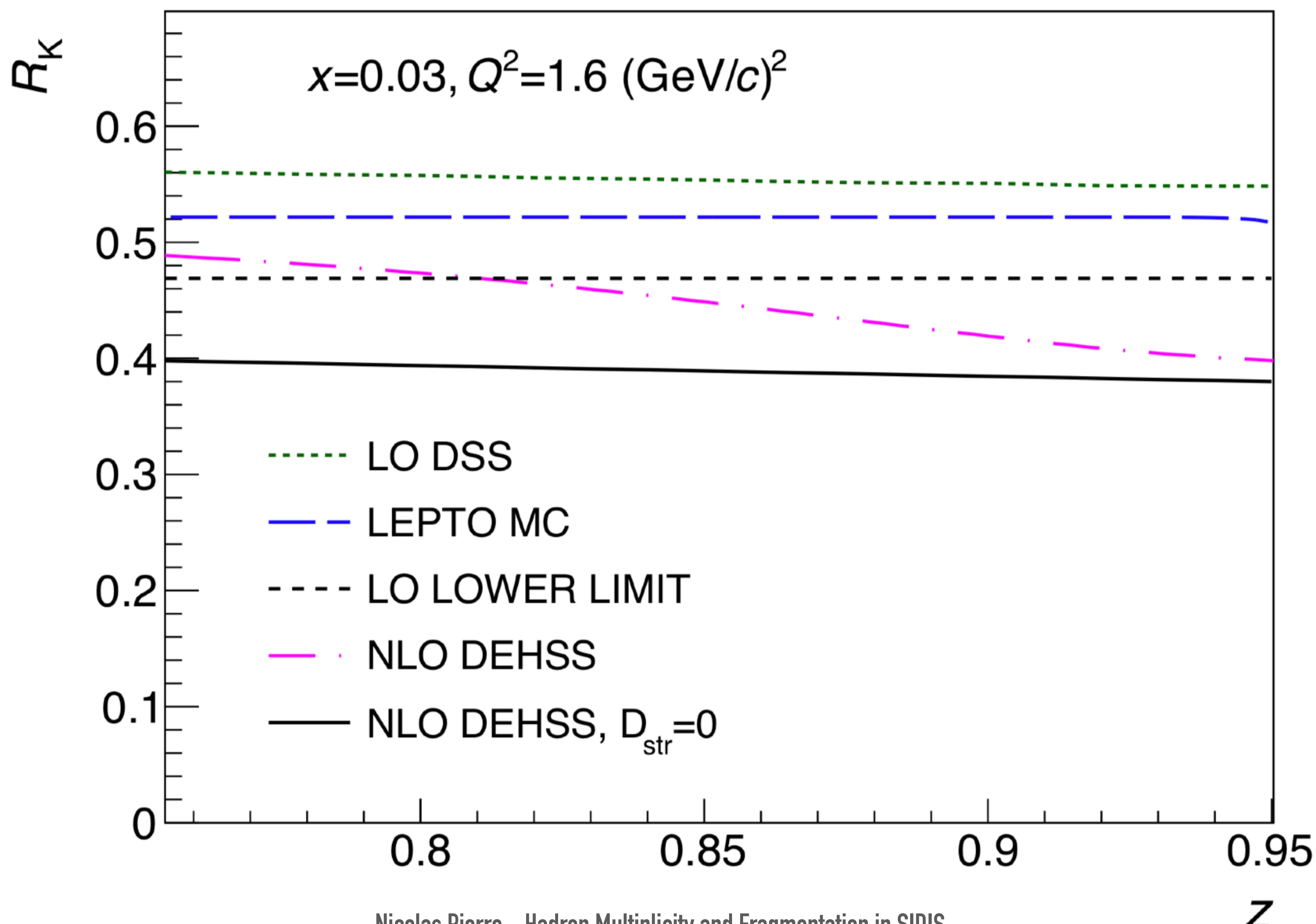
$$R_K(x,Q^2,z) = \frac{4(\bar{u}+\bar{d})D_{fav}^{K^-} + (s+\bar{s})D_{str}^{K^-}}{4(u+d)D_{fav}^{K^+} + (s+\bar{s})D_{str}^{K^+}}$$

Since $(s+\bar{s})D_{str}^K$ is positive, it can be neglected for limit calculation :

$$R_K > \frac{\bar{u}+\bar{d}}{u+d}$$

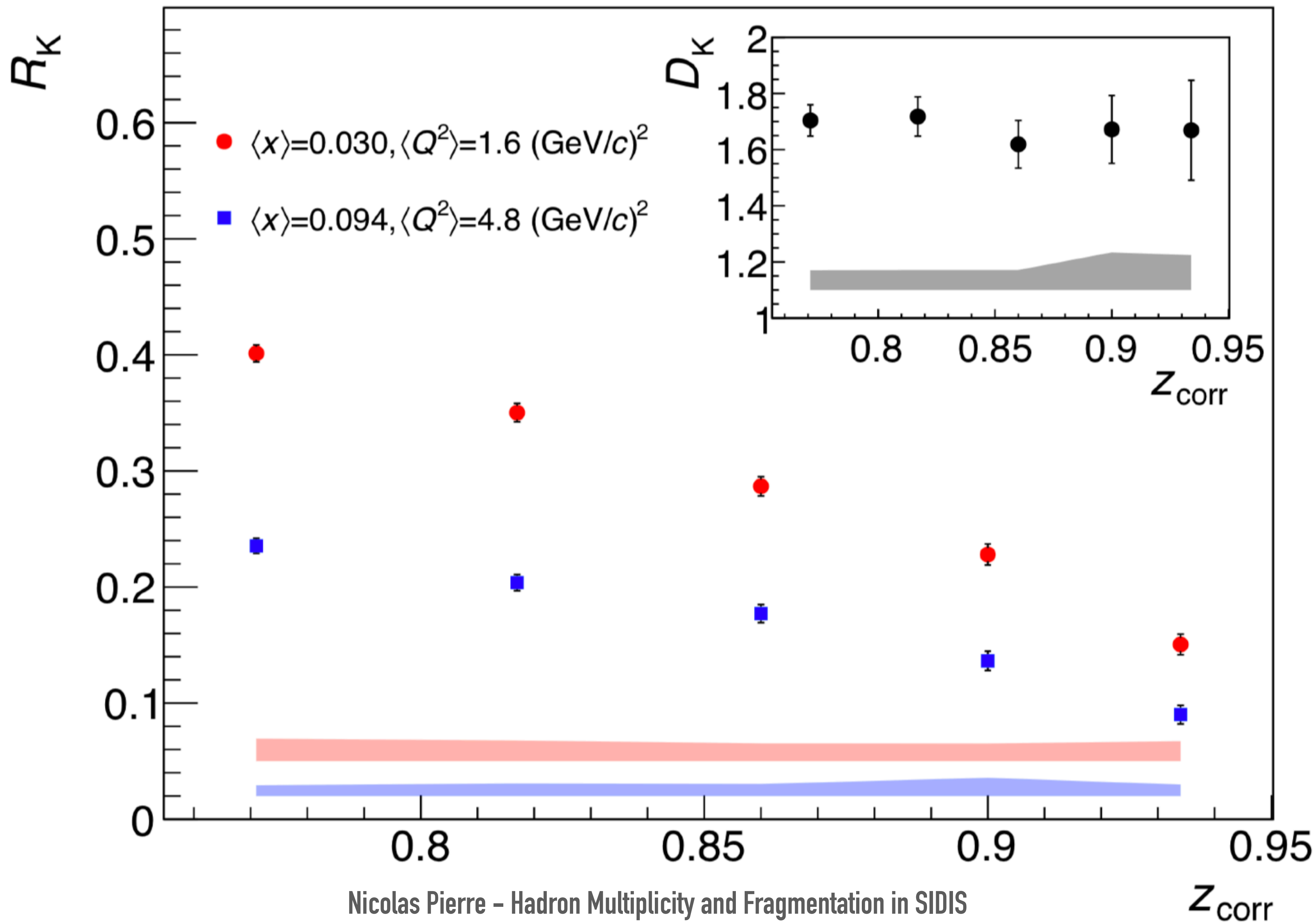
THEORY AND MODEL PREDICTION

Several expectations for R_K with LO pQCD limit :



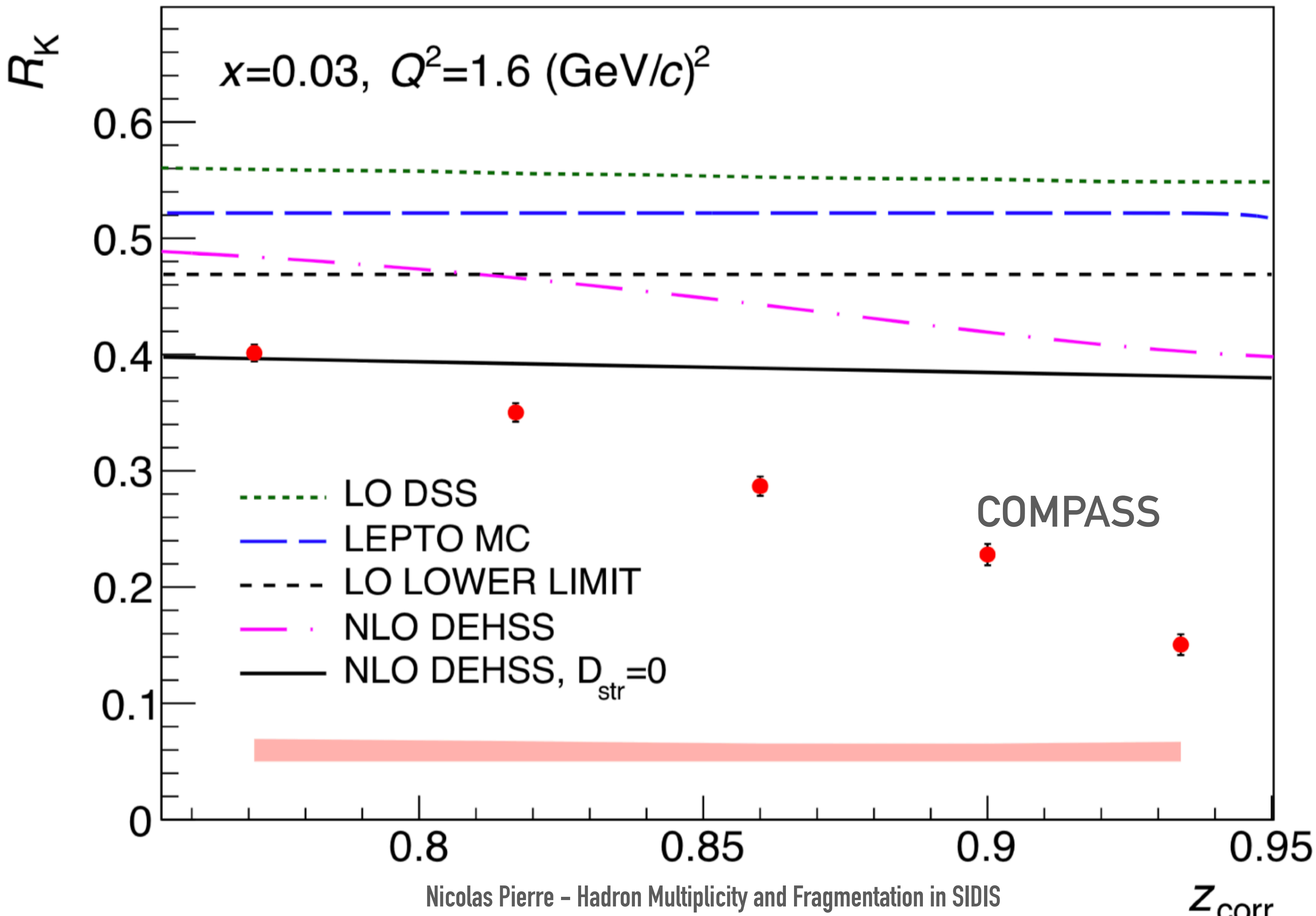
RESULTS

- Results for x < 0.05 and x > 0.05.
- R_K can be fitted by a simple functional form eg. $(1-z)^{\beta}$.
- D_K (double ratio of R_K in the two x-bins) is flat within uncertainties.



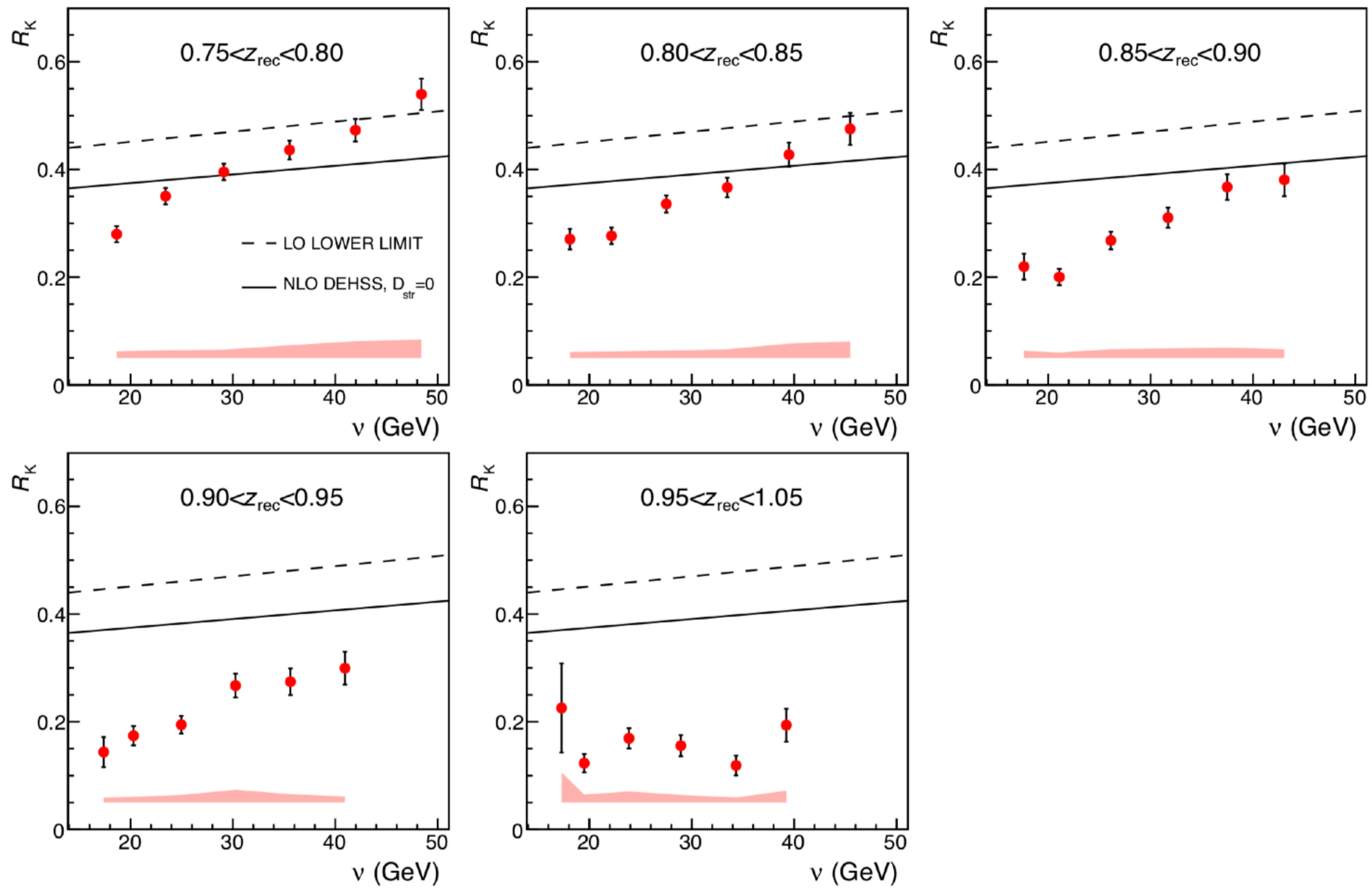
RESULTS VS PREDICTIONS

- Clear disagreement with models and LO/NLO limit observed (same holds for high x).



R_K AND ν DEPENDENCE

- A clear ν dependence of R_K is observed
- With higher ν, R_K closer to pQCD expectation

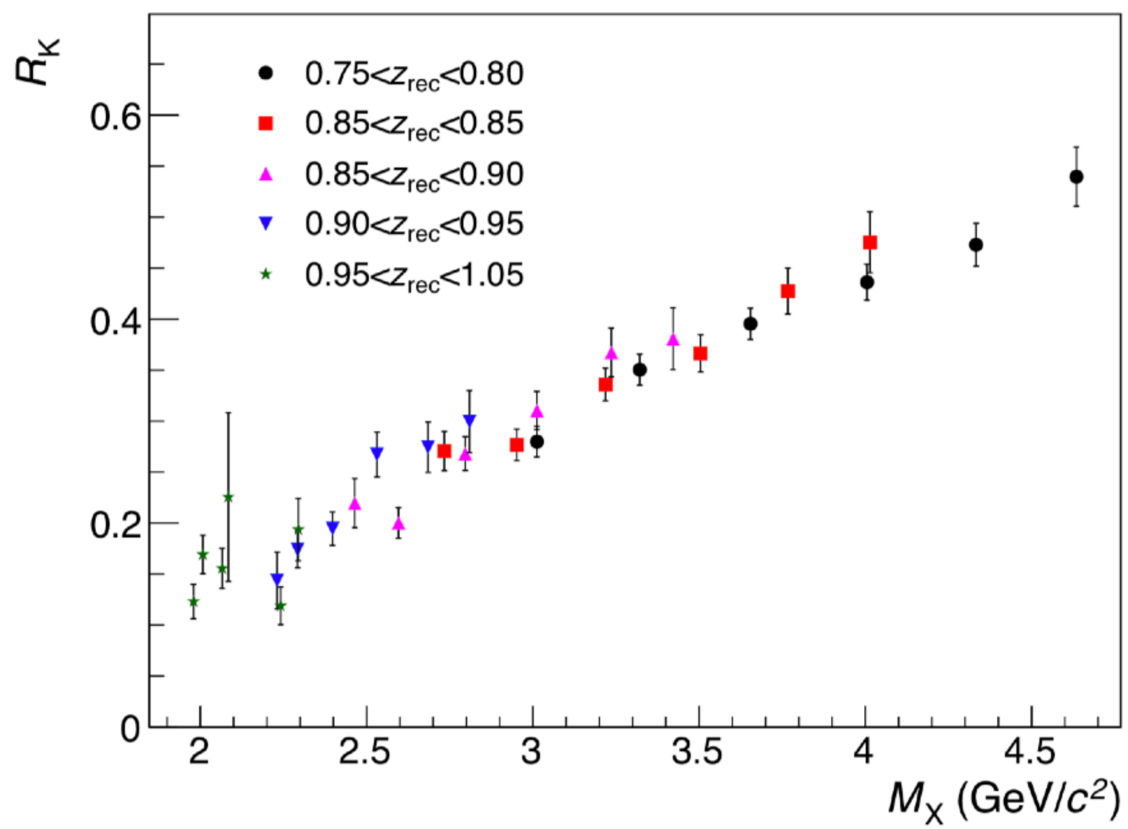


MISSING MASS AND R_K

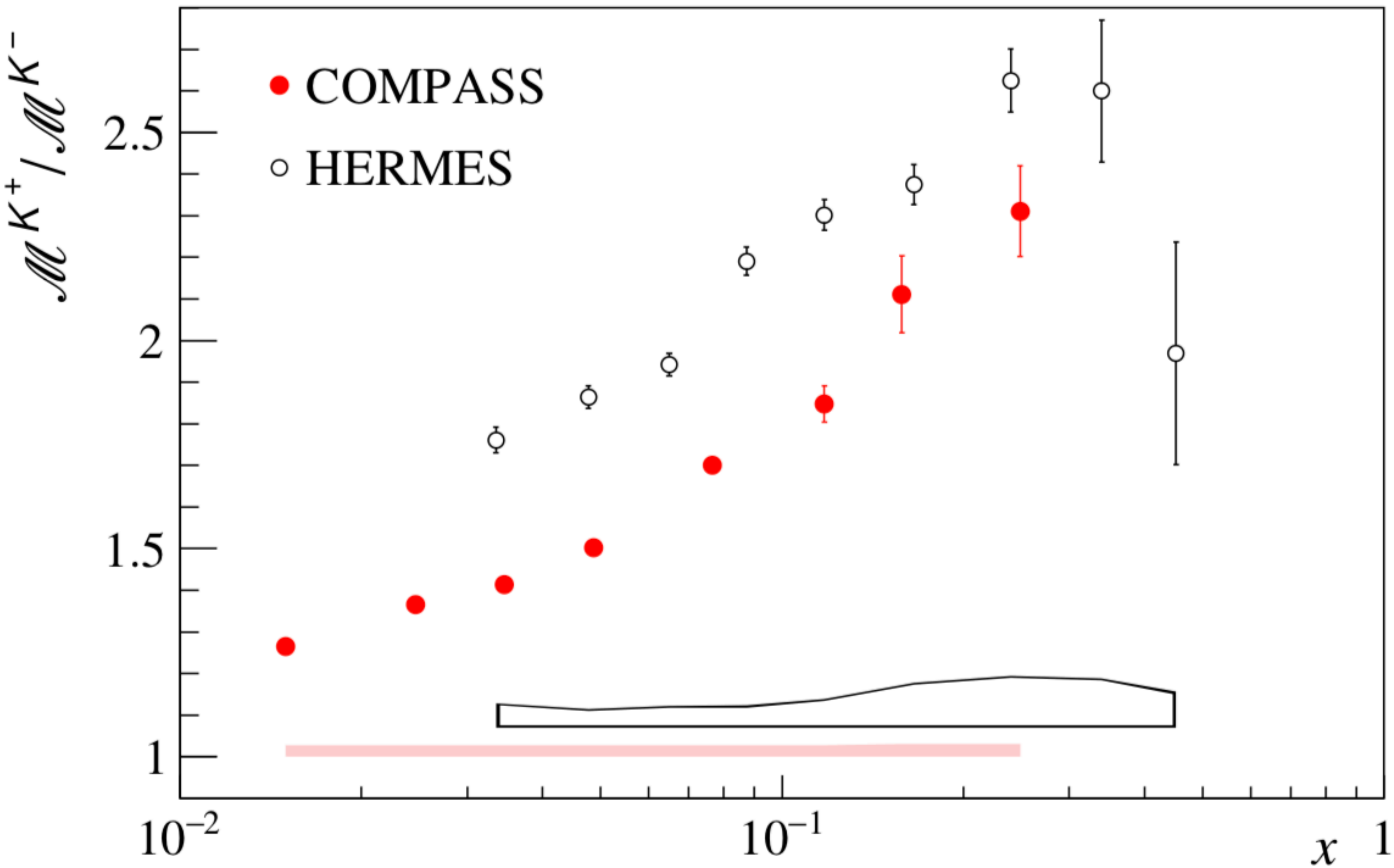
- High-z kaons → reduced phase space for other particles
- At the same time, conservation laws (eg. charge, baryon number, strangeness..)
- Missing mass M_X useful to study this region :

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

- R_K vs M_X are shown to be highly correlated !
- Suggests that correction within pQCD formalism is needed to take into account available phase space for target remnant hadronization.



R_K^{-1} : COMPASS VS HERMES DISCREPANCY



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R_K^{-1} : COMPASS VS HERMES DISCREPANCY

Experiment	$\langle x \rangle$	$\langle Q^2 \rangle$ $(\mathrm{GeV}/c)^2$	$\langle z \rangle$	$\langle \nu \rangle$ (GeV)	R_K
COMPASS	0.035	1.3	0.69	20.8	0.412 ± 0.032
HERMES	0.033	1.2	0.69	19.0	0.392 ± 0.042
COMPASS	0.049	1.9	0.69	20.8	0.372 ± 0.028
HERMES	0.048	1.4	0.69	15.4	0.300 ± 0.028
COMPASS	0.077	3.0	0.69	20.8	0.355 ± 0.026
HERMES	0.076	1.6	0.69	11.6	0.266 ± 0.016
COMPASS	0.118	4.6	0.69	20.8	0.270 ± 0.027
HERMES	0.118	2.2	0.69	9.8	0.211 ± 0.017
COMPASS	0.158	6.1	0.69	20.8	0.227 ± 0.033
HERMES	0.166	3.2	0.69	10.2	0.202 ± 0.020

- Strong ν dependence of R_K may contribute to observed disagreement
- Direct comparison in the only common kinematic data point : there reaches agreement.
- In neighbouring x bins, HERMES $< \nu >$ is smaller than COMPASS one and HERMES ratio is smaller than COMPASS one.

CONCLUSION

→ Pion and kaon multiplicities measured in SIDIS

- COMPASS : largest sample of kaon multiplicities to constrain FFs.

→ Integrated multiplicity sum

- Large discrepancies between COMPASS and HERMES for both pion and kaon multiplicity sums :
  - up to 25% in the integrated $M^{\pi+}+M^{\pi-}$ (COMPASS below HERMES).
  - up to 30-40% in the integrated $M^{K+}+M^{K-}$ (COMPASS above HERMES).

→ Kaon multiplicity ratio

- Large disagreement with pQCD limit (and model expectations) for COMPASS K+/K- ratio at high z low ν.
- Smooth behaviour of M_X suggests that correction within pQCD formalism is needed to take into account the available phase space for the target remnant hadronization.

OPEN QUESTIONS

→ Discrepancies in pion sums between COMPASS and HERMES..

- .. while extraction of FFs into pions looks solid.

→ Fitting kaon multiplicities : Problem in DSS approach

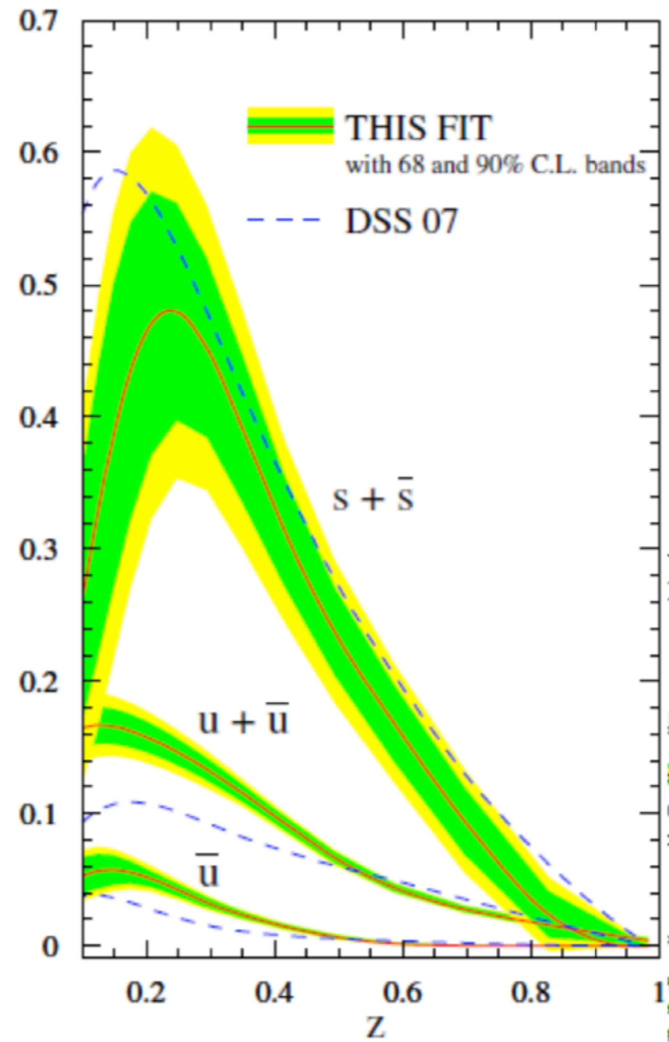
- DSS = only fit with both COMPASS and HERMES data
- Uses 2 projections of HERMES data without taking into account correlations
- Have to normalize the 2 projections in opposite directions
- Still high χ^2 for HERMES data

→ Input from theoreticians needed for interpretation of kaon data !

BACKUP

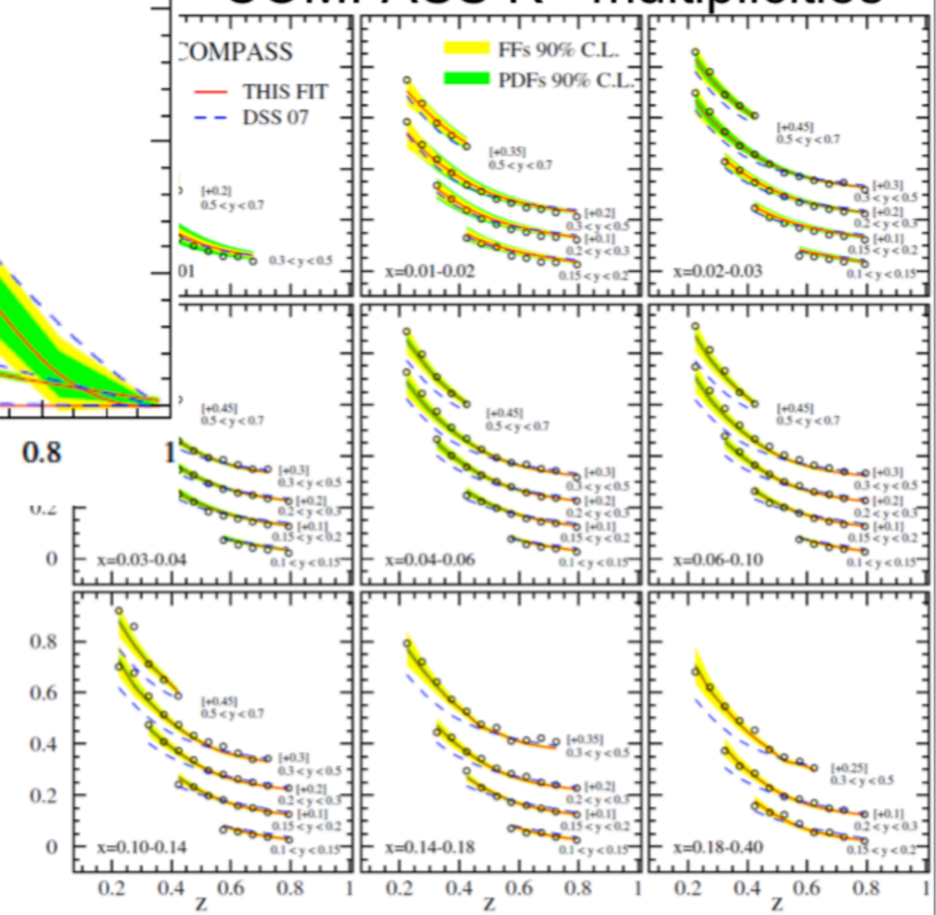
DEHSS GLOBAL FIT

Experiment	Data type	$\mathcal{N}_i$	# data in fit	χ^2
Tpc [38]	Inclusive	1.003	12	13.4
Sld [35]	Inclusive	1.014	18	17.2
	uds tag	1.014	10	31.5
	c tag	1.014	10	21.3
	b tag	1.014	10	11.9
Aleph [32]	Inclusive	1.026	13	29.7
Delphi [33]	Inclusive	1.000	12	6.9
	uds tag	1.000	12	13.1
	b tag	1.000	12	11.0
Opal [39]	*u* tag	0.778	5	9.6
	d tag	0.778	5	7.7
	s tag	0.778	5	23.4
	c tag	0.778	5	42.5
	b tag	0.778	5	16.9
BABAR [19]	Inclusive	1.077	45	30.6
Belle [20]	Inclusive	0.996	78	15.6
Hermes [21]	K^+ (p) Q^2	0.843	36	61.9
	K^- (p) Q^2	0.843	36	29.6
	K^+ (p) x	1.135	36	75.8
	K^- (p) x	1.135	36	42.1
	K^+ (d) Q^2	0.845	36	44.7
	K^- (d) Q^2	0.845	36	41.9
	K^+ (d) x	1.095	36	48.9
	K^- (d) x	1.095	36	44.4
Compass [24]	K^+ (d)	0.996	309	285.8
	K^- (d)	0.996	309	265.1
Star [26]	K^+,K^-/K^+	1.088	16	7.6
Alice [25] 2.76 TeV	K/π	0.985	15	21.6
Total			1194	1271.7



DEHSS, PRD95, 094019 (2017)

COMPASS K+ multiplicities



- Half of entries from COMPASS
- D_s^K smaller than in DSS07

DEHSS GLOBAL FIT

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BSS SIMULTANEOUS FIT

Borsa, Sassot & Stratmann arXiv:1708.01630v

Iterative procedure; fitting SIDIS charged kaon multiplicities from COMPASS and HERMES.

Concluding on NNPDF3.0 PDF set for s(x).

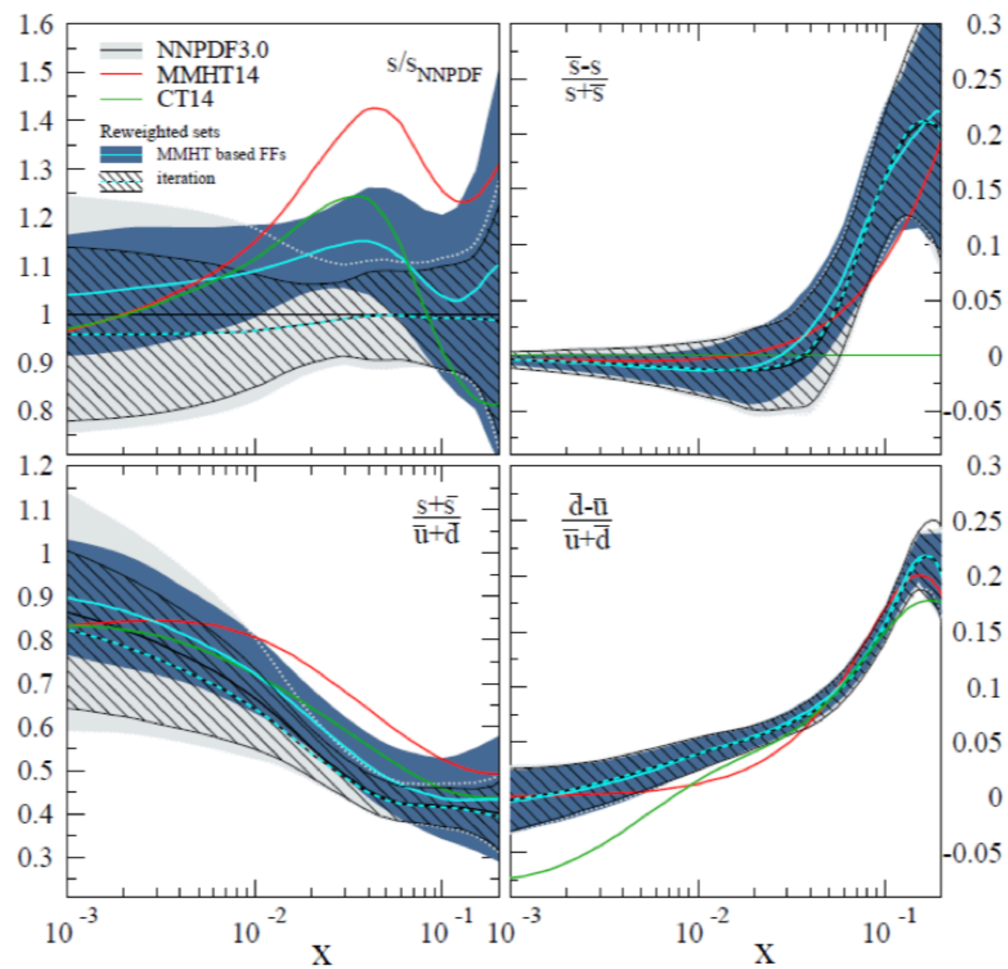

FIG. 5: Reweighting of the strange quark distribution (upper left panel) and for the PDF combinations sensitive to charge (upper right panel) and flavor (lower panels) symmetry breaking using the DSS 17 set of kaon FFs that is based on the MMHT 14 set of PDFs; see text. The dashed light blue and black lines and the hatched areas represent the results of one iteration of the reweighting procedure and the corresponding uncertainty bands, respectively; see text. All results are shown at a scale of $Q^2 = 5\,\mathrm{GeV}^2$.