π and K SIDIS multiplicities and K^-/K^+ at large *z* measured at COMPASS

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On behalf of COMPASS Collaboration

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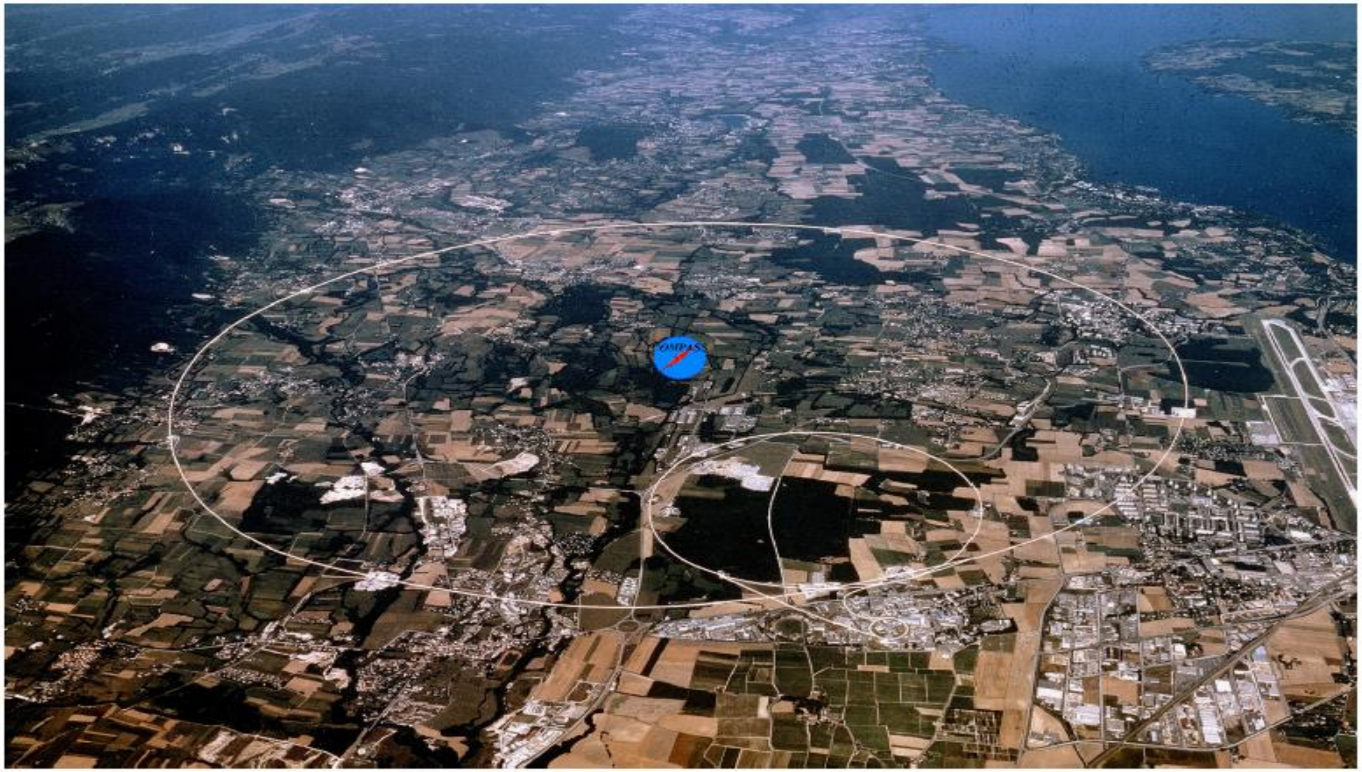
COmmon Muon Proton Apparatus for Structure and Spectroscopy



~240 physicists, 12 countries, 24 institutions

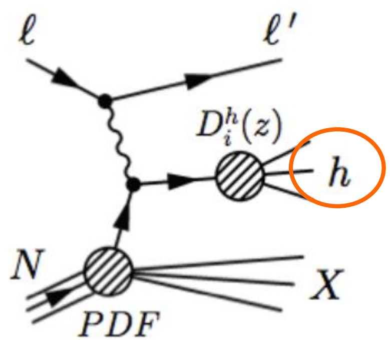
Fixed target experment, multi-purpose set-up.
Secondary ~200 GeV muon and hadron beams from CERN SPS
Various targets

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 unsufficient and at too high Q^2

→ Measure hadron multiplicities in **SIDIS:** $\mu^+ d \rightarrow \mu^+ h^\pm X$ 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

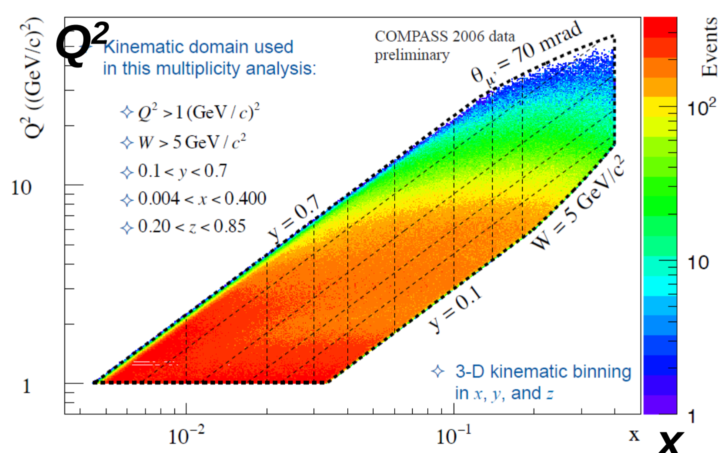
→ With kaons, access typically : $s(x,Q^2).D_s^K(z,Q^2)$

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**



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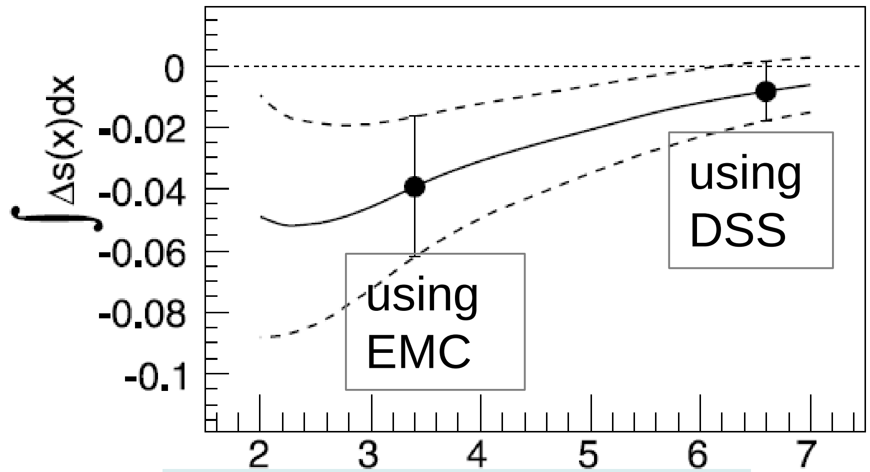
Longitudinal spin- Impact of FF on Δs extraction

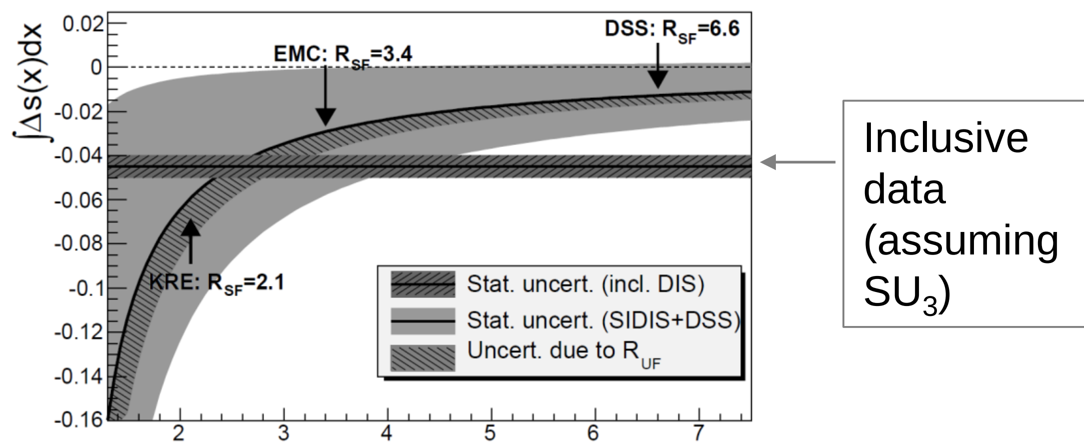
Δs extraction from SIDIS depends on value of D_s^K fragmentation function.

Δs vs R_{SF}

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



COMPASS, PLB 693 (2010) 227

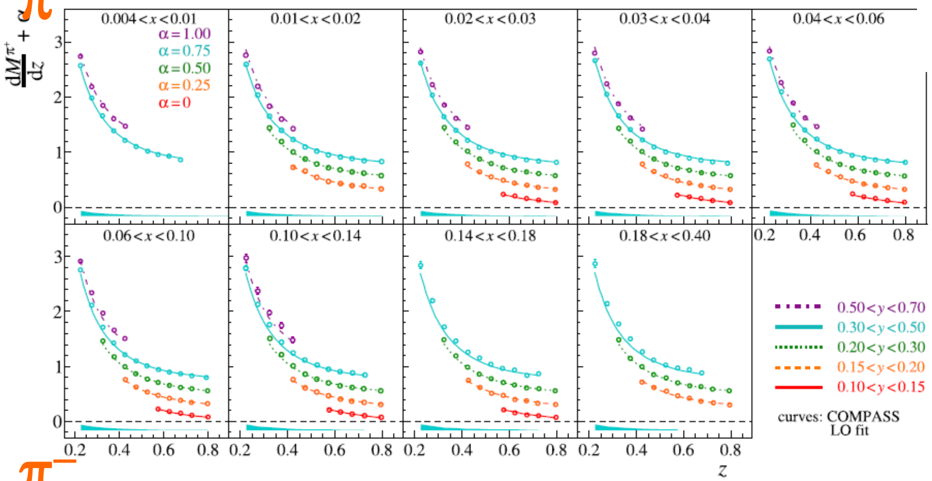


COMPASS, PLB 680 (2009) 217

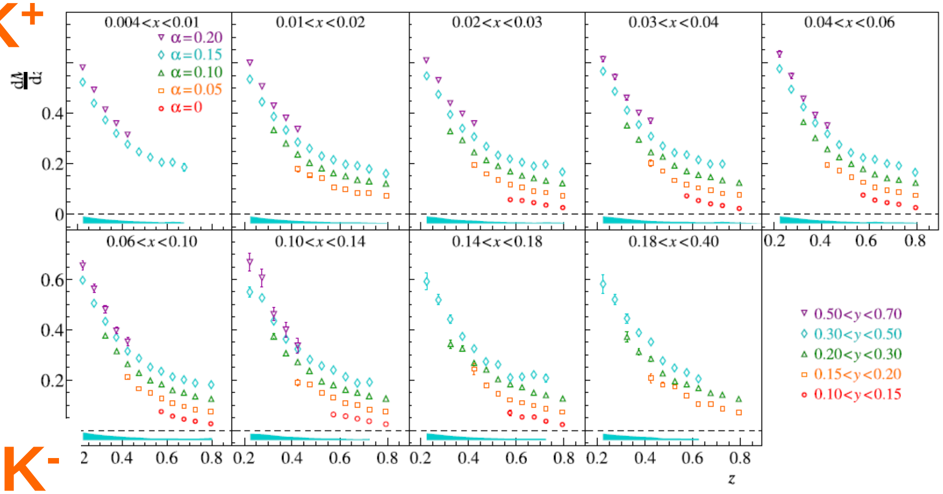
Most Δs extractions from SIDIS used the old DSS value. Could be revisited.

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

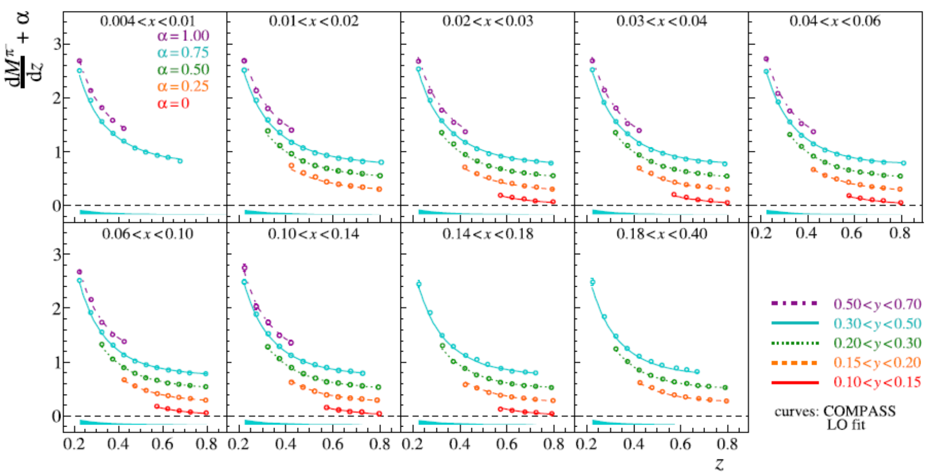
π^+



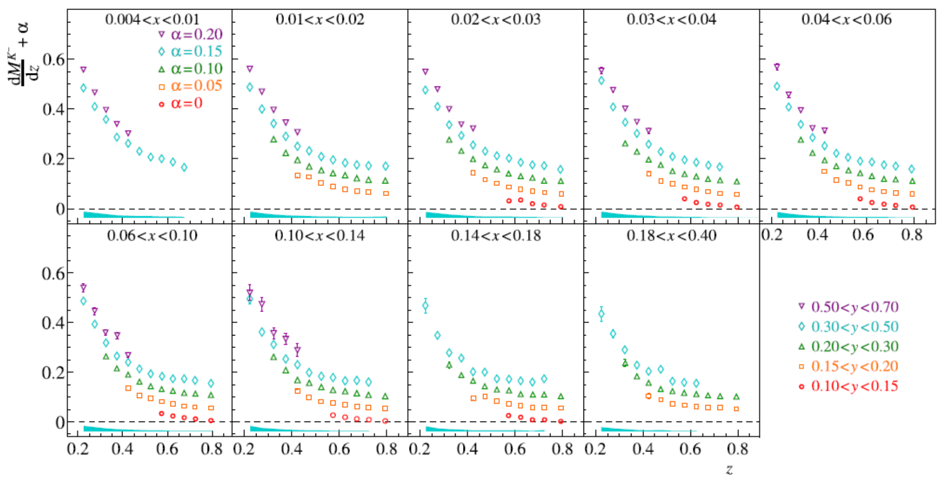
K+



π^-



K-



- More than 1200 points in total, various Q^2 staggered vertically for clarity
- Strong z dependance
- $M(\pi^+) \sim M(\pi^-)$ and $M(K^+) > M(K^-)$

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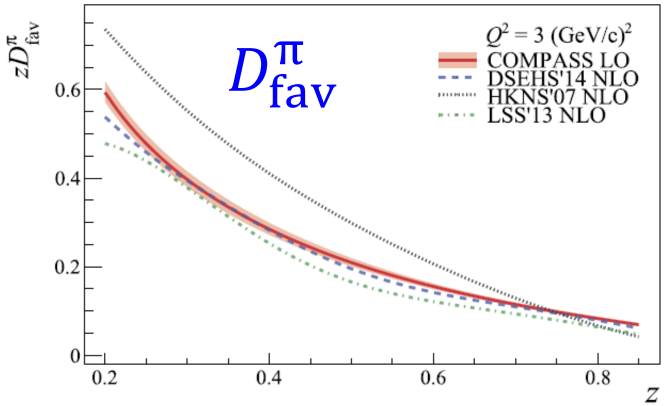
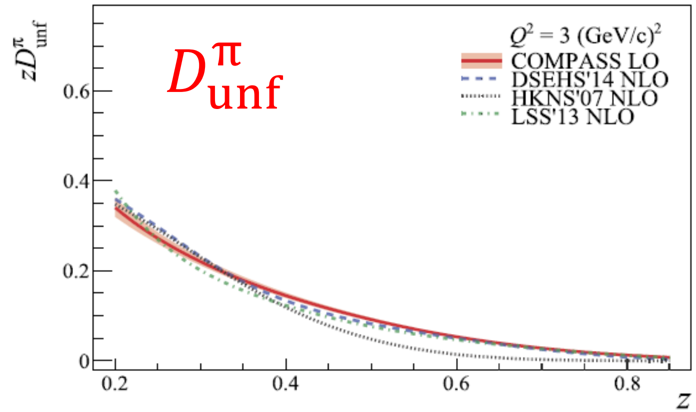
From multiplicities to quark Fragmentation Functions

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 contraints 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)

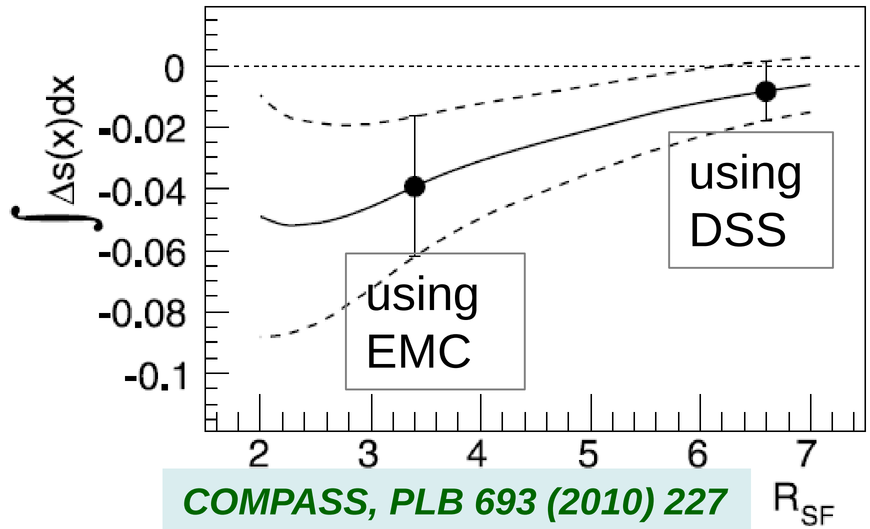
Borso, Sassot, Stratmann, arXiv:1708.01630

Longitudinal spin- Impact of FF on Δs extraction

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

Δs vs R_{SF}

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



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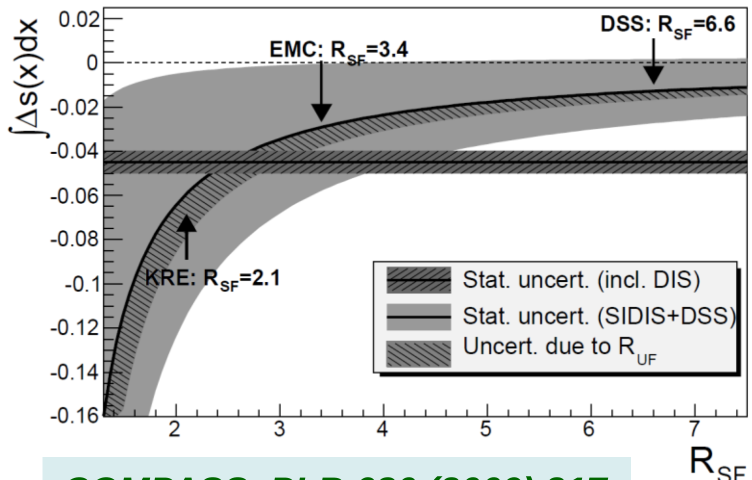

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Inclusive data (assuming SU_3)

Most Δs extractions from SIDIS used the old DSS value. Could be revisited.

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

For isoscalar target, simple dependence on FFs:

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

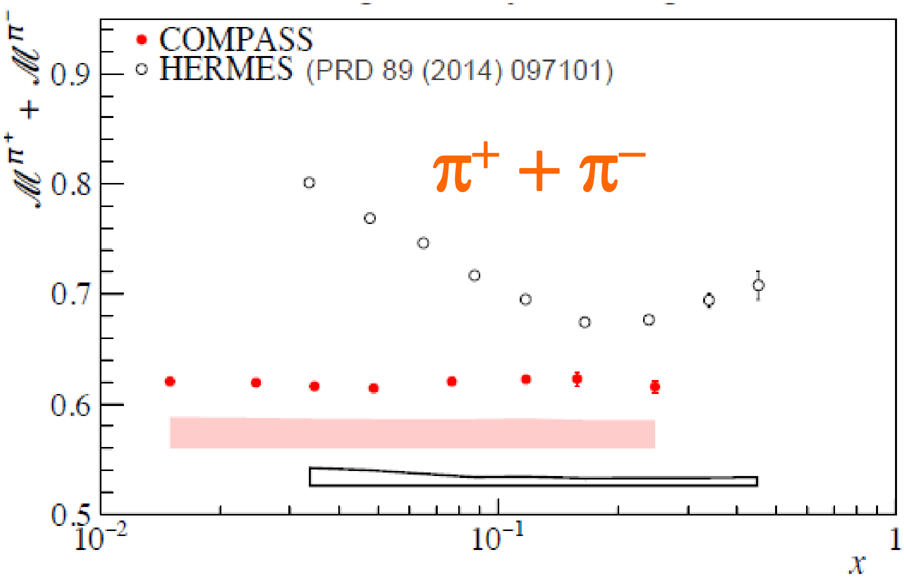
$$5M^{K^+ + K^-} = D_Q^K + S/Q\, D_S^K$$

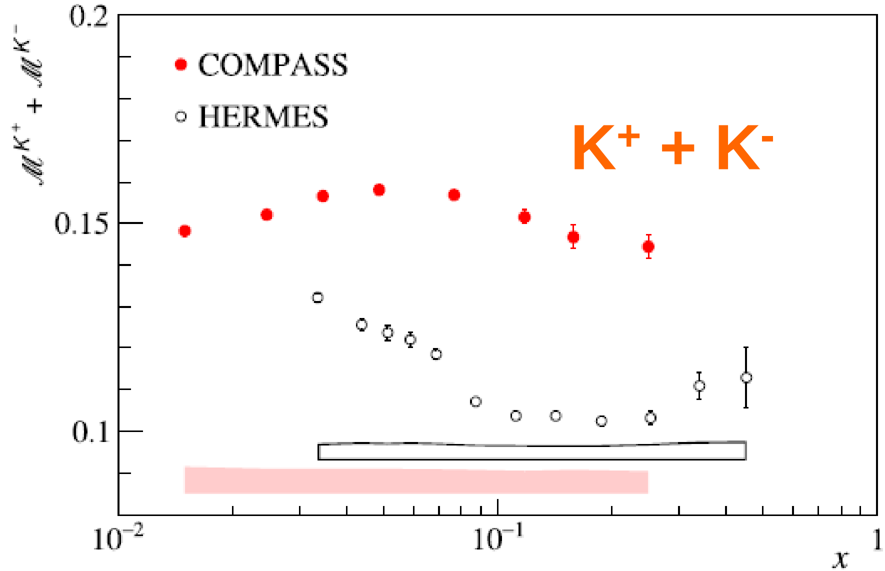
high x data *low x data*

At high *x*, ~no *x* dependence expected

where:

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





COMPASS pion data:

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

(as 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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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

Pions:

- Different *W* values could explain part of the overall discrepancy, but not the shape (MC studies).

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M(K$^-$)/ M(K$^+$) kaon muliplicity 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…) :

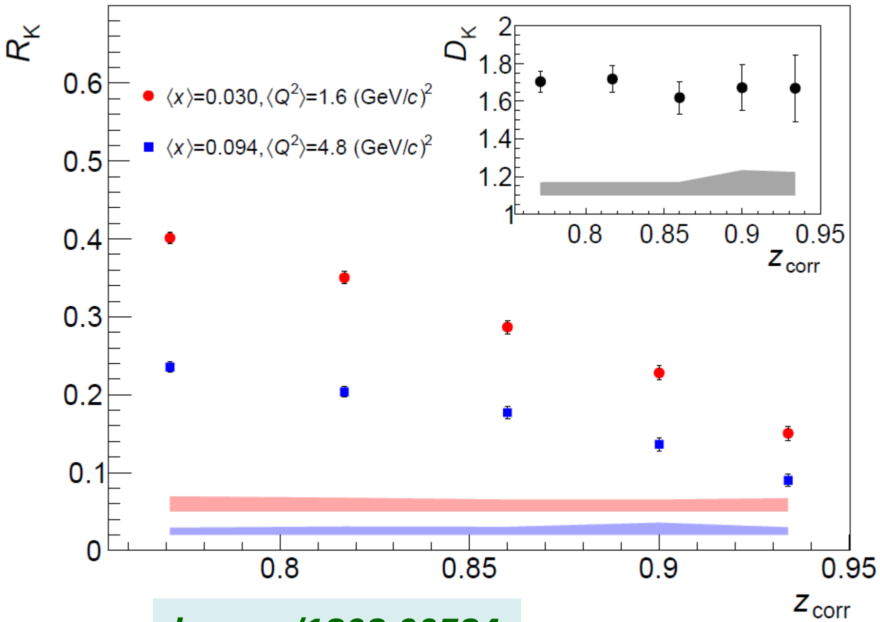
$$R_{\mathrm{K}} = \frac{4\bar{\mathrm{u}}D_{\mathrm{fav}} + \mathrm{s}D_{\mathrm{str}}}{4\mathrm{u}D_{\mathrm{fav}} + \bar{\mathrm{s}}D_{\mathrm{str}}}.$$

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

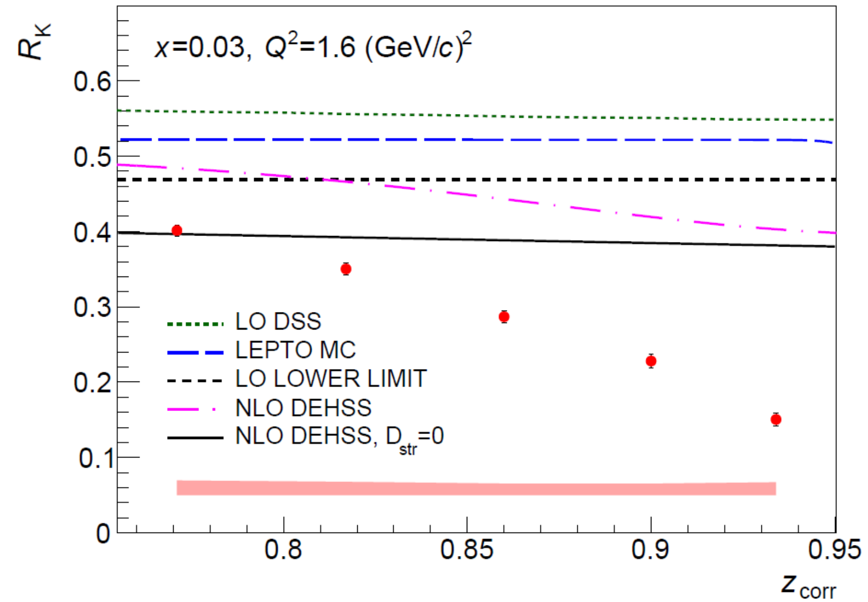
$M(K^-)/ M(K^+)$ at high z – Results vs z in two x bins

Ratio measured vs z in two x bins



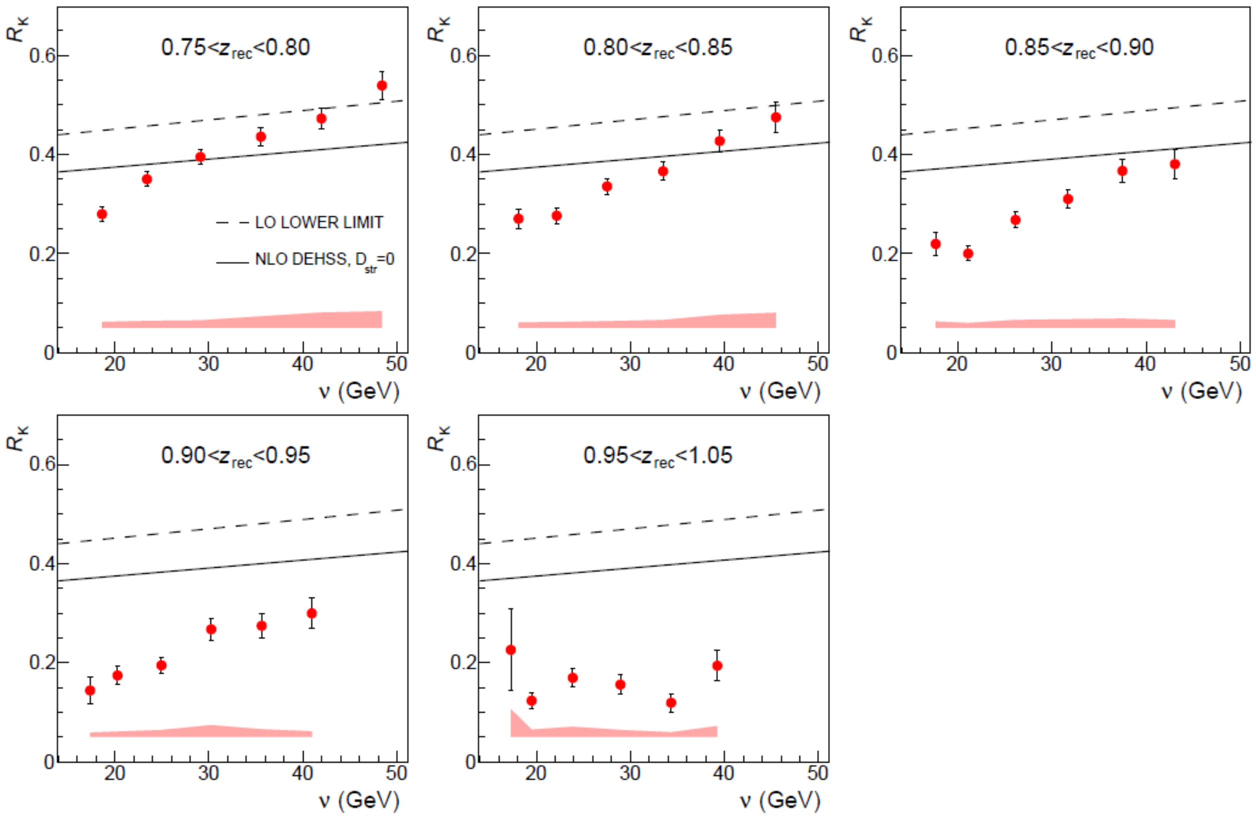
hep-ex/1802.00584
Subm. to PLB

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



for bin x=0.03

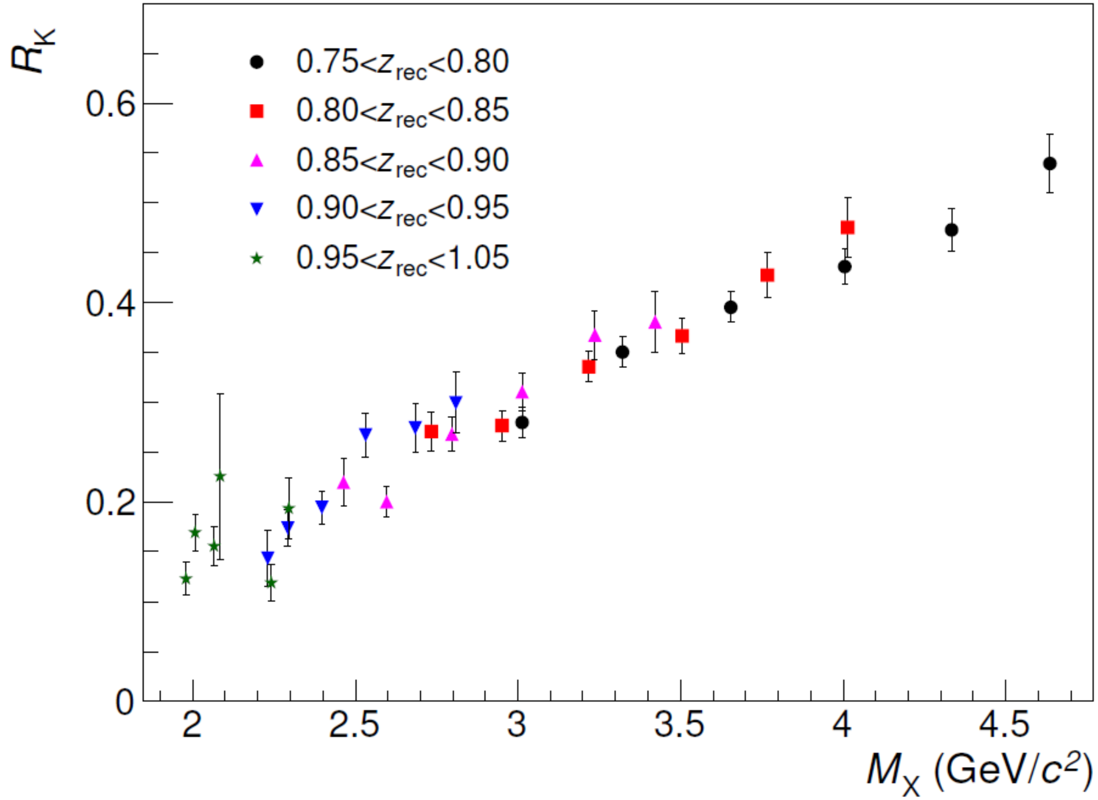
hep-ex/1802.00584
Subm. to PLB

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

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



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

Summary

Pion and kaon SIDIS multiplicities

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

- Some hints on reasons for large discrepancy COMPASS vs HERMES: up to 30-40% in *z*-integrated M(K^+)+ M(K^-).

- **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.

High *z* data for K^-/K^+ multiplicity ratio

- Data disagree with current NLO QCD calculations **at high *z* and low ν**

- Unexpected rise of ratio M(K^+) / M(K^-) with missing mass, suggesting to take into account the available phase space for hadronisation in formlism.

Backup slides

Comments on corrections for QED radiative effects

In the paper of kaon multiplicities:
Muon yields (denominator): use TERAD
Kaon yields (numerator): use TERAD, excluding elastic and quasi-elastic tails. But TERAD cannot account for a **z dependence**, and leads to an overestimate of the correction.

→ conservative approach: the correction is calculated for the two extreme cases, **no correction** and **full correction** to the number of kaons; half of the correction is applied to the multiplicities. This approach leads to an **overall correction between 1% and 7%** depending on kinematics.

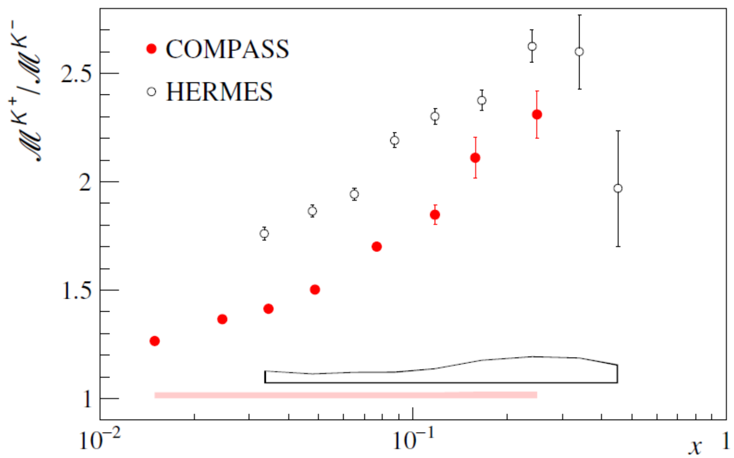
Further work done: use Djangoh which can account for z dependence:
- For muons, agreement Djangoh / TERAD within 3%
- For kaons, obtain a correction varying between 0 and 10% (dep. Kinematics) of the order of 5% in average.

Note that using RADGEN was excluded since it could not reproduce the photon spectrum observed in COMPASS

Ratios K^+/K^- and $\pi+/\pi-$ *z*-integrated multiplicities

COMPASS published data $0.1 < z < 0.8$

kaons



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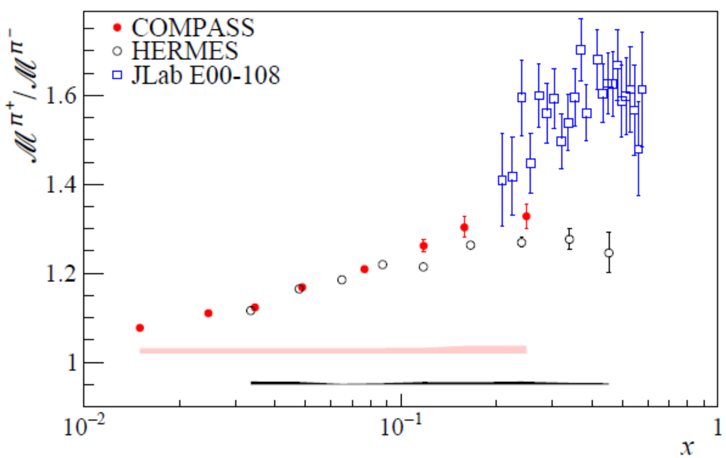
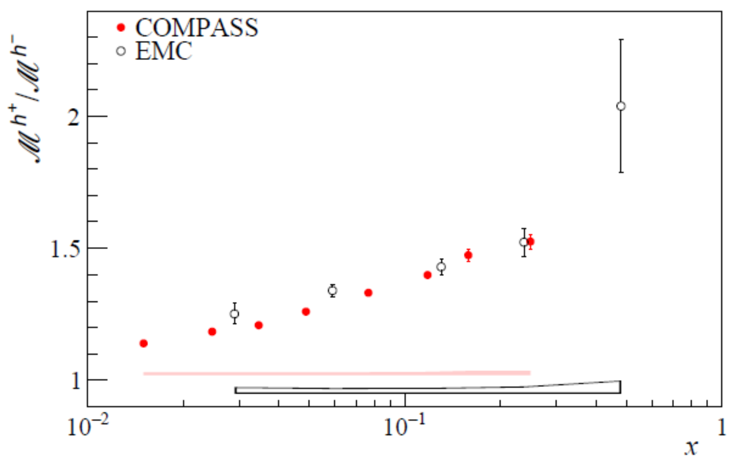
pions



hadrons



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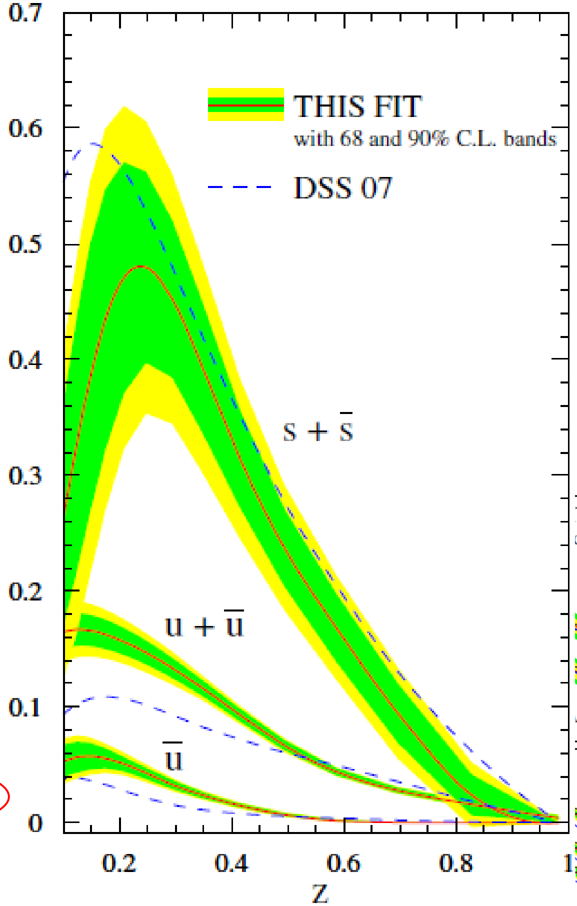
HERMES COMPASS discrepancy

- We note that, the strong ν dependence of R_K may contribute to the observed disagreement between R_K presented by COMPASS and HERMES
- A direct comparison of the two results is possible at the only common kinematic 'point', *i.e.* $x \approx 0.035$, $z \approx 0.7$ and $\nu \approx 20$ GeV, where COMPASS and HERMES results agree
- In the neighbouring x bins, the average value of ν is smaller for HERMES than for COMPASS. In all these cases, the multiplicity ratio tends to be smaller for HERMES than for COMPASS.

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

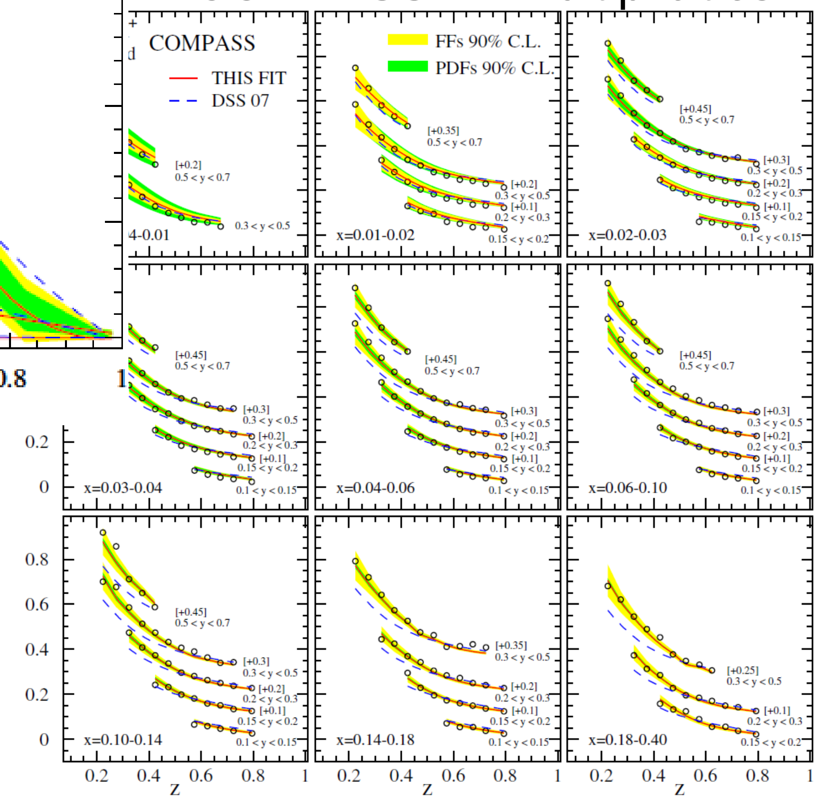
Strange quark FF. DEHSS global fit of kaon data

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

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DEHSS globat fit

	s tag	0.778	5	23.4
	c tag	0.778	5	42.5
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Total			1194	1271.7

Simultaneous study of PDF and FF

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).

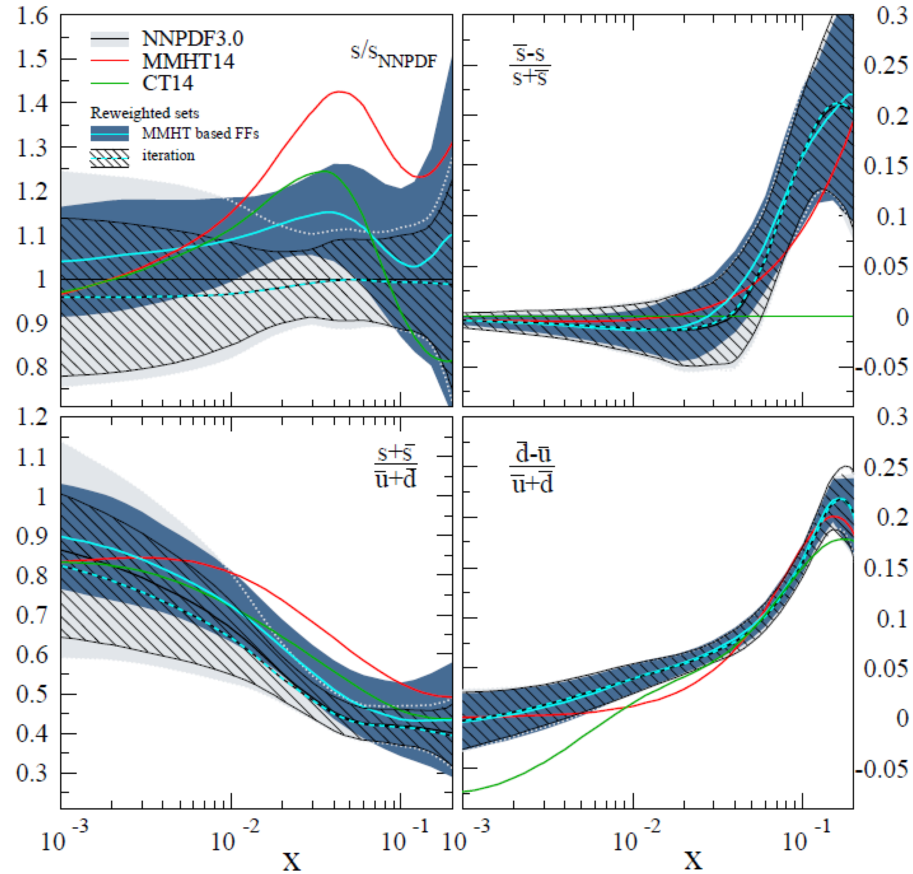
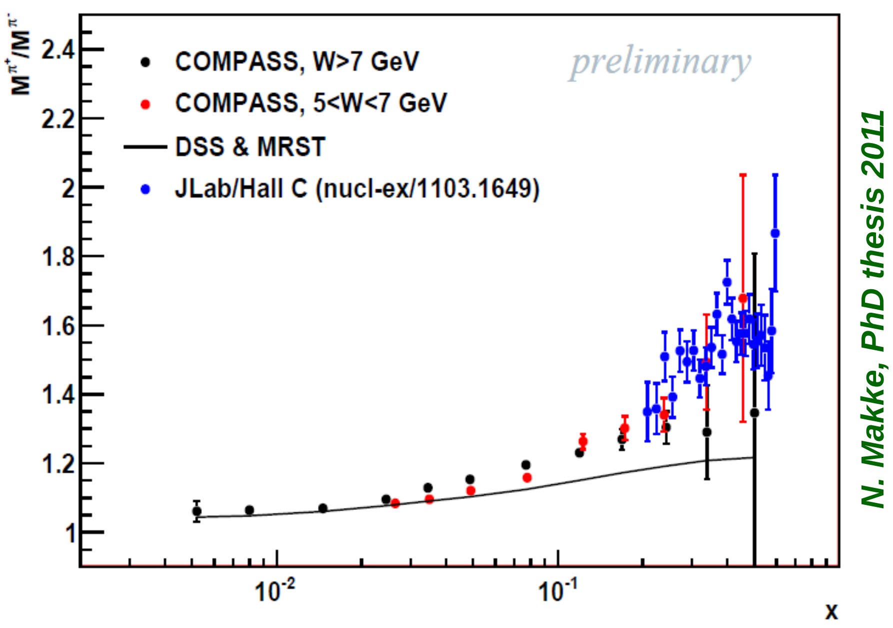


FIG. 5: Reweighting of the strange quark distribution (upper left panel) and for the PDF combinations sensitive to charge (upper right panel) and flavor (lower panels) symmetry breaking using the DSS 17 set of kaon FFs that is based on the MMHT 14 set of PDFs; see text. The dashed light blue and black 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 $Q^2 = 5\,\mathrm{GeV}^2$.

SIDIS multiplicities –
Additional plots on W dependence

z-integrated multiplicity ratio pi+ / pi-

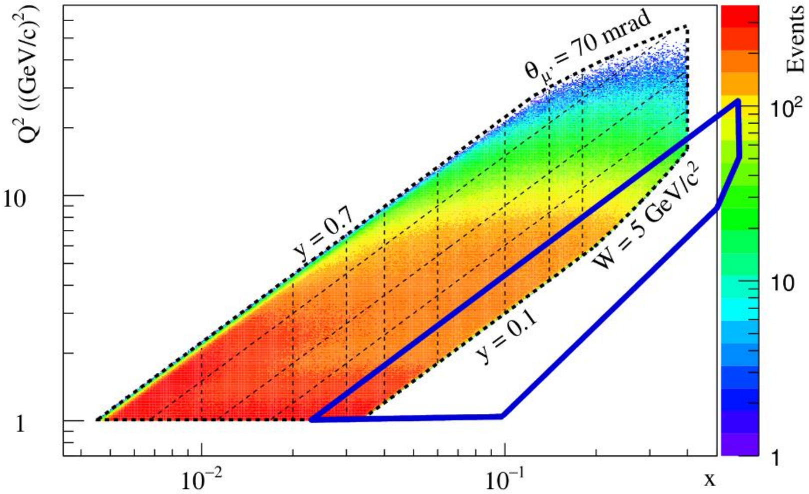
Comparison COMPASS (two W bins) / Jlab for pions (W>2)



Fair agreement COMPASS lower W bin with Jlab.
Recall also fair agreement COMPASS with HERMES for this ratio in pions.

COMPASS and HERMES kinematics coverage

COMPASS (W>5)



HERMES