Perceiving the Emergence of Hadron Mass through

AMBER@CERN

30 March 2020 to 3 April 2020
CERN, Geneve - Switzerland

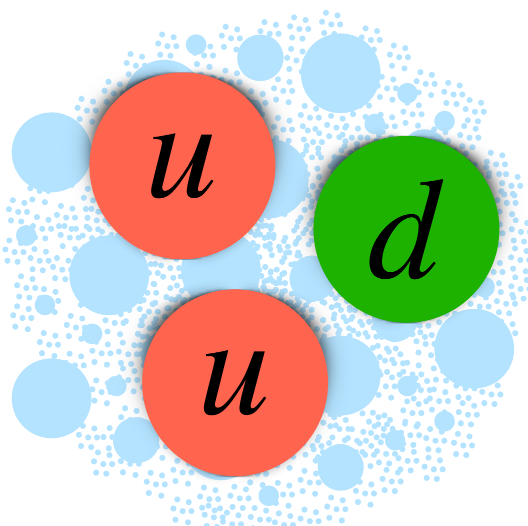
Drell-Yan measurements at AMBER
Studying the hadrons structure

Márcia Quaresma on behalf of the COMPASS++/AMBER working group

1. Pion structure with pion beams and a C target
2. Nuclear PDFs with pion beams and C and W targets
3. Nucleon structure with an anti-proton beam and a proton polarised target
4. Kaon structure with kaon beams and a C target

Studying the different hadrons

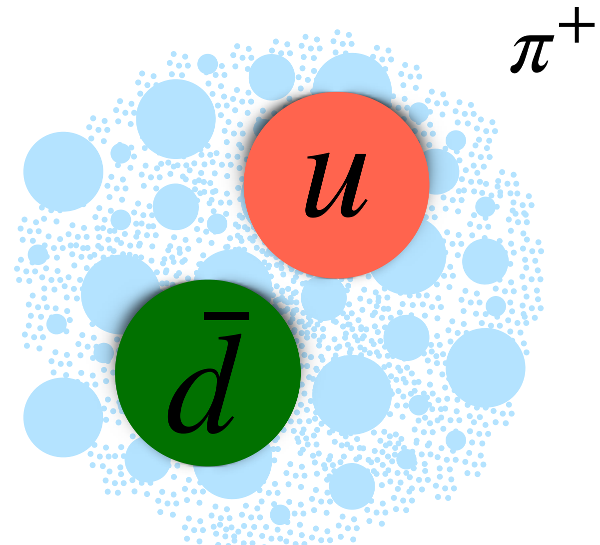
Proton



$M_p \sim 940\ MeV/c^2$

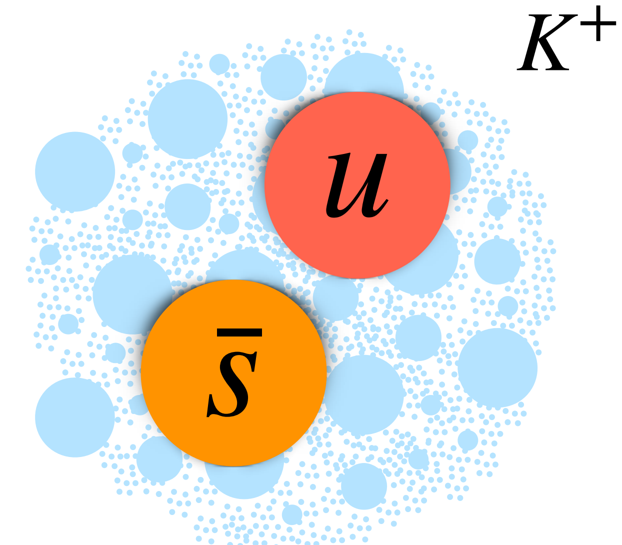
easier to access using a proton as a beam and/or a target

Pion



$M_\pi \sim 140\ MeV/c^2$

Kaon

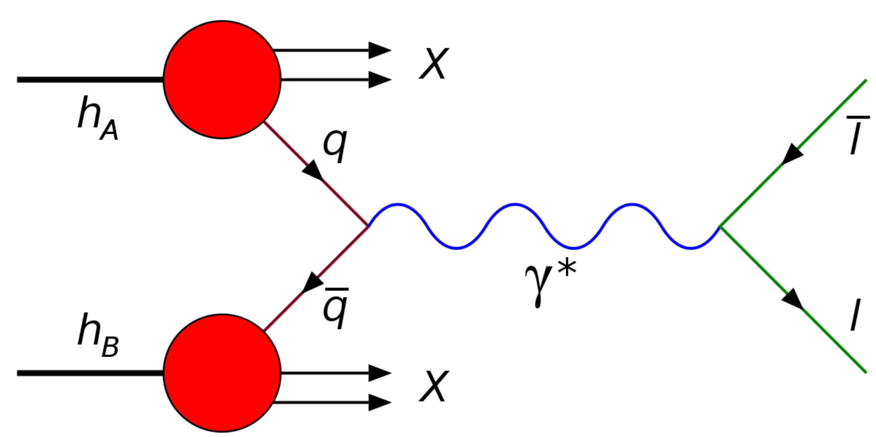


$M_K \sim 490\ MeV/c^2$

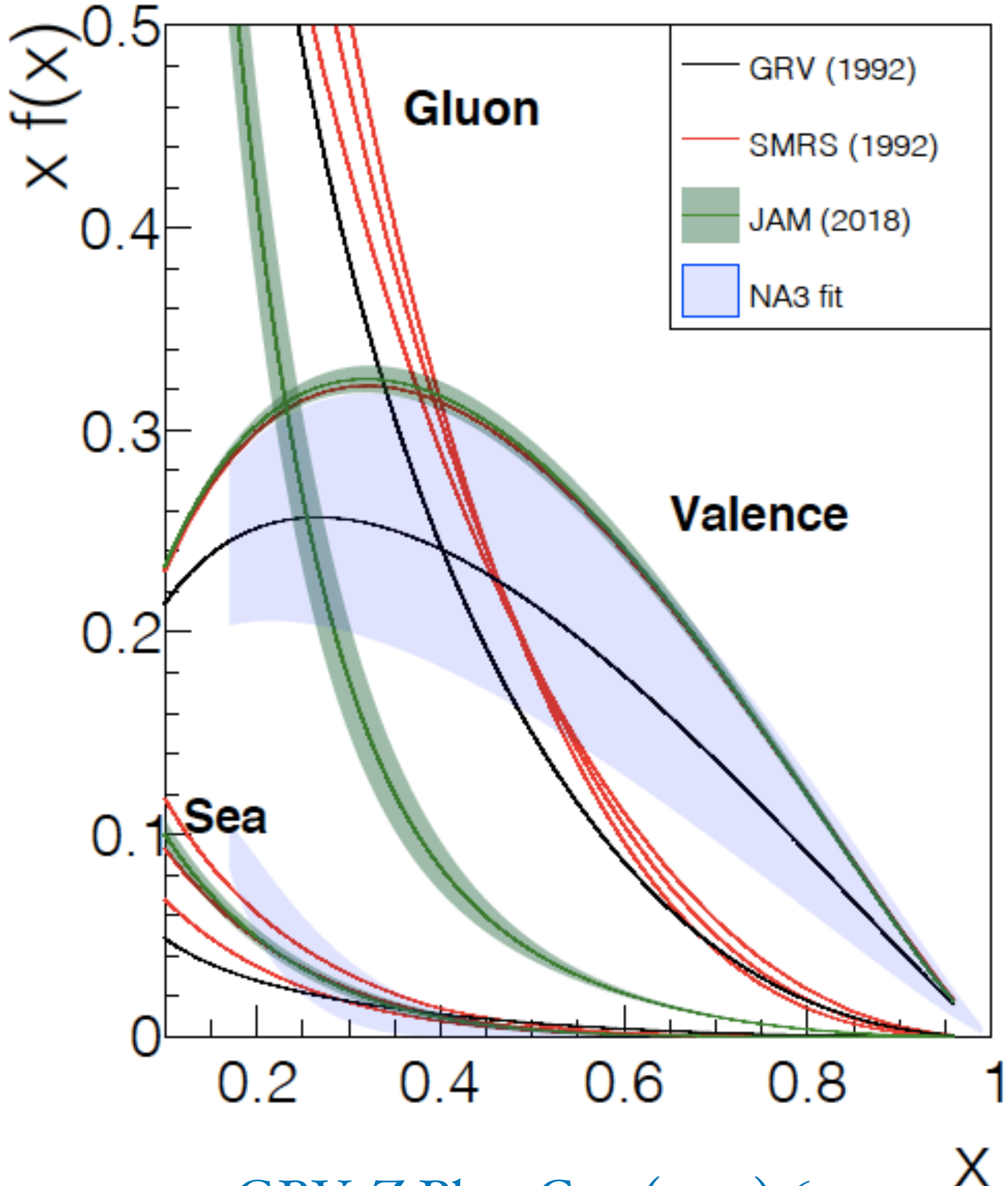
more difficult since there are no pion or kaon targets

pion or kaon beam

light isoscalar target



Pion PDFs - measurement of the sea



GRV: Z.Phys.C 53 (1992) 651
SMRS: PRD 45 (1992) 2349
JAM: PRL 121 (2018) 152001
NA3: Z.Phys.C 18 (1983) 281

inconsistent results among the different groups

GRV and **SMRS** analyses (1992):
π^- DY data from NA10 and E615 (no uncertainties)
direct photon data from WA70 and NA24

<u>sea content</u>
GRV - derived from momentum conservation
SMRS - three different scenarios (10%, 15% or 20%)

JAM analysis (2018):
DY data + leading neutron DIS (ZEUS and H1 from HERA)
strongly model dependent (pion cloud)

NA3 Drell-Yan data with $\pi^-$and π^+:
published fit coefficients and correlation matrix
(direct access to valence and sea)
<u>NOTE:</u> NA3 data was not used in other global analyses
because the cross-sections were not published

sea is the most unknown contribution

Pion induced Drell-Yan available data & predicted statistics

Experiment	Target type	Beam energy (GeV)	Beam type	Beam intensity (part/sec)	DY mass (GeV/c^2)	DY events
E615	20 cm W	252	π^+ π^-	17.6×10^7 18.6×10^7	4.05 – 8.55	5000 30000
NA3	30 cm H_2	200	π^+ π^-	2.0×10^7 3.0×10^7	4.1 – 8.5	40 121
	6 cm Pt	200	π^+ π^-	2.0×10^7 3.0×10^7	4.2 – 8.5	1767 4961
NA10	120 cm D_2	286 140	π^-	65×10^7	4.2 – 8.5 4.35 – 8.5	7800 3200
	12 cm W	286 194 140	π^-	65×10^7	4.2 – 8.5 4.07 – 8.5 4.35 – 8.5	49600 155000 29300
COMPASS 2015 COMPASS 2018	110 cm NH_3	190	π^-	7.0×10^7	4.3 – 8.5	35000 52000
This exp	75 cm C	190	π^+	1.7×10^7	4.3 – 8.5 4.0 – 8.5	21700 31000
		190	π^-	6.8×10^7	4.3 – 8.5 4.0 – 8.5	67000 91100
	12 cm W	190	π^+	0.4×10^7	4.3 – 8.5 4.0 – 8.5	8300 11700
		190	π^-	1.6×10^7	4.3 – 8.5 4.0 – 8.5	24100 32100

heavy nuclear target

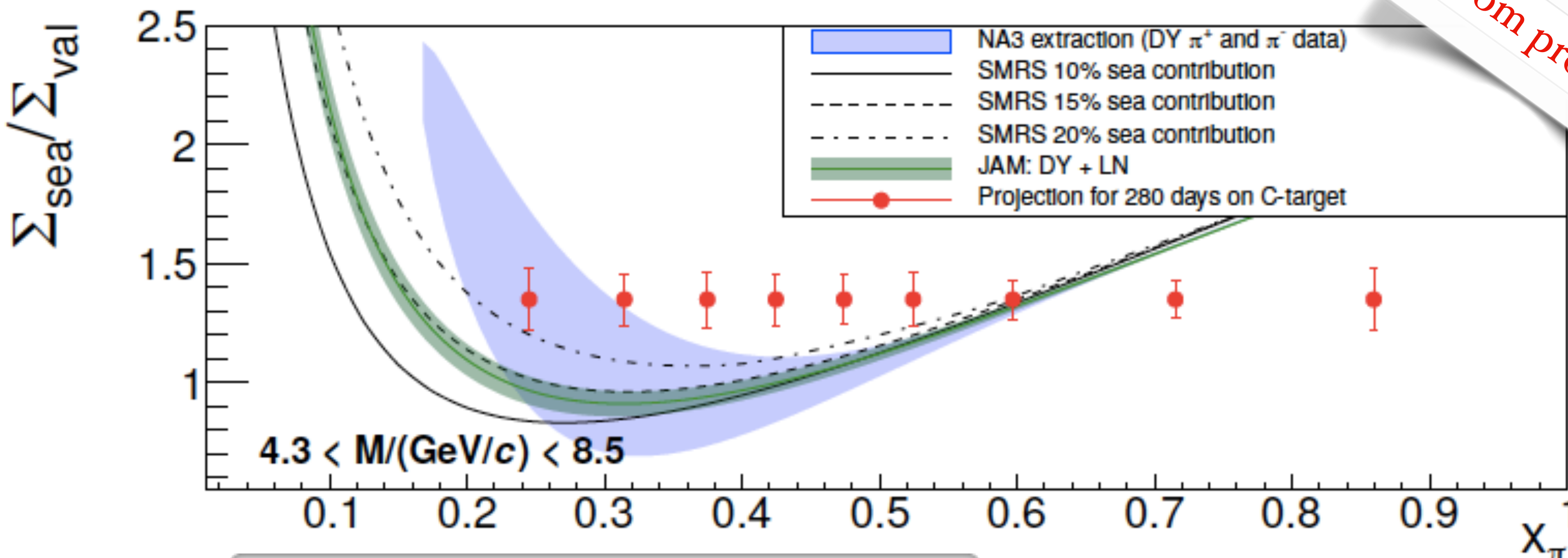
ratio 3:1 between π^+ and π^- due to the cross-section diff. and the hadron beam composition at cern M2 beam line

2 years of data taking: 213 days of π^+ and 67 of π^-

Pion PDFs - sea/valence

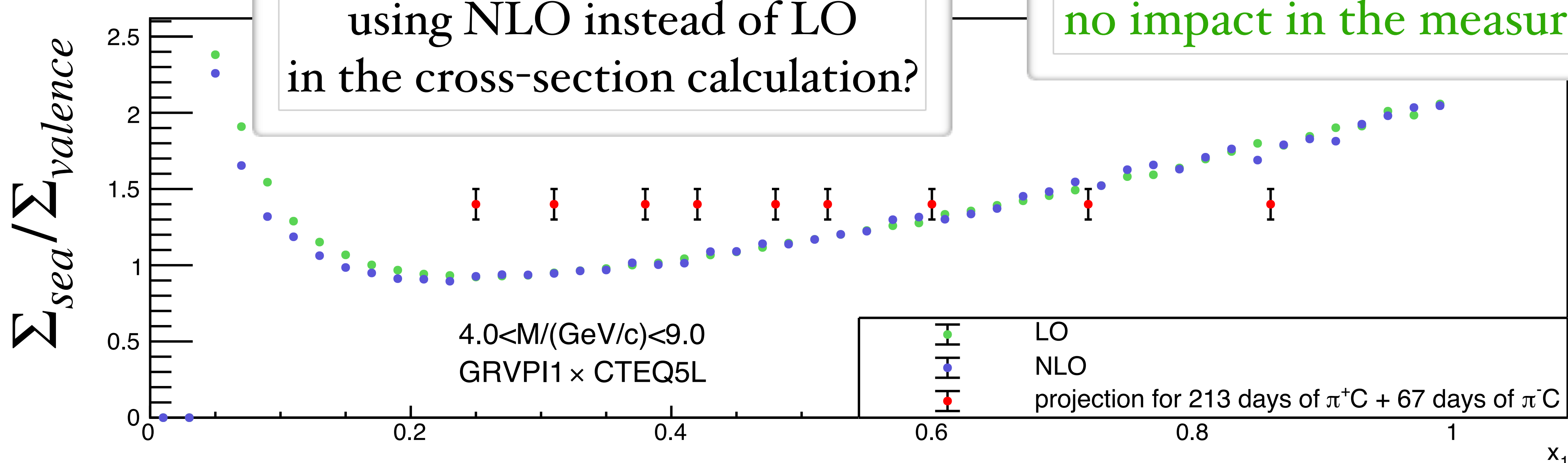
$$\frac{\Sigma_{sea}}{\Sigma_{valence}} = \frac{4\sigma^{\pi^+C} - \sigma^{\pi^-C}}{-\sigma^{\pi^+C} + \sigma^{\pi^-C}}$$

from proposal



what is the impact of using NLO instead of LO in the cross-section calculation?

no impact in the measured region

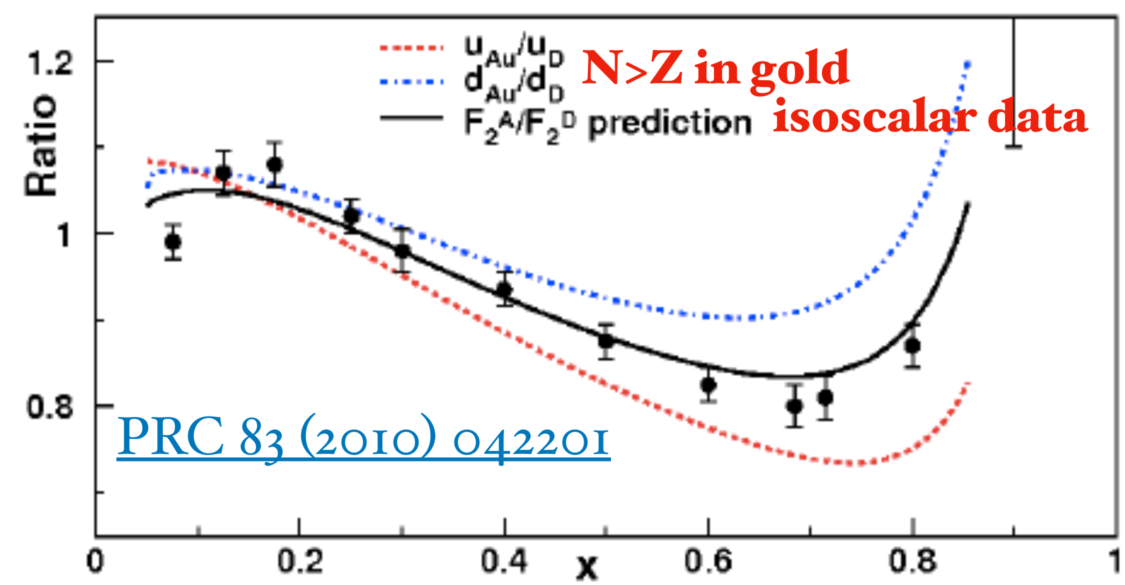


Nuclear dependence studies

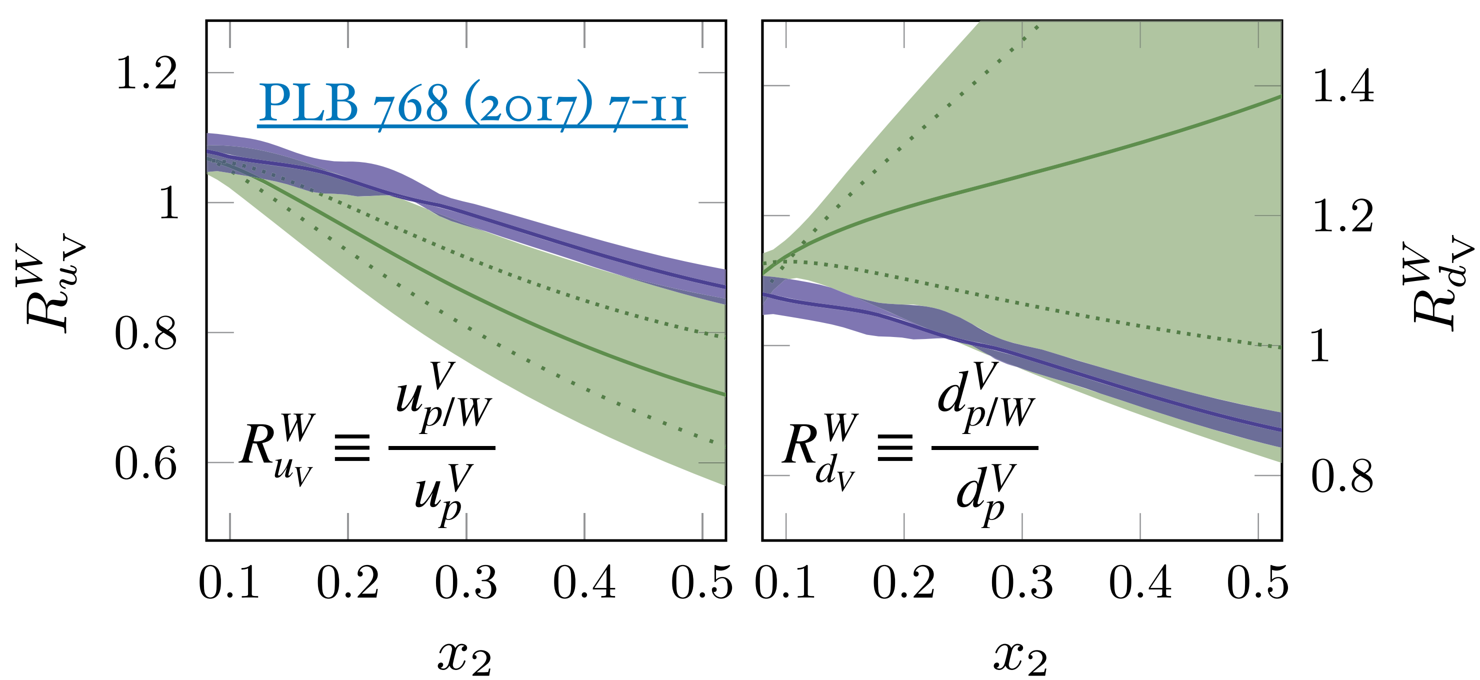
More than 30 years ago - the EMC effect
the parton distributions in a bound nucleon differ from those in a free nucleon

Contrary to DIS, Drell-Yan may probe the quark flavour involved and see if the nuclear effects depend on it

this may have a strong effect on global fits of nuclear PDFs



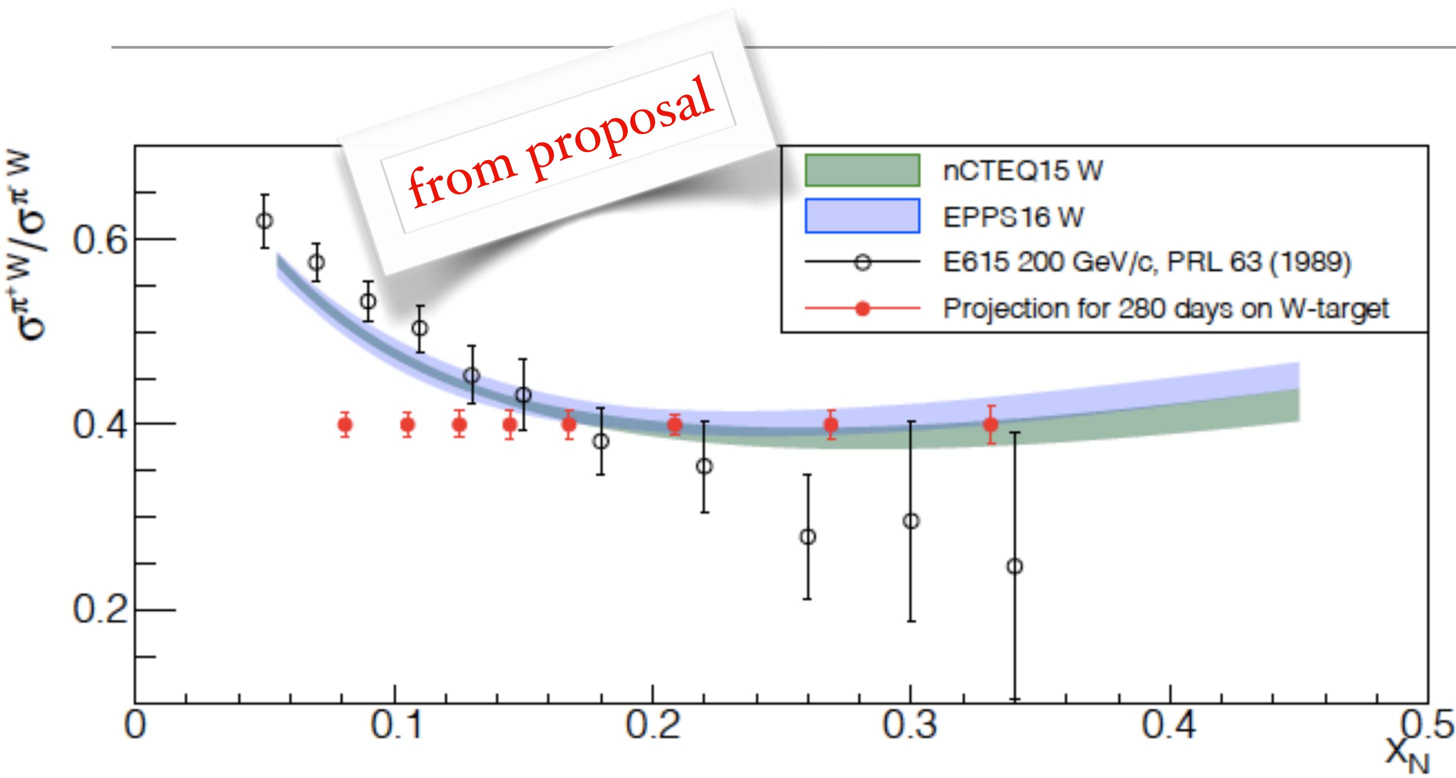
nuclear modification factors

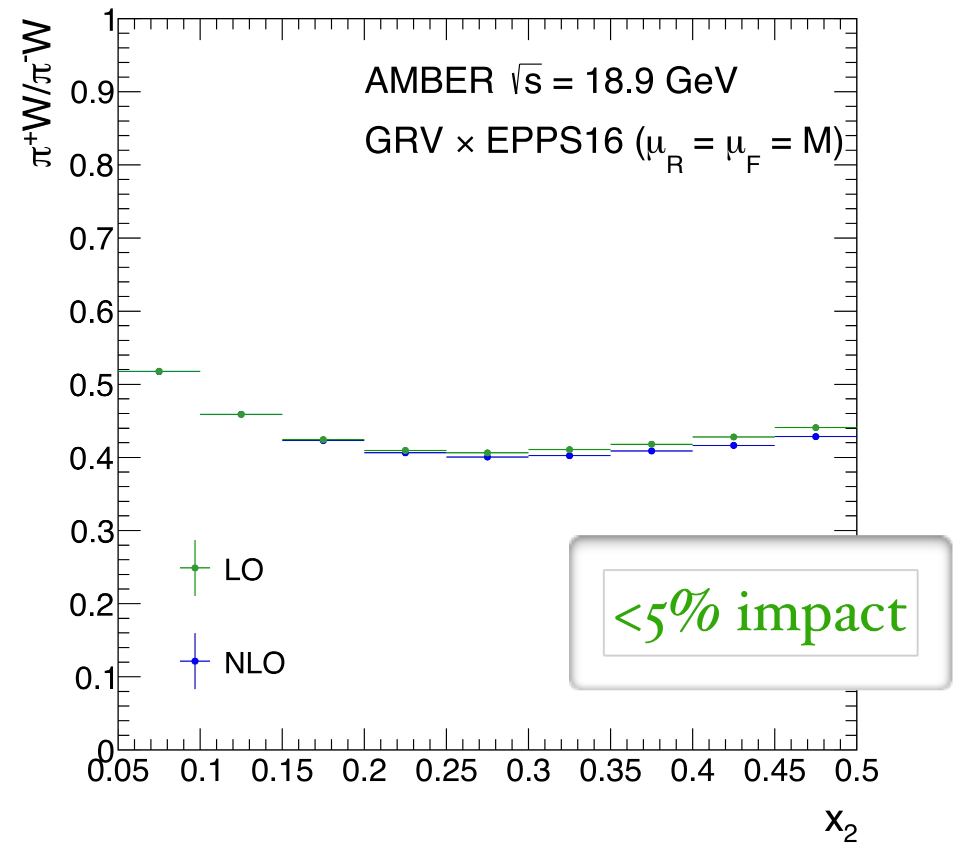


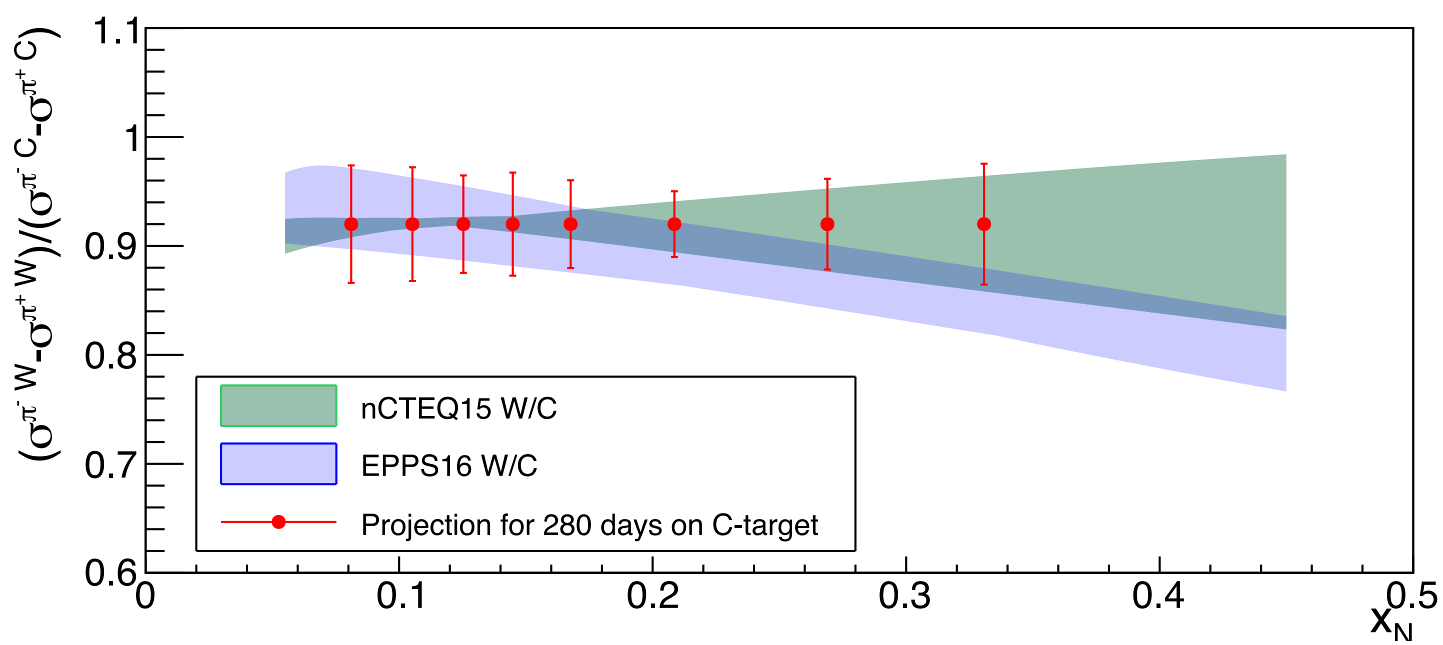
nCTEQ15 global fit with no quark flavour constrains

EPS09 global fit imposes the same nuclear modifications for u and d

Nuclear PDFs



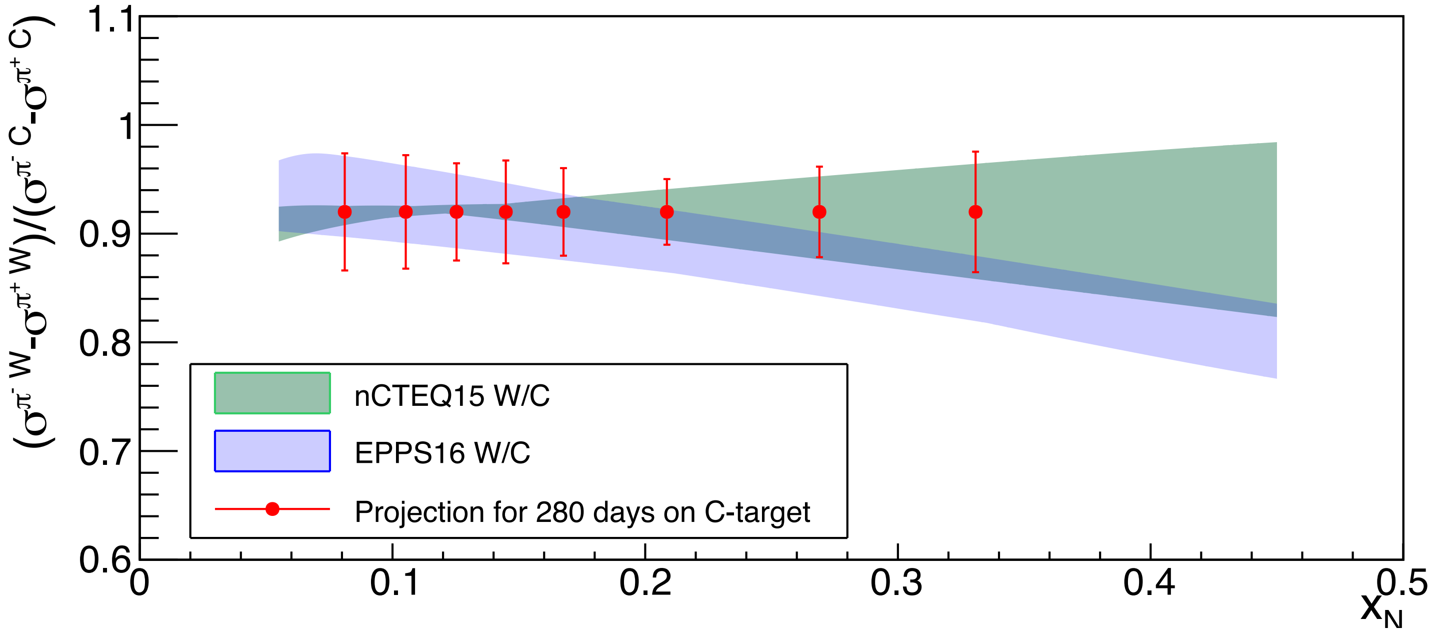




nCTEQ15: PRD 93 (2016) 085037
EPPS16: PLB 768 (2017) 7-11

Nuclear PDFs - impact of our projections

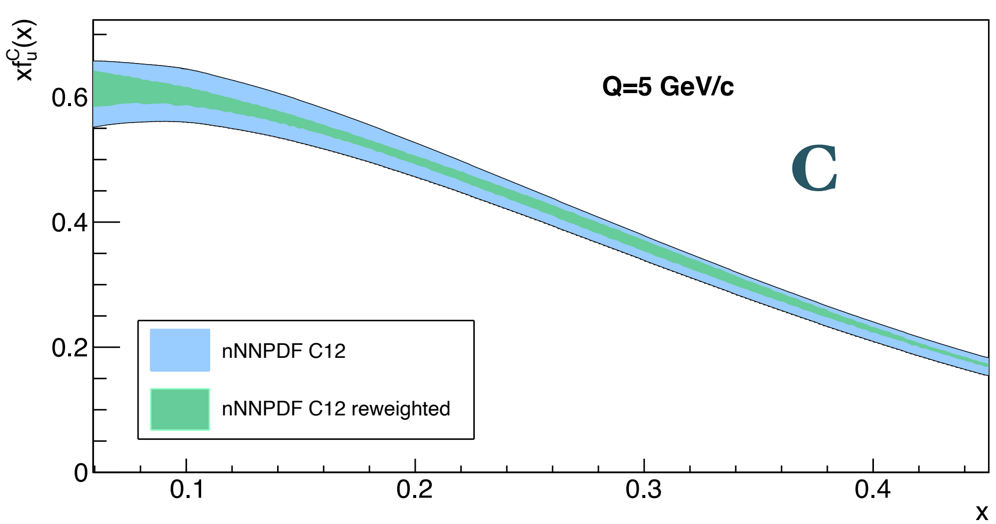
Work ongoing: re-weighting the nuclear PDFs with AMBER projected uncertainties

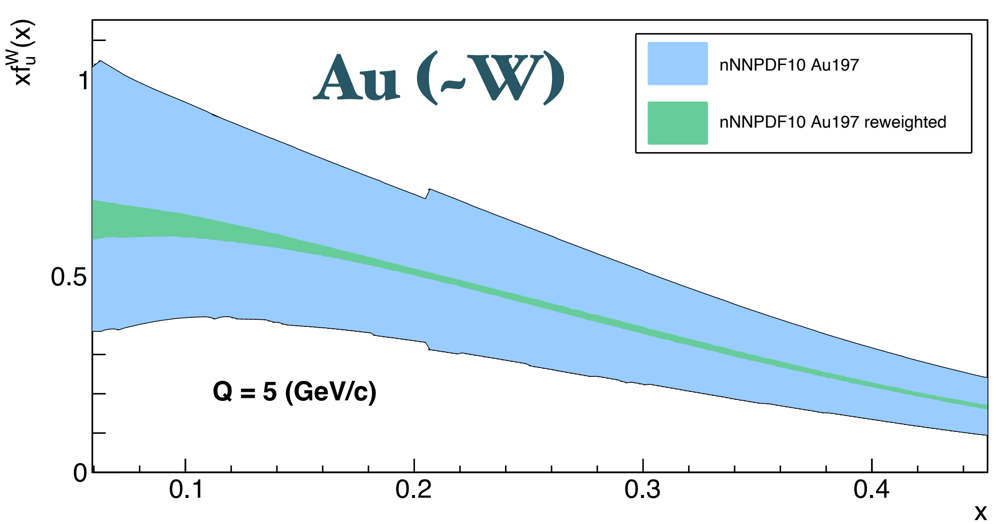


The re-weighting of nCTEQ15 and EPPS16 is not straightforward since they provide Hessian errors

awaiting for the EPPS16 re-weighted PDFs from the authors

Impact of the re-weighting in the nNNPDFs (using independent replicas in the re-weighting process):

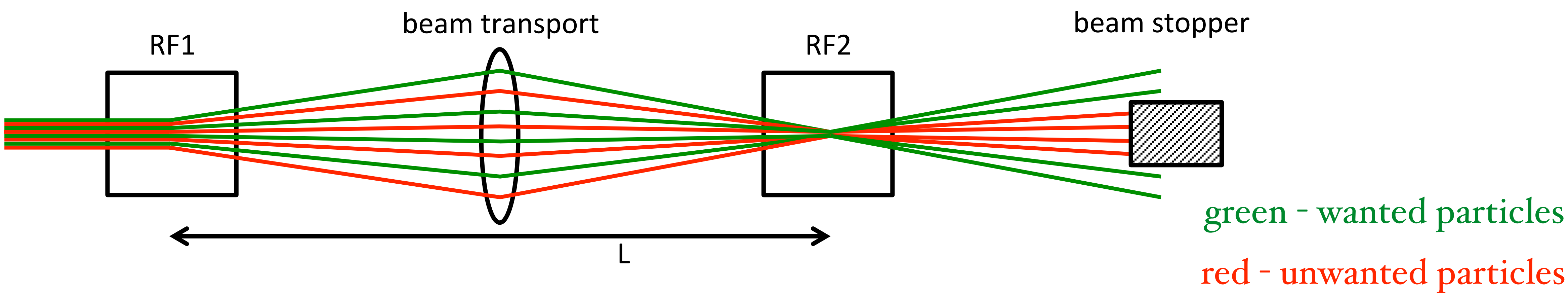




anti-proton and kaon beams at AMBER

Standard high-energy hadron beam have low content of kaons and anti-protons.

This can be overcome by the use of the Radio-Frequency (RF) separation technique.



Momentum limits with current technologies due to the length (1.1 km) of the M2 beam line:

kaon beam $\sim 75 \ GeV/c$

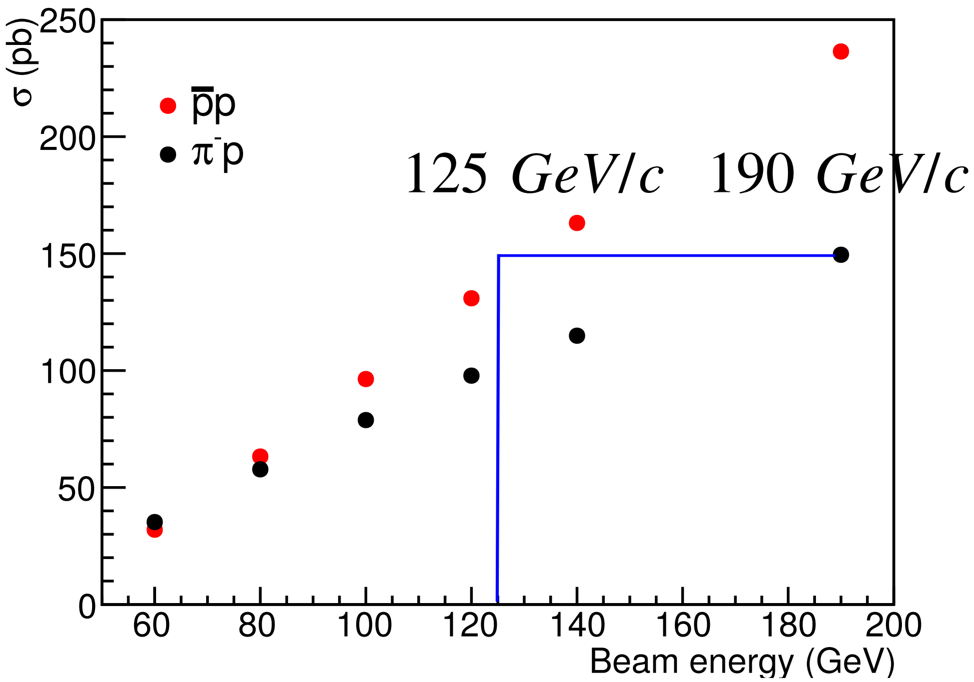
anti-proton beam $\sim 108 \ GeV/c$

↪ Further R&D should allow to increase these beam energies

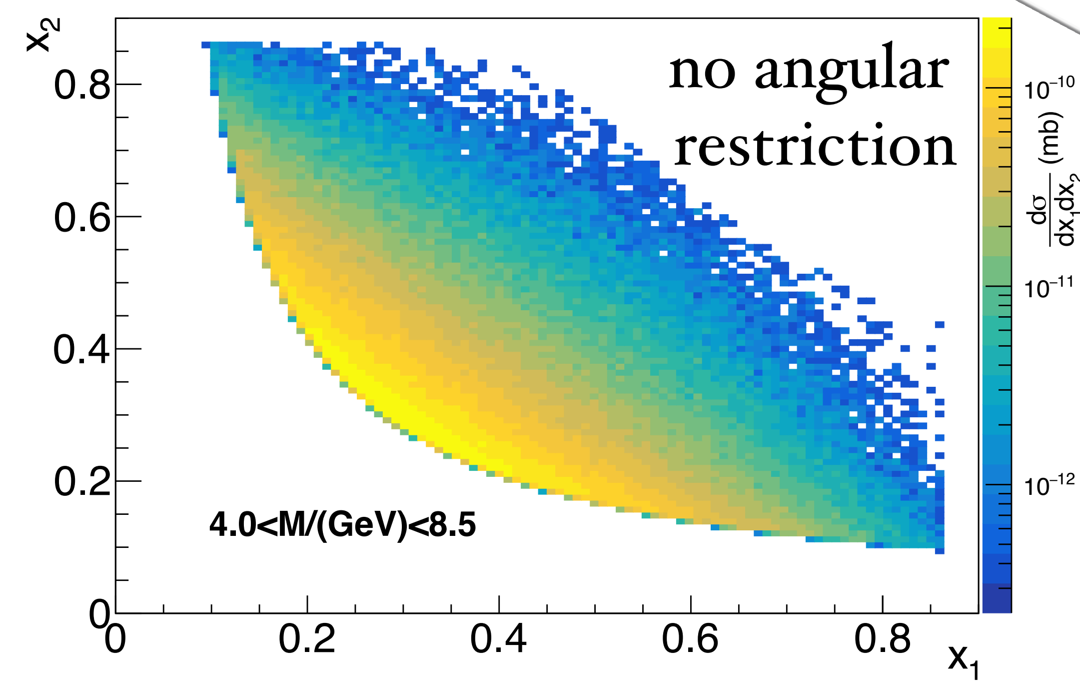
anti-proton and kaon induced Drell-Yan

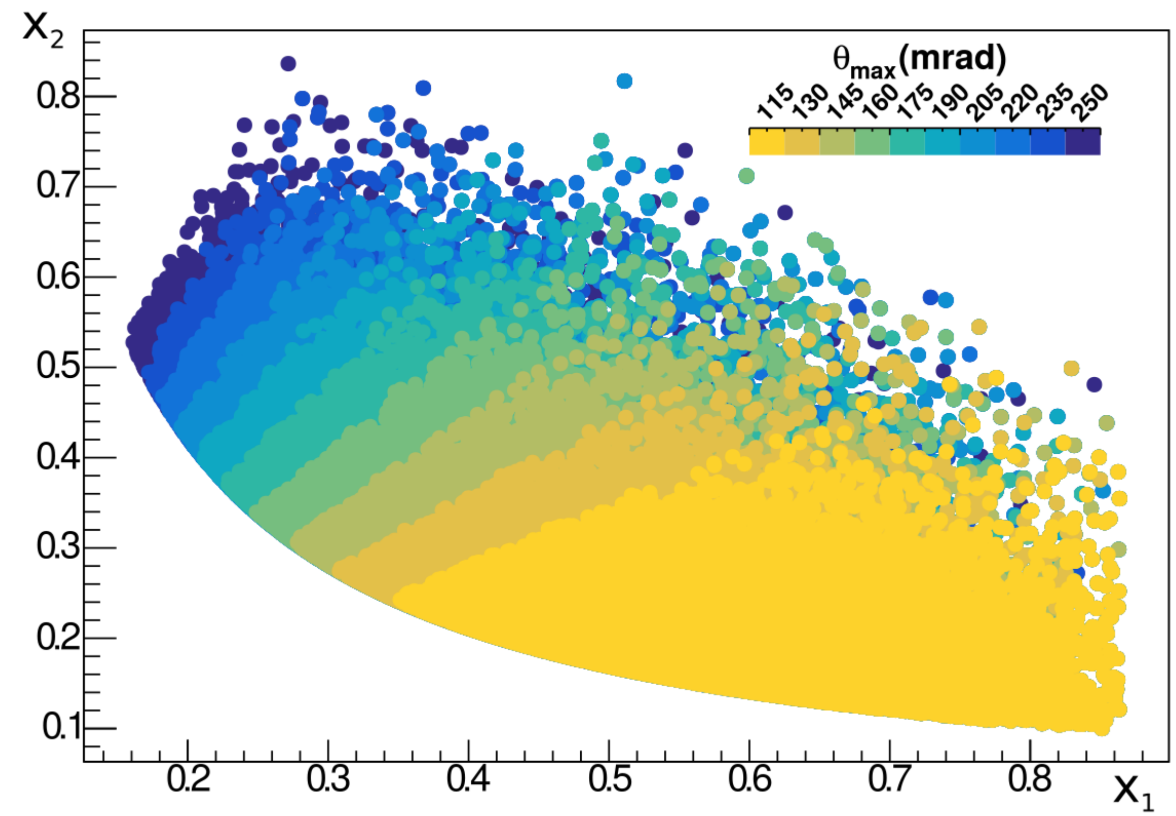
polarised target
as in COMPASS

to get exactly the same cross-section
as in pion induced Drell-Yan at COMPASS



$100\ GeV/c \quad \bar{p} + NH_3$





for acceptance $\sim 40\,\%$
angles up to $250\ mrad$

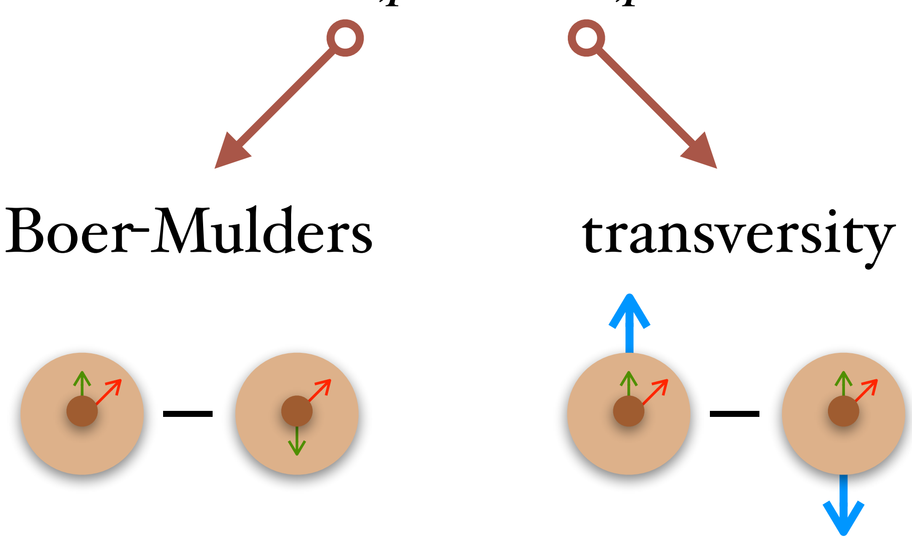
need of a compressed setup

TMD PDFs with anti-proton induced Drell-Yan

Study the nucleon Transverse Momentum Dependent (TMD) PDFs
as studied in COMPASS with Drell-Yan and SIDIS processes

Boer-Mulders function expected to take a major role at low pT data (in our accessed region)

$$A^{\sin(2\phi-\phi_S)} \propto h^{\perp q}_{1,\bar{p}} \otimes h^{q}_{1,p}$$



advantages in the measurement of the Boer-Mulders with respect to COMPASS:

- avoid the pion beam related uncertainties in the case of COMPASS Drell-Yan
- avoid the Cahn effects present in COMPASS SIDIS Boer-Mulders related asymmetry

Experiment	Target type	Beam type	Beam intensity (part/sec)	Beam energy (GeV)	DY mass (GeV/c^2)	DY events $\mu^+\mu^-$	DY events e^+e^-
This exp.	110 cm NH_3	$\bar{p}$	3.5×10^7	100	$4.0 - 8.5$	28,000	21,000
				120	$4.0 - 8.5$	40,000	27,300
				140	$4.0 - 8.5$	52,000	32,500

Note: In case of no polarised target the measurement of the unpolarised asymmetries from different particle beams induced Drell-Yan is still useful (study the effects for low-pT data)

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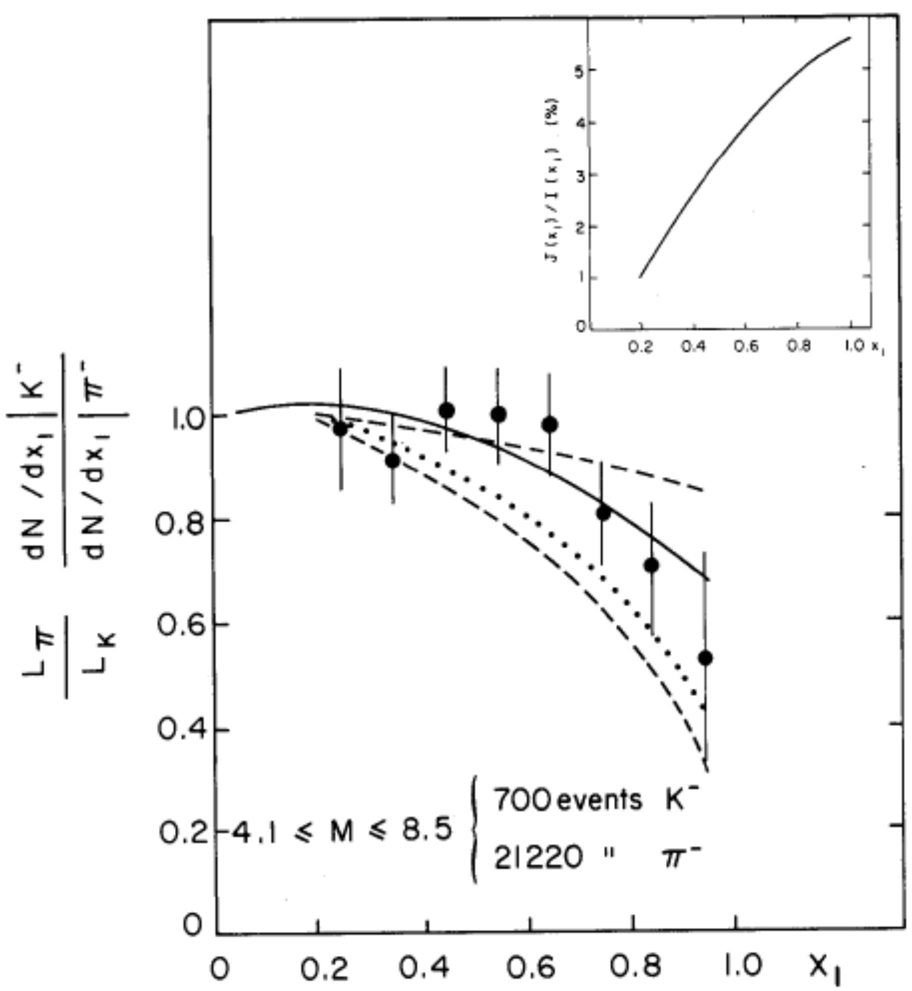
EHM workshop
30 March 2020

kaon structure - available data & predicted statistics

the kaon valence distributions are nearly unknown
there's no data on sea and gluon kaon distributions



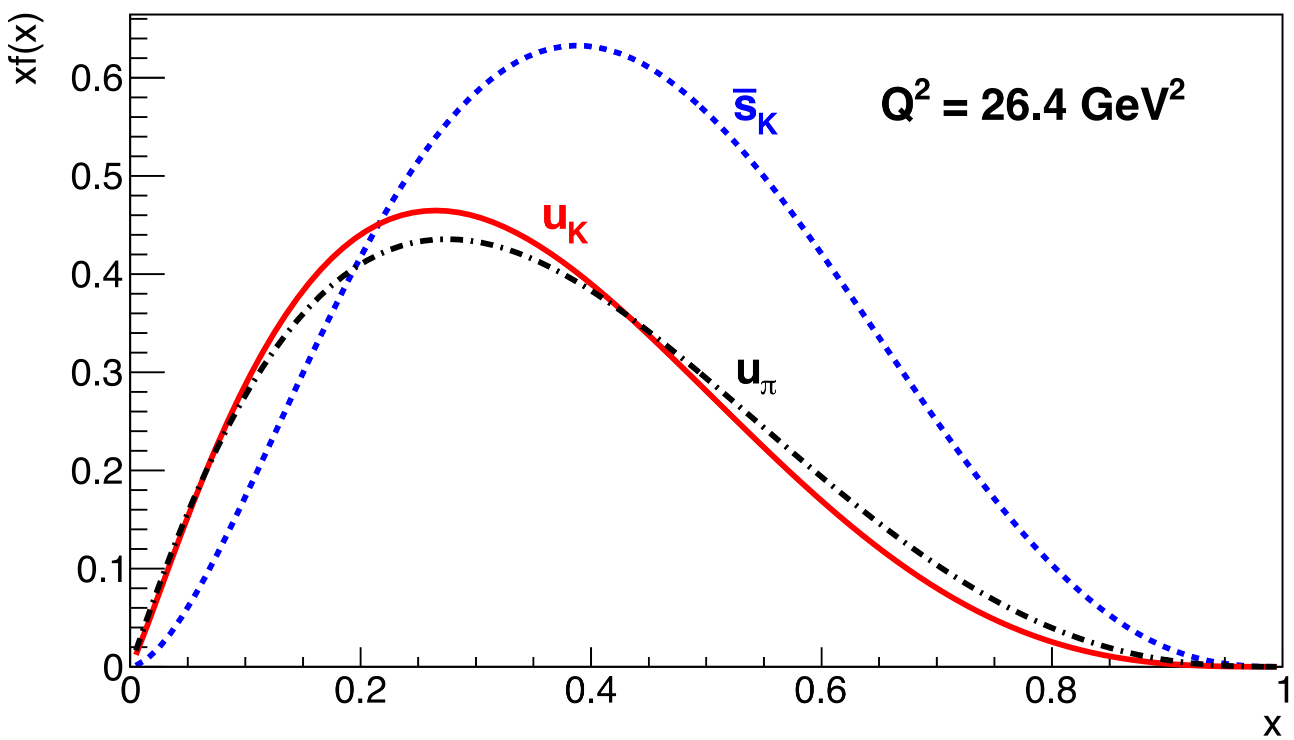
NA3: PLB 93 (1980) 354

only 700 kaon events

Experiment	Target type	Beam type	Beam intensity (part/sec)	Beam energy (GeV)	DY mass (GeV/c^2)	DY events $\mu^+\mu^-$	DY events e^+e^-
NA3	6 cm Pt	K^-		200	4.2 – 8.5	700	0
This exp.	100 cm C	K^-	2.1×10^7	80	4.0 – 8.5	25,000	13,700
				100	4.0 – 8.5	40,000	17,700
				120	4.0 – 8.5	54,000	20,700
		K^+	2.1×10^7	80	4.0 – 8.5	2,800	1,300
				100	4.0 – 8.5	5,200	2,000
				120	4.0 – 8.5	8,000	2,400
This exp.	100 cm C	π^-	4.8×10^7	80	4.0 – 8.5	65,500	29,700
				100	4.0 – 8.5	95,500	36,000
				120	4.0 – 8.5	123,600	39,800

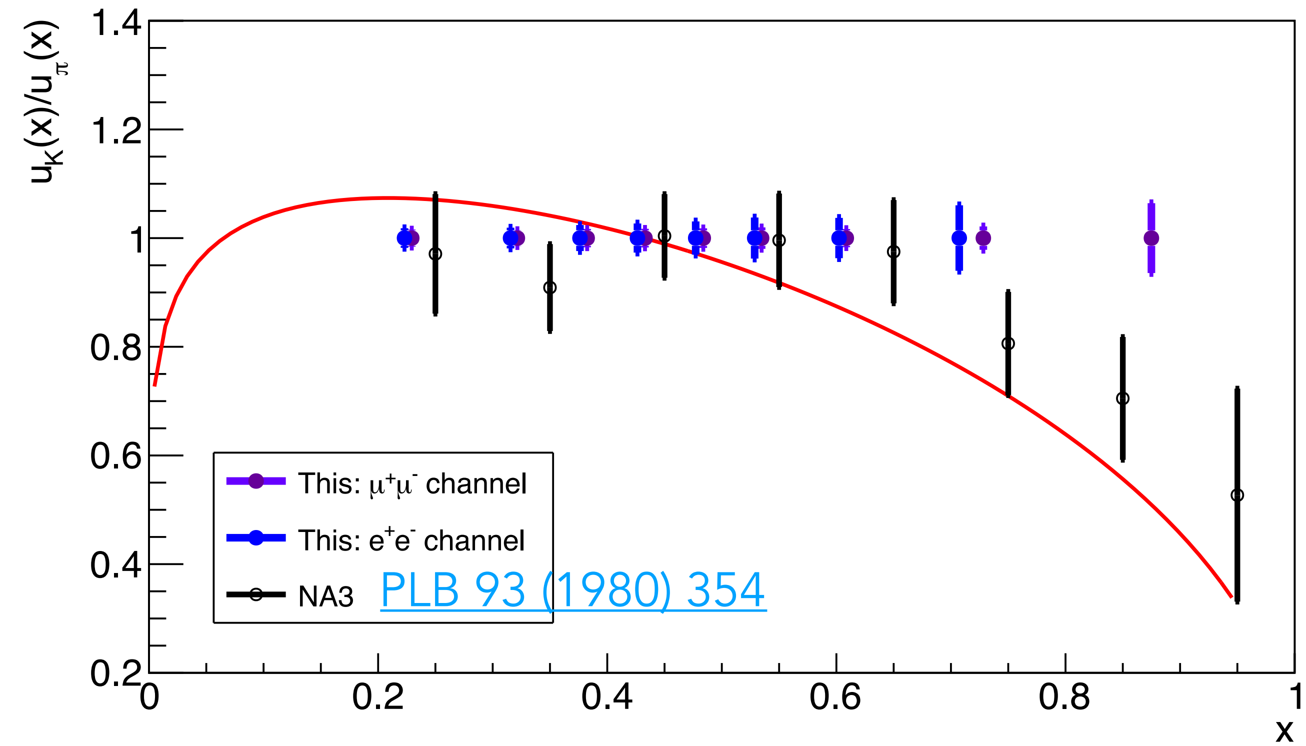
pion and kaon data are collected simultaneously

kaon structure - valence distribution



distributions calculated in the framework of the Dyson-Schwinger Equations (DSE)

u_K faster decrease than u_π for large x as confirmed by NA3



100 GeV/c kaon beam and C target
140 days of data taking

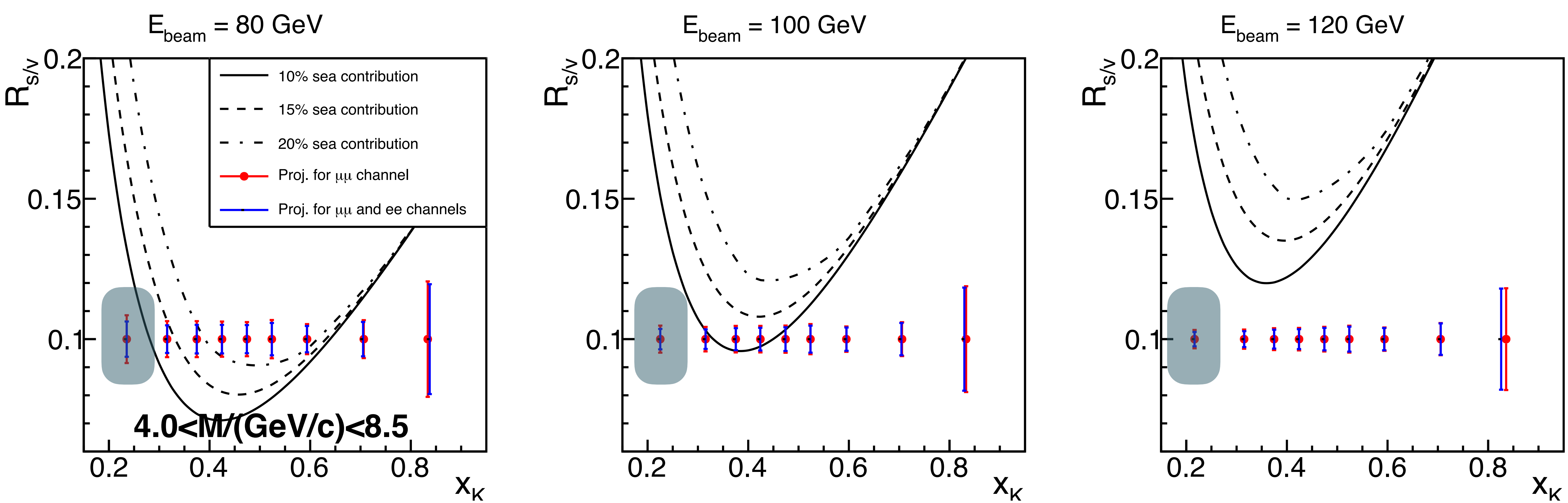
Red curve is a simplification of the DSE approach and must be updated with the DSE functional forms from Craig et al.: Phys. Rev. D93 (7) (2016) 074021

kaon structure - sea/valence separation

the sea distribution is unknown and can be determined by:

$$R_{s/v} = \frac{\sigma^{K^+C}}{\sigma^{K^-C} - \sigma^{K^+C}}$$

Higher beam energies allows to access lower x_K values with a better precision

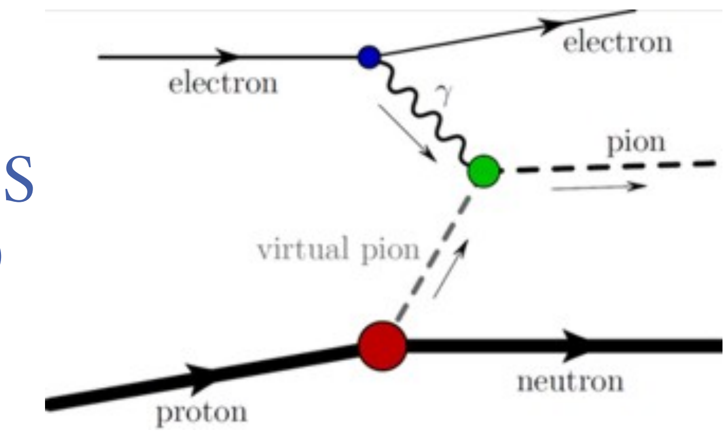


here the time sharing is equal between K^+ and K^-
as $\sigma_{K^+} < \sigma_{K^-}$ the statistical uncertainty can be improved by a better time sharing
at the price of reducing the significance of $u_K(x)/u_\pi(x)$ - a compromise is needed

pion/kaon structure - other measurements

pion/kaon structure with lepton beams:
- at JLab - will cover $0.4 < x < 0.95$
- at EIC - will cover lower x values

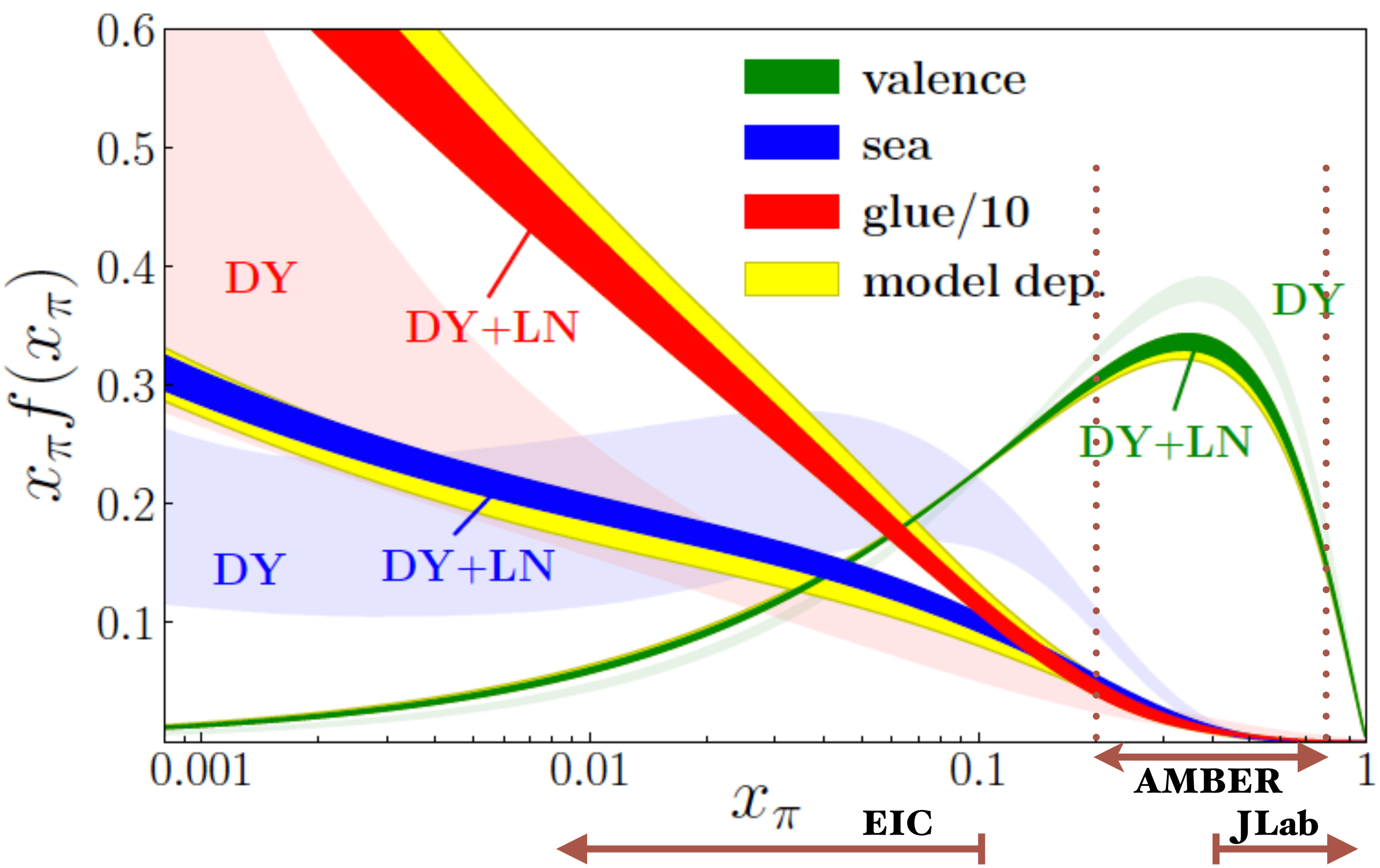
neutron tagged DIS
(Sullivan process)



based on the meson cloud model

model dependent
pion/kaon flux determination

Drell-Yan + HERA data on leading neutron (LN) DIS:
Phys. Rev. Lett. 121 (2018) 152001



pion/kaon induced Drell-Yan
is the most direct way
to access the pion/kaon structure

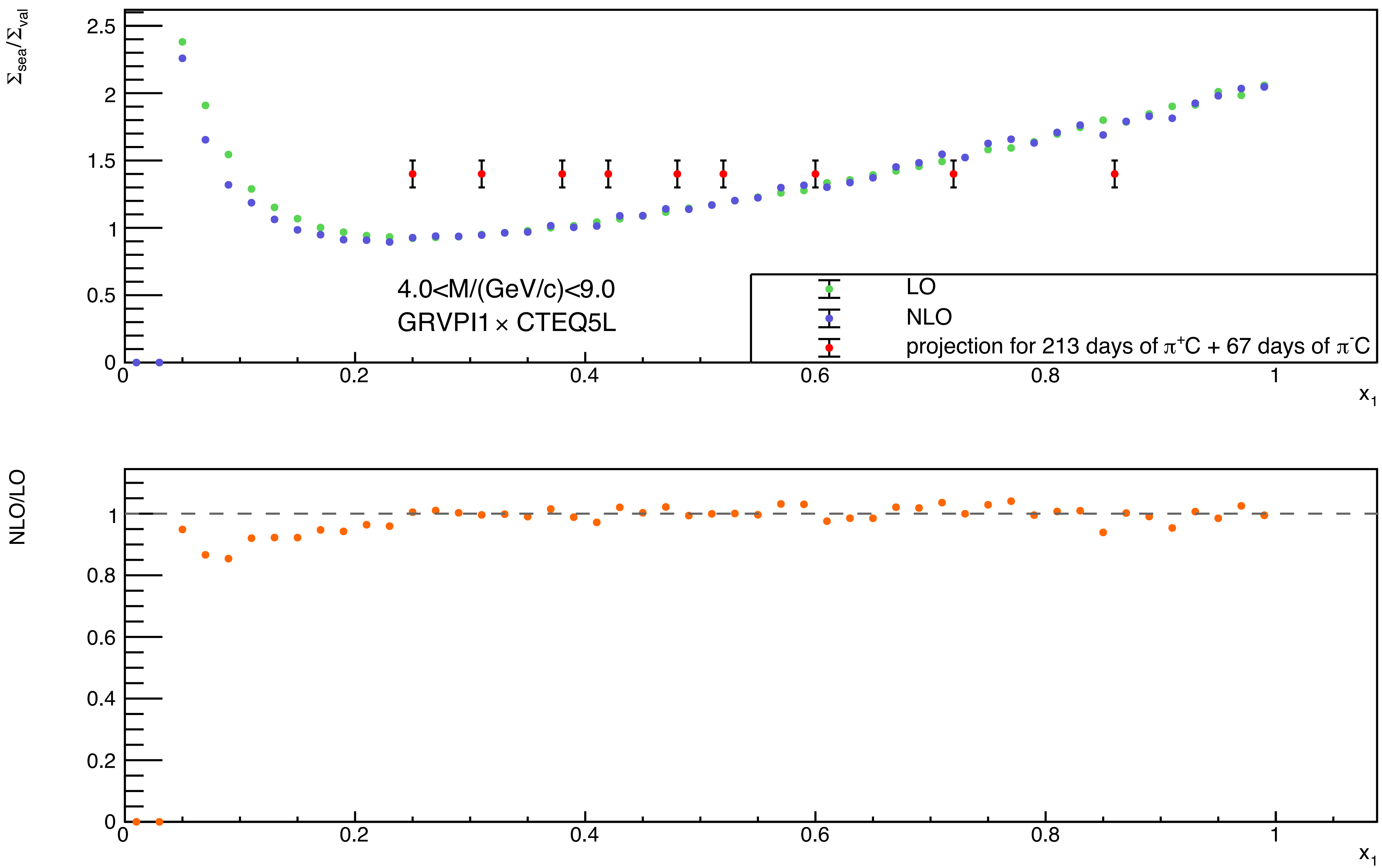
Summary

- AMBER aims to measure pion induced Drell-Yan with positive and negative beams and to learn more about the pion sea distribution
- In parallel to the pion studies, the nuclear PDFs can be studied with impact on the current nPDFs uncertainties
- The possibility to use anti-proton and kaon beams with RF separation technique would open a new window on the study of the structure of the kaon (and the proton TMD PDFs)
- The kaon structure is little known, mostly derived from the knowledge on the pion
- In addition to the meson-induced Drell-Yan measurements, the study of pion and kaon structure can be complemented by other indirect ones (meson cloud interactions), like at JLab and EIC

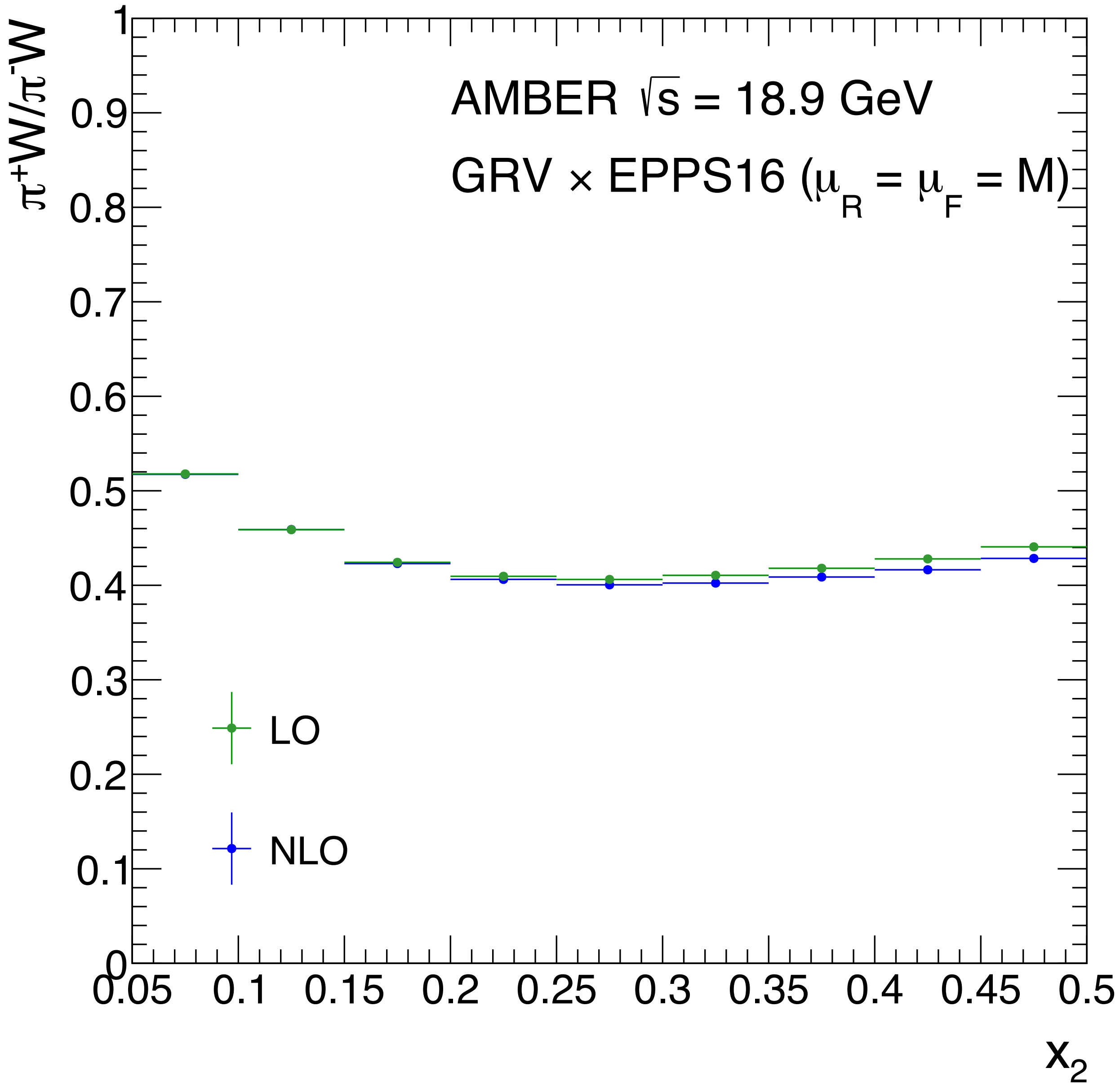

Thank you everybody for your attention

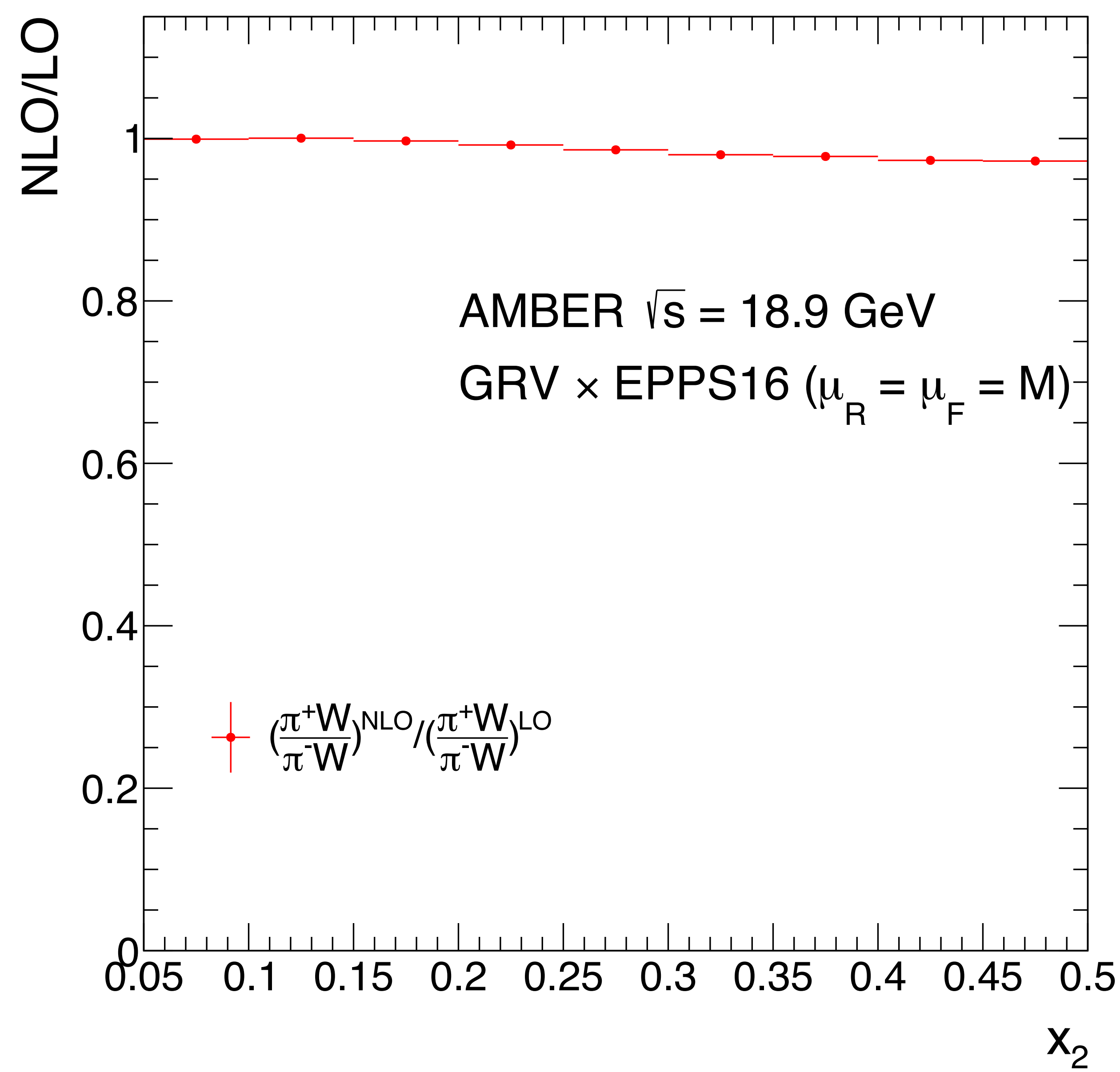
Backup

Impact of NLO/LO for sea/valence



Impact of NLO/LO for nPDFs





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Impact of re-weighting nNNPDF