Measurement of pion induced Drell-Yan at AMBER experiment

Márcia Quaresma

04 February 2020

Correlations in Partonic and Hadronic Interactions 2020

CPHI

LIP

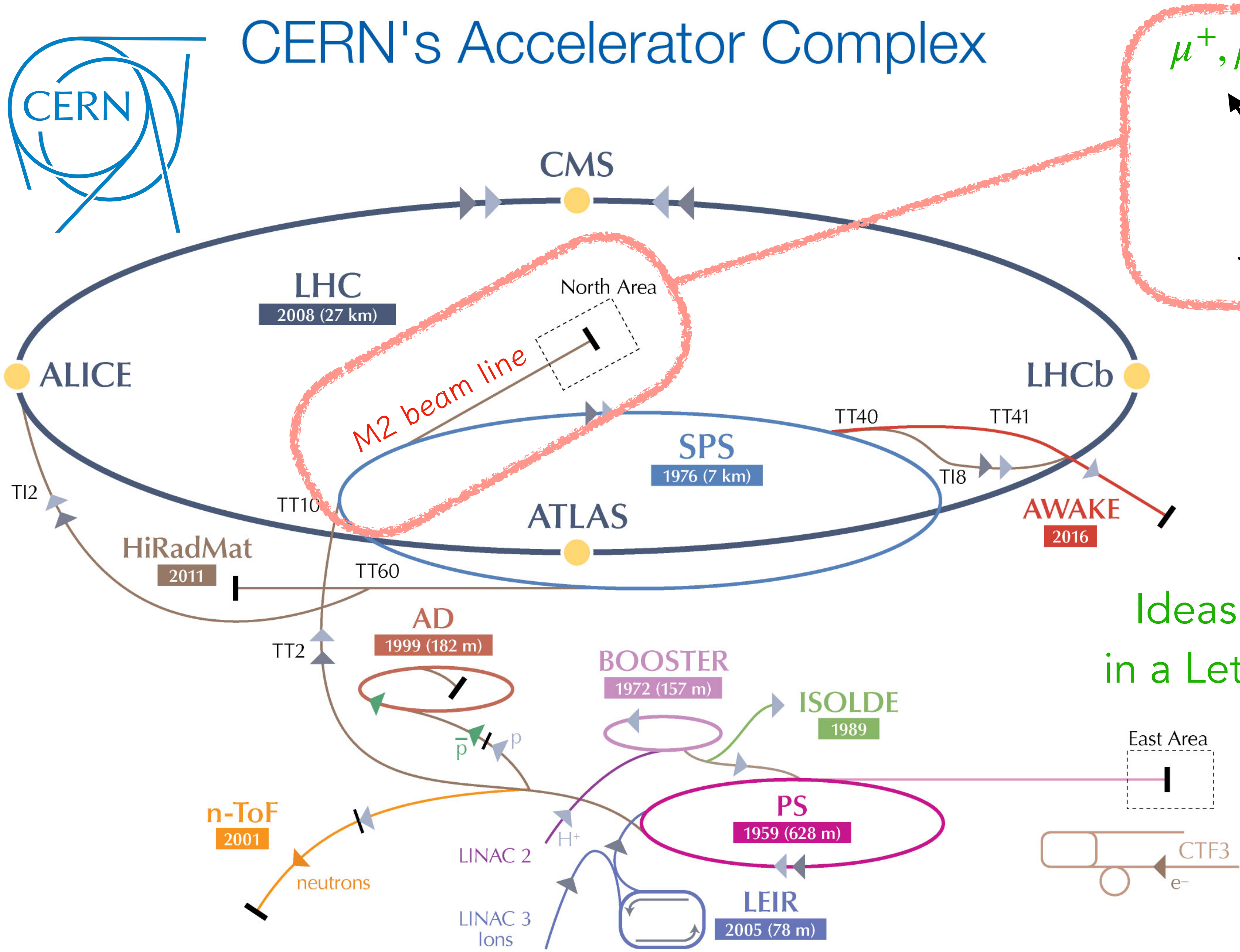
STRONG-2020

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 824093.

CERN

New QCD facility

End of COMPASS experiment (last run in 2021) ➡ Still many ideas for QCD studies



μ^+, μ^- $\pi^+, \pi^-, p, \bar{p}, K^+, K^-$

muon and hadron beams from the same beam line

UNIQUE WORLDWIDE

Ideas for AMBER are collected in a Letter of Intent (January 2019)

[CERN-SPSC-2019-003 (SPSC-I-250)]

AMBER experiment

Apparatus for Meson and Baryon Experimental Research

In the Letter of Intent:

1. Hadron physics with standard muon beams
2. Hadron physics with standard hadron beams
3. Hadron physics with RF-separated beams

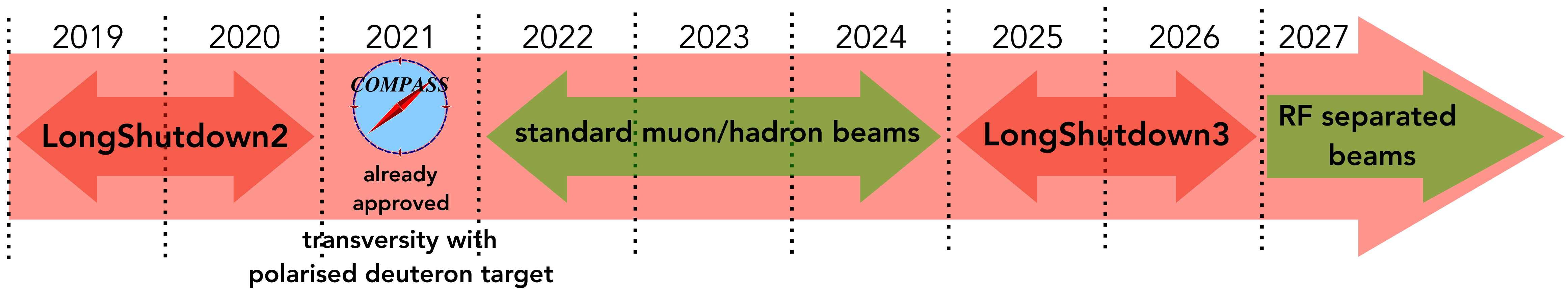
Far future - after LS3:

1. Spectroscopy of kaons
2. Drell-Yan Physics with high intensity kaon and antiproton beams
3. Study of the gluon distribution into kaon via prompt-photon production **See Alexey Guskov talk**
4. Primakoff reactions
5. Vector-meson production off nuclei by pion and kaon beams

CERN-SPSC-2019-022 (SPSC-P-360)

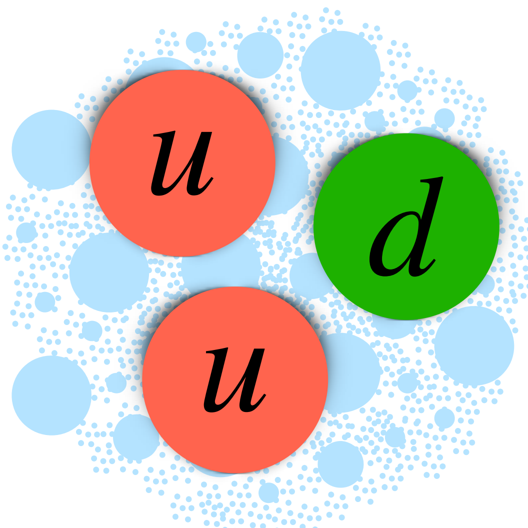
1st phase proposal (May 2019):

1. Proton-radius measurement using elastic muon-proton scattering **See Jan Friedrich talk**
2. Drell-Yan and Charmonium production using conventional hadron beams **See Igor Denisenko talk** (**This talk**: Drell-Yan)
3. Measurement of antiproton production cross sections for dark matter search



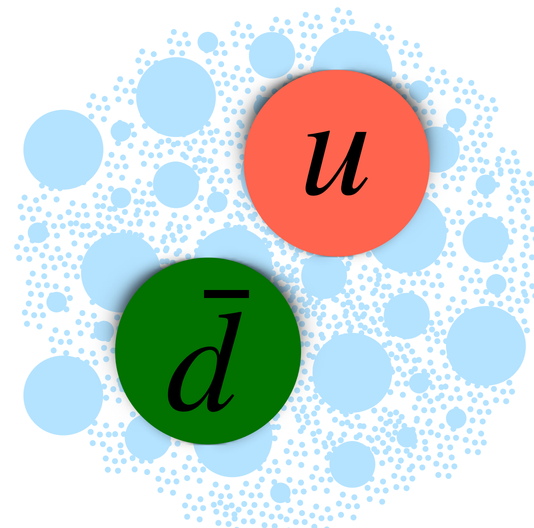
Emergence of the hadronic mass

How to explain the origin of the mass of composite hadrons?
How is their structure?



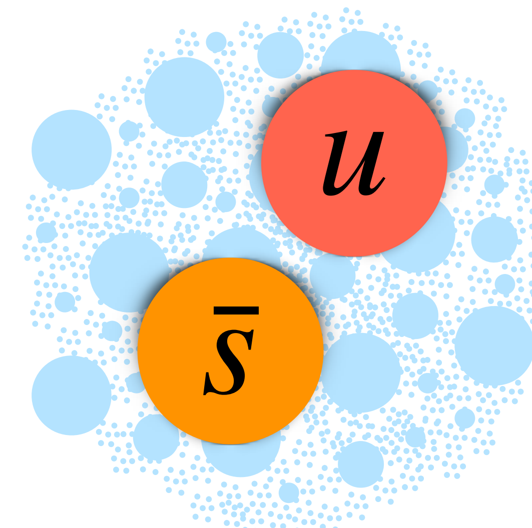
$M_p \sim 940\ MeV/c^2$

Three light valence quarks



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

Two light valence quarks



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

One light valence quark
plus
one "heavy" valence quark

The nucleon plus the meson PDFs are fundamental to understand the hadrons mass budget

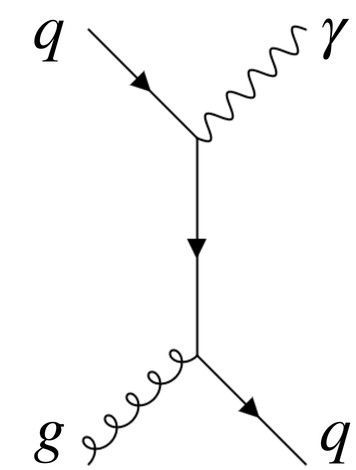
How to access the PDFs

proton **pion** **kaon**

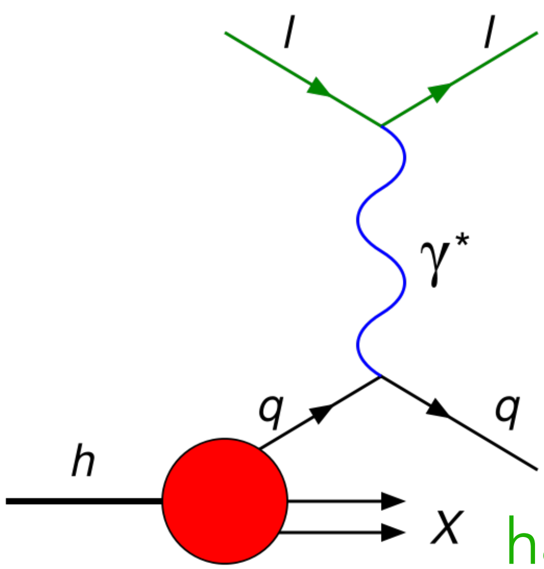
easier to access using a proton as a target and/or a beam

more difficult since there are no pion or kaon targets

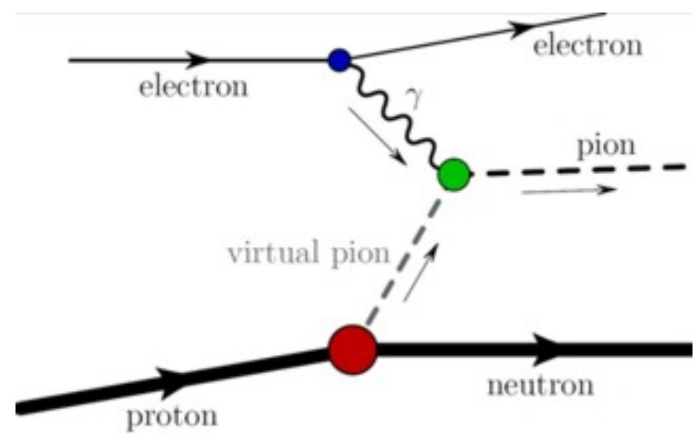
prompt photon production



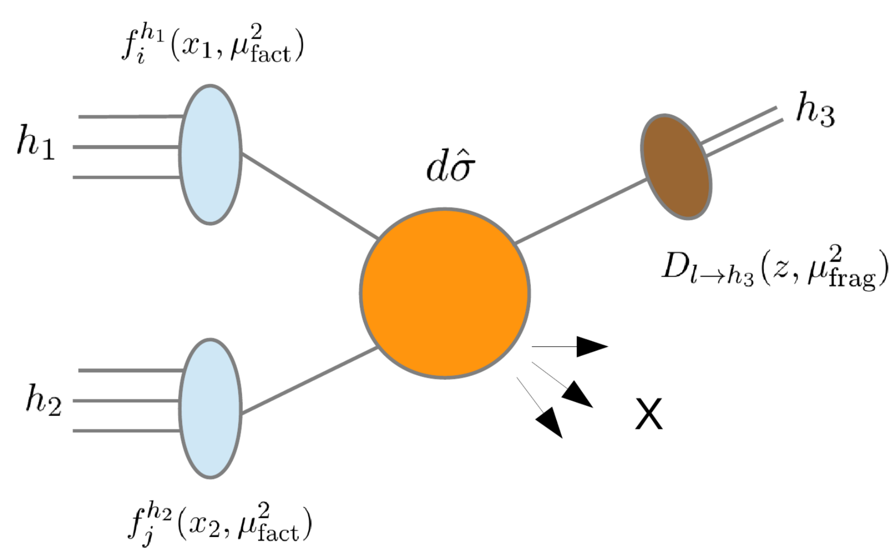
Deep-Inelastic Scattering (DIS)



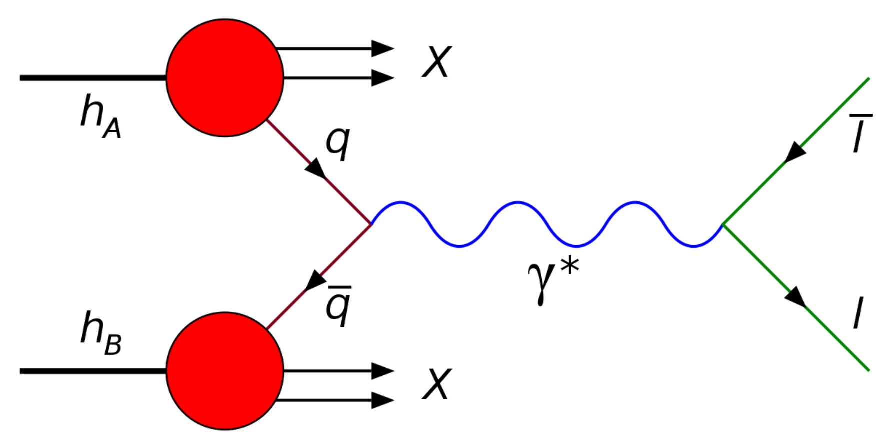
neutron tagged DIS (Sullivan process)



hadron-hadron production

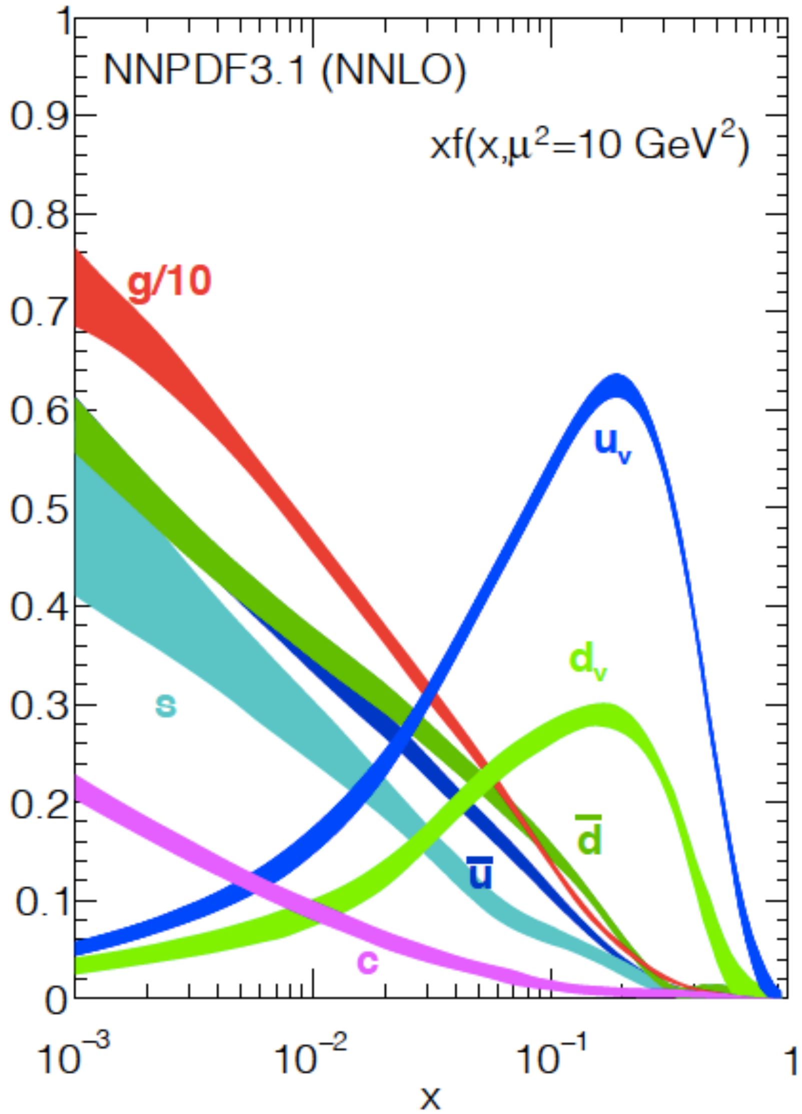


Drell-Yan



Current status of PDFs

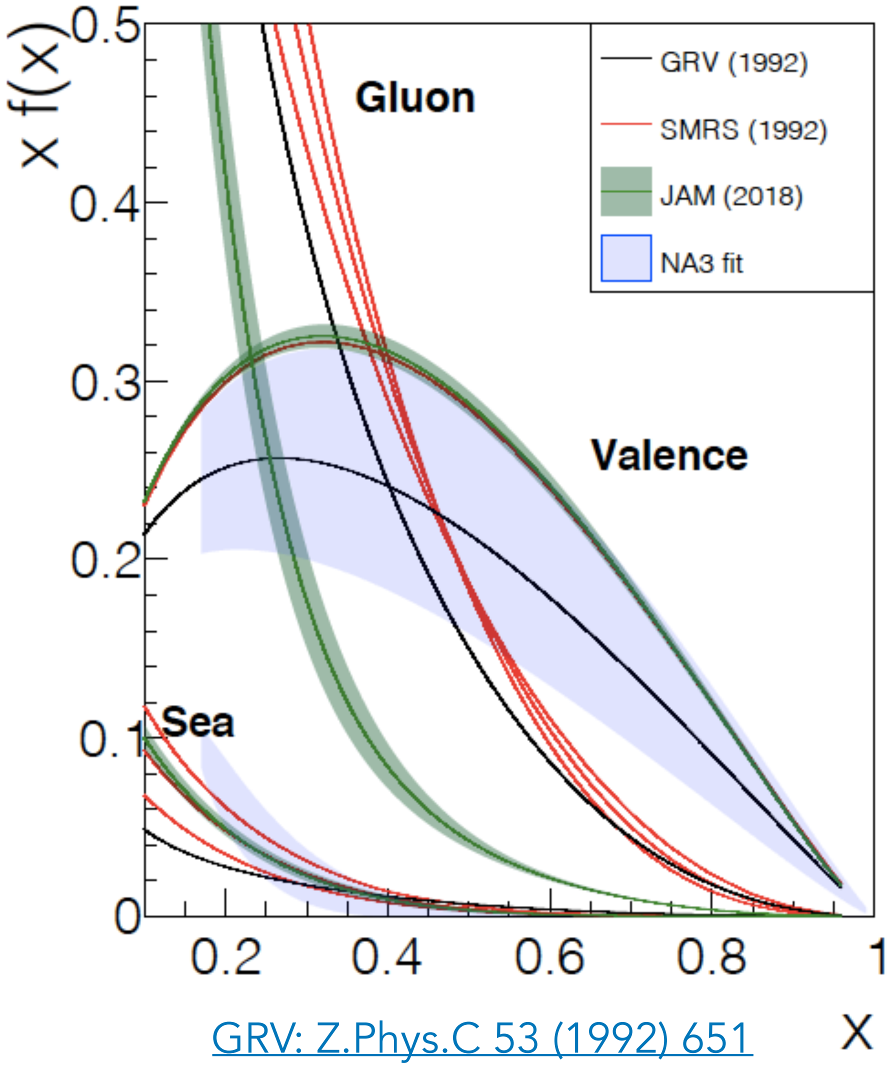
proton



EPJ C77 (2017) 663

good amount of data

pion



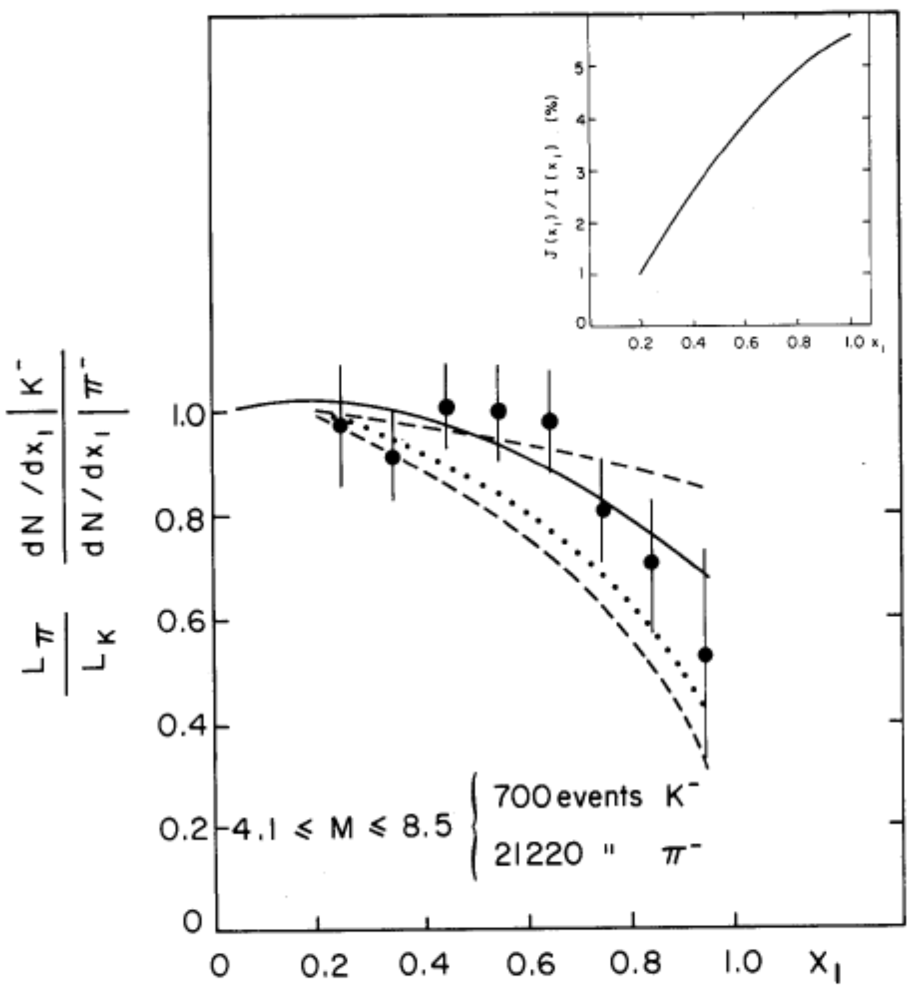
GRV: Z.Phys.C 53 (1992) 651

SMRS: PRD 45 (1992) 2349

JAM: PRL 121 (2018) 152001

few old data

kaon



NA3: PLB 93 (1980) 354

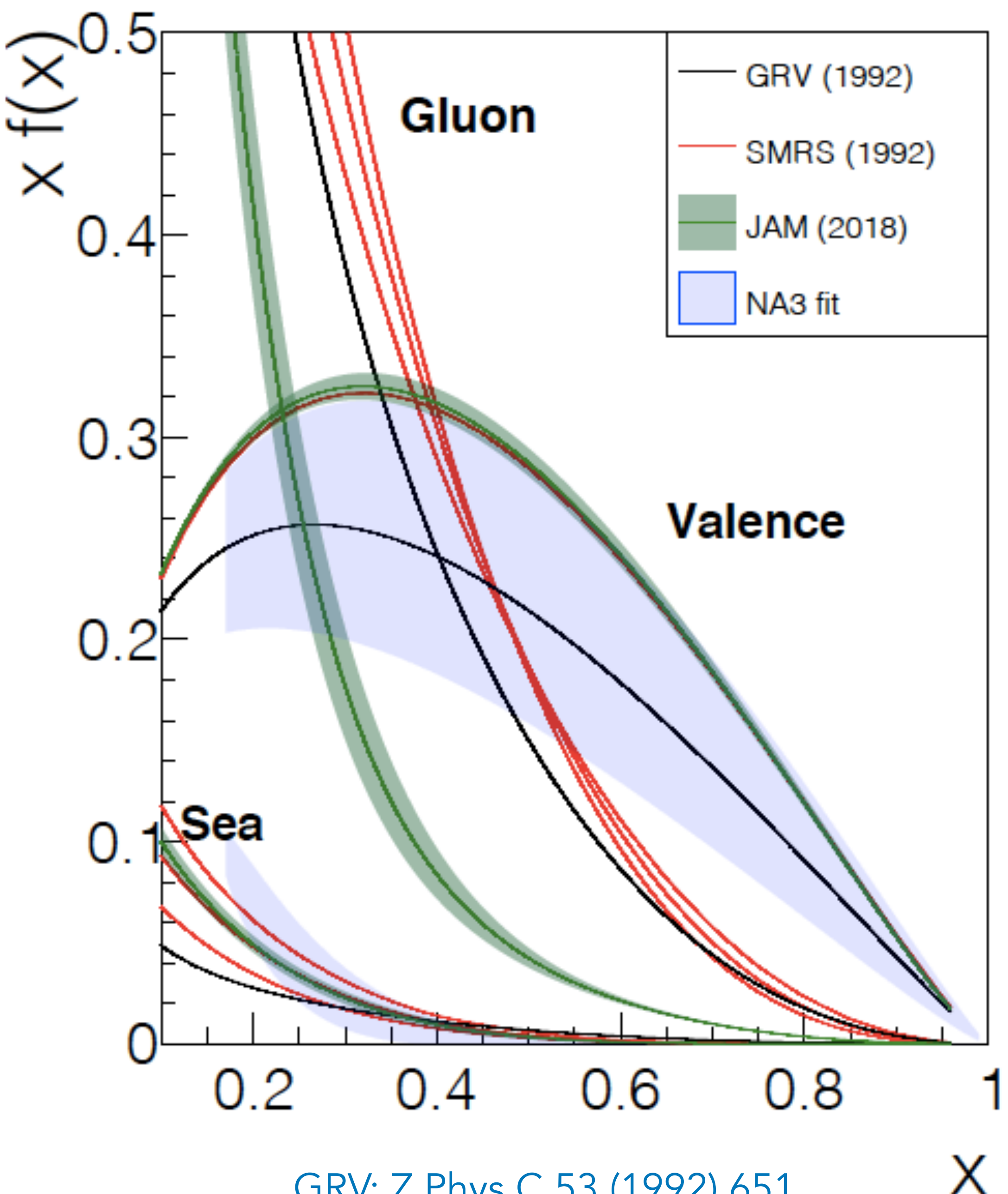
only 700 kaon events

scarce data amount

GRV and SMRS: data from DY, charmonia and prompt photon production (E615, NA10, WA70, NA24)

JAM: indirect measurement leading neutrons DIS (ZEUS and H1 from HERA)

Pion PDF - importance of measuring 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

two diff global analyses (SMRS and GRV)
using pi- DY data from NA10 and E615,
do not include uncertainties

SMRS analysis:
sea content - three different scenarios (10%, 15% or 20%)

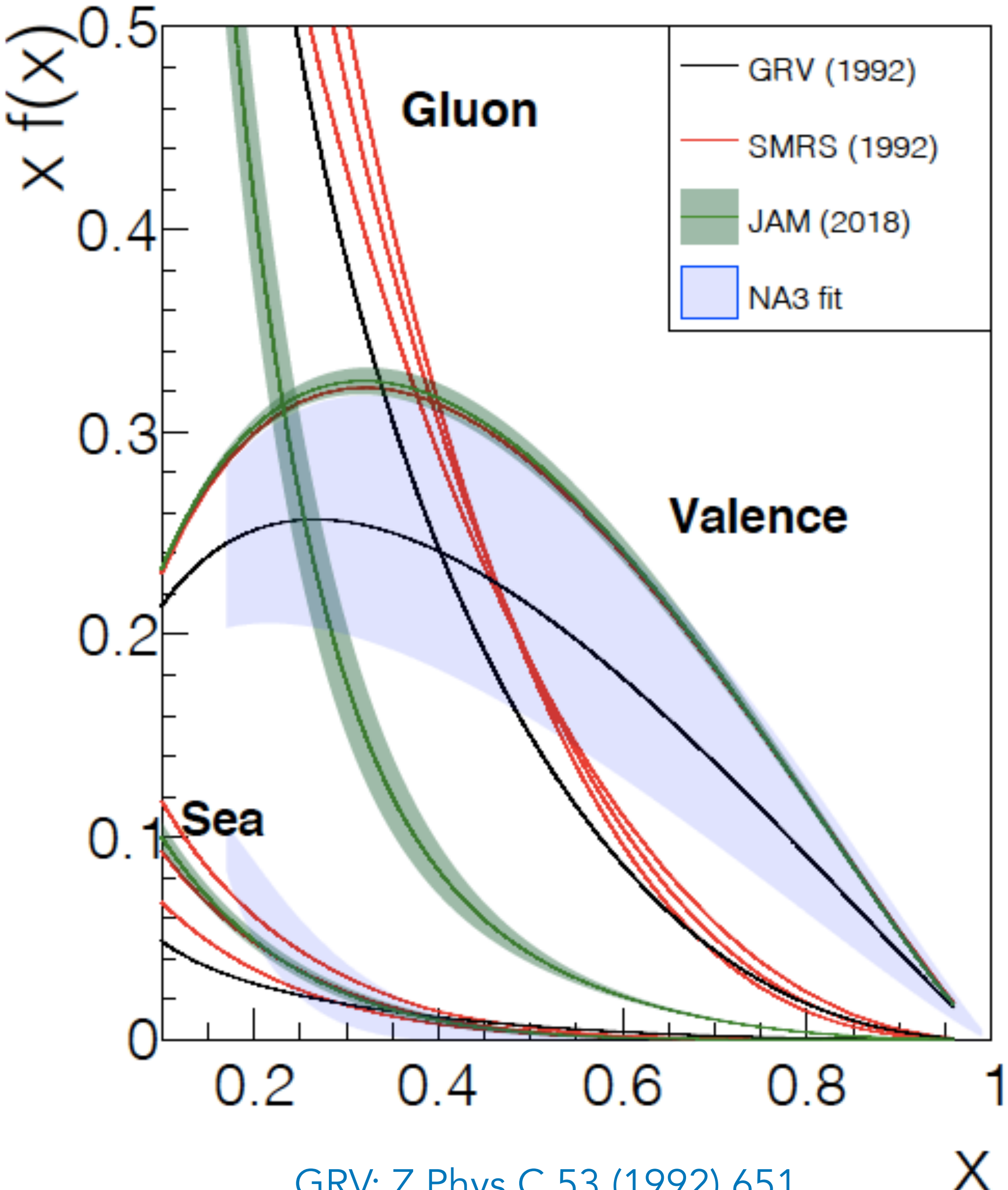
GRV analysis:
sea content - derived from momentum conservation
glue content - constrained by the direct photon measurements from WA70 and NA24

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

NA3 fit:
using the published fit coefficients and correlation matrix
using heavy nuclear target

sea is the most unknown contribution

Pion PDF - importance of measuring 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

sea is the most unknown contribution

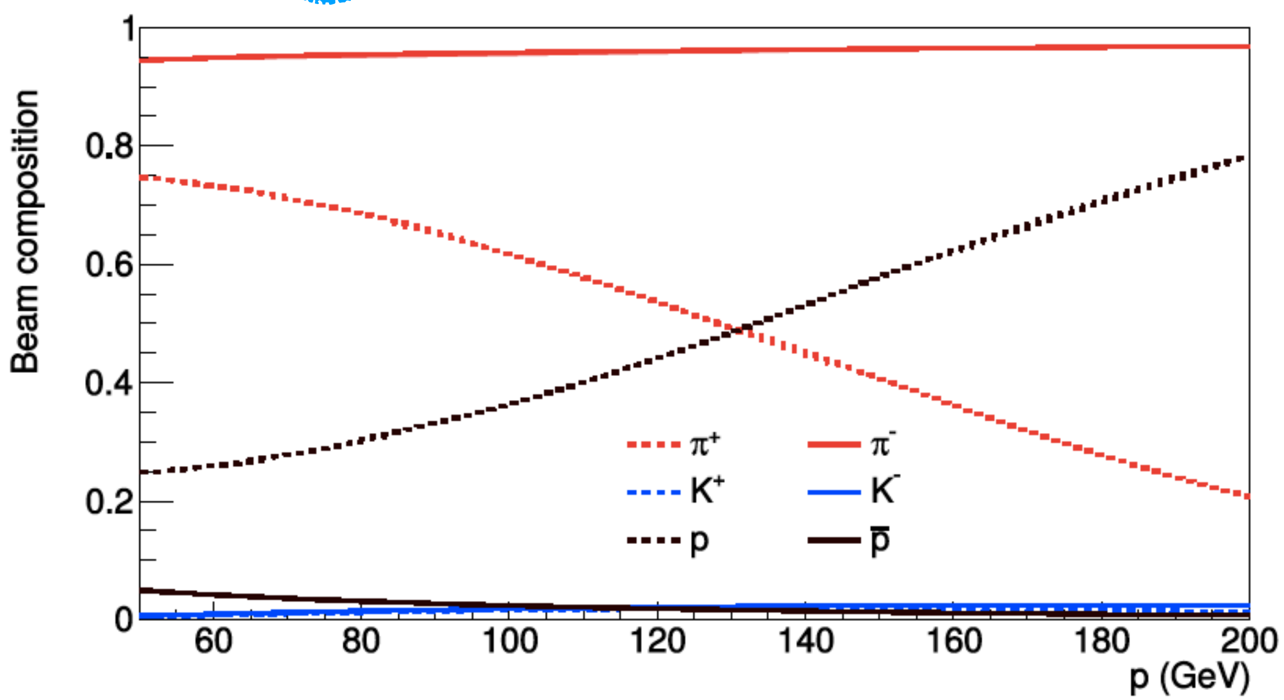
How can the sea be addressed?

comparing pi+ and pi- induced Drell-Yan

CERN is the only place with energetic secondary pion beams of both charges

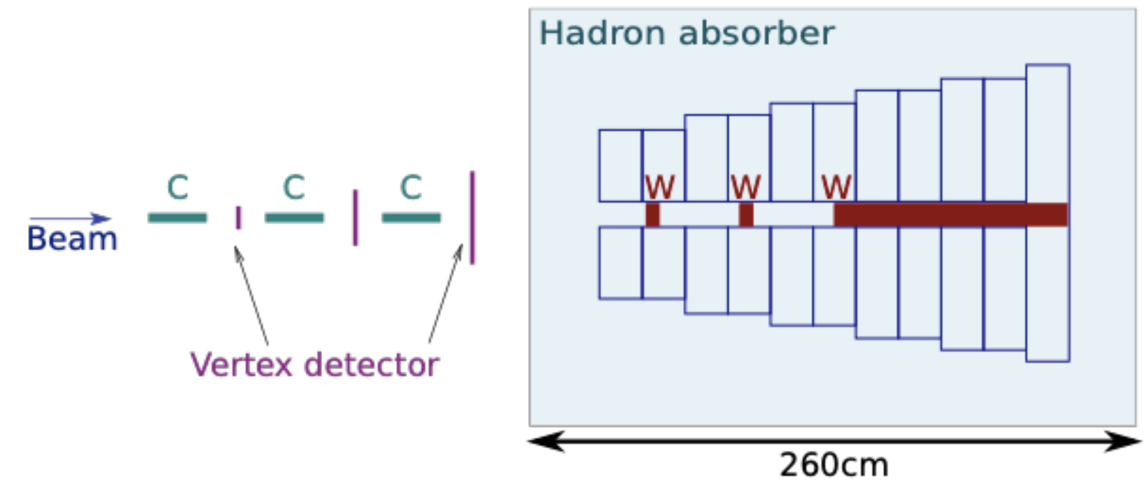
AMBER setup for phase-1 Drell-Yan

$190\ GeV/c\ h^{+}$ **or** h^{-} beam — in order to access the low x1

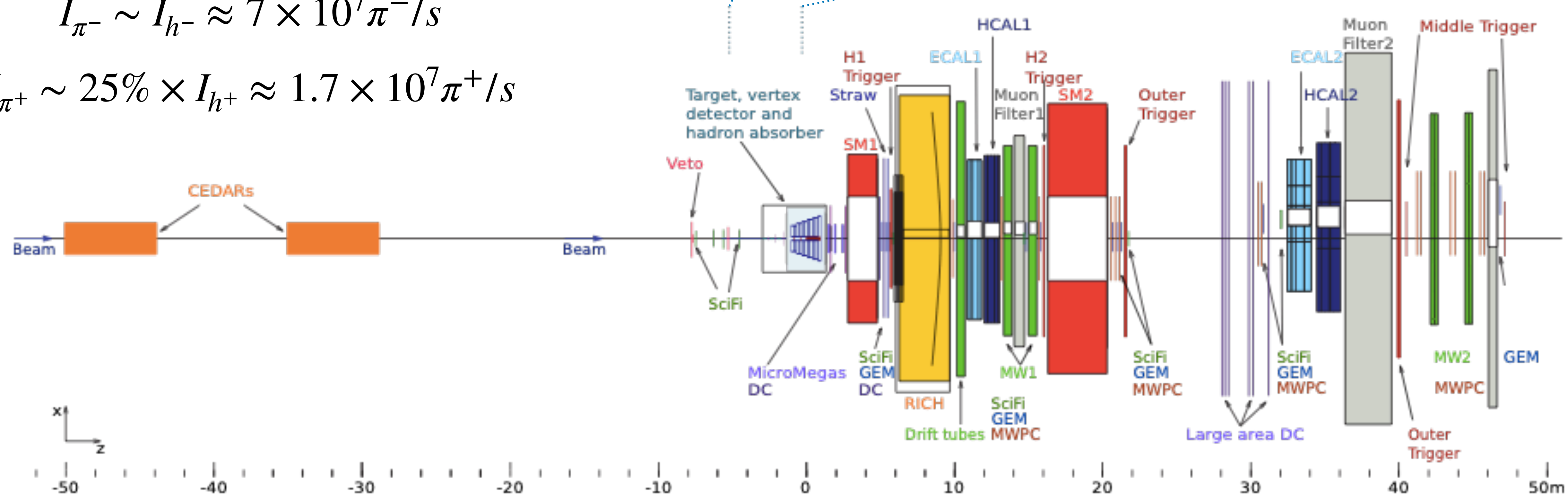


$$I_{\pi^-} \sim I_{h^-} \approx 7 \times 10^7 \pi^-/s$$

$$I_{\pi^+} \sim 25\% \times I_{h^+} \approx 1.7 \times 10^7 \pi^+/s$$

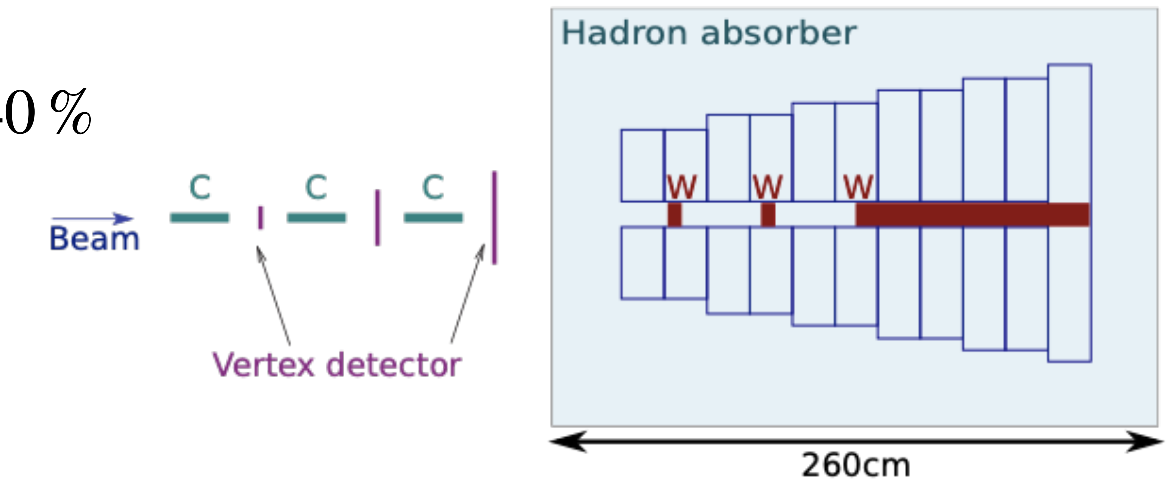


2024 Drell-Yan setup

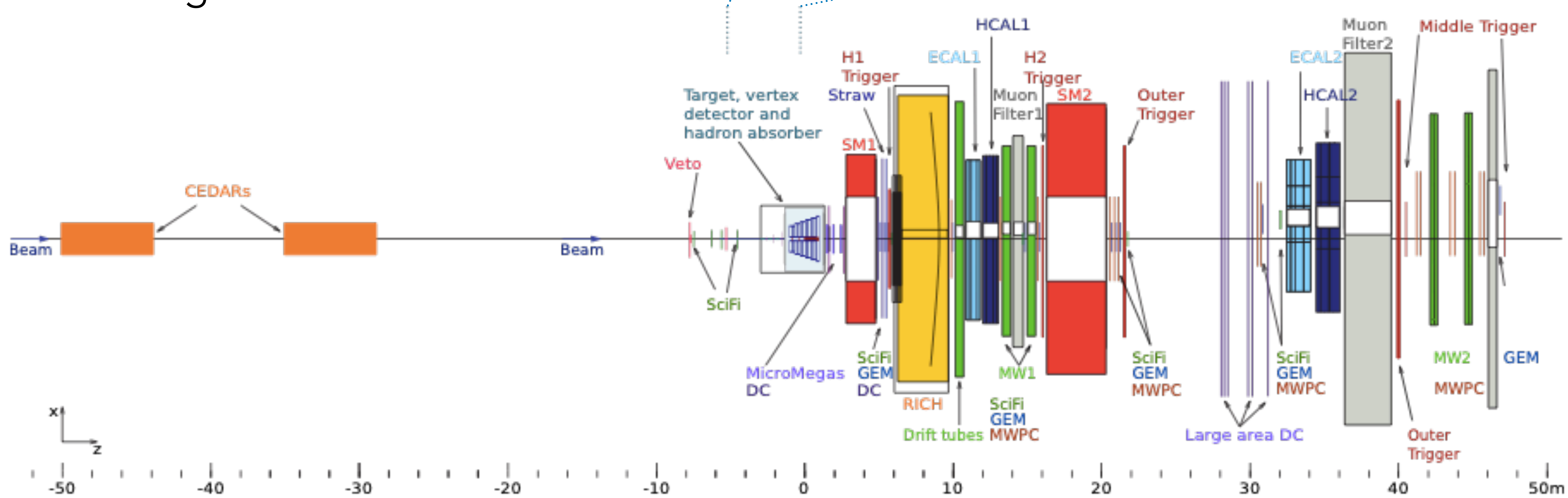


AMBER setup for phase-1 Drell-Yan

- ☑ large acceptance: $8\ mrad < \theta < 160\ mrad \sim 40\,\%$
- ☑ isoscalar target (Carbon), reduced nuclear effects
- ☑ additional targets (Tungsten) for nuclear studies
- ☑ vertex detector nearby the target cells for a good vertex resolution ⇒ good mass resolution
- ☑ CEDARs for a good beam PID

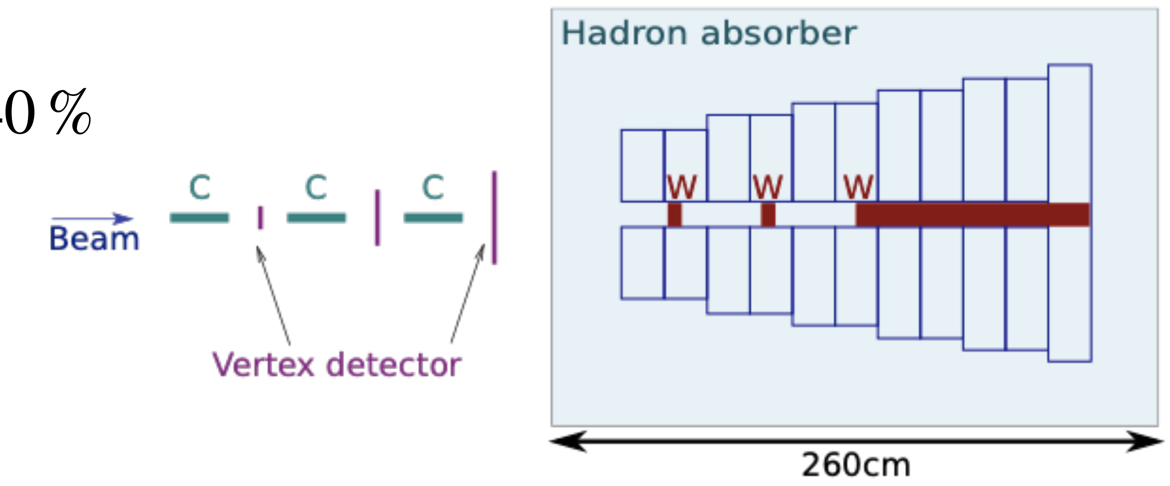


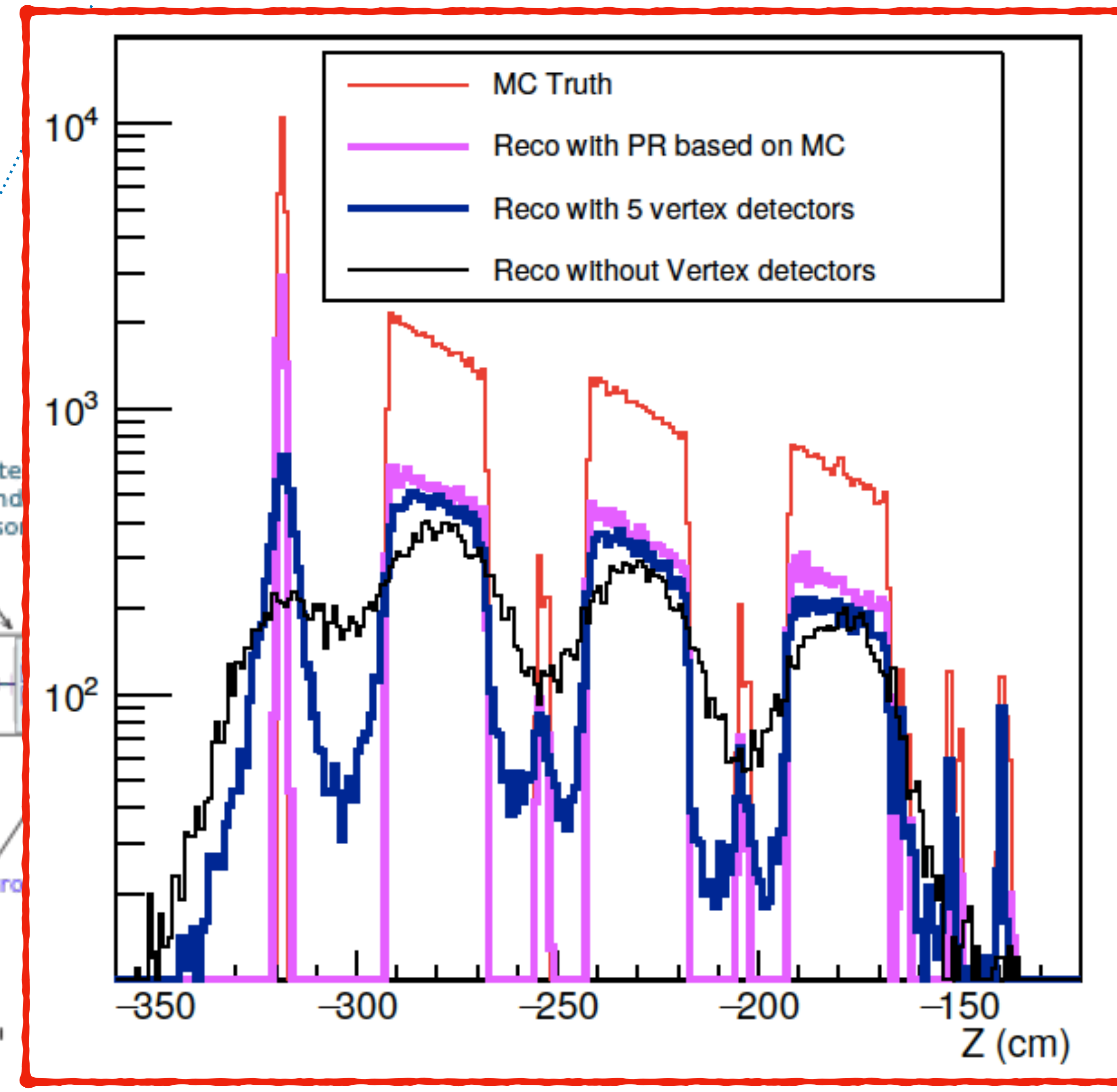
2024 Drell-Yan setup

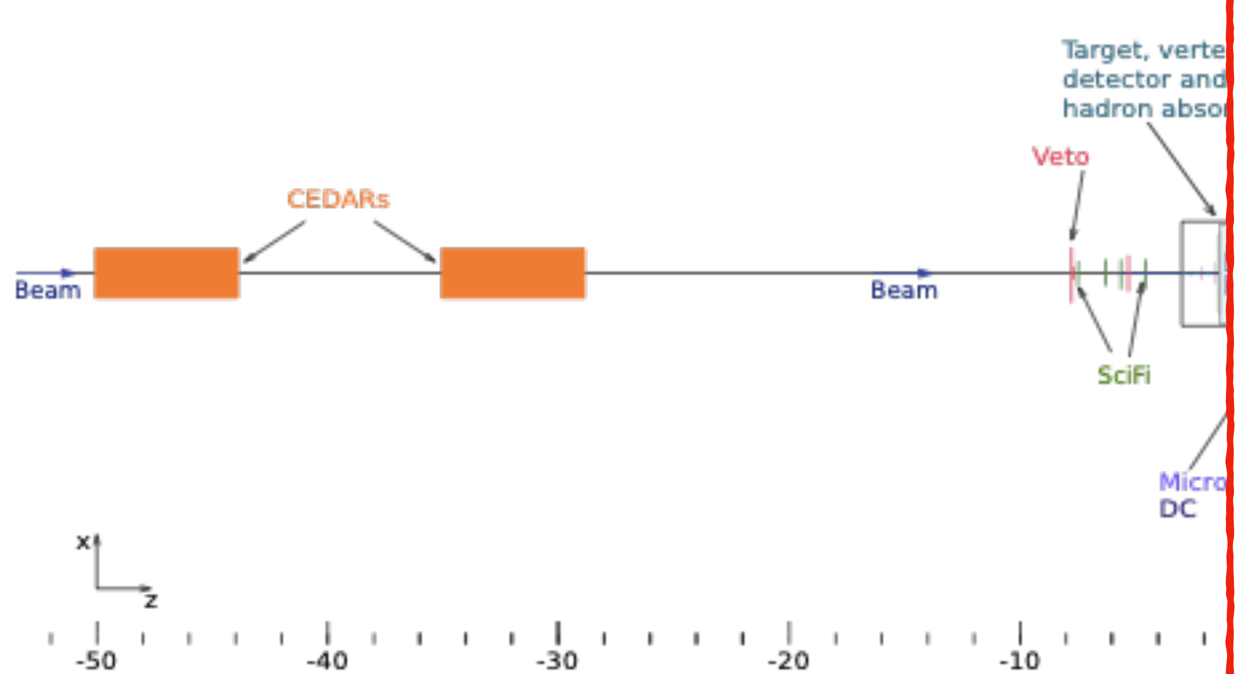


AMBER setup for phase-1 Drell-Yan

- ☑ large acceptance: $8\ mrad < \theta < 160\ mrad \sim 40\,\%$
- ☑ isoscalar target (Carbon), reduced nuclear effects
- ☑ additional targets (Tungsten) for nuclear studies
- ☑ vertex detector nearby the target cells for a good vertex resolution $\Rightarrow$ good mass resolution
- ☑ CEDARs for a good beam PID

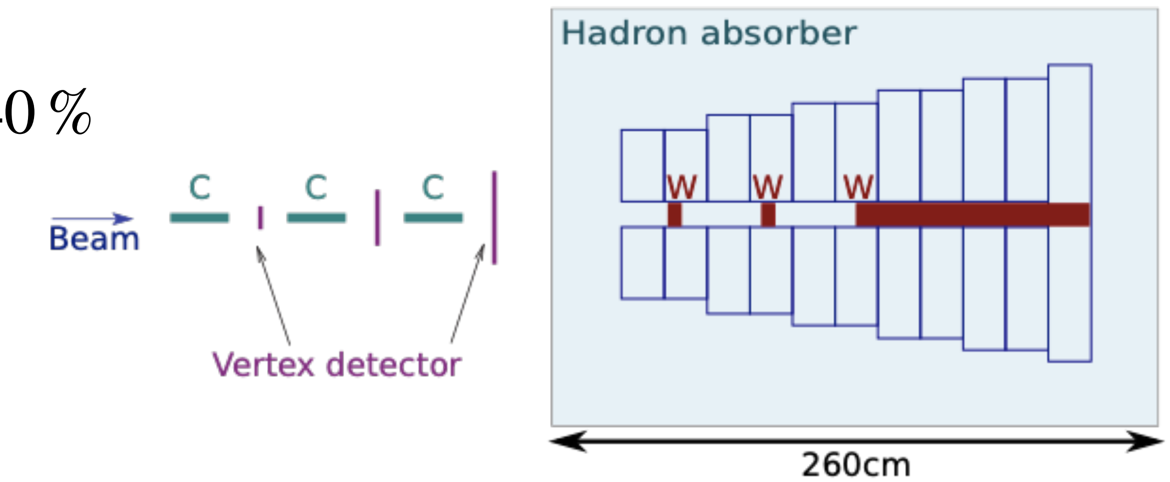




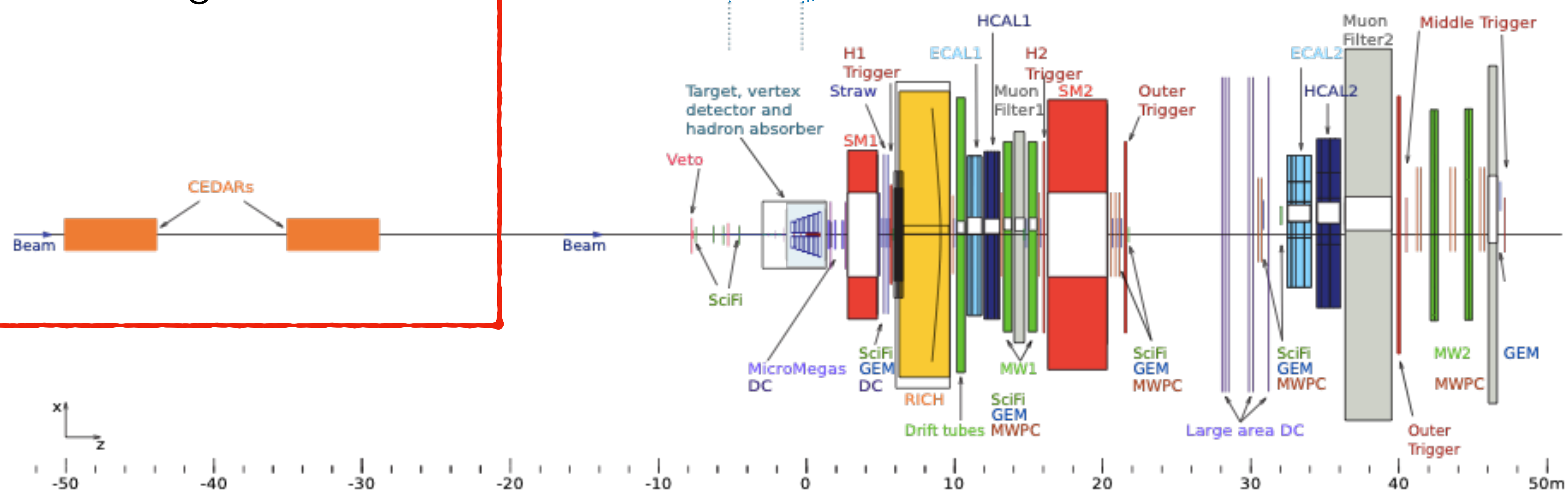


AMBER setup for phase-1 Drell-Yan

- ☑ large acceptance: $8\ mrad < \theta < 160\ mrad \sim 40\,\%$
- ☑ isoscalar target (Carbon), reduced nuclear effects
- ☑ additional targets (Tungsten) for nuclear studies
- ☑ vertex detector nearby the target cells for a good vertex resolution ⇒ good mass resolution
- ☑ CEDARs for a good beam PID



2024 Drell-Yan setup



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

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^+ + 67 of π^-

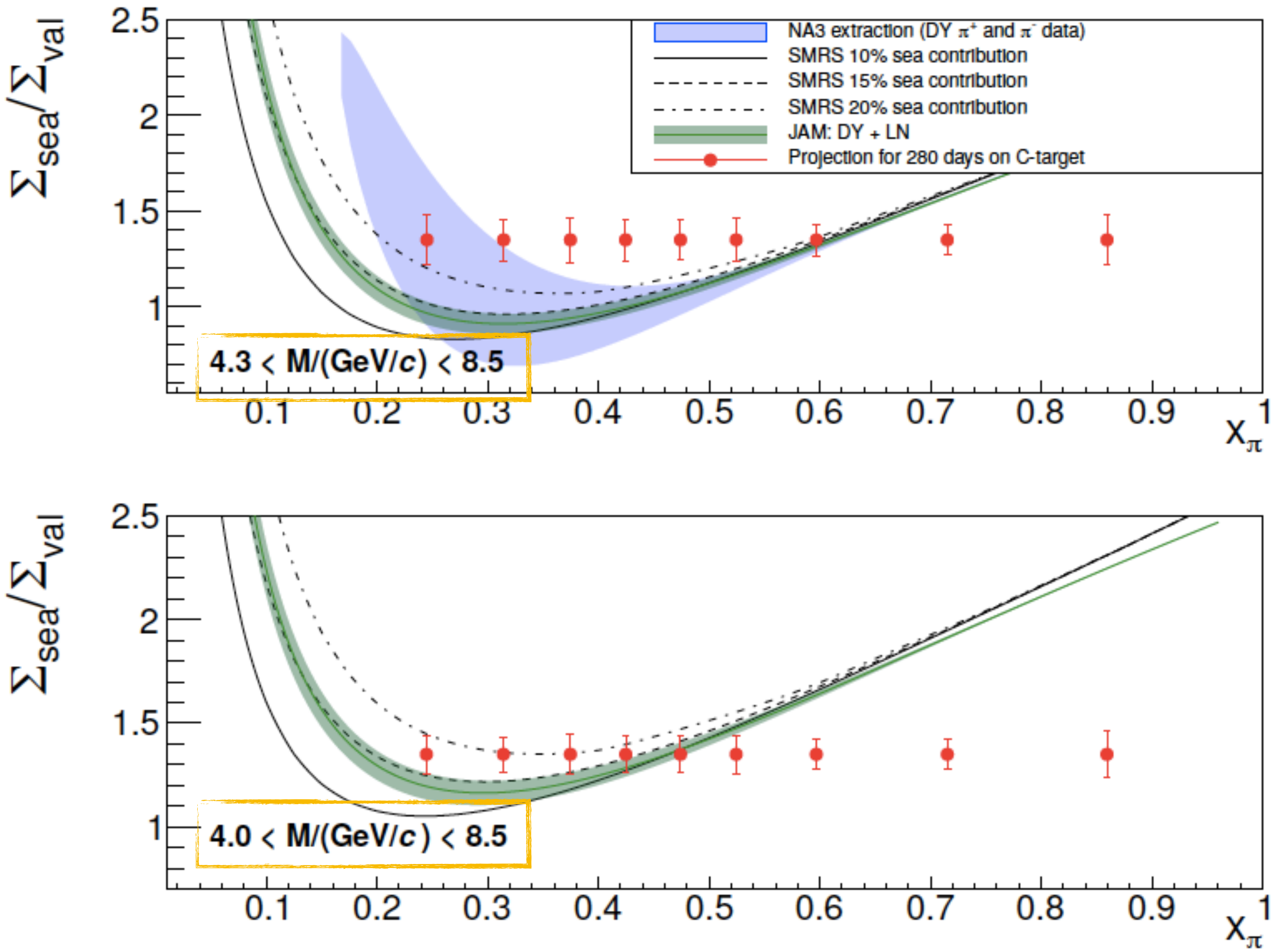
Accessing the pion sea

$$\sum_{val}^{\pi C} = -\sigma^{\pi^+ C} + \sigma^{\pi^- C}$$

only valence-valence terms

$$\sum_{sea}^{\pi C} = 4\sigma^{\pi^+ C} - \sigma^{\pi^- C}$$

valence-sea and sea-valence terms



Goal: precise cross-section measurements, with a level of 3% systematic uncertainty

background free DY mass range

- with an improved vertex/mass resolution thanks to the use of the vertex detectors
- with successful machine learning techniques able to isolate Drell-Yan from background

nuclear dependence studies

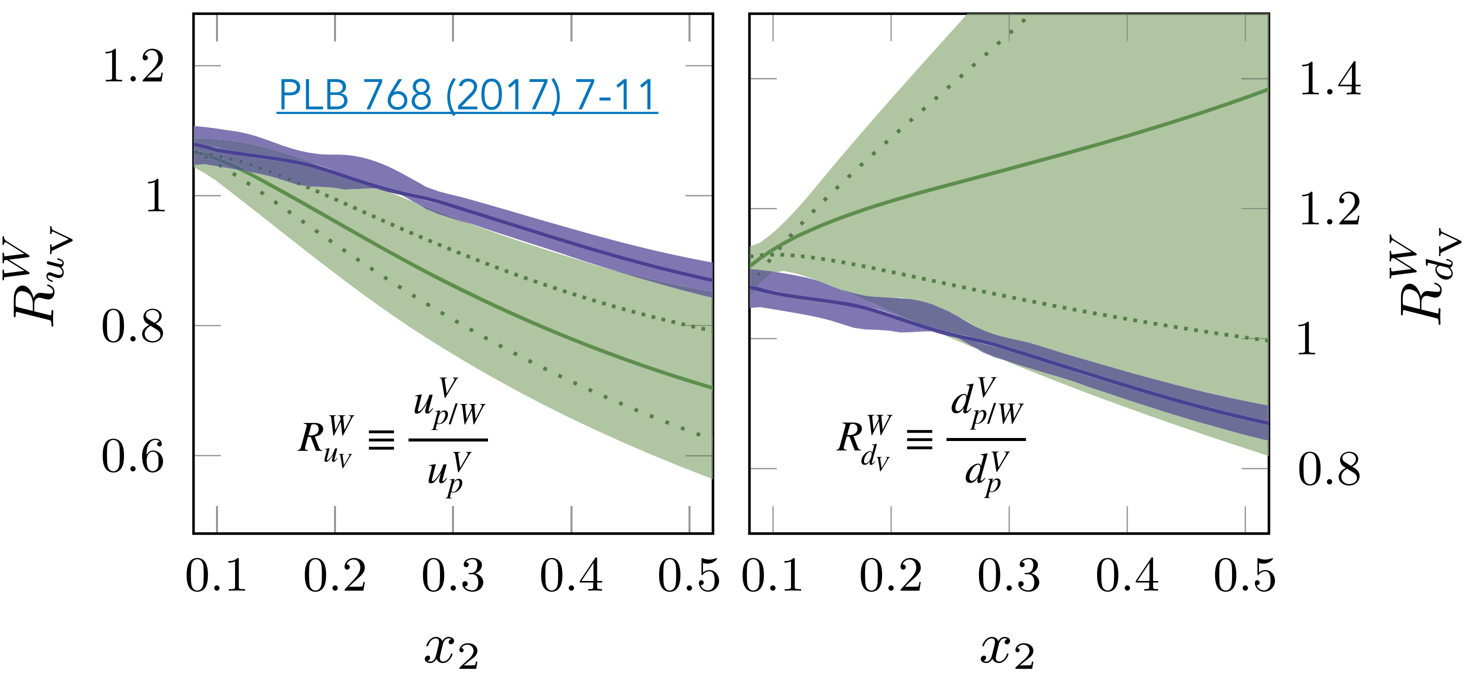
More than 30 years ago - the EMC effect

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

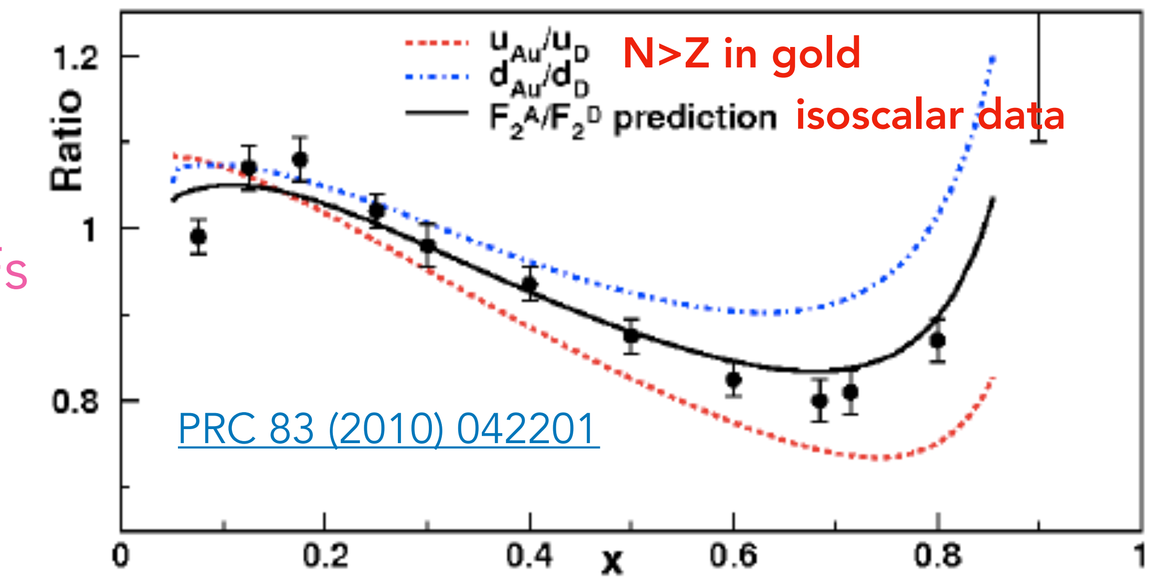
this may have a strong effect on global fits of nuclear PDFs

nuclear modification factors

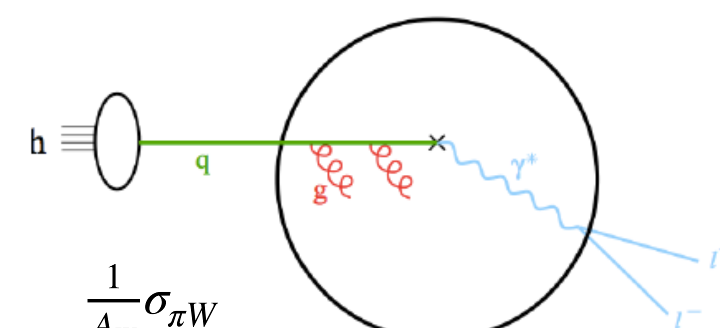


nCTEQ15 global fit with no quark flavour constrains

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



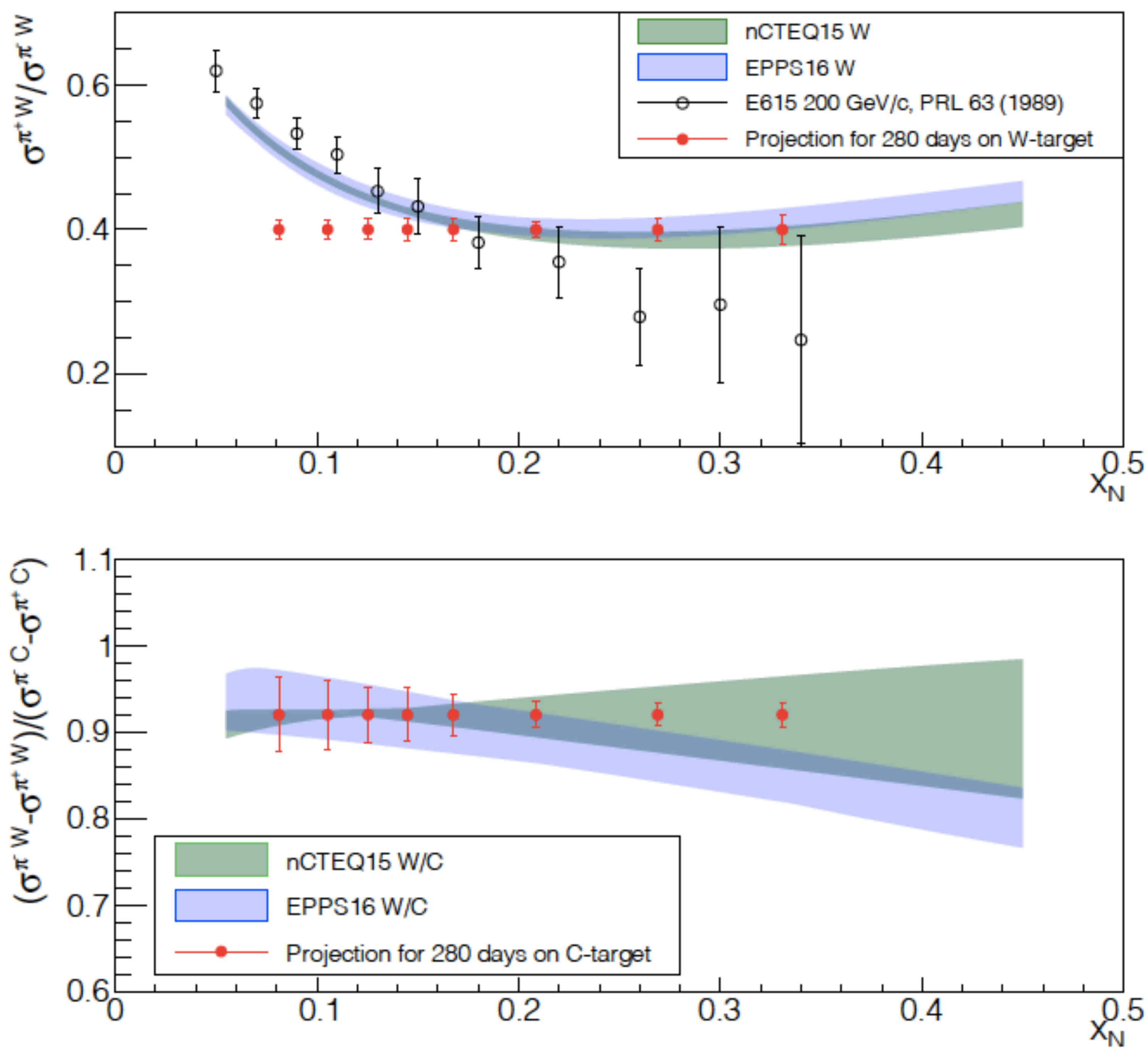
Also possible **Energy Loss** studies: multiple scattering of incoming quark in large nuclei



$$R(x_\pi) = \frac{\frac{1}{A_W}\sigma_{\pi W}}{\frac{1}{A_C}\sigma_{\pi C}}$$

nuclear dependence studies

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

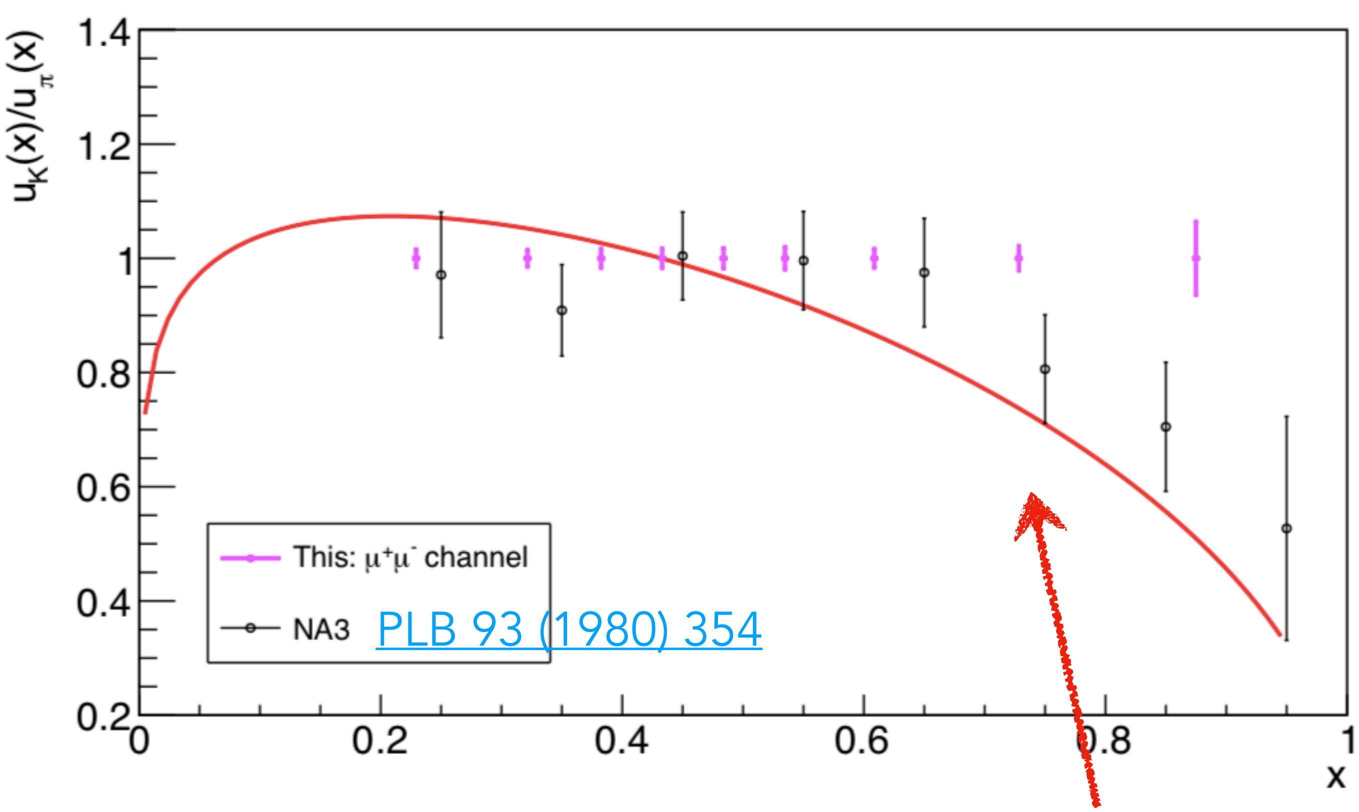


observable more sensitive to the nuclear valence asymmetry

far future: kaon structure

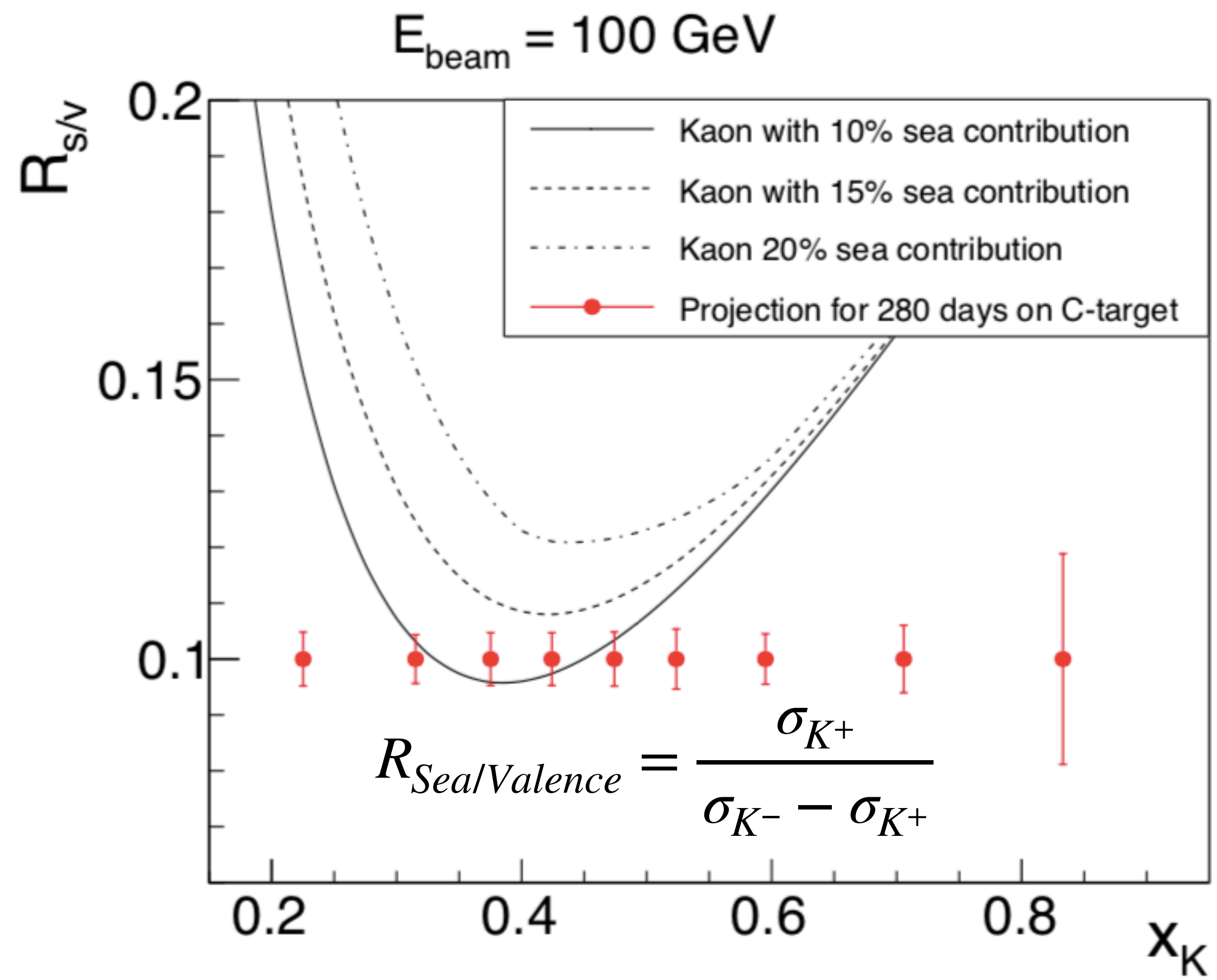
≫ 2026

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



Dyson-Schwinger Equations
PRD 93 (2016) 074021

Sea/Valence separation



In order to achieve these measurement:

Radio-frequency separated beams to enrich the kaons in the hadron beams

For more details check the LoI:
CERN-SPSC-2019-003 (SPSC-I-250)

Final remarks

- AMBER is being proposed as a new fixed target experiment at CERN with the aim of studying QCD
- Possibility to start measurements in 2022, with some minor changes/improvements
- Aim of using kaon beams (as well as anti-protons) in a far future (after the long shutdown 3)
- Through the pion/kaon induced Drell-Yan: improvement of the meson PDFs knowledge (important for the understanding of the hadrons masses)

More talks related with AMBER in this workshop:

1) Jan Friedrich - Proton radius with COMPASS++/AMBER
2) Alexey Guskov - Gluon structure of hadrons with prompt photons at COMPASS-AMBER and NICA-SPD
3) Igor Denisenko - Physics with charmonia at SPD and AMBER experiments

More info on the webpage https://nqf-m2.web.cern.ch/

Everybody is welcome to join

THANK YOU FOR YOUR ATTENTION

Perceiving the Emergence of Hadron Mass through AMBER@CERN

kick-off meeting of the initiative took place 11/12/2019, very good attendance

COMPASS++
AMBER

Joint CERN TH department and AMBER event, web site will be open by the end of the week

CERN

The goal of the workshop, location etc.

COMPASS++
AMBER

- Overview
- Timetable
- Committee
- Registration
- Participant List
- Submit abstract
- Book of Abstracts
- Venue
  - How to get to CERN
  - Visa information
  - Accomodation
  - Transportation
  - Network access
  - Visit CERN

Local Organizers

EHM-AMBER-2020-03...

+41 75 411 9025

The origin of the bulk of visible mass in the Universe is still unknown. Contrasting to the massiveness of the proton, the pion appears as unnaturally light, although both are of composite nature. This dichotomy forms a key part of the conundrum of "Emergence of Hadron Mass". The mechanism responsible for the generation of mass is the dynamical breaking of the scale invariance in Quantum Chromodynamics; and measurements of parton distribution functions (PDFs) are sensitive to this effect and its corollaries.

PDFs can be experimentally accessed via deep inelastic scattering, by pion and kaon-induced Drell-Yan interactions, charmonium production at moderate energies and hadro-production of direct photons. Remarkable theoretical progress has been achieved during the last decade. The resulting predictions require confrontation with accurate experimental data, like those that would become available at the AMBER experiment, very recently proposed at CERN. The prospects opened by the AMBER proposal provide now the opportunity for reviewing the present theoretical understanding of the Emergence of Hadron Mass, in order to harden and extend the list of experimental observables accessible at AMBER.

This Theory Initiative will join theorists from high-energy nuclear and particle physics, in a dialogue with the experimentalists, addressing the origin of hadron masses. The workshop is meant to start a collaborative effort between the experimentalists proposing this new measurement campaign, the phenomenologists doing global data analyses for parton distributions, and hadron-structure theorists.

Starts 30 Mar 2020, 09:00
Ends 3 Apr 2020, 18:00
Europe/Zurich

CERN
4/2-037 - TH meeting room

Craig Roberts
Oleg Denisov
Jan Friedrich
Wolf-Dieter Nowak
Catarina Quintans

Booking form Amber @CERN.docx
Booking form Amber @CERN.pdf