JINR participation in the AMBER experiment at CERN

AMBER
Apparatus for Meson and Baryon Experimental Research

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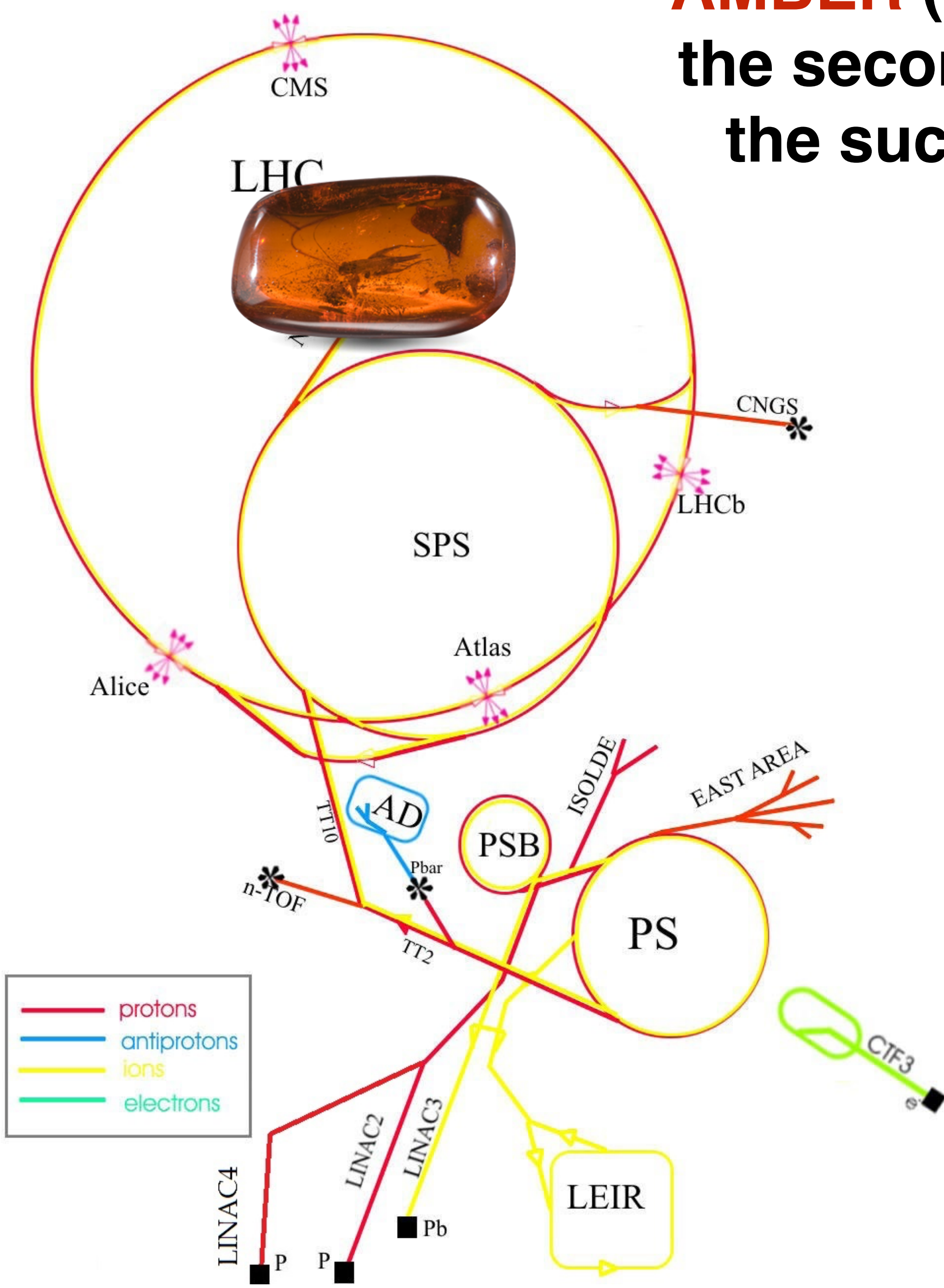
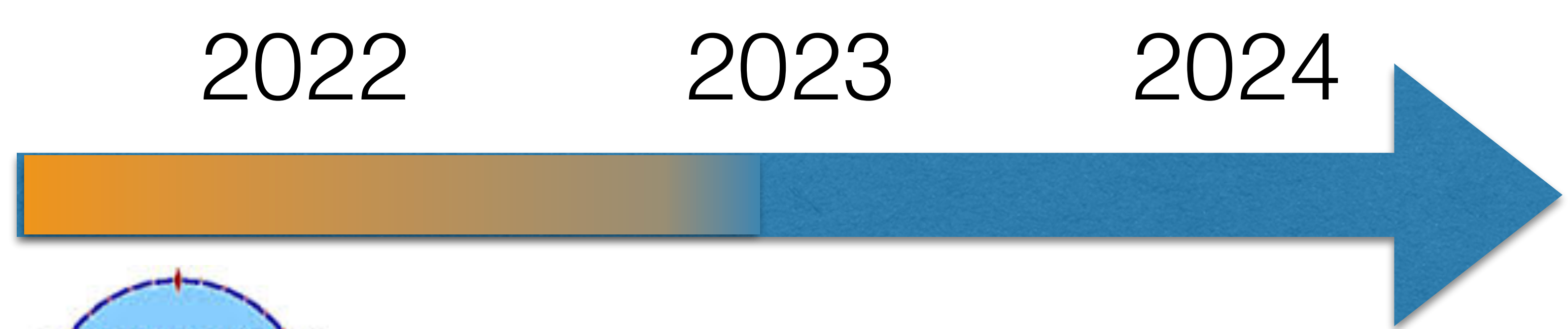
AMBER at CERN

AMBER (NA66) is a fixed target experiment at CERN at the secondary beam line of the SPS at the North Area, the successor of the COMPASS (NA58) experiment

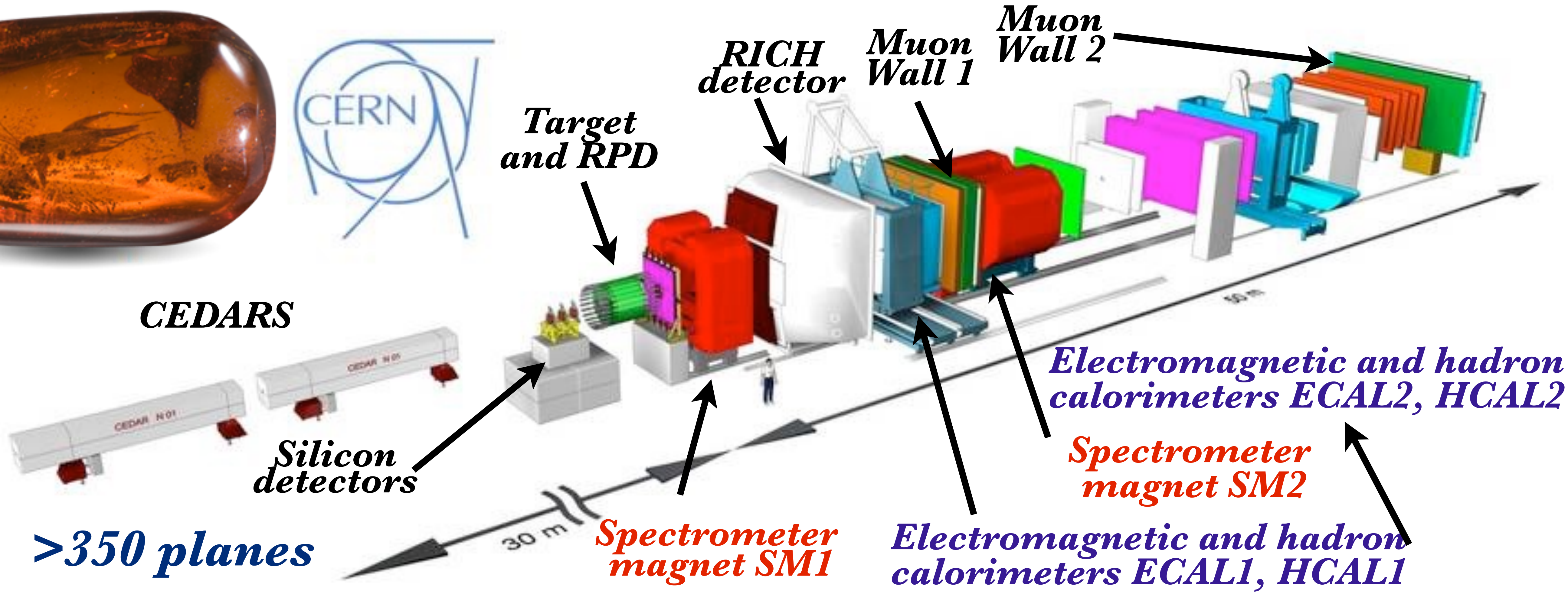




COMPASS

AMBER

The AMBER setup



Muon beam: $\mu^{+/-}$, P=160-200 GeV/c

Hadron beam: $h^{+/-}$, P=190 GeV/c

Particles	Positive beam	Negative beam
π	0.240	0.968
K	0.014	0.024
p	0.746	0.008

Composition of the T6 hadron beam

AMBER physics

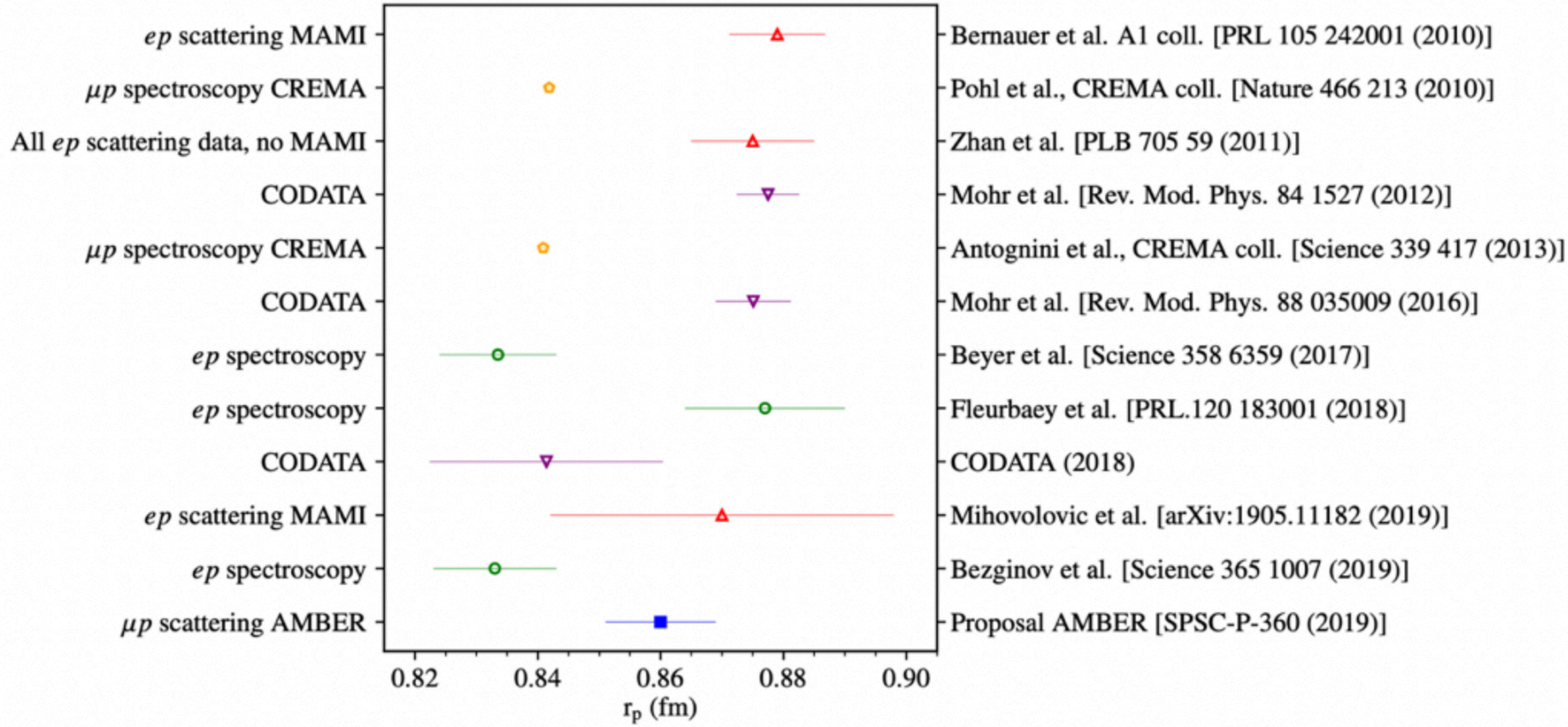
Phase I (approved by CERN SPSC)

Proton Radius Measurement
Pion structure with Drell-Yan and charmonia
Production of antiprotons for DM search in space

Phase II

Kaon structure
Kaon spectroscopy
Kaon Primakoff

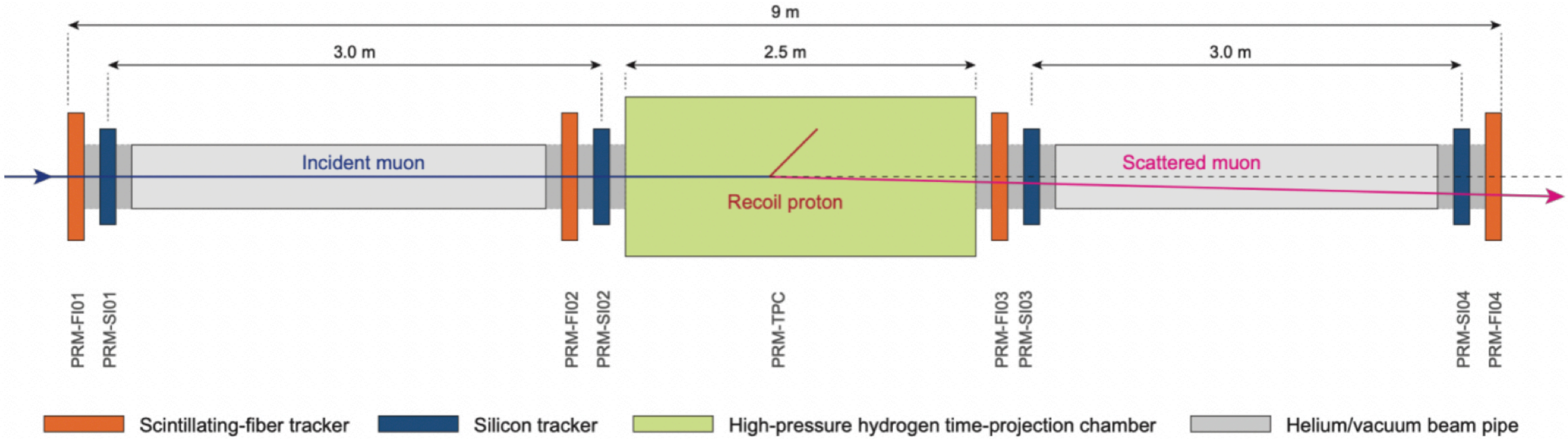
Proton radius puzzle



proton radius "puzzle"

- discrepancy between scattering and spectroscopy data
  - measuring the same thing?
  - systematic effects for electron scattering, e.g. radiative corrections?
  - new physics? lepton non-universiality?
  - . . .

The proposed setup



proposed set-up

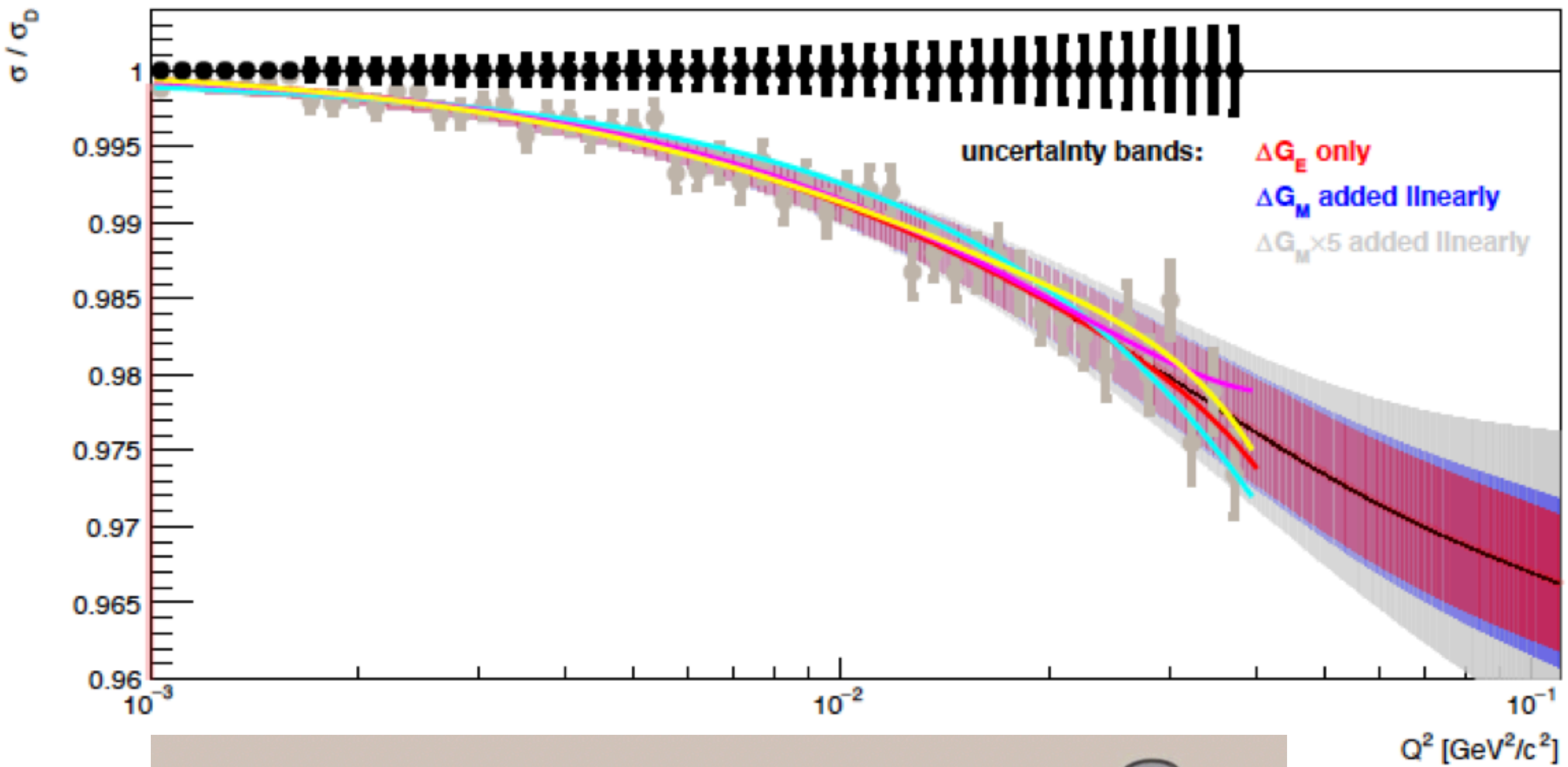
- hydrogen TPC acting as active target
  - measurement of energy of recoil proton
  - between 0.5 and 100 MeV
  - required resolution: $\Delta \approx 60$ keV)
- silicon telescopes up- and downstream of target
  - measurement of muon scattering angles
  - 300 μrad at $Q^2 \approx 10^{-3}$ $(\mathrm{GeV}/c)^2$
  - required resolution $\sigma \lessapprox 100$ μrad

uncertainty on $\sqrt{\langle r_E^2 \rangle} \approx 0.01$ fm

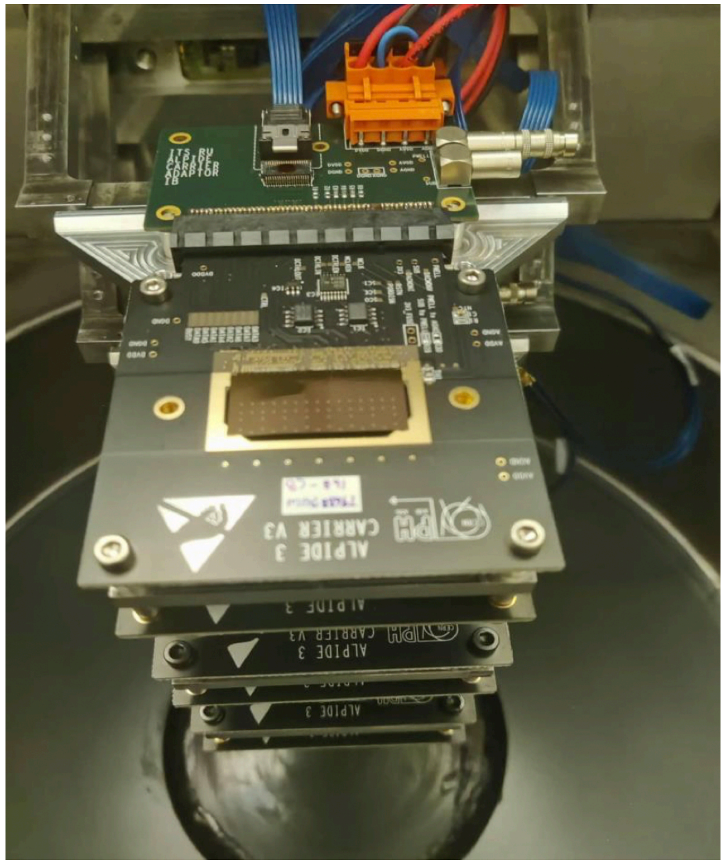
Beam setting	TPC pressure setting	Duration	Purpose
μ^+, 100 GeV	20 bars	92 days	$2.5 < Q^2/(10^{-3}\mathrm{GeV}^2) < 40.0$
μ^+, 100 GeV	4 bars	67 days	$1.0 < Q^2/(10^{-3}\mathrm{GeV}^2) < 8.0$
μ^-, 100 GeV	4 bars	67 days	control of charge dependence
μ^+, 60 GeV	4 bars	34 days	control of energy dependence

uncertainty source	estimate in %
Monte-Carlo acceptance correction	0.2
Q^2 resp. beam energy calibration	0.2
radiative corrections	0.1
fitting procedure	0.1
(linear) sum	<0.6

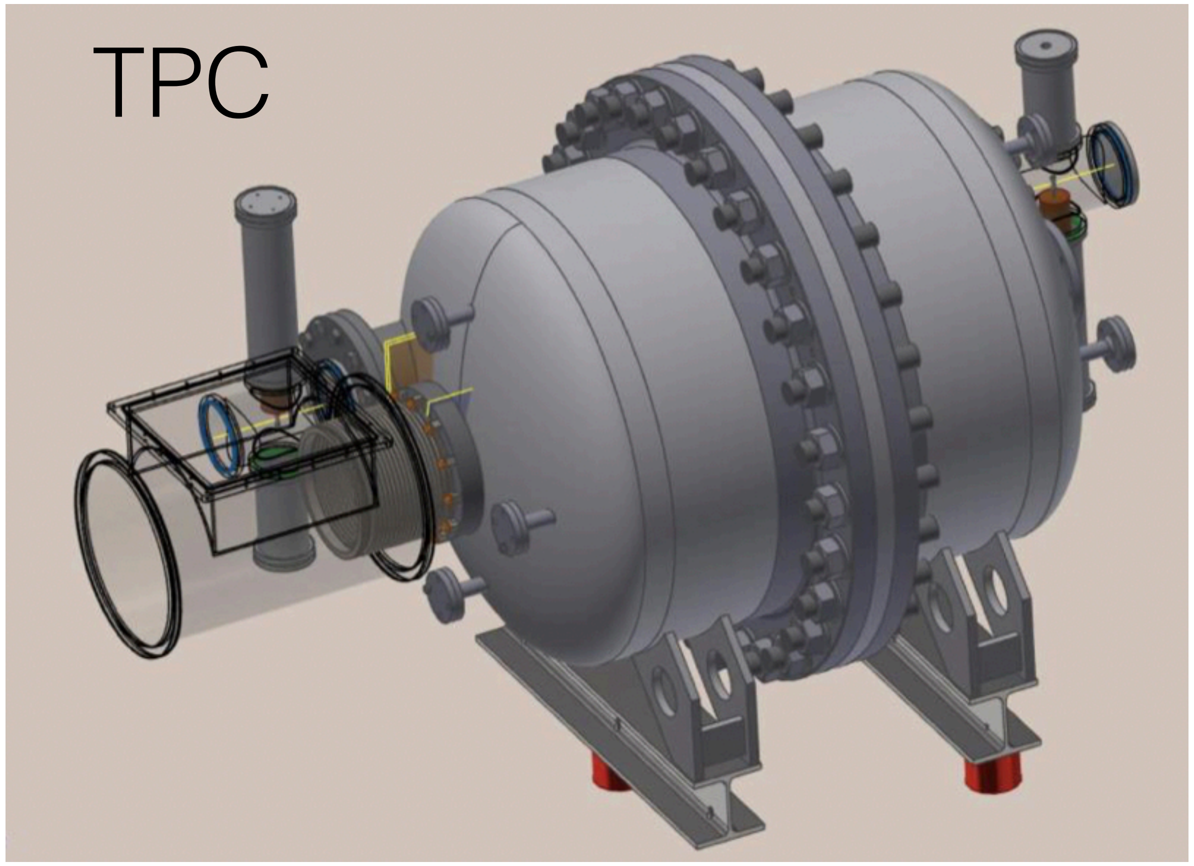
Proton radius measurement



ALPIDE telescope



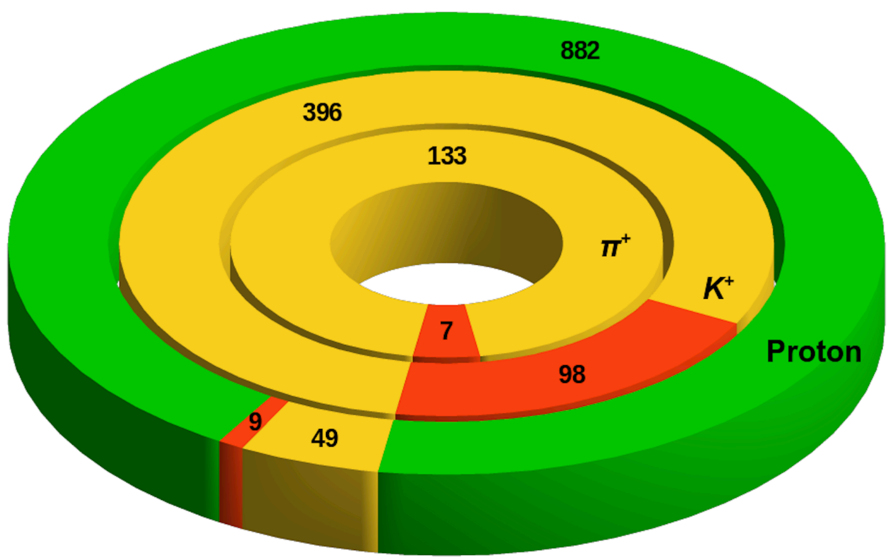
TPC



Test run 2023
in September

Emergence of hadron mass

Hadron Mass Budget



Higgs mechanism is a minor contributor to the mass of hadrons!

- Chiral Limit Mass
- Higgs Boson Current Mass
- DCSB Mass Generation + Higgs feedback

Experiment:

PDFs
Form-factors and radii
Polarizabilities
Hadronic spectra
…

- What is the origin of EHM?
- Does it lie within the Standard Model, i.e., within QCD?
- What are the connections with …
  - Gluon and quark confinement?
  - Dynamical chiral symmetry breaking (DCSB)?
  - Nambu-Goldstone modes = π & K?
- What is the role of Higgs in modulating observable properties of hadrons?
  - Critically, without Higgs mechanism of mass generation, π and K would be indistinguishable
- What is and wherefrom mass?

COMPASS++/AMBER

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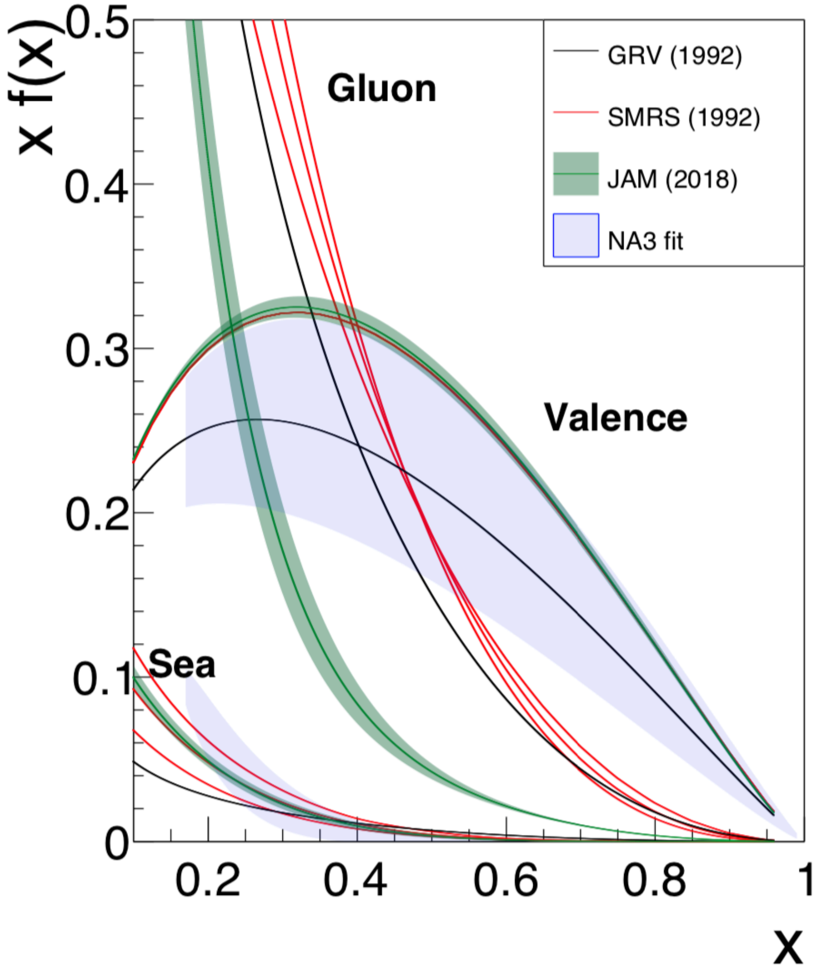
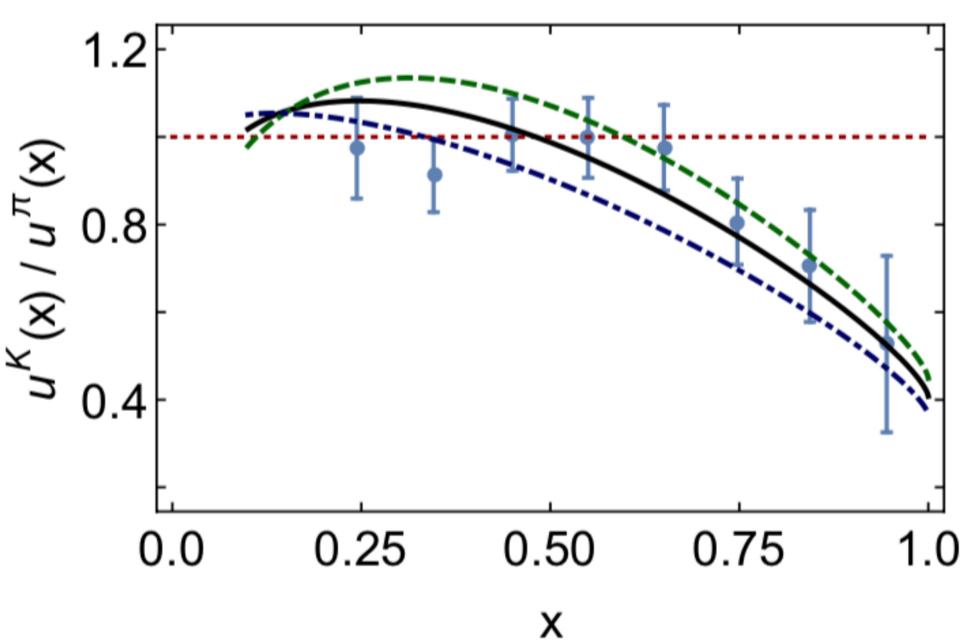
Meson PDFs



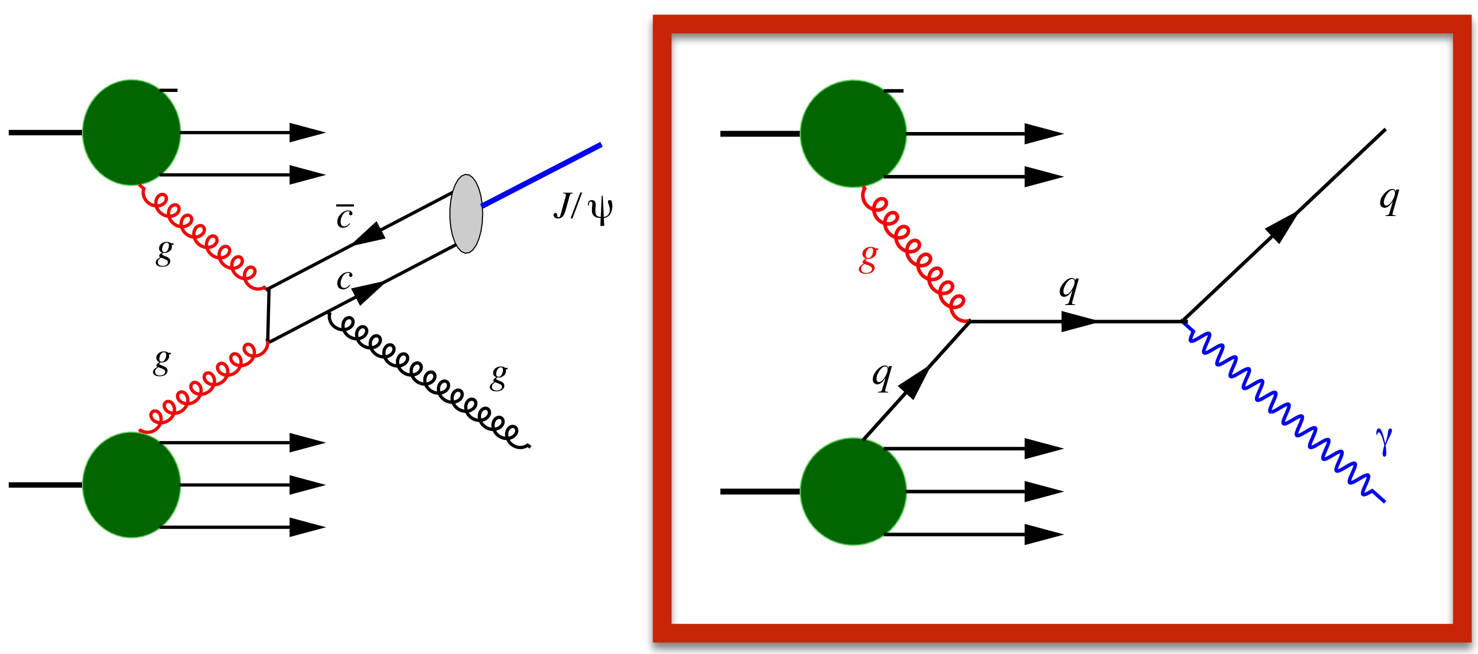


***GRV (1992)** set of pion PDFs: Drell-Yan, charmonia and prompt photon production experiments (**E615, NA10, WA70, NA24**).*

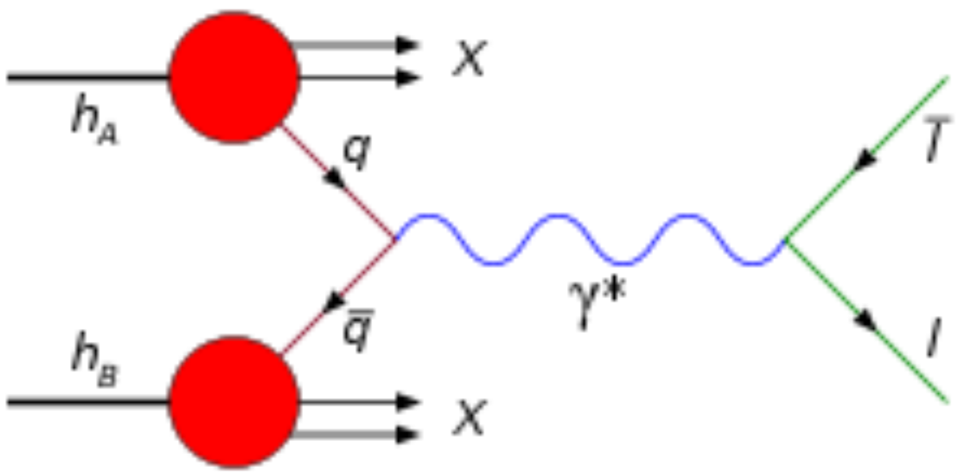
***SMRS (1992)**: basically the same old data.*

***JAM (2018)** set: production of leading neutrons in DIS at HERA (**ZEUS, H1**).*

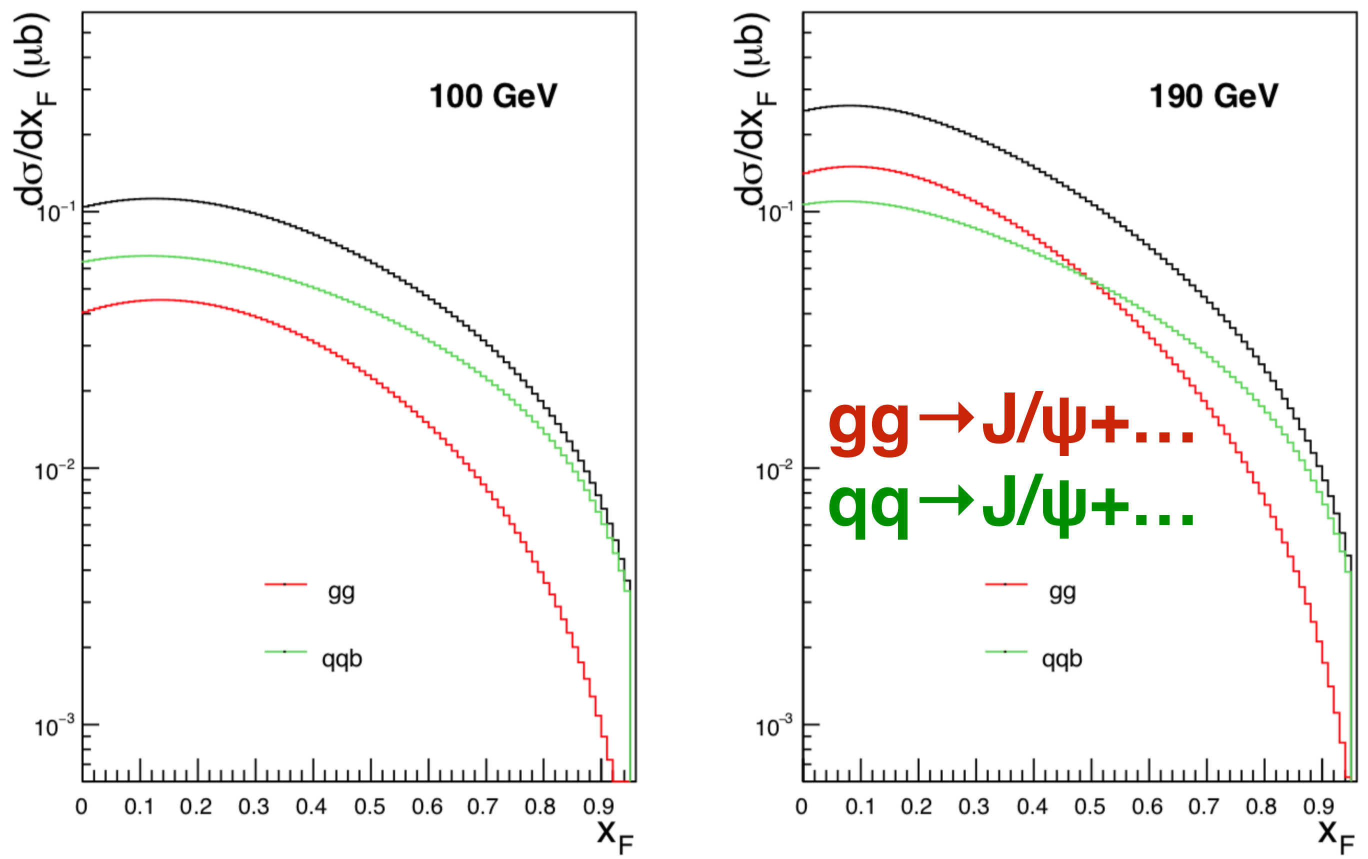
Kaon PDFs**: just 700 kaon-induced DY events at **NA3



Quarks and gluons in pion



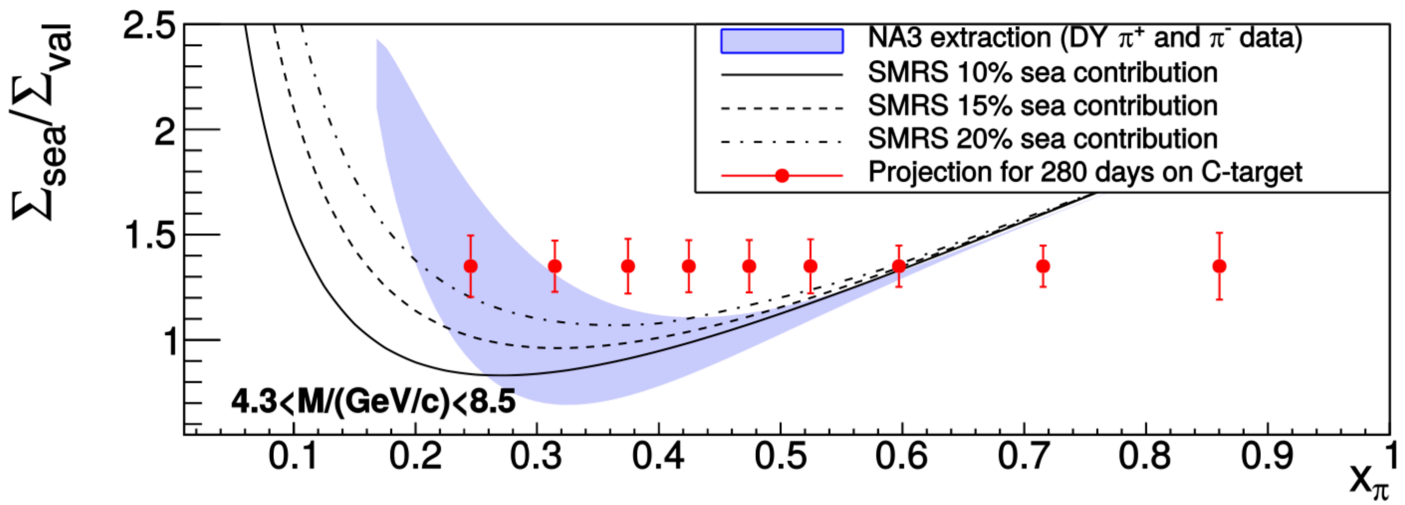
CEM



Sea/valence separation

$$\Sigma_{val}^{\pi D} = -\sigma^{\pi^+ D} + \sigma^{\pi^- D}$$

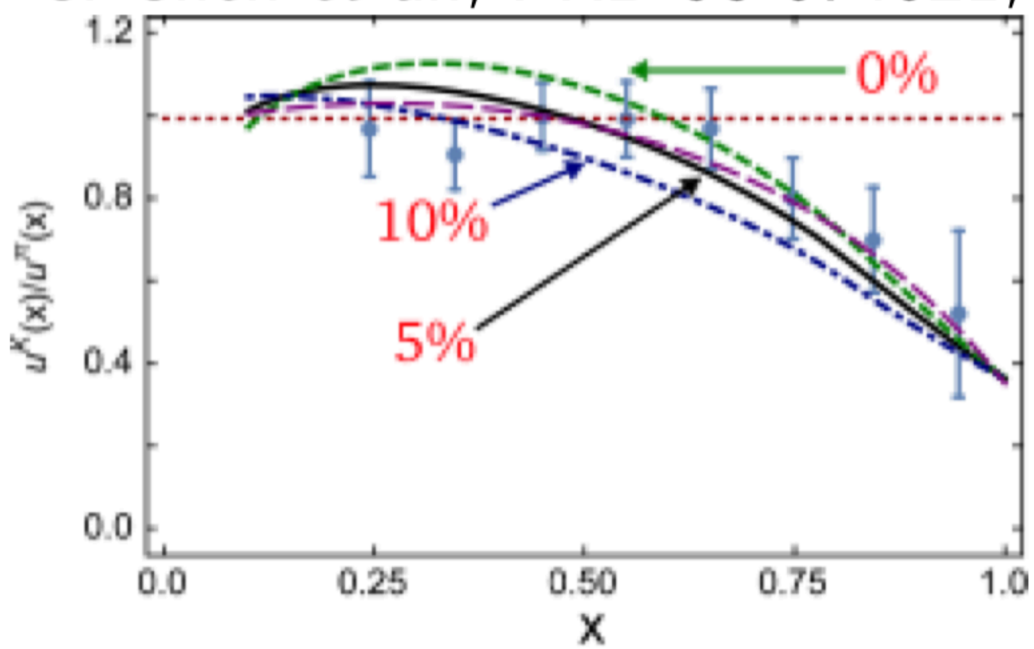
$$\Sigma_{sea}^{\pi D} = 4\sigma^{\pi^+ D} - \sigma^{\pi^- D}$$

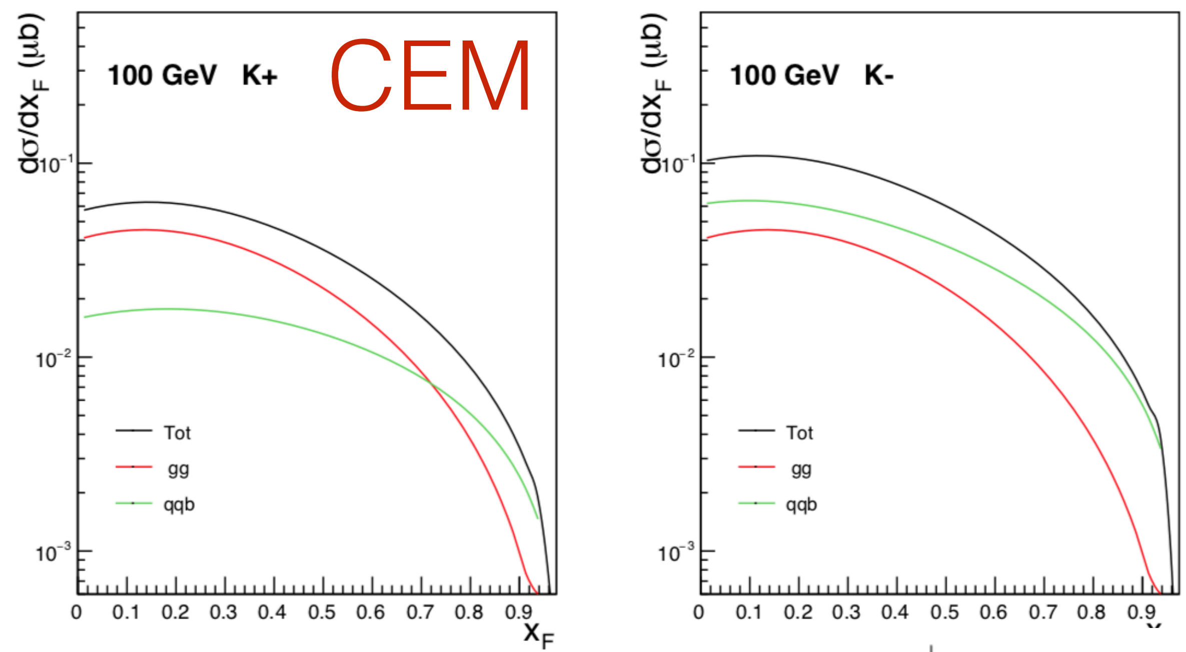


Model-dependent separation of gg and $q\bar{q}$ contributions using data collected with both positive and negative beams for pion.

Quarks and gluons in kaon

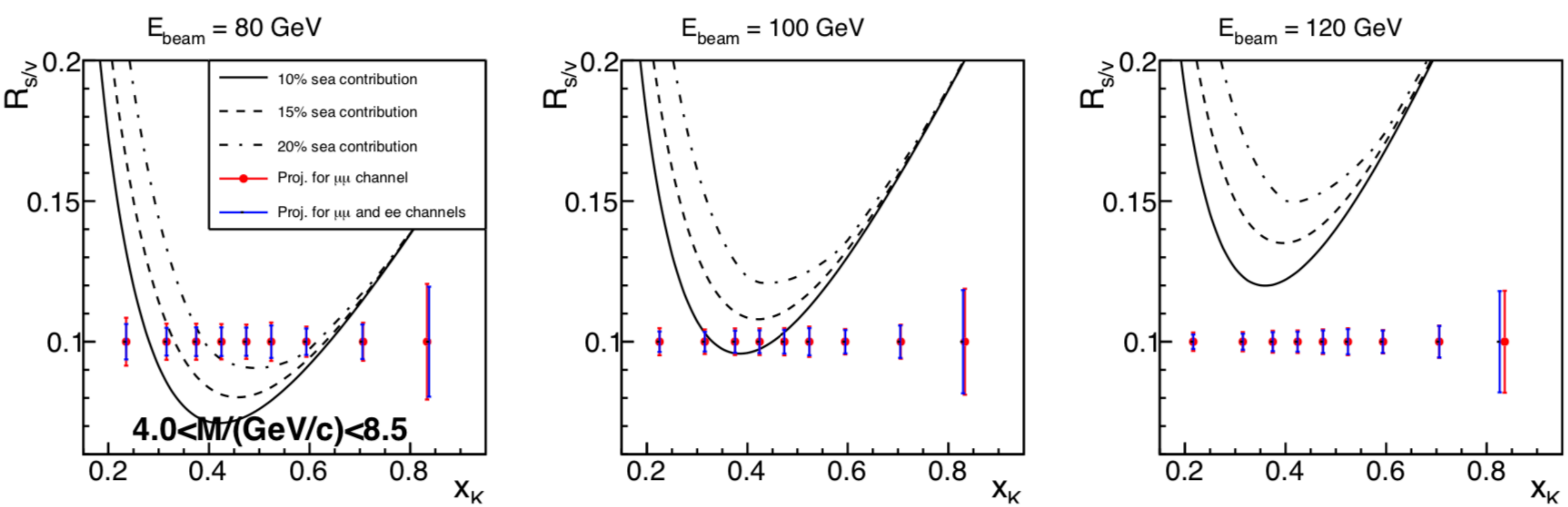
C. Chen *et al.*, PRD 93 074021, 2016



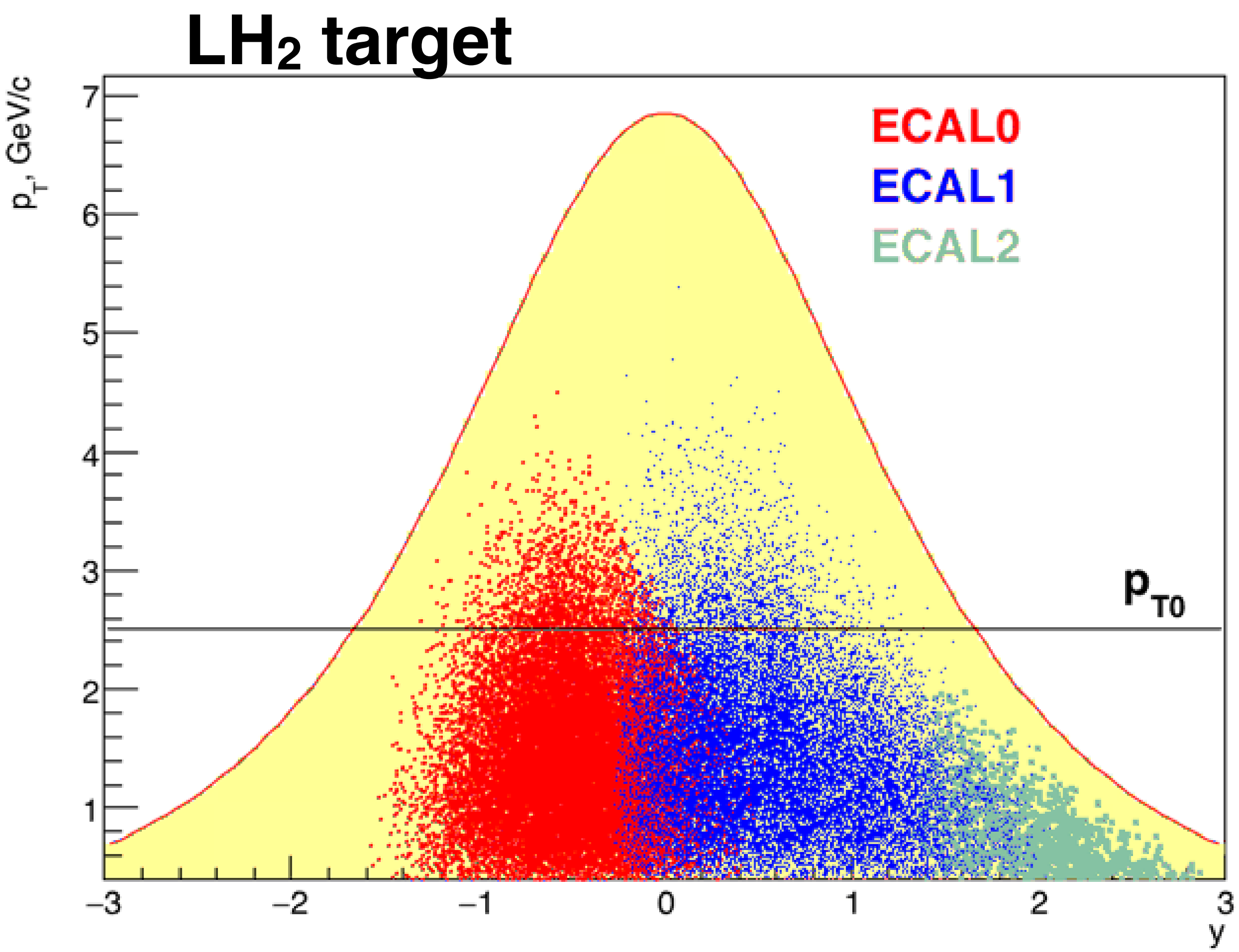


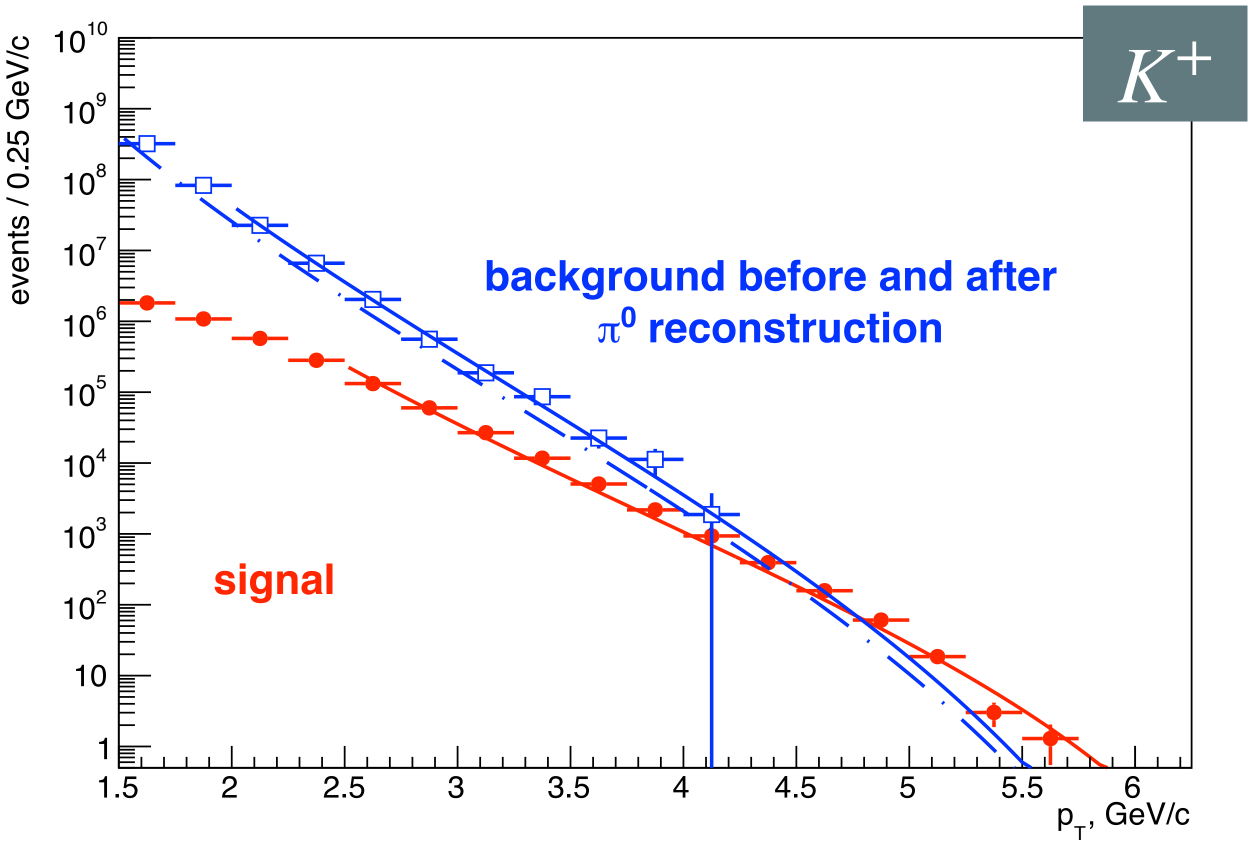
$$\sigma^{K^-}_{J/\psi} - \sigma^{K^+}_{J/\psi} \propto \bar{u}^{K^-} u^N$$

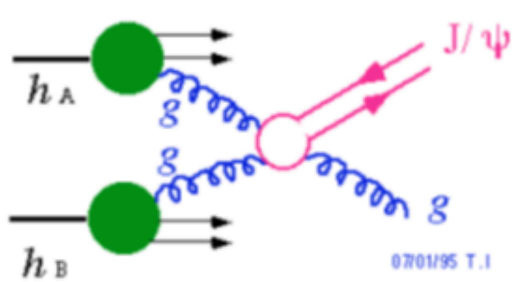
Poor knowledge of kaon valence PDFs, no info about sea



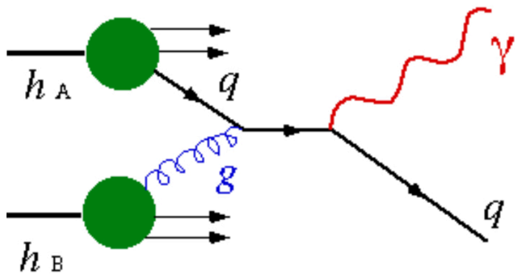
Gluon PDFs: prompt γ







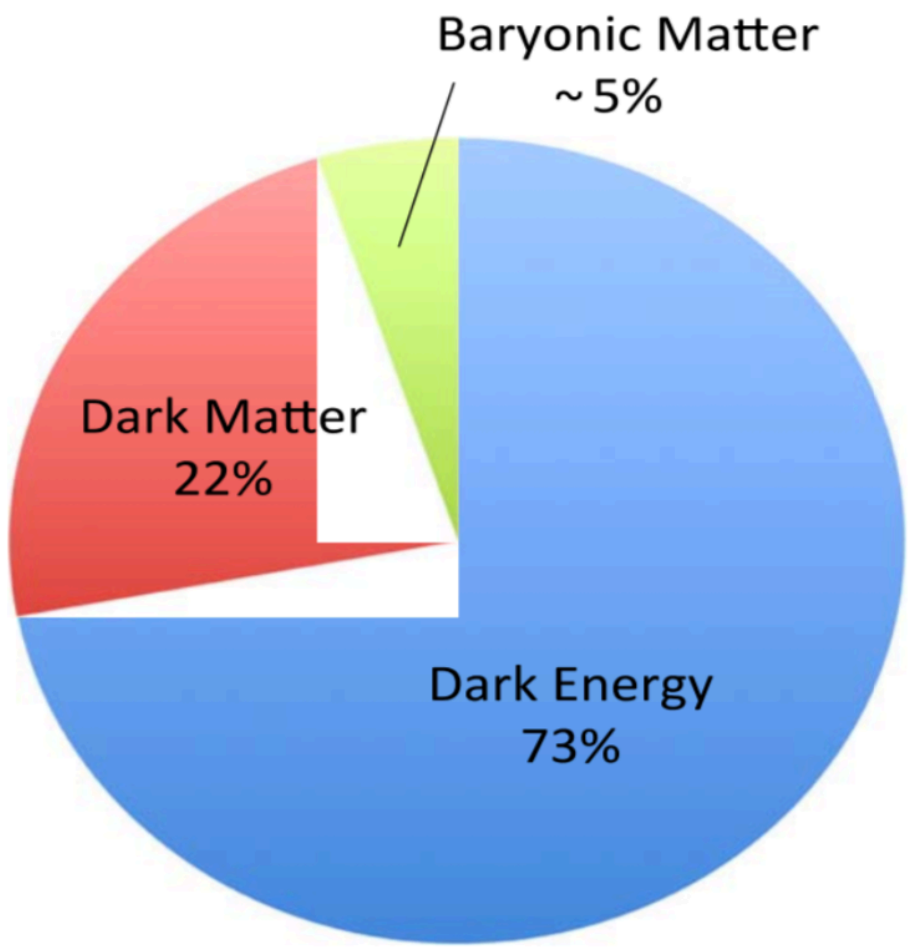
$x_{\pi,K} > 0.2$

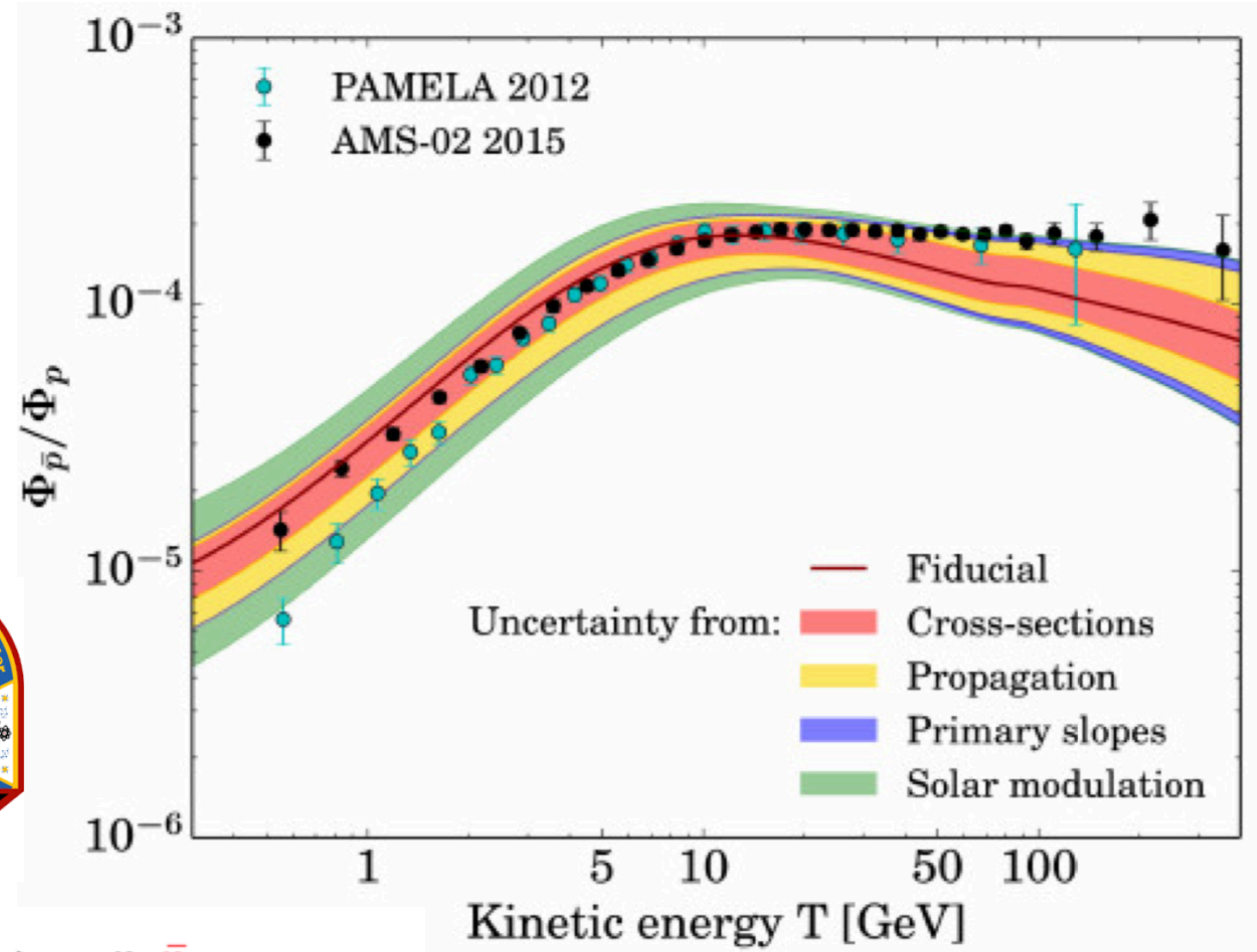


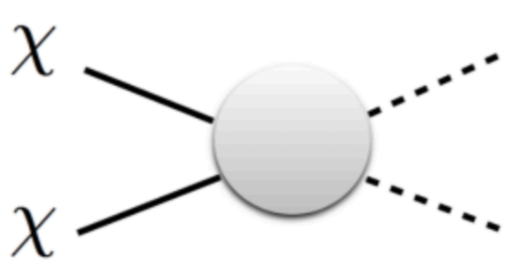
$x_{\pi,K} > 0.05$

Two different methods to touch g(x) — different systematics, different kinematic ranges.

Antiprotons: physics case







$W^-, Z, b, \tau^-, t, h, \ldots \longrightarrow p, \bar{p}, \ldots$

annihilation channel | decay | final products

$W^+, Z, \bar{b}, \tau^+, \bar{t}, h, \ldots \longrightarrow p, \bar{p}, \ldots$

But the most of antiprotons are produced in interaction of primary CR with interstellar matter

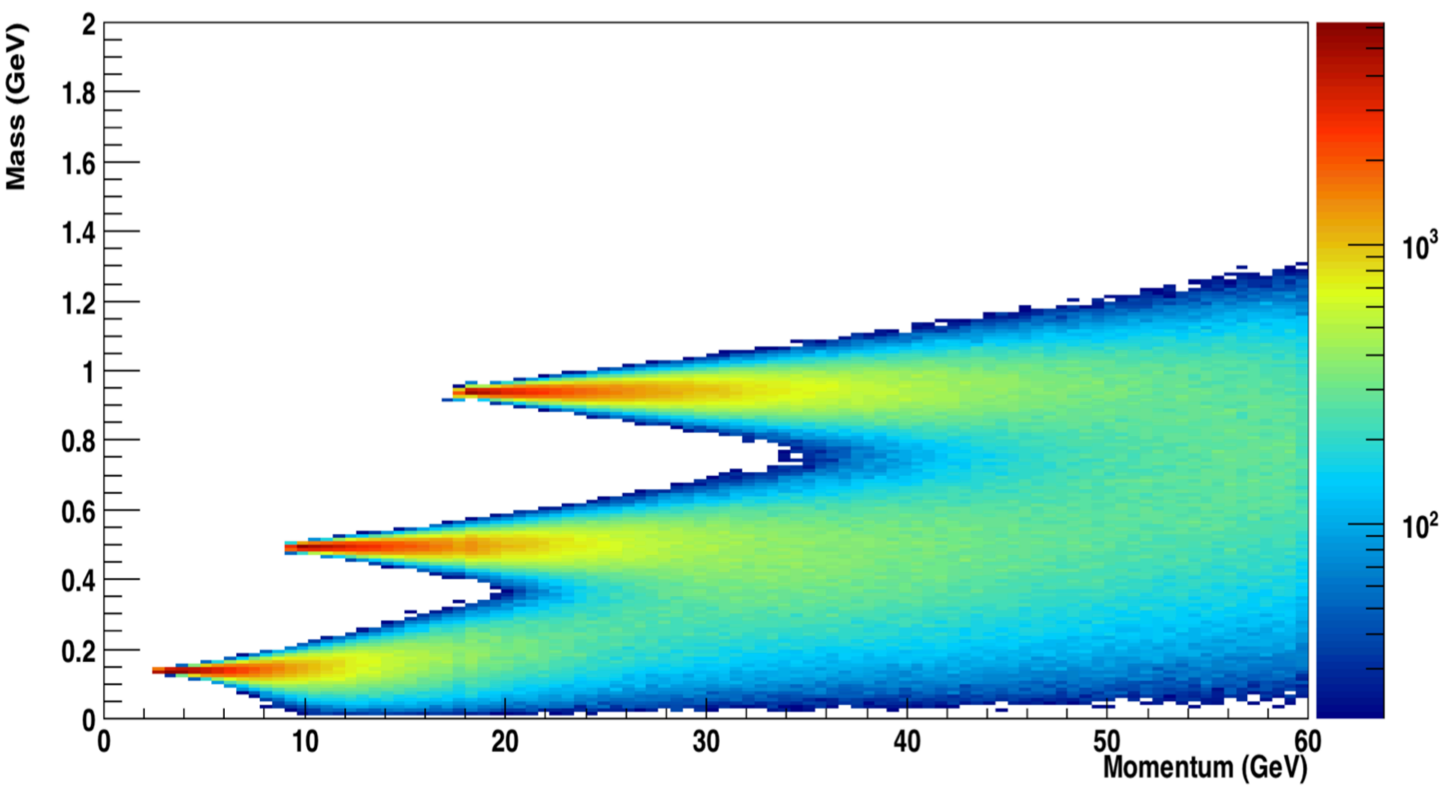
$$\begin{cases} p + H \to \bar{p} + X & \sim 70\% \\ \alpha + H \to \bar{p} + X & \sim 25\% \\ p + He \to \bar{p} + X & \sim 4\% \\ \alpha + He \to \bar{p} + X & \sim 1\% \end{cases}$$

Antiproton production

Existing data for antiproton production in p-p collisions

Experiment	$\sqrt{s}$ (GeV)	P_T (GeV)	x_R
Dekkers *et al.*, CERN 1965	6.1, 6.7	(0.00, 0.79)	(0.34, 0.65)
Allaby *et al.*, CERN 1970	6.15	(0.05, 0.90)	(0.40, 0.94)
Capiluppi *et al.*, CERN 1974	23.3, 30.6, 44.6, 53.0, 62.7	(0.18, 1.29)	(0.06, 0.43)
Guettler *et al.*, CERN 1976	23.0, 31.0, 45.0, 53.0, 63.0	(0.12, 0.47)	(0.036, 0.092)
Johnson *et al.*, FNAL 1978	19.4, 23.8, 27.4	(0.77, 6.15)	(0.08, 0.58)
Antreasyan *et al.*, FNAL 1979	23.0, 31.0, 45.0, 53.0, 63.0	(0.12, 0.47)	(0.036, 0.092)
BRAHMS, BNL 2008	200	(0.82, 3.97)	(0.11, 0.39)
NA49, CERN 2010	17.3	(0.10, 1.50)	(0.11, 0.44)
NA61, CERN 2017	6.3, 7.7, 8.8, 12.3, 17.3	—	—

Plans: p-He LHCb 86.7, 114.7 $2 < \eta < 5$

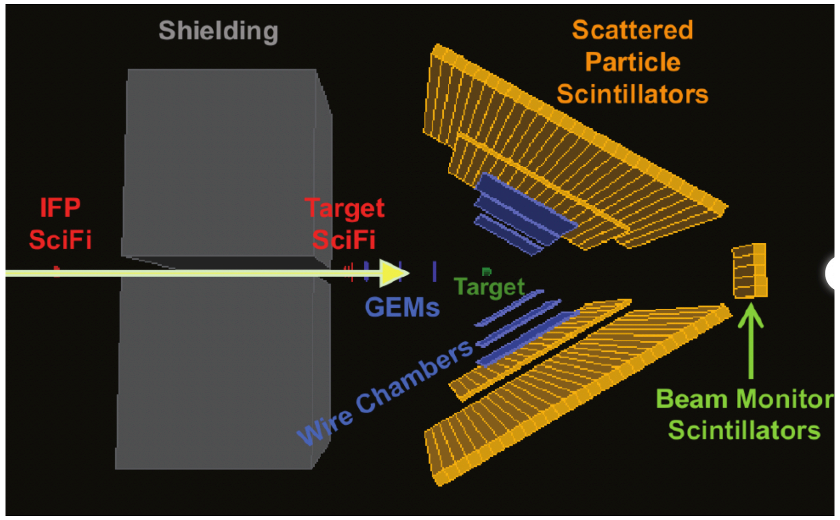


	pbar(18-45 GeV/c)	pbar (5-18 GeV/c)
p-p @ 0-280GeV/c	OK 2009 data @190GeV	RICH veto or RICH0
p-He @0-280GeV/c	new LHe target	RICH veto or RICH0

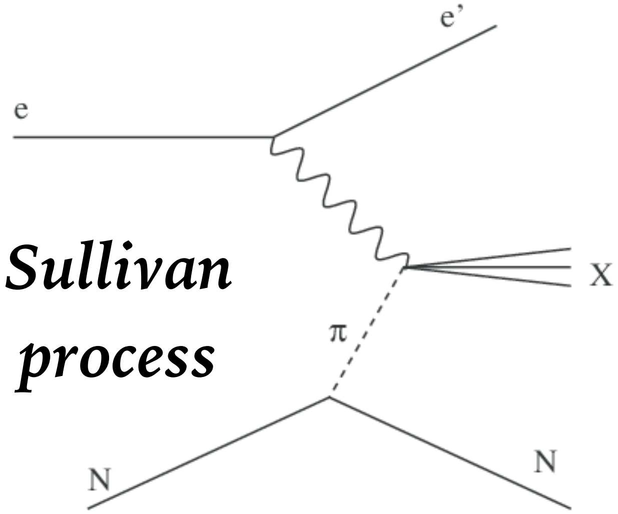
Also $\bar{p}$ from Λ and Σ decays

Our competitors

MUSE at PSI proposes to compare e-p and μ-p scattering in non-forward kinematics.



Pion and kaon partonic structure can be accessed by model-dependent way via Sullivan process at JLab and EIC. The J-PARC kaon beam has too low momentum for such kind of measurements.



Sullivan process

We are not aware of any other plans to measure kaon polarisabilities

Kaon spectroscopy: Belle II, BES III, LHCb: in decay of τ-lepton and D-mesons only states with mass below 1.8 GeV will be accessible. Limited dataset from decay of B-mesons. GlueX (JLab): photoproduction of KKππ final state. J-PARC - spectroscopy with low-momentum kaon beam.

AMBER & SPD

Physics:
- DY and charmonia production
- prompt photons (phase 2)
- kaon polarizabilities (phase 2)
- antiproton productions

Detectors:
- MW1, HCAL1, ECAL0
- new MM detectors
- DAQ

Physics:
- charmonia production and prompt photons - different global physics goal but similar physics processes at the same energy scale
- antiproton productions - we have the same program at SPD.

Detectors:
- MM detectors - we plan to use similar technology for the SPD Central tracker of the Phase-1
- Triggerless DAQ
- Triggerless electronics for MW1

People:

Opportunity for young people to participate in data taking and analysis

Requested resources

People

№№ n/a	Category employee	Core staff, Amount of FTE
1.	scientific staff	8
2.	engineers	2
3.	professionals	2
4.	employees	
5.	workers	
	Total:	**12**

Money

		Names of costs, resources, sources of funding	Cost (thousands of dollars) resource requirements	Cost, distribution by year			
				1st year	2nd year	3rd year	4th year
		International cooperation (IC)	300	90	120	90	
		Materials	90	30	30	30	
		Equipment and third-party services (commissioning)	200	80	80	40	
		Commissioning work					
		Services of research organisations					
		Acquisition of software					
		Design/construction					
		Service costs (*planned in case of direct project affiliation*)					
Resources required	**Normo-hours**	Resources					
		– the amount of FTE,	34	12	10	12	
		– accelerator/installation,					
		– reactor,….					
…f funding	**Budgetary resources**	JINR budget (*budget items*)	590	200	230	160	

SUMMARY

AMBER is a fixed-target experiment at CERN, successor of the COMPASS experiment, planning to study the structure and properties of hadrons, especially mesons

JINR was actively involved in developing the physical program of the experiment. New MM detectors could be used to replace aged trackers.

We are responsible for the existing detectors: HCAL1, MW1 and ECAL0.

Synergy with SPD