A new QCD facility at the CERN SPS M2 beam line

Michela Chiosso
On behalf of the
AMBER Collaboration

AMBER
10 years-long effort

Apparatus for Meson and Baryon Experimental Research

January 2019: Letter of Intent handed over to SPSC

April 2019: formation of Proto-Collaboration Board

May 2019: AMBER Phase–1 Proposal (update September)

AMBER recommendation by the SPSC on Oct. 12th 2020

AMBER* approval by RB on Dec. 2nd 2020

Phase–2 Proposal drafting to be started soon

> 250 authors,
51 institutions,
16 new institutions with respect to COMPASS (majority from USA, also Germany, Italy, Russia etc.)

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

CERN-SPSC-2019-003
SPSC-I-250
January 25, 2019

[hep-ex] 25 Jan 2019

Letter of Intent:

A New QCD facility at the M2 beam line of the CERN SPS*

COMPASS++†/AMBER‡

B. Adams[13,12], C.A. Aidala[1], R. Akhunzyanov[14], G.D. Alexeev[14], M.G. Alexeev[41], A. Amoroso[41,42],

Proposal for Measurements at the M2 beam line of the CERN SPS

Phase-1: 2022-2024

COMPASS++*/AMBER†

http://cds.cern.ch/record/2676885

CERN-SPSC-2019-022 / SPSC-P-360
31/05/2019

B. Adams[14,13], C.A. Aidala[1], G.D. Alexeev[15], M.G. Alexeev[41,42], A. Amoroso[41,42], V. Andrieux[44,20], N.V. Anfimov[15], V. Anosov[15], A. Antoshkin[15], K. Augsten[15,31], W. Augustyniak[46], C.D.R. Azevedo[4], B. Badełek[47], F. Balestra[41,42], M. Ball[8], J. Barth[8], R. Beck[8], J. Berenguer Antequera[41,42], J.C. Bernauer[33,45], J. Bernhard[20,p], M. Bodlak[30], F. Bradamante[39], A. Bressan[38,39], M. Büchele[17], V.E. Burtsev[40], C. Butler[3], C. Chatterjee[38,39], M. Chiosso[41,42], A.G. Chumakov[40], S.-U. Chung[18,c], A. Cicuttin[39,d], M. Connors[3], A. Contin[6], P. Correia[4], M.L. Crespo[39,d], S. Dalla Torre[39], S.S. Dasgupta[11], S. Dasgupta[39,11], N. Dashyan[50], I. Denisenko[15], O.Yu. Denisov[42], L. Dhara[11], F. Donato[43], S.V. Donskov[32], N. Doshita[49], Ch. Dreisbach[18], W. Dünnweber[e], R.R. Dusaev[40], A. Dzyuba[19], A. Efremov[15], P. Egelhof[16], A. Elagin[14], P.D. Eversheim[8], P. Faccioli[22], M. Faessler[e], J. Fedotova[25], M. Finger[30], M. Finger jr.[30], H. Fischer[17], C. Franco[22], J.M. Friedrich[18], V. Frolov[15], A. Futch[44], F. Gautheron[44], O.P. Gavrichtchouk[15], S. Gerassimov[27,18], S. Gevorkyan[15], Y. Ghandilyan[50], J. Giarra[24], I. Gnesi[41,42], M. Gorzellik[17], A. Grasso[41,42], A. Gridin[15], M. Grosse Perdekamp[44], B. Grube[18], R.I. Gushterski[15,l], A. Guskov[15], G. Hamar[39], D. von Harrach[24], X. He[3], R. Heitz[44], F. Herrmann[17], M. Hoffmann[8], N. Horikawa[29,f], S. Huber[18], A. Inglessi[19], A. Ilyichev[25], S. Ishimoto[49,h], A. Ivanov[15], N. Ivanov[50], T. Iwata[49], M. Jadhav [2], M. Jandek[30], V. Jary[31], C.-M. Jen[23], R. Joosten[8], P. Jörg[17], K. Juraskova[31], E. Kabuß[24], F. Kaspar[18], D. Keller[12], A. Kerbizi[38,39], B. Ketzer[8], G.V. Khaustov[32], Yu.A. Khokhlov[32,i], M. Kim[1], O. Kiselev[16], Yu. Kisselev[15], F. Klein[9]

A new QCD facility at the SPS M2-beam line

A unique opportunity:

In the COMPASS experimental hall:

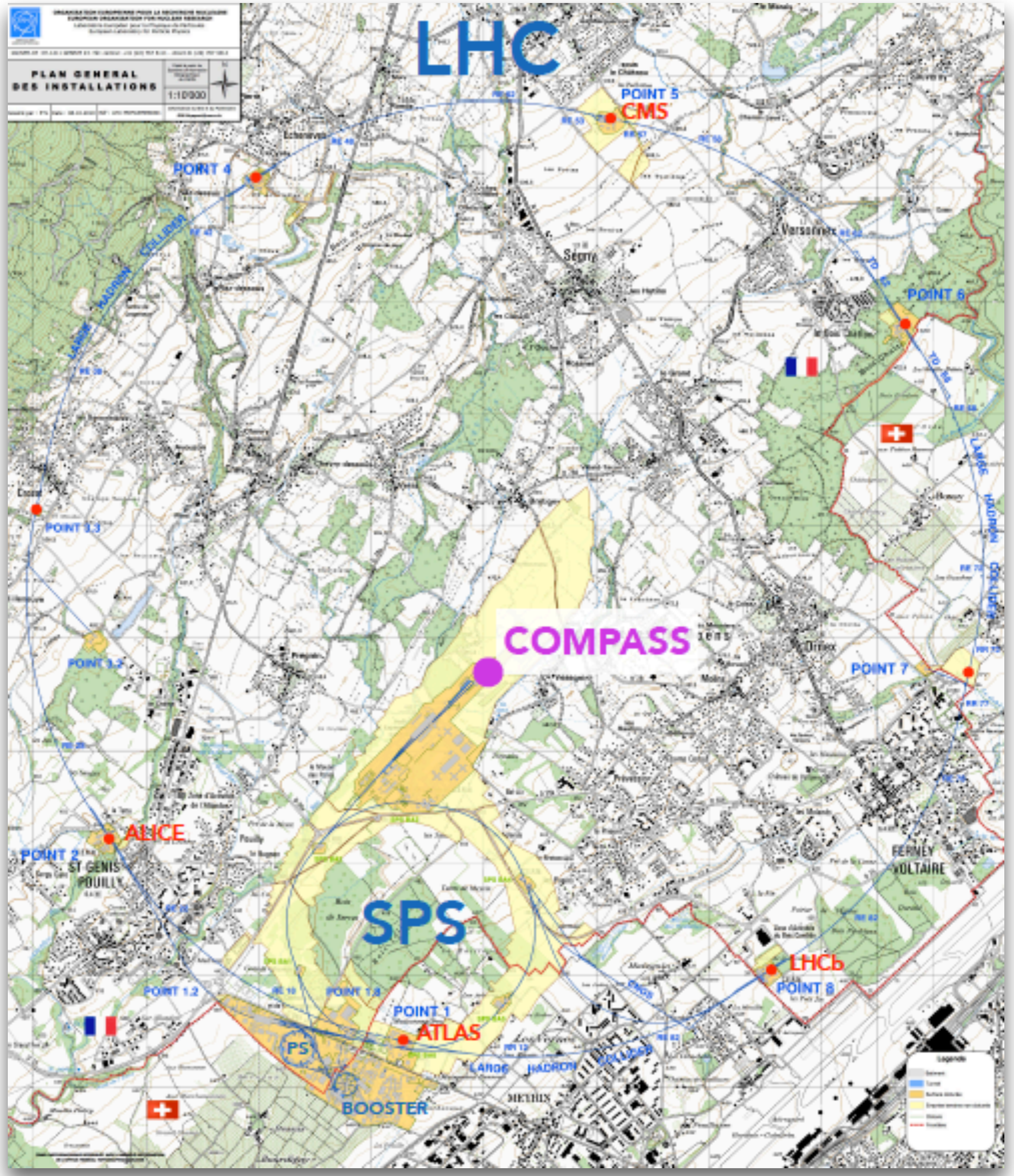
Availability of both hadron and muon (unique!) beams (M2 beam line)

Both beam charges available, and in wide range of energies (20-280 GeV/c)

Re-use of large aperture dipole magnets from COMPASS

Re-use of some of the most recent COMPASS detectors

Possible upgrade of the M2 beam line:
Using radio-frequency separation method, obtain kaon-enriched and antiproton-enriched beams



Approval of future experiments at CERN

CERN created in 2016 the Physics Beyond Colliders - PBC study group, with a mandate to prepare the next European HEP strategy update (2019-20) on projects for future CERN non-collider experiments.

Extract from the PBC mandate:
explore the opportunities offered by the CERN accelerator complex to address some of today's outstanding questions in particle physics through experiments complementary to high-energy colliders and other initiatives in the world.

http://pbc.web.cern.ch

AMBER* approval by RB on Dec. 2nd 2020

[…]

I am happy to inform you that the **AMBER proposal** was discussed at the Research Board yesterday, and was approved. This means that it will be assigned a new experiment reference number, likely to be NA66.

The actual beam time allocation will depend on arbitration with the other requests that are received, so will be subject to separate approval as part of the annual exercise of scheduling beam time.

This should be confirmed in the minutes of the Research Board, and I will let you know when they are available in the next month or so.

Best regards, Roger

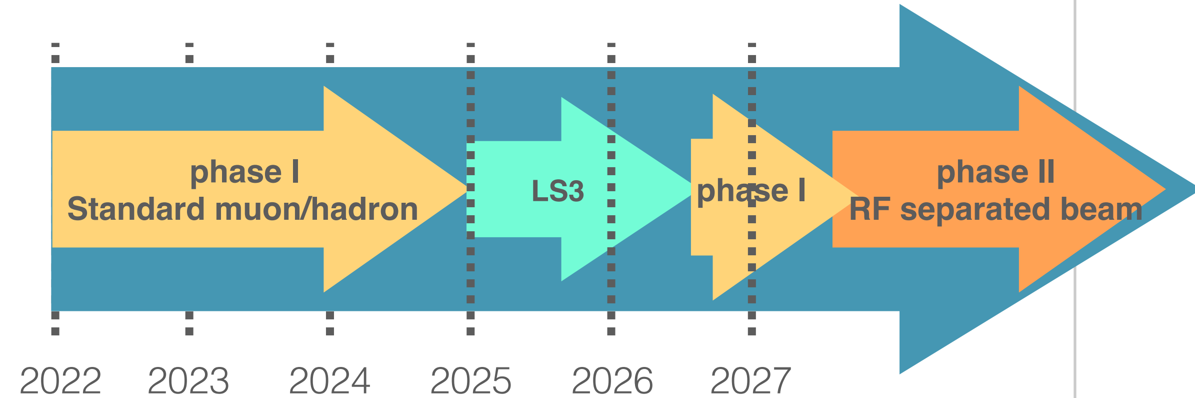
http://cds.cern.ch/record/2676885

AMBER physics program

Two phases program:

Phase 1 (shorter term) – current muon/hadron beam

Phase 2 (longer term) – RF-separated beam, after LS3



LOI complete program: phase 1 + phase 2

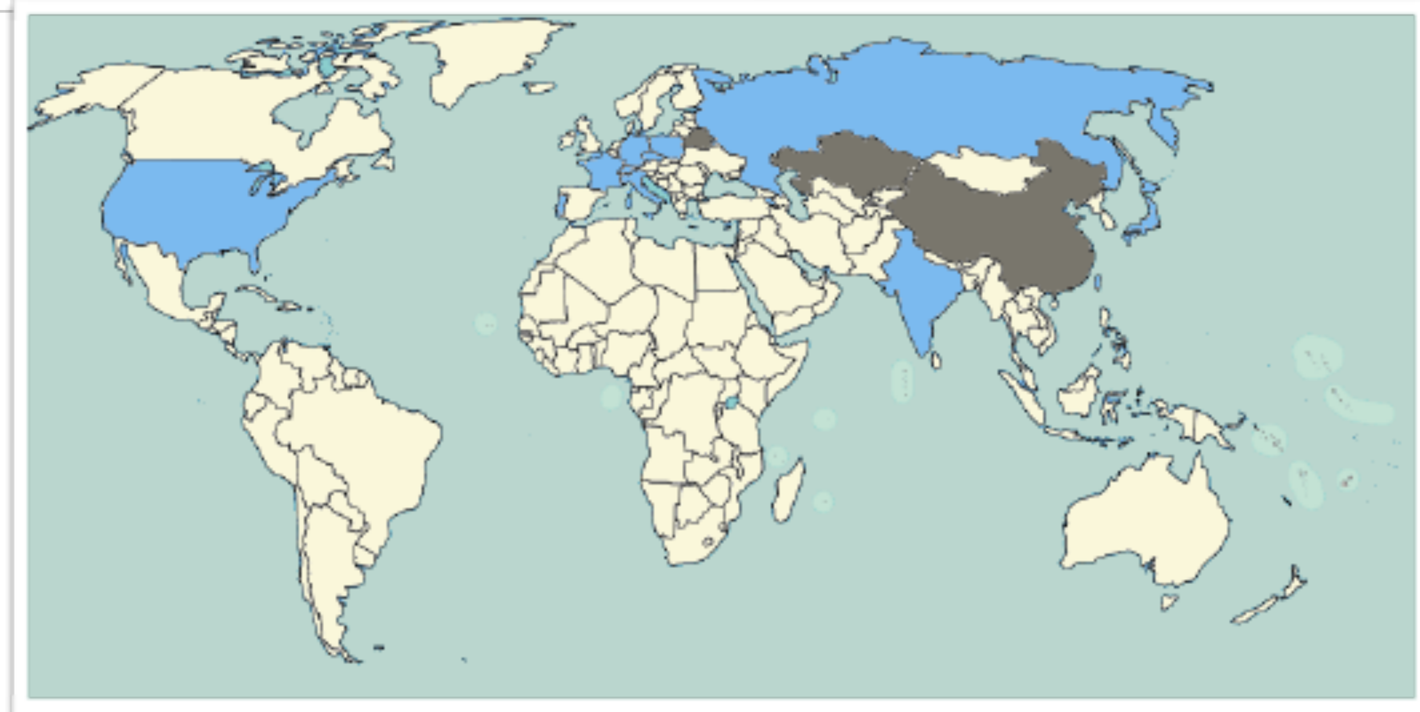
Program	Physics Goals	Beam Energy [GeV]	Beam Intensity $[s^{-1}]$	Trigger Rate [kHz]	Beam Type	Target	Earliest start time, duration	Hardware additions
muon-proton elastic scattering	Precision proton-radius measurement	100	$4 \cdot 10^6$	100	$\mu^\pm$	high-pressure H2	2022 2 years	active TPC, SciFi trigger, silicon veto,
Hard exclusive reactions	GPD E	160	$2 \cdot 10^7$	10	$\mu^\pm$	$NH_3^\uparrow$	2022 2 years	recoil silicon, modified polarised target magnet
Input for Dark Matter Search	$\overline{p}$ production cross section	20-280	$5 \cdot 10^5$	25	p	LH2, LHe	2022 1 month	liquid helium target
$\overline{p}$-induced spectroscopy	Heavy quark exotics	12, 20	$5 \cdot 10^7$	25	$\overline{p}$	LH2	2022 2 years	target spectrometer: tracking, calorimetry
Drell-Yan	Pion PDFs	190	$7 \cdot 10^7$	25	$\pi^\pm$	C/W	2022 1-2 years	
Drell-Yan (RF)	Kaon PDFs & Nucleon TMDs	$\sim$100	10^8	25-50	$K^\pm$, $\overline{p}$	$NH_3^\uparrow$, C/W	2026 2-3 years	"active absorber", vertex detector
Primakoff (RF)	Kaon polarisa-bility & pion life time	$\sim$100	$5 \cdot 10^6$	> 10	K^-	Ni	non-exclusive 2026 1 year	
Prompt Photons (RF)	Meson gluon PDFs	≥ 100	$5 \cdot 10^6$	10-100	$K^\pm$ $\pi^\pm$	LH2, Ni	non-exclusive 2026 1-2 years	hodoscope
K-induced Spectroscopy (RF)	High-precision strange-meson spectrum	50-100	$5 \cdot 10^6$	25	K^-	LH2	2026 1 year	recoil TOF, forward PID
Vector mesons (RF)	Spin Density Matrix Elements	50-100	$5 \cdot 10^6$	10-100	$K^\pm, \pi^\pm$	from H to Pb	2026 1 year	

Proposal program: phase 1

Year	Activity	Beam
2021	Proton radius test measurement	μ
2022	Proton radius measurement Antiproton production test measurement	μ p
2023	Antiproton production measurement Proton radius measurement	p μ
2024 2024+	Drell-Yan: pion PDFs and charmonium production mechanism	p, K^+, π^+, $\bar{p}, K^-, \pi^-$

a great variety of measurements to address fundamental issues of strong interactions in the medium and long-term future

A Collaboration ongoing



COMPASS + **AMBER**

- CERN
- Saclay, France
- Torino, Italy
- Trieste, Italy
- Lisbon, Portugal
- Aveiro, Portugal
- Bonn, Germany
- Munich, Germany
- Mainz, Germany
- Freiburg, Germany
- Bochum, Germany
- Prague, Czech Rep
- Kolkata, India
- Dubna, Russia
- Protvino, Russia
- Moscow, Russia
- Tel-Aviv, Israel
- Warsaw, Poland
- Yamagata, Japan
- Illinois, USA
- Taipei, Taiwan
- Tomsk, Russia
- Michigan, USA
- Chicago, USA
- Los Alamos, USA
- Tsinghua-Beijing, China
- Lanzhou, China
- Astana, Kazakhstan
- Bologna, Italy
- Trento, Italy
- Gatchina, Russia
- ...

A Collaboration ongoing

Proto-Collaboration board has been established:
nominations for 40 institutions completed
first collaboration board meeting took place on Nov. 24th 2020

Physics Program Coordinators have been appointed (Drell-Yan, Proton Radius, pbar xsec)

Technical Board established: in close collaboration with COMPASS TB to allow a smooth transition

MoU drafting group has been established, the goal is to have a Draft MoU in the summer 2021 and to finalise MoU by the end of 2021

First Collaboration Meeting will take place on May 6-7 2021

AMBER physics program

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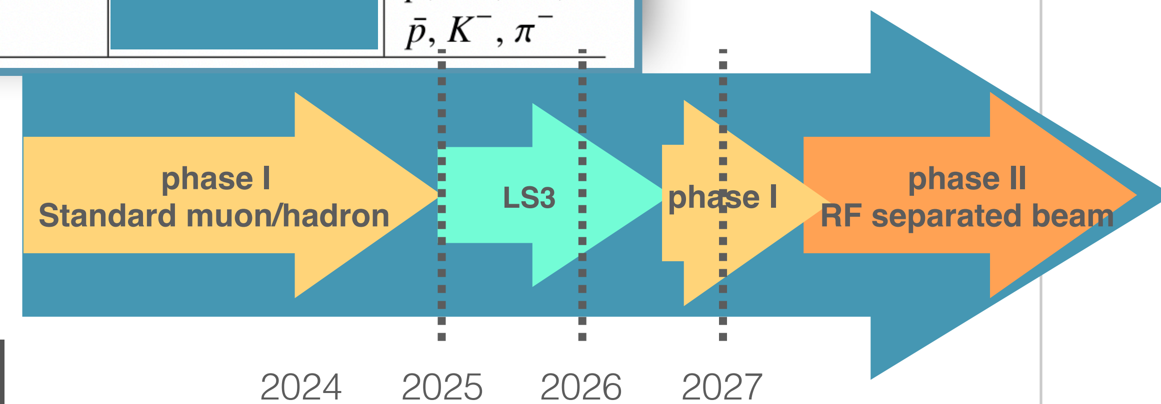


Hadron physics with muon beam

- Proton radius from muon-proton elastic scattering

Hadron physics with conventional hadron beams

- pbar production cross-sections for DM searches
- Pion structure from Drell-Yan and charmonium production

} Phase I

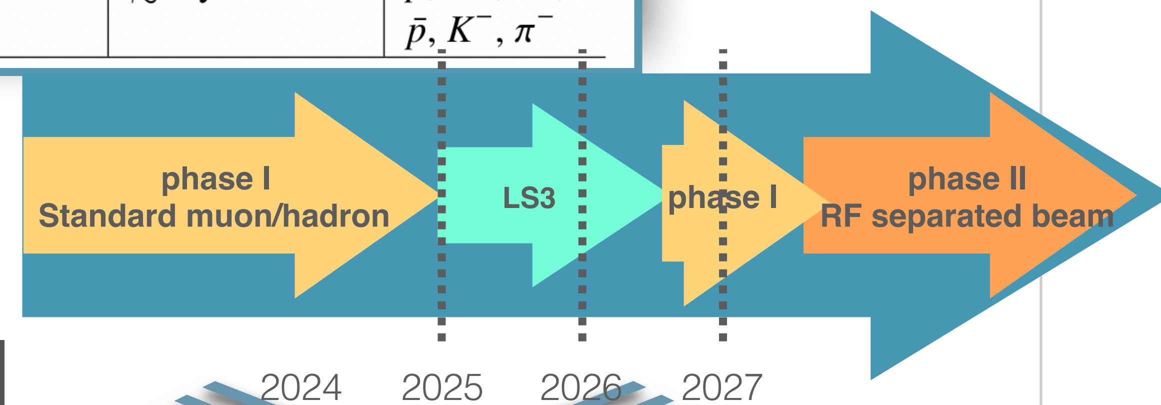
Hadron physics with RF-separated beams

- Kaon structure from Drell-Yan and direct photon production
- Spectroscopy of kaons
- Kaon polarizability from Primakoff reaction
- …

} Phase 2

AMBER physics program

Year	Activity	Duration	Beam
2021	Proton radius test measurement	20 days	μ
2022	Proton radius measurement Antiproton production test measurement	120 (+40) days 10 days	μ p
2023	Antiproton production measurement Proton radius measurement	20(+10) days 140 (+10) days	p μ
2024 2024+	Drell-Yan: pion PDFs and charmonium production mechanism	$\lesssim$ 2 years	p, K^+, π^+, $\bar{p}, K^-, \pi^-$



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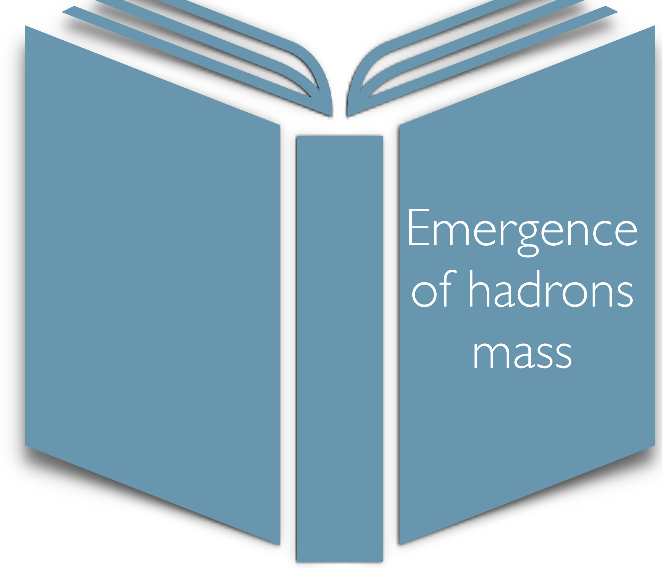
} Phase I

Hadron physics with RF-separated beams

- Kaon structure from Drell-Yan and direct photon production
- Spectroscopy of kaons
- Kaon polarizability from Primakoff reaction
- Pion and kaon-induced vector-meson production

} Phase 2



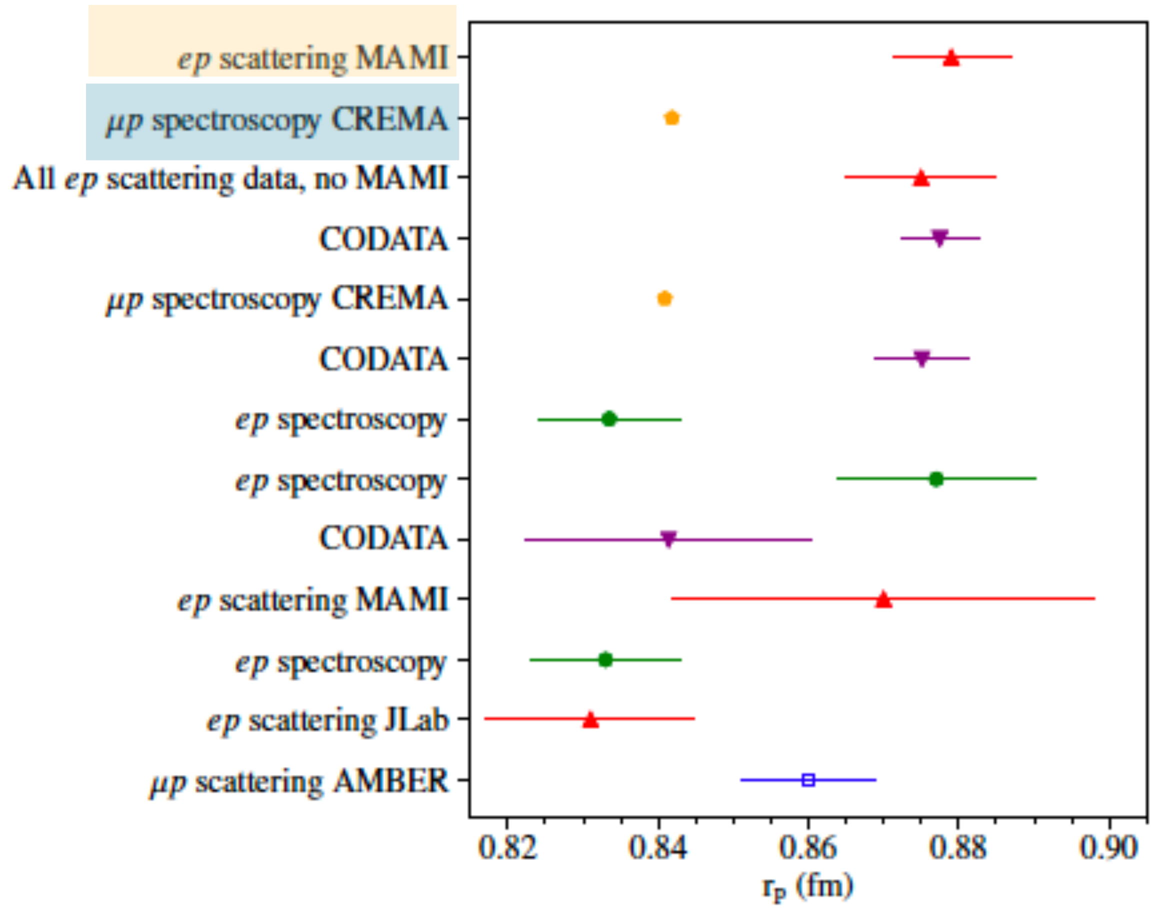
The proton radius puzzle

Data from atomic spectroscopy and lepton-proton scattering:

several experiments with different approaches measured the proton radius with contradicting results

Two significantly different values obtained → the proton-radius puzzle

The proton radius puzzle



- Hydrogen spectroscopy:
→ muonic or ordinary hydrogen
→ highest precision using laser spectroscopy
→ favoured value of (0.841±0.001) fm

- Electron-hydrogen scattering:
→ measurement using momentum transfer
→ recent data: MAMI A1 (2010) or JLab (2011)
→ favoured value of (0.879±0.008) fm
→ new in 2019: PRad value of (0.831±0.014) fm

	ep	μp
Spectroscopy	New measurements with ▪ lower systematics ▪ new transitions	✔
Scattering	New measurements with ▪ lower systematics ▪ reaching lower Q^2 ProRAD, ULQ2, ISR @ MESA, PRad	No data yet. MUSE at PSI coming soon

The proton radius puzzle

Proposal of a new measurement

Measurement of the cross section of high-energy elastic muon-proton scattering:

- Measure as close as possible to Q2 = 0
- Sufficient range to determine radius:

→ Aimed precision of below 1 %

→ Aimed Q2-range: 0.001 - 0.04 GeV2/c2

$$<r_p^2> = -6\hbar^2 \cdot \frac{dG_E(Q^2)}{dQ^2}\bigg|_{Q^2\to 0}$$

$$\frac{d\sigma^{\mu p\to\mu p}}{dQ^2} = \frac{4\pi\alpha^2}{Q^4}R\left(\epsilon G_E^2 + \tau G_M^2\right) \qquad \epsilon = \frac{E_\mu^2 - \tau\left(s - m_\mu^2\right)}{\vec{p}_\mu^{\,2} - \tau\left(s - 2m_p^2(1+\tau)\right)} \qquad \tau = \frac{Q^2}{(4m_p^2)}$$

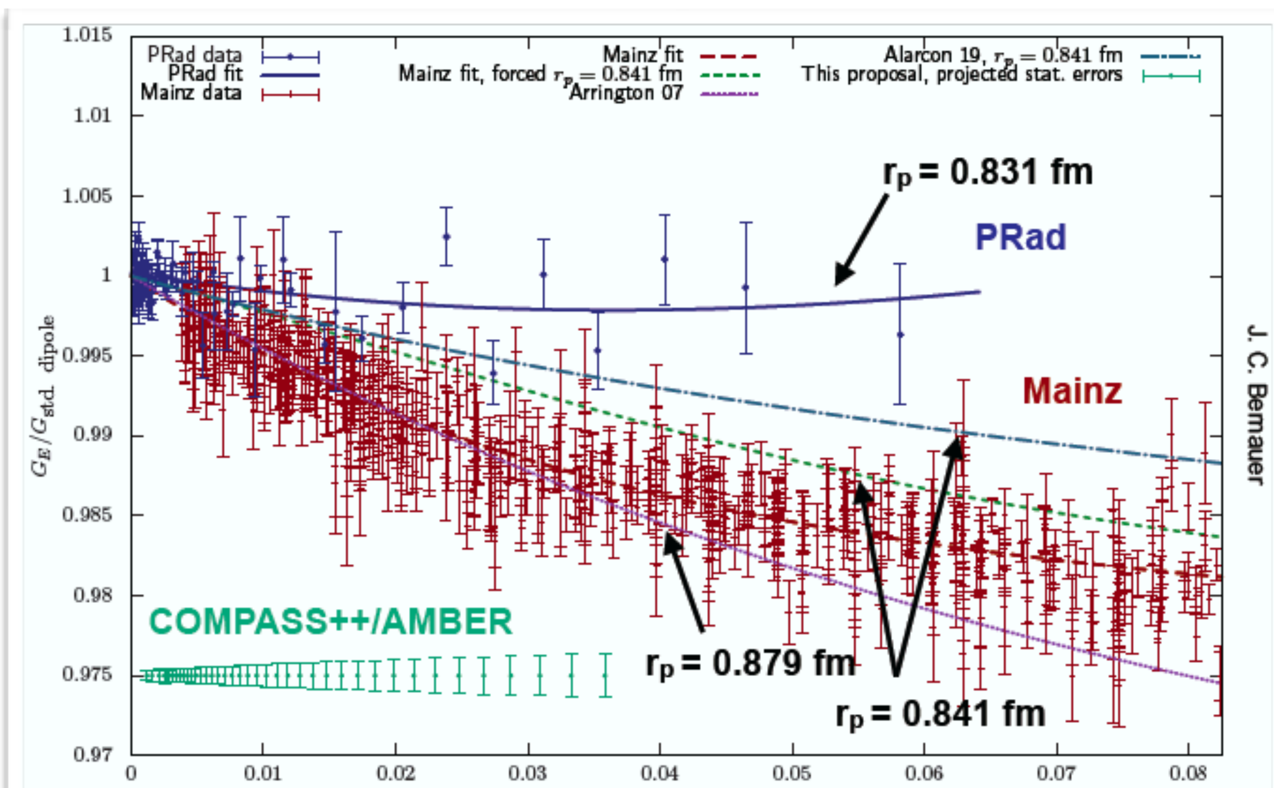
- Suppress magnetic form factor G_M^2
  → Requires $\tau \to 0$
  → Measurement at low-Q^2 values of $\mathcal{O}(<10^{-2})$
- Measurement at high-energy $\mathcal{O}$(10 - 100 GeV)
  → Results in $\varepsilon \to 1$
  → Cross-section directly proportional to G_E^2

- Deviation between previous data-sets:

→ Mainz and PRad: Q2 > 0.01 GeV2/c2

→ Inconsistency with other radii extractions

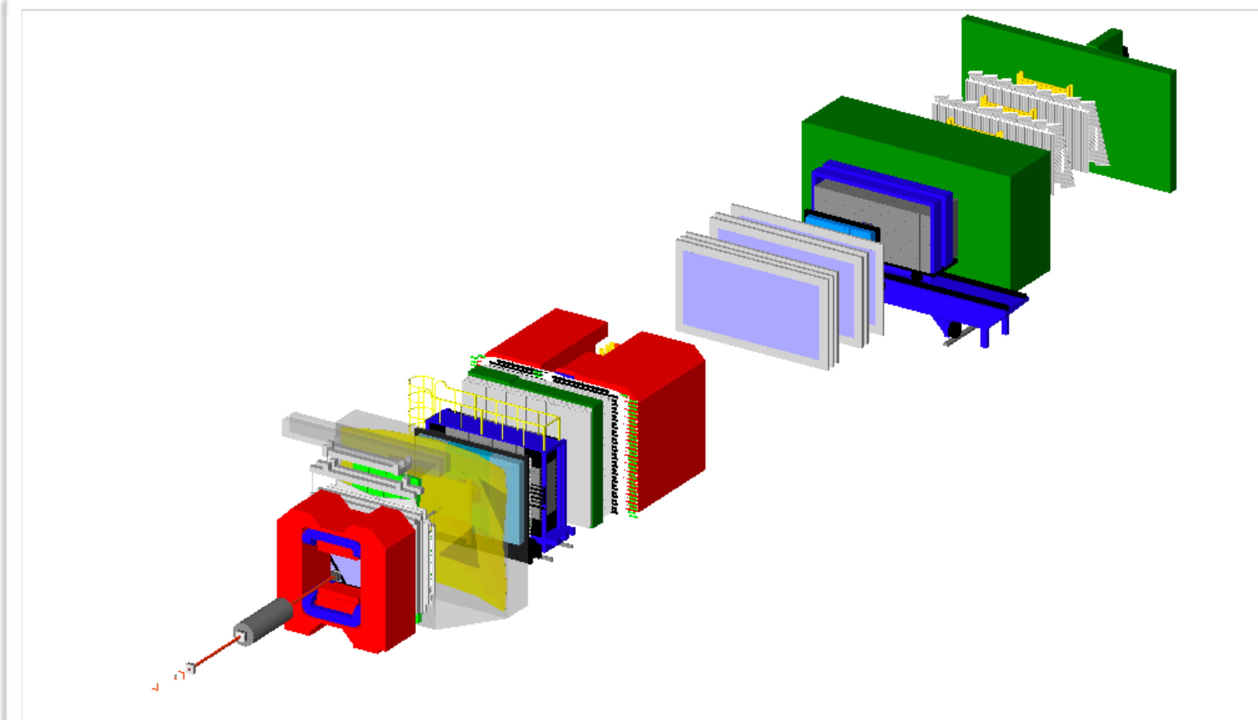
- Goal: Understanding of this situation

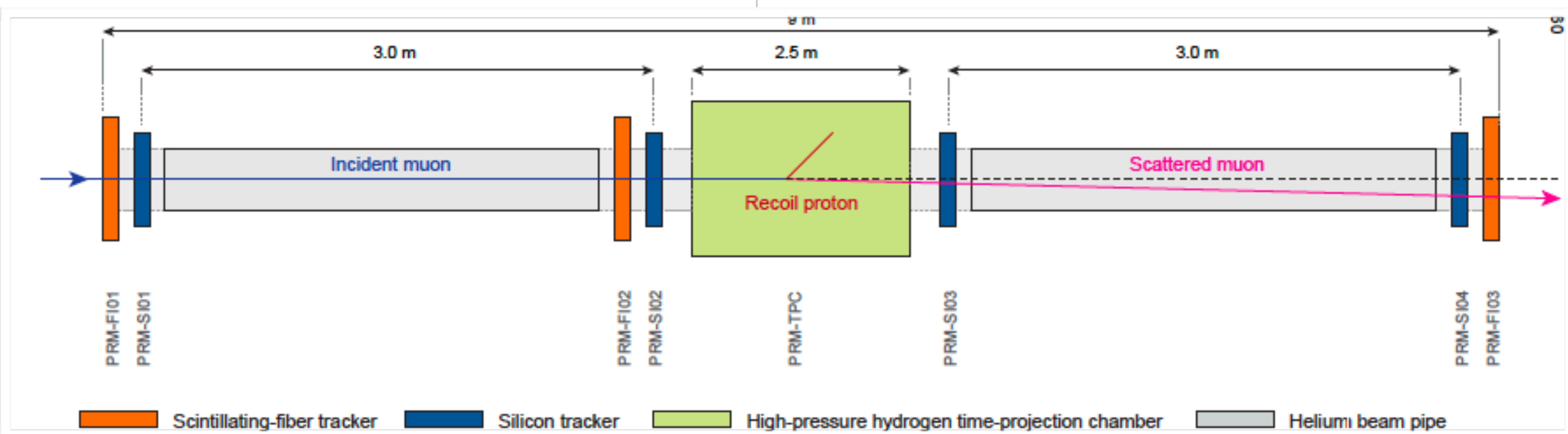


Layout of Proton-Radius Measurement in 2022

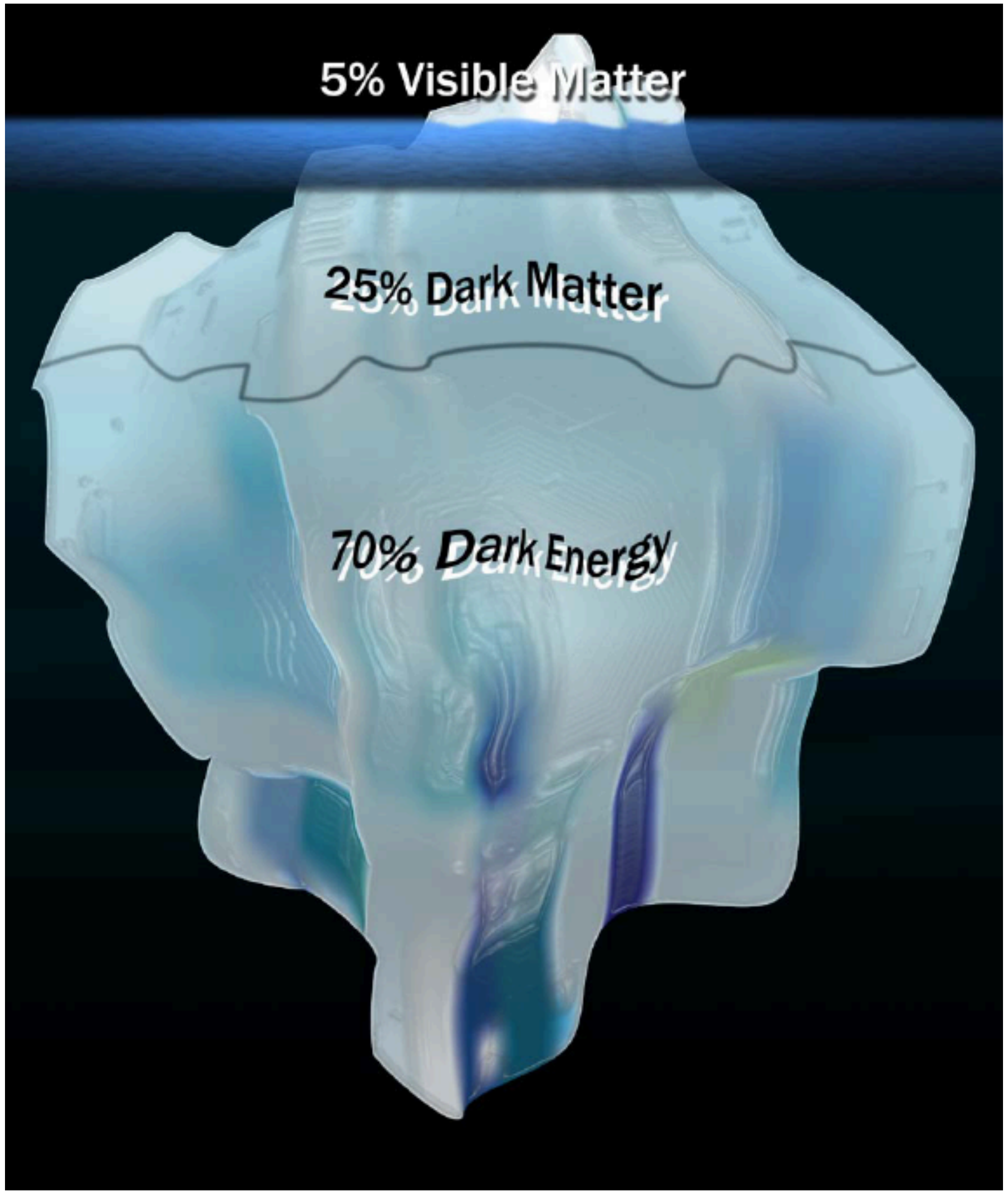
Measurement of low-Q2 elastic-scattering Detection of low-energetic recoil-protons and scattered muons with small scattering-angle.

- Silicon trackers along large leaver-arm to measure small scattering-angles
- Fiber tracker timing and trigger (fallback)
- TPC as an active target with the ability to measure the low-energetic recoil-proton
- New continuously-running DAQ





Dark matter searches: where can we help?



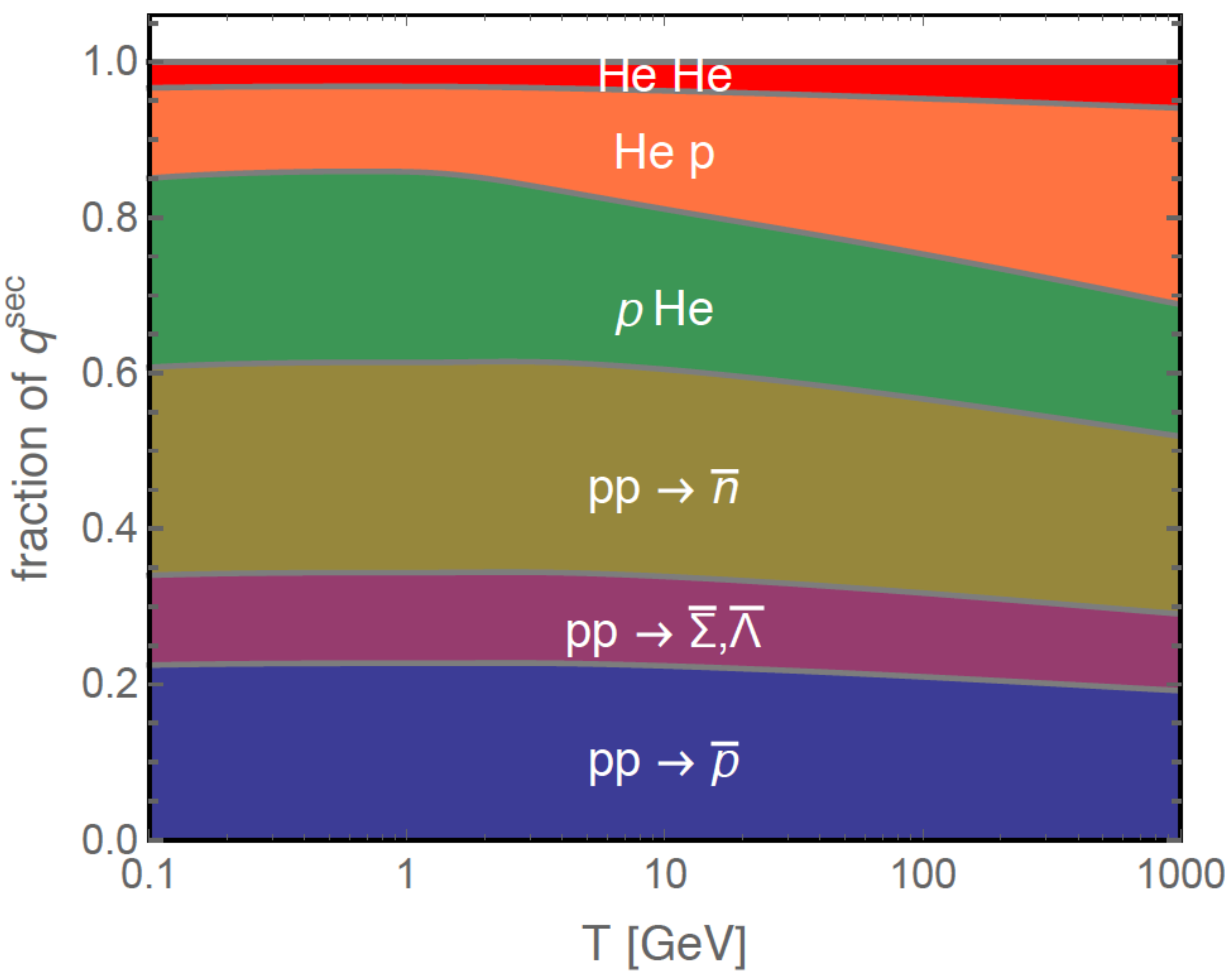
Empirical evidence indicates that Dark Matter constitutes the vast majority of all matter in the Universe; but its origin and nature are completely unknown.

Weakly interacting massive particles (WIMPs) present the most appealing solution to these puzzles.

The indirect detection of DM is based on the search for the products of DM annihilation or decay.

In particular cosmic-ray antimatter components promise to provide sensitivity to DM annihilation products on top of the standard astrophysical production.

Dark matter searches: where can we help?



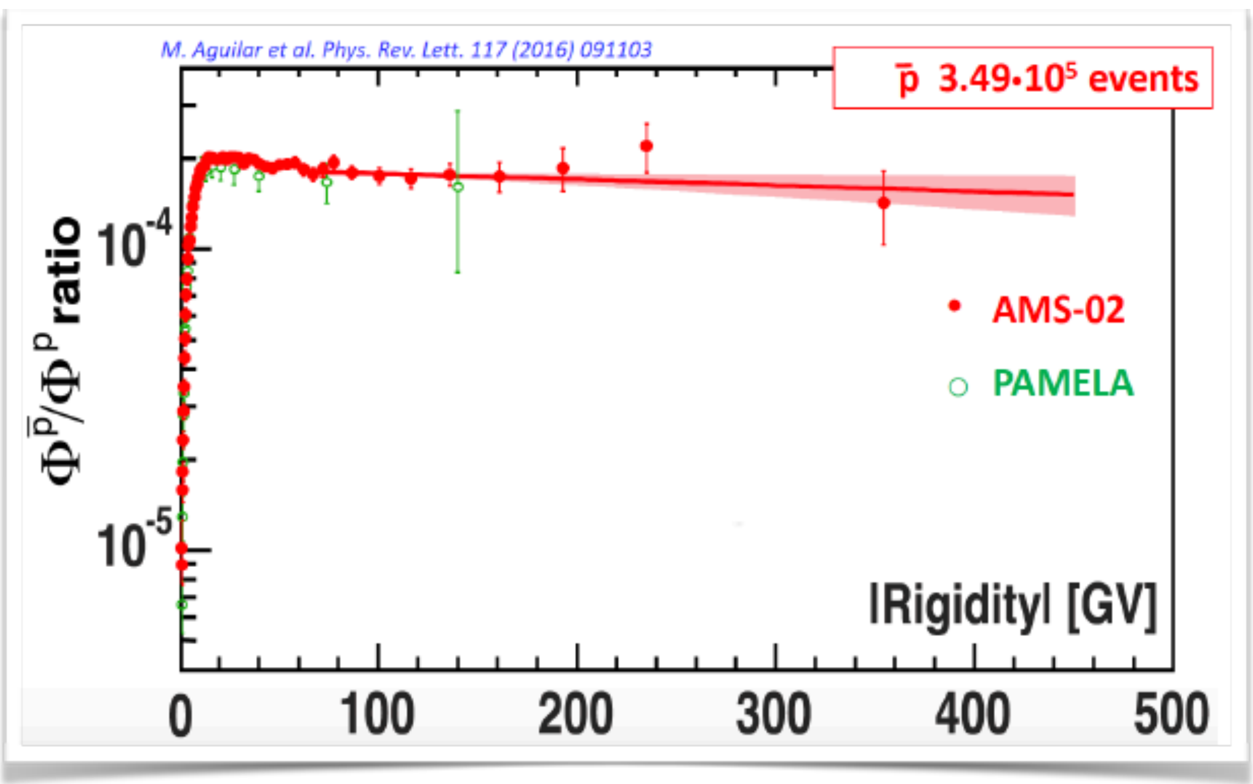
- an accurate prediction of the expected anti-p flux in cosmic rays in the rigidity range from few GeV to several hundreds of GeV is interesting to understand cosmic ray and possibly search for signals of new physics
- anti-p production cross section from p-p and p-He interactions is poorly measured and cannot simply constrained from available measurements
- we want to perform a measurement with the SPS protons between 50 and 280 GeV/c on fixed LH2 and LHe targets, and a magnetic spectrometer

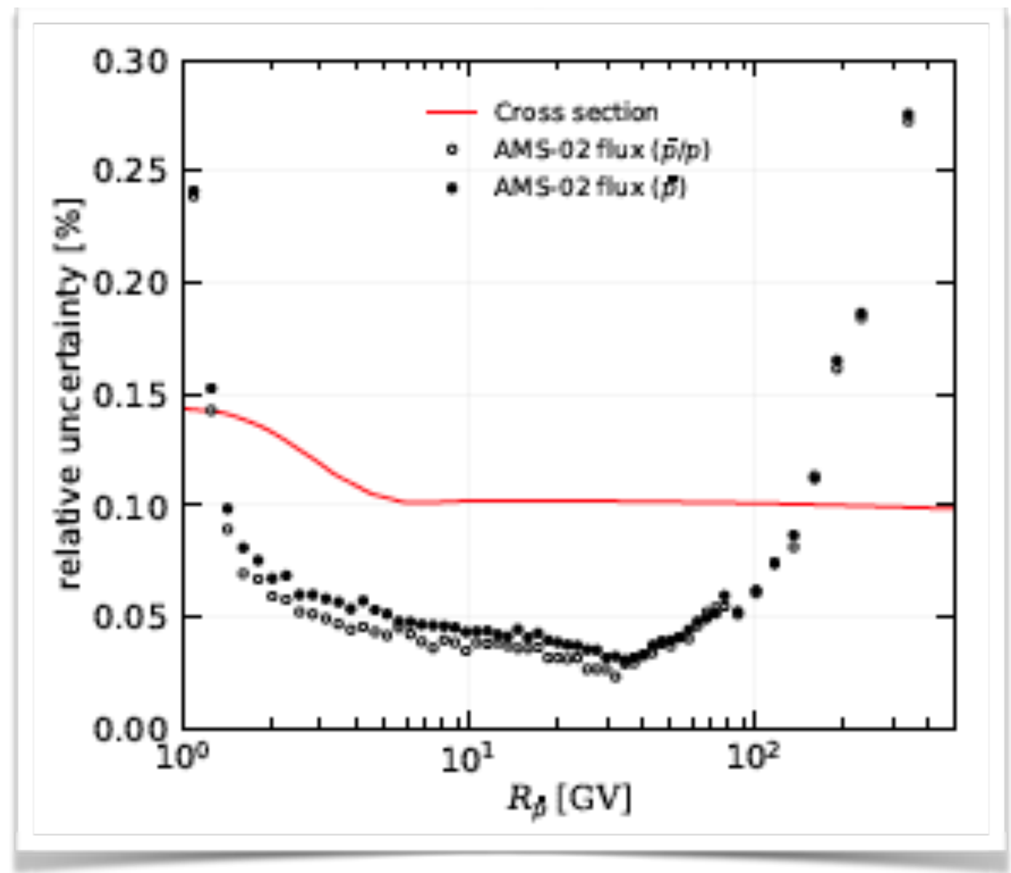
Dark matter searches: where can we help?

Two major uncertainties limit the prediction of the anti-p flux from CR interaction with ISM

• production cross sections p-p -> pbar +X p-He-> pbar + X

• CR propagation in the galaxy





pbar xsec measurement @AMBER

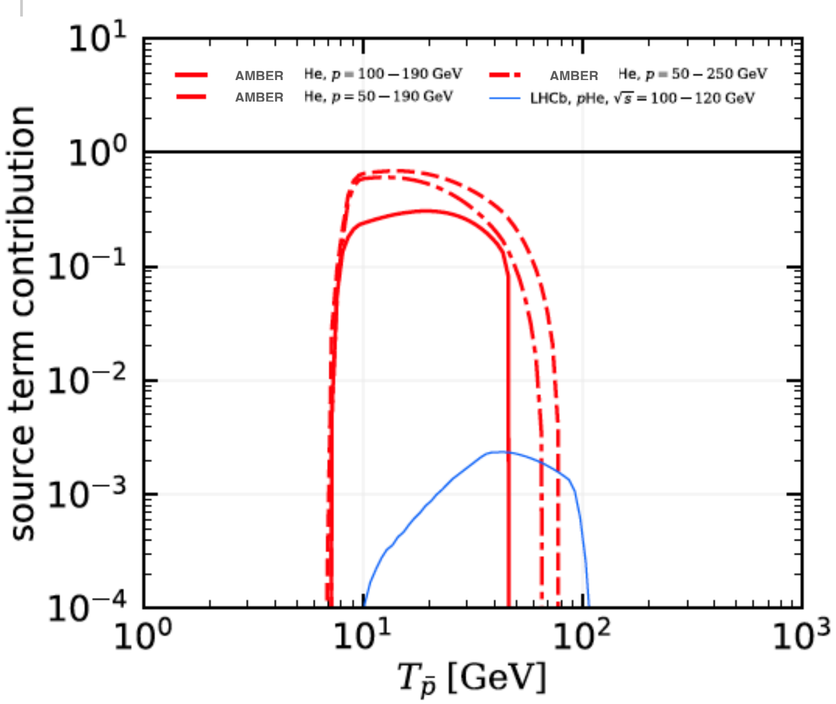
Relevance of the measurement

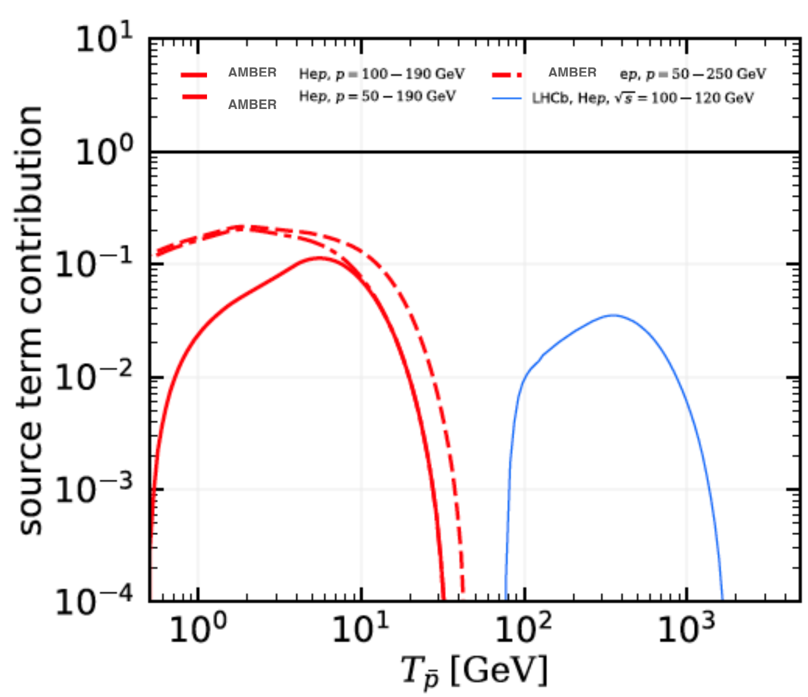
Measurement performed at 7 TeV p-He -> pbar + X (*LHCb-CONF-2017-002*)

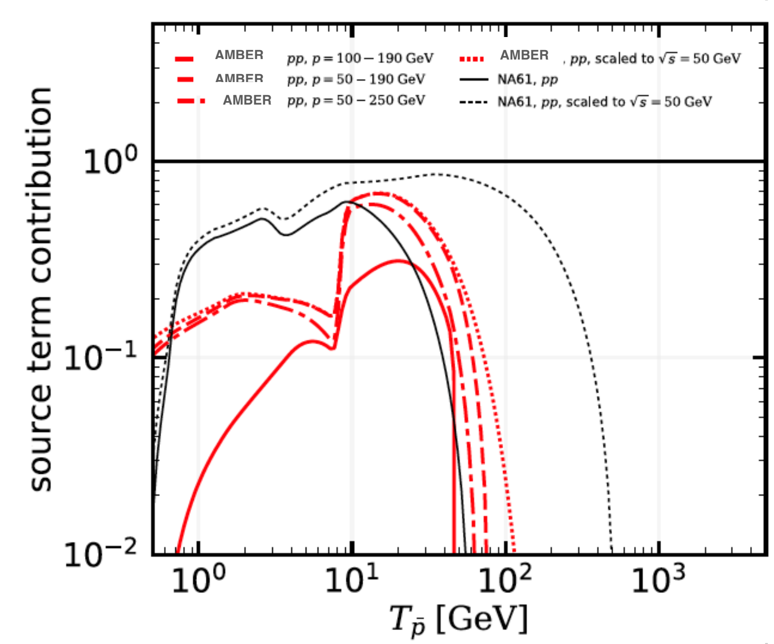
NA61 p+p data beam momenta of 20, 31, 40, 80, and 158 GeV/c (*Eur. Phys. J. C 77, 671 (2017)*)

p-He He-p source term coverage

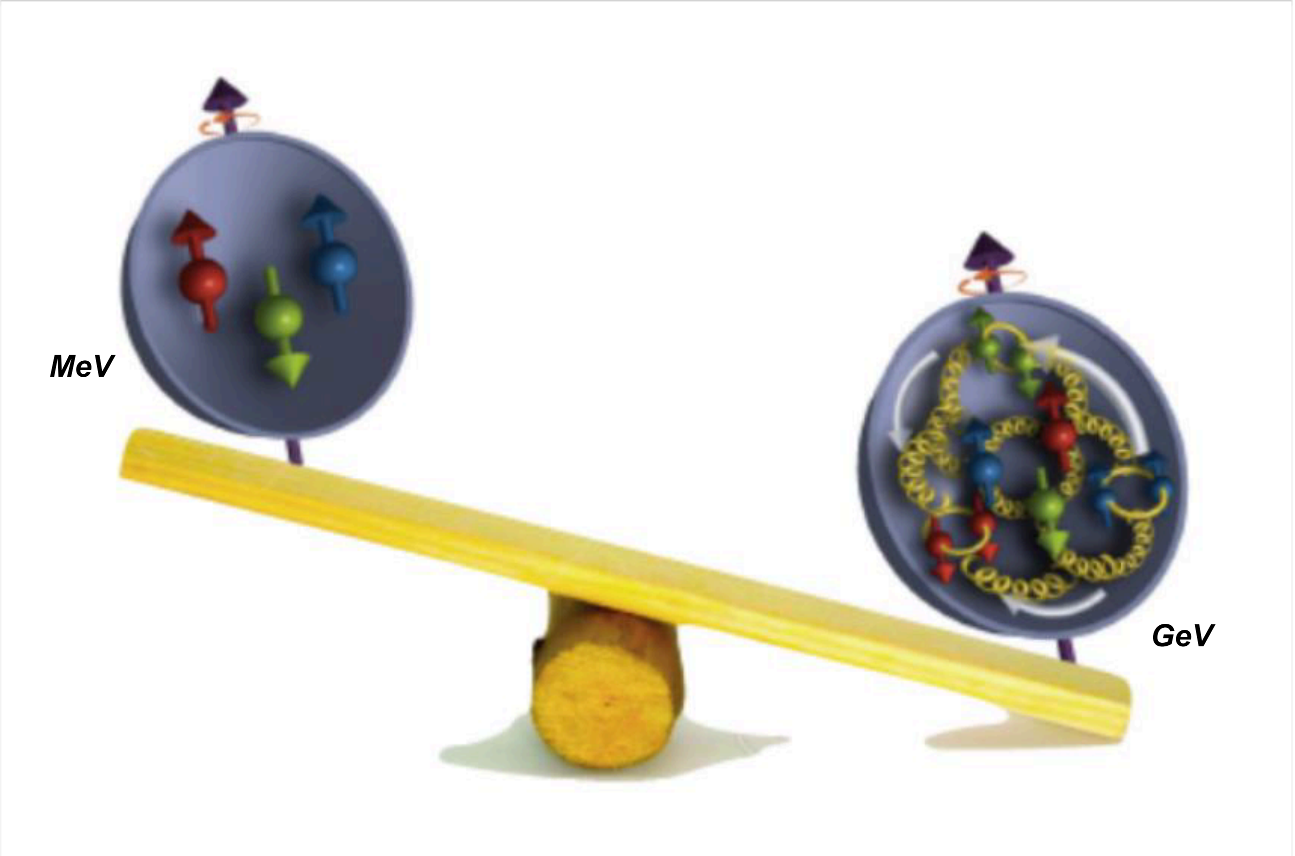
p-p source term coverage







Emergence of hadron mass

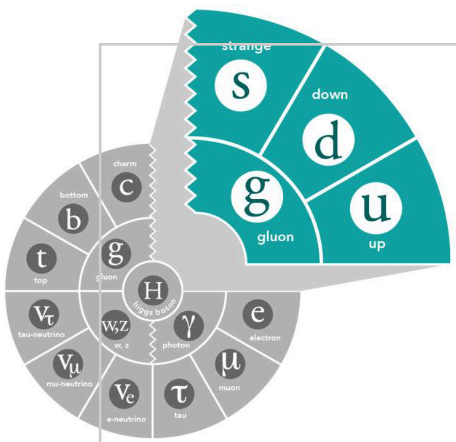


two mass generating mechanisms in the SM:

- One is related to the Higgs boson and fairly well understood
- The other is embedded in QCD:

although responsible for emergence of the roughly 1 GeV mass scale that characterises the proton and hence all observable matter, the source and impacts of this emergent hadronic mass (EHM) remain puzzling

Emergence of hadron mass



Visible world: mainly made of light quarks – its mass emerges from quark-gluon interactions
Higgs mechanism produces only a small fraction of all visible mass

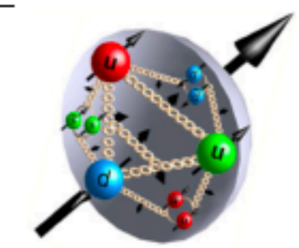
Pion

- $M_\pi \sim$ 140MeV
- Spin 0
- 2 light valence quarks

Kaon

- $M_K \sim$ 490MeV
- Spin 0
- 1 light and 1 "heavy" valence quarks

Proton



- $M_p \sim$ 940MeV
- Spin 1/2
- 3 light valence quarks

Higgs generated masses of the valence quarks:

M(u+d)~ 7 MeV   M(u+s)~ 100 MeV   M(u+u+d)~ 10 MeV

Pion

Quark structure: ud
Mass ~ 140 MeV
Exists only if mass is dynamically generated.
Empty or full of gluons?

Kaon

Quark structure: us
Mass ~ 490 MeV
Boundary between emergent- and Higgs-mass mechanisms.
More or less gluons than in pion?

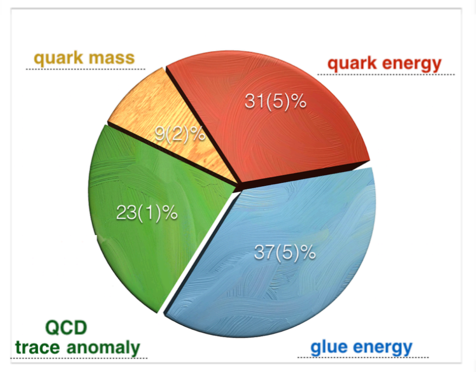
Proton

Quark structure: uud
Mass ~ 940 MeV (~1 GeV)
Most of mass generated by dynamics.

Gluon rise discovered by HERA e-p

Emergence of hadron mass

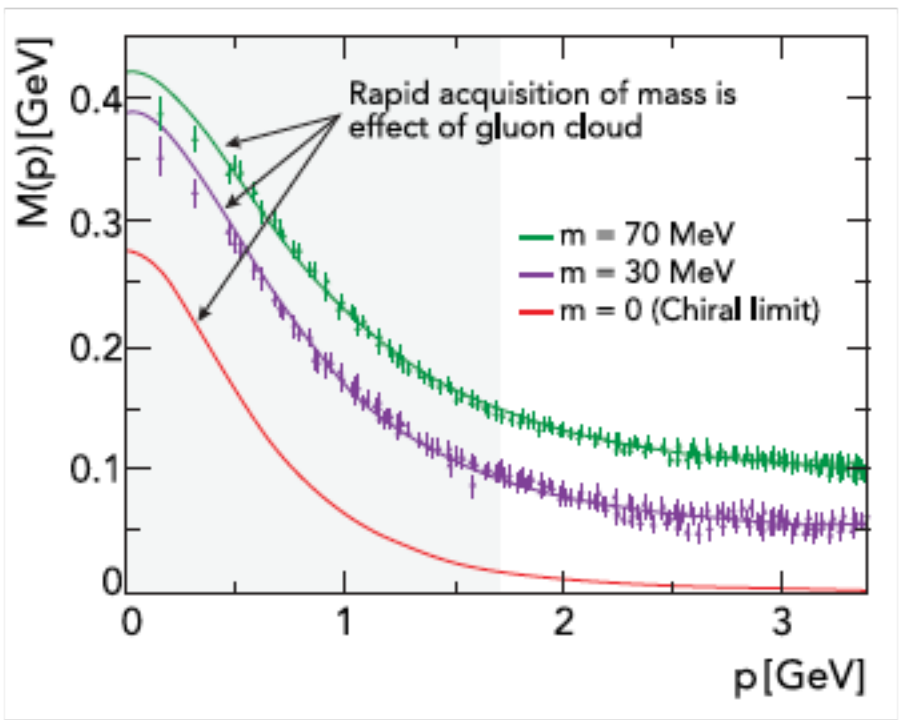
In the chiral limit proton mass is about 1/3 of its nominal mass; using a parton model basis: the entirety of the proton mass is produced by gluons and due to the trace anomaly



In the chiral limit pion is massless as Nambu-Goldstone boson

What does it mean?

Does the meson gluons disappear in the chiral limit and thus contribute nothing to the pion mass?



This is unlikely as quarks and gluons still dynamically acquire mass – this is a universal feature in hadrons – so more likely a cancellation of terms leads to "0"

Need to study pion and kaon PDFs

Pion –Kaon comparisons great place to study interference between the Standard Model's two mass-generating mechanisms

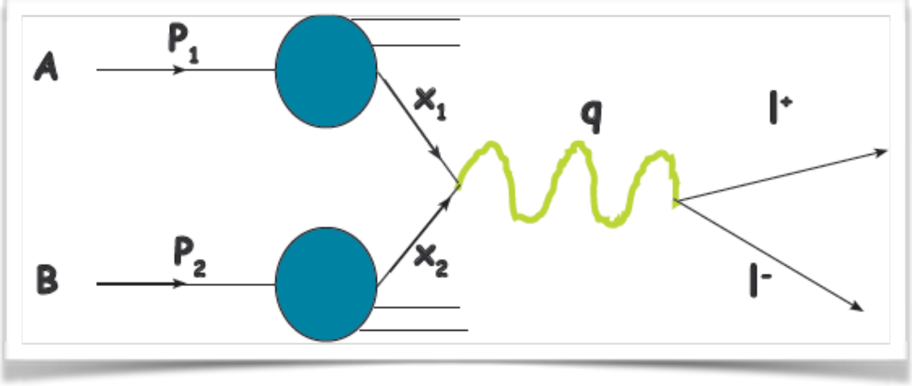
Emergence of hadron mass

Questions to be answered:

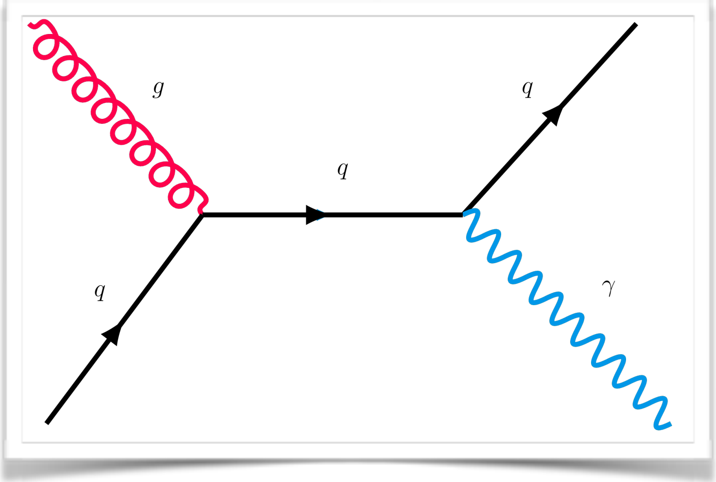
- Mass difference pion/proton/kaon
- Mass generation mechanism (emergent mass .vs. Higgs)
- Gluon content, especially important pion/kaon striking difference

Experimental access @AMBER (with pion and kaon beams):

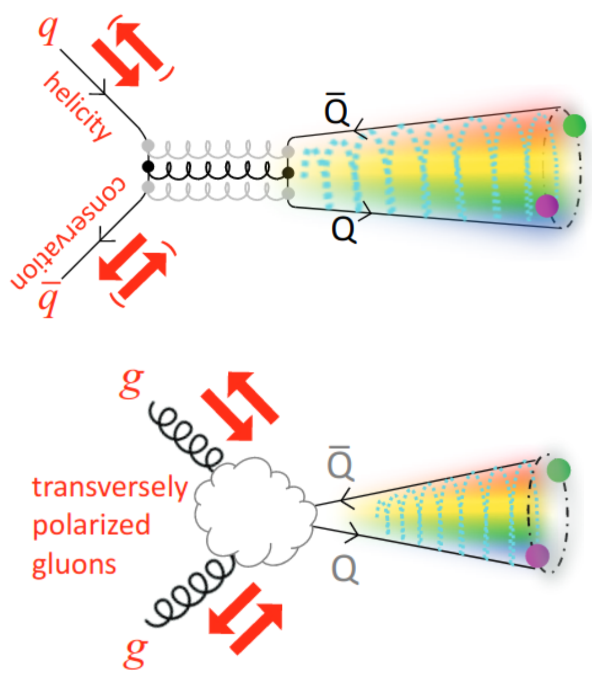
- Drell-Yan



- Prompt-photon production



- Charmonium production



What do we know about pion structure?

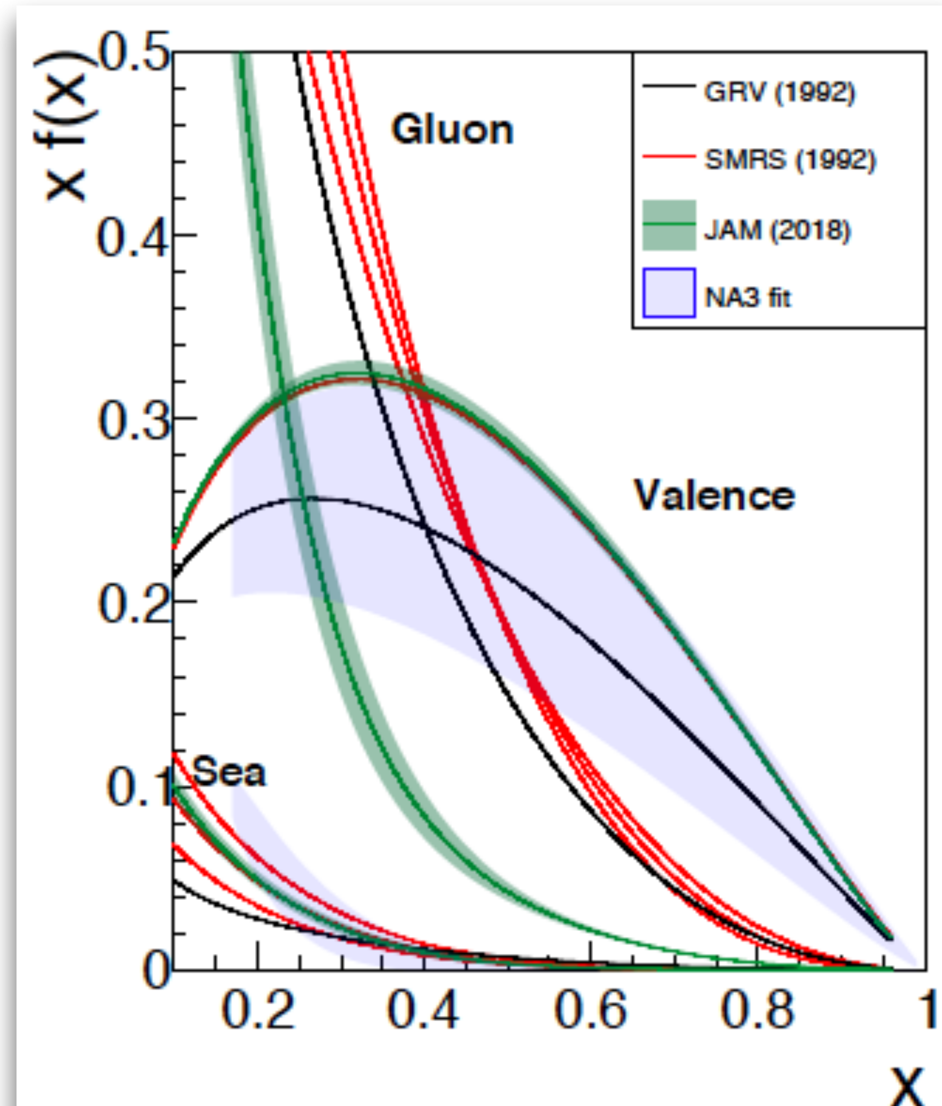
Pion-induced Drell-Yan data collected by NA3, NA10, WA39 (CERN) and E615 (Fermilab), more than 30 years ago —> access valence and sea (NA3 and WA39) distributions in the pion

Available data from direct-photon production also obtained at that time, by WA70 and NA24(CERN)

limited data sets —> sea quark distribution was derived from momentum-sum-rule conservation

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

JAM set - production of leading neutrons in DIS at HERA (ZEUS, H1)



GRV/S Z. Phys. C53 (1992) 651–656. ; Eur. Phys. J. C10 (1999)
SMRS Phys. Rev. D45 (1992) 2349–2359; Phys. Rev. Lett. 121 (2018) 152001
NA3 Z. Phys. C18 (1983) 281

Pion-induced Drell-Yan: experimental access to pion structure

- Mostly heavy target
—> nuclear effects
- Some did not publish cross-sections
- Limited data sets
—> sea quark distribution was derived from momentum-sum-rule conservation
- Some did not measure with both beam charges
—> no sea/valence separation

Isoscalar target

Both beam charges

High statistics

Experiment	Target type	Beam energy (GeV)	Beam type	Beam intensity (part/sec)	DY mass (GeV/c^2)	DY events
E615	20cm W	252	π^+ π^-	17.6×10^7 18.6×10^7	4.05 – 8.55	5,000 30,000
NA3	30cm H_2	200	π^+ π^-	2.0×10^7 3.0×10^7	4.1 – 8.5	40 121
	6cm Pt	200	π^+ π^-	2.0×10^7 3.0×10^7	4.2 – 8.5	1,767 4,961
NA10	120cm D_2	286 140	π^-	65×10^7	4.2 – 8.5 4.35 – 8.5	7,800 3,200
	12cm W	286 140	π^-	65×10^7	4.2 – 8.5 4.35 – 8.5	49,600 29,300
COMPASS 2015 COMPASS 2018	110cm NH_3	190	π^-	7.0×10^7	4.3 – 8.5	35,000 52,000
AMBER	100cm C	190	π^+	1.7×10^7	4.3 – 8.5 3.8 – 8.5	23,000 37,000
		190	π^-	6.8×10^7	4.3 – 8.5 3.8 – 8.5	22,000 34,000
	24cm W	190	π^+	0.2×10^7	4.3 – 8.5 3.8 – 8.5	7,000 11,000
		190	π^-	1.0×10^7	4.3 – 8.5 3.8 – 8.5	6,000 9,000

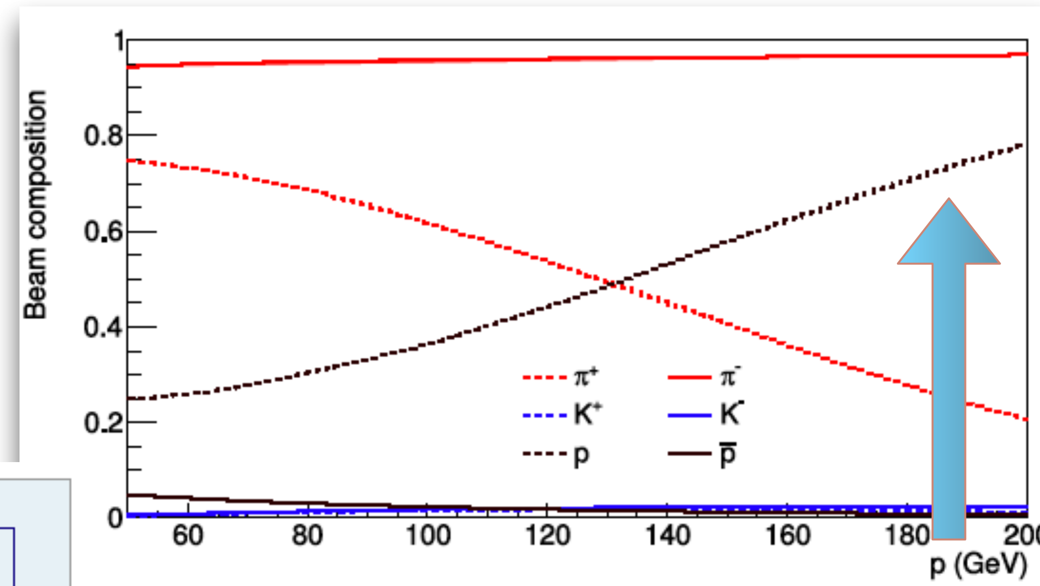
pion-induced Drell-Yan @AMBER

- High energy and intensity pion beams

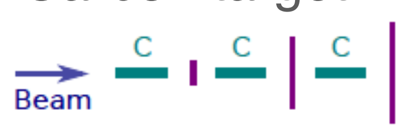
Example @ 190 GeV/c

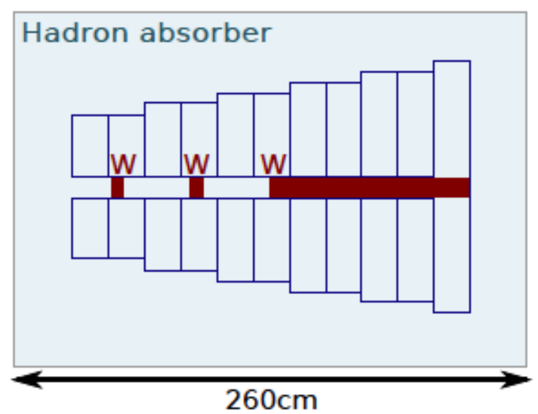
$I_{\pi^-} \sim I_{beam} = 7.0 \times 10^7/s$

$I_{\pi^+} \sim 25\% \, I_{beam} = 1.7 \times 10^7/s$



- COMPASS-like apparatus
- Segmented Carbon target





- Flavour dependent nuclear PDFs

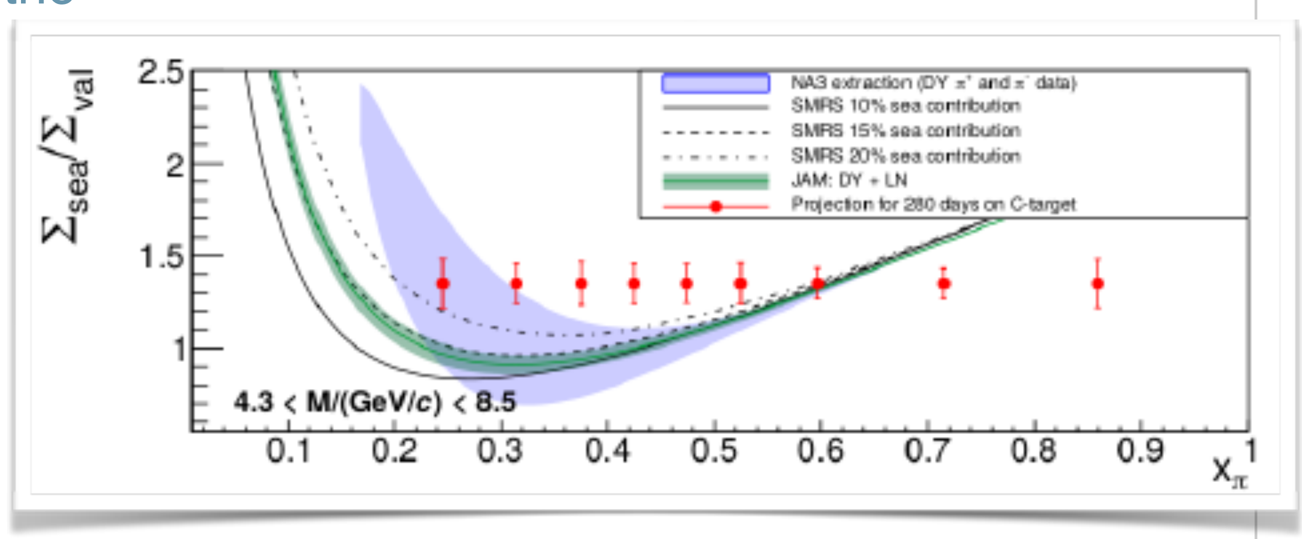
  Positive and negative pion beam on Carbon and Tungsten target

- Aim at the first precise direct measurement of the pion sea contribution

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

→ LO: only sea-val and val-sea terms (numerator)

→ LO: only val-val terms (denominator)



what can we learn from J/ψ production?

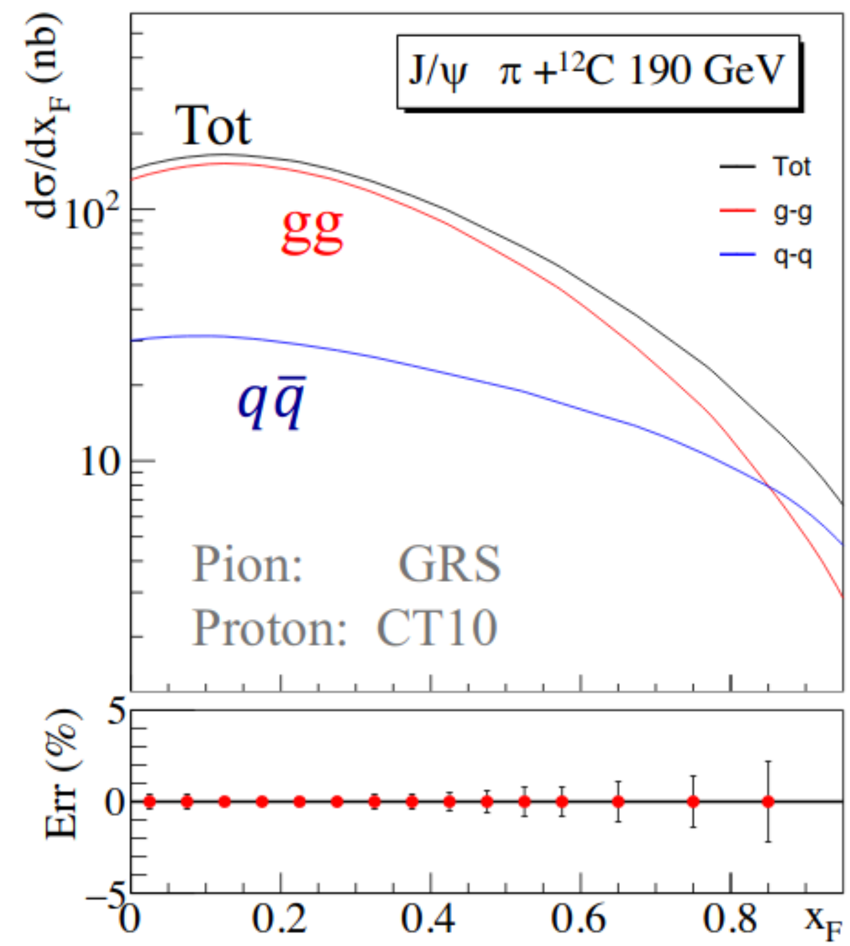
Two main mechanisms of J/ψ production in hadron collisions: gg → gJ/ψ and q̄q → J/ψ

1) test of charmonia production mechanisms: CEM vs NRQCD

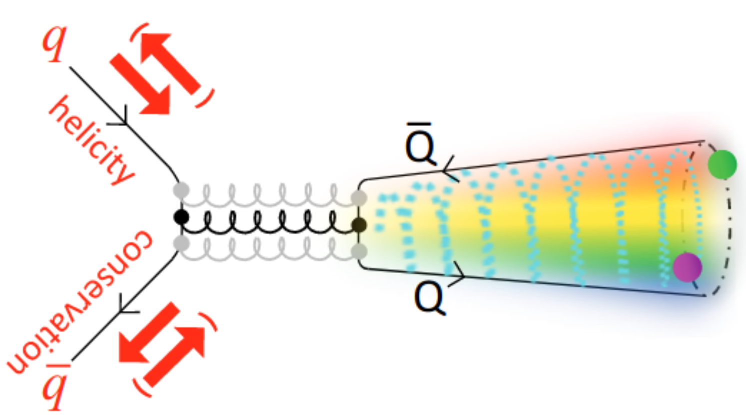
2) Model-dependent separation of gg and qq contributions using data collected with both positive and negative beams

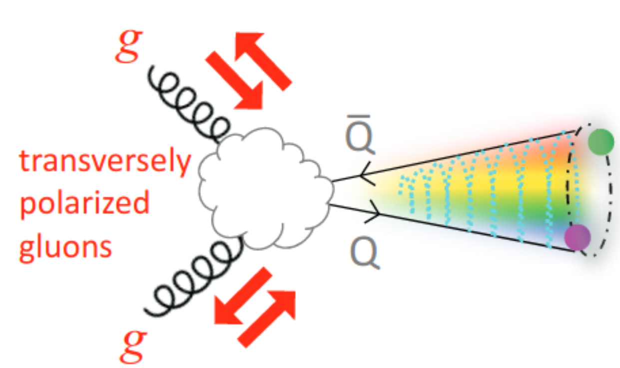
3) probe of gluon and quark PDFs

@AMBER: large statistics J/ψ production at dimuon channel, differential cross-section measurements, low-pT regime, expected significant feed-down: ψ(2S), χc1, χc2



Color Evaporation Model (ICEM)
Cheung and Vogt, PRD98, 114029 (2018)
and priv. comm.



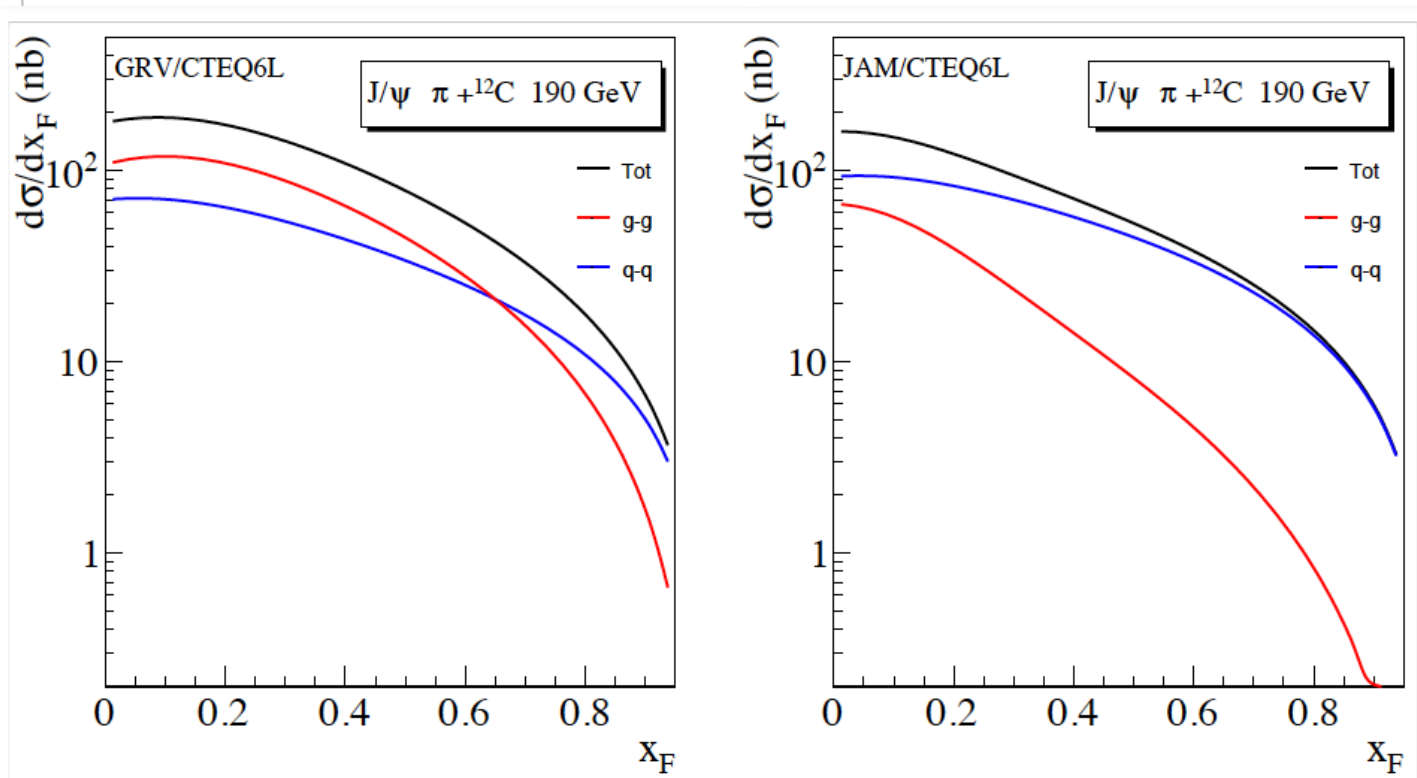


what can we learn from J/ψ production?

In the energy domain of AMBER and for sufficiently high xF values, the qq¯ component has a magnitude comparable or larger to that of the gg component.

The relative amount of both components is given by the overall amplitude and shape of the corresponding quark and gluon densities in the Bjorken x region between 0.05 and 0.95 for the pion and between 0.05 and 0.4 for the nucleon.

Since the nucleon PDFs are well known, the data may be used to infer the gluon distribution in the pion, obviously within the uncertainties of the hadronization model.



Experiment	Target type	Beam energy (GeV)	Beam type	J/ψ events
NA3 [76]	Pt	150	π^-	601000
		280	π^-	511000
		200	π^+	131000
			π^-	105000
E789 [129, 130]	Cu	800	p	200000
	Au			110000
	Be			45000
E866 [131]	Be, Fe, Cu	800	p	3000000
NA50 [132]	Be	450	p	124700
	Al			100700
	Cu			130600
	Ag			132100
	W			78100
NA51 [133]	p	450	p	301000
	d			312000
HERA-B [134]	C	920	p	152000
COMPASS 2015	110 cm NH_3	190	π^-	1000000
COMPASS 2018				1500000
AMBER	75 cm C	190	π^+	1200000
			π^-	1800000
			p	1500000
	12 cm W	190	π^+	500000
			π^-	700000
			p	700000

What do we know about kaon structure?

Kaon structure: a window to the region of interference between Higgs mechanism and EHM mechanism

Sole measurement from NA3

J. Badier et al., PLB93 354 (1984)

- Limited statistics: 700 events with K^-
- Mostly only model predictions

Interesting hint: At hadronic scale gluons carry only 5% of K's momentum vs 30% in π

- Scarce data on u-valence
- No measurements on gluons
- No measurements on sea quarks

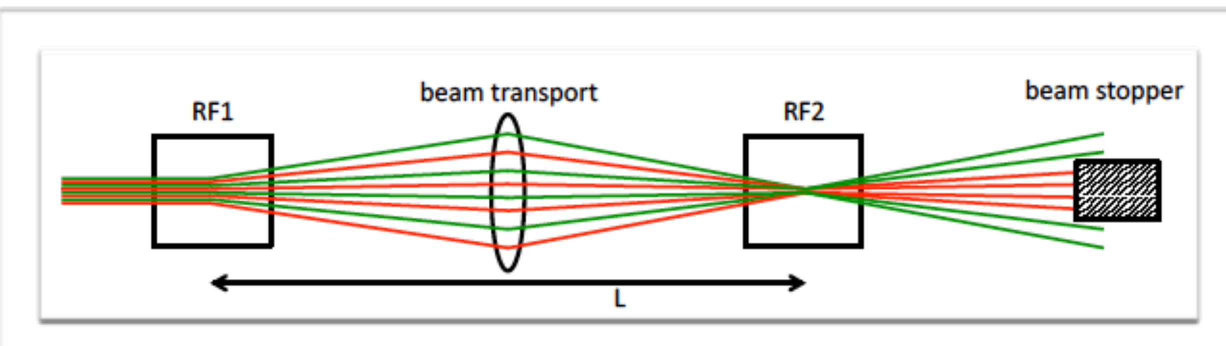
➤ How to improve the situation?

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
AMBER	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
AMBER	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

kaon-induced Drell-Yan @AMBER

Unique opportunities with RF separated beam

$$\Delta\phi \approx \frac{\pi f L}{c}\frac{m_w^2 - m_u^2}{p^2}$$



R&D from CERN Beams Department

Lower beam energies → compressed spectrometer, in order to keep large angular acceptance (~40%)

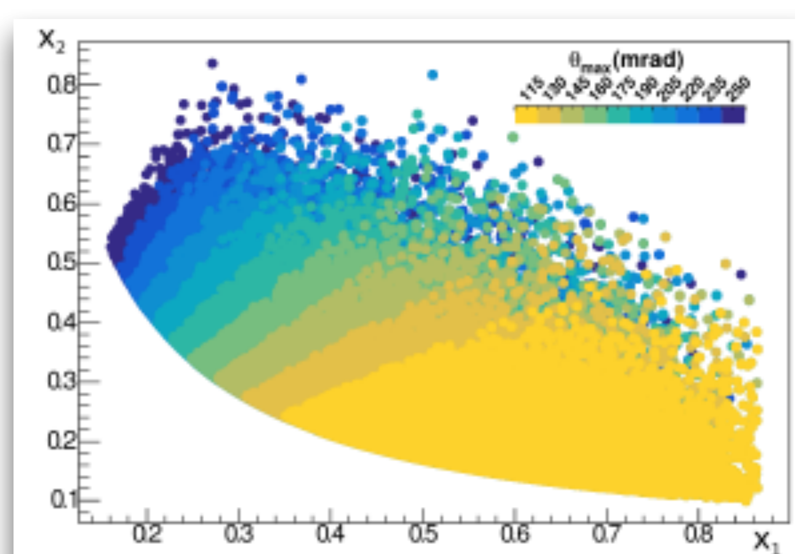
Active magnetized "absorber" → a calorimeter-like detector, under magnetic field and with high granularity, for muon pairs tracking and momentum measurement

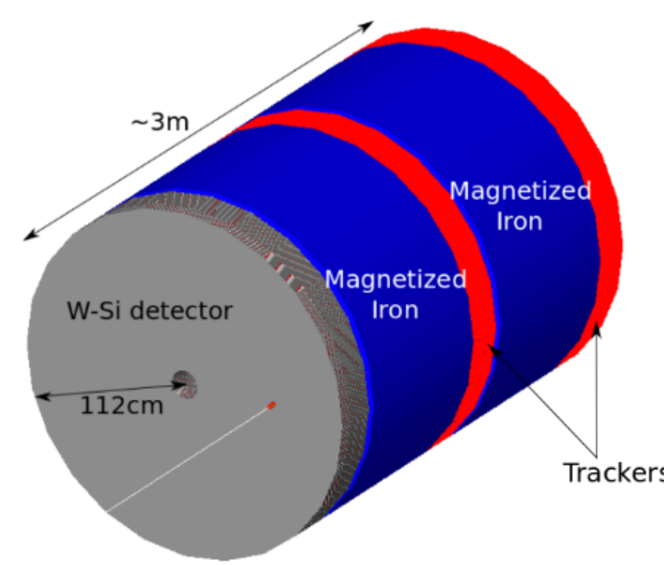
Tracking with magnetic field
Good resolution for vertexing
Capability to collect e–e+ DY pairs

Enriched K^- and pbar beams (~ 3x10^7/s)

Expected energies: 60-100 (80-110) GeV/c for K^-(pbar)

Lepton pairs emmitted at large angles



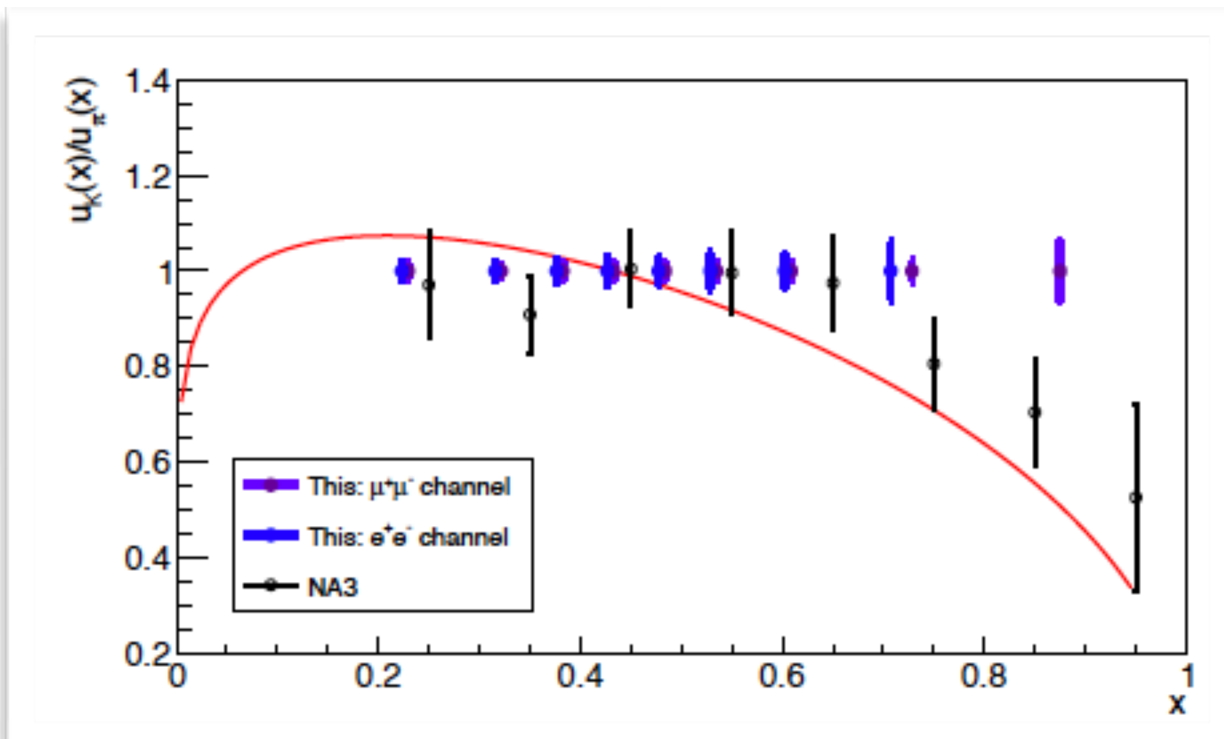


kaon-induced Drell-Yan @AMBER

Kaon structure: valence and sea

➤ More data points and more precise compared to NA3

- Discriminating power between models
- 1 year with ~ 2 x 10^7/s 100 GeV/c K^+ beam
- π taken simultaneously



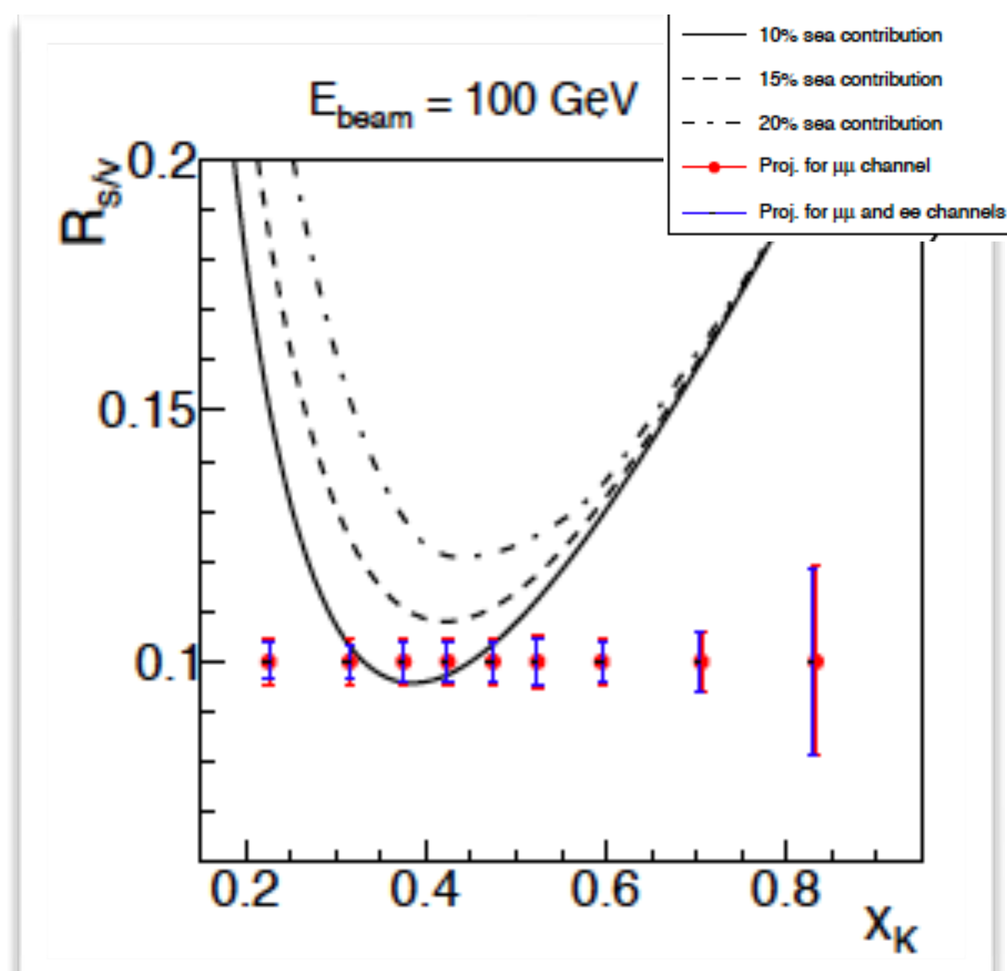
AMBER proj (100 GeV, μμ, 280 days)
NA3 data
DSE arXiv:2006.14075

➤ First measurement of sea in kaons

- Assuming the intensity for K^+ and K^- 2 x 10^7/s

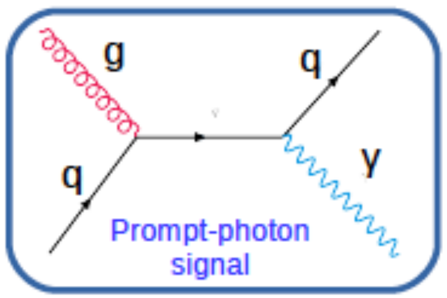
$$\Sigma_{val} = \sigma^{K^-A} - \sigma^{K^+A}$$

$$R_{s/v} = \sigma^{K^+A} / \Sigma_{val}$$

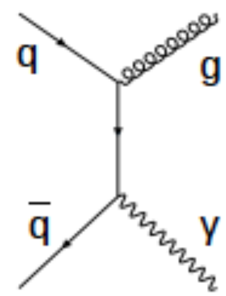


kaon-induced prompt-photon production at @AMBER

Gluon content in the kaon

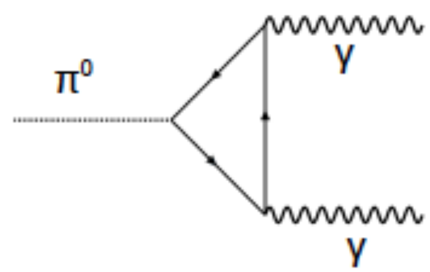


Direct access to the gluon PDF at $x_g^K > 0.05$, $Q^2 \sim p_T$



background

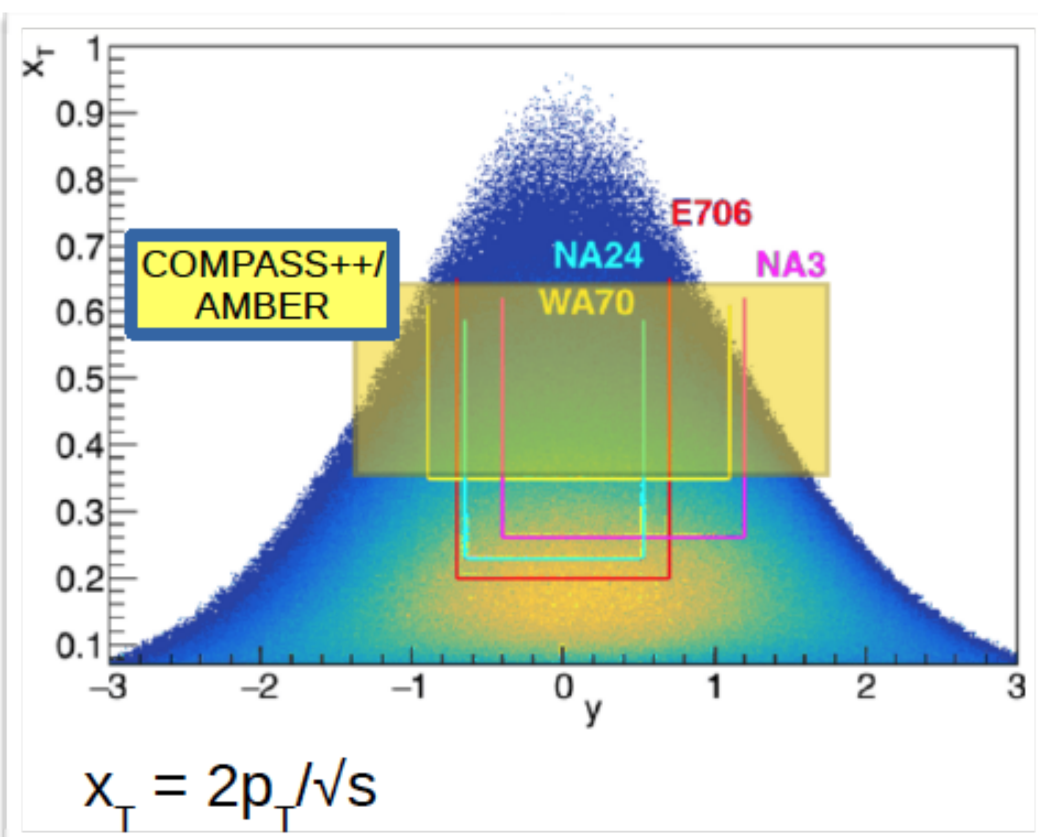
K^+ beam: minimize bkg

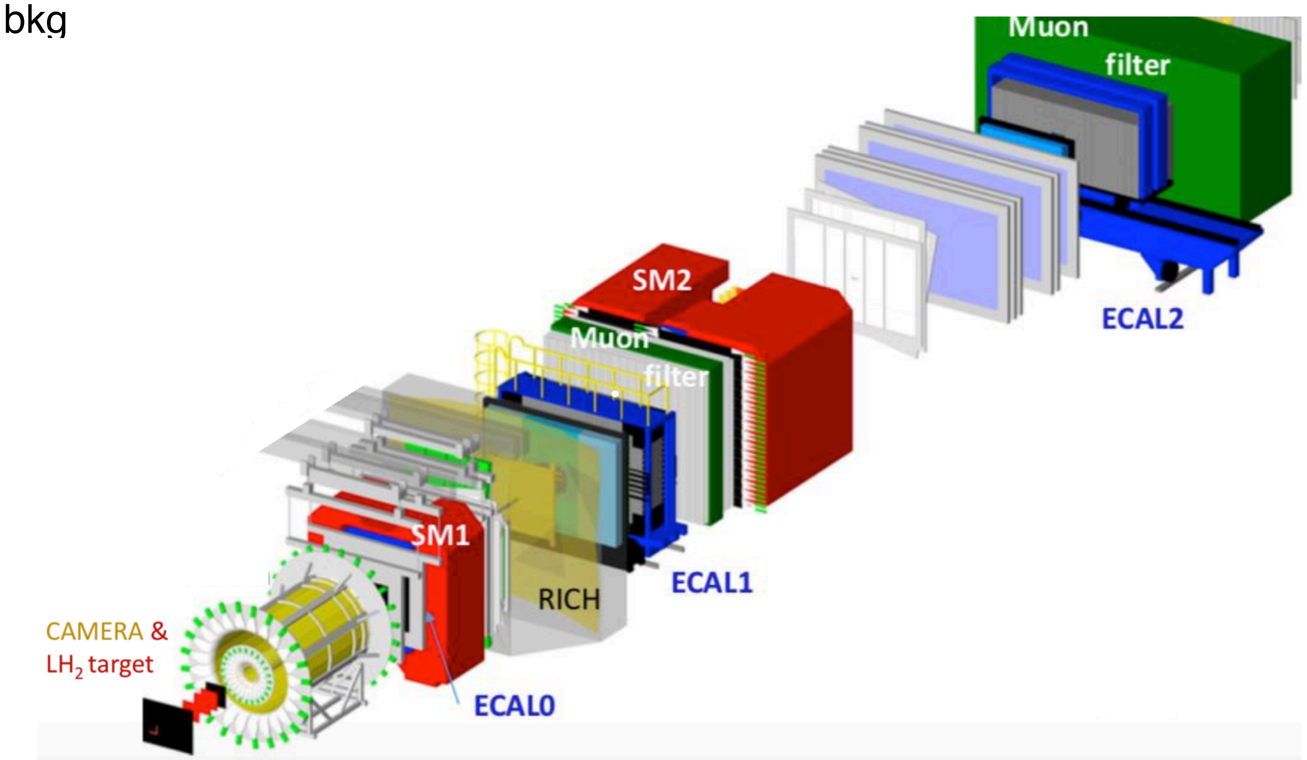


Minimum bias photons background

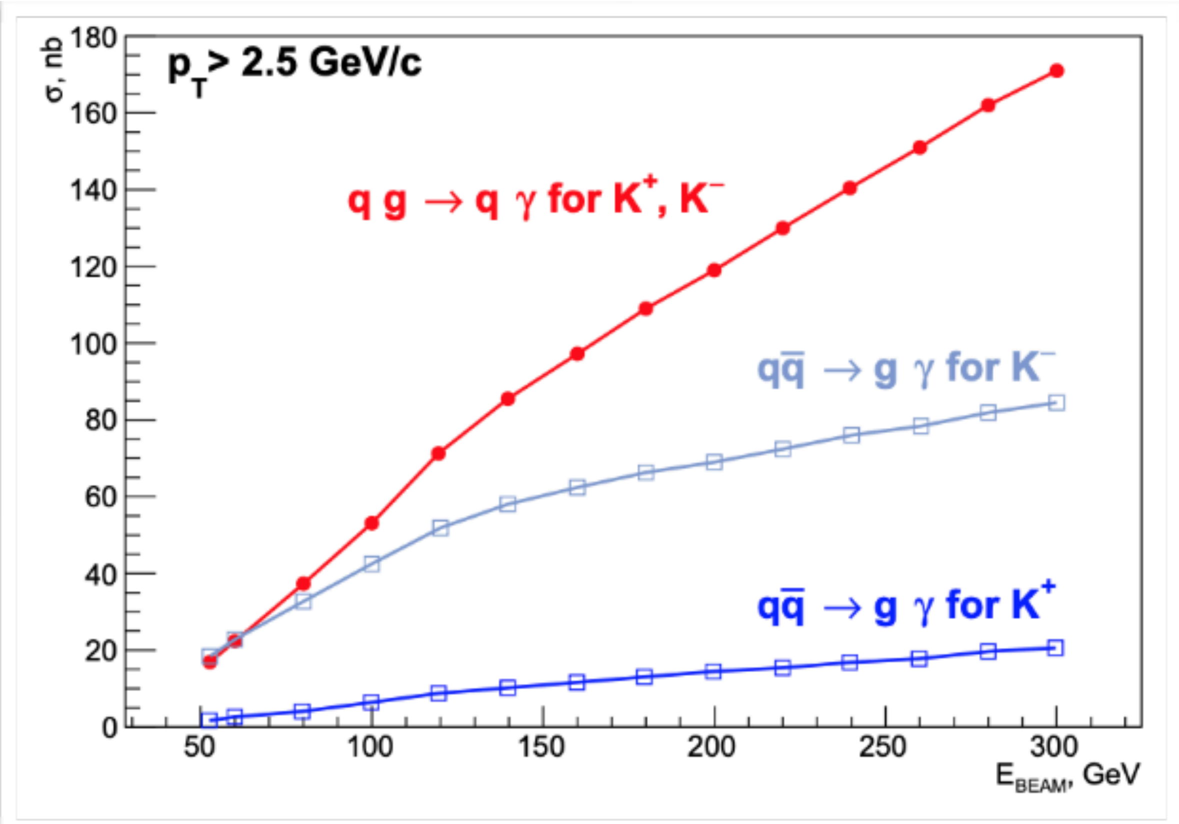
$p_T^\gamma > 2.5$ GeV/c: minimize photon bkg

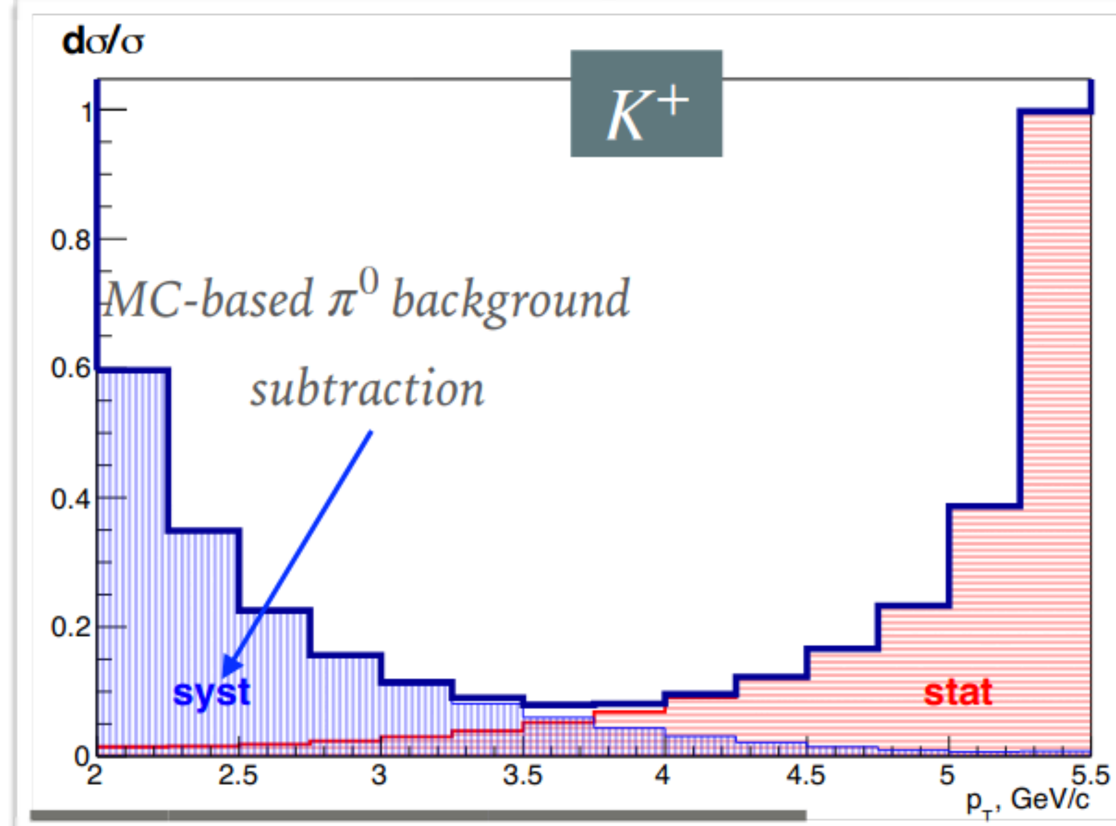
- ➤ 100 GeV K+ beam on a long lH2 target
- ➤ Open setup - possibility for semi-inclusive and exclusive reactions!





kaon-induced prompt-photon production at @AMBER





in 140 days

Experiment	Target type	Beam type	Beam Intensity (part/sec)	Beam Energy (GeV)	$\int \mathcal{L}$ (pb^{-1})	p_T range (GeV/c)	prompt-photon events
WA70	1m lH_2	π^+	2.5×10^6	280	1.3	$4 < p_T < 7$	—
		π^-	1.25×10^7	280	3.5	$4 < p_T < 7$	—
This exp	2m lH_2	K^+	2×10^7	100	50	$p_T > 2.5$	3.4×10^6
		π^+	2×10^7	100	50	$p_T > 2.5$	3.4×10^6

KAON STRUCTURE WITH RF-SEPARATED HADRON BEAM

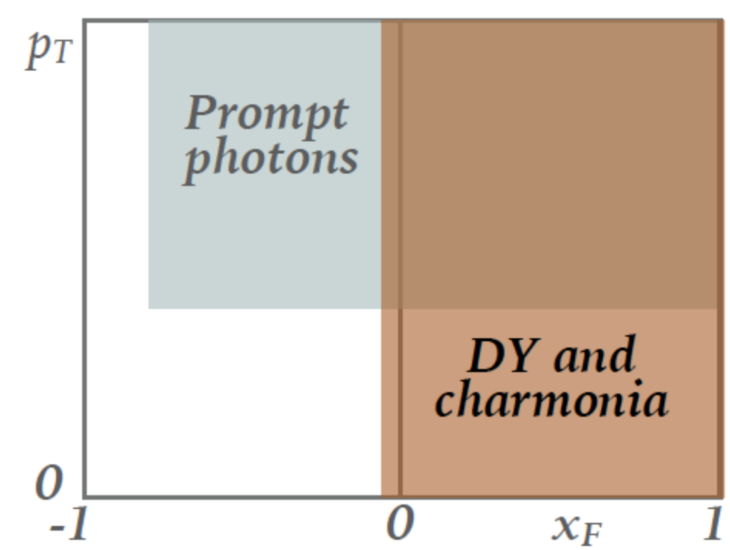
Different but overlapping kinematic ranges

	Drell-Yan	Charmonia	Prompt photons
Main hard process (LO)	$q\bar{q} \rightarrow l^+l^-$	$gg \rightarrow J/\psi\ g,\ q\bar{q} \rightarrow J/\psi$	$q(\bar{q})g \rightarrow q(\bar{q})\gamma,\ q\bar{q} \rightarrow \gamma g$
Content to be tested	valence and sea quarks	gluons and quarks	gluons and quarks
Kinematic range	$x_F>0$	$x_F>0$	$p_T>2$ GeV/c
Main target	C	C	LH_2
Expected statistics, 10^6	π: 0.1 (conv), K: 00.6 (RF)	π: 3 (conv), K: 00.6 (RF)	π, K (RF) : ~10

Both the Drell-Yan setup and the prompt-photon production setup will provide significant statistics of charmonium samples

- No absorber: distinguish prompt from non-prompt production
- Possibility to detect accompanying photon: access to χc1, χc2
- Improved resolution: separate J/ψ from ψ(2S)

A complementary input to the knowledge of gluon PDF in the kaon



Competition and complementarity

@ AMBER

- Studying the meson structure through meson-induced Drell-Yan charmonium and prompt-photon production processes is presently without direct competition —> high-energy pion beams exclusively available at CERN

@ Competition and complementarity

- Meson beam lines are presently under construction at the J-PARC facility in Japan —> the planned energies of up to 15 GeV remain too low for extensive studies of the pion structure.

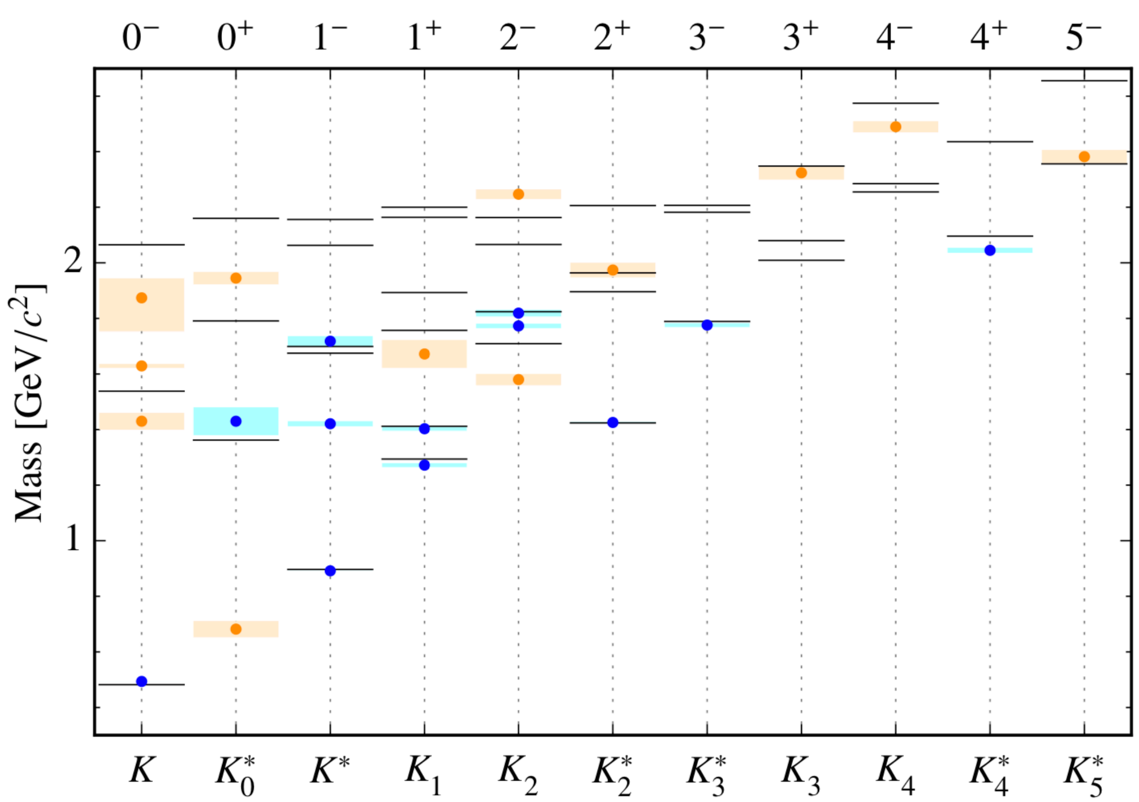
- The only alternative way to study meson structure is the Sullivan process, i.e. SIDIS off the meson cloud that surrounds the target nucleon —> model-dependent approach

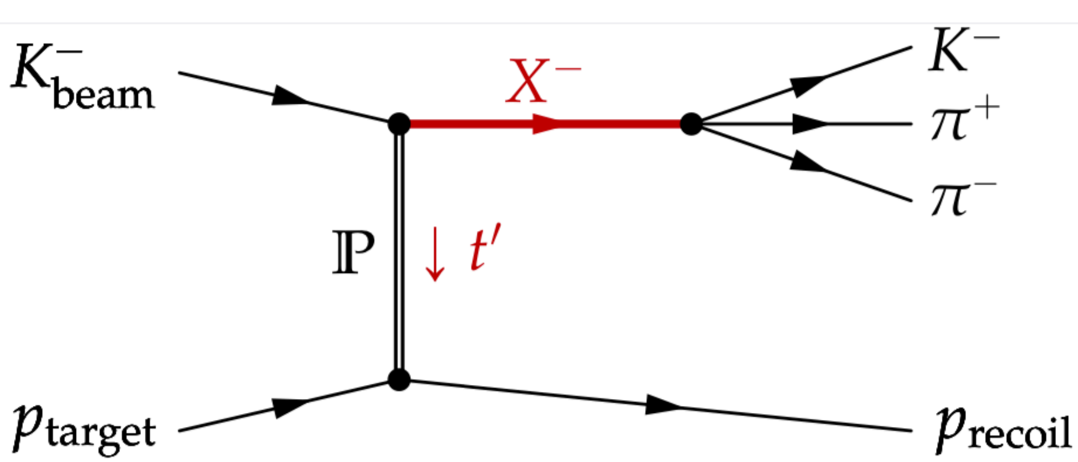
↓

JLab TDIS experiment aims at investigating the pion PDFs in the x region between 0.45 and 0.90, where valence quarks largely dominate

Measurements of the Sullivan process at higher energies are envisaged at the proposed EIC facility to study pion and kaon sea and gluon PDFs

Kaon beam: an opportunity for strange-meson spectroscopy





25 kaon states below 3.1 GeV can be found at PDG. But:

only 12 kaon states in summary table, 13 need confirmation;

most PDG entries more than 30 years old;

since 1990 only 4 kaon states added to PDG (only 1 to summary table)

COMPASS: 7×10^5 $K^-\pi^+\pi^-$ events

AMBER: $> 1 \times 10^7$ events

Interessi e coinvolgimento dei gruppi dell'INFN

BO, TN, TO, TS

costruzione apparati: partecipazione a progetti per nuovi rivelatori dedicati e general upgrades

analisi dati (e simulazioni MC): proton radius, pbar xsec e DY

2 nuovi gruppi

Trento: P. Zuccon (UniTN), F. Nozzoli (INFN), A. Dass(dottorando UniTn) + esperti ALPIDE

Bologna: N. Masi (INFN), A. Oliva (INFN)

TO e TS: gruppi COMPASS

Prossimi passi (Indicazione del Presidente della CSN1):
Presentazione in CSN1 a maggio per richiesta apertura sigla

New Hardware

the active-target TPC for the proton radius measurement

new silicon tracking-detectors (ALPIDE)

New liquid helium target for pbar xsec measurement

RICH0 —> lower momentum range (possibilità in fase di studio per pbar xsec e hadron spectroscopy with k beam)

General Upgrades

new triggerless readout (FE and DAQ)

large area MPGD

NEW CONTRIBUTIONS ARE WELCOME!

Thank you for your attention

Michela Chiosso
On behalf of the
AMBER Collaboration