Apparatus for Meson and Baryon Experimental Research

AMBER experiment at the M2 beam line of the CERN SPS

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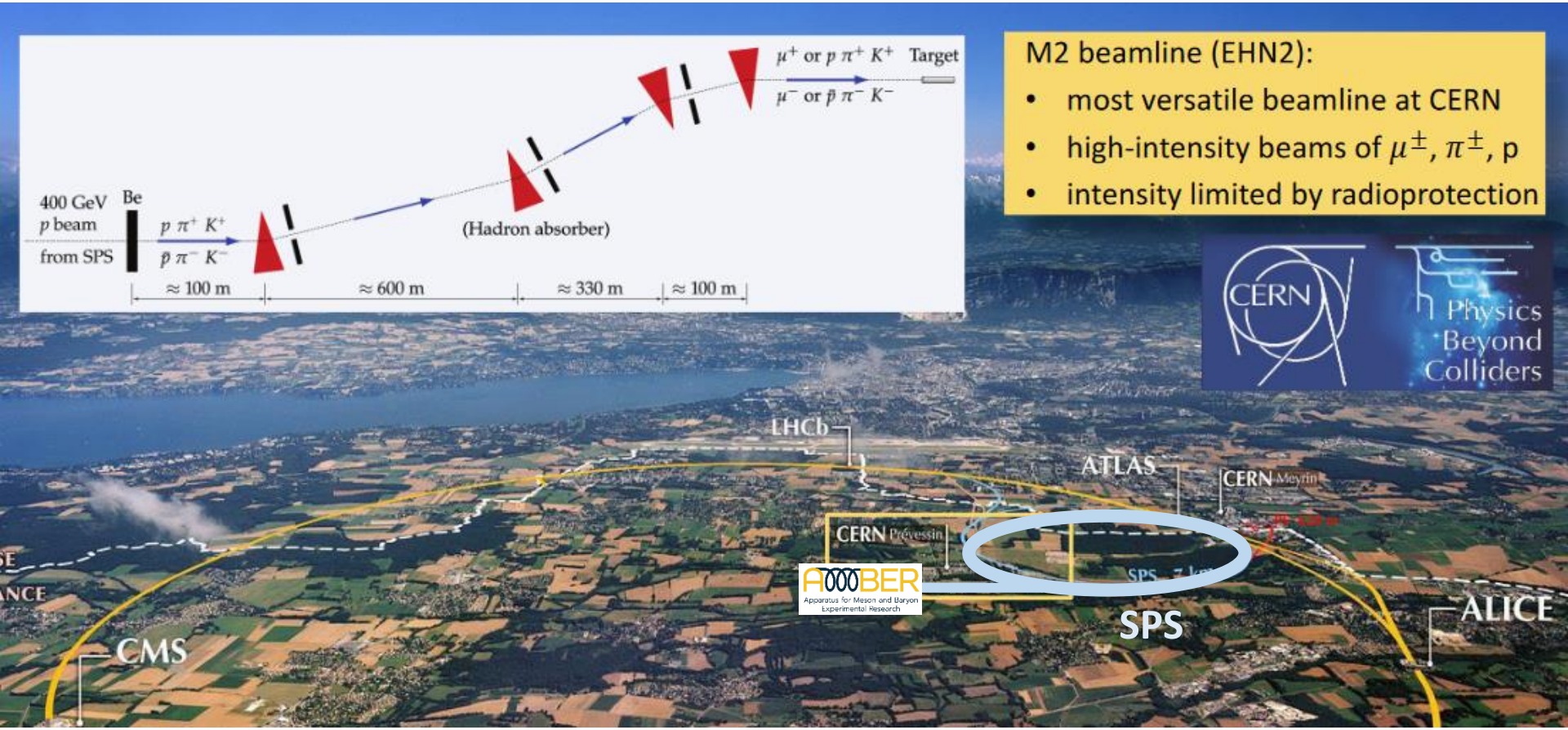
07th of September 2022

International Conference on Quarks and Nuclear Physics, QNP-2022, virtual

CERN SPS


400 GeV
p beam
from SPS
Be
p π+ K+
p̄ π− K−
(Hadron absorber)
μ+ or p π+ K+
μ− or p̄ π− K−
Target
≈ 100 m
≈ 600 m
≈ 330 m
≈ 100 m
M2 beamline (EHN2):
• most versatile beamline at CERN
• high-intensity beams of μ±, π±, p
• intensity limited by radioprotection
CERN
Physics Beyond Colliders
LHCb
ATLAS
CERN Meyrin
CERN Prévessin
SPS
ALICE
CMS

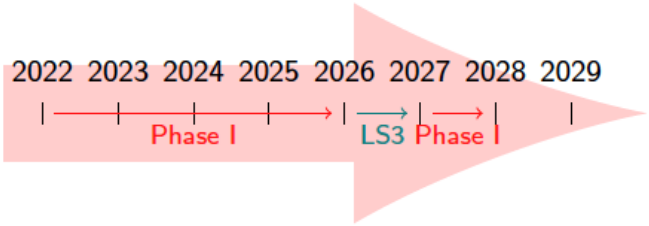
Apparatus for Meson and Baryon Experimental Research (NA66)

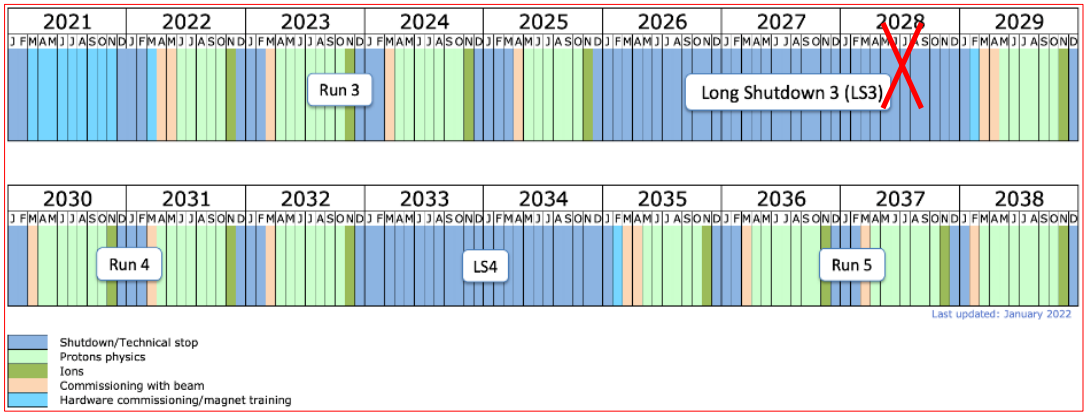
- Successor experiment of COMPASS, but a lot of new groups
- Letter of Intent 2018: arXiv:1808.00848
- Extension and upgrade of spectrometer
- Will use both conventional and radio frequency (RF) separated beams
- **Phase-1** proposal (CERN-SPSC-2019-022) is approved in 2020

		Beams	Targets
Discussed today in details	**1. PRM:** Measurement of proton charge radius	μ	p
	2. AXS: Antiproton production XS measurement for Dark Matter searches	p	He
	3. DY: Drell-Yan and J/ψ production using conventional M2 beam	π	C

- **Phase-2** proposal is planned to be submitted in 2023
  - Kaon structure / gluon parton distribution functions
  - Strange sector spectroscopy using RF-separated beams
  - Meson charge radii

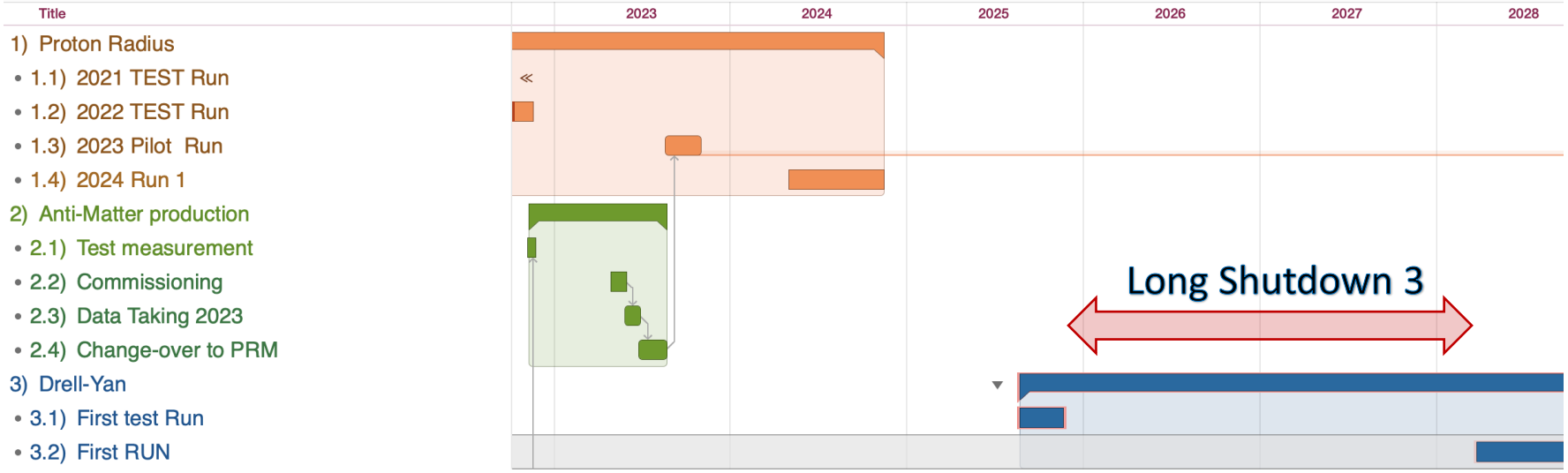
AMBER Phase-1 running plan





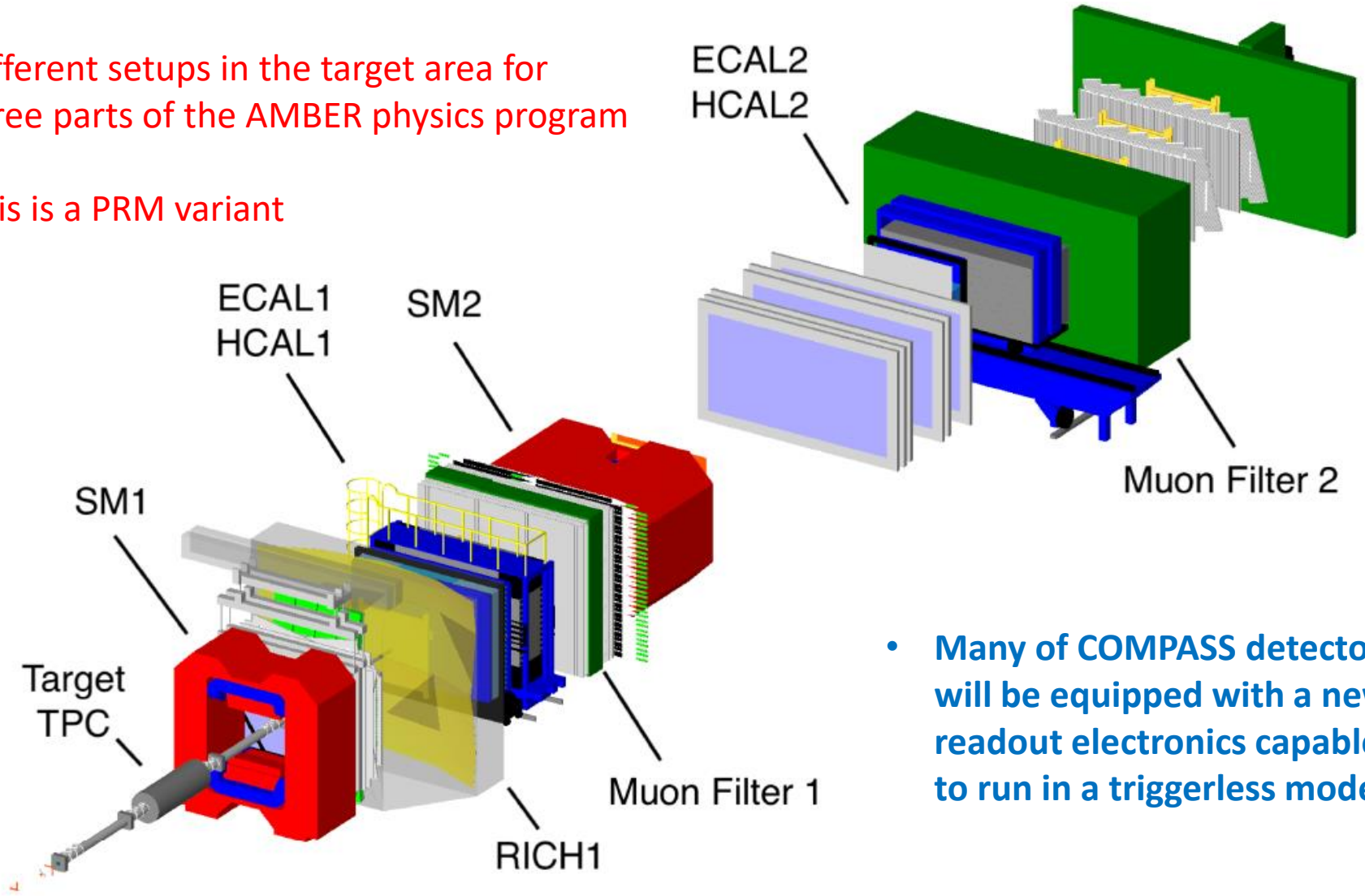
Approved AMBER Phase-1 Program:

- PRM: 1 + 1 year (conditionally)
- AXS: 2 months
- Drell-Yan: 2 years



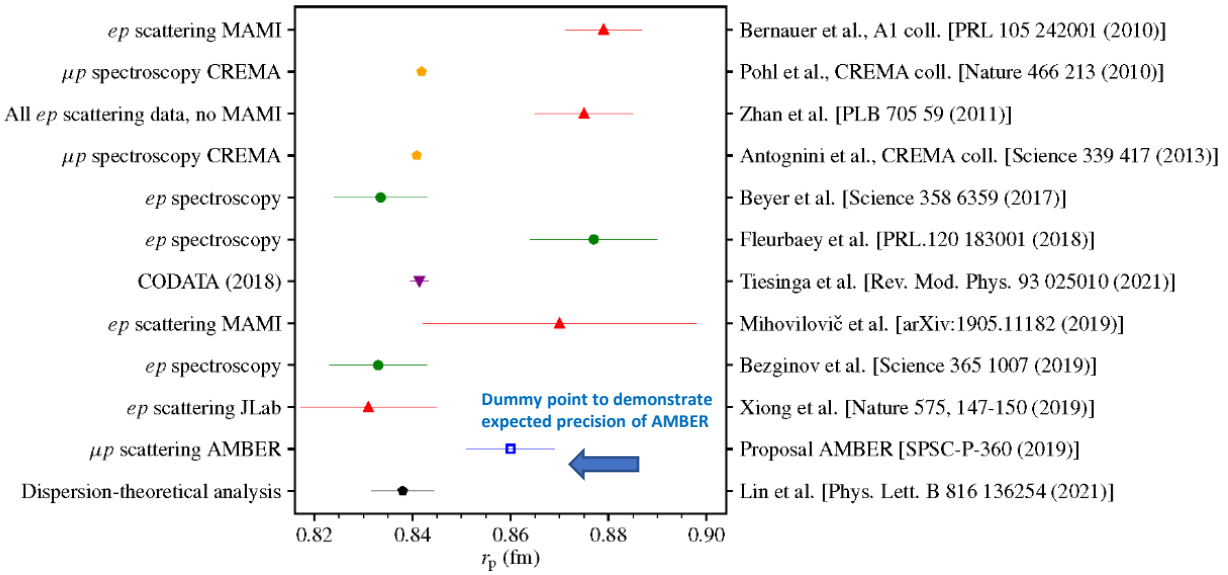
AMBER setup

- Different setups in the target area for three parts of the AMBER physics program
- This is a PRM variant



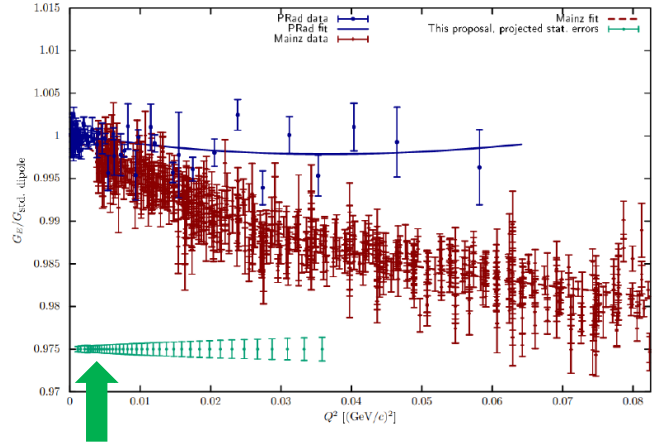
- **Many of COMPASS detectors will be equipped with a new readout electronics capable to run in a triggerless mode**

I) Addressing *proton radius puzzle*

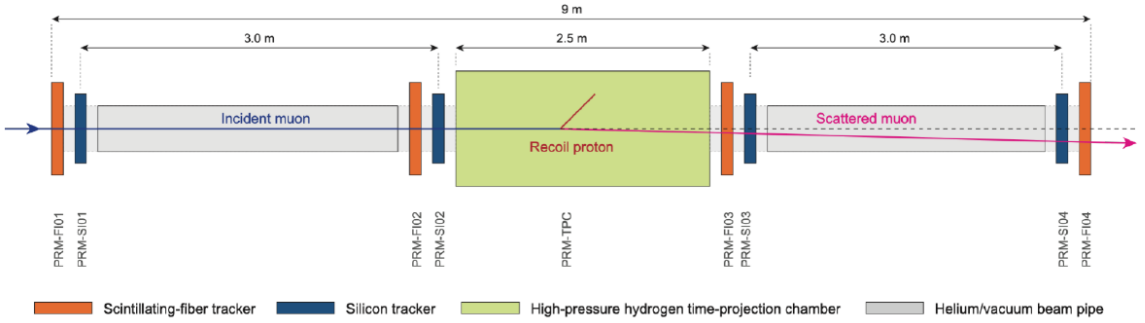


- ***μp*** scattering is different leptonic probe, which is not measured yet
- It provides different systematics, as well as low radiative corrections (wrt. ***e⁻p*** case)

Ratio of G_E to Dipole FF as a function of Q^2



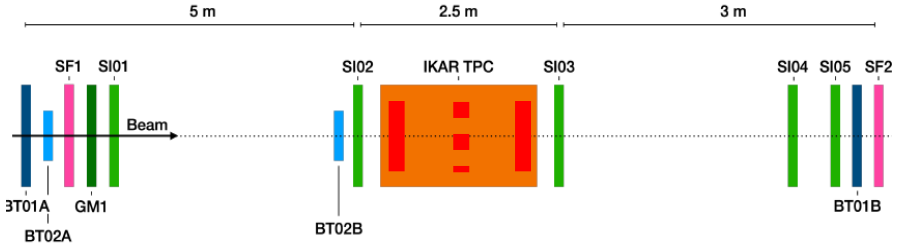
Expected precision of AMBER

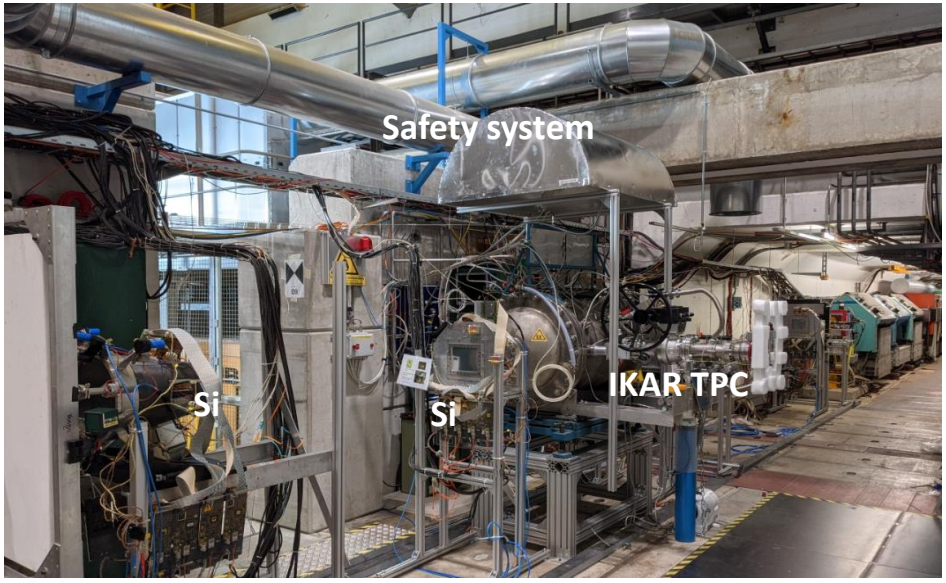


100 GeV muons; 20 bar H_2 Time-Projection Chamber (TPC) in an active target regime to cover **$10^{-3} < Q^2 < 4\times10^{-2}$ GeV^2**

Pilot run in 2021 to prove the idea

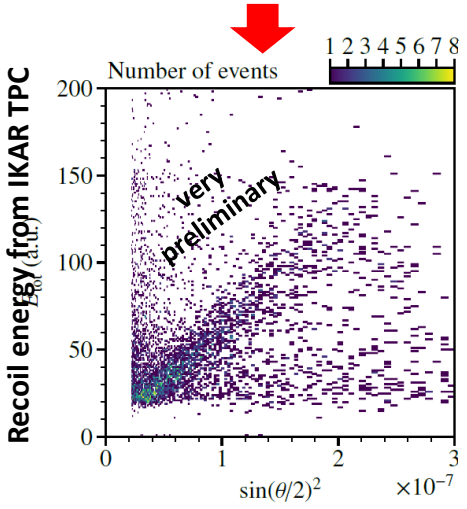
Setup for AMBER 2021 pilot run in a TPC area

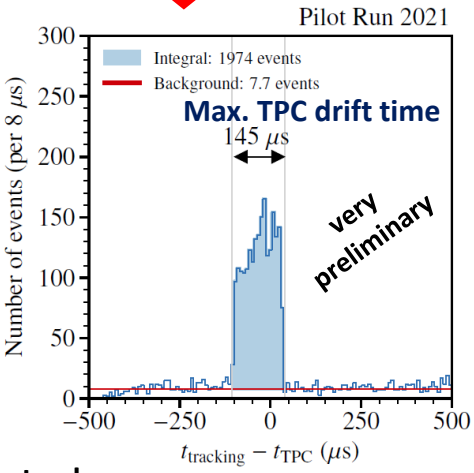




Many successful tests. Among them:

- high-pressure (8 bar) 2-cell TPC prototype (IKAR) with high-intensity μ beam: beam noise, p/T effects, new anode structure
- muon momentum reconstruction (only SM2)
- target tracking system (Silicon strip + SciFi) / match muon and recoil proton tracks





$\sin^2$ of ½ of angle reconstructed by tracker

Next steps:

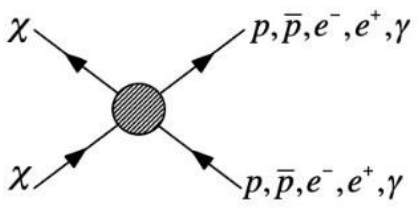
- Production of 20 bar TPC
- Final tests with ALPIDE + SciFi tracker
- Measurements in 2023-24

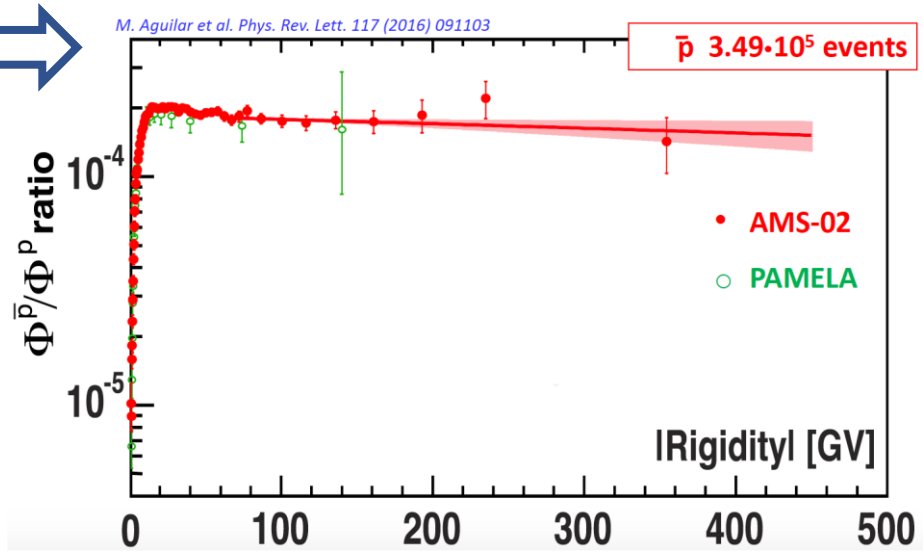
II) Antiproton production cross section

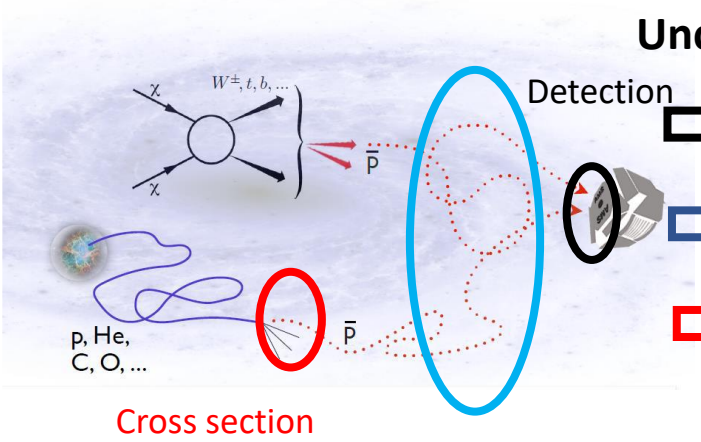
Ways to search for DM

LZ
DARKSIDE
XENON T
CDMS II
...

Scattering $\chi + p \rightarrow \chi + p$

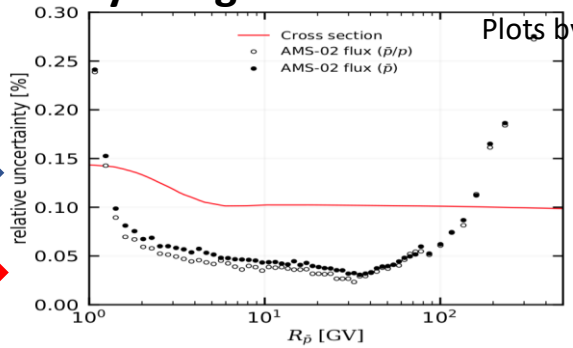


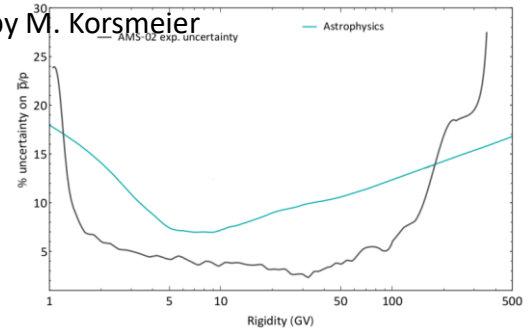




Uncertainty budget

Plots by M. Korsmeier

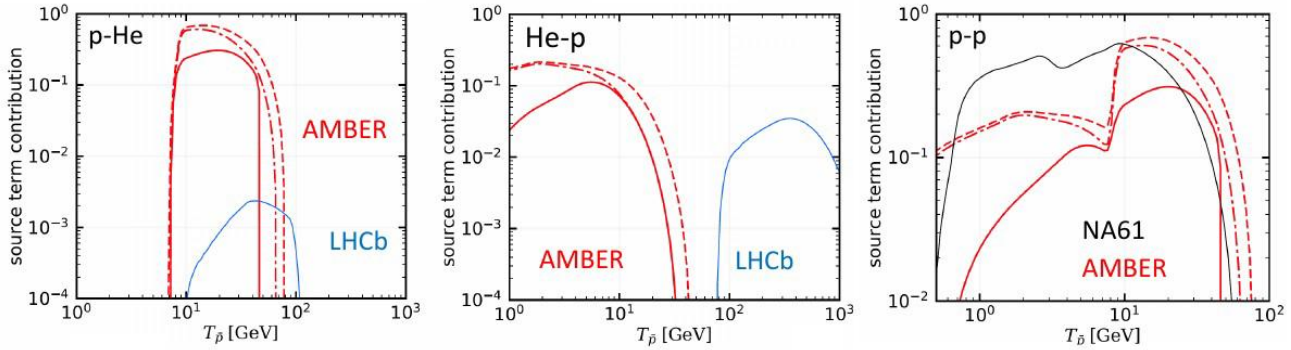


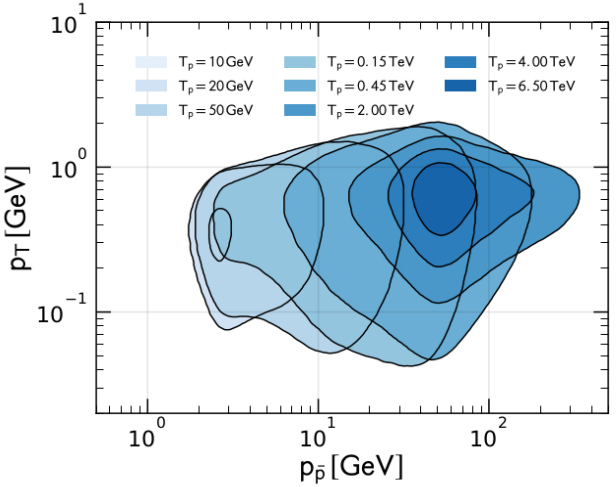


Goal: Reduce the uncertainties on the computation of the $\bar{p}$ flux to the AMS level

Antiproton production at AMBER

Plots: impact of measurements on constraining the production of $\bar{p}$ (fraction of total source term constrained by phase space of experiment)





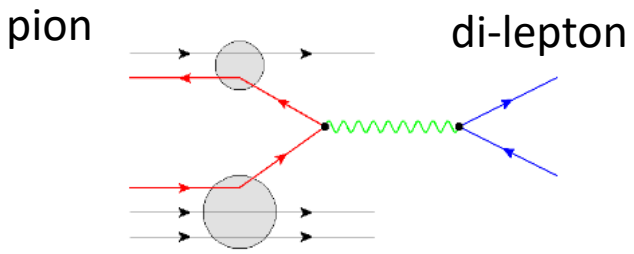
- **Parameter space for the pHe channel corresponding to an exemplary fixed target experiment.**
- **3% relative uncertainty within the blue regions (30% outside)**

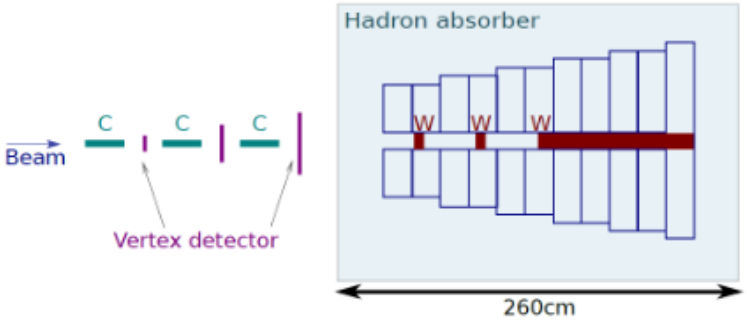
- Secondary *p* beam with 50, 100, 150, 200, 280 GeV
- Liquid H_2 and He target
- Minimum bias trigger allowing beam intensity of $5 \cdot 10^5\ s^{-1}$
- Beam proton ID in CEDARs, antiproton ID in RICH
- Measure differential cross section in 10 bins in p_p & η
- $2.4 < \eta < 5.6$
- Statistical uncertainty ≈ 0.5 − 1% per data point
- Total systematic uncertainty ≈ 5% (efficiencies, dead time)

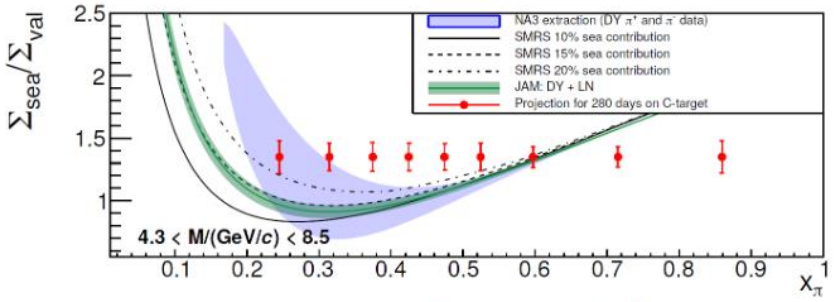
- AMBER pilot run for antiproton production measurements is scheduled in the end of 2022
  - LD target, setup tests , rates)
- **Main run is planned to 2023**

III) Pion PDFs at AMBER (via DY)

Drell-Yan production







$$\sigma_{DY}^{\pi^+ A} \propto \sum_i (e_i)^2 \left[\bar{q}_i^{\pi^+} q_i^A + q_i^{\pi^+} \bar{q}_i^A\right]$$

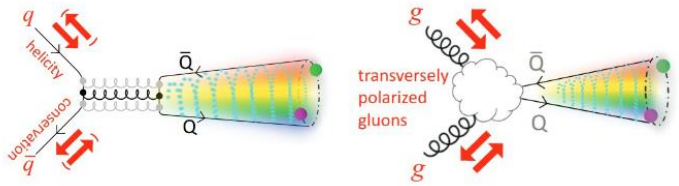
- Isoscalar target (^{12}C) to minimize nuclear effects
- Beams of positively and negatively charged pions to separate valence and sea contribution:

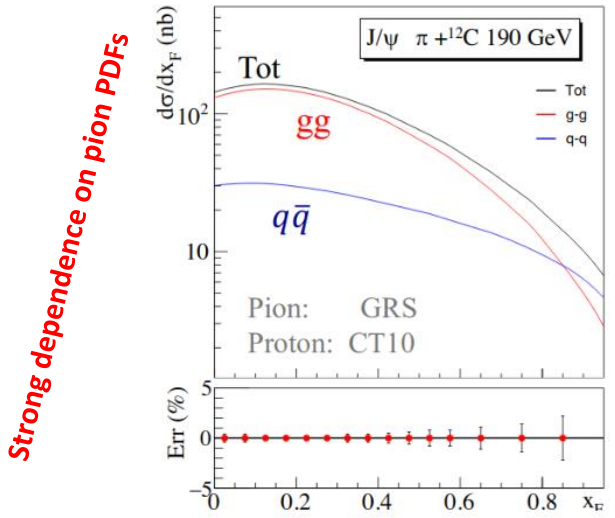
$$\frac{\Sigma_{sea}}{\Sigma_{val}} = \frac{4\sigma^{\pi^+ C} - \sigma^{\pi^- C}}{-\sigma^{\pi^+ C} + \sigma^{\pi^- C}}$$

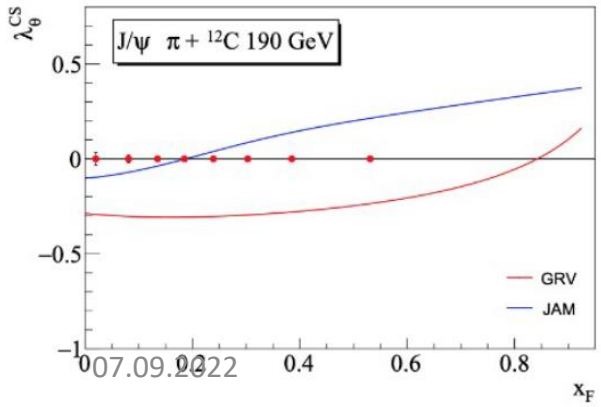
- 250k DY events expected (current available statistics 25k events)
- First precise and direct measurement of the sea quark distribution in the pion
- 190 GeV pion beam
- Target / vertex detector / hadron absorber
- Radiation protection
- Di-muon mass resolution of 100 MeV

J/ψ production

Possible mechanisms







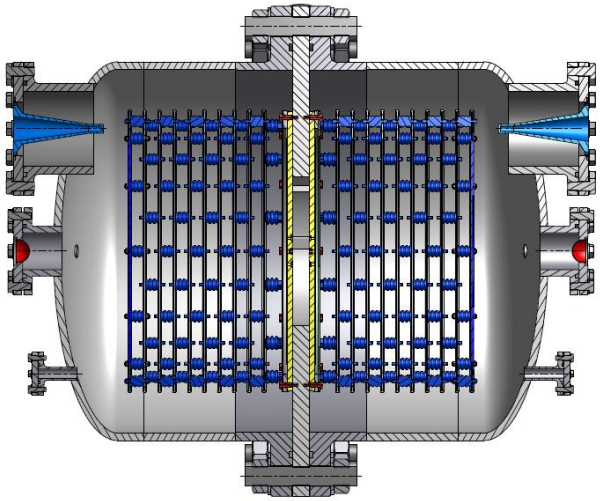
- Large statistics on J/ψ production at dimuon channel (30-50 times wrt. 'DY clean region')
- Inclusive measurements: due to the hadron absorber prompt production from the rest can't be separated
- Expected significant feed-down: $\psi(2S)$, χ_{c1}, χ_{c2}
- Expected to have dominant contribution from 2→1 processes
- Use J/ψ polarization to distinguish production mechanism (polarization is sensitive to relative contributions of quark- and gluon-induced productions)

- Angular distribution $\dfrac{d\sigma}{d\cos\theta} \propto 1 + \lambda\cos^2\theta$
  - $\lambda = +1 \Leftrightarrow J_z = \pm 1$ $\quad q\bar{q} \to J/\psi$
  - $\lambda = 0 \Leftrightarrow$ unpolarized
  - $\lambda = -1 \Leftrightarrow J_z = 0$ $\quad gg \to J/\psi$

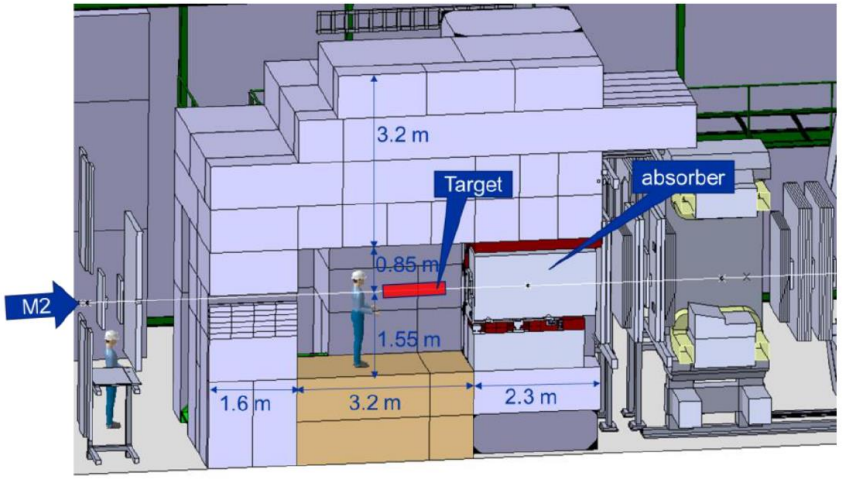
New equipment for AMBER Phase-1

- High-pressure hydrogen TPC
- SciFi/Silicon Pixel tracking stations
- C/W, LH2, LHe target
- DY vertex detector
- Large-area MPGD detectors with self-triggering readout
- Self-triggered electronics for ECAL
- Upgrade CEDAR electronics for high rates
- Triggerless DAQ and HLT

High-pressure TPC

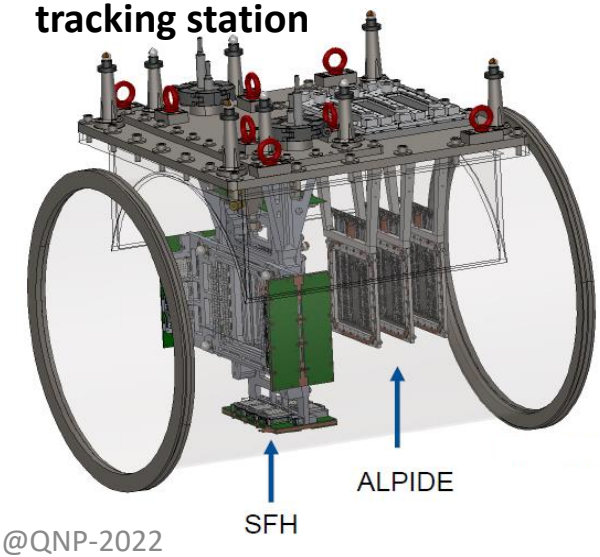


Elements of HLT farm

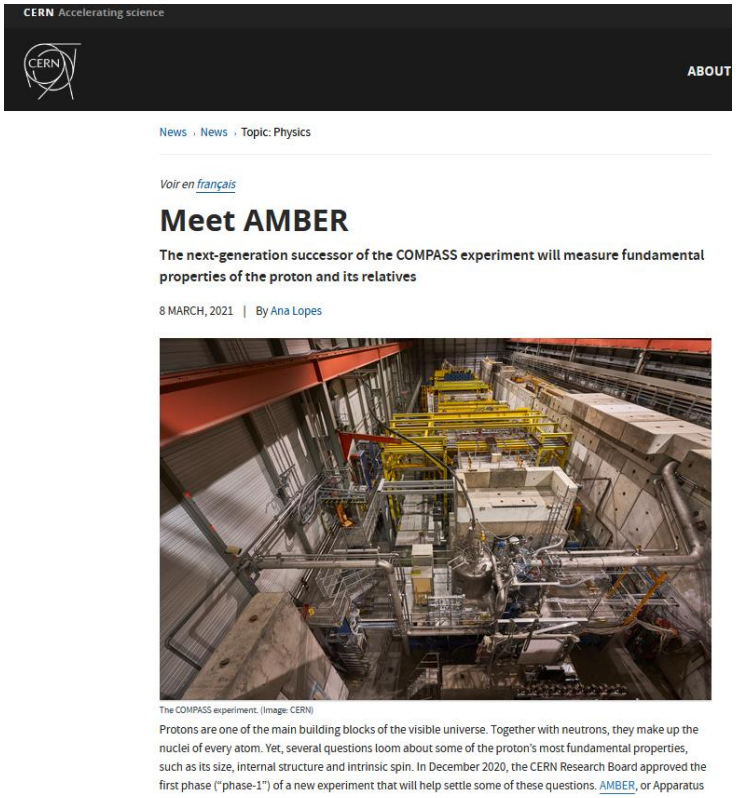


Radioprotection for DY setup

Inner design of unified tracking station

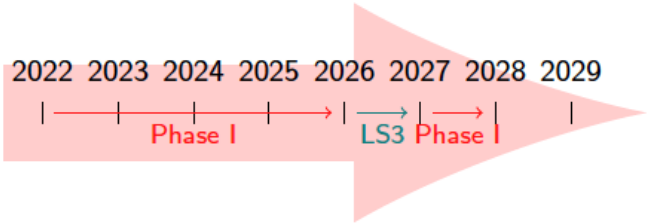


Summary



https://home.cern/news/news/physics/meet-amber

NA66/AMBER is a new experiment at CERN dedicated to study fundamental questions related to the emergence of hadron properties from QCD



Phase-1 is approved by CERN

- Proton radius with high-intensity muon beam
- Antiproton-production cross sections for DM searches
- Pion PDFs in Drell-Yan processes

Phase-2 being studied in the framework of Physics Beyond Colliders at CERN

- Kaon and meson gluon PDFs
- Strange spectroscopy
- Meson charge radii
- Unique RF-separated beams to M2