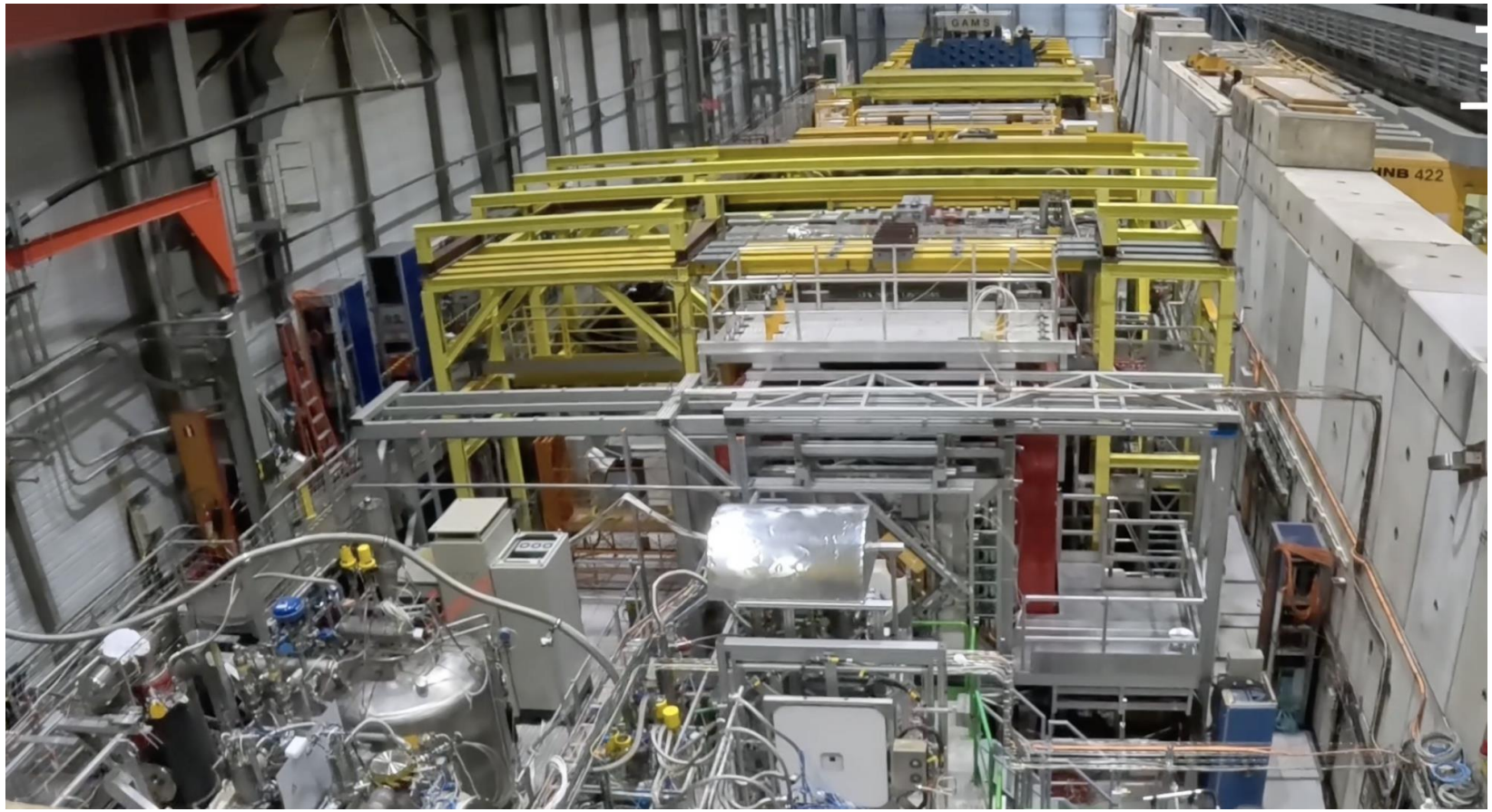
Annual Status Report

Apparatus for Meson and Baryon Experimental Research

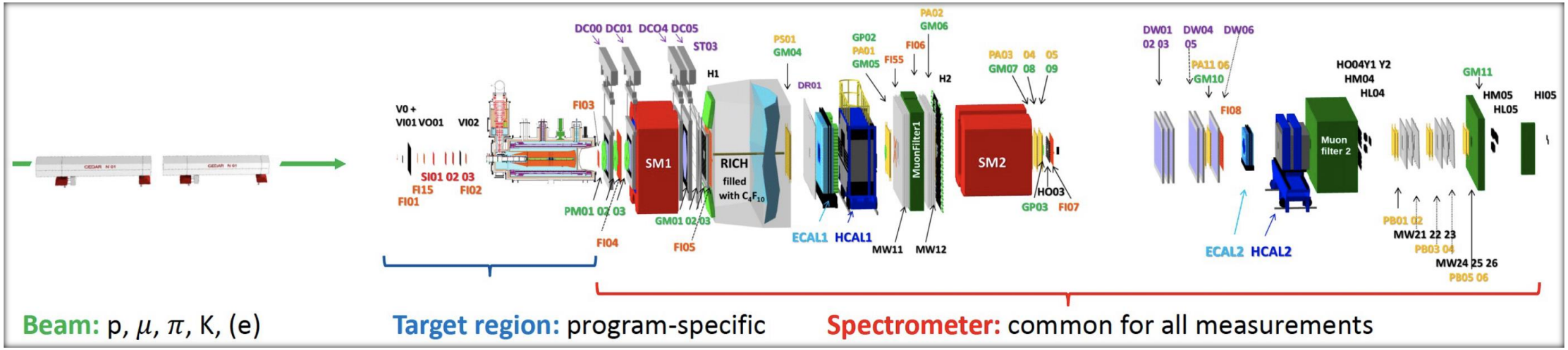
Outline

1. Collaboration overview
2. Run in 2024
   - Antiproton production cross-sections on H and D
   - Tests for Drell-Yan Measurements
   - Tests for the Proton Radius Measurement (PRM)
3. Hardware developments
4. Run in 2025
   - Plans for first physics data taking for PRM
5. Summary



SPSC Open Session 3.9.2024

AMBER Collaboration



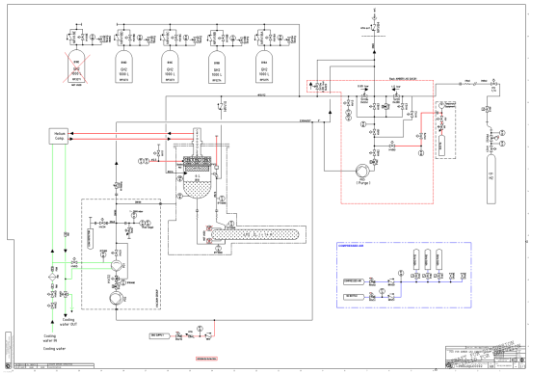
AMBER spectrometer (former COMPASS)

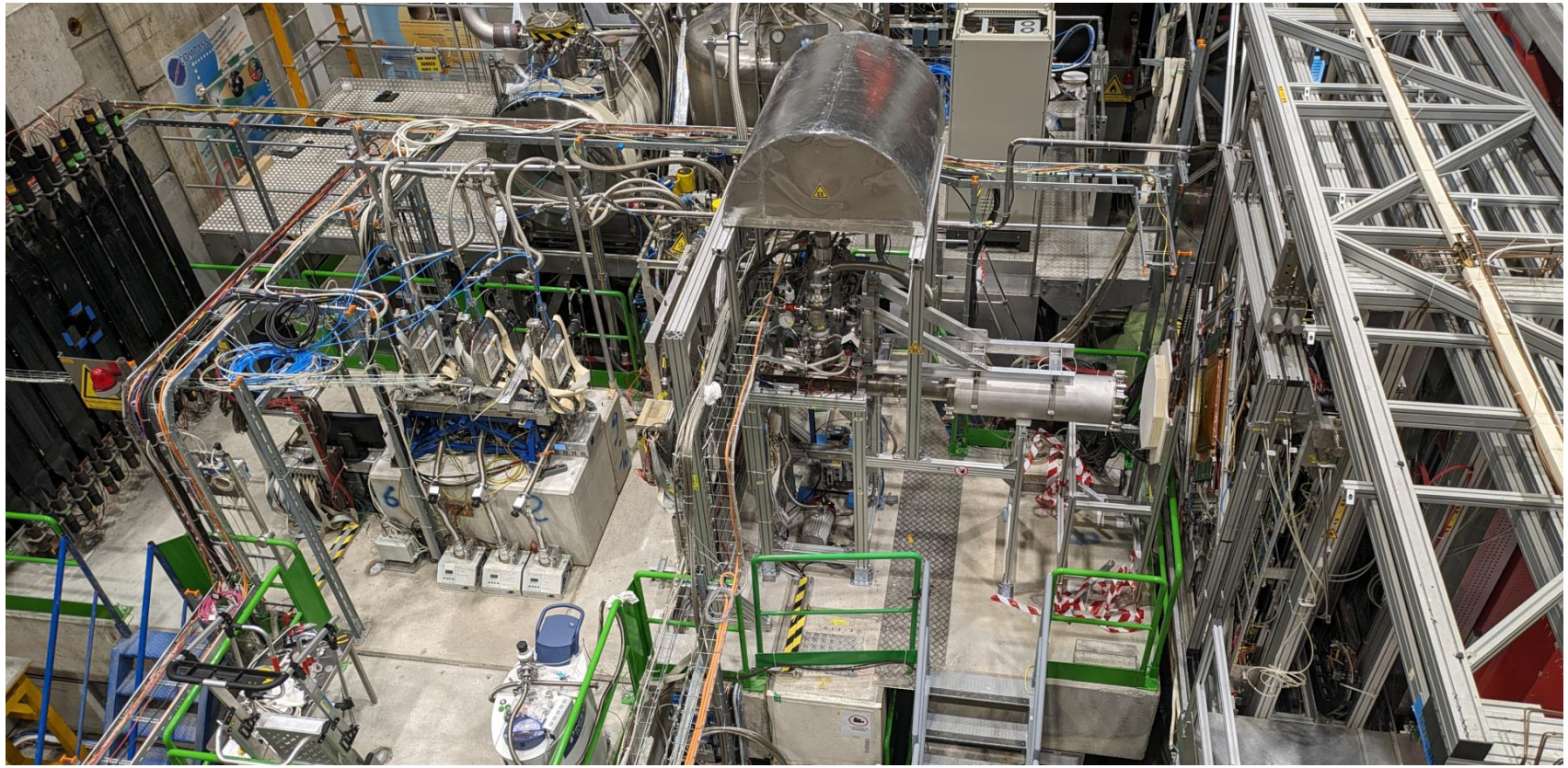
- currently 153 members from 36 institutions and 14 countries (plus master and bachelor students)
- Memorandum of Understanding July 2023
- New: Funding of the German groups by BMBF in the current period 2024-2027

Antiproton production cross-sections

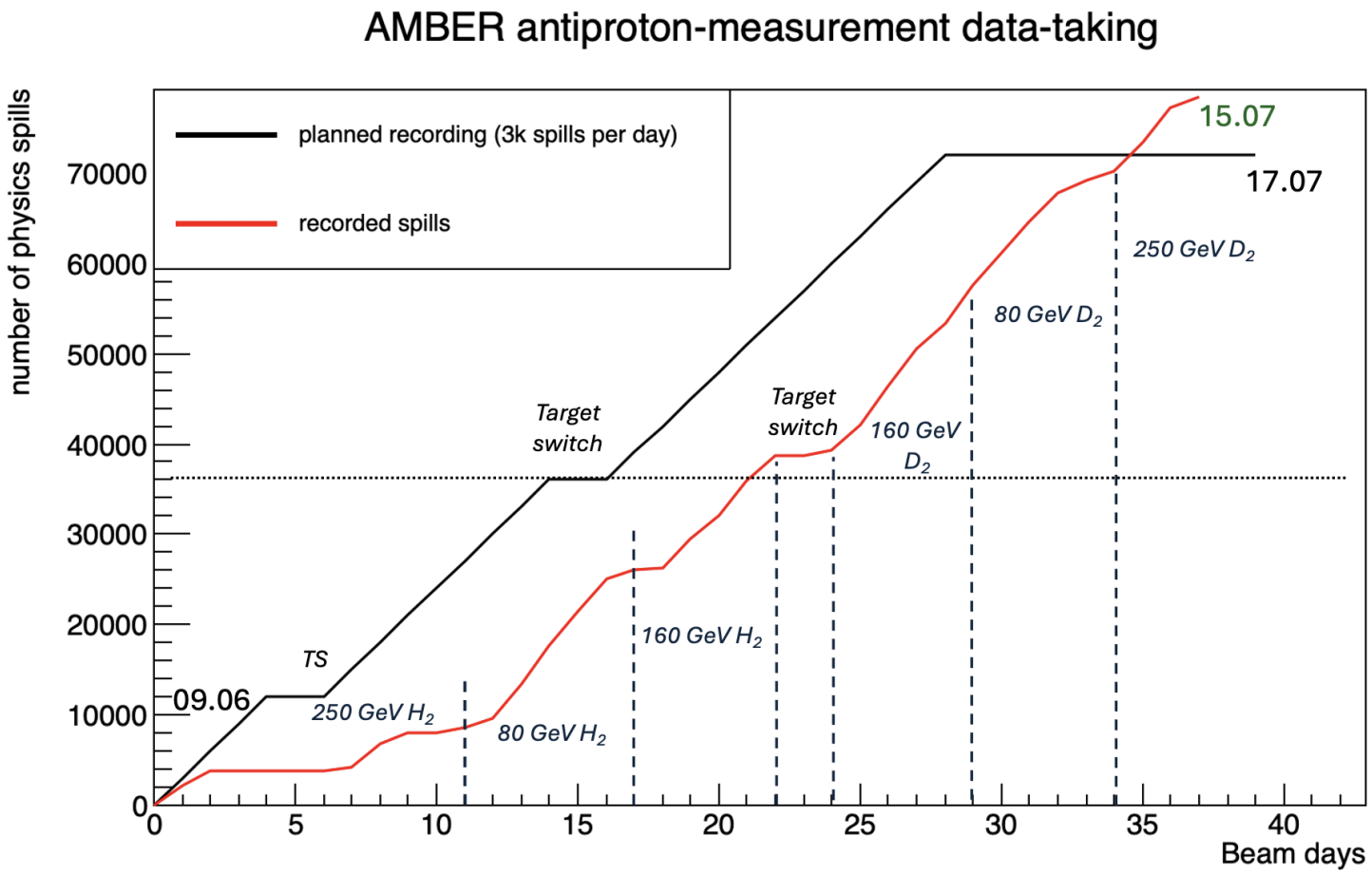
- AMBER aims at determining cross-sections for the production of antiprotons in p-He, p-p and p-d collisions
- Those will give a better understanding to the observed distributions of antiprotons in cosmic rays, including possible dark-matter contributions

- In 2023 p-He collisions have been measured at 6 beam energies from 60 to 250 GeV
- In 2024 we investigated p-p and p-d collisions in a newly built target



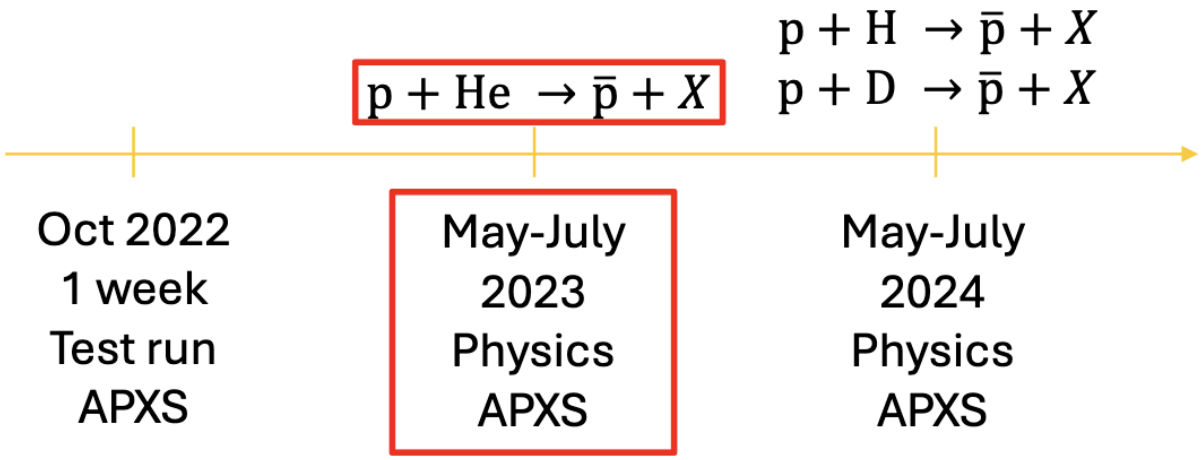


Data taking 9. June – 15. July 2024



- very tight preparation schedule, new target was delayed by new safety regulations – ***many thanks to all involved CERN people for helping in this!***
- after several issues with the SPS beam, data taking went smoothly
- we could extend the beam time by several days and thus complete the full foreseen program
- finally some 10% more spills were collected

Antiproton production cross-sections: Analysis



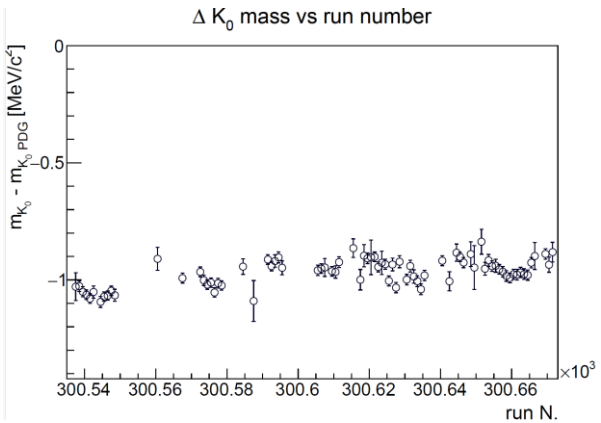
Period name	Beam mom. [GeV/c]	Collision energy $\sqrt{s_{NN}}$ [GeV]	Start Date	End Date	Number of spills
W02-W03	60	10.7	24.05	30.05	37000
W07	80	12.3	17.06	25.06	13400
W04	100	13.8	01.06	11.06	13700
W06	160	17.3	14.06	17.06	8500
W01	190	18.9	19.05	24.05	11000
W05	250	21.7	11.06	14.06	7300

we currently focus on the analysis of W01 of 2023

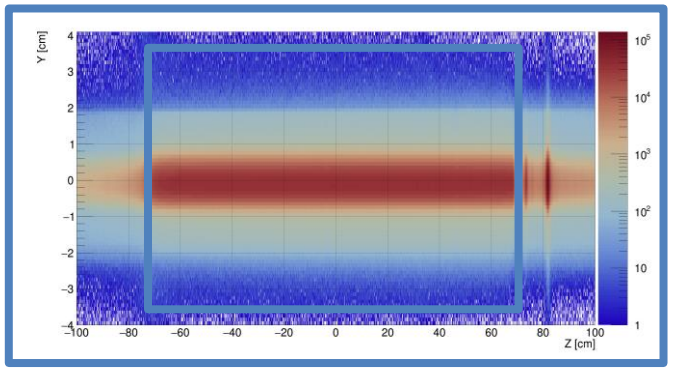
Target	Period name	Beam mom. [GeV/c]	~Spills
LH2	W01	250	8k
LH2	W02	80	16.5k
LH2	W03	160	…
Deuterium	…	…	…

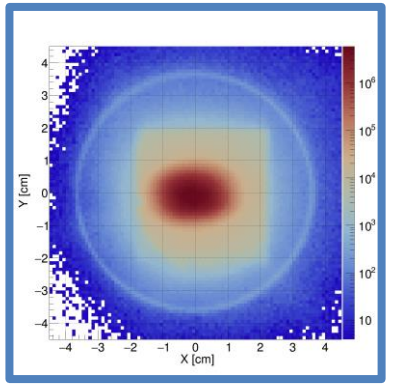
Steps of the analysis

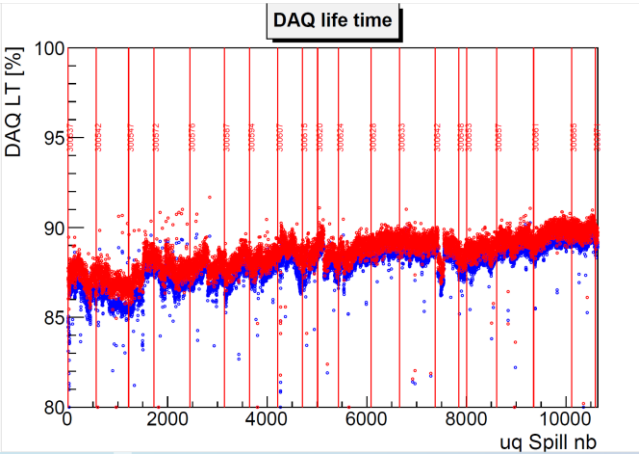
- Alignment
- Stability studies
- Study of the target dimension and position
- DAQ Lifetime correction
- PID: CEDAR and RICH-1
- Monte Carlo
- Extraction of hadron spectra
- First estimate of systematics from RICH PID matrix



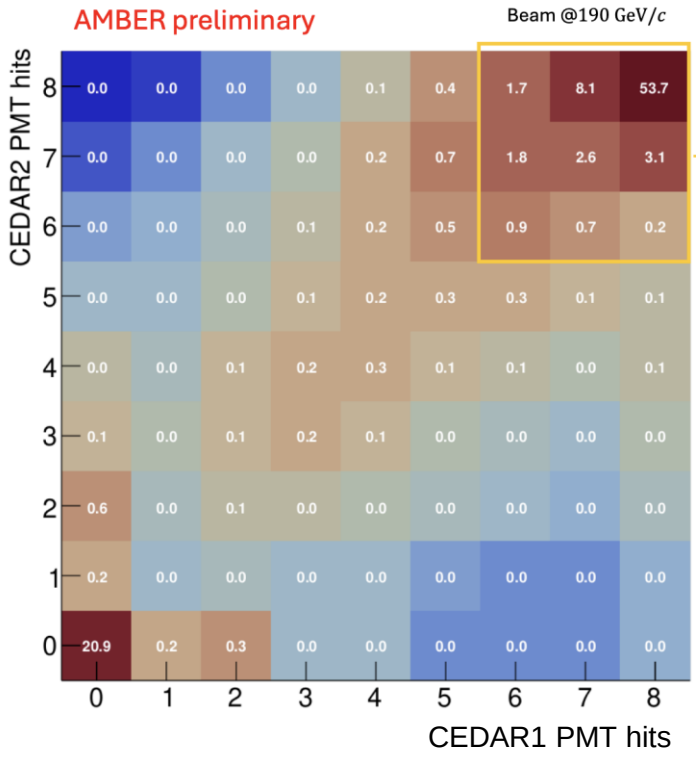
AMBER preliminary

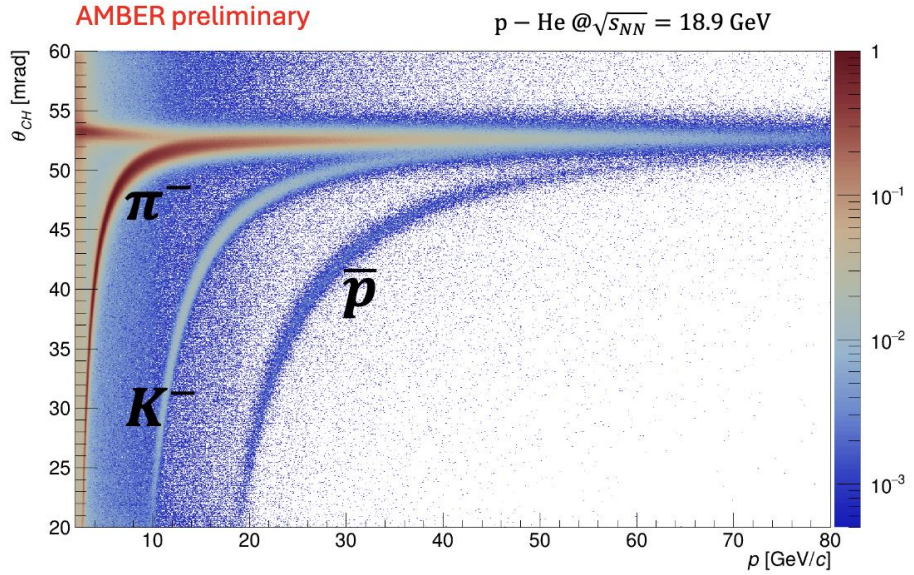


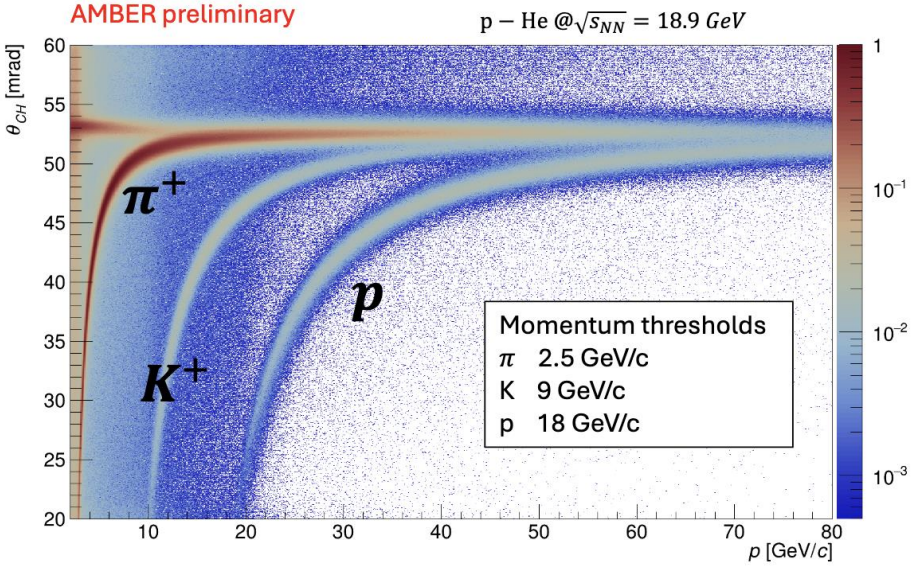




PID: CEDARs and RICH



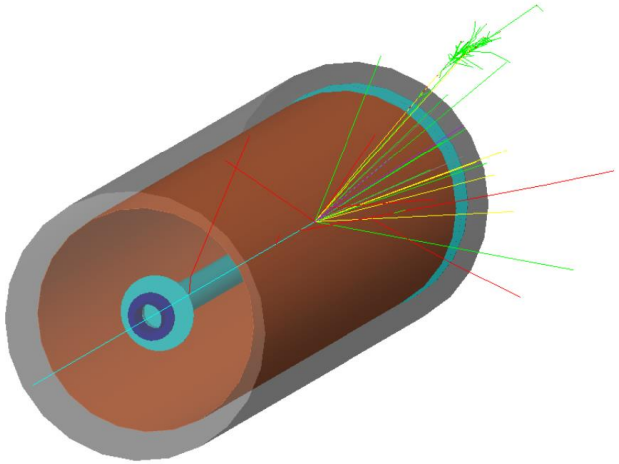


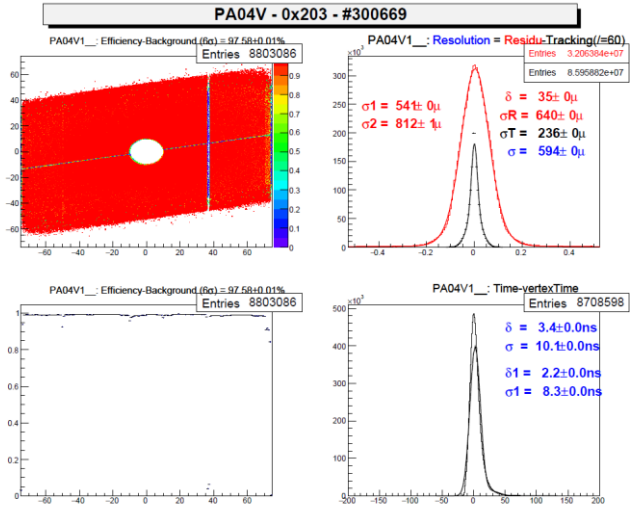


- CEDAR detectors to detect incoming protons
- RICH detector in the spectrometer to identify the produced antiprotons
- Detailed efficiency studies are required for reliable results of multiplicities and cross-sections

Monte Carlo simulation for antiproton production

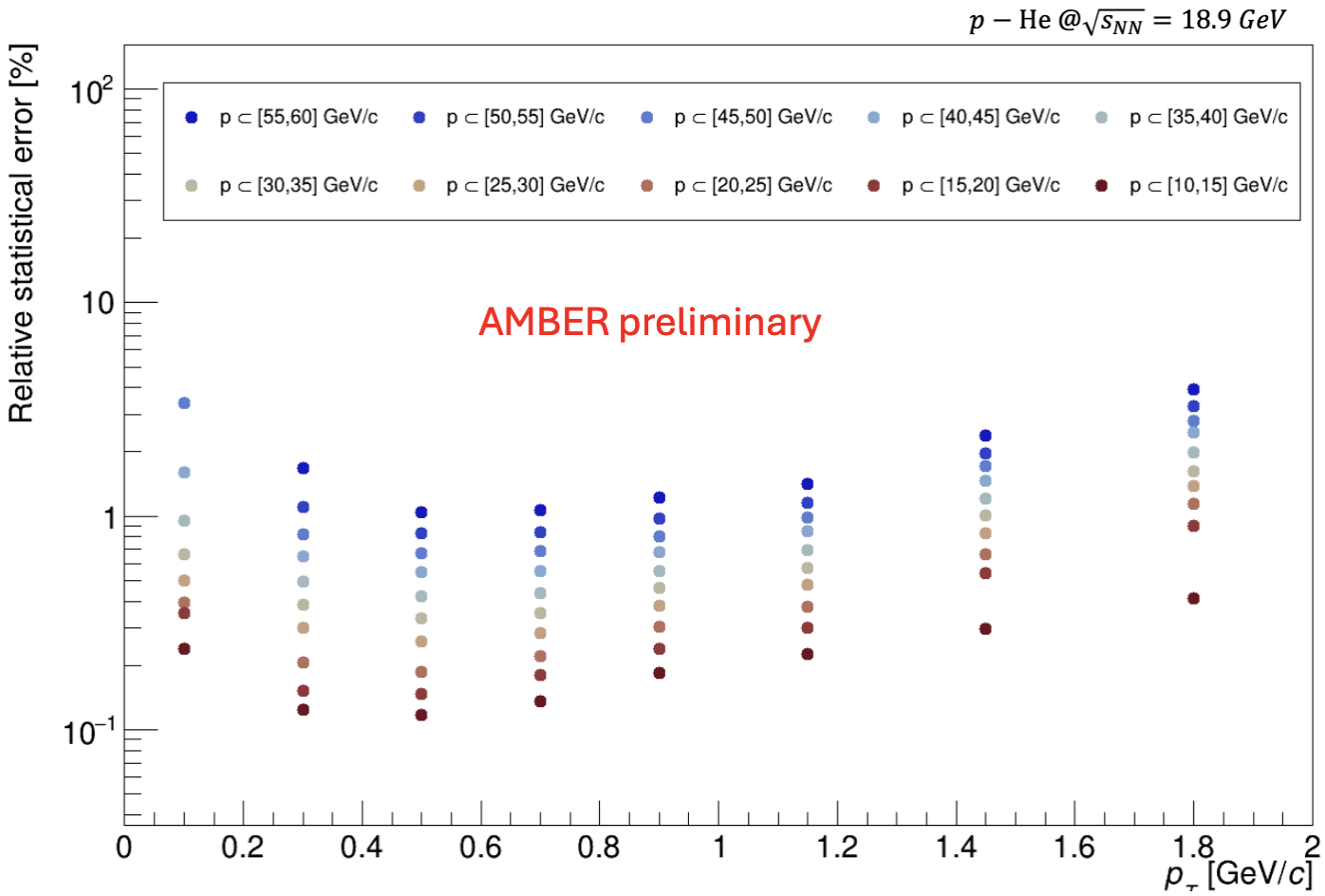
- target implementation currently only for 2023 available
- realistic “beam file” obtained from real data (random trigger)
- physics trigger: beam trigger FI01&FI02 (upstream) and beam killer !BK (downstream the target)
- event generator with PYTHIA8
- detector efficiencies and resolutions from real data
- result: MC acceptance





$$A^h\left(Z_{vtx}, p, p_T\right) = \frac{N_{rec}^{MC,h}\left(Z_{vtx}, p, p_T\right)}{N_{gen}^{MC,h}\left(Z_{vtx}, p, p_T\right)}$$

Uncertainty estimates for W01

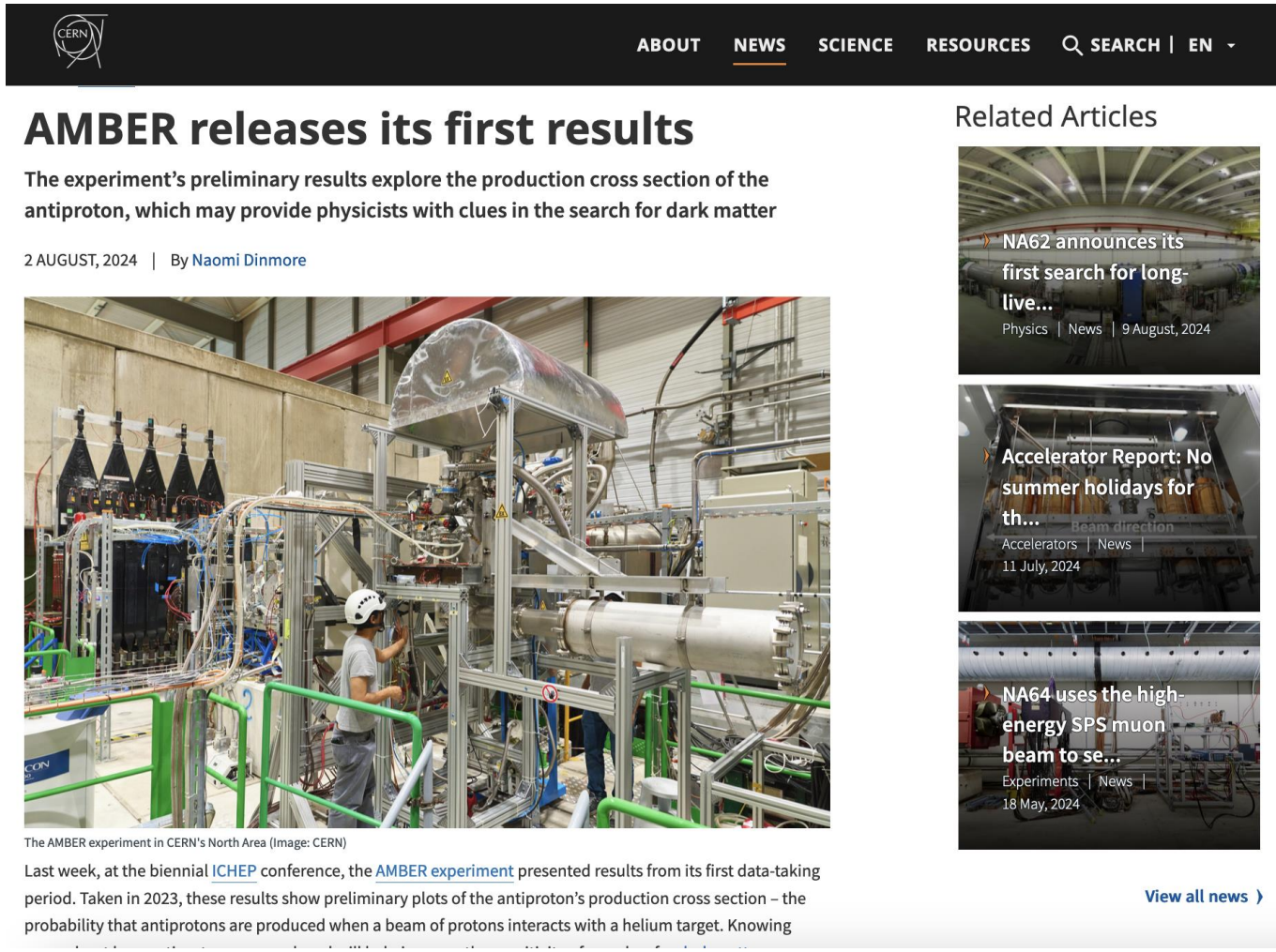


- A preliminary analysis shows that we collected ~6million antiprotons in
  - p [10, 60] GeV/c
  - p_T [0, 2] GeV/c
- Statistical uncertainty in most bins < 1%
- Leading systematic uncertainties expected from:
  - Luminosity
  - RICH

Results for antiproton production

- First results shown by *Davide Giordano* on ICHEP2024 (Prague) and at the JENAA2024 (CERN) workshop, also presented by *Thomas Pöschl* on the DPG spring meeting

- Next update for the workshop XSCRC2024: Cross sections for Cosmic Rays @ CERN



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AMBER releases its first results

The experiment's preliminary results explore the production cross section of the antiproton, which may provide physicists with clues in the search for dark matter

2 AUGUST, 2024 | By Naomi Dinmore

The AMBER experiment in CERN's North Area (Image: CERN)

Last week, at the biennial ICHEP conference, the AMBER experiment presented results from its first data-taking period. Taken in 2023, these results show preliminary plots of the antiproton's production cross section – the probability that antiprotons are produced when a beam of protons interacts with a helium target. Knowing

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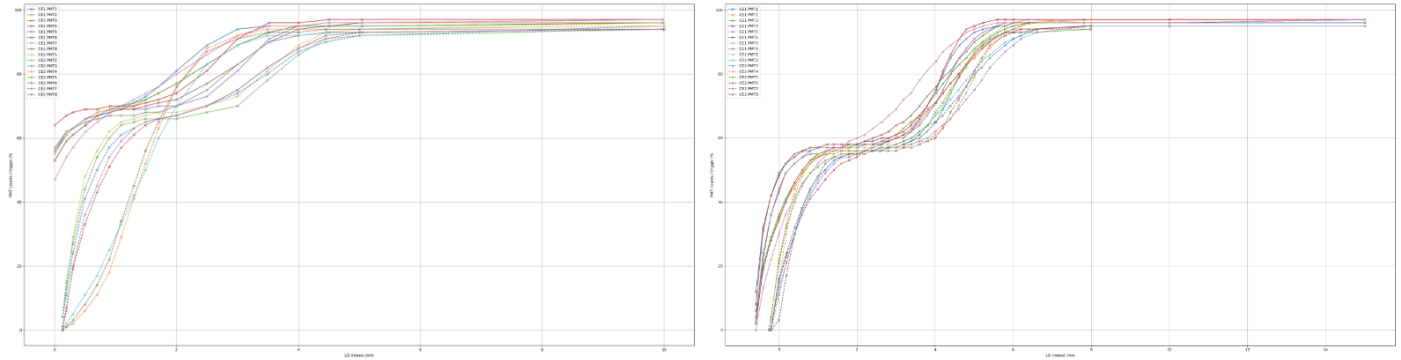
Preparations for Drell-Yan running

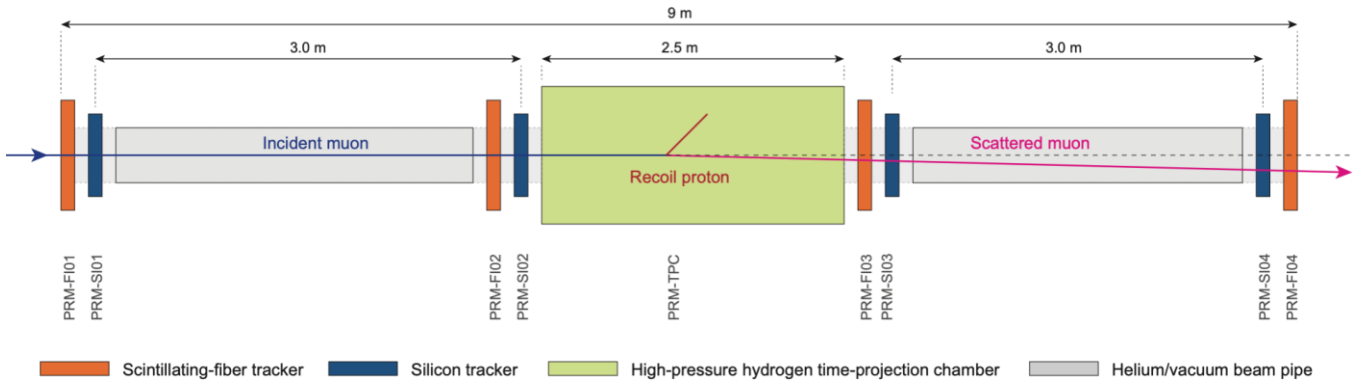
- For the AMBER Drell-Yan running, key is a reliable operation of the CEDAR detectors at high-intensity hadron beam to identify pions ad kaons
- The CEDARs were refurbished in several iterations by BE-EA and SY-BI (alignment system, diaphragm motor), solving issues observed in the 2023 testing an during the reinstallation this year
- Next test with beam in the beginning of October

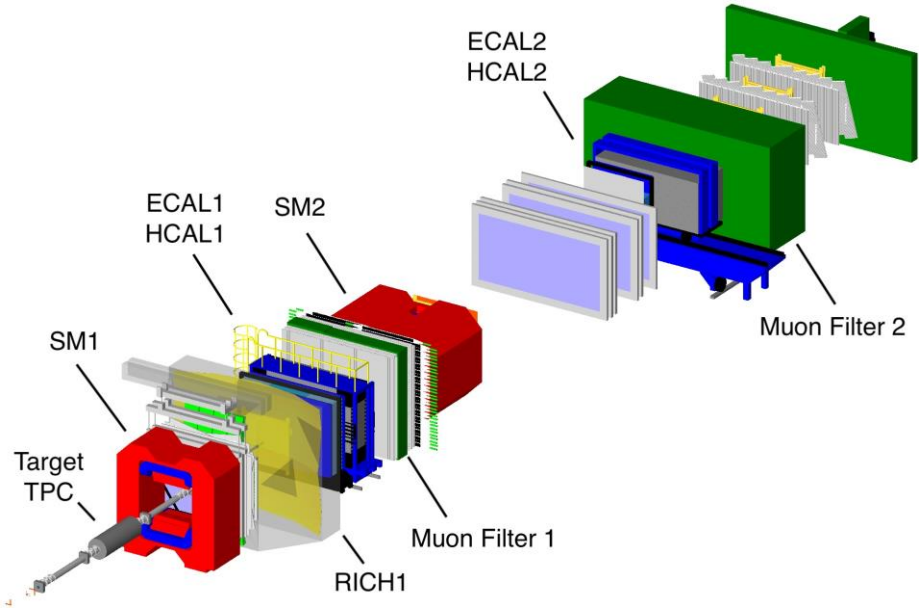


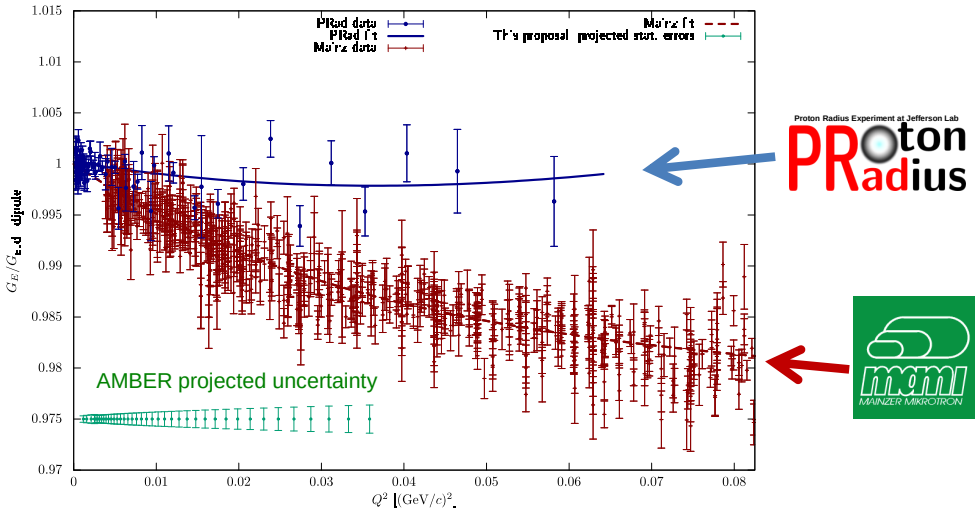
(a) (b)

Fig. 23: In (a) The diaphragm scan of CEDAR 2 before the intervention is shown which clearly shows a set of three PMTs with different behavior than the rest. In (b) The behavior of all PMT channels of CEDAR2 is similar.

Proton charge-radius measurement (PRM)







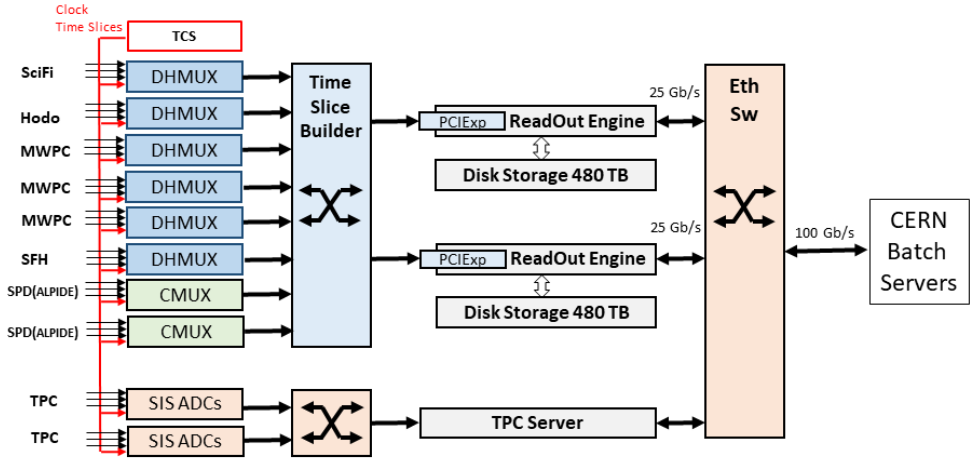
- 100 GeV **muon** beam
- Active-target TPC with high-pressure H_2
- high-precision tracking and spectrometer for muon reconstruction
- goal: 70 million elastic scattering events in $10^{-3} < Q^2 < 4 \cdot 10^{-2}$ GeV^2
- Precision on the proton radius ~0.01 fm

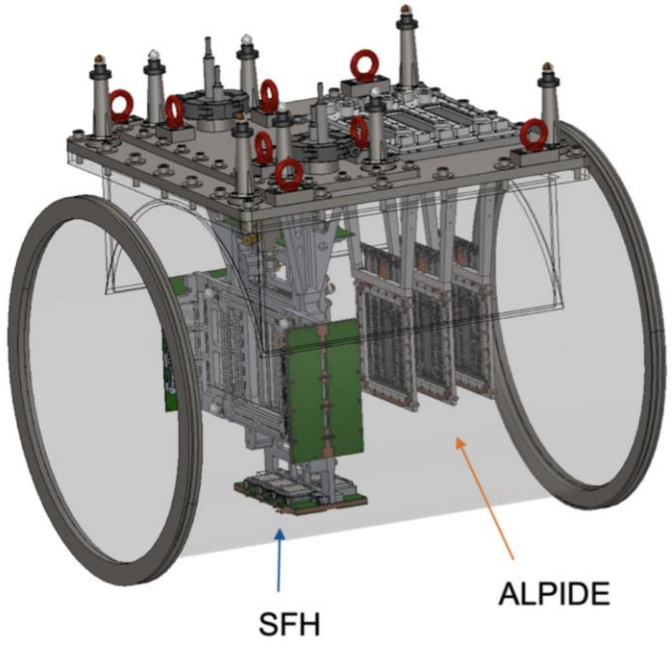
Needed New Equipment for PRM

TPC
- main component of the new PRM setup, but **several delays**
- after Nov. 2024, the new TPC will have to be completed without participation of Russian institutions
- Autumn 2024: profit from the Russian expertise as long as possible
- goal: first successful tests in 2024, and the new TPC operational for a physics run in 2025

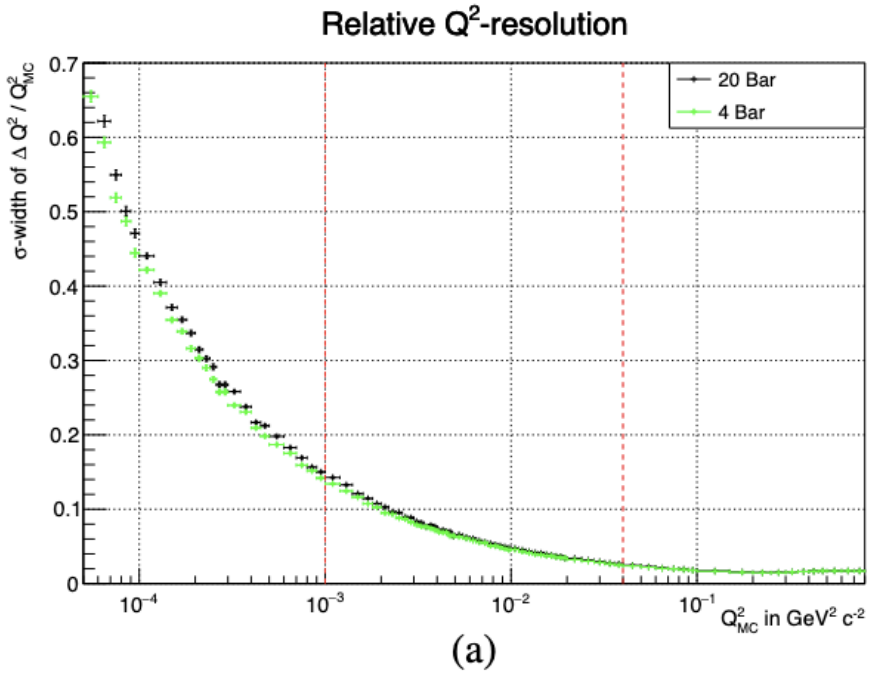
FriDAQ Streaming Data Acquisition System
- vast progress in the last year but especially the interfaces to the detectors still need substantial development work

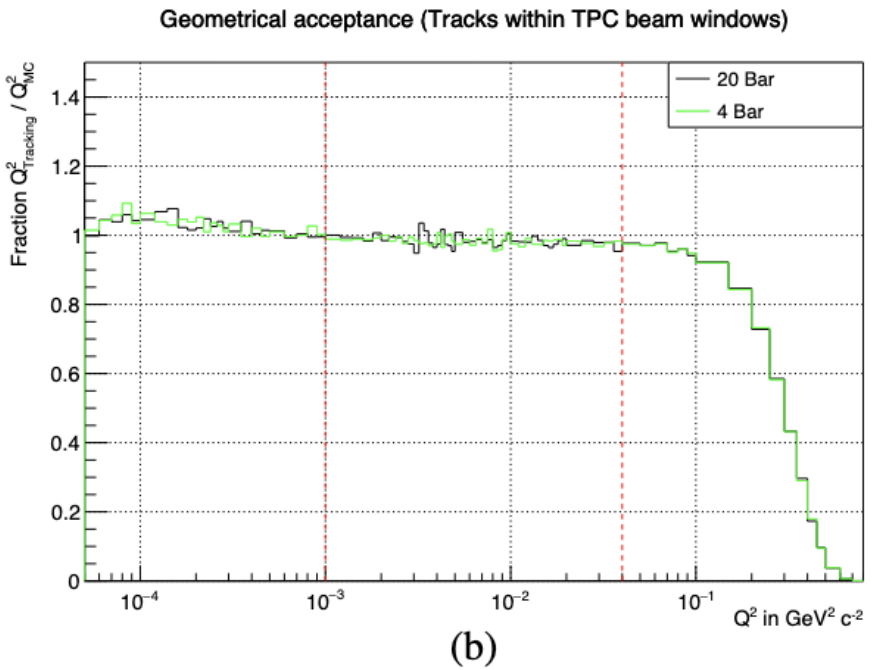
Unified Tracking Stations
- Scintillating Fiber Hodoscopes (SFH): readout electronics is designed and it is planned to test a first detector module in the beam in autumn 2024.
- Silicon Pixel Detectors (SPD): ALPIDE detectors suffered from several needed restructuring processes, focus on finding solutions and we plan to have them available in 2025





Monte-Carlo Studies for PRM

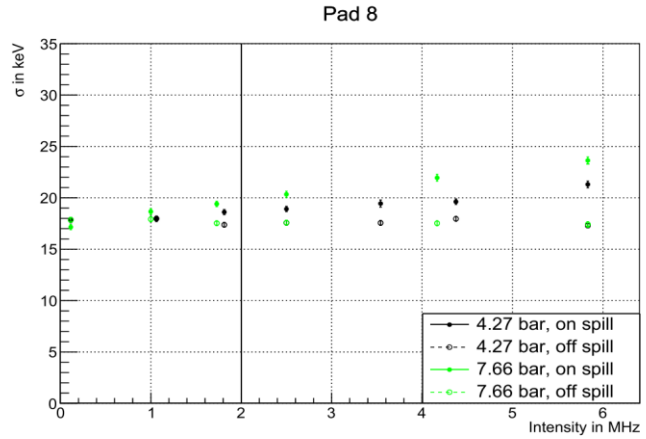


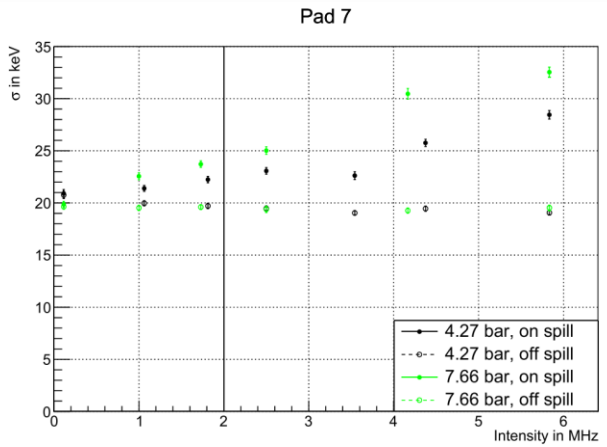


Monte-Carlo Studies

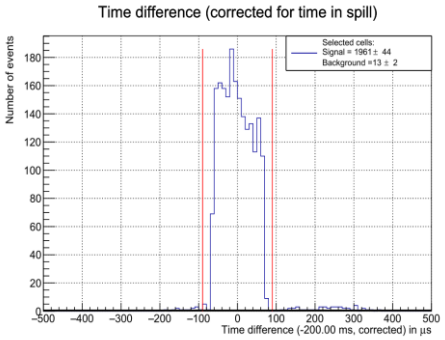
- Relative resolution of Q^2 for both pressure settings better than 15%.
- Additionally, we require the determination of the muon momentum using the spectrometer magnet (SM2) and a successful muon identification. The acceptance is found close to 1 and is flat in the relevant Q^2 range

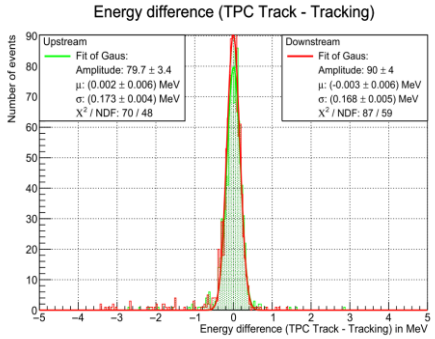
Analysis of 2021 pilot run data - TPC

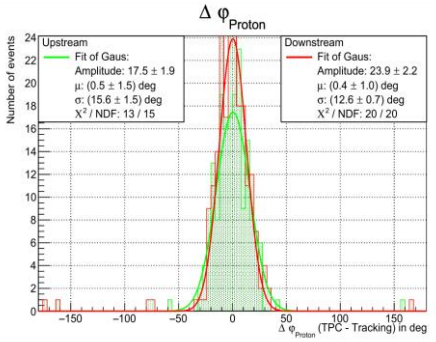




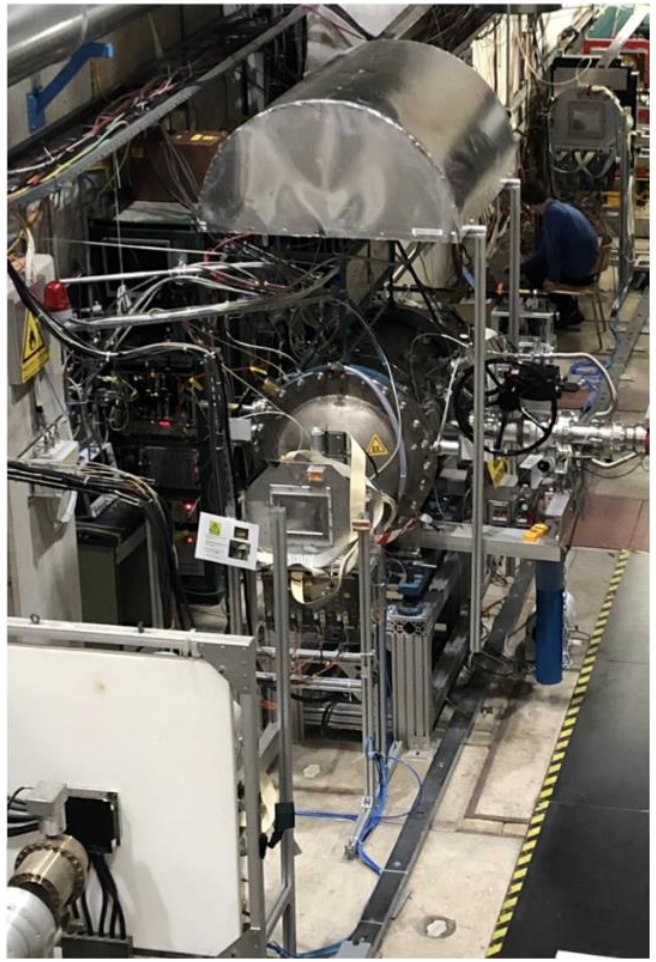
Beam and electronic noise for two TPC pads (in the center)







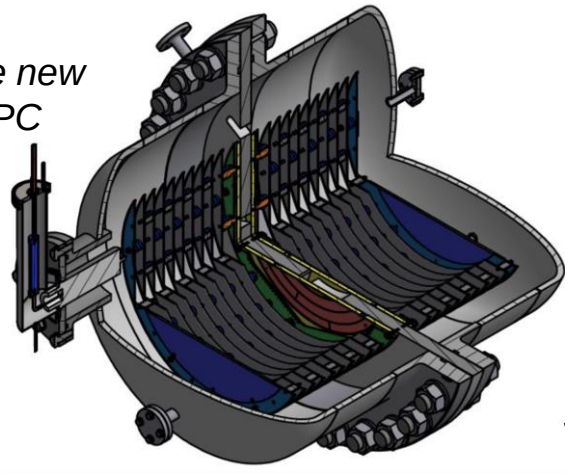
Correlations between muon scattering and proton recoil:
TPC drift time, and in energy and angles



2021 setup with IKAR TPC

Construction and Commissioning of the AMBER TPC

CAD of the new AMBER TPC



- Cooperation with GSI/FAIR (Germany), later usage is foreseen at FAIR/R3B
- Successful overpressure tests at the production site (up to 32 bar)
- Currently at GSI for commissioning, leak rate etc.
- Transport to CERN foreseen in September

Factory Acceptance Test at the Danish production site, May 2024

TPC gas system

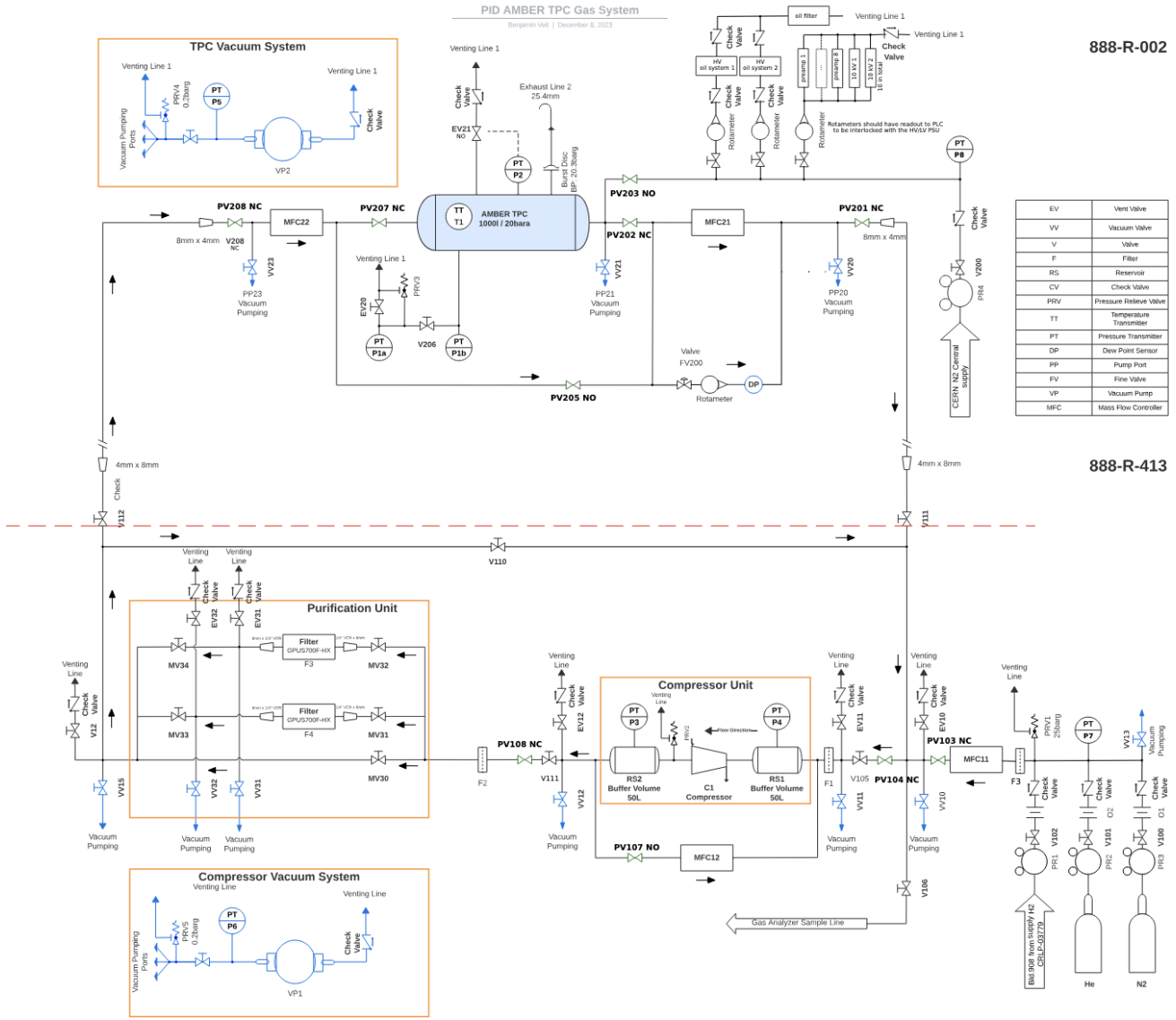


Fig. 27: TPC gas re-circulation and cleaning system.

The whole detector and the gas system, due to the usage of hydrogen, have been evaluated by an external company, and the risk assessment document was started. Several requirements and recommendations are taken into account for the design of the detector systems and surrounding elements.

Many thanks to CERN EP-DT, CERN HSE and GSI for support and help of the challenging issues with risk assessment and safety procedures!

The choice of the elements for the gas system is made taking into account the functionality and requirements according to the risk assessment. The elements are being procured and the whole system is supposed to be put together in **autumn 2024**.

TPC inner structure

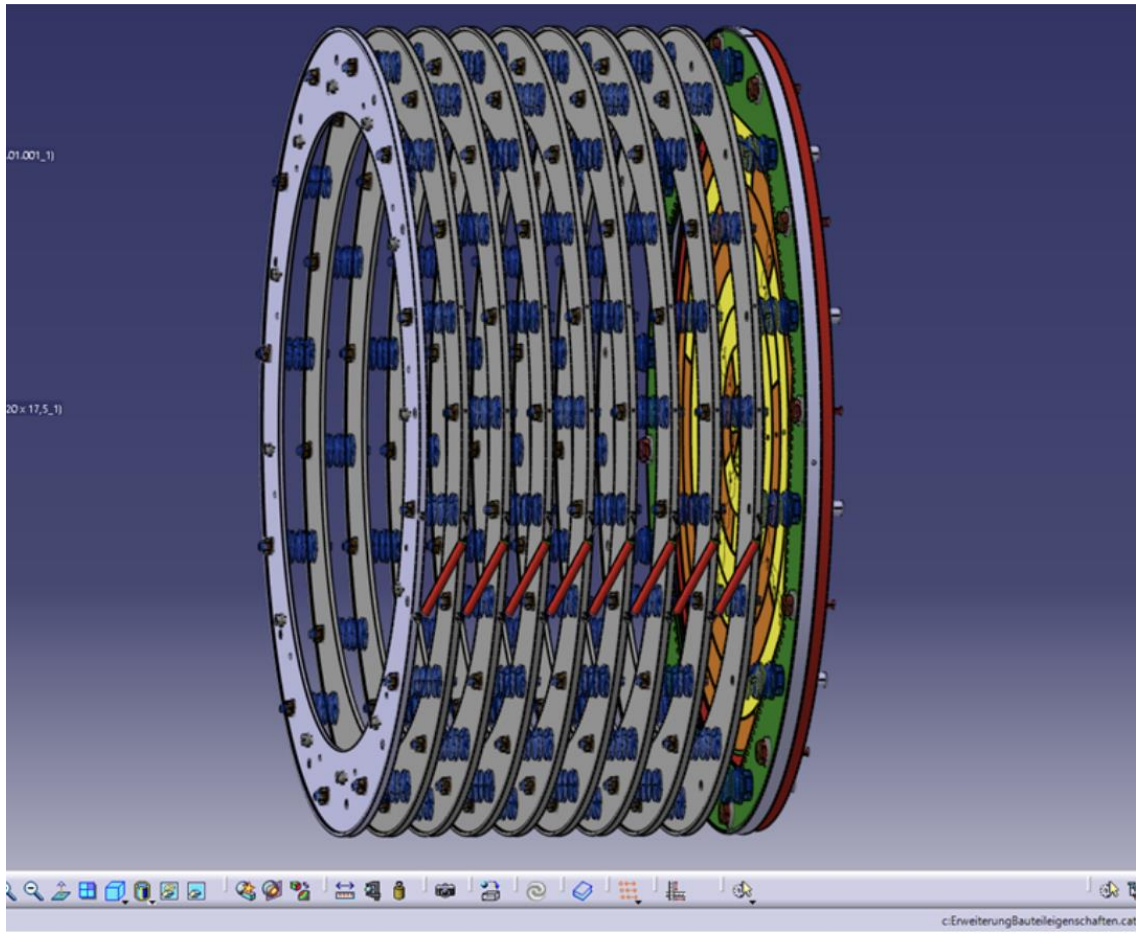
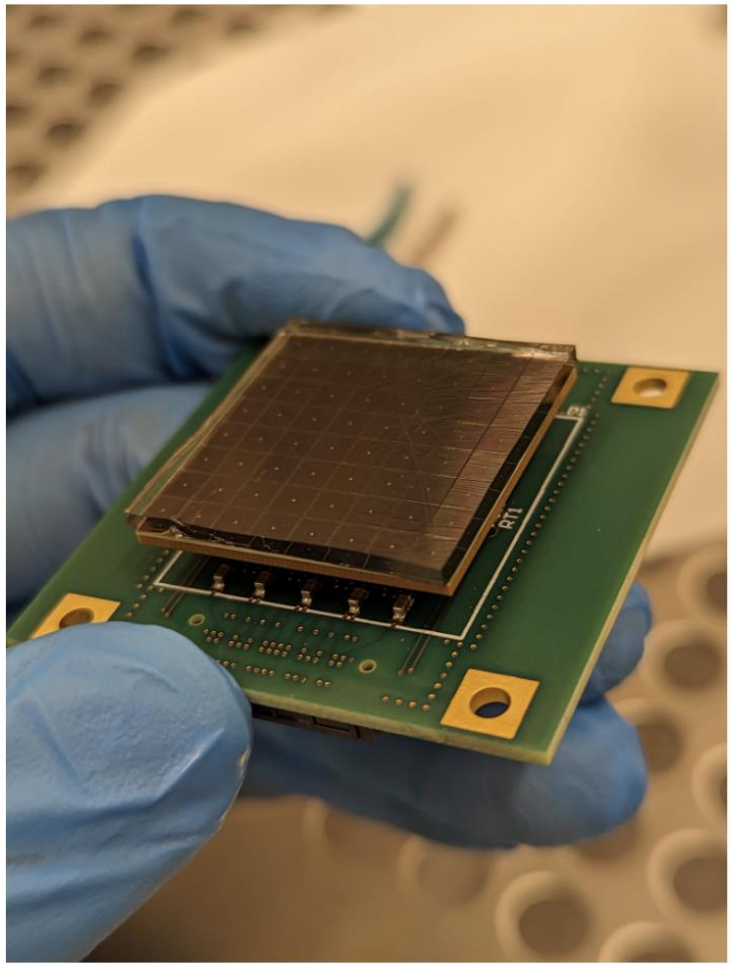


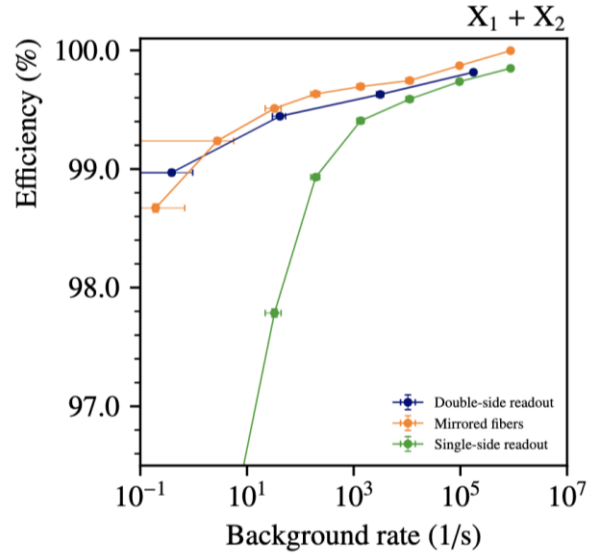
Fig. 26: CAD drawing of the TPC inner electrode structure.

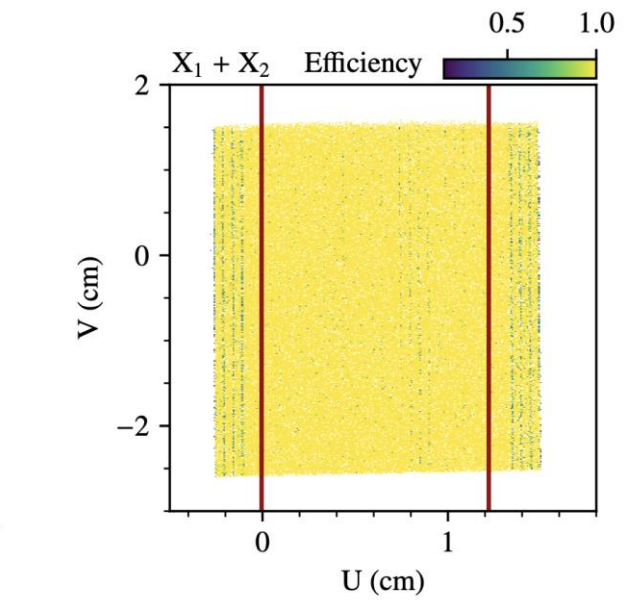
Parts are currently gathered, planned to be assembled in **Autumn 2024**.

SFH testing in 2023



(a) UTS with SFH prototype in the target area. (b) Gel pad used to improve the SiPM-fiber coupling in the SFH prototype.

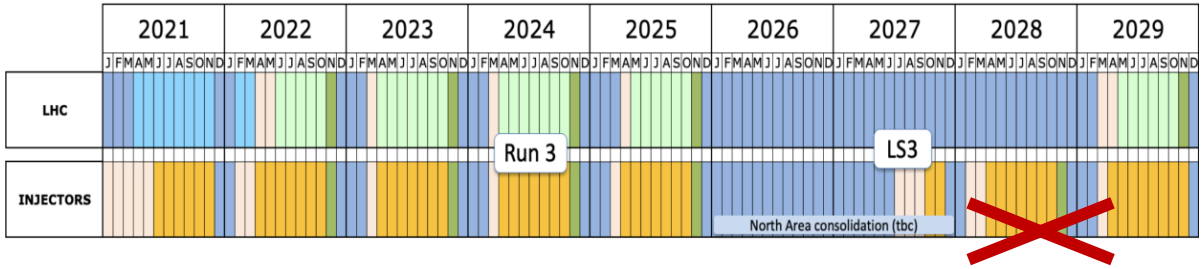


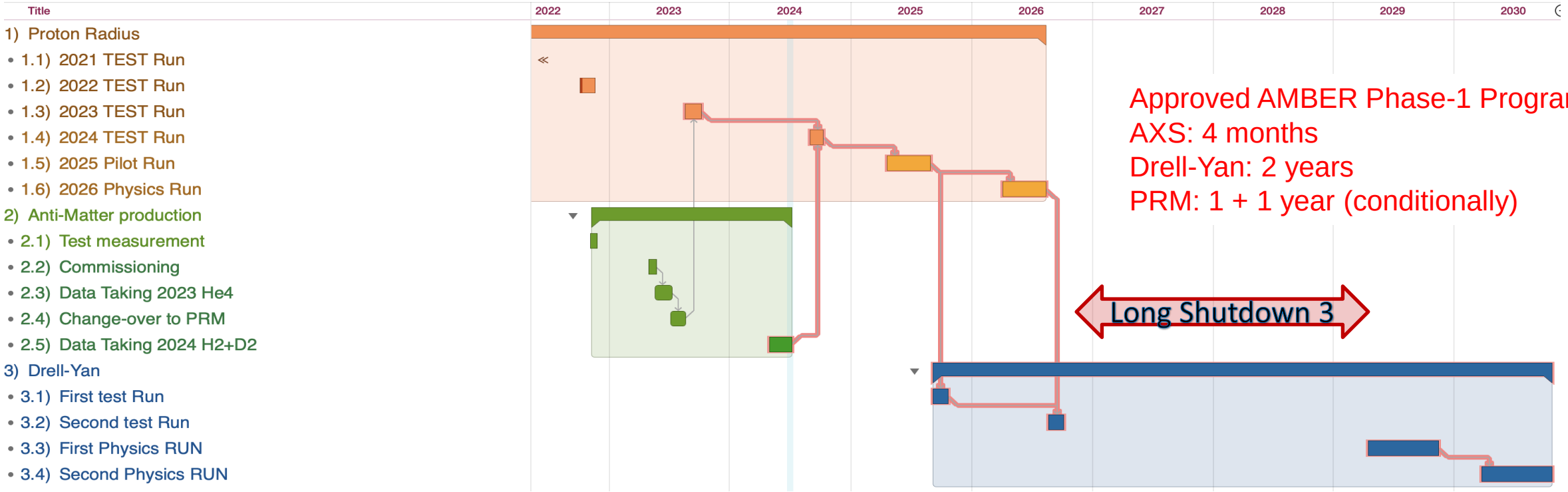


AMBER Phase-1 running plan

Milestones:

1. May 1st 2023, 2024 – Antimatter production Run (Std. DAQ)
2. Sep. 1st 2024 – PRM Test (FriDAQ, very limited setup)
3. June. 1st 2025 – PRM Pilot (FriDAQ, limited setup)
4. May. 1st 2026 – PRM Physics (FriDAQ, PRM setup)
5. Sep. 1st 2025, 2026 – DY Test (FriDAQ, all trackers + mu id)
6. May 1st 2029/30 – DY Run (FriDAQ, full Drell-Yan setup)

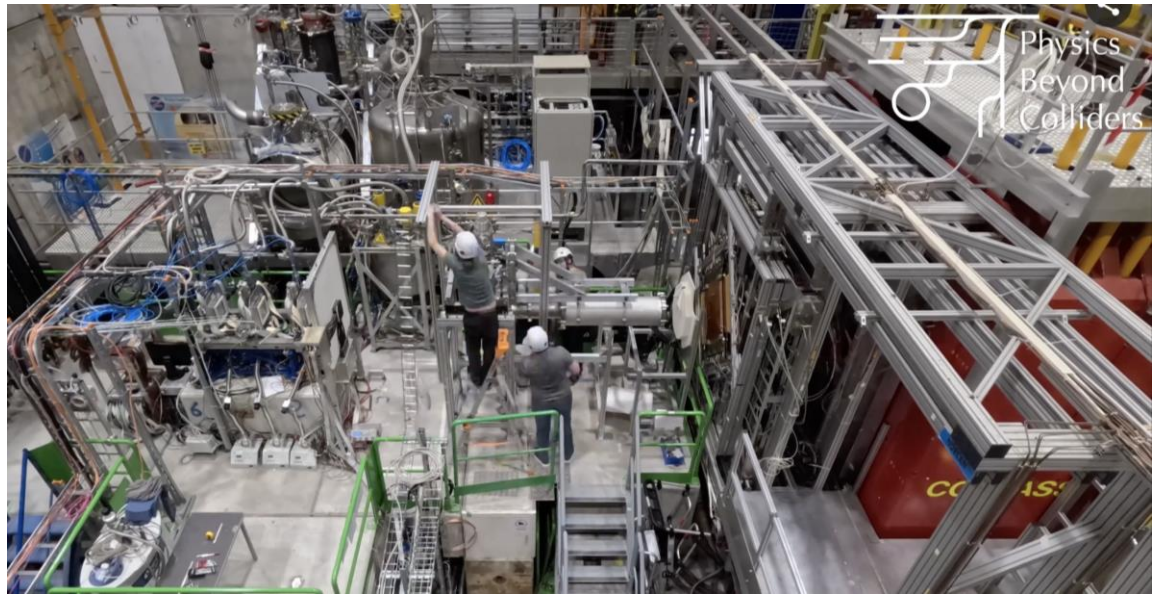




Approved AMBER Phase-1 Program:
AXS: 4 months
Drell-Yan: 2 years
PRM: 1 + 1 year (conditionally)

Conclusions

- AMBER had a successful running of antiproton production in p-p and p-d collisions at beam energies 60 – 250 GeV in the beginning of the 2024 SPS beam time
- Analysis ongoing, first physics results expected soon
- Preparations for the Proton Radius Measurement are in full swing, testing of new detector equipment in autumn 2024
- First physics data acquisition in the second half of the 2025 beam time
- in case of SPS running in 2026: completion of the PRM physics run



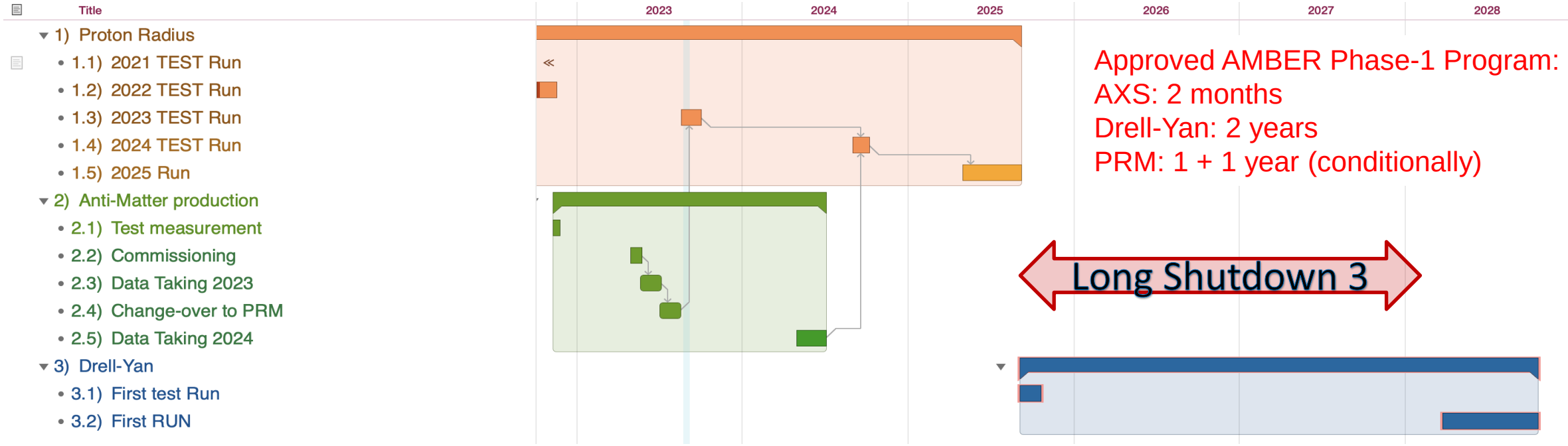

AMBER
Apparatus for Meson and Baryon
Experimental Research

Backup

AMBER Phase-1 running plan (as of June 2024)

Milestones:

1. May 1st 2023 – Antimatter production Run (Std. DAQ)
2. Sep. 1st 2023 – PRM pilot (FreeDAQ, very limited setup)
3. Sep. 1st 2024 – PRM Run (FreeDAQ, limited setup)
4. Sep. 1st 2025 – DY Pilot (FreeDAQ, all trackers + mu id)
5. May 1st 2028 – DY Run (Full Spectr. Ex. RICH, Calorimeters)



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AXS: 2 months
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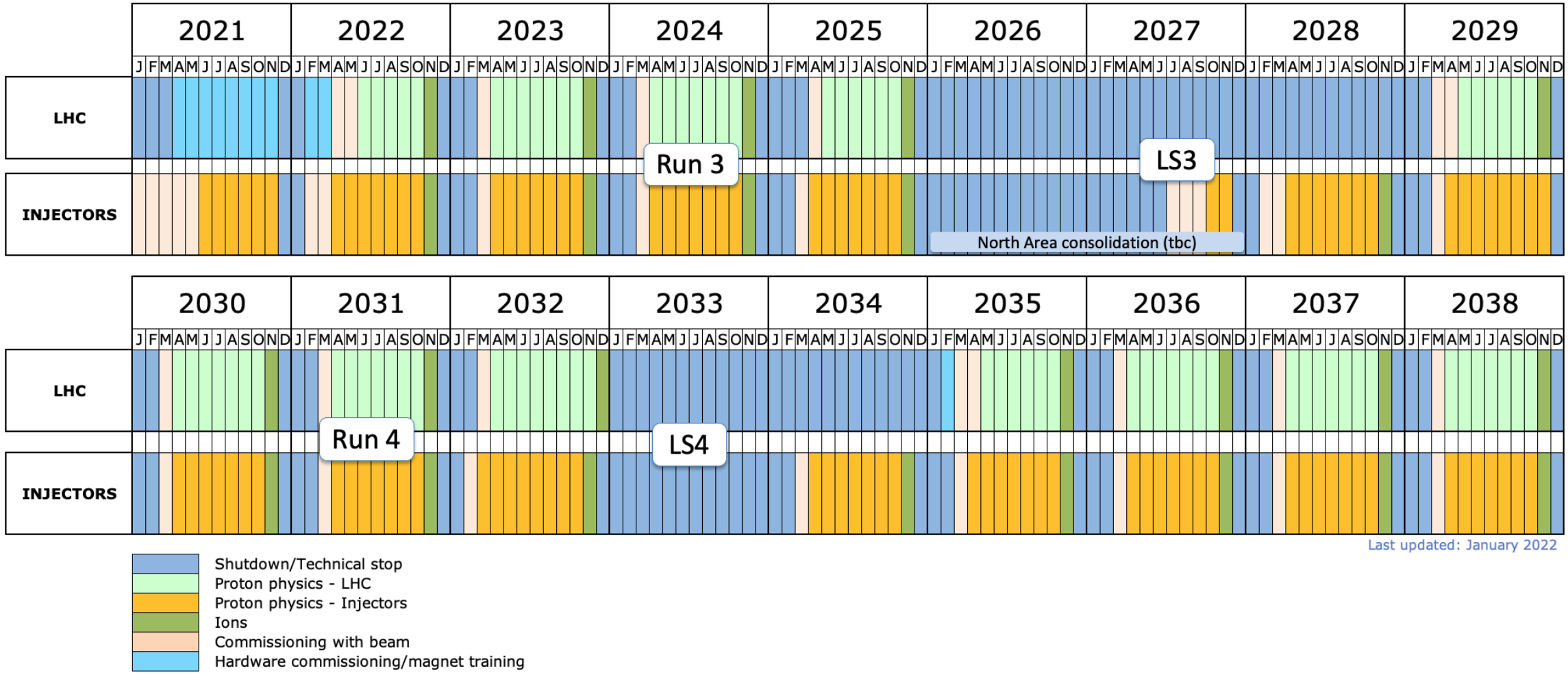
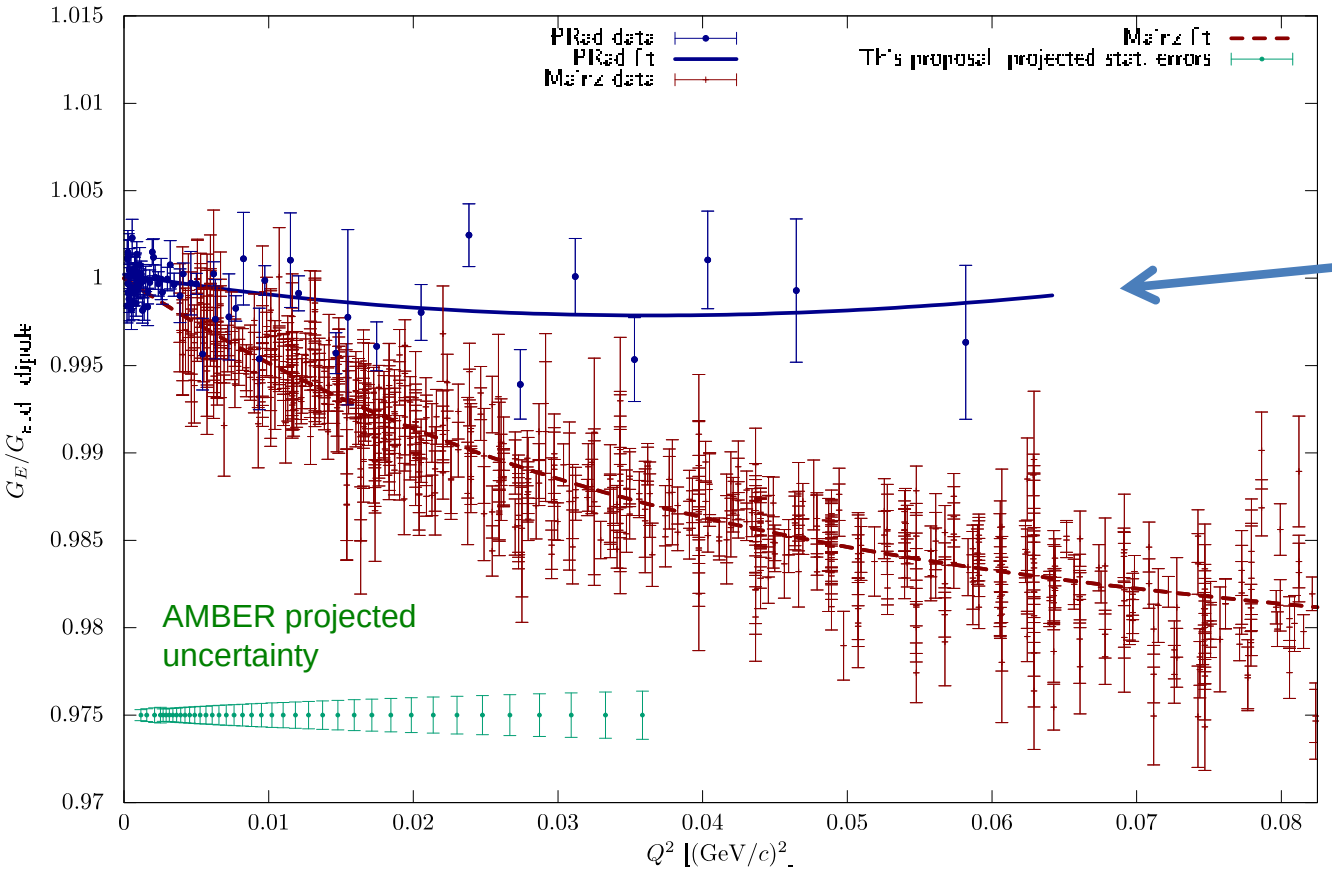
PRM: 1 + 1 year (conditionally)

Long Shutdown 3

LHC and Injectors (PS, SPS) long term schedule



Proton charge radius: slope of G_E^p at small Q^2



Proton Radius Experiment at Jefferson Lab

PRadius

MAINZER MIKROTRON

figure: J. Bernauer

PRM schedule

2018: First measurement of hydrogen TPC in high-energy muon beam

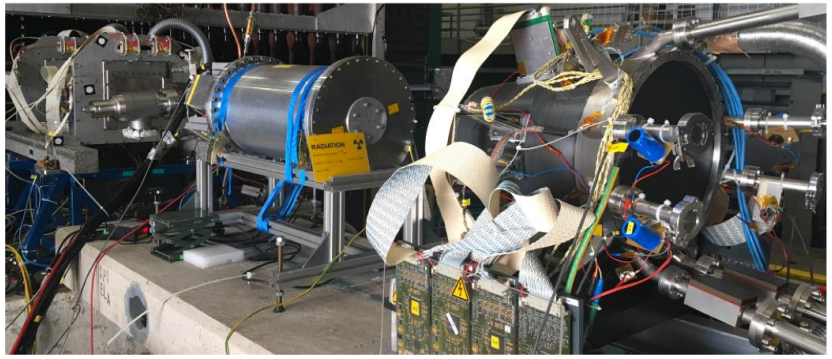
2021: First test run with IKAR TPC and already existing tracking detectors from COMPASS → *correlation between proton energy and muon scattering angle*

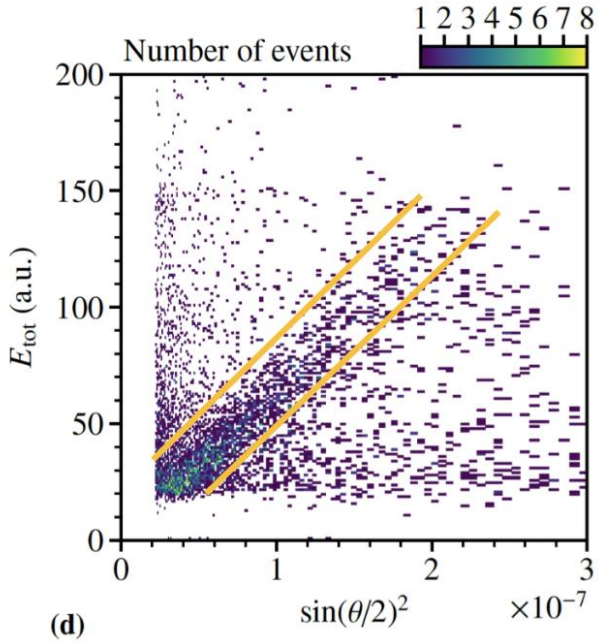
2023: Test run with new free-running DAQ (IKAR TPC, new tracking detector prototypes)

2024: Test run with IKAR/new TPC and UTS prototypes

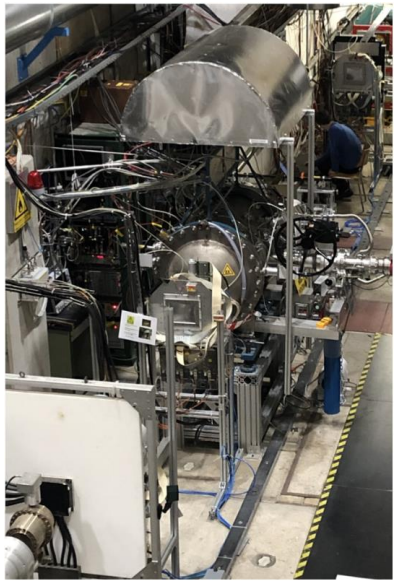
2025: Physics run with new TPC and final UTS

2018



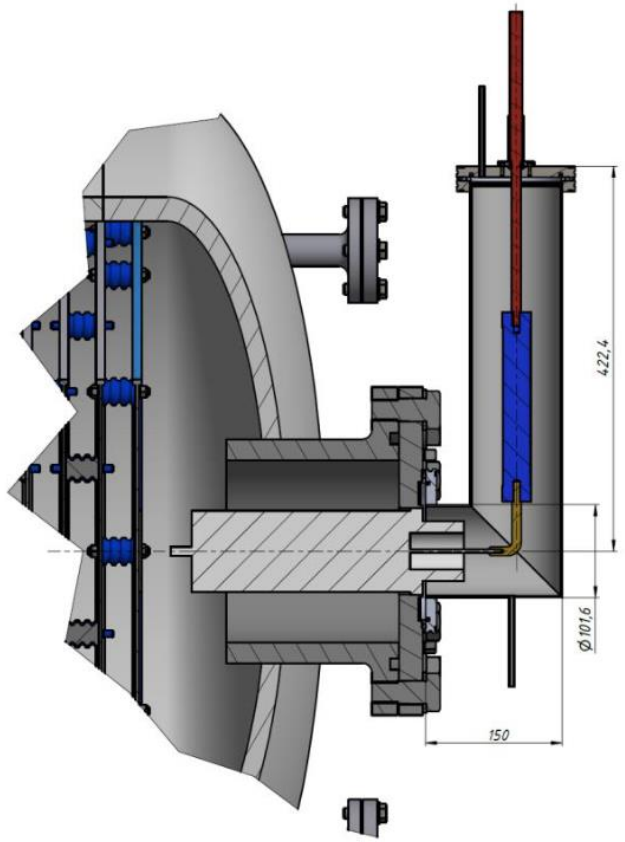


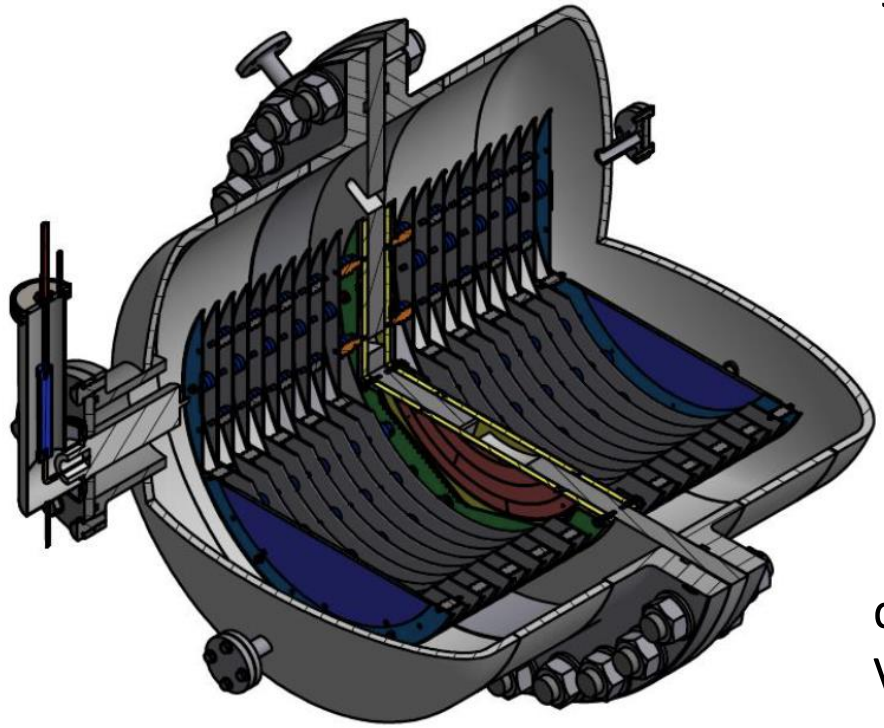
2021



Figures: C. Dreisbach, PhD Thesis (2022)

Active-Target Time Projection Chamber





slide by Oleg Kiselev (GSI) TB report

design by Marat Vznuzdaev, PNPI

- Meeting with CERN safety group in November 2023
- Feedthrough from Hositrad, testing made at MPV Darmstadt is basically approved
- Oil-filled design of the protection cylinder is basically approved, details need to be verified
- **Status November 2023**

TPC circulation gas system

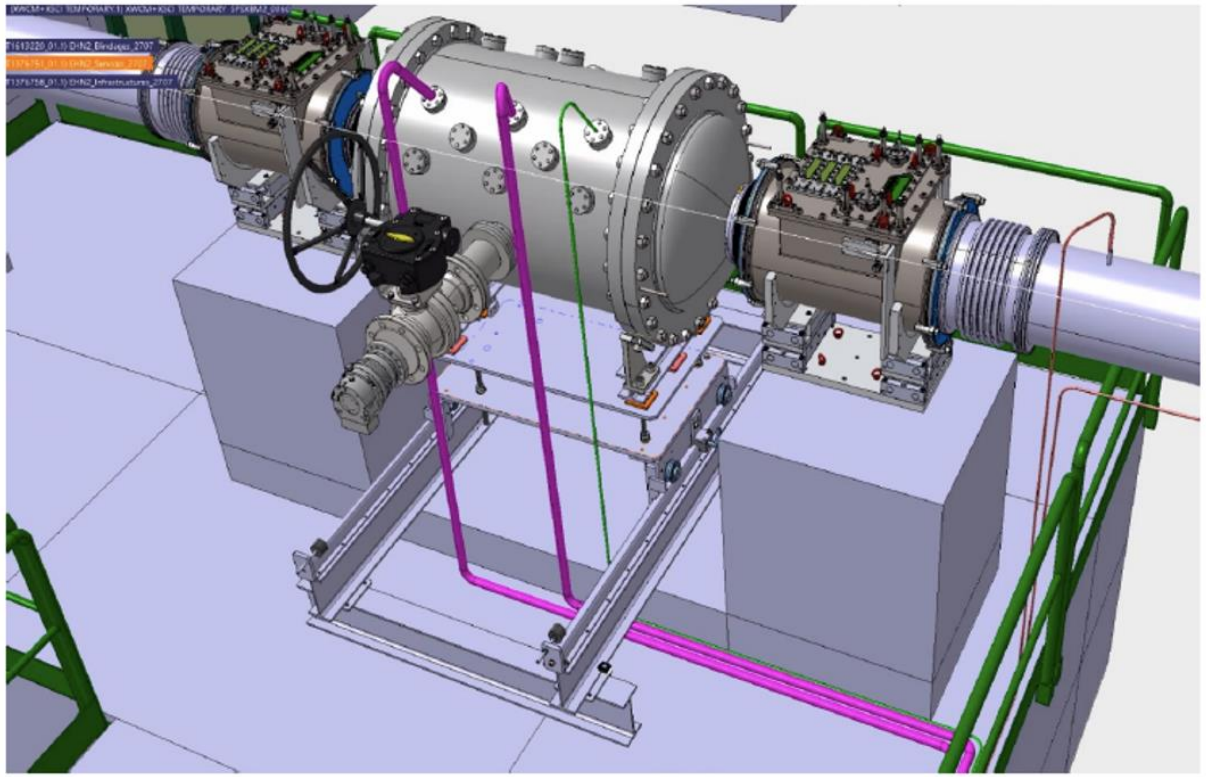


Fig. 29: Sketch of the foreseen IKAR TPC preparations in the target area sandwiched between two UTS. Hydrogen lines are indicated in purple.

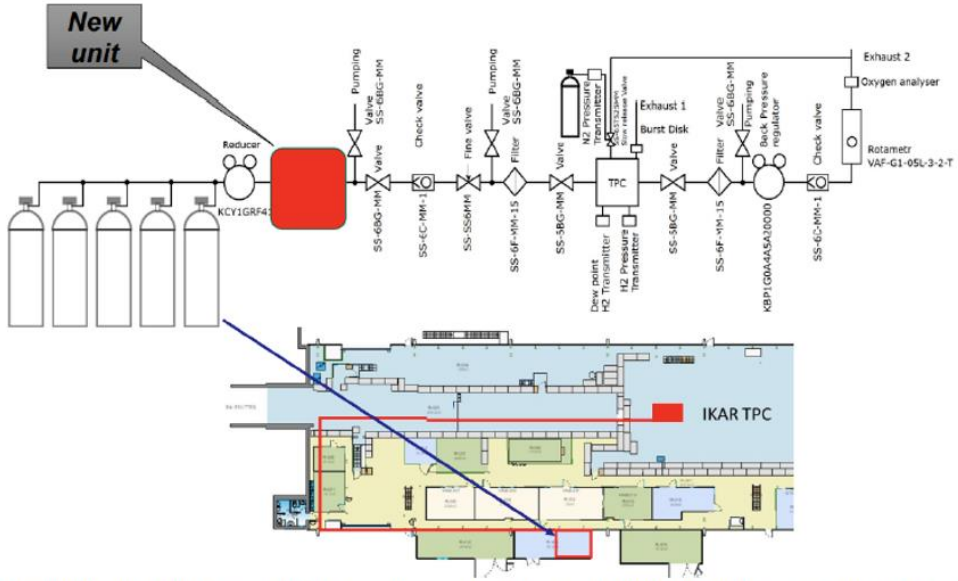
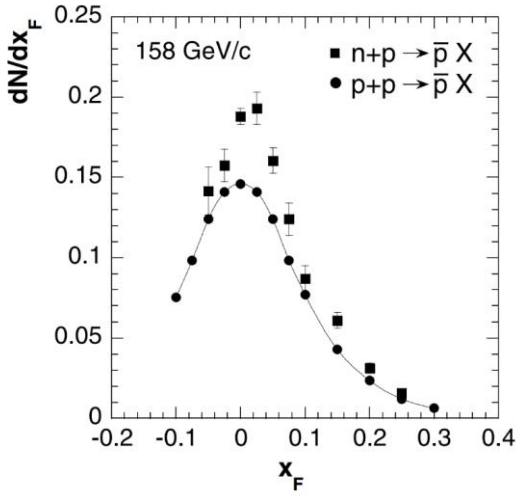


Fig. 30: Sketch of the foreseen IKAR gas system and installation in EHN2. The gas lines are indicated in red together with the new purification unit.

Isospin asymmetry for antiproton production



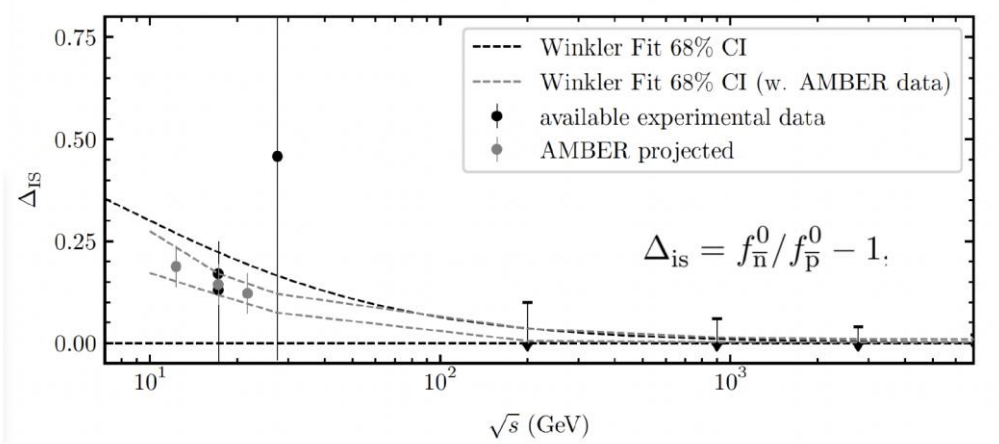


Fig. 7: Estimation of the impact of the AMBER measurement of the isospin factor using experimental data at 3 different collision energies.

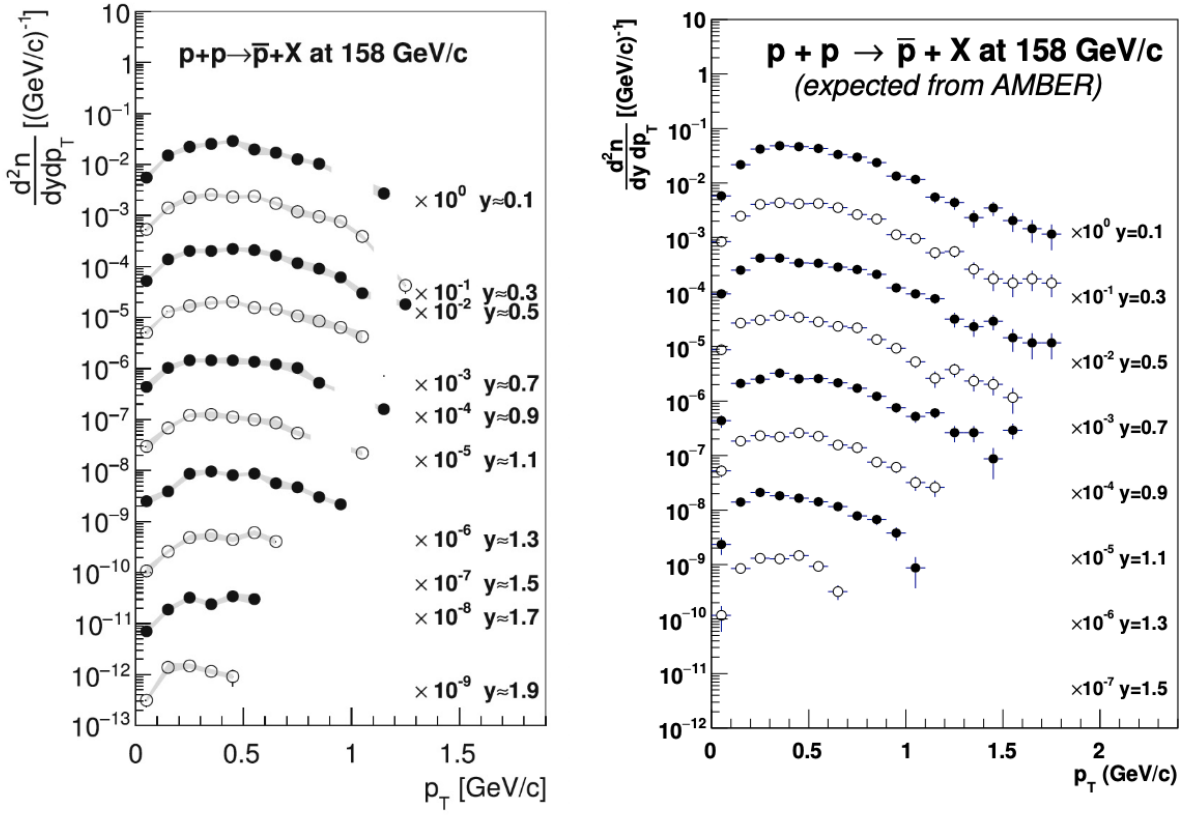


Fig. 2: Transverse momentum $\bar{p}$ spectra in rapidity slices produced in p+ p inelastic interactions at 158 GeV by NA61 (left figure) [3]. For comparison the expected results obtainable by AMBER in $p + p \to \bar{p} + X$ at 160 GeV/c are shown (right figure).