Antiproton production cross sections for dark matter search at the AMBER experiment @CERN SPS

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AMBER
Apparatus for Meson and Baryon Experimental Research

QuarkMatter 2023

AMBER Collaboration:
> 200 members,
41 participating institute, 14 countries.

Run 3 → Run 4

Phase-1 ✓

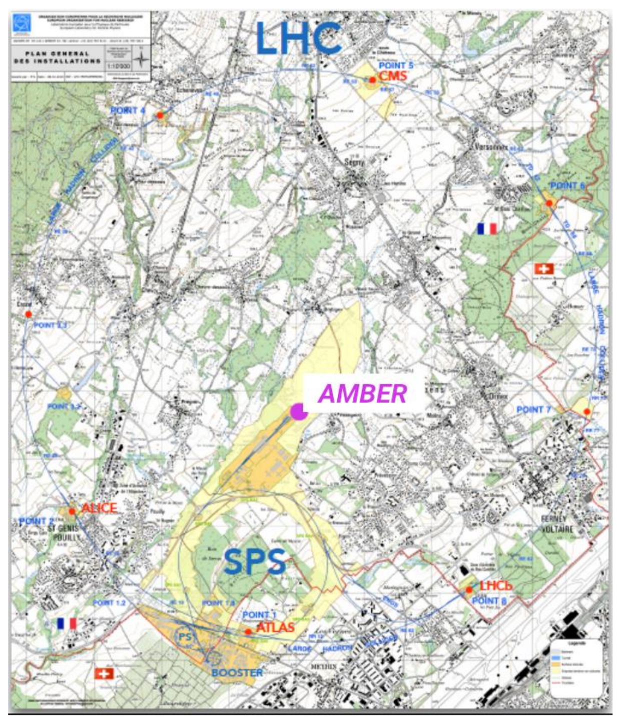
Proposal approved by RB on 02/12/2020

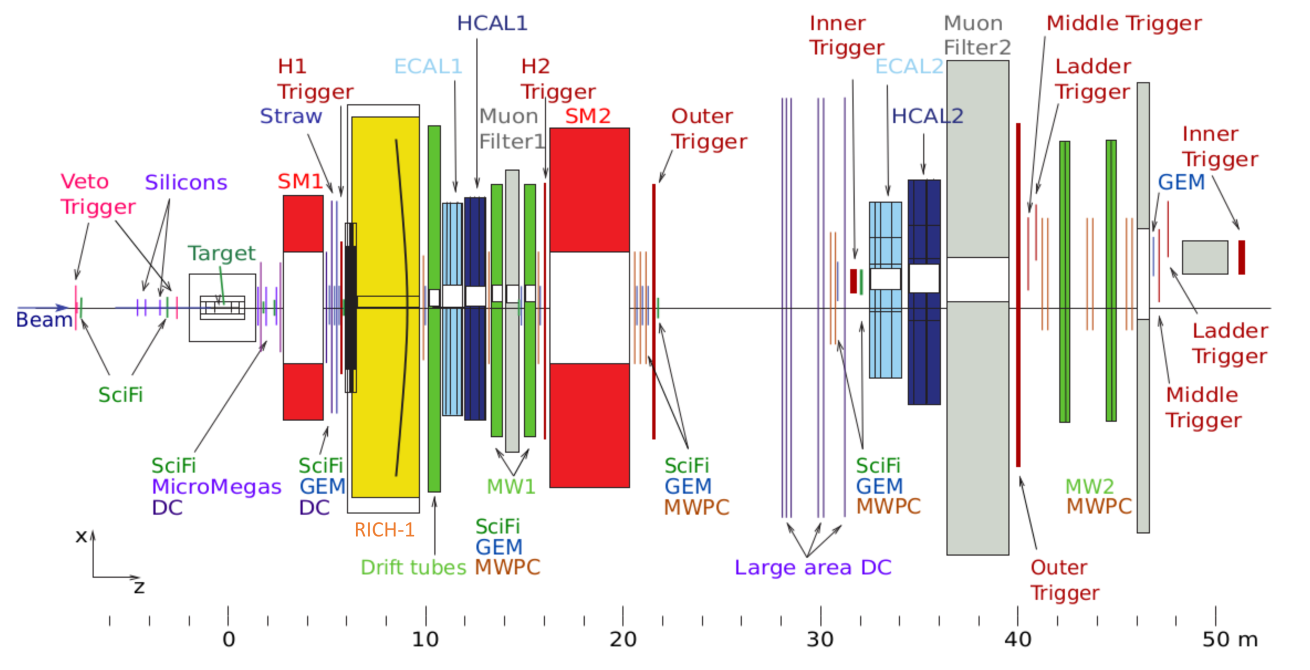
- Proton Radius Measurement
- Antiproton production cross section
- Pion structure (PDFs) via DY and charmonia

Phase-2

Proposal submission in preparation

- Kaon and pion structure
- High precision strange-meson spectrum
- Kaon and pion charge radii
- Kaon induced Primakoff reaction





Cosmic Rays as investigation tool for exotic sources

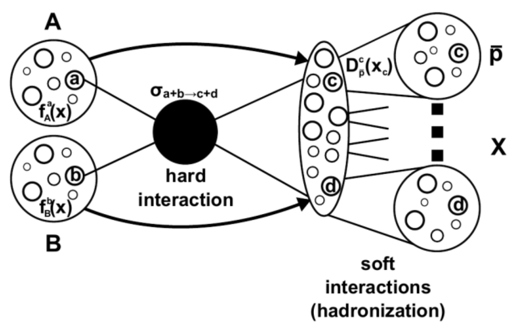
Cosmic Rays (CR) are a fundamental tool to understand the composition and the structure of our Universe. By studying the fluxes of CR we can validate models about their production, propagation in the Galaxy and their sources. The up-to-date propagation equation models includes several effect inside the galactic disc and halo such as energy-losses, reacceleration, spallation, diffusion and shock waves acceleration:

$$\frac{\partial\psi(\vec{r},p,t)}{\partial t} = q(\vec{r},p,t) + \vec{\nabla}\cdot(D_{xx}\vec{\nabla}\psi - \vec{V}\psi) + \frac{\partial}{\partial p}p^2 D_{pp}\frac{\partial}{\partial p}\frac{1}{p^2}\psi - \frac{\partial}{\partial p}\left[\dot{p}\psi - \frac{p}{3}(\vec{\nabla}\cdot\vec{V})\psi\right] - \frac{1}{\tau_f}\psi - \frac{1}{\tau_r}\psi$$

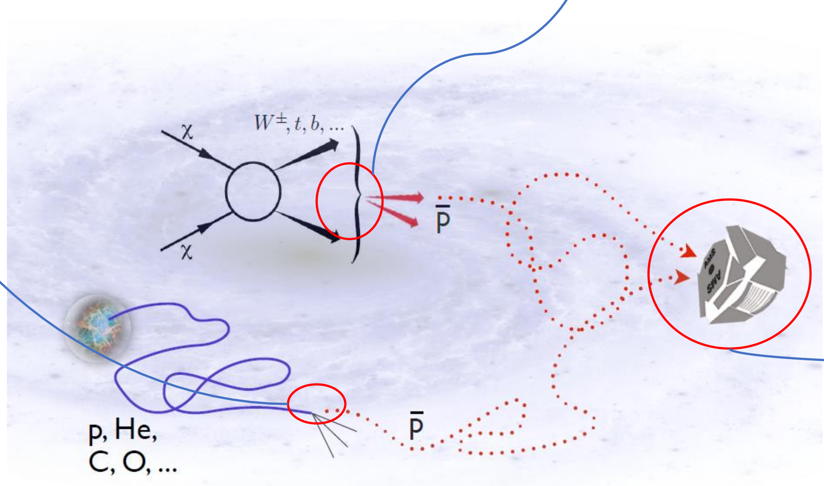
Antiproton production cross sections

$$q_{ij}(T_{\bar{p}}) = \int_{T_{th}}^{\infty} dT_i\, 4\pi\, n_{ISM,j}\, \phi_i(T_i) \frac{d\sigma_{ij}}{dT_{\bar{p}}}(T_i, T_{\bar{p}})$$

$$q_{\bar{p}}^{(DM)}(\boldsymbol{x}, E_{kin}) = \frac{1}{2}\left(\frac{\rho(\boldsymbol{x})}{m_{DM}}\right)^2 \sum_f \langle\sigma v\rangle_f \frac{dN_{\bar{p}}^f}{dE_{kin}}$$



Thomas Poeschl, PhD thesis

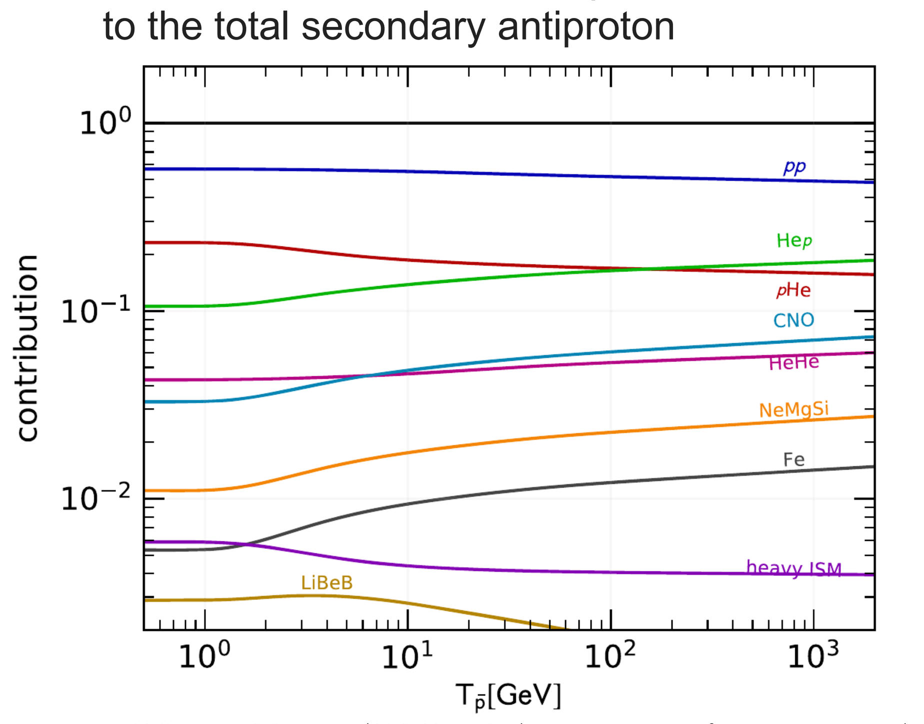


Uncertainties in measurements

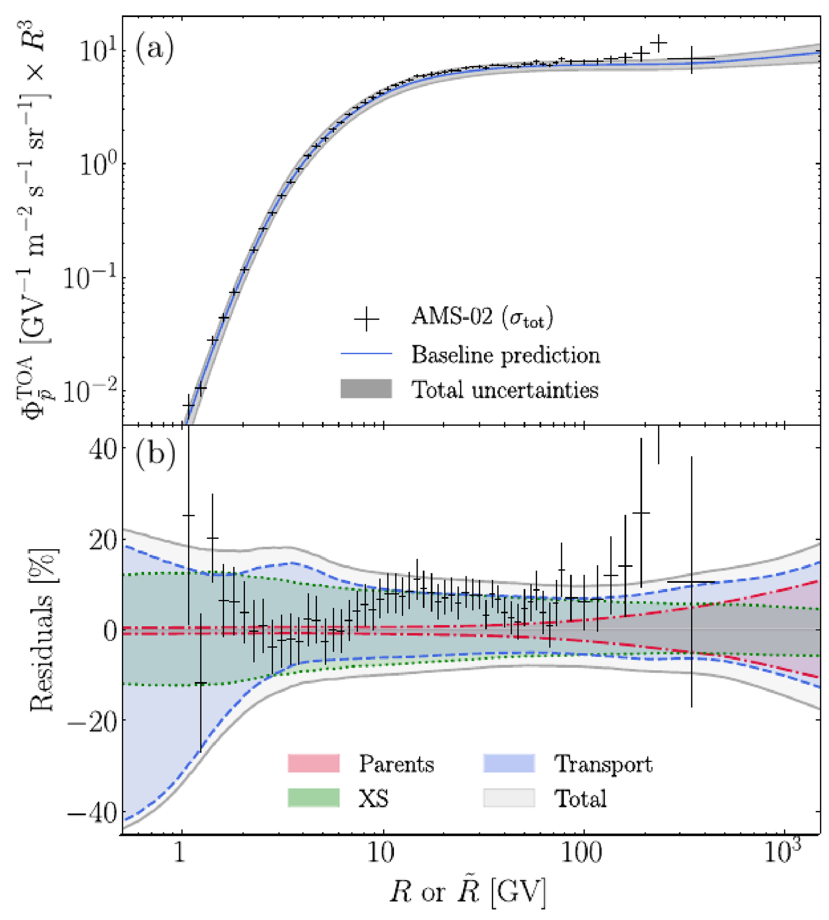
Among the plethora of particles and elements produced that we can detect, rare components like positrons, antiprotons and antideuterons are our most promising probe of exotic primary sources like Dark Matter (DM).

In particular, antiprotons arriving at Earth are mostly of secondary origin, i.e. produced in interaction of primary CRs with the InterStellar Medium (ISM). The ISM is composed at 99% of protons and Helium, so that the main reactions contributing to the source term of antiprotons are *p-p*, *p-He*, *He-p* and *He-He*.

Relative contribution of the production channels to the total secondary antiproton



M. Korsmeier, F. Donato, and M. Di Mauro, Production cross sections of cosmic antiprotons in the light of new data from the na61 and lhcb experiments, Phys. Rev. D97 (2018) 103019



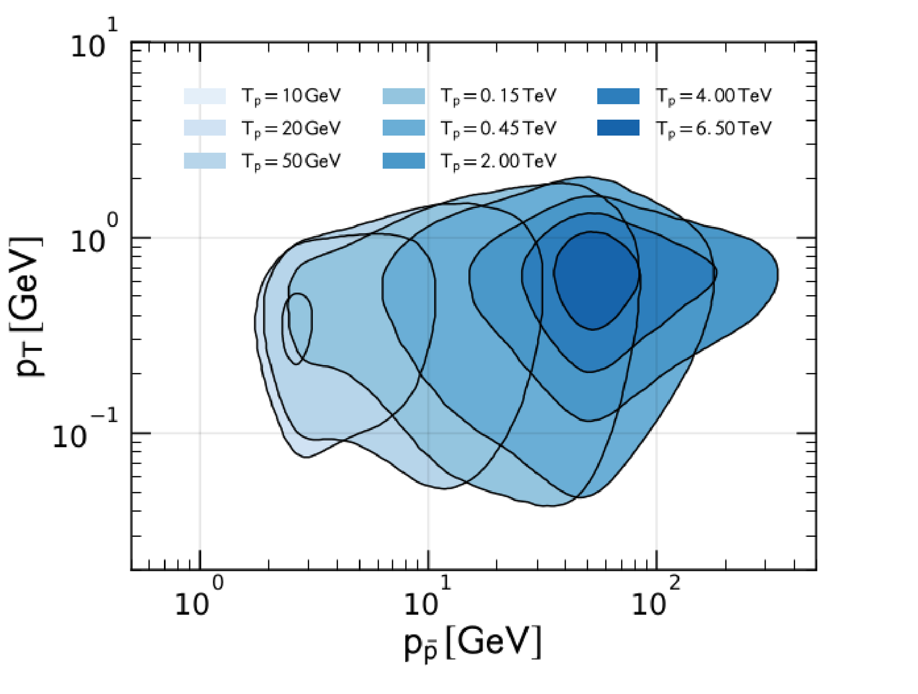
M. Boudaud, Y. Génolini, L. Derome, J. Lavalle, D. Maurin, P. Salati, and P. D. Serpico, AMS-02 antiprotons' consistency with a secondary astrophysical origin, Phys. Rev. Res. 2 (2020) 023022.

The antiproton flux was measured by balloon and space-based experiment in the past year like AMS, PAMELA, CREAM among the others, with AMS-02 releasing the most precise measurement in rigidity range of 1-300 GV (R = p/Q).

The precise results from AMS stimulated a lot of work in the interpretation of the flux of antiprotons, improving diffusion models and opening to DM candidates speculations.

However, errors on both theoretical models and nuclear data related to production processes are greater than the errors on the fluxes and it is difficult to confirm presence of DM in the game.

AMBER contribution – Antiproton measurement setup



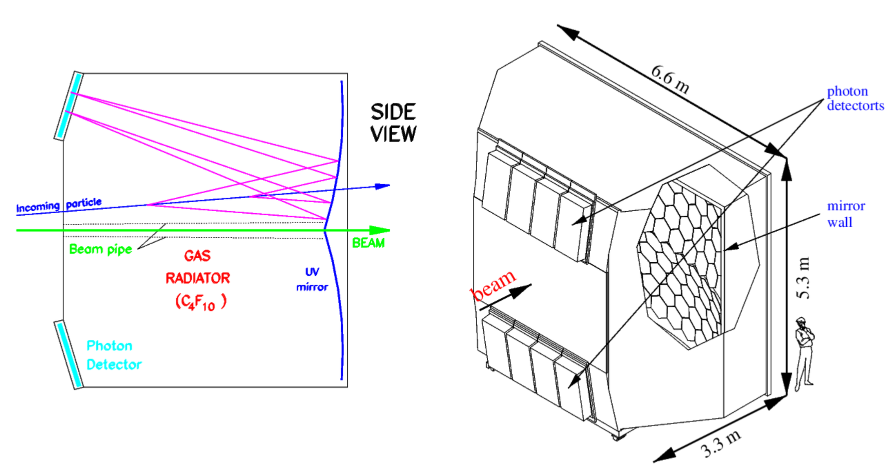
F. Donato, M. Korsmeier and M. Di Mauro,Prescriptions on antiproton cross section data for precise theoretical antiproton flux predictions,arXiv: 1704.03663v2[astro-ph.HE] 4 Jun 2018

- Parameter space for the *p-He* -> antiproton+ X channel corresponding to an exemplary fixed target experiment.
- 3% relative uncertainty within the blue regions (30% outside) is needed to match AMS precision

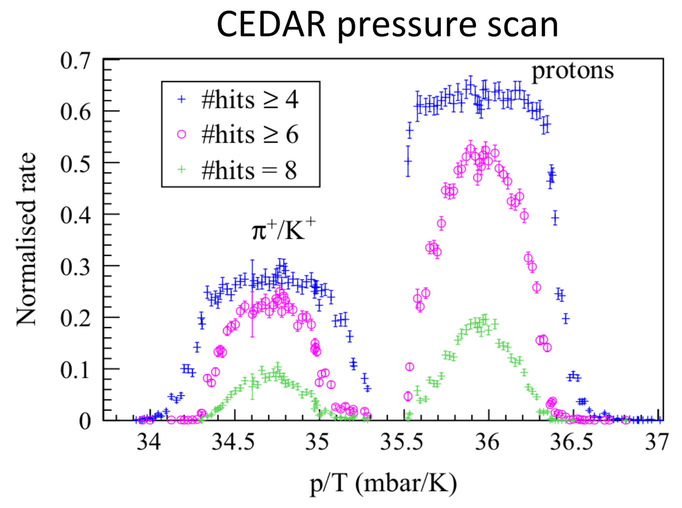
Dedicated data taking for measuring antiproton production cross section on *p-He* was performed by AMBER in May-June 2023.

The particles produced in interaction are tracked and identified by the AMBER spectrometer at the SPS.

- Secondary hadron beam at M2 beamline
- 140 cm liquid Helium fixed target
- > 300 tracking planes
- 2 CEDARs installed 30 m upstream the target region for the particle identification of the beam
- RICH-1 to identify hadrons in the final state



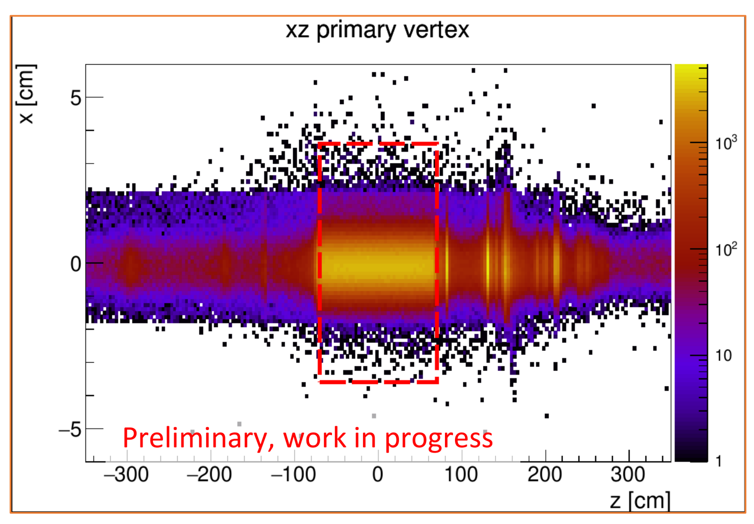
CEDAR pressure scan

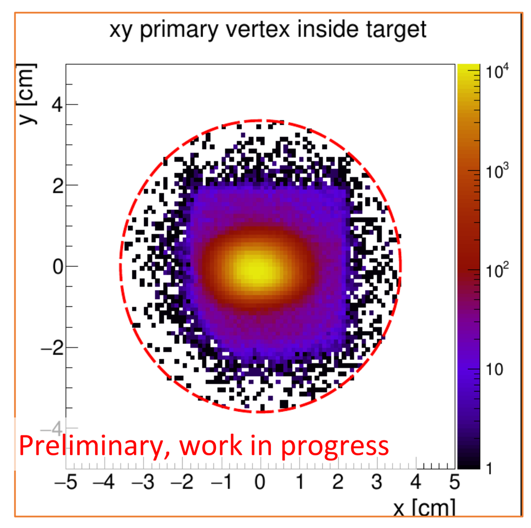


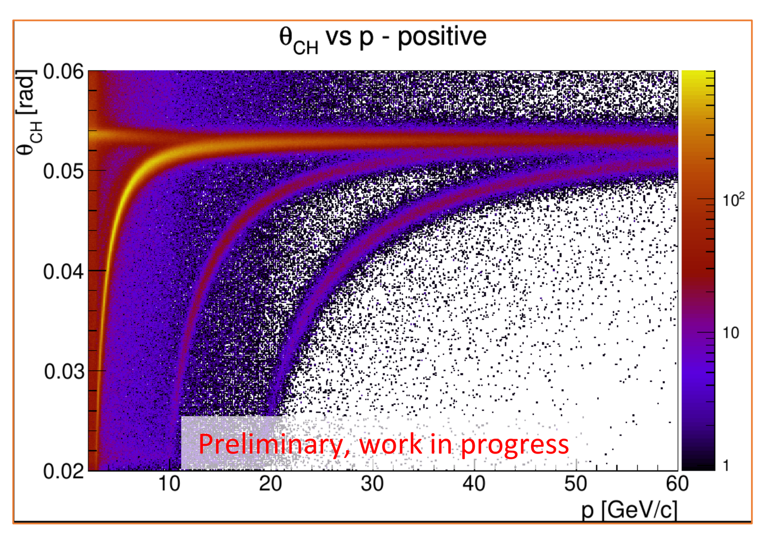
COMPASS collaboration, The compass setup for physics with hadron beams, Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment 779 (2015) 69–115. ISSN 0168-9002

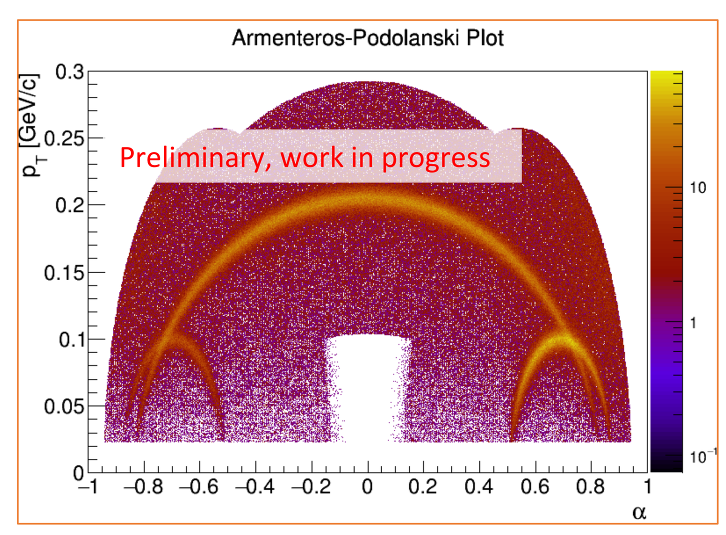
The beam used was tuned at momenta of 60, 100, 160, 190 and 250 *GeV/c* with a total of roughly 90k spills collected at 10^5 particles/spill intensity.
The projected statistical error is < 1% over most of the phase space covered.
On the left pressure scan of CEDARs showing good separation of beam protons with respect to kaon and pions.

Plots from the 2023 data @190 *GeV/c* (< 1% of the sample)
Top: Primary vertices distribution on xyz in spectrometer reference system where the target is clearly visible in between the dashed line.
Bottom left: Cherenkov angle in the RICH-1 vs momentum of charged particles;
Bottom right: Armenteros-Podolanski plot of secondary vertices showing K^0, Λ and $\bar{\Lambda}$ arcs.









First ever collected dataset on *p-He* at the energy range of AMS antiprotons

- directly pin down the uncertainty on the nuclear reactions happening in the Galaxy.
- anti-hyperon and π^0 inclusive production studies, relevant respectively for antiproton flux and interpretation of gammas spectra from experiments such as FERMI-LAT, AMS and others.