PROCEEDINGS OF SCIENCE

Measurement of antiproton production cross sections for dark matter search at the AMBER Experiment at CERN

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The dominant part of the antiprotons in our galaxy originates from inelastic scattering of incoming cosmic rays off interstellar-medium nuclei at rest and represents the background when searching for small contributions from exotic sources. The newborn AMBER experiment will be able to study the antiproton production cross sections in proton-proton and proton-4He scattering for projectile energies from several tens to a few hundreds of GeV. In combination with similar measurements by LHCb in the TeV range, this measurement will provide a fundamental data set that is expected to allow for a significantly higher accuracy of the predicted natural flux of antiprotons in the galactic cosmic rays.

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1. Dark Matter puzzle

Multiple and concurring evidence reveals that the vast majority of the matter content of the universe is non baryonic and electrically neutral. This component is usually called Dark Matter (DM), for its lack of electromagnetic interactions, and is measured to constitute about 25% of the energy density of the Universe. The Dark Matter origin and nature is one of the most intriguing puzzles still unresolved, however the most common hypothesis is that it consists of weakly interacting massive particles (WIMPs), supposed to be cold thermal relics of the Big-Bang.

The indirect detection of DM is based on the search of the products of DM annihilation or decay. They should appear as distortions in the gamma ray spectra and or in anomalies in the rare Cosmic Ray (CR) components. In particular, antimatter components, like antiprotons, antideuterons and positrons, promise to provide sensitivity to DM annihilation on top of the standard astrophysical production. The galactic cosmic rays span an energy range from about tens of MeV up to hundreds of TeV, and include nuclei from proton to iron and nickel, antiprotons, leptons and gamma-rays. The interpretation of galactic cosmic ray data requires the correct modeling of their sources and the turbulence spectrum of the galactic magnetic field, in addition to the knowledge of the cross sections that regulate the production of cosmic rays interacting with the interstellar medium (ISM). A precise measurement of the production mechanism is indeed required to disentangle a possible DM primary component from secondary production.

The large majority of the antiprotons in our Galaxy are mainly of secondary origin and produced by the scattering of cosmic proton and helium nuclei off the ISM. This component represents background in the search of small contributions from exotic sources. In the diffusion equation of CR, the production of antiprotons (as well as other particle species produced in collisions) is given by the so called source term equation:

$$q_{ij}\left(T_{\bar{p}}\right) = \int_{T_{\text{th}}}^{\infty} dT_i \; 4\pi \; n_{\text{ISM},j} \; \phi_i \left(T_i\right) \frac{d\sigma_{ij}}{dT_{\bar{p}}} \left(T_i, T_{\bar{p}}\right) \tag{1}$$

where T is the kinetic energy, n_{ISM} is the density of the ISM component j, ϕ is the energy differential flux of the i-CR component, σ the cross section of the process $i + j \to \bar{p} + X$ and T_{th} is the energy threshold to produce a i-particle. Eq. 1 shows that the uncertainty in the experimental cross section will contribute directly to the uncertainty in the source term. The main reactions contributing at the total production cross section are those involving pp, pHe and Hep that contribute up to 60-80% as shown in Fig. 1.

2. Antiproton production cross section at AMBER

After the breakthrough from the satellite-born PAMELA detector, the antiproton flux and the $\bar{p}/p$ flux ratios have been measured with an unprecedented accuracy of a few percent by AMS-02 (Fig. 2) over an energy range from below 1 GeV up to a few hundreds of GeV. However, the only currently measured production cross section is the proton-proton cross section, while all the reactions involving helium have no laboratory data in the AMS-02 antiproton energy range (0.1 − 100 GeV). This implies, in the parametrization of models, a scaling of the pp channel to pA interaction through approximation. The very first dataset on p-He collision was collected in 2016 by the LHCb experiment at 6.5 TeV [3].

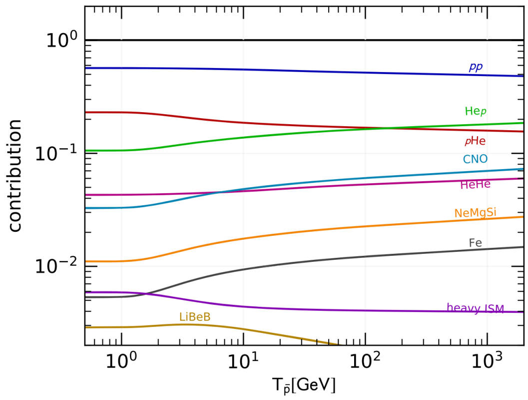

Figure 1: Fractional contribution to $\bar{p}$ production from different interactions on the ISM as a function of the kinetic energy of the produced $\bar{p}$ [1]

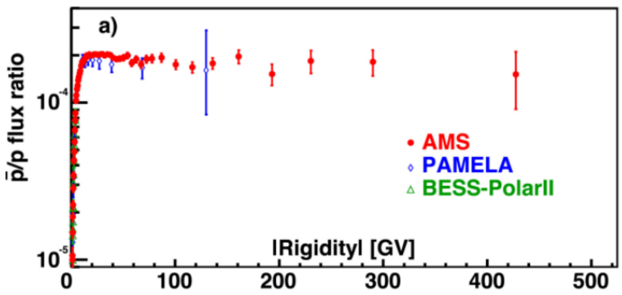

Figure 2: Antiproton to proton flux ratio as a function of rigidity as measured in AMS and other experiments [2].

A dedicated measurement campaign aimed at measuring the exclusive cross section $p + He$, with particular interest for the channel $\bar{p} + X$, is thus crucial for the search of DM signals in the spectra of antiprotons in cosmic rays. Fig. 3 shows the ideal kinematic range in which experiments should measure pHe cross section to match the uncertainty level of AMS-02.

The AMBER fixed target experiment at the M2 beam line at CERN will contribute to this fundamental DM search, performing a unique and complementary measurement with a proton beam of a few hundred GeV/c impinging on a LHe target. The proposed experiment aims to measure the double differential antiproton production cross-section for different proton beam energies from 60 to 250 GeV/c. The program for the experimental determination of the antiproton production cross-section in p+4He scattering is included in the first phase of the AMBER experiment which was approved by CERN in 2020. It is scheduled to run from 2023 onward. The contribution of AMBER to the total source term is shown in Fig. 4, with LHCb measurement for comparison. Altogether the result from AMBER will be essential to directly pin down the production of antiprotons in the relevant kinetic energy region.

References

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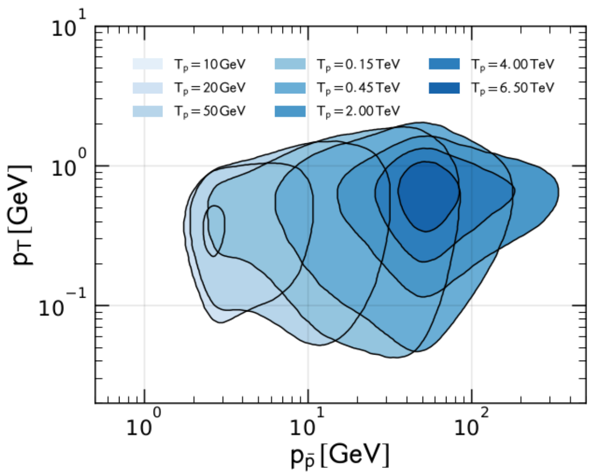

Figure 3: Parameter space of the $p + He \longrightarrow \bar{p} + X$ cross section which is necessary to determine the antiproton source term at the uncertainty level of AMS-02 measurements. A 3% accuracy is required on the cross section determination inside the blue shaded region, and a 30% accuracy outside the contours [1].

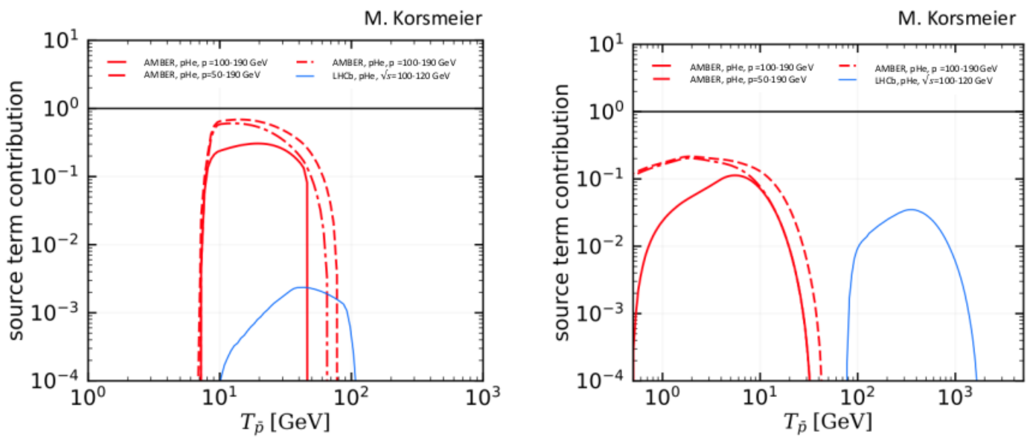

Figure 4: Source-term contribution of the AMBER experiment to the total source term shown in three different energy ranges. Left: p-He channel. Right: He-p channel. For comparison we show also the contribution of the LHCb measurement (thin blue line) [4]

[2] M. Aguilar et al. (AMS-02 Collaboration), The Alpha Magnetic Spectrometer (AMS) on the international space station: Part II — Results from the first seven years, Physics Reports, Volume 894, 2021, Pages 1-116, ISSN 0370-1573

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