PoS PROCEEDINGS OF SCIENCE

Proceedings ICHEP 2022: The cosmic antiproton puzzle

F. D'Angelo,[1,2] **N. Masi**[1] **and A. Oliva**[1]

[1]*Istituto Nazionale Fisica Nucleare (INFN) Bologna Division, Viale C. Berti Pichat 6/2, Bologna, Italy*
[2]*U University of Bologna Physics Department, Via Irnerio 46, Bologna, Italy*

E-mail: fdangelo@bo.infn.it

Cosmic rays antiprotons are believed to be produced by the interaction of primary cosmic rays (p, He, and nuclei with Z>2) interacting with the interstellar medium, and so they represent a good channel for indirect dark matter search. In the last decade, thanks to high precision measurements by AMS-02 and PAMELA, a possible tension between the observed antiproton flux and different predictive models has been highlighted, between 1 and 500 GeV in the antiproton kinetic energy. In the 10÷100 GeV range, the dominant uncertainties are the production cross section ones: the pp, p-He and He-p channels are responsible for almost all the cosmic antiprotons. Different models (MonteCarlo approaches, parametrisations etc) are used to predict the antiproton production cross section but they are in tension among themselves. For this purpose, the COMPASS++/AMBER experiment will help us to resolve this tension with incoming p-He collisions data.

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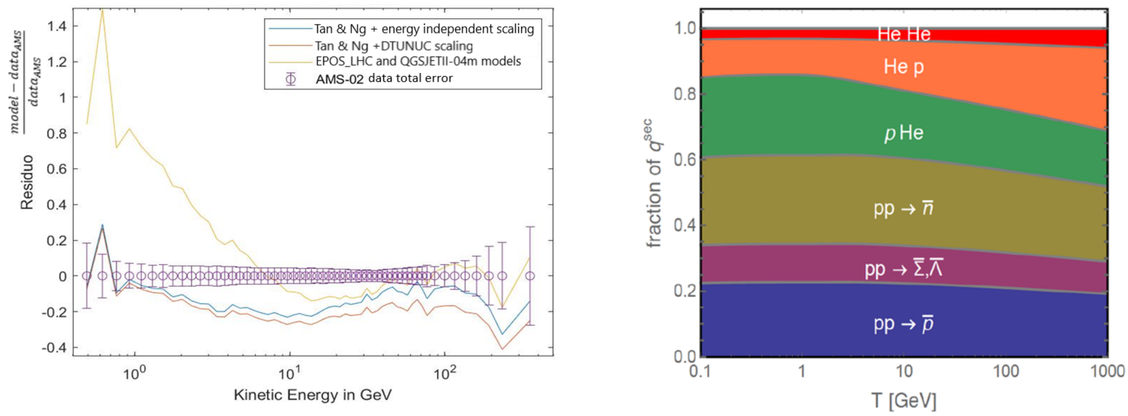

Figure 1: (Left) The residual between the AMS-02 antiproton flux and the flux predicted by GALPROP-HelMod [6] with three different models of production cross section[7-10]. (Right) Cosmic antiprotons production contributions expressed in percentage of the source term [2]. The contribution of nuclei heavier than the Helium is neglected.

1. Cosmic antiprotons production and propagation

The Cosmic Rays (CRs) are charged particles coming from outer space. The Alpha Magnetic Spectromer (AMS-02) is a high-energy particle detector on board of the International Space Station able to separate all CRs species (electron, positron, proton, anti-proton, nuclei with Z>1 and anti-nuclei). AMS-02 measured with unprecedented accuracy the CRs antiproton flux [1] that allowed for the search of a possible dark matter annihilation signal between 1 and 500 GeV.
The knowledge of the cosmic antiprotons production cross section is essential for the characterization of the background signal to better distinguish an eventual excess in the AMS-02 or other CRs experiment data.
The source term of secondary CRs is comprehensive of all the possible channels where the primary CR acts as the projectile and the ISM acts as the target of the fixed-target collision. The pure particle physics experiments can give us estimation about the cross section of the various production channels. Considering the composition of both the CRs component and the ISM, Fig. 1 shows an estimation of the cosmic antiproton production[2]. In a general way, the pp channel is responsible for roughly 50÷55% of the antiproton production, while the helium channels are responsible for the 40÷45%. Heavier channels are neglected or contribute to 1÷5% of the whole production.
Recently, the most used model to estimate it is a parametrization for the pp channel[3] and a scaling for the heavier nuclei[4] based on simple physics principles.
The most accurate, complete and used CR propagation model is the Diffusion- Convection-Reacceleration model implemented in the GALPROP code [5].
The conventional antiproton spectra is predicted by propagating particles produced at sources (mostly protons and helium nuclei) in the Galaxy and estimating the anti-proton produced by the inelastic collisions of those with the interstellar medium. In particular, using the GALPROP-HelMod environment described in [6], three different cross section models have been used to calculate the secondary production of antiprotons[7-10].
The GALPROP predicted flux has been compared with the antiprotons detected by AMS-02 (Fig.

1). Since the propagation model is fixed, the flux difference arises from the production cross section. The presence of a DM signal in the cosmic antiprotons is still debated. Several estimations of the uncertainty on the cosmic antiproton spectrum and background models show that the uncertainties are dominated by the cross section ones between 1 and 100 GeV of antiproton energy[4]. In the worst case, they can affect a significant fraction of the antiproton flux, but the precise estimation depends on the cross section model and the analysis technique.

2. The future AMBER experiment

The data available on the production of antiprotons in collisions arise from fixed-target or collider experiments. The dataset at high center of mass energy (cms energy) have projectiles with very high momentum that are flux-suppressed in CRs because they obey roughly a power law in energy $\frac{dn}{dE} \propto E^{-\gamma}$ with γ (called spectral index) of about 2.7.
The experimental constraints on the production cross section in the 1÷100 GeV antiproton energy range arise mainly from pp collisions. About the helium channels, we have no data in the energy range we are interested in and further investigation is needed, so the future AMBER experiment[2] will take data in the next years at SPS using a fixed helium target and incident protons in the 60÷250 GeV/c momentum range.
We have analyzed both the phasespace of the future AMBER experiment and the one of the cosmic antiproton production to understand the future impact of the experiment and if it can significantly improve our knowledge about the cross section. In figure 2, the probability distribution functions of the production of cosmic antiprotons of different energies energies are shown (integrated in the transverse momentum). The five black vertical solid lines are roughly the five AMBER proposal for the pHe collisions. As it's shown, the AMBER experiment will be able to capture the peak- i.e. the cms energies where the most part of the cosmic production occurs- up to roughly 60 GeV of produced antiprotons.

3. Cosmic antinuclei

The cosmic antinuclei are the future of the DM indirect detection because, as it's possible to see in Figure 2, a DM signal is expected to be clearly distinguishable from the background production. In the astroparticle physics, the most used model to predict the cosmic antinuclei background is the Coalescence Model[11]. This simple model depends on a parameter that should be determined experimentally and the ALICE experiment is trying to do it[12]. The Coalescence Model links the antinucleus spectrum with the antinucleons one: if two or more antinucleons are near enough in the phasespace (both momentum and coordinate space) they merge and form an antinucleus. The DM signal is expected to occur in the low kinetic energy part of the spectra because the DM annihilation occurs nearly at rest, while the antinucleons produced in cosmic collision have higher kinetic energy and the production channels have a threshold.
In the last years the interest of the scientific community in the cosmic antinuclei has raised up, and the community is actually looking to these channels as the future of the DM indirect search.

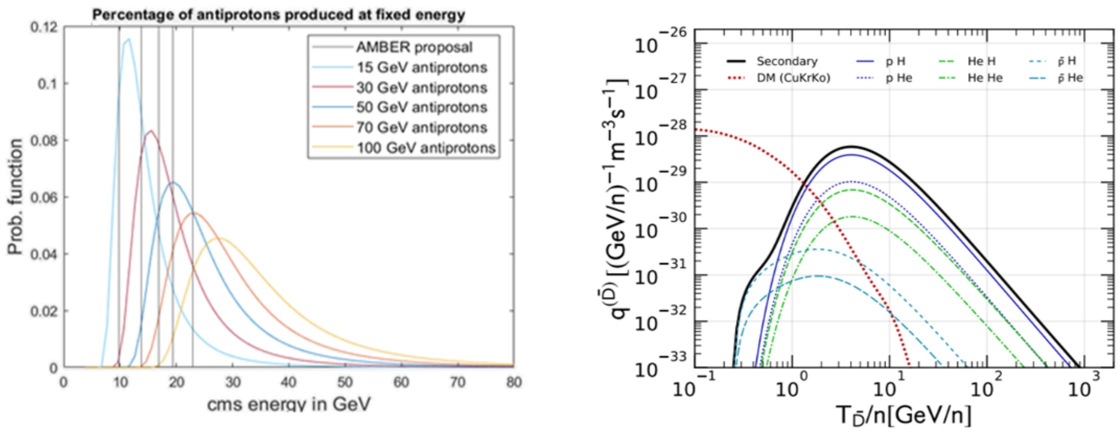

Figure 2: (Left) Probability density function, integrated in transverse momenta, of the production of the cosmic antiprotons with fixed energy in pHe collisions, according to the model in Ref[10]. The vertical solid lines are the five AMBER proposal for future data taking. (Right) Antideuteron source term function of kinetic energy, according to [11]. The DM will produce a low kinetic energy signal, clearly distinguishable from the high kinetic energy background.

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