THE COSMIC ANTIPROTON PUZZLE

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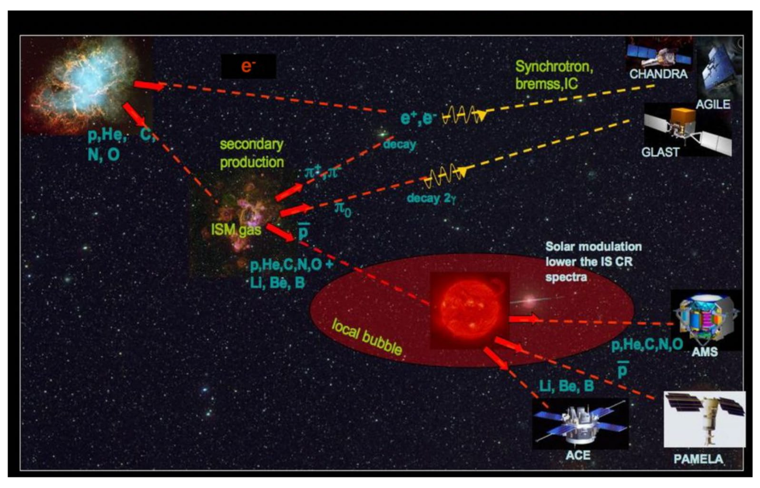
Abstract: The cosmic ray anti-proton spectra is a sensitive channel for the indirect search of dark matter. The main background for this search is the secondary anti-proton flux produced in collisions between primary cosmic rays with the interstellar medium. In the last decade, thanks to high precision measurements by AMS-02 and PAMELA, a possible tension between the observed antiproton flux and the cosmic ray diffusion models has been highlighted between 1 and 500 GeV in the antiproton kinetic energy.

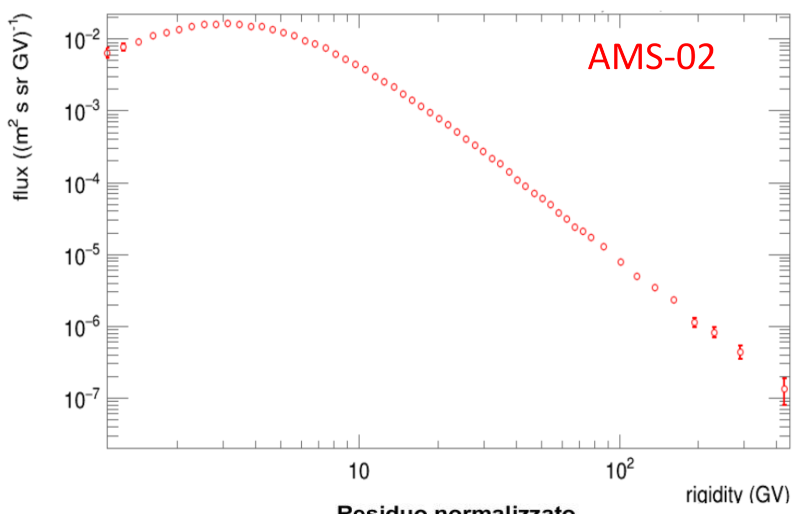
The large uncertainties which afflict antiproton flux predictions do not allow us to confirm the presence of an exotic signal. In the 10÷100 GeV range, the dominant uncertainties are the production cross section ones: the pp, p-He and He-p channels are responsible for almost all the cosmic antiprotons. In 2017 the NA61/SHINE experiment at SPS collected new data for pp collisions which were useful to study this discrepancy. In 2018 the SMOG experiment at LHCb made the very first p-He channel measurements. Additional p-He collisions data, with center-of-mass energies lower than the LHC ones, are still needed to reduce the cross section uncertainties for astroparticle physics. For this purpose, the COMPASS++/AMBER experiment will help us with incoming data on pp and p-He collisions. The state-of-the-art of the cosmic antiproton puzzle is presented, along with antiproton flux predictions using GALPROP and future perspective.

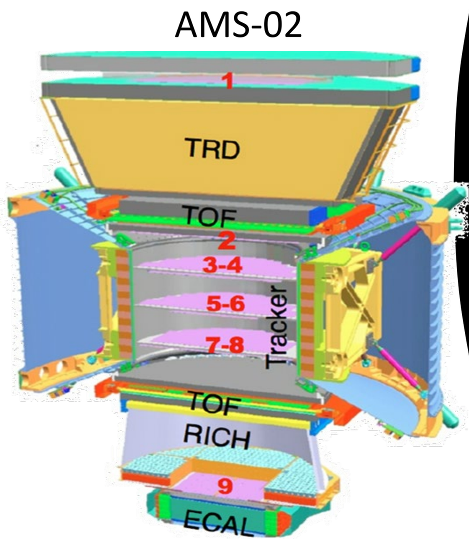
THE COSMIC ANTIPROTON FLUX

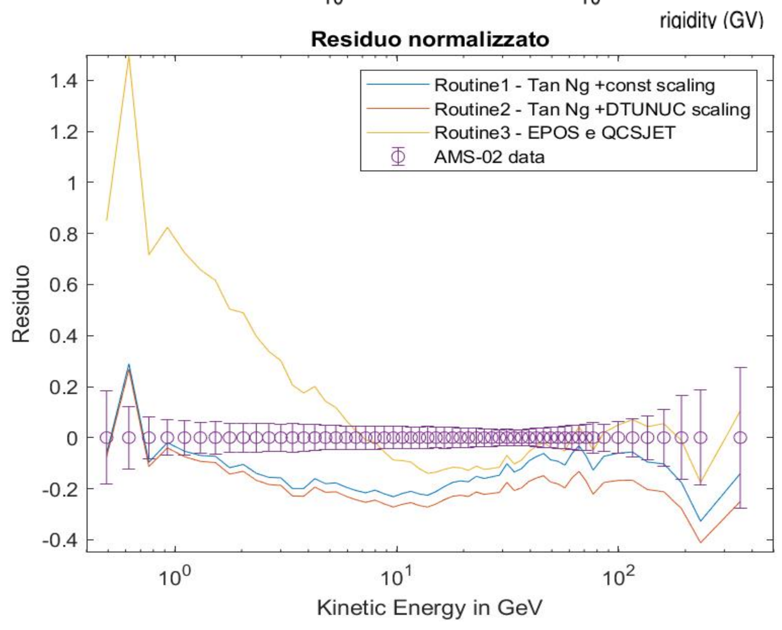


The cosmic antiprotons are mainly produced in the collision between incident cosmic rays (CR) and the interstellar medium.

AMS-02 [1] is a magnetic spectrometer located on board of International Space Station, operating since 2011. It delivered the most precise measurement of p-bar as of today [2].



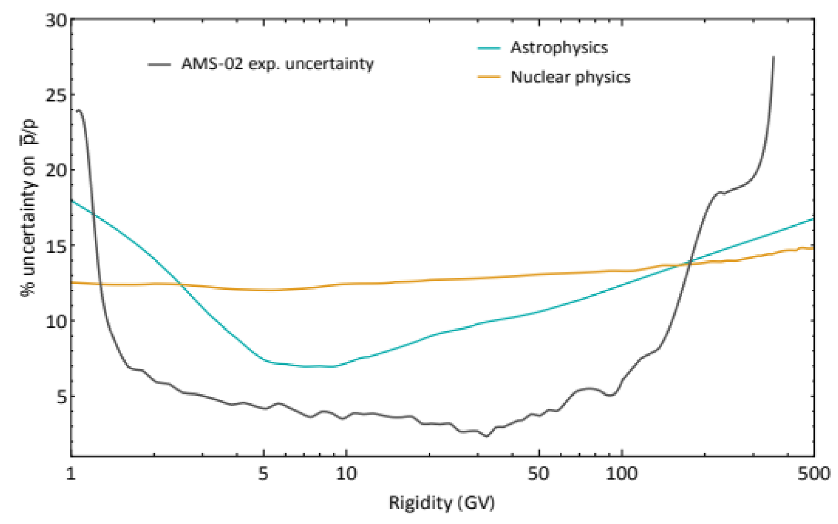


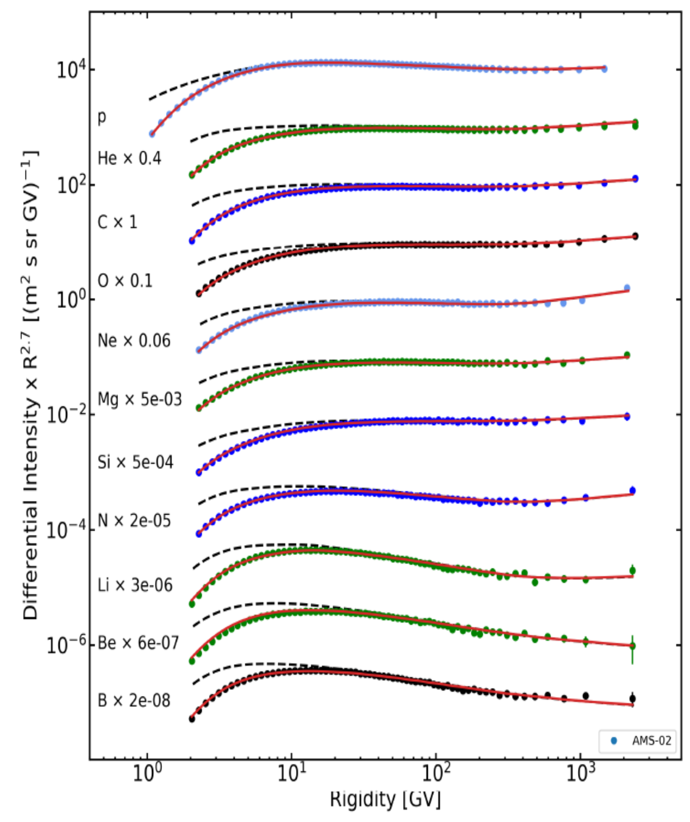


There is a discrepancy between the observed antiproton flux by AMS-02 and the CR propagation model tuned with the most recent AMS-02 nuclear data. The interpretation of the observed excess is however limited by the large uncertainties on model prediction related to the anti-proton production from primary CRs that are currently larger than the measured AMS-02 anti-proton flux ones.

SOURCE AND PROPAGATION MODELS

GALPROP [3] is one of the most complete cosmic ray galactic propagation model available. This model can be used in association with HelMod [4] code, a cosmic ray hemispheric propagation model. Both GALPROP and HelMod have been tuned to reproduce cosmic-ray fluxes of primary (p, He, …) and secondary components (Li, Be, B, …) observed by several experiments (AMS-02, PAMELA, …). The amount of secondary anti-proton flux in cosmic rays is then obtained as a prediction of the model, since no antiproton data is involved in the tuning procedure. The uncertainties on the antiproton flux are shown in the figure below.





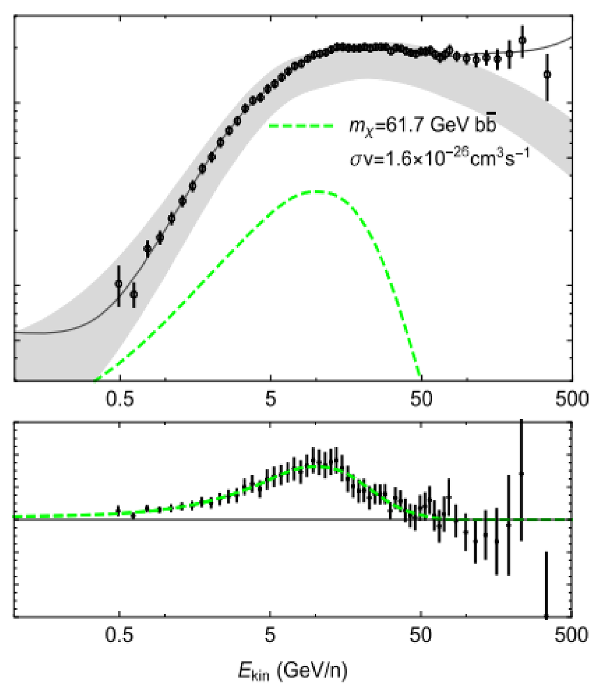
In the upper figure is shown the comparison between the predictions of GALPROP-HelMod model [5] and the AMS-02 data.
In the figure on the left are shown the uncertainties on the antiproton to proton ratio [6].

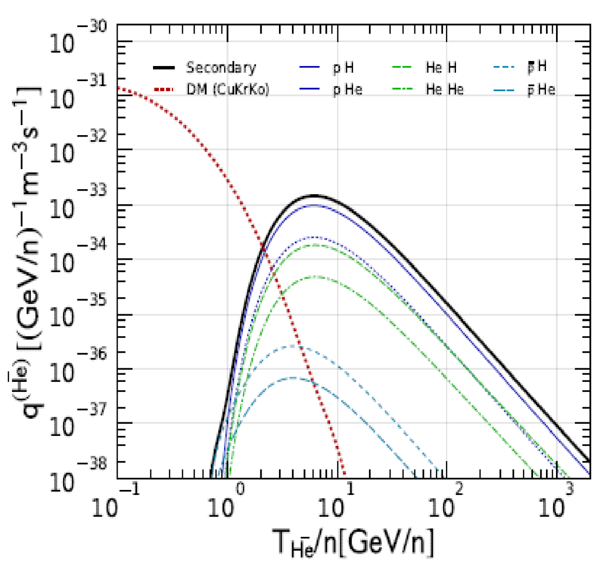
GALPROP

HelMod

IMPLICATIONS FOR COSMIC ANTINUCLEI

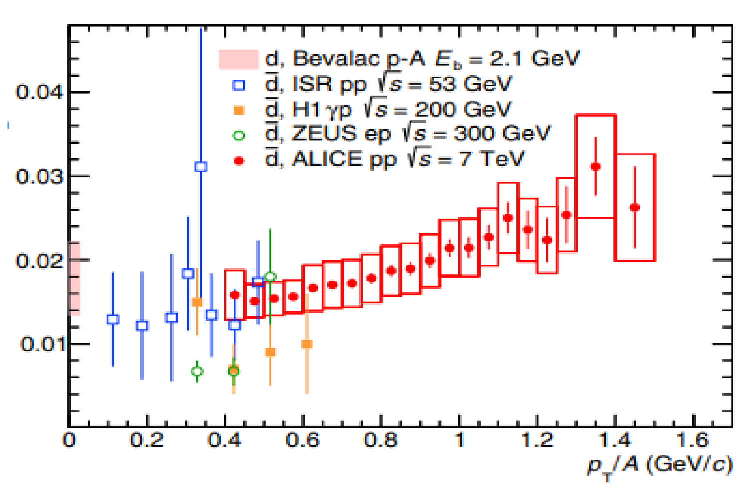
The antiprotons are responsible, according to the Coalescence Model, for the production of light antinuclei via a coalescence mechanism. Two or more antinucleons can merge together if their relative momentum is lower than a coalescence momentum. The background of cosmic antideuterons and antihelium nuclei is expected to be at higher kinetic energies than the peak of a hypothetical DM signal [9].

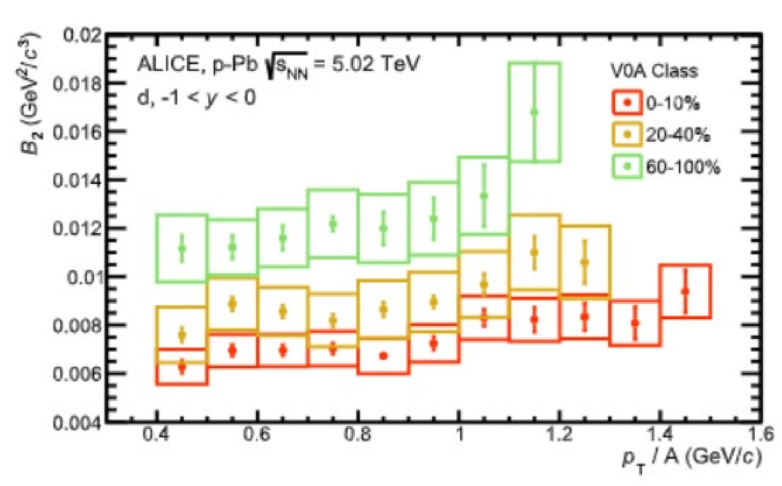




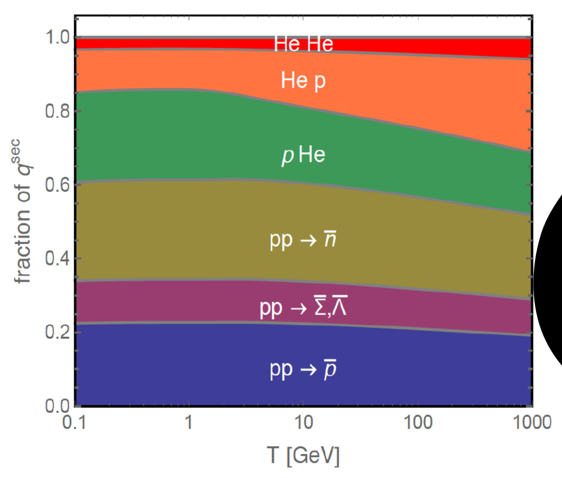
An excess of antiprotons (upper figure) [8] from dark matter can be directly link to a detectable anti-nuclei signal (left figure) [9] from current (AMS-02) or future (GAPS) experiments.

The most recent estimations of the coalescence momentum we have [10, 11]:





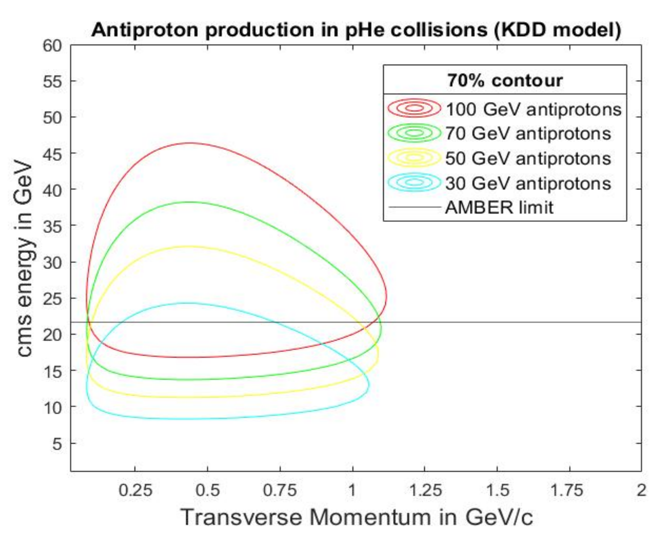
THE FUTURE: THE AMBER EXPERIMENT

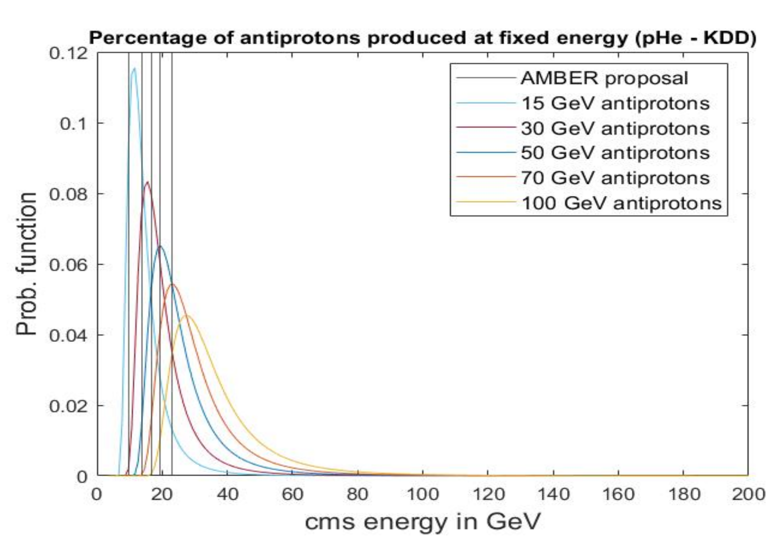


It's possible to predict the region of the AMBER phace-space where the production of antiprotons will be most important.

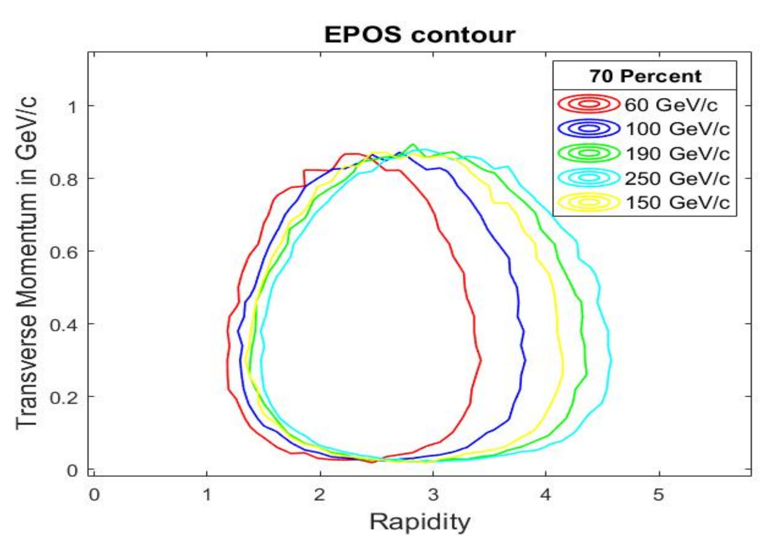
The AMBER experiment will help us to constrain the antiproton cross section for pHe and Hep channels in a range of proton incident momentum between 60 and 250 GeV/c, a region uncovered by any experiment. Helium channels are responsible for roughly the 40% of the antiproton production [6].

AMBER [6] will help us to better understand the production of cosmic antiprotons with energies up to 50 GeV. Higher center-of-mass energies are required for higher antiproton energies.





Probability density function of antiprotons production according to the model described in [7]



EPOS_LHC prediction in AMBER phace-space

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