Exploring Dark Matter with AMS-02 through Electroweak Corrections

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DOI: http://dx.doi.org/10.3204/DESY-PROC-2015-02/pellen_mathieu

The AMS-02 experiment is now measuring charged cosmic rays fluxes with an unprecedented precision. It is thus necessary to provide appropriate and complementary predictions for dark matter signals. To that end, computing electroweak corrections to the dark matter annihilation is an important task. It is particularly relevant for leptophilic models where anti-protons can be produced through the decay of massive gauge bosons. From the lack of particular spectral features in the AMS positron flux, we derive new model independent upper limits on the annihilation cross section. In particular we use a newly introduced background function that allows to set limits using all the energy spectrum probed by AMS-02. This is particularly interesting as important phenomena such as solar modulation take place at low energy. Using a new calculation of electroweak radiation for vector dark matter annihilation, we can predict the maximum flux of anti-protons in such leptophilic scenarios, to be compared with future AMS measurments.

1 Introduction

The Alpha Magnetic Spectrometer (AMS-02) experiment located on the International Space Station (ISS) measures charged cosmic rays fluxes and composition with unprecedented accuracy. The anomaly in the positron fraction measured by AMS-02 [1] could be either caused by poorly understood astrophysical background effects, originate from astrophysical phenomena such as nearby astrophysical source like pulsars or supernovae, or be due to dark matter annihilation in the halo. Advocating a pure dark matter origin for the AMS-02 signal requires rather contrived scenarios. In the following, we assume that the AMS-02 positron excess is mainly due to astrophysical sources and that the contribution due to dark matter annihilation in the Galaxy is sub-dominant.

To accommodate the presence of an excess in the positron fraction and the absence of such an excess in the antiproton fluxes, leptophilic dark matter models have been proposed, where dark matter annihilates directly only into leptons. This makes electroweak corrections relevant for dark matter annihilation [2, 3], as all stable standard model particles (including antiprotons) can be produced through the radiation of electroweak gauge bosons that subsequently decay. It is also worth noticing that electroweak corrections induce correlations between different fluxes. This opens great possibilities to explore complementary measurements.

In this work [4], we derive new model independent upper limits on the dark matter annihilation cross section for generic models annihilating into an electron/positron pair. We use the most recent data from the AMS-02 collaboration [1]. Finally, we use a newly introduced background function. This allows us to set upper limits over the whole energy range measured by the AMS-02 collaboration. In particular, we put particular effort into describing the low energy part of the spectrum where astrophysical effects such as solar modulation can be important and where most of a dark matter signal would concentrate. This constitutes an improvement over previous work [5] and allows for a more extensive use of the AMS-02 data. After this we compute all massive gauge boson radiations for a generic leptophilic dark matter model annihilating into electron/positron pairs. As we do not assume any particular model and do not invoke boost factors, we can simply assume in an agnostic way that a dark matter signal is lying at the exclusion limits. We then use this to make predictions for the maximum flux of antiproton thanks to the correlation between different fluxes through electroweak emission. This shows promising complementarity between the electron/positron flux and the antiproton flux searches.

2 Upper limits

Up to now, the fluxes measured by the AMS collaboration have been described by a very simple phenomenological model, where the fluxes are given by the sum of an individual diffuse power laws and a single common source. For our analysis, we use the improved background model:

$$\Phi_{e+} = \frac{E^2}{\widehat{E}^2} \left[C_{e+} \widehat{E}^{-\gamma_{e+}} + C_S \widehat{E}^{-\gamma_S} \exp\left(-\widehat{E}/E_S \right) \right], \tag{1}$$

and

$$\Phi_{e-} = \frac{E^2}{\widehat{E}^2} \left[C_{e-} \widehat{E}^{-\gamma_{e-}} + C_S \widehat{E}^{-\gamma_S} \exp\left(-\widehat{E}/E_S \right) \right]. \tag{2}$$

The modified energy $\widehat{E}$ is defined as $\widehat{E} = E + \Psi_\pm$, where $\Psi_\pm$ are effective parameters, intro-

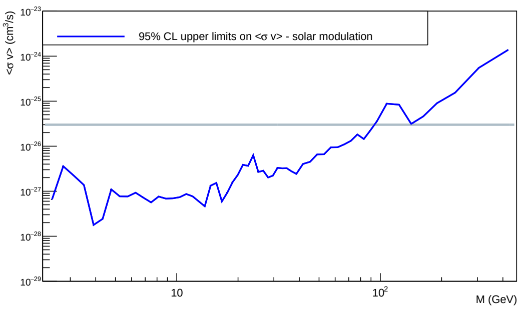

Figure 1: Model independent upper limits on the $2 \to 2$ dark matter annihilation cross section.

duced to take into account low energy effects, like solar modulation. Note that the parameter C_{e-} is energy dependant in order to also account for low energy effects. In the flux, λ quantifies the smoothness of the transition from a spectral index γ_{e-} below E_b to a spectral index

$\gamma_{e-} + \Delta\gamma_{e-}$ above E_b. The reason to use such a background function is that the simple phenomenological model is not reproducing properly the low energy part of the spectrum, where not well understood astrophysical phenomena, for instance solar modulation, play a significant role. Moreover, since a significant part of particles due to dark matter annihilation after propagating through the Galaxy would concentrate in the low energy region, it is necessary to have an appropriate description of the background also in the low energy part of the spectrum. The results of our upper-limit procedure to exclude any signal at 95% confidence level are shown in Fig. 1.

2.1 Anti-protons prediction

Even if electroweak corrections have only a relative impact on upper limits, they are nonetheless extremely important. Indeed they induce a correlation with the antiprotons flux. Assuming that a dark matter signal is just lying at the 95 % confidence level limit of the electron/positron data, one can then make predictions for the maximum flux of antiprotons. These predictions for the antiprotons/protons ratio can be compared to the measurements done by the PAMELA [6] and AMS-02 collaboration. They are shown in Fig. 2 for representative masses. There we consider the measurement made by the PAMELA and AMS-02 collaboration to be the astrophysical background. To this we add the dark matter signals that we have computed.

It shows that for dark matter masses of the order of 400 GeV or higher, the expected flux at high energy is increasing in magnitude. This is extremely interesting as it means that there could be a dark matter signal hiding in the electron/positron fluxes but appearing in the anti-proton. In particular, the signal that one expects from a dark matter source, would intriguingly accommodate the measurement and could still be consistent with the electrons/positrons measurements.

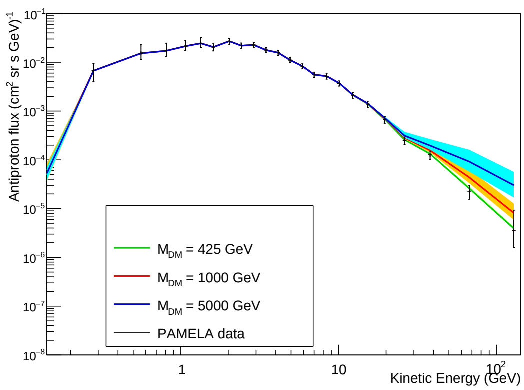

Figure 2: Prediction for maximum dark matter signal for the antiproton flux for $M_{\rm DM} = 425, 750, 1000, 3000, 5000$ GeV.

3 Conclusion

Electroweak corrections are small but important. For leptophilic dark matter models, they are of prime importance as they are the only way to obtain antiprotons. Moreover electroweak emissions introduce a correlation between different fluxes of particles. We have derived new upper limits using the last available data. To do that we have used a new background function that allow us to fit the whole energy spectrum of the electron/positron measurements. In particular this opens up the possibility to properly describe the low energy part of the spectrum. This is crucial as in this energy range, most of the dark matter signal would concentrate and interesting astrophysical phenomena such as solar modulation take place. By assuming that a dark matter signal is just about to be detected, we can predict the corresponding maximum antiprotons flux. The comparison of the expected fluxes with the existing data is very promising as the high energy part of the spectrum seems to be extremely sensitive. This demonstrates the extraordinary possibilities of complementary measurements linked by electroweak effects.

Acknowledgments

We would like to thank Henning Gast, Fabrizio Parodi and Stefan Schael for useful discussions. LAC and MP are grateful to the Mainz Institute of Theoretical Physics (MITP) for its hospitality and its partial support during the completion of this work. This work was supported by the Deutsche Forschungsgemeinschaft DFG through the research training group "Particle and Astroparticle Physics in the Light of the LHC" and by the Helmholtz Alliance for Astroparticle Physics (HAP).

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