Cosmic-Ray Positrons Strongly Constrain Leptophilic Dark Matter

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Cosmic-rays are a powerful probe of dark matter annihilation. In this work, we make use of the extremely precise cosmic-ray data from the AMS-02 experiment to set strong constraints on leptophilic dark matter contributions to the local positron flux. To accomplish this task, we assume a model that attributes the unexpected rise of the local positron flux at above 20 GeV to pulsars and then search for sharply peaked spectral features associated with dark matter contributions.

Our work builds on a similar analysis by Bergström *et al.* (2013). In our work, we improve on their limits in three ways: (1) Our analysis relies on a larger dataset with better statistical precision provided by the latest AMS-02 data. (2) We use the cosmic-ray propagation code Galprop to create a full cosmic-ray propagation model for the positron, proton and Helium flux. Our model allows a significant number of parameters (diffusion coefficient, a break in the diffusion spectrum and a spectral index below and above the break, Alfvén velocity, convection velocity, injection spectra of protons and Helium with a break and a spectral index below and above the break, respectively) in the fit to float, while Bergström *et al.* assume a fixed astrophysical background. (3) We implement a new solar modulation model (Cholis *et al.* 2020) that describes the effects on the cosmic-ray particles in the heliosphere more precisely by being time-, charge- and rigidity dependent, rather than approximating the solar modulation by a force-field potential.

Furthermore, we implement the contribution from pulsars, that produce e^+e^- pairs, directly into Galprop and adopt a pulsar spectrum by Hooper *et al.* (2009) and a pulsar distribution by Lorimer *et al.* (2006). Using minimizer codes (iminuit, multinest), we fit our model to the AMS-02 data for positrons, as well as the proton and Helium data to constrain the secondary positrons dominant at lower energies, providing a more realistic positron fit.

After obtaining the astrophysical background model, we add a dark matter contribution to the positron flux for four different leptonic final states: $\chi\chi \to \tau^+\tau^-$, $\chi\chi \to \mu^+\mu^-$, $\chi\chi \to e^+e^-$ and $\chi\chi \to \phi\phi \to e^+e^-e^+e^-$, where ϕ is a light mediator. For the $\tau^+\tau^-$, and $\mu^+\mu^-$ final states, we use dark matter spectra obtained with DarkSUSY v.5. For the $e^+e^-e^+e^-$ and e^+e^- states, we produce analytic calculations of the dark matter spectrum that we directly implement in Galprop. We then compute the 95% upper confident level on the dark matter annihilation cross section for dark matter masses between 5 and 2000 GeV for a local dark matter density of 0.4 GeV/cm^3, a core radius of 20 kpc and an NFW profile. Our results show no spectral bump correlated with leptophilic dark matter and we set constraints lower than the thermal annihilation cross-section for a wide range of dark matter masses for all final states. We obtain particularly strong limits for annihilations into e^+e^- where our limits are below the thermal cross section by two orders of magnitude at low masses ($\sim$ 30 GeV), ruling out even subdominant annihilations into e^+e^- pairs. Finally, our constraints improve on the limits by Bergström *et al.* by about a factor of 2.