Supplemental Material to
'New limits on dark matter annihilation from AMS cosmic ray positron data'

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Here, we describe additional tests carried out in order to estimate the degree to which our DM limits might vary under alternative assumptions pertaining to the astrophysical background and cosmic ray propagation. In addition, we quantify the significance of spectral features in the observed positron fraction.

In deriving our main results, as shown in Fig. 3, we used the phenomenological parameterization of the AMS collaboration [1] for the astrophysical contribution to the positron fraction, and adopted our reference assumptions of $L = 4$ kpc and $U_{rad} + U_B = 1.7$ eV cm^{-3}. In Fig. S1, for the case of direct DM annihilation to e^+e^-, we show in the *left panel* the impact of different propagation parameters when treating the astrophysical background in the same way as in Fig. 3. Changing the diffusion conditions ($L = 2 - 8$ kpc) in the Galaxy in that case only affects our limits by $O(10\%)$, while allowing for higher energy losses ($U_{rad}+U_B = 2.6$ eV cm^{-3}) can alter our limits by a factor of $\sim$2, with higher losses resulting in weaker limits (see also Fig. 1). In the *right panel*, we repeat this exercise, but replace the AMS background parametrization with physically motivated models for the primary e^-, secondary $e^\pm$, and pulsar originated $e^\pm$ fluxes (see discussion in the main text), calculated with the same galactic propagation model as used in determining the spectrum of CR leptons from DM. In this case, our results can be further altered by a factor of up to $\sim$3. The reason for this change is that our physically motivated models describe the individual components by power-laws with breaks at a few GeV. These spectral features in the background can be the result of different energy loss mechanisms kicking in,[1] or from individual local and recent supernovae affecting the high energy e^- spectrum. Also, observations at microwave and radio frequencies suggest a different spectral power-law for the CR $e^\pm$ at $\sim$1 GeV [2–4] compared to CR $e^\pm$ flux measurements at higher energies [5, 6]. While changes in the spectral power-law describing these components are motivated by the reasons just described, sharp breaks used to implement them are theoretically less accurate and fit slightly worse the AMS positron fraction spectrum.

In addition, our physically motivated models include the impact of solar modulation by using the force field approximation. Solar modulation modifies the position and normalization of the dark matter signal flux, but is negligible at energies >5 GeV.[2] We do not expect solar modulation to significantly smoothen a sharp spectral peak at higher energies.

Given that we consider a population of pulsars as one possible source of the rising positron fraction above 10 GeV (with TeV-scale DM or a single dominant pulsar being alternative possibilities), we will briefly discuss the impact of their modeling on our limits. For pulsars that eventually inject equal amounts of $e^\pm$ into the ISM, their injection spectra can be estimated from gamma-ray and synchrotron observations towards known pulsars, such as the Crab.[3] Typical injection power-law values for the differential spectrum are expected to be in the range of 1-2 leading to propagated spectra with power-laws in the range of 2.0 ± 0.5. Our fits for the averaged pulsar contribution agree with these expectations.

In addition, as suggested by Refs. [11–13], the total contribution from many pulsars – each with a different age, distance, initial rotational energy, injected energy into $e^\pm$, and unique environmental surroundings affecting energy losses and diffusion – is expected to give a spectrum with many peaks and dips, especially at higher energies where fewer pulsars significantly contribute. With

[1] At a few GeV the $e^\pm$ energy losses due to bremsstrahlung emission, dominant at lower energies, equal locally those due to synchrotron radiation and ICS (dominant at higher energies). Since the energy loss rate dE/dt due to bremsstrahlung radiation scales as E while the dE/dt due to synchrotron and ICS as E^2 (at the Thompson cross-section regime), a spectral change in the propagated $e^\pm$ around that energy is expected (see, e.g., Ref [2]).

[2] In certain models, solar modulation can also affect the observed height of the peak in the positron fraction by changing the ratio of electrons-to-positrons of same energy before entering the Heliosphere [7, 8].

[3] Yet the uncertainties are still large due to a lack of exact understanding of local environments or the type of relevant supernova remnants (within which the pulsars exist); typically, the $e^\pm$ also get further accelerated at the termination shock between the magnetosphere and the pulsar wind nebulae (PWN), and the $e^\pm$ injected to the ISM are dominantly coming from middle aged pulsars after their respective PWN have been disrupted (see Refs. [9–11])

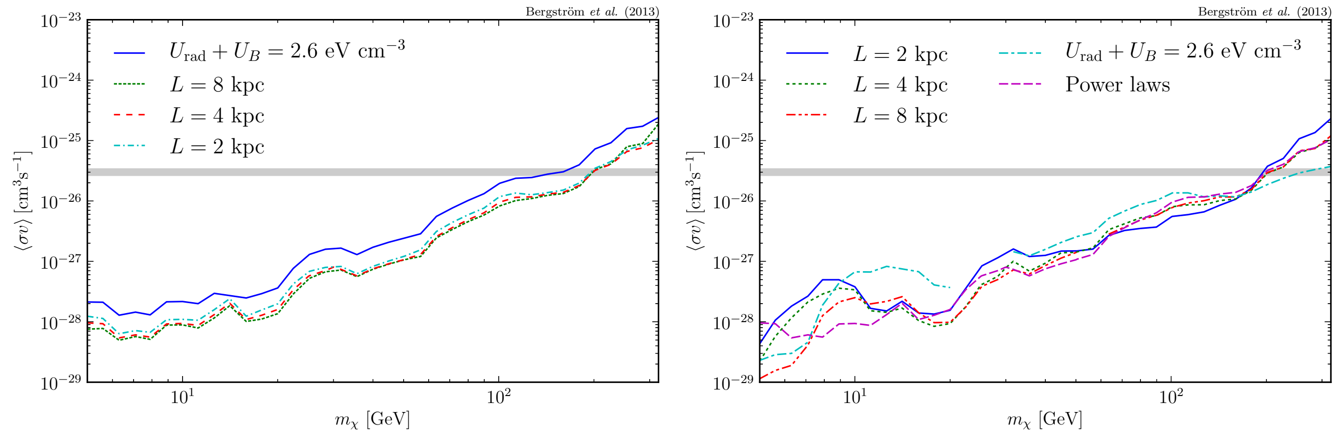

FIG. S1. *Left panel:* Limits obtained when different propagation models for the DM signal are adopted, using the power-law background model adopted in the main text. *Right panel:* Limits derived using different, physically motivated, background models. In both frames, the results are for the case of DM annihilations to e^+e^-. If not stated otherwise, we adopt the benchmark values for $L = 4\,$kpc and the local radiation plus magnetic field density $1.7\,$eV cm^{-3}.

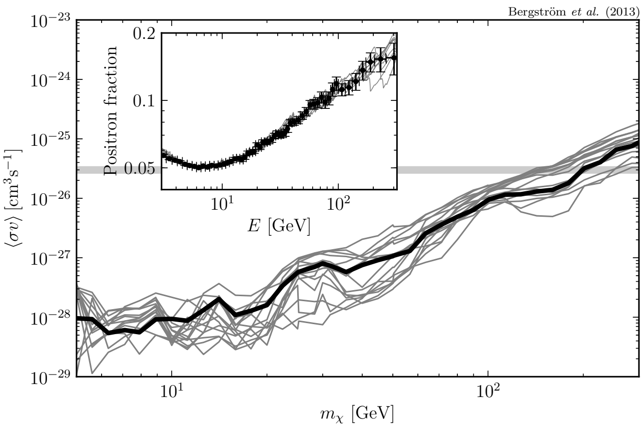

FIG. S2. The *black line* shows our nominal limit on e^+e^- final states, obtained by adopting the power-law background model. The *gray lines*, in contrast, show limits obtained when the contribution from many pulsars is taken into account (for 15 different realizations).

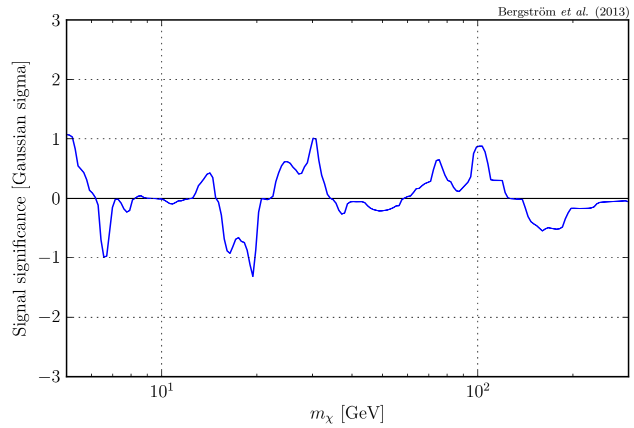

FIG. S3. Significance for a contribution from a e^+e^- DM signal to the AMS-02 positron fraction, for different DM energies, in units of Gaussian sigma. Negative values correspond to negative (but unphysical) signal normalizations.

fine enough energy resolution and high statistics, one should be able to observe such spectral features. By using the data from the ATNF pulsar catalogue [14] and implementing the parametrization of Ref. [11], we ran multiple realizations of such combined spectra to study the impact of possible dips and peaks in the background spectrum on the derived DM limits. In particular, we include in these realizations all pulsars within 4 kpc from us, except for millisecond pulsars and pulsars in binary systems. While we keep their individual locations and ages in all realizations fixed, we vary i) the local CR diffusion properties and energy-losses, ii) the cuts on the current spin-down power of pulsars as recorded in the ATNF catalogue and, most importantly, iii) the fraction η of initial rotational energy of the individual neutron stars that is injected into the ISM in the form of $e^\pm$.

We then fit to the AMS data the injection spectral properties (taken to be the same for all pulsars), the *averaged* value of η, the primary SNe e^-, secondary $e^\pm$ CR flux normalizations and the solar modulation potential. Even though the injection $e^\pm$ spectrum is taken to be the same for simplicity, however, the propagated pulsar spectra differ because of the different ages, distances and energy outputs; this is clearly seen in the inset of Fig. S2 where we plot the resulting positron fraction. For DM channels that give broad continuous spectra, such as muons and taus (see Fig. 1), the presence of multiple peaks and dips is unimportant. For hard spectra such as from monochromatic $e^\pm$, however, our limits can be modified by a factor of up to $\sim$3, as also shown in Fig. S2.

In Fig. S3 we show, for the case of e^+e^- final states, the local significance for a DM signal as function of the DM mass. The significance is plotted in units of Gaussian sigma, and given by the square-root $\sqrt{TS}$ of the Test Statistics $TS = -2\log\mathcal{L}_{\rm null}/\mathcal{L}_{\rm alt}$. Here, $\mathcal{L}_{\rm alt/null}$ denote respectively the likelihood of the alternative (DM signal) and null (no DM signal) hypothesis. For illustration, we also allow negative (obviously unphysical) signal normalizations in the fit, which are mapped onto the negative y-axis. As background model in the fit we use the reference power-law model from Ref. [1]. We do not find any indications for local, edge-like, features in the AMS data.

Lastly, as a simple cross-check, we have also run DarkSUSY [15] with standard parameters for propagation (based on the prescription given in Ref. [16]) and an NFW profile normalized to 0.4 GeV cm^{-3}. For the electron spectrum, we used a simple broken power law which agrees with the PAMELA electron data [6] for $E > 5\,\mathrm{GeV}$. Knowing that the AMS positron fraction measurement is well described by a simple background model, we then just demand that the DM signal does not exceed the reported 2σ error bars at the energy of the feature. The resulting limit curve agrees well with the more sophisticated treatment described in the main text.

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