Revisiting multicomponent dark matter with new AMS-02 data

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We revisit the multicomponent leptonically decaying dark matter (DM) scenario to explain the possible electron/positron excesses with the recently updated AMS-02 data. We find that both the single- and two-component DM models can fit the positron fraction and e^+/e^- respective fluxes, in which the two-component ones provide better fits. However, for the single-component models, the recent AMS-02 data on the positron fraction limit the DM cutoff to be smaller than 1 TeV, which conflicts with the high-energy behavior of the AMS-02 total $e^+ + e^-$ flux spectrum, while the two-component DM models do not possess such a problem. We also discuss the constraints from the Fermi-LAT measurement of the diffuse γ-ray spectrum. We show that the two-component DM models are consistent with the current DM lifetime bounds. In contrast, the best-fit DM lifetimes in the single-component models are actually excluded.

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I. INTRODUCTION

Recently, the AMS-02 collaboration has updated the measurements on the positron fraction [1] and electron/positron respective fluxes [2] in the cosmic rays (CRs), which have further confirmed the electron/positron excesses observed by the previous experiments, such as AMS [3,4], ATIC [5], PAMELA [6,7], and Fermi-LAT [8–10]. More interestingly, the new data show some features that have not been observed previously. The most important message is that the positron fraction stops increasing with energy [1]. For the electron/positron fluxes, both spectra become harder at ∼30 GeV [2] so that they cannot be fitted with the usual single power-law functions. Moreover, from 20 to 200 GeV, the positron spectral index is larger than the electron one, which indicates that the uprise behavior in the positron fraction originates from the hardening of the positron fluxes, a typical hint toward the need for the primary e^+/e^- sources. Among the possible primary e^+/e^- origins, pulsars [11–13] and annihilating [12–18]/decaying [12,18–27] dark matters (DMs) are two popular interpretations extensively studied in the literature. One stringent constraint on the DM interpretation is the PAMELA measurement of the antiproton flux [28], which agrees with the conventional astrophysical prediction very well. More recently, AMS-02 Collaboration [29] has presented its preliminary measurements of the antiproton-to-proton ratio as well as the latest data on the flux spectra of protons and helium with some new features. Nevertheless, in Refs. [30,31], it has been pointed out that the new AMS-02 data are still in accord with the PAMELA ones, which can be explained by the usual secondary antiprotons. By fitting with the AMS-02 data, some stronger constraints on the DM models have been given in Refs. [30,31]. A simple way to avoid such constraints is to assume that the DMs couple to the Standard Model only via the lepton sector, which is usually called the leptophilic DM scenario. Note that it was also shown in Ref. [32] that the anomalous behavior of positron flux could be possibly explained within the conventional astrophysical framework by introducing some unconventional positron secondary production mechanisms and nonstandard propagation models.[1]

Before the recent release of the AMS-02 data, the AMS-02 positron fraction published last year [4] and the Fermi-LAT total $e^+ + e^-$ flux [8] represented two of the most precise measurements of the CRs. However, the simplest scenario in which a single DM component annihilating or decaying into lepton pairs cannot fit these two data sets simultaneously [27]. In Refs. [34,35], we have proposed a multicomponent DM scenario [36] in order to overcome this difficulty. In particular, two DM components with the heavy DM decaying solely to $\mu^+\mu^-$ and the light one predominantly to $\tau^+\tau^-$ with the energy cutoff at $E_{cL} =$ 100 GeV could already provide a good fit to the combined data set of the AMS-02 positron fraction and Fermi-LAT total $e^+ + e^-$ flux. As a result, this two-component DM model can explain the apparent substructure at around 100 GeV in both spectra as the light DM drops at that energy. Another advantage of this multicomponent scenario is that it gives us a mechanism to evade the strong DM lifetime bound from the diffuse γ-ray spectrum measured recently by Fermi-LAT [37], which has already greatly constrained the simple two-body leptonically decaying DM models. We have also checked that the addition of the HESS total $e^+ + e^-$ data [38] in the fitting would not change this general conclusion.

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[1]We mention that the results in the first paper of Ref. [32] were recently questioned by Ref. [33].

In light of the updated data from AMS-02, it is useful and necessary to revisit the single- and two-component DM models. More remarkably, the new data from AMS-02 still show the substructure around 100 GeV, which strengthens our confidence of the investigation of the multicomponent DM scenario. In this work, we shall only use the latest AMS-02 measurements of the positron fraction and fluxes of e^- and e^+ in our fitting procedure. In this way, we can avoid many systematic uncertainties involved in the AMS-02/Fermi-LAT combined data set [12], due to the differences in the experiment designs, detector responses, and data-taking periods in the solar cycle. Thus, we expect that the final fitting result should be more consistent, which is another motivation for the present work.

The paper is organized as follows. In Sec. II, we briefly introduce our multicomponent decaying DM models and the propagation physics of CRs in the Galaxy. The fitting results about the single- and two-component DM models are presented in Sec. III. In Sec. IV, we discuss the Fermi-LAT diffuse γ-ray constraints on these models. Finally, we give a short summary in Sec. V.

II. SIGNALS AND BACKGROUNDS

In our multicomponent DM framework, the total electron flux is composed of primary, secondary, and DM-decay-induced electrons, while only secondary positrons and the ones from the DM decays contribute to the total positron flux, which can be written as follows:

$$\Phi_e^{(\mathrm{tot})} = \kappa_1 \Phi_e^{(\mathrm{primary})} + \kappa_2 \Phi_e^{(\mathrm{secondary})} + \Phi_e^{\mathrm{DM}},$$
$$\Phi_p^{(\mathrm{tot})} = \kappa_2 \Phi_p^{(\mathrm{secondary})} + \Phi_p^{\mathrm{DM}}. \quad (1)$$

The primary electrons are widely believed to be generated from the supernova remnants distributed in our Galaxy [39], and the injection spectrum is usually assumed to be a broken power-law function with respect to the rigidity ρ. Here, we choose the reference electron primary injection spectrum to be the three-piece broken power law, $q^e(\rho) \propto (\rho/\rho_{e1,2})^{-\gamma_{e1,2,3}}$, where $\rho_{e1,2}$ refer to the two reference rigidities and $\gamma_{e1,2,3}$ refer to the three spectral indices with the relevant parameters shown in Table I. Note that we insert a parameter κ_1 to account for the normalization uncertainty in the primary electrons. Secondary electron/positron fluxes $\Phi_{e,p}^{(\mathrm{secondary})}$ are the final products of the collisions of the charged particles in the CRs, such as protons and other nuclei, with the interstellar medium in the Galaxy. In the present work, we follow the diffusion-reacceleration CR propagation model, in which the spatial diffusion coefficient is parametrized as a power law $D_{xx} = \beta D_0 (\rho/rho_r)^\delta$ with ρ_r as the reference rigidity, $\beta = v/c$ as the velocity, and δ as the power spectral index. The reacceleration process is described by the diffusion coefficient in momentum space $D_{pp} = 4v_A^2 p^2/(3D_{xx}\delta(4-\delta^2)(4-\delta))$. The primary CR proton spectrum is also assumed to follow a broken power-law function: $q^n(\rho) \propto (\rho/rho_n)^{\gamma_{n1,2}}$. To concretely compute the CR spectra, we use the GALPROP code [40] to simulate the productions and propagations of these background electrons and positrons with the fixed diffusion coefficients and primary proton parameters shown in Table I. For other details of the calculation, especially the choice of the astrophysical parameters, we refer to our earlier work in Ref. [34]. However, the calculation of secondary e^-/e^+ fluxes involves the uncertainties from, for instance, nuclei collision cross sections, form factors of heavy nuclei, and propagation coefficients, which are partially taken into account with the parameter κ_2 to rescale the calculated secondary fluxes [12]. The parameters $\kappa_{1,2}$ will be determined with other model parameters in the following fitting procedure.

As for the DM signal $\Phi_{e,p}^{\mathrm{DM}}$, we assume that the whole DM density in the Galaxy and Universe is carried out by a single- or multiple-component DM particles χ_i, the decays of which can explain the positron/electron anomalies. The dominant decay channels for all DM components are taken to be

$$\chi_i \to l^\pm Y^\mp, \quad (2)$$

where $l = e, \mu$, and τ, and Y is another new charged particle of which the further decay is irrelevant to our following discussion. This decay mode can be easily embedded into a full-fledged particle physics model. For example, it is possible that $Y^\pm$ can decay into its neutral partner Y^0 plus charged leptons. If mass difference between $Y^\pm$ and Y^0 is less than 100 MeV, the corresponding $e^\pm$ signal is too soft to affect the high-energy $e^\pm$ spectra in which we are interested, and the energy released to the early Universe is so limited that its effect on the CMB power spectrum is also suppressed [41]. Such a decay channel naturally realizes the leptophilic scenario so that it can satisfy the PAMELA constraint on the antiproton [28]. The e^+/e^- source terms $Q_{e,p}^{\mathrm{DM}}$ induced by the DM decays can be parametrized as

$$Q_{e,p}^{\mathrm{DM}}(\mathbf{x}, p) = \sum_i \frac{\rho_i(\mathbf{x})}{\tau_i M_i} \left(\frac{dN_{e,p}}{dE}\right), \quad (3)$$

TABLE I. Parameters for the diffuse propagation, primary electrons, and primary protons.

Diffuse coefficients				Primary electrons					Primary protons		
$D_0(\mathrm{cm}^2\,\mathrm{s}^{-1})$	ρ_r(GV)	δ	$v_A(\mathrm{km\,s}^{-1})$	ρ_{e1}(GV)	ρ_{e2}(GV)	γ_{e1}	γ_{e2}	γ_{e3}	ρ_n(GV)	γ_{n1}	γ_{n2}
5.3×10^{28}	4.0	0.33	33.5	4.0	67.6	1.46	2,72	2.6	11.5	1.88	2.39

where M_i, τ_i, and $\rho_i(\mathbf{x})$ are the mass, lifetime, and energy density distribution for the ith DM component, respectively. For simplicity, we assume that each DM component carries the same fraction of the entire energy density, so that $\rho_i(\mathbf{x}) = \rho(\mathbf{x})/N$, where $\rho(\mathbf{x})$ is the DM density distribution in the Galaxy as the widely used Navarro, Frenk, and White (NFW) profile [42]. Here, $(dN_{e,p}/dE)_i$ is the differential e^-/e^+ multiplicity for each annihilation, given by the mixture of the three leptonic channels,

$$\left(\frac{dN_{e,p}}{dE}\right)_i = \frac{1}{2}\left[\epsilon_i^e\left(\frac{dN^e}{dE}\right)_i + \epsilon_i^\mu\left(\frac{dN^\mu}{dE}\right)_i + \epsilon_i^\tau\left(\frac{dN^\tau}{dE}\right)_i\right], \quad (4)$$

where $\epsilon_i^{e,\mu,\tau}$ denote the corresponding branching ratios satisfying the normalization condition $\epsilon_i^e + \epsilon_i^\mu + \epsilon_i^\tau = 1$ and the factor $1/2$ takes into account that e^+ and e^- are generated in two separated channels. Since the decay channels shown in Eq. (2) are all two-body processes, we can easily determine the normalized injection spectrum for each decay process only by the kinematics. Concretely, the injection spectra for e and μ channels can be calculated analytically,

$$\left(\frac{dN^e}{dE}\right)_i = \frac{1}{E_{ci}}\delta(1-x), \quad (5)$$

$$\left(\frac{dN^\mu}{dE}\right)_i = \frac{1}{E_{ci}}\left[3(1-x^2) - \frac{4}{3}(1-x)\right]\theta(1-x), \quad (6)$$

with $x = E/E_{ci}$, while the τ-channel spectrum is simulated with PYTHIA [43] due to the complicated τ hadronic decays. E_{ci} is the energy cutoff of $e^\pm$ for each DM component and can be determined as follows:

$$E_{ci} = \frac{M_i^2 - M_Y^2}{2M_i}. \quad (7)$$

The propagation of electrons and positrons between the DM e^-/e^+ sources and the Earth is very complicated [44], and it involves the deflection of e^-/e^+ in the Galactic magnetic fields and energy loss via the inverse Compton scattering, bremsstrahlung, and synchrotron radiation. In this work, such a sophisticated propagation is consistently solved by the GALPROP codes with the same set of diffusion coefficients as the background fluxes shown in Table I. Finally, it is generally believed that the solar modulation affects the e^-/e^+ flux spectra greatly, especially at energies below and around 10 GeV. But our focus here is the high-energy range that is known to be less impacted by this solar modulation. Therefore, we follow the simple force-field approximation [45] with the Fisk potential $\phi_F = 0.55$ GV. Note that the choice of this fixed value of the Fisk potential is just for illustration, rather than guaranteeing the spectra at energies smaller than 10 GeV to be followed by the our fit.

It is well known that the computation of the spectra of various CR particles always suffers from many astrophysical uncertainties, such as the specific values of diffusion coefficients and the choice of DM halo profiles. However, the purpose of the present paper is to investigate the viability of the multicomponent DM scenario in light of the new AMS-02 data. Thus, we ignore such a complicated issue involving astrophysical uncertainties and only fix the astrophysical parameters to the specific values in Table I. It is also expected that the use of other DM halo profiles should not modify our general results much, since only $e^\pm$ generated within the local region of about 1 kpc around the Sun can contribute to the signal. We have checked this statement with the isothermal profile [46].

III. FITTING RESULTS

The data sets used in our study include the latest AMS-02 measurements of the positron fraction [1] and electron and positron respective fluxes [2]. These three groups of the data may correlate to each other, as the positron fraction can be calculated from positron and electron fluxes. Nevertheless, since they have different systematic uncertainties, we adopt all of them simultaneously in our fitting procedure. Furthermore, we restrict to the data with the energy above 10 GeV in order to reduce the effects of the solar modulation. Thus, we have totally 140 data points. For the fitting procedure, we use the simple χ^2-minimization method to obtain the best-fit point and assess the goodness of the fit. In the following two subsections, we present the fitting results for the single- and two-component decaying DM models, which are the simplest ones in the general multicomponent DM scenario. After fixing the best-fit model parameters, we can predict the total $e^+ + e^-$ flux spectrum and compare it with the latest measurement by AMS-02 [47].

A. Results for single-component dark matter models

In this section, we focus on the simplest case with a single DM component. To obtain the meaningful physical results, we fix the DM mass to be $M = 3030$ GeV. Therefore, we have a total of six parameters: the primary and secondary normalization factors κ_1 and κ_2, energy cutoff E_c, DM lifetime τ, and two independent decay branching ratios ϵ^e and ϵ^τ, together with the constraint $\epsilon^e + \epsilon^\tau \leq 1$. To simplify the fitting procedure, we fix the cutoff E_c to be 600, 800, 1000, and 1500 GeV, respectively.

The best-fit results are summarized in Table II and Fig. 1 for different energy cutoffs. From Table II, we find that, for the first three cases with the energy cutoff smaller than 1 TeV, the single-component DM model can already give good fits to the AMS-02 measurements of the positron fraction and e^+/e^- respective fluxes, while the last benchmark with $E_c = 1.5$ TeV is not very reasonable due to the

TABLE II. Parameters leading to the minimal values of χ^2 with the cutoff of the single DM being 600, 800, 1000, and 1500 GeV, respectively.

E_c(GeV)	κ_1	κ_2	ϵ^e	ϵ^μ	ϵ^τ	$\tau(10^{26}$ s)	$\chi^2_{\rm min}$	$\chi^2_{\rm min}$/d.o.f.
600	0.94	1.60	0.07	0	0.93	0.43	115	0.85
800	0.94	1.62	0.02	0	0.98	0.47	128	0.95
1000	0.94	1.65	0	0	1	0.51	145	1.08
1500	0.94	1.65	0	0.15	0.85	0.54	215	1.60

too-large value of $\chi^2_{\rm min}$/d.o.f. Note that in Fig. 1(d) we show the predictions of the total $e^+ + e^-$ flux with the best-fit parameters. By comparing these predictions with the latest AMS-02 data on the total $e^+ + e^-$ flux, we find that the $e^+ + e^-$ spectrum for $E_c \geq 1$ TeV either stops too early or decays too fast so that it cannot follow the measured high-energy behavior, especially for the data with energies larger than 400 GeV. In contrast, the case with $E_c =$ 1.5 TeV can give a good description at the high energy, though it proves a bad fit for the other three data sets. From this point of view, the single-component DM models encounter some problems: the AMS-02 data for the positron fraction and e^+/e^- fluxes seem to favor a DM with its cutoff smaller than 1 TeV, but such a DM makes the total $e^+ + e^-$ flux at the high-energy region difficult to explain.

B. Results for two-component dark matter models

We now turn to the two-component DM case, in which we use $\mathrm{DM}_{L(H)}$ to represent the light (heavy) DM. Note that we want to explain the substructure around 100 GeV in terms of the light DM stopping to decay at the energy, resulting in that the cutoff E_{cL} of DM_L is fixed to be 100 GeV. However, the cutoff E_{cH} of the heavy DM is free, which is taken to be 600, 800, 1200, and 1500 GeV in our numerical investigations, respectively. Here, we choose the mass of the heavy particle Y to be 300 GeV for simplicity so that the two DM masses can be determined via Eq. (7) to be $M_L = 416$ GeV and $M_H = 1271$, 1654, 2437, and 3030 GeV, respectively.

The fitting results are presented in Table III, and the predictions with the best-fit parameters are shown in Fig. 2. Generally speaking, all of the four two-component DM

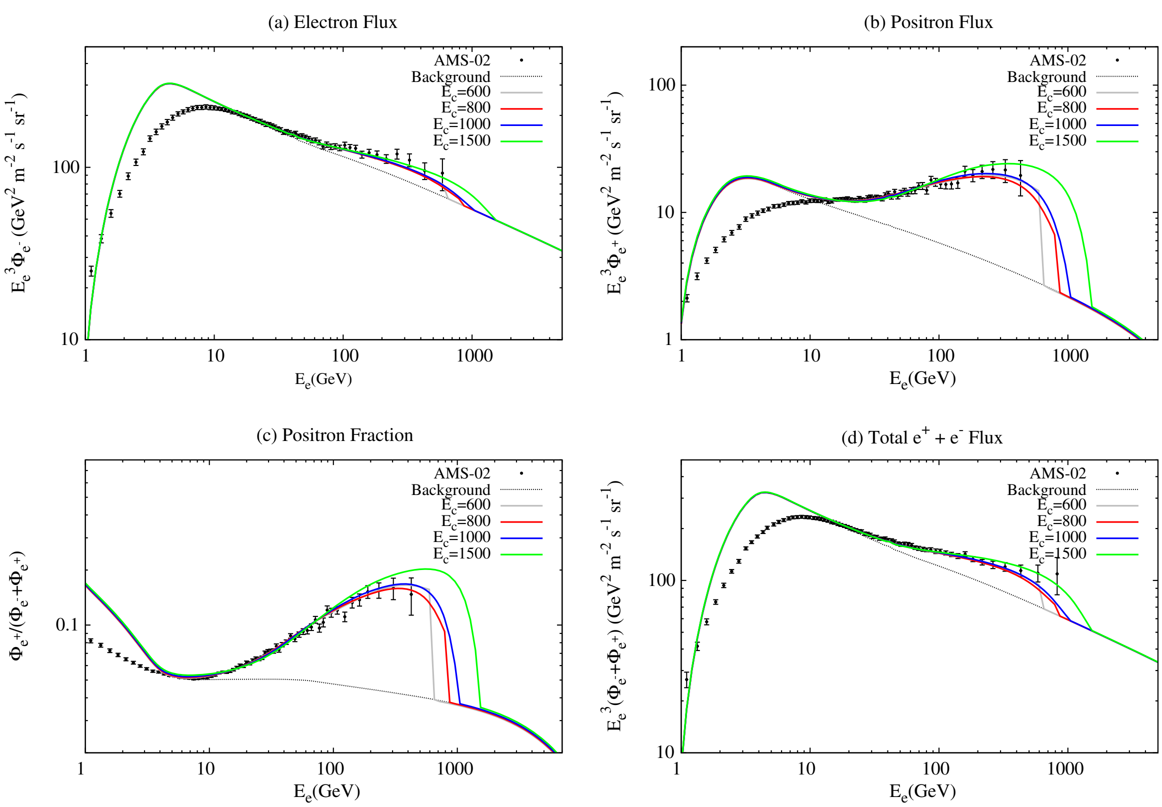

FIG. 1 (color online). (a) Electron flux, (b) positron flux, (c) positron fraction, and (d) total $e^+ + e^-$ flux from the single-component DM contributions with the best-fitting parameters given in Table II for $E_{cH} = 600$, 800, 1000, and 1500 GeV, respectively.

TABLE III. Parameters leading to the minimal values of χ^2 with the cutoffs of heavy DM being 600, 800, 1200, and 1500 GeV, respectively.

E_{cH}(GeV)	κ_1	κ_2	$\epsilon^e_{H,L}$	$\epsilon^\mu_{H,L}$	$\epsilon^\tau_{H,L}$	$\tau_{H,L}(10^{26}\ \mathrm{s})$	χ^2_{min}	χ^2_{min}/d.o.f.
600	0.94	1.49	0.18, 0.02	0.74, 0.00	0.08, 0.98	1.06, 0.93	102	0.78
800	0.94	1.49	0.04, 0.02	0.65, 0.00	0.31, 0.98	0.75, 0.97	102	0.78
1200	0.94	1.50	0.00, 0.01	0.80, 0.00	0.20, 0.99	0.43, 1.12	102	0.78
1500	0.94	1.50	0.00, 0.04	1.00, 0.17	0.00, 0.79	0.42, 1.39	102	0.78

models can fit to the AMS-02 data pretty well as $\chi^2_{\mathrm{min}}/\mathrm{d.o.f.} < 1$, which are much better than any single-component DM model considered in the previous subsection. The flavor structures are almost the same in these cases, in which the heavy DM decays primarily through the μ channel, while the light one favors the τ channel. The hardening feature observed in the e^+/e^- flux spectra around 30 GeV is explained by the transition from the background-dominated region to the DM-dominated one. Even better, the positron fraction spectrum with $E_{cH} = 800$ GeV shows the start of the decreasing behavior with the maximum at around 300 GeV, which coincides with the striking claim in Ref. [1]. Unfortunately, the predicted total $e^+ + e^-$ flux spectrum for this heavy DM cutoff goes back to the background level too early as compared with the most recent AMS-02 data, giving a bad description of the last two points. In contrast, the spectra with $E_{cH} = 1200$ and 1500 GeV can reduce or solve this problem by extending the DM $e^+ + e^-$ flux to high energies. However, in the latter two cases, the increasing behaviors in the positron fraction also continue to high energies, already exceeding 500 GeV, which disagrees with the conclusion in Ref. [1]. In summary, similar to the single-component cases, the current AMS-02 data on the positron fraction seems to be best fit with a relatively small heavy-DM cutoff, which is in mild tension with the excesses at higher energies in the total $e^+ + e^-$ flux. But all the benchmarks can give good enough fit to the AMS-02 data, which cannot be achieved by the single-DM models with the cutoff larger than 1 TeV.

Now, we hope to make clear the role of the DM masses M_i and the electron/positron cutoffs E_{ci} played in our fit. In

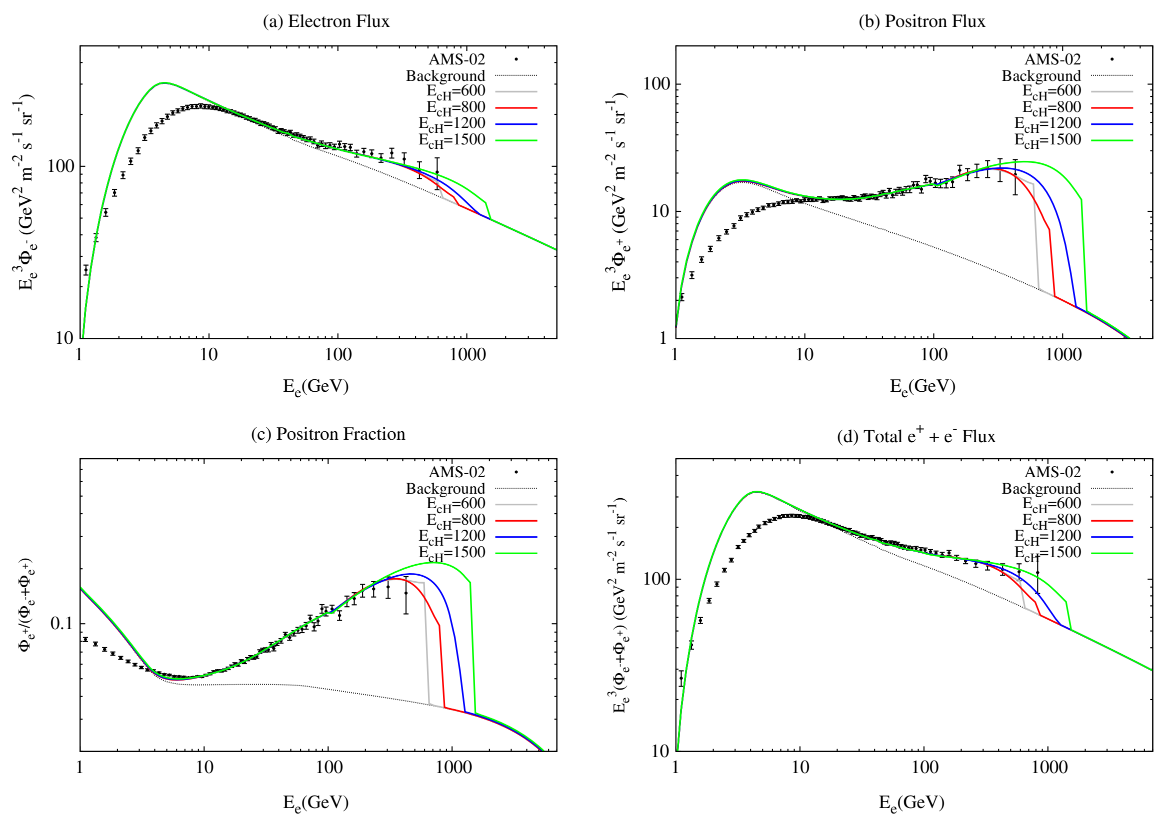

FIG. 2 (color online). (a) Electron flux, (b) positron flux, (c) positron fraction, and (d) total $e^+ + e^-$ flux from the two-component DM contributions with the best-fitting parameters given in Table III for $E_{cH} = 600$, 800, 1200, and 1500 GeV, respectively.

the present paper, we consider the decay process $\chi_i \to \ell^\pm Y^\mp$ for each of the DM components χ_i with a unique $Y^\mp$. The existence of extra particle $Y^\pm$ breaks the degeneracy between the electron cutoff E_{ci} and the DM mass $M_i = 2E_{ci}$ in the conventional modes $\chi_i \to \ell^+\ell^-$. Instead, they obey the new relation specified in Eq. (7). In other words, they are totally independent when M_Y is free. Note that E_{ci} and M_i have different effects on the predicted injection spectra. Specifically, the DM cutoffs E_{ci} affect the shape of the final spectra by determining the energy scale at which the injected $e^\pm$ fluxes drop, while the DM mass M_i enters the spectra only through the DM $e^\pm$ source terms in the product with the DM lifetimes τ_i in Eq. (3). To put it another way, the product $\tau_i M_i$ is the only independent parameter that the fitting procedure can determine. In this sense, the DM lifetimes get their values and meanings by specifying the DM masses. Also note that the goodness of the fit is essentially controlled by the overall normalization factor $\tau_i M_i$ and the shape of the spectra, which is in turn closely related to the cutoffs E_{ci} and the decay modes considered. Therefore, the variation of the DM masses M_i alone will not change the goodness of the fit, i.e., the value of the minimum χ^2. Rather, we only need to tune the DM lifetimes M_i to make the combination $M_i\tau_i$ constant.

IV. REMARKS ON THE DIFFUSE γ-RAY CONSTRAINTS

Finally, we would make some comments on the diffuse γ-ray constraints in the present single- and two-component decaying DM scenarios. As pointed in Refs. [20,48–54], the current diffuse γ-ray measurement by Fermi-LAT has already excluded a large range of the parameter space of the single-component leptophilic decaying DM models trying to explain the positron/electron excesses. However, it has been shown in Refs. [34,35] that the present two-component decaying DM scenario is promising to reconcile the tension between these two kinds of experiments, in which the prediction of the diffuse γ-ray spectrum is done by summing all the contributions to the background and DM signals. In the following, we shall argue that this feature persists for the results in Tables II and III. Since the final predictions of the diffuse γ-ray spectrum are similar to those shown in Refs. [34,35], we shall not repeat such a calculation again. Instead, we would like to reach this conclusion by arguing the reasons behind it.

References [48,49] have made the detailed discussions of the diffuse γ-ray constraints on the single-component decaying DM models with the conventional decay channels, representing the standard references in the literature. Our present study is mainly based on the comparison between our scenario to these two papers. First of all, the interpretation of the Fermi-LAT diffuse γ-ray data in Ref. [48], which assumes that the measured spectrum should be fitted with a simple power-law function arising from the conventional astrophysical sources, is very different from our viewpoint. The possible contribution from DM could only be manifested as the residue after the subtraction of the data to this background, leading to very stringent DM lifetime bounds. From our perspective, however, the measured spectrum is the total summation of the astrophysical background and the signals from DM decays. Therefore, the constraints in Ref. [48] cannot be applied to our cases.

On the other hand, the constraints from Ref. [49] are more relevant to our present scenario since the authors, Papucci and Strumia (PS), did not assume any astrophysical background in their derivation. The bounds $\tau^{\rm PS}$ for various decay channels are shown in Fig. 8 in Ref. [49], from which we can read off the lowest DM lifetime bounds for the corresponding DM masses. However, these DM lifetime bounds have to be transformed before they can be used here. One prominent difference lies in that, in our scenario, we have N components with an equal amount DM density by assumption so that there is a factor $1/N$ suppression for each channel. Moreover, the DM decay processes in this paper have only one lepton in the final states, rather than a lepton pair in the usual models in Ref. [49], so that additional one-half suppression should be also taken into account. Another aspect is that the DM masses in our scenario are different from those in the lepton pair decay processes in which $m_{\rm DM}^{\rm PS} = 2E_c$. By considering all these effects, we can transform the DM lifetime bounds shown in Ref. [49] into those for our models via

$$\tau_l = \frac{M_{\rm DM}^{\rm PS}\tau_l^{\rm PS}}{2NM_i}, \tag{8}$$

where the subscript l denotes the corresponding lepton channel.

For the single-component DM models in Table II, the dominant decay channels are all τ modes. Since the DM cutoffs are 600, 800, 1000, and 1500 GeV, the corresponding lifetime bounds for the tau-pair final state lie in the range $2\text{–}3 \times 10^{26}$ s, from which the lifetime bounds for our scenario can be obtained via Eq. (8) as $1\text{–}1.5 \times 10^{26}$ s. Obviously, the best-fit lifetimes in Table II are already excluded by these bounds. Therefore, it is seen that the single-component DM models used to explain the AMS-02 excesses have some kind of tension with the Fermi-LAT diffuse γ-ray results.

However, our two-component DM models do not possess this problem. For example, the light DM with $E_{cL} = 100$ GeV predominantly decays via the τ channel as shown in Table III. The relevant lifetime bound in Ref. [49] is $\tau_\tau^{\rm PS} = 1.5 \times 10^{26}$ s for DM $\to \tau^+\tau^-$ with $M_{\rm DM}^{\rm PS} = 200$ GeV, which corresponds to $\tau_\tau = 2 \times 10^{25}$ s with the light DM mass $M_L = 416$ GeV. The same argument can also lead us to the heavy DM lifetime bounds $\tau_\mu = 0.75\text{–}1.25 \times 10^{25}$ s for the dominant μ channels with $E_{cH} = 600\text{–}1500$ GeV. It is clear that these bounds are still much lower than the two best-fit DM lifetimes in all of the four benchmarks listed in Table III, from which we can obtain the conclusion that the two-component decaying DM models are more favorable than their single-component cousins by the Fermi-LAT diffuse γ-ray data.

V. CONCLUSION

The recent release of the AMS-02 data on the positron fraction and electron/positron respective fluxes has given us some new hints toward the DM interpretation of the positron/electron excesses. In the present paper, we have revisited the multicomponent decaying DM scenario introduced in our previous work [34,35] with the updated AMS-02 data sets. It is found that both single- and two-component DM models can yield consistent fits to the aforementioned data sets, with the two-component cases being even better. The hardening behavior in e^+/e^- fluxes around 30 GeV can be explained by the transition from the background-dominated to the DM-signal regions. For the single-component DM models, the AMS-02 data, especially the positron fraction, constrain the dominant DM decay channel to be the τ mode with its cutoff lighter than 1 TeV, resulting in that the total $e^+ + e^-$ flux stops excessing too early to explain the data. In comparison, the two-component DM models provide an even better fit to the AMS-02 data, in which the heavy DM decays predominately via the μ channel, while the light one with $E_{cL} = 100$ GeV decays mostly via the τ channel. We have also made some comments on the diffuse γ-ray constraint from the Fermi-LAT measurement. We have found that the corresponding data set has already excluded the best-fit lifetimes of the single-component DM models with the dominant τ decay channels, while still allowing the two-component DM model benchmarks listed in Table III. In summary, the two-component DM models are more favored by the current indirect DM searches, providing a better fit to the AMS-02 e^+/e^- data, which are also in good agreement with the Fermi-LAT diffuse γ-ray data.

Moreover, our best-fit parameters with the heavy DM cutoff $E_{cH} = 800$ GeV predict the decline tendency above 300 GeV claimed in Ref. [1], while a heavy DM with $E_{cH} = 1200$ or 1500 GeV can give a better description of the high-energy behavior of the AMS-02 $e^+ + e^-$ flux data. However, there is no model to accommodate both high-energy features, regarded as some tensions among the AMS-02 data sets. We hope that the more precise AMS-02 data in the near future can settle down this problem.

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