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New interpretation of the recent result of AMS-02 and multi-component decaying dark matters with non-Abelian discrete flavor symmetry

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Abstract Recently the AMS-02 experiment has released the data of positron fraction with a very small statistical error. Because of the small error, it is no longer easy to fit the data with single dark matter for a fixed diffusion model and dark matter profile. In this paper, we propose a new interpretation of the data: that it originates from decay of two-component dark matter. This interpretation gives a rough threshold of the lighter DM component. When DM decays into leptons, the positron fraction in the cosmic rays depends on the flavor of the final states, and this is fixed by imposing a non-Abelian discrete symmetry on our model. By assuming two gauge-singlet fermionic decaying DM particles, we show that a model with non-Abelian discrete flavor symmetry, e.g. T_{13}, can give a much better fitting to the AMS-02 data compared with a single-component dark matter scenario. Few dimension-six operators of the universal leptonic decay of DM particles are allowed in our model, since its decay operators are constrained by the T_{13} symmetry. We also show that the lepton masses and mixings are consistent with current experimental data, due to the flavor symmetry.

1 Introduction

The latest experiment of Planck [1] tells us that about 26.8 % of the energy density of the universe consists of Dark Matter (DM). Many experiments are being performed to search DM signatures. The recent result of the indirect detection experiment of AMS-02 [2] is in favor of previous experiments such as PAMELA [3,4] and Fermi-LAT [5], which had reported an excess of positron fraction in the cosmic rays. Moreover, it smoothly extends the anomaly line of positron fraction with energy up to about 350 GeV with a small statistical error compared with the previous experiments. These observations can, in general, be explained by scattering and/or decay of the GeV/TeV-scale DM particles. In addition, leptophilic DM is preferable, since PAMELA observed no antiproton excess [6]. Along this line of thought, several papers have been released [7–15]. Due to the smallness of the statistical error of AMS-02, it became difficult to make a fit to the data, in the same way as previous experiments like PAMELA [14].

In this paper, we show that we can obtain a better fitting to the data with two-component decaying DM. We introduce two kinds of fermionic DM particles, with mass of $\mathcal{O}(100)$ GeV and $\mathcal{O}(1)$ TeV, into the framework of a T_{13} flavor symmetric model [16]. In our model, the flavor symmetry T_{13} works at least in two ways.

(i) It constrains the interactions between DM and the Standard Model (SM) particles. DM particles which are gauge-singlet fermions X and X' couple with leptons by dimension-six operators $\bar{L}E\bar{L}X^{(\prime)}/\Lambda^2$ due to the T_{13} symmetry, thus these are leptophilic. DM particles decay into leptons via these operators with the suppression factor $\Lambda \sim 10^{16}$ GeV, giving the desired lifetime of DM particles, $\Gamma^{-1} \sim ((\mathrm{TeV})^5/\Lambda^4)^{-1} \sim 10^{26}$ s [17,18].

(ii) The flavor of the final states of DM decay is determined by the T_{13} symmetry.

We give a concrete example of the universal final states $X/X' \to \nu_e e^+ e^- / \nu_\mu \mu^+ \mu^- / \nu_\tau \tau^+ \tau^-$. Due to a specific selection rule by the flavor symmetry mentioned above, we show that the two-component DM model is preferable for the explanation of the precise AMS-02 result. In addition to that, we find a set of parameters that is consistent with the observed lepton masses and their mixings, especially a somewhat large angle of θ_{13}, as recently reported by several experiments [19–25].

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Table 1 The T_{13} and Z_3 charge assignment of the SM fields and the Majorana DM X and the Dirac DM X', where $\omega = e^{2i\pi/3}$

	Q	U	D	L	E	H	H'	X	X'
$SU(2)_L \times U(1)_Y$	$\mathbf{2}_{1/6}$	$\mathbf{1}_{2/3}$	$\mathbf{1}_{-1/3}$	$\mathbf{2}_{-1/2}$	$\mathbf{1}_{-1}$	$\mathbf{2}_{1/2}$	$\mathbf{2}_{1/2}$	$\mathbf{1}_0$	$\mathbf{1}_0$
T_{13}	$\mathbf{1_{0,1,2}}$	$\mathbf{1_{0,1,2}}$	$\mathbf{1_{0,1,2}}$	$\mathbf{3_1}$	$\mathbf{3_2}$	$\mathbf{3_1}, \mathbf{\bar{3}_2}$	$\mathbf{1_{0,1,2}}$	$\mathbf{1_0}$	$\mathbf{1_1}$
Z_3	1	ω	ω^2	1	1	1	ω	1	1

This paper is organized as follows. In Sect. 2, we briefly mention the T_{13} symmetric model and construct mass matrices of the lepton sector with the definite choice of the T_{13} assignment of the fields. We show that there exists a consistent set of parameters. In Sect. 3, we show that desirable dimension-six DM decay operators are allowed by the T_{13} symmetry and that the leptonic decay of the two DM particles by those operators shows good agreement with the cosmic-ray anomaly experiments. Sect. 4 is devoted to the conclusions.

2 Lepton masses and mixings with T_{13} flavor symmetry

First of all, we briefly review our model based on the non-Abelian discrete group T_{13}, which is isomorphic to $Z_{13} \rtimes Z_3$ [16,26–29]. The T_{13} group is a subgroup of $SU(3)$, and it is known as the minimal non-Abelian discrete group having two complex triplets as the irreducible representations; see Ref. [16] for details.

Lepton masses and mixings are derived from the setup shown in Table 1. Here, Q, U, D, L, E, $H(H')$, and $X(X')$ denote left-handed quarks, right-handed up-type quarks, right-handed down-type quarks, left-handed leptons, right-handed charged leptons, Higgs bosons, and gauge-singlet fermions, respectively.[1] Here one should notice that X and X' are Majorana- and Dirac-type DM, respectively, which directly comes from the charge assignment of T_{13}. Due to the T_{13} flavor symmetry in addition to an appropriate choice of the additional Z_3 symmetry, triplet Higgs bosons $H(\mathbf{3_1})$ and $H(\mathbf{\bar{3}_2})$ couple only to leptons, while T_{13} singlet Higgs bosons $H'(\mathbf{1_{0,1,2}})$ couple only to quarks. Hence a linear combination of H' is the SM-like Higgs boson and is created at LHC by gluon fusion. Therefore, the mass matrices of the quark sector are not constrained, while those of the lepton sector are determined by the T_{13} symmetry. For the neutrino sector, since the Yukawa couplings LHX and LHX' are forbidden by the T_{13} symmetry, the left-handed Majorana neutrino mass terms are derived from dimension-five operators $LHLH$. Here notice that X and X' have dimension-six operators $\bar{L}E\bar{L}X$, $\bar{L}ELX'$, and mass terms $m_X XX$, $m_{X'}\bar{X}'X'$. For the matter content and the T_{13} assignment given in Table 1, the charged-lepton and neutrino masses are generated from the T_{13} invariant operators

$$\begin{aligned}\mathcal{L}_Y &= \sqrt{2}a_e \bar{E}LH^c(\mathbf{\bar{3}_2}) + \sqrt{2}b_e \bar{E}LH^c(\mathbf{3_1}) \\ &\quad + \frac{a_\nu}{\Lambda}LH(\mathbf{\bar{3}_2})LH(\mathbf{\bar{3}_2}) + \frac{b_\nu}{\Lambda}(LH(\mathbf{\bar{3}_2}))_{\mathbf{\bar{3}_2}}(LH(\mathbf{3_1}))_{\mathbf{3_2}} \\ &\quad + \frac{c_\nu}{\Lambda}(LH(\mathbf{\bar{3}_2}))_{\mathbf{3_1}}(LH(\mathbf{3_1}))_{\mathbf{\bar{3}_1}} + \text{h.c.},\end{aligned} \tag{2.1}$$

where $H^c = \epsilon H^*$, and $LH(\mathbf{\bar{3}_2})LH(\mathbf{3_1})$ is T_{13} invariant in two different products, corresponding to b_ν and c_ν. The fundamental scale $\Lambda = 10^{11}$ GeV is needed for the certain neutrino mass scale ($\Lambda/\sqrt{\lambda} \sim 10^{16}$ GeV is required to obtain the desired lifetime of DM, where λ is the coupling constant of the DM decay operators, as we will discuss later). After the electroweak symmetry breaking, the Lagrangian Eq. (2.1) gives rise to mass matrices of the charged leptons M_e and neutrinos M_ν as follows:

$$M_e = \begin{pmatrix} 0 & b_e v_1 & a_e \bar{v}_2 \\ a_e \bar{v}_3 & 0 & b_e v_2 \\ b_e v_3 & a_e \bar{v}_1 & 0 \end{pmatrix}, \tag{2.2}$$

$$M_\nu = \frac{1}{\Lambda}\begin{pmatrix} c_\nu \bar{v}_3 v_2 & a_\nu \bar{v}_1^2 + b_\nu \bar{v}_3 v_1 & a_\nu \bar{v}_3^2 + b_\nu \bar{v}_2 v_3 \\ a_\nu \bar{v}_1^2 + b_\nu \bar{v}_3 v_1 & c_\nu \bar{v}_1 v_3 & a_\nu \bar{v}_2^2 + b_\nu \bar{v}_1 v_2 \\ a_\nu \bar{v}_3^2 + b_\nu \bar{v}_2 v_3 & a_\nu \bar{v}_2^2 + b_\nu \bar{v}_1 v_2 & c_\nu \bar{v}_2 v_1 \end{pmatrix}, \tag{2.3}$$

where the vacuum expectation values (VEVs) of the Higgs bosons are defined as $\langle H(\mathbf{3_1})^i \rangle = v_i/\sqrt{2}$, $\langle H(\mathbf{\bar{3}_2})^i \rangle = \bar{v}_i/\sqrt{2}$, $\langle H'(\mathbf{1_{0,1,2}}) \rangle = v'_i/\sqrt{2}$, $\sum_{i=1}^{3}\left(v_i^2 + \bar{v}_i^2 + v'^2_{i-1}\right) = (246\text{ GeV})^2$.

Now we give a numerical example. By the following choice of parameters:

$$\begin{aligned}&v_1 = 0.4269\text{ GeV}, \quad v_2 = 16.11\text{ GeV}, \quad v_3 = 7.862\text{ GeV}, \\ &\bar{v}_1 = 1\text{ GeV}, \quad \bar{v}_2 = 16.82\text{ GeV}, \quad \bar{v}_3 = 0.004836\text{ GeV}, \\ &a_e = 0.1057, \quad b_e = 0, \quad a_\nu = -8.220 \times 10^{-3}, \\ &b_\nu = 8.439 \times 10^{-3}, \quad c_\nu = 3.632 \times 10^{-1},\end{aligned} \tag{2.4}$$

the mass matrices of Eqs. (2.2) and (2.3) give rise to mass eigenvalues and related observables as follows:

[1] All the assignments and particle contents are the same as our previous work [16] except the DM sector.

$$m_e = 0.511 \text{ MeV}, \quad m_\mu = 105.7 \text{ MeV}, \quad m_\tau = 1{,}777 \text{ MeV},$$
$$m_{\nu 1} = 6.324 \times 10^{-3} \text{ eV}, \quad m_{\nu 2} = 1.078 \times 10^{-2} \text{ eV},$$
$$m_{\nu 3} = 5.046 \times 10^{-2} \text{ eV},$$
$$\Delta m_{21}^2 = m_{\nu 2}^2 - m_{\nu 1}^2 = 7.62 \times 10^{-5} \text{ eV}^2,$$
$$\Delta m_{32}^2 = m_{\nu 3}^2 - m_{\nu 2}^2 = 2.43 \times 10^{-3} \text{ eV}^2,$$
$$\langle m \rangle_{ee} = 2.83 \times 10^{-4} \text{ eV}, \quad \sum_i m_{\nu i} = 5.49 \times 10^{-2} \text{ eV}, \tag{2.5}$$

and the mixing matrices are given by

$$U_{eL} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix}, \quad U_{eR} = \begin{pmatrix} 0 & 0 & 1 \\ 1 & 0 & 0 \\ 0 & 1 & 0 \end{pmatrix}, \tag{2.6}$$

$$U_{\text{MNS}} = U_{eL}^\dagger U_\nu = \begin{pmatrix} 0.819 & 0.552 & -0.156 \\ -0.304 & 0.648 & 0.698 \\ -0.487 & 0.524 & -0.698 \end{pmatrix},$$
$$\theta_{12} = 34^\circ, \quad \theta_{23} = -45^\circ, \quad \theta_{13} = -9^\circ, \tag{2.7}$$

which are all consistent with the present experimental data [30,31]. In particular in the case of $U_{eL} = 1$, the mass matrices in Eqs. (2.2) and (2.3) require a normal hierarchy $m_{\nu 1} < m_{\nu 2} < m_{\nu 3}$ of the neutrino masses and $(U_{\text{MNS}})_{e3} \neq 0$. A comprehensive analysis of the T_{13} symmetric models has been made by several authors [32–35]. Although one can sweep the whole range of parameters, we adopt those of Eq. (2.4), giving universal final states due to the mixing matrices Eq. (2.6), since such an analysis is out of scope of the present paper.

As for the Higgs sector, since the present model contains nine Higgs doublets, it causes flavor changing neutral current processes such as $\bar{K}^0$–K^0 mixings. Therefore, extra Higgs bosons must be heavy enough. Moreover, additional massless bosons appear because the T_{13} symmetric Higgs potential has accidental $U(1)$ symmetry. Therefore one can introduce soft T_{13} breaking terms such as $H_{\mathbf{1_0}}'^\dagger H_{\mathbf{1_1}}' + H_{\mathbf{1_0}}'^\dagger H_{\mathbf{1_2}}' + H_{\mathbf{1_2}}'^\dagger H_{\mathbf{1_0}}'$ and $H_{\mathbf{1_0}}^\dagger \sum_i H(\bar{3}_2)^i$ in order to avoid those problems.

3 Decaying dark matter in the T_{13} model

It is well known that the cosmic-ray anomalies measured by PAMELA [3] and Fermi-LAT [5] can be explained by DM decay with lifetime of $\Gamma^{-1} \sim 10^{26}$ s. If the DM (X and X' in our case) decays into leptons by dimension-six operators $\bar{L}E\bar{L}X^{(\prime)}/\Lambda^2$ with $\Lambda \sim 10^{16}$ GeV, such a long lifetime can be achieved. In general, however, there exist several gauge invariant decay operators of lower dimensions; dimension-four operators inducing too rapid DM decay, and dimension-six operators including quarks, Higgs, and gauge bosons in the final states, which must be forbidden in a successful model. By the field assignment of Table 1, most decay operators listed in Table 2 [36] are forbidden due to the T_{13} symmetry, except for $\bar{L}E\bar{L}X^{(\prime)}$.[2] Therefore, one does not have to be worried about production of antiprotons and secondary positrons by scattering with a nucleon and the interstellar medium. With the notation $L_i = (\nu_i, \ell_i) = (U_{eL})_{i\alpha}(\nu_\alpha, \ell_\alpha)$ and $E_i = (U_{eR})_{i\beta} E_\beta$ ($i = 1, 2, 3, \ \alpha, \beta = e, \mu, \tau$), the four-Fermi decay interaction is explicitly written as

Table 2 The higher dimensional operators which cause decay of X and X' up to dimension six [36]

Dimensions	DM decay operators
4	$\bar{L}H^c X^{(\prime)}$
5	–
6	$\bar{L}E\bar{L}X^{(\prime)}$, $H^\dagger H\bar{L}H^c X^{(\prime)}$, $(H^c)^t D_\mu H^c \bar{E}\gamma^\mu X^{(\prime)}$, $\bar{Q}D\bar{L}X^{(\prime)}$, $\bar{U}Q\bar{L}X^{(\prime)}$, $\bar{L}D\bar{Q}X^{(\prime)}$, $\bar{U}\gamma_\mu D\bar{E}\gamma^\mu X^{(\prime)}$, $D^\mu H^c D_\mu \bar{L}X^{(\prime)}$, $D^\mu D_\mu H^c \bar{L}X^{(\prime)}$, $B_{\mu\nu}\bar{L}\sigma^{\mu\nu}H^c X^{(\prime)}$, $W_{\mu\nu}^a \bar{L}\sigma^{\mu\nu}\tau^a H^c X^{(\prime)}$

$B_{\mu\nu}$, $W_{\mu\nu}^a$, and D_μ are the field strength tensors of hypercharge gauge boson, weak gauge boson, and the electroweak covariant derivative

$$\begin{aligned}
\mathcal{L}_{\text{decay}} &= \frac{\lambda_X}{\Lambda^2}\sum_{i=1}^{3}(\bar{L}_i E_i)\bar{L}_i X \\
&\quad + \frac{\lambda_{X'}}{\Lambda^2}\sum_{i=1}^{3}\left(\omega^{2(i-1)}\right)\left(\bar{L}_i E_i\right)\bar{L}_i X' + \text{h.c.} \\
&= \frac{\lambda_X}{\Lambda^2}\sum_{i=1}^{3}\sum_{\alpha,\beta,\gamma}(U_{eL})_{i\alpha}^*(U_{eR})_{i\beta}(U_{eL})_{i\gamma}^* \\
&\quad \times \left[\left(\bar{\nu}_\alpha P_R E_\beta\right)\left(\bar{\ell}_\gamma P_R X\right) - \left(\bar{\ell}_\gamma P_R E_\beta\right)\left(\bar{\nu}_\alpha P_R X\right)\right] \\
&\quad + \left(X \to X'\right) + \text{h.c.},
\end{aligned} \tag{3.1}$$

where the factor $(\omega^{2(i-1)})$ is only for the case of X' decay because of the multiplication rule of the T_{13} flavor symmetry. As seen from Eq. (3.1), the decay mode of the DM particles X and X' depends on the mixing matrices U_{eL} and U_{eR}, which are given in Eq. (2.6).

Next, we consider the decay width of the decaying DM through the T_{13} invariant interaction Eq. (3.1). Due to the particular generation structure, the DM particles X and X' decay into a final state with several tri-leptons with a mixing-dependent rate. The decay width of DM X per each flavor is defined as $\Gamma_{\alpha\beta\gamma} \equiv \Gamma(X \to \nu_\alpha \ell_\beta^+ \ell_\gamma^-) + \Gamma(X \to \overline{\nu_\alpha} \ell_\beta^+ \ell_\gamma^-)$,

[2] Notice that $H^\dagger H\bar{L}H^c X^{(\prime)}$ and $H^\dagger H X X'$ cannot be forbidden by any symmetries that hold unitarity. Moreover, these interactions induce decay of one DM to the other DM. Here we assume the couplings of these surviving terms to be tiny enough. The most stringent constraint process is $X' \to X, h$, which comes from $H^\dagger H X X'$, where h is the standard model Higgs boson, whose mass is 126 GeV [37,38]. We find that its coupling should be less than $\mathcal{O}(10^{-18})$ in order to conservatively satisfy the no excess constraint of the antiproton for the lifetime of DM to be longer than $\mathcal{O}(10^{28})$ s.

and the decay width $\Gamma_{\alpha\beta\gamma}$ is calculated as

$$\Gamma_{\alpha\beta\gamma} = \frac{|\lambda_X|^2 m_X^5}{32(4\pi)^3 \Lambda^4}\left(U_{\alpha\beta\gamma} + U_{\alpha\gamma\beta}\right), \tag{3.2}$$

where

$$U_{\alpha\beta\gamma} = \left|\sum_{i=1}^{3}(U_{eL})^*_{i\alpha}(U_{eR})_{i\beta}(U_{eL})^*_{i\gamma}\right|^2. \tag{3.3}$$

The decay width of X', denoted $\Gamma'_{\alpha\beta\gamma}$, is obtained by replacing $X \to X'$. The differential decay width is written as

$$\frac{\mathrm{d}\Gamma_{\alpha\beta\gamma}}{\mathrm{d}x} = \frac{|\lambda_X|^2 m_X^5}{48(4\pi)^3\Lambda^4}x^2 \times \Big((6-2x)U_{\alpha\beta\gamma} + (15-14x)\,U_{\alpha\gamma\beta}\Big), \tag{3.4}$$

where $x = 2E_{\ell^+_\beta}/m_X$. This is required to enable one to calculate the energy distribution function of the injected $e^\pm$ from DM decay, $\mathrm{d}N_{e^\pm}/\mathrm{d}E$. Here we have neglected the masses of the charged leptons in the final states. In both the X and the X' DM cases, the flavor dependent factor $U_{\alpha\beta\gamma}$ gives a factor 3 when one takes the sum of flavor indices α, β and γ. That is, not by a particular choice of parameters Eq. (2.4), but by the T_{13} symmetry. Therefore, the branching fraction of each decay mode is given by $\mathrm{Br}(X \to \nu_\alpha \ell^+_\beta \ell^-_\gamma, \overline{\nu_\alpha}\ell^+_\beta\ell^-_\gamma) = \left(U_{\alpha\beta\gamma} + U_{\alpha\gamma\beta}\right)/6$. The DM mass m_X and the total decay width $\Gamma_X = \sum_{\alpha,\beta,\gamma}\Gamma_{\alpha\beta\gamma}$ are chosen to be free parameters in the following analysis, since it can be always tuned with the coupling λ_X and the cut-off scale Λ.

Given the differential decay width and the branching ratios, the primary source term of the positron and electron coming from DM decay at the position r of the halo associated with our galaxy is expressed as

$$Q(E,r) = n_X(r)\,\Gamma_X \sum_f \mathrm{Br}(X \to f)\left(\frac{\mathrm{d}N_{e^\pm}}{\mathrm{d}E}\right)_f + \left(X \to X'\right), \tag{3.5}$$

where $(\mathrm{d}N_{e^\pm}/\mathrm{d}E)_f$ is the energy distribution of $e^\pm$ coming from the DM decay with the final state f, and E is the energy of the injected $e^\pm$. We use the PYTHIA 8 [39] to evaluate the energy distribution function. Although it is often assumed that the relic density of the DM is thermally determined, non-thermal production of the DM dark matter is also possible [41]. We thus do not specify the origin of the relic DM in the following analysis, and we assume that the number densities of X and X' are the same for the simplest cases. The non-relativistic DM number density $n_X(r)$ is rewritten by $n_X(r) = \rho_X(r)/m_X$ with the DM profile $\rho(r)$. In this work, we adopt the Navarro–Frank–White (NFW) profile [42],

$$\rho_{\mathrm{NFW}}(r) = \rho_\odot \frac{r_\odot(r_\odot + r_c)^2}{r(r+r_c)^2}, \tag{3.6}$$

where $\rho_\odot \simeq 0.40$ GeV/cm^3 is the local DM density at the solar system, r is the distance from the galactic center whose special values $r_\odot \simeq 8.5$ kpc and $r_c \simeq 20$ kpc are the distance to the solar system and the core radius of the profile, respectively. The diffusion equation must be solved to evaluate the $e^\pm$ flux observed at the Earth, and it depends on the diffusion model. The observable $e^\pm$ flux at solar system, $\mathrm{d}\Phi_{e^\pm}/\mathrm{d}E$, which is produced by DM decay is given by

$$\frac{\mathrm{d}\Phi_{e^\pm}}{\mathrm{d}E} = \sum_{X,X'}\frac{v_{e^\pm}}{4\pi b(E)}\frac{\rho_\odot}{m_X}\Gamma_X\sum_f \mathrm{Br}(X\to f) \times \int_E^{m_X}\left(\frac{\mathrm{d}N_{e^\pm}}{\mathrm{d}E'}\right)_f I_\odot(E,E')\,\mathrm{d}E', \tag{3.7}$$

where $b(E)$ is a space-independent energy loss coefficient written as $b(E) = E^2/(\tau_\odot \cdot 1\mathrm{GeV})$ with $\tau_\odot = 5.7 \times 10^{15}$ s, and $I_\odot(E,E')$ is the reduced halo function at the solar system which is expressed by a Fourier–Bessel expansion [43]. A fitting function for the reduced halo function $I(\lambda_D)$ is given in Ref. [43] as a function of the single parameter λ_D, which is called the diffusion length. It is given by

$$\lambda_D^2 = \frac{4K_0\tau_\odot}{1-\delta}\left[E^{\delta-1} - E'^{\delta-1}\right], \tag{3.8}$$

where we use the following diffusion parameters: $\delta = 0.70$, $K_0 = 0.0112$ kpc^2/Myr, which is called MED. In addition, the diffusion zone is considered as a cylinder that sandwiches the galactic plane with height of $2L$ and radius R where $L = 4$ kpc and $R = 20$ kpc.

As seen from Eqs. (2.6) and (3.2), the DM decays into $e^\pm$ as well as $\mu^\pm$ and $\tau^\pm$ in equal rates. As a result, pure leptonic decays give dominant contributions, and it is consistent with no antiproton excess of the PAMELA results [6]. We may take into account the gamma-ray constraint since a lot of gamma rays are produced by the hadronization of $\tau^\pm$. As we shall see below, the obtained lifetimes of the DM particles X and X' are roughly $\tau_X, \tau_{X'} \gtrsim 5 \times 10^{26}$ s. Thus, we do not need to consider the gamma-ray constraint seriously as long as we are comparing with Ref. [44].

3.1 Result for AMS-02

We use 31 data points of AMS-02 which are higher than 20 GeV for our chi-square analysis. The only statistical error is taken into account as the experimental errors here [2]. The positron fraction for the scenario of the leptonically decaying DM with T_{13} symmetry is depicted in Fig. 1 with the experimental data of AMS-02 and PAMELA. The flux coming from only one-component DM is also shown in the figure for comparison. The obtained best fit point for one-component DM is $m_X = 521$ GeV, $\Gamma_X^{-1} = 5.1 \times 10^{26}$ s with $\chi^2_{\mathrm{min}} = 172.2$ (29 d.o.f.). For the single DM, the positron fraction at high

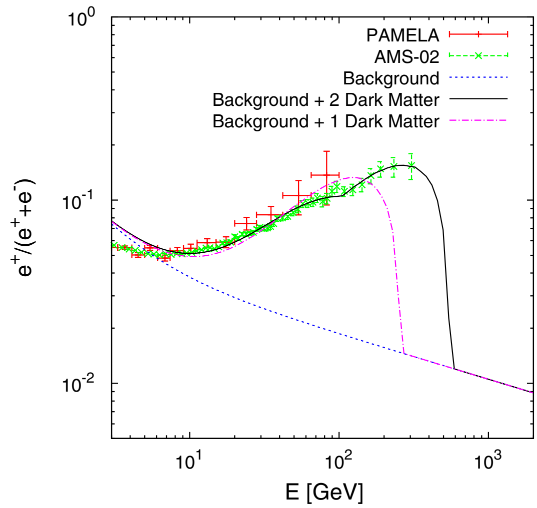

Fig. 1 The positron fraction [2,3] predicted in the leptonically decaying two-component DM scenario with T_{13} symmetry (*solid*) and single-component scenario (*dashed*). For two-component DM, we have fixed to the best fit point: $m_X = 208$ GeV, $m_{X'} = 1{,}112$ GeV, $\Gamma_X^{-1} = 1.9 \times 10^{27}$ s and $\Gamma_{X'} = 4.7 \times 10^{26}$ s

energy cannot be fit well as one can see from the figure. This is because the experimental data in the low-energy region $E \sim 20$ GeV has much higher precision, and the energy spectrum $\mathrm{d}N_{e^\pm}/\mathrm{d}E$ is fixed by the imposed flavor symmetry. Thus the predicted flux in the higher energy region is almost determined by the flavor symmetry. One should note that fitting with one-component DM would be better for different diffusion models or different DM halo profiles, since the evaluated $e^\pm$ flux has a large dependence on them.

On the other hand, the fitting parameters for two-component DM are

$$m_X = 208\ \text{GeV}, \quad \Gamma_X^{-1} = 1.9 \times 10^{27}\ \text{s}, \tag{3.9}$$

$$m_{X'} = 1112\ \text{GeV}, \quad \Gamma_{X'}^{-1} = 4.7 \times 10^{26}\ \text{s}, \tag{3.10}$$

with $\chi^2_{\text{min}} = 22.62$ (27 d.o.f) at the best fit point. Therefore a much better fitting is obtained with the two-component case. This is the result of multi-component DM and the fixed flavor of final states by T_{13} symmetry. That is, not by the particular choice of parameters Eq. (2.4), but by the T_{13} symmetry as mentioned below Eq. (3.4). A sharper drop-off is expected if we have a larger branching ratio for directly produced positrons.

4 Conclusions

We revisited a decaying DM model with a non-Abelian discrete symmetry T_{13}, and we extended it to the two-component DM scenario by adding extra DM X'. We have shown that our model is consistent with all the observed masses and mixings in the lepton sector. Also due to the specific selection rule of T_{13}, we have found that both DM particles have a universal decay coming from dimension-six operators, which gives a promising model for current indirect detection searches of DM.

Fitting to the positron fraction with single-component DM under the assumption of the MED diffusion model and the NFW DM profile can no longer give a good interpretation of the positron excess by DM decay because of the precise measurement of AMS-02. However, taking into account two-component DM as our model gives a much better fitting to the AMS-02 observation. The obtained parameters are $m_X = 208$ GeV with $\Gamma_X^{-1} = 1.8 \times 10^{27}$ s and $m_{X'} = 1{,}112$ GeV with $\Gamma_{X'}^{-1} = 4.7 \times 10^{26}$ s, assuming that X and X' have an equal number density.

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