Virtual Internal Bremsstrahlung of Dark Matter and Positron Excess of AMS-02

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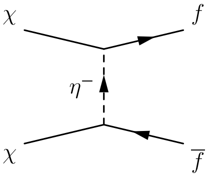
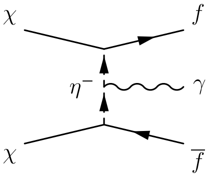
Outline

1. Introduction
2. Virtual Internal Bremsstrahlung of Dark Matter and extended interection
3. Gamma-ray and $e^{\pm}$ Flux
4. Summary

$e^{\pm}$ flux:



γ-ray flux :

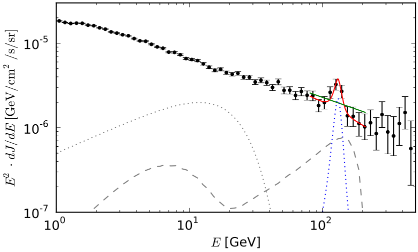


Introduction

Cosmi-rays Observations

· Cosmic-rays may be produced by annihilation of Dark Matter.

· Gamm-ray

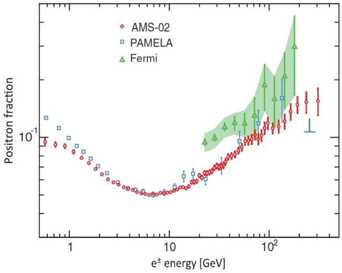


arXiv:1210.3013, 1203.1312

· gamma-ray excess at around 130 GeV

· $\langle \sigma v \rangle \sim 10^{-27}$ cm^3/s

· Positron



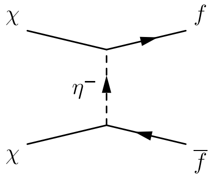
PRL 110 (2013) 14, 141102

· unkown source in higher energy region

Final State Radiation and Virtual Internal Bremsstrahlung

Majorana DM χ

$$\mathcal{L} = y\eta^{+}\overline{\chi}P_L f + \mathrm{h.c.}$$

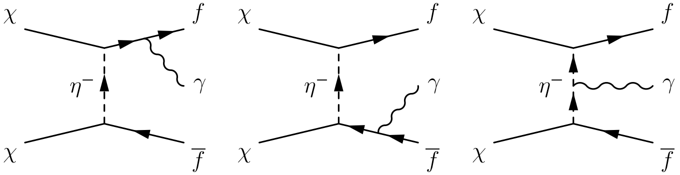


- The cross section for $\chi\chi \to f\overline{f}$ is expanded as $\sigma v_{f\overline{f}} \approx a + bv^2$

$$\sigma v_{f\overline{f}} = \frac{y^4}{32\pi m_\chi^2}\frac{m_f^2}{m_\chi^2}\frac{1}{(1+\mu)^2} + \frac{y^4}{48\pi m_\chi^2}\frac{1+\mu^2}{(1+\mu)^2}v^2, \quad \mu \equiv \frac{m_\eta^2}{m_\chi^2} > 1$$

· If $m_f \ll m_\chi$, s-wave is negligible. $\to$ chiral suppression
· DM relative velocity $v \sim 10^{-3}$ at the present universe
· The p-wave is effective at the early universe.

- Leading process of photon emission
  Radiative correction for 2-body process $\chi\chi \to f\overline{f}$



· The differential cross section

$$\frac{d\sigma v_{f\overline{f}\gamma}}{dx} = \frac{d\sigma v^{\mathrm{FSR}}_{f\overline{f}\gamma}}{dx} + \frac{d\sigma v^{\mathrm{VIB}}_{f\overline{f}\gamma}}{dx}, \quad x \equiv \frac{E_\gamma}{m_\chi}$$

FSR : Broad gamma-ray spectrum
VIB : Line like spectrum

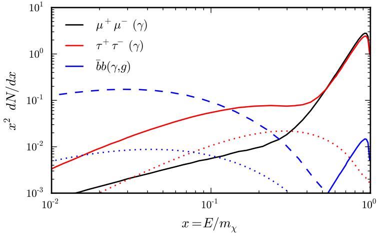
$$\text{FSR}: \frac{d\sigma v^{\rm FSR}_{f\bar{f}\gamma}}{dx} = \sigma v_{f\bar{f}} \frac{\alpha_{\rm em}}{\pi} \frac{1+(1-x)^2}{x} \log\left(\frac{4m_\chi^2(1-x)}{m_f^2}\right) + \text{Hadronization}$$

$$\text{VIB}: \frac{d\sigma v^{\rm VIB}_{f\bar{f}\gamma}}{dx} = \frac{\alpha_{\rm em} y^4}{32\pi^2 m_\chi^2}(1-x)\left[\frac{2x}{(\mu+1)(\mu+1-2x)} - \frac{x}{(\mu+1-x)^2} - \frac{(\mu+1)(\mu+1-2x)}{2(\mu+1-x)^3}\log\left(\frac{\mu+1}{\mu+1-2x}\right)\right]$$

FSR : model independent

The energy spectrum

- We can see characteristic signal only if FSR $\ll$ VIB
- chiral suppression
- $e^\pm$ emission is suppressed.



arXiv:1203.1312

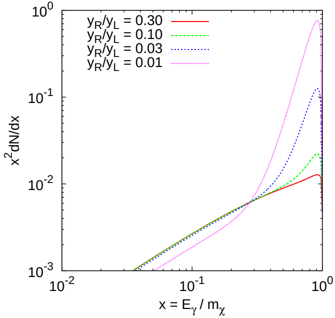
We add right-handed Yukawa to get s-wave for 2-body process.

$$\mathcal{L} = y_L \eta^+ \overline{\chi} P_L f + y_R \eta^+ \overline{\chi} P_R f + \mathrm{h.c.} \quad \text{for Majorana DM}$$

(We can also consider scalar DM case.)

$$\sigma v_{f\overline{f}} \approx \frac{y_L^2 y_R^2}{8\pi m_\chi^2} \frac{1}{(1+\mu)^2} + \cdots$$

$$\sigma v_{f\overline{f}\gamma} \approx \sigma v_{f\overline{f}\gamma} \left(y^4 \to y_L^4 + y_R^4\right) + y_L^2 y_R^2 \text{ terms}$$



- $y_R \to 0$, only gamma line can be seen.
- $y_R \approx y_L$, only $e^\pm$ source can be obtained.
- $y_R \ll y_L$, gamma line and $e^\pm$ source may be obtained.

Gamma-ray Flux

- Gamma-ray Background

$$\frac{d\Phi_\gamma^{\rm bkg}}{dE_\gamma} = 2.4 \times 10^{-5} E_\gamma^{-2.55}\ [\mathrm{GeV^{-1}cm^{-2}s^{-1}sr^{-1}}]$$

- DM source

$$\frac{d\Phi_\gamma^{\rm DM}}{dE_\gamma} = \eta \frac{r_\odot}{8\pi}\frac{\rho_\odot^2}{m_\chi^2}\overline{J}\langle\sigma v_\gamma\rangle\frac{dN_\gamma}{dE_\gamma}$$

η : symmetry factor, $\overline{J}$: integral of $\rho(r)$ in target region

· Parameter setting

DM profile : generalized NFW profile $\rho(r)$ with $\alpha = 1.15$

Normalization : $\rho_\odot = 0.4\ \mathrm{GeV/cm^3}$, $r_\odot = 8.5\ \mathrm{kpc}$

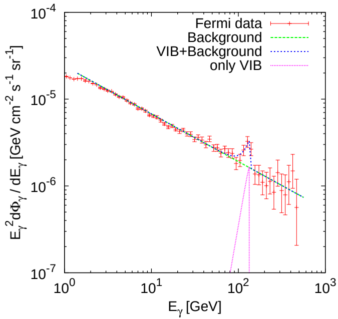
target region : $|\ell| \lesssim 10^\circ$, $|b| \lesssim 15^\circ$

Fitting to Fermi gamma-ray

53 data are used in higher energy region.

$$m_\chi = 155\ \mathrm{GeV}, \quad \mu = 1.02, \quad y_L = 1.29, \quad \chi^2_{\mathrm{Fermi}} = 63.7\ (50)$$

for Majorana DM



- Mass degeneracy between χ and η is needed.
  $\mu = 1.02 \leftrightarrow$ degeneracy $\approx 1\%$
- Thermal production of DM is too small for Majorana DM.
- But it could be consistent for scalar DM.

Electron and Positron Flux

- $e^{\pm}$ Background

$$\frac{d\Phi_{e^+}^{\rm bkg}}{dE} = 2.17 \times 10^{-3} E^{-3.80}, \qquad \frac{d\Phi_{e^-}^{\rm bkg}}{dE} = 2.38 \times 10^{-2} E^{-3.17}$$

with the unit $[\mathrm{GeV}^{-1}\mathrm{cm}^{-2}\mathrm{s}^{-1}\mathrm{sr}^{-1}]$

- Unknown source

$$\frac{d\Phi_{e^+}^{\rm s}}{dE} = C_s E^{-\gamma_s} e^{-E/E_s}$$

Three parameters : C_s, γ_s, E_s

- DM source

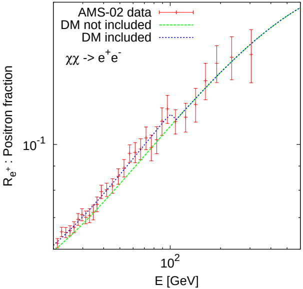
$$\frac{d\Phi_{e^\pm}^{\rm DM}}{dE} = \frac{v_{e^\pm}}{4\pi b(E)} \frac{\rho_\odot^2}{2m_\chi^2} \langle \sigma v \rangle \int_E^{m_\chi} \frac{dN_{e^\pm}}{dE_s} \mathcal{I}(E, E_s) dE_s$$

Fitting to AMS-02

Fitting parameters

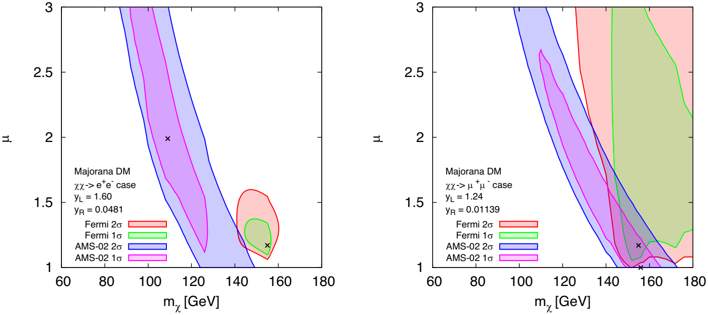
	m_χ [GeV]	$\langle \sigma v \rangle$ [cm^3/s]	$\chi^2_{\rm AMS}$
e^+e^-	109	2.5×10^{-26}	9.54/26
$\mu^+\mu^-$	156	9.5×10^{-26}	11.25/26

C_s, γ_s, E_s are also fixed.
No DM case : $\chi^2_{\rm AMS} = 11.56/28$
(data over 20 GeV are used.)



- We can obtain a better fitting for $e^\pm$ case than no DM contribution, but not for $\mu^\pm$.
- Unknown source is dominant, and DM is subdominant source in high energy region.
  $\rightarrow$ the required cross sections are not so large.

Fitting to both Fermi and AMS



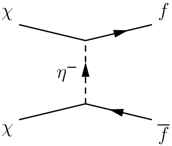
- $e^{\pm}$ case gives a better fitting than $\mu^{\pm}$ case for Fermi. But the required masses are different.
- For $\mu^{\pm}$, the required masses are almost same. But fitting for Fermi is not good.
- sizable FSR contribution for $\mu^{\pm}$ case

$$\frac{\mathrm{FSR}_{\mu}}{\mathrm{FSR}_{e}} = \frac{\langle \sigma v_{\mu^+\mu^-} \rangle}{\langle \sigma v_{e^+e^-} \rangle} \frac{\log(2m_\chi/m_\mu)}{\log(2m_\chi/m_e)} \approx 2.37$$

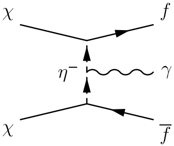
Summary

- We investigated a relation between Gamma-ray and $e^{\pm}$ fluxes by introducing left and right handed Yukawa couplings.

$e^{\pm}$ flux:



γ-ray flux :



- For $e^{+}e^{-}$ case, better fitting is obtained for Fermi and AMS. But the required masses are different.
- For $\mu^{+}\mu^{-}$ case, fitting is not good. But the requried masses are close.
- It is difficult to be consistent with the thermal DM relic density. (Especially for Majorana DM $\rightarrow$ Non-thermal production) Scalar DM could be consistent.

Thank you for your attention!