Virtual Internal Bremsstrahlung of Dark Matter and Connection with AMS-02 Result

Takashi Toma

Durham Univeristy
Institute for Particle Physics Phenomenology

TAUP2013 Asilomar California USA
8th-13th September 2013

Based on PRL 111 091301 (2013) and 1309.XXXX

In Collaboration with C. Boehm and S. Pascoli (Durahm University)

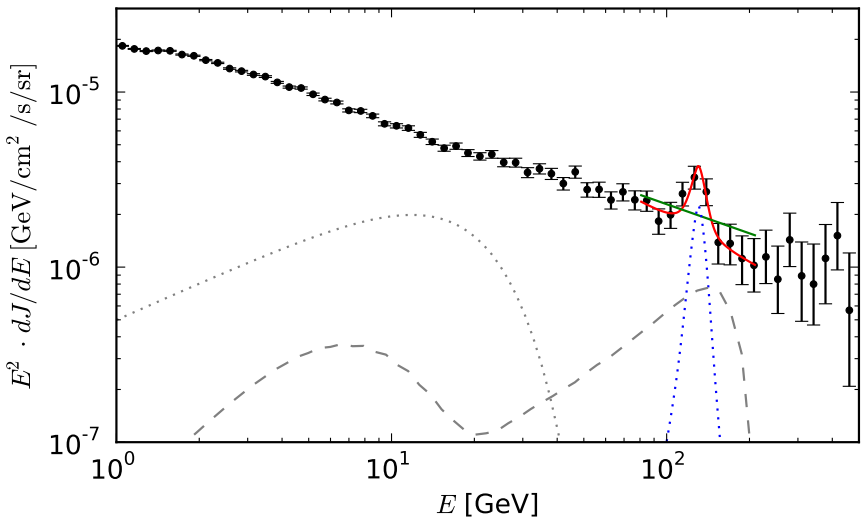
Outline

1. Introduction
2. Strong gamma-ray signature from Dark Matter
   · Internal Bremsstrahlung
3. Gamma-ray and positron fraction observed by AMS-02
4. Summary

Indirect detection of Dark Matter

· $e^{\pm}$, γ-ray, neutrinos may be produced by annihilation or decay of DM.

· γ-ray



arXiv:1210.3013, 1203.1312

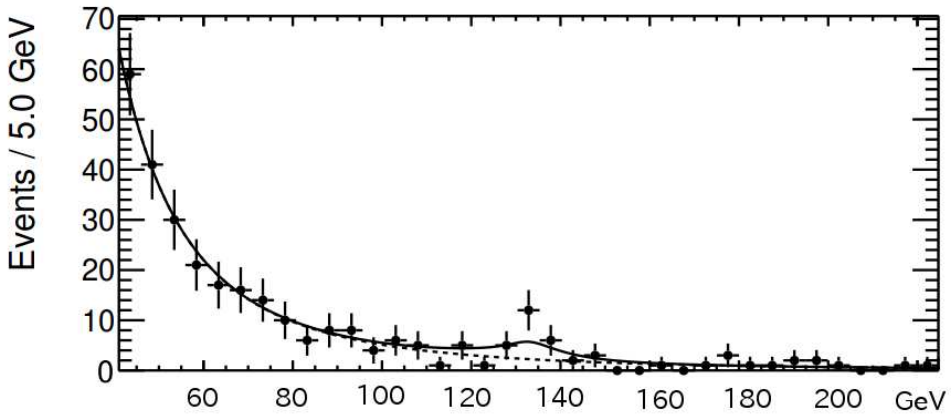
· γ-ray excess around 130 GeV

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

thermal DM $\leftrightarrow 10^{-26}\ \mathrm{cm}^3/\mathrm{s}$

· Fermi Collaboration

Significance is 1.6 σ at 133 GeV.



arXiv: 1305.5597

· we need high statistics and high resolution.

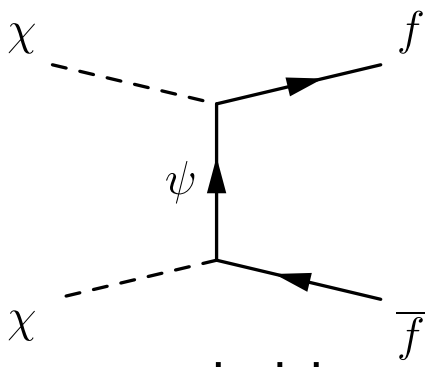
Can we obtain such a strong γ-ray signal from DM annihilation?

Internal Bremsstrahlung of real scalar DM

The strong gamma-ray signal from DM annihilation

Consider a real scalar DM χ

$$\mathcal{L} = y\chi\overline{\psi}P_L f + \text{h.c.}$$



- The cross section of $\chi\chi \to f\overline{f}$ is expanded by v. $\sigma v_{f\overline{f}} \approx a + bv^2$

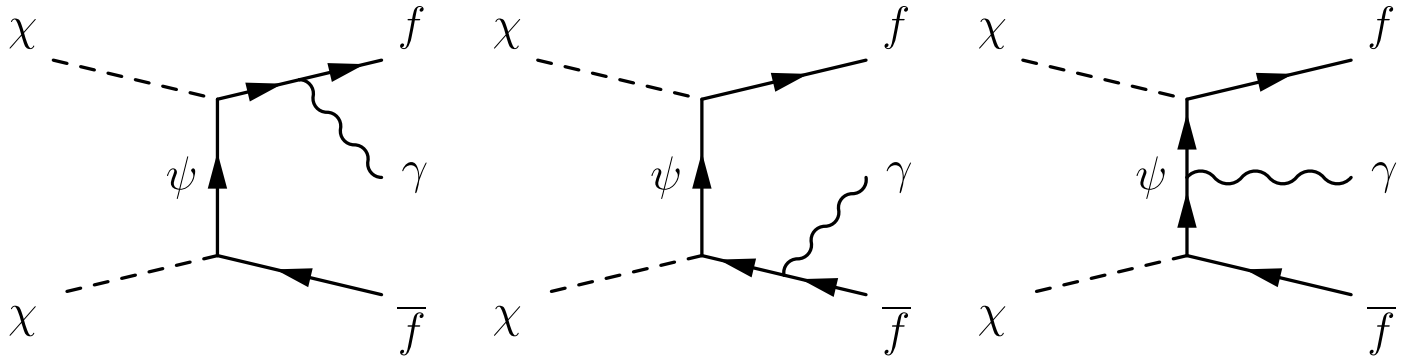
$$\sigma v_{f\overline{f}} = \frac{y^4}{4\pi m_\chi^2}\frac{m_f^2}{m_\chi^2}\frac{1}{(1+\mu)^2} - \frac{y^4}{6\pi m_\chi^2}\frac{m_f^2}{m_\chi^2}\frac{1+2\mu}{(1+\mu)^4}v^2 + \frac{y^4}{60\pi m_\chi^2}\frac{1}{(1+\mu)^4}v^4 + \mathcal{O}(v^6), \qquad \mu \equiv \frac{m_\psi^2}{m_\chi^2}$$

· when $m_f \ll m_\chi$, s-wave and p-wave can be negligible.

$\to$ chiral suppression

· DM relic abundance is determined by d-wave.

- Internal Bremsstrahlung (radiative correction for $\chi\chi \to f\overline{f}$)



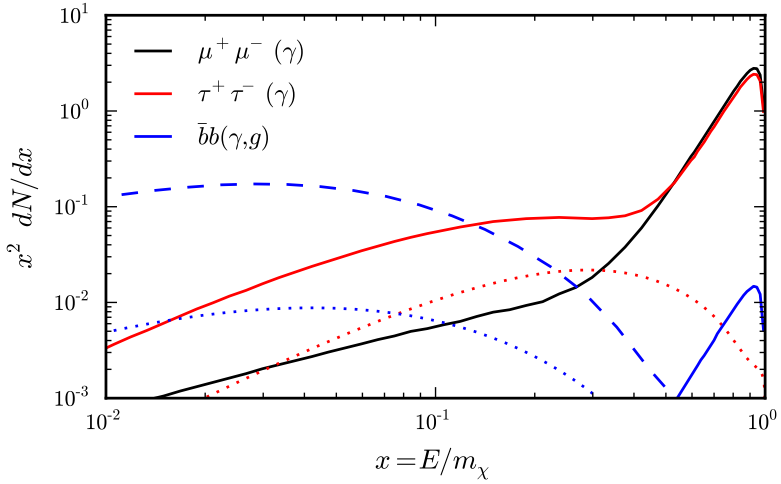
· differential cross section

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

(interference term is negligible)

FSR : broad energy spectrum
VIB : a sharp peak around $E_\gamma \sim m_\chi$

- if FSR $\ll$ VIB,
  a sharp peak can be seen.



arXiv:1203.1312

The concrete formula of differential cross section

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

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

FSR : model independent formula

The other DM candidates

2-body cross section $\sigma v_{f\bar{f}}$

	Majorana	Dirac	Real scalar	Complex scalar
dominant term	p-wave	s-wave	d-wave	p-wave

- Chiral suppression is the most effective for real scalar DM.
- Strong gamma-ray emission can be consistent with thermal DM.

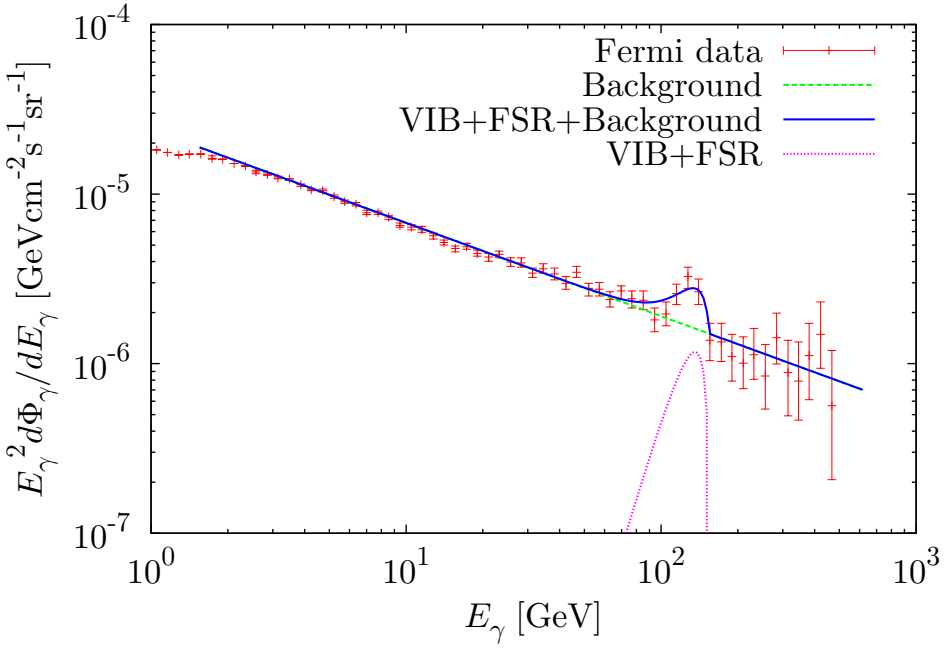
Fitting to Gamma-ray flux

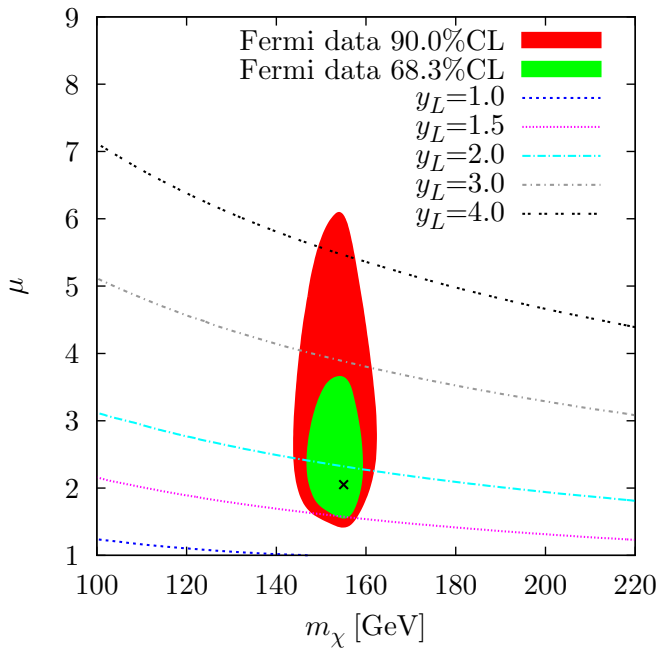
53 Fermi data points are used.

constraint from thermal relic density of DM : $\Omega h^2 = 0.12$

three parameters : m_χ, μ, y. $\rightarrow$ one of them is fixed by $\Omega h^2 = 0.12$
$\rightarrow$ the degree of freedom is 2.

$m_\chi = 155\ \mathrm{GeV},\ \mu = 2.05,\ y_L = 1.82,\ \rightarrow\ \langle \sigma v \rangle = 4.7 \times 10^{-27}\ \mathrm{cm}^3/\mathrm{s}$

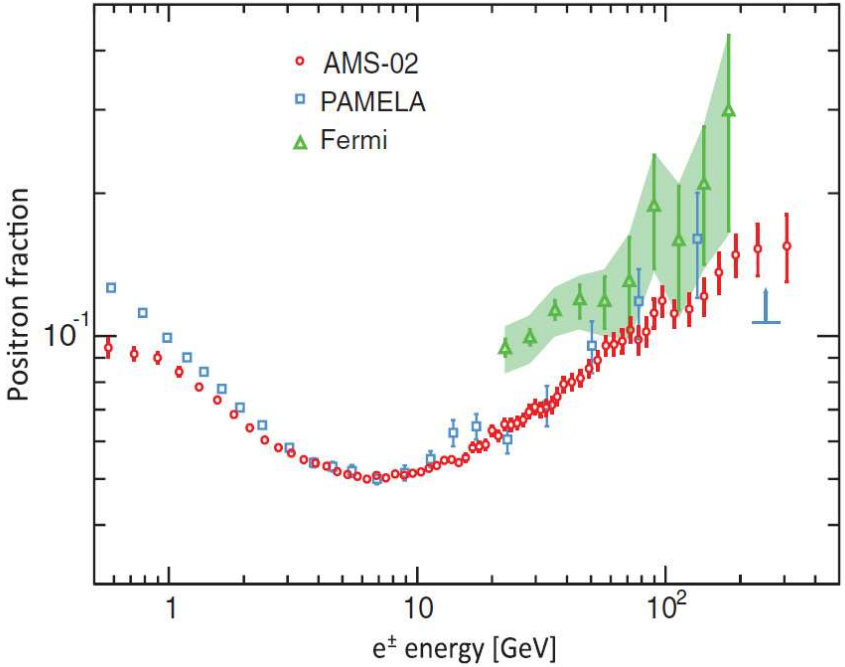




Positron excess of AMS-02

AMS-02 result

· Positron fraction



PRL 110 (2013) 14, 141102

· unkown source in high energy region ($E \gtrsim 10$ GeV)

· Astrophysics interpretation
$\rightarrow$ pulser

· Particle physics interpretation
$\rightarrow$ DM annihilation or decay
Large cross section required.
Leptophilic DM.

· We would like to connect gamma-ray and positron flux.
$(\chi\chi \rightarrow f\bar{f}\gamma)$ $(\chi\chi \rightarrow f\bar{f})$

But 2-body process was suppressed by chiral suppression.
$\rightarrow$ extention of interaction

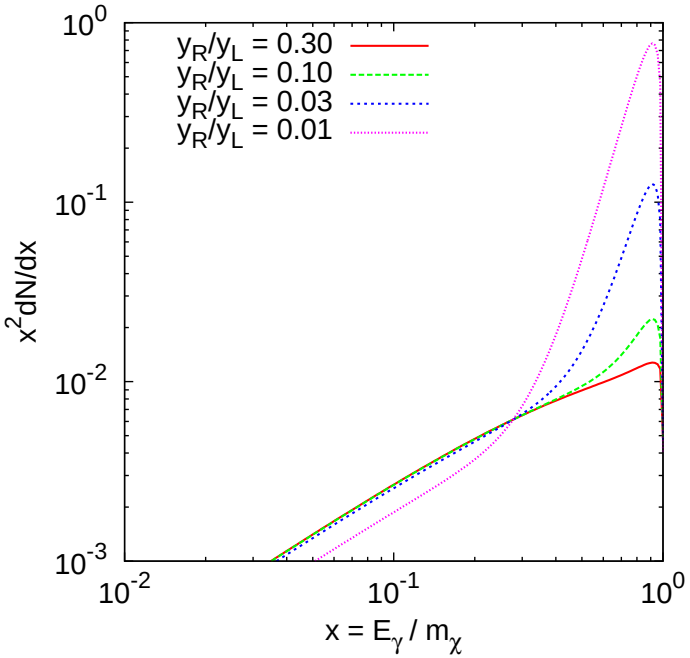
We add right-handed Yukawa to get s-wave for 2-body process.

$$\mathcal{L} = y_L \chi \overline{\psi} P_L f + y_R \chi \overline{\psi} P_R f + \mathrm{h.c.} \quad \text{for real scalar DM}$$

(fermion case can be also considered.)

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

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



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

Electron and Positron Flux

- $e^{\pm}$ Background

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

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

- DM source

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

- Unknown source

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

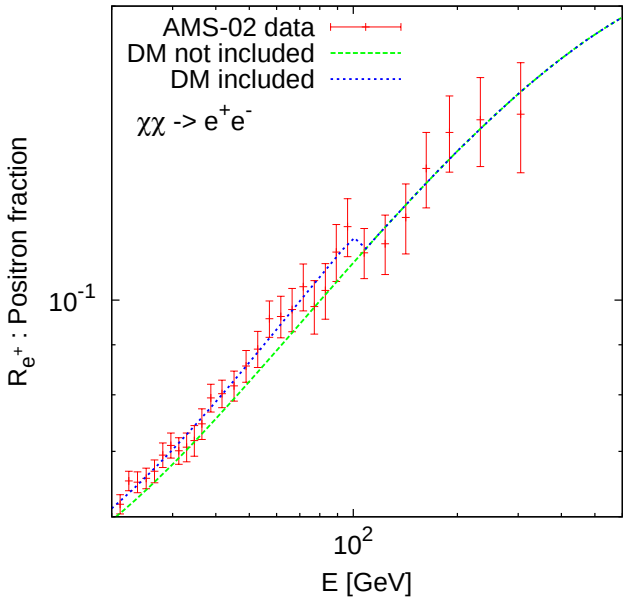
Three parameters : C_s, γ_s, E_s

Fitting to AMS-02

Fitting parameters

	m_χ [GeV]	$\langle\sigma v\rangle$ [cm^3/s]	χ^2_{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 : $\chi^2_{\mathrm{AMS}} = 11.56$ (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.

Summary

- Internal Bremsstrahlung of DM shows a sharp peak spectrum of gamma-ray.
- strong gamma-ray emmision can be consistent with thermal DM production for only real scalar DM.

- We investigated a relation between Gamma-ray and $e^{\pm}$ fluxes by introducing left and right handed Yukawa couplings.
- For e^+e^- case, better fitting is obtained for AMS. For $\mu^+\mu^-$ case, the required masses for gamma-ray and positron fraction are very close.

- Future work:
  Fitting to gamma-ray and positron fraction both at the same time is required.

Thank you for your attention!