

Virtual Internal Bremsstrahlung of Dark Matter

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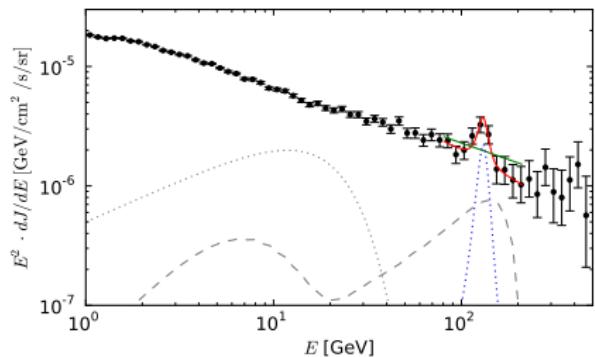
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Based on arXiv:1307.6181 accepted in PRL



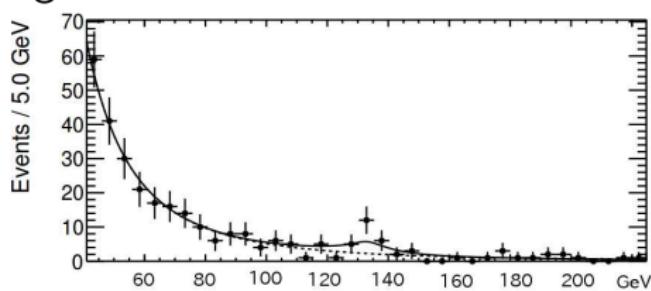
Indirect detection of DM

- e^\pm , γ -ray, neutrinos may be produced by annihilation or decay of DM.
- γ -ray flux
- But Fermi Co. is negative.
Significance is 1.6σ at 133 GeV.



[arXiv:1210.3013, 1203.1312](#)

- γ -ray excess around 130 GeV
- $\langle \sigma v \rangle \sim 10^{-27} \text{ cm}^3/\text{s}$
thermal DM $\leftrightarrow 10^{-26} \text{ cm}^3/\text{s}$



[arXiv: 1305.5597](#)

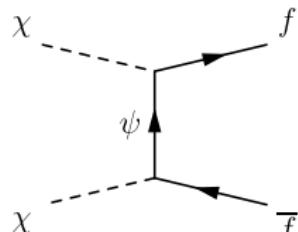
- we need higher resolution.
ex. GAMMA400
- $0.1 < E_\gamma < 3000 \text{ GeV}$
- $\Delta\theta/\theta \sim 0.01 \text{ deg}$
- $\Delta E/E \sim 1 \%$

Internal Bremsstrahlung of real scalar DM

The strongest gamma-ray signal from DM annihilation

Consider a real scalar DM χ

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



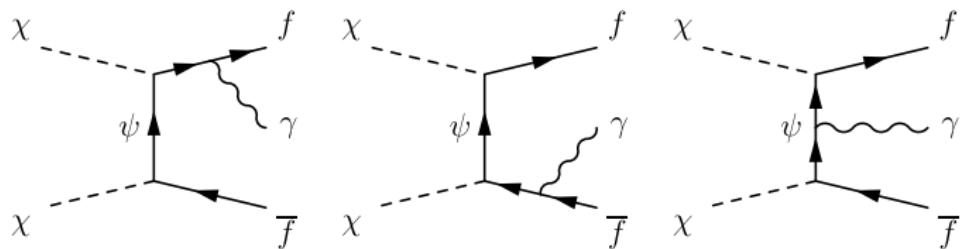
- The cross section of $\chi\chi \rightarrow f\bar{f}$ is expanded by v . $\sigma v_{f\bar{f}} \approx a + bv^2$

$$\sigma v_{f\bar{f}} = \frac{y^4}{4\pi m_\chi^2} \frac{m_f^2}{m_\chi^2} \frac{1}{(1+\mu)^2} - \frac{y^4}{6\pi m_\chi^2} \frac{m_f^2}{m_\chi^2} \frac{1+2\mu}{(1+\mu)^4} v^2$$

$$+ \frac{y^4}{60\pi m_\chi^2} \frac{1}{(1+\mu)^4} v^4 + \mathcal{O}(v^6), \quad \mu \equiv \frac{m_\psi^2}{m_\chi^2}$$

- when $m_f \ll m_\chi$, s-wave and p-wave can be negligible.
→ chiral suppression
- DM relic abundance is determined by d-wave.

■ Internal Bremsstrahlung (radiative correction for $\chi\chi \rightarrow f\bar{f}$)



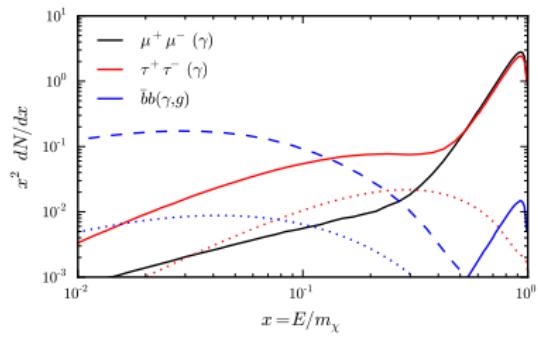
- differential cross section

$$\frac{d\sigma v_{f\bar{f}\gamma}}{dx} = \frac{d\sigma v_{f\bar{f}\gamma}^{\text{FSR}}}{dx} + \frac{d\sigma v_{f\bar{f}\gamma}^{\text{VIB}}}{dx}, \quad x \equiv \frac{E_\gamma}{m_\chi}, \quad (\text{interference term is negligible})$$

FSR : broad energy spectrum

VIB : a sharp peak around $E_\gamma \sim m_\chi$

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



The concrete formula of differential cross section

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

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

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.

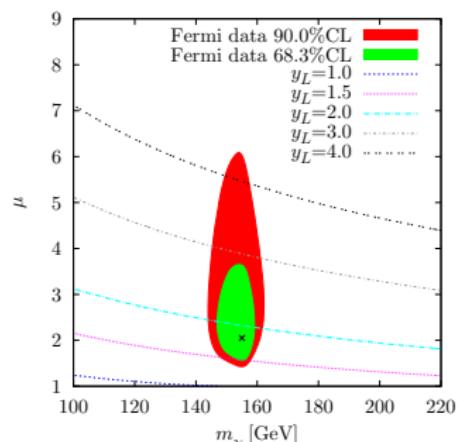
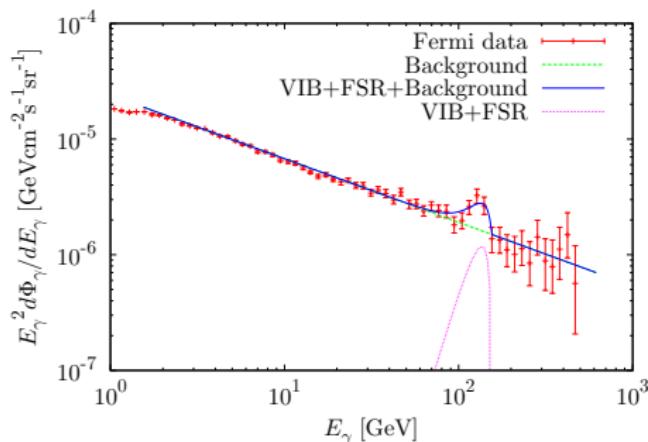
Fitting to Gamma-ray flux

53 Fermi data points are used.

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

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

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



Constraint from Anomalous Magnetic Moment Experiments

$$\delta a_e = a_e(\text{SM}) - a_e(\text{exp}) = 1.06 \times 10^{-12}$$

$$\delta a_\mu = a_\mu(\text{SM}) - a_\mu(\text{exp}) = 25.5 \times 10^{-10}$$

From Yukawa interaction

$$\delta a_f = \frac{y^2}{(4\pi)^2} \frac{m_f^2}{m_\chi^2} \frac{2 + 3\mu - 6\mu^2 + \mu^3 + 6\mu \log \mu}{6(1 - \mu)^4}$$

using the fitting parameters

$$\delta a_e = 9.4 \times 10^{-15}, \quad \delta a_\mu = 4.0 \times 10^{-10}$$

→ satisfy the constraint.

But, if we have the Yukawa interaction with different flavor at the same time, LFV such as $\mu \rightarrow e\gamma$ gives a strong constraint.

Summary

- Internal Bremsstrahlung of DM shows a sharp peak spectrum of gamma-ray.
- s-wave should be suppressed in order to see the signature.
- In the case of real scalar DM, the annihilation cross section is dominated by d-wave.
→ strong gamma-ray emission can be consistent with thermal DM production.
- A strong constraint would be obtained from LFV.