Generic dark matter signature for gamma-ray telescopes

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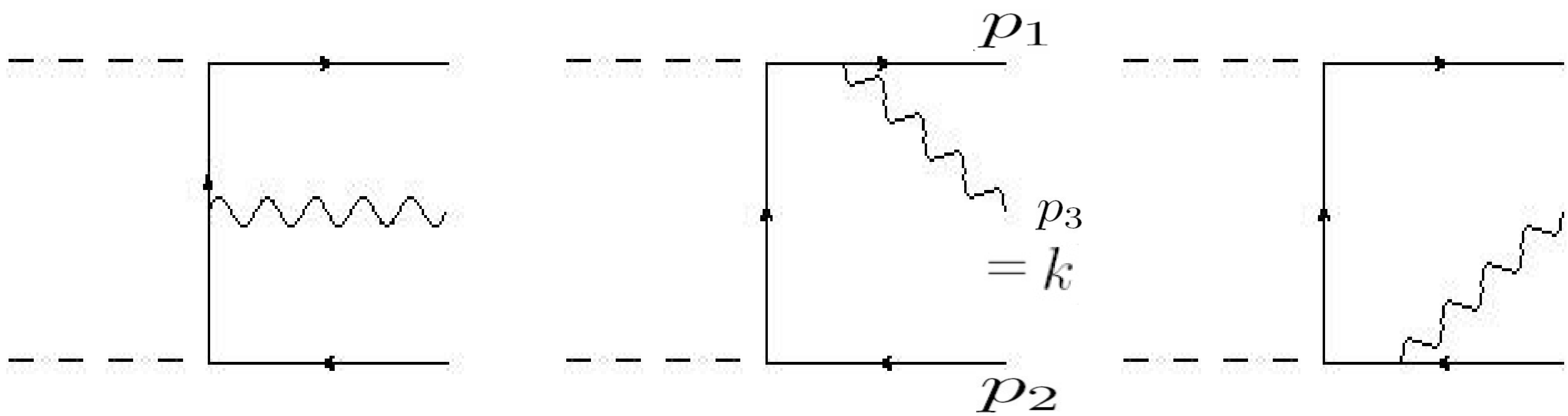
Flores, Olive, Rudaz PLB (1989)
Bringmann, Bergstrom, Edsjo, arXiv: 0710.3169

$$\phi + \phi \to e(p_1) + \bar{e}(p_2) + \gamma(p_3)$$



$\ell^T = (\nu, e^-)_L$ $\qquad L^T_{L,R} = (N^0, E^-)_{L,R}$ $\qquad \mathcal{L} \supset y\overline{\ell_L} L_R \phi$

$$\mathcal{M}_1 = \frac{y^2 \bar{u}_L(p_1) e \gamma_\mu (\not{p}_1 + \not{k})[\frac{1}{2}(\not{p}_1 - \not{p}_2 + \not{k}) + m_E] v_L(p_2)}{(p_1 + k)^2 [\frac{1}{2^2}(p_1 - p_2 + k)^2 - m_E^2]} \times 2$$

$$\phi + \phi \to e(p_1) + \bar{e}(p_2) + \gamma(p_3)$$

$$\mathcal{M}_1 = \frac{y^2 \bar{u}_L(p_1) e\gamma_\mu (\not{p}_1 + \not{k})[\frac{1}{2}(\not{p}_1 - \not{p}_2 + \not{k}) + m_E] v_L(p_2)}{(p_1+k)^2[\frac{1}{2^2}(p_1 - p_2 + k)^2 - m_E^2]} \times 2$$

$$\mathcal{M}_2 = \frac{y^2 \bar{u}_L(p_1)[\frac{1}{2}(\not{p}_1 - \not{p}_2 - \not{k}) + m_E](-\not{p}_2 - \not{k}) e\gamma_\mu v_L(p_2)}{[\frac{1}{2^2}(p_1 - p_2 - k)^2 - m_E^2](p_2+k)^2} \times 2$$

$$\mathcal{M}_3 = \frac{y^2 \bar{u}_L(p_1)[\frac{1}{2}(\not{p}_1 - \not{p}_2 - \not{k}) + m_E] e\gamma_\mu [\frac{1}{2}(\not{p}_1 - \not{p}_2 + \not{k}) + m_E] v_L(p_2)}{[\frac{1}{2^2}(p_1 - p_2 - k)^2 - m_E^2][\frac{1}{2^2}(p_1 - p_2 + k)^2 - m_E^2]} \times 2$$

$$\not{p}_2 \gamma_\mu \not{p}_1 = -2(p_1 \cdot p_2)\gamma_\mu$$

$$\mathcal{M} = -2 \times \frac{4y^2 e \bar{u}_L(p_1)(\not{p}_2 \gamma_\mu \not{k} + \not{k} \gamma_\mu \not{p}_1) v_L(p_2)}{[(p_1 - p_2 + k)^2 - 4m_E^2][(p_1 - p_2 - k)^2 - 4m_E^2]} \,.$$

$$-\mathrm{Tr}(\not{p}_1 \not{p}_2 \gamma_\mu \not{k} \not{p}_2 \not{k} \gamma^\mu \not{p}_2) = 4(2p_2 \cdot k)^2(2p_1 \cdot p_2)$$

$$v_{\mathrm{rel}} \frac{d\sigma}{dx_3 dx_1} = \frac{1}{4\pi^3} \frac{(y^2 e)^2}{m_\phi^2} \frac{[(1-x_1)^2 + (1-x_2)^2](1-x_3)}{(1-2x_1-r)^2(1-2x_2-r)^2}$$

$$r = m_E^2/m_\phi^2 \quad x_i = E_i/m_\phi \quad x_1 + x_2 + x_3 = 2$$

$$z = x_3$$

$$v_{\mathrm{rel}} \frac{d\sigma}{dz} = \frac{(y^2 e)^2/m_\phi^2}{32\pi^3} \frac{1-z}{(1+r-z)^2} \left(2z \frac{z^2 + (1+r-z)^2}{(1+r)(1+r-2z)} - \frac{(1+r)(1+r-2z)}{1+r-z} \ln \frac{1+r}{1+r-2z} \right)$$

$$\frac{e}{\Lambda_L^3}\Phi F^{\mu\nu}\partial_\nu(\bar{\psi}_{eL}\gamma_\mu\psi_{eL})$$

$$\mathcal{M} = \frac{e}{\Lambda_L^3}(k^\mu\epsilon^\nu - k^\nu\epsilon^\mu)(p_1+p_2)_\nu\bar{u}_L(p_1)\gamma_\mu v_L(p_2)$$

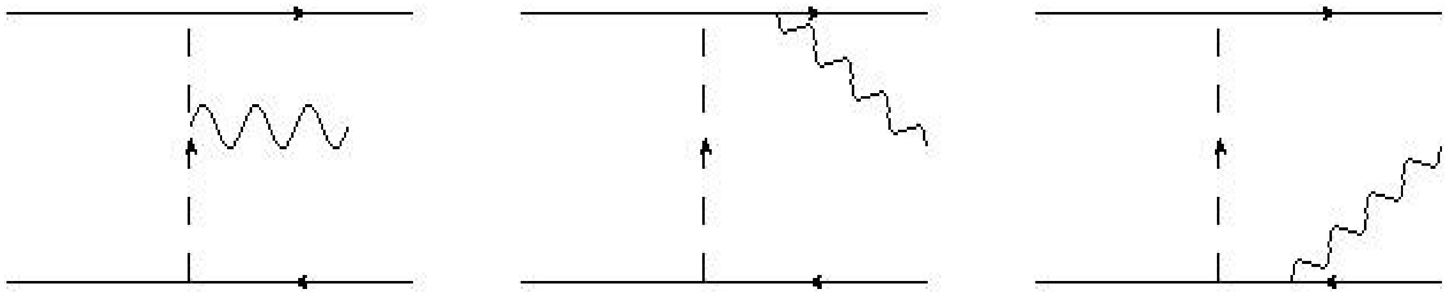
$$\mathcal{M} = \frac{e}{2\Lambda_L^3}\bar{u}_L(p_1)(\not{p}_2 \not{\epsilon} \not{k} + \not{k} \not{\epsilon} \not{p}_1)v_L(p_2)$$

$$\sum|\mathcal{M}|^2 = \left(\frac{e}{2\Lambda_L^3}\right)^2 2[(2p_1\cdot p_2)(2p_1\cdot k)^2 + (2p_1\cdot p_2)(2p_2\cdot k)^2]$$

$$2p_1\cdot p_2 = M_\Phi^2(1-x_3),\ 2k\cdot p_1 = M_\Phi^2(1-x_2),\ 2k\cdot p_2 = M_\Phi^2(1-x_1)$$

$$\frac{1}{\Gamma}\frac{d\Gamma}{dx_3} = 20(1-x_3)x_3^3 \qquad \frac{1}{\Gamma}\frac{d\Gamma}{dx_2} = 15x_2^2 - 30x_2^3 + \frac{35}{2}x_2^4$$

SUSY-like DM pair $\chi\chi \to \ell\bar{\ell}\gamma$



$$i\mathcal{M}_{\rm tree} = (i)^5 e g^2_{L,R} T^c \bar{u}(p_1)\cdots[u(K/2)\bar{v}(K/2) - v(K/2)\bar{}(K/2)]\cdots v(p_2)$$

$$u(K/2)\bar{v}(K/2) - v(K/2)\bar{u}(K/2) = (m_\chi + \not{K}/2)\gamma_5$$

$$A_1 = \frac{\not{\epsilon}^* \frac{1}{\not{p}_1 + \not{k}} (\not{K}/2)\gamma_5}{(K/2 - p_2)^2 - \widetilde{M}^2} \longrightarrow \frac{\not{\epsilon}^* \gamma_5/2}{(K/2 - p_2)^2 - \widetilde{M}^2}$$

$$A_2 = \frac{(\not{K}/2)\gamma_5 \frac{1}{-\not{p}_2 - \not{k}}\ \not{\epsilon}^*}{(-K/2 + p_1)^2 - \widetilde{M}^2} \longrightarrow -\frac{\not{\epsilon}^* \gamma_5/2}{(-K/2 + p_1)^2 - \widetilde{M}^2}$$

$$A_3 = \frac{\not{K}\gamma_5/2 \quad (p_1 - p_2)\cdot\epsilon^*}{[(-K/2 + p_1)^2 - \widetilde{M}^2][(K/2 - p_2)^2 - \widetilde{M}^2]}$$

$$A = \frac{1}{2}\frac{(p_2 - p_1)\cdot K \not{\epsilon}^{*} + \not{K}(p_1 - p_2)\cdot \epsilon^{*}}{[(-K/2 + p_1)^2 - \widetilde{M}^2][(K/2 - p_2)^2 - \widetilde{M}^2]}\gamma_5$$

$$\mathcal{M}_{\rm tree} = \frac{1}{2} e g_{L,R}^2 \bar{u}(p_1)\frac{(p_2 - p_1)\cdot k \not{\epsilon}^{*} + \not{k}(p_1 - p_2)\cdot \epsilon^{*}}{[(-K/2 + p_1)^2 - \widetilde{M}^2][(K/2 - p_2)^2 - \widetilde{M}^2]}\gamma_5 v(p_2)$$

$$\bar{u}(p_1)(p_2\cdot k \not{\epsilon}^{*} - \not{k} p_2\cdot \epsilon^{*})v(p_2) = -\tfrac{1}{2}\bar{u}(p_1) \not{p}_2 \not{\epsilon}^{*} \not{k} v(p_2)$$

$$\bar{u}(p_1)(p_1\cdot k \not{\epsilon}^{*} - \not{k} p_1\cdot \epsilon^{*})v(p_2) = -\tfrac{1}{2}\bar{u}(p_1) \not{k} \not{\epsilon}^{*} \not{p}_1 v(p_2)$$

$$\mathcal{M}_{\rm tree} = \frac{1}{4} e g_{L,R}^2 \bar{u}(p_1)\frac{\not{k} \not{\epsilon}^{*} \not{p}_1 - \not{p}_2 \not{\epsilon}^{*} \not{k}}{[(-K/2 + p_1)^2 - \widetilde{M}^2][(K/2 - p_2)^2 - \widetilde{M}^2]}\gamma_5 v(p_2)$$

Two effective operators

$$\bar{u}(p_1)\ \not{p}_2\ \not{\epsilon}^*\ \not{k} v(p_2) = \bar{u}_1(2p_2\cdot\epsilon^*\ \not{k} - 2p_2\cdot k\ \not{\epsilon}^*)v(p_2) \longleftarrow 2\mathcal{O} \qquad \mathcal{O} = F^{\mu\nu}\bar{\psi}\gamma_\nu\partial_\mu\psi$$

$$\bar{u}(p_1)\ \not{k}\ \not{\epsilon}^*\ \not{p}_1 v(p_2) = \bar{u}_1(2p_1\cdot\epsilon^*\ \not{k} - 2p_1\cdot k\ \not{\epsilon}^*)v_2 \longleftarrow 2\mathcal{O}^\dagger \qquad \mathcal{O}^\dagger = F^{\mu\nu}(\partial_\mu\bar{\psi})\gamma_\nu\psi$$

Chisholm identity $\gamma^\alpha\gamma^\beta\gamma^\mu = g^{\alpha\beta}\gamma^\mu - g^{\alpha\mu}\gamma^\beta + g^{\beta\mu}\gamma^\alpha - i\epsilon^{\alpha\beta\mu\nu}\gamma_\nu\gamma_5$

$$\bar{u}(p_1)\ \not{p}_2\ \not{\epsilon}^*\ \not{k} v(p_2) = \bar{u}_1(p_2\cdot\epsilon^*\ \not{k} - p_2\cdot k\ \not{\epsilon}^* + \underbrace{k\cdot\epsilon^*\ \not{p}_2}_{\hookrightarrow 0} - i\epsilon^{p_2,\epsilon^*,k,\mu}\gamma_\mu\gamma_5)v(p_2)$$

$$\bar{u}(p_1)\ \not{p}_2\ \not{\epsilon}^*\ \not{k} v(p_2) = -2i\epsilon^{p2,\epsilon^*,k,\mu}\bar{u}(p_1)\gamma_\mu\gamma_5 v(p_2)$$

$$\bar{u}(p_1)\ \not{k}\ \not{\epsilon}^*\ \not{p}_1 v(p_2) = +2i\epsilon^{p1,\epsilon^*,k,\mu}\bar{u}(p_1)\gamma_\mu\gamma_5 v(p_2)$$

$$\mathcal{O} = F^{\mu\nu}\bar{\psi}\gamma_\nu\partial_\mu\psi = -i\widetilde{F}^{\mu\nu}\bar{\psi}\gamma_\nu\gamma_5\partial_\mu\psi$$

$$\mathcal{O}^\dagger = F^{\mu\nu}(\partial_\mu\bar{\psi})\gamma_\nu\psi = i\widetilde{F}^{\mu\nu}(\partial_\mu\bar{\psi})\gamma_\nu\gamma_5\psi$$

$\widetilde{F}^{\mu\nu} = \frac{1}{2}\epsilon^{\mu\nu\alpha\beta}F_{\alpha\beta}$

dual substitution interchanges

$\mathbf{E} \leftrightarrow \mathbf{B}$

$$\mathcal{O} + \mathcal{O}^\dagger = F^{\mu\nu}\partial_\mu(\bar{\psi}\gamma_\nu\gamma_5\psi) \equiv \mathcal{F} \ ,$$

$$i(\mathcal{O} - \mathcal{O}^\dagger) = \widetilde{F}^{\mu\nu}\partial_\mu(\bar{\psi}\gamma_\nu\gamma_5\psi) \equiv \widetilde{\mathcal{F}}$$

LR-like model

non-linear Feynman gauge

$$\Gamma_{W'(q')_\lambda \to W(q)_\rho \gamma(k)_\mu} = e\left[g^{\lambda\rho}(q'+q)^\mu + g^{\rho\mu}(2k)^\lambda + g^{\lambda\mu}(-2k)^\rho\right]$$

$$\not{\epsilon}^*(\not{p}_1 + \not{p}_2)\not{k} - \not{k}\,(\not{p}_1 + \not{p}_2)\not{\epsilon}^*$$

$$\not{\epsilon}^*\not{p}_1\not{k} - \not{k}\not{p}_1\not{\epsilon}^* = +\not{k}\not{\epsilon}^*\not{p}_1$$

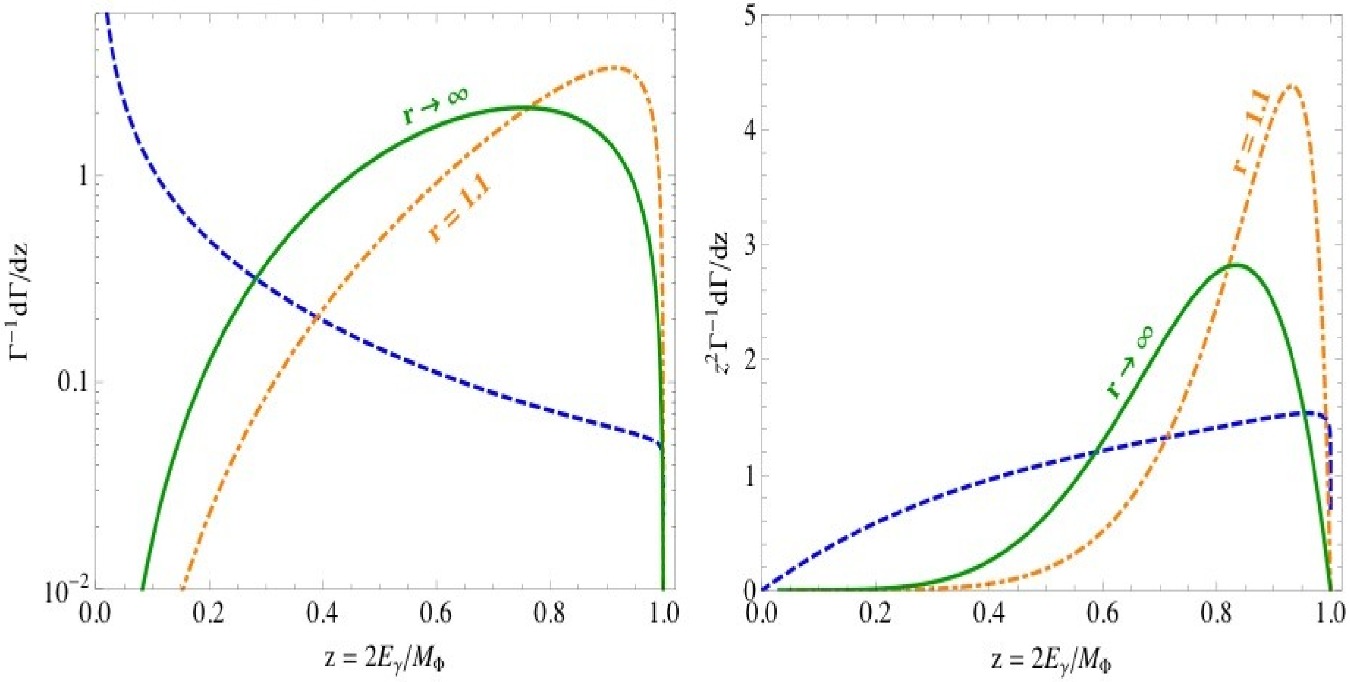
$$\not{\epsilon}^*\not{p}_2\not{k} - \not{k}\not{p}_2\not{\epsilon}^* = -\not{p}_2\not{\epsilon}^*\not{k}$$

$$-2 \quad +4 \quad + (m_N/m_{W'})^2$$

Model	1	2	3
DM	Majorana χ	Majorana N	Scalar ϕ
Exchange	Scalar S	Vector W'	Fermion E
Interaction $\mathcal{L}_I$	$g' S^\dagger \bar{\chi} e_R$	$g' W'^{\dagger}_{\mu} \bar{N} \gamma^\mu e_R$	$g' \bar{E} \phi e_R$

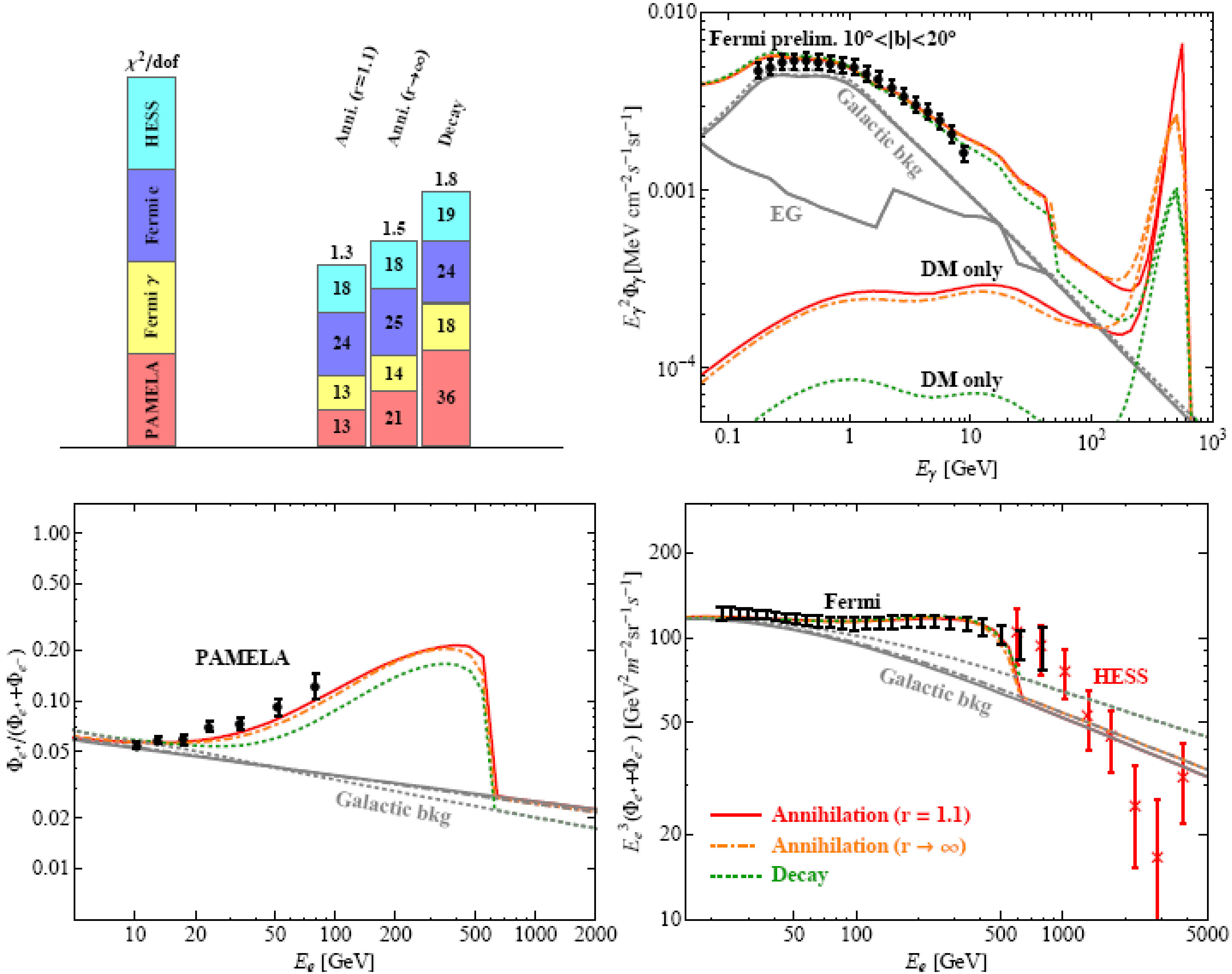
$$\mathcal{M} = -\frac{C}{2} \frac{g'^2 e \bar{u}_R(p_1)(\not{p}_2 \gamma_\mu \not{k} \mp \not{k} \gamma_\mu \not{p}_1) v_R(p_2)}{[\frac{1}{4}(p_1 - p_2 + k)^2 - m_X^2][\frac{1}{4}(p_1 - p_2 - k)^2 - m_X^2]}$$

$$C = \begin{cases} \frac{i}{\sqrt{2}} & \text{for Model 1,} \\ \frac{i}{\sqrt{2}}(2 + \frac{m_D^2}{m_X^2}) & \text{for Model 2,} \\ 1 & \text{for Model 3.} \end{cases}$$

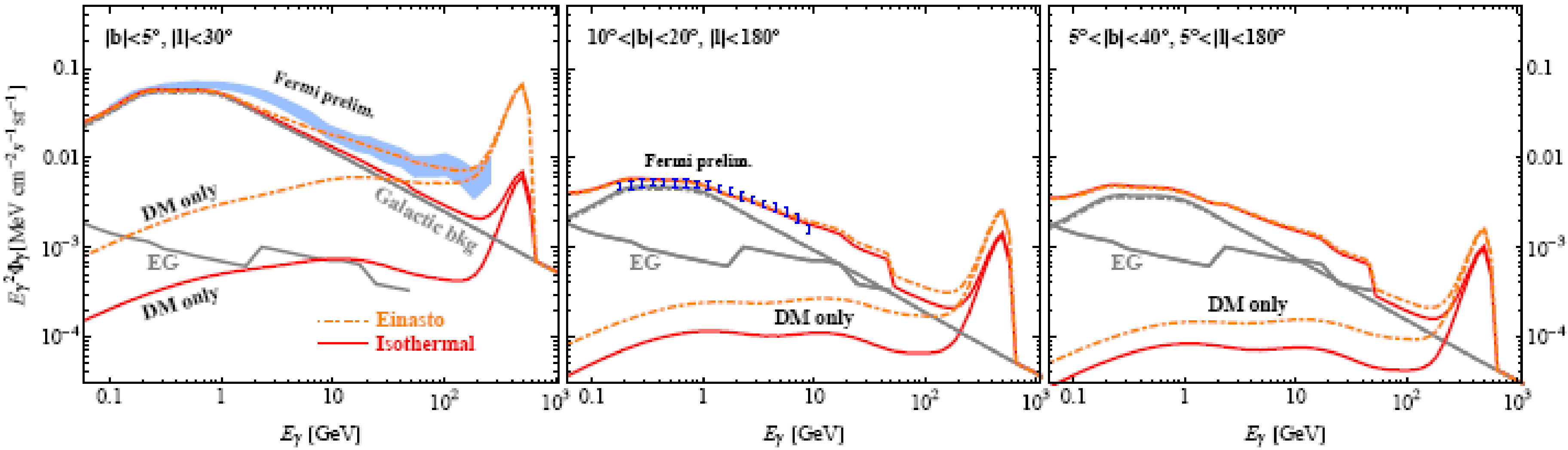


$$\frac{1}{\Gamma}\frac{d\Gamma}{dz} = 20(1-z)z^3\,,$$

$$\frac{1}{\Gamma}\frac{d\Gamma}{dx_2} = 5(3-6x_2+\tfrac{7}{2}x_2^2)x_2^2$$



χ²/dof
HESS
Fermi e
Fermi γ
PAMELA
Anni. (r=1.1)
Anni. (r→∞)
Decay
1.3
1.5
1.8
18
24
13
13
18
25
14
21
19
24
18
36
Fermi prelim. 10°<|b|<20°
Galactic bkg
EG
DM only
DM only
E_γ² Φ_γ [MeV cm⁻² s⁻¹ sr⁻¹]
E_γ [GeV]
PAMELA
Galactic bkg
Φ_e+/(Φ_e+ + Φ_e−)
E_e [GeV]
Fermi
HESS
Galactic bkg
E_e³(Φ_e+ + Φ_e−) [GeV² m⁻² sr⁻¹ s⁻¹]
E_e [GeV]
Annihilation (r = 1.1)
Annihilation (r → ∞)
Decay



CANGAROO	Collab. Of Austrialia and Nippon for a Gamma Ray Observatory in the Outback
MAGIC	Major Atmospheric Gamma-ray Imaging Cerenkov Telescope
CTA	Cerenkov Telescope Array
AGIS	Advanced Gamma Ray Imaging System
VERITAS	Very Energetic Radiation Imaging Telescope Array System

Summary

Unique form of photon/lepton energy spectrum for chirality preserving interaction

Prompt photon / lepton are good messenger of DM