Research of dark matter particle decays into positrons with suppression of FSR to explain positron anomaly

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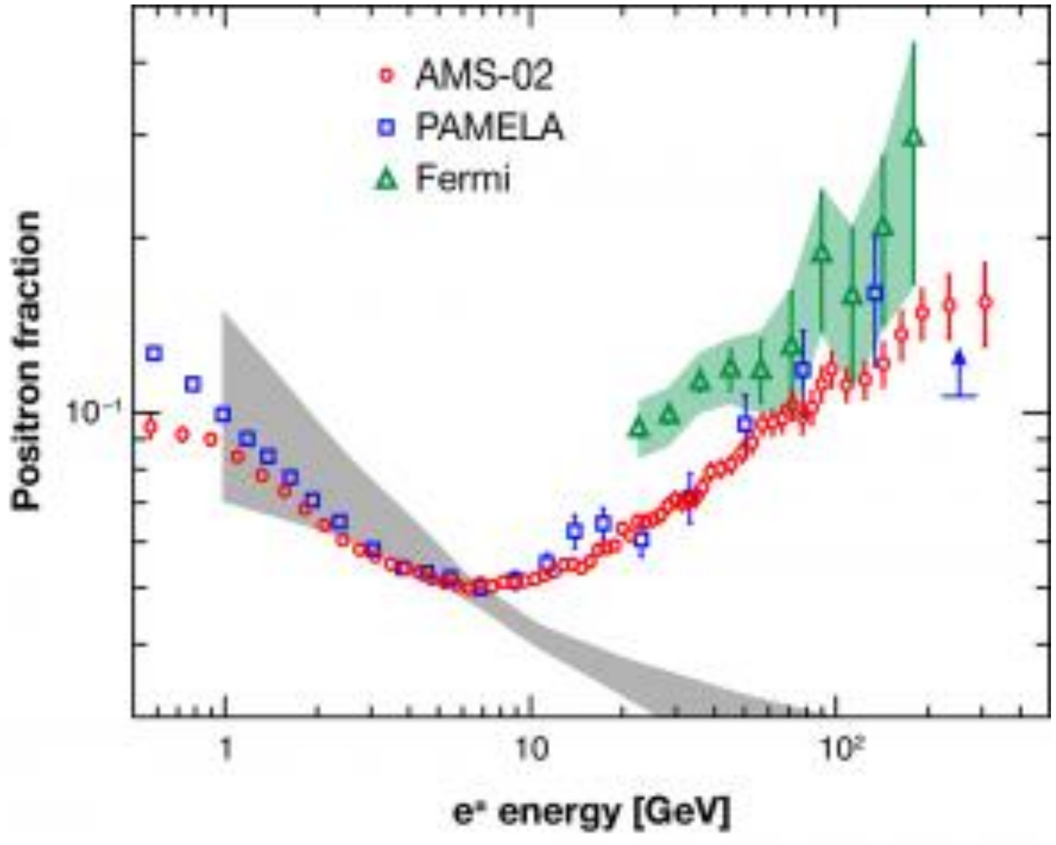
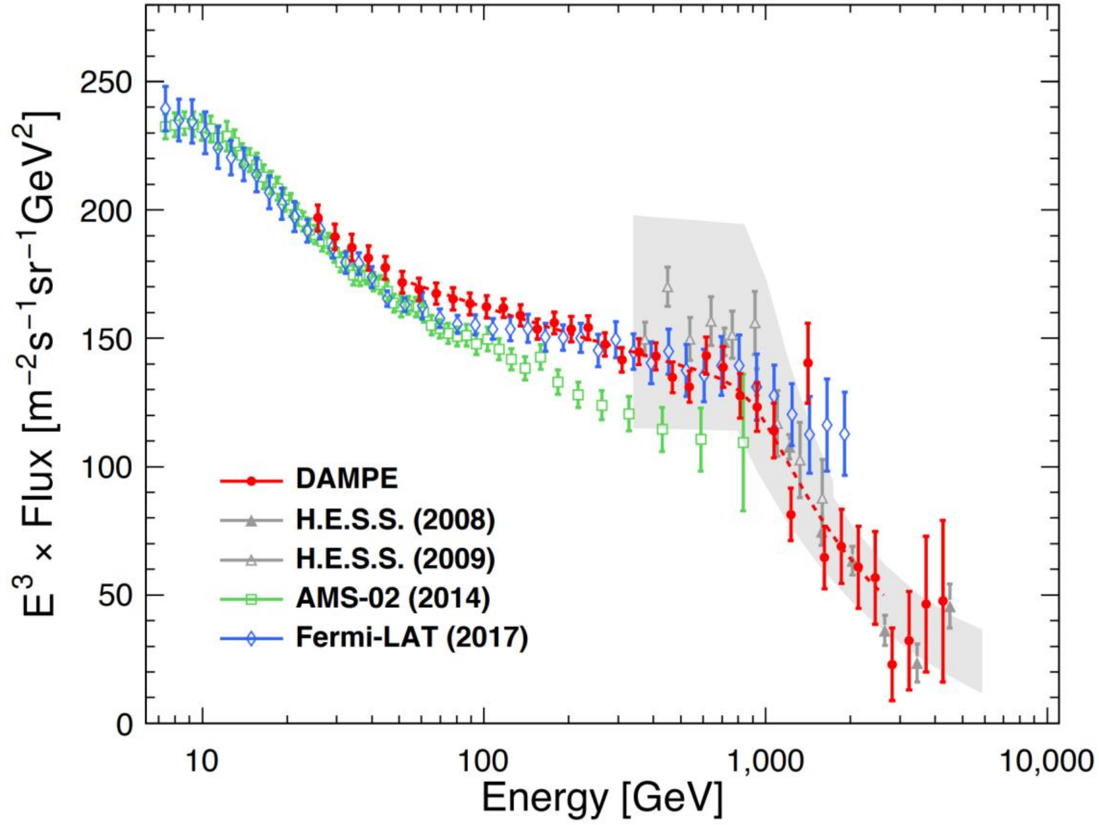
14.07.2025

Positron Anomaly

Anomalous amount of cosmic ray positrons of 10-1000 GeV. For the first time it was measured by PAMELA then confirmed by AMS-02 and Fermi

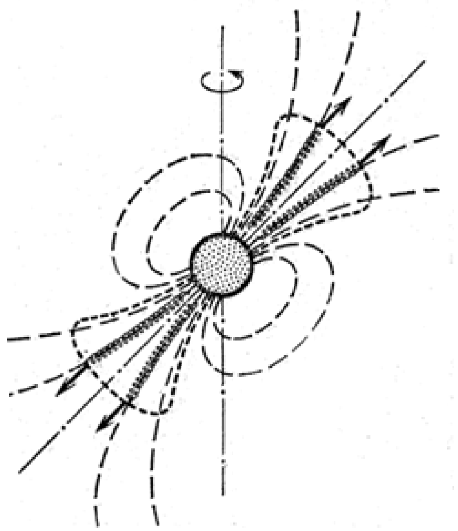


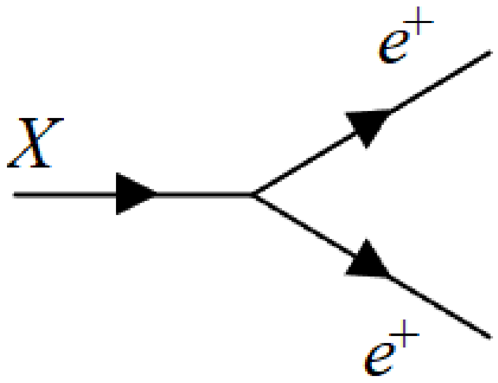


Positron Anomaly

Potential explanations of the positron anomaly:

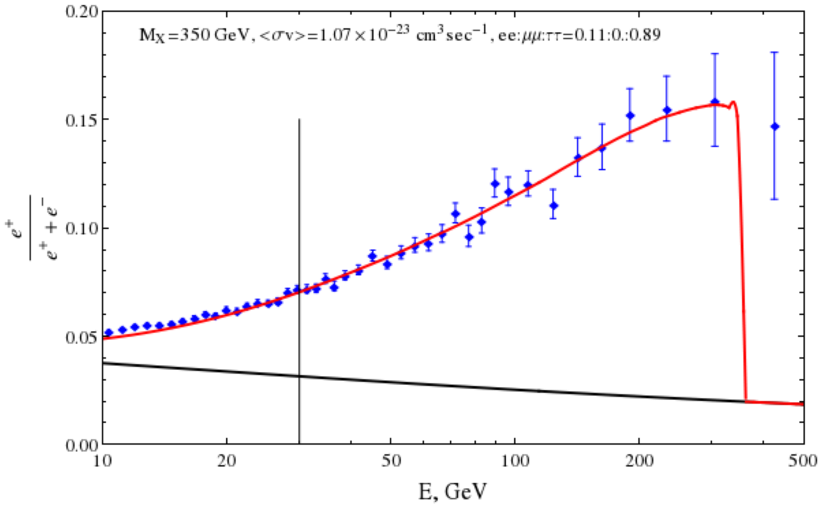
- Secondary positrons in case of modified diffusion models (two-halo scenario of diffusive propagation, inhomogeneous diffusion model)
- Pulsars with super-strong magnetic fields
- Dark matter decaying or annihilating into positrons particles in Galaxy

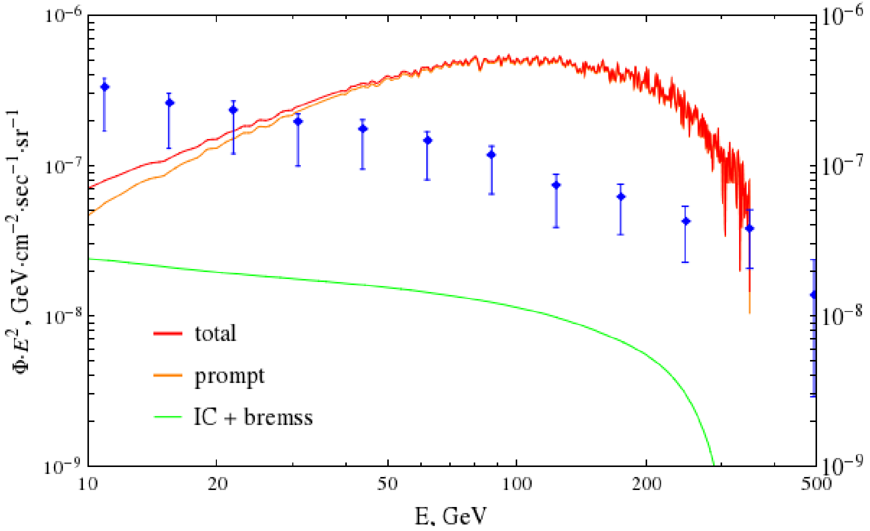


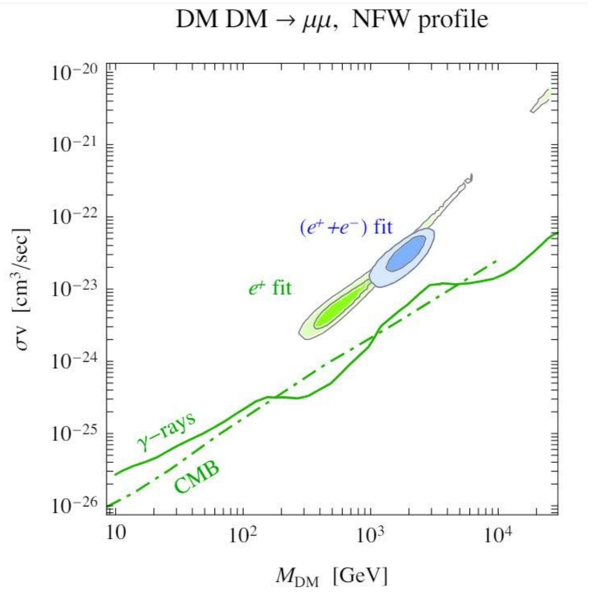


Positron Anomaly

Dark matter decays or annihilations produce gamma-ray (final state radiation). Existing models can explain positron spectrum but not gamma-ray spectrum in case of halo DM distribution model







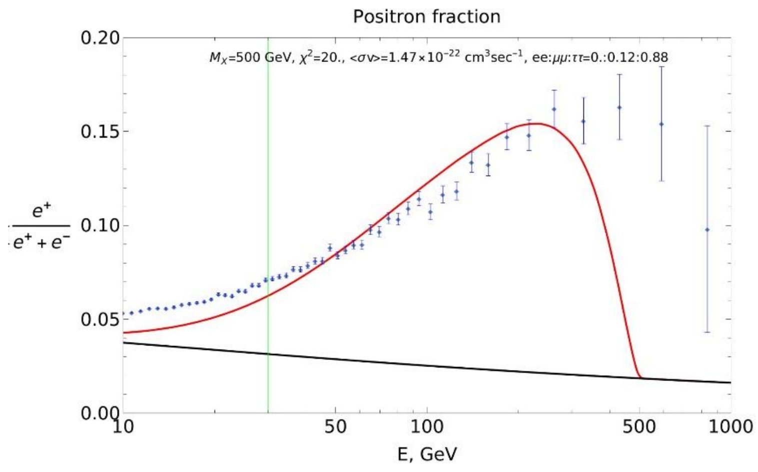
DM-Halo distribution model

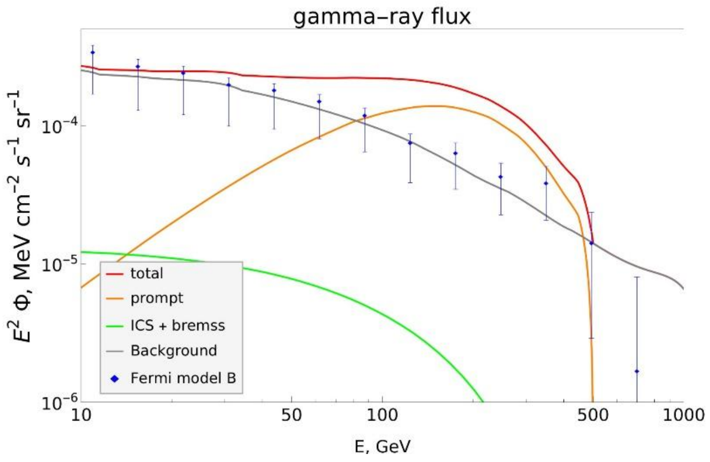
Possible Positron Anomaly Solutions with DM

Spatial distribution of DM component
(D. Kalashnikov's talk)

Physics of DM interaction (Lagrangian)
This talk

Suppression of final state radiation (FSR) which can be reached due to changing physical model of decay or annihilation





DM-Disk distribution model

Other Motivation of the search for FSR suppression

Classical case: dipole radiation vanishes when d=0 (**e+ e+**)

Quantum case: Single Photon Theorem

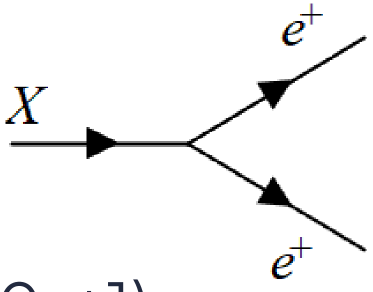
Considered Models

Mass of **X – 1000 GeV**. Mass of **Y – 0 GeV**.

Goal is to reduce gamma to positron ratio in final state

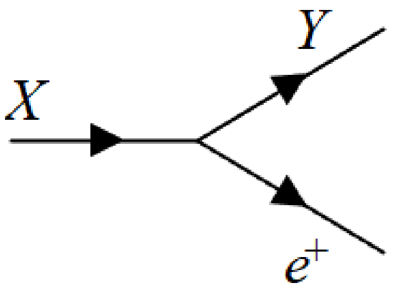
Dark matter particle **X** for decay **X -> e^+ + $e^\pm$**:

- scalar **boson X** (charge 0, +2);
- vector **boson X** (charge 0, +2).



Dark matter particle **X** and **Y** for decay **X -> e^+ + Y**:

- scalar **boson X** (charge 0, +1, +2), **fermion Y** (charge -1, 0, +1);
- vector **boson X** (charge 0, +1, +2), **fermion Y** (charge -1, 0, +1);
- **fermion X** (charge +1), scalar **boson Y** (charge 0);
- **fermion X** (charge +1), vector **boson Y** (charge 0).



Considered Models. Case 1

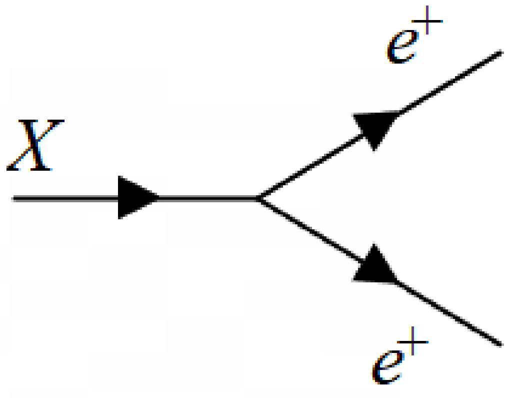
Case of boson X particle decay into electron and positron or 2 positrons

$$\mathcal{L}_{X^0S} = \frac{1}{2}\partial_\mu X \partial^\mu X - \frac{1}{2}M_X^2 X^2 - \lambda\overline{\psi}X\psi,$$

$$\mathcal{L}_{X^0V} = -\frac{1}{4}F_{\mu\nu}F^{\mu\nu} + \frac{1}{2}M_X^2 X_\mu X^\mu - \lambda\overline{\psi}\gamma^\mu X_\mu\psi,$$

$$\mathcal{L}_{X^{++}S} = \partial_\mu X^+ \partial^\mu X - M_X^2 X^+ X - \lambda\overline{\psi}X^+\psi^C - \lambda\overline{\psi^C}X\psi,$$

$$\mathcal{L}_{X^{++}V} = -\frac{1}{2}F_{\mu\nu}^+ F^{\mu\nu} + M_X^2 X_\mu^+ X^\mu - \lambda\overline{\psi}\gamma^\mu X_\mu^+\psi^C - \lambda\overline{\psi^C}\gamma^\mu X_\mu\psi.$$



Considered Models. Case 2

Case of uncharged X particle decay into Y^{-1} particle and positron

$$\mathcal{L}_{X^0F,Y-S} = \overline{X}(i\gamma^\mu\partial_\mu - M_X)X + (D_\mu Y)^+(D^\mu Y) - M_Y^2 Y^+ Y - \lambda Y\overline{\psi}X - \lambda\overline{X}\psi Y^+,$$

$$\mathcal{L}_{X^0F,Y-V} = \overline{X}(i\gamma^\mu\partial_\mu - M_X)X - \frac{1}{2}F_{\mu\nu}^+ F^{\mu\nu} + M_Y^2 Y_\mu^+ Y^\mu - \lambda\gamma^\mu Y_\mu\overline{\psi}X - \lambda\overline{X}\psi\gamma^\mu Y_\mu^+,$$

$$\mathcal{L}_{X^0S,Y-F} = \frac{1}{2}\partial_\mu X\partial^\mu X - \frac{1}{2}M_X^2 X^2 + \overline{Y}(i\gamma^\mu D_\mu - M_Y)Y - \lambda\overline{Y}\psi X - \lambda X\overline{\psi}Y,$$

$$\mathcal{L}_{X^0V,Y-F} = -\frac{1}{4}F_{\mu\nu}F^{\mu\nu} + \frac{1}{2}M_X^2 X_\mu X^\mu + \overline{Y}(i\gamma^\mu D_\mu - M_Y)Y - \lambda\overline{Y}\psi\gamma^\mu X_\mu - \lambda\overline{\psi}\gamma^\mu X_\mu Y.$$

Considered Models. Case 3

Case of -1 charged X particle decay into Y particle and positron

$$\mathcal{L}_{X^+F,Y^0S} = \overline{X}(i\gamma^\mu D_\mu - M_X)X + \frac{1}{2}\partial_\mu Y\partial^\mu Y - \frac{1}{2}M_Y^2 Y^2 - \lambda Y\overline{\psi}X - \lambda\overline{X}\psi Y,$$

$$\mathcal{L}_{X^+F,Y^0V} = \overline{X}(i\gamma^\mu D_\mu - M_X)X - \frac{1}{4}F_{\mu\nu}F^{\mu\nu} + \frac{1}{2}M_Y^2 Y_\mu Y^\mu - \lambda\gamma^\mu Y_\mu\overline{\psi}X - \lambda\overline{X}\psi\gamma^\mu Y_\mu,$$

$$\mathcal{L}_{X^+S,Y^0F} = (D_\mu X)^+(D^\mu X) - M_X^2 X^+X + Y(i\gamma^\mu\partial_\mu - M_Y)Y - \lambda\overline{Y}\psi X^+ - \lambda X\overline{\psi}Y,$$

$$\mathcal{L}_{X^+V,Y^0F} = -\frac{1}{2}F^+_{\mu\nu}F^{\mu\nu} + M_X^2 X^+_\mu X^\mu + Y(i\gamma^\mu\partial_\mu - M_Y)Y - \lambda\overline{Y}\psi\gamma^\mu X^+_\mu - \lambda\gamma^\mu X_\mu\overline{\psi}Y.$$

Considered Models. Case 4

Case of -2 charged X particle decay into Y^{+1} particle and positron

$$\begin{aligned}
\mathcal{L}_{X^{++}S,Y^{+}F} &= \overline{X}(i\gamma^\mu D_\mu - M_X)X + (D_\mu Y)^+(D^\mu Y) - M_Y^2 Y^+ Y - \lambda Y \overline{\psi} X - \lambda \overline{X} \psi Y^+, \\
\mathcal{L}_{X^{++}F,Y^{+}V} &= \overline{X}(i\gamma^\mu D_\mu - M_X)X - \frac{1}{2}F^+_{\mu\nu}F^{\mu\nu} + M_Y^2 Y_\mu^+ Y^\mu - \lambda\gamma^\mu Y_\mu \overline{\psi} X - \lambda \overline{X}\psi\gamma^\mu Y_\mu^+, \\
\mathcal{L}_{X^{++}S,Y^{+}F} &= (D_\mu X)^+(D^\mu X) - M_X^2 X^+ X + \overline{Y}(i\gamma^\mu D_\mu - M_Y)Y - \lambda \overline{Y}\psi X^+ - \lambda X \overline{\psi} Y, \\
\mathcal{L}_{X^{++}V,Y^{+}F} &= -\frac{1}{2}F^+_{\mu\nu}F^{\mu\nu} + M_X^2 X_\mu^+ X^\mu + \overline{Y}(i\gamma^\mu D_\mu - M_Y)Y - \lambda \overline{Y}\psi\gamma^\mu X_\mu^+ - \lambda\gamma^\mu X_\mu \overline{\psi} Y.
\end{aligned}$$

Modeling

Decay modeling was carried out using the **CompHEP** and **MadGraph5**. The Standard Model extension files were created using **FeynRules** and UFO format.

Considered decay processes:

$$X_{S_X}^{Q_X} \to e^{\pm} + e^{+} + \gamma \qquad X_{S_X}^{Q_X} \to Y_{S_Y}^{Q_Y} + e^{+} + \gamma$$

Modeling

Model parameters of decay $X_{S_X}^{Q_X} \to e^{\pm} + e^{+} + \gamma$

Charge of X, Q_X	Spin of X, S_X	Products
0	0	$e^- + e^+$
0	1	$e^- + e^+$
2	0	$e^+ + e^+$
2	1	$e^+ + e^+$

Modeling

Model parameters of decay $X_{S_X}^{Q_X} \to Y_{S_Y}^{Q_Y} + e^+ + \gamma$

Charge of X, Q_X	Charge of Y, Q_Y	Spin of X, S_X	Spin of Y, S_Y
0	-1	$1/2$	0
		$1/2$	1
		0	$1/2$
		1	$1/2$
+1	0	$1/2$	0
		$1/2$	1
		0	$1/2$
		1	$1/2$
+2	+1	$1/2$	0
		$1/2$	1
		0	$1/2$
		1	$1/2$

Modeling

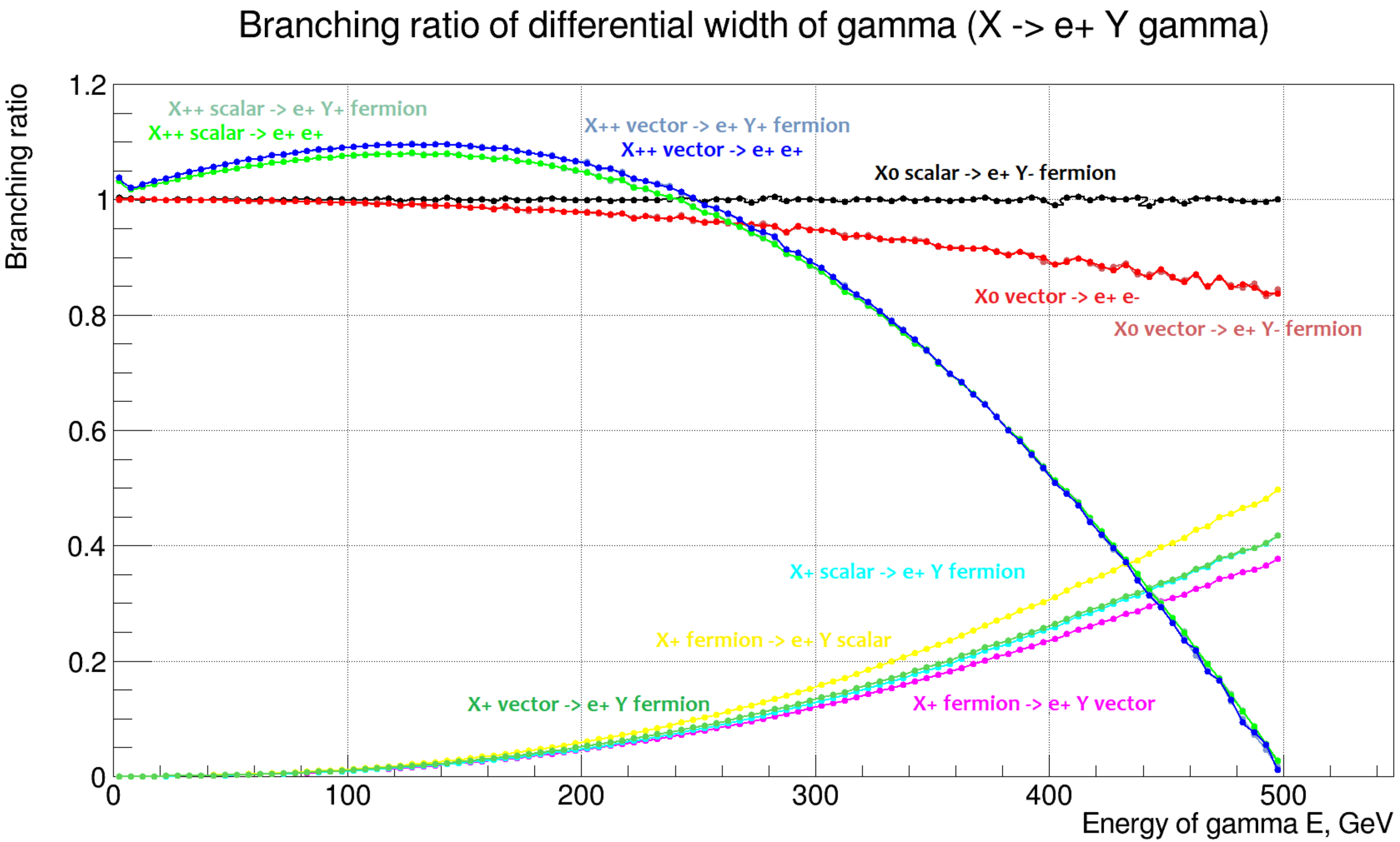
MEPhI

Differential spectrum ratio is taken as quality indicator of gamma-ray suppression in range 10-1000 GeV. Comparison is made for considered models and the most often used model of X decay into electron and positron

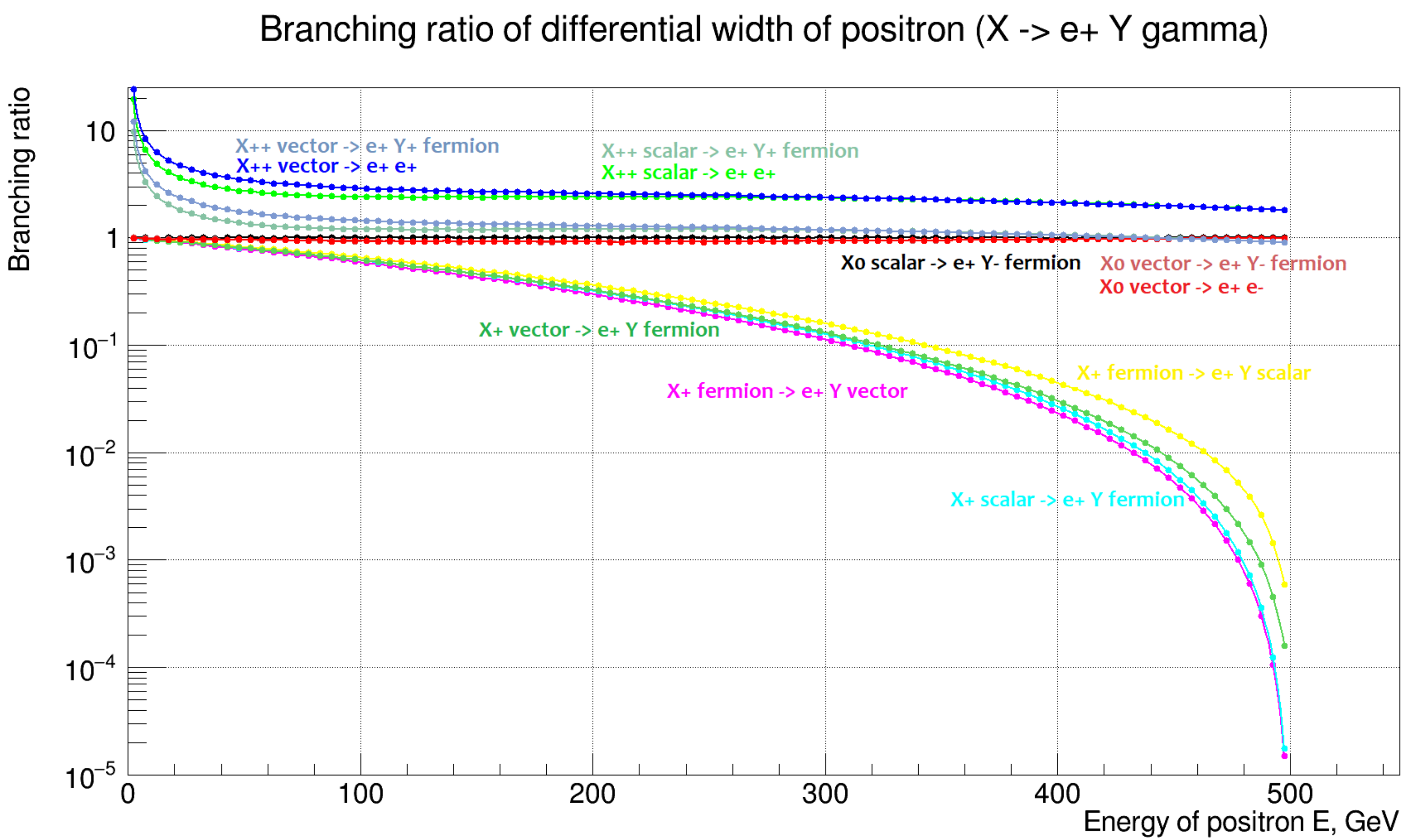
$$Br = \frac{\Gamma(X \to eY\gamma)}{\Gamma(X \to eY)}, \quad \frac{dBr}{dE} = \frac{1}{\Gamma(X \to eY)} \frac{d\Gamma(X \to eY\gamma)}{dE},$$

$$R = \frac{dBr(decay)}{dE} \Big/ \frac{dBr(X^0_{scalar} \to e^- e^+)}{dE}$$

Results


Branching ratio of differential width of gamma (X -> e+ Y gamma)
Branching ratio
Energy of gamma E, GeV
1.2
1
0.8
0.6
0.4
0.2
0
0
100
200
300
400
500
X++ scalar -> e+ Y+ fermion
X++ scalar -> e+ e+
X++ vector -> e+ Y+ fermion
X++ vector -> e+ e+
X0 scalar -> e+ Y- fermion
X0 vector -> e+ e-
X0 vector -> e+ Y- fermion
X+ scalar -> e+ Y fermion
X+ fermion -> e+ Y scalar
X+ vector -> e+ Y fermion
X+ fermion -> e+ Y vector

Results



Branching ratio of differential width of positron (X -> e+ Y gamma)
Branching ratio
Energy of positron E, GeV
X++ vector -> e+ Y+ fermion
X++ vector -> e+ e+
X++ scalar -> e+ Y+ fermion
X++ scalar -> e+ e+
X0 scalar -> e+ Y- fermion
X0 vector -> e+ Y- fermion
X0 vector -> e+ e-
X+ vector -> e+ Y fermion
X+ fermion -> e+ Y scalar
X+ fermion -> e+ Y vector
X+ scalar -> e+ Y fermion

Results

The minimal gamma to positron ratio is obtained in the case of the **X with charge +1** decay mode. However, the difference between the considered **X +1** models is small.

X++ in high energies has suppression of gamma (>300 GeV).

X +1, +2 decay models can be considered as a part of cascade model decay of even heavier neutral dark matter particle or dark atom models.

Results

The next step of the work is to model multiparticle final state decay modes (i.e. cascade models) and search for analytical solution. As a separate task: comparison of the system’s radiation in quantum and classical cases.

Also, modeling should be checked with using other Monte-Carlo generators (Sherpa, Herwig, Whizard).

Thank you for your attention

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