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Possible effects in cosmic gamma radiation from decay or annihilation of dark matter particles

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Cosmic rays experiments

PAMELA
Satellite: “Resurs DK-1”
Since: 15 June 2006

The study of fluxes of antiparticles in cosmic rays in the range from ~ 100 MeV to hundreds of GeV.

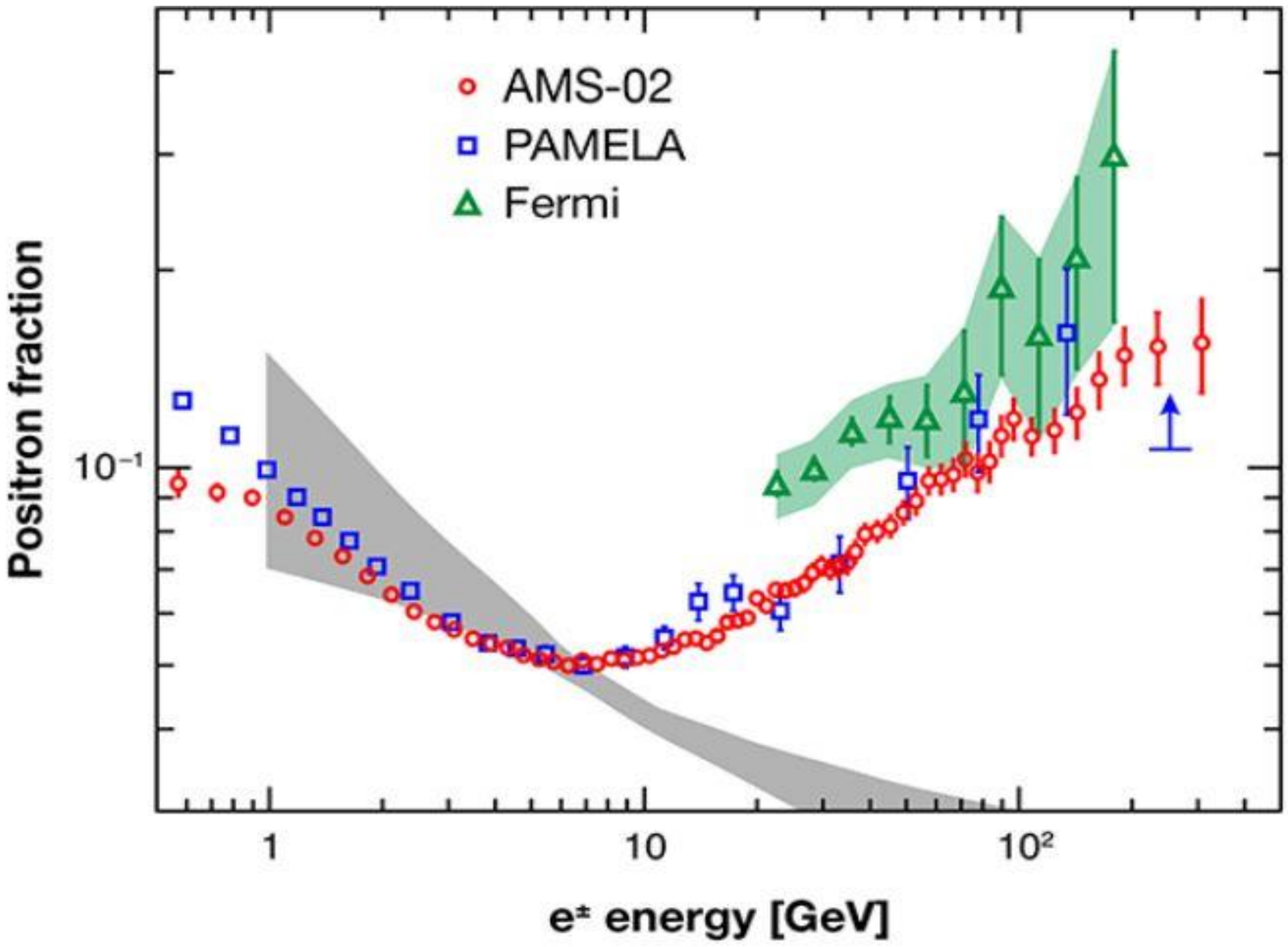
AMS – 02
Installed on the ISS
Since: 16 May 2011

Designed to study the composition of cosmic rays, the search for antimatter and dark matter

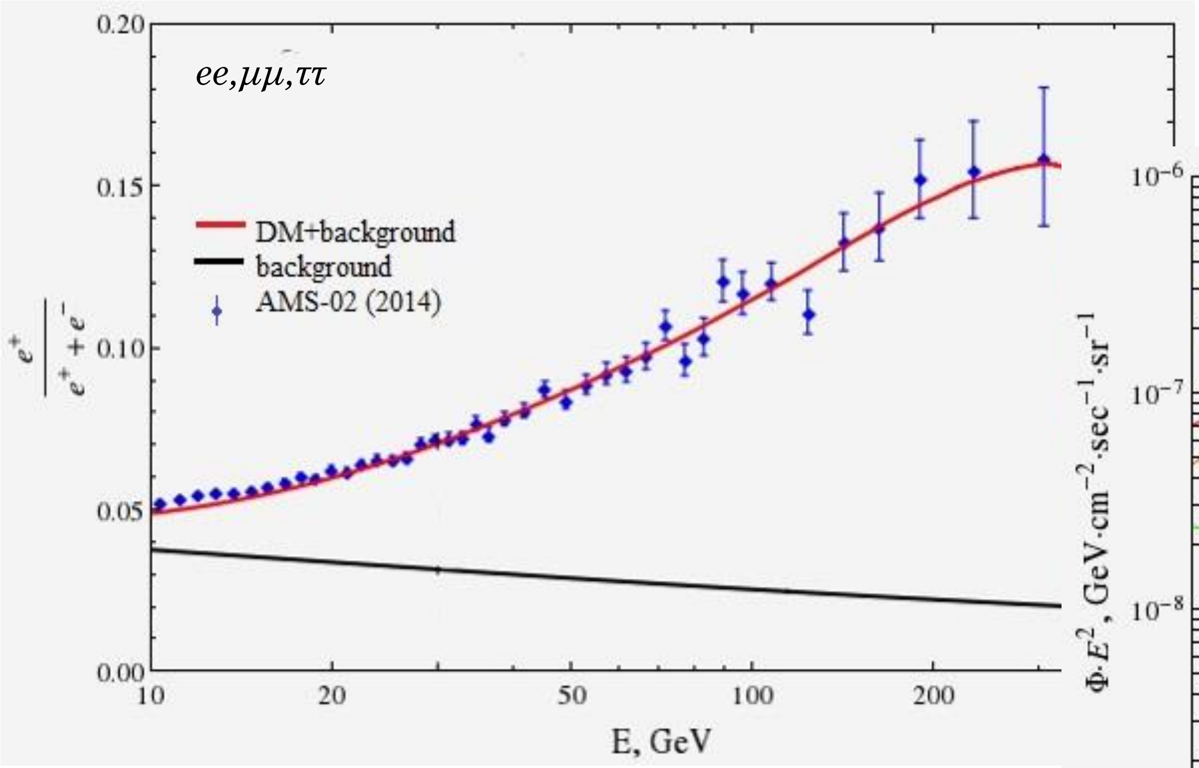
Fermi-LAT
Space gamma telescope
Since: 11 June 2008

The study of astrophysical and cosmological processes in the centers of galaxies, gamma-ray bursts, the search for dark matter

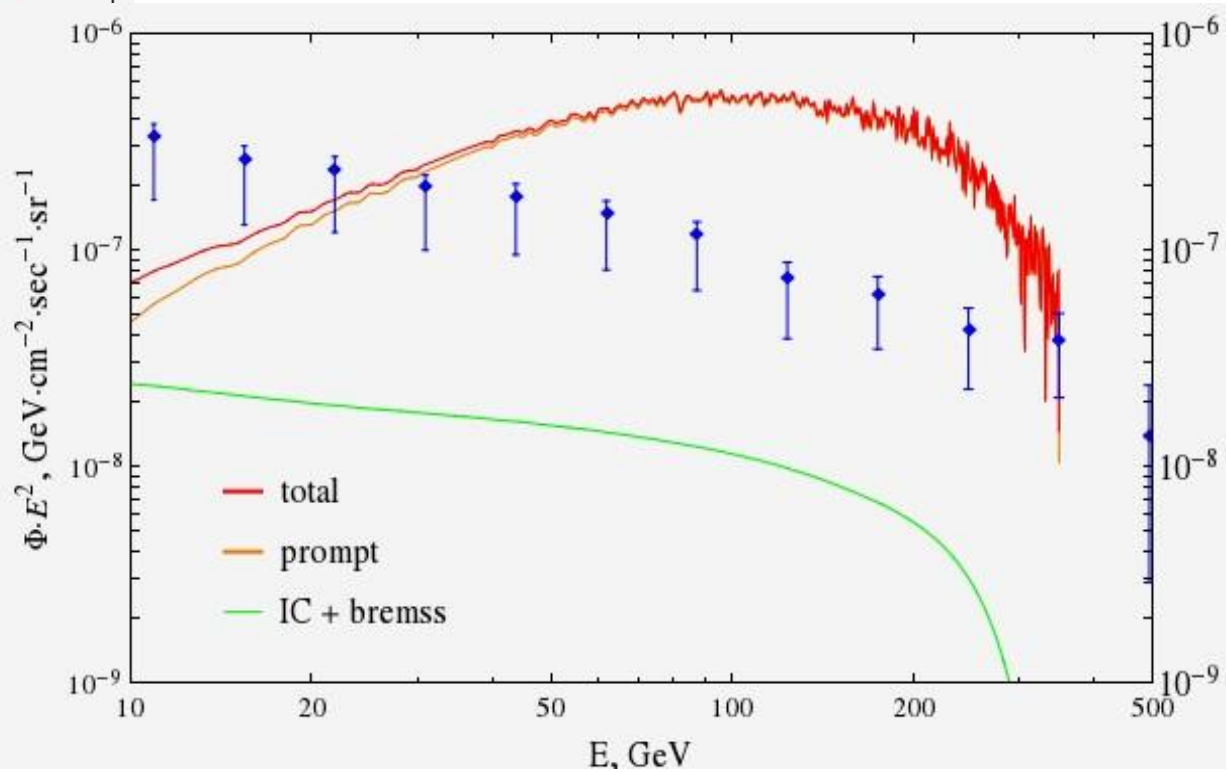
Positron anomaly



Contradictions with gamma data (dark halo model)



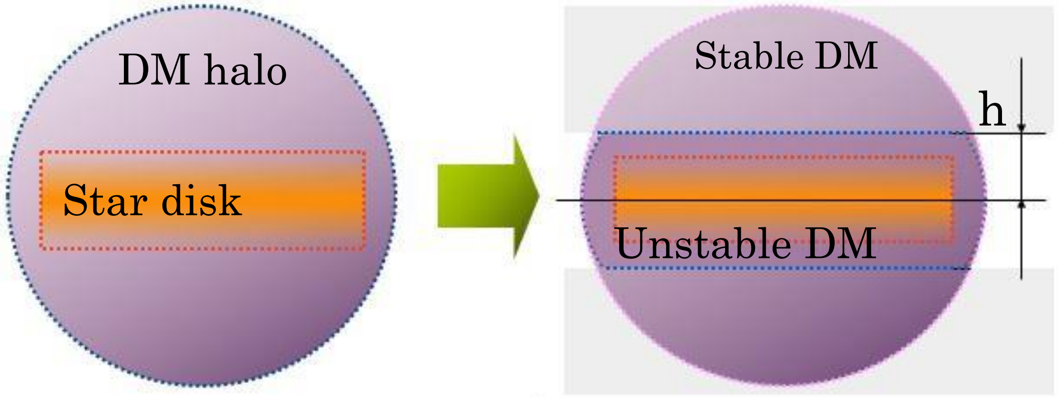
Agrees with positron data



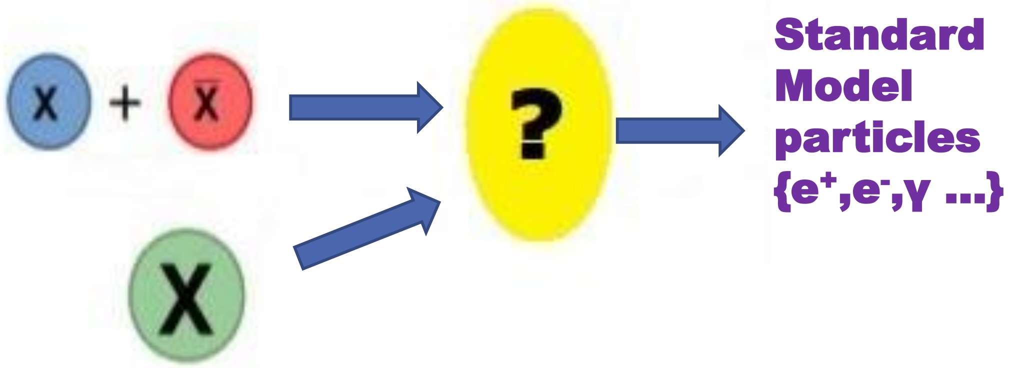
Contradictions with IGBR

Possible ways of gamma suppression

- **Due to space DM distribution (dark halo and dark disk models, clumps)**



- **Physics of DM interaction:**



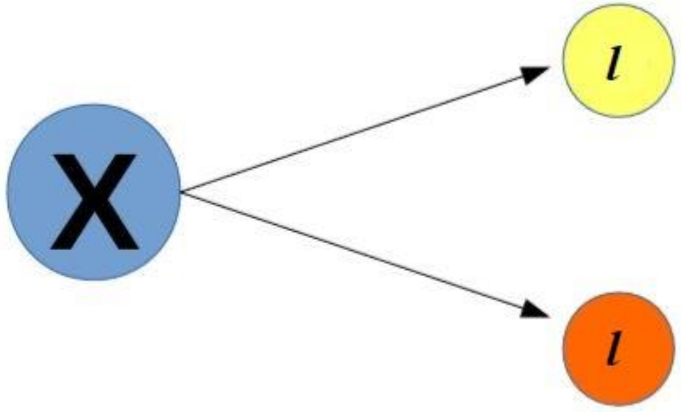
- **???**

Possible DM interaction types

We consider the decay of a hypothetical massive particle *X* into two leptons:

DM particle ***X*** can be:

- Scalar $$\mathscr{L}_{scalar} = X\overline{\psi}\psi$$
- Pseudoscalar $$\mathscr{L}_{scalar\gamma^5} = X\overline{\psi}\gamma^5\psi$$
- Vector $$\mathscr{L}_{vector} = \overline{\psi}\gamma^\mu\psi X_\mu$$
- Axial vector $$\mathscr{L}_{vector\gamma^5} = \overline{\psi}\gamma^\mu\gamma^5\psi X_\mu$$



Parametrization of interaction Lagrangian

The idea is to use different combinations of vector and pseudo-vector coupling, or scalar and pseudoscalar, to understand which coupling constants must be chosen **in order to suppress a FSR.**

$$\mathscr{L}_{scalar} = X\overline{\psi}(a + b\gamma^5)\psi$$

$$\mathscr{L}_{vector} = \overline{\psi}\gamma^\mu(a + b\gamma^5)X_\mu\psi$$

- Then suppression of the FSR means that:

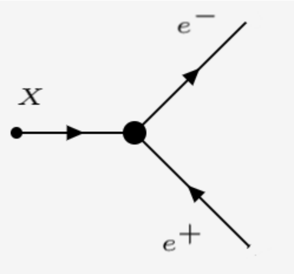
$$\frac{\Gamma(X \to e^+e^\pm\gamma)}{\Gamma(X \to e^+e^\pm)} = \min$$

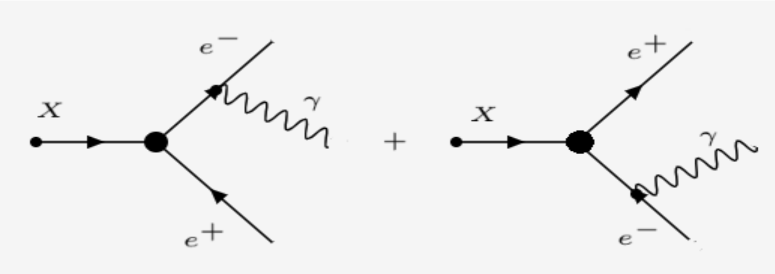
The simplest DM particle decay models

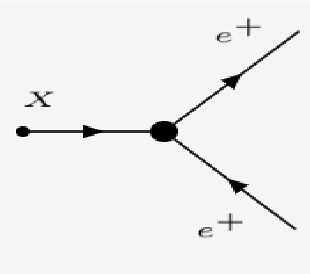
Mainly, two models of a dark matter particle were considered:

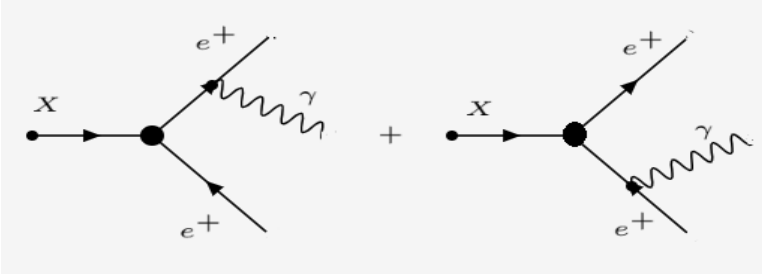
The simplest model of the decay of a dark matter particle into two oppositely charged leptons ($X \to e^+e^-$, $X \to e^+e^-\gamma$)

The model DM particle decay into two positrons ($X \to e^+e^+$, $X \to e^+e^+\gamma$)









$$L = X\bar{\psi}(a + b\gamma^5)\psi + X\bar{\psi}(a - b\gamma^5)\psi + \bar{\psi}\gamma^\mu A_\mu \psi$$

$$L = X\bar{\psi}^C(a + b\gamma^5)\psi + X^*\bar{\psi}(a - b\gamma^5)\psi^C + \bar{\psi}\gamma^\mu A_\mu \psi$$

Results for two-positrons model

To obtain the squared matrix elements of the above processes, LanHEP and CalcHEP packages were used.

For scalar X

$\mathbf{X \rightarrow e^+ + e^+}$

$$|M|^2 = 4m_x^2(\underline{a^2 + b^2})$$

$\mathbf{X \rightarrow e^+ + e^+ + \gamma}$

$$|M|^2 \sim 16(\underline{a^2 + b^2})\ldots$$

For vector X

$\mathbf{X \rightarrow e^+ + e^+}$

$$|M|^2 = 8m_x^2\underline{b^2}$$

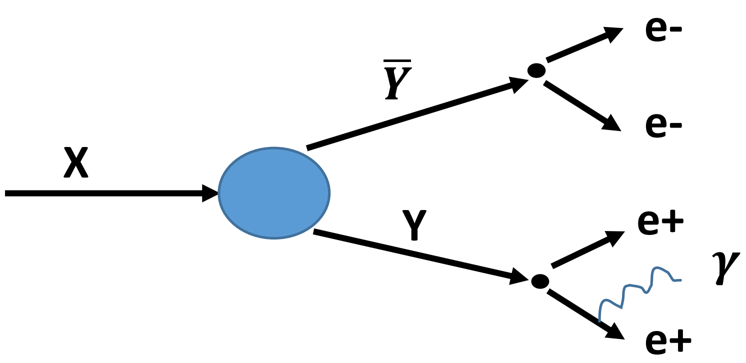
$\mathbf{X \rightarrow e^+ + e^+ + \gamma}$

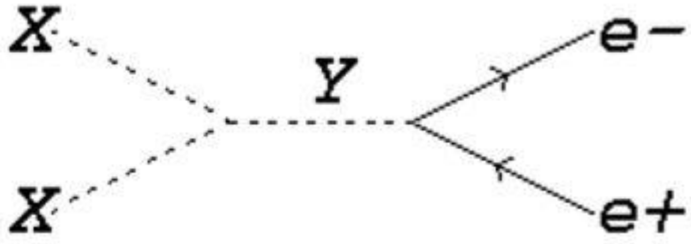
$$|M|^2 \sim 16\underline{b^2}\ldots$$

Ratio of decay widths does not depend on a and b parameters. Thus, we can conclude that in decays of this type of particle, the FSR is not suppressed, due to parameters a,b.

The DM model with a heavy intermediate particle

It is necessary to complicate the models, therefore in the following, we consider the decay of an uncharged self-conjugate particle X into Y (Q = +2), $\bar{Y}$ (Q=-2) and annihilating DM models:





Thus, we can consider different variations of such a model:

1. X,Y – scalars;
2. X-vector, Y-scalar;
3. X,Y-vectors;
4. X-scalar,Y-vector;

…

Results for the DM model with a heavy intermediate particle

Decay models:

1) **X,Y – scalars:**

$$\mathcal{L} = XY^*Y + Y\overline{\psi^c}(a + b\gamma^5)\psi + Y^*\bar{\psi}(a - b\gamma^5)\psi^c - \bar{\psi}\gamma^\mu A_\mu \psi + A_\mu Y\partial^\mu Y^* + A_\mu Y^*\partial^\mu Y$$

In this case, there was also a reduction in parameterization.

2) **X – vector, Y – scalar:**

$$\mathcal{L} = Y\partial^\mu X_\mu Y^* + X_\mu \partial^\mu Y Y^* + X_\mu \partial^\mu Y^* Y + X_\mu A^\mu Y^* Y + Y\overline{\psi^c}(a + b\gamma^5)\psi + Y^*\bar{\psi}(a - b\gamma^5)\psi^c - \bar{\psi}\gamma^\mu A_\mu \psi + A_\mu Y\partial^\mu Y^* + A_\mu Y^*\partial^\mu Y$$

$|M|^2 = 0$ (two-body decay)

Annihilating DM models:

$$\mathcal{L} = XYX + Y\bar{\Psi}(a + b\gamma^5)\Psi + \bar{\Psi}\gamma^\mu A_\mu \Psi$$

$$\mathcal{L} = X^\mu Y X_\mu + Y\bar{\Psi}(a + b\gamma^5)\Psi + \bar{\Psi}\gamma^\mu A_\mu \Psi$$

Single-photon Theorem

- Arising of "radiation zeros" in various models
- Narrow area of kinematic parameters

Theorem:

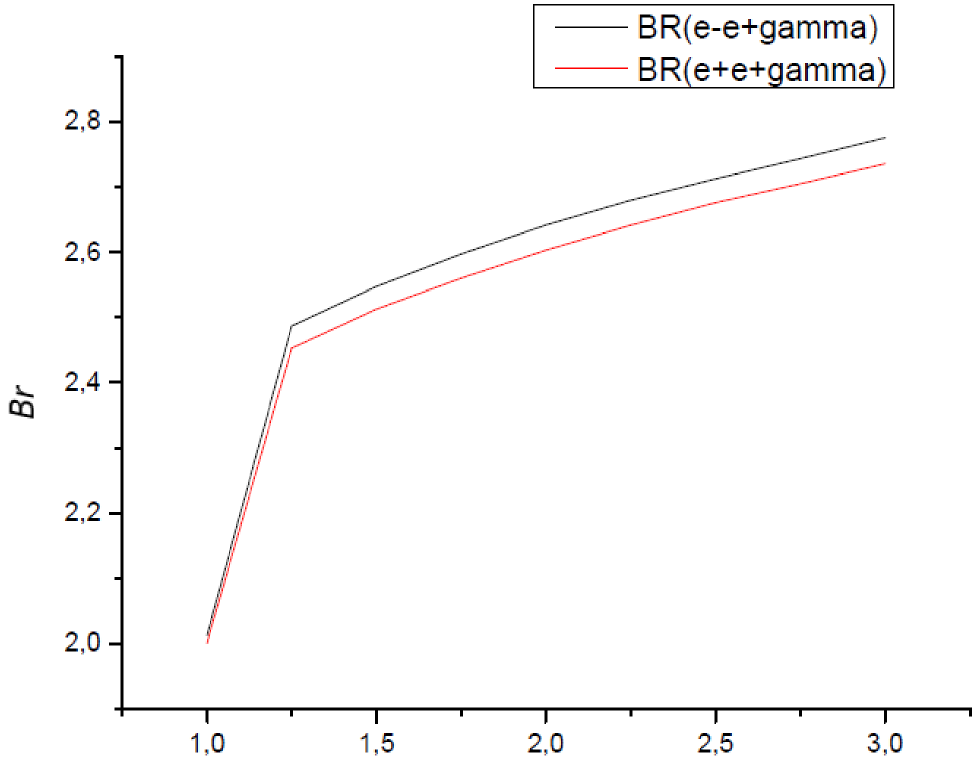
$$M_\gamma = 0,$$
$$\text{If } \frac{Q_i}{p_i \cdot q} = same, all\ i$$

Contribution analysis:

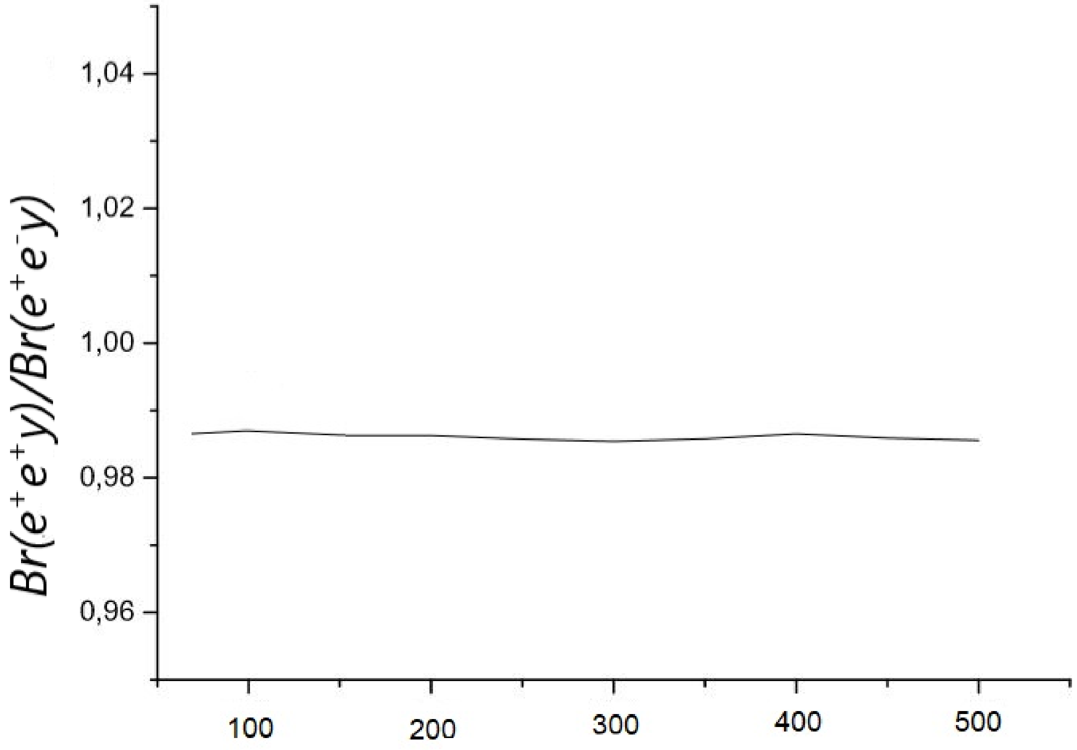
$$\frac{Br(e^+e^+\gamma)}{Br(e^+e^-\gamma)} = \min$$

The i-th particle has a charge Q_i and a 4-momentum p_i,
q is a 4-momentum of a photon

Contribution to Photon Suppression

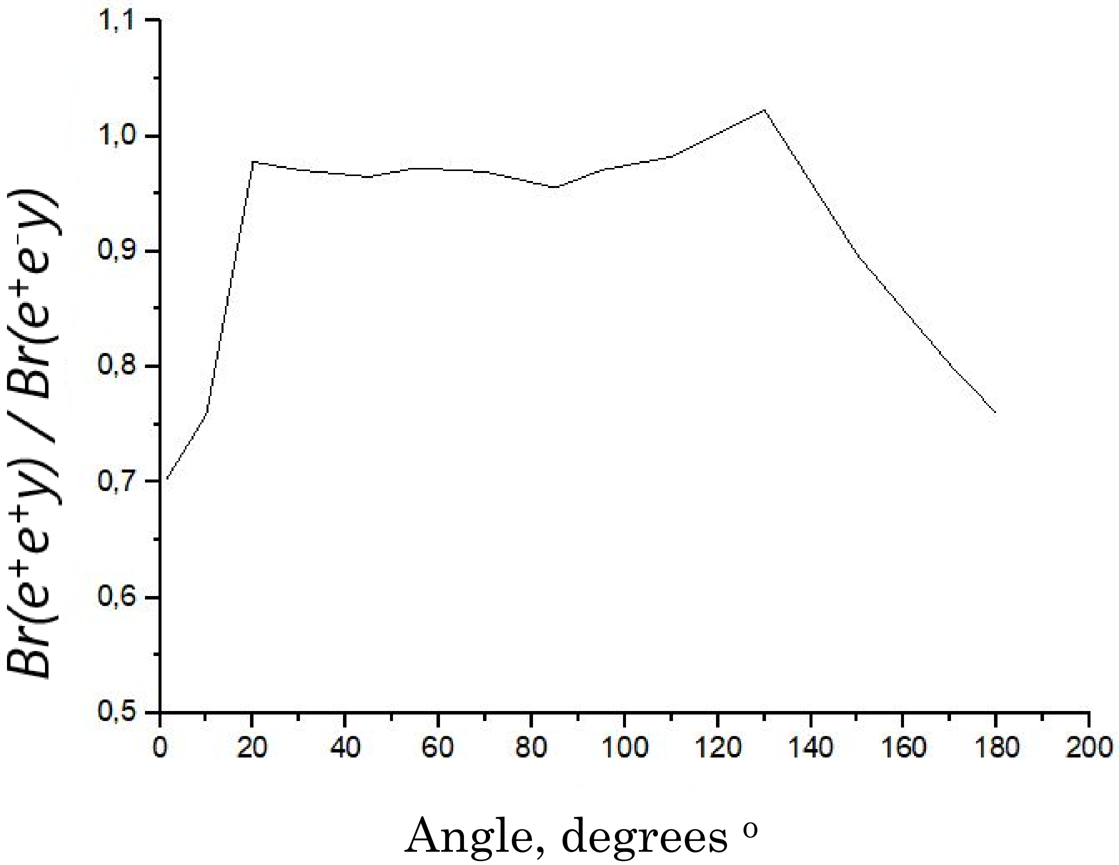


Mass of DM particle, TeV



E_{gamma}, GeV

Contribution to Photon Suppression

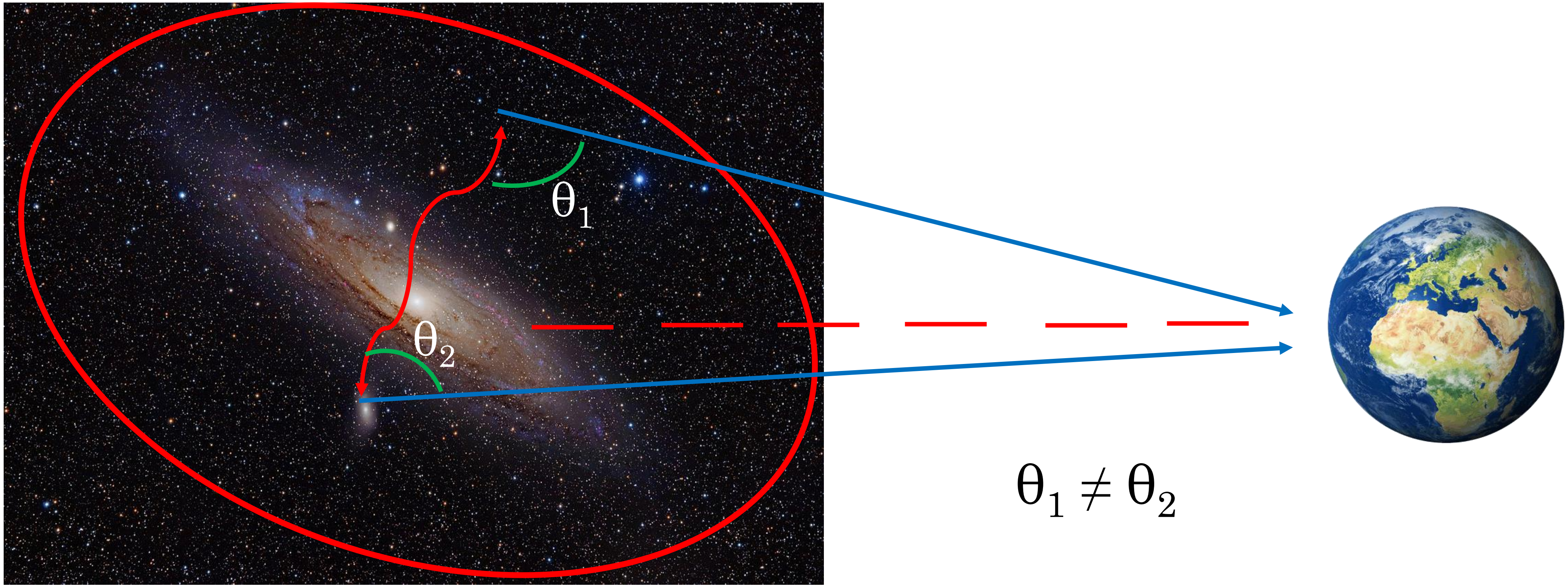


There is a range of scattering angles between the photon and the corresponding particle, in which some suppression of the photon yield is observed (about 30%)

GAMMA-RADIATION DUE TO INVERSE COMPTON SCATTERING FROM ANNIGILATION OF THE DARK MATER PARTICLE

Angular anisotropy from ics photons

$$\frac{d\sigma}{d\epsilon_1' d\Omega_1'} = \frac{3}{16\pi}\sigma_T \left(\frac{\epsilon_1'}{\epsilon'}\right)^2 \left(\frac{\epsilon'}{\epsilon_1'} + \frac{\epsilon_1'}{\epsilon'} - \sin^2\theta_1'\right) \delta\left(\epsilon_1' - \frac{\epsilon'}{1 + \frac{\epsilon'}{m}(1 - \cos\theta_1')}\right)$$



Differential flux calculation

$$\frac{d\Phi}{d\epsilon_1} = \frac{1}{\epsilon_1}\frac{\langle\sigma_{ann}v\rangle}{4\pi} r_\odot \frac{\rho_0^2}{M_{DM}^2} \bar{J}\Delta\Omega \int_{m_e}^{M_{DM}} dE\, \mathcal{P}(\epsilon_1, E, r)$$

Angular anisotropy is not taken into account!

$\bar{J}$ - geometrical factor

$$\bar{J}\Delta\Omega = \int_{\Delta\Omega} d\Omega \int_{\text{line-of-sight}} \frac{ds}{r_\odot}\left(\frac{\rho(r)}{\rho_\odot}\right)^2$$

$\mathcal{P}(\epsilon_1, E, r)$ - is the differential power emitted into photons of energy ϵ_1 by an electron with energy E

ϵ_1 – energy of the scattered photon

ϵ – energy of the original photon

$\langle\sigma_{ann}v\rangle \approx 3\cdot 10^{-26}$ cm^3/s – annihilation cross section

ρ_0 - dark matter density in M31

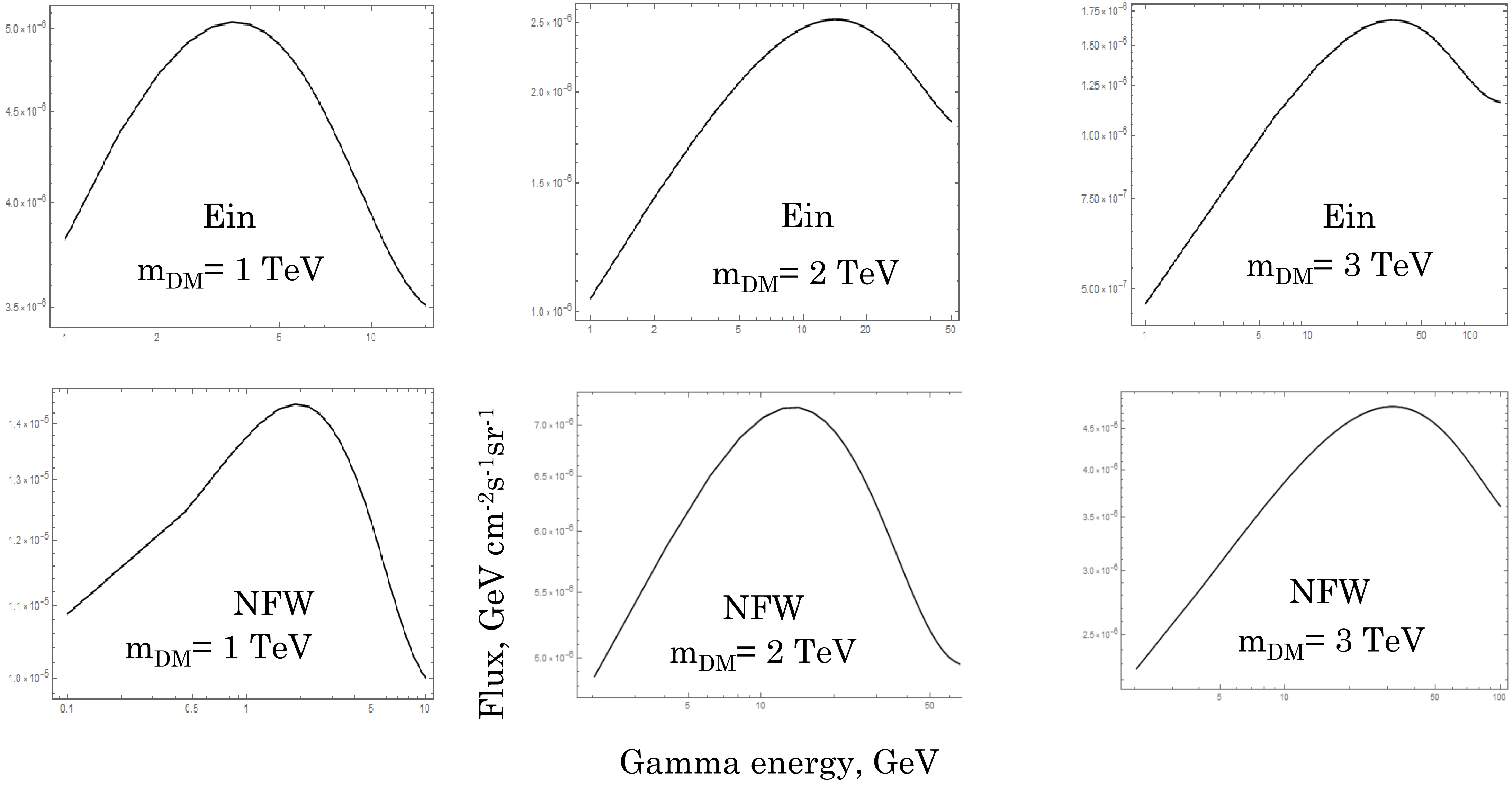
M_{DM} = 1 – 3 TeV – DM particle mass

$\Delta\Omega = 3^\circ \times 5^\circ$ - Solid angle

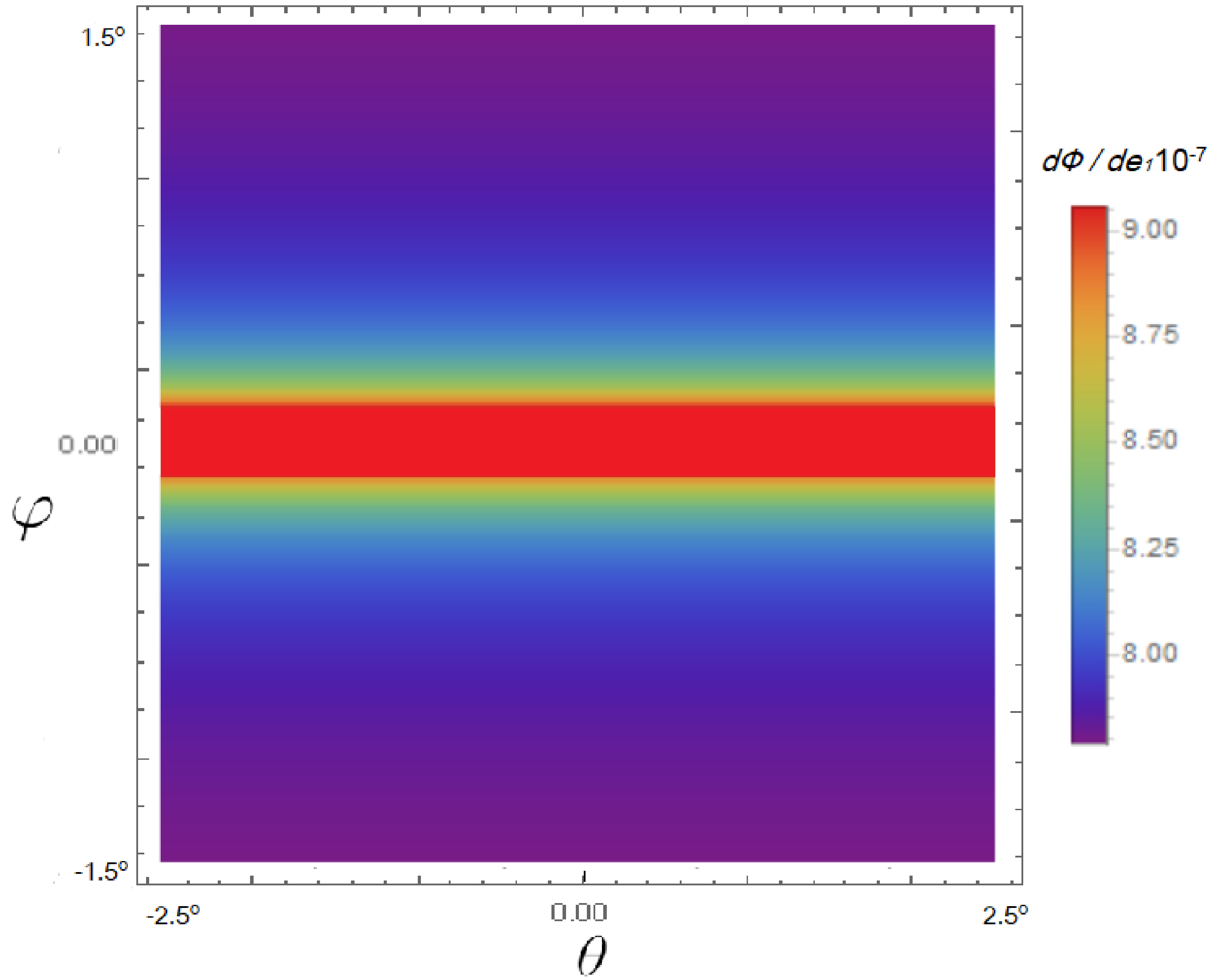
$$\rho_{Ein}(r) = \rho_s \exp\left[-\frac{2}{\alpha}\left(\left(\frac{r}{r_s}\right)^\alpha - 1\right)\right], \quad \alpha = 0.17$$

$$\rho_{NFW}(r) = \rho_s \frac{r_s}{r}\left(1 + \frac{r}{r_s}\right)^{-2}$$

Signals from ics photons



Isotropic flux map



Anisotropic flux map

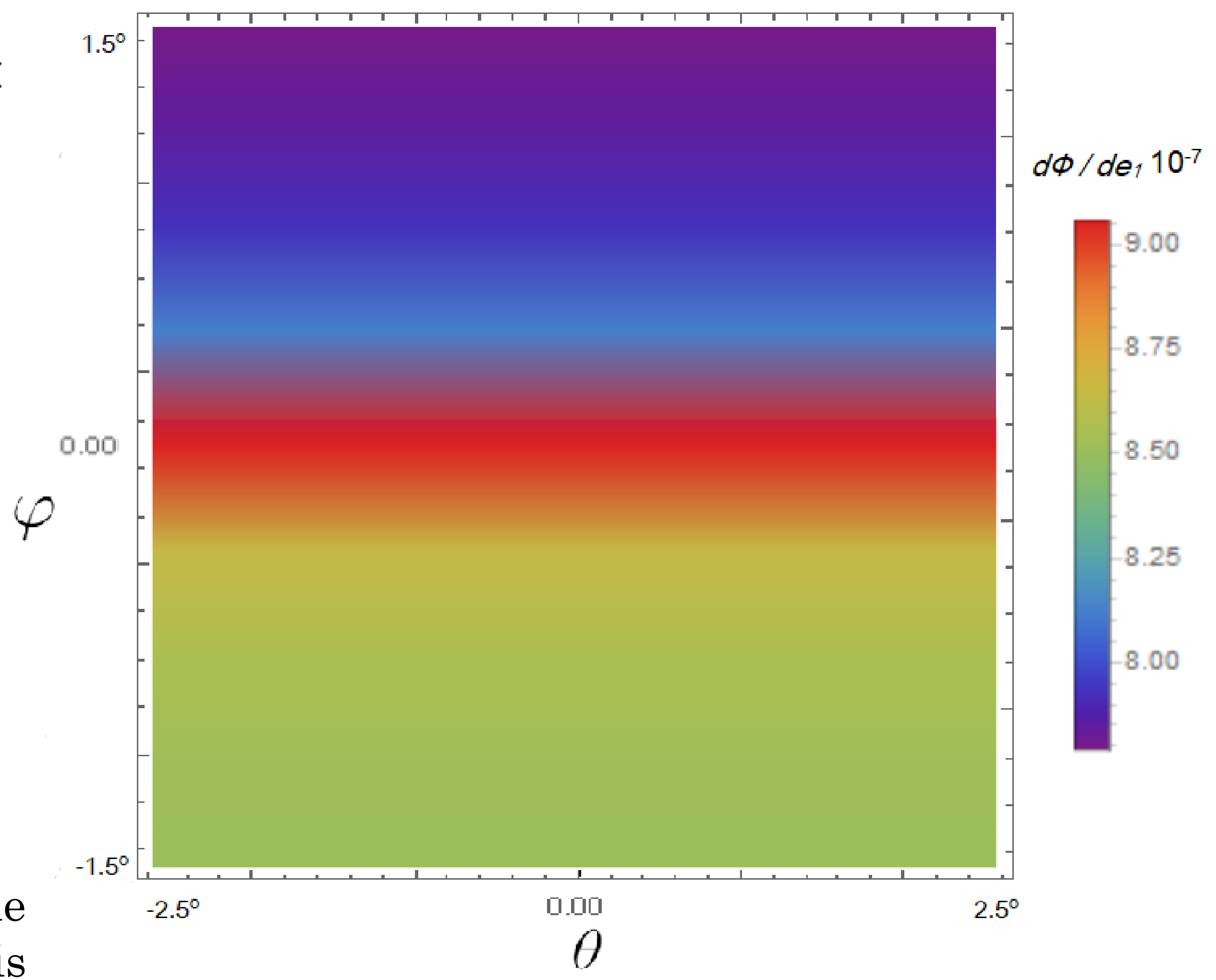
$$\frac{d\Phi}{d\epsilon_1} = \frac{1}{\epsilon_1}\frac{\langle\sigma_{ann}v\rangle}{4\pi}r_0\frac{\rho_0^2}{M_{DM}^2}\int_{\Delta\Omega} d\Omega \int_{\mathrm{l.o.s.}} \frac{ds}{r_0}\left(\frac{\rho(r)}{\rho_0}\right)^2 \times$$
$$\times \int_{\Omega_\gamma} d\Omega_\gamma Q_\gamma(\Omega_\gamma) \int_{m_e}^{M_{DM}} dE\, \mathcal{P}(\epsilon_1, E, r).$$

$$Q_\gamma(r,\alpha) = \frac{1}{\pi Y(r)}\left(1 - \frac{r^2}{R^2}\sin^2\alpha\right)^{-1/2},$$

$$Y(r) = 1 - \frac{r^2 - R^2}{2rR}\ln\left(\frac{r+R}{r-R}\right)$$

$$\left(1 - \frac{R^2}{r^2}\right)^{1/2} \leq \cos\alpha \leq 1$$

α is the photon incident angle, R is the radius of the galactic dark halo M31, and r is the distance to M31



Conclusions

- development and analysis of various dark matter models was carried out, with an emphasis on models decaying into two identical positrons in the final state;
- Two mechanisms of FSR suppression were proposed: parameterization of the interaction Lagrangian and identity of particles in the final state;
- It was found that partial suppression of the photon (about 30%) is observed in the case of identical positrons at certain values of the angle between the photon and the particle emitting it;

Conclusions

- the methodology for calculating the isotropic differential flux of gamma radiation from annihilation or decay of dark matter particles arising due to ICS on photons of the interstellar medium in the case of their isotropic scattering in this process was considered;
- A flux map was constructed for a selected part of the sky (for the Andromeda Nebula);
- The method for calculating the spectrum of ICS photons was generalized to a realistic anisotropic case and a galactic flux map was obtained for the Andromeda nebula with explicit anisotropy;