THE NEUTRINO NATURE THROUGH CROSS SECTIONS IN THE LEFT-RIGHT SYMMETRIC MODEL

COMHEP

4^{th} Colombian Meeting on High Energy Physics

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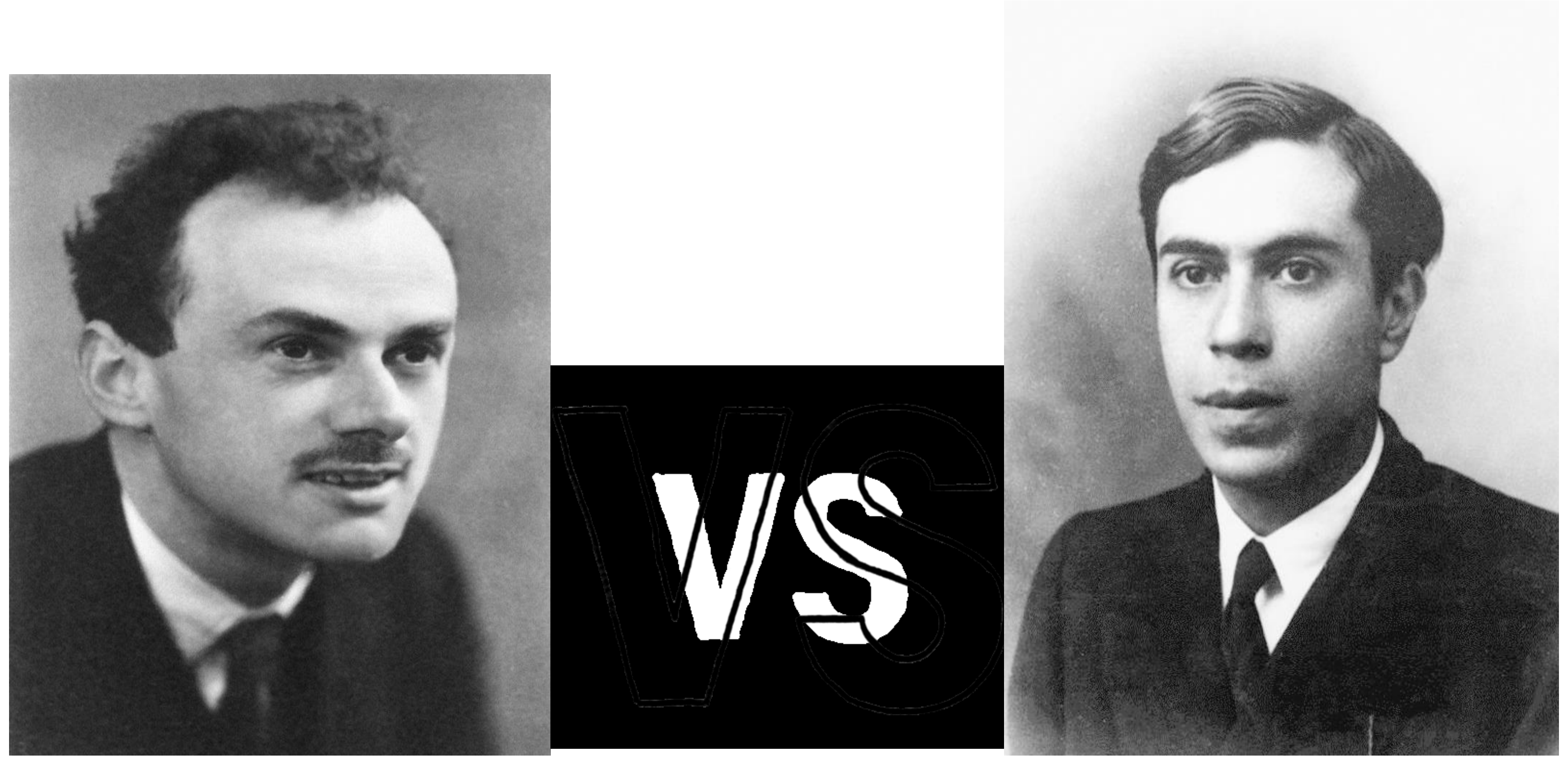
DIRAC OR MAJORANA NATURE

DIRAC	MAJORANA
$\nu \neq \overline{\nu}$	$\nu = \overline{\nu}$



- Every particle has its own antiparticle
- Neutrinos are uncharged, they could be their own antiparticles
- If neutrinos are Majorana particles, the leptonic number is not conserved
- Massive neutrinos → Physics beyond the SM

THE LEFT-RIGHT SYMMETRIC MODEL
$\mathbf{SU(3)_C \otimes SU(2)_L \otimes SU(2)_R \otimes U(1)_Y}$

ST_L | ST_R

Mirror symmetry is introduced in the SM, replacing the right singlet states by doublet states.

The new symmetric group $\boldsymbol{SU(2)}_R$ includes 3 non-ST bosons: $W_R^{\pm}$, and the Z_R

These new bosons interact similarly like the other weak bosons do.

The Lagragian for leptons contains Left-Right charged current (CC), and neutral current (CN) interactions.

$$\mathcal{L}_l = \mathcal{L}_{L,R}^{CC} + \mathcal{L}_{L,R}^{CN} \qquad (1)$$

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CC INTERACTION

For the first leptonic family:

$$\mathcal{L}^{CC}_{L,R} = -\frac{g}{2\sqrt{2}}[\overline{\nu_e}(1-\gamma_5)\gamma_\mu W^\mu_L e + \overline{\nu_e}(1+\gamma_5)\gamma_\mu W^\mu_R e + H.c] \quad (2)$$

W^μ_L is the standar weak boson field.

W^μ_R is the new weak boson field for right CC interactions.

In the same way as W_L, W_R has positive or negative charge, but is heavier than the particles that have been discovered so far.

CN INTERACTION

For the first leptonic family:

$$\mathcal{L}_{L,R}^{CN} = -\frac{g}{\cos\theta_W}\left(\frac{1}{2}\overline{\nu}_{eL}\not{Z}\nu_{eL} + \frac{\sin^2\theta'\cos\theta_W}{2\cos\theta'}\overline{\nu}_{eL}\not{Z}'\nu_{eL} - \left(\frac{1}{2} - \sin^2\theta_W\right)\overline{e}_L\not{Z}e_L \right.$$
$$\left. + \frac{\sin^2\theta'\cos\theta_W}{2\cos\theta'}\overline{e}_L\not{Z}'e_L + \frac{\cos\theta_W}{2\cos\theta'}\overline{\nu}_{eR}\not{Z}'\nu_{eR} + \sin^2\theta_W\overline{e}_R\not{Z}'e_R + \sin^2\theta_W\overline{e}_R\not{Z}e_R\right)$$
$$- g\sin\theta_W\overline{e}\not{A}e \tag{3}$$

- $\sin\theta' = \tan\theta_W$ New mixing angle

θ_W is the Weinberg's angle

Z' is the new weak boson field for right CN interactions

CN INTERACTION

For the first leptonic family:

$$\mathcal{L}_{L,R}^{CN} = -\frac{g}{\cos\theta_W}\left(\frac{1}{2}\overline{\nu}_{eL}\not{Z}\nu_{eL} + \frac{\sin^2\theta'\cos\theta_W}{2\cos\theta'}\overline{\nu}_{eL}\not{Z}'\nu_{eL} - \left(\frac{1}{2} - \sin^2\theta_W\right)\overline{e}_L\not{Z}e_L \right.$$
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$$- g\sin\theta_W\overline{e}\not{A}e \tag{3}$$

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θ_W is the Weinberg's angle

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Charge of the electron has not changed!

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From the Lagrangian we can extract the coupling constants of some leptons with the Z and Z' bosons

Z

$$g_L^\nu = \frac{1}{2}$$
$$g_R^\nu = 0$$
$$g_L^e = -\frac{1}{2} + \sin^2\theta_W$$
$$g_R^e = \sin^2\theta_W$$

SM coupling constants have not changed

Z'

$$b_L^\nu = \frac{\sin^2\theta' \cos\theta_W}{2\cos\theta'}$$
$$b_R^\nu = \frac{\cos\theta_W}{2\cos\theta'}$$
$$b_L^e = \frac{\sin^2\theta' \cos\theta_W}{2\cos\theta'}$$
$$b_R^e = -\frac{1}{2} + \sin^2\theta_W$$

The new boson Z' is uncharged as Z

Is heavier than the particles that have been discovered so far.

Is not common to study the $\nu\nu \rightarrow \nu\nu$ interactions

- Bilenky, M., Bilenky, S. M., & Santamaria, A. Invisible width of the Z-boson and “secret” v-v interactions. Physics Letters B, 301(2-3), 287–291. doi:10.1016/0370-2693(93)90703-k (2013)
- Ioka, K., & Murase, K. *IceCube PeV-EeV neutrinos and secret interactions of neutrinos. Progress of Theoretical and Experimental Physics, 2014(6), 61E01–0.* doi:10.1093/ptep/ptu090 (2014).
- Kolb, E. W., & Turner, M. S. *Supernova 1987A and the secret interactions of neutrinos. Physical Review D, 36(10), 2895–2900.* doi:10.1103/physrevd.36.2895 (1987).
- E. Flowers, P. Sutherland. *Neutrino-neutrino scattering and supernovae.* Astrophysical Journal, vol. 208, Aug. 15, 1976, pt. 2, p. L19-L21. (1976)….

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Is extremely weak

2νββ

$$2n \rightarrow 2p + 2e + 2\overline{\nu}_e$$

DIRAC

0νββ

$$2n \rightarrow 2p + 2e$$

MAJORANA

[Universo cuántico, los misterios del universo, “antipartículas, esas cosas raras”
https://universocuantico.wordpress.com/2009/04/18/antiparticulas-esas-cosas-raras-i/]

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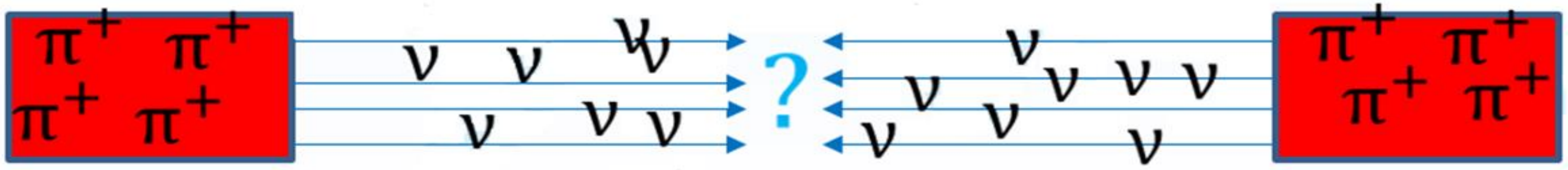
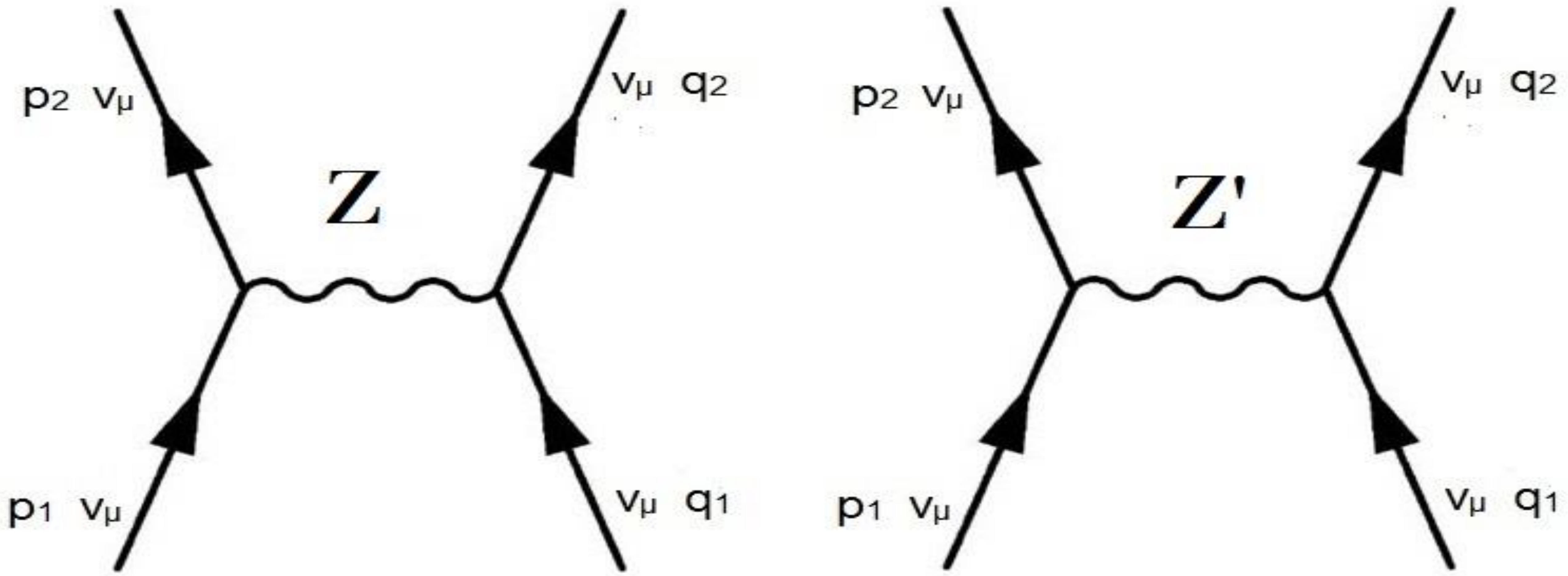
One reason to study the neutrino nature is the asymmetry between matter and antimatter in the universe



Proposal for study the neutrino cross section



$$\mathcal{M} = \mathcal{M}_Z + \mathcal{M}_{Z'} \qquad (4)$$

The $\nu_\mu + \nu_\mu \rightarrow \nu_\mu + \nu_\mu$ cross section is calculated for both natures in the LRSM

DIRAC

$$\sigma_D(E_\nu, m_\nu, M_{Z'}) = \frac{(m_\nu^2 - 4E_\nu^2)^4(\beta + 3\gamma) - 32\rho m_\nu^2 E_\nu^2(16E_\nu^4 - 20m_\nu^2 E_\nu^2 + m_\nu^4)}{768\pi E_\nu^6} \quad (5)$$

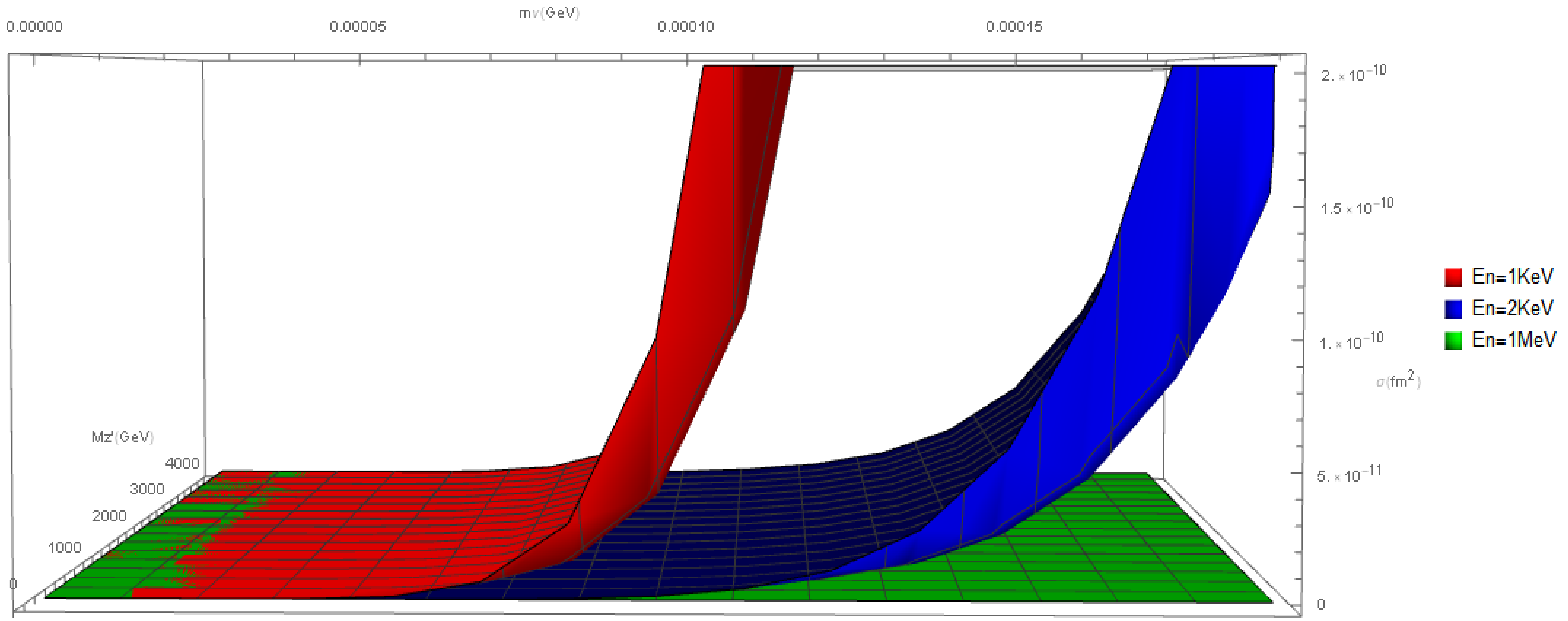
MAJORANA

$$\sigma_M(E_\nu, m_\nu, M_{Z'}) = G_F^2({g_L^\nu}^2 + {b_L^\nu}^2)^2 \frac{1280E_\nu^8 - 768m_\nu^2 E_\nu^6 + 736m_\nu^4 E_\nu^4 - 48m_\nu^6 E_\nu^2 + 5m_\nu^8}{512\pi E_\nu^6} \quad (6)$$

This model includes massive neutrinos

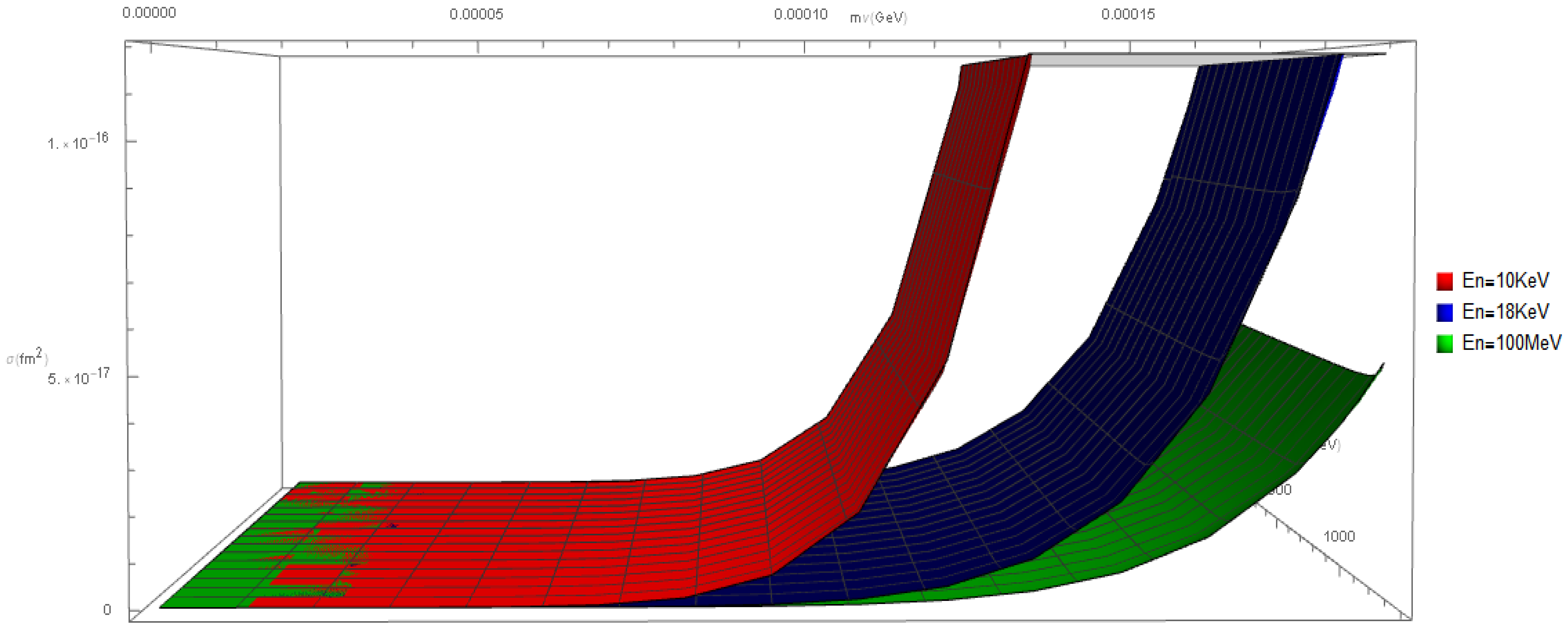
ρ, γ, β are different combinations of the coupling constants

$\sigma_D - \sigma_M$



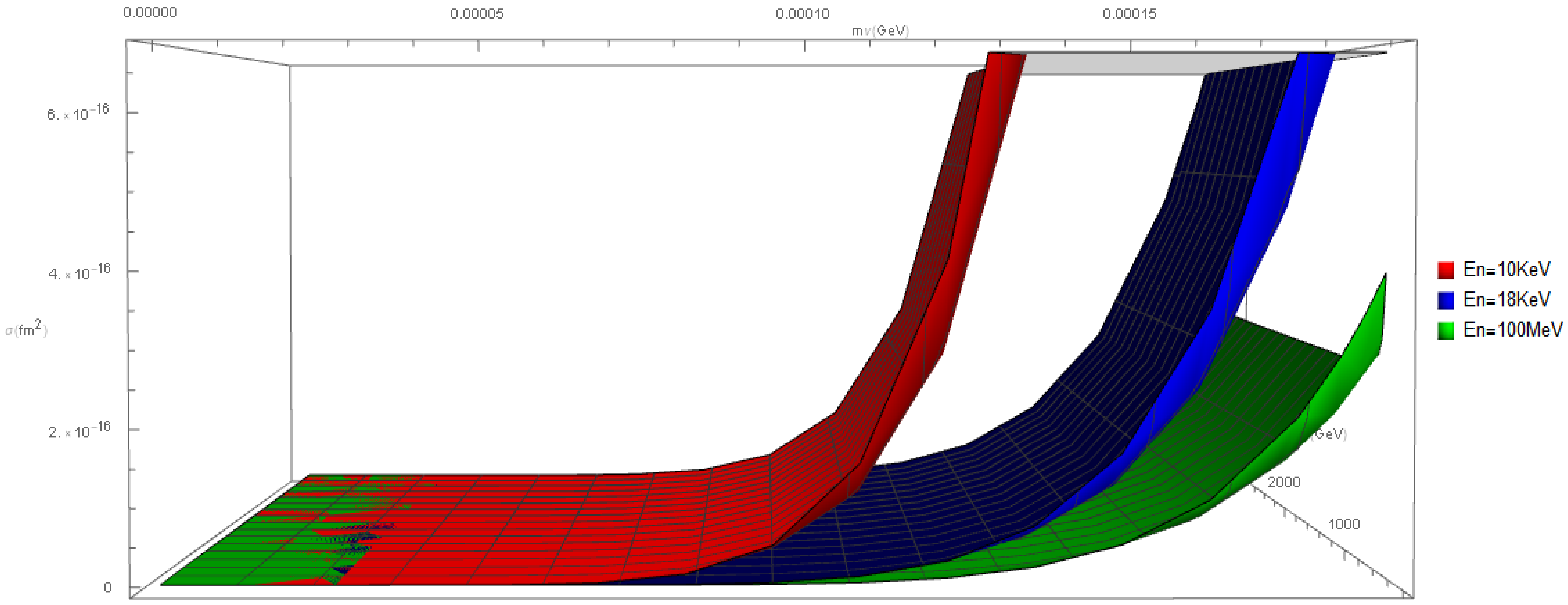
Cross Section Difference is bigger for low energy neutrinos

Majorana Neutrino Mass



Cross section depends aswell of the neutrino mass

Dirac Neutrino Mass



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Conclusion

- Neutrinos nature can be determinated by their cross section
- Low energy neutrinos (KeV) are usefull for this task, because at high energies region, Majorana and Dirac Natures, have similar cross section
- New symmetries can provide more information about neutrino masses

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