Contribution to the neutrino form factors coming from the charged Higgs of a two Higgs doublet model Type I,II

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- Bibliography

What we know about the neutrinos

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- Neutrino are an essential part of stellar phenomenon.

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- The standard model must be extended to account for neutrino masses, introducing right-handed neutrinos.

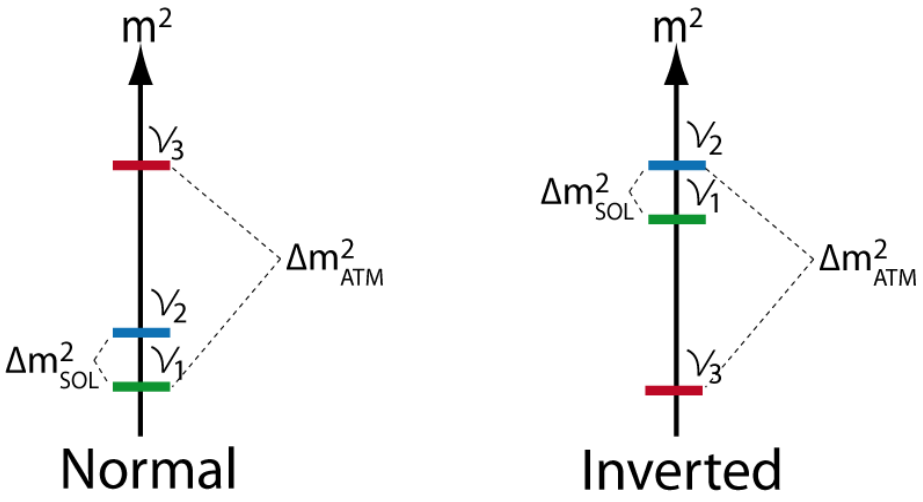

Figure: The two three-neutrino schemes allowed by the hierarchy $\Delta m^2_{SOL} \ll \Delta m^2_{ATM}$

What we know about the neutrinos

- The transition probability can be approximated by

$$P_{\nu_\alpha \to \nu_\beta}(x) = \sum_{k,j} U^*_{\alpha k} U_{\beta k} U_{\alpha j} U^*_{\beta j} \exp\left(-i \frac{\Delta m^2_{kj} x}{2E}\right) \tag{1}$$

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  where L is the oscillation length.
- Over neutrino mass only have upper bounds[1]

$$\begin{aligned} m_{\nu_e} &\leq 2.2eV \\ m_{\nu_\mu} &\leq 170KeV \\ m_{\nu_\tau} &\leq 18.2MeV \end{aligned} \tag{3}$$

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- No elementary particle in the Standard Model is known to be a Majorana fermion. However, the nature of the neutrino is not yet definitely settled
- Neutrino can be a Majorana fermion or it might be a Dirac fermion.
- In the Standard Model the observation of neutrinoless double beta decay necessarily implies Majorana nature of neutrinos

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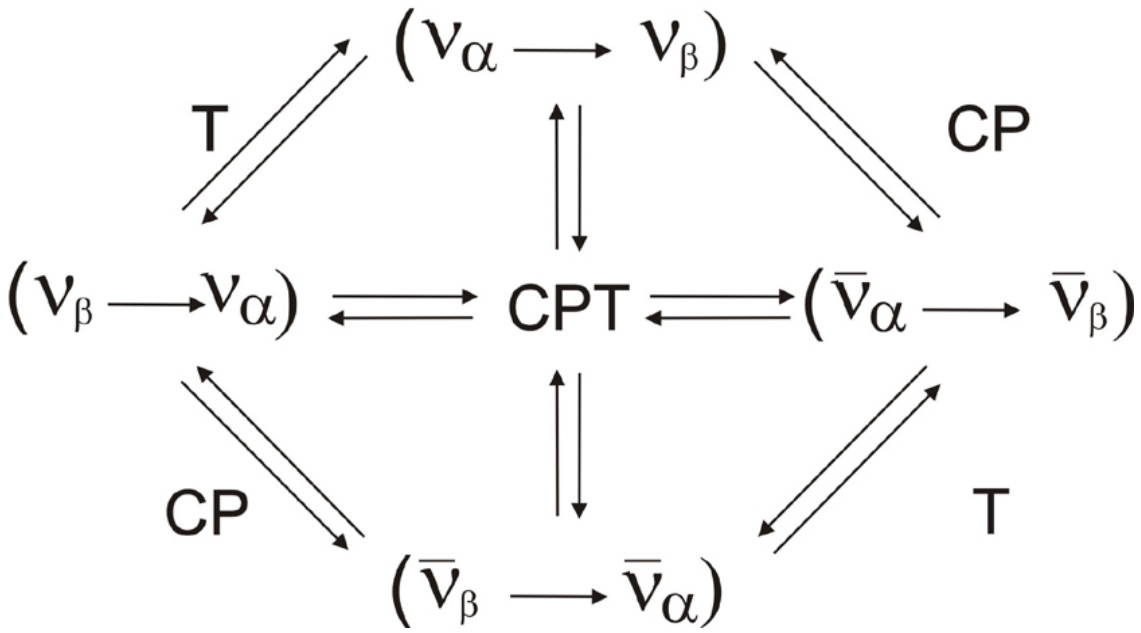
Symmetries C, CP, CPT to Dirac Neutrino

- To Dirac neutrinos if we applied the symmetries **C**, **T**, **CP** and **CPT**, we have



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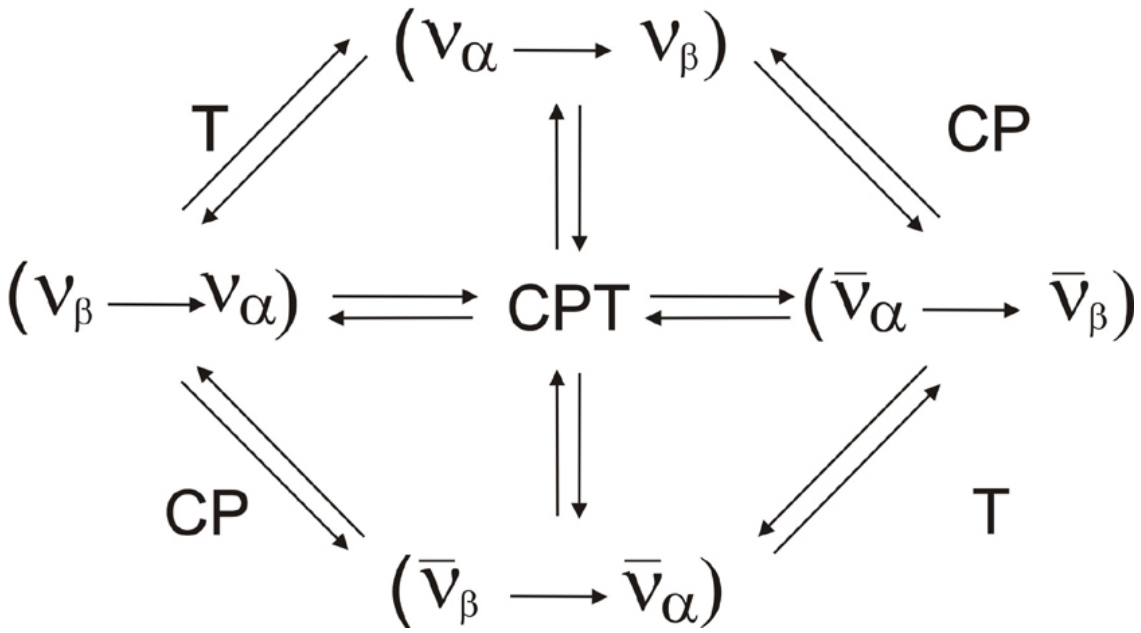

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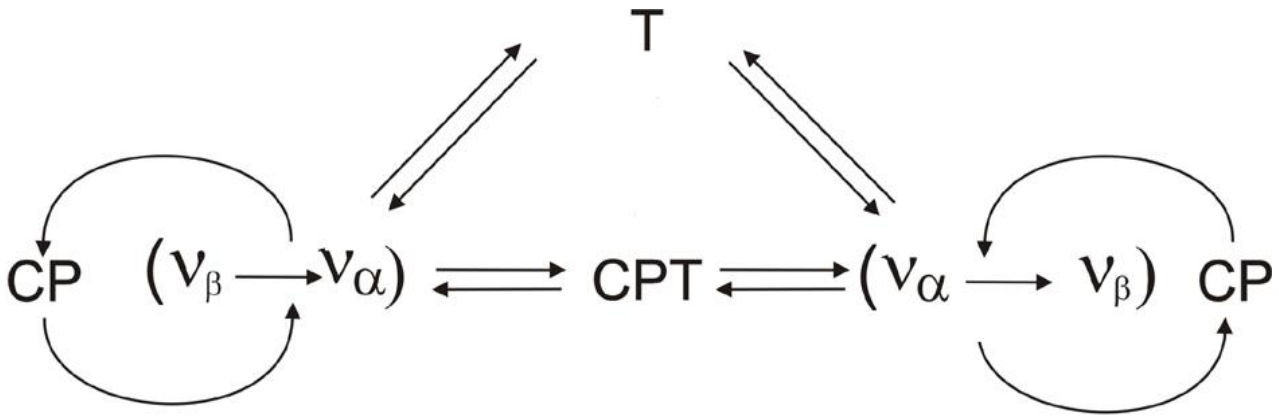

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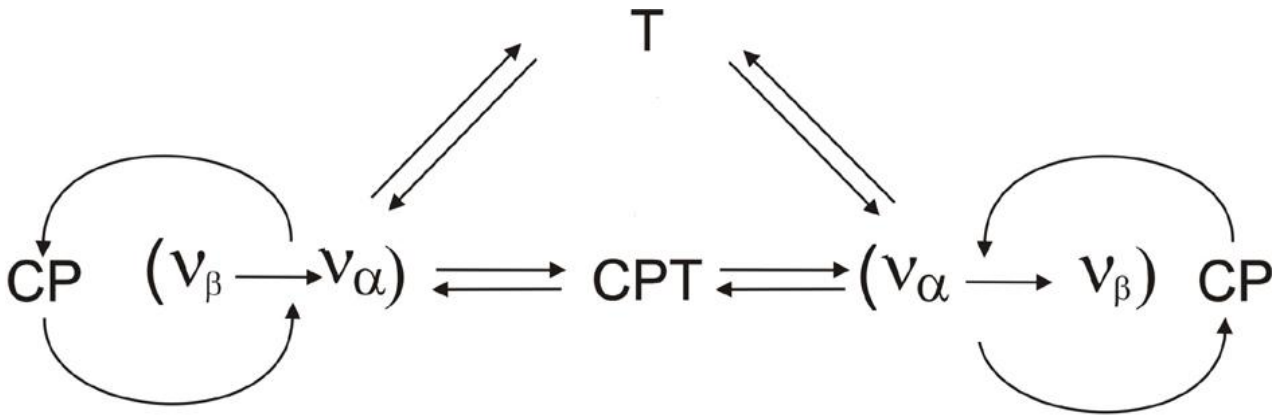

- If we start a process of neutrino flavor change, there are only two possible states endings, under the discrete symmetries C, CP and CPT

Properties of electromagnetic form factors

- To find all the electromagnetic form factors, we can arrive at the general expression for the current

$$\left\langle \nu(p,\lambda)|J_{\mu}^{EM}(x)|\nu\left(p',\lambda'\right)\right\rangle = \overline{\nu}(p,\lambda)\Lambda_{\mu}(l,q)\nu\left(p',\lambda'\right) \tag{4}$$

where $q_{\mu} = p'_{\mu} - p_{\mu}$, $l_{\mu} = p'_{\mu} + p_{\mu}$ and $\nu\left(p,\lambda\right)$, $\nu\left(p',\lambda'\right)$ are the initial and final states.and Λ_{μ} is a matrix acting on the spinors[2].

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  - Finally, the current conservation (or gauge invariance) $\partial_\mu J_\mu^{EM} = 0$ can be recast into

$$q^\mu\overline{\nu}\left(p',\lambda'\right)\Lambda_\mu(l,q)\nu(p,\lambda) = 0 \tag{6}$$

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The electromagnetic form factors

- The most general expression for $\Lambda_\mu(l, q)$ is[3]

$$\Lambda_\mu(q) = F_Q(q^2)\gamma_\mu + F_M(q^2) i\sigma_{\mu\nu}q^\nu + F_E(q^2)\sigma_{\mu\nu}q^\nu\gamma_5 + F_A(q^2)(q^2\gamma_\mu - q_\mu \not{q})\gamma_5 \quad (7)$$

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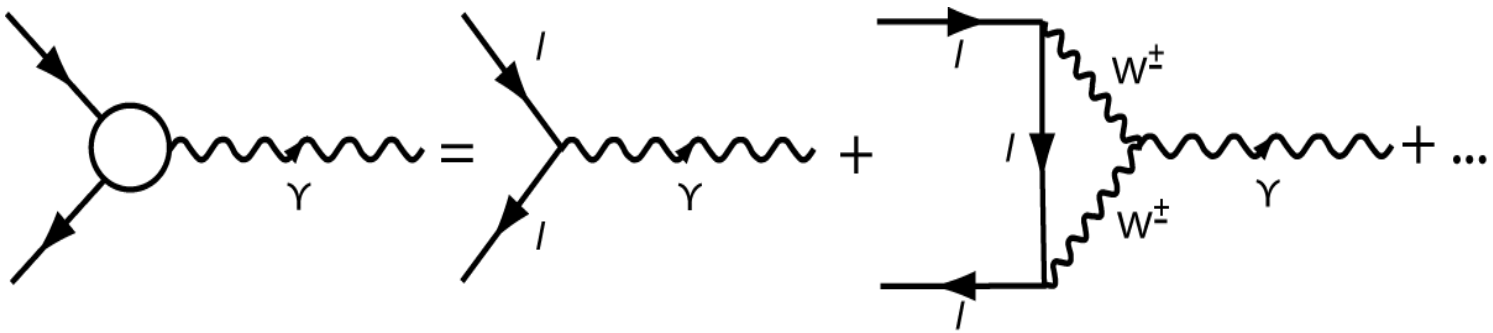

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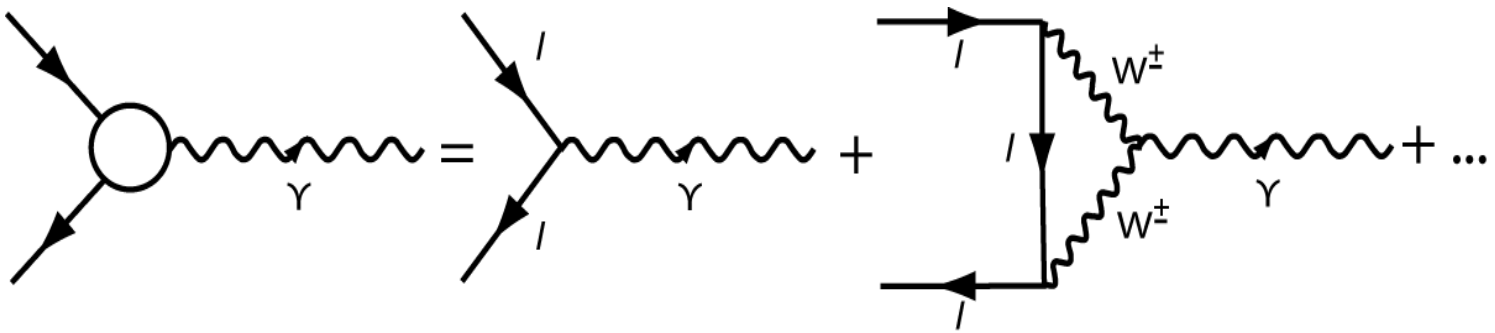
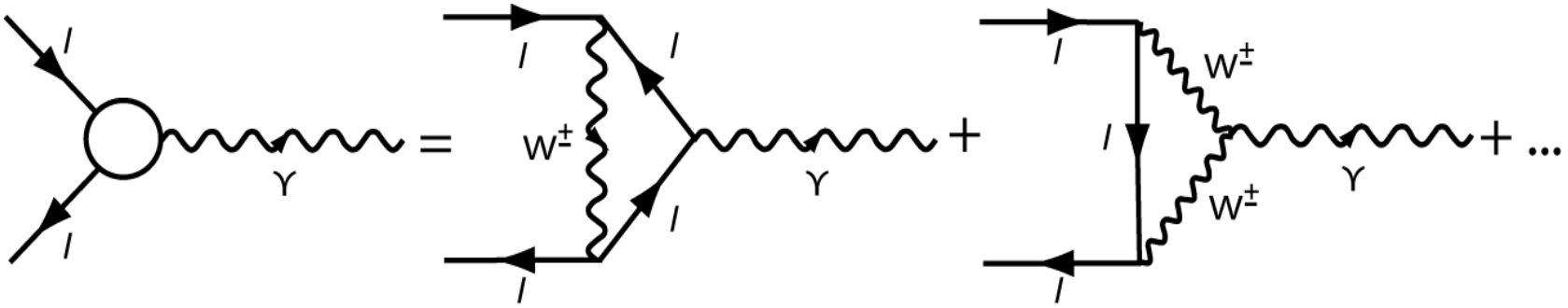


- For neutral particles like neutrinos



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- For proton and neutron the magnetic moment term is called anomalous magnetic moment.
- The dipole electric moment and anapole moment only appears like corrections to loop.

For the lepton charged

- This table we can summarize the electromagnetic properties of leptons charged[4]

l	Mass$\left(\frac{MeV}{c^2}\right)$	EC(e)	MDM	EDM$\left(\frac{e}{2m_l}\right)$
e	0.51	1	$1.159 \times 10^{-3}\mu_B$	$< 1 \times 10^{-16}$
μ	105.658	1	$1.159 \times 10^{-3}\frac{e}{2m_\mu}$	$< 2 \times 10^{-6}$
τ	1.776×10^3	1	$1.159 \times 10^{-3}\frac{e}{2m_\tau}$	$< 2 \times 10^{-2}$

[4] Lepton dipole moments (ed B. Roberts, J. Marciano) world Scientific, 2010

.... And for neutrinos case

- Like other particles, neutrinos can be described by electromagnetic form factors that can be manifested in many processes

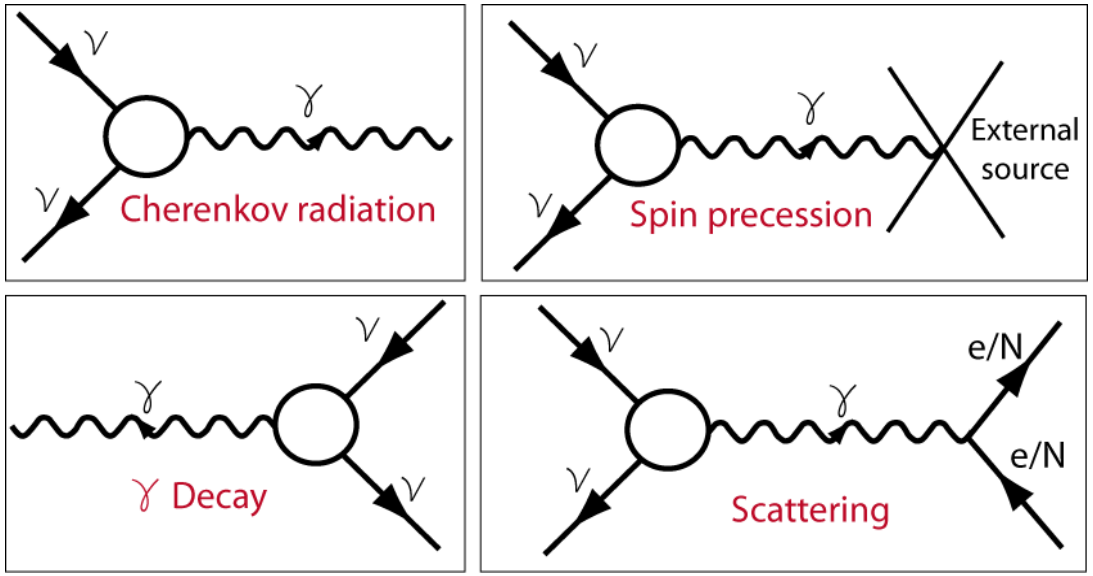

Figure: Schematic diagrams for the various experimental manifestations of neutrino-photon couplings

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- In particular, can be described by electromagnetic form factors with vertex function

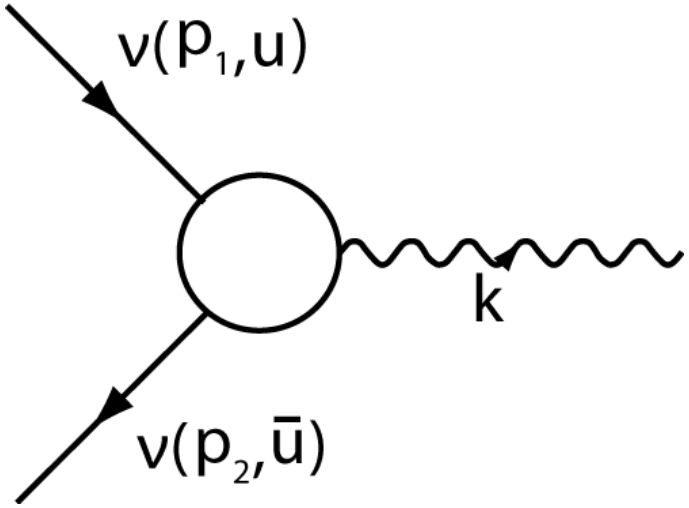

Figure: The circle represents schematically the neutrino electromagnetic vertex function

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- For the anomalous magnetic moment the leading contribution is

$$a_{\nu_i} = -\frac{3G_F m_{\nu_i}}{4\sqrt{2}\pi^2} m_e \tag{8}$$

where $G_\mu = 1.166 \times 10^{-5} GeV^{-2}$.

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- For Dirac neutrinos only F_M are possible, because the other terms vanish owing to CP invariance and hermiticity of J_μ^{EM}.
- For Majorana neutrinos only F_A is possible, because the other terms vanish owing to the self-conjugate nature of Majorana neutrinos.

For neutrinos

- This table we can summarize the electromagnetic properties of massive neutrinos[5]

l	Mass$\left(\frac{MeV}{c^2}\right)$	EC(e)	MDM
ν_e	$< 2.2 \times 10^{-6}$	0	$\lesssim 3 \times 10^{-19} \mu_B$
ν_μ	< 0.17	0	$\lesssim 3 \times 10^{-14} \mu_B$
ν_τ	< 18.2	0	$\lesssim 3 \times 10^{-12} \mu_B$

[5] Lepton dipole moments (ed B. Roberts, J. Marciano) world Scientific, 2010

The two Higgs doublet model

- The 2HDM is a minimal extension to the SM, which contains five Higgs boson in its spectrum[6].

[6] J. Gunion, H. Haber, G. Kane, S. Dawson. Higgs hunter´s guide, Perseus publishing. 2000

[7] R. A. Díaz, Ph.D. Thesis [arXiv: hep-ph/0212237].

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- $\bar{l}_{iL}^{0}$ denote the quark and lepton weak isospin left handed doublets respectively. The superscript "0" indicate that the fields are not mass eigenstates yet.

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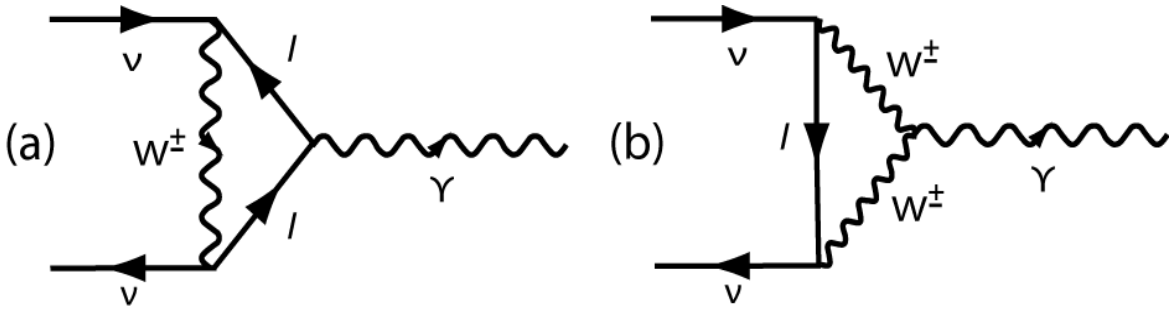

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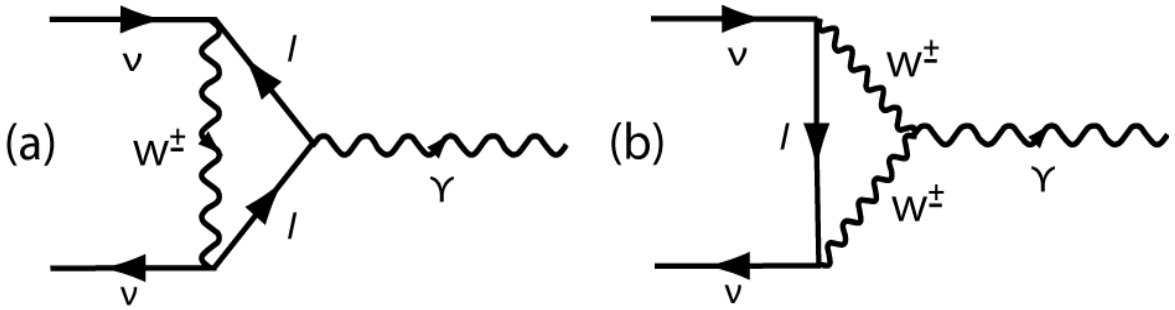

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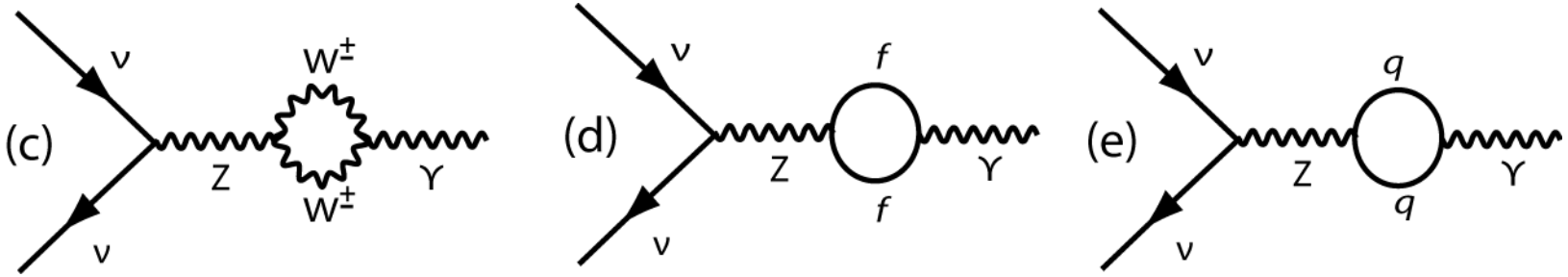

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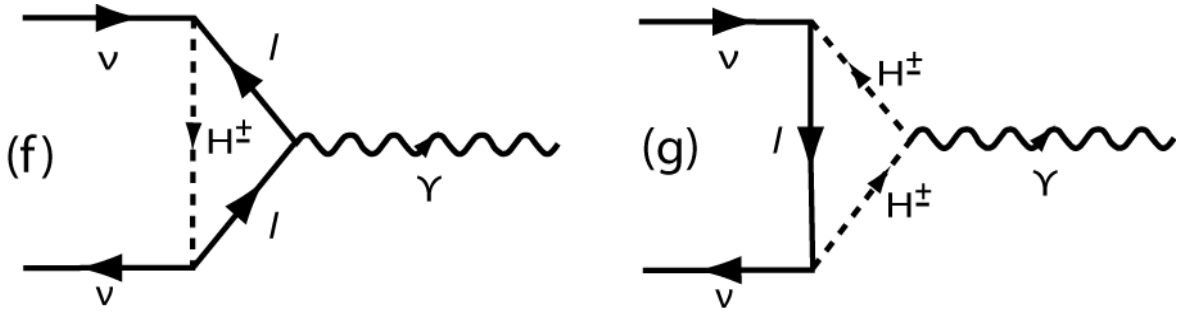

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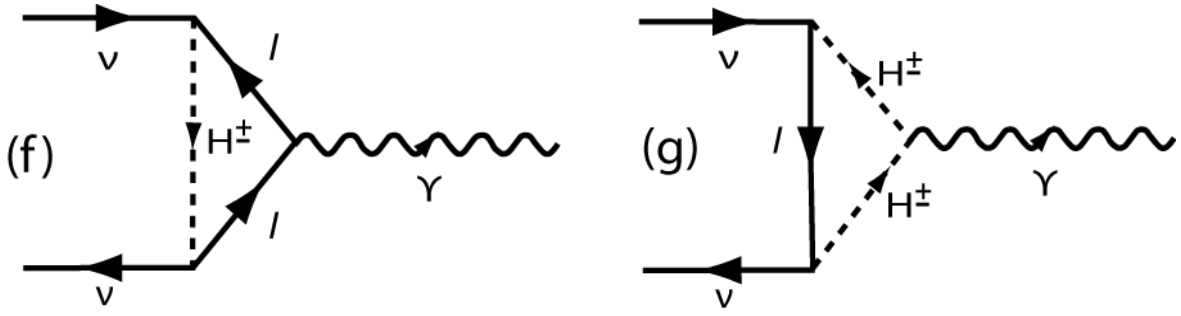

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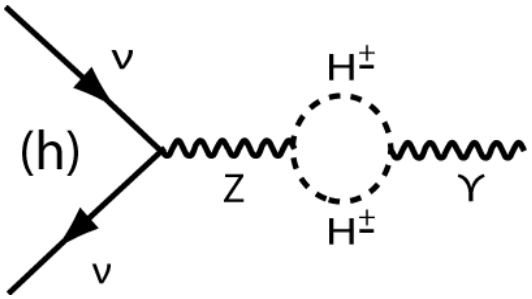

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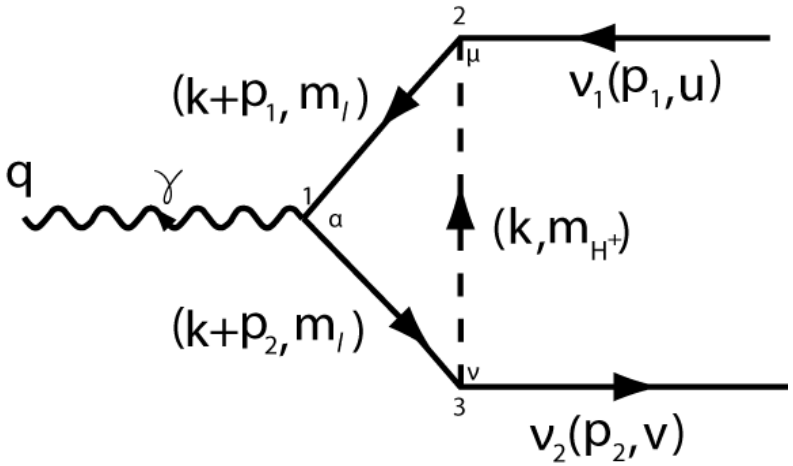

- The contribution to MDM

$$\frac{eQ_f}{16\pi^2}\int_0^1 dx\int_0^x dy\left(\frac{1}{P^2}\left(2x^2 m_\nu + x\left(m_l - m_\nu\right)\right)\left(ac+bd\right)\right)$$

where a, b, c and d are values for 2HDM type I, II and

$$P^2 = (y-x)^2 - \left(\frac{m_{H^\pm}^2 - m_l^2 - m_\nu^2}{m_\nu^2}\right)(y-x) + \frac{m_l^2}{m_\nu^2}$$

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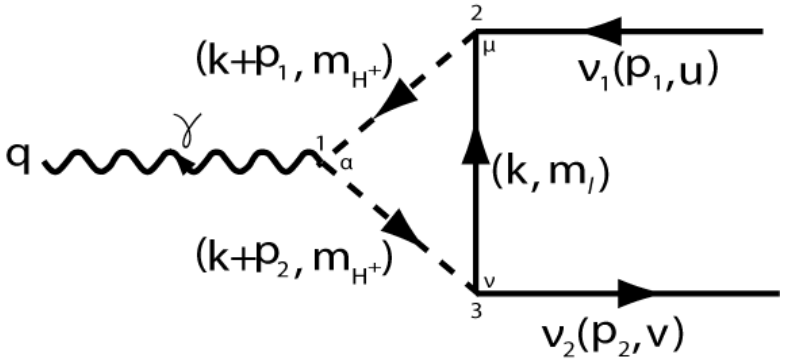

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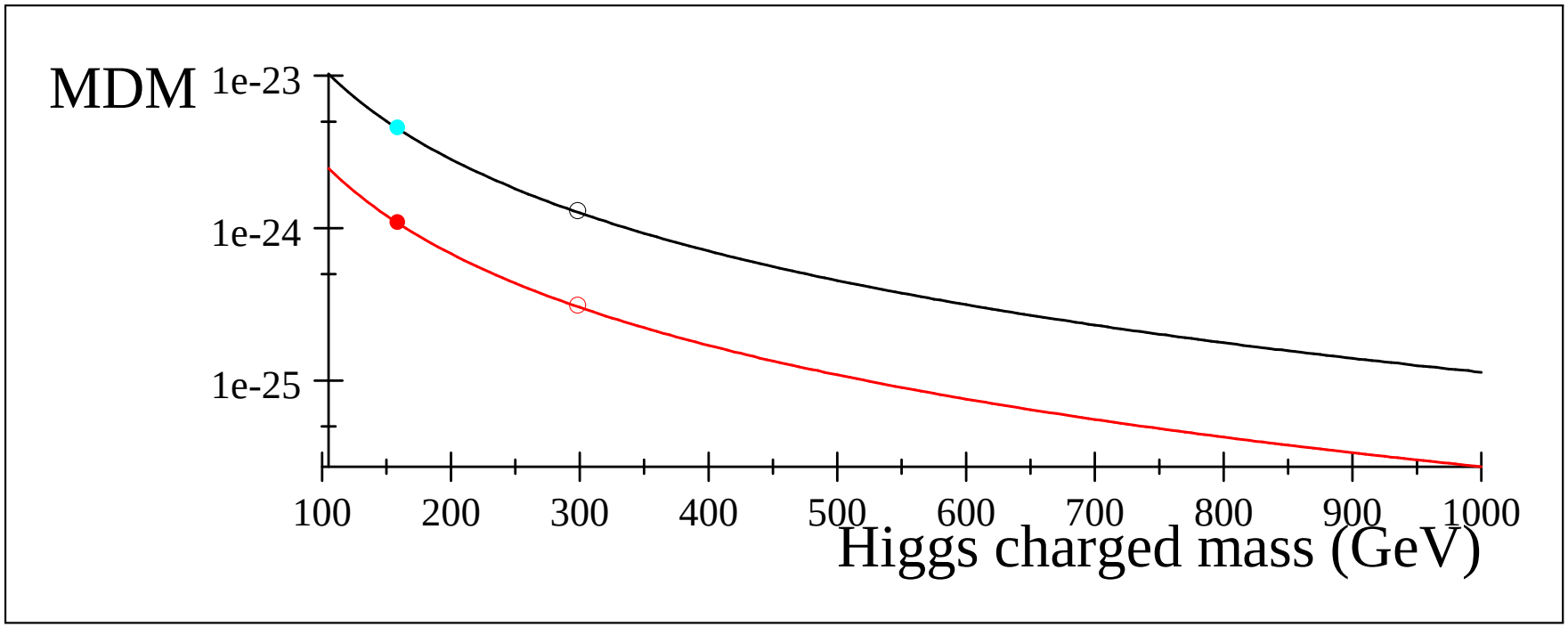

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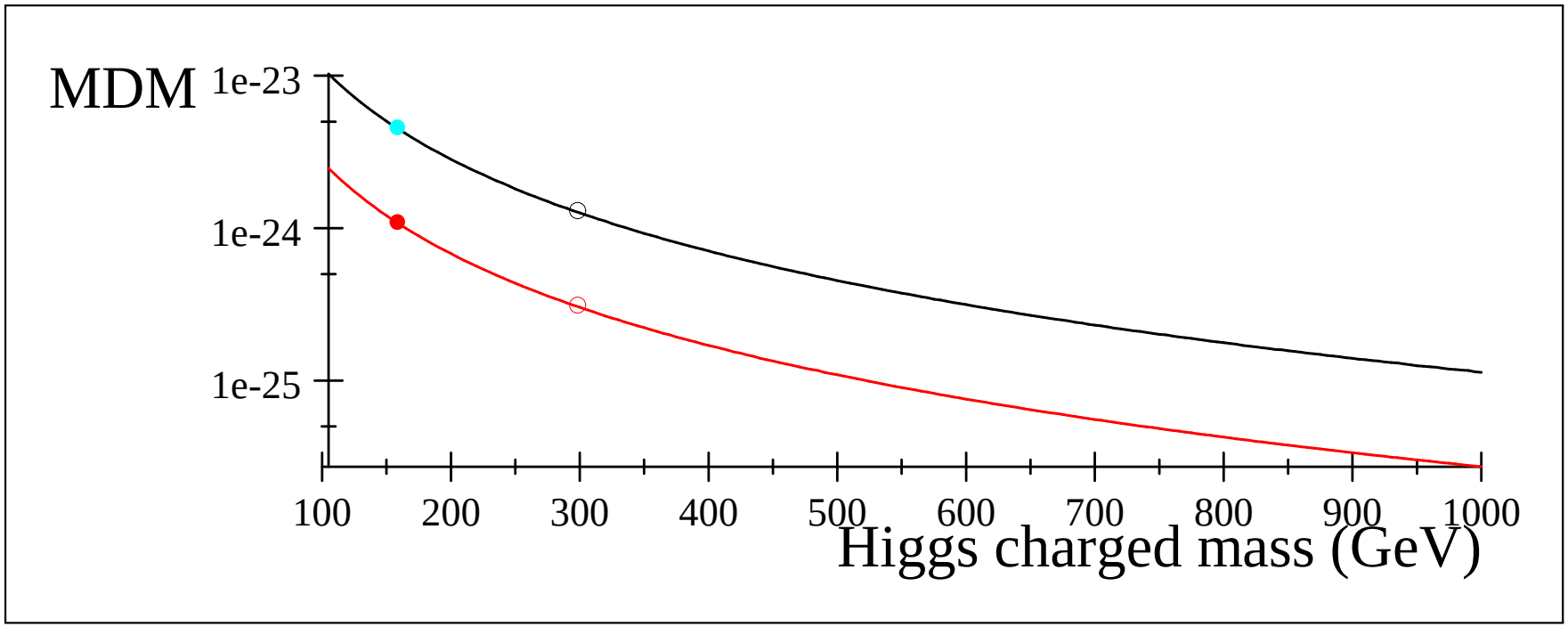

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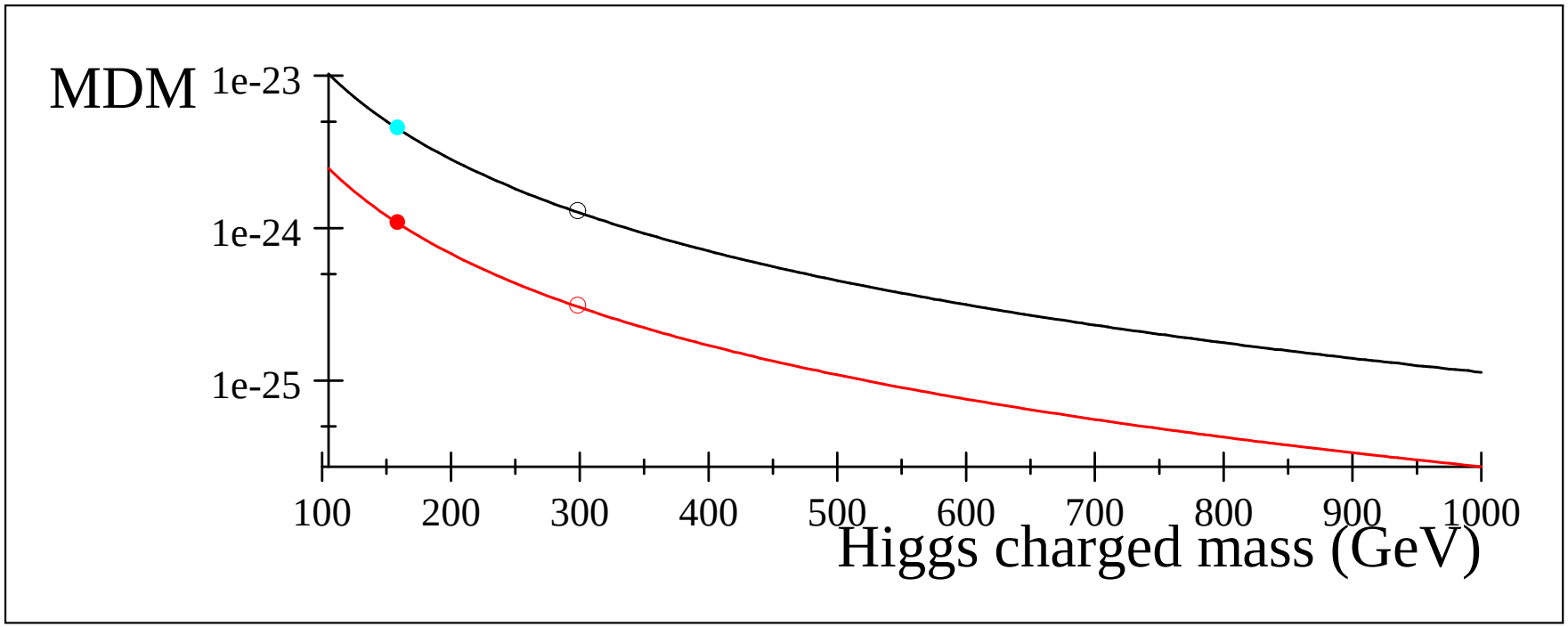

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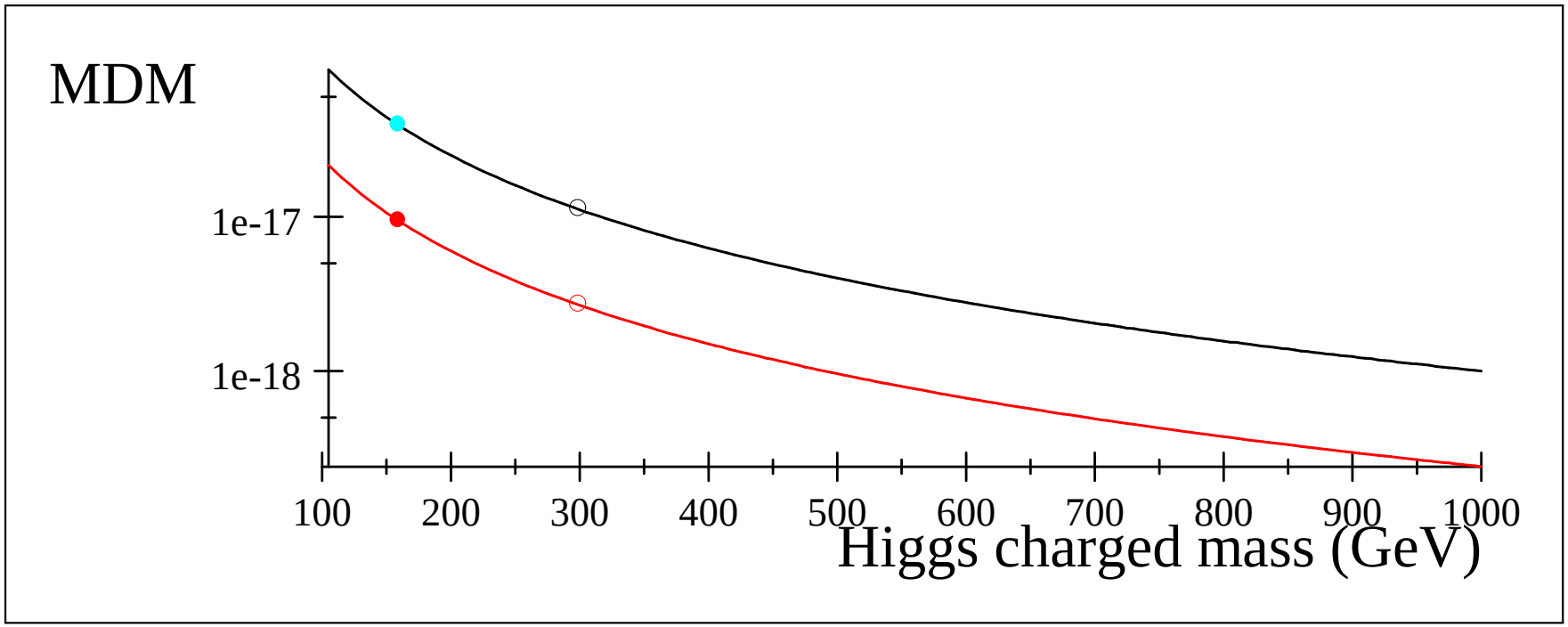

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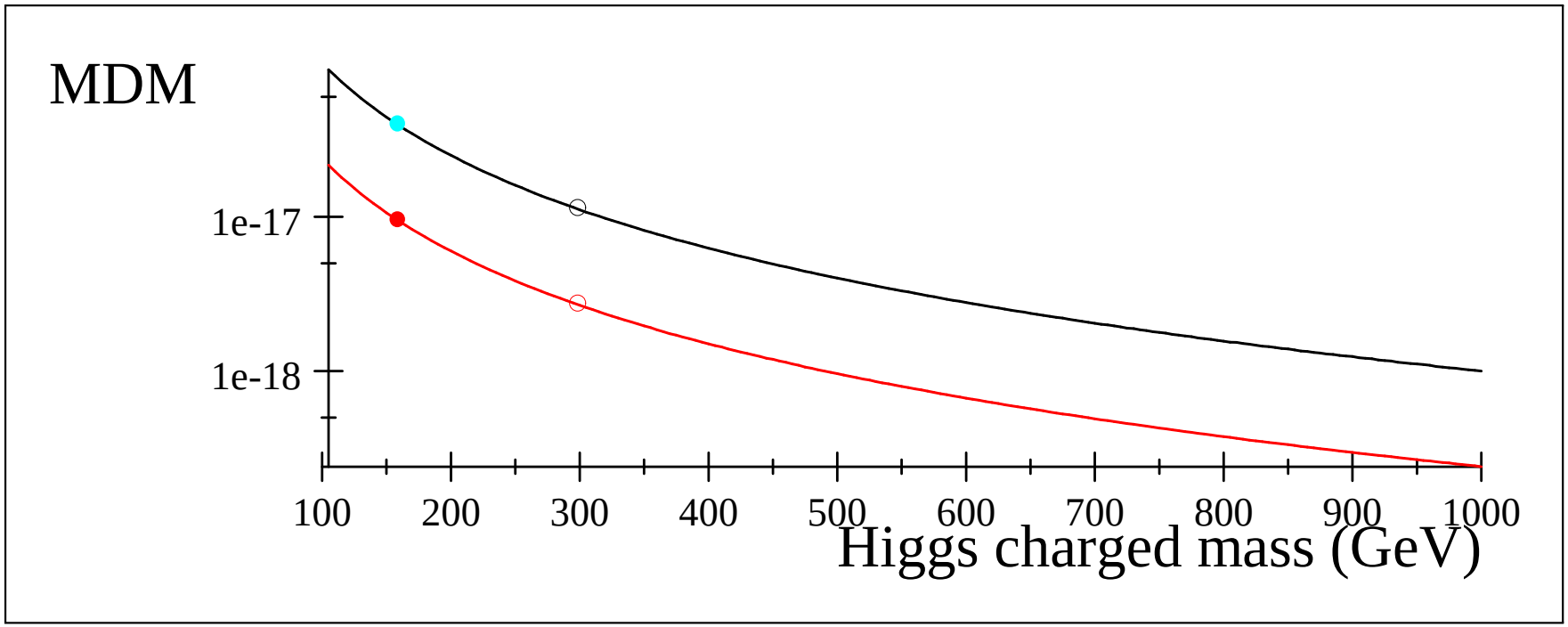

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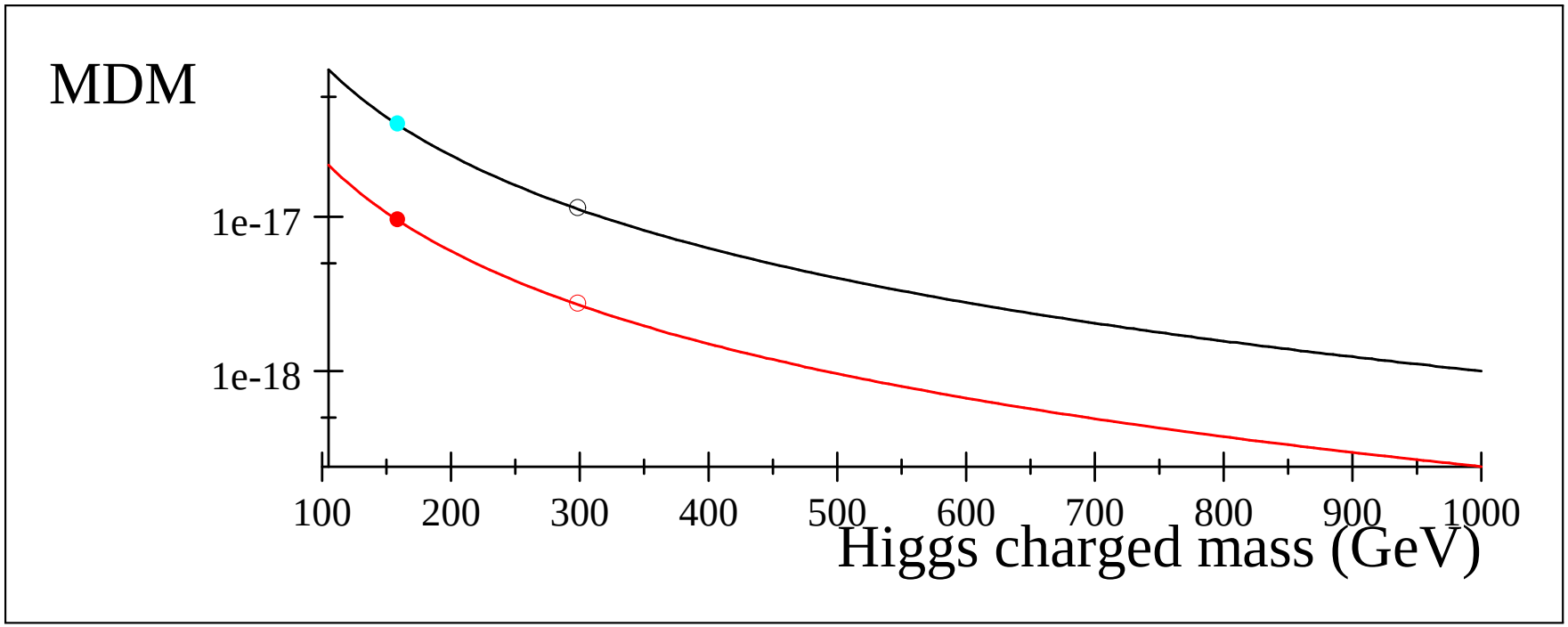

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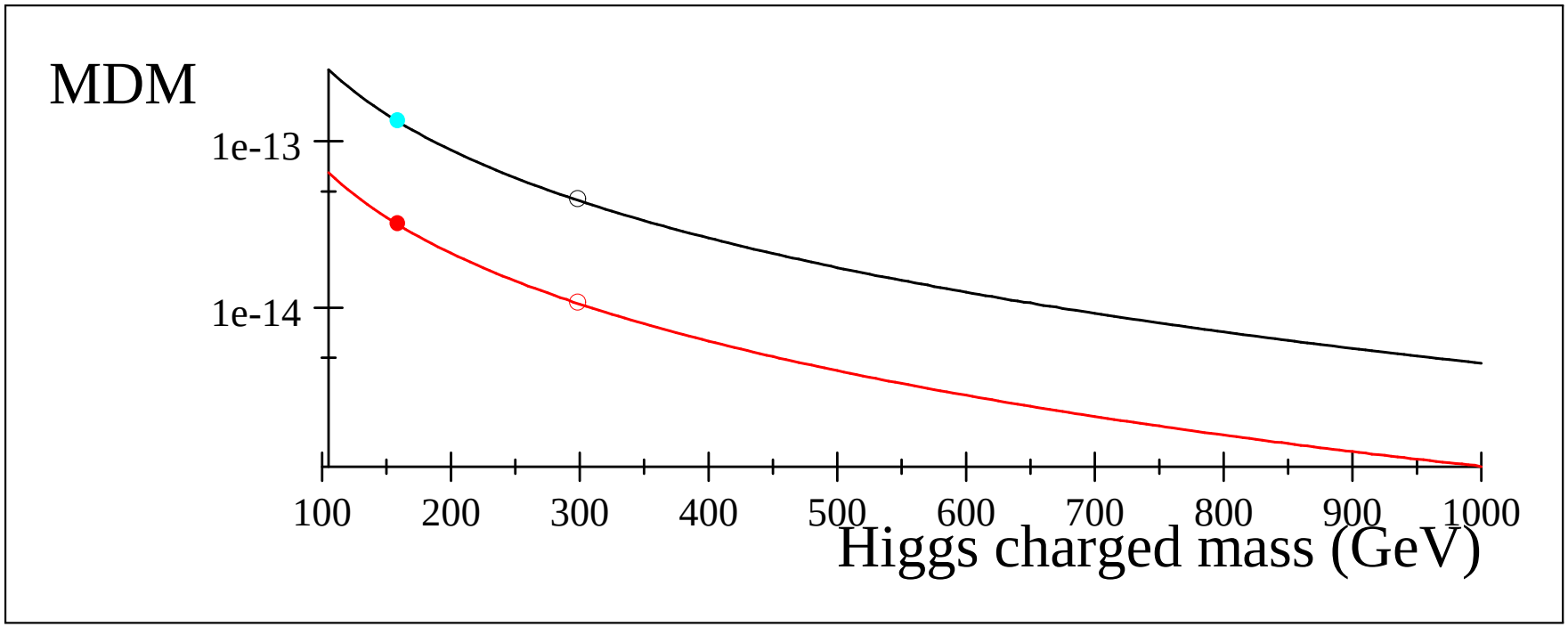

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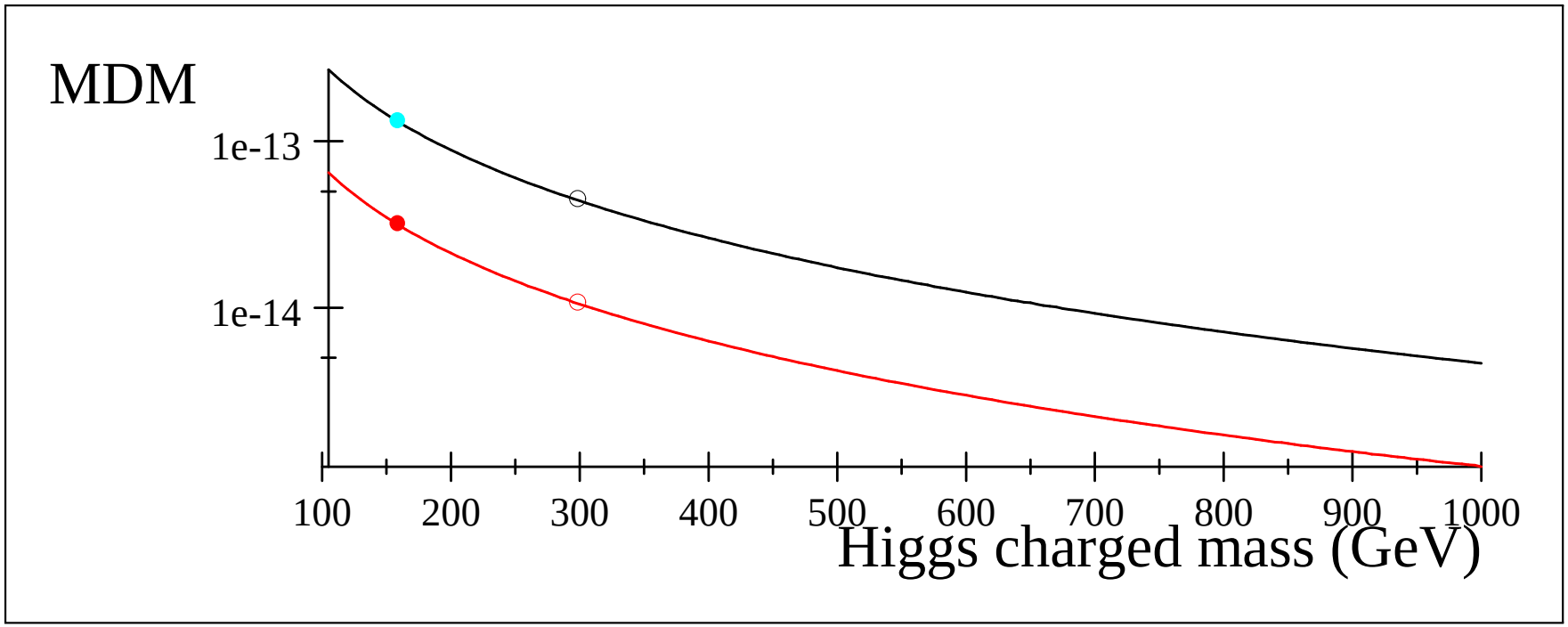

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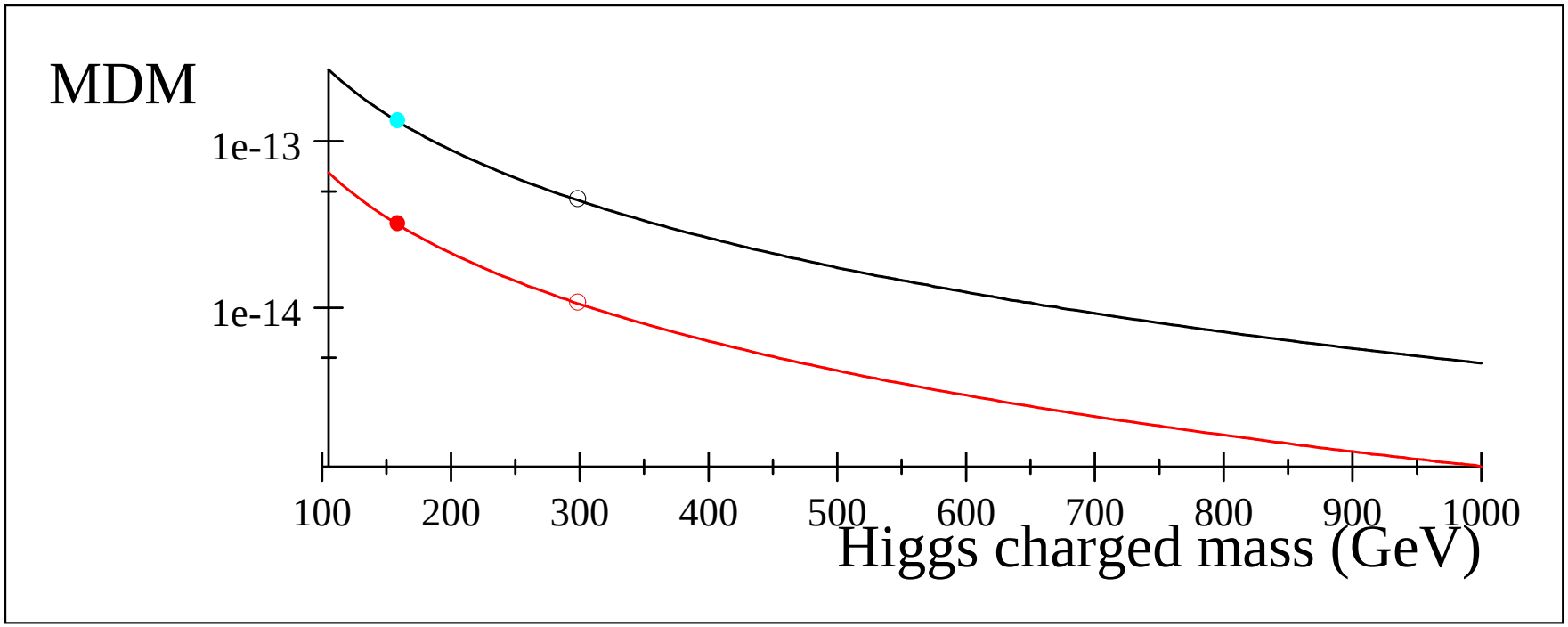

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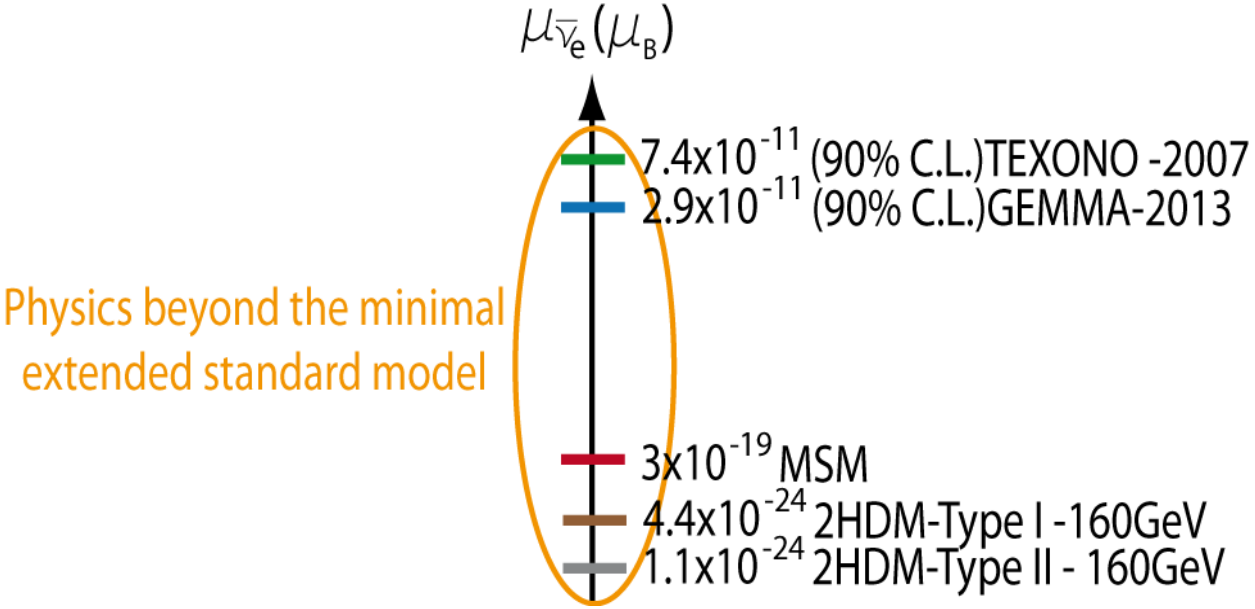

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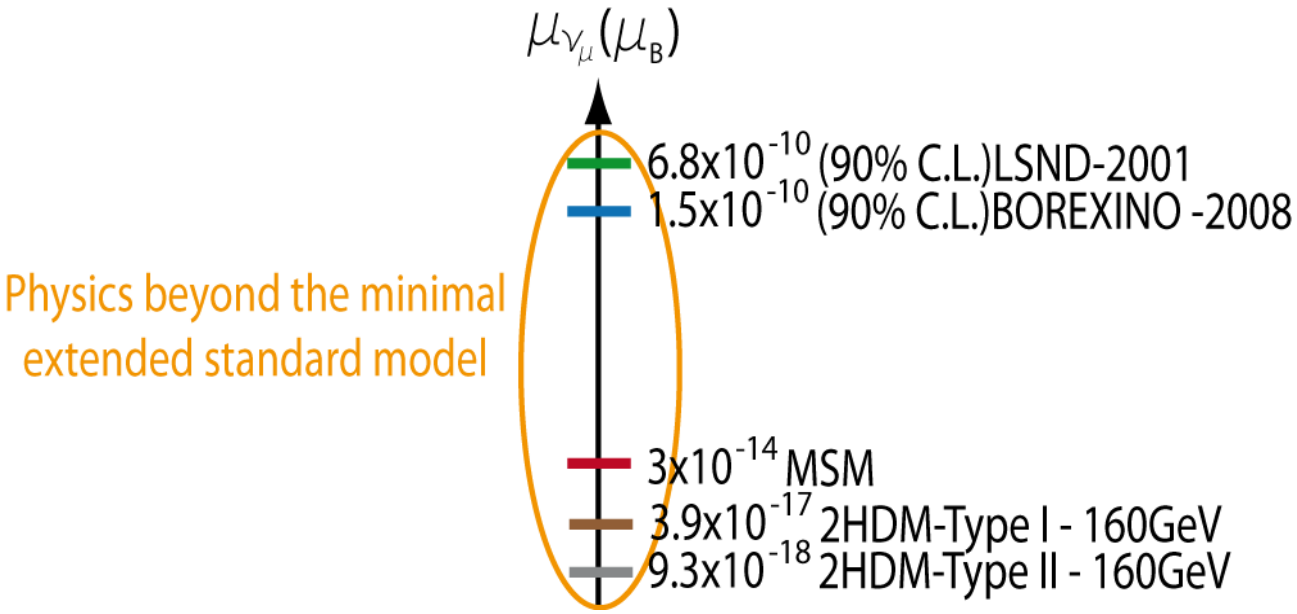
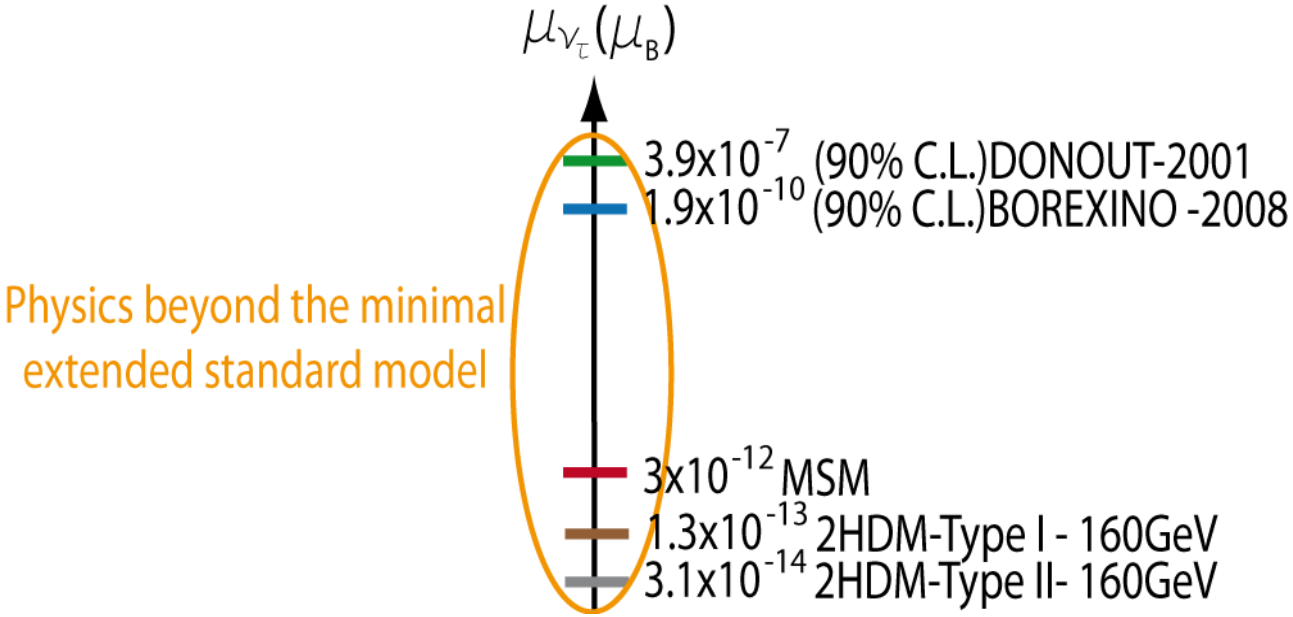


Our results for the contribution of 2HDM

- We can summarize the dipole magnetic moment of tau neutrino in MSM and 2HDM type I and type II with $\tan\beta = 10$ and Higgs charged mass $160\,GeV$.



Summary and perspectives

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- The electromagnetic form factors are elements that contribute to the scattering matrix and describe neutrino interactions with real photons.

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- Is necessary to analyze all the parameters that could help in the search for representative contributions for current or near future detectors.

Thanks for your company

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Magnetic dipolar moment (MDM)

- The interaction of a particle with a magnetic moment, usually called Dirac magnetic moment, expressed in terms of the Lande $g-\text{factor}$

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- Thus even uncharged particles may have MDM, for such particles, the entire MDM is anomalous.

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- Whereas that CP as well if CPT holds.

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- The anapole moment has no classical analog, as it does not correspond to a multipolar distribution.

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  - Change quark and lepton flavor and are likely to be suppressed by mixing effects and unitary cancellations.
  - They are expected to be proportional to $\frac{m_{f_i}}{\Lambda^2}$, where Λ^2 is the scale of new physics responsible for those quantum loop generated amplitude.

Symmetries and electric and magnetic fields

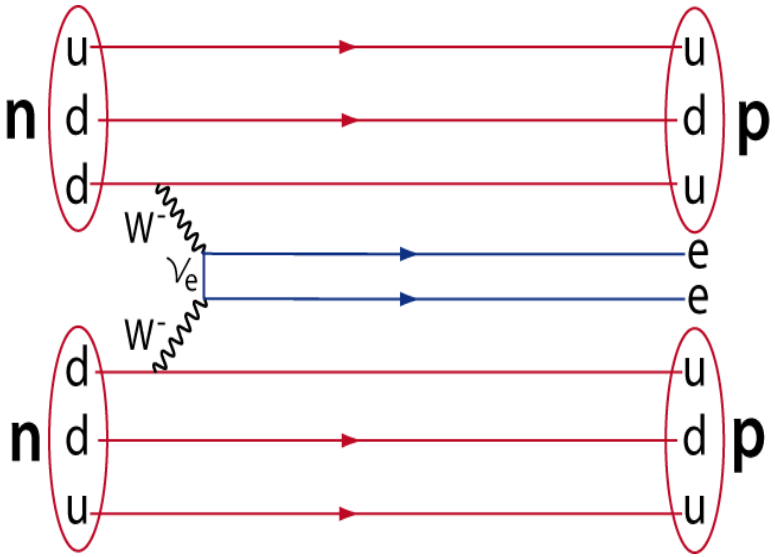
To discrete symmetries like **C**, **P**, **T** and **CPT**

	$\vec{A}$	$\vec{\sigma}$	$\vec{p}$	φ	$\vec{B} = \nabla \times \vec{A}$	$\vec{E} = -\nabla\varphi - \frac{\partial \vec{A}}{\partial t}$
C	$-$	$+$	$+$	$-$	$-$	$-$
P	$-$	$+$	$-$	$+$	$+$	$-$
T	$-$	$+$	$-$	$+$	$-$	$+$
CPT	$-$	$-$	$+$	$-$	$+$	$+$

(14)

Neutrinoless double-beta decay

- The processes Implies that the neutrino is a Majorana particle (meaning that the antineutrino and the neutrino are actually the same particle)
- The neutrinos in the above diagram are virtual particles. With only the two electrons in the final state



- The collaboration Heidelberg-Moscow claims to have seen the process.

Magnetic dipole moment (MDM)

- For the electron case

$$\vec{\mu} = g\left(\frac{e}{2m_e}\right)\vec{s} \tag{15}$$

  where g is the $g-\text{factor}$ for spin
- BUT for the proton and neutron the $g-\text{factor}$ is ~ 5.5 and ~ -3.8 respectively.
- It became convenient to break the magnetic moment into two pieces

$$\mu = (1+a)\frac{e\hbar}{2m} \quad \text{where } a = \frac{g-2}{2}$$

  The first piece is the predicted by the Dirac equation and the second is the anomalous (Pauli) moment.

Dipole electric moment (EDM)

- The electric dipole moment must be along the spin

$$\vec{d} = \eta \left(\frac{e}{2mc} \right) \vec{s} \tag{16}$$

where η is dimensionless constant.

Some experimental results

- The experimental value of magnetic moment are

Paper \ Form factor	F_Q	F_M	F_E	F_A
D. A. Krakauer[14]	X	$\mu_{\nu_e} < 10.8 \times 10^{-10} \mu_B$ at $90\% CL$ $\mu_{\nu_\mu} < 7.4 \times 10^{-10} \mu_B$ at $90\% C.L.$	X	X
D.W. Liu[15]	X	$\mu_\nu < 1.1 \times 10^{-10} \mu_B$ at $90\% CL$	X	X
H. B. Li[16]	X	$\mu_\nu < 1 - 1.3 \times 10^{-10} \mu_B$ at $90\% CL$	X	X
C. Arpesella[17]	X	$\mu_\nu < 5.4 \times 10^{-11} \mu_B$ at $90\% CL$	X	X

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What we know about the neutrinos

Where we got $\Delta m^2_{SOL} = \Delta m^2_{21}$ and $\Delta m^2_{ATM} = \left|\Delta m^2_{31}\right|$ with

$$\begin{aligned} \Delta m^2_{21} &= (7.59 \pm 0.2) \times 10^{-5} eV^2 \\ \Delta m^2_{31} &= (2.43 \pm 0.13) \times 10^{-3} eV^2 \end{aligned} \tag{17}$$