Contribution to the neutrino form factors coming from the charged Higgs of a two Higgs doublet model in presence of magnetic fields

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Abstract

The presence of a charged Higgs in the two Higgs doublet model in presence of magnetic field induces aditional corrections to the neutrino form factors. We calculate and analyze such contributions in the parameter space of the two Higgs doublet model type I and type II. The characterization of the neutrino form factors could discriminate between Majorana and Dirac neutrinos.

Introduction

The magnetic fields $\vec{B}$ are present in many aspects ranging from tiny magnets to magneto stars, through such beautiful effects as the aurora borealis, for the case of particle physics presence of magnetic fields of the order of $(1 \times 10^{14}G)$ affects relations dispersion in charged particles and even rats decay with respect to those obtained in a vacuum, to analyze the contributions of $\vec{B}$ in a Cherenkov decay in a model with two Higgs doublets (2HDM) type I and II, we consider as the propagators of the particles within the loop change, also the structure of the form factors to discriminate the types of contributions

Electromagnetic form factors

To analyze the electromagnetic form factors we analyze the interaction of the particle with the photon , however for neutrinos this is not possible at tree level , therefore we must analyze the interaction vertex
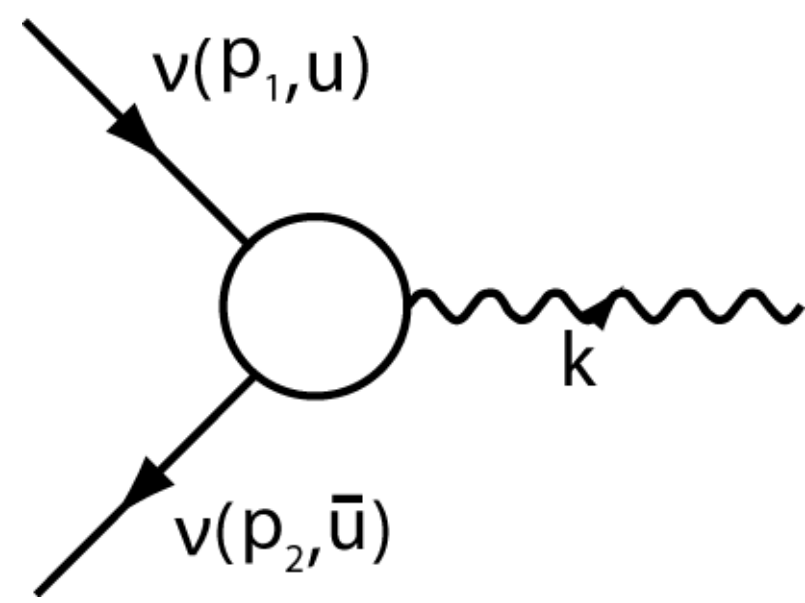
The general expression for the vertex $\Lambda_\mu(l,q)$ is:

$$\Lambda_\mu(l,q) = F_Q(q^2)\gamma_\mu + F_M(q^2)i\sigma_{\mu\nu}q^\nu + F_E(q^2)\sigma_{\mu\nu}q^\nu\gamma_5 + F_A(q^2)(q^2\gamma_\mu - q_\mu\slashed{q})\gamma_5$$

where $F_Q(q^2)$ is associated with the factor of electric charge, $F_M(q^2)$ is associated with the anomalous magnetic moment , $F_E(q^2)$ is associated with the electric dipole moment and $F_A(q^2)$ is called anapolar moment.

In the Minimal Standard Model , the vertex $\nu \to \nu\gamma$ at one loop, has the following contributions at three points
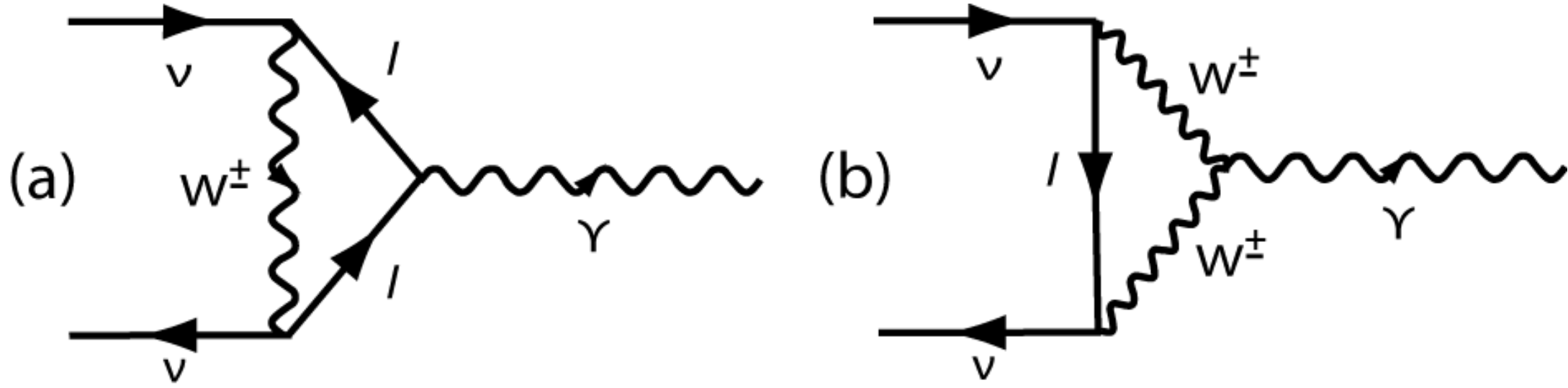
and due to two points
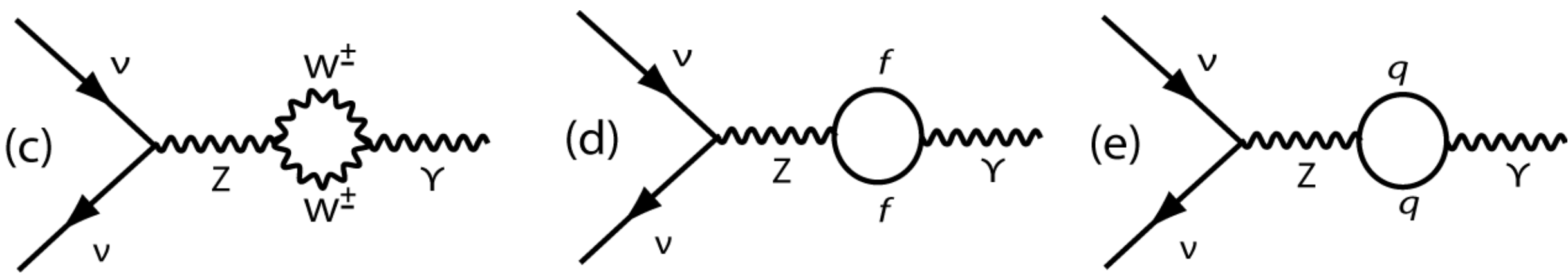
One loop contributions to the electromagnetic form factors in 2HDM

The mechanism of symmetry breaking in the 2HDM scheme is $SU(2)_L \times U(1)_Y \to U(1)_Q$ by introducing two complex doublets with the same quantum numbers, which have the following mass eigenstates parameters

$$\Phi_1 = \frac{1}{\sqrt{2}}\begin{pmatrix} \sqrt{2}(G^+\cos\beta - H^+\sin\beta) \\ v\cos\beta - h^0\sin\alpha + H\cos\alpha + i(G^0\cos\beta - A^0\sin\beta) \end{pmatrix}$$

$$\Phi_2 = \frac{1}{\sqrt{2}}\begin{pmatrix} \sqrt{2}(G^+\sin\beta + H^+\cos\beta) \\ v\sin\beta + h^0\cos\alpha + H\sin\alpha + i(G^0\sin\beta + A^0\cos\beta) \end{pmatrix}$$

with $\tan\beta = v_2/v_1$. the fermion-scalar Lagrangian most general gauge invariant for the 2HDM is

$$-\mathcal{L}_Y = \eta_{ij}^{E,0}\bar{l}_{iL}^0\Phi_1 E_{jR}^0 + \xi_{ij}^{E,0}\bar{l}_{iL}^0\Phi_2 E_{jR}^0 + \eta_{ij}^{\nu,0}\bar{l}_{iL}^0\Phi_1\nu_{jR}^0 + \xi_{ij}^{\nu,0}\bar{l}_{iL}^0\Phi_2\nu_{jR}^0 + Quark\ sector + h.c.$$

For the charged Higgs sector have for the 2HDM type I ($\Phi_1 \to \Phi_1$, $\Phi_2 \to -\Phi_2$, $E_{jR} \to -E_{jR}$ and $\nu_{jR} \to -\nu_{jR}$)

$$-\mathcal{L}_Y = \frac{g\cot\beta}{\sqrt{2}M_W}l\left(M_l^{diag}P_R - M_\nu^{diag}P_L\right)\nu H^+ + h.c.$$

Likewise for type II ($\Phi_1 \to \Phi_1$, $\Phi_2 \to -\Phi_2$, $E_{jR} \to E_{jR}$ y $\nu_{jR} \to -\nu_{jR}$), we have

$$\mathcal{L}_Y = \frac{g}{\sqrt{2}M_W}\nu\left[\left(\cot\beta M_\nu^{diag}P_L + \tan\beta M_l^{diag}P_R\right)\right]lH^+ + h.c.$$

Interaction with the magnetic field

In the presence of magnetic fields the structure of the propagators change, which can facilitate certain types of processes that previously would see more restricted , since the neutrino does not couple at tree level with the photon

We must consider an interaction 1 loop so as to allow such coupling , since we are working under a model where we consider charged Higgs then we must rewrite the propagators of virtual particles of the loop, for this we consider a static magnetic field homogeneous and which can take this in the direction k , having chosen a preferential direction of the magnetic field in space, causes the Lorentz invariance of the system is restricted because an arbitrary boost could not preserve only the magnetic field, a boost along the direction of the field magnetic or rotation about the direction of the external field , are the only permitted changes now to preserve the preferential direction , therefore the structure of the four- breaks in a parallel and a perpendicular part , therefore we have for any four-vector

$$\begin{aligned} a_\parallel^\mu &= (a^0, 0, 0, a^3) \\ a_\perp^\mu &= (0, a^1, a^2, 0) \\ &\Rightarrow a^\mu = a_\parallel^\mu + a_\perp^\mu = (a^0, a^1, a^2, a^3) \end{aligned}$$

so it

$$(a \cdot b)_\parallel = a^0 b^0 - a^3 b^3$$

The propagator for leptons will be

$$\begin{aligned} S_B^f(p) &= \frac{i}{p^2 - m^2}\left[(m + \gamma \cdot p_\parallel) + \gamma \cdot p_\perp \frac{m^2 - p_\parallel^2}{p_\perp^2}\right] - \frac{\gamma_1\gamma_2(m + \gamma \cdot p_\parallel)}{(p^2 - m^2)^2}eB + \frac{i\gamma \cdot p_\perp}{p_\perp^2} + S_{B_2}^V(p) \\ &= \frac{i(m + \slashed{p})}{p^2 - m^2} - \frac{\gamma_1\gamma_2(m + \gamma \cdot p_\parallel)}{(p^2 - m^2)^2}eB + S_{B_2}^V(p) + S_{B_4}^V(p) \end{aligned} \tag{1}$$

where the first term of the above equation represents the fermionic propagator of one charged particle in a vacuum, while the second term will be the correction to first order in the magnetic field and the remaining terms will be higher order corrections .

While the propagator for a scalar particle

$$iD_B^s(p) = \frac{i}{p_\parallel^2 - p_\perp^2 - m^2}\left(1 - \frac{(eB)^2}{(p_\parallel^2 - p_\perp^2 - m^2)^2} - \frac{2(eB)^2 p_\perp^2}{(p_\parallel^2 - p_\perp^2 - m^2)^3}\right) \tag{2}$$

the contributions at three points in presence of magnetic field for 2HDM
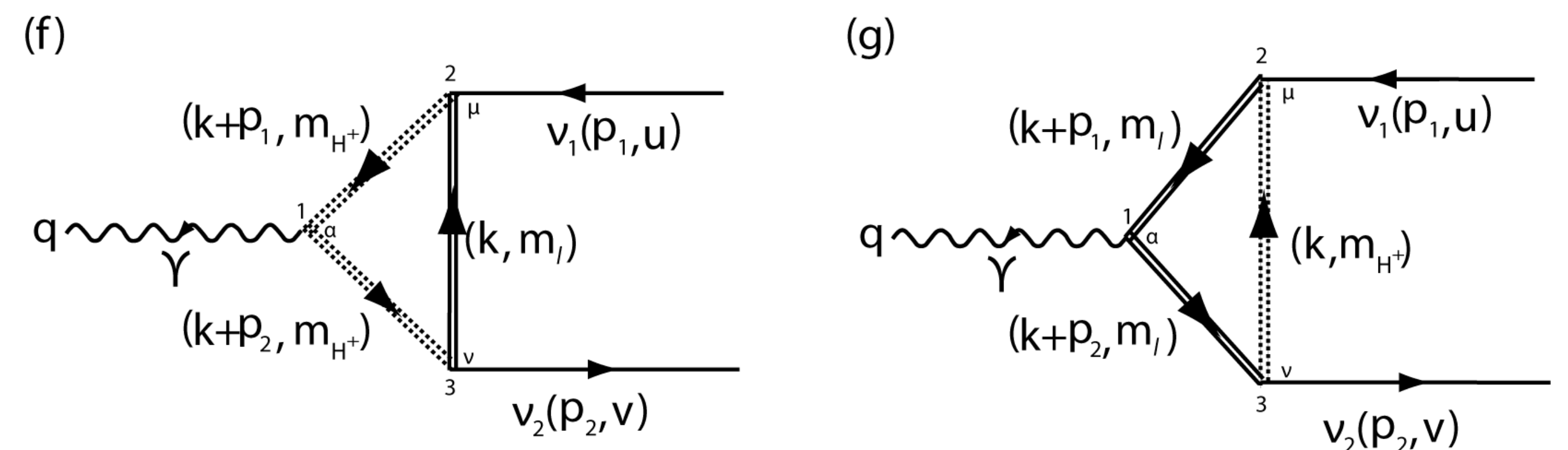
The integral associated with the triangle diagram (f) is

$$\begin{aligned} \Lambda_{2H1L_B}^\alpha(q,l) = &-e\int \frac{d^4k}{(2\pi)^4}\frac{(2k^\alpha + p_2^\alpha + p_1^\alpha)A(m_l + \slashed{k})C}{((k+p_1)^2 - m_{H^\pm}^2)((k+p_2)^2 - m_{H^\pm}^2)(k^2 - m_l^2)} \\ &-ie^2B\int \frac{d^4k}{(2\pi)^4}\left(\frac{(2k^\alpha + p_2^\alpha + p_1^\alpha)A\gamma_1\gamma_2(m_l + g_{\varphi\eta}g_\parallel^{\theta\eta}\gamma^\varphi k_\theta)C}{\left(((k+p_1)^2 - m_{H^\pm}^2)((k+p_2)^2 - m_{H^\pm}^2)(k^2 - m_l^2)\right)^2}\right) \end{aligned} \tag{3}$$

while the associated integral to (g) is

$$\begin{aligned} &\Lambda_{2L1H_B}^\alpha(q,l) \\ &= -e\int \frac{d^4k}{(2\pi)^4}\left(\frac{A(\slashed{k} + \slashed{p}_1 + m_l)\gamma^\alpha(\slashed{k} + \slashed{p}_2 + m_l)C}{\left((k+p_1)^2 - m_l^2\right)\left((k+p_2)^2 - m_l^2\right)(k^2 - m_H^2)}\right) \\ &-e^2Bi\int \frac{d^4k}{(2\pi)^4}\left(\frac{A\gamma_1\gamma_2(m_l + \gamma^\varphi g_{\varphi\eta}g_\parallel^{\theta\eta}(k+p_1)_\theta)\gamma^\alpha(\slashed{k} + \slashed{p}_2 + m_l)C}{\left((k+p_1)^2 - m_l^2\right)^2\left((k+p_2)^2 - m_l^2\right)(k^2 - m_H^2)}\right) \\ &-e^2Bi\int \frac{d^4k}{(2\pi)^4}\left(\frac{A(\slashed{k} + \slashed{p}_1 + m_l)\gamma^\alpha\gamma_1\gamma_2(m_l + \gamma^\vartheta g_{\vartheta\varsigma}g_\parallel^{\tau\varsigma}(k+p_2)_\tau)C}{\left((k+p_1)^2 - m_l^2\right)\left((k+p_2)^2 - m_l^2\right)^2(k^2 - m_H^2)}\right) \\ &+e^3B^2\int \frac{d^4k}{(2\pi)^4}\left(\frac{A\gamma_1\gamma_2(m_l + \gamma^\varphi g_{\varphi\eta}g_\parallel^{\theta\eta}(k+p_1)_\theta)\gamma^\alpha\gamma_1\gamma_2(m_l + \gamma^\vartheta g_{\vartheta\varsigma}g_\parallel^{\tau\varsigma}(k+p_2)_\tau)C}{\left((k+p_1)^2 - m_l^2\right)^2\left((k+p_2)^2 - m_l^2\right)^2(k^2 - m_H^2)}\right) \end{aligned} \tag{4}$$

where $A = cP_L + dP_R$ and $C = cP_L + dP_R$

Conclusions and comments

We found a large difference between the values obtained for form factors in a vacuum and when we have magnetic fields below of the critical value of the magnetic field, the magnetic field favoring greater contribution to the magnetic dipole moment

Acknowledgements

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