Reunión Anual de la División de Partículas y Campos
Sociedad Mexicana de Física

New source of CP violation

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OUTLINE

1.- Introduction.

2.- Electric dipole moments.

3.- CP violation in Triple neutral gauge boson couplings.

4.- CP violation in Anomalous Higgs boson couplings.

5.- Conclusions.

INTRODUCTION

The Baryogenesis is the theoretical process in modern cosmology that lead baryon asymmetry in the early universe. According to Shakarov's criteria are three conditions that are required for baryogenesis :

1.-Baryon number violation.

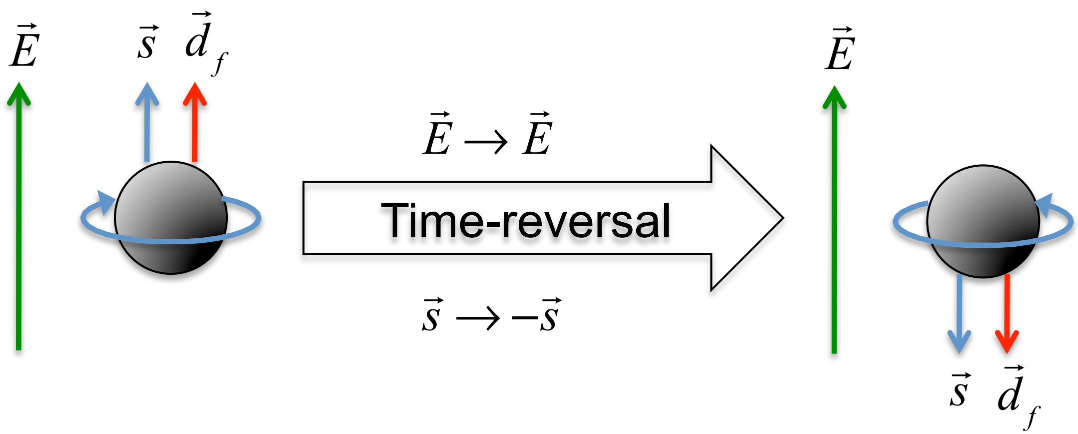
2.- C and CP-symmetry violation.

3.- Interaction out the thermal equilibrium.

The CP violation is included in the SM by the complex phase of the CKM mixing matrix, and have measured small amounts of CP violation in neutral mesosn decays. Unfortunatly, it is not enough to explain the baryon asymmetry, so it is important the study of new sources of CP violation beyond SM..

ELECTRIC DIPOLE MOMENT

The electric dipole moment violates parity and time-reversal symmetries, and in the context of the CPT theorem, violate the CP symmetry.



$$\vec{d}_f = \frac{eQ_f\eta}{2m_f}\frac{\vec{\sigma}}{2}$$

$$H = -\vec{d}_f \bullet \vec{E} \qquad H' = +\vec{d}_f \bullet \vec{E}$$

Therefore, the EDM is forbiden at tree level in the SM.

ELECTRIC DIPOLE MOMENT

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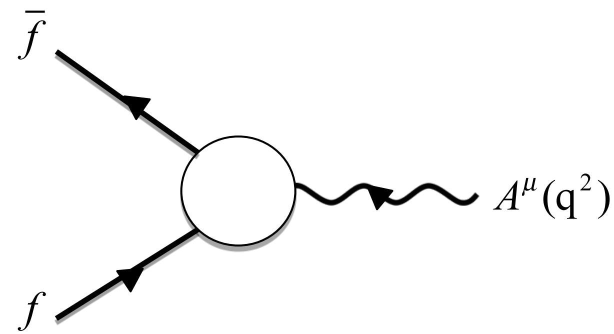
The EDM is induced at multi-loop level in the SM, therefore the respective prediction it is very small.



$d_e \sim d_\tau < 10^{-34}\, e\cdot cm$ NPB341, 322 (1990)

On other hand, the experimental bound are not comparable:

$|d_\mu^-| \le 1.5\times 10^{-19}\, e\cdot cm$ Muon (g-2), PRD80, 052008 (2009)

$-(0.22 + i0.25) < \dfrac{d_\tau}{10^{-16}\, e\cdot cm} < (0.45 + i0.08)$ Belle C. PLB,551, 16 (2003)

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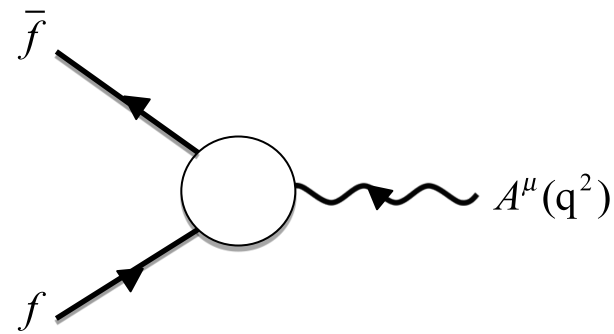

$$\mathcal{L}_{\text{spin-1/2}} = -\boxed{d_f}\frac{i}{2}(\bar{f}\sigma^{\mu\nu}\gamma^5 f)F_{\mu\nu} + \boxed{a_f}\frac{e}{4m_f}(\bar{f}\sigma^{\mu\nu}f)F_{\mu\nu}$$

EDM MDM

Then, the vertex function is given by:

$$\Gamma_V^{\mu}(q^2) = i\boxed{F_2(q^2)}\frac{\sigma^{\mu\nu}q_{\mu}}{2m} + \boxed{F_3(q^2)}\frac{\sigma^{\mu\nu}\gamma_5 q_{\mu}}{2m}$$

CP-even CP-odd

Thus:

$a_f = F_2(q^2 = 0)$ MDM

$d_f = eF_3(q^2 = 0)$ EDM

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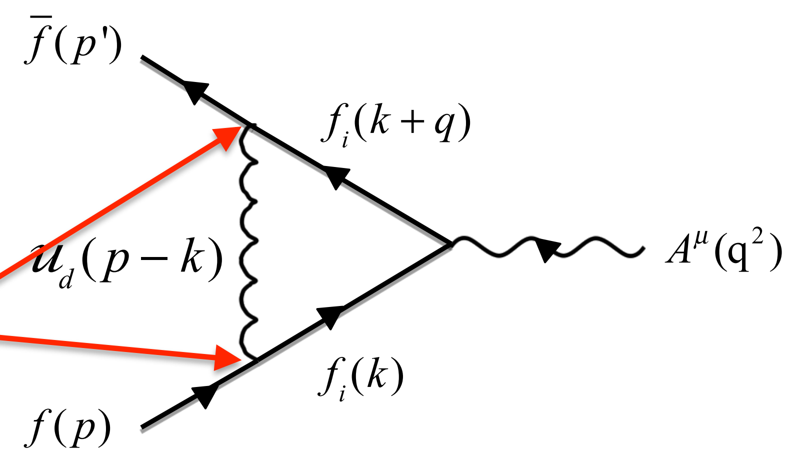
Unparticles framework

$$\mathcal{L}_{\text{spin-1/2}} = \boxed{-d_f} \frac{i}{2}(\bar{f}\sigma^{\mu\nu}\gamma^5 f)F_{\mu\nu} + a_f \frac{e}{4m_f}(\bar{f}\sigma^{\mu\nu} f)F_{\mu\nu}$$



What do you need to induce the EDM?

1.- Non-diagonal coupling in any SM extension.

2.- Complex coupling constants.

$$\mathcal{L}_{\mathcal{U}_{spin-0}} = \frac{\boxed{\lambda^s_{ij}}}{\Lambda_{\mathcal{U}}^{d-1}} \bar{f}_i f_j O_{\mathcal{U}} + i\frac{\boxed{\lambda^p_{ij}}}{\Lambda_{\mathcal{U}}^{d-1}} \bar{f}_i \gamma^5 f_j O_{\mathcal{U}}$$

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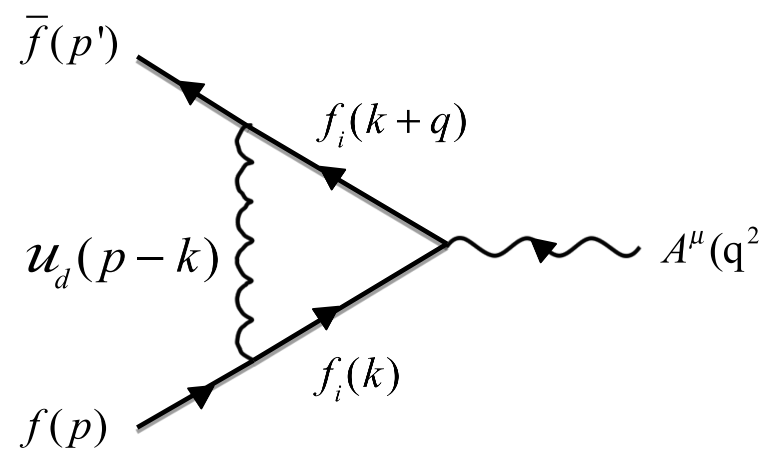

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$$d_f^{\mathcal{U}} = \sum_{(m,n)}^{(s,p),(v,a)} \sum_{i,j=1}^{3} \boxed{\mathrm{Im}(\lambda_m^{ij}\lambda_n^{ij}*)} \frac{m_i^{2d-2}}{\Lambda_{\mathcal{U}}^{2d-2}} \frac{eA_d}{32\pi^2 m_i \sin(d\pi)} \mathcal{G}^k(d, r_{fi}^{\frac{1}{2}})$$

Particularly

$$d_\mu \sim \mathrm{Im}(\lambda_m^{ij}\lambda_n^{ij}*)(10^{-16} - 10^{-21})e\cdot cm$$

PRD84, 073010 (2011)

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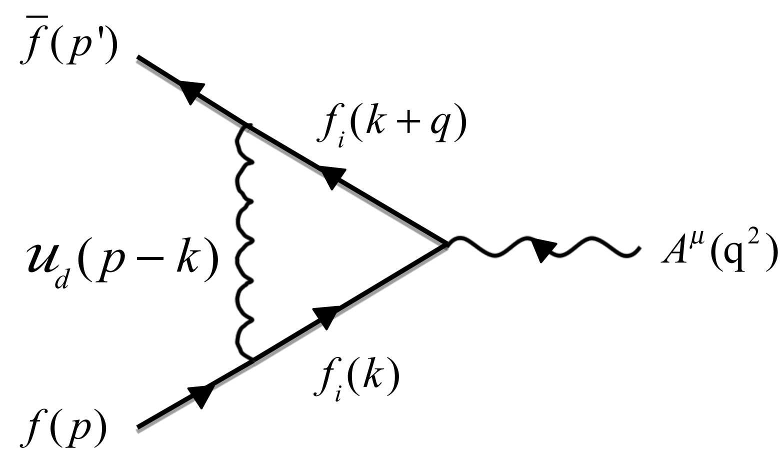

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Particularly

$$\mathrm{Re}(d_\tau) \sim \mathrm{Im}(\lambda_m^{ij}\lambda_n^{ij}*)(10^{-16} - 10^{-21})e\cdot cm$$

$$\mathrm{Im}(d_\tau) \sim \mathrm{Im}(\lambda_m^{ij}\lambda_n^{ij}*)(10^{-16} - 10^{-21})e\cdot cm$$

PRD86, 013014 (2012)

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What do you need to induce the EDM?

1.- Non-diagonal coupling in any SM extension.

2.- Complex coupling constants.

Another results for tau lepton:

Scalar leptoquark interactions

$$d_\tau \sim 10^{-22}\, e\cdot cm$$

PRD89, 055025 (2012)

MSSM with a additional multiplet

$$d_\tau \simeq 6.5\times 10^{-18}\, e\cdot cm - 3.0\times 10^{-22}\, e\cdot cm$$

PRD81, 033007 (2010)

THDM

$$d_\tau \sim 10^{-24}\, e\cdot cm$$

PRD53, 5222(1996)

EPJC11, 293 (1999)

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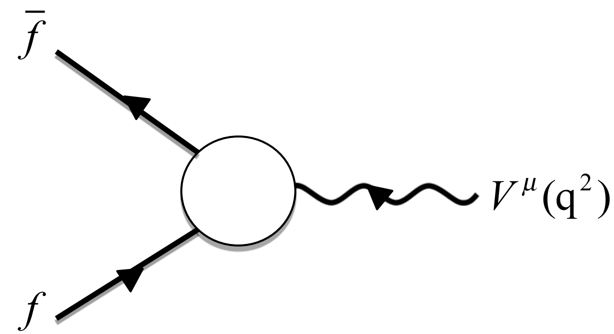

$$\mathcal{L}_{\text{spin-1/2}} = \boxed{-d_f}\frac{i}{2}(\bar{f}\sigma^{\mu\nu}\gamma^5 f)F_{\mu\nu} + a_f \frac{e}{4m_f}(\bar{f}\sigma^{\mu\nu} f)F_{\mu\nu}$$

But we have another types of EDMs

$$\boxed{-d_f^W}\frac{i}{2}(\bar{f}\sigma^{\mu\nu}\gamma^5 f)F_{\mu\nu}^W + a_f^W \frac{e}{4m_f}(\bar{f}\sigma^{\mu\nu} f)F_{\mu\nu}^W$$

Weak dipole moments

$$\boxed{-d_q^g}\frac{i}{2}(\bar{q}T^a\sigma^{\mu\nu}\gamma^5 q)G_{\mu\nu}^a + a_f^g \frac{e}{4m_f}(\bar{q}T^a\sigma^{\mu\nu} q)G_{\mu\nu}^a$$

Cromo dipole moments

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$$-\boxed{d_f^W}\frac{i}{2}(\bar{f}\sigma^{\mu\nu}\gamma^5 f)F_{\mu\nu}^W + a_f^W \frac{e}{4m_f}(\bar{f}\sigma^{\mu\nu} f)F_{\mu\nu}^W$$

WEDM

SM prediction: $d_\tau^W < 8\times 10^{-34}\, e\cdot cm$

Z. Phys. C43,117 (1989)

The ALEPH current best limit:

$$d_\tau < (0.50 + i1.1)\times 10^{-17}\, e\cdot cm$$

EPJ C30,291 (2003)

Unparticles

$$\mathrm{Re}(d_\tau^W) \sim \mathrm{Im}(\lambda_m^{ij}\lambda_n^{ij}*)10^{-24}\, e\cdot cm$$

$$\mathrm{Im}(d_\tau^W) \sim \mathrm{Im}(\lambda_m^{ij}\lambda_n^{ij}*)10^{-25}\, e\cdot cm$$

PRD86, 013014 (2012)

Scalar leptoquark

$$\mathrm{Re}(d_\tau^W) \sim 10^{-22}\, e\cdot cm$$

$$\mathrm{Im}(d_\tau^W) \sim 10^{-24}\, e\cdot cm$$

PRD81, 033007 (2010)

MSSM

$$\mathrm{Re}(d_\tau^W) \sim 10^{-21}\, e\cdot cm$$

PLB425, 322 (1998)

THDM

$$\mathrm{Re}(d_\tau^W) \sim 10^{-22}\, e\cdot cm$$

PRD53, 5222(1996)

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But we have another types of EDMs

$$-d_f^W \frac{i}{2}(\bar{f}\sigma^{\mu\nu}\gamma^5 f)F_{\mu\nu}^W + a_f^W \frac{e}{4m_f}(\bar{f}\sigma^{\mu\nu} f)F_{\mu\nu}^W$$

$$-\boxed{d_q^g}\frac{i}{2}(\bar{q}T^a\sigma^{\mu\nu}\gamma^5 q)G_{\mu\nu}^a + a_f^g \frac{e}{4m_f}(\bar{q}T^a\sigma^{\mu\nu} q)G_{\mu\nu}^a$$

CEDM

Current limit for top quark:

$$|d_t^g| < 4.8010\times10^{-16}\, e\cdot cm$$

PRD88,034033 (2013)

THDM

$$d_t^g = 6.8586\times10^{-18}\, e\cdot cm$$

PRD92,094025 (2015)

MSSM

$$d_t^g \sim 10^{-19}\, e\cdot cm$$

PRD92, 035013 (2015)

4GTHDM

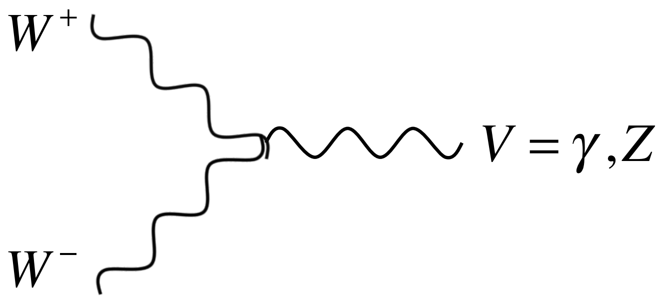
$$d_t^g \sim 10^{-22}\, e\cdot cm$$

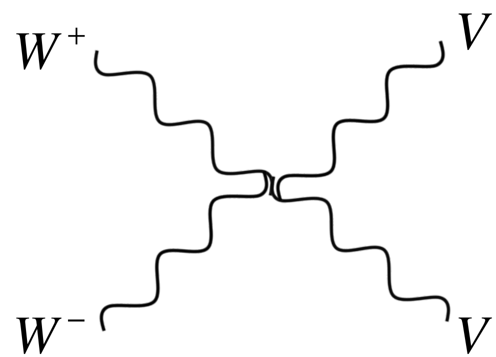
Mr. Alan in poster section

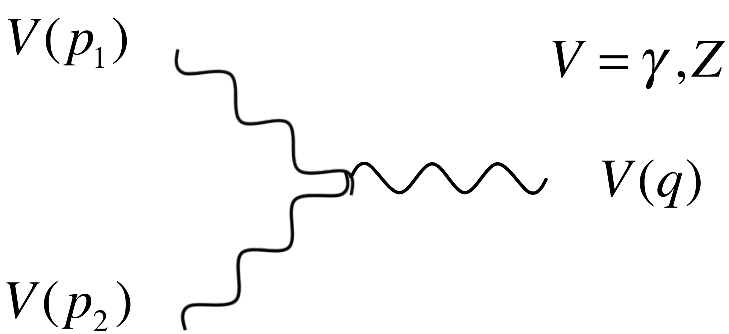
CP VIOLATION IN TNGBC

At tree level the Yang-Mills sector of the SM, only have two types of couplings between gauge bosons:

$$\mathcal{L} = -\frac{1}{4} W_{\mu\nu}^{i} W_{i}^{\mu\nu} - \frac{1}{4} B_{\mu\nu} B^{\mu\nu}$$







Then, the triple neutral gauge boson couplings (TNGBC) are not induced at tree level.

On other hand, Landau-Yang's theorem forbids any TNGBC with tree on-shell gauge bosons.

$$p_1^2 = m^2 \qquad p_2^2 = m^2 \qquad q^2 = m^2$$

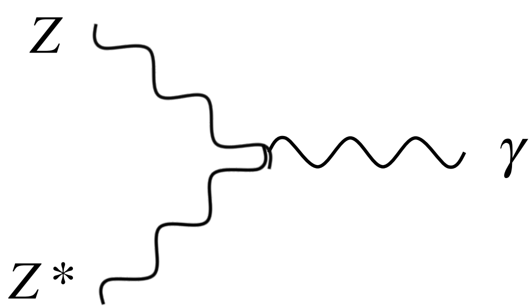
L. D. Landau, Dokl. Akad. Nawk., USSR 60, 207 (1948);
C. N. Yang, Phys. Rev. 77, 242 (1950).

CP VIOLATION IN TNGBC

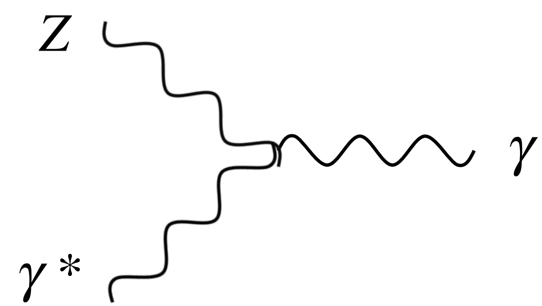
But by the Landau-Yang's theorem there are only two vertex functions describing four distintict TNGBCs with one off-shell gauge boson:

Type $ZV^*\gamma$

$ZZ^*\gamma =$

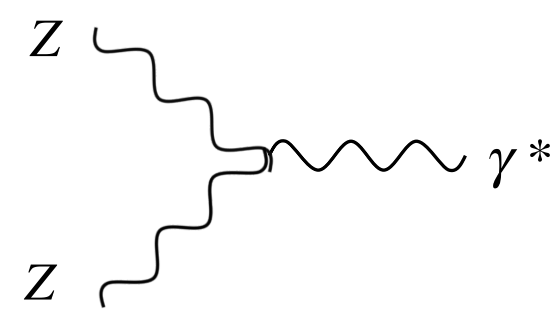


$Z\gamma^*\gamma =$

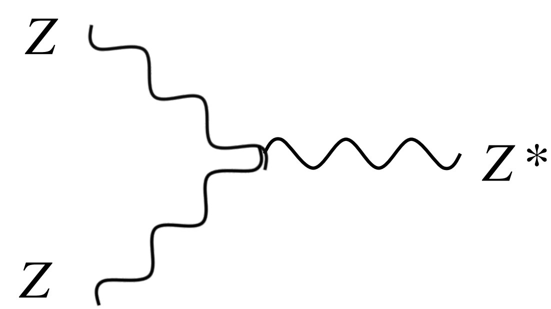


Type ZZV^*

$ZZ\gamma^* =$



$ZZZ^* =$



While the $\gamma\gamma\gamma$ *coupling is forbidden by Furry's theorem.*

CP VIOLATION IN TNGBC

But by the Landau-Yang's theorem there are only two vertex functions describing four distintict TNGBCs with one off-shell gauge boson:

Type $ZV^*\gamma$

This coupling is described by the following efective Lagrangian

$$\mathcal{L}_{ZV^*\gamma} = \frac{e}{m_Z^2}\Big\{-[\underbrace{h_1^\gamma}_{\text{CP-odd}}(\partial^\alpha F_{\alpha\mu}) + \underbrace{h_1^Z}_{\text{CP-odd}}(\partial^\alpha Z_{\alpha\mu})]Z_\beta F^{\mu\beta}$$

$$-\frac{1}{m_Z^2}\Big[\underbrace{h_2^\gamma}_{\text{CP-odd}}(\partial_\alpha \partial_\beta \partial^\rho F_{\rho\mu}) + \underbrace{h_2^Z}_{\text{CP-odd}}[\partial_\alpha \partial_\beta (\partial^2 + m_Z^2)Z_\mu]\Big]Z^\alpha F^{\mu\beta}$$

$$-[\underbrace{h_3^\gamma}_{\text{CP-even}}(\partial_\beta F^{\beta\mu}) + \underbrace{h_3^Z}_{\text{CP-even}}(\partial_\beta Z^{\beta\mu})]Z^\alpha \tilde{F}_{\mu\alpha}$$

$$+\frac{1}{2m_Z^2}[\underbrace{h_4^\gamma}_{\text{CP-even}}(\partial^2 \partial^\beta F^{\mu\alpha}) + \underbrace{h_4^Z}_{\text{CP-even}}(\partial^2 + m_Z^2)\partial^\beta Z^{\mu\alpha}]Z_\beta \tilde{F}_{\mu\alpha} \quad \Big\}$$

CP VIOLATION IN TNGBC

But by the Landau-Yang's theorem there are only two vertex functions describing four distintict TNGBCs with one off-shell gauge boson:

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$$-\frac{1}{m_Z^2}\Big[\boxed{h_2^\gamma}(\partial_\alpha\partial_\beta\partial^\rho F_{\rho\mu}) + \boxed{h_2^Z}[\partial_\alpha\partial_\beta(\partial^2 + m_Z^2)Z_\mu]\Big]Z^\alpha F^{\mu\beta}$$

$$-[h_3^\gamma(\partial_\beta F^{\beta\mu}) + h_3^Z(\partial_\beta Z^{\beta\mu})]Z^\alpha \tilde{F}_{\mu\alpha}$$

$$+\frac{1}{2m_Z^2}[h_4^\gamma(\partial^2\partial^\beta F^{\mu\alpha}) + h_4^Z(\partial^2 + m_Z^2)\partial^\beta Z^{\mu\alpha}]Z_\beta\tilde{F}_{\mu\alpha}\Big\}$$

For CP-odd part the vertex function is given by

$$\Gamma_{ZV^*\gamma}^{\alpha\beta\mu}(p_1,p_2,q) = i\frac{(p_2^2 - m_V^2)}{m_Z^2}\left[\boxed{h_1^V}(q^\beta g^{\alpha\mu} - q^\alpha g^{\beta\mu}) + \frac{\boxed{h_2^V}}{m_Z^2}p_2^\alpha[(q\cdot p_2)g^{\beta\mu} - q^\beta p_2^\mu]\right]$$

CP VIOLATION IN TNGBC

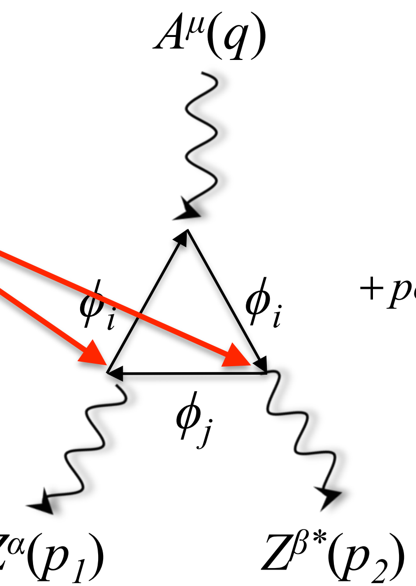
But by the Landau-Yang's theorem there are only two vertex functions describing four distintict TNGBCs with one off-shell gauge boson:

Type $ZV^*\gamma$ Example: $Z_\alpha(p_1)Z_\beta{}^*(p_2)A_\mu(q)$

Same situation, What do you need to induce the CP-odd couplings?

1.- Non-diagonal coupling in any SM extension.

2.- Complex coupling constants.



$+\,permutations$

$$\mathcal{L}_{FV} = ig\sum_{i\neq j} Z_\mu \boxed{g_{ij}^Z} \phi_i^+ \overleftrightarrow{\partial}^\mu \phi_j^- + h.c.$$

Then, we have the following result:

$$h_1^Z = \frac{m_Z^2 g_{ii}^\gamma \boxed{\mathrm{Im}(g_{ij}^Z g_{ji}^{Z*})}}{12\pi^2 (m_Z^2 - p_2^2)^3} H_1(p_2^2, \Delta m_{ij}, m_i^2)$$

$$h_2^Z = \frac{m_Z^4 g_{ii}^\gamma \boxed{\mathrm{Im}(g_{ij}^Z g_{ji}^{Z*})}}{6\pi^2 (m_Z^2 - p_2^2)^4} H_2(p_2^2, \Delta m_{ij}, m_i^2)$$

$$\mathrm{Re}(h_1^Z) \sim \mathrm{Im}(g_{ij}^Z g_{ji}^{Z*})(10^{-3} - 10^{-7})$$
$$\mathrm{Im}(h_1^Z) \sim \mathrm{Im}(g_{ij}^Z g_{ji}^{Z*})(10^{-5} - 10^{-7})$$

$$\mathrm{Re}(h_2^Z) \sim \mathrm{Im}(g_{ij}^Z g_{ji}^{Z*})(10^{-5} - 10^{-8})$$
$$\mathrm{Im}(h_2^Z) \sim \mathrm{Im}(g_{ij}^Z g_{ji}^{Z*})(10^{-6} - 10^{-9})$$

PRD91,093005 (2015)

CP VIOLATION IN TNGBC

But by the Landau-Yang's theorem there are only two vertex functions describing four distintict TNGBCs with one off-shell gauge boson:

Type ZZV^*

This type of coupling is described by the following efective lagrangian

$$\mathcal{L}_{ZZV^*} = \frac{e}{m_Z^2}\left\{-[\underbrace{f_4^\gamma}_{\text{CP-odd}}(\partial_\mu F^{\mu\beta}) + \underbrace{f_4^Z}_{\text{CP-odd}}(\partial_\mu Z^{\mu\beta})]Z_\alpha(\partial^\alpha Z_\beta) + [\underbrace{f_5^\gamma}_{\text{CP-even}}(\partial^\alpha F_{\alpha\mu}) + \underbrace{f_5^Z}_{\text{CP-even}}(\partial^\alpha F_{\alpha\mu})]\tilde{Z}^{\mu\beta}Z_\beta\right\}$$

For CP-odd part the vertex function is given by

$$\Gamma^{\alpha\beta\mu}_{ZZV^*}(p_1, p_2, q) = i\frac{(q^2 - m_V^2)}{m_Z^2}\boxed{f_4^V}(q^\alpha g^{\beta\mu} + q^\beta g^{\alpha\mu})$$

Same situation, again, we need:

1.- Non-diagonal coupling in any SM extension.

2.- Complex coupling constants.

CP VIOLATION IN TNGBC

But by the Landau-Yang's theorem there are only two vertex functions describing four distintict TNGBCs with one off-shell gauge boson:

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$$\mathcal{L}_{ZZV^*} = \frac{e}{m_Z^2}\left\{-[f_4^\gamma(\partial_\mu F^{\mu\beta}) + f_4^Z(\partial_\mu Z^{\mu\beta})]Z_\alpha(\partial^\alpha Z_\beta) + [f_5^\gamma(\partial^\alpha F_{\alpha\mu}) + f_5^Z(\partial^\alpha F_{\alpha\mu})]\tilde{Z}^{\mu\beta}Z_\beta\right\}$$

Example: $Z_\alpha(p_1)Z_\beta(p_2)Z_\mu^*(q)$

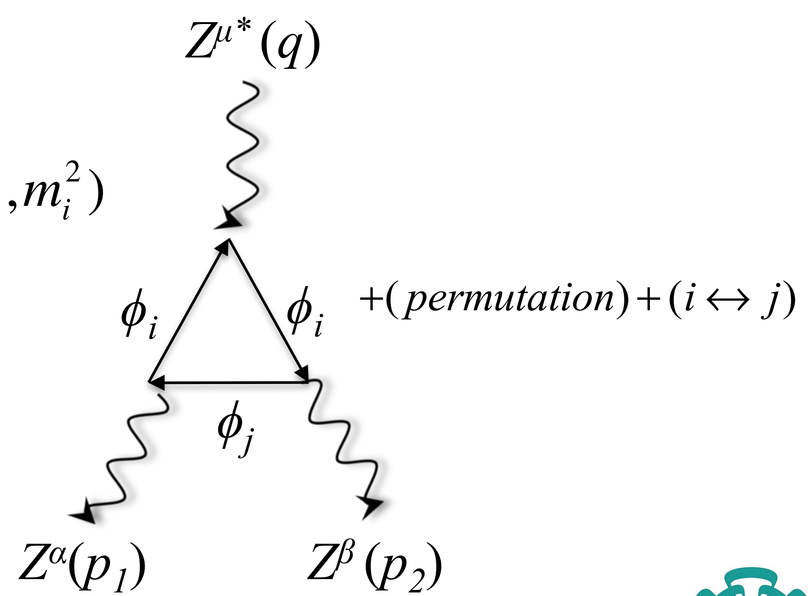
Then, we have the following result:

$$f_4^Z = \frac{m_Z^2 g_{ii}^Z \boxed{\mathrm{Im}(g_{ij}^Z g_{ji}^{Z*})}}{24\pi^2 s_W q^2 (q^2 - 4m_Z^2)(q^2 - m_Z^2)^2} F_4^Z(q^2, \Delta m_{ij}, m_i^2)$$

$$\mathrm{Re}(f_4^Z) \sim \mathrm{Im}(g_{ij}^Z g_{ji}^{Z*})(10^{-2} - 10^{-5})$$

$$\mathrm{Im}(f_4^Z) \sim \mathrm{Im}(g_{ij}^Z g_{ji}^{Z*})(10^{-4} - 10^{-6})$$

PRD91,093005 (2015)



CP VIOLATION IN TNGBC

New contributions to the CP-odd form factors are induced by fermionic non-diagonal coupling with a four family:

$$\mathcal{L}_{FV} = i\sum_{i\neq 4} \boxed{g_{4i}^{f}} Z_\mu \bar{f}_4 \gamma^\mu (1+\gamma^5) f_i + h.c.$$

complex coupling constant

Some phenomelogical results with the fourth family:
Mrs. Chamorro in talk section
Mr. Alan in poster section

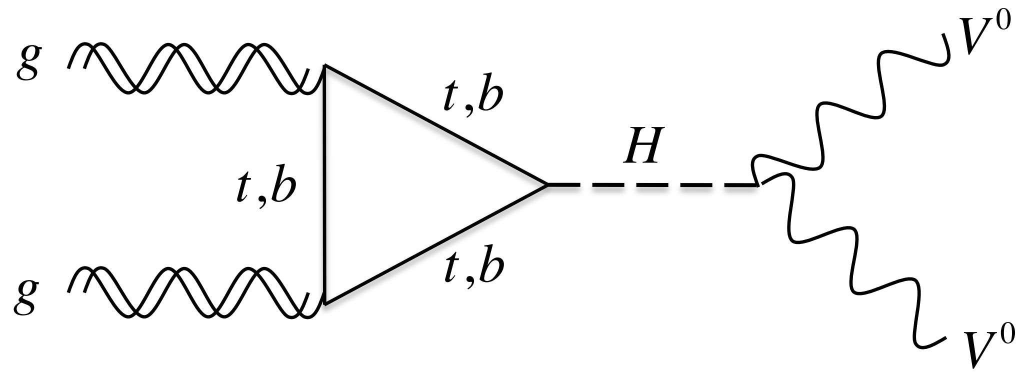
$$\Gamma^{\alpha\beta\mu}_{ZV^*\gamma}(p_1,p_2,q) = i\frac{(p_2^2-m_V^2)}{m_Z^2}\left[h_1^V(q^\beta g^{\alpha\mu} - q^\alpha g^{\beta\mu}) + \frac{h_2^V}{m_Z^2} p_2^\alpha [(q\cdot p_2) g^{\beta\mu} - q^\beta p_2^\mu]\right]$$

$$\Gamma^{\alpha\beta\mu}_{ZZV^*}(p_1,p_2,q) = i\frac{(q^2-m_V^2)}{m_Z^2} f_4^V (q^\alpha g^{\beta\mu} + q^\beta g^{\alpha\mu})$$

In progress….

CP VIOLATION IN HIGGS DECAYS

The main mechanism for Higgs boson production at hadron colliders is gluon fusion, in which the gluons couple to Higgs bosons via top and bottom quark loops



The Higgs can be decay into gauge boson, for example:

$h^0 \to ZZ^* \to 4\ell$ — *ATLAS,PLB716,1(2012)*

$h^0 \to \gamma\gamma^* \to 4\ell$ — *ATLAS,PRD90,052004(2014)*, *CMS, PRL114,191803(2015)*

$h^0 \to WW^* \to \nu\ell\nu\ell$ — *CMS,PLB716,30(2012)*

$h^0 \to Z\gamma \quad Z \to \ell\ell$ — *ATLAS,PLB732,8(2014)*, *CMS,PLB753,341(2016)*

All the results are compatibles with the expectations from a standard model Higgs boson. However, a future deviations from the predictions of the Standard Model can be signal of new physics.

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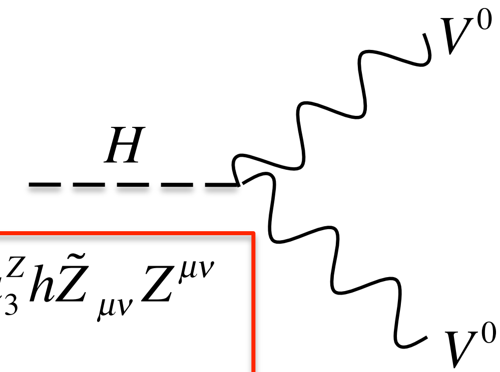
The Higgs boson couplings to gauge bosons is induced at tree level in the SM.
At one loop level we have new interesting contributions:



$$\mathcal{L}_{hZZ} = \frac{g m_Z}{2\cos^2\theta_W} h Z_\mu Z^\mu + a_1^Z Z_{\mu\nu} Z^\nu \partial^\mu h + a_2^Z h Z_{\mu\nu} Z^{\mu\nu} + a_3^Z h \tilde{Z}_{\mu\nu} Z^{\mu\nu}$$

$$\mathcal{L}_{hWW} = g m_W h W_\mu W^\mu + a_1^W W_{\mu\nu} W^\nu \partial^\mu h + a_2^W h W_{\mu\nu} W^{\mu\nu} + a_3^W h \tilde{W}_{\mu\nu} W^{\mu\nu}$$

$$\mathcal{L}_{h\gamma\gamma} = 0 \qquad + a_1^\gamma A_{\mu\nu} A^\nu \partial^\mu h + a_2^\gamma h A_{\mu\nu} A^{\mu\nu} + a_3^\gamma h \tilde{A}_{\mu\nu} A^{\mu\nu}$$

Tree level CP-even CP-odd

But in general the vertex function can be written as:

$$\Gamma^{\alpha\beta}(p_1, p_2) = a_1^V g^{\alpha\beta} + a_2^V [(p_1 \cdot p_2) g^{\alpha\beta} - p_1^\alpha p_2^\beta] + a_3^V \varepsilon^{\alpha\beta\mu\nu} p_{1\mu} p_{2\nu}$$

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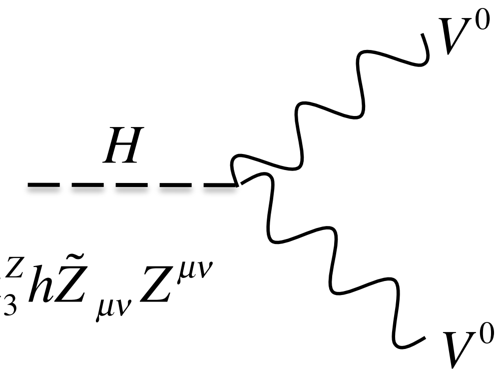

$$\mathcal{L}_{hZZ} = \frac{g m_Z}{2\cos^2\theta_W} h Z_\mu Z^\mu + \boxed{a_1^Z} Z_{\mu\nu} Z^\nu \partial^\mu h + \boxed{a_2^Z} h Z_{\mu\nu} Z^{\mu\nu} + a_3^Z h \tilde{Z}_{\mu\nu} Z^{\mu\nu}$$

$$\mathcal{L}_{hZZ} = g m_W h W_\mu W^\mu + \boxed{a_1^W} W_{\mu\nu} W^\nu \partial^\mu h + \boxed{a_2^W} h W_{\mu\nu} W^{\mu\nu} + a_3^W h \tilde{W}_{\mu\nu} W^{\mu\nu}$$

$$\mathcal{L}_{h\gamma\gamma} = 0 \qquad + \boxed{a_1^\gamma} A_{\mu\nu} A^\nu \partial^\mu h + \boxed{a_2^\gamma} h A_{\mu\nu} A^{\mu\nu} + a_3^\gamma h \tilde{A}_{\mu\nu} A^{\mu\nu}$$

CP-even form factors

But in general the vertex function can be written as:

$$\Gamma^{\alpha\beta}(p_1, p_2) = \boxed{a_1^V} g^{\alpha\beta} + \boxed{a_2^V}[(p_1 \cdot p_2) g^{\alpha\beta} - p_1^\alpha p_2^\beta] + a_3^V \varepsilon^{\alpha\beta\mu\nu} p_{1\mu} p_{2\nu}$$

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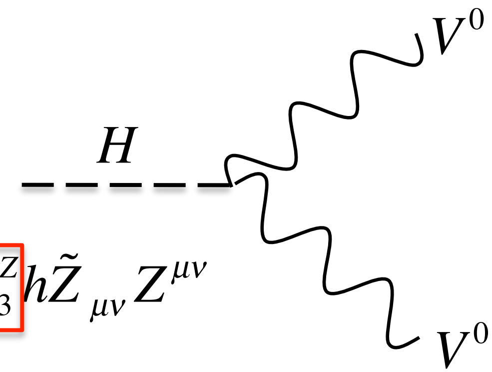

$$\mathcal{L}_{hZZ} = \frac{g m_Z}{2\cos^2\theta_W} hZ_\mu Z^\mu + a_1^Z Z_{\mu\nu} Z^\nu \partial^\mu h + a_2^Z h Z_{\mu\nu} Z^{\mu\nu} + \boxed{a_3^Z} h\tilde{Z}_{\mu\nu} Z^{\mu\nu}$$

$$\mathcal{L}_{hZZ} = g m_W h W_\mu W^\mu + a_1^W W_{\mu\nu} W^\nu \partial^\mu h + a_2^W h W_{\mu\nu} W^{\mu\nu} + \boxed{a_3^W} h\tilde{W}_{\mu\nu} W^{\mu\nu}$$

$$\mathcal{L}_{h\gamma\gamma} = 0 \qquad + a_1^\gamma A_{\mu\nu} A^\nu \partial^\mu h + a_2^\gamma h A_{\mu\nu} A^{\mu\nu} + \boxed{a_3^\gamma} h\tilde{A}_{\mu\nu} A^{\mu\nu}$$

CP-odd form factors

But in general the vertex function can be written as:

$$\Gamma^{\alpha\beta}(p_1, p_2) = a_1^V g^{\alpha\beta} + a_2^V [(p_1 \cdot p_2) g^{\alpha\beta} - p_1^\alpha p_2^\beta] + \boxed{a_3^V} \varepsilon^{\alpha\beta\mu\nu} p_{1\mu} p_{2\nu}$$

SUMMARY

1.- More source of CP violation are necesary to explain the baryogenesis.

2.- We explore some theorical source of CP-violation:

a) Electric dipole moments.

b) Triple nuetral gauge boson couplings.

c) Anomalous coupling of the Higgs boson.

3.- To induce these theorical source is necesary non-diagonal couplings in any SM extension*, and that the respective coupling constant shoure be complex numbers.*