Probing New Physics in Higgs Couplings to Gauge Bosons

Seminario del Cuerpo Académico de Física de Partículas Elementales

A. I. Hernández-Juárez,

alan.hernandezjua@alumno.buap.mx

23rd October 2026

Phys.Rev.D 107 (2023) 11, 115031

Phys.Rev.D 111 (2025) 1, 015001

Phys.Rev.D 114 (2026) 5, 055036

Chin.Phys.C 48 (2024) 11, 113103

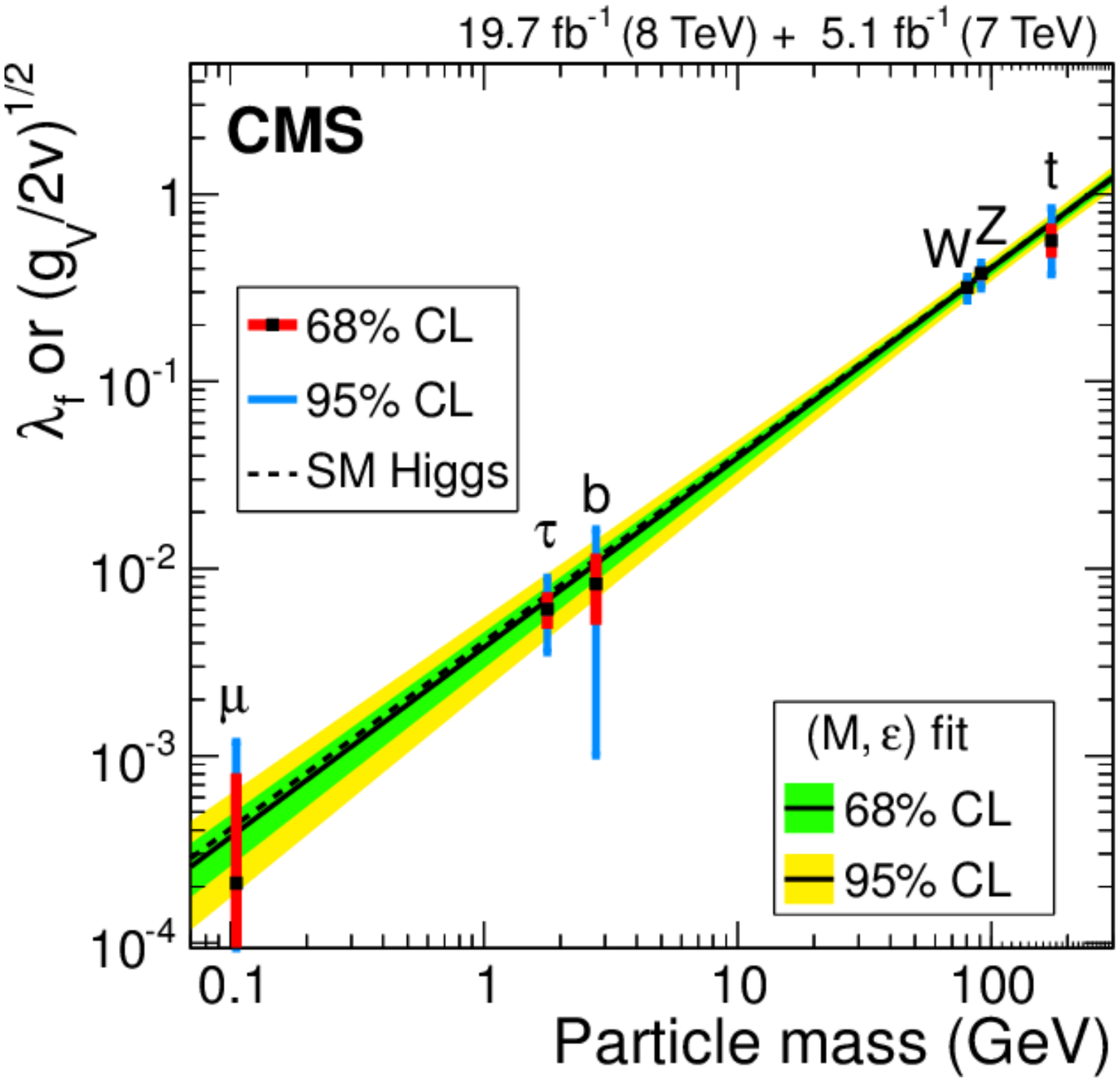
Phys.Rev.D 112 (2025) 3, 033006

Phys.Rev.D 114 (2026) 5, 055036

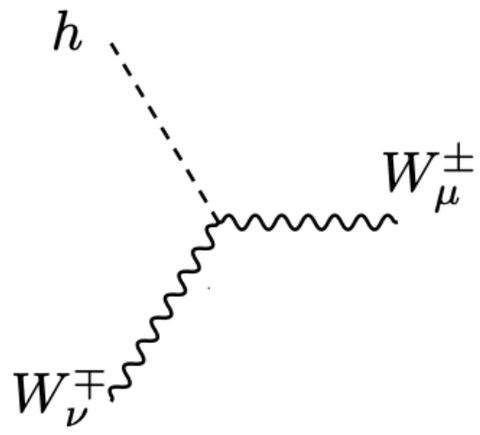
Theory

The Higgs boson's coupling to a particle is proportional to that particle's mass.

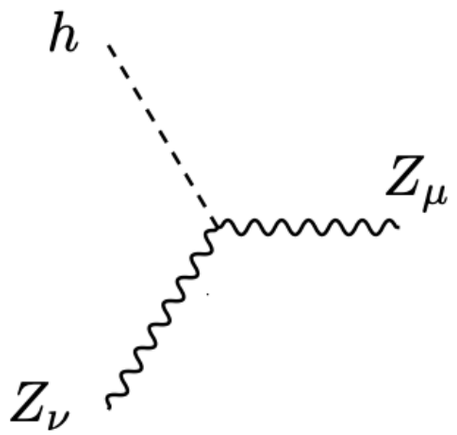
(See Dr Luis Flores lectures)



Couplings of the Higgs boson with gauge bosons in the SM:



$$ig\, m_W\, g_{\mu\nu}$$

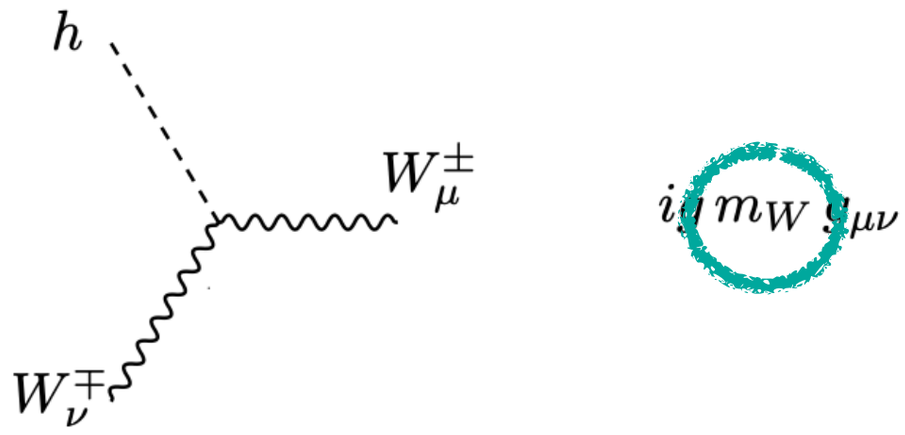


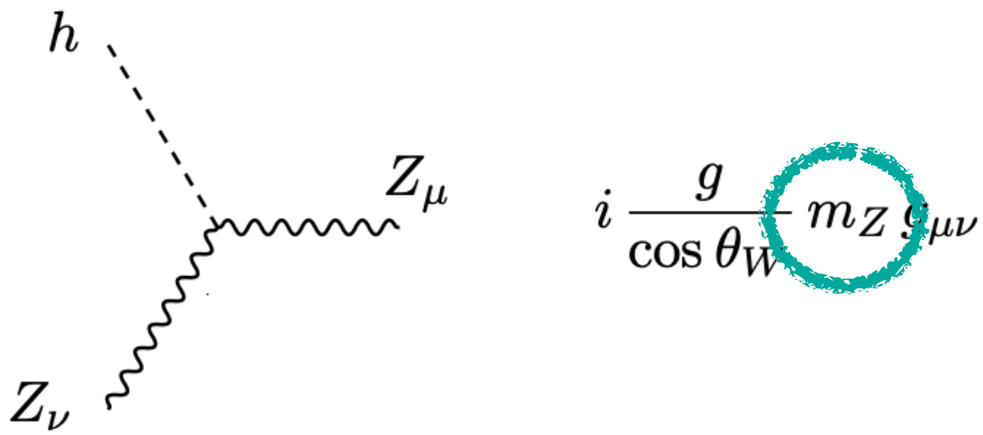
$$i\,\frac{g}{\cos\theta_W}\, m_Z\, g_{\mu\nu}$$

1. **Induced at tree level**

Theory

Couplings of the Higgs boson with gauge bosons in the SM:

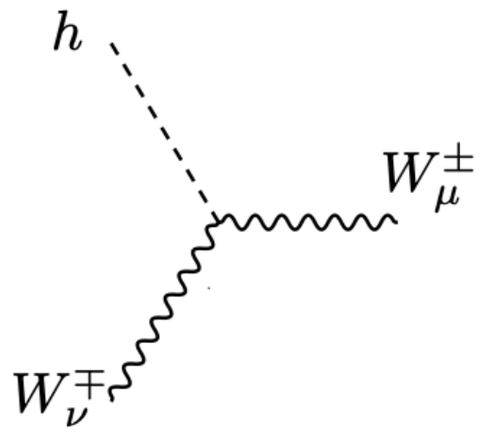




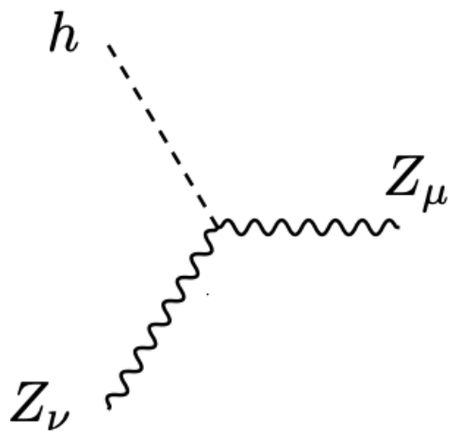
1. **Induced at tree level**
2. **Feynman rule** $\sim m_V$

Theory

Couplings of the Higgs boson with gauge bosons in the SM:

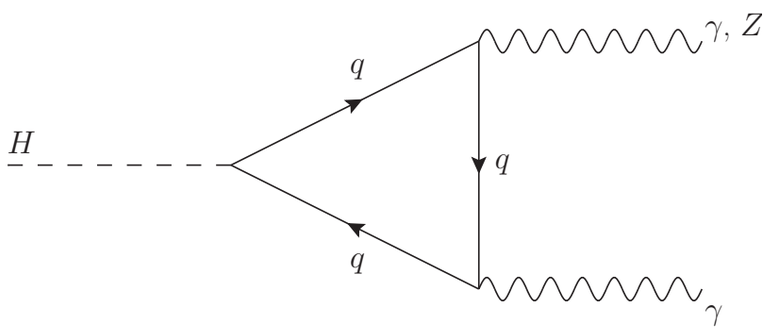


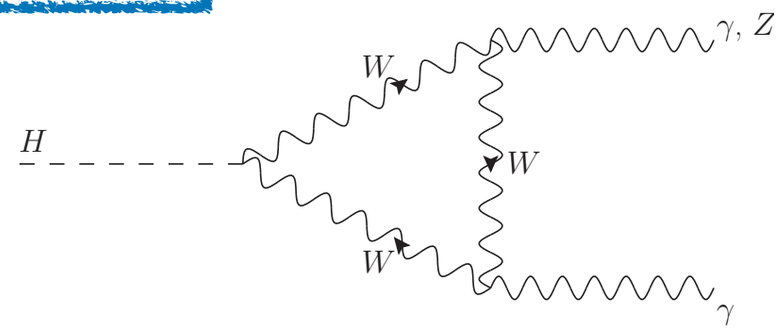
$$ig\, m_W\, g_{\mu\nu}$$

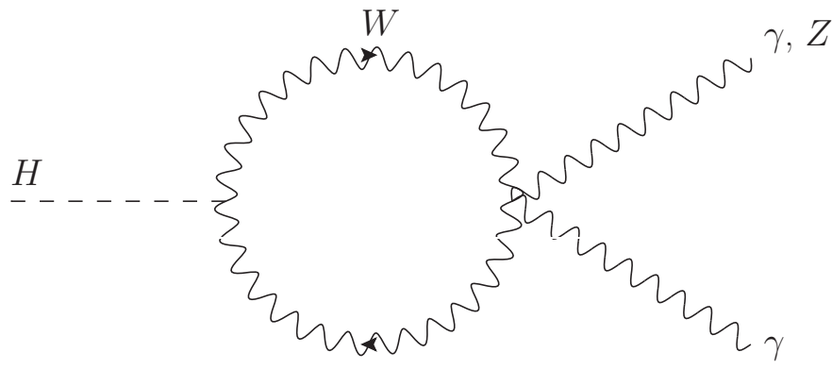


$$i\,\frac{g}{\cos\theta_W}\, m_Z\, g_{\mu\nu}$$

$H\gamma\gamma$ and $HZ\gamma$ couplings induced at one-loop level





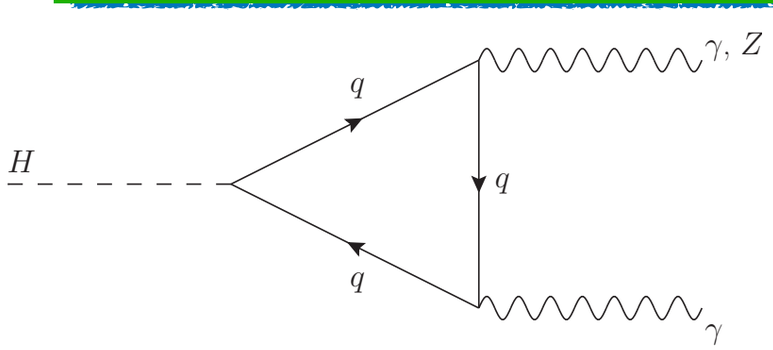


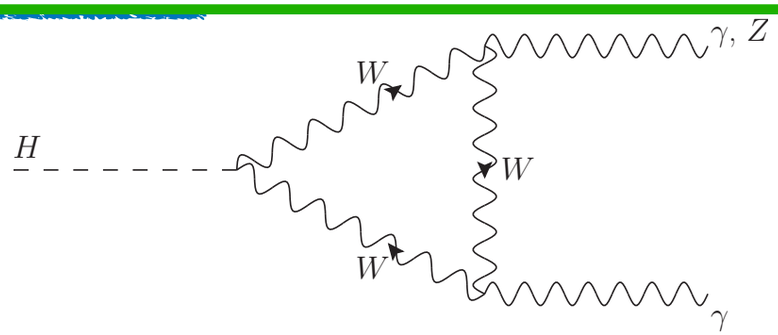
Theory

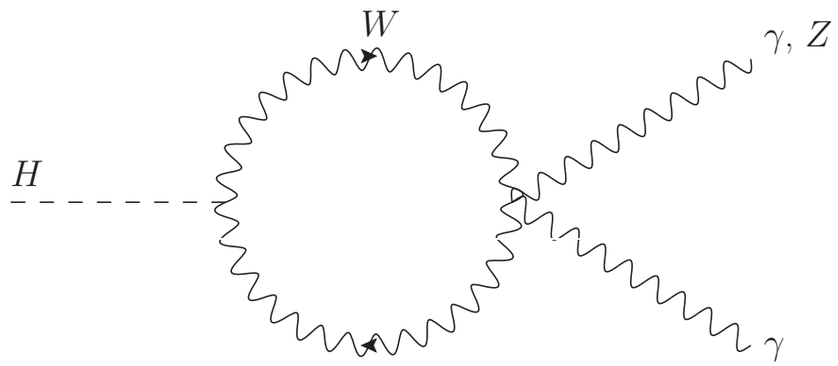
Couplings of the Higgs boson with gauge bosons in the SM:

We can describe these interactions in an effective way:

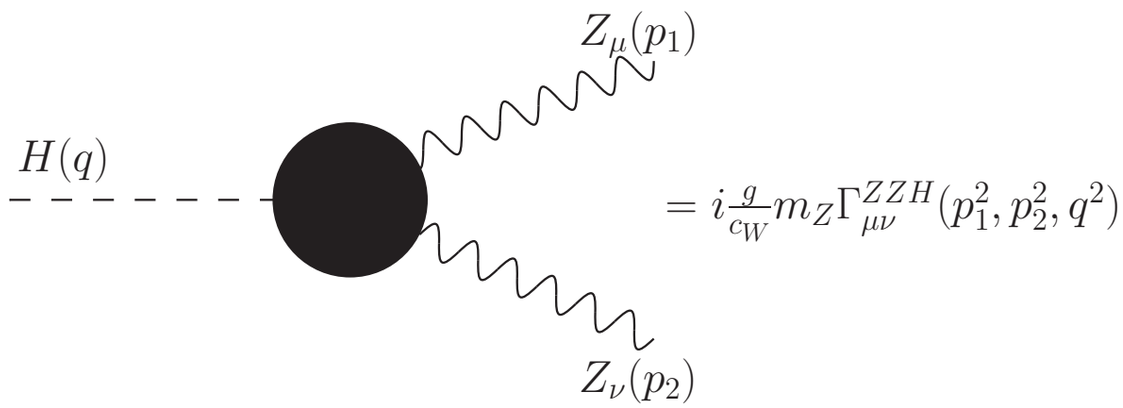
$$\mathscr{L}_{EFT} = \mathscr{L}_{d=4} + \sum_{d=5}^{\infty} \frac{1}{M^{d-4}} \sum_{i=1}^{n_d} C_i^{(d)} Q_i^{(d)}$$



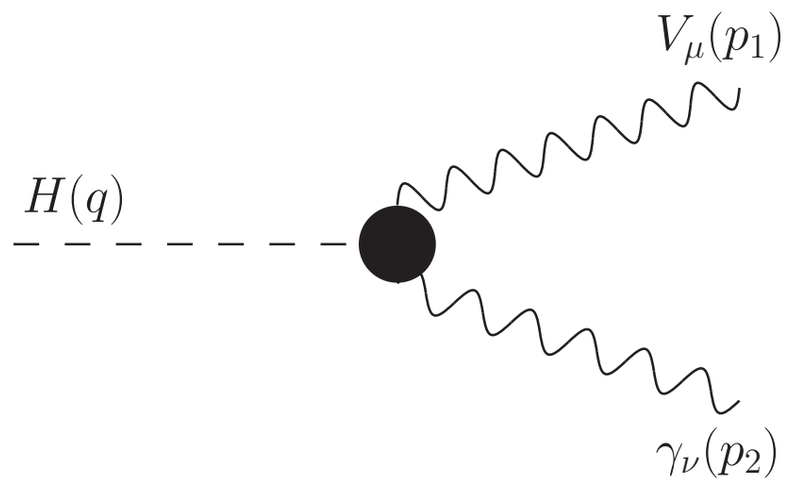




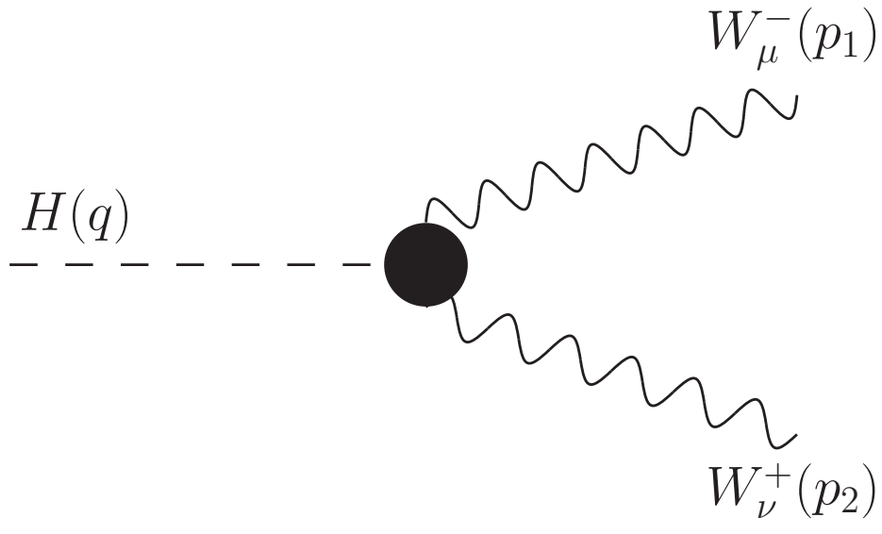
The HWW, HZZ, $H\gamma\gamma$ and $HZ\gamma$ can be parametrized by the vertex function $\Gamma^{V_1V_2H}$



$$= i\frac{g}{c_W} m_Z \Gamma^{ZZH}_{\mu\nu}(p_1^2, p_2^2, q^2)$$



$$= ig\Gamma^{V\gamma H}_{\mu\nu},\ (V = \gamma,\ Z).$$



$$= ig\ m_W \Gamma^{W^-W^+H}_{\mu\nu}$$

Theory

The HWW, HZZ, $H\gamma\gamma$ and $HZ\gamma$ can be parametrized by the vertex function $\Gamma^{V_1V_2H}$

3 form factors: h_1, h_2 and h_3

$$\Gamma^{ZZH}_{\mu\nu} = h_1^V(q^2,p_1^2,p_2^2)g_{\mu\nu} + \frac{h_2^V(q^2,p_1^2,p_2^2)}{m_Z^2}p_{1\nu}p_{2\mu} + \frac{h_3^V(q^2,p_1^2,p_2^2)}{m_Z^2}\epsilon_{\mu\nu\alpha\beta}p_1^\alpha p_2^\beta,$$

$$\Gamma^{W^-W^+H}_{\mu\nu} = h_1^V g_{\mu\nu} + \frac{h_2^V}{m_W^2}p_{1\nu}p_{2\mu} + \frac{h_3^V}{m_W^2}\epsilon_{\mu\nu\alpha\beta}p_1^\alpha p_2^\beta,$$

$$\Gamma^{\mu\nu}_{V\gamma H} = h_1^{V\gamma}g^{\mu\nu} + \frac{1}{m_Z^2}\left\{h_2^{V\gamma}p_1^\nu p_2^\mu + h_3^{V\gamma}\epsilon^{\mu\nu\alpha\beta}p_{1\alpha}p_{2\beta}\right\}, \quad (V=\gamma,Z),$$

Theory

The HWW, HZZ, $H\gamma\gamma$ and $HZ\gamma$ can be parametrized by the vertex function $\Gamma^{V_1V_2H}$

3 form factors: h_1, h_2 and h_3

$$\Gamma^{ZZH}_{\mu\nu} = h_1^V(q^2,p_1^2,p_2^2)g_{\mu\nu} + \frac{h_2^V(q^2,p_1^2,p_2^2)}{m_Z^2}p_{1\nu}p_{2\mu} + \frac{h_3^V(q^2,p_1^2,p_2^2)}{m_Z^2}\epsilon_{\mu\nu\alpha\beta}p_1^\alpha p_2^\beta,$$

$$\Gamma^{W^-W^+H}_{\mu\nu} = h_1^V g_{\mu\nu} + \frac{h_2^V}{m_W^2}p_{1\nu}p_{2\mu} + \frac{h_3^V}{m_W^2}\epsilon_{\mu\nu\alpha\beta}p_1^\alpha p_2^\beta,$$

$$\Gamma^{\mu\nu}_{V\gamma H} = h_1^{V\gamma}g^{\mu\nu} + \frac{1}{m_Z^2}\left\{h_2^{V\gamma}p_1^\nu p_2^\mu + h_3^{V\gamma}\epsilon^{\mu\nu\alpha\beta}p_{1\alpha}p_{2\beta}\right\}, \quad (V=\gamma,Z),$$

CP-conserving

Theory

3 form factors: h_1, h_2 and h_3

The HWW, HZZ, $H\gamma\gamma$ and $HZ\gamma$ can be parametrized by the vertex function $\Gamma^{V_1V_2H}$

$$\Gamma^{ZZH}_{\mu\nu} = h_1^V(q^2,p_1^2,p_2^2)g_{\mu\nu} + \frac{h_2^V(q^2,p_1^2,p_2^2)}{m_Z^2}p_{1\nu}p_{2\mu} + \frac{h_3^V(q^2,p_1^2,p_2^2)}{m_Z^2}\epsilon_{\mu\nu\alpha\beta}p_1^\alpha p_2^\beta,$$

$$\Gamma^{W^-W^+H}_{\mu\nu} = h_1^V g_{\mu\nu} + \frac{h_2^V}{m_W^2}p_{1\nu}p_{2\mu} + \frac{h_3^V}{m_W^2}\epsilon_{\mu\nu\alpha\beta}p_1^\alpha p_2^\beta,$$

$$\Gamma^{\mu\nu}_{V\gamma H} = h_1^{V\gamma} g^{\mu\nu} + \frac{1}{m_Z^2}\left\{h_2^{V\gamma} p_1^\nu p_2^\mu + h_3^{V\gamma}\epsilon^{\mu\nu\alpha\beta}p_{1\alpha}p_{2\beta}\right\}, \quad (V=\gamma,Z),$$

CP-conserving

CP-odd

The HWW, HZZ, $H\gamma\gamma$ and $HZ\gamma$ can be parametrized by the vertex function $\Gamma^{V_1V_2H}$

3 form factors: h_1, h_2 and h_3

Potential sources of CP violation: necessary to explain the matter–antimatter asymmetry in the Universe

(See Dra Myriam Mondragón lectures)

$$\Gamma^{W^-W^+H}_{\mu\nu} = h_1^V g_{\mu\nu} + \frac{h_2^V(q^2,p_1^2,p_2^2)}{m_W^2} p_{1\nu}p_{2\mu} + \frac{h_3^V(q^2,p_1^2,p_2^2)}{m_W^2}\epsilon_{\mu\nu\alpha\beta}p_1^\alpha p_2^\beta,$$

$$\Gamma^{ZZH}_{\mu\nu} = h_1^Z g_{\mu\nu} + \frac{h_2^Z(q^2,p_1^2,p_2^2)}{m_Z^2} p_{1\nu}p_{2\mu} + \frac{h_3^Z(q^2,p_1^2,p_2^2)}{m_Z^2}\epsilon_{\mu\nu\alpha\beta}p_1^\alpha p_2^\beta,$$

$$\Gamma^{\mu\nu}_{V\gamma H} = h_1^{V\gamma} g^{\mu\nu} + \frac{1}{m_Z^2}\left\{h_2^{V\gamma} p_1^\nu p_2^\mu + h_3^{V\gamma}\epsilon^{\mu\nu\alpha\beta}p_{1\alpha}p_{2\beta}\right\}, \quad (V=\gamma, Z),$$

CP-conserving

CP-odd

Theory

The HWW, HZZ, $H\gamma\gamma$ and $HZ\gamma$ can be parametrized by the vertex function $\Gamma^{V_1V_2H}$

3 form factors: h_1, h_2 and h_3

$$\Gamma^{ZZH}_{\mu\nu} = h_1^V(q^2,p_1^2,p_2^2)g_{\mu\nu} + \frac{h_2^V(q^2,p_1^2,p_2^2)}{m_Z^2}p_{1\nu}p_{2\mu} + \frac{h_3^V(q^2,p_1^2,p_2^2)}{m_Z^2}\epsilon_{\mu\nu\alpha\beta}p_1^\alpha p_2^\beta,$$

$$\Gamma^{W^-W^+H}_{\mu\nu} = h_1^V g_{\mu\nu} + \frac{h_2^V}{m_W^2}p_{1\nu}p_{2\mu} + \frac{h_3^V}{m_W^2}\epsilon_{\mu\nu\alpha\beta}p_1^\alpha p_2^\beta,$$

$h_1^V = 1$ **at tree level**

$$\Gamma^{\mu\nu}_{V\gamma H} = h_1^{V\gamma}g^{\mu\nu} + \frac{1}{m_Z^2}\left\{h_2^{V\gamma}p_1^\nu p_2^\mu + h_3^{V\gamma}\epsilon^{\mu\nu\alpha\beta}p_{1\alpha}p_{2\beta}\right\}, \quad (V=\gamma,Z),$$

Theory

The HWW, HZZ, $H\gamma\gamma$ and $HZ\gamma$ can be parametrized by the vertex function $\Gamma^{V_1V_2H}$

3 form factors: h_1, h_2 and h_3

$$\Gamma^{ZZH}_{\mu\nu} = h_1^V(q^2,p_1^2,p_2^2)g_{\mu\nu} + \frac{h_2^V(q^2,p_1^2,p_2^2)}{m_Z^2}p_{1\nu}p_{2\mu} + \frac{h_3^V(q^2,p_1^2,p_2^2)}{m_Z^2}\epsilon_{\mu\nu\alpha\beta}p_1^\alpha p_2^\beta,$$

$$\Gamma^{W^-W^+H}_{\mu\nu} = h_1^V g_{\mu\nu} + \frac{h_2^V}{m_W^2}p_{1\nu}p_{2\mu} + \frac{h_3^V}{m_W^2}\epsilon_{\mu\nu\alpha\beta}p_1^\alpha p_2^\beta,$$

$$\Gamma^{\mu\nu}_{V\gamma H} = h_1^{V\gamma}g^{\mu\nu} + \frac{1}{m_Z^2}\left\{h_2^{V\gamma}p_1^\nu p_2^\mu + h_3^{V\gamma}\epsilon^{\mu\nu\alpha\beta}p_{1\alpha}p_{2\beta}\right\}, \quad (V=\gamma,Z),$$

Induced at the one-loop level in the SM

Theory

3 form factors: h_1, h_2 and h_3

The HWW, HZZ, $H\gamma\gamma$ and $HZ\gamma$ can be parametrized by the vertex function $\Gamma^{V_1V_2H}$

Induced at three-loop level in the SM $\sim 10^{-11}$

$$\Gamma^{ZZH}_{\mu\nu} = h_1^V(q^2,p_1^2,p_2^2)g_{\mu\nu} + \frac{h_2^V(q^2,p_1^2,p_2^2)}{m_Z^2}p_{1\nu}p_{2\mu} + \frac{h_3^V(q^2,p_1^2,p_2^2)}{m_Z^2}\epsilon_{\mu\nu\alpha\beta}p_1^\alpha p_2^\beta,$$

$$\Gamma^{W^-W^+H}_{\mu\nu} = h_1^V g_{\mu\nu} + \frac{h_2^V}{m_W^2}p_{1\nu}p_{2\mu} + \frac{h_3^V}{m_W^2}\epsilon_{\mu\nu\alpha\beta}p_1^\alpha p_2^\beta,$$

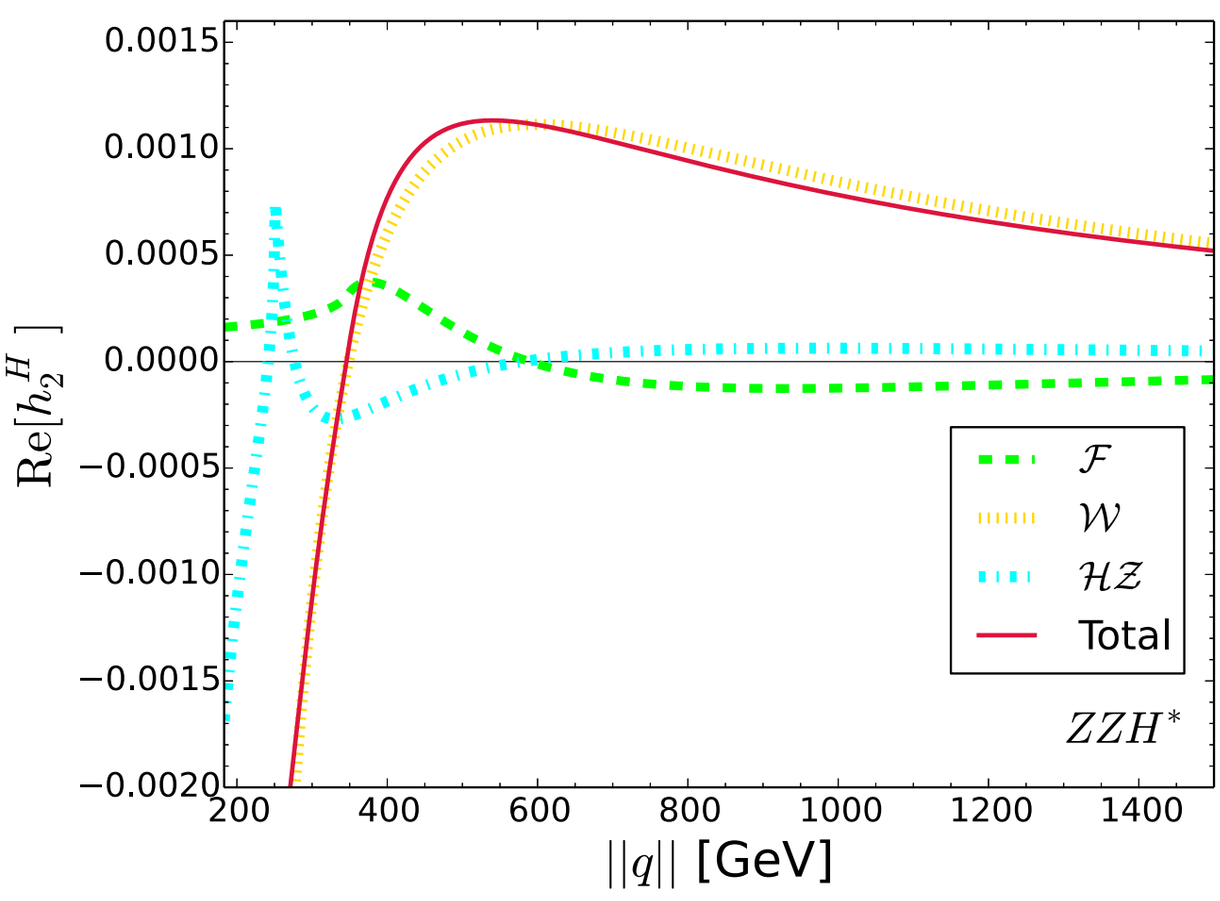
$$\Gamma^{\mu\nu}_{V\gamma H} = h_1^{V\gamma}g^{\mu\nu} + \frac{1}{m_Z^2}\left\{h_2^{V\gamma}p_1^\nu p_2^\mu + h_3^{V\gamma}\epsilon^{\mu\nu\alpha\beta}p_{1\alpha}p_{2\beta}\right\}, \quad (V=\gamma,Z),$$

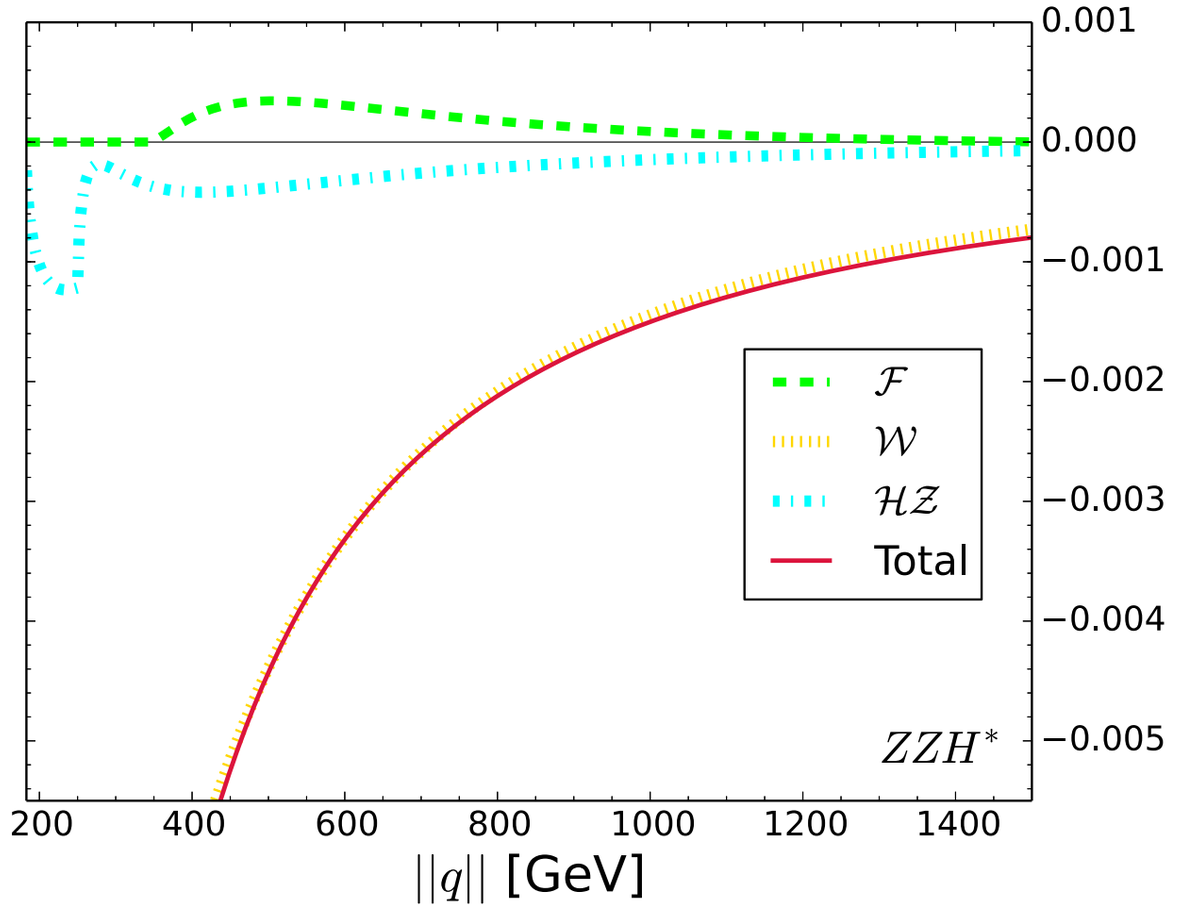
HZZ coupling

ONE LOOP CONTRIBUTIONS

ZZH^* in the SM

A. I. Hernández-Juárez, G. Tavares-Velasco, and A. Fernández-Téllez, New evaluation of the HZZ coupling: Direct bounds on anomalous contributions and CP-violating effects via a new asymmetry, Phys. Rev. D 107, 115031 (2023).





h_2^H is complex

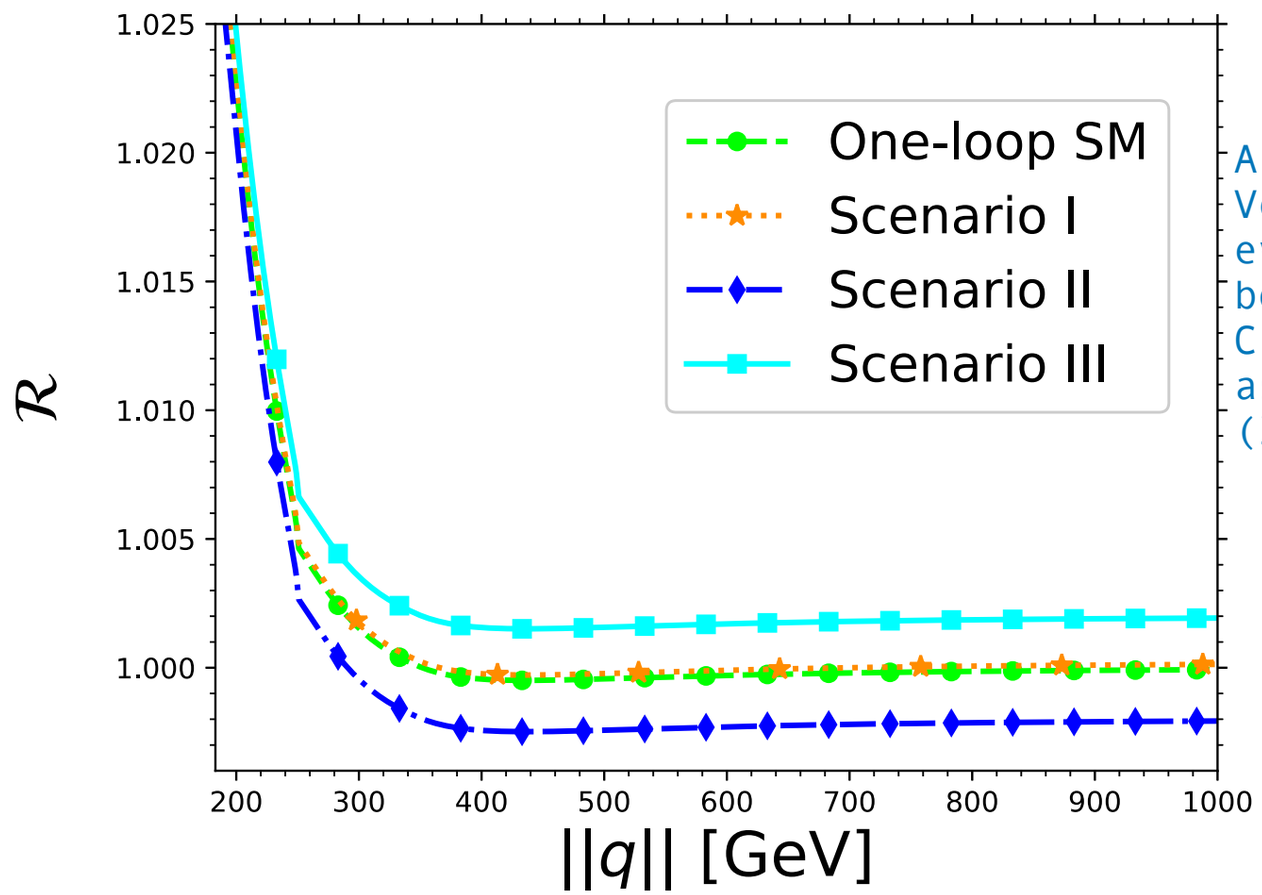
ZZH COUPLING

We considere the anomalous couplings as complex → $h_i^V = \mathrm{Re}[h_i^V] + i\mathrm{Im}[h_i^V]$

We calculate the partial width

$\Gamma_{H^* \to ZZ}$

No difference between SM results and the anomalous couplings contributions.



A. I. Hernández-Juárez, G. Tavares-Velasco, and A. Fernández-Téllez, New evaluation of the HZZ coupling: Direct bounds on anomalous contributions and CP-violating effects via a new asymmetry, Phys. Rev. D 107, 115031 (2023).

$$\mathscr{R} = \frac{\Gamma_{H^* \to ZZ}}{\Gamma^{Tree}_{H^* \to ZZ}}.$$

ZZH COUPLING

We considere the anomalous couplings as complex → $h_i^V = \mathrm{Re}[h_i^V] + i\mathrm{Im}[h_i^V]$

We calculate the partial width

$\Gamma_{H^* \to ZZ}$

No difference between SM results and the anomalous couplings contributions.

$$\Gamma_{H^* \to ZZ} = \frac{g^2\sqrt{q^2 - 4m_Z^2}}{512\pi q^2 c_W^2 m_Z^6}\Big\{4q^6 m_Z^2\Big(\left(\mathrm{Im}\left[h_1^H\right] - 2\mathrm{Im}\left[h_2^H\right]\right)\mathrm{Im}\left[h_2^H\right] + \left(\mathrm{Re}\left[h_1^H\right] - 2\mathrm{Re}\left[h_2^H\right]\right)\mathrm{Re}\left[h_2^H\right]\Big)$$
$$+ 4q^4 m_Z^4\Big(2\left(2\mathrm{Im}\left[h_2^H\right]^2 + \mathrm{Im}\left[h_3^H\right]^2 + 2\mathrm{Re}\left[h_2^H\right]^2 + \mathrm{Re}\left[h_3^H\right]^2\right) + \mathrm{Im}\left[h_1^H\right]^2 - 6\mathrm{Im}\left[h_2^H\right]\mathrm{Im}\left[h_1^H\right]$$
$$+ \mathrm{Re}\left[h_1^H\right]^2 - 6\mathrm{Re}\left[h_1^H\right]\mathrm{Re}\left[h_2^H\right]\Big) - 16q^2 m_Z^6\Big(2\left(\mathrm{Im}\left[h_3^H\right]^2 + \mathrm{Re}\left[h_3^H\right]^2\right) + \mathrm{Im}\left[h_1^H\right]^2 - 2\mathrm{Im}\left[h_2^H\right]\mathrm{Im}\left[h_1^H\right]$$
$$+ \mathrm{Re}\left[h_1^H\right]^2 - 2\mathrm{Re}\left[h_1^H\right]\mathrm{Re}\left[h_2^H\right]\Big) + 48m_Z^8\left(\mathrm{Im}\left[h_1^H\right]^2 + \mathrm{Re}\left[h_1^H\right]^2\right) + q^8\left(\mathrm{Im}\left[h_2^H\right]^2 + \mathrm{Re}\left[h_2^H\right]^2\right)\Big\},$$

A. I. Hernández-Juárez, G. Tavares-Velasco, and A. Fernández-Téllez, New evaluation of the HZZ coupling: Direct bounds on anomalous contributions and CP-violating effects via a new asymmetry, Phys. Rev. D 107, 115031 (2023).

POLARIZATIONS

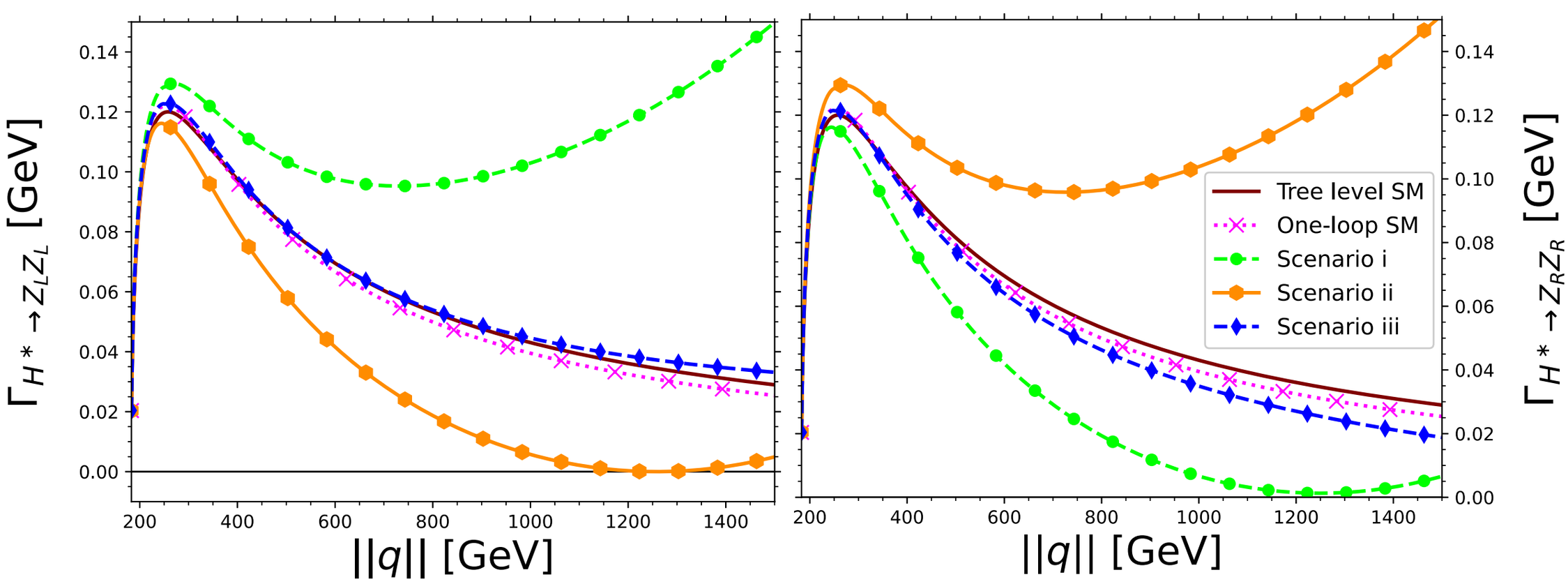
A. I. Hernández-Juárez, G. Tavares-Velasco, and A. Fernández-Tállez, New evaluation of the HZZ coupling: Direct bounds on anomalous contributions and CP-violating effects via a new asymmetry, Phys. Rev. D 107, 115031 (2023).

We considere the anomalous couplings as complex

$$h_i^V = \mathrm{Re}[h_i^V] + i\mathrm{Im}[h_i^V]$$

We calculate the partial width

$$\Gamma_{H^*\to ZZ} = \Gamma_{H^*\to Z_R Z_R} + \Gamma_{H^*\to Z_L Z_L} + \Gamma_{H^*\to Z_0 Z_0}$$



POLARIZATIONS

A. I. Hernández-Juárez, G. Tavares-Velasco, and A. Fernández-Tállez, New evaluation of the HZZ coupling: Direct bounds on anomalous contributions and CP-violating effects via a new asymmetry, Phys. Rev. D 107, 115031 (2023).

We considere the anomalous couplings as complex → $h_i^V = \mathrm{Re}[h_i^V] + i\mathrm{Im}[h_i^V]$

We calculate the partial width

$$\Gamma_{H^*\to ZZ} = \Gamma_{H^*\to Z_R Z_R} + \Gamma_{H^*\to Z_L Z_L} + \Gamma_{H^*\to Z_0 Z_0}$$

Asymmetry

$$\mathscr{A}_{LR} = \frac{\Gamma_{H^*\to Z_L Z_L} - \Gamma_{H^*\to Z_R Z_R}}{\Gamma_{H^*\to Z_L Z_L} + \Gamma_{H^*\to Z_R Z_R}}$$

POLARIZATIONS

A. I. Hernández-Juárez, G. Tavares-Velasco, and A. Fernández-Tállez, New evaluation of the HZZ coupling: Direct bounds on anomalous contributions and CP-violating effects via a new asymmetry, Phys. Rev. D 107, 115031 (2023).

We considere the anomalous couplings as complex → $h_i^V = \mathrm{Re}[h_i^V] + i\mathrm{Im}[h_i^V]$

We calculate the partial width

$$\Gamma_{H^*\to ZZ} = \Gamma_{H^*\to Z_+Z_+} + \Gamma_{H^*\to Z_-Z_-} + \Gamma_{H^*\to Z_0Z_0}$$

Asymmetry

$h_3^H = 0$ **in the SM at tree level**

$$\mathscr{A}_{LR} = 0$$

$$\mathscr{A}_{LR} = \frac{4m_Z^2\|q\|\sqrt{q^2-4m_Z^2}\left(\mathrm{Re}\left[h_1^H\right]\mathrm{Im}\left[h_3^H\right] - \mathrm{Re}\left[h_3^H\right]\mathrm{Im}\left[h_1^H\right]\right)}{q^2\left(q^2-4m_Z^2\right)\left(\mathrm{Re}\left[h_3^H\right]^2 + \mathrm{Im}\left[h_3^H\right]^2\right) + 4m_Z^4\left(\mathrm{Im}\left[h_1^H\right]^2 + \mathrm{Re}\left[h_1^H\right]^2\right)}$$

POLARIZATIONS

A. I. Hernández-Juárez, G. Tavares-Velasco, and A. Fernández-Tállez, New evaluation of the HZZ coupling: Direct bounds on anomalous contributions and CP-violating effects via a new asymmetry, Phys. Rev. D 107, 115031 (2023).

We considere the anomalous couplings as complex → $h_i^V = \mathrm{Re}[h_i^V] + i\mathrm{Im}[h_i^V]$

We calculate the partial width

$$\Gamma_{H^*\to ZZ} = \Gamma_{H^*\to Z_R Z_R} + \Gamma_{H^*\to Z_L Z_L} + \Gamma_{H^*\to Z_0 Z_0}$$

Asymmetry

$h_3^H = 0$ **in the SM at tree level**

$$\mathscr{A}_{LR} = 0$$

CP-odd

$$\mathscr{A}_{LR} = \frac{4m_Z^2\|q\|\sqrt{q^2-4m_Z^2}\left(\mathrm{Re}\left[h_1^H\right]\mathrm{Im}\left[h_3^H\right] - \mathrm{Re}\left[h_3^H\right]\mathrm{Im}\left[h_1^H\right]\right)}{q^2\left(q^2-4m_Z^2\right)\left(\mathrm{Re}\left[h_3^H\right]^2 + \mathrm{Im}\left[h_3^H\right]^2\right) + 4m_Z^4\left(\mathrm{Im}\left[h_1^H\right]^2 + \mathrm{Re}\left[h_1^H\right]^2\right)}$$

POLARIZATIONS

A. I. Hernández-Juárez, G. Tavares-Velasco, and A. Fernández-Tállez, New evaluation of the HZZ coupling: Direct bounds on anomalous contributions and CP-violating effects via a new asymmetry, Phys. Rev. D 107, 115031 (2023).

We considere the anomalous couplings as complex → $h_i^V = \mathrm{Re}[h_i^V] + i\mathrm{Im}[h_i^V]$

We calculate the partial width

$$\Gamma_{H^*\to ZZ} = \Gamma_{H^*\to Z_+Z_+} + \Gamma_{H^*\to Z_-Z_-} + \Gamma_{H^*\to Z_0Z_0}$$

Asymmetry

$h_3^H = 0$ **in the SM at tree level**

$$\mathscr{A}_{LR} = 0$$

CP-odd

$$\mathscr{A}_{LR} = \frac{4m_Z^2\|q\|\sqrt{q^2-4m_Z^2}\left(\mathrm{Re}\left[h_1^H\right]\mathrm{Im}\left[h_3^H\right] - \mathrm{Re}\left[h_3^H\right]\mathrm{Im}\left[h_1^H\right]\right)}{q^2\left(q^2-4m_Z^2\right)\left(\mathrm{Re}\left[h_3^H\right]^2 + \mathrm{Im}\left[h_3^H\right]^2\right) + 4m_Z^4\left(\mathrm{Im}\left[h_1^H\right]^2 + \mathrm{Re}\left[h_1^H\right]^2\right)}$$

Imaginary parts

POLARIZATIONS

A. I. Hernández-Juárez, G. Tavares-Velasco, and A. Fernández-Tállez, New evaluation of the HZZ coupling: Direct bounds on anomalous contributions and CP-violating effects via a new asymmetry, Phys. Rev. D 107, 115031 (2023).

We considere the anomalous couplings as complex → $h_i^V = \mathrm{Re}[h_i^V] + i\mathrm{Im}[h_i^V]$

We calculate the partial width

To induce a non-zero asymmetry 2 elements are required

1. **CP-odd form factor**
2. **Complex anomalous couplings**

$h_3^H = 0$ **in the SM at tree level**

$$\mathscr{A}_{LR} = 0$$

Asymmetry

CP-violation

$$\mathscr{A}_{LR} = \frac{4m_Z^2\|q\|\sqrt{q^2-4m_Z^2}\left(\mathrm{Re}\left[h_1^H\right]\mathrm{Im}\left[h_3^H\right] - \mathrm{Re}\left[h_3^H\right]\mathrm{Im}\left[h_1^H\right]\right)}{q^2\left(q^2-4m_Z^2\right)\left(\mathrm{Re}\left[h_3^H\right]^2 + \mathrm{Im}\left[h_3^H\right]^2\right) + 4m_Z^4\left(\mathrm{Im}\left[h_1^H\right]^2 + \mathrm{Re}\left[h_1^H\right]^2\right)}$$

Imaginary parts

HWW coupling

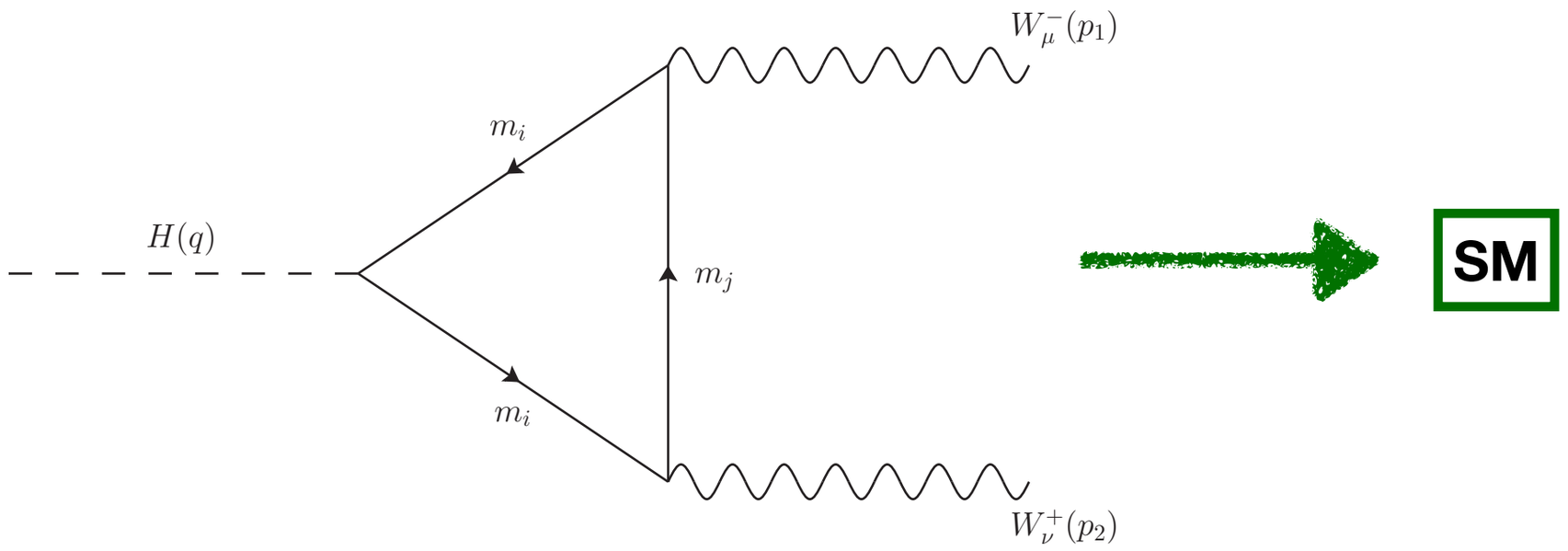
The HWW, HZZ, $H\gamma\gamma$ and $HZ\gamma$ can be parametrized by the vertex function $\Gamma^{V_1V_2H}$

$$\Gamma^{ZZH}_{\mu\nu} = h_1^V(q^2,p_1^2,p_2^2)g_{\mu\nu} + \frac{h_2^V(q^2,p_1^2,p_2^2)}{m_Z^2}p_{1\nu}p_{2\mu} + \frac{h_3^V(q^2,p_1^2,p_2^2)}{m_Z^2}\epsilon_{\mu\nu\alpha\beta}p_1^\alpha p_2^\beta,$$

$$\Gamma^{W^-W^+H}_{\mu\nu} = h_1^V g_{\mu\nu} + \frac{h_2^V}{m_W^2}p_{1\nu}p_{2\mu} + \frac{h_3^V}{m_W^2}\epsilon_{\mu\nu\alpha\beta}p_1^\alpha p_2^\beta,$$

Same structure

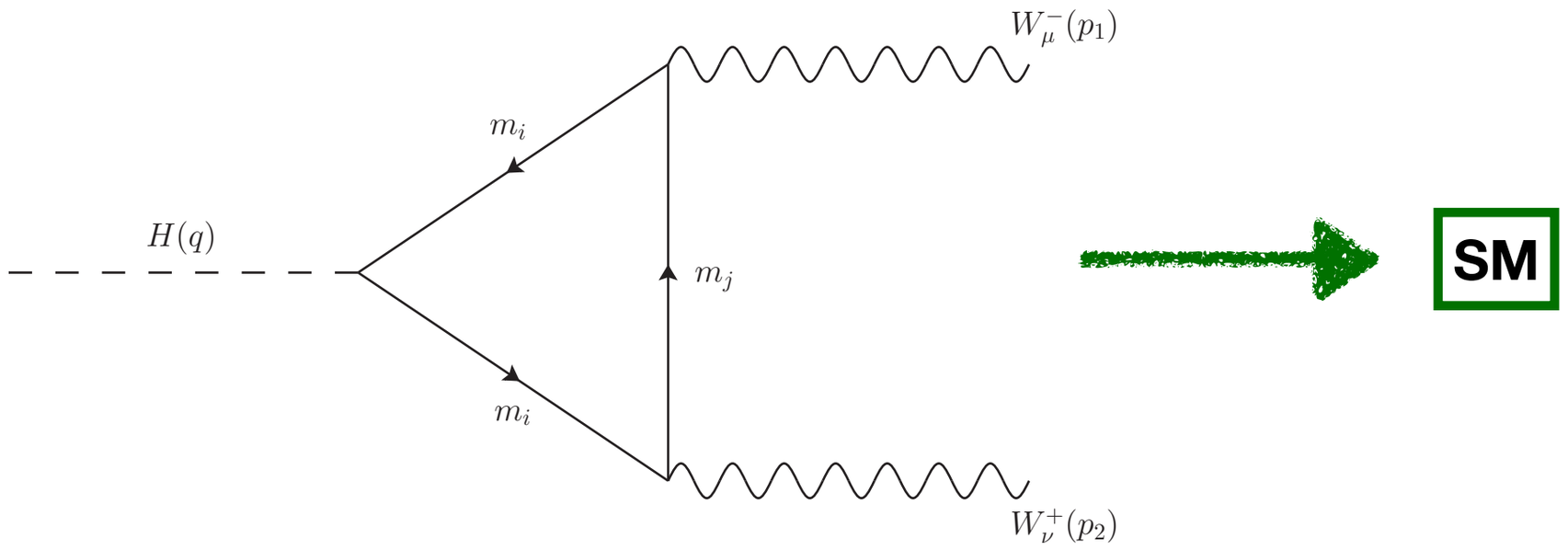
HWW



The CP-odd form factor is induced:

$$h_3^V = \frac{ig^2 N_c \left|V_{ij}\right|^2 m_i^2}{32\pi^2\left[(p_1-p_2)^2-q^2\right]\left[(p_1+p_2)^2-q^2\right]}\Big\{\left[p_1^2-p_2^2\right]\left[\left(2m_i^2-2m_j^2+p_1^2+p_2^2-q^2\right)\mathrm{C}_0\left(p_1^2,p_2^2,q^2,m_i^2,m_j^2,m_i^2\right)\right.$$
$$\left.-2\mathrm{B}_0\left(q^2,m_i^2,m_i^2\right)\right]+\left(3p_1^2+p_2^2-q^2\right)\mathrm{B}_0\left(p_1^2,m_i^2,m_j^2\right)-\left(p_1^2+3p_2^2-q^2\right)\mathrm{B}_0\left(p_2^2,m_i^2,m_j^2\right)-\left(m_i\leftrightarrow m_j\right)\Big\}$$

HWW

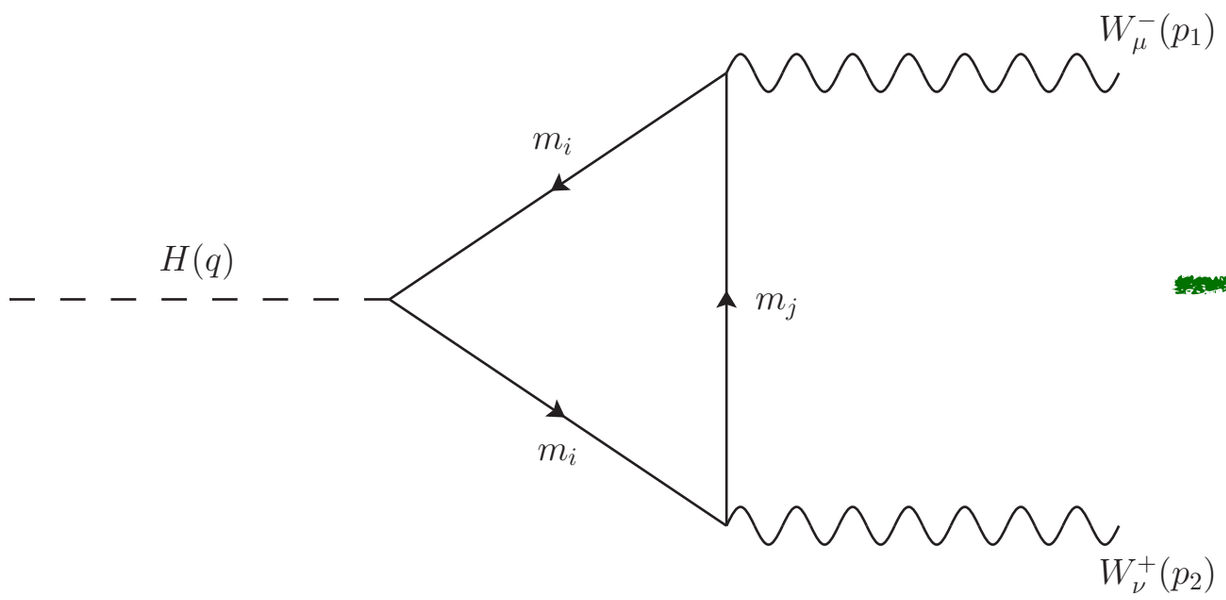


The CP-odd form factor is induced:

$$h_3^V = \frac{ig^2 N_c \left|V_{ij}\right|^2 m_i^2}{32\pi^2\left[(p_1-p_2)^2-q^2\right]\left[(p_1+p_2)^2-q^2\right]}\Big\{\left[p_1^2-p_2^2\right]\left[\left(2m_i^2-2m_j^2+p_1^2+p_2^2-q^2\right)\mathrm{C}_0\left(p_1^2,p_2^2,q^2,m_i^2,m_j^2,m_i^2\right)\right.$$
$$\left.-2\mathrm{B}_0\left(q^2,m_i^2,m_i^2\right)\right]+\left(3p_1^2+p_2^2-q^2\right)\mathrm{B}_0\left(p_1^2,m_i^2,m_j^2\right)-\left(p_1^2+3p_2^2-q^2\right)\mathrm{B}_0\left(p_2^2,m_i^2,m_j^2\right)-(m_i\leftrightarrow m_j)\Big\}$$

Is this CP violation?

HWW





SM

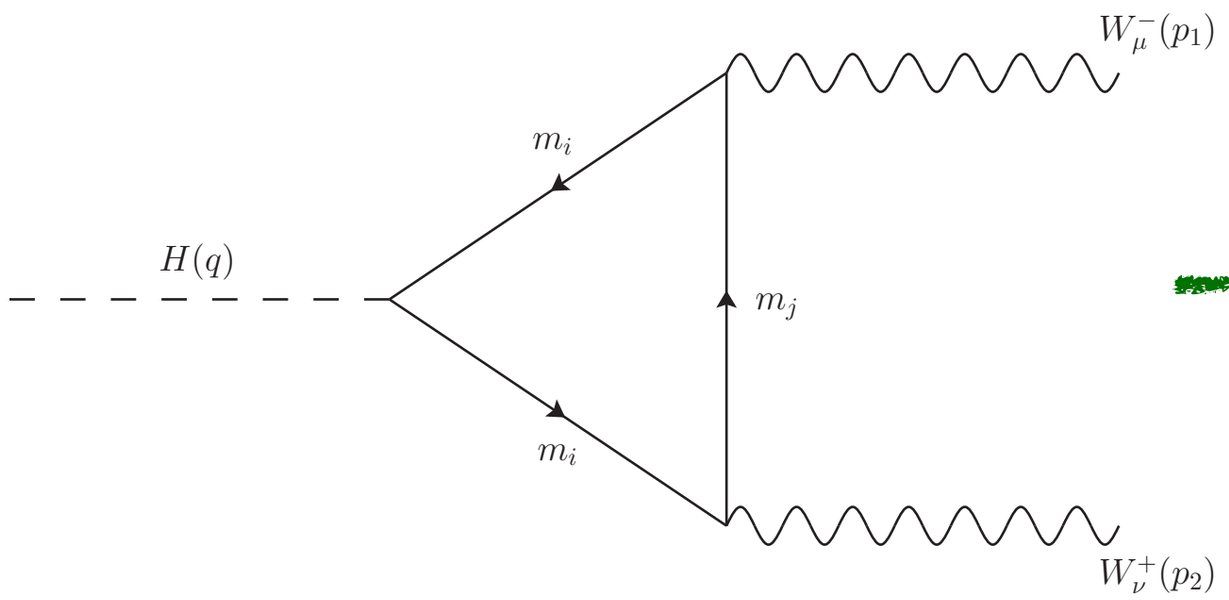
The CP-odd form factor is induced:

No complex phase is present

$$h_3^V = \frac{ig^2 N_c \left|V_{ij}\right|^2 m_i^2}{32\pi^2\left[(p_1-p_2)^2-q^2\right]\left[(p_1+p_2)^2-q^2\right]}\Big\{\left[p_1^2-p_2^2\right]\left[\left(2m_i^2-2m_j^2+p_1^2+p_2^2-q^2\right)\mathrm{C}_0\left(p_1^2,p_2^2,q^2,m_i^2,m_j^2,m_i^2\right)\right.$$
$$\left.-2\mathrm{B}_0\left(q^2,m_i^2,m_i^2\right)\right]+\left(3p_1^2+p_2^2-q^2\right)\mathrm{B}_0\left(p_1^2,m_i^2,m_j^2\right)-\left(p_1^2+3p_2^2-q^2\right)\mathrm{B}_0\left(p_2^2,m_i^2,m_j^2\right)-\left(m_i\leftrightarrow m_j\right)\Big\}$$

Is this CP violation?

HWW





SM

The CP-odd form factor is induced:

No complex phase is present

$$h_3^V = \frac{ig^2 N_c |V_{ij}|^2 m_i^2}{32\pi^2 \left[(p_1-p_2)^2 - q^2\right]\left[(p_1+p_2)^2 - q^2\right]} \Big\{ \left[p_1^2 - p_2^2\right] \left[\left(2m_i^2 - 2m_j^2 + p_1^2 + p_2^2 - q^2\right) \mathrm{C}_0\left(p_1^2, p_2^2, q^2, m_i^2, m_j^2, m_i^2\right) \right.$$
$$\left. - 2\mathrm{B}_0\left(q^2, m_i^2, m_i^2\right) \right] + \left(3p_1^2 + p_2^2 - q^2\right) \mathrm{B}_0\left(p_1^2, m_i^2, m_j^2\right) - \left(p_1^2 + 3p_2^2 - q^2\right) \mathrm{B}_0\left(p_2^2, m_i^2, m_j^2\right) - (m_i \leftrightarrow m_j) \Big\}$$

Is this CP violation?

It is not a source of CP violation, but it constitutes a background in searches for CP-violating effects.

HWW

RADIATIVE CORRECTIONS FOR H → W $^+$W $^-$(γ) IN THE STANDARD MODEL

Bernd A. KNIEHL

Department of Physics, University of Wisconsin, Madison, WI 53706, USA

Received 10 January 1991

The

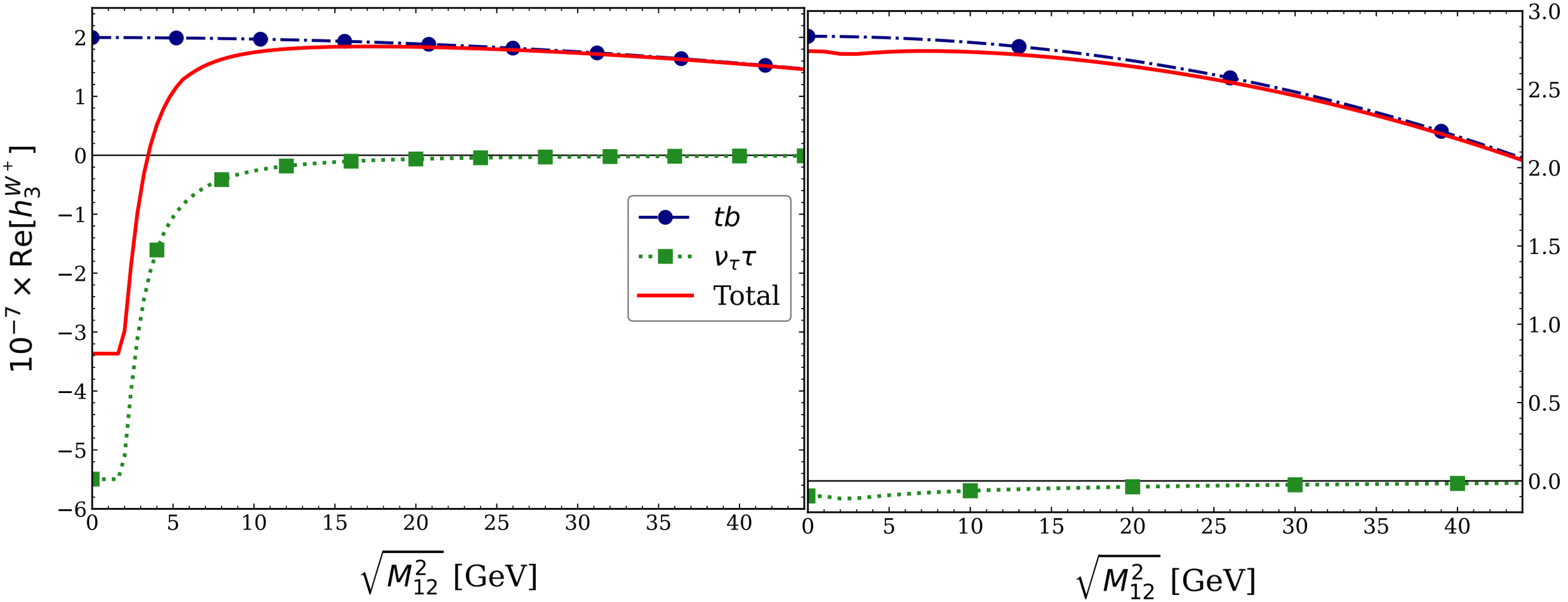
$$h_3^V = \frac{ig^2 N_c |V_{ij}|^2 m_i^2}{32\pi^2 \left[(p_1-p_2)^2-q^2\right]\left[(p_1+p_2)^2-q^2\right]} \Big\{ \left[p_1^2-p_2^2\right]\left[\left(2m_i^2-2m_j^2+p_1^2+p_2^2-q^2\right) \mathrm{C}_0\left(p_1^2,p_2^2,q^2,m_i^2,m_j^2,m_i^2\right) - 2\mathrm{B}_0\left(q^2,m_i^2,m_i^2\right)\right] + \left(3p_1^2+p_2^2-q^2\right)\mathrm{B}_0\left(p_1^2,m_i^2,m_j^2\right) - \left(p_1^2+3p_2^2-q^2\right)\mathrm{B}_0\left(p_2^2,m_i^2,m_j^2\right) - (m_i \leftrightarrow m_j)\Big\}$$

First reported in 1991.

Forgotten for 35 yers!

HWW

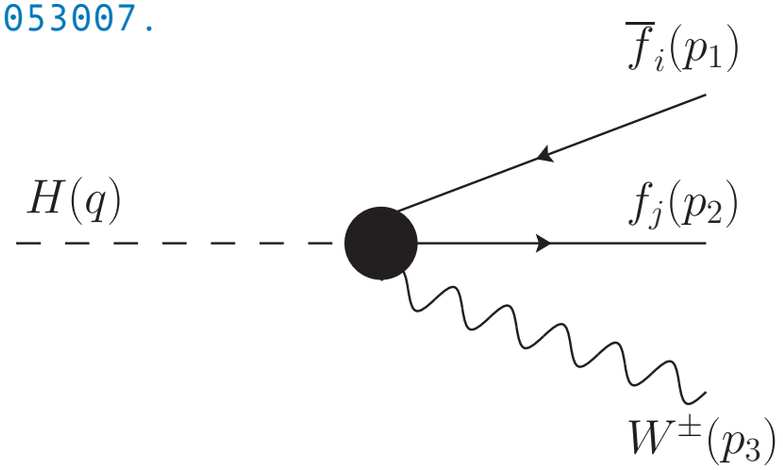
First numerical evaluation!

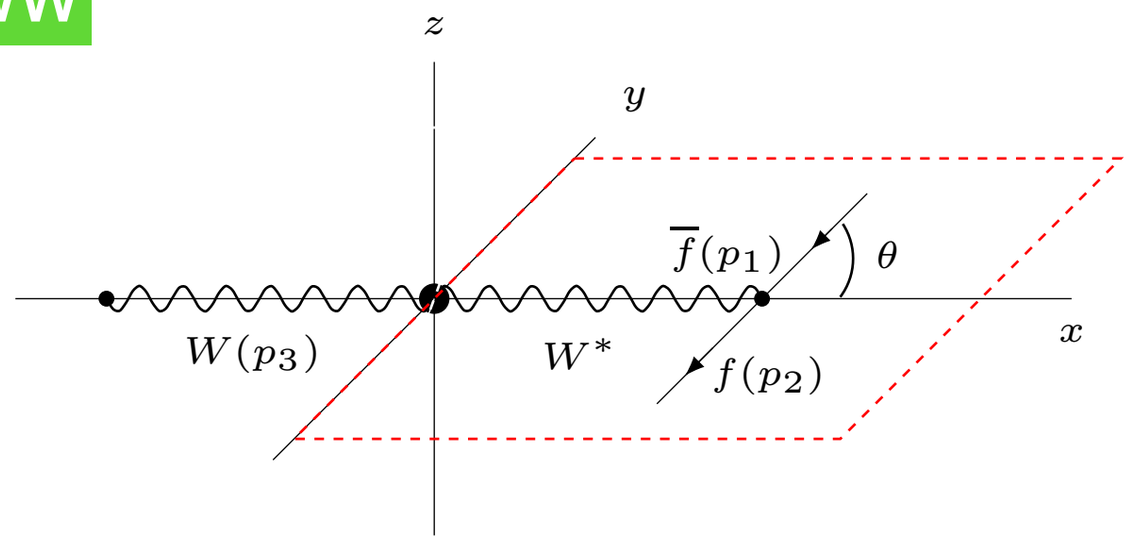


A. I. Hernández-Juárez, G. Tavares-Velasco, and J. Martínez-Ramón, Phys.Rev.D 114 (2026) 5, 053007.

A. I. Hernández-Juárez, G. Tavares-Velasco, and J. Martínez-Ramón, Phys.Rev.D 114 (2026) 5, 053007.

HWW

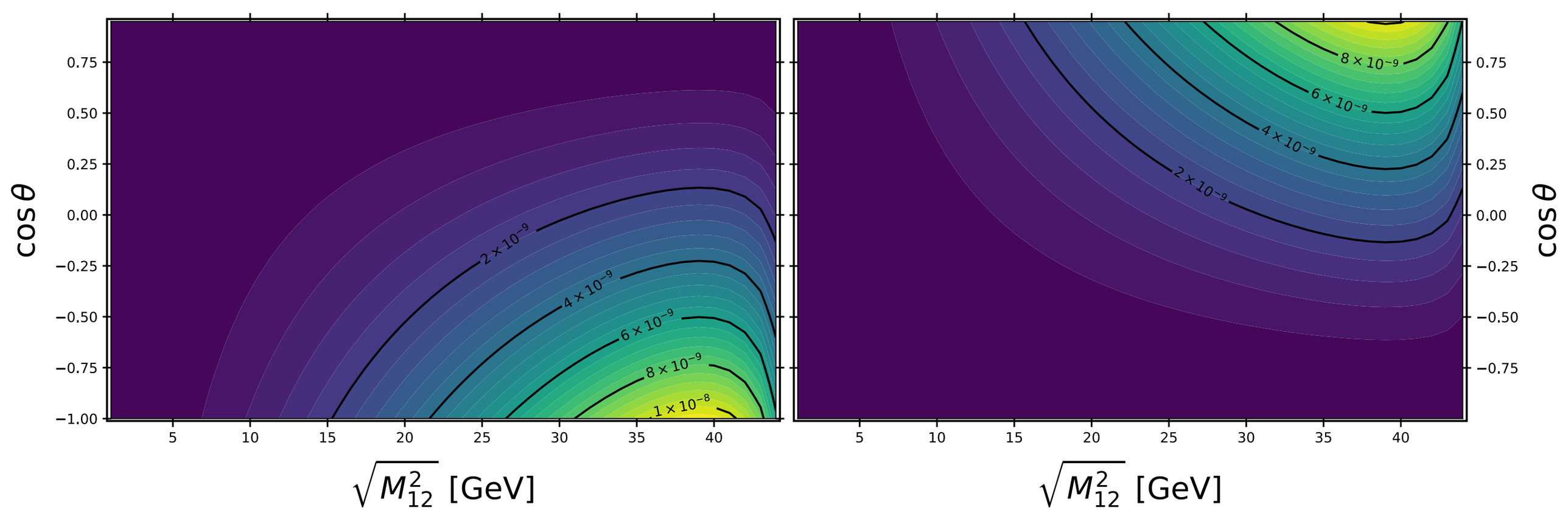




$$\mathscr{A}_{LR}^{V} = \frac{4m_W^2\sqrt{-2M_{12}^2(m_H^2+m_W^2)+M_{12}^4+(m_H^2-m_W^2)^2}}{G(m_H^2,m_W^2)}\left(\mathrm{Re}\left[h_1^V\right]\mathrm{Im}\left[h_3^V\right]-\mathrm{Im}\left[h_1^V\right]\mathrm{Re}\left[h_3^V\right]\right)$$

$$\frac{d\Gamma^L(H\to\overline{\ell}_i\nu_{\ell_i}W_L^+)}{d\cos\theta\, dM_{12}^2}$$

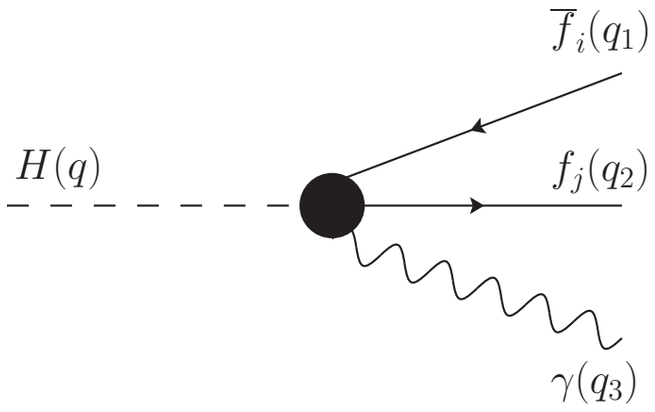
$$\frac{d\Gamma^R(H\to\overline{\ell}_i\nu_{\ell_i}W_R^+)}{d\cos\theta\, dM_{12}^2}$$

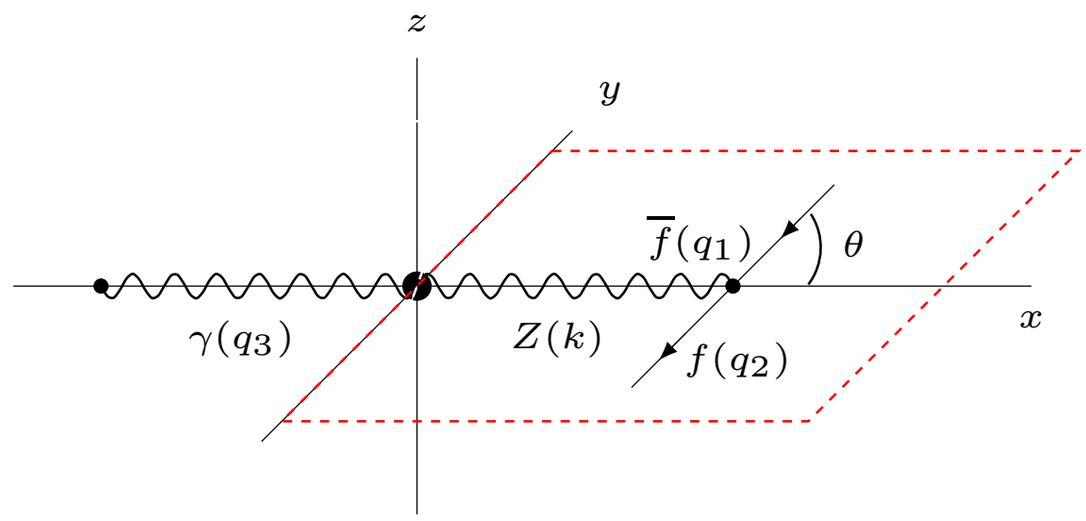


$HZ\gamma$ coupling

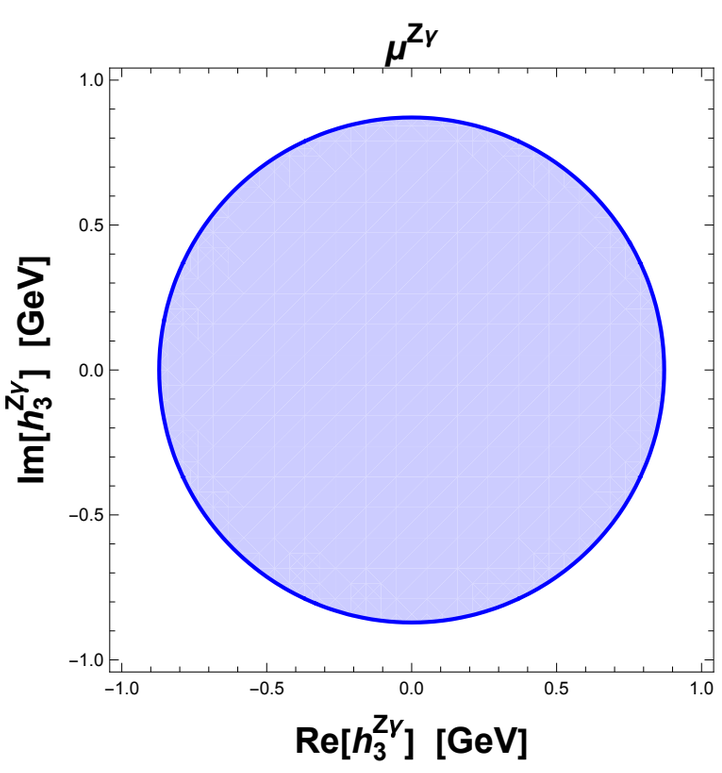
A. I. Hernández-Juárez, G. Tavares-Velasco, A. Fernández-Téllez and D. Watko, Phys.Rev.D 114 (2026) 5, 053007.

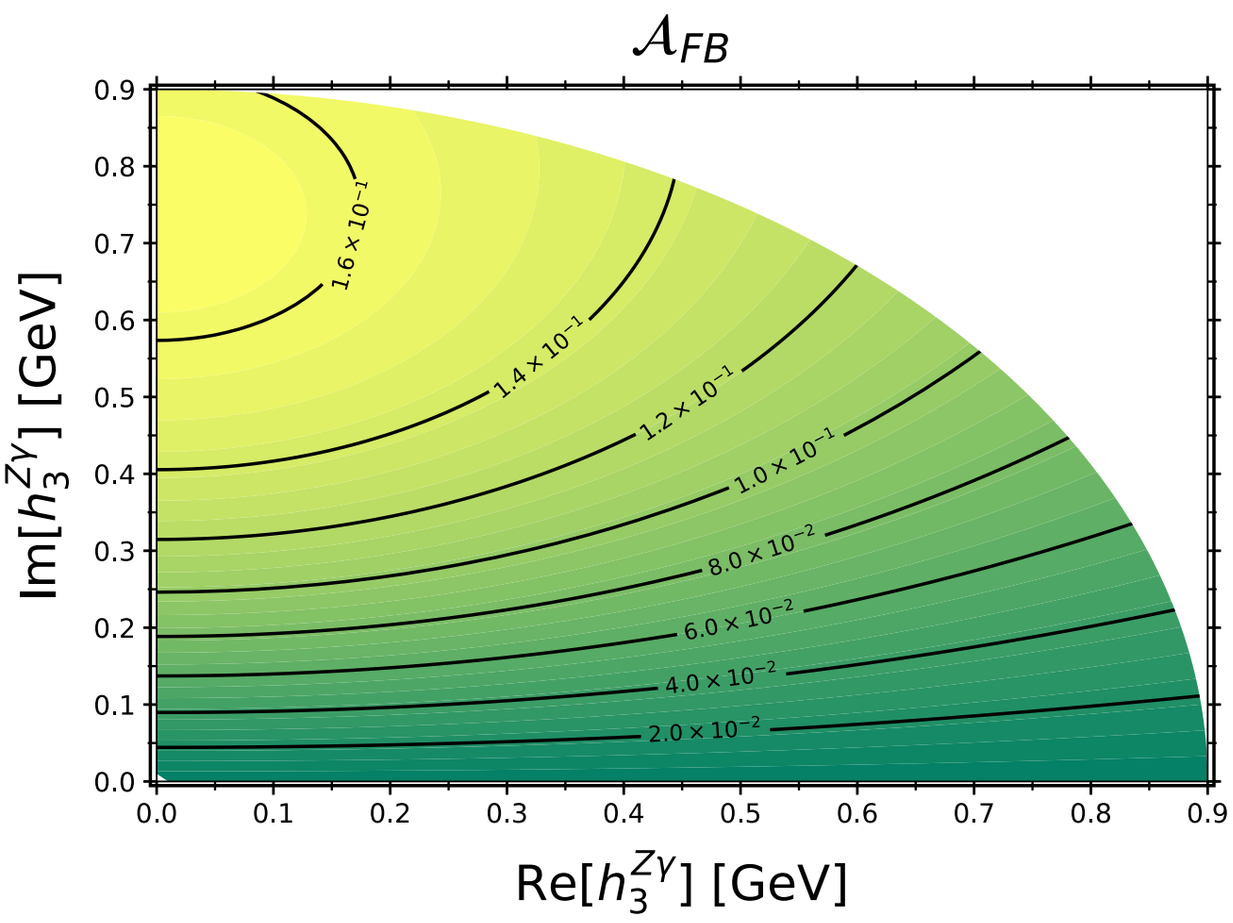
$HZ\gamma$





$$\mathcal{A}_{FB} = \frac{6\, g_A g_V m_Z^2 (m_H^2 - m_Z^2)\, N_c}{(g_A^2 + g_V^2)} \left\{ \frac{-\mathrm{Im}\left[h_1^{Z\gamma} (h_3^{Z\gamma})^*\right]}{4|h_1^{Z\gamma}|^2\, m_Z^4 + |h_3^{Z\gamma}|^2 (m_H^2 - m_Z^2)^2} \right\}.$$



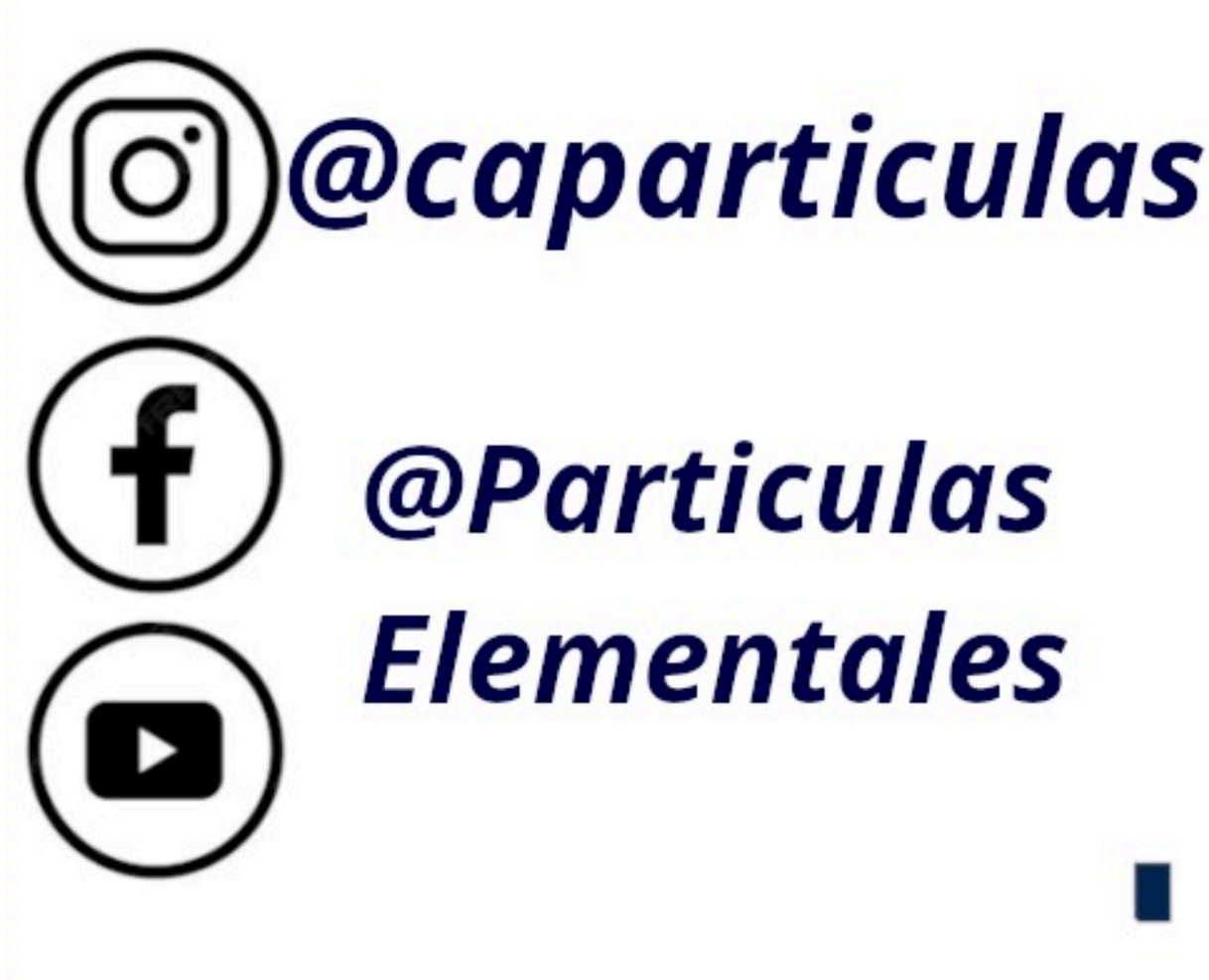


Conclusions

- We have found new observables for CP-odd effects in Higgs decays into gauge bosons.

- Polarized and angular observables are sensitive to CP-odd effects.

Follo us!


@caparticulas
@Particulas
Elementales


CUERPO
ACADÉMICO
PARTÍCULAS
ELEMENTALES
BUAP



Comparte una idea...

Partículas Elementales

5646 seguidores · 22 seguidos

Página oficial de Facebook del Cuerpo Académico de Partícu

Creador digital · caparticulas

División de Partículas y Campos - SMF

1731 seguidores · 4 seguidos

Cuenta oficial de la División de Partículas y Campos de la Soc
SMF)

Ciencia, tecnología e ingeniería

CIIEC-BUAP

1141 seguidores · 9 seguidos

Centro Interdisciplinario de Investigación y I

Científico



¡Gracias!

