Constrain HZZ anomalous couplings in Higgs off-shell regions

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matrix element likelihood approach

$$L(\mathrm{HVV}) \sim a_1 \frac{m_Z^2}{2} \mathrm{HZ}^{\mu}\mathrm{Z}_{\mu} - \frac{\kappa_1}{(\Lambda_1)^2} m_Z^2 \mathrm{HZ}_{\mu}\Box \mathrm{Z}^{\mu} - \frac{1}{2} a_2 \mathrm{HZ}^{\mu\nu}\mathrm{Z}_{\mu\nu} - \frac{1}{2} a_3 \mathrm{HZ}^{\mu\nu}\tilde{\mathrm{Z}}_{\mu\nu}$$

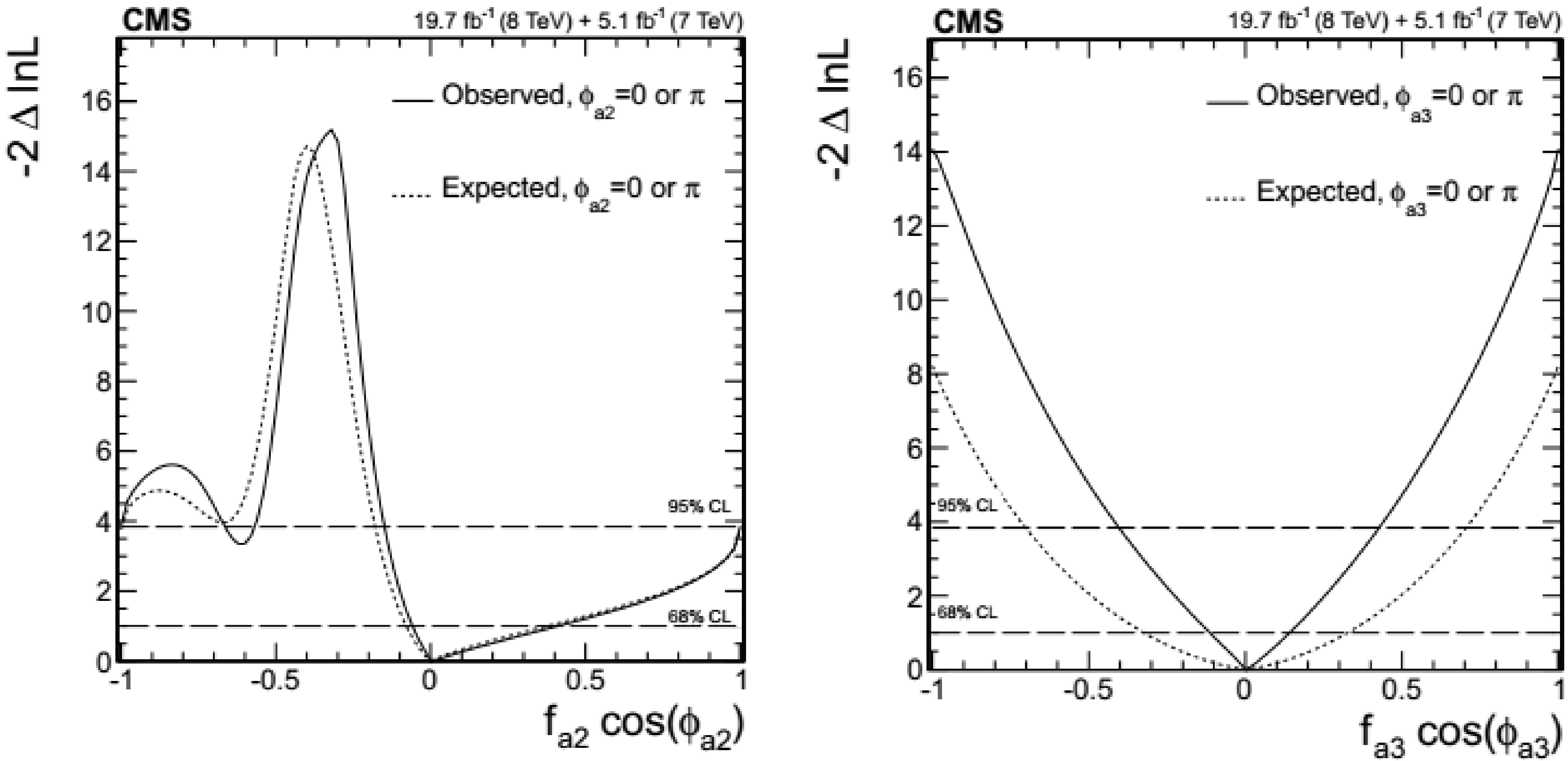
The effective fractional cross sections f_{ai} and phases ϕ_{ai}

$$f_{ai} = |a_i|^2\sigma_i \Big/ \sum |a_j|^2\sigma_j, \text{ and } \phi_{ai} = \arg\left(a_i/a_1\right)$$

$$\left|\frac{a_i}{a_1}\right| = \sqrt{\frac{f_{ai}}{f_{a1}}}\sqrt{\frac{\sigma_1}{\sigma_i}}$$

$$Z_{\mu'\nu'} = \partial_{\mu'} Z_{\nu'} - \partial_{\nu'} Z_{\mu'} \qquad \tilde{Z}_{\mu'\nu'} = \tfrac{1}{2}\epsilon_{\mu'\nu'\rho\sigma} Z^{\rho\sigma}$$

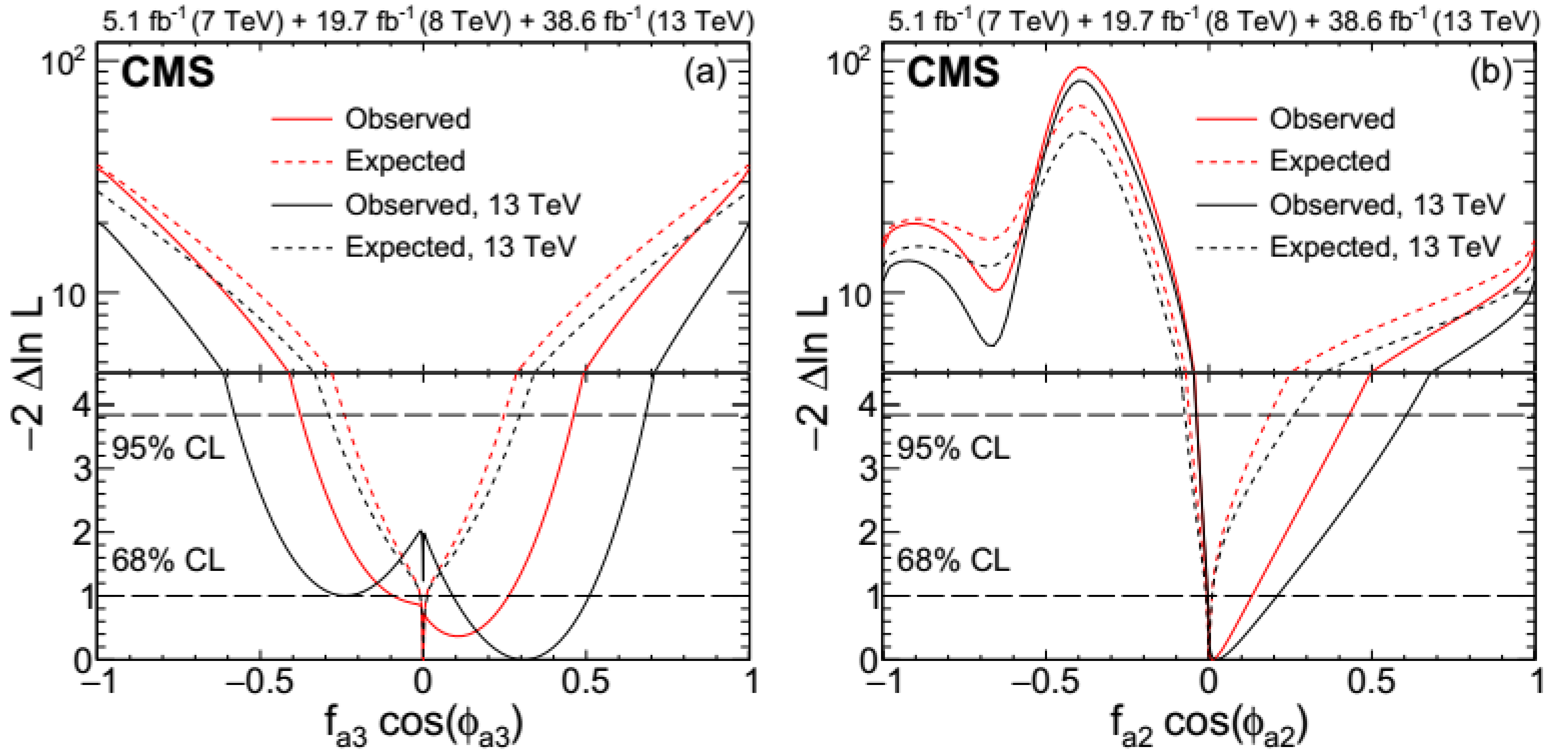
The experimental measurements in Higgs on-shell region



Parameter	Observed	Expected
$(\Lambda_1 \sqrt{\lvert a_1 \rvert}) \cos(\phi_{\Lambda_1})$	$[-\infty, -119\,\text{GeV}] \cup [104\,\text{GeV}, \infty]$	$[-\infty, 50\,\text{GeV}] \cup [116\,\text{GeV}, \infty]$
a_2/a_1	$[-2.28, -1.88] \cup [-0.69, \infty]$	$[-0.77, \infty]$
a_3/a_1	$[-2.05, 2.19]$	$[-3.85, 3.85]$

a destructive interference with SM
in on-shell Higgs region

Phys.Rev. D92 (2015) no.1, 012004, 1411.3441

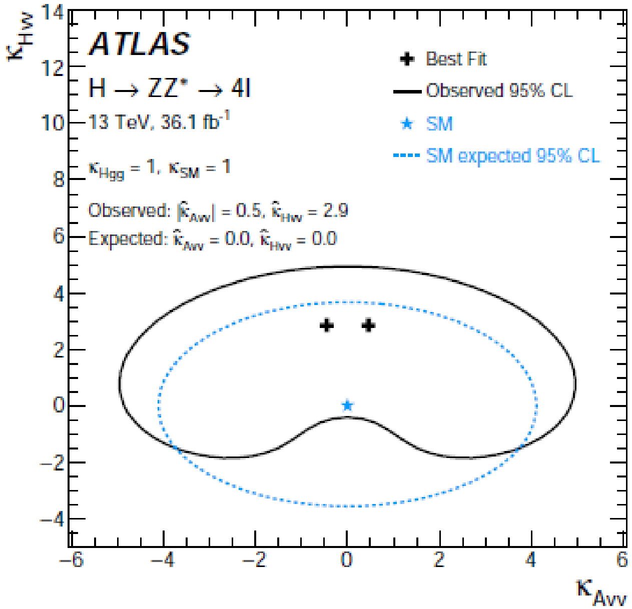


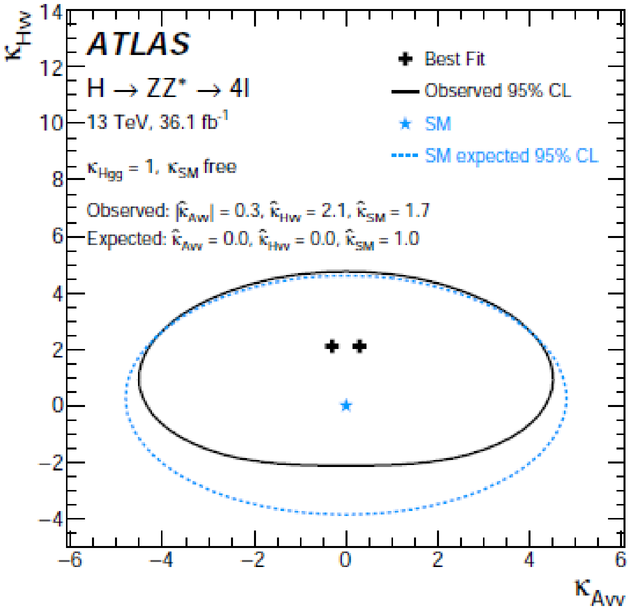
Parameter	Observed	Expected
$f_{a3}\cos(\phi_{a3})$	$0.00^{+0.26}_{-0.09}$ $[-0.38, 0.46]$	$0.000^{+0.010}_{-0.010}$ $[-0.25, 0.25]$
$f_{a2}\cos(\phi_{a2})$	$0.01^{+0.12}_{-0.02}$ $[-0.04, 0.43]$	$0.000^{+0.009}_{-0.008}$ $[-0.06, 0.19]$

$$-0.34 \leq a_2 \leq 1.45, -2.0 \leq a_3 \leq 2.36,$$

Phys.Lett. B775 (2017) 1-24, 1707.00541

$$\mathcal{L}_0^V = \left\{ \kappa_{\rm SM} \left[\frac{1}{2} g_{HZZ} Z_\mu Z^\mu + g_{HWW} W_\mu^+ W^{-\mu} \right] \right.$$
$$- \frac{1}{4} \left[\kappa_{Hgg} g_{Hgg} G_{\mu\nu}^a G^{a,\mu\nu} + \tan\alpha \kappa_{Agg} g_{Agg} G_{\mu\nu}^a \tilde{G}^{a,\mu\nu} \right]$$
$$- \frac{1}{4} \frac{1}{\Lambda} \left[\kappa_{HZZ} Z_{\mu\nu} Z^{\mu\nu} + \tan\alpha \kappa_{AZZ} Z_{\mu\nu} \tilde{Z}^{\mu\nu} \right]$$
$$\left. - \frac{1}{2} \frac{1}{\Lambda} \left[\kappa_{HWW} W_{\mu\nu}^+ W^{-\mu\nu} + \tan\alpha \kappa_{AWW} W_{\mu\nu}^+ \tilde{W}^{-\mu\nu} \right] \right\} X_0.$$





JHEP 03 (2018) 095

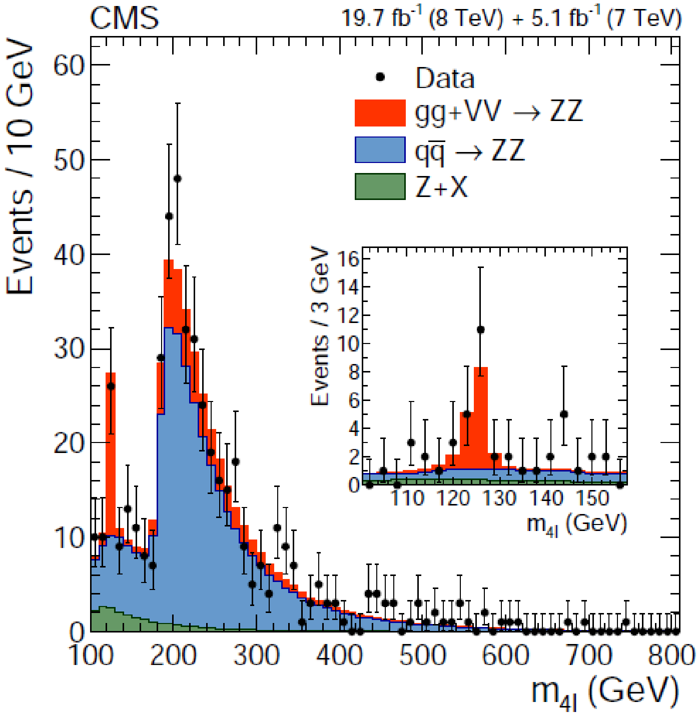
Higgs off-shell region physics

In gluon fusion production mode, the off-shell production cross section has been shown to be sizeable at high ZZ invariant mass

CMS PAS HIG-14-002

1307.4935

constraining the Higgs boson width from off-shell production and decay to ZZ(4l)



interference effects from the

anomalous HZZ couplings in on-shell and off-shell Higgs regions

Available on the CERN CDS information server — CMS PAS HIG-18-002

CMS Physics Analysis Summary

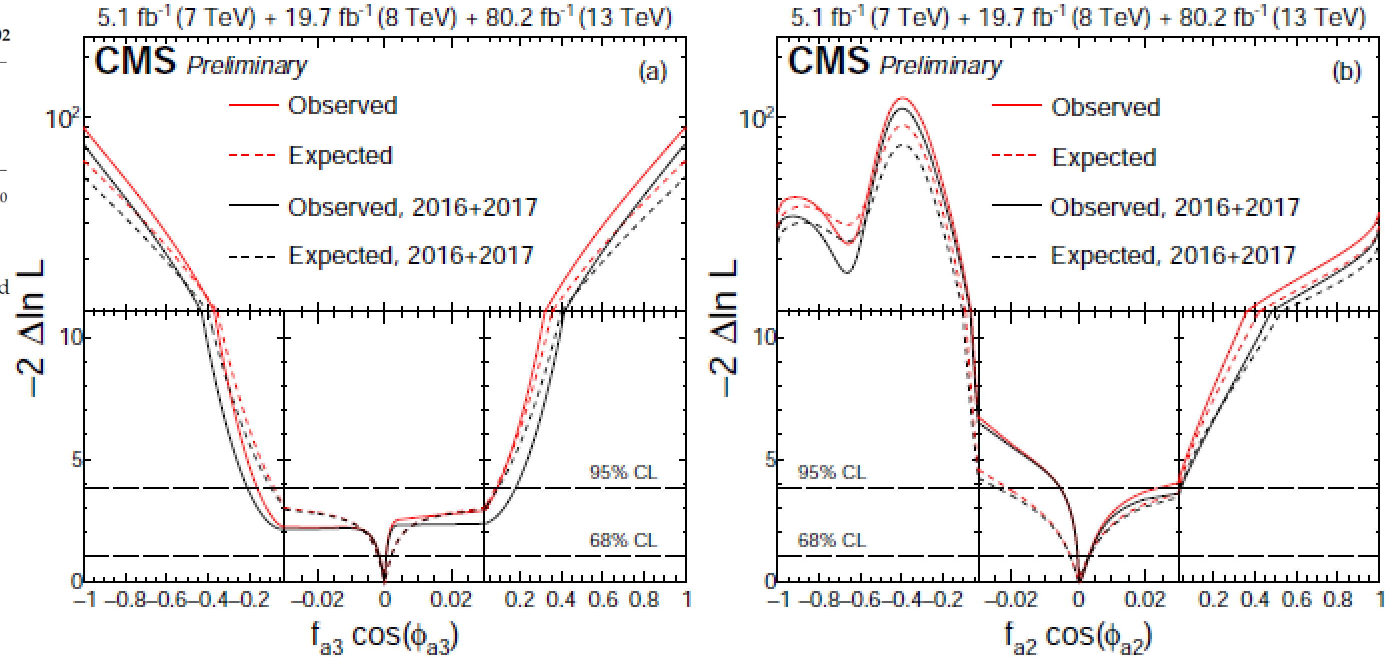
Contact: cms-pag-conveners-higgs@cern.ch — 2018/09/20

Measurements of Higgs boson properties from on-shell and off-shell production in the four-lepton final state

The CMS Collaboration

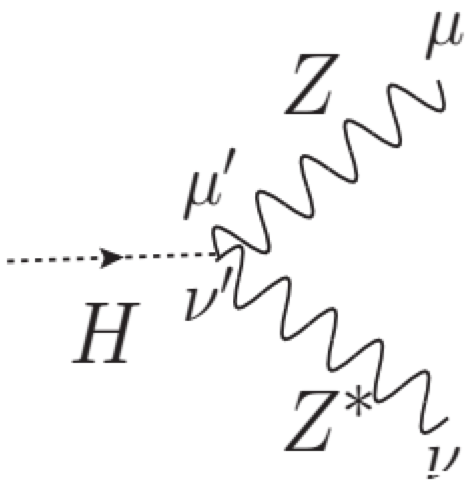
$$a_2 \in [-0.09, 0.19]$$

$$a_3 \in [-0.20, 0.18]$$



The gg → $ZZ/Z\gamma^* \to 4\ell$ background process is simulated with MCFM 7.0 [18, 50–52]. The VBF and triple-gauge-boson (VVV) background is simulated with PHANTOM [53]. Both the MCFM and PHANTOM generators allow one to model the H boson signal, background, and their interference in the off-shell production. However, this does not allow modeling of anomalous interactions. Therefore, a dedicated program based on signal modeling, which includes anomalous interactions, from JHUGEN and background modeling from MCFM [18, 52] has been developed for both gluon fusion and VBF with triple-gauge-boson production. This program is included within the JHUGEN and MELA packages. See Ref. [22] for details. A large number of samples with anomalous couplings have been generated with these packages, including re-weighting from any hypothesis to the others.

Effective Lagrangian

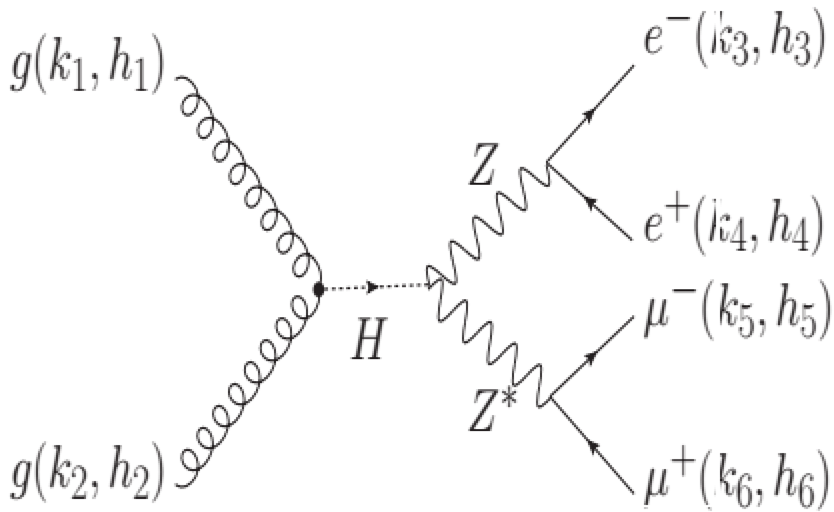


$$\mathcal{L} = \frac{a_1}{v} M_Z^2 H Z^\mu Z_\mu - \frac{a_2}{v} H Z^{\mu\nu} Z_{\mu\nu} - \frac{a_3}{2v} H Z^{\mu\nu} \tilde{Z}_{\mu\nu}$$

CP even SM | CP even BSM | CP odd BSM

$$\Gamma^{\mu\nu}(k,k') = i\frac{2}{v}\sum_{i=1}^{3} a_i \Gamma_i^{\mu\nu}(k,k') = i\frac{2}{v}[a_1 M_Z^2 g^{\mu\nu} + 2a_2(k^\nu k'^\mu - k\cdot k' g^{\mu\nu}) + 2a_3 \epsilon^{\mu\nu\rho\sigma} k_\rho k'_\sigma]$$

Helicity amplitude calculation



Helicity amplitude for Higgs mediated process

$$\mathcal{A}^{gg\to H\to ZZ\to 2e2\mu}(1_g^{h_1}, 2_g^{h_2}, 3_{e^-}^{h_3}, 4_{e^+}^{h_4}, 5_{\mu^-}^{h_5}, 6_{\mu^+}^{h_6})$$

$$= [a_1\mathcal{A}_{\rm SM}^H + a_2\mathcal{A}_{CP-{\rm even}}^H + a_3\mathcal{A}_{CP-{\rm odd}}^H](1_g^{h_1}, 2_g^{h_2}, 3_{e^-}^{h_3}, 4_{e^+}^{h_4}, 5_{\mu^-}^{h_5}, 6_{\mu^+}^{h_6}) \ ,$$

$$= \mathcal{A}^{gg\to H}(1_g^{h_1}, 2_g^{h_2}) \times \frac{P_H(s_{12})}{s_{12}} \times \sum_{i=1}^{3} a_i\mathcal{A}_i^{H\to ZZ\to 2e2\mu}(3_{e^-}^{h_3}, 4_{e^+}^{h_4}, 5_{\mu^-}^{h_5}, 6_{\mu^+}^{h_6})$$

h=+,-

$$P_H(s) = \frac{s}{s - M_H^2 + iM_H\Gamma_H}$$

$$\langle ij\rangle = \bar{u}_-(p_i)u_+(p_j), \ [ij] = \bar{u}_+(p_i)u_-(p_j)$$

$$\langle ij\rangle[ji] = 2p_i \cdot p_j, \ s_{ij} = (p_i + p_j)^2,$$

$$\mathcal{A}^{gg\to H}(1_g^+, 2_g^+) = \frac{2c_g}{v}[12]^2$$

$$\mathcal{A}^{gg\to H}(1_g^-, 2_g^-) = \frac{2c_g}{v}\langle 12\rangle^2$$

$$\frac{c_g}{v} = \frac{1}{2}\sum_f \frac{\delta^{ab}}{2}\frac{i}{16\pi^2}g_s^2 4e\frac{m_f^2}{2M_W s_W}\frac{1}{M_H^2}[2 + M_H^2(1-\tau_H)C_0^{\gamma\gamma}(m_f^2)]$$

$$\mathcal{A}^{H\to ZZ\to 2e2\mu}(3_{e^-}^{h_3}, 4_{e^+}^{h_4}, 5_{\mu^-}^{h_5}, 6_{\mu^+}^{h_6}) = \sum_{i=1}^{3} a_i \mathcal{A}_i^{H\to ZZ\to 2e2\mu}(3_{e^-}^{h_3}, 4_{e^+}^{h_4}, 5_{\mu^-}^{h_5}, 6_{\mu^+}^{h_6})$$

$$\mathcal{A}_1^{H\to ZZ\to 2e2\mu}(3_{e^-}^-, 4_{e^+}^+, 5_{\mu^-}^-, 6_{\mu^+}^+) = f \times l_e^2 \frac{M_W^2}{\cos^2\theta_W}\langle 35\rangle[46],$$

$$\mathcal{A}_2^{H\to ZZ\to 2e2\mu}(3_{e^-}^-, 4_{e^+}^+, 5_{\mu^-}^-, 6_{\mu^+}^+) = f \times l_e^2 \times$$

$$\Big[-2k\cdot k'\langle 35\rangle[46] - (\langle 35\rangle[45] + \langle 36\rangle[46])(\langle 35\rangle[36] + \langle 45\rangle[46])\Big]$$

$$\mathcal{A}_3^{H\to ZZ\to 2e2\mu}(3_{e^-}^-, 4_{e^+}^+, 5_{\mu^-}^-, 6_{\mu^+}^+) = f \times i\ l_e^2 \times$$

$$\Big[2(k\cdot k' + \langle 46\rangle[46])\langle 35\rangle[46] + \langle 35\rangle[45](\langle 35\rangle[36] + \langle 45\rangle[46])$$

$$+\langle 36\rangle[46](\langle 35\rangle[36] - \langle 45\rangle[46])\Big].$$

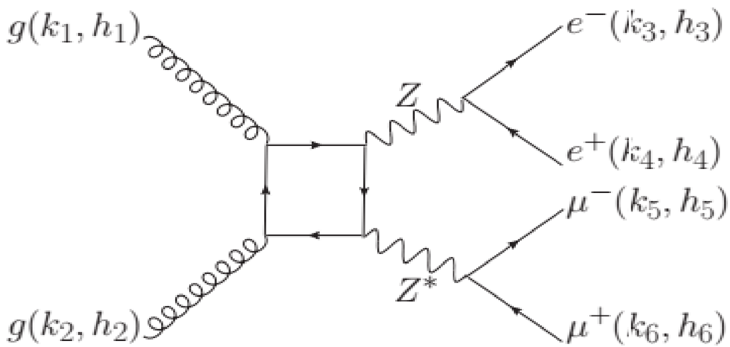
$$f = -2ie^3\frac{1}{M_W \sin\theta_W}\frac{P_Z(s_{34})}{s_{34}}\frac{P_Z(s_{56})}{s_{56}}$$

$$l_e = \frac{-1 + 2\sin^2\theta_W}{\sin(2\theta_W)}, r_e = \frac{2\sin^2\theta_W}{\sin(2\theta_W)}$$

for the other three helicity combinations $(-,+,+,-)(+,-,-,+)\ (+,-,+,-)$

with some exchanges like $l_e \leftrightarrow r_e$, $4 \leftrightarrow 6$, $3 \leftrightarrow 5$, $[] \leftrightarrow \langle\rangle$

★ the amplititude for box process



JHEP 1404 (2014) 060

$$
\begin{aligned}
&A(1_g^{h_1},2_g^{h_2},3_e^-,4_{\bar{e}}^+,5_\mu^-,6_{\bar{\mu}}^+) = \\
&A_{LL}(1_g^{h_1},2_g^{h_2},3_e^-,4_{\bar{e}}^+,5_\mu^-,6_{\bar{\mu}}^+)\left(P^{L,L,-,-}(s_{34},s_{56})+P^{R,R,-,-}(s_{34},s_{56})\right) \\
+\ &A_{LR}(1_g^{h_1},2_g^{h_2},3_e^-,4_{\bar{e}}^+,5_\mu^-,6_{\bar{\mu}}^+)\left(P^{L,R,-,-}(s_{34},s_{56})+P^{R,L,-,-}(s_{34},s_{56})\right)
\end{aligned}
$$

$$
\begin{aligned}
P^{L,L,-,-}(s_{34},s_{56}) &= (Q_i q_e + L_i l_e \mathcal{P}_Z(s_{34}))(Q_i q_e + L_i l_e \mathcal{P}_Z(s_{56})) \\
P^{L,R,-,-}(s_{34},s_{56}) &= (Q_i q_e + L_i l_e \mathcal{P}_Z(s_{34}))(Q_i q_e + R_i l_e \mathcal{P}_Z(s_{56})) \\
P^{R,L,-,-}(s_{34},s_{56}) &= (Q_i q_e + R_i l_e \mathcal{P}_Z(s_{34}))(Q_i q_e + L_i l_e \mathcal{P}_Z(s_{56})) \\
P^{R,R,-,-}(s_{34},s_{56}) &= (Q_i q_e + R_i l_e \mathcal{P}_Z(s_{34}))(Q_i q_e + R_i l_e \mathcal{P}_Z(s_{56}))
\end{aligned}
$$

$$A_{LL}(1_g^{h_1}, 2_g^{h_2}, 3_e^-, 4_{\bar{e}}^+, 5_\mu^-, 6_{\bar{\mu}}^+) = \sum_{j=2}^{3} d_j^{d=6}(1^{h_1}, 2^{h_2})\ D_0^{d=6}(j) + \sum_{j=1}^{3} d_j(1^{h_1}, 2^{h_2})\ D_0(j)$$
$$+ \sum_{j=1}^{6} c_j(1^{h_1}, 2^{h_2})\ C_0(j) + \sum_{j=1}^{6} b_j(1^{h_1}, 2^{h_2})\ B_0(j) + R(1^{h_1}, 2^{h_2})$$

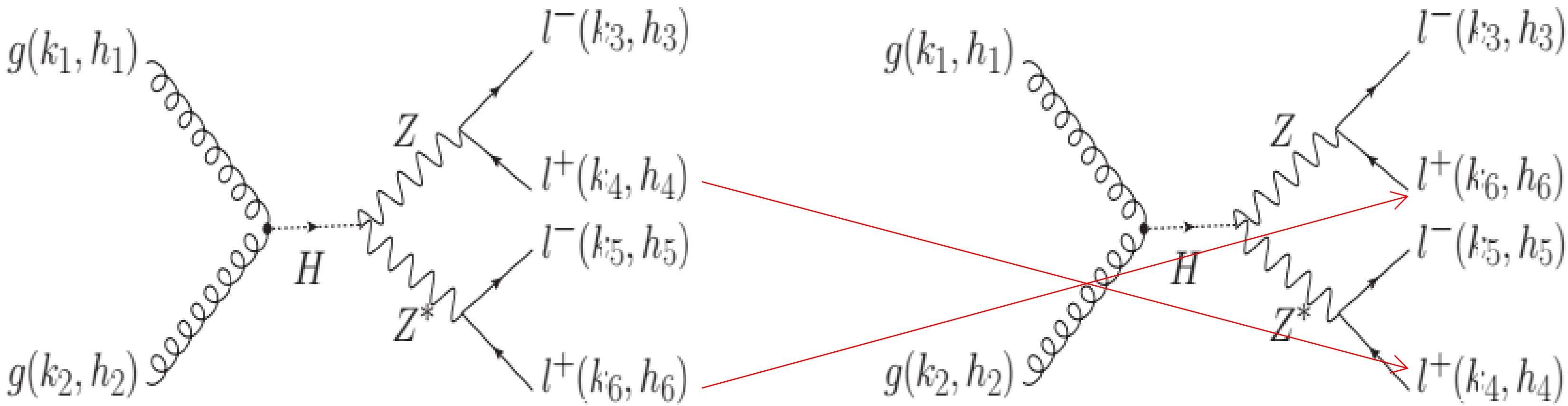
$$\epsilon_\mu^-(p_1)\epsilon_\nu^+(p_2)P_{LR}^{\mu\nu\rho\sigma} = \frac{1}{2}\frac{1}{s_{12}^2}\Big[-2g^{\rho\sigma}\frac{\langle 1|(3+4)|2]}{\langle 2|(3+4)|1]}s_{12}^2 A_2 - \langle 1|\gamma^\rho|2]\langle 1|\gamma^\sigma|2]s_{12}(A_3+A_4)$$
$$- \langle 1\,2\rangle[2|\gamma^\rho\gamma^\sigma|2]\langle 1|(3+4)|2]A_5 + \langle 1|\gamma^\rho\gamma^\sigma|1\rangle[1\,2]\langle 1|(3+4)|2]A_5\Big] \qquad \text{(B15)}$$

$$\frac{e^2}{s_{34}s_{56}}\langle 3|\gamma^\rho|4]\langle 5|\gamma^\sigma|6]$$

$$A(1_g^-, 2_g^+, 3_e^-, 4_{\bar{e}}^+, 5_\mu^-, 6_{\bar{\mu}}^+) = \frac{1}{s_{12}s_{34}s_{56}}\Big[\langle 3\,5\rangle[4\,6]\frac{\langle 1|(3+4)|2]}{\langle 2|(3+4)|1]}s_{12}\,A_2 - \langle 1\,3\rangle\langle 1\,5\rangle[2\,4][2\,6]\,(A_3+A_4)$$
$$+ \Big(\frac{\langle 3\,5\rangle[2\,4][6\,2]}{[1\,2]} + \frac{\langle 1\,3\rangle\langle 1\,5\rangle[4\,6]}{\langle 1\,2\rangle}\Big)\langle 1|(3+4)|2]\,A_5\Big], \qquad \text{(B19)}$$

Coded in MCFM and gg2VV

★ the identical final state 4e/4μ



swapping the two positive charged leptons ($4 \leftrightarrow 6$)

To increase statistics.

The calculation is similar as 2e2μ ,but there are two differences :

1、the cross section should times a symmetry factor 0.25

2、the interference term dictate a factor -1

Simulation by MCFM

Adding anomalous ($a_2, a_3 \neq 0$) Higgs mediated helicity amplitudes in MCFM program, considering its interference with gg->ZZ box diagram.

	SM	BSM
$gg \to H \to Z(e^+e^-)Z(\mu^-\mu^+)$	√	×
$gg \to H \to 4e/4\mu$	√	×
the interference term between Higgs mediated diagram and box diagram for 2e2\mu and for identical final states	√	×
box process $gg \to ZZ \to 2e2\mu$	√	

$$d\hat{\sigma}(s_{12}) \propto \left| \mathcal{A}_{\rm box}^{gg\to ZZ\to 4\ell} + \mathcal{A}^{gg\to H\to ZZ\to 4\ell} \right|^2 ,$$
$$\propto \left| \mathcal{A}_{\rm box}^{gg\to ZZ\to 4\ell} + a_1 \mathcal{A}_{\rm SM}^{H} + a_2 \mathcal{A}_{CP-{\rm even}}^{H} + a_3 \mathcal{A}_{CP-{\rm odd}}^{H} \right|^2$$

$$\sigma_{k,l} \sim \begin{cases} |\mathcal{A}_k|^2, & k = l; \\ 2{\rm Re}(\mathcal{A}_k^* \mathcal{A}_l), & k \neq l. \end{cases}$$

$k, l = \{{\rm box}, {\rm SM}, CP\text{-even}, CP\text{-odd}\}$

★ CMS cuts for 2e2μ final states

$P_{T,\mu} > 5{\rm GeV},\ |\eta_\mu| < 2.4$

$P_{T,e} > 7{\rm GeV},\ |\eta_e| < 2.5$

$m_{ll} > 4{\rm GeV},\ {\rm m}_{4l} > 100{\rm GeV}$

$P_{T,l}(hardest) > 20{\rm GeV}$

$40{\rm GeV} < {\rm m_{ll}(near)} < 120{\rm GeV}$

$P_{T,l}(2nd, hardest) > 10{\rm GeV}$

$12{\rm GeV} < {\rm m_{ll}(other)} < 120{\rm GeV}$

$gg \to 2e2\mu$ process

8 TeV , $m_{4\ell} < 130$ GeV

$\sigma_{k,l}$(fb)		box	Higgs-med. SM	Higgs-med. CP-even	Higgs-med. CP-odd
box		0.011	0	0	0
Higgs-med.	SM	0	0.232	-0.257	0
Higgs-med.	CP-even	0	-0.257	0.093	0
Higgs-med.	CP-odd	0	0	0	0.035

8 TeV , $m_{4\ell} > 220$ GeV

$\sigma_{k,l}$(fb)		box	Higgs-med. SM	Higgs-med. CP-even	Higgs-med. CP-odd
box		0.479	-0.056	0.198	0
Higgs-med.	SM	-0.056	0.031	-0.047	0
Higgs-med.	CP-even	0.198	-0.047	0.228	0
Higgs-med.	CP-odd	0	0	0	0.219

8 TeV , $m_{4\ell} > 330$ GeV

$\sigma_{k,l}$(fb)		box	Higgs-med. SM	Higgs-med. CP-even	Higgs-med. CP-odd
box		0.091	-0.032	0.094	0
Higgs-med.	SM	-0.032	0.023	-0.023	0
Higgs-med.	CP-even	0.094	-0.023	0.165	0
Higgs-med.	CP-odd	0	0	0	0.164

Advantages: Relatively large interference cross section between box & CP-even Higgs-mediated process in off-shell region.

$gg \to 2e2\mu$ process

13 TeV , $m_{4\ell} < 130$ GeV					
$\sigma_{k,l}$(fb)		box	Higgs-med.		
			SM	CP-even	CP-odd
box		0.024	0	0	0
Higgs-med.	SM	0	0.503	-0.558	0
	CP-even	0	-0.558	0.202	0
	CP-odd	0	0	0	0.075

13 TeV , $m_{4\ell} > 220$ GeV					
$\sigma_{k,l}$(fb)		box	Higgs-med.		
			SM	CP-even	CP-odd
box		1.283	-0.174	0.571	0
Higgs-med.	SM	-0.174	0.100	-0.137	0
	CP-even	0.571	-0.137	0.720	0
	CP-odd	0	0	0	0.716

13 TeV , $m_{4\ell} > 330$ GeV					
$\sigma_{k,l}$(fb)		box	Higgs-med.		
			SM	CP-even	CP-odd
box		0.284	-0.111	0.297	0
Higgs-med.	SM	-0.111	0.078	-0.074	0
	CP-even	0.297	-0.074	0.593	0
	CP-odd	0	0	0	0.582

No interference because antisymmetric tensor $\epsilon_{\mu\nu\rho\sigma}$

$$\sigma_{\mathrm{box},l} \sim 2\mathrm{Re}(\mathcal{A}^*_{\mathrm{box}}\mathcal{A}_l) \ ,$$

$$\sim 2\mathrm{Re}\left(\mathcal{A}^*_{\mathrm{box}}\mathcal{A}^{gg\to H}P_H(s_{12})\mathcal{A}_i\right) \ ,$$

ε

suppressed

$$\sim 2\frac{(s_{12}-M_H^2)\mathrm{Re}\left(\mathcal{A}^*_{\mathrm{box}}\mathcal{A}^{gg\to H}\mathcal{A}_i\right) + M_H\Gamma_H\mathrm{Im}\left(\mathcal{A}^*_{\mathrm{box}}\mathcal{A}^{gg\to H}\mathcal{A}_i\right)}{(s_{12}-M_H^2)^2+M_H^2\Gamma_H^2}$$

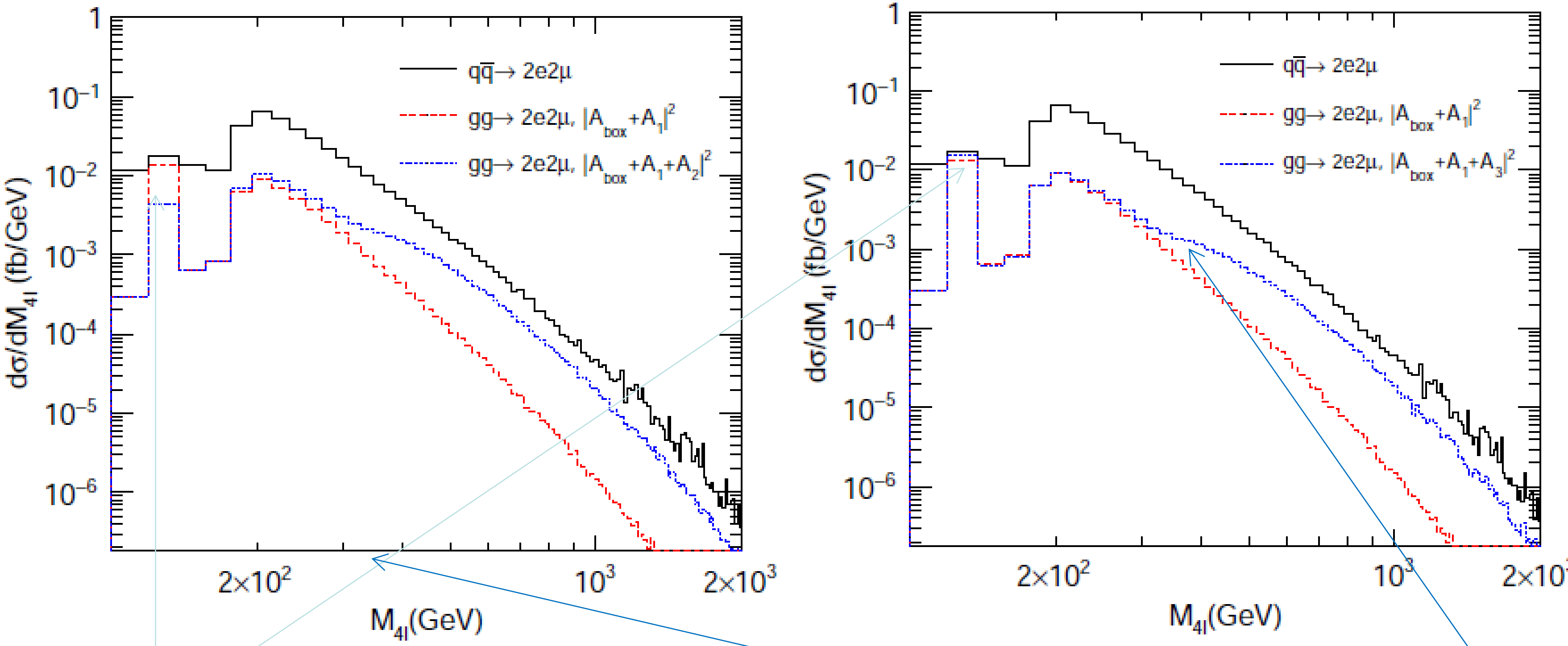
antisymmetric around M_H^2

Have imaginary part when $\sqrt{s} > 2m_t$

In Higgs off-shell regions, interference between Higgs-mediated process and Continuum background could not be ignored.

cross section for the $2e2\mu$ final state $\sqrt{s} = 8$ TeV

$a_{1,2} = 1$ $a_{1,3} = 1$



Interference larger than self-conjugated terms in on-shell region

The total cross section of CP-even Higgs mediated process increase suddenly beyond the top pair threshold.

8TeV LHC real experimental measurements to constraint the anomalous coupling coefficients

CMS PAS HIG-14-002

		Full region	Signal-enriched region
	$gg + \mathrm{VBF} \to 4\ell$ (signal, $\Gamma_H/\Gamma_H^{SM} = 1$)	$2.22\,^{+0.15}_{-0.17}$	$1.20\,^{+0.08}_{-0.09}$
	$gg + \mathrm{VBF} \to 4\ell$ (background)	$31.1\,^{+3.0}_{-3.1}$	2.12 ± 0.21
(a)	$gg + \mathrm{VBF} \to 4\ell$ (total, $\Gamma_H/\Gamma_H^{SM} = 1$)	$29.6\,^{+2.8}_{-2.9}$	$1.73\,^{+0.16}_{-0.17}$
	$gg + \mathrm{VBF} \to 4\ell$ (total, $\Gamma_H/\Gamma_H^{SM} = 15$)	$51.8\,^{+4.9}_{-5.0}$	13.1 ± 1.1
(b)	$q\bar{q} \to 4\ell$	154.7 ± 7.4	8.6 ± 0.4
(c)	Reducible background	3.7 ± 0.6	0.44 ± 0.08
(a+b+c)	Total expected ($\Gamma_H/\Gamma_H^{SM} = 1$)	188.0 ± 7.9	10.8 ± 0.4
	Observed	183	8

- The k factor are set to be equal for signal, background and interference.
- Assume the efficiency is also the same

$$N^{\mathrm{theo}}_{\mathrm{SM+box}} = 29.6^{+2.8}_{-2.9}$$

$$N^{\mathrm{theo}}(a_2, a_3) = \sigma_{\mathrm{tot}} \times \mathcal{L} \times k \times \epsilon$$

$$N^{\mathrm{theo}}(a_2, a_3) = \frac{N^{\mathrm{theo}}_{\mathrm{SM+box}}}{\sigma_{\mathrm{SM+box}}} \times [\sigma_{\mathrm{SM+box}} + a_2^2 \sigma^H_{CP-\mathrm{even},CP-\mathrm{even}} + a_2 \sigma^{int}_{CP-\mathrm{even}} + a_3^2 \sigma^H_{CP-\mathrm{odd},CP-\mathrm{odd}}]$$

$N^{\mathrm{theo}}(a_2, a_3)$ represent the total number of events for $gg + \mathrm{VBF} \to 4\ell$ process

$$\sigma_{\text{SM+box}} = \sigma_{\text{SM,SM}} + \sigma_{\text{SM,box}} + \sigma_{\text{box,box}}$$

$$\sigma^{int}_{CP-\text{even}} = \sigma_{CP-\text{even,SM}} + \sigma_{CP-\text{even,box}}$$

$$N^{obs} = 183$$

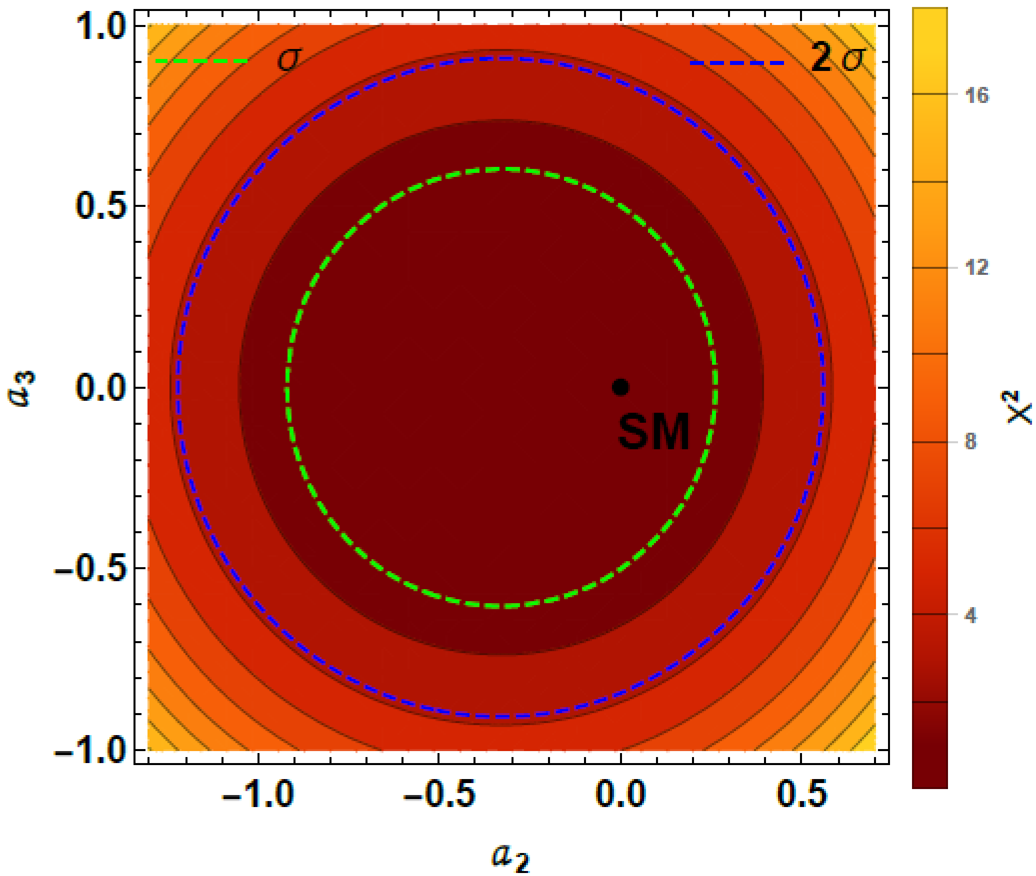
$$N^{\text{theo}}_{bg} = 158.4 \pm 7.4$$

$$N^{\text{theo}}(a_2, a_3) = 29.6 + 14.9 \times a_2^2 + 9.8 \times a_2 + 14.3 \times a_3^2$$

$$\chi^2 = \left(\frac{N^{\text{theo}}(a_2, a_3) + N^{\text{theo}}_{\text{bg}} - N^{\text{obs}}}{\sigma_N} \right)^2$$

$$a_2 \in [-0.881, 0.223]$$

$$a_3 \in [-0.569, 0.569]$$



Summary

- CP properties of HZZ couplings are studied.
- Existed experimental results constraint HZZ anomalous coefficients in both Higgs on-shell off-shell region, but interference effects are not complete in their simulation Codes.
- We calculate Helicity amplitudes of HZZ anomalous decay, implemented it in MCFM.
- HZZ anomalous coefficients are constrained in Higgs off-shell region, with considering the interference between anomalous Higgs mediated process between gg->4l box diagram.

Thank you