New physics and its interference effect

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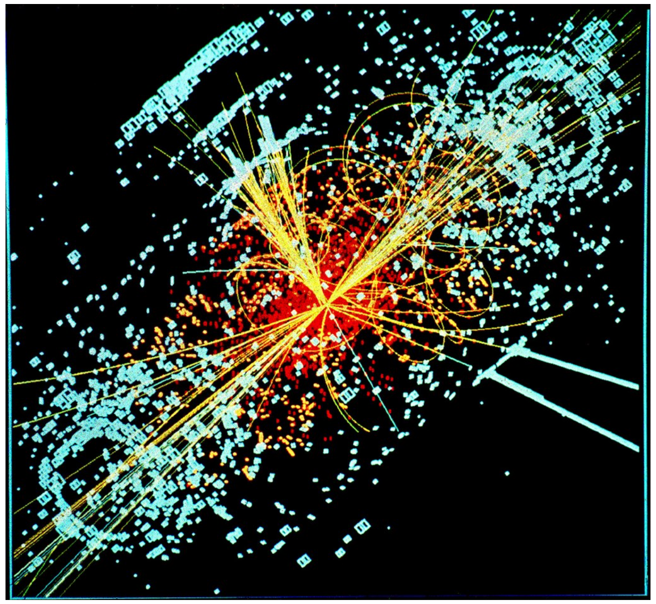
Outline

- Motivation of New Physics and its interference with Standard Model.

- The interference @LHC in channels of

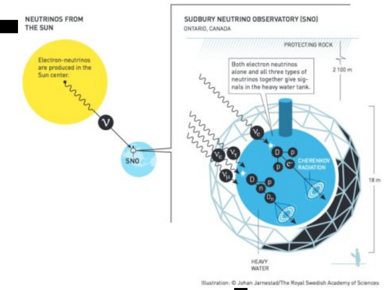
    1. $H \to \gamma\gamma$
    2. $H \to \gamma Z \to \gamma \ell\ell$
    3. $H \to ZZ \to 4\ell$



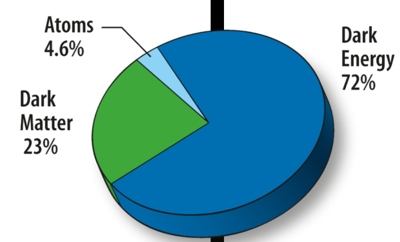
- Summary

New physics before LHC

- Neutrino mass



- Dark matter, Dark energy



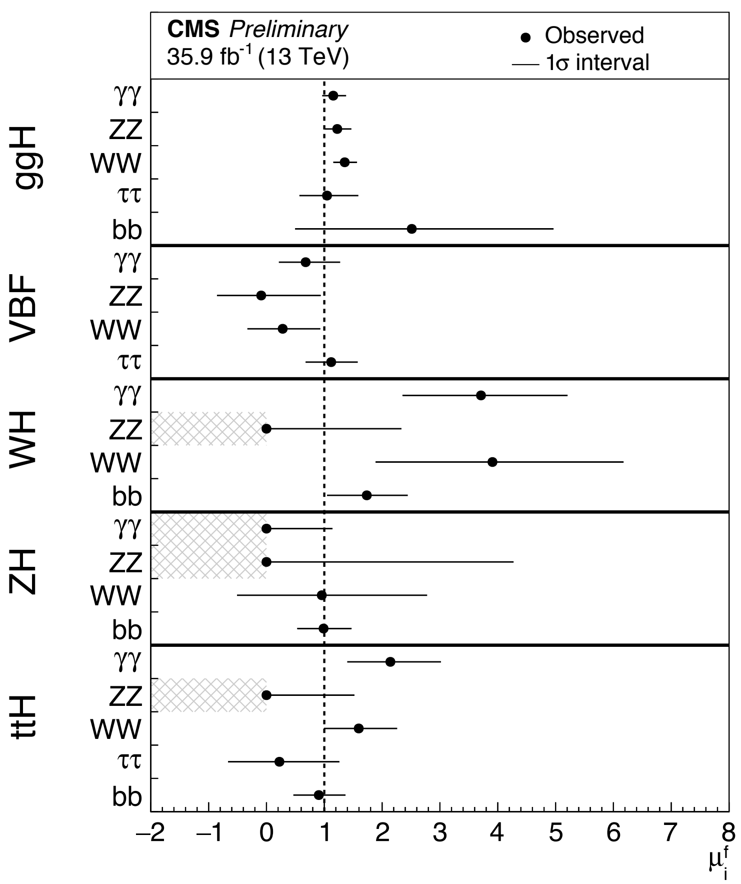
- Matter-antimatter asymmetry

- Gravity
- ……

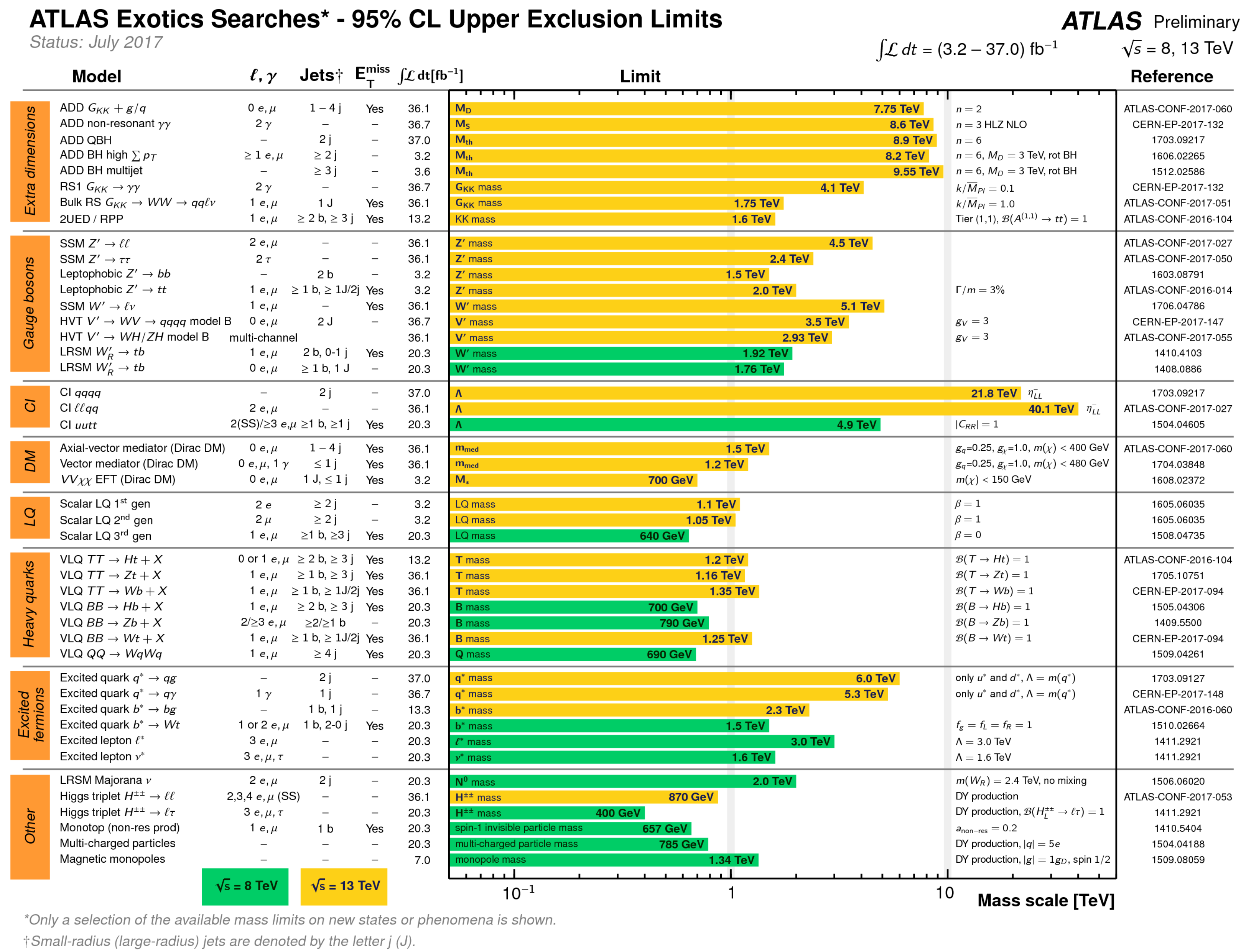
- Higgs mass hierarchy
- Number of parameters
- Strong CP problem
- ……

New Models: Supersymmetry Models, Extra dimension, GUT, String Theory, ……

Where is New physics @ LHC



CMS-PAS-HIG-17-003

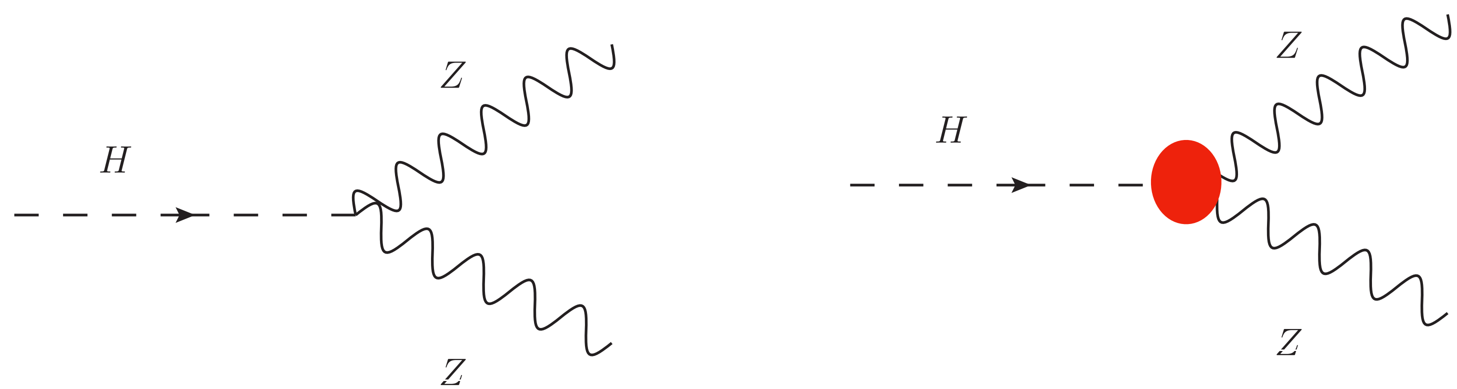


Around 100GeV~1TeV, effectively new physics is highly suppressed !

Interference effect may become relatively large

$$|\mathcal{M}_{\rm SM}+\mathcal{M}_{\rm new}|^2 = |\mathcal{M}_{\rm SM}|^2 + |\mathcal{M}_{\rm new}|^2 + 2Re(\mathcal{M}_{\rm SM}\mathcal{M}^*_{\rm new})$$

e.g.

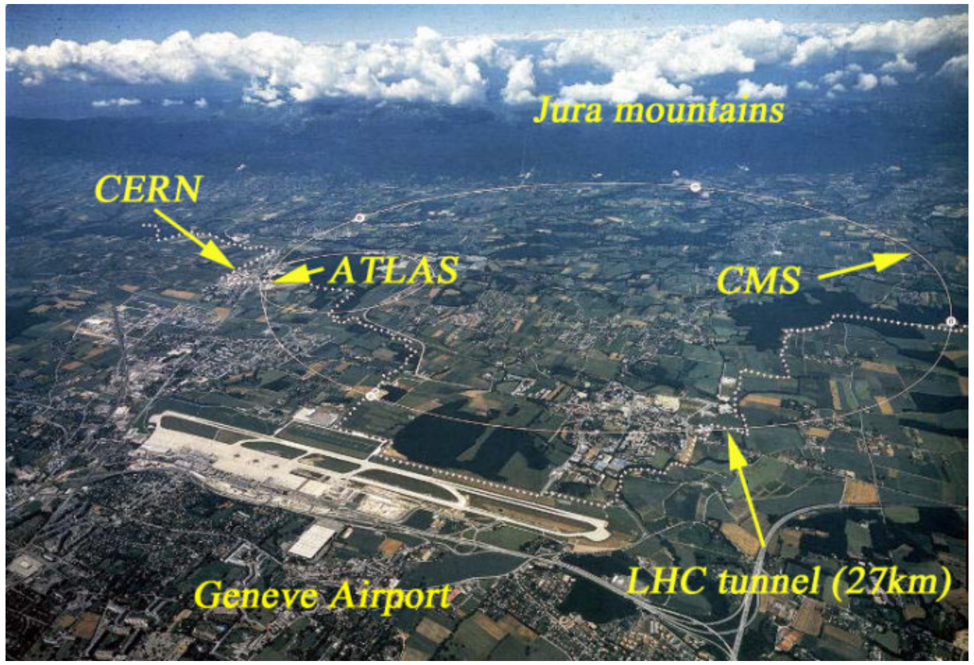


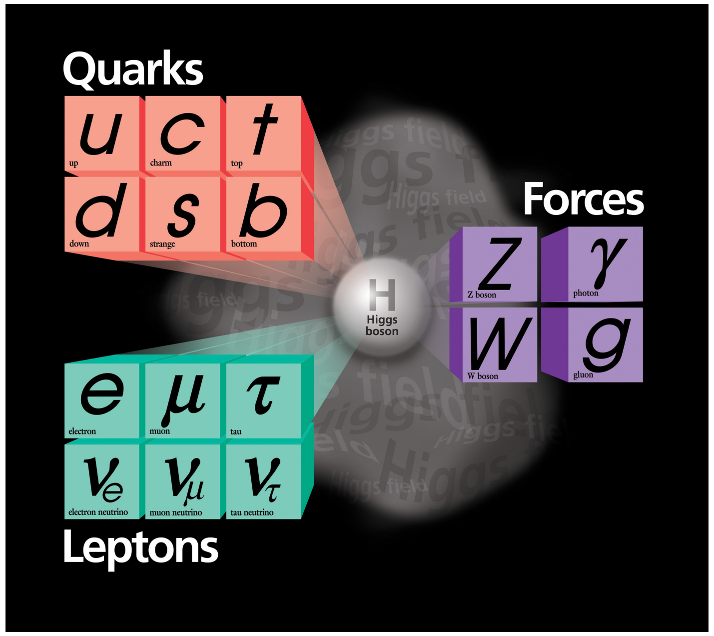
$$L(HZZ) \sim a_1 \frac{m_Z^2}{2} HZ^\mu Z_\mu + a_2 \frac{1}{2} HZ^{\mu\nu} Z_{\mu\nu}$$

a_1=1,a_2=1 $\sqrt{s}$=13 TeV, $gg \to H \to ZZ \to e^+e^-\mu^+\mu^-$

$\sigma_{\rm SM}$	$\sigma_{\rm new}$	$\sigma_{interference}$
0.533fb	0.220fb	-0.599fb

Is there a new observable (method) from interference effect to probe new physics ?





$$1.\quad H \to \gamma\gamma$$

XW, Youkai Wang, arXiv:1712.00267

$$2.\quad H \to \gamma Z \to \gamma \ell\ell$$

Xuan Chen, Gang Li, XW, PRD96, 055023 (2017)

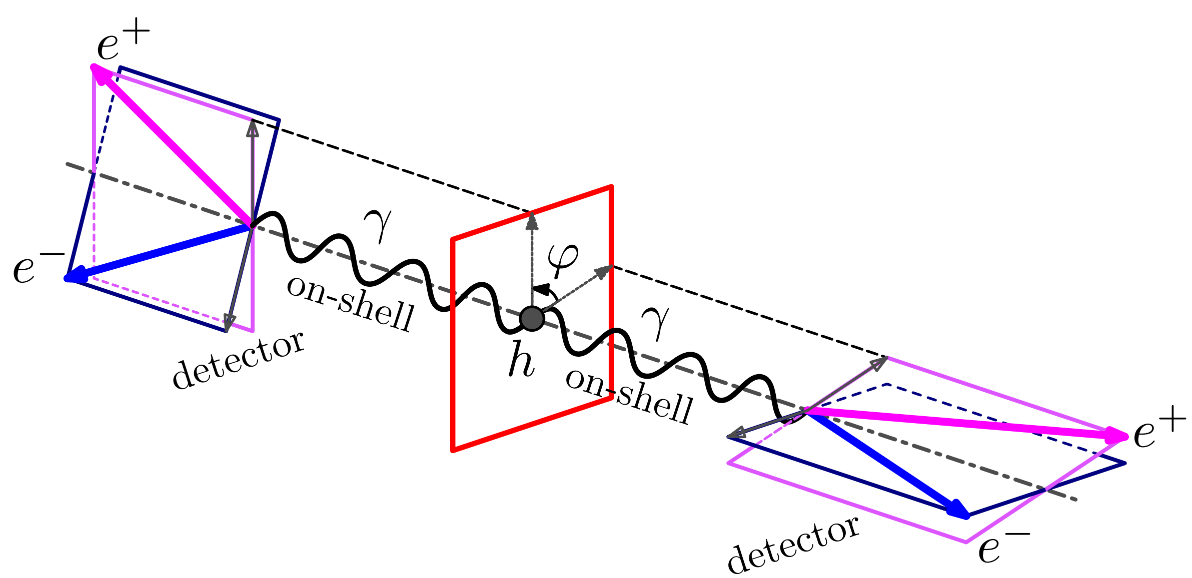
$$3.\quad H \to ZZ \to 4\ell$$

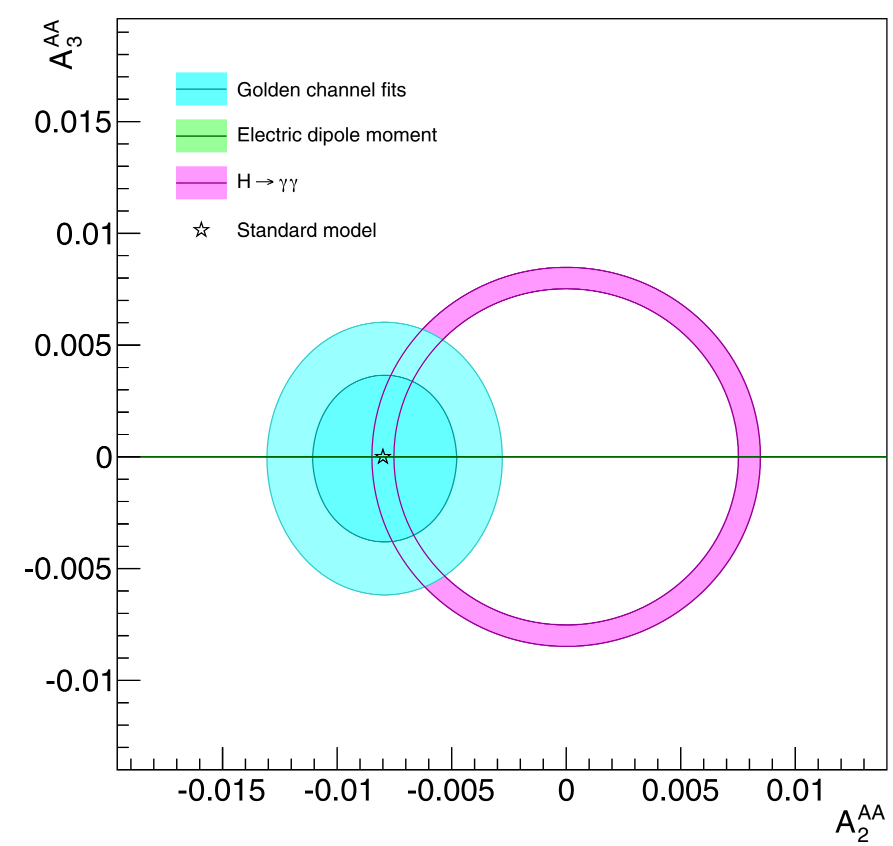
Huarong He, XW, Youkai Wang in progress

1. CP violation in $H\gamma\gamma$

$$\mathcal{L}_{\rm h} = \frac{c_\gamma \cos\xi_\gamma}{v}\; h\, F_{\mu\nu}F^{\mu\nu} + \frac{c_\gamma \sin\xi_\gamma}{2v}\; h\, F_{\mu\nu}\tilde{F}^{\mu\nu} + \frac{c_g}{v}\; h\, G^a_{\mu\nu}G^{a\mu\nu}$$

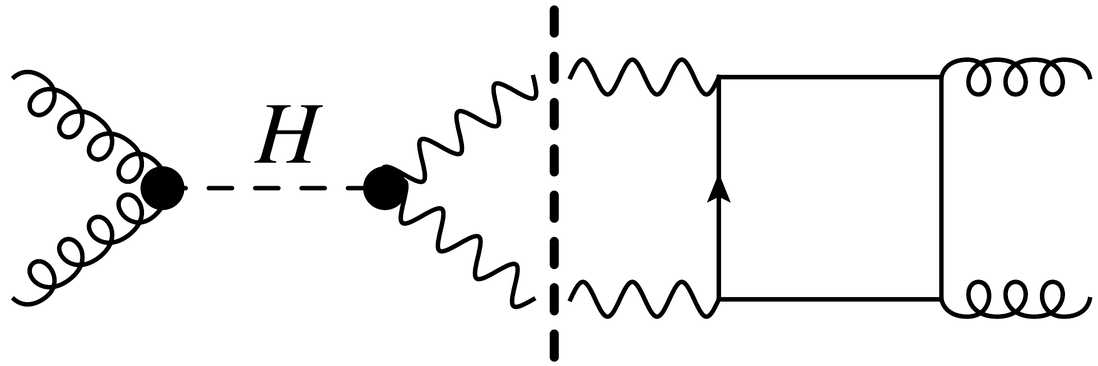
$$H \to \gamma^*\gamma^* \to 4\ell$$





F. Bishara, etc. JHEP04, 084 (2014)
Y. Chen, etc. PRL113, 191801 (2014)

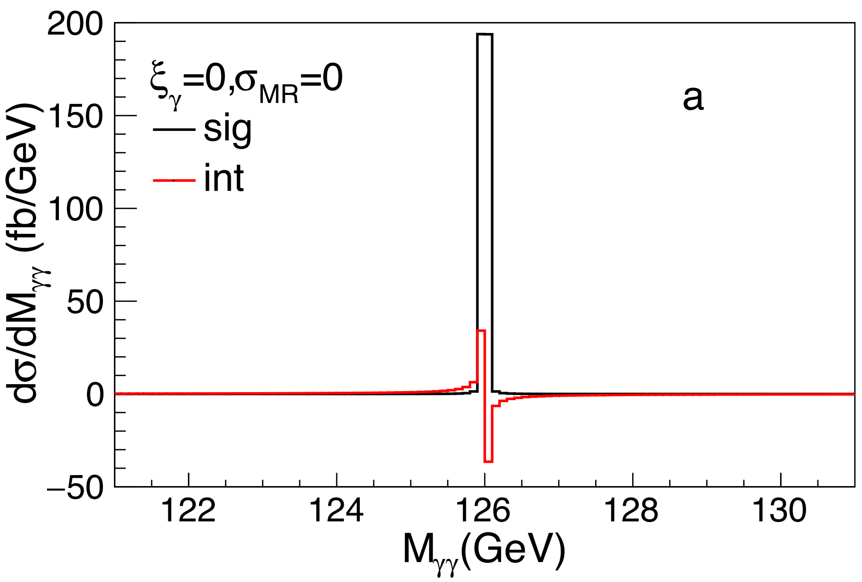
Interference

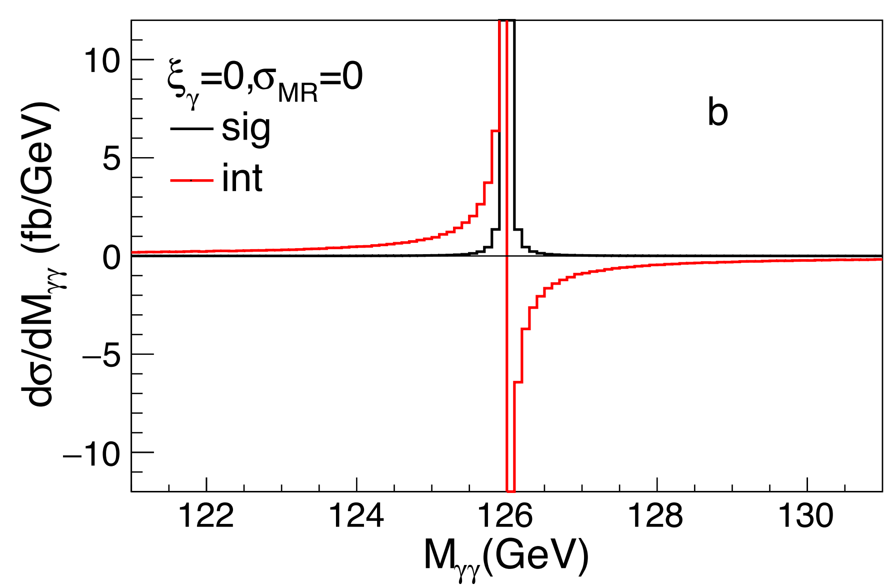


$$\mathcal{M} = -e^{-ih_3\xi_\gamma}\delta_{h_1h_2}\delta_{h_3h_4}\frac{M_{\gamma\gamma}^4}{v^2}\frac{4c_g c_\gamma}{M_{\gamma\gamma}^2 - M_H^2 + iM_H\Gamma_H} + 4\alpha\alpha_s\delta^{ab}\sum_{f=u,d,c,s,b} Q_f^2 \mathcal{A}_{box}^{h_1h_2h_3h_4} \; ,$$

$$\frac{d\sigma_{int}}{dM_{\gamma\gamma}} \propto \frac{(M_{\gamma\gamma}^2 - M_H^2)\,\mathrm{Re}\,(c_g c_\gamma) + M_H\Gamma_H\,\mathrm{Im}\,(c_g c_\gamma)}{(M_{\gamma\gamma}^2 - M_H^2) + M_H^2\Gamma_H^2}$$
$$\times \int dz[\mathcal{A}_{box}^{++++} + \mathcal{A}_{box}^{++--}]\,\underline{\cos\xi_\gamma},$$

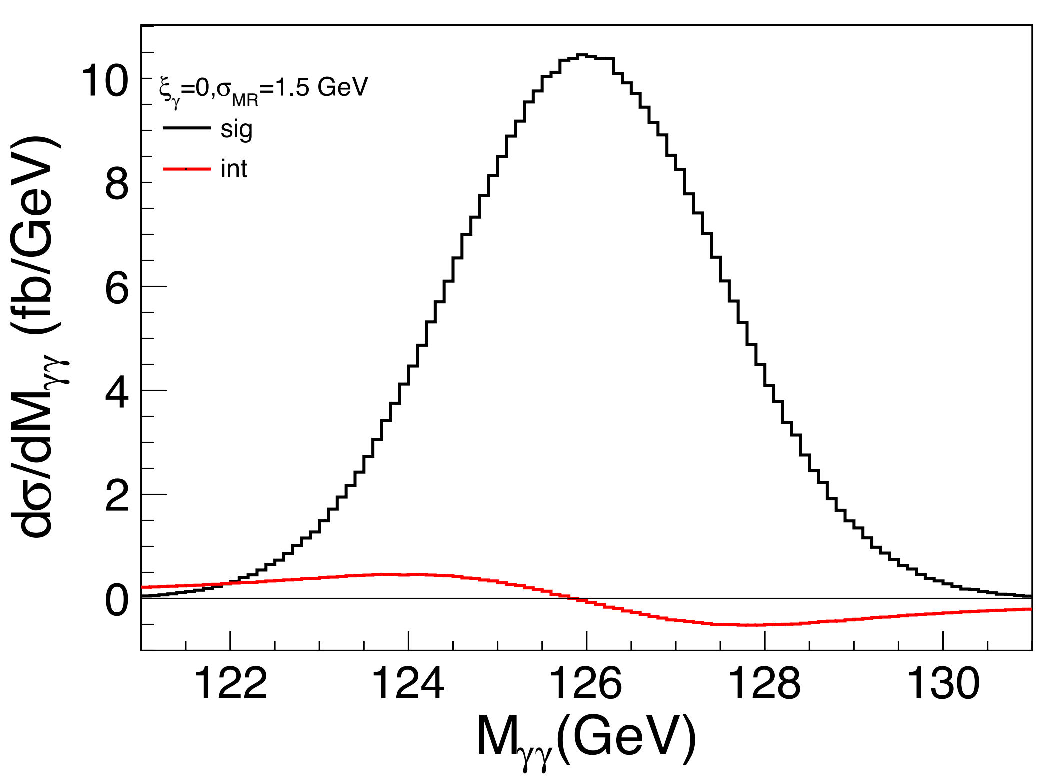
Interference in SM





$$A_{int}(\xi_\gamma) = \frac{\int dM_{\gamma\gamma}\frac{d\sigma_{int}}{dM_{\gamma\gamma}}\Theta(M_{\gamma\gamma}-M_H)}{\int dM_{\gamma\gamma}\frac{d\sigma_{sig}}{dM_{\gamma\gamma}}} ,$$

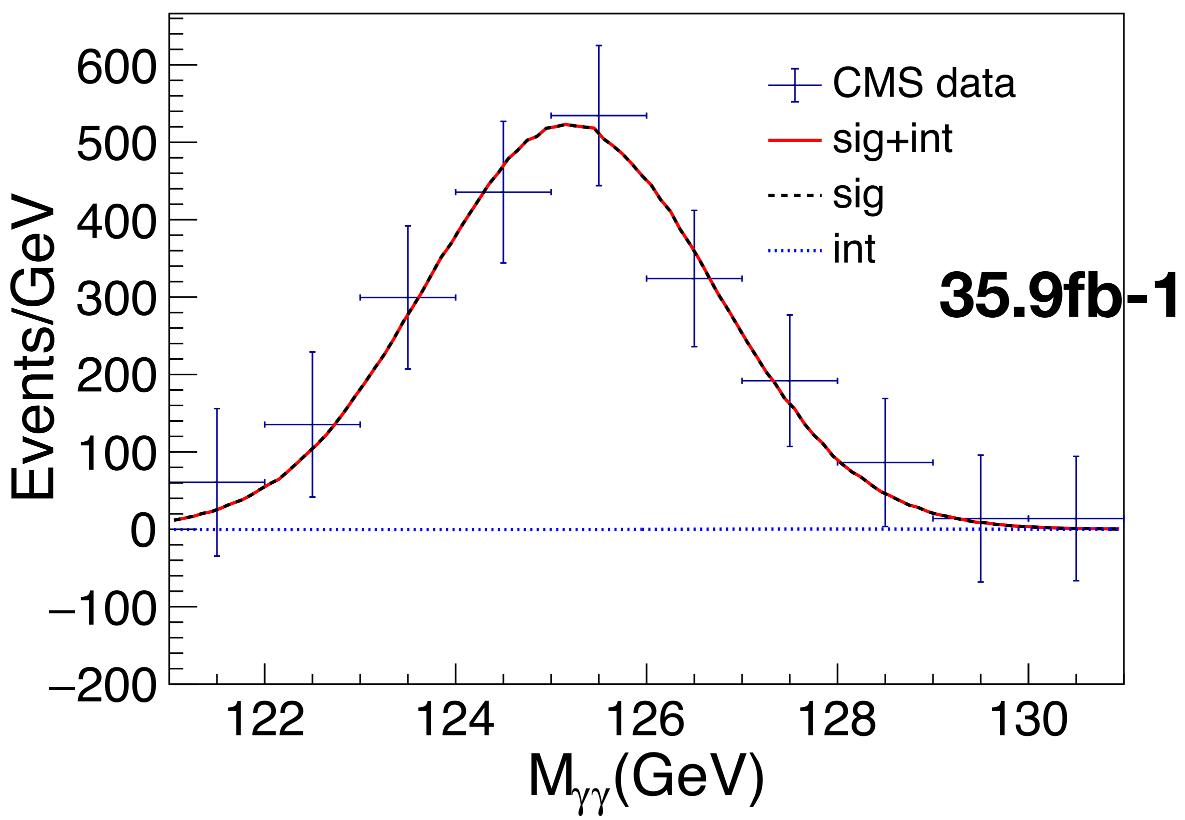
$$\Theta(x) \equiv \begin{cases} -1, & x<0 \\ 1, & x>0 \end{cases}$$

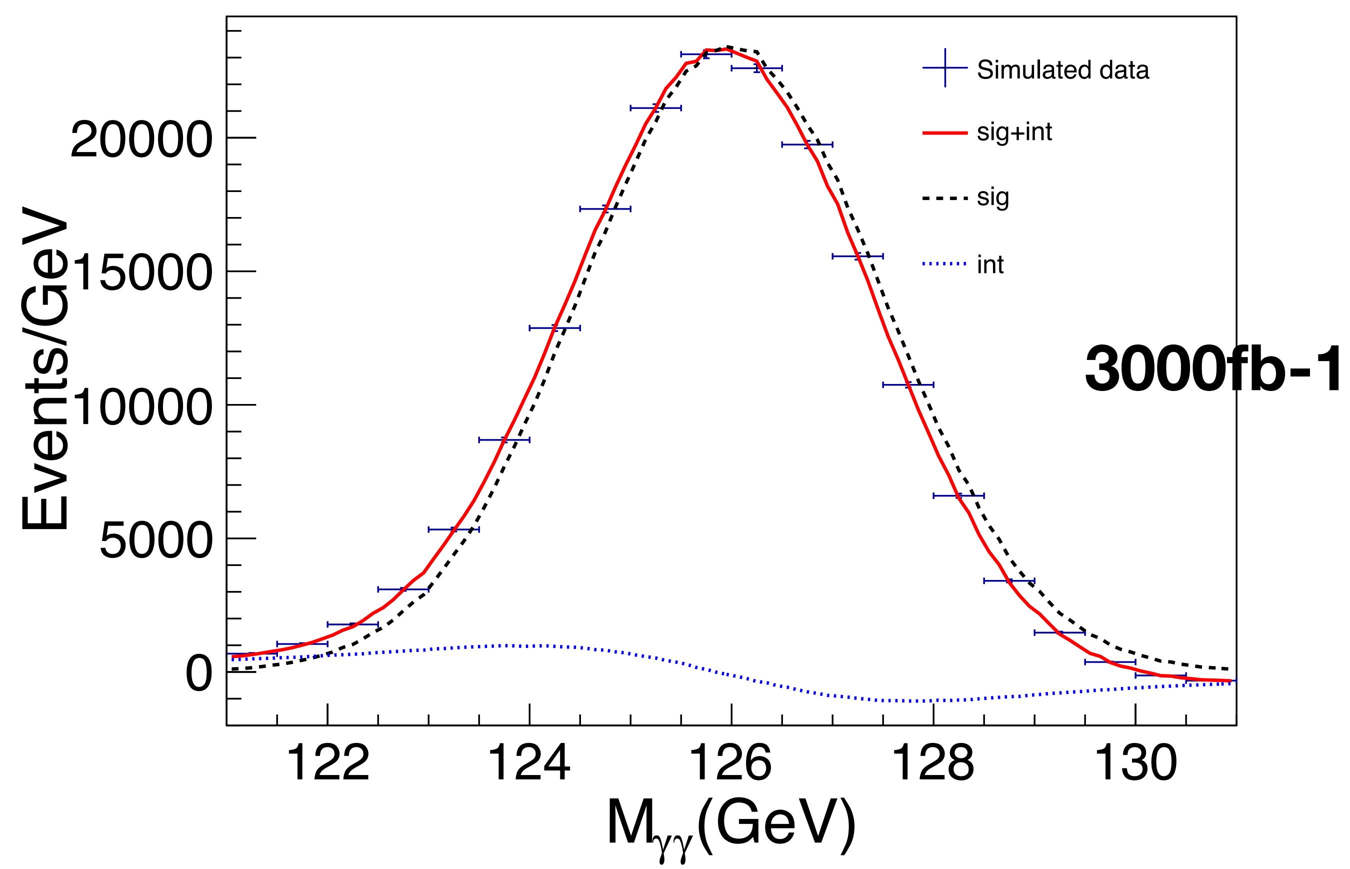


σ_{MR} (GeV)	A_{int}^{SM} denominator (fb)	A_{int}^{SM} numerator (fb)	A_{int}^{SM} (%)
0	39.3	14.3	36.3
1.1	39.3	4.0	10.2
1.3	39.3	3.7	9.4
1.5	39.3	3.4	8.6
1.7	39.3	3.1	7.9
1.9	39.3	2.8	7.2

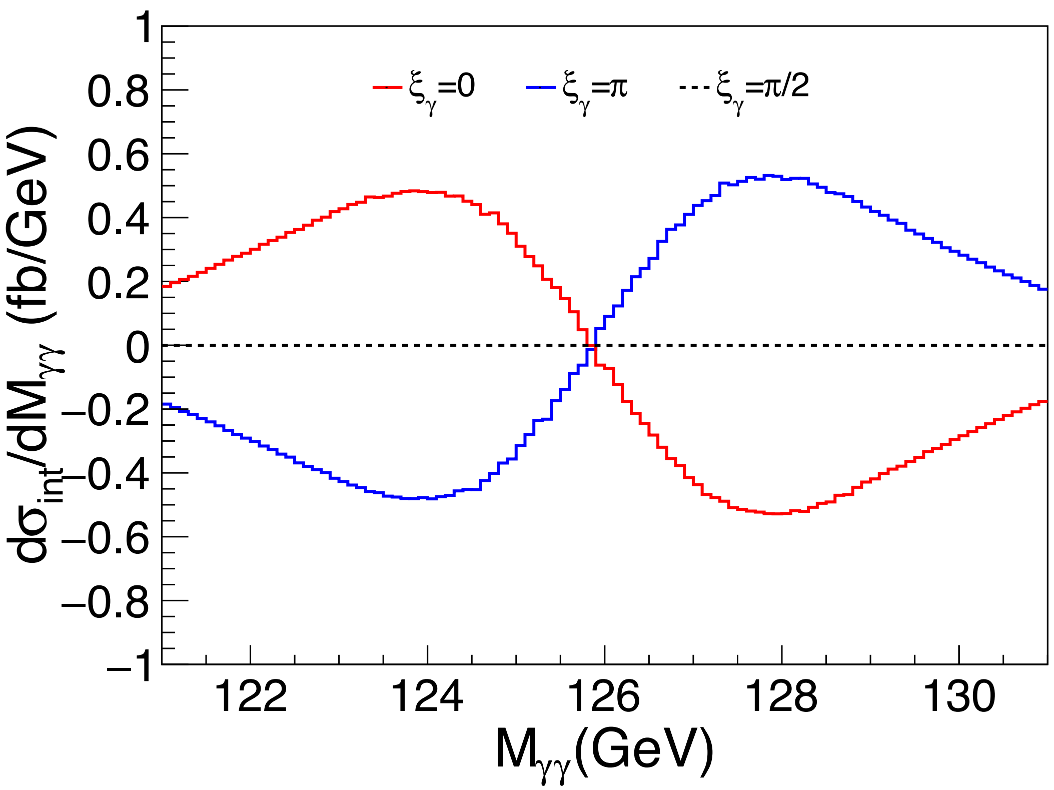
Fitting

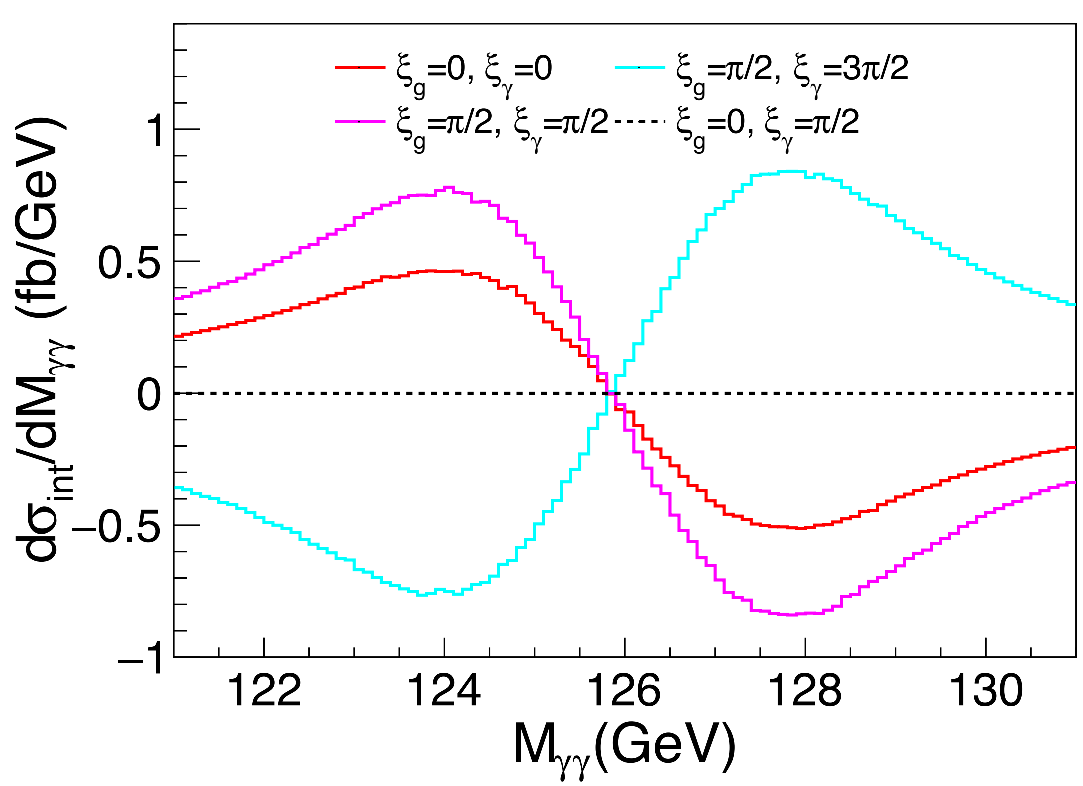
$$f(m) = c_1 \times f_{sig}(m - \delta m) + c_2 \times f_{int}(m - \delta m),$$





Interference in BSM



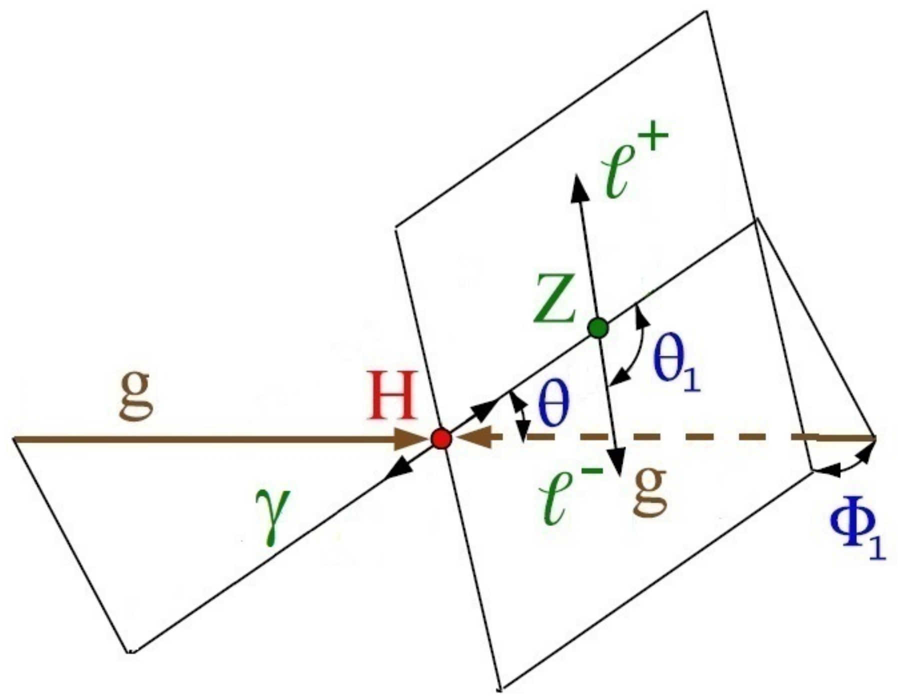


$$A_{int} \sim \pm 16\%$$

2. CP violation in $H\gamma Z$

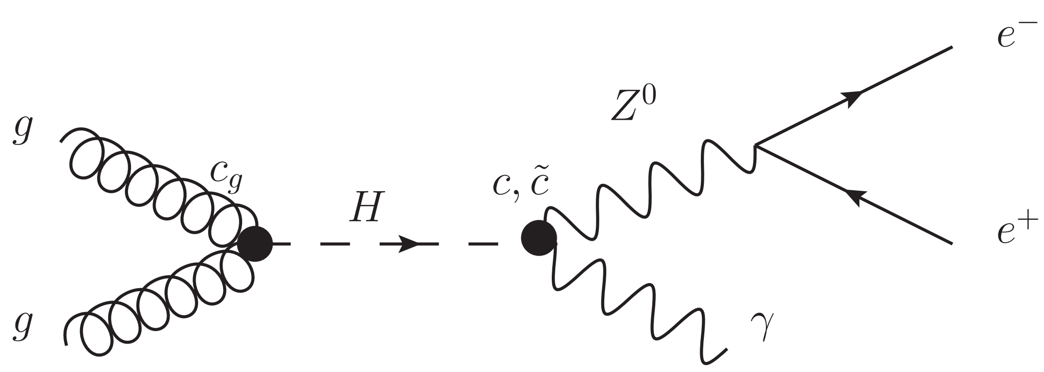
$$\mathcal{L}_{\mathrm{h}} = \frac{c}{v}\; h\, F_{\mu\nu} Z^{\mu\nu} + \frac{\tilde{c}}{2v}\; h\, F_{\mu\nu} \tilde{Z}^{\mu\nu} + \frac{c_g}{v}\; h\, G^a_{\mu\nu} G^{a\mu\nu}$$

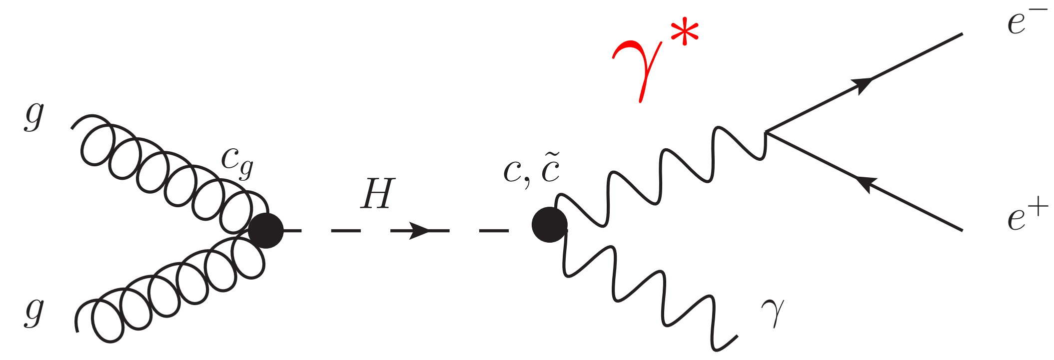
$$\xi = \tan^{-1}(\tilde{c}/c)$$



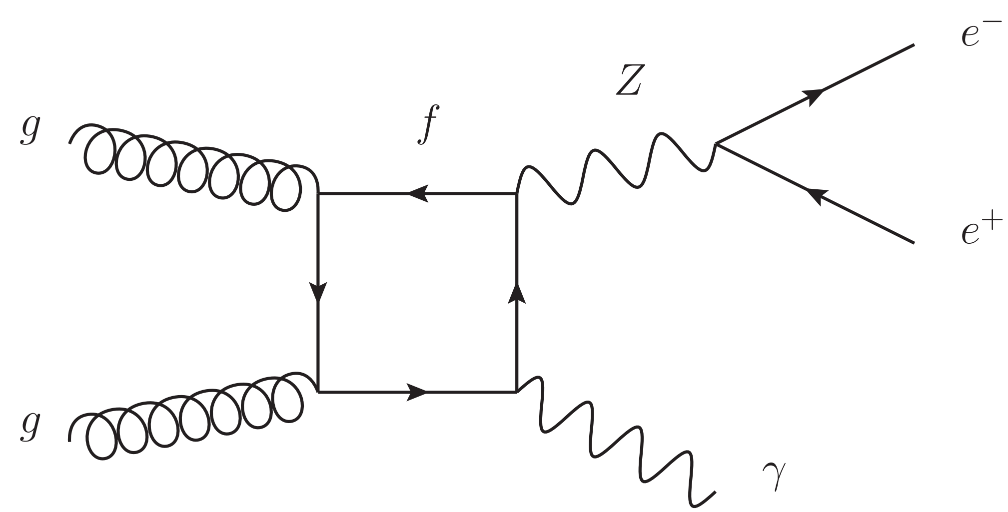
Kinematics has no sensitivity to ξ

Interference





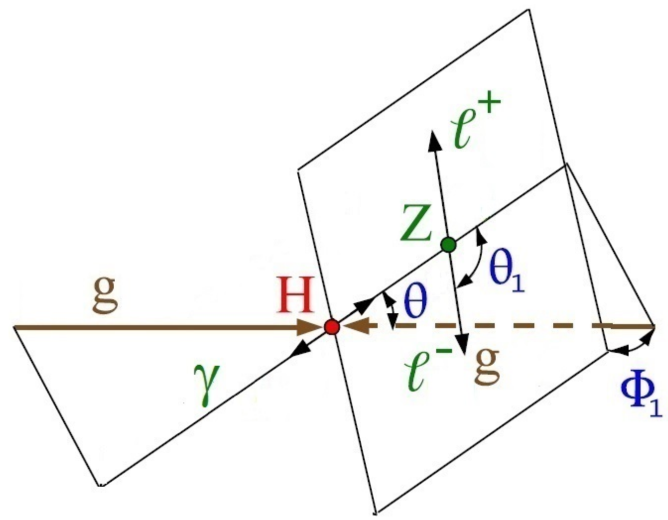
Yi Chen, etc PRD90, 113006 (2014)



Xuan Chen, Gang Li, Xia WAN PRD96, 055023 (2017)

Forward-backward Asymmetry

$$g(p_1)g(p_2) \to H(p_{12}) \to \gamma(p_3)Z(p_{45}) \to \gamma(p_3)\ell^-(p_4)\ell^+(p_5),$$



$$\theta_1 = \cos^{-1}\left(-\frac{\vec{p}_3 \cdot \vec{p}_4}{|\vec{p}_3||\vec{p}_4|}\right)$$

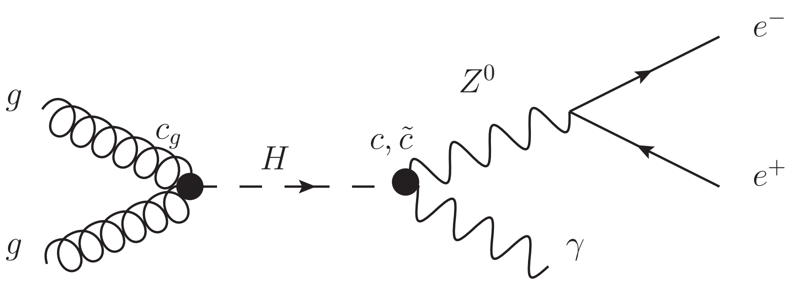
$\vec{p}_3$ in H rest frame,

$\vec{p}_4$ in Z rest frame.

$$A_{FB}(s_{12}) = \frac{(\int_0^1 - \int_{-1}^0) d\cos\theta_1 \int_{-1}^1 d\cos\theta \int_{-\pi}^{\pi} d\phi_1 \frac{d\hat{\sigma}(s_{12},\theta;\theta_1,\phi_1)}{d(\cos\theta)d(\cos\theta_1)d\phi_1}}{(\int_{-1}^1) d\cos\theta_1 \int_{-1}^1 d\cos\theta \int_{-\pi}^{\pi} d\phi_1 \frac{d\hat{\sigma}(s_{12},\theta;\theta_1,\phi_1)}{d(\cos\theta)d(\cos\theta_1)d\phi_1}}$$

$$\propto \; 4\,\mathrm{Im}[\tilde{\sigma}^{2\to 2}_{H,box}]_{++} \sin\xi$$

A_{FB} value



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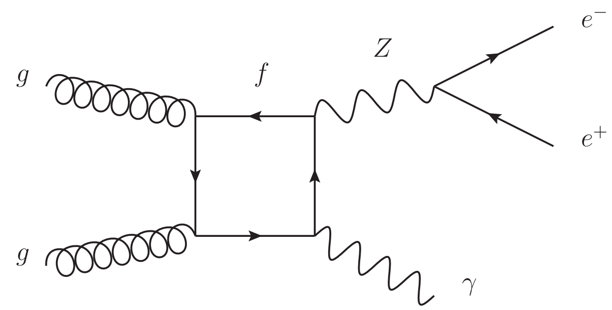
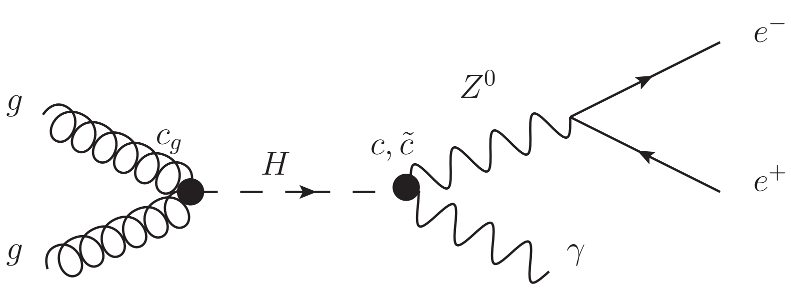


A_{FB} <1% for $\xi_{H\gamma Z} = \frac{\pi}{2}$



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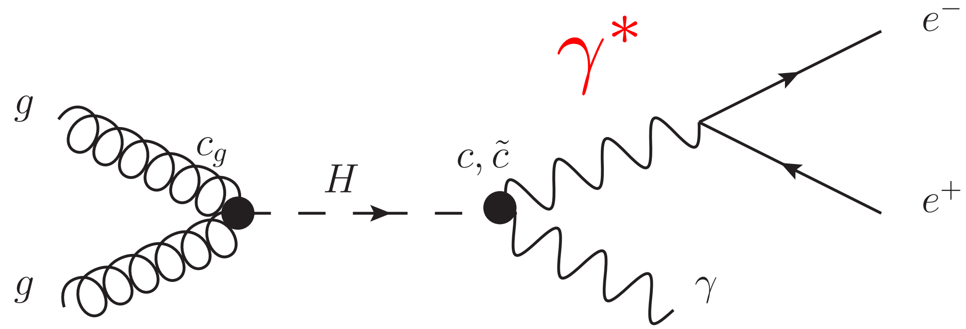


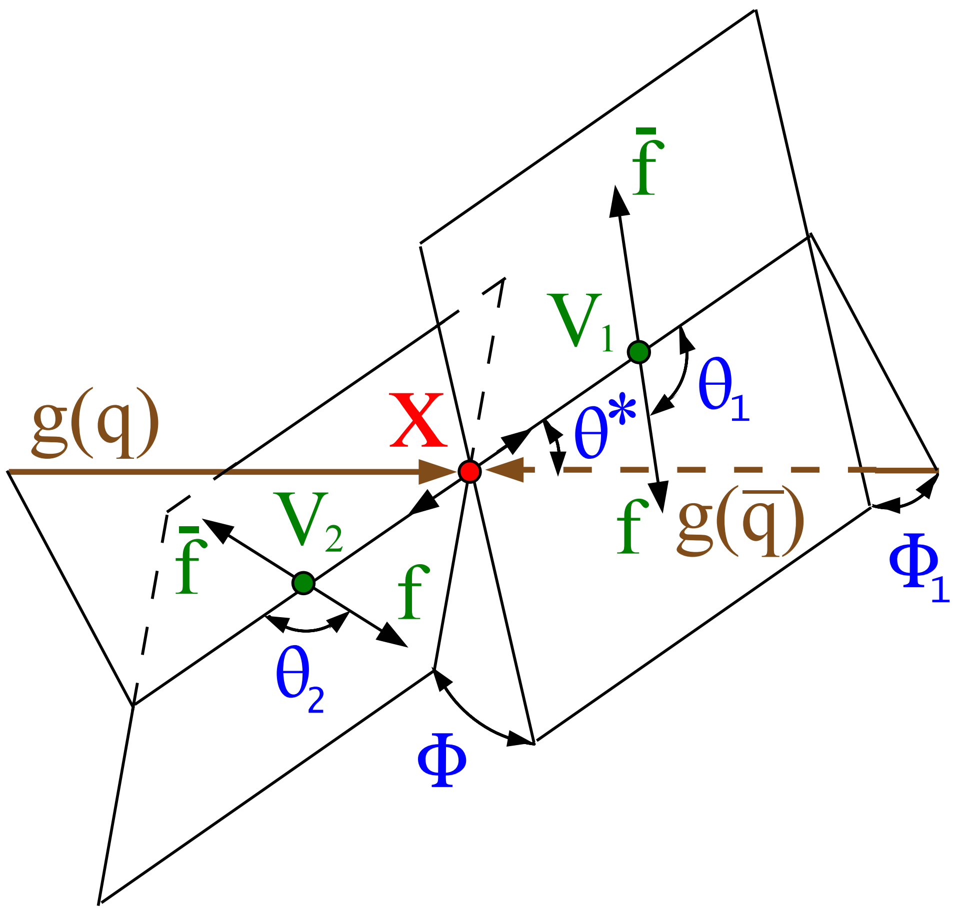
A_{FB} ~4% for

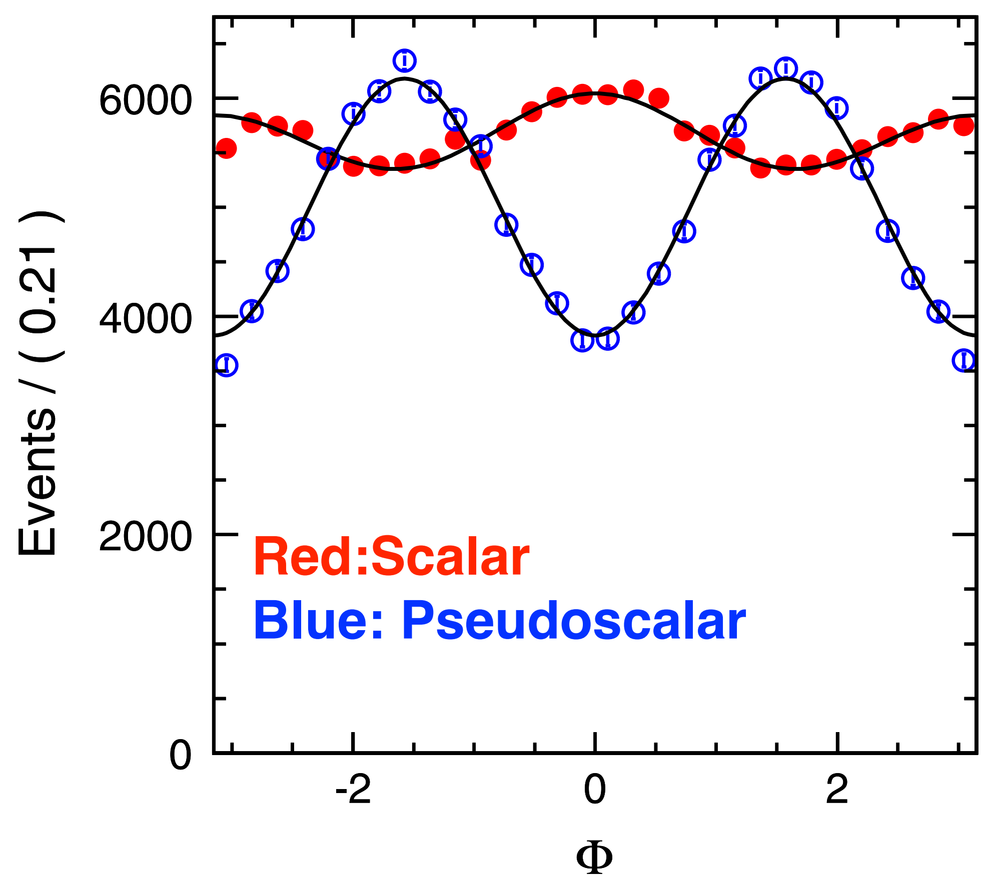
$\xi_{H\gamma Z} = \frac{\pi}{2}, \xi_{H\gamma\gamma} = 0$

Yi Chen, etc, PRD90,113006

3. Anomalous couplings in HZZ

$$L(HZZ) \sim a_1 \frac{m_Z^2}{2} H Z^\mu Z_\mu + a_2 \frac{1}{2} H Z^{\mu\nu} Z_{\mu\nu} + a_3 \frac{1}{2} H Z^{\mu\nu} \tilde{Z}_{\mu\nu}$$

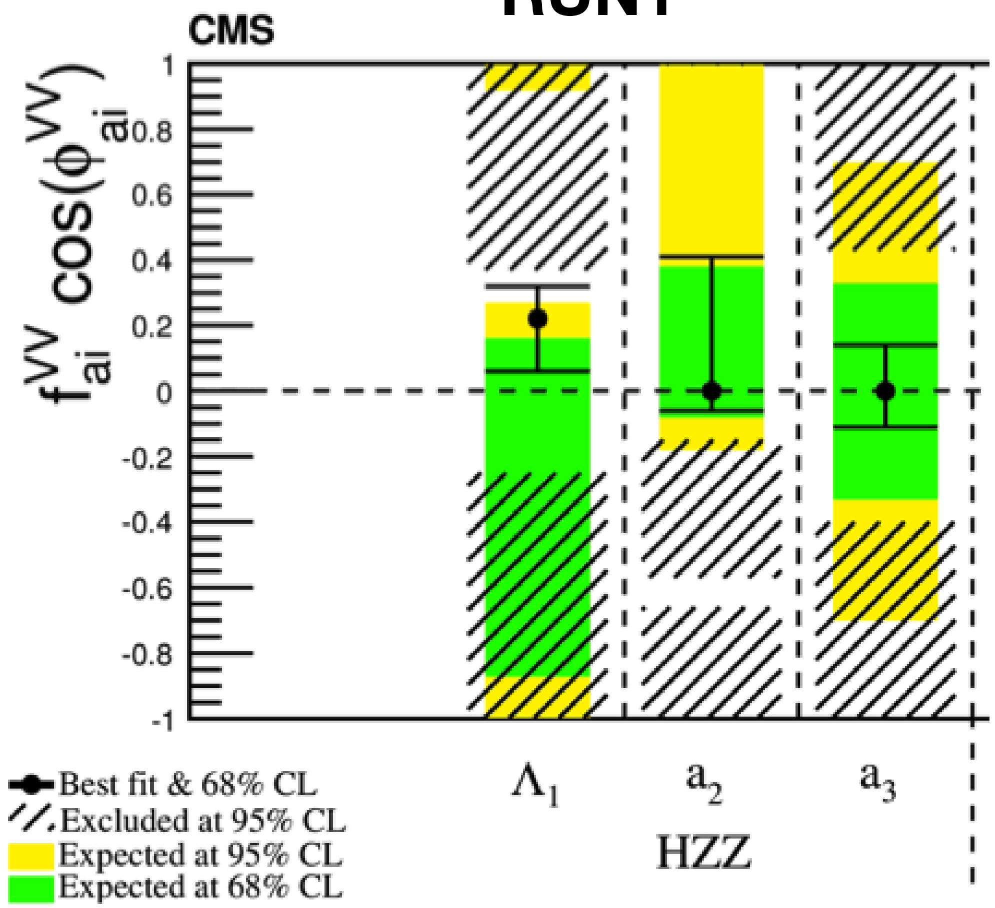




Y. Gao,etc PRD81, 075022

Constraints from experiments

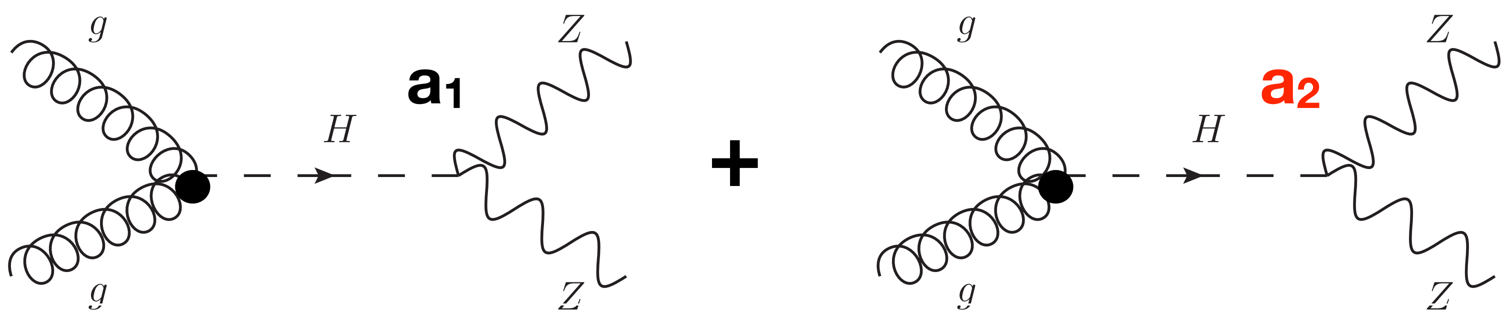
RUN1



CMS, PRD92, 012004 (2014)

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

Interference in on-shell region



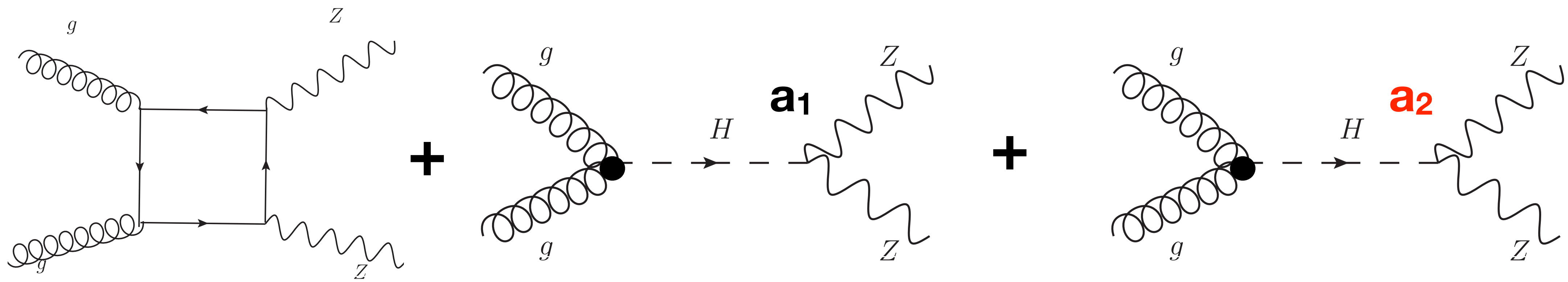
$\sqrt{s}$=8 TeV,$gg \to H \to ZZ \to e^+e^-\mu^+\mu^-$,$M(4\ell) < 130$ GeV

a_1=1,a_2=1

σ_{SM}	σ_{new}	$\sigma_{interference}$
0.245fb	0.101fb	-0.275fb

Interference in off-shell region

SM



$\sqrt{s}$=8 TeV,$gg(\to H^*) \to ZZ \to e^+e^-\mu^+\mu^-$,$M(4\ell) > 220$ GeV

a_1=1,a_2=1

σ_{SM}	σ_{new}	$\sigma_{interference}$
0.45fb	0.23fb	0.15fb

Constraints in off-shell region

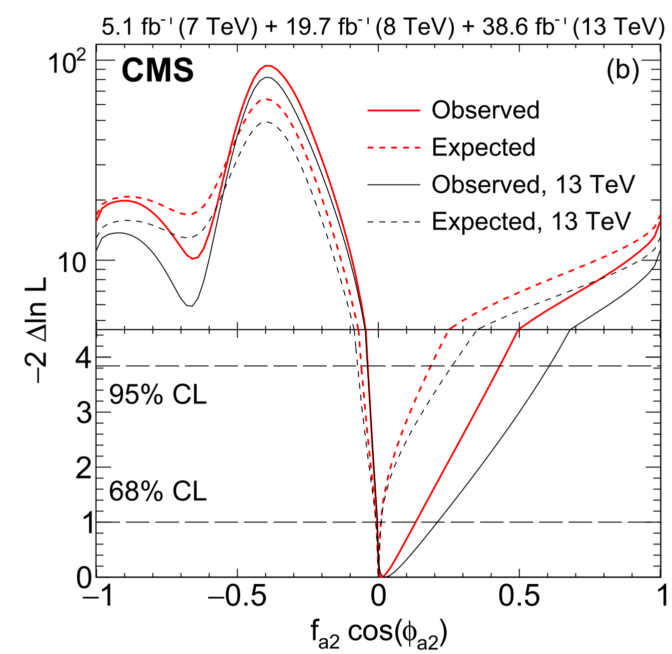
CMS data for off-shell region **CMS PAS Higg-14-002**

		Full region	Signal-enriched region
	gg + VBF $\to 4\ell$ (signal, $\Gamma_H/\Gamma_H^{SM} = 1$)	$2.22^{+0.15}_{-0.17}$	$1.20^{+0.08}_{-0.09}$
	gg + VBF $\to 4\ell$ (background)	$31.1^{+3.0}_{-3.1}$	2.12 ± 0.21
(a)	gg + VBF $\to 4\ell$ (total, $\Gamma_H/\Gamma_H^{SM} = 1$)	$29.6^{+2.8}_{-2.9}$	$1.73^{+0.16}_{-0.17}$
	gg + 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

$$a_2 \subset [-2.0, 1.4]$$

$$a_3 \subset [-1.7, 1.7]$$

run2, on-shell



$$a_2 \subset [-0.34, 1.5]$$

$$a_3 \subset [-2.0, 2.4]$$

Summary

The interference effect of new physics are studied in three Higgs processes at LHC.

- The antisymmetric lineshape in $H \to \gamma\gamma$ could be extracted to probe CP-violating $H\gamma\gamma$ coupling.
- The forward-backward symmetry of the lepton in Z rest frame could totally reach as large as $\sim 4\%$ for a maximal CP violation in $H\gamma Z$ coupling.
- Constraints of anomalous HZZ couplings in Higgs off-shell region could be good complement for the experimental measurements in on-shell region.

Thanks!