Probe CP violation in $H\gamma\gamma$ coupling through interference

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collaborate with Youkai Wang (SNNU), on progress

EW and Flavor Physics @CEPC
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Outline

- Introduction

CP violation **Effective Field Theory (EFT)** **Constraints of CP violation in Higgs couplings**

- Probe CP violation in $H\gamma\gamma$ coupling

Interference between $gg \to H \to \gamma\gamma$ and $gg \to \gamma\gamma$

A new observable A_{int} **in SM and CP violation cases**

- Summary

CP violation in Cosmology

- Matter-antimatter asymmetry.

$$\eta \equiv \frac{n_B - n_{\bar{B}}}{n_\gamma} \sim 10^{-10}$$

- Sakharov's conditions:

1. **Baryon number violation.**
2. **C and CP violation.**
3. **Interactions out of thermal equilibrium.**

$$e_L^- \overset{CP}{\longleftrightarrow} e_R^+$$

CP violation in SM

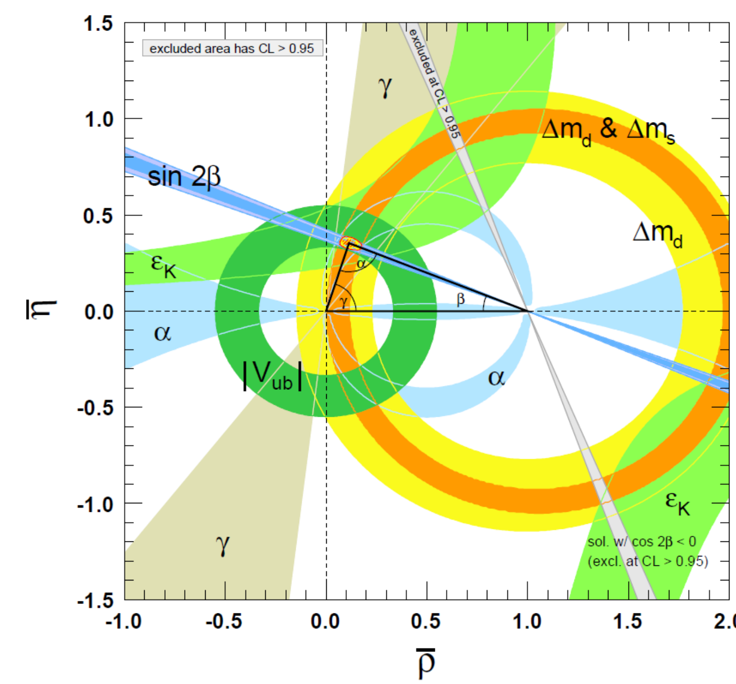
$$\frac{-g}{\sqrt{2}}(\overline{u_L}, \overline{c_L}, \overline{t_L})\gamma^\mu W_\mu^+ V_{\rm CKM}\begin{pmatrix} d_L \\ s_L \\ b_L \end{pmatrix} + \text{h.c.} \qquad V_{\rm CKM} \equiv V_L^u V_L^{d\dagger} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

$$\theta_{12}, \theta_{23}, \theta_{13}, \delta$$

M. Kobayashi, T. Maskawa,
Prog.Theor.Phys. 49 (1973) 652

$$J = c_{12}c_{23}c_{13}^2 s_{12}s_{23}s_{13}\sin\delta = (3.04^{+0.21}_{-0.20}) \times 10^{-5}.$$

C. Jarlskog, Z.Phys. C29 (1985) 491-497



Baryon asymmetry $\sim 10^{-20} \ll \eta$

M.E. Shaposhnikov, Nucl.Phys. B287 (1987) 757

CP violation from Higgs dynamics

- SM

$$\theta_{12}, \theta_{23}, \theta_{13}, \delta$$

$$V_{CKM} = U_u^\dagger U_d,$$
$$\lambda_u = U_u D_u W_u^\dagger, u_L^i \to U_u^{ij} u_L^j,$$

- For Example, 2HDM, SUSY

$$\Phi_i = \begin{pmatrix} \varphi_i^+ \\ (v_i + \eta_i + i\chi_i)/\sqrt{2} \end{pmatrix} \qquad i = 1,2$$

$$\begin{pmatrix} h_1 \\ h_2 \\ h_3 \end{pmatrix} = R \begin{pmatrix} \eta_1 \\ \eta_2 \\ A \end{pmatrix}$$

CP-even: η_1, η_2

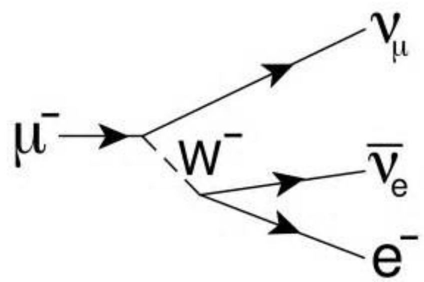
CP-odd: $A = -\sin\beta\chi_1 + \cos\beta\chi_2$

Effective Field Theory

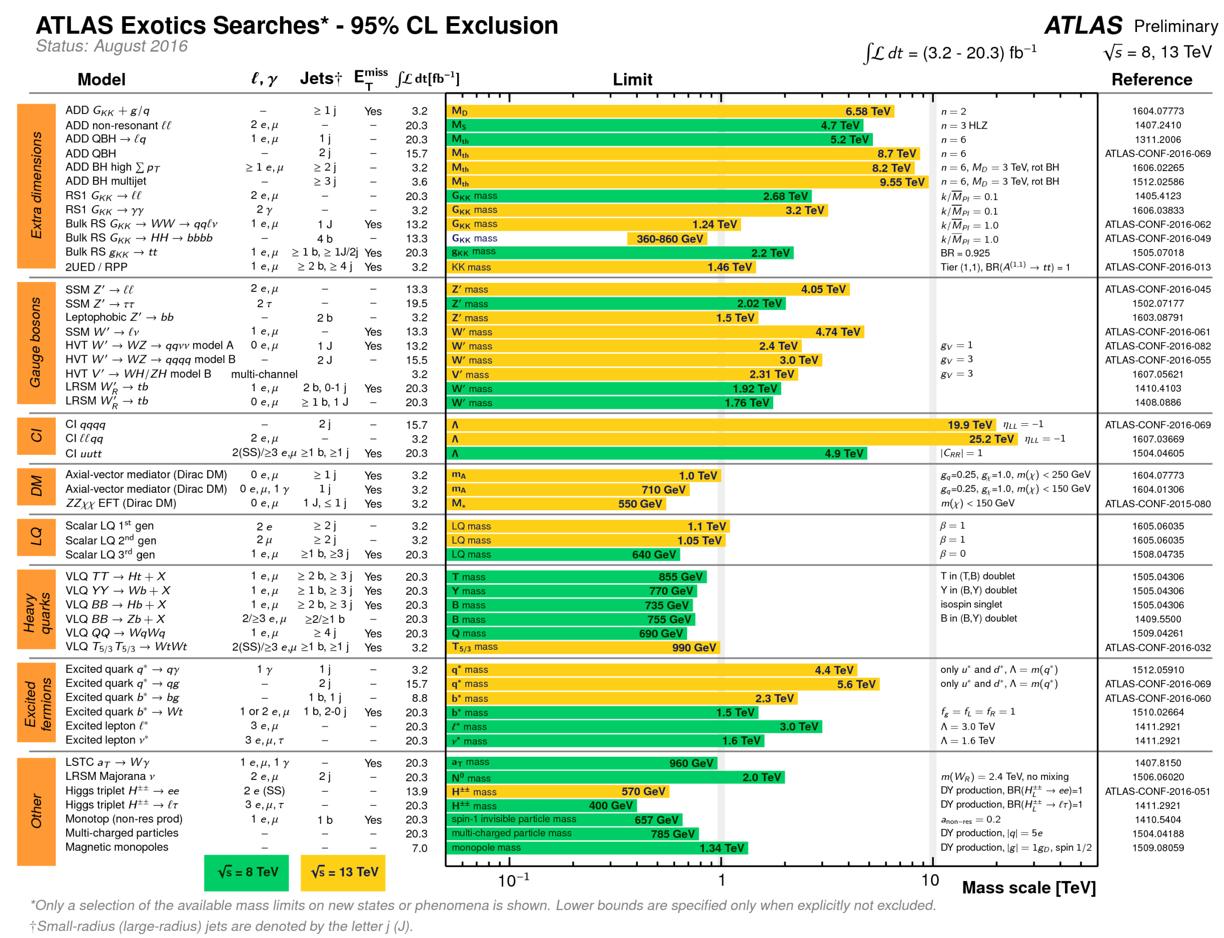
- Full theory (2HDM SUSY   Little Higgs   ......)

Howard Georgi, Annu.Rev.Nucl.Part. Sci.1993.43:209-52

$$L(\psi_{li},\psi_h)$$



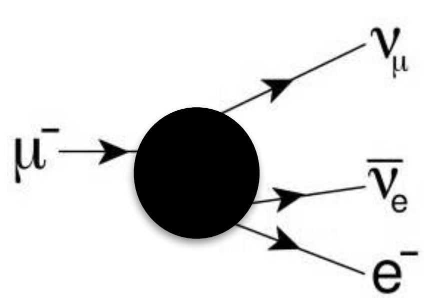
Large Scale
Heavy Particles
Light particles



Renormalization Group

$\mu = M$ Matching

Renormalization Group



Low Energy
Light particles

$$L(\psi_{li})$$

Appelquist-Carazzone Decoupling theorem:

$$L = L_{SM}^4 + \sum_i \frac{C_i}{\Lambda^2} O_i,$$

Dimension-six operators

B. Grzadkowski, M. Iskrzynski, M. Misiak, J. Rosiek, JHEP 1010 (2010) 085
R. Contino, M. Ghezzi, C. Grojean, M. Muhlleitner, M. Spira, JHEP07(2013)035

$$\mathcal{L}_{D=6} \equiv \sum_i \bar{c}_i \bar{O}_i = \Delta\mathcal{L}_{SILH} + \Delta\mathcal{L}_{CP} + \cdots$$

$$\begin{aligned}
\Delta\mathcal{L}_{SILH} =& \frac{\bar{c}_H}{2v^2}\partial^\mu(H^\dagger H)\partial_\mu(H^\dagger H) + \frac{\bar{c}_T}{2v^2}\left(H^\dagger \overleftrightarrow{D^\mu} H\right)\left(H^\dagger \overleftrightarrow{D}_\mu H\right) - \frac{\bar{c}_6\,\lambda}{v^2}(H^\dagger H)^3 \\
&+ \left(\left(\frac{\bar{c}_u}{v^2} y_u\, H^\dagger H\, \bar{q}_L H^c u_R + \frac{\bar{c}_d}{v^2} y_d\, H^\dagger H\, \bar{q}_L H d_R + \frac{\bar{c}_l}{v^2} y_l\, H^\dagger H\, \bar{L}_L H l_R\right) + h.c.\right) \\
&+ \frac{i\bar{c}_W\, g}{2m_W^2}\left(H^\dagger \sigma^i \overleftrightarrow{D^\mu} H\right)(D^\nu W_{\mu\nu})^i + \frac{i\bar{c}_B\, g'}{2m_W^2}\left(H^\dagger \overleftrightarrow{D^\mu} H\right)(\partial^\nu B_{\mu\nu}) \\
&+ \frac{i\bar{c}_{HW}\, g}{m_W^2}(D^\mu H)^\dagger \sigma^i (D^\nu H) W^i_{\mu\nu} + \frac{i\bar{c}_{HB}\, g'}{m_W^2}(D^\mu H)^\dagger (D^\nu H) B_{\mu\nu} \\
&+ \frac{\bar{c}_\gamma\, g'^2}{m_W^2} H^\dagger H B_{\mu\nu} B^{\mu\nu} + \frac{\bar{c}_g\, g_S^2}{m_W^2} H^\dagger H G^a_{\mu\nu} G^{a\mu\nu},
\end{aligned}$$

$$\rightarrow \quad iIm(\bar{c}_f) y_f \bar{q}\gamma_5 q H$$

$$\begin{aligned}
\Delta\mathcal{L}_{CP} =& \frac{i\tilde{c}_{HW}\, g}{m_W^2}(D^\mu H)^\dagger \sigma^i (D^\nu H)\tilde{W}^i_{\mu\nu} + \frac{i\tilde{c}_{HB}\, g'}{m_W^2}(D^\mu H)^\dagger (D^\nu H)\tilde{B}_{\mu\nu} \\
&+ \frac{\tilde{c}_\gamma\, g'^2}{m_W^2} H^\dagger H B_{\mu\nu}\tilde{B}^{\mu\nu} + \frac{\tilde{c}_g\, g_S^2}{m_W^2} H^\dagger H G^a_{\mu\nu}\tilde{G}^{a\mu\nu} \\
&+ \frac{\tilde{c}_{3W}\, g^3}{m_W^2}\epsilon^{ijk} W^{i\,\nu}_{\mu} W^{j\,\rho}_{\nu} \tilde{W}^{k\,\mu}_{\rho} + \frac{\tilde{c}_{3G}\, g_S^3}{m_W^2} f^{abc} G^{a\,\nu}_{\mu} G^{b\,\rho}_{\nu} \tilde{G}^{c\,\mu}_{\rho},
\end{aligned}$$

$$\tilde{F}_{\mu\nu} = \frac{1}{2}\epsilon_{\mu\nu\rho\sigma} F^{\rho\sigma},\ \ F = W, B, G.$$

$$\bar{c}_f \sim \mathcal{O}(1)$$

$$\tilde{c}_{HW}, \tilde{c}_{HB} \sim \frac{1}{16\pi^2}\mathcal{O}(1)$$

$$\tilde{c}_\gamma, \tilde{c}_g \sim \frac{1}{16\pi^2}\mathcal{O}(1)$$

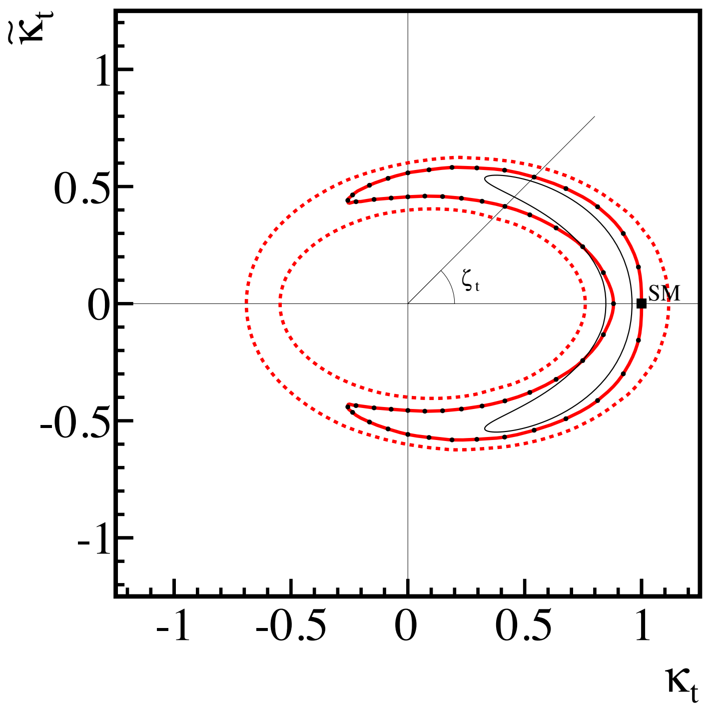
C. Arzt, M.B. Einhorn, J. Wudka Nucl.Phys. B433 (1995) 41-66

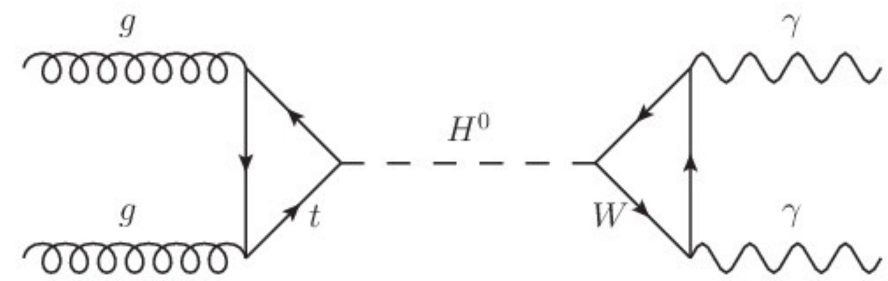
Sensitivity to probe CP violation

	SM	CP-odd coupling	sensitivity
$Hf\bar{f}$	tree	tree	✔
HZZ, HWW	tree	loop	✘
$H\gamma\gamma, Hgg$	loop	loop	✔

Experimental Constraints: $Ht\bar{t}$

$$\mathcal{L}_t = -\frac{m_t}{v}\left(\kappa_t \bar{t}t + i\tilde{\kappa}_t \bar{t}\gamma_5 t\right) H$$



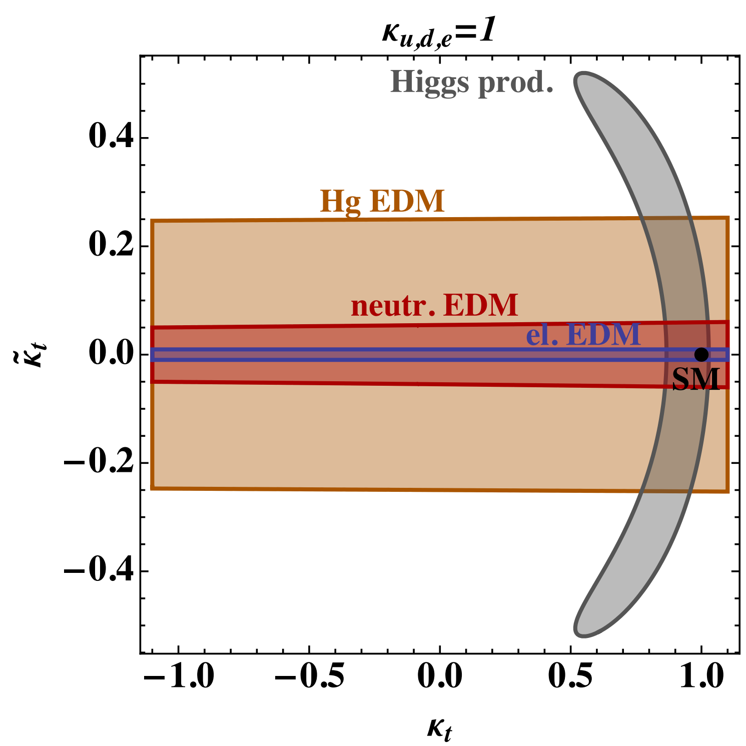


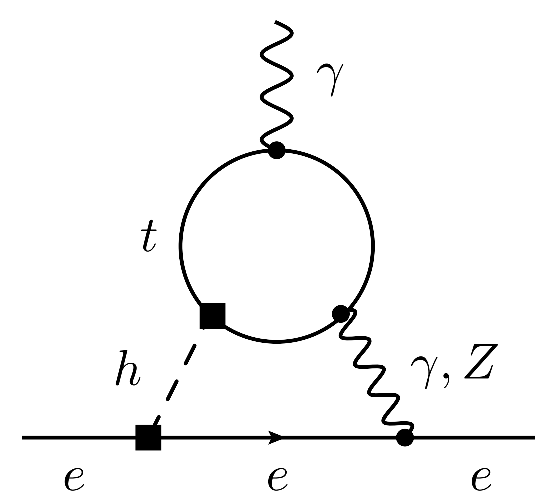
$$\mu_{gg} \simeq \kappa_t^2 + 2.6\tilde{\kappa}_t^2 + 0.11\kappa_t(\kappa_t - 1)\,,$$

$$\mu_{\gamma\gamma} \simeq (1.28 - 0.28\kappa_t)^2 + (0.43\tilde{\kappa}_t)^2\,.$$

J. Ellis, etc. JHEP04(2014),001

arxiv:1312.5736

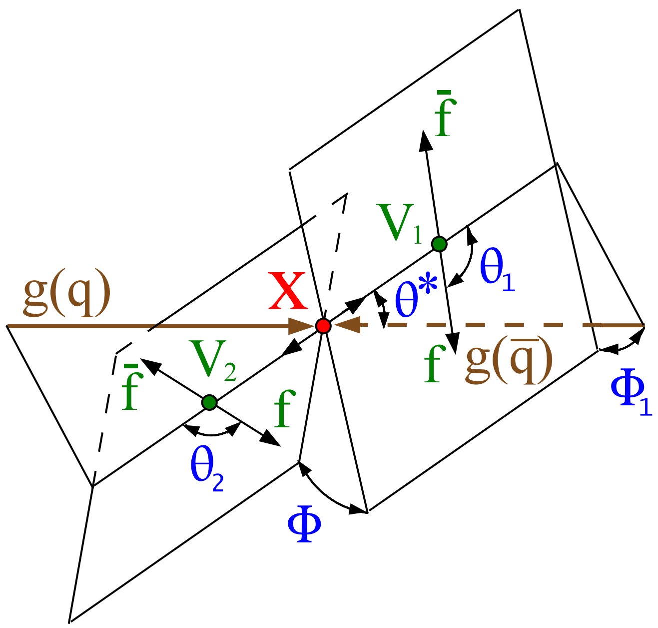


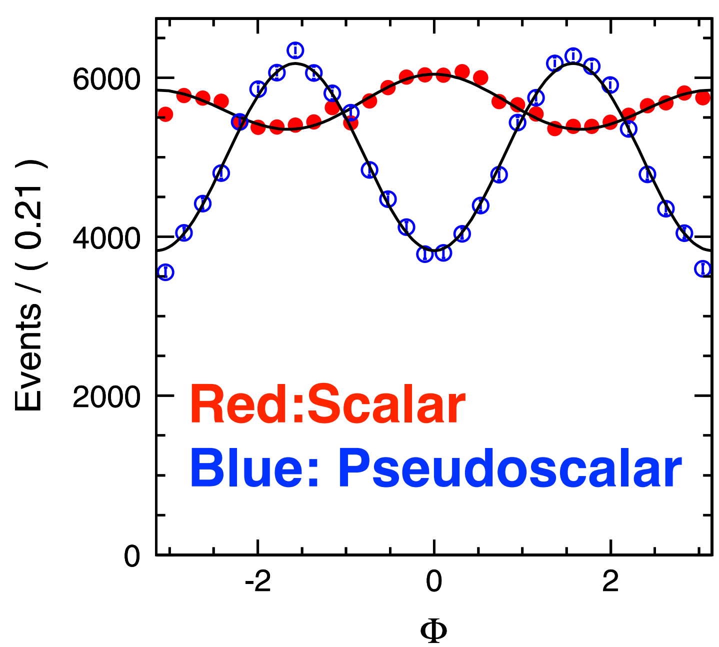


J. Brod, U. Haisch, J, Zupan
JHEP 1311 (2013) 180

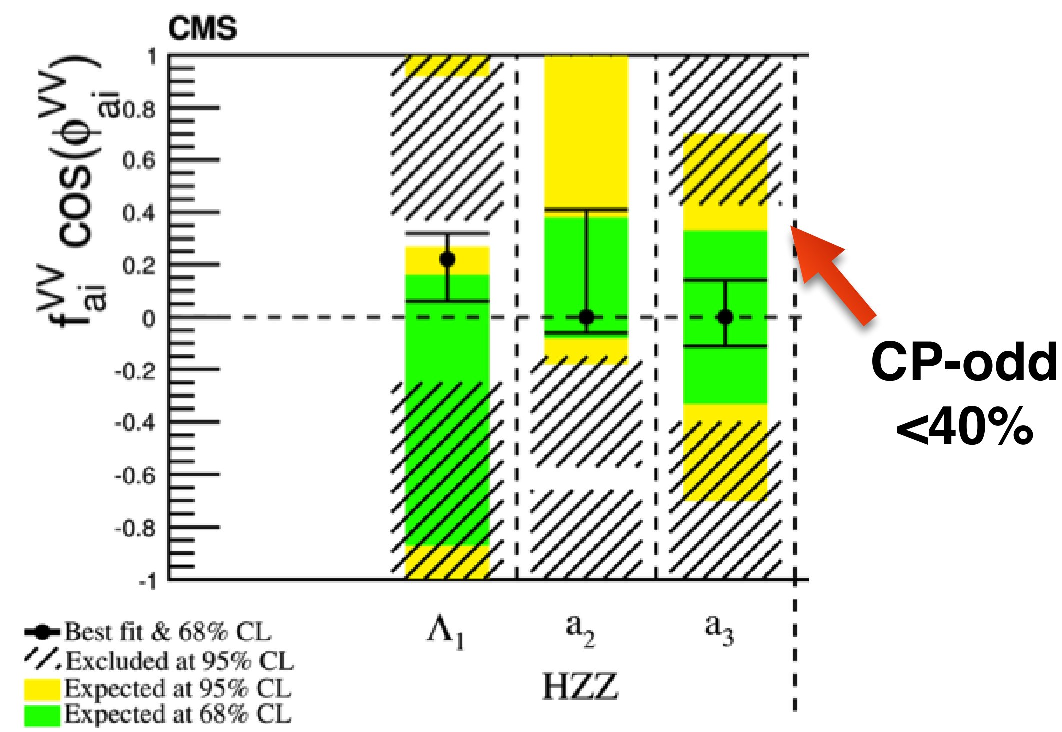
Experimental Constraints: HZZ

$$A(\mathrm{HVV}) \sim \left[a_1^{\mathrm{VV}} + \frac{\kappa_1^{\mathrm{VV}} q_{\mathrm{V1}}^2 + \kappa_2^{\mathrm{VV}} q_{\mathrm{V2}}^2}{\left(\Lambda_1^{\mathrm{VV}}\right)^2}\right] m_{\mathrm{V1}}^2 \epsilon_{\mathrm{V1}}^* \epsilon_{\mathrm{V2}}^* + a_2^{\mathrm{VV}} f_{\mu\nu}^{*(1)} f^{*(2),\mu\nu} + a_3^{\mathrm{VV}} f_{\mu\nu}^{*(1)} \tilde{f}^{*(2),\mu\nu},$$





Y. Gao,etc PRD81, 075022



CMS, PRD92, 012004

$$\Phi = \frac{\boldsymbol{q}_1 \cdot (\hat{\boldsymbol{n}}_1 \times \hat{\boldsymbol{n}}_2)}{|\boldsymbol{q}_1 \cdot (\hat{\boldsymbol{n}}_1 \times \hat{\boldsymbol{n}}_2)|} \times \cos^{-1}(-\hat{\boldsymbol{n}}_1 \cdot \hat{\boldsymbol{n}}_2)$$

$$\hat{\boldsymbol{n}}_1 = \frac{\boldsymbol{q}_{11} \times \boldsymbol{q}_{12}}{|\boldsymbol{q}_{11} \times \boldsymbol{q}_{12}|}, \qquad \hat{\boldsymbol{n}}_2 = \frac{\boldsymbol{q}_{21} \times \boldsymbol{q}_{22}}{|\boldsymbol{q}_{21} \times \boldsymbol{q}_{22}|}$$

$$c_{HZ} \sim \mathcal{O}(1)$$
$$\tilde{c}_{HZ} \sim \frac{1}{16\pi^2}\mathcal{O}(1)$$

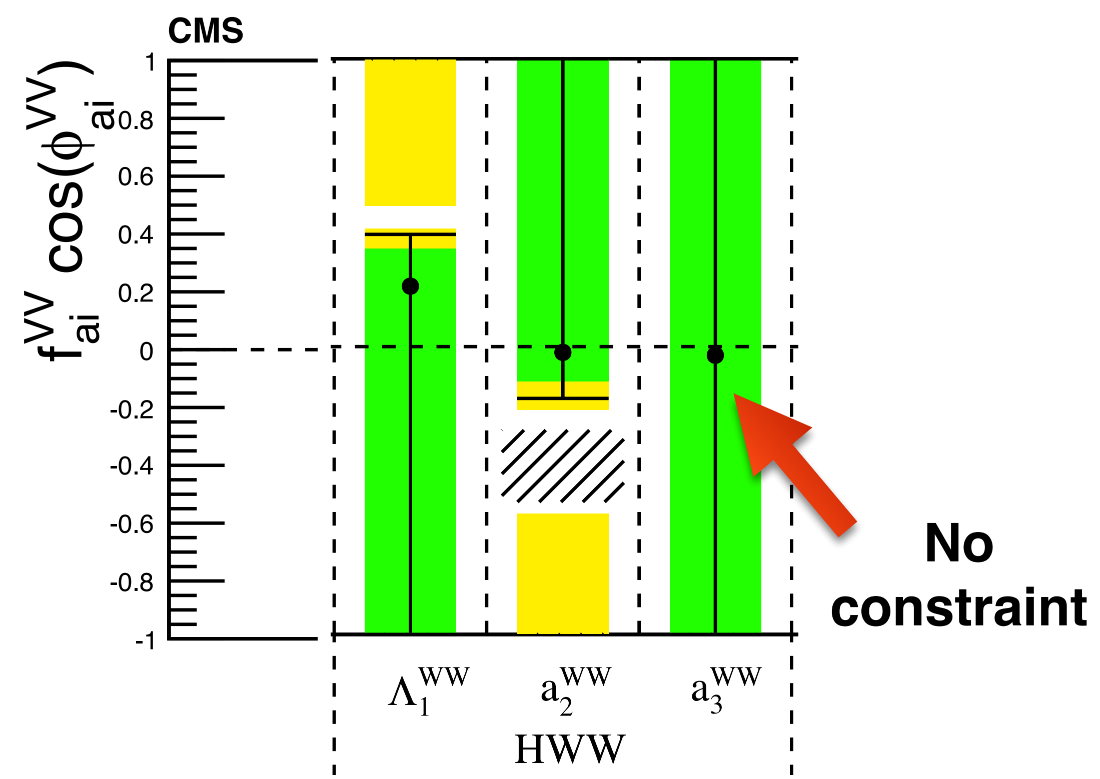
Experimental Constraints: HWW

$$A(\mathrm{HVV}) \sim \left[a_1^{\mathrm{VV}} + \frac{\kappa_1^{\mathrm{VV}} q_{\mathrm{V1}}^2 + \kappa_2^{\mathrm{VV}} q_{\mathrm{V2}}^2}{\left(\Lambda_1^{\mathrm{VV}}\right)^2}\right] m_{\mathrm{V1}}^2 \epsilon_{\mathrm{V1}}^* \epsilon_{\mathrm{V2}}^* + a_2^{\mathrm{VV}} f_{\mu\nu}^{*(1)} f^{*(2),\mu\nu} + a_3^{\mathrm{VV}} f_{\mu\nu}^{*(1)} \tilde{f}^{*(2),\mu\nu},$$

HWW^*

$$m_{\mathrm{T}}^2 = 2 p_{\mathrm{T}}^{\ell\ell} E_{\mathrm{T}}^{\mathrm{miss}} (1 - \cos\Delta\phi(\ell\ell, \vec{E}_{\mathrm{T}}^{\mathrm{miss}}))$$

$$\Delta\phi(\ell\ell, \vec{E}_{\mathrm{T}}^{\mathrm{miss}})$$

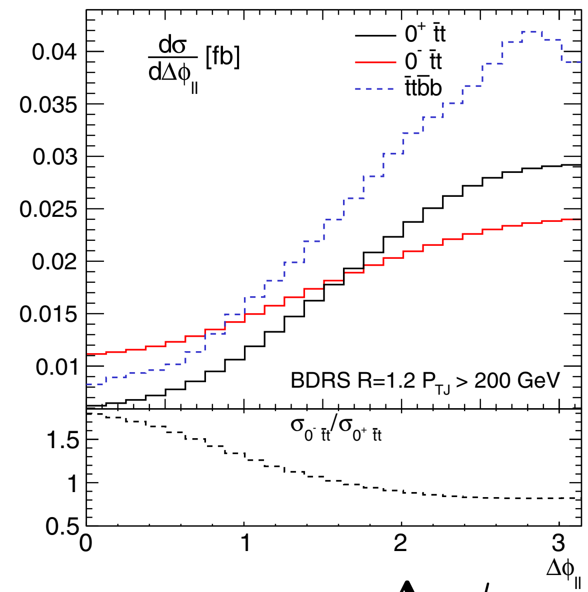


CMS, PRD92, 012004

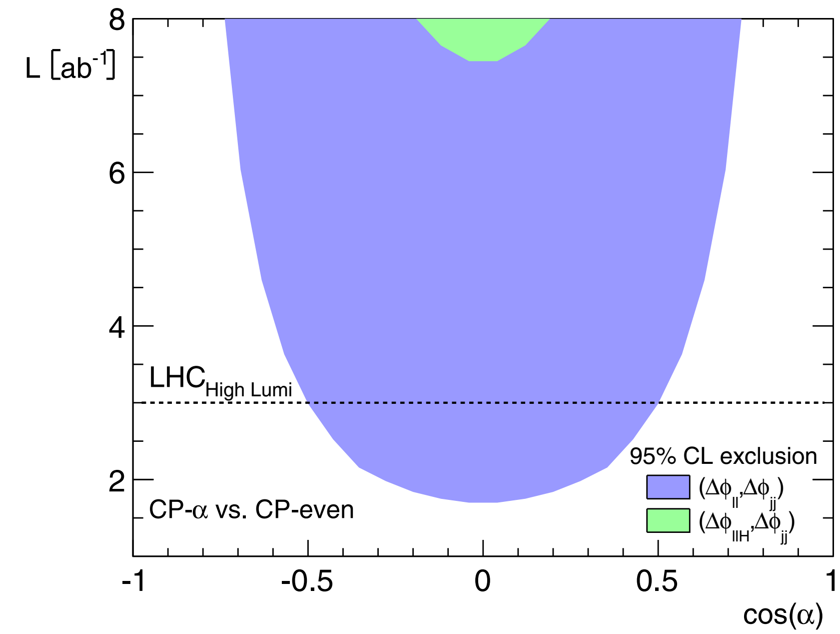
Some theoretical proposals

$$\mathcal{L} \supseteq -\frac{m_t}{v} K \bar{t}(\cos\alpha + i\gamma_5 \sin\alpha) t H,$$

$H t\bar{t}$



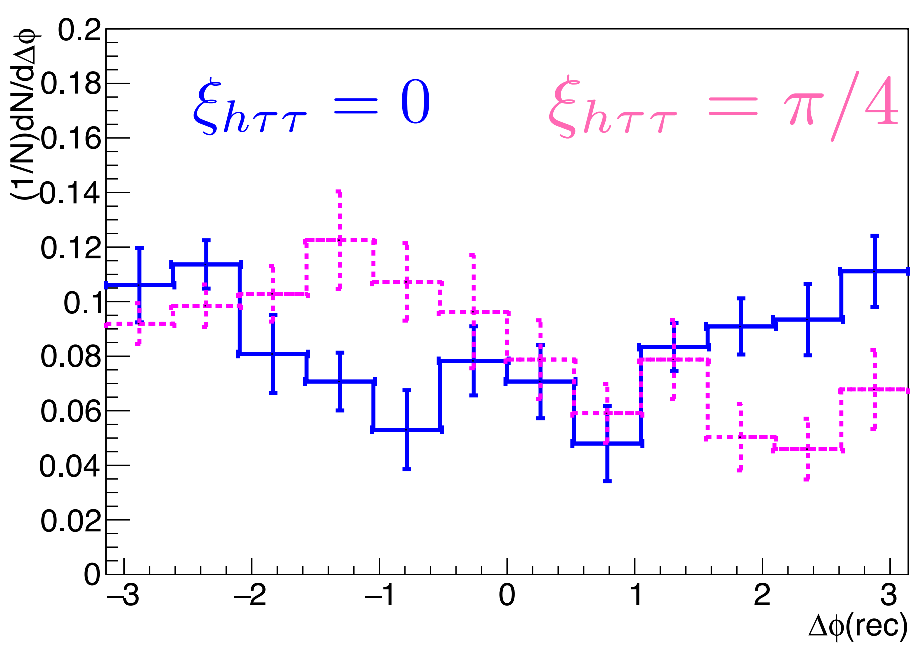
$\Delta\phi_{\ell\ell}$



PRL116,091801(2016)
M. Buckley, etc.

$H\tau\tau$

$$\mathcal{L} = -g_{h\tau\tau} h\big(\cos\xi_{h\tau\tau}\bar{\tau}\tau + i\sin\xi_{h\tau\tau}\bar{\tau}\gamma^5\tau\big)$$



$\Delta\xi_{h\tau\tau} \approx 0.2$

$3\ \mathrm{ab}^{-1}$ at $\sqrt{s} = 14$ TeV

PRL118,171802(2017)
K. Hagiwara, etc.

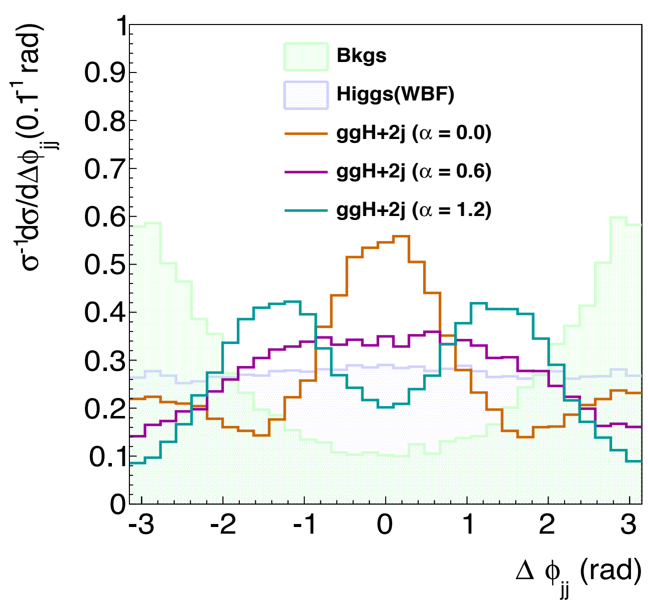
Some theoretical proposals

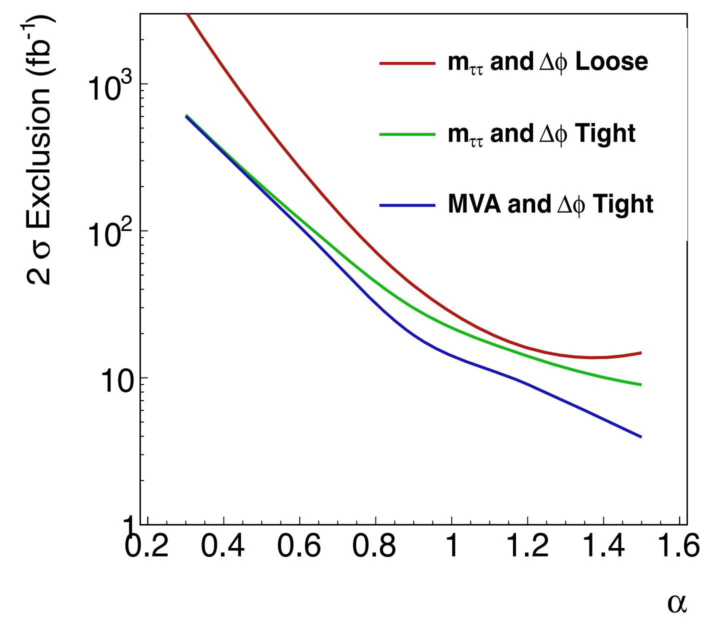
$$\mathcal{L}_{h\bar{f}f} = \cos\alpha\, y_f \bar{\psi}_f \psi_f h + \sin\alpha\, \widetilde{y}_f \bar{\psi}_f i\gamma_5 \psi_f h$$

$$\mathcal{L}_{hgg} = \cos\alpha\, \frac{\alpha_S}{12\pi v} h G^a_{\mu\nu} G^{a,\mu\nu} + \sin\alpha\, \frac{\alpha_S}{4\pi v} h G^a_{\mu\nu} \widetilde{G}^{a,\mu\nu}$$

Hgg

$gg \to Hjj, H \to \tau\tau$

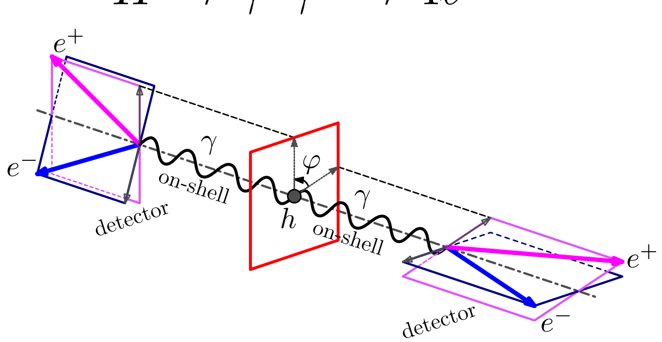




PRD 90, 073008 (2014)
M.J. Dolan, etc.

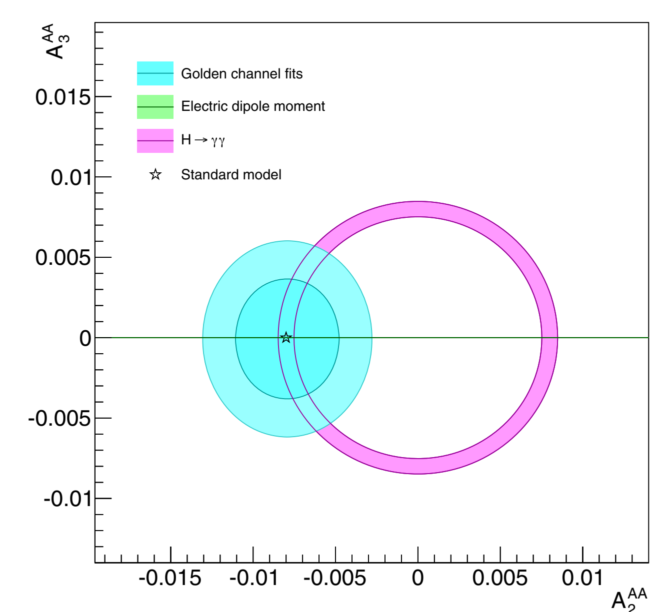
$H\gamma\gamma$

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



$$\mathcal{L} \supset \frac{h}{4v}\left(2A_1^{ZZ} m_Z^2 Z^\mu Z_\mu + A_2^{ZZ} Z^{\mu\nu} Z_{\mu\nu} + A_3^{ZZ} Z^{\mu\nu} \tilde{Z}_{\mu\nu}\right.$$
$$+ 2A_2^{Z\gamma} F^{\mu\nu} Z_{\mu\nu} + 2A_3^{Z\gamma} F^{\mu\nu} \tilde{Z}_{\mu\nu} + A_2^{\gamma\gamma} F^{\mu\nu} F_{\mu\nu}$$
$$\left. + A_3^{\gamma\gamma} F^{\mu\nu} \tilde{F}_{\mu\nu}\right),$$

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

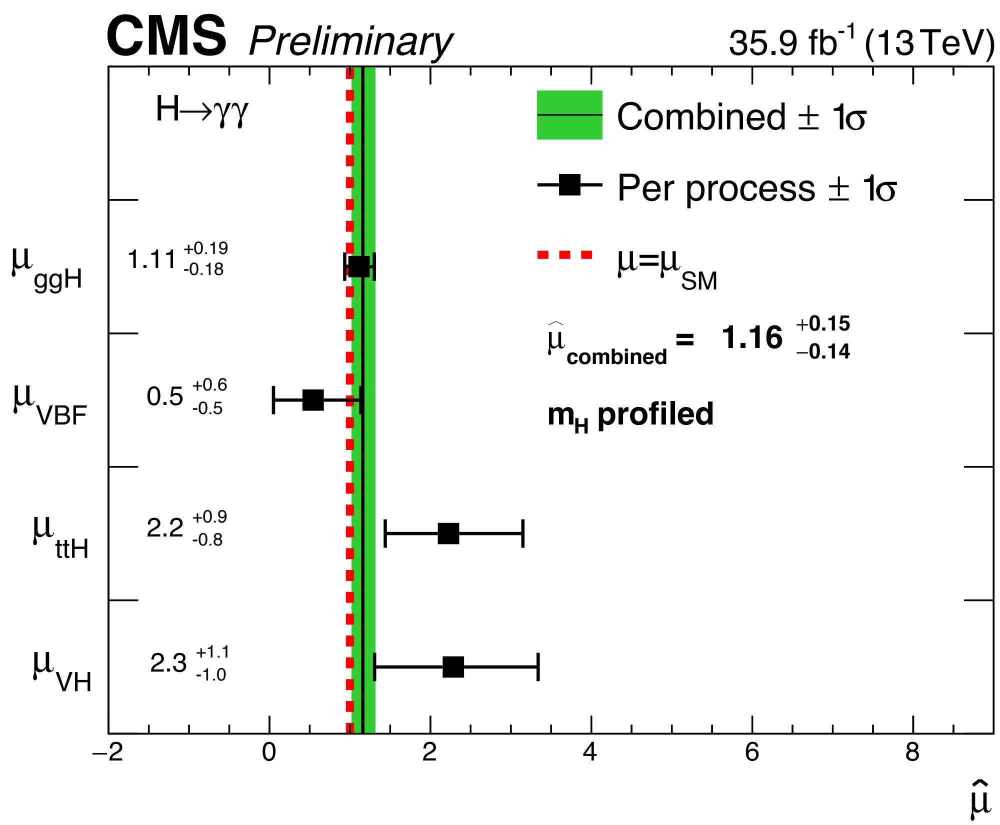


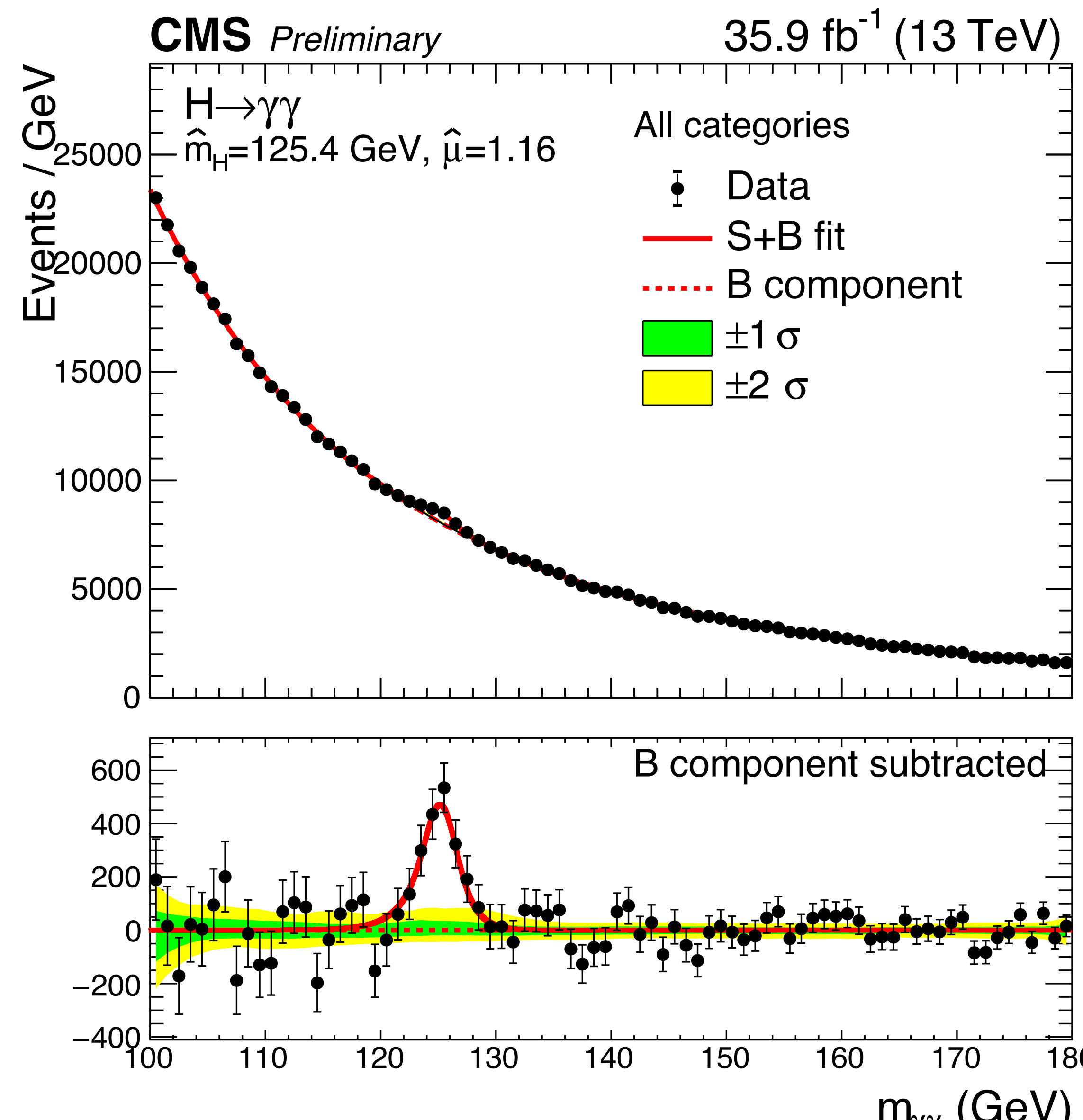
Methods and Feasibility

coupling	decay channel	sensitive observable	feasibility @LHC,	@HL-LHC	feasibility @CEPC
HWW	$H \to WW \to 2\ell 2\nu$	$\Delta\phi_{\ell\ell}$	✓	✓	
$Ht\bar{t}$	$H \to t\bar{t} \to 2\ell 2\nu b\bar{b}$	$\Delta\phi_{\ell\ell}$	✗	✓	
$H\tau\tau$	$H \to \tau\tau \to \pi^+\pi^- 2\nu$	$\Delta\phi_{\pi^+\pi^-}$	✗	✓	
HZZ	$H \to ZZ \to 4\ell$	$\Delta\phi$	✓	✓	✓
Hgg	$gg \to Hjj$	$\Delta\phi_{jj}$	✓	✓	
$H\gamma\gamma$	$H \to \gamma\gamma \to 4\ell$	$\Delta\phi$	✗	✗	

Precise measurement from $H \to \gamma\gamma$

- Include **Signal strength, Mass**, Width, Spin,





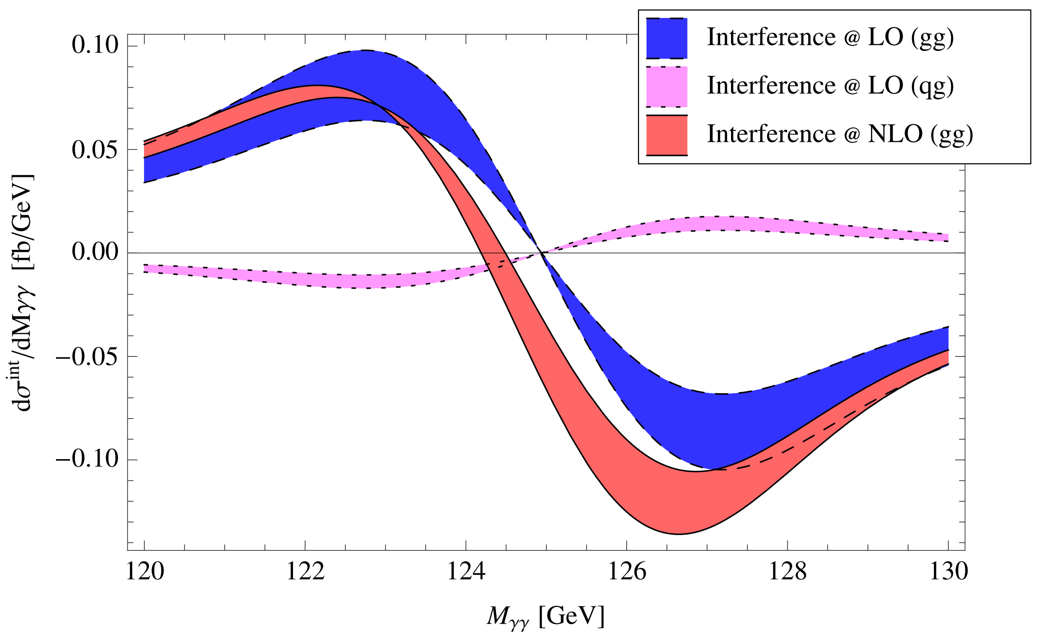
CMS-PAS-HIG-16-040

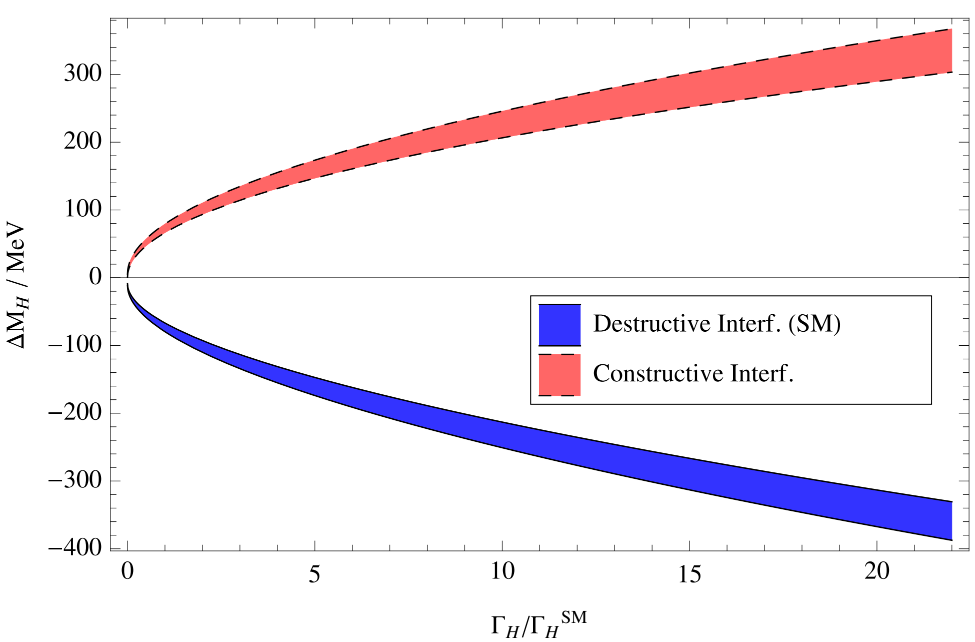
$$\widehat{\mu} = 1.16^{+0.15}_{-0.14} = 1.16^{+0.11}_{-0.10}\ (\text{stat.})\ ^{+0.09}_{-0.08}\ (\text{syst.})\ ^{+0.06}_{-0.05}\ (\text{theo.})$$

$$M_H = 125.4 \pm 0.15(stat.) \pm 0.2 \sim 0.3(syst.)\ GeV$$

Precise measurement from $H \to \gamma\gamma$

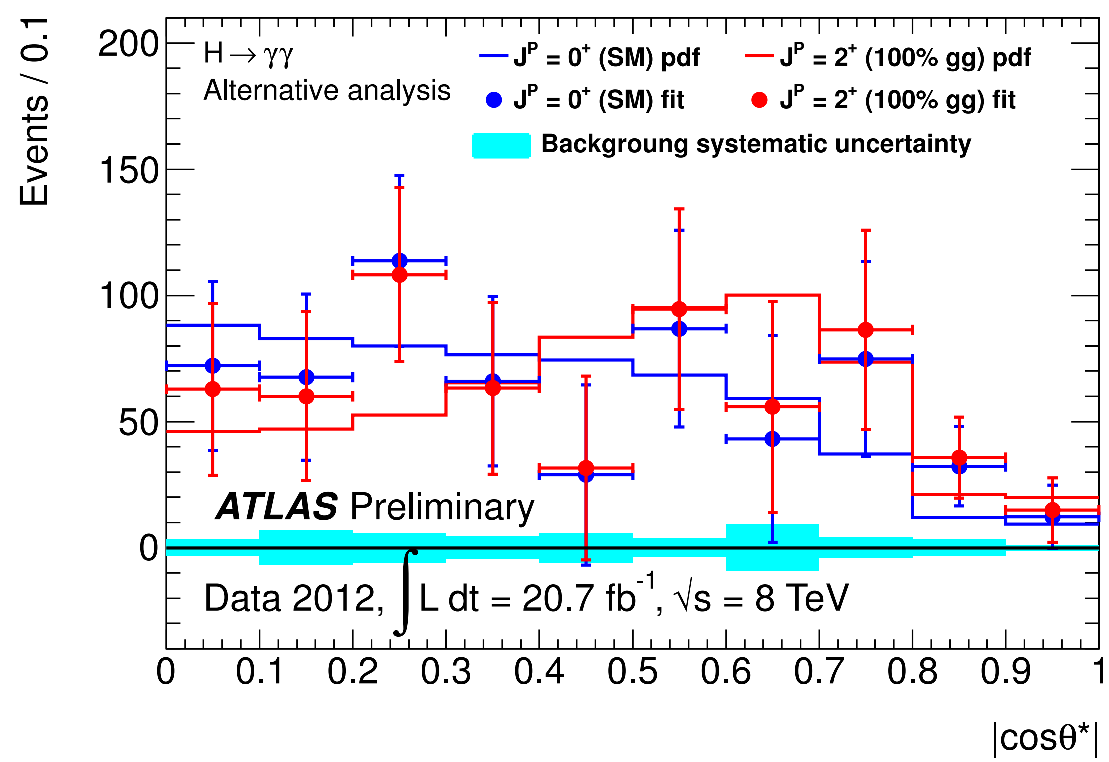
- Include Signal strength, Mass, **Width, Spin**





$\Gamma_H < 15\,\Gamma_H^{SM}$ (14 TeV, 3 ab^{-1}, 95% CL)

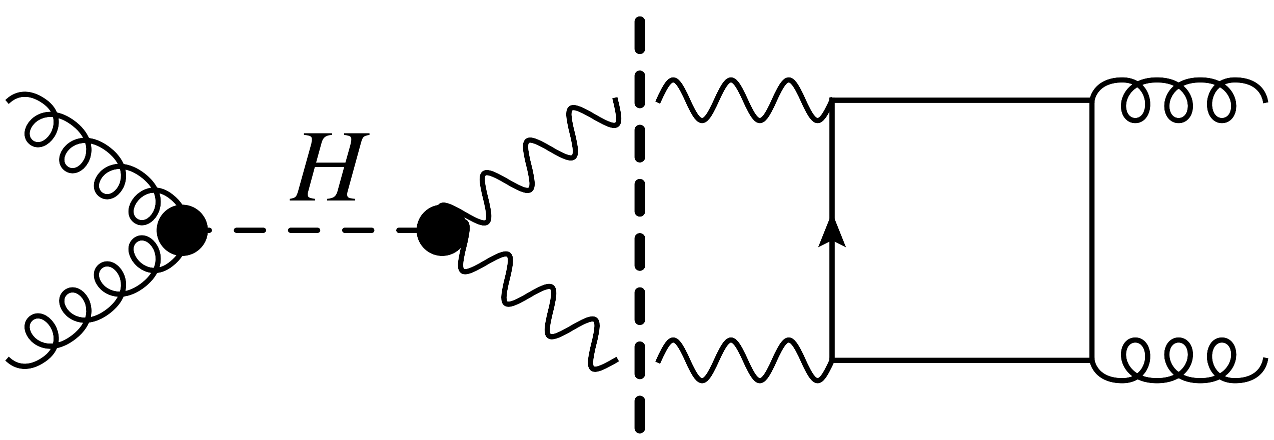
L.Dixon, etc. PRL111,111802



ATLAS-CONF-2013-029

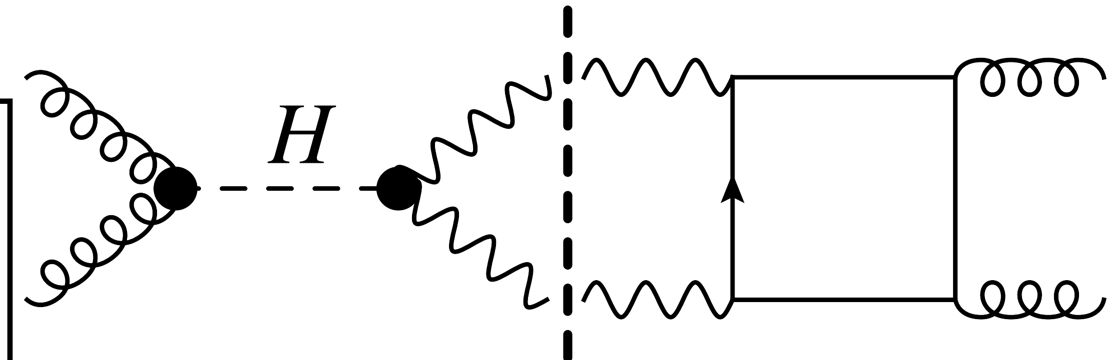
Spin-2 is excluded at 99.9% C.L.

Probe CP violation in $H\gamma\gamma$ coupling through interference



Interference

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



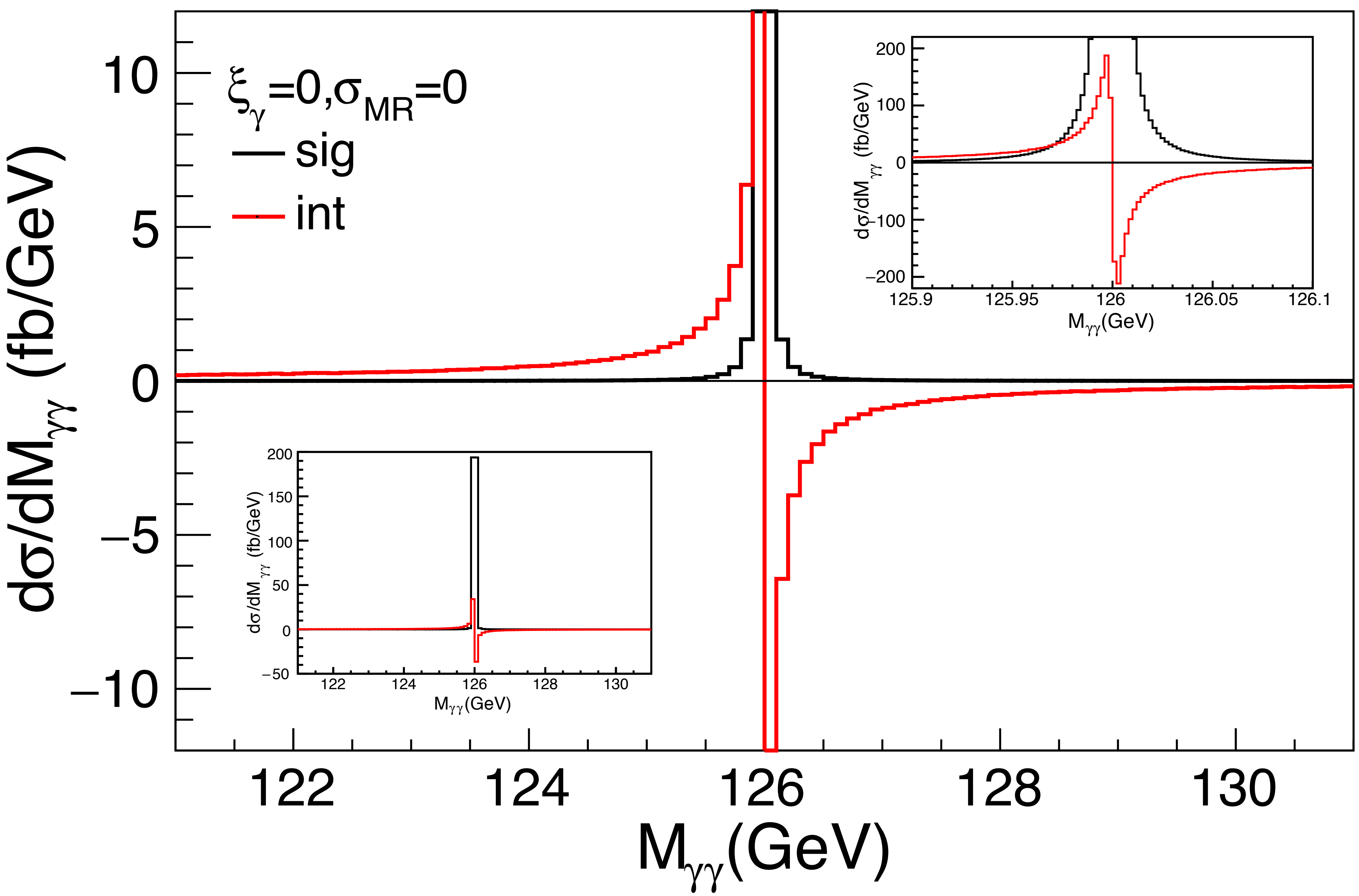
$$\mathcal{M} = -e^{-ih_3\xi_\gamma}\delta_{h_1h_2}\delta_{h_3h_4}\frac{M^4_{\gamma\gamma}}{v^2}\frac{4c_gc_\gamma}{M^2_{\gamma\gamma}-M^2_H+iM_H\Gamma_H} + 4\alpha\alpha_s\delta^{ab}\sum_{f=u,d,c,s,b} Q_f^2\mathcal{A}^{h_1h_2h_3h_4}_{box}\,,$$

$$\mathcal{A}^{++++}_{box} = \mathcal{A}^{----}_{box} = 1$$
$$\mathcal{A}^{++--}_{box} = \mathcal{A}^{--++}_{box} = -1 + z\ln\left(\frac{1+z}{1-z}\right) - \frac{1+z^2}{4}\left[\ln^2\left(\frac{1+z}{1-z}\right)+\pi^2\right]$$

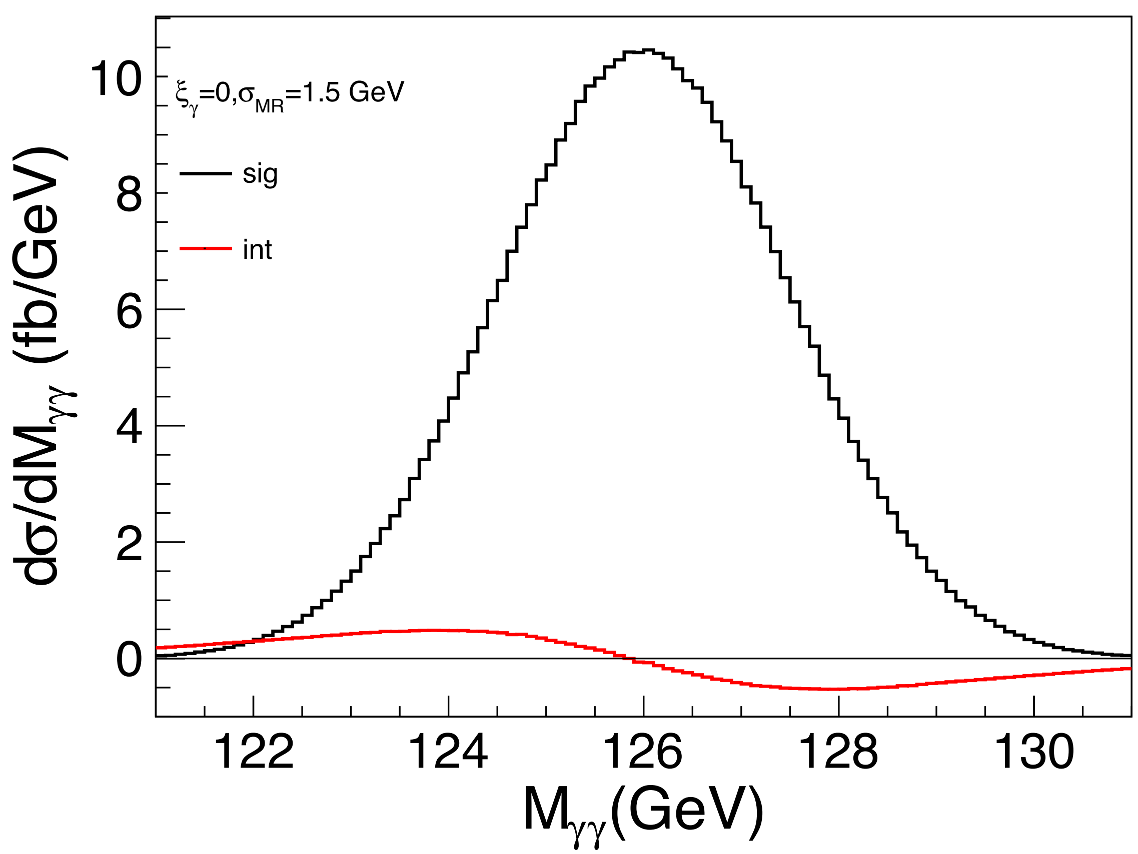
$$z = \cos\theta$$

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

Lineshape of Interference (SM)



After mass resolution (SM)

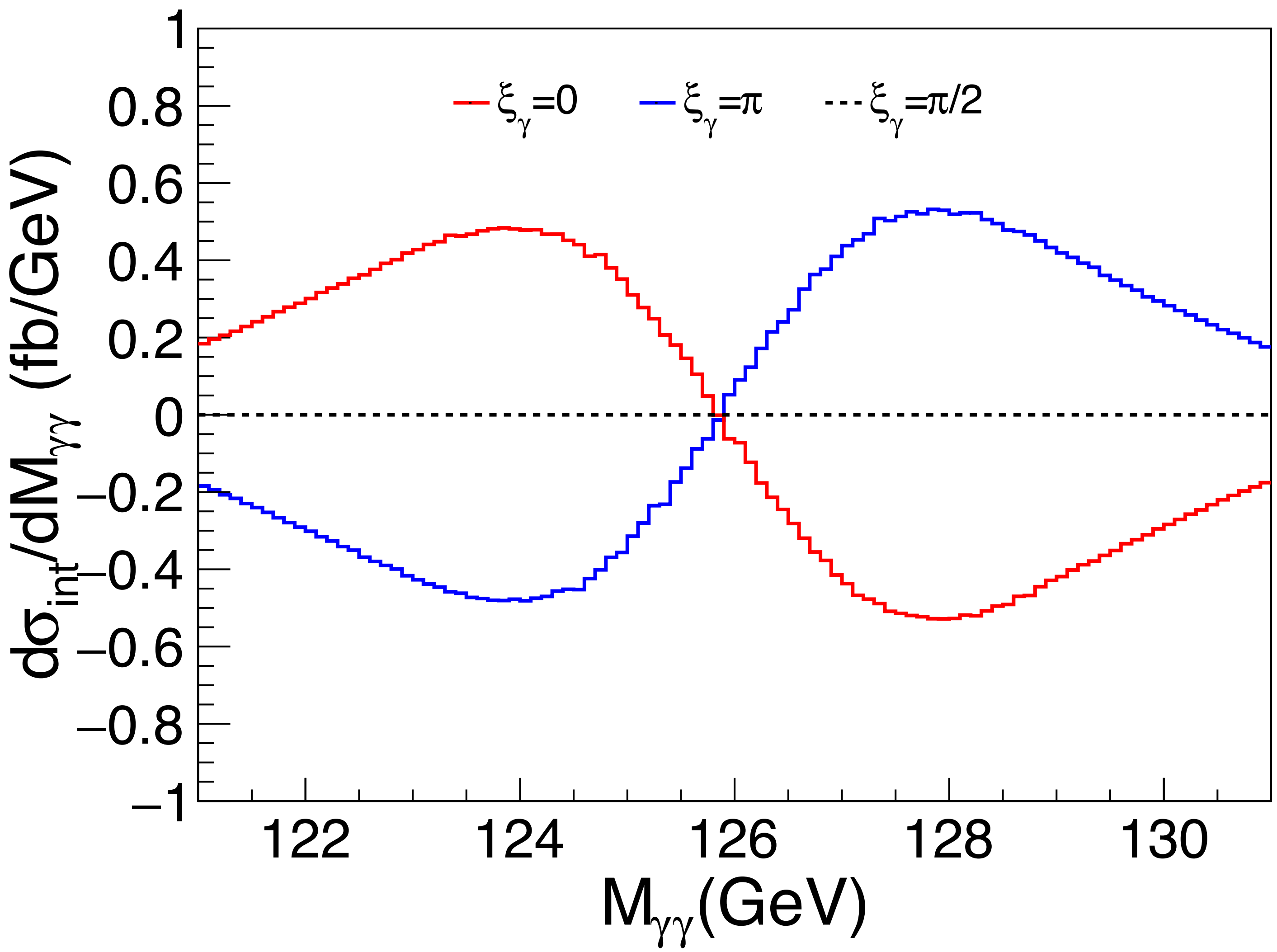


$$A_{int}(\xi_\gamma) = \frac{\int dM_{\gamma\gamma} \frac{d\sigma_{int}}{dM_{\gamma\gamma}} \Theta(M_{\gamma\gamma} - M_H)}{\int dM_{\gamma\gamma} \frac{d\sigma_{sig}}{dM_{\gamma\gamma}}} ,$$

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

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	4.1	10.4
1.3	39.3	3.8	9.6
1.5	39.3	3.5	8.8
1.7	39.3	3.2	8.2
1.9	39.3	3.0	7.5

Lineshape of CP-violating $H\gamma\gamma$ coupling



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

$$A_{int}(\xi_\gamma) = A_{int}^{SM} \times \cos\xi_\gamma$$

Significance

$$\text{Significance} = \frac{|A_{int} - A_{int}^{SM}|}{\sqrt{|\delta A_{int}|^2 + |\delta A_{int}^{SM}|^2}}$$

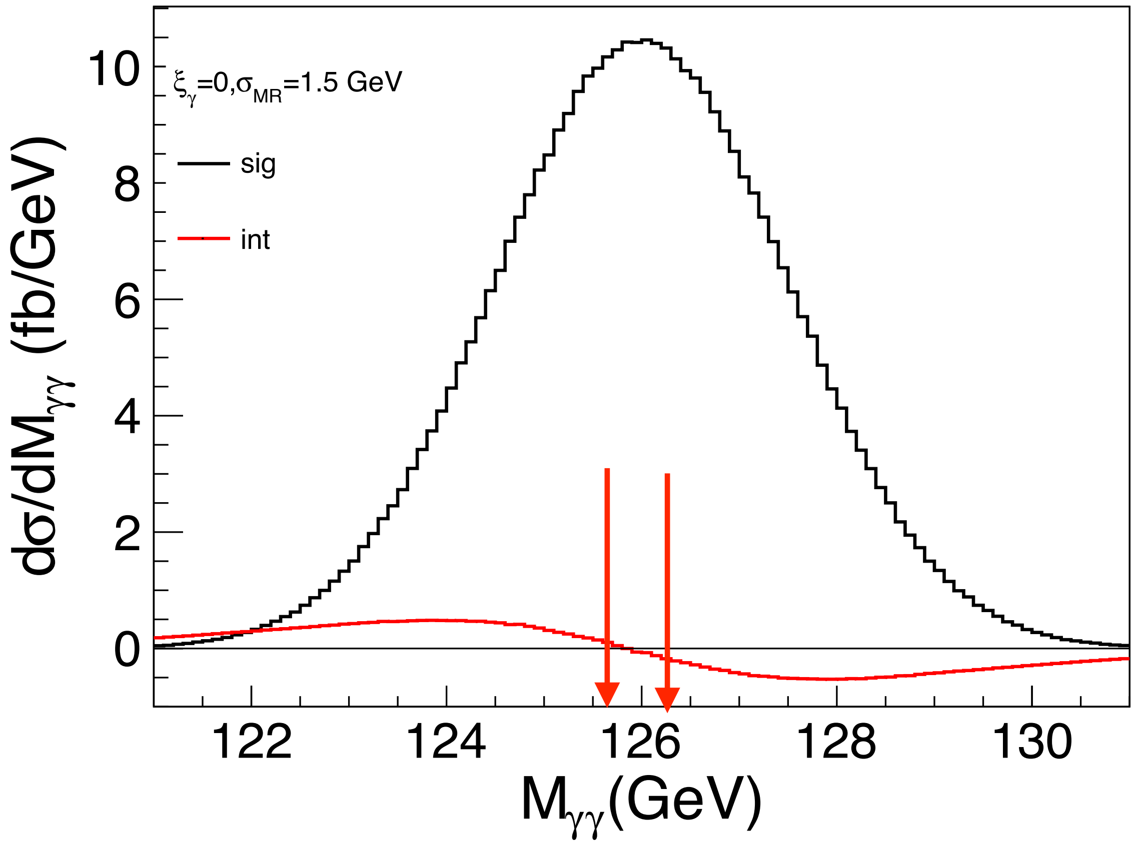
$$\delta A_{int} = A_{int} \times \frac{1}{\sqrt{L}} \sqrt{\frac{1}{|\sigma_{int}^I|} + \frac{1}{\sigma_{sig}^I}} \ ,$$

$$\sigma_{int}^I = \int^I dM \frac{d\sigma_{int}}{dM}, \ \sigma_{sig}^I = \int^I dM \frac{d\sigma_{sig}}{dM},$$

ξ_γ	$A_{int}(\%)$	Significance($L = 30fb^{-1}$)
0	8.8	-
π	-8.8	9
$\frac{\pi}{2}$	0	7

$$\xi_\gamma \notin [\pi/2, 3\pi/2] \text{ at } 99.9\% \text{ C.L.}$$

Mass uncertainty



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

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

$$M_H = 125.4 \pm 0.15(stat.) \pm 0.2 \sim 0.3(syst.)\ GeV$$

Mass uncertainty of ~0.4 GeV doesn't affect much

A general framework

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

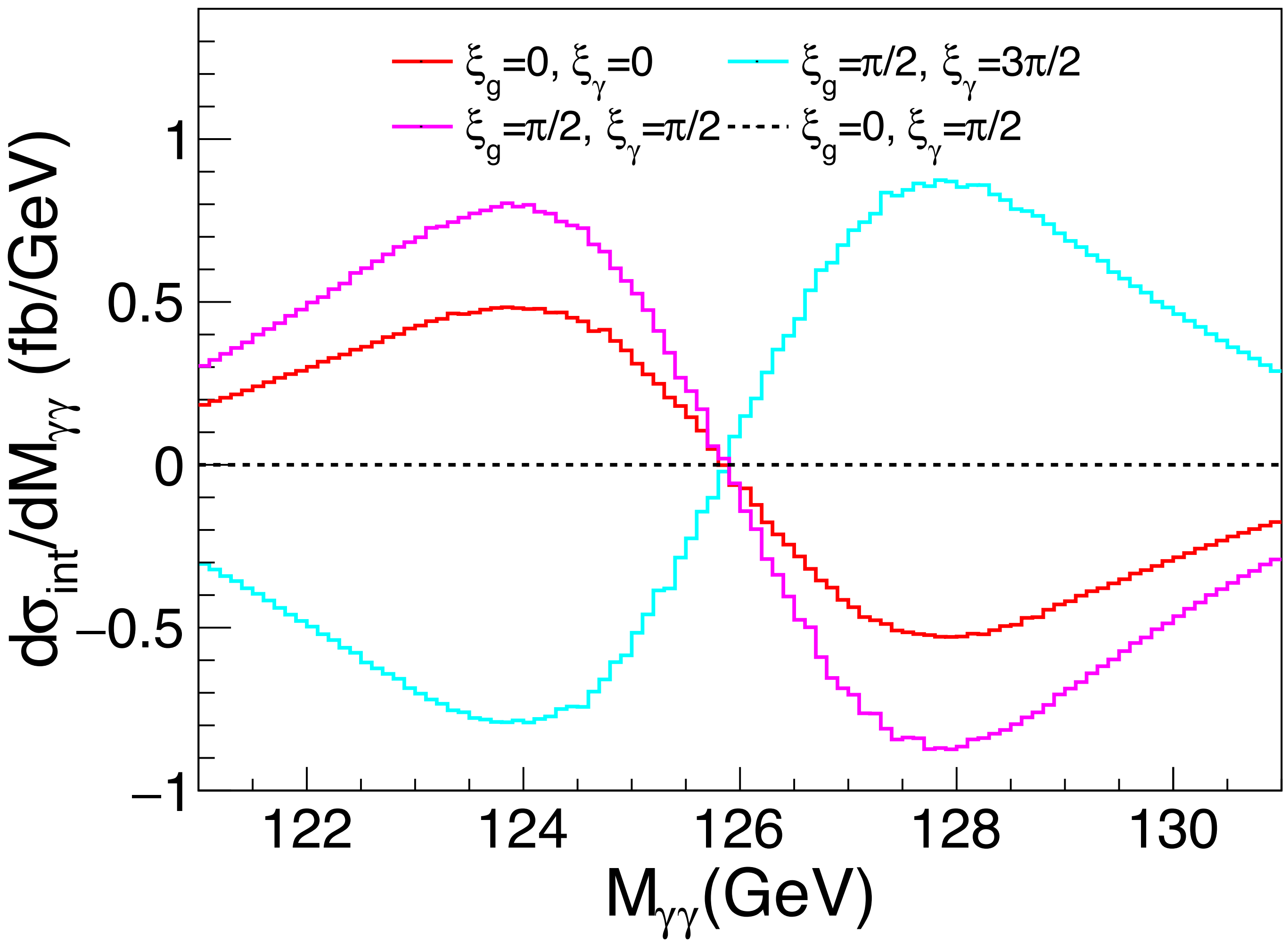
$$\mathcal{M} = -e^{-ih_1\xi_g}e^{-ih_3\xi_\gamma}\delta_{h_1h_2}\delta_{h_3h_4}\frac{M^4_{\gamma\gamma}}{v^2}\frac{4c_gc_\gamma}{M^2_{\gamma\gamma}-M^2_H+iM_H\Gamma_H}$$
$$+ 4\alpha\alpha_s\delta^{ab}\sum_{f=u,d,c,s,b} Q^2_f\mathcal{A}^{h_1h_2h_3h_4}_{box}\;, \qquad (17)$$

$$\frac{d\sigma_{int}}{dM_{\gamma\gamma}} \propto \frac{(M^2_{\gamma\gamma}-M^2_H)\,\mathrm{Re}\,(c_gc_\gamma) + M_H\Gamma_H\,\mathrm{Im}\,(c_gc_\gamma)}{(M^2_{\gamma\gamma}-M^2_H)+M^2_H\Gamma^2_H}$$
$$\times \int dz[\cos(\xi_g+\xi_\gamma)\mathcal{A}^{++++}_{box} + \cos(\xi_g-\xi_\gamma)\mathcal{A}^{++--}_{box}](18)$$

Lineshapes

$$A_{int}(\xi_g,\xi_\gamma) = A_{int}^{SM} \times \frac{\int dz[\cos(\xi_g+\xi_\gamma)\mathcal{A}_{box}^{++++} + \cos(\xi_g-\xi_\gamma)\mathcal{A}_{box}^{++--}]}{\int dz[\mathcal{A}_{box}^{++++} + \mathcal{A}_{box}^{++--}]}$$

If $|\eta^\gamma| < 2.5$, $A_{int}(\xi_g,\xi_\gamma) \approx A_{int}^{SM} \times \frac{2\cos(\xi_g+\xi_\gamma) - 9\cos(\xi_g-\xi_\gamma)}{-7}$



ξ_g	ξ_γ	$A_{int}(\%)$	Significance($L = 30 fb^{-1}$)
0	0	8.8	-
$\frac{\pi}{2}$	$\frac{\pi}{2}$	14.5	3
$\frac{\pi}{2}$	$\frac{3\pi}{2}$	-14.5	10
0	$\frac{\pi}{2}$	0	7

Summary

- CP violation have been studied variously in Higgs decays. For single channels with multiple final states such as $HZZ \to 4l$, $H \to t\bar{t} \to 2\ell 2\nu 2jet$, $\Delta\phi(\Delta\phi_{\ell\ell})$ is a sensitive observable. But it is not suitable for $H \to \gamma\gamma$.

- Interference between $gg \to H \to \gamma\gamma$ and $gg \to \gamma\gamma$ is studied. Based on the antisymmetric line shape of interference at leading order, We propose an integral odd around M_H ($\int^{M_H} - \int_{M_H}$) to get the contribution of interference and divide it by the total cross section of Higgs signal, which makes a new observable A_{int}.

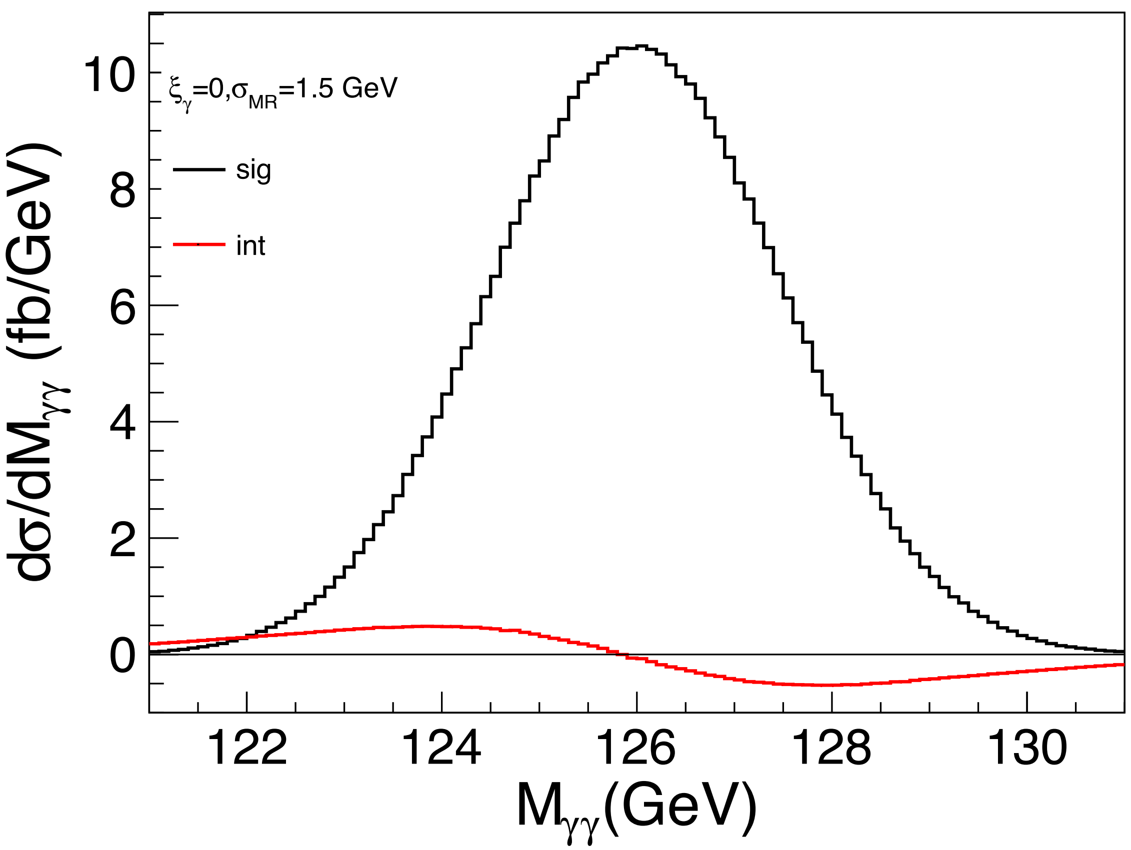
- A_{int} could reach about 10% in SM, and the significance of deviation caused by CP violation could be large as $5 \sim 10\sigma$, which could constrain the CP violation phase $\xi_\gamma \notin [\pi/2, 3\pi/2]$ at 99.9% confidence level.

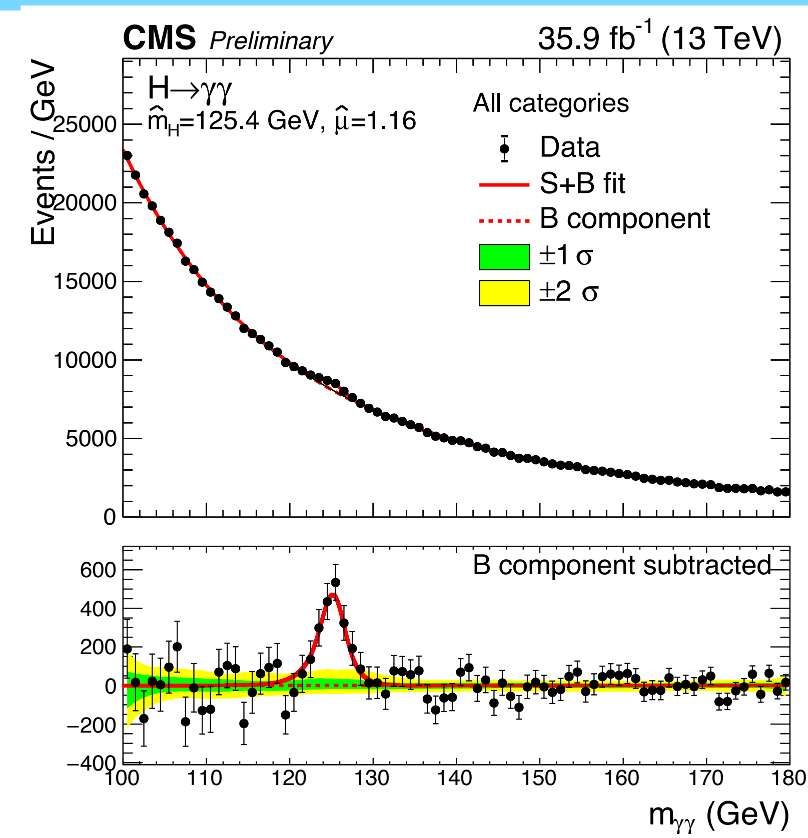
- The A_{int} with both CP-violating $H\gamma\gamma$ and Hgg couplings are also studied, which could have larger deviation and significance.

Thanks for your attention!

Backups

How to separate lineshapes





$$\hat{\mu} = 1.16^{+0.15}_{-0.14} = 1.16^{+0.11}_{-0.10}\,(\text{stat.})\,^{+0.09}_{-0.08}\,(\text{syst.})\,^{+0.06}_{-0.05}\,(\text{theo.})$$

σ_{MR} (GeV)	A^{SM}_{int} denominator (fb)	A^{SM}_{int} numerator (fb)	A^{SM}_{int} (%)
0	39.3	14.3	36.3
1.1	39.3	4.1	10.4
1.3	39.3	3.8	9.6
1.5	39.3	3.5	8.8
1.7	39.3	3.2	8.2
1.9	39.3	3.0	7.5

Separate lineshape of signal and interference is hopeful