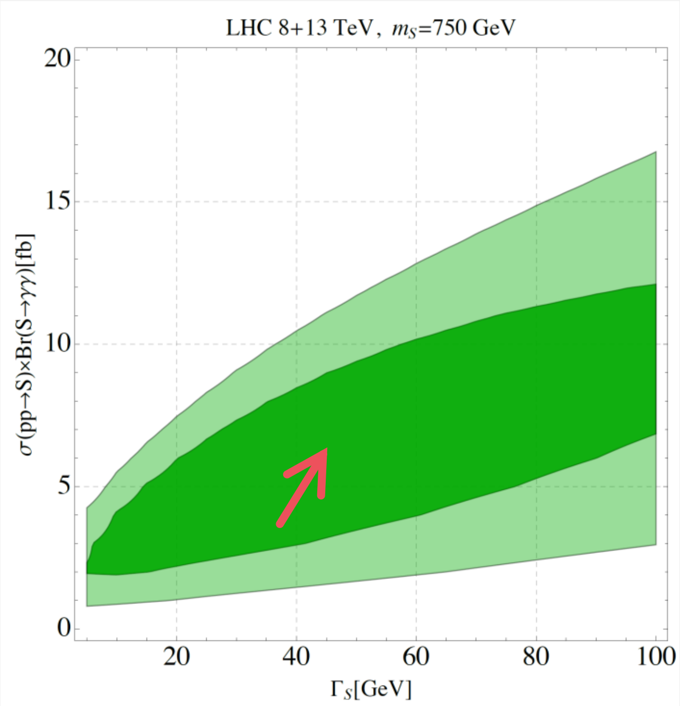
How Resonance-Continuum Interference Changes 750 GeV Diphoton Excess: Signal Enhancement and Peak Shift

Yeo Woong Yoon (KU)

Overview on the recent diphoton excess at the LHC Run 2. Jan. 8, 2016

based on 1601.00006
in collaboration with
Jeonghyeon Song, Sunghoon Jung

How difficult is it to explain 750GeV diphoton excess



Falkowski, Slone, Volansky 1512.05777

For $\Gamma_\phi = 45\text{GeV}, \quad \sigma_{\gamma\gamma} = 6\text{ fb}$

For the 2HDM, alignment limit

$M_H = M_A = 750\text{ GeV}, t_\beta = 1, \sqrt{s} = 13\text{ TeV}$

$\sigma(gg \to H/A) = 0.60\ (0.87)\text{ pb}$

with NNLO-QCD + NLO-EW from **HIGLU**(Spira 9510347)

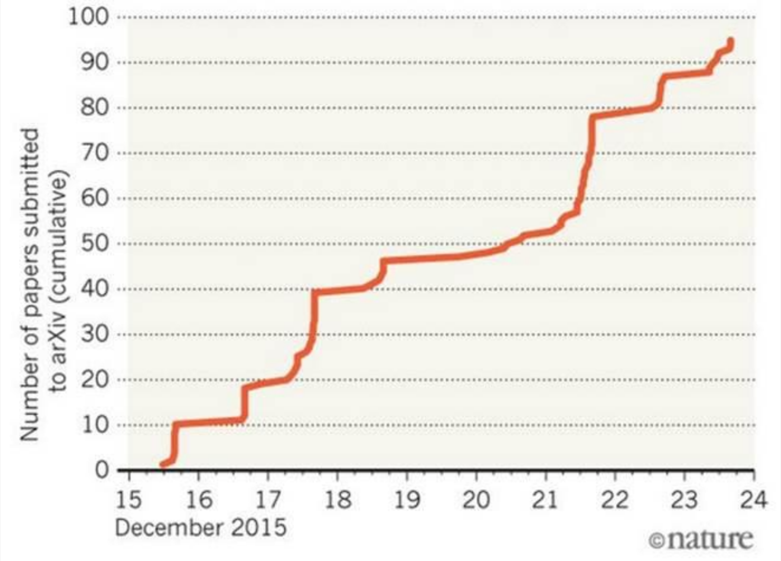
$\Gamma(H/A \to \gamma\gamma) = 2.4\ (3.4) \times 10^{-4}\text{ GeV}$

$$\sigma(gg \to H/A \to \gamma\gamma) = \sigma(gg \to H/A)\frac{\Gamma(H/A \to \gamma\gamma)}{\Gamma_\phi}$$

$= \mathbf{0.01fb}$

→ We need order 100 enhancement factor!!

Many Ideas to explain the 750 GeV excess



captured from T. Dorigo's blog

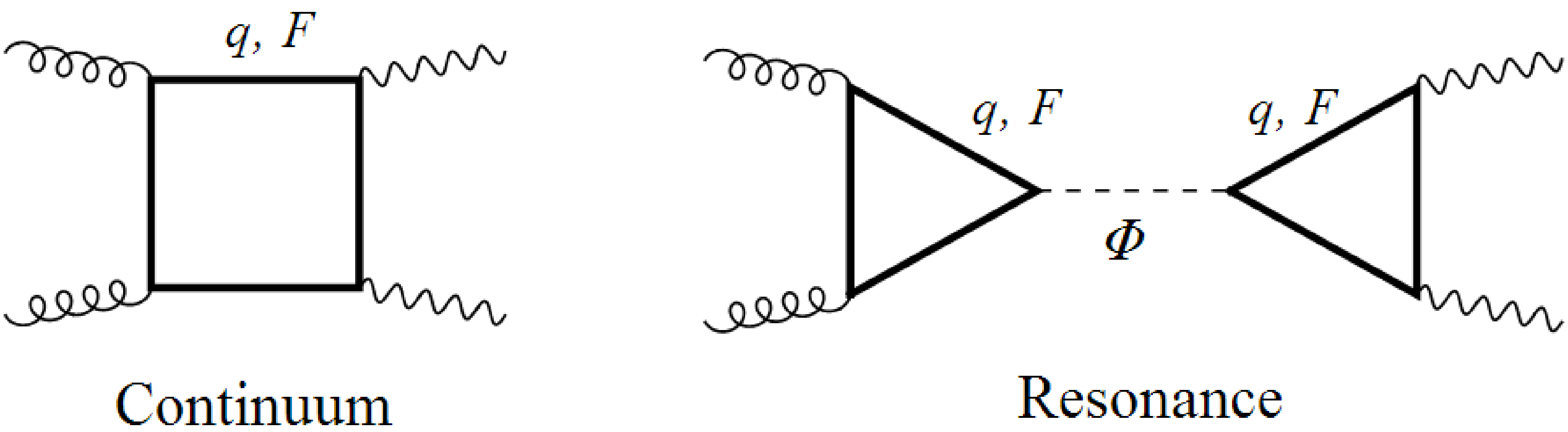
Until now,
we have $\mathcal{O}(100)$ papers.

Mostly focusing on new resonances

But, Surprisingly, no one (seriously) consider the interference effect between resonance and continuum bg.

Resonance-Continuum Interference

Resonance-Continuum Interference is always there



This must be taken into account for any new resonance

Resonance-Continuum Interference

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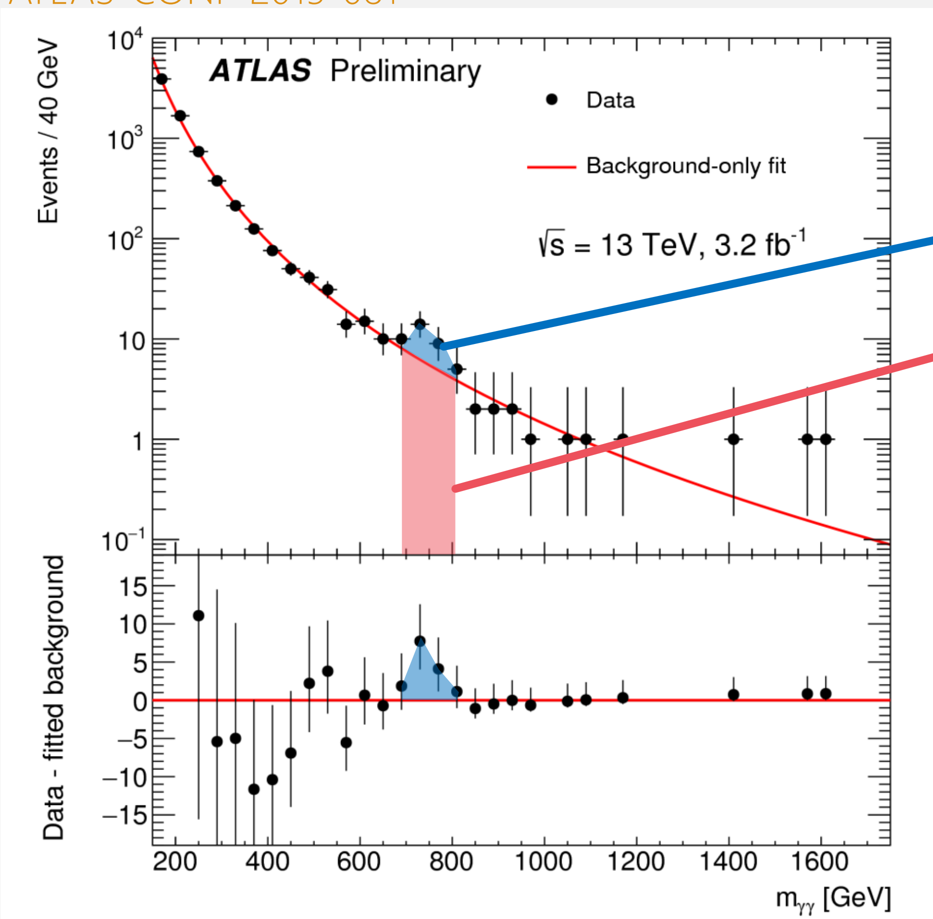


Rough estimation of Interference effect

\# of RES 15

\# of BG 23 (2.3 for gg)

\# of Intf

$$2 \cdot \sqrt{15} \cdot \sqrt{2.3}$$

$$= 11.7$$

$$11.7/15 = 78\%$$

(VERY NAÏVE ESTIMATION)

Resonance-Continuum Interference

Song, Jung, YWY, 1505.00291, 1510.03450

$$\hat{\sigma} = \hat{\sigma}_{\rm bg} + \hat{\sigma}_{\rm res} \frac{M^4}{(\hat{s}-M^2)^2 + M^4 w^2}\left[1 + \frac{2w}{R}\sin\phi + \frac{2(\hat{s}-M^2)}{M^2}\frac{\cos\phi}{R}\right]$$

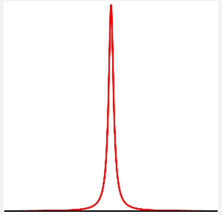
- 3 Key Parameters

$w = \Gamma/M$

$R \approx \mathcal{A}_{\rm res}/\mathcal{A}_{\rm bg}$

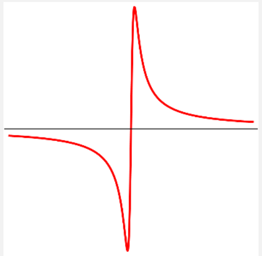
$\phi \approx {\rm Arg}(\mathcal{A}_{\rm res}/\mathcal{A}_{\rm bg})$

Im-Intf.



$\phi = \pm\frac{\pi}{2}$

Re-Intf.



$\phi = 0, \pi$

② 2HDM+VLL

① Singlet+VLF

1.Real Interference ($\phi = 0, \pi$) - Peak Shift

Model: Singlet + VLQ/VLL

$$\mathcal{L} \ni \frac{1}{2} M_\Phi^2 \Phi^2 + \sum_Q (s_Q \Phi + M_Q) \overline{Q} \gamma_5 Q + \sum_L (s_L \Phi + M_L) \overline{L} \gamma_5 L,$$

Quantum Numbers:

$$Q \equiv Q^{7/6} = (\mathbf{3}, \mathbf{2}, 7/6) \quad L \equiv L^{3/2} = (\mathbf{1}, \mathbf{2}, 3/2)$$

Parameter set:

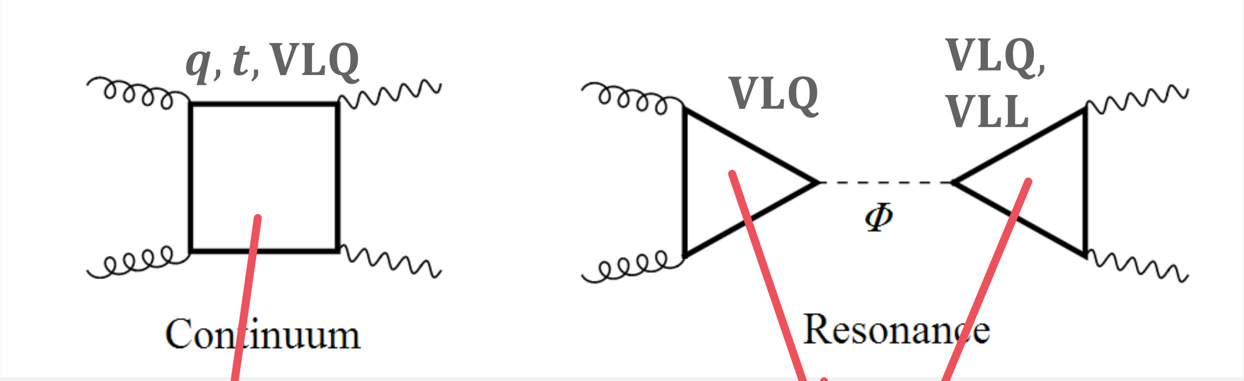
$$M_Q = 1\,\text{TeV},\ N_Q = 2,\ s_Q = 0.2.$$

$$M_L = 400\,\text{GeV},\ N_L = 6,\ s_L \text{ is varied}$$

$$\Gamma_\Phi = 5\,\text{GeV}$$

1.Real Interference $(\phi = 0, \pi)$ - Peak Shift

What about relative complex phase ϕ :



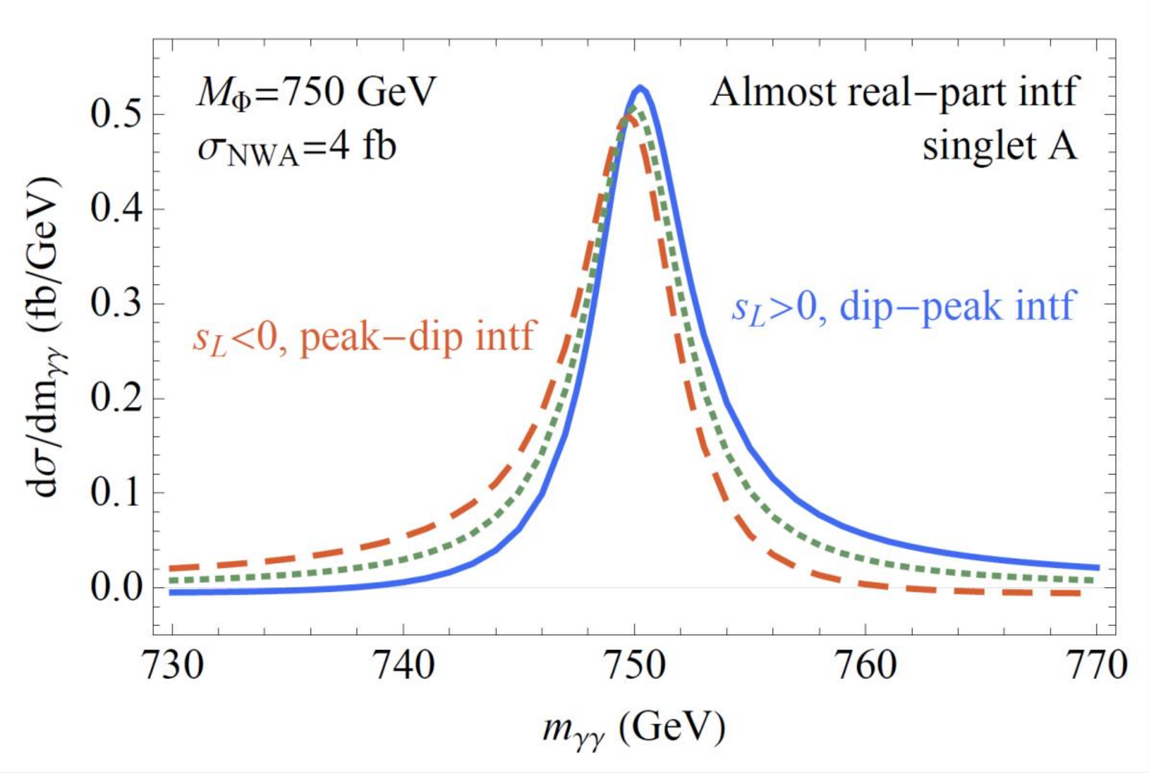
Small phase from top loop

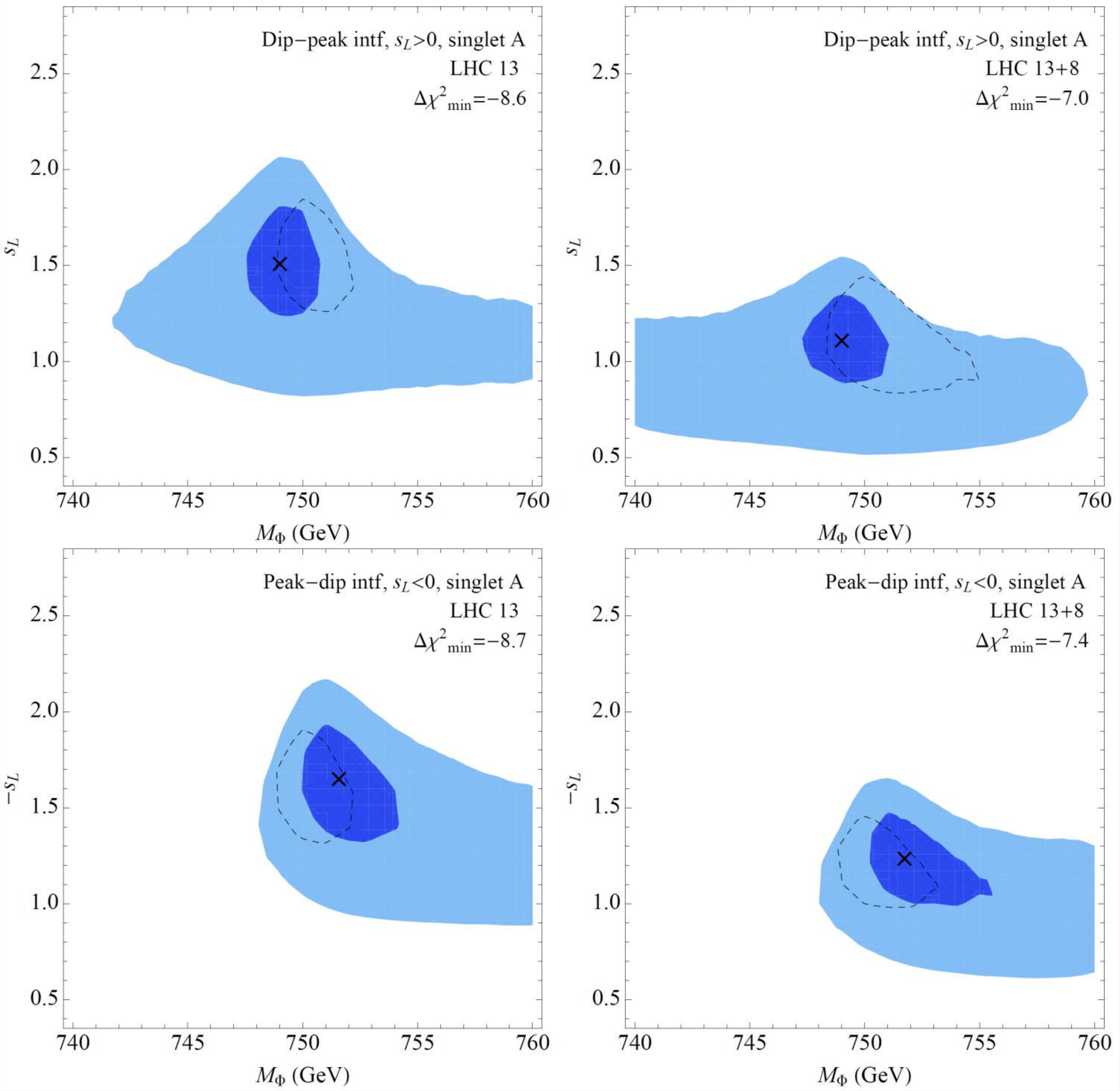
No phase since $M_\phi < 2M_{\mathrm{VLF}}$

$$\phi \simeq \begin{cases} 8.3^\circ & \text{for } s_L > 0; \\ 188.3^\circ & \text{for } s_L < 0, \end{cases}$$

$\cos\phi \simeq \pm 1$, $\sin\phi \simeq 0$ → Real Interference

1.Real Interference ($\phi = 0, \pi$)
- Peak Shift





The Peak Shift can be 1~4 GeV

2.Imaginary Interference ($\phi = \pm\frac{\pi}{2}$) (Signal Enhancement)

Model: 2HDM+VLL

$$-\mathcal{L} = Y_D \overline{L}_L H_1 D_R + Y'_D \overline{L}_R H_1 D'_L + Y_E \overline{L}_L \tilde{H}_2 E'_R + Y'_E \overline{L}_R \tilde{H}_2 E'_L + \left[M \overline{L}_L L_R + M_E \overline{E}'_L E_R + M_D \overline{D}'_L D_R + \text{h.c.} \right].$$

Quantum Numbers:

		$SU(3) \times SU(2) \times U(1)_Y$
$L_L = \begin{pmatrix} E_L \\ D_L \end{pmatrix}$	$L_R = \begin{pmatrix} E'_R \\ D'_R \end{pmatrix}$	$(\mathbf{1}, \mathbf{2}, -\frac{3}{2})$
E_R	E'_L	$(\mathbf{1}, \mathbf{1}, -1)$
D_R	D'_L	$(\mathbf{1}, \mathbf{1}, -2)$

Parameter set: $M_\phi = M_H = M_A = 750\,\text{GeV}$, N_{VLL}=3

$$M_E \gg M, Y_E v_2 \text{ and } M_D \gg M, Y_D v_1$$

→ Light masses are degenerated

2.Imaginary Interference ($\phi = \pm\frac{\pi}{2}$) (Signal Enhancement)

VLL contribution in $\Phi \to \gamma\gamma$:

$$\mathcal{A}^{\Phi}_{\gamma\gamma,\mathrm{VLL}} = \sum_{\mathrm{VLL}} \sum_{i=1,2} \left[Q^2_{E_i} \frac{\hat{y}^{\Phi}_t y_E v}{M_{E_i}} A^{\Phi}_{1/2}(\tau_{E_i}) + Q^2_{D_i} \frac{\hat{y}^{\Phi}_b y_D v}{M_{D_i}} A^{\Phi}_{1/2}(\tau_{D_i}) \right]$$

We fix $\mathbf{y_D}$ as follows to avoid the SM Higgs precision

$$y_D = -\frac{Q_E^2}{Q_D^2} y_E = -0.25 y_E$$

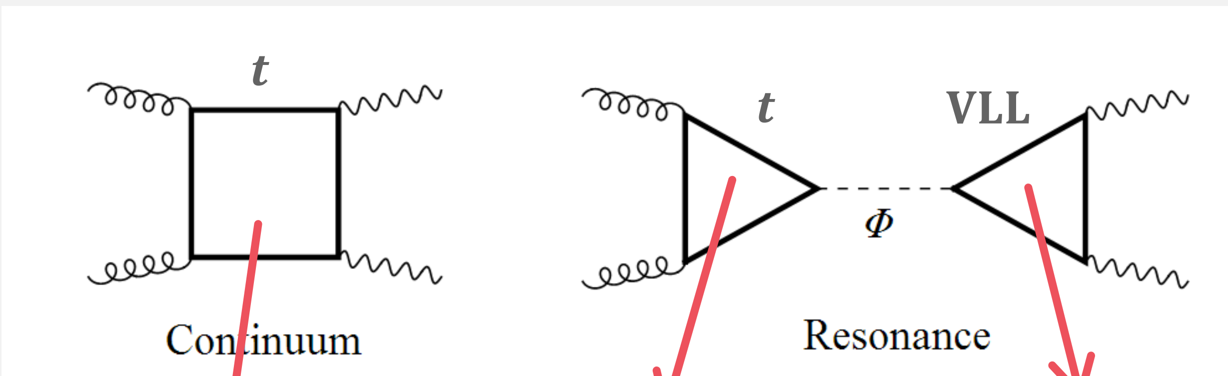
We set $t_\beta = 0.7$ to raise up the pseudo-scalar Higgs contribution

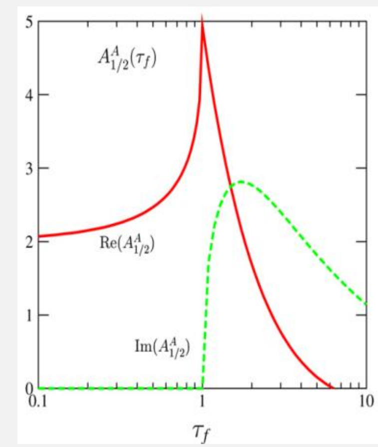
Total decay rate is determined by dominant ttbar decays:

$$\Gamma_{H(A)} = 46(58)\ \mathrm{GeV}$$

2.Imaginary Interference ($\phi = \pm\frac{\pi}{2}$) (Signal Enhancement)

What about relative complex phase $\boldsymbol{\phi}$:





Small phase
from top loop

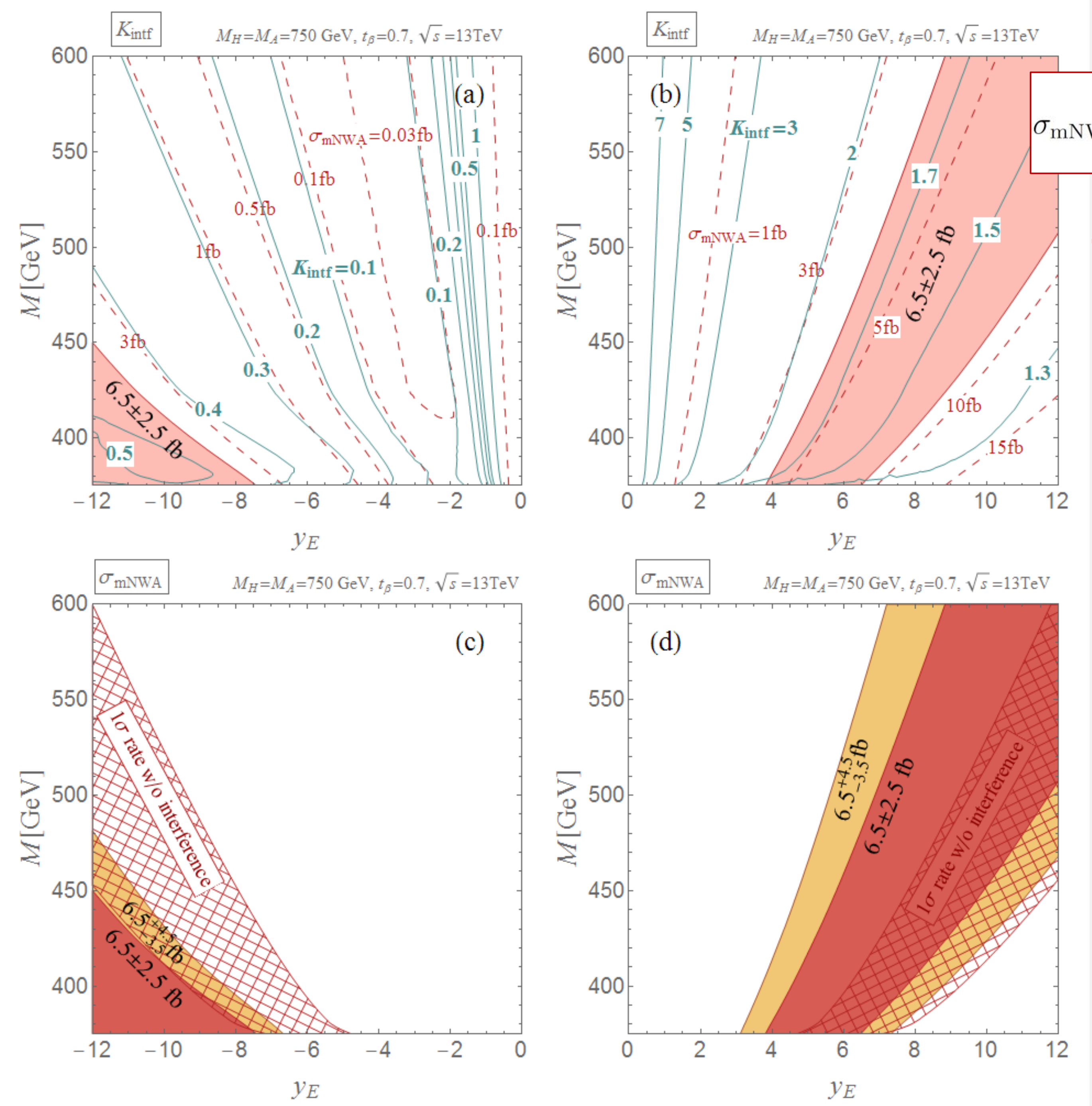
Phase $\mathbf{90°}$

No phase
since $\boldsymbol{M_\phi < 2M_{\mathrm{VLL}}}$

$$\phi \simeq \begin{cases} 90^\circ & \text{for } y_E > 0; \\ -90^\circ & \text{for } y_E < 0. \end{cases}$$

$\mathbf{\cos\phi \simeq 0,}$
$\mathbf{\sin\phi \simeq \pm 1}$

→ Imaginary Interference



$$\sigma_{\rm mNWA} = \int_{M-\Delta}^{M+\Delta} dm_{\gamma\gamma} \left[\frac{d\sigma_{\rm sig}}{dm_{\gamma\gamma}}\right]_{\rm peak}$$

→ Total cross section w/ interference

$$K_{\rm intf} = \frac{\sigma_{\rm mNWA}}{\sigma_{\rm prod}\cdot {\rm Br}_{\gamma\gamma}}$$

→ Ratio of total cross Section w/ intf. to w/o intf.

$K_{\rm intf}$ = 1.6 for 6fb
2 for 3 fb
4 for 1 fb

Summary

- Interference effect Is inevitable and significant for diphoton resonance.
- We find two distinct interference effects:

  1. Signal Enhancement from imaginary interference

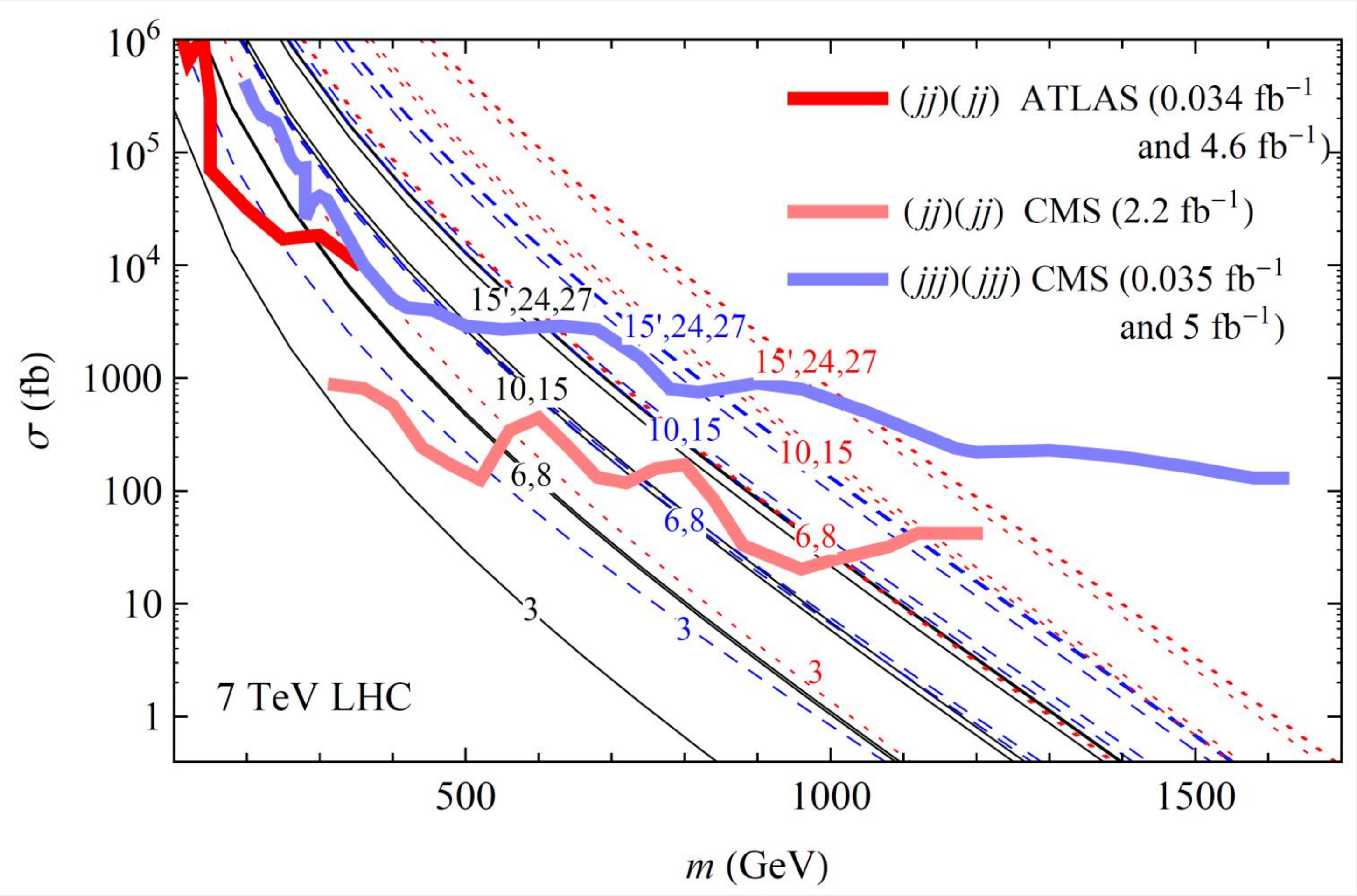
     - factor 1.6, 2, 4, for the signal rate 6fb, 3fb, 1fb.

  2. Peak Shift from real interference

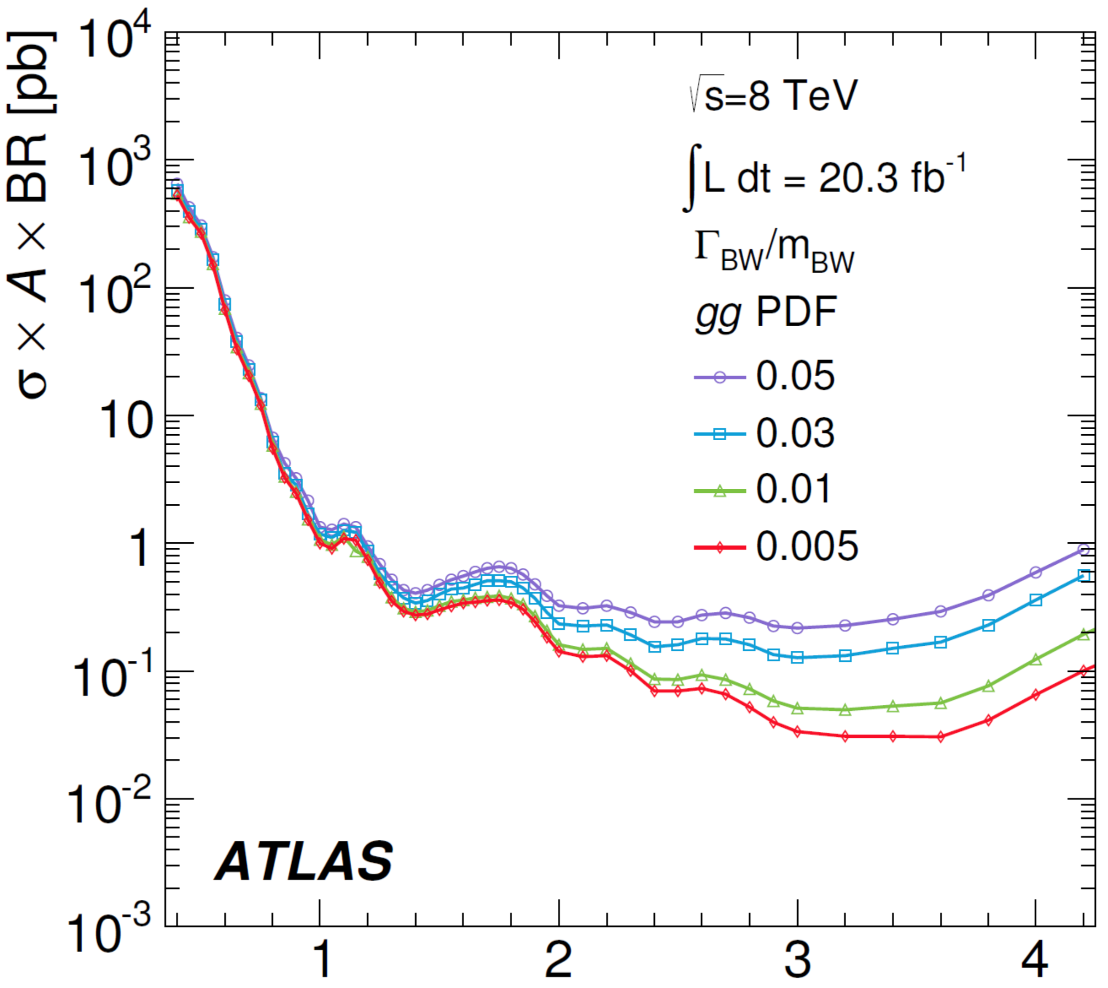
     - 1~4 GeV

- We are going to survey the interference effects for other models.

Back-up Slides



Kats, Strassler, arXiv:1204.1119



ATLAS 1407.1376