Interference effect on Heavy Higgs search in VV channels

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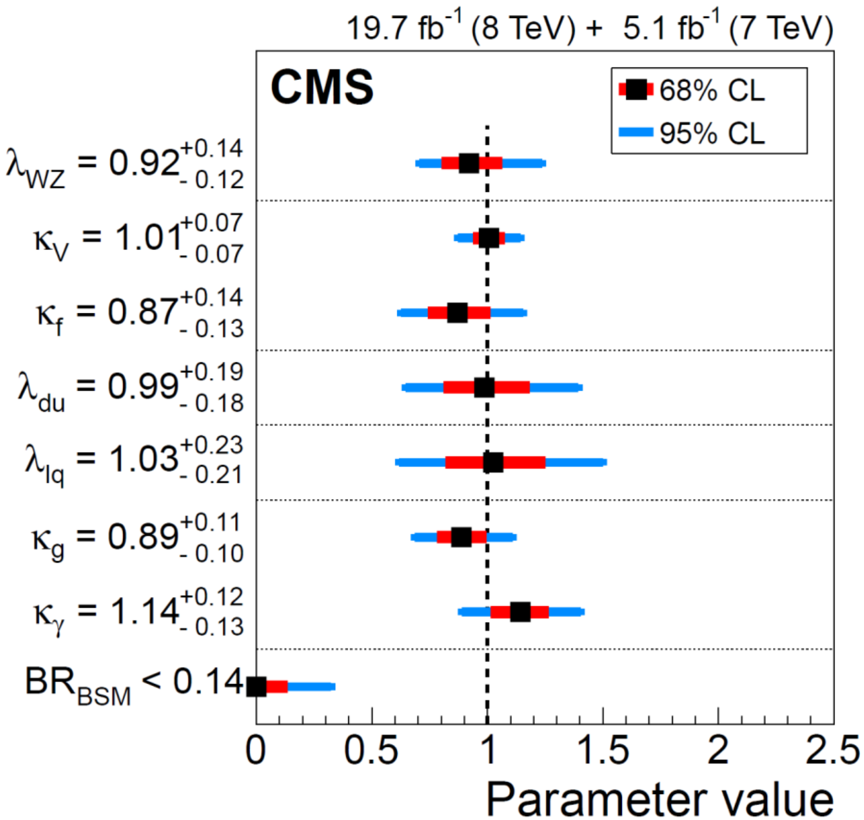
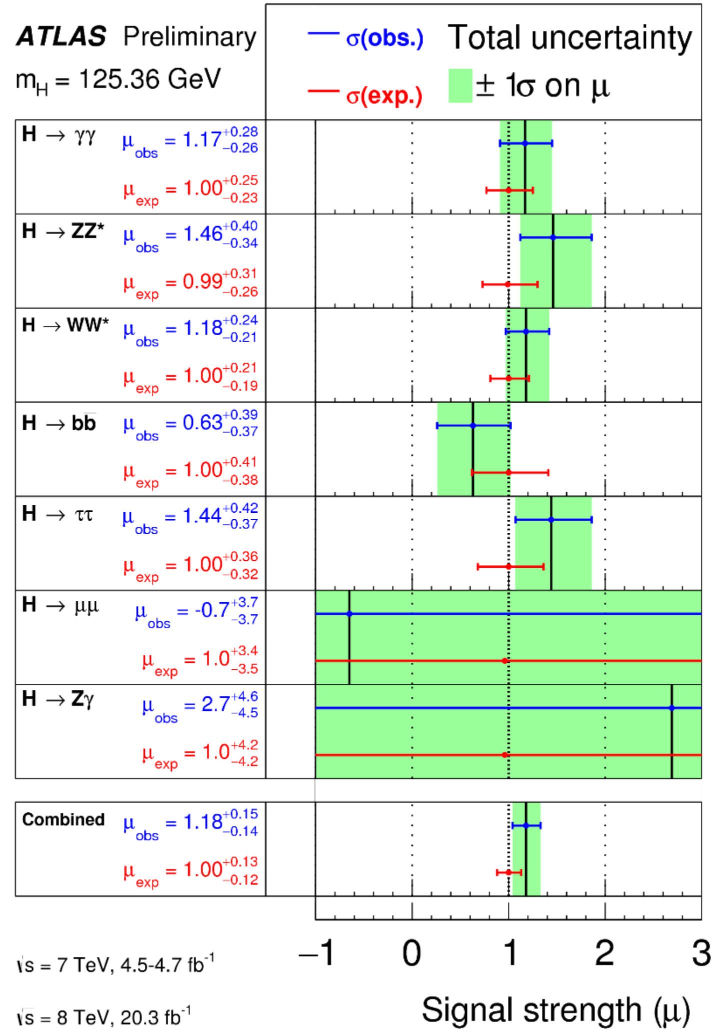
Based on 1505.00291, 1510.XXXXX

Precision measurement on Higgs (7+8TeV)



CMS, EPJC 75, 5, 212 (2015)



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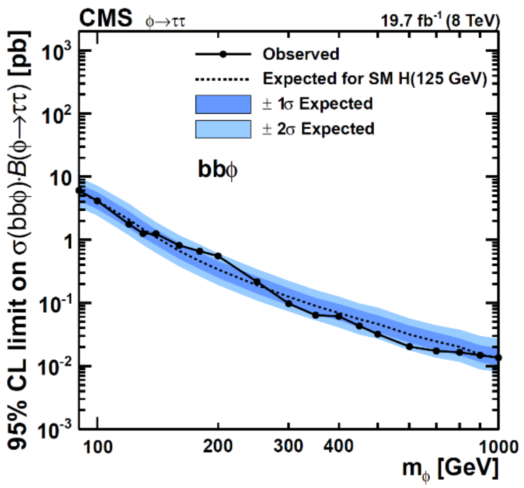
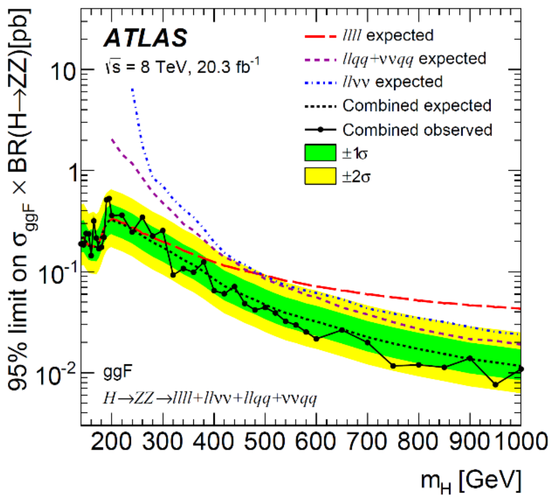
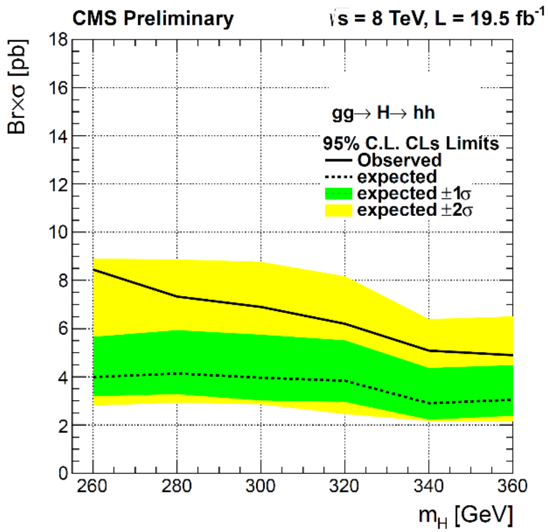
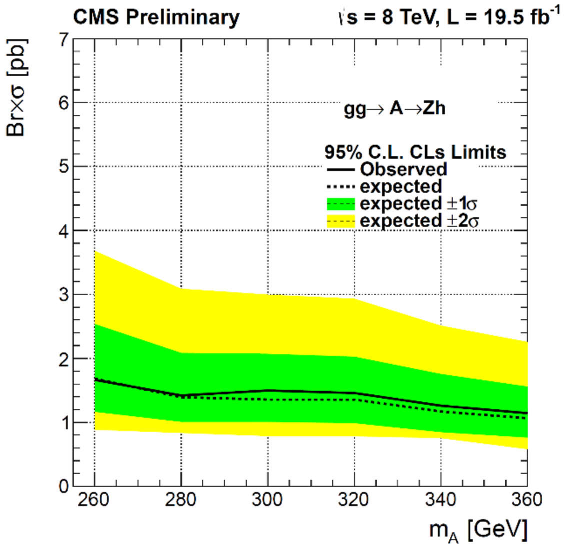
Extra Heavy Higgs search at the LHC (8TeV)









No observation of Heavy Higgs signal

Higgs sector of 2HDM & MSSM

With additional Higgs doublet. → Simplest extension of the SM

$$V(\phi) = -\mu^2|\phi|^2 + \lambda|\phi|^4$$

↓

$$V(\phi_1, \phi_2) = m_{11}^2\Phi_1^\dagger\Phi_1 + m_{22}^2\Phi_2^\dagger\Phi_2 - m_{12}^2\left(\Phi_1^\dagger\Phi_2 + \Phi_2^\dagger\Phi_1\right) + \frac{\lambda_1}{2}\left(\Phi_1^\dagger\Phi_1\right)^2 + \frac{\lambda_2}{2}\left(\Phi_2^\dagger\Phi_2\right)^2 + \lambda_3\Phi_1^\dagger\Phi_1\Phi_2^\dagger\Phi_2 + \lambda_4\Phi_1^\dagger\Phi_2\Phi_2^\dagger\Phi_1 + \frac{\lambda_5}{2}\left[\left(\Phi_1^\dagger\Phi_2\right)^2 + \left(\Phi_2^\dagger\Phi_1\right)^2\right].$$

After EW-SB and mass diagonalization

We have 7 Free parameters in 2HDM $\tan\beta, \alpha, m_h^2, M_H^2, M_A^2, M_{H^+}^2, M^2$

2 parameters in MSSM $\tan\beta, M_A$

MSSM Higgs spectrum is very restricted

In the MSSM with loop correction (hMSSM scenario, Djouadi et. al. 1502.05653)

M_H, M_{H^+}, M_A ~ 300 GeV

$m_h = 125$ GeV

2HDM has much freedom for Higgs masses

$$M_H^2, M_A^2, M_{H^+}^2, M^2$$

Under the theoretical constrains from Perturbativity, Unitarity, Stability.

Alignment Limit

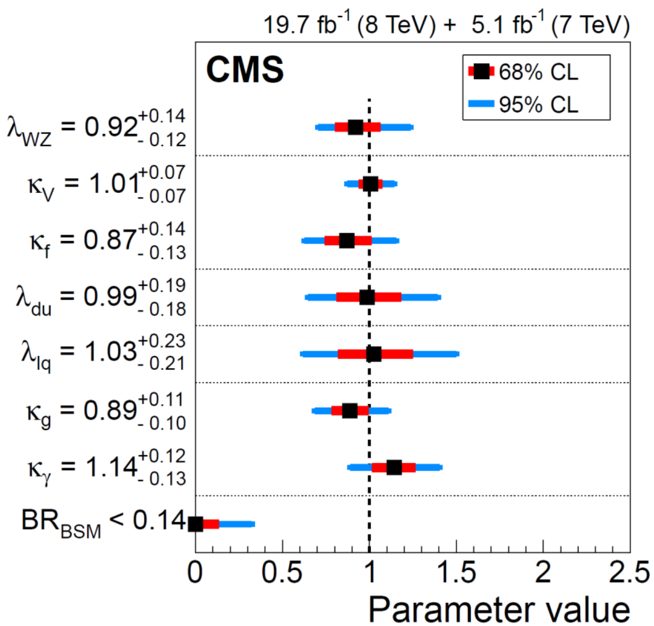
We have 3 neutral Higgses and 2 charged Higgses. Other 3 are eaten by weak gauge bosons after SB.

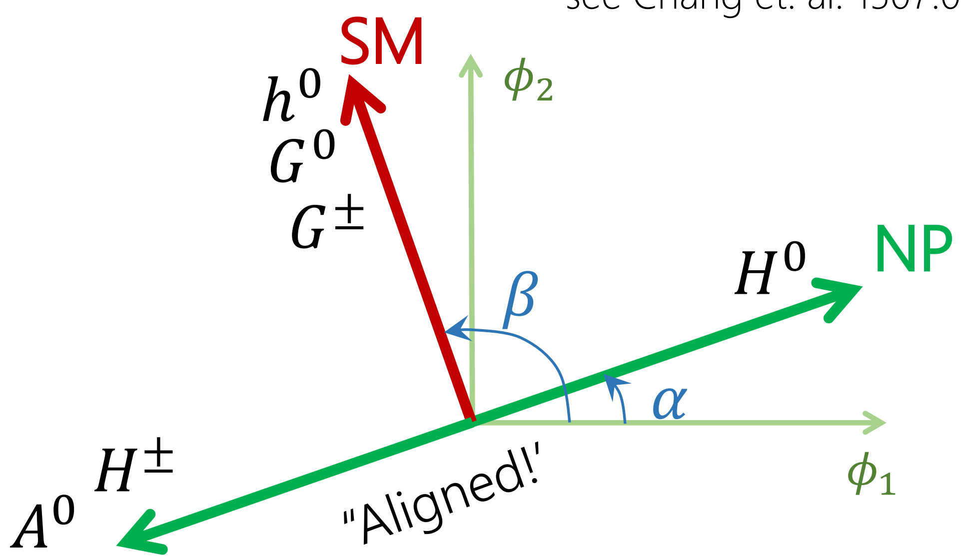
$$h^0, H^0, A^0, \quad H^+, H^-$$

The SM Higgs is such as $h^0_{SM} = \sin(\beta - \alpha) h^0 + \cos(\beta - \alpha) H^0$

Exp. data prefers $\sin(\beta - \alpha) = 1$. (Alignment limit)

* For another possibility, $\cos(\beta - \alpha) = 1$, see Chang et. al. 1507.03618





More on Alignment Limit

The Heavy Higgs are decoupled from the SM.

HWW, HZZ

Hhh, AZh, H^+W^-h

→ All vanish at tree level

Except Yukawa coupling $\mathcal{L}_Y = \mathcal{L}_Y^{SM} + \frac{m_t}{v} \hat{y}_H^u \, Ht\bar{t} + \ldots$

And also,

hH^+H^-

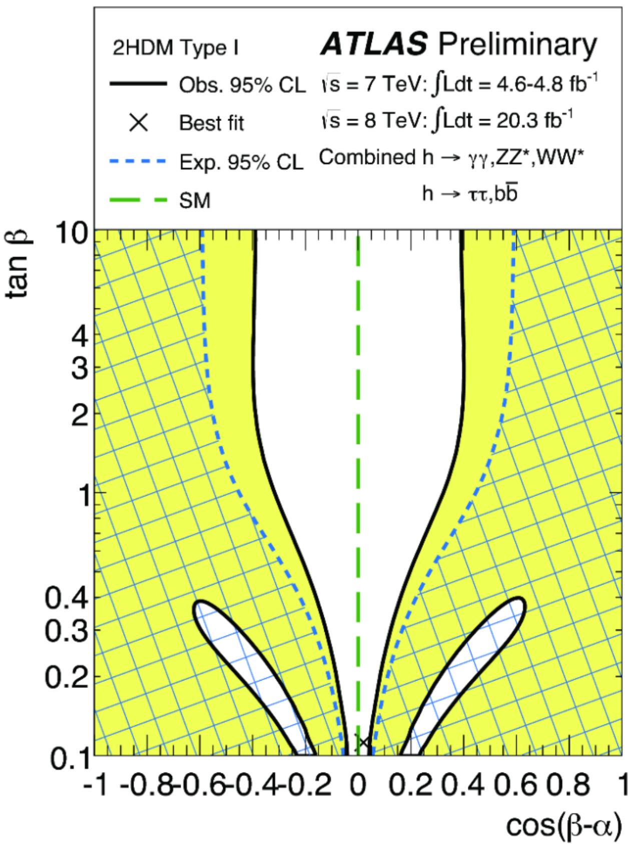
HH^+H^-

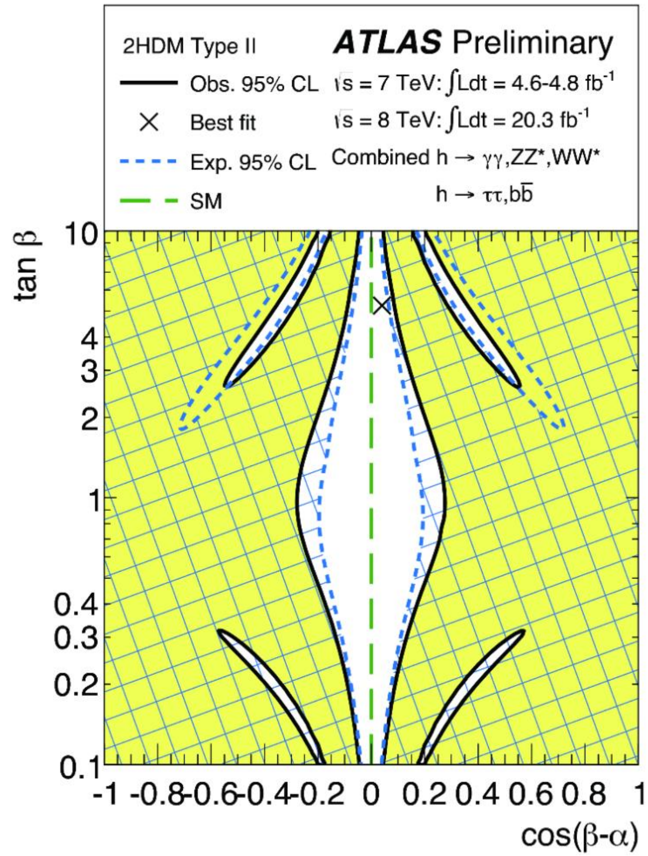
Do not vanish in alignment limit.

→ Charged Higgs can contribute to gg→h/H→$\gamma\gamma$ via H^+ loop.

New neglect these contribution by assuming large enough charged Higgs mass

How much can it be off alignment limit ?





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$$\hat{y}_h^d = -\frac{\sin\alpha}{\cos\beta} = \sqrt{1-c_{\beta-\alpha}^2} - t_\beta c_{\beta-\alpha}$$

For type II.

$$\hat{y}_h^u = \frac{\cos\alpha}{\sin\beta} = \sqrt{1-c_{\beta-\alpha}^2} + \frac{c_{\beta-\alpha}}{t_\beta}$$

For type I, II.

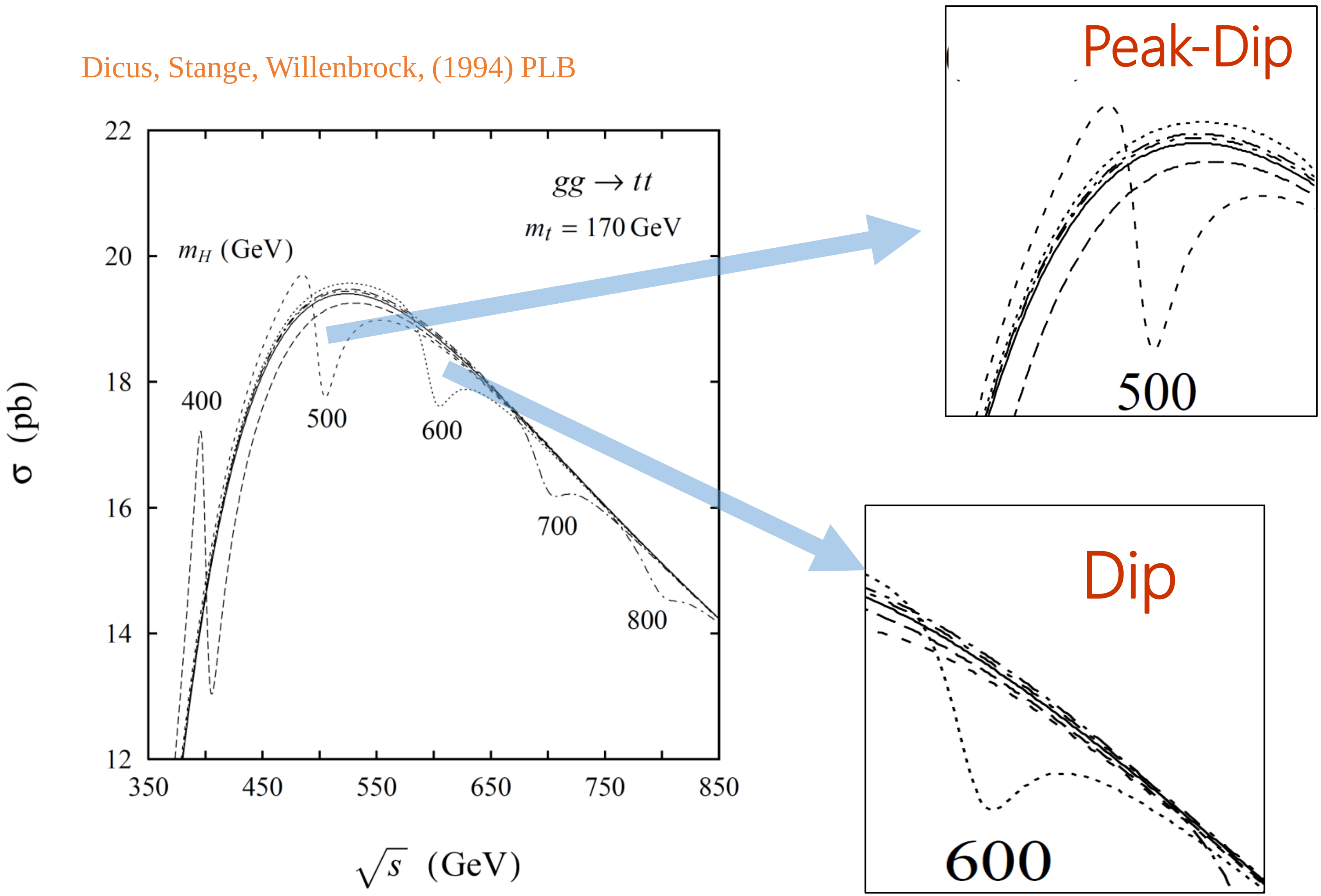
Possible choice for off-alignment limit:

Type1: $\cos(\beta-\alpha) = \pm 0.4,\ \tan\beta = 1\sim 50$

Type2: $\cos(\beta-\alpha) = \pm 0.1,\ \tan\beta = 1\sim 5$

Interference effect – a game changer

Dicus, Stange, Willenbrock, (1994) PLB



Quantifying Interference effect S. Jung, J. Song, YYW, 1505.00291

$$\frac{d\hat{\sigma}}{dz} = \frac{1}{32\pi\hat{s}} \sum \left| \mathcal{A}_{\rm bg} e^{i\phi_{\rm bg}} + \frac{M^2}{\hat{s} - M^2 + iM\Gamma} \cdot \mathcal{A}_{\rm res} e^{i\phi_{\rm res}} \right|^2$$

$$w \equiv \frac{\Gamma}{M} \qquad R \simeq \frac{\mathcal{A}_{\rm res}}{\mathcal{A}_{\rm bg}}, \qquad \phi \simeq \phi_{\rm res} - \phi_{\rm bg}$$

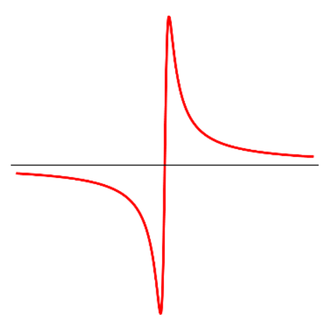
$$\begin{aligned} \hat{\sigma} \;&=\; \hat{\sigma}_{\rm bg} + \frac{M^4}{(\hat{s} - M^2)^2 + M^4 w^2} \\ &\times \left[\frac{2(\hat{s} - M^2)}{M^2}\, \hat{\sigma}_{\rm int} c_\phi + \hat{\sigma}_{\rm res} \left(1 + \frac{2w}{R} s_\phi \right) \right] \end{aligned}$$

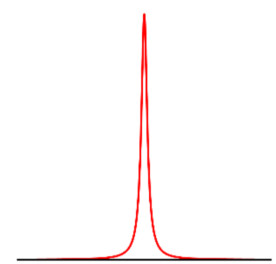
Real-part Interference

BW-Res.

Imaginary-part Interference

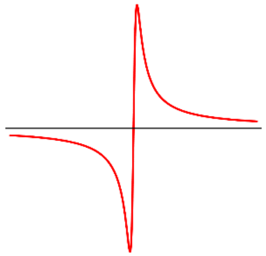
Interference affects
Event Shape and
Event Rate



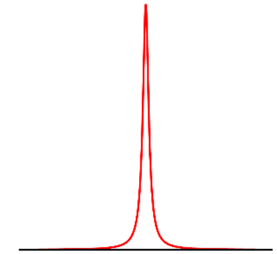


Quantifying Interference effect

S. Jung, J. Song, YYW, 1505.00291



$$\left[\frac{2(\hat{s}-M^2)}{M^2}\hat{\sigma}_{\rm int}c_\phi + \hat{\sigma}_{\rm res}\left(1+\frac{2w}{R}s_\phi\right)\right]$$



To be washed out — Estimated by NWA

We propose modified NWA as

Cross section for production and decays : $\sigma \cdot \mathrm{Br} \cdot C$

Very Fast & convenient to estimate Interference effect

$$C = \left(1+\frac{2w}{R}s_\phi\right)$$

→ *Correction factor, and simple measure of resonance shape*

$$\begin{aligned} C<0: &\quad \text{deficit,} \\ C=0: &\quad \text{nothingness,} \\ C>0: &\quad \text{excess.} \end{aligned}$$

Quantifying Interference effect S. Jung, J. Song, YYW, 1505.00291

Imaginary-Part Interference ($c_\phi = 0$)

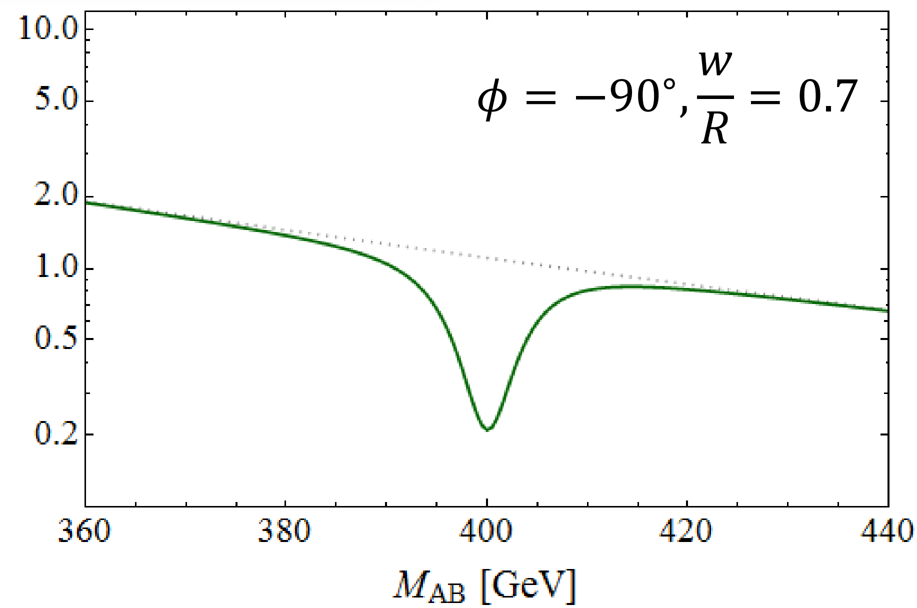
$$\left[\frac{2(\hat{s}-M^2)}{M^2}\hat{\sigma}_{\rm int}c_\phi + \hat{\sigma}_{\rm res}\left(1+\frac{2w}{R}s_\phi\right)\right]$$

→BW-shape is preserved

"Pure Dip"

$$C = \left(1+\frac{2w}{R}s_\phi\right) < 0$$

$$\phi = -\frac{\pi}{2},\quad \frac{w}{R} > 0.5$$



Pure Dip prefers sizable width
and small R value (small signal to bg ratio).

Quantifying Interference effect S. Jung, J. Song, YYW, 1505.00291

Imaginary-Part Interference ($c_\phi = 0$)

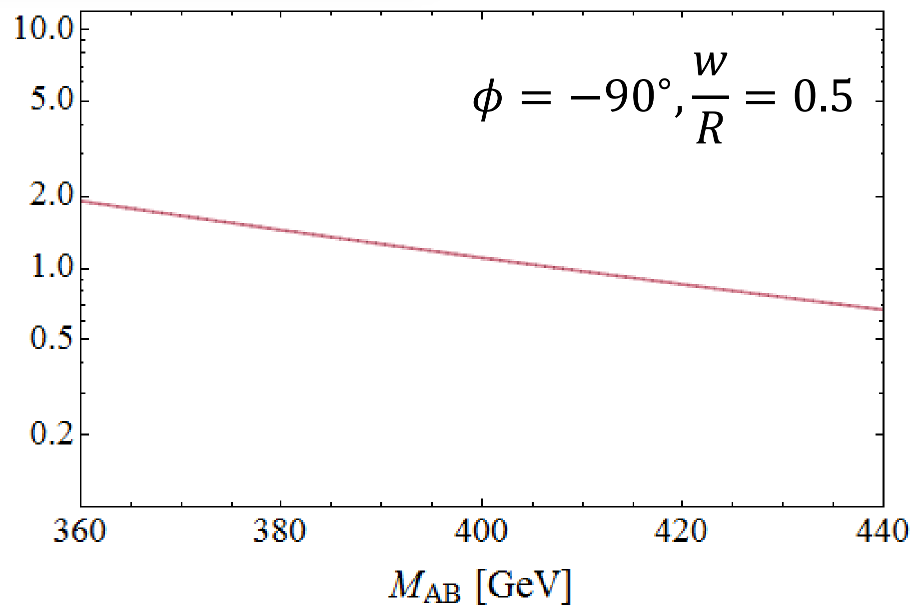
$$\left[\frac{2(\hat{s}-M^2)}{M^2}\hat{\sigma}_{\rm int}c_\phi + \hat{\sigma}_{\rm res}\left(1+\frac{2w}{R}s_\phi\right)\right]$$

→BW-shape is preserved

"Nothingness"

$$C = \left(1+\frac{2w}{R}s_\phi\right) = 0$$

$$\phi = -\frac{\pi}{2},\ \ \frac{w}{R} = 0.5$$



Quantifying Interference effect

S. Jung, J. Song, YYW, 1505.00291

Imaginary-Part Interference ($c_\phi = 0$)

$$\left[\frac{2(\hat{s}-M^2)}{M^2}\hat{\sigma}_{\rm int}c_\phi + \hat{\sigma}_{\rm res}\left(1+\frac{2w}{R}s_\phi\right)\right]$$

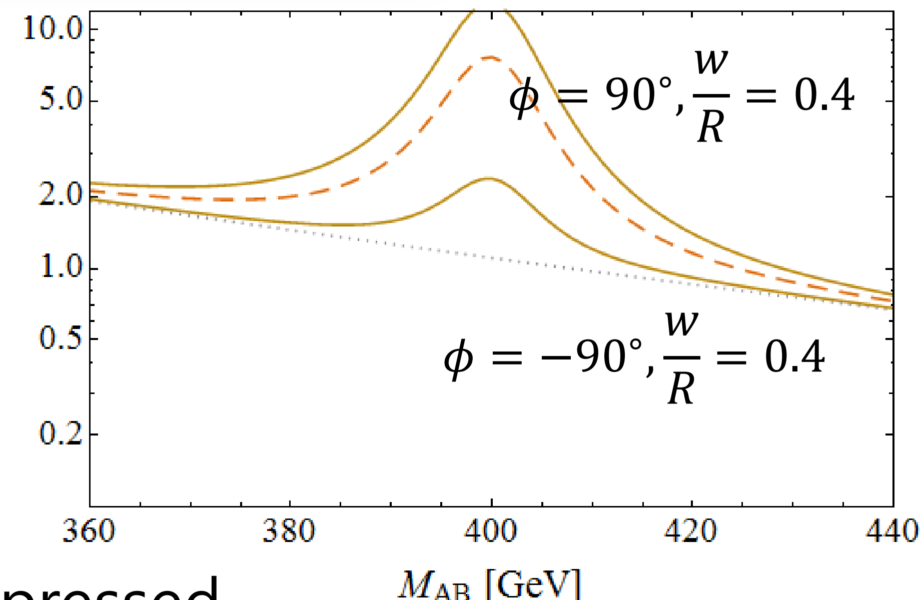
→BW-shape is preserved

"Pure Peak"

$$C = \left(1+\frac{2w}{R}s_\phi\right) > 0$$

$\phi = \frac{\pi}{2}$, : enhanced

$\phi = -\frac{\pi}{2}$, $\frac{w}{R} < 0.5$: suppressed



Summary of Interference effect (ggF)

$$C = \left(1 + \frac{2w}{R} s_\phi\right) \qquad w \equiv \frac{\Gamma}{M} \quad R \simeq \frac{\mathcal{A}_{\rm res}}{\mathcal{A}_{\rm bg}}, \quad \phi \simeq \phi_{\rm res} - \phi_{\rm bg}$$

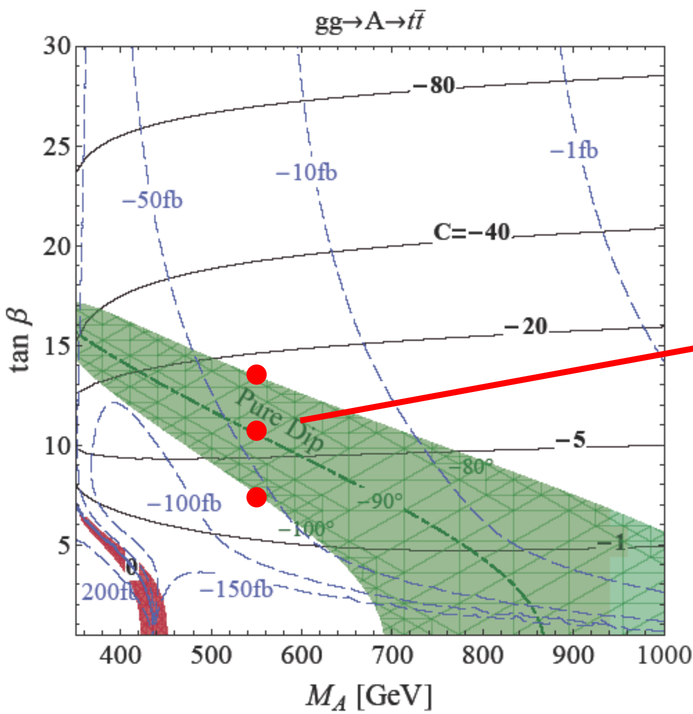
When does large Interference arise?

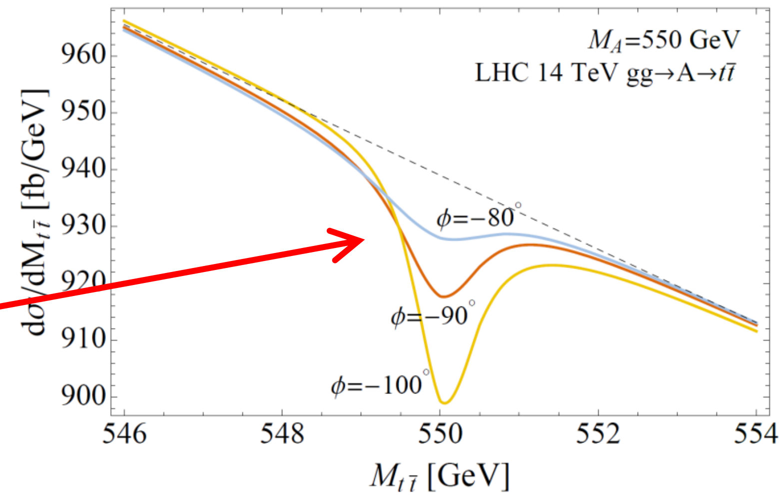
→ 1. Large decay width
2. sizable relative phase
3. Large SM background
4. Small resonance amplitude

	$t\bar{t}$	$\gamma\gamma$	ZZ	$\tau^+\tau^-$
SM	tree	1 loop	1 loop	2loop
Res	1 loop	2 loop	1 loop	1 loop
interference	large	large	small	None
Signal rate	good	bad	good	good

Interference effect for $gg \to A \to t\bar{t}$

S. Jung, J. Song, YYW, 1505.00291





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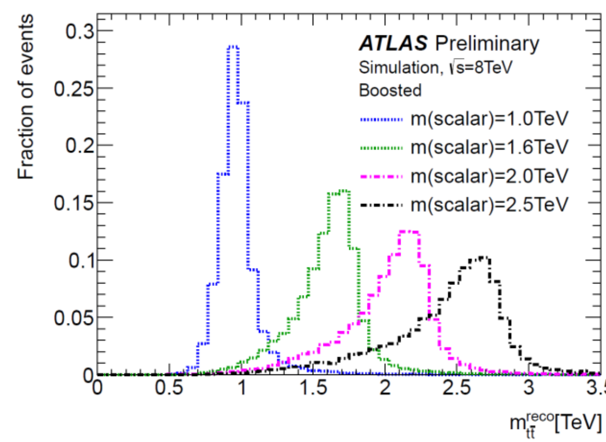
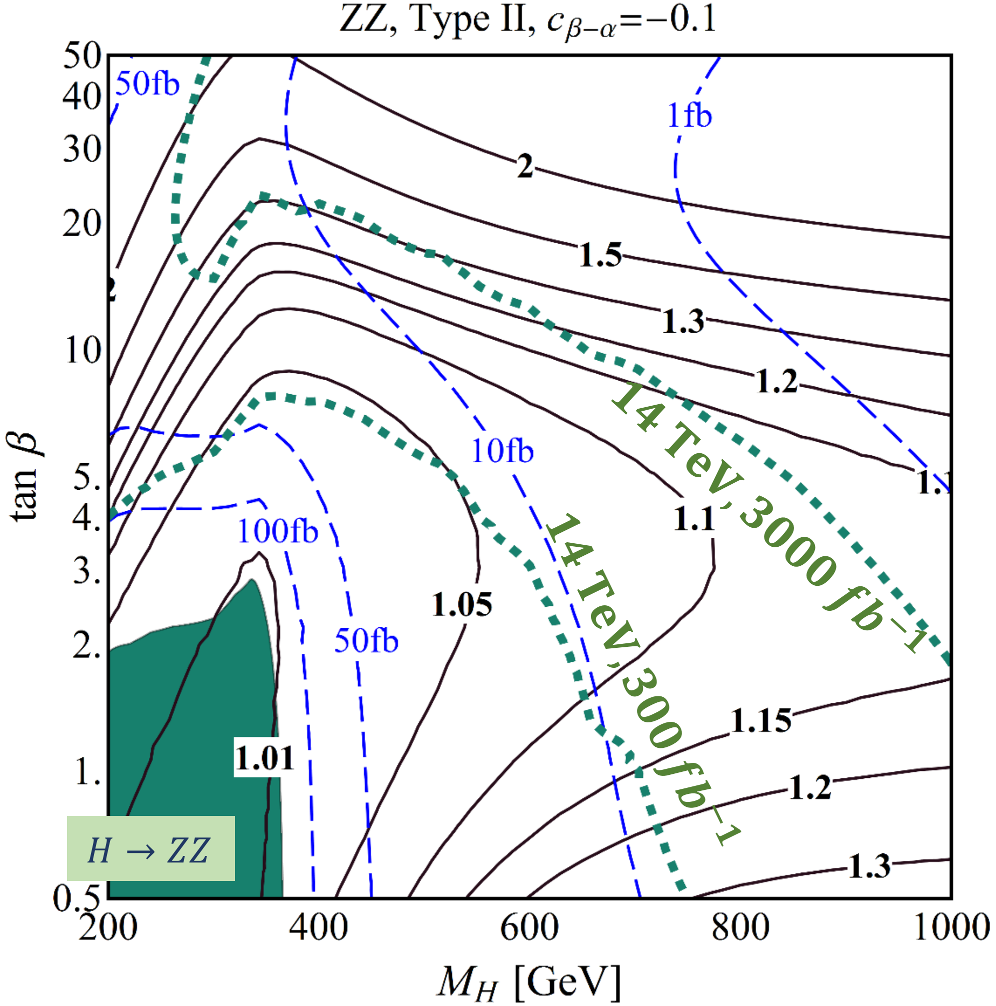


(d) Scalar.

Even though A→$t\bar{t}$ is dominant. The search is very challenging due to significant destructive intf. and Smearing effect.

Interference effect for $gg \to H \to ZZ$

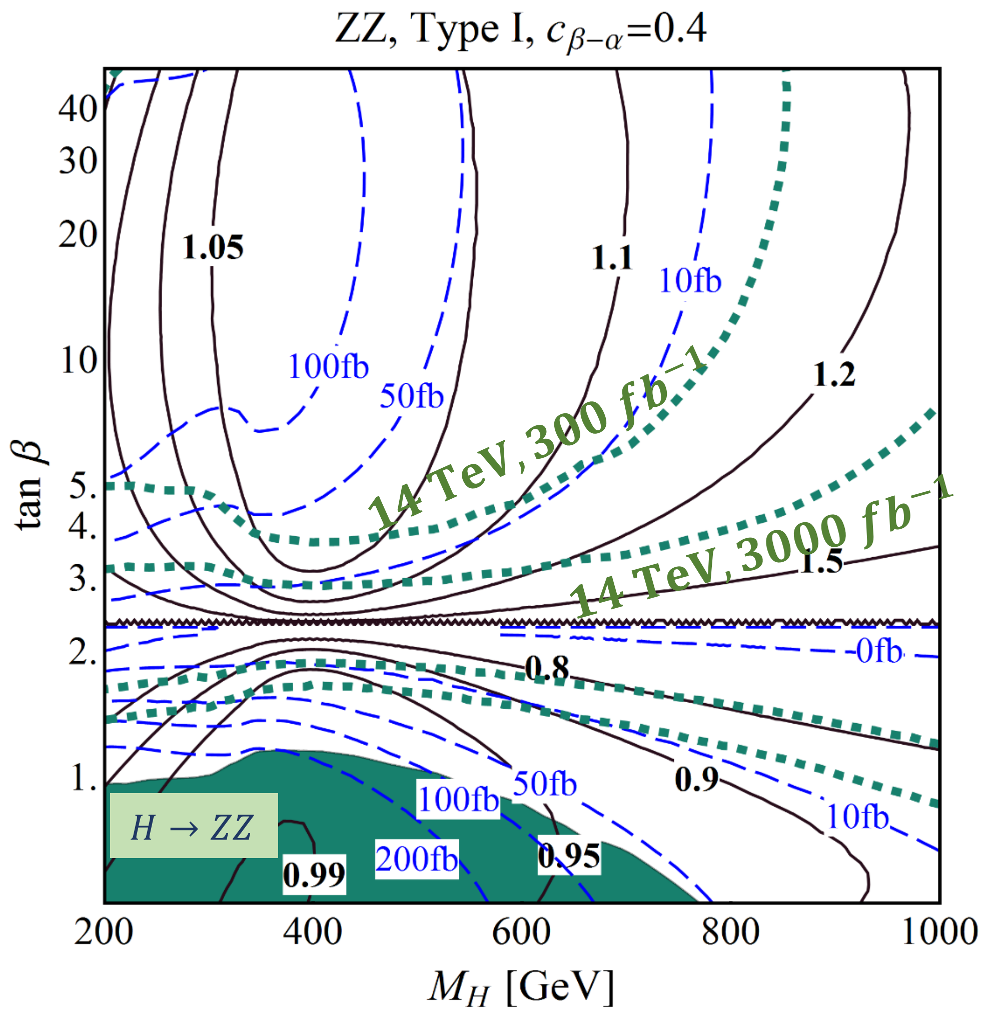
For Type II, $\cos(\beta - \alpha) = -0.1$



Preliminary

Interference effect for $gg \to H \to ZZ$

For Type I, $\cos(\beta - \alpha) = 0.4$



Preliminary

Summary

- We show a useful parametrization for quantifying interference effects with 3 parameters for any heavy resonance.
- We investigated Interference effect in off-alignment limit in VV channels of 2HDM.
- For ZZ channel, the interference effect for 8TeV data is just a few %.

  But with the sensitivity of 14TeV, 300/fb and 3000/fb data, up to 30% interference effect should be taken into account