750 GeV Diphoton Excess: Resonance Shape and Enhancement

Sunghoon Jung
SLAC National Accelerator Lab

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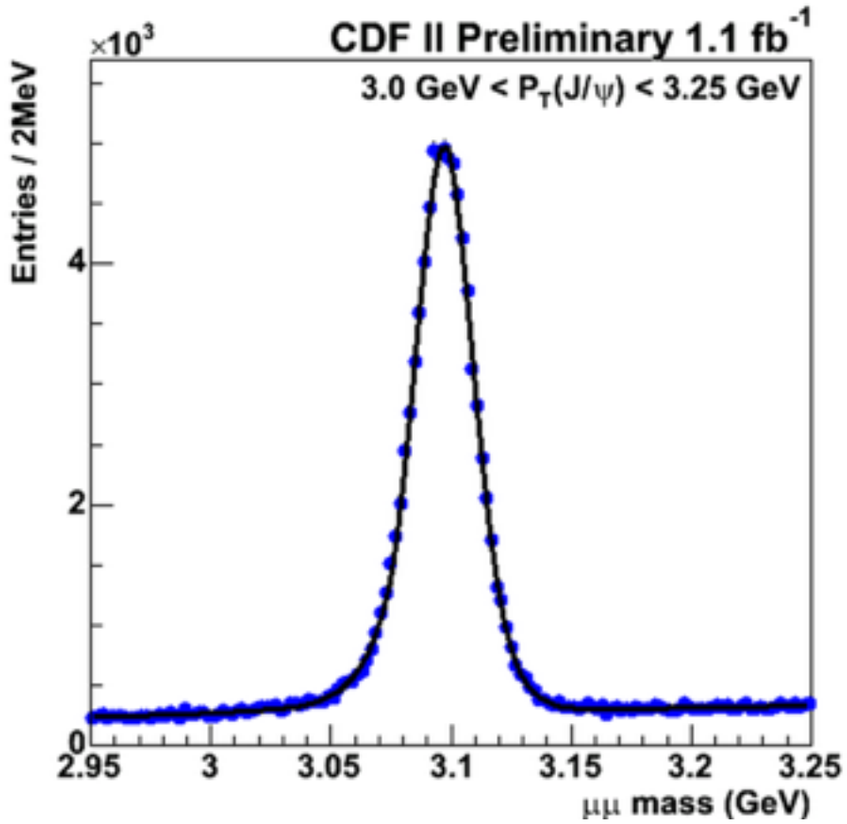
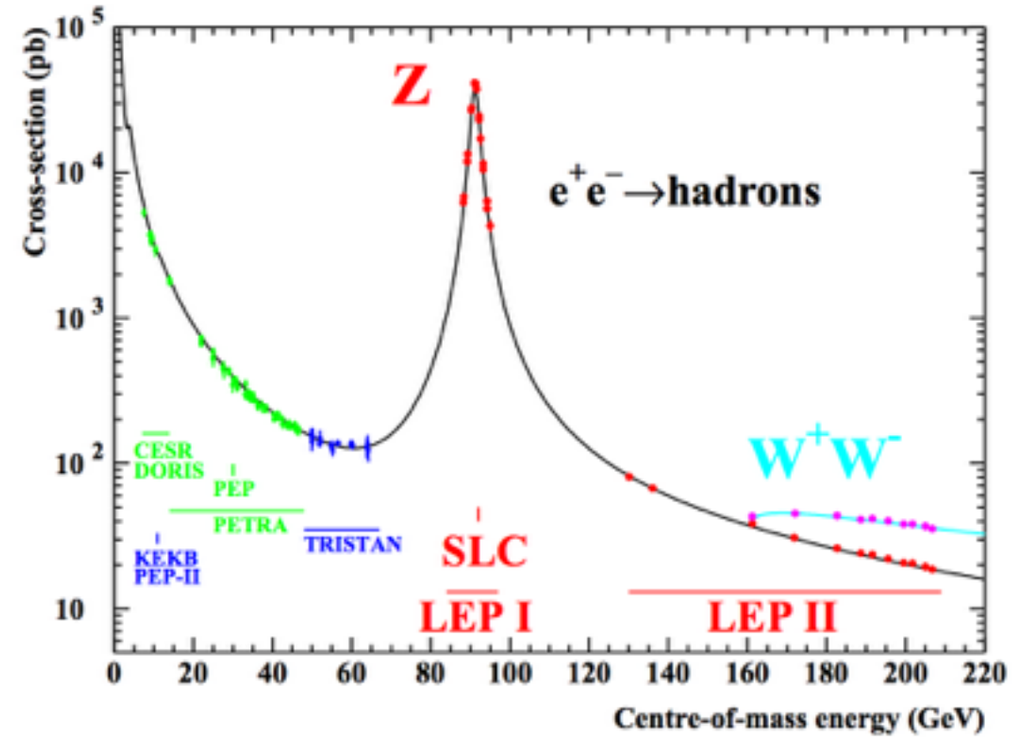
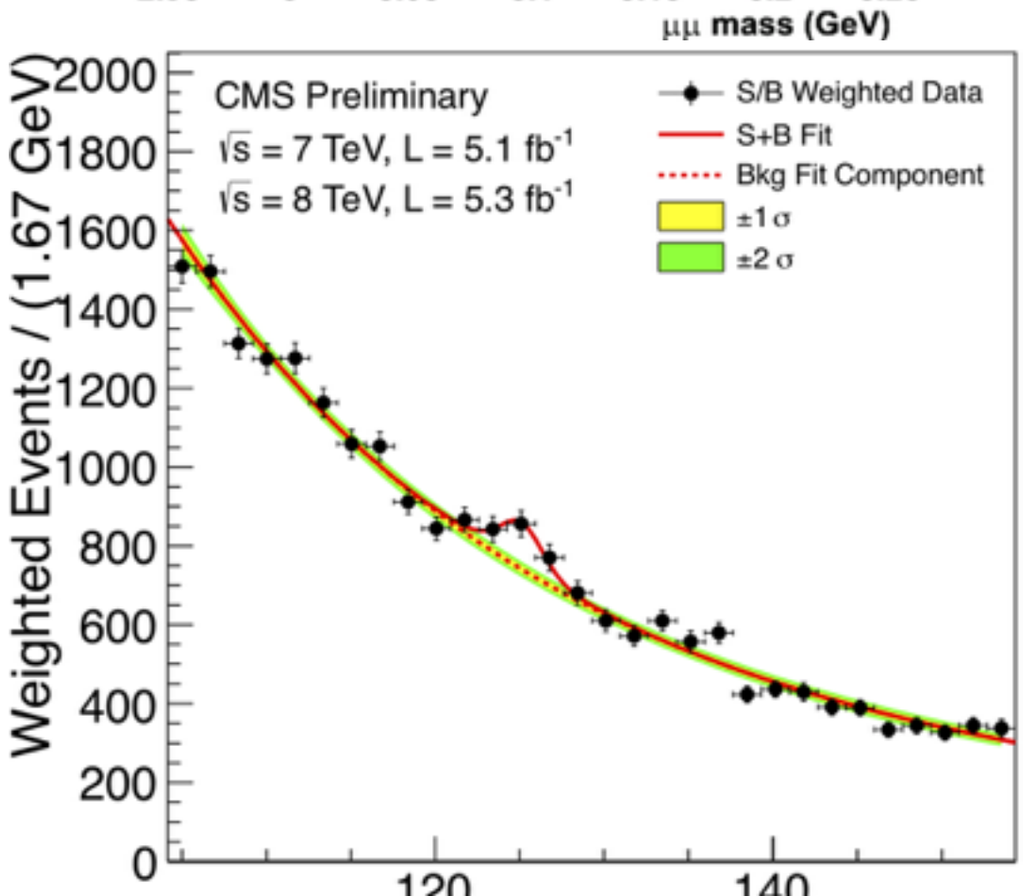
mainly 1601.00006, but also 1505.00291, 1510.03450

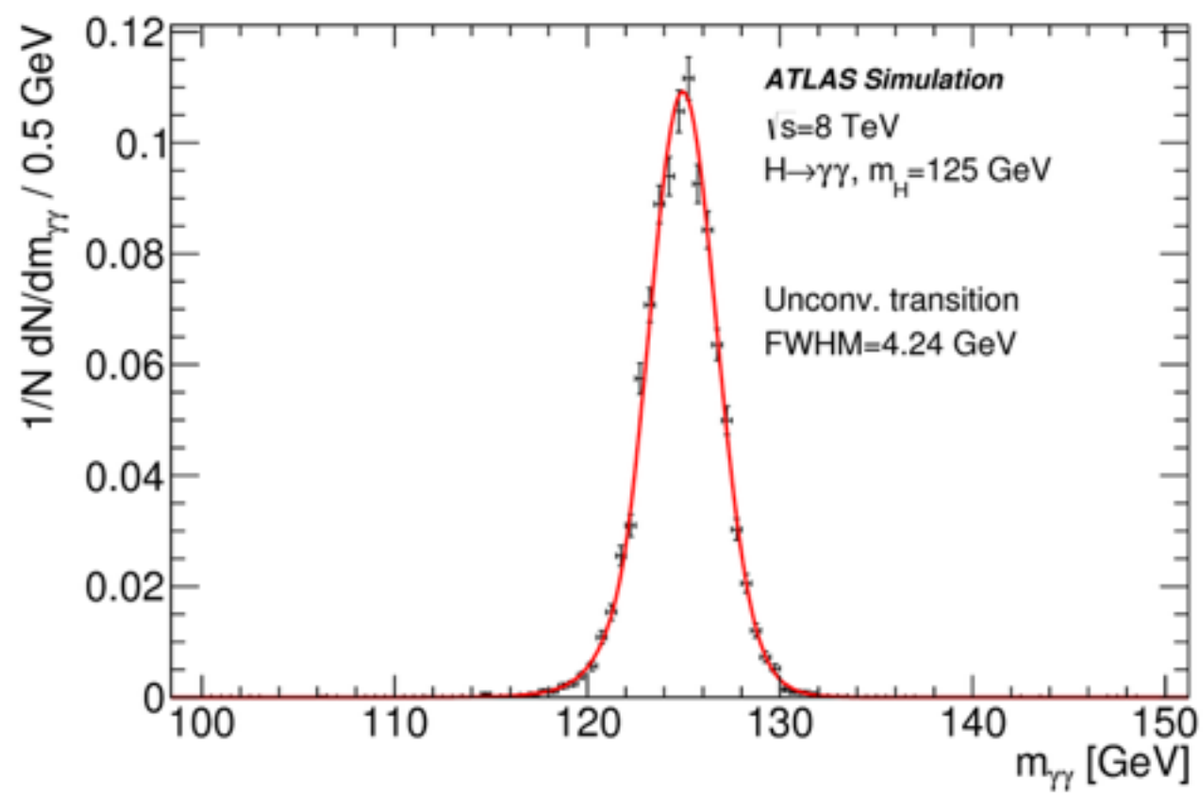
with Jeonghyeon Song, Yeo Woong Yoon

Resonances in history

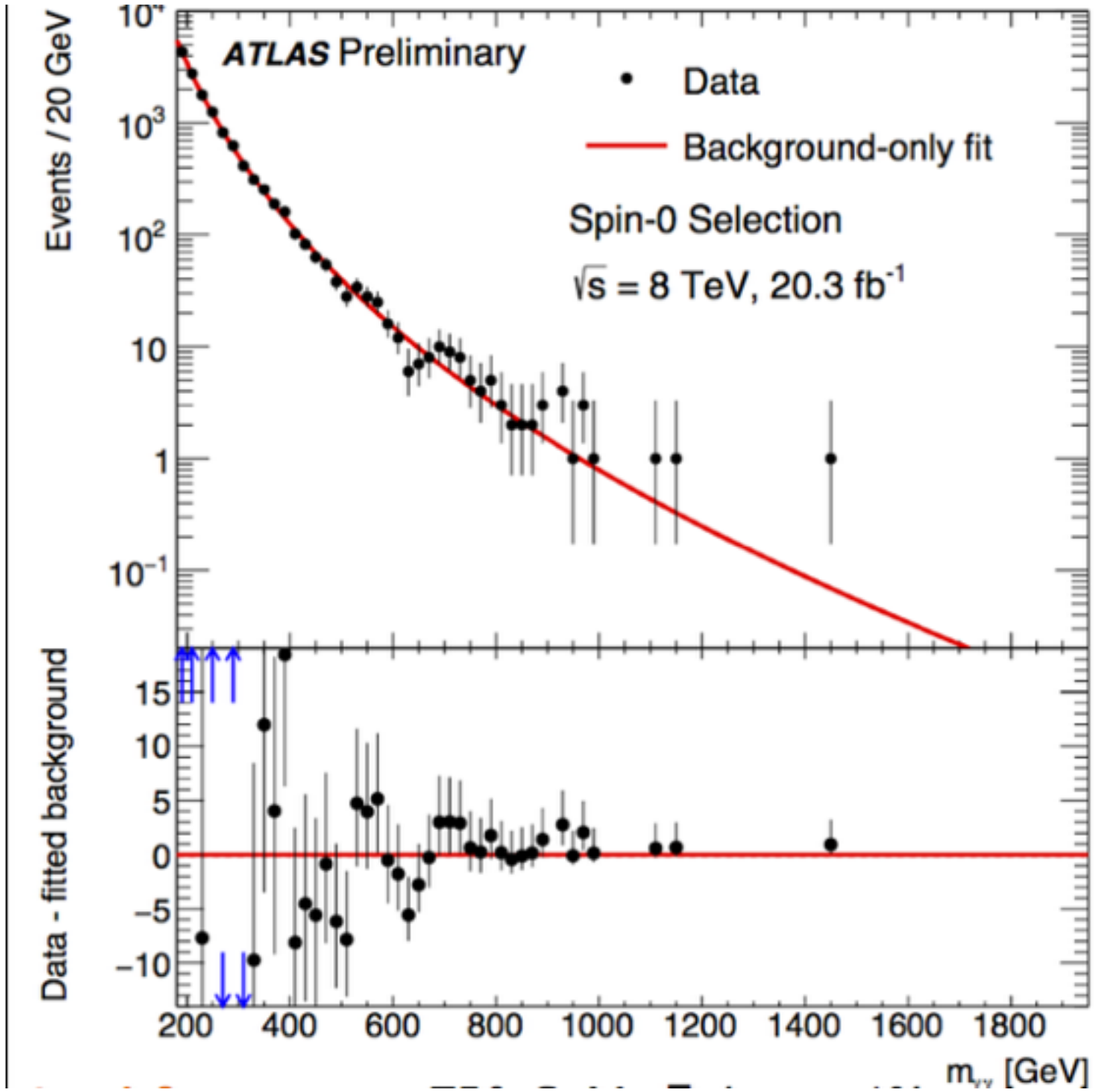




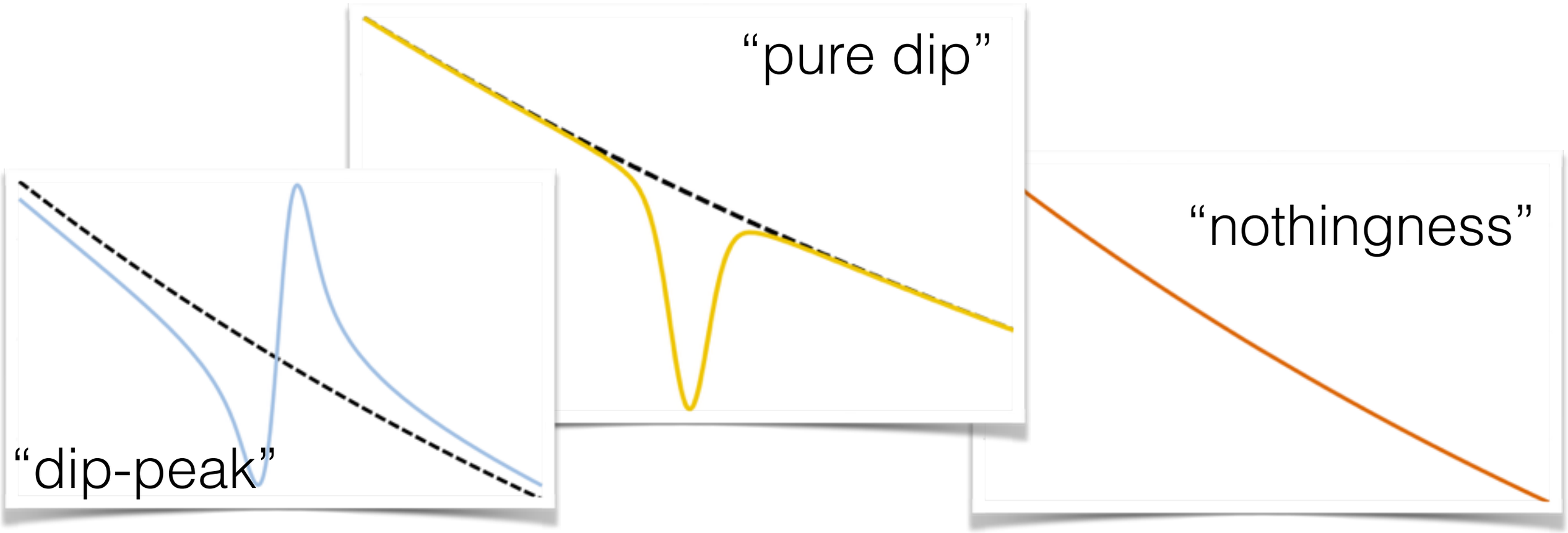




Excitement on new excess



Resonance shapes



- Good reasons why not seen in elementary particle physics. Also why will be more generic phenomena.
- Not just a mere mathematical possibility.

What my talk is about

1. Origin of various resonance shapes.

2. Best-fit analysis of two representative example models:
   (1) maximum shape distortion/peak-shift
   (2) maximum signal enhancement/suppression

3. Prospects

1. Origin: Resonance-continuum interference

Resonance-continuum interference

- Continuum SM background and resonant processes with same initial-final states can interfere:

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

- Amplitudes M can, in general, be complex (besides complex BW): complex couplings or loops with Cutkosky cuts.

Purely real interference

- Continuum SM background and resonant processes with same initial-final states can interfere:

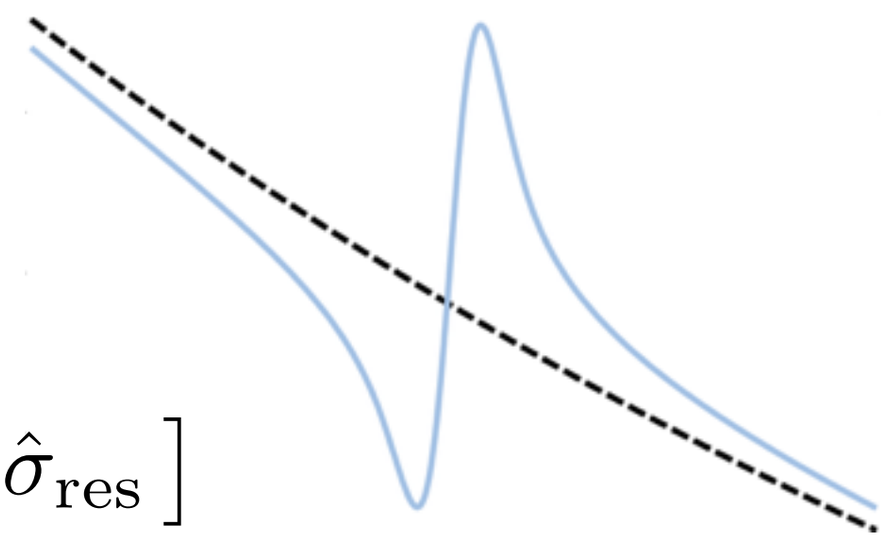
$$\frac{d\hat{\sigma}}{dz} = \frac{1}{32\pi\hat{s}} \sum \left| \mathcal{M}_{\rm bg} + \frac{M^2}{\hat{s} - M^2 + iM\Gamma} \cdot \mathcal{M}_{\rm res} \right|^2$$

- If the interference is purely real,

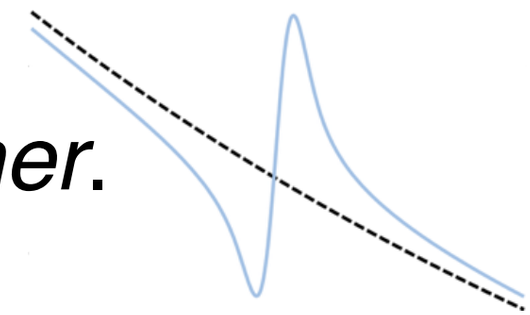
$$\hat{\sigma} = \hat{\sigma}_{\rm bg} + \frac{1}{(\hat{s} - M^2) + M^4 w^2}$$

$$\times \left[M^2(\hat{s} - M^2)\hat{\sigma}_{\rm int} + M^4 \hat{\sigma}_{\rm res} \right]$$

odd in s-hat



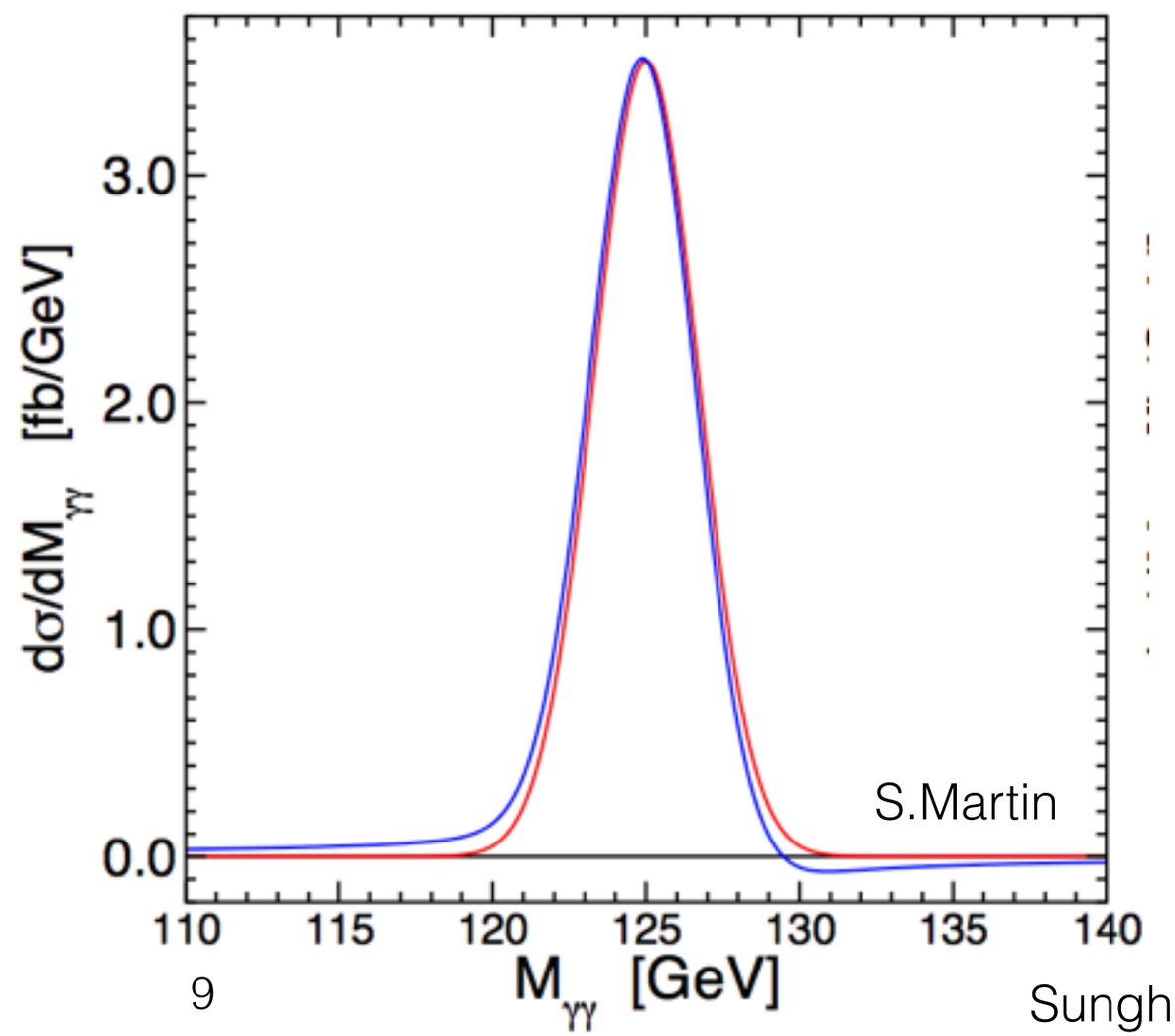
Purely real interference



- The real-part induces a peak and dip *together*.
- Shifting the location of a peak (affecting the pole mass measurement).

~70 MeV shift to the 125 GeV Higgs mass,
L.Dixon et al.

but can be much bigger for new resonances.



with relative phases

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- The resonance-continuum interference with a relative phase.

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

NB: Complex phases can arise from either *loops* with Cutkosky cuts or from *CPV*.

with relative phases

SJ, Song, Yoon

- The resonance-continuum interference with a relative phase.

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

$$\hat{\sigma} = \hat{\sigma}_{\rm bg} + \frac{1}{(\hat{s} - M^2) + M^4 w^2}$$

even in s-hat

$$\times \left[M^2(\hat{s} - M^2)\hat{\sigma}_{\rm int} c_\phi + M^4 \hat{\sigma}_{\rm res} \left(1 + \frac{2w}{R} s_\phi \right) \right]$$

$$w = \Gamma/M$$

$$R = \frac{\hat{\sigma}_{\rm res}}{\hat{\sigma}_{\rm int}} \simeq \frac{A_{\rm res}}{A_{\rm bg}}$$

$$\phi \simeq \phi_{\rm res} - \phi_{\rm bg}$$

usual real-part interference

resonance square

imaginary interference

Purely imaginary intf

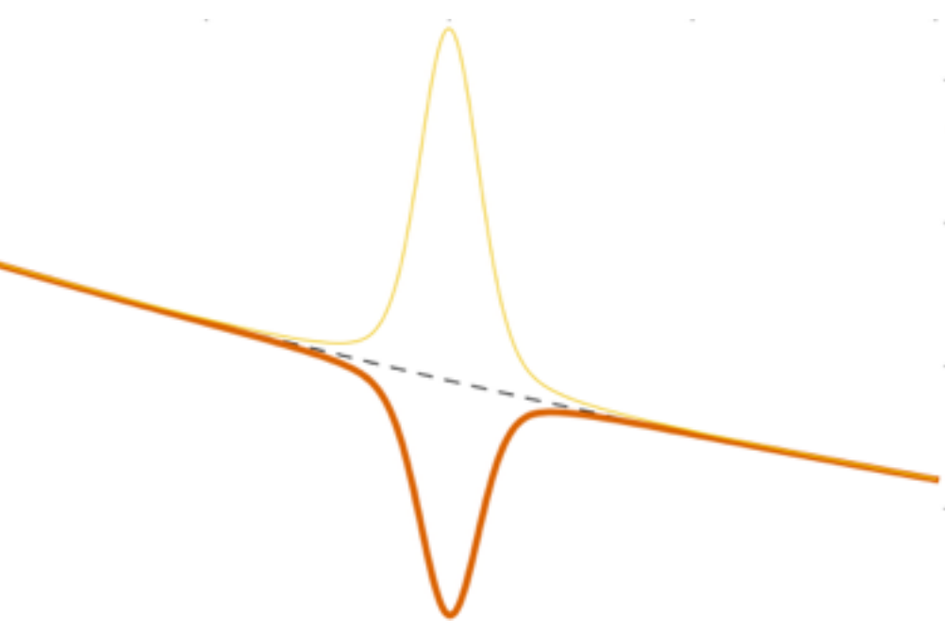
SJ, Song, Yoon

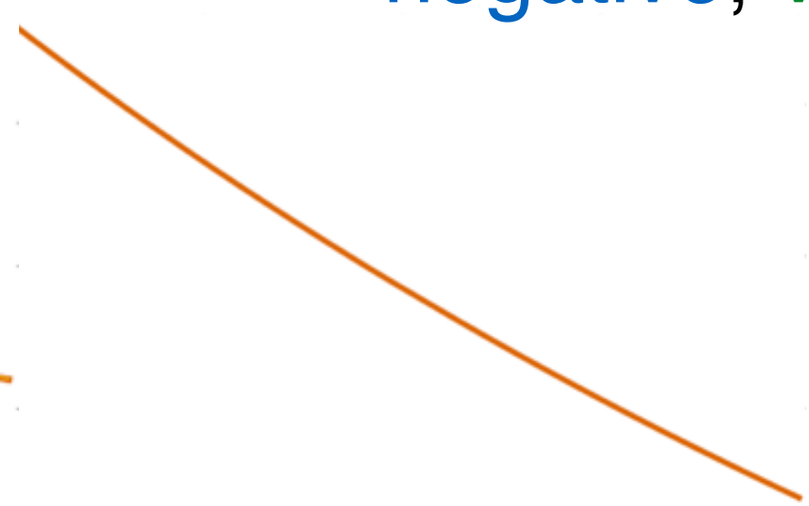
- Pure dip, nothingness, and rescaled pure peak can be newly produced.

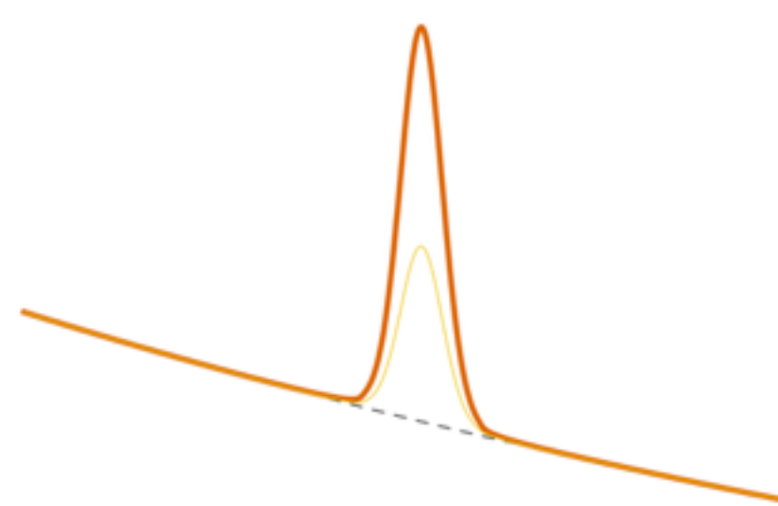
even in s-hat

$$\hat{\sigma} = \hat{\sigma}_{\rm bg} + \frac{1}{(\hat{s} - M^2) + M^4 w^2} \left[0 + M^4 \hat{\sigma}_{\rm res} \left(1 \pm \frac{2w}{R} \right) \right]$$

negative, vanishing, positive





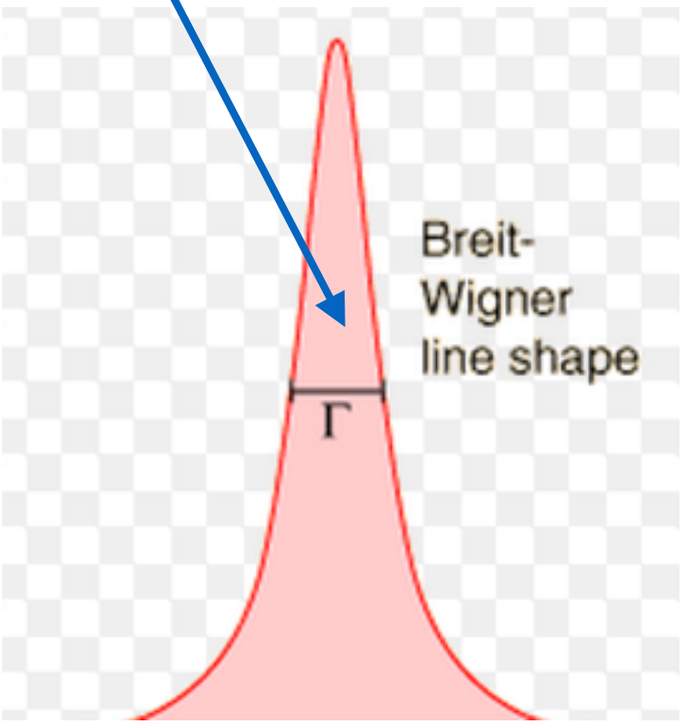


Narrow width approximation (NWA)

- The total resonance rate is the area below the BW peak, and is estimated approximately/easily by NWA.

$$\frac{1}{(\hat{s}-M^2)^2+M^2\Gamma^2} \quad \rightarrow \quad \frac{\pi}{M\Gamma}\delta(\hat{s}-M^2)$$

$$\sigma(H/A)\cdot BR(H/A\rightarrow t\bar{t})$$



Modified NWA

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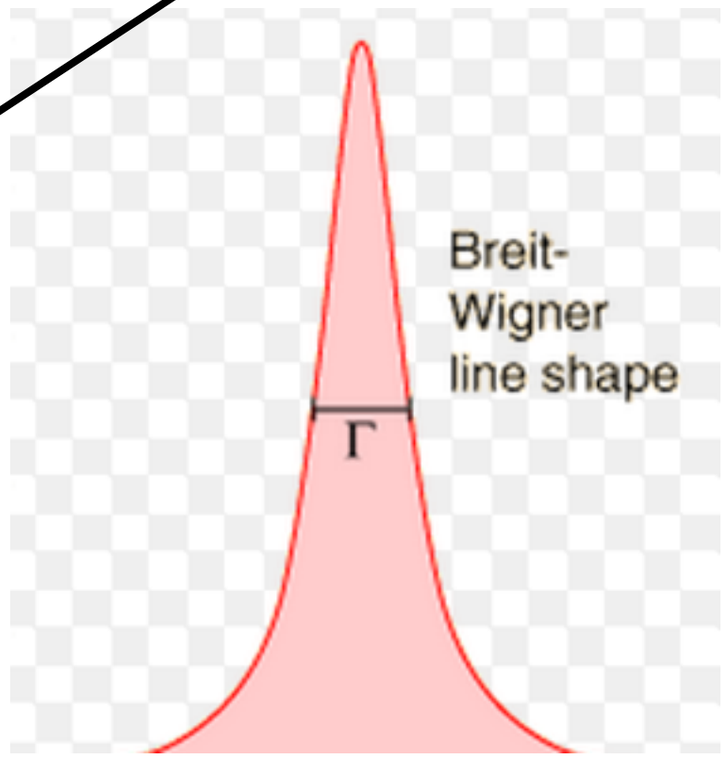
- The imaginary-part now does contribute to the total rate; usual NWA is not valid with the imaginary-part.

- We can modify the NWA by a multiplicative C-factor.

$$\sigma(H/A) \cdot BR(H/A \to t\bar{t}) \cdot \left(1 + 2\frac{w}{R} s_\phi\right)$$



MSSM Heavy Higgs in most channels can be dips!

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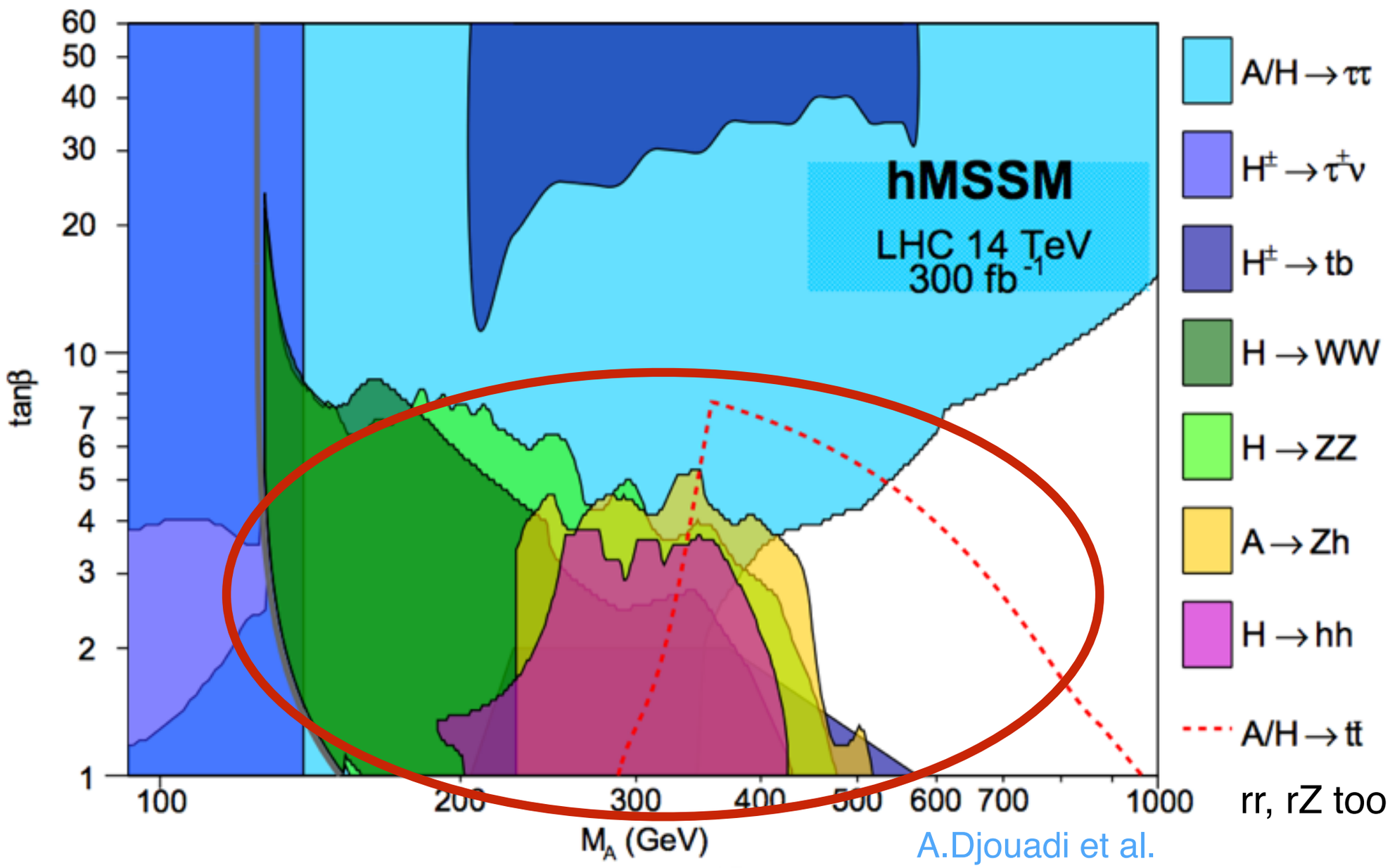

rr, rZ too

A.Djouadi et al.

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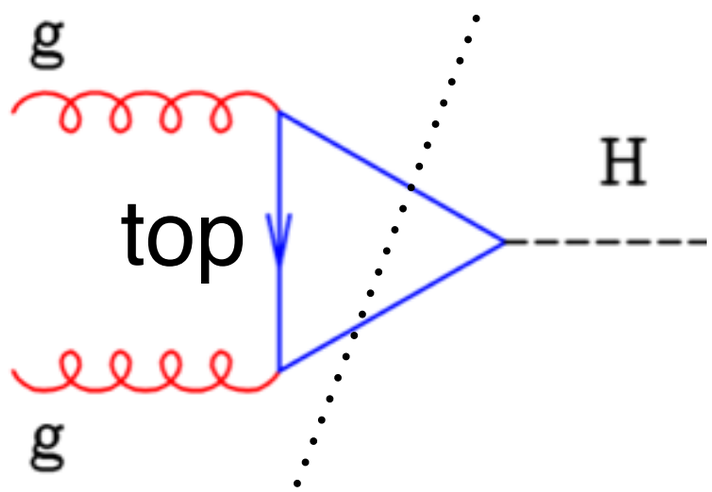
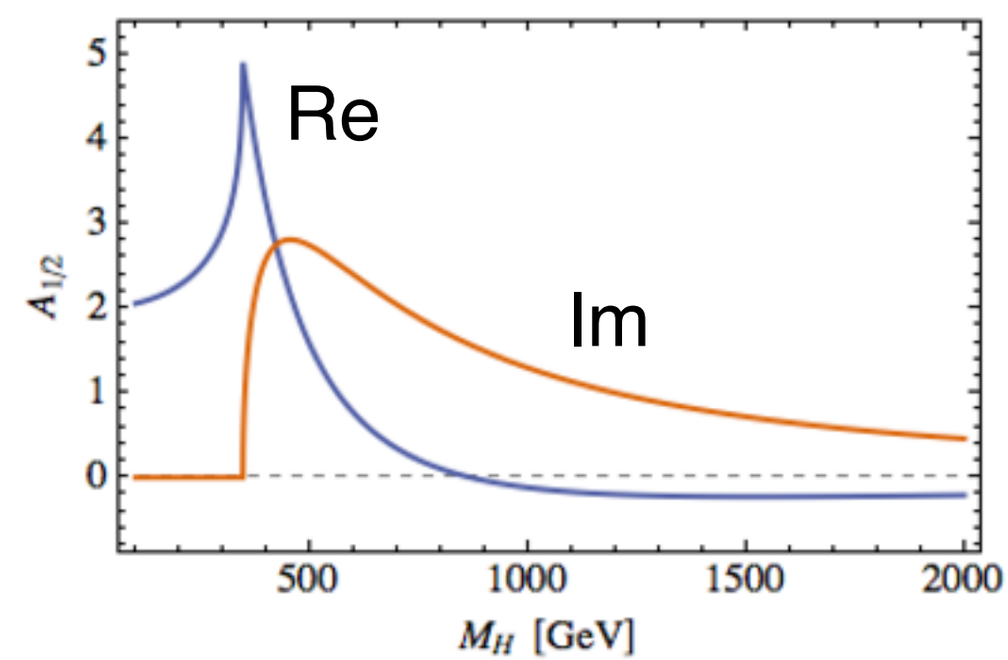
Phases from top-loop



phase
when mH>2mt



2. Implications:

750 GeV Diphoton Excess from a Scalar Resonance

Two representative models

- (1) Purely real: Maximum shape distortion/peak-shift

- (2) Purely imaginary: Maximum signal enhancement/suppression

(1) shape distortion

- 750 GeV scalar resonance: singlet, gg->diphoton.
- 400 GeV VL leptons + TeV VL quarks. (fitting rate, no phases)
- Width=5 GeV. (by some hidden decay modes)

(1) shape distortion

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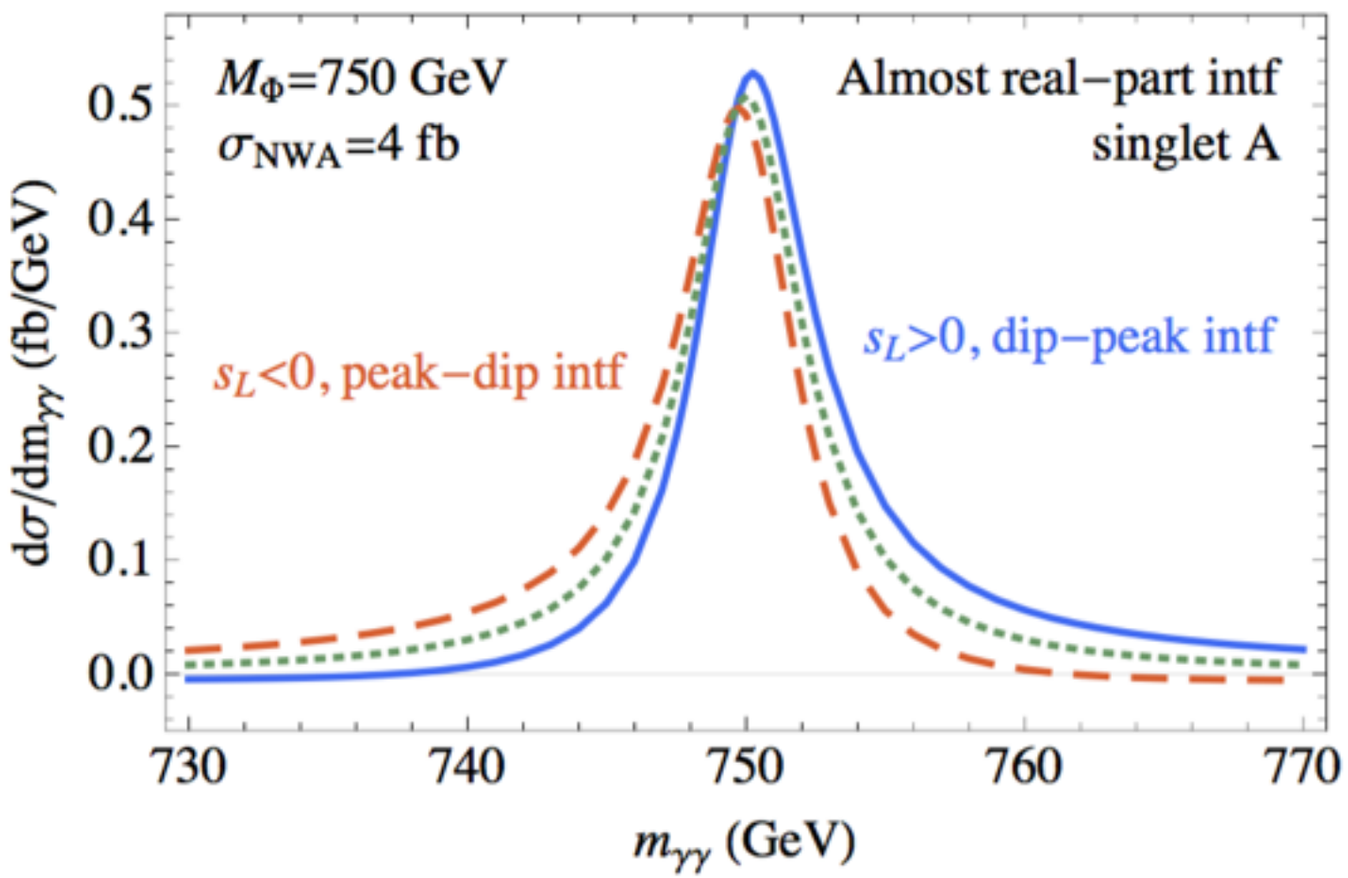

(1) shape distortion

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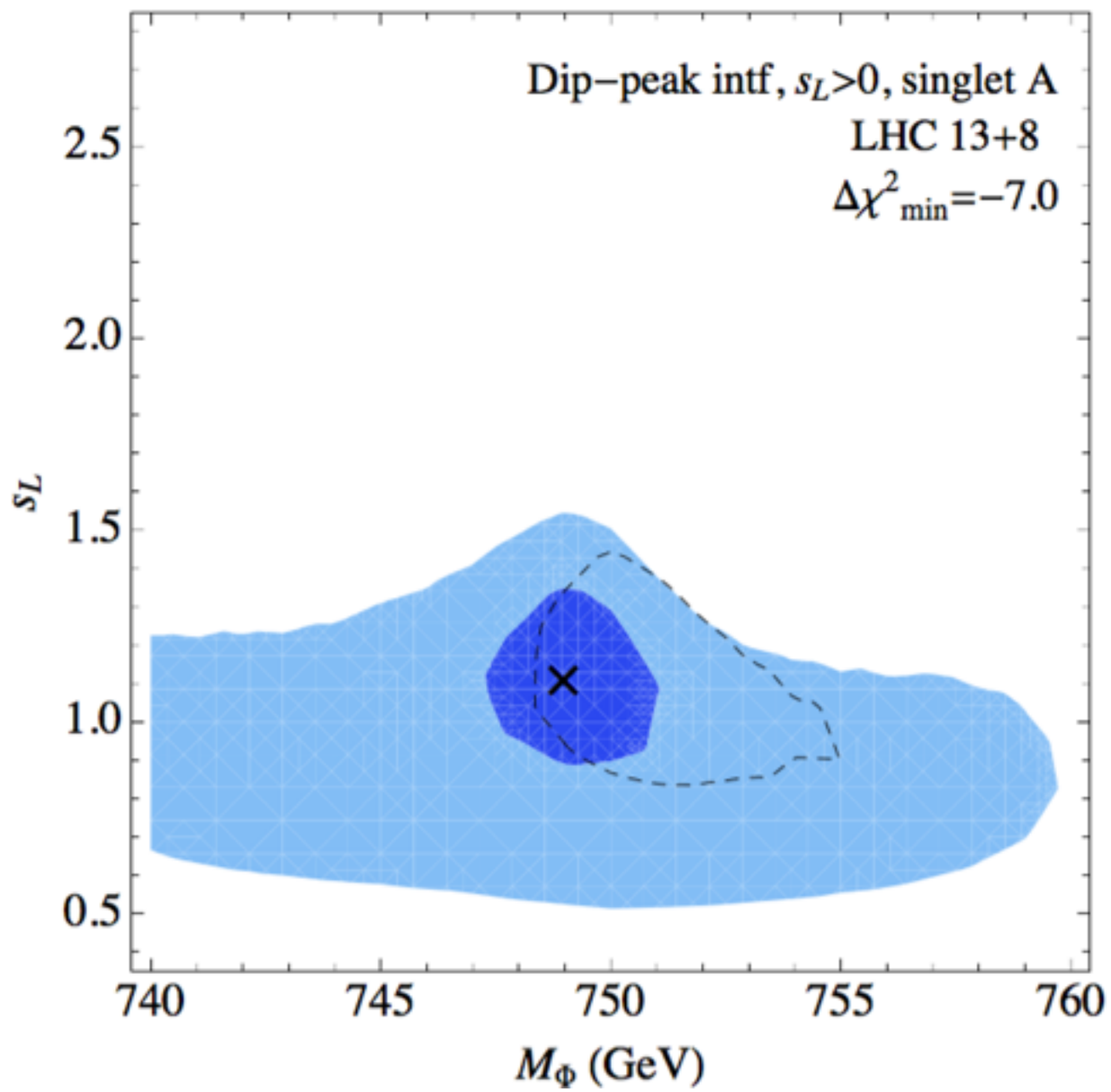

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(2) resonance enhancement

- 2HDM + VL leptons: 750 GeV heavy Higgses in gg->diphoton.
- Almost purely complex with the top-loop.
- Width ~ 50 GeV.

(2) resonance enhancement

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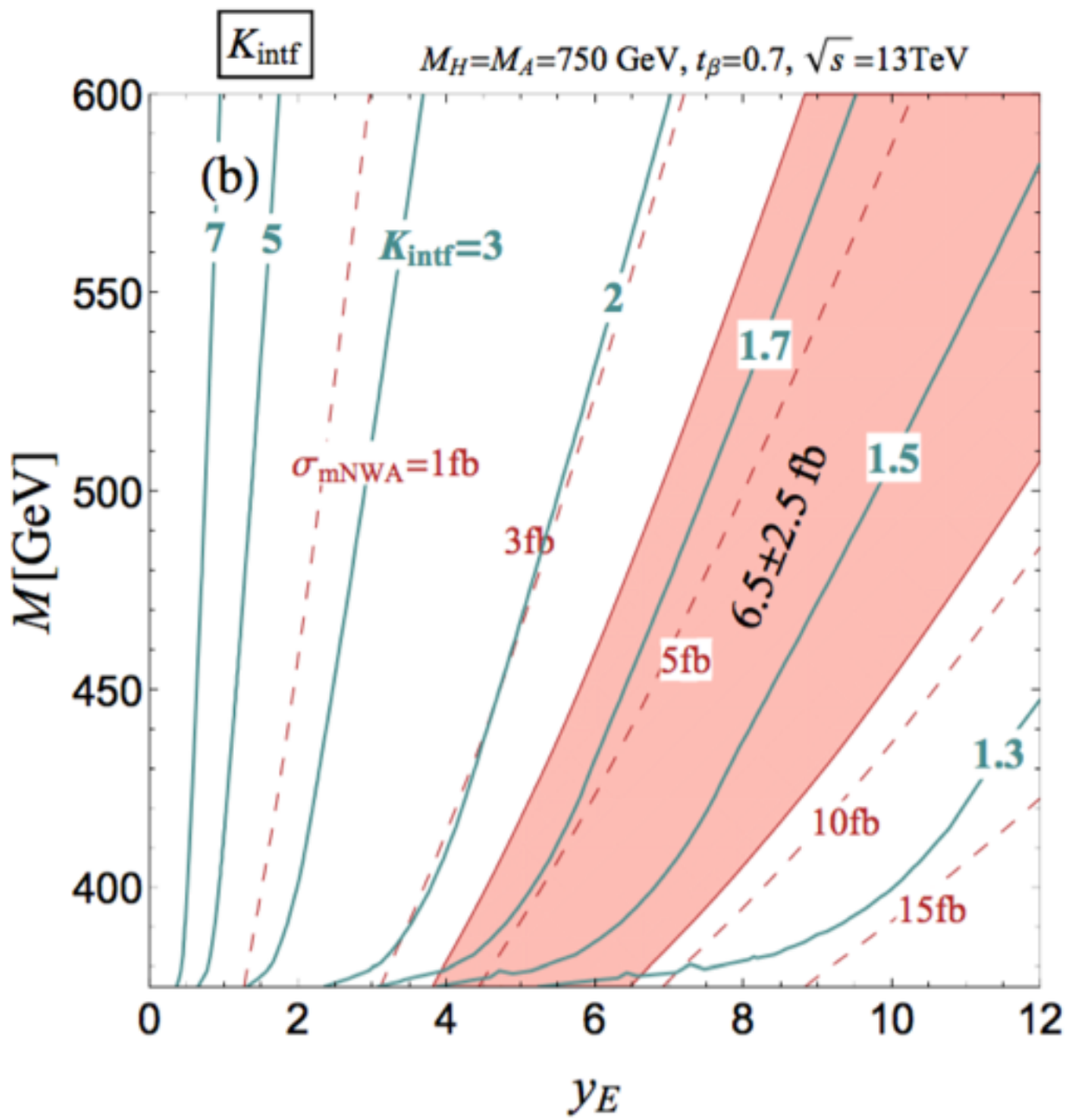

$$\left(1 \pm \frac{2w}{R}\right)$$

$$w = \Gamma/M$$

$$R = \frac{\hat{\sigma}_{\rm res}}{\hat{\sigma}_{\rm int}} \simeq \frac{A_{\rm res}}{A_{\rm bg}}$$

Summary & prospect

- The 750 GeV gg->diphoton scalar resonance can be complicated by resonance-continuum interference.

- For the current O(1) fb excess rate,

  - resonance shape is likely to be pure BW peak (shifting the peak by O(1) GeV),
  - signal rate can be enhanced/suppressed by ~1.5 .

- For smaller excess rate in the future, intf effects will be larger, providing non-trivial test of a spin-0 resonance.

Backup

Why not seen so far?

- 1. Narrow resonances

- 2. Small complex phases