Higgs Lineshape

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SNU

Higgs Mini-Workshop: Precision, Cosmology and BSM

with Jeonghyeon Song, Yeo Woong Yoon

1505.00291, 1510.03450, 1601.00006

Overlooked Higgs Physics: Resonance Dips

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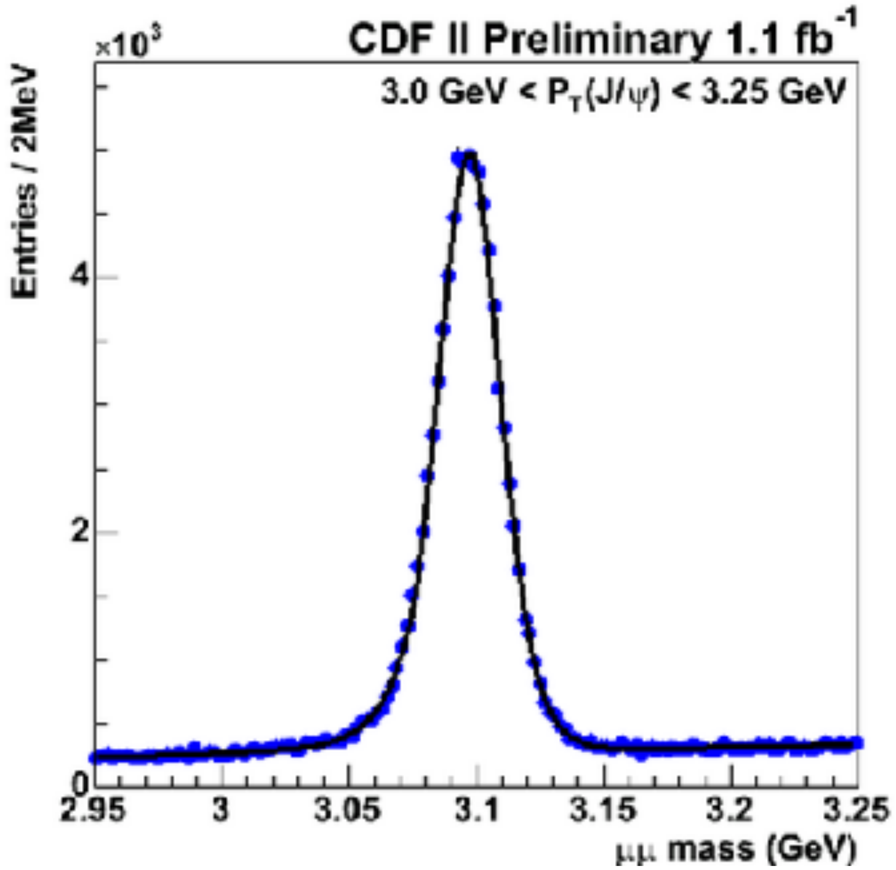
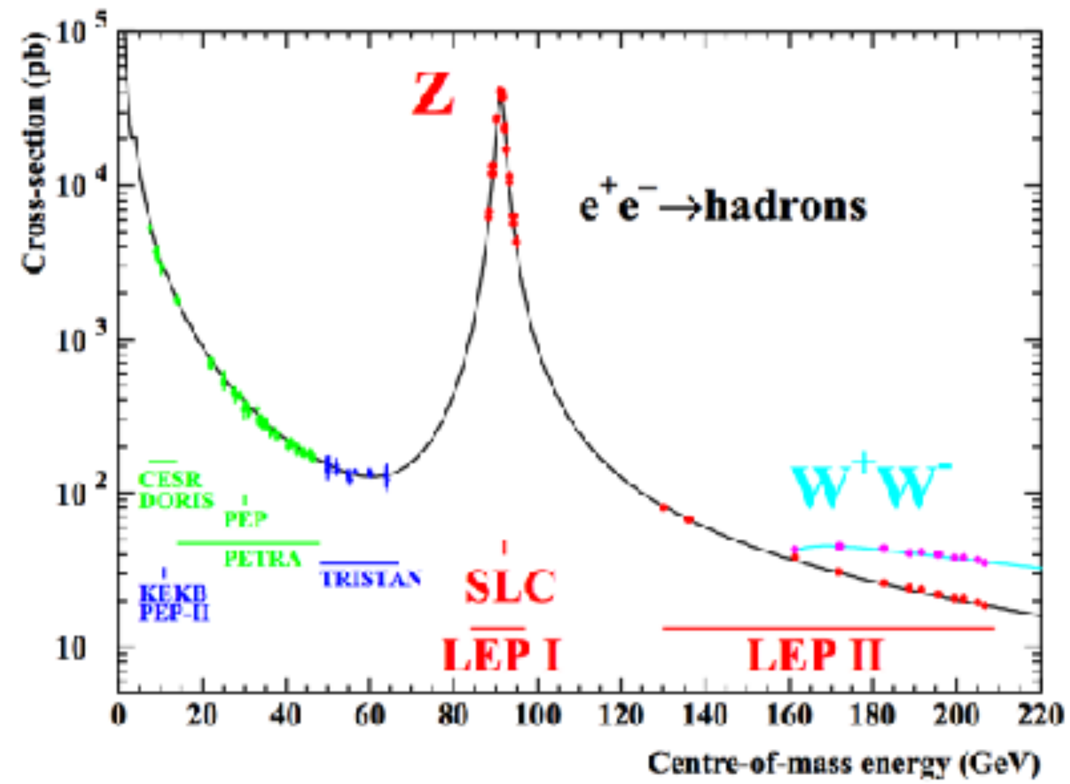
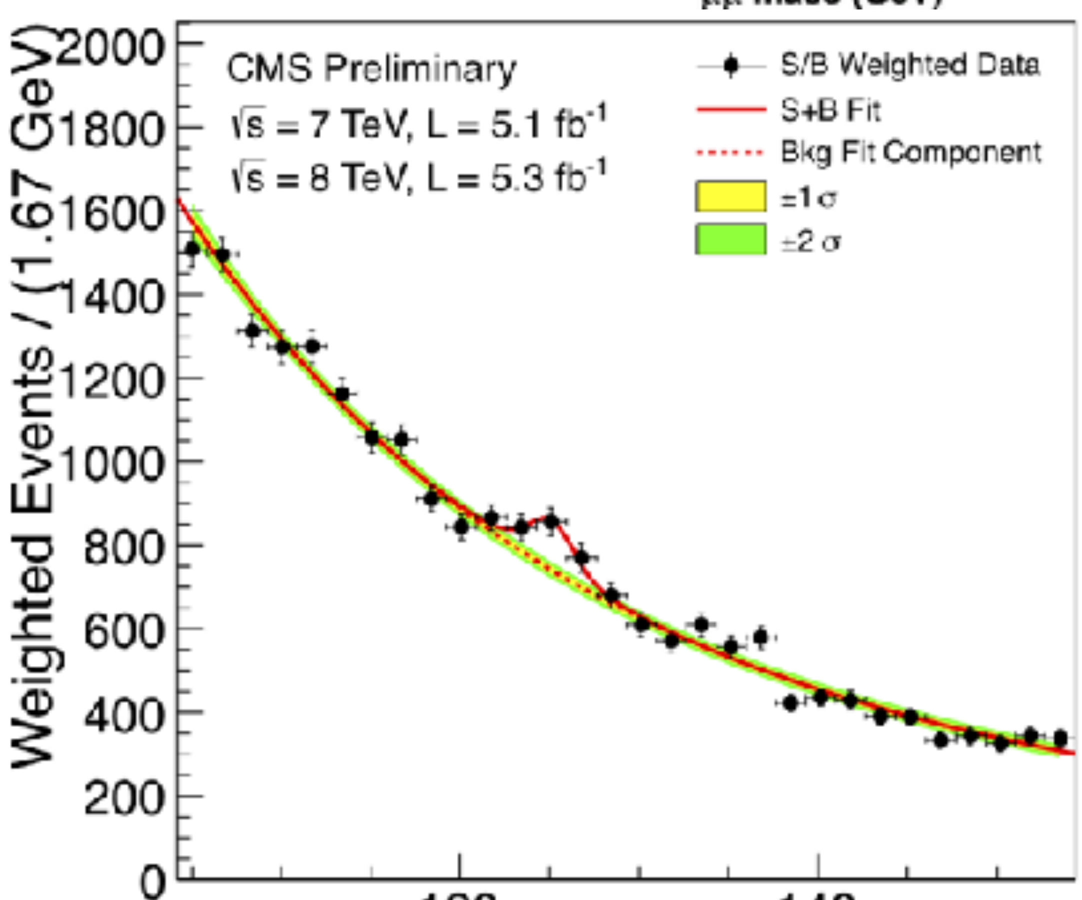
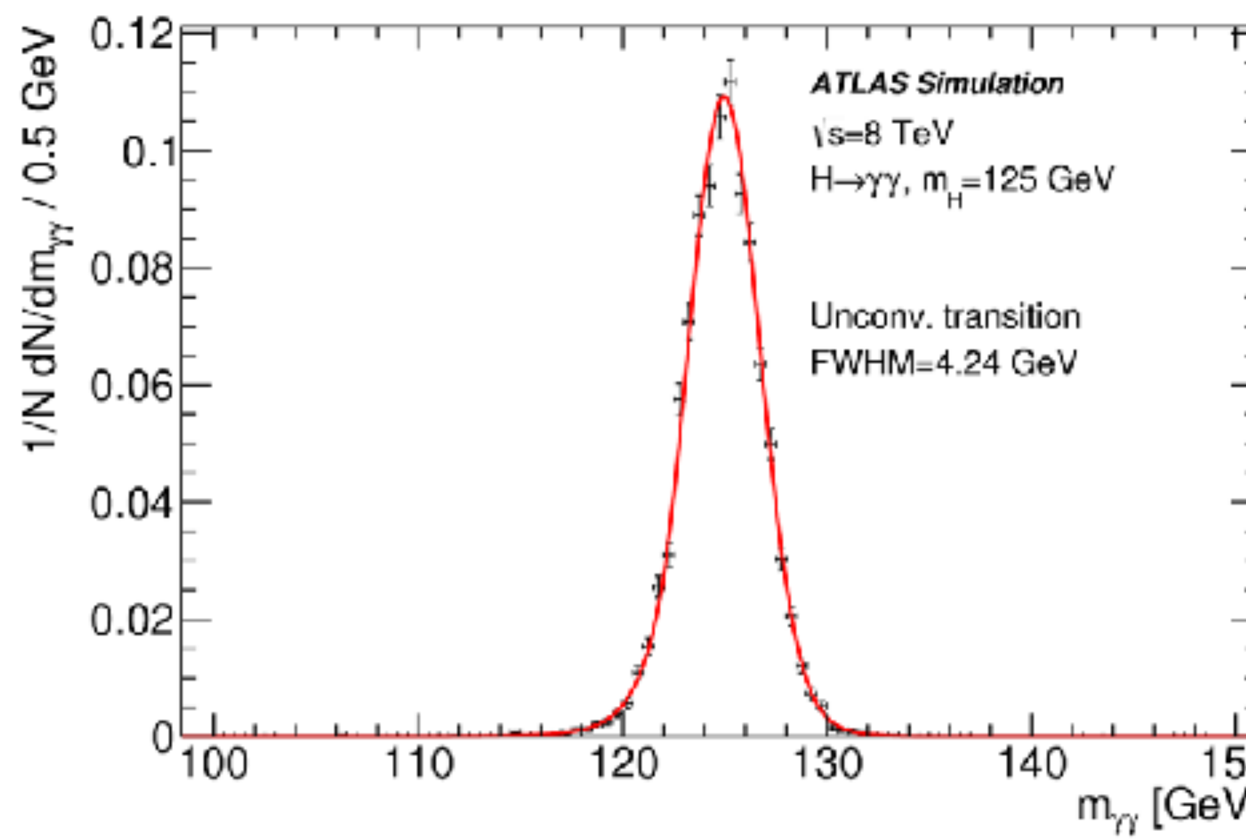
Resonances in history









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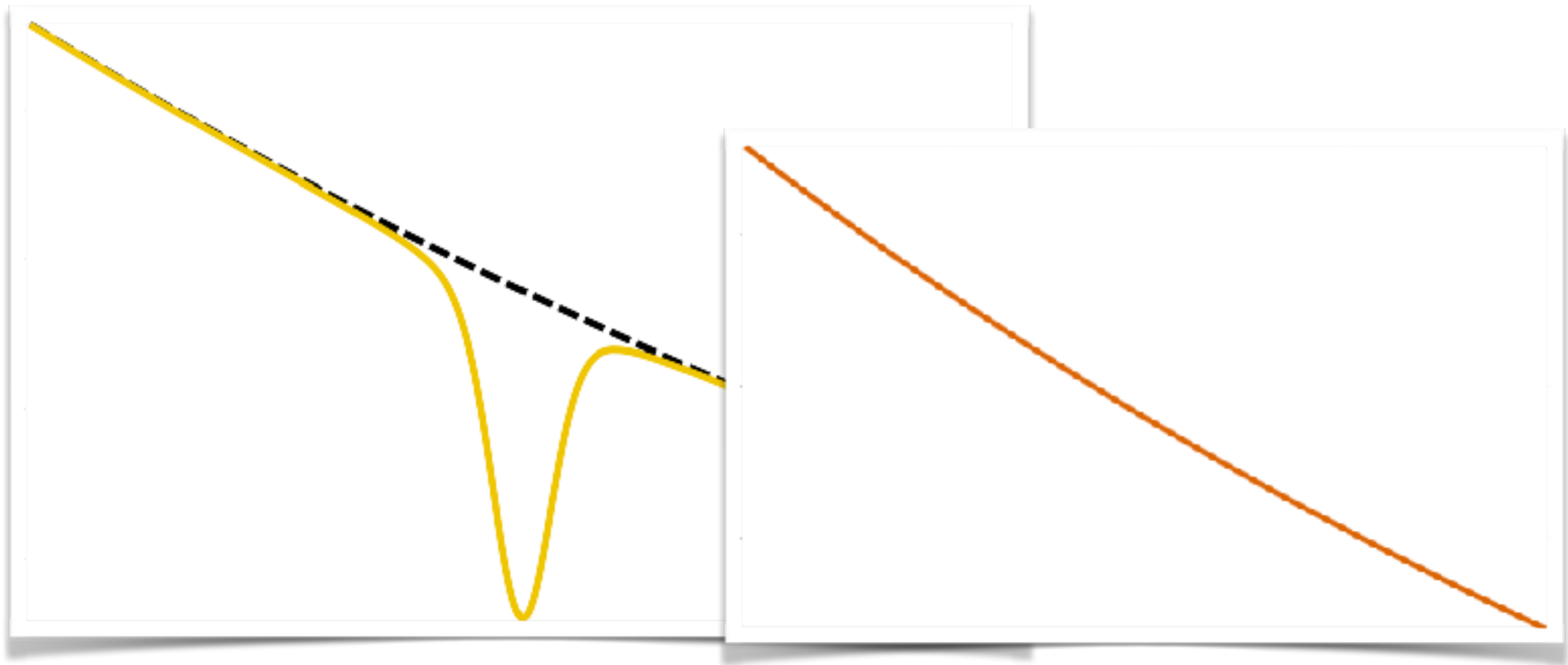
A Resonance (pure) Dip



- 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. The resonance dip is a qualitatively new interference phenomena.
   - what is it? and why now?

2. a generic phenomena in 2HDM and MSSM.
   - which channels? what parameters?
   - general rule of thumb

3. inducing new LHC challenges, but also exciting possibilities

1. The resonance dip is a qualitatively new interference phenomena.

- what is it? and why now?

Resonance-continuum interference

- Breit-Wigner resonance peak can be modified from the interference with continuum.

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

Purely real interference

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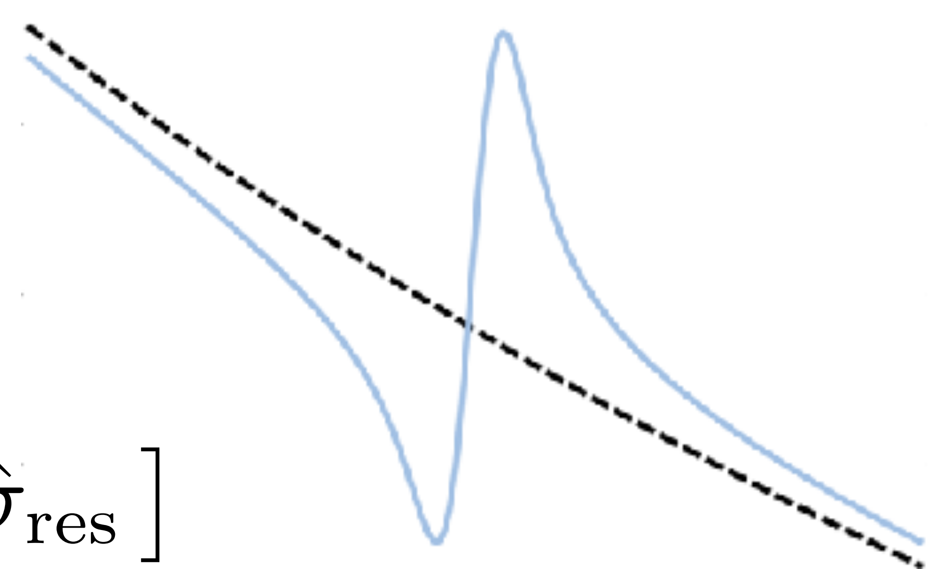
- A typical example: purely real intf



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

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

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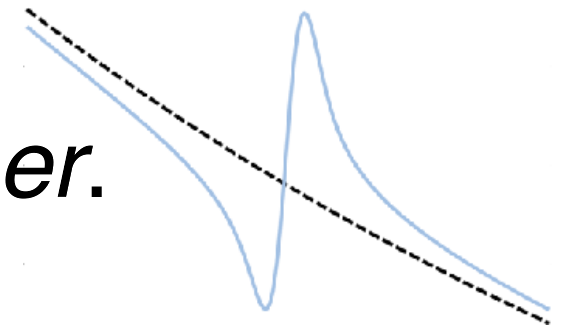
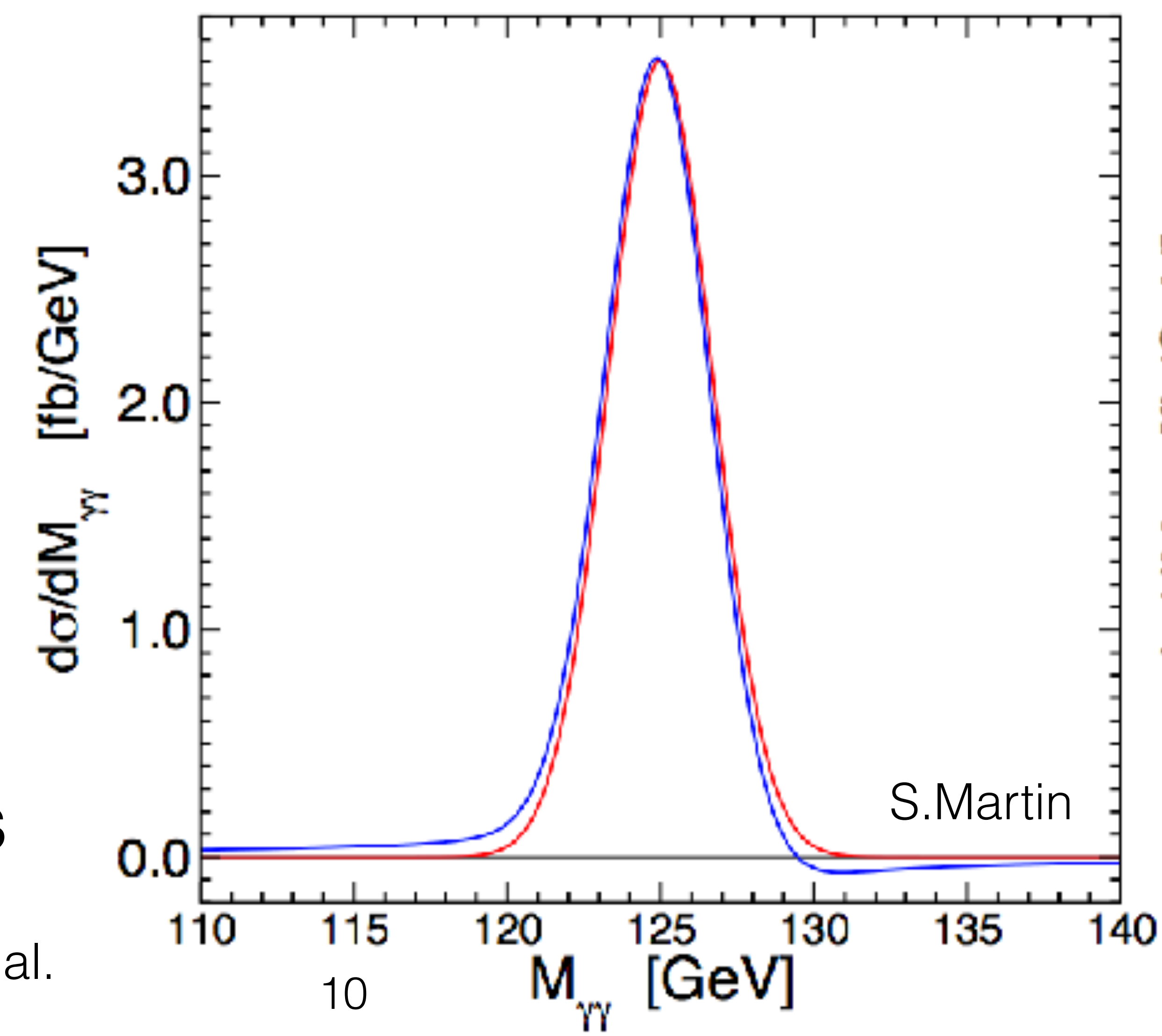
Purely real interference



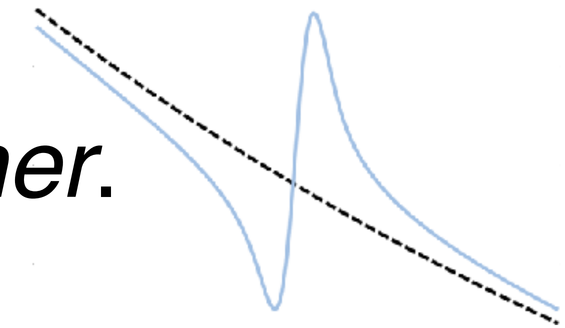
- The real-part induces a peak and dip *together*.
- Shifting the location of a peak (affecting the pole mass measurement).

~70 MeV shift to the 125 GeV Higgs mass



L.Dixon et al.

Purely real interference



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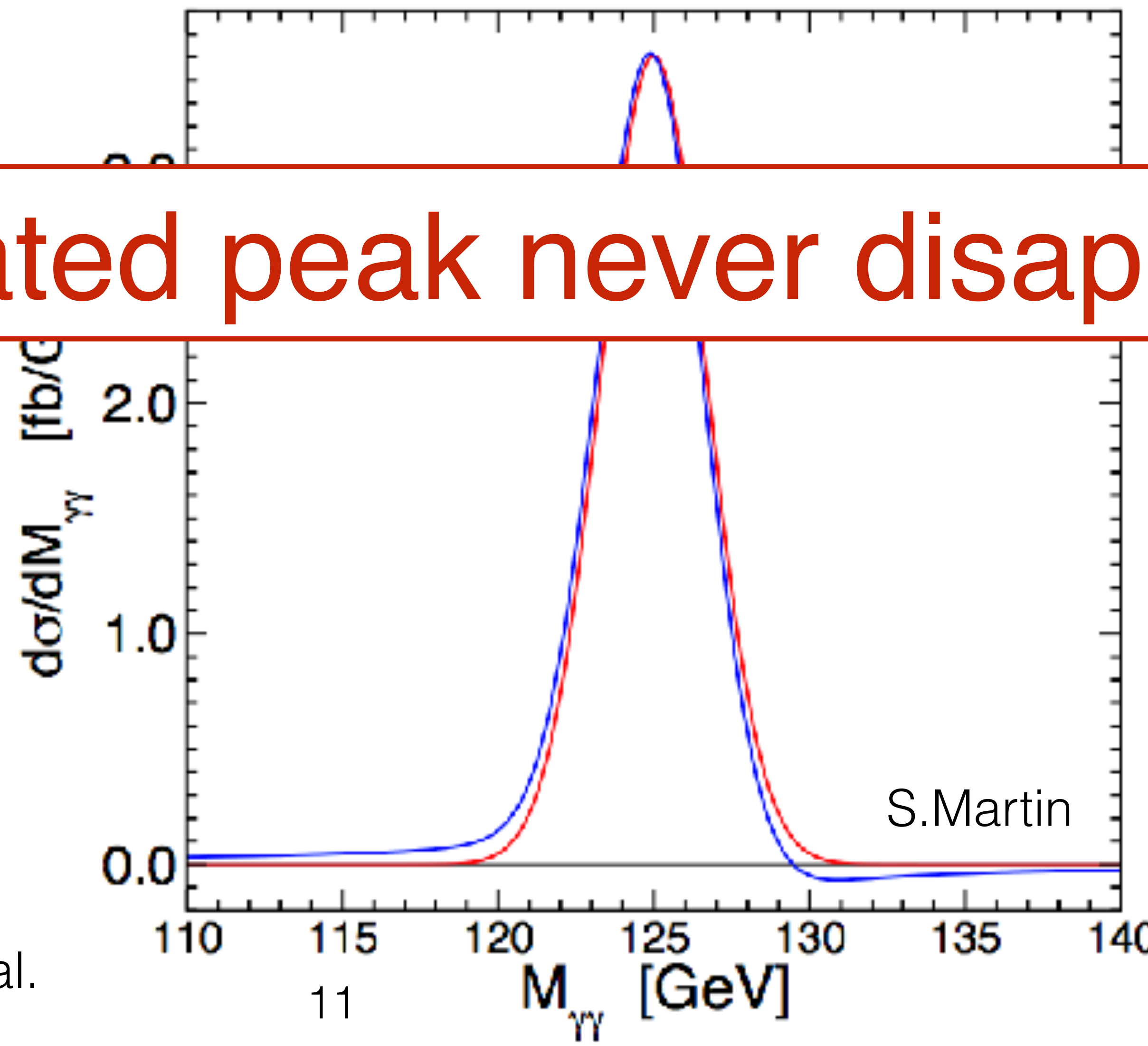

But the associated peak never disappears!

~70 MeV shift to the 125 GeV Higgs mass

L.Dixon et al.

Now with a relative phase

SJ, Song, Yoon

- The resonance-continuum interference with a relative phase.

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

Now with a relative phase

SJ, Song, Yoon

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

$$w = \Gamma / M$$

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

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

typical real-part interference

resonance square

imaginary interference

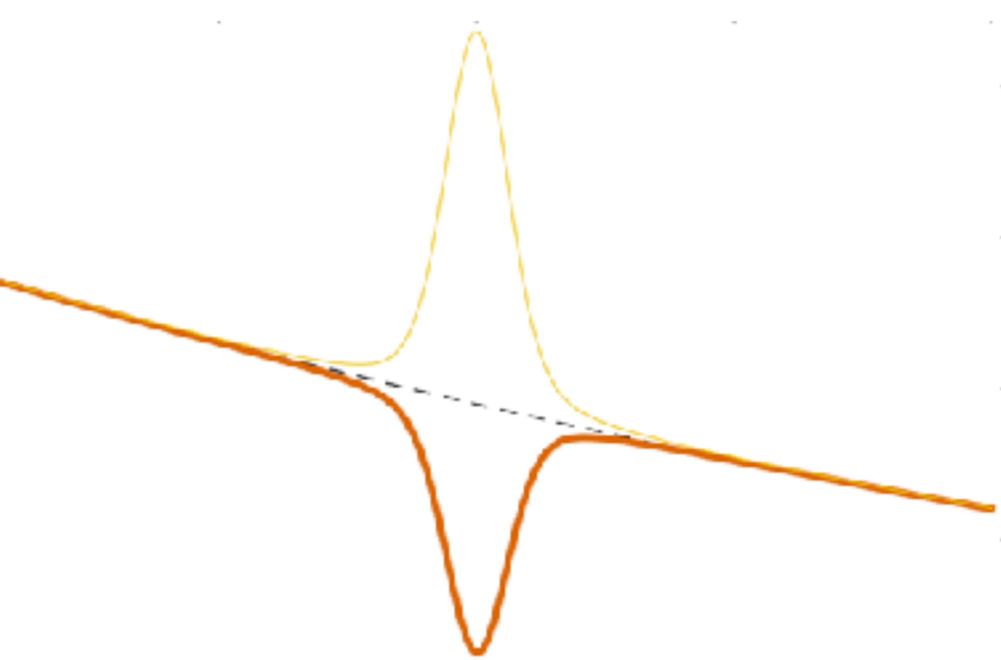
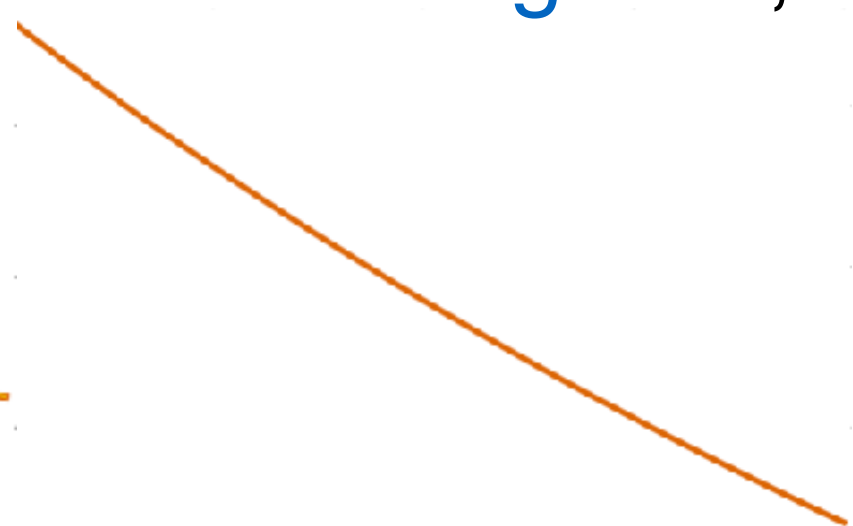
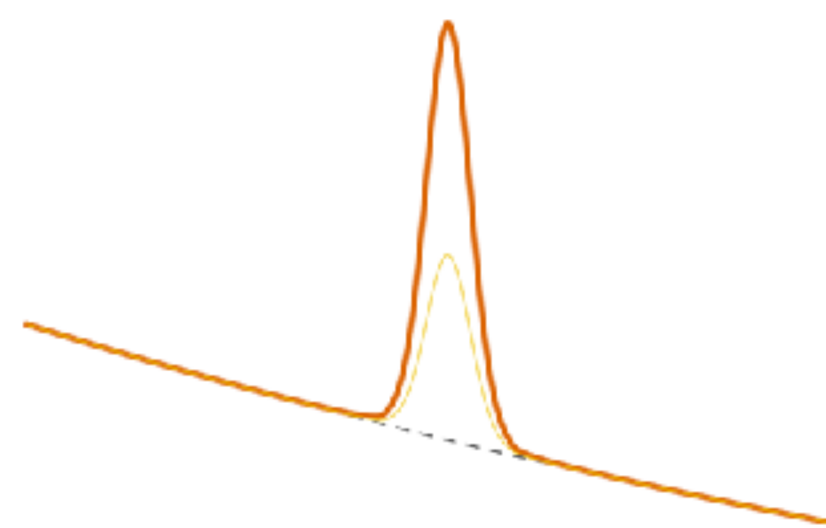
Purely imaginary intf

SJ, Song, Yoon

- New lineshapes:
  pure dip, nothingness, and rescaled pure peak.

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

negative, vanishing, positive

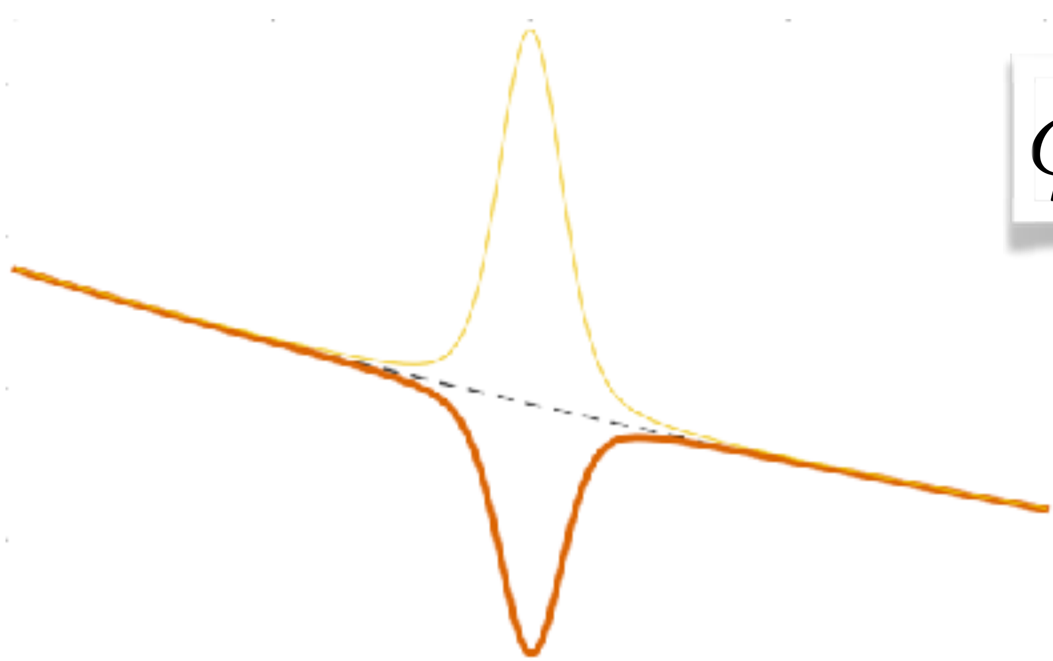




Pure resonance dip

SJ, Song, Yoon

- I'll focus on the pure dip in this talk—not only most extreme case, but also turns out to be useful.

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



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

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

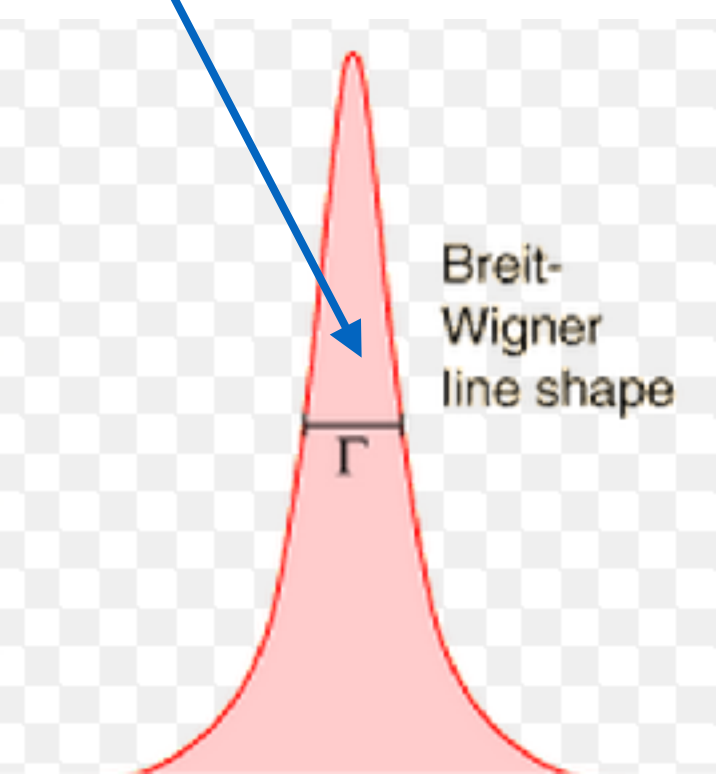
$$w = \Gamma/M$$

Narrow width approximation (NWA)

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

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

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



Modified NWA

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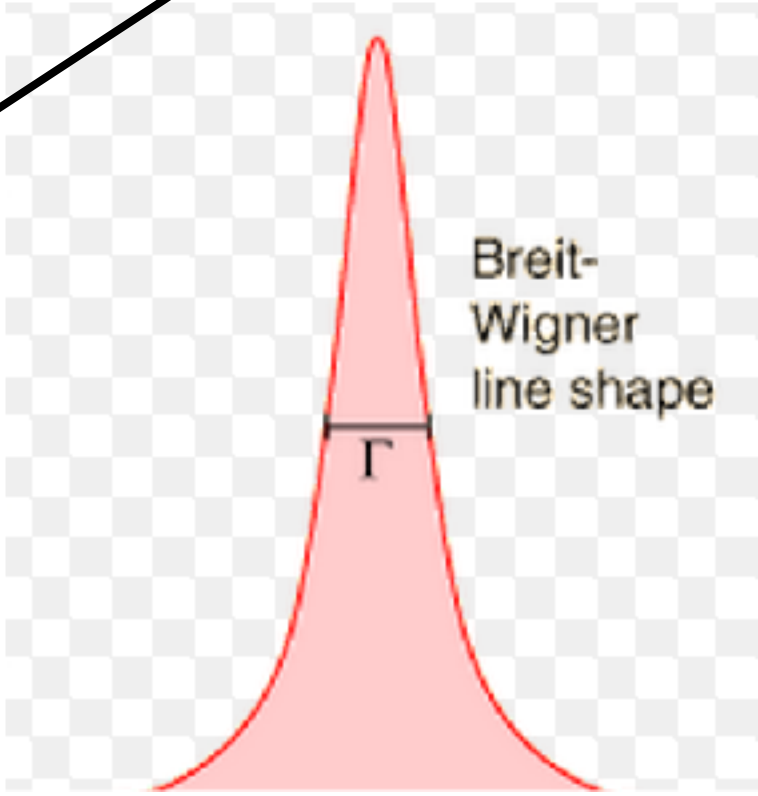
- The imaginary-part now does contribute to the total rate; usual NWA is not valid with the imaginary-part.
- We can modify the NWA by the multiplicative C-factor.

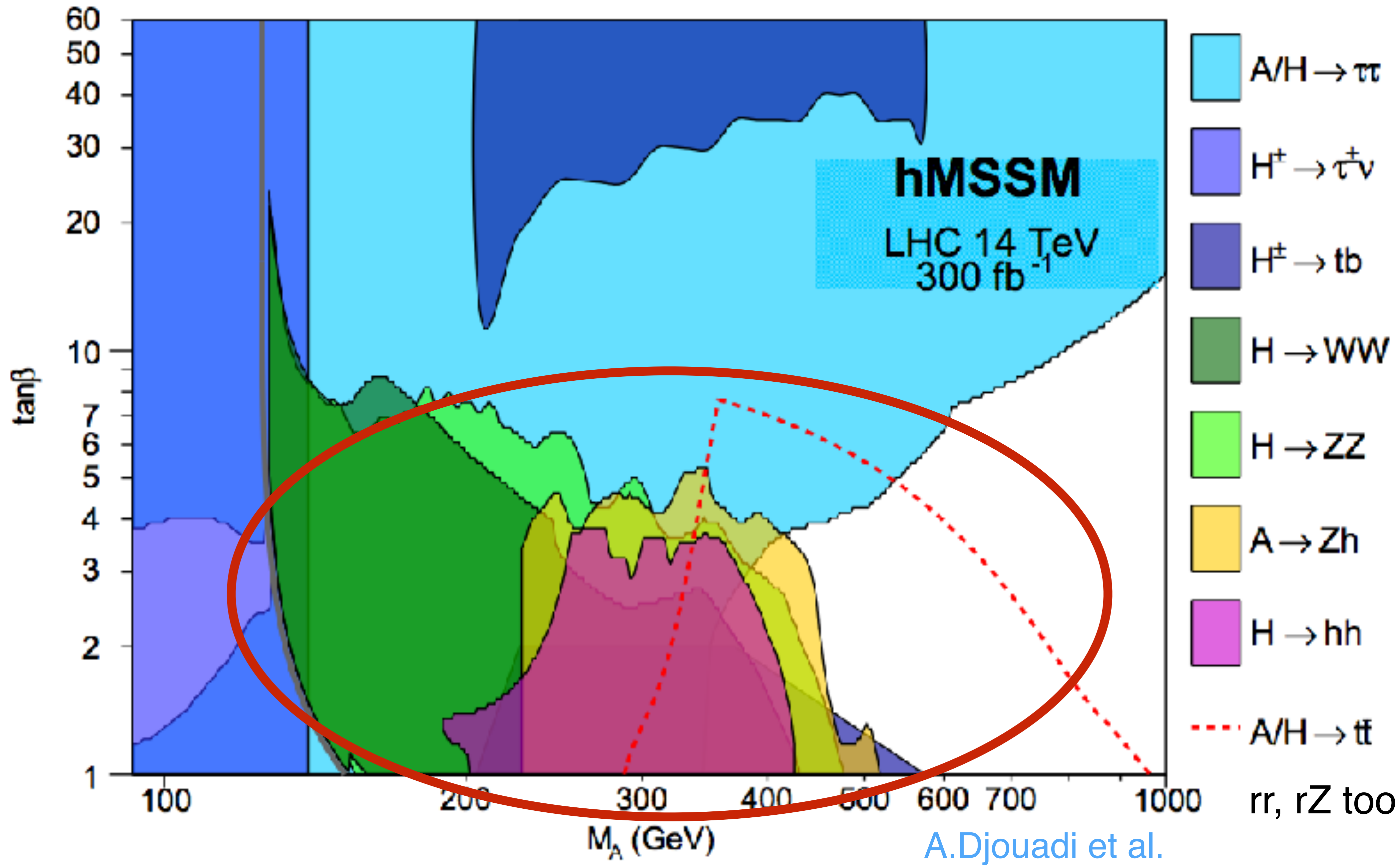
$$\sigma(H/A) \cdot BR(H/A \to t\bar{t}) \cdot \left(1 + 2\frac{w}{R} s_\phi\right)$$



2. It is a generic phenomena in 2HDM and MSSM.

- which channels? what parameters?
- general rule of thumb

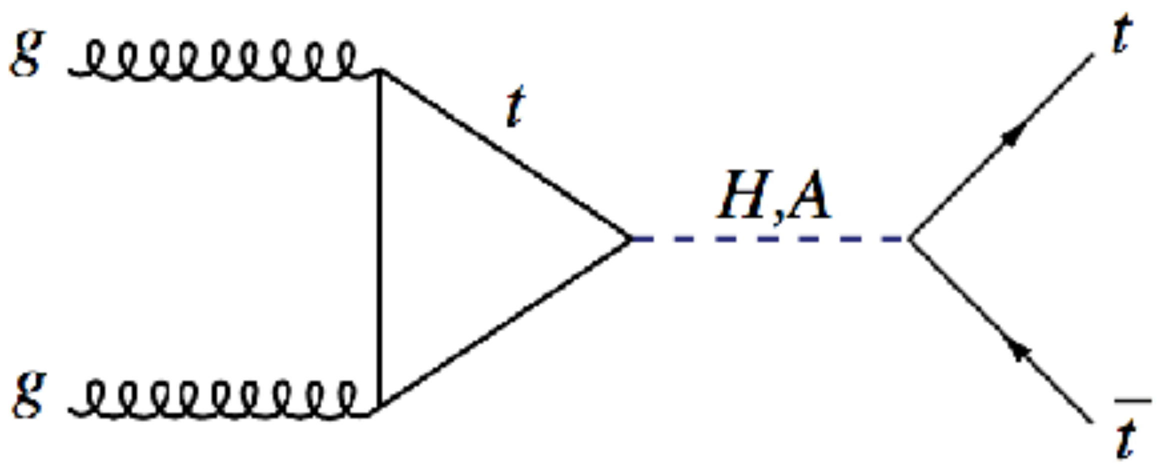
MSSM Heavy Higgs in most channels can be dips!



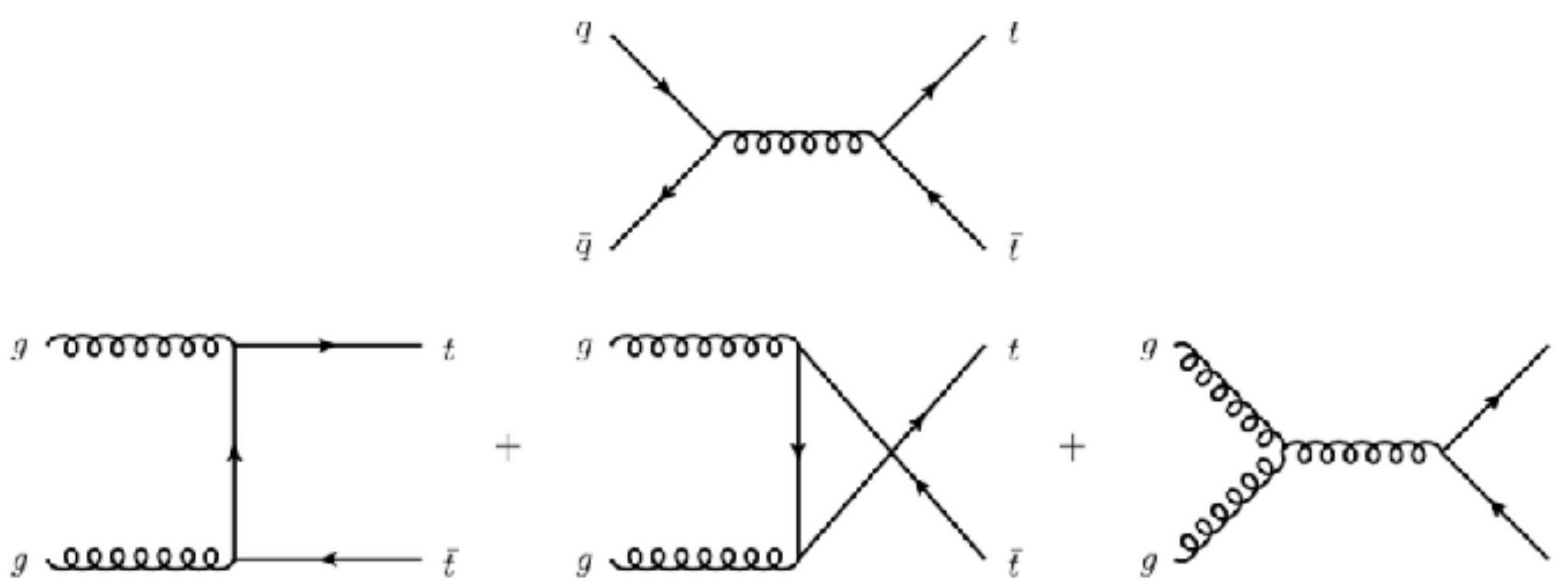
rr, rZ too

A.Djouadi et al.

Heavy Higgs in ttbar



alignment scenario,
but similar in general



Mechanism 1: vanishing Re.

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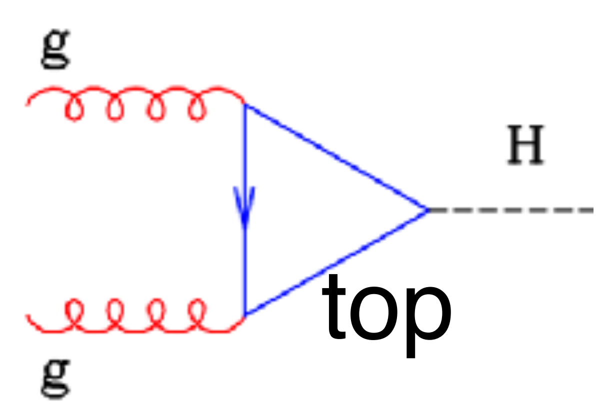
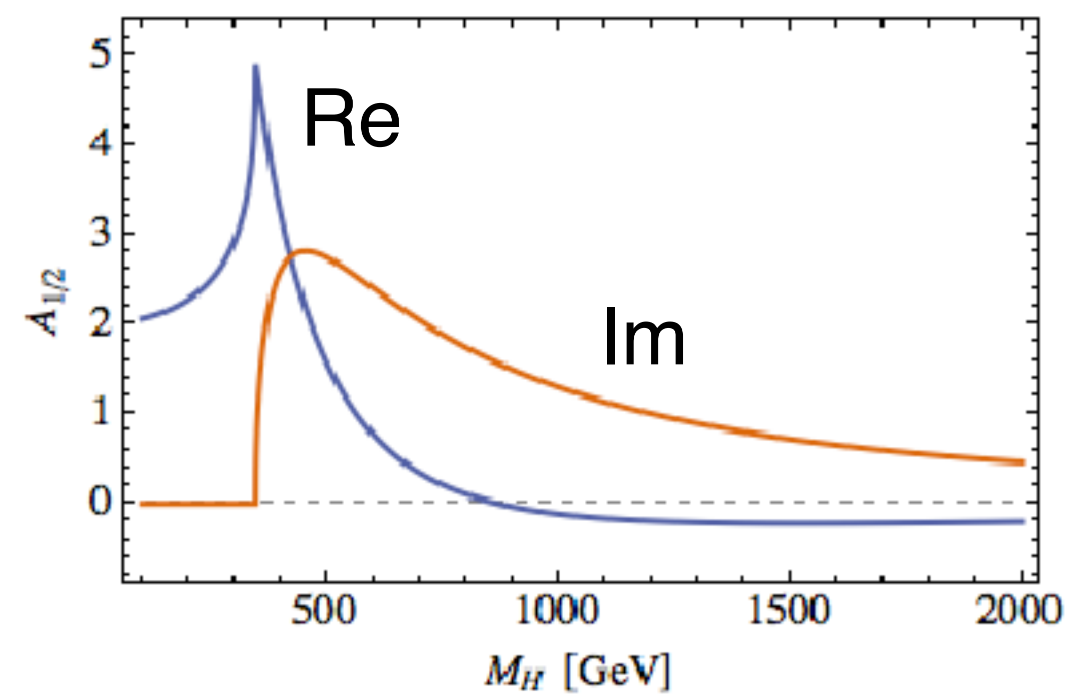


- The triangle loop function can accidentally have a *vanishing* Real part.

- For tb=2, MA=850, MH=1150 are pure dips.



Mechanism 2: cancelling Re.

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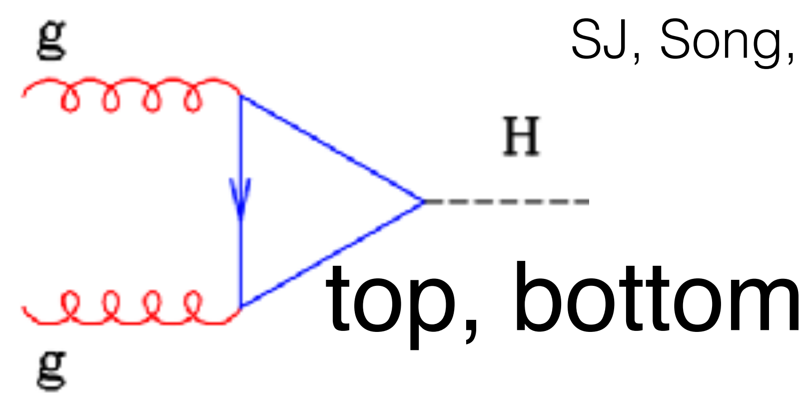
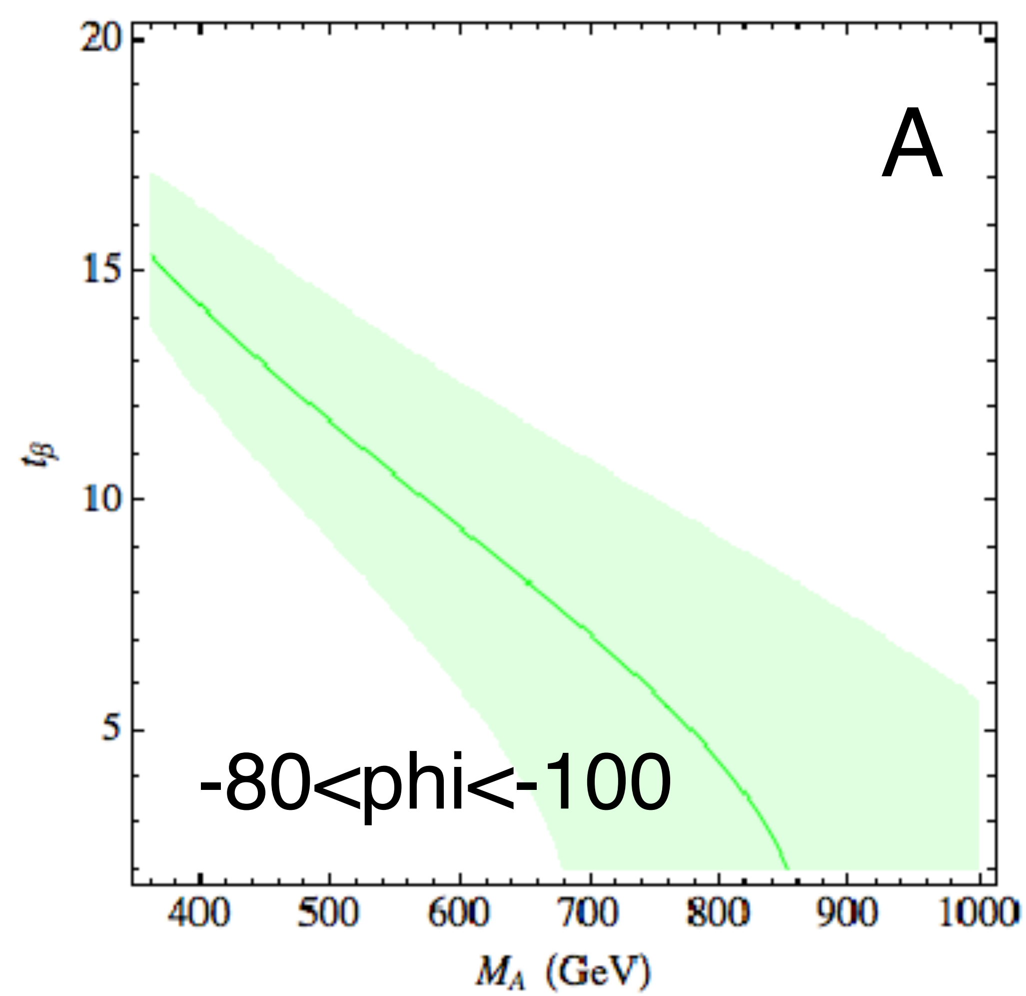


- For larger tan beta, the t-loop and b-loop can *cancel* their Real parts.

- Any 2mt<MA<850 can be a pure ttbar dip.



Demonstration

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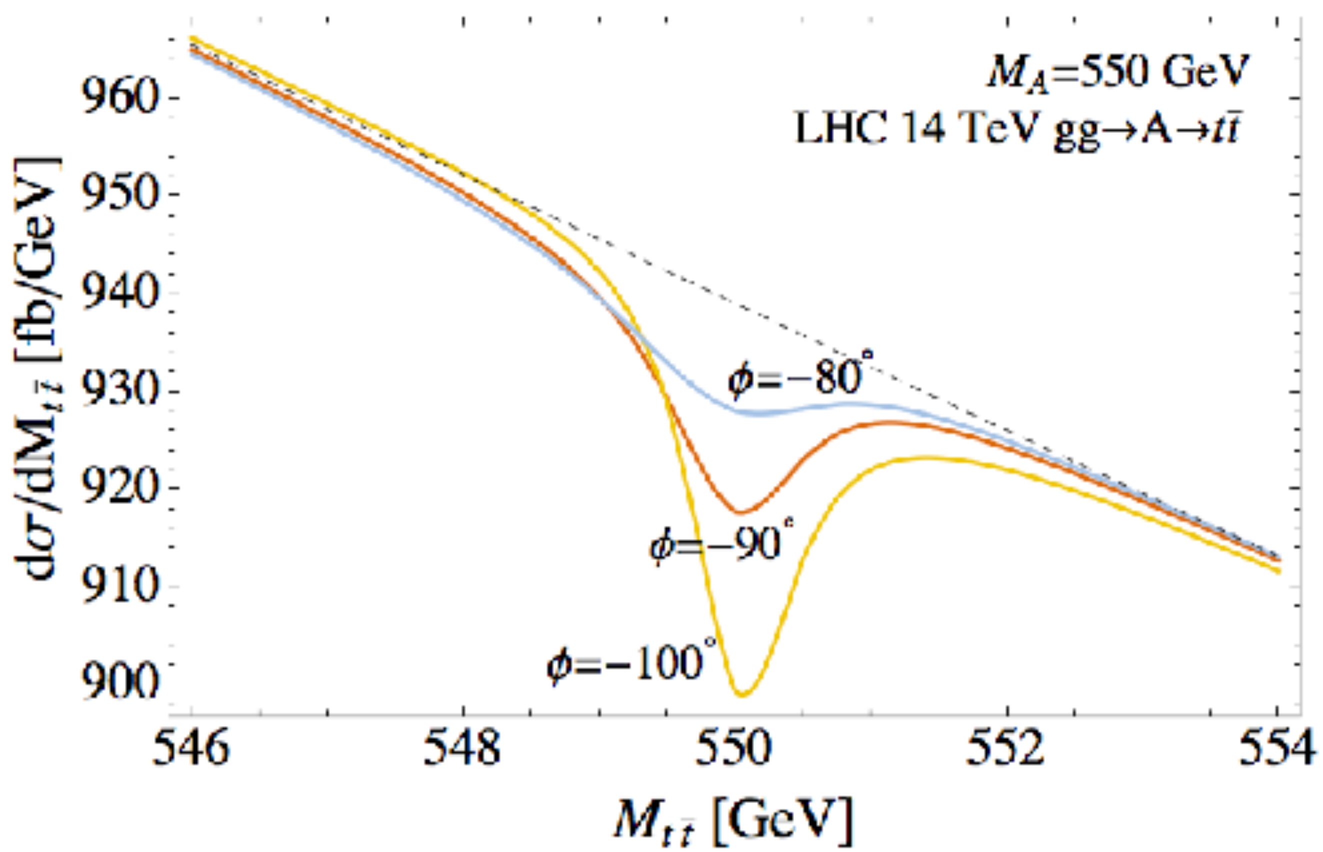

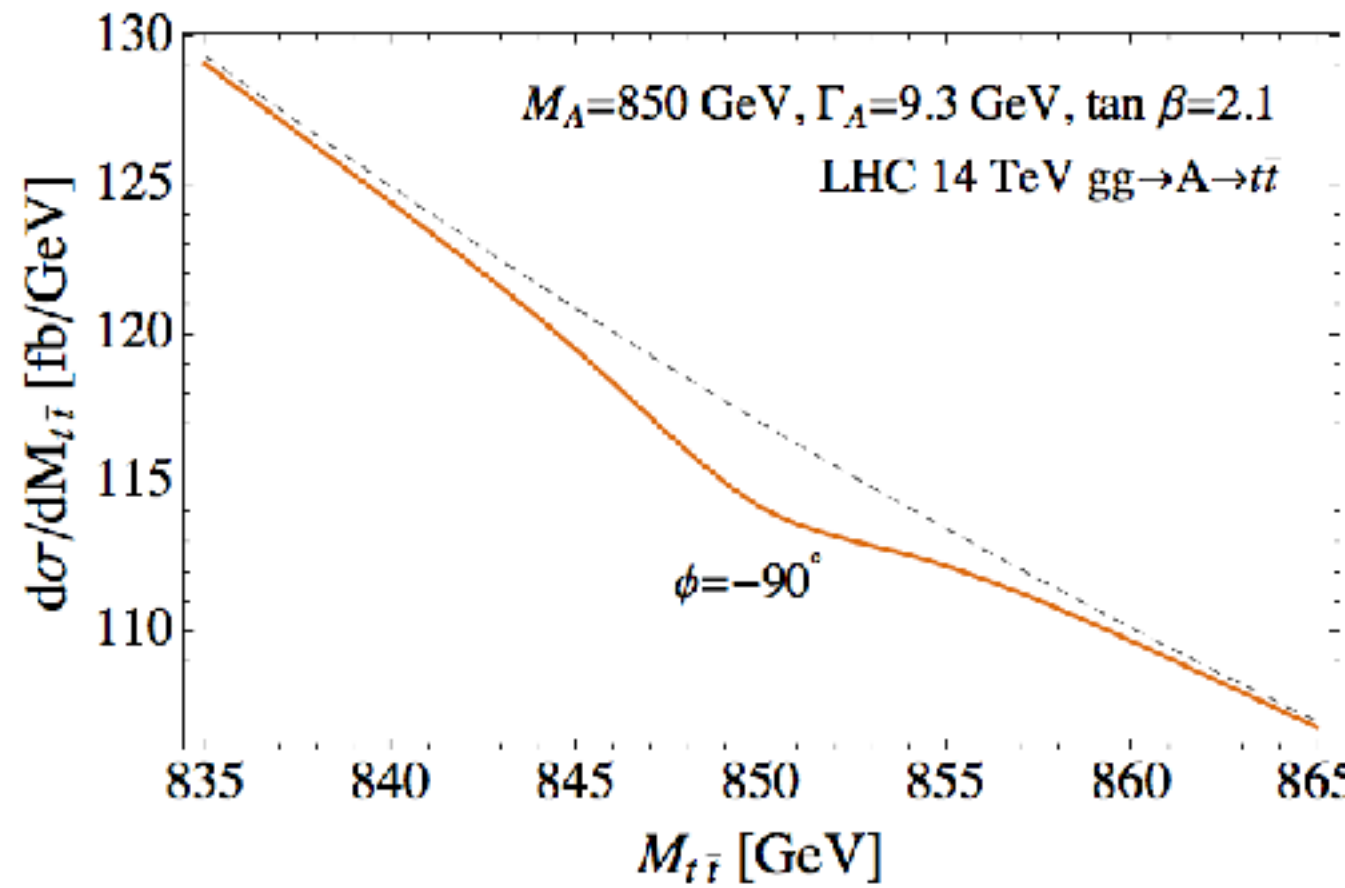

ttbar resonance shapes

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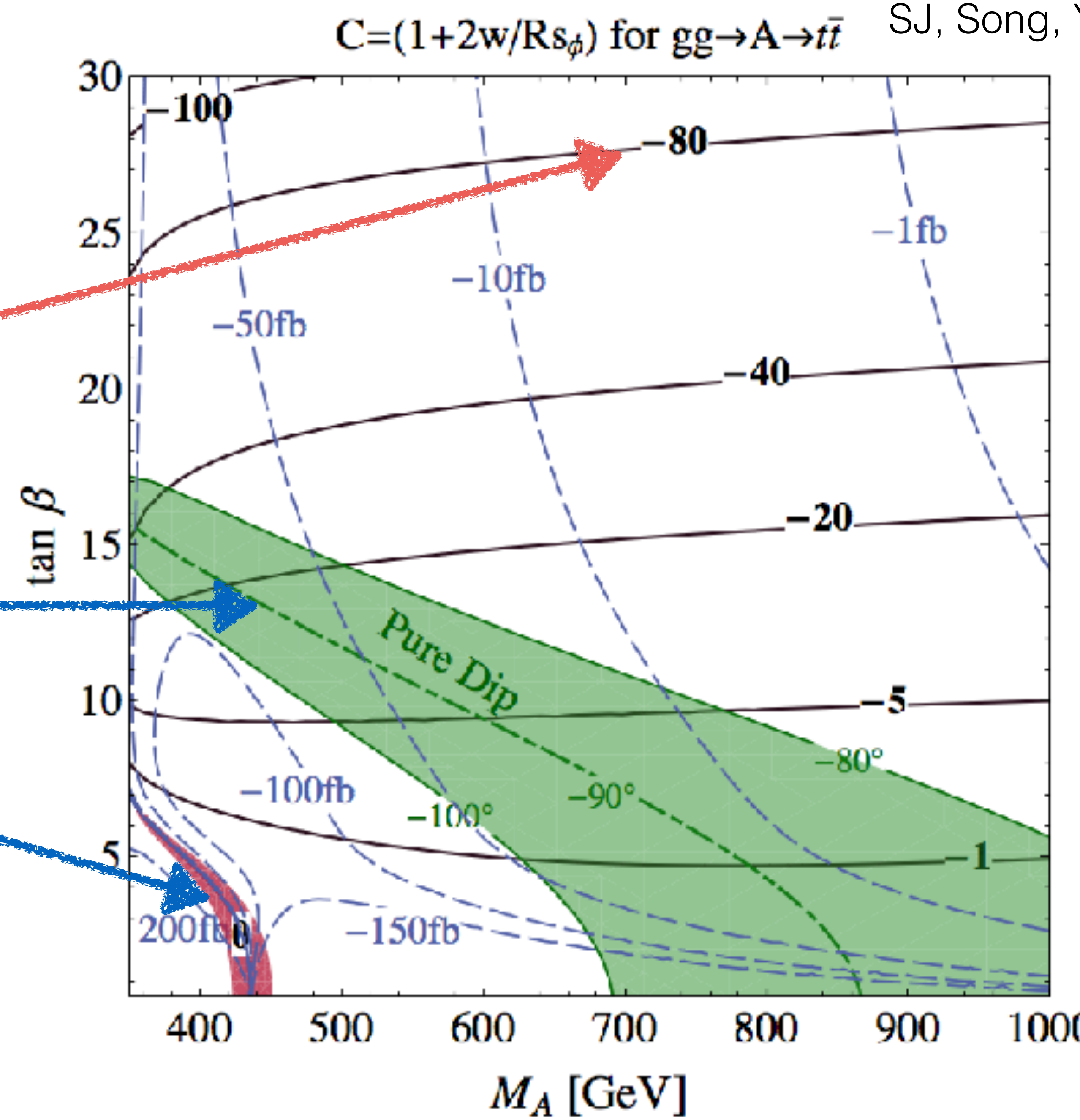
$$C = \left(1 + 2\frac{w}{R}s_\phi\right)$$

- Pure dip and nothingness regions.



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3. New LHC challenges and exciting possibilities

LHC Challenges

- M(ttbar) resolution is O(10) GeV at best, smearing/ canceling out any delicate shapes.
- Huge simulation time (varieties of line shapes, loop processes).

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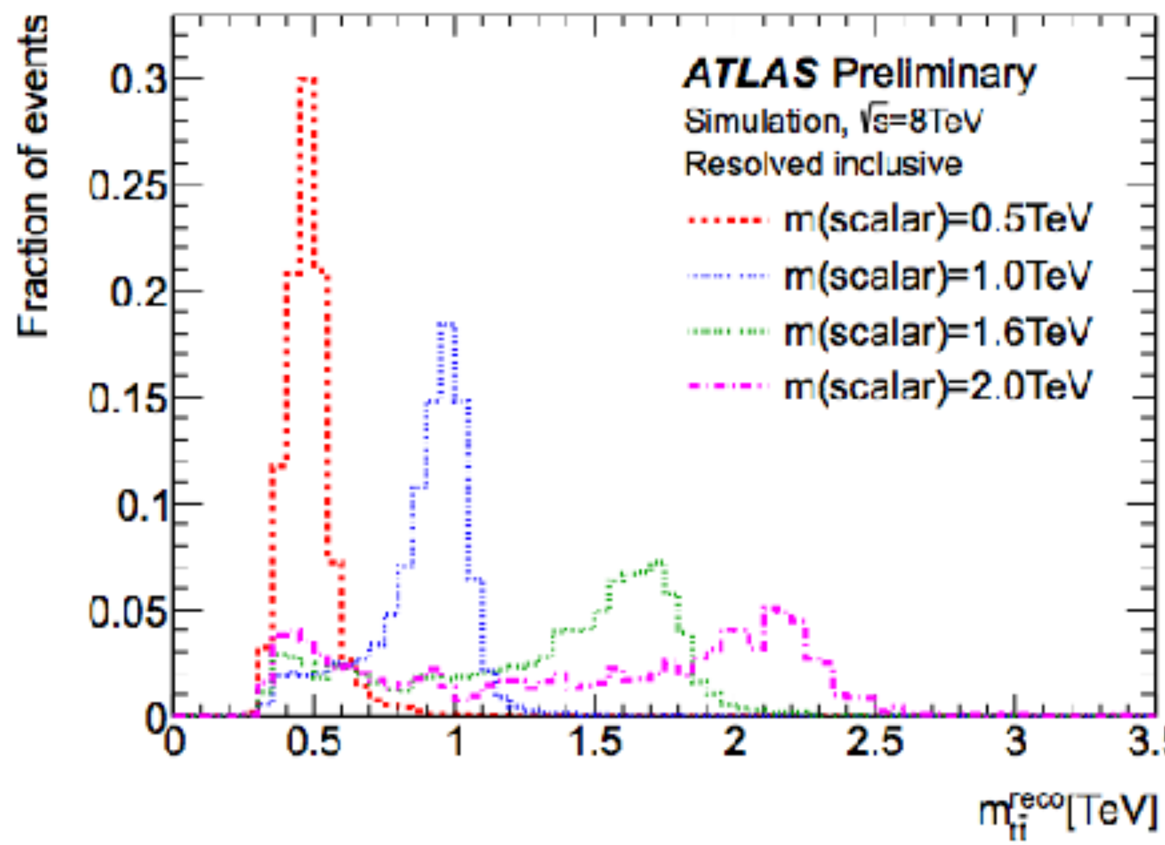
(CMS: 1309.2030)



NB: one can look for other channels: ttH, bbH, etc.
(J.Hajer et al, N.Craig et al.)

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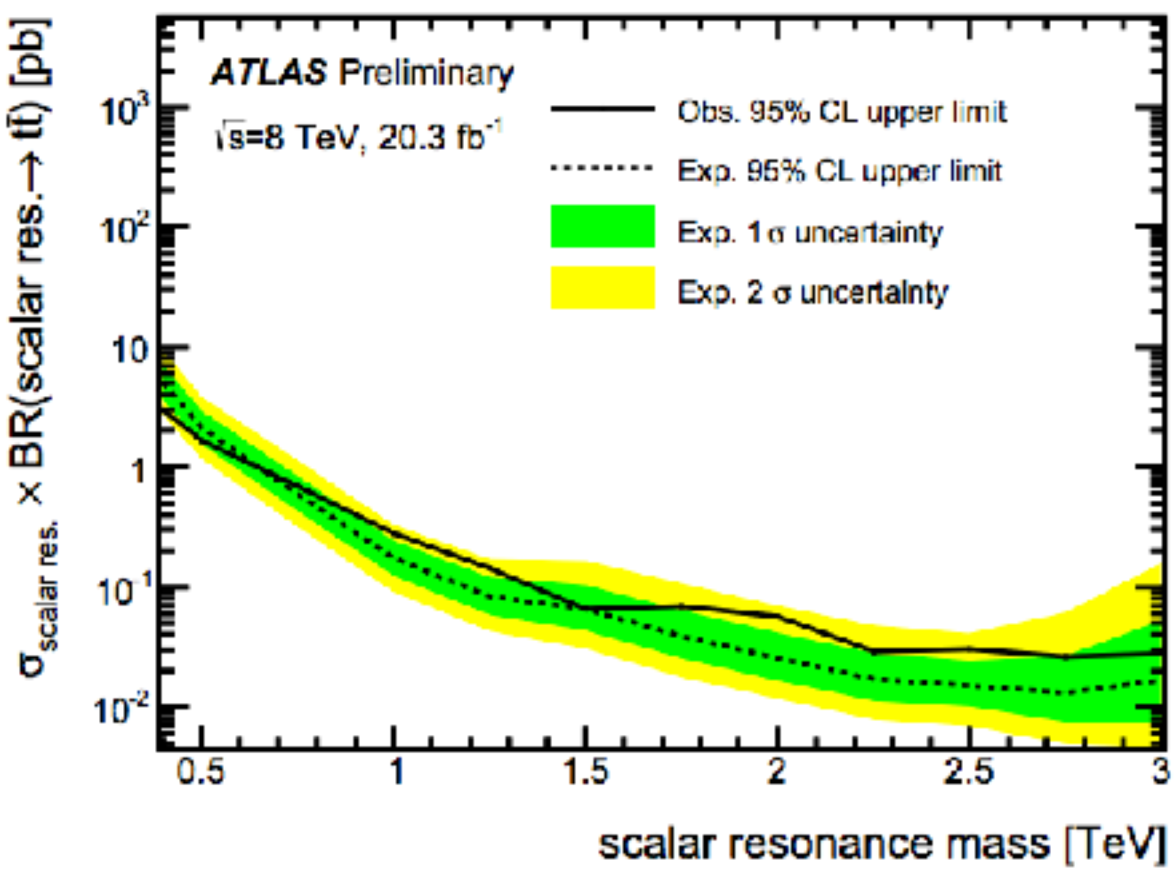
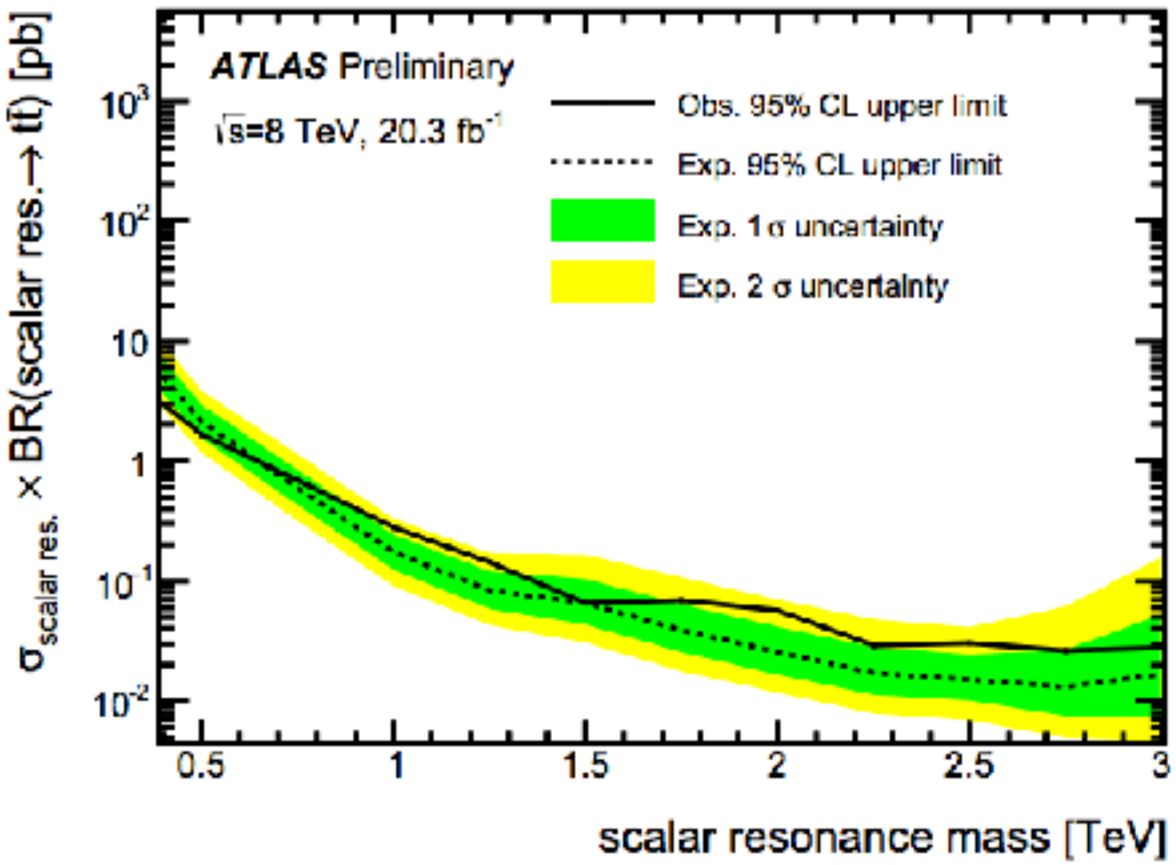
Current H/A->ttbar search



ATLAS-CONF-2015-009
(CMS: 1309.2030)

- Currently, no interferences are accounted for. (but all realistic effects are accounted)
- No predictions overlaid b/c no such scalar model.

Current H/A->ttbar search



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(CMS: 1309.2030)

BUT, this exp result is applicable to pure dips
(even w/o interference accounted for)!

Sensitivities to pure dip

- Same shapes for BW peaks and pure dips as if no interferences.
- Searches inherently sensitive to both excess(peak) and deficit(dip)—just deviation.
- Thus, current results apply to pure dips as is now.

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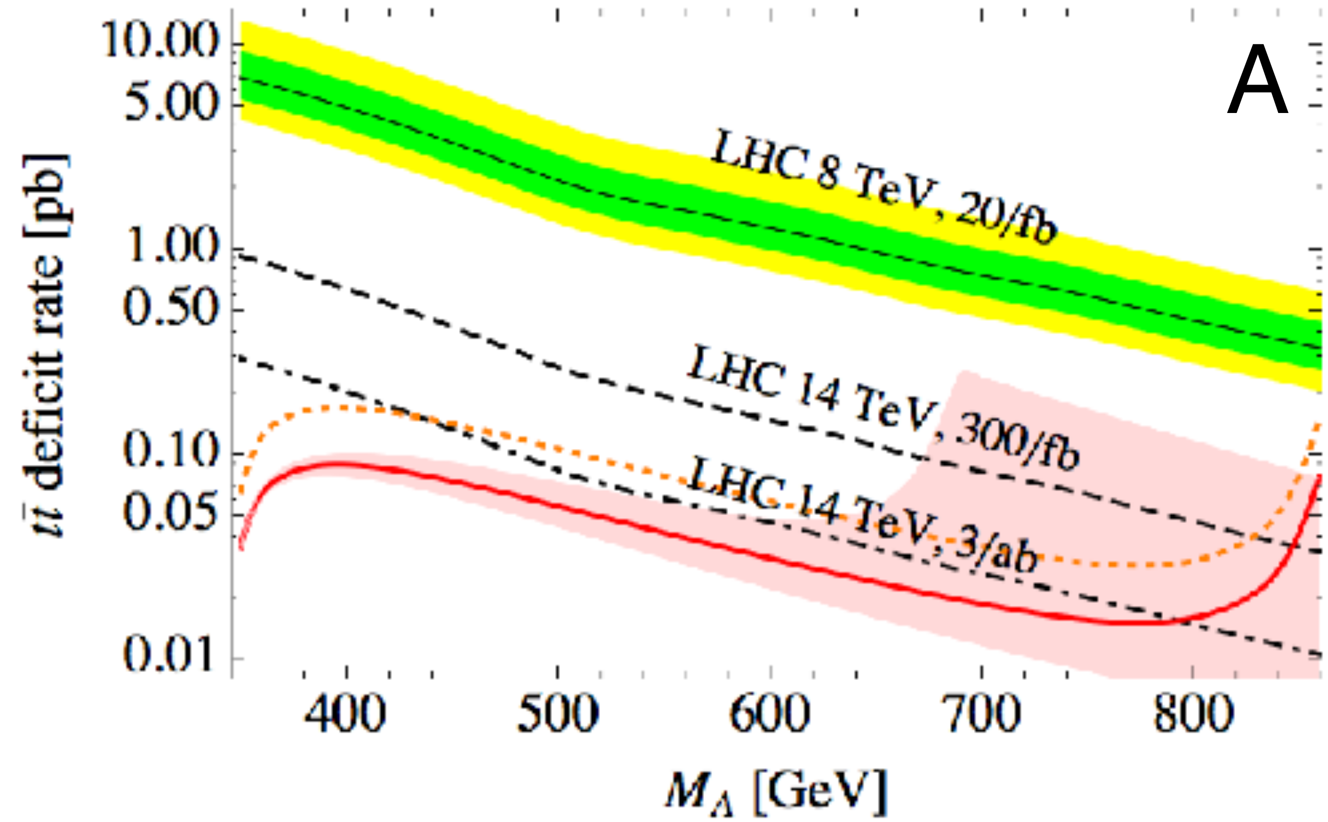

$$\sigma(H/A) \cdot BR(H/A \to t\bar{t}) \cdot \left(1 + 2\frac{w}{R}s_\phi\right)$$

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

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Summary

- The qualitatively new interference effect generally arise in MSSM/2HDM in heavy Higgs Golden channels.

- A few ideas to circumvent the LHC challenges were proposed, but many more are plausible/needed.

- Can arise more generically in various new models and channels.

Are we missing any deficits or nothingness?!