Di-Higgs production at hadron colliders in the 2HDM: invariant mass distributions

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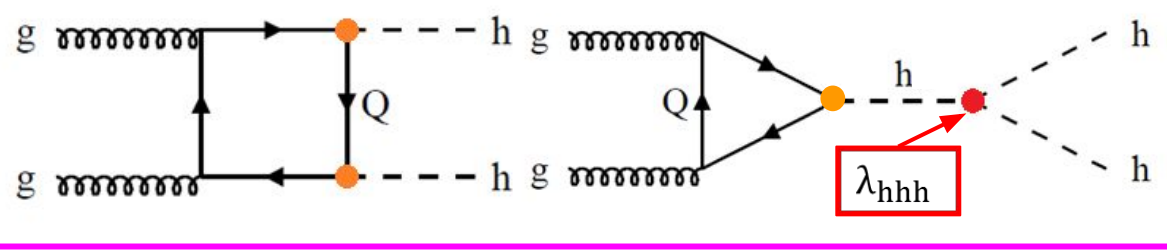
Di-Higgs production (gg → hh)

Dominant process at the LHC → Gluon Fusion

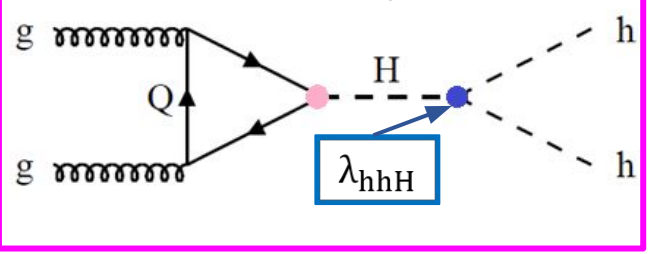
➢ Free parameters of the 2HDM:
(Type I and II are analysed)

$$m_h,\ m_A,\ m_H, m_{H^\pm},\ m_{12}^2, v,\ \cos(\beta-\alpha),\ \tan\beta$$

the continuum



resonant diagram



Diagrams that exist in the SM:
They have a negative interference

Diagrams that are sensitive to triple Higgs couplings

To obtain the cross section prediction for this process we use a modified version of the code **HPAIR** that contains the **2HDM** model.

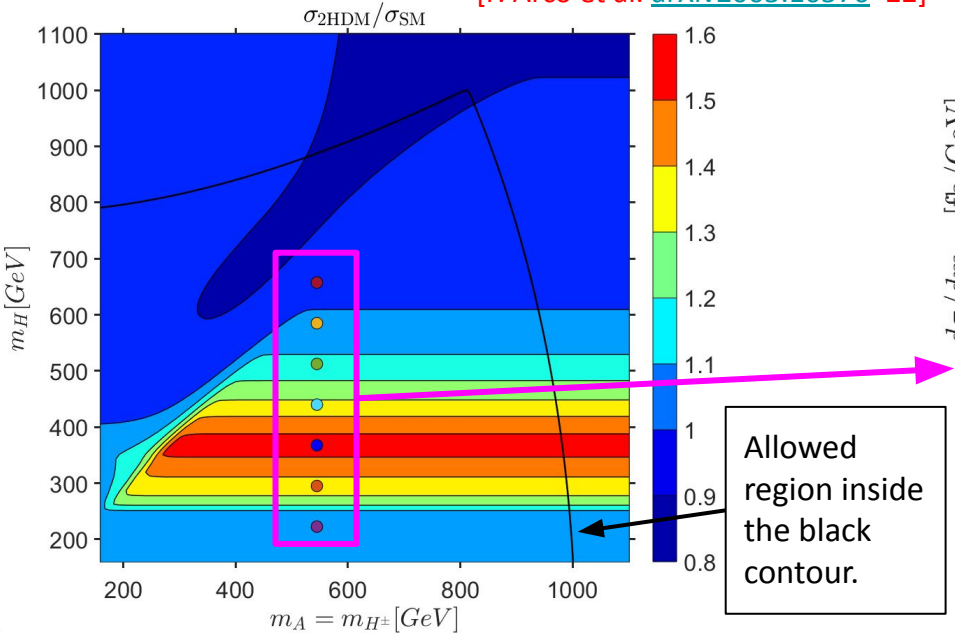
[Abouabid et al. arXiv:2112.12515 '21]

1. Effect of the mass of the heavy Higgs

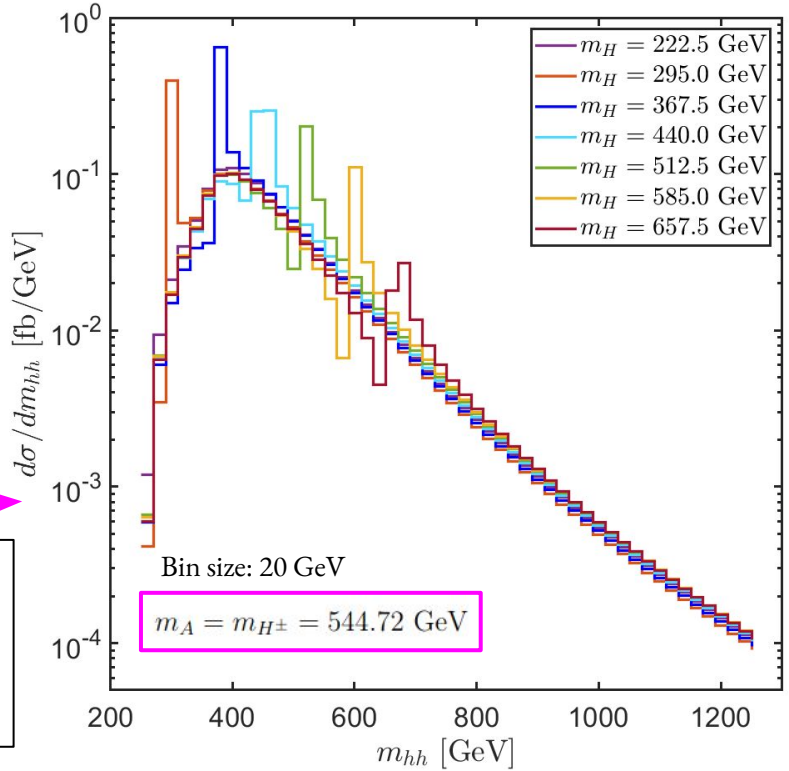
➢ We vary the mass of the heavy Higgs boson leaving the rest of the parameters of the model fixed.

BP: Type I, $\cos(\beta-\alpha)=0.2$, $\tan\beta=10$, $m_{12}^2=m_H^2\cos^2\alpha/\tan\beta$

[F. Arco et al. arXiv2005.10576 '22]



Allowed region inside the black contour.

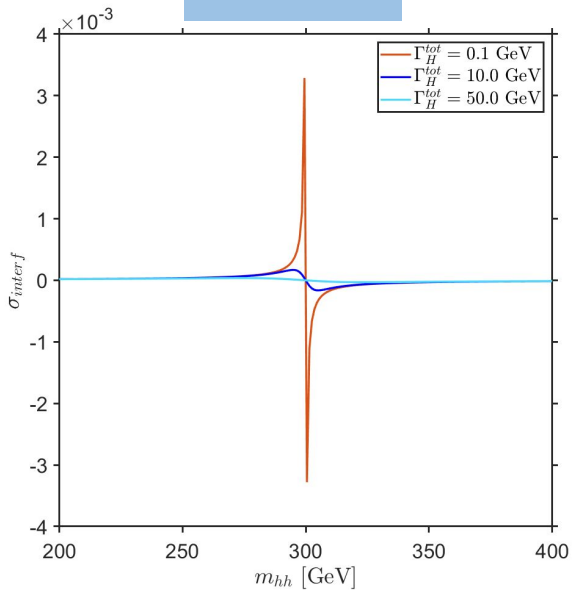


Enhancement in the total cross section is resonance dominated. **Location** of the resonance is related to the mass of **H**

2. Effect of the total decay width

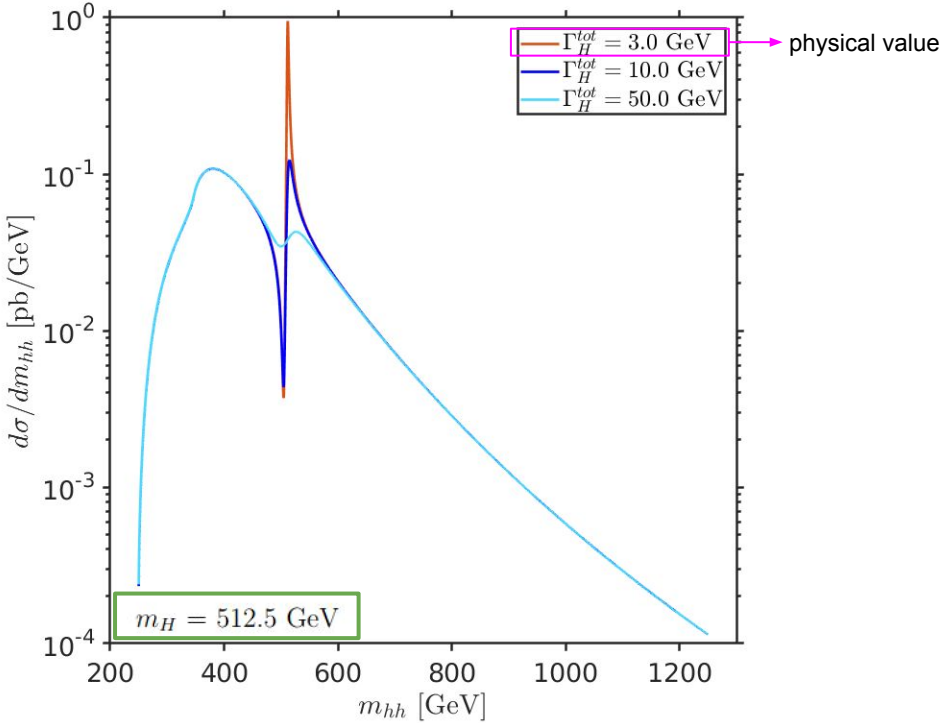
$$\frac{1}{Q^2 - M_{h/H}^2 + i\Gamma_{h/H} M_{h/H}}$$

Toy model



$$\sigma_{\text{interf}} \propto \frac{Q^2 - m_H^2}{(Q^2 - m_H^2)^2 + m_H^2 \Gamma_H^2}$$

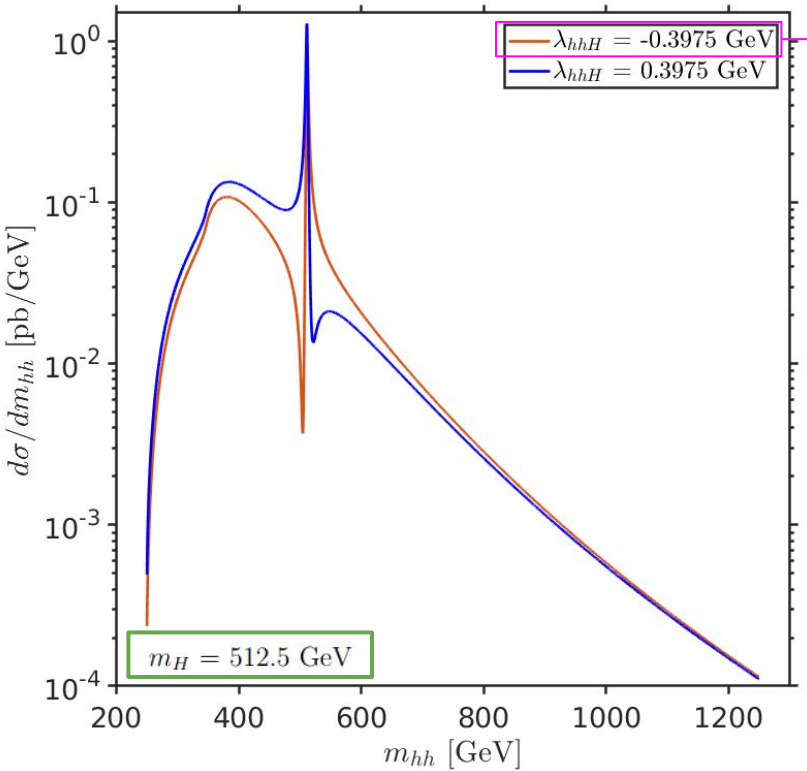
➢ For the green point of the previous benchmark plane we artificially change the total decay width of the heavy Higgs H:

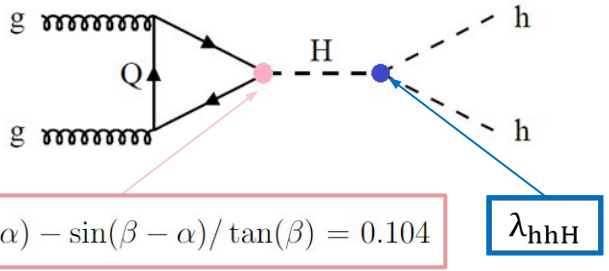


For larger **total decay widths** the **height** of the resonance changes but the width where the effect can be seen does not change.

3. Effect of the couplings

➢ What is the effect of the couplings on the invariant mass distributions ?

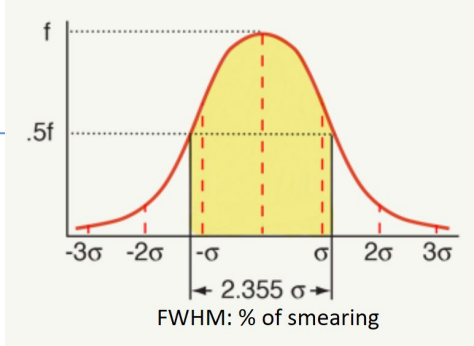




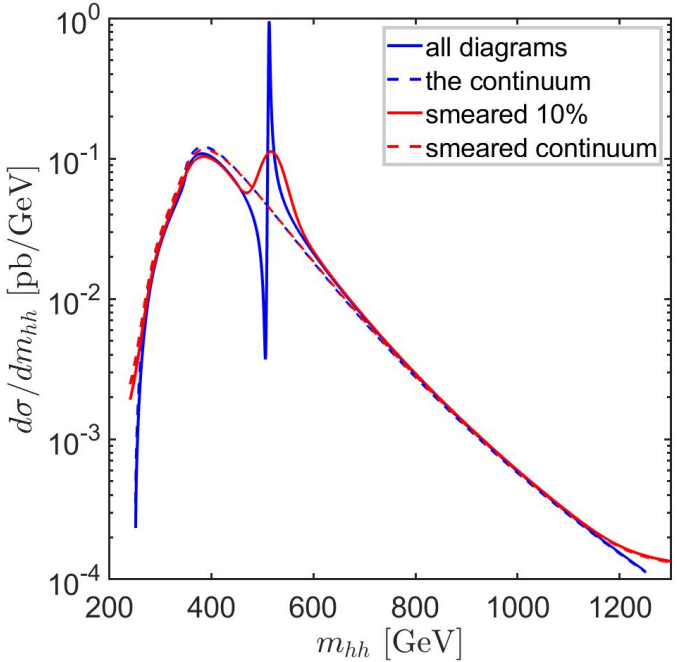
The **relative sign** of the top Yukawa and the BSM coupling to the heavy Higgs gives a **structure** to the resonance:

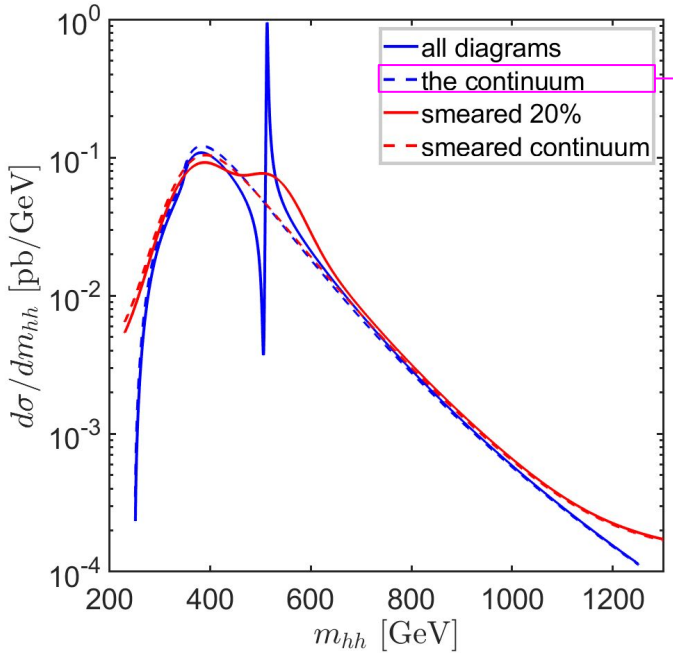
sign $(\lambda_{hhH} \cdot \xi_H^t)$	structure
+	peak-dip
-	dip-peak

Experimental challenges: smearing

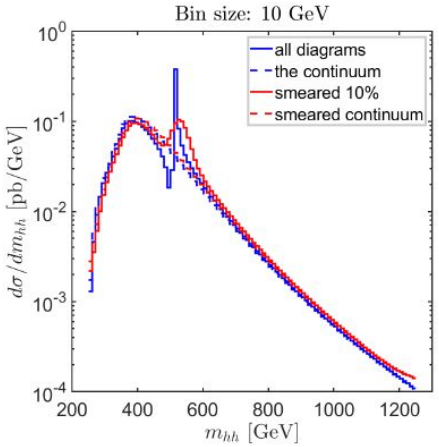


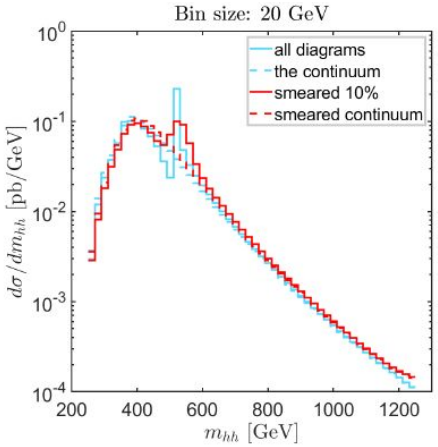
- Differential cross section measurements are affected by the finite resolution of particle detectors → observed spectrum is "**smeared**".
- We try to mimic this effect by artificially smearing the theoretical prediction introducing **Gaussian uncertainties** in the invariant mass.

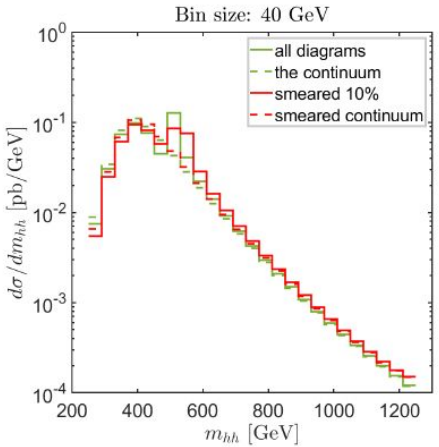


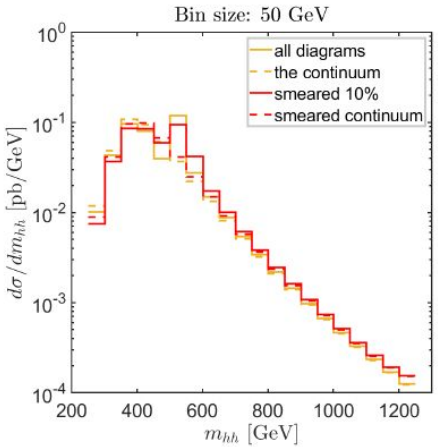


Smearing (10%)









- We define a value for the 'significance of the signal' according to the excess of the number of events. Assuming: $\mathcal{L} = 6000\ \text{fb}^{-1}$.

events below resonant smeared contribution

events below continuum smeared contribution

$$R = \frac{|N^R - N^C|}{\sqrt{N^C}}$$

Bin size	R
10 GeV	3.03
20 GeV	3.03
40 GeV	3.04
50 GeV	2.94

Adding up both (smearing + binning) effects the resonance gets less significant.

Q: What determines (experimentally) a realistic scenario?

Conclusion

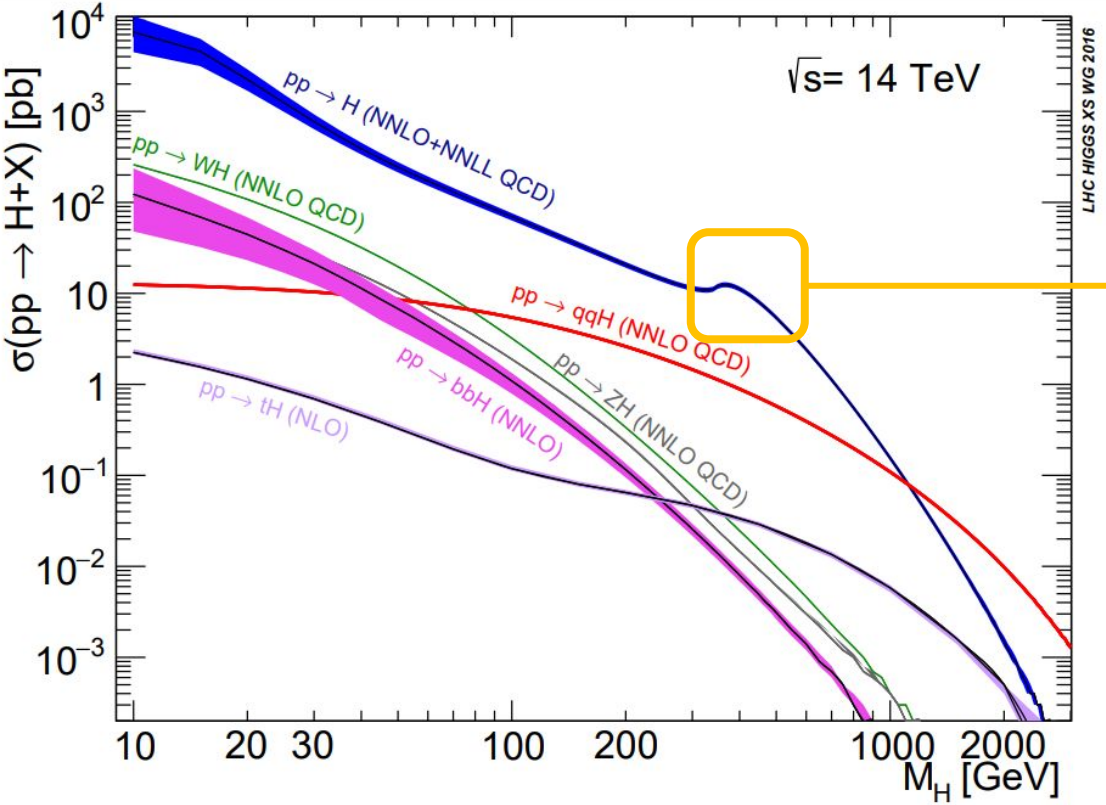
Invariant mass distributions give information about **resonant production** that can be embedded in BSM models:

- **mass** of the intermediate Higgs boson → **position** of the resonance.
- **total decay width** of the resonance → **height** of the resonance.
- relative sign of the **couplings** → **structure** of the resonance.

These effects may be (partially) washed out by experimental precision (**smearing**).

Q: How to choose a particular benchmark (best ranges for these parameters)?

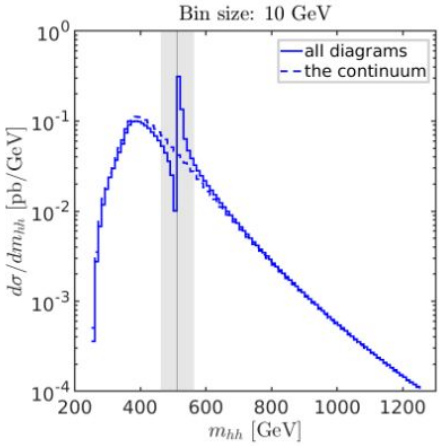
Backup: Single Higgs production

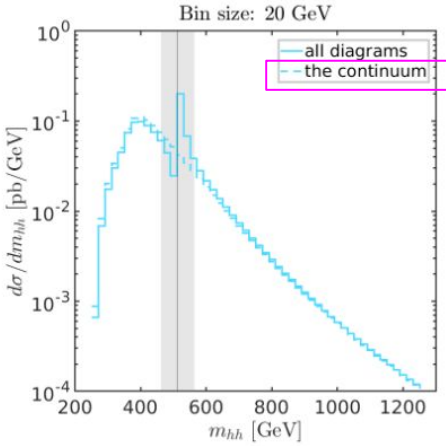


Top pair threshold → gives a hint on the results for Higgs pair production

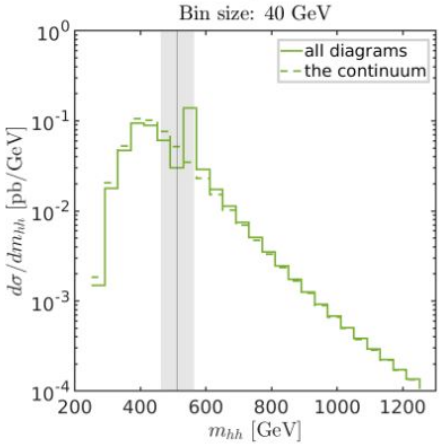
[LHC Higgs Working Group: CERN Yellow Report 4]

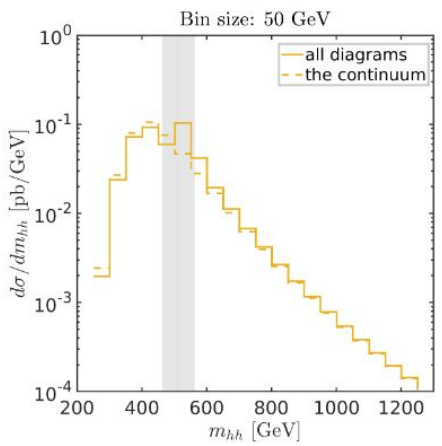
Backup: Effect of the bin size





box diagram + SM-like Higgs exchange





- Defining a window of the resonant enhancement of:

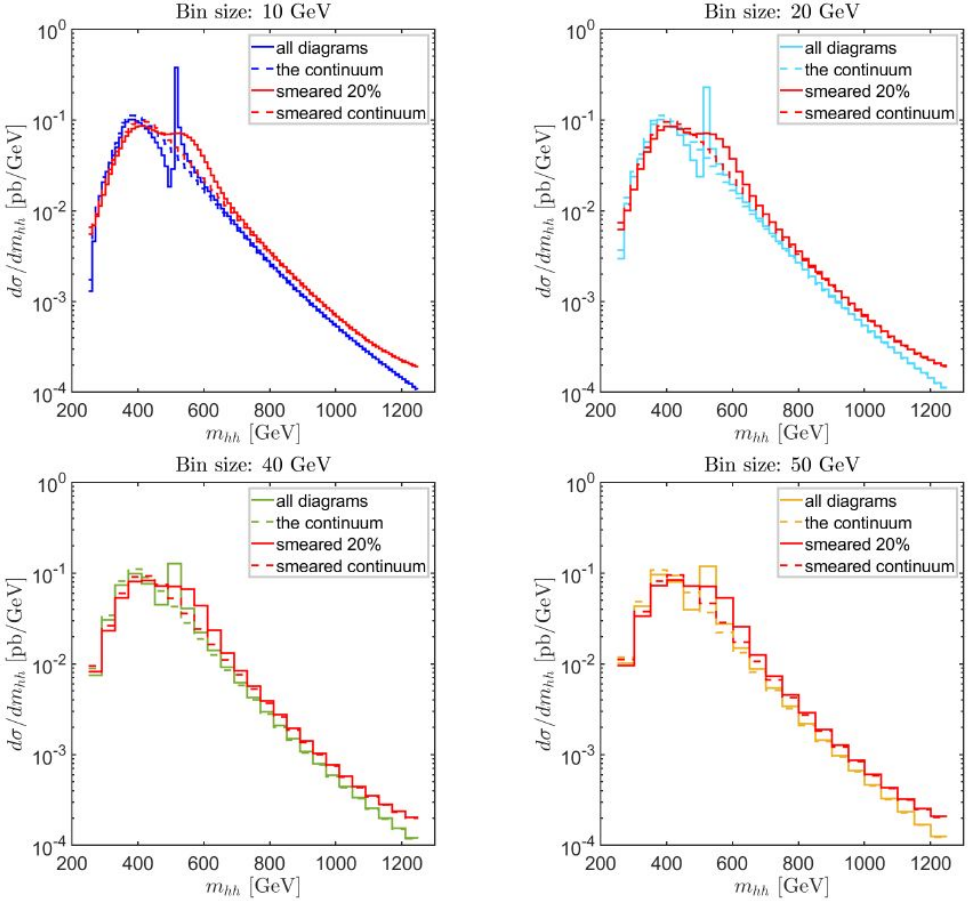
$$m_H = 512.5 \pm 50 \text{ GeV}$$

- The significance of the signal decreases as the bin size increases.

- The structure persists.

Q: What determines (experimentally) a realistic bin width?

Backup: Smearing (20%)



Bin size	R
10 GeV	2.46
20 GeV	2.45
40 GeV	2.42
50 GeV	2.32

The significance of the signal is smaller, the more smeared the data.