Signal interpretation in H$\rightarrow$WW high mass analysis

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Introduction

- We performed a search for a high mass resonance in the dileptonic H → WW channel
  - Currently published as PAS (cds.cern.ch/record/2803723)
  - To be combined with semileptonic analysis before published as paper

- The signal is assumed to have a certain non-zero width → Interference effects with background become relevant
- In the following, details are presented on the signal interpretation and on the interference contributions

Analysis strategy

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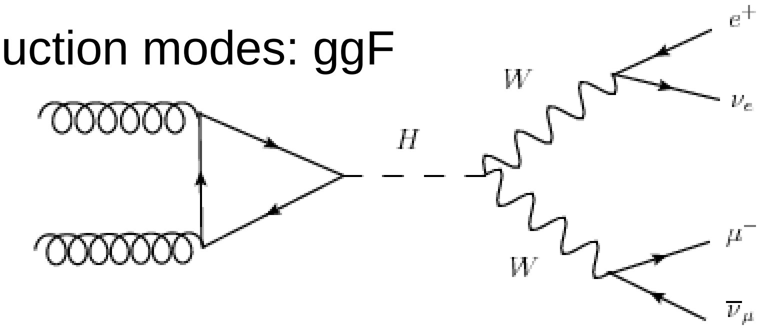
- Opposite lepton flavor
  H → WW → eμ + νν
  and same lepton flavor
  H → WW → ee/μμ + νν
  final states are considered

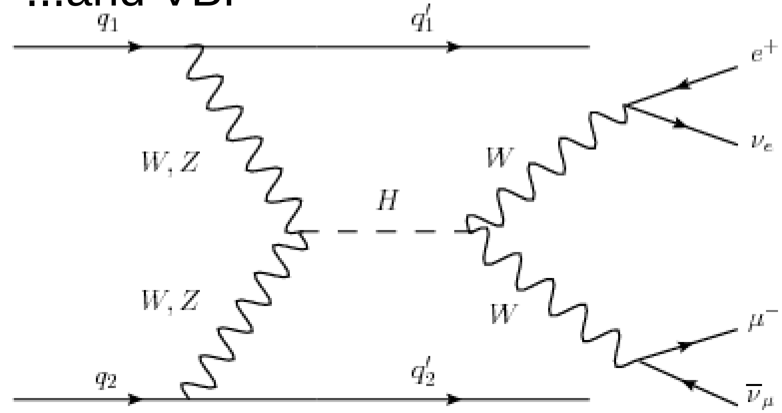
- Signal mass: 115 – 5000 GeV

- Events categorized by DNN:
  - ggF
  - VBF
  - background / untagged

Production modes: ggF



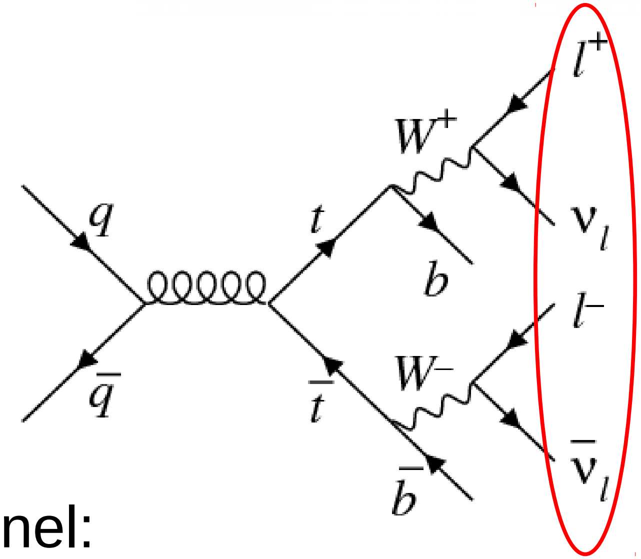
...and VBF



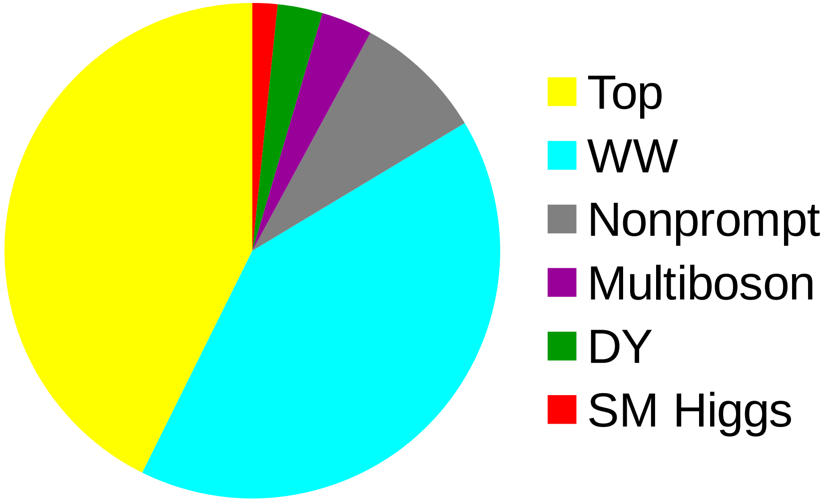
diagrams from arXiv:1305.1883

Backgrounds

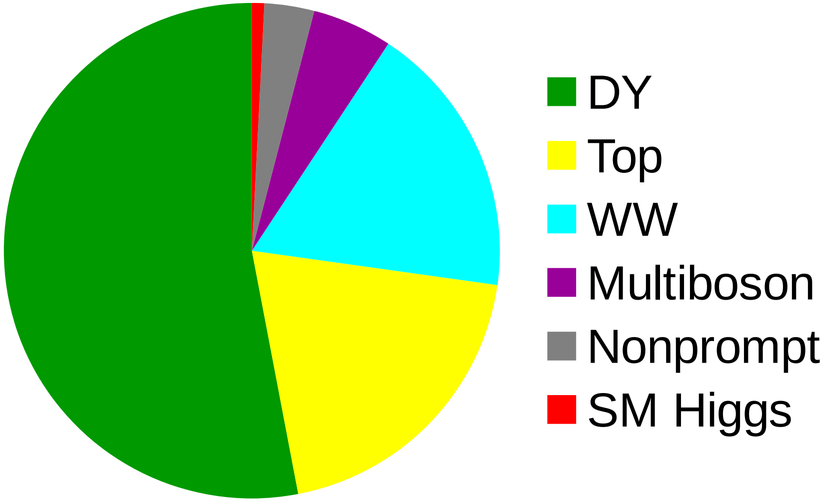
- Background from top quarks largest in eμ channel
- Z→ee and Z→μμ becomes dominant in ee and μμ channels



eμ channel:



ee/μμ channel:



Signal samples

- Signals were produced with POWHEG, and the W boson decay simulated with JHUGen
- For mass ≤ 1 TeV, assumes a width of a SM-like Higgs boson of higher mass
  - Small width in O(100) GeV range, but becomes large approaching TeV range
  - 647 GeV width for 1 TeV signal
  - Also includes width effects from Complex Pole Scheme
- Above 1 TeV, a width of half the resonance mass is assumed

  → Very large and unphysical widths

  → Reweighting the signal distributions to follow scenarios of smaller widths

Signal widths

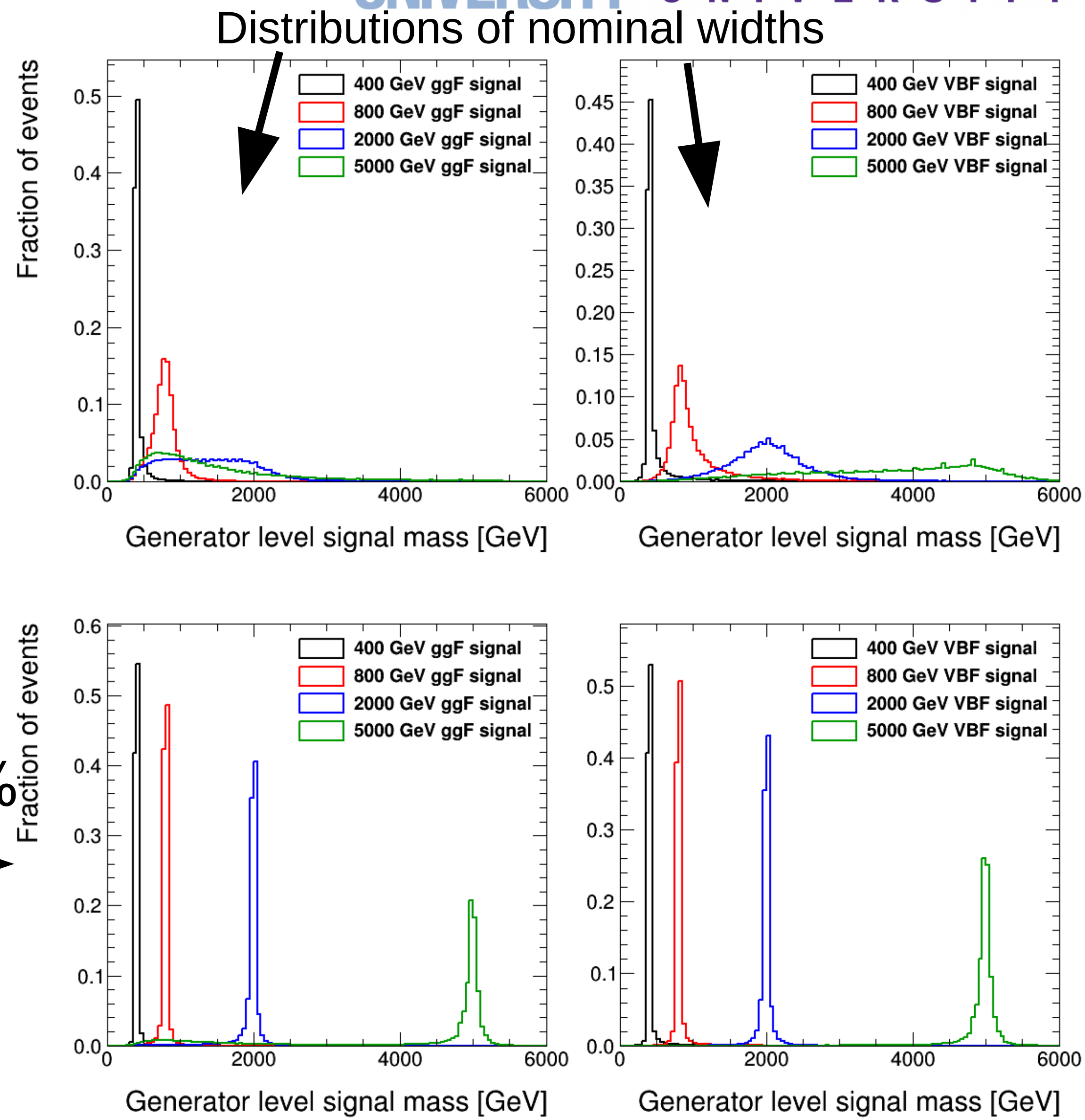
- An event with gen-level mass $\mathbf{m_H}$ from a sample with mean resonance mass **M** following width **G** is described by Breit-Wigner:

$$\frac{m_H \cdot G}{\left(M^2 - m_H^2\right)^2 + \left(m_H \cdot G\right)^2}$$

- The weight given per event is:
  - this function for “***G*** = *new width*“
  - over the same function with „***G*** = *CPS width*“
- Weights are normalized so integral over all events remains the same

Signal widths

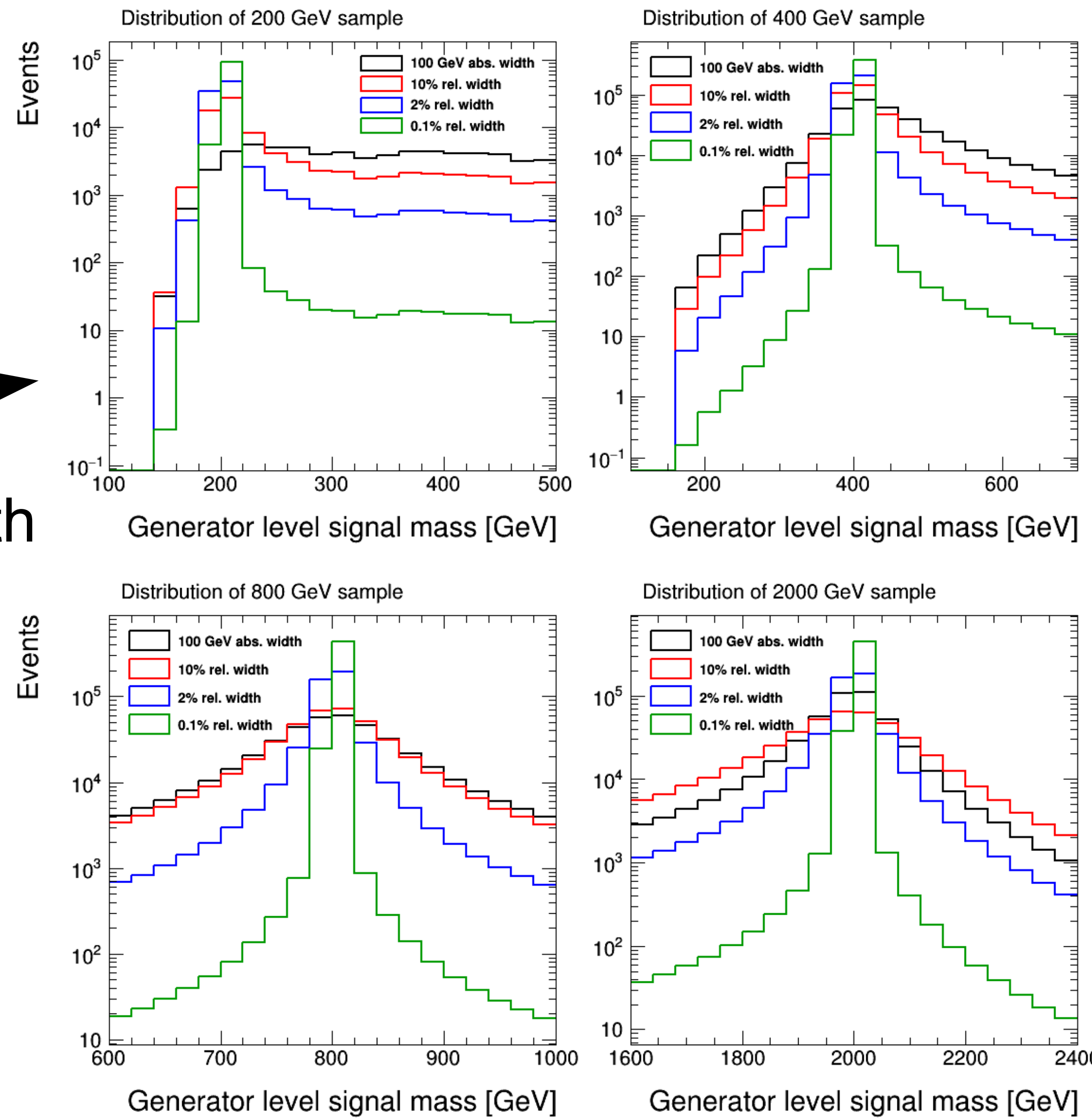
- Can consider fixed relative or absolute width
- For analysis: Considered relative widths of 0.1, 1, 2, 5, 10% w.r.t. resonance mass
- „Main scenario“ is 2% relative width



Signal widths

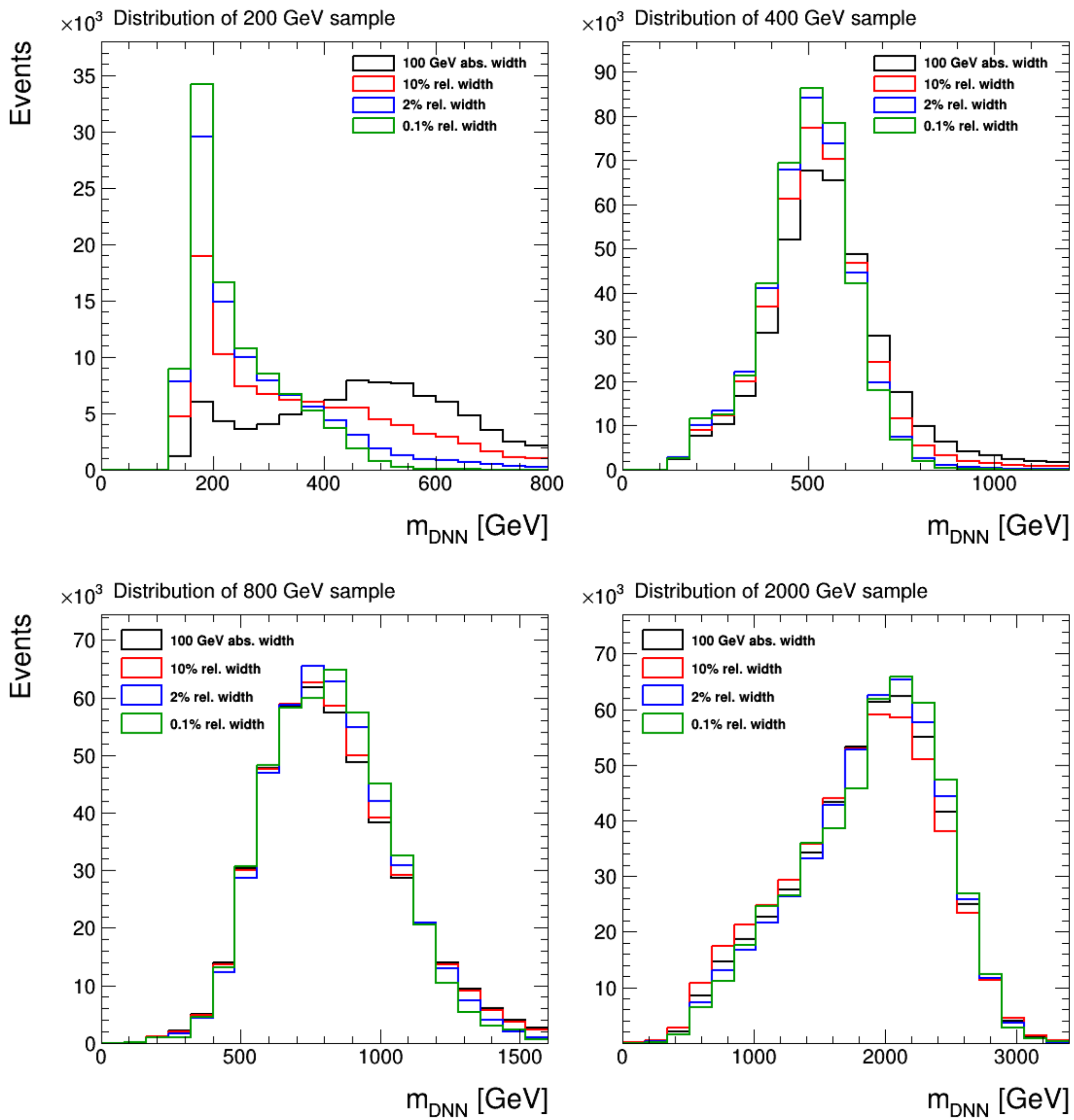
- Reweighting to different scenarios generally works fine, expect for low mass resonances
- Already produced with very low width

  → Problems with statistical precision when reweighting to follow larger width



Signal widths

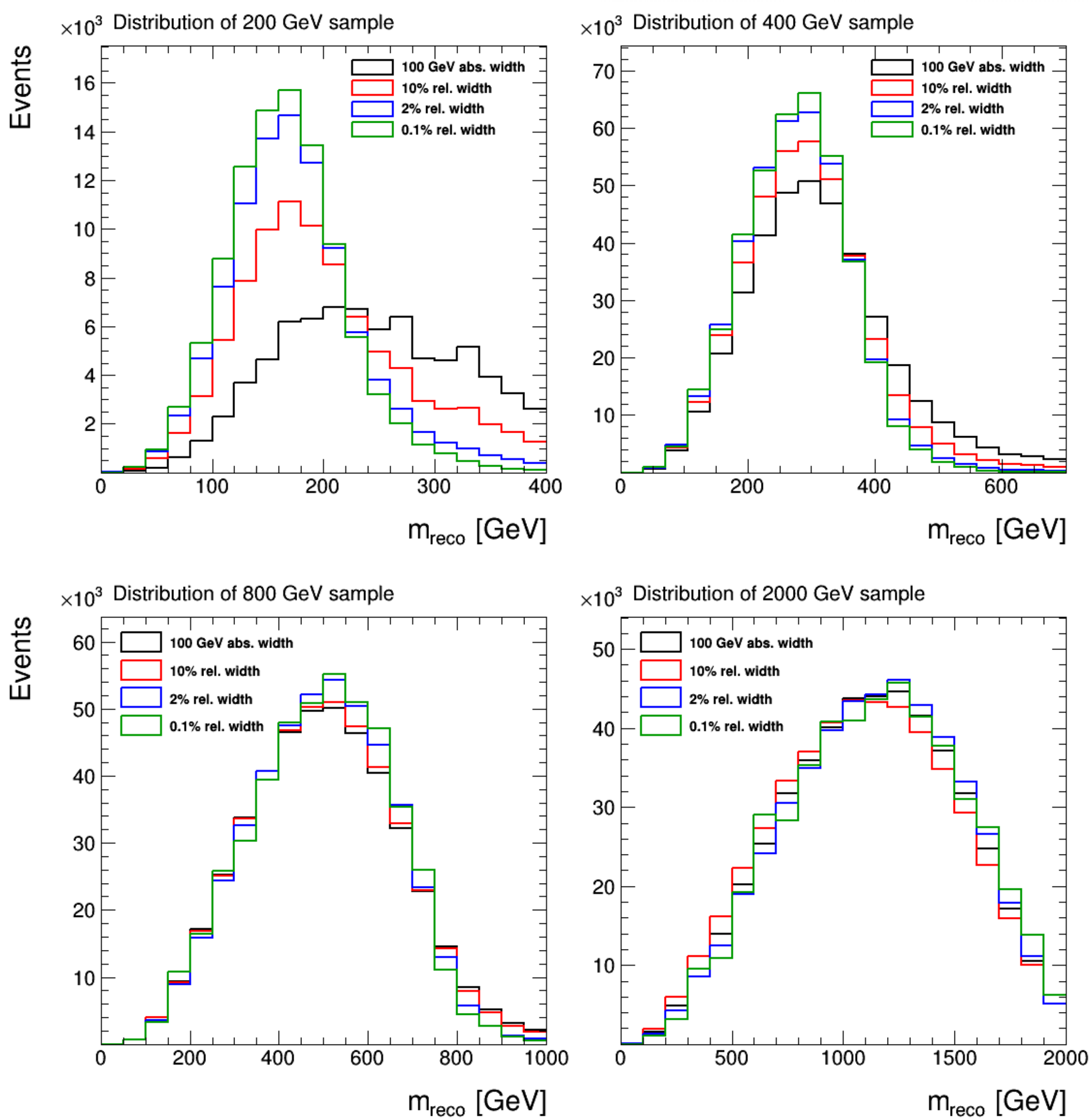
- No large difference for different widths in distribution over discriminating variable used in the analysis
  - Except when weighting low mass signals to larger widths
- Discriminating variable is DNN based



Signal widths

- No large difference for different widths in distribution over discriminating variable used in the analysis

- No big differences either looking at reconstructed discriminating variable



Interference

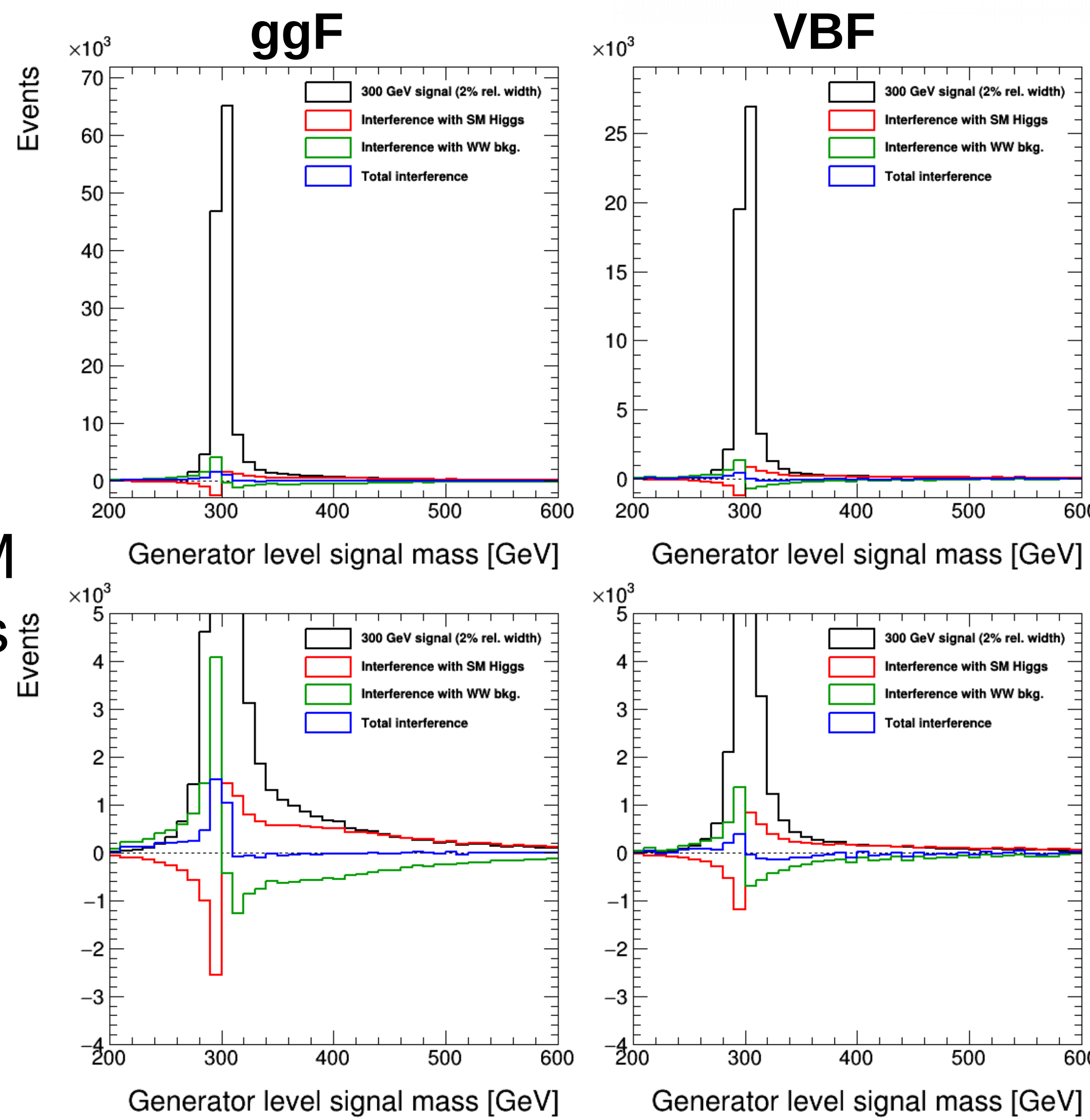
- An additional high mass resonance with non-zero width will interfere with background events:
  - ggF signal:
    - Non-resonant WW produced from gluons over quark loop
    - SM ggF H $\rightarrow$ WW
  - VBF signal
    - Non-resonant WW produced from vector boson scattering with two additional quarks
    - SM VBF H $\rightarrow$ WW

Interference

- Additional weights, applied on the high mass signal events, model the contribution from the interference
- Using MELA to obtain weights, using the packages:
  - JHUGenMELA (GitHub code)
  - MelaAnalytics
- MELA inputs are:
  - Mean mass and width of signal
  - Generator level variables: Four momenta & IDs of
    - Incoming particles
    - Final state particles
    - Other outgoing LHE particles

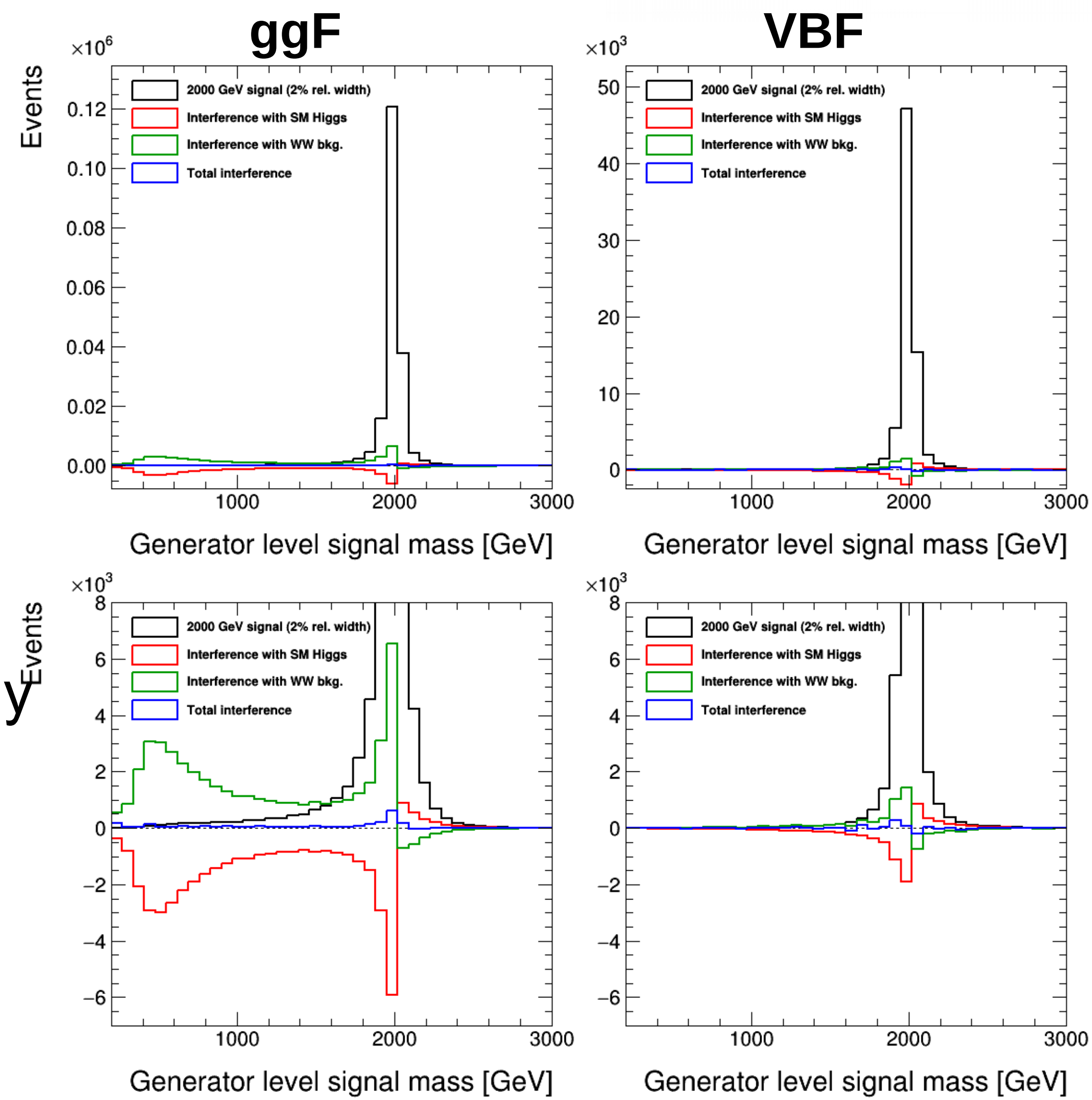
Interference

- Interference for 2% rel. width, 300 GeV signal
- Interference from non-res. WW and SM HWW mostly cancels out
  - Still has a small but non-negligible contribution to signal



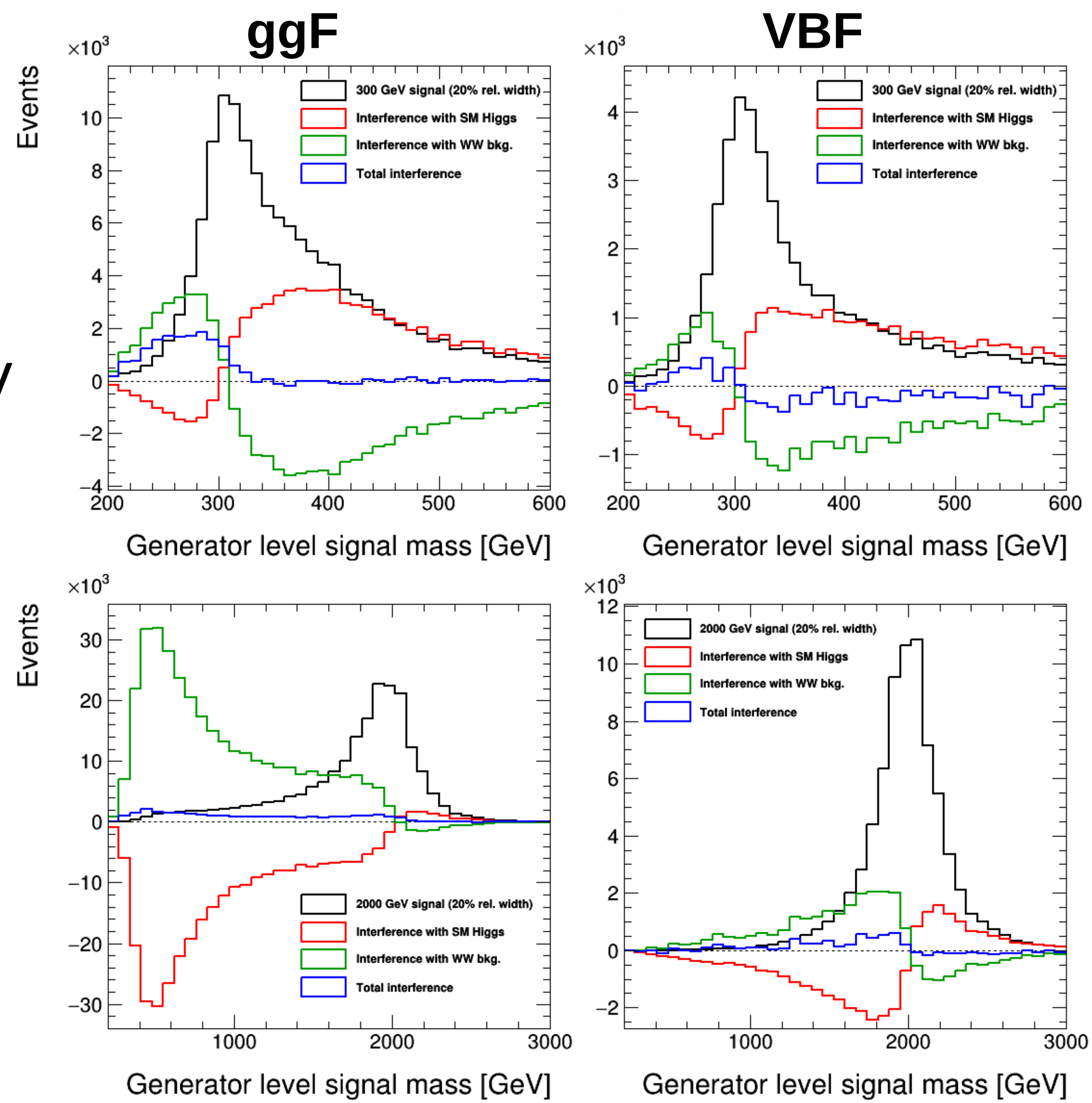
Interference

- Interference for 2% rel. width, 2000 GeV signal
- For high mass signals, larger contribution in low mass tail, for ggF only
  - Still mostly compensated by both interfering terms



Interference

- Interference for 20% rel. width signal
  - Top: 300 GeV
  - Bottom: 2000 GeV
- Contribution from interference much larger for larger widths



Interference

- Contribution to interference (whether constructive or destructive) is added to the signal by a factor of the square root of the signal strength modifier (“r”)

$$\begin{aligned} \text{Yield} &= \left(k \cdot A_{sig} + A_{SM} + A_{WW} + A_B\right)^2 \\ &= k^2 \cdot \boldsymbol{A_{sig}^2} + k \cdot 2 A_{sig} A_{SM} + k \cdot 2 A_{sig} A_{WW} + \dots \\ &= r \cdot \boldsymbol{S} + \sqrt{r} \cdot I + B \end{aligned}$$

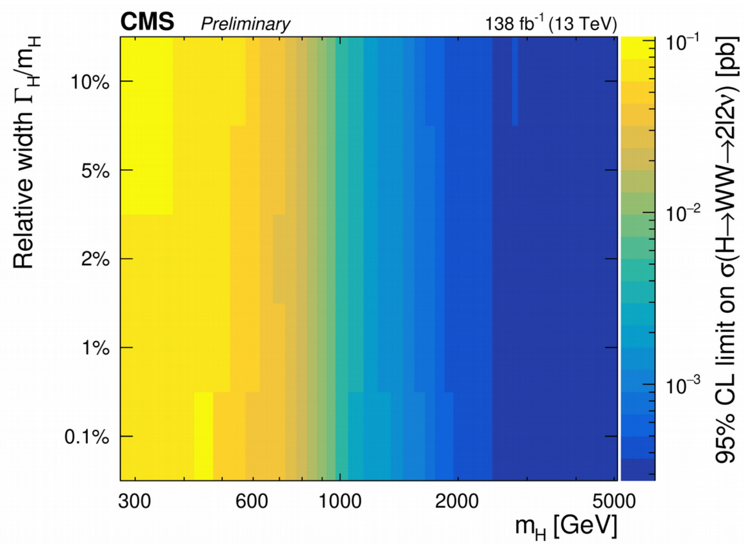
- To avoid a negative PDF of the interference term in the evaluation, consider combination of signal, background and interference (“SBI”) and scale S and B accordingly

$$S \cdot \left(r - \sqrt{r}\right) + SBI \cdot \sqrt{r} + B \cdot \left(1 - \sqrt{r}\right)$$

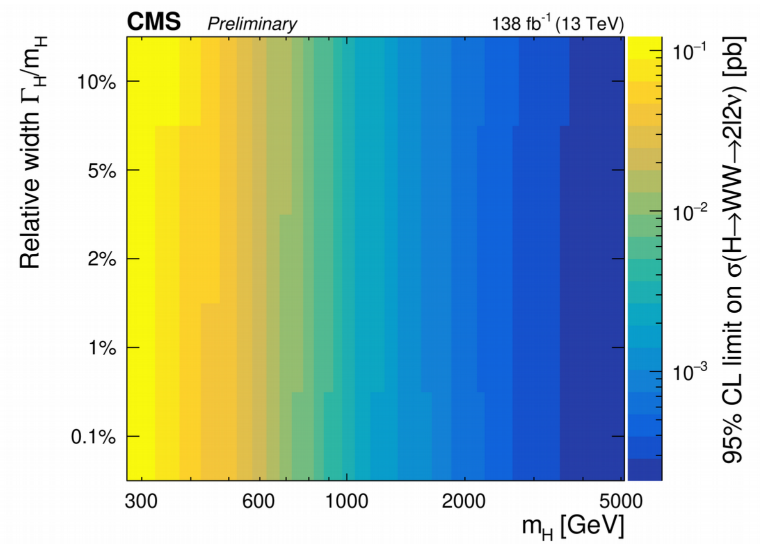
Results

- Results are given as a function of the signal contribution from VBF over ggF
  - This slide: Ratio as expected from SM-like Higgs boson
  - Results seem mostly independent on signal width

Observed 95% upper limits



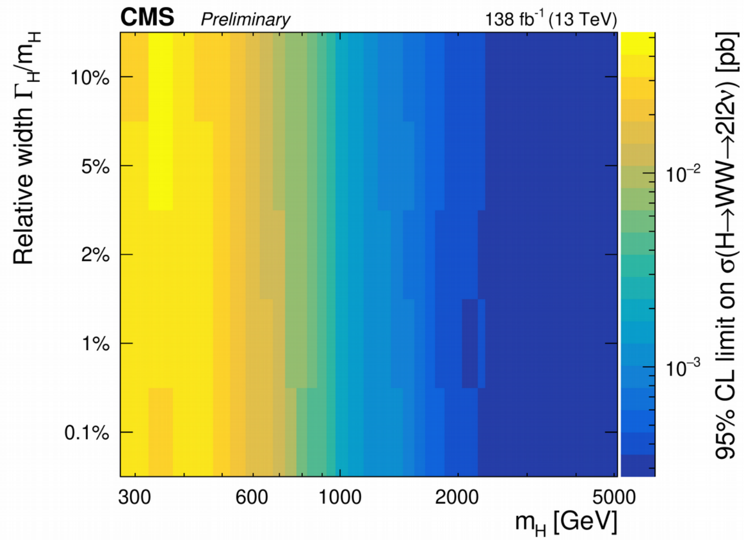
Expected 95% upper limits



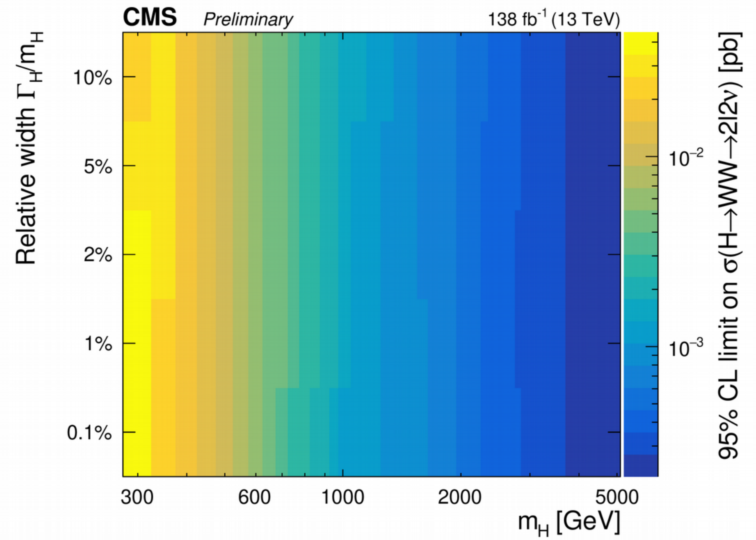
Results

- Results are given as a function of the signal contribution from VBF over ggF
  - This slide: VBF only
  - Results seem mostly independent on signal width

Observed 95% upper limits



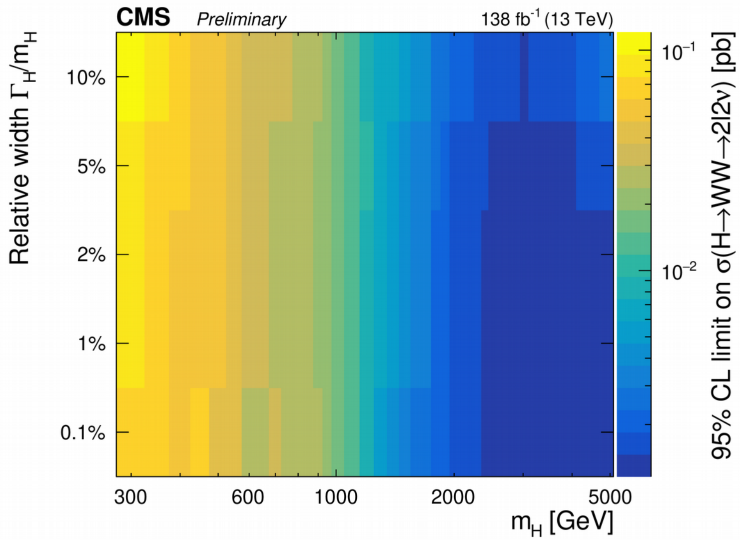
Expected 95% upper limits



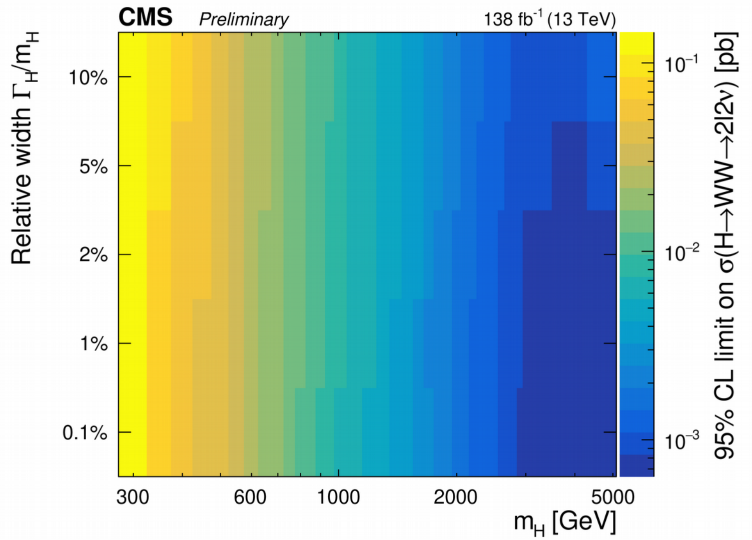
Results

- Results are given as a function of the signal contribution from VBF over ggF
  - This slide: ggF only
  - Higher (i.e., less sensitive) limits for larger widths, and also at large width and high mass

Observed 95% upper limits



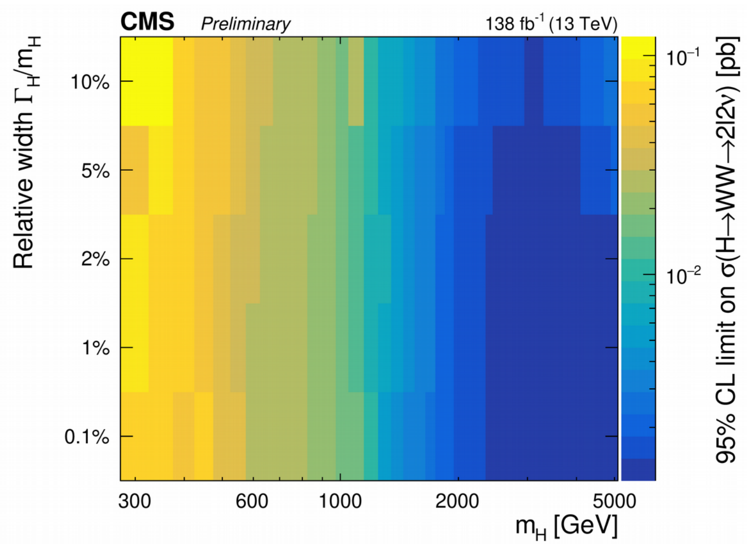
Expected 95% upper limits



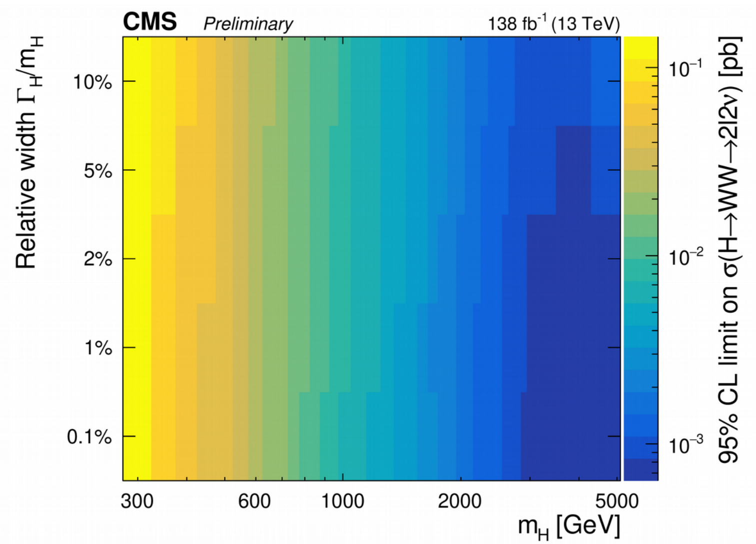
Results

- Results are given as a function of the signal contribution from VBF over ggF
  - This slide: Fraction left floating, determined by fit to data
  - Higher (i.e., less sensitive) limits for larger widths, and also at large width and high mass

Observed 95% upper limits



Expected 95% upper limits



Conclusion

- In the H→WW high mass analysis, we look for a signal with non-zero width
- We consider different width scenarios by reweighting the signal distributions to different Breit-Wigner models
- Interference is taken into account by additional weights, determined by MELA
  - Effect is small for our „main“ 2% relative width scenario, but is added regardless
- Results seem mostly independent between the considered width scenarios

Backup

Links

- Previous presentation last year by Andrei Gritsan on the JHUGen / MELA framework, see here

  → New features in the JHU generator framework: constraining Higgs boson properties from on-shell and off-shell production (arXiv:2002.09888)