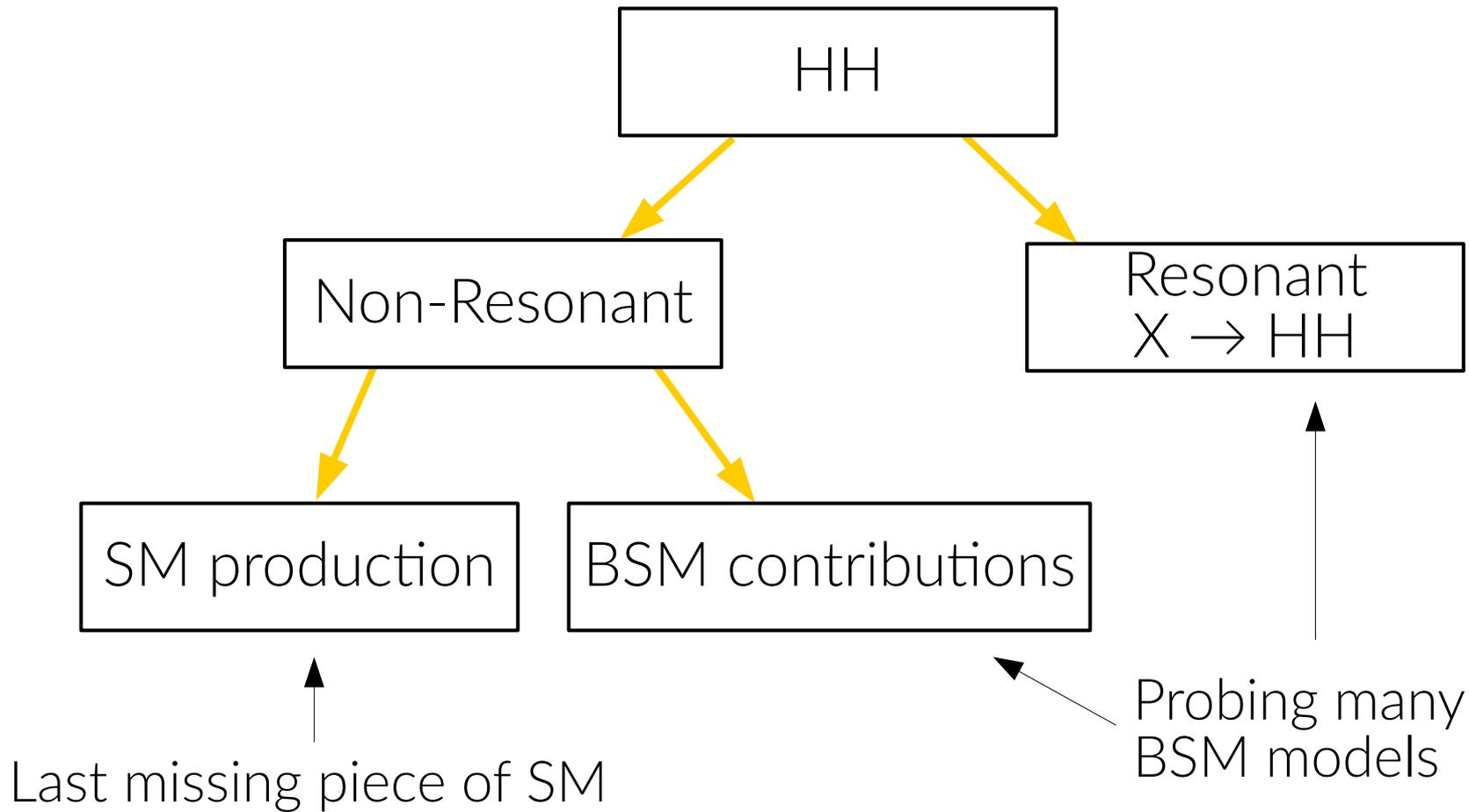




HH production at Run 2 and perspectives for the High-Luminosity LHC with CMS

Lucas Corcodilos
Johns Hopkins University
Lake Louise Winter Institute 2019
2/11/2019

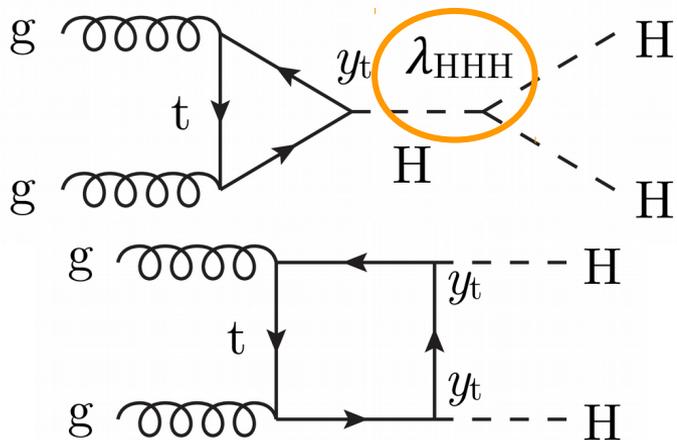
HH Search Breakdown



HH Search Breakdown

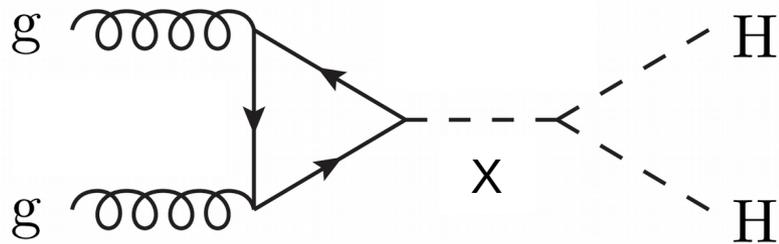
Non-Resonant

- Higgs boson self-coupling is a fundamental test of SM
 - Probes shape of Higgs potential
- SM predicts extremely small cross-section for HH prod.
 - 33.5 fb @ 13 TeV



Resonant

- Several accessible BSM models
 - Model independent searches
- Broad mass range
 - 250 – 3000 GeV
- Different search channels are complimentary



HH Complimentary Channels

$H \rightarrow bb$

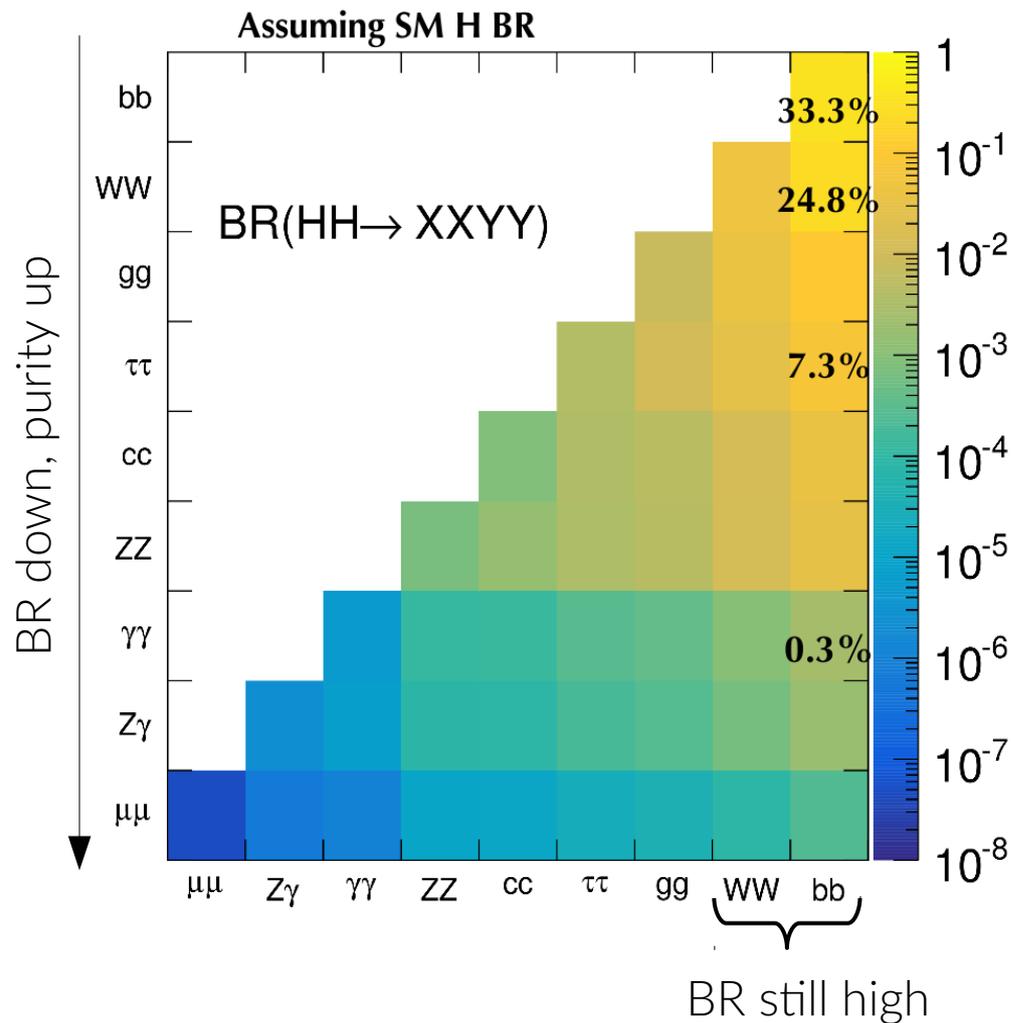
- High BR
- But high backgrounds from QCD

$H \rightarrow \gamma\gamma$

- Low BR but low backgrounds
- Excellent mass resolution

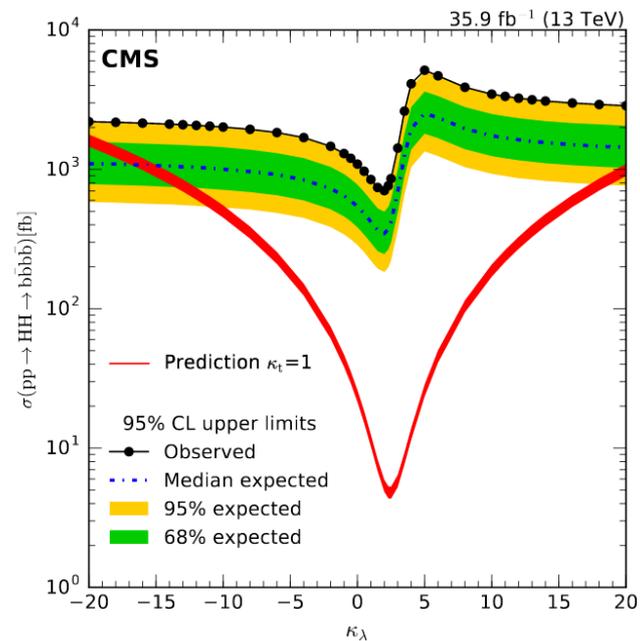
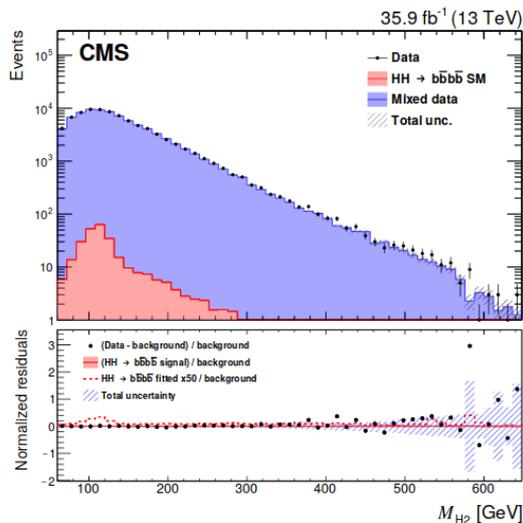
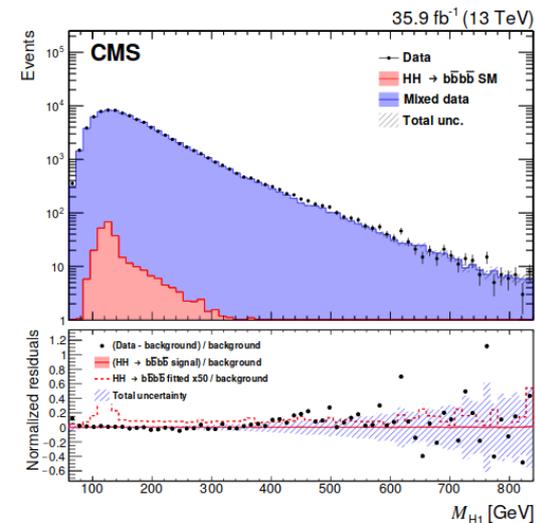
Four channels Combined for CMS in the 2016 dataset (35.9 fb^{-1})

- $bbbb$
- $bb\tau\tau$
- $bbWW$
- $bb\gamma\gamma$



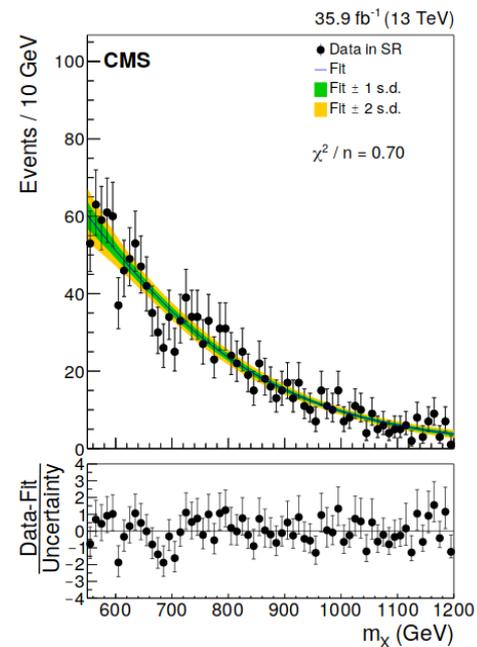
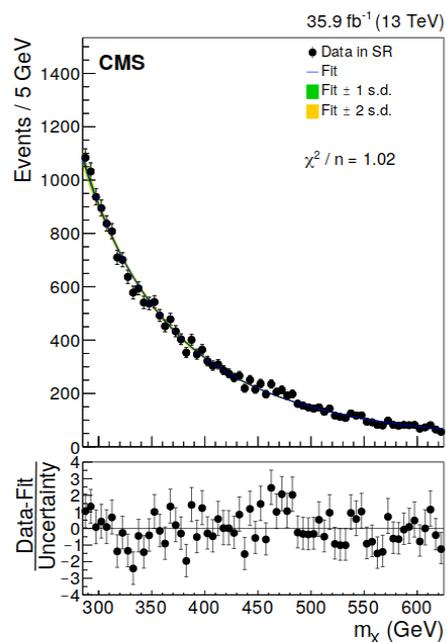
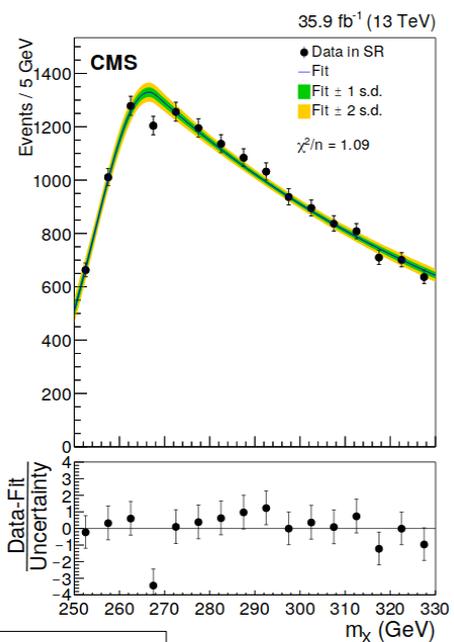
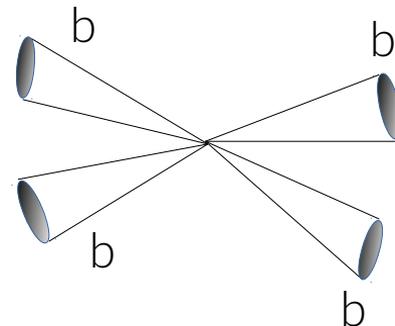
HH \rightarrow $bbbb$ - Non-resonant

- BDT classifier used to differentiate SM signal and background
- “Hemisphere mixing” used to artificially replicate background events from data for BDT training, validation, and optimization



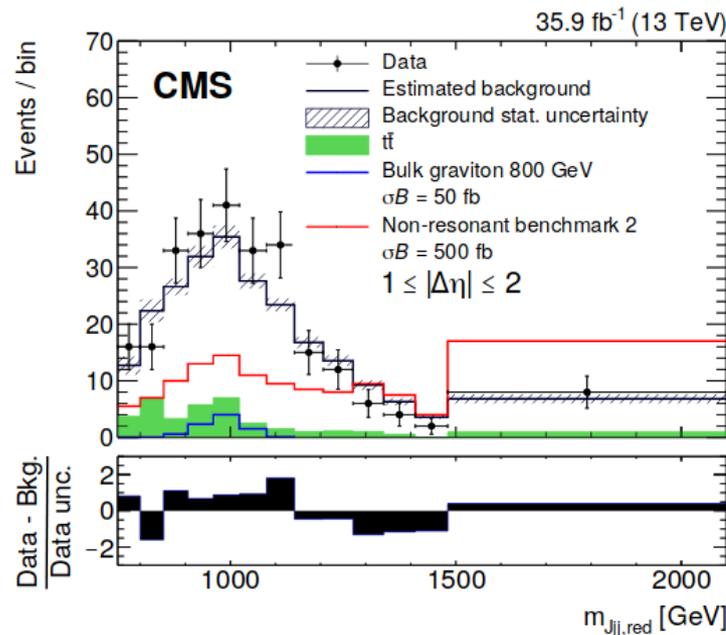
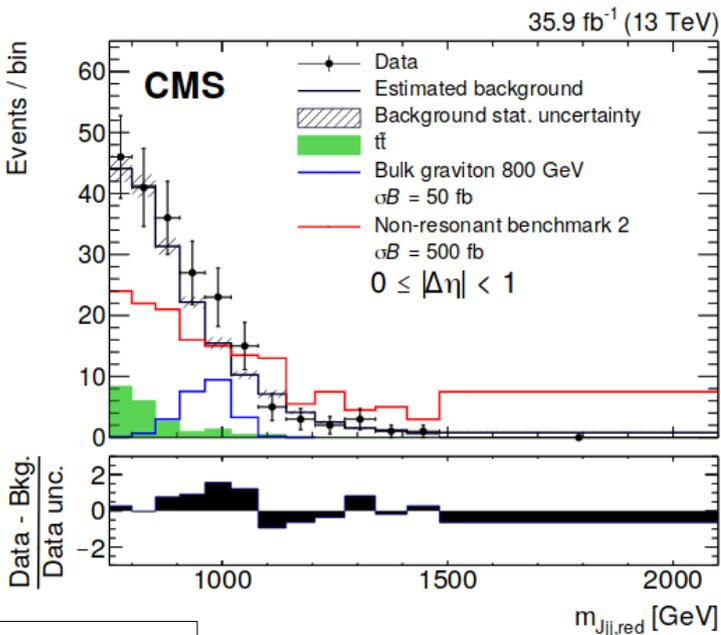
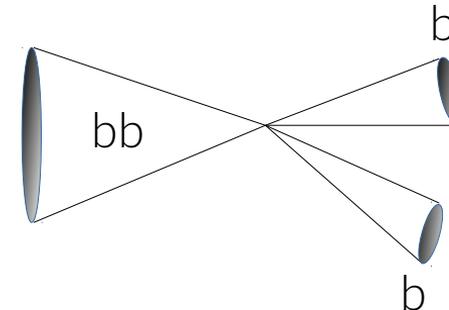
HH \rightarrow $bbbb$ – Resonant (Resolved)

- Resonance search in three mass regions
 - Spans 260-1200 GeV
- 4 b-tagged jets, data driven multi-jet estimate



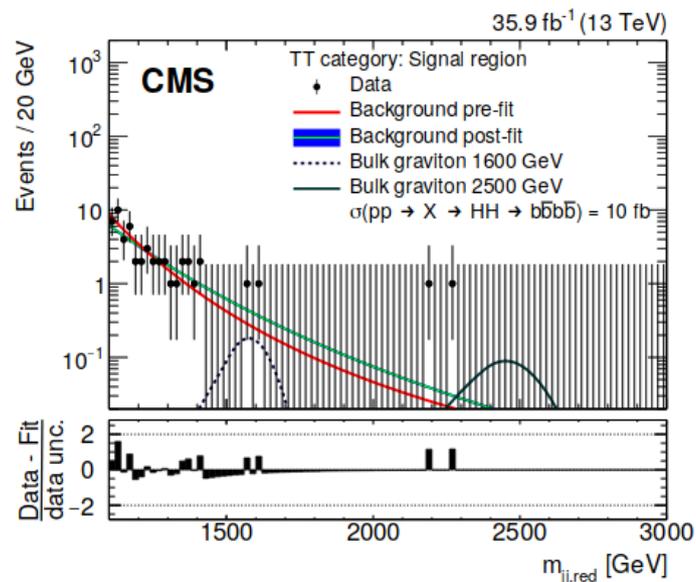
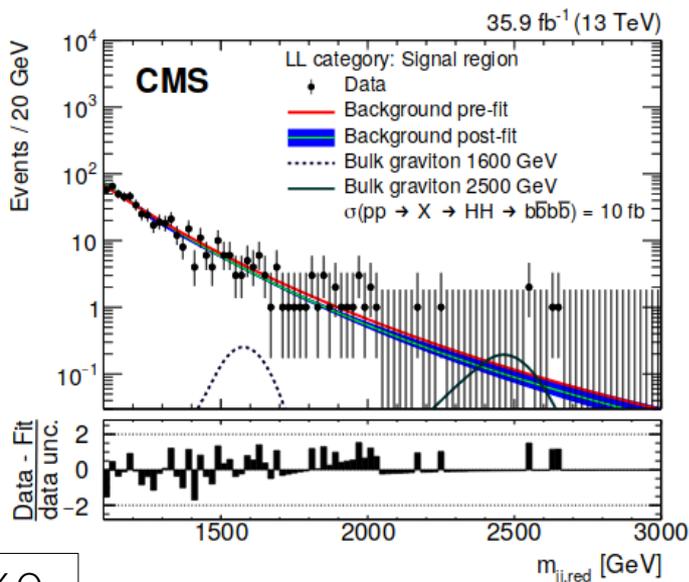
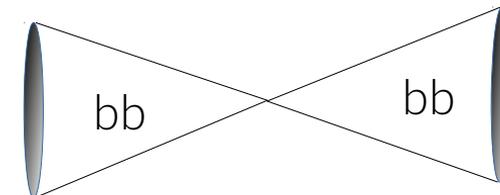
HH \rightarrow $bbbb$ - Resonant (Semi-Resolved)

- Resonance search from 750 to 3000 GeV
- High momentum \rightarrow half-boosted event topology
 - Tag double b “fat jet” and two resolved b jets



HH \rightarrow $bbbb$ – Resonant (Merged)

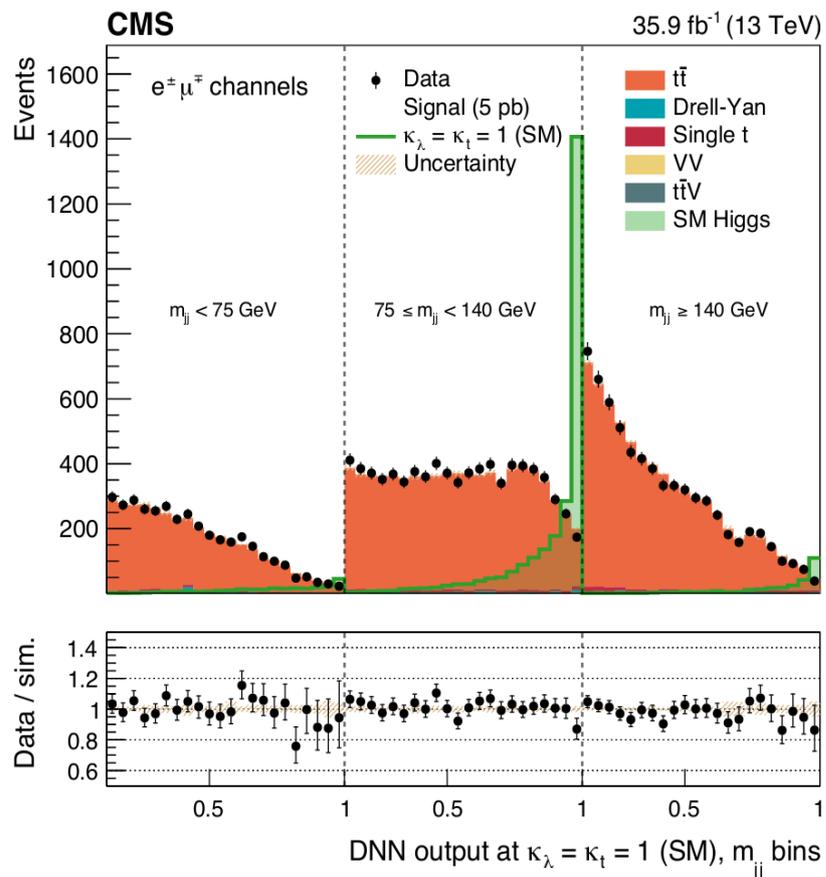
- Same mass region search as semi-resolved
 - Different topology
 - Two tagged double b “fat” jets
- Data driven background estimate



$$HH \rightarrow bbW(l\nu)W(l\nu)$$

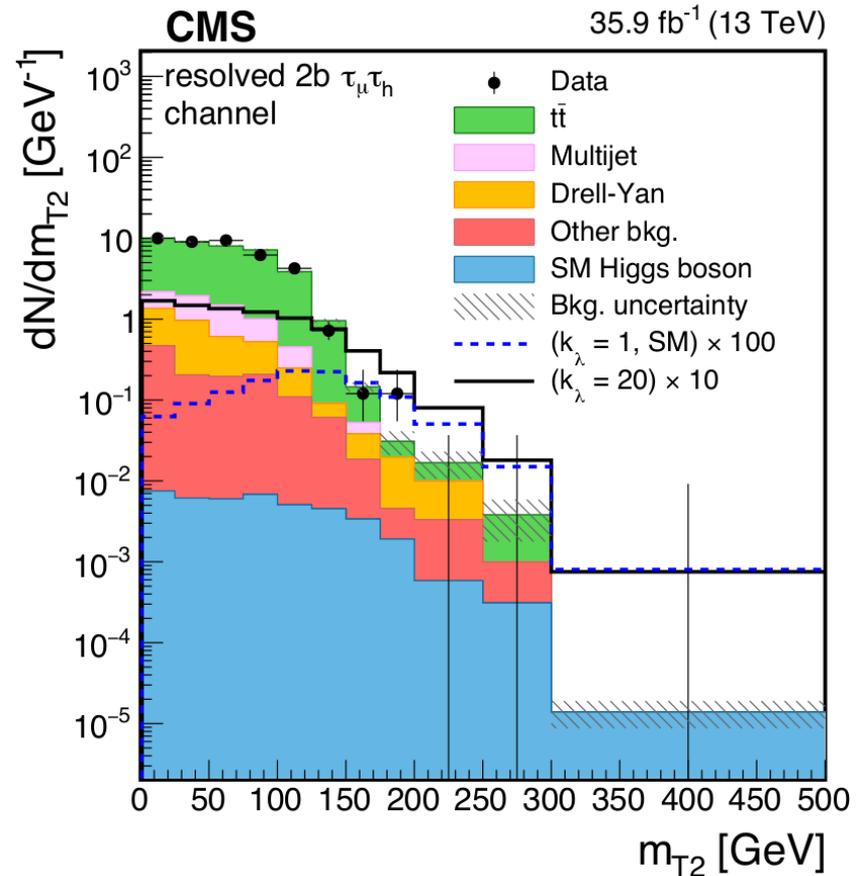
- Non-resonant and resonant search performed with same method
 - 260-900 GeV
- Background: ttbar and Drell-Yan
 - Sideband constrains ttbar MC
 - Drell-Yan estimated from data
- Neural network used to discriminate signal from background
 - Parameterized as function of k_λ and k_t
 - m_{jj} and DNN classifier used to categorize events

arXiv: 1708.04188



$HH \rightarrow bb\tau\tau$

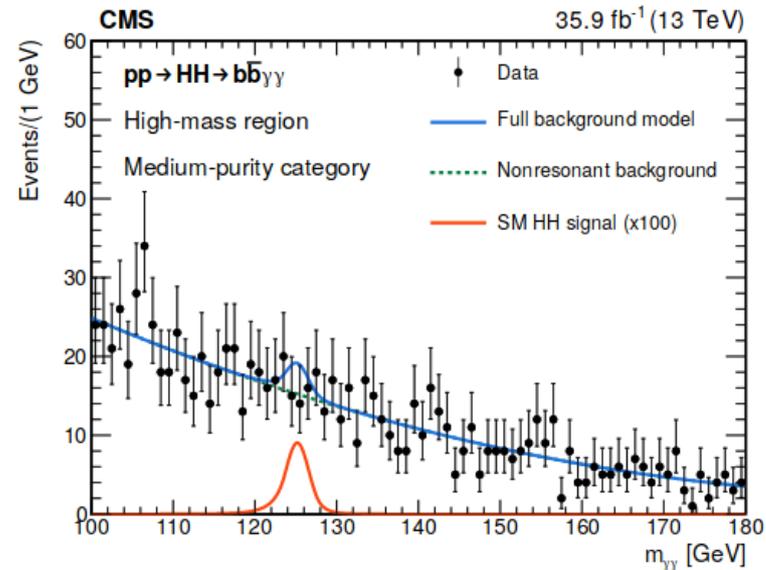
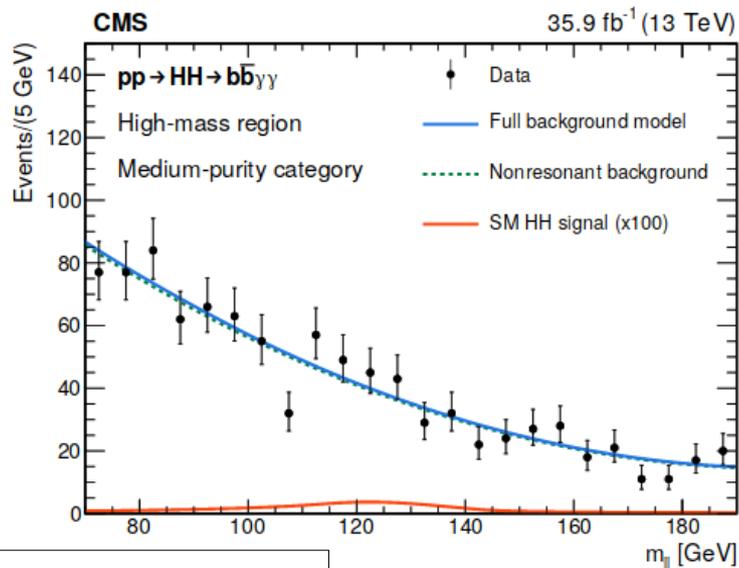
- Non-resonant and resonant search
- Three tau states, three bb states
 - $\tau_h\tau_\mu, \tau_h\tau_e, \tau_h\tau_h$
 - 1b1j, 2b, merged
- BDT used to discriminate signal from $t\bar{t}$ and $\tau\tau$ backgrounds
 - Based on angular separation of leptons and visible mass
- Invariant mass is reconstructed using a kinematic fit (m_{HH}^{KinFit})
- m_{T2} used to extract signal for non-resonant analysis



HH \rightarrow $b\bar{b}\gamma\gamma$

- Non-resonant and resonant search
- 2 photons, 2 b jets
- Main background: γ +jets

- 2D fit of m_{bb} vs $m_{\gamma\gamma}$
 - γ +jets \rightarrow smooth surface
 - SM single higgs \rightarrow ridge



CMS Run II Combination

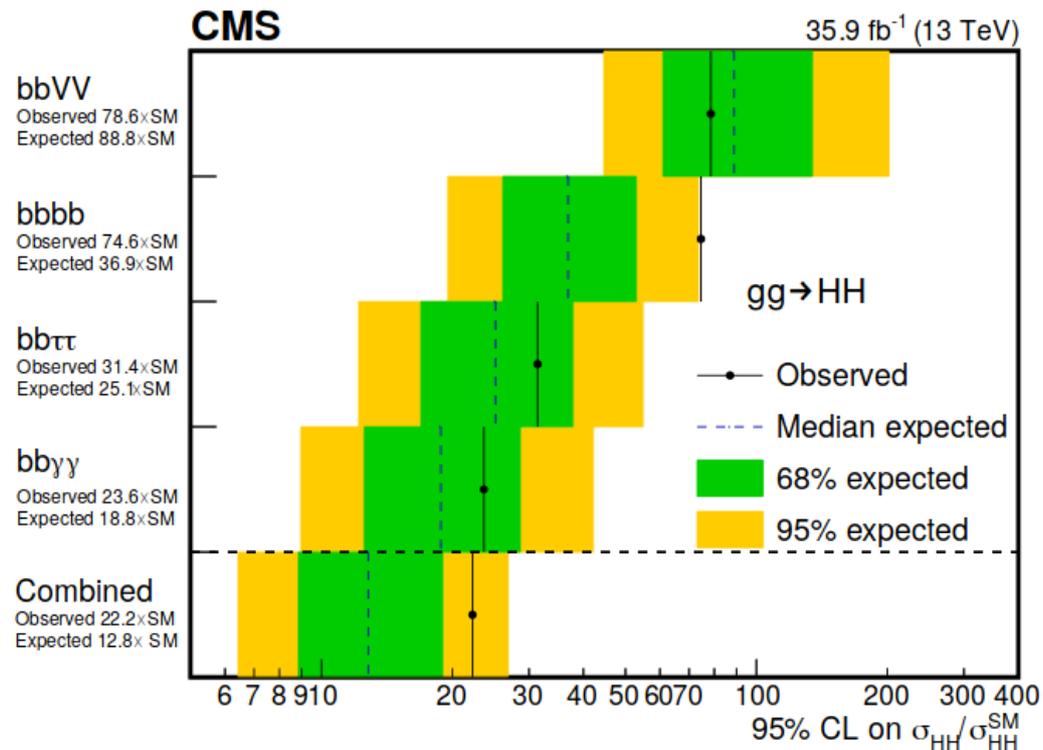
Signal strength

$$\mu = \sigma_{HH}/\sigma_{HH}^{SM}$$

Observed: 22.2

Expected: 12.8

Slightly weaker limit than expectation due to upwards data fluctuations



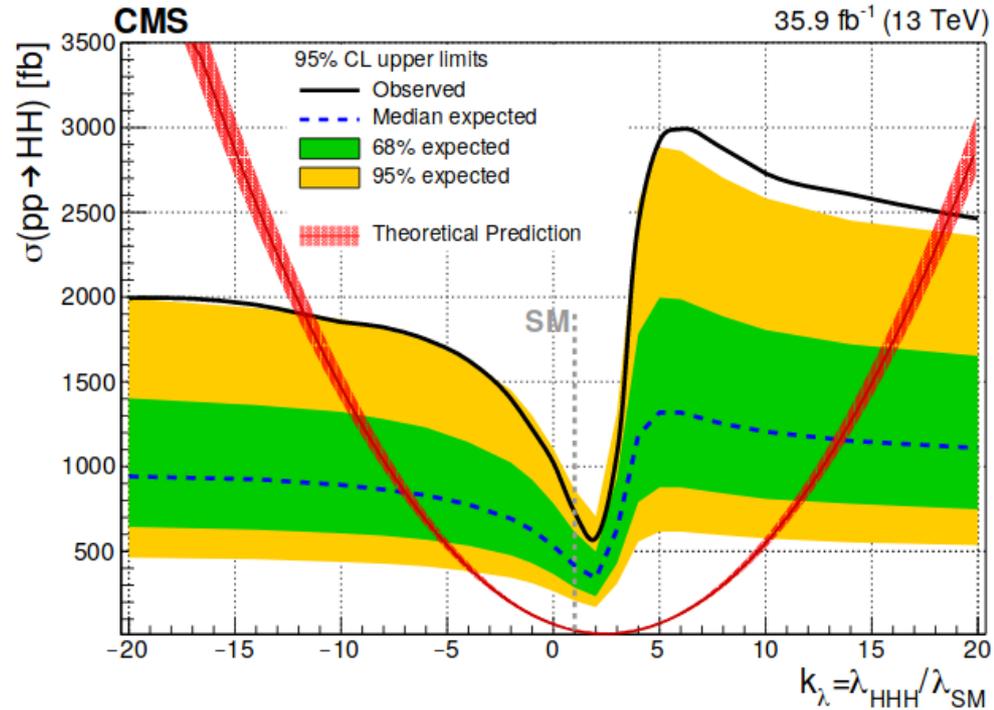
CMS Run II Combination

Allowed k_λ range

Observed: $-11.8 < k_\lambda < 18.8$

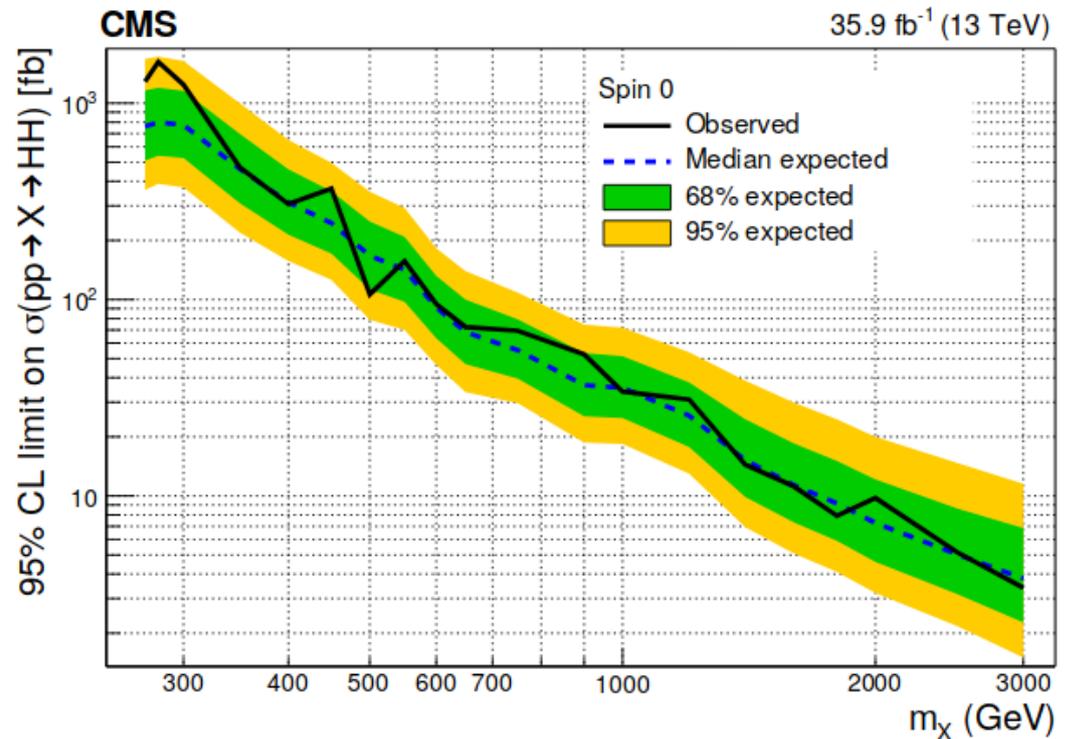
Expected: $-7.1 < k_\lambda < 13.6$

Shape directly related to interference between diagrams and ability to discriminate signal as m_H spectrum changes



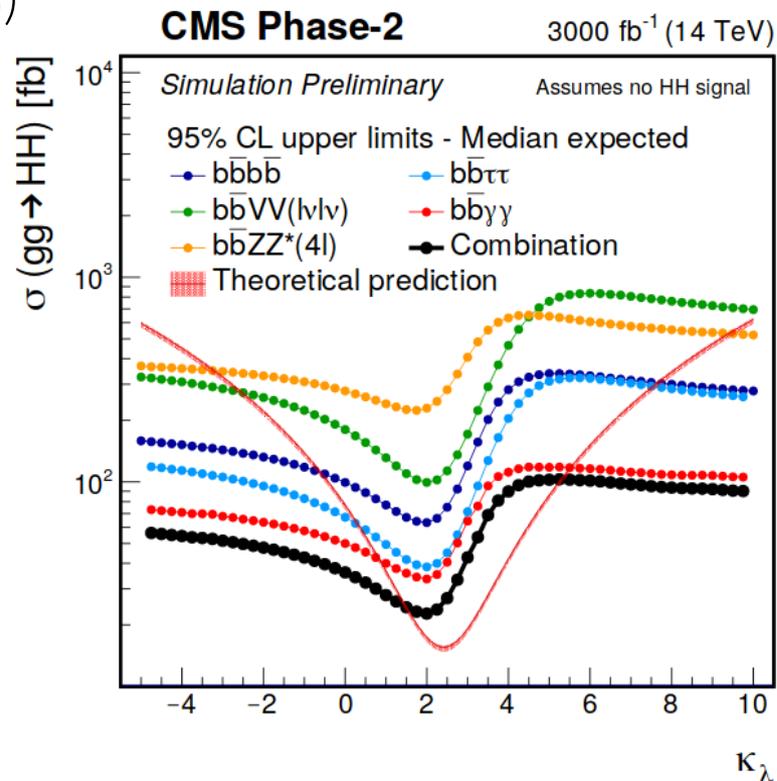
CMS Run II Combination

- Limits set for spin-0 and spin-2 resonances
 - No signs of a resonance in 2016 data
- Complimentary channels allow for coverage of wide mass range (250 to 3000 GeV)



HL-LHC Perspectives

- Projections recently updated! (Dec 21, 2018)
- Improvements to the detector, amount of data and collision energy, and analysis methods/tools
- Projected integrated luminosity of 3000 fb^{-1}
 - Expected significance for SM HH signal of 2.6σ
- Confidence intervals for k_λ
 - **68%:** $0.35 < k_\lambda < 1.9$
 - **95%:** $-0.18 < k_\lambda < 3.6$

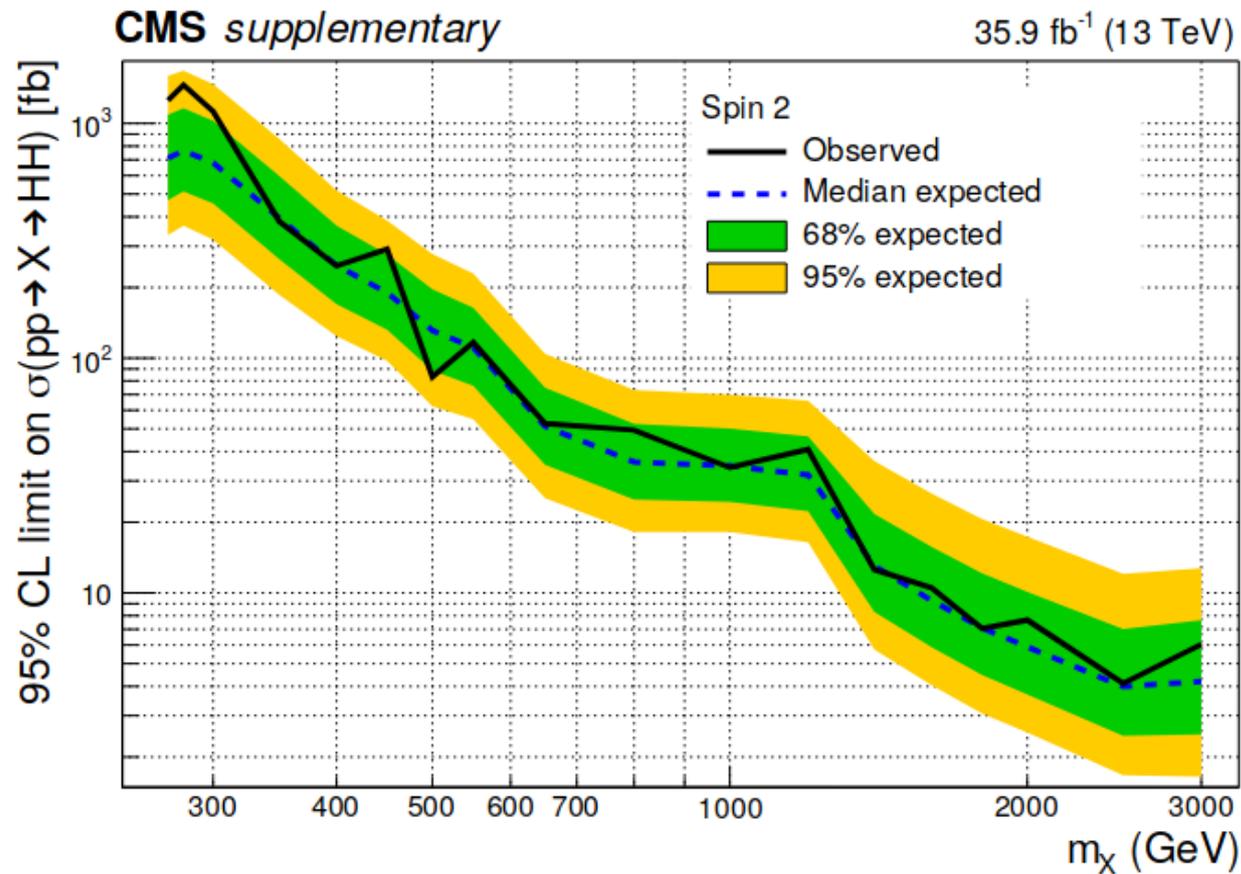


Conclusion

- Broad program of searches at CMS for both resonant and non-resonant HH
 - Channels are complimentary
- Only the 2016 Run II data has been analyzed!
 - About 100 fb^{-1} more data from 2017 and 2018
- New tools in development to improve analysis sensitivity
- Future looks exciting with HL-LHC projections

Backup

Spin-2 Limits



HH in BSM (non-resonant)

- Dimension 6 operators parameterized using EFT
 - modifications to $\mathbf{K}_\lambda = \lambda/\lambda_{SM}$ and $\mathbf{K}_t = y_t/y_{t,SM}$
 - three new interactions: \mathbf{C}_2 , \mathbf{C}_{2g} , \mathbf{C}_g

