HH searches at CMS

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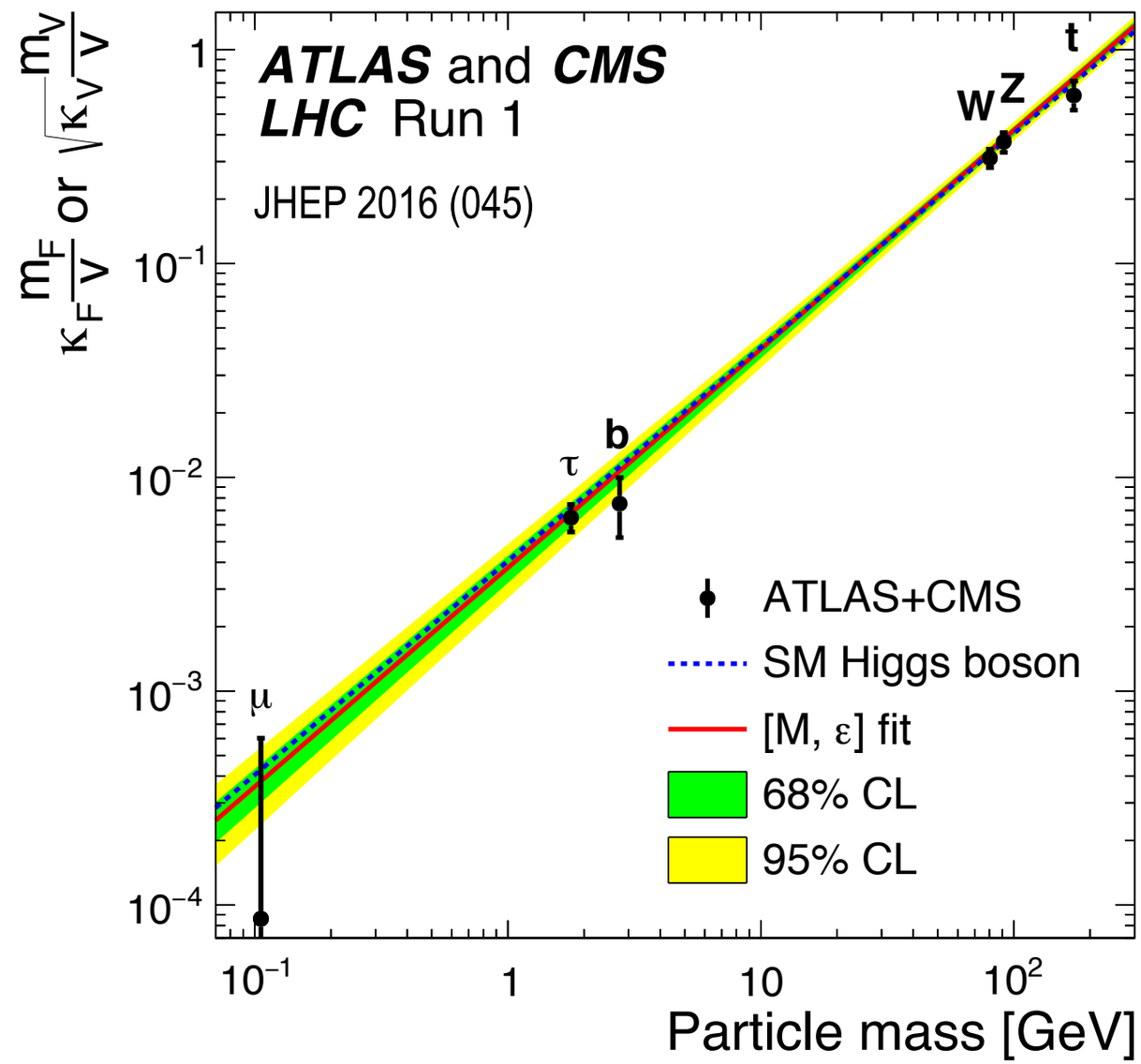
Higgs boson self-coupling

- m_H = 125.09 ± 0.24 GeV
- Interactions with fermions and vector bosons established…



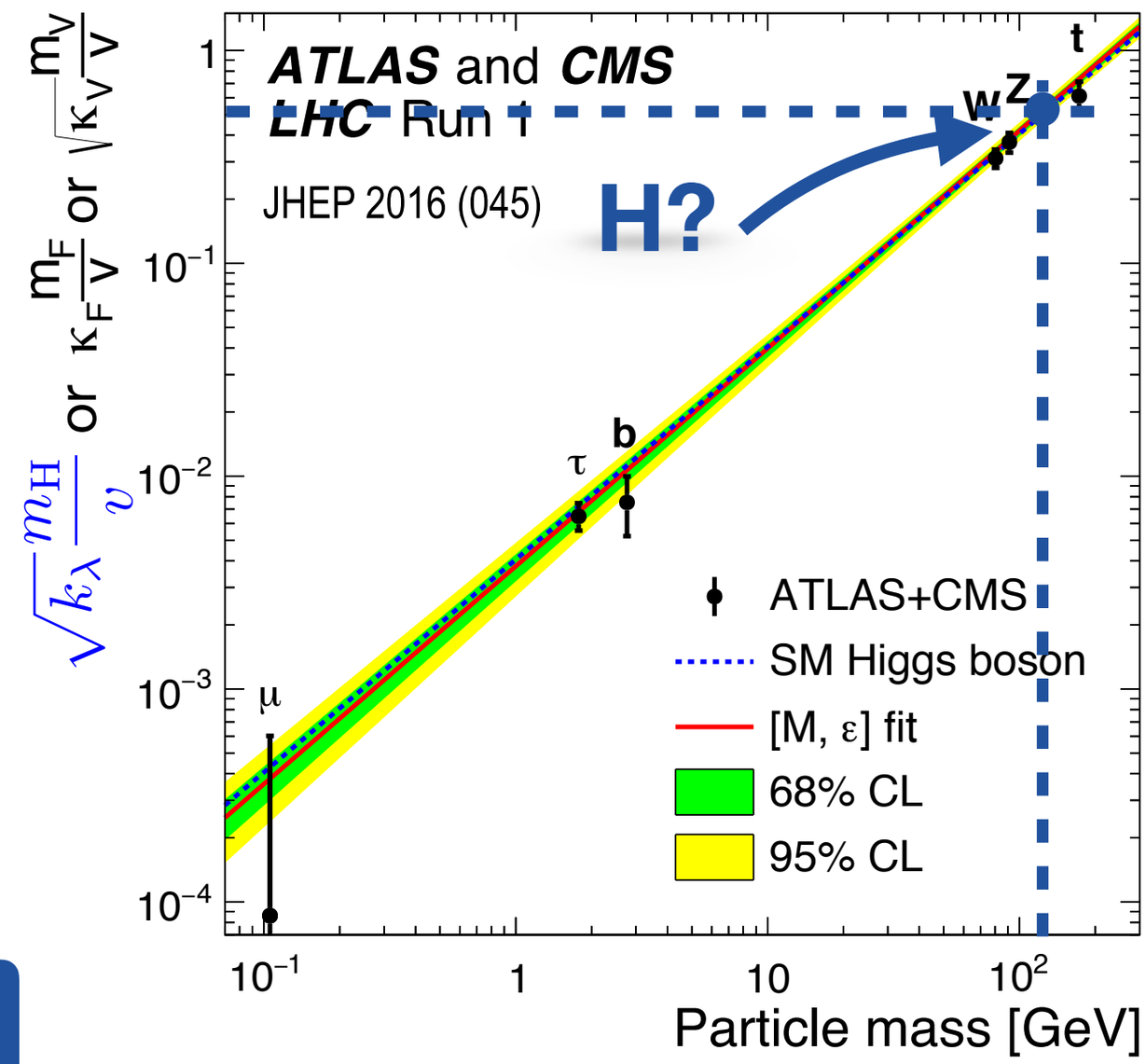
Higgs boson self-coupling

- m_H = 125.09 ± 0.24 GeV
- Interactions with fermions and vector bosons established…
- … but self-interactions not measured experimentally!

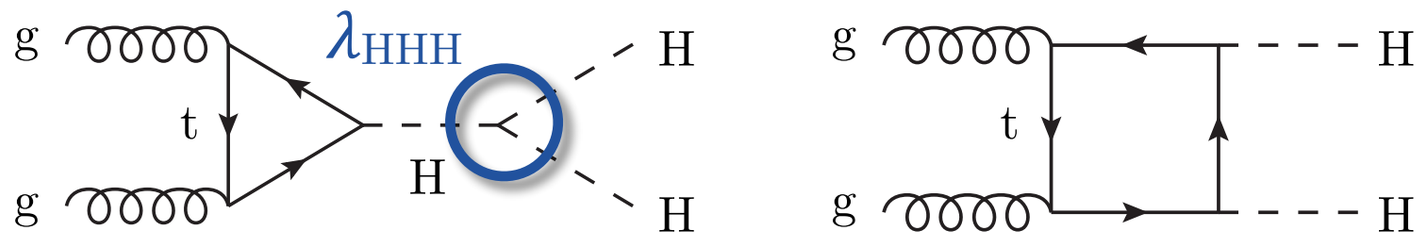
$$V(H) = \frac{1}{2}m_{\mathrm{H}}^2 H^2 + \lambda_{\mathrm{HHH}} v H^3 + \frac{1}{4}\lambda_{\mathrm{HHHH}} H^4 - \frac{\lambda}{4}v^4$$

$$\lambda_{\mathrm{HHH}} = \lambda_{\mathrm{HHHH}} = \lambda = \frac{m_{\mathrm{H}}^2}{2v^2} \approx 0.13$$

λ_{HHH} : direct access to the shape of the scalar potential

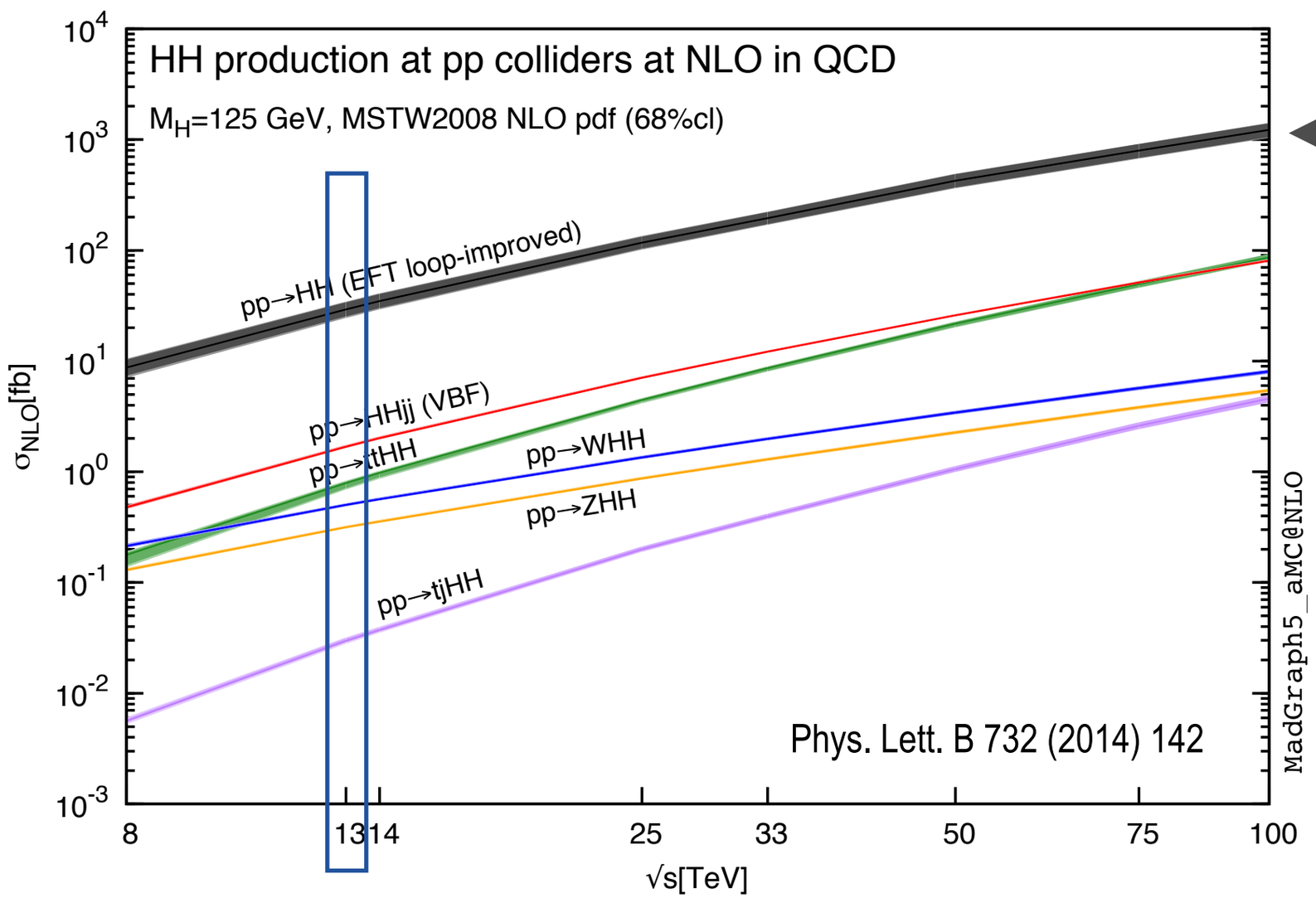


HH production in the SM



$$\sigma_{HH}^{SM} = 33.49^{+7.3\%}_{-8.4\%}\ \text{fb}\ (\text{scale} \oplus \text{PDF} \oplus \alpha_S \oplus m_t)$$

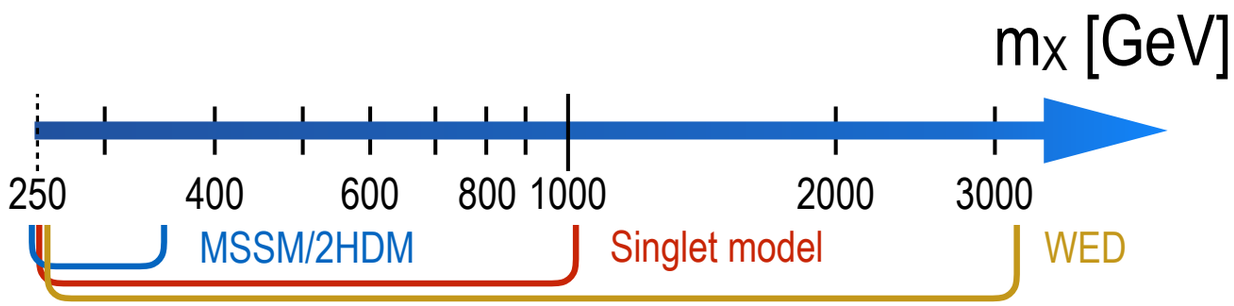
NNLO + NNLL with top quark mass effects at NLO



- **Gluon fusion**: dominant production mode
- Large destructive interference ⟹ tiny cross section
  - not sensitive to SM prediction with current data

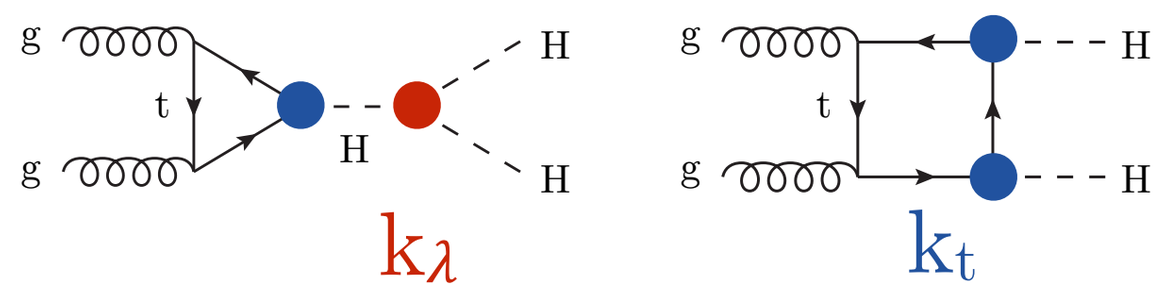
HH production beyond the SM

Resonant production



- Several BSM models can be probed with the same signature
  - model-independent searches
- Need to cover a broad m_X range

Nonresonant production



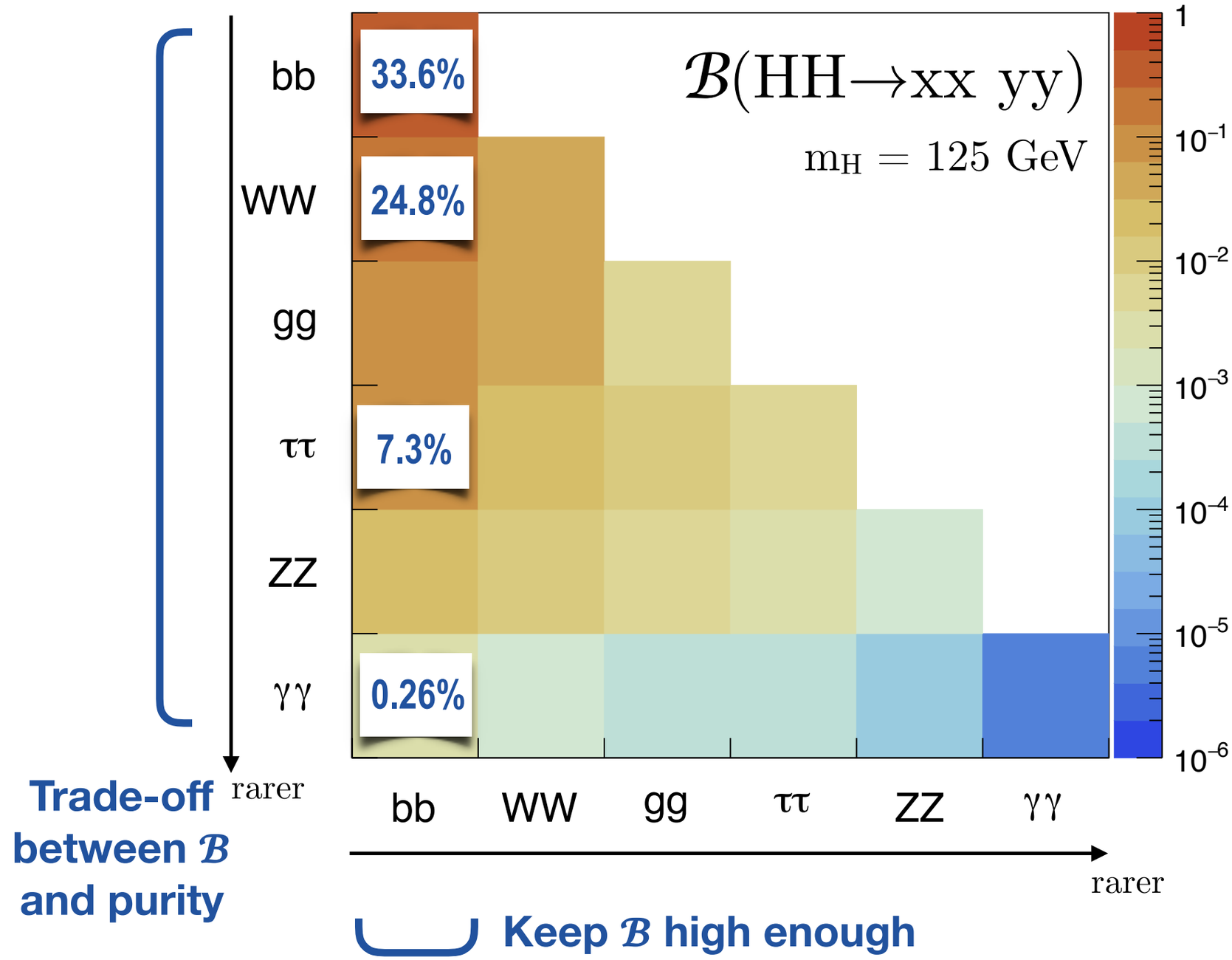
- Anomalous Higgs boson couplings
  - strong effect on both cross-section and shapes
- Described with EFT approach

HH is an ideal place to look for BSM physics

Sensitive with current LHC data

Which decay channel?

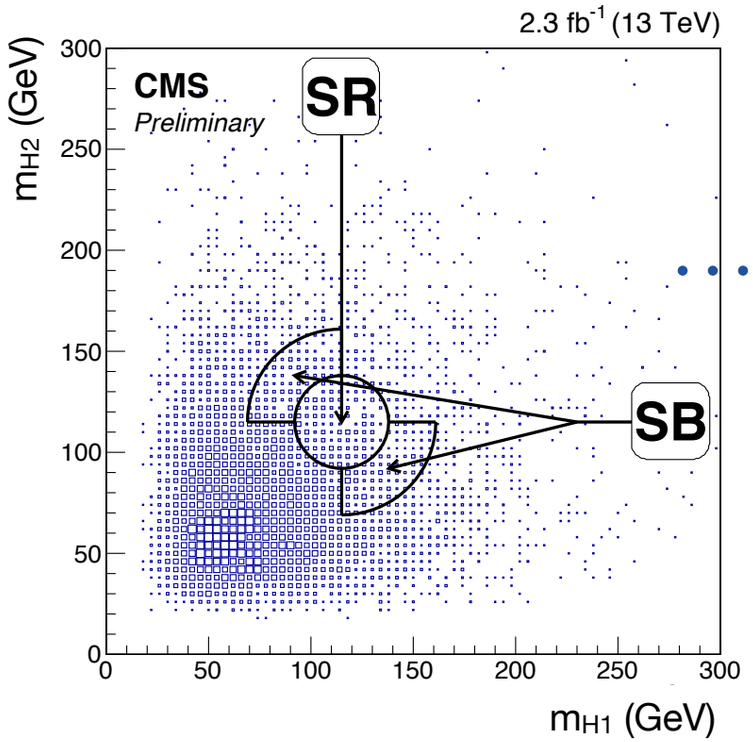
- Four decay channels explored at 13 TeV
  - common techniques across channels + channel-specific challenges
- Complementarity of the channels
  - similar sensitivity to nonresonant production
  - different coverage in m_X



Looking for a signal

Resonant

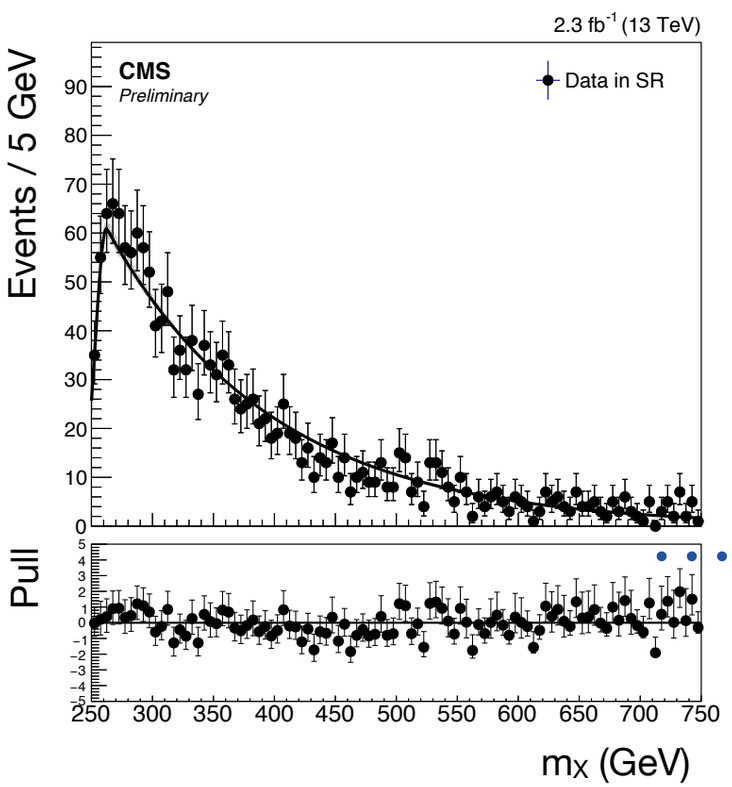
HH→bbbb, HIG-16-002

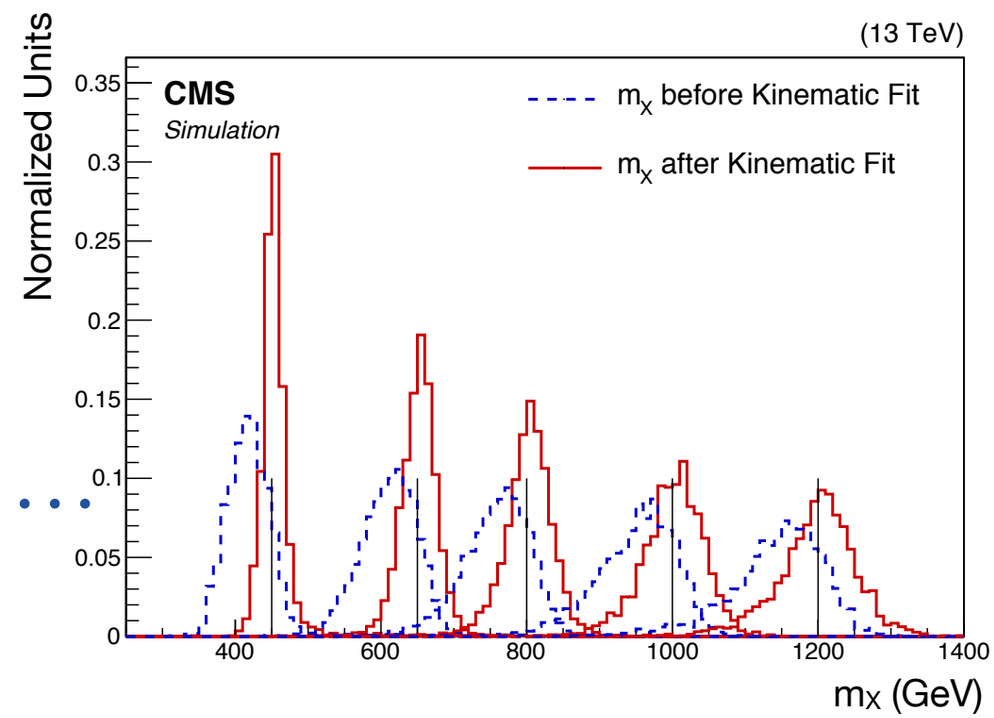


Select events compatible with HH production

Improve mass resolution with kinematic fit

Look for a localised excess

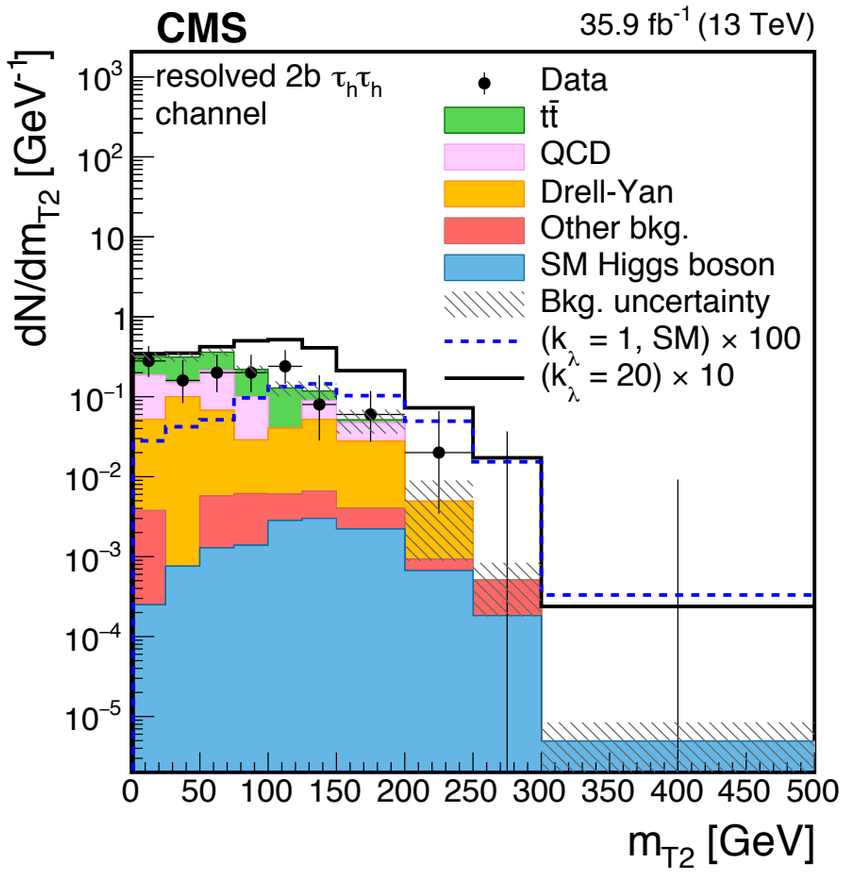




Boosted topologies also explored to enhance sensitivity to high m_X

Looking for a signal

arXiv:1707:02909

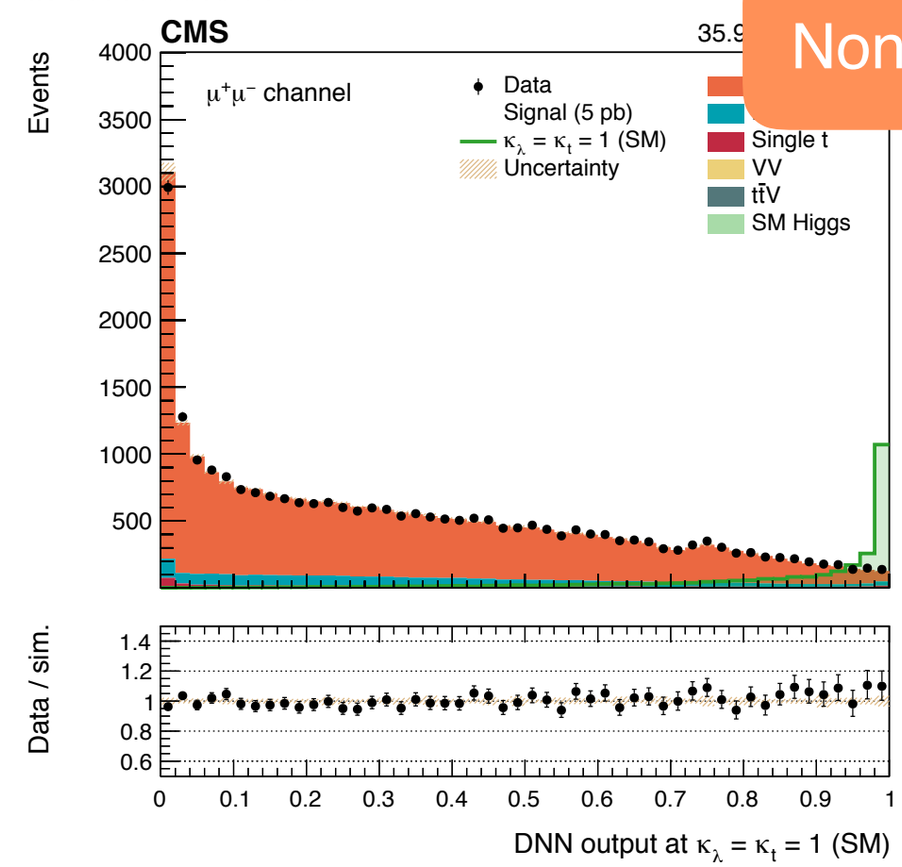


m_{T2}

(HH→bb$\tau\tau$)

arXiv:1708:04188

Nonresonant



Neural network

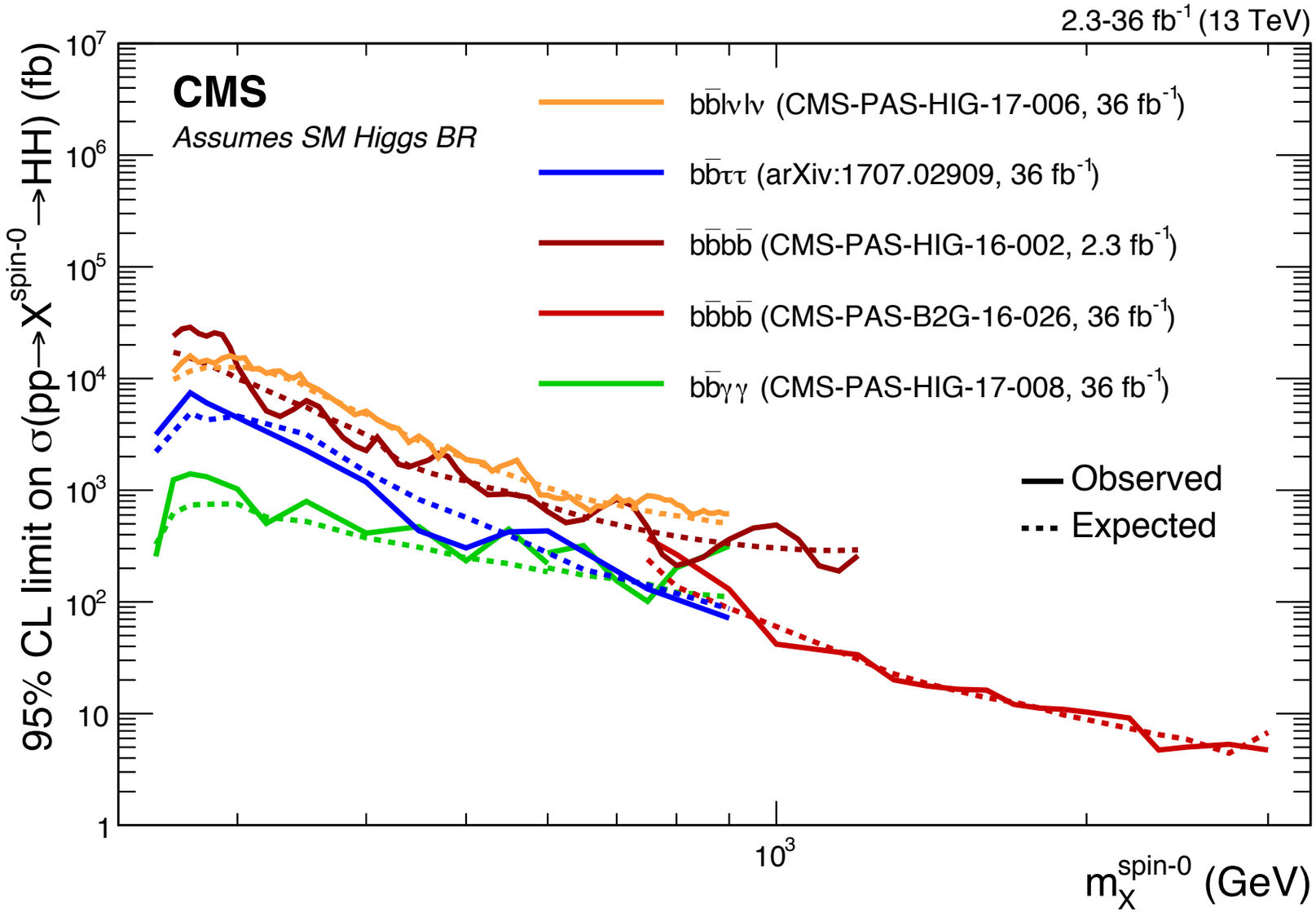
(HH→bbVV→bb$\ell\nu\ell\nu$)

- Define observables sensitive to the HH kinematics to separate from background
  - some final states not fully reconstructed (bb$\tau\tau$, bbVV)

Results

Resonant

All channels must to be explored for a broad m_X coverage



bbbb results using 36 fb^{-1} will be released soon

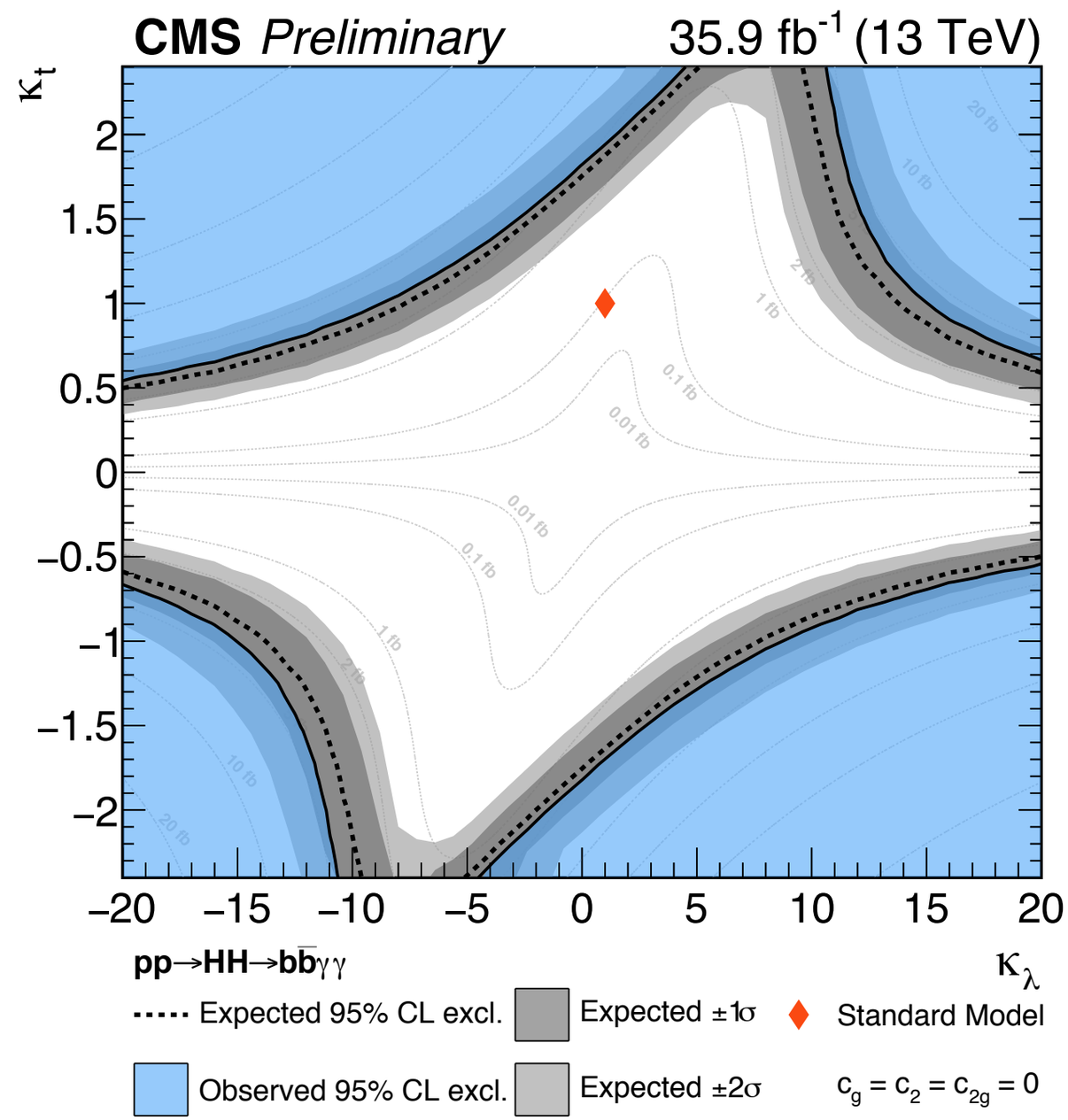
Results

Nonresonant

- Constraints set on anomalous Higgs boson couplings
- Similar sensitivity from several channels

Channel	Obs. (exp.) 95% C.L. limit on σ/σ_{SM}	Reference
bbbb	342 (308)	HIG-16-026
bbVV	79 (89)	arXiv:1708:04188
bb$\tau\tau$	31 (25)	arXiv:1707:02909
bb$\gamma\gamma$	19 (16)	HIG-17-008

2.3 fb^{-1} 35.9 fb^{-1}

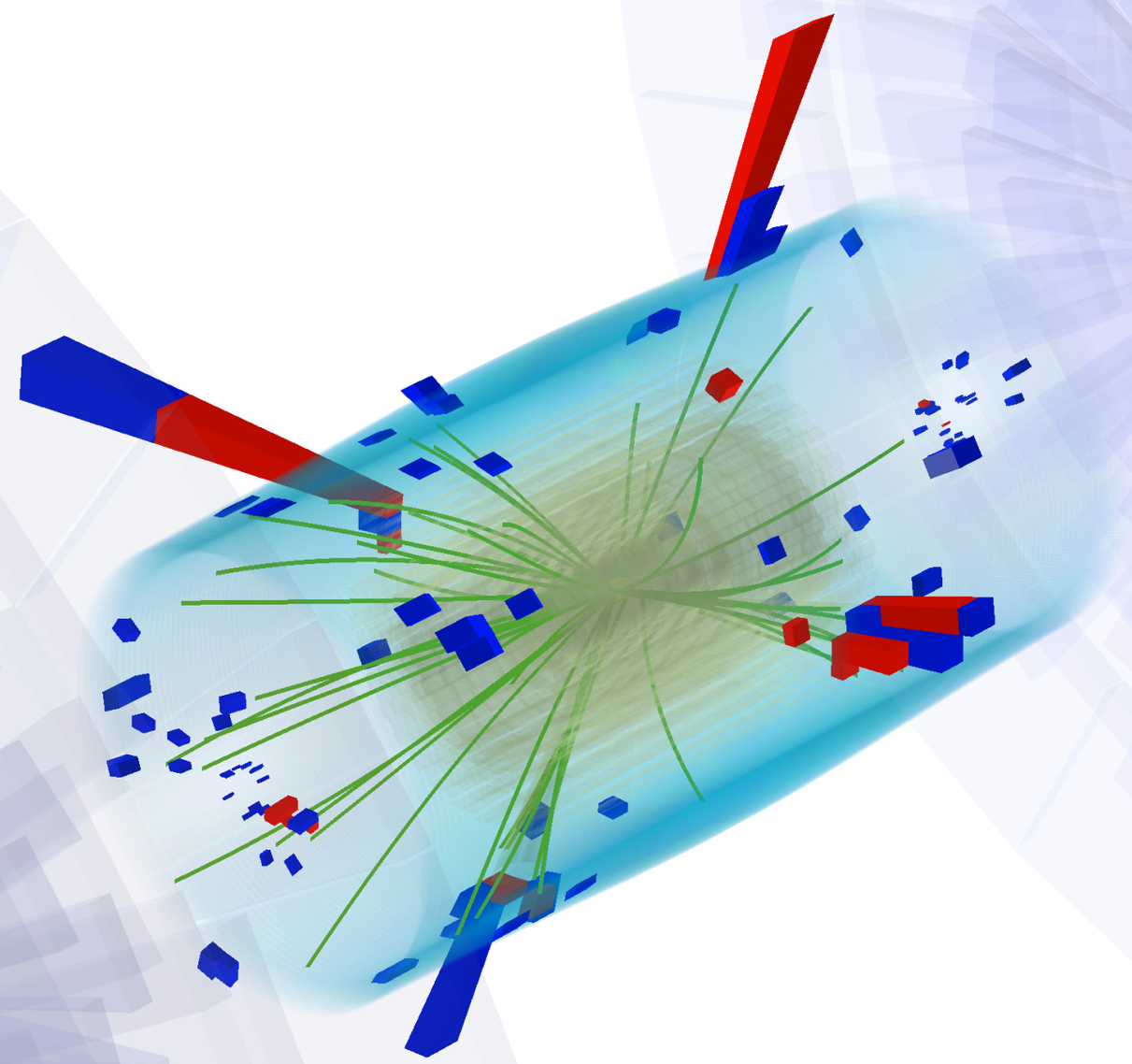


HH→bb$\gamma\gamma$, HIG-17-008

Conclusions

HH production

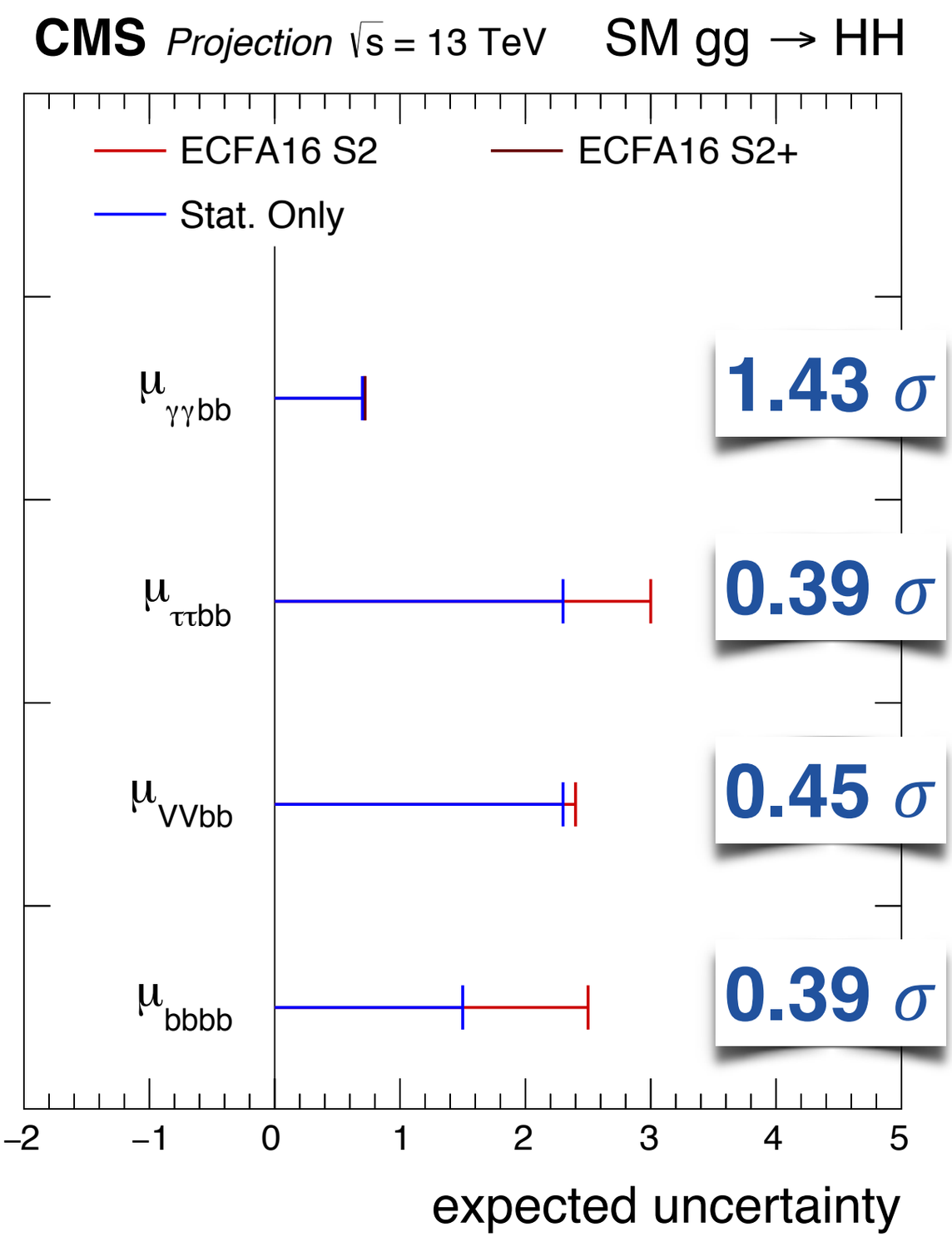
- **Why?**
  - invaluable information on the scalar sector
  - resonant + nonresonant production to probe (B)SM
- **How?**
  - four final states studied at 13 TeV at CMS
- **What's next?**
  - more final states and combination
  - exciting research subject for future (HL-)LHC operations



An HH→bb$\tau\tau$ event candidate recorded in 2016

Additional material

Future prospects for HL-LHC

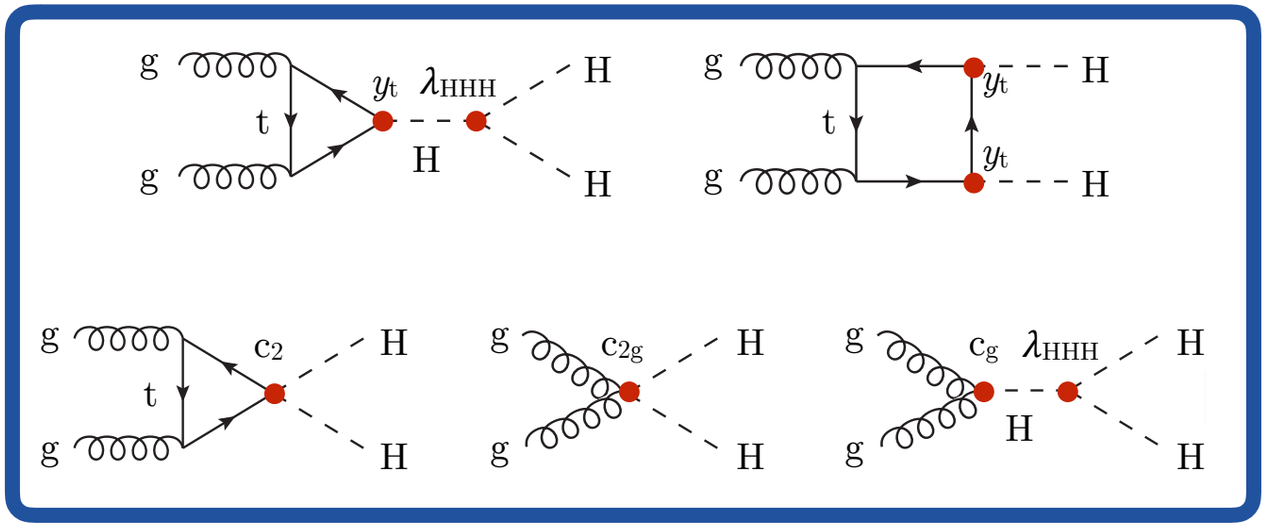


- Projections of early Run II results (2.3/2.7 fb^{-1}) to 3000 fb^{-1}
  - conservative: improvements already achieved in full 2016 dataset analyses

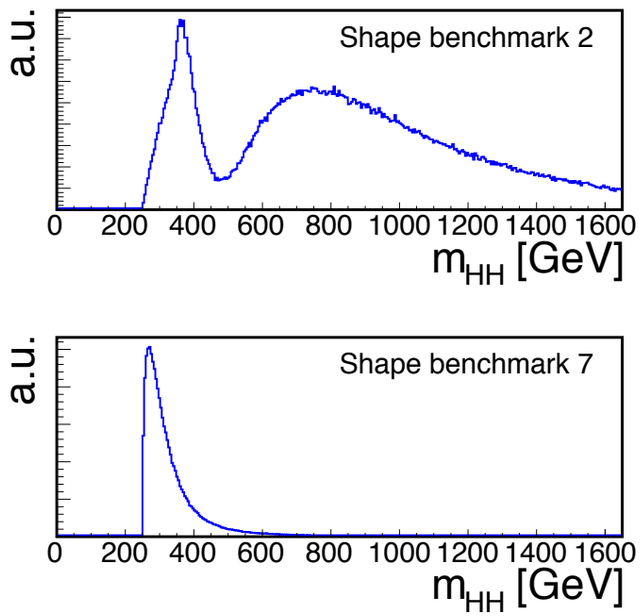
Decay channel combination is essential for an evidence of HH production

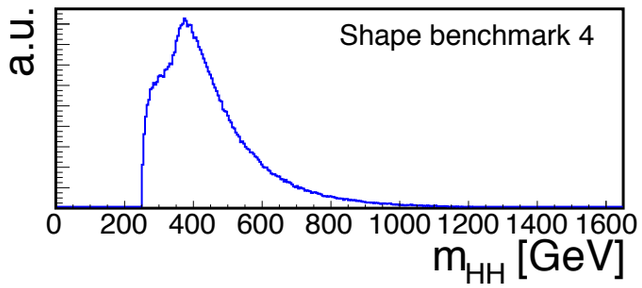
HH in EFT

$$\mathcal{L} = \mathcal{L}_{\mathrm{SM}} + \sum_i \frac{c_i}{\Lambda^2} \mathcal{O}_i^6 + \cdots$$



- Five-dimensional parameter space to be explored
  - 12 points defined as benchmarks of representative shapes





(few representative examples, 12 benchmarks in total)