Caltech

Re-interpretable Results CMS perspective

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On behalf of the CMS Collaboration

Higgs Pairs mini-workshop 2021

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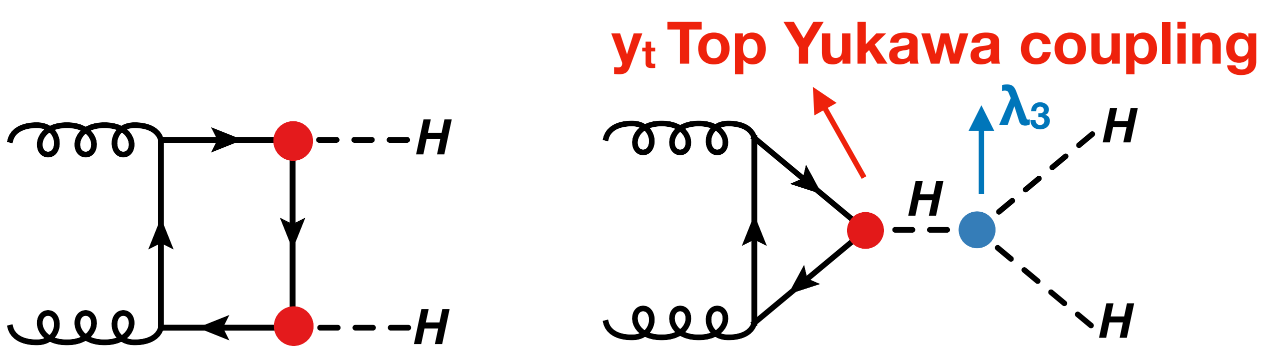
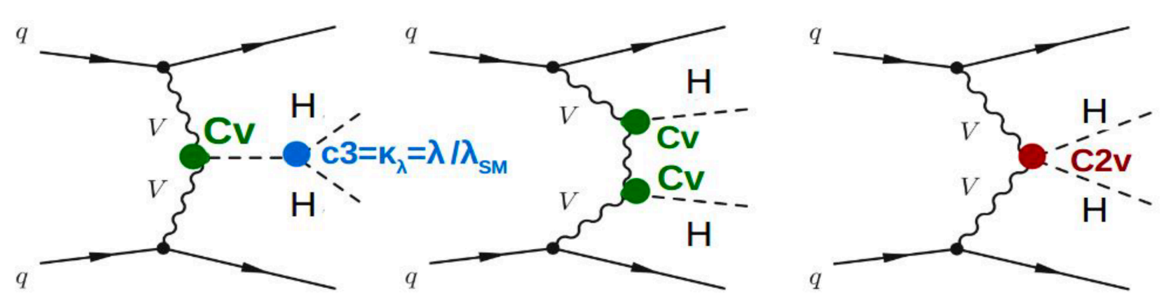
Overview of nonresonant HH analysis status

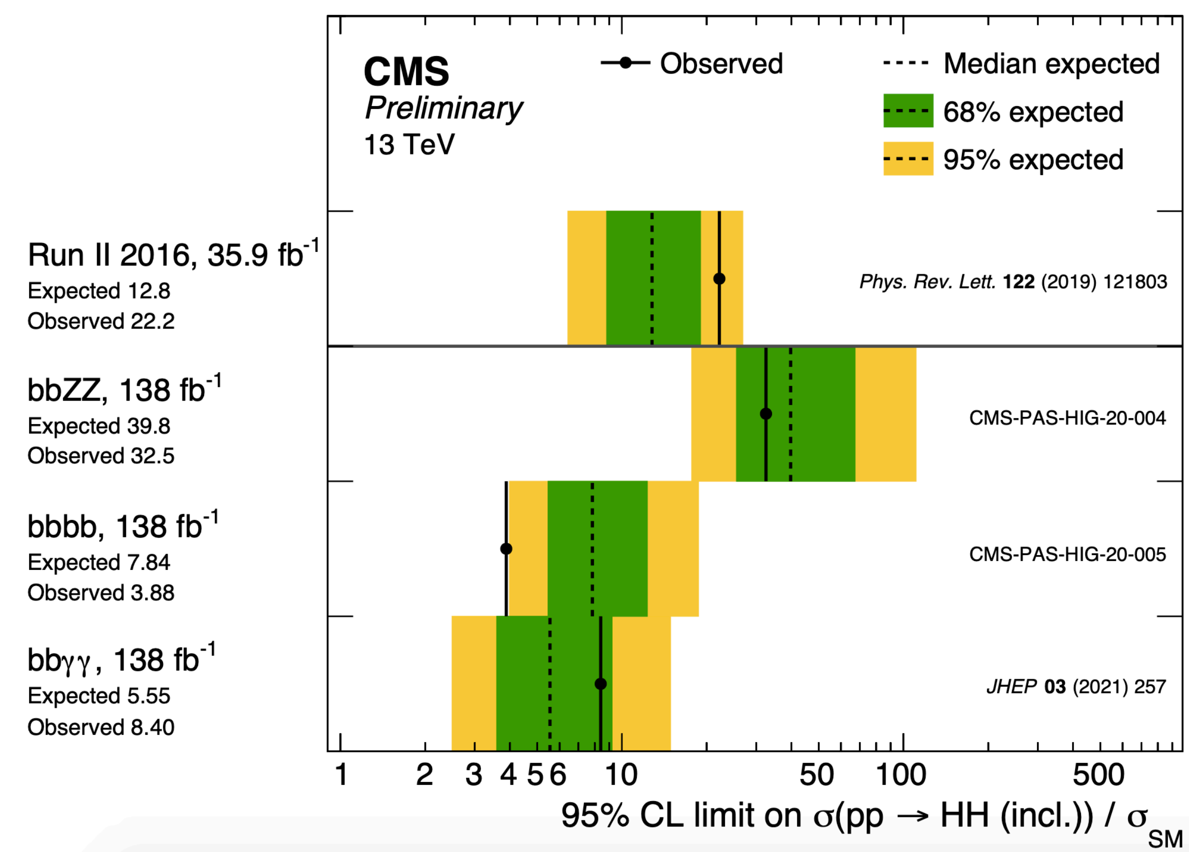
- Probing trilinear Higgs self-coupling (λ_3) via HH production
  - Run 2 published results have probed gluon fusion (ggF HH) and VBF HH production modes
- VBF HH offers access to the HHVV quartic coupling (C_{2V})
- Increasing use of machine learning techniques
- Combination of H and HH:
  - decouple λ_3 from other SM couplings
  - use single Higgs boson production and Higgs boson decay to constrain λ_3 through NLO EW corrections

- main production mode ggF ~31.05 fb @13 TeV $\mathrm{NNLO}_{\mathrm{FTapprox}}$



- sub-leading VBF ~1.73 fb @13 TeV N3LO QCD



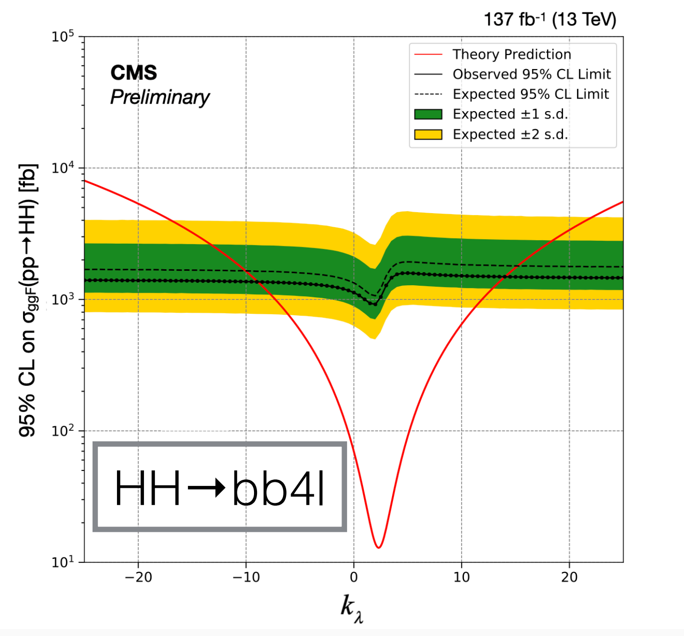


https://twiki.cern.ch/twiki/bin/view/CMSPublic/SummaryResultsHIG

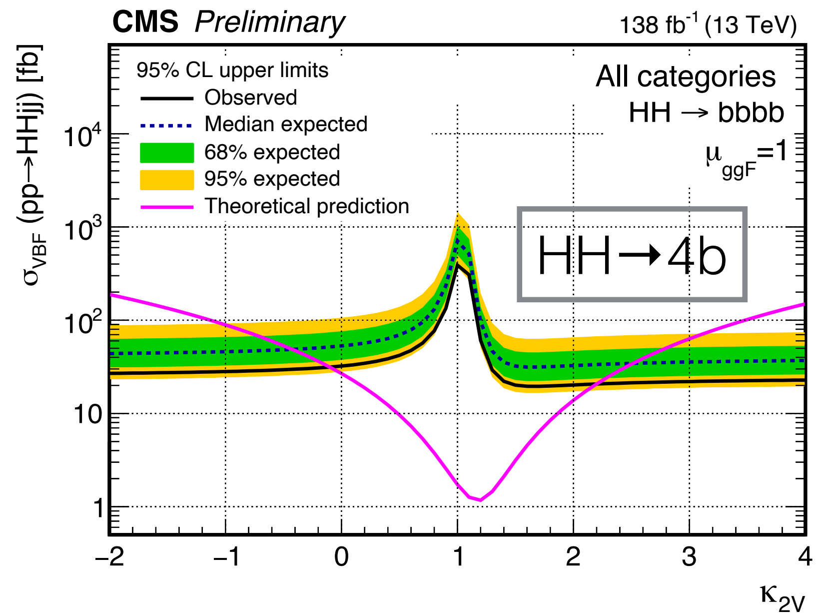
Nonresonant HH: presentation of results

HIG-20-005, B2G-21-001, JHEP 03 (2021) 257 , HIG-20-004

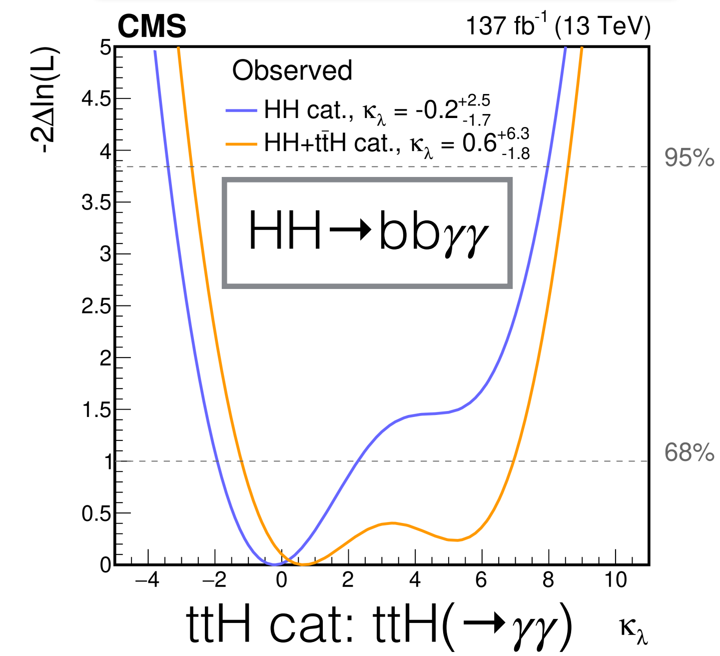
Upper limit of $\sigma_{ggF\ HH}$ vs $\kappa_\lambda=\lambda_3/\lambda_{SM}$



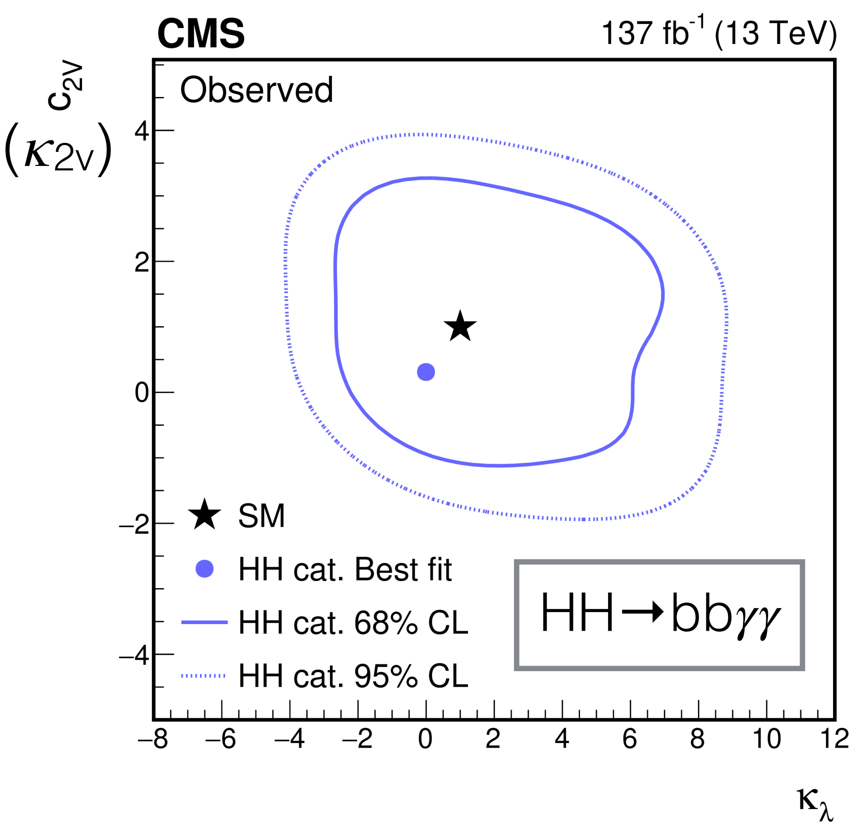
Upper limit of $\sigma_{VBF\ HH}$ vs κ_{2V}



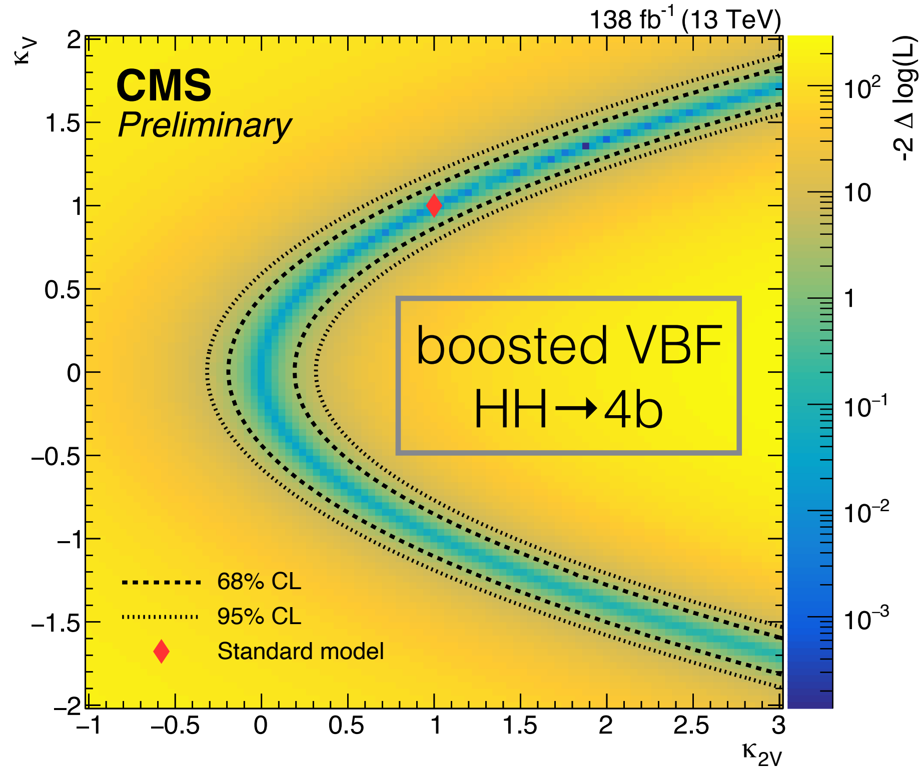
1D likelihood scan of κ_λ



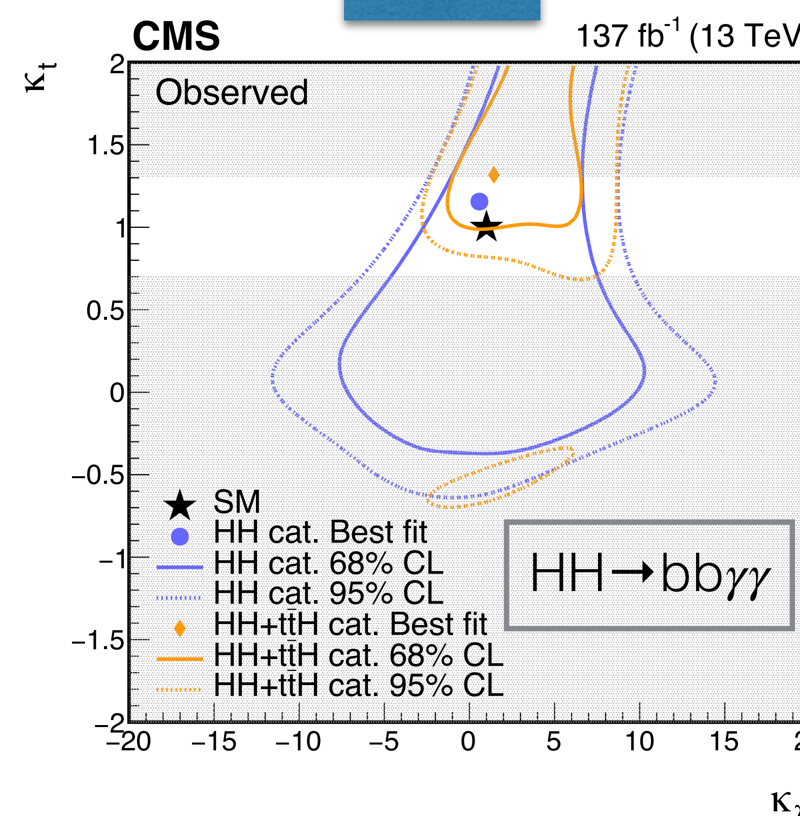
2D likelihood scan: κ_{2V} vs κ_λ



2D likelihood scan: κ_V vs κ_{2V}

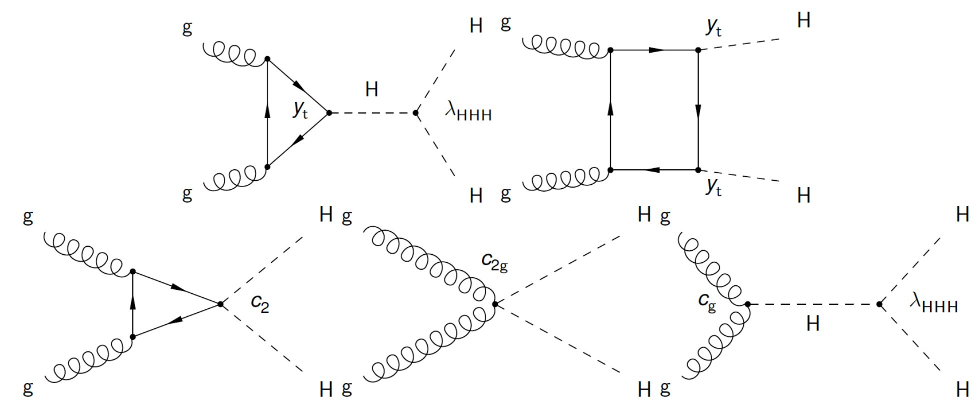


κ_t vs κ_λ



Nonresonant HH: shape benchmarks

JHEP 03 (2021) 257, LHC Higgs WG YR4
JHEP04(2016)126, JHEP02(2021)049

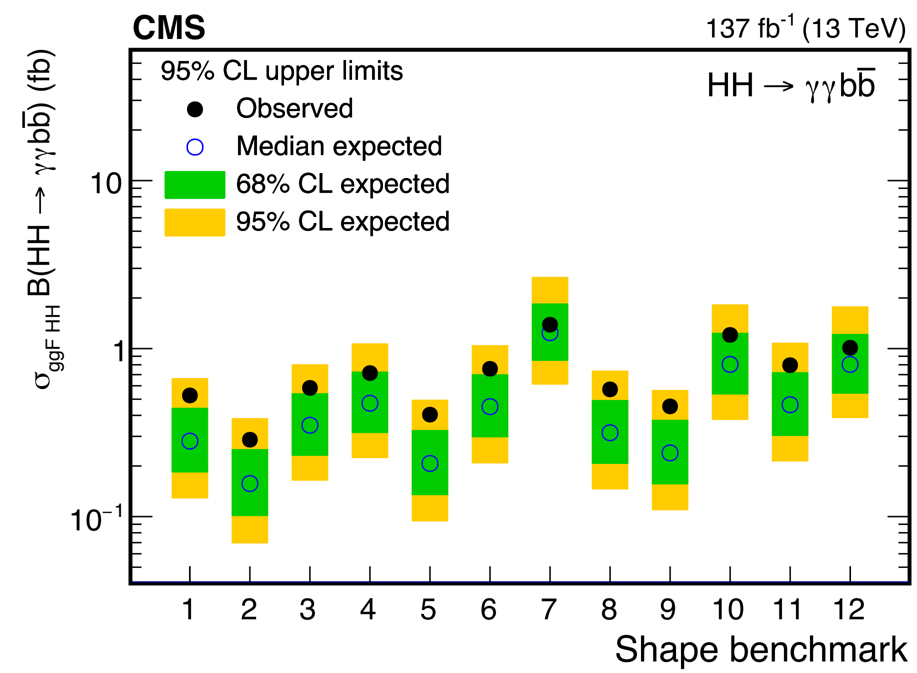


- BSM processes can modify HH cross section and kinematic properties. Use EFT approach to probe potential BSM physics:
  - We currently use extension of SM Lagrangian with dimension 6 operators, contributing at tree-level to gg→HH, modeled by five parameters k_λ, k_t, c_2, c_{2g}, c_g

$$\mathcal{L}_h = \frac{1}{2}\partial_\mu h \partial^\mu h - \frac{1}{2}m_h^2 h^2 - \kappa_\lambda \lambda_{SM} v\, h^3 - \frac{m_t}{v}\left(v + \kappa_t\, h + \frac{c_2}{v}\, h\, h\right)(\bar{t}_L t_R + \text{h.c.}) + \frac{1}{4}\frac{\alpha_s}{3\pi v}\left(c_g\, h - \frac{c_{2g}}{2v}\, h\, h\right) G^{\mu\nu}G_{\mu\nu}\,.$$

  - We have published result of 12 shape benchmarks
    - we will ALSO consider other shape benchmarks in future publications [Matteo Capozi, Gudrun Heinrich J. High Energ. Phys. 2020, 91 (2020)]
  - Shape benchmark result can be used to estimate the result in any other part of the parameter space by mapping shape similarity

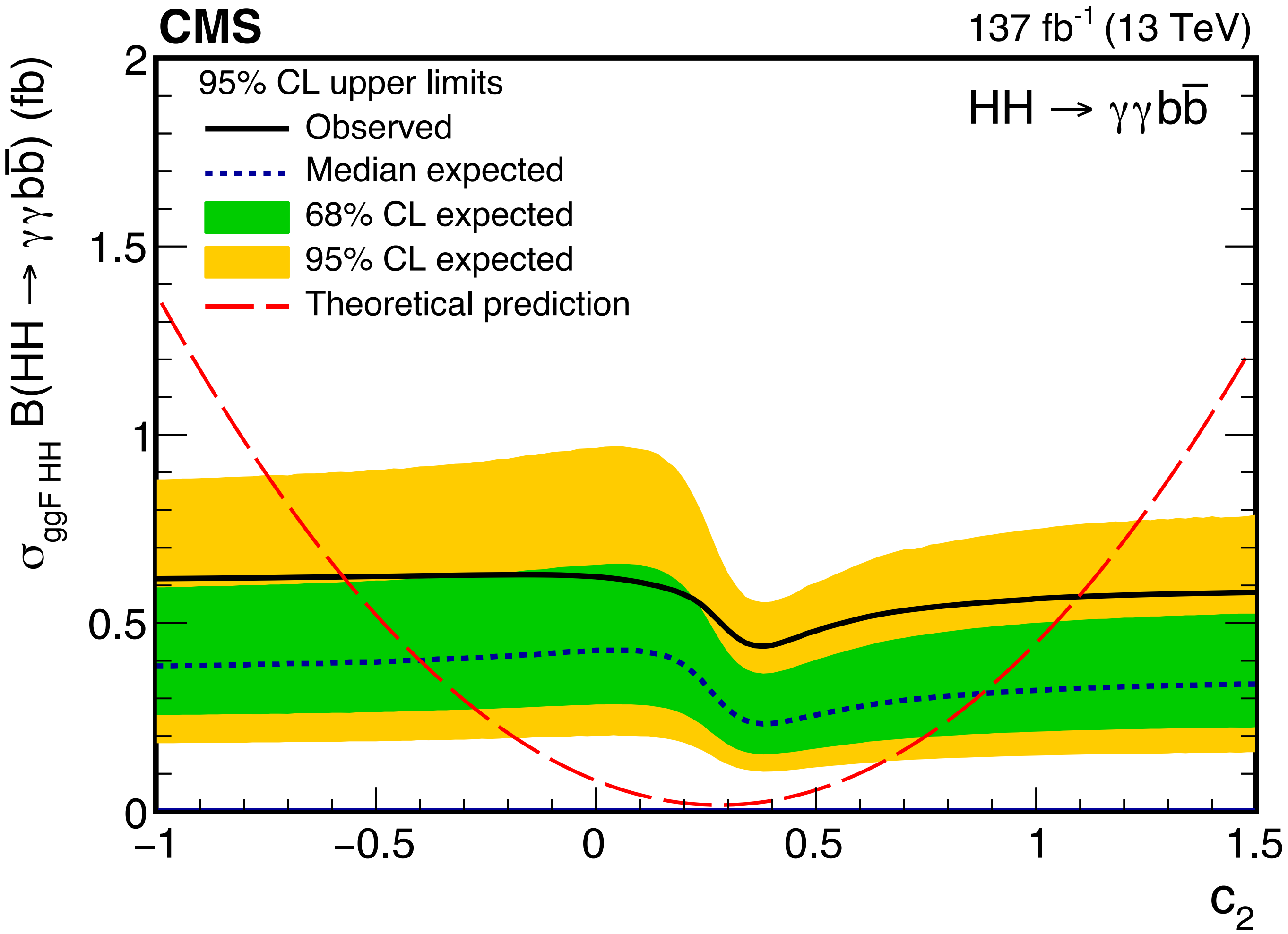
Upper limit of ggF HH cross section for the 12 shape benchmarks



Nonresonant HH: Higgs anomalous couplings

JHEP 03 (2021) 257, LHC Higgs WG YR4
JHEP04(2016)126, JHEP02(2021)049

Upper limit of ggF HH cross sections with different C_2 values

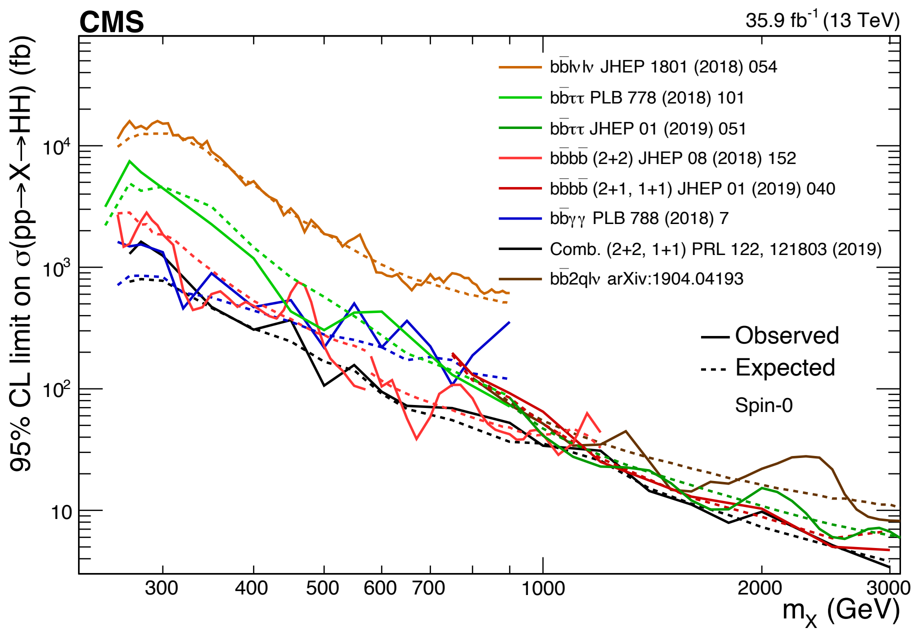


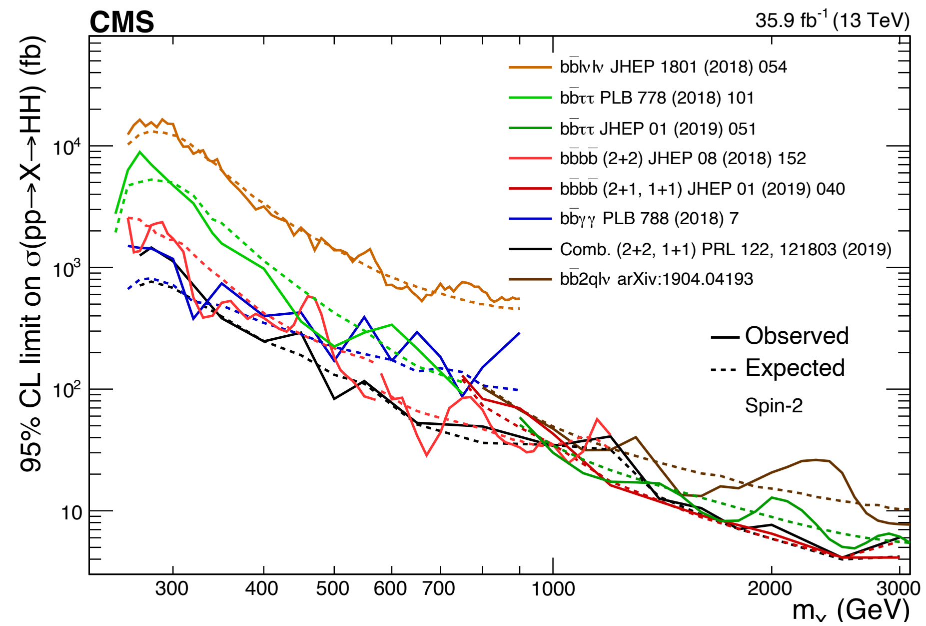
- We can do any scan that involves k_λ, k_t, C_2 or combinations
- We are open to suggestions on publishing other parameter scans that can allow a larger plethora of EFT reinterpretations

Resonant searches X→HH

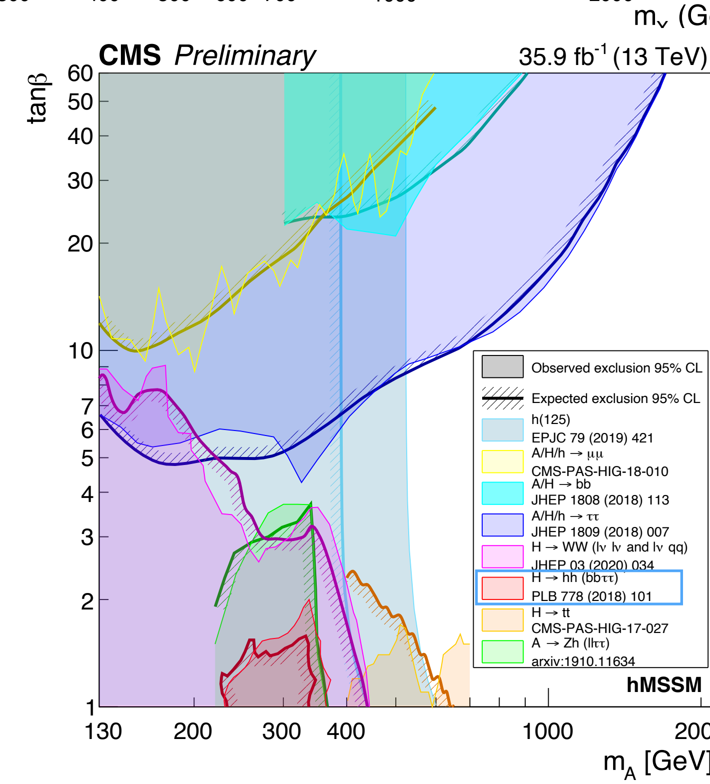
[CMS Higgs summary plot](#)

- Model independent exclusion limits placed on σ(gg→X)×B(X→HH) spin-0 and spin-2 hypotheses with narrow width approximation (NWA):
  - NWA valid typically up to 10%width





- Results interpreted in benchmark models
  - spin-2 graviton, spin-0 radion, 2HDMs, MSSM etc



HEPData

- Published results are submitted to HEPData
  - example: CMS HH combination using 2016 data

https://www.hepdata.net/record/ins1704939

HEPData Search HEPData Search About Submission Help Sign in

Browse all Sirunyan, Albert M et al. Last updated on 2019-06-03 11:28 Accessed 585 times Cite JSON

Hide Publication Information

Combination of searches for Higgs boson pair production in proton-proton collisions at $\sqrt{s} = 13$ TeV

The CMS collaboration

Sirunyan, Albert M , Tumasyan, Armen , Adam, Wolfgang , Ambrogi, Federico , Asilar, Ece , Bergauer, Thomas , Brandstetter, Johannes , Dragicevic, Marko , Erö, Janos , Escalante Del Valle, Alberto

Phys.Rev.Lett. 122 (2019) 121803, 2019.

https://doi.org/10.17182/hepdata.89935

Journal INSPIRE Resources

Abstract (data abstract)

This Letter describes a search for Higgs boson pair production using the combined results from four final states: \bbgg, \bbtt, \bbbb, and \bbvv, where V represents a \PW or \PZ boson. The search is performed using data collected in 2016 by the CMS experiment from LHC proton-proton collisions at $\sqrt{s} = 13$\TeV, corresponding to an integrated luminosity of 35.9\fbinv.Limits are set on the Higgs boson pair production cross section. A 95\% confidence level observed (expected) upper limit on the nonresonant production cross section is set at 22.2\,(12.8) times the standard model value.A search for narrow resonances decaying to Higgs boson pairs is also performed in the mass range 250--3000\GeV. No evidence for a signal is observed, and upper limits are set on the resonance production cross section

https://www.hepdata.net

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Filter 10 data tables

Figure 6

Data from Figures 1 and 6

10.17182/hepdata.89935.v1/t1

Expected and observed 95\% \CL exclusion limits on the HH production signal strength for the different channels and their combination.

Figure 2

Data from Figure 2

10.17182/hepdata.89935.v1/t2

Expected and observed 95\% \CL exclusion limits on the HH production cross section as a function of the k_lambda parameter.

Figure 3

Data from Figure 3

10.17182/hepdata.89935.v1/t3

Expected and observed 95\% \CL exclusion limits on the production of a narrow, spin zero resonance (X) decaying into a...

Figure 4 all channels

Data from Figure 4 and 5

10.17182/hepdata.89935.v1/t4

Expected and observed 95\% \CL exclusion limits on the HH production cross section for the different channels and their combination...

Figure 4 bbVV channel

Data from Figure 4

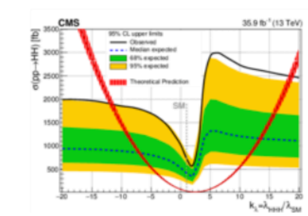
10.17182/hepdata.89935.v1/t5

Figure 2 10.17182/hepdata.89935.v1/t2

Resources https://www.hepdata.net JSON

Data from Figure 2

Expected and observed 95\% \CL exclusion limits on the HH production cross section as a function of the k_lambda parameter.



observables

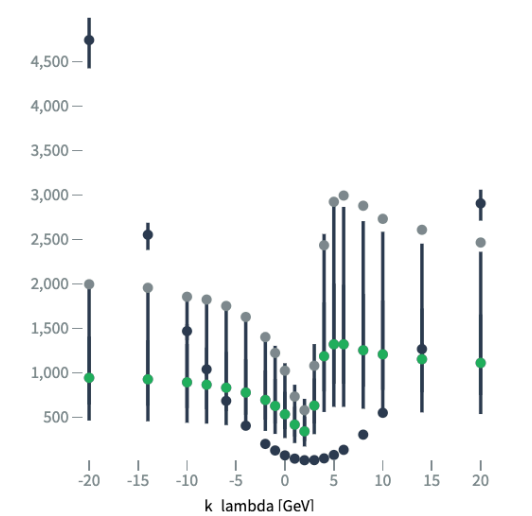
SIG

reactions

P P --> HIGGS HIGGS

Limit	Observed	Expected		
SQRT(S)	13 TeV			
LUMINOSITY	35.9 fb^{-1}			
Cross-section	Theoretical			
k_lambda [GeV]	**Observed cross section upper limit at 95% CL [fb]**	**Expected cross section upper limit at 95% CL with 1 sigma band [fb]**	**Expected cross section upper limit at 95% CL with 2 sigma band [fb]**	**Theoretical cross-section from EFT [fb]**
-20.0	1996.1	943.03 +462.35 -298.58 1 s.d.	943.03 +1050.7 -480.72 2 s.d.	4744.2 +251.44 -317.86 1 s.d.
-14.0	1956.3	926.27 +439.36 -296.96 1 s.d.	926.27 +1011.8 -472.18 2 s.d.	2553.3 +135.33 -171.07 1 s.d.

Visualize



Sum errors Log Scale (X) Log Scale (Y)

Questions, challenges and future prospect (discussion)

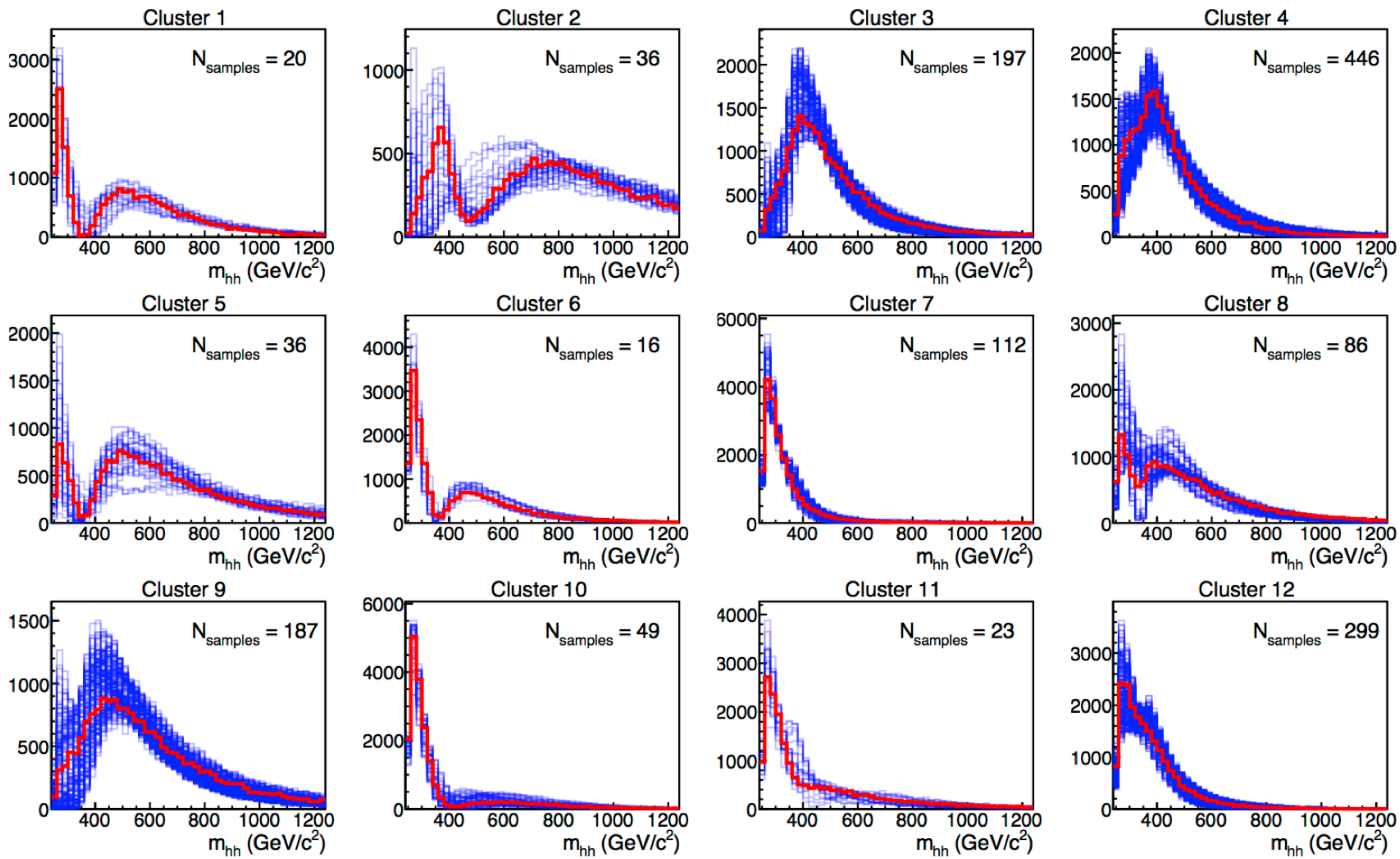
- Continuing progress in the combination of single and double Higgs studies
- Continue improving presentation of results to facilitate re-interpretation.
  - Note: a lot of effort has already been made in this direction, ref: Forum on the Interpretation of the LHC Results for BSM studies report: "Reinterpretation of LHC Results for New Physics: Status and Recommendations after Run 2"
- How to make experimental results employing machine learning techniques easier for re-interpretation by the theory community?
- What BSM models is the HH channel the most sensitive to, among all channels?
- Any uncovered BSM models and phase space to pay more attention to, using HH signatures?
- Explore possibility to publish the simplified likelihood functions
- How we can in practice make the differential m_{HH} information available? simplified likelihood functions plus a statistical framework for re-interpretation might be a good approach

backup slides

References

- Forum on the Interpretation of the LHC Results for BSM studies https://twiki.cern.ch/twiki/bin/view/LHCPhysics/InterpretingLHCresults
- PhyStat Seminar “Can we really "Re"-interpret data from the LHC?” by Nicholas Wardle https://indico.cern.ch/event/1012319
- LHCHXSWG-2016-001 “Analytical parametrization and shape classification of anomalous HH production in EFT approach” Alexandra Carvalho, Martino Dall’Osso, Pablo de Castro Manzano, Tommaso Dorigo, Florian Goertz, Maxime Gouzevich, and Mia Tosi: http://cds.cern.ch/record/2199287
- https://arxiv.org/abs/2003.07868 “Reinterpretation of LHC Results for New Physics: Status and Recommendations after Run 2”
- arXiv:2109.04981 “Publishing statistical models: Getting the most out of particle physics experiments”

Nonresonant HH: shape benchmarks



Resonant searches X→HH

- Distributions of final observables (some analysis selection efficiencies at each step) are published

Example: bb+leptons B2G-20-007

SL channel selection	Bkg eff.	1 TeV eff.	3 TeV eff.
b-jet veto	0.31	0.87	0.82
$D_{\mathrm{Z/H \to b\bar{b}}} \geq 0.8$	0.07	0.81	0.84
$\tau_2/\tau_1 \leq 0.75$	0.69	0.91	0.92
$D_{\ell\nu q\bar{q}} \leq 11.0$	0.63	0.87	0.83
$p_{\mathrm{T}}/m \geq 0.3$	0.87	0.97	0.86

DL channel selection	Bkg eff.	1 TeV eff.	3 TeV eff.
b-jet veto	0.45	0.86	0.84
$D_{\mathrm{Z/H \to b\bar{b}}} \geq 0.8$	0.05	0.81	0.83
MET $\geq 85\,\mathrm{GeV}$	0.55	0.88	0.97
$6 \leq m_{\ell\ell} \leq 75\,\mathrm{GeV}$	0.62	0.95	0.94
$\Delta R_{\ell\ell} \leq 1.0$	0.51	0.93	0.998
$\lvert\Delta\phi(\vec{p}_{\mathrm{T}}^{\,\mathrm{miss}}, \vec{p}_{\ell\ell})\rvert \leq \pi/2$	0.83	0.98	0.97

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