Non-resonant di-Higgs searches in four b final state at CMS

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Chuyuan Liu (Carnegie Mellon University)
on behalf of the CMS collaboration

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Motivation

- Direct measurement of the Higgs trilinear self-coupling ($\kappa_\lambda = \lambda_3/\lambda_3^{\mathrm{SM}}$)

$$\mathcal{L} \supseteq \frac{1}{2} m_H^2 \phi^2 + \lambda_3 \phi^3 + \lambda_4 \phi^4$$

- Largest branching fraction $\mathrm{BR}(HH \to \mathrm{b\bar{b}b\bar{b}}) = 33.9\%$ but dominant by QCD multijet background which is hard to simulate.
- The following analyses will be presented:

Production mode		SM cross section(pb)		Analysis
gluon fusion(ggF)		$31.1^{+2.1}_{-7.2}$		Phys.Rev.Lett. 129, 081802(2022)(resolved)
vector boson fusion(VBF)		1.726 ± 0.036		arXiv:2205.06667(CMS-B2G-22-003)(boosted)
VHH	W^-HH	0.865	0.173 ± 0.005	CMS-HIG-22-006
	W^+HH		0.329 ± 0.007	
	ZHH		$0.363^{+0.013}_{-0.011}$	

Resolved ggF and VBF

Phys.Rev.Lett. 129, 081802(2022)

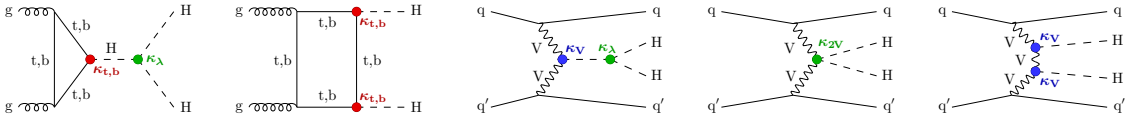


Figure: ggF(1-2) and VBF(3-5) Feynman diagrams

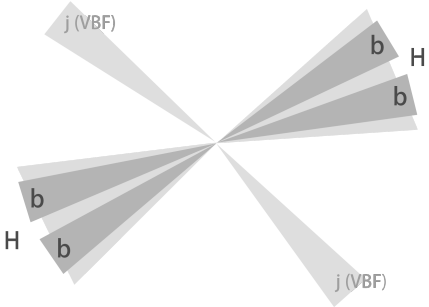


Figure: Resolved topology

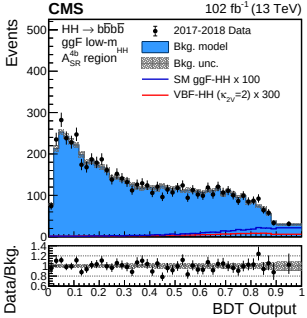


Figure: QCD multijet and $t\bar{t}$: reweighted 3b data

Boosted ggF and VBF

arXiv:2205.06667 (CMS-B2G-22-003)

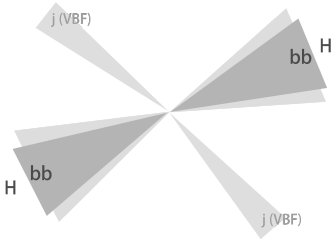


Figure: Boosted topology

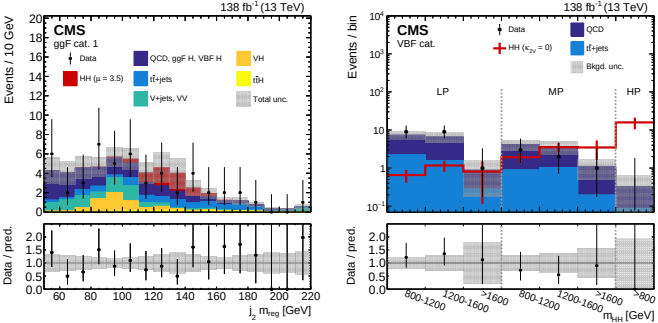


Figure: QCD: reweighted data with jets failing the $D_{b\bar{b}}$ selection
Other: simulation

ggF and VBF

Results

Discriminating variables used in the likelihood fit:

- Resolved:
  - ggF: signal vs background (SvB) BDT output distribution
  - VBF SM-like: m_{HH} distribution
  - VBF κ_{2V}-like: number of events
- Boosted: m_{HH}, $D_{\mathrm{b\bar{b}}}$, m_{reg} and BDT distribution.

Observed (expected) 95% CL upper limit at SM

- Resolved:
  - $3.9(7.8) \times \sigma^{\mathrm{theory}}_{\mathrm{ggF+VBF}}$ at SM
  - $226(412) \times \sigma^{\mathrm{theory}}_{\mathrm{VBF}}$ at SM
- Boosted:
  - $9.9(5.1) \times \sigma^{\mathrm{theory}}_{\mathrm{ggF+VBF}}$ at SM

ggF and VBF

κ_λ Scan

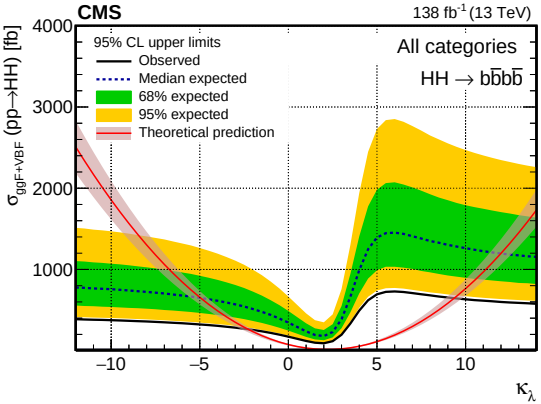


Figure: Resolved, $-2.3(-5.0) < \kappa_\lambda < 9.4(12.0)$

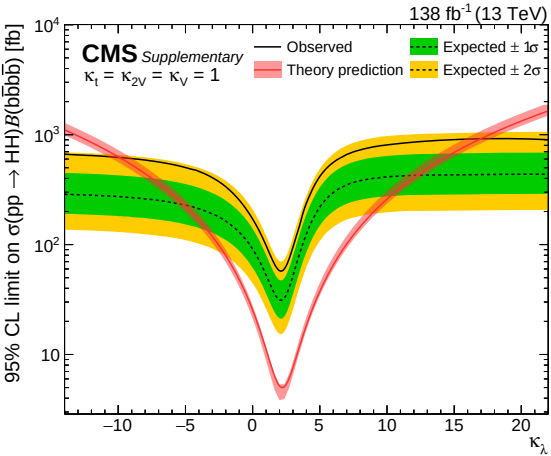


Figure: Boosted, $-9.9(-5.1) < \kappa_\lambda < 16.9(12.2)$

ggF and VBF

κ_{2V} scan

Excluding $\kappa_{2V} = 0$ with 6.3σ from boosted VBF

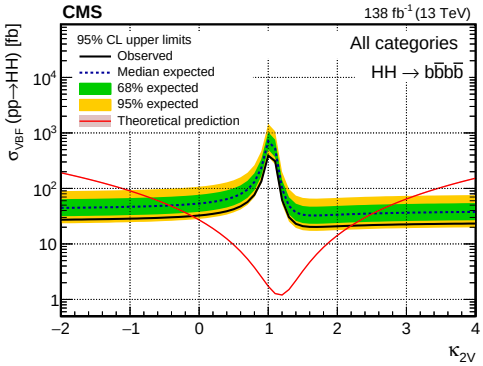


Figure: Resolved, $-0.1(-0.4) < \kappa_{2V} < 2.2(2.5)$

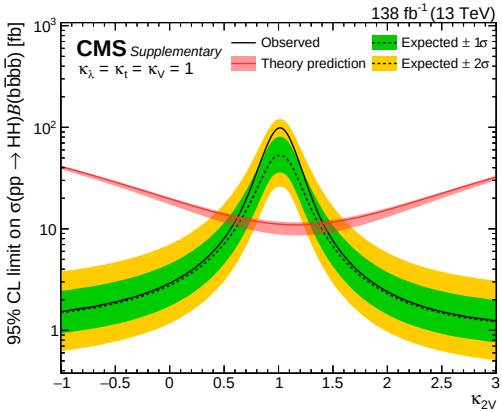
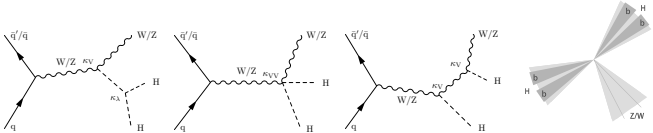


Figure: Boosted, $0.62(0.66) < \kappa_{2V} < 1.41(1.37)$

VHH

CMS-HIG-22-006

- Four analysis channels based on vector boson decay: 2L: $\mathrm{Z} \to ll$, 1L: $\mathrm{W} \to l\nu$, MET: $\mathrm{Z} \to \nu\nu$, FH: $\mathrm{Z/W} \to jj$. Resolved H in all channels. Boosted H in MET and 1L



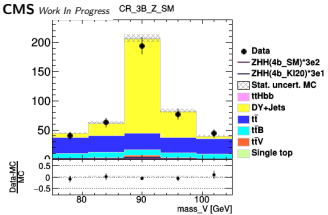


Figure: Reweighted simulated background

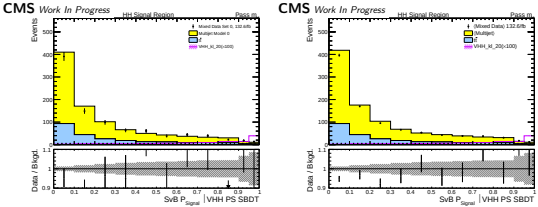
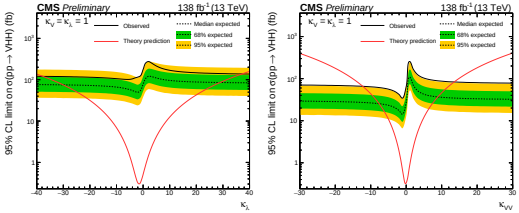


Figure: FH background comparing to hemisphere-mixing data(left: 1 set, right: averaged over 15 sets): QCD multijet: reweighted 3b data, $\mathrm{t\bar{t}}$: simulation

VHH

Results

- Discriminating variables used in the likelihood fit: SvB classifier output distribution.
- Observed (expected) 95% CL upper limits:
  - $-37.7(-30.1) < \kappa_\lambda < 37.2(28.9)$
  - $-12.2(-7.2) < \kappa_{2V} < 13.5(8.9)$
  - $294(124) \times \sigma_{VHH}^{\text{theory}}$ at SM
- Decomposed κ_{2W} and κ_{2Z} according to vector boson decay:
  - $-14.0(-10.2) < \kappa_{2W} < 15.4(11.6)$
  - $-17.4(-10.5) < \kappa_{2Z} < 18.5(11.6)$
- For SM signal, the observed significance is 2.6σ.



Systematic Uncertainties

Leading sources of systematic uncertainties:

- Resolved ggF + VBF: background modeling, trigger efficiency, jet energy scale and resolution, b-tagging efficiency
- Boosted ggF + VBF: bb-tagging efficiency, jet energy scale and resolution
- VHH: background modeling, b-tagging efficiency, jet energy scale and resolution

one of the most important and the hardest to constrain, but we have a new good idea for doing it in a principled way

Combination of ggF and VBF

Nature 607, 60–68(2022)

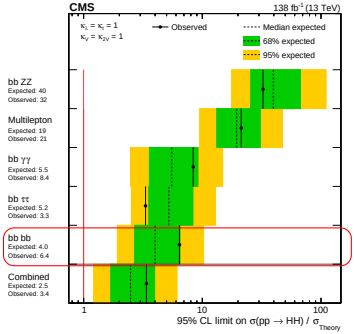


Figure: Upper limit at SM

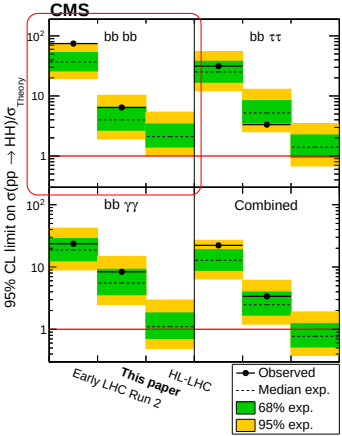
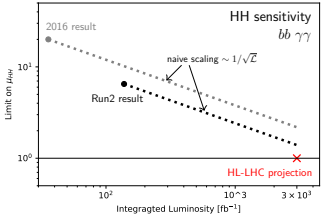


Figure: HL-LHC projection



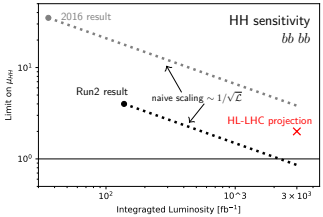


Figure:
$bb\ \gamma\gamma$ (up, dominant by stat unc.)
$bb\ bb$ (down, dominant by syst unc.)

Summary

- Results from ggF, VBF and VHH to $\mathrm{b\bar{b}b\bar{b}}$ have been presented
- VHH will contribute to the next combination.
- The performance of $\mathrm{b\bar{b}b\bar{b}}$ channel in HL-LHC may be further improved when the systematic uncertainties are better constrained.

Backup Slides

Resolved ggF and VBF

SvB and m_{HH}

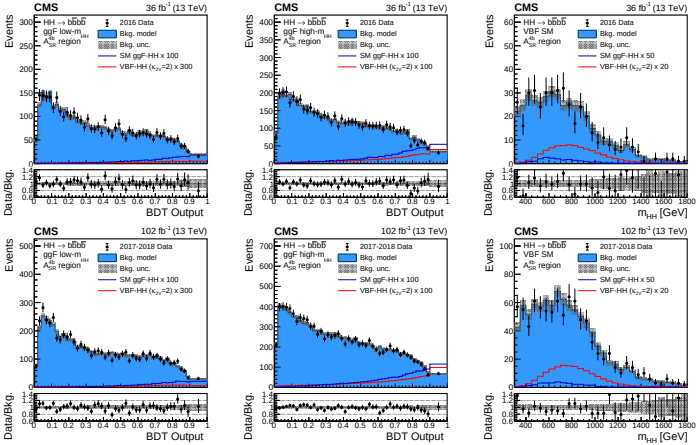


Figure: The two leftmost columns show the BDT output in the low- and high-mass categories, and the rightmost column shows the m_{HH}distribution in the VBF SM-like category

κ_V scan

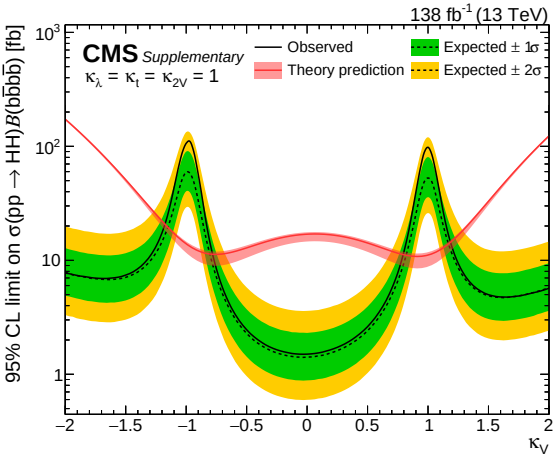


Figure: Boosted ggF and VBF

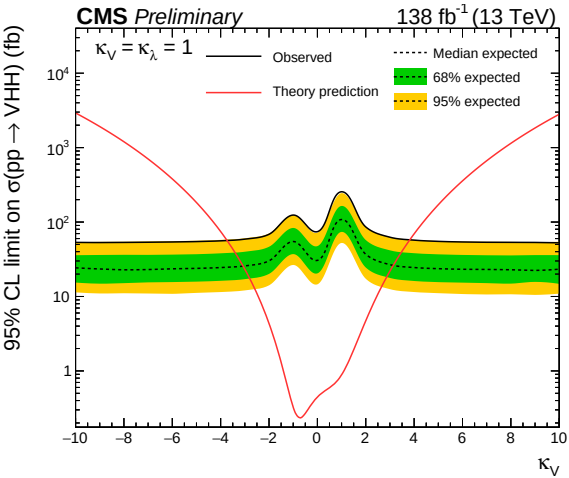


Figure: VHH

Boosted ggF and VBF

Results

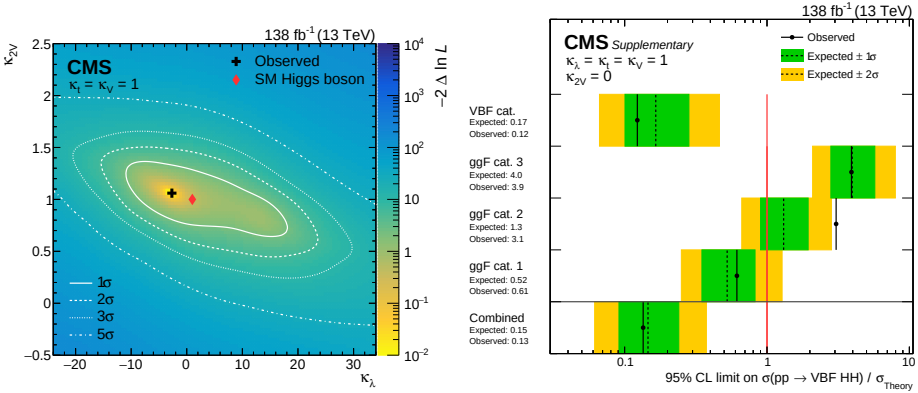


Figure: κ_λ vs κ_{2V} scan (left) and upper limit at $\kappa_{2V} = 0$ (right)

VHH

Signal Strength

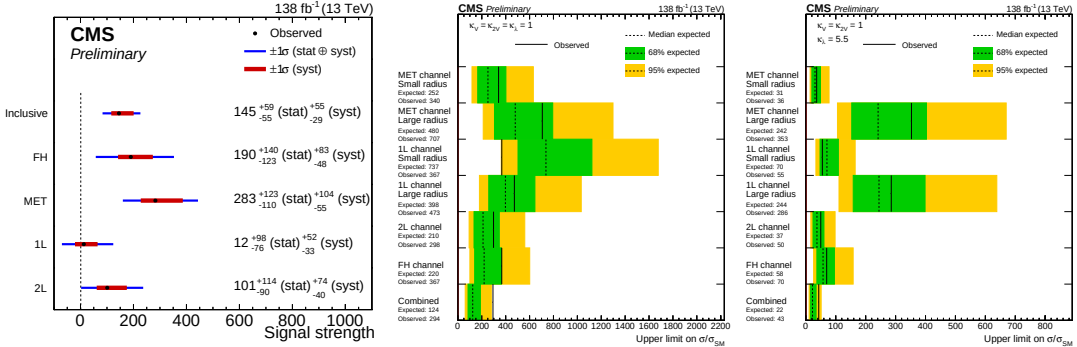


Figure: Best fit signal strength at SM (left), upper limit at SM (middle) and upper limit at $\kappa_\lambda = 5.5$

VHH

Results

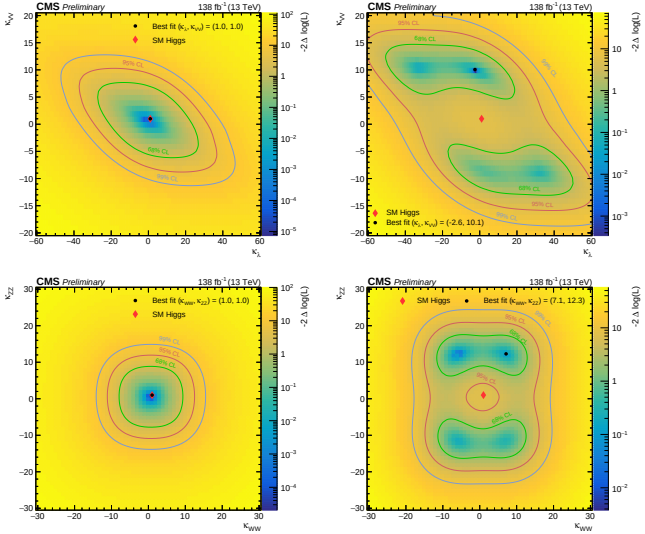


Figure: Expected (left) and observed (right) likelihood scans of κ_λ vs κ_{2V} (up) and κ_{2W} vs κ_{2Z}(down)