



CMS Search for Nonresonant Higgs Pair Production

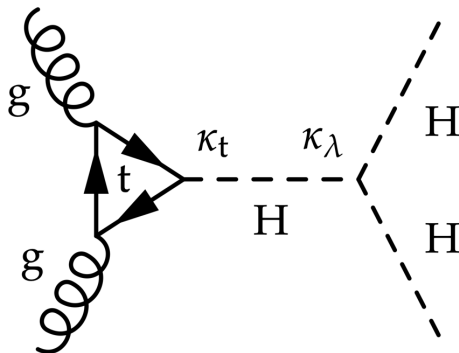
Benjamin Lawrence-Sanderson
Northwestern University
On behalf of the CMS Collaboration

QCD@LHC, Oxford, UK
29 September 2026

Higgs Potential

$$V(H) = \underbrace{\frac{1}{2}m_H^2 H^2}_{\text{Mass term}} + \underbrace{\lambda_3^{SM} v H^3}_{\text{HH Production}} + \underbrace{\frac{1}{4}\lambda_4^{SM} H^4}_{\text{HHH Production}}$$

$$m_H \text{ and } v \text{ are precisely known} \Rightarrow \lambda_3^{SM} = \lambda_4^{SM} = \frac{m_H^2}{2v^2} \approx 0.13$$

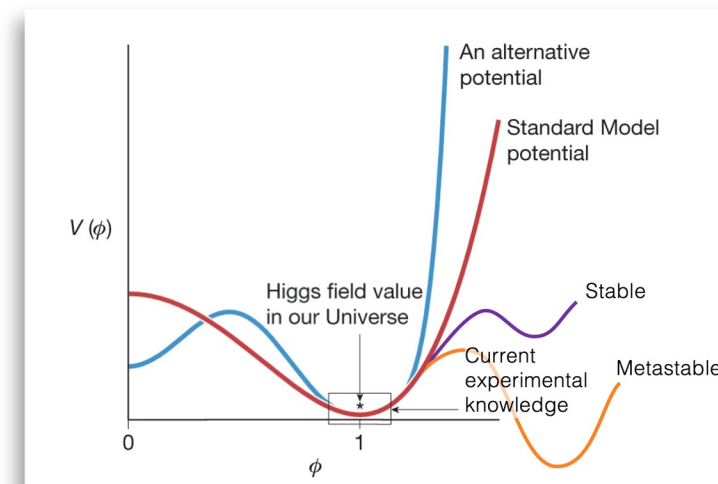


$$\kappa_\lambda = \frac{\lambda_3}{\lambda_3^{SM}}$$

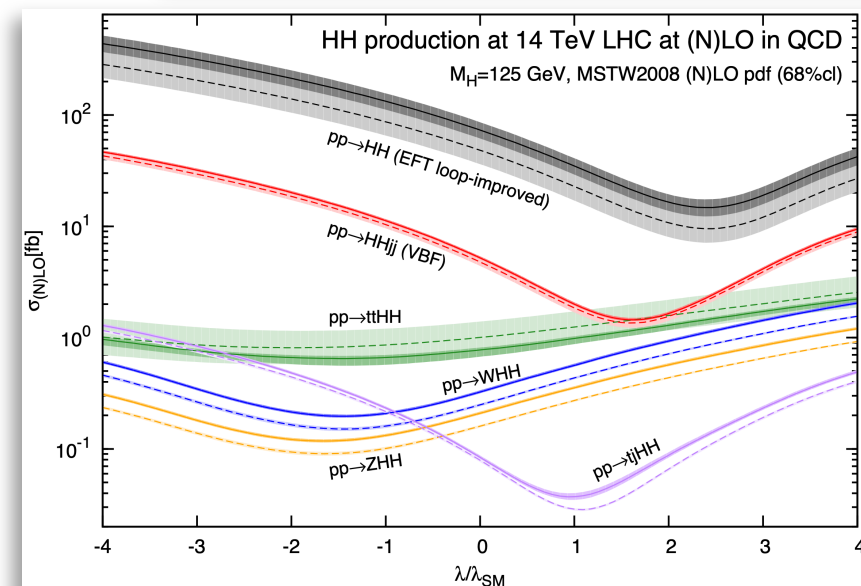
$$\kappa_t = \frac{y_t}{y_t^{SM}}$$

HH Probes $\sigma_{pp \rightarrow HH}$
 $\Rightarrow$ Infer κ_λ from $\sigma_{pp \rightarrow HH}$
 $\Rightarrow \kappa_\lambda$ describes Higgs potential

Higgs potential can be distorted by new physics!

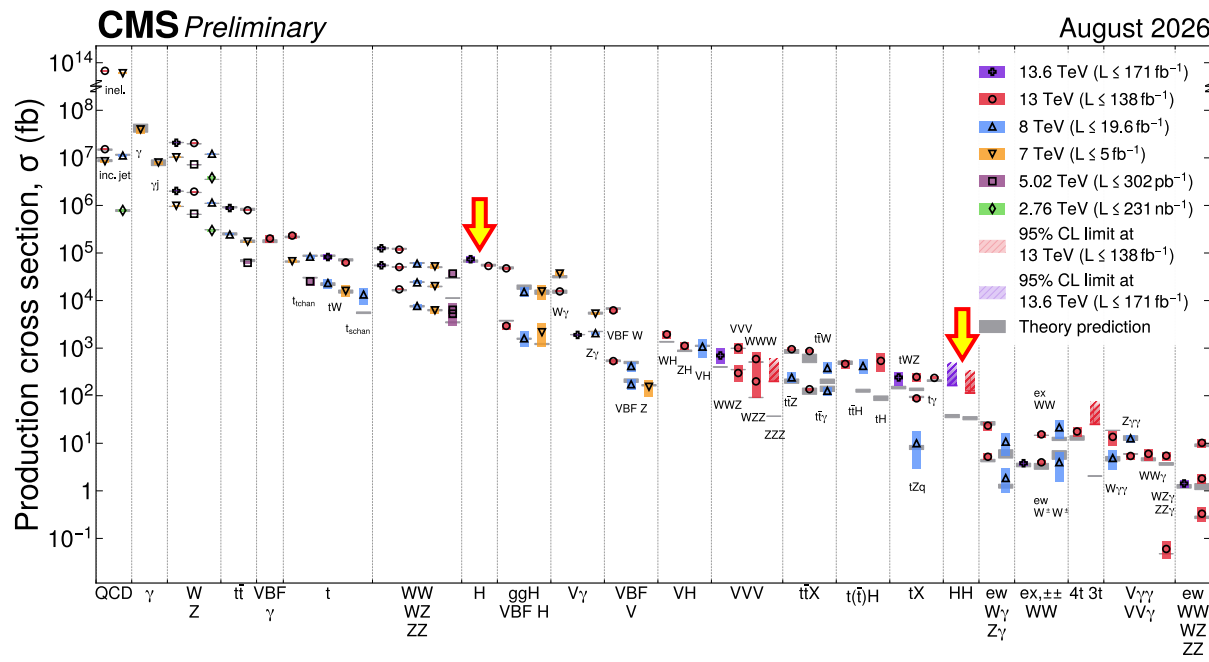


Adapted from
[Nature 607, 41–47 \(2022\)](#)



HH Production Modes at LHC

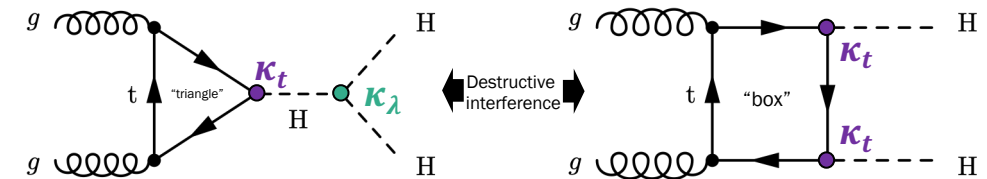
- Very challenging measurement
 - SM HH cross section is ~ 1000 times smaller than that of single Higgs production
 - Dominated by ggF production mode: destructive interference between “box” and “triangle” diagrams
 - Additional production modes VBFHH, VHH, ttHH



Gluon-Gluon Fusion

$$\sigma_{ggF} = 31.05 \text{ fb @ NNLO } \sqrt{s} = 13 \text{ TeV}$$

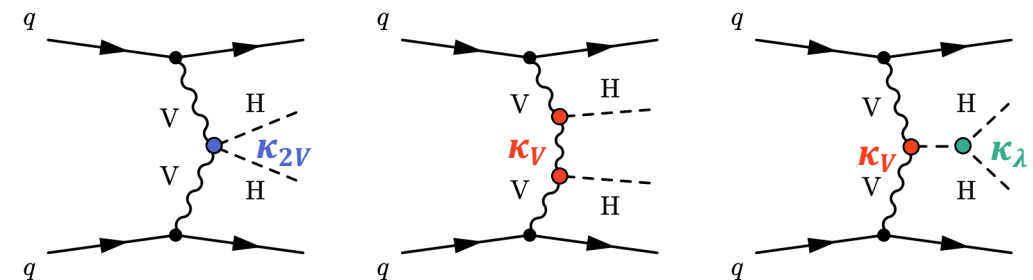
Leading HH production mode



Directly probes κ_λ

Vector Boson Fusion

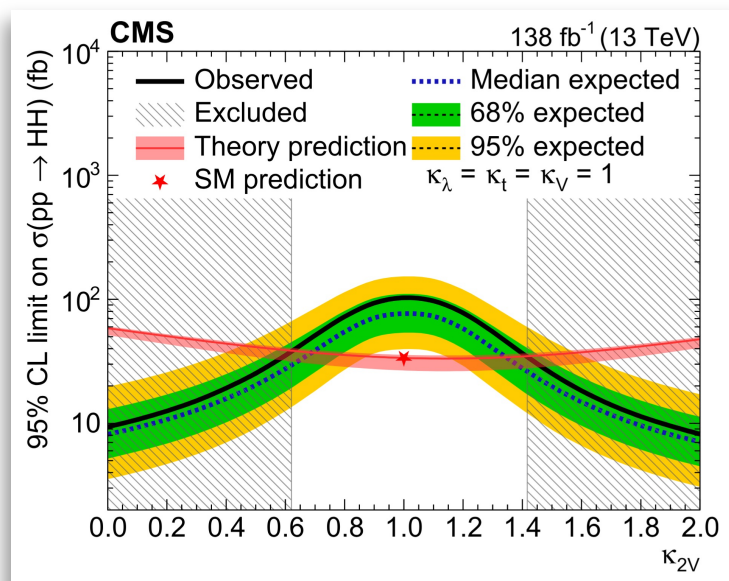
$$\sigma_{VBF} = 1.73 \text{ fb @ N}^3\text{LO } \sqrt{s} = 13 \text{ TeV}$$



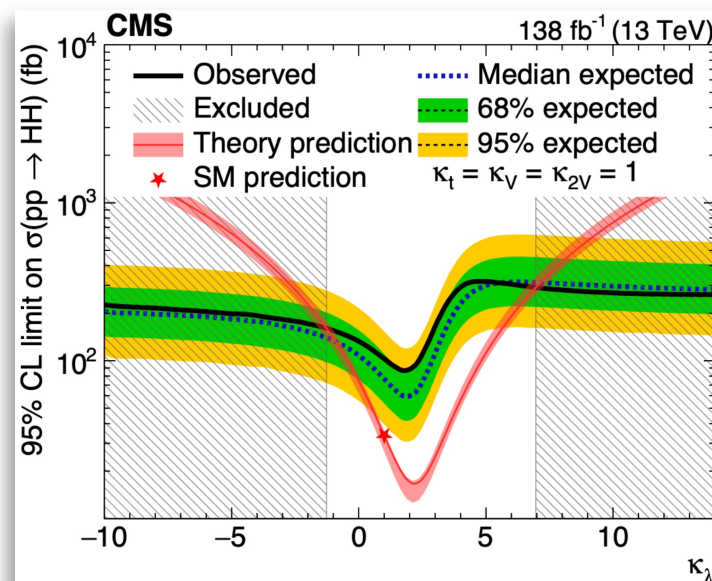
Probes κ_λ , κ_V , and κ_{2V}

CMS HH Run 2 Combination

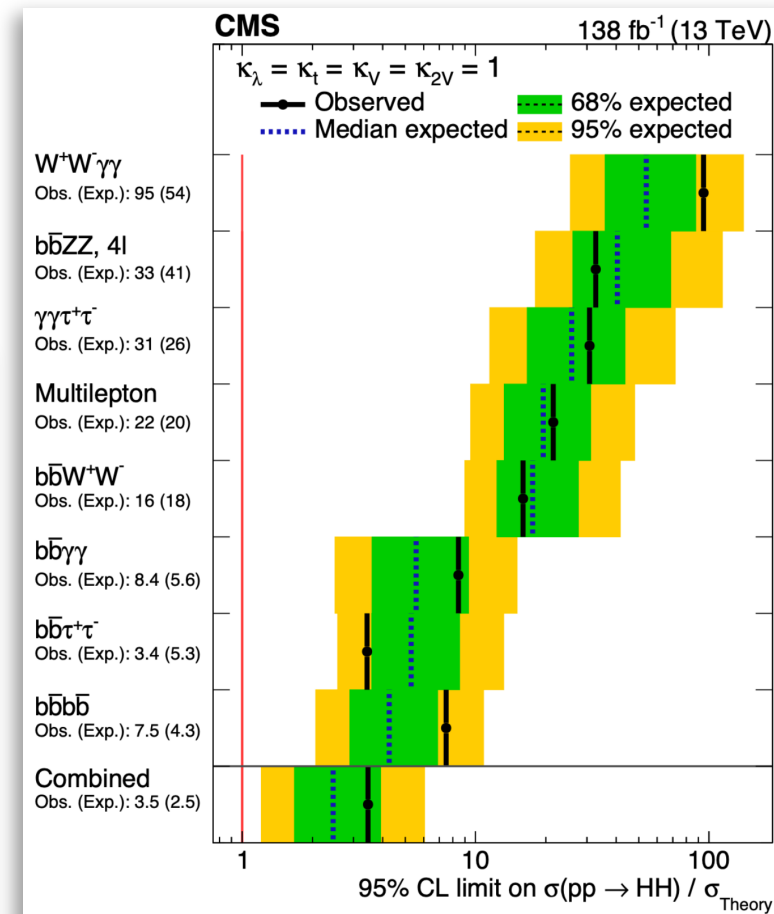
- Combined analysis of 138 fb^{-1} of Run 2 data at $\sqrt{s} = 13 \text{ TeV}$ from 2016-2018 from eight HH analysis channels
- Set limits on anomalous couplings to the Higgs boson using the Higgs Effective Field Theory (HEFT) framework
- Significant accomplishment



$\kappa_{2V} = 0$ excluded at 6.6 σ
(profile likelihood; other couplings fixed to SM)



Observed 95% CL constraints
 $-1.35 \leq \kappa_\lambda \leq 6.37$

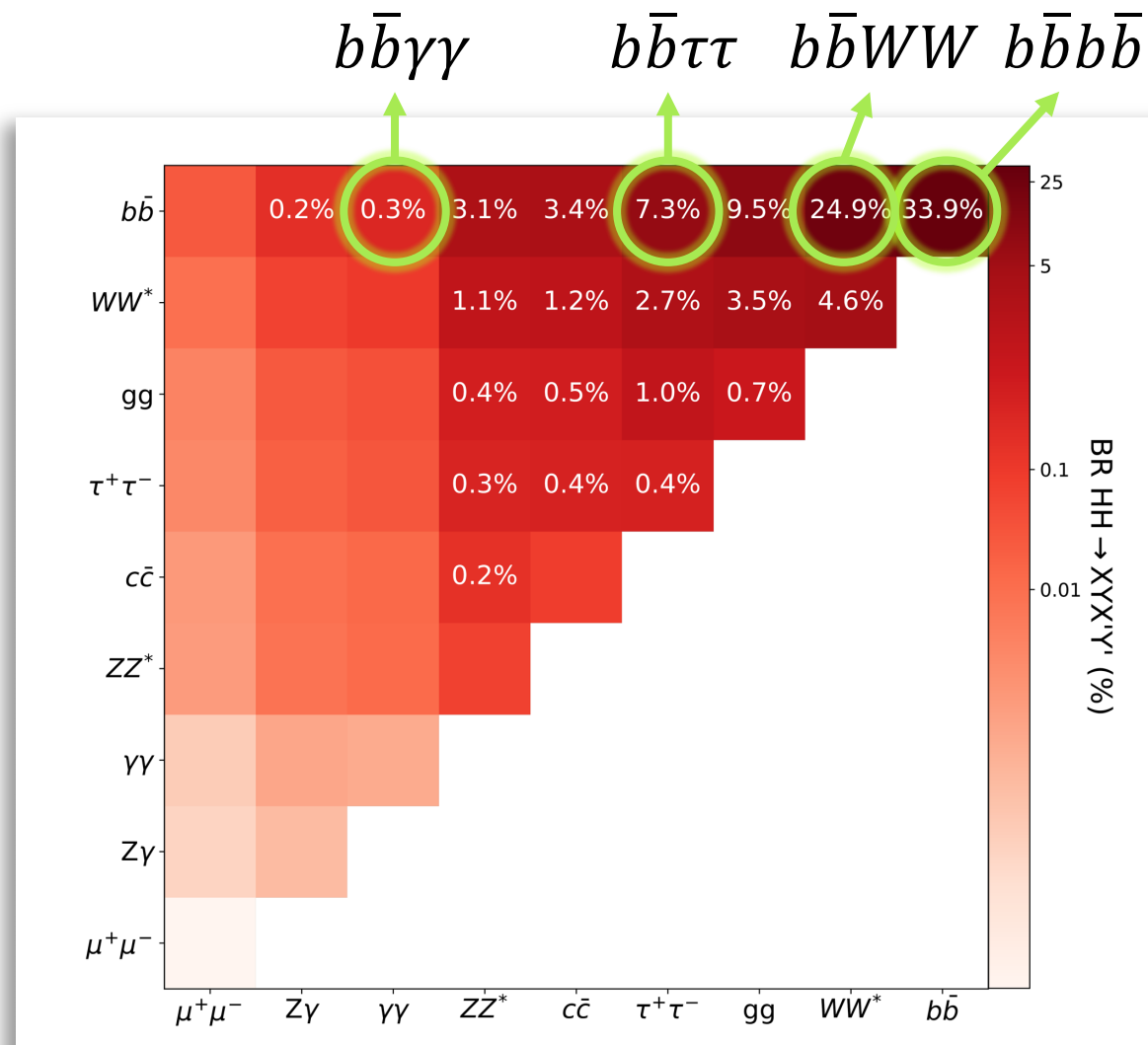


Observed (Expected) 95% CL UL
 $\sigma(pp \rightarrow HH) < 3.5 (2.5) \sigma_{\text{Theory}}^{\text{SM}}$

CMS HH Analyses in Run 3

- Run 3 HH analyses showcase major advancements in analysis techniques
- Partial Run 3 CMS analyses public for **four** decay channels

Bold progress on CMS Run 3 di-Higgs program



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

$HH \rightarrow b\bar{b}b\bar{b}$ Analysis Strategy



- Largest branching ratio $\sim 33\%$



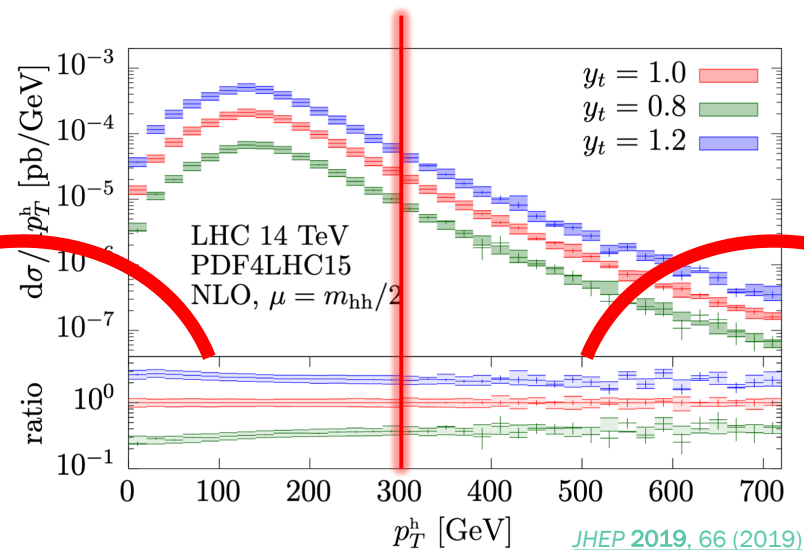
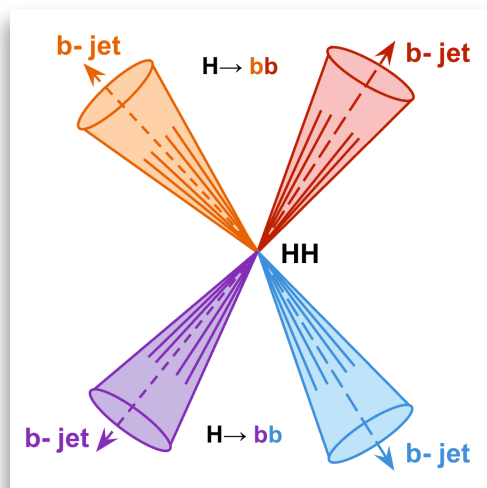
- Overwhelming QCD background

- Small expected S/B makes signal extraction difficult
- QCD poorly modeled by Monte-Carlo and lacks higher order corrections, further complicating the background methodology



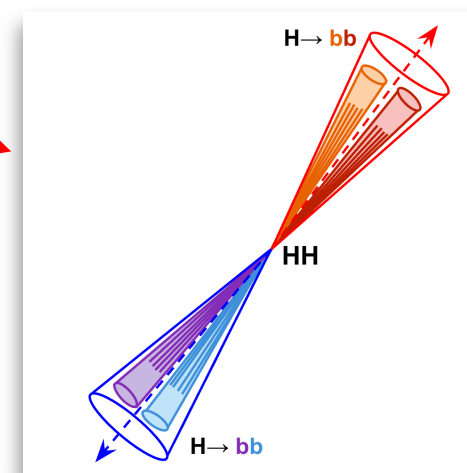
- Merged $b\bar{b}$ topology has better S/B and allows measurement of higher Higgs boson p_T range

Resolved Topology



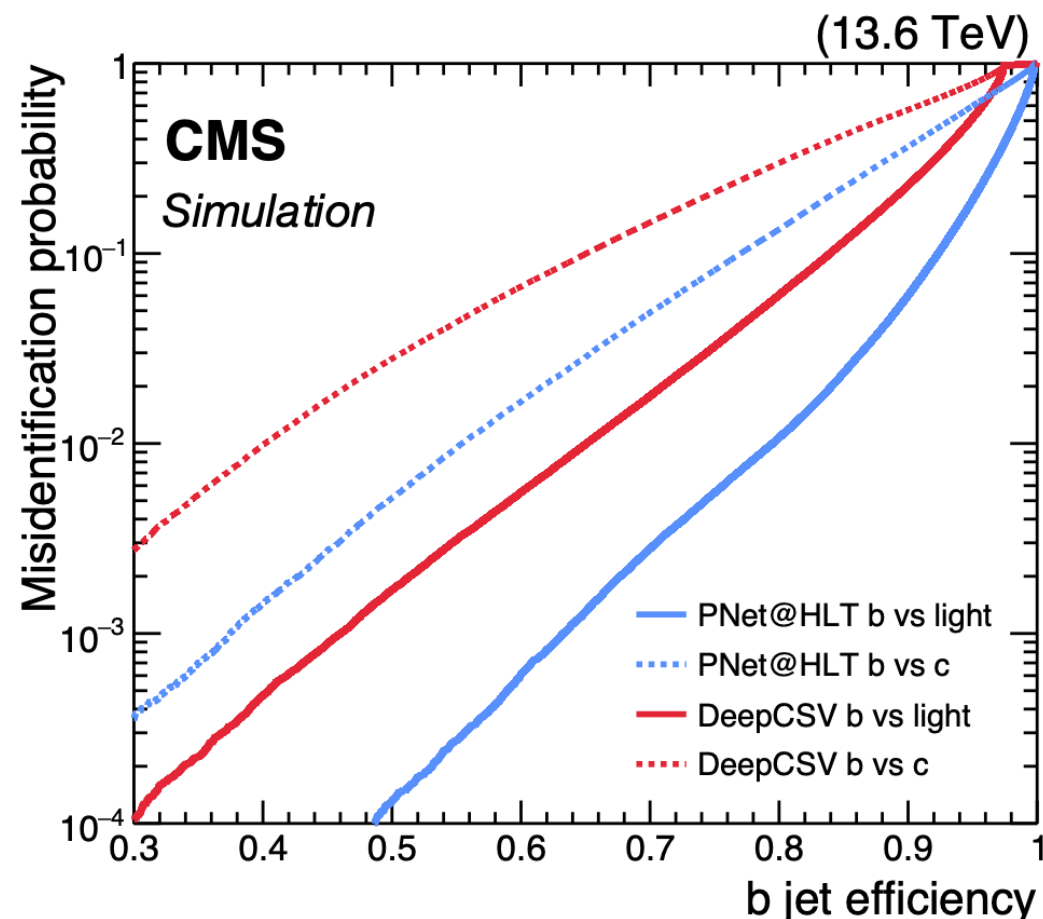
Leading Higgs boson p_T

Merged Topology

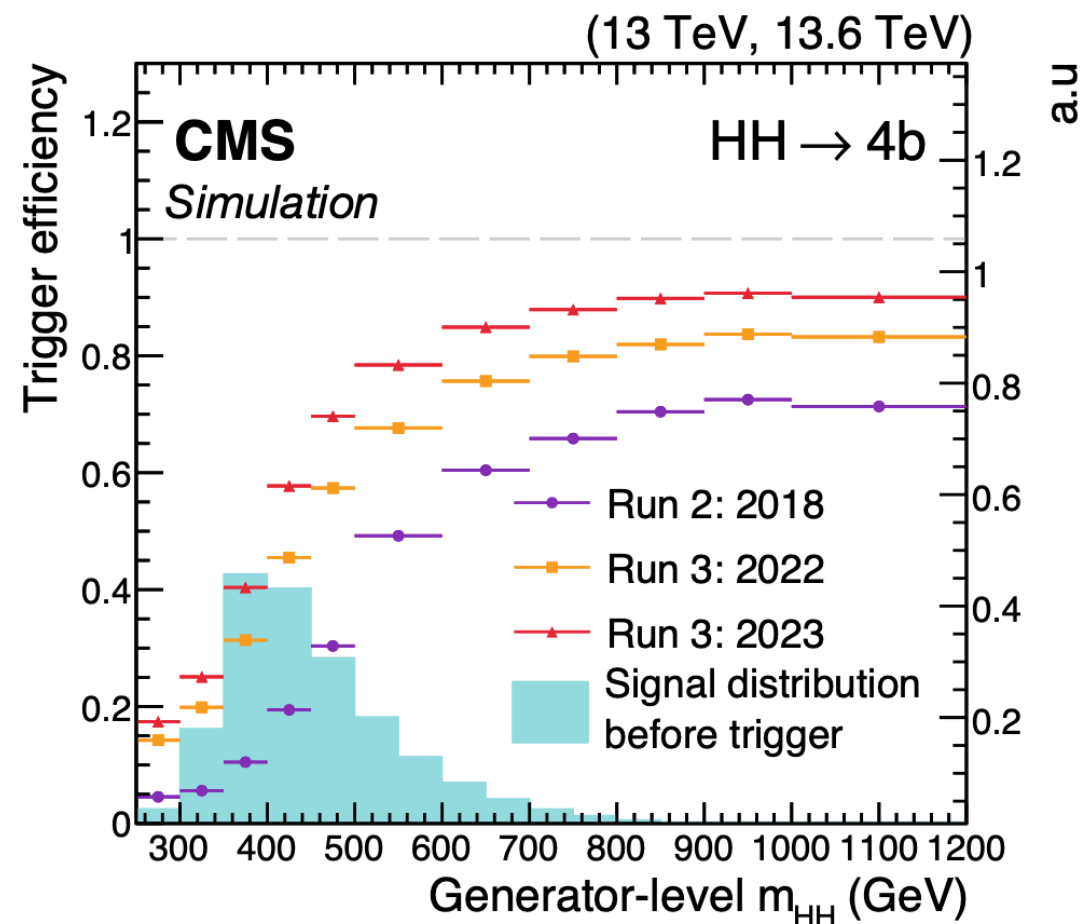


$HH \rightarrow b\bar{b}b\bar{b}$ Run 3 Improvements

Resolved



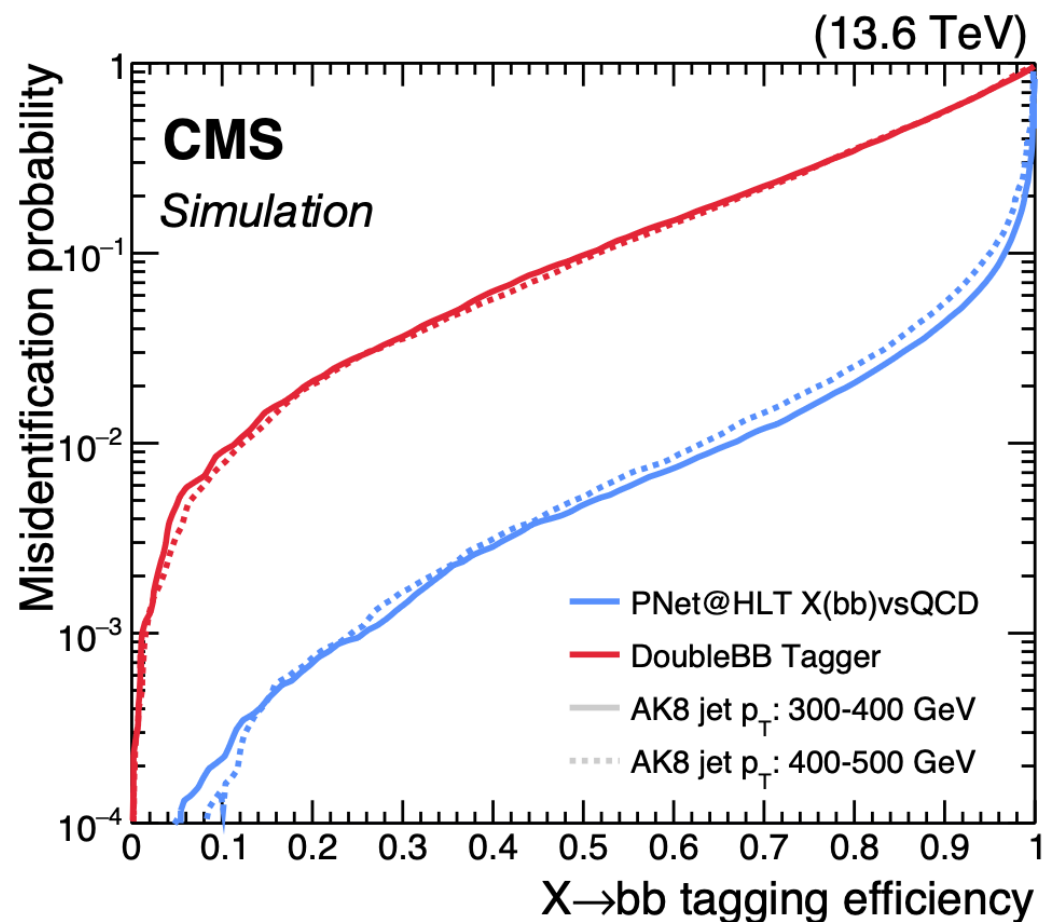
b-tagging performance of **Run 3 algorithm** and **Run 2 algorithm**, from $t\bar{t}$ MC evaluated on trigger-level AK4 jets with $p_T > 30\text{ GeV}$ and $|\eta| < 2.5$.



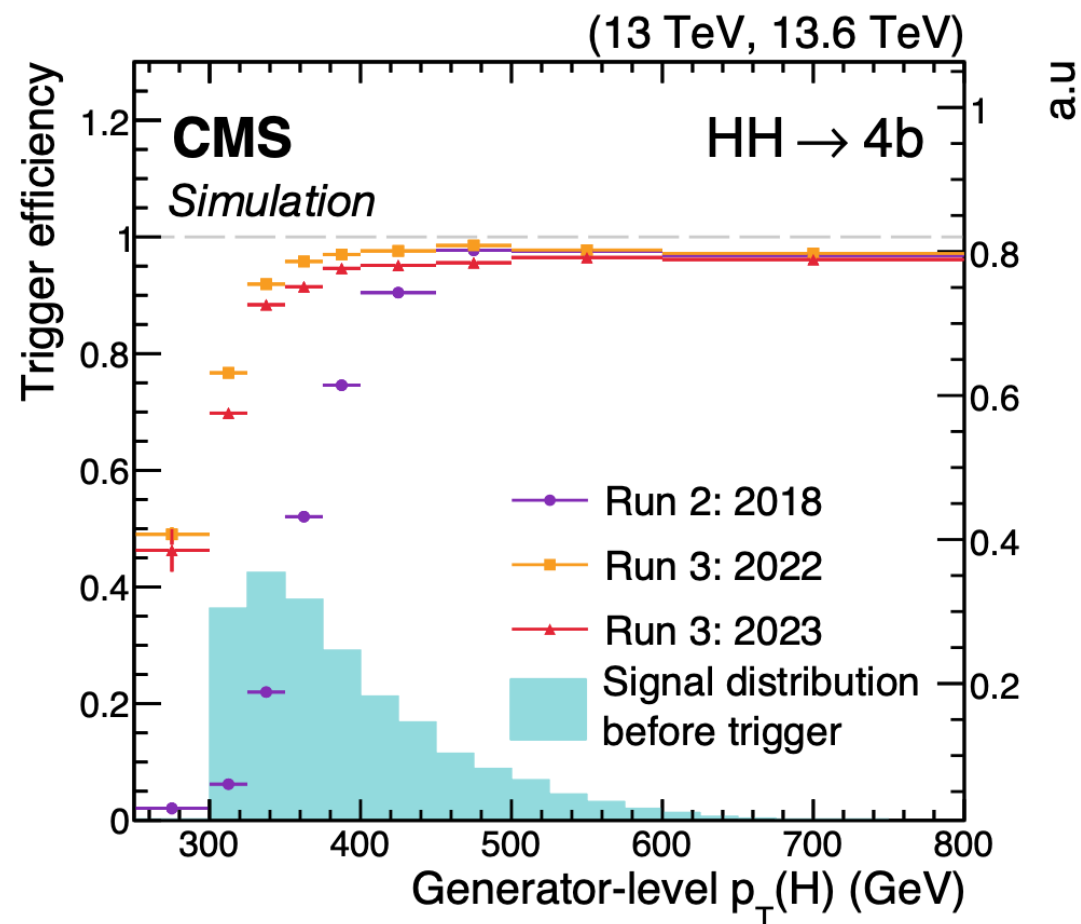
Trigger efficiency for resolved topology as a function of generator-level m_{HH} in simulated SM $HH \rightarrow 4b$ with generator level b-jets satisfying $p_T > 25\text{ GeV}$ and $|\eta| < 2.5$.

$HH \rightarrow b\bar{b}b\bar{b}$ Run 3 Improvements

Merged



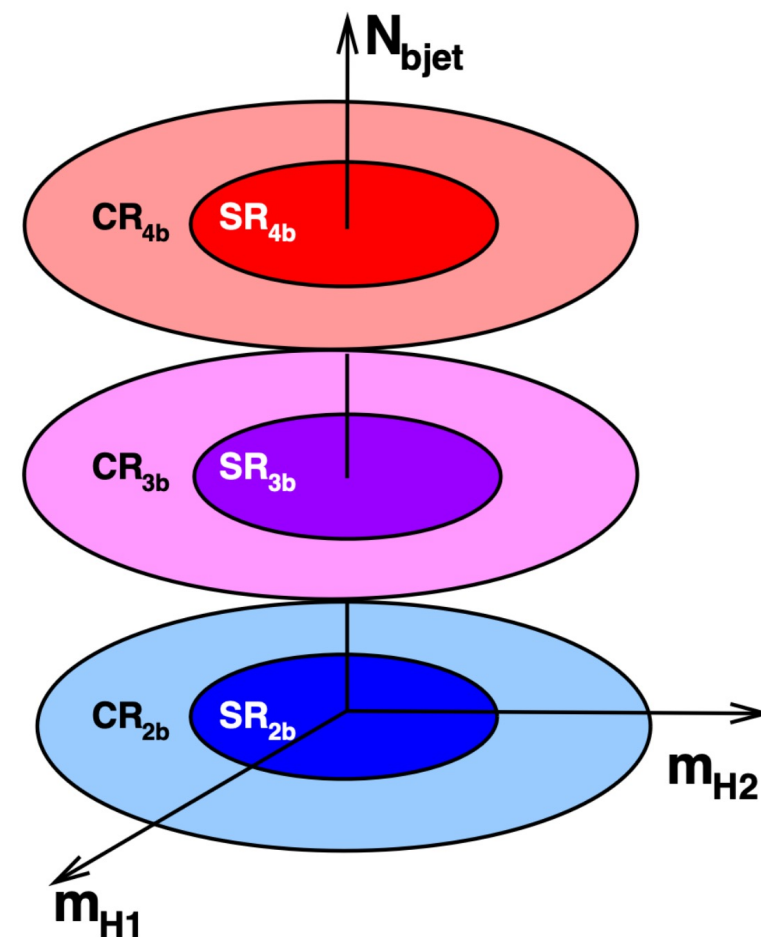
b-tagging performance of [Run 3 algorithm](#) and [Run 2 algorithm](#), evaluated on AK8 jets in the HLT from MC $HH \rightarrow 4b$ and QCD multijet events.



Trigger efficiency for merged topology as a function of generator-level H-candidate p_T^{lead} in simulated SM $HH \rightarrow 4b$ $\Delta R(b, \bar{b}) < 0.8$ events.

$HH \rightarrow b\bar{b}b\bar{b}$ Signal Extraction

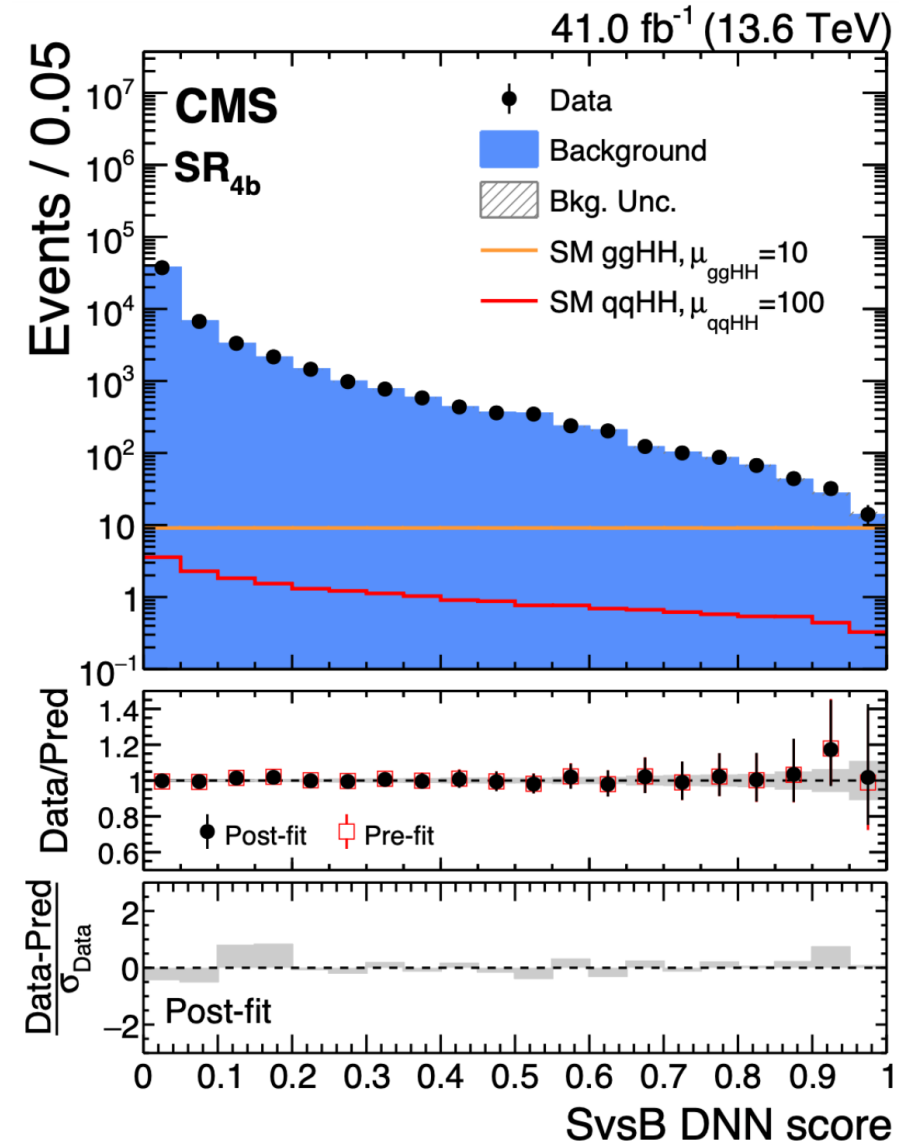
- QCD($+t\bar{t}$) dominant background, estimated from data
- DNN-based multivariate reweighting to estimate background in **signal regions** from **background dominated control regions**.



Run 3 HLT allows 10x more **2b**-tag dataset than **3b** to estimate background in **4b**

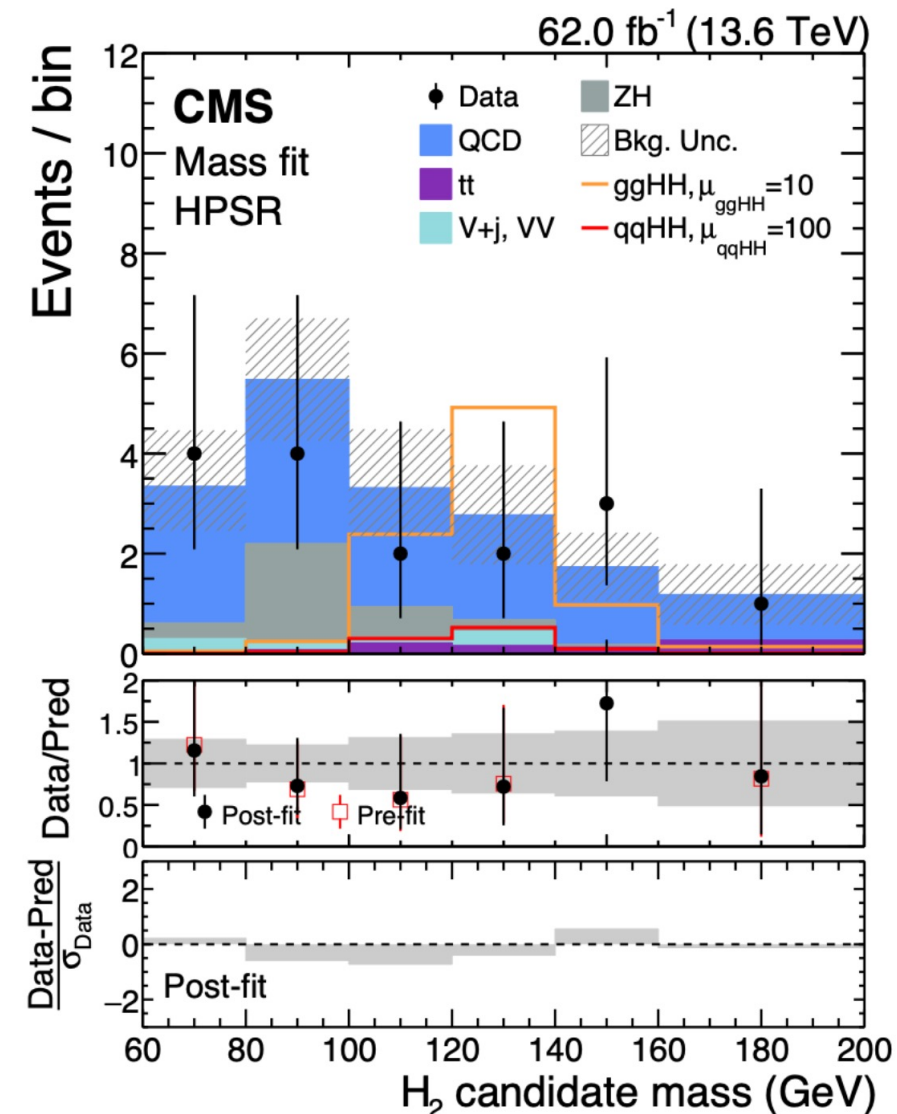
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- QCD($+t\bar{t}$) dominant background, estimated from data
- DNN-based multivariate reweighting to estimate background in **signal regions** from **background dominated control regions**.
- Separate signal versus background classifier DNNs trained and evaluated on ggHH and VBFHH categories.
- Signal in the **resolved topology** is extracted via a binned profile likelihood fit to the **DNN $\mathcal{P}_{HH}$ score distribution**.



$HH \rightarrow b\bar{b}b\bar{b}$ Signal Extraction

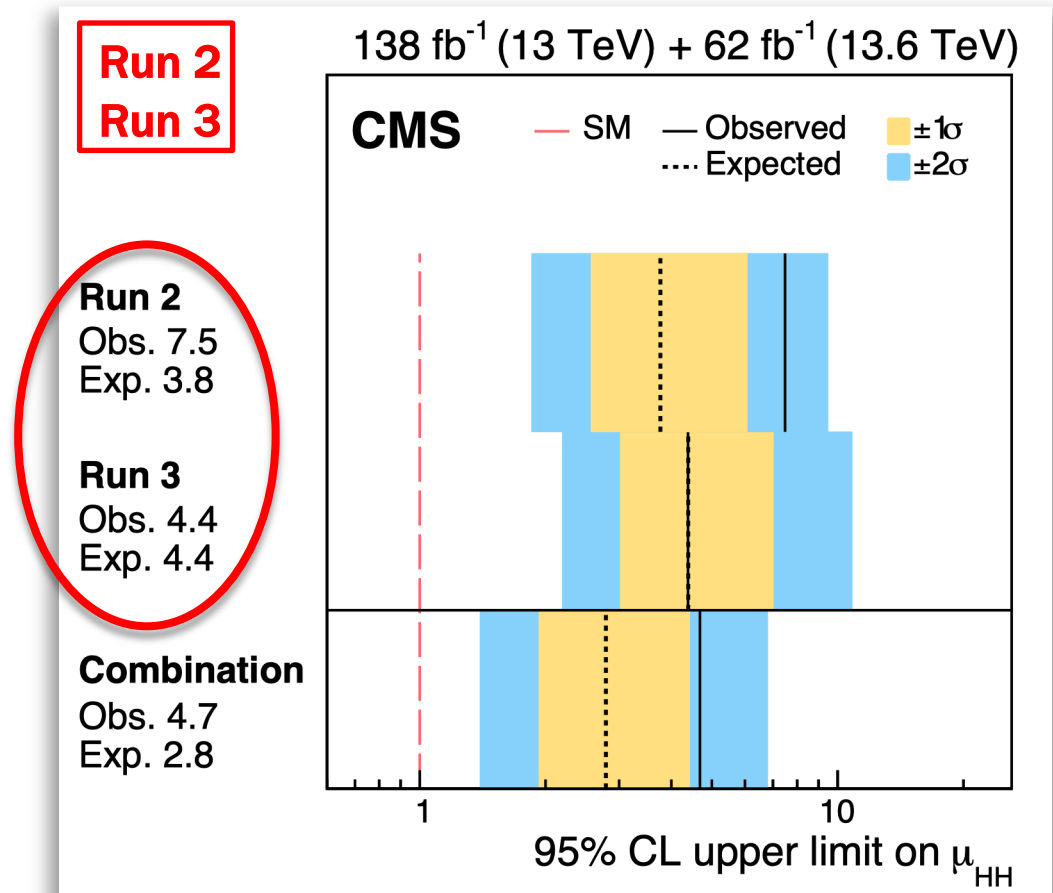
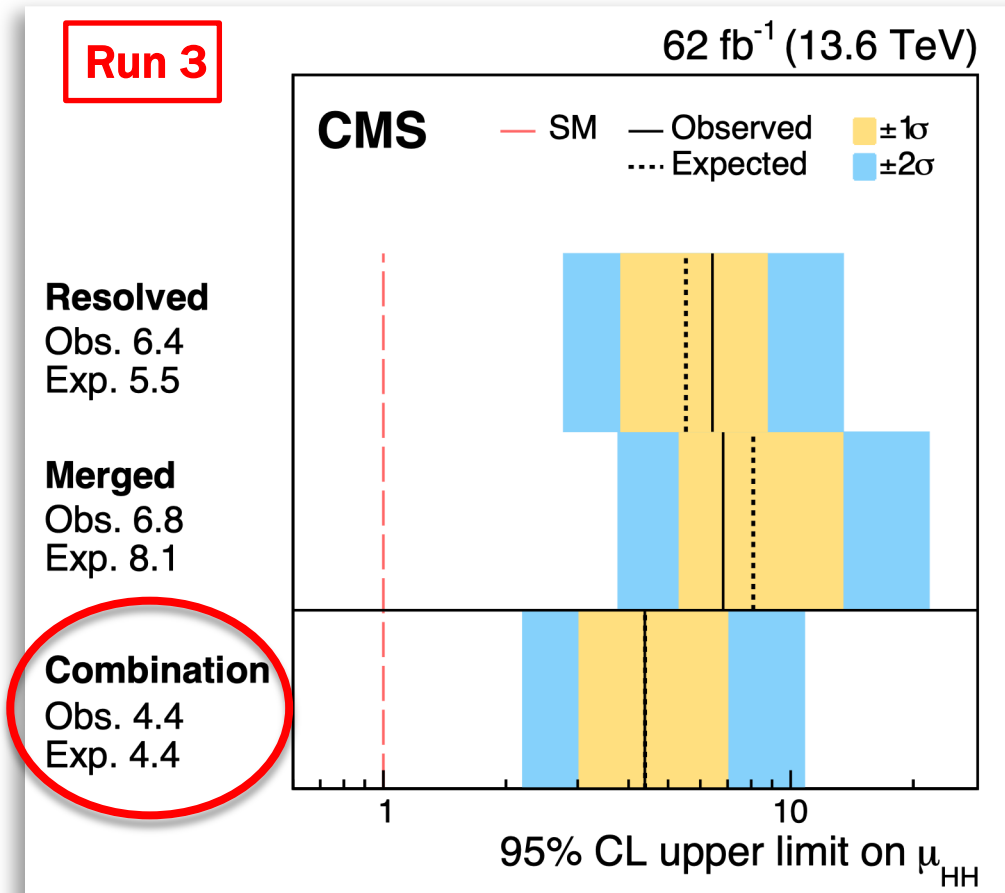
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- DNN-based multivariate reweighting to estimate background in **signal regions** from **background dominated control regions**.
- Separate signal versus background classifier DNNs trained and evaluated on ggHH and VBFHH categories.
- Signal in the **resolved topology** is extracted via a binned profile likelihood fit to the **DNN $\mathcal{P}_{HH}$ score distribution**.
- Events in the **merged topology** are grouped into **categories** by DNN score and then signal is extracted by a binned profile likelihood fit to the **subleading Higgs mass distribution**, per category.



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

Resolved topology 200% improvement in sensitivity compared to Run 2!

95% CL UL on HH signal

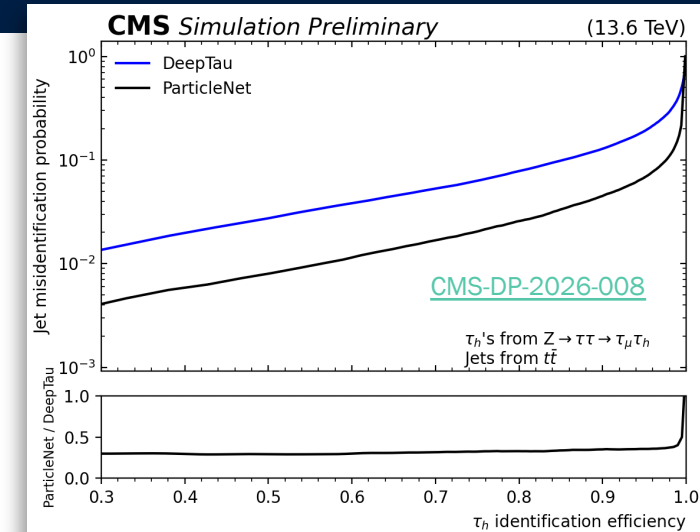


With only 62 fb^{-1} integrated luminosity, Run 3 achieves comparable sensitivity to Run 2 at 138 fb^{-1} .

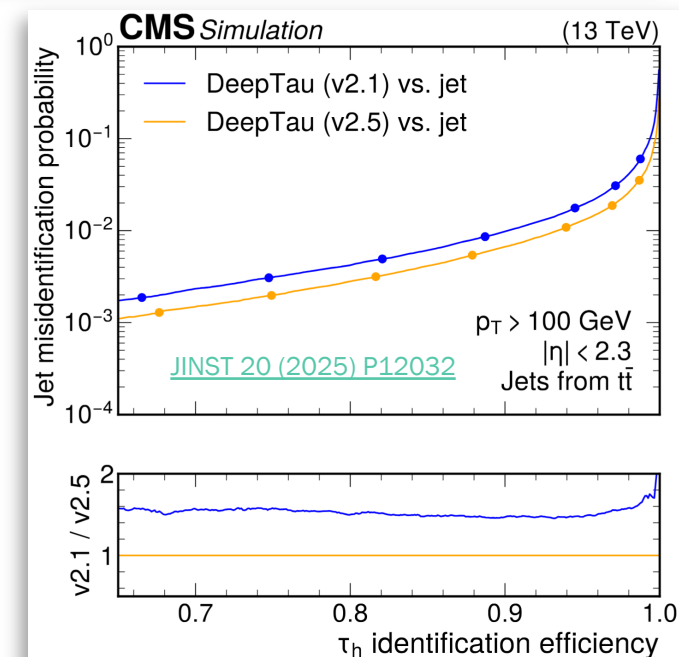
$$HH \rightarrow b\bar{b}\tau\tau$$

$HH \rightarrow b\bar{b}\tau\tau$ Analysis Strategy

- Sizeable branching fraction (7.3%)
- Balance between purity and yield:
 - $H \rightarrow \tau\tau$ clean experimental signature
 - $H \rightarrow b\bar{b}$ large branching ratio
- Targets three $\tau\tau$ channels: $(e\tau_h, \mu\tau_h, \tau_h\tau_h)$
- Several improvements over the Run 2 analysis:
 - Improved online (HLT) and offline τ identification
 - More inclusive HLT paths, enhancing signal acceptance
 - Inclusion of merged event topologies, accessing merged $\tau_h\tau_h$
 - Improved τ_h momentum assignment with a DNN regression



HLT τ_h
reco.

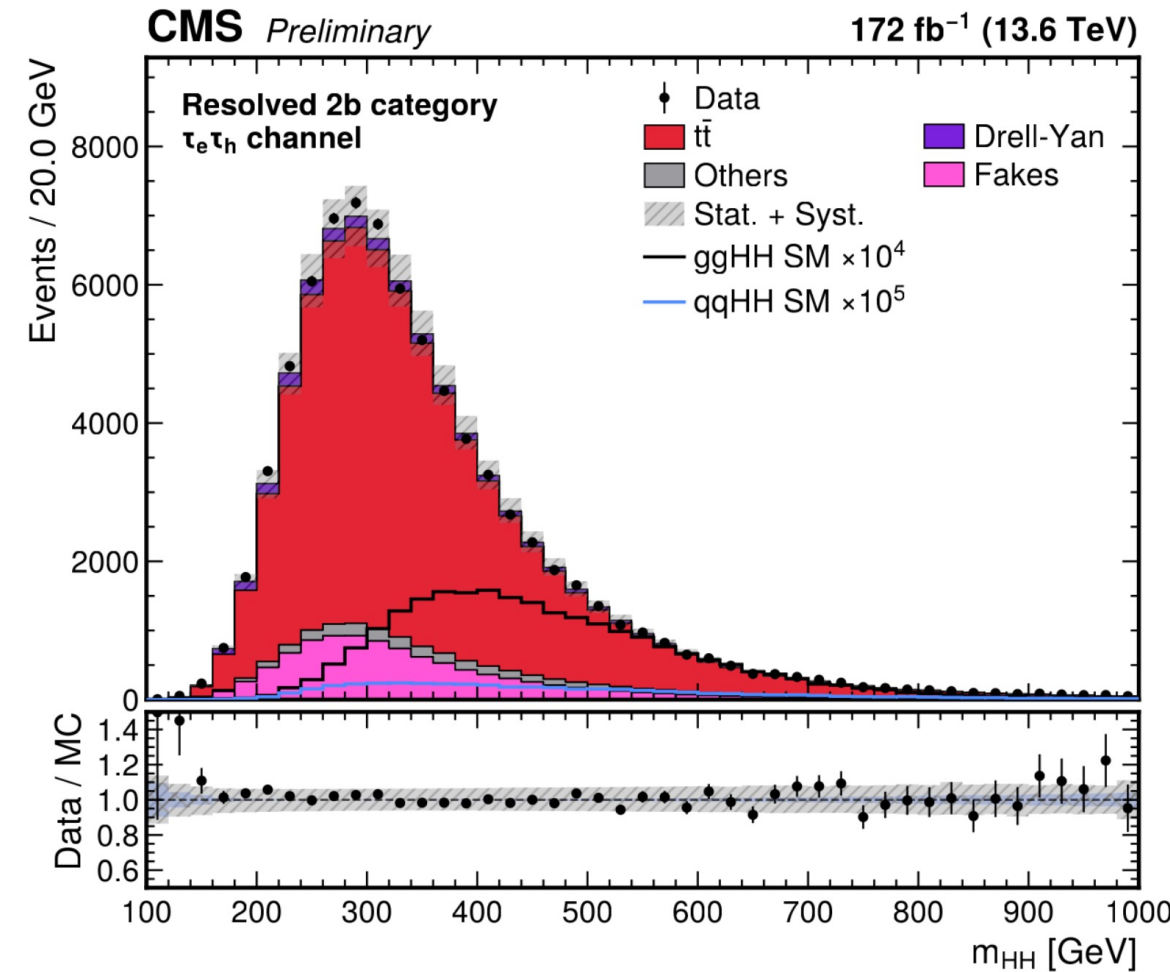


DeepTau

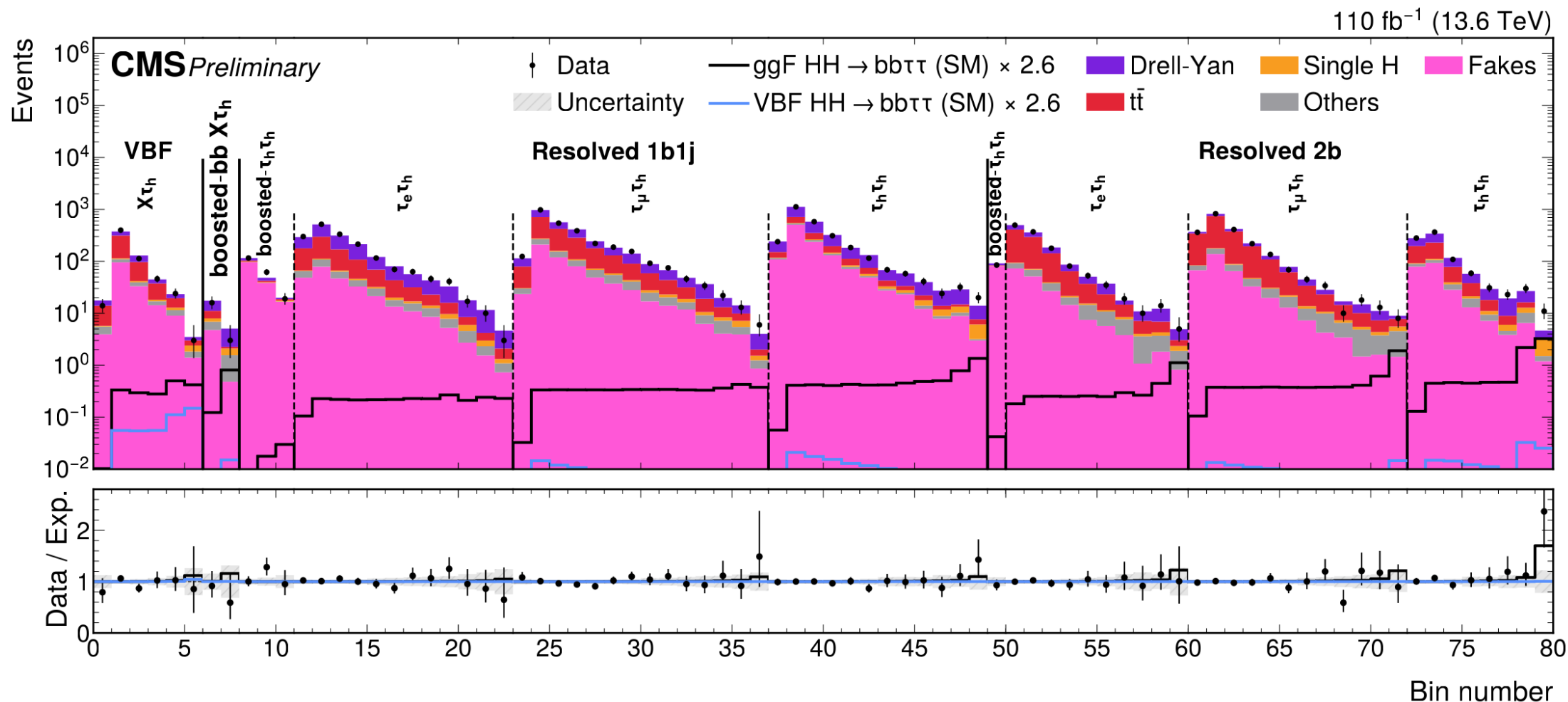
$HH \rightarrow b\bar{b}\tau\tau$ Signal Extraction

Several backgrounds

- $t\bar{t}$ and single-Higgs backgrounds with genuine τ_h
 - Modeled from MC
- Irreducible Drell-Yan $Z/\gamma^* \rightarrow \tau\tau$
 - Estimated from MC
 - Validated on Z enriched CR
- Non-prompt τ_h background from QCD, W +jets, $t\bar{t}$
 - Derived using fake factor (FF) methods from dedicated CR



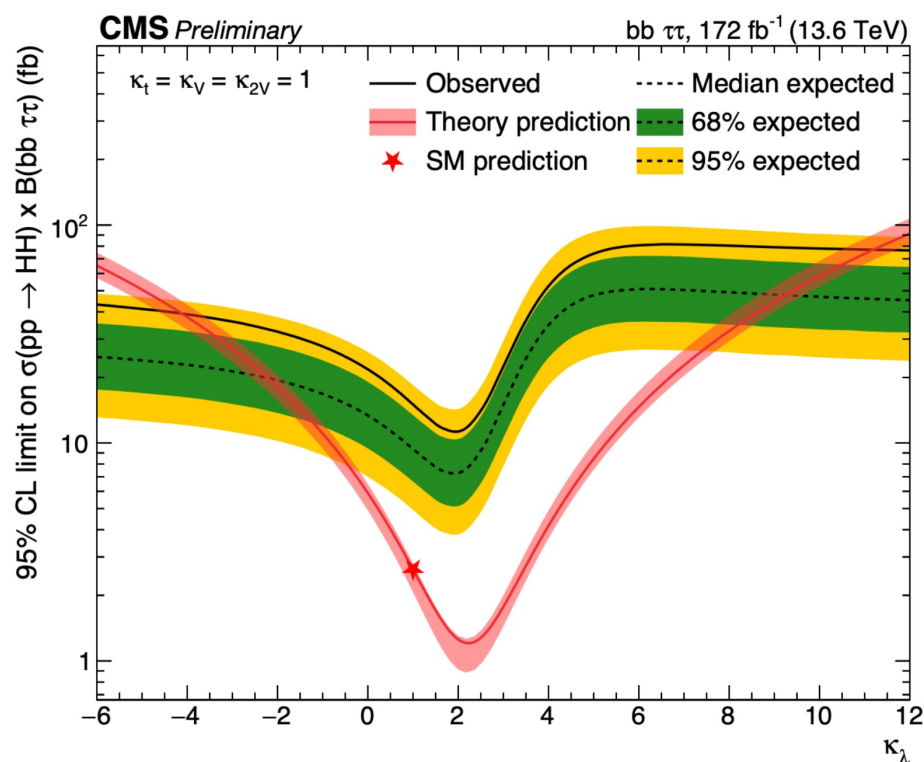
$HH \rightarrow b\bar{b}\tau\tau$ DNN Score Distributions



DNN score distributions in the 2024 signal regions after maximum likelihood fit to data, used to extract signal.

$HH \rightarrow b\bar{b}\tau\tau$ Results: Early Run 3

- Sensitivity dominated by category with two resolved b-jets
- Dominant experimental systematic uncertainties from fake factor calculation of the τ_h and b-tagging
- 20% higher sensitivity than Run 2
 - [Phys. Lett. B 842 \(2023\) 137531](#)



VBF

Expected: 23
Observed: 21

bb-boosted

Expected: 21
Observed: 16

resolved 1b1j

Expected: 15
Observed: 18

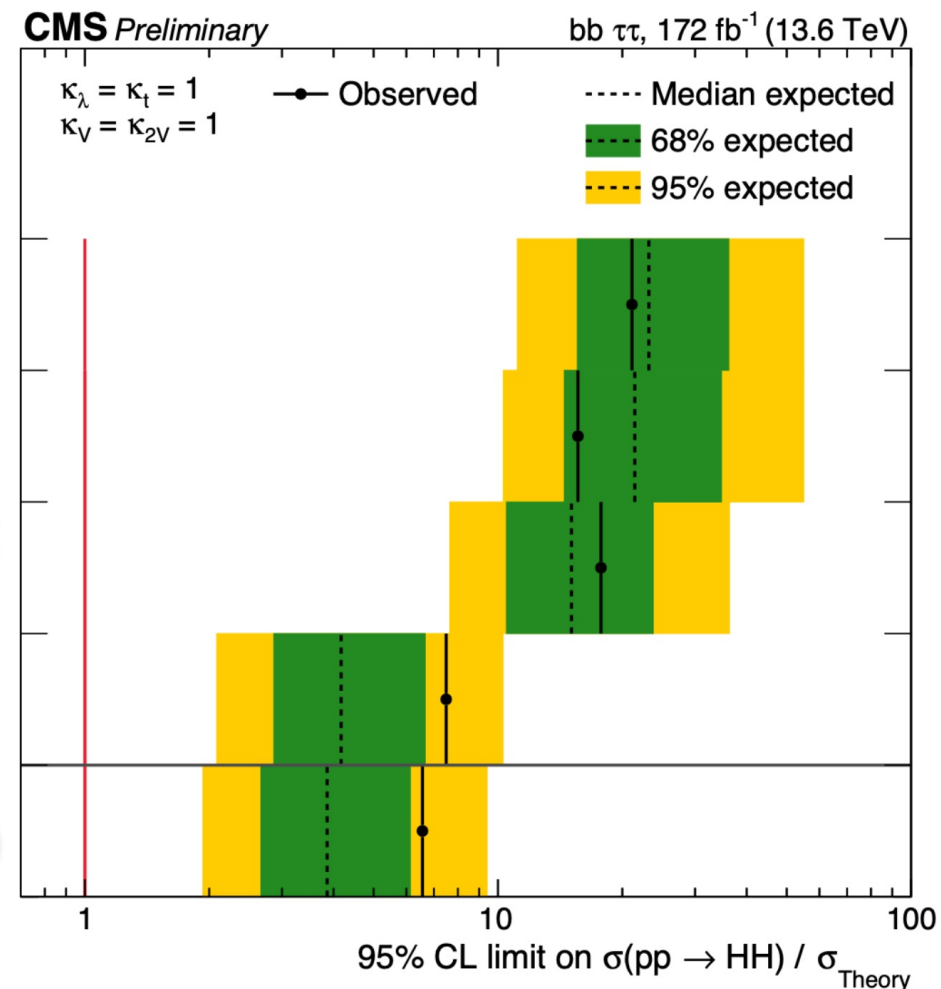
resolved 2b

Expected: 4.2
Observed: 7.5

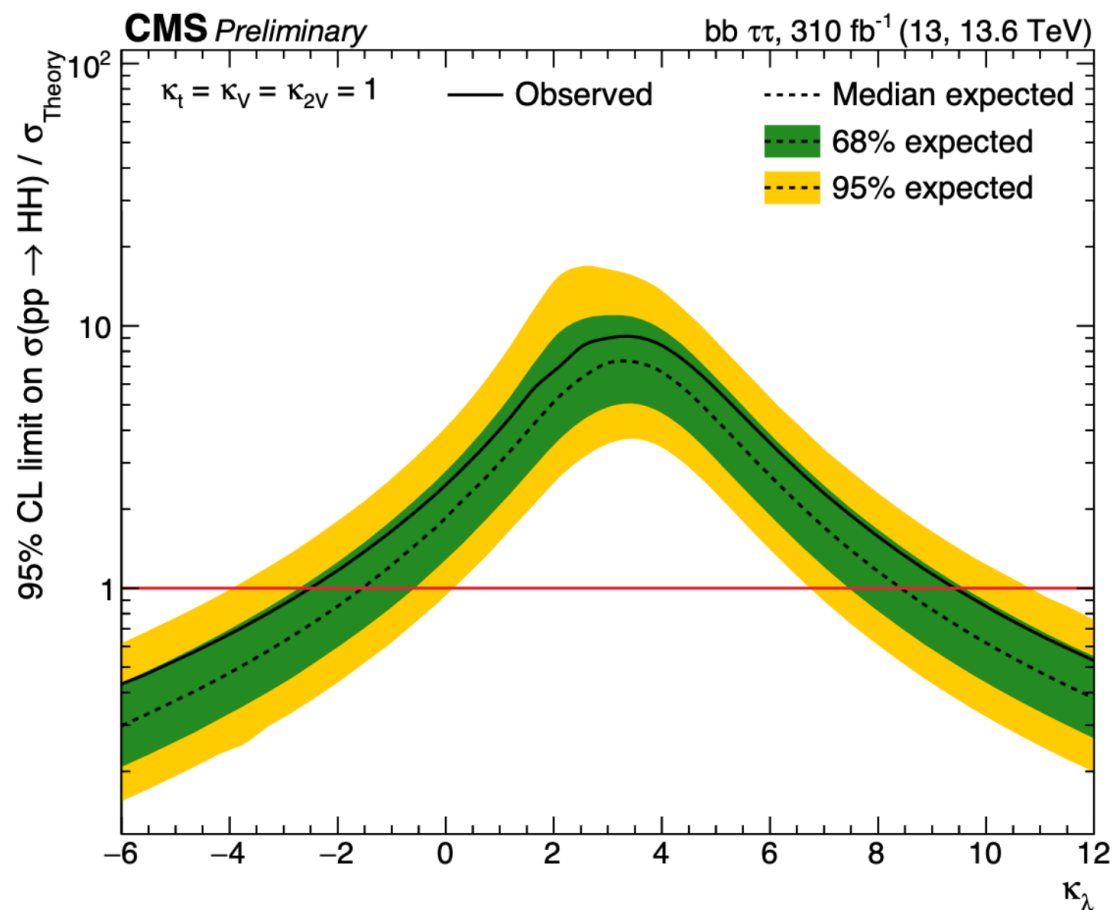
Combined

Expected: 3.9
Observed: 6.6

95% CL UL on HH signal



$HH \rightarrow b\bar{b}\tau\tau$ Results: Run 2 + Early Run 3

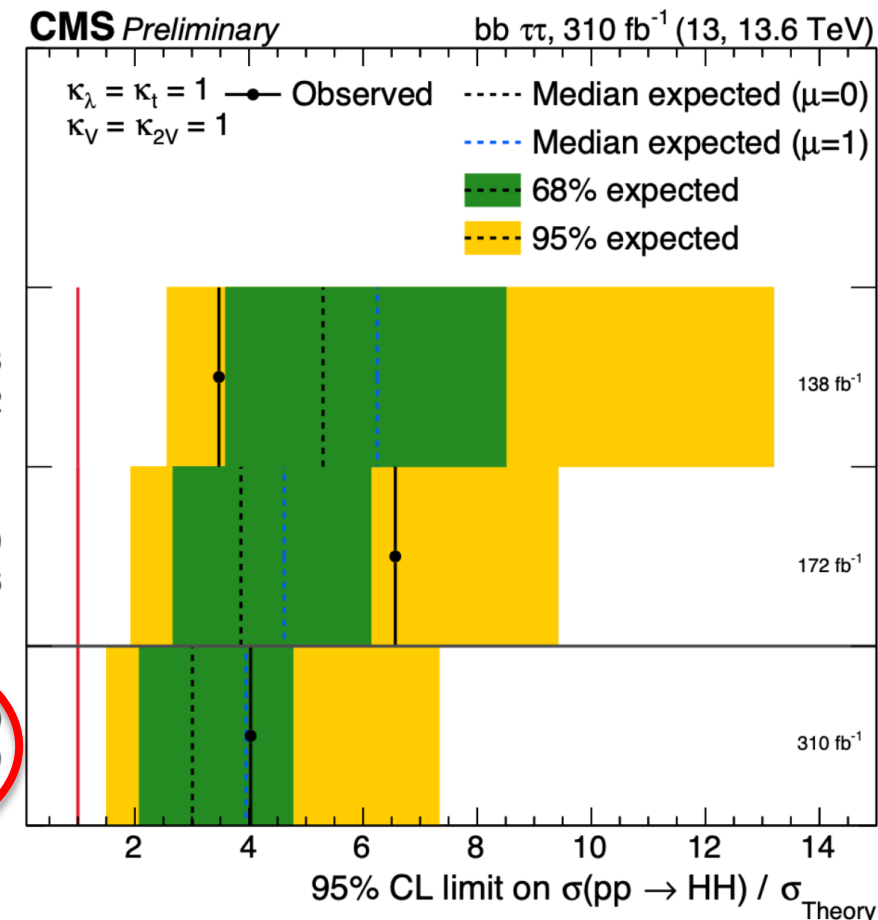


13 TeV
 Expected ($\mu=0$): 5.3
 Expected ($\mu=1$): 6.2
 Observed: 3.5

13.6 TeV
 Expected ($\mu=0$): 3.9
 Expected ($\mu=1$): 4.6
 Observed: 6.6

Combined
 Expected ($\mu=0$): 3.0
 Expected ($\mu=1$): 3.9
 Observed: 4.0

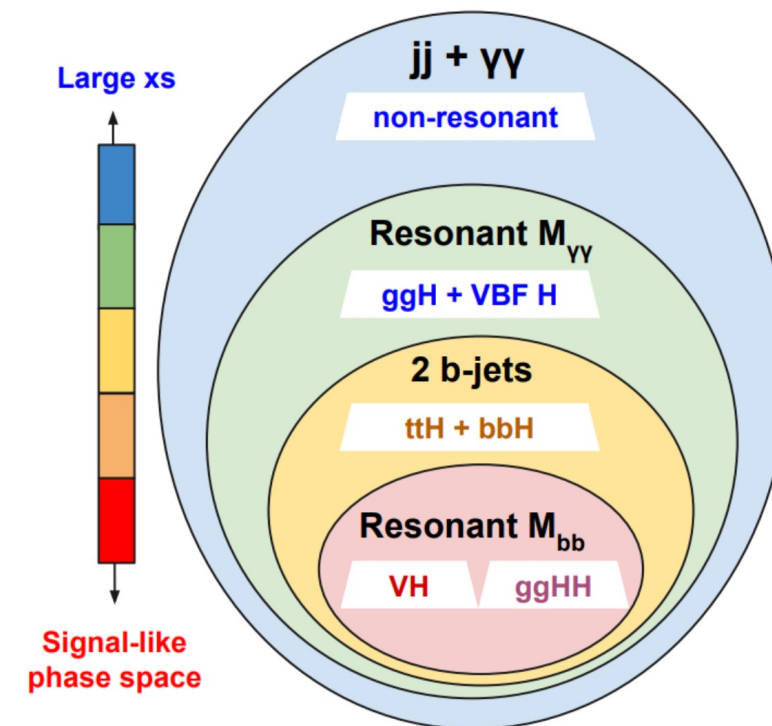
95% CL UL on HH signal



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

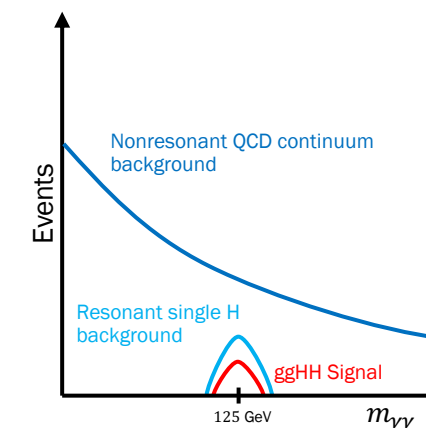
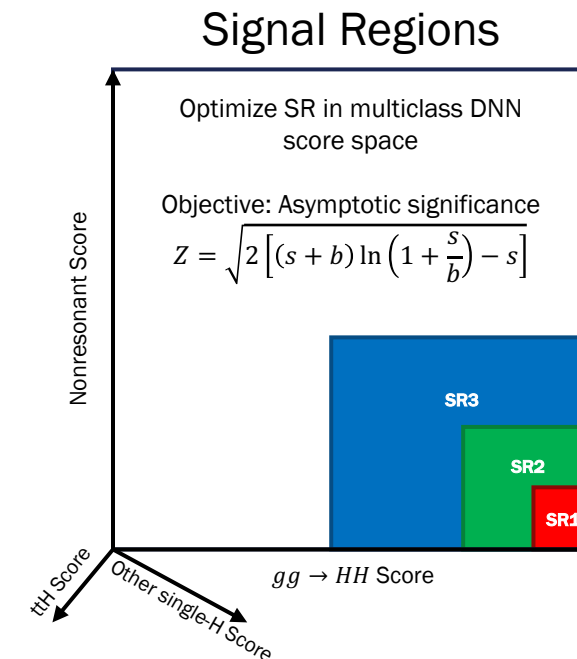
$HH \rightarrow b\bar{b}\gamma\gamma$ Analysis Strategy

- **Small branching ratio** (0.3%) but high signal efficiency
- $H \rightarrow \gamma\gamma$: **very high $m_{\gamma\gamma}$ mass resolution** (1 – 2%)
- **Clean signal bump** at $m_{\gamma\gamma} \sim 125\text{ GeV}$ over continuum QCD falling background
- **Two main background categories:**
 - **Nonresonant QCD:** γ +Jets, $\gamma\gamma$ +Jets
 - **Resonant $H \rightarrow \gamma\gamma$ single Higgs:** ggH , $VBFH$, VH , ttH (with true b-jets)



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

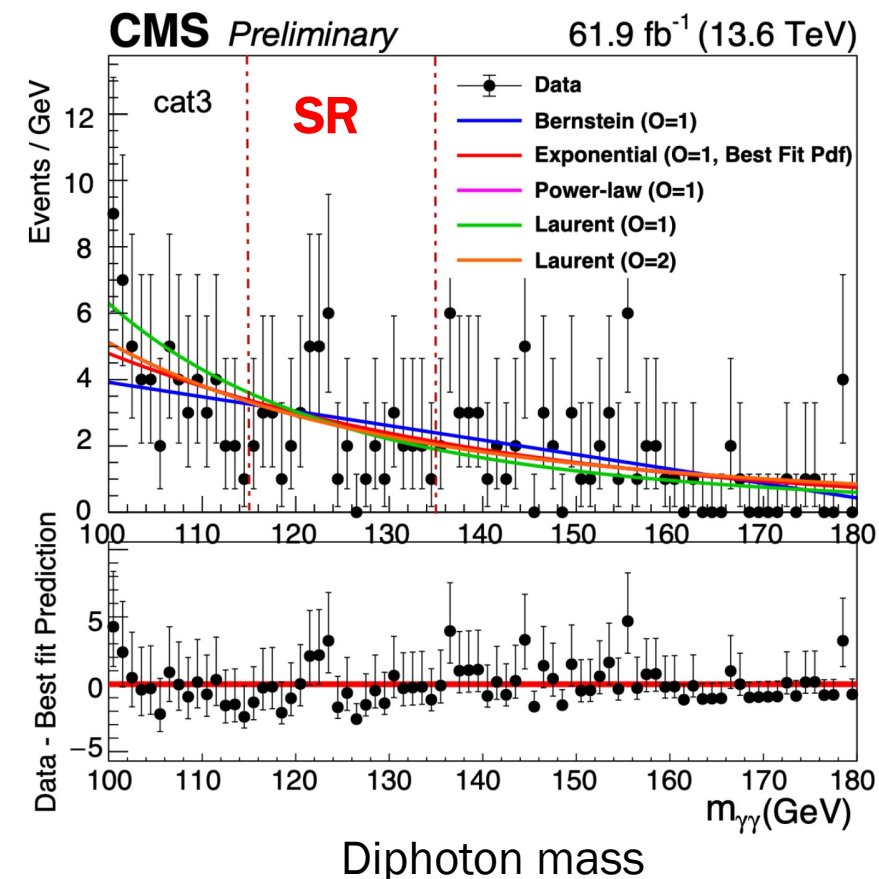
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- **Two main background categories:**
 - **Nonresonant QCD:** γ +Jets, $\gamma\gamma$ +Jets
 - **Resonant $H \rightarrow \gamma\gamma$ single Higgs:** ggH , $VBFH$, VH , $t\bar{t}H$ (with true b-jets)
- Multiclass DNN discriminates signal vs. backgrounds
 - DNN uncorrelated with $m_{\gamma\gamma}$ and m_{jj} , fitted for final signal extraction
- Categorization in DNN discriminant signal purity regions



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

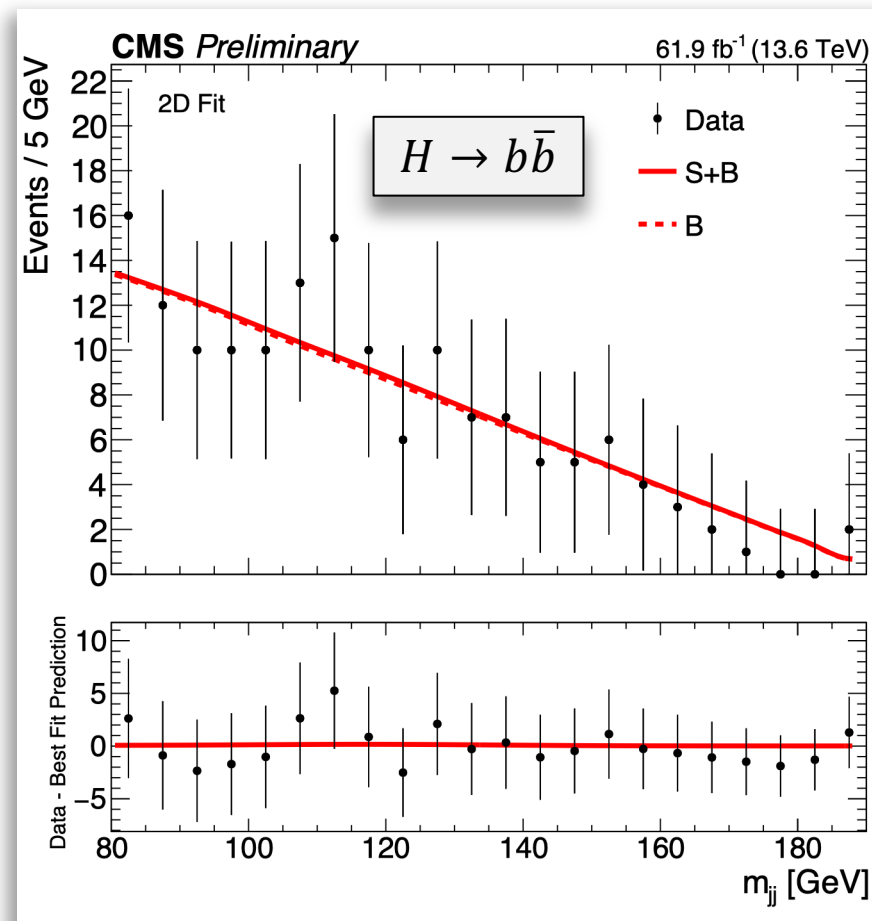
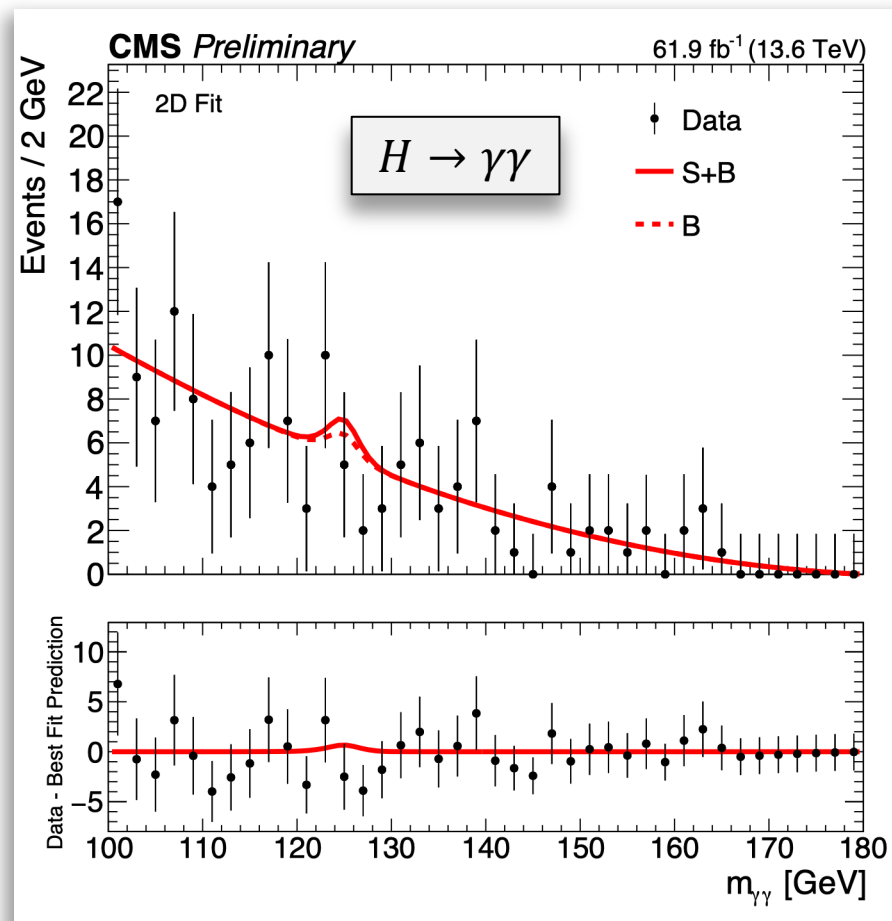
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- **Two main background categories:**
 - **Nonresonant QCD: γ +Jets, $\gamma\gamma$ +Jets**
 - **Resonant $H \rightarrow \gamma\gamma$ single Higgs: ggH , $VBFH$, VH , ttH (with true b-jets)**
- Multiclass DNN discriminates signal vs. backgrounds
 - DNN uncorrelated with $m_{\gamma\gamma}$ and m_{jj} , fitted for final signal extraction
- Categorization in DNN discriminant signal purity regions
- In each analysis category, fit:
 - **Continuum QCD background from data**, excluding $m_{\gamma\gamma}$ blinded signal region, with **family of polynomial and exponential functions**
 - **Resonant background MC** with **double Crystal Ball functions** and **families of smoothly falling functions**, depending on process and $\gamma\gamma/jj$ -leg
 - **Signal MC** with **sum of Gaussians**
- Sensitivity gain attributed to improved corrections, categorization algorithm, and DNN techniques

Example nonresonant background fit, highest statistics category:



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

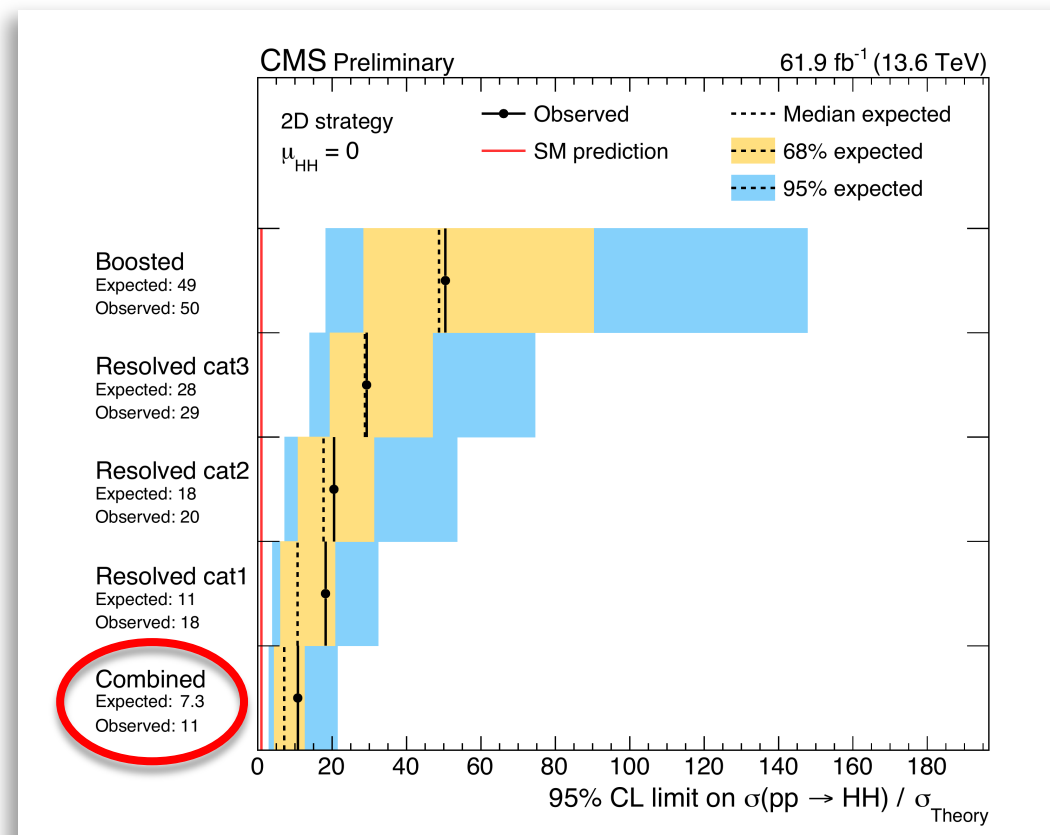
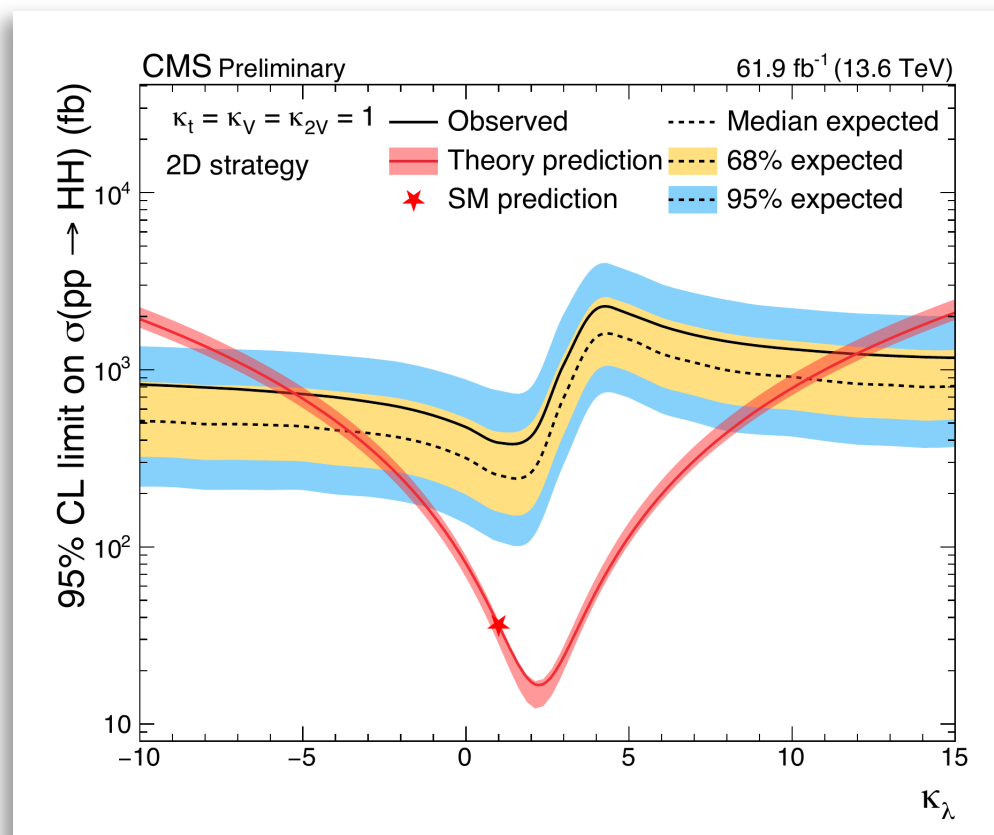
- Two strategies of signal extraction:
 - 1D Fit: Only fit to $m_{\gamma\gamma}$ distribution
 - 2D Fit: Simultaneous fit to $m_{\gamma\gamma}$ and $m_{b\bar{b}}$ distributions, assuming minimal correlation between $H \rightarrow \gamma\gamma$ and $H \rightarrow b\bar{b}$



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

- **2D Fit** approach shows better sensitivity over **1D Fit**
- Analysis is **statistically limited**
- **Sensitivity improvement of 5-10%** over Run 2

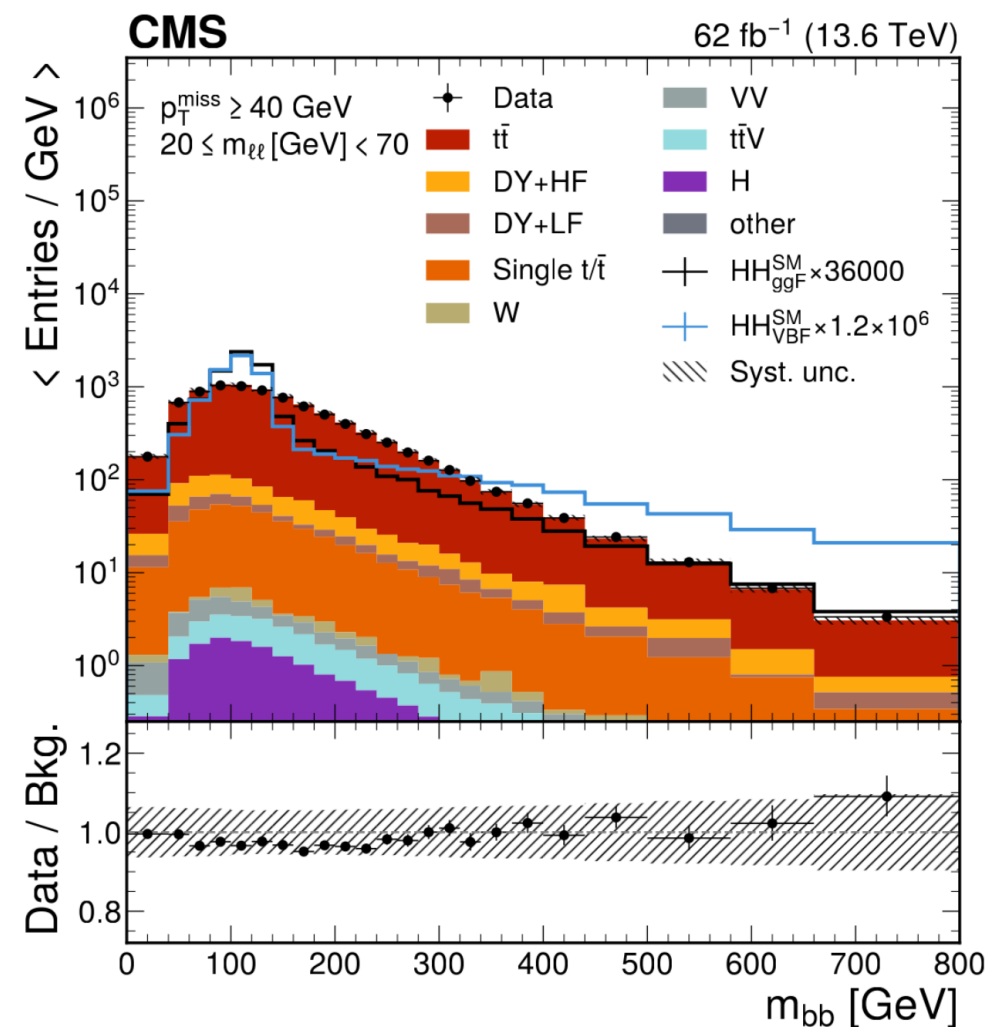
Observed (Expected) 95% CL UL
 $\sigma(pp \rightarrow HH) < 11.0 (7.3) \sigma_{Theory}$



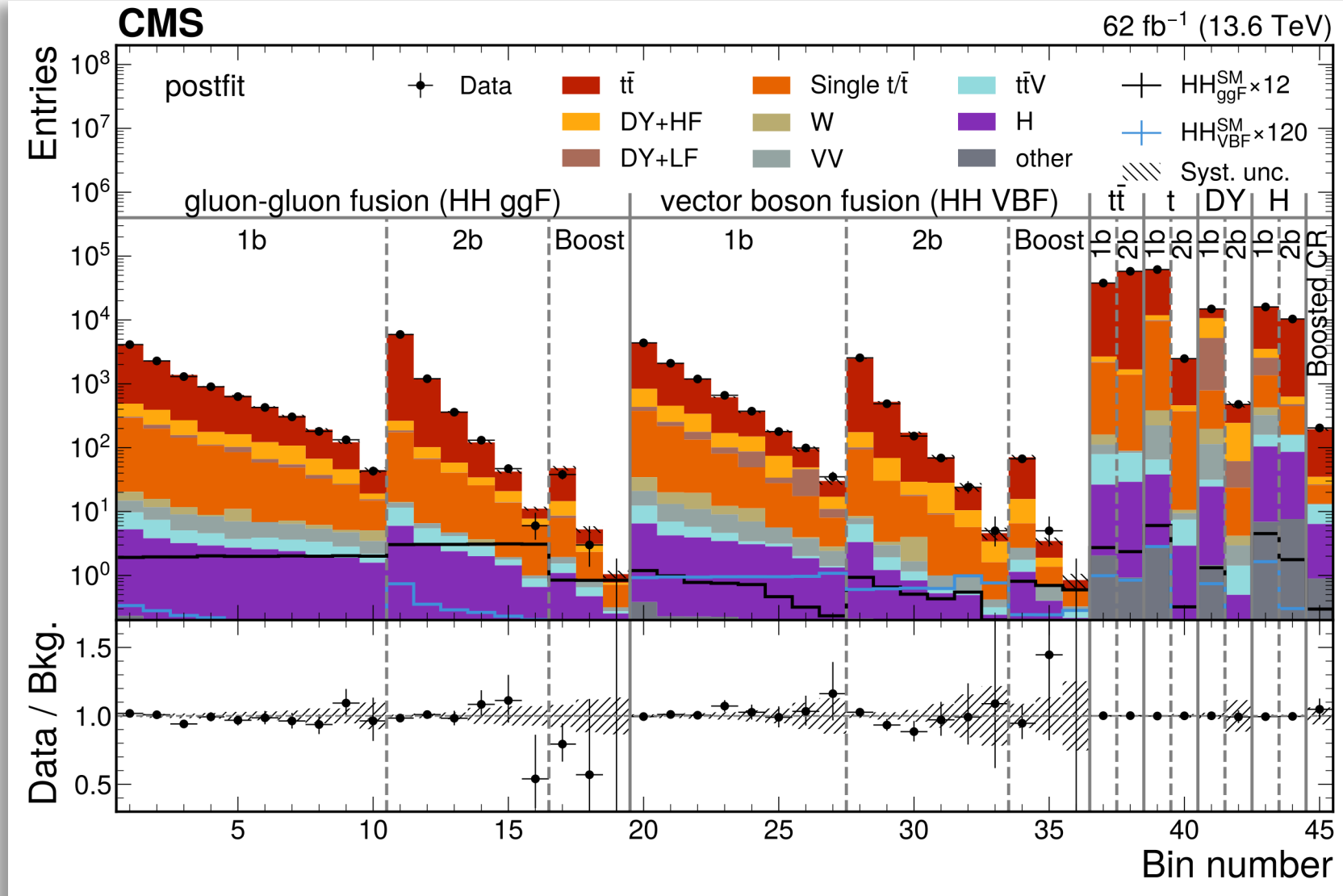
$$\underline{HH \rightarrow b\bar{b}WW \rightarrow b\bar{b}2\ell 2\nu}$$

$HH \rightarrow b\bar{b}WW \rightarrow b\bar{b}2\ell 2\nu$ Analysis Strategy

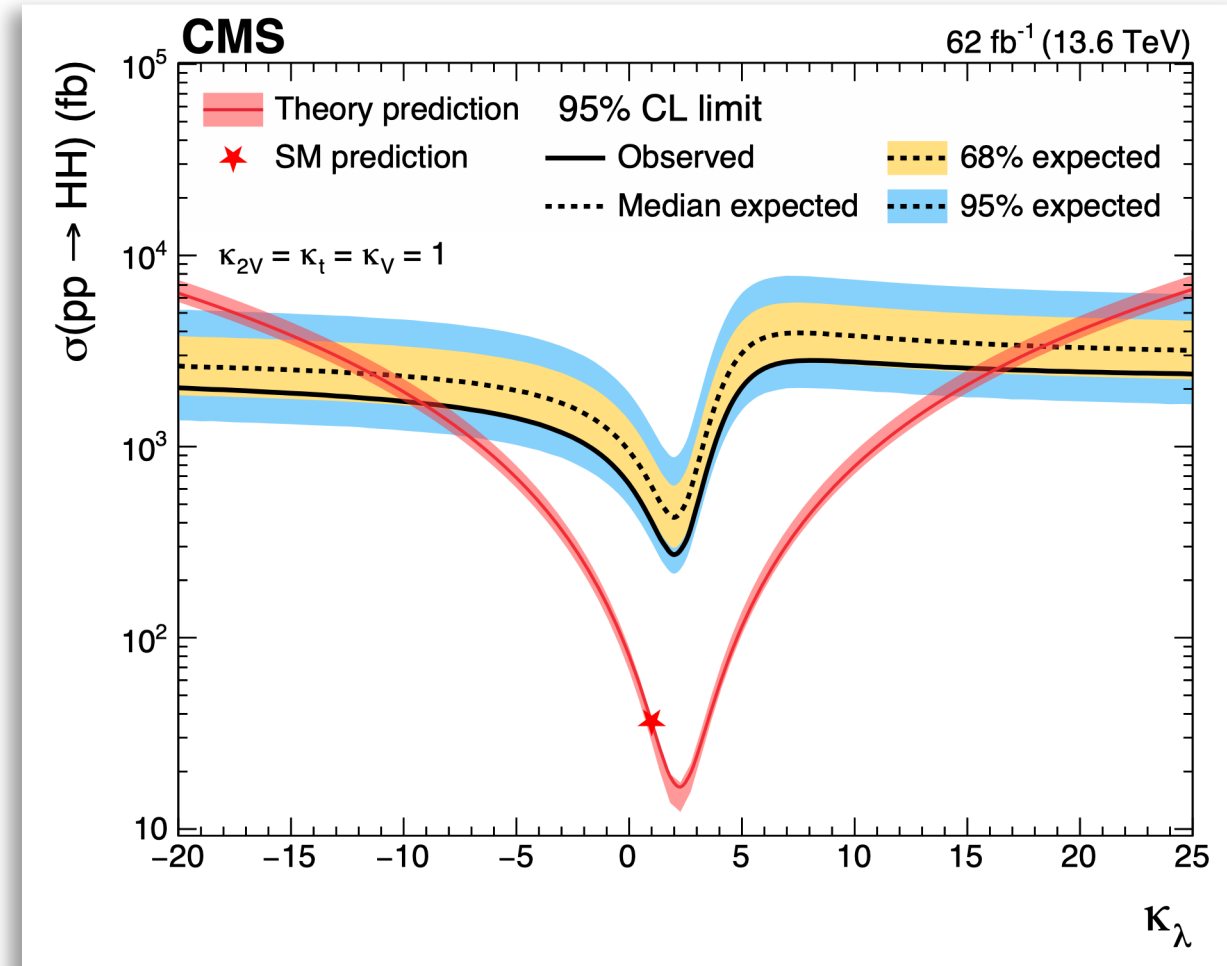
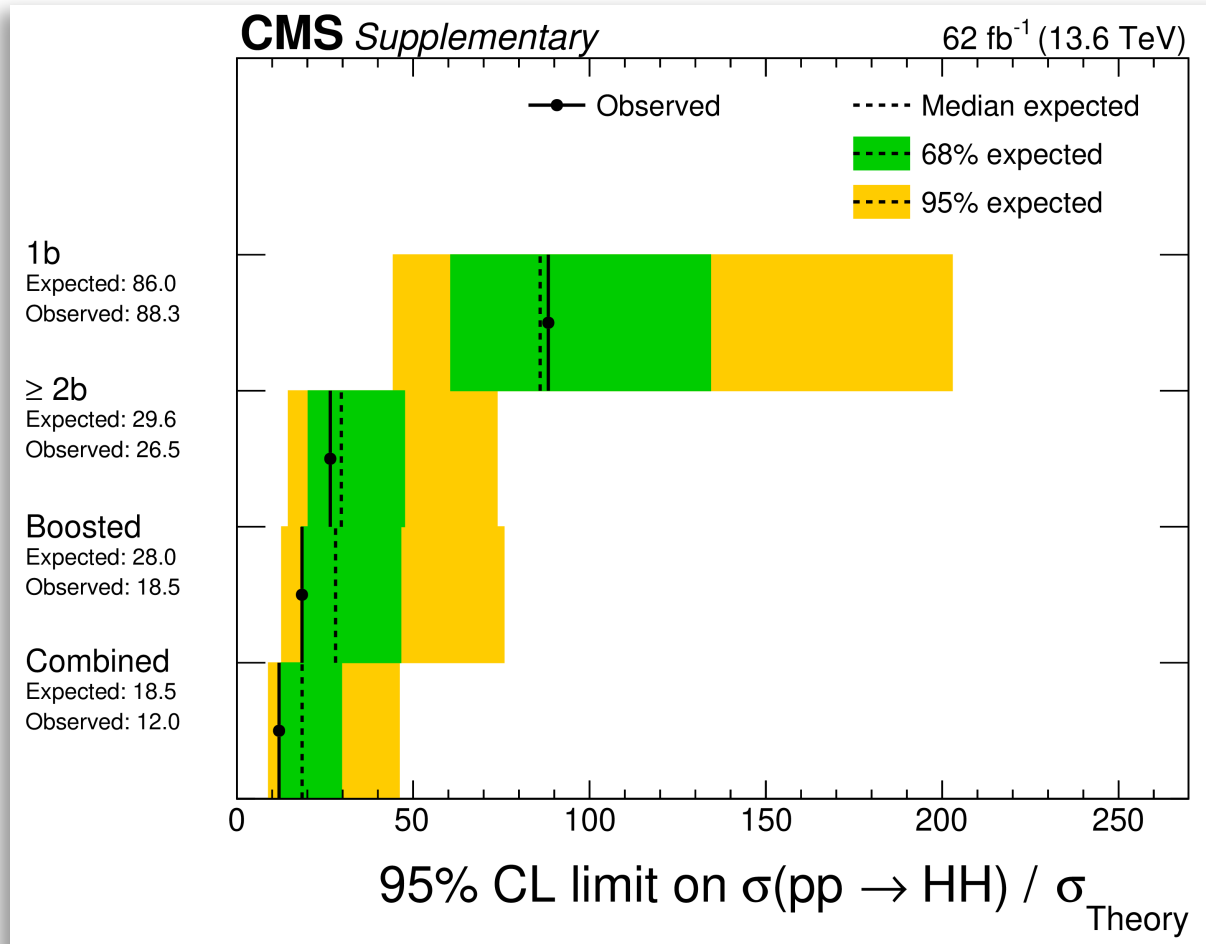
- Events are selected with two oppositely signed charged leptons: $(\mu^+\mu^-, e^+e^-, e^\pm\mu^\mp)$
 - Split into SR and background CRs by multiclassifier DNN
 - Events in SR classified into VBF, ggF, background
- Main backgrounds:
 - $t\bar{t}$
 - single- $t/\bar{t} + W$
 - Drell-Yan (DY) $Z/\gamma^* + \text{jets}$
- Signal extraction:** Simultaneous binned profile likelihood fit of signal and background templates to the observed discriminant distributions
- Several improvements from Run 2:
 - Optimized multiclass-plus-binary DNN** approach improved sensitivity by 50%
 - Improved trigger strategy** for e^+e^- ($e^\pm\mu^\mp$) events increased signal yield by 5% (1%) inclusive and up to 17% (3%) for most signal-populated analysis regions
 - Improved b-tagging algorithm** with higher Run 3 c.o.m. energy produced 5% increase in $S/\sqrt{B}$



$HH \rightarrow b\bar{b}WW \rightarrow b\bar{b}2\ell 2\nu$ Signal Extraction



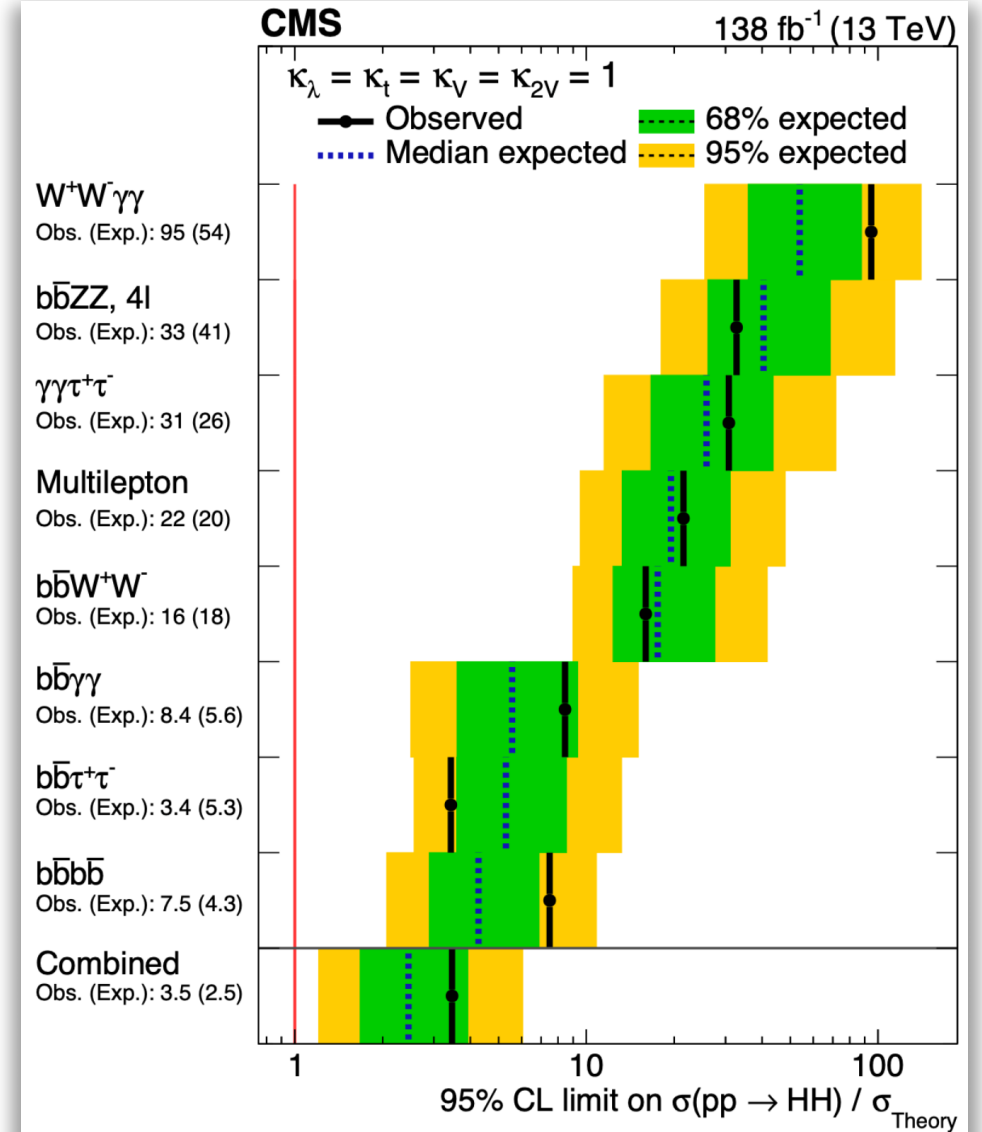
$HH \rightarrow b\bar{b}WW \rightarrow b\bar{b}2\ell 2\nu$ Results



Summary

- Run 2 Combination leverages 8 channels.

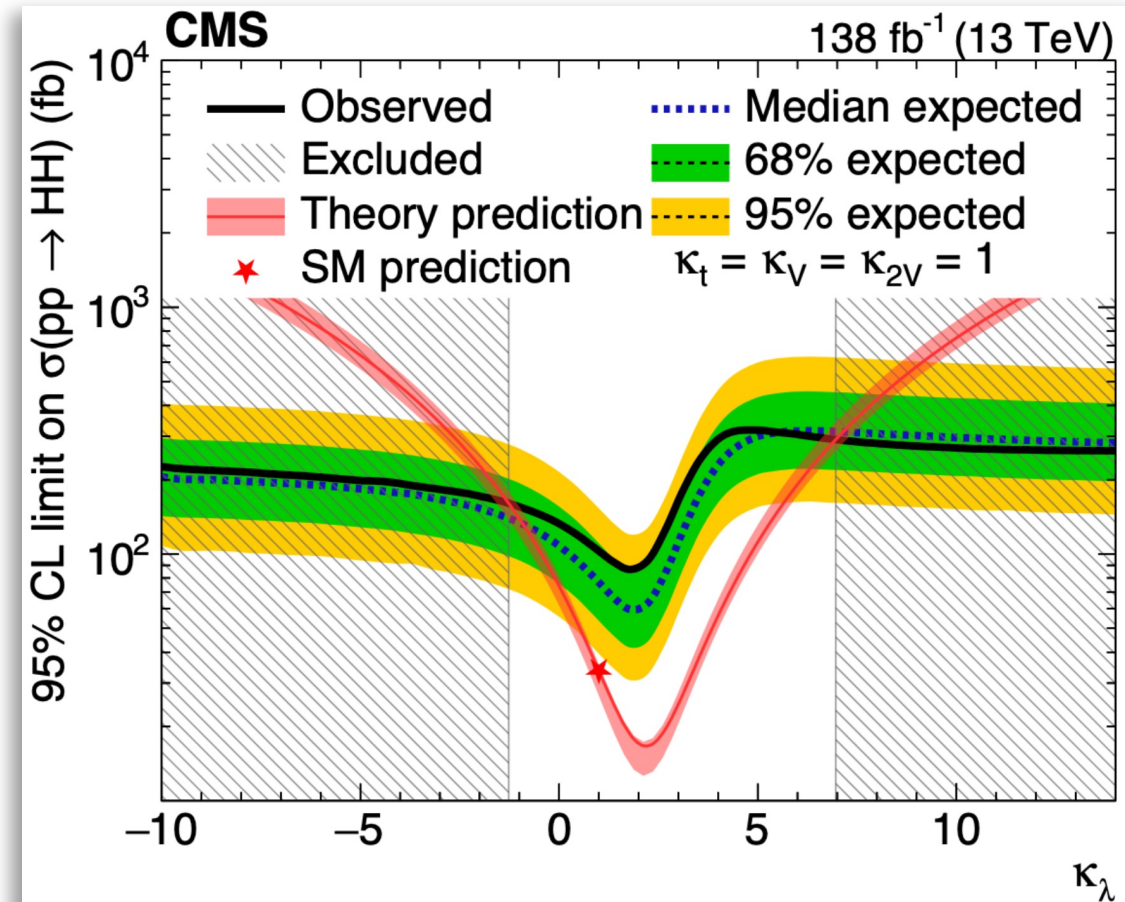
$$\text{Observed (Expected) 95\% CL UL} \\ \sigma(pp \rightarrow HH) < 3.5 \text{ (2.5)} \sigma_{Theory}^{SM}$$



Summary

- Run 2 Combination leverages 8 channels.
95% CL UL:
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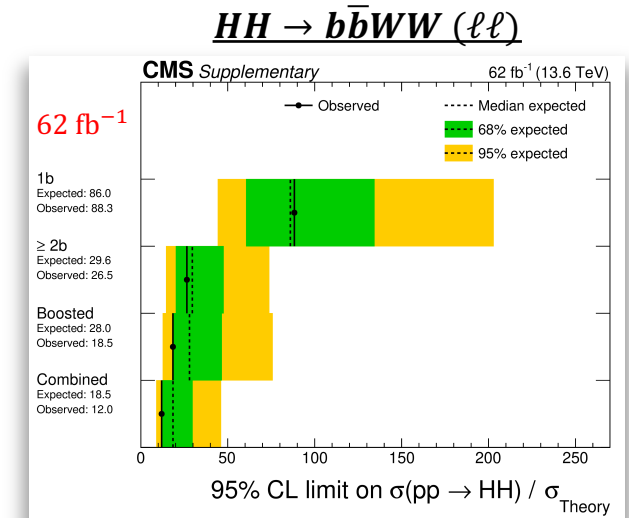
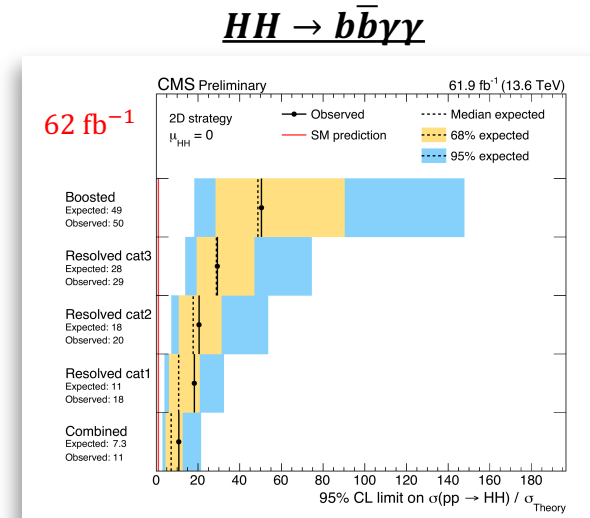
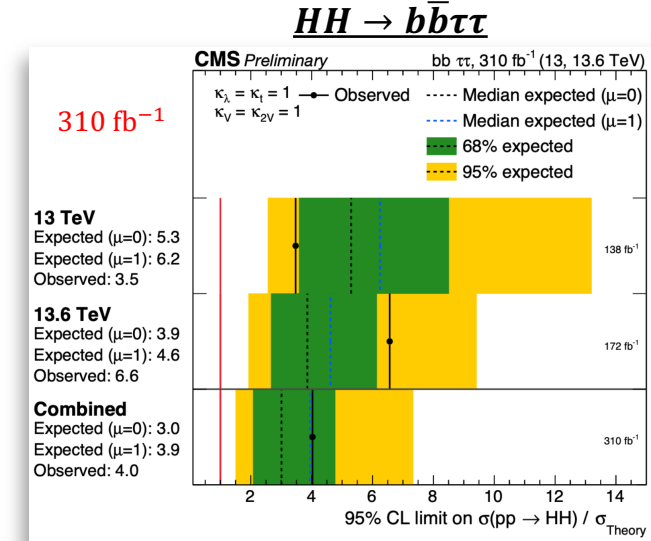
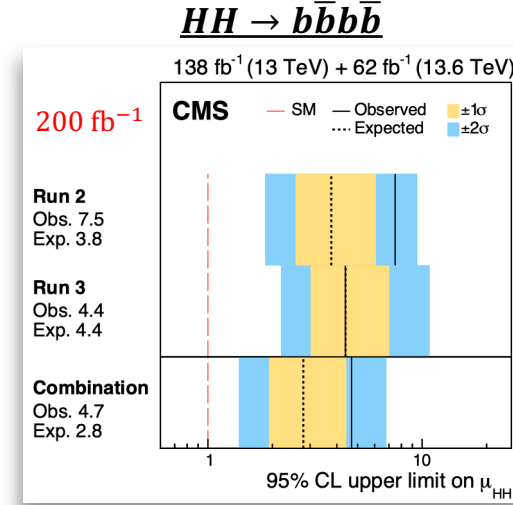
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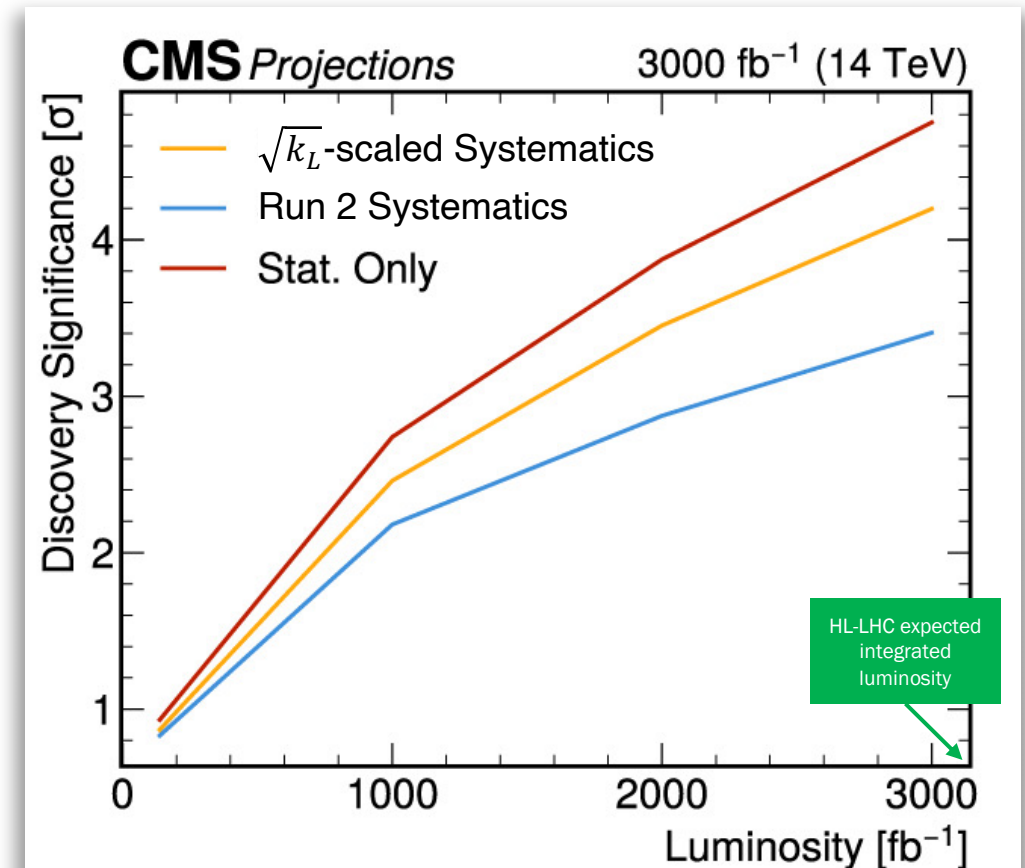
- Four CMS Run 3 nonresonant HH

- $HH \rightarrow b\bar{b}b\bar{b}$
- $HH \rightarrow b\bar{b}\tau\tau$
- $HH \rightarrow b\bar{b}\gamma\gamma$
- $HH \rightarrow b\bar{b}WW \rightarrow b\bar{b}2\ell 2\nu$



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 - $HH \rightarrow b\bar{b}b\bar{b}$
 - $HH \rightarrow b\bar{b}\tau\tau$
 - $HH \rightarrow b\bar{b}\gamma\gamma$
 - $HH \rightarrow b\bar{b}WW \rightarrow b\bar{b}2\ell 2\nu$
- CMS di-Higgs analyses continue to exceed $1/\sqrt{\mathcal{L}}$ improvement
- CMS combinations expected to begin seeing a *small* tension with $\mu_{HH} = 0$ in the coming years
- CMS di-Higgs program pushing forward, full steam ahead



[J. Phys. G: Nucl. Part. Phys. 53 095001](#)

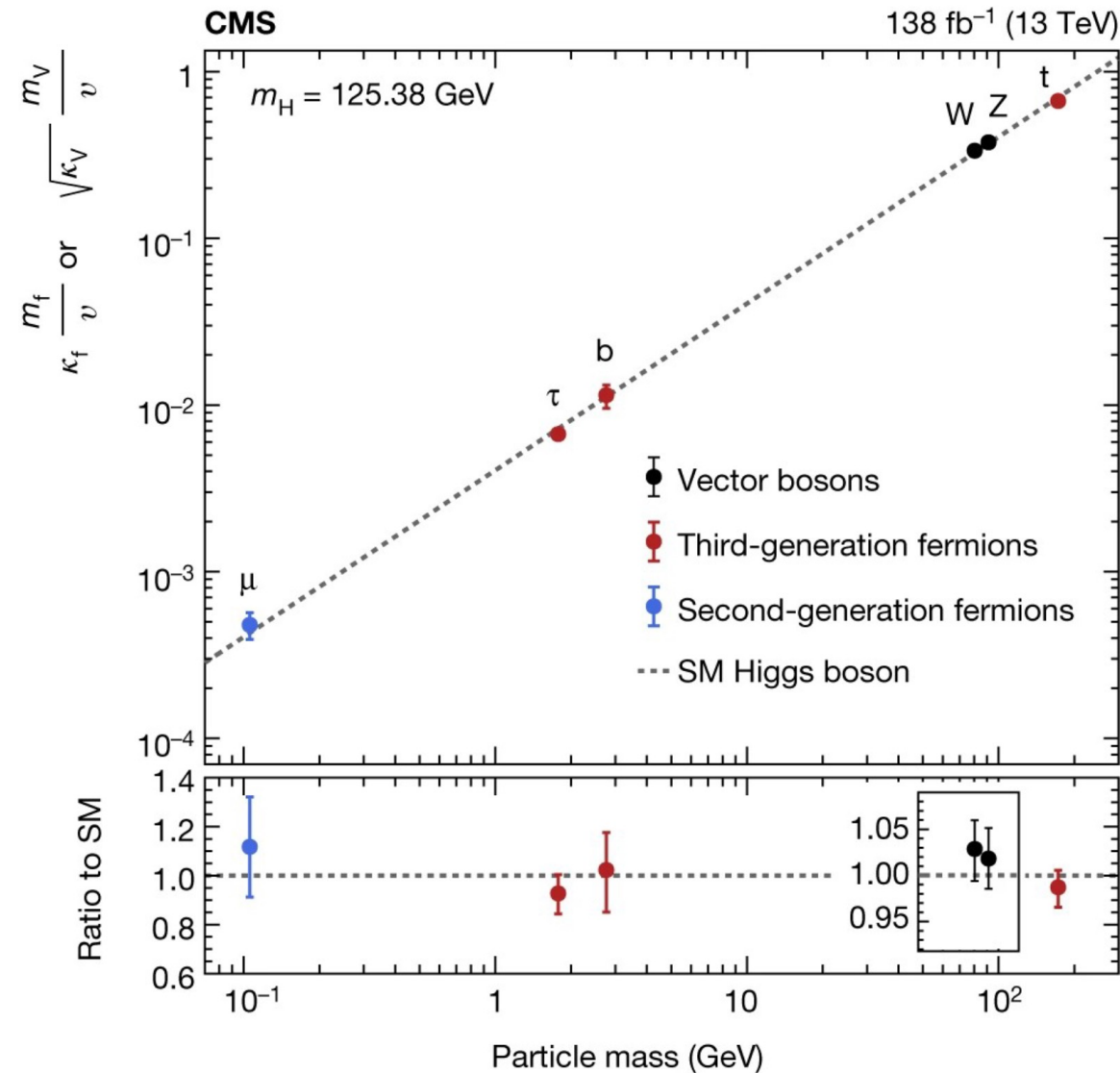
Full Run 3 and Run 2+3 analyses coming soon!

$$k_L \equiv L/L_{Run2}$$

Thank You

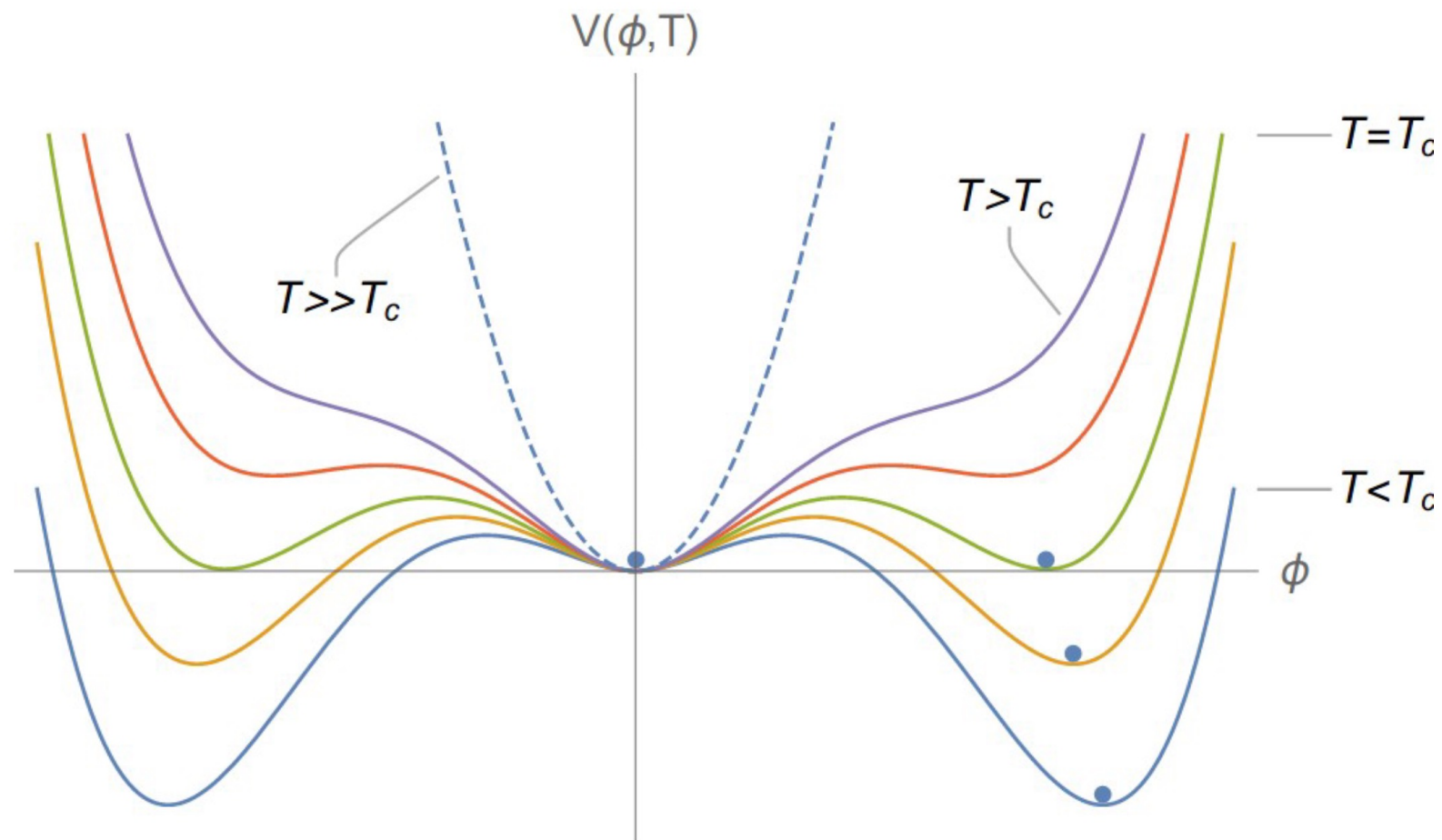
Supplemental

Higgs Coupling to Other Particles



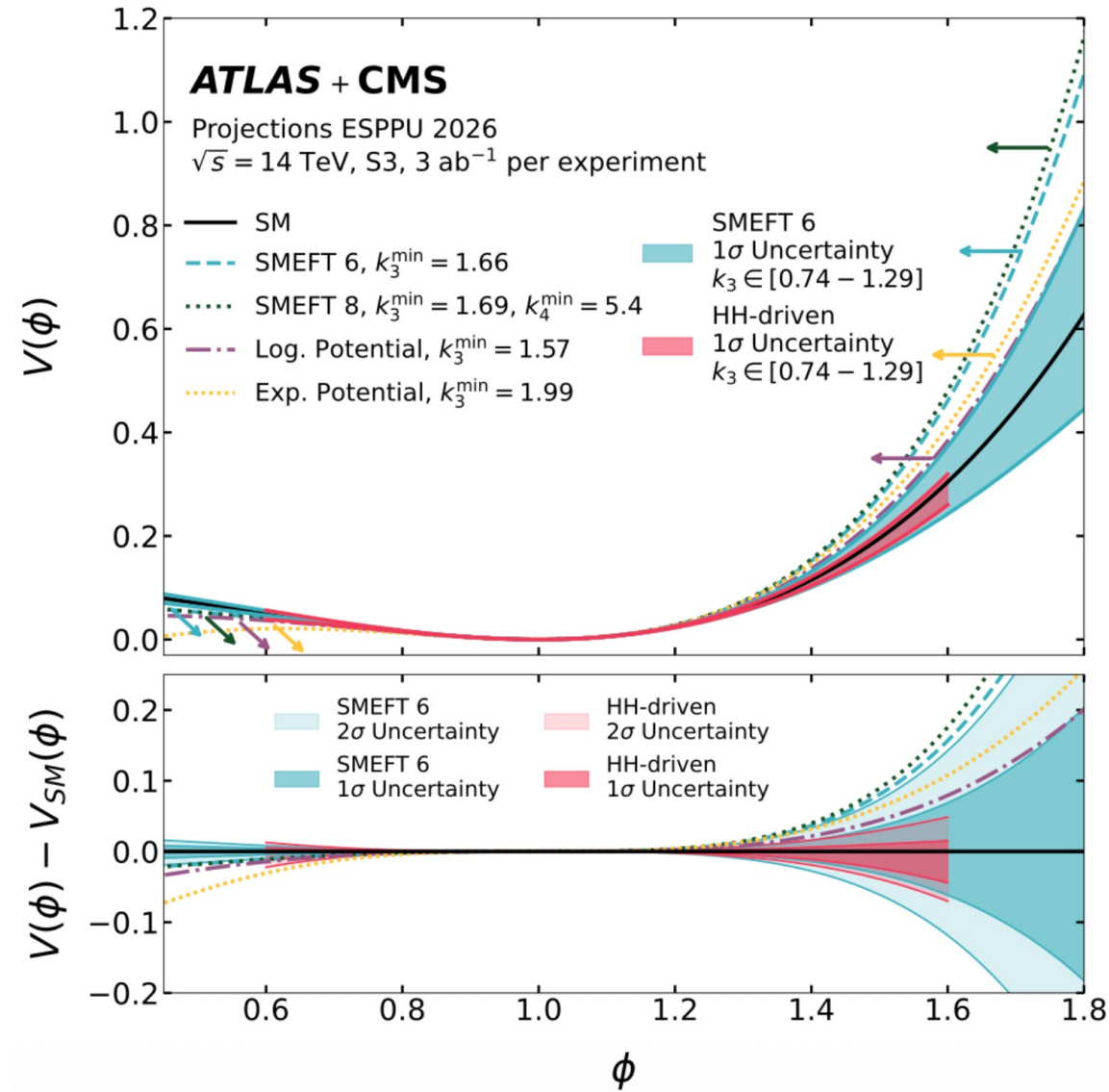
[Nature 607, 60–68 \(2022\)](#)

Evolution of the Higgs Potential During EWPT

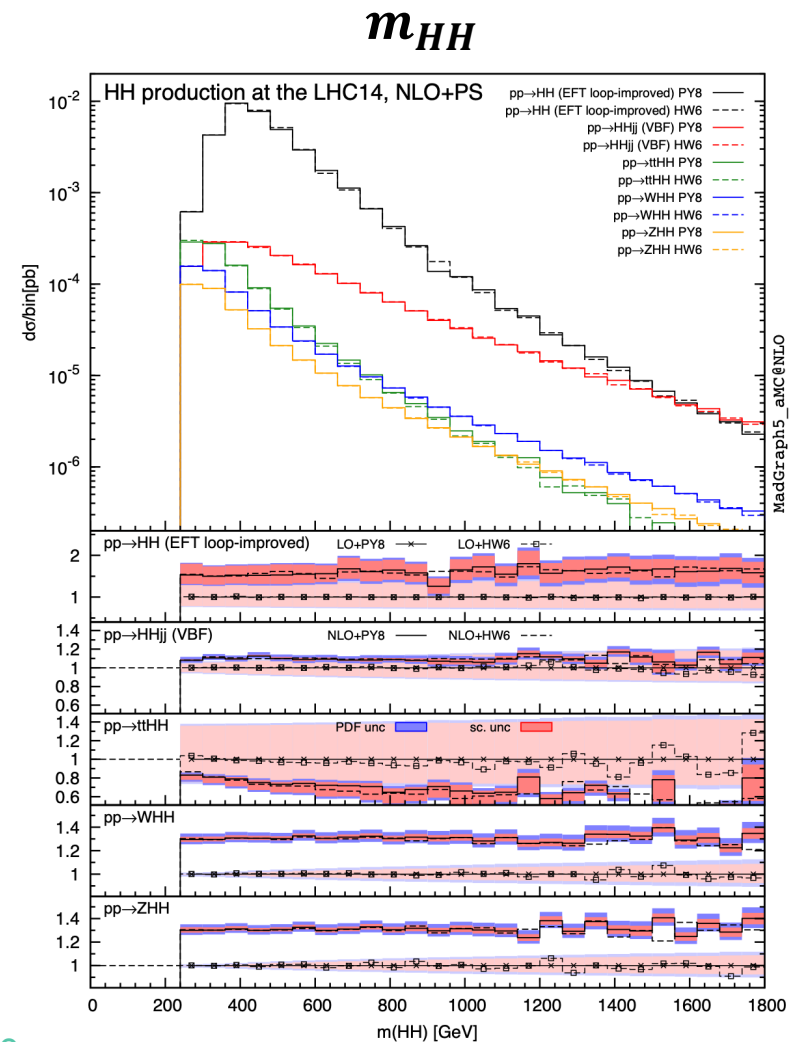
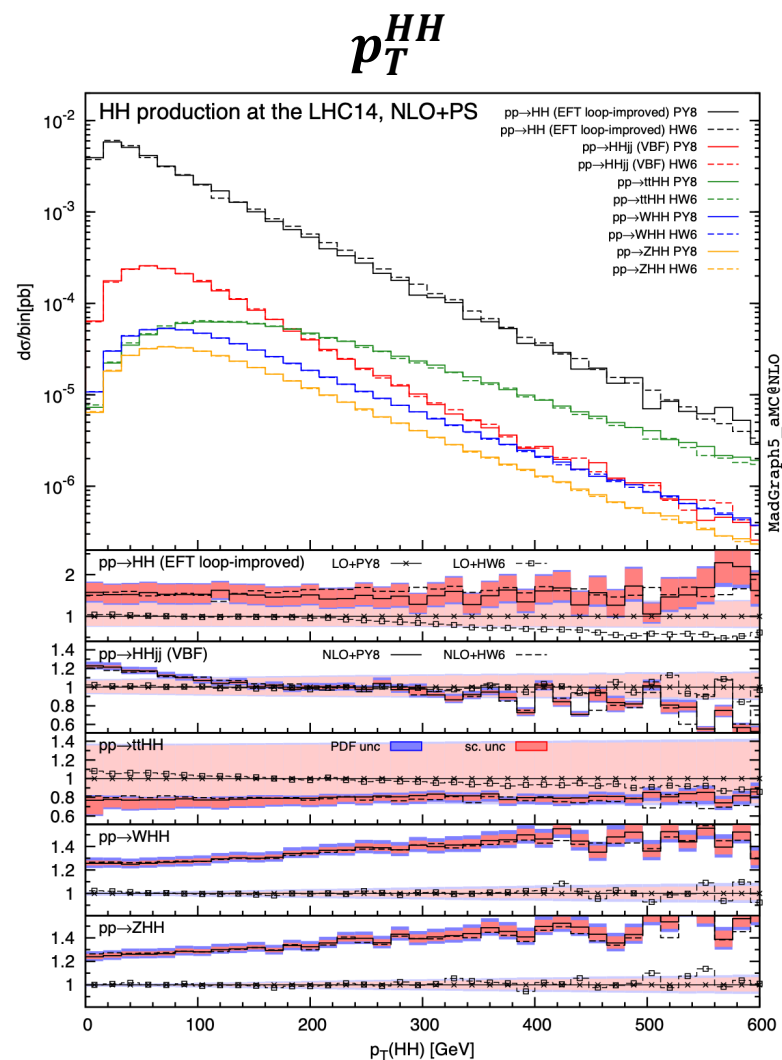


Credit: Rikard Enberg

Deviation in the SM Higgs Potential from BSM Physics



NLO SM p_T^{HH} and m_{HH} Distributions



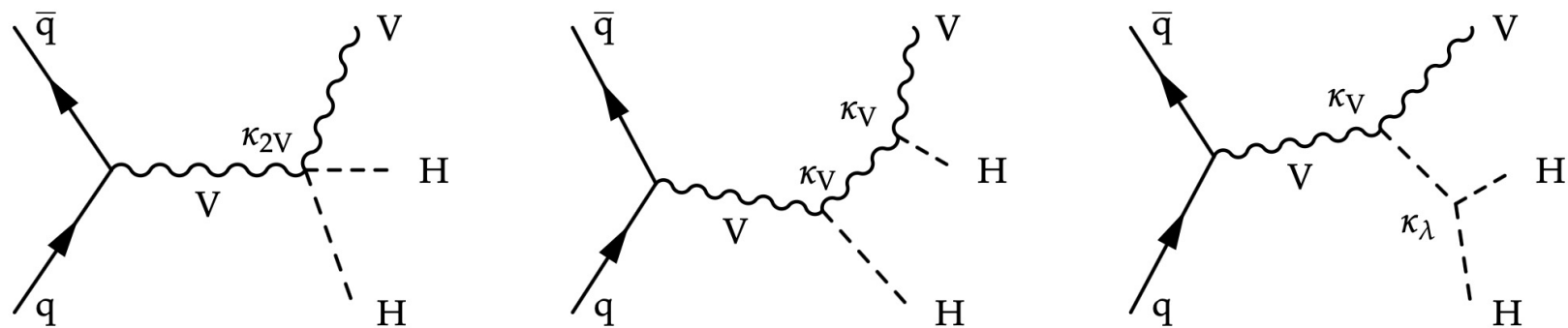
[arXiv:1401.7340](https://arxiv.org/abs/1401.7340)

ggF HH Cross Section

$$\sigma(\kappa_\lambda, \kappa_t) = \kappa_\lambda^2 \kappa_t^2 t + \kappa_t^4 b + \kappa_\lambda \kappa_t^3 i$$

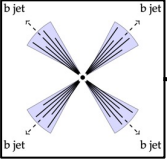
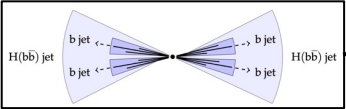
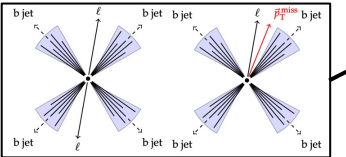
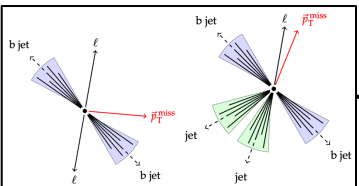
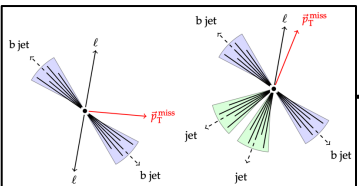
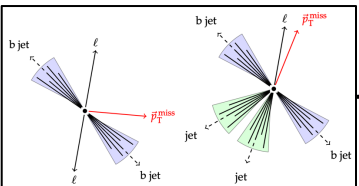
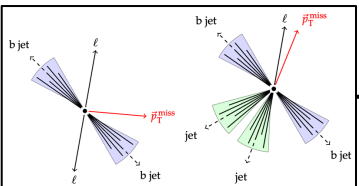
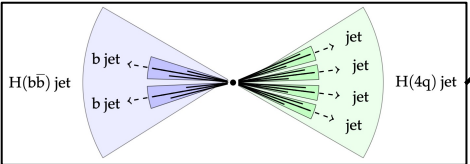
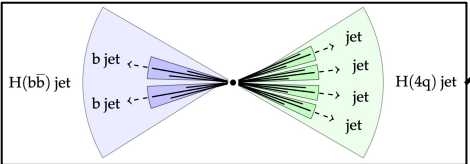
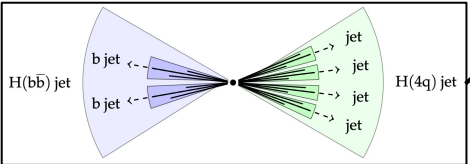
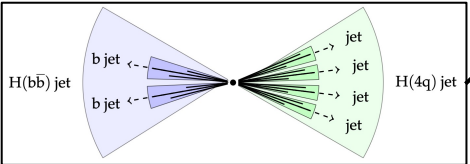
$$t = |T|^2, \quad b = |B|^2, \quad i = TB^* + BT^*$$

LO SM VHH Production:

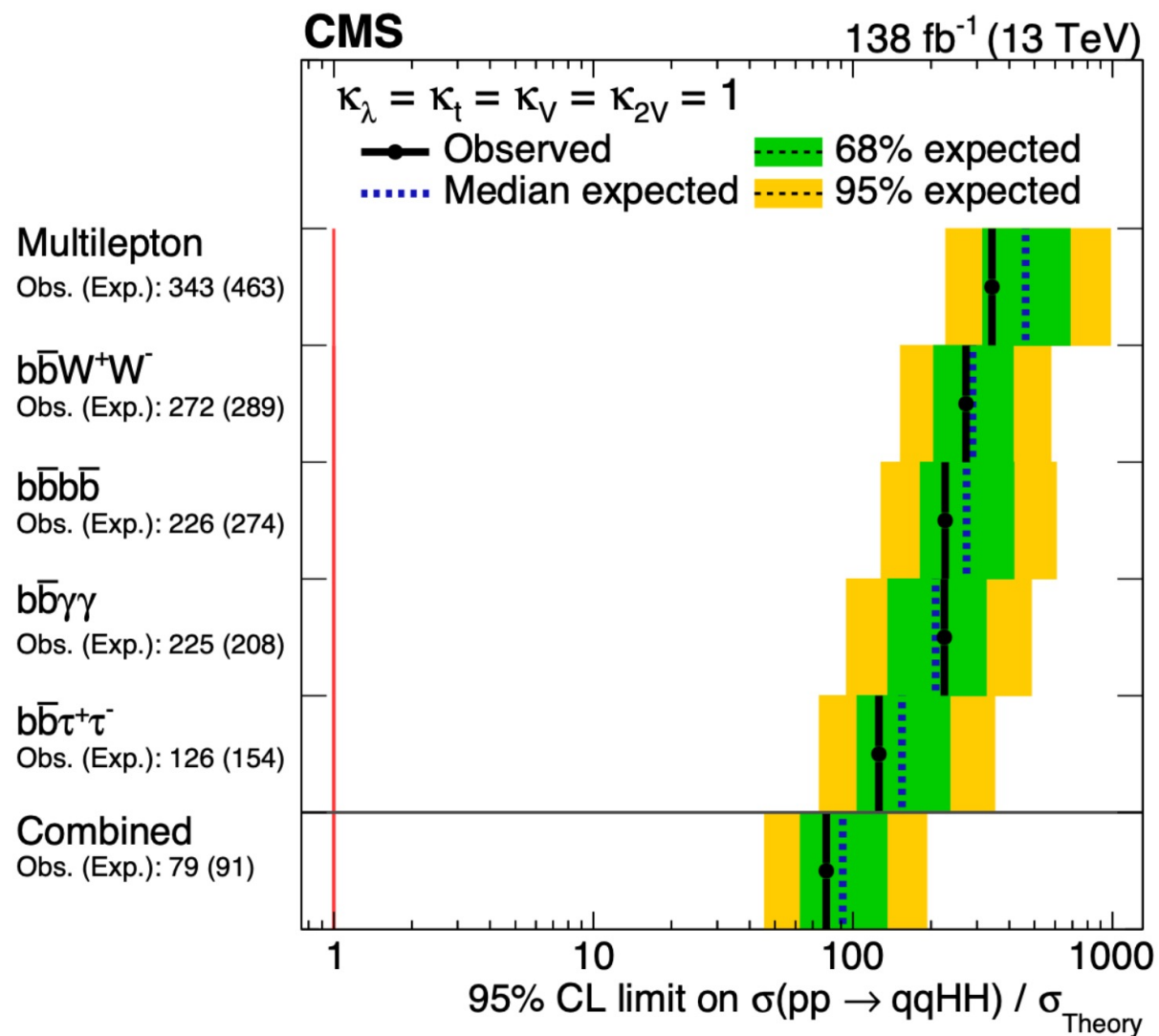


Supplemental: Combination

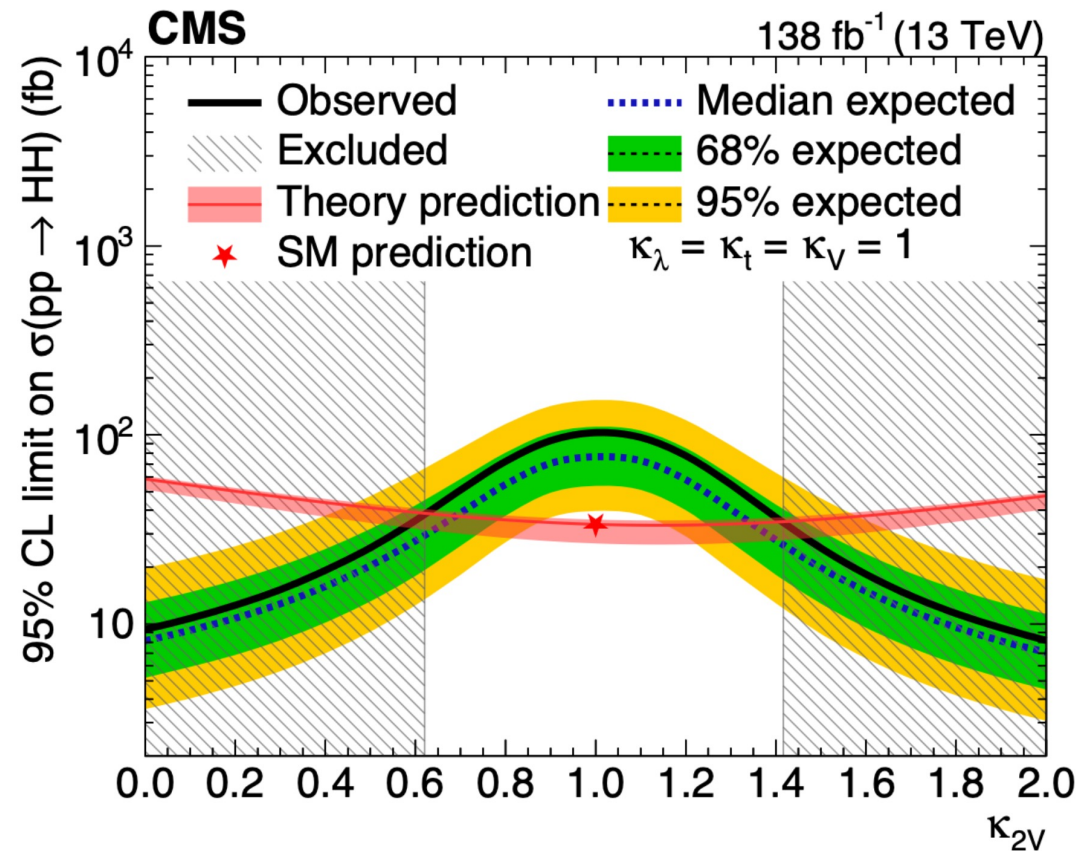
CMS Run 2 HH Combination

	Analysis	μ	κ_λ	κ_{2V}	HEFT
	$b\bar{b}b\bar{b}$, resolved jets [69]	3.9 (7.8)	$[-2.3, 9.4]$	$[-0.1, 2.2]$	✓
	$b\bar{b}b\bar{b}$, merged jets [70]	9.9 (5.1)	$[-9.9, 16.9]$	$[0.62, 1.41]$	✓
	VHH, $HH \rightarrow b\bar{b}b\bar{b}$ [71]	$\mu_{VHH} < 294$ (124)	$[-37.7, 37.2]$	$[-12.2, 8.9]$	—
	$b\bar{b}\tau\tau$ [72]	3.3 (5.2)	$[-1.7, 8.7]$	$[-0.4, 2.6]$	✓
	$b\bar{b}\gamma\gamma$ [73]	7.7 (5.2)	$[-3.3, 8.5]$	$[-1.3, 3.5]$	✓
	$b\bar{b}WW$, $WW \rightarrow \ell\nu qq/2\ell 2\nu$ [74]	14 (18)	$[-7.2, 13.8]$	$[-8.7, 15.2]$	✓
	$b\bar{b}WW$, $WW \rightarrow 4q$	141 (69)	—	$[-0.04, 2.05]$	—
	HH multilepton [75]	21.3 (19.4)	$[-6.9, 11.1]$	—	✓
	$\tau\tau\gamma\gamma$ [76]	33 (26)	$[-13, 18]$	—	—
	$b\bar{b}ZZ$ [77]	32.4 (39.6)	$[-8.8, 13.4]$	—	—
	$WW\gamma\gamma$	97 (53)	$[-25.8, 14.4]$	—	✓

Run 2 Combination: VBFHH Upper Limits

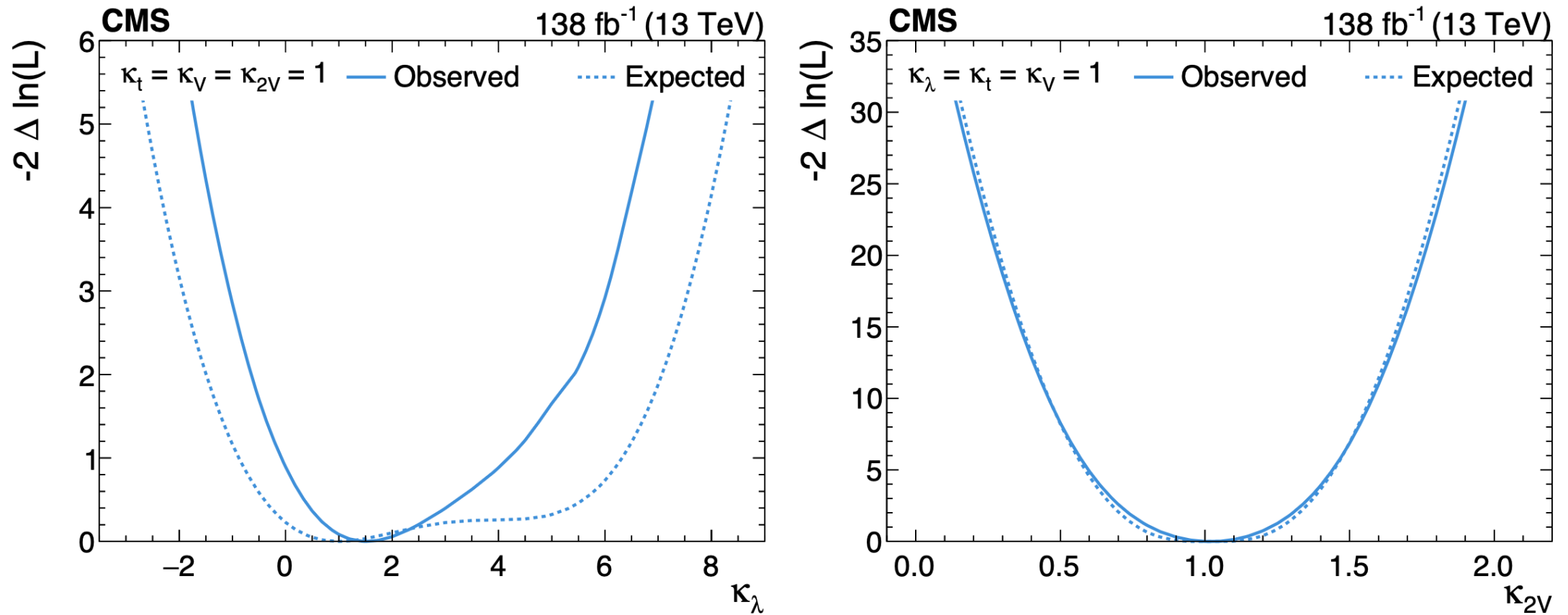


Run 2 Combination: κ_{2V} Upper Limit



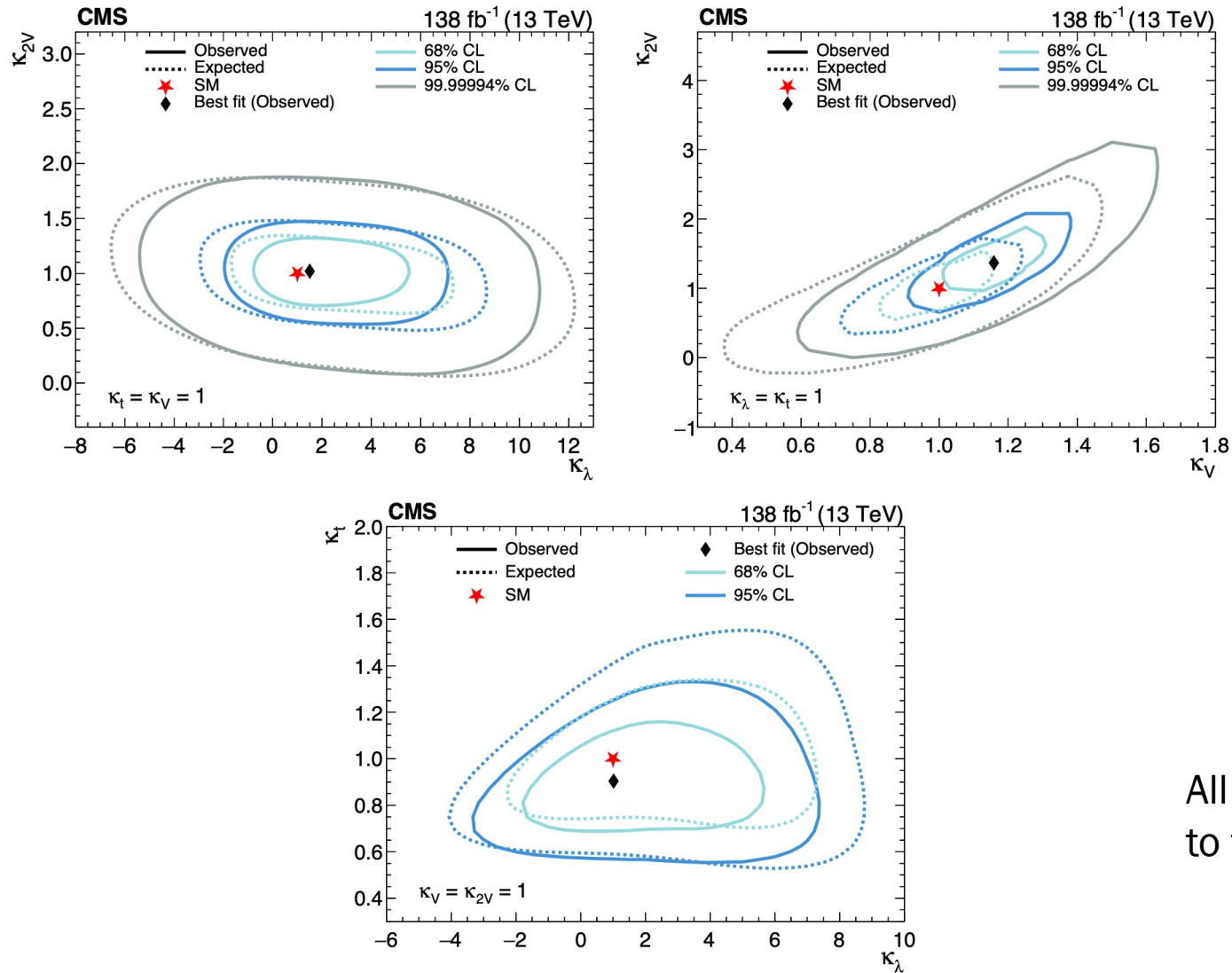
95% CL upper limits on the inclusive HH cross section as a function of κ_{2V} . Theoretical uncertainties in the ggF and VBF HH signal cross sections are not incorporated because the constraints are computed directly on the *measured* cross-section. All other couplings set to SM-predicted value. UL computed using a background-only hypothesis.

Run 2 Combination Likelihood Scans



Combination of all channels when all other parameters are fixed to their SM values.

Run 2 Combination 2D Likelihood Contours



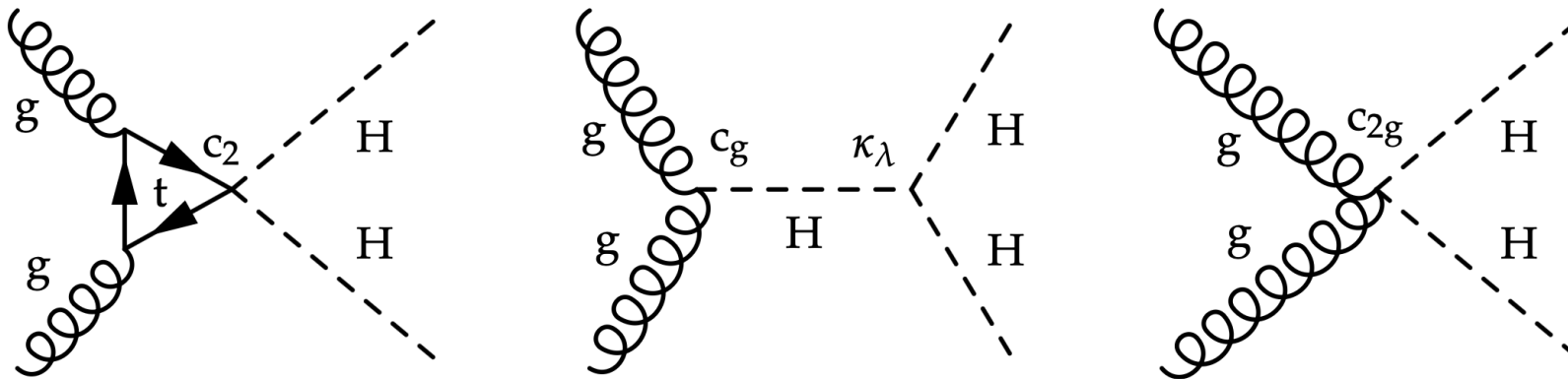
Higgs Effective Field Theory

Standard Model

$$\kappa_\lambda = \kappa_t = \kappa_V = \kappa_{2V} = 1$$

$$c_2 = c_g = c_{2g} = 0$$

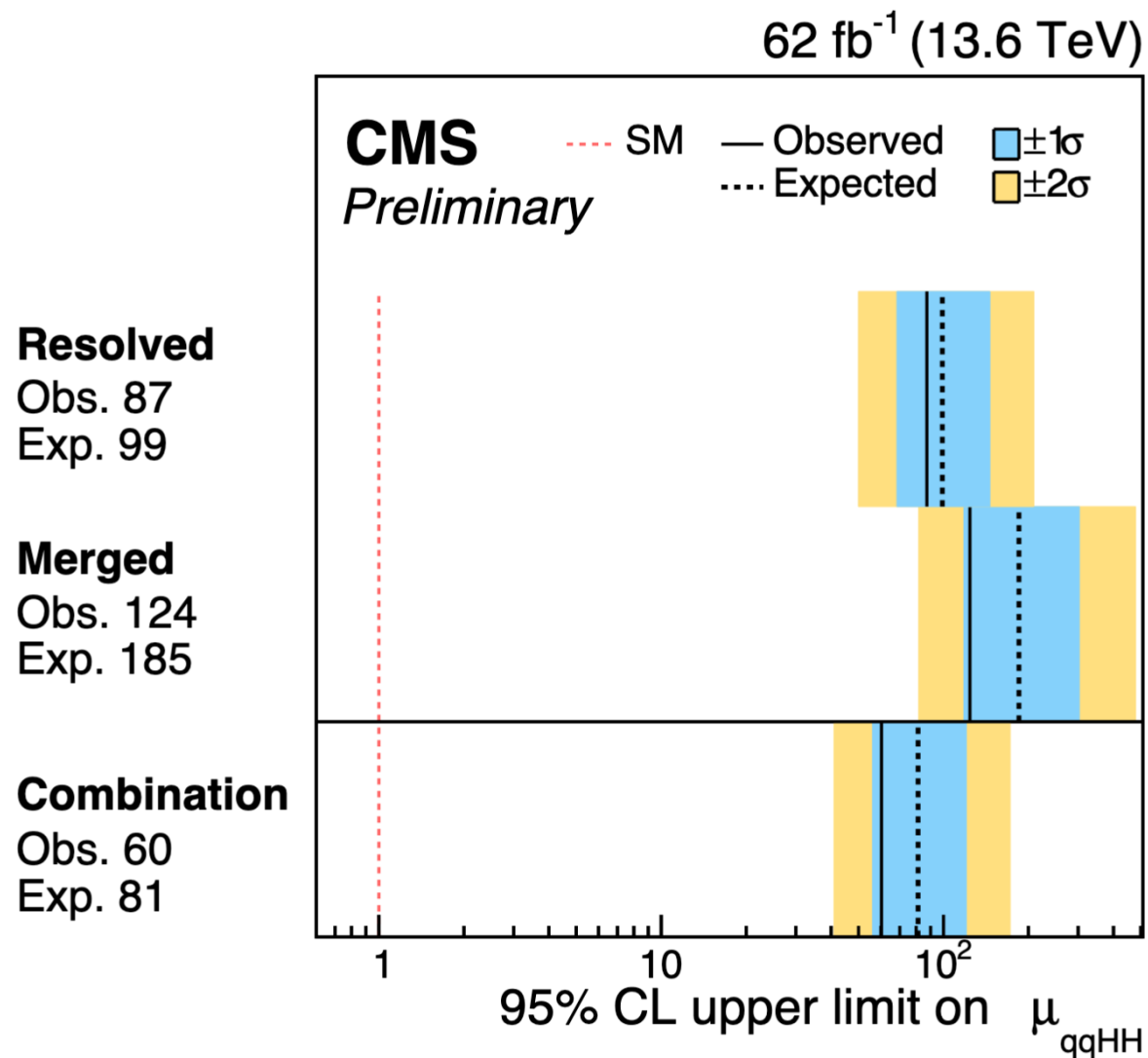
BSM HH Production:



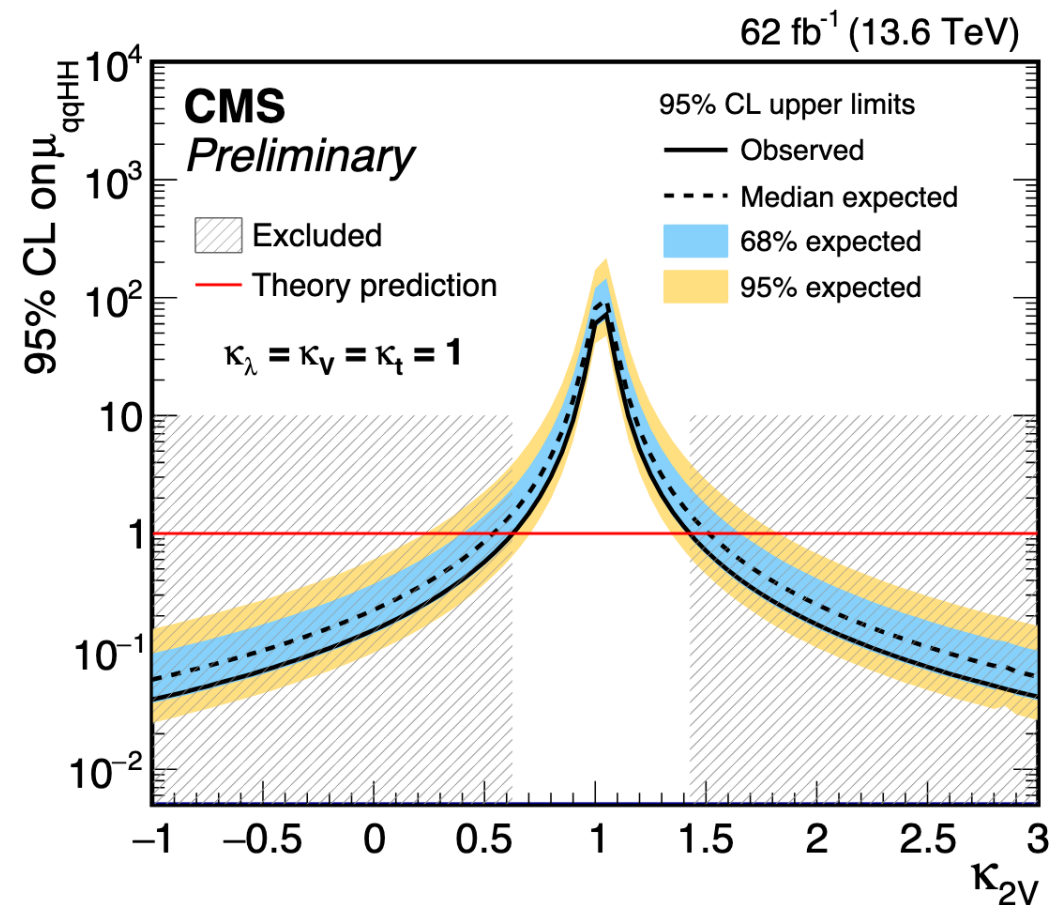
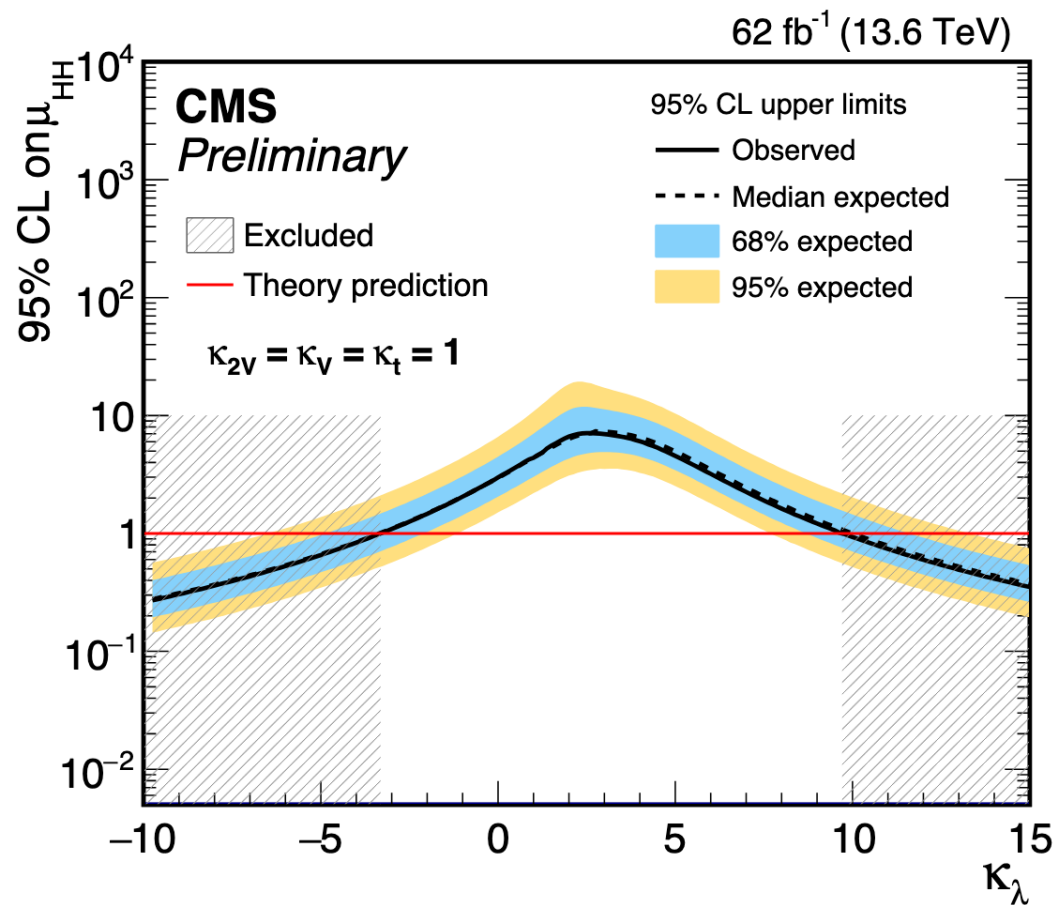
$$\begin{aligned} \Delta\mathcal{L}_{\text{HEFT}} = & -m_t \left(\kappa_t \frac{h}{v} + c_2 \frac{h^2}{v^2} \right) \bar{t}t - \kappa_\lambda \frac{m_H^2}{2v} h^3 + \frac{\alpha_S}{8\pi} \left(c_g \frac{h}{v} + c_{2g} \frac{h^2}{v^2} \right) G_{\mu\nu}^a G^{a,\mu\nu} \\ & + \left(2\kappa_V \frac{h}{v} + \kappa_{2V} \frac{h^2}{v^2} \right) \left(m_W^2 W_\mu^+ W^{-\mu} + \frac{1}{2} m_Z^2 Z_\mu Z^\mu \right). \end{aligned}$$

Supplemental: $HH \rightarrow b\bar{b}b\bar{b}$

$HH \rightarrow b\bar{b}b\bar{b}$ UL on VBFHH Production

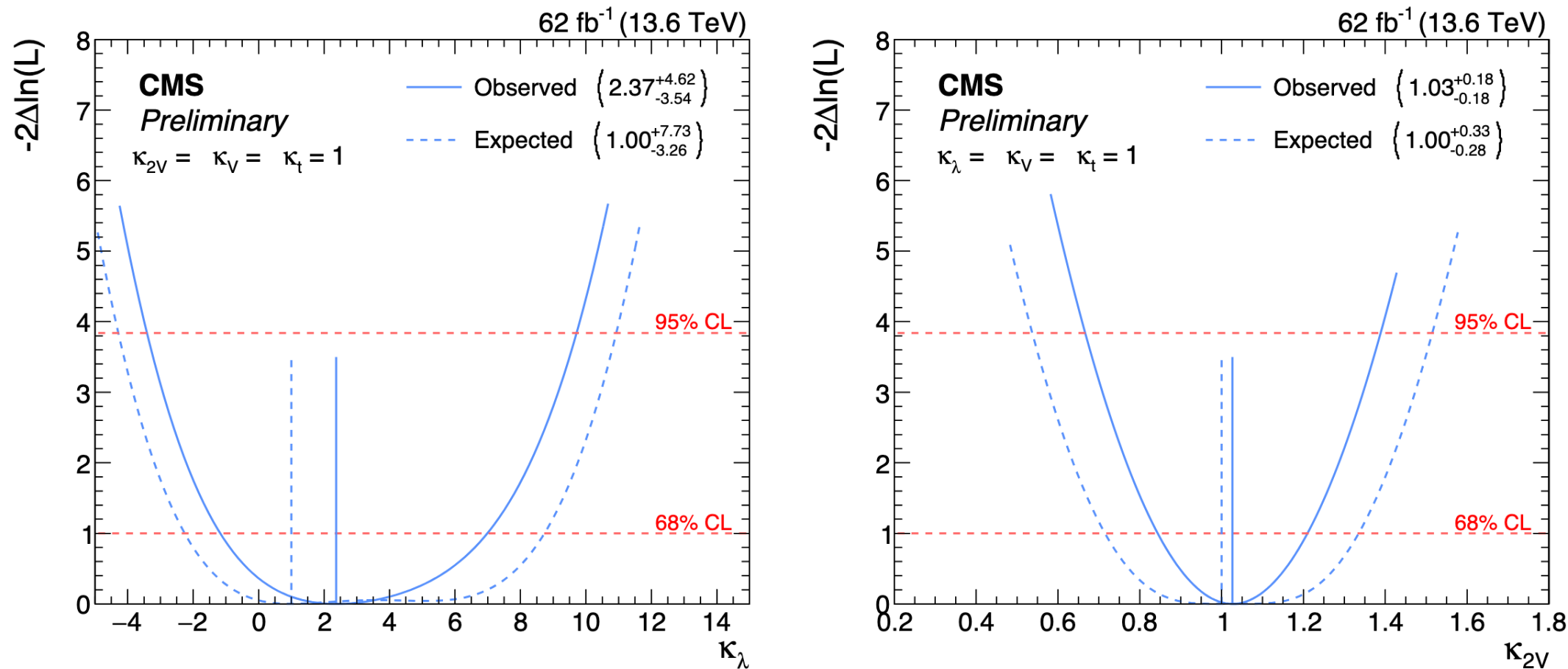


$HH \rightarrow b\bar{b}b\bar{b}$ UL as a Function κ_λ and κ_{2V}



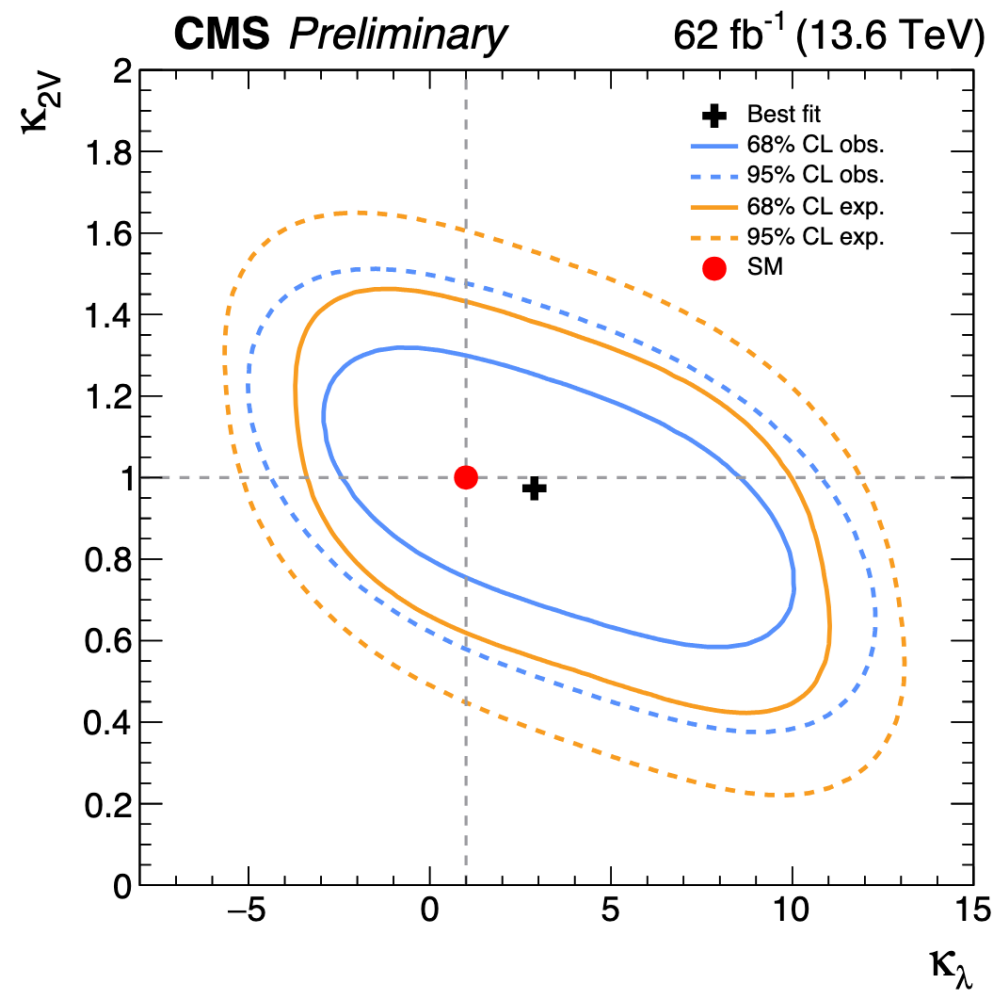
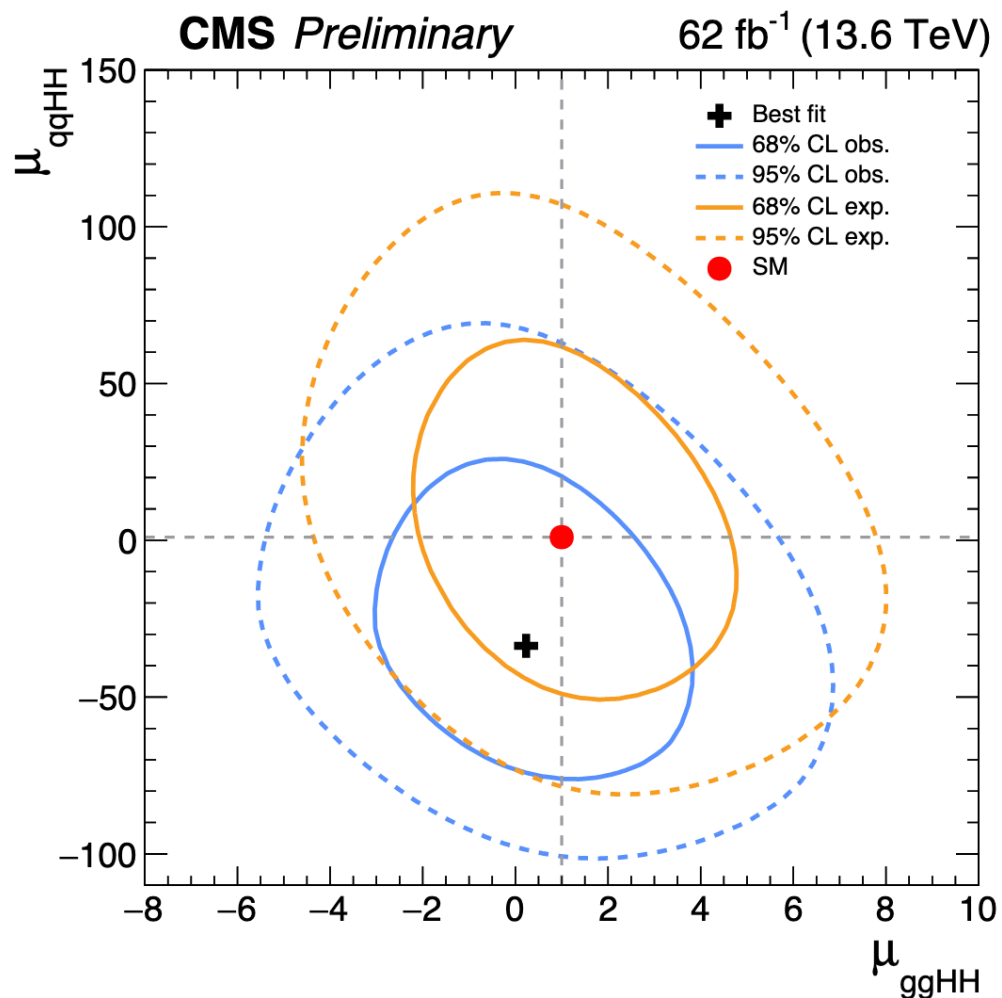
Combined merged and resolved analyses. μ_{HH} is the signal strength of inclusive HH production and μ_{qqHH} is the signal strength of VBFHH production.

$HH \rightarrow b\bar{b}b\bar{b}$ Profile Likelihood Ratios as a Function of κ_λ and κ_{2V}



Combined merged and resolved analyses. Expected is obtained from an Asimov dataset defined by fixing the nuisance parameters to their maximum likelihood estimate obtained from data in which $\mu_{HH} = 1$.

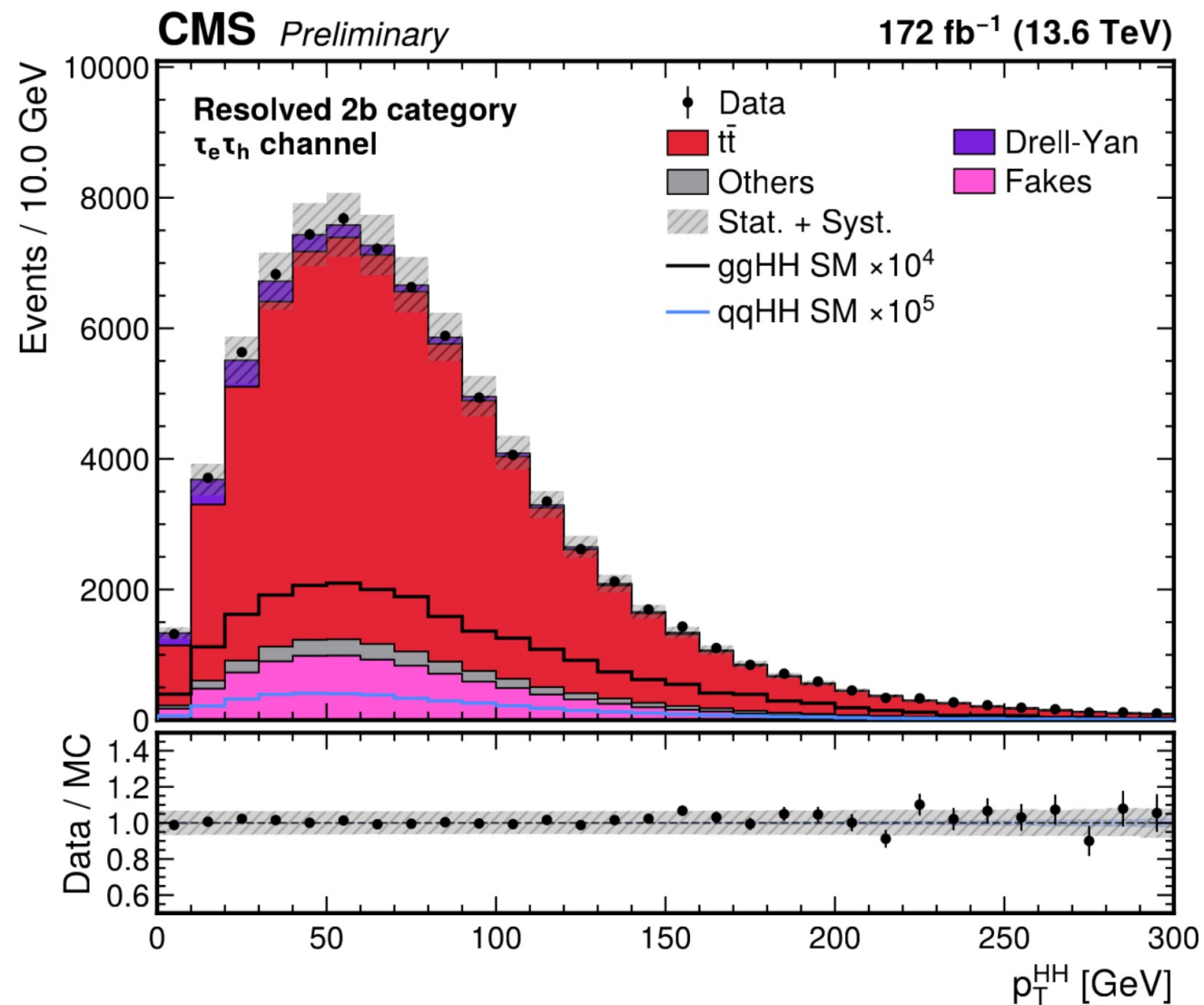
$HH \rightarrow b\bar{b}b\bar{b}$ 2D Likelihood Scans



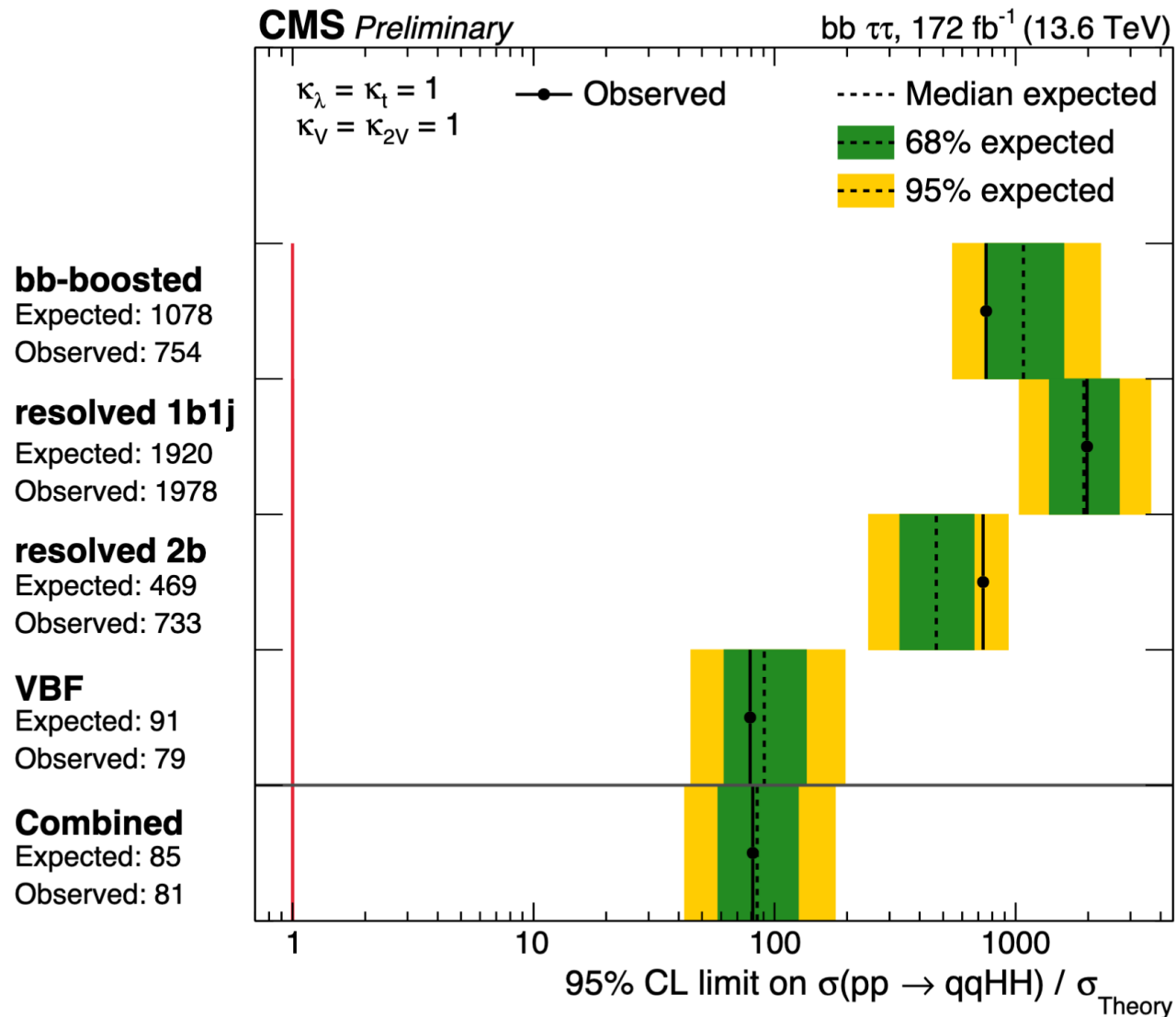
Combined merged and resolved analyses.

Supplemental: $HH \rightarrow b\bar{b}\tau\tau$

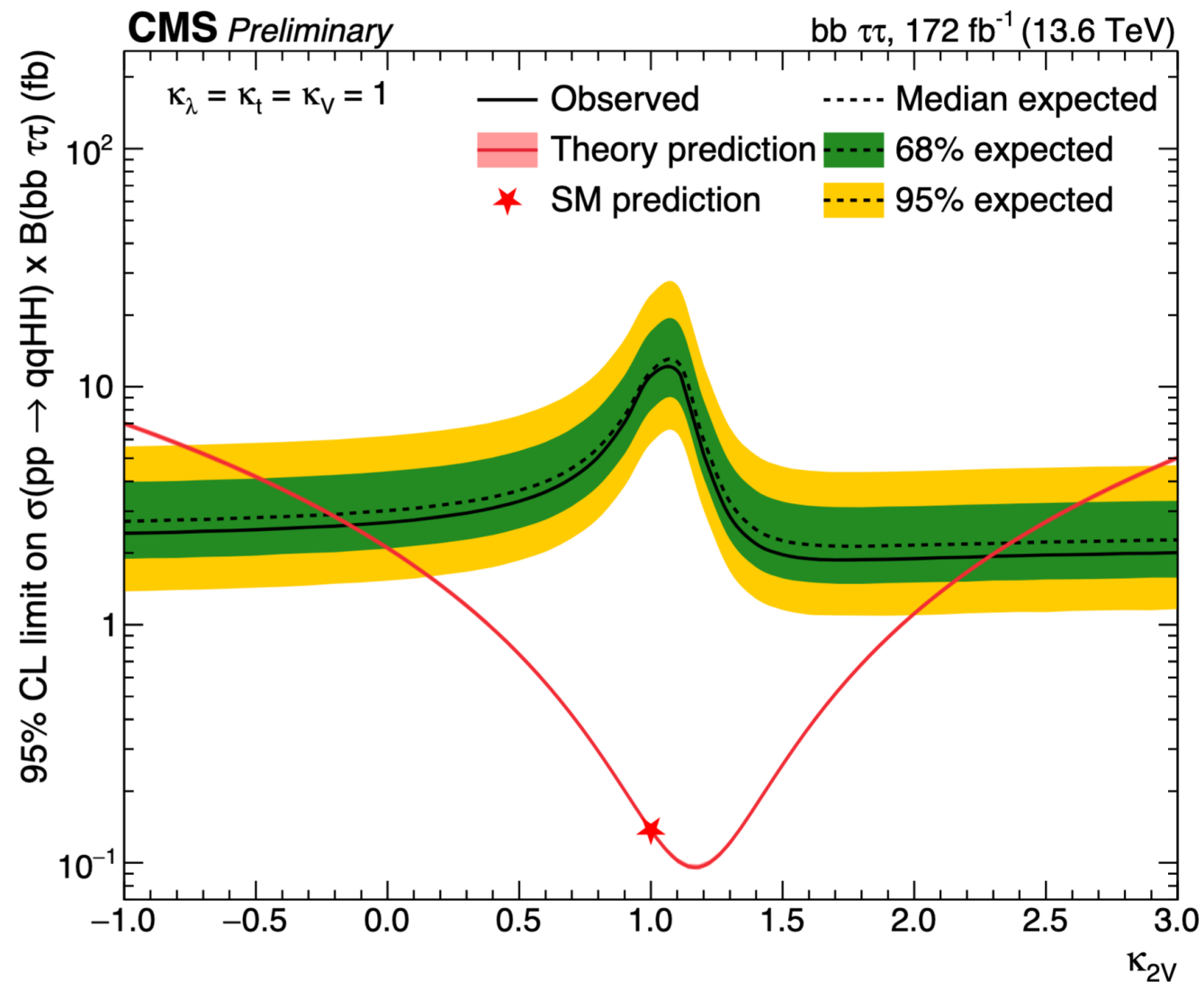
$HH \rightarrow b\bar{b}\tau\tau$ Reconstructed HH p_T



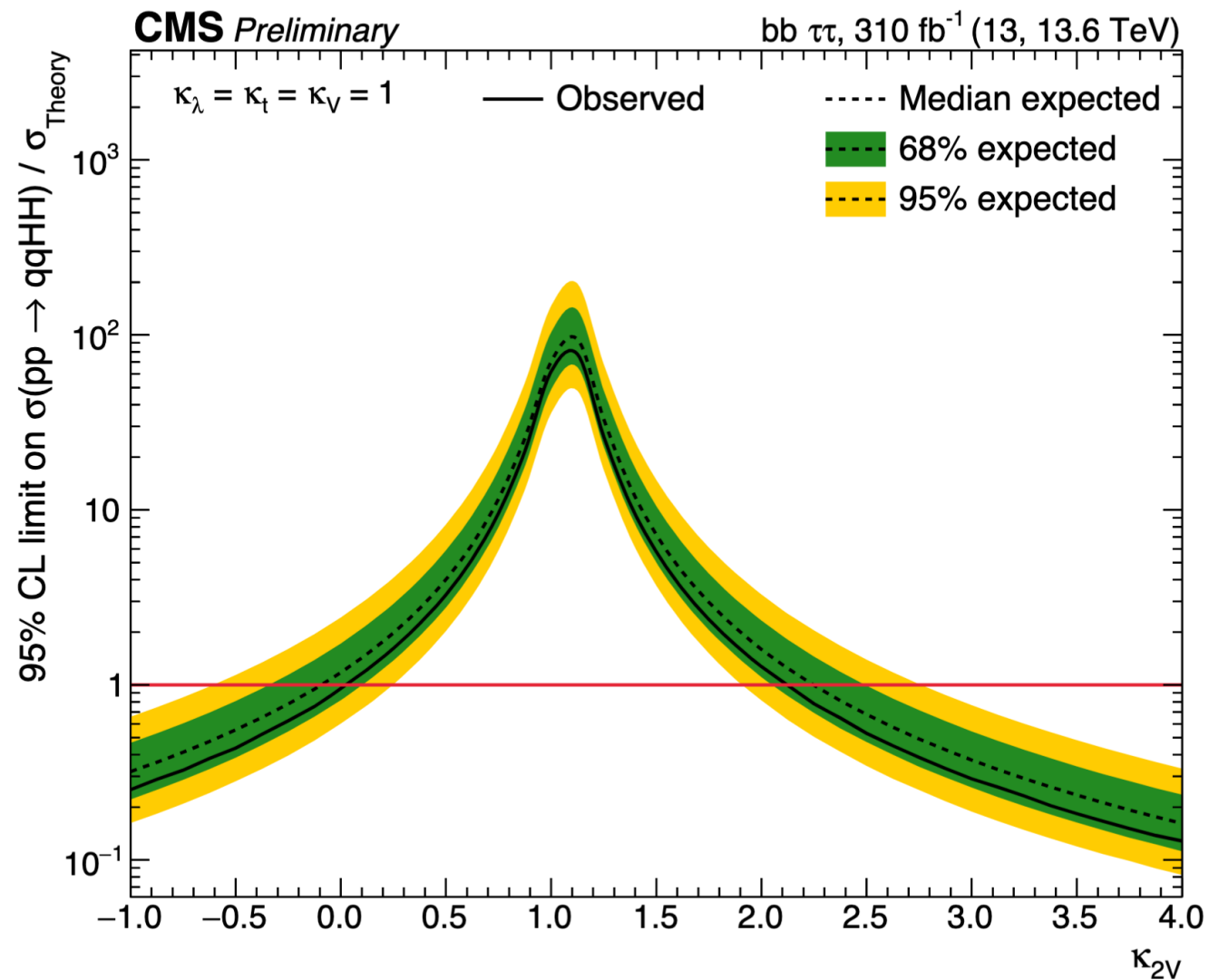
$HH \rightarrow b\bar{b}\tau\tau$ UL on VBFHH Production Cross Section



$HH \rightarrow b\bar{b}\tau\tau$ Early Run 3 UL on VBFHH Production as a function of κ_{2V}

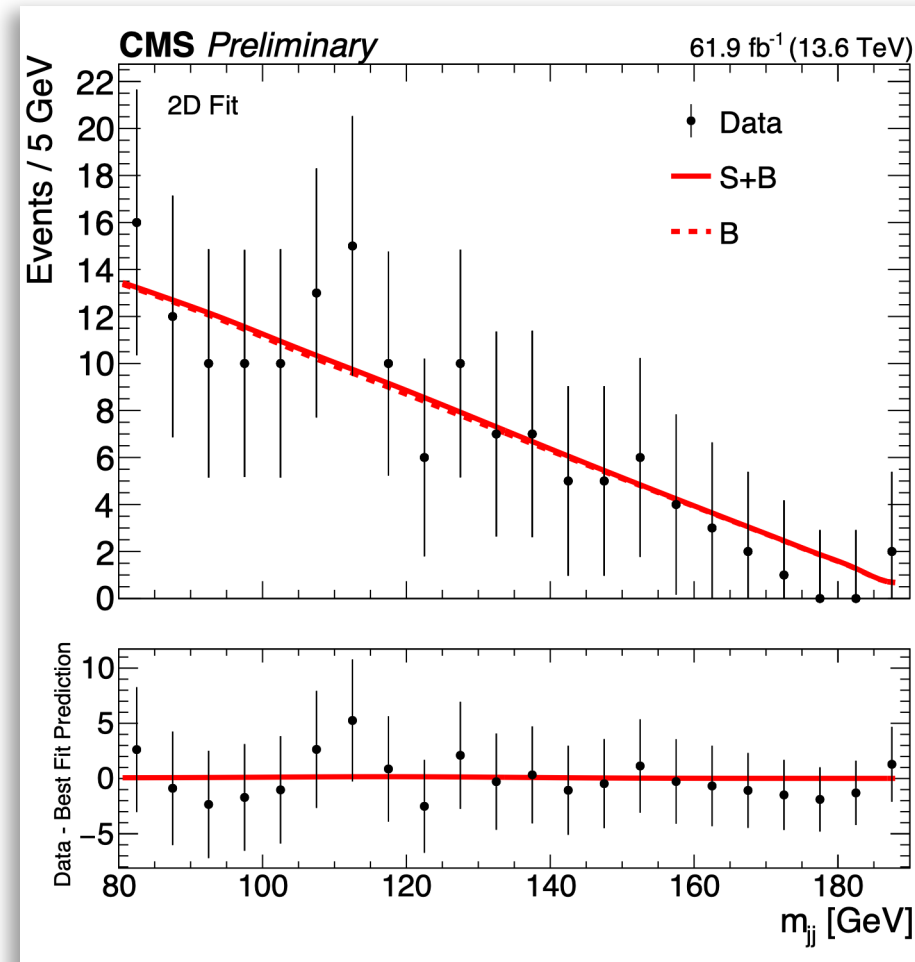
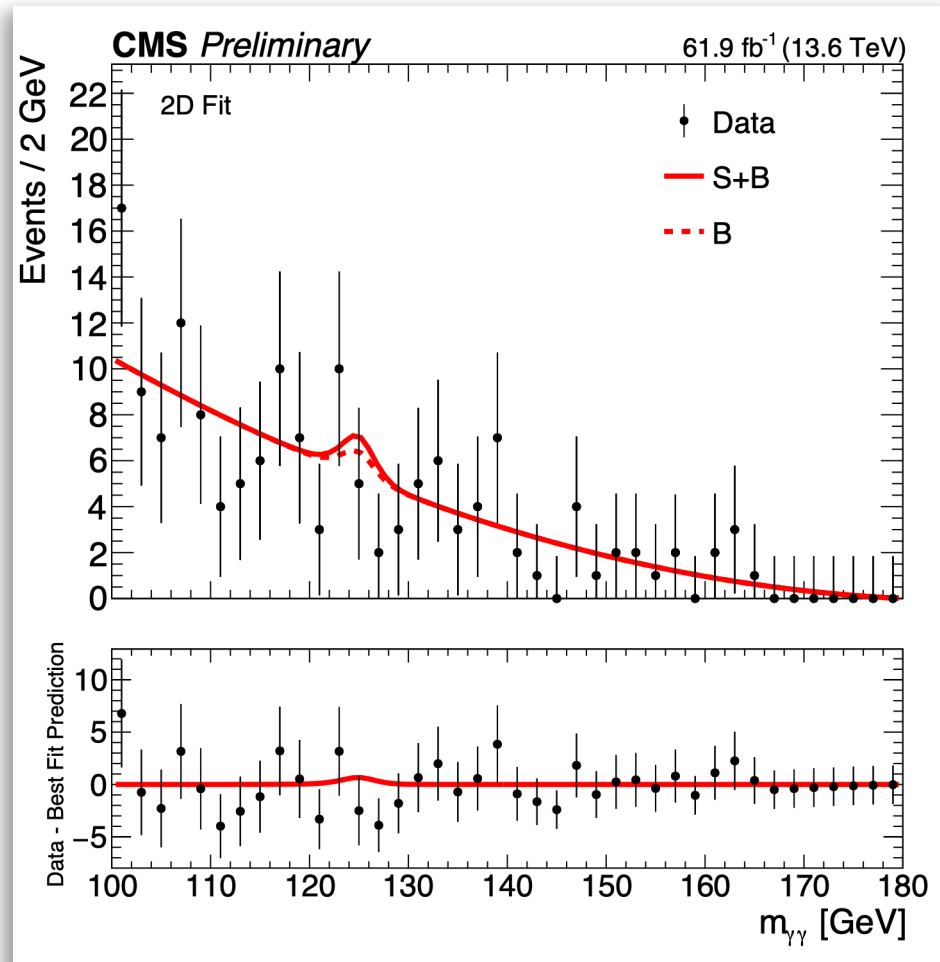


$HH \rightarrow b\bar{b}\tau\tau$ Run 2 + Early Run 3 VBFHH UL as a Function of κ_{2V}

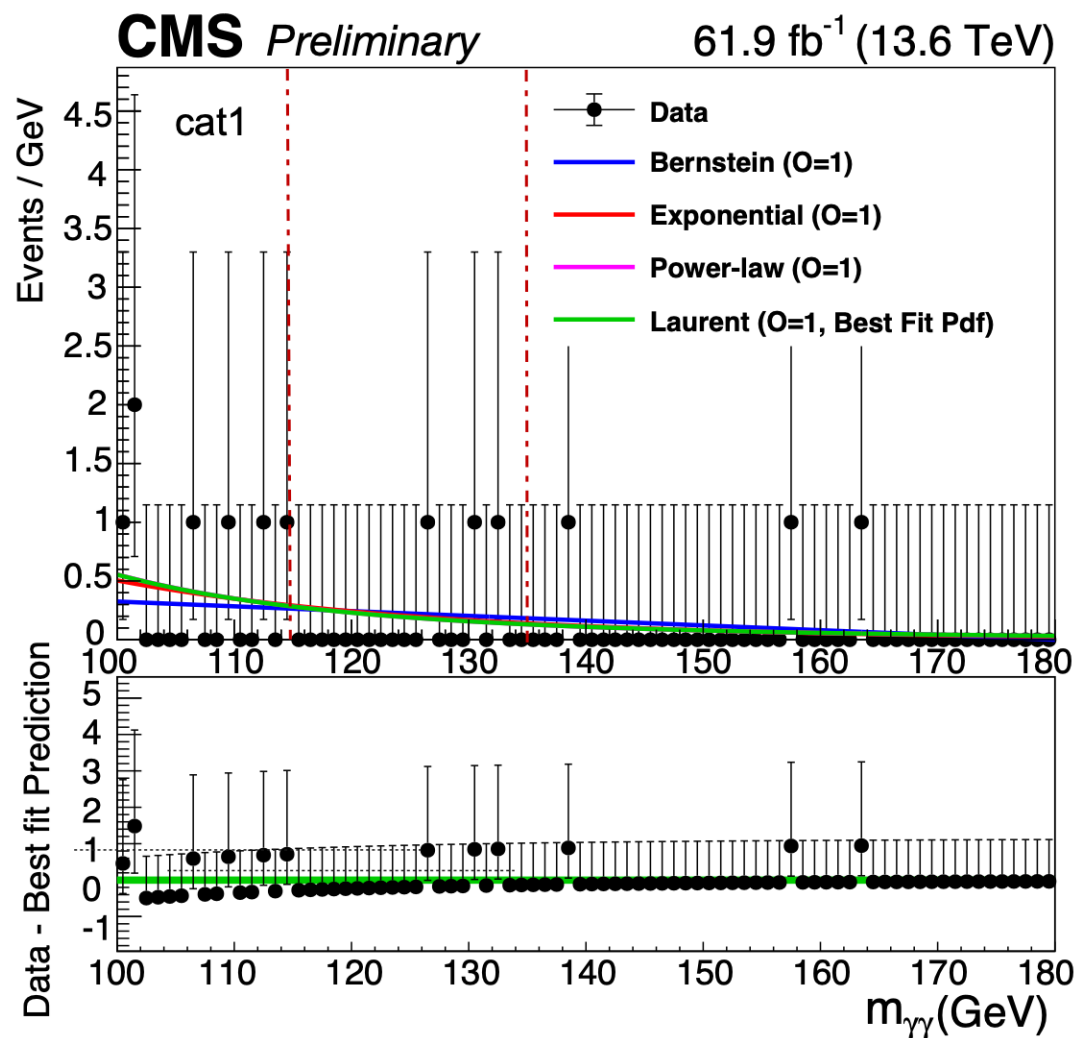


Supplemental: $HH \rightarrow b\bar{b}\gamma\gamma$

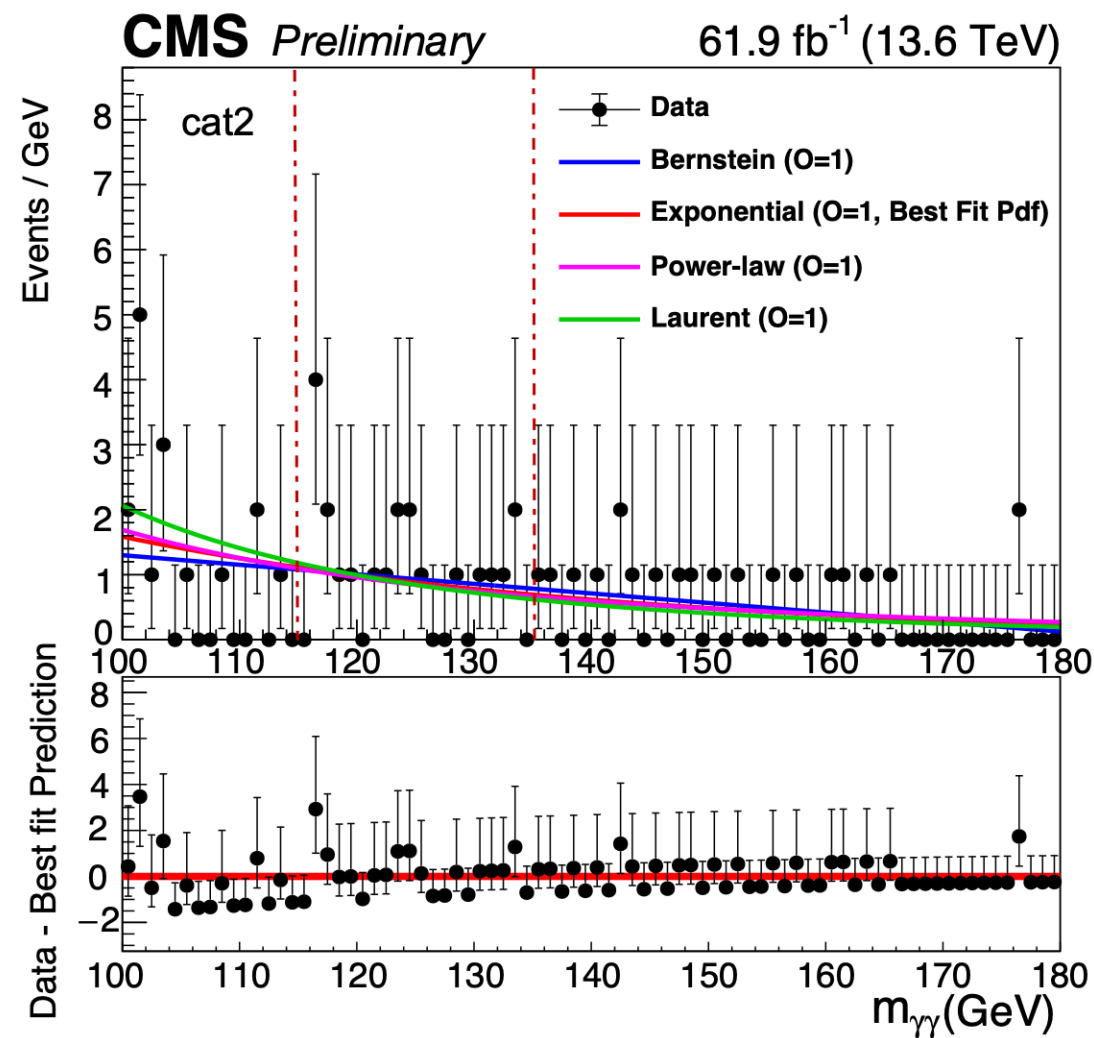
Category 3



$HH \rightarrow b\bar{b}\gamma\gamma$ Category 1 and 2

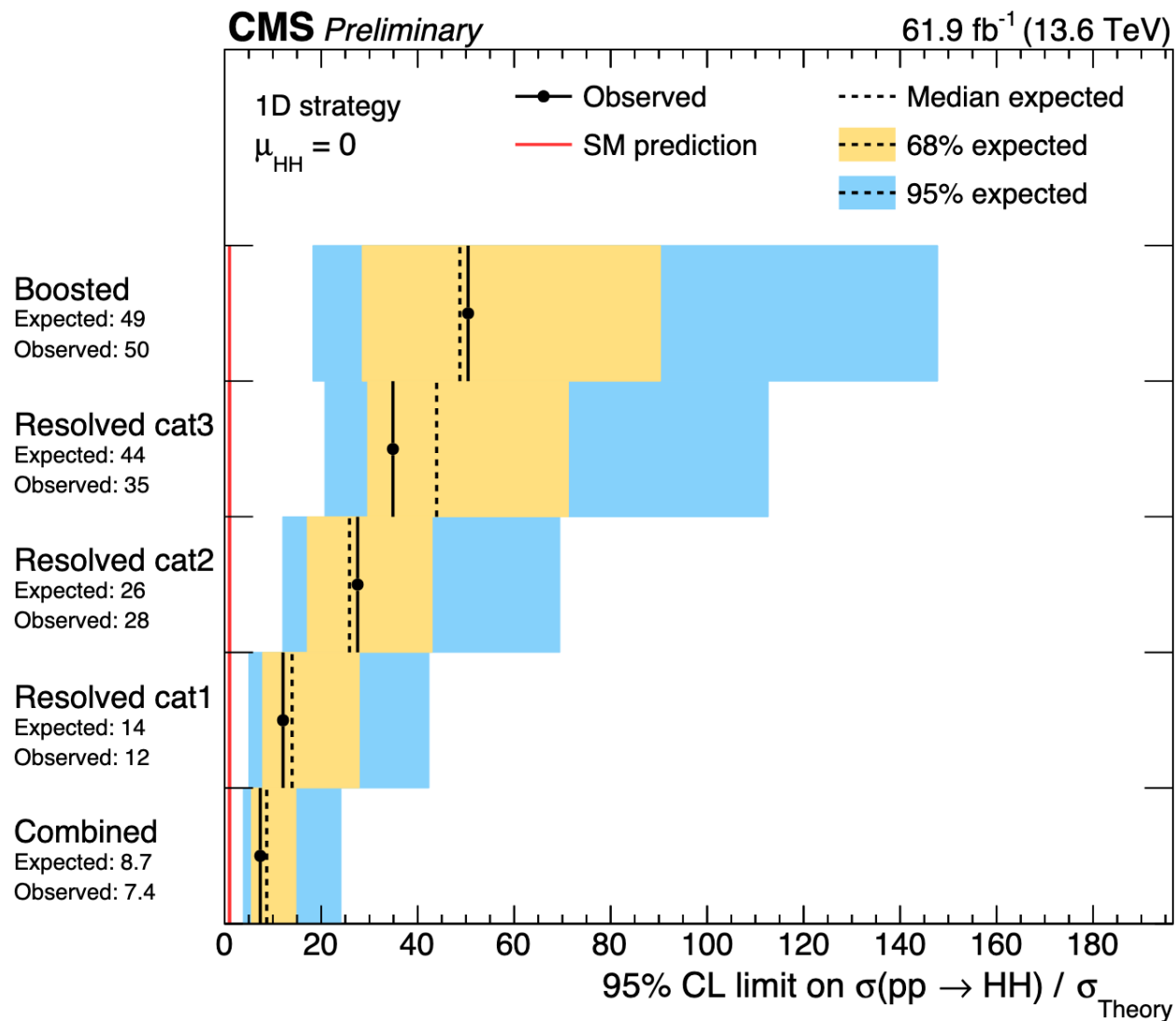


Category 1: highest purity

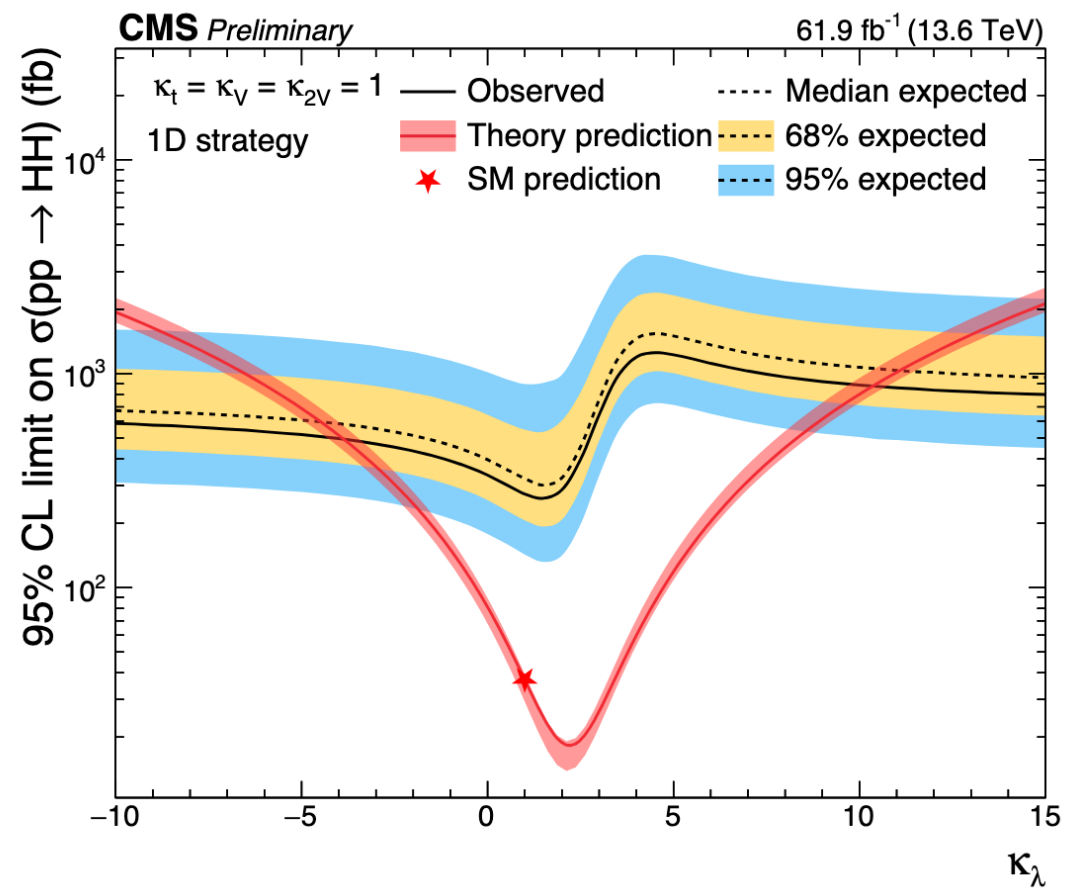
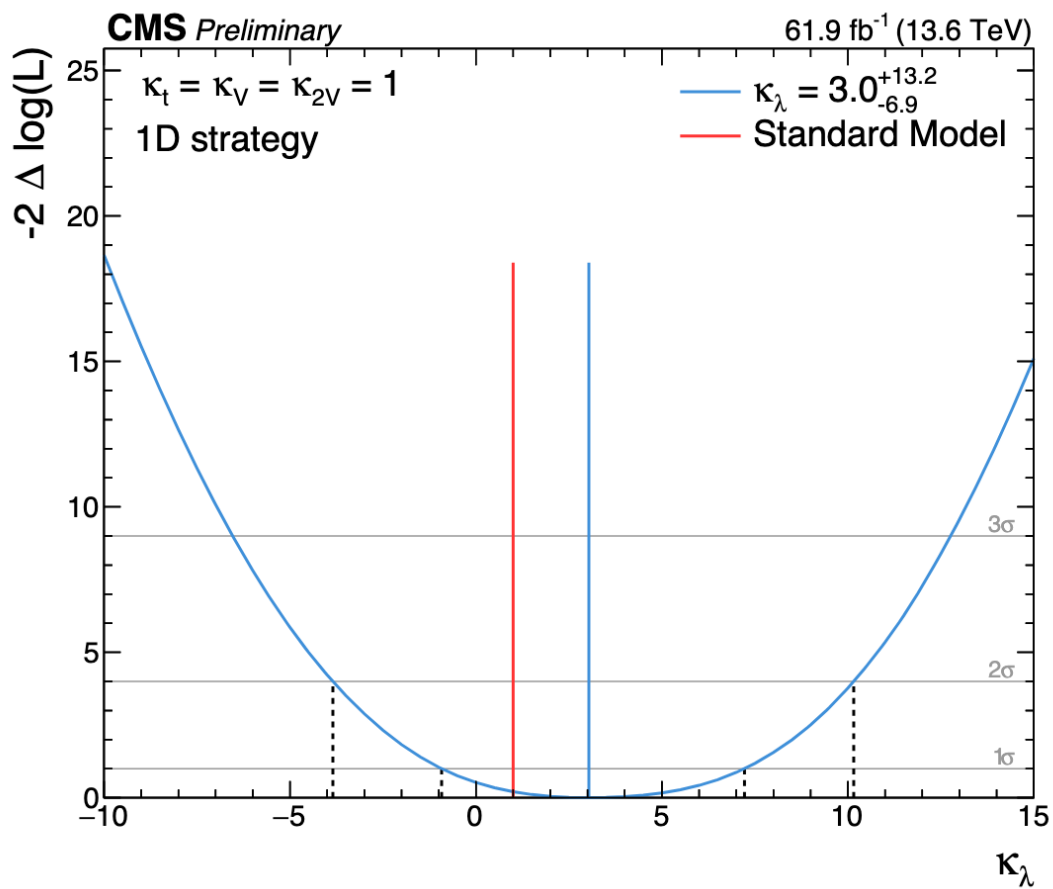


Category 2: intermediate purity

$HH \rightarrow b\bar{b}\gamma\gamma$ UL from the 1D Analysis

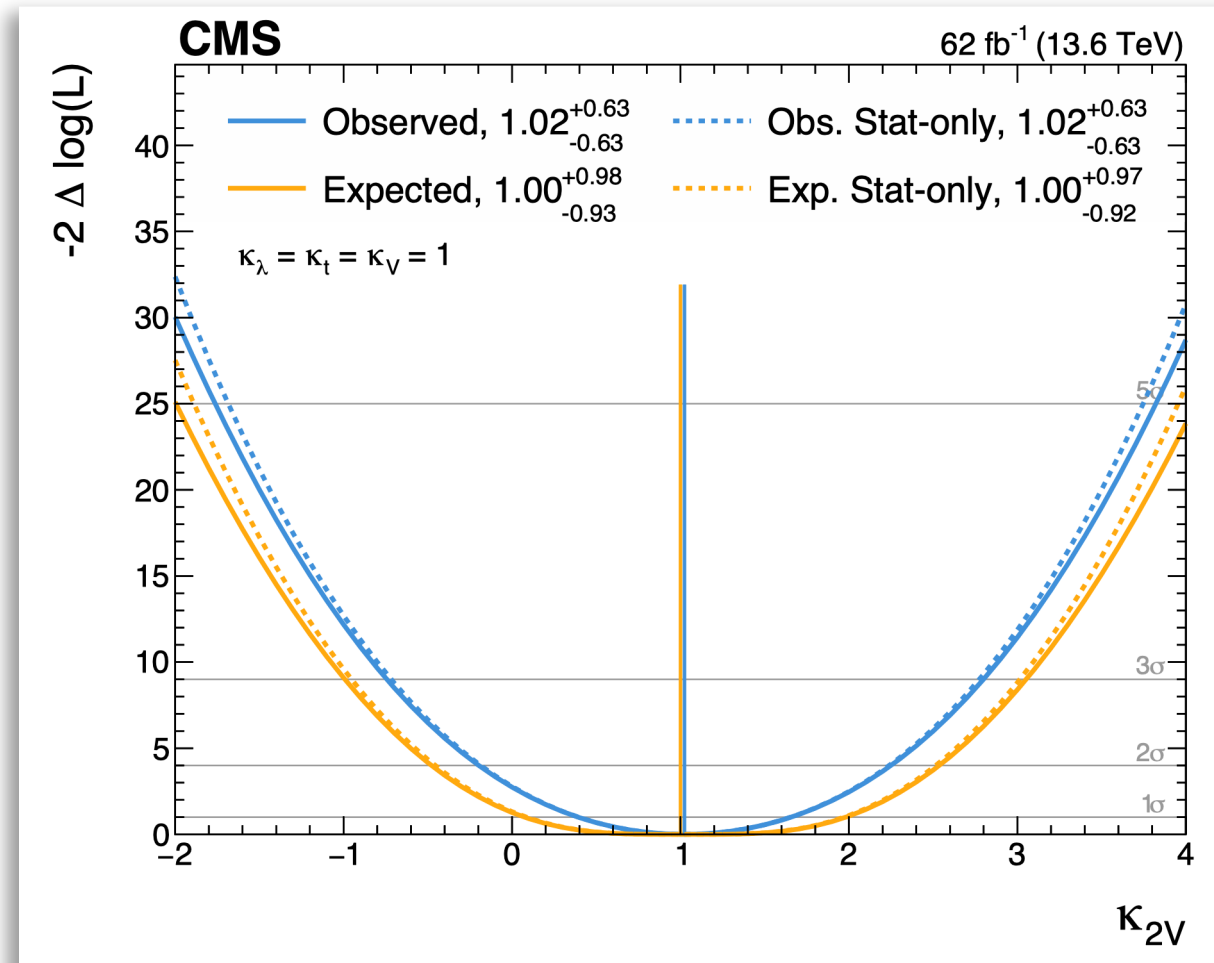
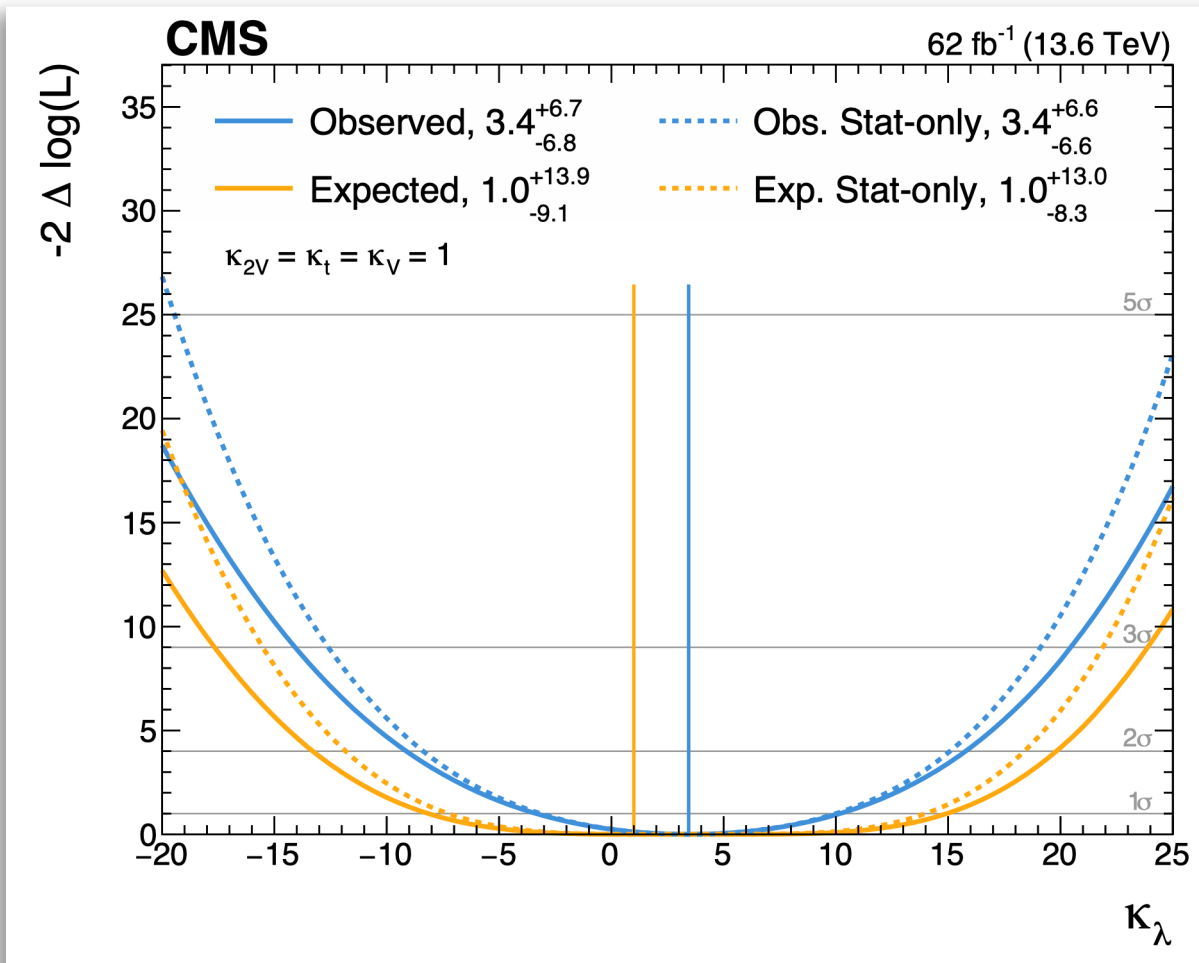


$HH \rightarrow b\bar{b}\gamma\gamma$ 1D Analysis Results

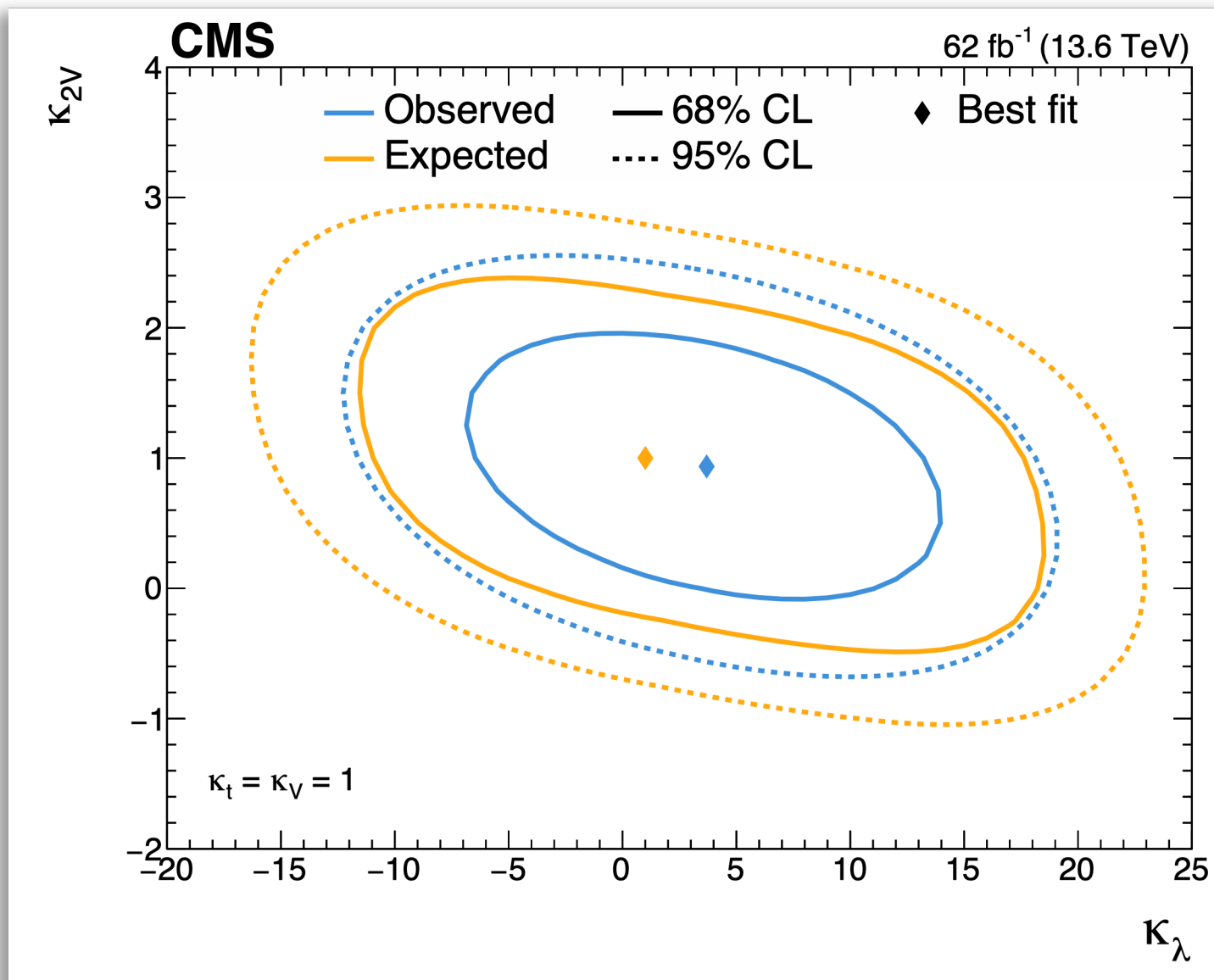


Supplemental: $HH \rightarrow b\bar{b}WW$

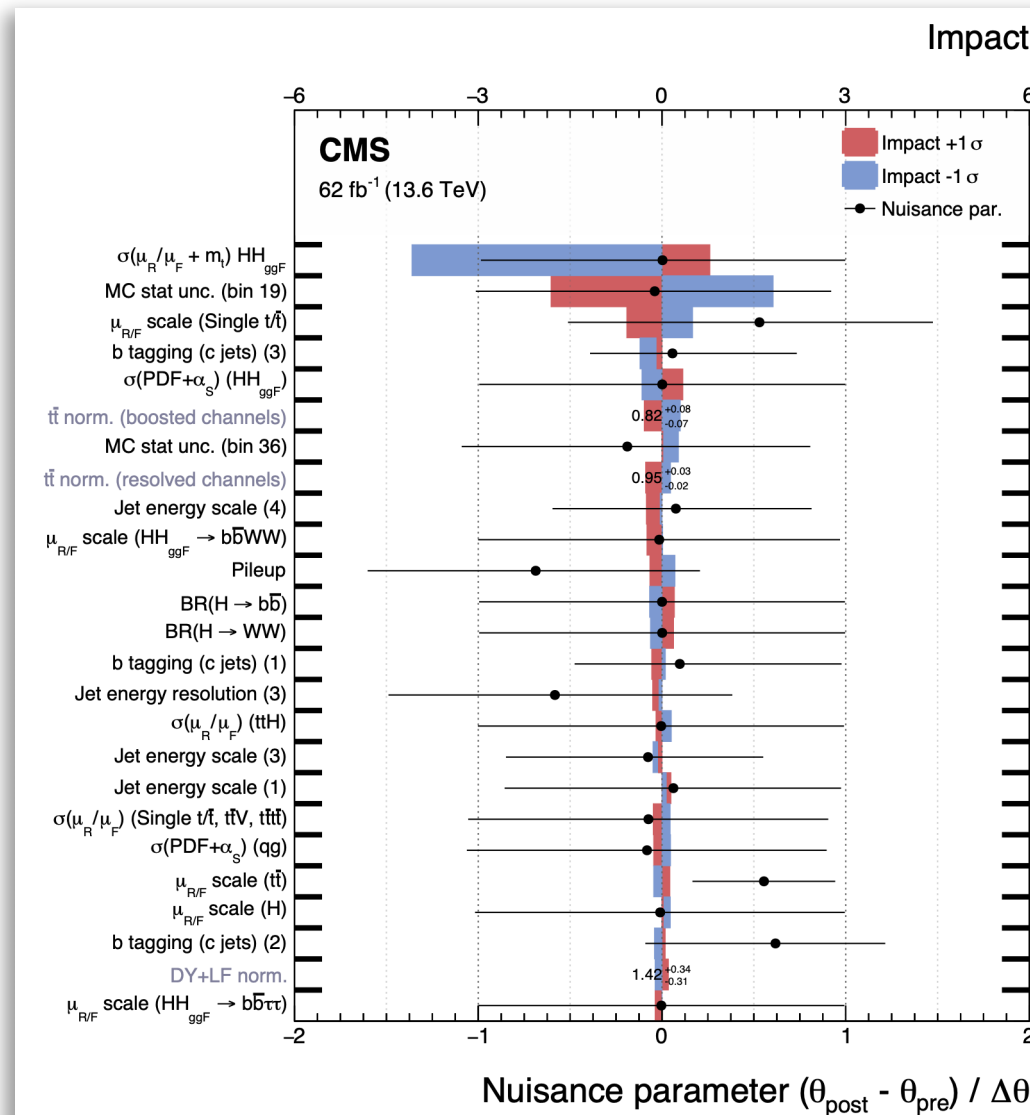
$HH \rightarrow b\bar{b}WW$ κ_λ and κ_{2V} Likelihood Scans



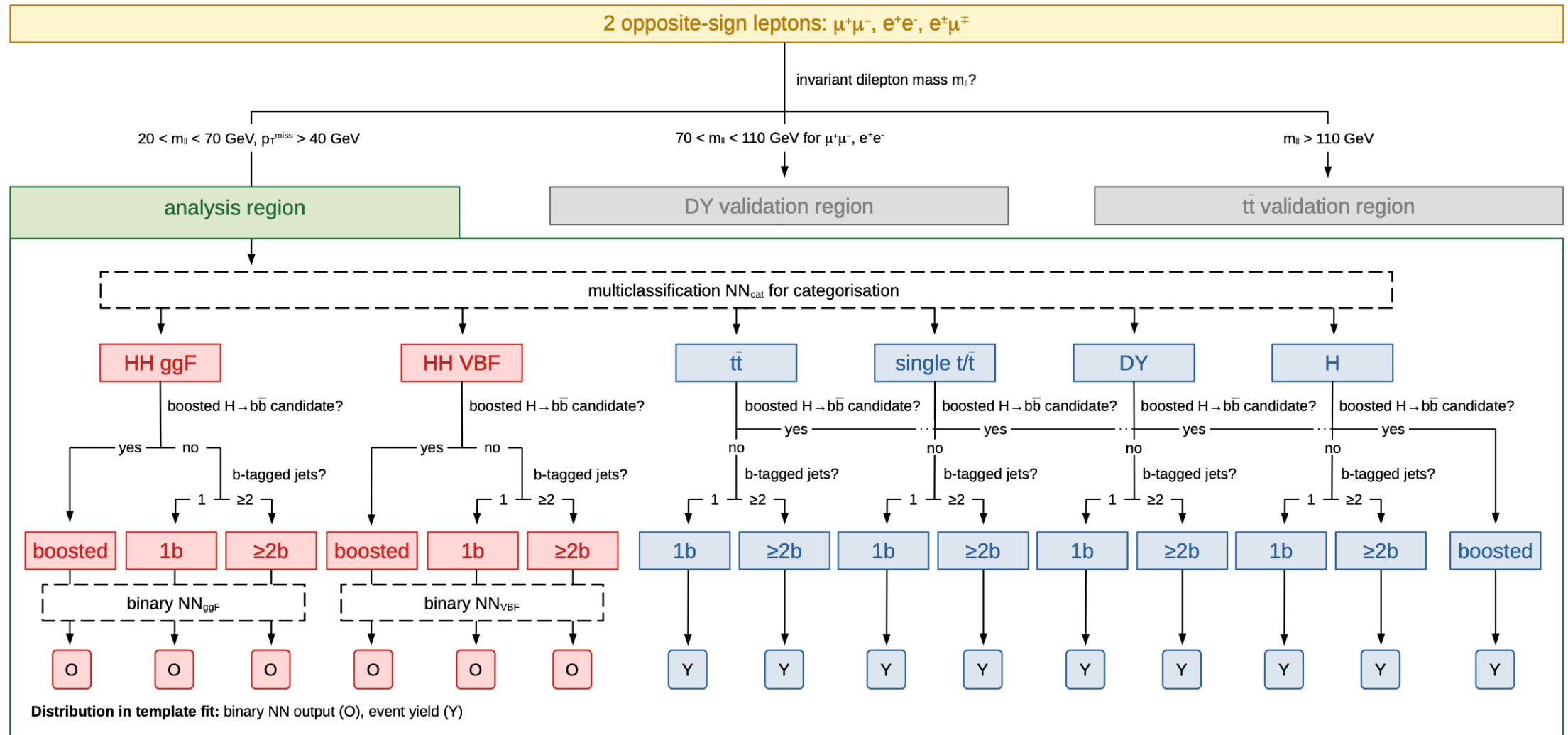
$HH \rightarrow b\bar{b}WW$ $\kappa_\lambda \times \kappa_{2V}$ Likelihood Scan



$HH \rightarrow b\bar{b}WW$ Nuisance Parameter Impacts



$HH \rightarrow b\bar{b}WW$ Analysis Strategy

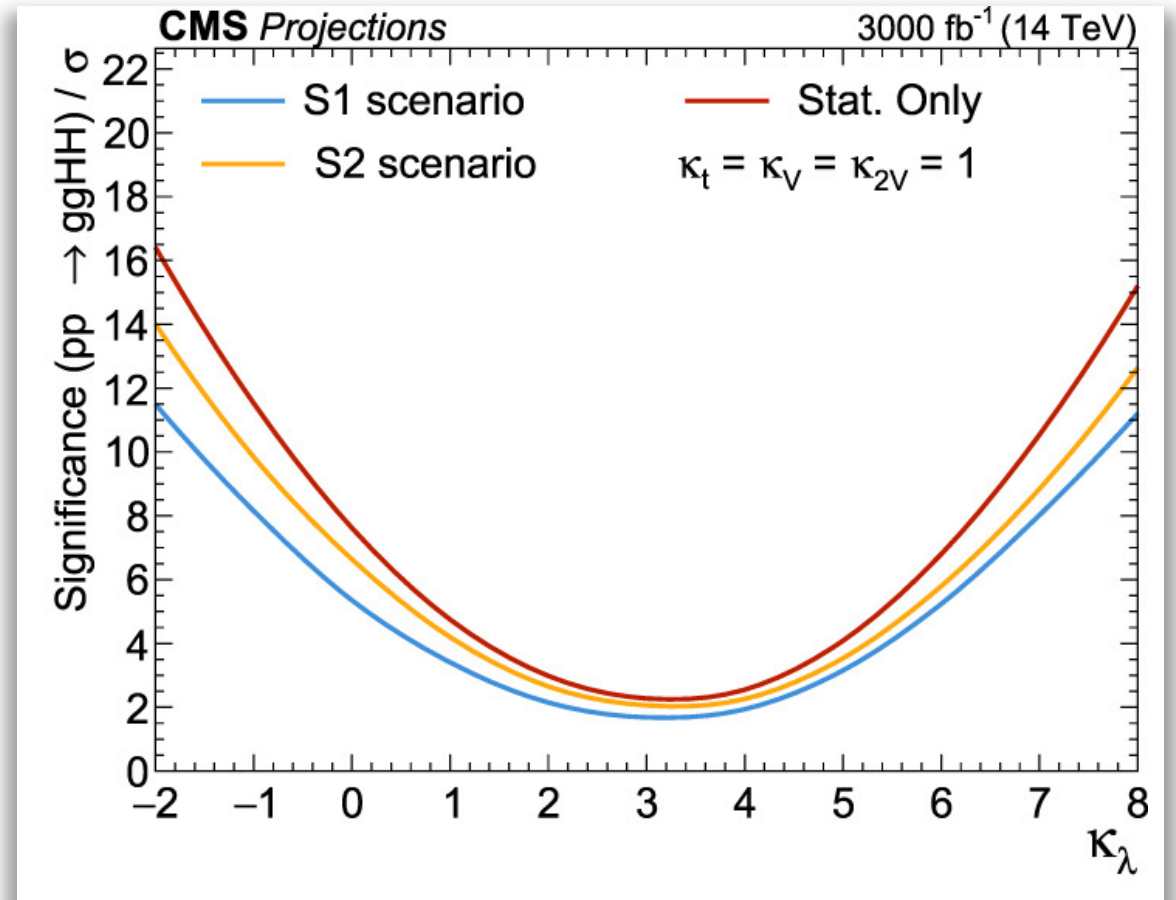
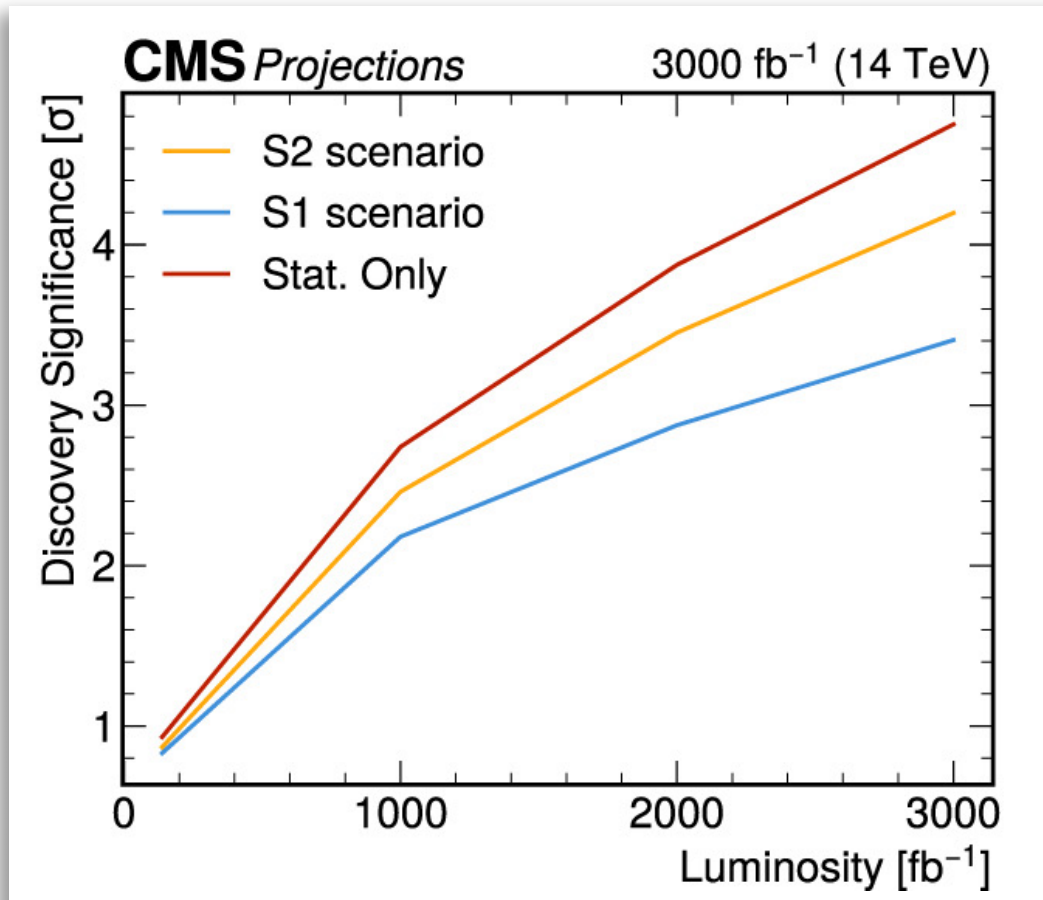


Supplemental: Projections

HH Discovery Significance per Luminosity

S1 – Scenario 1: Run 2 systematics

S2 – Scenario 2: Systematic uncertainties of statistical origin (e.g. data/MC scale factors) are reduced by $\sqrt{k_L}$ until reasonable “floor” values are reached.



Treatment of Systematics $\sqrt{k_L}$ Scaling

S2 scenario

Uncertainty	Scaling with respect to Run 2
Theoretical uncertainties	1/2
Stat. uncertainties in MC simulation	Removed
b-tagging efficiency stat. component	$1/\sqrt{k_L}$
b-tagging efficiency (nonstat. component)	Unchanged
AK4 jet absolute energy scale	$\max(0.3, 1/\sqrt{k_L})$
AK4 jet energy scale dependence on flavour	$\max(0.5, 1/\sqrt{k_L})$
AK4 jet relative energy scale	$\max(0.2, 1/\sqrt{k_L})$
AK4 jet energy scale method	$1/\sqrt{k_L}$
AK4 jet energy resolution	$\max(0.5, 1/\sqrt{k_L})$
E_T^{miss}	$\max(0.5, 1/\sqrt{k_L})$
Luminosity	0.6
τ_h ID	Unchanged
τ_h energy scale	Unchanged
Pileup	Unchanged
Run-2 issues	Removed

HH Expected Upper Limits vs. Lumi

S1 – Scenario 1: Run 2 systematics

S2 – Scenario 2: Systematic uncertainties of statistical origin (e.g. data/MC scale factors) are reduced by $\sqrt{k_L}$ until reasonable “floor” values are reached.

