

Higgs self-coupling Measurements with the CMS Experiment

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PASCOS

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**2024
QUY NHON**

Introduction: Higgs self-coupling

Since the discovery, many precision measurements done on Higgs, all agree with the SM !
To test further...

$$V(H) = \frac{1}{2}m_H^2 H^2 + \lambda v H^3 + \frac{1}{4}\lambda H^4$$

can directly be accessed by the HH production, and indirectly by the single H

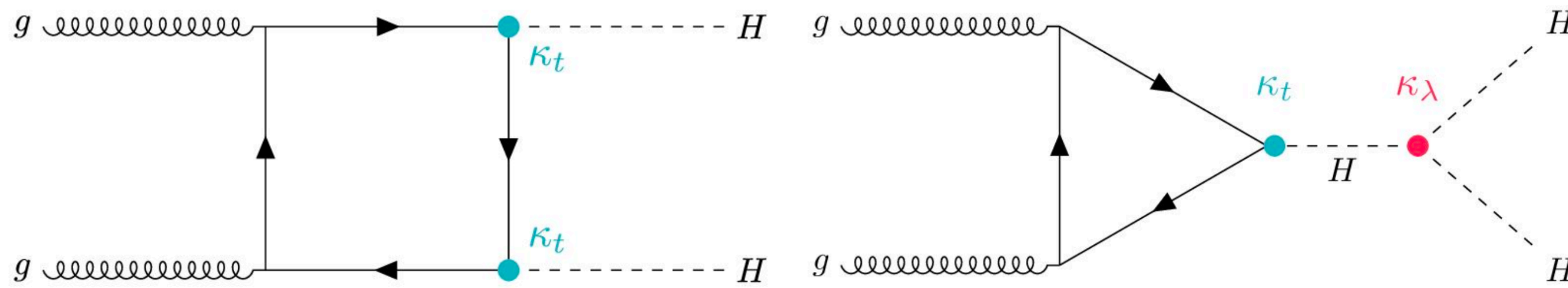
HHH, out of reach of LHC

- self-coupling λ not yet measured - will help to understand the Higgs potential, **but upper limits are in place**

Recipe to access λ at the LHC

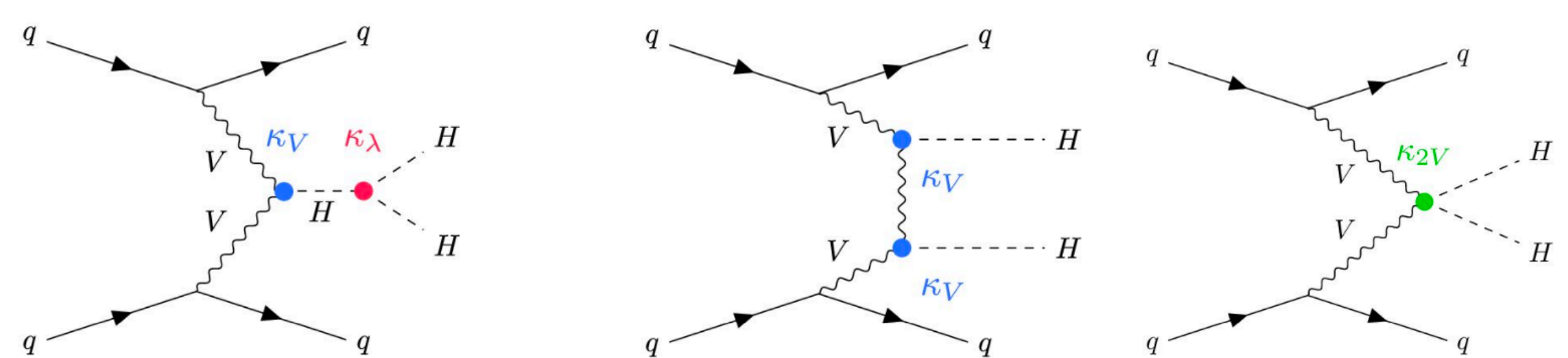
1- **gluon-gluon fusion**: dominant mode - destructive Feynman diagrams

$$\sigma_{HH}^{GGF}(13TeV) \cong 31.05 fb$$



2- **vector boson fusion**: 2nd dominant

$$\sigma_{HH}^{VBF}(13TeV) \cong 1.71 fb$$

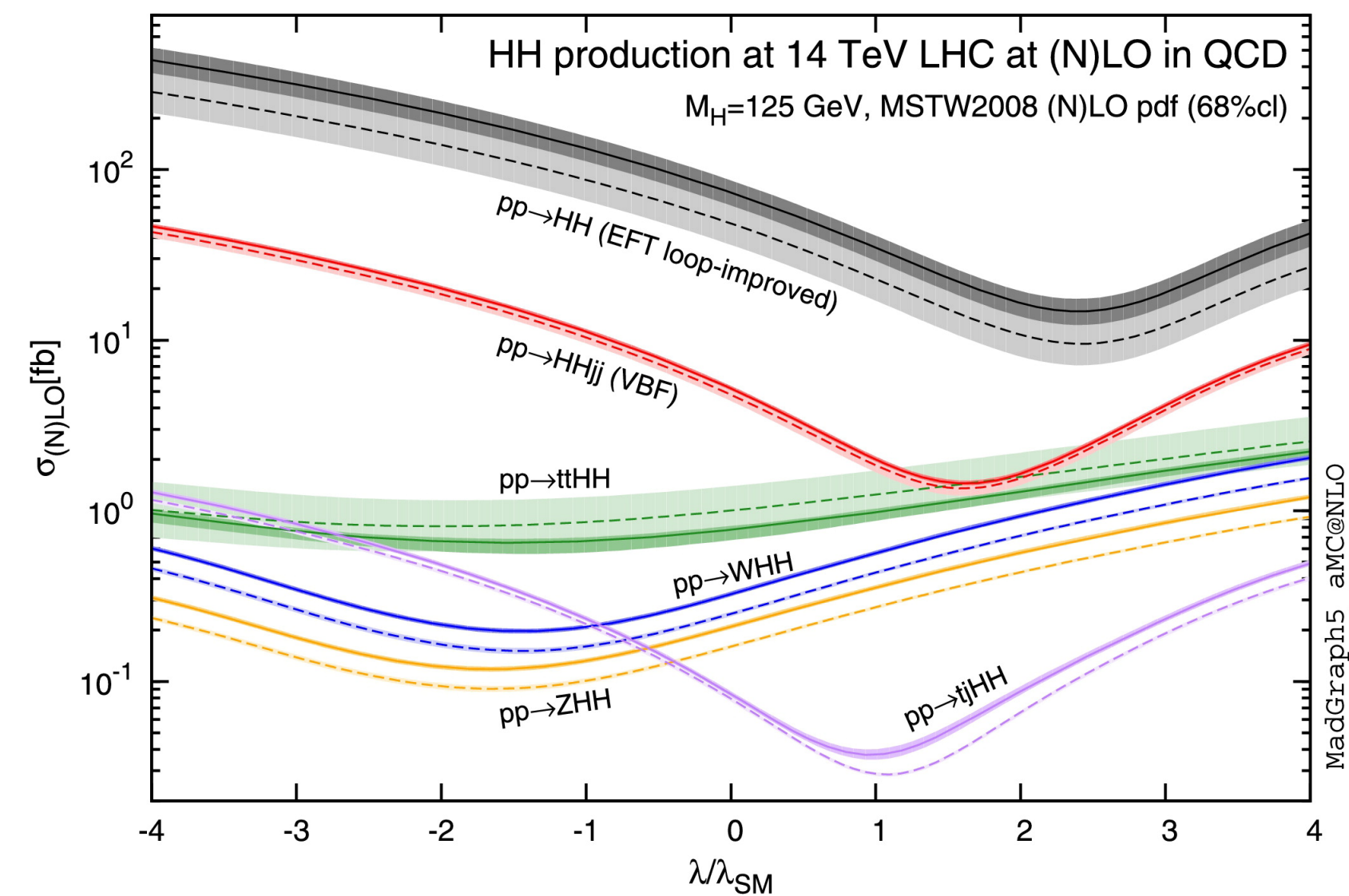
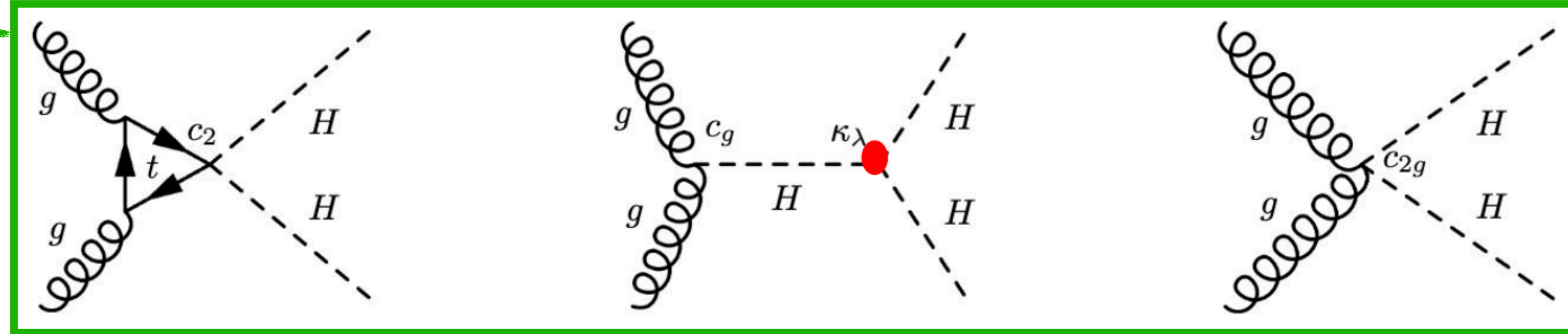


Rare VHH, ttHH and single H productions also contribute - diagrams in the next slides...

3 BSM couplings: c_2 , c_g , c_{2g} ,

(with 6 dim L expansion) ([Higgs EFT at CMS](#))

which modify the cross section and kinematic properties of Higgs



[Physics Letters B \(2014\) 142-149](#)

Measurements are done on coupling modifiers:

$$\kappa_\lambda = \frac{\lambda}{\lambda_{SM}}$$

Modifiers are grouped into two schema with benchmarks in 5D space:

1 - JHEP03:

- unsupervised machine learning
- identify shape variations in m_{HH}
- 7 benchmarks
- [JHEP03\(2020\)091](#)

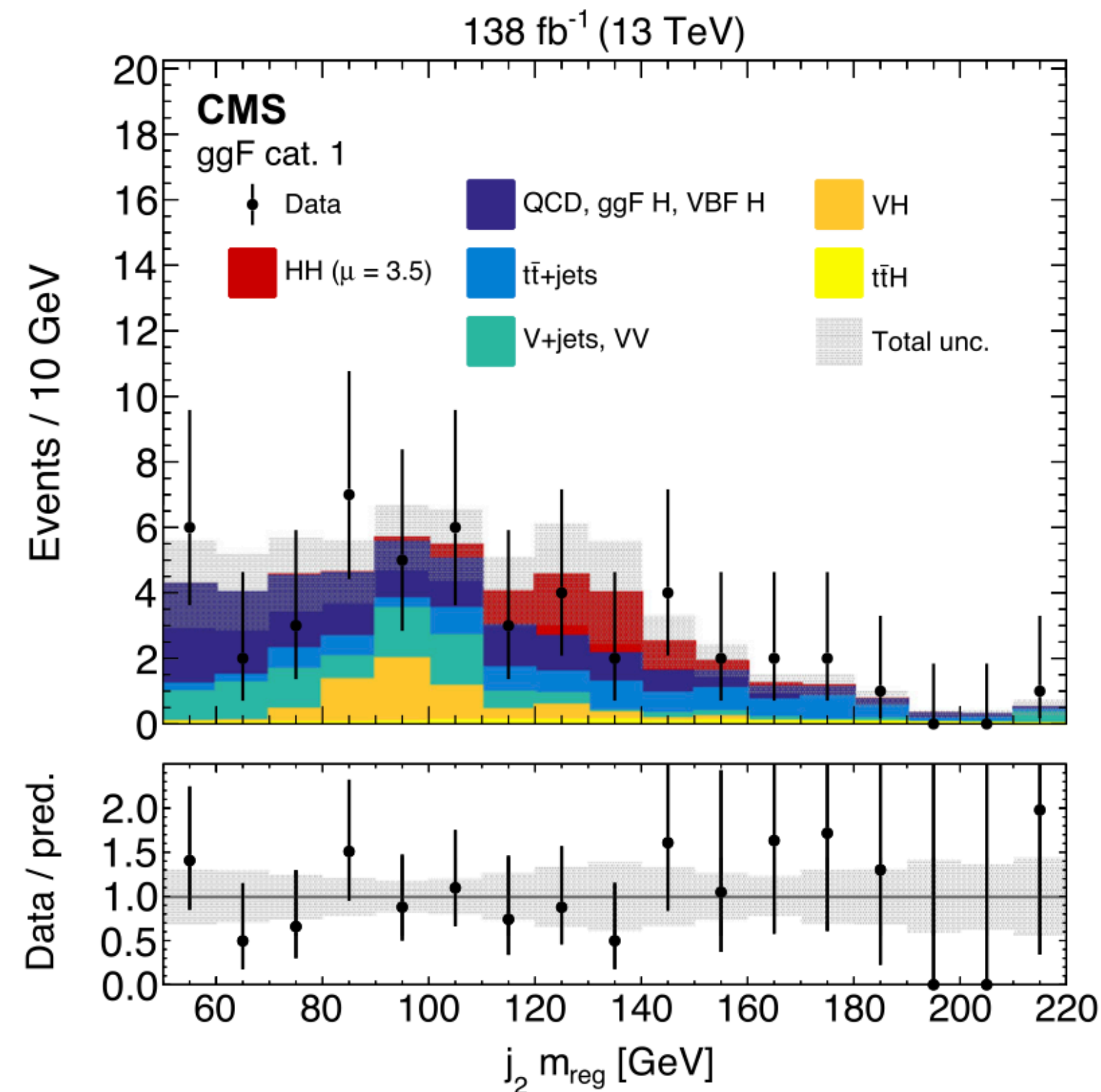
benchmark	c_t	c_{hhh}	c_{tt}	c_{ggh}	c_{gghh}
1	0.94	3.94	$-\frac{1}{3}$	0.5	$\frac{1}{3}$
2	0.61	6.84	$\frac{1}{3}$	0.0	$-\frac{1}{3}$
3	1.05	2.21	$-\frac{1}{3}$	0.5	0.5
4	0.61	2.79	$\frac{1}{3}$	-0.5	$\frac{1}{6}$
5	1.17	3.95	$-\frac{1}{3}$	$\frac{1}{6}$	-0.5
6	0.83	5.68	$\frac{1}{3}$	-0.5	$\frac{1}{3}$
7	0.94	-0.10	1	$\frac{1}{6}$	$-\frac{1}{6}$

2 - JHEP04:

- distributions:
 - m_{HH}
 - $\cos\theta$ between H and beam
- 12 benchmarks
- [JHEP04\(2016\)126](#)

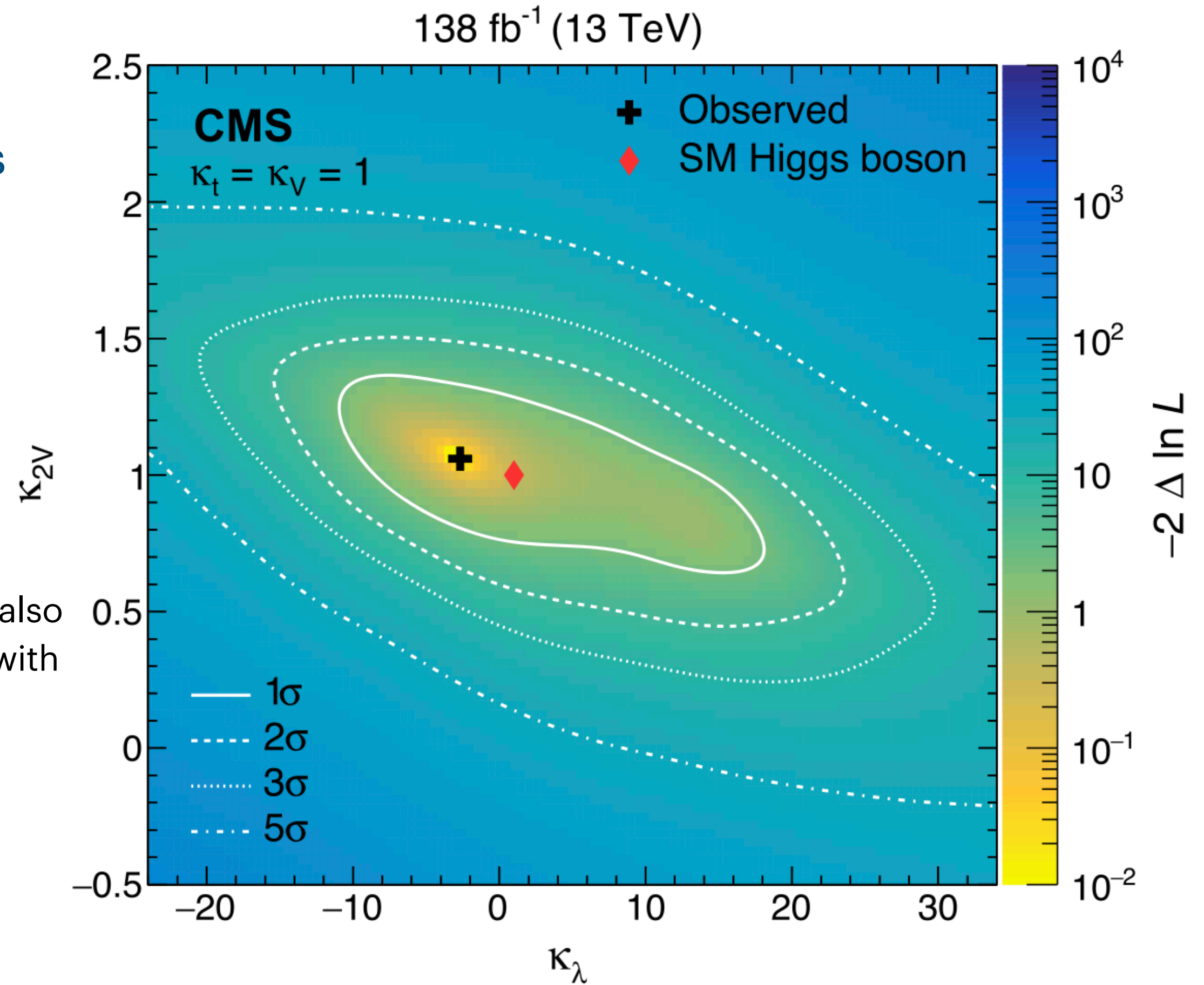
Benchmark	κ_λ	κ_t	c_2	c_g	c_{2g}
1	7.5	1.0	-1.0	0.0	0.0
2	1.0	1.0	0.5	-0.8	0.6
3	1.0	1.0	-1.5	0.0	-0.8
4	-3.5	1.5	-3.0	0.0	0.0
5	1.0	1.0	0.0	0.8	-1
6	2.4	1.0	0.0	0.2	-0.2
7	5.0	1.0	0.0	0.2	-0.2
8	15.0	1.0	0.0	-1	1
9	1.0	1.0	1.0	-0.6	0.6
10	10.0	1.5	-1.0	0.0	0.0
11	2.4	1.0	0.0	1	-1
12	15.0	1.0	1.0	0.0	0.0
SM	1.0	1.0	0.0	0.0	0.0

- [Phys. Rev. Lett. 131, 041803 - 2023](#)
- **highest BR** with GGF and VBF productions
- [particleNet](#) (DNN) algorithm to identify & reconstruct AK8 jets
- **BDT** used in GGF production with specific score categories
- CR used to estimate QCD multi-jet background
- m_{HH} fitted in SR and CR to extract signal



$D_{b\bar{b}}$ sub leading jet reg. mass at the most sensitive BDT category

$\kappa_{2V} = 0$ is also excluded with 6.3σ !



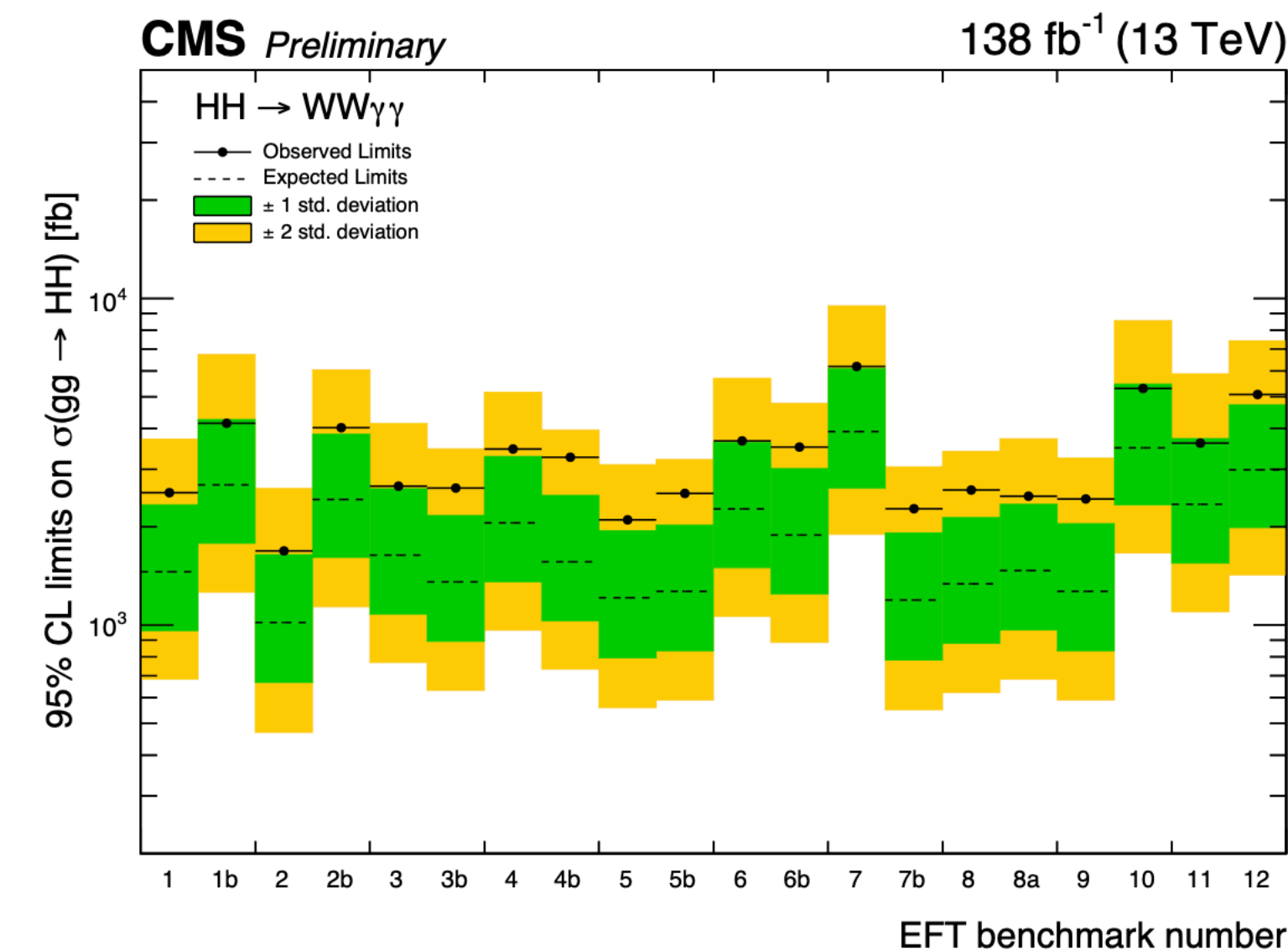
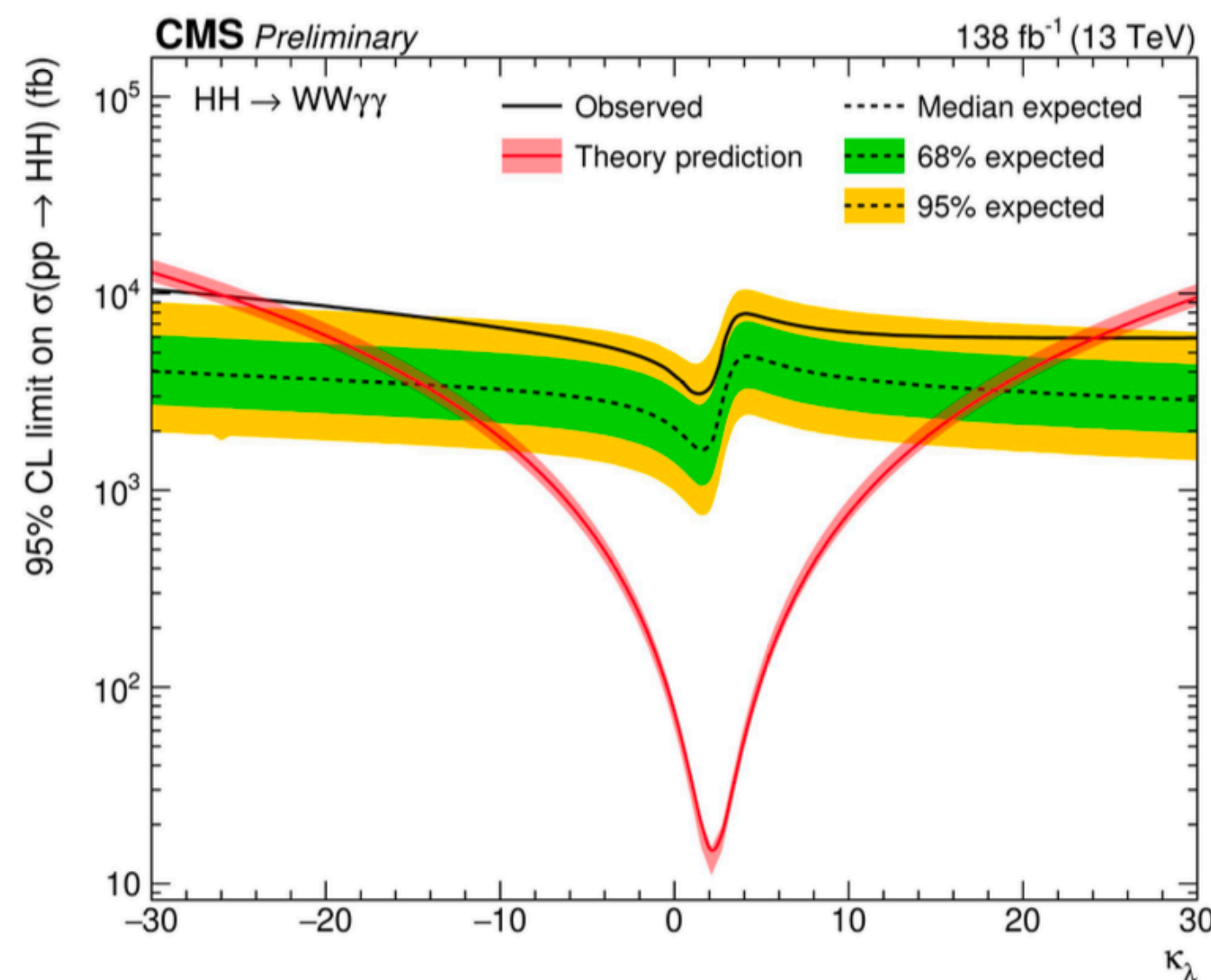
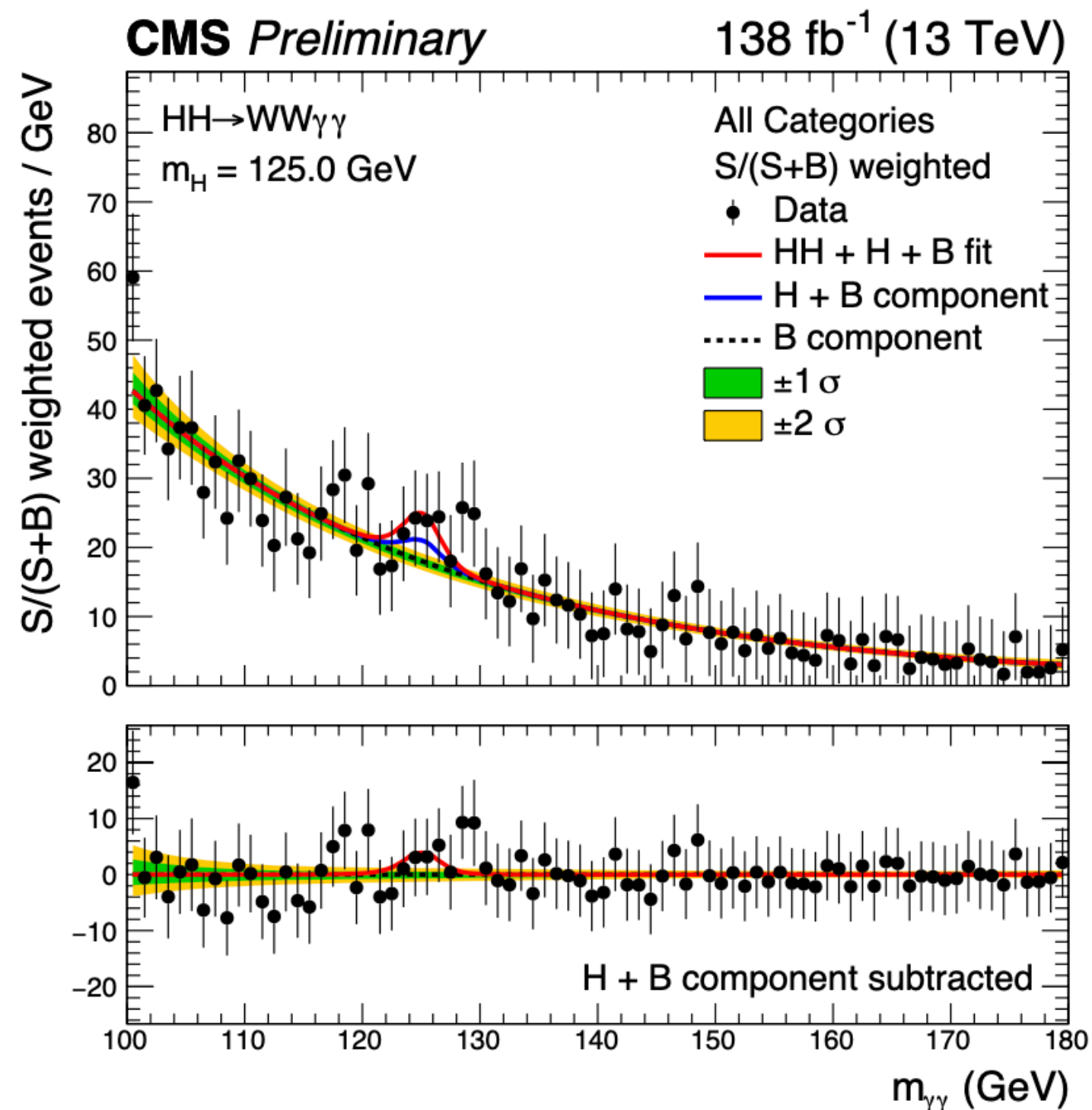
Results

Constraint on the κ_λ : **Obs (Exp): -9.9 (-5.1) < κ_λ < 16.9 (12.2)**

Upper limit on σ_{HH} : **Obs (Exp) σ/σ_{SM} < 9.9 (5.1)**

- [CMS PAS HIG-21-014 - 2022](#)

- small BR but **good resolution** in $m_{\gamma\gamma}$
- hadronic, semi/leptonic
- **single H background** - modelled by MC while continuum BG - by data
- channels use either NN or cut-based analysis
- $m_{\gamma\gamma}$ fitted to extract signal



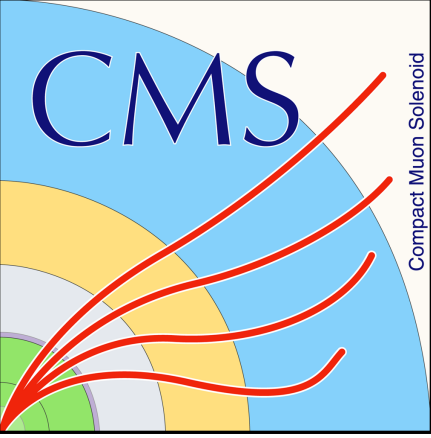
Results:

Constraint on the κ_λ : **Obs(Exp): -25.8 (-14.4) < κ_λ < 24.1 (18.3)**

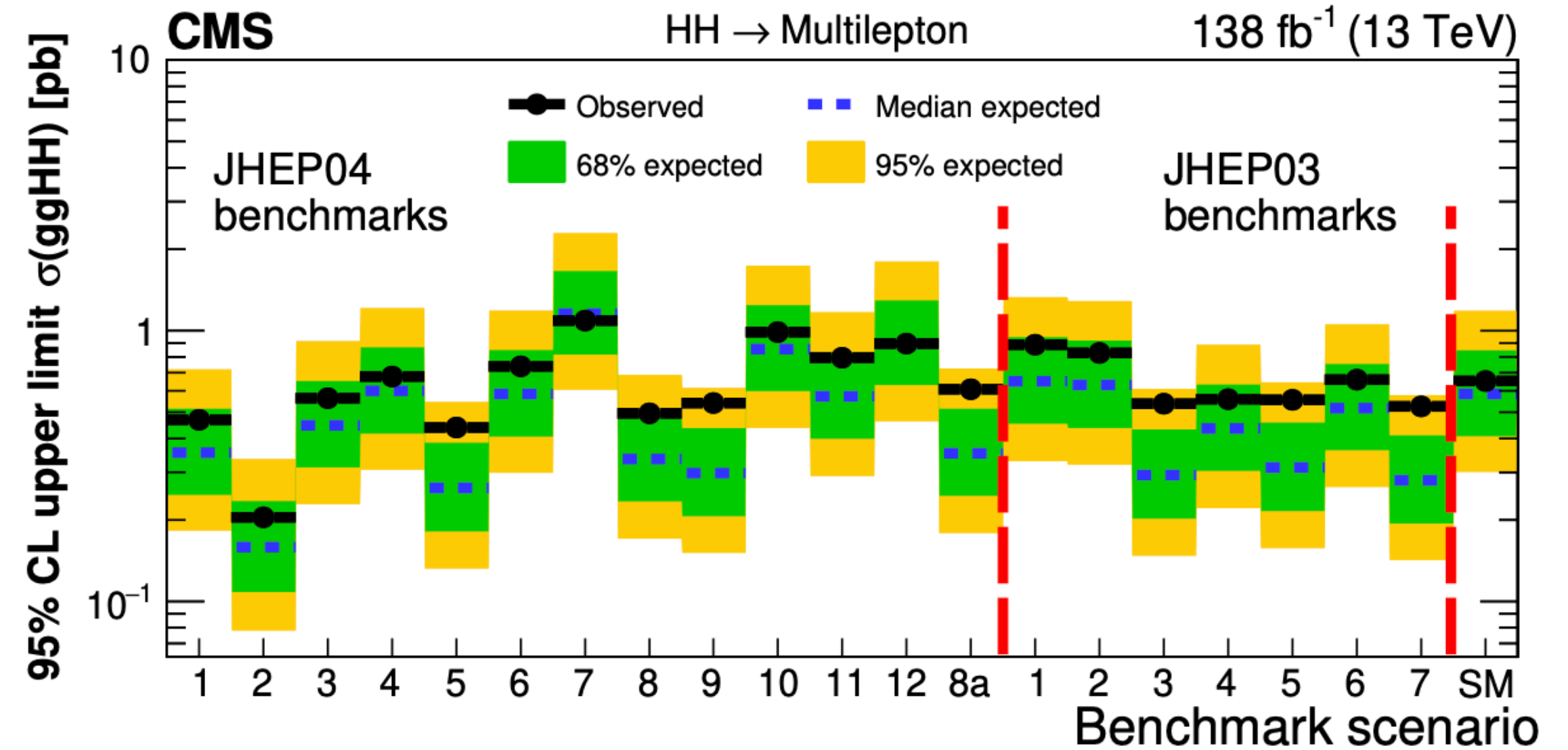
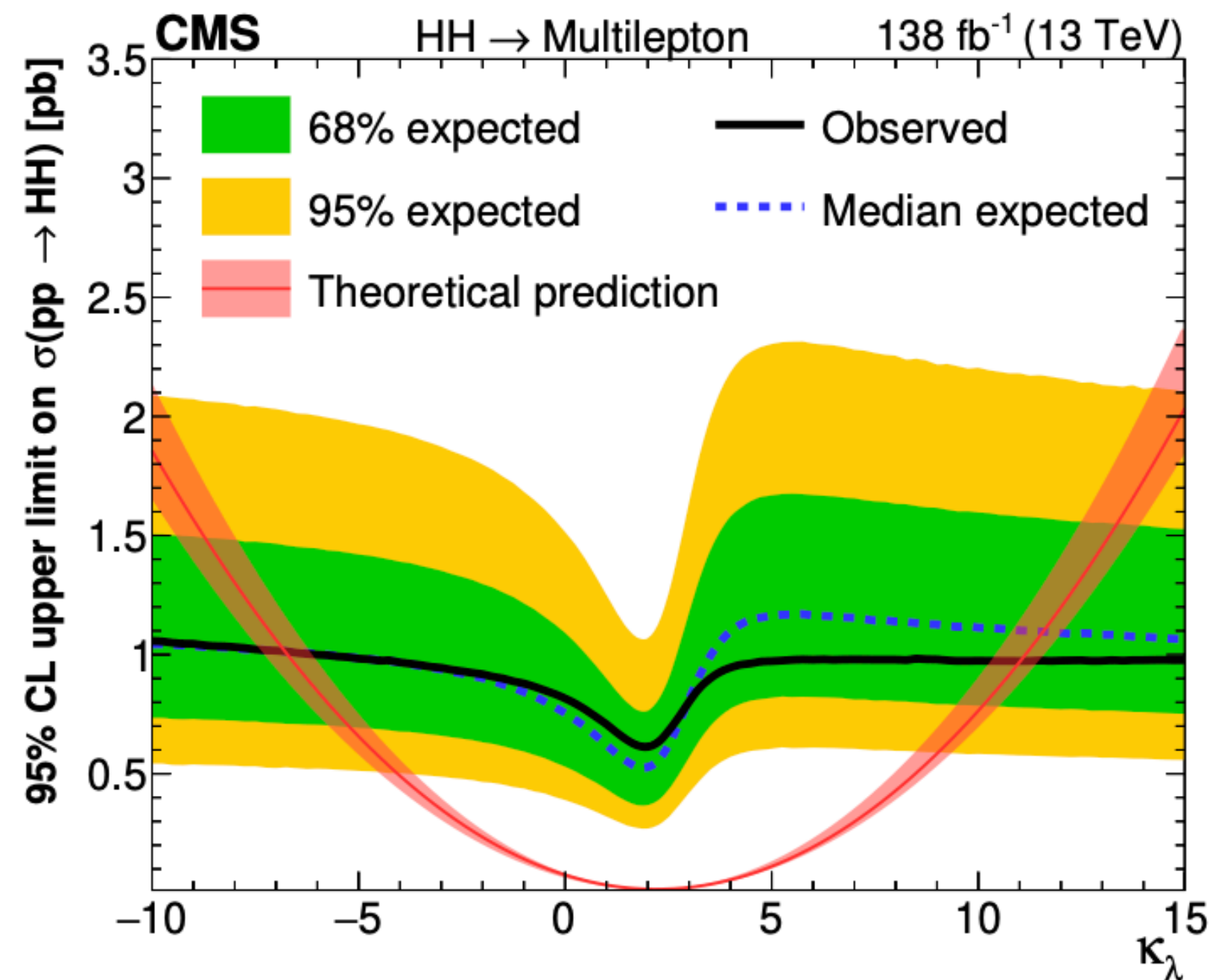
Upper limit on σ_{HH} : **Obs(Exp) σ/σ_{SM} < 97(53)**

Upper limit on σ_{HH} with benchmark points: **Obs(Exp): 1.7 to 6.2 (1.0 to 3.9) pb**

$HH \rightarrow WWWW, WW\tau\tau, \tau\tau\tau\tau$ (multi-lepton)



- [JHEP07\(2023\)095](#) - **2023** - GGF production only - low BR and low bkg
- 2-3-4 leptons (e, μ) along with τ_h , 7 channels in total
- Bkgs by **simulation**
 - except fake leptons, taus and misID from **data**
- **WZ** and **ZZ** bkgs constrained separately in two CRs
- simultaneous fit of **BDT** scores to extract signal



Results:

Constraint on the κ_λ : **Obs(Exp): -6.9 (-6.9) < κ_λ < 11.7 (11.7)**

Upper limit on σ_{HH} : **Obs(Exp) σ/σ_{SM} < 21(19)**

Upper limit on σ_{HH} with benchmark points: **Obs(Exp): 0.21 to 1.09 (0.16 to 1.16)**
pb

- [Phys. Lett. B 842 \(2023\) 137531](#) - GGF and VBF - rel. large BG & distinct τ signature

- $e\tau_h, \mu\tau_h, \tau_h\tau_h$ channels

- **a special elliptical cut** to increase S/B ratio

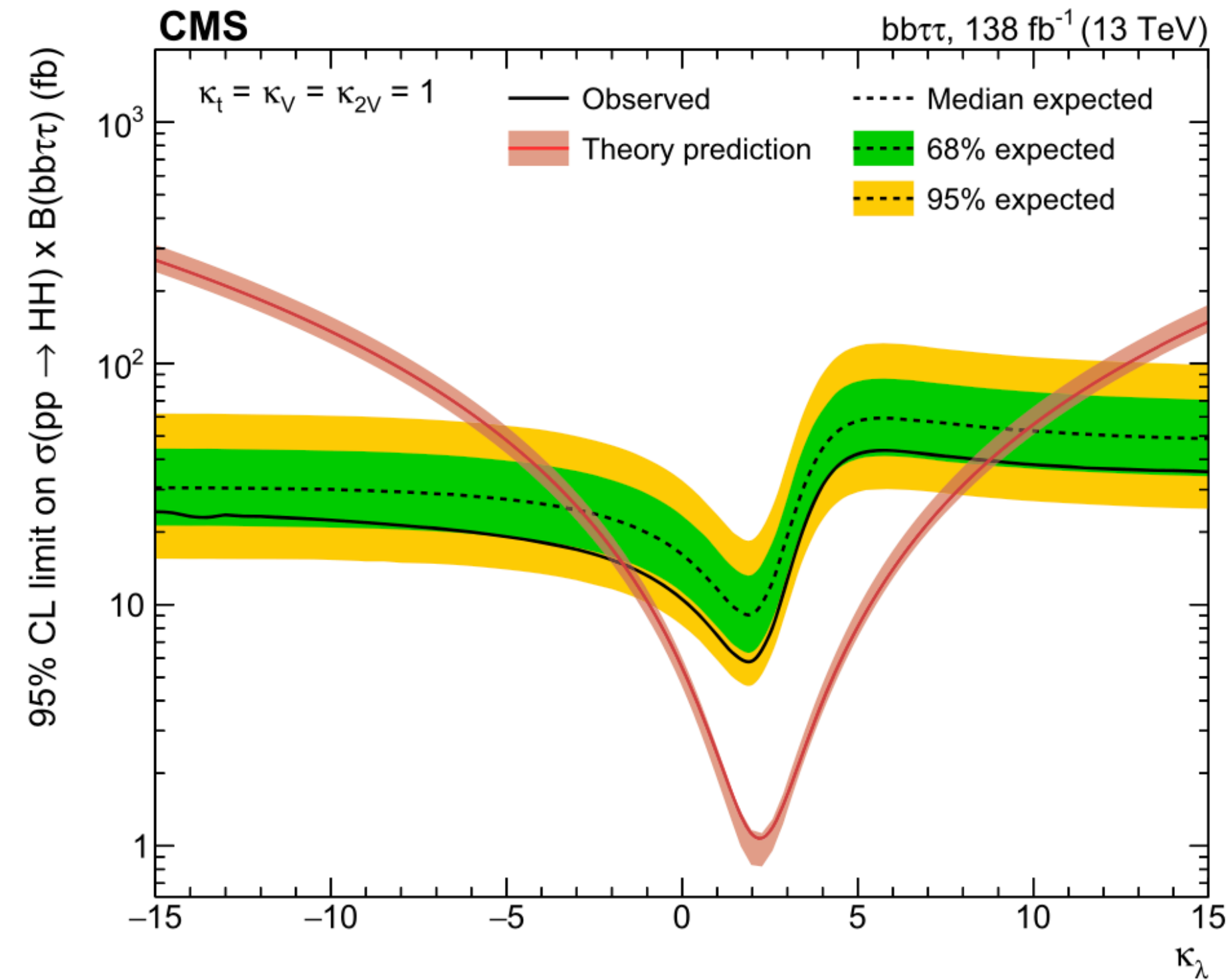
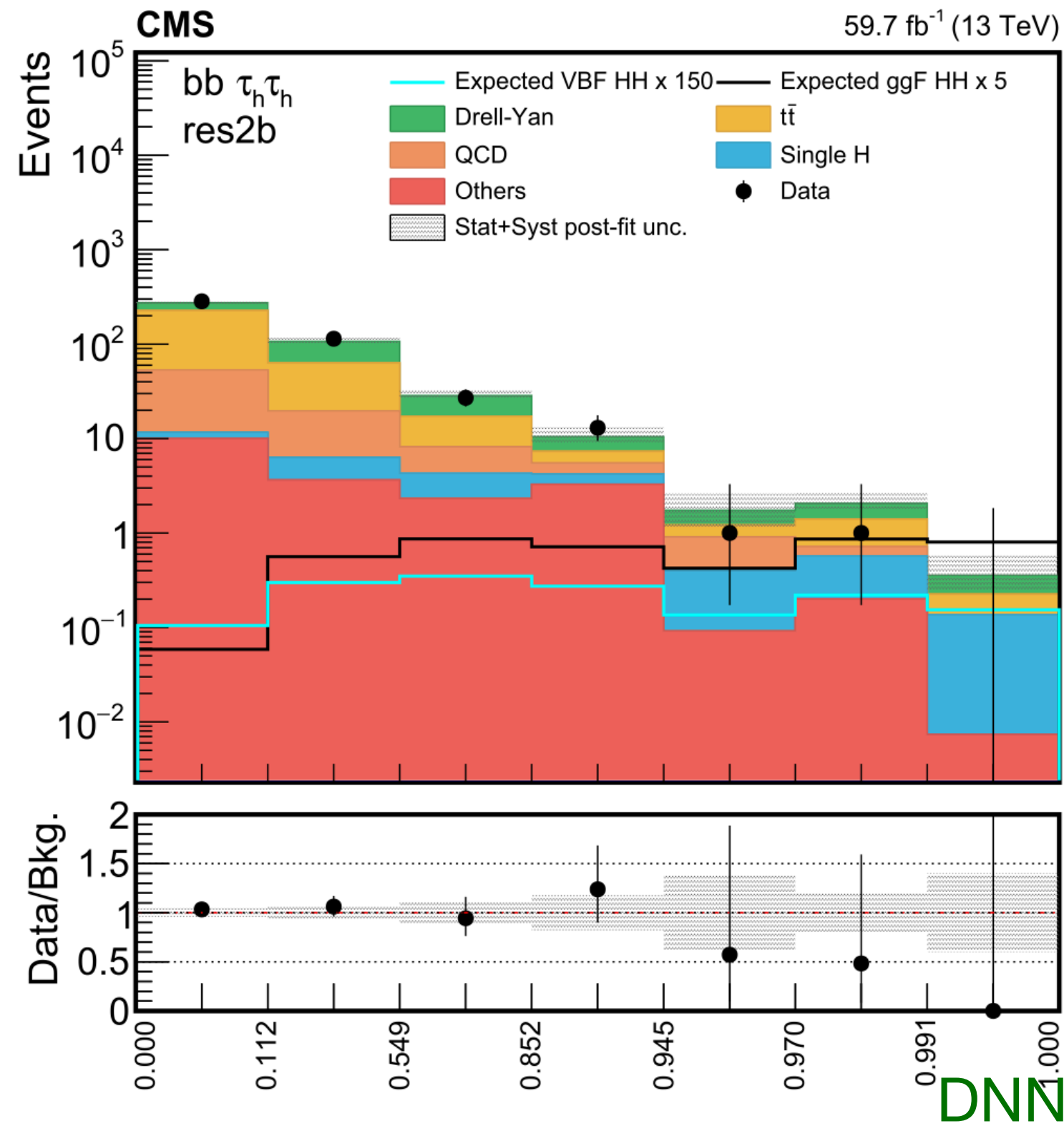
- **Bkgs estimated** from MC, except QCD multi-jet from data

- DNN to discriminate GGF, VBF and bkgs

- **DNN scores used to extract signal**

$$\frac{(m_{\tau\tau} - 128 \text{ GeV})^2}{(60 \text{ GeV})^2} + \frac{(m_{bb} - 159 \text{ GeV})^2}{(94 \text{ GeV})^2} < 1 \quad \rightarrow \text{for resolved}$$

(values by a random search which yields %90 signal eff.)



Results:

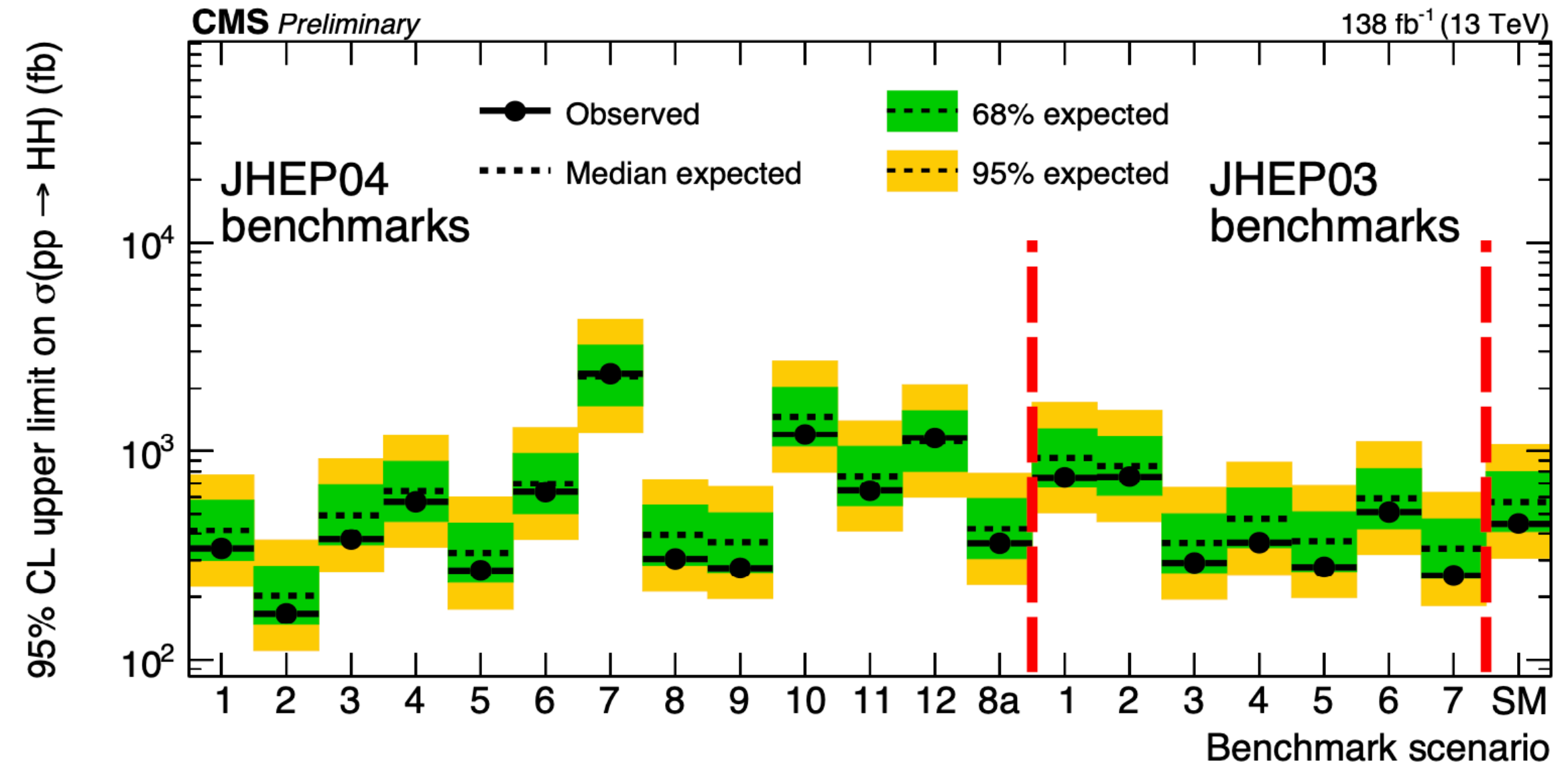
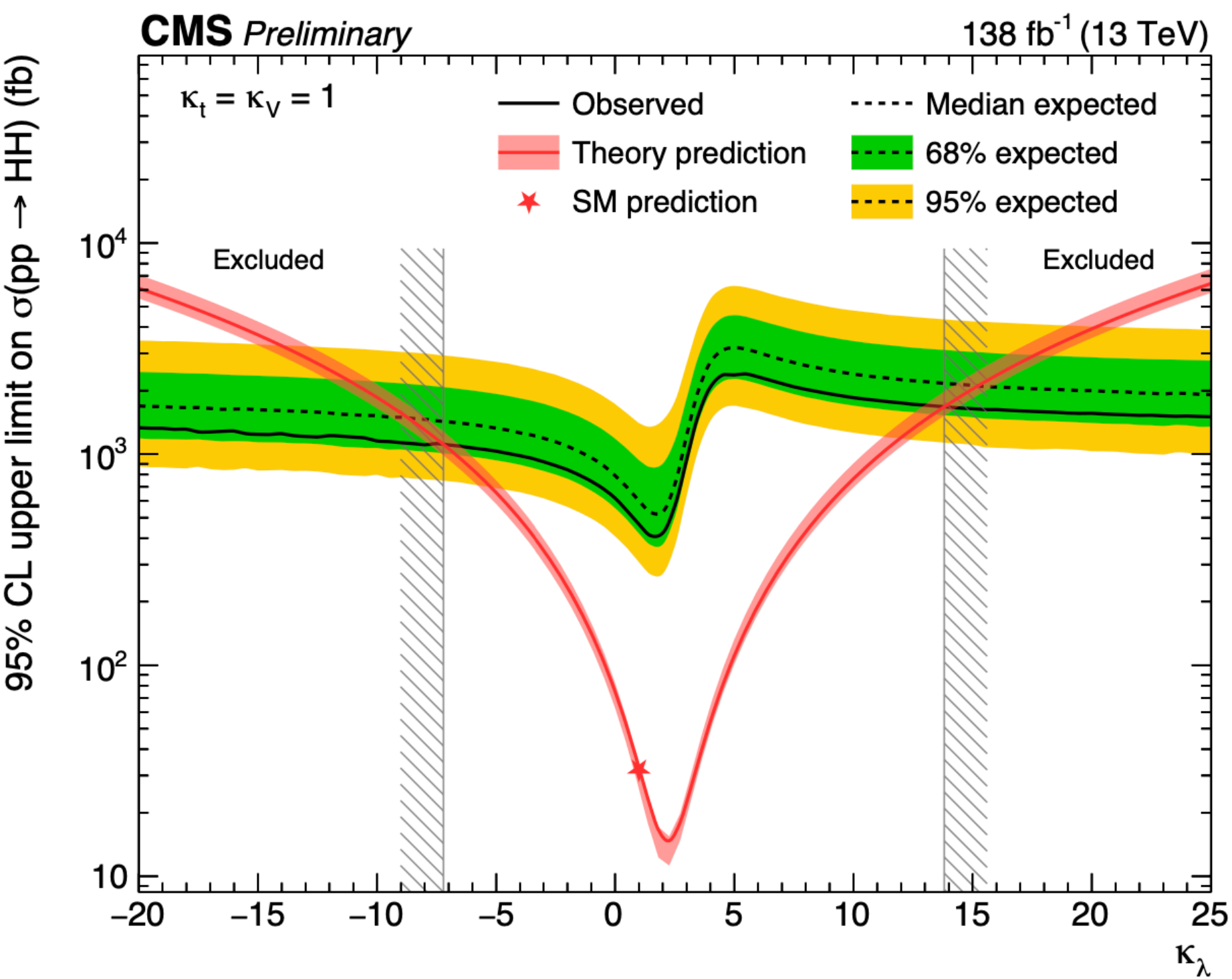
Constraint on the κ_λ

Obs(Exp): -1.7 (-2.9) < κ_λ < 8.7 (9.8)

Upper limit on σ_{HH}

Obs(Exp) $\sigma/\sigma_{SM} < 3.3(5.2)$

- [arXiv:2403.09430](https://arxiv.org/abs/2403.09430) - 2024, GGF and VBF, 2nd highest BR, higher bkg
- **DL** and **SL** channels from **W** decays
- **DNN multi-classification** for signal and bkg
- **DNN scores** used to extract signal



Results:

Constraint on the κ_λ

$$\text{Obs(Exp): } -7.2 \text{ (-8.7)} < \kappa_\lambda < 13.8 \text{ (15.2)}$$

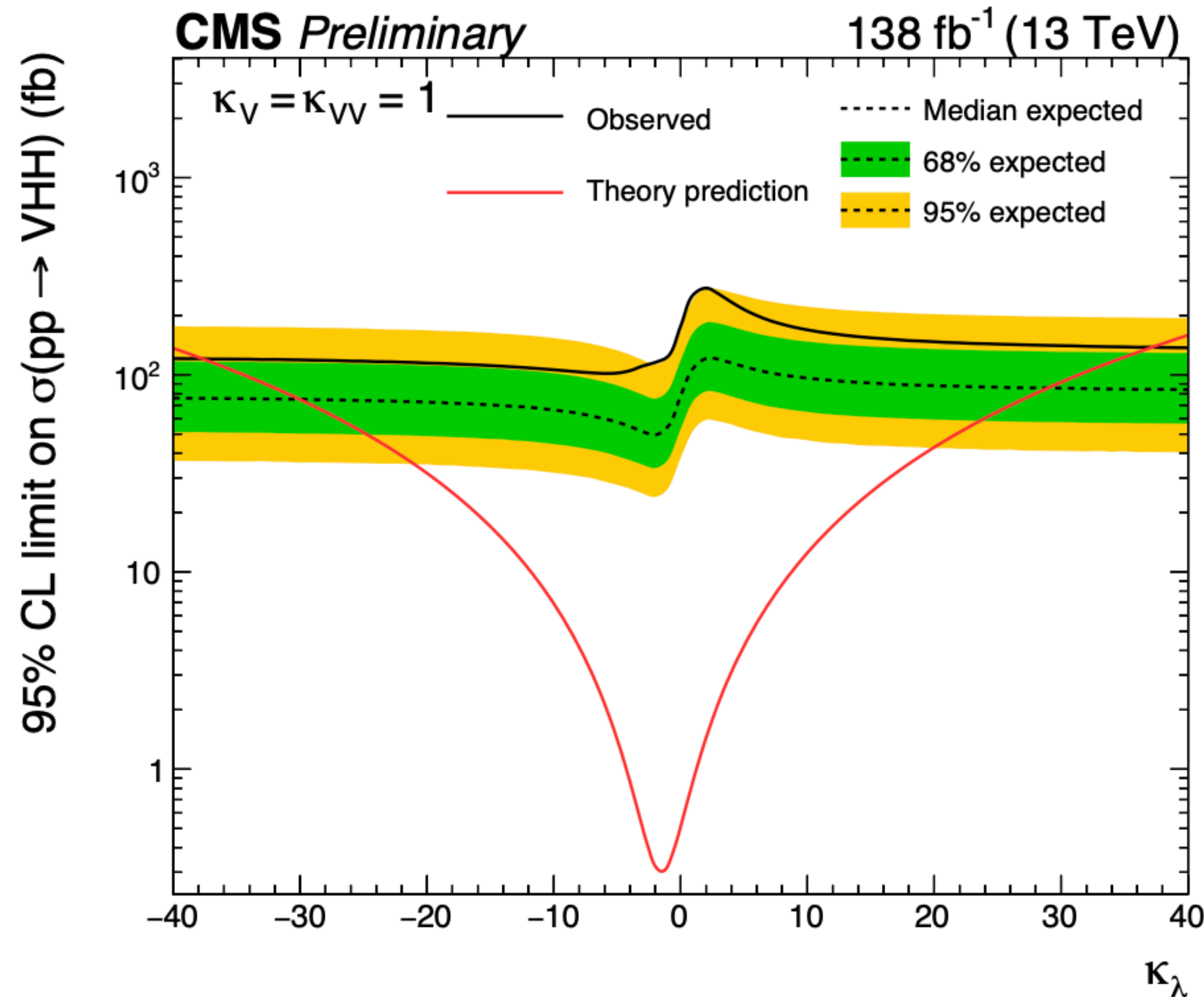
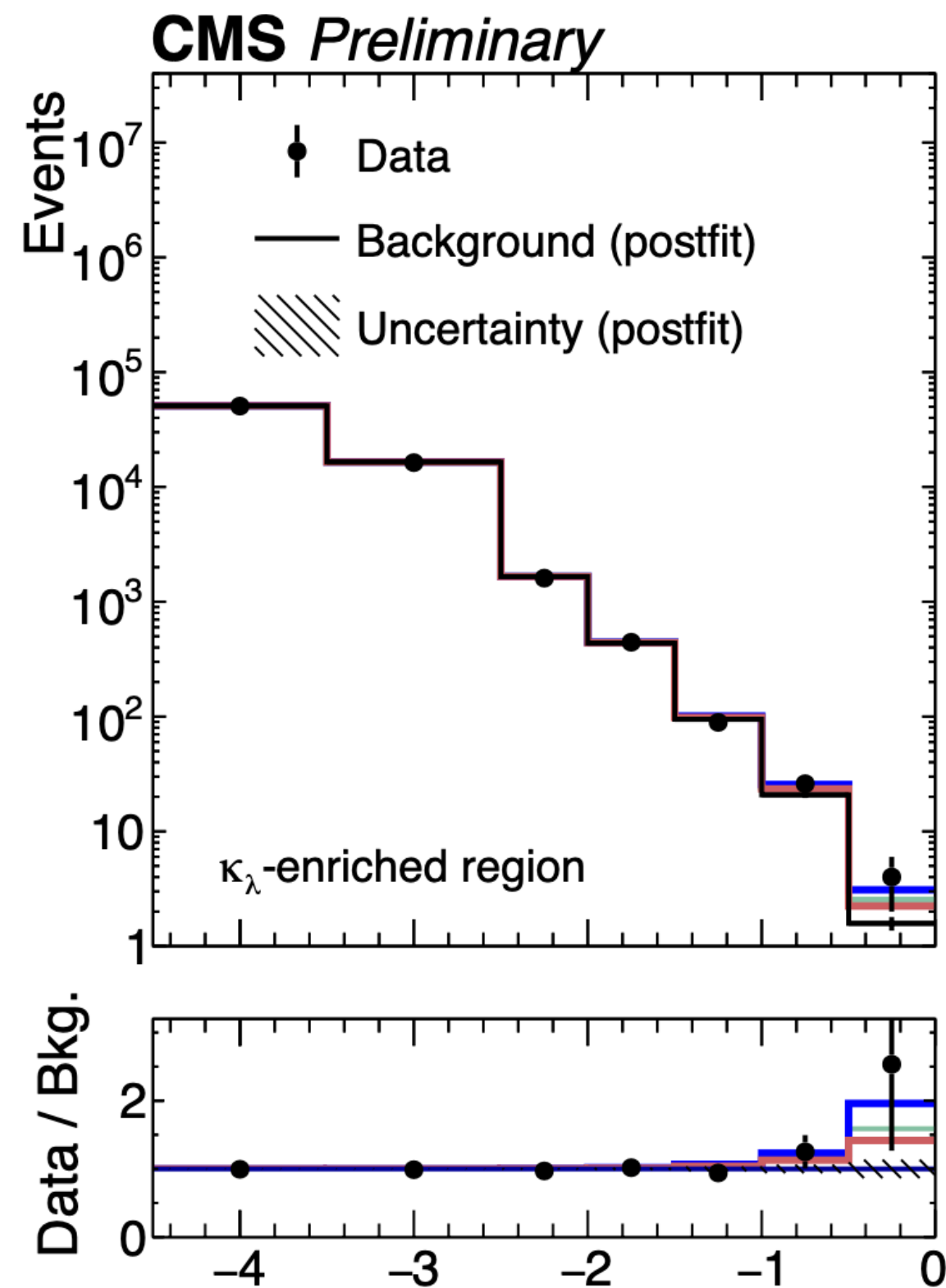
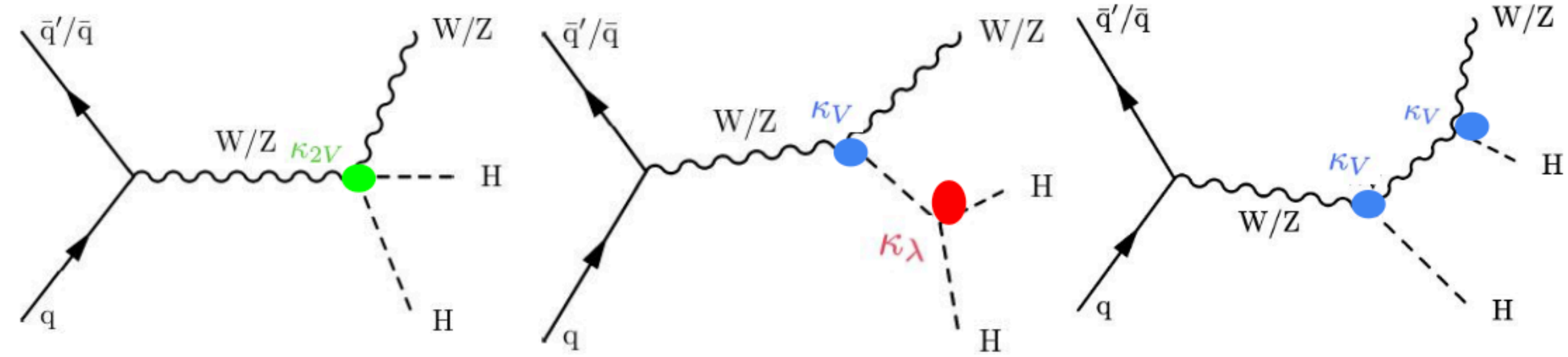
Upper limit on σ_{HH}

$$\text{Obs(Exp) } \sigma / \sigma_{SM} < 14 \text{ (18)}$$

Upper limit on σ_{HH} with benchmark points:

$$\text{Obs(Exp): } 0.16 \text{ to } 2.3 \text{ (0.2 to 2.2) pb}$$

- [CMS HIG-22-006 - 2023](#) - VHH production (no destructive contribution from diagrams) (0.86 fb)
- small BR, large bkg
- SL, DL, FH and MET($Z \rightarrow \nu\nu$) channels
- **BDT** to separate κ_λ and κ_{VV} regions, and **sub-BDTs** to discriminate S vs bkg
- BDT scores in CRs, and SRs use to extract signal



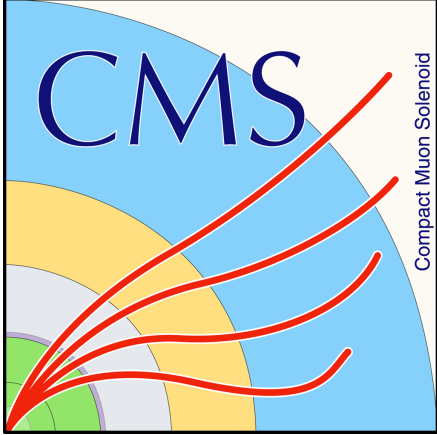
Results:

Constraint on the κ_λ

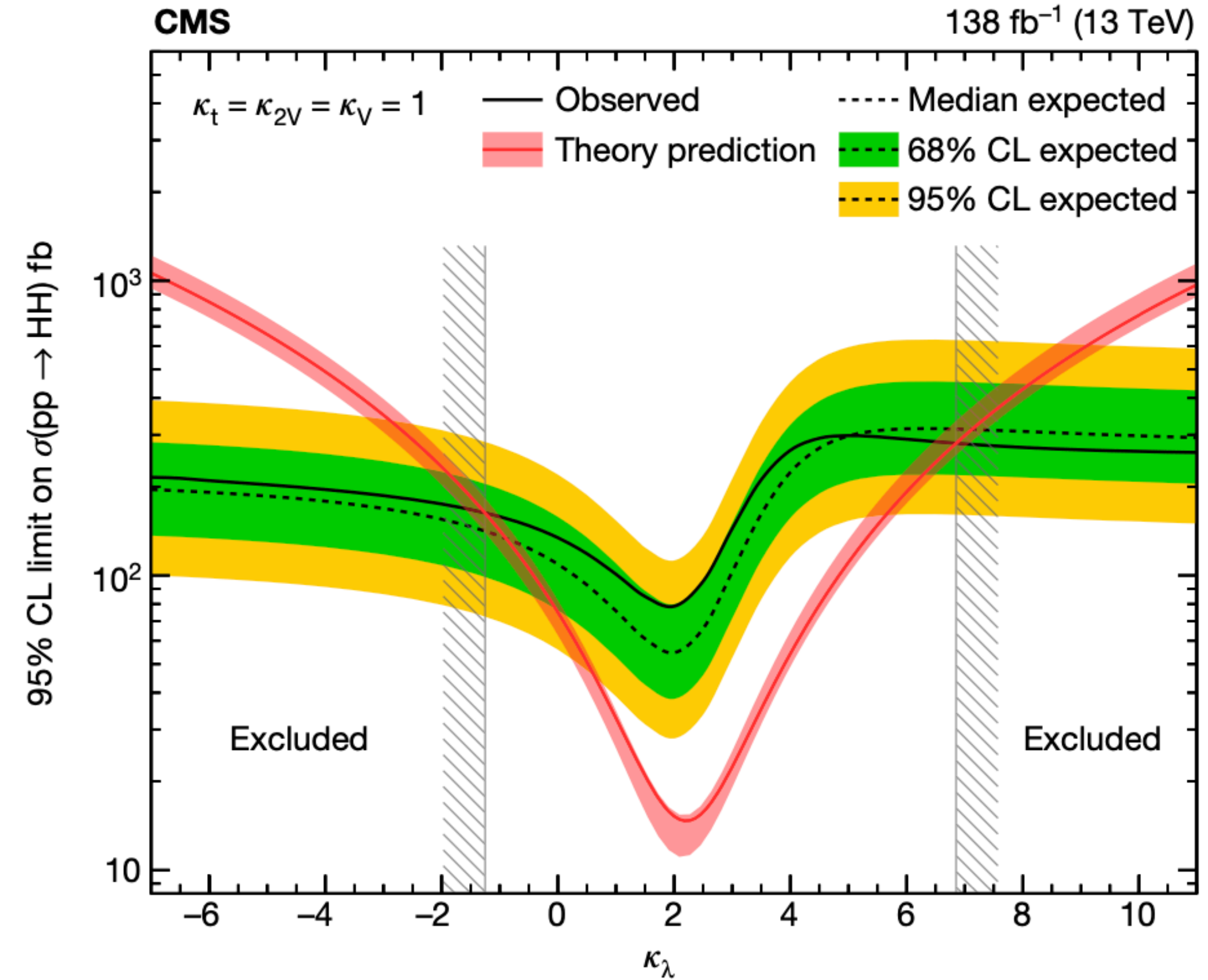
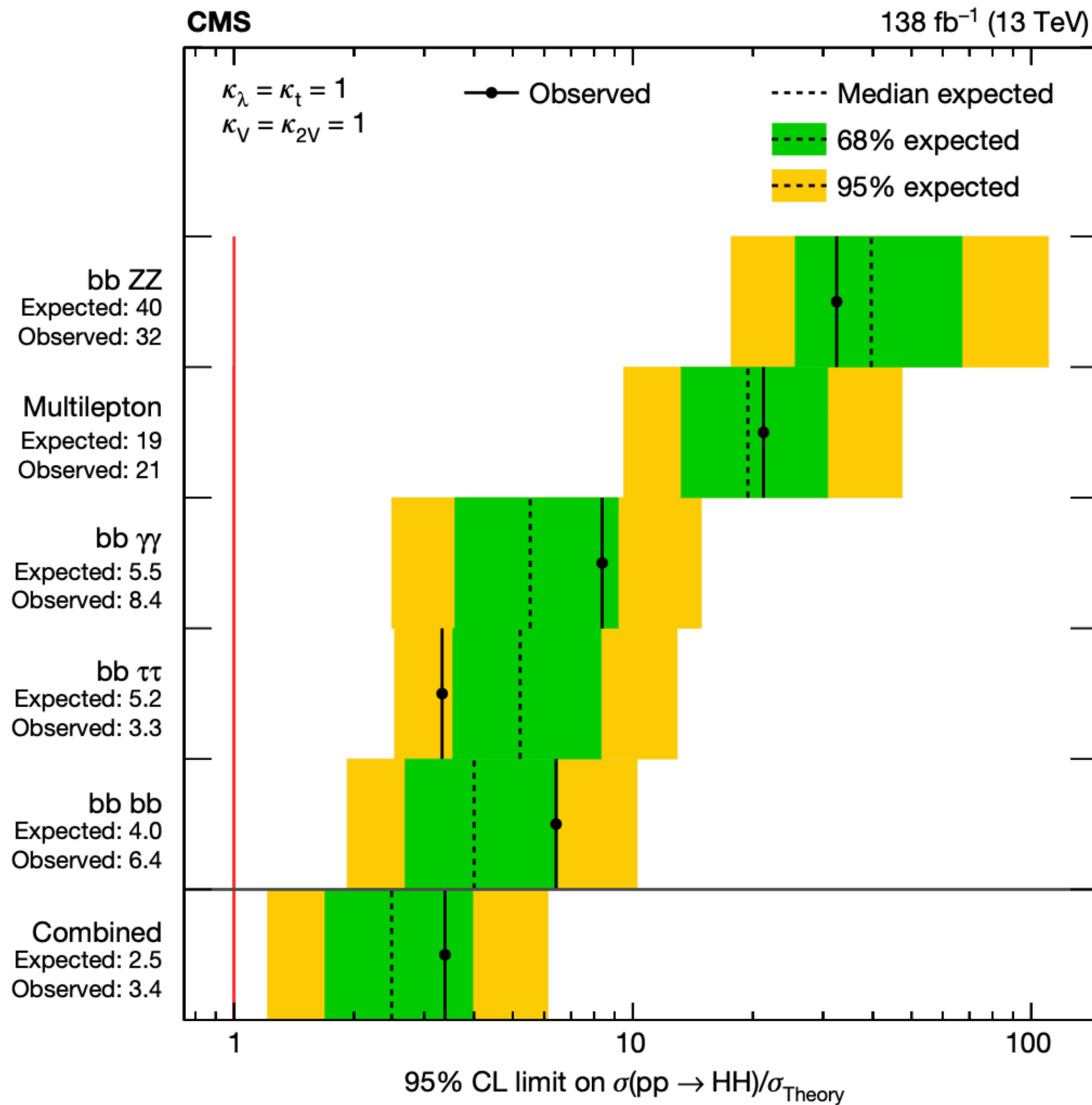
Obs(Exp): -37.7 (-30.1) $< \kappa_\lambda < 37.2$ (28.9)

Upper limit on σ_{HH}

Obs(Exp) $\sigma/\sigma_{SM} < 294$ (124)



- [Nature 607 \(2022\) 60-68](#) - full Run2
- 5 channels considered



Results:

Constraint on the κ_λ : $-1.24 < \kappa_\lambda < 6.49$

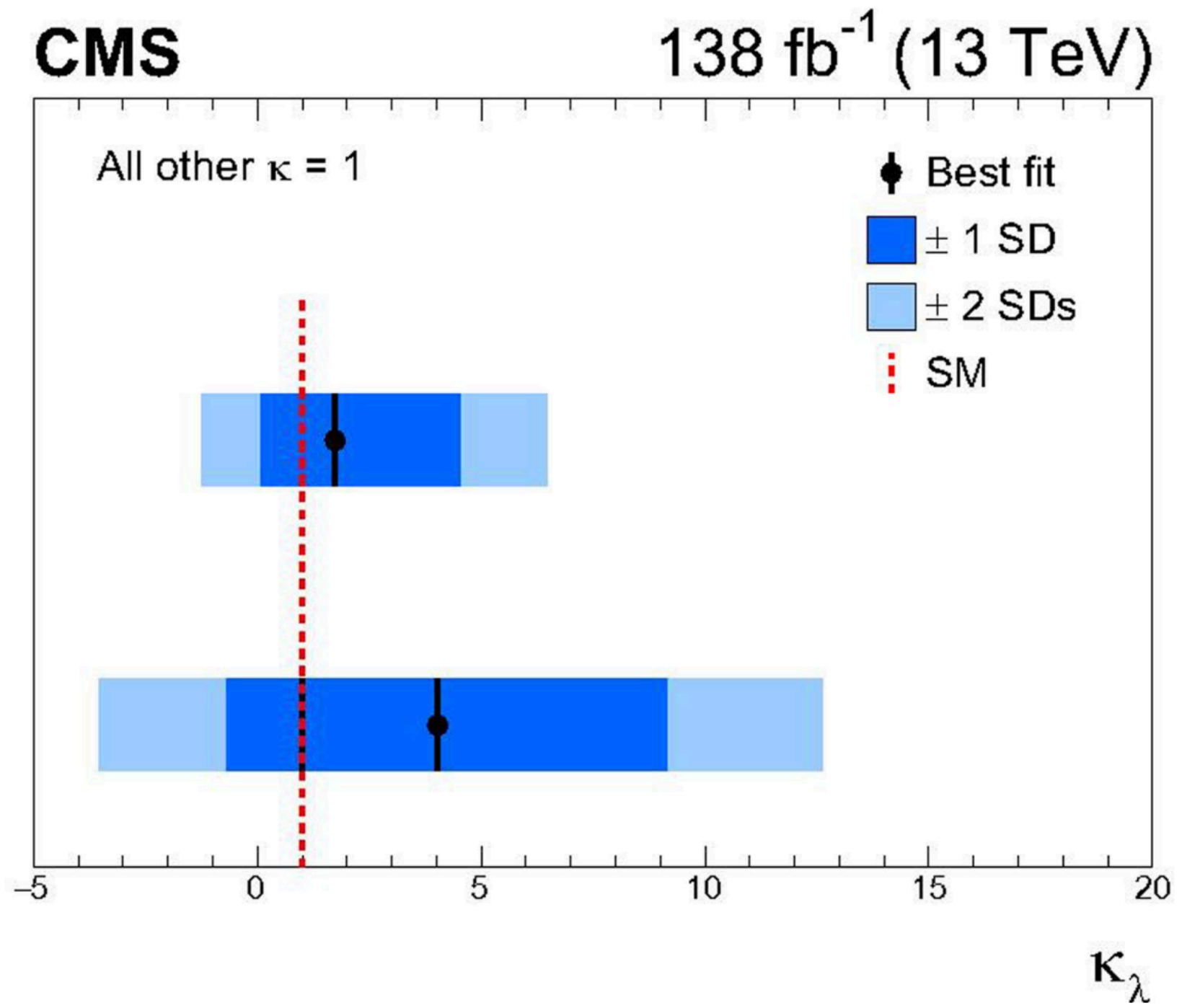
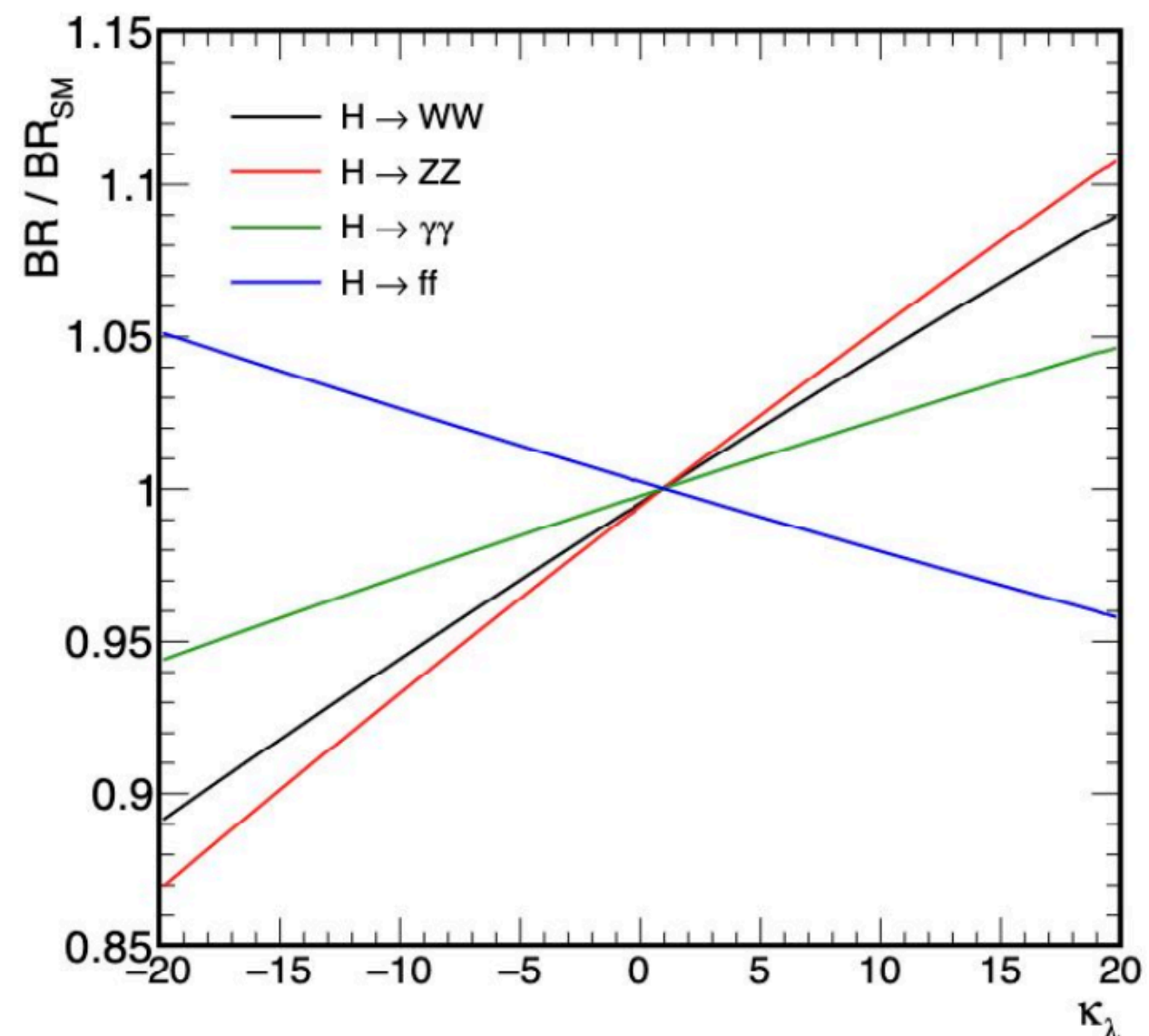
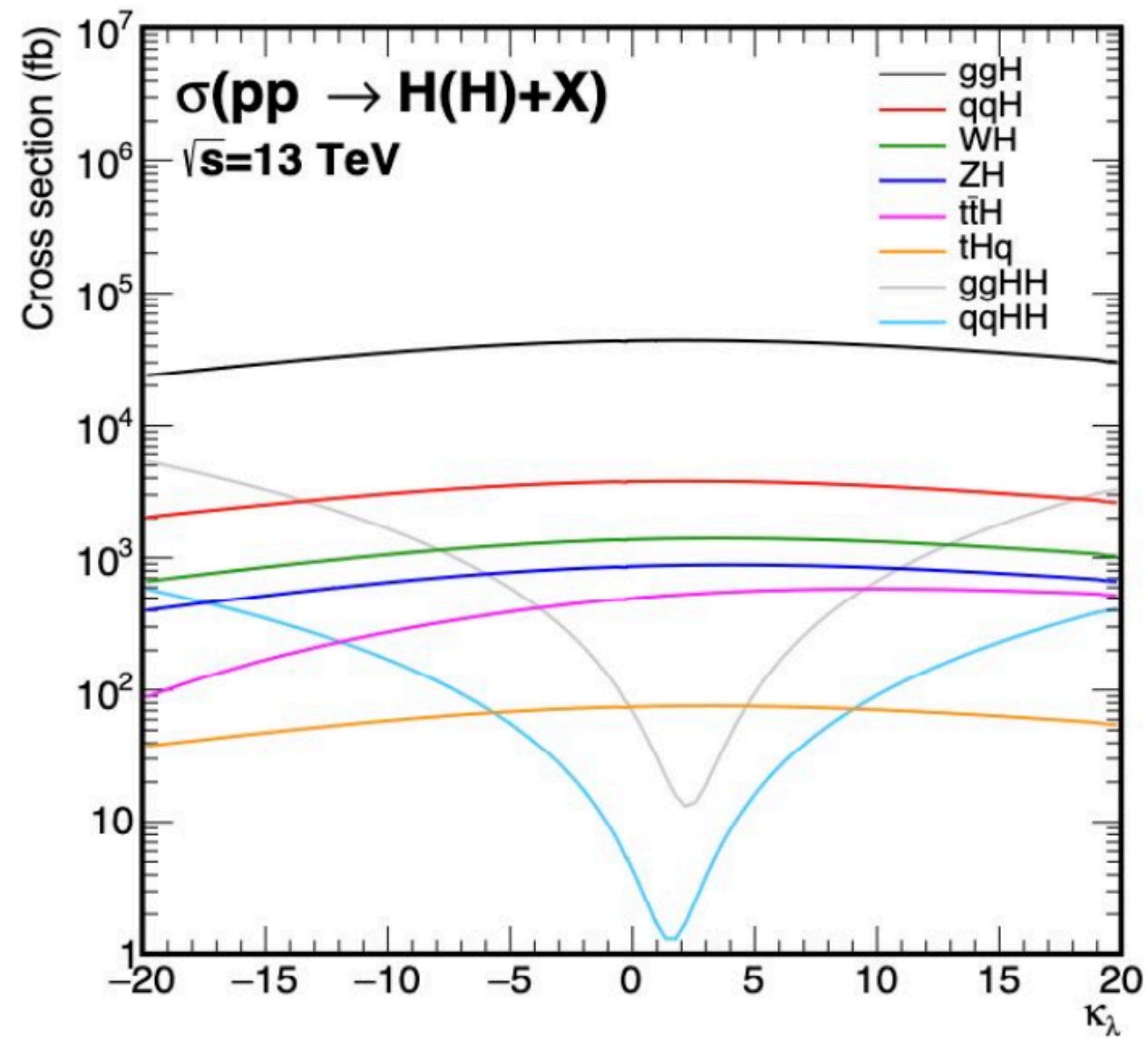
Upper limit on σ_{HH} : $\sigma/\sigma_{SM} < 3.4$

- [LHCHWG-2022-002](#)

- [Nature 607 \(2022\) 60-68](#)

- analyses considered are;

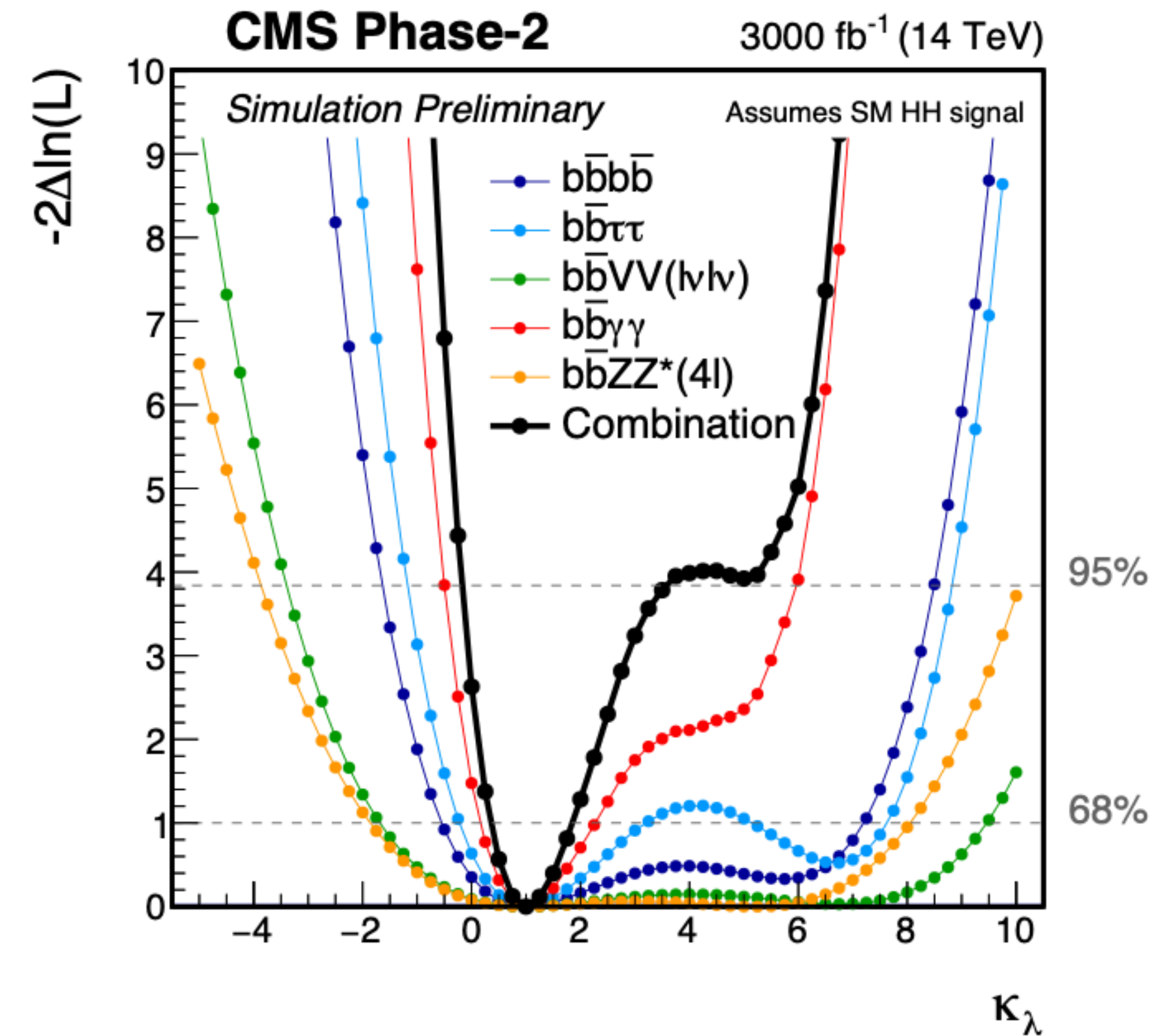
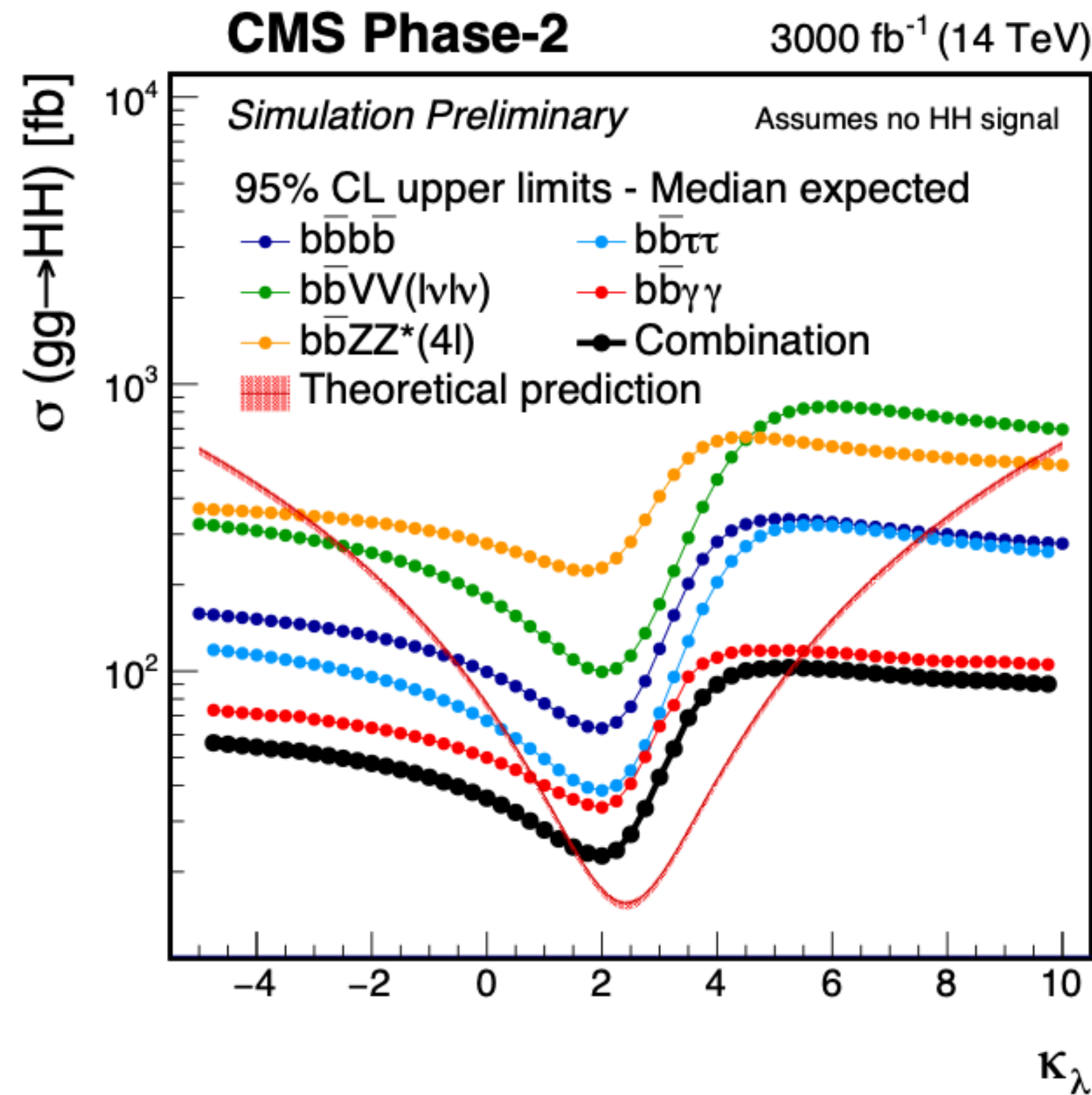
- $H \rightarrow \gamma\gamma$
- $H \rightarrow ZZ(4l)$
- $H \rightarrow WW$
- $H \rightarrow bb$
- $H \rightarrow \tau\tau$
- $ttH \rightarrow multilepton$
- $H \rightarrow \mu\mu$
- $H \rightarrow invisible$



Results:

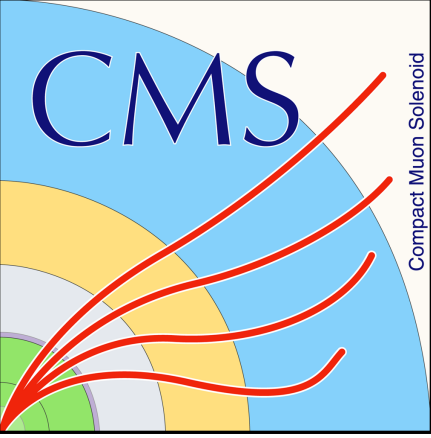
Constraint on the κ_λ : $-3.55 < \kappa_\lambda < 12.61$

- [CERN Yellow Report from 2018](#)
- 3000 fb^{-1} and 14 TeV
- 5 channels considered



Results:

Constraint on the κ_λ : $-0.8 < \kappa_\lambda < 3.6$ at 95% CL



Results on Higgs self-coupling from CMS
EFT interpretations are discussed
CMS is improving its measurements

Partial combination with full Run2 data measures 3.4 times the SM value for cross section
Works are ongoing for a combination including other channels

Stay tuned !