CMS Higgs results

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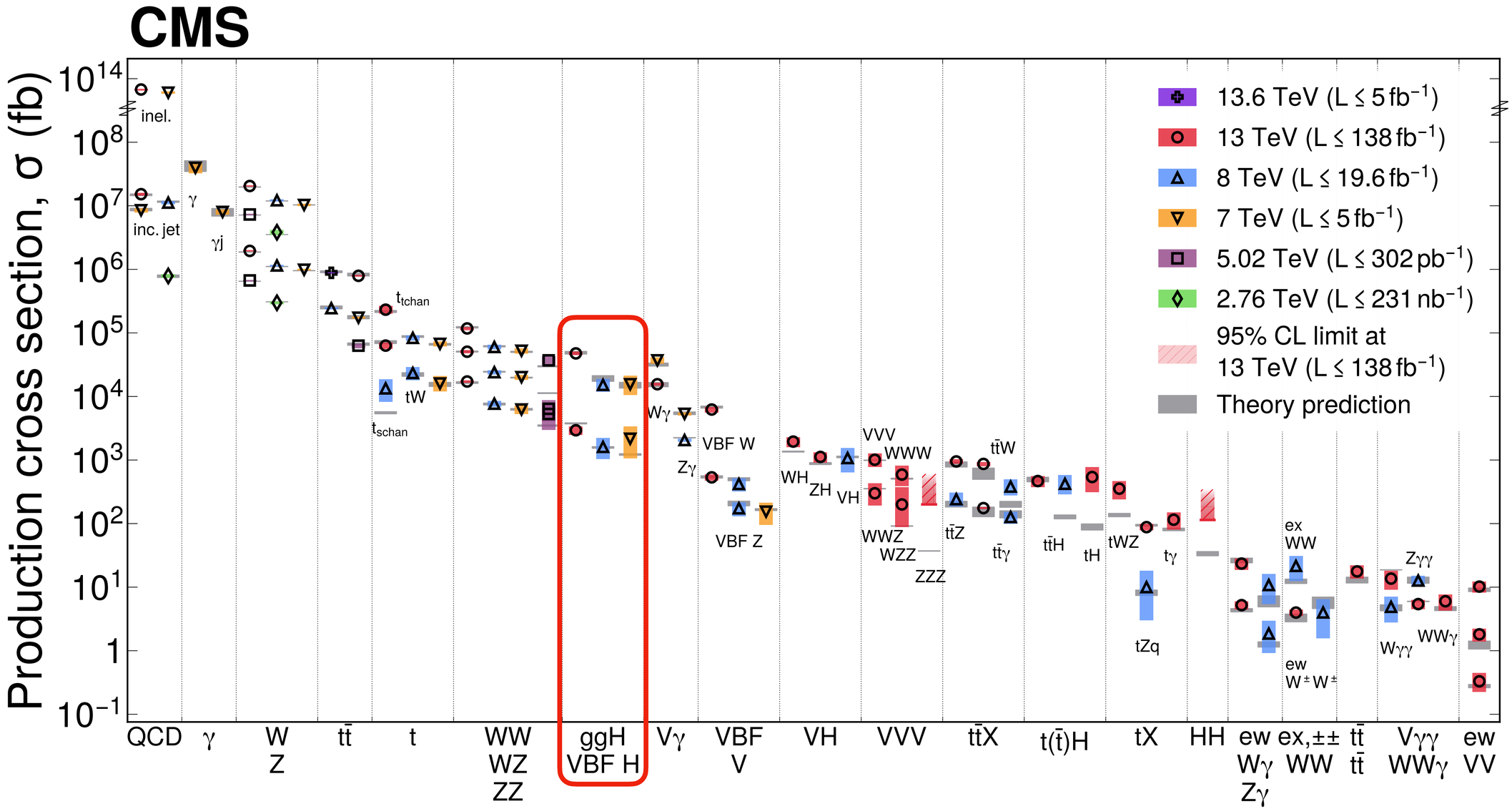
LHC physics

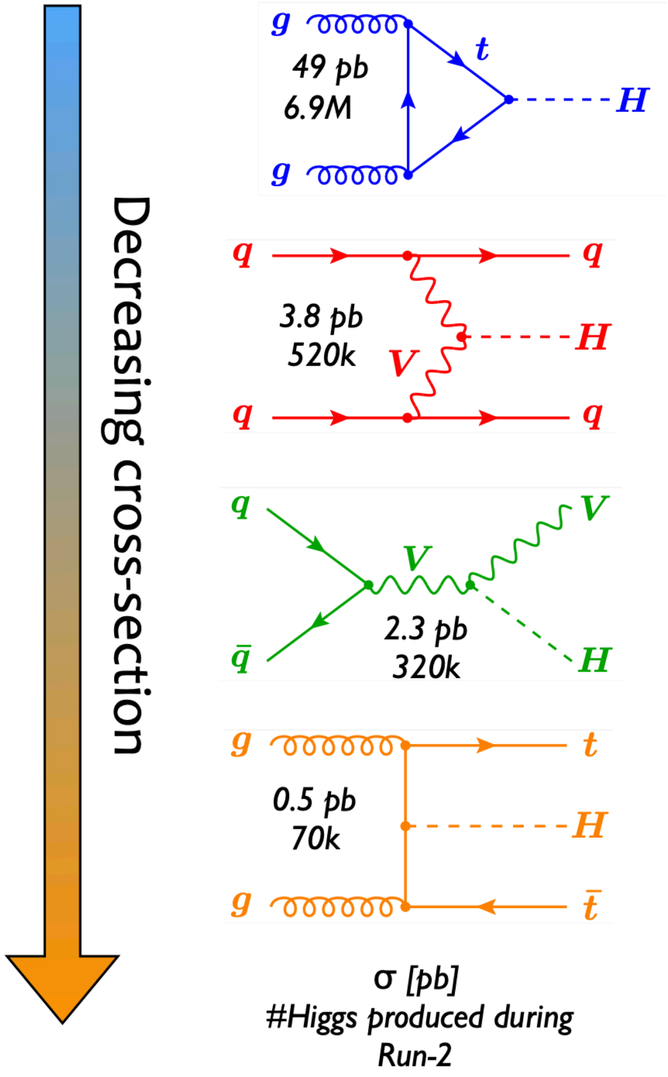
Physics Report 1115 (2025) 3

CMS has broad physics programs



Higgs at the LHC

Taken from E. Di Marco



gluon fusion
ggH: 86%

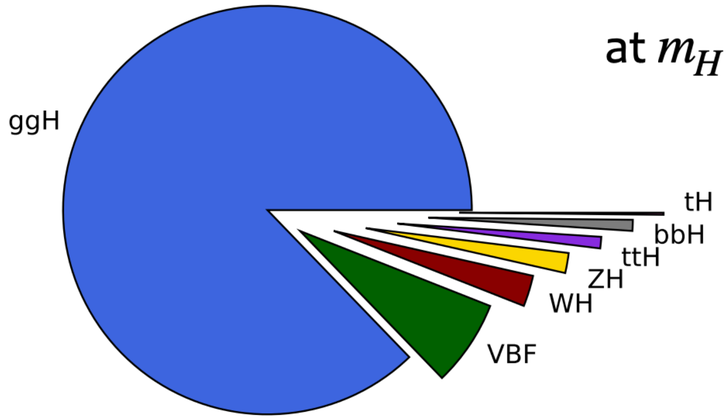
vector boson fusion (**VBF**): **6.5%**

W,Z associated production
WH/ZH: 4%

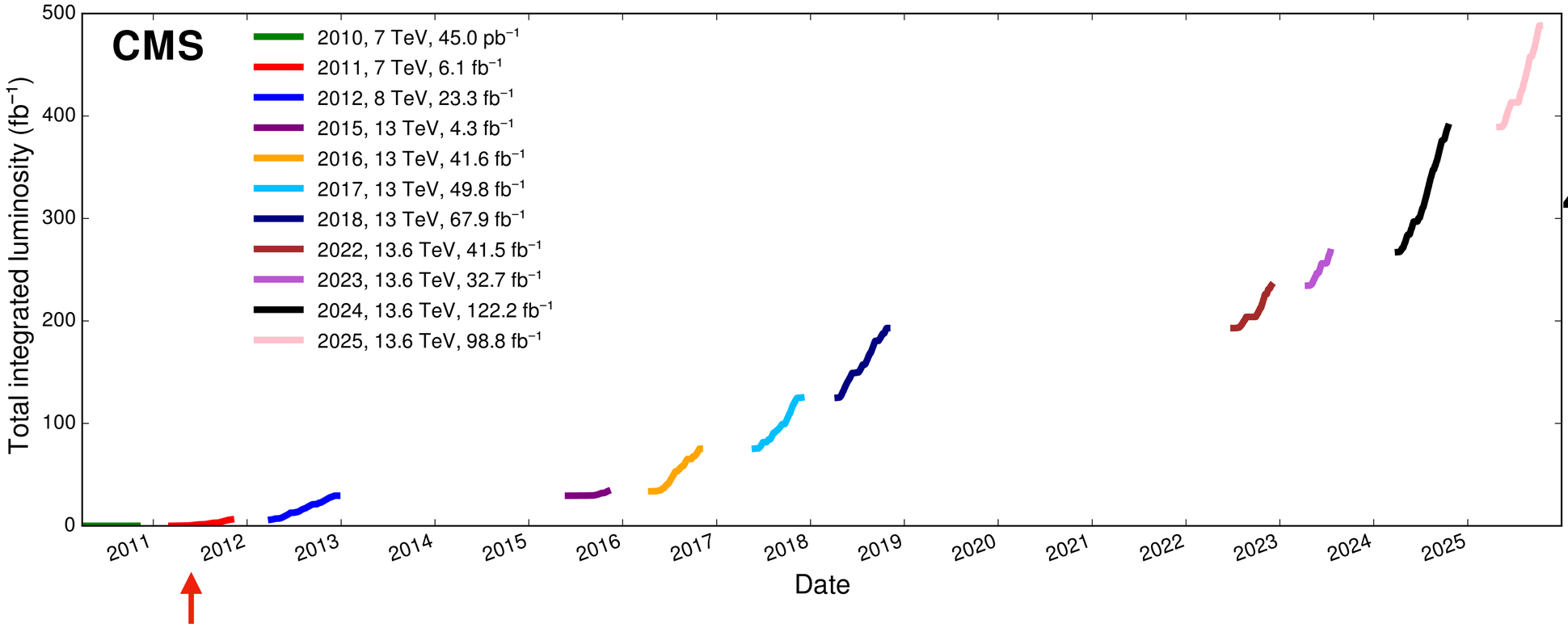
$t\bar{t}H$ associated production: **1%**

- **LHC is a Higgs factory**
- About **8 million Higgs bosons** produced by LHC during Run-2 **per experiment**
- Since $m_H \sim 125$ GeV, a wide range of production and decay modes accessible

Higgs production cross sections at $m_H \sim 125$ GeV



LHC and Higgs

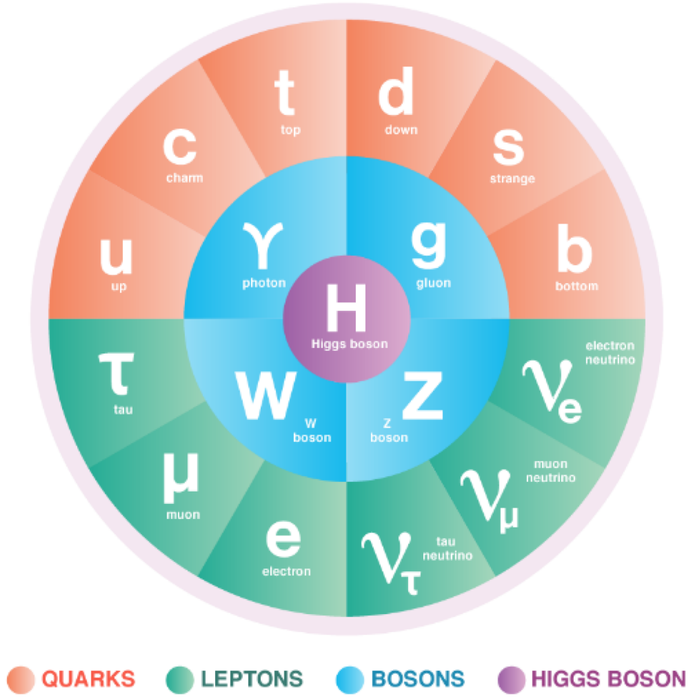


Today
407 fb^{-1} data

Higgs discovery
20 fb^{-1} data

Extensive studies of the Higgs boson

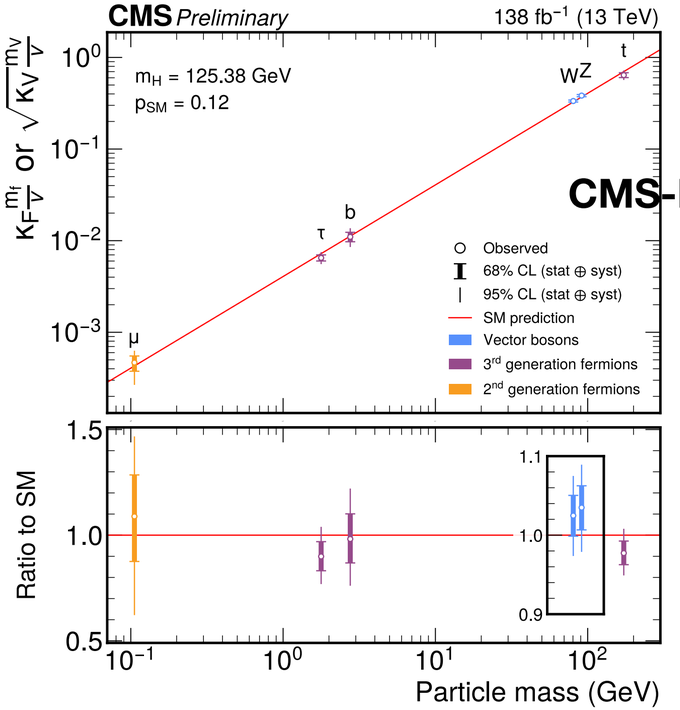
Overview of Higgs coupling to SM particles



II fermion	III fermion	Boson
c (κ < 3.0)	t (5%)	Z/W (5%)
s	b (12%)	g
μ (3σ)	τ (8%)	γ
		H (μ<3.5)

Observed (direct/loop)
Measured but not observed
Not measured

- Yukawa couplings
  - 3rd generation confirmed
  - 2nd generation on the way: evidence of Hμμ with Run2 data
- Couplings to bosons measured with high precision
  - Self-coupling is the next big thing

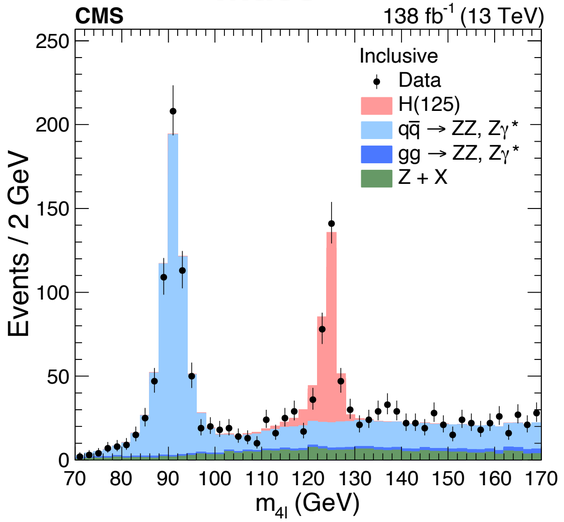


CMS-PAS-HIG-21-018

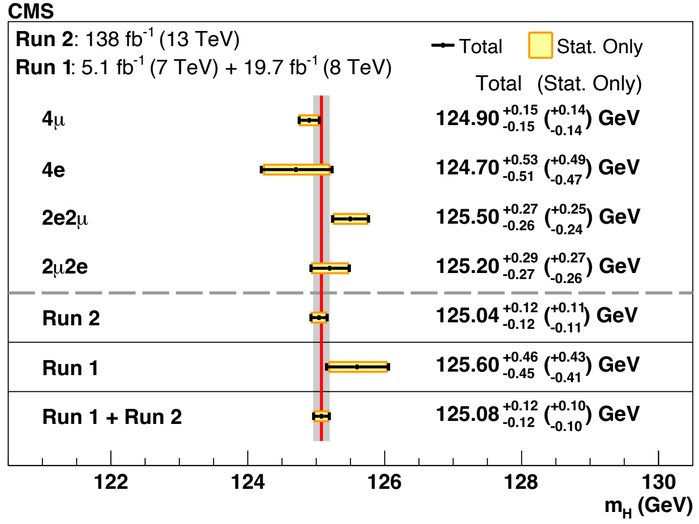
Overview of Higgs properties

- Spin/parity: 0^+ established
- Mass: 125.04 ± 0.12 GeV from 4l
- Width: on-shell in 4l/γγ, off-shell in ZZ/WW, $3.0^{+2.0}_{-1.5}$ MeV, exclude 0 width
- CP/Anomalous couplings/EFT: in all the main channels, no significant deviation from SM

Mass



Mass



Width

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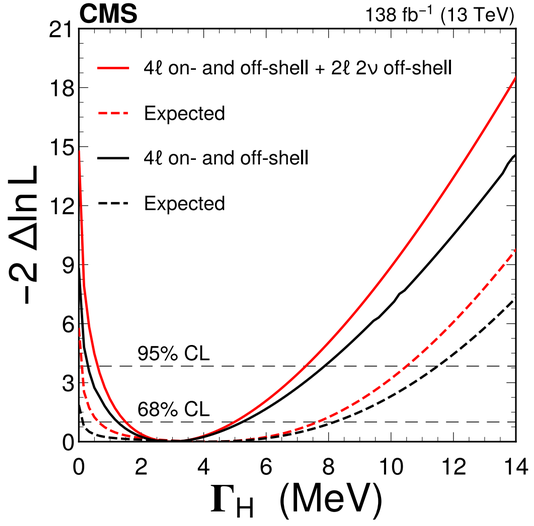
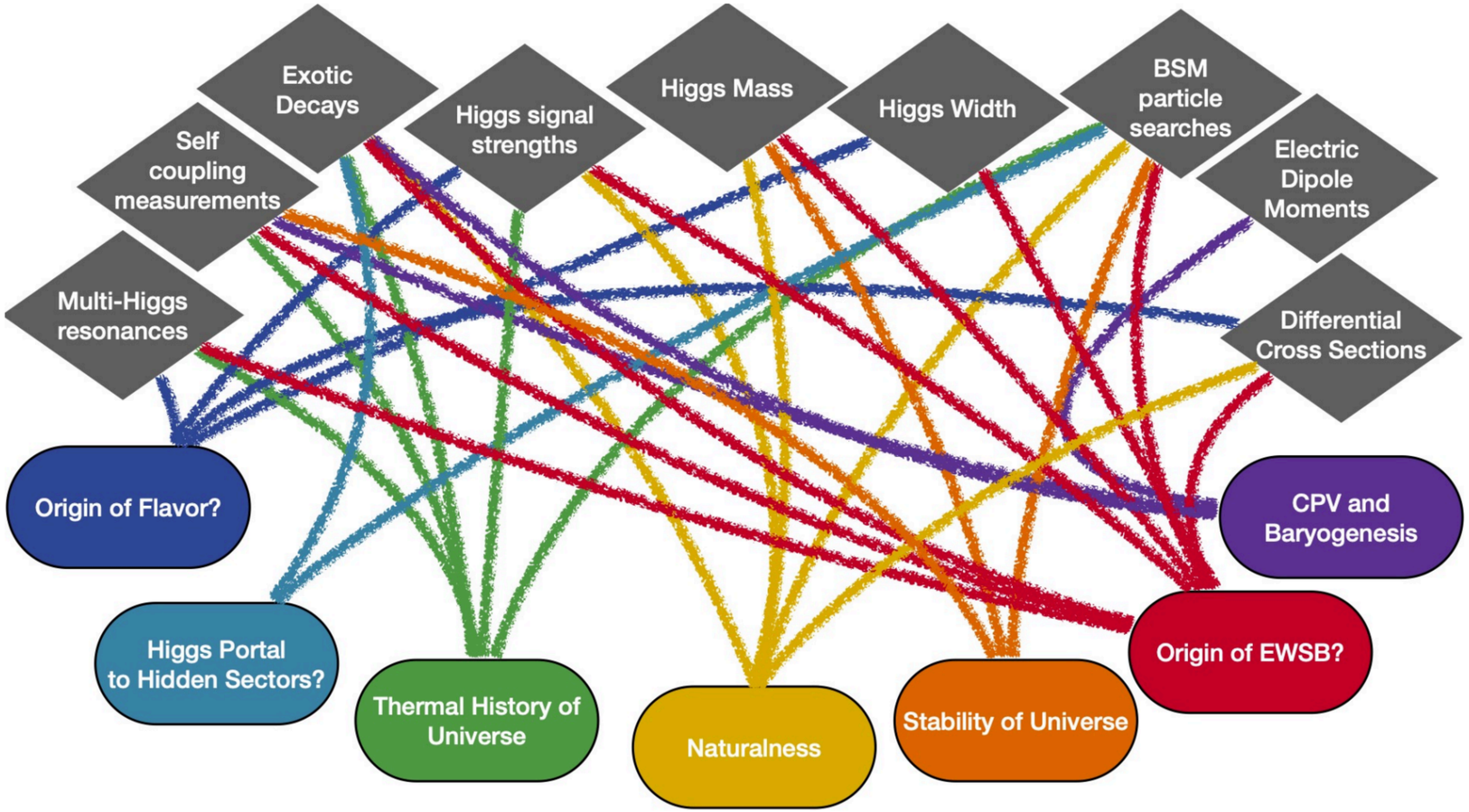


Motivation of Higgs precision measurements

arXiv:2209.07510
Snowmass report



Topics of the talk

- Pick a few recent CMS highlights
  - Combination of H couplings
  - Combination of Run2 HH searches
  - Run2 HHH->6b search and Run3 HH → bbγγ search
  - H→ cc searches
  - Higgs width measurement in H→ γγ

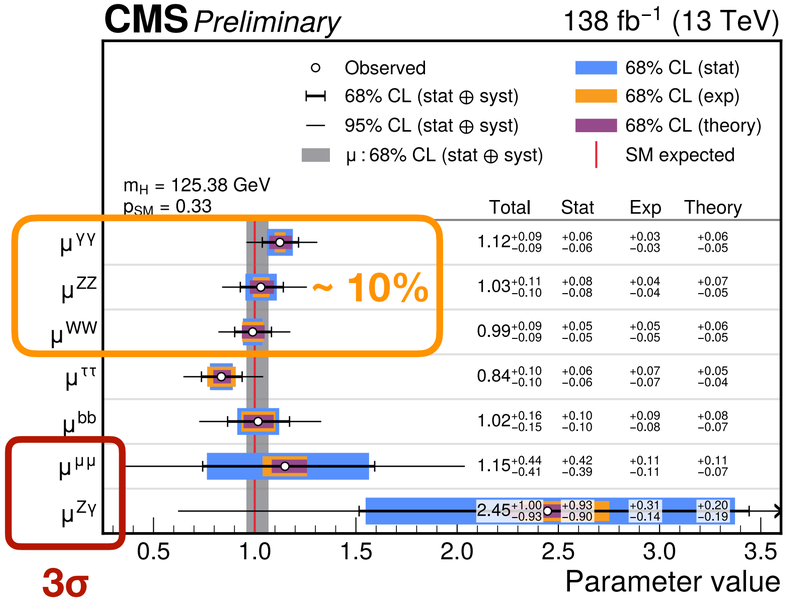
H coupling combination

A grand combination of 16 CMS published results

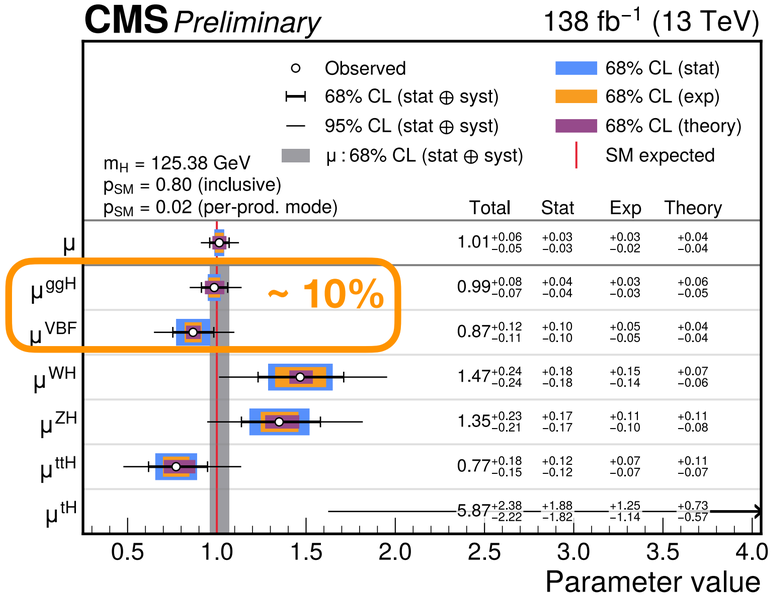
$$\mu = 1.014^{+0.055}_{-0.053} = 1.014 \pm 0.028(\textbf{stat.})^{+0.025}_{-0.024}(\textbf{exp.})^{+0.040}_{-0.039}(\textbf{theo.})$$

Theoretical uncertainty has become dominant

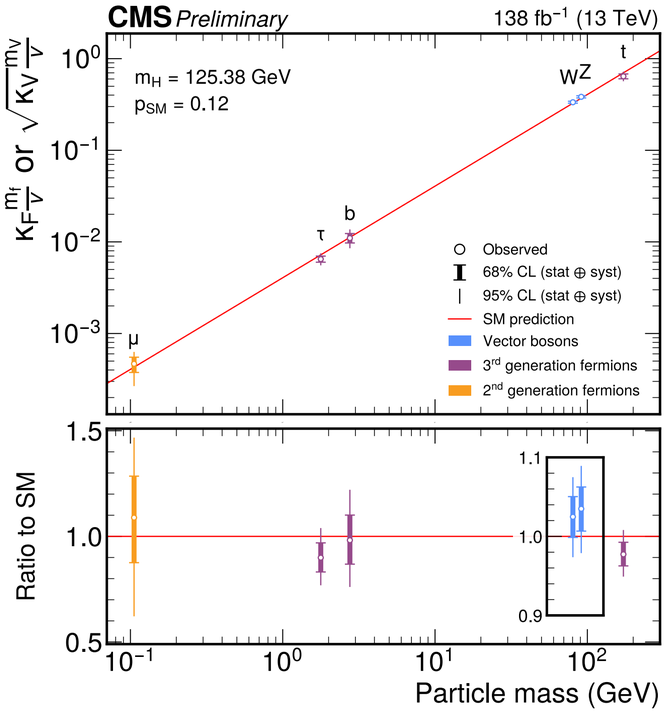
7 decay modes



6 production modes

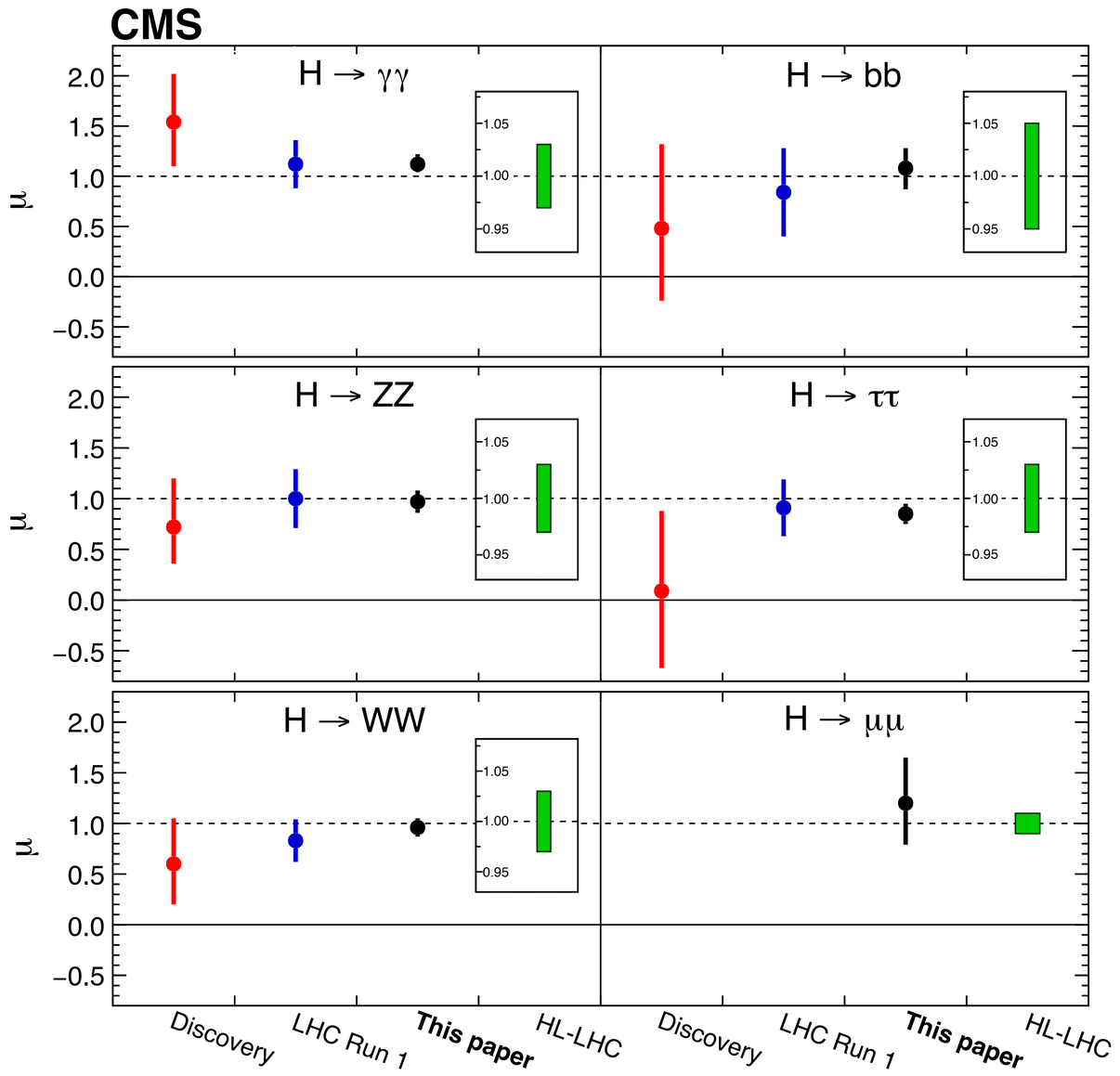


κ coupling strength



Similar to Nature paper

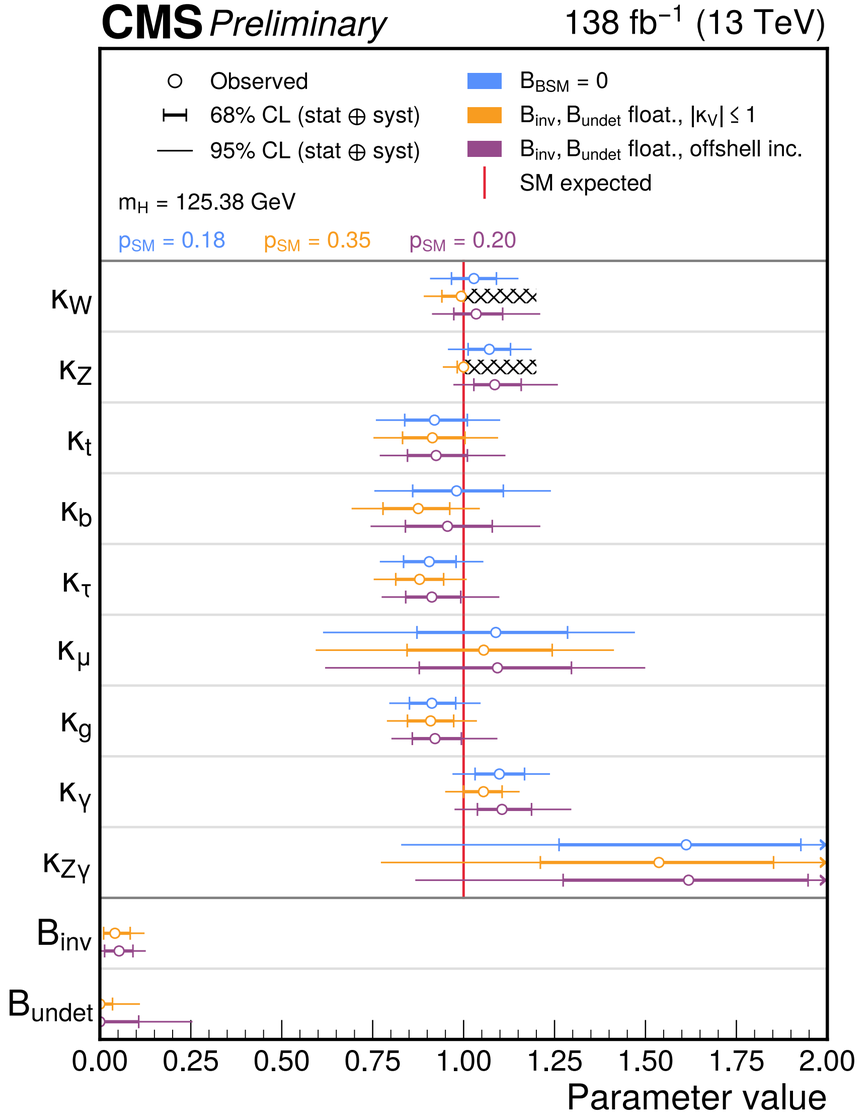
What to expect for HL-LHC



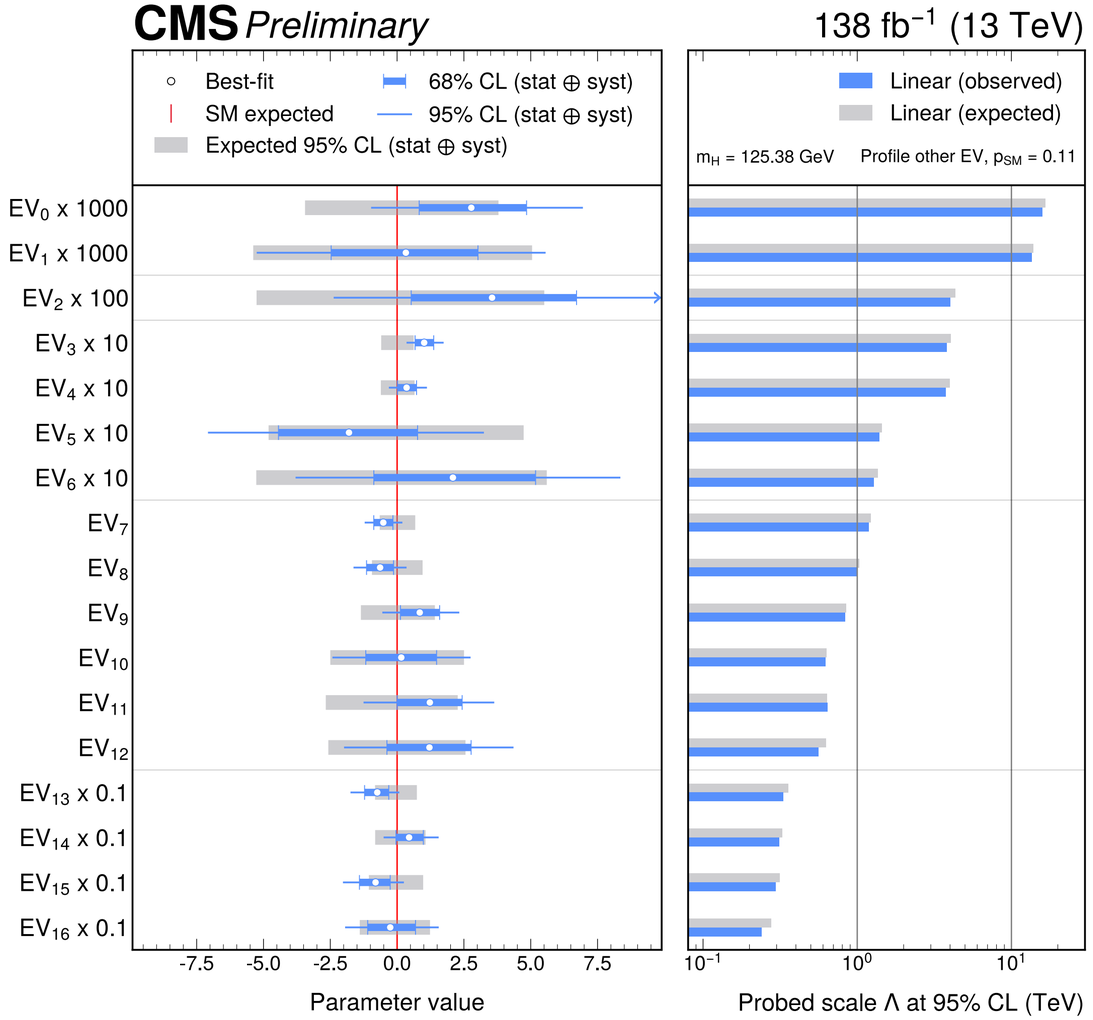
~ 2-5% expected at HL-LHC

H coupling combination

Invisible Br < 13% including off-shell measurement

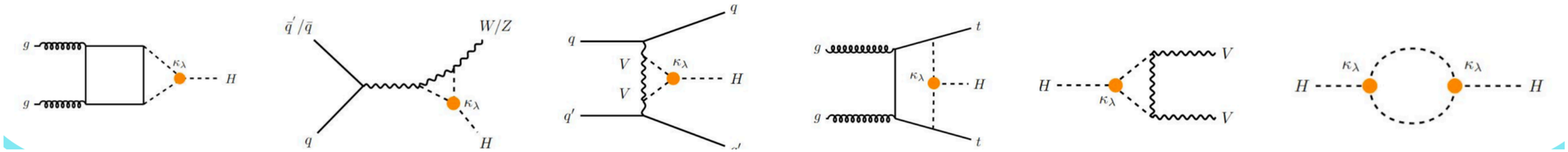


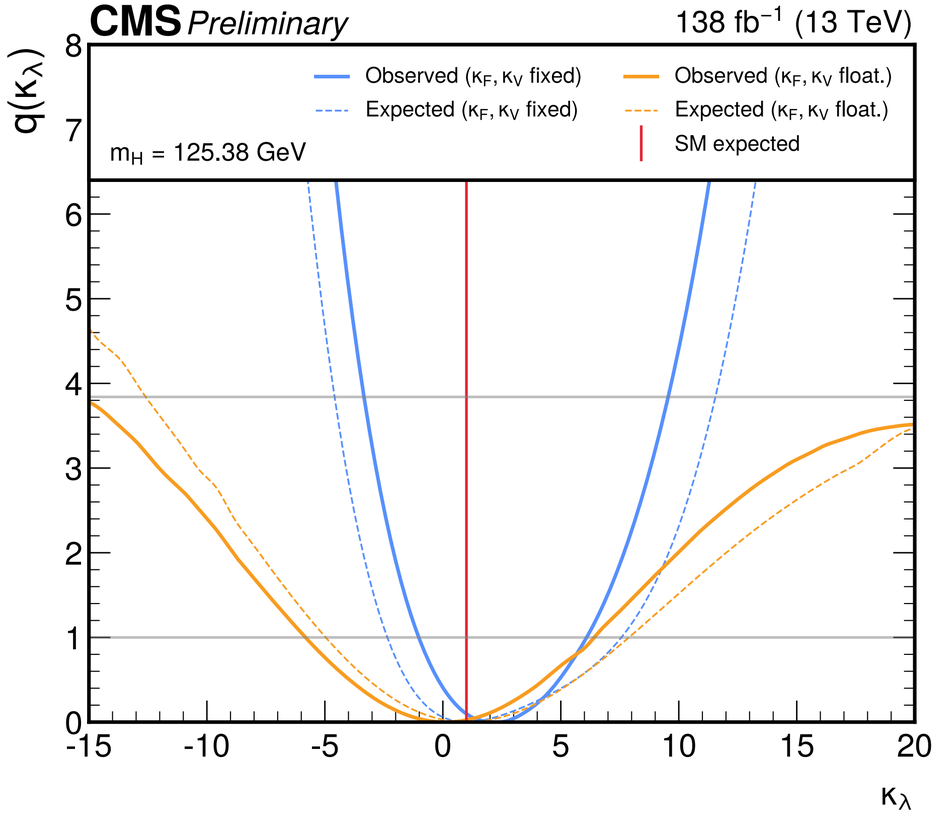
Constraints on EFT operators



H coupling combination

Constraint on Higgs self-coupling
NLO EW corrections to H production and decay rates



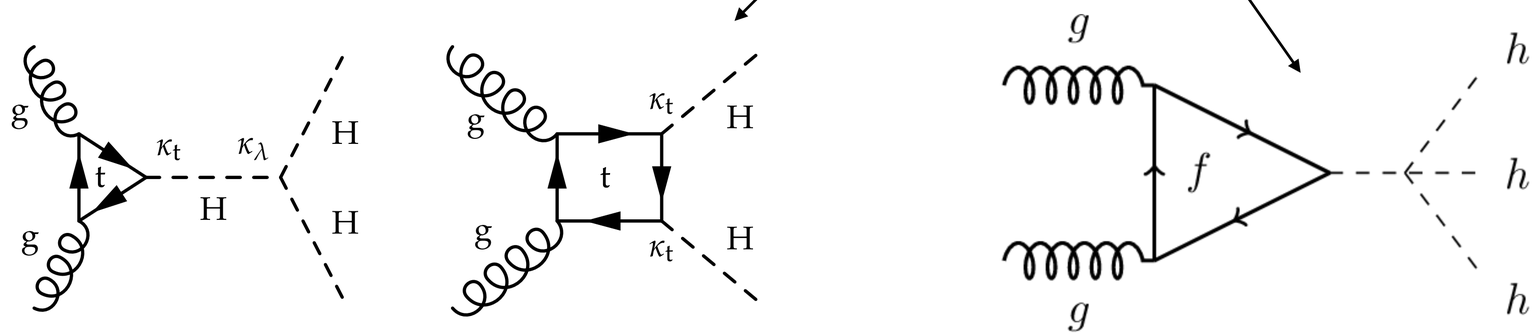


$$\kappa_\lambda = 2.1^{+4.0}_{-3.2}$$

H self-coupling

A key to understand EWSB

$$V(H) = \frac{1}{2} m_H^2 H^2 + \lambda_3 v H^3 + \frac{1}{4} \lambda_4 H^4$$

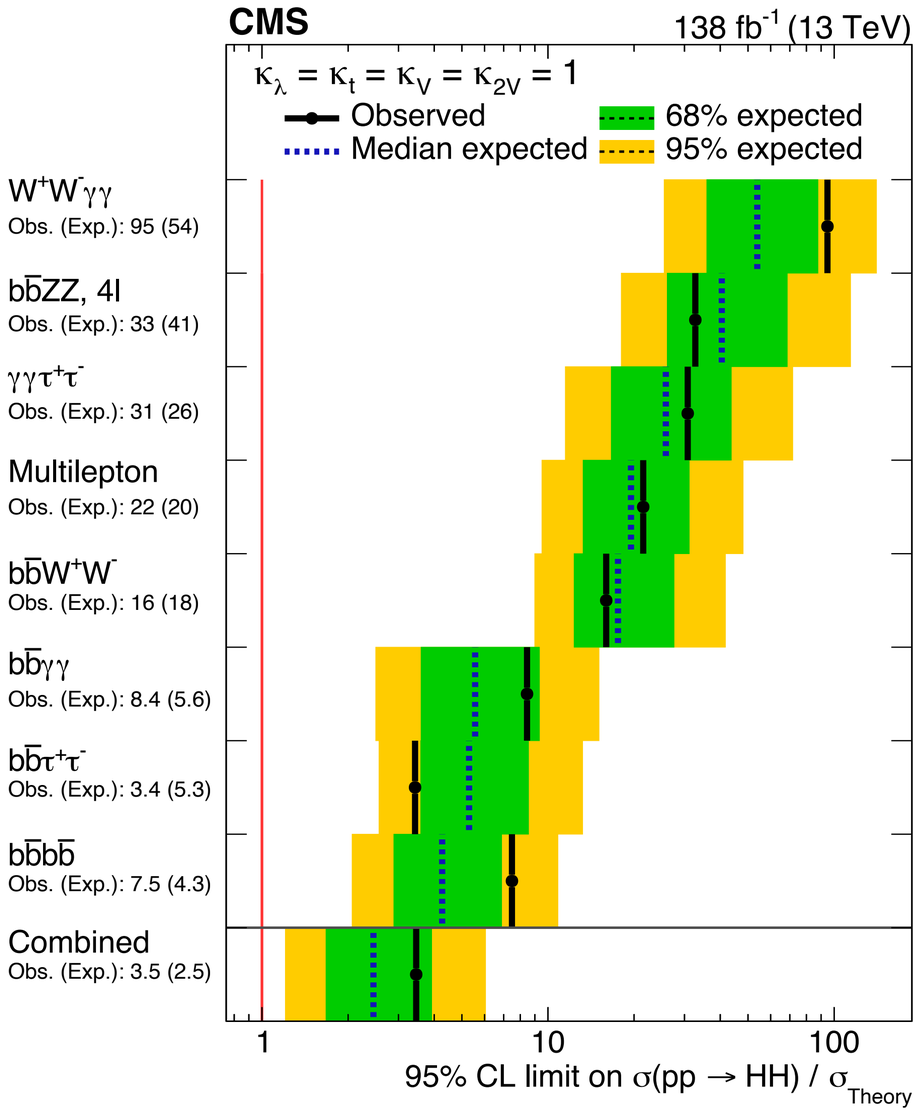


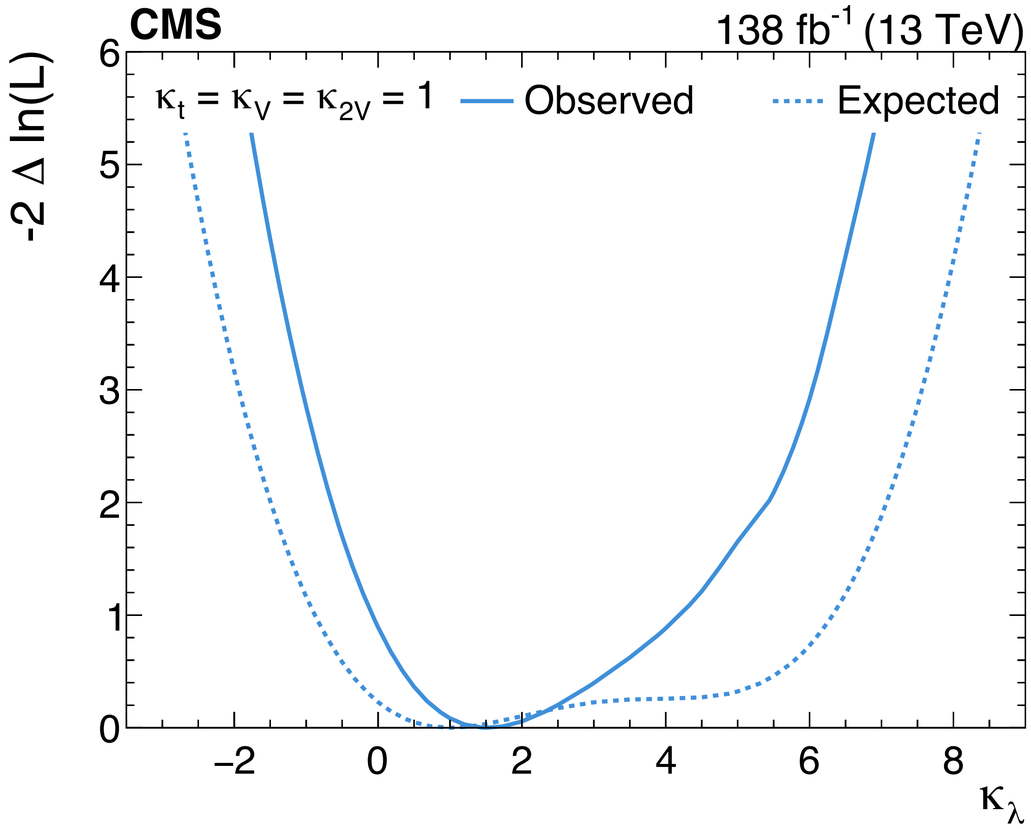
ggHH: rare process, xsec 1/1000 of ggH

HHH: even rarer, 1/500 of HH

A lot of studies in different final states

HH combination



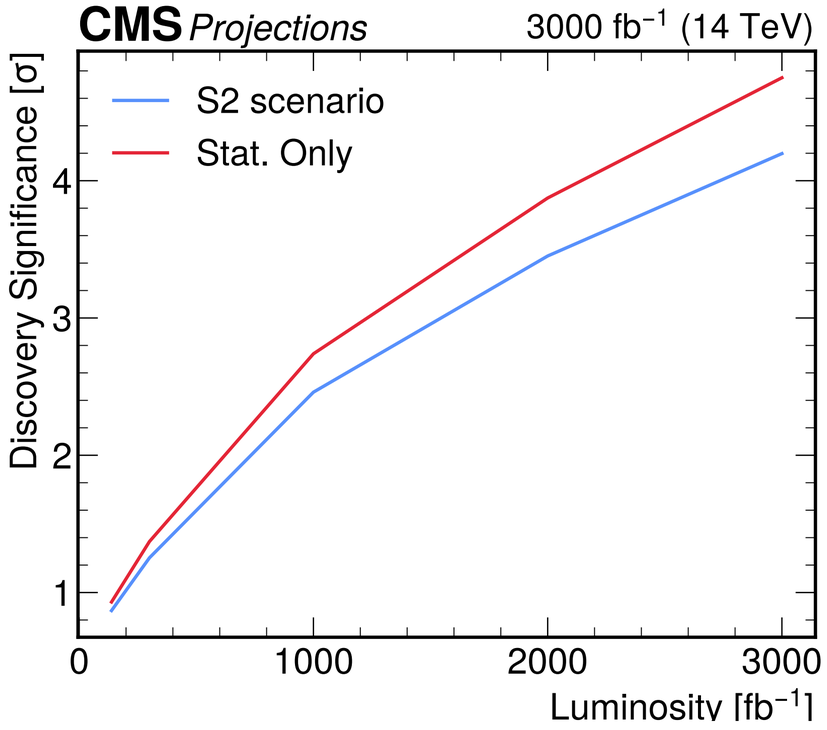


$$-1.35 < \kappa_\lambda < 6.37$$

Future on HH

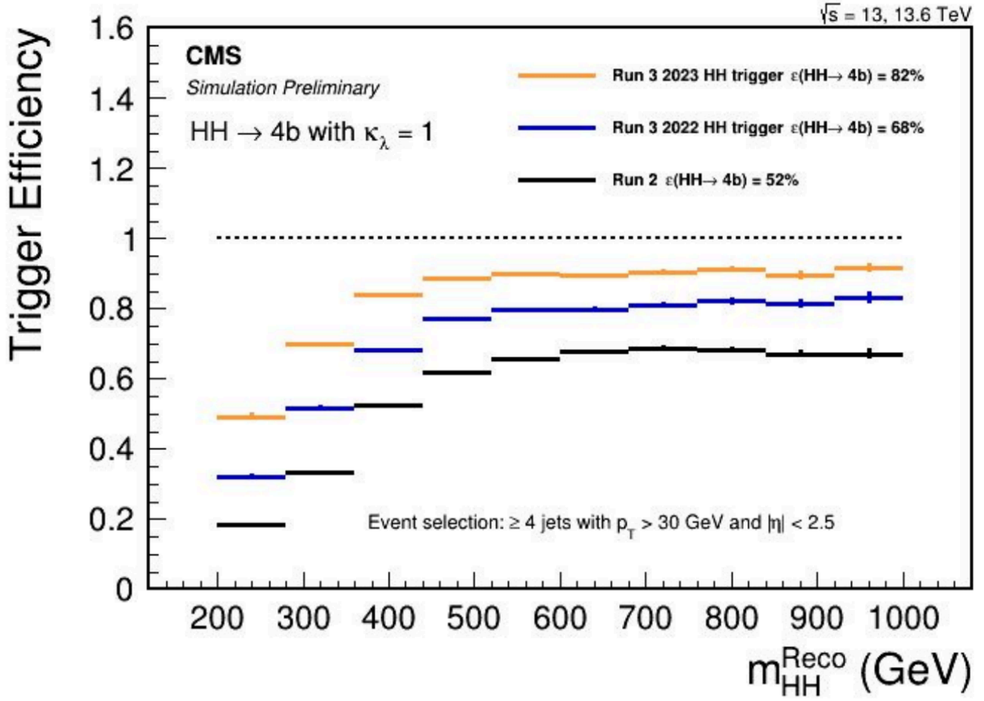
CMS-HIG-21-018
CMS-DP-2023-050

Projection based on Run2
Evidence ~ 1500 fb^{-1}



Already foresee significant improvements in Run3

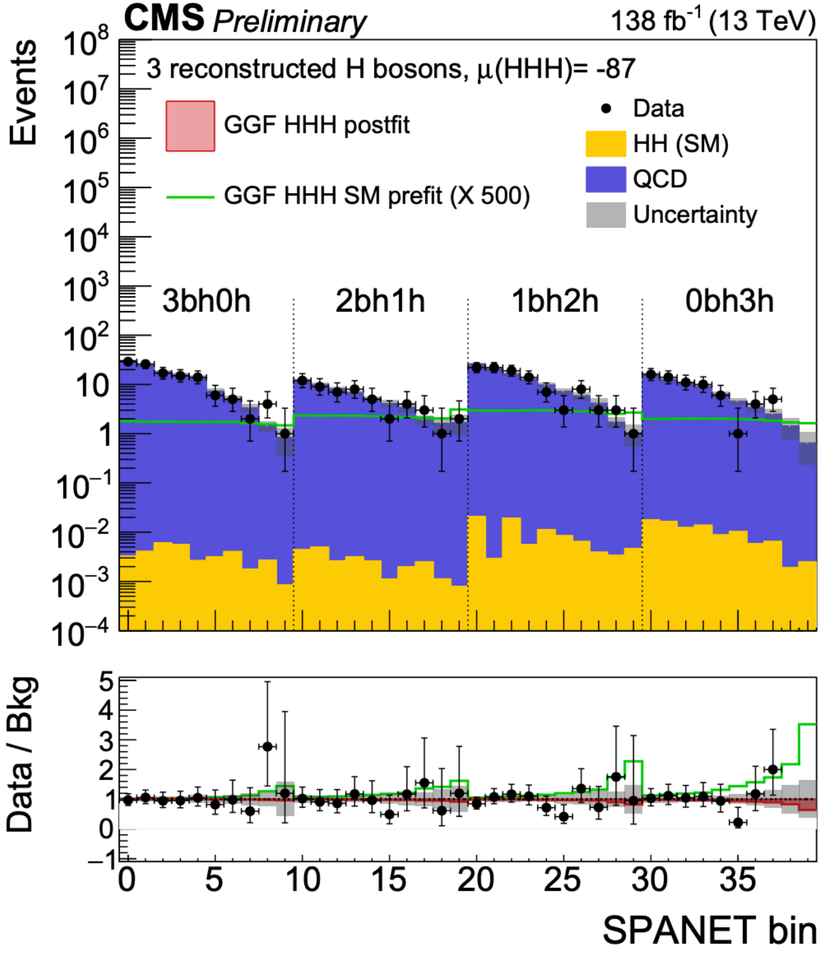
New triggers with improved b-tagging
50% gain in efficiency

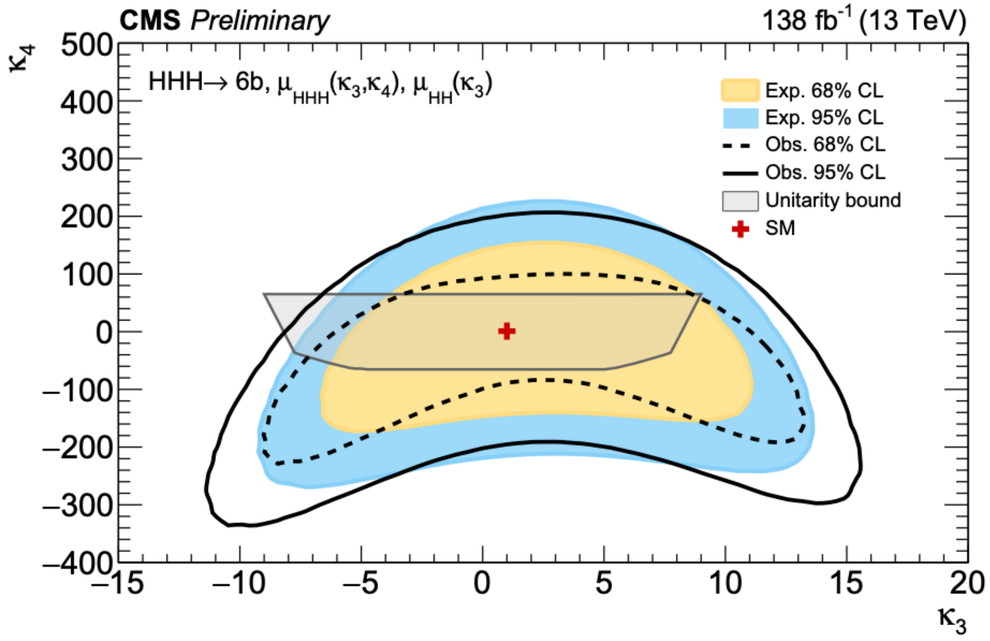


HHH coupling

A search in 6b final state

HH and HHH categories in resolved, semi-boosted and boosted final states

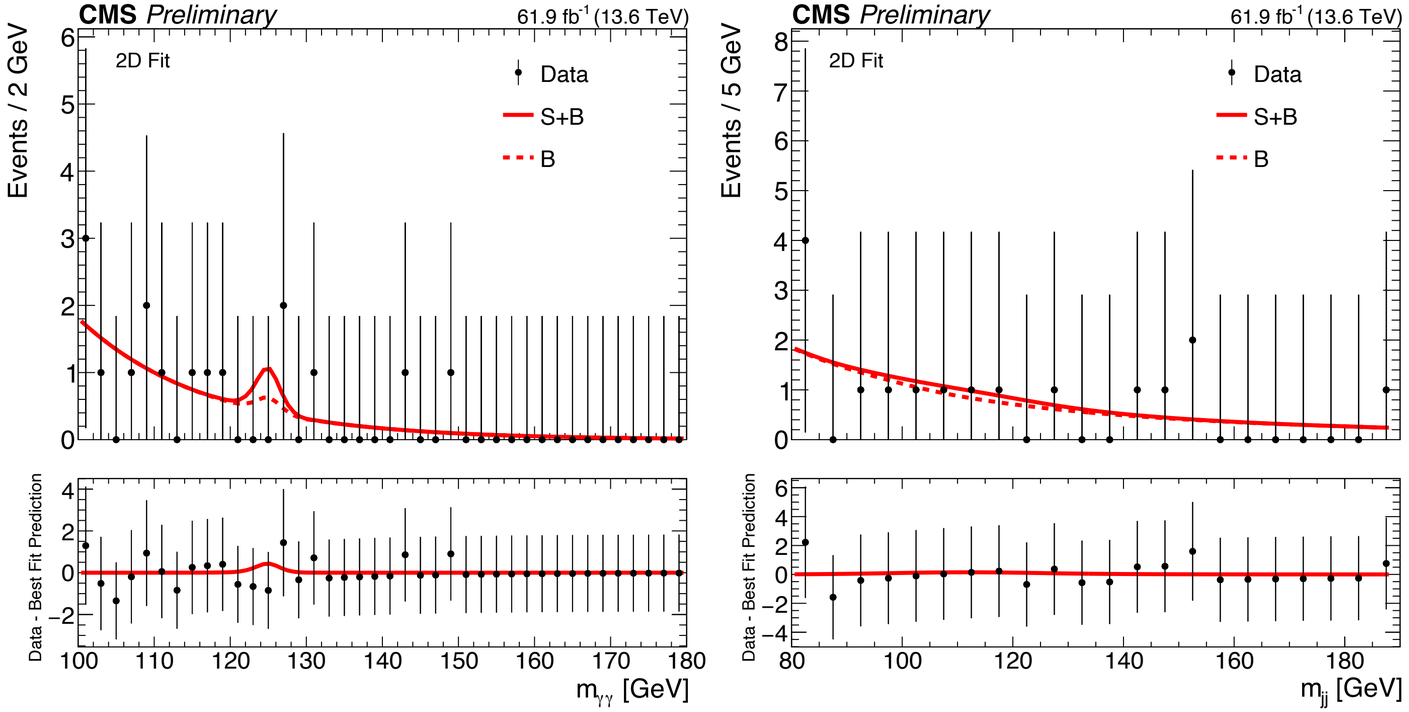


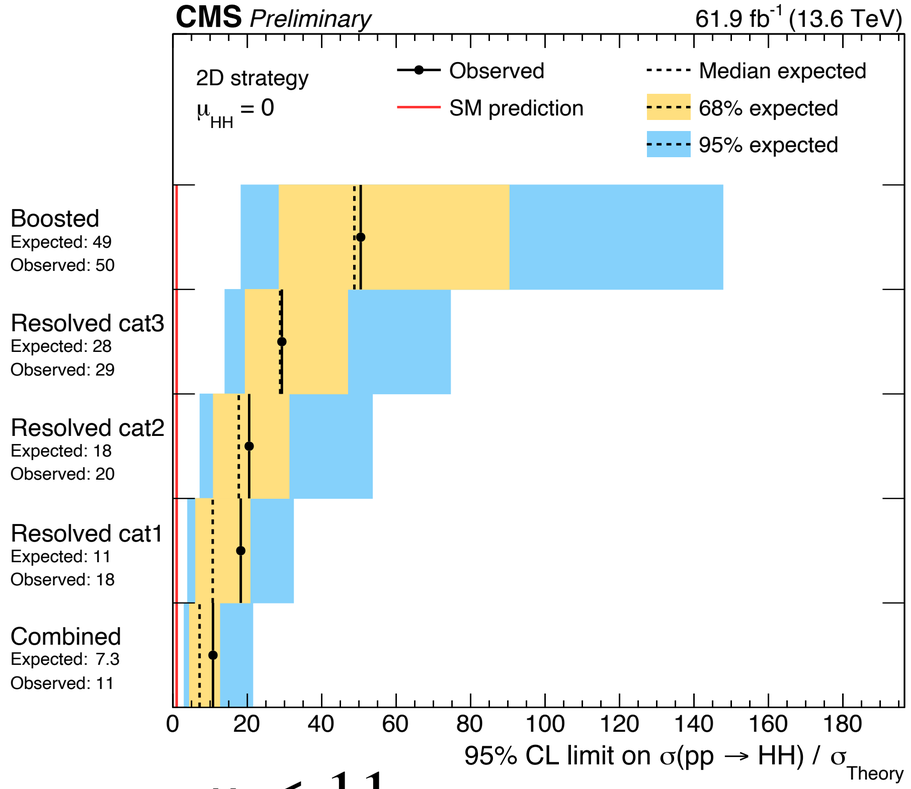


$$-190 < \kappa_4 < 190$$

Run3 HH→ bbγγ

- Using 22+23 data, 62 fb^{-1}
- 2D fit of mγγ and mbb mass
- Resolved and boosted topologies



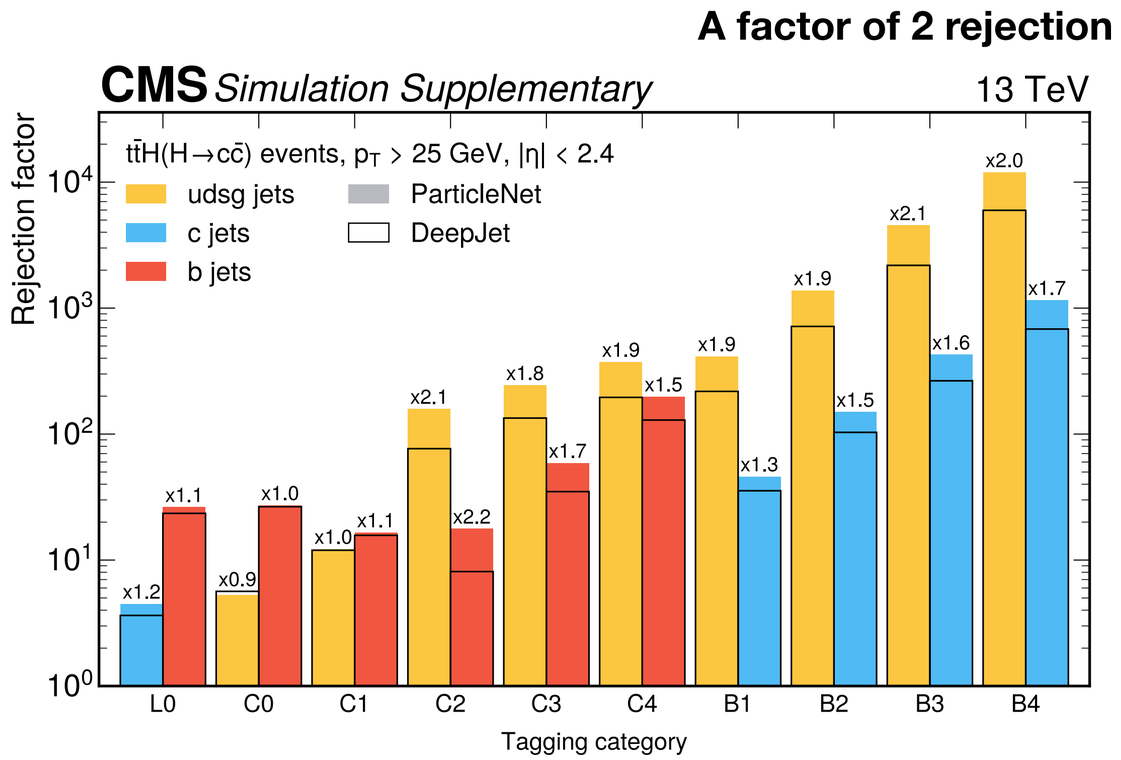


$\mu < 11$

ttH→ bb/cc

arXiv:2509.22535

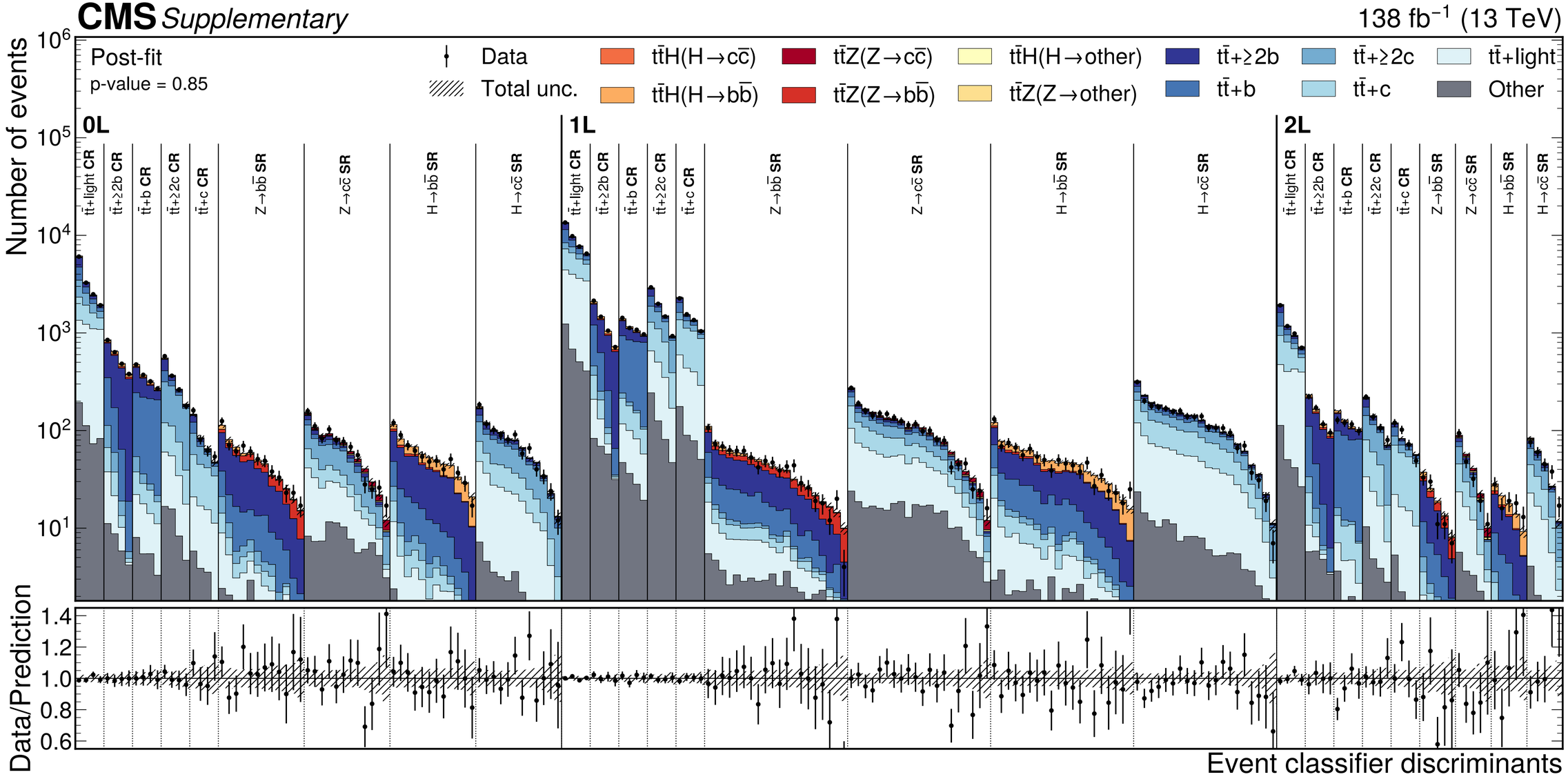
- H→ cc, Br 2.9%, difficult task to observe
- ttH, a small production mode
- Benefit from jet tagging improvements



ttH→ bb/cc

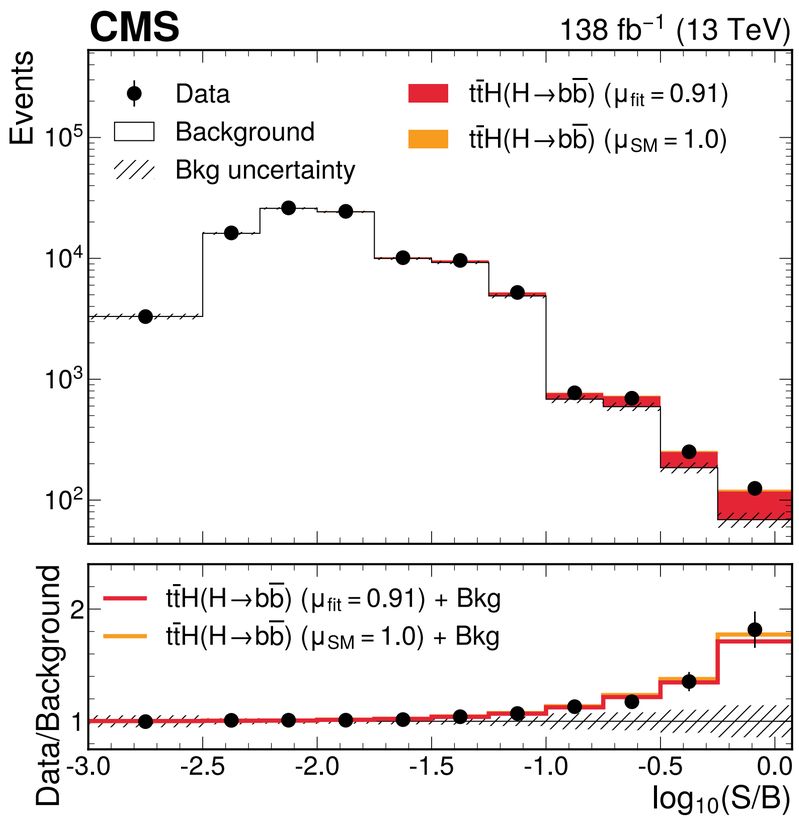
arXiv:2509.22535

A simultaneous fit of ttH→ bb, cc and ttZ SM candles

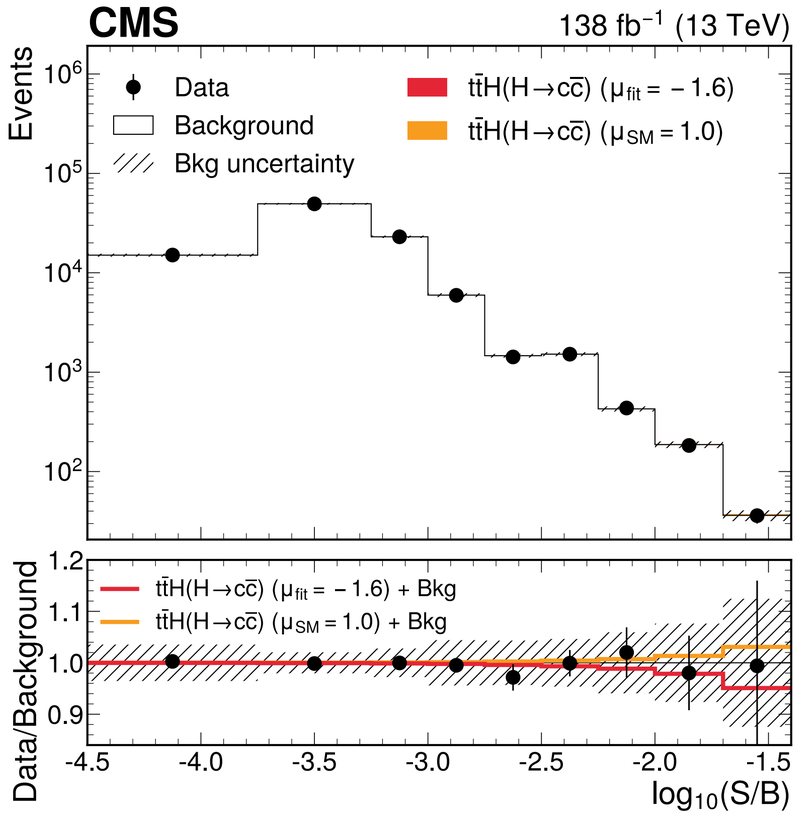


ttH→ bb/cc

arXiv:2509.22535



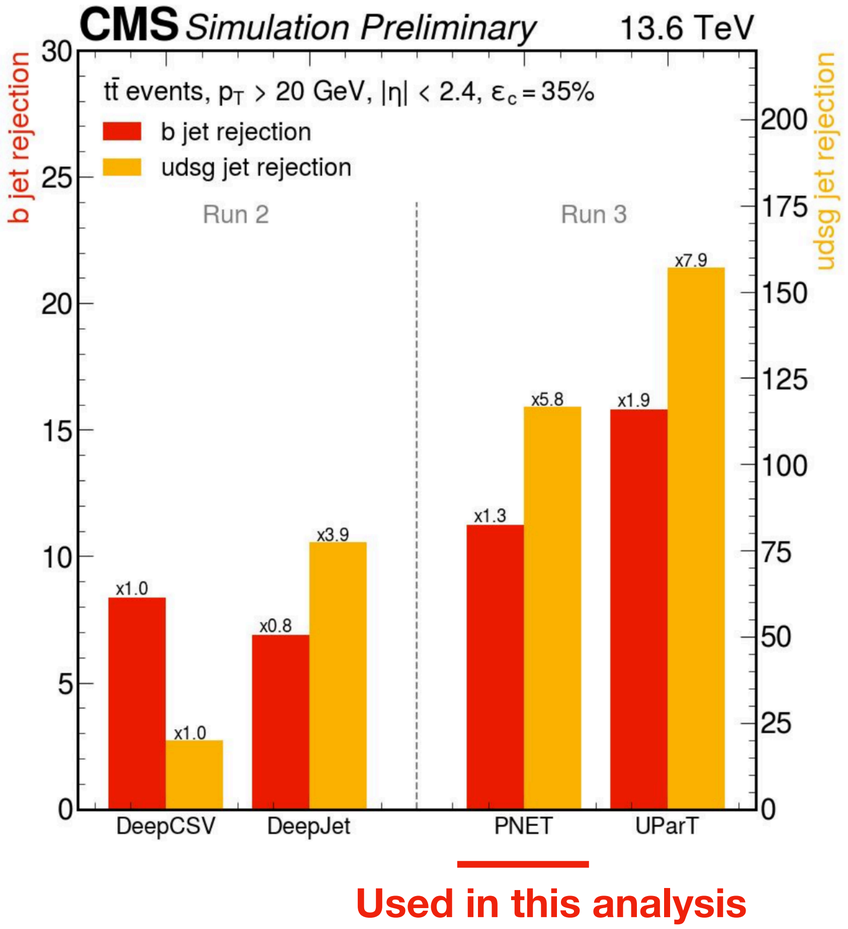
4.4σ ttH(bb)



κ_c < 3.0 @ 95%CL
μ < 7.8 @ 95% CL

Toward future improvements

arXiv:2509.22535

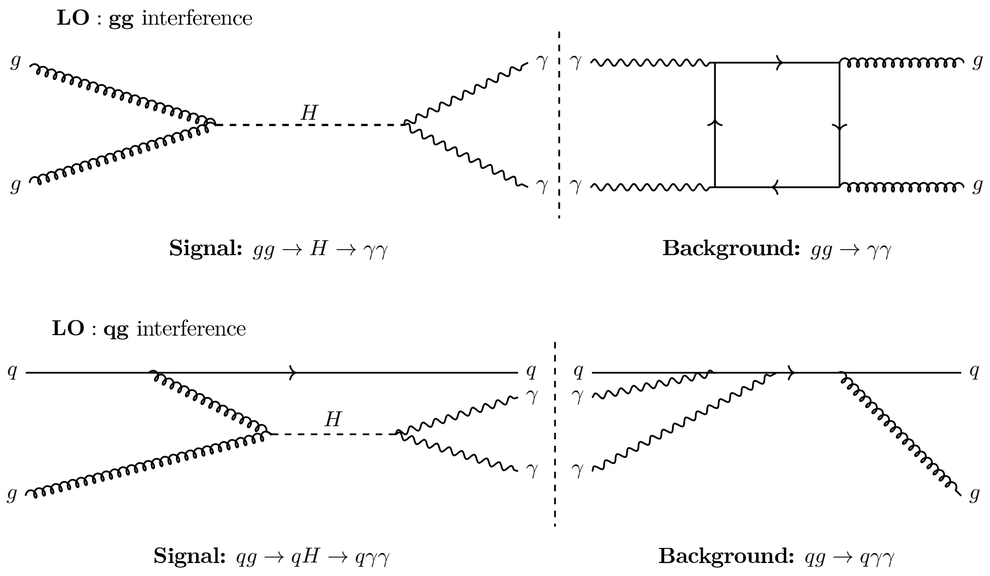


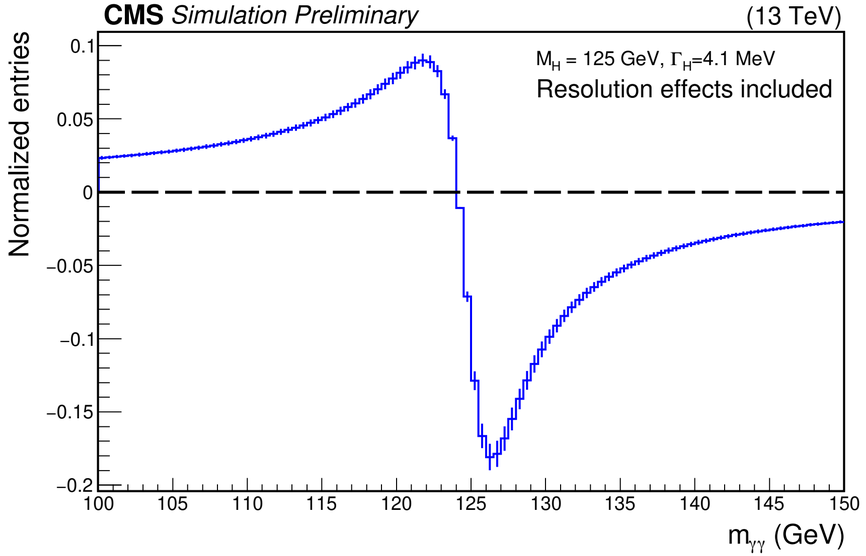
Further improvements expected in Run3

Expecte μ < 1 @ HL-LHC with Run2 VH performance

Higgs width

- SM Higgs width: 4 MeV, difficult to reach with current detector resolution
- Measurement from off-shell region: $3.0^{+2.0}_{-1.5}$ MeV, exclude 0 width
  - Assume the same coupling in the on-shell and off-shell region
- A proposal to measure via H→ γγ on-shell interference effect long time ago

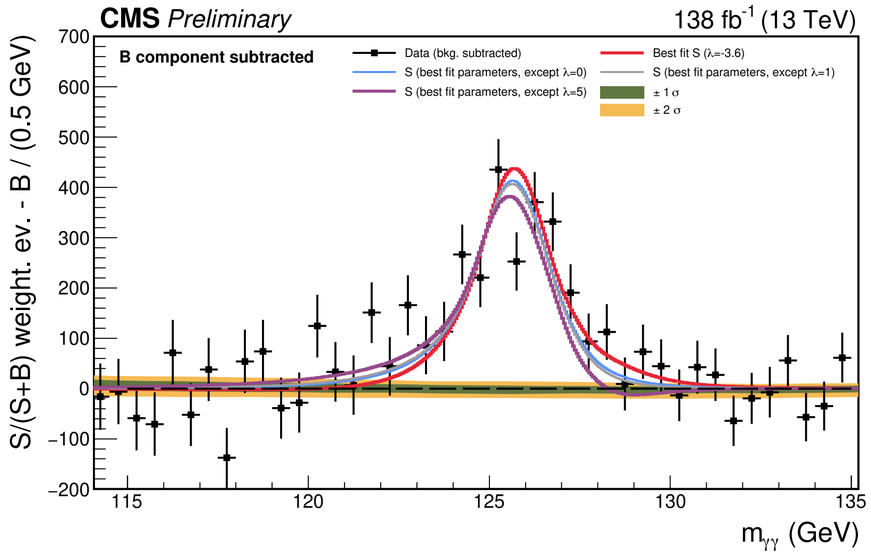


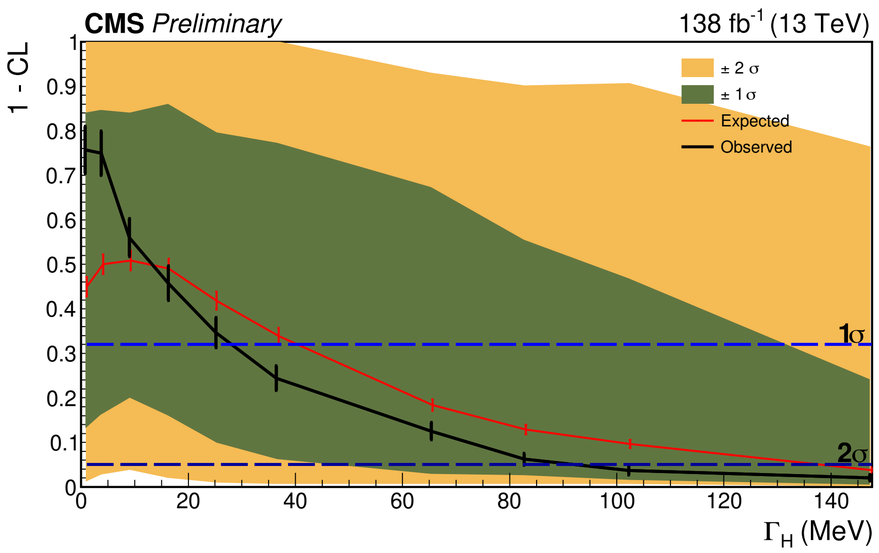


Higgs width

Using Run2 data, full line shape is parameterized taking into account the interference

$\Gamma_H < 92$ MeV @ 95% CL, compared to < 330 MeV from H→ 4l on-shell





Summary

- Rich program of Higgs at CMS
- 3rd generation couplings established and to be improved with higher precision
- Next important things
  - 2nd generation coupling Hμμ and Hcc
  - Self-coupling
- Improvements in methodologies, such as flavor tagging, trigger helps to speed up the discoveries
- Properties of Higgs boson with higher precision and new methods
- With in total ~500 fb^{-1} data by the end of 2026, exciting results will arrive very soon

Backup

$t\bar{t}$+≥1b bkg. model	$\mu_{t\bar{t}H(H\to c\bar{c})}$	(95% CL)	$\mu_{t\bar{t}H(H\to b\bar{b})}$	(Sign. [s.d.])	$\mu_{t\bar{t}Z(Z\to c\bar{c})}$	(Sign. [s.d.])	$\mu_{t\bar{t}Z(Z\to b\bar{b})}$	(Sign. [s.d.])
Default	-1.6 ± 4.5	(<7.8)	$0.91^{+0.26}_{-0.22}$	(4.4)	$1.02^{+0.79}_{-0.84}$	(1.2)	$1.47^{+0.45}_{-0.41}$	(3.5)
Simple PS	-0.4 ± 4.4	(<8.8)	$0.91^{+0.27}_{-0.22}$	(4.4)	$0.94^{+0.82}_{-0.73}$	(1.3)	$1.47^{+0.44}_{-0.39}$	(3.6)
$\mu_F \times 2$	$-1.7^{+4.2}_{-4.3}$	(<8.0)	$0.94^{+0.26}_{-0.23}$	(4.4)	$1.06^{+0.77}_{-0.75}$	(1.4)	$1.62^{+0.43}_{-0.38}$	(4.1)
$\mu_F \times 2$ & Simple PS	-1.0 ± 4.4	(<8.5)	$0.97^{+0.28}_{-0.23}$	(4.5)	$1.04^{+0.77}_{-0.78}$	(1.3)	$1.67^{+0.42}_{-0.37}$	(4.2)
5FS	-1.8 ± 4.3	(<7.7)	$0.97^{+0.24}_{-0.20}$	(5.7)	$1.17^{+0.77}_{-0.71}$	(1.6)	$1.14^{+0.41}_{-0.38}$	(3.0)
5FS & Simple PS	-0.9 ± 4.5	(<7.6)	$1.02^{+0.26}_{-0.21}$	(6.0)	$1.19^{+0.77}_{-0.71}$	(1.6)	$1.10^{+0.40}_{-0.37}$	(2.9)