

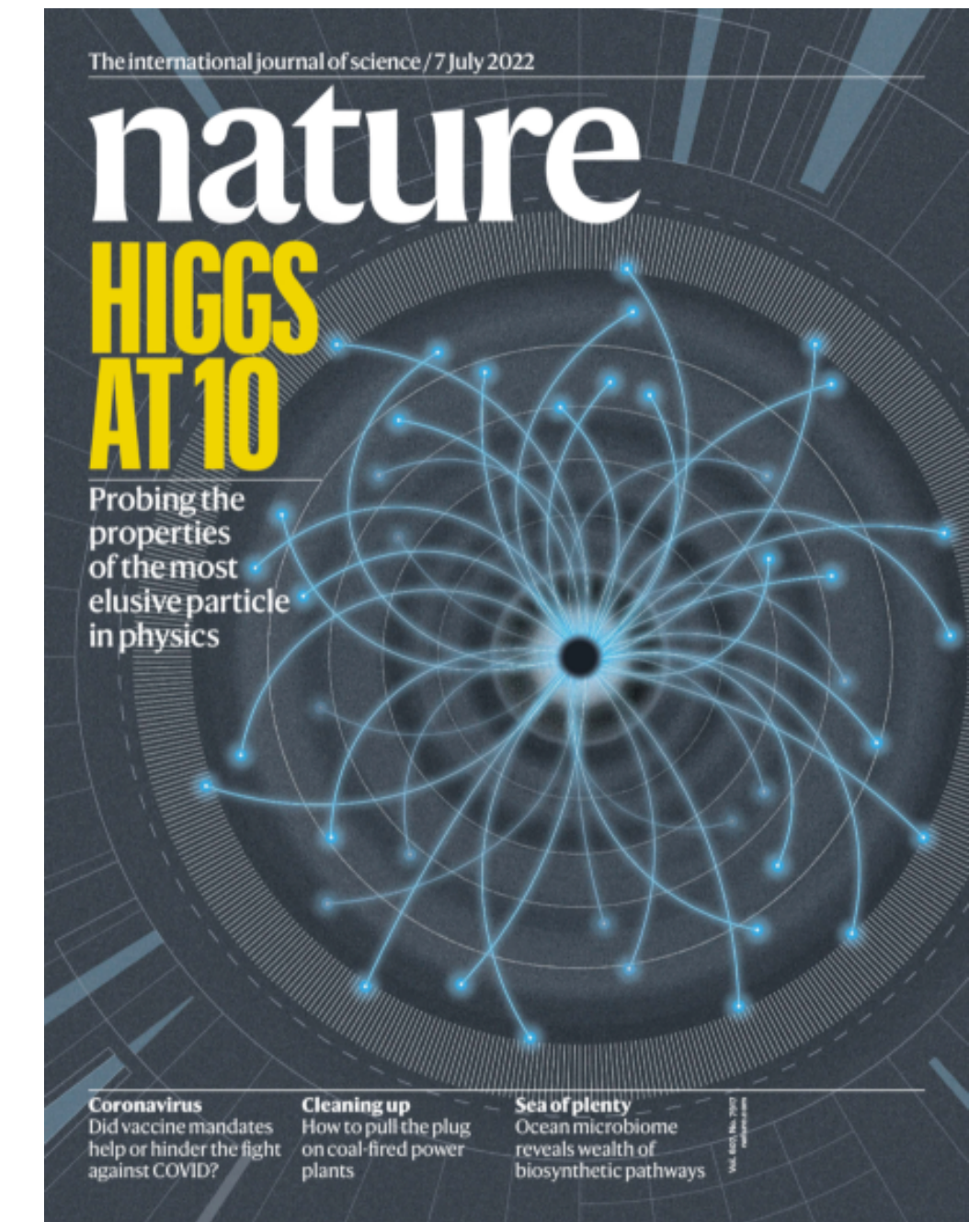
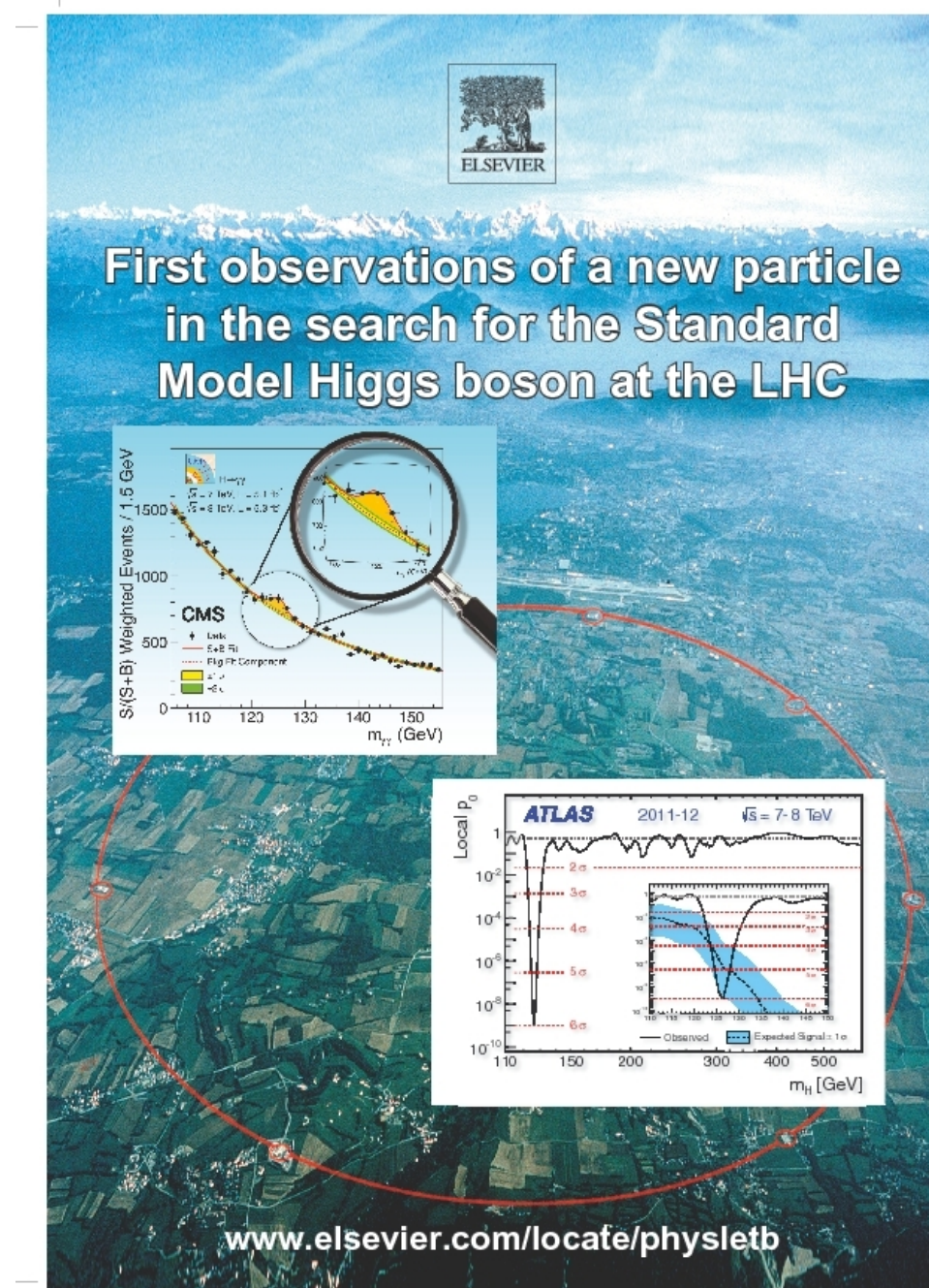
Combined Higgs measurements with the CMS experiment

Chen Zhou
Peking University

17th FCPPN/L workshop
Lyon, France, 29 June 2026

Introduction

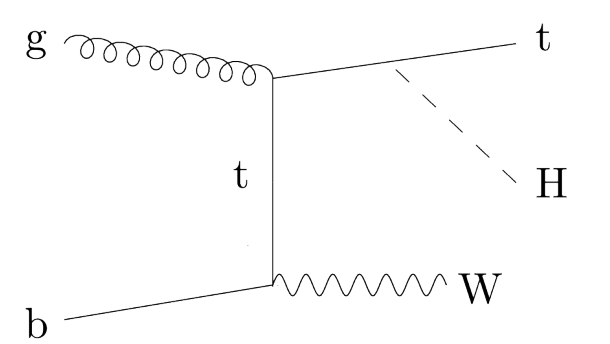
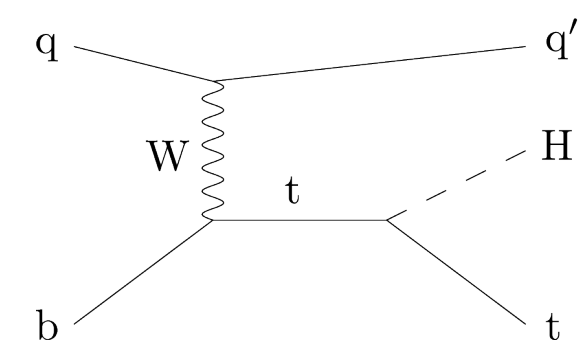
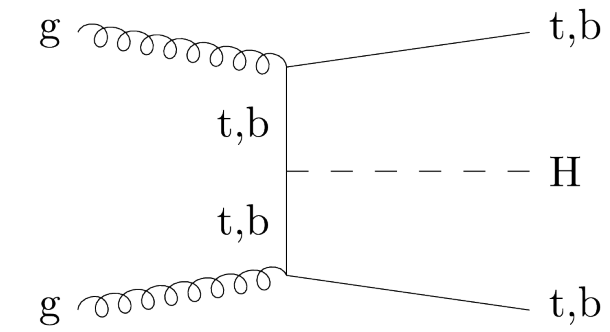
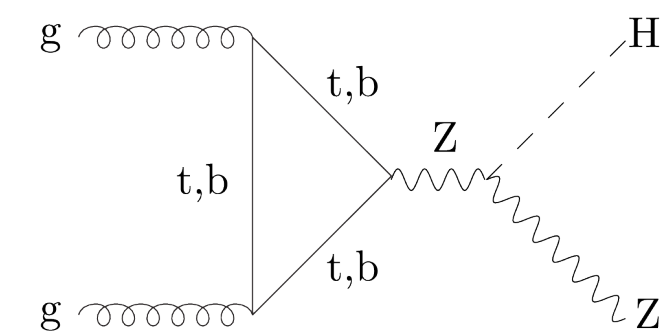
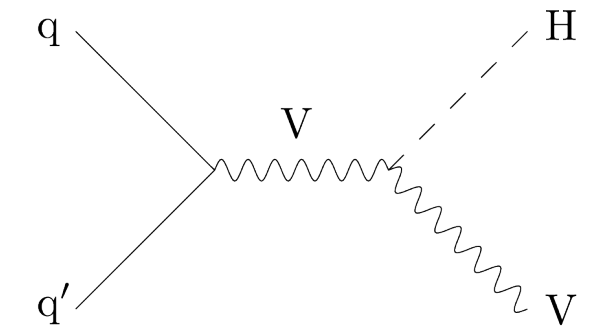
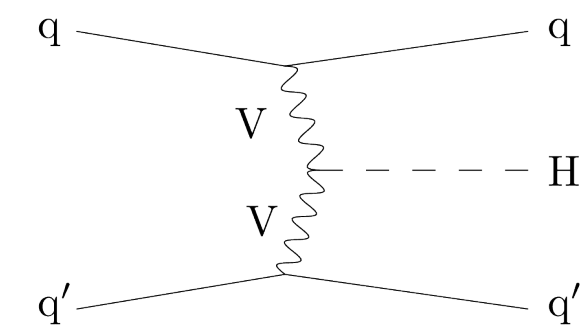
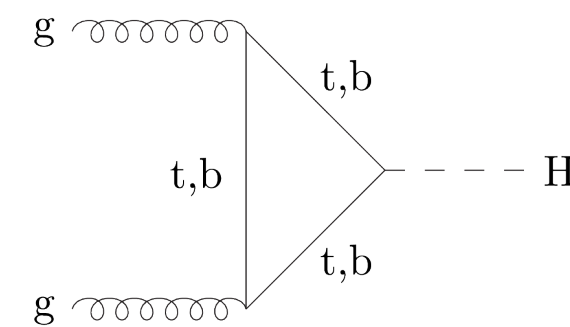
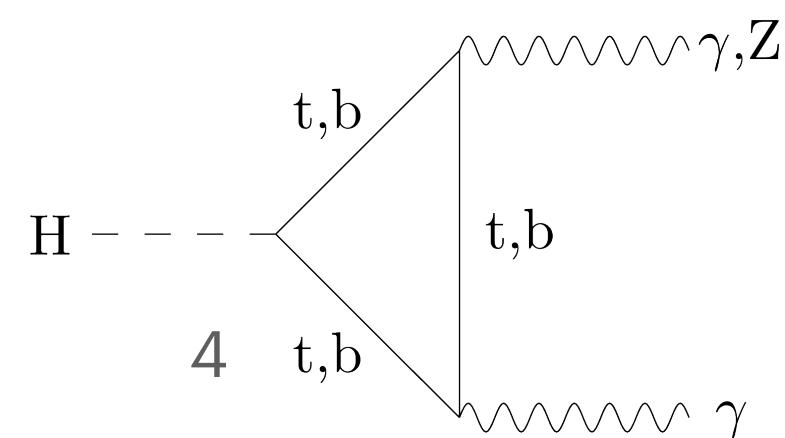
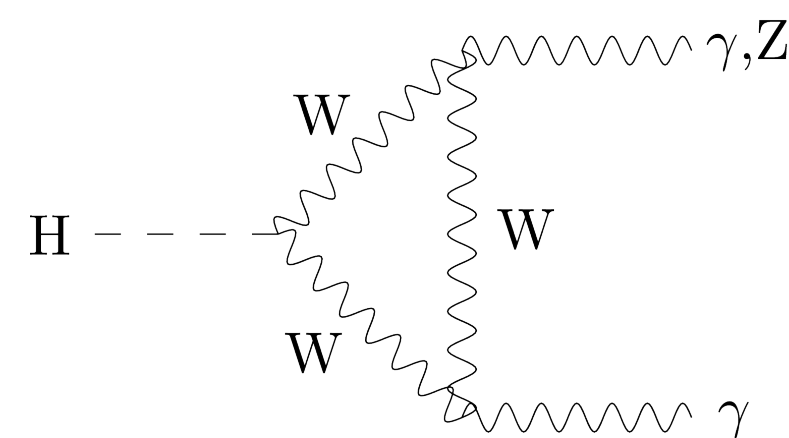
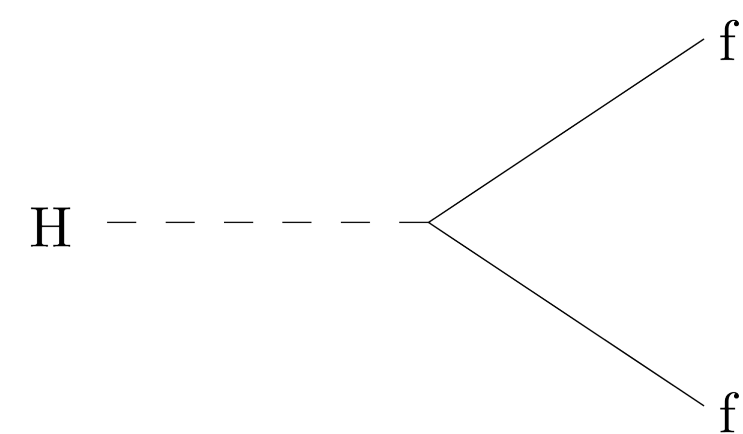
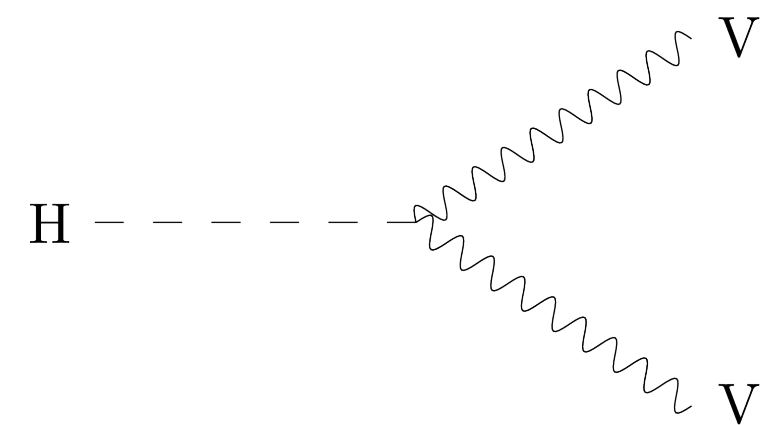
- **The Higgs boson** was discovered by the ATLAS and CMS experiments at the Large Hadron Collider (LHC) in 2012
 - a major milestone for particle physics
- It opened a new way to refine our understanding of the electroweak sector
 - many studies of **Higgs boson properties** have been performed
 - deviation from the Standard Model (SM) predictions on Higgs boson properties would provide clue for new physics
- Today: combined measurements of Higgs boson production and decays with the CMS detector
 - combined measurements provide the best precision and granularity



CMS Run-2 Single Higgs

Combined measurements of Higgs productions and decays

- Based on analyses of **various Higgs decay channels**
 - Each decay channel targets **multiple Higgs production modes**
- Searches for **invisible Higgs decays** and measurement of **offshell Higgs production** are also considered

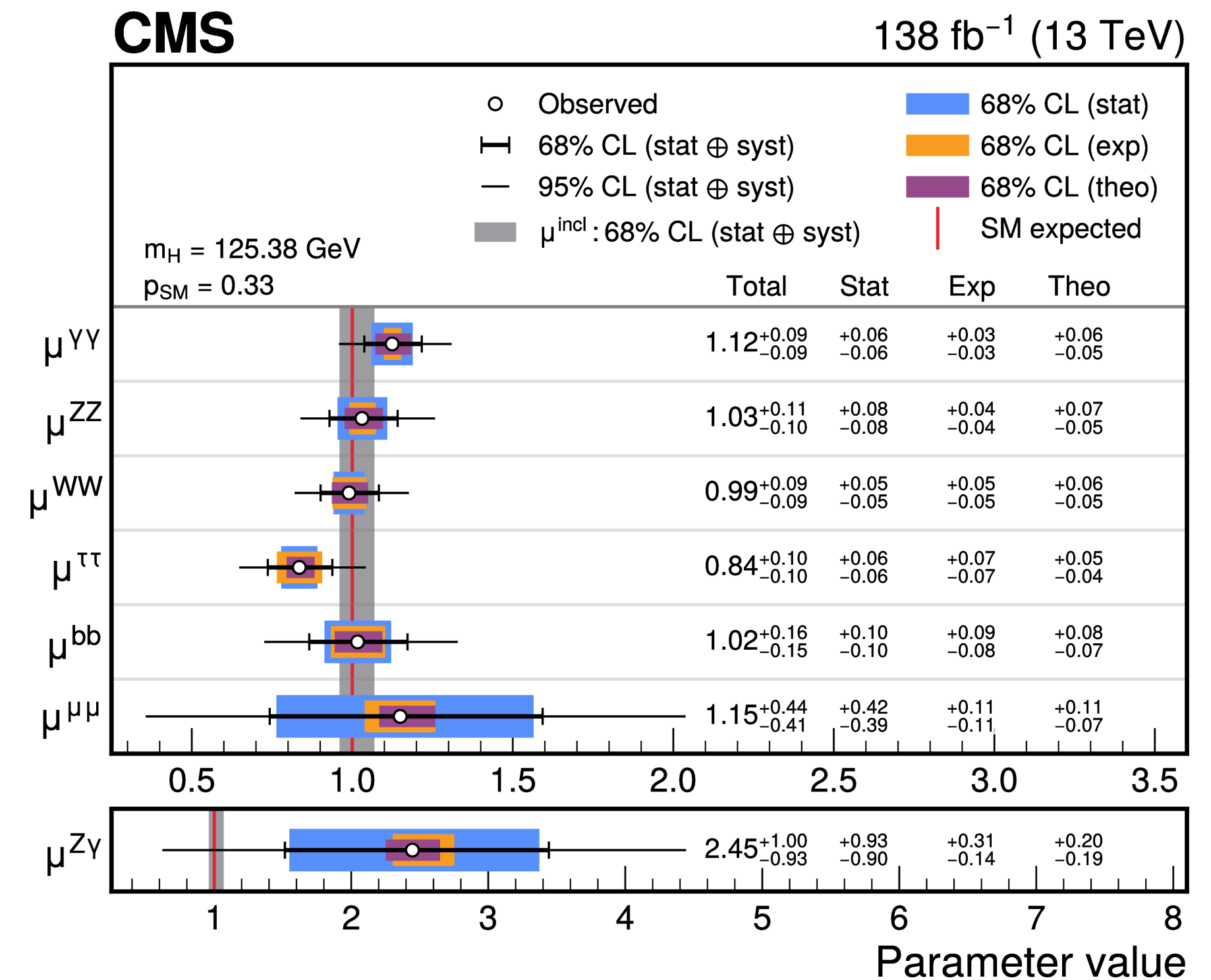
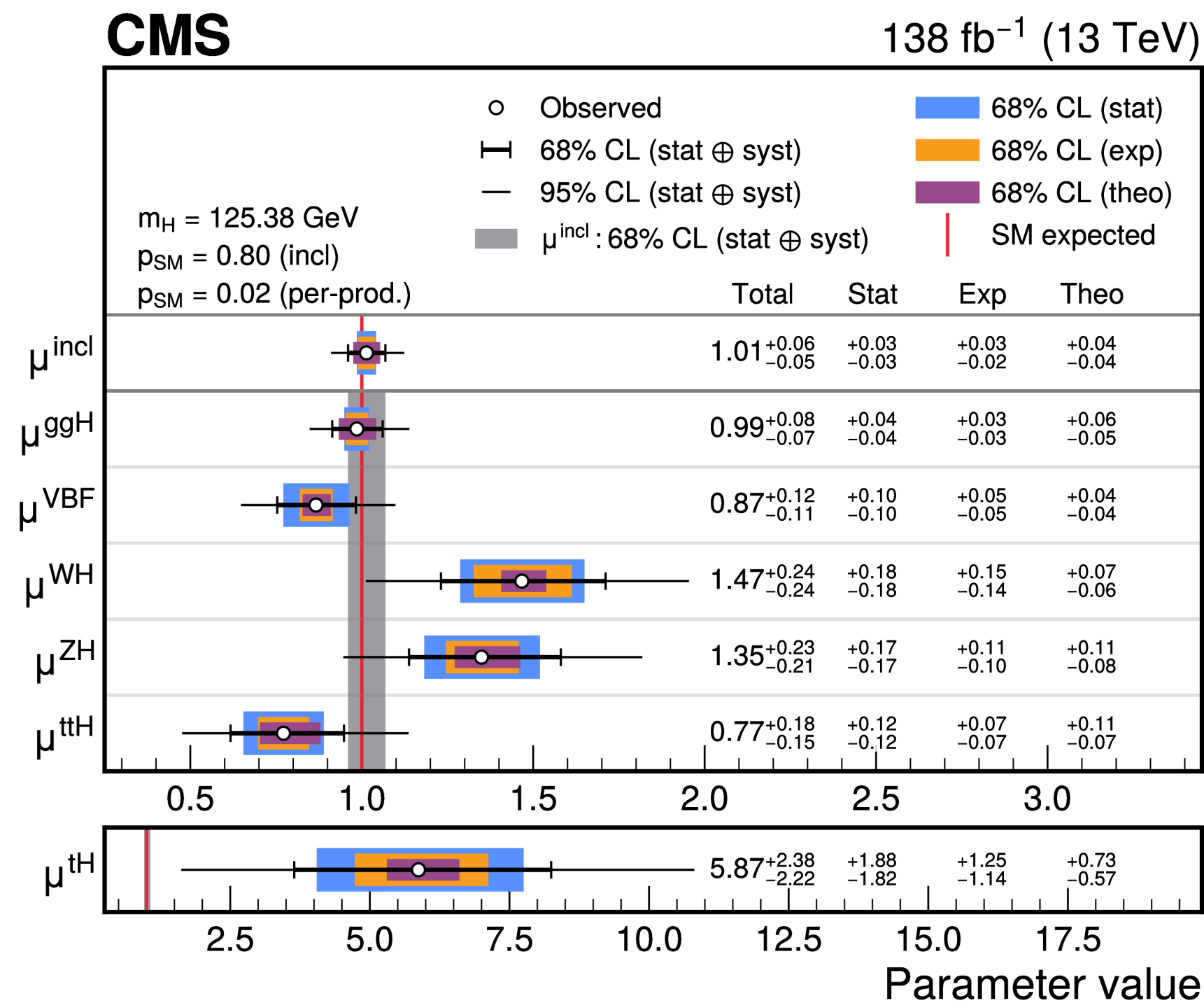


Combined measurements of Higgs productions and decays

Inclusive Signal Strength:

$$\begin{aligned}\mu &= 1.014^{+0.055}_{-0.053} \\ &= 1.014^{+0.040}_{-0.039}(\text{theory})^{+0.025}_{-0.024}(\text{exp}) \pm 0.028(\text{stat}).\end{aligned}$$

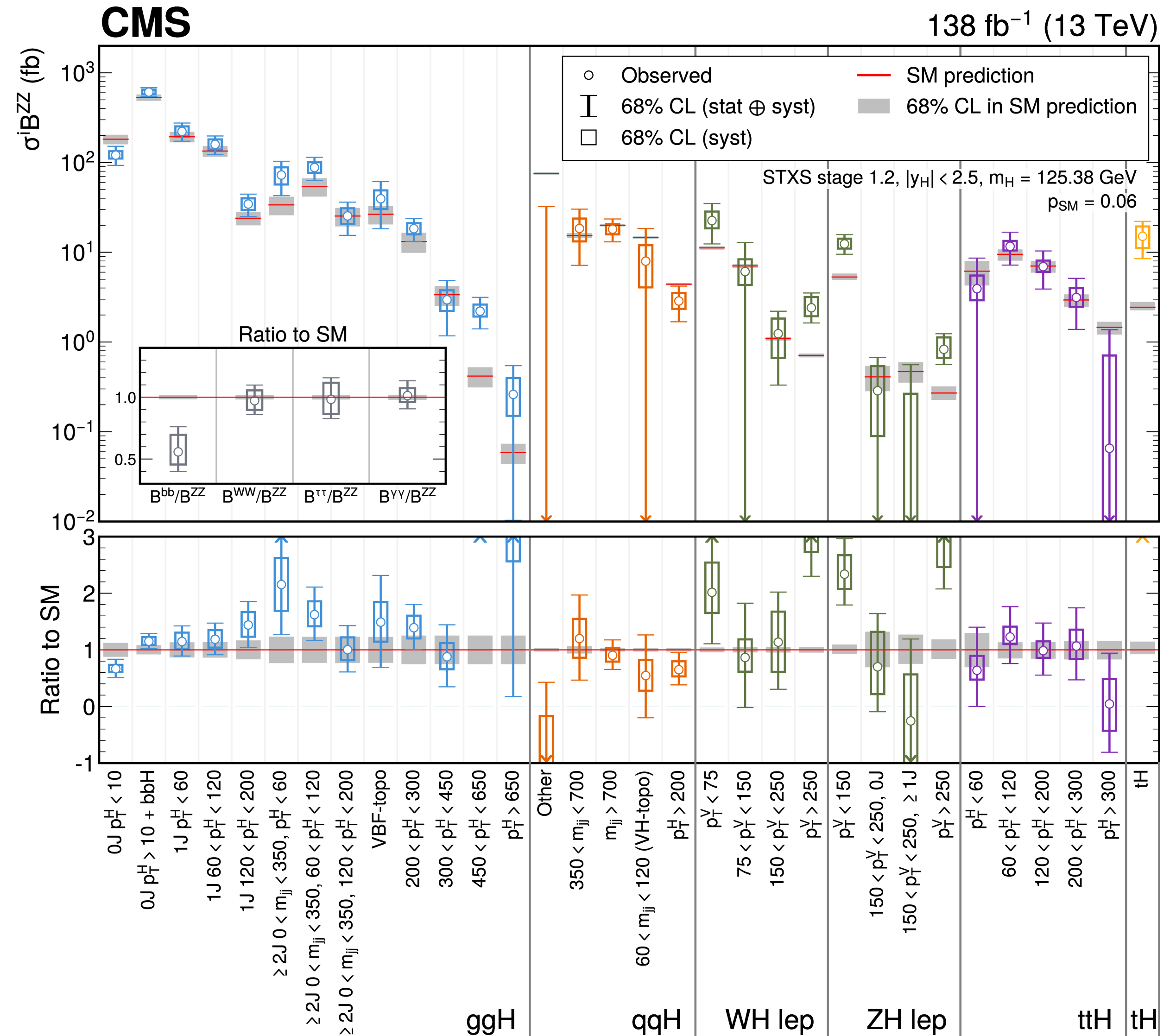
Combined measurements of Higgs productions and decays



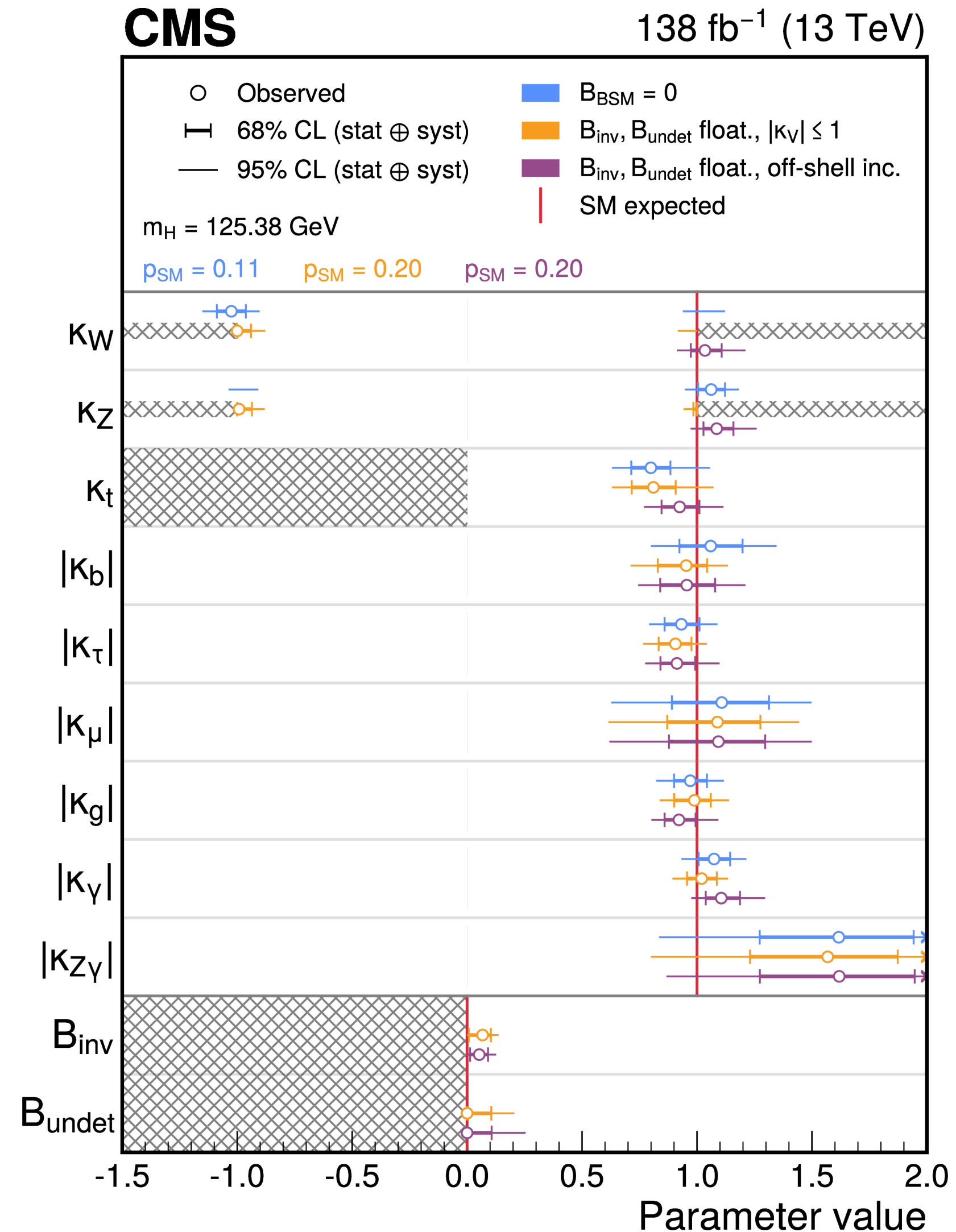
- All major production modes (ggF, VBF, WH, ZH, ttH) and decay modes (H→γγ, H→ZZ, H→WW, H→ττ, H→bb) are observed

Combined measurements of Higgs productions and decays

- 32 kinematic regions defined by stage 1.2 simplified template cross section framework are measured simultaneously



Combined measurements of Higgs productions and decays

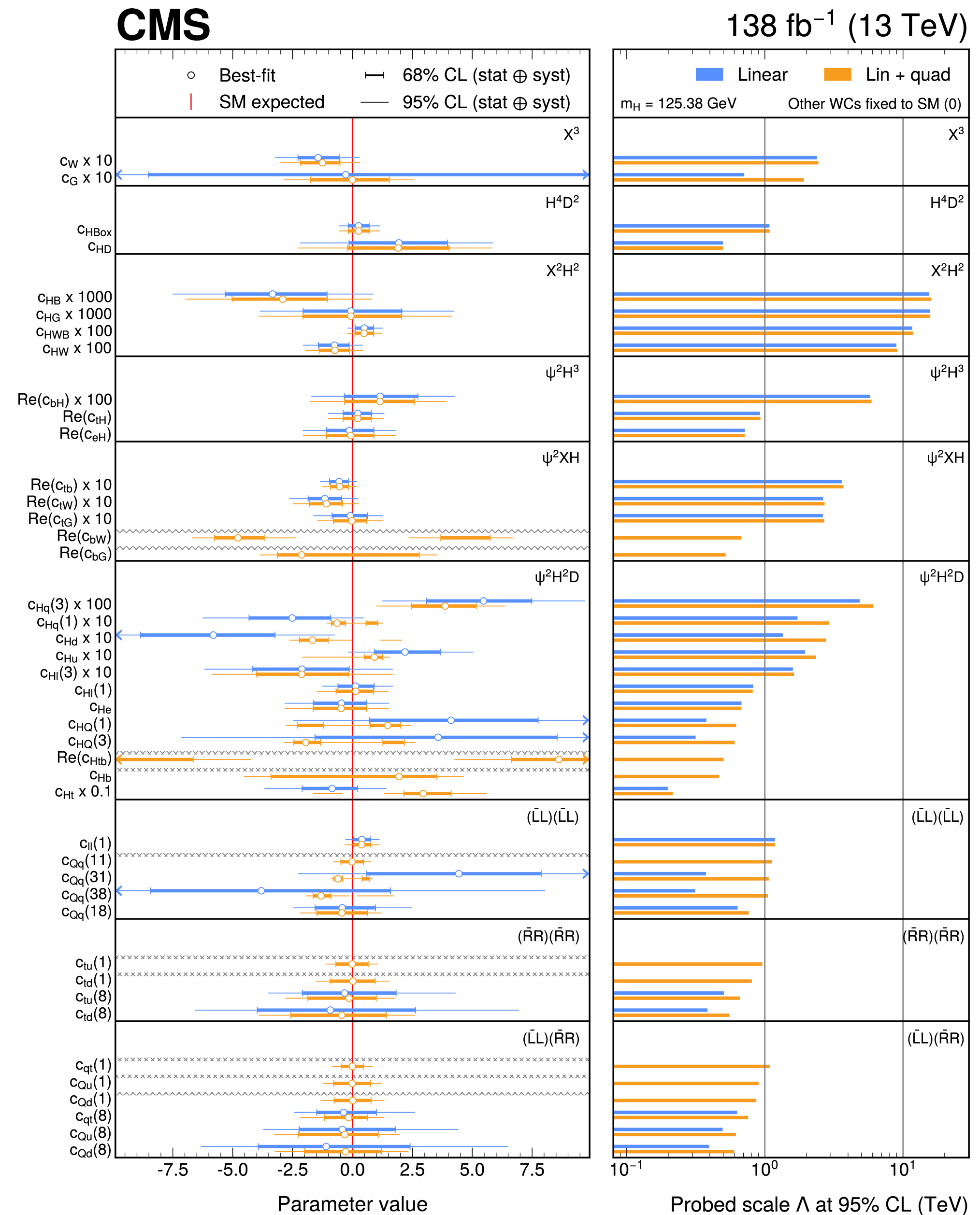


- Assign coupling modifier to each interaction vertex (e.g. κ_W , κ_t ...)
- different assumptions on the total Higgs boson decay width are provided

Combined measurements of Higgs productions and decays

$$\mathcal{L}_{\text{SMEFT}} = \mathcal{L}_{\text{SM}} + \sum_i^{N_{d6}} \frac{c_i}{\Lambda^2} O_i^{(6)} + \sum_j^{N_{d8}} \frac{b_j}{\Lambda^4} O_j^{(8)} + \dots$$

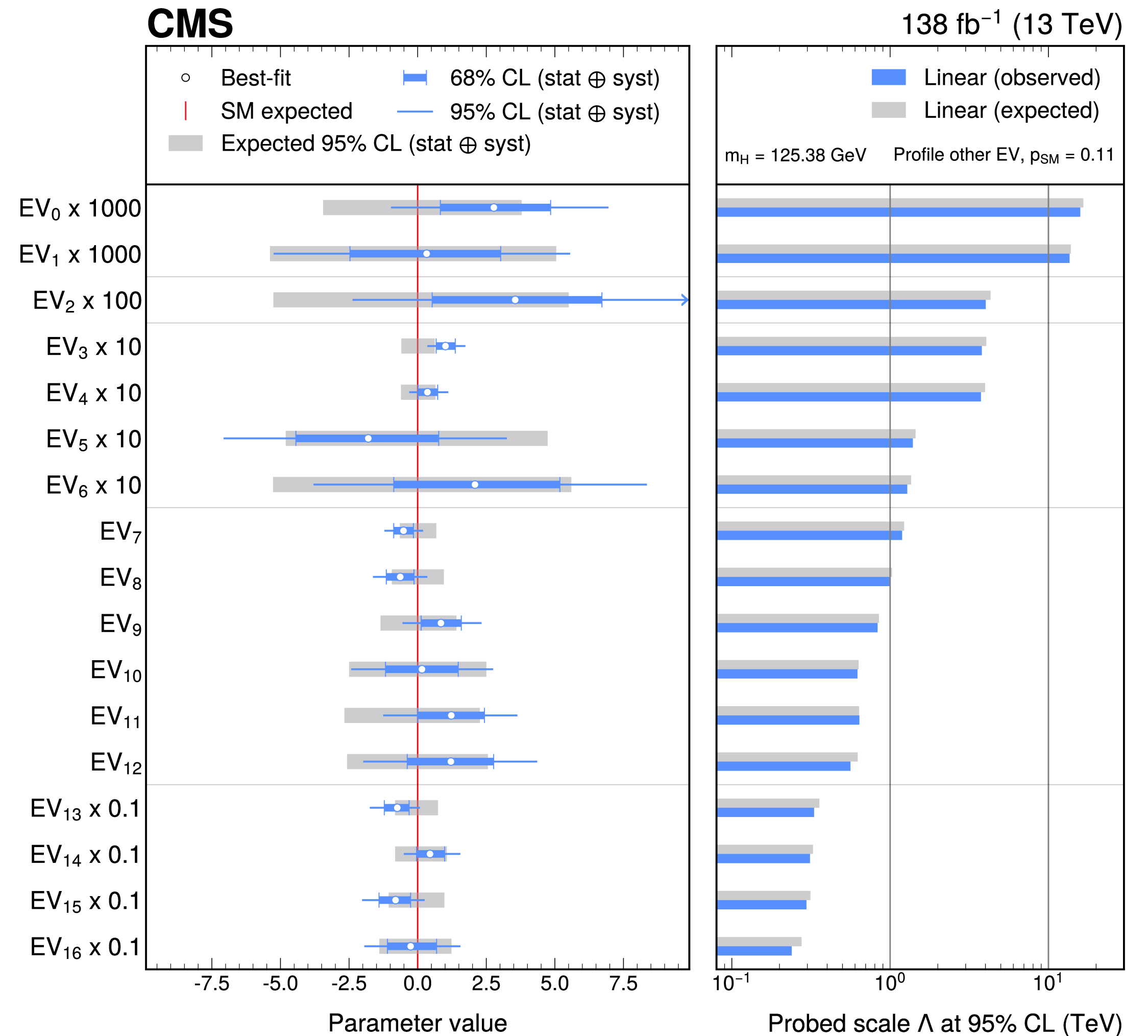
- Interpretations in standard model effective field theory (SMEFT) framework are also provided
 - individual constraints on 43 SMEFT Wilson coefficients
 - simultaneous constraints on 17 linear combinations of SMEFT operators



Combined measurements of Higgs productions and decays

$$\mathcal{L}_{\text{SMEFT}} = \mathcal{L}_{\text{SM}} + \sum_i^{N_{d6}} \frac{c_i}{\Lambda^2} O_i^{(6)} + \sum_j^{N_{d8}} \frac{b_j}{\Lambda^4} O_j^{(8)} + \dots$$

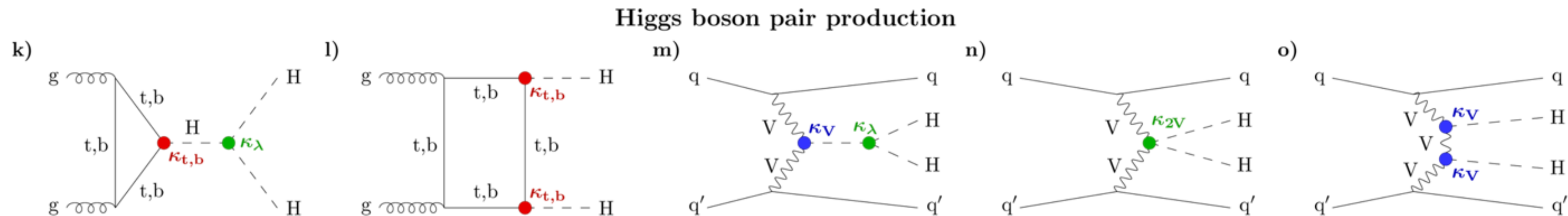
- Interpretations in standard model effective field theory (SMEFT) framework are also provided
 - individual constraints on 43 SMEFT Wilson coefficients
 - simultaneous constraints on 17 linear combinations of SMEFT operators



CMS Run-2 Double Higgs

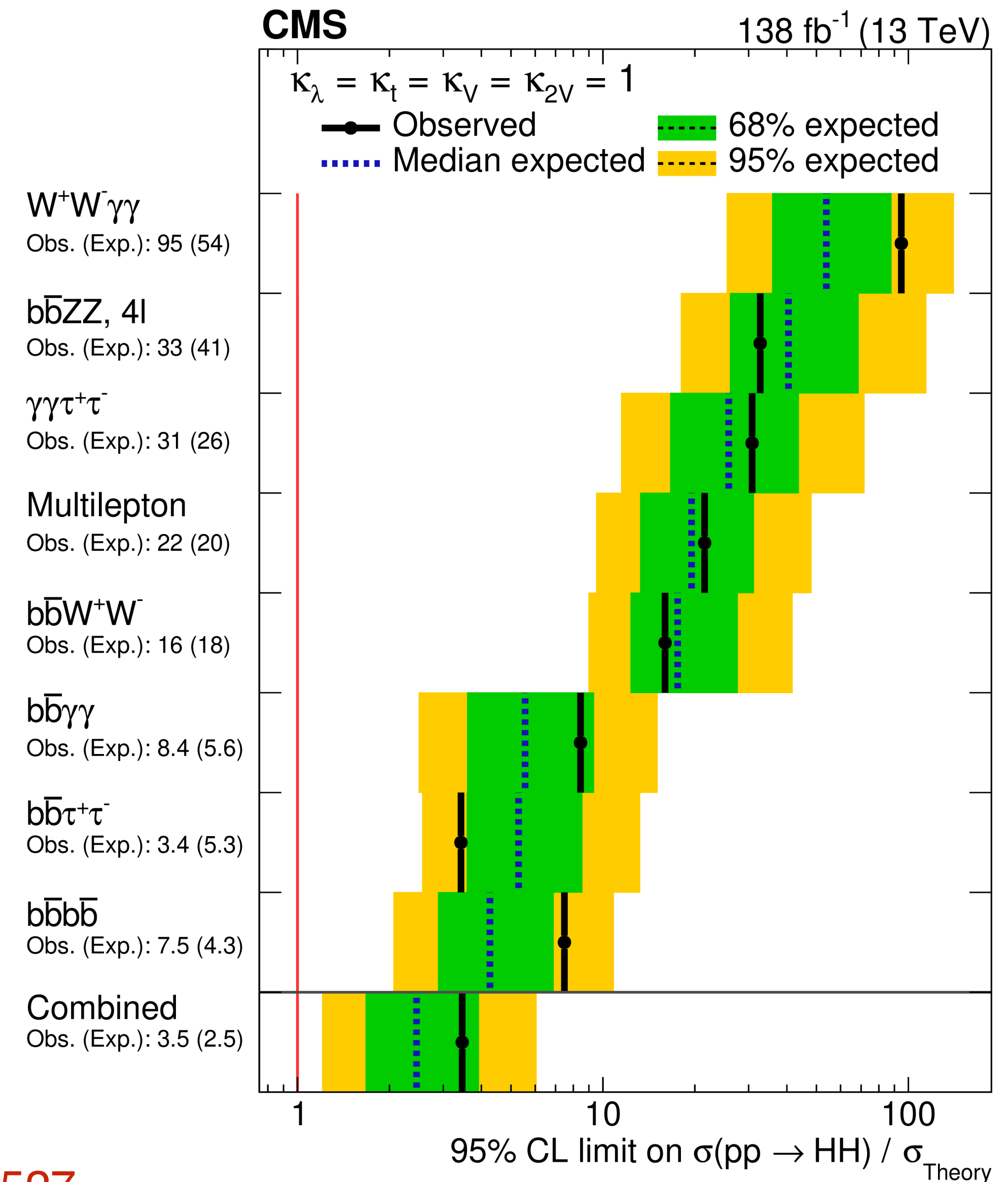
CMS combined analysis of double Higgs production

- **Higgs self-coupling is one of the deepest questions of SM and may provide a portal to new physics beyond it**
 - Vacuum stability, early universe evolution, ...
- **Double Higgs production is the way to directly probe Higgs self-couplings at the LHC**
 - Extremely low cross-section in the SM
 - Non-SM self-coupling strength can change cross-section and kinematics of double Higgs production



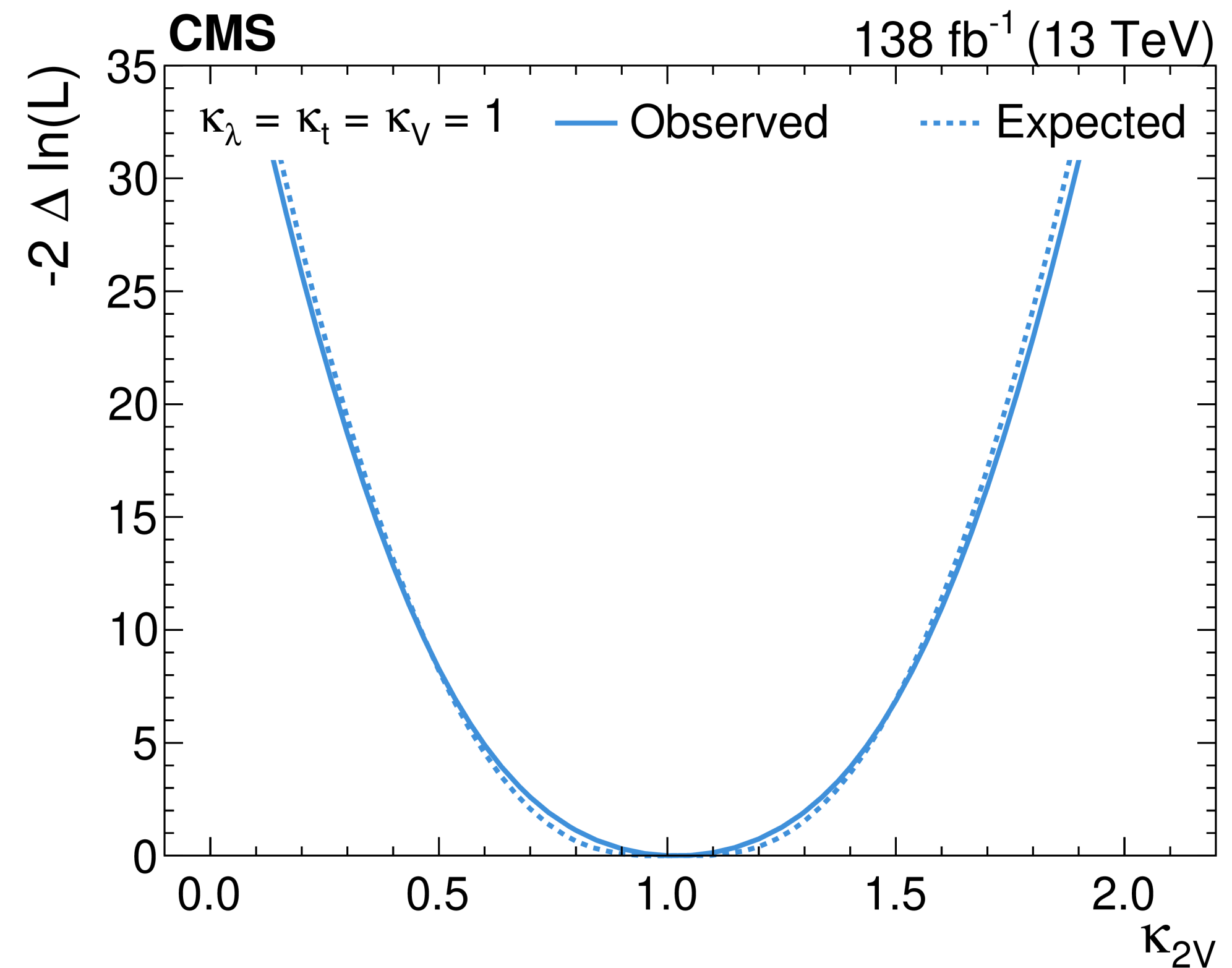
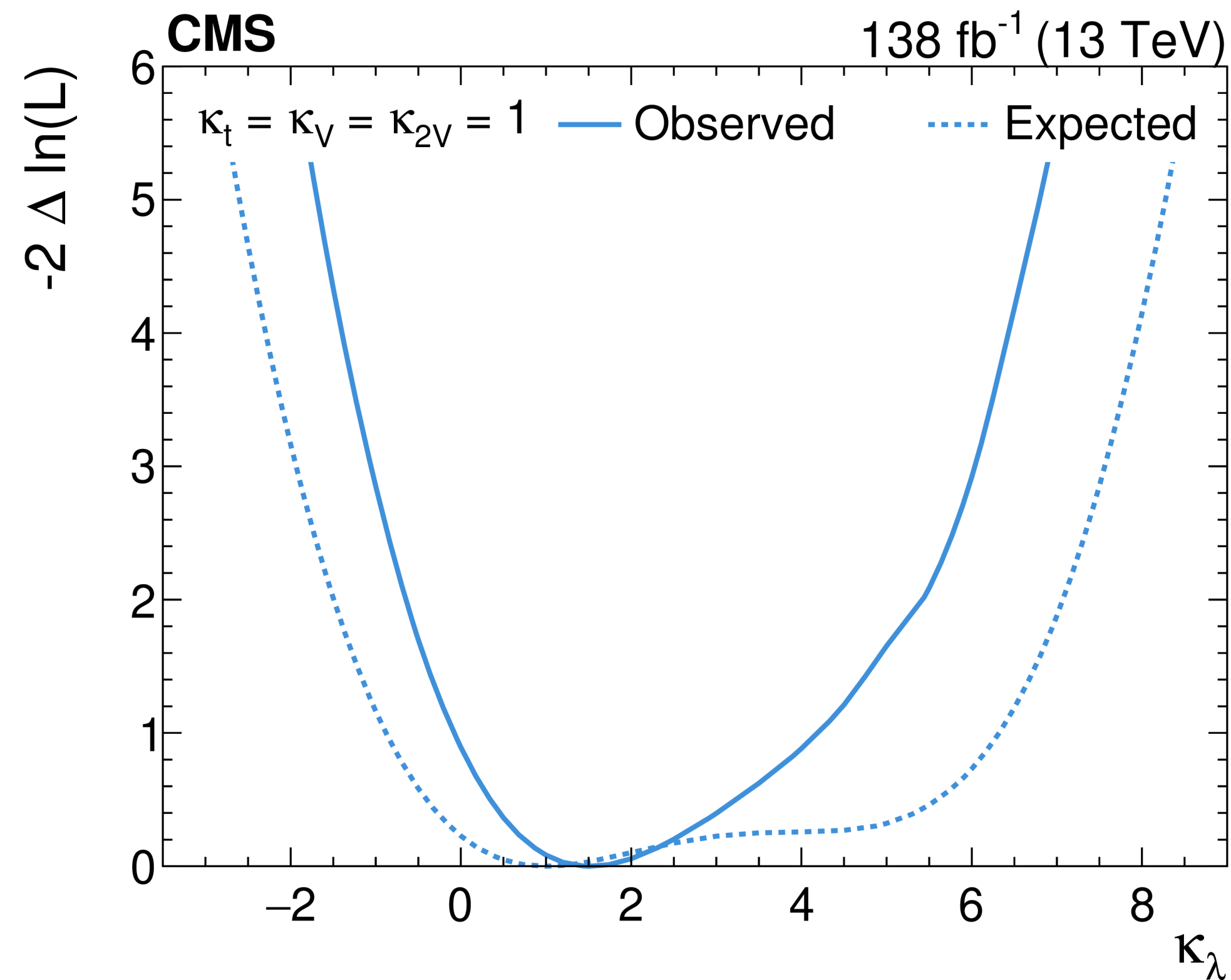
CMS combined analysis of double Higgs production

- Various decay channels have been analyzed and combined
- **Upper limit on the inclusive HH production cross section relative to the SM prediction is found to be 3.5**



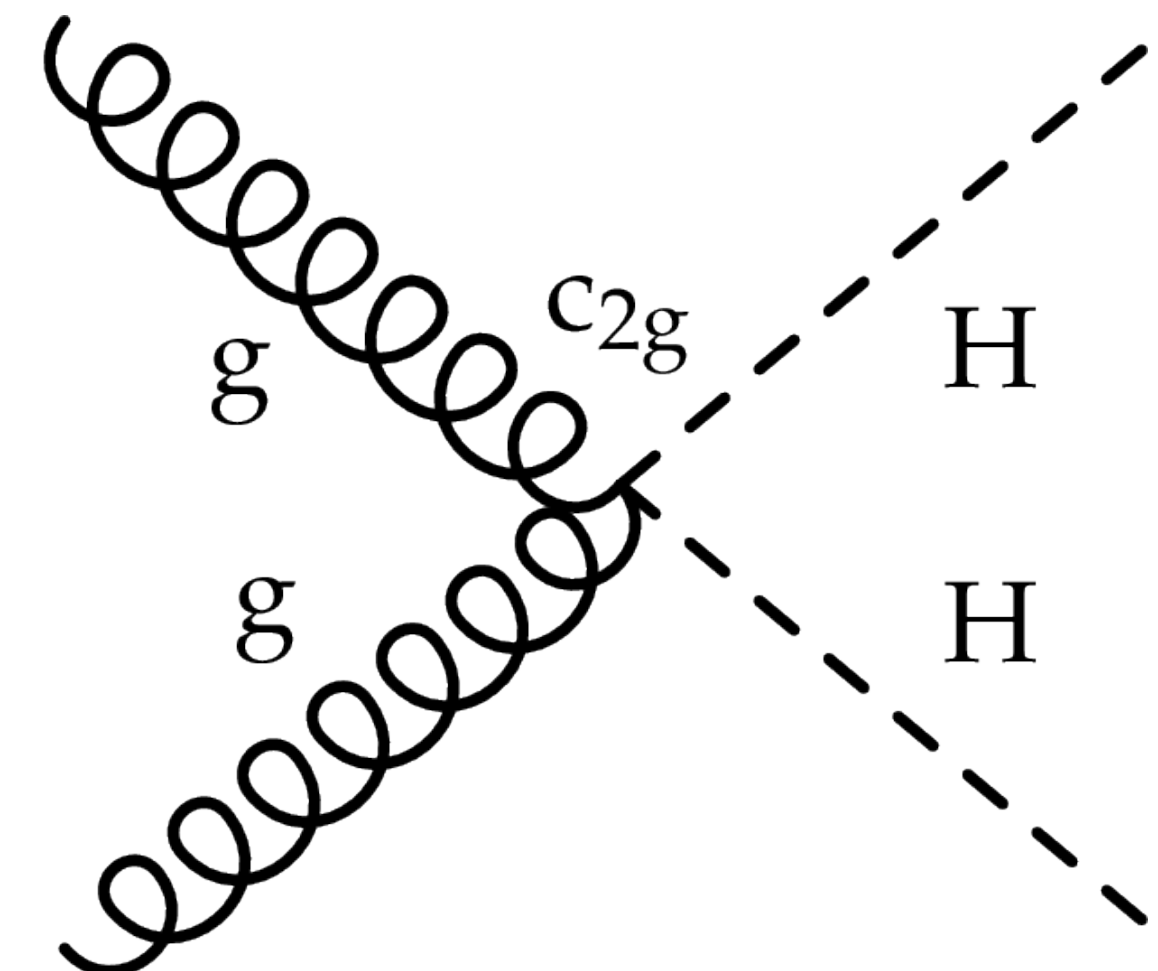
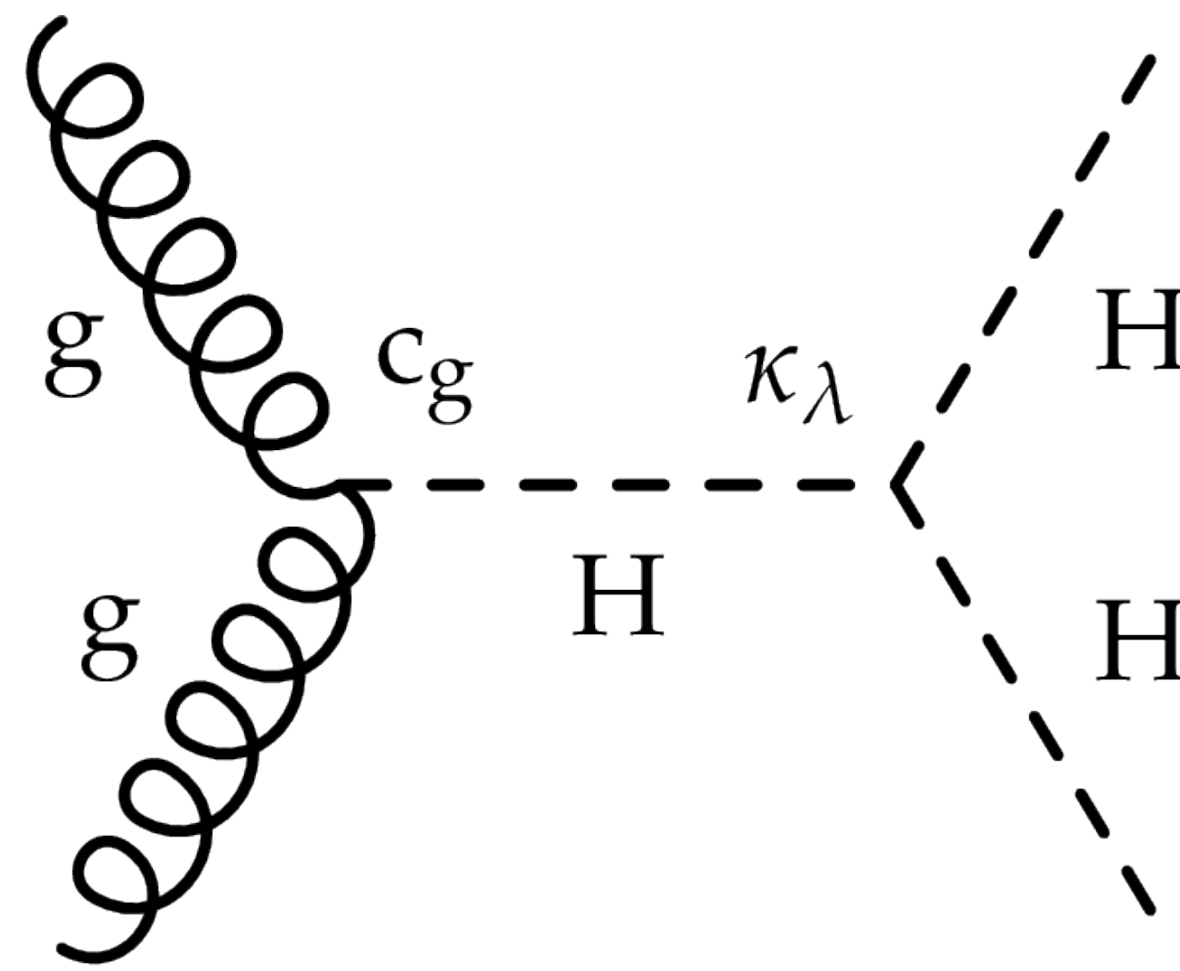
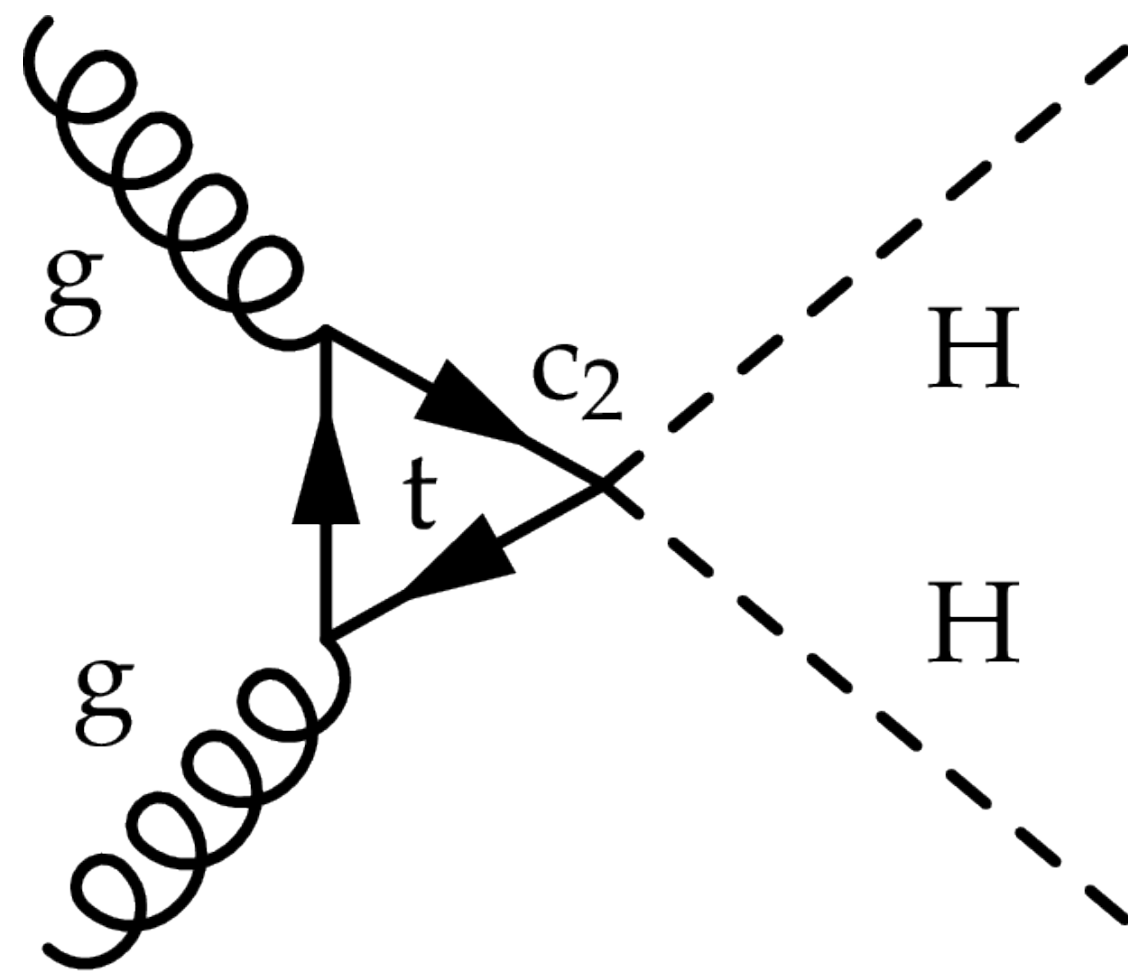
CMS combined analysis of double Higgs production

- **HHH trilinear self-coupling modifier: $-1.35 < \kappa_\lambda < 6.37$**
- **HHVV quartic coupling modifier: $0.64 < \kappa_{2V} < 1.40$**



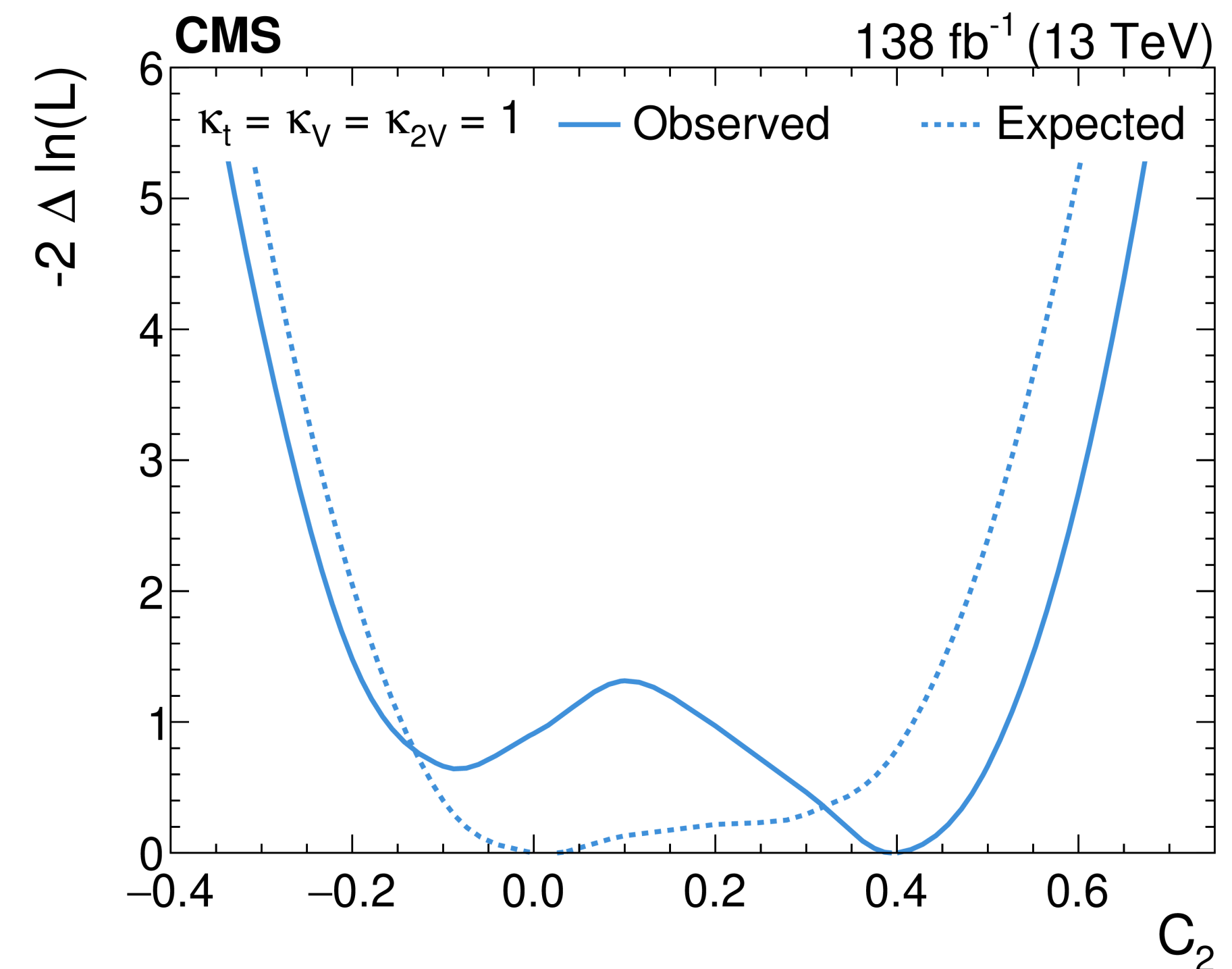
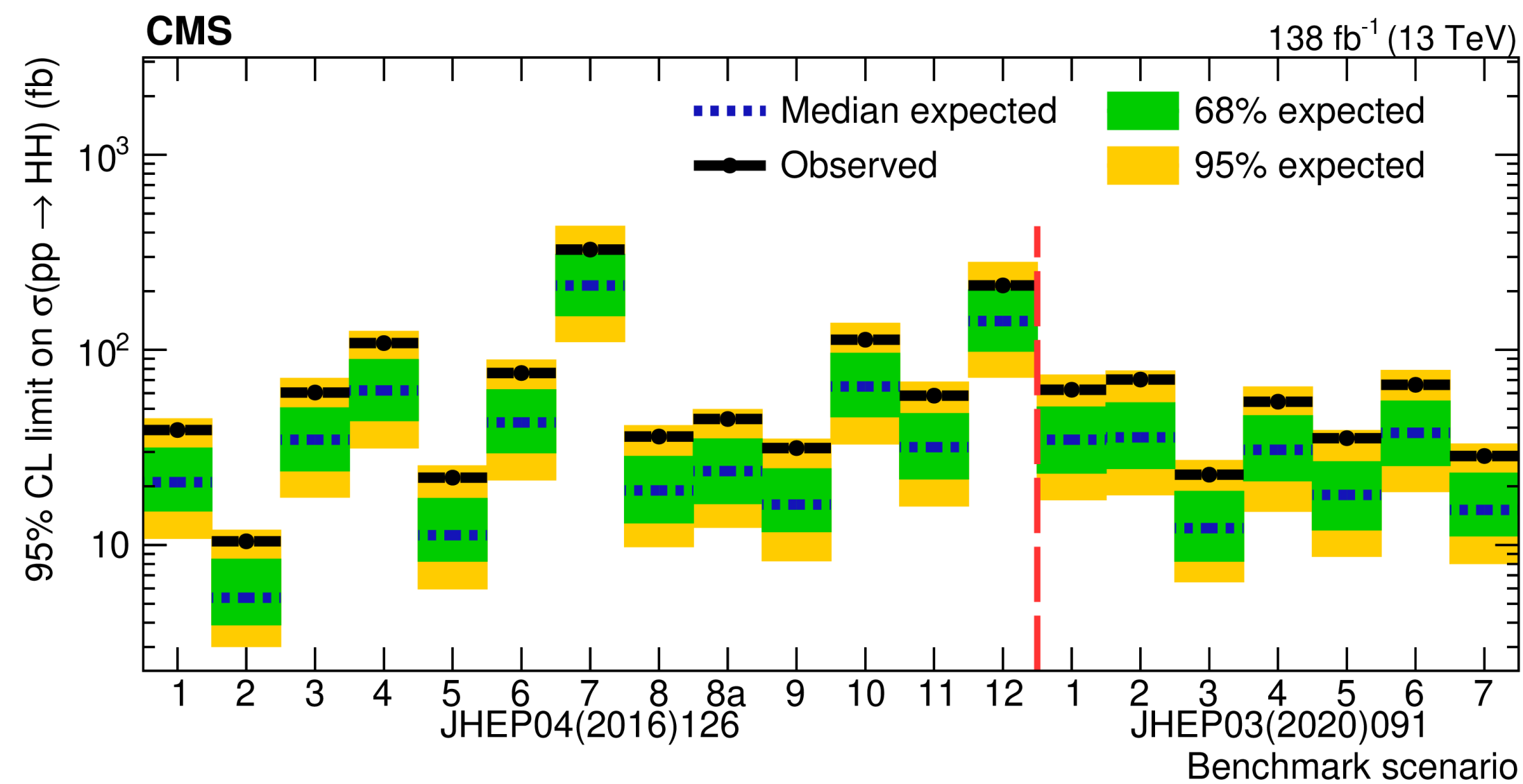
CMS combined analysis of double Higgs production

- Using Higgs effective field theory (HEFT) framework, cross section of ggF HH production was parametrized as a function of anomalous couplings of Higgs boson



CMS combined analysis of double Higgs production

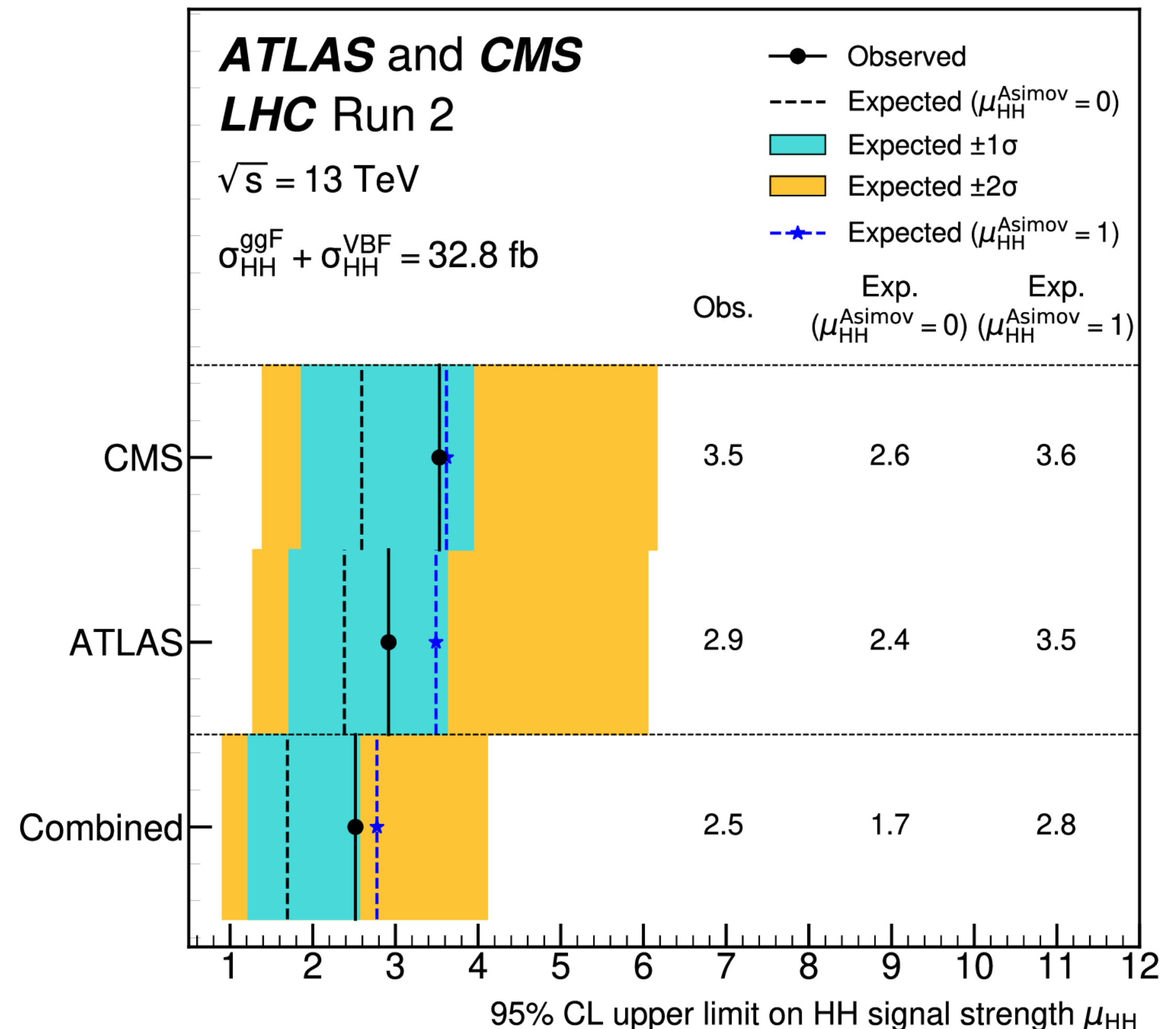
- Limits are set for benchmark signals under different anomalous coupling scenarios
- BSM coupling modifier $c_2(=c_{ttHH})$ is constrained between -0.28 and 0.59
- HEFT framework is further exploited to study various ultraviolet complete models with an extended Higgs sector



LHC Run-2 Double Higgs

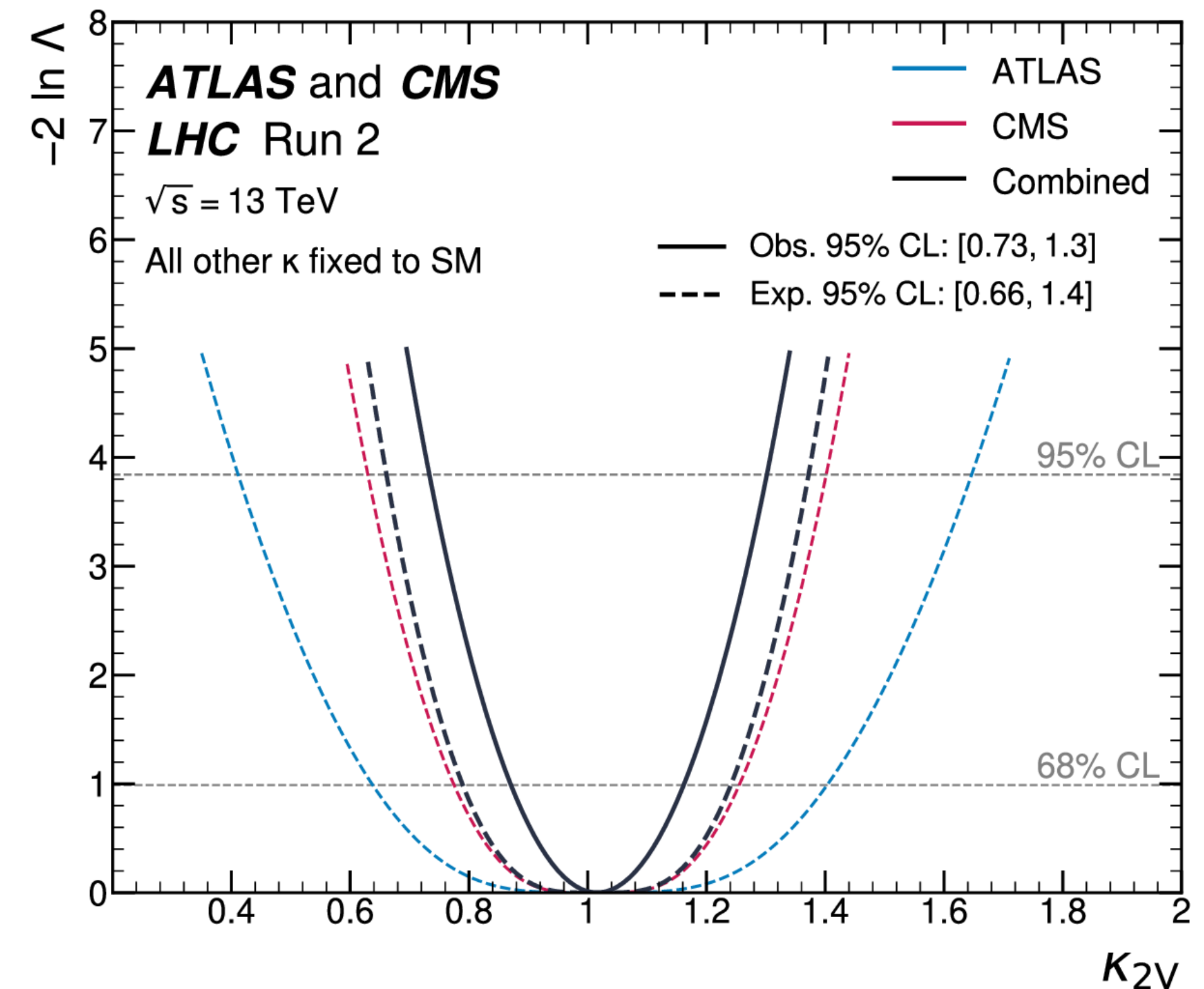
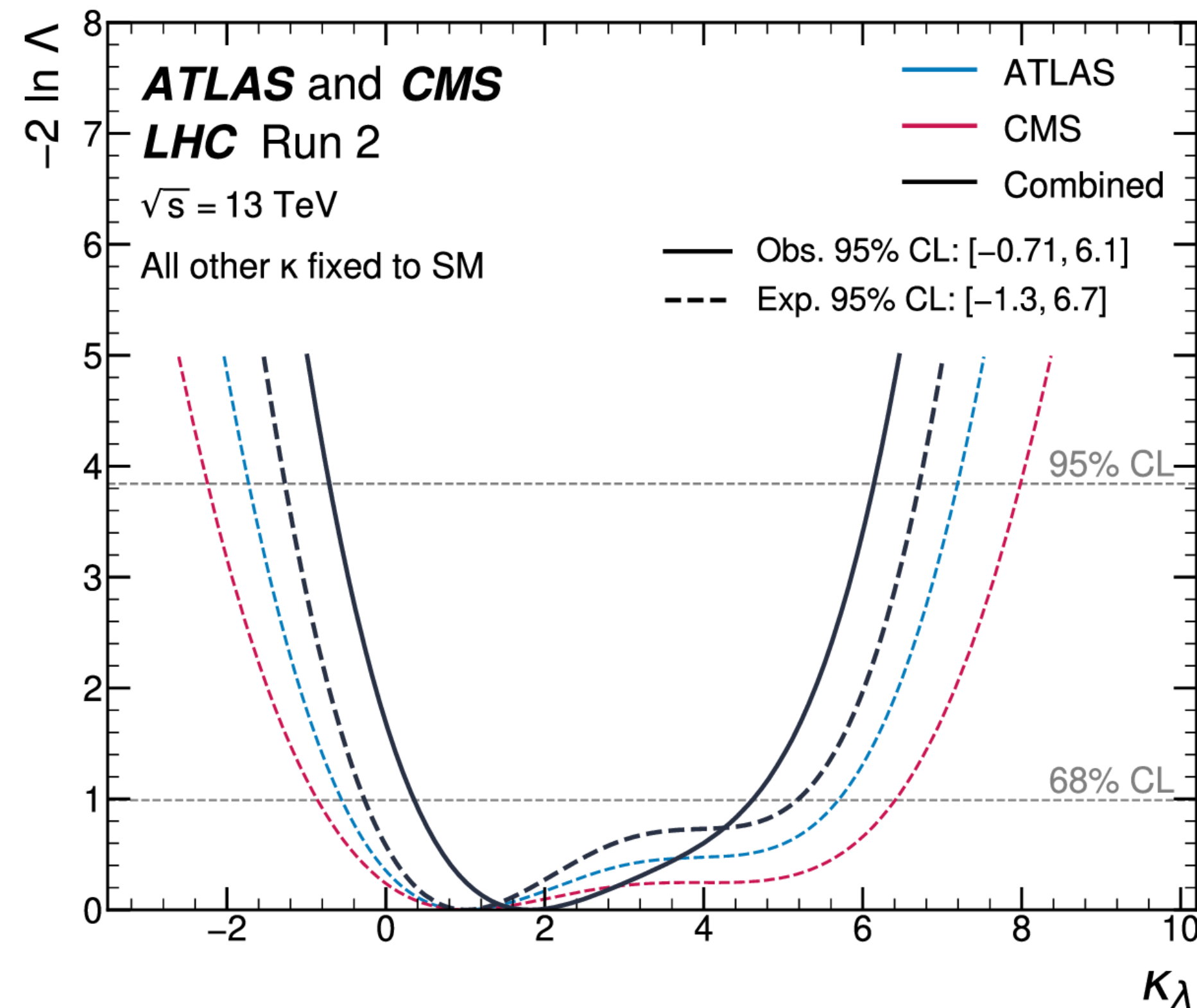
LHC combined analysis of double Higgs production

- First combination of ATLAS and CMS HH searches
- **Upper limit on the inclusive HH production cross section relative to the SM prediction is found to be 2.5**
- **Observed significance: 1.1sigma**



CMS combined analysis of double Higgs production

- **HHH trilinear self-coupling modifier: $-0.71 < \kappa_\lambda < 6.1$**
- **HHVV quartic coupling modifier: $0.73 < \kappa_{2V} < 1.3$**



Summary and outlook

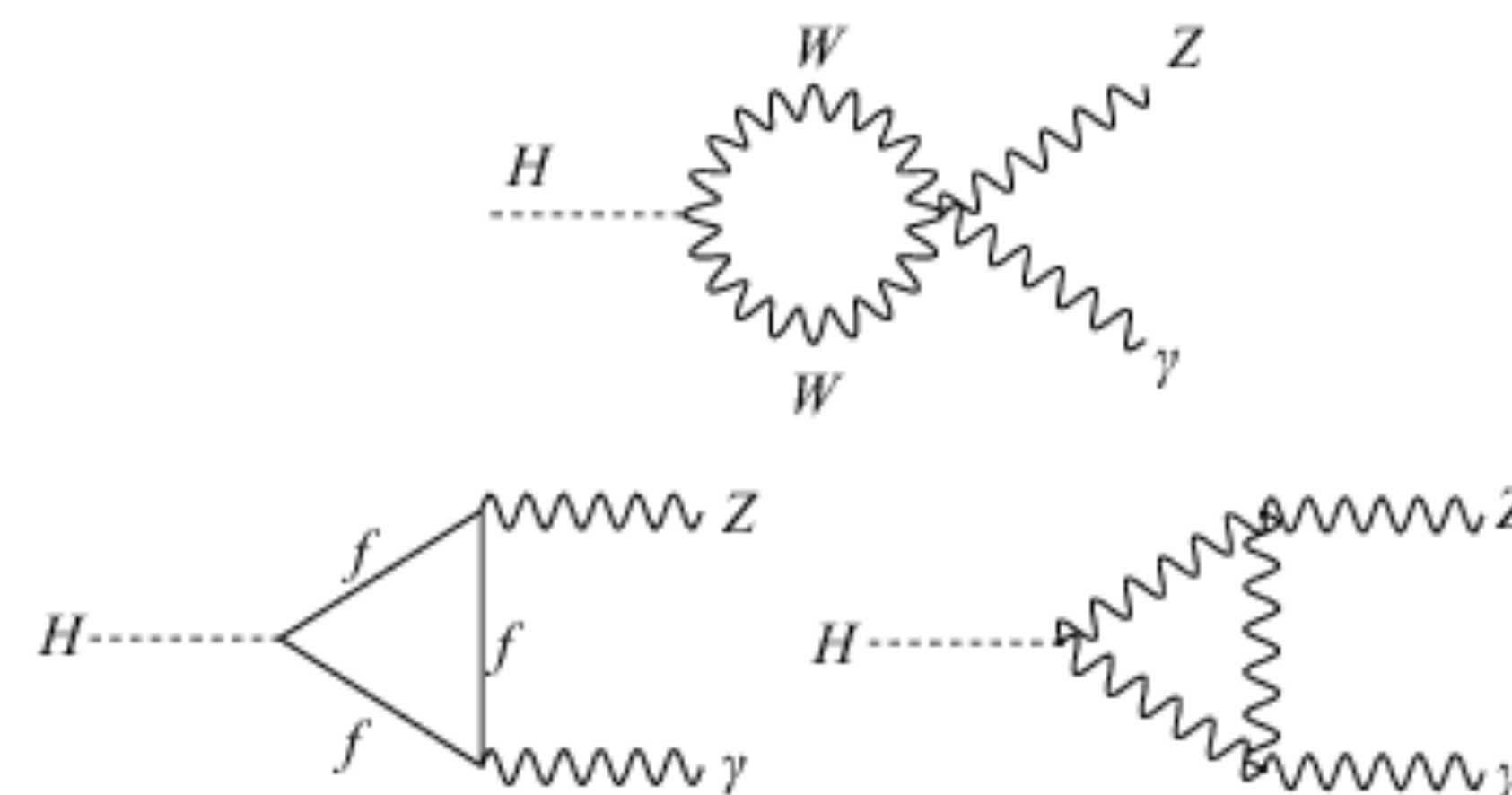
Summary and outlook

- CMS experiment keeps **improving precision and granularity in combined Higgs measurements**
 - Results can be interpreted using kappa and EFT models
 - Currently in agreement with the SM predictions
- Run 2 data analysis should be completed soon:
 - LHC combination of single Higgs (mass and couplings), etc.
- Run 3 data taking is finished! We foreseen:
 - CMS combination of single Higgs (e.g. differential cross sections), double Higgs, etc.

Thank you!

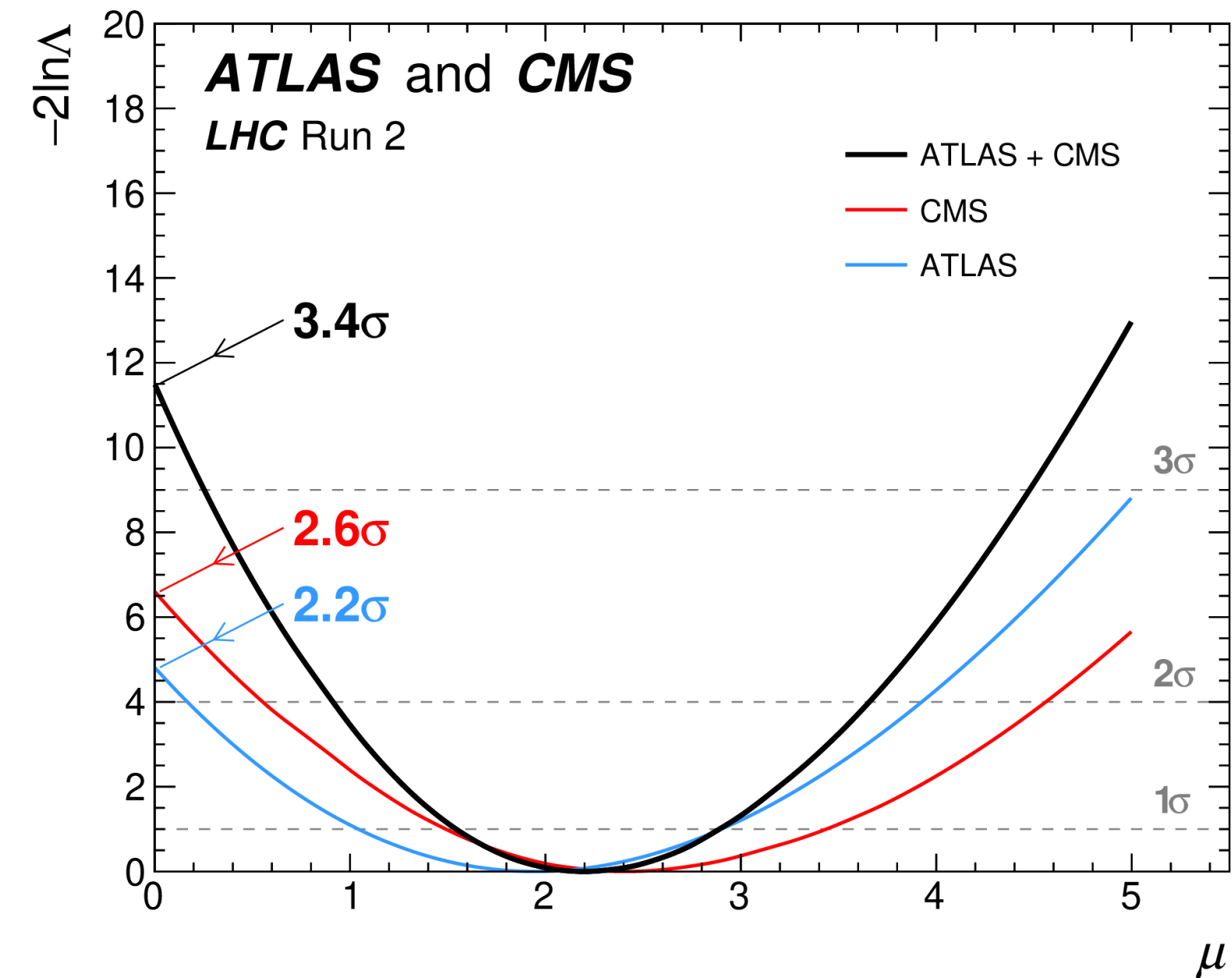
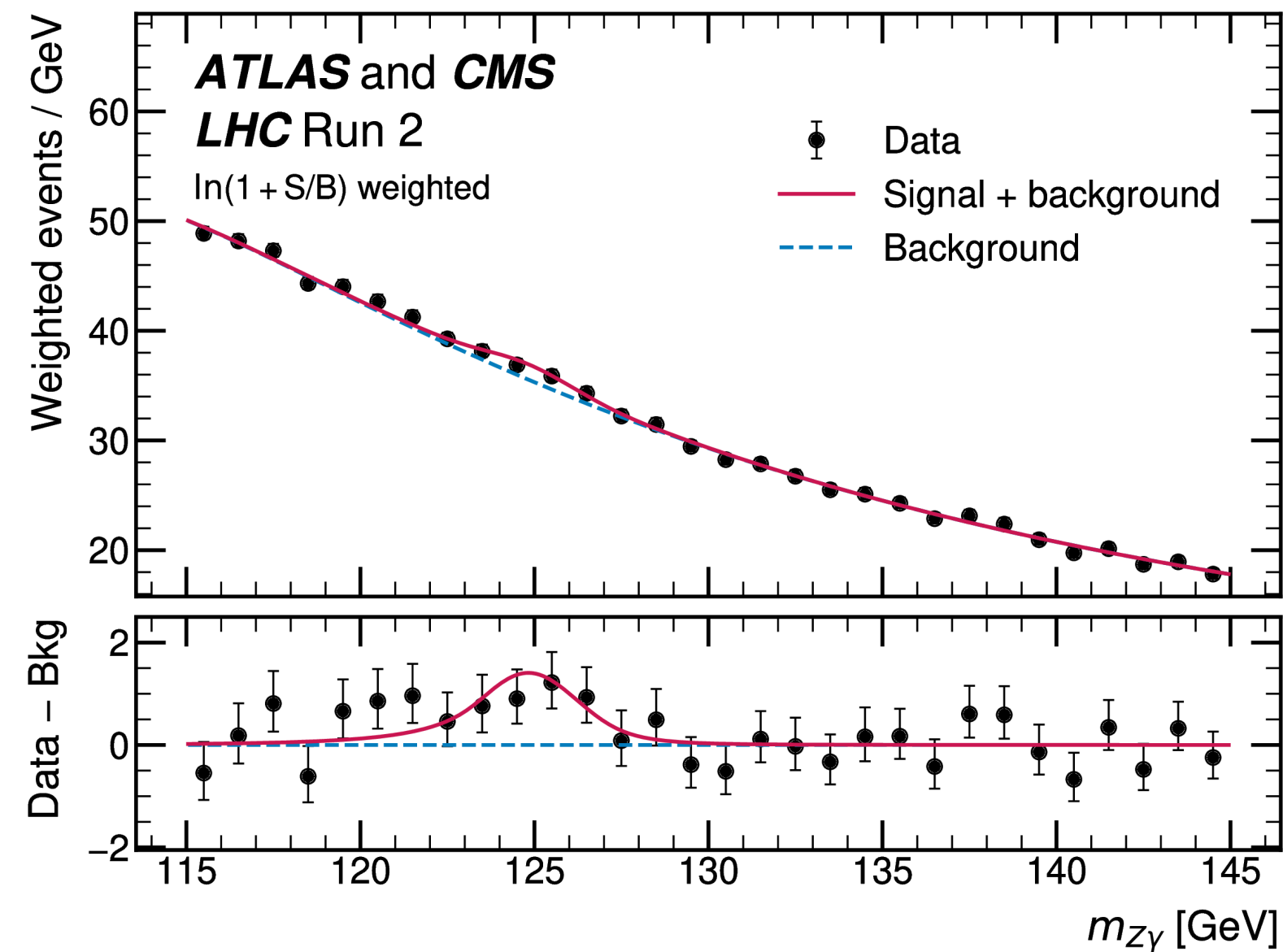
LHC combined analysis of $H \rightarrow Z\gamma$ decay

- BSM particles & couplings could be present in the quantum loops
- Difference between $H \rightarrow Z\gamma$ decay and $H \rightarrow \gamma\gamma/H \rightarrow ZZ$ decay sensitive to new physics
 - (e.g. Qing-Hong Cao et al. *Phys. Lett. B* 789 (2019) 233)
- Small branching ratio in SM (1.6×10^{-3}); main bkg: non-Higgs $Z\gamma$, Z +jets
- Select events with two leptons ($m_{ll} \sim 90$ GeV) and one photon and separate them to multiple categories to target various production modes
- Fit in $l\bar{l}\gamma$ mass distribution over all categories



LHC combined analysis of $H \rightarrow Z\gamma$ decay

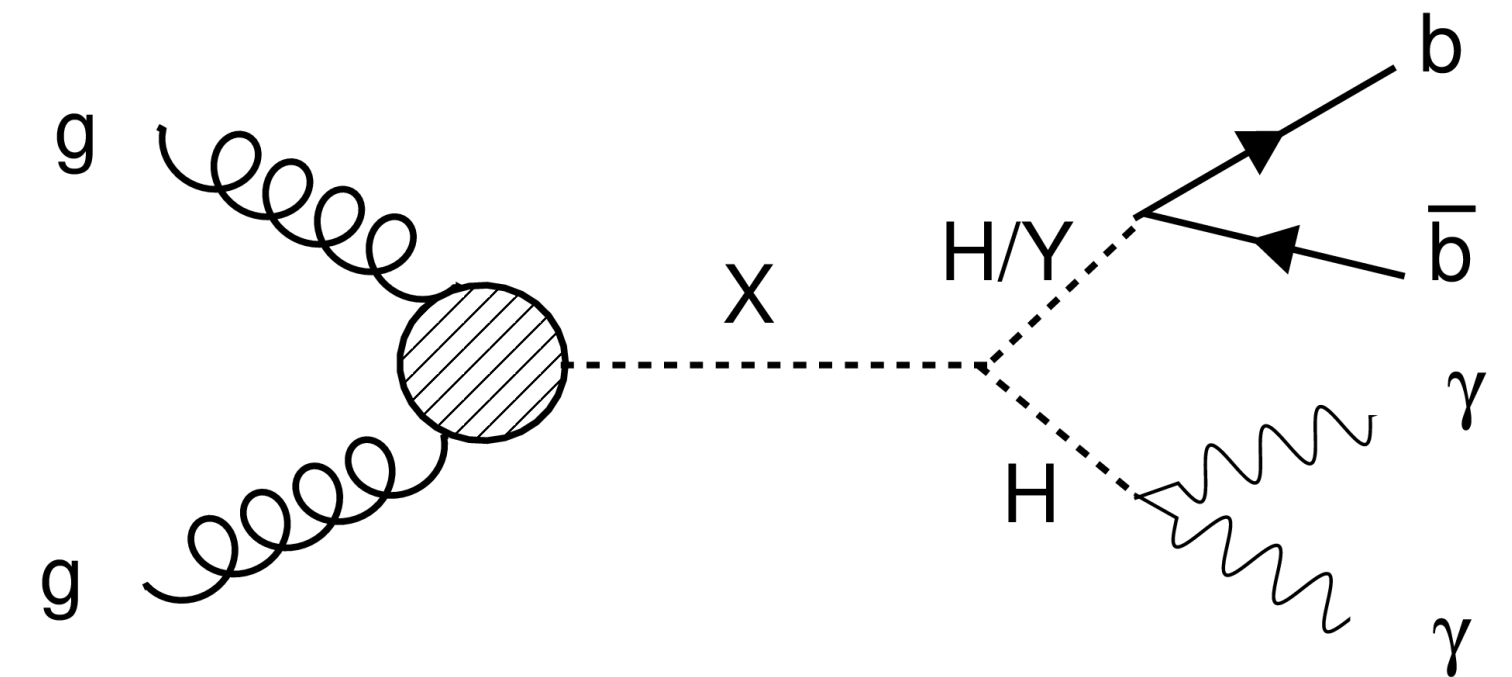
[Phys. Rev. Lett. 132 \(2024\) 021803, Featured in Physics](#)



- The observed $H \rightarrow Z\gamma$ significance in ATLAS+CMS combined result is **3.4σ** (expected 1.6σ)
- **First evidence** of the $H \rightarrow Z\gamma$ decay
- Signal strength is 2.2 ± 0.7 : agrees with theoretical expectation within **1.9σ**
- With the ongoing Run3 of the LHC, we will be able to improve the precision of this rare Higgs decay

Resonant production of Higgs boson

- Heavy resonance search channels including at least one Higgs boson have formed an important part of the program of new physics searches at the LHC
- Sensitive to many new physics models, including extended Higgs sectors and extra dimensions



Resonant production of Higgs boson

- Summarizing and combining search channels at CMS, we obtain cross section limits on resonant production of Higgs boson and constraints on relevant new physics models

