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Measurement of Higgs boson properties from ATLAS and CMS

Hongtao Yang (杨洪洮)

University of Science and Technology of China

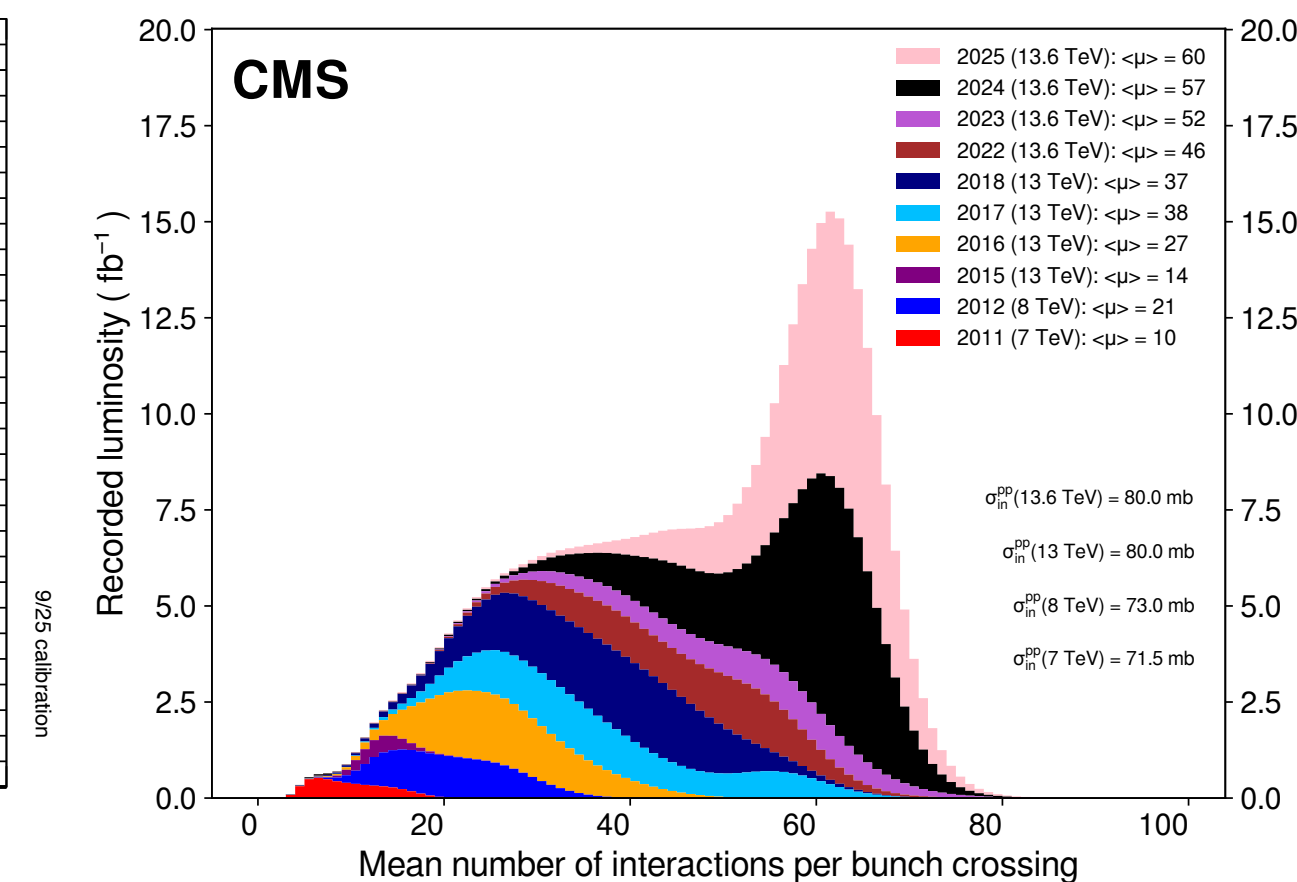
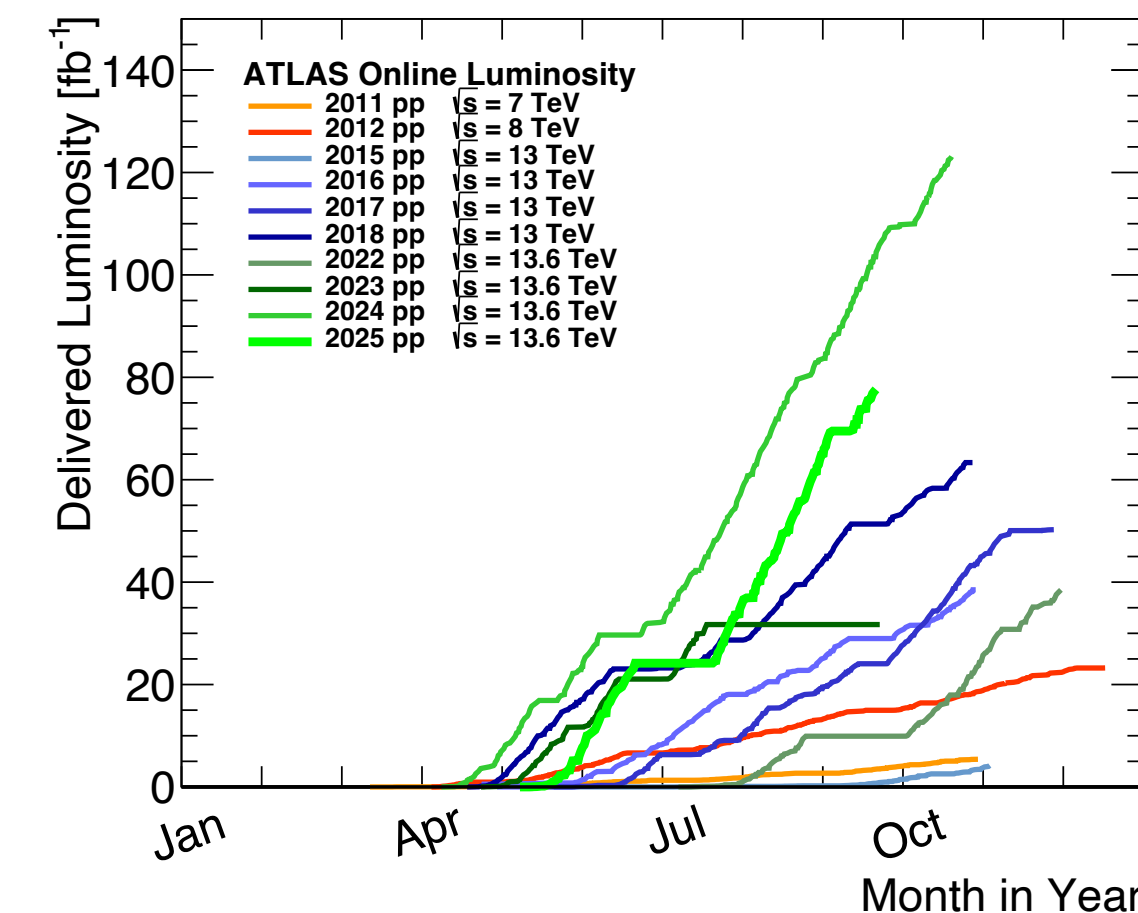
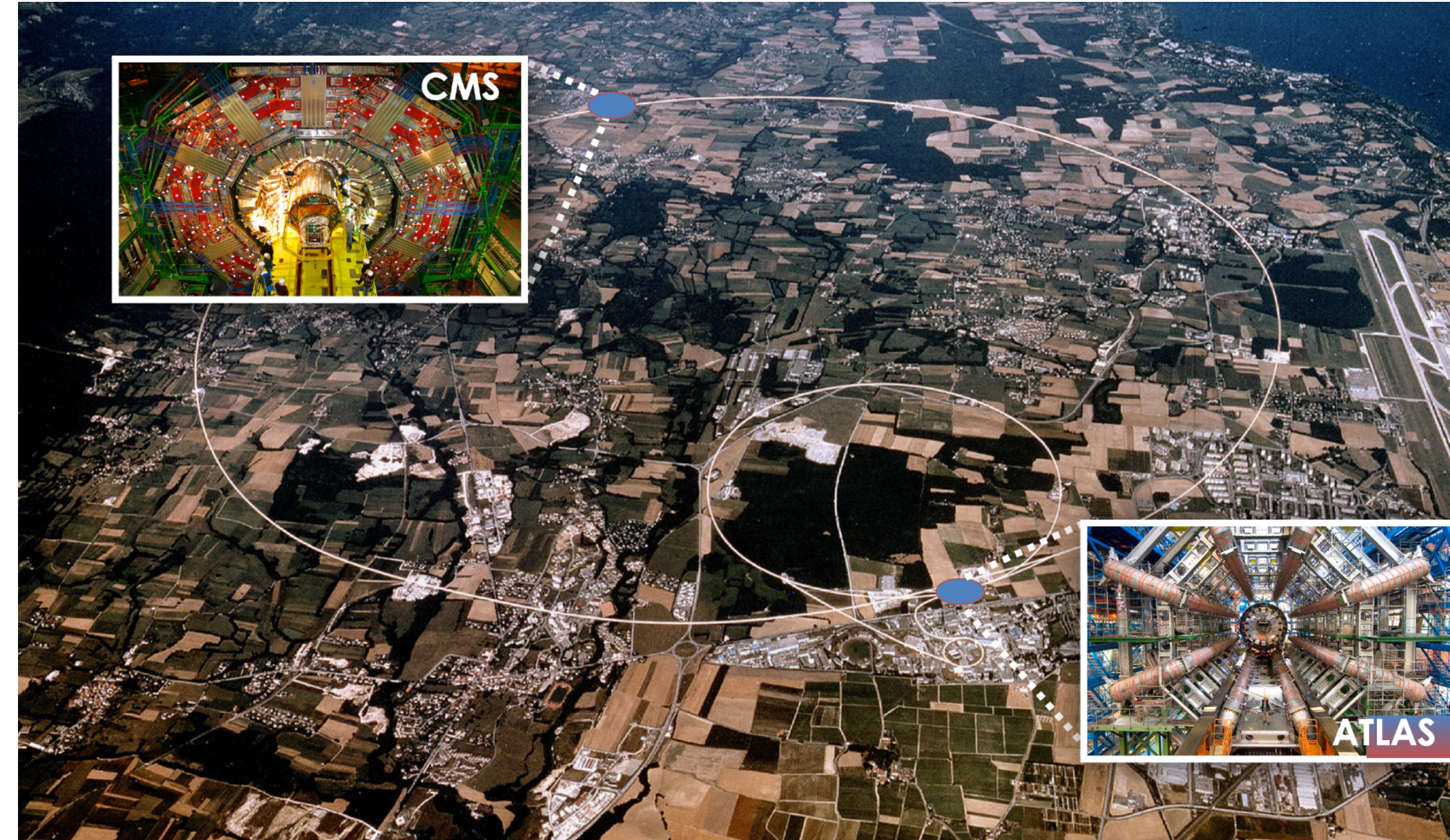
The 11th China LHC Physics Conference, Xinxiang, Henan

October 31, 2025



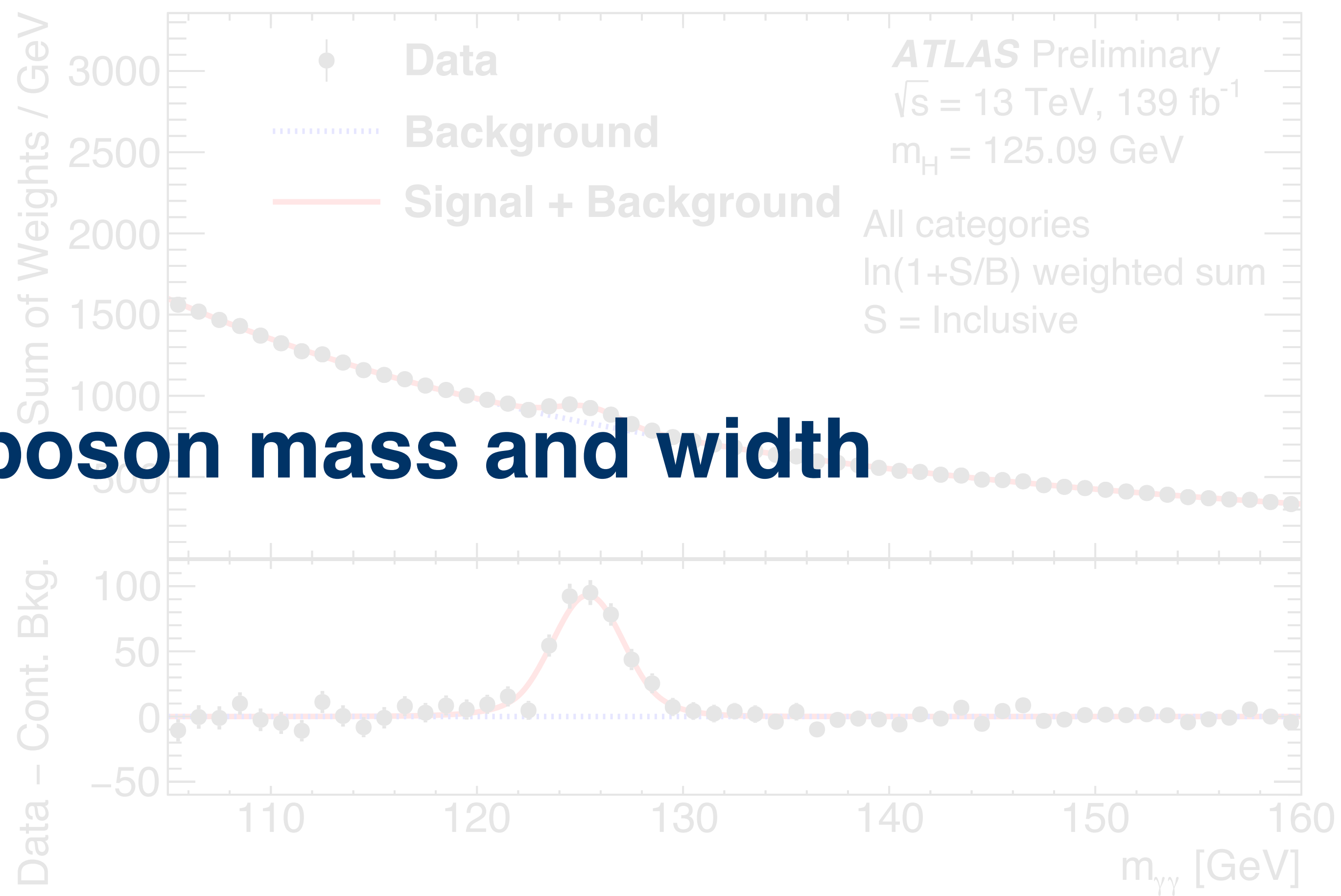
Introduction

- LHC provides unique opportunities to study Higgs boson properties
 - Complementary to future Higgs factory
 - Great test ground for new techniques
- Chinese community make strong contributions to LHC Higgs physics
- My talk will focus on results released since CLHCP 2024
 - Including **Run 3** results & results just released for the **Higgs 2025** conference!
 - *Biased personal selection. Apologies if your favorite topic is not covered!*

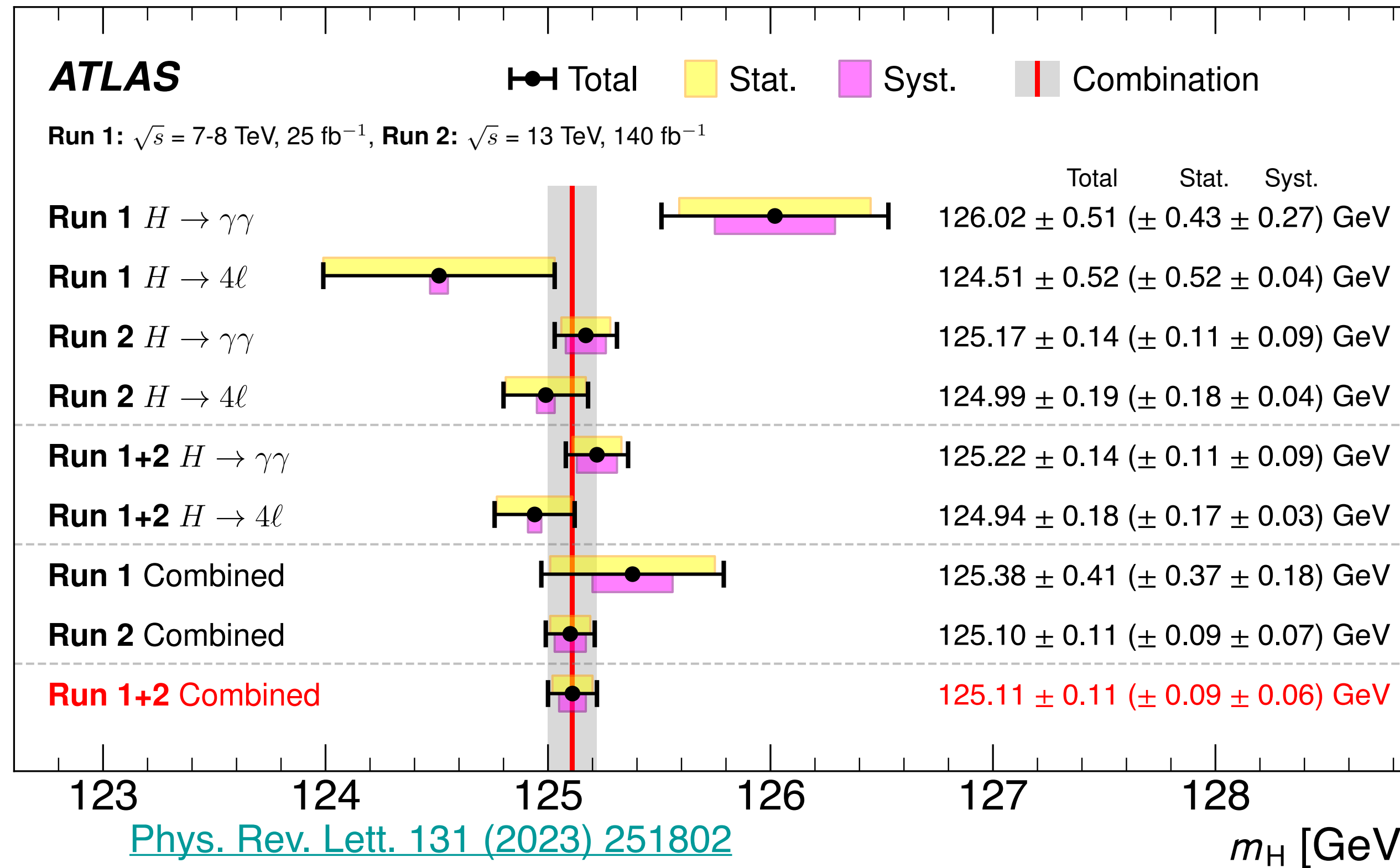




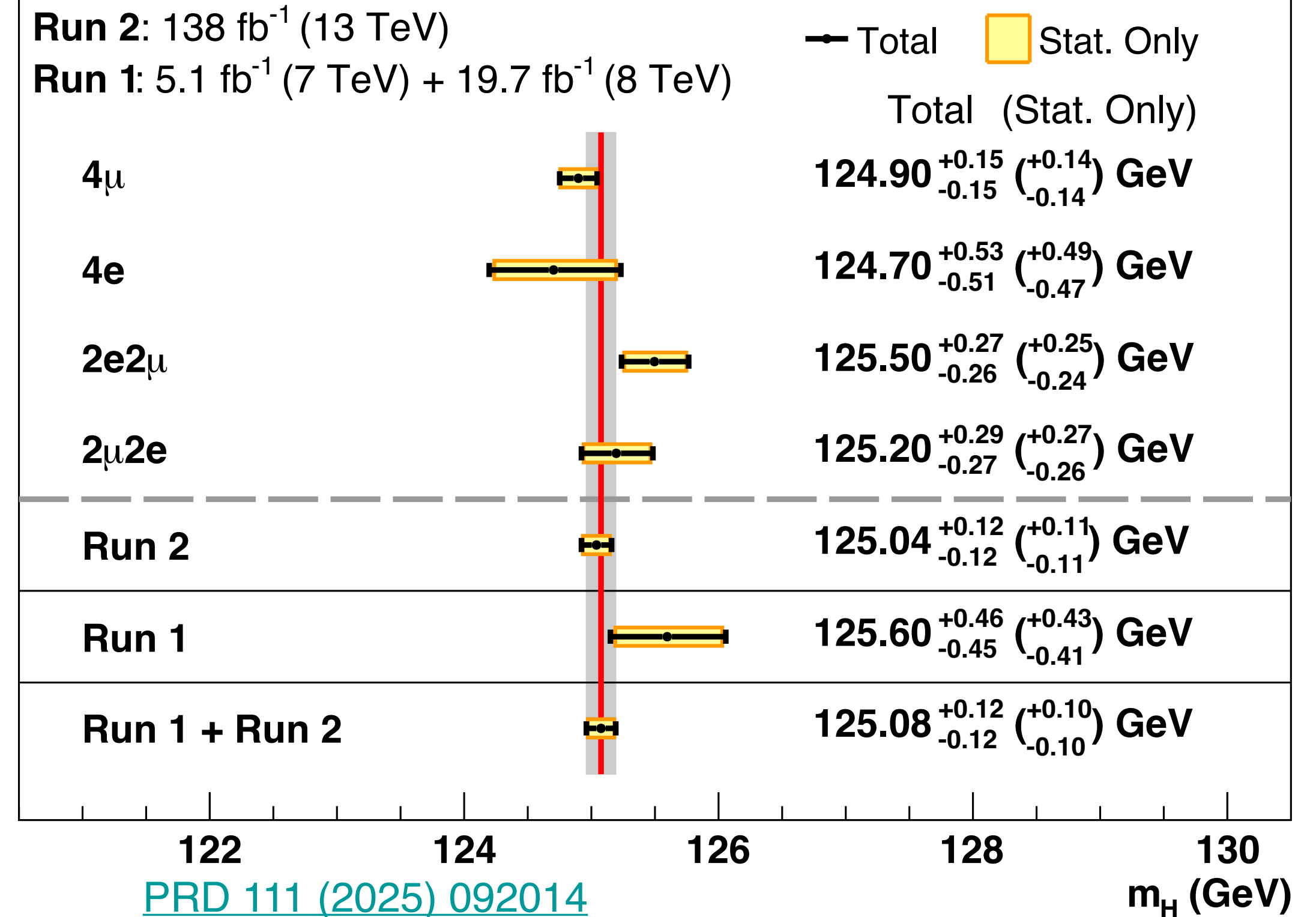
Higgs boson mass and width



Higgs boson mass measurement



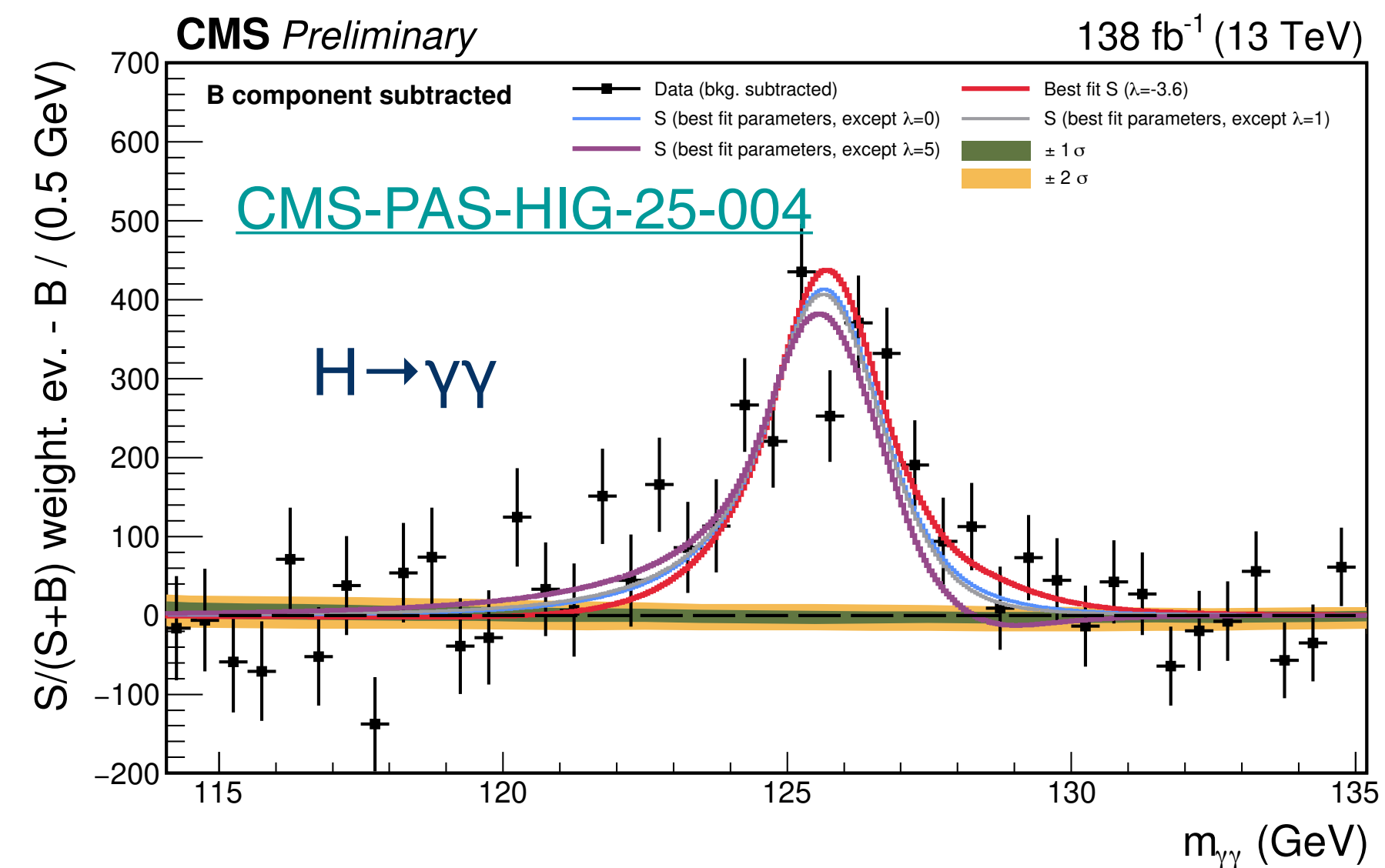
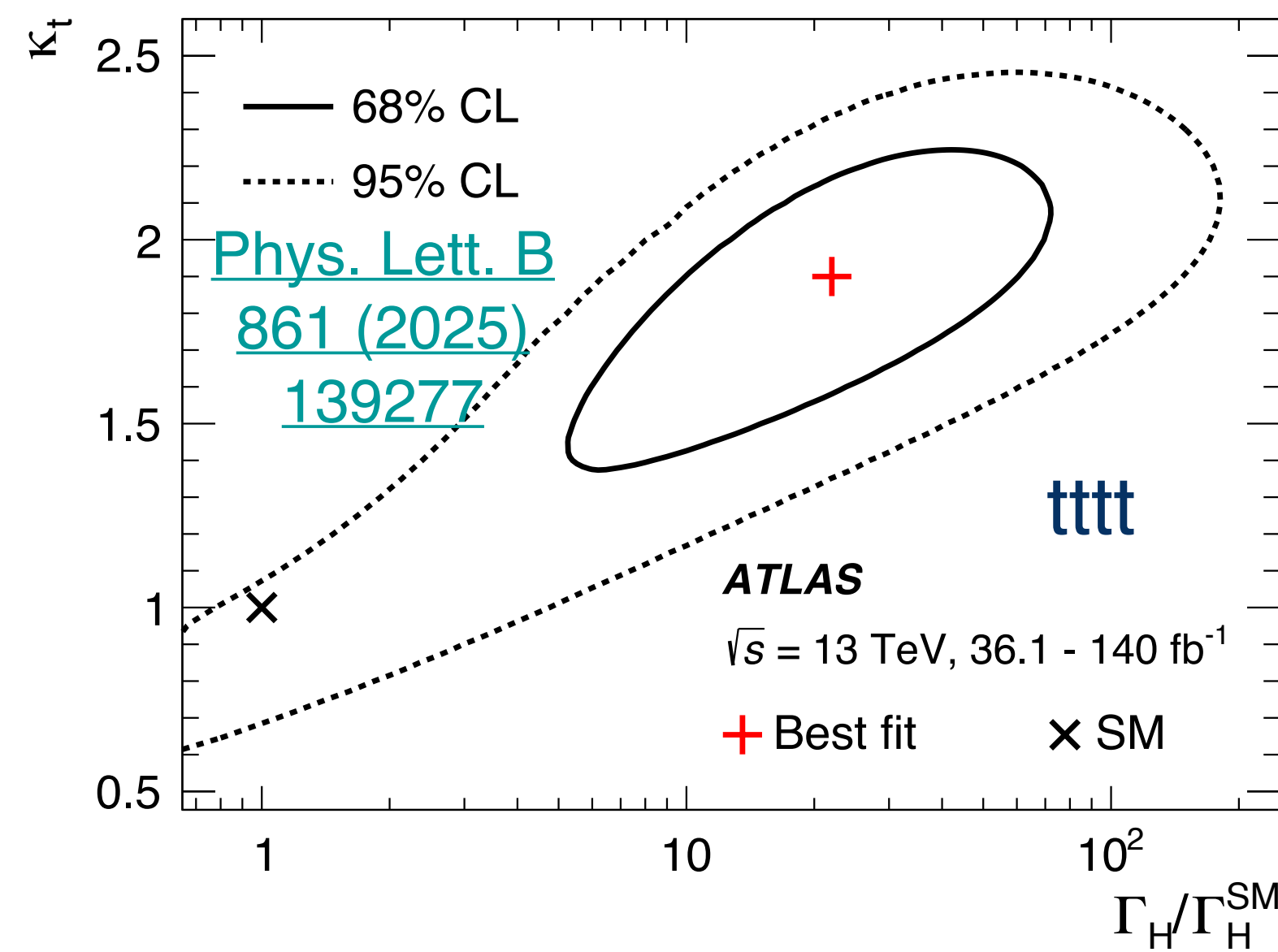
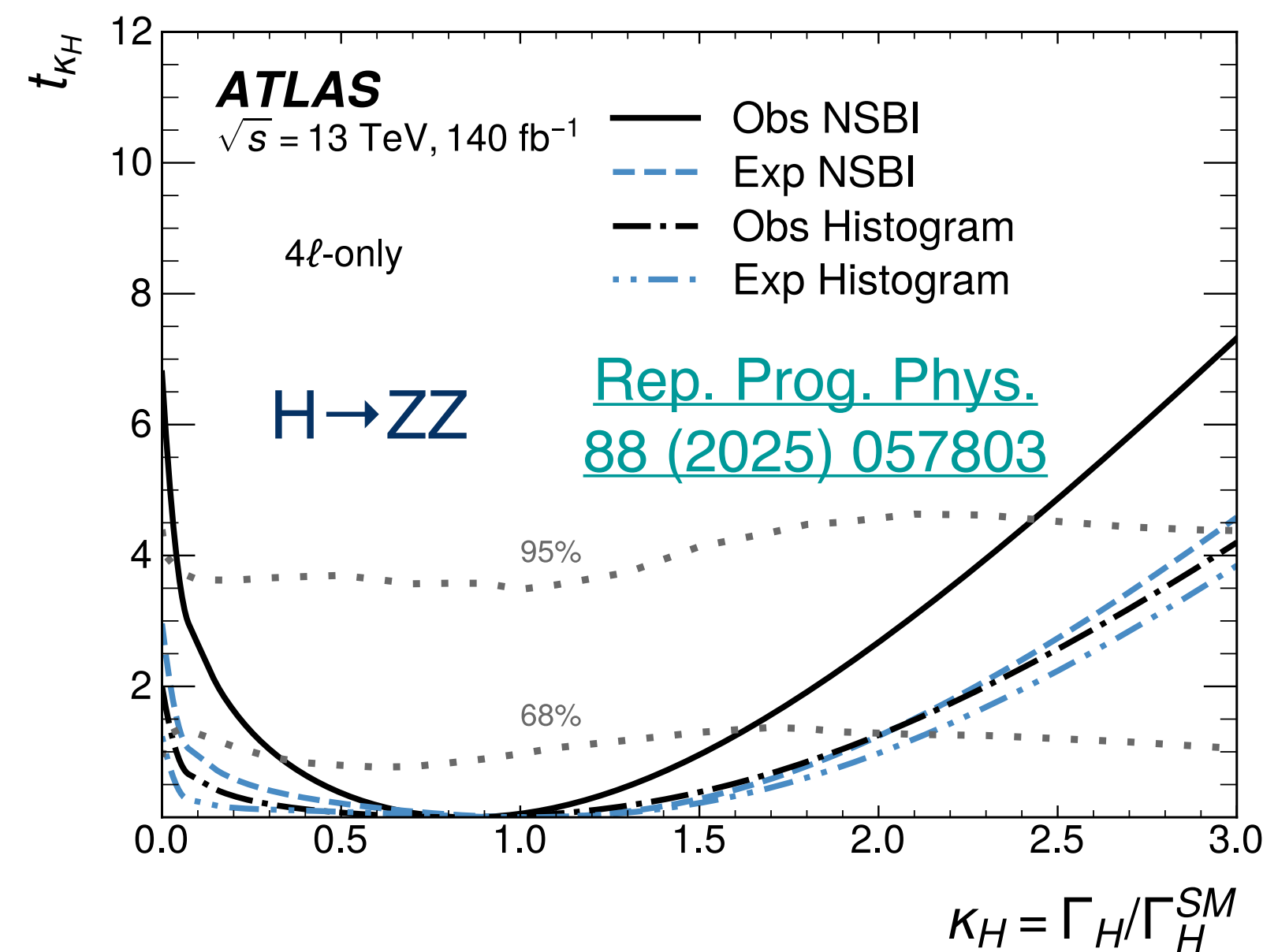
CMS



- m_H is a free parameter in SM to be measured by experiment
 - Important for validating SM consistency, understanding vacuum stability etc.
- LHC combination to be carried out after CMS $H \rightarrow \gamma\gamma$ available

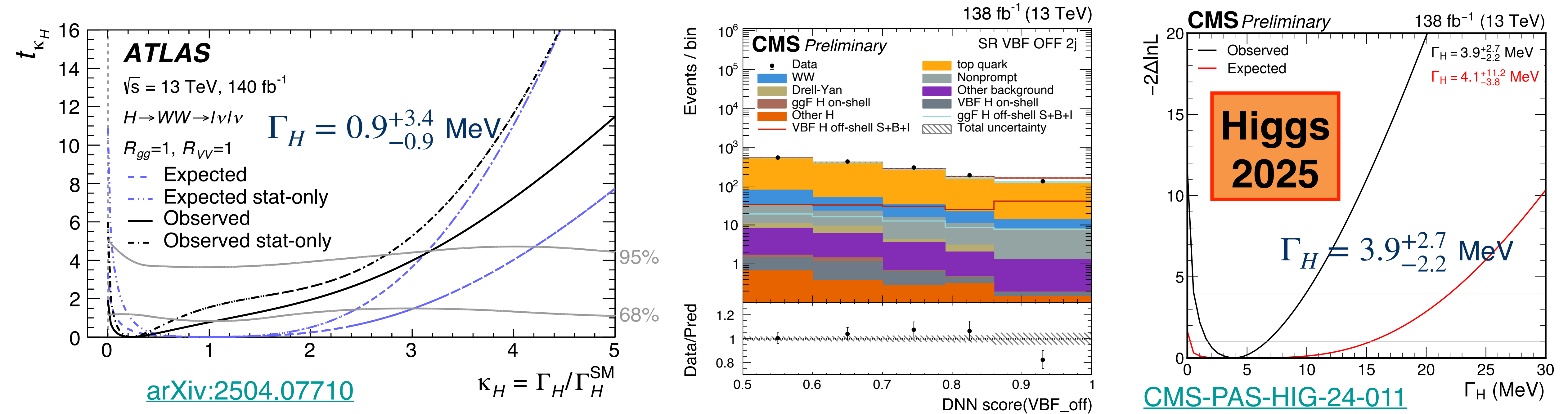


New ideas for Higgs boson width measurement



- Γ_H is a key property of Higgs boson. Results based on new ideas:
 - $H \rightarrow ZZ$ neural-network-based likelihood: $\Gamma_H = 4.3^{+2.7}_{-1.9} \text{ MeV}$
 - Direct top Yukawa coupling from tttt/ttH: $\Gamma_H < 450 \text{ MeV @95% CL}$
 - Interference between $H \rightarrow \gamma\gamma$ and $\gamma\gamma$ continuum: $\Gamma_H < 92 \text{ MeV @95% CL}$

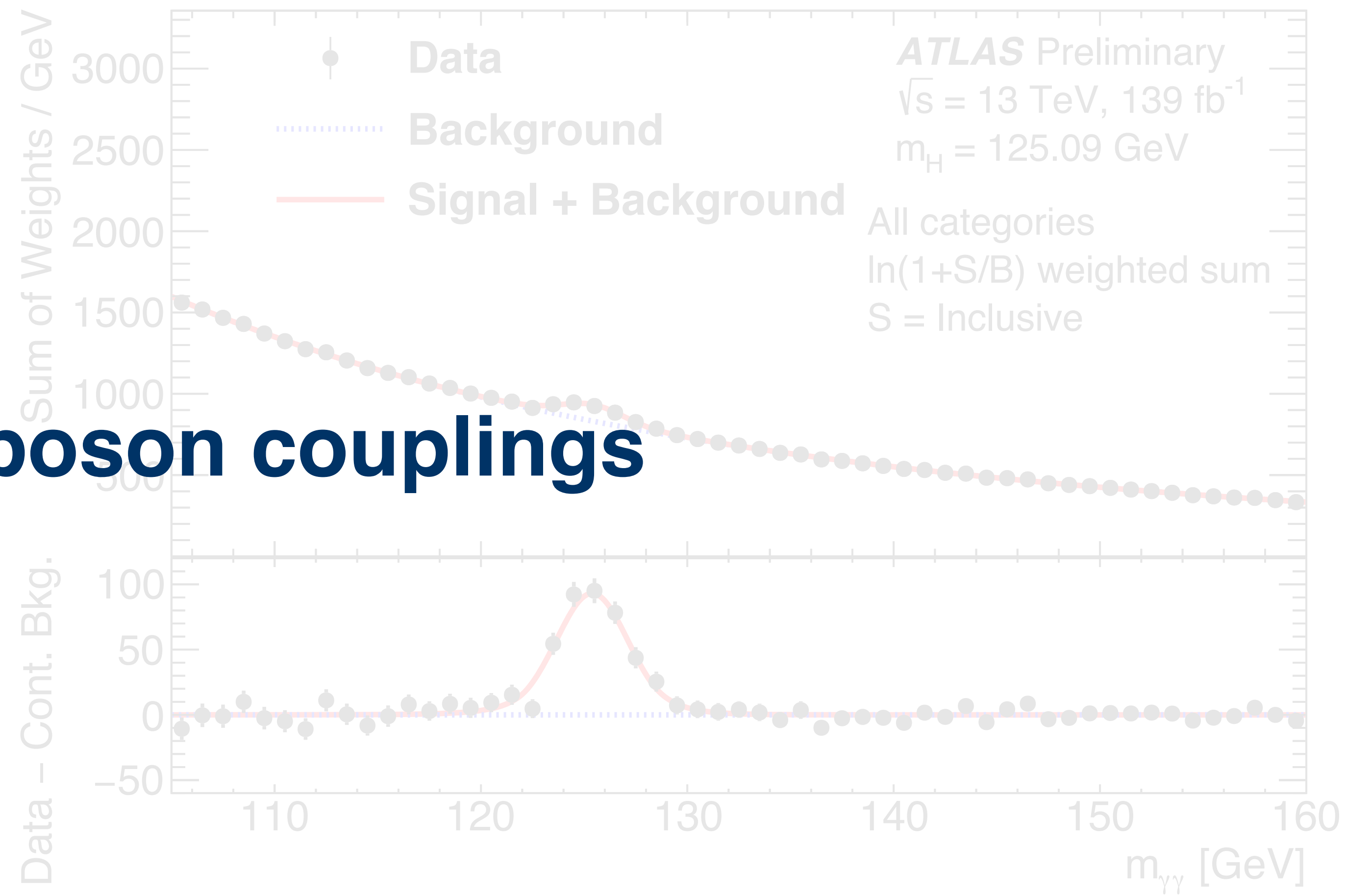
Updated $H \rightarrow WW$ measurement of Γ_H



- $H \rightarrow WW \rightarrow l\nu/l\nu$ gives similar sensitivity to $H \rightarrow ZZ \rightarrow ll ll / ll \nu\nu$
 - In particular, CMS off-shell signal significance has reached obs. 3.4σ (exp. 1.3σ)
- Combination of all the off-shell channels will be interesting for probing new physics
- Combination between ATLAS and CMS interesting to consider



Higgs boson couplings



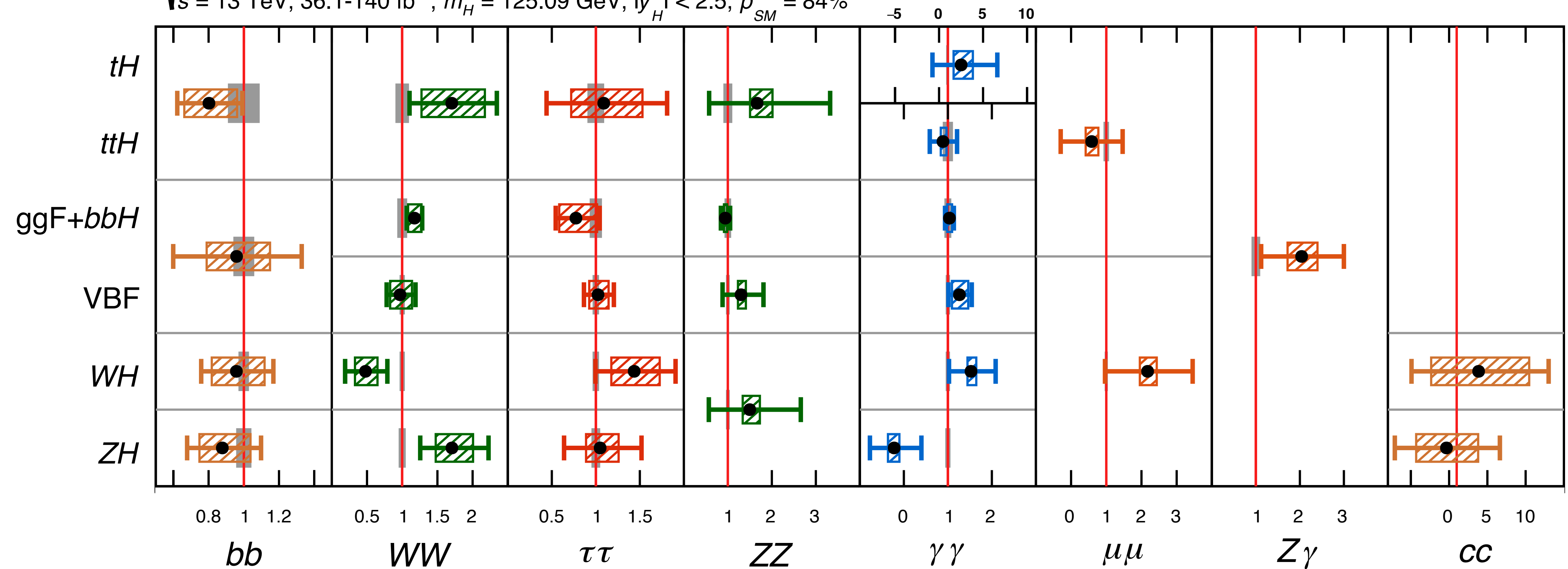


Signal strength, productions and decays

ATLAS Preliminary

$\sqrt{s} = 13 \text{ TeV}$, $36.1\text{-}140 \text{ fb}^{-1}$, $m_H = 125.09 \text{ GeV}$, $|y_H| < 2.5$, $p_{SM} = 84\%$

● Data (Total Unc.) ▨ Syst. Unc. ■ SM prediction

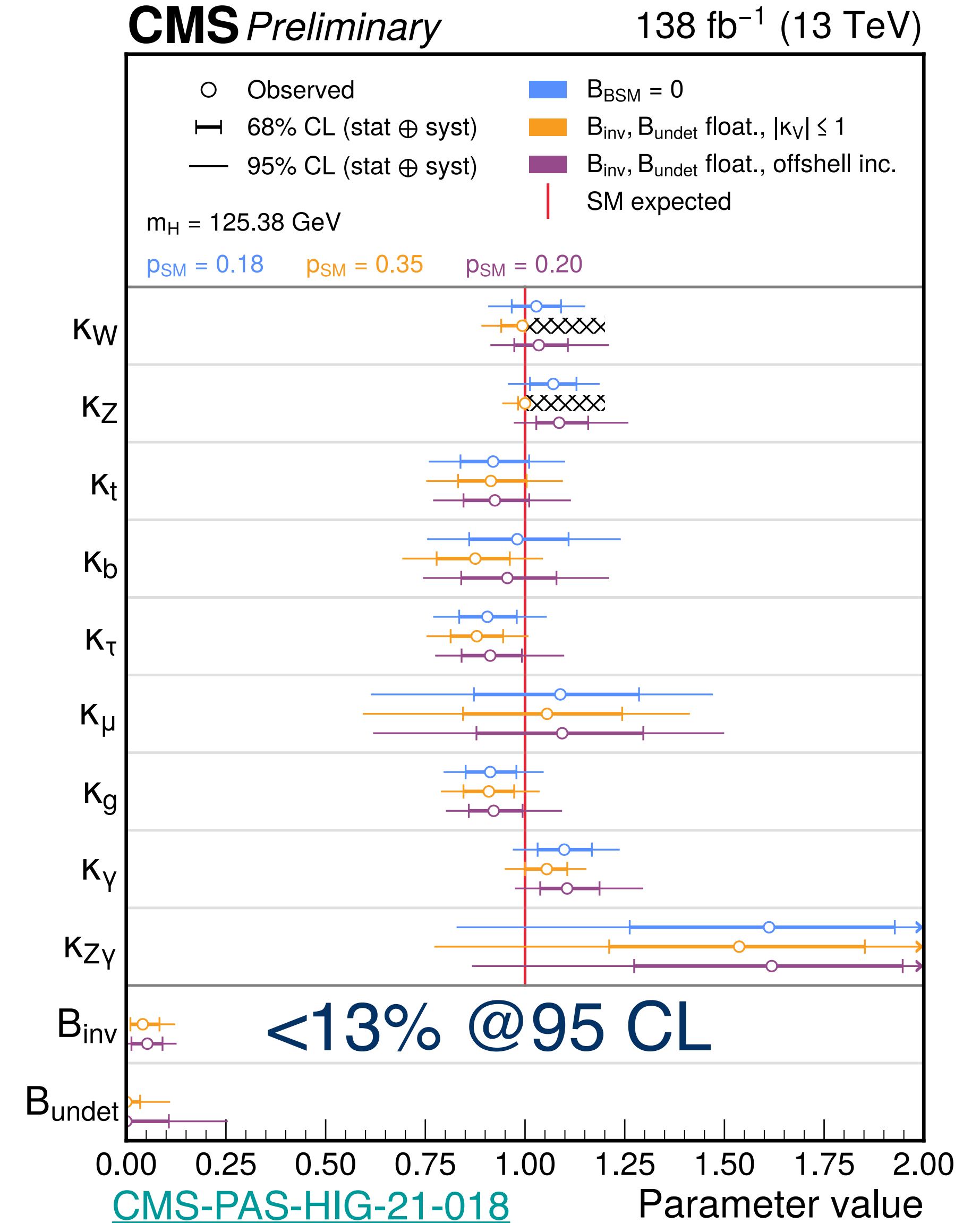
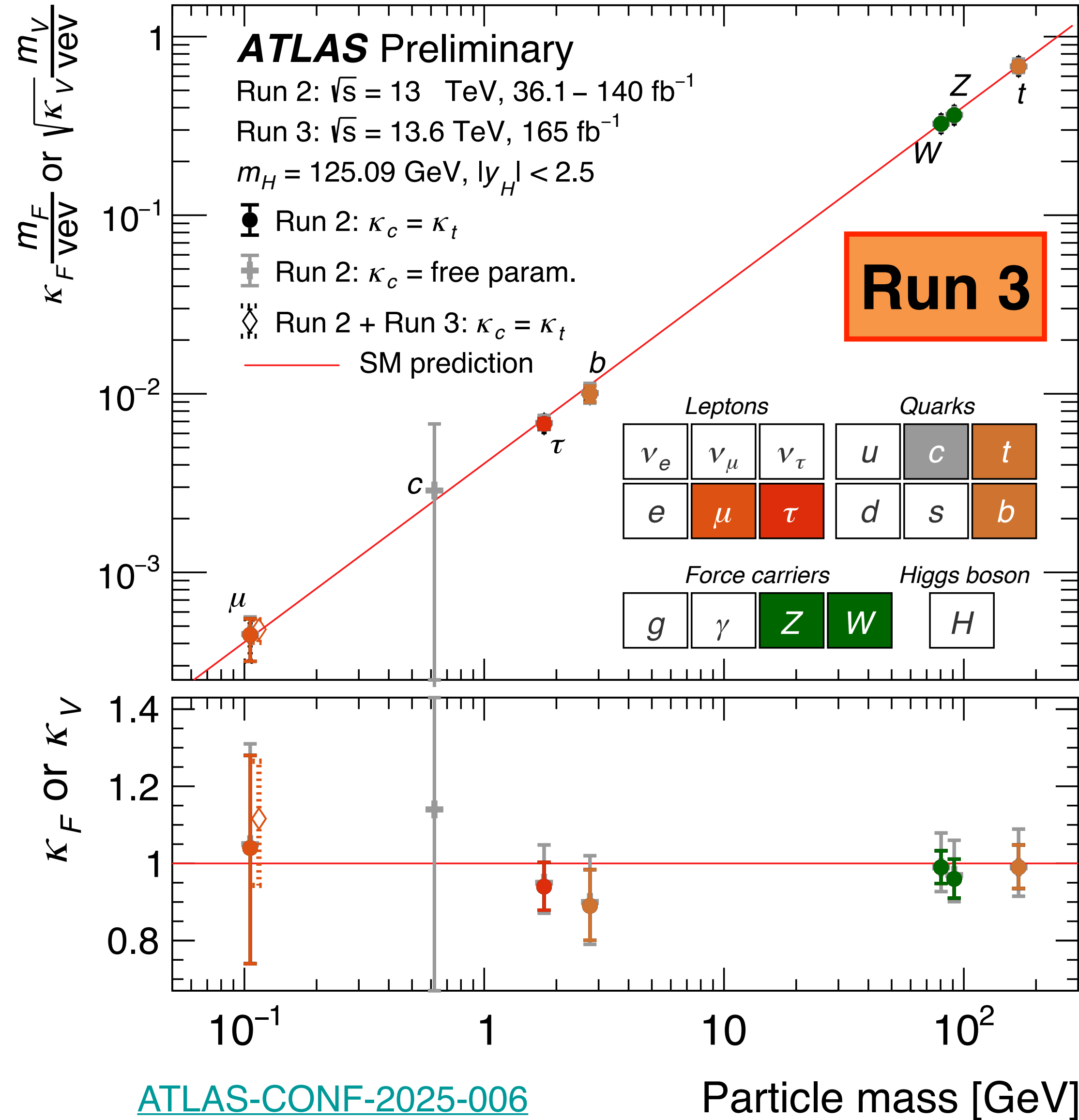


[ATLAS-CONF-2025-006](#)

$\sigma \times B$ normalized to SM prediction

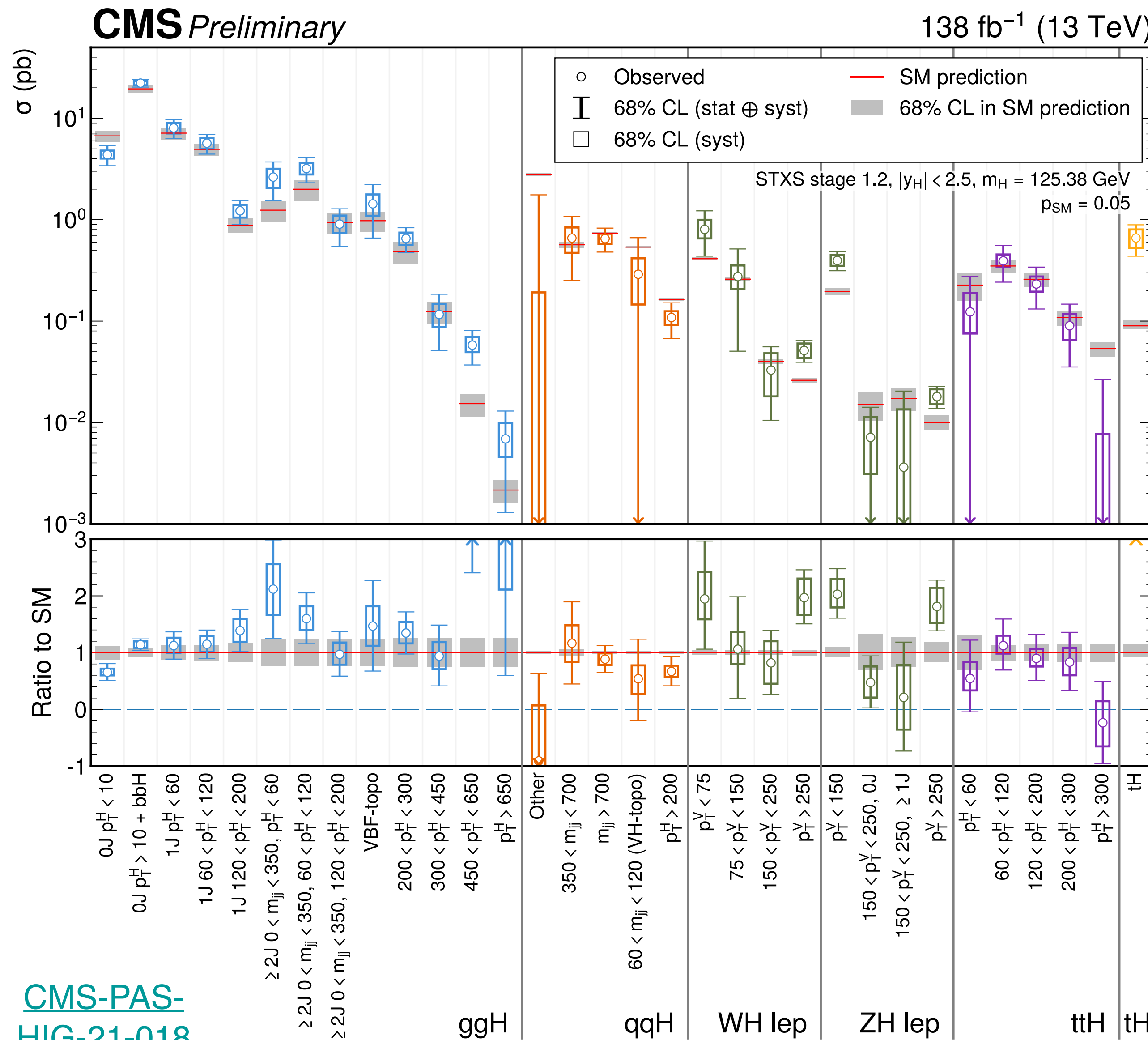
- ATLAS: $\mu = 1.023^{+0.056}_{-0.053} = 1.023 \pm 0.028 \text{ (stat.)}^{+0.026}_{-0.025} \text{ (exp.)}^{+0.039}_{-0.036} \text{ (sig. theo.)} \pm 0.012 \text{ (bkg. theo.)}$
- CMS: $\mu = 1.014^{+0.055}_{-0.053} = 1.014 \pm 0.028 \text{ (stat.)}^{+0.025}_{-0.024} \text{ (exp.)}^{+0.040}_{-0.039} \text{ (theo.)}$

Coupling strength interpretations

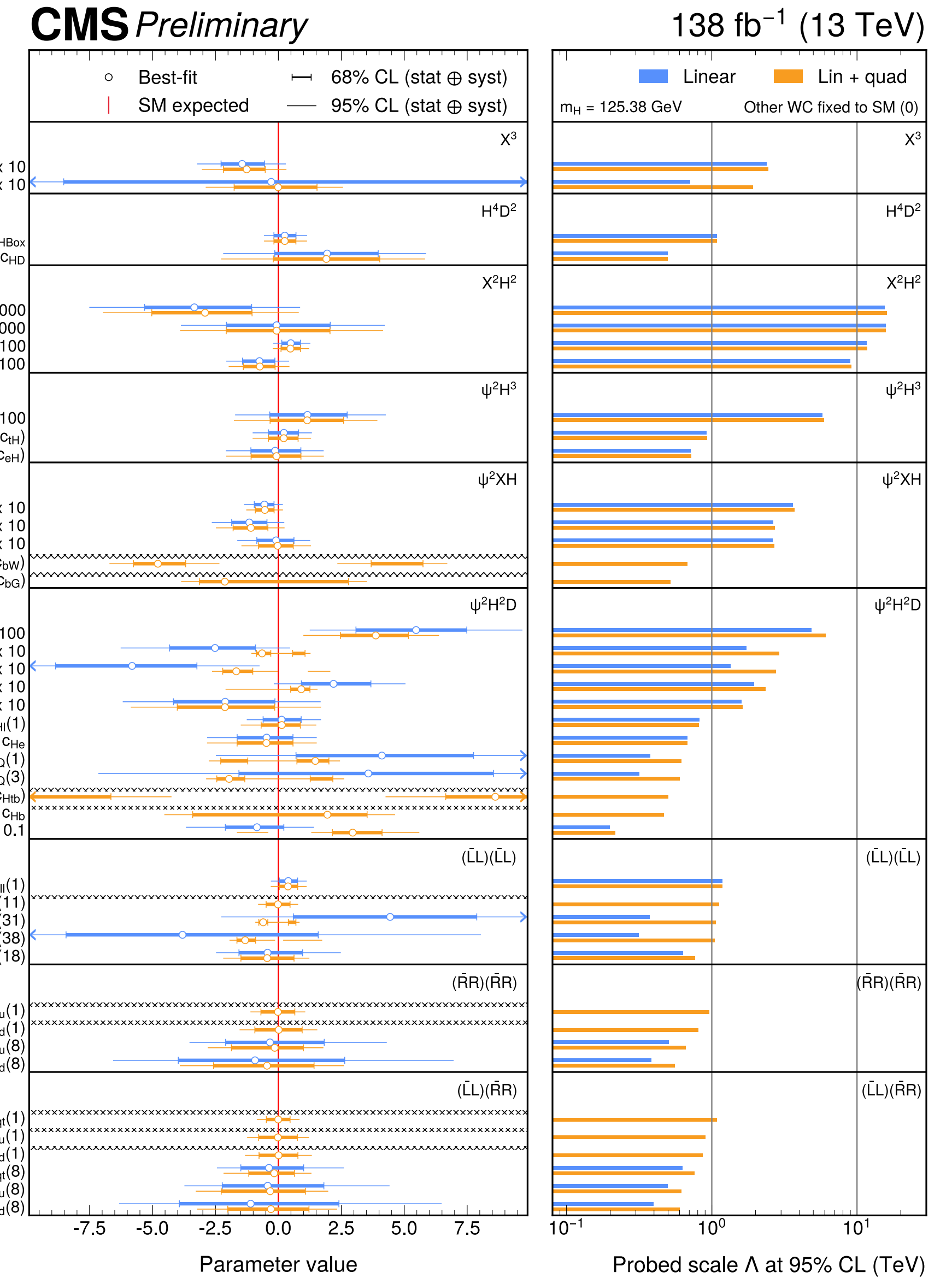




Simplified Template Cross Sections (STXS)

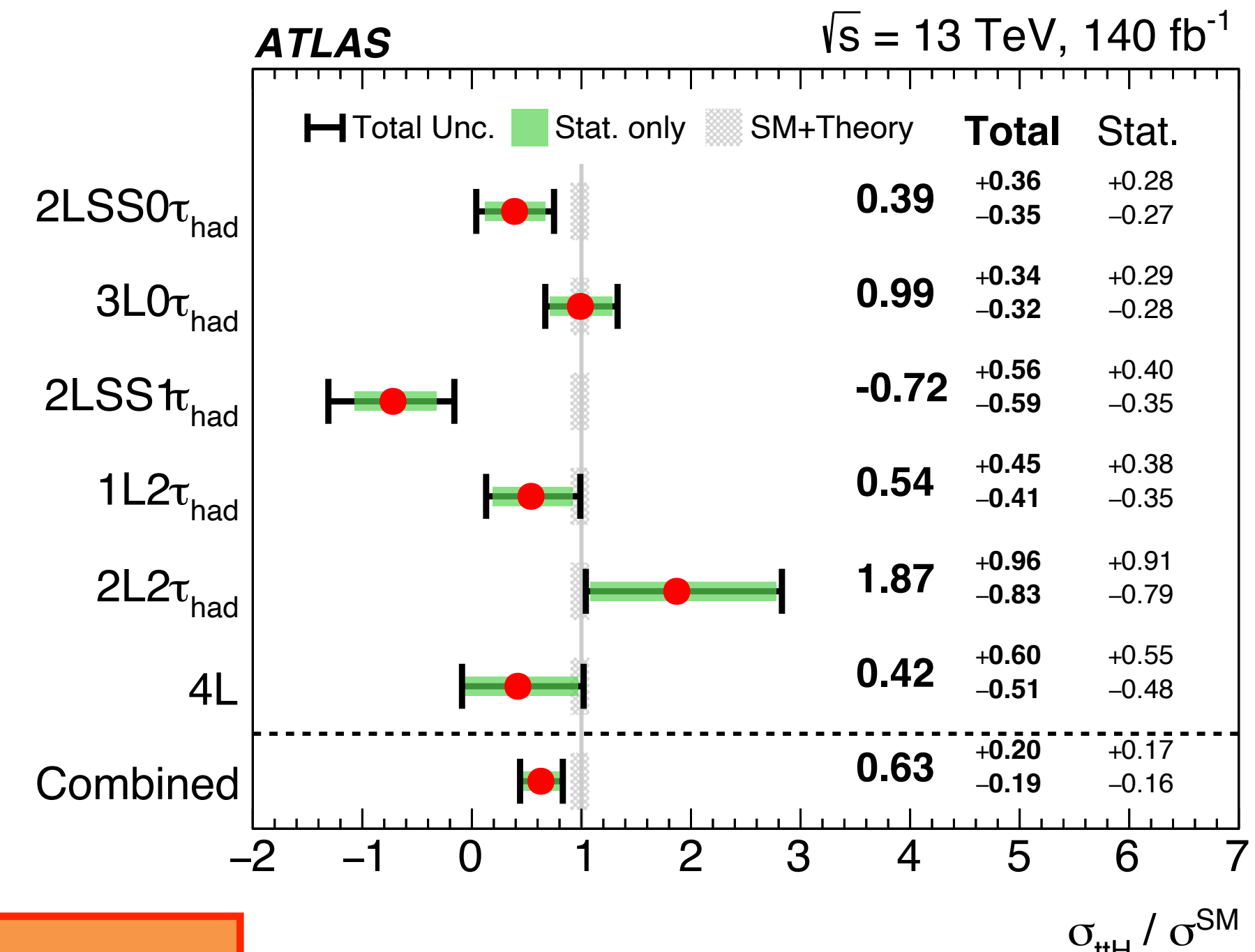
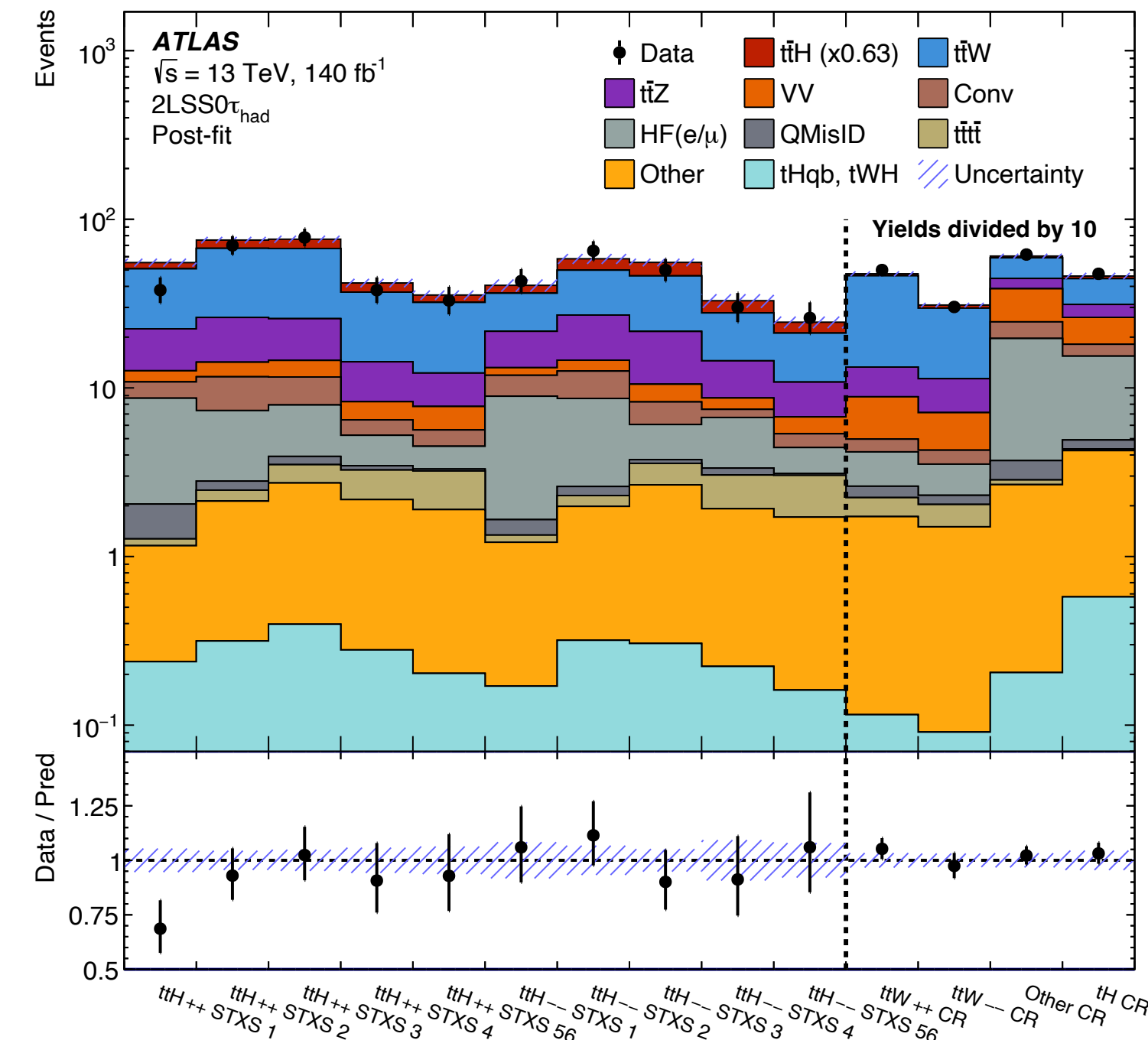
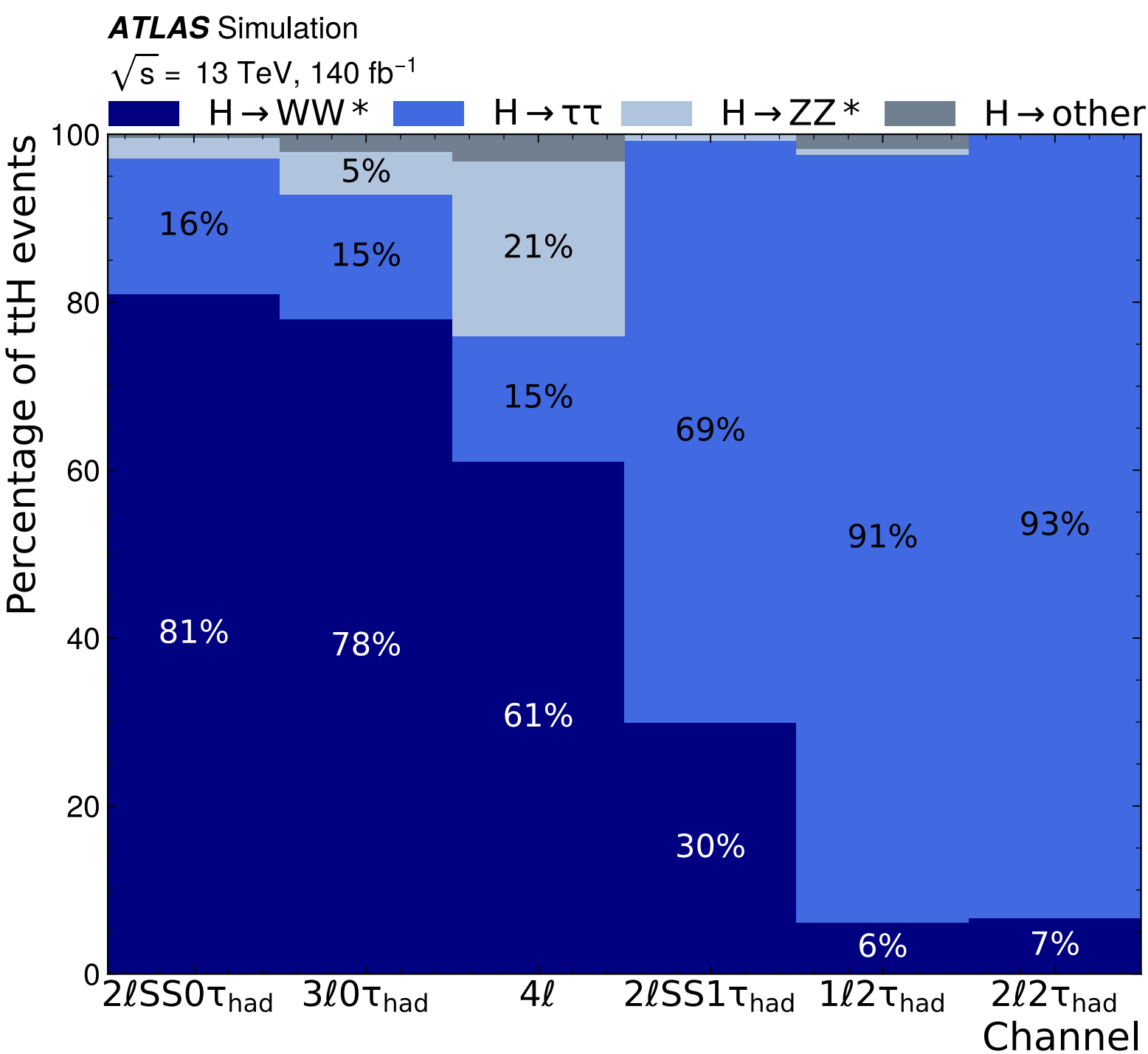


CMS-PAS-
HIG-21-018



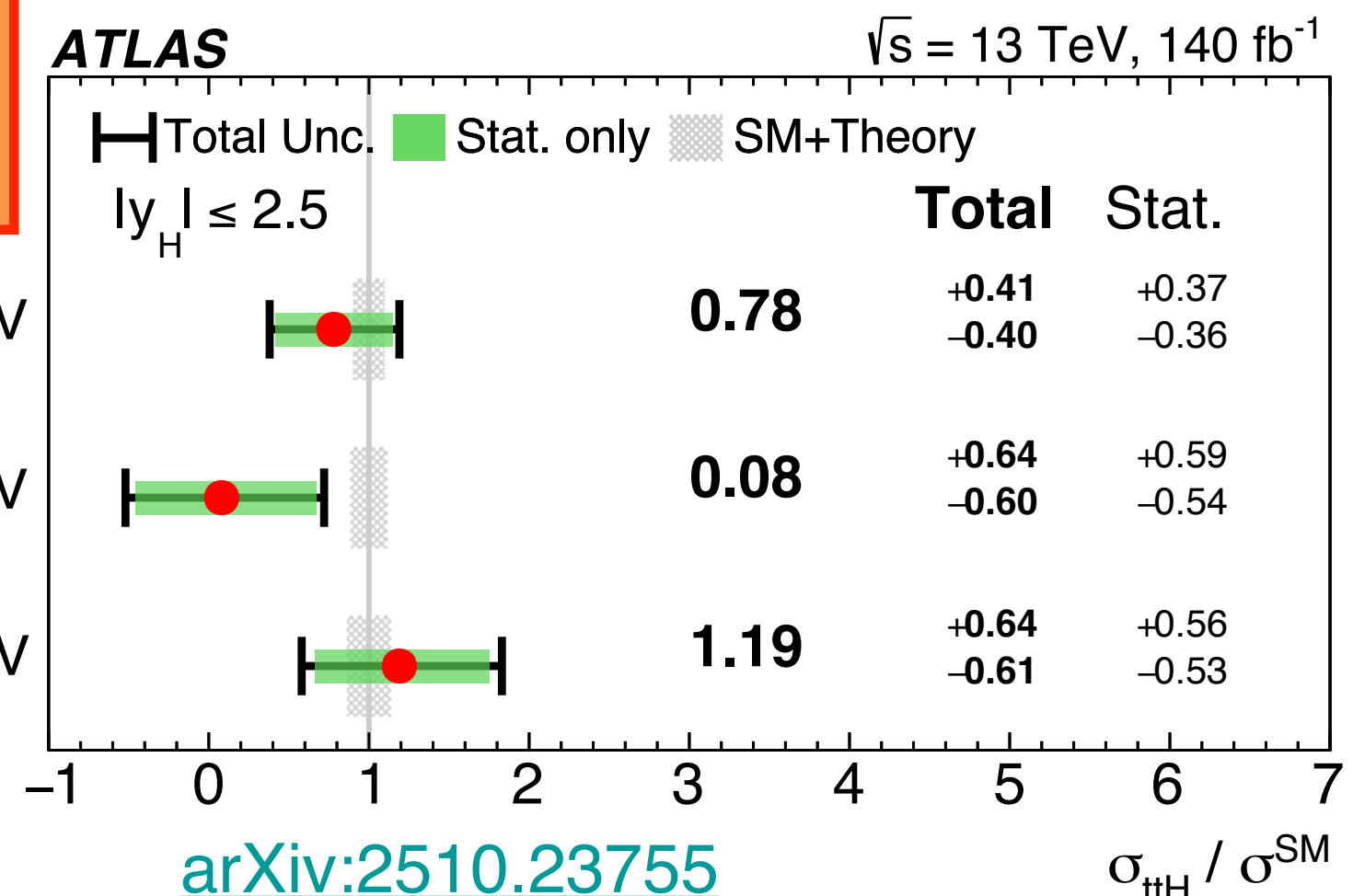


ttH production: multi-lepton channel



**Higgs
2025**

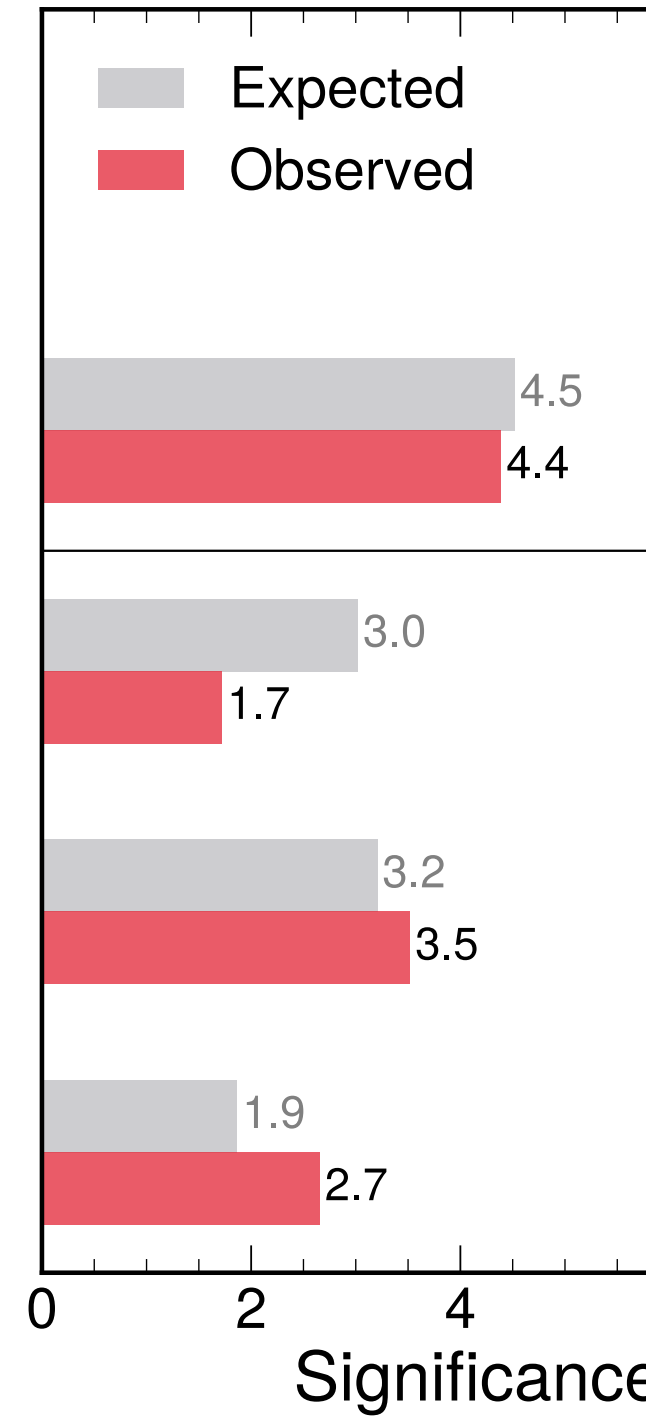
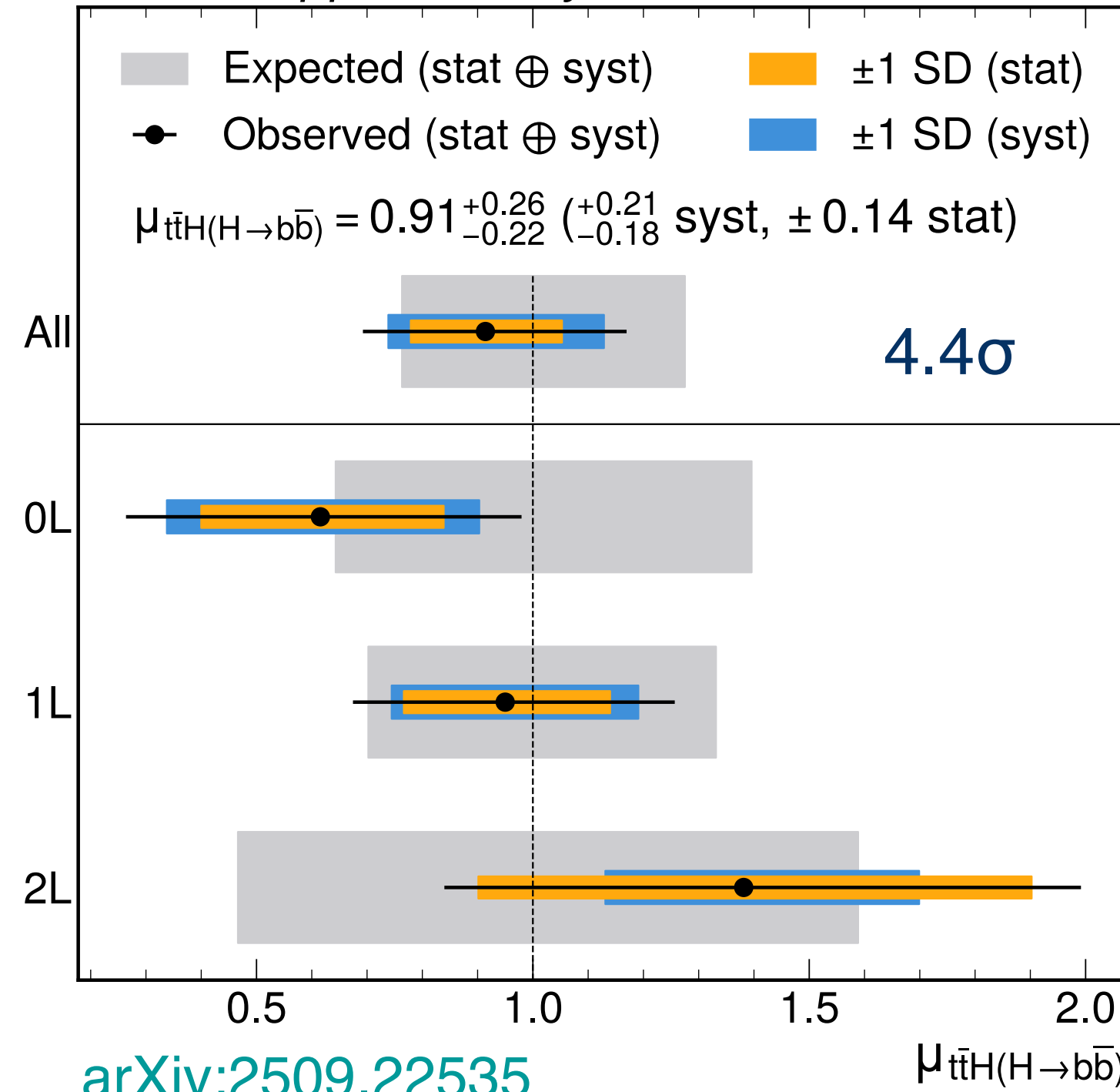
$p_T^H < 120 \text{ GeV}$
 $120 \text{ GeV} \leq p_T^H < 200 \text{ GeV}$
 $p_T^H \geq 200 \text{ GeV}$



- $\mu = 0.63_{-0.19}^{+0.20}$, Obs. 3.3σ (exp. 5.3σ)
- Very challenging analysis: need to make sure background under control

ttH production: bb channel

CMS Supplementary 138 fb⁻¹ (13 TeV)



$p_T^H \in [0, 60)$ GeV

$p_T^H \in [60, 120)$ GeV

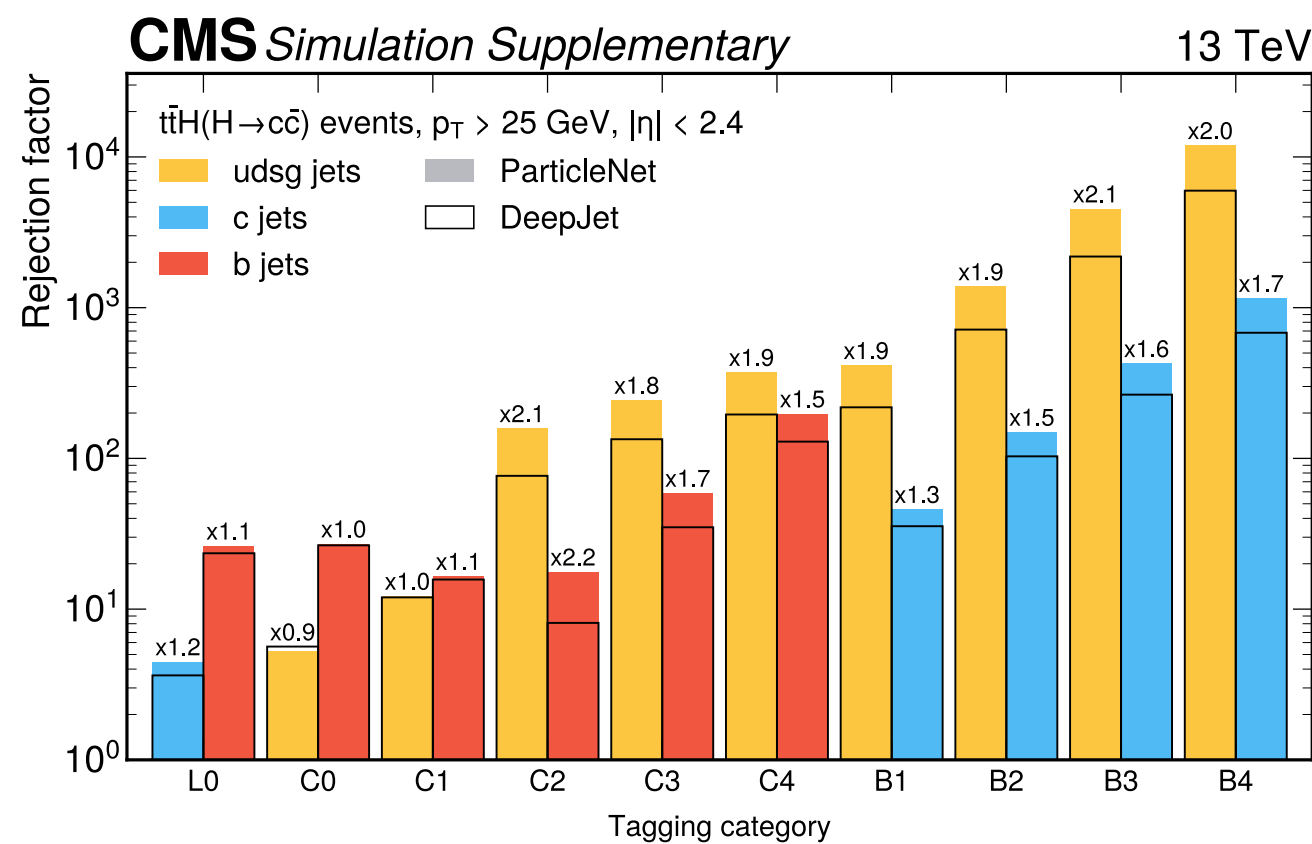
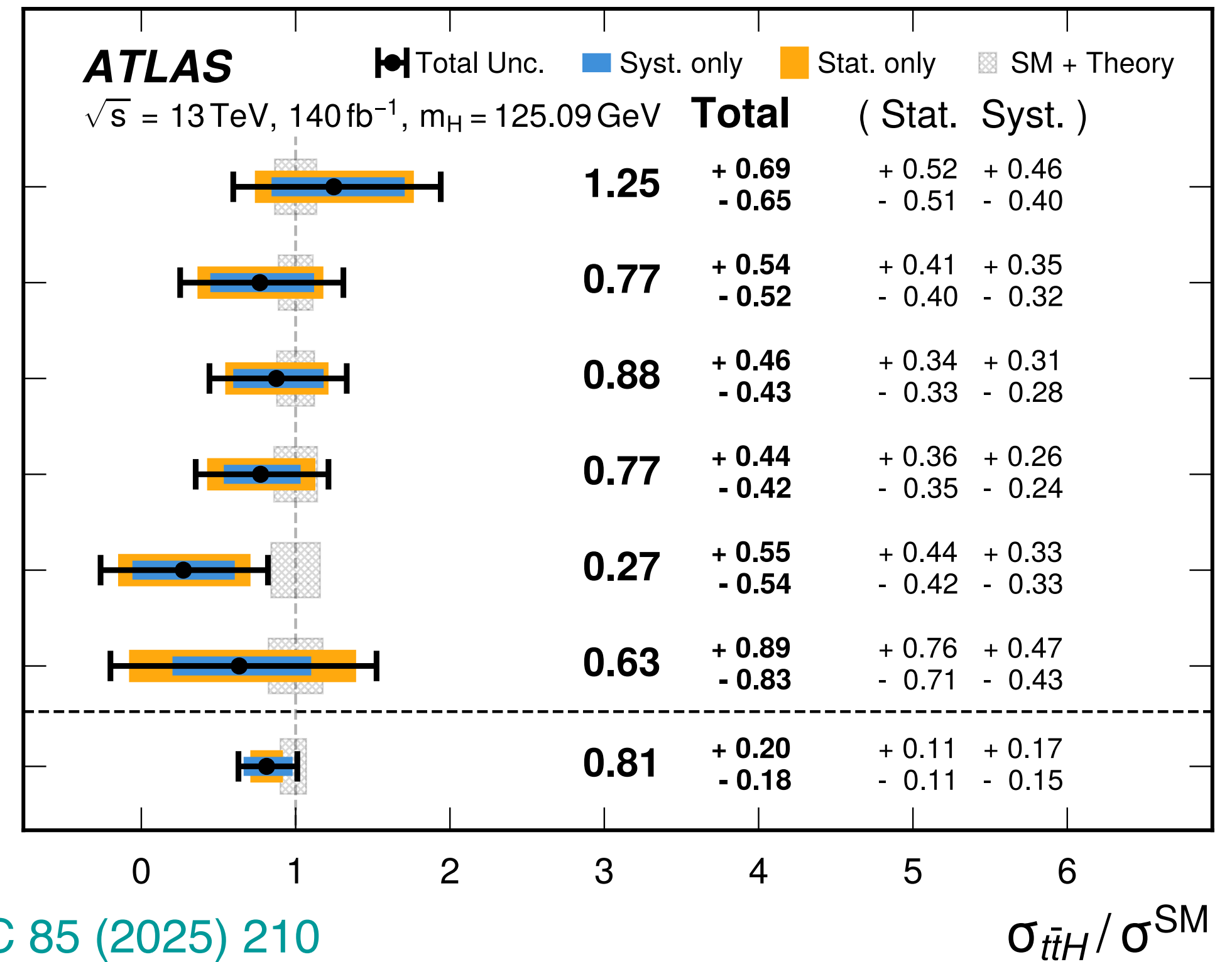
$p_T^H \in [120, 200)$ GeV

$p_T^H \in [200, 300)$ GeV

$p_T^H \in [300, 450)$ GeV

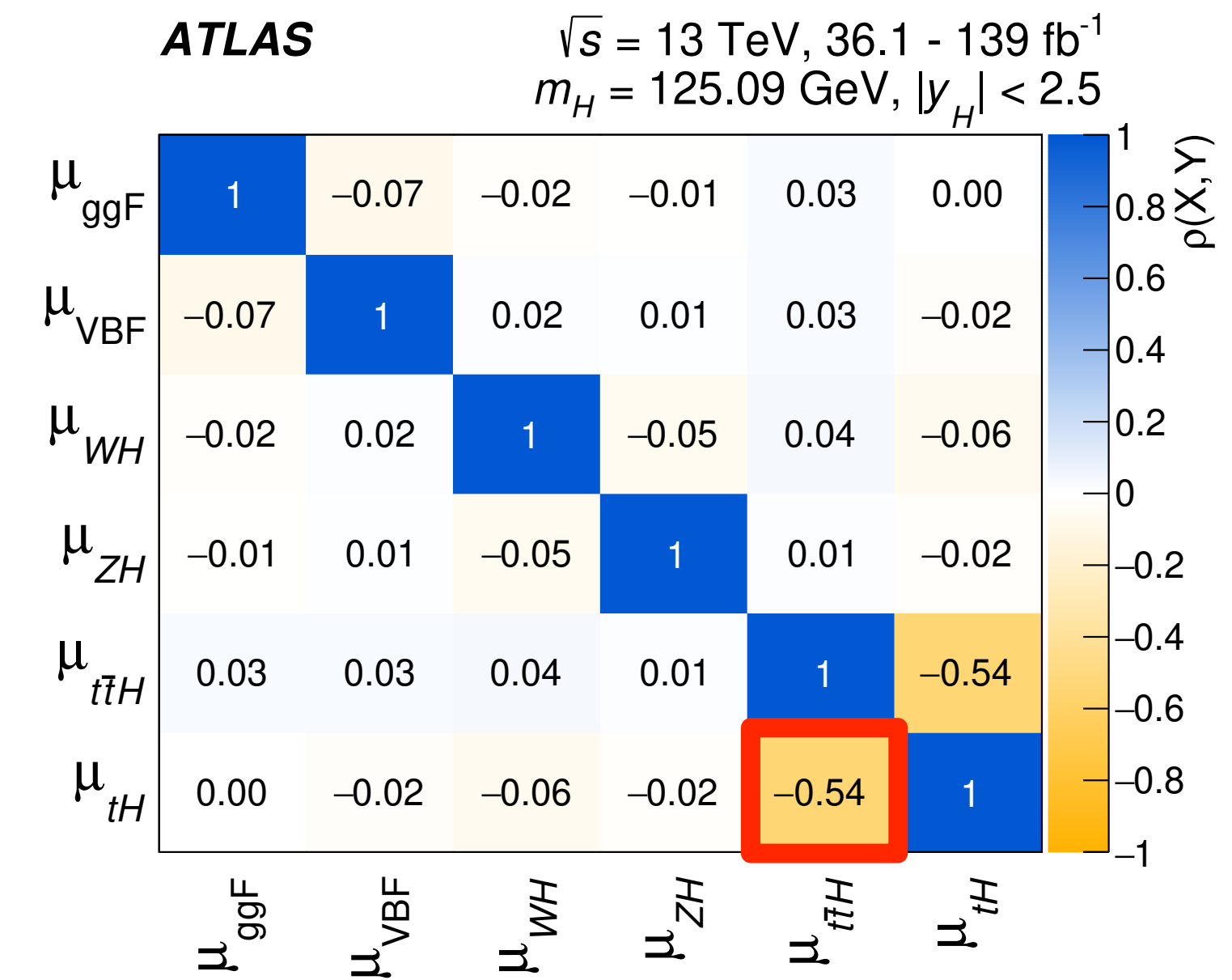
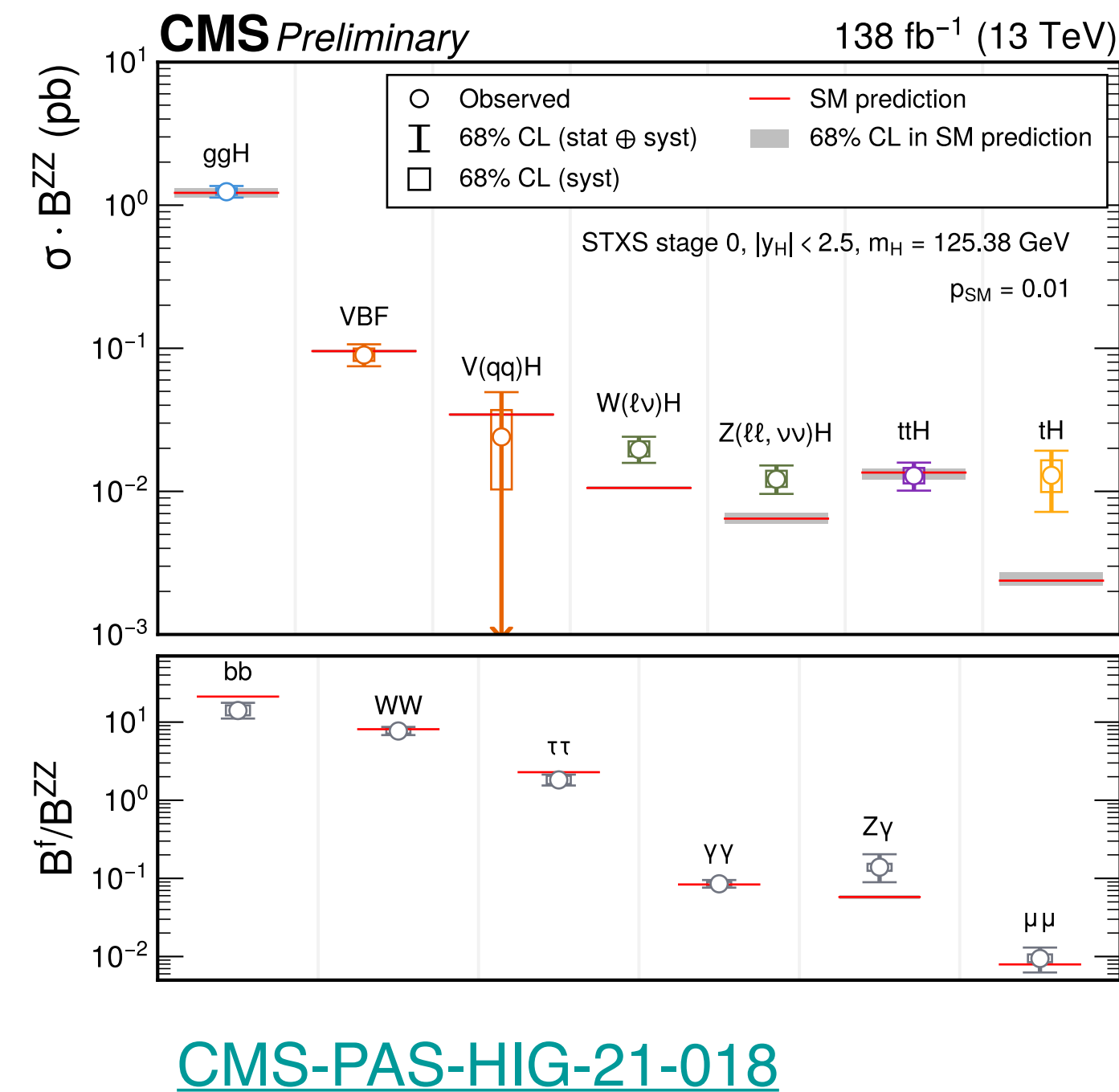
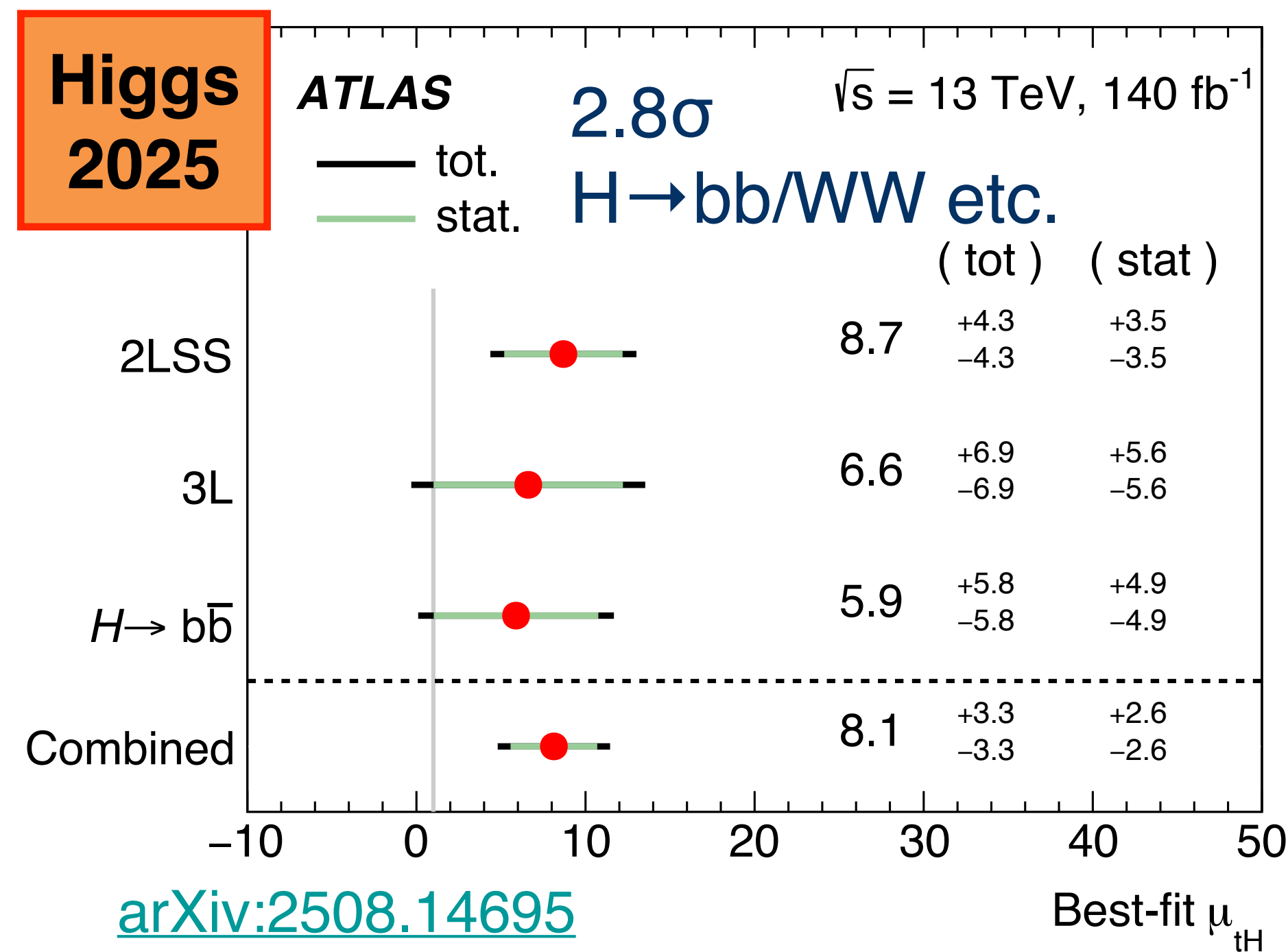
$p_T^H \in [450, \infty)$ GeV

Inclusive

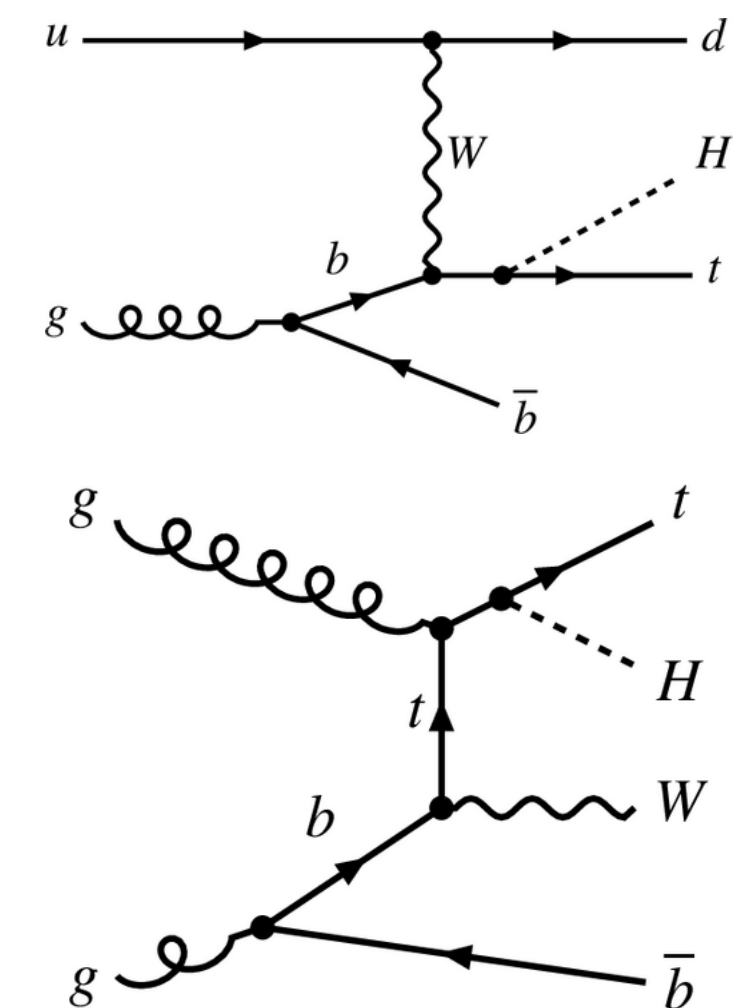


- Complex final state, good test ground for advanced machine learning
- Powerful STXS measurements

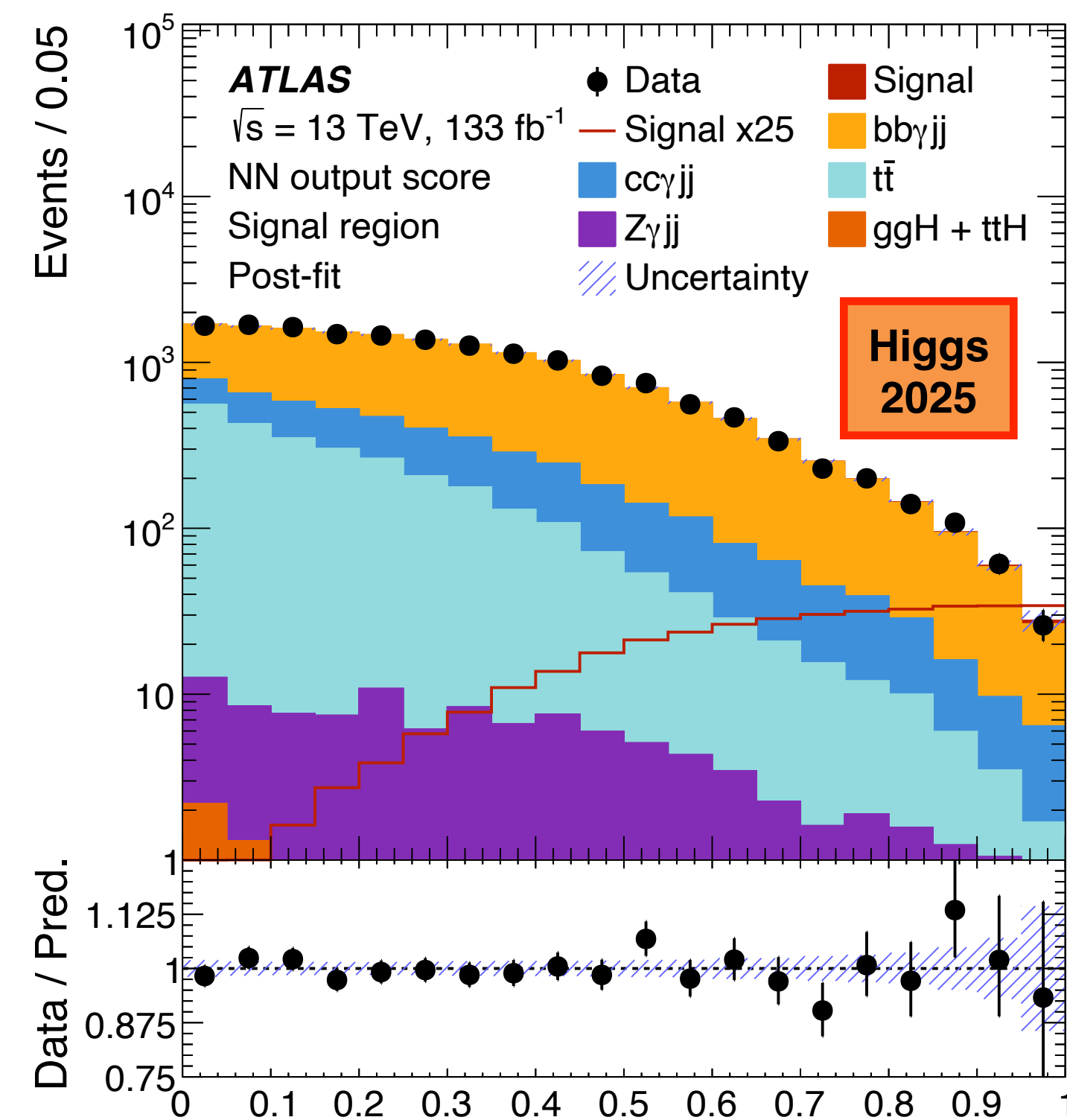
tH production



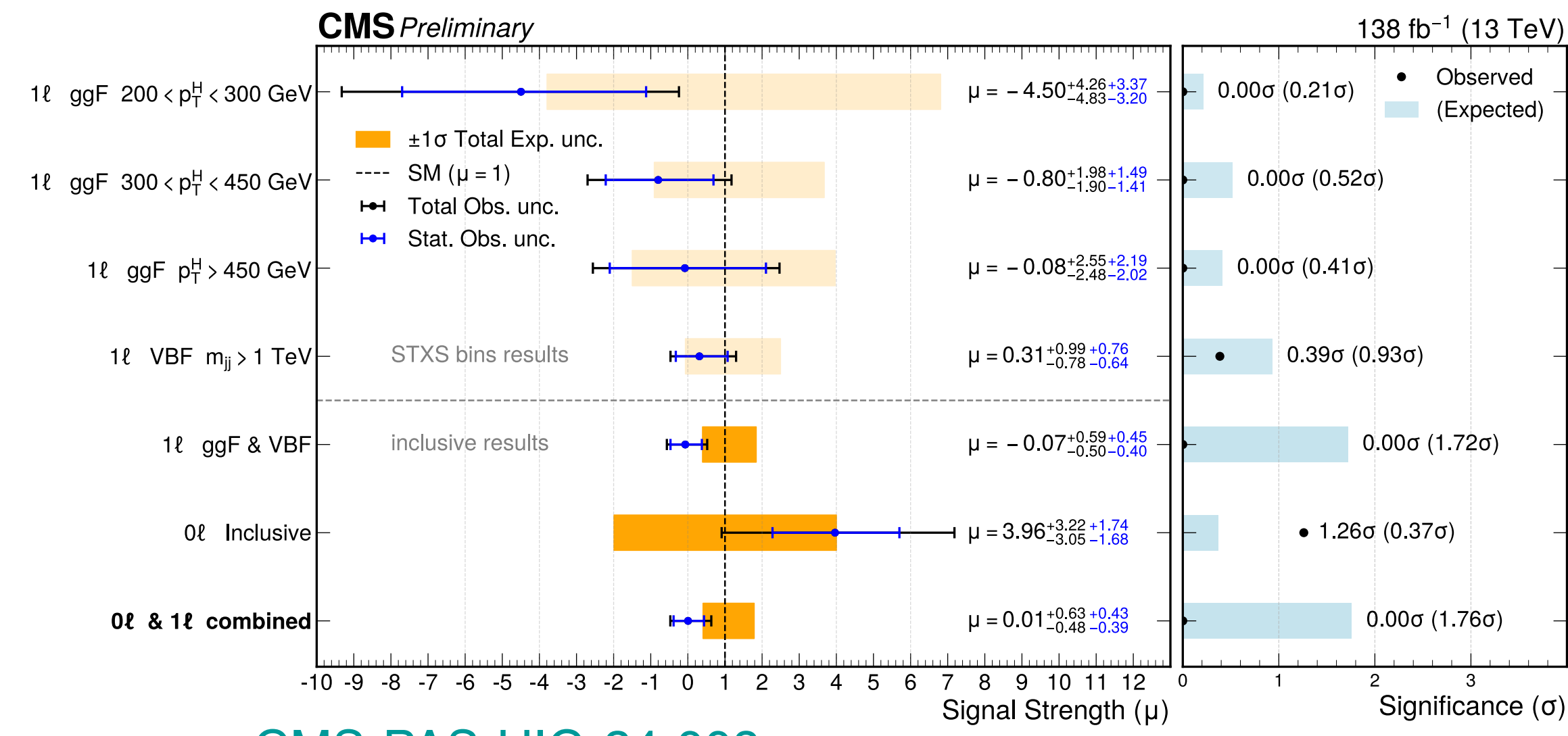
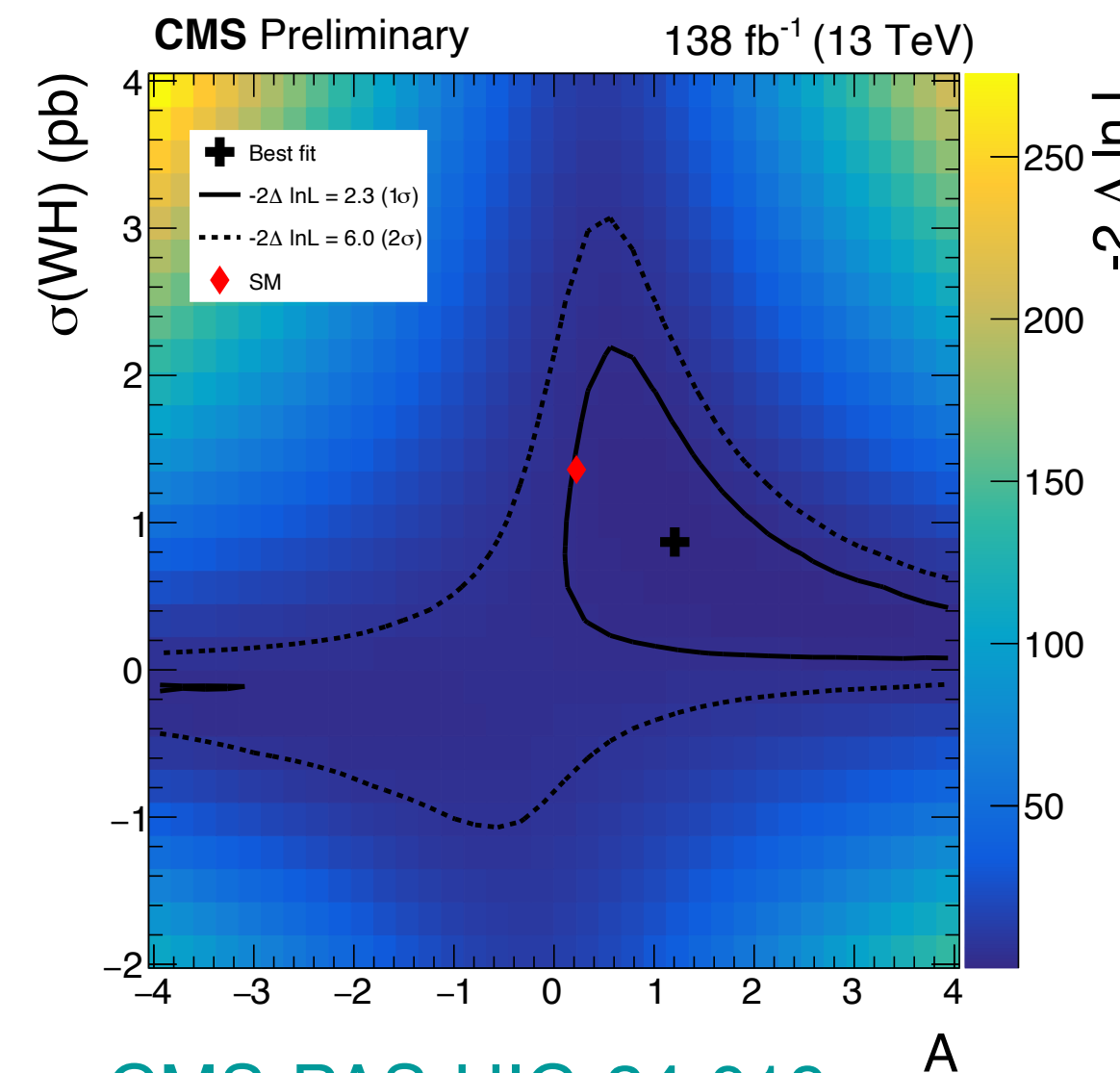
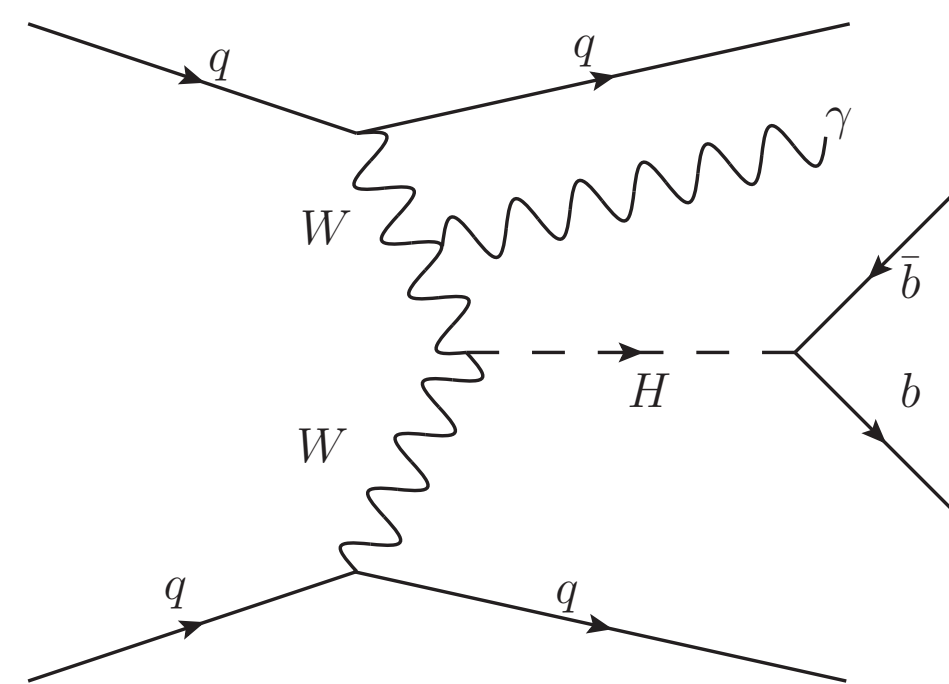
- tH production mode seems to show excess (?) over SM prediction ($\sim 0.1 \text{ pb}$ @ 13 TeV) in both ATLAS and CMS
- However, very strong correlation with ttH!
- Need more data, and more coherent treatment between tH and ttH



Novel signatures



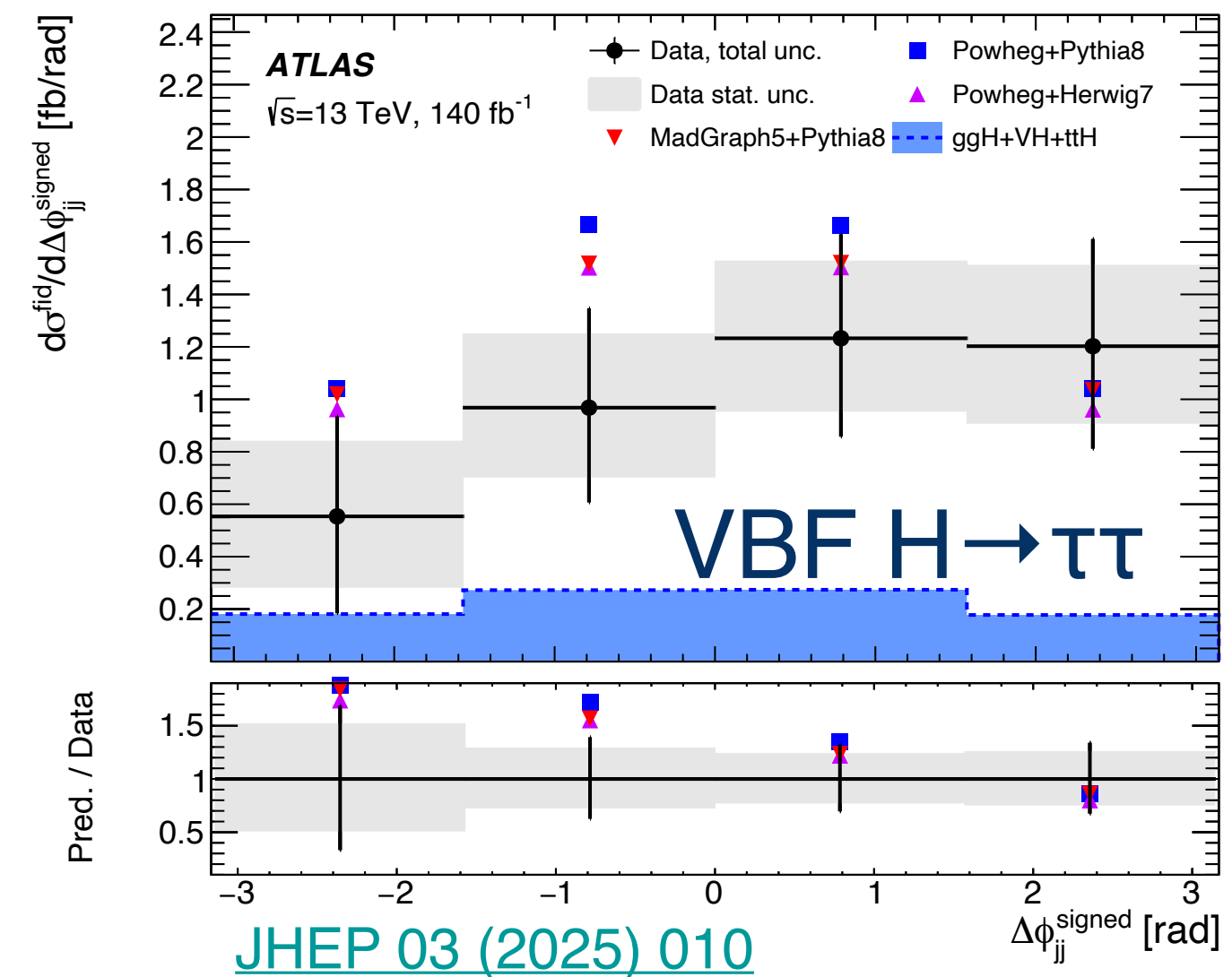
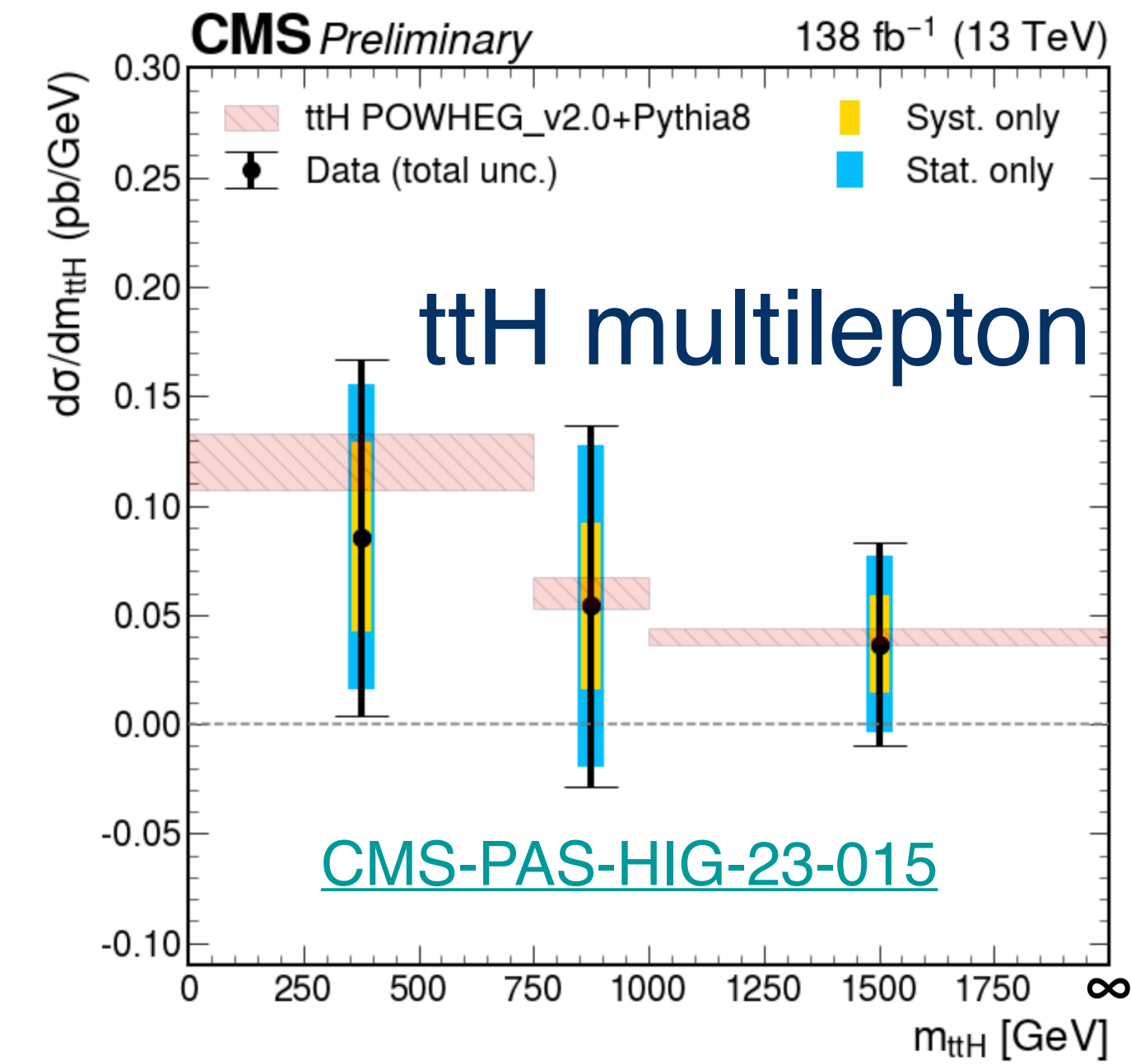
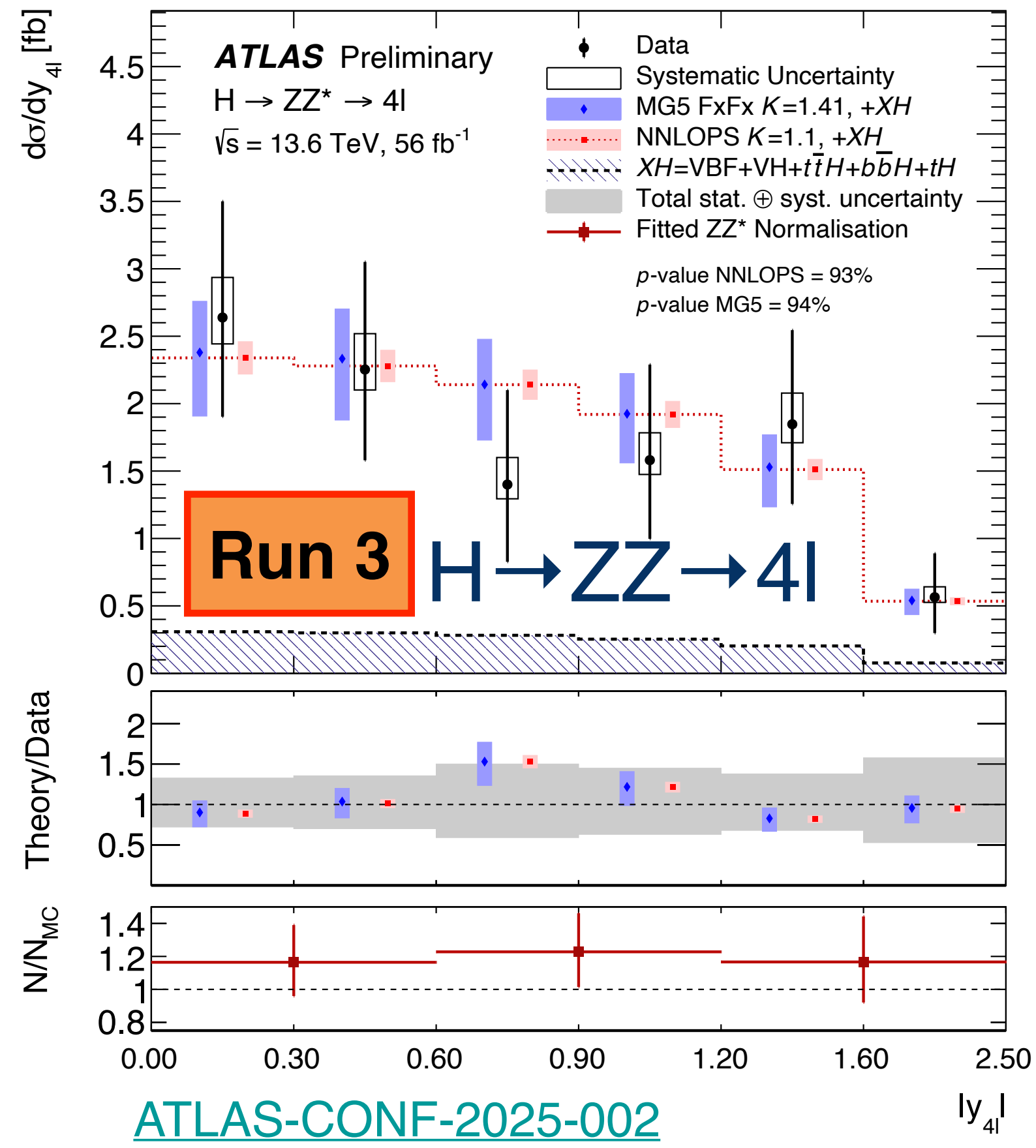
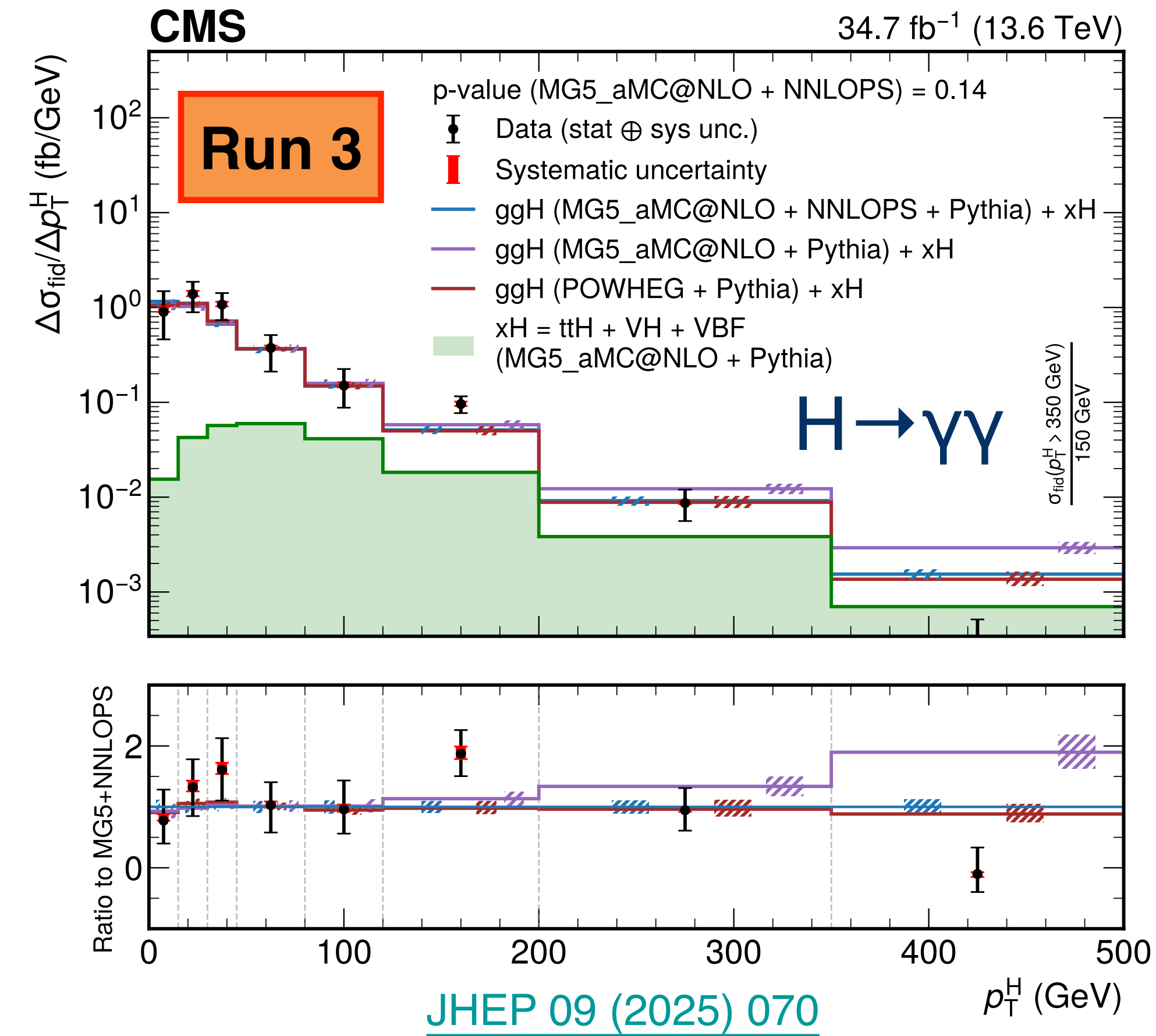
[arXiv:2509.14005](https://arxiv.org/abs/2509.14005) NN score



CMS-PAS-HIG-24-008

- VBF+ γ : $\mu = 0.2 \pm 0.7, 0.3\sigma (1.5\sigma \text{ exp.})$
- WH, $H \rightarrow \tau\tau$: measure charge asymmetry between W^+H and W^-H productions
- $H \rightarrow WW$ 0/1-lep boosted: probe high p_T regime

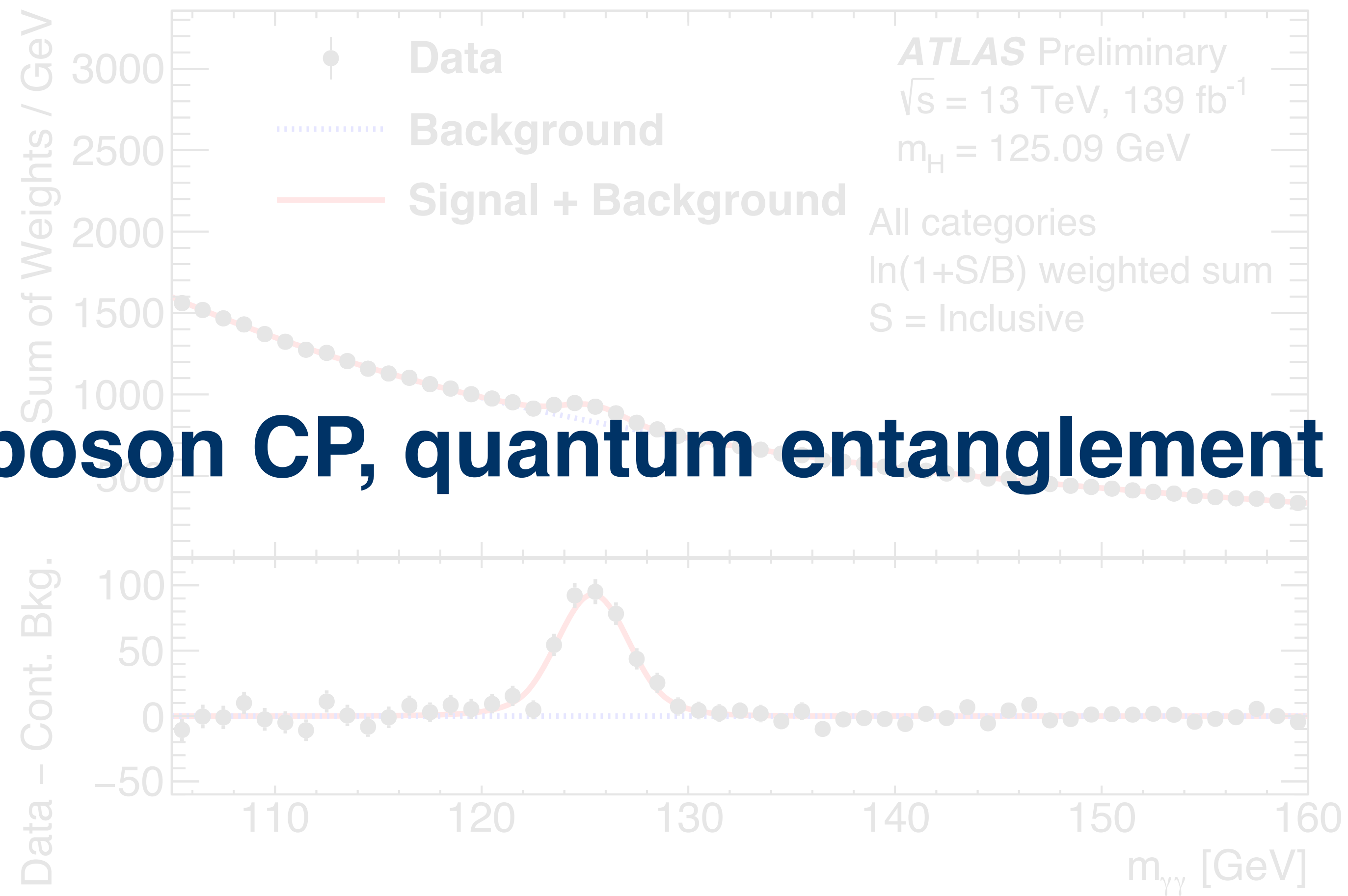
Fiducial/differential cross-section measurements



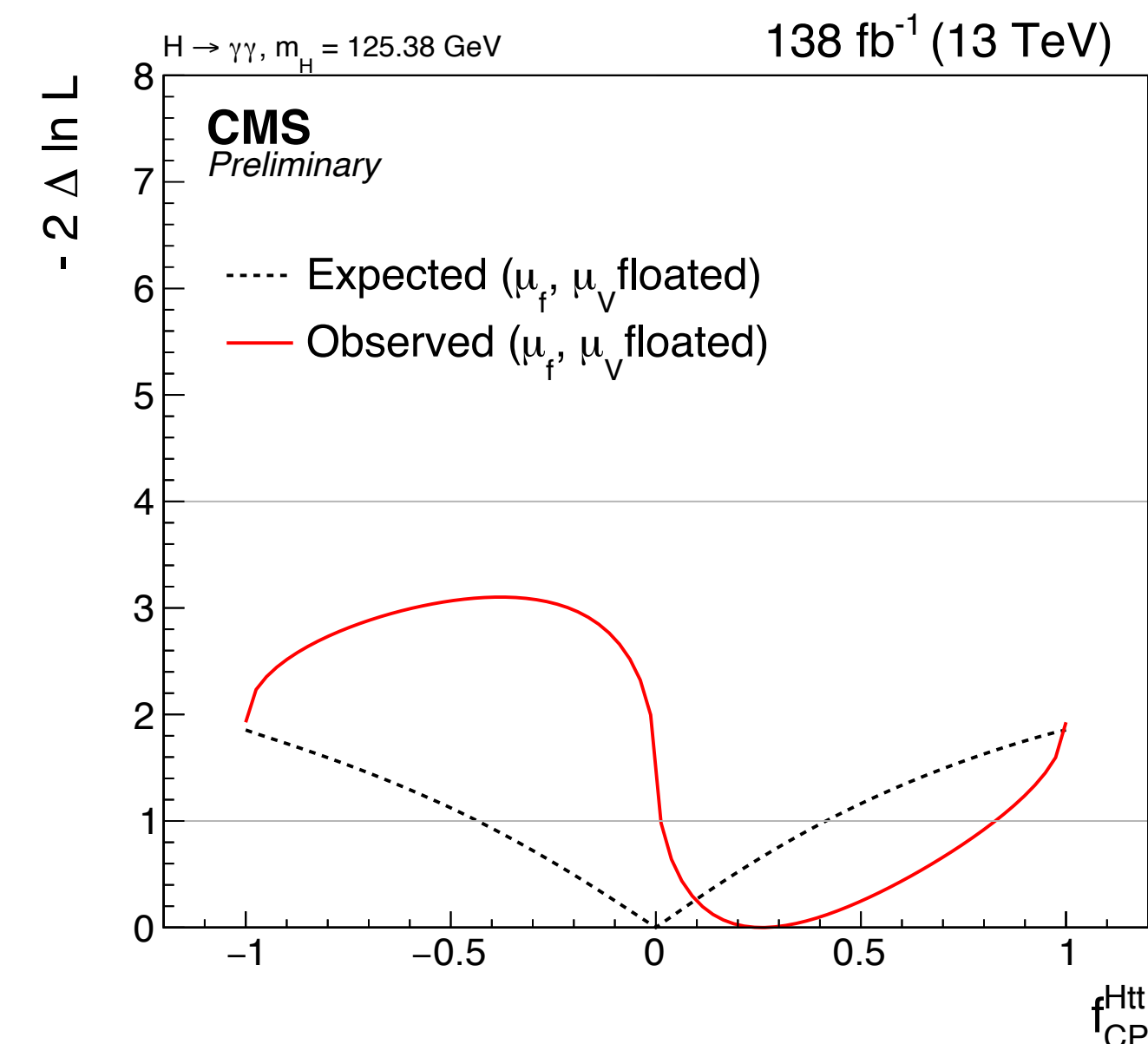
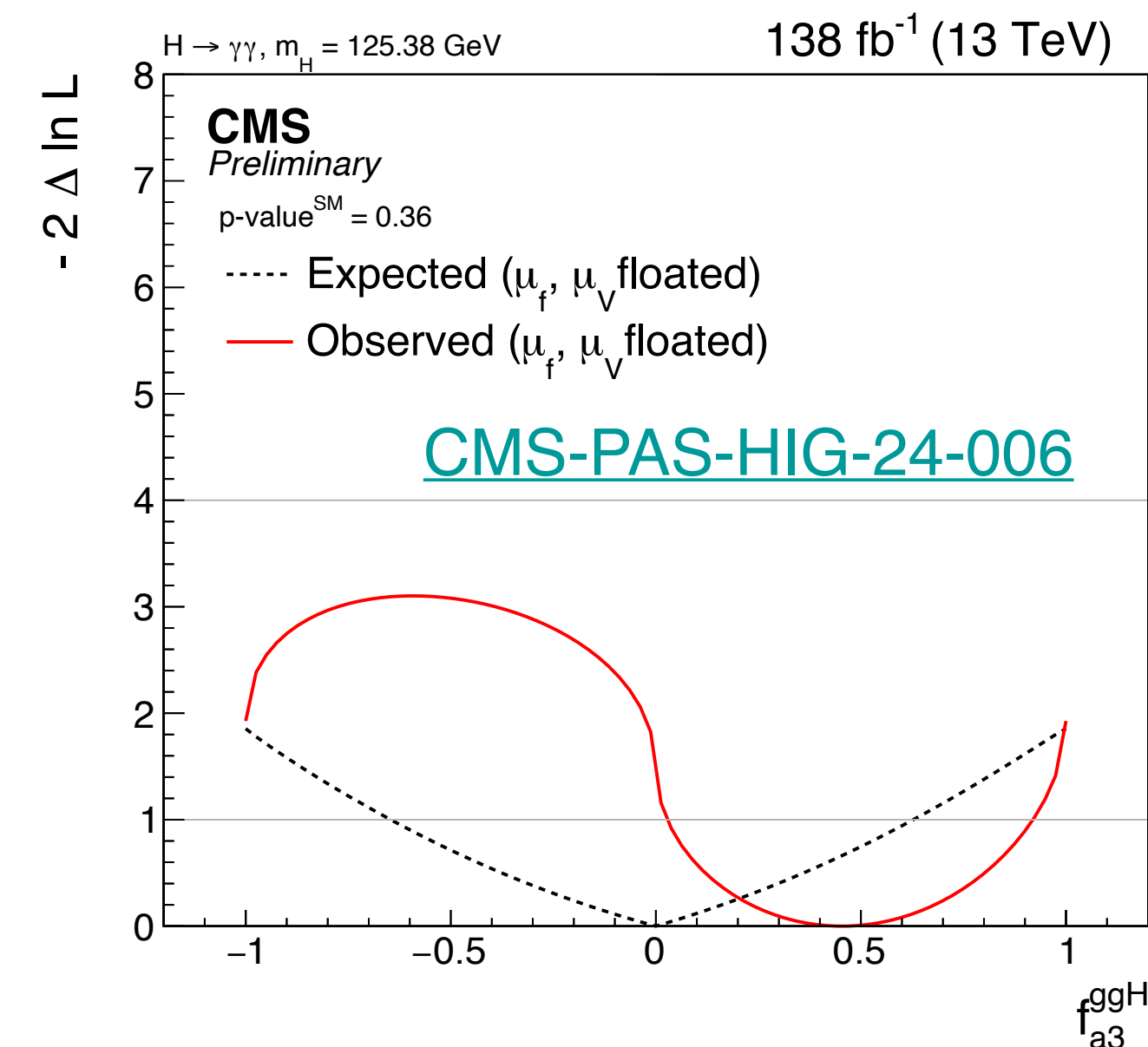
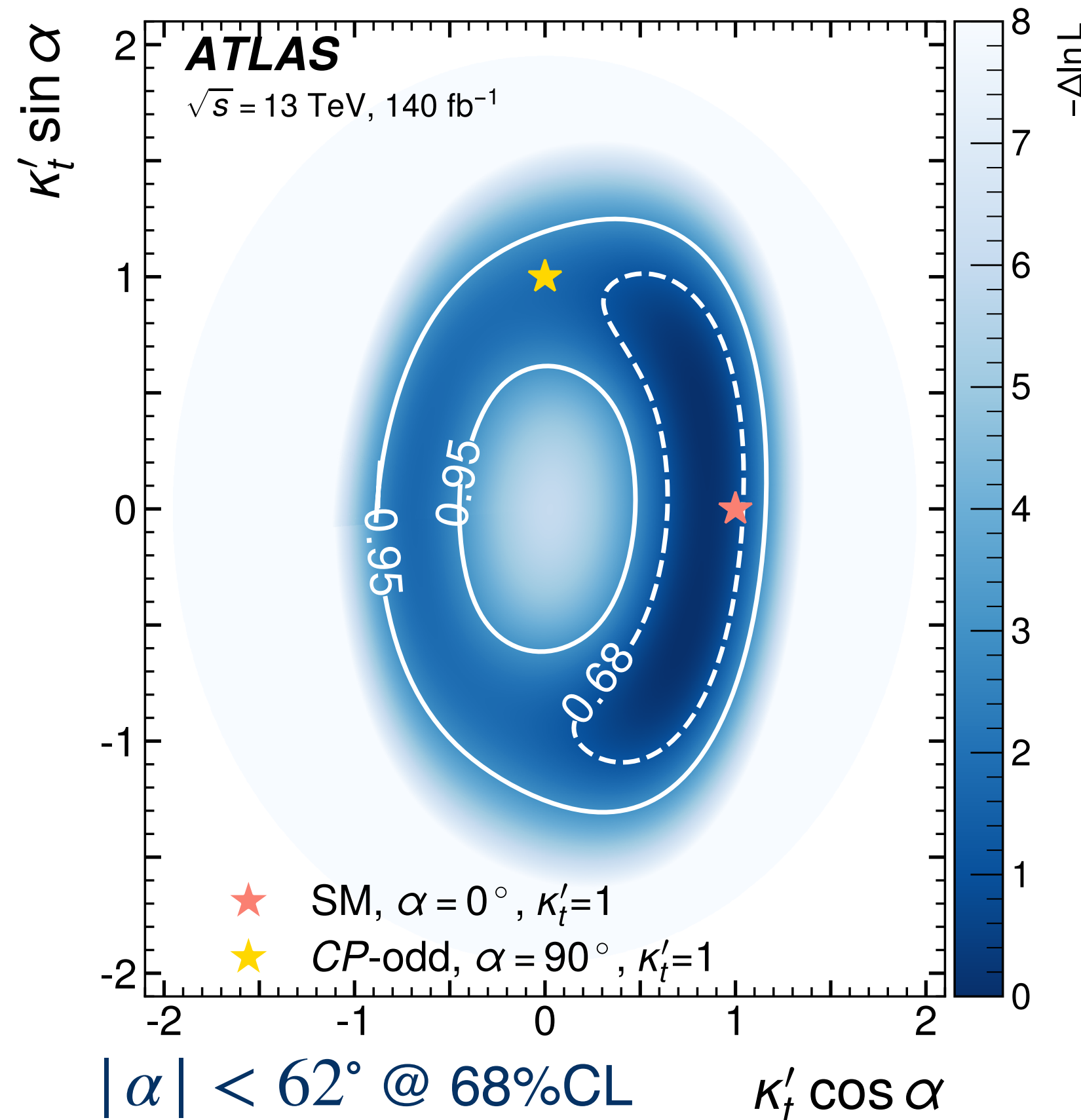
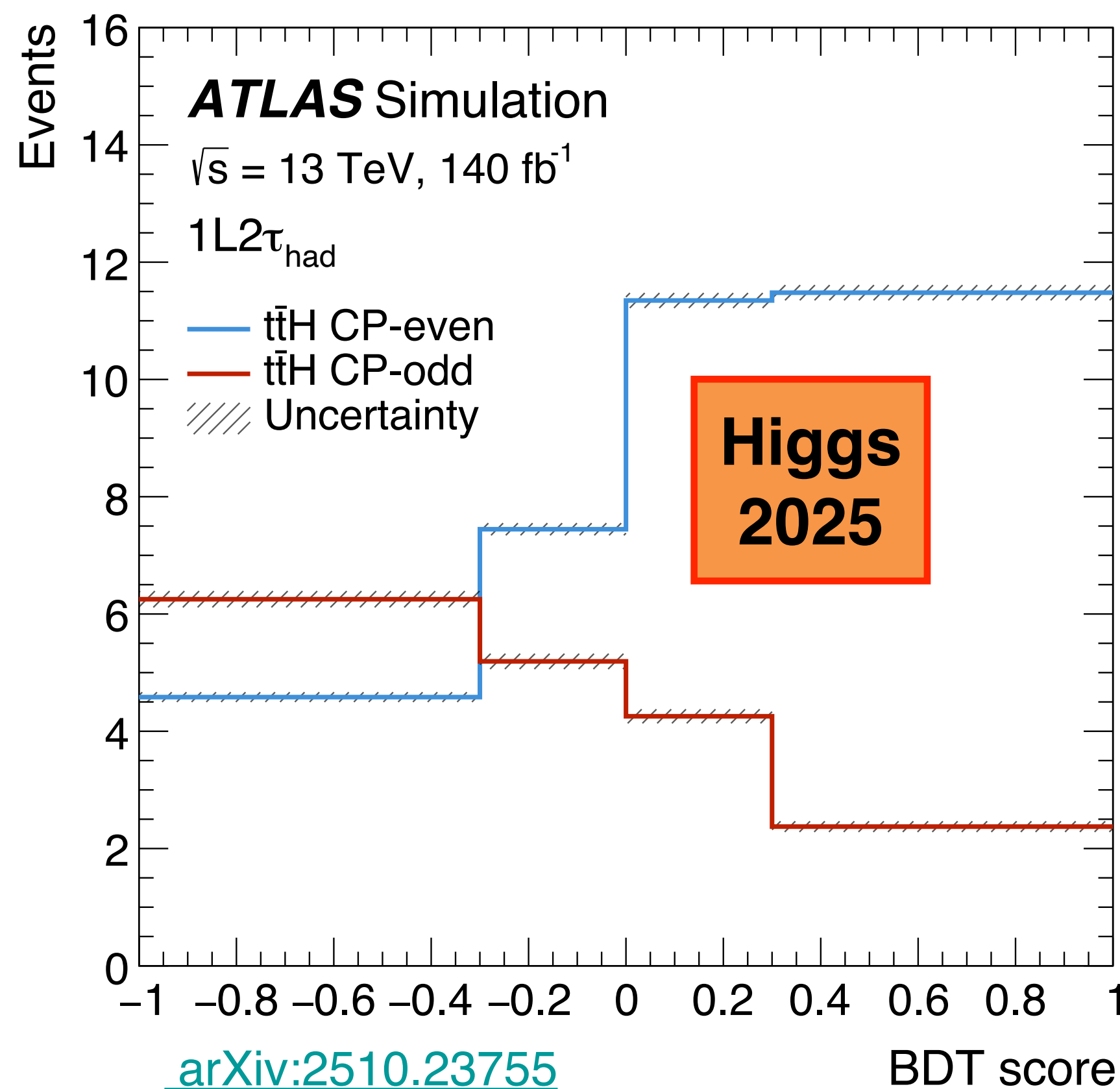
- **Less model dependence.** Flexible to measure different observables in different phase-spaces



Higgs boson CP, quantum entanglement

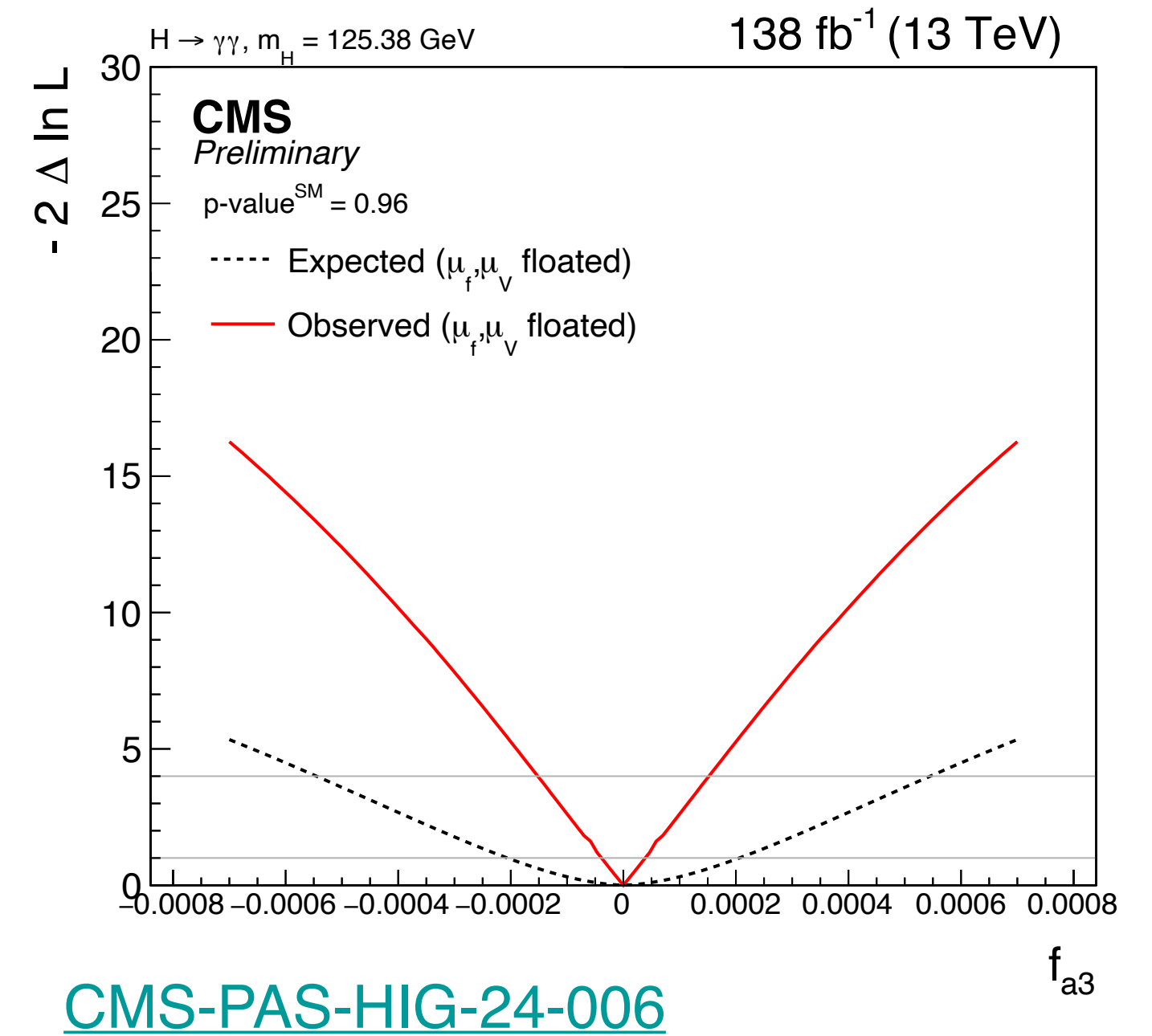
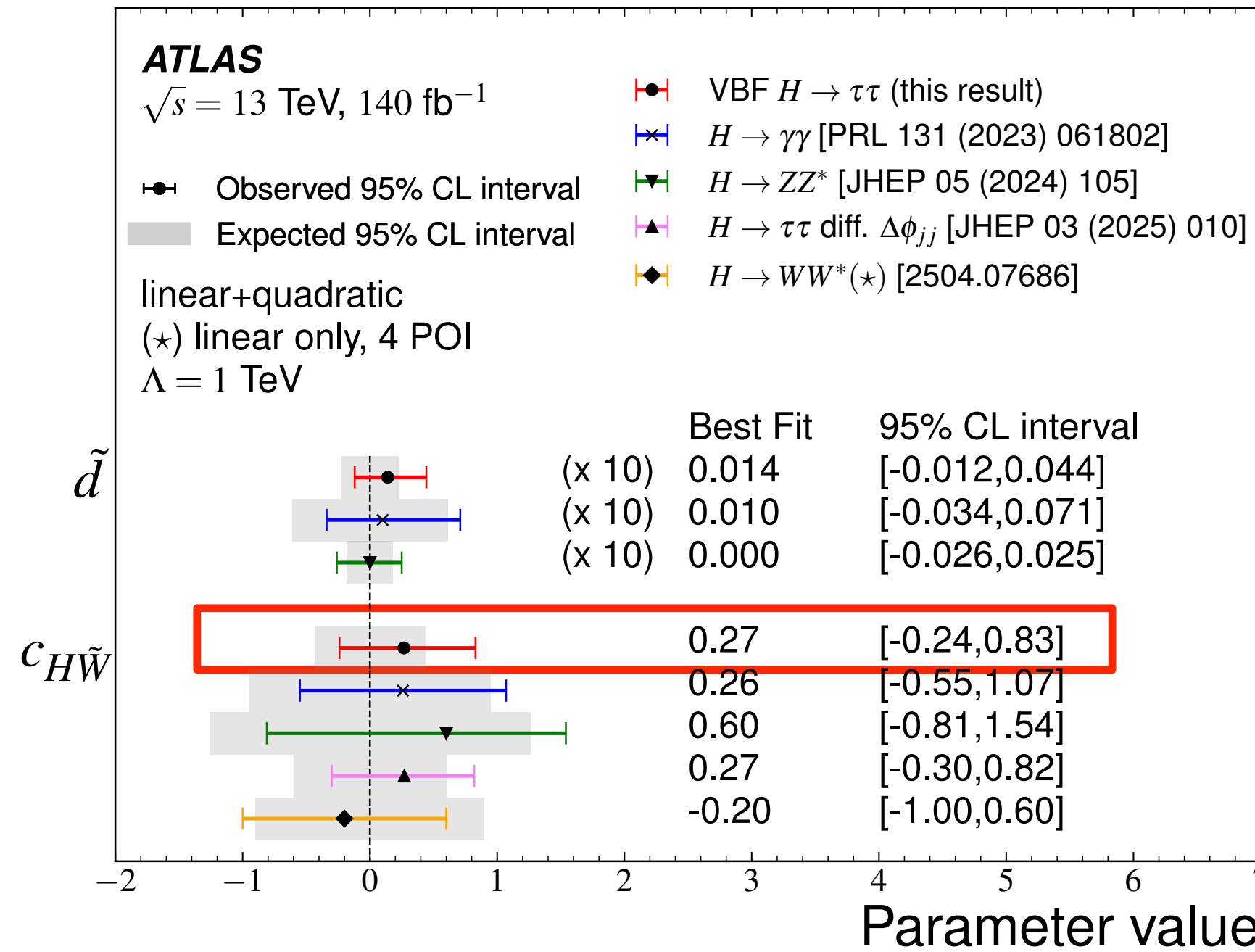
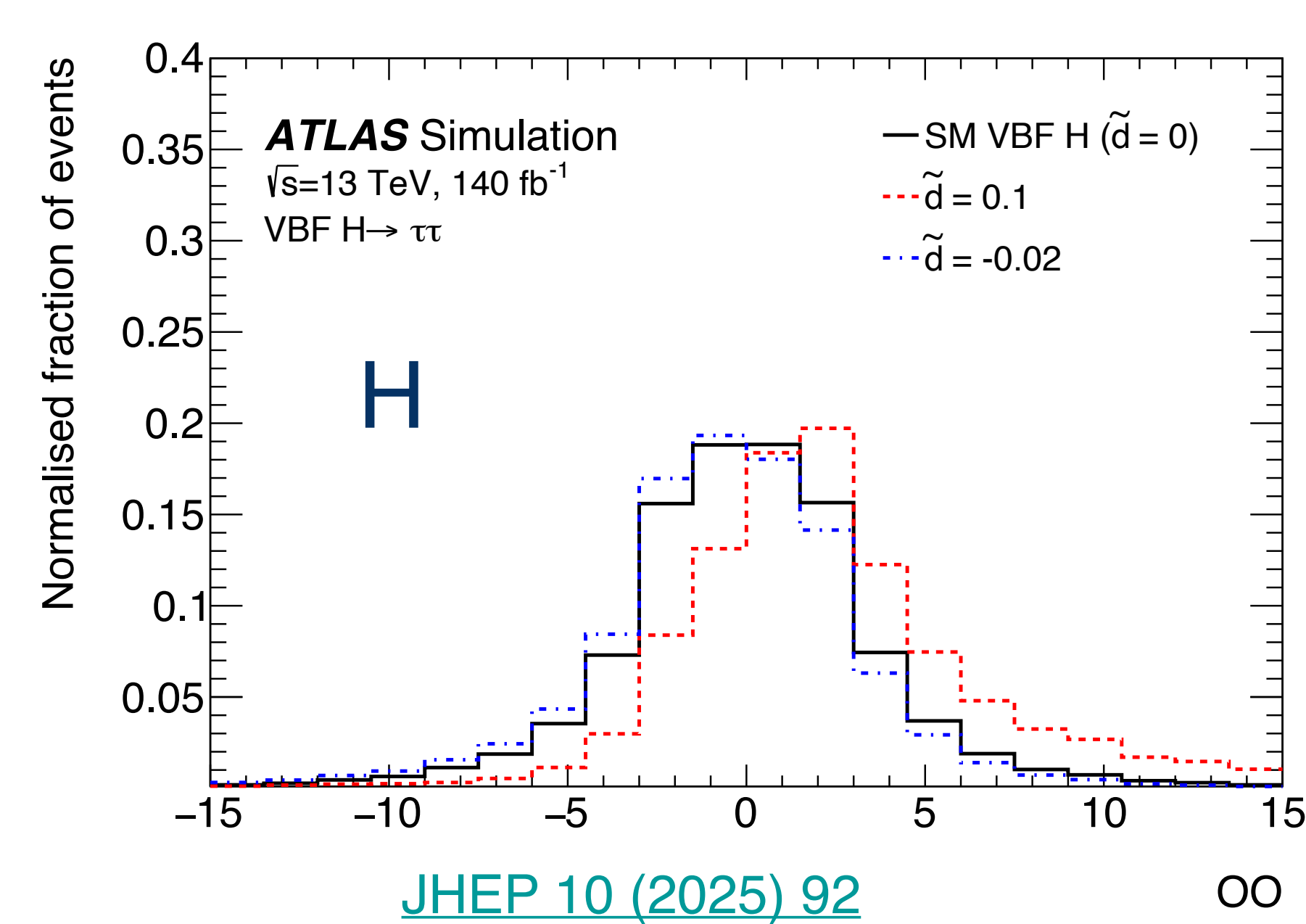


CP property of Yukawa couplings

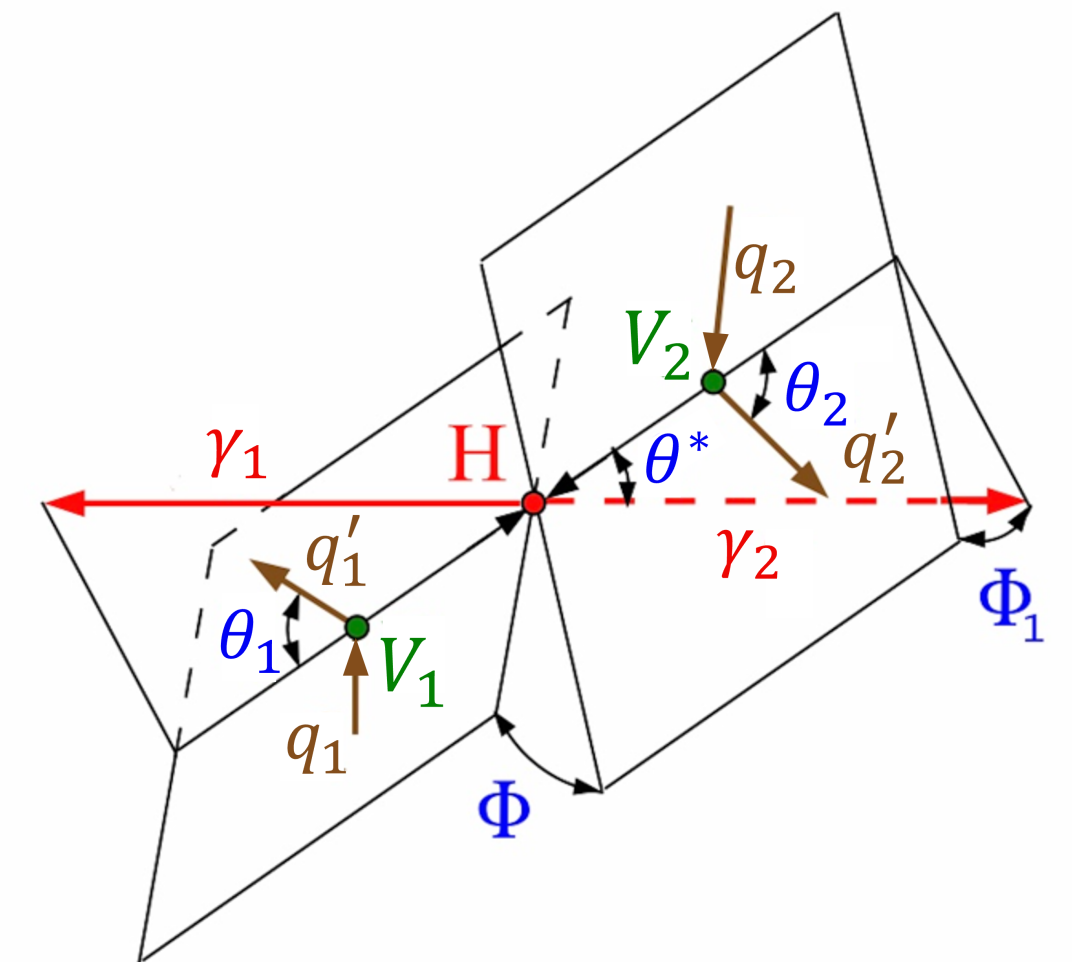


- CP violation of Yukawa coupling could happen at tree level
- Top Yukawa: studied with $t\bar{t}H/tH$ (direct) and ggF (indirect)

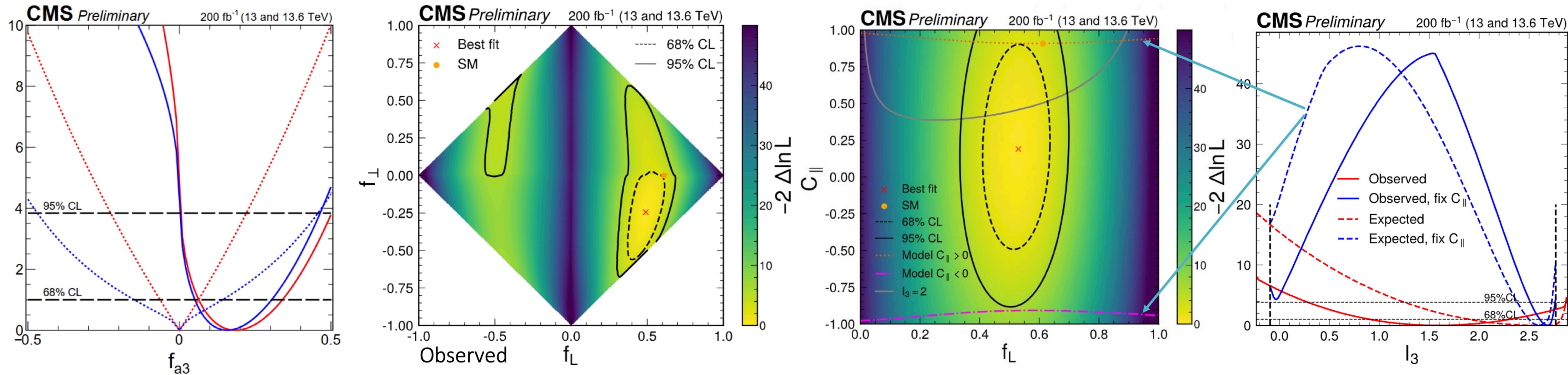
CP properties of gauge couplings



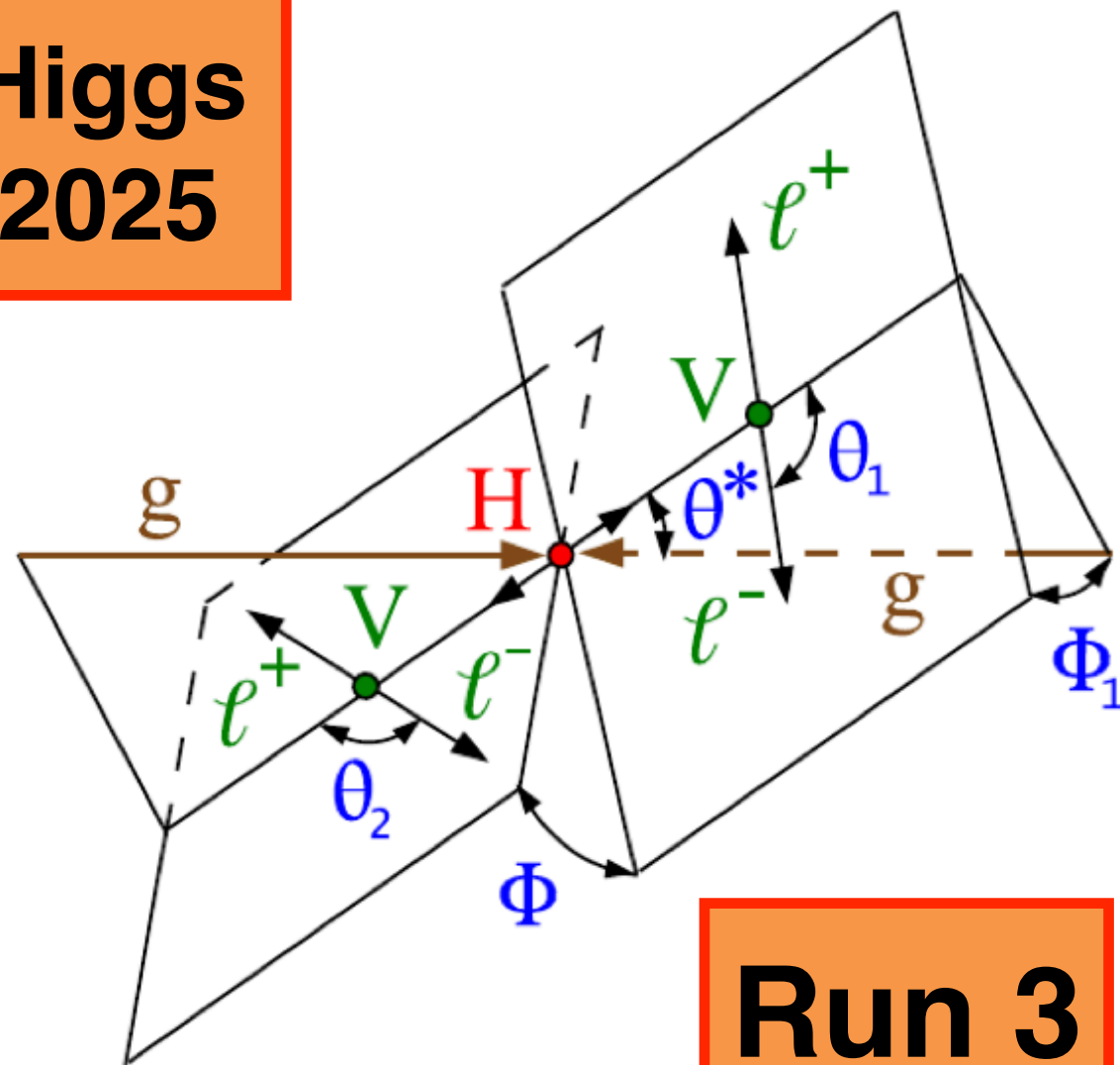
- Rely on VBF ($\Delta\Phi_{jj}$ etc.), VH , $H \rightarrow VV$
- Different interpretation framework between ATLAS and CMS
 - To be coordinated in the new CP subgroup under LHC Higgs Working Group 2 in light of possible combination



$H \rightarrow ZZ \rightarrow 4l$: CP, polarization, and quantum entanglement



Higgs
2025



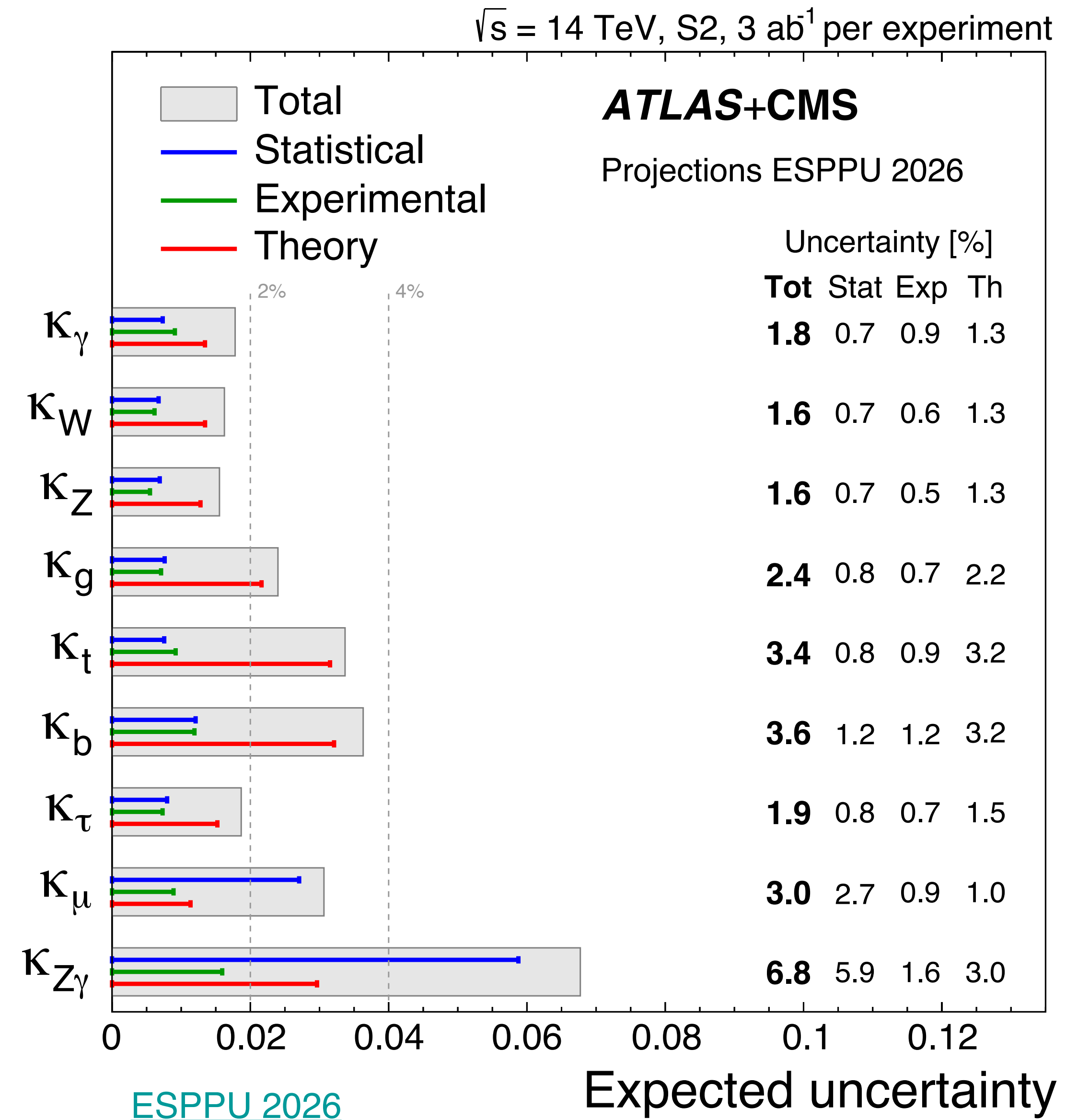
Run 3

- $H \rightarrow ZZ \rightarrow 4l$ final state contains rich angular info
- Search for CP violation in ZZ polarizations
- Use qutrits formed by Z boson to study quantum entanglement (spin-correlation)



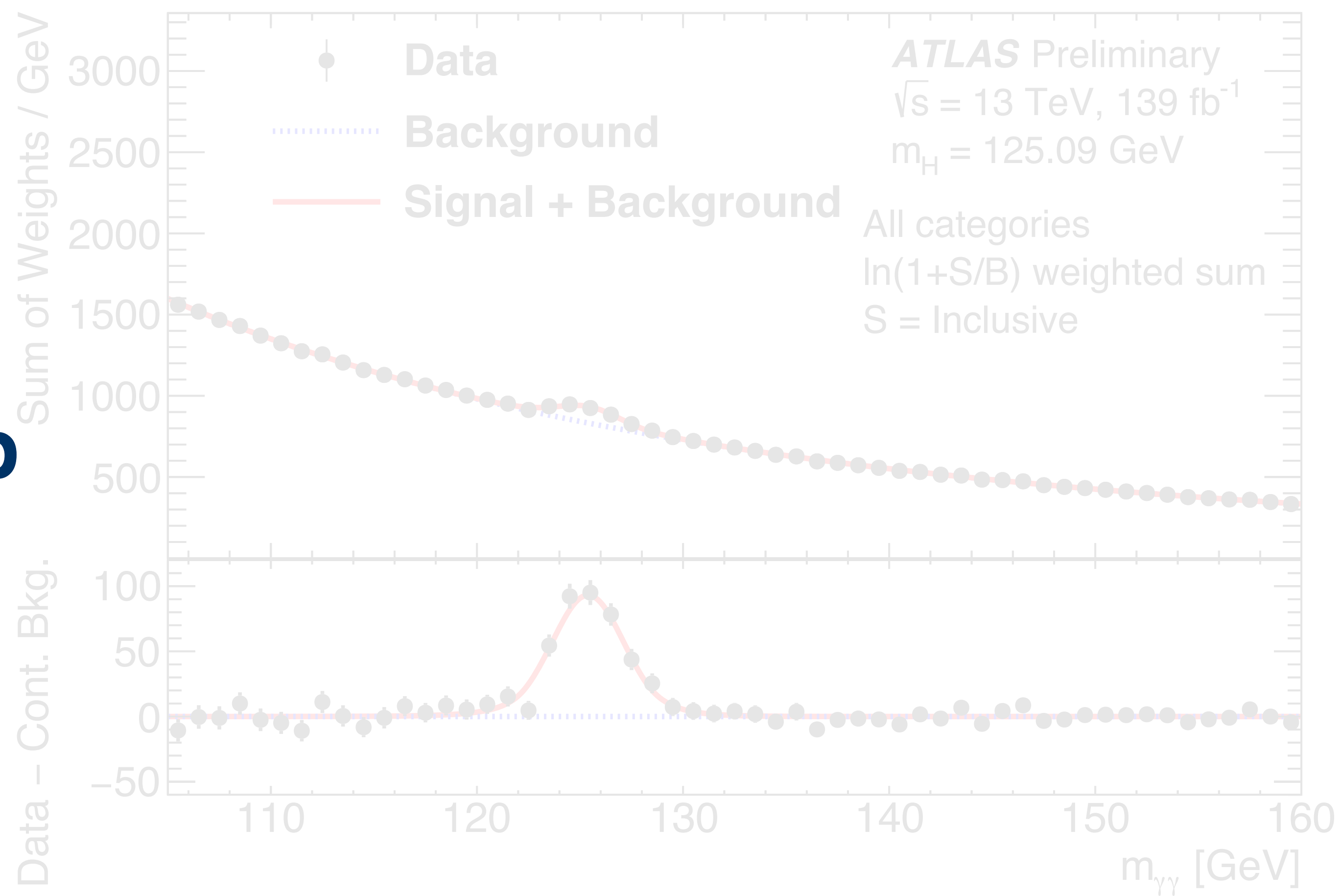
Conclusions

- LHC Higgs physics program in full swing.
More Run 3 results to come
 - LHC dataset is a valuable asset for Higgs physics and many others
 - There will be **~30M Higgs bosons** in Run 2 & Run 3 data. **We must exploit its full potential**
- **Strong theory-experiment partnership is essential for achieving this goal**
 - Theorists friends: please feel free contact us if you have any suggestions or even complaints.
Look forward to establishing a strong partnership with you!



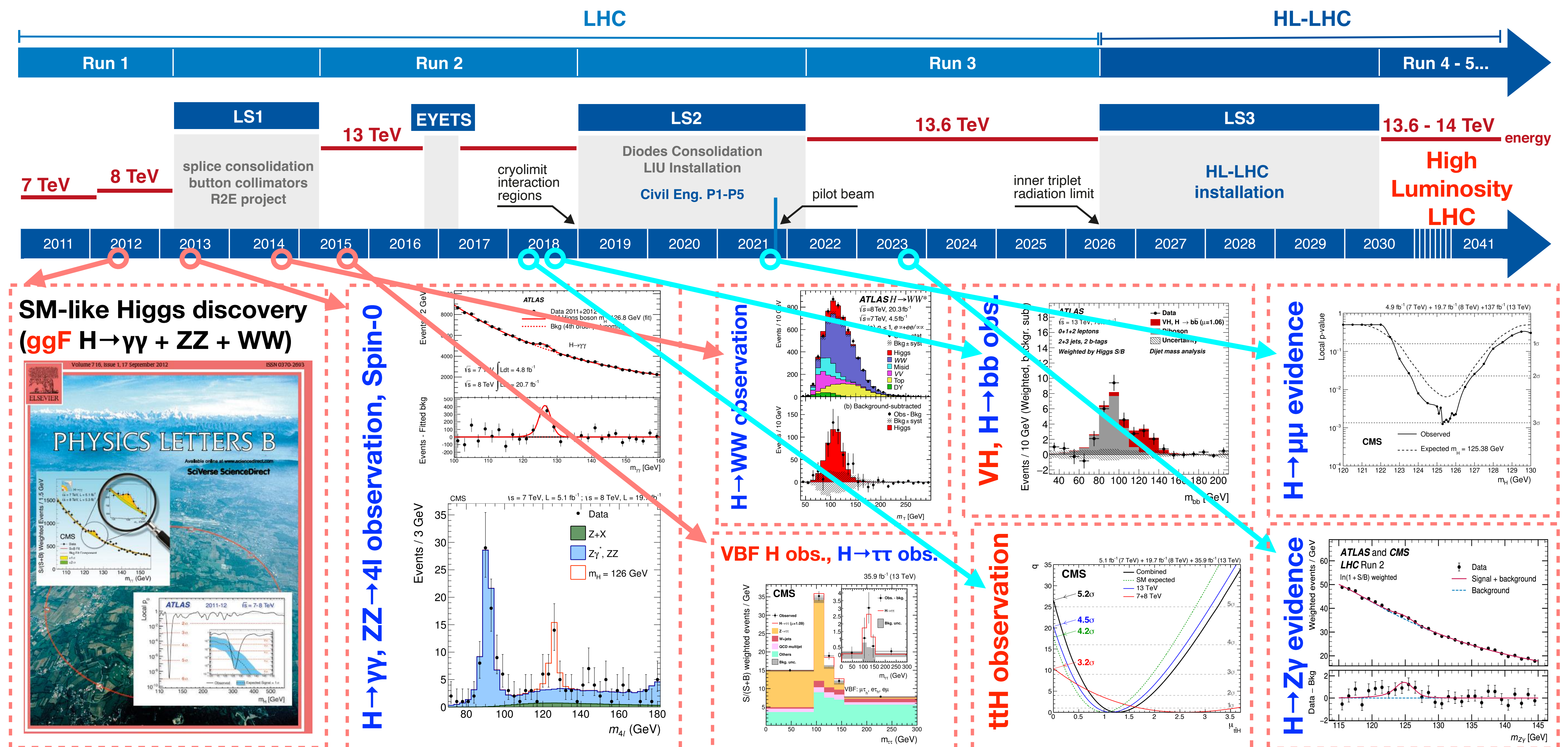


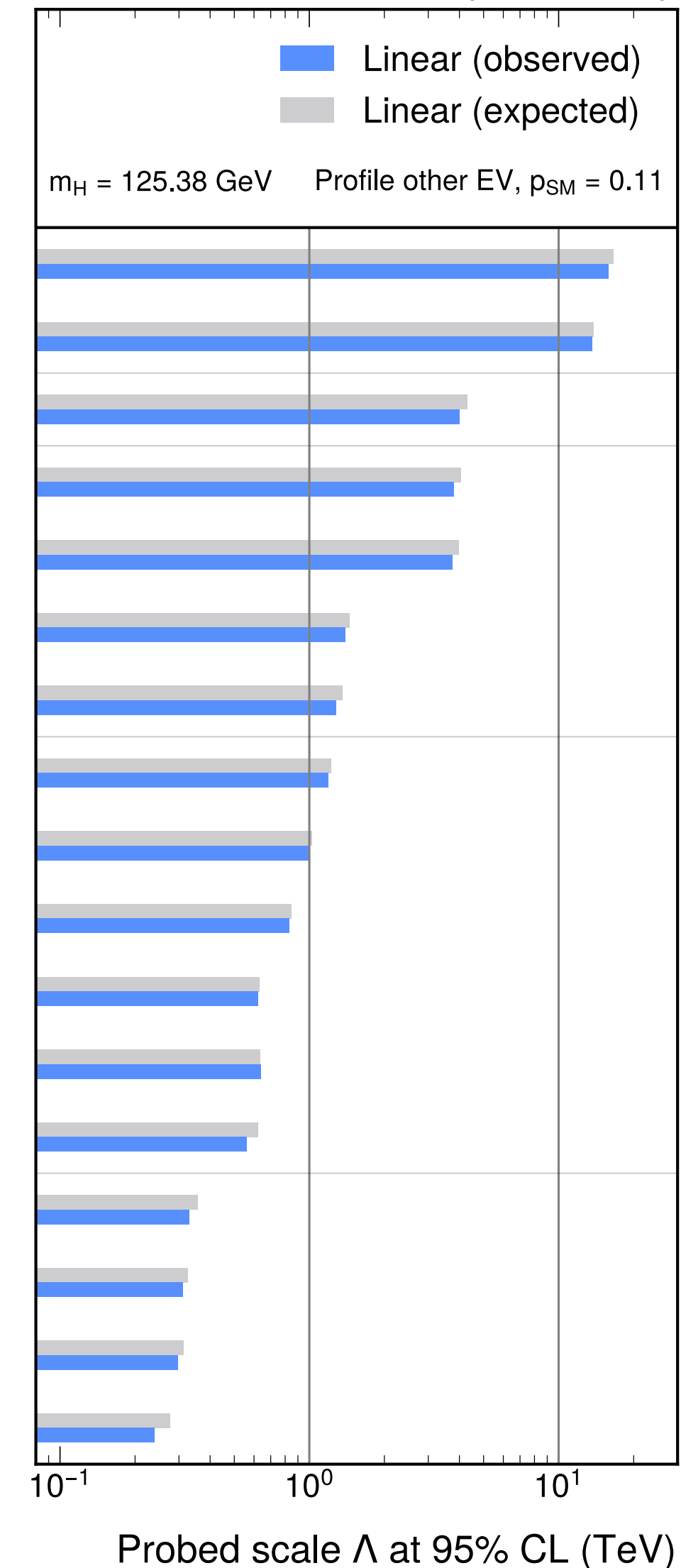
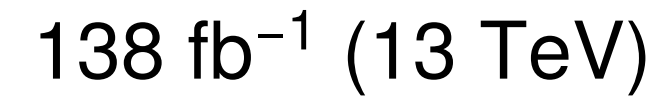
Backup





Roadmap of Higgs boson measurements (Courtesy of Kun Liu)





- Strong correlation among Wilson coefficients
- When fitting simultaneously, can only probe eigenvectors



Number of Higgs boson selected every /fb at 13 TeV

Decay	Total	ggF	VBF	WH	ZH	$t\bar{t}H+tH$
$H \rightarrow \gamma\gamma$	46.4	41.1	3.19	0.998	0.676	0.505
$H \rightarrow ZZ^*$	1.50	1.24	0.109	0.0316	0.0222	0.104
$H \rightarrow WW^*$	42.2	29.8	3.05	0.758	0.209	8.36
$H \rightarrow \tau\tau$	17.1	9.31	3.82	0.715	0.419	2.85
$H \rightarrow b\bar{b}$	66.0	9.68	9.68	4.81	6.30	35.5
$H \rightarrow \mu\mu$	6.67	5.96	0.474	0.143	0.0765	0.0112

Numbers are not most up to date (back in 2019)