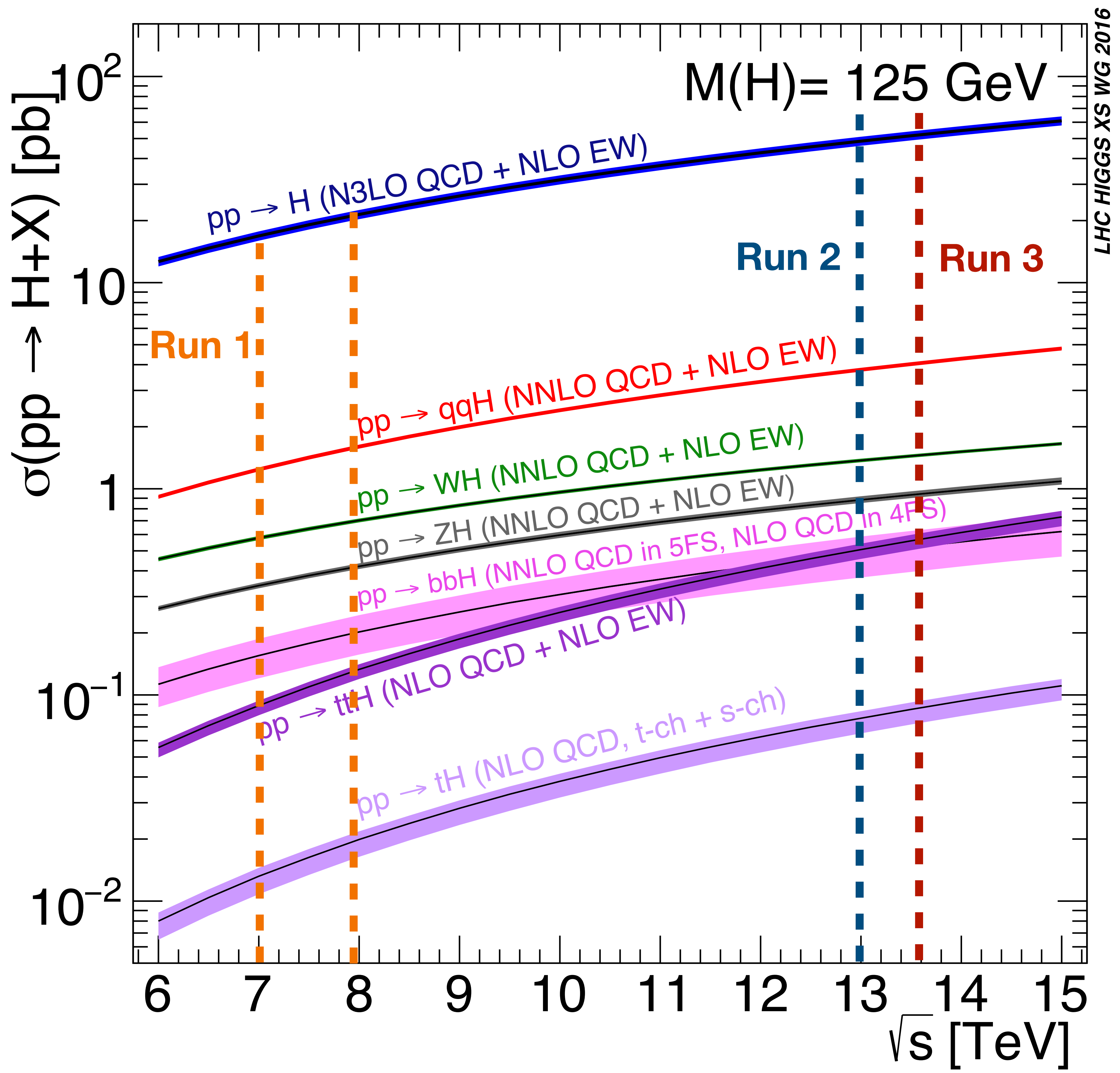
Measurements of Higgs boson production and properties at ATLAS and CMS

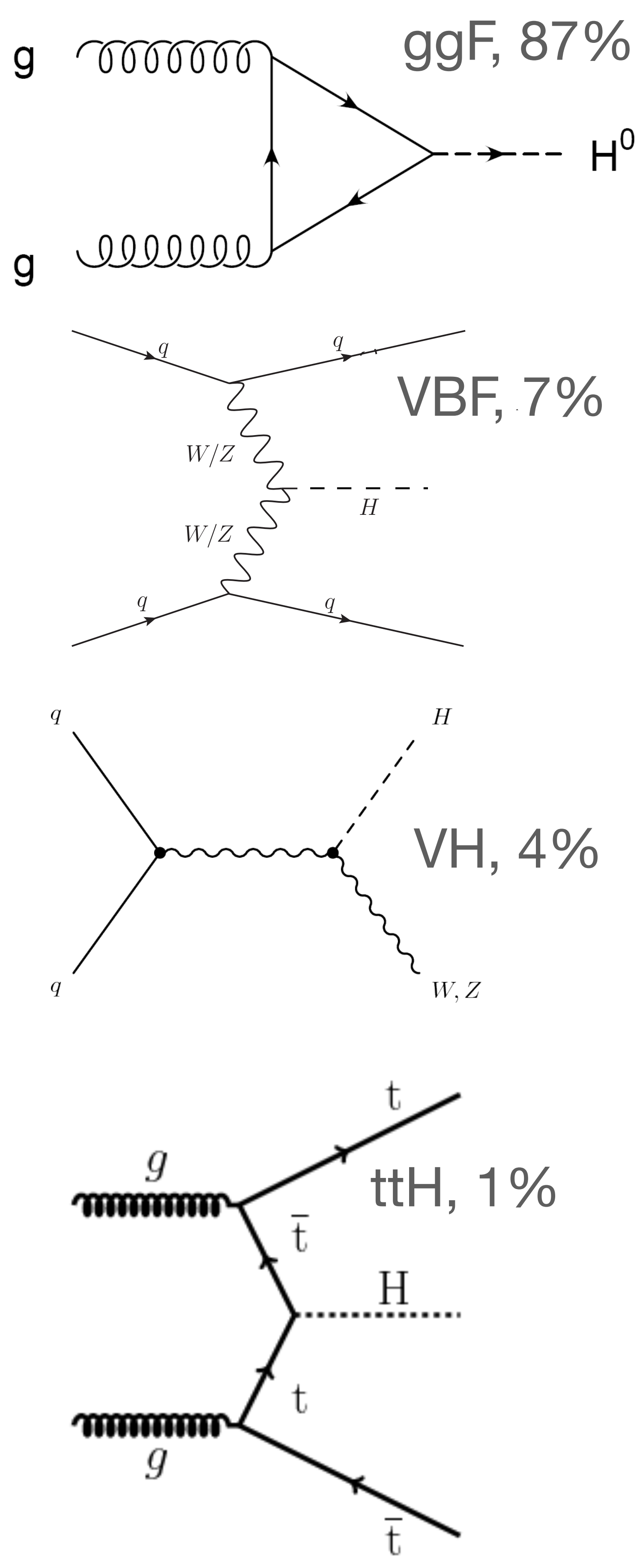
A. de Wit on behalf of the ATLAS and CMS Collaborations

Introduction

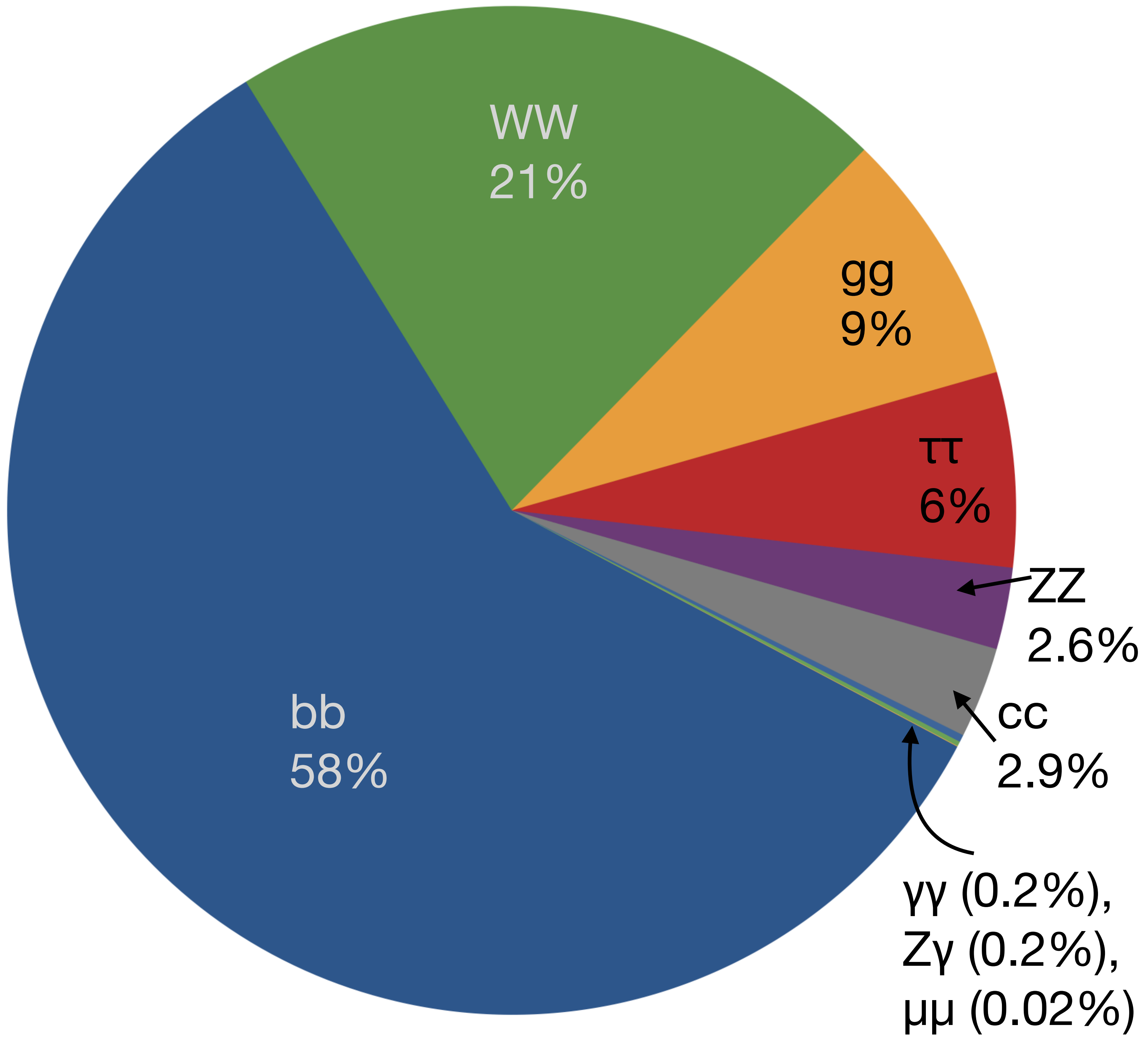
- Over a decade of Higgs boson physics at the LHC ➔ probing Higgs boson properties ever more precisely

Main production modes





Decay channels



Higgs boson production cross sections

Higgs boson production measurements

Model dependence ⟷ **Data needs**

(Inclusive) signal strength or cross section

Simplified template cross sections

Differential, fiducial measurements

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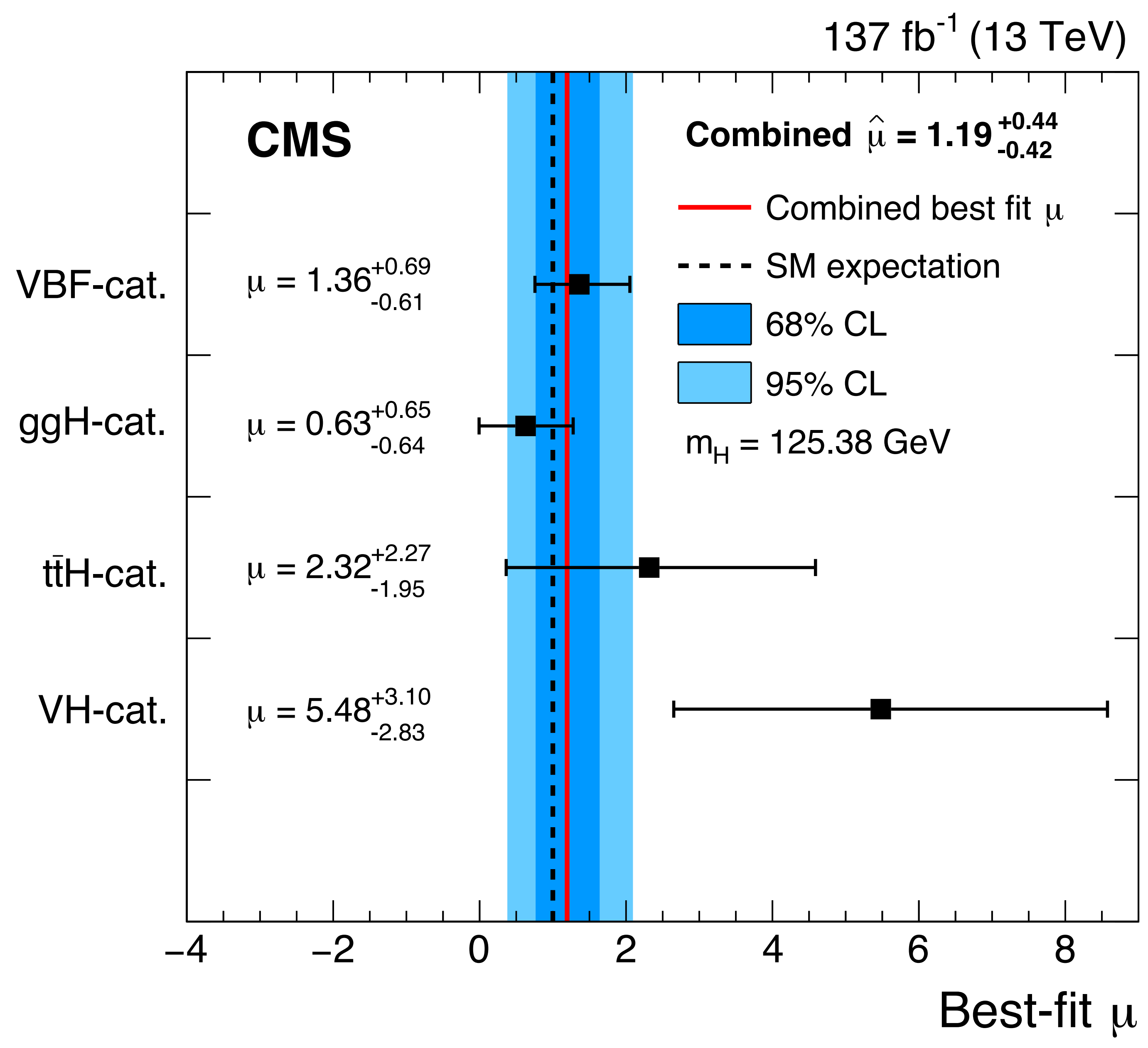
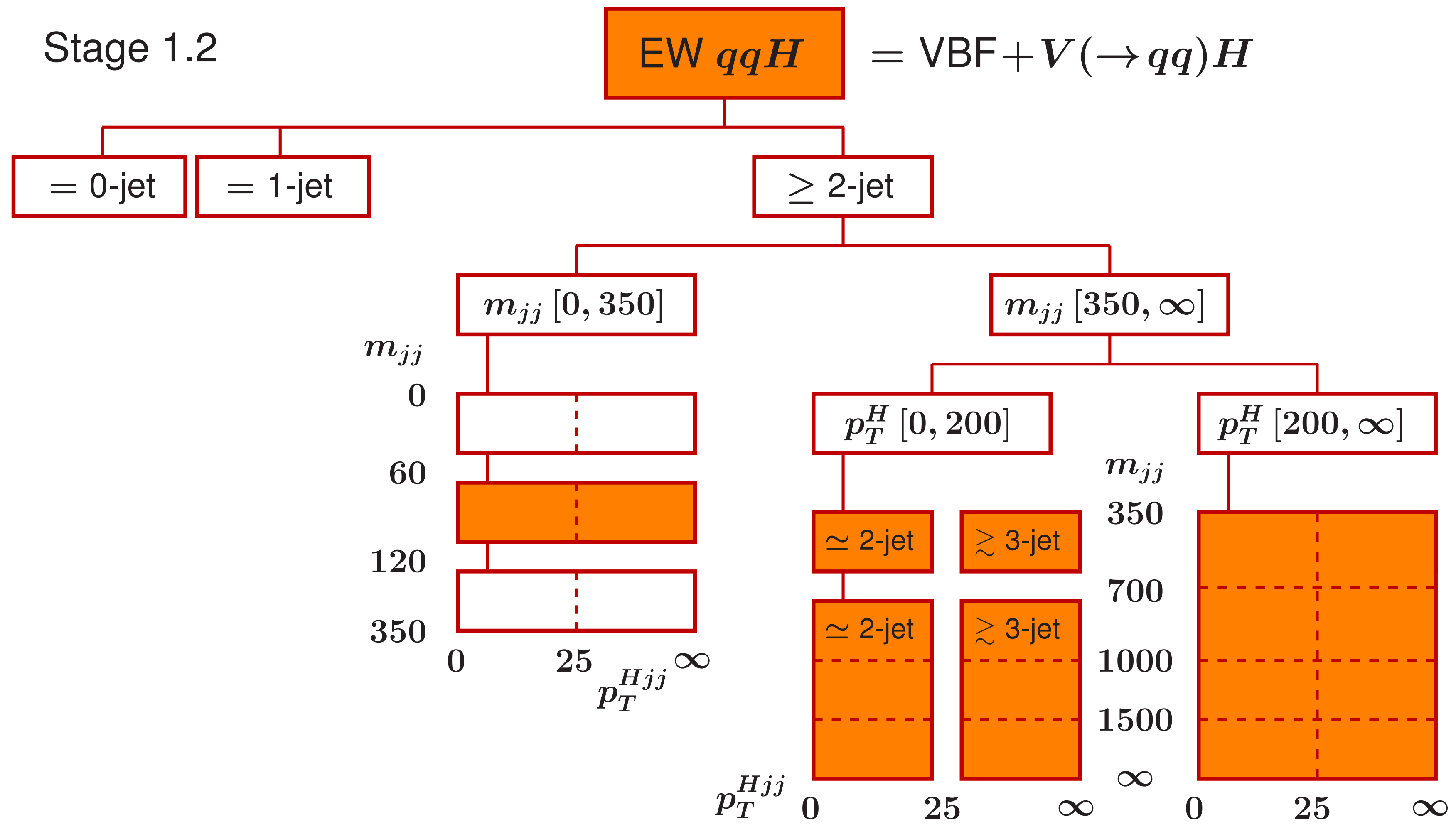
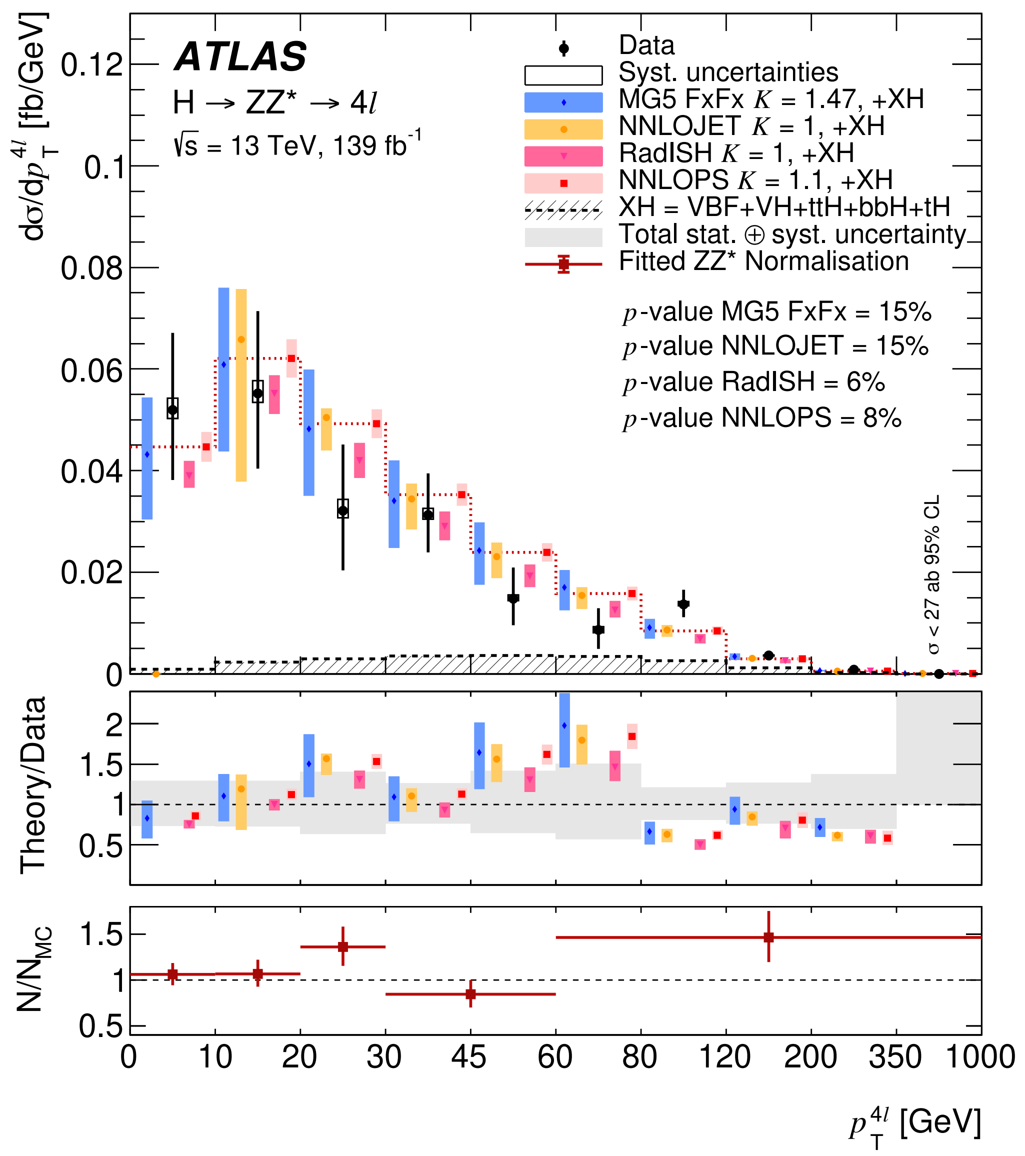






See talks in the parallel sessions (S. Chatterjee, G. Callea)

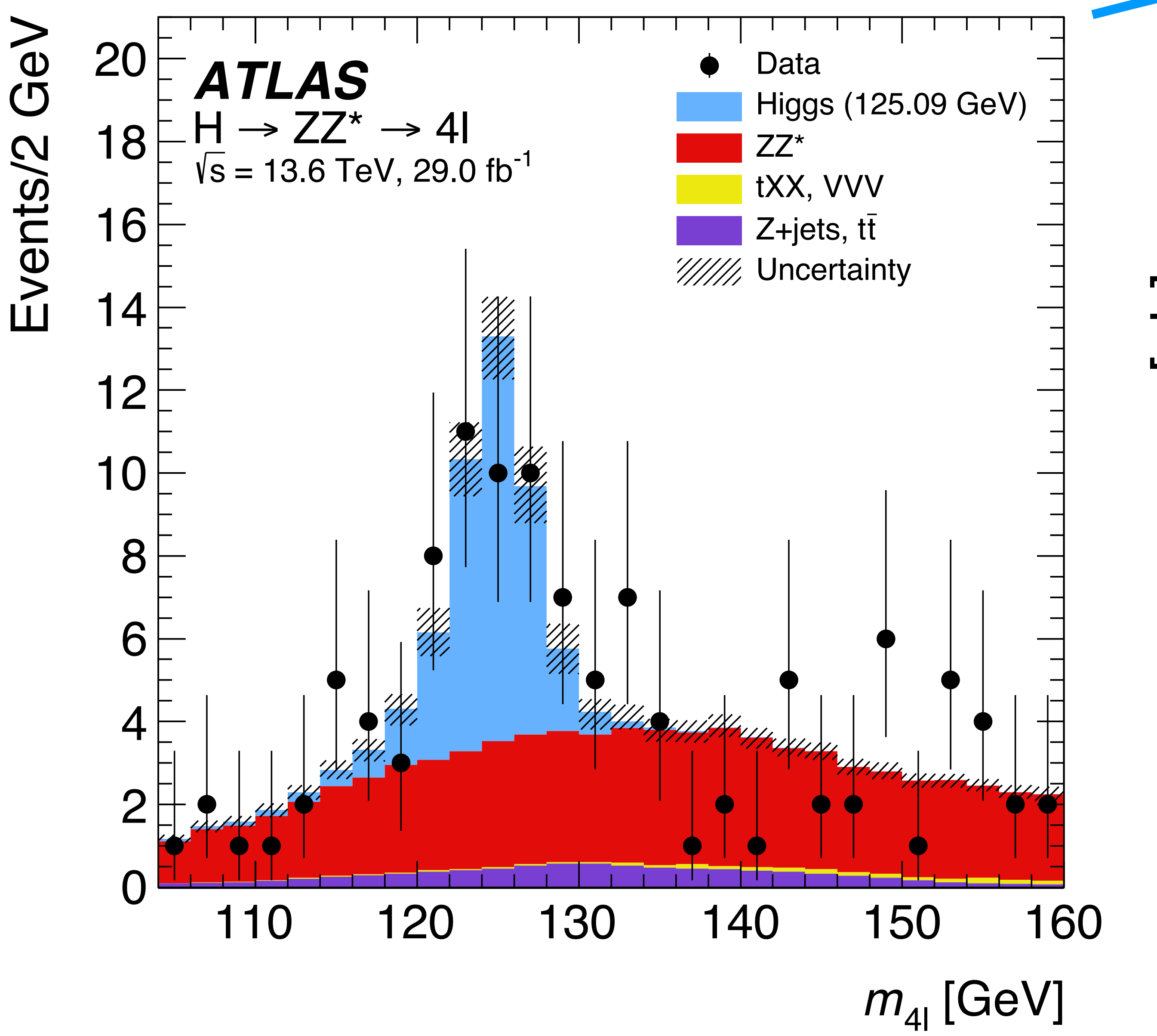
Cross sections at 13.6 TeV

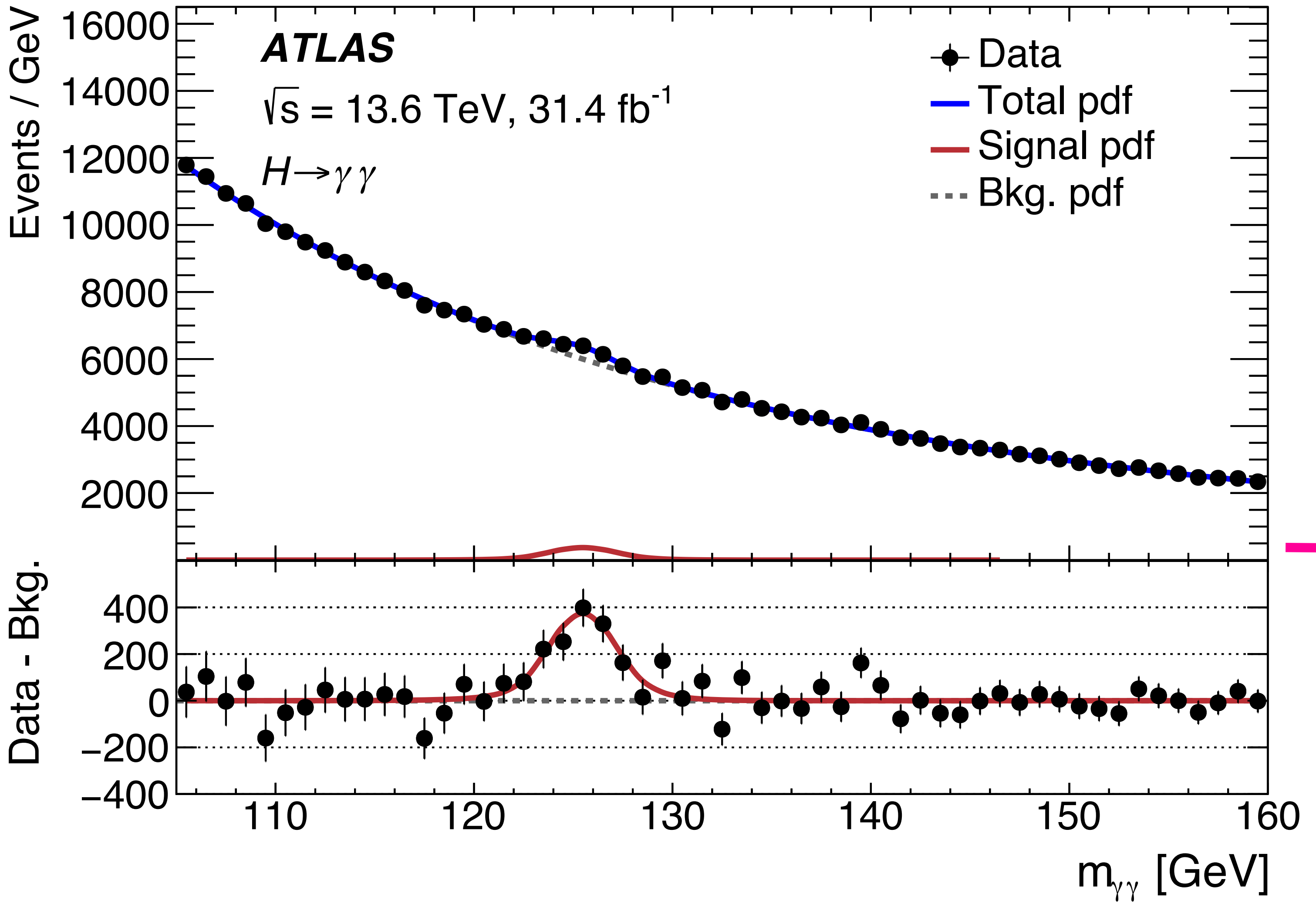
- Measurements with 2022 data
- Fiducial cross section measurements extrapolated to full phase space to combine:

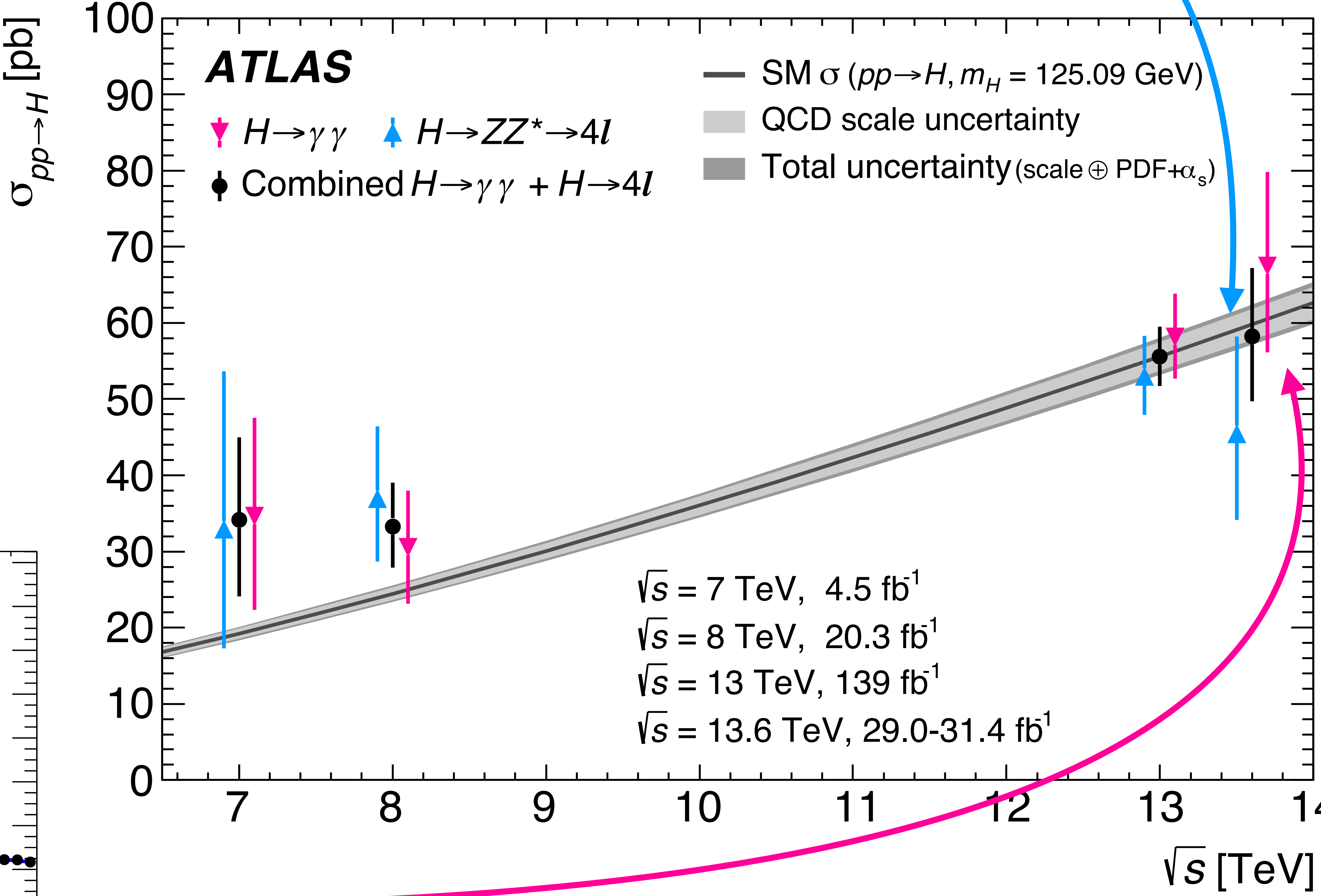
σ_H = 58.2 ± 8.7 pb
(exp: 59.9 ± 2.6 pb)

@13.6 TeV

- Main uncertainty component statistical (for now)

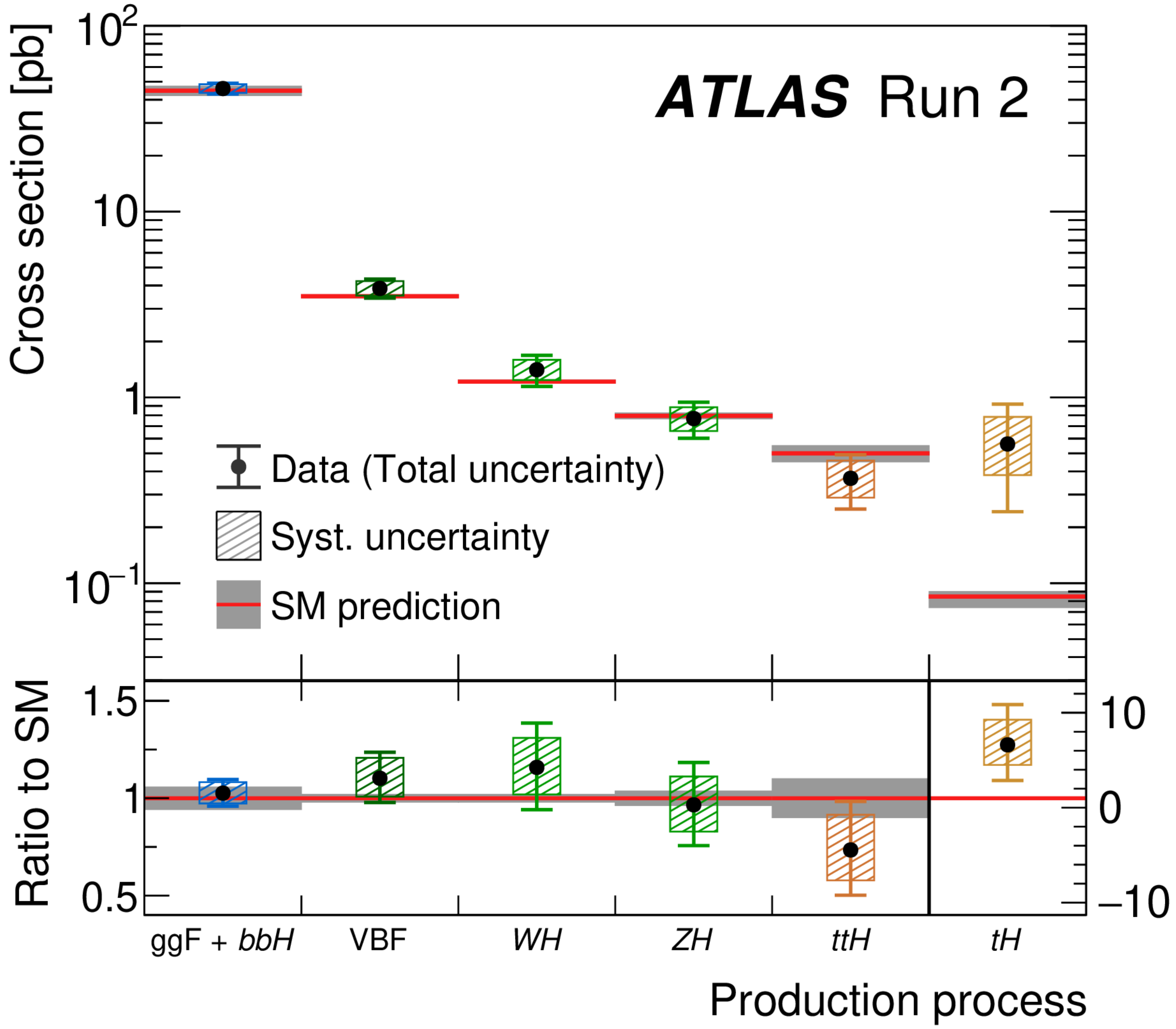


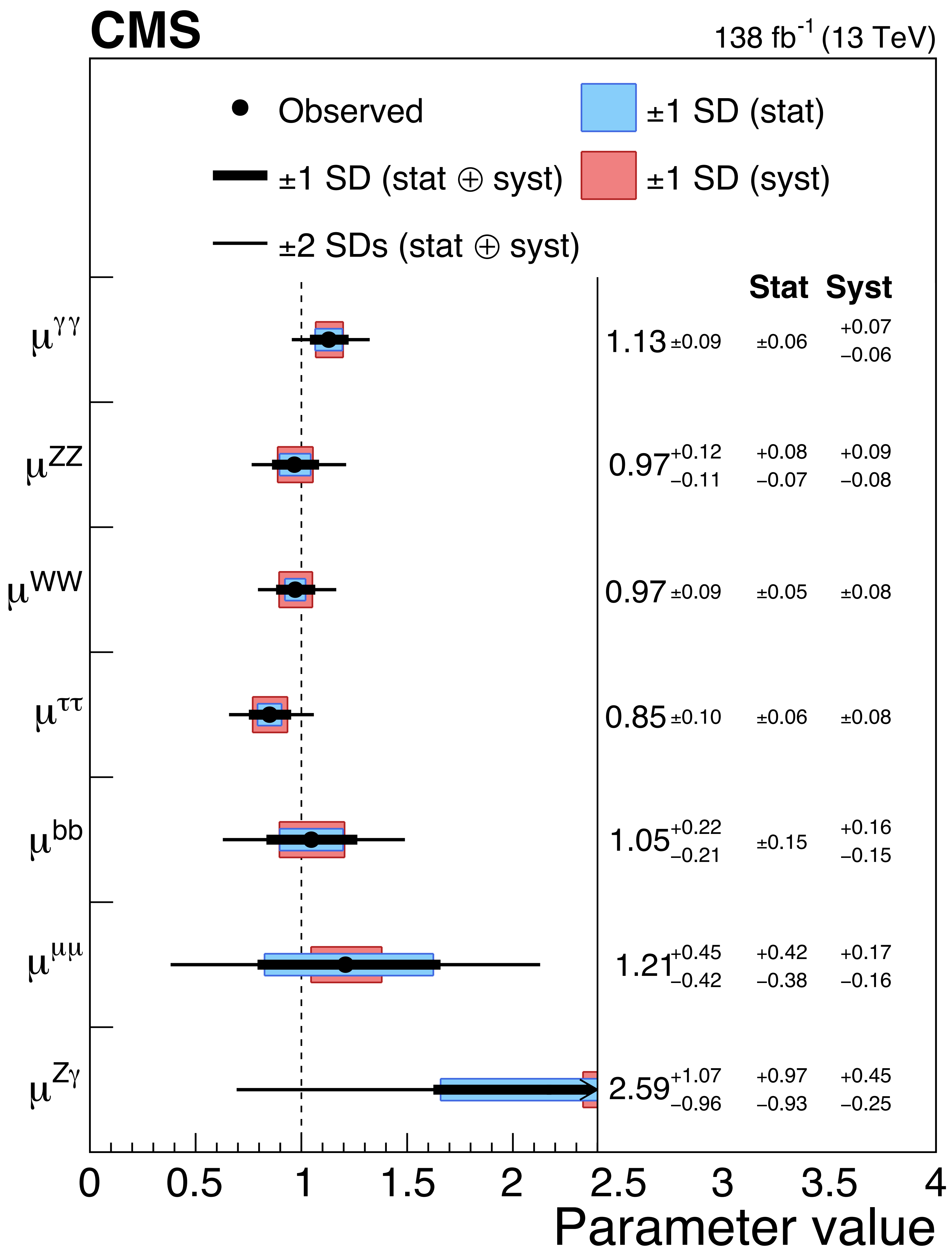




Cross sections per production/decay mode

Nature 607 (2022) 52



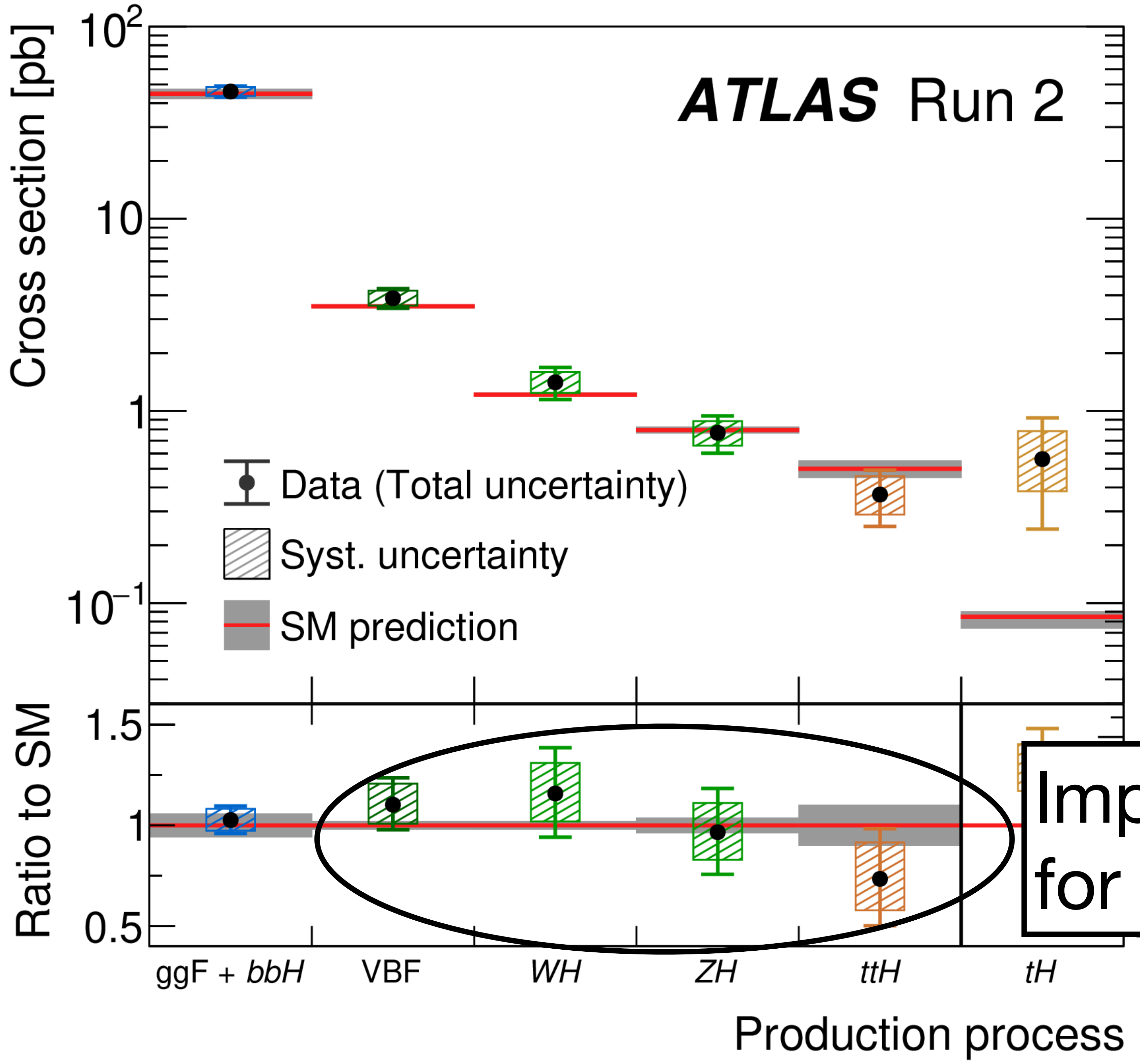


Nature 607 (2022) 60

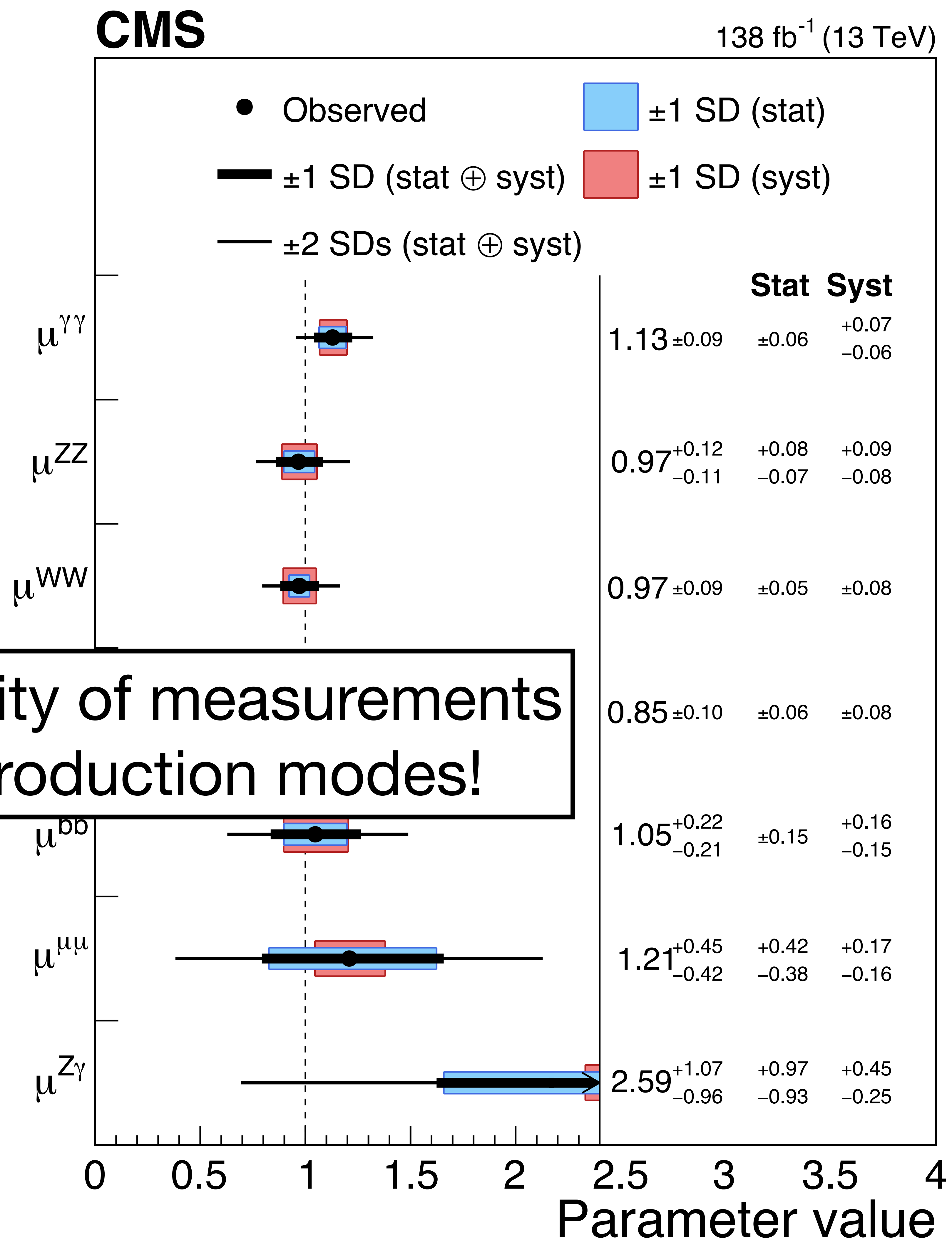
- Precision **better than 10%** for ggF, **10-20% precision** on most other production modes
- Decays into bosons, tau leptons: **precision ~10%**

Cross sections per production/decay mode

Nature 607 (2022) 52



Improving granularity of measurements for less common production modes!



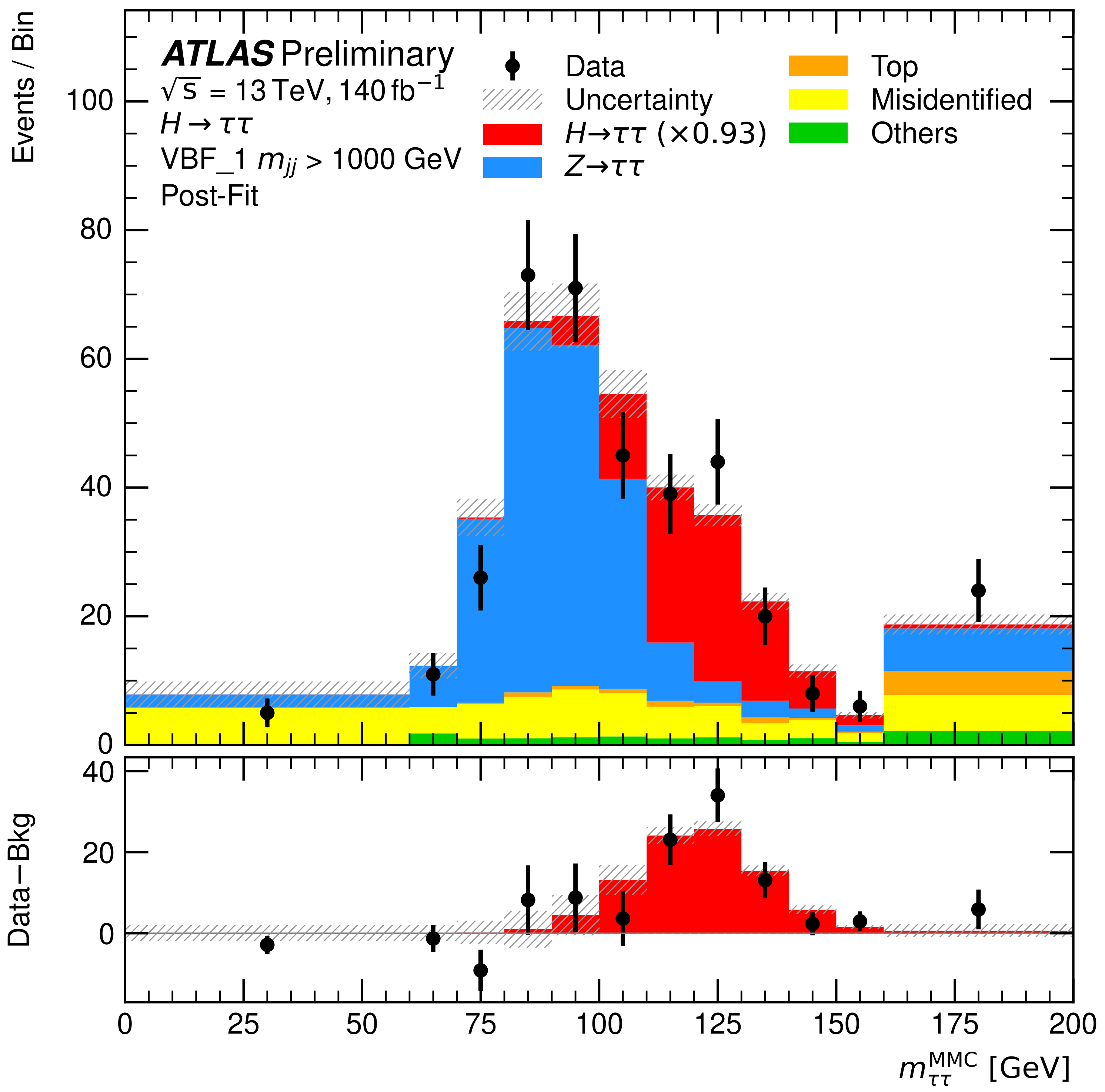
Nature 607 (2022) 60

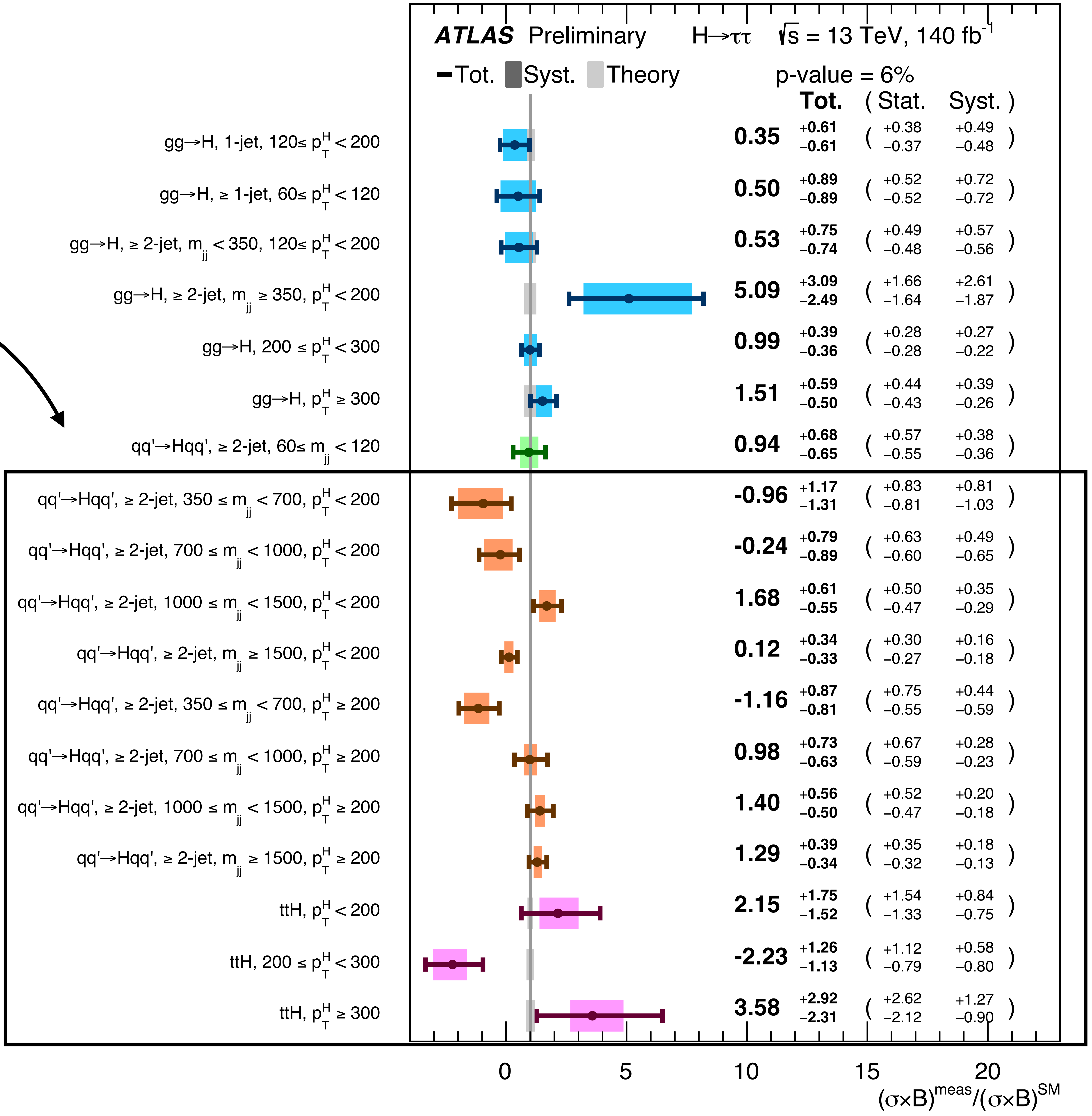
- Precision **better than 10%** for ggF, **10-20% precision** on most other production modes
- Decays into bosons, tau leptons: **precision ~10%**

New

STXS H→ττ

- Number of measured STXS bins **doubled** wrt previous measurement
  - Additional bins in VBF, ttH
    Enabled by NN $p_T(H)$-regression and S/B MVA

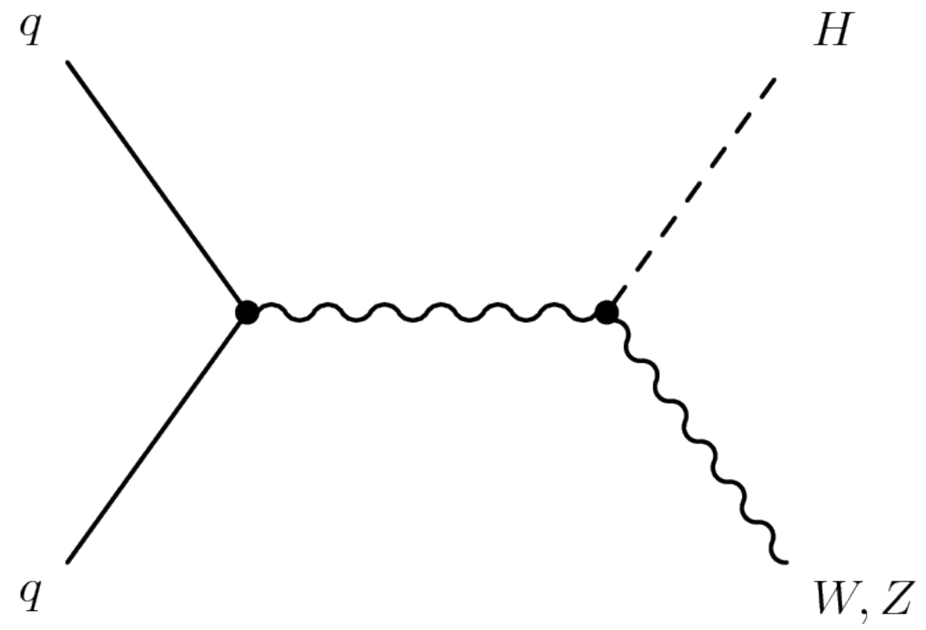


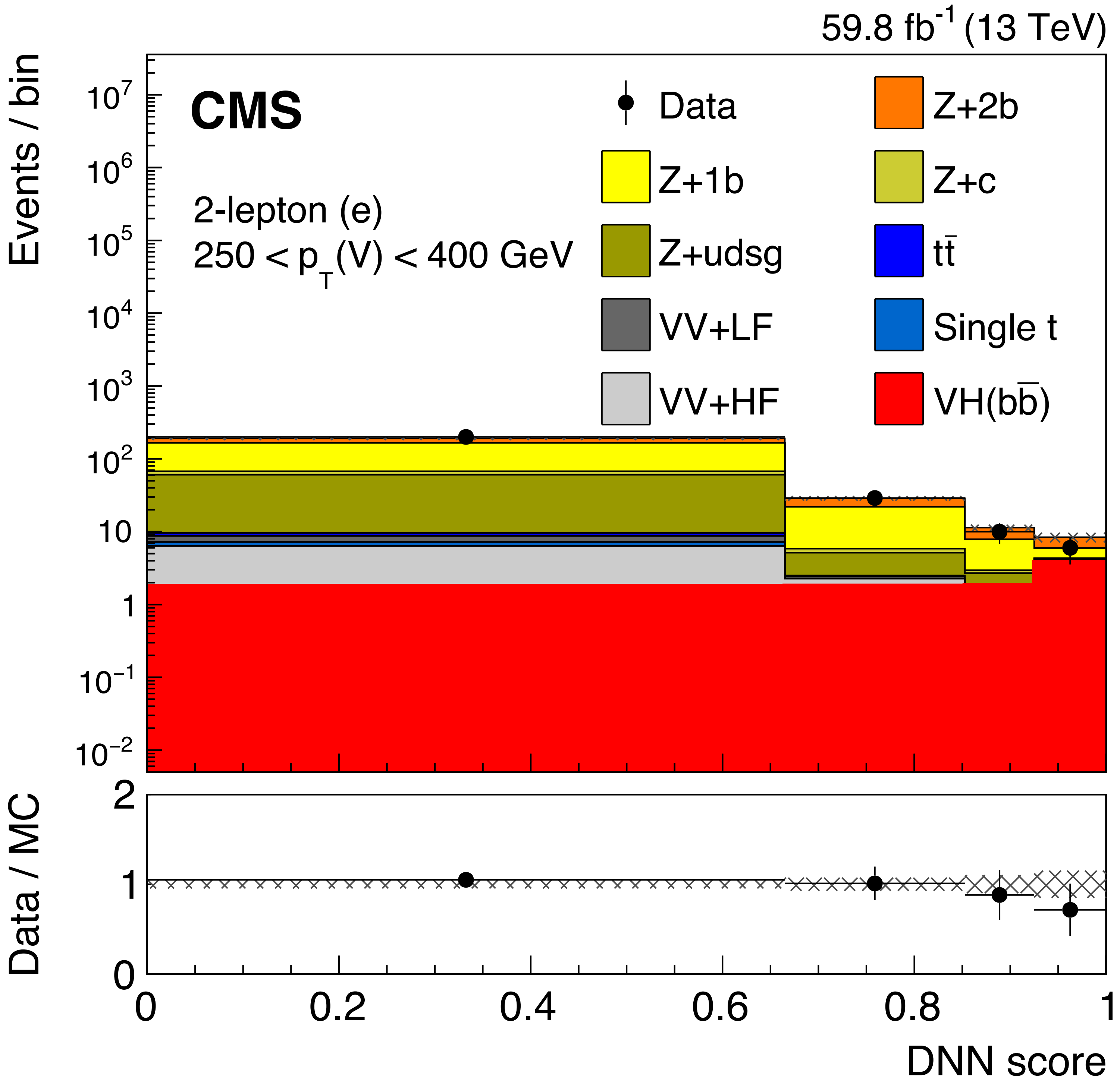


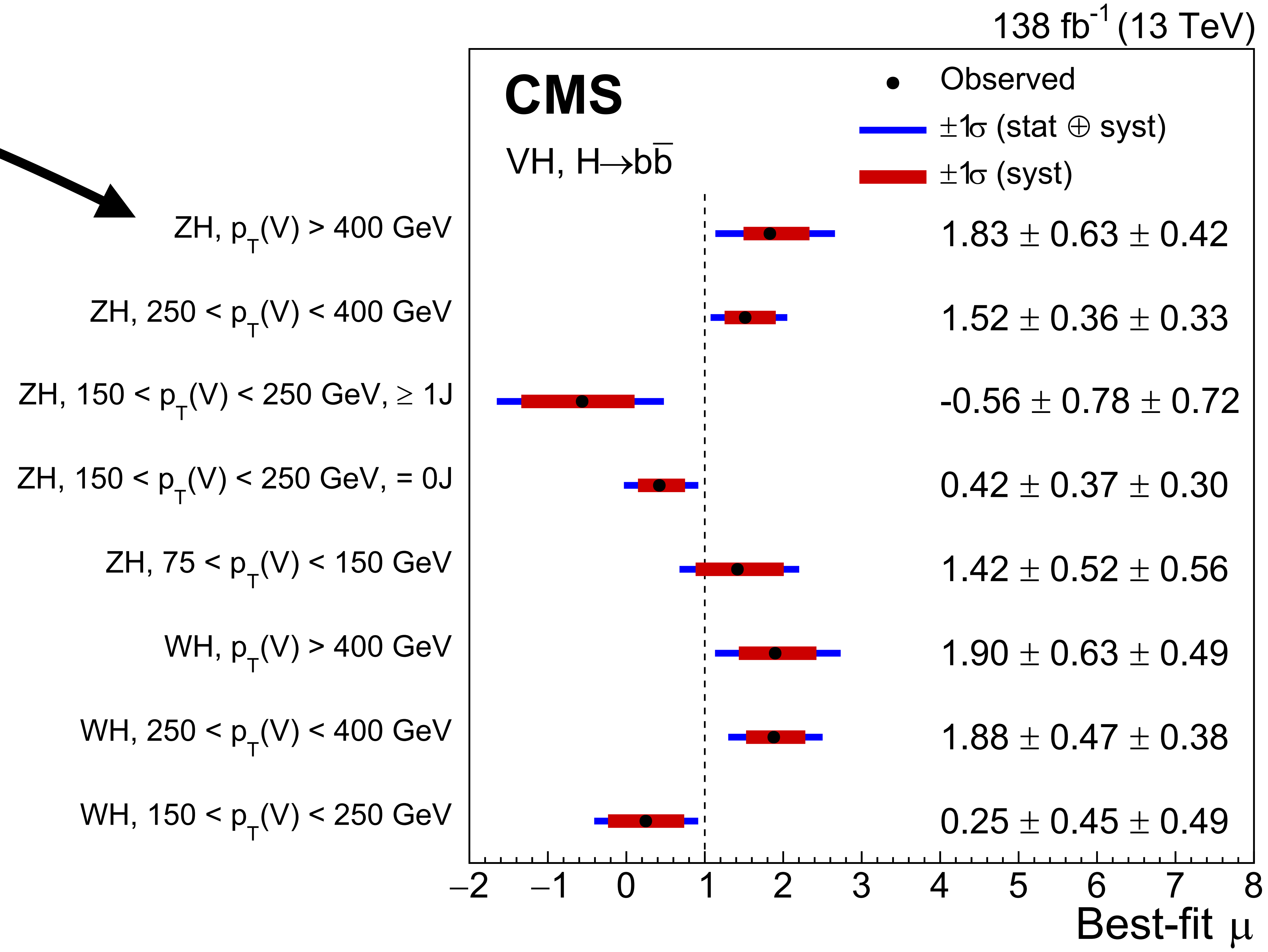
See A. Gomez Delegido's talk in the parallel session tomorrow

VH, H→bb

- Rare process (V→leptons): large-branching fraction final states
- Rely on multivariate analysis techniques to improve sensitivity
- Inclusive **(μ=1.15±0.21)**, per-production mode signal strengths and STXS





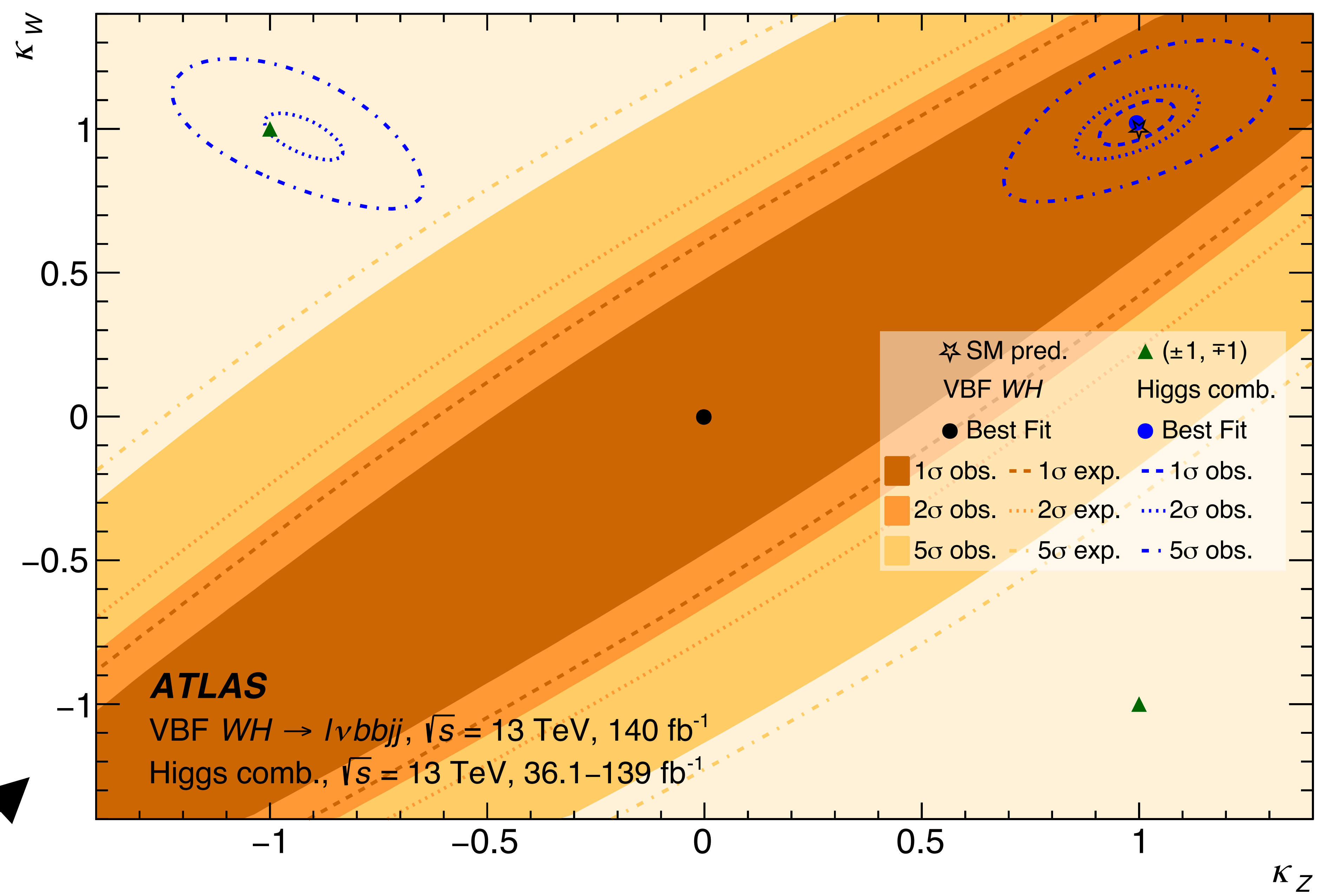


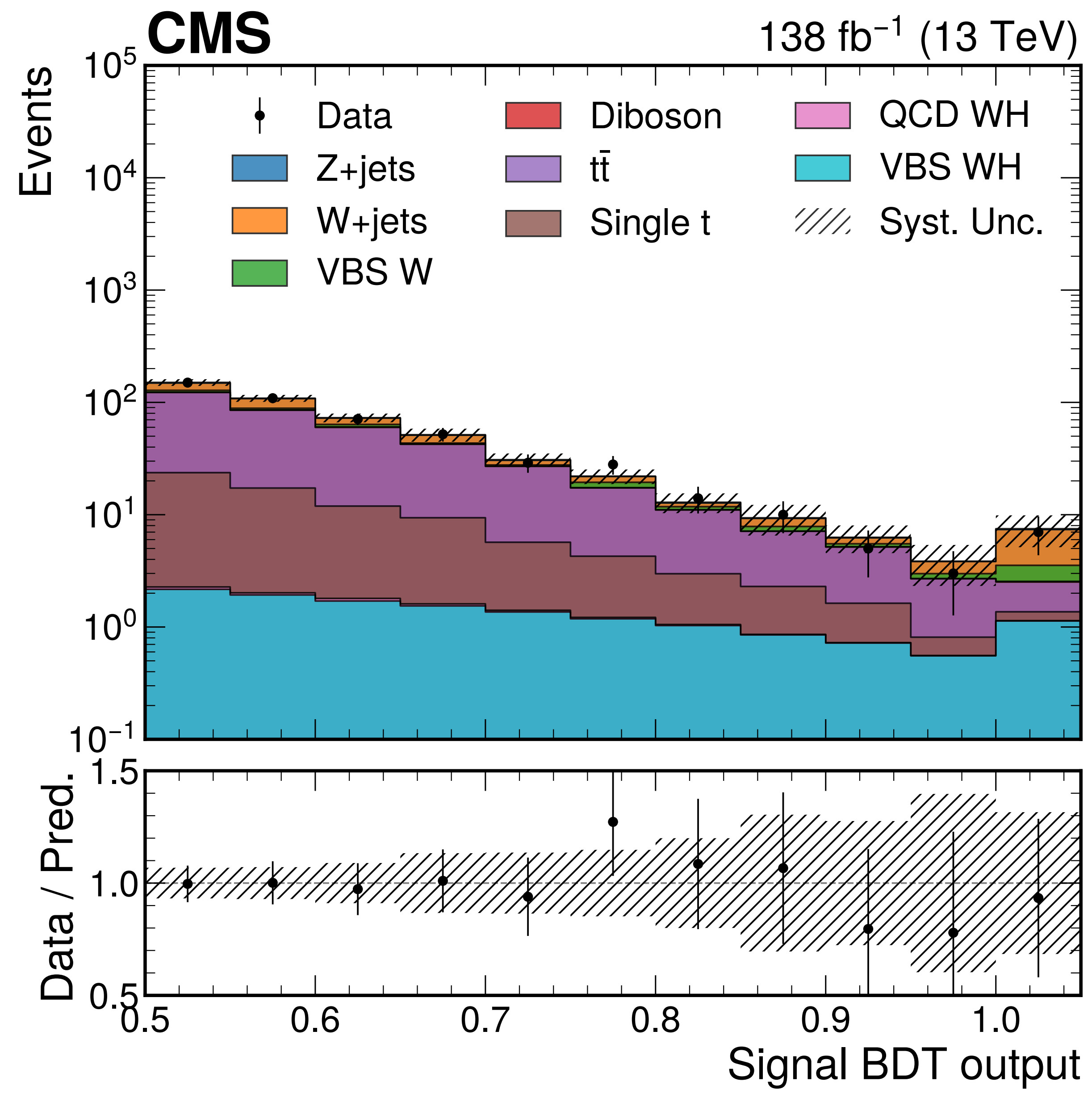
arXiv:2402.00426 (sub'd to PRL)

arXiv:2405.16566 Sub to PLB

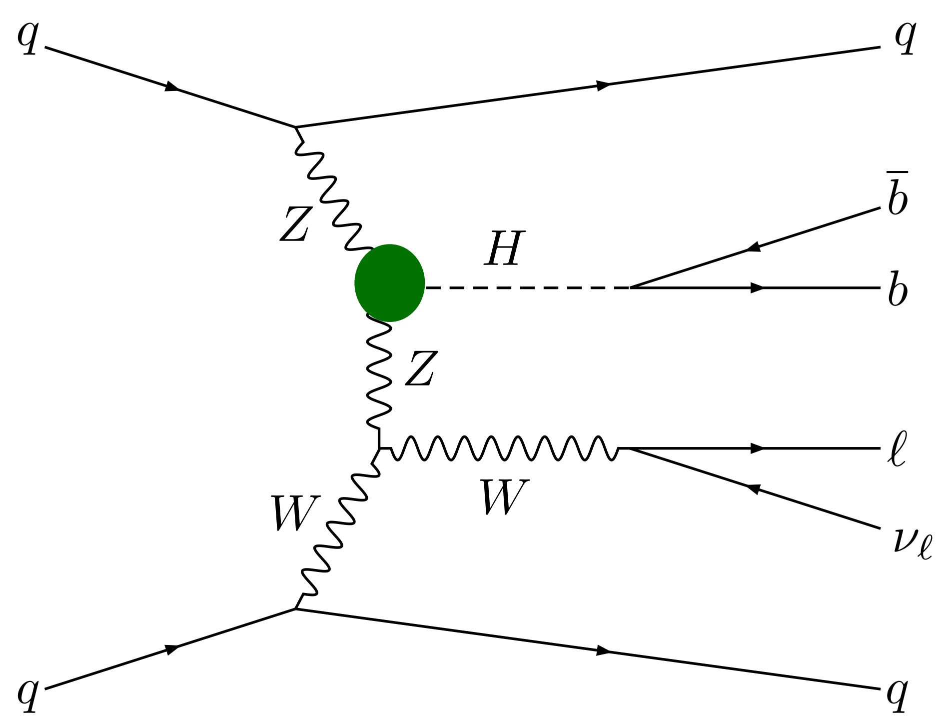
Electroweak VH

- EW production of WH sensitive to relative sign $\lambda_{WZ} = \frac{\kappa_W}{\kappa_Z}$
- H➔bb final state (CMS including merged jets)
- ATLAS and CMS both **exclude values λ_{WZ}<0** consistent with existing measurements **(@ more than 5σ)**



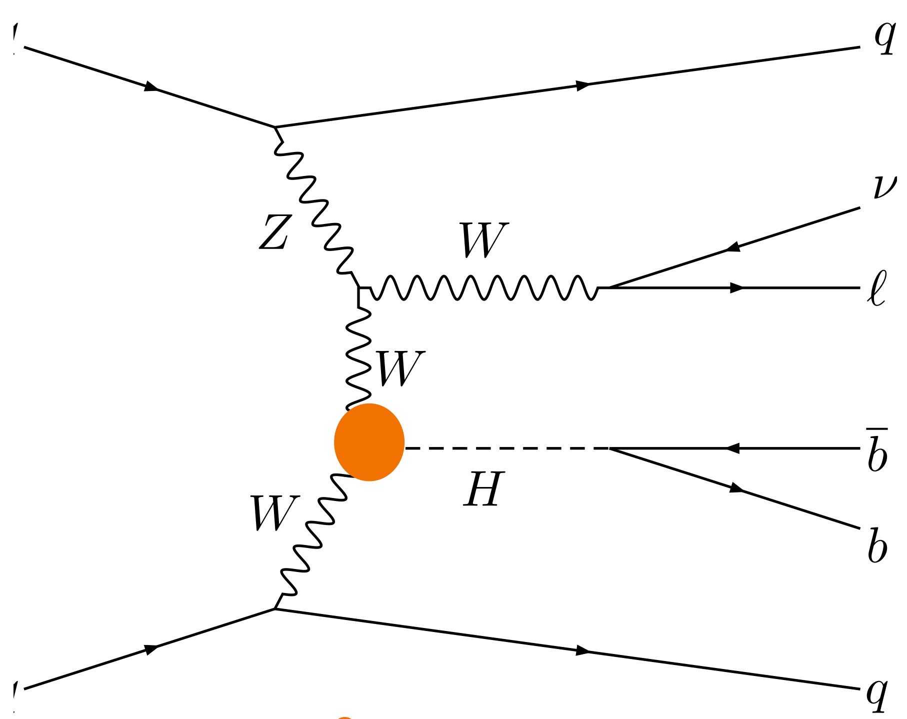


Observed (expected) upper limits on SM process @ 95% CL:
ATLAS: 9.0x (8.7x) SM expectation
CMS: 14.3 (9.0x) SM expectation **New**



κ_Z^2

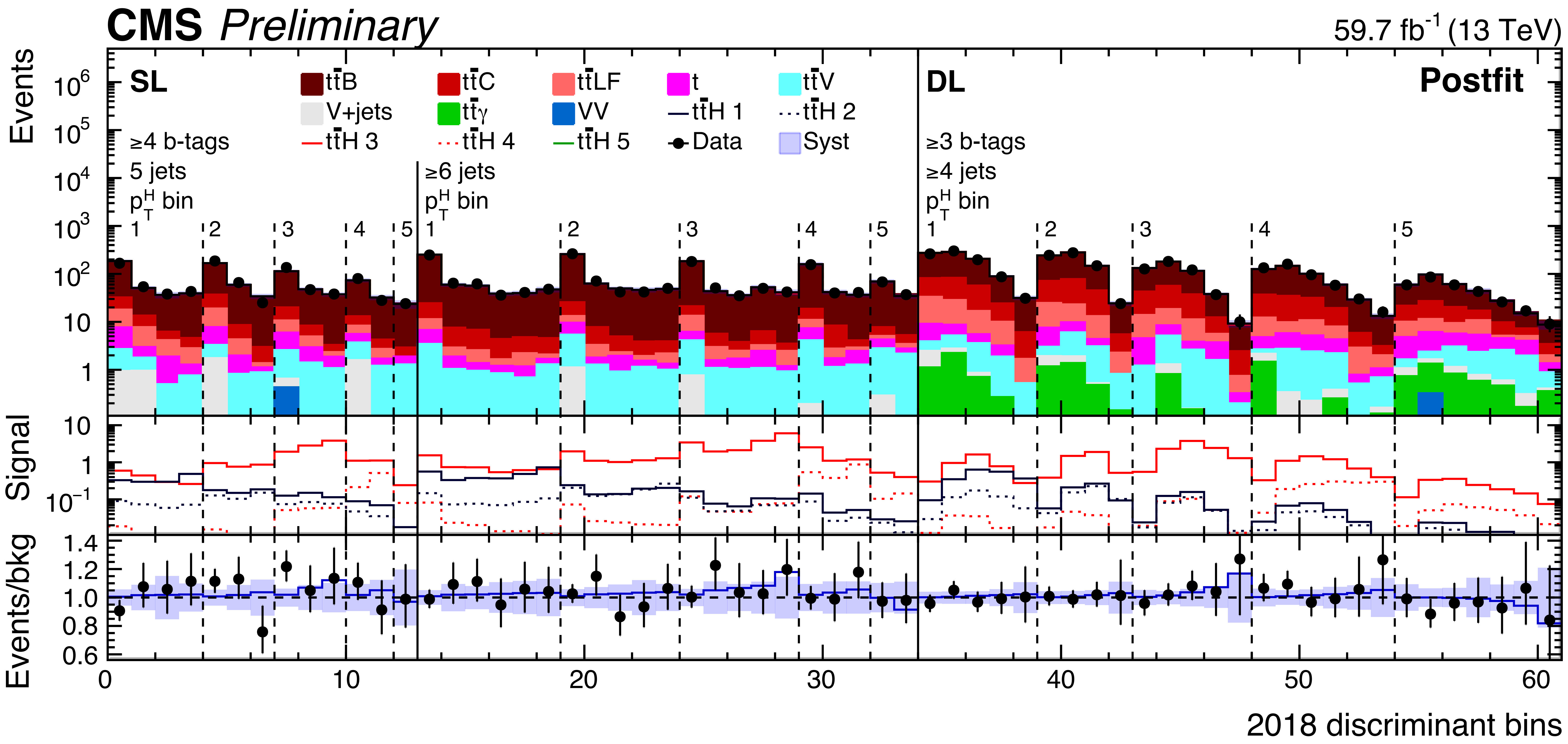
+interference ~$\kappa_W \kappa_Z$

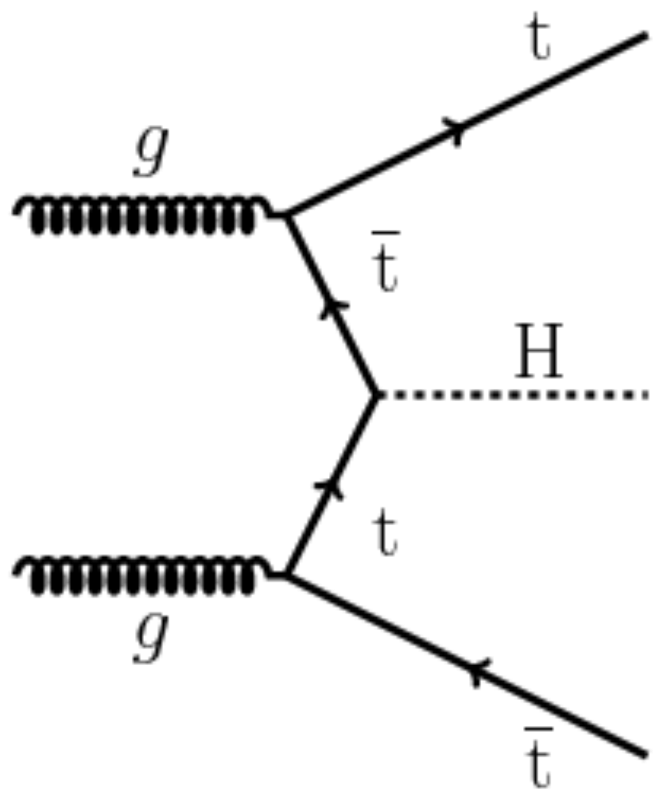


κ_W^2

ttH production

- 1% of Higgs bosons
- Direct probe of top quark Yukawa coupling
- H➔bb: ML for S/B discrimination, CRs for backgrounds





CMS-PAS-HIG-19-011
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ttH production

- 1% of Higgs bosons
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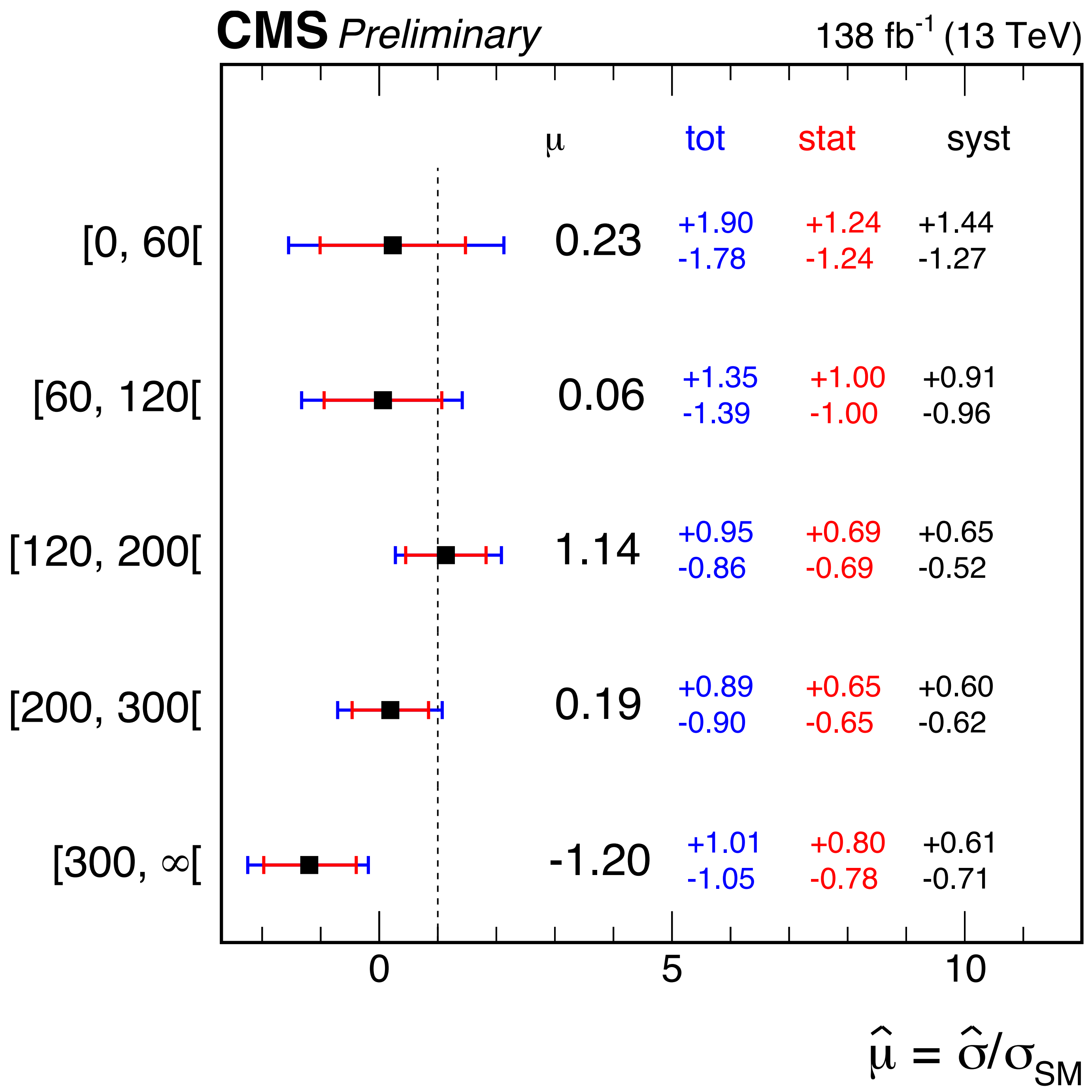
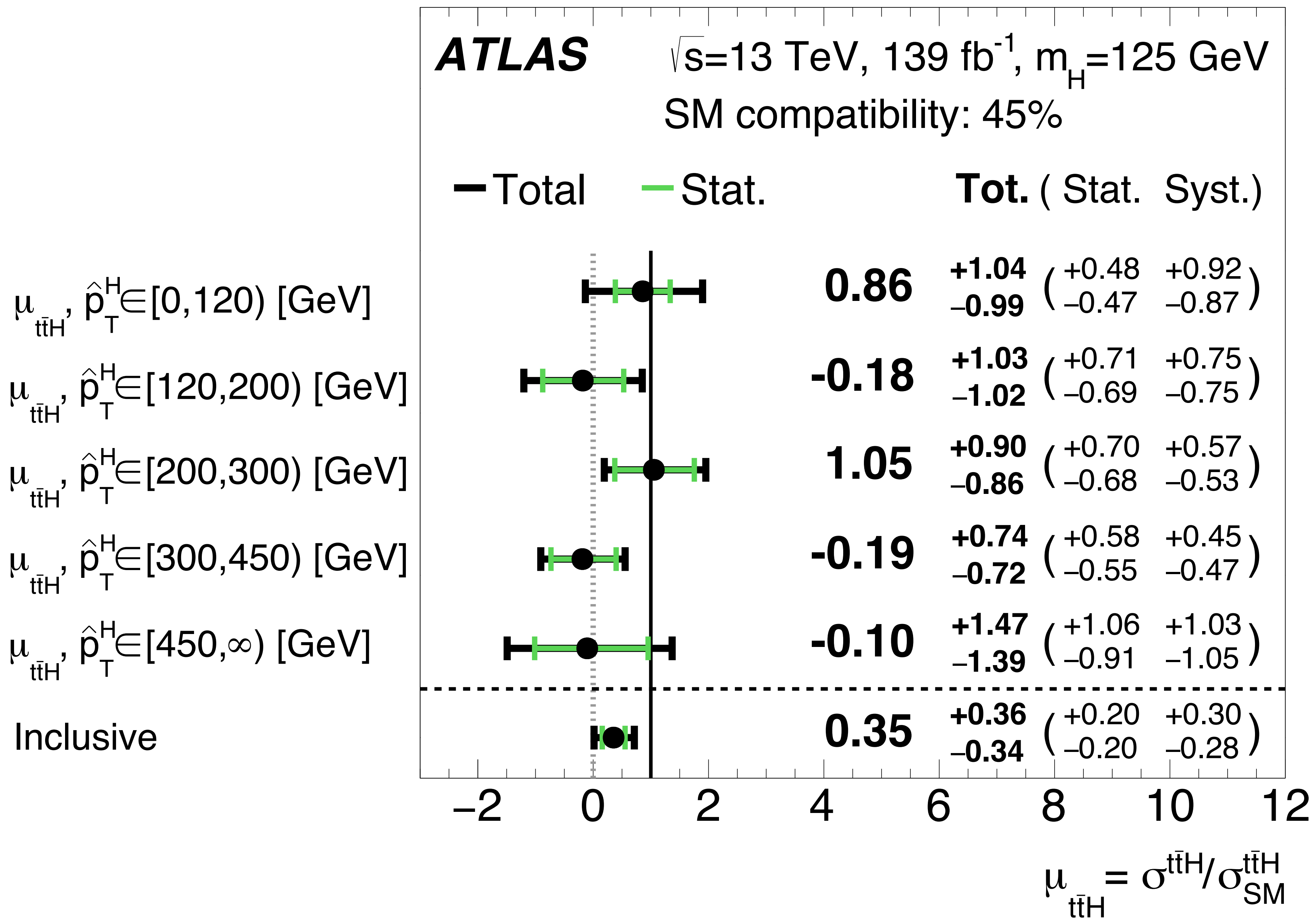
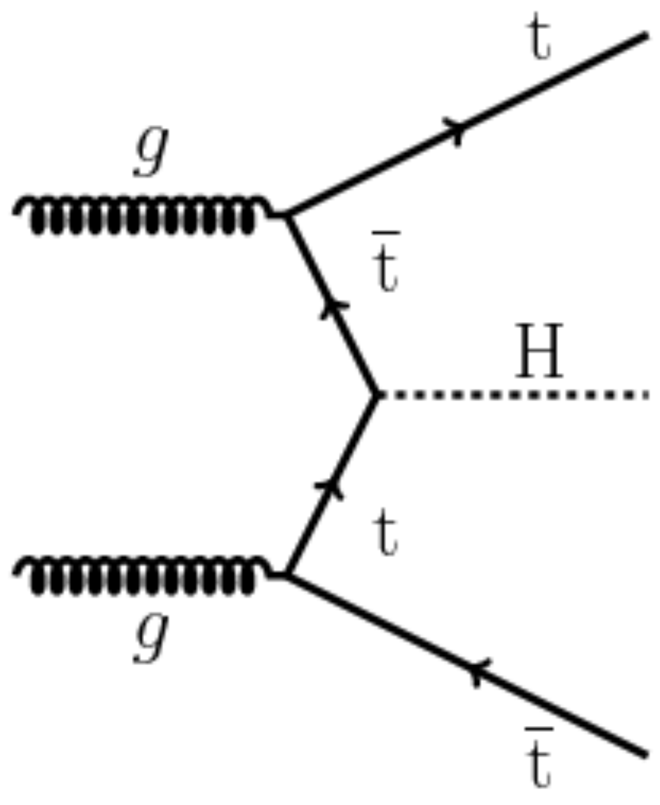




μ_{incl} = 0.33 ± 0.17 (stat) ± 0.21 (syst)

μ_{incl} = 0.35 ± 0.20 (stat) ± 0.29 (syst)

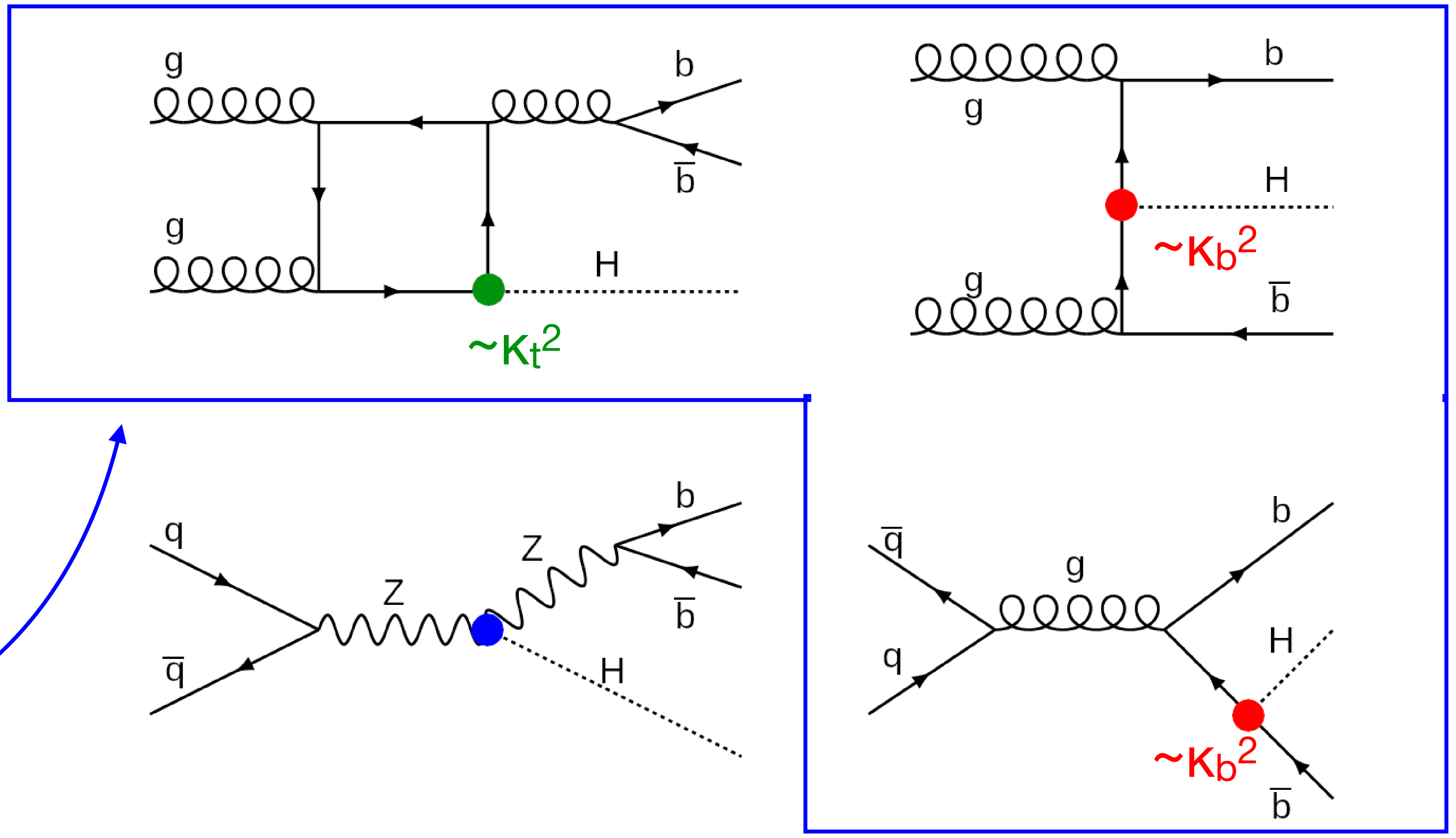


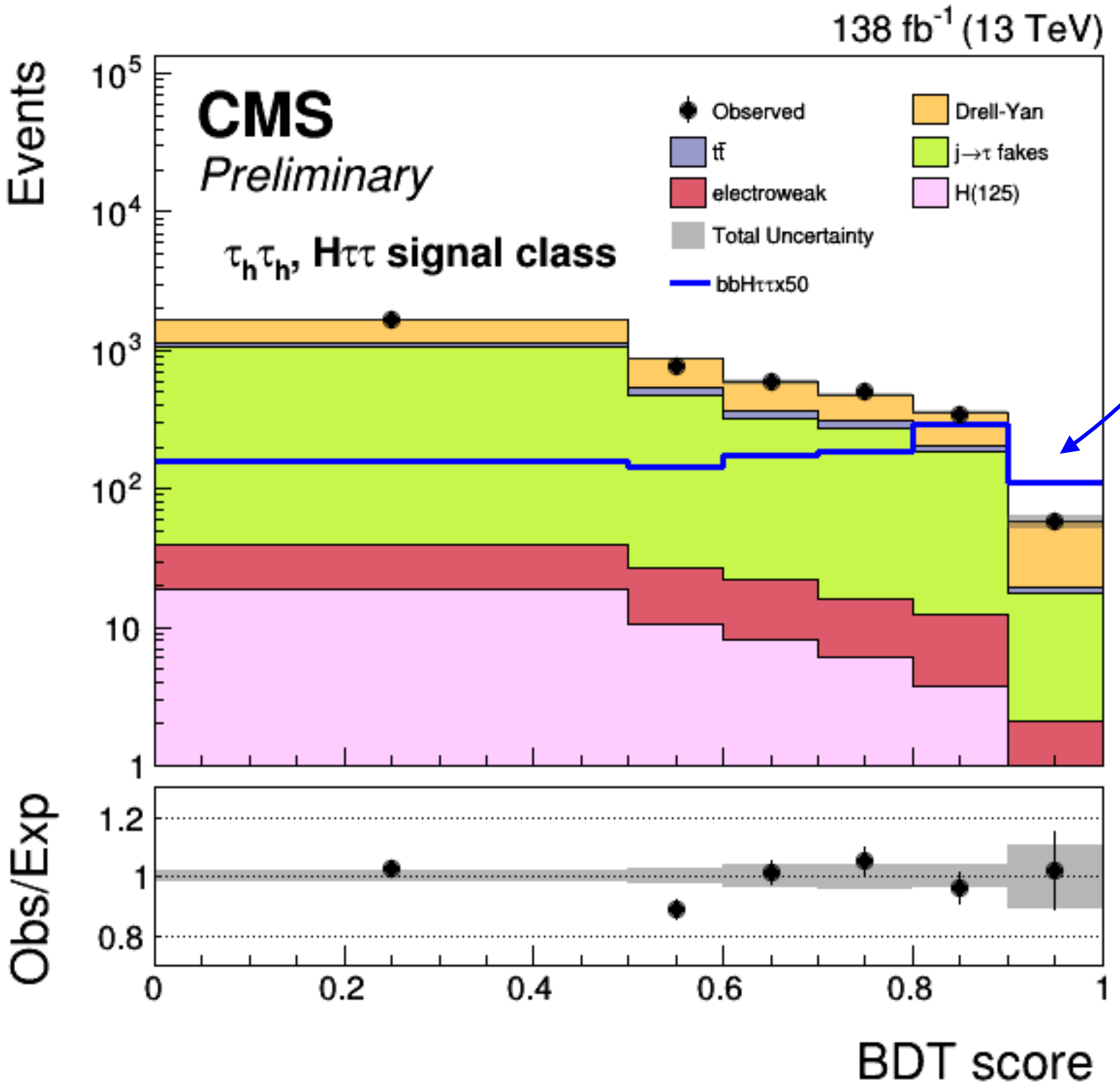
Same bin boundaries, grouped differently between ATLAS and CMS

CMS-PAS-HIG-23-003

b-associated production

- b-associated production (via b-fusion and gluon fusion with gluon➔bb splitting) studied in final states with leptons (WW, ττ)
- Obs (exp) upper limit: 3.7 (6.1) x SM





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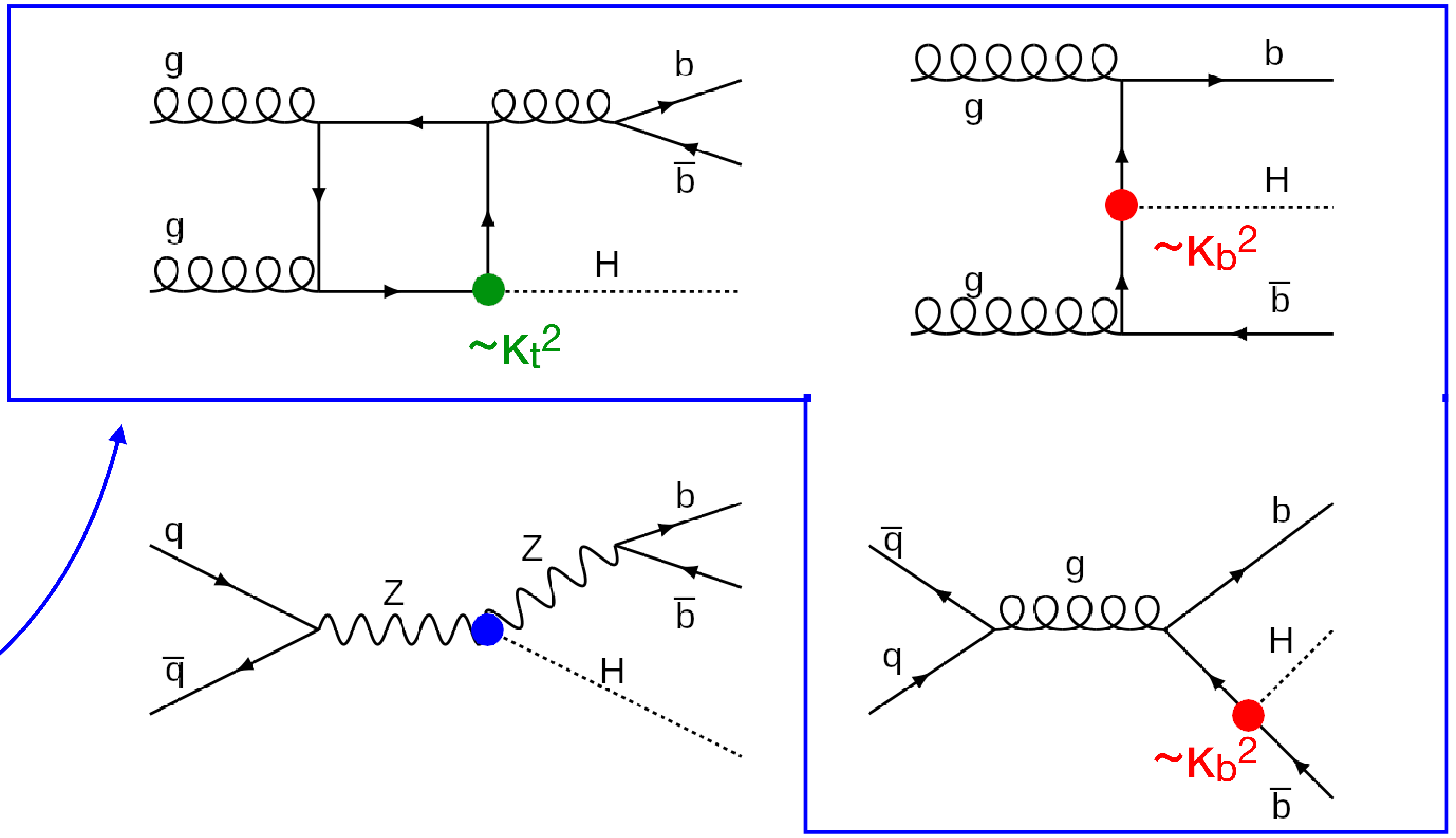
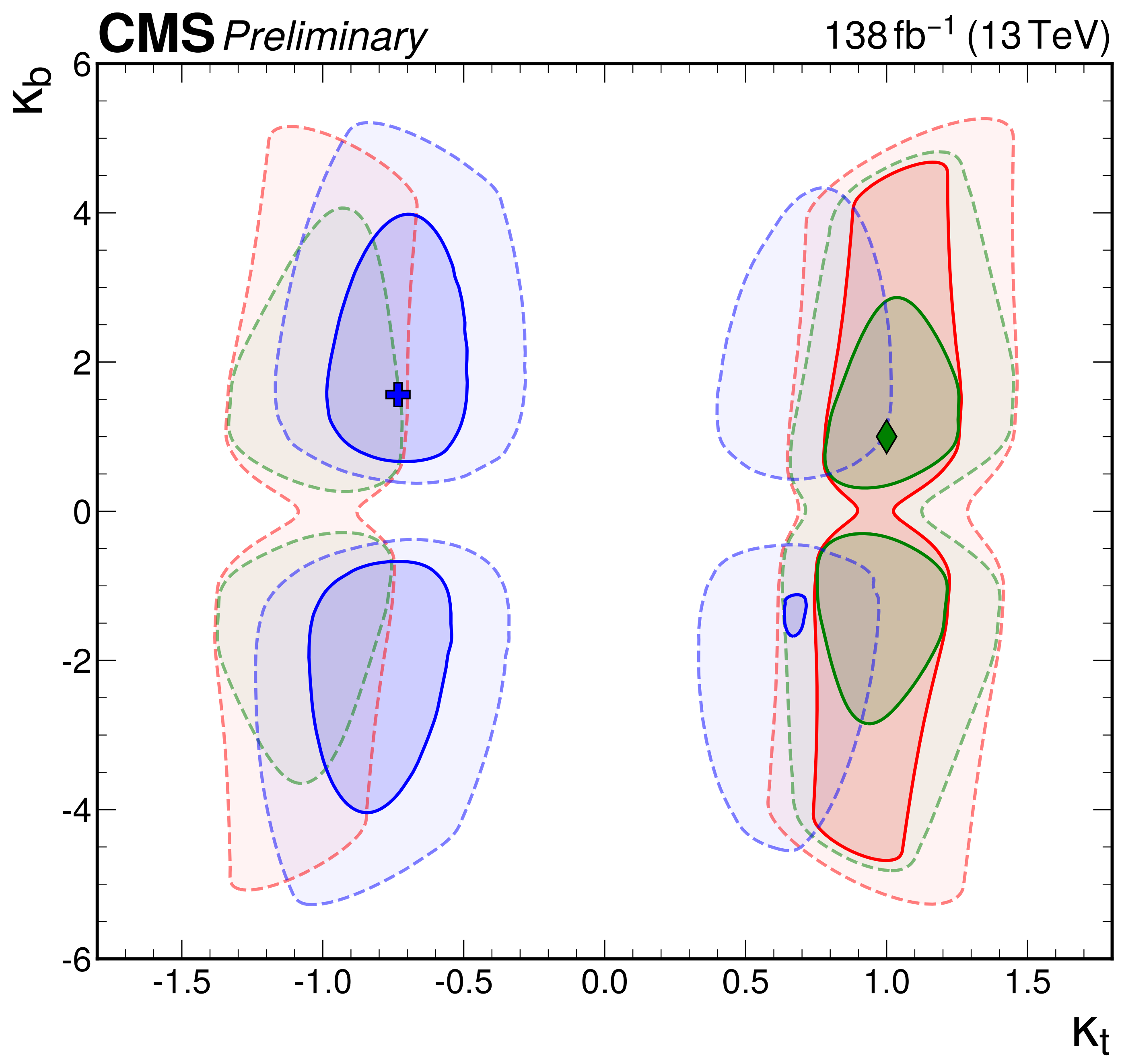
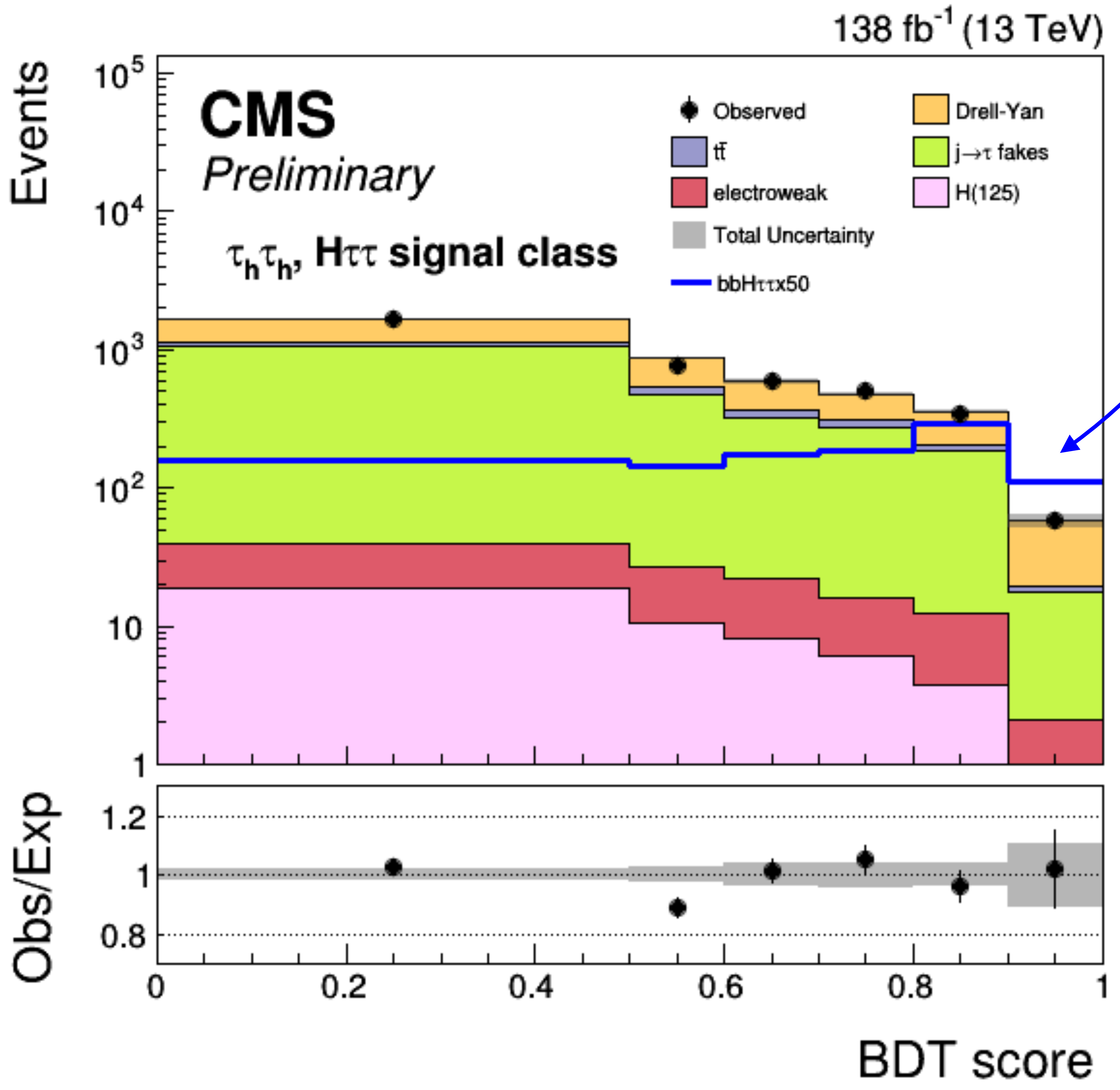
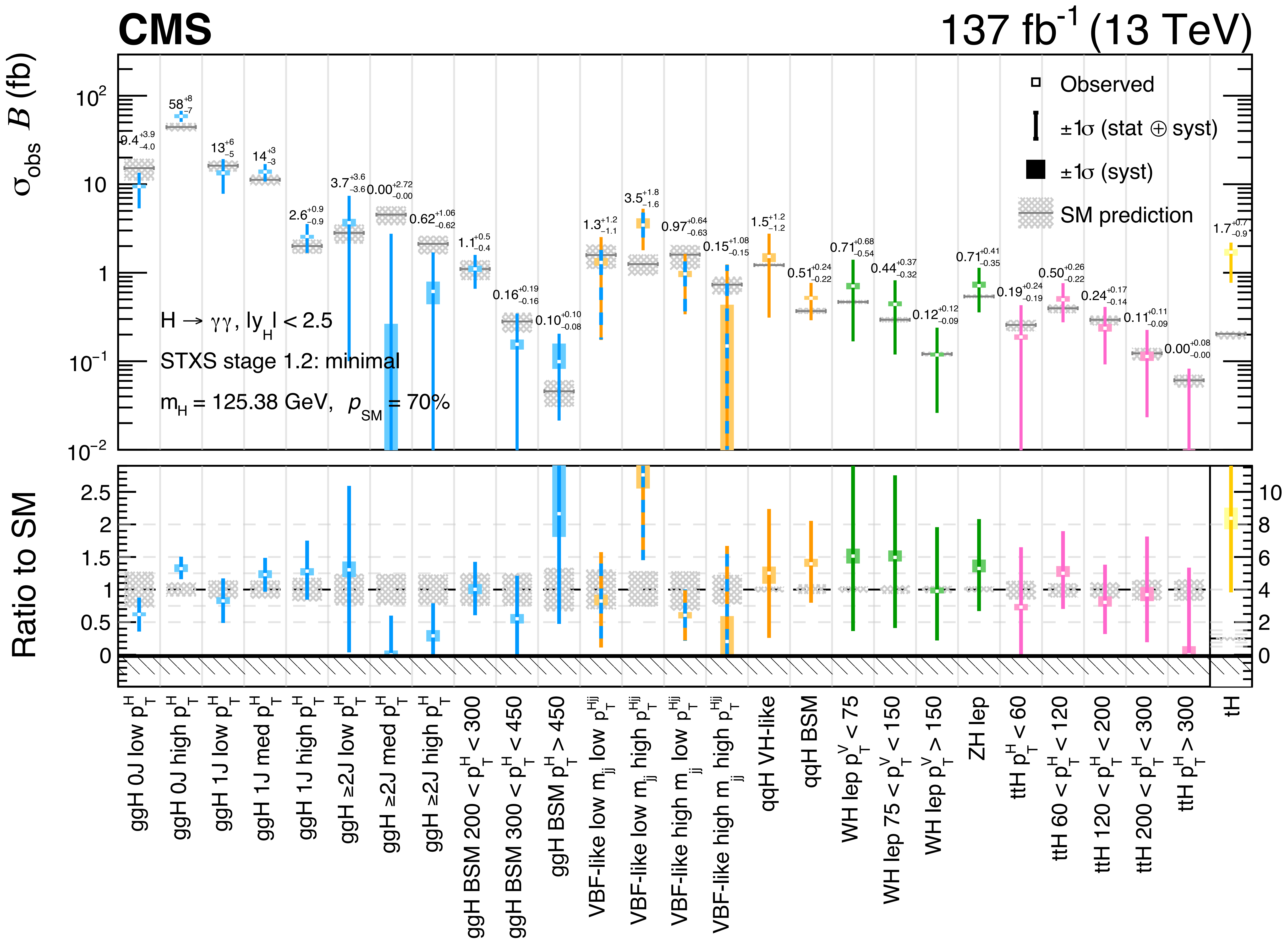




Constraints in κ_t, κ_b plane, combining with non b-associated H➔ττ measurement



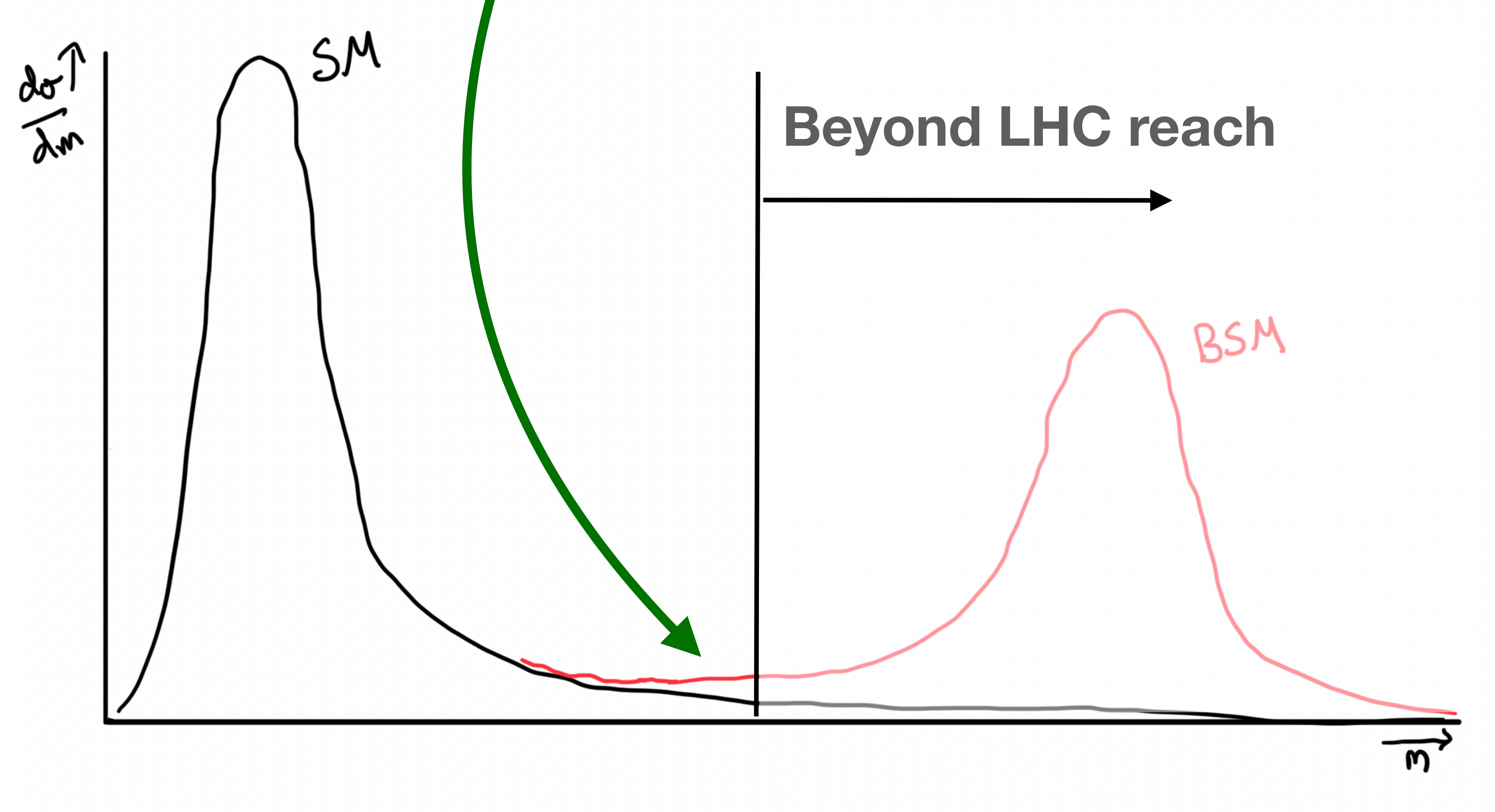
STXS interpretations



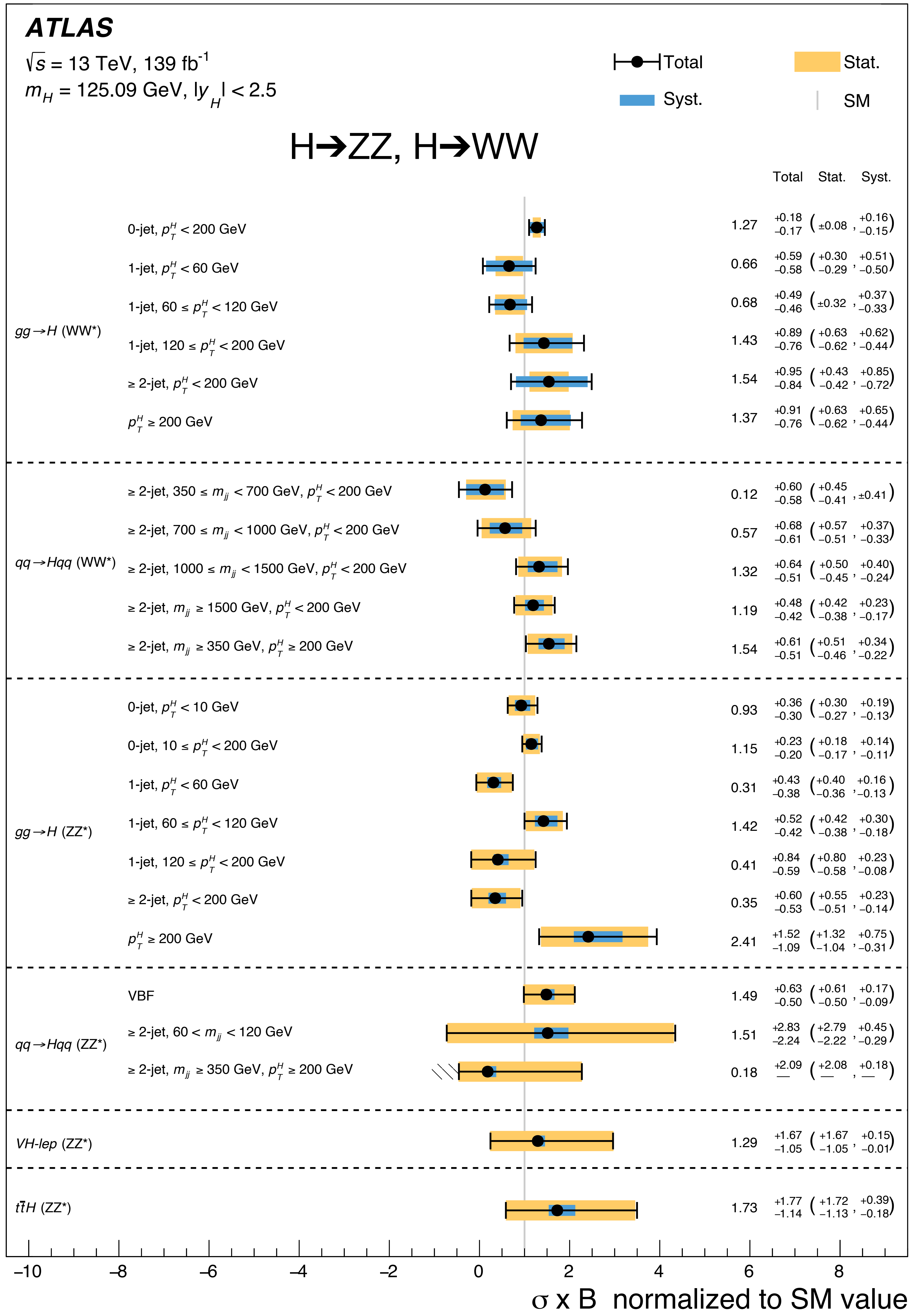
Example: STXS measurements in H→γγ

Use fine-grained measurements to constrain new physics, e.g. in EFT context

$$\mathscr{L} = \mathscr{L}_{SM} + \sum_i \frac{c_i \mathcal{O}_i^d}{\Lambda^{d-4}} = \mathscr{L}_{SM} + \sum_i^{N_{d6}} \frac{c_i \mathcal{O}_i^{(6)}}{\Lambda^2} + \ldots$$



STXS interpretations



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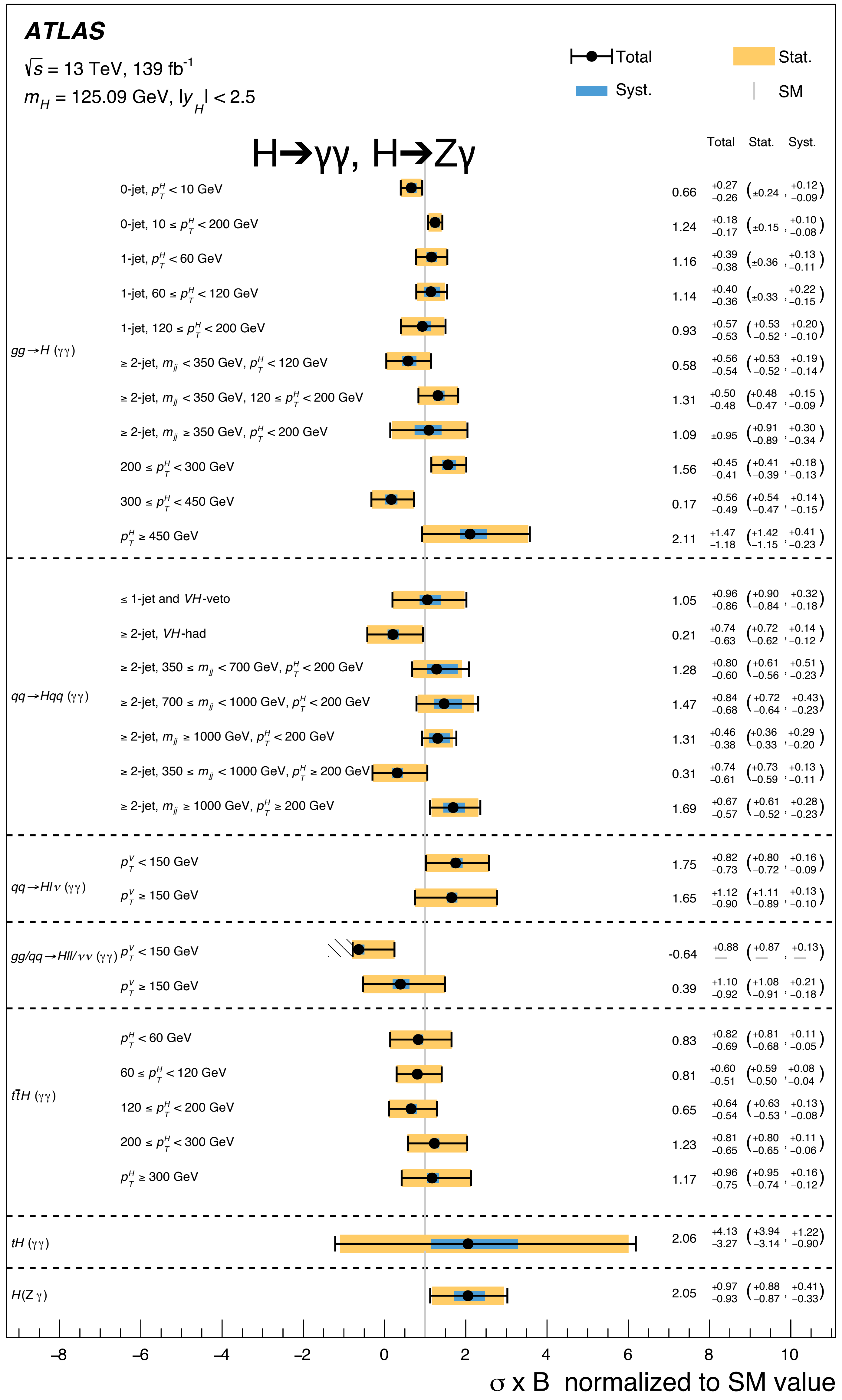

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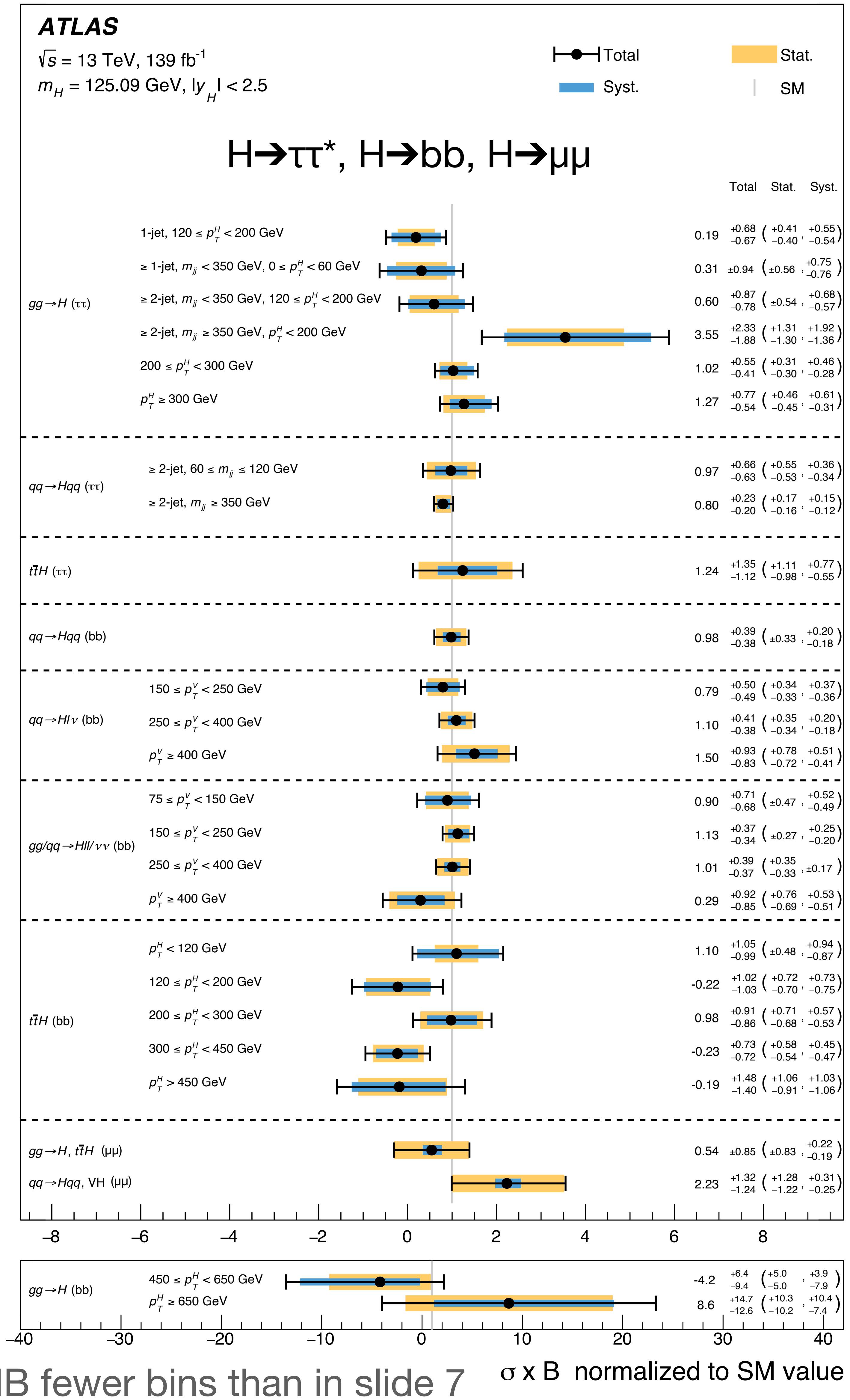
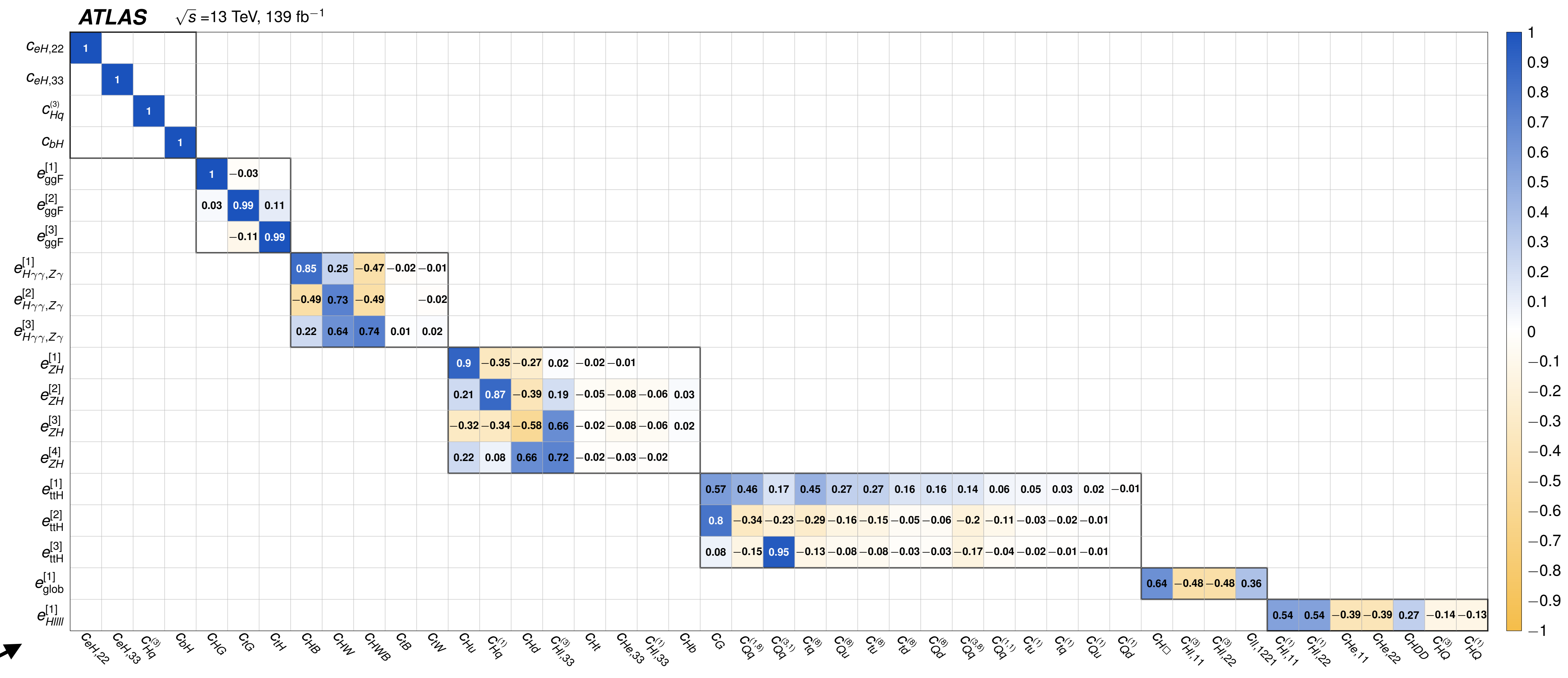


*NB fewer bins than in slide 7

BSM interpretations of STXS measurements

- **2499** dim-6 operators ➔ reduced to less than **200** through symmetries
    - **50** remaining CP-conserving operators relevant for Higgs sector
    - Degeneracies ➔ identify & study **19** independent directions



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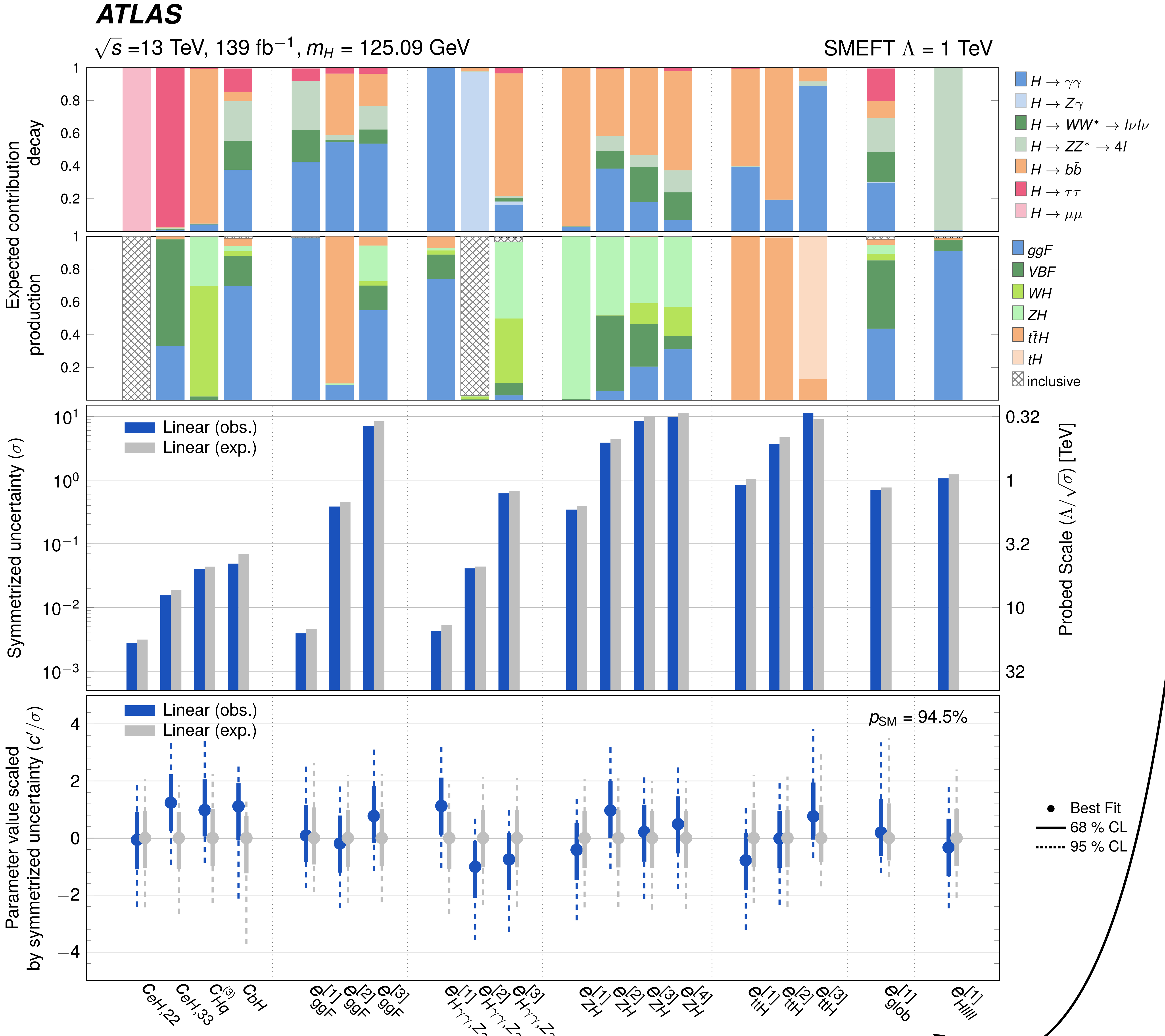
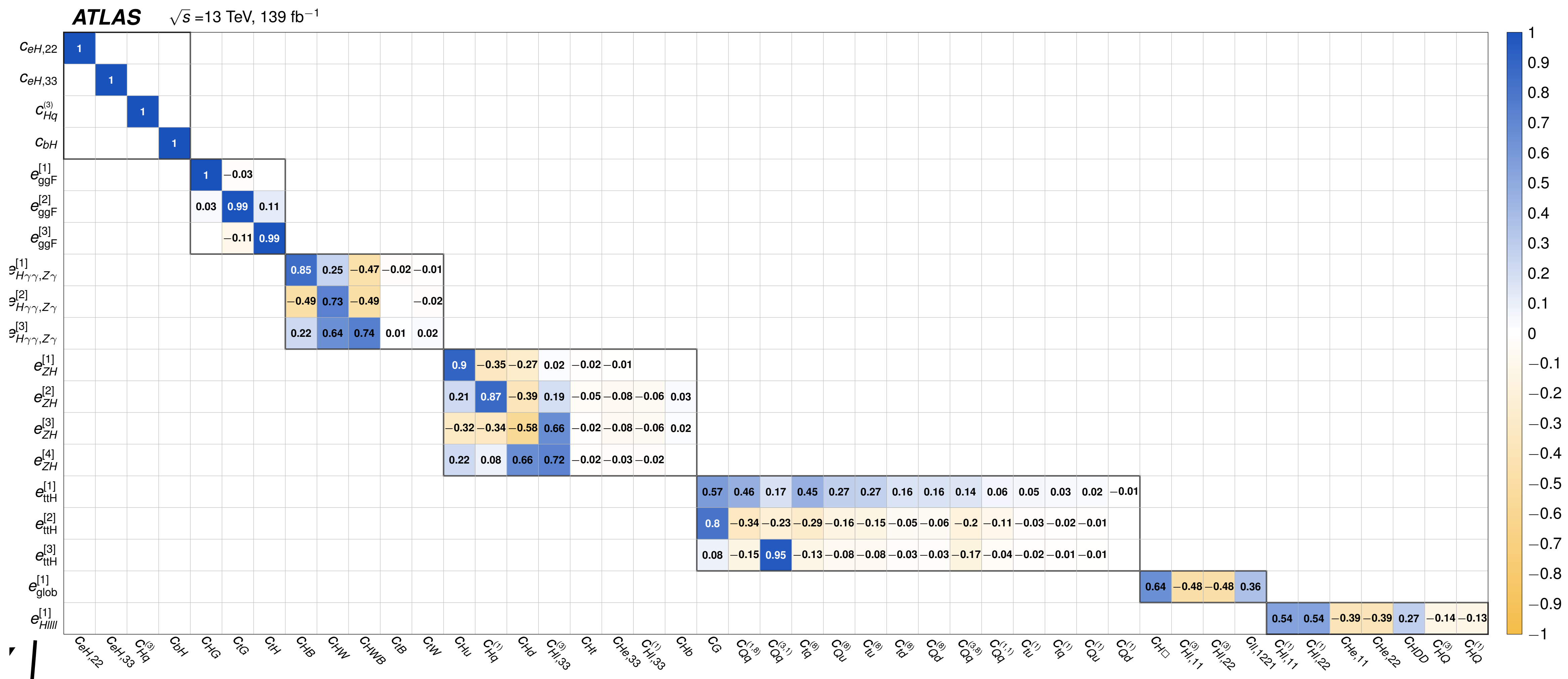
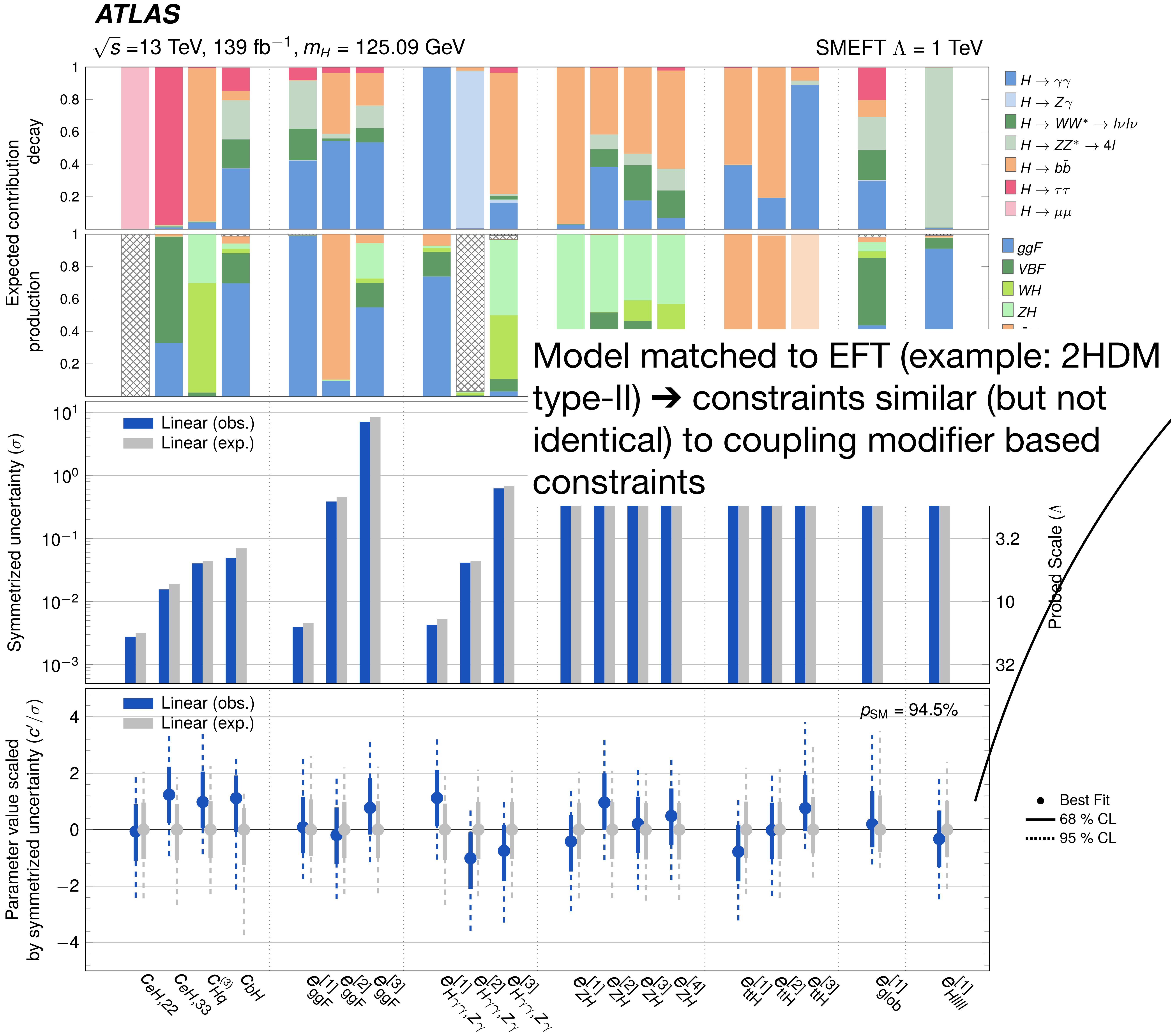


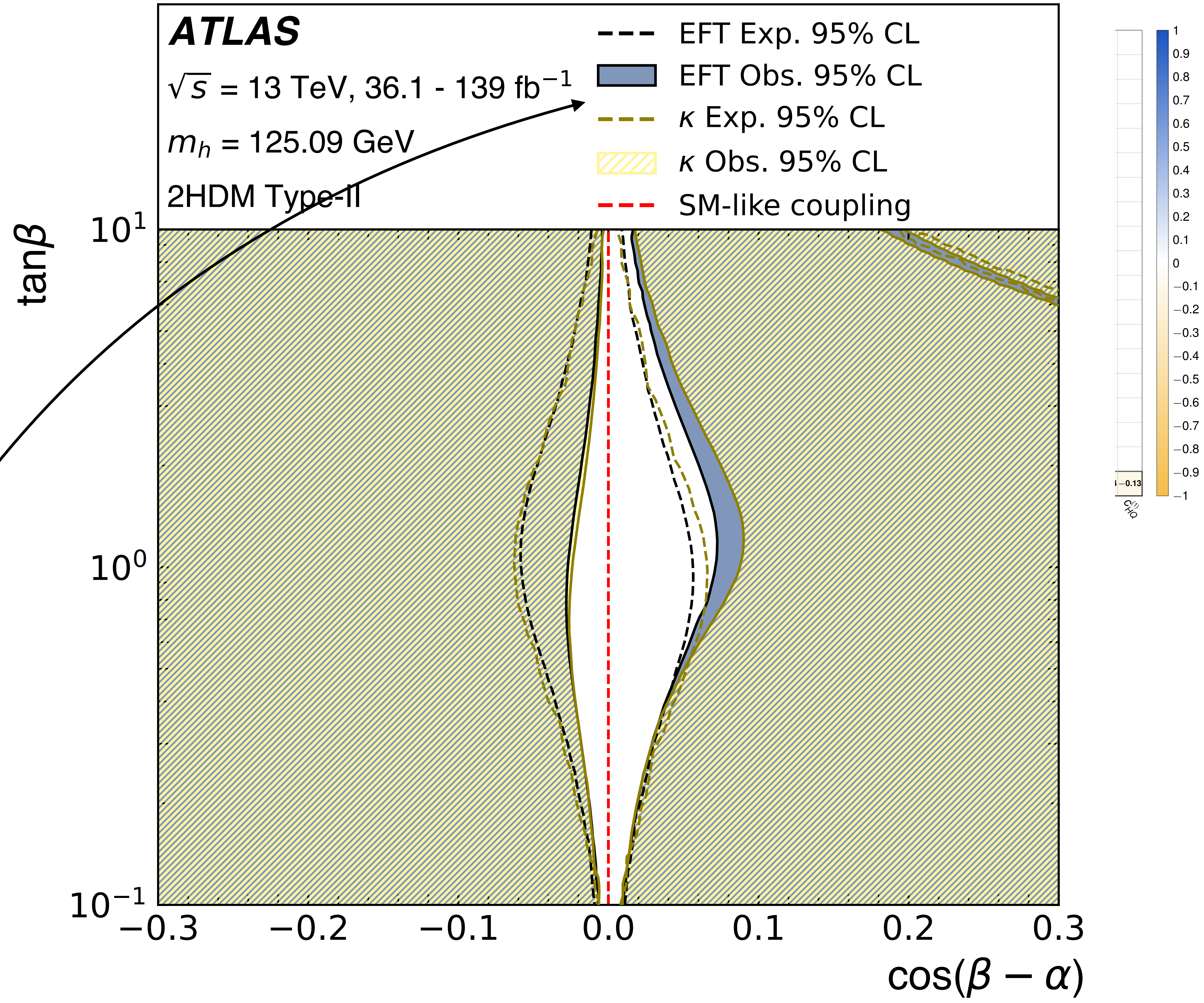


Constraints on linear combinations of Wilson coefficients; probed NP scale

BSM interpretations of STXS measurements



Model matched to EFT (example: 2HDM type-II) ➔ constraints similar (but not identical) to coupling modifier based constraints

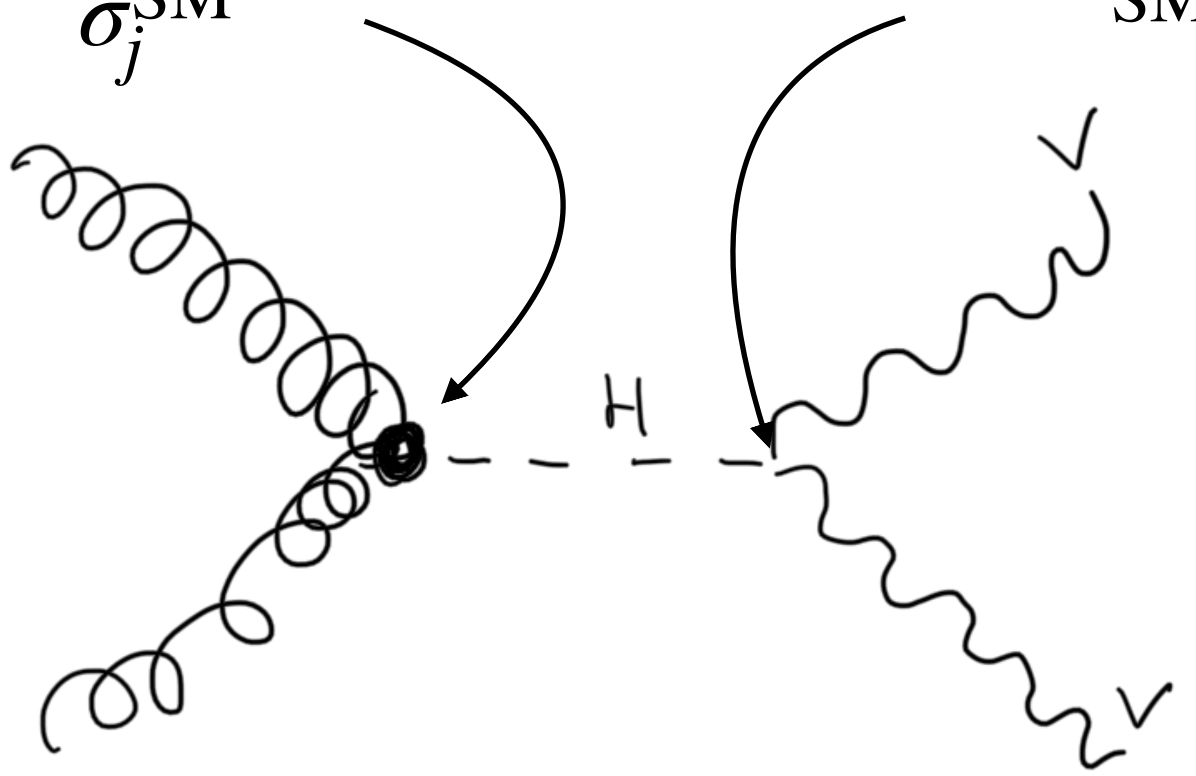


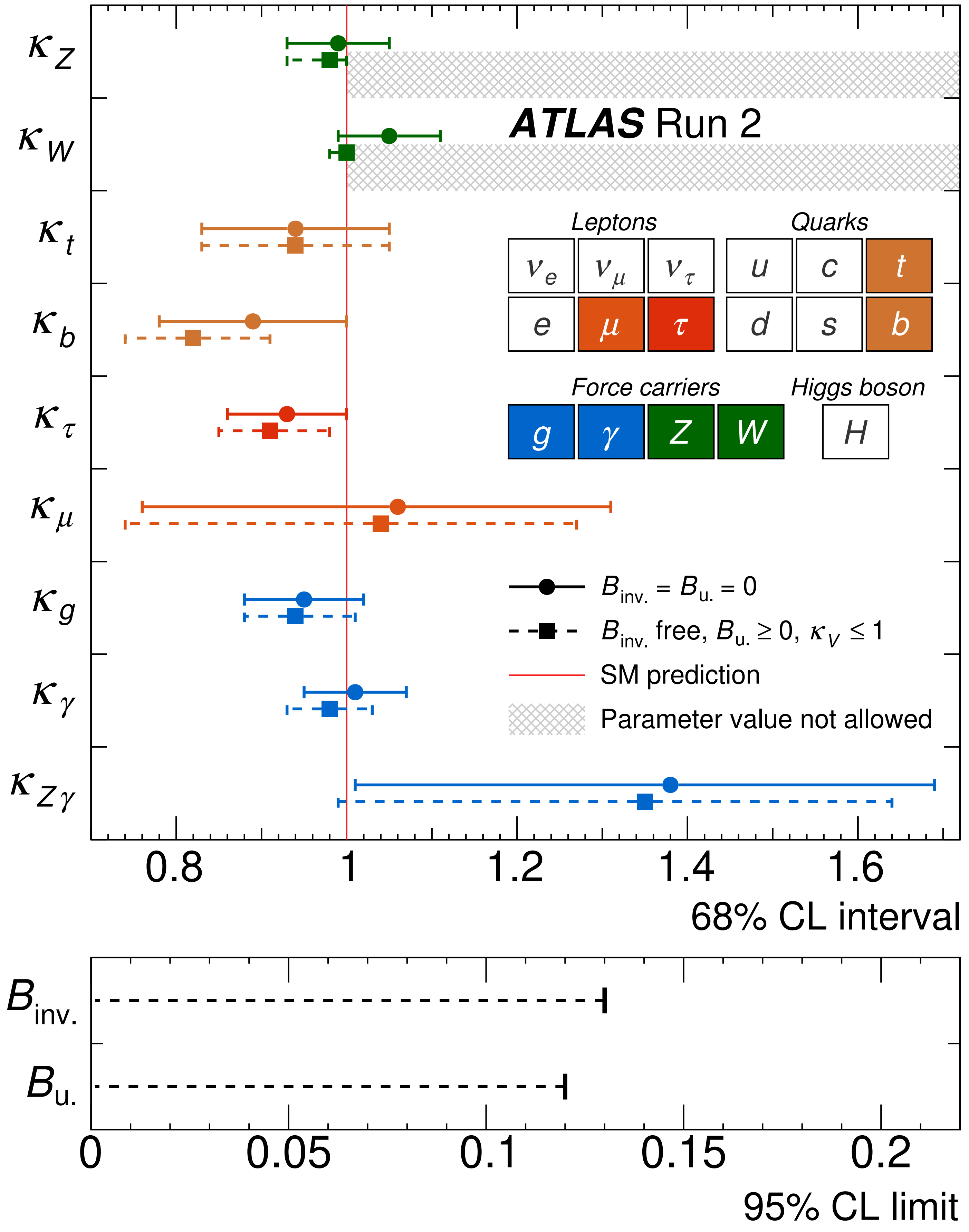
(Anomalous) couplings

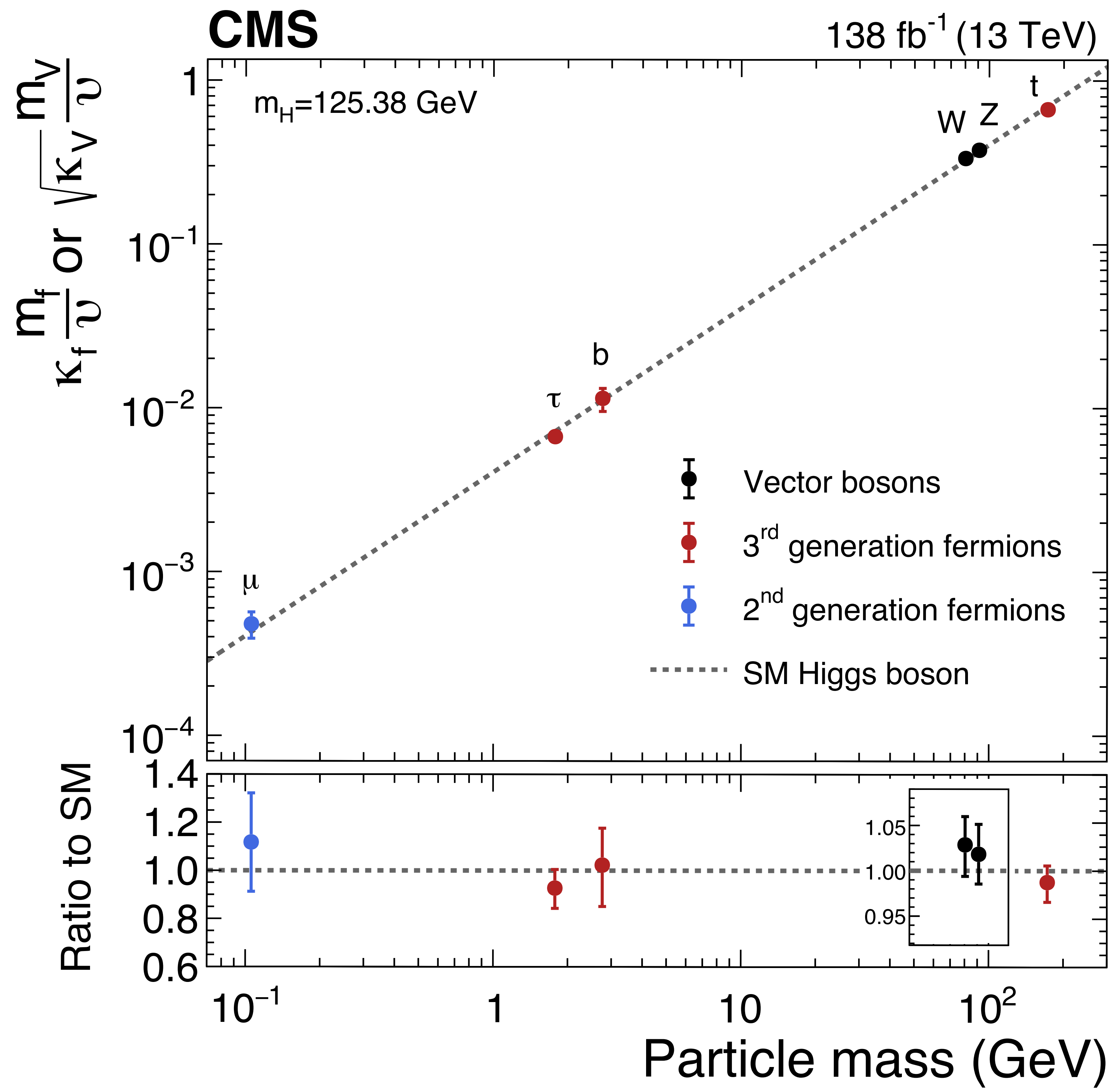
Overview

- Inclusive production and decay rates ➔ couplings (coupling modifiers)
- Not all effects can be covered by this

$$\kappa_j^2 = \frac{\sigma_j}{\sigma_j^{\mathrm{SM}}} \qquad \kappa_j^2 = \frac{\Gamma^j}{\Gamma^j_{\mathrm{SM}}}$$







Very good agreement with the SM expectation!

Anomalous Higgs interactions

- Higgs boson confirmed to be spin-0, and consistent with CP++ since run 1
- Pure CP-odd state excluded ≠ CP-even state ➔ active field of study
- **Compatible** with the SM expectation so far
- Here: H➔VV; previous results with H➔ττ, ttH available

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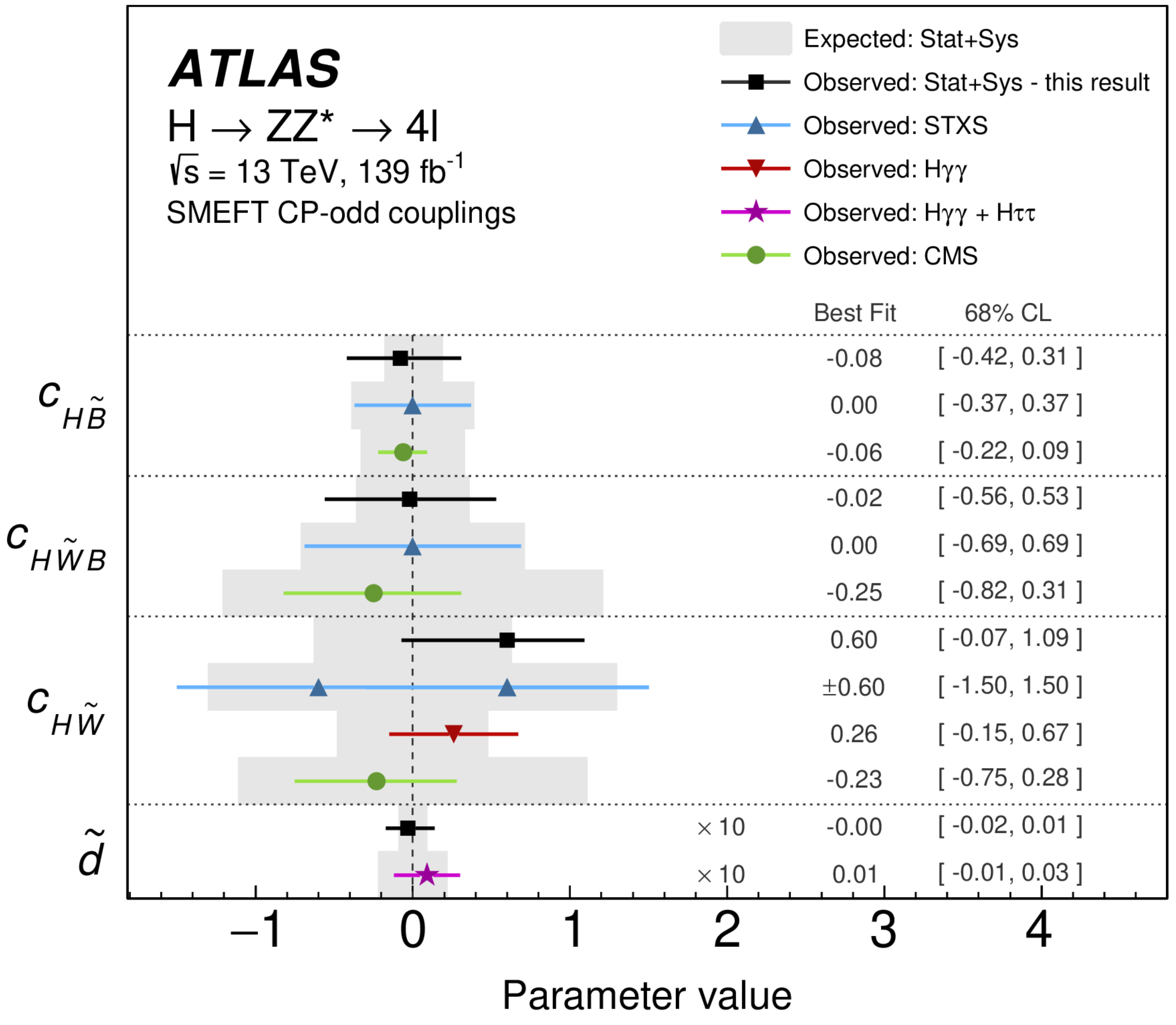
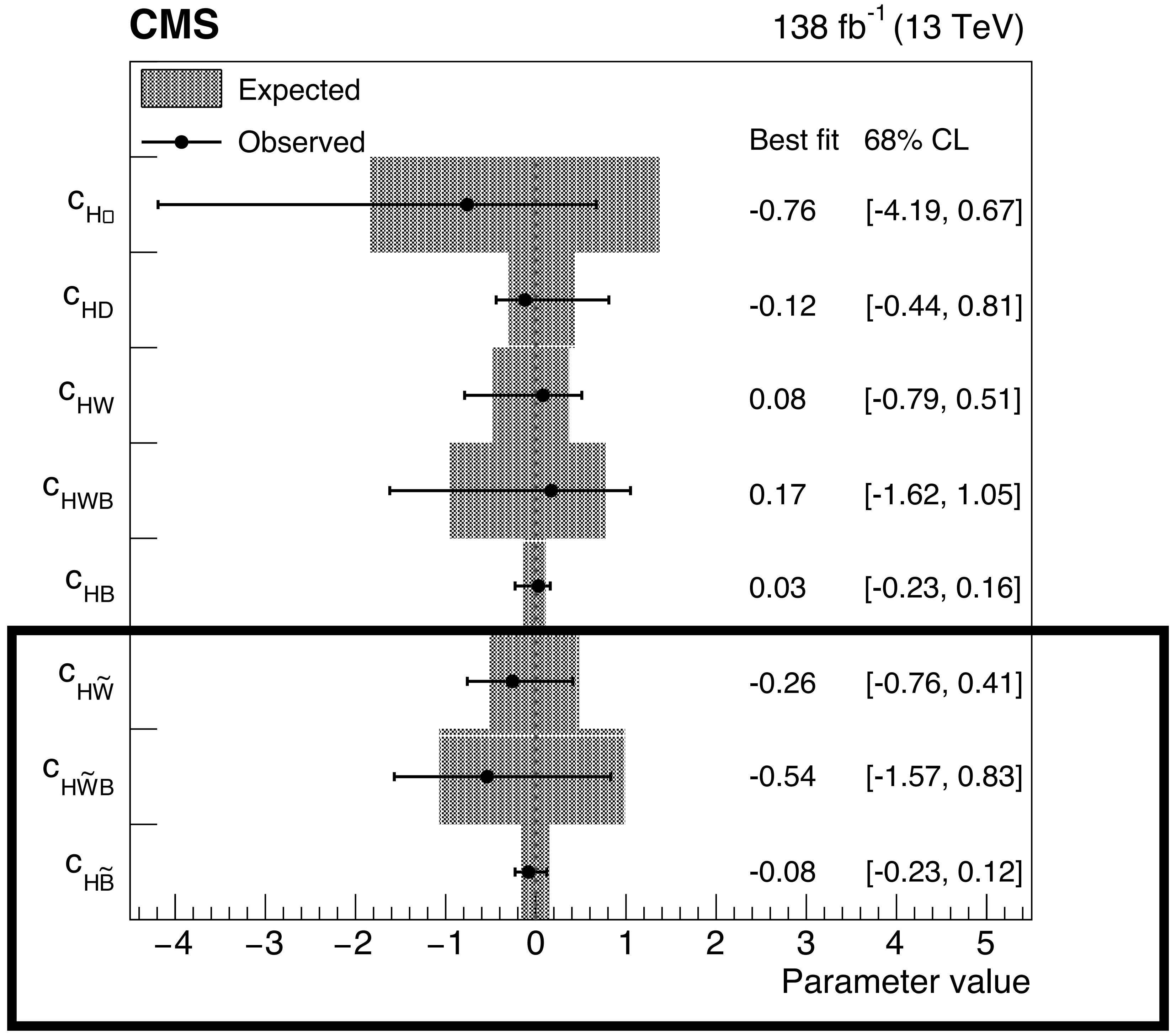


Constraints on CP-odd Wilson coefficients in SMEFT H➔ZZ➔4l (black points) + comparison with other approaches



Constraints on CP-even and CP-odd Wilson coefficients H➔WW➔2l2v

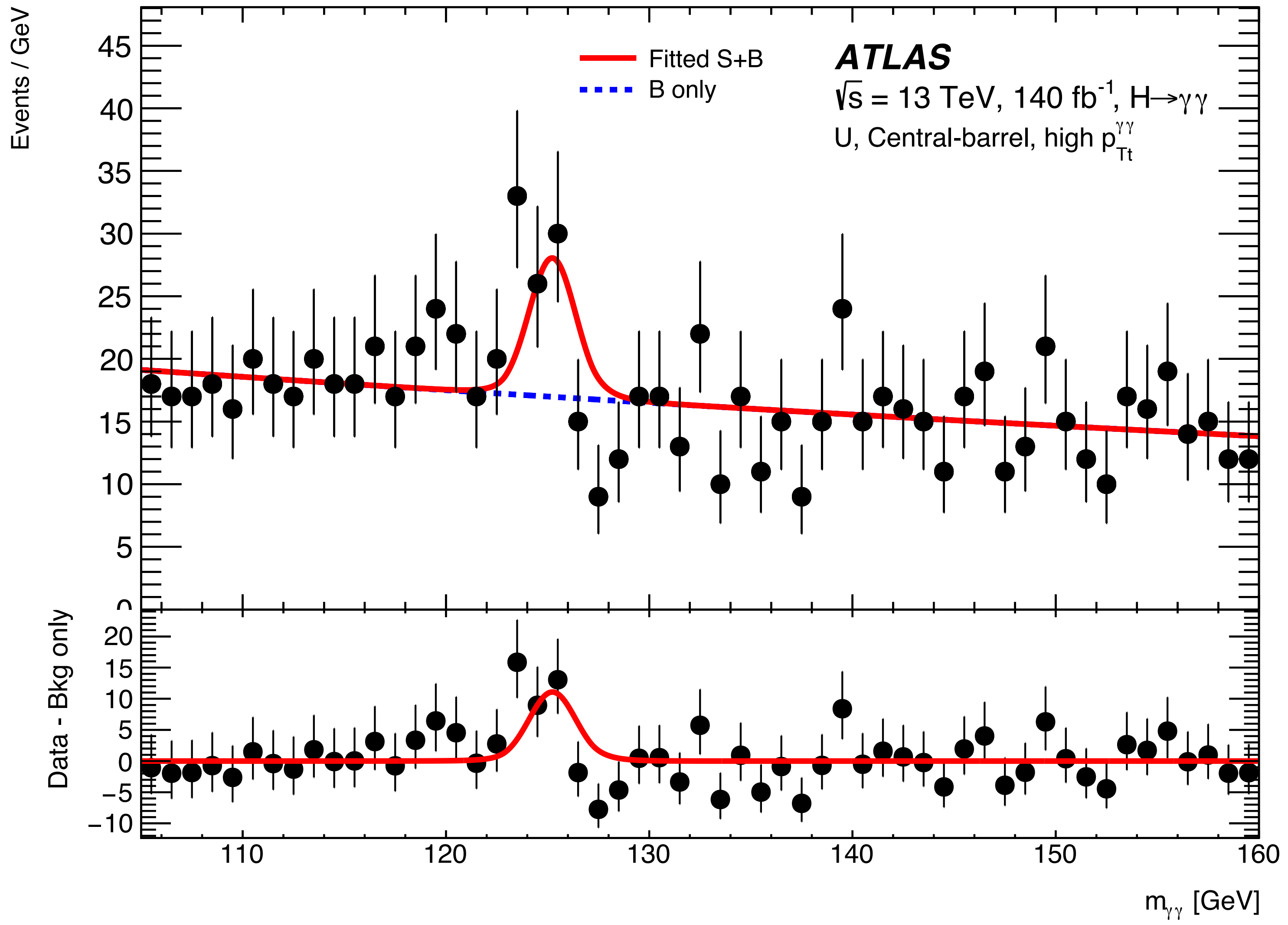
arXiv:2403.00657 (acc by EPJC)

Mass & width

Overview of mass and width measurements

- Mass: Exploit best-resolution channels: H➔γγ and H➔ZZ➔4l
  - **m_H** measured from fitting the reconstructed Higgs boson invariant mass distribution (categorized by resolution)
- Width: H➔ZZ➔4l, 2l2ν
  - Indirect measurement, using

$$\frac{\Gamma_H}{\Gamma_H^{SM}} = \frac{\mu_{\text{off-shell}}}{\mu_{\text{on-shell}}}$$



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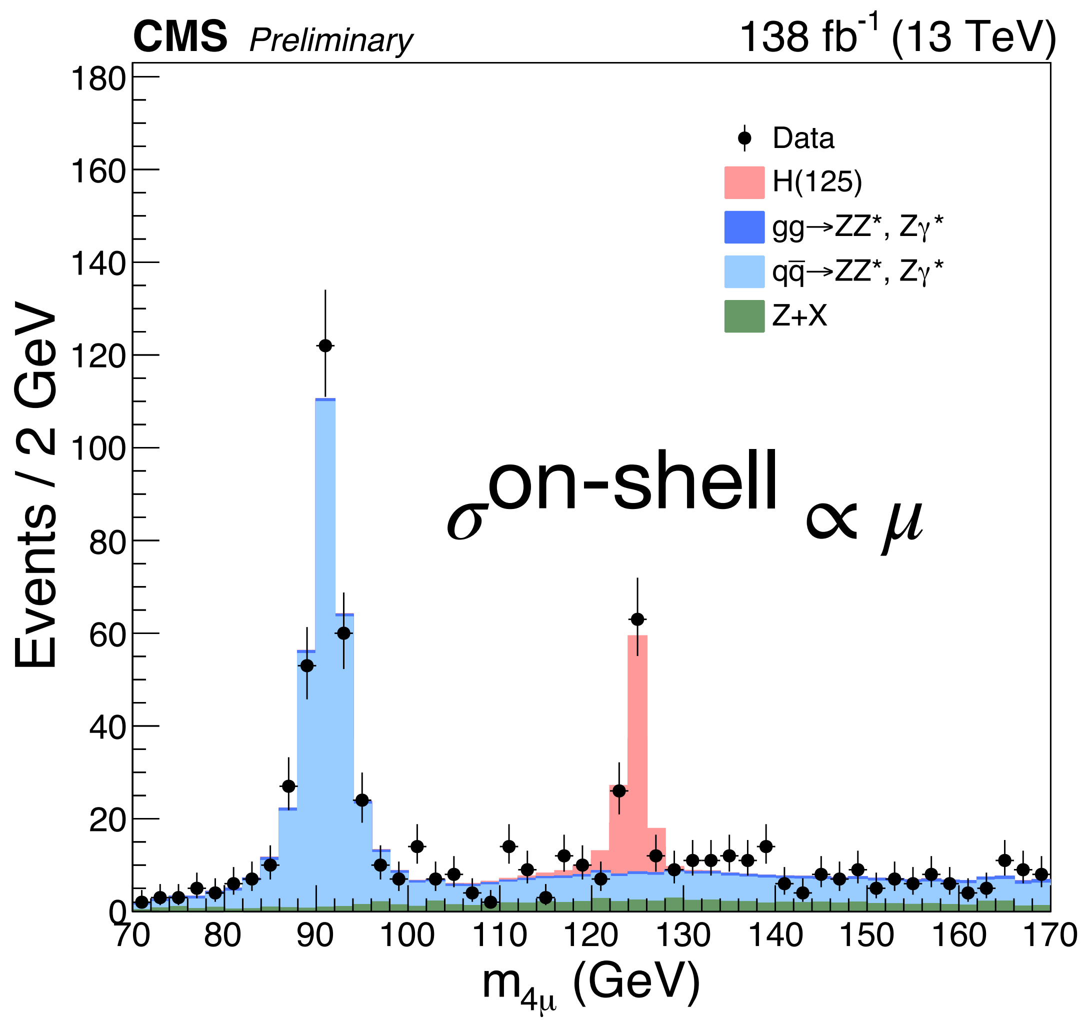

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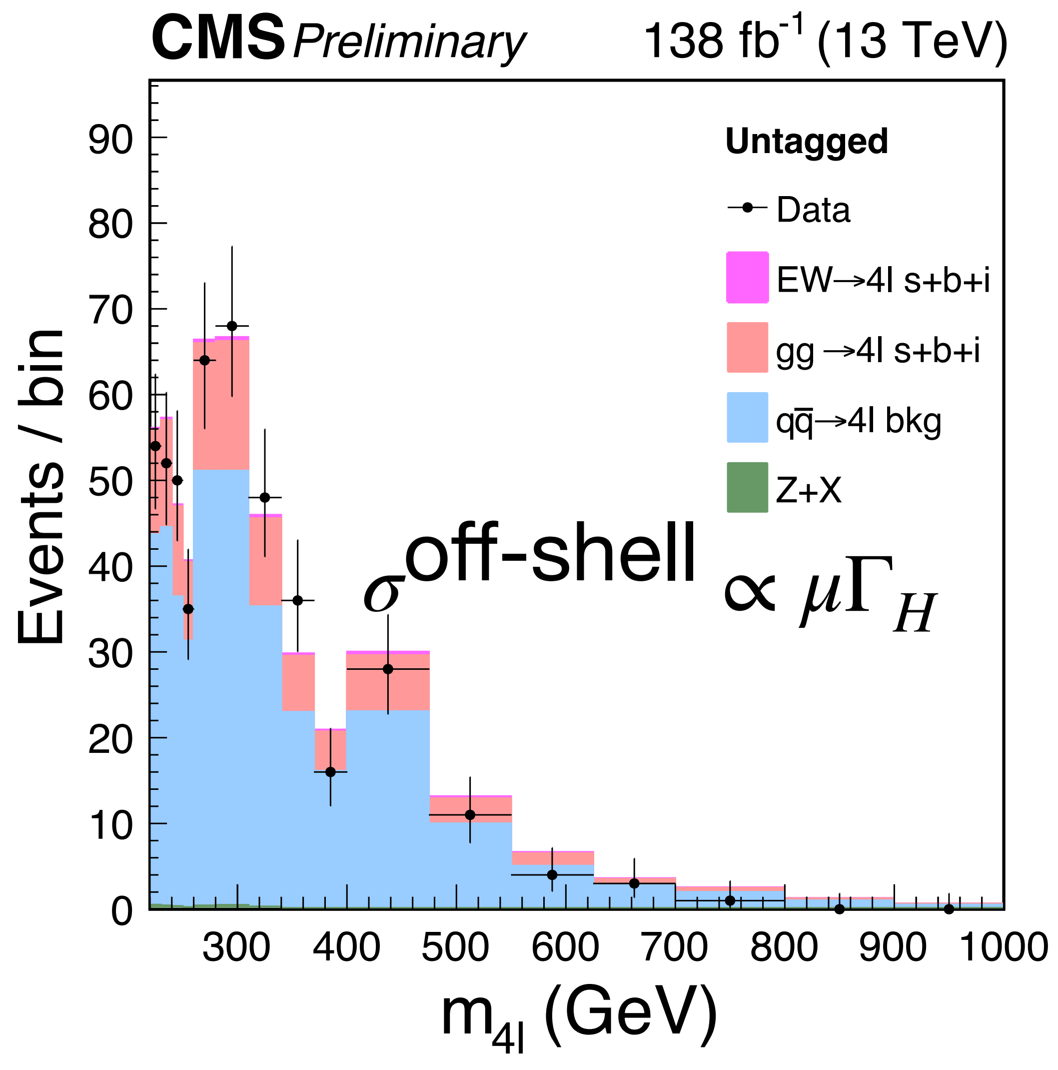
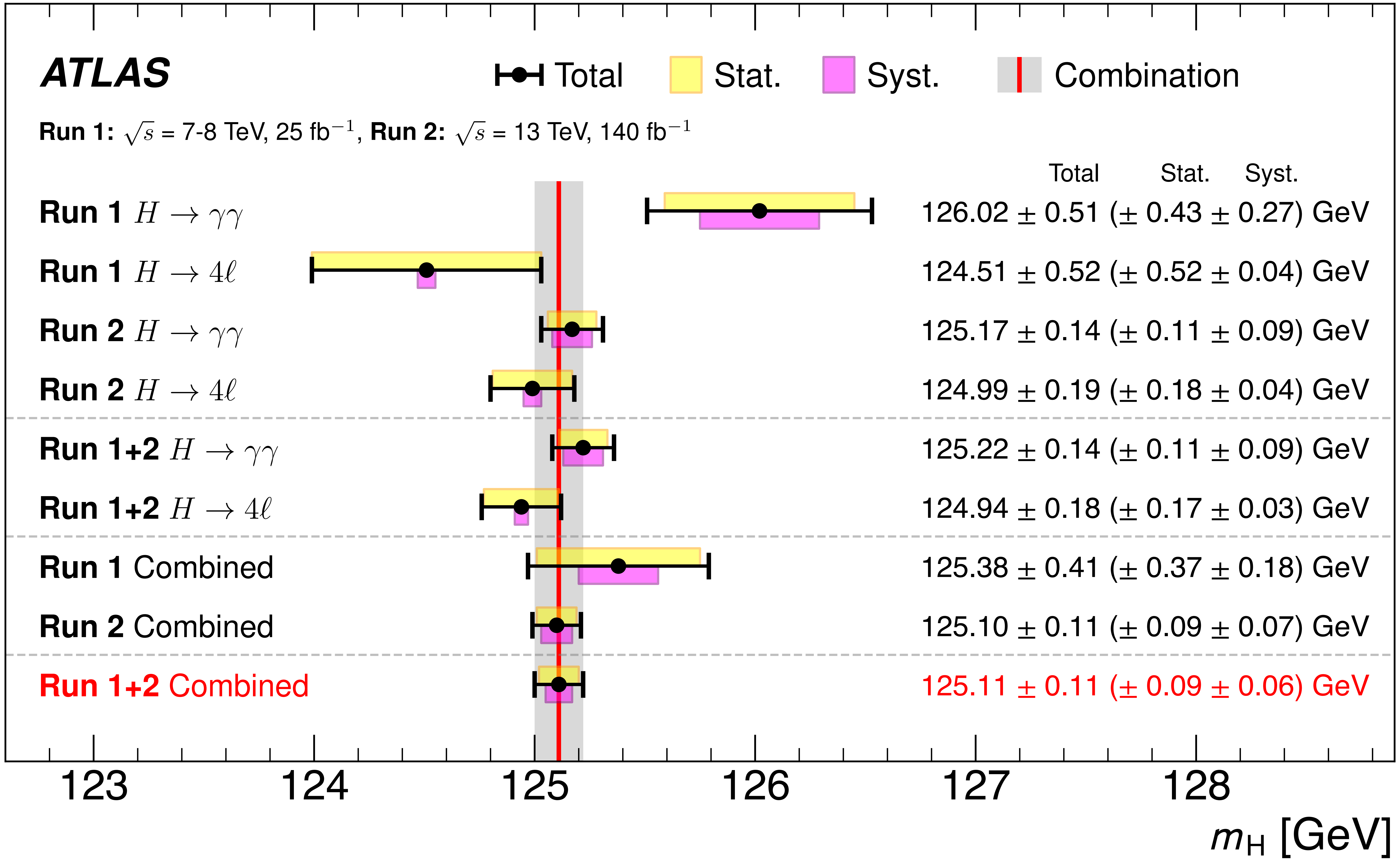


CMS-PAS-HIG-21-019

Mass measurements - ATLAS

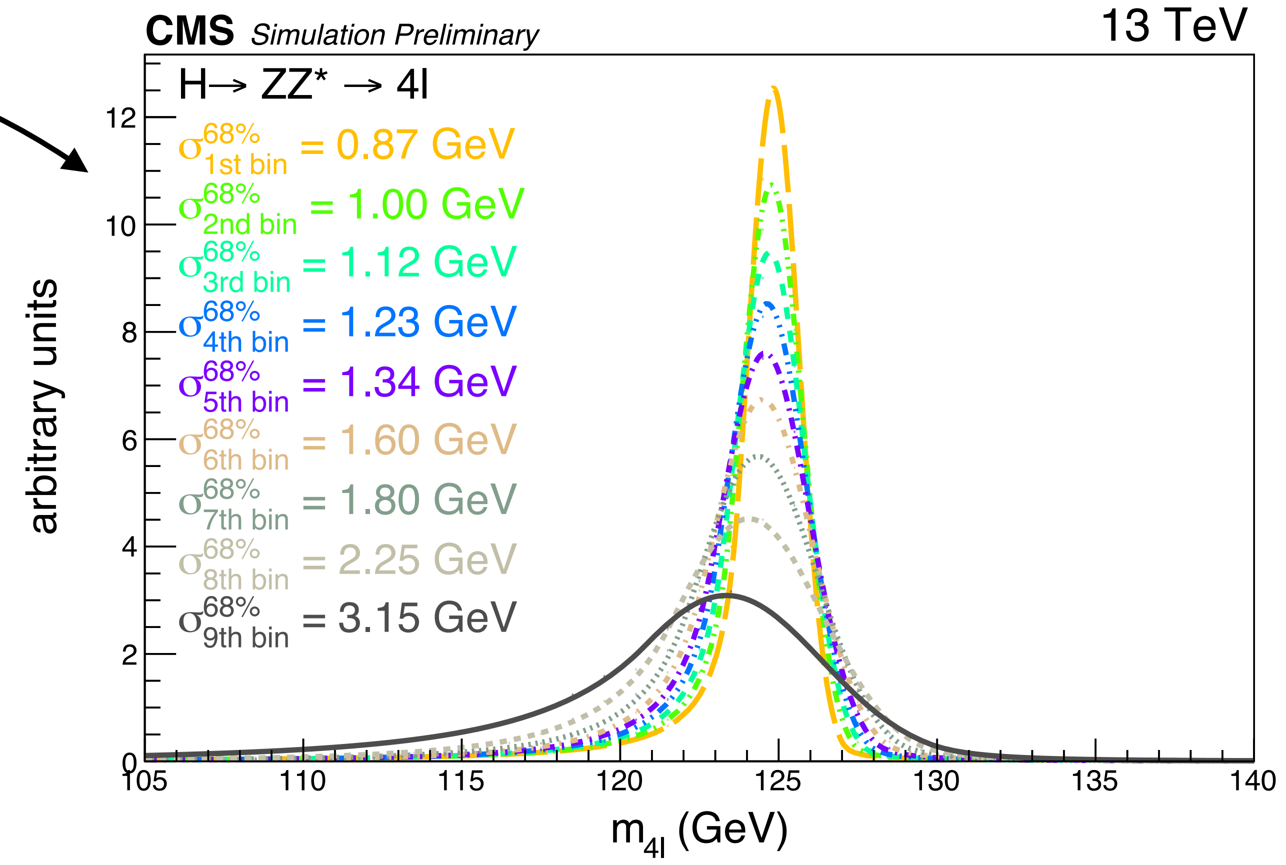
- Combination of H➔γγ and H➔ZZ➔4l

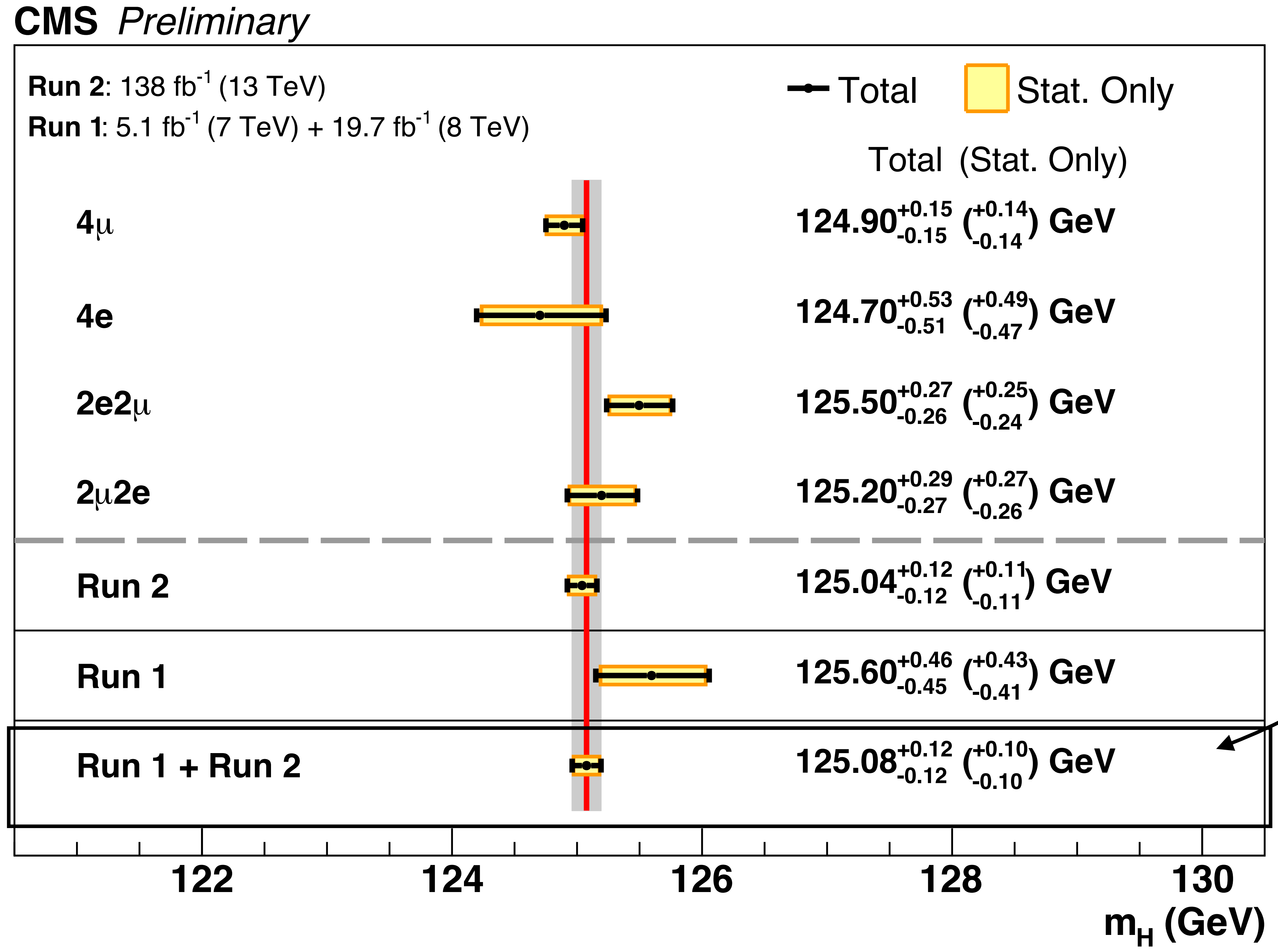


Run 1+2 combined: **m_H= 125.11±0.11 (±0.09 (stat.)±0.06 (syst.)) GeV ➔ 0.09% relative precision** (most precise measurement to date)

Mass measurements - CMS

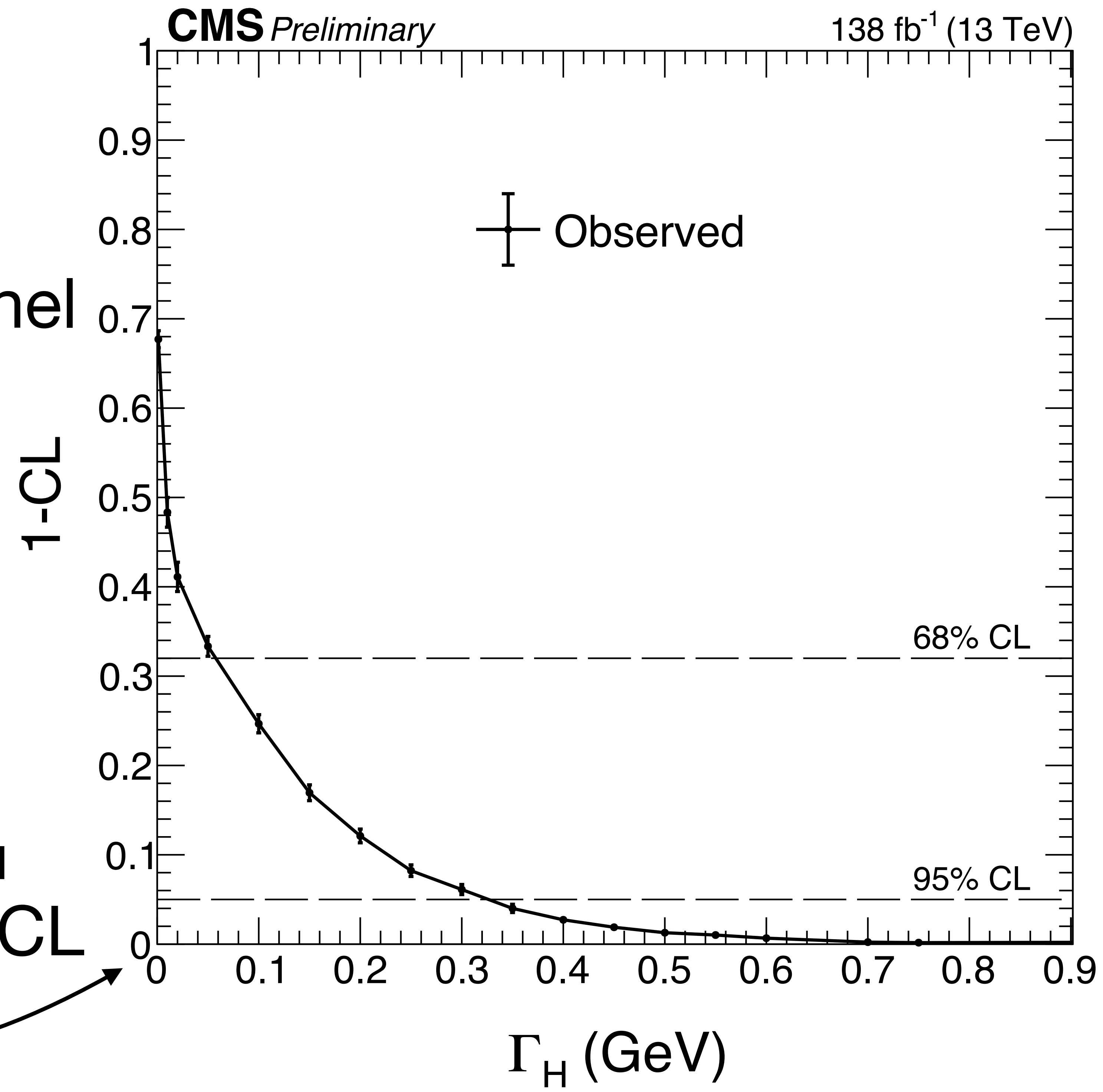
- m_H measured in 9 mass resolution categories
- 2D fit: reconstructed m_{4l} and kinematic discriminant
- Direct constraint on Γ_H





m_H = 125.08±0.12 GeV (0.1% precision)
most precise single-channel measurement

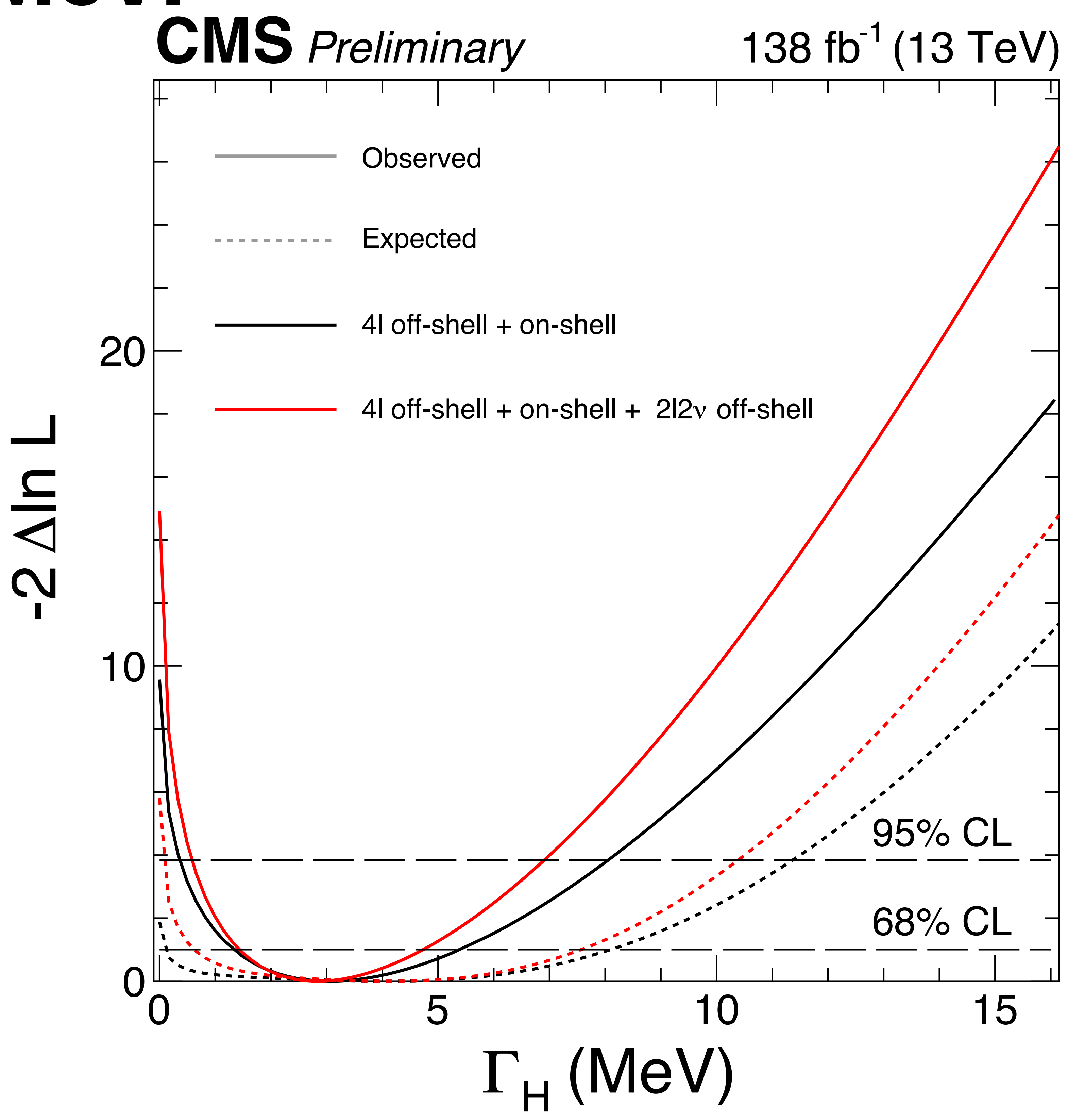
Direct constraint on Γ_H
Γ_H < 330 MeV @ 95% CL



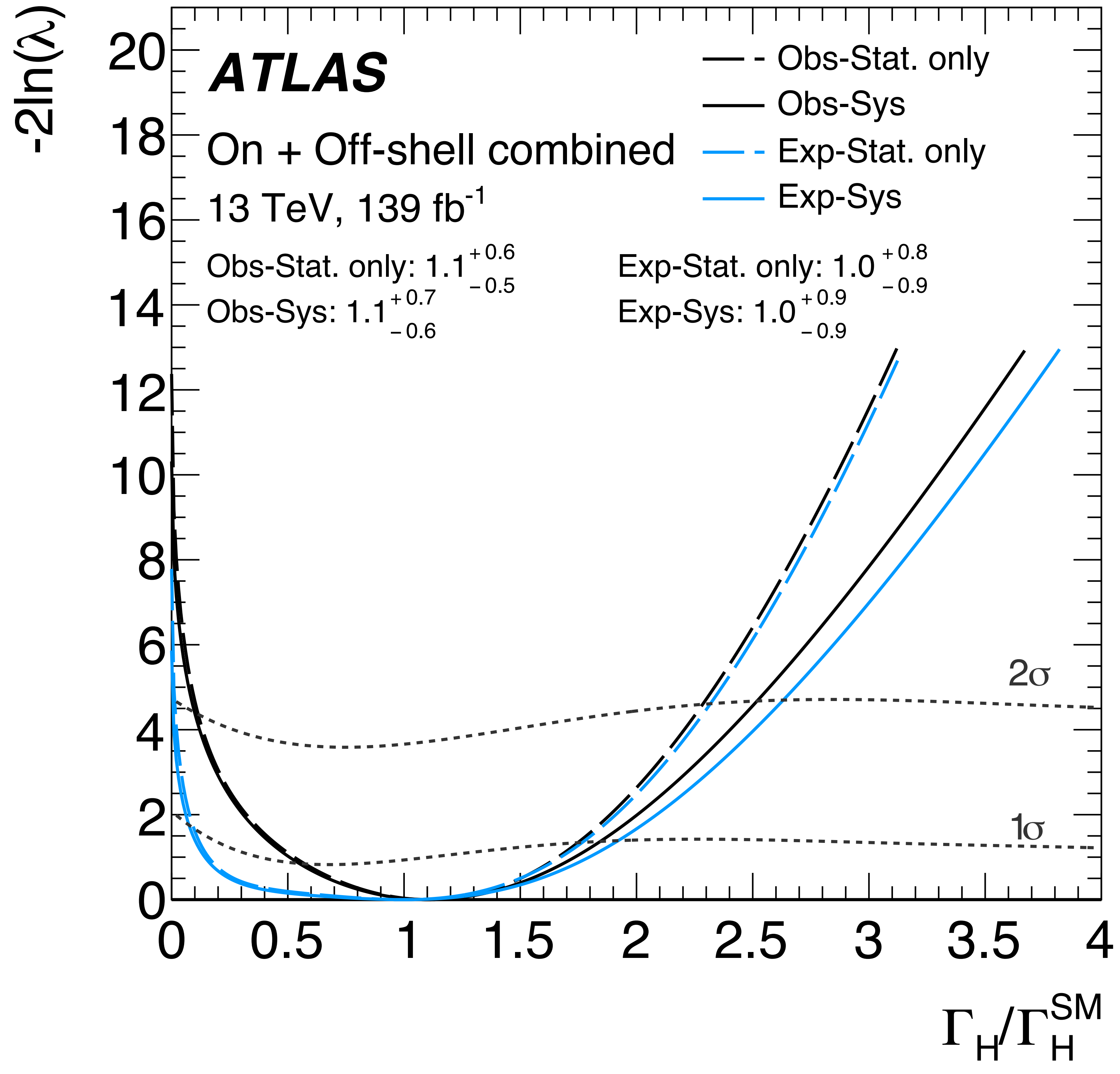
Width measurements

- Off-shell region (m_{4l}^{reco} > 200 GeV) studied in H➔ZZ➔4l and H➔ZZ➔2l2ν channels + combination with on-shell H➔ZZ➔4l
- 3D observable (CMS) / NN (ATLAS) ➔ comparable sensitivity **O(70%) precision - 2-3 MeV!**

CMS-PAS-HIG-21-019



$\Gamma_H = 2.9^{+1.9}_{-1.4}$ MeV @ 68% CL (expected : 4.1 ± 4.0 MeV)

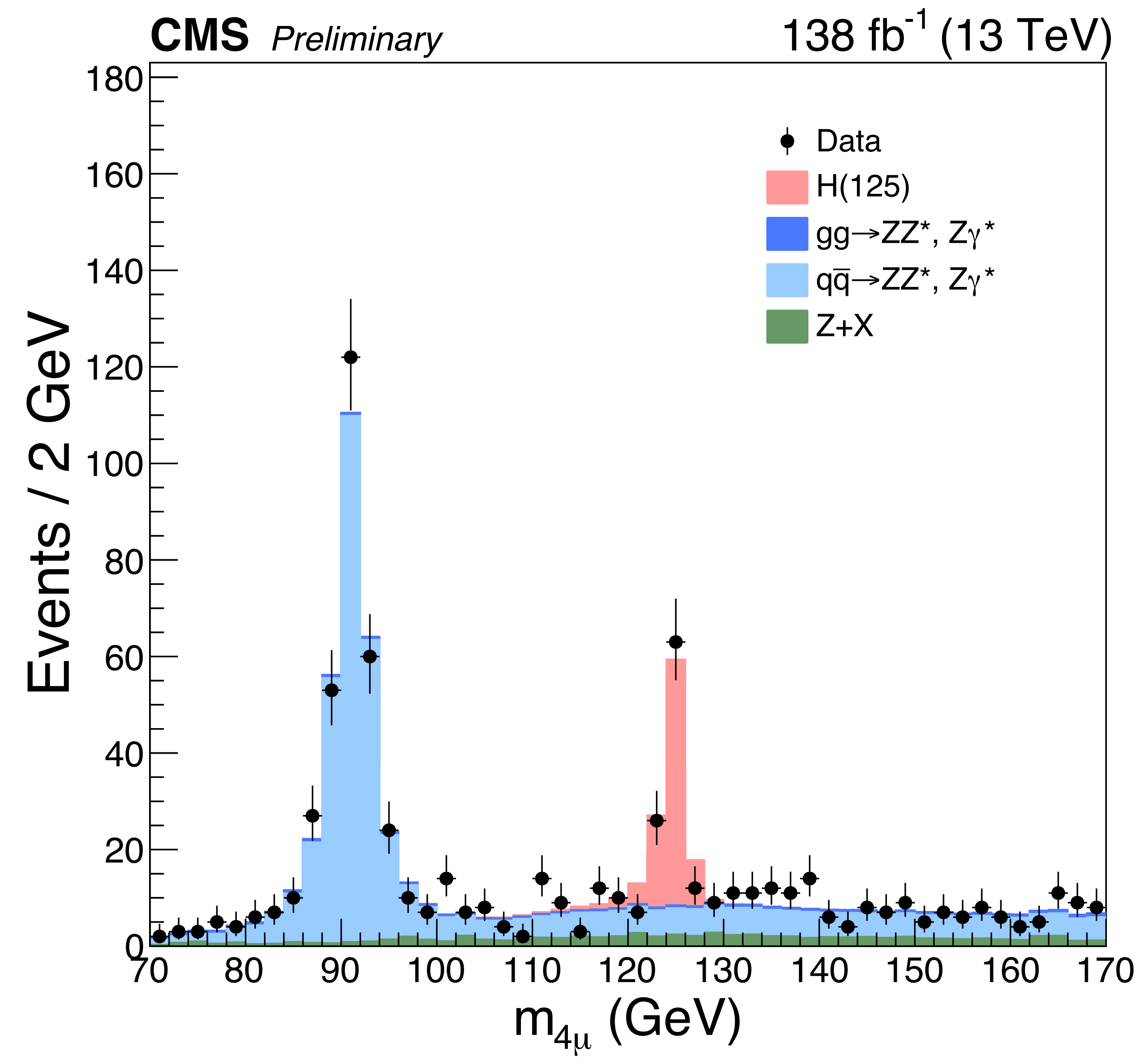


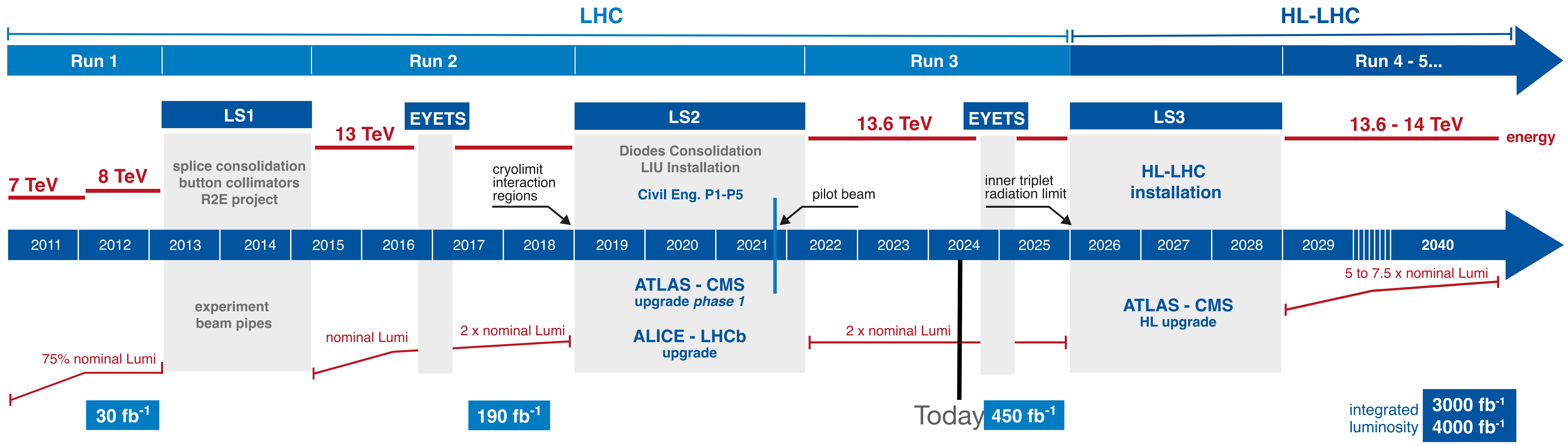
$\Gamma_H = 4.5^{+3.3}_{-2.5}$ MeV @ 68% CL (expected: $4.1^{+3.3}_{-3.7}$ MeV)

PLB 846 (2023) 138223

Summary & outlook

- Many Higgs boson production and property measurements already performed with Run 2 data
- Run 3 well underway ➔ expect more Higgs measurements at 13.6 TeV soon
- Much more to be learned about the Higgs boson with Run 3 and HL-LHC data !





Summary & outlook

Tue 04/06 | Wed 05/06 | All days

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Time	Talk	Speaker	Room	Slot
11:00	NLO EW corrections to HH production	*Huan-Yu Bi*	*ISEC Room 102*	11:00 - 11:18
	Non-resonant di-Higgs searches and measurements with the ATLAS detector	*Arely Cortes Gonzalez*	*ISEC Room 102*	11:18 - 11:36
	Non-resonant di-Higgs searches and measurements with the CMS detector	*Irene Dutta*	*ISEC Room 102*	11:36 - 11:54
12:00	Light Yukawa couplings from H* production	*Marco Vitti*	*ISEC Room 102*	11:54 - 12:12
	Higgs property measurements (mass, width, CP) with the ATLAS detector	*Sebastien Rettie*	*ISEC Room 102*	12:12 - 12:30
	Higgs propery measurements (mass, width, CP) with the CMS detector	*Lucas Kang*	*ISEC Room 102*	12:30 - 12:48
13:00				
14:00	ttH+tH Production (ATLAS)	*Anastasia Kotsokechagia*	*ISEC Room 102*	14:00 - 14:18
	ttH+tH Production (CMS)	*Matteo Marchegiani*	*ISEC Room 102*	14:18 - 14:36
	tt+HF measurements including ttbb (ATLAS+CMS)	*Luisa Carvalho*	*ISEC Room 102*	14:36 - 14:54
15:00	Top-Bottom Interference Contribution to Higgs Production	*Mr Marco Niggetiedt*	*ISEC Room 102*	14:54 - 15:12
	4top searches including constraints on Top Yukawa (ATLAS+CMS)	*Nick Manganelli*	*ISEC Room 102*	15:12 - 15:30

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Time	Talk	Speaker	Room	Slot
11:00	Higgs differential measurements and EFT interpretation in CMS	*Suman Chatterjee*	*ISEC Room 102*	11:00 - 11:18
	Higgs differential measurements and EFT interpretation in ATLAS	*Giuseppe Callea*	*ISEC Room 102*	11:18 - 11:36
	Uniqueness of the matching in the HEFT	*Duarte Fontes*	*ISEC Room 102*	11:36 - 11:54
12:00	ZH production in SMEFT from ggF	*Marion Thomas*	*ISEC Room 102*	11:54 - 12:12
	Higgs boson coupling measurements in CMS	*Clara Ramon Alvarez*	*ISEC Room 102*	12:12 - 12:30
	Higgs boson coupling measurements in ATLAS	*Antonio Jesus Gomez Delegido*	*ISEC Room 102*	12:30 - 12:48

More details in the parallel talks **today** and **tomorrow** !
See also J. Alison's talk on di-Higgs production in tomorrow's plenary,
and S. Hirose's talk on rare/BSM Higgs boson decays in yesterday's plenary

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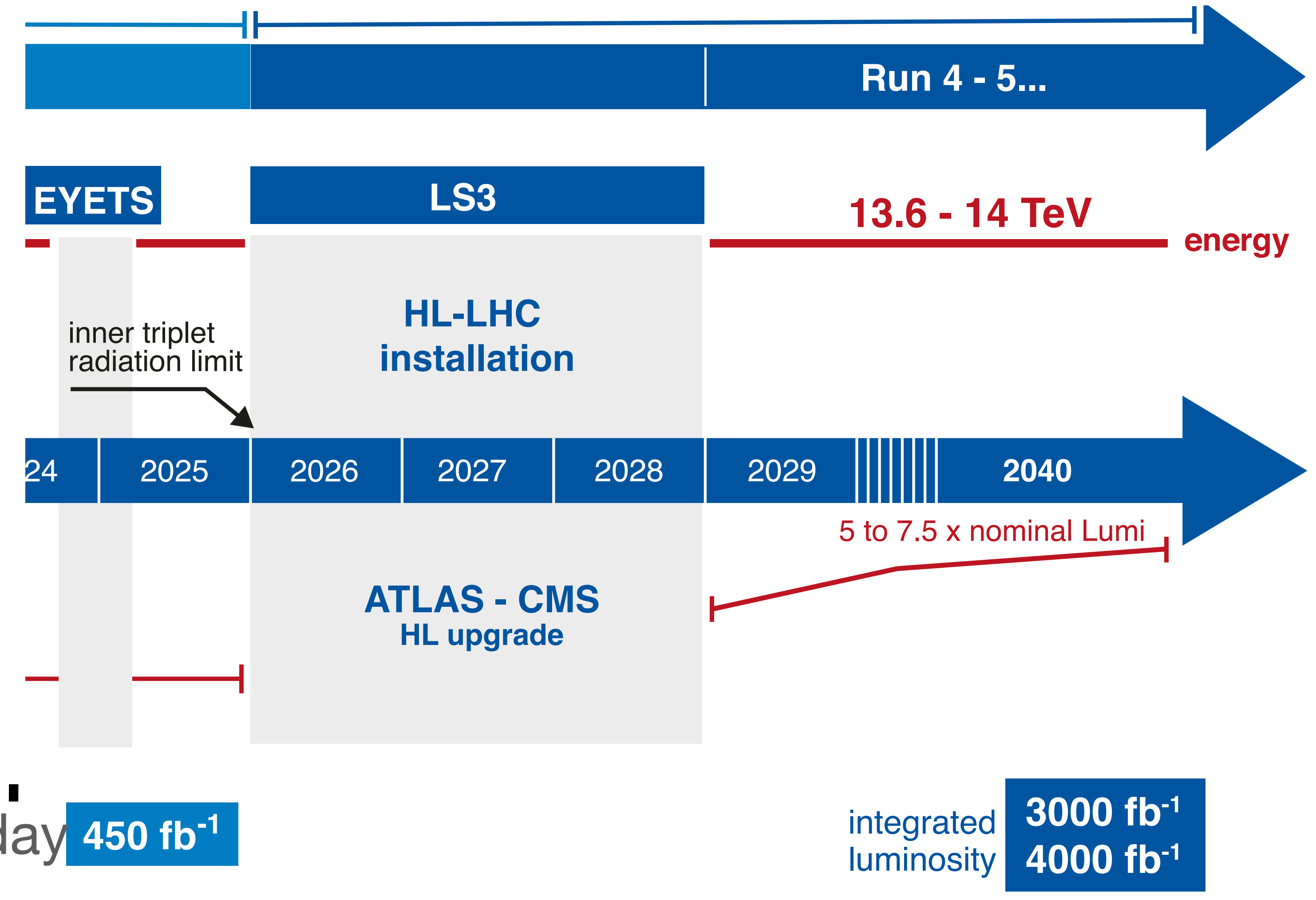

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