Higgs Differential Cross Sections and Couplings

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On behalf of ATLAS and CMS Collaborations,

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Introduction

- Importance of m_H in several aspects of our understanding of fundamental physics.

Power law expansion of the potential

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

$$\begin{aligned}\mathcal{L} = & -\frac{1}{4}F_{\mu\nu}F^{\mu\nu} \\ & + i\bar{\Psi}\not{D}\psi \\ & + D_\mu\Phi^\dagger D^\mu\Phi - V(\Phi) \\ & + \bar{\Psi}_L\hat{Y}\Phi\Psi_R + h.c.\end{aligned}$$

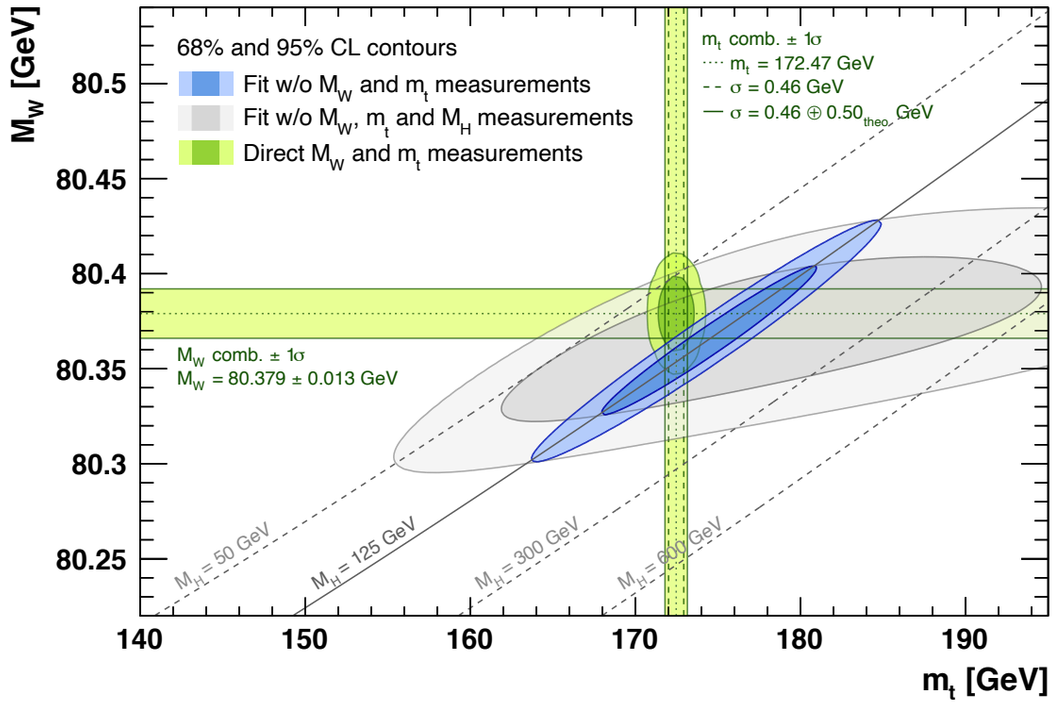
- Understanding the perturbative expansion of its potential ($\lambda v^2 h^2$).

- Precise higher order corrections to the theory predictions of the Higgs interactions depend on the value of m_H.

- Input to the precision global fit of the Standard Model.

- Free parameter to be determined by the experiment.

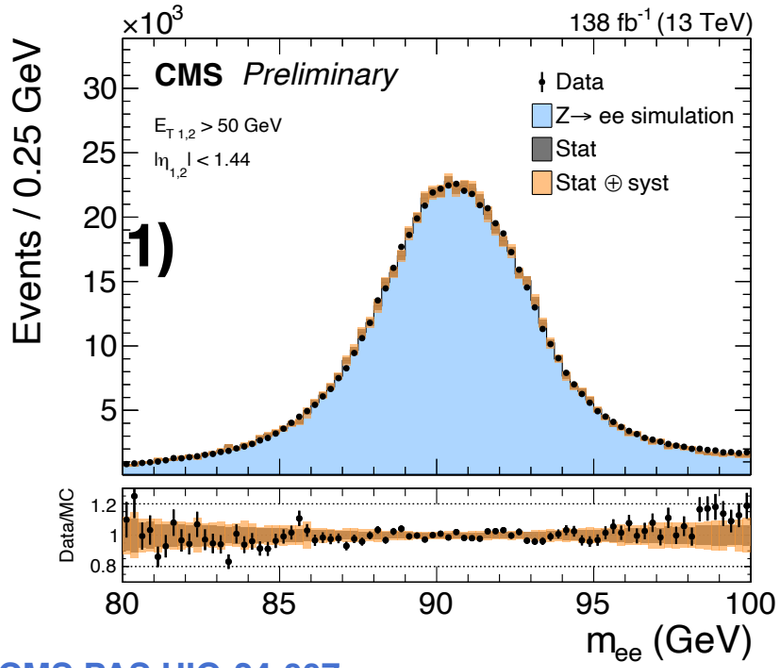
- A gauge of our detector understanding

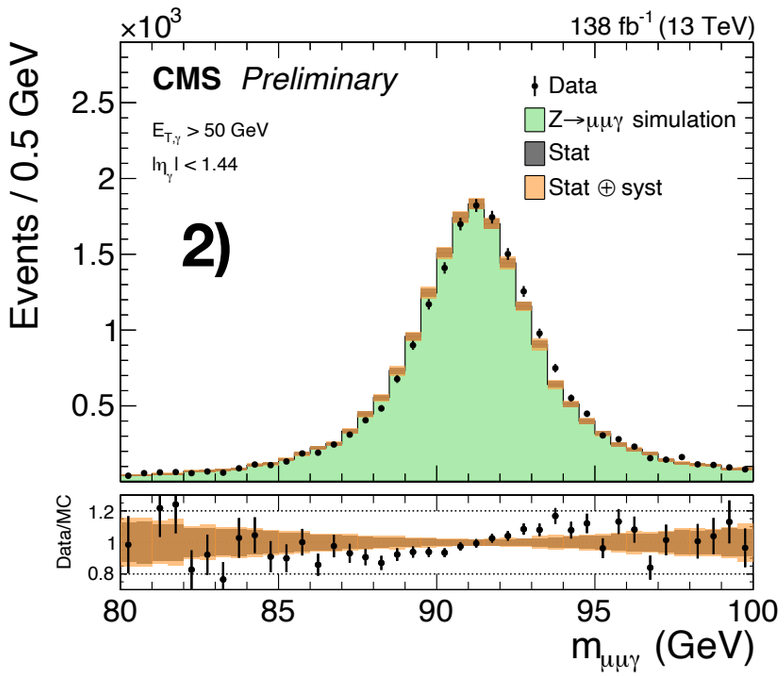


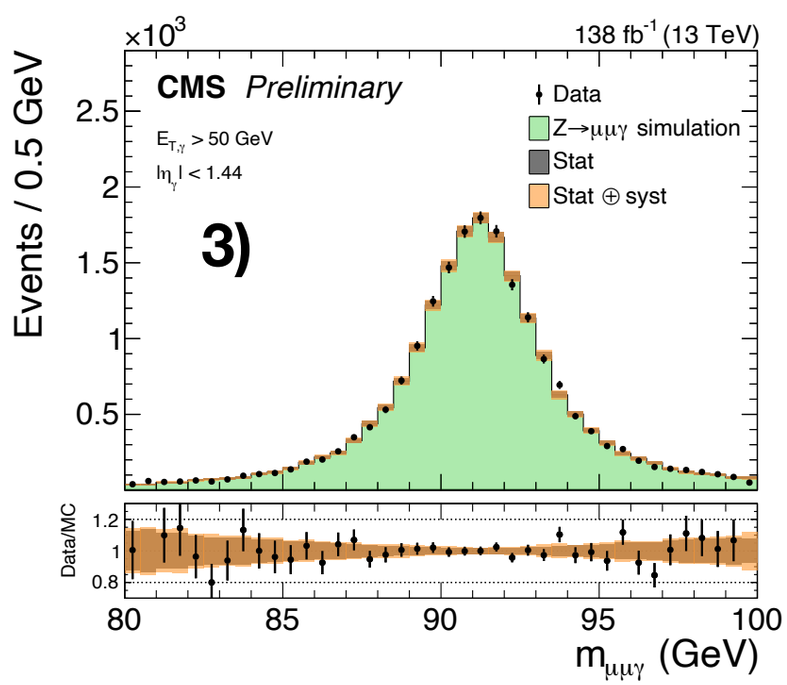
Global Electroweak fits from the Gfitter Collaboration

Precision calibration

- *New calibration for* $E_T(\gamma)$: three-stage corrections:
  1) Likelihood-based for scale and MC smearing from Z→ee.
  2) Uniformity correction on R9 > 0.96
  3) $Z \to \mu\mu\gamma$ events (data and simulation) to correct residual electron–photon scale differences.
     - ✦ Using full Run-2
     - ✦ In 20 bins: five |η| bins, two R9 bins (low/high), and two ET bins (30 < ET < 45 GeV and ET > 45 GeV).
     - ✦ Corrections range up to 0.9%.







[CMS PAS HIG-24-007]

Precision calibration

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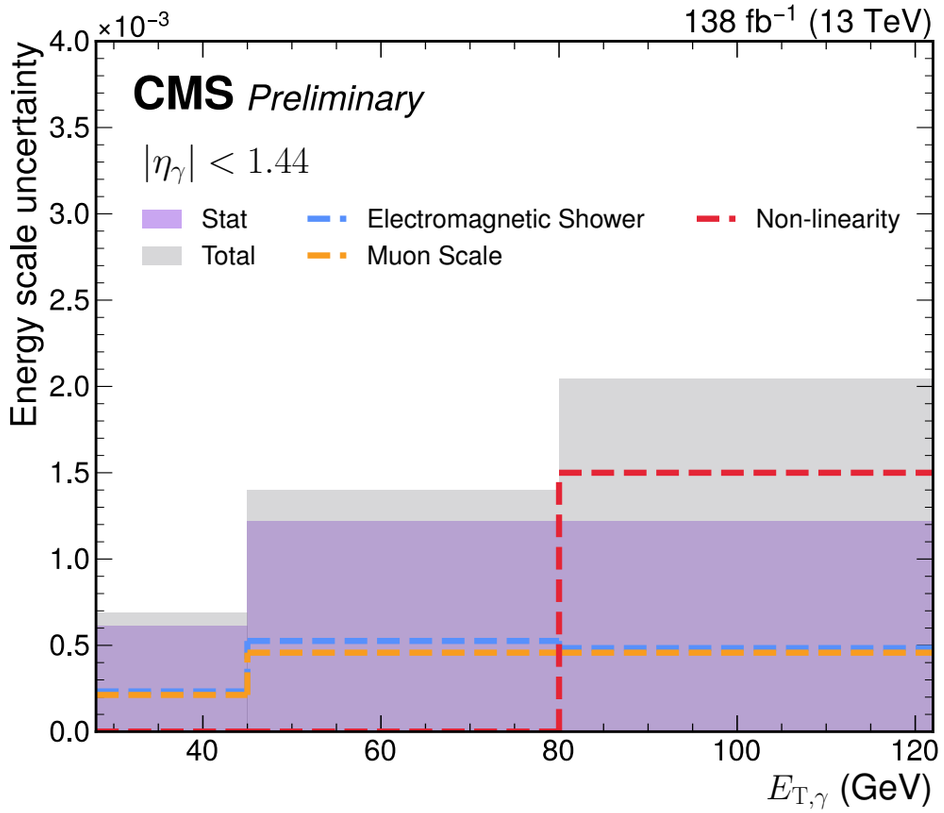
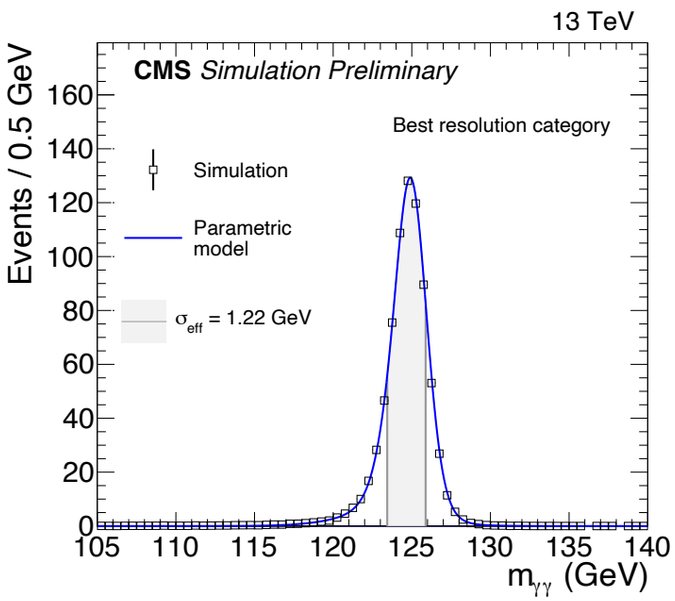
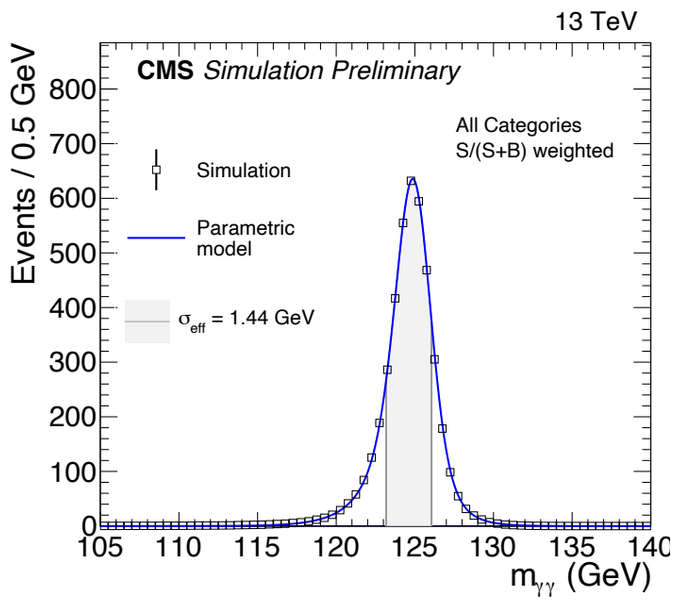
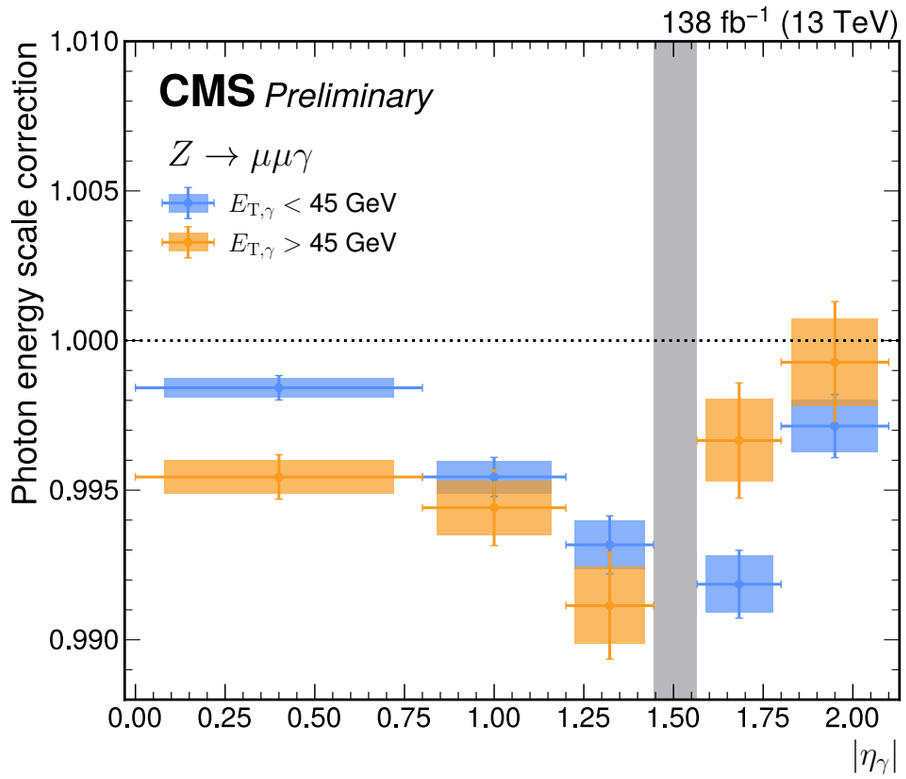


New





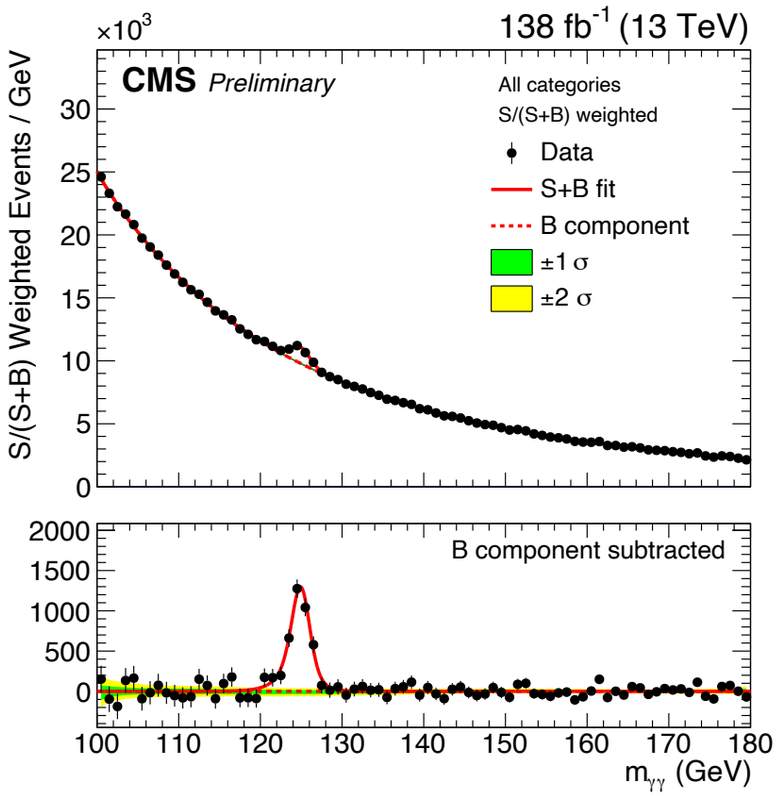


[CMS PAS HIG-24-007]

- $H\to\gamma\gamma$ updated result at Run II with 138 fb^{-1}. CMS PAS HIG-24-007
  - Analytical $m_{\gamma\gamma}$ background functions in kinematic and detector-related categories.
  - Reduction of uncertainty through categorisation of events as a function of:
    - resolution and signal significance.
    - Systematic uncertainties.

- Expected statistical uncertainty of 0.10 GeV and 0.11 GeV systematic uncertainty

$$m_{\mathrm{H}} = 125.14 \pm 0.10\ (\mathrm{stat}) \pm 0.11\ (\mathrm{syst})\ \mathrm{GeV}$$



- Combined with Run I

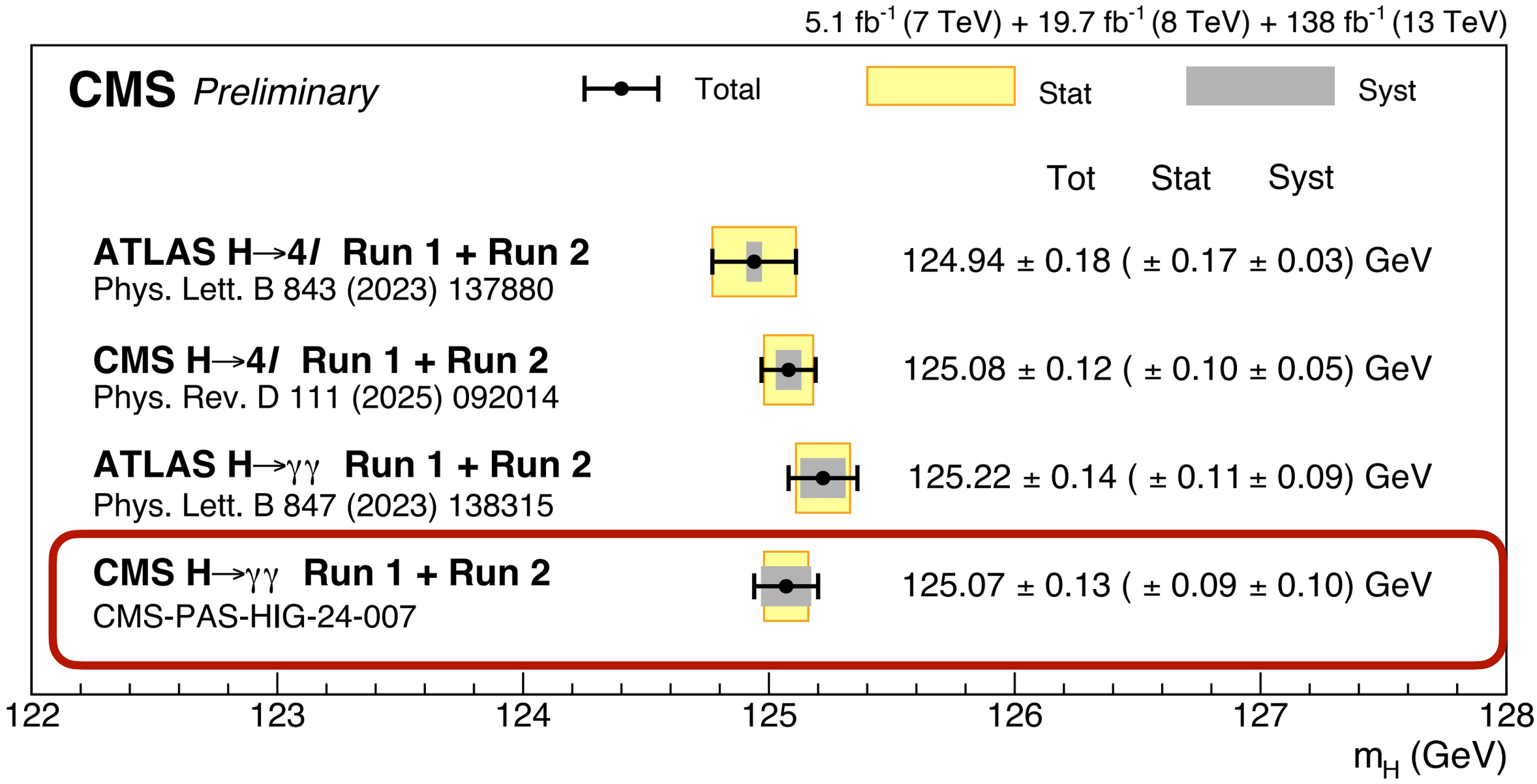
$$m_{\mathrm{H}} = 125.07 \pm 0.09\ (\mathrm{stat}) \pm 0.10\ (\mathrm{syst})\ \mathrm{GeV}$$

Source	Contribution (MeV)
Photon energy scale	
Statistical uncertainty of muon sample	75
Residual non-linearity	64
Muon momentum	38
Electromagnetic shower	23
Photon energy resolution	7
Interference between ggH signal and background	27
Other sources	13
Statistical uncertainty	100
Total uncertainty	150

Mass measurement

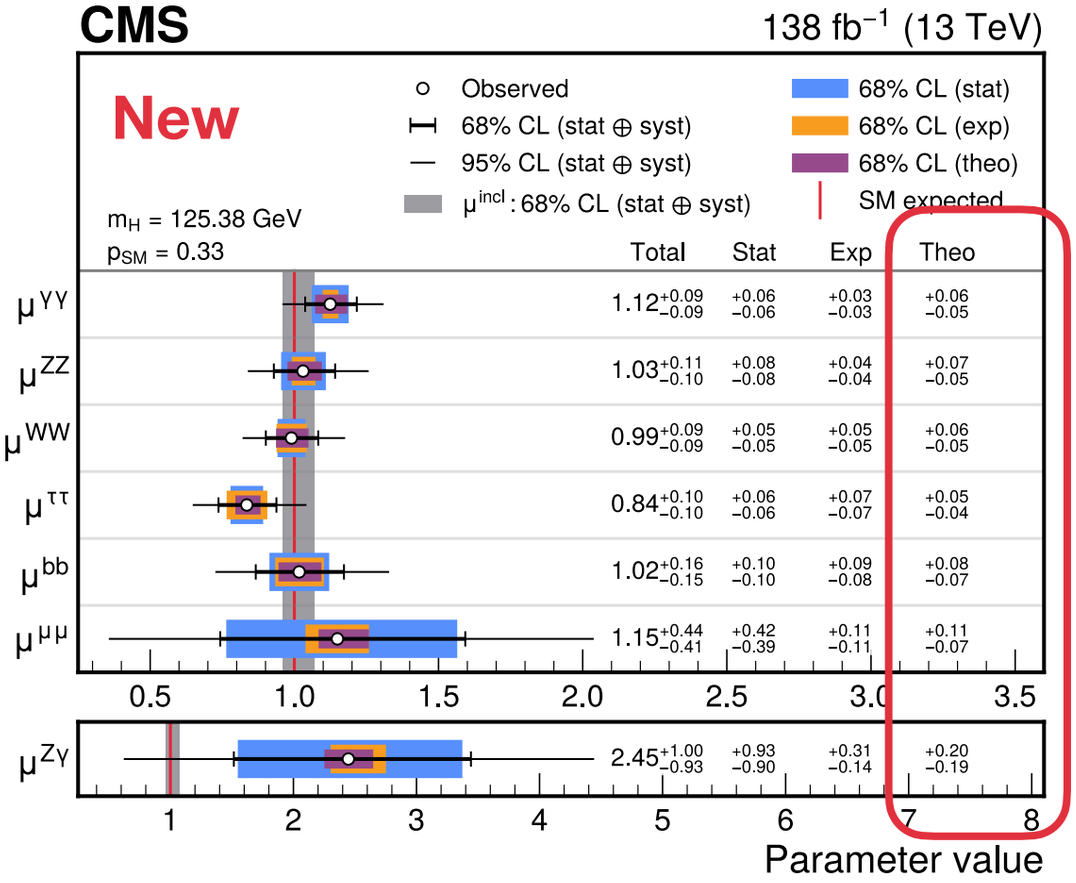
- Impressive agreement between 4ℓ and $\gamma\gamma$ and ATLAS and CMS
- Reflective of the level of understanding of our detectors

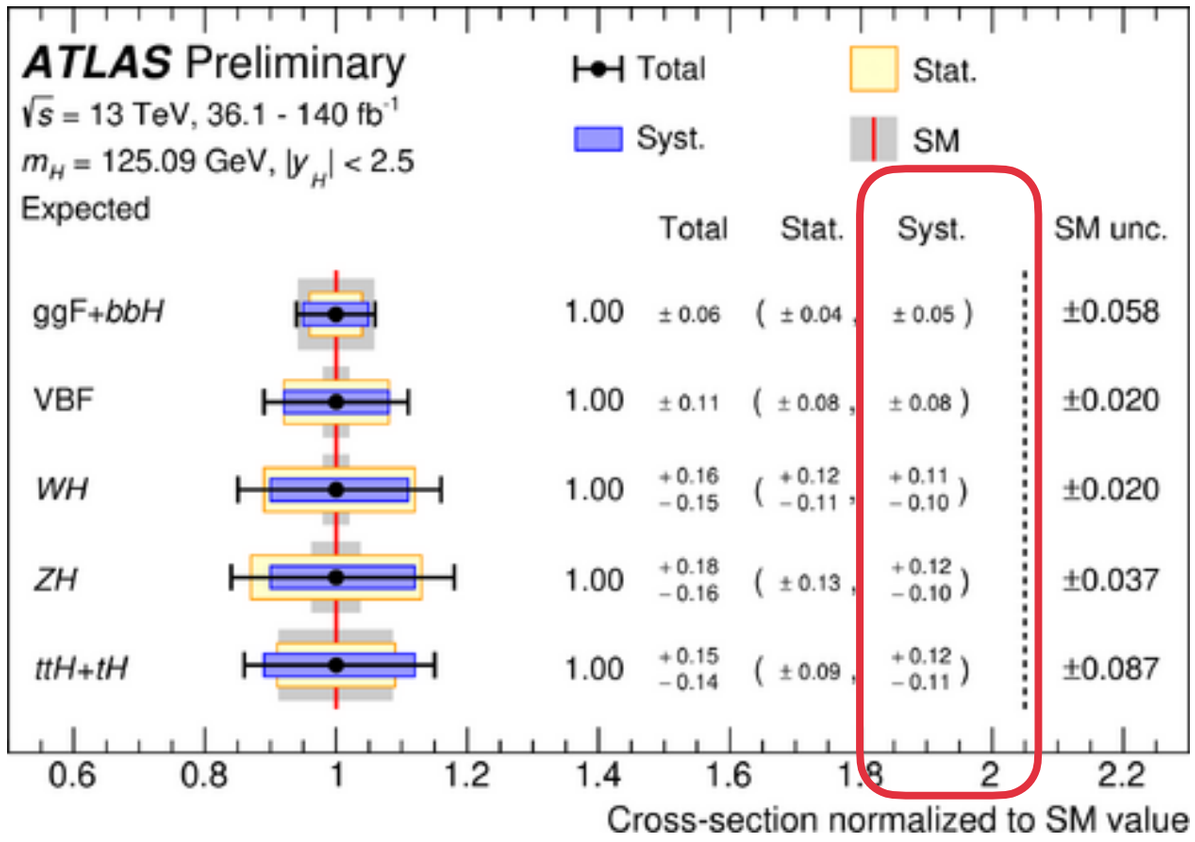
CMS PAS HIG-24-007



Inclusive combination

- Final Run-2 picture from both experiments, with a combination of all major channels.
  - Precision reaching the level of modelling uncertainties, projected to be a bottleneck at Run-4





- Inclusive CMS rate

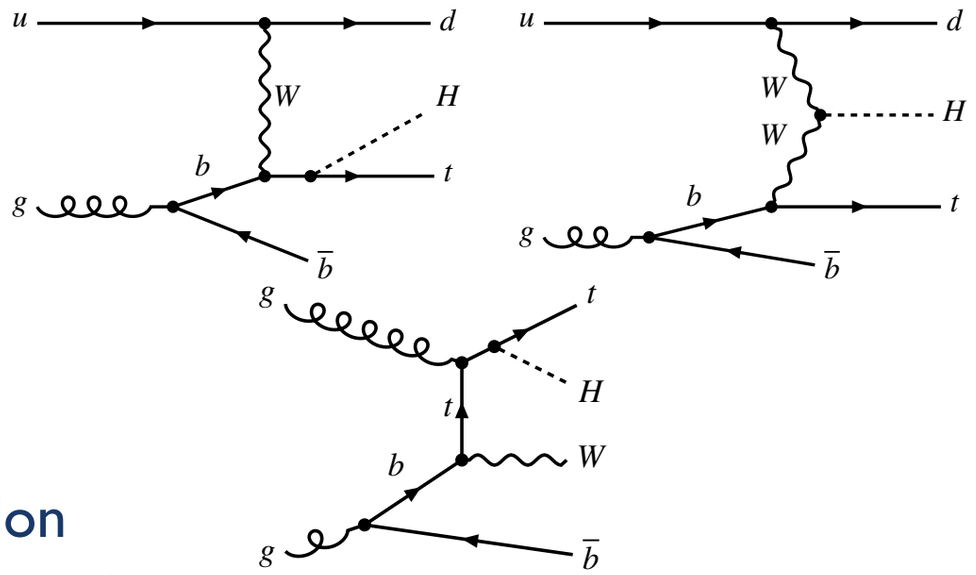
$$\mu^{\text{incl}} = 1.014^{+0.055}_{-0.053}$$
$$= 1.014^{+0.040}_{-0.039}\,(\text{theo})^{+0.025}_{-0.024}(\text{exp}) \pm 0.028\,(\text{stat})$$

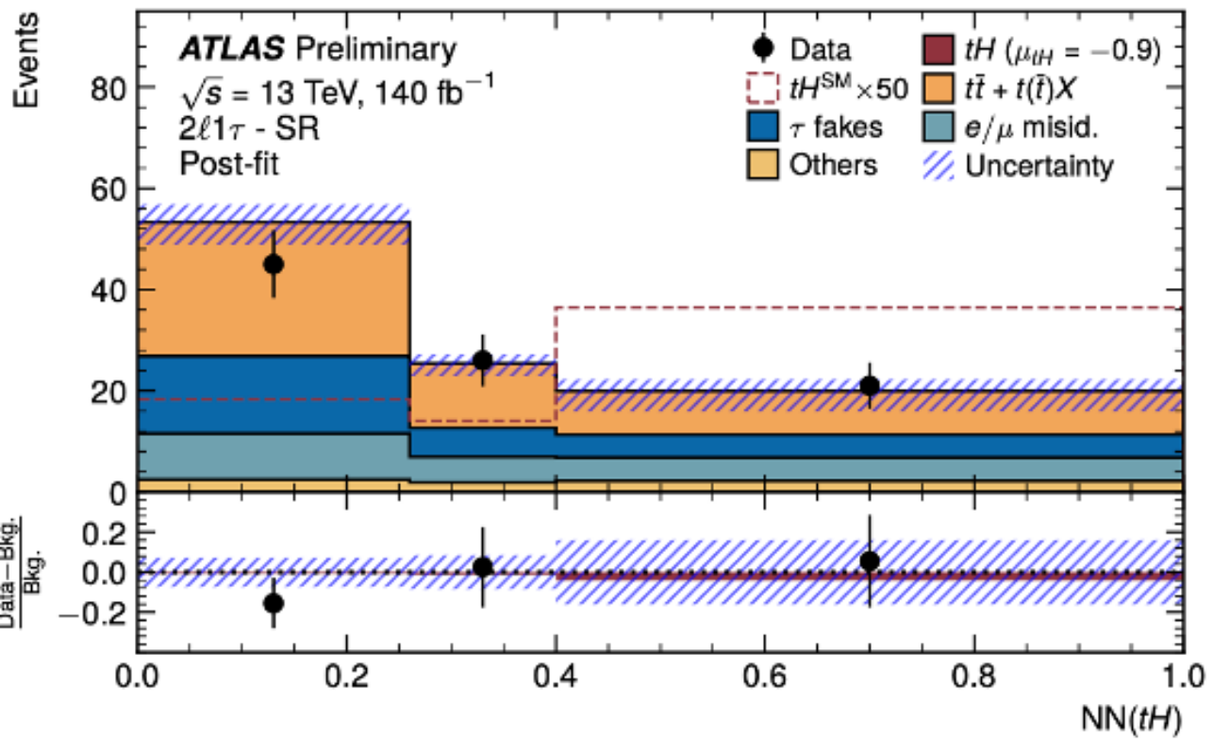
$\sqrt{s} = 13$ TeV	YR4	YR5	Comments
σ	48.58 pb	48.09 pb	Reduced by -1.01%
δ(scale)	$^{+0.21\%}_{-2.37\%}$	$^{+0.29\%}_{-3.33\%}$	$M_t^{\overline{\text{MS}}} \to M_t^{\text{OS}}$, 3-point scale variation
δ(EWK)	$\pm 1\%$	$\pm 1\%$	Mixed QCD-EW approx. checked against full calculati 33]
$\delta(t,b,c)$	$\pm 0.83\%$	$\pm 0.34\%$	Included $\sigma^{\text{NNLO},(t)}$, $\sigma^{\text{NNLO},(t\times b)}$
$\delta(1/m_t)$	$\pm 1\%$	0	Included $\sigma^{\text{NNLO},(t)}$, remaining uncertainty included in $\delta(t,b,c)$
δ(trunc)	$\pm 0.37\%$	0	Included complete N^{3}LO HTL correctior .8]
δ(theory)	$^{+3.41\%}_{-5.57\%}$	$^{+1.63\%}_{-4.67\%}$	–
$\delta(\text{PDF} + \alpha_s)$	$\pm 3.2\%$	$^{+2.69\%}_{-2.28\%}$	PDF4LHC15 → PDF4LHC21
δ(PDF-TH)	$\pm 1.16\%$	$\pm 2.31\%$	Increased by ×2

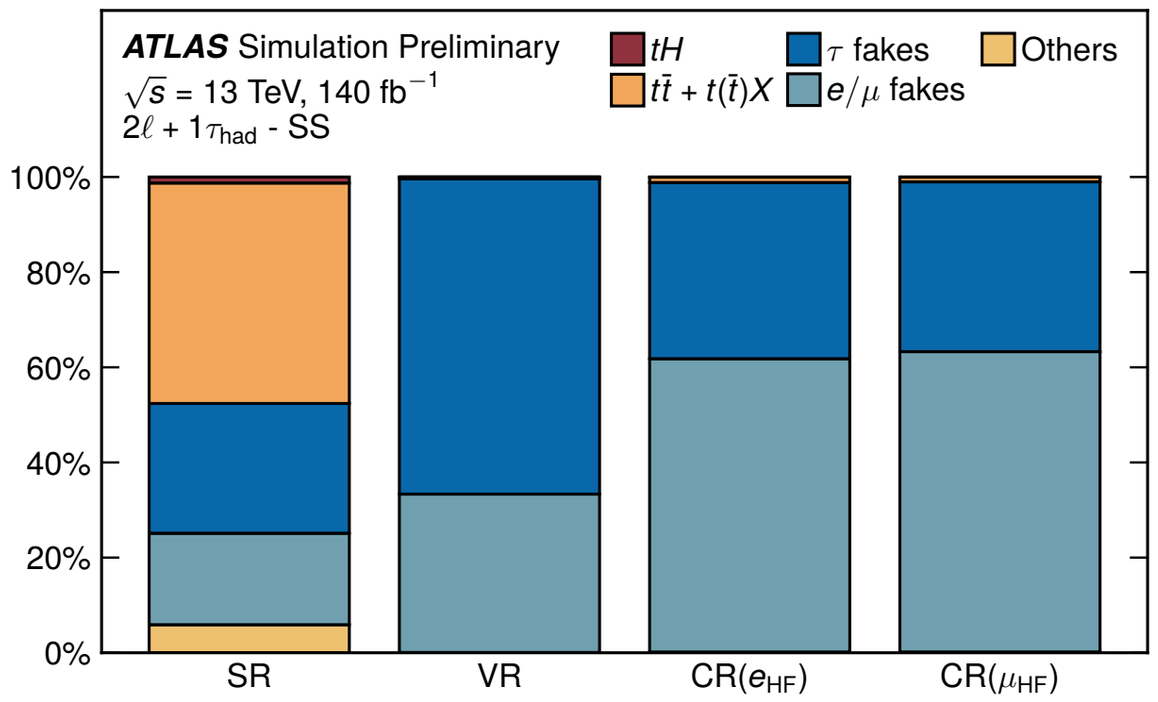
Towards a tH measurement

- Exploring the tH production in $H \to \tau\tau$ decays.
- Low s/b challenge due to three $(2\ell + 1\tau_{\text{had}})$ or four neutrinos $(1\ell + 2\tau_{\text{had}})$ in the final state

  →Employ neural networks for s/b separation
- Background estimation from data for fake estimates
  - Use normalisations for each fake (background) contribution
  - Events with multiple fake objects are scaled by the product of the associated normalisation factors
  - τ-fake NFs are correlated across both channels

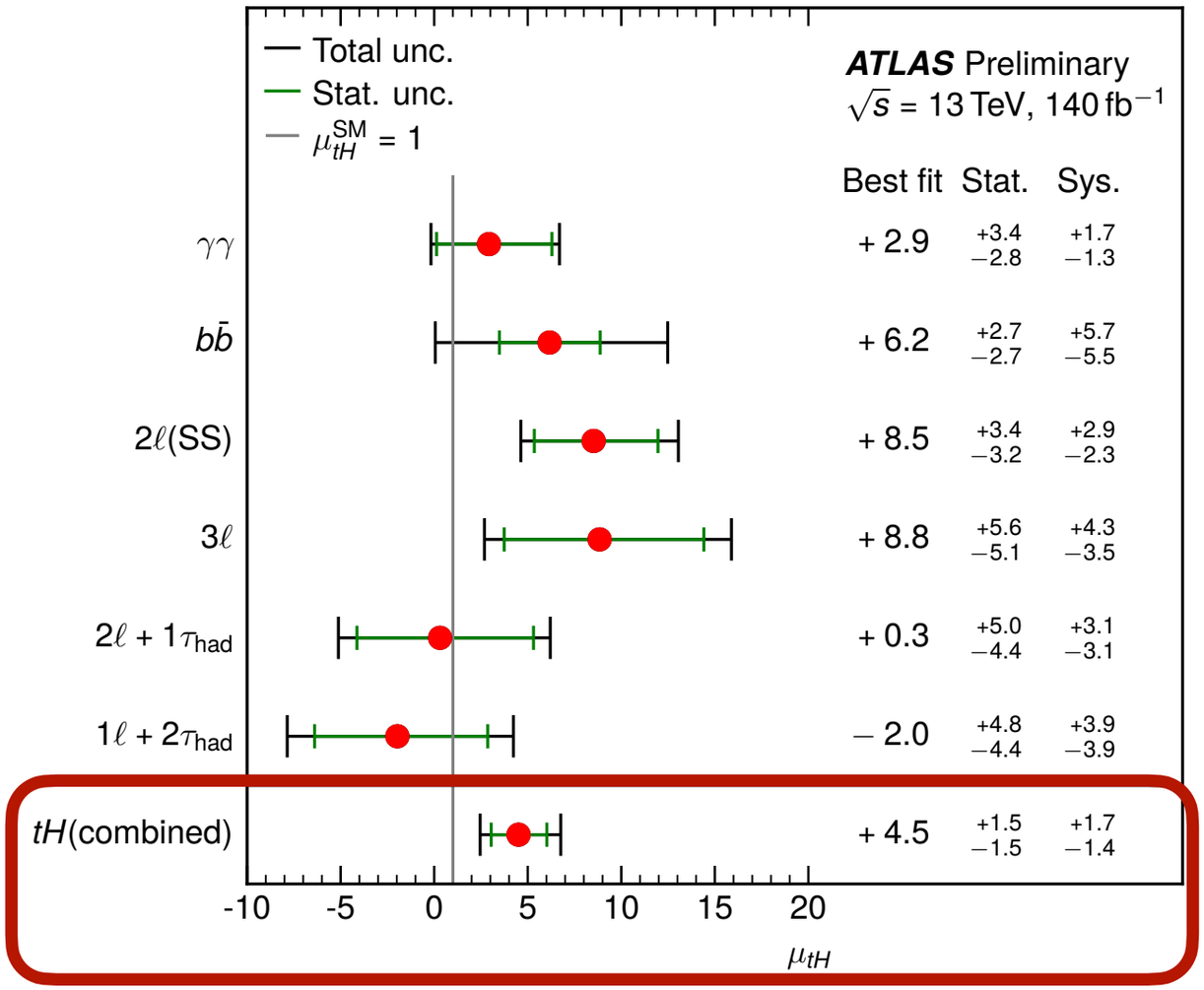


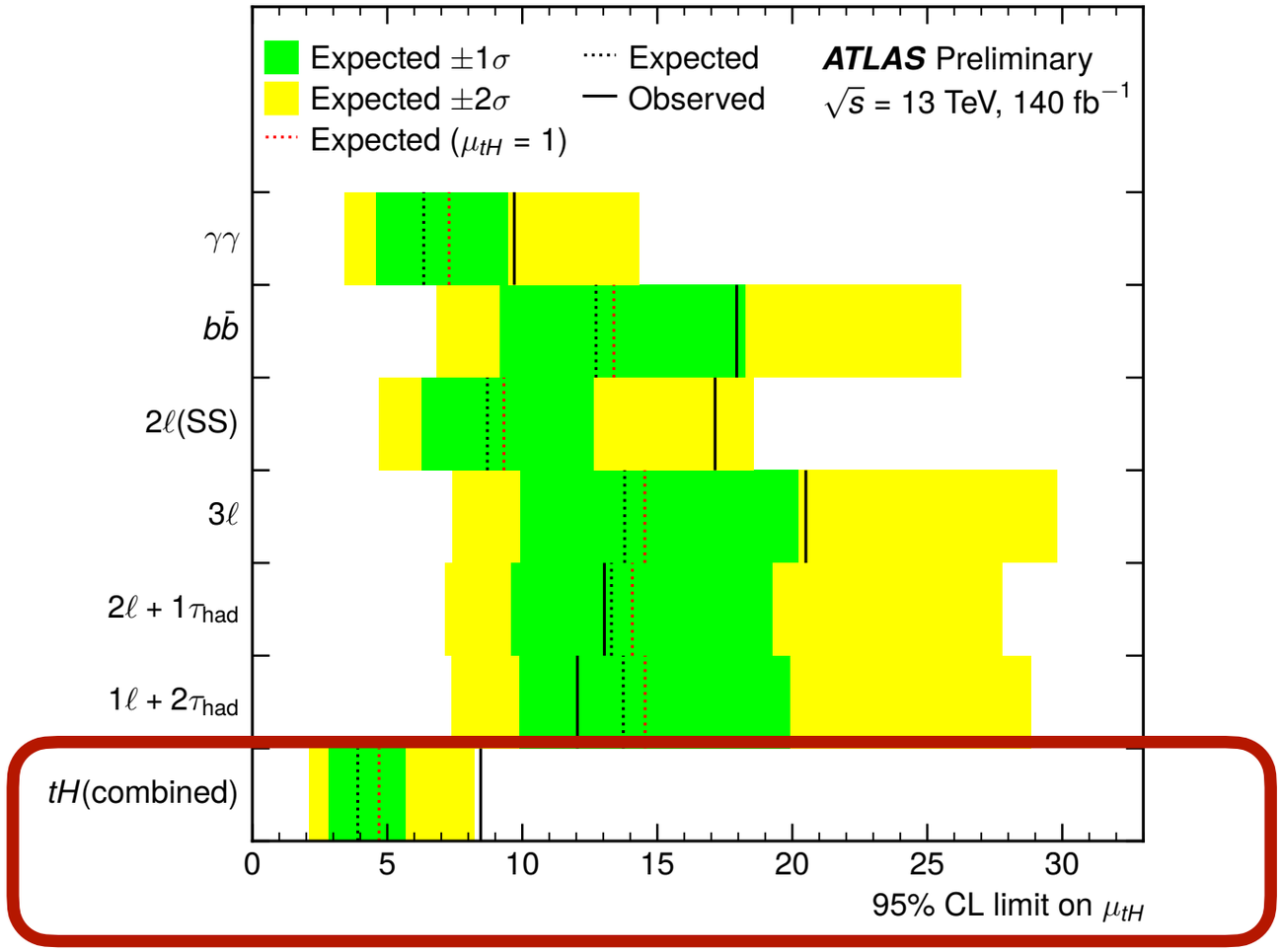




CONF-HIGP-2025-07

Towards a tH measurement





- Combination of $\tau\tau$ measurement with $H \to \gamma\gamma$ and bb:
  - Observed (expected) upper limit: 8.5 (3.9) on signal rate of tH production

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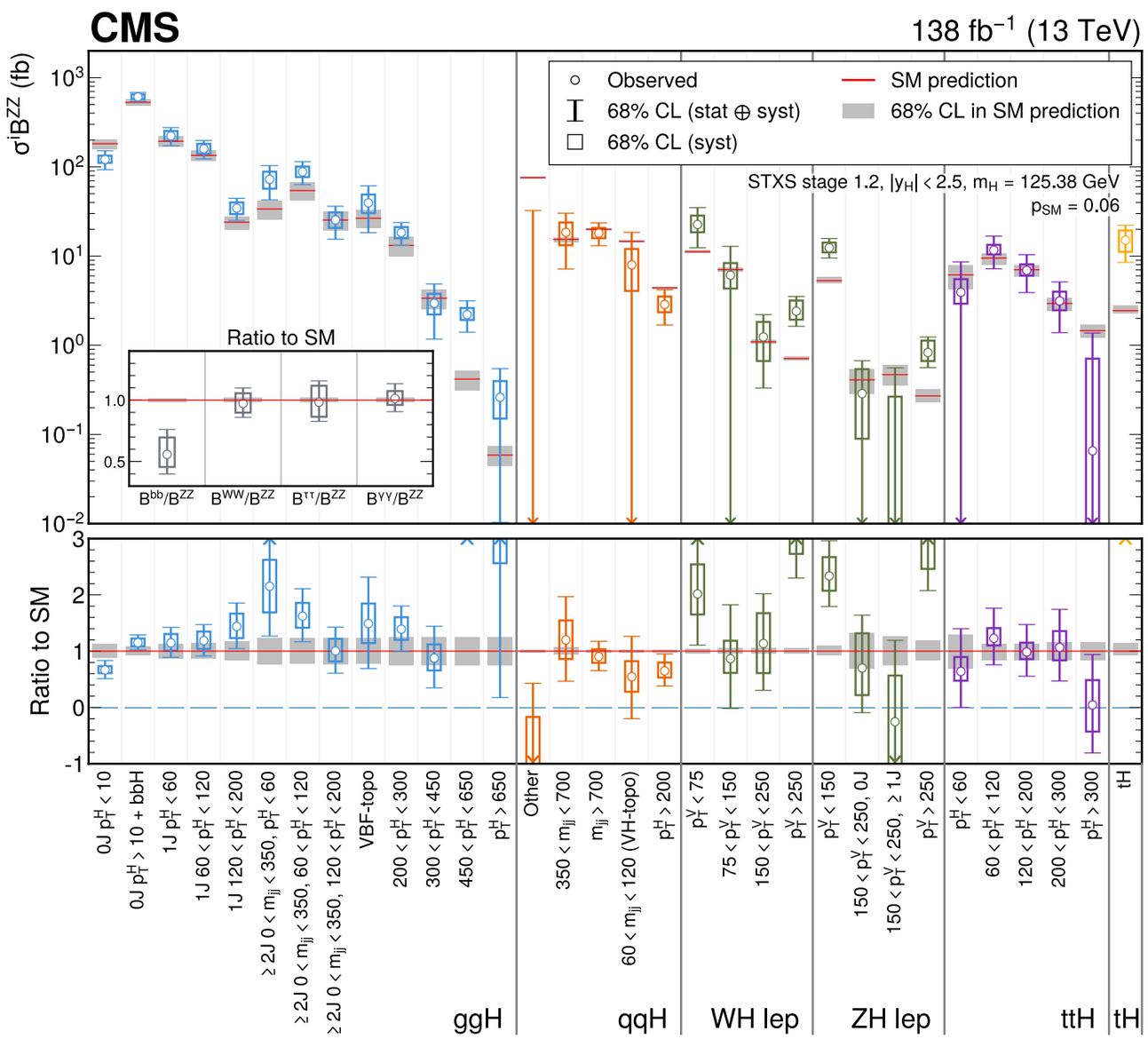
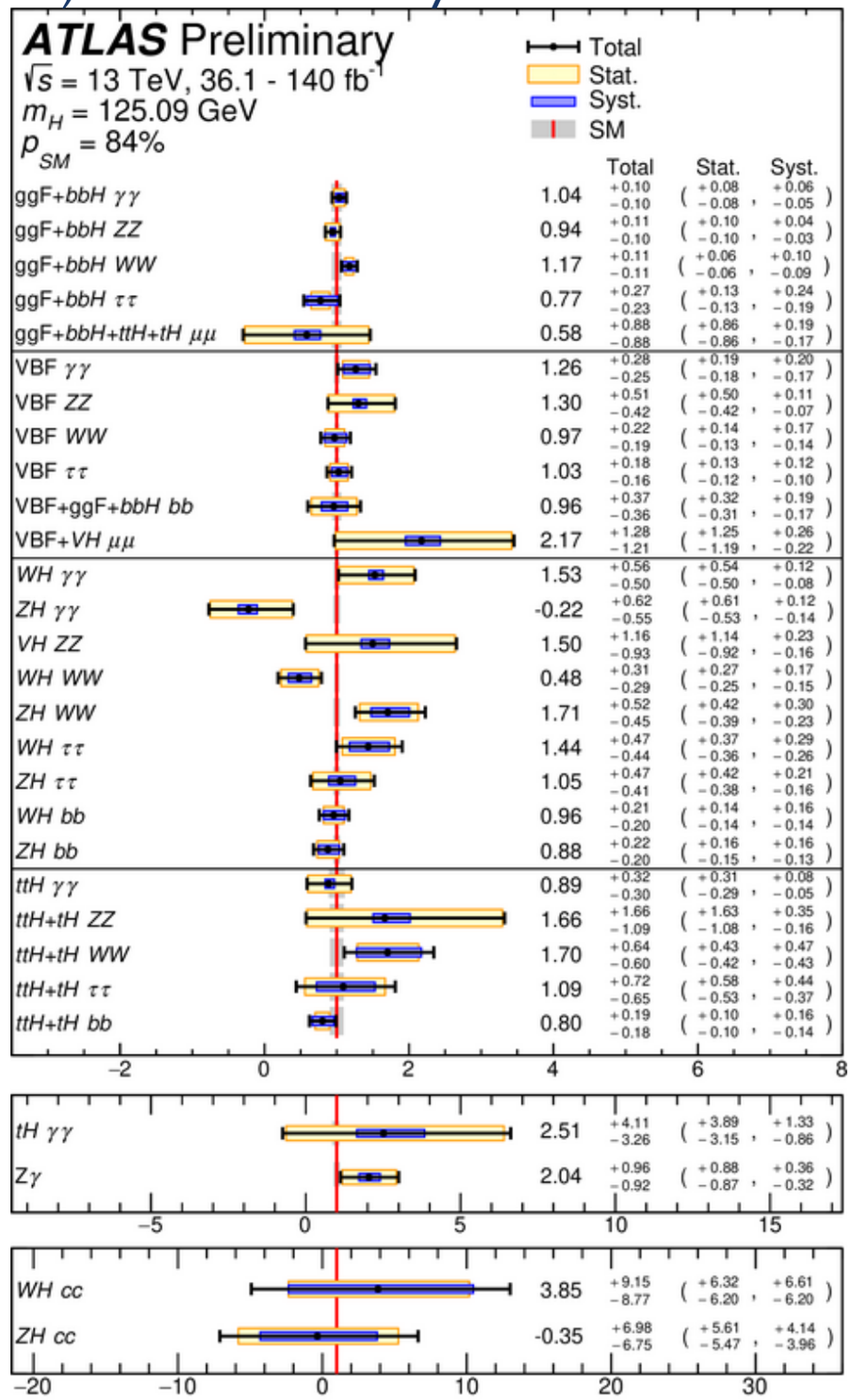
Couplings

- Simplified Template Cross Section Framework standard candle for characterising Higgs couplings at production
  - For the run we agreed on Stage 1.2, and further splitting (Stage 1.3) for CP sensitivity for Run-3

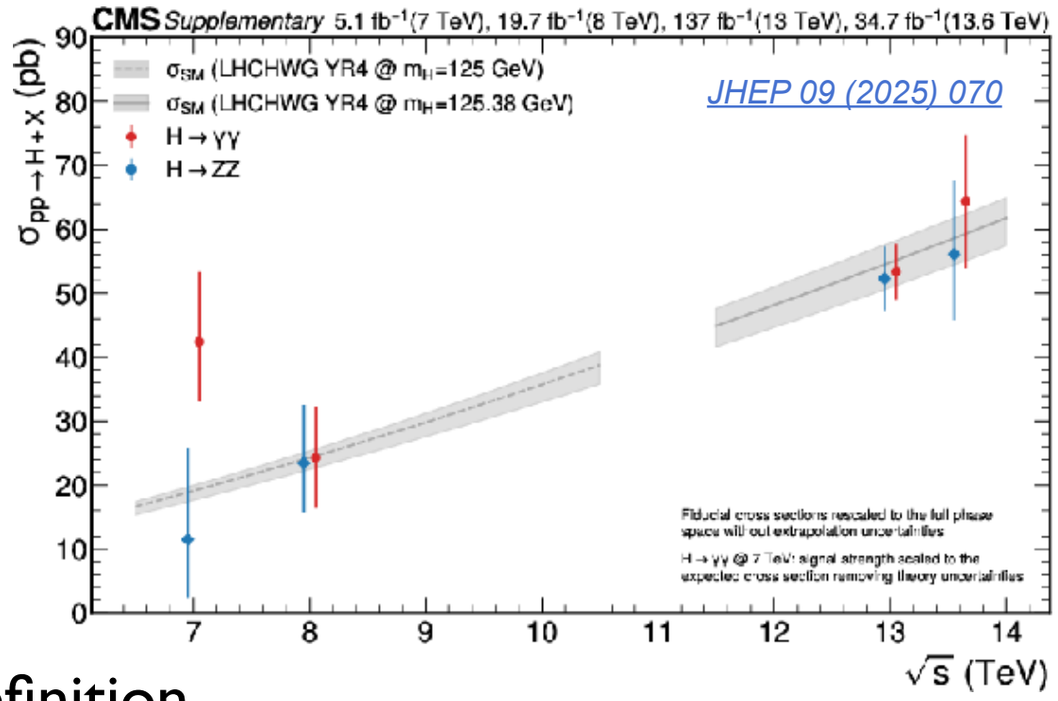




CERN-EP-2026-009, Submitted to Reports on Progress in Physics

ATLAS-CONF-2025-006

Differential measurements



- Fiducial cross-section definition
  - including detector efficiency (C) , detector acceptance (A) and branching $\mathcal{B}$

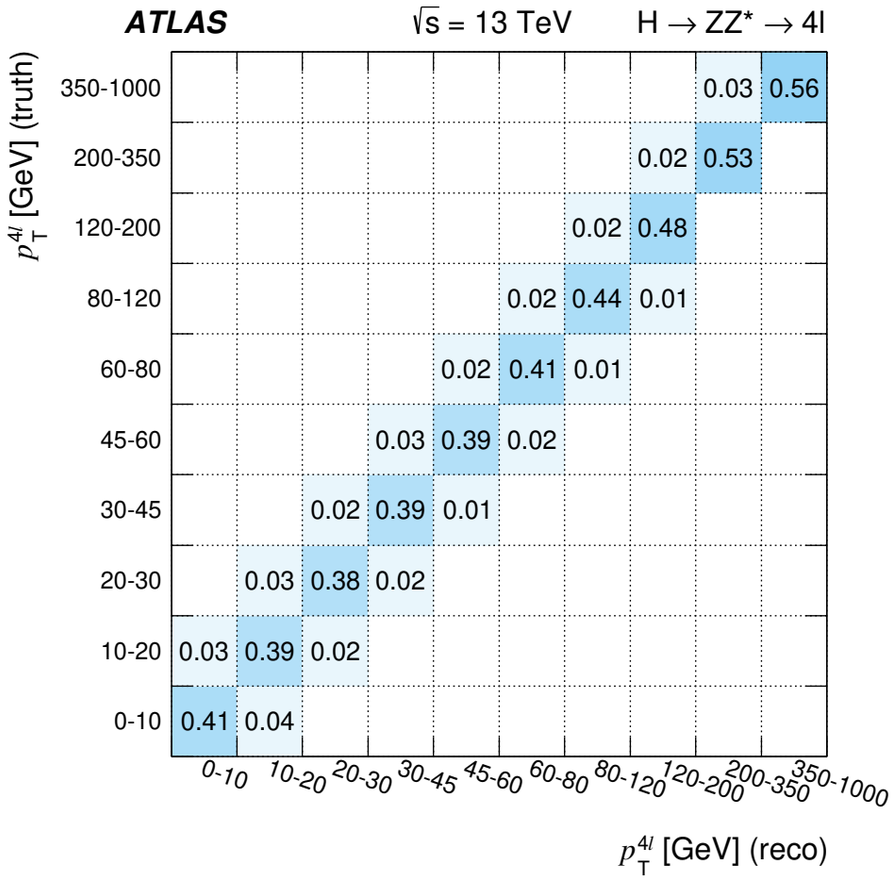
$$\sigma_{i,\mathrm{fid}} = \sigma_i \times A_i \times \mathcal{B} = \frac{N_{i,\mathrm{fit}}}{\mathcal{L} \times C_i}$$

  - Cuts mimicking reconstruction selection:

    (i) Model independent result.

    (ii) No extrapolation beyond measurable phase-space

- In standard candles channels, a resonant peak over a smooth background
  - Good resolution on final-state particles, in particular in $H \to 4\ell$, $\gamma\gamma$



Differential measurements

- Model-independent fiducial cross-sections measurements
  - Move to more challenging topologies and more complex final states, WW, $\tau\tau$, bb, . .
  - Constrain VBF topologies in 2-jet regions with differential measurements
  - Challenge in employing ML methods while maintaining model-independence,
  - Complementary methods adopted by ATLAS & CMS
    - ✦ Such as adversarial NN (CMS) or Multidimensional bootstrapped BDTs (ATLAS)
    - ✦ Correlations (including uncertainty constraints) also provided via bootstrap among measured observables

arXiv:2509.07959

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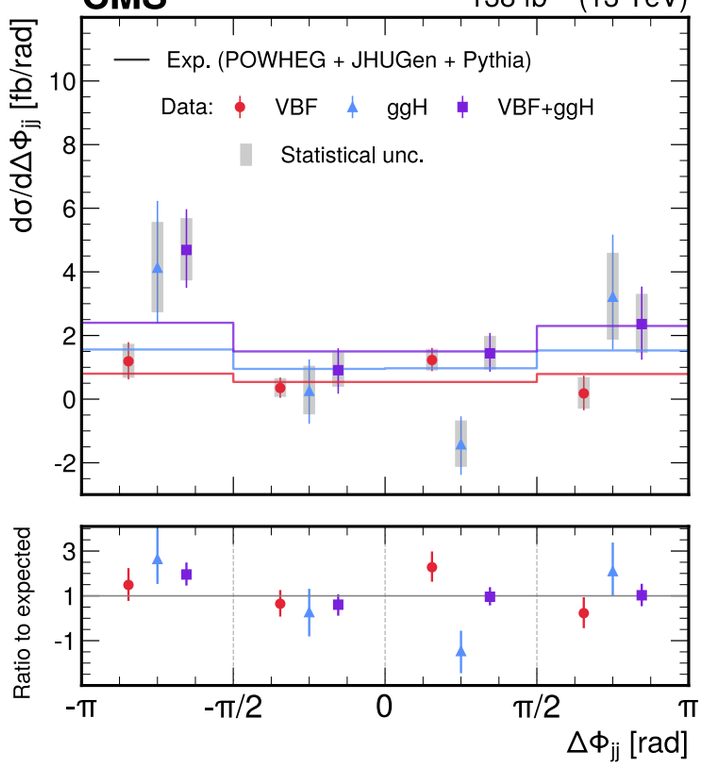
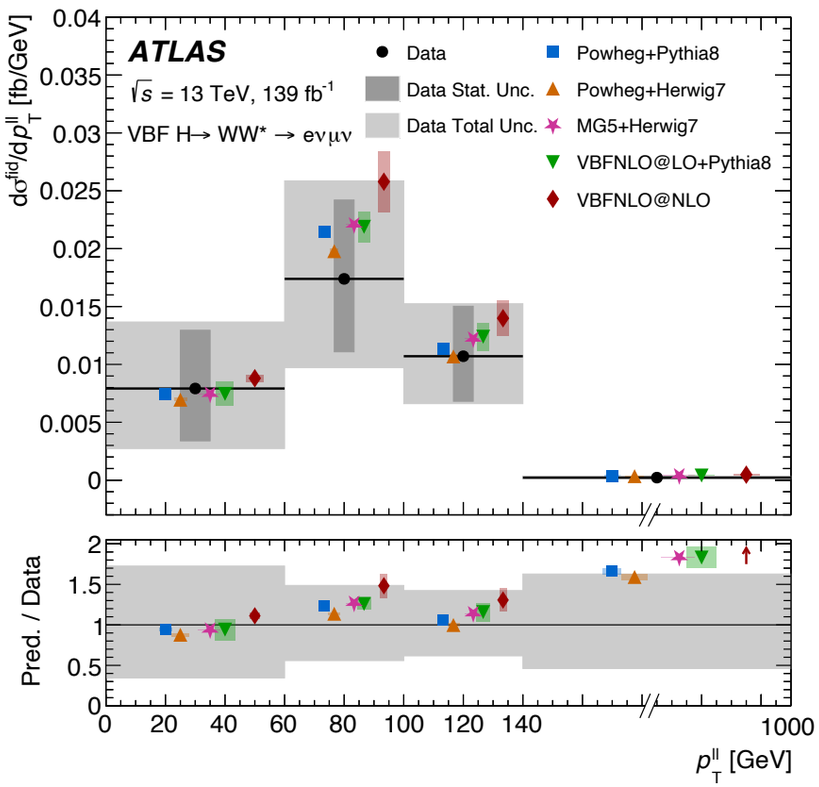
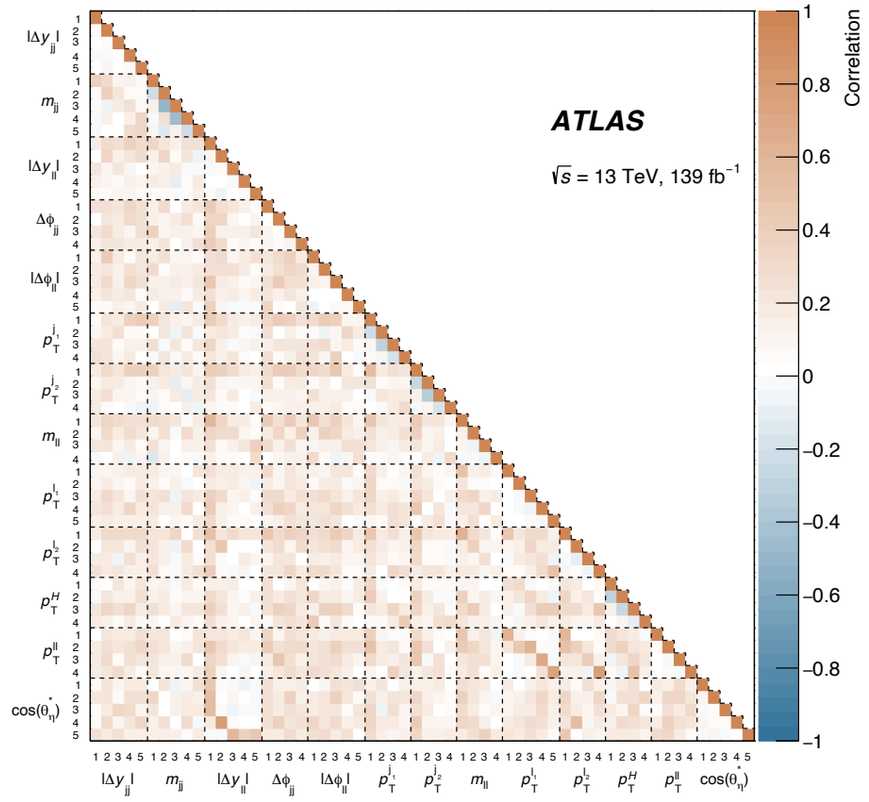
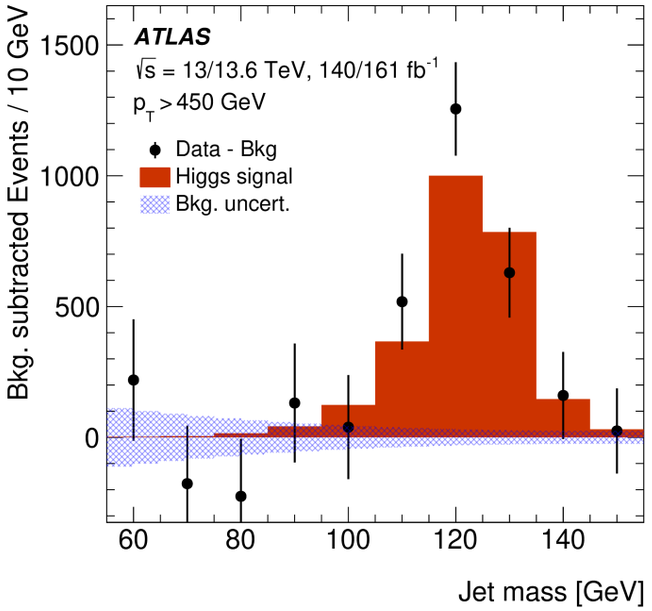


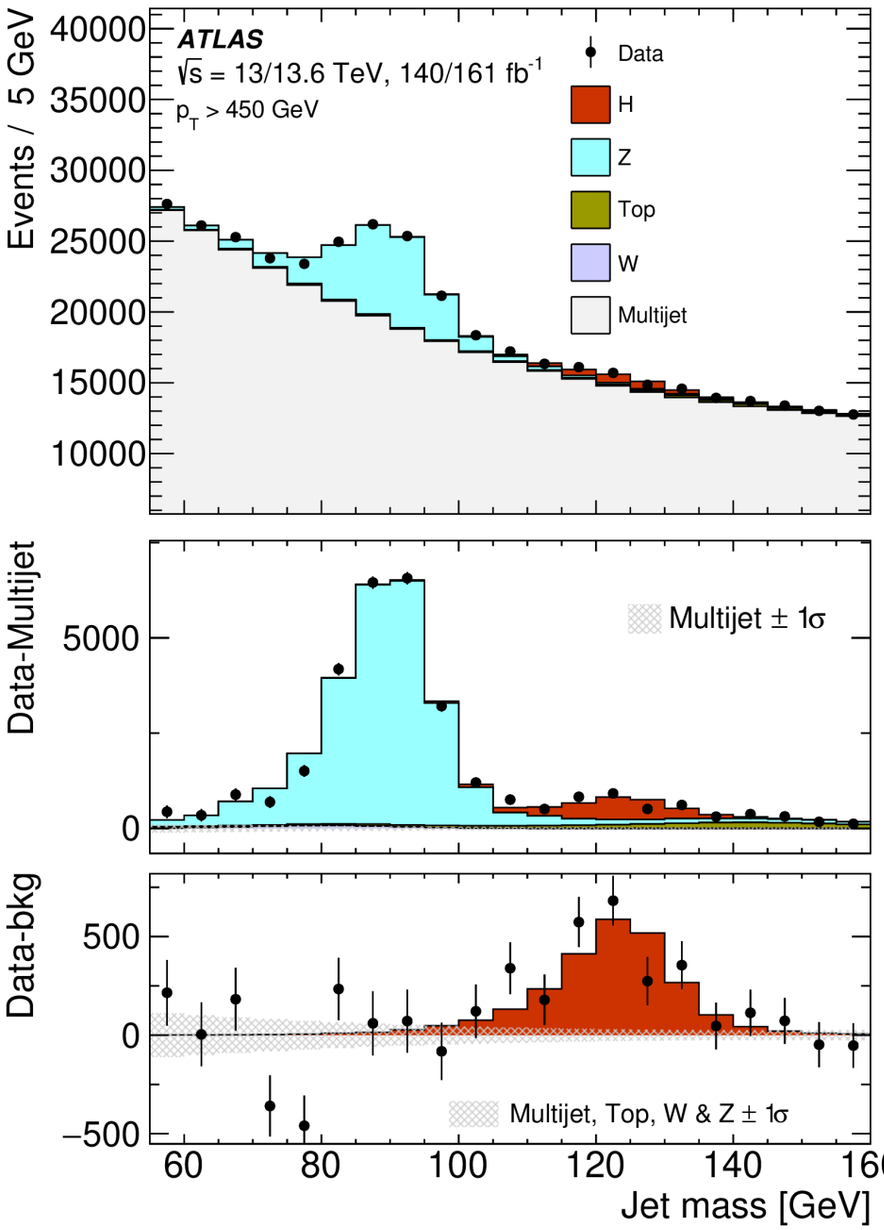




Differential measurements

- Exploring high-energy dynamics differentially
  - Boosted bb with Run-2 and Run-3 data, exploring the high $p_{\mathrm{T}}^{\mathrm{H}}$ region
  - Merged jet reconstruction tagging with improved taggers (GN2X)
  - Mass regression with a *new* algorithm (bJR)



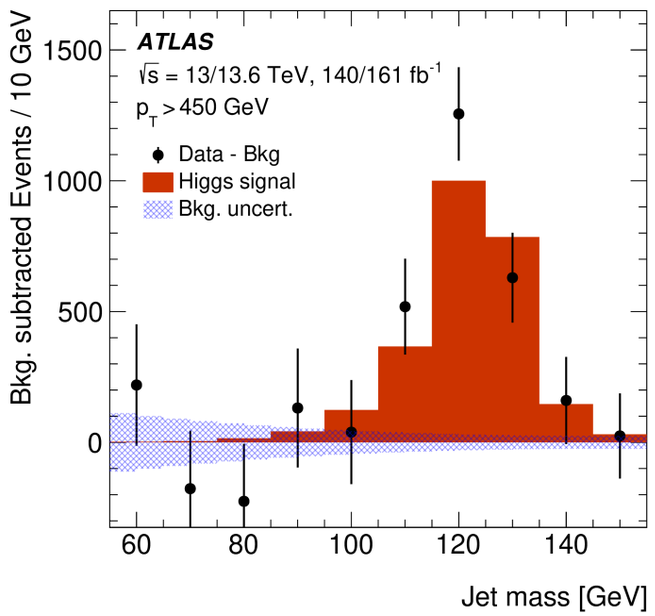


New

CERN-EP-2026-082

Differential measurements

- Exploring high-energy dynamics differentially
  - Boosted bb with Run-2 and Run-3 data, exploring the high $p_{\mathrm{T}}^{\mathrm{H}}$ region
  - Evidence with $3.8\ \sigma$ for $p_{\mathrm{T}}^{\mathrm{H}} > 450$ GeV,
  - with μ of $1.53 \pm 0.27\ (\mathrm{stat.})\ ^{+0.33}_{-0.27}\ (\mathrm{syst.})\ \pm 0.17\ (\mathrm{theo.})$
  - Improvement of a factor of 10 with respect to previous Run-2 result



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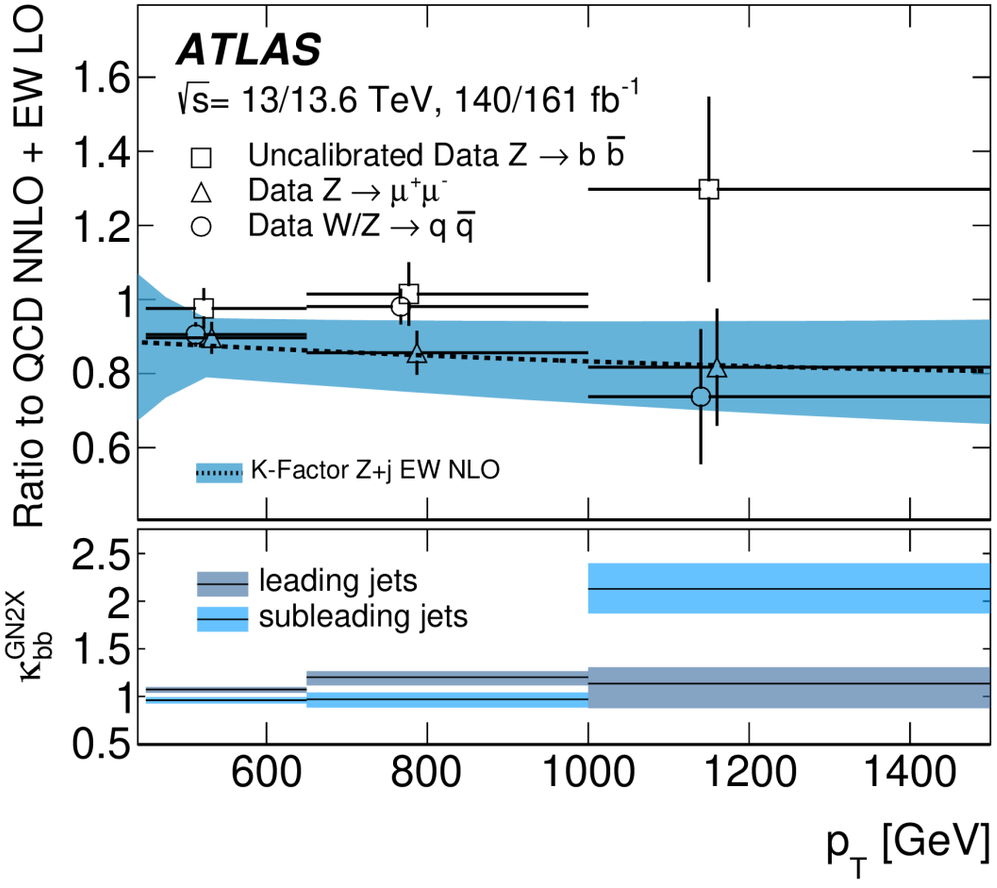
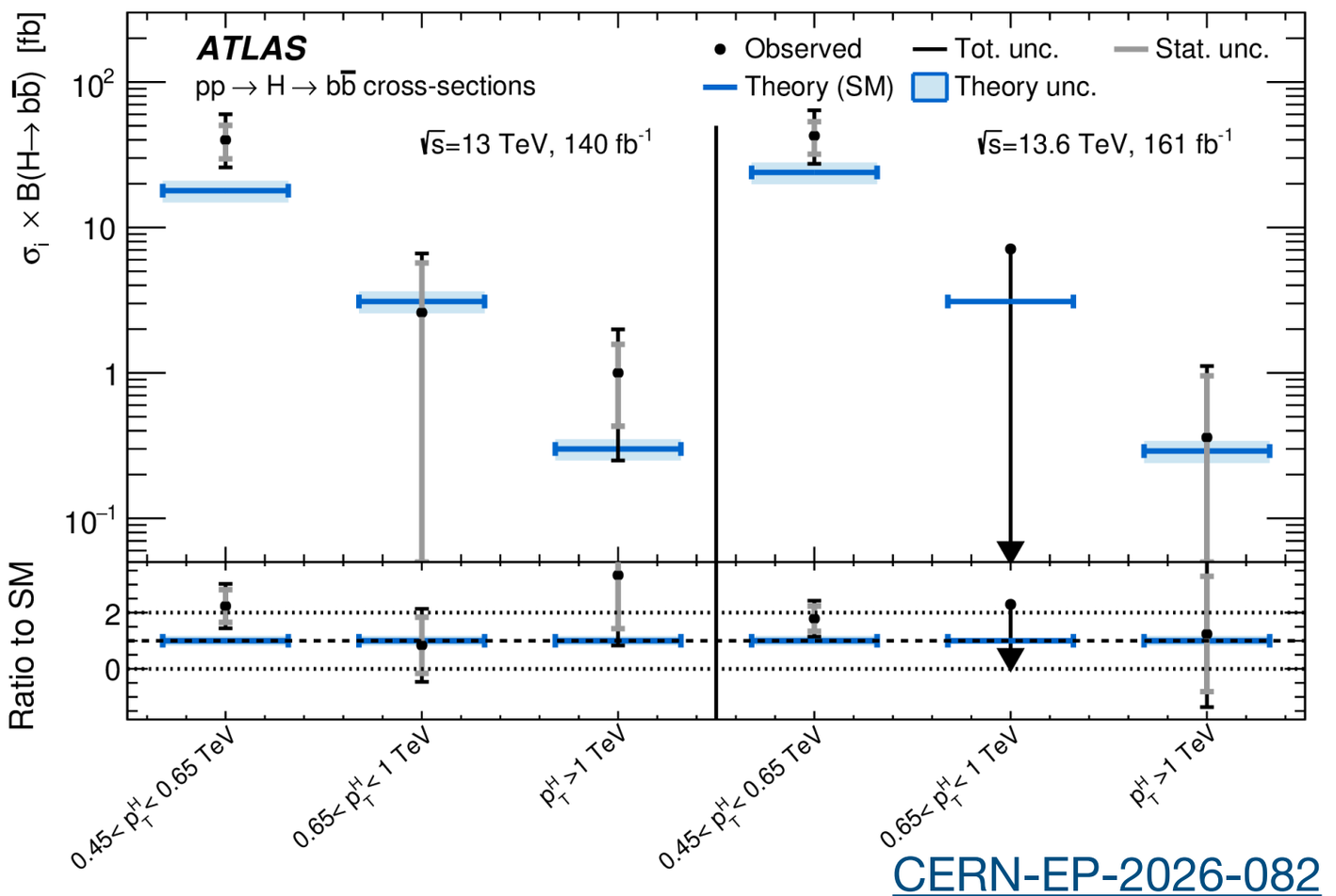
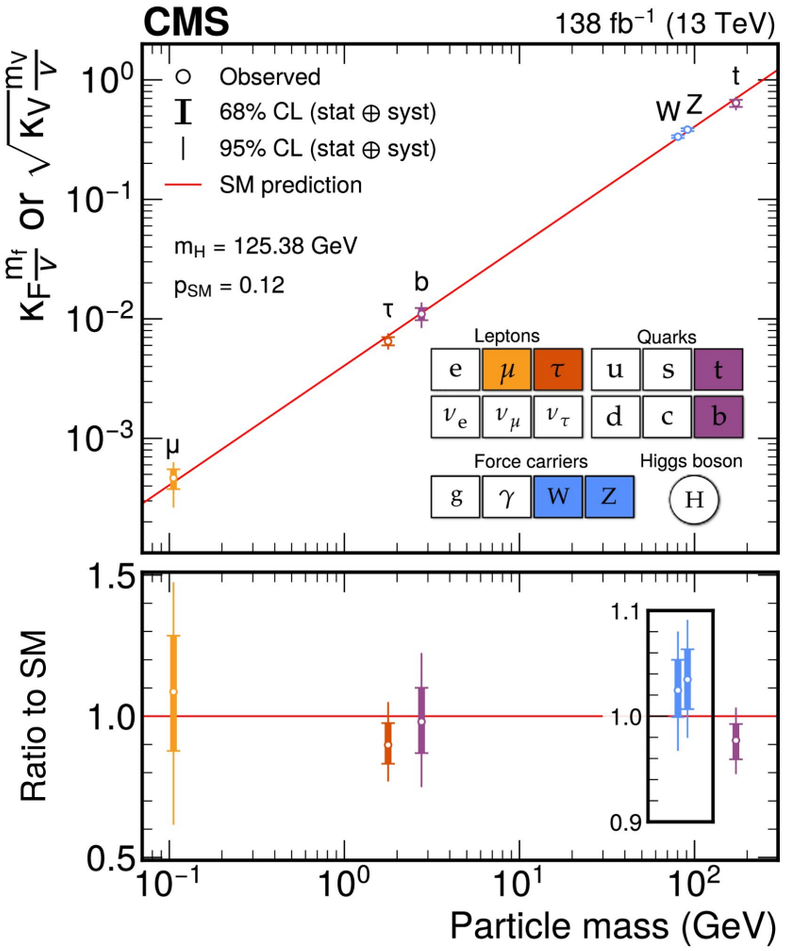




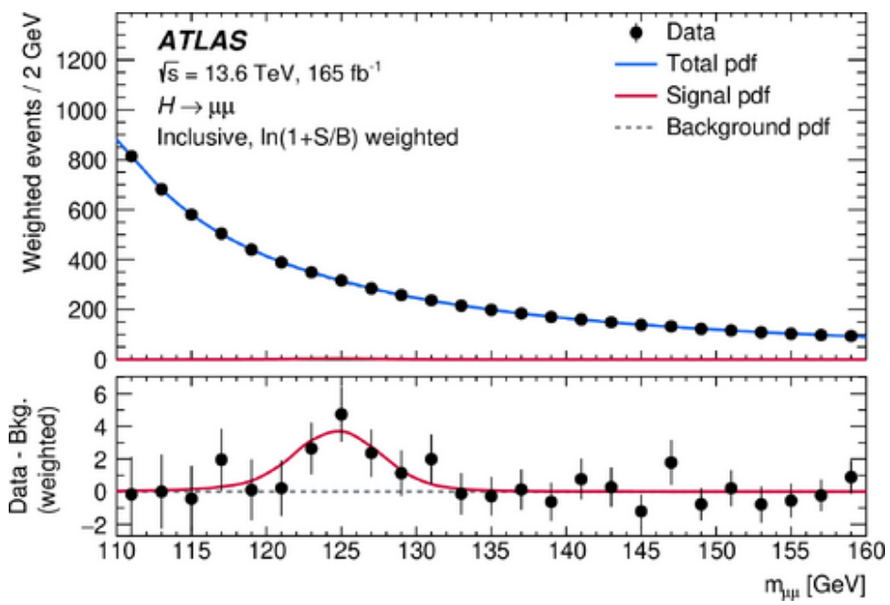
CERN-EP-2026-082

Conclusions

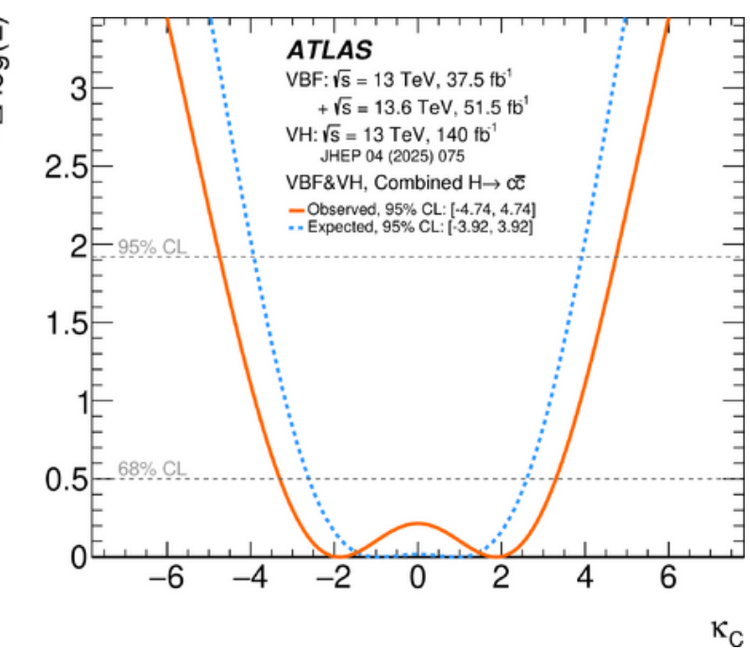
- Couplings, properties, and spectral extractions are the core of the LHC Higgs program
  - Run-1 discovery, first properties measurements
  - (Run+1) Run-2 first precision measurements (m_{H}), differential measurements, precision inclusive couplings
  - (Run-2)+Run-3 ATLAS & CMS explore complex final states (double differential, multiple jet topologies), and channels with lower s/b for both BSM probes, and they challenge the most-precise (N3LO) SM precision models.
  - Presented only a selection of the most recent results showing the evolution of our understanding of Higgs couplings.



Phys. Rev. Lett. 135 (2025) 231802



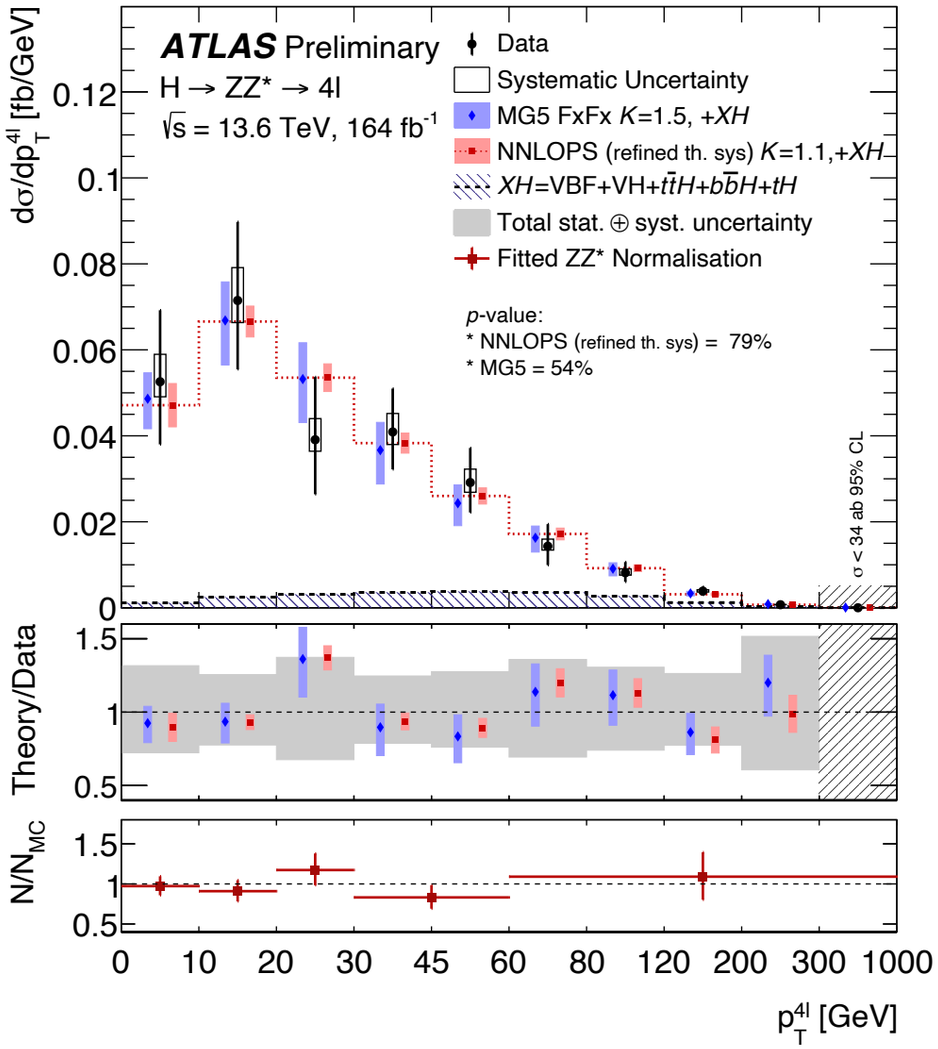
arXiv:2511.21911



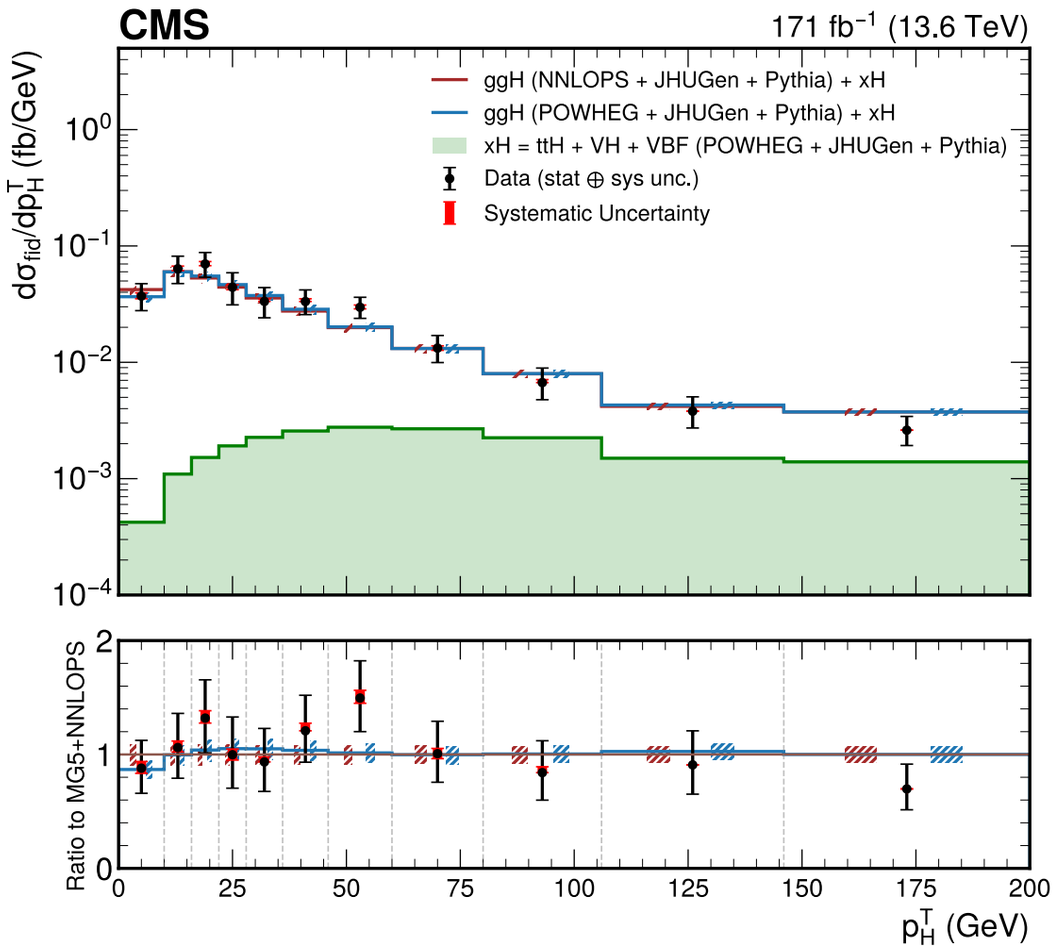
Differential measurements

- In parallel, analysis of Run-3 datasets at 13.6 TeV is progressing from both experiments
  - Evolving detector performance due to aging and pile-up conditions imposes new reconstruction and calibration methods for standard candle analyses.
  - Maturity of measurements reflected in double-differential measurements, EFT-interpretations,

New **See. Lailin Xu's Talk**



See. Martina Mannoni's Talk **New**

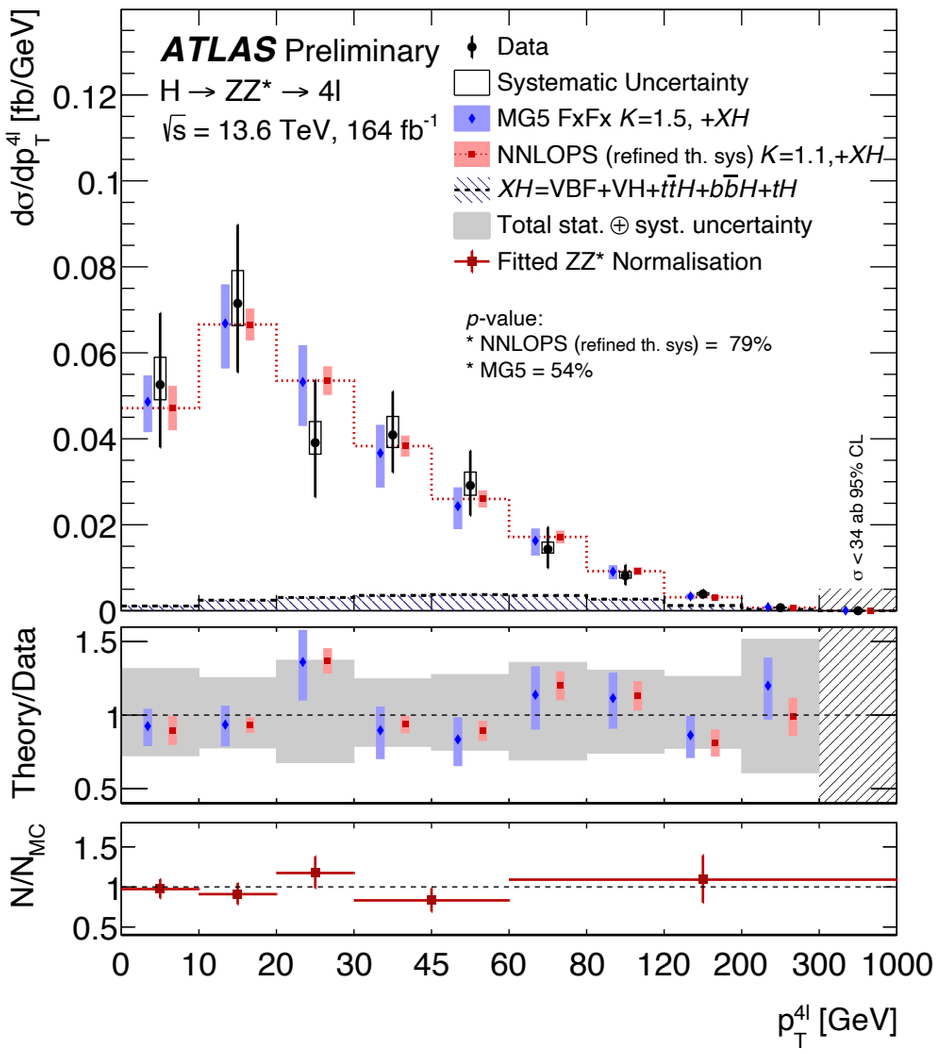


Additional material

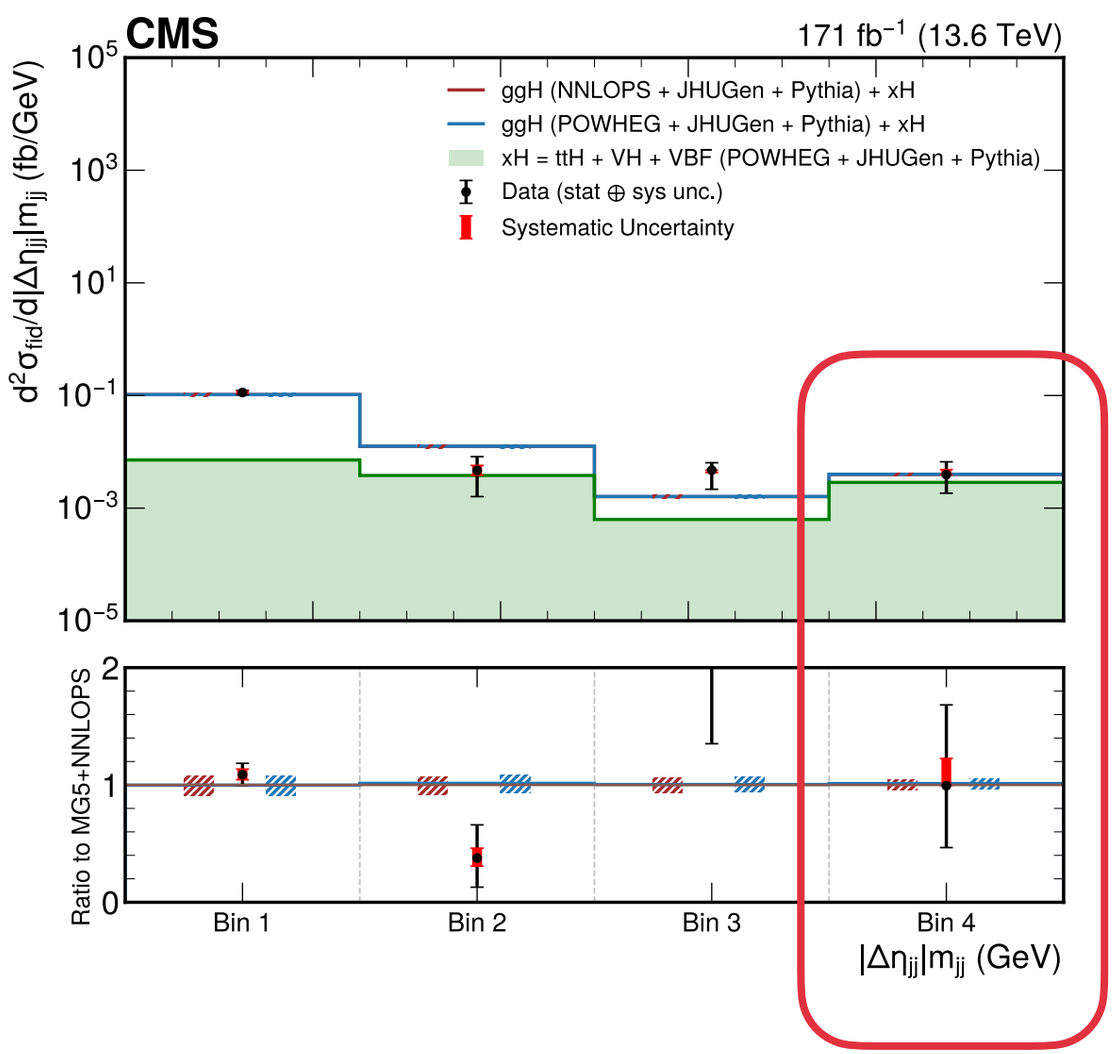
Differential measurements

- In parallel, analysis of Run-3 datasets at 13.6 TeV is progressing from both experiments
  - Evolving detector performance due to aging and pile-up conditions imposes new reconstruction and calibration methods for standard candle analyses.
  - Maturity of measurements reflected in double-differential measurements, EFT-interpretations,
  - VBF-dedicated model-independent measurements with 4ℓ

New **See. Lailin Xu's Talk**



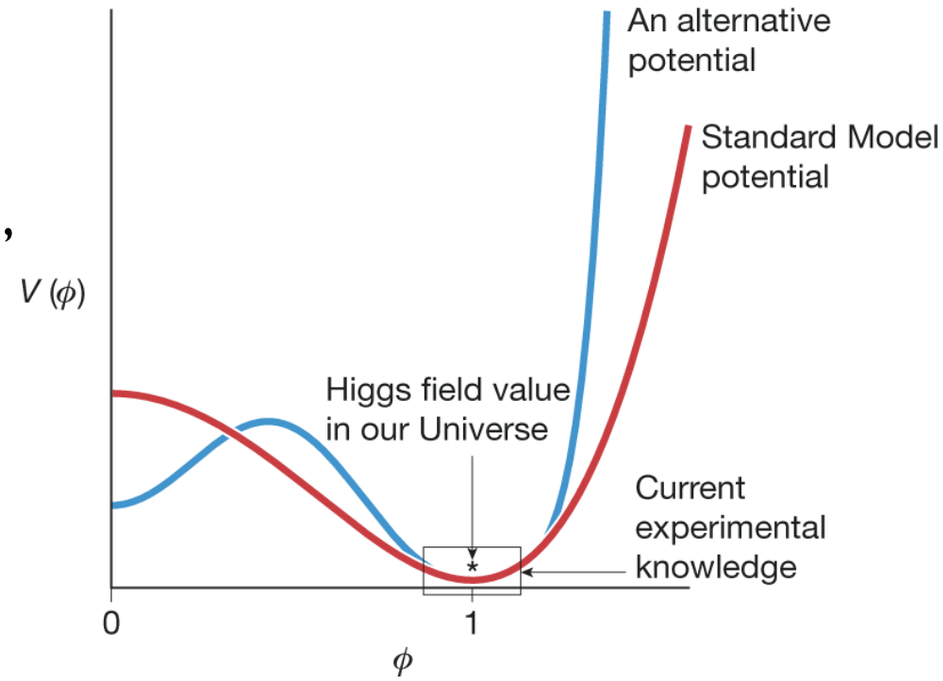
See. Martina Mannoni's Talk **New**



Introduction

- The study of H boson properties, including those involving two or three H bosons, is a top priority for the (HL-)LHC physics program

- Understanding the H boson's couplings, including the self-interaction, and the Yukawa sector is crucial
  - for probing the shape of the Higgs potential, linked to the EW phase transition
  - for the program of search for indirect and direct BSM physics



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

Couplings

- Simplified Template Cross Section Framework standard candle for characterising Higgs couplings at production
  - For the run we agreed on Stage 1.2, and further splitting (Stage 1.3) for CP sensitivity for Run-3