Higgs Hunting 2026

Results and prospects in the electroweak symmetry breaking sector

Higgs property measurements with ATLAS

Higgs Hunting 2026, Orsay/Paris, France

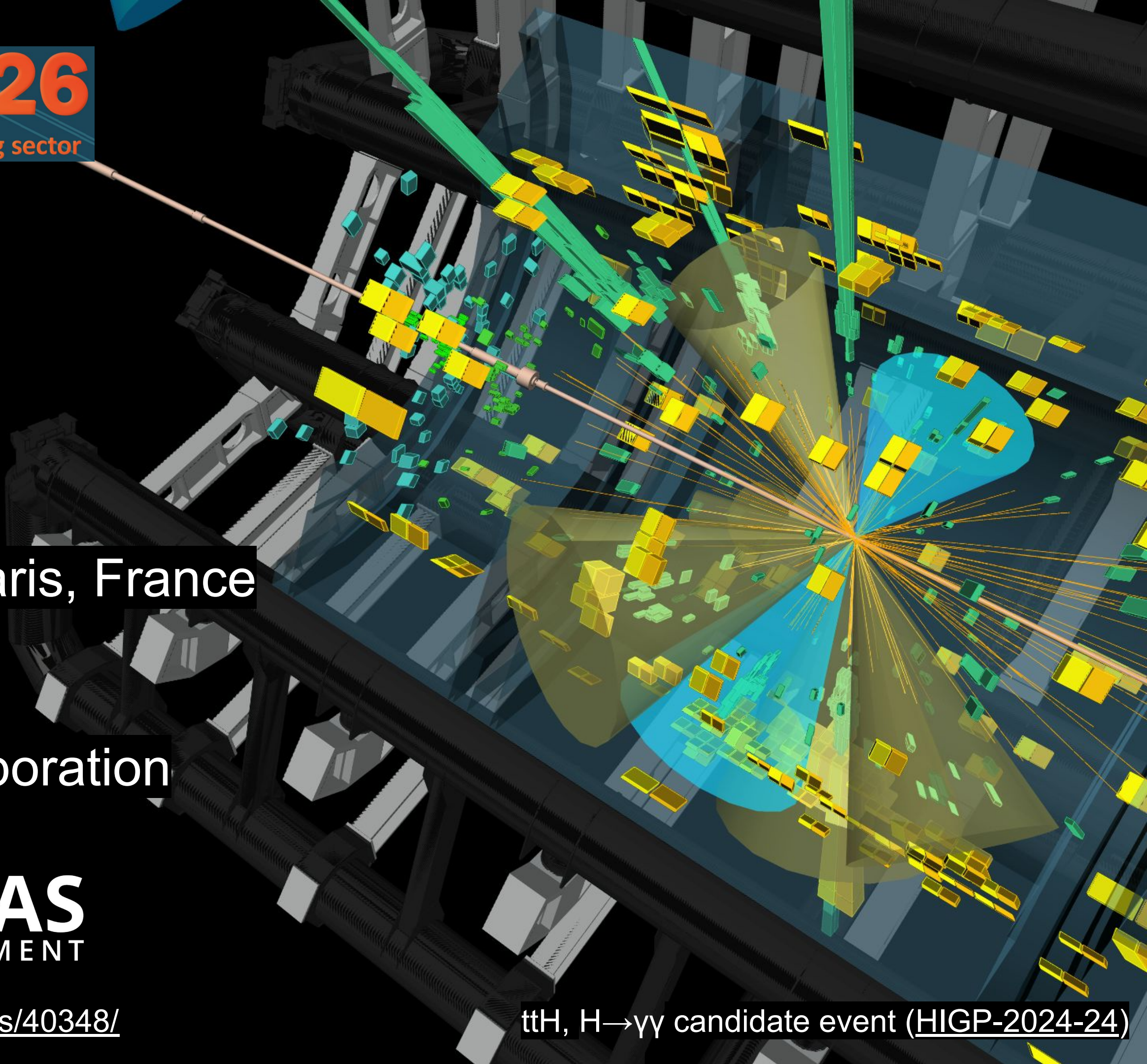
September 16, 2026

Matthew Basso (TRIUMF),

On behalf of the ATLAS Collaboration

TRIUMF ATLAS EXPERIMENT

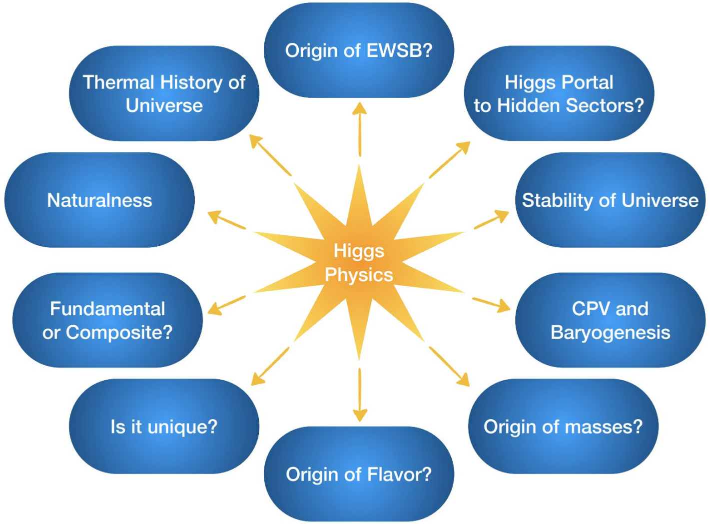
https://indico.ijclab.in2p3.fr/event/12648/contributions/40348/



ttH, H→γγ candidate event (HIGP-2024-24)

Introduction

- **Standard Model (SM)** has been **extremely successful** at describing experimental observations from the past 50 years
  - Last missing piece: **Higgs boson**
- Precision measurements serve as “stress tests” of the SM → reveal subtle differences between our predictions and measurements as well as provide new input to our models
- **I’ll present an overview of recent Higgs boson property measurements by ATLAS**



arXiv:2209.07510

All about Higgs properties

Higgs properties

Rare signatures (e.g. rare decays or boosted signatures) → sensitive to new physics

Fundamental properties: mass, natural width, spin, CP symmetry, …

Cross-sections: total, Simplified Template Cross-Sections (STXS), fiducial → flagship results

Vector and fermion couplings (e.g. top quark Yukawa) → study EW symmetry breaking

All about Higgs properties

I'll address all these topics ***except*** Higgs mass → see the Backup for the latest combination!

Rare signatures (e.g. rare decays or boosted signatures) → sensitive to new physics

Higgs properties

Fundamental properties: **mass**, natural width, spin, CP symmetry, …

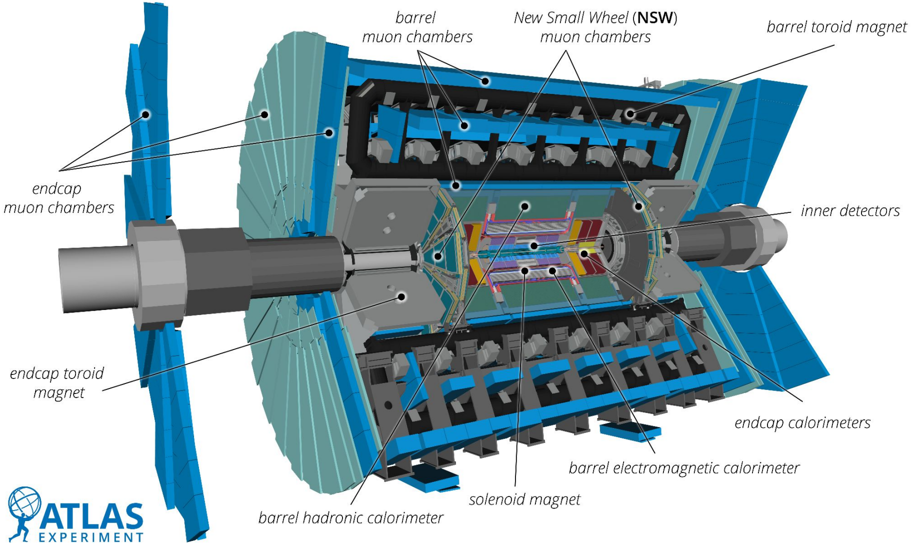
Cross-sections: total, Simplified Template Cross-Sections (STXS), fiducial → flagship results

Flow of talk

Vector and fermion couplings (e.g. top quark Yukawa) → study EW symmetry breaking

The ATLAS detector at the Large Hadron Collider

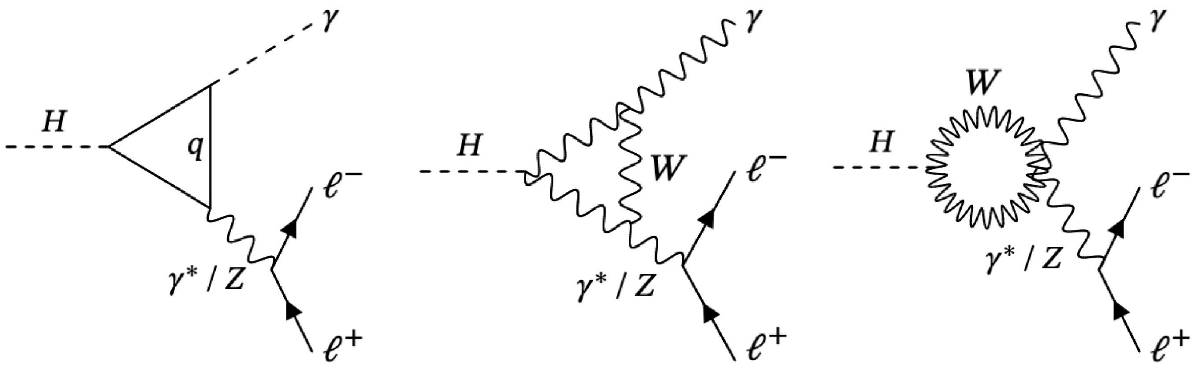
- General purpose particle detector, with subsystems including:
  - Inner detector for charged particle tracking in a 2 T field
  - Calorimeters for reconstructing electron/photons and jets
  - Muon spectrometer built around toroid magnet field
- Measurements presented today use the **full Run 2** (2015–18: 140 fb^{-1}) and/or the **partial Run 3** (2022–24: 164 fb^{-1}) datasets



ATLAS-PHOTO-2022-055

Low-mass dilepton systems: H→ℓℓγ

- Targeting H→γ*γ→ℓℓγ with dilepton invariant mass < 30 GeV
    - **Off-shell photon** sensitive to **new physics** and **three-body decay** sensitive to **CP structure**
- Events split into μμ and resolved/merged ee channels, using a boosted decision tree (BDT) to identify merged ee candidates, and further split by topology into **nine signal regions** (SRs)



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Low-mass dilepton systems: H→ℓℓγ

- Fit ℓℓγ invariant mass in each SR → combine with [Run 2 measurement] to yield an observed (expected) significance of **3.4 (3.3) σ!**

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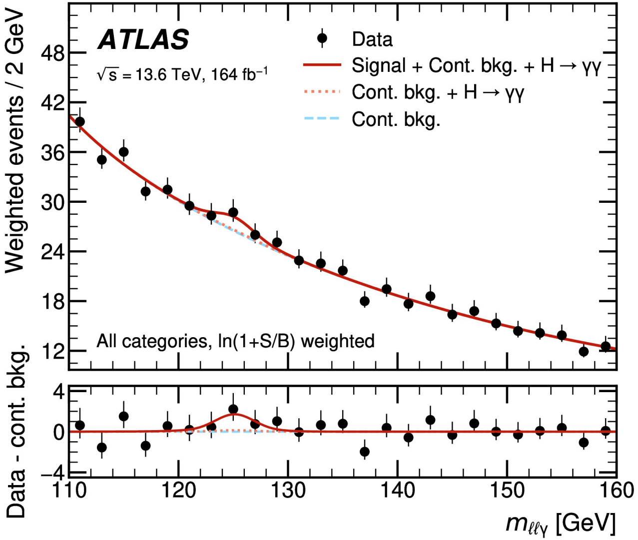

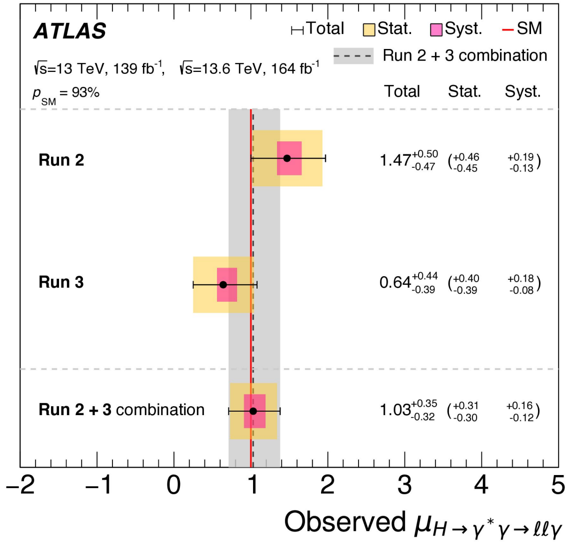

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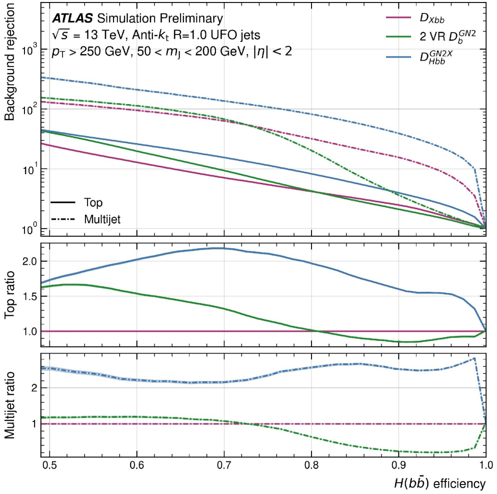
ATLAS EXPERIMENT

Boosted signatures: H→bb and H→ττ

- **Boosted signatures** → sensitive to **new physics** as a function of Higgs p_T
- H→bb: large-radius jets containing bb identified using transformer-based tagger (GN2X), with improved p_T/mass response using a different transformer
- H→ττ: di-tau candidates reconstructed from subjets within a large-radius jet, with additional identification using a transformer (“OMNI” tagger)



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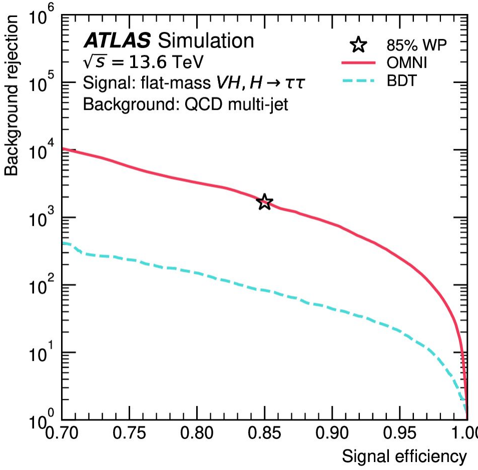

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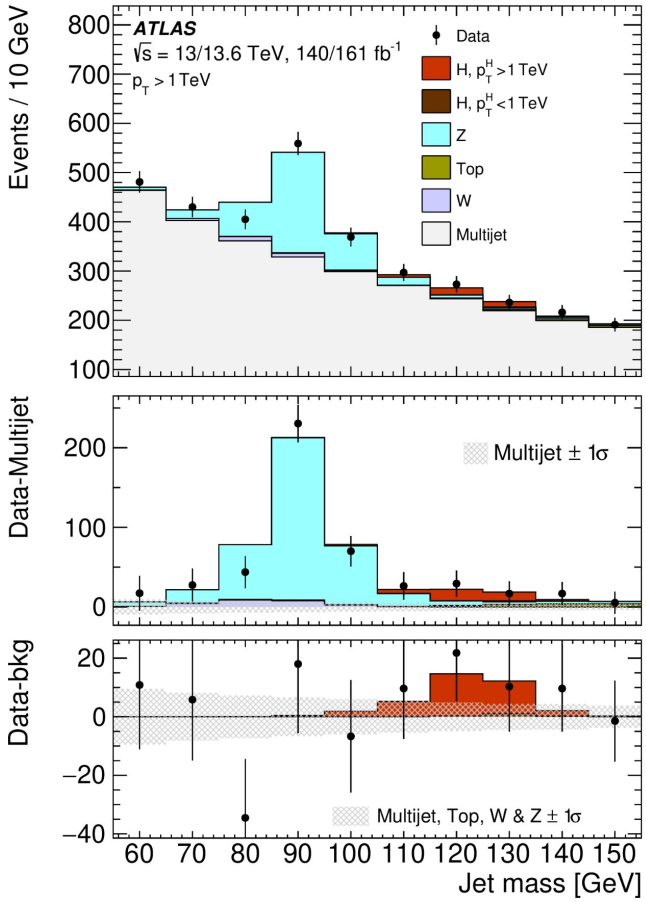
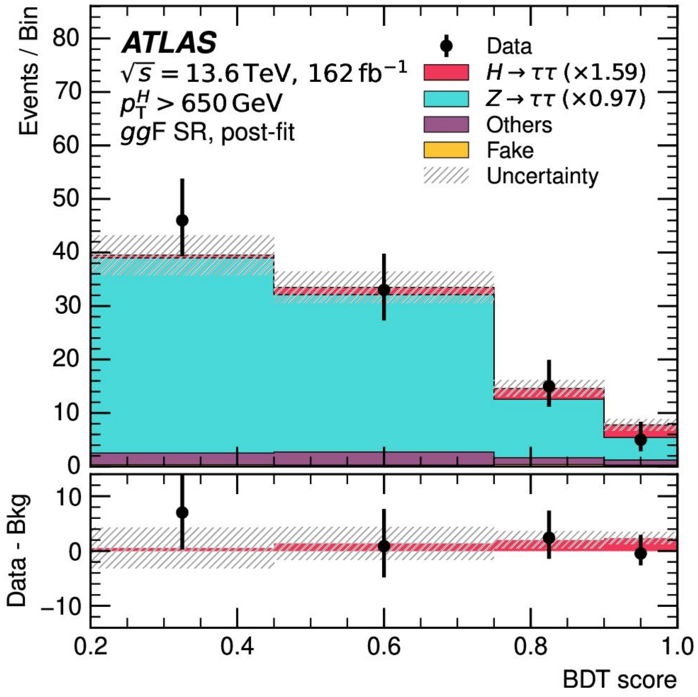
Boosted signatures: H→bb and H→ττ

PRL 137 (2026) 071801





HIGP-2024-49

Boosted signatures: H→bb and H→ττ

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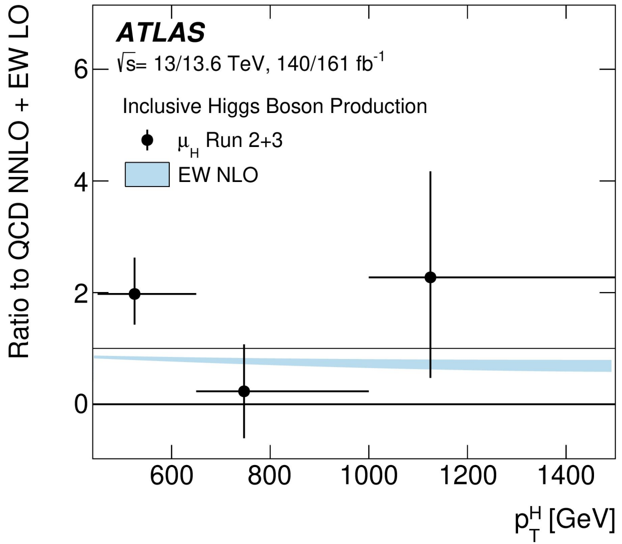
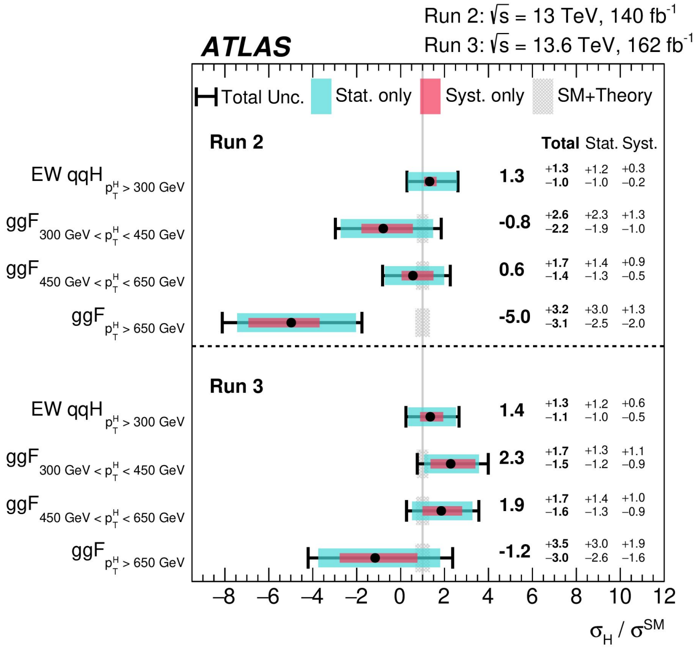


$$\mu_H = 1.53 \pm 0.27\,(\text{stat.})\,^{+0.33}_{-0.27}\,(\text{syst.}) \pm 0.17\,(\text{theo.})$$

Observed (expected) significance of **3.8 (2.5) σ** → **evidence** for Higgs boson production with Higgs p_T > 450 GeV (**7–10 × improvement** over Run 2!)



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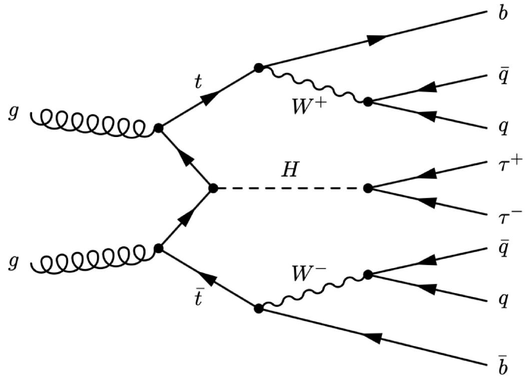
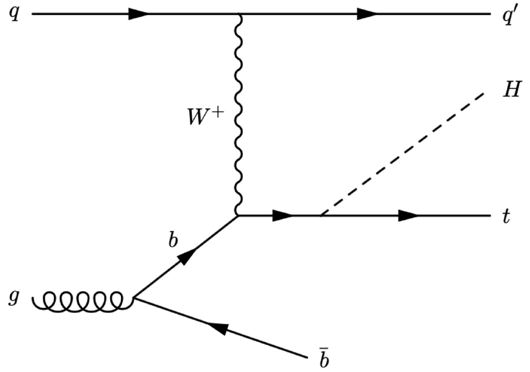
Observed (expected) significance of **3.8 (3.3) σ** → **also evidence,** for Higgs p_T > 300 GeV

Top couplings: ttH+tH, H→ττ/γγ

- **Strong coupling** of top quark to Higgs → top quark could play a **special role** in EW symmetry breaking
- ttH provides **direct access** to **top Yukawa coupling** and the **Higgs' CP structure**
- H→ττ: two reconstructed taus and hadronically decaying top quarks
- H→γγ: two reconstructed photons and hadronic/semileptonic top quarks
- Both: at least one b-tagged jet (GN2)

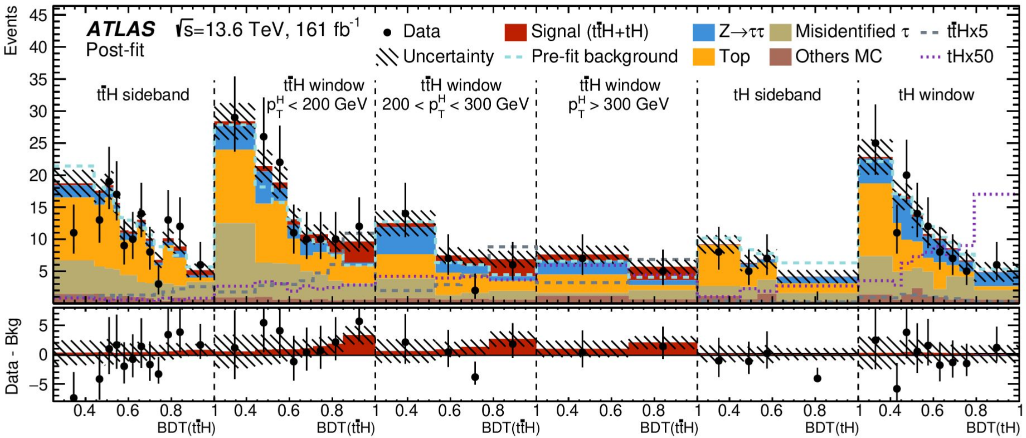




HIGP-2024-52

Top couplings: ttH+tH, H→ττ/γγ

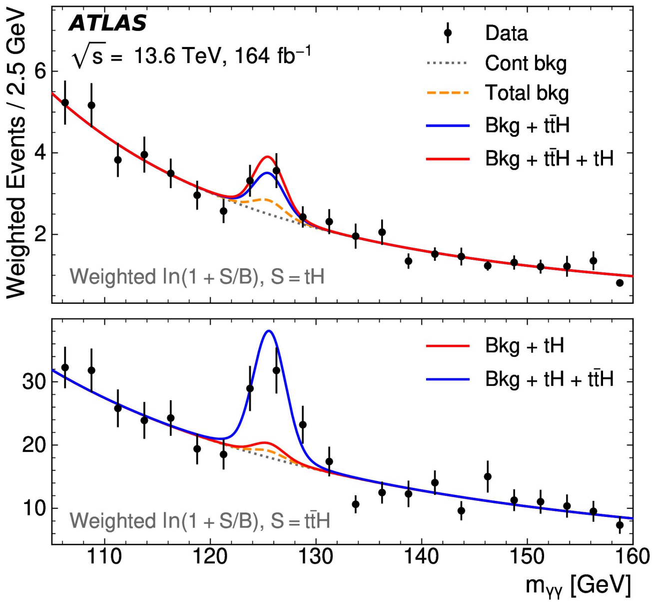
[HIGP-2024-52]



BDT separating signal processes from each other and background → BDTs subsequently fitted

(More details in [Morvan's talk] this afternoon!)

[HIGP-2024-24]

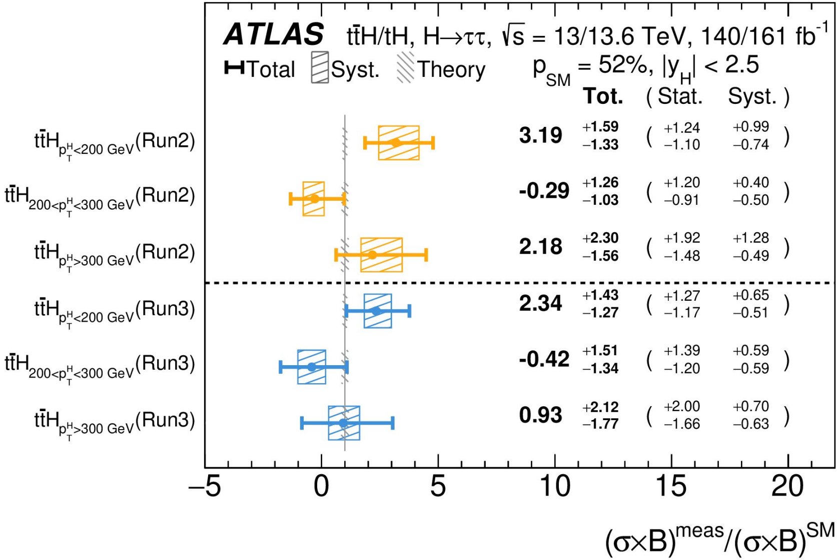


Graph neural networks (GNNs) separate ttH/tH from other Higgs production and non-resonant background → diphoton mass fitted among 32 categories, with further splitting by CP-even/odd-ness using a different GNN

Top couplings: ttH+tH, H→ττ/γγ

30% improvement in tH sensitivity compared to Run 2!

HIGP-2024-52



Results in the **STXS framework**

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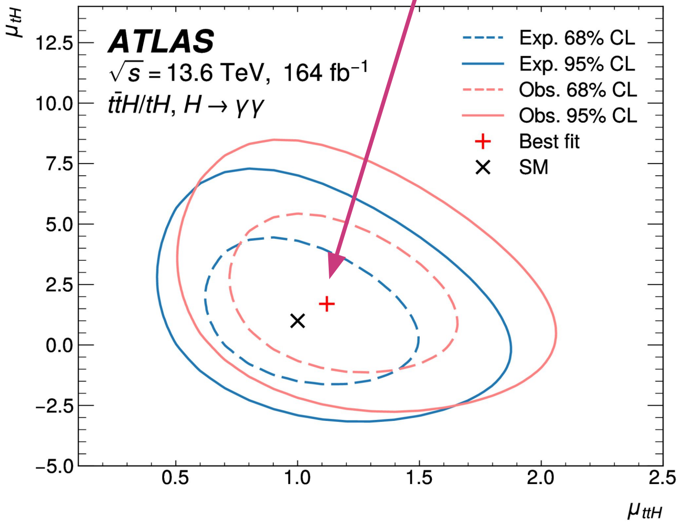
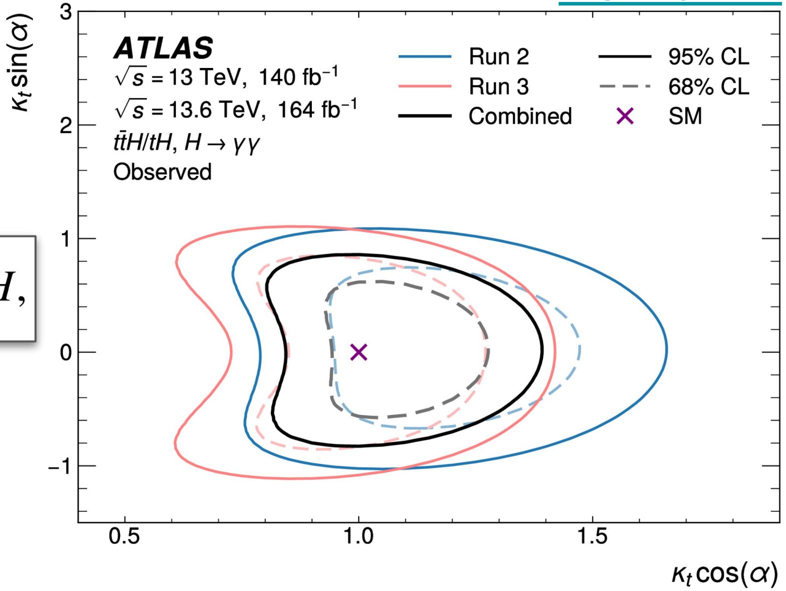


Observed (expected) significances of **5.0 (4.7) σ for ttH (observation!)** and **0.87 (0.54) σ for tH**

Limits on CP mixing angle from ttH+tH, H→γγ

HIGP-2024-24

$$\mathcal{L} = -\frac{m_t}{v}\left\{\bar{\psi}_t \kappa_t \boxed{[\cos(\alpha) + i\sin(\alpha)\gamma_5]}\psi_t\right\} H,$$



Run 2+3: exclude **CP mixing angle |α| > 38°** at 95% confidence level (CL) → **strongest constraint** on CP violation in Higgs-top interaction to date

Run 2+3 combined search for tH production

- tH production is uniquely sensitive to the **sign** of the top Yukawa coupling
- Exercised combination of tH searches from Run 2+3
- Observed (expected) 95% CL upper limit of **6.1 (2.7) × SM** and a significance of **2.3 (0.8) σ → most precise result** to date

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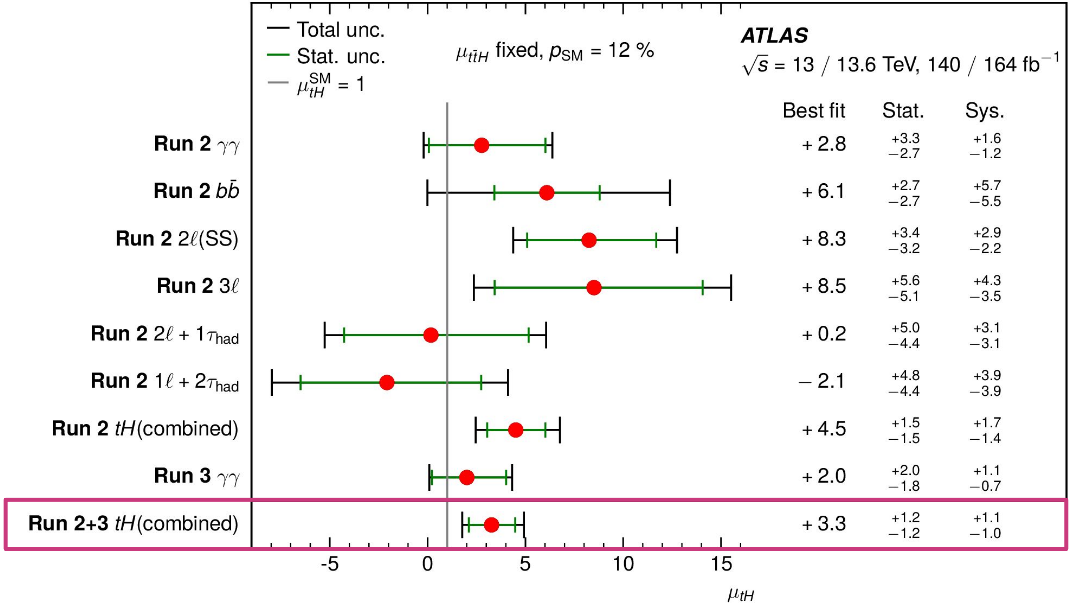
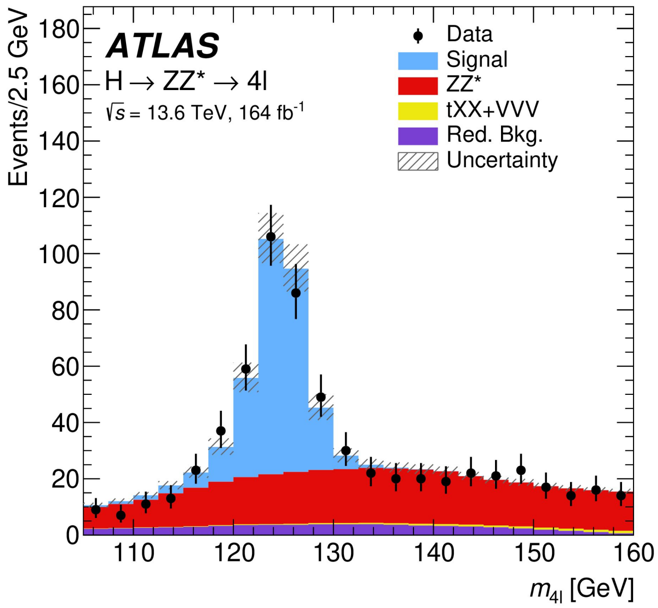


H→ZZ*→4ℓ: couplings and cross-sections

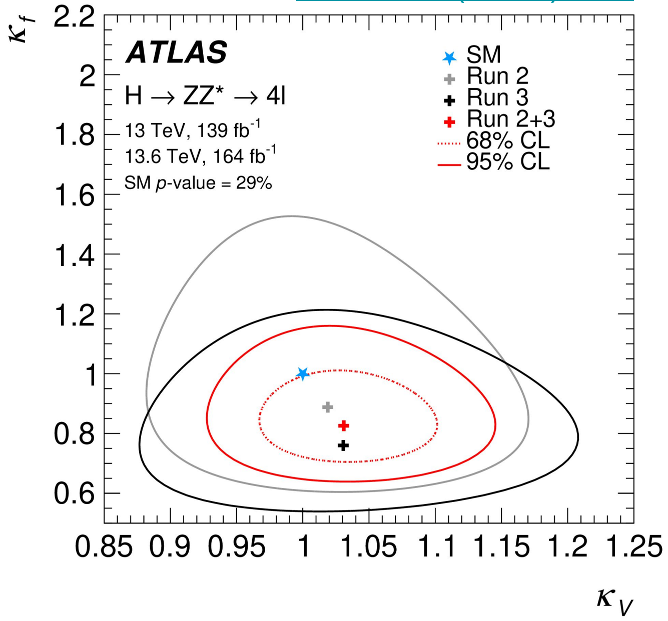
- Final state provides a clean signature, excellent signal-to-background, and full reconstruction of the final state
- Measured couplings (κ framework) and cross-sections (total, STXS, and fiducial)
  - STXS → profits from set transformers for event classification
  - See Elena's talk from earlier today on fiducial cross-sections results



JHEP 08 (2026) 052

H→ZZ*→4ℓ: couplings and cross-sections

JHEP 08 (2026) 052



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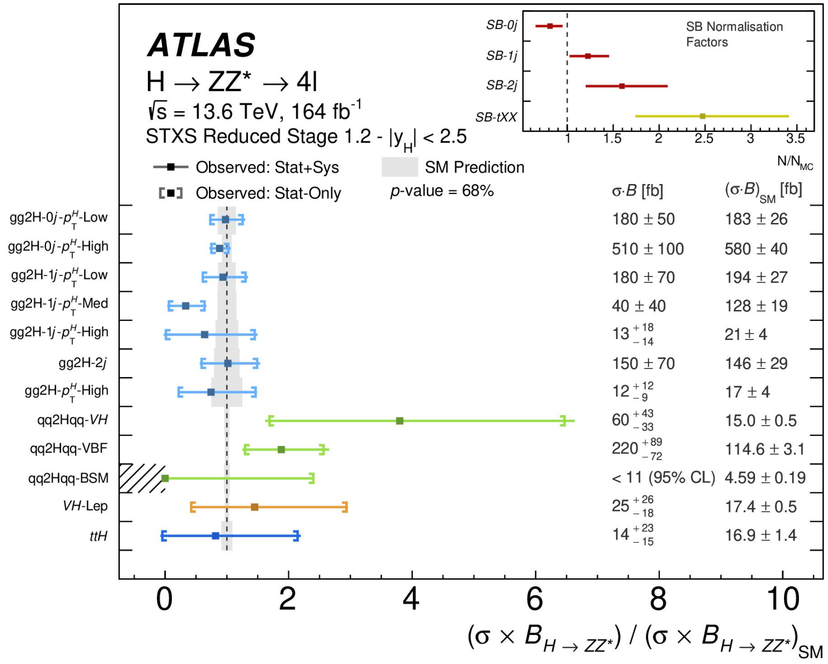
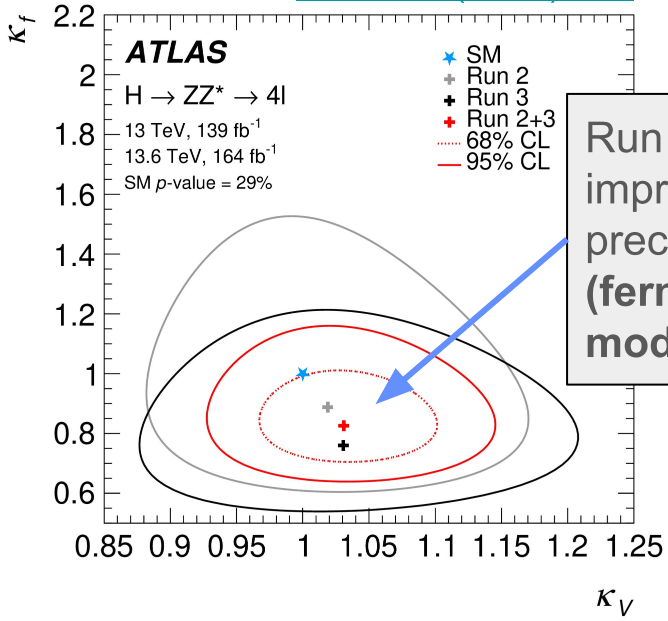


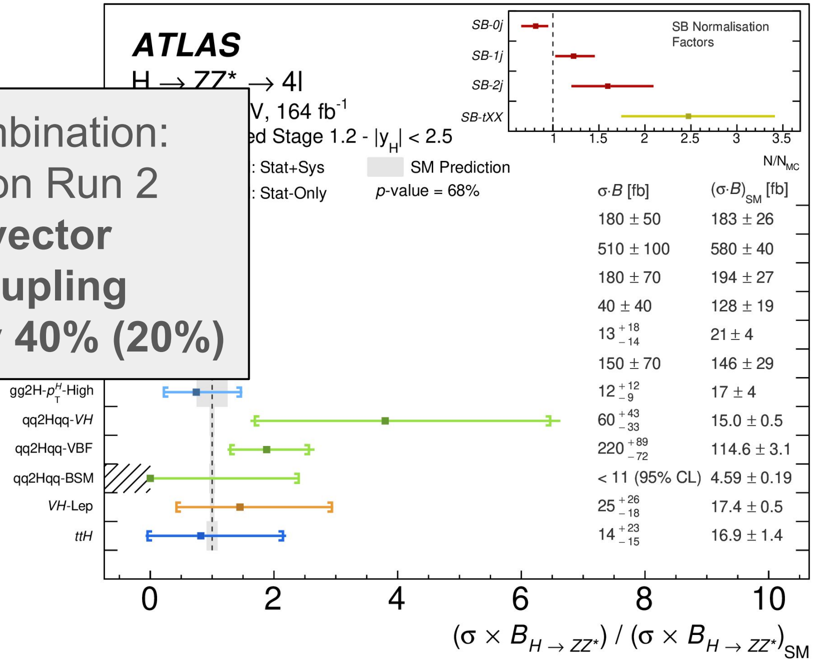
H→ZZ*→4ℓ: couplings and cross-sections

JHEP 08 (2026) 052



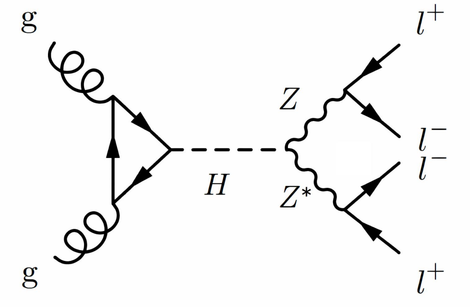
Run 2+3 combination: improves upon Run 2 precision of **vector (fermion) coupling modifiers** by **40% (20%)**

JHEP 08 (2026) 052



Z boson entanglement in H→ZZ*→4ℓ

- Recent and significant interest in studies of **quantum entanglement (QE)** at colliders
    - Already studied by ATLAS in top quark pairs
- Up next: **H→ZZ***
    - Spin-1 Z boson described by **three helicity states**: $|+\rangle$, $|-\rangle$, and $|0\rangle$
    - Higgs is spin-0, so **three possible ZZ spin states**: $|+-\rangle$, $|-+\rangle$, and $|00\rangle$
- Lepton angles in the rest frame of the decayed Z bosons serve as **spin analyzers** of the parent, which can be used to…



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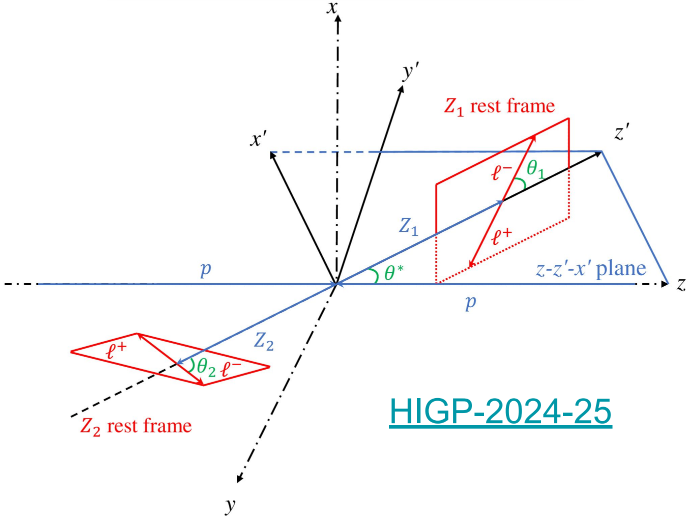
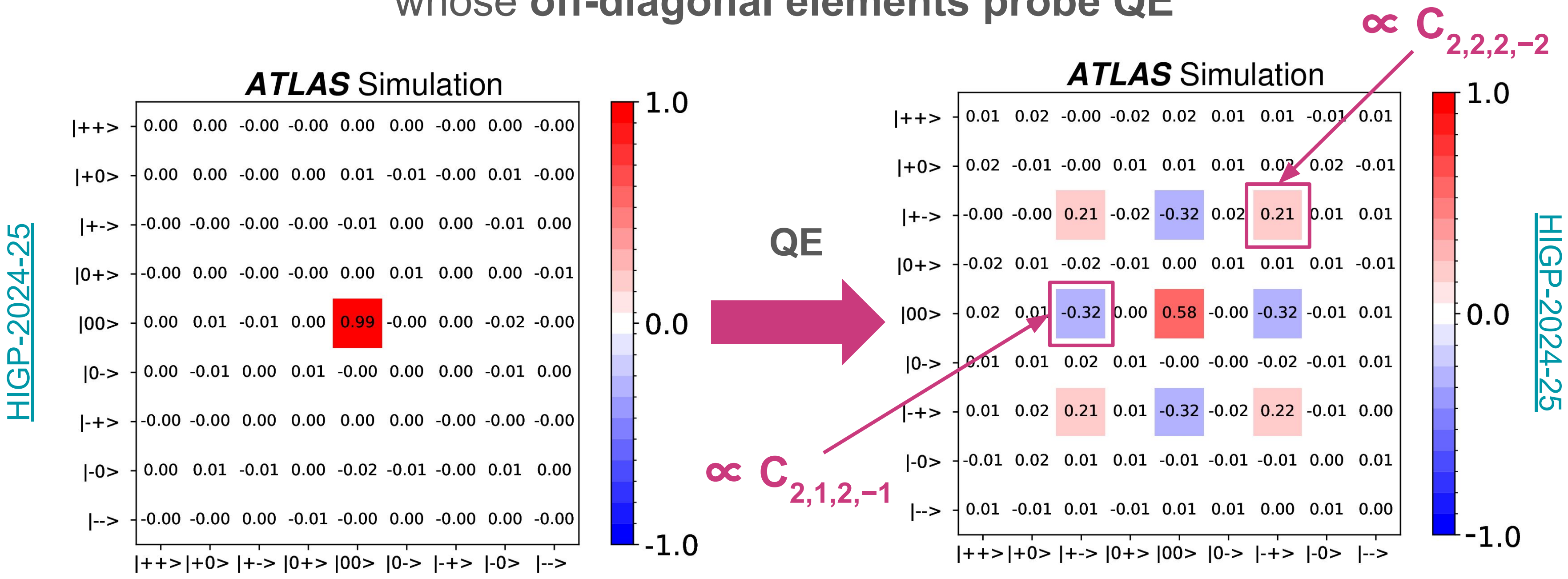


HIGP-2024-25

Z boson entanglement in H→ZZ*→4ℓ

…reconstruct the **spin density matrix**,
whose **off-diagonal elements probe QE**



Z boson entanglement in H→ZZ*→4ℓ

- ***Nonzero*** $C_{2,1,2,-1}$ or $C_{2,2,2,-2}$ → **marker of QE**
- Measured their mean values using Run 2+3 data:

$$\mathbf{C_{2,1,2,-1} = -0.71 \pm 0.45}\ (\text{SM: } -0.97)$$

$$\mathbf{C_{2,2,2,-2} = 0.08 \pm 0.44}\ (\text{SM: } 0.64)$$

- Uncertainties dominated by the availability of data

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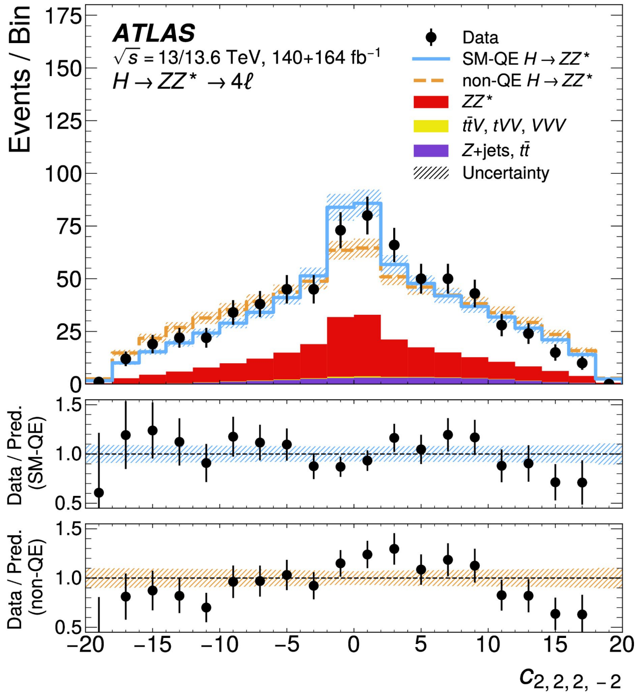

Z boson entanglement in H→ZZ*→4ℓ

- $C_{2,2,2,-2}$ distribution used to perform a **hypothesis test** of the QE vs. longitudinal-only polarized Z bosons hypotheses: observed (expected) significance of **4.7 (4.9) σ** over longitudinal-only hypothesis

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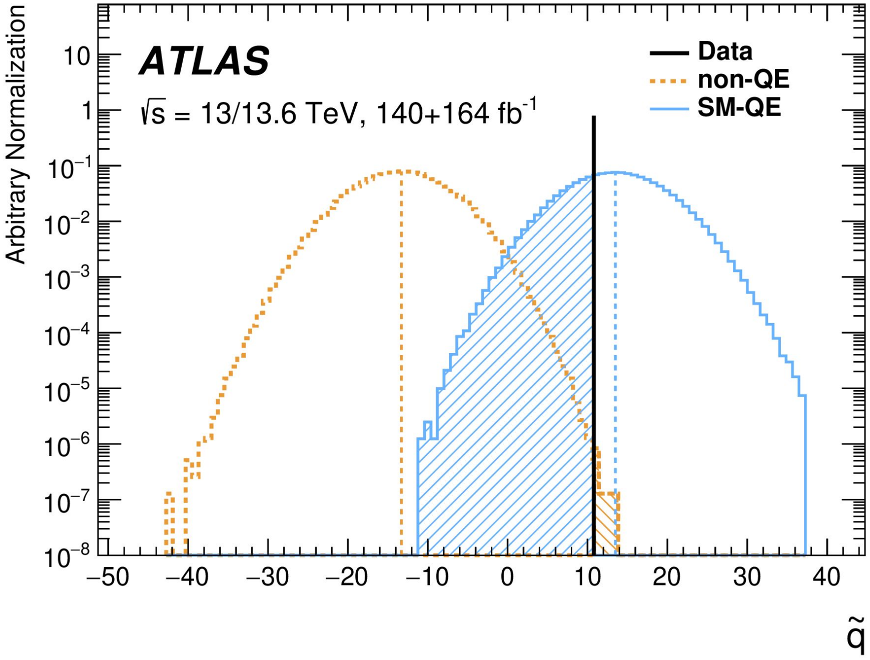

Combination of Higgs boson measurements

- Statistical combinations of Higgs boson measurements performed using the **"legacy"** Run 2 measurements as well as **new/expanded** measurements
  - Provide a holistic picture of Higgs boson production as measured by ATLAS
- Measured total cross sections (inclusively and split by production mode), couplings, differential information, …

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Analysis	Prod. modes	$\mathcal{L}$ [fb^{-1}]	Ref.	Comparison with Ref.	Measurements Incl.	κ	STXS
$H \to ZZ^* \to 4\ell$	All	140		Unchanged	✓	✓	✓
$H \to WW^* \to \ell\nu\ell\nu$	ggF, VBF	140		Updated	✓	✓	✓
$H \to WW^* \to \ell\nu\ell\nu, \ell\nu jj$	VH	140		Full Run 2	✓	✓	✓
$H \to \gamma\gamma$	All	140		Unchanged	✓	✓	✓
$H \to Z\gamma$	All	140		Unchanged	✓	✓	
$H \to \tau\tau$	All, except $(V \to \text{leptons})H$	140		Updated	✓	✓	✓
$H \to \tau\tau$	$(V \to \text{leptons})H$	140		New	✓	✓	
$H \to \mu\mu$	All	140		Unchanged	✓	✓	
$H \to bb$	VBF	126		Unchanged	✓	✓	✓
$H \to bb, cc$	$(V \to \text{leptons})H$	140		Updated	✓	✓	✓
$H \to bb$ (high p_T^H)	All	136		Unchanged			✓
$H \to$ multileptons	ttH	140		Full Run 2	✓	✓	✓
$H \to bb$	ttH	140		Updated	✓	✓	✓
$H \to bb$	tH	140		Updated	✓	✓	✓
$H \to$ invisible	VBF	140		Unchanged		✓	
$H \to$ invisible	VBF + γ	140		New		✓	
$H \to$ invisible	$(V \to \text{leptons})H$	140		Unchanged		✓	
$H \to$ invisible	ttH	140		New		✓	
$H^{(*)} \to ZZ^{(*)}$	ggF, VBF	140		Updated		✓	
$H^{(*)} \to WW^{(*)}$	ggF, VBF	140		New		✓	
$HH \to bbbb$	ggF, VBF	126		New		✓	
$HH \to bbbb$ (high p_T^H)	VBF	140		New		✓	
$HH \to bb\tau\tau$	ggF, VBF	140		New		✓	
$HH \to bb\gamma\gamma$	ggF, VBF	140		New		✓	
$HH \to bb\ell\ell + E_T^{\text{miss}}$	ggF, VBF	140		New		✓	
$HH \to$ multileptons	ggF, VBF	140		New		✓	

(More about HH in Shota's talk this afternoon!)

Higgs boson couplings vs. mass and natural width

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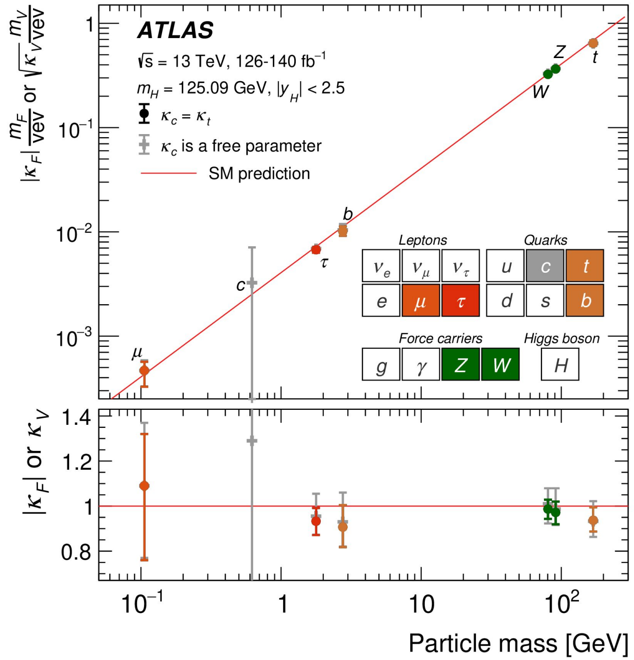

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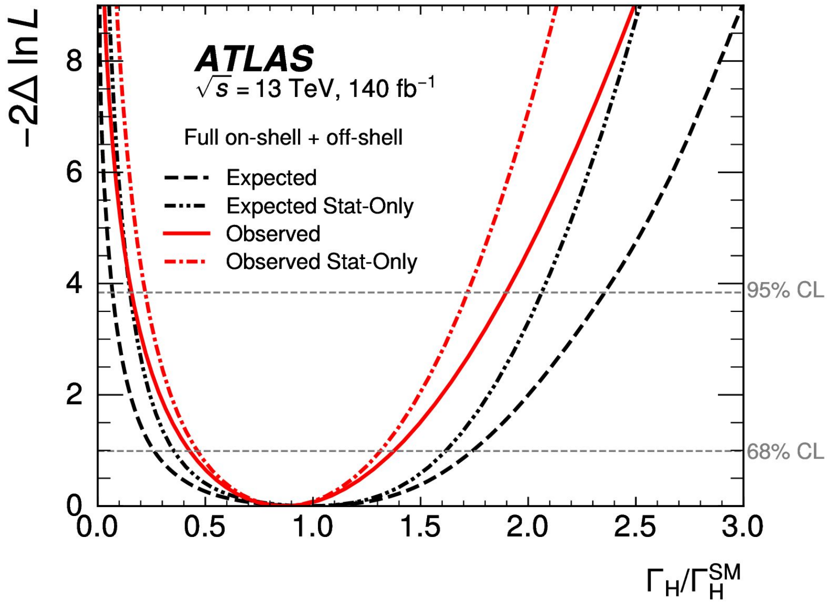
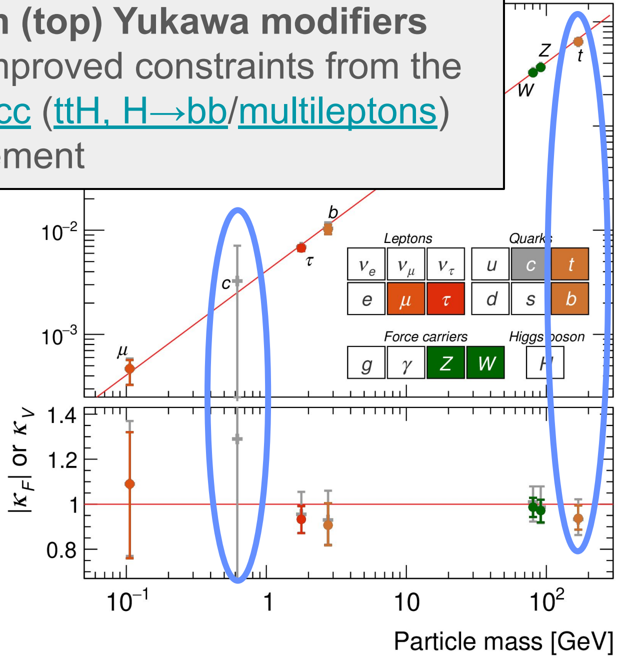


$$\Gamma_H = 3.6^{+2.1}_{-1.6}\ \mathrm{MeV} = 3.6^{+1.9}_{-1.4}\ (\mathrm{stat.})\ ^{+0.9}_{-0.8}\ (\mathrm{syst.})\mathrm{MeV}.$$

Higgs boson couplings vs. mass and natural width

50% (15%) improvement in precision of **charm (top) Yukawa modifiers** due to improved constraints from the VH, H→cc (ttH, H→bb/multileptons) measurement



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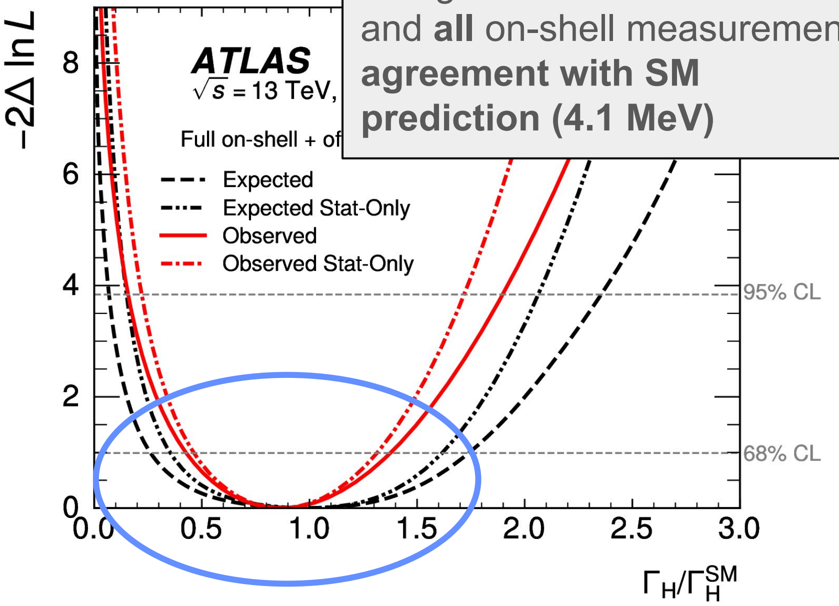
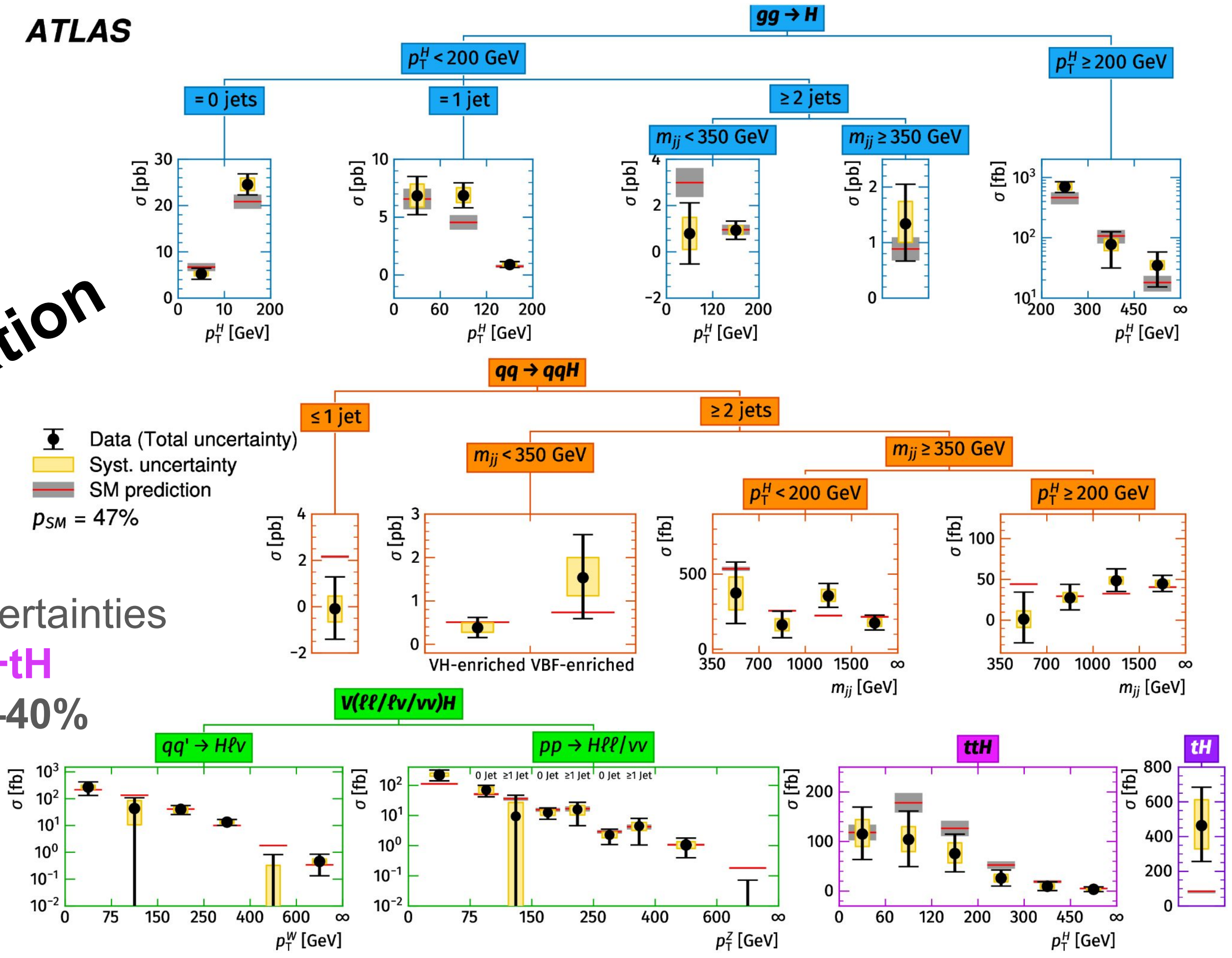
Using a combination of H*→VV and **all** on-shell measurements: **agreement with SM prediction (4.1 MeV)**



$$\Gamma_H = 3.6^{+2.1}_{-1.6}\ \text{MeV} = 3.6^{+1.9}_{-1.4}\ (\text{stat.})\ ^{+0.9}_{-0.8}\ (\text{syst.})\text{MeV}.$$

Full STXS combination



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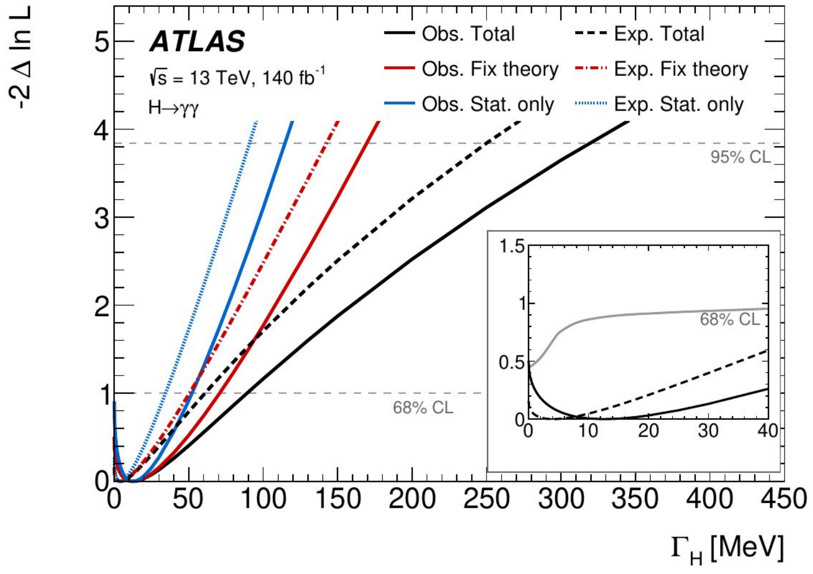
Inclusively, uncertainties on VH and ttH+tH reduced by **20–40%**

Hot off the presses! Natural width from H→γγ

- Natural width can also be extracted from signal-background interference effects on ***on-shell*** signal
    - Shift γγ invariant mass peak and modify its normalization (Backup)
    - More **model independent** than off-shell measurements
- Parameterize gg→γγ process in terms of width → report observed (expected) 95% CL upper limit of **307 (258) MeV**
    - Limited by **theory uncertainties** (e.g. interference NLO→NNLO k-factor of 1.64)

HIGP-2024-12



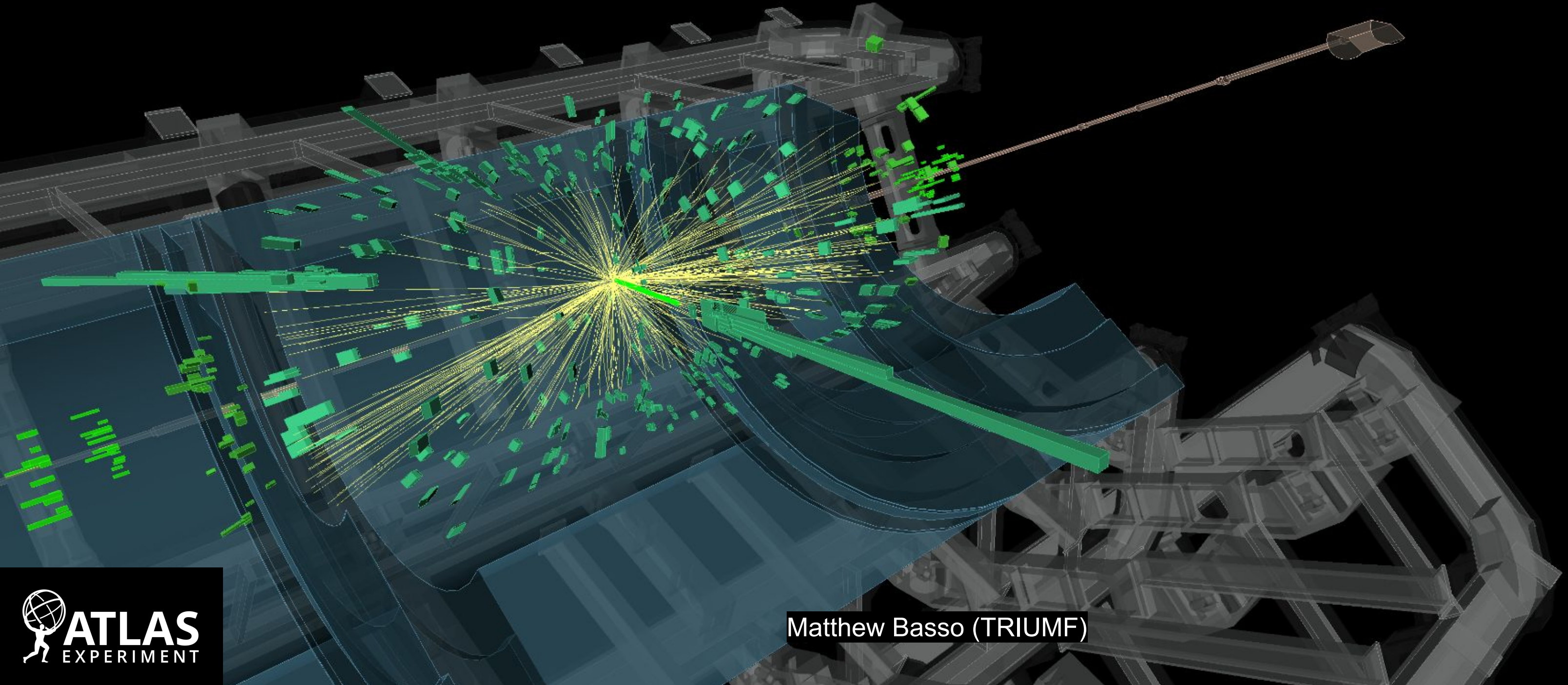
High-Luminosity LHC projection: expected 95% CL upper limit of **21 MeV**

Summary

- **Comprehensive program** of Higgs measurements pursued by ATLAS across all production modes and final states and with **spectacular precision**
  - In many cases: precision limited by the **availability of data** (especially when splitting measurements differentially)
  - **Advanced analysis techniques** (e.g. machine learning) have also led to improvements (e.g. in boosted $H \to bb$, $ttH(\to\gamma\gamma)$, …)
- **No deviations from the SM have been observed**
- Many of these measurements also consider **Effective Field Theory (EFT) interpretations** → covered in Michiel's talk tomorrow

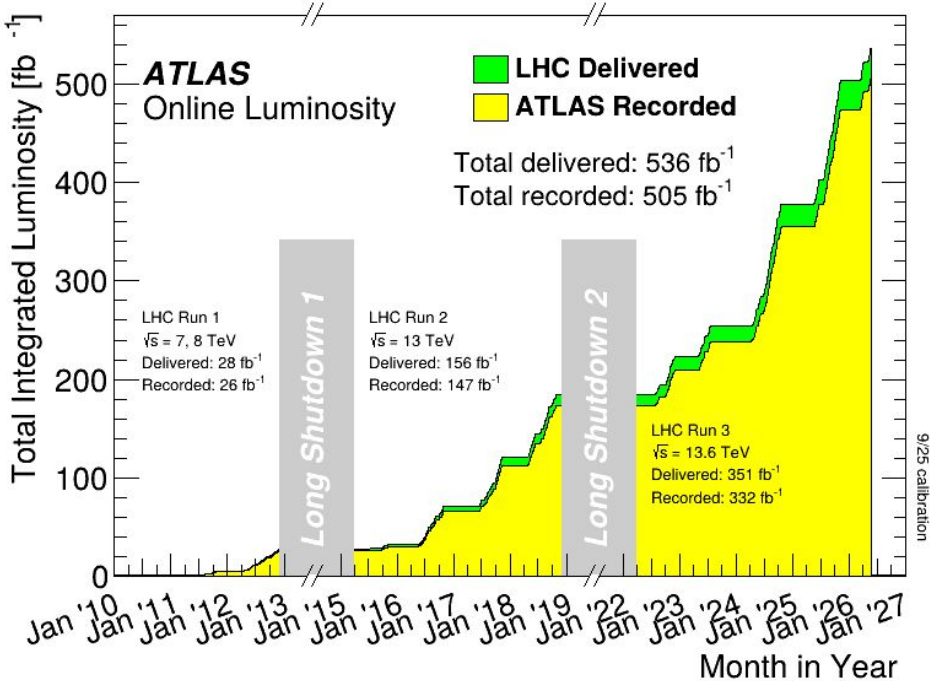
Candidate H→γγ* event (HIGP-2024-16)

Thank you for listening!
Any questions?



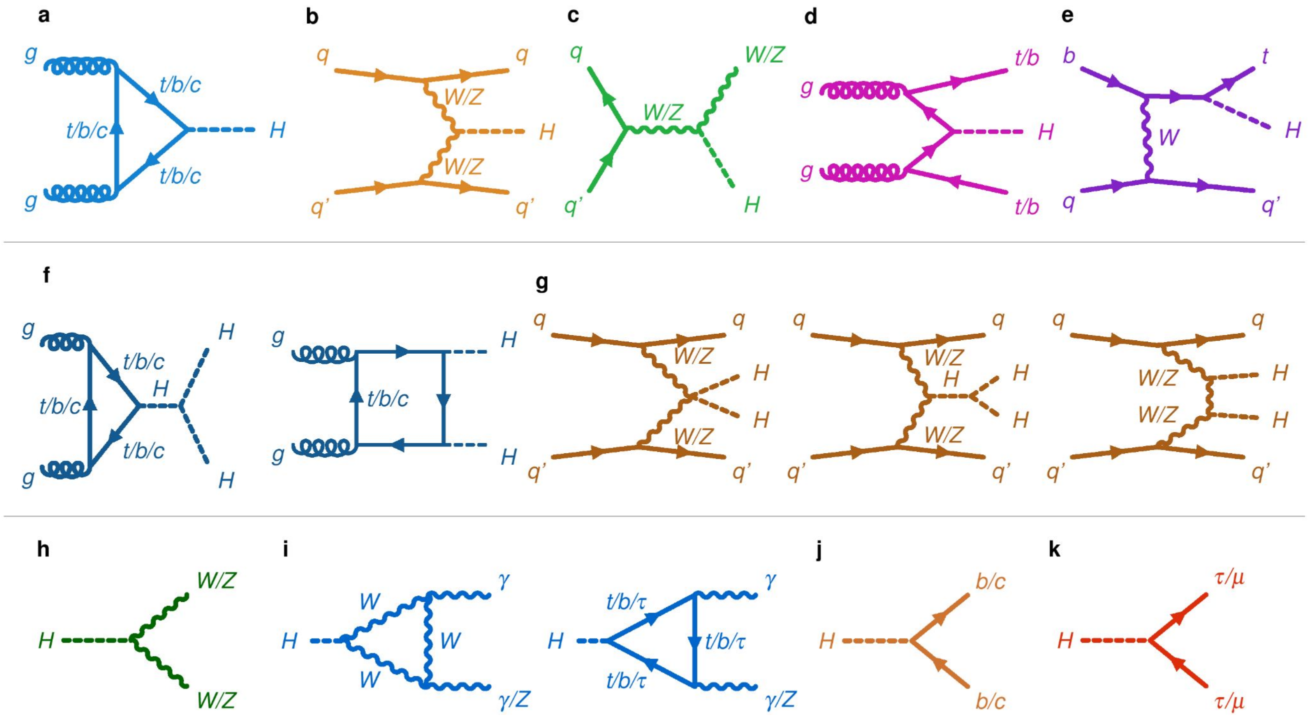
Backup

Integrated luminosity recorded by ATLAS



[Public luminosity results]

Higgs production modes and decays



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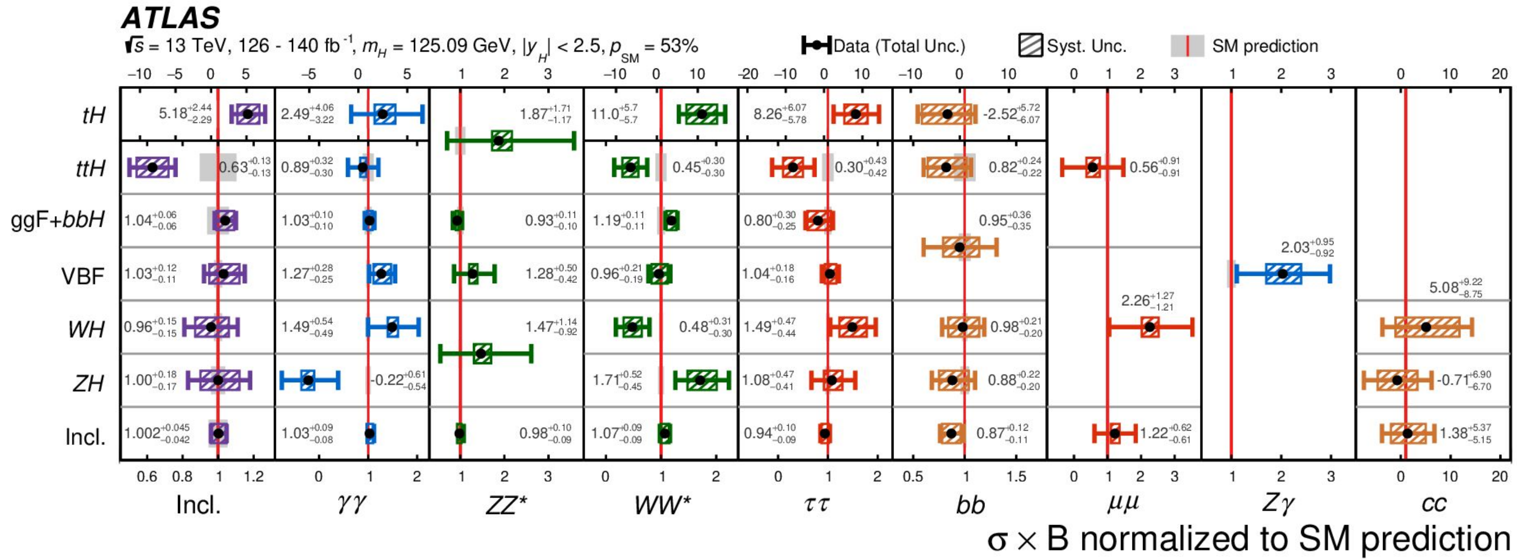
Production cross-sections among decay channels



HIGP-2025-16

Higgs boson coupling modifiers

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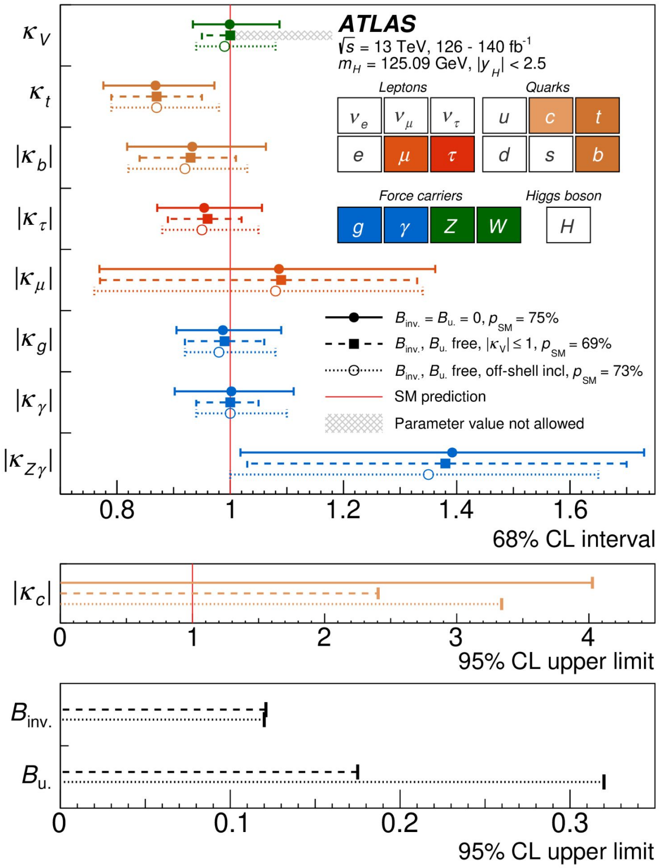
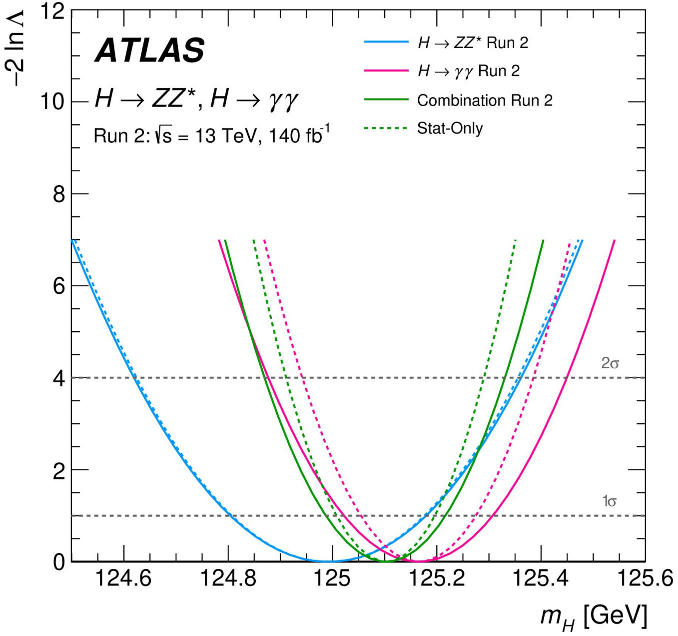
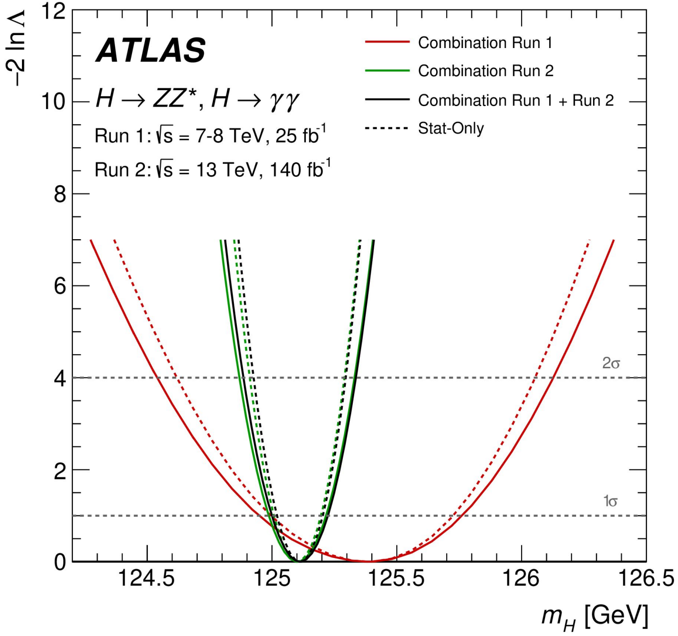


Run 1+2 Higgs mass combination

PRL 131 (2023) 251802





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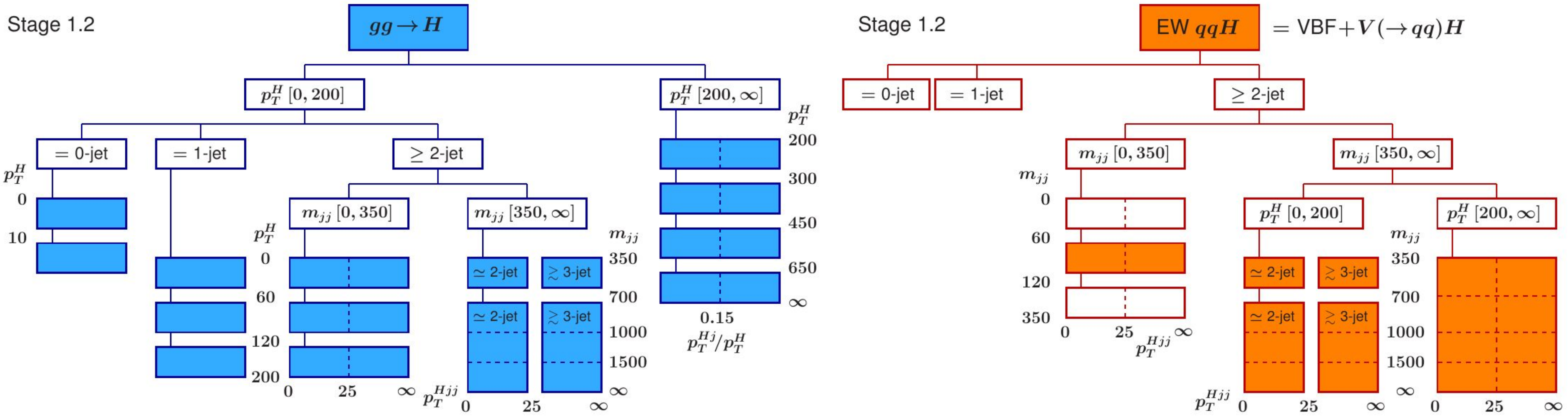
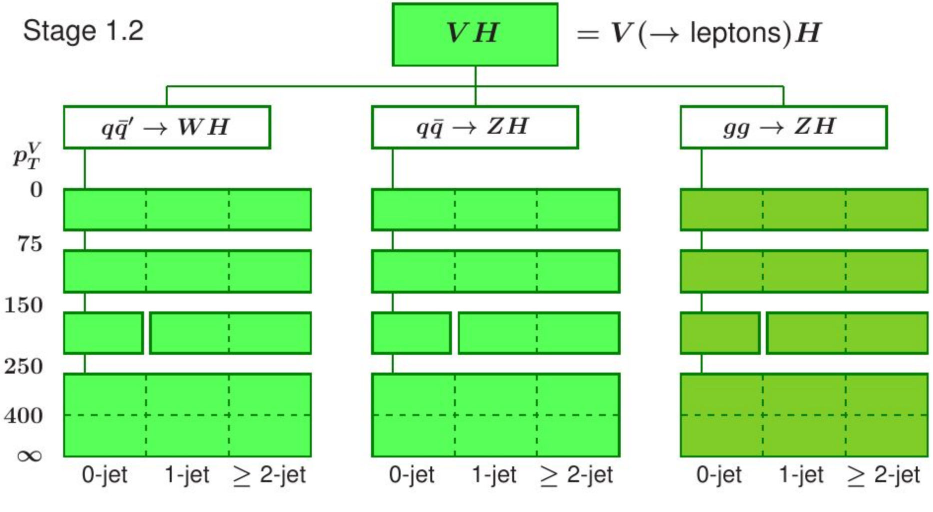
$$m_H = 125.11 \pm 0.09\,(\text{stat.}) \pm 0.06\,(\text{syst.}) = 125.11 \pm 0.11\,\text{GeV}.$$

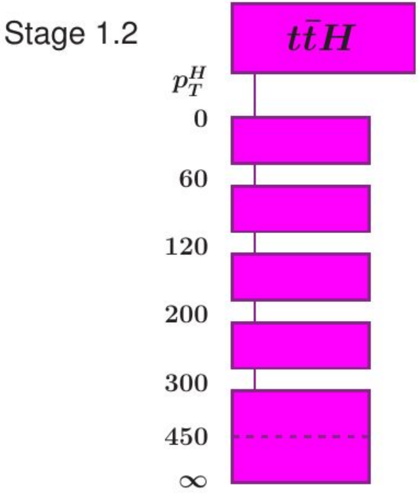
STXS Stage 1.2 categorization scheme



arXiv:1906.02754

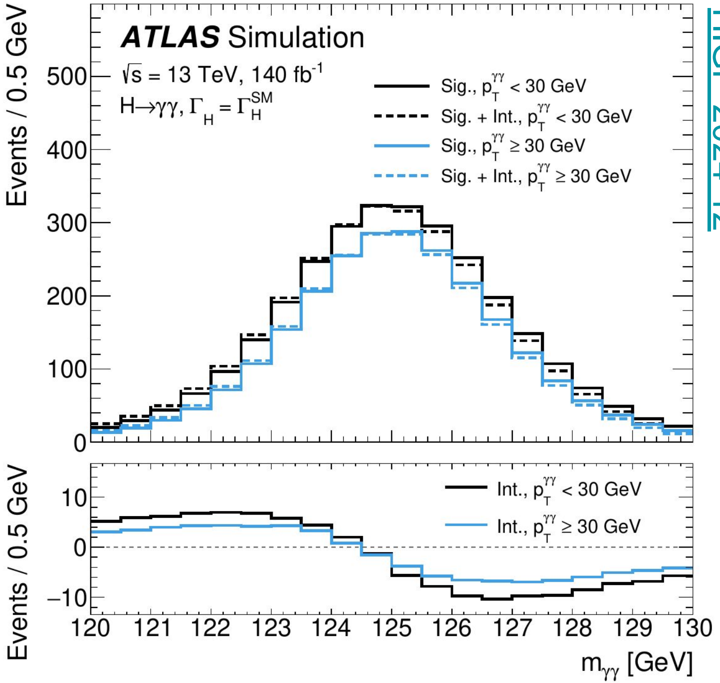
STXS Stage 1.2 categorization scheme





arXiv:1906.02754

Effects of interference on H→γγ signal peak



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