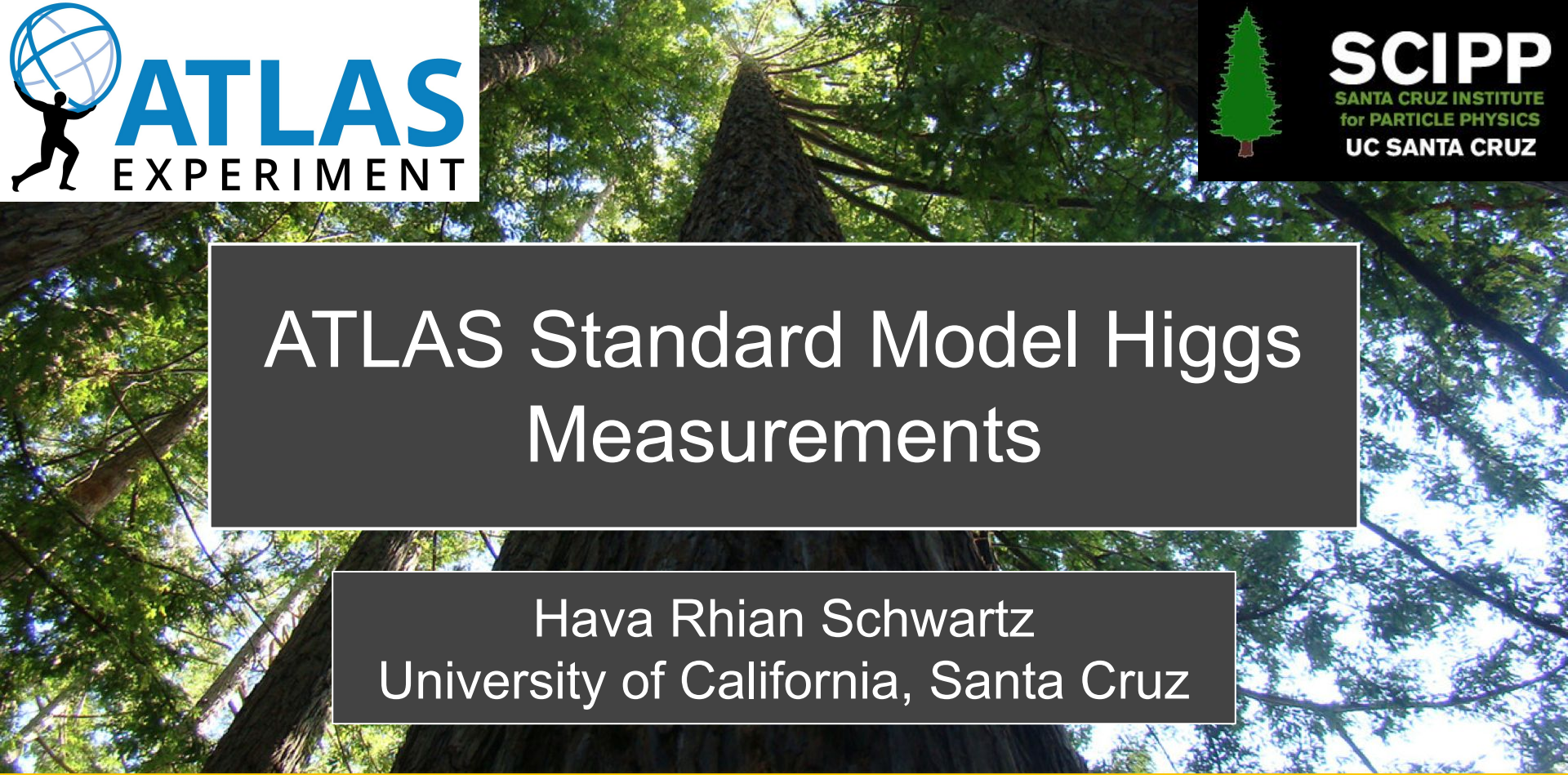


ATLAS Standard Model Higgs Measurements

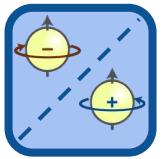
Hava Rhian Schwartz
University of California, Santa Cruz

Outline

Overview of Recent Results

Higgs Production Measurements

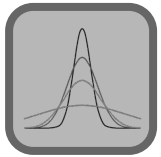
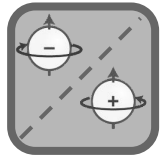
Mass & Total Width Measurements



CP and Quantum Properties

Future Outlook

Overview of Recent Results


General Studies

H→γγ, Run 2	December 2023
Off-shell H→ZZ, Run 2	**December 2023**
H→γγ + H→ZZ, Runs 1 + 2	**January 2024**
H→γγ + H→ZZ, Run 3	**February 2024**
H→Zγ, ATLAS+CMS, Run 2	**March 2024**
H(→γγ) + c, Run 2	July 2024
H→ττ, Run 2	July 2024

Gluon Fusion Studies

H→WW*→e$\nu\mu\nu$, Run 2	September 2023

VBF/VH Studies

VBF H→WW*→e$\nu\mu\nu$, Run 2	November 2023
VH H→ττ, Run 2	December 2023
VBF H→γγ, Run 2	December 2023
VBF WH Production, Run 2	**February 2024**
High-p_T VH→qqbb, Run 2	April 2024
VBF H→ZZ→4ℓ, Run 2	**May 2024**
VH H→bb/cc, Run 2	**July 2024**

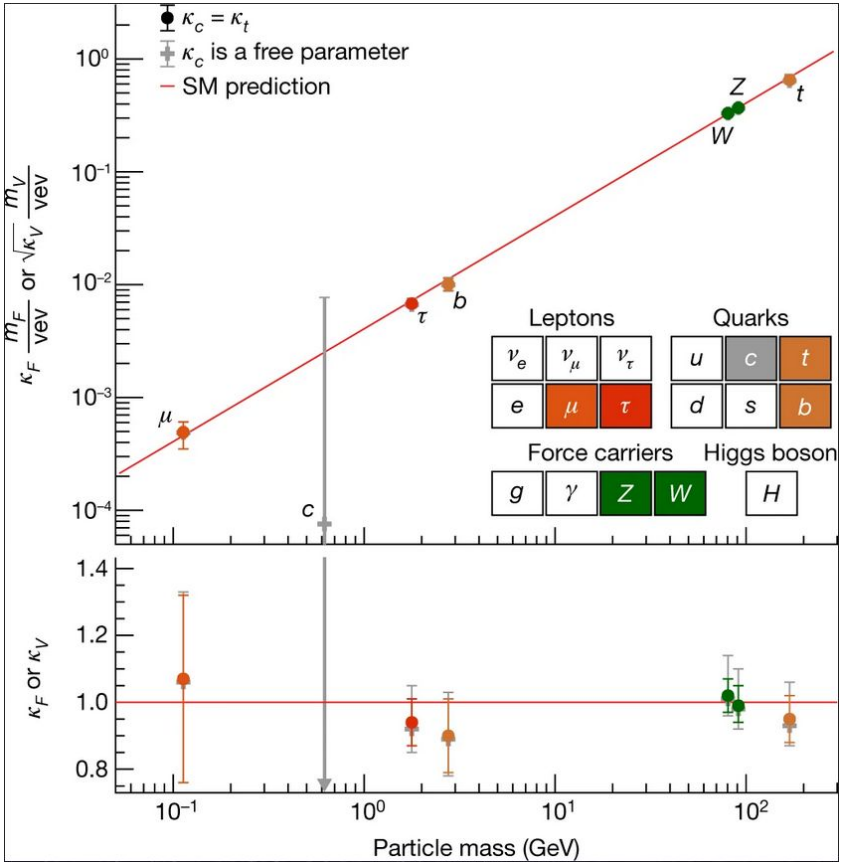
ttH Studies

ttH + tH H→bb CP, Run 2	**April 2024**
ttH H→bb, Run 2	July 2024
ttH + 4-top, Run 2	**July 2024**

H. Schwartz (UC Santa Cruz, ATLAS)

Overview of Recent Results

- Growing numbers of Higgs production and decay modes have been combined to investigate interactions
  - Third-generation Higgs couplings well measured
  - Second-generation coupling measurements emerging
  - Remarkable alignment with SM predictions, constraining BSM models
- Coupling definition for particle p:
  - $\kappa_p^2 = (\sigma_p/\sigma_p^{SM})$ or (Γ_p/Γ_p^{SM})
- Signal strength definition:
  - $\mu_{if} = (\sigma_i/\sigma_i^{SM})(B_f/B_f^{SM})$



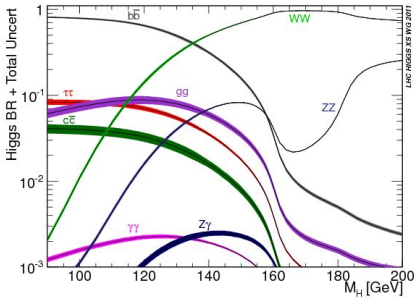
Nature 607, 52–59 (2022)

Higgs Production Measurements

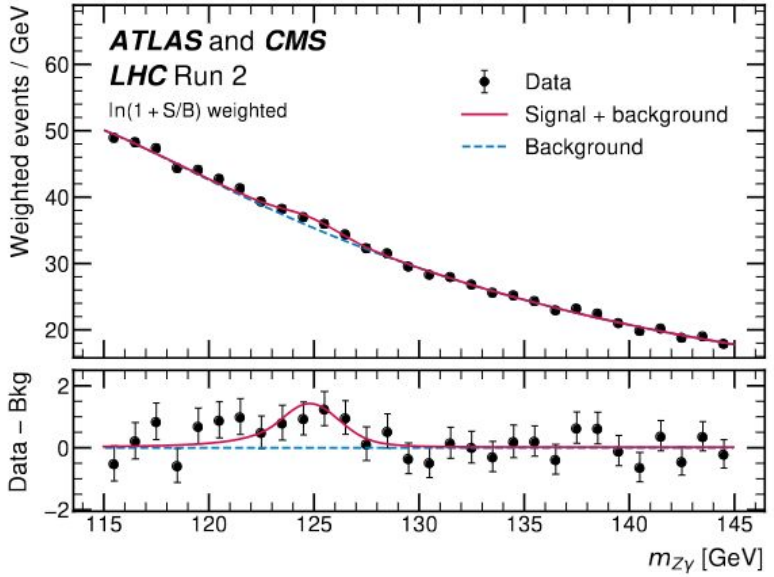
Search for Higgs Boson Decay to a Z Boson and a Photon (CMS + ATLAS)

First evidence of H→Zγ!

- Combined ATLAS and CMS Result
  - ATLAS signal strength: $\mu_{H\to Z\gamma} = 2.0^{+1.0}_{-0.8}$
  - CMS signal strength: $\mu_{H\to Z\gamma} = 2.4^{+1.0}_{-0.9}$
  - Combined: $\mu_{H\to Z\gamma} = 2.2 \pm 0.7$
- Observed significance
  - Relative to μ=0 null hypothesis: 3.4σ
  - Relative to SM prediction: 1.9σ (p-value=6%)
- Measured branching fraction: $(3.4 \pm 1.1) \times 10^{-3}$



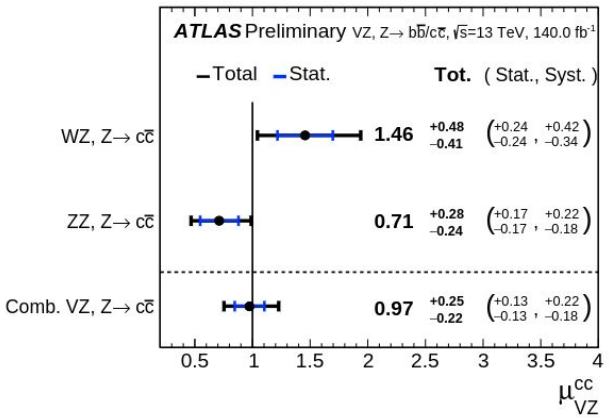
arXiv:1101.0593



Phys. Rev. Lett. 132 (2024) 021803

Higgs Production Measurements

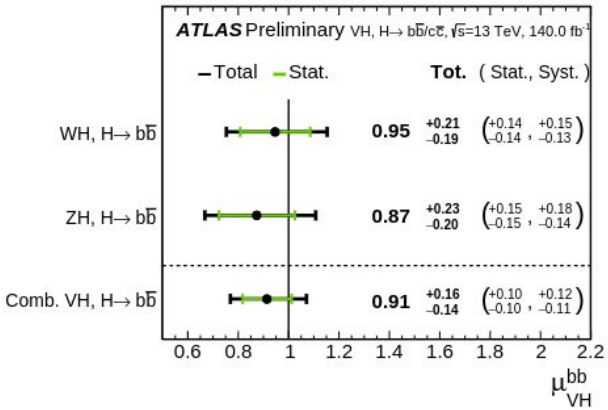
Measurements of VH Higgs Production with Decays to Bottom and Charm Quarks



First observation of Z→cc with greater than 5σ!

- VZ measurements performed as validation
  - VZ, Z→cc measured with significance 5.2σ
  - VZ, Z→bb measured with greater than 10σ
- VH Signal Strengths
  - $\mu_{VH,bb} = 0.91^{+0.16}_{-0.14}$
  - $\mu_{VH,cc} = 1.0^{+5.4}_{-5.2}$
- VH, H→bb Significance
  - Combined: 7.4σ
  - ZH: 4.9σ
  - WH: 5.3σ

First observation of WH, H→bb with more than 5σ!

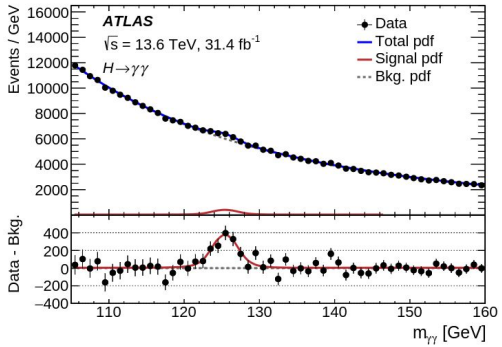


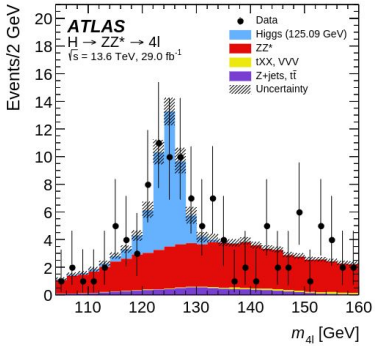
ATLAS-CONF-2024-010

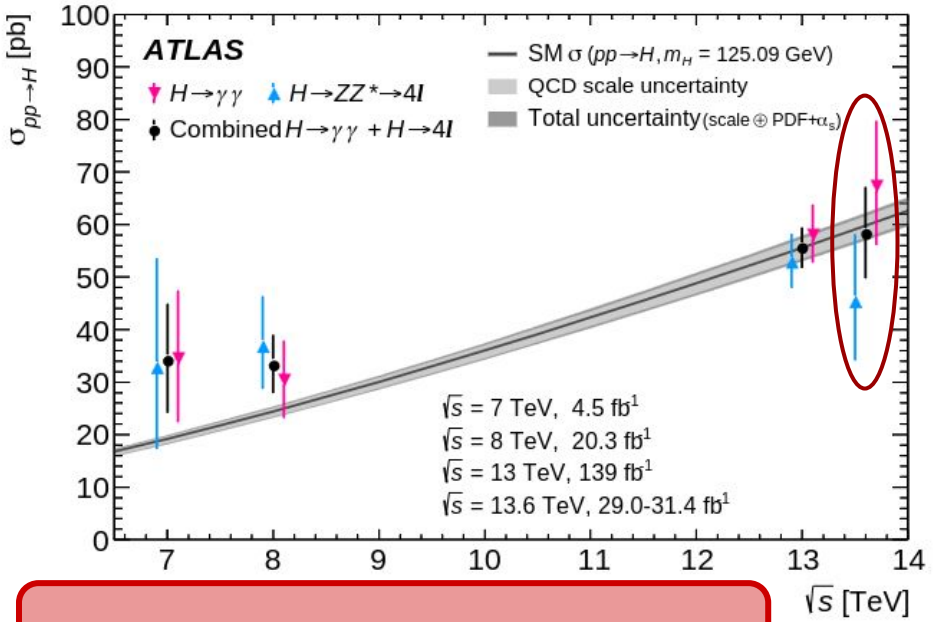
Higgs Production Measurements

Measurement of H→γγ and H→ZZ*→4ℓ at √s=13.6TeV

- H→γγ: Extrapolated Higgs Cross-section
  - $\sigma_{pp\to H} = 67^{+12}_{-11}$ pb
- H→4ℓ: Extrapolated Higgs Cross-section
  - $\sigma_{pp\to H} = 46 \pm 12$ pb
- Combined: $\sigma_{pp\to H} = 58.2 \pm 8.7$ pb
  - SM prediction: $\sigma^{SM} = 59.9 \pm 2.6$ pb







First Run 3 look at H→γγ and H→4ℓ!

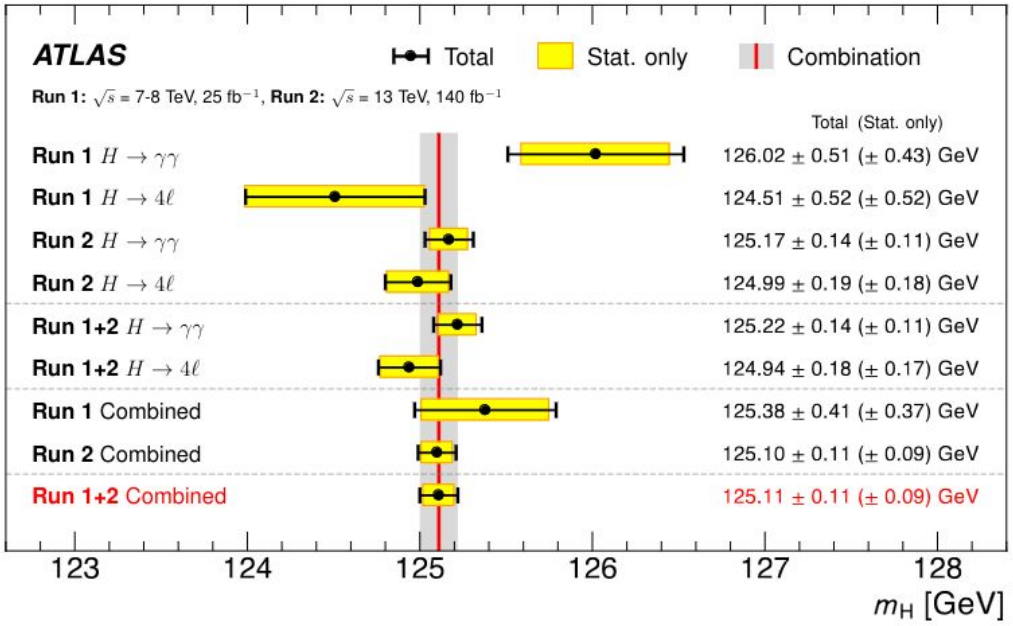
Phys. J. C 84 (2024) 78

Mass & Width Measurement

Higgs Mass Measurement from H→γγ and H→ZZ*→4ℓ Runs 1 and 2

With precision of 0.09%, most precise Higgs mass measurement to date!

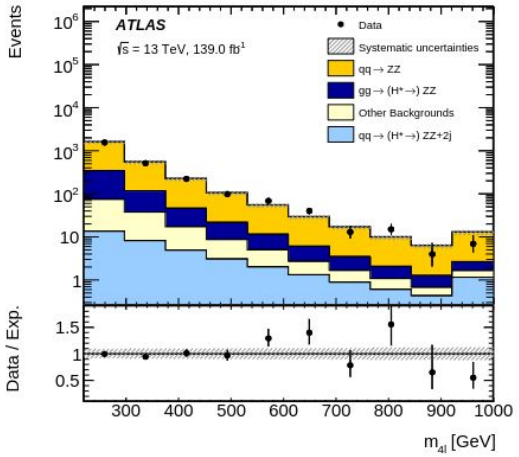
- Measured m_H=125.11 ± 0.09(stat.) ± 0.06(syst.) GeV
- Major improvements in H→γγ channel
  - 4x better photon energy calibration
  - Most precise mass measurement in a single decay mode (0.11% precision)
- 4 combined measurements are compatible with a p-value of 18%



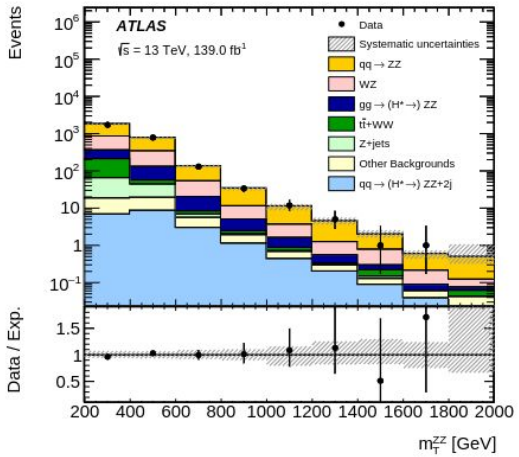
Phys. Rev. Lett. 131 (2023) 251802

Mass Width Measurement

Evidence of Off-shell H→ZZ* and Constraints on Higgs Total Width



ZZ→4ℓ



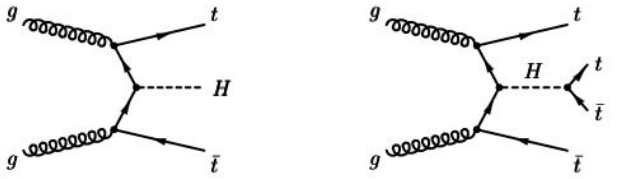
ZZ→2ℓ2ν

- Evidence of off-shell H→ZZ* production, consistent with CMS experimental result
- ZZ→4ℓ and ZZ→2ℓ2ν channels combined, with $m_{ZZ} \geq 200$ GeV
  - $\mu_{\text{off-shell}} = 1.1^{+0.7}_{-0.6}$
  - Observed (exp) signif. = 3.3σ (2.2σ)
- Higgs Total Width Measurement
  - $\Gamma_H = 4.5^{+3.3}_{-2.5}$ MeV
  - $\Gamma_H \leq 10.5$ (10.9) MeV

Phys. Lett. B 846 (2023) 138223

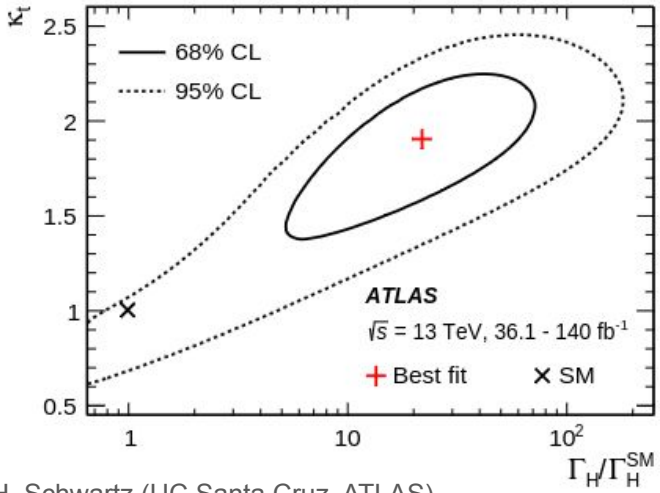
Mass Width Measurement

Higgs Total Width Constraint from On-shell and Off-shell Higgs Boson Measurements



On-shell

Off-shell



First Higgs total width constraint using both on-shell and off-shell Higgs production measurements

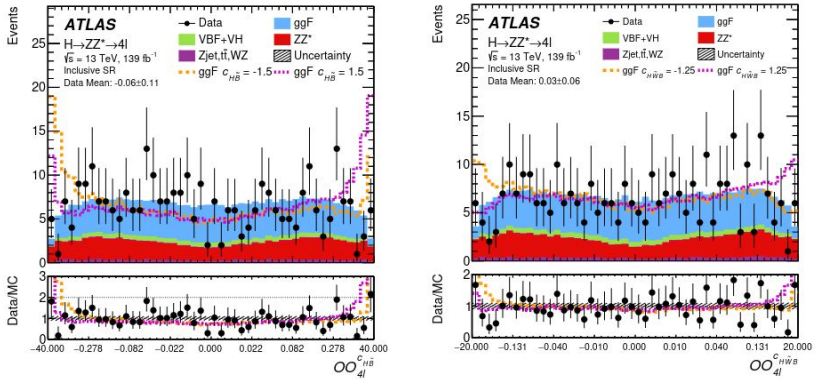
- Combination uses 4-top and ttH Higgs production measurements
- Observed (Exp) 95% CL Upper Limit:
  - $\Gamma_H \leq 450\ (75)$ MeV
- If assuming only SM particles in loop processes:
  - $\Gamma_H \leq 160\ (55)$ MeV
- Sensitivity dominated by modeling uncertainties, predominantly of 4-top-quark production

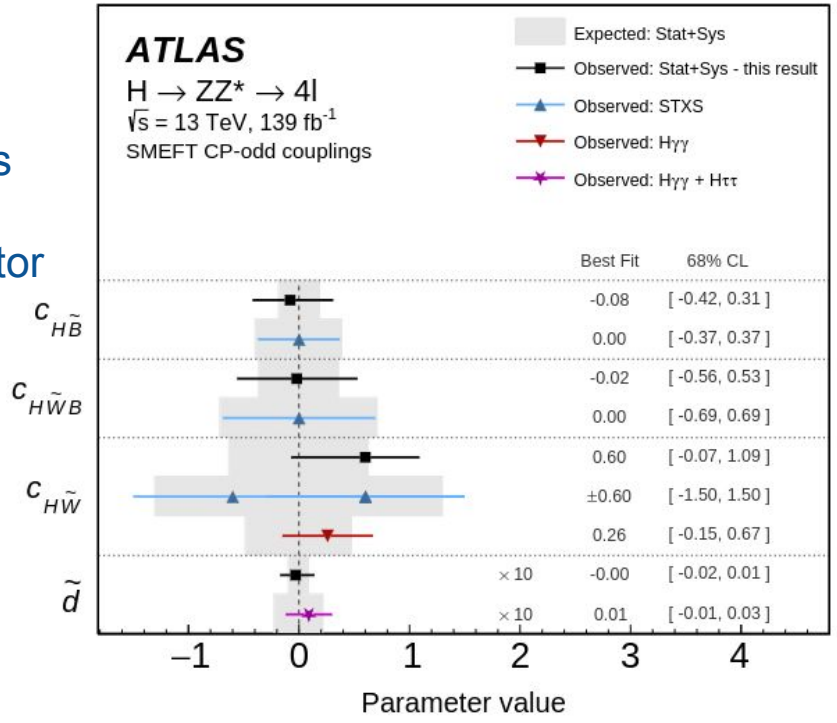
arXiv:2407.10631, EPJC 83 (2023) 496, EPJC 84 (2024) 156, Nature 607 (2022) 52

CP and Quantum Properties

CP-Invariance in Higgs Electroweak Couplings via VBF Higgs to 4 Leptons

- Fit to shapes of *optimal observables*
  - Normalized interference terms, CP-odd by construction
- *Shape-only* contributions avoid uncertainties in cross-section measurements
- Some of the tightest HVV vertex EFT operator constraints to date

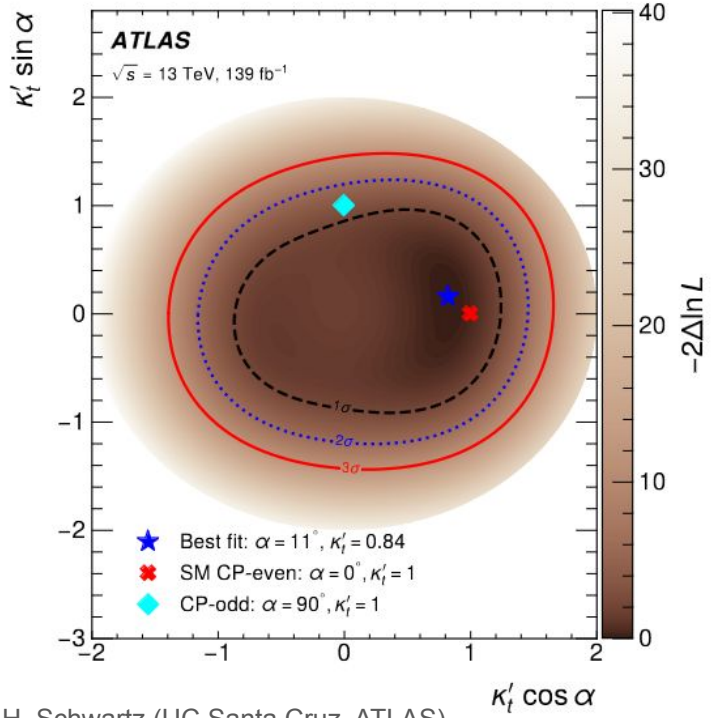




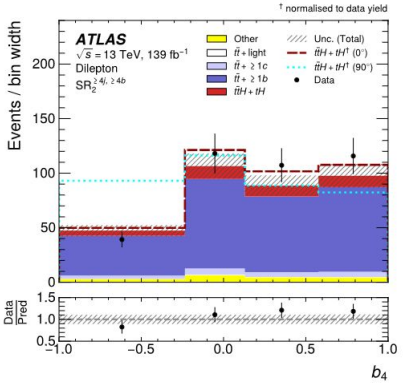
JHEP 05 (2024) 105

CP and Quantum Properties

CP-Nature of top-Higgs Yukawa Coupling via ttH and tH with Higgs to bb



- First study of CP properties of top-Higgs Yukawa coupling in this decay mode
- Fit to dedicated CP-sensitive variables
  - Reliant on angular separations between reconstructed top quarks or lepton candidates
- Dominated by modeling uncertainties of the tt + ≥ 1b background



$$b_4 = \frac{(\vec{p}_1 \cdot \hat{z})(\vec{p}_2 \cdot \hat{z})}{|\vec{p}_1||\vec{p}_2|}$$

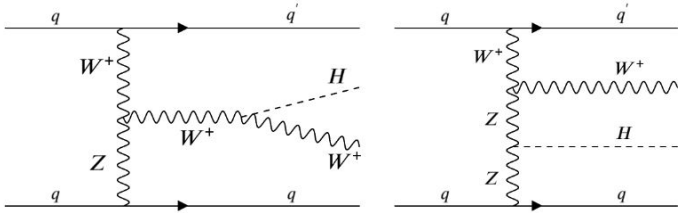
where p_i are the momenta of the event top quarks (tend to be produced closer to beamline in CP-odd scenario)

Phys. Lett. B 849 (2024) 138469

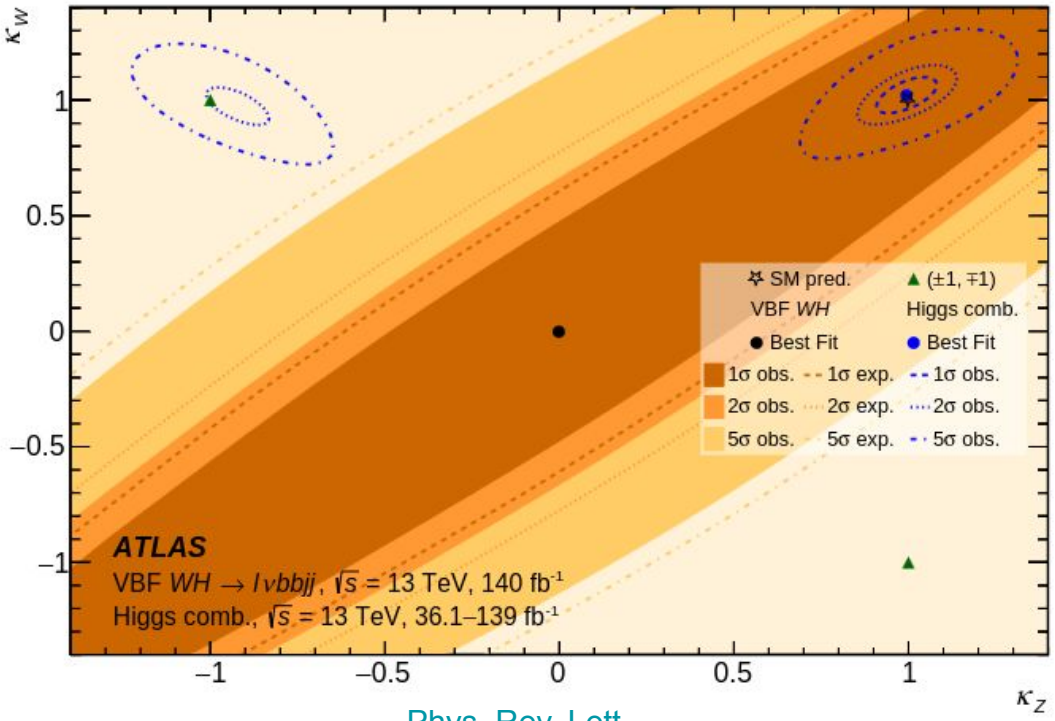
CP and Quantum Properties

Determination of the Relative Sign of HW and HZ Couplings via VBF WH

Opposite-sign W and Z Higgs couplings excluded at greater than 5σ!

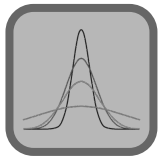
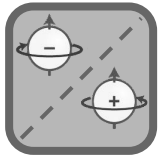


- Opposite-sign couplings would enhance VBF production of WH
- 70 data events observed in SR
  - Same-sign expectation: 80.6 ± 8.6
  - Opposite-sign exp.: 361 ± 46
- Observed signal strength:
  - μ=0.9 ± 2.5(stat.) ± 3.3(syst.)



Phys. Rev. Lett.




Future Outlook

Exciting measurements to look out for in Run 3:

- Boosted Higgs
- Di-Higgs and Multi-Higgs Measurements
- ZH production
- Off-shell Higgs and Total Width Measurements
- STXS Measurements with binning modifications
- CP Violation via ttH

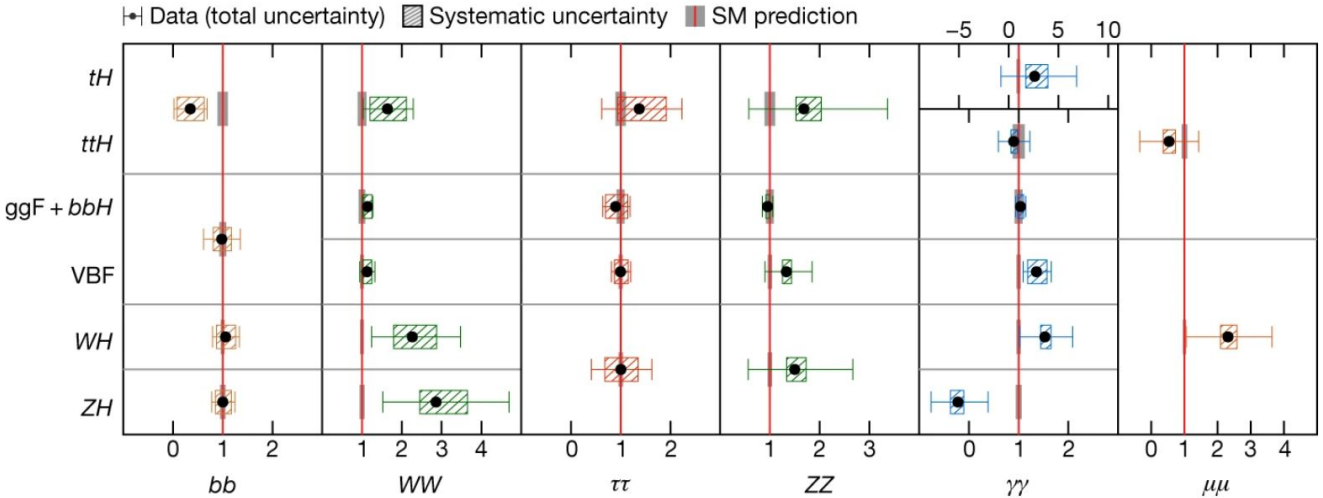
Upcoming improved tools:

- GN2 Tagging
- N^3LO PDF's
- Improved ggZH MC
- Controlled PS Uncertainties

Concluding Remarks

★ Many wonderful Higgs results in the last year from ATLAS. We witnessed:

- First evidence of H→Zγ
- First observation of WH H→bb
- Most precise Higgs mass measurement to date
- Strongest constraints to date on CP properties and coupling modifiers



★ Having already achieved double the data with Run 3, results will push above the evidence and observation thresholds in the near future!

Nature 607, 52–59 (2022)

Back-Up