Measurements of Higgs boson coupling properties to vector bosons with the ATLAS detector

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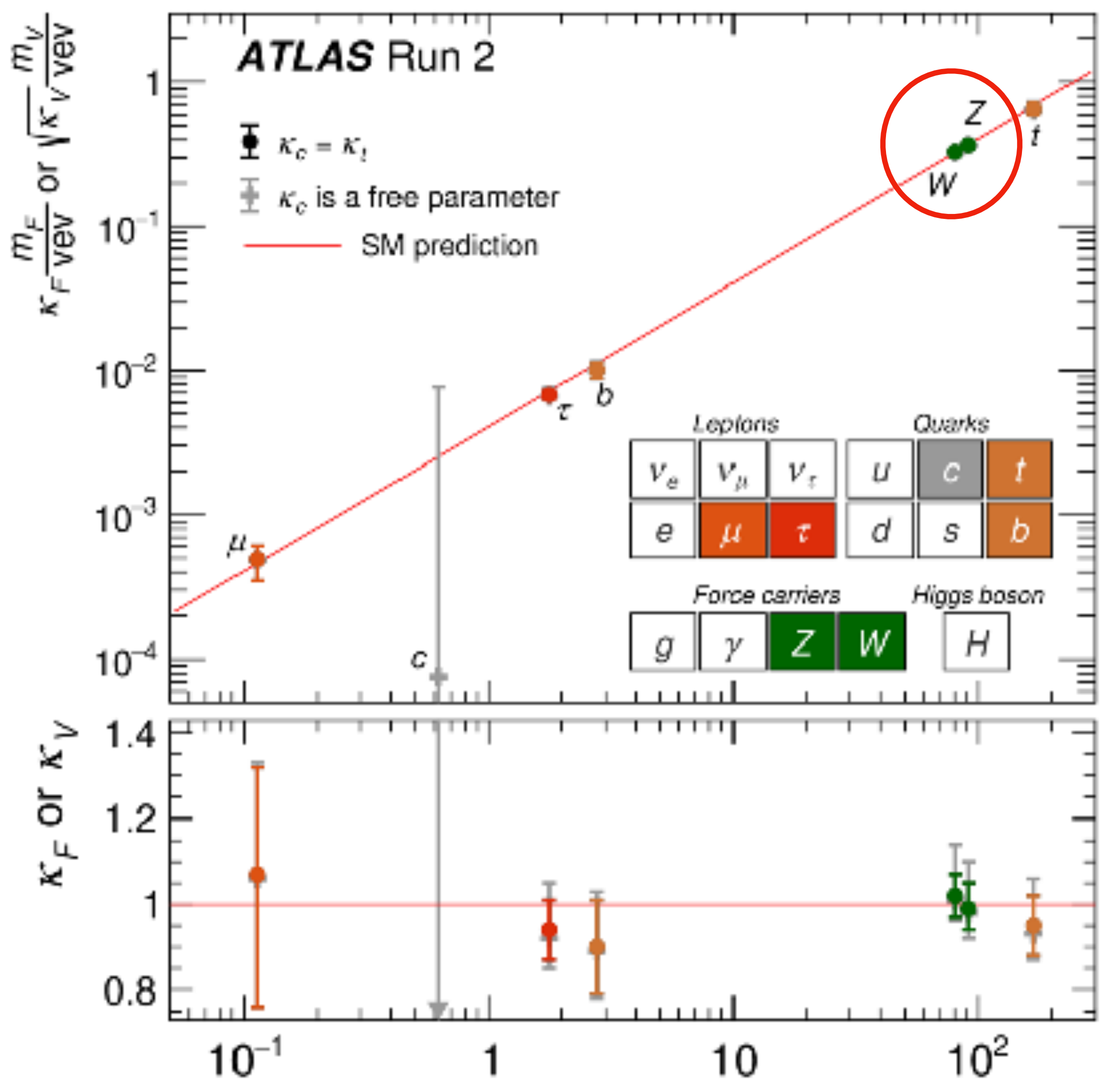
on behalf of the ATLAS Collaboration

Introduction

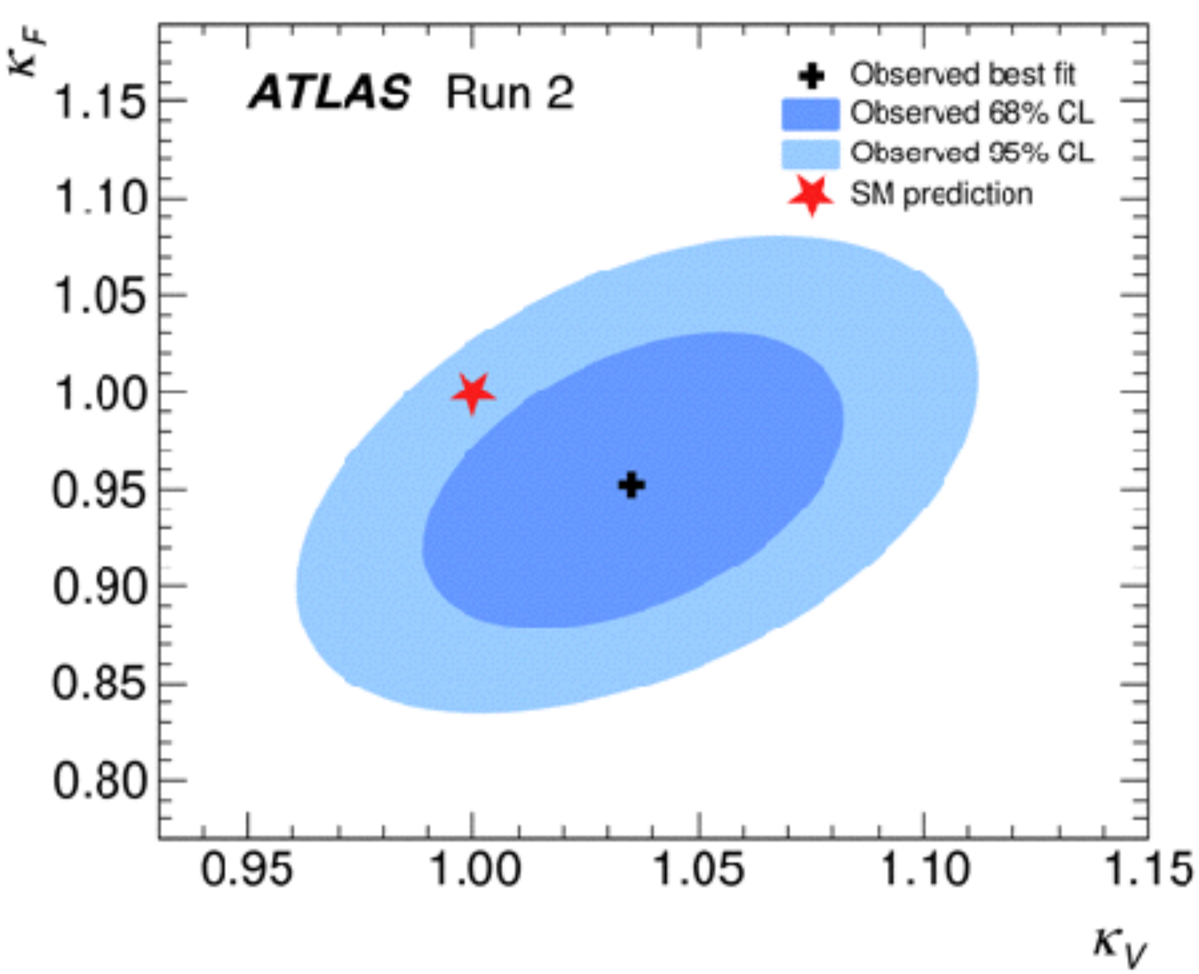
- It is easy to forget that the Higgs boson is still a relatively new discovery, where we still have a lot to learn about it.
  - The couplings to the W and Z bosons take a special place, as the longitudinal components are obtained from the Higgs field itself.
  - The nature of the Higgs boson looks very SM-like, but deviations that originate from higher-order corrections are typically only at the percent-level. Precision measurements are key!
- High-precision measurements require a large amount of well-calibrated detector data and cutting-edge analysis techniques.
  - Most of what I present today is based on the Run 2 dataset, but towards the end we will look at a few early results using the first part of Run 3 data.
- Results are typically reported on the signal strength parameter $\mu = \sigma/\sigma_{SM}$.
  - Coupling modifiers κ are defined $\kappa = c/c_{SM}$ where c is some coupling.

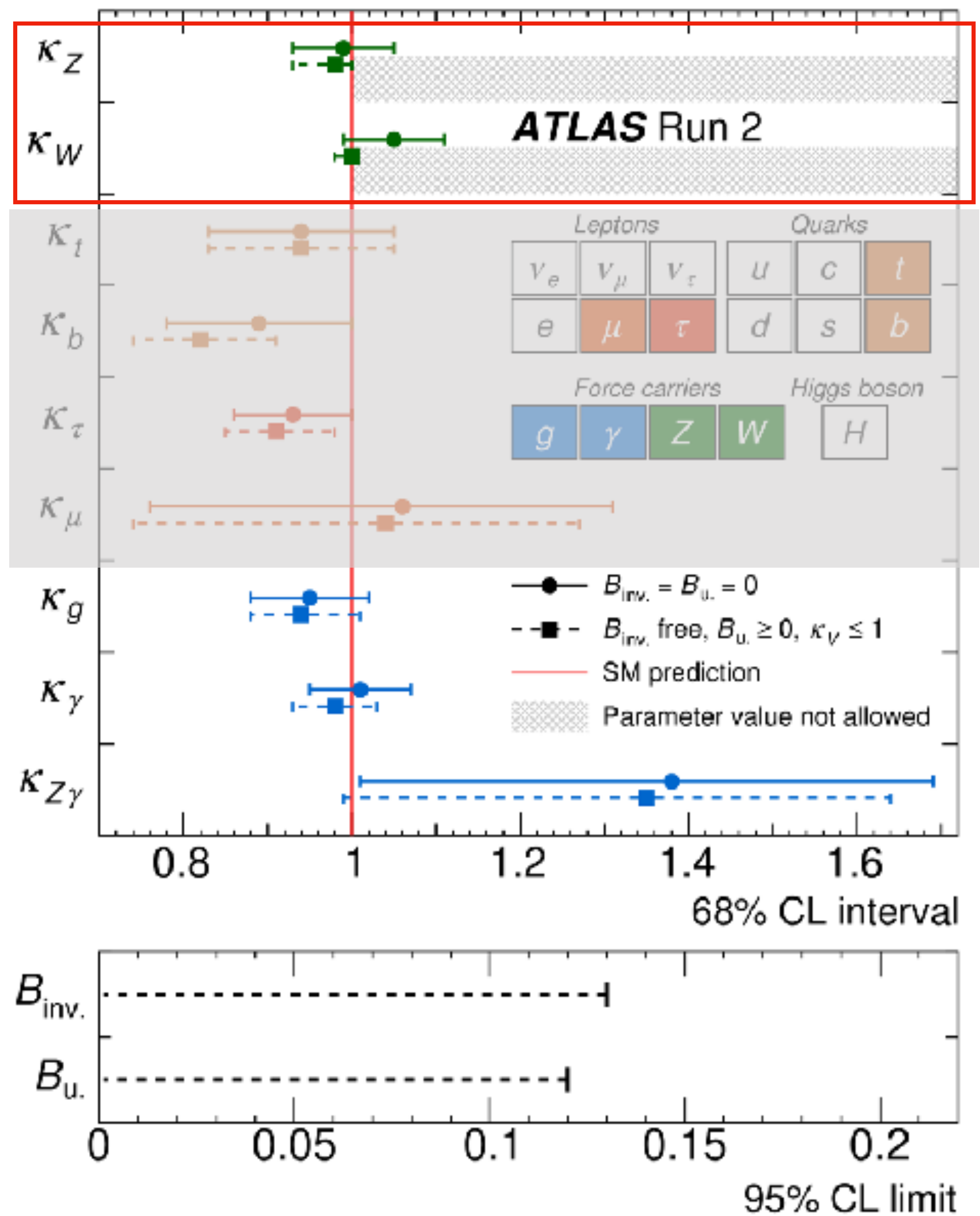


[Nature 607 52 (2022)](#)

Couplings to Z and W bosons

- Couplings to the massive vector bosons are constrained to within ~7-8% of the expected SM value.
- Effective couplings to gluons and photons arise through loops.
  - Such loops contribute to both the Higgs boson production (i.e. gluon fusion), and decays (for example to γγ and Zγ).





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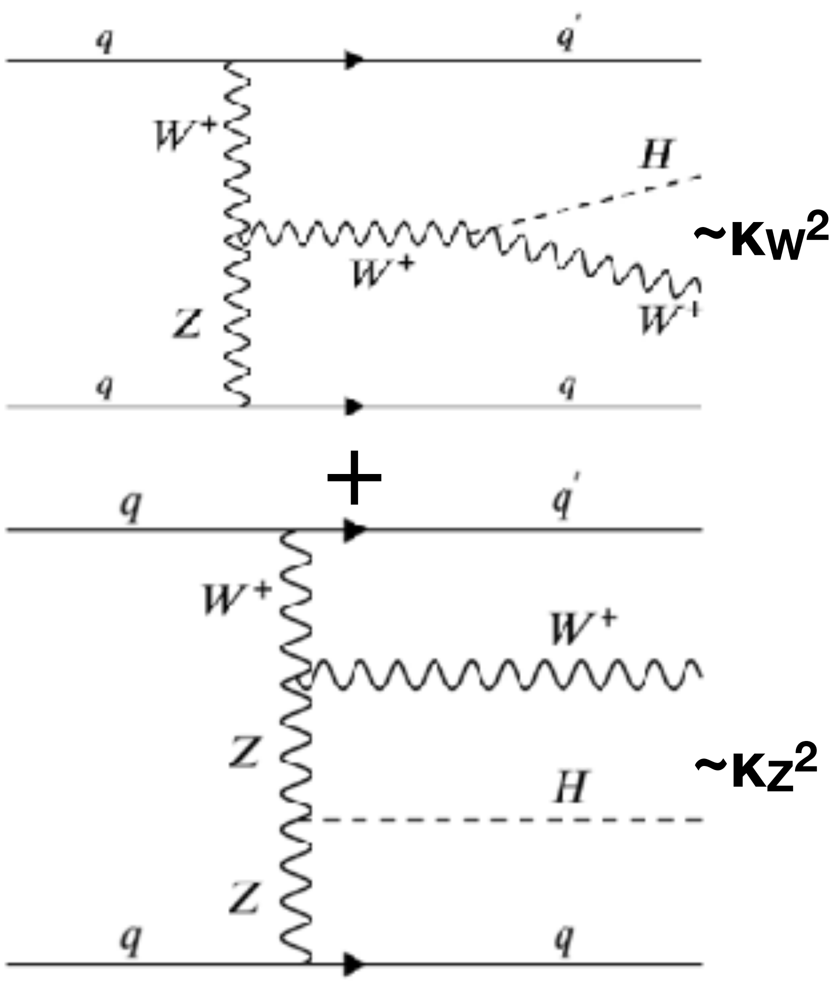
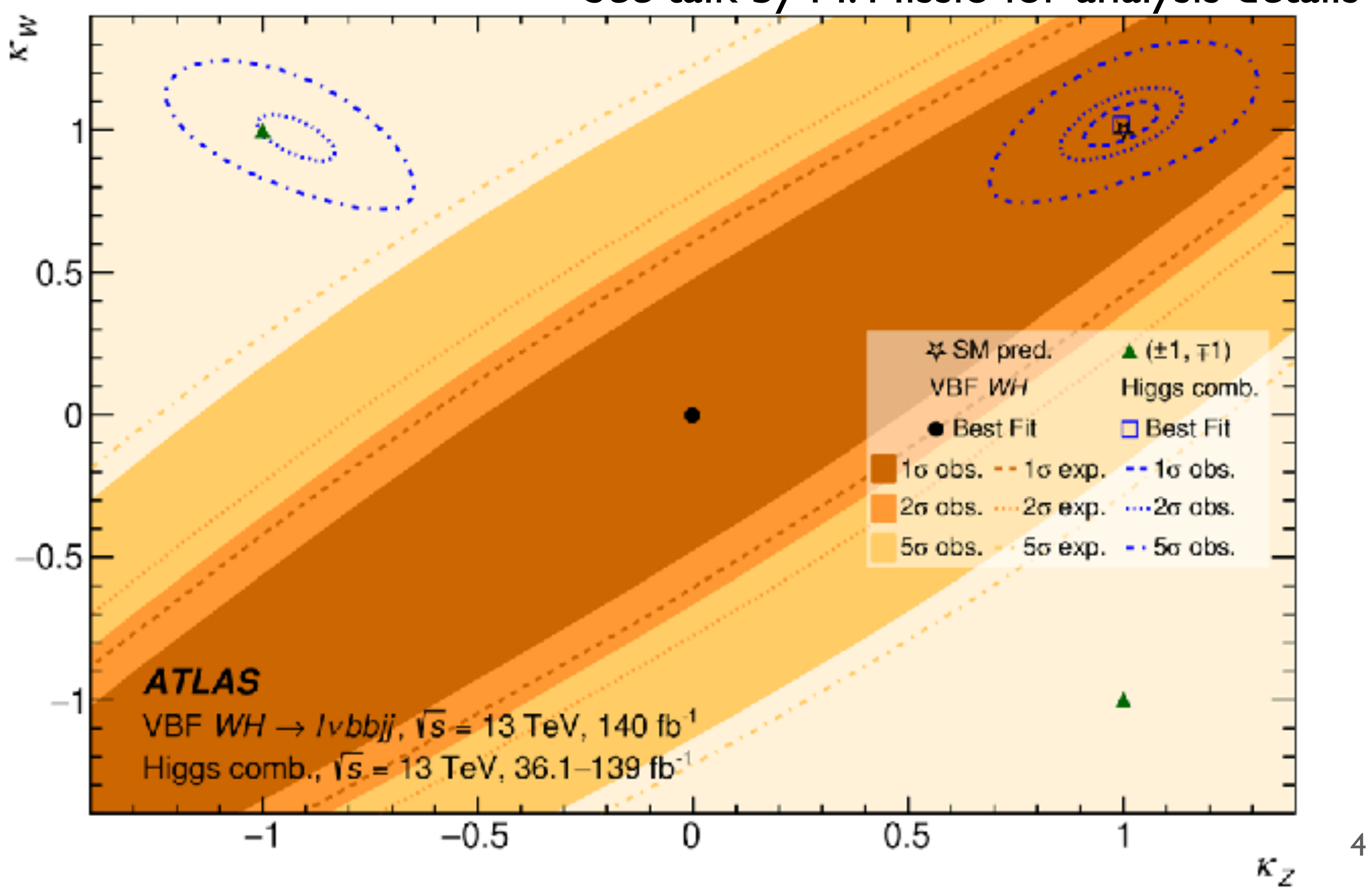
Relative sign of the W-H and Z-H couplings

- We can define the parameter $\lambda_{WZ}=\kappa_W/\kappa_Z$ which the SM predicts to be one since κ_W and κ_Z both are one. Previous measurements from ATLAS and CMS have constrained $|\lambda_{WZ}|$ to be equal to one within 6%.
- The sign degeneracy can be disentangled in the VBF WH production, where the two leading diagrams interfere destructively if λ_{WZ} is positive.
  - A negative value for λ_{WZ} is excluded with a significance of more than 5σ.

See talk by M. Missio for analysis details



interference $\sim\kappa_W\kappa_Z$



Phys. Rev. Lett. 133 (2024) 141801

Interpretation within Effective Field Theories

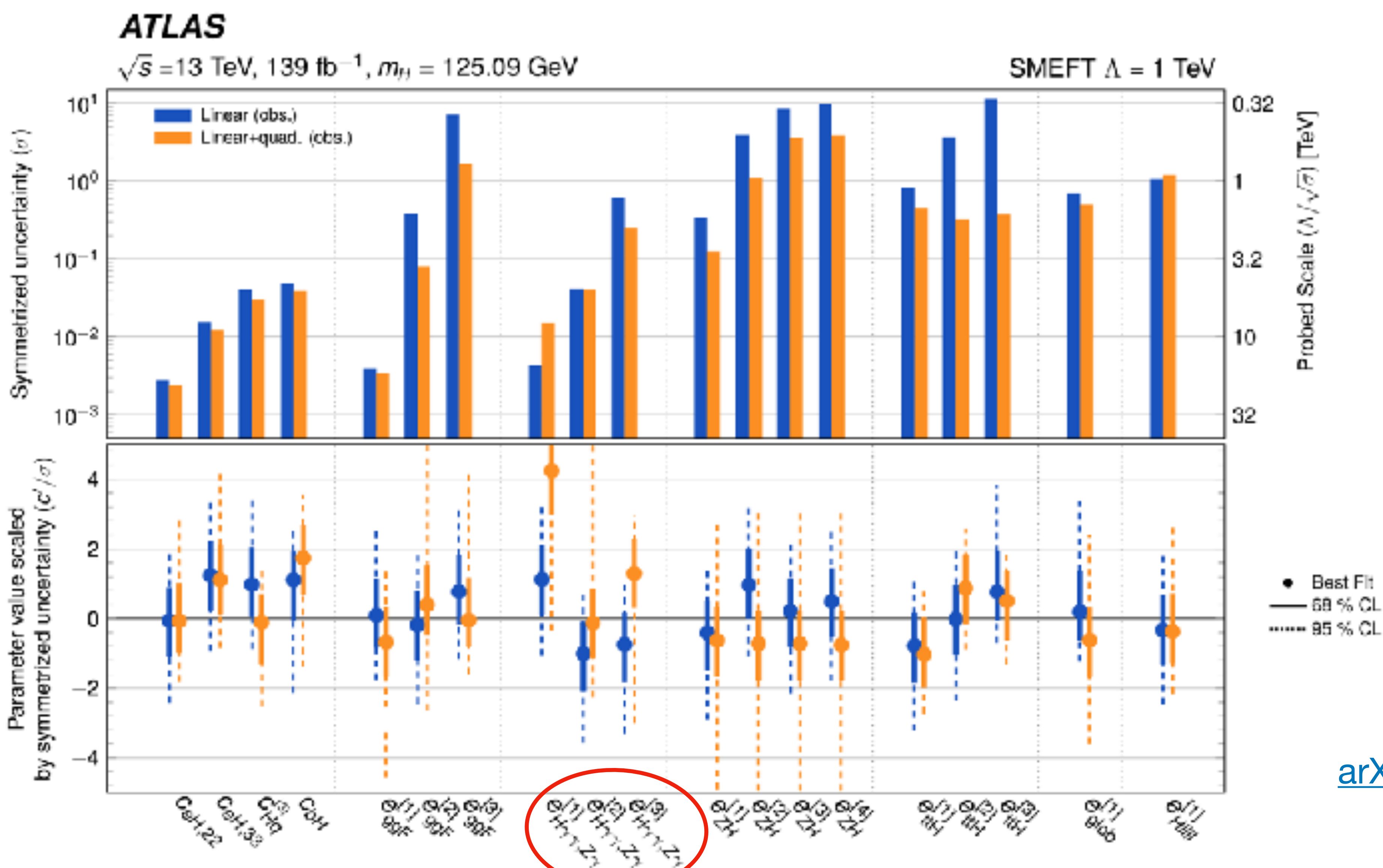
- The effect of potential new heavy particles living at an energy scale Λ can be incorporated as effective couplings at the electroweak scale:

$$\mathcal{L}_{SM} = \mathcal{L}_{SM}^{(4)} + \frac{1}{\Lambda}\sum_k C_k^{(5)} Q_k^{(5)} + \frac{1}{\Lambda^2}\sum_k C_k^{(6)} Q_k^{(6)} + \mathcal{O}\left(\frac{1}{\Lambda^3}\right)$$

c_k Wilson coefficients

Do not conserve lepton/baryon number

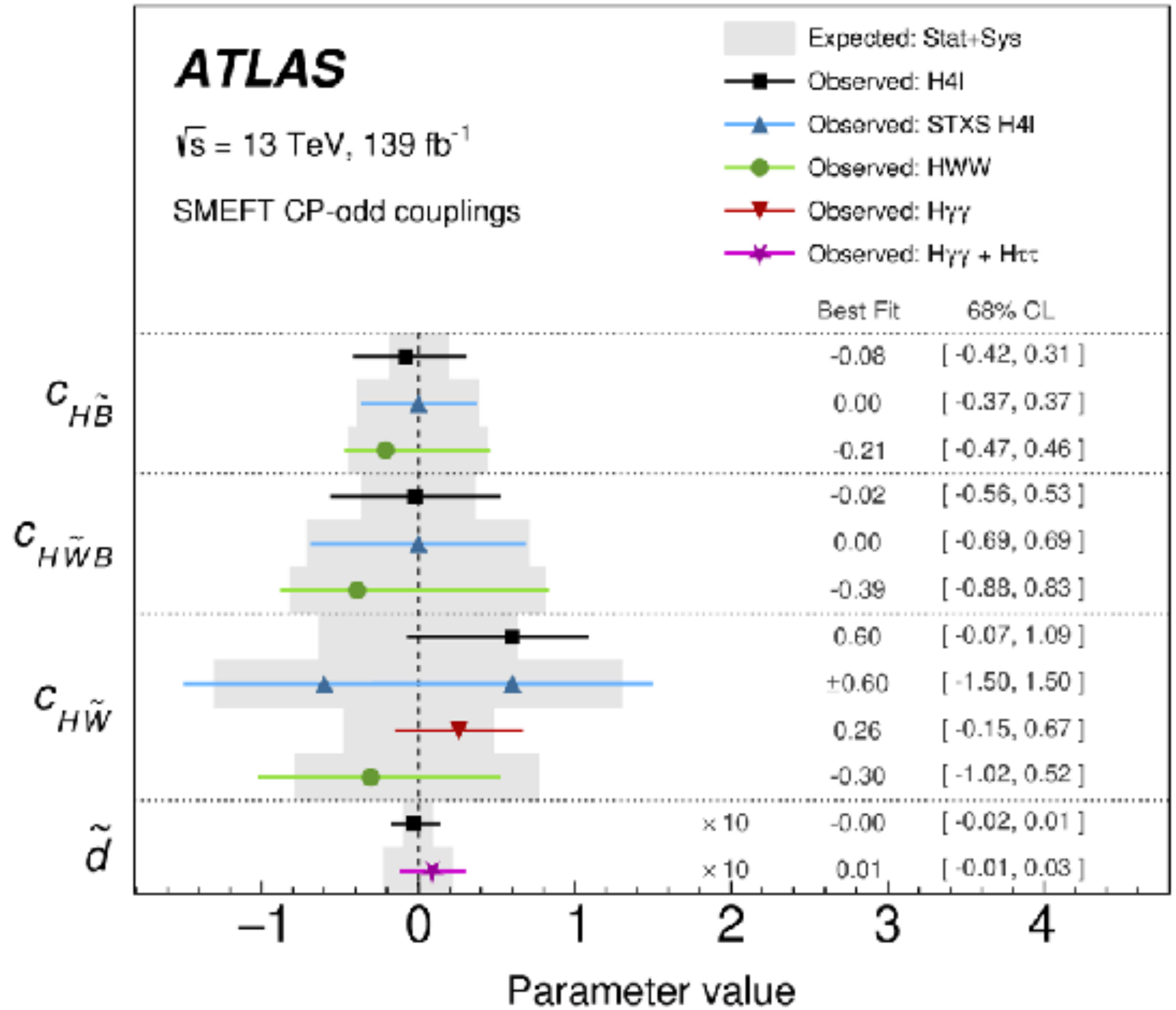
- Use SMEFT in the Warsaw basis (only CP-even operators) to interpret the combined Higgs STXS measurements.



arXiv:2402.05742

CP violation in the Higgs boson couplings

- Kinematic distributions can be sensitive to the CP nature of the Higgs boson.
  - Could be contributing to the explanation of the matter-antimatter asymmetry in the universe.
  - Pure anomalous states excluded by the discovery channels, but small admixtures of non-SM CP couplings are possible.
- Results in the following channels are considered:
  - $H \to ZZ \to 4l$
  - VBF $H \to WW \to e\nu\mu\nu$
  - VBF $H \to \gamma\gamma$, also in combination of VBF $H \to \tau\tau$.

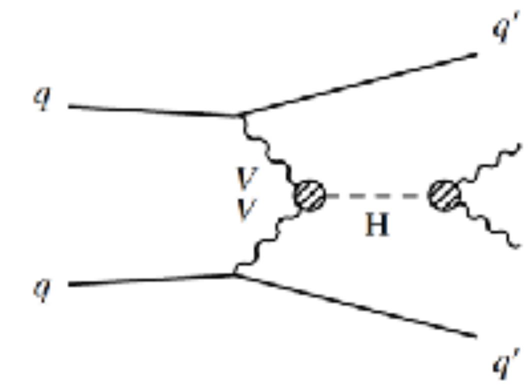


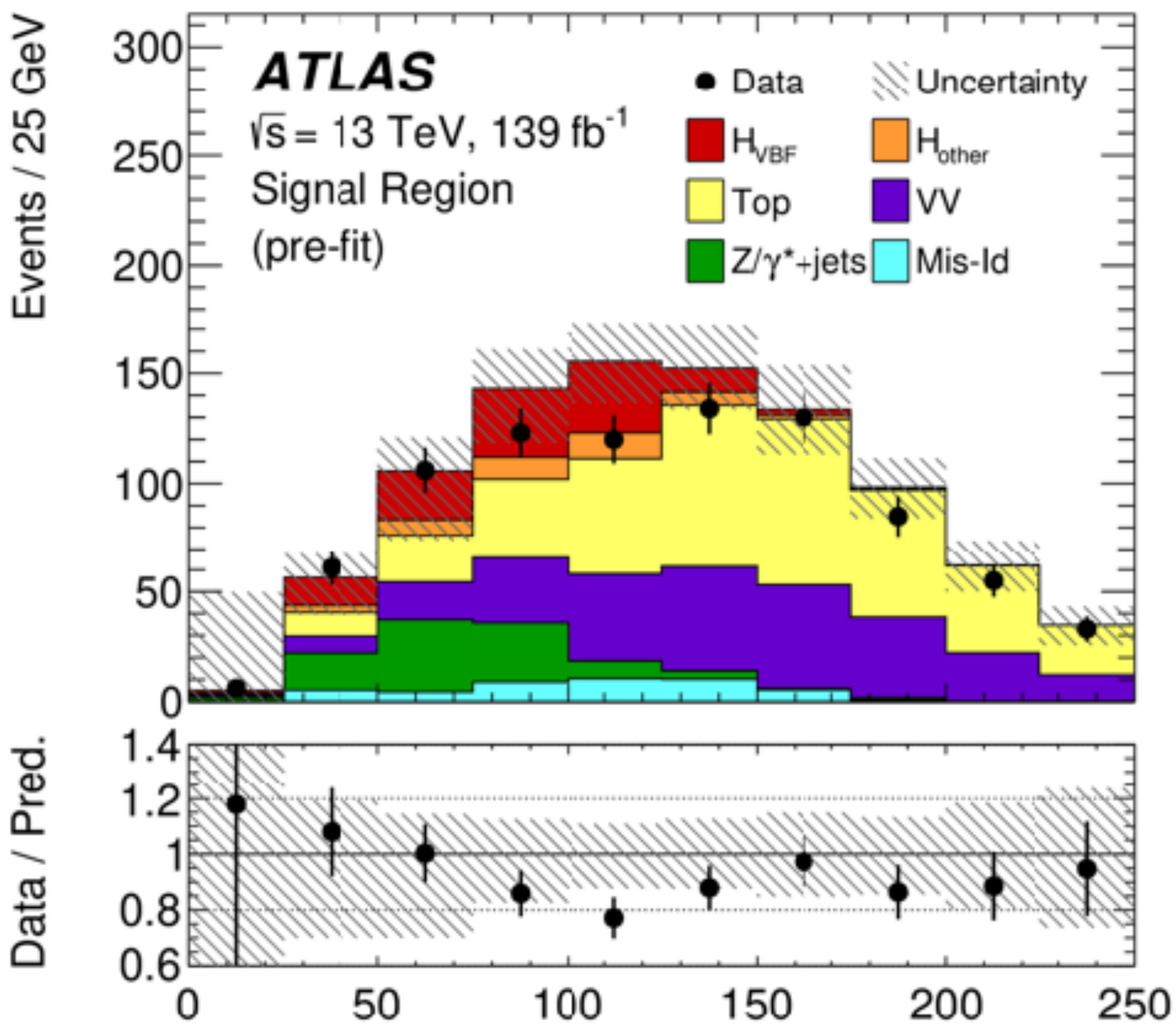
arXiv:2404.05498

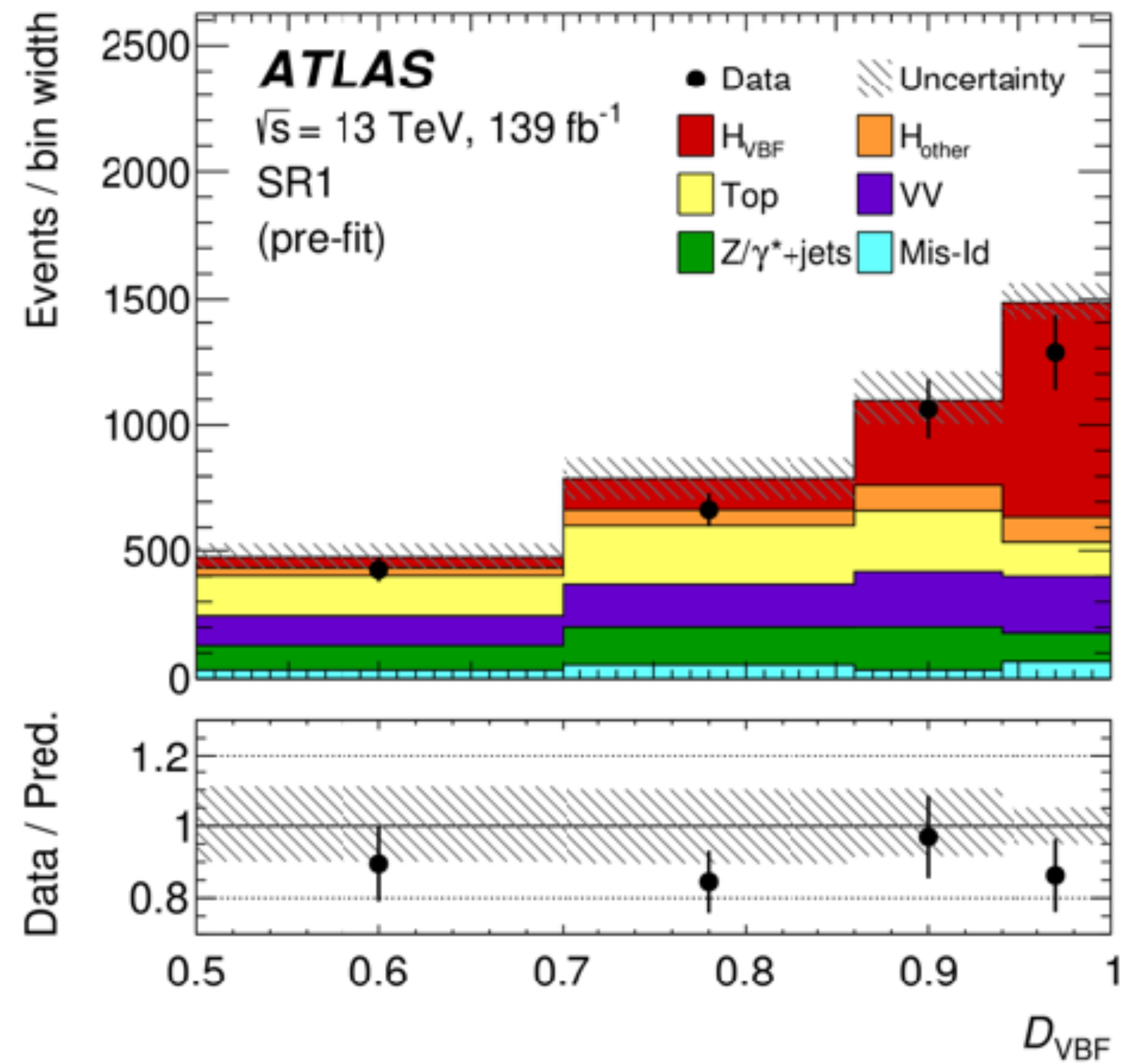
- No evidence for anomalous couplings, but strong constraints on these EFT parameters.

VBF with $H \to WW \to e\nu\mu\nu$

- In Run 2, there is a wealth of Higgs boson events decaying to WW even when restricting to a two-jet phase-space targeting VBF production.
  - Here are shown the transverse mass m_T and the VBF-discriminant output.
- These events have been used to perform inclusive and differential cross section measurements, which are used to put constraints on EFT operators.



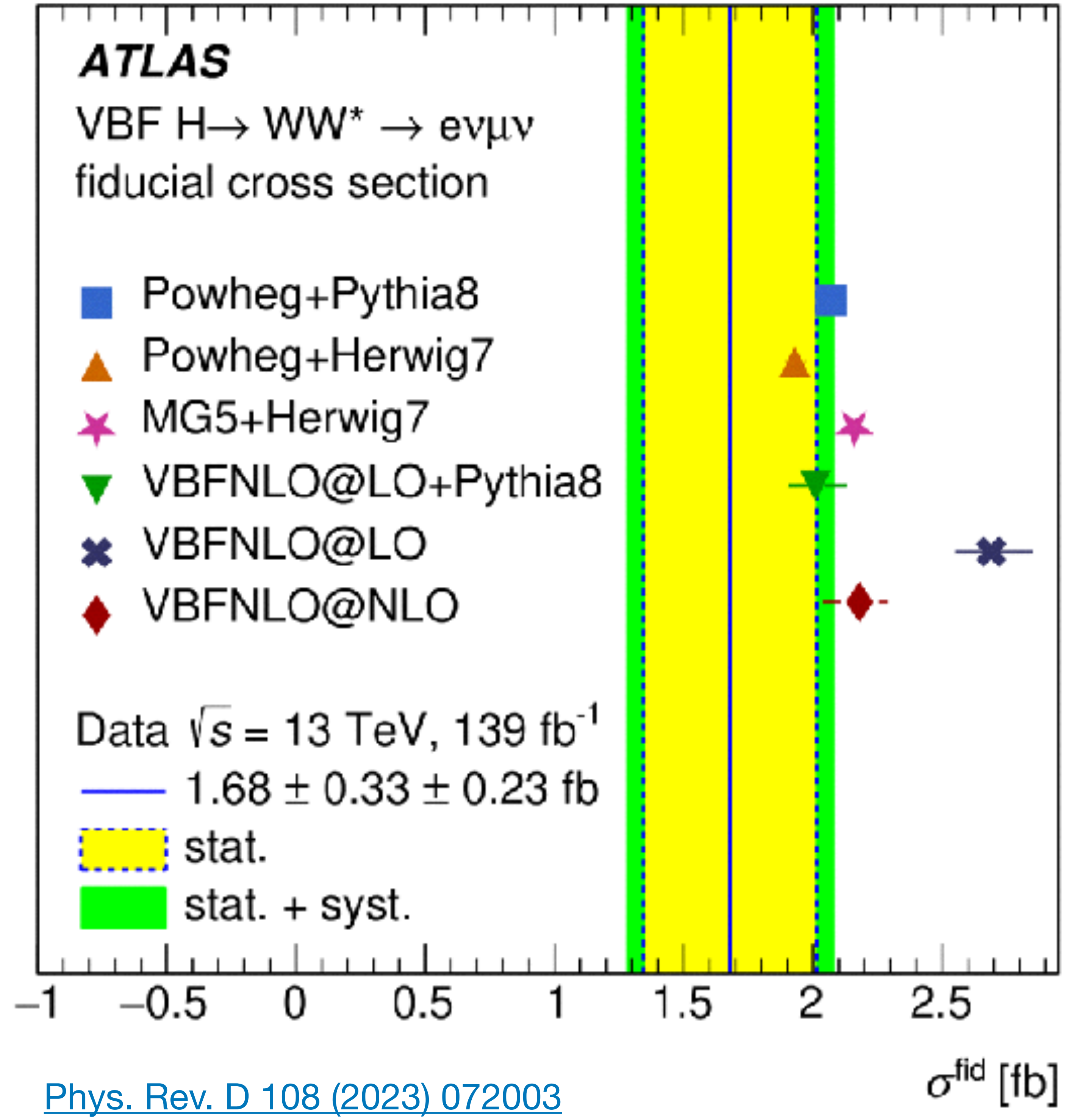




[Phys. Rev. D 108 (2023) 072003]

Inclusive fiducial cross section

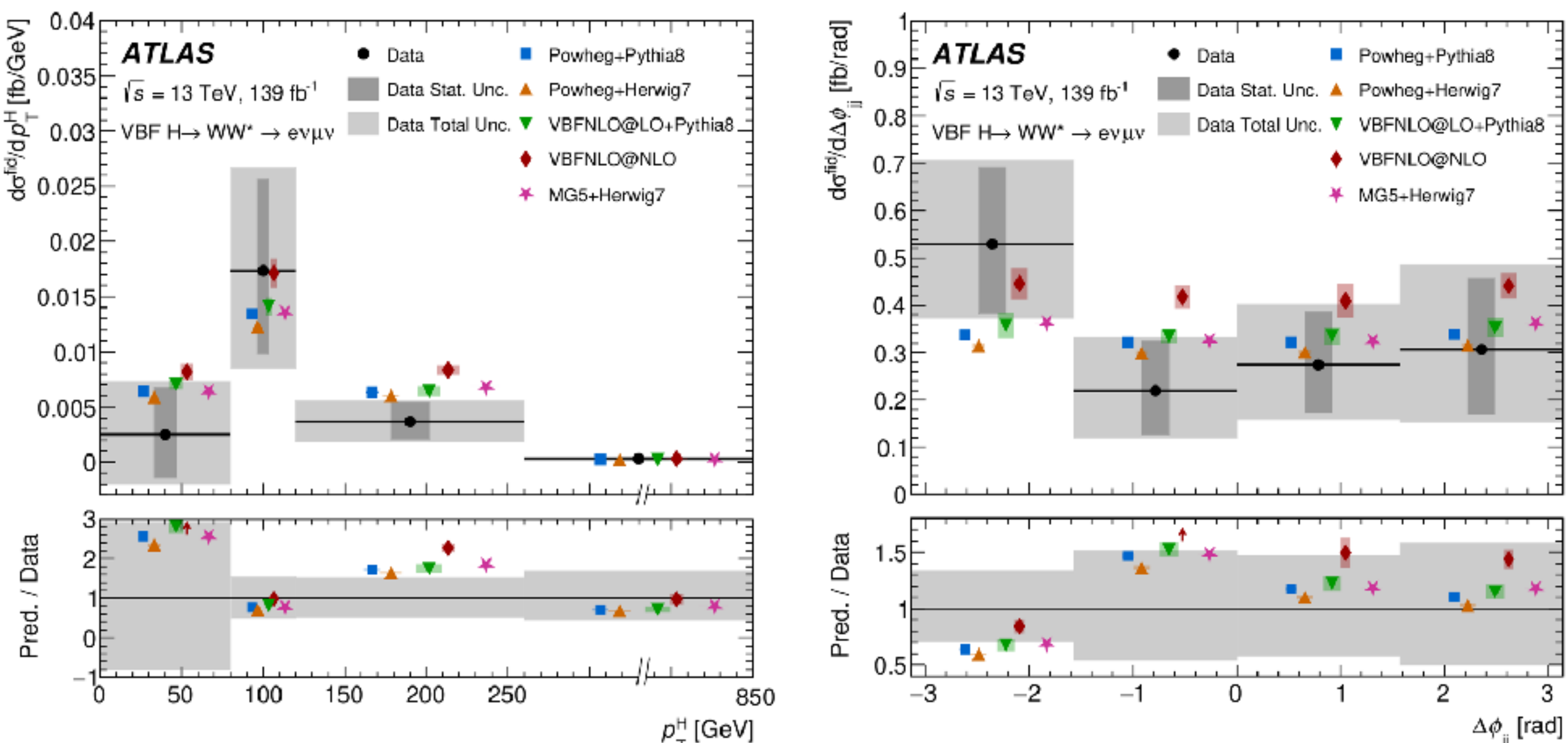
- The VBF $H \to WW \to e\nu\mu\nu$ cross section is measured to be: **σ^{fid} = 1.68 ± 0.33 (stat) ± 0.23 (syst) fb**
- The measurement is compared to the predictions of parton shower generators at the particle level, and to parton-level calculations.
  - Overall the measured value is lower than the predictions, but within the uncertainty.
- The data statistical uncertainty dominates in the total uncertainty, with systematic uncertainties coming mainly from theoretical uncertainties on the signal and background modeling, and from the jet + pile-up + MET modeling.



Phys. Rev. D 108 (2023) 072003

Differential cross section measurements

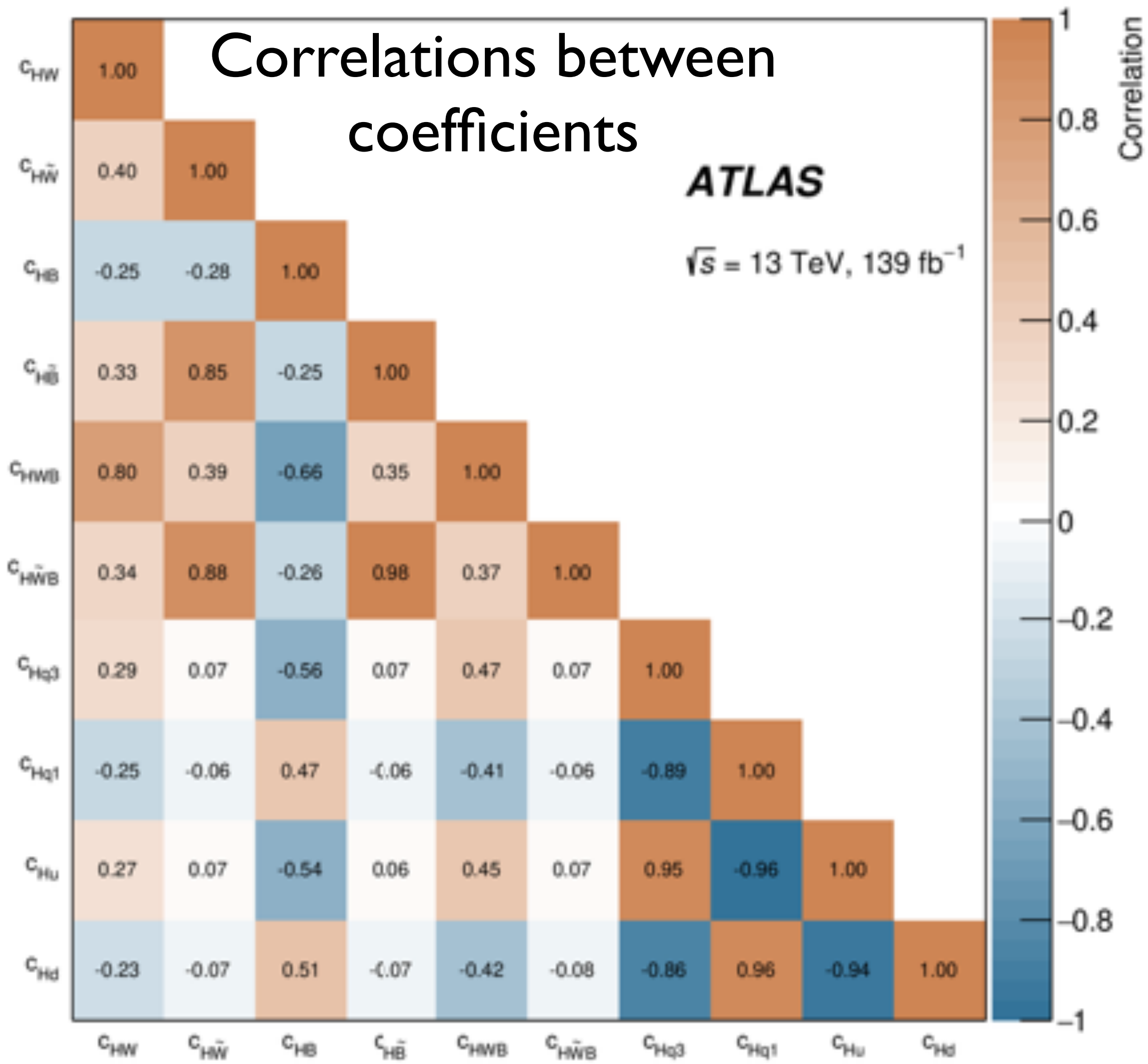
- Differential cross section measurements can be used to validate our MC generators, and to put constraints on higher-order operators that modify the kinematic properties predicted by the SM.
  - Shown are the Higgs boson p_T spectrum and the opening angle between the jets in the VBF $H \to WW \to e\nu\mu\nu$ channel.



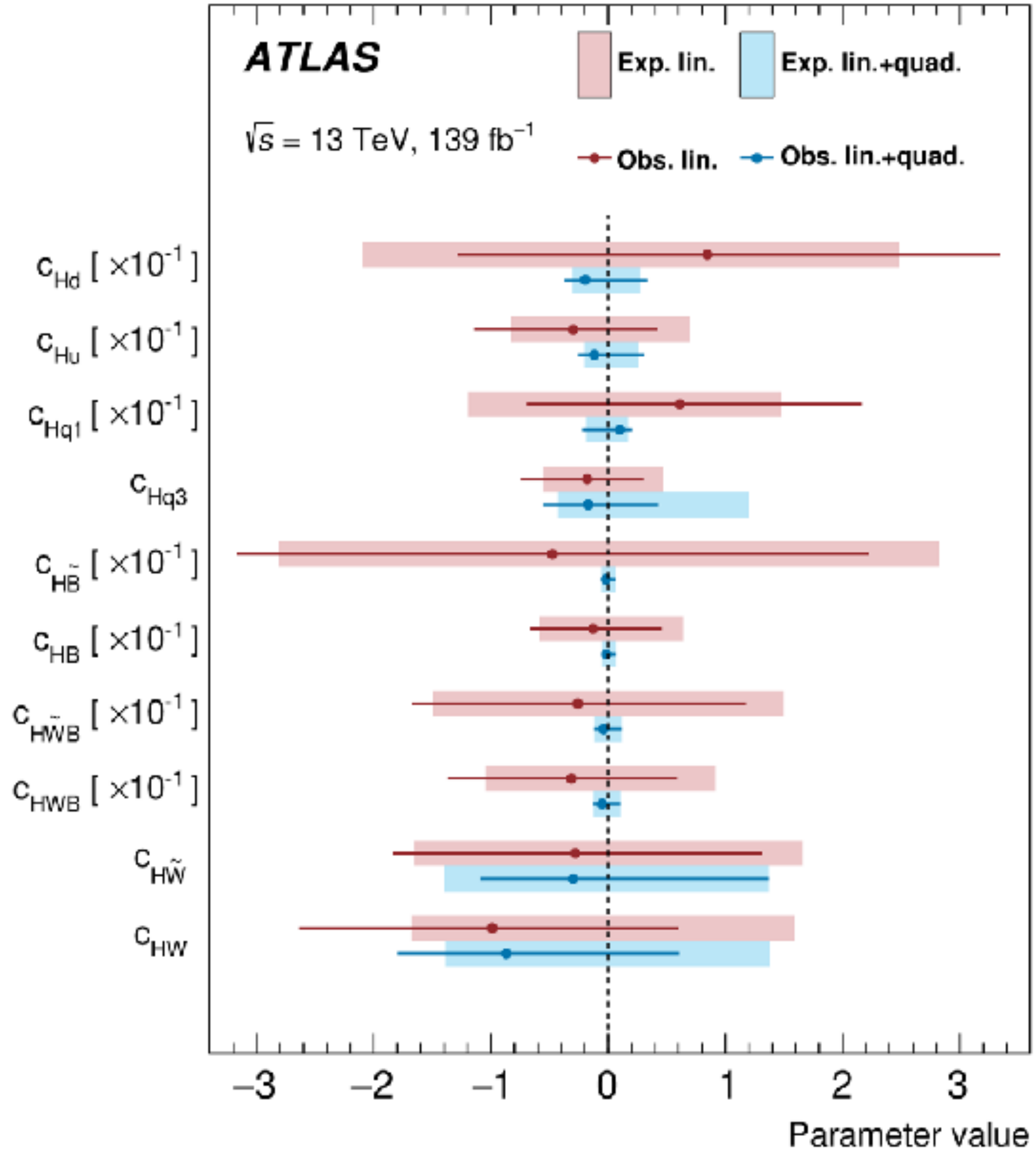
[Phys. Rev. D 108 (2023) 072003](https://doi.org/10.1103/PhysRevD.108.072003)

EFT interpretations

- The differential cross section distributions are used to put constraints on the Wilson coefficients in the SMEFT.
  - One coefficient at the time is left floating, and the others are fixed to their SM values.



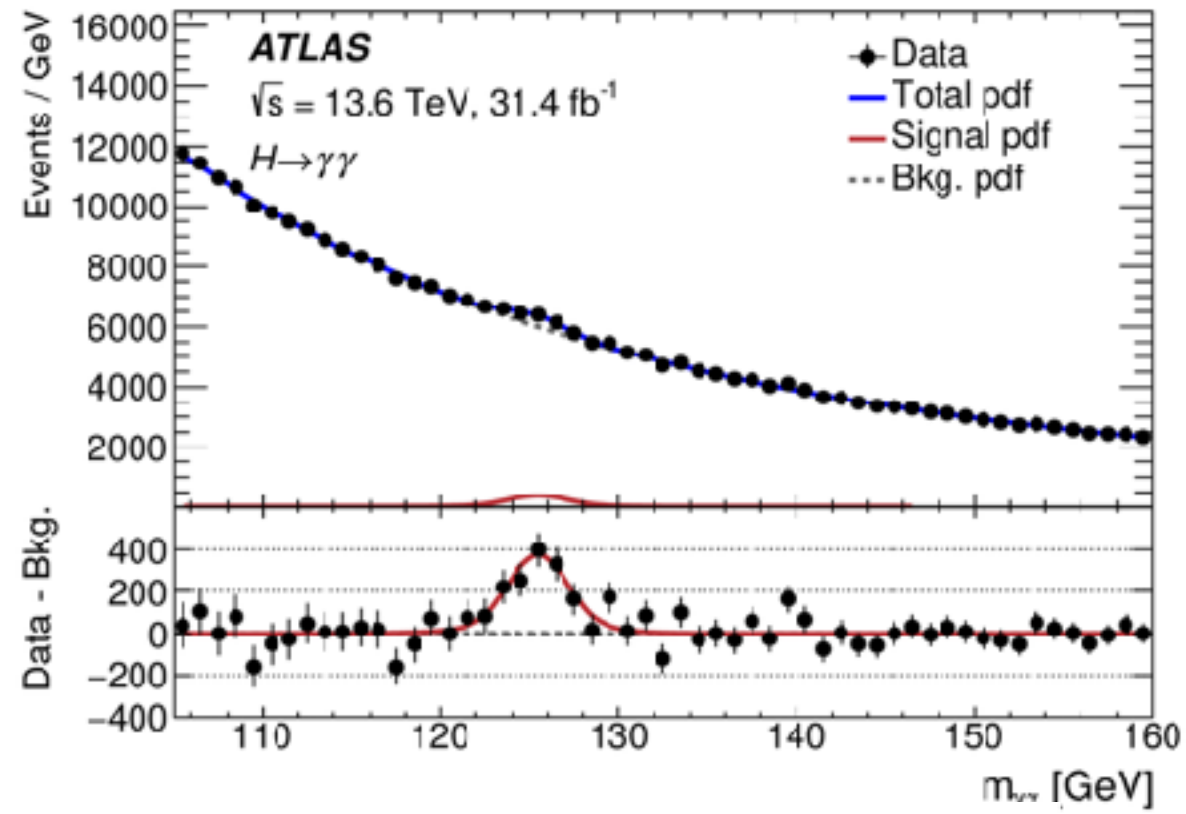
Correlations between coefficients

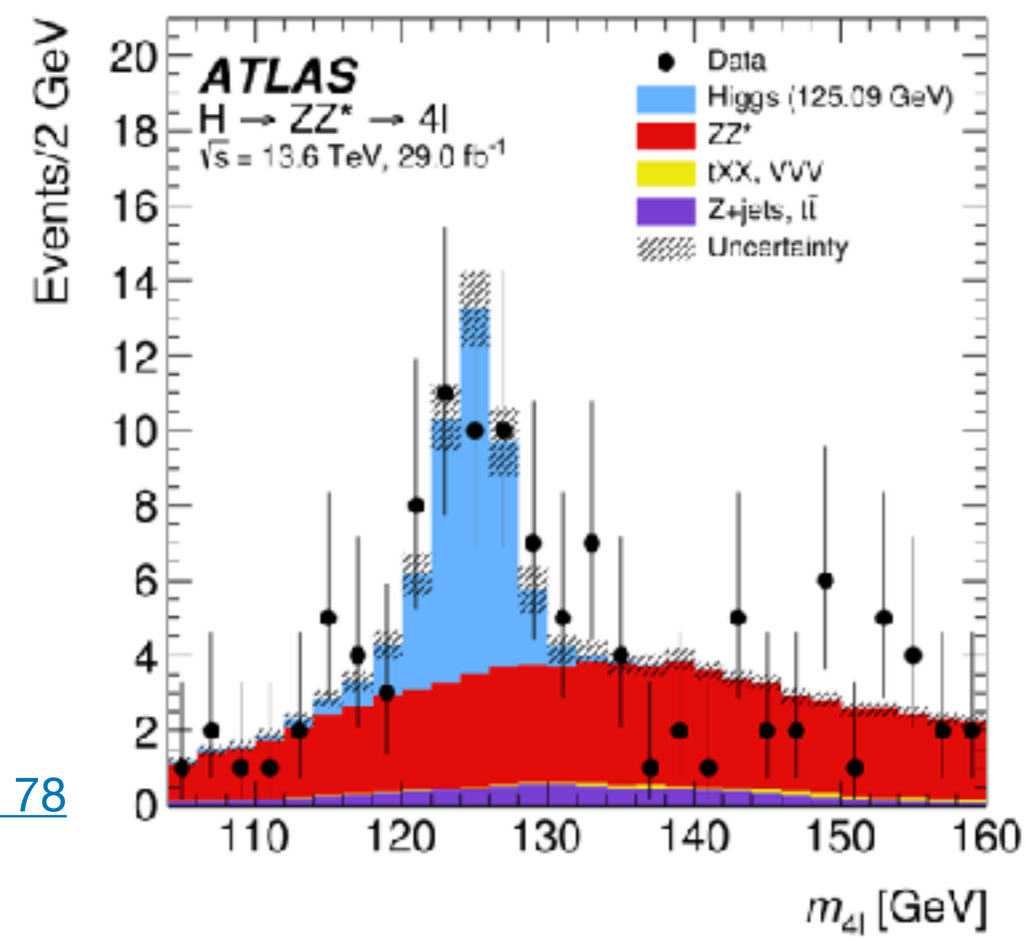


Phys. Rev. D 108 (2023) 072003

$H \rightarrow ZZ \rightarrow 4l$ and $H \rightarrow \gamma\gamma$ results at 13.6 TeV

- The data from the first two years of Run 3 have been analysed:
  - 31.4 fb^{-1} for the $H \rightarrow \gamma\gamma$ channel.
  - 29.0 fb^{-1} for the $H \rightarrow ZZ \rightarrow 4l$ channel.
- The expected peaks in the invariant mass spectra are clearly visible.
  - Cross sections are measured in the fiducial region and extrapolated to inclusive cross sections assuming SM BR, which can then be combined.
- The measured fiducial cross sections are:
  - $\sigma_{fid,\gamma\gamma} = 76^{+14}_{-13}$ fb (67.6 ± 3.7 fb SM exp)
  - $\sigma_{fid,4l} = 2.80 \pm 0.74$ fb (3.67 ± 0.19 fb SM exp)
- Statistical uncertainties still dominate both cross section measurements.





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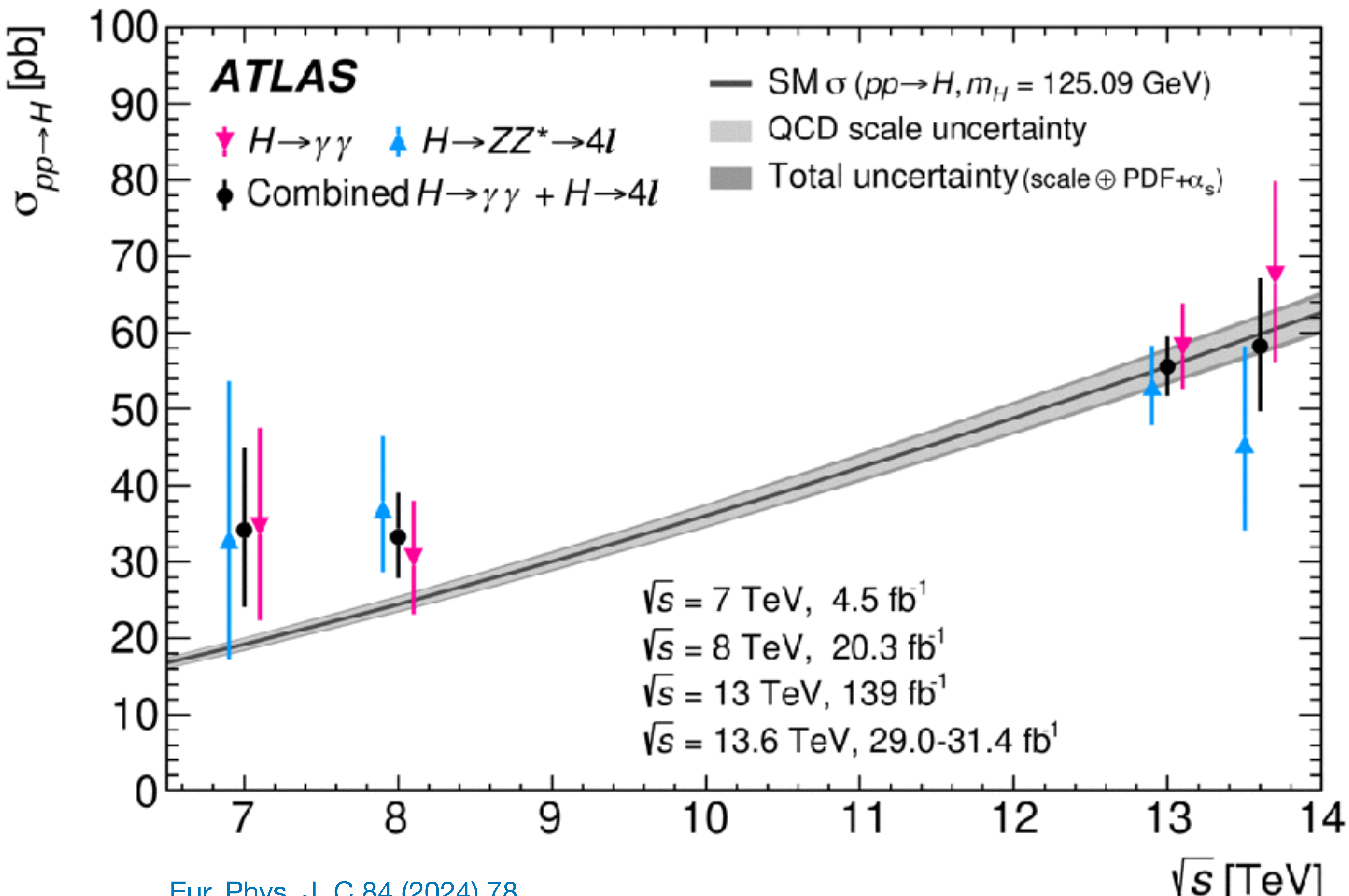
H→ZZ→4*l* and H→γγ results at 13.6 TeV

- The plot with Higgs boson cross sections as a function of collision energy has been updated to incorporate measurements at the new centre-of-mass energy.



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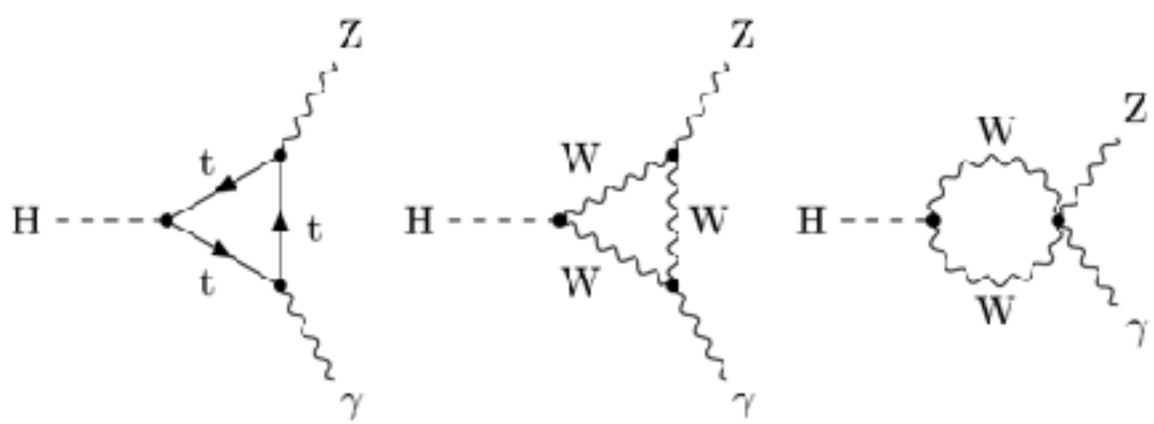
Summary and Conclusions

- We have an extensive set of Higgs boson measurements using the Run 2 data.
  - The Higgs boson couplings to W and Z bosons are compatible with the SM expectations and have a precision of around 10%.
  - The relative sign between the H-W and H-Z couplings has been measured, with the opposite-sign scenario excluded.
  - New results in the VBF $H\to WW\to e\nu\mu\nu$ channel with differential cross section measurements and EFT interpretations.
- We have seen the first results at 13.6 TeV in the $H\to ZZ\to 4l$ and $H\to\gamma\gamma$ channels, using around 30 fb^{-1} of data.
  - We have already collected three times more data in 2024 alone.
- We should always keep in mind that the full LHC program promises to deliver an order of magnitude more data again, and that we can look forward to significant increases in the precision of our measurements. A future e+e- collider will surely deliver another increase in the precision.
  - The SM will be put under severe test from the measurements in the Higgs sector.

Stay tuned for more exciting Higgs boson results!

Backup

Higgs boson decays to Zγ



- The Higgs boson can decay to a Zγ pair through a loop of heavy particles.
  - Sensitive to contribution from new heavy particles.
- Look for a bump in the invariant Zγ spectrum.
- A combination of results from ATLAS and CMS results in a more than 3σ significance observation of this decay.
- Extracing the branching ratio yields: BR(H→Zγ) = $(3.4 \pm 1.1) \times 10^{-3}$

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