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Search for CP violating effects in HWW vertex in the WH production channel in 13 TeV pp collisions with the ATLAS detector

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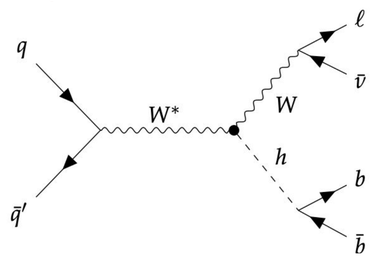
Introduction

Baryon asymmetry of the Universe

- One of three Sakharov conditions:
  - Charge-Parity symmetry violation
- SM Higgs boson - scalar particle
  - CP violating interactions allowed

Search for CP-violating effects in WH production channel ([1])



SMEFT formalism

$$\mathcal{L}_{\text{SMEFT}} = \mathcal{L}_{\text{SM}} + \sum_{d>4}\sum_{i}\frac{c_i O_i^{(d)}}{\Lambda^{(d-4)}}$$

- Warsaw basis
- WH is purely sensitive to HWW **CP-odd coupling ($c_{H\tilde{W}}$)**
- Focus only on CP-odd **SM-SMEFT**

Goal: constrain $c_{H\tilde{W}}$

$$|\mathcal{M}|^2 = |\mathcal{M}_{SM}|^2 + \frac{c_{H\widetilde{W}}}{\Lambda^2} 2\Re\left(\mathcal{M}^*_{O_{H\widetilde{W}}}\mathcal{M}_{SM}\right) + \frac{c^2_{H\widetilde{W}}}{\Lambda^4}|\mathcal{M}_{O_{H\widetilde{W}}}|^2$$

Analysis strategy

Spin-off of *WH* and *ZH* with H→bb production measurements ([2])

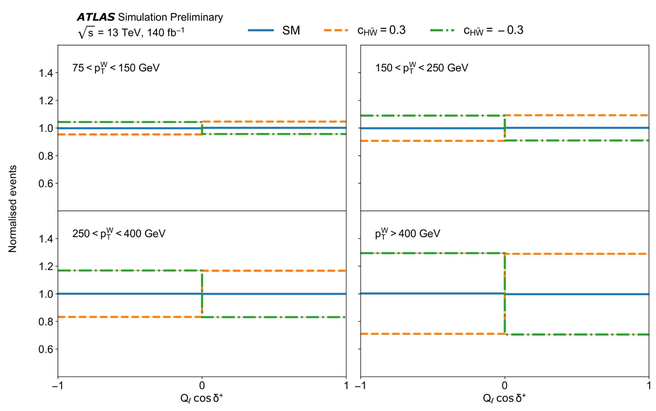
Angular observable: $Q_\ell Cos\delta^+$

$$\cos\delta^+ = \frac{\mathbf{p}_\ell^{(W)} \cdot (\mathbf{p}_H \times \mathbf{p}_W)}{|\mathbf{p}_\ell^{(W)}| \cdot |\mathbf{p}_H \times \mathbf{p}_W|}$$

Energy-related observable: p_T^W

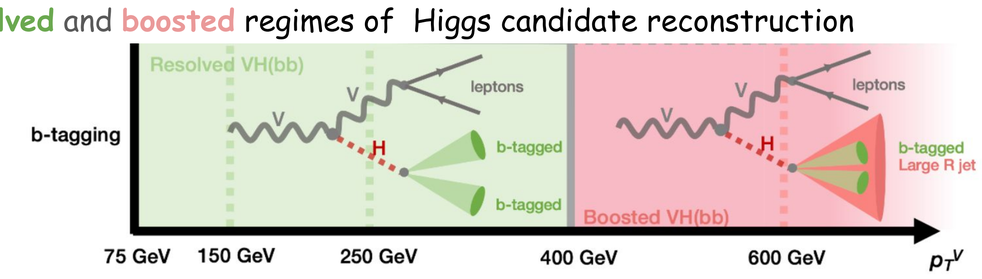
- **STXS measurements:**
  - p_T^W x $Q_\ell Cos\delta^+$ bins event classification (2D fit)
- **SMEFT interpretation:**
  - constrain $c_{H\tilde{W}}$, only via linear term
  - Truth-level cross-section in each STXS bin as a function of $c_{H\tilde{W}}$ using SMEFTSIM 3.0 ([4])

Normalized distributions of angular observable in four p_T^W regions (SM,BSM)



Event selection and categorisation

Resolved and boosted regimes of Higgs candidate reconstruction



Multivariate analysis:

- Set of Boosted Decision Trees

Signal WH process:

- Isolated lepton
- Missing transverse energy from the neutrino
- 2 b-jets in the final state

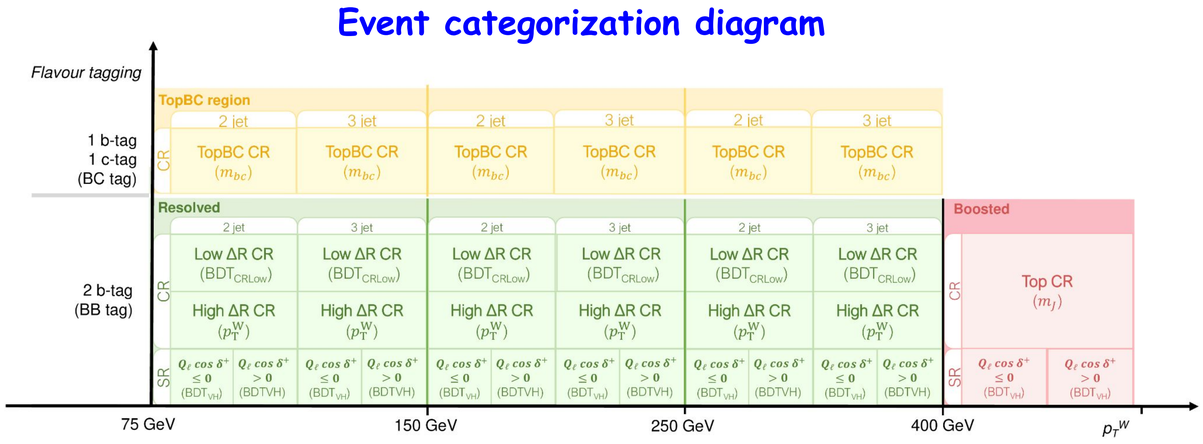
Dominant backgrounds:

- Top quark ($t\bar{t}$, Wt)
- W+jets (mainly heavy flavoured)

Minor backgrounds:

- Single top s/t-channels
- Diboson, Z+jets, Multijets

Event categorization diagram



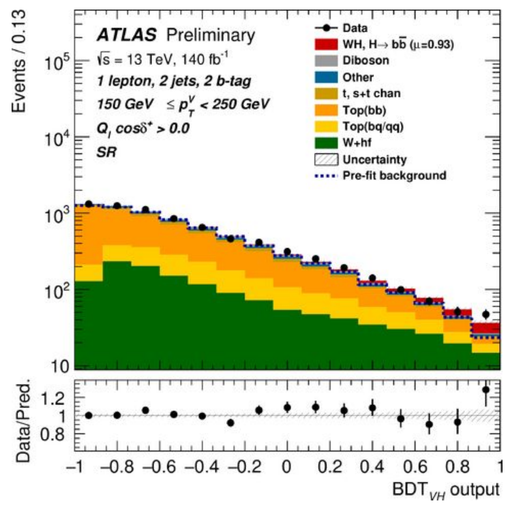
Fit Model

- **Maximum likelihood fit**
  - Float normalisation of dominant backgrounds
  - Effect of systematics - via nuisance parameters

Systematic uncertainties:

- **Experimental**
- **Modelling:** Normalisation uncertainties, acceptance ratios, shape uncertainties

WH (H→bb) inclusive signal strength fit



BDT distribution after WH (H→bb) inclusive signal strength fit in:

- 2-jet resolved signal regions for p_T^W:150-250 GeV, $Q_\ell Cos\delta^+$>0

WH, H→bb inclusive signal strength

$$\mu_{WH}^{bb} = 0.93^{+0.22}_{-0.21} = 0.93^{+0.15}_{-0.15}(\text{stat.})^{+0.16}_{-0.15}(\text{syst.})$$

Observed (expected) significance:

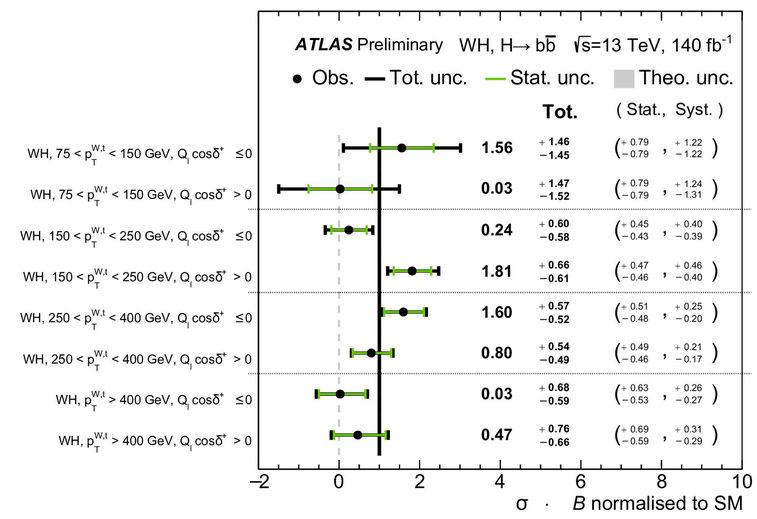
- 4.7σ (5.0σ)
- Good agreement with SM

STXS measurements

Simplified template cross section framework

- Signal MC events are classified with truth p_T^W and $Q_\ell Cos\delta^+$
- 8 STXS reconstruction-level regions
- The fraction of correctly assigned events ranges between 60-80%

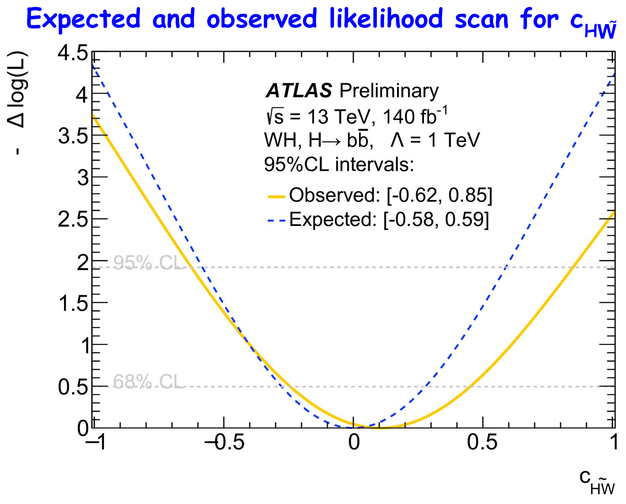
Measured *WH* production cross sections times branching ratios



- The results are in agreement with SM
- The experimental precision is generally dominated by the statistical uncertainty

CP-odd interpretation

Expected and observed likelihood scan for $c_{H\tilde{W}}$



Fit to STXS regions:

- Use only the shape of $Q_\ell Cos\delta^+$ in each p_T^W region to fit $c_{H\tilde{W}}$
- Ensures sensitivity to only CP-odd effects

Observed 95% CL limits: [-0.62,0.85]

Results are among the most stringent ATLAS measurement:

- VBF H→ττ ([3]): 95% CL [-0.23, 0.70]
- Fewer assumptions on other coefficients

References

1. Search for CP violation in *WH* production in 13 TeV *p p* collisions with the ATLAS detector ATL-PHYS-PUB-2025-022

2. The ATLAS collaboration., Aad, G., Aakvaag, E. *et al.* Measurements of *WH* and *ZH* production with Higgs boson decays into bottom quarks and direct constraints on the charm Yukawa coupling in 13 TeV *pp* collisions with the ATLAS detector. *J. High Energ. Phys.* 2025, 75 (2025). https://doi.org/10.1007/JHEP04(2025)075

3. Probing the Higgs boson CP properties in vector-boson fusion production in the H→τ+τ− channel with the ATLAS detector, arXiv:2506.19395

4. I. Brivio, SMEFTsim 3.0 — a practical guide, JHEP 04 (2021) 073, arXiv: 2012.11343

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