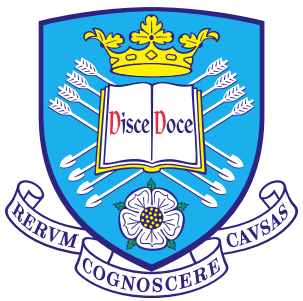
Combined ALTAS Higgs boson measurements and their interpretations in EFT and new physics models

Lepton Photon 2021, 11 Jan 2022, Manchester

Hannes Mildner on behalf of
the ATLAS collaboration



The University Of Sheffield.

Introduction

Presenting three recently published combined Higgs boson measurements with new-physics interpretations

- ATLAS-CONF-2021-053:
  Combined measurement of Higgs boson production and decay (Nov 2021)
- ATLAS-CONF-2021-051:
  Combined measurement of $VH(b\bar{b})$ in "boosted" + "resolved" channel (Sep 2021)
- ATLAS-CONF-2022-002
  Combined measurement of Higgs boson (differential) cross sections (Jan 2022)

Higgs combination

ATLAS-CONF-2021-053 Combined measurement of Higgs boson production and decay

- New channels w.r.t. previous combination
- Updates to full Run 2 data set
- Allows for improved granularity of STXS meassurement

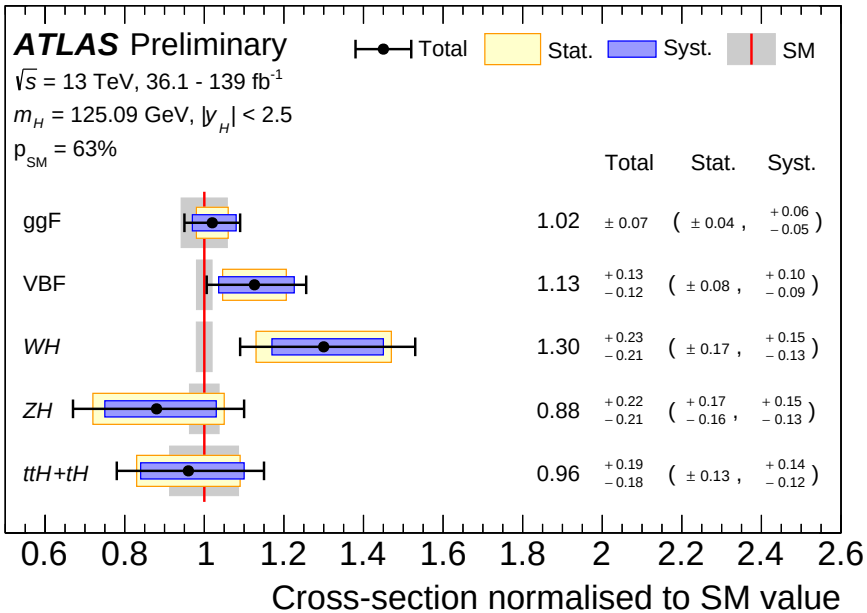
Decay channel		Target Production Modes	$\mathcal{L}$ [fb^{-1}]	
$H \to \gamma\gamma$		ggF, VBF, $WH, ZH, t\bar{t}H, tH$	139	
$H \to ZZ^*$		ggF, VBF, $WH, ZH, t\bar{t}H(4\ell)$	139	
		$t\bar{t}H$	36.1	
$H \to WW^*$		ggF, VBF	139	Update
		$t\bar{t}H$	36.1	
$H \to \tau\tau$	New channels	ggF, VBF, $WH, ZH, t\bar{t}H(\tau_{\text{had}}\tau_{\text{had}})$	139	Update
		$t\bar{t}H$	36.1	
$H \to b\bar{b}$	New: boosted Higgs	WH, ZH	139	
		VBF	126	Update
		$t\bar{t}H$	139	Update
$H \to \mu\mu$		ggF, VBF, $VH, t\bar{t}H$	139	
$H \to Z\gamma$	NEW	ggF, VBF, $VH, t\bar{t}H$	139	
$H \to inv$		VBF	139	

- Total signal strength uncertainty reduced by 10%

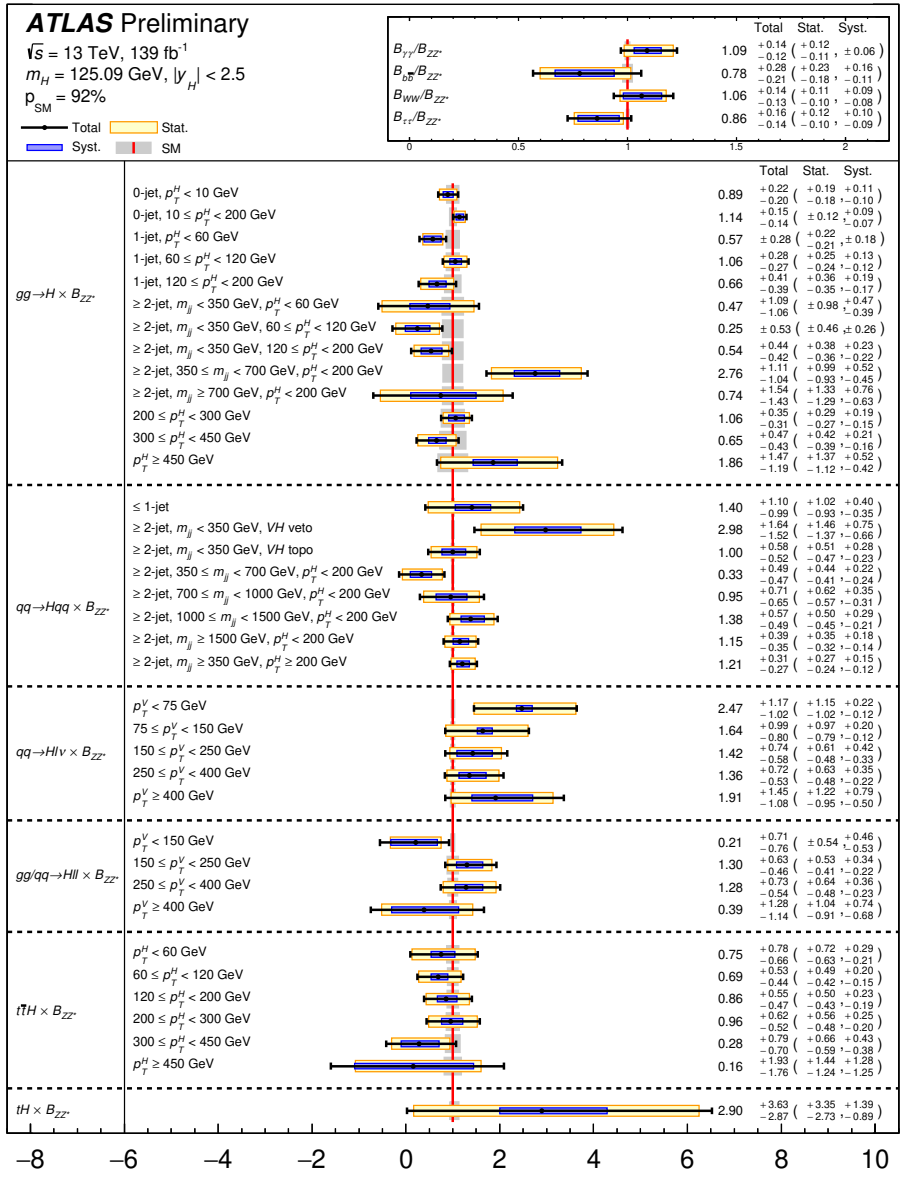
$$\mu_{\text{global}} = \frac{\sigma_{\text{meas.}}}{\sigma_{\text{SM}}} = 1.06 \pm 0.03\,(\text{stat.}) \pm 0.03\,(\text{exp.}) \pm 0.04\,(\text{sig. th.}) \pm 0.02\,(\text{bkg. th.})$$

- Interpretations in various signal-strength and coupling parametrizations performed – some presented today

Higgs combination: cross-sections and STXS



- Top: production cross section measurement, normalized to SM
- Right: Simplified Template Cross-section measurement
  - Parametrization in terms of prod process, partitioned in phase space + ratios of branching ratios



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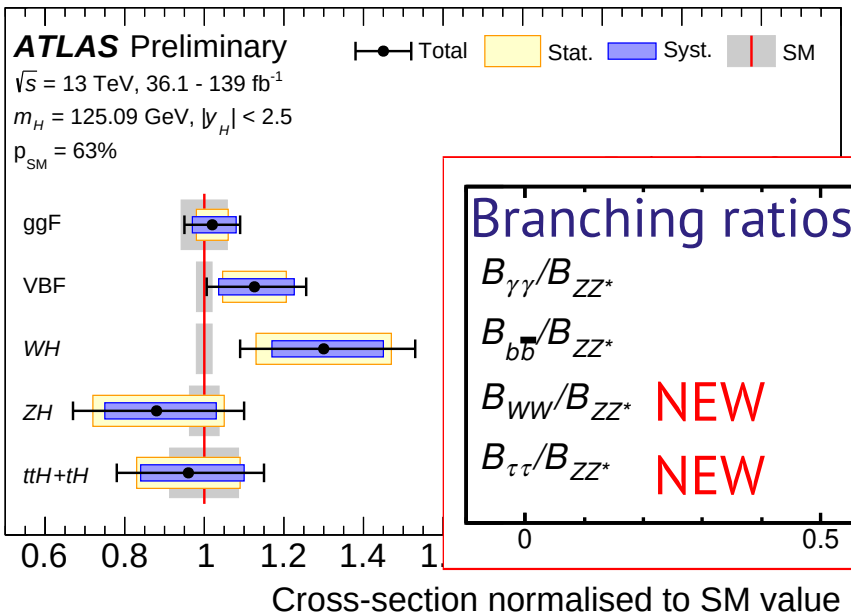

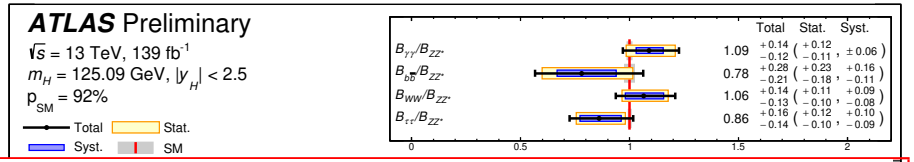

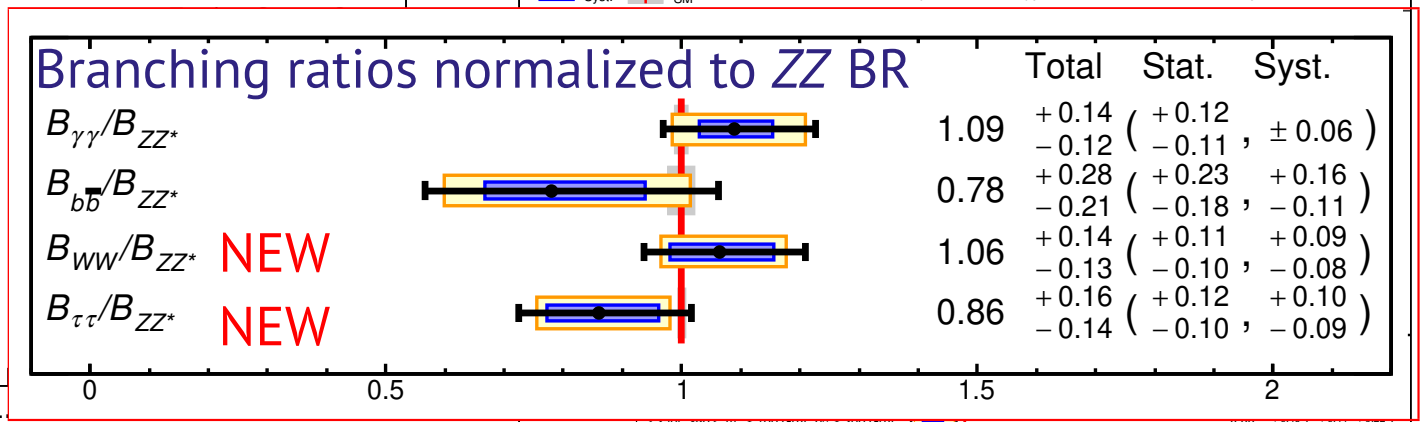

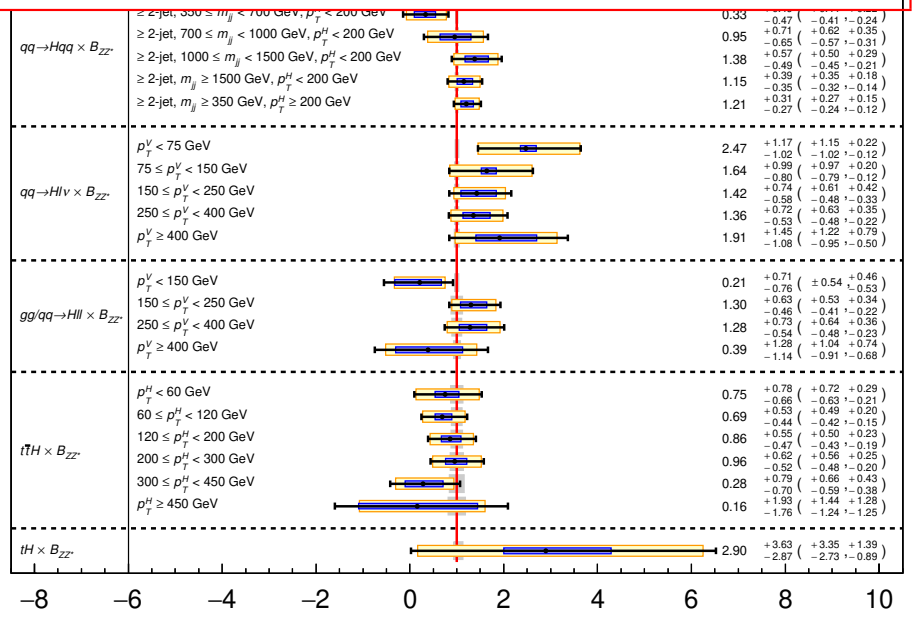

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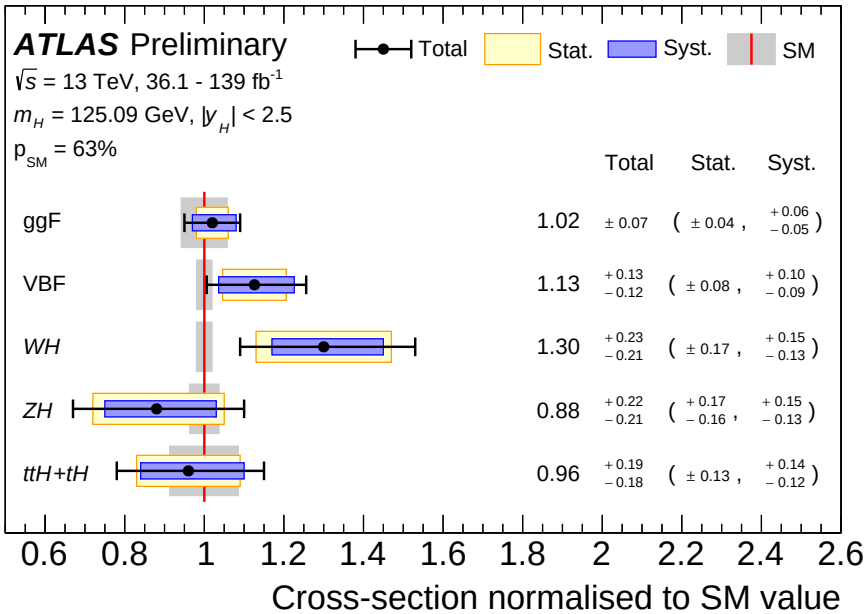
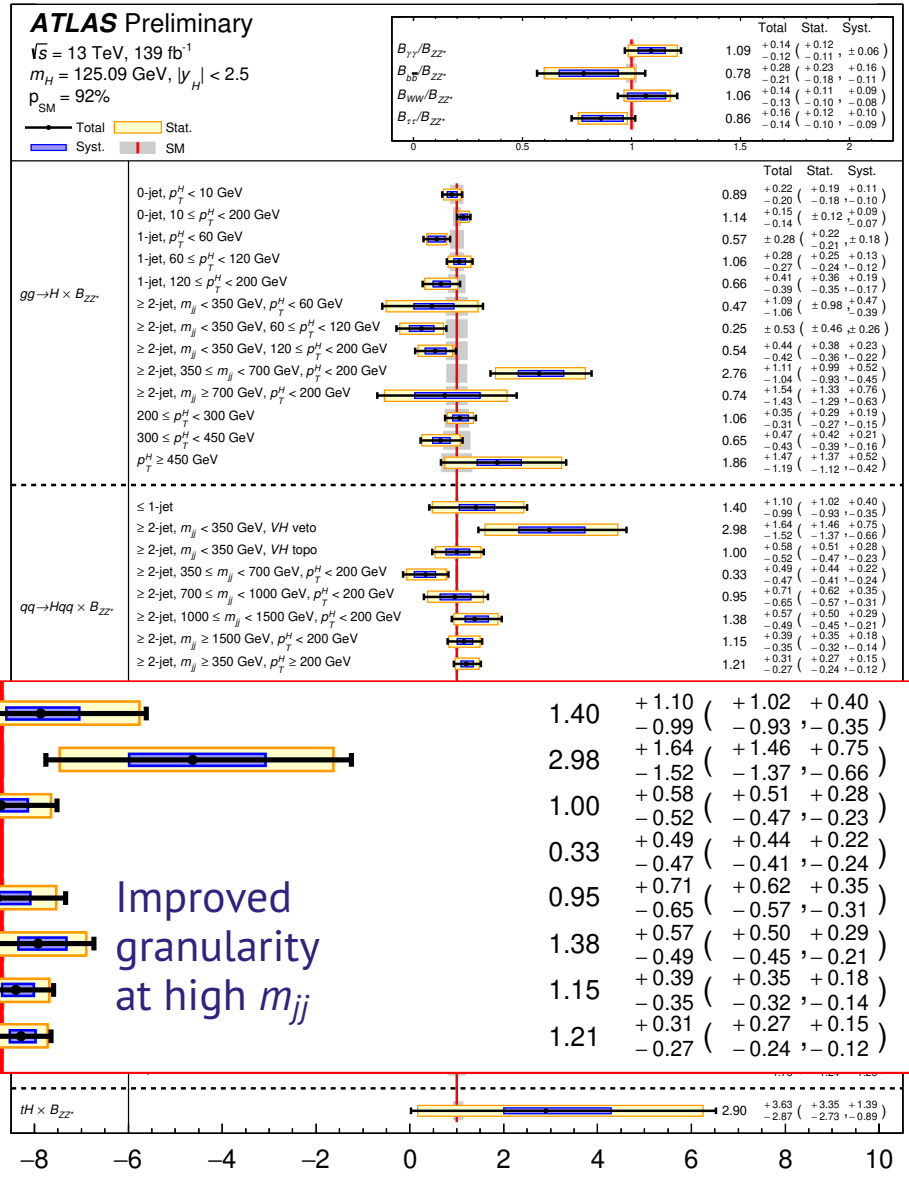




- Top: production cross section

- space + ratios of branching ratios

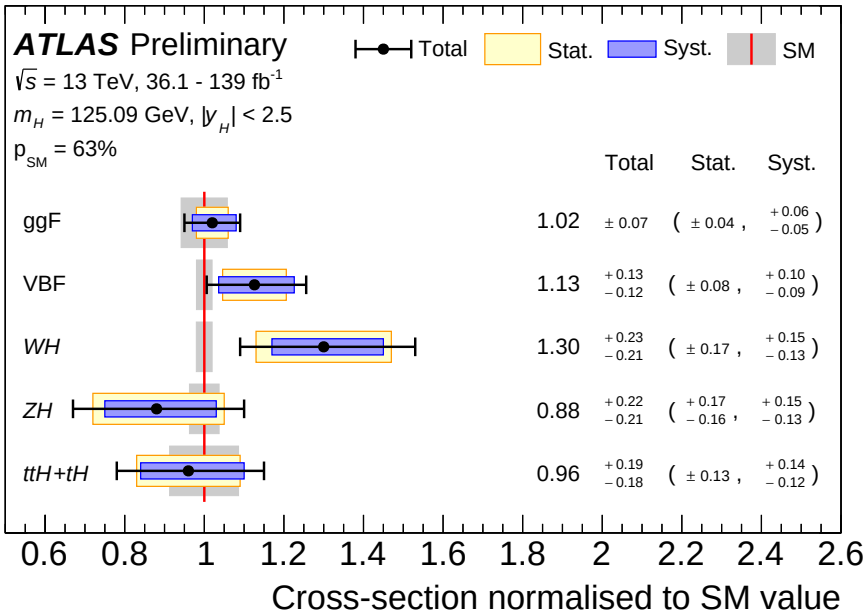
VBF and $V(jj)H$

$qq \to Hqq \times B_{ZZ^*}$

- ≤ 1-jet
- ≥ 2-jet, m_{jj} < 350 GeV, *VH* veto
- ≥ 2-jet, m_{jj} < 350 GeV, *VH* topo
- ≥ 2-jet, 350 ≤ m_{jj} < 700 GeV, p_T^H < 200 GeV
- ≥ 2-jet, 700 ≤ m_{jj} < 1000 GeV, p_T^H < 200 GeV
- ≥ 2-jet, 1000 ≤ m_{jj} < 1500 GeV, p_T^H < 200 GeV
- ≥ 2-jet, m_{jj} ≥ 1500 GeV, p_T^H < 200 GeV
- ≥ 2-jet, m_{jj} ≥ 350 GeV, p_T^H ≥ 200 GeV

Improved granularity at high m_{jj}

Higgs combination: cross-sections and STXS



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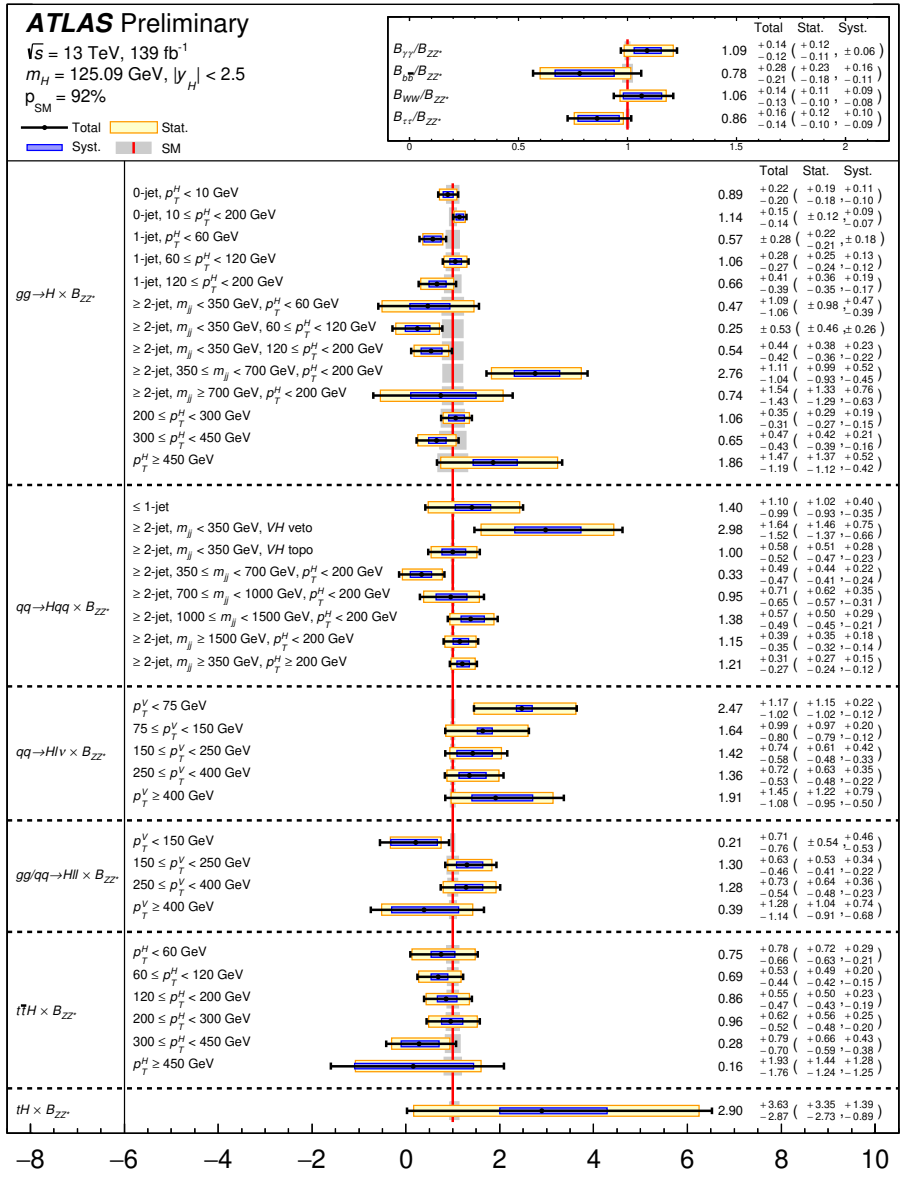
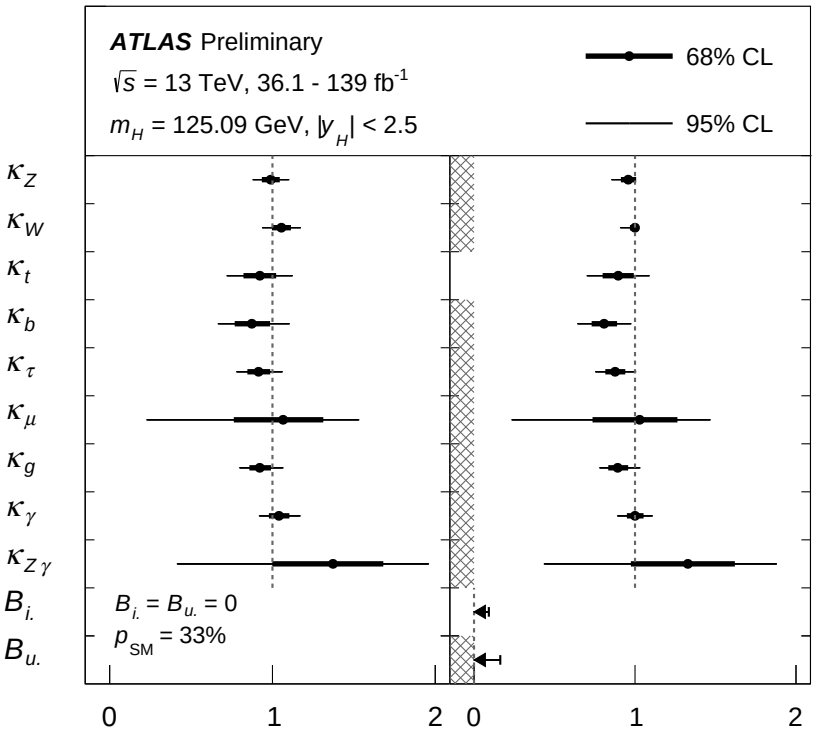


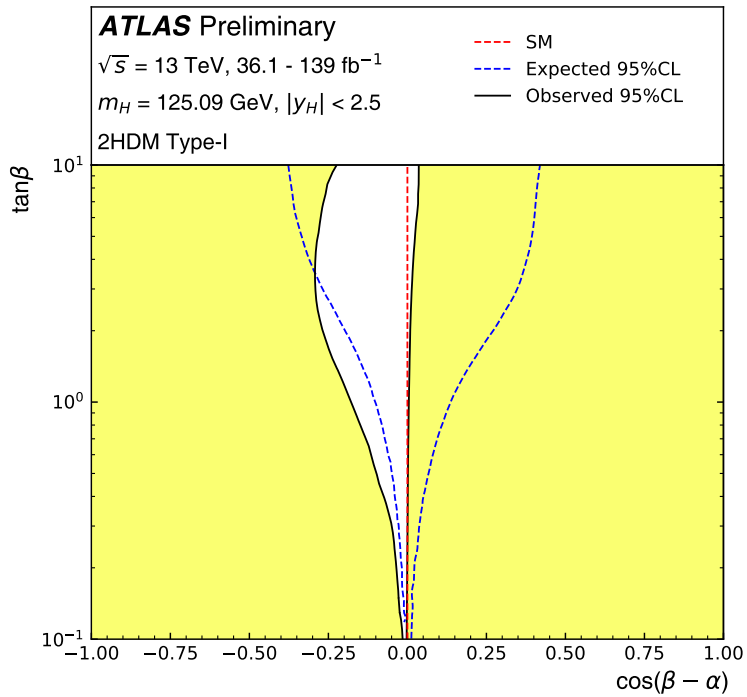
Higgs combination: coupling modifiers and 2HDM



No invisible/un-detected decays

$|\kappa_V| < 1$

- Coupling modifier param.
- Here including effective couplings κ_g, κ_γ, and $\kappa_{Z\gamma}$ (new)



- Interpretation in 2HDMs
- Assume observed Higgs is light CP-even neutral scalar
- Type-I 2HDM: $\kappa_V = \sin(\beta-\alpha)$, $\kappa_f = \sin(\beta-\alpha) + \cos(\beta-\alpha)/\tan(\beta)$

Higgs combination: SMEFT interpretation

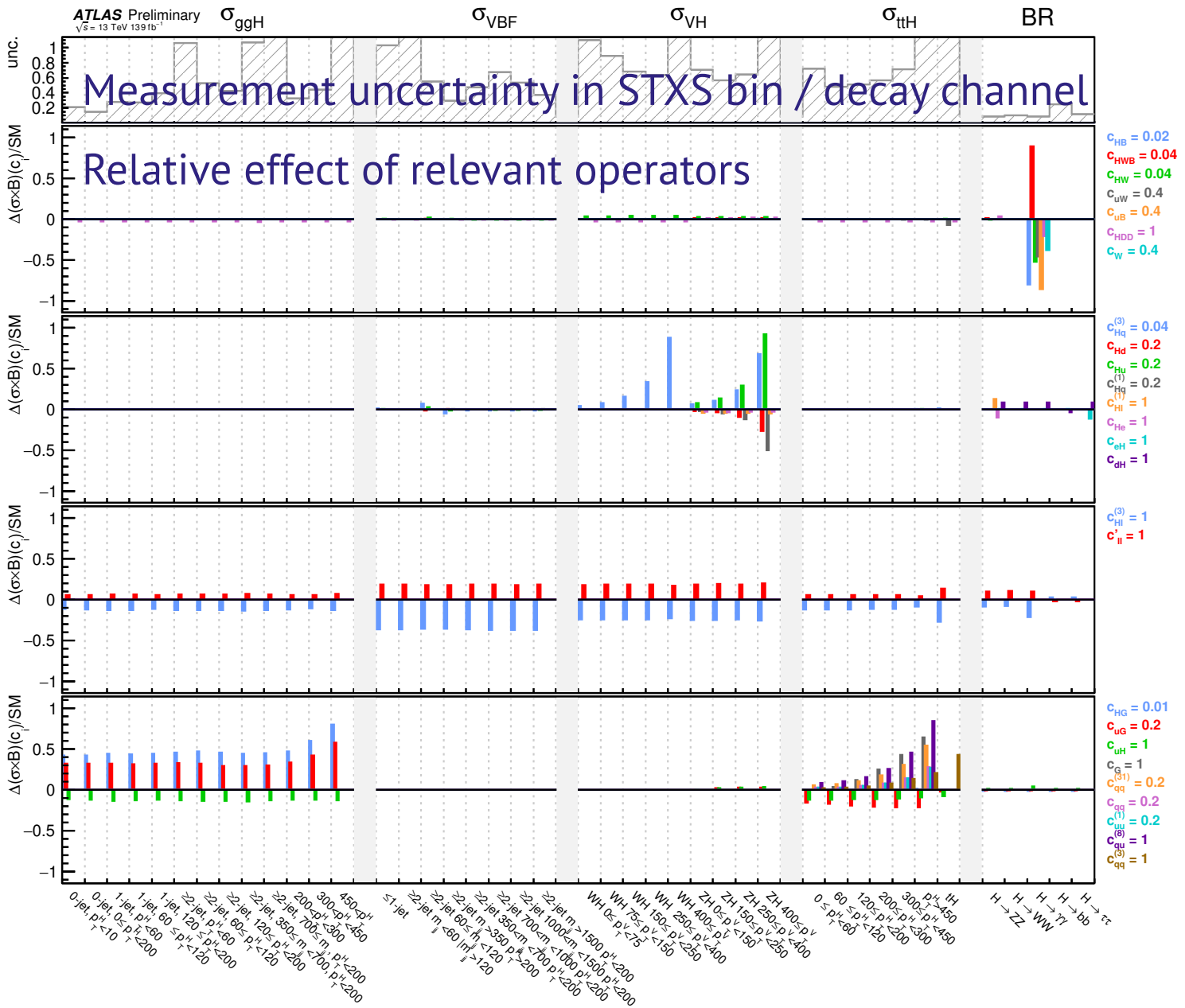
- Interpretation in Standard Model Effective Field Theory (SMEFT)

$$\mathcal{L}_{\text{SMEFT}} = \mathcal{L}_{\text{SM}} + \sum_{i}^{N_{d6}} \frac{c_i}{\Lambda^2} O_i^{(6)} + \sum_{j}^{N_{d8}} \frac{b_i}{\Lambda^4} O_i^{(8)} + \ldots,$$

- $O_i^{(n)}$ affect rates and kinematics
- STXS bins and Higgs BRs reparametrized in terms of dimension-six Wilson coefficients c_i in Warsaw basis
- Correction for modified acceptance in $H \to 4\ell$ and $H \to \ell\nu\ell\nu$
- $U(3)^5$ flavour symmetry assumed, linearized in Wilson coefficients contribution (linear contribution $\propto \Lambda^{-2}$, expected to be leading)
- LO parametrization multiplied by state-of-the-art SM prediction
- All 32 Wilson coefficients with significant impact considered

$\to$ New measurements improve precision and reduce ambiguity

Higgs combination: operator impact



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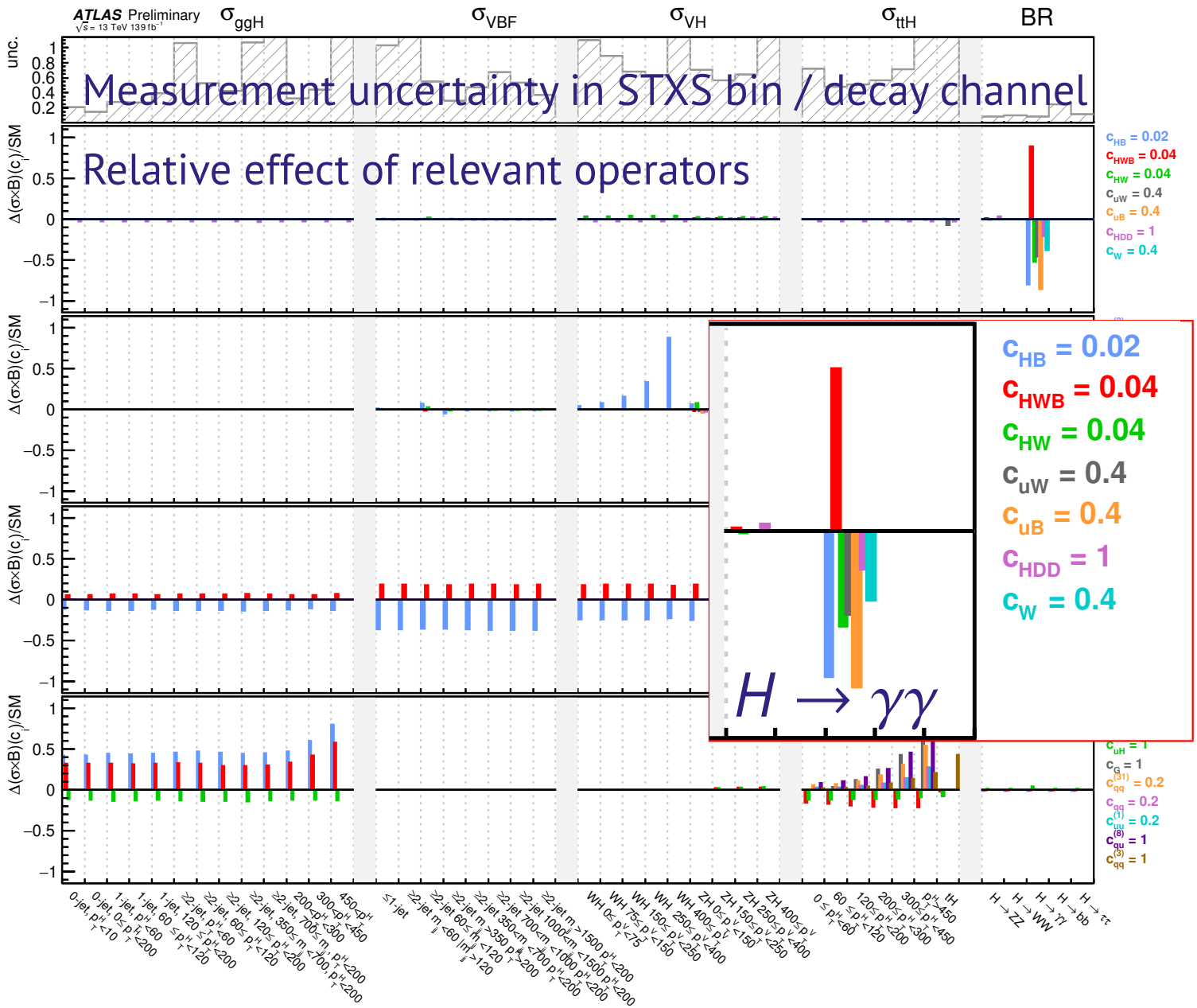
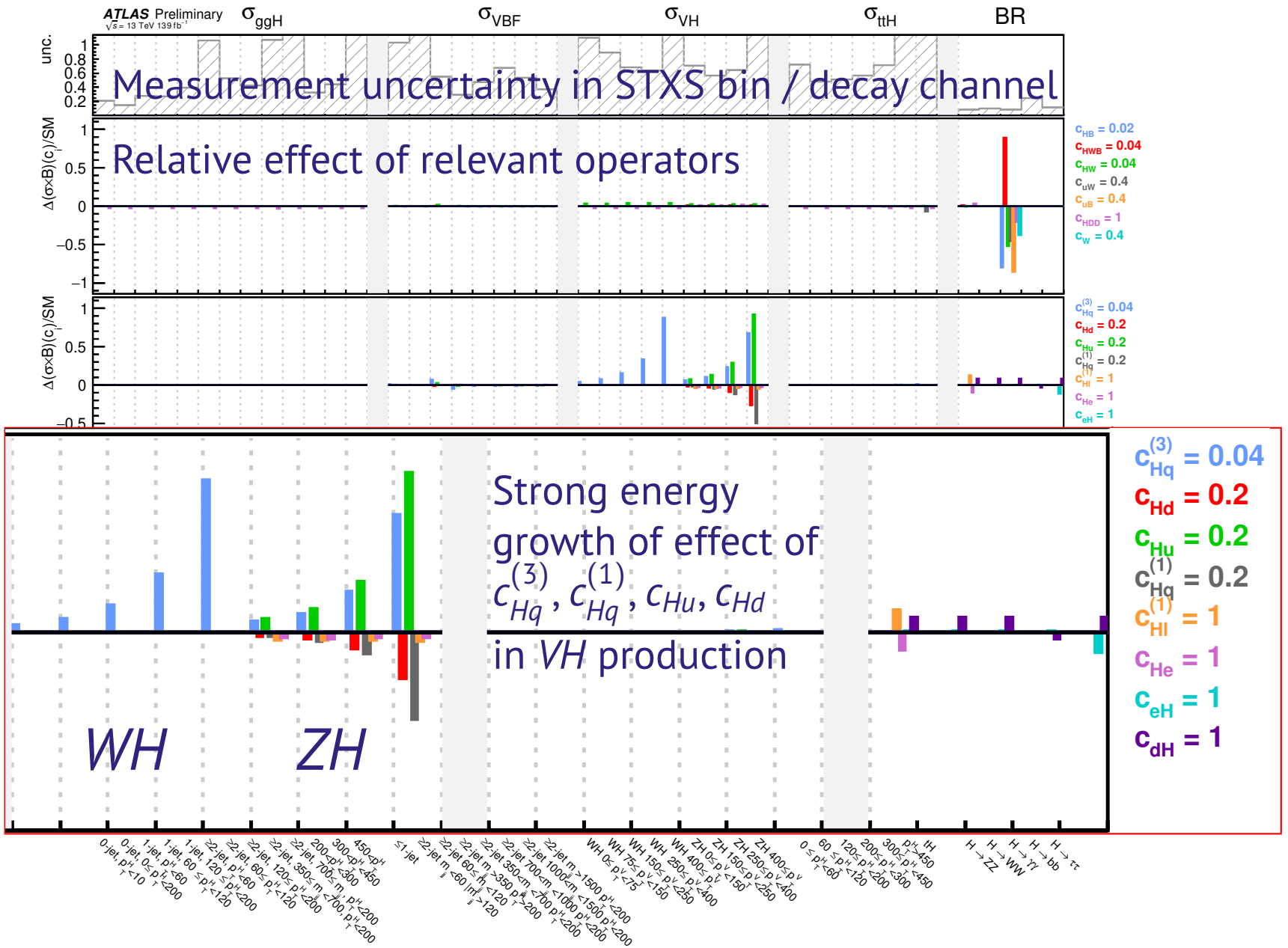


O(1) effects for small small values of c_{HB}, c_{HW}, c_{HWB} (tree level $H \to \gamma\gamma$)

Higgs combination: operator impact



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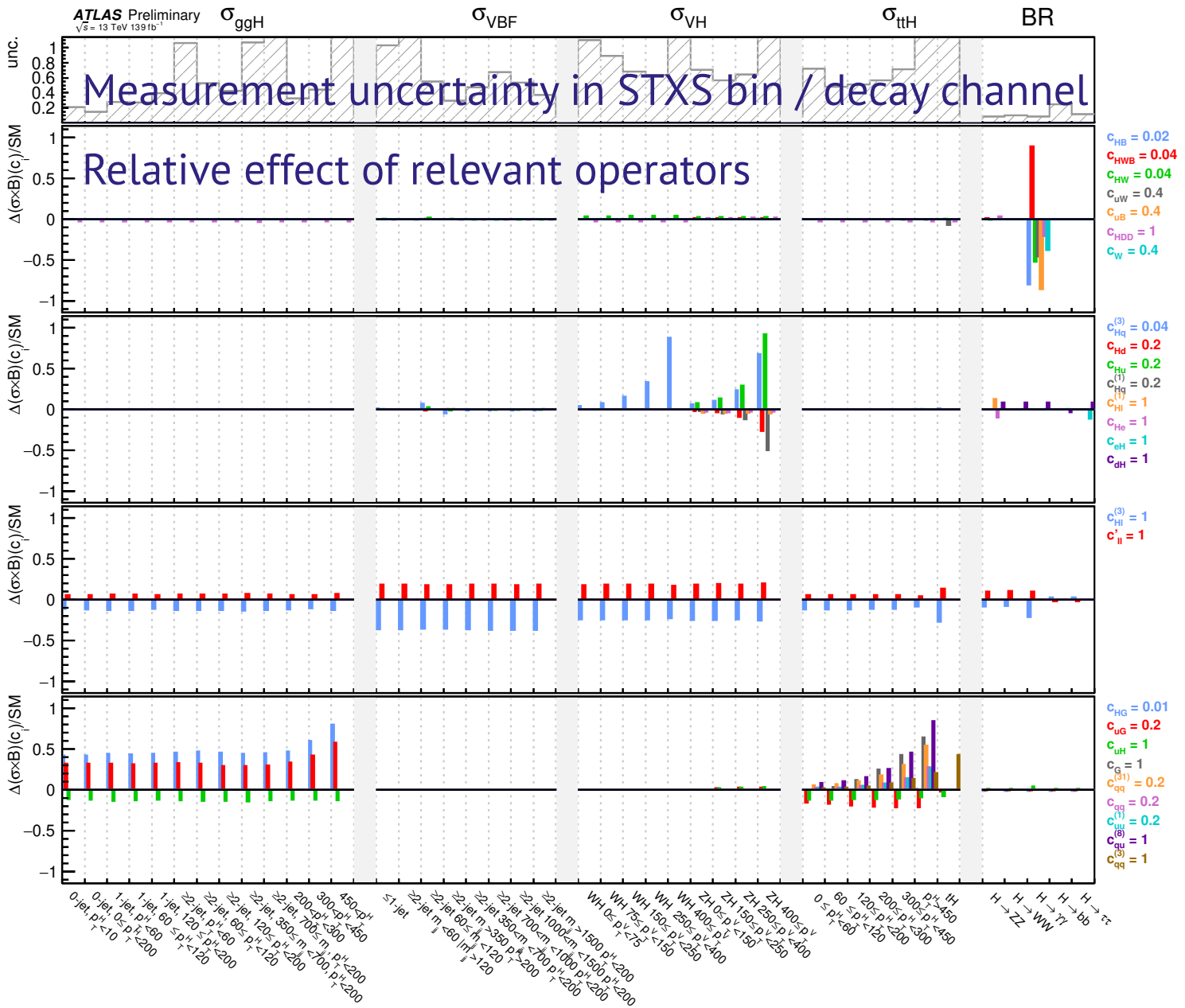
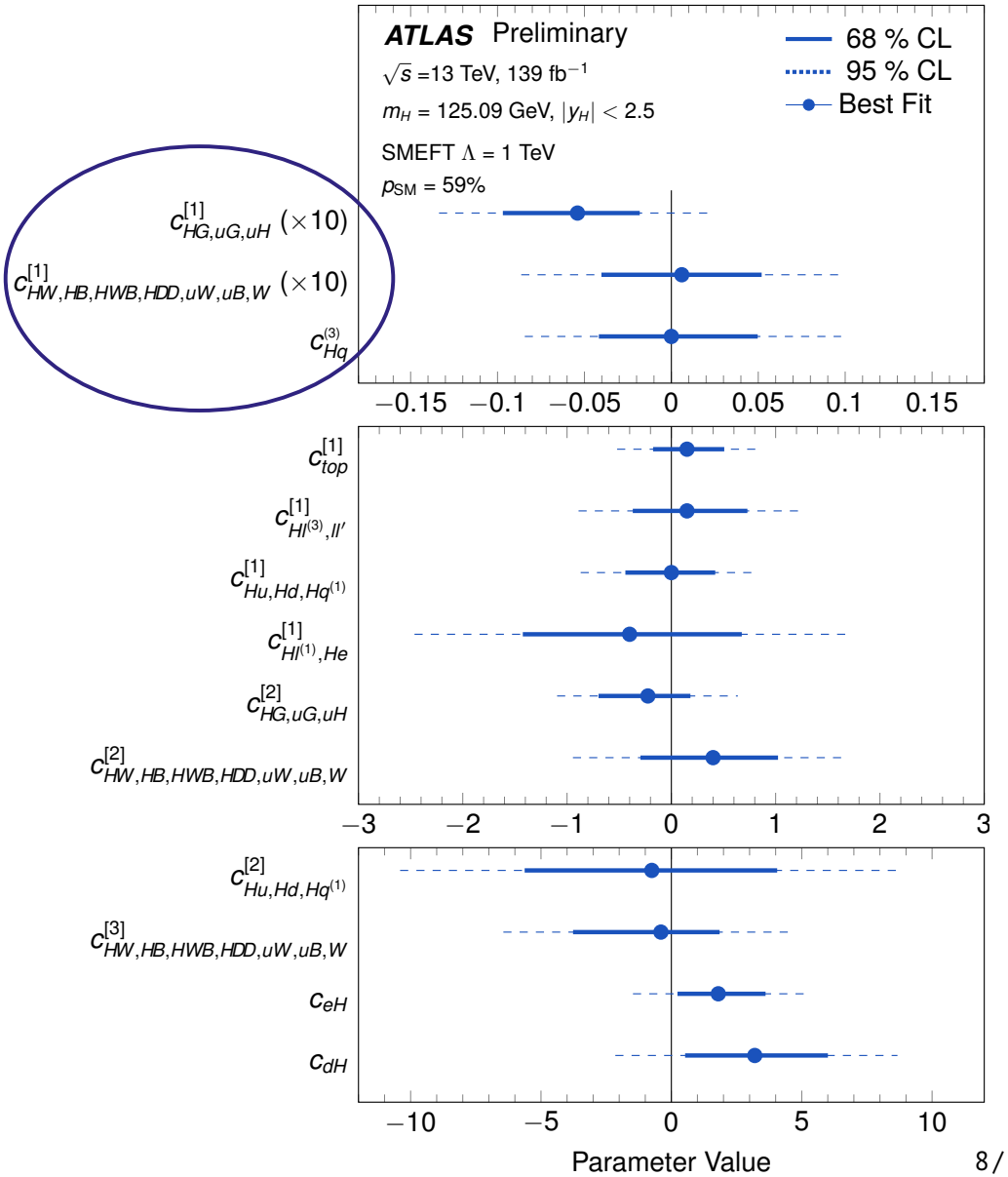


Higgs combination: combined SMEFT results

Simulatenously constraining all coefficients impossible – fit performed in *sensitive directions*: linear combinations informed by principal component analysis

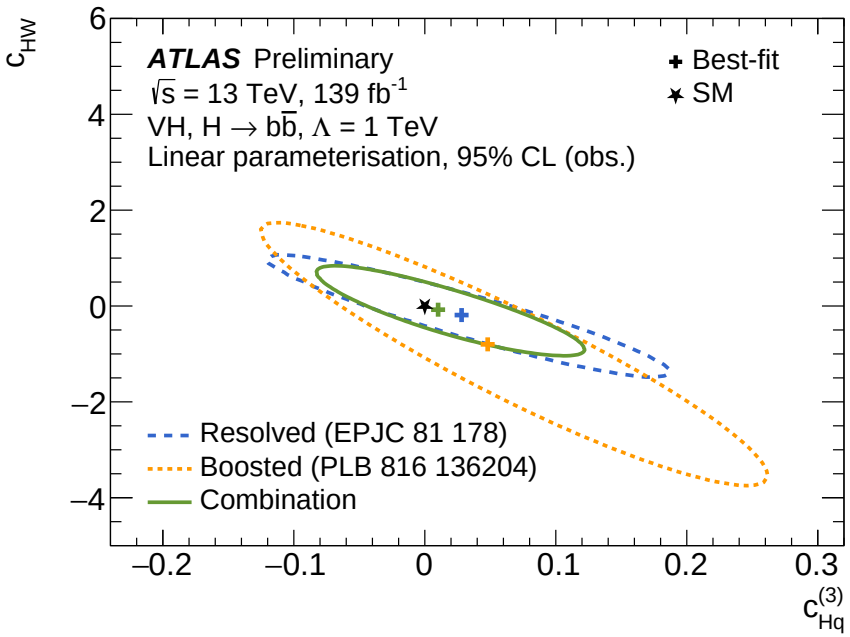
- $c^{[1]}_{HG,uG,uH}$: linear comb. with strong impact on $gg \to H$
- $c^{[1]}_{HW,HB,HWB,HDD,uW,uB,W}$: strong impact on $H \to \gamma\gamma$
- $c^{(3)}_{Hq}$: unique impact on VH
- 10 additional directions corresponding to subdominant effects
- Poorly constrained directions fixed to zero

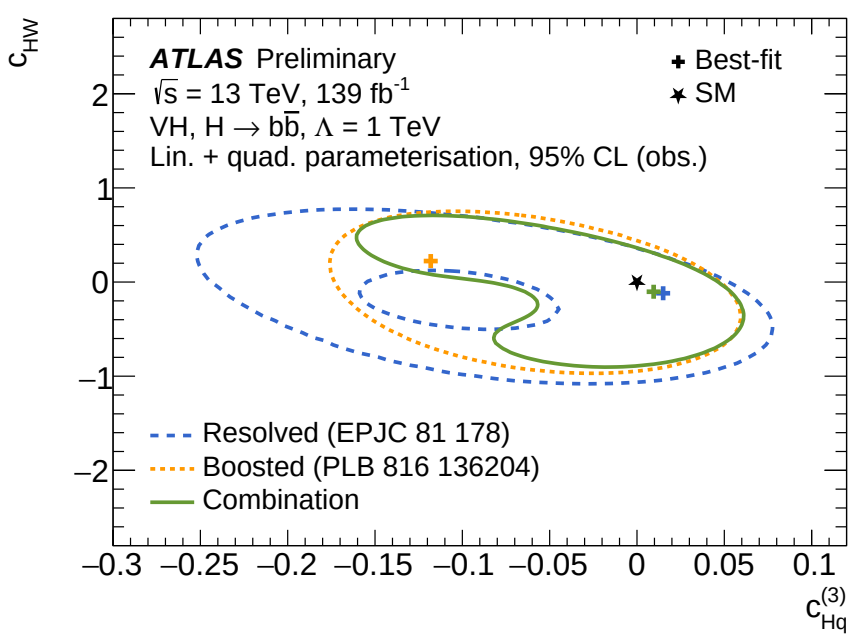


VH combination

ATLAS-CONF-2021-051: $VH(b\bar{b})$ boosted + resolved combination

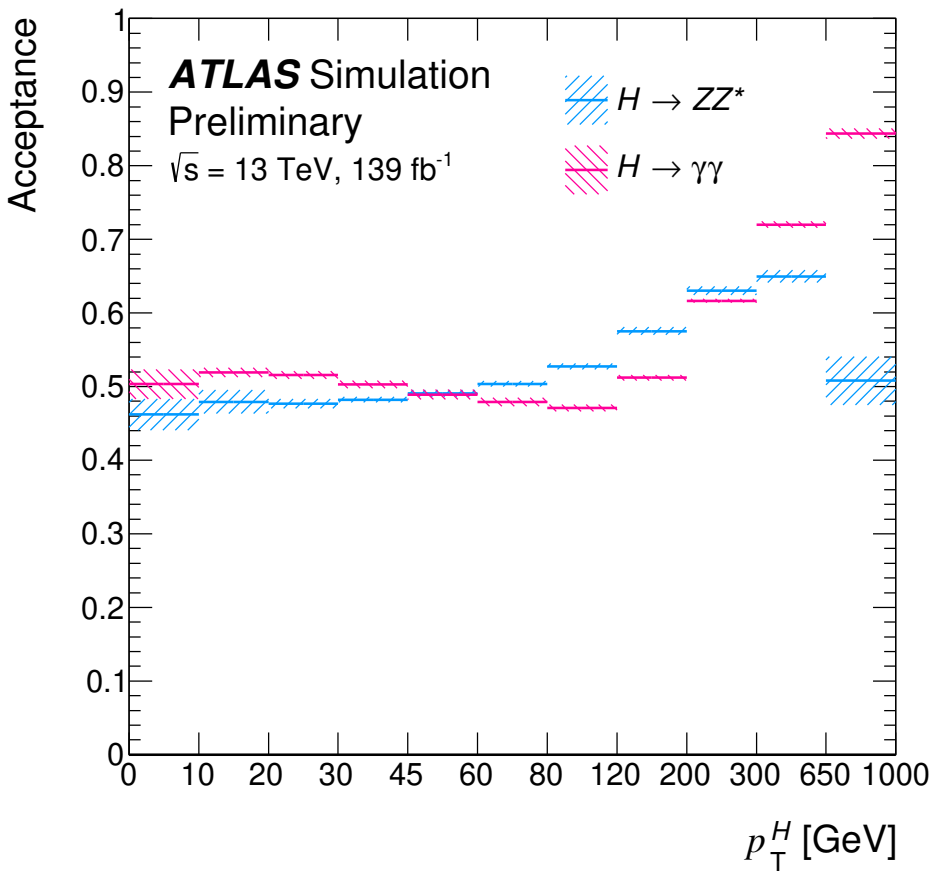
- $H \to b\bar{b}$ either reconstructed as two separate R=0.4 jets ("resolved") or one large radius (R=1.0) jet ("boosted")
- Above $p_T^V > 400$ GeV "boosted" analysis becomes more precise
- Resolved analysis dominates the combination in linear SMEFT but "boosted" helps distinguishing effect of $c_{Hq}^{(3)}$ and c_{HW}
- Quadratic effects (strong energy growth) important for "boosted"

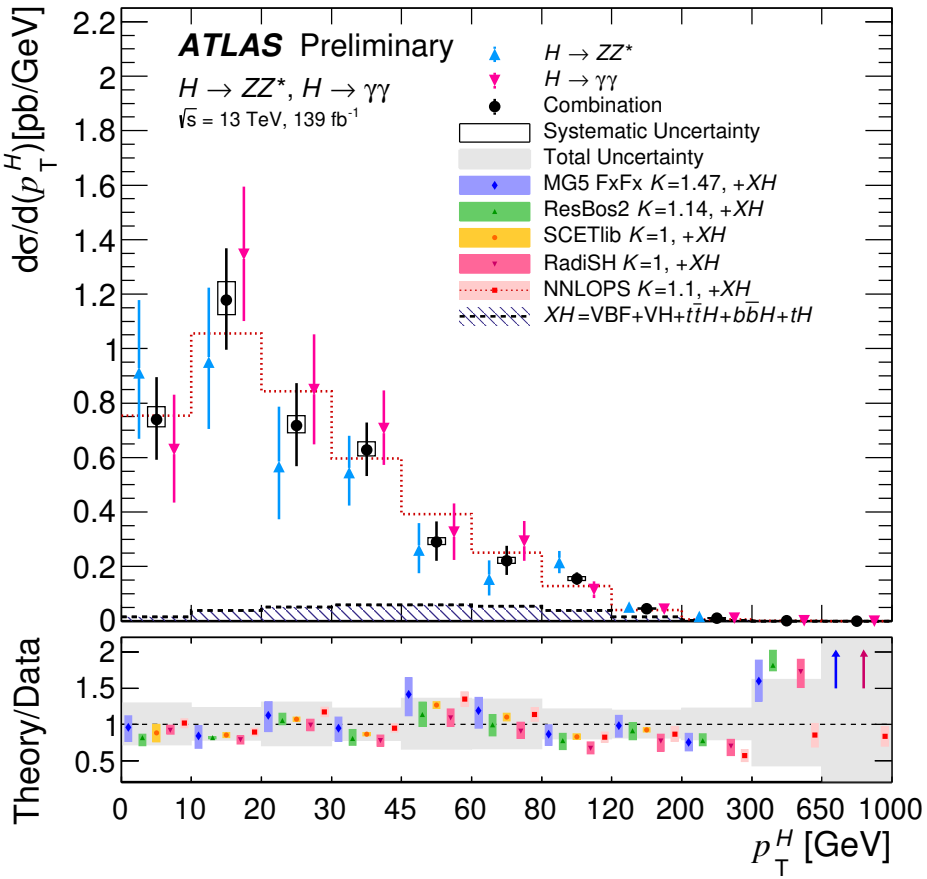




Higgs (differential) cross-section combination

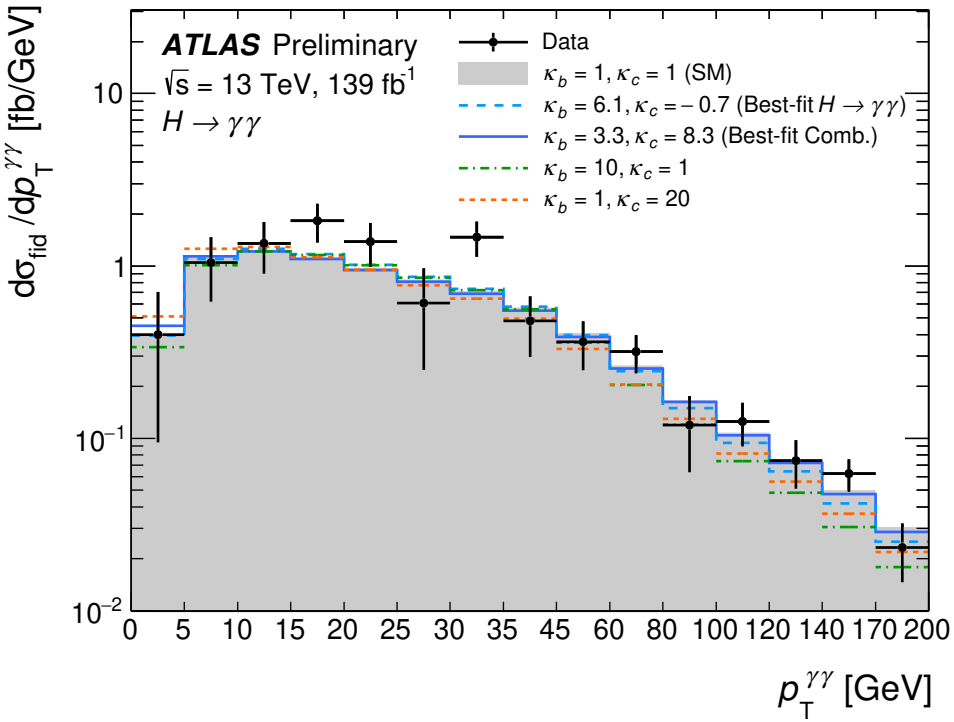
ATLAS-CONF-2022-002: Combined differential cross sections (just out!)

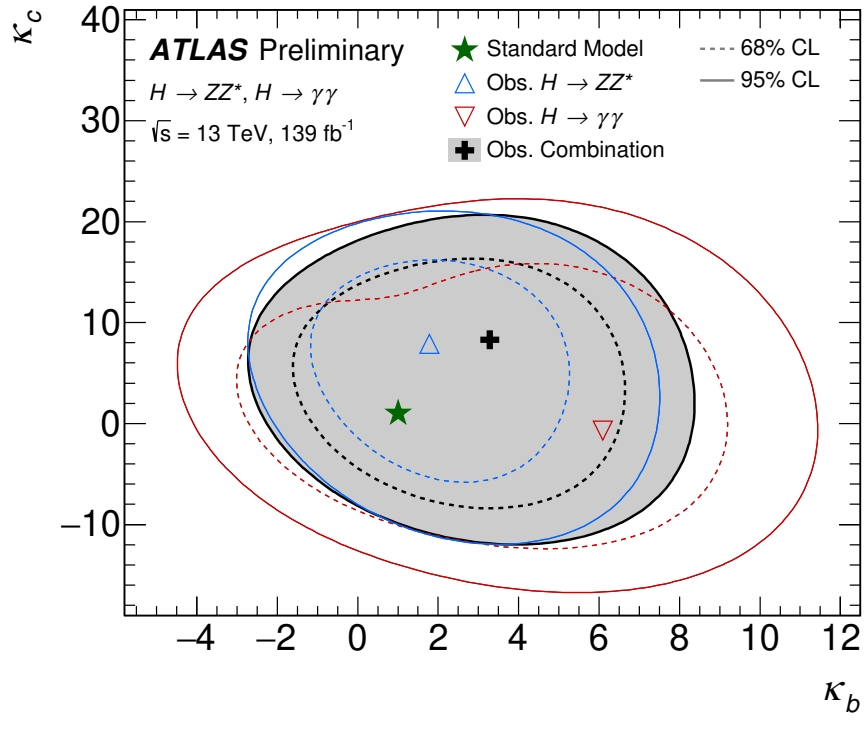




- Combination of $H(4\ell)$ and $H(\gamma\gamma)$ cross-sections in full phase space
- 20%-40% reduction in uncertainties despite extrapolation
- Excellent agreement with various SM predictions

Higgs (differential) cross-section: interpretation



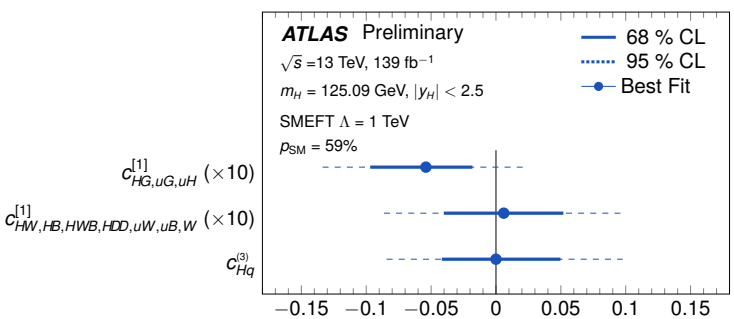


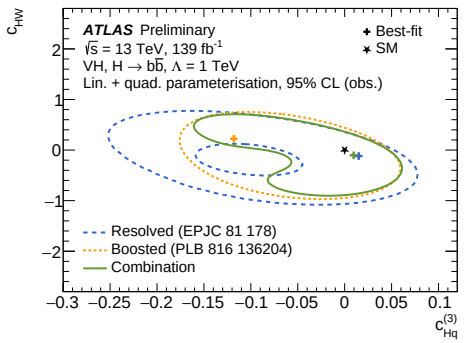
- $gg \to H$ and $qq \to H$ sensitive to b and c quark Yukawa couplings
- p_T^H *shape* in $H(4\ell)$ and $H(\gamma\gamma)$ channels analyzed to set limits
- $\kappa_b = 3.3^{+2.4}_{-4.4}$ and $\kappa_c = 8.3^{+5.5}_{-13.8}$
  $\to$ sensitivity to κ_c comparable to direct searches for $H \to c\bar{c}$

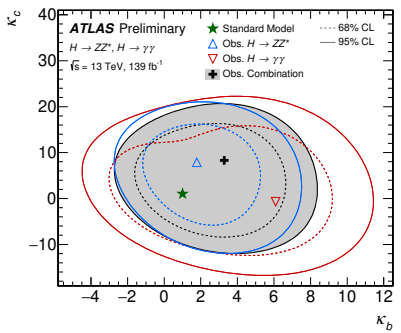
Conclusion

Presented three recent combined Higgs boson measurements with new-physics interpretations

- Combined measurement of Higgs boson production and decay
- Combined analysis of boosted and resolved $VH(b\bar{b})$
- Combined measurement of Higgs boson (differential) cross-sections







Thank you for your attention!