Experimental Potential for *CP* sensitivity from STXS splitting

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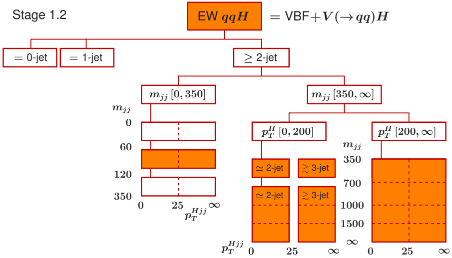
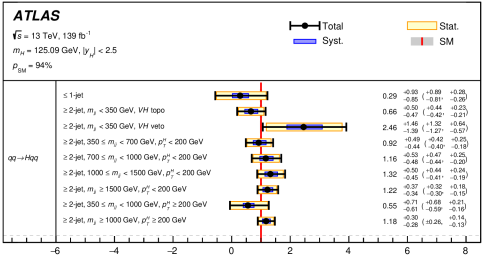
Introduction

- The STXS framework is a powerful tool to combine Higgs measurements in various decay channels to constrain coupling parameters
- So far STXS does not provide sensitivity to *CP* violation
- This talk:
  - discuss how to make STXS sensitive to *CP* violation
  - STXS is designed to study Higgs production. Will discuss VBF and ggF
  - ignore *CP* violation in Higgs decays. STXS analyses are not affected since special effort must be made to observe it
  - ATLAS and CMS are expected to have similar sensitivity for measurements dicussed and this is the case where both have results already. Selected figures such that the talk is most clear

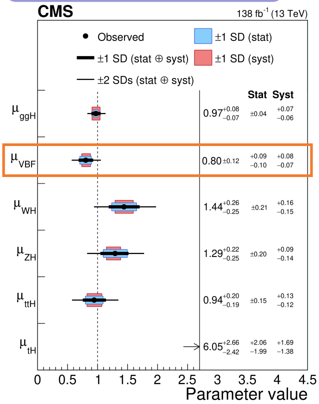
STXS Measurements for VBF



▸ ATLAS combination, Nature 607 (2022) 52



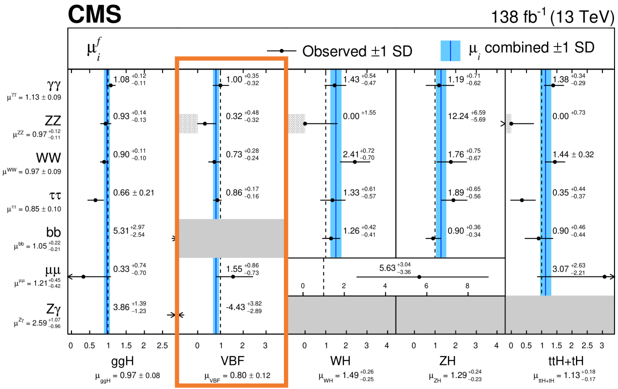
▸ CMS combination, Nature 607 (2022) 60



- Have measured VBF to $\Delta\mu = 12\%$ inclusively and to $30 - 50\%$ for several STXS bins
- STXS is stat. dominated. Run 3 will facilitate better precision and granularity

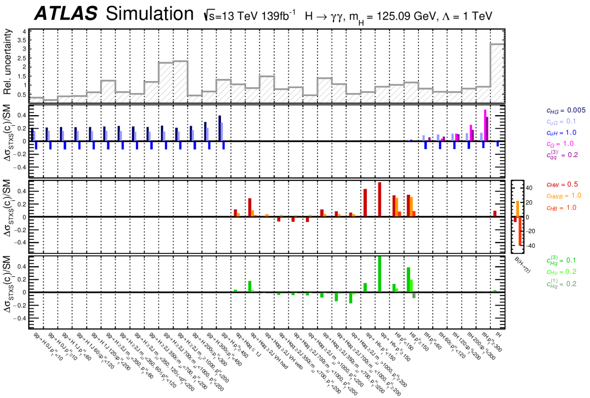
Contributions per Decay Channel

CMS combination, Nature 607 (2022) 60



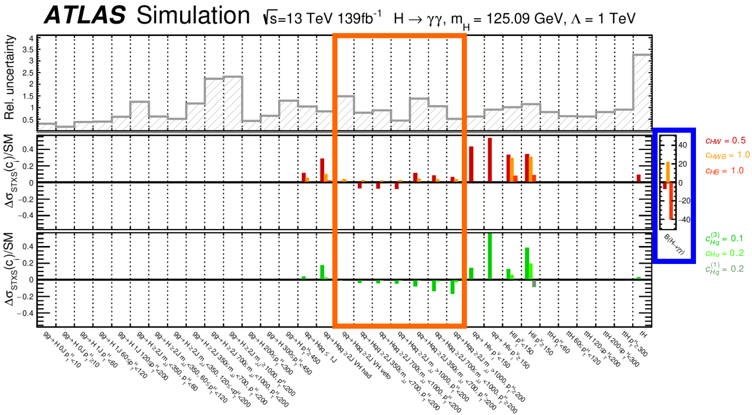
- Currently driven by $\tau\tau$ and WW, which will remain dominant for high m_{jj} and $p_T^H > 200\,\text{GeV}$. ($H \to bb$ may contribute/dominate for extreme phase space)
- $\gamma\gamma$ and ZZ catching up for inclusive and for low m_{jj} with $p_T^H < 200\,\text{GeV}$

EFT Interpretation of STXS Measurement



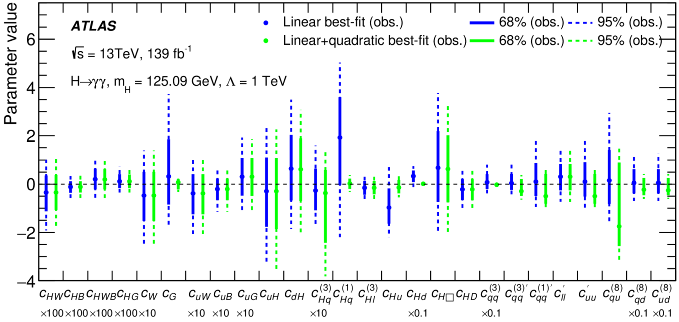
- STXS provides sensitivity to Wilson coefficients (Wilsons) that change overall normalization or relative yields of catergories. Use SMEFT parametrisation
- EFT interpretations of ATLAS and CMS combinations are yet to be performed
- Take ‣ ATLAS $H \to \gamma\gamma$ STXS measurement with EFT interpretation for illustration

EFT Interpretation of STXS Measurement



- The $H \to \gamma\gamma$ VBF categories are sensitive to c_{HW}, c_{HWB}, c_{HB}, $c_{Hq}^{(3)}$, and c_{Hu}
- The $H \to \gamma\gamma$ branching ratio is extremely sensitive to c_{HW}, c_{HWB} and c_{HB}
- Current STXS with *CP*-even observables only: linear terms from *CP*-odd Wilsons have no effect. Effect of quadratic terms similar to that of *CP*-even counterparts

EFT Interpretation of STXS Measurement



- Top: limits for single Wilsons if all others vanish
- Right: limits for 12 eigenvectors after PCA. Eigenvector composition in appendix

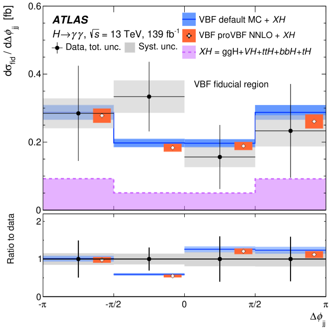
Linear SMEFT parameterization, linear+quadratic in paper

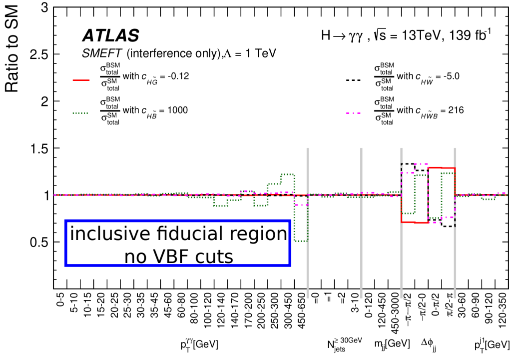
Model parameter	Observed			Expected	
	Value	Uncertainty		Uncertainty	
		68% CL	95% CL	68% CL	95% CL
EV1	−0.0008	$^{+0.0017}_{-0.0018}$	$^{+0.0032}_{-0.0037}$	$^{+0.0016}_{-0.0018}$	$^{+0.0031}_{-0.0036}$
EV2	0.000	±0.006	$^{+0.012}_{-0.010}$	$^{+0.006}_{-0.005}$	$^{+0.011}_{-0.010}$
EV3	0.04	±0.10	$^{+0.18}_{-0.21}$	$^{+0.09}_{-0.10}$	$^{+0.18}_{-0.20}$
EV4	−0.04	$^{+0.25}_{-0.22}$	$^{+0.5}_{-0.4}$	$^{+0.24}_{-0.21}$	$^{+0.5}_{-0.4}$
EV5	−0.2	±0.6	$^{+1.2}_{-1.3}$	±0.6	$^{+1.1}_{-1.3}$
EV6	0.2	±0.8	$^{+1.7}_{-1.6}$	$^{+0.8}_{-0.7}$	±1.5
EV7	−1.7	±1.0	$^{+2.0}_{\mathbf{-1.3}}$	$^{+1.1}_{-1.0}$	$^{+2.2}_{-2.1}$
EV8	−0.7	$^{+3.5}_{-3.2}$	$^{+7}_{-6}$	$^{+3.9}_{-3.4}$	$^{+8}_{-7}$
EV9	7.5	$^{\mathbf{+2.5}}_{-5.2}$	$^{\mathbf{+2.5}}_{-11}$	$^{+5}_{-5}$	$^{+10}_{-11}$
EV10	0	$^{+7}_{-9}$	$^{\mathbf{+8}}_{-19}$	$^{+5}_{-7}$	$^{+9}_{-16}$
EV11	−6	$^{+9}_{-10}$	$^{+18}_{-19}$	±10	±19
EV12	3	$^{\mathbf{+12}}_{-13}$	$^{\mathbf{+12}}_{-25}$	±12	±24

Can already measure multiple Wilsons at once with $H \to \gamma\gamma$. Will do better when combining with other channels, ATLAS+CMS and Run 2+3

How to Make STXS Sensitive to *CP*

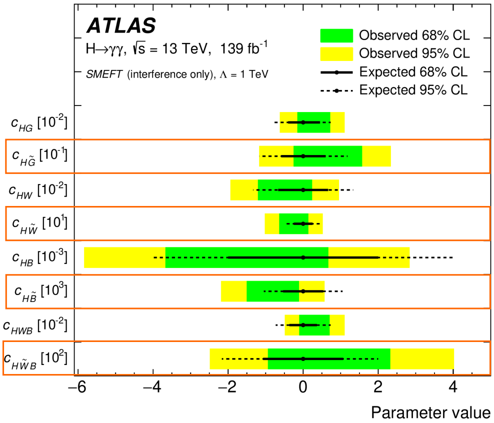
$\Delta\phi_{jj}$ for VBF fiducial region ▸ ATLAS $H \to \gamma\gamma$ differential





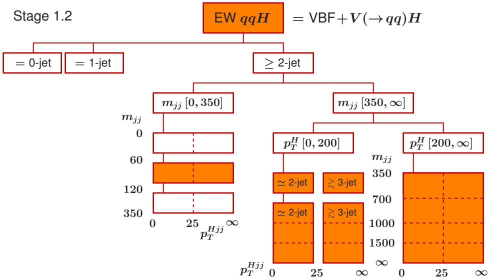
- Dedicated *CP* measurements utilize complex observables constructed from the matrix elements, see examples ▸ CMS $H \to \tau\tau$ ▸ CMS $H \to ZZ^*$ ▸ ATLAS $H \to \gamma\gamma$ ▸ ATLAS $H \to \tau\tau$
- The $\Delta\phi_{jj}$ observable is more suitable for STXS and provides good sensitivity to *CP*. Sign is set via rapidity order of jets
- Bin correlations $\leq 7\%$ for $H \to \gamma\gamma$. Can reconstruct $\Delta\phi_{jj}$ well for all decay modes

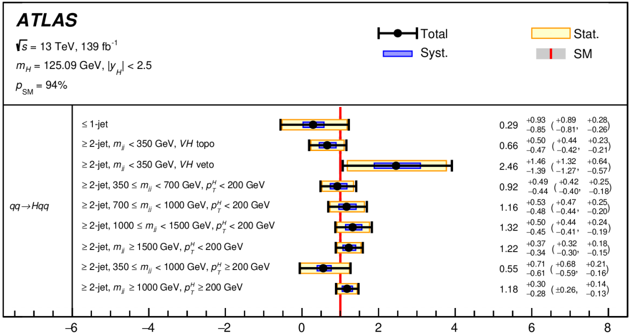
How to Make STXS Sensitive to *CP*



- *CP* odd operators measured from $\Delta\phi_{jj}$ observable
- The binning from the previous slide (4 bins) would likely be a good choice
- The $\Delta\phi_{jj}$ observable should be most sensitive for large m_{jj}. At least this was true in Run 1 $\rightarrow$ to be reviewed with new MC and for what we now call "large m_{jj}"

For Discussion: Options for Run 2+3 for VBF

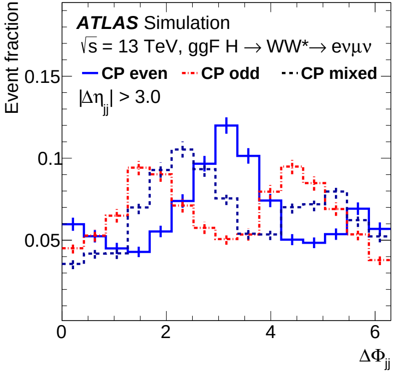




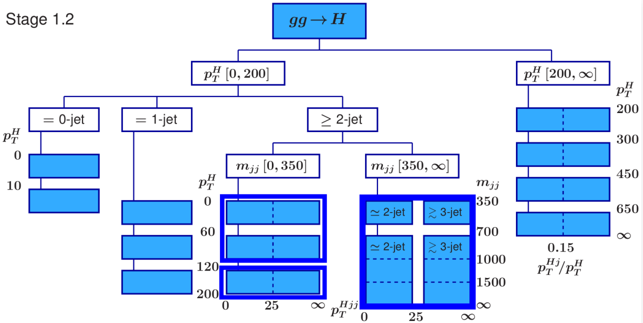
- Try to measure more stage 1.2 bins
  - Already measure all for $p_T^H < 200$ except p_T^{Hjj}
  - For key $H \to \tau\tau$ and $H \to WW^*$ channels the E_T^{miss} resolution makes it hard to bin in p_T^{Hjj}
- Be more accurate for same/similar binning as now. Could be done, we are stat. limited
- Suggestion: split each current bin to e.g. four $\Delta\phi_{jj}$ bins for CP sensitivity

CP Sensitivity in ggF

ATLAS *HWW* properties



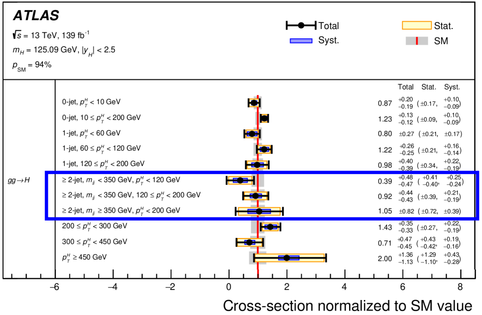
Boxes: ggF+ ≥ 2 jet bins in ATLAS combination, Nature 607 (2022) 52

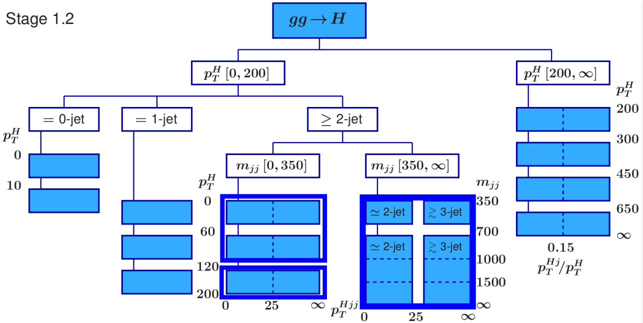


- $\Delta\phi_{jj}$ also provides sensitivity to *CP* for ggF with ≥ 2 jets
- Currently measure 3 bins for ggF with ≥ 2 jets in combinations
- No N_{jet} splitting for $p_{\text{T}}^{H} > 200\,\text{GeV}$. Splitting N_{jet} and $\Delta\phi_{jj}$ likely not feasible for Run 2+3

For Discussion: Options for Run 2+3 for ggF

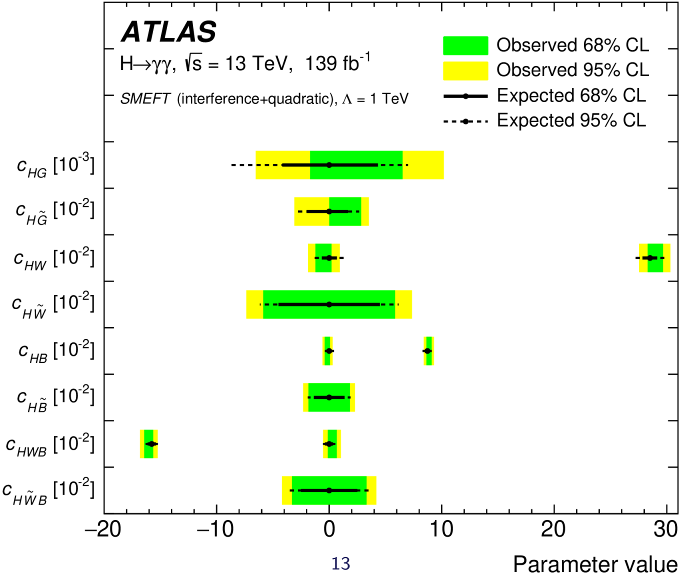
▸ ATLAS combination, Nature 607 (2022) 52





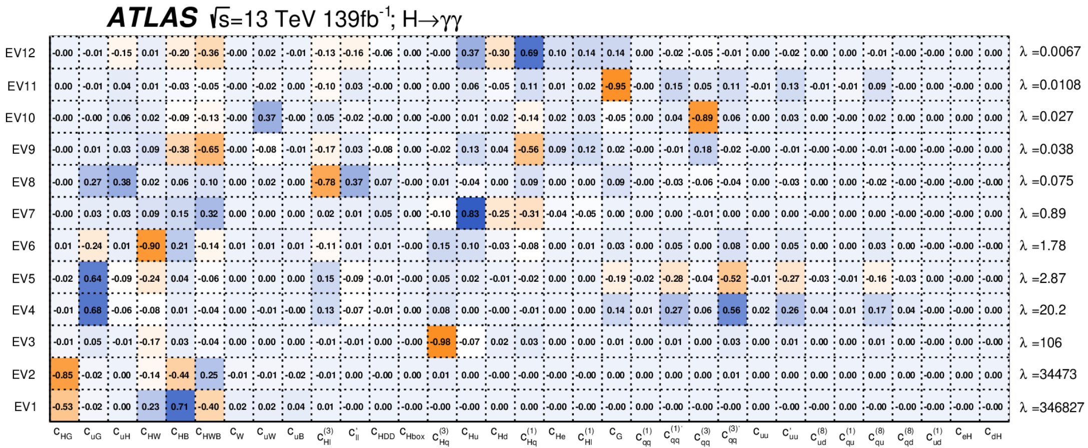
- Try to measure more stage 1.2 bins. Splitting p_{T}^{Hjj} is difficult for $H \to \tau\tau$ and $H \to WW^*$. But they are much less important than $H \to \gamma\gamma$ other than for VBF
- Could consider splitting into $\Delta\phi_{jj}$ instead of improving granularity for p_{T}^{H} and p_{T}^{Hjj}

Backup: Results from ATLAS $H \to \gamma\gamma$ differential with linear+quadratic terms



Backup: EFT eigenvectors

▸ for ATLAS $H \rightarrow \gamma\gamma$ STXS



Backup: Summary Signal Strengths

ATLAS combination, Nature 607 (2022) 52