Measurements and Interpretations of Simplified Template Cross-Sections, differential and fiducial cross sections in $H \rightarrow \gamma\gamma$ decays with the ATLAS detector

Tom Schwarz
University of Michigan

On behalf of the ATLAS Collaboration

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SM Higgs Production and Decay

Gluon-gluon fusion

Vector-boson fusion

$q \rightarrow V \rightarrow H$

Associated production with vector boson (VH)

Associated production with top quark pair (ttH)

Showing Full Run 2 Results in this Talk!

Decay modes:

- H → bb, BR ~58%
- H → ZZ, 3%
- H → WW, 22%
- H → ττ, 8%
- H → cc, 6%
- H → 4γ, 3%

Observed (5σ) production modes:
- Gluon gluon fusion, VBF (Run-1)
- ttH, VH (Run-2)

Observed (5σ) decay modes:
- To bosons: H → ZZ, H → WW, H → γγ
- To fermions: H → ττ, H → bb
STXS Measurements

- Analysis measures production cross-sections in the Simplified Template Cross-Sections (STXS) framework, in which Higgs production phase space is partitioned by production process, kinematics, and event properties.

- Provides strong sensitivity to the cross-sections of primary Higgs boson production modes: gluon-gluon fusion (ggF), vector-boson fusion (VBF), and associated production with a vector boson or top quark (VH or ttH).

- Events split into classes targeting 45 STXS regions (based on Stage 1.2 binning) using a multi class BDT. Only report on 28 regions.

- Additional classifier (BDT/NN) trained in each class to further separate events into 101 categories.

- A simultaneous fit to $M_{\gamma\gamma}$ is performed in each of the categories, where the distribution is modeled with analytic functions for both signal and background.
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28 STXS Categories

93% Compatibility with SM
Interpretation of the STXS Results ($\kappa$ Framework)

Note: $tHjb$ category sensitive to negative $Kt$
Interpretation in SMEFT used to set constraints on possible new physics.

• Using STXS results, individual Wilson coefficients ($c_k$) are measured while fixing others to zero.

• A simultaneous measurement of all SMEFT parameters is also performed (see paper).

  ➡ A principal component analysis is being performed to identify sensitive directions for the simultaneous measurement.

$$\mathcal{L} = \mathcal{L}_{\text{SM}} + \sum_k \frac{c_k}{\Lambda^2} O_k$$
Interpretation of the STXS Results (SM EFT)

$\mathcal{L} = \mathcal{L}_{SM} + \sum_k \frac{c_k}{\Lambda^2} O_k$

ATLAS

$\sqrt{s} = 13$ TeV, 139 fb$^{-1}$

$H \rightarrow \gamma\gamma$, $m_H = 125.09$ GeV, $\Lambda = 1$ TeV

0 means SM
Fiducial Cross-Sections

• Fiducial measurements of $H \rightarrow \gamma\gamma$ observables allow for a more model independent comparison with predictions by measuring fiducial phase space that closely matches the available analysis phase space - minimizing extrapolations.

• Results can constrain couplings not directly accessible (such as $c_H$) and can be applied to Wilson coefficient in SM EFT
Differential Fiducial Cross-Sections

\( H \rightarrow \gamma \gamma, \ \sqrt{s} = 13 \text{ TeV}, \ 139 \text{ fb}^{-1} \)

**ATLAS**

- Data, tot. unc.
- Syst. unc.
- \( gg\rightarrow H \) default MC + \( XH \)
- \( gg\rightarrow H \) SCETlib\(q_T + XH \)
- \( gg\rightarrow H \) RadiSH+NNLOJET + \( XH \)
- \( gg\rightarrow H \) ResBos2 + \( XH \)
- \( gg\rightarrow H \) LHCHWG \( [008.07743] + XH \)
- \( XH = VBF+VH+ttH+bbH+tH \)

**ATLAS**

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- Syst. unc.
- \( gg\rightarrow H \) default MC + \( XH \)
- \( gg\rightarrow H \) Sherpa+MCFM+OpenLoops + \( XH \)
- \( gg\rightarrow H \) NNLOJET + \( XH \)
- \( gg\rightarrow H \) GoSam+Sherpa + \( XH \)
- \( gg\rightarrow H \) STWZ, BLPTW + \( XH \)
- \( XH = VBF+VH+ttH+bbH+tH \)

\( \rho_{\gamma\gamma}^\text{ATLAS} \) vs. \( p_T^{\gamma\gamma} \) [GeV]

\( \sigma_{\text{fid}}^\text{ATLAS} \) vs. \( N_{\text{jets}} \)

13
Fiducial Cross-Sections

- Interpretation in SMEFT used to set constraints on possible new physics.

- Using fiducial differential results, individual Wilson coefficients ($c_k$) are measured while fixing others to zero.
A model independent search for new physics examines 22 final states categorized by objects produced in association with \( H \rightarrow \gamma \gamma \).

Signal regions can roughly be classified into six groups: events with heavy flavor jets; events with high jet multiplicity or larger \( H_T \); events with large \( E_T^{\text{miss}} \); events with leptons; events with additional photons; and events with top quarks.

No significant excess above SM observed and limits on production cross-sections placed at 95% CL.

Detector efficiencies are reported for all 22 signal regions which are used to convert detector-level cross section limits to particle-level cross-section constraints.
Model-independent Search in $H \rightarrow \gamma\gamma$

- An example using an Ewk SUSY production model to demonstrate how to derive constraints on a given BSM model

- In this process, a chargino and neutralino pair decay to a final state W boson, Higgs, and two undetectable neutralinos (so large $E_{T}^{\text{miss}}$).

- The $E_{T}^{\text{miss}} > 100$ GeV signal region for this analysis placed a 95% CL limit at the detector level of 0.4 fb.

- Accounting for detector efficiency (0.68 reported in paper), the particle level limit on the BSM cross-section is 0.59 fb at 95% CL, which would exclude the considered SUSY model ($\sigma = 1.05 \text{ fb}$ at particle level).
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Conclusions

- SM Higgs physics in the $H \rightarrow \gamma\gamma$ channel have been probed in a variety of ways - simplified template cross sections, fiducial measurements, full phase space differential measurements.

- Interpretations of the results have been performed in the $\kappa$ framework and in SM Effective Field Theory.

- All measurements/interpretations are consistent with the SM.

- However, the results are mostly dominated by statistical uncertainties, so future runs will probe deeper into Higgs properties.