Differential cross section of the Higgs boson measured in the diphoton decay channel with the ATLAS detector --- 8 TeV proton-proton collision data

Yanping Huang\textsuperscript{1,2}
(on behalf of ATLAS Collaboration)

\textsuperscript{1} WITS, IFIC
\textsuperscript{2} CERN

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Outline

❖ Introduction and motivation
❖ Observables
❖ Analysis results
  ✦ Overview
  ✦ Systematic uncertainties
  ✦ Signal yield at reconstructed level
  ✦ Measurement of fiducial cross section at particle level
❖ Conclusion
A local significance of 7.4 σ @ 126.8 GeV excess over background - Discovery!

The total rate to SM : $1.55 \pm 0.23 \text{ (stat)} \pm 0.21 \text{ (syst)}$
Motivation for differential cross section measurement

For the first time, directly measure several kinematic distributions of the Higgs boson in robust and close to model independent way

✦ Many of the current Higgs results make assumptions on the Higgs kinematics, these results provide a cross check of the validity of these assumptions

✦ Correct measured spectra for detector effects to provide easy and direct comparison with theoretical predictions at particle level

$p_T$ of the Higgs, constructed from the two photons. The coupling measurement is sensitive to the kinematics of this variable.

In this talk, the measurement of this variable is shown!
We cannot really constrain precise SM calculations yet with current data statistics, but rather test if there are significant deviations from the SM in any of the kinematic distribution.
unbinned Likelihood function definition

\[ L(m_{\gamma\gamma}; \nu^\text{sig}, \nu^\text{bkg}, m_H) = \prod_i \left\{ \frac{e^{-\nu_i}}{n_i!} \prod_j^{n_i} \left[ \nu_i^{\text{sig}} S_i(m_{\gamma\gamma}^j; m_H) + \nu_i^{\text{bkg}} B_i(m_{\gamma\gamma}^j) \right] \right\} \times \prod_k G_k \]

\( \nu_i^{\text{sig}} \): # of signal in i\textsuperscript{th} bin
\( \nu_i^{\text{bkg}} \): # of background in i\textsuperscript{th} bin
\( G_k \): Constrain term of the k\textsuperscript{th} nuisance parameter

▷ Fiducial photon definition
  • \( p_T/m_{\gamma\gamma} > 0.35 \) (0.25) for leading(sub-leading) photon
  • \( |\eta| < 2.37 \) (without 1.37\( \leq |\eta| \leq 1.56 \) for reco)

▷ Jet definition
  • Anti-\( k_t \) \( R = 0.4 \), \( p_T > 30 \text{ GeV} \), \( |y| < 4.4 \)

Selected data are divided in bins of observable
Analysis overview

- **Fiducial photon definition**
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1. Signal extraction @ reconstructed level
Signal extracted with S+B unbinned likelihood fit of $m_{\gamma\gamma}$ separately for each bin of the observable.

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2. Bin-by-bin correction for detector effects

3. Fiducial cross section measurement
   @ particle level
   can be directly compared with theory

\[ \int L \ dt = 20.3 \text{ fb}^{-1} \]
Systematic Uncertainty

Potential biases of bin-by-bin correction have been carefully studied and the systematic uncertainties are evaluated.

- **Luminosity uncertainty**
- **Generator modelling uncertainty**
  - Composition of different production modes
  - Shape
- **Detector modelling uncertainty**
  - Photon object selection: trigger efficiency, PID, isolation efficiency, photon energy resolution and scale
  - Jet object selection: Jet energy scale/resolution, pileup modelling and suppression efficiency (JVF)
  - Signal extraction in m_{Y+Y} fitting: signal shape and signal/background modelling

Figure 6: The fractional experimental uncertainties and the consecutive addition of luminosity, generator modelling, detector modelling, and the statistical uncertainty associated with the yield extraction are shown for the observables of the inclusive distribution. The large variations on the fractional uncertainties on p_T and |cos(✓)| derive from fluctuations on the yield, rather than on variations in the absolute size of the uncertainties.

Statistical uncertainty dominates.
Higgs kinematic distribution
-- measured Higgs signal yield in bins of $p_T$

$\gamma\gamma \rightarrow H$

\[ \int L \, dt = 20.3 \text{ fb}^{-1} \]

$H \rightarrow \gamma\gamma$, $\sqrt{s} = 8 \text{ TeV}$

$XH = \text{VBF} + (\text{VH} + \text{ttH})$

(Powheg+Pythia8 and Pythia8)

Uncertainties:

- \textit{Theoretical prediction uncertainty:}
  including higher order perturbative corrections, PDF, underlying event modeling and branching ratio systematics

- \textit{Detector modelling uncertainty:}
  photon/jet selection uncertainty

- Possible global excess as signal strength measurement.

- Data tend to be slightly harder.

- Agreement within uncertainties with the SM prediction

ATLAS Preliminary:
- data
- syst. unc.

$gg\rightarrow H$: Powheg+Pythia8 ($m_H = 125\text{GeV}$)

$XH = \text{VBF} + (\text{VH} + \text{ttH})$

(Powheg+Pythia8 and Pythia8)

Insets:

- $\gamma\gamma$
- $p_T$

no detector unfolding applied
First measurements of Higgs kinematic distributions
-- Higgs signal yield in bins of other observables
Fiducial differential cross section
-- Higgs $p_T$

Proportions from $\chi^2$ test, considering the full covariance between bins

|                | $N_{\text{jets}}$ | $p_T^{\gamma\gamma}$ | $|y^{\gamma\gamma}|$ | $|\cos \theta^*|$ | $p_T^{jj}$ | $\Delta \phi_{jj}$ | $p_T^{\gamma\gamma jj}$ |
|----------------|-------------------|-----------------------|----------------------|------------------|----------|------------------|------------------|
| POWHEG         | 0.54              | 0.55                  | 0.38                 | 0.69             | 0.79     | 0.42             | 0.50             |
| MINLO          | 0.44              | –                     | –                    | 0.67             | 0.73     | 0.45             | 0.49             |
| HRES 1.0       | –                 | 0.39                  | 0.44                 | –                | –        | –                | –                |

No significant difference between the predicted shapes and the observation.

full detector unfolding applied
brings the measurements to particle level
Agreement within uncertainties with the SM prediction.

The measurement of $\cos \theta^*$ is complementary to what is determined in the dedicated spin analysis, and the individual yields are extracted in a model independent way.
More conservative uncertainty estimation with the procedure of reference [Phys. Rev. D 85, 034011 (2012)] using input uncertainties from MCFM.

Good agreement on the jet veto fraction distribution indicates that we have a fair understanding.
Fiducial differential cross section
-- leading jet $p_T$

The 0-30 GeV bin contains the cross section for events without any jet above 30 GeV

\[ \int L \, dt = 20.3 \text{ fb}^{-1} \]

\[ H \rightarrow \gamma \gamma, \sqrt{s} = 8 \text{ TeV} \]

**ATLAS Preliminary**

- **data**
- **syst. unc.**
- $gg \rightarrow H$, NLO+PS (POWHEG+Py8) + $XH$
- $gg \rightarrow H+1j$, NLO+PS (MINLO+HJ+Py8) + $XH$
- $XH = VBF + VH + iTH$

**Same data points but different more precise theoretical prediction!**

\[ \int L \, dt = 20.3 \text{ fb}^{-1} \]

- **ATLAS Preliminary**
- **data**
- **syst. unc.**
- $gg \rightarrow H$, NNLO+NNLL' (STWZ2) + $XH$
- $gg \rightarrow H$, NNLO+NNLL (JETVHETO) + $XH$
- $XH = VBF + VH + iTH$

- **Theory predictions describe the spectrum well**
- **Comparison is made with the predictions with STWZ [PRL. 109, 202001 (2012)] and JETVHETO [hep-ph:1307.1808] calculation, which are precise to NNLO +NNLL’ and NNLO+NNLL respectively.**
**Fiducial differential cross section**

--- **di-jet observables**

- Largest excess in last $\Delta\phi_{jj}$ bin. Carefully checked for systematic biases.
- Predictions for both distributions are consistent with the observed spectra.
Conclusion

• First measurements of Higgs differential cross sections with the full 2012 dataset and comparisons with several MC predictions are presented.

• The measured spectra of 7 observables and the jet veto fraction are sensitive to the fundamental kinematic properties of Higgs boson, probe its spin and parity and test the QCD theoretical prediction.

• Except for possible global excess as signal strength measurement, with the limited statistics of the measurement, the predicted shapes agree with the observation, and no significant deviation from the SM expectation is observed.
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More interesting observable will be measured
With more statistics in RunII, more meaningful conclusion may be drawn from these measurements.
Exciting times ahead :)

13年8月15日星期四
Comparison with theoretical predictions

- **ggH prediction:**
  - POWHEG H @ NLO + Py8
  - MINLO H + 1jet @ NLO + Py8
  - HRES H & NNLO + approx. NNLL.
  - JetVheto H @ NNLO/NNLL
  - STWZ H + 1jet @NNLO/NNLL’

- **XH prediction:**
  - VBF: POWHEG H @ NLO + Py8
  - Other: Py8 @ LO
  - All scaled with k-factor of the Higgs

- **Theoretical prediction uncertainties**
  (Stat. + (Scale+PDF) + UE + BR):
  - Sum in quadrature of PDF+ $\alpha_s$ variations
  - Envelop of Renormalization/factorization/resummation
  - Underlying event modeling
  - Branching ratio of Higgs decay

| $N_{jets}$ | $p_{T}^{\gamma\gamma}$ | $|y^{\gamma\gamma}|$ | $|cos \theta^{\gamma}|$ | $p_{T}^{j_1}$ | $\Delta\phi_{jj}$ | $p_{T}^{\gamma\gamma jj}$ |
|-----------|-----------------|-----------------|-----------------|-------------|----------------|----------------|
| POWHEG    | 0.54            | 0.55            | 0.38            | 0.69        | 0.79          | 0.42           | 0.50           |
| MINLO     | 0.44            | –               | –               | 0.67        | 0.73          | 0.45           | 0.49           |
| HRES 1.0  | 1.0             | –               | 0.39            | 0.44        | –             | –              | –              |

Predicted shapes mostly agree well with the observation.
Signal extraction

Background $m_{\gamma\gamma}$ modelling
- smooth function used
- validated using the same procedure as used in main analysis (ATLAS-CONF-2013-029)

Signal $m_{\gamma\gamma}$ shape modelling
- Crystal Ball function + a wide gaussian, parameterized as a function of mH

Figure 1: Diphoton invariant mass distributions are presented for the 4 bins of $N_{\text{jets}}$ extraction. The curves show the results of the single simultaneous fit to data for all $N_{\text{jets}}$ bins. The red line is the combined signal and background PDF, and the dashed line shows the background PDF. The difference of the two curves is the extracted signal yield. The bottom inset displays the residuals of the data with respect to the fitted background component, and the dotted red line corresponds to the signal PDF.

ATLAS Preliminary
$pp \rightarrow H \rightarrow \gamma \gamma$, $\sqrt{s} = 8$ TeV
$\int L \ dt = 20.3 \ fb^{-1}$
$N_{\text{jets}} = 1$

Events / GeV

Preliminary ATLAS = 8 TeV $s$
$\gamma \gamma \rightarrow H \rightarrow pp$
$dt = 20.3 \ fb$
$L \int = 1$
$N_{\text{jets}} \geq 3$
Fiducial differential cross section
--Jet multiplicity

Theory unc. of large $N_{\text{jets}}$ are unnaturally small, because scale variations do not significantly shift the predictions from the parton shower algorithm.

Good agreement indicates that we have a fair understanding of this.

More conservative uncertainty estimation with the ST procedure [Phys. Rev. D 85, 034011 (2012)] using input uncertainties from MCFM.
Unfolding treatment

- Bin-by-bin unfolding method is used to correct for detector effect.
- Unfolding factor: \( C_i = \frac{n_{i\text{particle}}}{n_{i\text{reconstructed}}} \), is derived bin-by-bin. This unfolding procedure corrects for all efficiencies, acceptances and resolution effects.

\[ \begin{align*}
\text{Unfolding Factor} \\
1.2 & \quad 1.4 & \quad 1.6 & \quad 1.8 \\
N_{jets} & \quad -0.5 & \quad 0 & \quad 0.5 & \quad 1 & \quad 1.5 & \quad 2 & \quad 2.5 & \quad 3 & \quad 3.5
\end{align*} \]

- The distributions at particle level are restored by multiplying the extracted binned signal yield by unfolding factor.
- Potential biases have been carefully studied and systematic uncertainties are evaluated.