Search for the scalar boson in the diphoton channel in ATLAS

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On behalf of the ATLAS Collaboration
Moriond 2012 (~5 fb\(^{-1}\) at 7 TeV):
- Only mass range not excluded at the 99% CL is 115 \(-\) 130 GeV!
- Close to 3\(\sigma\) local excess around 126 GeV (mainly from \(H \rightarrow \gamma\gamma\))

Result presented today:
- Improved analysis of 7 TeV dataset
- Combined result with new 8 TeV dataset (~11 fb\(^{-1}\) in total)
H → γγ at the LHC

Within the SM, small BR ~0.2%

→ Compensate with high mass resolution (1–2%)

Main production and decay through loops

- Sensitive to beyond SM physics
- σ(gg→H) known at NNLO, uncertainty O(15%)

Large event yield due to the large gluon-fusion production rate, simple signature, effective triggering, simple analysis selection

~40% final selection efficiency  ~200 events in 11/fb  S/B ~10%
Clean discovery channel: Select events with two isolated high $p_T$ photons. Look for bump in steeply falling diphoton mass spectrum

$$p_T^1 > 40 \text{ GeV}, \quad p_T^2 > 30 \text{ GeV}$$

Relevant analysis aspects:
- Photon identification / background rejection
- Good diphoton mass resolution
- Background estimation / signal extraction

Main focus in past months/year:
- Further optimise analysis using 2011 data, keep 2012 data blinded
- Prepare for 2012 pileup challenges
Photon selection I.

Photon reco and selection based on longitudinal and lateral shower profile

- Shower shape variables in S2
- Fine S1 granularity ~0.003 in $\eta$
- Calorimeter based isolation

$\pi^0$-$\gamma$ Rejection

$\rightarrow$ New: NN based photon selection (+8-9% efficiency w/ same jet-rejection)
(So far only used in the 2011 selection.)

$\rightarrow$ New: Improved isolation with pile-up robust noise subtraction algorithm
Photon selection II.

Conversion reconstruction in the inner detector crucial for this analysis

- Apply dedicated identification criteria and calorimeter energy correction
- New: more robust conversion finding for high pileup

Photon selection efficiency cross-checked with several data based methods

(Z→llγ events, Z→ee extrapolating e to γ, isolated direct γ events)

Typical uncertainty ~5% (gives dominant uncertainty on signal yield ~10%)
Diphoton selection

Main backgrounds

- Irreducible: SM $\gamma\gamma$ production
- Reducible: $\gamma j, jj$ production with $q/g \rightarrow \pi^0$

Irreducible

Reducible

Critical to reach rejections $O(10^4)$

Estimate diphoton sample composition with different data based methods

$\gamma\gamma$ purity: $(80/75 \pm 4)\%$

in 2011/2012 selection

$\gamma j \sim 20\%$

$\gamma\gamma \sim 80\%$
Photon energy calibration

MC based calibration at cluster level tuned in test beam

Need accurate material description for $e \rightarrow \gamma$ extrapolation
(Cross checked with photon conversions, hadronic interactions, EM shower shapes and E/p, …)

Energy scale corrections from Z decay to electrons (scarce $\gamma$ calibration signal)
Calibration checks

In-situ energy calibration results and their stability checked with different methods ($E/p$ with $W \rightarrow e\nu$, $J/\psi \rightarrow ee$)

Stability of EM calorimeter response vs time/pile-up better than 0.1%

Uncertainty on the diphoton mass scale 0.6% (correlated between 7/8 TeV data)

- Material effects (separately for volumes before and after $|\eta| = 1.8$)
- Presampler scale (separately for barrel and end-cap)
- Uncertainty on the in-situ calibration method
Photon energy resolution

Resolution corrections to the MC derived from Z decay to electrons

- Add effective constant term to perfect MC resolutions through smearing
- 1% in barrel, 1.2 – 2.1% in endcap

![Barrel and Endcap Plots]

Uncertainty on photon energy resolution:

- Uncertainty on sampling term (from test-beam)
- Uncertainty in ‘effective’ constant term
- Uncertainty on e→γ extrapolation (material upstream calorimeter)

→ 12% uncertainty on diphoton mass resolution
Photon polar angle measurement

Important ingredient for mass resolution

\[ m_{\gamma\gamma}^2 = 2E_1 E_2 (1 - \cos \theta) \]

Beam spot spread ~5-6 cm, assuming detector centre origin adds 1.4 GeV in mass resolution (equivalent to intrinsic CAL resolution)

Resolution with pointing ~1.5 cm, better when conversion vertex used

~10-20% improvement
Primary vertex selection

Identify specific vertex with Likelihood combining information from pointing and track based vertex selection (needed to reject jets from pile-up)

Check pointing resolution in data with electrons, where track gives ‘true’ angle

Mass resolution pile-up robust with pointing
Events categorisation

Separate events into categories with different S/B and resolutions, based on:

- **New**: Vector boson fusion (VBF) signature category
- Presence of photon conversions
- Photon impact point on CAL
- Diphoton $p_T$ related variable

$\rightarrow$ 25% increase in expected sensitivity

**Examples:**

- Both $\gamma$ unconverted and central, high $\gamma\gamma$ $p_T$
- At least one $\gamma$ converted and not central, low $\gamma\gamma$ $p_T$

**Signal model:** sum of Crystal Ball and Gaussian functions
VBF signature category

To enhance and separate sensitivity to Higgs production in VBF, separate events consistent with VBF signature

- Two high pT jets from the PV and $\Delta \phi_{\gamma\gamma-jj} > 2.6$
- Separated in rapidity: $\Delta \eta_{jj} > 2.8$ and $m_{jj} > 400$ GeV

VBF purity $\sim 70\%$ of total signal contribution in this selection category

Large uncertainties on selected gluon-fusion events due to uncertainties on the perturbative calculation (25%) and UE model (30%)
Background model

To choose a fit model for each category, use:

- Several different high statistics simulations with and w/o parameterised corrections for detector resolution and acceptance
- Data driven background estimates/cross checks

→ Require that for each of these the fit bias is <10% of expected signal or <20% of $\sqrt{B}$ at any mass point in the search range

The residual small bias is taken into account as systematic uncertainty

Higher stat. categories: polynomial based, lower stat. categories: exponential
Mass spectrum

Mass spectra of the individual categories consisting the final result
Mass spectrum

After final selection 59059 events in the combined dataset

Signal + background fit with $m_H = 126.5$ GeV on inclusive mass spectrum
Exclusion limits

Sensitivity below SM expectation in whole search range up to 140 GeV

Excluded at 95% CL: 112-122.5 GeV, 132-143 GeV

Excess around $m_{\gamma\gamma} \sim 126$ GeV
Quantifying excess

Maximum deviation from background only expectation at $m_{\gamma\gamma} = 126.5$ GeV

$\rightarrow$ Local significance 4.5$\sigma$ (expected from SM Higgs 2.4$\sigma$)

Global significance (including LEE) 3.6$\sigma$

Excess consistent in both datasets, and in inclusive analysis without categories
Best-fit signal strength

Fit S+B hypothesis to observed data, allow signal strength to vary
→ Obtain best-fit signal strength

Best fit for $m_H = 126.5$ GeV
$\mu = 1.9 \pm 0.5$

Consistent results from different categories
Best-fit signal strength vs mass

Likelihood contours in the $(\mu, m_H)$ plane

Uncertainty on best fit position for $m_H$ mainly depends on the statistical uncertainty and energy scale systematics
Conclusions

Observation of a narrow excess in the diphoton mass spectrum around 126.5 GeV with a local significance of 4.5\(\sigma\) (global 3.6\(\sigma\))

Excess is consistently observed in 2011 and 2012 datasets, in the sharing among categories and in the inclusive analysis

Next steps: establish the true nature of symmetry breaking with property measurements → ~126 GeV is the ideal place for the diphoton decay mode!

Not from spin 1 decay (Landau-Yang theorem)
Backup
Photon isolation

Calorimeter based isolation: $E_T < 4$ GeV inside cone $\Delta R < 0.4$ around $\gamma$

- Corrected for pileup and underlying event contributions by subtracting ambient energy density event-by-event
- *New:* improve pileup robustness with topological clusters which are based on calo cells with significant signal over noise ratio
- Good stability with position of colliding bunches in train $\rightarrow$ robust with pileup
Photon based categories

Both unconverted:
- Central
- Rest

At least one converted:
- Central
- Transition
- Rest

Central and Rest divided into $p_{Tt} < 60 \text{ GeV}$ and $p_{Tt} > 60 \text{ GeV}$

$p_{Tt}$ vs $p_T$:
- Better detector resolution
- Retains monotonically falling $m_{\gamma\gamma}$ distribution
7 TeV dataset

New analysis of 7 TeV dataset consistent with published result

15% improvement in expected sensitivity:
- Mainly due to improved photon identification and isolation calculation
- Also, VBF category and higher $p_T^{T_t}$ and sub-leading photon cuts
Best-fit signal strength for separate datasets

$\sqrt{s} = 7 \text{ TeV}, \int Ldt = 4.8 \text{ fb}^{-1}$

$\text{SM } H \rightarrow \gamma\gamma$

$m_H = 126.5 \text{ GeV}$

Data 2011

Data 2012

$\sqrt{s} = 8 \text{ TeV}, \int Ldt = 5.9 \text{ fb}^{-1}$

$\text{SM } H \rightarrow \gamma\gamma$

$m_H = 126.5 \text{ GeV}$

Data 2011, $\sqrt{s} = 7 \text{ TeV}$

$\int Ldt = 4.8 \text{ fb}^{-1}$

Data 2012, $\sqrt{s} = 8 \text{ TeV}$

$\int Ldt = 5.9 \text{ fb}^{-1}$