$H \rightarrow \gamma \gamma$
measurements at the ATLAS experiment

IUPAP Young Scientist Award

Kerstin Tackmann

Thanks to all my colleagues I had the pleasure to work with
ICHEP 2012 in Melbourne.
From discovery to measurements (and searches).

disentangle production modes: couplings to SM particles

M. Kado, D. Gillberg, ...

differential cross sections

Y. Huang, D. Gillberg, M. Kado

spin

K. Prokofiev

search for $hh \rightarrow \gamma\gamma b\bar{b}$

S. Laplace, M. Kado

search for FCNC $t \rightarrow Hc$

E. Shabalina

mass measurement

M. Kado, S. Laplace, R. Harrington, A. Gabrielli

limit on width

M. Kado, R. Harrington

search for other narrow resonances with mass of 65-600 GeV

Z. Barnovska, S. Laplace, M. Kado

Presented already in 9 (+2) talks and posters
What do we need for $H \rightarrow \gamma\gamma$?

- Efficient $\gamma$ reconstruction + good separation of converted and unconverted $\gamma$
- Precise calibration of $\gamma$ energy scale, good resolution
- Performant $\gamma\gamma$ trigger, compromise between high signal acceptance and low enough rate

J. Mitrevski

J.-B. Blanchard, M. Kado
ATLAS Inner Detector (ID) and EM Calorimeter.

$|\eta| < 2.5$, barrel-endcaps geometry
- 3 layers Si Pixel
- 4 double layers Si strips (SCT)
- straw-tube Transition Radiation Tracker (TRT)
  - $e^\pm$ identification capabilities through transition radiation

$|\eta| < 3.2$, barrel-endcaps geometry
- Pb-LAr sampling calorimeter
- 3 longitudinal layers with accordion geometry and presampler inside of cryostat
- Fine granularity allows measurement of shower shape
Photon reconstruction.

- Conversion tracks from
  - Inside-out tracking seeded in Si detectors
  - Back-tracking seeded in TRT and extended into Si
  - Standalone TRT tracking
- Track selection relies on transition radiation in TRT

- \( \sim 40\% \) of photons convert before reaching the calorimeter
- Efficient reconstruction of converted photons needed for dedicated
  - photon energy calibration
  - photon identification

\[ \gamma \rightarrow e^+ e^- \]
Photon reconstruction (8 TeV).

- Reconstruction of conversion vertices seeded from loosely selected electromagnetic clusters
  - 2-track vertices consistent with decay of massless particle
  - “1-track vertices” missing hits in innermost layer(s)

- Reconstructed secondary vertices (and tracks) matched to clusters in calorimeter

- Clusters without matching vertices or tracks: unconverted photons

- Reconstruction robust against pileup
Photon identification.

- Powerful jet-rejection ($\mathcal{O}(10^4)$) needed to suppress dominant hadronic background
- Fine granularity of electromagnetic calorimeter allows photon identification based on shower shape

After photon identification and requiring photon candidates to be isolated in calorimeter and tracker

- 75% $\gamma\gamma$ events
- 22% $\gamma$-jet events
- 3% jet-jet events
Efficiency measurements.

Id efficiency for isolated photons: $E_{T}^{iso} < 4 \text{ GeV}$

Radiative $Z$ decays $E_{T}^{\gamma}$ of 10-80 GeV
Photon purity
- $\sim 90\%$ (10-15 GeV)
- $\geq 98\%$ (> 15 GeV)

$Z \rightarrow ee$ tag-and-probe
+ transformation of electron showers to resemble photon showers

“Matrix method”

Purity determination from track isolation, combined with reversed shower shape cuts $\rightarrow$ id efficiency
Efficiency measurements.

- Partial overlap in $E_T$ regions covered by the different methods
  - Combination of measurements in overlap regions
- 1-2% uncertainties for $E_T < 40$ GeV, 0.5-1% above 40 GeV

Uncertainty on $H \rightarrow \gamma\gamma$ signal yield

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Second-largest experimental uncertainty on $H \rightarrow \gamma\gamma$ signal strength (Phys. Lett. B 726 (2013))
Energy calibration.

- Improved simulation of upstream material using longitudinal shower shapes
  - Radiation length can be measured to 4-6% $X_0$
- Relative calibration of calorimeter layers using $\mu$, $e$ and $\gamma$
- New MC-based energy calibration (separate for $e$, converted and unconverted $\gamma$)
  - Improvement of $\gamma\gamma$ invariant mass resolution of $\sim10$
- Absolute energy scale determined from $Z \rightarrow ee$
- Energy scale stable with pileup within 0.05%
Energy calibration.

Cross checks

- Energy scale measured from $Z \rightarrow ℓℓγ$ agrees within uncertainties
- Linearity checked with $J/ψ$ and $Z \rightarrow ee$

Resolution

- Resolution correction obtained from $Z \rightarrow ee$
- Uncertainties
  - $Z \rightarrow ee$ measurement
  - Material simulation
  - Calorimeter sampling term
  - Pileup
Mass measurement.

Dedicated event categorization:
10 categories according to $\eta\gamma$, converted/unconverted $\gamma$ and $p_Tt$

$$m_H = 125.98 \pm 0.42\text{(stat)} \pm 0.28\text{(syst)} \text{ GeV}$$

$$\mu = 1.29 \pm 0.30$$

- Dominant systematic uncertainty from energy scale

Substantial improvement over previous measurement:

$$m_H = 126.8 \pm 0.2 \pm 0.7 \text{ GeV}$$

- Observed shift consistent with expectation from new calibration (-0.45±0.35 GeV)
- Decreased systematic uncertainty (1/2.5) thanks to improved calibration
Separating production processes.

Dedicated categories enriched in gluon fusion, vector boson fusion and associated production

gluon fusion categories according to resolution and S/B
Separating production processes.

\[ \mu_{\text{VH}} \]

\[ \mu_{\text{VBF}} \]

\[ \mu_{\text{ggH+ttH}} \]

\[ \mu \]

\[ s = 7 \text{ TeV} \int \mathcal{L} \text{dt} = 4.8 \text{ fb}^{-1} \]

\[ s = 8 \text{ TeV} \int \mathcal{L} \text{dt} = 20.7 \text{ fb}^{-1} \]

\[ \text{ATLAS} \]

\[ 2011-2012 \]

\[ m_H = 126.8 \text{ GeV} \]

\[ \mu = 1 \Rightarrow \text{SM} \]

\[ \mu = 1.55 \pm 0.23 \text{(stat)} \pm 0.15 \text{(syst)} \pm 0.15 \text{(theo)} \] (at \( m_H = 12.5.5 \text{ GeV} \))

Largest contributions to systematic uncertainty

- Invariant mass resolution
- Photon identification efficiency

Have been improved and will be used for the next update
Differential cross section measurements.

Full 8 TeV dataset allows to make first differential cross section measurements

- Almost model-independent measurements of production and decay kinematics
- Measure kinematic distributions of Higgs, of associated jets, ...

\[ H \rightarrow \gamma\gamma \] decay well suited thanks to good resolution and “high” signal yield

- Background subtracted in a simultaneous signal-plus-background fit to all bins
Differential cross section measurements.

- Bin-by-bin unfolding for detector acceptance, resolution and efficiency
- Unfold to fiducial region defined by photons (and jets)
  \[ p_T^{\gamma_1(\gamma_2)} > 0.35 \ (0.25) \ m_{\gamma\gamma}, \quad |\eta^{\gamma_1,2}| < 2.37 \]
  \[ p_T^j > 30 \ \text{GeV}, \quad |y^j| < 4.4 \]

- Differential measurements presently dominated by statistical uncertainties
- Data and predictions agree within current uncertainties
Conclusions and outlook.

- Successful transition from Higgs search to Higgs measurements over the past two years
- Precise measurement of mass, measurements of couplings, differential cross sections, limits on width, ...
- Most measurements currently limited by statistical uncertainties
  - Effort to improve calibration, efficiency measurements, ... paid off

→ Precision of measurements will improve with larger datasets in Run2

- But will also have to work hard to improve systematic uncertainties
Mass measurement: systematic uncertainties.
Mass measurement: statistical uncertainties.

$m_H = 125.98 \pm 0.42 \text{ (stat)} \pm 0.28 \text{ (syst)} \text{ GeV} \quad (\mu = 1.29 \pm 0.30)$

to be compared with:

The previous measurement: $126.8 \pm 0.2 \pm 0.7 \text{ GeV}$

- observed shift (0.8 GeV) consistent with expected shift $-0.45 \pm 0.35 \text{ GeV}$
- syst. error decreased by factor 2.5
- stat. error:

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<td>1.55</td>
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(S. Laplace, Thursday)