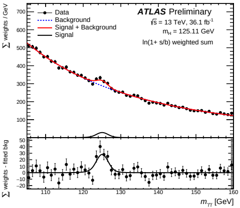
# Measurement of the SM Higgs boson mass in the diphoton and 4l decay channels using the ATLAS detector





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Deutsches Elektronen-Synchrotron


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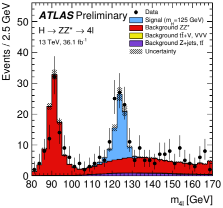
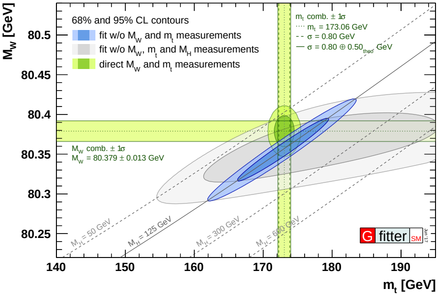


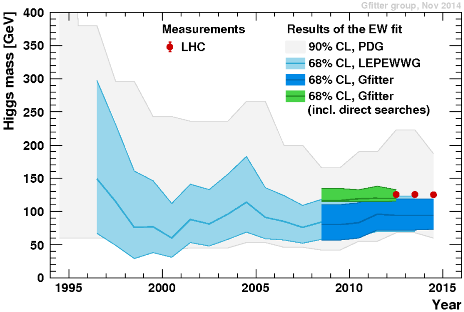
# Higgs Boson Mass

- The mass of the Higgs Boson ($m_H$) is not predicted by the SM: need to measure it
- Measurement required for precise calculation of EW observables
  - incl. Higgs production and decay properties
- High mass resolution (1-2%) channels: $H \to \gamma\gamma$ and $H \to ZZ^* \to 4\ell$

Measurement:

- $m_H$ measured from the position of the peak in the $4\ell$ or $\gamma\gamma$ invariant mass distribution
- Using constraints on $E$ and $p$ scale and res. of leptons and photons from control samples

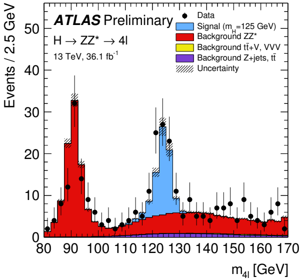


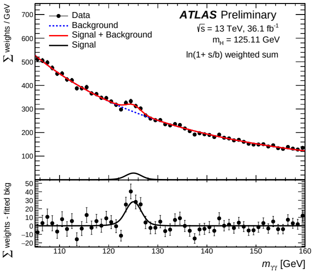

For latest Gfitter results, see talk by Thomas Peiffer

# Channels

$H \to ZZ^* \to 4\ell$




$H \to \gamma\gamma$

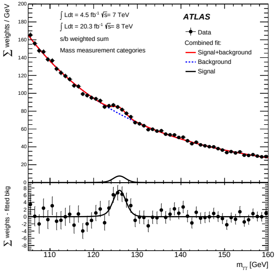


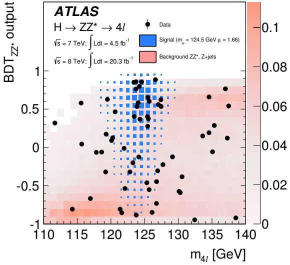

- Fully reconstructed Higgs boson
- BR $\sim 1.3 \times 10^{-4}$ @ 13 TeV
- High $S/B \sim 2.3$
- $m_H$ resolution: 1-2% $m_H$

- BR $\sim 2 \times 10^{-3}$ @ 13 TeV
- Low $S/B \sim 0.02$
- $m_H$ resolution: 1-2% $m_H$

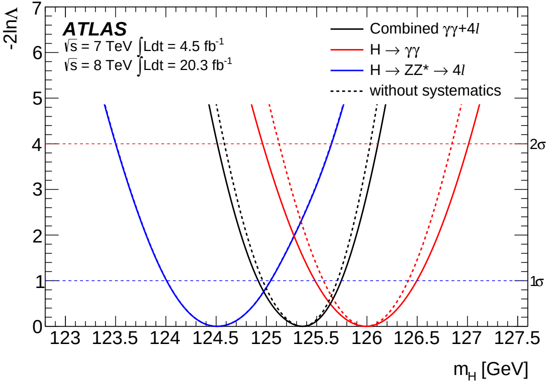
More info in talks by Ruchi Gupta, Tamara Vazquez Schroeder, and Andrea Gabrielli

# ATLAS Run-1: $H \to \gamma\gamma$ and $H \to ZZ^* \to 4\ell$




Phys. Rev. D. 90, 052004 (2014)



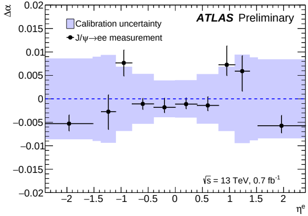

| Channel | Mass measurement [GeV] |
|---|---|
| $H \to \gamma\gamma$ | $125.98 \pm 0.42(\text{stat}) \pm 0.28(\text{syst}) = 125.98 \pm 0.50$ |
| $H \to ZZ^* \to 4\ell$ | $124.51 \pm 0.52(\text{stat}) \pm 0.06(\text{syst}) = 124.51 \pm 0.52$ |
| Combined | $125.36 \pm 0.37(\text{stat}) \pm 0.18(\text{syst}) = 125.36 \pm 0.41$ |

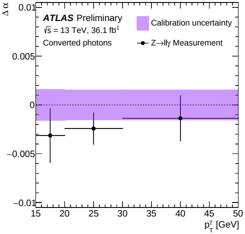
$2\sigma$ compatibility with individual channels ($P = 4.8\%$)

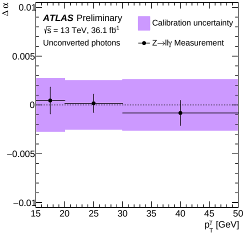
# Object Reconstruction in Run-2

Global calorimeter energy scale (after energy corr.)

- Determined from $Z \to e^+e^-$
- Verified using $J/\psi \to e^+e^-$ and $Z \to \ell^+\ell^-\gamma$

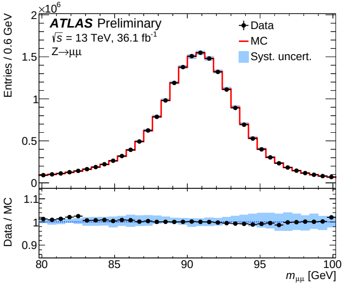



Muon momentum and scale calib.

- Obtained from $J/\psi \to \mu^+\mu^-$ and $Z \to \mu^+\mu^-$



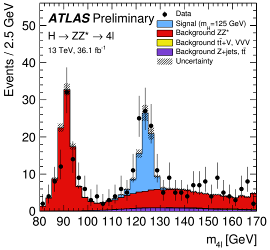

ATLAS-CONF-2017-046

# Run 2 - $H \to ZZ^* \to 4\ell$

Common Event Selection (details in backup):

- 2 OS SF leptons, $p_T(\ell_1, \ell_2, \ell_3) > (20, 10, 15)$ GeV; 4$^{\text{th}}$ lepton: $p_T > (5, 7)$ GeV $(\mu, e)$
  - $\text{Vtx}_{4\ell}$ cut to handle increase in bkg. due to muon $p_T^{\ell_4}$ cut relaxed from 6 to 5 GeV
- BDT($p_T^{4\ell}$, $\eta_{4\ell}$, ME $K_D$) separating $H \to ZZ^* \to 4\ell$ form $ZZ^* \to 4\ell$ (6% better mass res.)
- With $m_Z$ constraint to improve 4-lepton mass resolution (15% improvement)
- Using events with $110 < m_{4\ell} < 135$ GeV

| Final state | Signal (125 GeV) | $ZZ^*$ | $Z+$jets, $t\bar{t}$, $WZ$, $ttV$,$VVV$ | Expected | Observed |
|---|---|---|---|---|---|
| $4\mu$ | $20.6 \pm 1.7$ | $15.9 \pm 1.2$ | $2.0 \pm 0.4$ | $38.5 \pm 2.1$ | 38 |
| $2e2\mu$ | $14.6 \pm 1.1$ | $11.2 \pm 0.8$ | $1.6 \pm 0.4$ | $27.5 \pm 1.4$ | 34 |
| $2\mu 2e$ | $11.2 \pm 1.0$ | $7.4 \pm 0.7$ | $2.2 \pm 0.4$ | $20.8 \pm 1.3$ | 26 |
| $4e$ | $11.1 \pm 1.1$ | $7.1 \pm 0.7$ | $2.1 \pm 0.4$ | $20.3 \pm 1.3$ | 24 |
| Total | $57 \pm 5$ | $41.6 \pm 3.2$ | $8.0 \pm 1.0$ | $107 \pm 6$ | 122 |



# Run 2 - $H \to ZZ^* \to 4\ell$ – Measurement

- Per-event method, using probability of measuring $m_{4\ell}^{\mathrm{meas}}$ for a true mass $m_{4\ell}^{\mathrm{true}}$:

$$S_{m_H}(m_{4\ell}^{\mathrm{meas}}) = \int_0^\infty F(m_{4\ell}^{\mathrm{meas}} - m_{4\ell}^{\mathrm{true}}) \cdot BW(m_{4\ell}^{\mathrm{true}}, m_H)\, dm_{4\ell}^{\mathrm{true}}$$

- Lepton energy response PDF parameterized as $\sum_{g=1}^{3} w_g \cdot \mathcal{N}(m_{4\ell}^{\mathrm{meas}} - m_{4\ell}^{\mathrm{true}}; \mu_g, \sigma_g)$, obtained separately for $e$ and $\mu$ and depending on lepton energy and detector region
- Response function $F$ derived from lepton energy response functions and parameterized as

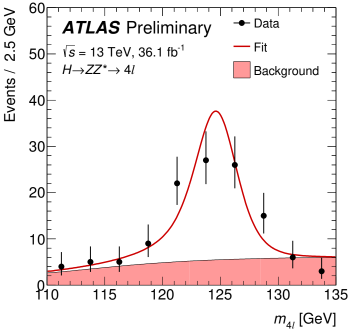
$$F(m_{4\ell}^{\mathrm{meas}} - m_{4\ell}^{\mathrm{true}}) = \sum_{g=1}^{4} w_g \cdot \mathcal{N}(m_{4\ell}^{\mathrm{meas}} - m_{4\ell}^{\mathrm{true}}; \mu_g, \sigma_g)$$

  (4 $\mathcal{N}$ obtained form $3^4 = 81$ $\mathcal{N}$ distributions replacing close-by dist. by one, until 4 remain)
- Maximizing likelihood function (for $N$ events)

$$L(m_H) = \prod_{k=1}^{N} \left[ S_{m_H}^{(k)} \left( m_{4\ell}^{\mathrm{meas(k)}} \right) + B \left( m_{4\ell}^{\mathrm{meas(k)}} \right) \right]$$

- Validation using $Z \to 4\ell$ events: $m_Z$ within $1.3\sigma$ of world average (data)
- Cross-check with template method: stat. unc. on same-size data sample is 1.4% larger

# Run 2 - $H \rightarrow ZZ^* \rightarrow 4\ell$

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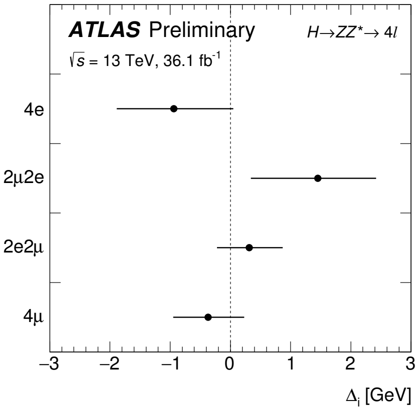
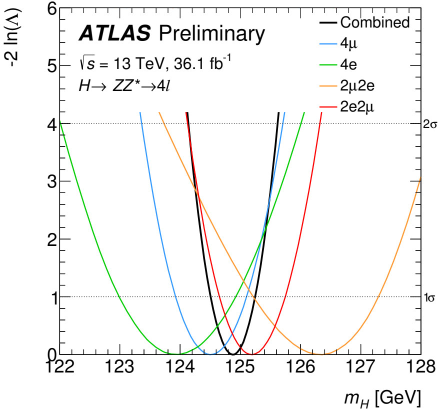
| Systematic effect | Uncertainty on $m_H^{ZZ^*}$ [MeV] |
|---|---|
| Muon momentum scale | 40 |
| Electron energy scale | 20 |
| Background modelling | 10 |
| Simulation statistics | 8 |

$$m_H^{ZZ^*} = 124.88 \pm 0.37\ \text{(stat)} \pm 0.05\ \text{(syst) GeV} = 124.88 \pm 0.37\ \text{GeV}$$

Template method cross-check: $\Delta m_H = 0.16$ GeV
uncertainty: $^{+0.41}_{-0.40}$ GeV (stat $\oplus$ sys) [+35 MeV]

# Run 2 - $H \to ZZ^* \to 4\ell$ - Compatibility Between Channels



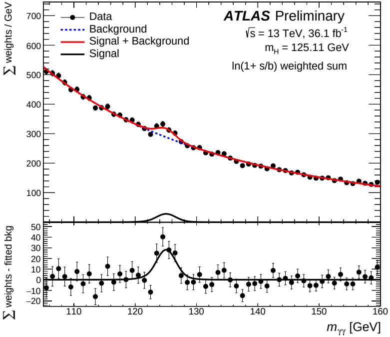



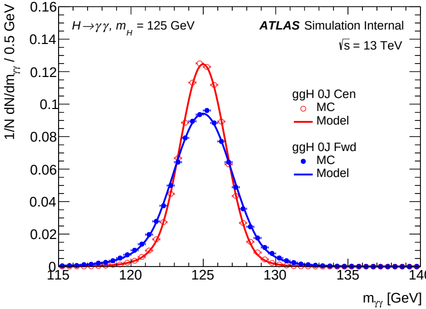

- $m_H$ compatible with independent measurements in each channel

# Run 2 - $H \to \gamma\gamma$

Common Event Selection (details in backup):

- Two photons with $E_T > 25$ GeV and $|\eta| < 2.37$ (excl. $1.37 \leq |\eta| \leq 1.52$)
- Leading (sub-leading) photon with $E_T/m_{\gamma\gamma} > 0.35$ (0.25) with tight ID and isolation
- Using events with $105 \leq m_{\gamma\gamma} \leq 160$ GeV
- Using 31 categories with different $\sigma_{m_{\gamma\gamma}}$ and $S/B$
  - Categories optimized for measurement of simplified template cross-sections

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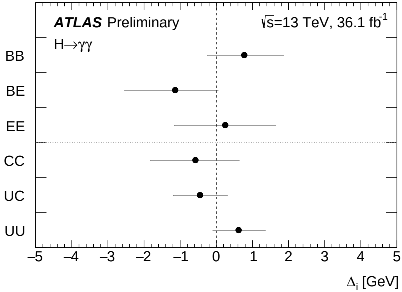
# Run 2 - $H \to \gamma\gamma$

$$m_H^{\gamma\gamma} = 125.11 \pm 0.21\ \text{(stat)} \pm 0.36\ \text{(syst)}\ \text{GeV} = 125.11 \pm 0.42\ \text{GeV}$$




| Systematic effect | $\delta m_H^{\gamma\gamma}$ [MeV] |
|---|---|
| LAr cell non-linearity | $^{+200}_{-190}$ |
| Layer calibration | $\pm 190$ |
| Other material (not ID) | $\pm 120$ |
| Lateral shower shape | $\pm 110$ |
| ID material | $\pm 110$ |
| Conversion reconstruction | $\pm 50$ |
| $Z \to ee$ calibration | $\pm 50$ |
| Background model | $^{+30}_{-50}$ |
| Signal model | $\pm 40$ |
| Primary vertex effect on mass scale | $^{+30}_{-40}$ |

Consistency checks:

- Effect of mis-calibration checked using two categorization schemes, using
  - impact point in the calorimeter: $|\eta| < 1.37$ (barrel, B) or $|\eta| > 1.52$ (endcap, E)
  - conversion status: converted (C) or unconverted (U)
- Effect of common $\mu$ (with SM relative ratios), instead of one per production mode: 20 MeV

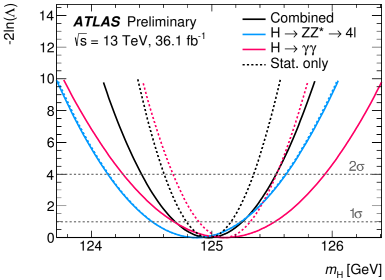
# Preliminary Run-2 Combination

$$\Lambda(m_H) = \frac{L(m_H, \hat{\hat{\mu}}^{ZZ}(m_H), \hat{\hat{\mu}}^{\gamma\gamma}_{\rm ggH}(m_H), \hat{\hat{\mu}}^{\gamma\gamma}_{\rm VBF}(m_H), \hat{\hat{\mu}}^{\gamma\gamma}_{\rm VH}(m_H), \hat{\hat{\mu}}^{\gamma\gamma}_{\rm ttH}(m_H), \hat{\hat{\theta}}(m_H))}{L(\hat{m}_H, \hat{\mu}^{ZZ}, \hat{\mu}^{\gamma\gamma}_{\rm ggH}, \hat{\mu}^{\gamma\gamma}_{\rm VBF}, \hat{\mu}^{\gamma\gamma}_{\rm VH}, \hat{\mu}^{\gamma\gamma}_{\rm ttH}, \hat{\theta})}$$

| Channel | Mass measurement [GeV] |
|---|---|
| $H \to ZZ^* \to 4\ell$ | $124.88 \pm 0.37$ (stat) $\pm 0.05$ (syst) $= 124.88 \pm 0.37$ |
| $H \to \gamma\gamma$ | $125.11 \pm 0.21$ (stat) $\pm 0.36$ (syst) $= 125.11 \pm 0.42$ |
| Combined | $124.98 \pm 0.19$ (stat) $\pm 0.21$ (syst) $= 124.98 \pm 0.28$ |

Good agreement with Run-1:

- ATLAS:
  $m_H = 125.36 \pm 0.41$ GeV
- ATLAS+CMS:
  $m_H = 125.09 \pm 0.24$ GeV

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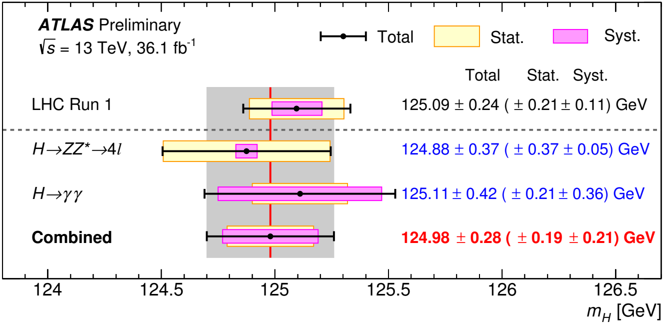
$$\Delta m_H^{4\ell,\gamma\gamma} = 0.23 \pm 0.42 \text{ (stat)} \pm 0.36 \text{ (syst)}$$
$$= 0.23 \pm 0.55 \text{ GeV}$$

| Source | Systematic uncertainty on $m_H$ [MeV] |
|---|---|
| LAr cell non-linearity | 90 |
| LAr layer calibration | 90 |
| Non-ID material | 60 |
| ID material | 50 |
| Lateral shower shape | 50 |
| $Z \to ee$ calibration | 30 |
| Muon momentum scale | 20 |
| Conversion reconstruction | 20 |

# Summary

- Improved measurements of $m_H$ in the $H \to \gamma\gamma$ and $H \to ZZ^* \to 4\ell$ channels with 36.1 $\text{fb}^{-1}$ of data at a centre-of-mass energy of $\sqrt{s} = 13$ TeV
- Using latest calibrations for muons, electrons, and photons, and improved analysis techniques w.r.t. Run-1




- Result in excellent agreement with, and similar uncertainty to, LHC Run-1 average $m_H = 125.09 \pm 0.24$ GeV

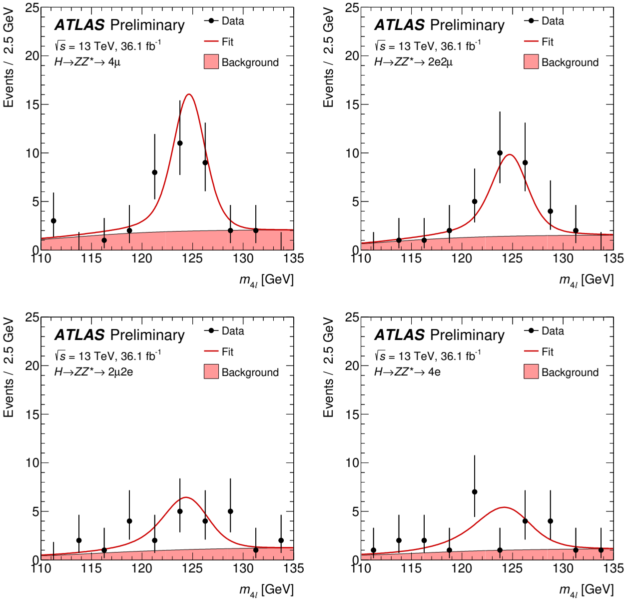
# Backup Slides

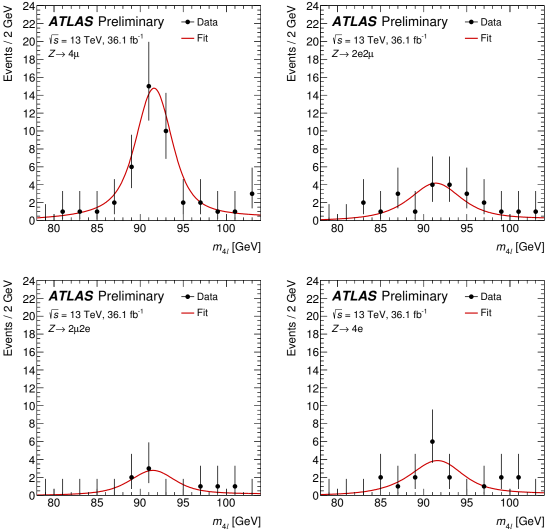
# References


- Phys. Rev. D. 90, 052004 (2014): "Measurement of the Higgs boson mass from the $H \to \gamma\gamma$and $H \to ZZ^* \to 4\ell$ channels with the ATLAS detector using 25 fb$^{-1}$ of pp collision data"
- ATLAS-CONF-2017-032: "Measurement of inclusive and differential fiducial cross sections in the $H \to ZZ^* \to 4\ell$ decay channel at 13 TeV with the ATLAS detector"
- ATLAS-COM-CONF-2017-045: "Measurements of Higgs boson properties in the diphoton decay channel with 36.1 fb$^{-1}$ pp collision data at the center-of-mass energy of 13 TeV with the ATLAS detector"
- ATLAS-CONF-2017-046: "Measurement of the Higgs boson mass in the $H \to ZZ^* \to 4\ell$ and $H \to \gamma\gamma$ channels with $\sqrt{s} = 13$ TeV pp collisions using the ATLAS detector "

# $H \to ZZ^* \to 4\ell$ Event Selection

| | |
|---|---|
| **Leptons and jets** | |
| Muons: | $p_{\mathrm{T}} > 5$ GeV, $\lvert\eta\rvert < 2.7$ |
| Electrons: | $p_{\mathrm{T}} > 7$ GeV, $\lvert\eta\rvert < 2.47$ |
| Jets: | $p_{\mathrm{T}} > 30$ GeV, $\lvert y\rvert < 4.4$ |
| Jet-lepton overlap removal: | $\Delta R(\mathrm{jet}, \ell) > 0.1\,(0.2)$ for muons (electrons) |
| **Lepton selection and pairing** | |
| Lepton kinematics: | $p_{\mathrm{T}} > 20, 15, 10$ GeV |
| Leading pair ($m_{12}$): | SFOS lepton pair with smallest $\lvert m_Z - m_{\ell\ell}\rvert$ |
| Subleading pair ($m_{34}$): | remaining SFOS lepton pair with smallest $\lvert m_Z - m_{\ell\ell}\rvert$ |
| **Event selection (at most one quadruplet per channel)** | |
| Mass requirements: | $50 < m_{12} < 106$ GeV and $12 < m_{34} < 115$ GeV |
| Lepton separation: | $\Delta R(\ell_i, \ell_j) > 0.1\,(0.2)$ for same- (different-) flavour leptons |
| $J/\psi$ veto: | $m(\ell_i, \ell_j) > 5$ GeV for all SFOS lepton pairs |
| Mass window: | $115\ GeV < m_{4\ell} < 130$ GeV |

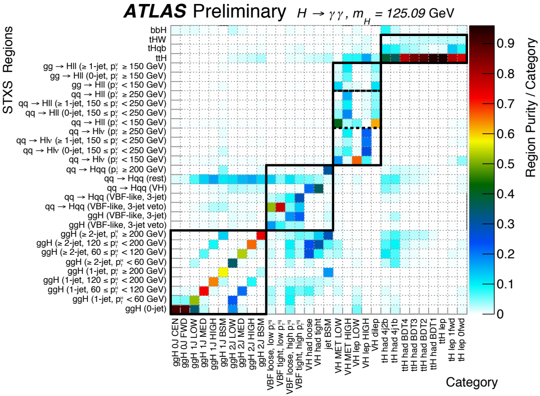

ATLAS Preliminary
√s = 13 TeV, 36.1 fb-1
H→ZZ*→ 4μ
H→ZZ*→ 2e2μ
H→ZZ*→ 2μ2e
H→ZZ*→ 4e
Data
Fit
Background
Events / 2.5 GeV
m4l [GeV]

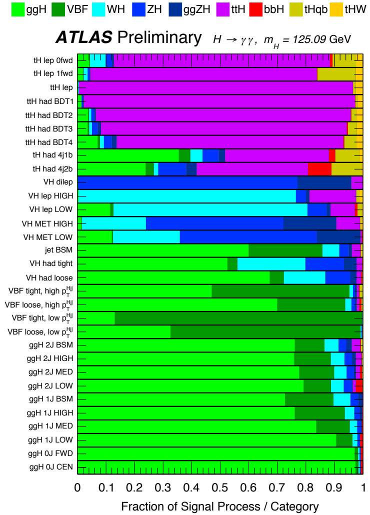

ATLAS Preliminary
√s = 13 TeV, 36.1 fb-1
Z→ 4μ
Z→ 2e2μ
Z→ 2μ2e
Z→ 4e
Data
Fit
Events / 2 GeV
m4l [GeV]

# $H \to \gamma\gamma$ Event Selection

| Process | Measurement region | Stage 1 region |
|---|---|---|
| ggH + $gg \to Z(\to qq)H$ | 0-jet | 0-jet |
| | 1-jet, $p_{\mathrm{T}}^{H} < 60\,GeV$ | 1-jet, $p_{\mathrm{T}}^{H} < 60\,GeV$ |
| | 1-jet, $60 \leq p_{\mathrm{T}}^{H} < 120\,GeV$ | 1-jet, $60 \leq p_{\mathrm{T}}^{H} < 120\,GeV$ |
| | 1-jet, $120 \leq p_{\mathrm{T}}^{H} < 200\,GeV$ | 1-jet, $120 \leq p_{\mathrm{T}}^{H} < 200\,GeV$ |
| | $\geq$ 1-jet, $p_{\mathrm{T}}^{H} > 200\,GeV$ | 1-jet, $p_{\mathrm{T}}^{H} > 200\,GeV$ |
| | | $\geq$ 2-jet, $p_{\mathrm{T}}^{H} > 200\,GeV$ |
| | $\geq$ 2-jet, $p_{\mathrm{T}}^{H} < 200\,GeV$ or VBF-like | $\geq$ 2-jet, $p_{\mathrm{T}}^{H} < 60\,GeV$ |
| | | $\geq$ 2-jet, $60 \leq p_{\mathrm{T}}^{H} < 120\,GeV$ |
| | | $\geq$ 2-jet, $120 \leq p_{\mathrm{T}}^{H} < 200\,GeV$ |
| | | VBF-like, $p_{\mathrm{T}}^{Hjj} < 25\,GeV$ |
| | | VBF-like, $p_{\mathrm{T}}^{Hjj} \geq 25\,GeV$ |
| $qq' \to Hqq'$ (VBF + $VH$) | $p_{\mathrm{T}}^{j} < 200\,GeV$ | $p_{\mathrm{T}}^{j} < 200\,GeV$, VBF-like, $p_{\mathrm{T}}^{Hjj} < 25\,GeV$ |
| | | $p_{\mathrm{T}}^{j} < 200\,GeV$, VBF-like, $p_{\mathrm{T}}^{Hjj} \geq 25\,GeV$ |
| | | $p_{\mathrm{T}}^{j} < 200\,GeV$, VH-like |
| | | $p_{\mathrm{T}}^{j} < 200\,GeV$, Rest |
| | $p_{\mathrm{T}}^{j} > 200\,GeV$ | $p_{\mathrm{T}}^{j} > 200\,GeV$ |
| $VH$ (leptonic decays) | $VH$ leptonic | $q\bar{q} \to ZH$, $p_{\mathrm{T}}^{Z} < 150\ GeV$ |
| | | $q\bar{q} \to ZH$, $150\ GeV < p_{\mathrm{T}}^{Z} < 250\ GeV$, 0-jet |
| | | $q\bar{q} \to ZH$, $150\ GeV < p_{\mathrm{T}}^{Z} < 250\ GeV$, $\geq$ 1-jet |
| | | $q\bar{q} \to ZH$, $p_{\mathrm{T}}^{Z} > 250\ GeV$ |
| | | $q\bar{q} \to WH$, $p_{\mathrm{T}}^{W} < 150\ GeV$ |
| | | $q\bar{q} \to WH$, $150\ GeV < p_{\mathrm{T}}^{W} < 250\ GeV$, 0-jet |
| | | $q\bar{q} \to WH$, $150\ GeV < p_{\mathrm{T}}^{W} < 250\ GeV$, $\geq$ 1-jet |
| | | $q\bar{q} \to WH$, $p_{\mathrm{T}}^{W} > 250\ GeV$ |
| | | $gg \to ZH$, $p_{\mathrm{T}}^{Z} < 150\ GeV$ |
| | | $gg \to ZH$, $p_{\mathrm{T}}^{Z} > 150\ GeV$, 0-jet |
| | | $gg \to ZH$, $p_{\mathrm{T}}^{Z} > 150\ GeV$, $\geq$ 1-jet |
| top-associated production | top | $t\bar{t}H$ |
| | | $tHW$ |
| | | $tHqb$ |
| $b\bar{b}H$ | merged w/ ggH | $b\bar{b}H$ |

| Category | Selection |
|---|---|
| tH lep 0fwd | $N_{\mathrm{lep}} = 1$, $N_{\mathrm{jets}}^{\mathrm{cen}} \leq 3$, $N_{\mathrm{b-tag}} \geq 1$, $N_{\mathrm{jets}}^{\mathrm{fwd}} = 0$ ($p_{\mathrm{T}}^{\mathrm{jet}} > 25\,\mathrm{GeV}$) |
| tH lep 1fwd | $N_{\mathrm{lep}} = 1$, $N_{\mathrm{jets}}^{\mathrm{cen}} \leq 4$, $N_{\mathrm{b-tag}} \geq 1$, $N_{\mathrm{jets}}^{\mathrm{fwd}} \geq 1$ ($p_{\mathrm{T}}^{\mathrm{jet}} > 25\,\mathrm{GeV}$) |
| ttH lep | $N_{\mathrm{lep}} \geq 1$, $N_{\mathrm{jets}}^{\mathrm{cen}} \geq 2$, $N_{\mathrm{b-tag}} \geq 1$, $Z_{\ell\ell}$ veto ($p_{\mathrm{T}}^{\mathrm{jet}} > 25\,\mathrm{GeV}$) |
| ttH had BDT1 | $N_{\mathrm{lep}} = 0$, $N_{\mathrm{jets}} \geq 3$, $N_{\mathrm{b-tag}} \geq 1$, $\mathrm{BDT}_{\mathrm{ttH}} > 0.92$ |
| ttH had BDT2 | $N_{\mathrm{lep}} = 0$, $N_{\mathrm{jets}} \geq 3$, $N_{\mathrm{b-tag}} \geq 1$, $0.83 < \mathrm{BDT}_{\mathrm{ttH}} < 0.92$ |
| ttH had BDT3 | $N_{\mathrm{lep}} = 0$, $N_{\mathrm{jets}} \geq 3$, $N_{\mathrm{b-tag}} \geq 1$, $0.79 < \mathrm{BDT}_{\mathrm{ttH}} < 0.83$ |
| ttH had BDT4 | $N_{\mathrm{lep}} = 0$, $N_{\mathrm{jets}} \geq 3$, $N_{\mathrm{b-tag}} \geq 1$, $0.52 < \mathrm{BDT}_{\mathrm{ttH}} < 0.79$ |
| tH had 4j1b | $N_{\mathrm{lep}} = 0$, $N_{\mathrm{jets}}^{\mathrm{cen}} = 4$, $N_{\mathrm{b-tag}} = 1$ ($p_{\mathrm{T}}^{\mathrm{jet}} > 25\,\mathrm{GeV}$) |
| tH had 4j2b | $N_{\mathrm{lep}} = 0$, $N_{\mathrm{jets}}^{\mathrm{cen}} = 4$, $N_{\mathrm{b-tag}} \geq 2$ ($p_{\mathrm{T}}^{\mathrm{jet}} > 25\,\mathrm{GeV}$) |
| VH dilep | $N_{\mathrm{lep}} \geq 2$, $70\,\mathrm{GeV} \leq m_{\ell\ell} \leq 110\,\mathrm{GeV}$ |
| VH lep HIGH | $N_{\mathrm{lep}} = 1$, $\lvert m_{e\gamma} - 89\,\mathrm{GeV}\rvert > 5\,\mathrm{GeV}$, $p_{\mathrm{T}}^{l+E_{\mathrm{T}}^{\mathrm{miss}}} > 150\,\mathrm{GeV}$ |
| VH lep LOW | $N_{\mathrm{lep}} = 1$, $\lvert m_{e\gamma} - 89\,\mathrm{GeV}\rvert > 5\,\mathrm{GeV}$, $p_{\mathrm{T}}^{l+E_{\mathrm{T}}^{\mathrm{miss}}} < 150\,\mathrm{GeV}$, $E_{\mathrm{T}}^{\mathrm{miss}}$ significance $> 1$ |
| VH MET HIGH | $150\,\mathrm{GeV} < E_{\mathrm{T}}^{\mathrm{miss}} < 250\,\mathrm{GeV}$, $E_{\mathrm{T}}^{\mathrm{miss}}$ significance $> 9$ or $E_{\mathrm{T}}^{\mathrm{miss}} > 250\,\mathrm{GeV}$ |
| VH MET LOW | $80\,\mathrm{GeV} < E_{\mathrm{T}}^{\mathrm{miss}} < 150\,\mathrm{GeV}$, $E_{\mathrm{T}}^{\mathrm{miss}}$ significance $> 8$ |
| jet BSM | $p_{\mathrm{T,j1}} > 200\,\mathrm{GeV}$ |
| VH had tight | $60\,\mathrm{GeV} < m_{\mathrm{jj}} < 120\,\mathrm{GeV}$, $\mathrm{BDT}_{\mathrm{VH}} > 0.78$ |
| VH had loose | $60\ GeV < m_{\mathrm{jj}} < 120\,\mathrm{GeV}$, $0.35 < \mathrm{BDT}_{\mathrm{VH}} < 0.78$ |
| VBF tight, high $p_T^{Hjj}$ | $\Delta\eta_{\mathrm{jj}} > 2$, $\lvert\eta_{\gamma\gamma} - 0.5(\eta_{\mathrm{j1}} + \eta_{\mathrm{j2}})\rvert < 5$, $p_T^{Hjj} > 25\,\mathrm{GeV}$, $\mathrm{BDT}_{\mathrm{VBF}} > 0.47$ |
| VBF loose, high $p_T^{Hjj}$ | $\Delta\eta_{\mathrm{jj}} > 2$, $\lvert\eta_{\gamma\gamma} - 0.5(\eta_{\mathrm{j1}} + \eta_{\mathrm{j2}})\rvert < 5$, $p_T^{Hjj} > 25\,\mathrm{GeV}$, $-0.32 < \mathrm{BDT}_{\mathrm{VBF}} < 0.47$ |
| VBF tight, low $p_T^{Hjj}$ | $\Delta\eta_{\mathrm{jj}} > 2$, $\lvert\eta_{\gamma\gamma} - 0.5(\eta_{\mathrm{j1}} + \eta_{\mathrm{j2}})\rvert < 5$, $p_T^{Hjj} < 25\,\mathrm{GeV}$, $\mathrm{BDT}_{\mathrm{VBF}} > 0.87$ |
| VBF loose, low $p_T^{Hjj}$ | $\Delta\eta_{\mathrm{jj}} > 2$, $\lvert\eta_{\gamma\gamma} - 0.5(\eta_{\mathrm{j1}} + \eta_{\mathrm{j2}})\rvert < 5$, $p_T^{Hjj} < 25\,\mathrm{GeV}$, $0.26 < \mathrm{BDT}_{\mathrm{VBF}} < 0.87$ |
| ggH 2J BSM | $\geq 2$ jets, $p_{\mathrm{T}}^{\gamma\gamma} \geq 200\,\mathrm{GeV}$ |
| ggH 2J HIGH | $\geq 2$ jets, $p_{\mathrm{T}}^{\gamma\gamma} \in [120, 200]$ GeV |
| ggH 2J MED | $\geq 2$ jets, $p_{\mathrm{T}}^{\gamma\gamma} \in [60, 120]$ GeV |
| ggH 2J LOW | $\geq 2$ jets, $p_{\mathrm{T}}^{\gamma\gamma} \in [0, 60]$ GeV |
| ggH 1J BSM | $= 1$ jet, $p_{\mathrm{T}}^{\gamma\gamma} \geq 200\,\mathrm{GeV}$ |
| ggH 1J HIGH | $= 1$ jet, $p_{\mathrm{T}}^{\gamma\gamma} \in [120, 200]$ GeV |
| ggH 1J MED | $= 1$ jet, $p_{\mathrm{T}}^{\gamma\gamma} \in [60, 120]$ GeV |
| ggH 1J LOW | $= 1$ jet, $p_{\mathrm{T}}^{\gamma\gamma} \in [0, 60]$ GeV |
| ggH 0J FWD | $= 0$ jets, one photon with $\lvert\eta\rvert > 0.95$ |
| ggH 0J CEN | $= 0$ jets, two photons with $\lvert\eta\rvert \leq 0.95$ |


ATLAS Preliminary $H \rightarrow \gamma\gamma$, $m_H$ = 125.09 GeV
STXS Regions
Region Purity / Category
Category


ggH VBF WH ZH ggZH ttH bbH tHqb tHW
ATLAS Preliminary $H \rightarrow \gamma\gamma$, $m_H$ = 125.09 GeV
Fraction of Signal Process / Category

# Modeling

| Process | Generator | Showering | PDF set | Order of calculation | $\sigma$[pb] $\sqrt{s}=13$ TeV |
|---|---|---|---|---|---|
| ggH | Powheg NNLOPS | Pythia8 | PDF4LHC15 | $\mathrm{N^3LO(QCD)+NLO(EW)}$ | 48.52 |
| VBF | Powheg Box | Pythia8 | PDF4LHC15 | NNLO(QCD)+NLO(EW) | 3.78 |
| $WH$ | Powheg Box | Pythia8 | PDF4LHC15 | NNLO(QCD)+NLO(EW) | 1.37 |
| $q\bar{q}' \to ZH$ | Powheg Box | Pythia8 | PDF4LHC15 | NNLO(QCD)+NLO(EW) | 0.76 |
| $gg \to ZH$ | Powheg Box | Pythia8 | PDF4LHC15 | NNLO(QCD)+NLO(EW) | 0.12 |
| $t\bar{t}H$ | MadGraph5_aMC@NLO | Pythia8 | NNPDF3.0 | NLO(QCD)+NLO(EW) | 0.51 |
| $b\bar{b}H$ | MadGraph5_aMC@NLO | Pythia8 | CT10 | 5FS(NNLO)+4FS(NLO) | 0.49 |
| $tHq\bar{b}$ | MadGraph5_aMC@NLO | Pythia8 | CT10 | 4FS(LO) | 0.07 |
| $tHW$ | MadGraph5_aMC@NLO | Herwig++ | CT10 | 5FS(NLO) | 0.02 |
| $\gamma\gamma$ | Sherpa | Sherpa | CT10 | | |