Higgs Searches at ATLAS

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In 2010:
- Proton-proton collisions
- ATLAS recorded $\sim 45 \text{ pb}^{-1}$ of integrated luminosity at $\sqrt{s}=7 \text{ TeV}$
- Depending on data quality selections, 35 pb$^{-1}$ or more used in analysis

In 2011:
- Running since mid-February with $\sqrt{s}=7 \text{ TeV}$, $\sim 260 \text{ pb}^{-1}$ recorded so far...but no public results on this data yet
- Aim for 1 fb$^{-1}$ or more of integrated luminosity before the end of the year

Beyond:
- Run in 2012, at $\sqrt{s}=7 \text{ TeV}$ or possibly at $\sqrt{s}=8 \text{ TeV}$
- Long shutdown, then run at higher energy
In the Standard Model, Higgs boson production primarily through gluon fusion and Weak Boson Fusion.

- Some modes (e.g. $H \rightarrow \gamma \gamma$, $bb$) receive contribution from $WH/ZH/ttH$ too.

In MSSM/2HDM, $H^0$ is also produced in with two $b$ quarks (if $\tan \beta$ is large). $H^\pm$ is produced in top decays if $M_{H^+}$ is small, or in association with top ($gb$ fusion) if $M_{H^+}$ is large.

- Right: cross-sections (top) and branching ratios (bottom) in the Standard Model (SM)

- Standard Model decay modes presented here:
  - $H \rightarrow WW$
  - $H \rightarrow ZZ$
  - $H \rightarrow \gamma \gamma$

- MSSM decay modes presented here:
  - $H^+ \rightarrow \tau \nu$
  - $A/H^0 \rightarrow \tau \tau$

- Studied in sensitivity projections but not shown here:
  - VBF $H \rightarrow \tau \tau$
  - $WH/ZH \rightarrow bb$
Event selection exploits different angular distributions caused by kinematics and by spin correlations. Above: $M_{ll}$ (left) and $\Delta \phi_{ll}$ (right) in events with no jets.

The analysis also includes contributions from $H+1j$ and $H+2j$. These variables are similarly useful there.
Backgrounds are estimated with control samples:

- **W+jets**: loosened lepton selection (above left & right)
- **ttbar**: altered jet cuts & b-tagging
- **Z+jets**: altered $M_{ll}$ and $P_T^{miss}$ cuts (lower right)
- **Diboson**: altered $M_{ll}$ and $\Delta \phi_{ll}$ cuts
The H+2j analysis exploits jet angular distributions to suppress backgrounds. These cuts favor signal from Weak Boson Fusion over signal from gluon fusion.

Above: distributions of pseudorapidity gap between two leading jets in the event (left) and invariant mass of the two jets (right), before applying MET cut.

Z+jets MC models these distributions well, but need more data to make a strong statement about other backgrounds and about the presence or absence of WBF signal.
Above: combined limits from $H \rightarrow 0/1/2j$ ($H \rightarrow WW \rightarrow l\nu l\nu$)

For $M_H = 160$ GeV, exclude 1.2 times the Standard Model prediction
With $H \rightarrow WW \rightarrow l\nu qq$, one can to reconstruct the Higgs mass by assuming that the invariant mass of the lepton and neutrino is $M_W$

- This only works for $M_H > 2M_W$

Background is normalized with a fit to the $M_{WW}$ distribution

- Exponential for background, histogram PDF for signal
- Separate categories for $e$, $\mu$, $H+0j$, and $H+1j$
- Because of the background shape, only fit the range $M_H > 200$ GeV
At $M_H = 400$ GeV, exclude Higgs production cross-sections larger than 11.2 times the Standard Model prediction.
Loosened selection for 2010 data: two opposite-sign lepton pairs satisfying mass cuts, but no isolation/IP requirements

- Two candidates after loosened selection (left), but no candidates observed after full selection

ZZ → 4l background yield normalized to observed Z → ll yield

Modeling of background from Z + heavy quarks is checked by studying $P_T$ of additional leptons in events with Z and one or more additional leptons (right)
With 2010 data, \( H \rightarrow ZZ \rightarrow 4l \) is not the most sensitive channel at any \( M_H \), although for \( M_H = 200 \) GeV it is comparable to other channels.

However, it is a very clean channel, so one can expect the limit to improve as \( \sim 1/L_{\text{int}} \).
Select events with two leptons and two jets, both with invariant mass close to $M_Z$.

- Left: the invariant mass of the jet pair

Plot the invariant mass of the $lljj$ system and look for a bump (right)

For $M_H \geq 360$ GeV, add cuts on $\Delta \phi_{jj}$ and $\Delta \phi_{ll}$ to suppress $Z$+jets background

This channel is analyzed together with $H \rightarrow ZZ \rightarrow ll\nu\nu$
Select events with two leptons on the Z peak and large $E_T^{\text{miss}}$ (left)

Final discriminating variable is transverse mass (right)

Background estimation: ZZ/WW/WZ from MC (15% uncertainty). Other backgrounds measured from control samples.
Above: expected and observed limits for $ll\nu\nu$ (left) and $llqq$ (right)

Bottom right: limits from $ll\nu\nu$ and $llqq$ combined

Exclude $\sim3.5\times-30\times$ Standard Model prediction, depending on mass
Signal is extracted using a fit: Gaussian+Crystal Ball for signal, exponential for background.

Normalization of background from jets is checked using loosened photon ID cuts.

- Measured background is compatible with predictions
- Dominant uncertainties on signal are from cross-section (+20/-15%), photon ID (11%), isolation (10%)
- Left: $M_{\gamma\gamma}$ distribution for data (points) and MC $\gamma\gamma$+data-driven $\gamma j/jj$+error (yellow band)
- Right: exclude 8x-38x SM, depending on mass
Analysis includes only $\tau\tau\rightarrow lh$, and is based on invariant mass of visible $\tau$ decay products

- $Z\rightarrow \tau\tau$ Monte Carlo checked by replacing muons in $Z\rightarrow \mu\mu$ data events with simulated taus. (left)
- QCD/$W+$jets estimated with same-sign control sample
- Observation is consistent with background (right)
The observation in 35 pb$^{-1}$ excludes a large region of the $M_A$/tan($\beta$) plane (beyond current limits)
Bump hunt for low-mass scalar A in the search ranges 6-9 GeV and 11-12 GeV.

Fit the $M_{\mu\mu}$ distribution (left) with a Gaussian signal on a 4th order polynomial background.

Upper bound is set on the cross-section (right).

- Observed limit fluctuations should be interpreted with thought to the look-elsewhere effect. Trials factor $\sim 70-90$.
Search for $t \rightarrow bH^+ \rightarrow b\tau\nu$.

ATLAS has performed checks on the background modeling (left), background extraction, and more powerful discriminating variables, but has not published observed limits.

Expect to set strong limits in early data.
Expect to exclude a SM Higgs in \( \sim 130 < M_H < 460 \) GeV with 1 fb\(^{-1}\) of integrated luminosity.

Reach down to the LEP limit with 5 fb\(^{-1}\).
With 5-10 fb\(^{-1}\) at 8 TeV, exclude full mass range up to 600 GeV, or reach 5\(\sigma\) discovery if there is a SM Higgs in 130\(<M_H<500\) GeV

114-130 GeV is still challenging at this \(\sqrt{s}\) and luminosity
Summary

- Using the $H \rightarrow WW \rightarrow l l \nu \nu$ channel, ATLAS has made good progress toward confirming the SM Higgs boson exclusion published by Tevatron.

- $H \rightarrow WW \rightarrow l l \nu \nu \bar{q} q$ search excludes between 5 and 40 times the SM prediction in $200 < M_H < 600$ GeV.

- $H \rightarrow ZZ \rightarrow ll \nu \nu / ll \bar{q} \bar{q}$ search excludes between 3.5 and 30 times the SM prediction in $200 < M_H < 600$ GeV.

- $H \rightarrow \gamma \gamma$ search excludes between 8 and 38 times the SM prediction.

- $H/A \rightarrow \tau \tau$ search has extended the excluded region of MSSM plane.

- Low-mass dimuon search sets limit on NMSSM $a_1$ particle.

- In this year's data, ATLAS expects to discover a SM Higgs near the $WW$ threshold or exclude it in $\sim 130 < M_H < 460$ GeV.