Mass measurement of the Higgs boson in the $H \rightarrow ZZ^{*} \rightarrow 4l$ channel at the ATLAS detector

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Introduction

- An overview of the improved measurement of the Higgs boson mass with 25 fb^{-1} of proton-proton collisions at 7 and 8 TeV center-of-mass energy.
- Reduction of statistical error in measurement from use of a two-dimensional model in four lepton mass (m_{4l}) and irreducible ZZ background discriminant (BDT).
- Improvement in detector calibration gives large reduction in major systematic uncertainties from electron energy scale and muon momentum scale.
- Combined results with $H \rightarrow \gamma\gamma$ published in Summer 2014:
  - arXiv: 1406.3827
  - Phys. Rev. D: 90, 052004

H→ZZ*→4l Overview

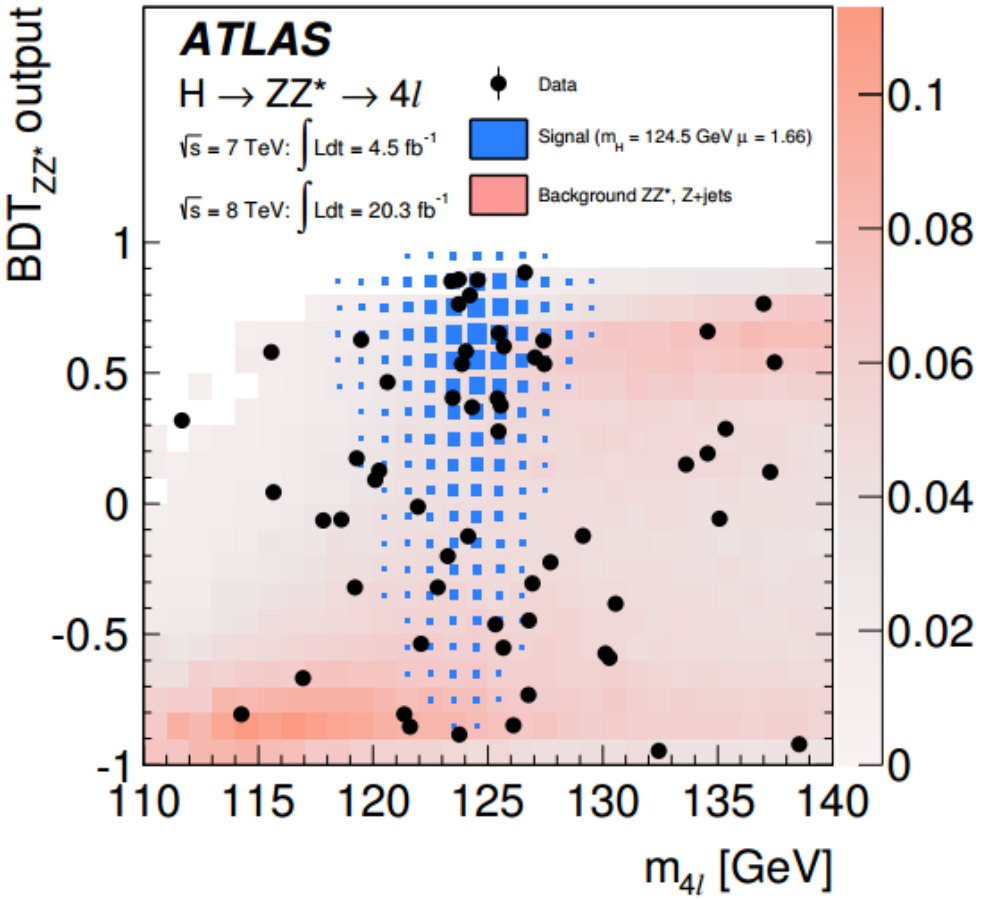
- H→ZZ*→4l, or H4l, analysis has been given the nickname “the golden channel” due to its large S/B ratio in the region around the Higgs boson mass.
- Suffers from low statistics from the small H→ZZ* cross section and small branching ratio of the Z boson to charged leptons.
- Due to the absence of jets and missing transverse energy, channel has good mass resolution (~1%).
- The analysis is split into four categories based on the final states of the four leptons. In order of decreasing resolution: 4μ, 2e2μ, 2μ2e, and 4e.

Final state	Signal full mass range	Signal	ZZ^*	Z + jets, $t\bar{t}$	s/b	Expected	Observed
			$\sqrt{s}$ = 7 TeV and $\sqrt{s}$ = 8 TeV				
4μ	6.80 ± 0.67	6.20 ± 0.61	2.82 ± 0.14	0.79 ± 0.13	1.7	9.81 ± 0.64	14
$2e2\mu$	4.58 ± 0.45	4.04 ± 0.40	1.99 ± 0.10	0.69 ± 0.11	1.5	6.72 ± 0.42	9
$2\mu2e$	3.56 ± 0.36	3.15 ± 0.32	1.38 ± 0.08	0.72 ± 0.12	1.5	5.24 ± 0.35	6
$4e$	3.25 ± 0.34	2.77 ± 0.29	1.22 ± 0.08	0.76 ± 0.11	1.4	4.75 ± 0.32	8
Total	18.2 ± 1.8	16.2 ± 1.6	7.41 ± 0.40	2.95 ± 0.33	1.6	26.5 ± 1.7	37

Number of expected and observed events in the four final state categories, as well as their S/B.

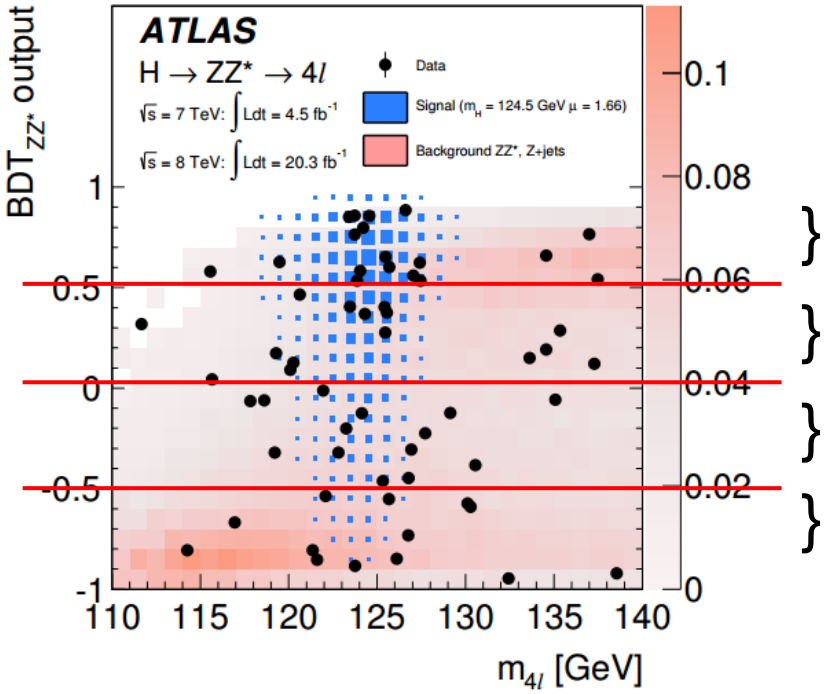
ZZ Background Discriminant

- To enhance the statistical resolution of the measurement, a second dimension was added to the analysis in the form of a boosted decision tree, or BDT.
- The BDT was trained on three values: the Matrix Element Kinematic Discriminant (KD), $p_{T,4l}$, and η_{4l}.
- Inclusion of the BDT gave about a 7-8% decrease in the expected statistical error on the mass and signal strength measurements, as well as a 20% increase of the expected significance.



Two-dimensional histogram of BDT versus m_{4l}, overlaid with the observed data.

Signal and Background Models



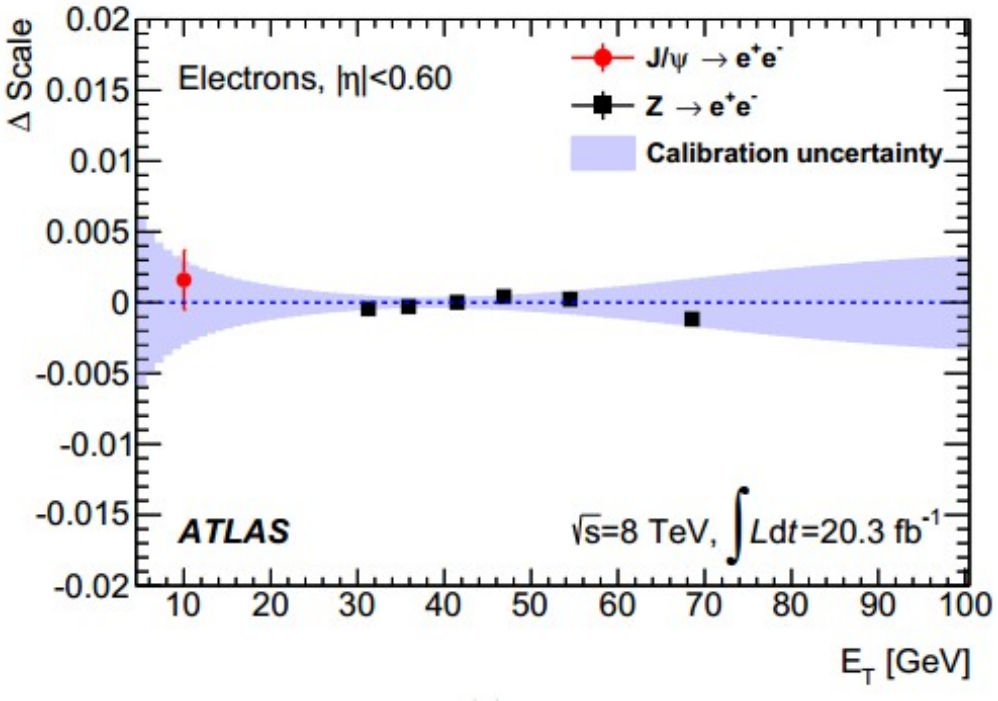
- Higgs boson production in the H4l analysis has contributions from all major production mechanisms: ggF, VBF, VH, and ttH.
- Shapes smoothed from Monte Carlo predictions using the kernel estimation technique (KEYS). Normalizations also taken from MC.
- The signal model used was a conditional two-dimensional model in four bins of BDT (to enhance sensitivity in highest BDT bin):

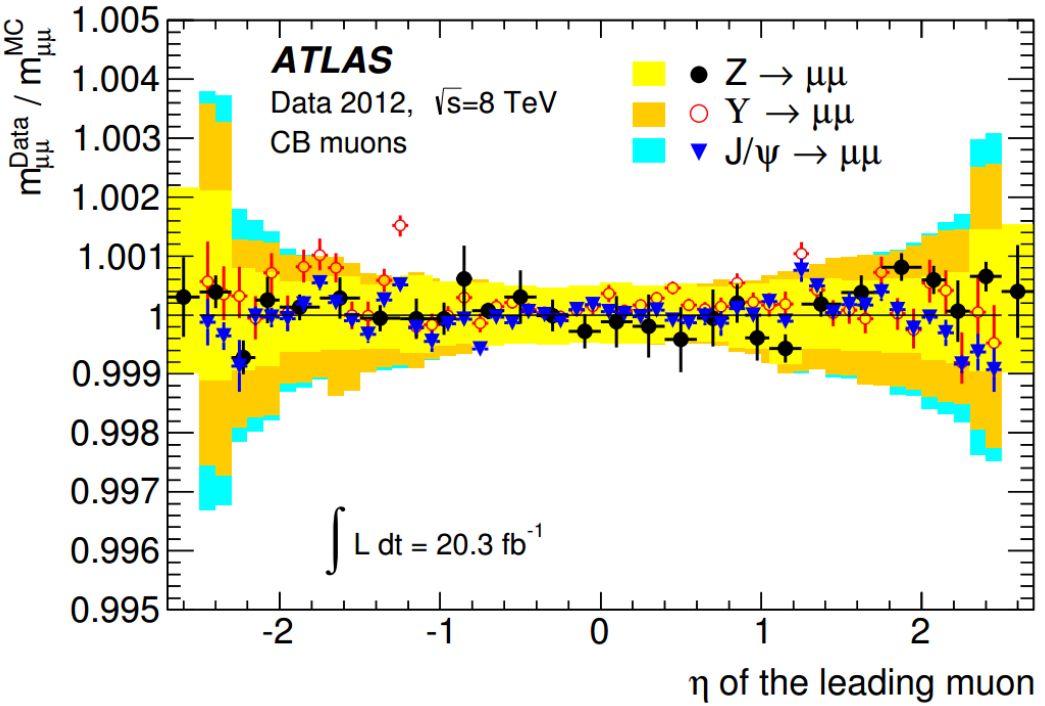
$$p(m_{4l}, BDT) = p_{m4l}(m_{4l}|BDT) * p_{BDT}(BDT) = n * \left(\sum_{i=1}^{4} p_i(m_{4l}; m_H)\theta_i(BDT)\right) * p_{BDT}(BDT; m_H)$$

- The major backgrounds are:
  - Irreducible ZZ production, shapes and normalizations obtained from MC.
  - Reducible Z + light jets, affecting final states where the subleading Z decays to electrons, normalization and shape evaluated using data driven methods.
  - Reducible Z + heavy jets and di-top production, affecting final states where the subleading Z decays to muons, also evaluated using data driven methods.

Systematic Uncertainties

- Variety of systematic uncertainties introduced, mostly to account for lepton resolution.
- Major reduction in electron energy scale and muon momentum scale reduces systematic uncertainty greatly (see plot below).





- Additional uncertainties come from lepton reconstruction efficiency, theory uncertainty (PDF and QCD scale), and additional cuts placed on leptons in quadruplets.

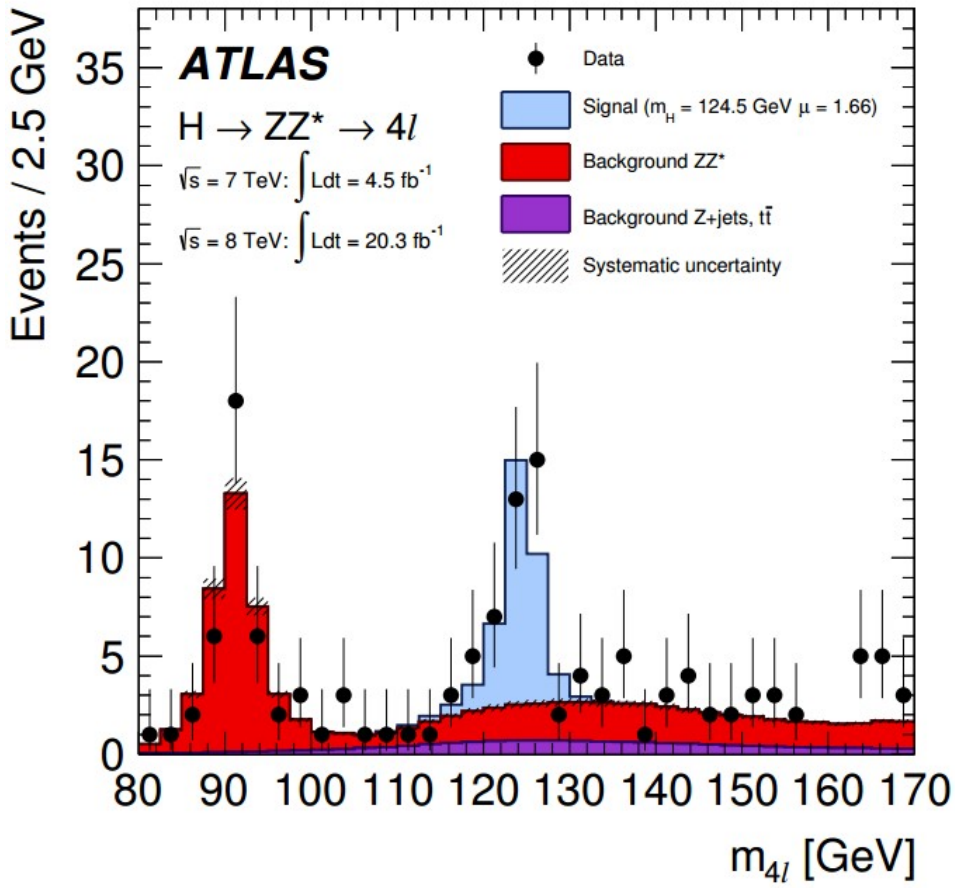
Observed Results

- 4.7 fb^{-1} of data recorded during 2011 at center-of-mass energy = 7 TeV, and 20.3 fb^{-1} of data recorded during 2012 at center-of-mass energy = 8 TeV.

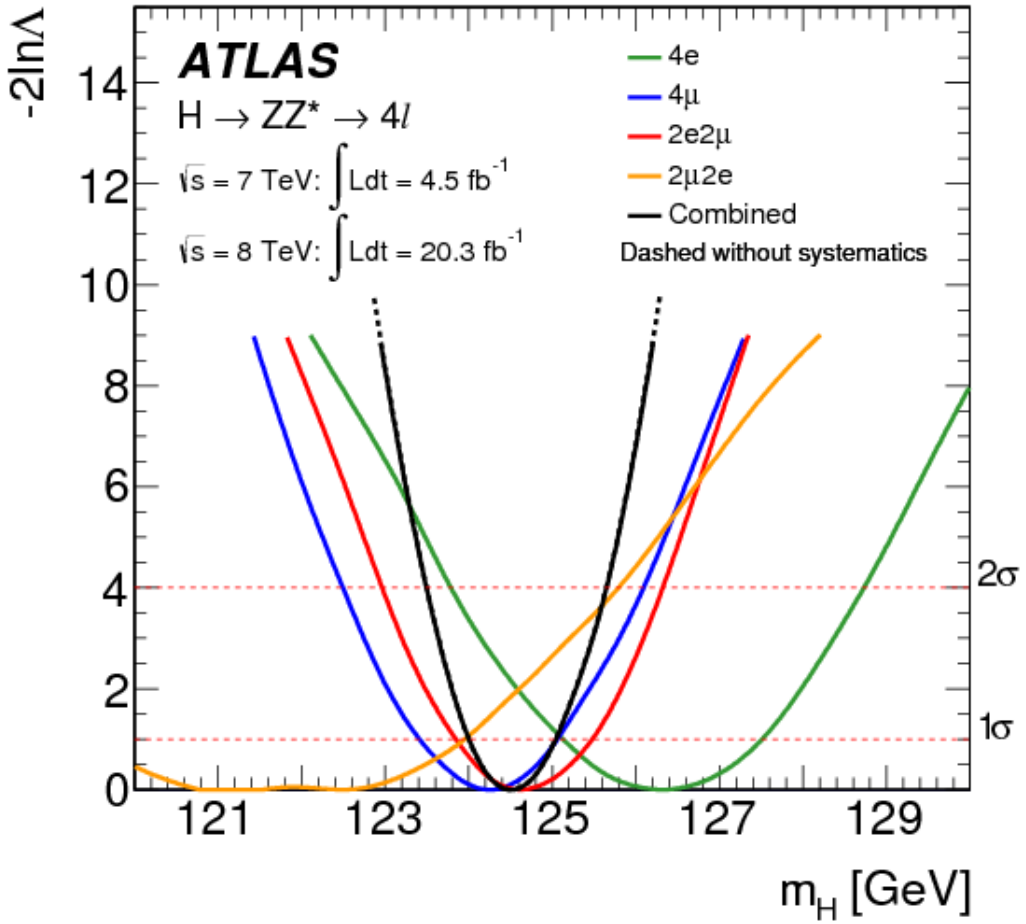
- Best fit mass and signal strength values are:

$$m_H = 124.51 \pm 0.52 \pm 0.06\ \text{GeV},\ \mu = 1.66^{+0.45}_{-0.38}$$

- The plot to the right shows the overlay of the observed data with the Monte Carlo predictions, with the signal scaled by the best fit signal strength value.



Observed Results



Negative log likelihood curves from scans over Higgs mass values, showing results for all four channels as well as the combined, final result.

Conclusions

- The measured best fit of the Higgs boson mass and signal strength in the $H \rightarrow ZZ^{*} \rightarrow 4l$ channel is:

$$m_H = 124.51 \pm 0.52 \text{ GeV} \qquad \mu = 1.66^{+0.45}_{-0.38}$$

- Preliminary prospects for this channel in the next run expect a decrease in the statistical error due to the increased amount of data taken, as well as the increase of Higgs boson production cross section at higher center-of-mass energy.

- Many thanks to the HSG2 group and Higgs Working Group in ATLAS for the work put into this measurement.