Searches for the Standard Model Higgs boson decay $H \rightarrow ZZ^{(*)} \rightarrow 4\ell$ with the ATLAS detector

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Abstract

- The LHC was built to explore physics beyond current knowledge
- The ATLAS detector (A Toroidal LHC Apparatus) is the largest experiment at the proton-proton colliding LHC
- Precise electroweak fits predict a light SM Higgs boson, most likely $m_H = 95^{+30}_{-20}$ GeV
- In July 2012 a new particle was discovered at around 125 GeV hinting at a possible discovery of the SM Higgs boson [2]

Event display of a Higgs candidate decaying into $ZZ^{(*)} \rightarrow 4\ell$ zoomed into the tracking detector where the muon tracks are highlighted in red. This event 71903630 during run 204769 was recorded by ATLAS on 10-Jun-2012, 13:24:31 CEST. [3]

ATLAS Detector

- Built to explore physics up to a design energy of 14 TeV and a design luminosity of $10^{33} cm^{-2} s^{-1}$
- Consists of an inner detector, calorimeters, a muon system and forward detectors embedded in a superconducting magnet-system
- The reconstruction efficiency depends on the detector region e.g. barrel vs. crack (1.37 < |η| < 1.52, between barrel and endcap) region [4]

Schematic of the ATLAS detector. [5]

H → ZZ^{(*)} → 4ℓ analysis

- Channel with high potential to discover the SM Higgs boson
- Exploiting 110 GeV < $m_H$ < 600 GeV as sensitive over large mass range
- The final state $ℓ^+ ℓ^- ℓ'^+ ℓ'^-$ abbreviated as 4ℓ denotes to electrons or muons
- Currently separated into four final states: $4\ell$, $2\ell 2\nu$, $4\nu$, $2\nu 2\ell$
- $2\nu 2\ell$ and $2\ell 2\nu$ differ for $m_H < 182$ GeV where the second lepton pair originates from an off-shell Z boson
- Even though many channels have higher $σ$ BR, $H \rightarrow ZZ^{(*)} \rightarrow 4\ell$ has a higher sensitivity due to its clean signature

SM Higgs boson production cross section times branching ratio at $E_{cm} = 8$ TeV [6]

Statistical treatment of $H \rightarrow ZZ^{(*)} \rightarrow 4\ell$

- Improvements which are in progress:
- Implementation of an unbinned fit to exploit the full potential of the limited statistics of the data
- Event separation into detector categories of reconstruction efficiencies
- Implementation of per-event errors as an alternative option where each event is allocated to its associated error
- Developing analytical models for background and signal
- To apply these improvements a new workspace is developed which is part of RooStats containing projects with models and datasets to facilitate combinations

Resolution of simulated $H \rightarrow ZZ^{(*)} \rightarrow 4\ell$ produced by gg fusion. The resolution is obtained as the sigma of the Crystal ball (CB) when fitting the sum of a CB and a Gaussian distribution to $m_{4\ell}$

Background of $H \rightarrow ZZ^{(*)} \rightarrow 4\ell$

- The main background comes from the continuum ($Z^{(*)}/\gamma^{(*)})(Z^{(*)}/\gamma^{(*)}$)
- In the low mass range Z+jets and tt contribution to the background [2]

Results

- The datasets used have integrated luminosities of approximately 4.8 fb$^{-1}$ collected at $\sqrt{s} = 7$ TeV in 2011 and 5.8 fb$^{-1}$ at $\sqrt{s} = 8$ TeV in 2012
- The $H \rightarrow ZZ^{(*)} \rightarrow 4\ell$ channel excluded with 95% confidence level the SM Higgs boson in the following mass regions: 131-162 GeV and 170-460 GeV
- The $H \rightarrow ZZ^{(*)} \rightarrow 4\ell$ channel observed an excess of events around $m_H = 125$ GeV with 3.4 standard deviations [7]

Selected candidates of the $H \rightarrow ZZ^{(*)} \rightarrow 4\ell$ analysis shown for the four-lepton invariant mass, $m_{4\ell}$. The data is compared to the background and signal expectation for a SM Higgs with $m_H = 125$ GeV. [7]

The discovery of a neutral boson at 126.0 ± 0.4 (stat)±0.4 (sys) GeV was observed by the combined ATLAS Higgs analyses

This observation with a significance of 5.9 standard deviations is compatible with the SM Higgs boson [2]

References

[2] [arXiv:1007.2147v1]
[4] [arXiv:1109.0165v1]
[5] [arXiv:1201.1641v1]
[7] [arXiv:1205.3540v1]