Search for the Standard Model Higgs boson using the decay channel $H\rightarrow ZZ^*\rightarrow 4l$ and simulation with the ATLAS detector

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Higgs searches today

- Recently, it was announced by the ATLAS and CMS experiments, that a new particle was discovered.
- The invariant mass of this particle, measured by ATLAS, is $126.0\pm 0.4$ (stat) $\pm 0.4$ (syst) GeV [1].
- The datasets used correspond to integrated luminosities of 4.6-4.8 fb$^{-1}$ at $\sqrt{s} = 7$ TeV collected in 2011 and 5.8-6.9 fb$^{-1}$ at $\sqrt{s} = 8$ TeV in 2012 [1].
- This observation has a significance of 5.9 standard deviations.

Monte Carlo (MC) simulations of physics events and of the detailed detector response are imperative for almost every analysis in high-energy physics experiments like ATLAS.

Physics analyses often require large MC datasets for modeling background processes, estimation of systematic effects, and studies with small cross sections. This is a very CPU demanding task.

The ATLAS simulation process is carried out in three steps.

1. Event Generation
2. Simulation of the detector (Physics and detector response)
3. Digitization (Digitization software transforms the hits into the detector electronic response).

Simulation in the ATLAS detector

- Monte Carlo (MC) simulations of physics events and of the detailed detector response are imperative for almost every analysis in high-energy physics experiments like ATLAS.
- The ATLAS simulation process is carried out in three steps.
- The ISF vision for different simulation frameworks, different tests results and/or detector regions in one and the same experiment was performed against MC12 Monte Carlo samples to check agreement with the new framework.

How do we search for the Higgs?

- The most important processes for Higgs boson production at hadron colliders are shown above.
- We search for the Higgs boson decay products, see figure 2.
- The most likely decay is to $b\bar{b}$ pair (at low mass), but has large background, it has a very small probability of decaying into $\gamma\gamma$ (produced in a loop), but it is very sensitive search channel.
- Even though, the Higgs boson has a small probability on decaying into $ZZ^*$ (at low mass), it has a large $S/B$ and excellent mass resolution.

H$\rightarrow ZZ^*\rightarrow 4l$ searches

- The searches are divided into four categories: $\mu\mu$, $ee$, $\mu\mu$, and depending upon which pair of leptons comes from the off shell $Z$: $e\mu$, $\mu\mu$.
- Search range is: 110 - 600 GeV.
- Excesses observed at: $m_{ll} = 125, 244$ and 500 GeV [2].

Likelihood fits and ensemble testing

- 2011 data was used to validate a new workspace using the RooStats package from ROOT framework [3].
- The workspace contains all the information from the Likelihood function construction: parameters, p.d.f.s and the final likelihood function for every signature.
- Ensemble testing was done over 4l channel with MCStudy tool from RooStats.
- The searches are performed as a background-only operation to be more sensitive than the observation. Individual channels and the combination in the full mass range of 110-600 GeV are shown. The full curves give the observed individual and combined $p_\nu$. The dashed bands show the median expected values under the hypothesis of a SM Higgs boson signal at that mass. The horizontal dashed lines indicate the corresponding $p_\nu$ at significances of 0.05 (corresponding to $\sigma = 1$).
- The local probability $p_\nu$ for a background-only operation to be more sensitive than the observation. Individual channels and the combination in the full mass range of 110-600 GeV are shown. The full curves give the observed individual and combined $p_\nu$. The dashed bands show the median expected values under the hypothesis of a SM Higgs boson signal at that mass. The horizontal dashed lines indicate the corresponding $p_\nu$ at significances of 0.05 (corresponding to $\sigma = 1$).

ISF validation

- Main obstacle for simulation is the requirement for large MC samples in the minimum amount of time possible and with high precision.
- High precision may not be required in every region and for every particle. Solution: Integrated Simulation Framework (ISF) [6]. An example of an ISF validation is shown in figure 10.

Regression tests

- The SimCoreTest package is in charge of all the testing of the core simulation software of ATLAS detector to check the main features of the simulation.

• A new tool has been created for this task. Now we can compare results from yesterday with present results.
• An example is given in figure 11, it is comparing the very distributions from yesterday with today.

Figure 11: Regression test results for the distribution plot of the event distribution of mass.