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

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Physics Analysis ⟷ Simulation

An overview of the H→ZZ*→4l search status and analysis with the ATLAS detector at the LHC is presented. Likelihood fits over data and background were performed and statistical experiment ensemble testing results are presented. In addition, an overview of the studies done for Core Simulation in the ATLAS experiment is shown. One study is the creation of a new regression test tool in the context of the RunTimeTester for software testing on ATLAS. Another study was made in the context of the Integrated Simulation Framework, where validation was performed against MC12 Monte Carlo samples to check agreement with the new framework.

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 ± 0.4 (stat) ± 0.4 (sys) 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 5.8-5.9 fb^{-1} at $\sqrt{s}$ = 8 TeV in 2012 [1].
- This observation has a significance of 5.9σ, compatible with the production and decay of the Standard Model Higgs boson (the signal strength parameter is $\hat{\mu} = 1.4 \pm 0.3 = \sigma / \sigma_{SM}$).

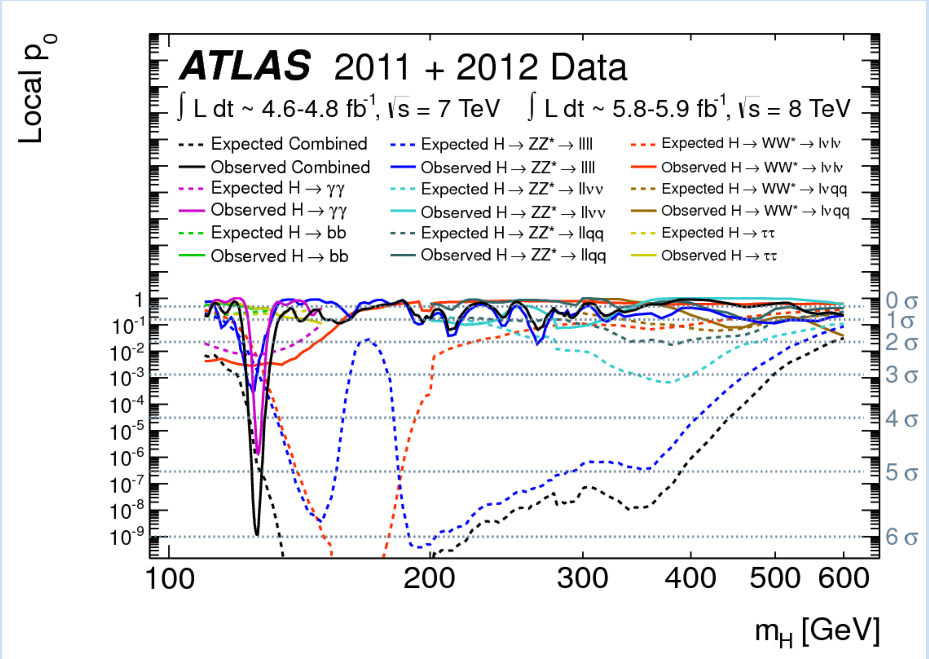


Figure 1: The local probability p_0 for a background-only experiment to be more signal-like than the observation. Individual channels and the combination in the full mass range of 110-600 GeV are shown. The full curves give the observed (individual and combined) p_0. The dashed curves show the median expected value under the hypothesis of a SM Higgs boson signal at that mass. The horizontal dashed lines indicate the corresponding p_0 to significances of 0σ to 6σ depending on m_H.

How do we search for the Higgs?

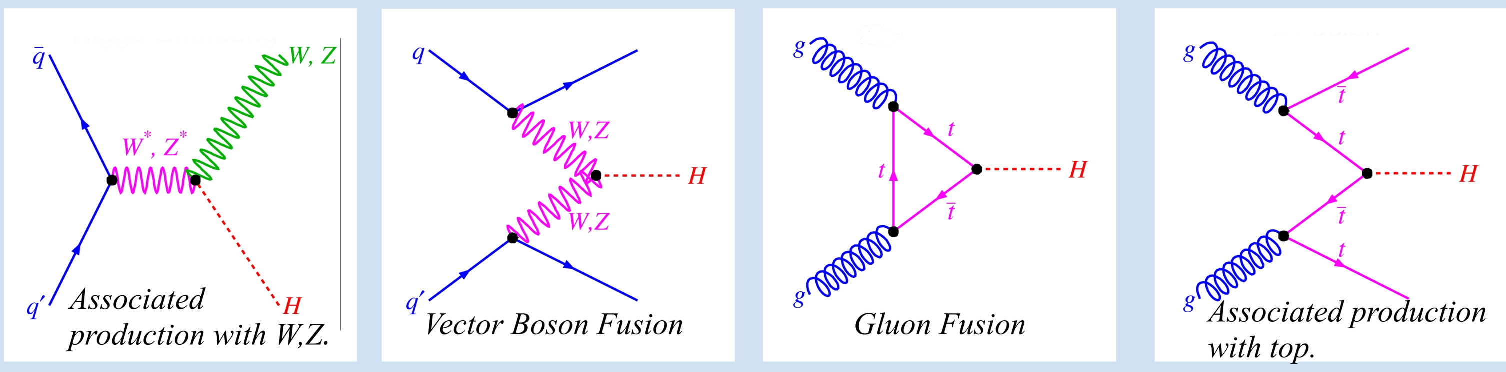
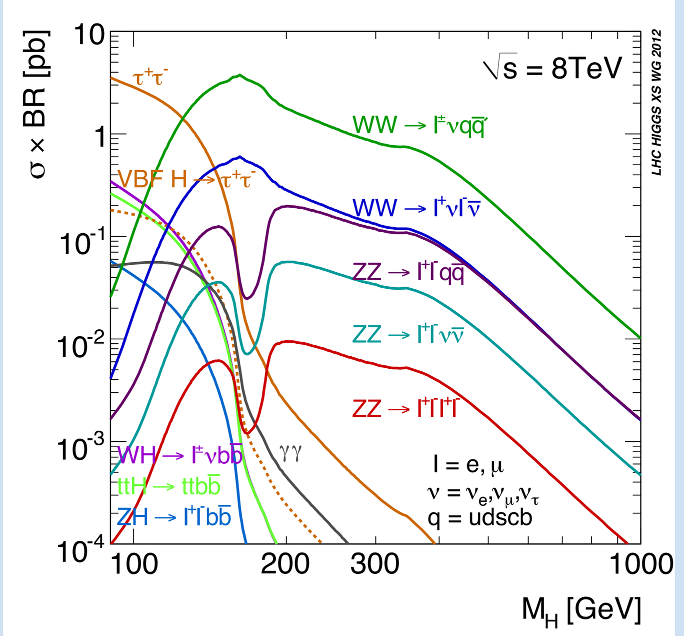


Figure 2: SM Higgs boson cross section times its branching ratio for different masses at E_{CM} = 8 TeV.



- 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 (due to large 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→ZZ*→llll searches

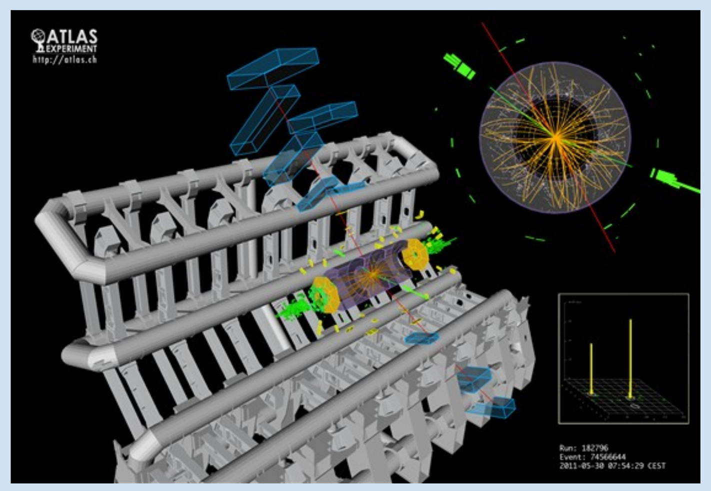


Figure 3: An ATLAS event containing two electrons and two muons. This event is consistent with coming from two Z particles decaying: one Z decays to two muons, the other to two electrons. The two muons are picked out as red tracks penetrating the detector. The two electrons are picked out as green tracks in the inner detector, matching narrow green clusters of energy in the barrel part of the calorimeters.

- The searches are divided into four categories: μμμμ, eeee, and depending upon which pair of leptons comes from the off shell Z: eeμμ, μμee.
- Search range is: 110 - 600 GeV.
- Backgrounds: Z+jets, irreducible ZZ* and $t\bar{t}$, $Zb\bar{b}$.
- Excesses observed at: m_H = 125, 244 and 500 GeV [2].

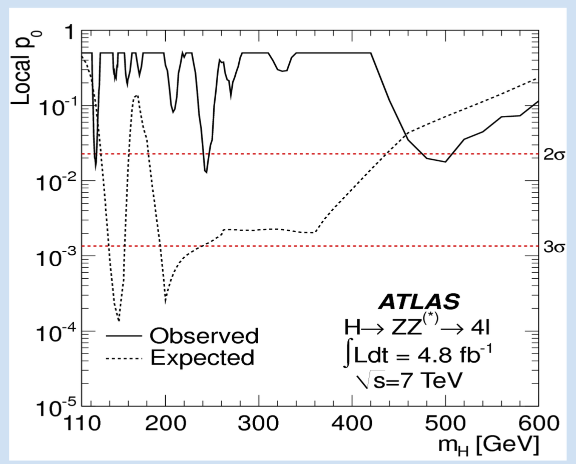


Figure 4: Local p-value for 4l signal with respect to the SM Higgs mass.

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 4μ channel with MCStudy tool from RooStats.

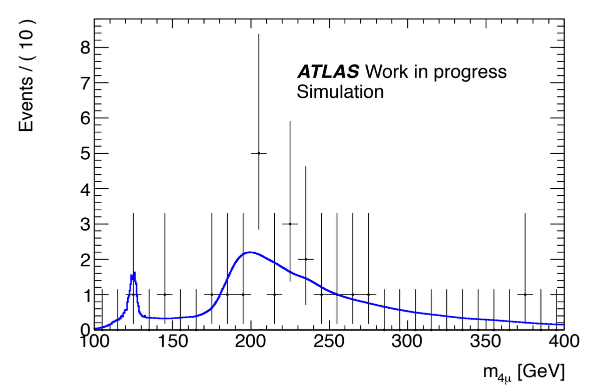


Figure 6: Likelihood fit function to 4μ channel.

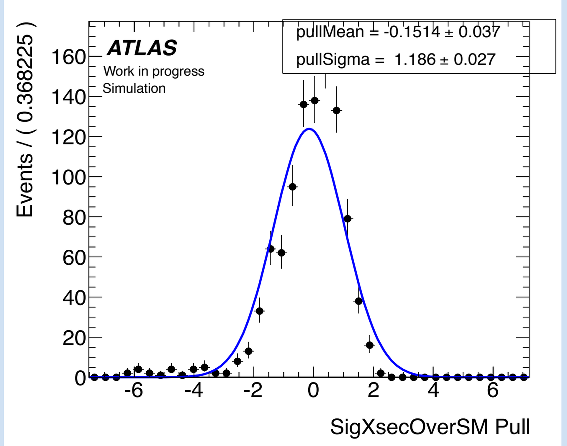
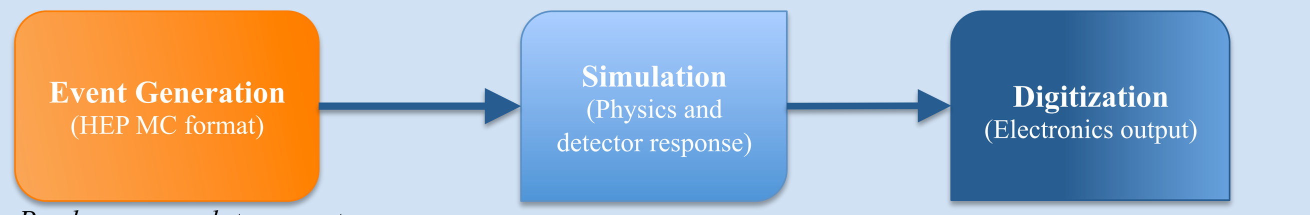


Figure 5: Plot of $\sigma_{4\mu} / \sigma_{SM}$ parameter pull distribution.

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.
- 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.



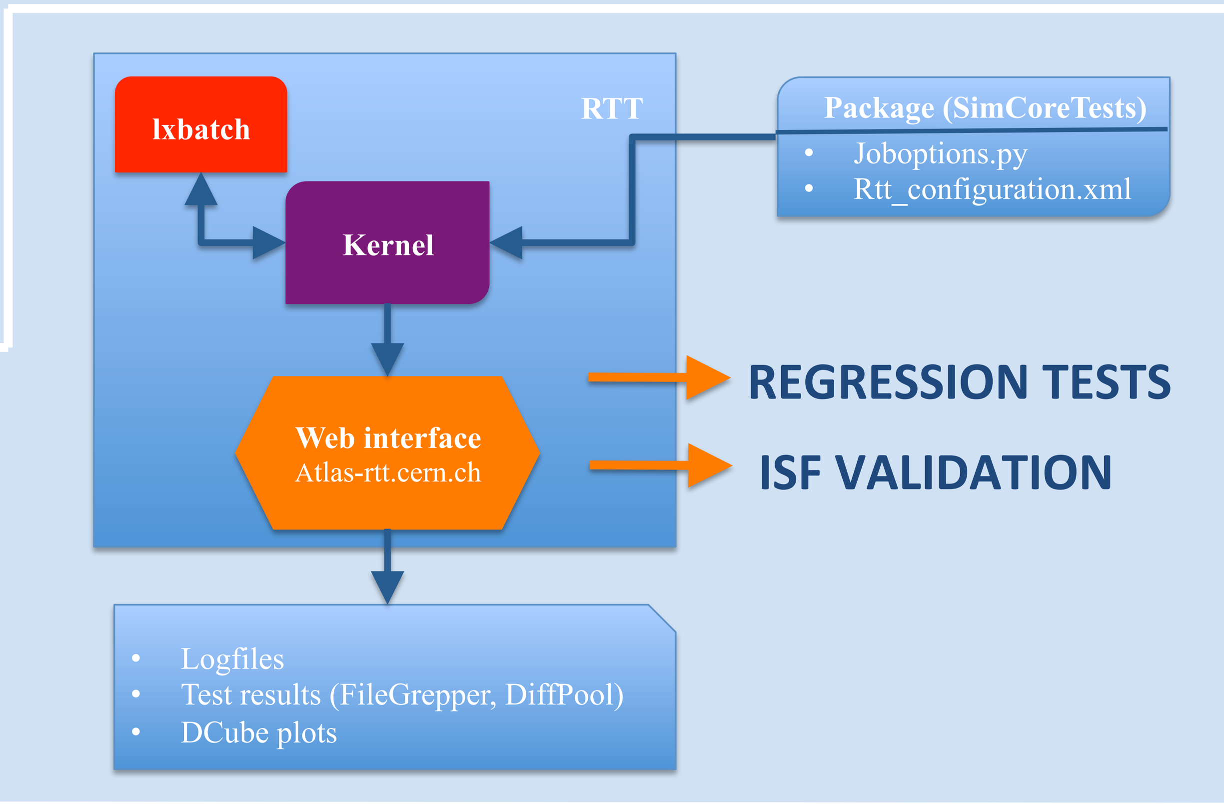
Produce complete events starting from proton-proton collisions with generators.

Simulation of the detector physics processes and the response (GEANT4).

The digitization software transforms the hits into the detector electronic response.

RunTimeTester (RTT):

- ✓ Framework based on python to test the ATLAS experiment software [5].
- ✓ The package contains the job options and the setup for the RTT job which is stored in an xml file.
- ✓ RTT recognizes the packages to be tested and sends the jobs to lxbatch, where they are run.
- ✓ The results of the tests are displayed in the RTT web interface (atlas-rtt.cern.ch) where the user can access logfiles, different tests results and/or DCube plots.



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.

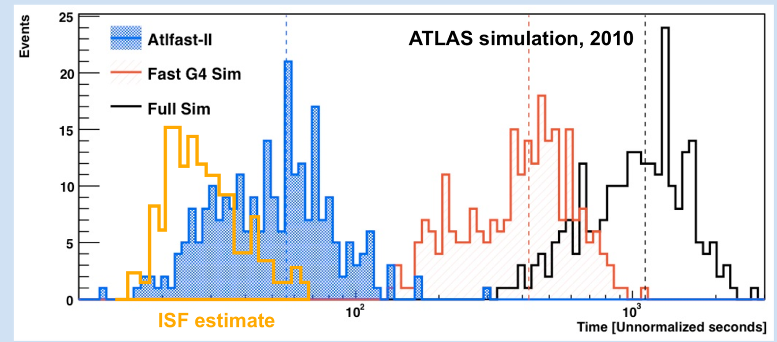


Figure 8: Comparison of CPU time spent for the simulation of ttbar events with and estimated timescale for the ISF framework.

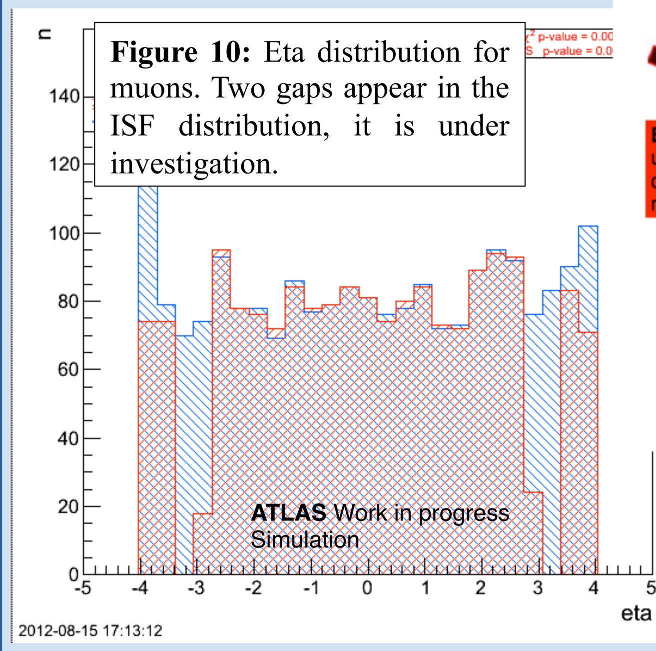


Figure 10: Eta distribution for muons. Two gaps appear in the ISF distribution, it is under investigation.

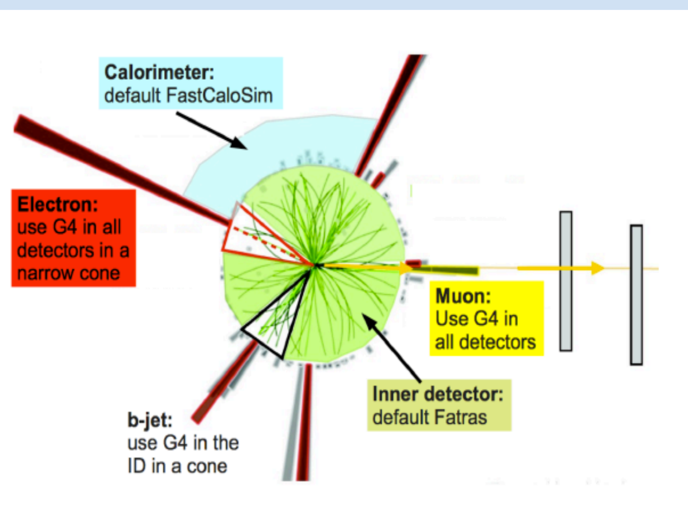
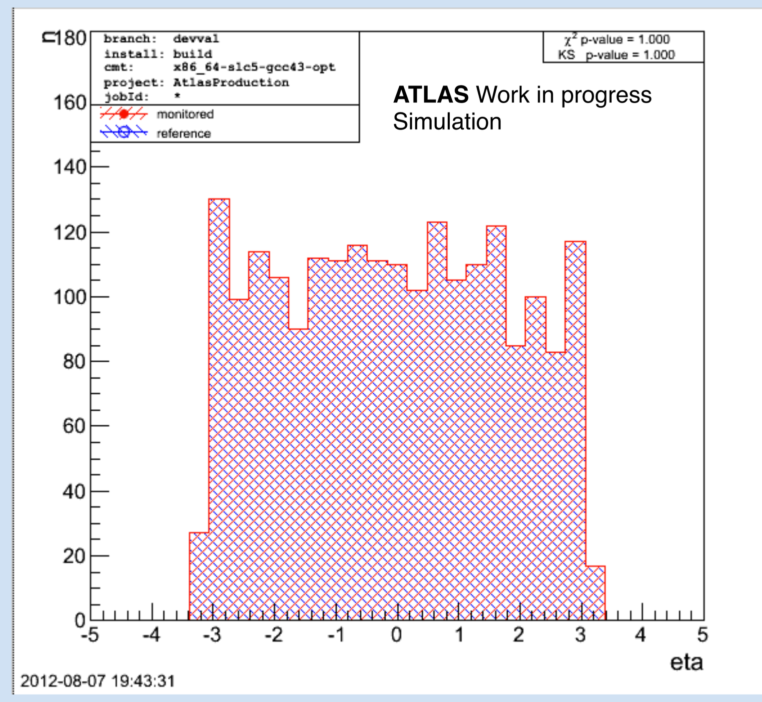


Figure 9: The ISF vision for different simulation strategies. They are used for different particles and/or detector regions in one and the same event.

Regression tests

- The SimCoreTest package is in charge of all the testing of the core simulation software of ATLAS 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 eta distributions from yesterday with today.

Figure 11: Regression test results for the distribution plot for the eta distribution of muons.

References:

[1] *Observation of a New Particle in the Search for the Standard Model Higgs Boson with the ATLAS Detector at the LHC*, The ATLAS Collaboration, arXiv:1207.7214v1 [hep-ex],2012.

[2] Search for the Standard Model Higgs boson in the decay channel H -> ZZ*->4l with 4.8 fb^{-1} of pp collision data at ps = 7 TeV with ATLAS, The ATLAS Collaboration, arXiv:1202.1415v4, 2012.

[3] *RooStats User's Guide,* Cranmer K. et al., http://root.cern.ch/svn/root/branches/dev/roostatsFeb2011/roofit/roostats/doc/usersguide/RooStats_UsersGuide.pdf, 2009.

[4] *The ATLAS Simulation Infraestructure,* The ATLAS Collaboration, arXiv:1005.4568v1, 2010.

[5] *The RunTimeTester User Guide*, https://atlas-rtt.cern.ch/prod/docs/site/guide.

[6] *Fast Simulation for ATLAS: Atlfast-II and ISF*, Poster presented CHEP 2012 conference, http://indico.cern.ch/contributionDisplay.pycontribId=478&sessionId=8&confId=149557, 2012.

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