ATLAS EXPERIMENT: PHYSICS HIGHLIGHT EXAMPLES

Physics Highlight Examples

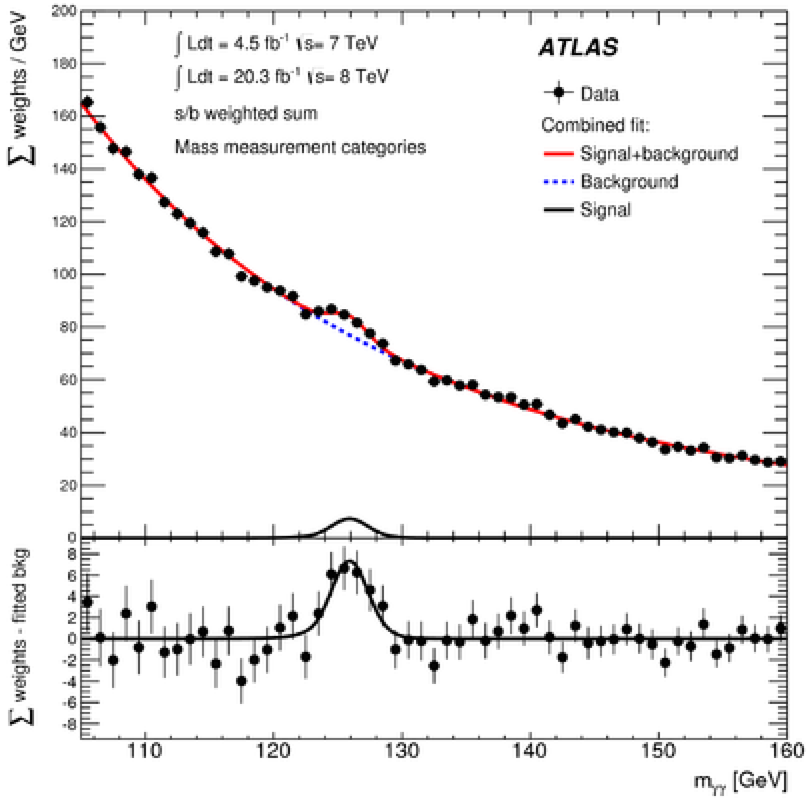

Figure 8: The invariant mass distribution in GeV for events with two photons. The black points are the data. The blue dashed line is an estimate of the background contribution, while the black line is an estimate of the signal contribution from a Higgs particle. The red curve is the signal plus background fit to the data. The lower figure shows the difference between the data and the background only model.

Before the turn-on of the LHC, the biggest question of the day was: Does the Higgs boson, the last of the undiscovered particles in the Standard Model, exist? For the last several decades, the Standard Model theory of particle physics has withstood rigorous experimental verification. One critical aspect of that theory is that elementary particles in the Standard Model obtain their mass through the so-called Brout–Englert–Higgs mechanism, and therefore the Higgs boson should also exist. The beams at the LHC have a high enough energy to produce Higgs particles. This particle, though, is not stable and will decay immediately into other Standard Model particles, such as two photons or two Z bosons. By detecting and measuring the two photons, the mass of the Higgs can then be reconstructed as shown in Figure 8. The figure shows a smooth falling background, which comes from, for example, quark/gluon interactions producing two photons. At around an invariant mass of 125 GeV, a bump above the expected background is seen, which comes from Higgs decays into two photons. In Figure 9 the corresponding invariant mass can be seen for decays to four charged leptons via two Z bosons. Studying the difference in the decay rates allows one to understand the coupling of the Higgs boson to Standard Model particles. Since the July 2012 discovery, all new studies indicate that the new particle is the Higgs boson as predicted by the Standard Model; however, many more detailed studies are needed to confirm this.

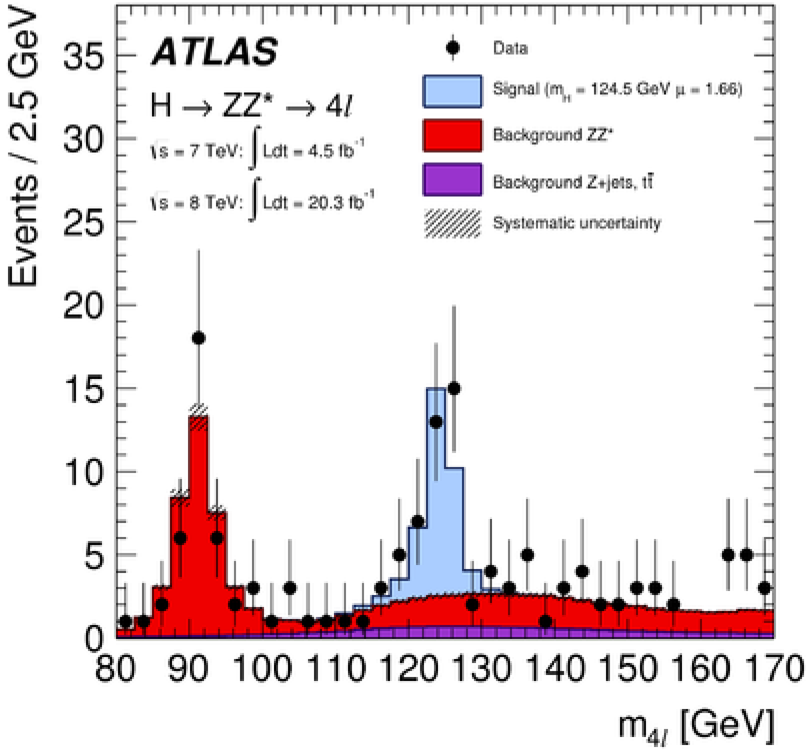

Figure 9: The invariant mass distribution in GeV for events with four charged leptons. The data are shown by the black points. The Higgs signal is shown by the blue histogram while the expected backgrounds are shown by the red and purple histograms.

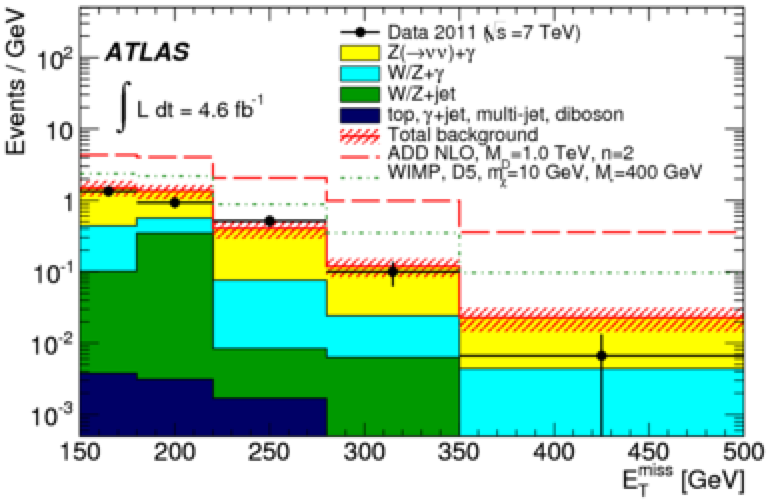

Figure 10: The missing transverse momentum (ETmiss) in the event in GeV. The data are shown by the black points and the Standard Model backgrounds are shown by the coloured histograms. The hashed red line shows the sum of the Standard Model backgrounds with uncertainties. The predictions from two additional theories are also shown; "ADD" is a theory with additional large extra spatial dimensions. "WIMP, D5" is a theory with pair production of dark matter particles.

Although the Standard Model has been experimentally well tested, many physicists believe that it is not a complete description of Nature. For example the Standard Model has no explanation for Dark Matter, which has been inferred from observations by astronomers and is expected to make up 25% of the energy density of the universe. Also the Standard Model does not include gravity in its description. New theories which extend the Standard Model have been proposed to explain these and other open questions. Many of these new theories postulate additional particles, which can be produced at the LHC. Figure 10 illustrates the results of such a search, where events are required to have large amounts of missing transverse momentum and an energetic photon. In this search, the ETmiss in the data is compared to the predictions from the Standard Model theory. Two example theories, which include heavy dark matter particles or additional space dimensions, are also shown on the figure. These theories predict massive new particles, which do not interact in the detector and are therefore measured as ETmiss. No difference between the data and the Standard Model predictions are seen, therefore limits can be set on the masses for any new particles for these theories. The LHC experiments have searched extensively for new particles in the data and as of yet, found none.

The LHC programme includes every year also a running period of a few weeks where not proton beams collide, but beams of lead nuclei (producing either Pb-Pb or Pb-p collisions). These so-called Heavy Ion (HI) collisions allow one to study the behaviour of hadronic matter under extreme conditions, known as quark-gluon plasma. To make measurements in these extreme conditions, the versatility of the ATLAS detector plays a strong role; for example its ability to measure high transverse momenta jets and bosons over a large rapidity range. The many interesting results from ATLAS complement those from the dedicated LHC HI experiment ALICE.

Outlook

The LHC operation at 7 and 8 TeV during the first three years has been successful beyond expectations. The collider performed beyond its initial designs, reaching peak luminosities of 7 x 10^{33} cm^{-2} s^{-1}. The centre-of-mass energy will nearly double to 13-14 TeV in 2015 and the luminosity will continue to be increased in two major steps: the first in 2020 and a second in 2025. The ATLAS detector will also be improved to keep up with the higher collision rates and maintain its good performance of measurements of objects like leptons, photons and jets. Already for the operation starting in 2015 a fourth cylindrical barrel layer of pixel detectors has been added very close to a new beam pipe. This ‘Insertable B-Layer’ at an average radial distance of 33 mm will improve the secondary vertex measurements at high luminosity. Furthermore, the trigger system has been improved to accept a rate of up to 100 kHz after the Level-1 trigger.

After a shutdown to upgrade parts of the accelerator, the LHC will resume in 2020 at luminosity of up to 2-3 x 10^{34} cm^{-2} s^{-1} and the number of simultaneous interactions per crossing will increase by a factor of two. Additional collisions result in unwanted particle interactions in the detector, which can lead to a worsening of the energy resolution in the calorimeters and complicate the reconstruction of charged particle tracks. To run under these conditions, one of the main improvements to ATLAS will be the trigger system. The Level-1 trigger will be enhanced, so that it can continue to reject events quickly in this new hostile environment. To achieve this, new tracking detectors will be added to the muon trigger system. This will reduce the amount of spurious tracks that are detected and misidentified as muons in some critical regions. The front-end electronics of the electromagnetic calorimeter will be improved to send the full calorimeter granularity to the Level-1 calorimeter trigger. This will help in distinguishing electrons from jets and therefore improve the trigger acceptance.

In 2025 after a second upgrade phase, the LHC will reach the luminosity of 5 x 10^{34} cm^{-2} s^{-1}. At this point, the components of the ATLAS detector will be 15-20 years old and therefore major upgrades of many sub-detectors will be necessary, most notably the tracking detector, which in its current form will not survive the harsher radiation environment. To meet this demand, the tracking detectors will be completely replaced with a new all-silicon detector design. The Level-1 trigger will also have to undergo major renovations to cope with the increased event rates. To achieve this, an additional decision layer will be added to the trigger system. The current Level-1 system will be upgraded to reduce the overall event rate to 500 kHz within six microseconds. Next, a new trigger system will be added which uses information from the tracking detector to reduce the rate to 100 kHz within 14 microseconds. Major changes are also planned for the forward calorimeters to be more resilient to radiation damage. In addition the computing model will be overhauled to handle the even larger data samples.

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