HELEN

High Energy Physics Latinamerica – European Network

Final Report

Production and Detection of New Neutral Gauge Bosons at LHC/ATLAS

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Goal

The ATLAS performance simulation in Athena framework for the detection of new neutral gauge bosons forecast by standard model extensions and contributions to *JiveXML* package used by Atlantis Event Display.

1 Introduction

The ATLAS Experiment will search for new physics predicted by a number of theories beyond Standard Model, like Supersymmetry and Grand Unified Theories. The expectation that signals from extraordinary physics might appear at energies covered by LHC has motivated a lot of people to work hardly in simulations, analysis tools and hardware development. Nowadays, the ATLAS collaboration has 1800 physicists from 150 universities and laboratories in 35 countries.

The official control framework of ATLAS Experiment is the Athena, a very complex set of packages used to generated and simulated data, as well as reconstruct real data. It is based upon the GAUDI architecture that was originally developed by LHCb, but now it is a joint development project.

During my HELEN training at CERN, I have learned the main Athena features and used it to study the possibility of detecting new gauge bosons at ATLAS. The work also included small improvements to the software as I will describe in next sections.

2 The ATHENA Framework

The Athena source code is organised in a hierarchical structure of packages. These packages include specific algorithms for each subdetector (InnerDetectorSoftware, MuonSoftware, TileCalorimeter, etc), generators (PYTHIA, CompHep, Hewging, etc), Trigger, Reconstruction, tools and so on. They are subdivide in several sub-packages. The InnerDetectoSoftware, for instance, has about 20 sub-packages.

Athena applications are managed through Python (an interactive programming language) jobOptions files which allow users to load specific libraries of algorithms, determine the algorithm execution order, and configure each algorithm behavior. In other words, a typical Athena application is defined by a jobOptions file which plays the following tasks: load libraries, read data, run specifics algorithms in a given order, configure each algorithm in a given way and output selected data.

In order to perform a detailed simulation of a process in Athena, we have to follow five steps, namely

Generation: Generation refers to the production of particle four vectors from specified physics processes. The event generators available in Athena are: AcerMC, AlpGen, Cascade, GeneratorsRTT, CompHep, CosmicGenerator, GenzModuleEvent, Phojet, Herwig, Photos, EvtGen, Hijing, Pythia, PythiaB, Isajet, Tauola, TopRex, MadCUP.

Simulation: Simulation is the process whereby generated events are passed through a GEANT4 Simulation of the ATLAS Detector to produce GEANT4 Hits i.e. a record of where each particle traversed the detector and how much energy, etc was deposited.

Digitization: Digitization is the process whereby the GEANT4 Hits from the simulation are subjected to the response of the detector to produce Digits, like times and voltages, as produced in the Raw Data from the real detector.

Reconstruction: Reconstruction is the process whereby the raw data Digits, such as times and voltages, are reconstructed into tracks and energy deposits as Event Summary Data (ESD). The EDS consists of sufficient information to re-run (parts of) the reconstruction, such track refitting, jet calibration, etc.

Producing AOD: The Analysis Object Data (AOD), consists of a reduced size output of physics quantities from the reconstruction that should suffice for most kinds of analysis work.

The full chain of steps takes a long computing time. The simulations of $Z^0 \to e^+ e^-$, for example, takes about 15 minutes/event. A faster simulation can be done using Atlfast, a fast simulation package for ATLAS. It replaces the full detector simulation and reconstruction phases of the full chain. Fast simulation is performed by smearing the Monte Carlo truth information directly with resolutions measured in full simulation studies.

3 The Atlantis Event Display

Atlantis is a Java-based application for visualizing ATLAS events. The program provide a visual investigation and the understanding of the physics of complete events. Besides, it helps develop reconstruction and analysis algorithms, to facilitate debugging during commisioning and to create pictures and animations for publications or presentations.

In order to display an event using Atlantis, we have to convert the event data to XML files, which can be read in by the software. The Athena package used for this task is called **JiveXML**. Both fully reconstructed and fast simulated events can be converted to XML and viewed with Atlantis.

4 Cosmic Rays and the Tile Calorimeter

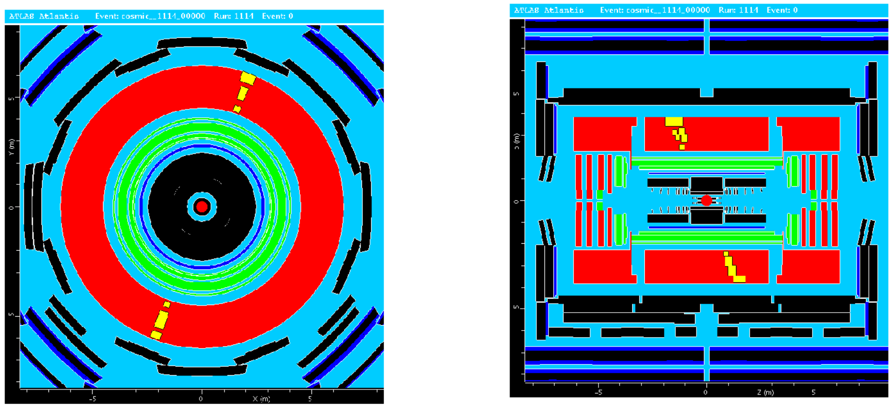
The cosmic ray flux in ATLAS is the direct result of the flux of high energy cosmic ray protons, nuclei and photons on the Earth's atmosphere. An estimated 1 million cosmic muons enter the ATLAS cavern every 3 min, and some of them were used for the commissioning of the detector. Many studies can be performed using cosmic rays data, like calorimeter calibration.

The ATLAS Tile Calorimeter is a sampling calorimeter using iron as the absorber and scintillating tiles as active material. Two sides of the tiles are read out by wavelength shifting fibres into two separated photomultipliers (PMTs). The PMTs have low dark current and are fast (rise and transient time of few nanoseconds). The shaper transform the current pulse from the PMT into a unipolar pulse of FWHM of 50 ns.

One used ATHENA 11.2.0 to reconstruct the cosmic rays data took in June 2005, with the *TileCalorimeter* package. In the JobOptions we can set commands to create ntuples and prepare XML files for Atlantis event display.

In the Figure 1 is shown one cosmic ray event reconstructed and displayed with Atlantis. The Figure 1a represents the $x\ y$ projection, and the second one is the $\rho\ z$ projection. The tile calorimeter appears in red, while the yellow trapezoids represent the energy deposited in the tiles. This is a characteristic muon from cosmic rays: it passes close to the interaction region, and give the impression of back-to-back tracks.

The Atlantis also gives us physics information, like the energy and average time from two PMTs together, i.e., energy = energy1+energy2, time = (time1+time2)/2. In order to improve the data analysis, I have changed the code from JiveXML package to produce xml files with individual PMT information. The last Atlantis releases are able to read the new xml files and provide individual PMTs information.



(A) (B)

Figure 1 – A typical cosmic ray event at ATLAS Calorimeter. In the left we have the $x\,y$ projection, and on the right the $\rho\,z$ projection.

5 Searching for Z' with Athena

In this part of the work, we have investigate the possibility of detecting a new neutral gauge boson forecast by 3 – 3 – 1 model at ATLAS using Athena framework.

The 3 – 3 – 1 model is a SM extension that try to solve the number of families problem. It is based on $S(3)_C \; x \; SU(3)_L \; x \; U(1)_X$ gauge group and predict the existence of three new heavy quarks (*D, S, T*) and five new gauge bosons, one of them been neutral (Z'). One interesting feature of this model is the theoretical upper Z' mass, $M_{Z'} < 3.1\ TeV$, which can be checked at LHC/ATLAS.

The CompHep package was used to generated events for the process $pp \rightarrow e^+e^-$, with the Z' as the new mediator. This channel was chosen because it is a very clean signal to detect new physics at TeV region. An Athena job then takes these events, hadronizes them with PYTHIA and passes them down the Athena event chain. In this work, one performed a fast detector simulation.

One assumes a Z' mass of 1.5 TeV. Two scenarios was taken into account: firstly, we consider that the heavy quarks masses are degenerated and equal to 1 TeV, then decays like $Z' \rightarrow Q\bar{Q}$ ($Q = D, S, T$) are kinematically forbidden. In the second scenario, one sets $M_Q = 500\ GeV$ and the decay $Z' \rightarrow Q\bar{Q}$ is allowed. In these cases, the Z' width are 232 GeV and 475 GeV, respectively.

In the Fig. 2 is presented the reconstructed $e^{+}e^{-}$ invariant mass. It is possible to see a clear Z' signal at 1.5 TeV when the decay into heavy quarks is forbidden. In the second case, the number of events around the Z' peak has decreased a lot, which suggest that at larger Z' masses we will not get a signal statistically significant if decays into heavy quarks are kinematically allowed.

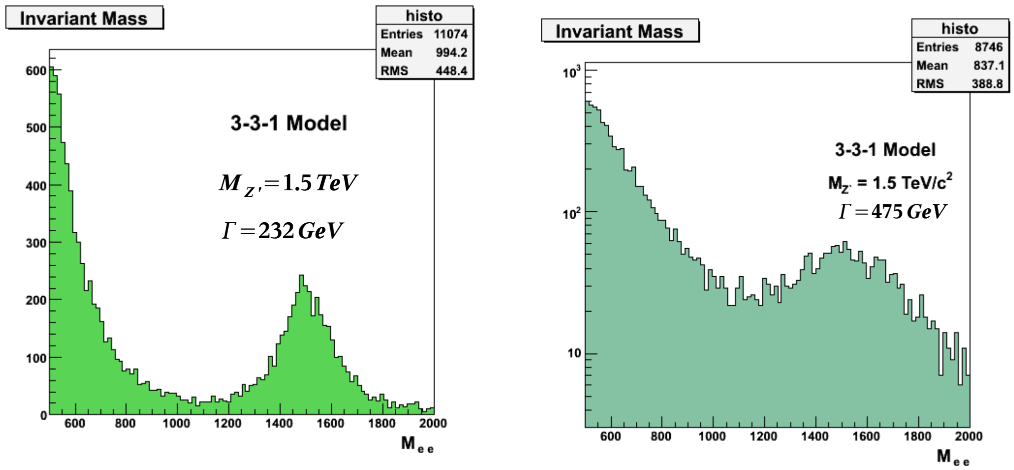


Figure 2 – e^{+} e^{-} invariant mass for two Z' widths.

The total decay width can be obtained by fitting a relativistic Breit-Wigner function to the invariant mass distribution, with a exponential to take into account the interference term. As the Z' width is larger than the detector resolution, we are able to get very good fit results, as is shown in Fig. 3.

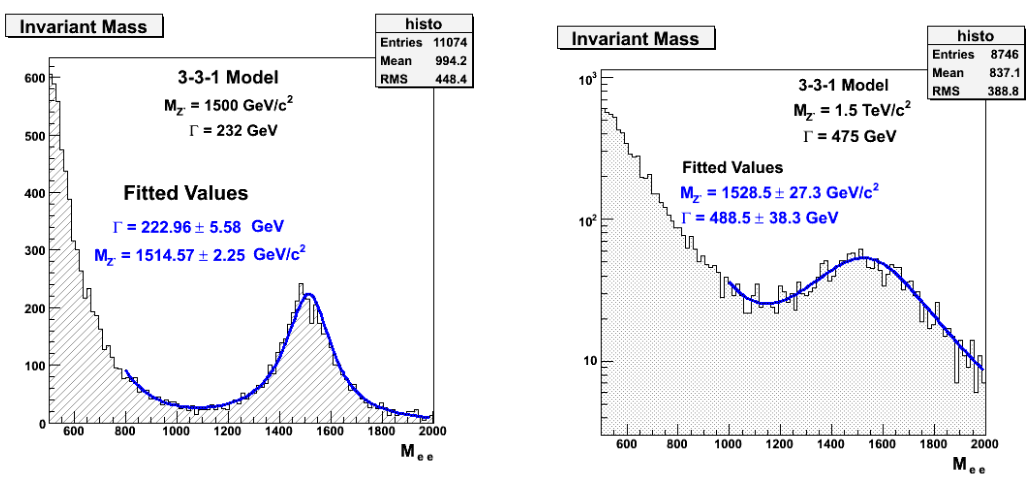


Figure 3 – Fit results to the invariant mass.

As there are a number of models that foreseen new neutral gauge boson, we have to find specific signatures of each model in order to distinguish them. Our results showed that the Forward – Backward (taking the Z' reconstructed direction as the quark direction) in rapidity bins is a good variable to distinguish the models.

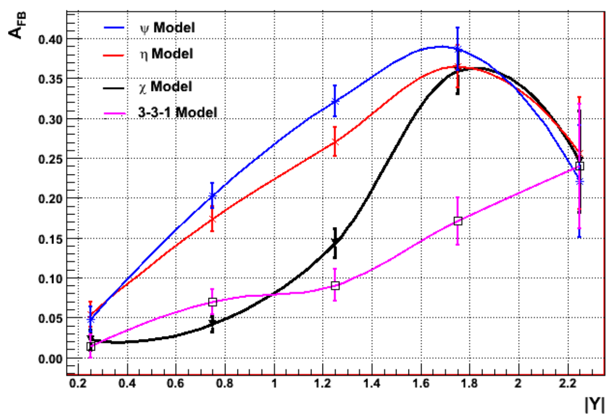


Figure 4 – Forward – Backward Asymmetry in rapidity bins for $M_Z' = 1.5\ TeV$. The models χ, η, ψ are Grand unified models based on E_6 group.

6 Conclusion

During my HELEN training I have added some features to the JiveXML package in order to get additional information from the Cosmic Rays data. These data has been used to look at calibration of calorimeter and to fix some problems, and I believe that my small contribution will be useful to the future cosmic rays analysis.

The simulations done for Z' boson from 3 – 3 – 1 model showed that a clear signal can be obtained if $M_{Z'} = 1.5$ TeV. The Z' width is dominated by exotic decays, and one believes that we will not get a significant signal for larger Z' masses if exotic decays are kinematically allowed.

The knowledge that I have acquired at CERN has been very useful for my future PhD thesis. The HELEN training was a great opportunity to learn and to take part of big experiment like LHC. Besides, the possibility of discussing with notable researchers and learn from their experience was very beneficial.