

Hybrid Pupil's Analysis Tool for Interactions in ATLAS

Dušan Vudragović, Antun Balaž, Aleksandar Belić
Scientific Computing Laboratory, Institute of Physics Belgrade, Serbia
Christine Kourkoumelis, Dimitrios Fassouliotis, Stylianos Vourakis
National and Kapodistrian University of Athens, Greece

Abstract - HYPATIA (the Hybrid Pupil's Analysis Tool for Interactions in ATLAS) framework is designed to enable high school students and their teachers to study elementary particles and their interactions. This is provided by visualization of particle collisions detected by the ATLAS experiment at LHC, the world's most powerful particle accelerator located at the European Particle Research Centre (CERN). At the same time, HYPATIA provides access to relevant scientific analysis tools, inspiring students to become researchers and introduces them to the environment of large-scale international collaborations.

I. INTRODUCTION

The interest of young students in natural sciences is dropping steadily over the past two decades in Europe and other regions of the world. This could present a serious problem not only for the development of science, but also for the overall technological development of the society in the future if proper steps are not taken. Dissemination of interesting scientific results and popularization of science can be used to leverage this situation. Experiments at the forefront of physics research can play an important role in promoting modern physics at schools. HYPATIA (Hybrid Pupil's Analysis Tool for Interactions in ATLAS) makes possible for high-schools students and their teachers to closely study the fundamental particles of matter and their interactions through the graphic visualization of particle collisions detected by the ATLAS experiment [1], [2] at the Large Hadron Collider [3] (LHC).

The LHC is the world's largest particle accelerator, colliding counter-propagating proton beams. LHC is built at the European Organization for Nuclear Research [4] (CERN) with the aim to test the Standard Model of interactions in high-energy physics, to probe the existence of the long sought Higgs boson, the properties of the large family of new particles predicted by super-symmetric extensions of the standard model, new discoveries, etc.

ATLAS (A Toroidal LHC ApparatuS) is the largest of the six particle detector experiments (ALICE [5], ATLAS, CMS [6], TOTEM [7], LHCb [8], and LHCf [9]) installed at the LHC. When the proton beams collide at the center of this general-purpose particle detector, a variety of different particles with a broad range of energies are produced. Rather than focusing on a specific physical process, ATLAS is designed to measure the broadest possible range of signals.

Using the ATLANTIS event display [10] library, HYPATIA framework enables a student to study products of the LHC proton beams collision products in the ATLAS detector. One collision product registered by the detector is called an event. In the HYPATIA framework is possible to analyze real events registered directly by the ATLAS

detector, as well as, events produced by numerous Monte Carlo generators and simulations of the ATLAS detector. Within the framework students can accomplish various types of projects:

- Select interesting events from different event streams;
- Display all (or selected) events one at a time;
- Interact and manipulate with the event displays;
- Study the traces of the particles in different parts of the ATLAS detectors;
- Look at reconstructed particle tracks, their properties, and analyze them;
- Discover new particles by reconstructing them from their decay products;
- Summarize the results in a presentation, which contains substantial event samples.

HYPATIA was initiated as a part of the ATLAS Student Event Challenge [11] (ASEC), and developed within the LA@CERN (Learning with ATLAS at CERN) project [12]. HYPATIA aims to help students in obtaining a better understanding of the interactions between the constituents of matter by working on the most advanced visualization techniques used by modern particle physics.

II. HYPATIA FRAMEWORK

In order to enable students and their teachers to accomplish various educational projects, the HYPATIA framework provides the following components:

- Necessary documentation with the background scientific information and links to further references;
- Analysis tool for the investigation and visualization of collision products;
- Collection of event files for the analysis;
- Set of exercises and assignments.

All these components of HYPATIA framework are made available at the HYPATIA web page [13]. Starting from the home page, through the *Read About* section, one can become familiar with the elementary knowledge of experimental particle physics and its vocabulary. While these pages contain only elementary introduction to the experimental particle physics, the *Useful Links* section provides a comprehensive set of essential educational references. *Basics* section of the web page aims to introduce users with the physical quantities that can be measured in the ATLAS detector. In this section we give an introduction to the idea of a track as a detectable quantity, to the invariant mass of a particle decaying to other particles, and the concepts of the particle width and the missing energy. The section *Use HYPATIA* in details explains the structure and usage of the HYPATIA analysis tool, and provides a list of exercises and assignments for

students. The students can work on the proposed exercises under the supervision of teachers, while assignments can be given as homework problems and completed by students individually. The exercises and assignments demand different levels of skills, and teachers are invited to add new ones. Some of the above projects can be accomplished in a few hours, while others could take more time, depending on the number of events and level of details taken into account. For this reason we have developed several special views of the HYPATIA analysis tool for high-school students. Although we will describe only the full version of the analysis tool in the following chapter, a simplified version of the tool can be called from the application. The main difference is that the simplified version does not include the Invariant Mass Window, and only single tracks can be studied.

The HYPATIA analysis tool, together with different collections of event files is available at the *Download* section. HYPATIA is open source software, and the source code is available from SCL's SVN software repository service [14]. This allows users and other interested parties to study and examine how the developed tools work and to possibly use them as a base for further developments and/or student and teaching projects.

Usually, a new version of the HYPATIA analysis tool is released quarterly, and it is recommended to regularly check and use the updated version. New sets of event files are released typically together with the new software release, although sometimes this is done more frequently. Since the tool is developed in the Java programming language, it works on any modern operating system (Linux, Windows, MacOS, etc.) if the appropriate Java Runtime Environment [15] is installed.

III. HYPATIA ANALYSIS TOOL

The HYPATIA analysis tool (Fig. 1.) uses a general framework of the ATLANTIS canvas display for events visualization, and goes a step further in the reconstruction and analysis of the collision products for educational purposes. The tool is organized in four different windows that provide information relevant for the analysis: Invariant Mass Window, Canvas Window, Track Momenta Windows, and Control Window.

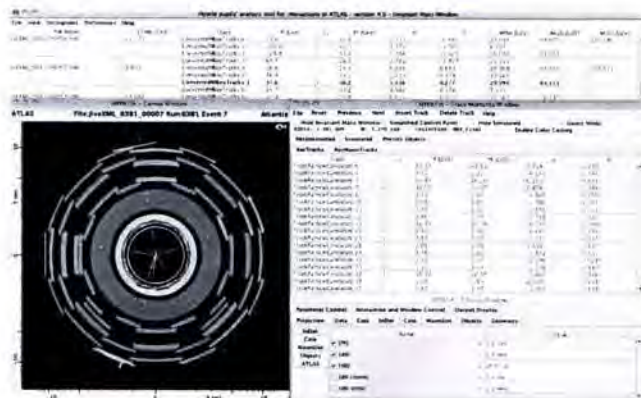


Fig. 1. Four windows of the HYPATIA analysis tool.

A. Invariant Mass Window

The Invariant Mass Window is the main window of the HYPATIA analysis tool. Tracks of interest chosen by a user from different events and their main physical quantities (momentum, charge, position in the detector, etc.) are presented in a tabular form. The Invariant Mass Table keeps together tracks coming from the same event, and automatically calculates and displays the invariant (or transverse) masses of track combination. For the time being, the tool is able to calculate three kinds of invariant masses: transverse mass of a track, the missing transverse energy of the event (designated m_{\perp}), the invariant mass of two tracks (designated m_{ii}), and the invariant masses of four tracks (designated m_{iii}). In addition, the Invariant Mass Table contains physical quantities (missing transverse energy, etc.), characterizing the event particles. In this way, all parameters necessary for invariant (or transverse) masses calculation are present in the table, so one is able to calculate the invariant mass using the analytic formulae, and to check the result with the number displayed in the Invariant Mass Window.

The main menu of the HYPATIA analysis tool is positioned at very top of the Invariant Mass Window, and contains the following items:

- 1) *File* menu item is used to perform operations on event files and on HYPATIA project files. It provides options for loading a new event file or a set of event files from a local computer or a remote destination. With Clear/Load/Save HYPATIA Project options one can perform operations on the Invariant Mass Table – clear the table, load previously inserted tracks information, or save information currently displayed in the table. Features inherited from the ATLANTIS event display framework, such as animation of an event, loop over several events, and graphical snapshot of an event, are also available in this menu item.
- 2) Primary features and information of HYPATIA analysis tool are provided in the four main windows, but a set of secondary utilities are also available, and can be called and displayed in independent windows. Sometimes, in order to optimize number of open windows, it is useful to close windows that are not used. Such windows can be reopened from the *View* menu item.
- 3) *Histogram* item provides a facility to make histograms of the desired quantities from the Invariant Mass Table (momentum, invariant or transverse masses, missing transverse energy, etc.). The shell and a histogram are built, and they enable users to modify style, add additional notes, change scale, export pictures, and etc.
- 4) *Preferences* menu item is responsible for customizing the application. The canvas shape and layout, color map, and level of the verbosity can be tuned from this item.
- 5) *Help* menu item provides an easy way to obtain help information. Currently it provides ATLANTIS online documentation, but very soon it will be improved with the additional HYPATIA online documentation.

B. Canvas Window

Canvas Window is a standard ATLANTIS display window where structure of the ATLAS detector and tracks of loaded event are drawn. It can be divided into one or more sub-windows, the canvas pads. This feature enables view of the same event in different projections (linear,

non-linear, 3D, etc.). The possible canvas pad configurations are specified in layout sets, which are available from Preferences menu option of the Invariant Mass Window.

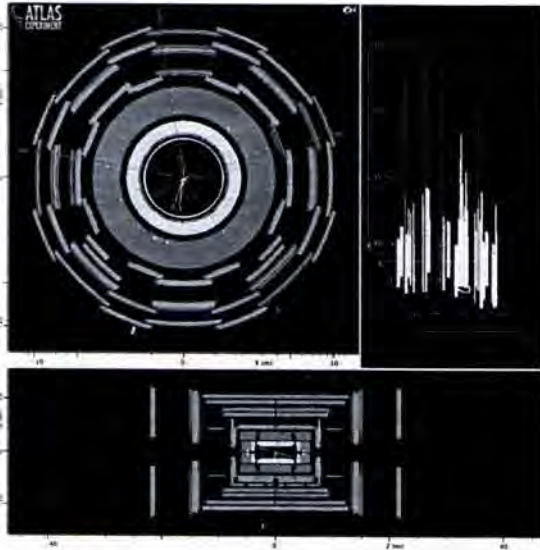


Fig. 2. Standard ATLANTIS display window – Canvas Window.

Each event display pad has associated interaction and parameter set with its projection, which can be chosen from the Parameter Control tab of the Control Window.

C. Track Momenta Window

While the Invariant Mass Window contains only user selected tracks from different events, the Track Momenta Window contains all tracks from one event that satisfy cut conditions specified in the Control Window. Different types of tracks are separated into several tabs, and within each tab tracks parameters (energy, momenta, angle parameters, etc.) are presented in the tabular form. By default, tables are formatted without background colors, but after turning on the option *Enable Color Coding*, the information on each track will be filled by the color specific for the particle type (only for simulated events).

From the Track Momenta Window users can select tracks of interest for further analysis, and copy them to the Invariant Mass Window using the Insert Track button from the top of this window. When a set of event files is used, easy navigation is achieved with *Previous Event* and *Next Event* buttons, also available in this window. This window has also tabs to activate different options:

- To be used to select or not the simplified version;
- To select the demonstration version where a continuous view of user selected simulated files can be shown;
- In case of simulation files, we can choose to show or hide the simulation information.

D. Control Window

The Control Window is used to view and modify the parameters and selections, and to control the graphs drawn on the Canvas Window and the tracks displayed in the

Track Momenta Window. It is divided in the three main tabs: Parameter Control, Interaction and Window Control, and Output Display.

1) *Parameter Control* provides the functionality for viewing and changing various parameters (data selection, cuts, detector, sub-detector systems, projections, etc.). The parameters are combined into a number of groups that are accessed via sub-tabs. The tabs are similar to the ones used by ATLANTIS, but with the modified startup conditions (cuts, projections and data selection).

2) *Interaction and Window Control* is used to activate an interaction in a canvas pad, to modify interaction-specific control options of the activated interaction, and to create sub-windows under the Canvas Window.

3) *Output Display* is used as a replacement for the standard terminal output. It provides information in a more readable format by using multiple fonts and colors.

IV. HYPATIA USAGE

Here we describe one example of the HYPATIA usage, but we stress that the whole framework is flexible and could be used in many ways. It is up to the supervisor/teacher to decide on the appropriate set of projects for his/her students, and to adjust the usage of the HYPATIA framework accordingly. One may find the HYPATIA web page especially useful in this induction process during which students should become familiar with the background information, detectors for particle physics experiments, and the ATLAS detector in particular.

A set of exercises is divided into three the more or less distinct parts: Single Tracks, Track Combination (mainly Z particles), and Higgs particle. Each of exercise is followed with several ideas on additional tasks that can be performed by students.

A. Part I – Single Tracks

The very first HYPATIA exercise should be based on working with single tracks. Users have to inspect the Track Momenta Window where all information regarding single tracks are stored. Picking the tracks from the Canvas Window or marking them in the list of tracks from different tabs of the Track Momenta Window, it is possible to establish a connection between track information and its graphical representation. It is important to observe how the total number of tracks is changed when different types and values of cuts from the Control Window are applied. Students should be able to recognize relationship between track curve in the Canvas Window and the sign of the track given in the Track Momenta Window.

In this exercise students are familiarized with single particles and learn about the different detector parts, the matching between different detectors, the methods to identify different kinds of particles. Since this approach is mainly focused on hardware, this exercise can be also used for courses on detectors and experimental techniques. Modified version of the HYPATIA analysis tool is already used as a laboratory exercise for the students of the undergraduate course of Elementary Particles in the University of Athens.

As a home assignment, students can investigate the different detector signatures of different simulated single

particles. In addition, the students can learn how to distinguish between electrons, muons, photons and hadrons from a file of mixed tracks. In the case of muons, it is possible to associate the Inner Detector tracks with the Muon Detector tracks, which can be given as homework.

B. Part II – Track Combination

In this exercise all four HYPATIA analysis tool windows have to be used. Users have to pick and insert up to four tracks from the Track Momenta Window to the Invariant Mass Window. The invariant mass of the combination is calculated as the tracks are being inserted. In order to change tracks in the combination, the *Delete Track* button from the Track Moment Window can be used.

When only one track is inserted, the invariant mass of the track and the missing energy of the event is calculated and displayed in column marked with m_{IV} for each track. For two tracks, besides m_{IV} the invariant mass of two inserted tracks (muons, electrons, etc.) is also calculated, and displayed in the column marked with m_{II} .

As an assignment, students can copy/paste the Invariant Mass Table to a spreadsheet application (OpenOffice Spreadsheet, Microsoft Excel, iWork, etc.), and using the analytic formula may calculate invariant masses and compare results with the appropriate HYPATIA table rows. Also, it may be interesting to reconstruct the mass of Z particles using combinations of muon-muon, electron-muon and electron-electron of different or the same charge tracks, and from there practically check the charge and the lepton number conservation. Furthermore, creating histograms of the reconstructed Z mass and the W transverse mass, the students could be able to determine the Z and W mass and width, and compare them to the experimental widths and the standardized PDG [16] values.

C. Part III – Higgs Particle

The cleanest signatures of the Higgs bosons, which students can study within the HYPATIA framework, are decays of the Higgs to four leptons. For this purpose – if the Higgs is discovered – the students could insert four leptons in the Invariant Mass Window. They should pick the four tracks that they think (from the previous experience) are most probable to belong to a possible Higgs decay. The invariant mass of these four tracks will be automatically calculated and displayed in the m_{III} column of the Invariant Mass Table. If for some reason the invariant mass of a particular combination of four tracks is not the expected one, the student can replace (from one to four tracks) with another one, using the *Insert/Delete* buttons of the Track Momenta Window. The analysis tool will automatically update the invariant mass under the relevant column.

If enough statistics is available (after years of running or from simulation), then the histogram of the invariant masses m_{III} can be generated. If the Higgs particle exists, and if the students have picked up the right tracks, then an accumulation of events around a specific mass (which is hopefully the Higgs mass) will become apparent in the histogram, as shown in Figure 3.

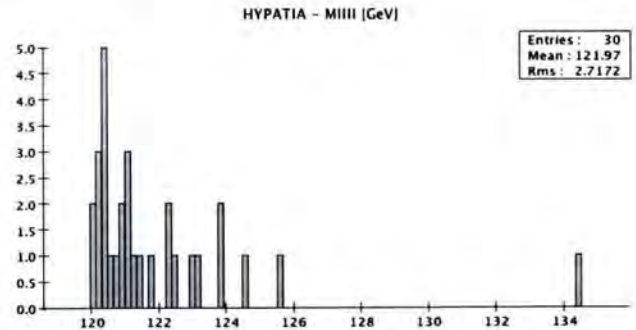


Fig. 3. Histogram of **simulated** Higgs particles decaying to four leptons accumulated using the HYPATIA analysis tool

As an assignment, students may be asked to create a histogram of the invariant masses of four muons, as well as background, perhaps separately for four electrons or muons, and two muon-two electron combinations. In addition, they can calculate the total charge of all the tracks and the average masses of each different combination.

V. CONCLUSION

The HYPATIA framework is developed and maintained as a part of the Learning with ATLAS at CERN project. It is designed to help students learn about particle physics, to give them access to visualization and analysis tools for event analysis. Starting from 2009, it is used in the International Masterclasses for High School Students [17]. The increase in the number of visits to the HYPATIA web page also shows that the developed HYPATIA framework is becoming more widely used.

ACKNOWLEDGEMENTS

This work is supported in part by the European Commission LLP project Learning with ATLAS at CERN, and by the Serbian Ministry of Science project No. OI141035.

REFERENCES

- [1] A Toroidal LHC Apparatus (ATLAS), <http://atlas.ch/>
- [2] G.Aad et al, "The ATLAS experiment at the LHC", JINST 3:S08003, 2008
- [3] Large Hadron Collider (LHC), <http://lhc.web.cern.ch/>
- [4] European Organization for Nuclear Research (CERN), <http://public.web.cern.ch/>
- [5] A Large Ion Collider Experiment (ALICE), <http://aliceinfo.cern.ch/>
- [6] Compact Muon Solenoid (CMS), <http://cms.web.cern.ch/>
- [7] TOTAL cross section, Elastic scattering and diffraction dissociation Measurement at the LHC (TOTEM), <http://totem-experiment.web.cern.ch/>
- [8] Large Hadron Collider beauty (LHCb), <http://lhcb.web.cern.ch/>

- [9] Large Hadron Collider forward (LHCf),
<http://www.stelab.nagoya-u.ac.jp/LHCf/>
- [10] Atlantis event display for ATLAS,
<http://atlantis.web.cern.ch/>
- [11] D. Fassouliotis, C. Kourkoumelis, Z. Roupas and D. Vudragovic, "The ATLAS Student Event Challenge",
CERN Note (2007), ATL-OREACH-PUB-2007-001
- [12] Learning with ATLAS at CERN (LA@CERN),
<http://www.ea.gr/ep/lacern/>
- [13] HYPATIA web page, <http://hypatia.scl.rs/>
- [14] SCL SVN repository service, <https://viewvc.scl.rs/>
- [15] Java Runtime Environment (JRE), <http://www.java.com/>
- [16] Particle Data Group (PDG), <http://pdg.lbl.gov/>
- [17] International Masterclasses for High School Students,
<http://www.physicsmasterclasses.org/>