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## **The ATLAS Student Event Challenge**

D. Fassouliotis, C. Kourkoumelis, Z.Roupas  
*University of Athens*

D.Vudragovic  
*Institute of Physics, Belgrade*

### **Abstract**

The ASEC (ATLAS Student Event Challenge) is an educational project which allows the students to learn about the elementary particles by studying “events”, the products of beam collisions at the LHC. The events are collected by the ATLAS detector and displayed graphically using the ATLANTIS package. The students are given the means to select and analyse the events on-line, and subsequently present the results and draw conclusions.



## ***Introduction***

The ASEC (ATLAS Student Event Challenge) is an educational project at the frontier of Particle Physics within the framework of the ATLAS Education and Outreach project [1]. The ASEC enables high schools students together with their teachers to study the fundamental particles of matter and their interactions through the inspection of the graphic visualization/display of the products of particle collisions. These products are "events" detected by the ATLAS experiment. The high school students become part of the ATLAS Experiment by sharing the actual ATLAS events with the experiment's members. The students have access to both real and simulated data, they are provided with tools to analyze these events and therefore, are given the opportunity to participate in discoveries.

Past experiences with the QuarkNet [2] and Hands on CERN [3] projects have shown that students and teachers are very willing to work with real data and can spend in the analysis time intervals ranging from a day up to a few weeks.

One of the applications of the ASEC would be its development to future international Masterclasses [4]. The ATLAS institutions and research centres across the world will greatly profit from holding such "Masterclasses". They can have the form of one-day workshops to familiarize the local students with the ATLAS Experiment through lectures and demonstrations. Then the students can work on the data and their conclusions will be communicated and discussed on-line with other student groups in different countries. These students will carry back to their schools and families their enthusiasm and act as "ambassadors" of the experiment to a wider public. This way a wider audience will be informed of the physics goals being pursued in the LHC and of the advanced communication means developed for the international HEP community.

Some selected students can also be part of teams (including their teachers) which could visit CERN or the local institutions for periods of about a week to carry out small projects/extensions of the ASEC interacting with the ATLAS physicists in "situ".

## ***Overall Structure of the ASEC***

Students worldwide can have web access to both real and simulated data which will be processed through the GRID. The students are able to study and analyse the events using the ATLANTIS [5] event display and the ASEC analysis tools. More precisely, they can accomplish the following projects:

- Select the events they wish, from different event streams
- Display all (or selected events) one at a time
- Interact and manipulate the event displays
- Study the traces of the particles in different parts of the ATLAS detectors
- Tag the selected reconstructed particle tracks, study their properties and analyze them
- "Look" and analyze new particles by reconstructing them from their decay products
- Summarize the results in presentations which contain substantial event samples
- Collaborate with students and physicists worldwide, sharing results and observations
- Discover the physics lying in the datasets

This way the students, by working on the most advanced techniques used by modern particle physics, obtain a better understanding of the interactions between the constituents of matter

Some parts of the ASEC can also be used by undergraduate and even graduate physics students. There are exercises which demand different skills and the coordinator is invited to add his/her own ones. Some of the above projects can be accomplished in few hours, others could take more time, depending on the number of events and detail one is willing to reach. For the high school students, a simpler version of the ASEC has been developed (called simplified ASEC sv), see section on Downloads.

## Description of the ASEC

The ASEC project uses the general framework of the ATLANTIS canvas displays to display the events and goes a step further in the reconstruction and analysis of the collisions products for educational purposes.

In order to accomplish the above, four different windows have been created, which provide all the information needed for the project. There are the:

- Event display Window (the standard ATLANTIS canvas window)
- Control Window
- Track list Window
- Invariant Mass determination Window

These windows, shown on Figure 1, open all simultaneously arranged on a single screen when the project is started. Each can be closed/opened as desired. They all close together when the invariant mass window gets closed. The main ASEC webpage is: <http://asec.phy.bg.ac.yu/>.

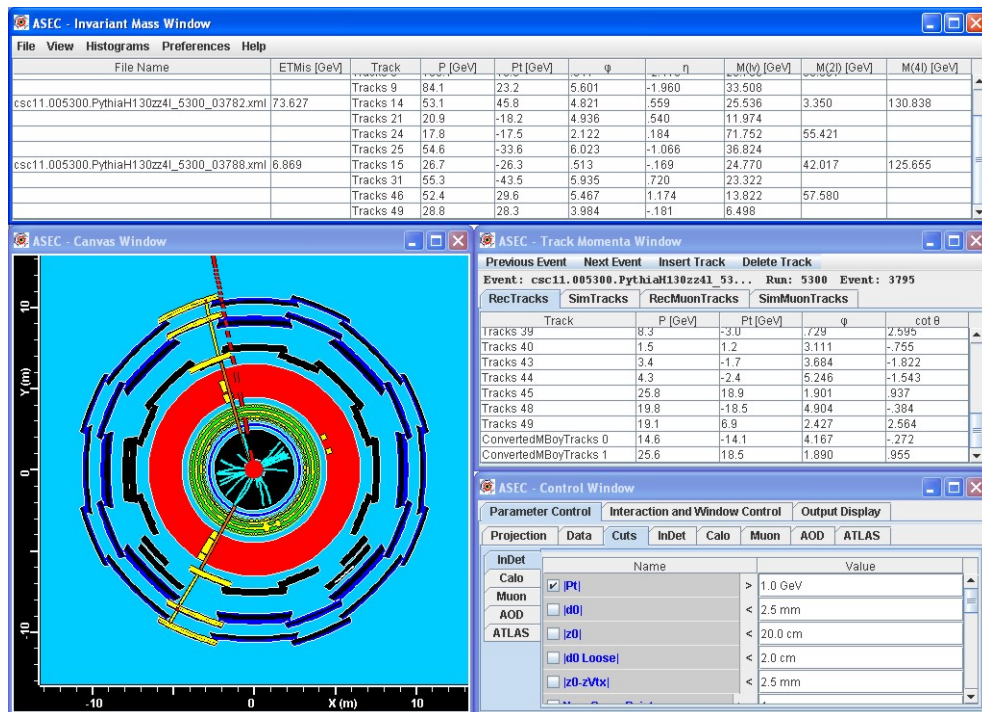


Figure 1: The main ASEC screen

Below, a brief description of each window is given.

## **Event display Window**

This is the standard ATLANTIS canvas window where the ATLAS detectors and tracks of the events are drawn. The Event display has a user selectable shape with the associated layout set. A layout set is a set of predefined subwindows within the selected shape. These subwindows are used to draw pictures and are called event display pads. The user may select a shape via the Preferences->Layout menu option of the Menu of the Invariant Mass determination Window. The layout set of the selected shape is displayed in and controlled via the Window Control of the Control Window.

Each event display pad has associated with it a projection (Control Window->Parameter Control->Projections), an interaction (Control Window->Interaction and Window Control) and a parameter set (Control Window->Parameter Control).

## **Control window**

The Control Window is used to view and modify the parameters and the selections which control the pictures drawn on the Event display window and the tracks displayed in Track list Window. In the normal version the Control Window contains the following tabs:

- Parameter Control
- Interaction and Window Control
- Output Display

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

**The Interaction and Window Control** part of the Control Window is used to activate an interaction in a event display pad, to modify interaction specific control options of the activated interaction and to create subwindows, the event display pads.

**The output Display** part of the Control window, is used as a replacement for a standard terminal output. It provides information in a more readable format by using multiple fonts and colours.

The simplified version contains only three subwindows (Figure 2): the **Projection**, which provides the choice for the display of the end-view or side-view of the Event. The **Interaction** subwindow, allows zooming or picking on a track in order to display its parameters.

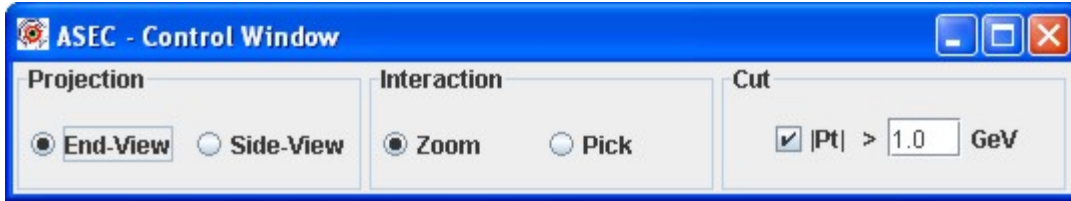


Figure 2: The Control window of the simplified version.

Finally, the **Cut** subwindow allows a continuous variation of the tranverse momentum cut, above which the tracks are displayed in the Event Display Window.

### Track list Window

In the Track list Window (Figure 3) the energies, momenta and angle parameters ( $\phi$ ,  $\cot \theta$ ) of all the tracks, above the cut chosen, are displayed. There are four kind of tracks which can be picked through the tabs (reconstructed Inner Detector tracks, Simulated tracks, Reconstructed Muon Tracks either MuonBoy or by Moore and the Simulated Muon tracks). In the simplified version only one kind of tracks, by default, the Inner detector reconstructed tracks plus the Muon reconstructed tracks are displayed (Figure 4).

One can load the previous or next event by the relevant buttons. Furthermore, the main function of this window is to allow the user to pick the “preferred” tracks and insert (or delete) them to the invariant mass determination Window for further analysis.

Track	Type	P [GeV]	Pt [GeV]	$\phi$	$\cot \theta$
STr 5	$\mu^+$	49.2	41.9	5.582	.617
STr 6	$e^-$	15.4	-14.1	2.027	.445
STr 7	$e^+$	19.1	18.5	3.306	.257
STr 14	$\pi^-$	5.0	-1.5	.227	3.129
STr 17	Antiproton	5.1	-1.4	3.263	-3.471
STr 18	$\pi^+$	3.1	1.5	3.311	-1.748
STr 20	$\pi^-$	313.3	-1.0	3.080	306.962
STr 33	$K^+$	13.7	1.5	5.265	9.316

Figure 3: The Track list window from the normal version.

Previous Event Next Event Insert Track Delete Track  
Event: csc11.005300.PythiaH130zz4l\_53... Run: 5300 Event: 57258

RecTracks

Track	P [GeV]	Pt [GeV]	$\phi$	$\cot \theta$
InDetTrack 19	7.2	1.6	6.242	4.551
InDetTrack 20	9.8	-2.5	4.661	-3.786
InDetTrack 21	11.9	4.7	.457	-2.338
InDetTrack 22	4.6	1.3	4.709	-3.481
InDetTrack 23	4.5	1.0	5.987	4.154
InDetTrack 24	6.3	1.0	2.816	-6.055
InDetTrack 25	6.0	-1.0	4.530	-5.809
InDetTrack 26	11.3	-5.6	.551	-1.735
InDetTrack 29	6.3	-1.0	4.800	-6.067
InDetTrack 30	74.1	52.1	1.714	-1.013
InDetTrack 33	8.4	1.3	3.011	-6.191
InDetTrack 34	18.1	-4.7	4.789	-3.749
InDetTrack 36	5.9	2.6	.526	-2.067
InDetTrack 38	83.0	-20.4	3.755	-3.949
MuonTrack 0	99.3	19.1	2.235	-5.097
MuonTrack 1	44.3	-26.7	2.778	-1.322

Figure 4: The Track list window from the simplified version.

## Invariant Mass Determination window

The Invariant Mass determination window (Figure 5) is the main analysis window of ASEC. It can be used for the display of the user chosen tracks of each event and values of their main physical quantities (momentum etc.). For each event the invariant (or transverse) masses of combinations of chosen particles are automatically calculated and displayed. For the time being there are three kinds of invariant masses formed. The transverse mass of a track and the missing transverse energy of the event (called  $m_{IV}$ ), the invariant mass of two tracks (called  $m_{II}$ ) and the invariant masses of four tracks called ( $m_{IIII}$ ).

File View Histograms Preferences Help

File Name	ETMis [GeV]	Track	P [GeV]	Pt [GeV]	$\phi$	$\eta$	M(IV) [GeV]	M(II) [GeV]	M(IIII) [GeV]
csc11.005300.PythiaH130zz4l_5300_03782.xml	73.627	Tracks 14	53.1	45.8	4.821	.559	25.536	3.350	130.838
		Tracks 21	20.9	-18.2	4.936	.540	11.974		
		Tracks 24	17.8	-17.5	2.122	.184	71.752	55.421	
csc11.005300.PythiaH130zz4l_5300_03788.xml	6.869	Tracks 25	54.6	-33.6	6.023	-1.066	36.824		
		Tracks 15	26.7	-26.3	.513	-.169	24.770	42.017	125.655
		Tracks 31	55.3	-43.5	5.935	.720	23.322		
csc11.005300.PythiaH130zz4l_5300_03790.xml	46.816	Tracks 46	52.4	29.6	5.467	1.174	13.822	57.580	
		Tracks 49	28.8	28.3	3.984	-.181	6.498		
		Tracks 8	18.9	17.9	3.427	-.341	17.120	47.256	122.189

Figure 5: The invariant mass determination window. The red rectangular shows the invariant mass calculation of four tracks.

The Invariant Mass determination menu items are the following:

- **File** item  
The File menu item is used to perform operations on event files and on the ASEC project information. **Read event** displays a dialog window where one can choose which event file to read from the local computer or web. With **Save/Load/Clear**

**ASEC Project** one can perform operations on the current table in Invariant Mass determination Window and the corresponding events.

- **View** item  
Here one can choose the windows to view.
- **Histograms** item  
The Histograms item provides a facility to make histograms of the desired quantities of the table (momentum, masses etc.).
- **Preferences** item  
The Preferences menu item is responsible for customizing the application.
- **Help** item  
The Help menu item provides a way to get access to help information.

### ***Preliminary tasks/Background knowledge***

Before starting, the students:

- Should become familiar with the background information and the ATLAS detector, given in the **“Read about”** section of the ASEC webpage. There, the particle physics is very briefly outlined and links are provided for further reference. Only the particles which the students will study are defined. Also very brief information for the ATLAS detector and subdetectors is given and the students are referred to the ATLAS public pages.
- Should also read the material given in **“Basics”** section in order to get familiar with the aims of the analysis tools and the physics quantities which they will measure. Firstly, they are introduced to the idea of a track as a detectable quantity, then to the invariant mass of a particle which decays to other particles. Lastly come the ideas of the particle width and the missing energy. These are quite hard notions for the student to understand. The coordinator can decide if he/she wants to omit those, depending on the level of the students and the time available. If done so, the exercises have to be modified accordingly.
- Finally, in order to learn about the different windows of the ASEC project, the students should read the how to **“Use ASEC”** section.

Here we stress again the fact that the Challenge is quite flexible and that is up to the coordinator to decide which experience he/she wants to push through and how deeply (detectors, analysis, discoveries etc) in order to modify accordingly the emphasis on the necessary background knowledge.

Below we describe the three different parts of the Challenge together with their relevant exercises (more can be added by the coordinator).

### ***Main parts of the ASEC***

#### **Part I – Working with Single tracks**

All the students need, is the Track list window where all the single track information is displayed. The students can choose different kinds of tracks with the different tabs or put cuts on the tracks using the "cuts" tab of the Control Window. They can also pick tracks from the Event display using the “pick” tab of the Control Window.

The students can familiarize themselves with single particles (learning about the

different detector parts, the matching between different detectors, the methods to identify different kinds of particles). This is a mainly “hardware” task and could eventually be used by a graduate course on “Detectors/Experimental Techniques”.

In the download file area, there are some examples of xml files of few (5-10) single tracks of muons, electrons, pions and neutrinos. One can load these events and look at the detector signatures. The students should also be given directions how to recognize the sign of the tracks.

## **Part II – Working with combinations of tracks and reconstructing the Z and W particles masses. Combine tracks to observe and measure known particles.**

This is done using the provided specialized window called Invariant Mass Determination Window. The students can pick and insert to this window several tracks from the Track List window (no more than four tracks/event). The track(s) are copied and the invariant mass of the combinations, as the tracks are being inserted, is calculated. The students can also delete tracks with the "Delete track" button and replace them with others.

One track inserted: (To be used for the  $W \rightarrow l\nu$  (neutrino) lepton decays). The invariant mass of this track and the missing  $E_T$  of the event, is automatically calculated and displayed under the  $m_{\nu l}$  column.

Two tracks inserted: (To be used for the  $Z \rightarrow \text{lepton-lepton}$  decays). The invariant mass of the two inserted tracks (muons, electrons, one of each etc.) is calculated automatically and displayed under the  $m_{ll}$  column.

## **Part III – Discovery of the Higgs particle**

The easiest decays of the Higgs, for the students to look for within the ASEC framework, are those to four leptons. For this purpose the students should use the Invariant mass determination Window and insert four tracks. They should pick and insert to this window the four tracks which they think (from the previous experience) are more probable to belong to a possible Higgs decay. Then the four track invariant mass will be automatically calculated and displayed in the  $m_{llll}$  column. If for some reason the student does not "like" the invariant mass of a particular combination of four tracks, then he/she can replace (from one to four tracks) with another(s). The window will automatically update the invariant mass under the relevant column.

If enough (more than 10-20 events) are loaded and looked at, then the histogram of the  $m_{llll}$  can be displayed. 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 6..



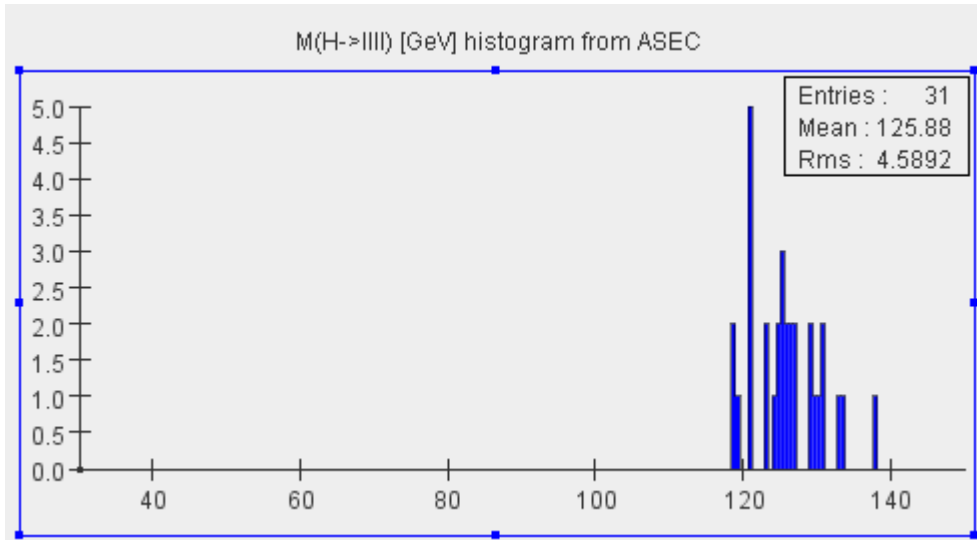


Figure 6. A histogram of few generated Higgs particles decaying to four leptons accumulated using the ASEC analysis tools

## Exercises

Some examples are given for each part. Obviously the coordinator can make up more.

### Part I

- The students can investigate the different detector signatures of different simulated single particles.
- The students can learn to distinguish between electrons, muons, photons and hadrons from a file of mixed tracks. They can also investigate the effect of the “cut” button.
- The students can learn to associate the Inner Detector tracks with the Muon tracks in the case of muons.

### Part II

- The students can calculate the invariant mass of two tracks using the analytic formula (or eventually of 3 or 4 particles). This can be done by copying the momentum information in an excel file. They can check their results with the numbers calculated in the invariant mass determination window.
- Examples of these events could be Z's (and eventually Higgs if we have them but wait for the 3rd part!). So by using selection possibilities the students should be able to isolate the electrons or muons which are the Z decay products in an event picture and then calculate their invariant mass.
- The students should try to reconstruct the mass of the Z using combinations of muon-muon, electron-muon and electron-electron of different or same charge tracks. This way they can learn about the charge and lepton number conservation
- The students can histogram the reconstructed Z mass and the W transverse mass. From them, they can try to determine the Z mass and width and compare them to the PDG values. This way they can learn about the influence of the experimental

errors and mass resolution. They can also study the connection between the Z and W widths.

### **Part III**

- The students can histogram the invariant masses of four muons, perhaps separately for four electrons or muons and two muon-two electron combinations. They should be asked to calculate the total charge of all the tracks and the average masses of each different combination.
- They can also look at the two track combinations, at the sum of the sign of the two particles, at their mass histograms and decide if they observe any accumulation around the mass of the previously reconstructed Z particle.
- Lastly and more complicated: the students can try to reconstruct the  $t\bar{t}$  events. They can first try to reconstruct the two W's from their  $bW$  decays. They could also learn about b's and the signature of their semileptonic decays.

### ***Downloads and further help***

All the executable versions of the ASEC can be obtained from the "Download" tab. If there are any problems with the downloads or running the program, please use the "Contact us" tab.

There is also a tab with "Useful links" where the students can have access to different relevant outreach web pages.

For installing the most recent running version of the program, click on the upper right line of the first or the second (for the simplified version) part. The lower right line gives access to older versions.

All versions contain a file of few example events. If more events are required, then they can be downloaded from the third part. They can also be saved in local PC's and then loaded by using the "file" -> "read event" tab in the Invariant mass determination window.

### ***GRID usage***

The ASEC program will give the users/students the opportunity to use virtual GRID data tools and techniques which provide:

- Computing resources
- Data on the GRID (both real and simulated). The data will be processed and kept on several streams and the users can select a number of events from one or several streams.
- Systematized data analysis (metadata)
- Collaboration tools for reporting their results and having online discussions about their conclusions with fellow students and peers. The results can also be presented both orally and written through blogs, wiki sites etc.

## **Summary**

The ATLAS Event Challenge is expected to help students learn about particle physics, giving them access to data and the relevant analysis tools worldwide and inspiring to them the ideas of international collaboration.

At the same time the wider public will become aware of the rich LHC program and more specifically the ASEC will help to bring special focus to milestone events in the start-up of LHC and the ATLAS Experiment.

## **References**

- [1] The Education and Outreach project of ATLAS—a new participant in physics education R Michael Barnett and K Erik Johansson 2006, Physics Education 41 (2006) 432-436
- [2] QuarkNet webpage: <http://QuarkNet.fnal.gov> and documentation references.
- [3] Hands on CERN - a Particle Physics Education Project utilising the Internet, K.E. Johansson and T.M. Malmgren, Physics Education 34/5(1999) 286-293, Hands on CERN web-page: <http://hands-on-cern.physto.se>
- [4] Masterclasses webpage: <http://www.physicsmasterclasses.org/mc.htm>
- [5] ATLANTIS: <http://www.hep.ucl.ac.uk/atlas/atlantist/>