1.1 HYPATIA (Hybrid Pupil's Analysis Tool for Interactions in ATLAS) – Find the Higgs

Name of the Institution: IASA

Title of the educational scenario template: Inquiry-based teaching

Title of the educational scenario: HYPATIA (Hybrid Pupil's Analysis Tool for Interactions in ATLAS) – Find the Higgs

Version: 1.3

Educational problem:

High school students have very little knowledge about particle physics and modern physics in general. Most of the school curriculum is focused on basic physics concepts that have been known for centuries. There is very little information about the current state and direction of physics and state-of-the-art research. Also nuclear and particle physics is very rarely mentioned in class. This leaves students with a very stale and antiquated perception of physics and fails to ignite their interest in the subject.

Educational scenario objectives:

The scenario's goal is to allow high school students to visualize the complexity of the hadron - hadron interactions through the graphical representation of ATLAS event data and interact with them in order to study different aspects of the fundamental building blocks of nature. They also learn about the fundamentals of particle detector operation and explain the way particles interact with them and leave a characteristic signature according to their different types.

The students who most likely have never came in contact with particle physics are shown what a real researcher does, and how new particles are discovered. This gives students a realistic and exciting look at the research being done at CERN and stimulates an enthusiastic interest in it. It also inspires teachers to talk to their students about particle physics and shows them a way to integrate it into their class at a level that is suitable to their students.

Using HYPATIA, students can experience how a researcher works and appreciate the difficulty and complexity of the work being done. They see how scientific inquiry works in real life. This has the objective of igniting the student's interest in particle physics, and physics in general. Our aim is to drive the students to learn more on their own and investigate further (and even pursue a career in physics).

Characteristics and needs of students:

The students involved in this scenario have to have basic knowledge of physics and electromagnetism. Also a basic knowledge of the structure of the atom (or even elementary particles) is desired. Students work on pc's using the Hypatia software which is intuitive and easy to use. Still basic computer skills are required. Finally the students have to prepare a report with their partners to show their results and understanding of the subject.

This scenario involving HYPATIA can be used by very young students to visualize the collisions of high energy protons and their products. In Greece this means 15 to 18 year old students.

Rationale of the Educational approach and Parameters guaranteeing its implementation:

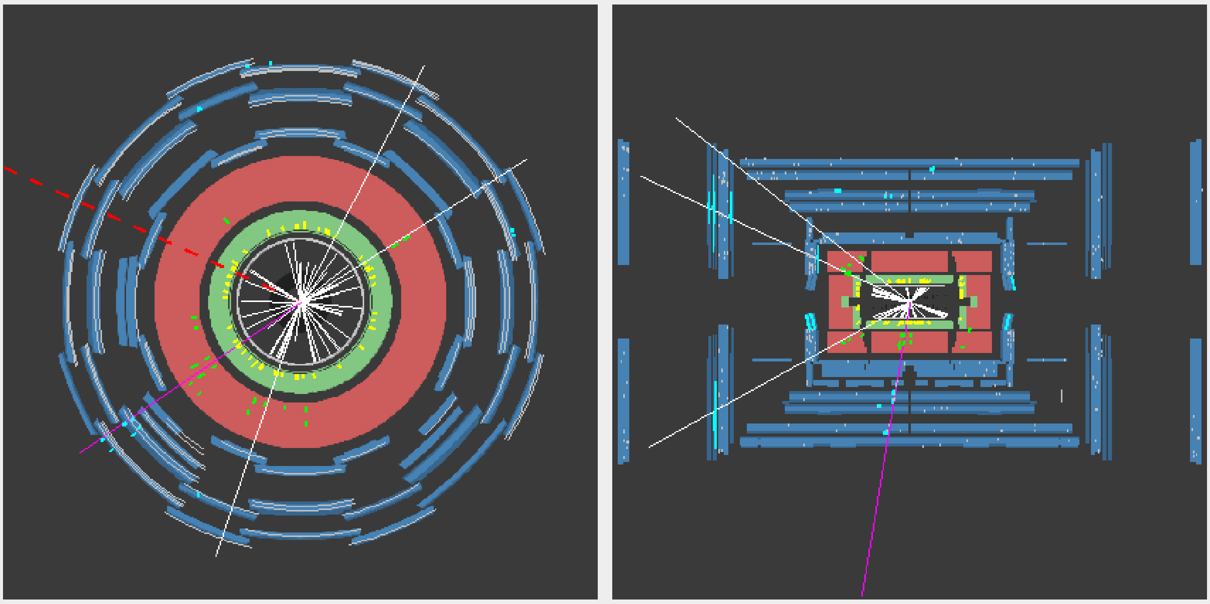
This scenario is created to give the students the opportunity to discover certain physics principles on their own. They have to gather their own results and draw conclusions based on them, the guidance of their teacher and the lectures they were given. They also have to prepare a report that outlines their results and discuss it with other students from different teams. In general the students are given as much freedom as possible to gather and interpret their own results and reach conclusions.

Learning activities:

- **Question-eliciting activities**
    - Lecture about particle physics by experts
    - Lecture about CERN and the LHC and detectors by experts
    - Discussion/question/answer session with the students and teachers and experts

- **Active investigation**
  - Introduction to the software that will be used (Hypatia or other ATLAS event analysis tool)
  - LHC interactive event analysis (from other experiments)
  - Possible video Conference with other schools (for students)
  - Quiz (for students)

Students using HYPATIA look at a number of real events that are detected by the ATLAS experiment at CERN. They have to determine based on the information they have been given in the lectures and the data that is presented by the event display application whether a specific track represents an electron or a muon.



Previous Event | Next Event | Insert Electron | Insert Muon | Delete Track | Zoom :

Event: 6/10 (2934237/178044) 2011-03-22 ETMiss: 10,601 GeV φ: 2,72 rad | Higgs | event_06.xml | p_T 1 GeV

Track	+/-	p [GeV]	p_T [GeV]	φ	θ
Tracks_0	-	8,93	1,88	2,638	2,929
Tracks_2	+	7,57	1,25	0,546	2,975
Tracks_3	-	6,04	1,82	-1,366	-0,306
Tracks_4	-	36,65	36,16	-2,546	-1,734
Tracks_5	-	21,51	4,13	0,495	2,948
Tracks_6	+	87,87	37,43	0,566	2,702
Tracks_9	+	2,86	1,02	0,424	2,779
Tracks_10	-	5,17	1,50	0,231	2,848
Tracks_11	-	1,34	1,10	0,662	0,968
Tracks_12	+	5,90	1,96	1,221	2,803
Tracks_13	-	70,34	43,63	1,088	2,472
Tracks_15	+	89,31	43,27	-1,892	-2,636
Tracks_16	-	1,27	1,20	2,554	1,893
Tracks_17	+	1,42	1,22	-1,885	-2,105
Tracks_18	+	2,26	1,60	-1,362	-0,790
Tracks_20	-	1,55	1,10	-2,896	-0,785

File Name	ETMiss [GeV]	Track	p [GeV]	±	p_T [GeV]	φ	θ	m_{ll} [GeV]	m_{llll} [GeV]	e/μ
event_06.xml	10,60	Tracks_13	70,34	-	43,63	1,088	2,472	27,52	181,15	μ
		Tracks_6	87,87	+	37,43	0,566	2,702			μ
		Tracks_15	89,31	+	43,27	-1,892	-2,636	55,94		μ
		Tracks_4	36,65	-	36,16	-2,546	-1,734			μ

- **Creation using the HYPATIA Analysis Tool**

The Higgs boson is an unstable particle that quickly decays and is impossible to detect directly. One of the ways in which it decays is into a pair of Z bosons, which in turn each decay into a pair of leptons. We therefore have the following possibilities of Higgs bosons decaying into four leptons:

- $H \rightarrow 2e^- 2e^+$
- $H \rightarrow 2\mu^- 2\mu^+$
- $H \rightarrow e^+ e^- \mu^+ \mu^-$

The criteria with which to distinguish muon or electron tracks coming from Z decays are as follows:

Electrons

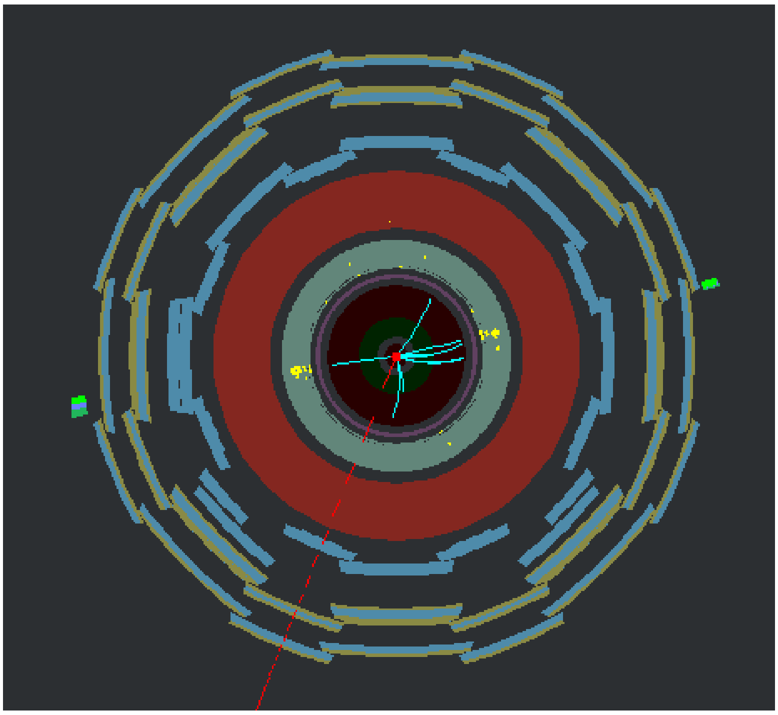
- Short tracks shown only on the inner detector
- Can be positive (positrons) or negative (electrons)
- Are usually isolated (not close to many other tracks)
- Leave a lot of energy (yellow marks) on the electromagnetic calorimeter

Muons

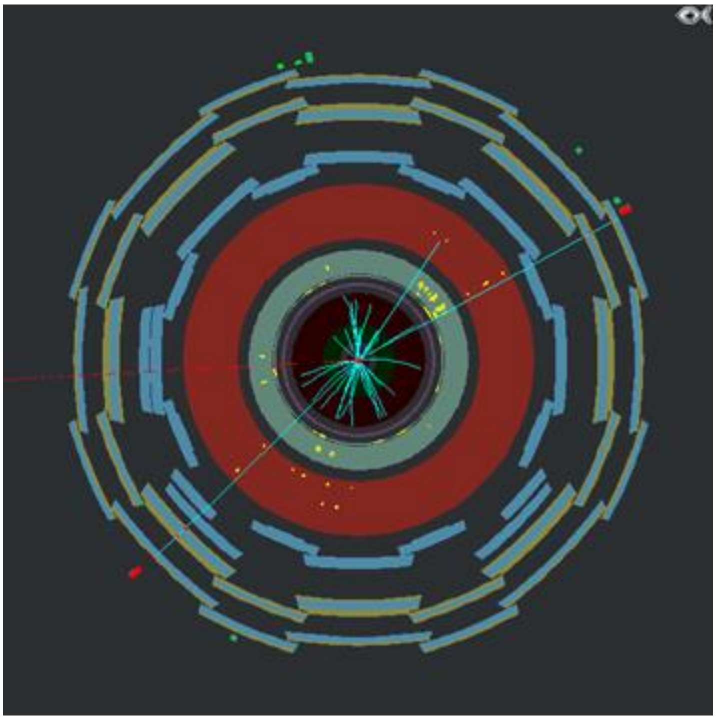
- Long tracks shown going through the entire detector
- Can be positive (antimuons) or negative (muons)
- Are usually isolated (not close to many other tracks)
- The only tracks that reach the muon chambers (light blue area)

Track examples

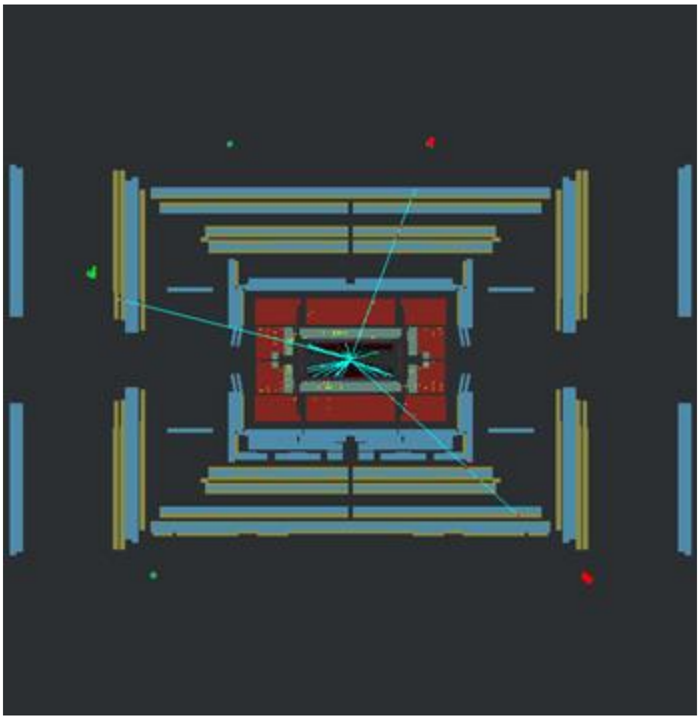
In the screenshot below we see a pair of electron (or positron) tracks. They can be clearly identified as they are short, isolated tracks that leave a lot of energy in the electromagnetic calorimeter. We cannot tell the charge of the particles by looking at the tracks. We have to click on them and then look at the track momenta table which includes the appropriate column.



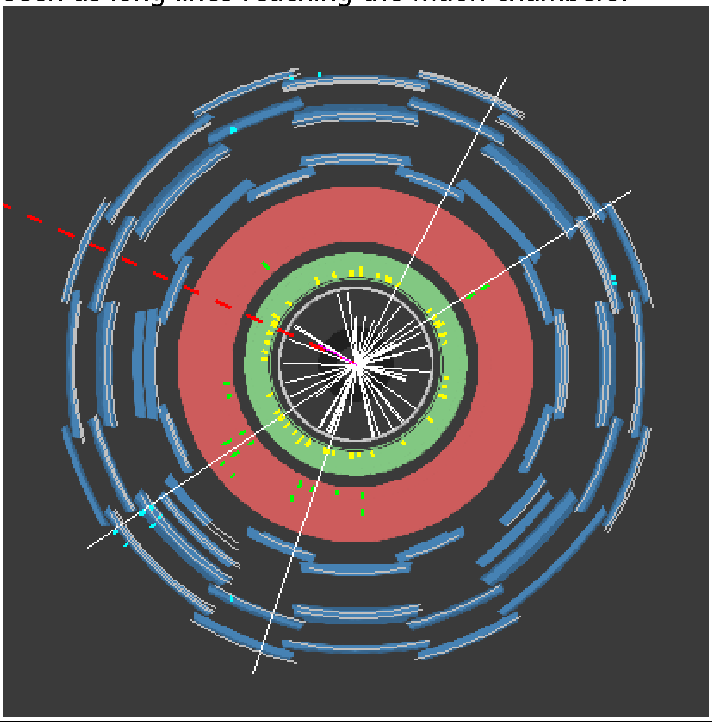
In the screenshot below we can see two muons (or antimuons) which can be clearly identified as they are long tracks reaching the muon chambers.



We also see a third track that is long but does not seem to reach the muon chambers. It seems to stop at the hadronic calorimeter. This is again a muon track, but this time it forms a small angle with the direction of the beams. This means that the track's projection on this plane is small and deceptive. We can easily identify the track as a muon by looking at the side view of the detector where we see the track reaching the muon chambers.



In this screenshot we see a Higgs boson decaying into four muons. The tracks can be clearly seen as long lines reaching the muon chambers.



- **Discussion**

Students compare their results with other students and discuss the results and the differences they may contain.

- **Reflection**

Students discuss their results with the teachers and compare them with known quantities.

Participating roles:

Students

- Learn how real researchers work
- Learn about the constituents of matter
- Learn about CERN and ATLAS

Teacher

- Lectures about particle physics
- Directs discussion
- Supervises laboratory work
- Evaluates results
- Helps with conclusions

Tools, services and resources:

The scenario requires the use of:

Hardware

- Computer
- Projector
- Internet connection

Software

- Java
- HYPATIA (http://hypatia.phys.uoa.gr/applet)

HYPATIA is an event analysis tool for data collected by the ATLAS experiment of the LHC at CERN. Its goal is to allow high school and university students to visualize the complexity of the hadron - hadron interactions through the graphical representation of ATLAS event data and interact with them in order to study different aspects of the fundamental building blocks of nature.

HYPATIA allows the use of events that have been collected by the ATLAS experiment or simulated using the Monte Carlo method. The user can:

- Select the desired events from dedicated sets of selected events streams
- Browse the events with any order
- Study the particle tracks either through their graphical representation or through the tables
- Select from a variety of detector graphical representations
- Customize the display of information to his particular needs
- Combine multiple tracks to infer the existence of short lived particles "invisible" which decay very fast to a number of secondary particles.
- Collect interesting tracks and plot histograms of their properties
- Aggregate particles and study the distribution of their mass, momentum, angles, missing energy etc
- Use the techniques used by physicists in actual research

HYPATIA can be used on most modern operating systems such as Windows, Linux, Unix, Solaris, MacOS etc.

The graphical representation (canvas) ensures very accurate and detailed display of the event tracks. Also it ensures that the computing power required will be minimal and so HYPATIA will run on almost any computer regardless of memory or processor speed. The canvas allows even inexperienced users to interact with the events using simple point-and-click functionality. The multiple views of the ATLAS detector that are available ensure that the user will get an accurate view of all the particle tracks that make up an event.

Laboratory use

HYPATIA has been extensively used in student Masterclasses in different schools in Greece and in the HST school at CERN in summer 2012. It is easy to use, and our web site provides extensive help tools.