

D3.1.x HYPATIA an online tool for visualization and discoveries using elementary particle collisions

Project 665917

Reference:

Code: D 3.1.x

**Version &
Date:**

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1 Introduction / Demonstrator Identity

1.1 Subject Domain

High Energy Physics at CERN

1.2 Type of Activity

Workshop with students: Introductory to elementary particles followed by hands-on activity with PC's. The students visualize the particle collisions, study their products and possibly make discoveries.

1.3 Duration

2 and 1/2 hours

1.4 Setting (formal / informal learning)

Formal and informal

1.5 Effective Learning Environment

- Simulations aiming to enable the visualization of theoretical models and facilitate inquiry-based experimentation
- Dialogic space / argumentation aiming to engage students in argumentation and dialogic processes for a better insight into the nature of scientific enquiry and the ways in which scientists work
- Experimentation (Science laboratories and eScience applications) aiming to enhance students' physical and intellectual interaction with instructional materials through 'hands-on' experimentation and 'minds-on' reflection.
- Visits to research centres (virtual/physical) aiming to connect the science classroom with research infrastructures, addressing the enhancement of informal learning settings.

2 Rational of the Activity / Educational Approach

- Active participation in modern discoveries
- Development of analytical and critical skills
- Understanding of scientific concepts and phenomena
- Emulation of cutting edge research work using complex learning environments
- Involvement in high end scientific data analysis
- Develop skills of teamwork

2.1 Challenge

School curriculum focuses on the fundamental concepts of physics. That is undoubtedly necessary as a basis to understand more complex concepts. However focusing on discoveries made centuries ago and ignoring recent advances promotes an antiquated view of physics and fails to spark the students' interest towards it. It is necessary for them to learn how physics has evolved and what the current scientific view of the world around us is. This will not only give them a more complete view of what physics represents but also motivate them to take in interest in the physical sciences.

In this exercise, the students are offered high stimulating environments through which they get acquainted with the most advanced technological equipment. They are expected to understand quite complicated processes which take place when two very high energy particles collide to produce hundreds of fragments. They are also encouraged to collaborate with their teammate and among other teams to evaluate and explain their results.

2.2 Added Value

- Familiarize themselves with cutting edge technology required to build world's most complicated detectors
- Learn by interactive complex analysis in PCs
- Virtual visits to CERN and its experiments
- Live discussion with researchers at CERN
- Involvement in high end scientific data analysis
- Development of analytical thinking and critical skills
- Encouragement of decision independent making
- Understanding of scientific concepts and phenomena
- Develop skills of teamwork

3 Learning Objectives

School curriculum is usually limited to basic physics concepts that were discovered decades ago. While this is an important foundation for the understanding of modern physics, it also leaves the students with a very antiquated view of physics.

With this demonstrator we aim to present to the students a realistic view of how modern particle physics research is conducted at the most advanced particle accelerator in the world, the LHC, and its experiments. This will not only give students a detailed view of the advances in particle physics but also teach them about the structure of matter, the existence of a multitude of subatomic particles and their interactions. In addition it introduces them to the most advanced technological progress. It will also help them realize that working in experimental physics is something that they could do if they wish.

Furthermore, the exercise will help them develop analytical and teamwork skills that are required in most research environments even beyond physics.

3.1 Domain specific objectives

The students will learn about subatomic particles and their interactions, the structure of matter and the four fundamental forces in nature. They will also learn how modern particle physics research is conducted and new particles are discovered.

3.2 General skills objectives

Students will learn to apply their knowledge, analytical skills and reasoning to select the proper tracks from each event and combine them to “discover” new particles. They will also learn about teamwork and collaboration in comparing their results and discussing their differences.

4 Demonstrator characteristics and Needs of Students

4.1 Aim of the demonstrator

This demonstrator 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.

4.2 Student needs addressed

The students involved in this exercise should 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.

The HYPATIA demonstrator includes four different exercises with increasing level of difficulty. The lower one can be used by very young students to visualize the collisions of high energy protons and their products. The more complex involve 16 to 18 year old students.

5 Learning Activities & Effective Learning Environments

- **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 HYPATIA software that will be used
- LHC interactive event analysis including possible discoveries of new particles
- Possible video Conference with other schools (for students)
- Active participation in the discovery of scientific concepts
- Development of analytical and critical skills
- Understanding of scientific concepts and phenomena

- Emulation of cutting edge research work
- Involvement in high end scientific data analysis
- Develop skills of teamwork

More Specifically:

- Students will learn the principles of basic science, concepts beyond the school curriculum
- Students will learn through playing games (at the entry level) and performing realistic high energy physics data analysis (at higher level)

Students will engage in hands-on activities which will allow them to understand and become familiar with the work of physicists working in the field of high energy. This will expose them to key concepts in modern physics and will help them develop an interest in it. They will learn about the building blocks of nature and their interactions.

<p>Science topic: Particle physics. (Not part of most national curriculums)</p> <p>Class information</p> <p>Year Group:</p> <p>Age range: 15-18</p> <p>Sex: both</p> <p>Pupil Ability: Basic computer usage required</p>	<p>Materials and Resources: A computer laboratory with one pc for each student or group of 2 students. A projector. Internet connection.</p> <p><i>Where will the learning take place? On site or off site? In several spaces? (e.g. science laboratory, drama space etc), or one? In a computer laboratory</i></p> <p><i>Health and Safety implications? None</i></p> <p><i>Technology?</i></p> <p><i>Teacher support?</i> It is desired that the teacher would talk to the students during the previous days and introduce some of the concepts necessary for the exercise. This will make it easier for the students to absorb the multitude of information necessary to conduct the exercise.</p>
<p>Prior pupil knowledge: Basic understanding of electromagnetism and atomic structure.</p>	



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Individual session project objectives (*What do you want pupils to know and understand by the end of the lesson?*)

The aim of the lesson is twofold. First the students will understand important principles of high energy physics, subatomic particles and the structure of matter. Second they will learn how to work like actual researchers by evaluating and analyzing real data from the ATLAS experiment at CERN.

As an additional outcome it can be combined with the art classes and the students to be asked to make their own visualization of the products of particle collisions and/or produce short artist videos which explain their findings.

Assessment

Differentiation

How can the activities be adapted to the needs of individual pupils?

Key Concepts and Terminology

Subatomic particles, structure of matter, fundamental forces, particle decay

Science terminology:

-see above-

Arts terminology:

Particle collision visualization, Photographs, video, paintings



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Session Objectives:

During this demonstrator, students will analyze data from the ATLAS experiment at CERN. They will perform the same tasks as actual researchers and will “discover” the Higgs boson. After the end of their analysis they will compare their results with those of other groups to confirm them and discuss possible differences, something that is also a basic part of physics research.

Learning activities in terms of CREATIONS Approach

IBSE Activity	Interaction with CREATIONS Features	Student	Teacher	Potential arts activity
<p>Phase 1: QUESTION: students investigate a scientifically oriented question</p>	<p>Students pose, select, or are given a scientifically oriented question to investigate. <i>Balance and navigation</i> through <i>dialogue</i> aids teachers and students in creatively navigating educational tensions, including between open and structured approaches to IBSE. Questions may arise through <i>dialogue</i> between students’ scientific knowledge and the scientific knowledge of professional scientists and science educators, or through <i>dialogue</i> with different ways of knowledge inspired by <i>interdisciplinarity</i> and personal, embodied learning. <i>Ethics and trusteeship</i> is an important consideration in experimental design and collaborative work, as well as in the initial choice of question</p>	<p>The main idea of this introduction is to get students to learn interactively about the cutting edge research done at the European Center of Particle Physics (CERN) located in Geneva across the French-Swiss border. At the same time they will become familiar with the new technologies developed in order to construct and operate the giant accelerator</p>	<p>Teachers should make a brief introduction to their students about CERN and basic research and engage them in watching videos about CERN in general and about the ATLAS detector which they will use for identifying particles in phase 3. The goal is to give</p>	<p>Possible initial collaboration with arts teachers to visualize elementary constituents of matter</p>



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		and the experiments installed in it. Engage with teacher's questions. Watch videos and use the web to gather more information.	students a basic idea about the research being conducted at CERN but also learn about some of the fundamental physics principles that are necessary to understand before proceeding with data analysis.	
<p>Phase 2:</p> <p>EVIDENCE: students give priority evidence to</p>	<p>Students determine or are guided to evidence/data, which may come from <i>individual, collaborative and communal activity</i> such as practical work, or from sources such as data from professional scientific activity or from other contexts. <i>Risk, immersion and play</i> is crucial in <i>empowering</i> pupils to generate, question and discuss evidence.</p>	<p>The students will briefly learn about the operation of the LHC accelerator, the discoveries it made about the elementary particles and how they can be classified in families. Students need to understand that modern physics has moved far beyond the structure of the</p>	<p>The teacher, after an introduction to the particle world, should try to talk to the students about the Higgs boson. He/she should explain its role in particle physics and its significance in</p>	<p>Possible collaboration with arts teachers to visualize and create an art project about particle accelerators</p>



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		atom than they learn at school. In order to conduct the exercise they need to become familiar with the characteristics and properties of some of the subatomic particles that have been discovered in recent decades as well as the signatures they leave in the ATLAS detector.	shaping the world around us. This will highlight the importance of its discovery four years ago.	
Phase 3: ANALYSE: students analyse evidence	Students analyse evidence, using active investigation and <i>dialogue</i> with each other and the teacher to support their developing understanding.	This is the main part of the demonstrator. Students using the HYPATIA tool (hypatia.iasa.gr) look at a number of real events that were detected by the ATLAS experiment at CERN. They have to determine based on the information they have been given in the previous phases and the information	The teachers should closely monitor and guide the students to the use of the tool, the understanding of track characteristics and the combination of tracks. The tool is complex and about a teacher for every group of 6-8	Collaborate with arts teachers to draw the results of high energy particle collisions. The students could also create a short video where they could combine in



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		that is presented by the event display application whether a specific track represents an electron or a muon which originated from a Z or Higgs boson decay. Furthermore they should combine two or four electrons/muons to reconstruct the mass of the Z boson and finally discover the Higgs particle!	students is needed.	an artistic way events shown by HYPATIA's Step 1.
Phase 4: EXPLAIN: students formulate an explanation based on evidence	Students use evidence they have generated and analysed to consider <i>possibilities</i> for explanations that are original to them. They use argumentation and <i>dialogue</i> to decide on the relative merits of the explanations they formulate, <i>playing</i> with ideas.	The student should summarize their results here. They should discuss within their teams which of their results are acceptable and which should be removed. They should look at the differences (if any) between the electron and muon results they have	The teacher should help students interpret the histograms, discuss errors and deviations. It is important for the students to understand the difference between	Visualize in artistic way data collection and display of results



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		gathered and attempt to explain them.	an experimental error and a wrong measurement. They should explain that evaluating and assessing experimental errors is a vital part of experimental physics and that students should not expect perfect results when conducting real experiments.	
<p>Phase 5: CONNECT: students connect explanations to scientific knowledge</p>	<p>Students connect their explanations with scientific knowledge, using <i>different ways of thinking and knowing</i> ('knowing that', 'knowing how', and 'knowing this') to relate their ideas to both disciplinary knowledge and to <i>interdisciplinary</i> knowledge to understand the origin of their ideas and reflect on the strength of their evidence and explanations in relation to the original question.</p>	<p>The students should compare their results with already known measurements in literature (if they exist). Deviations from the known values should be discussed.</p>	<p>Teachers should help students search in the literature and critically compare results (eg. if taken under the same conditions etc). It is</p>	<p>Continue visualization using digital modes as well (photos, films)</p>



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			important for the teacher to emphasize that in many cases (such as the Higgs discovery) when the theories can't provide the exact properties of the particles it is through this detailed and accurate experimental process that those properties are determined.	
Phase 6: COMMUNICATE : students communicate and justify explanation	Communication of <i>possibilities</i> , ideas and justifications through <i>dialogue</i> with other students, with science educators, and with professional scientists offer students the chance to test their new thinking and experience and be <i>immersed</i> in a key part of the scientific process.	Students compare their results with other students and discuss the results and the differences they may contain. They can also make short presentations of their	The teachers should make sure that enough time for discussion and	Continue visualization using digital modes as well (photos, films)



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	<p>Such communication is crucial to an <i>ethical</i> approach to working scientifically.</p>	<p>results while they explain any deviation from the expected measurements (electron/muon asymmetries, mass or width deviations etc).</p>	<p>communication is given to each group of participating students. They should also emphasize that comparing and discussing results of different groups is the actual process that leads to discoveries. Results that can't be independently verified and methodologies that are not precisely determined are not accepted in the scientific world.</p>	
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<p>Phase 7: REFLECT: students reflect on the inquiry process and their learning</p>	<p><i>Individual, collaborative and community-based</i> reflective <i>activity for change</i> both consolidates learning and enables students and teachers to balance educational tensions such as that between open-ended inquiry learning and the curriculum and assessment requirements of education.</p>	<p>Time to look back at what they have learned. Students can compare their views of particle physics and subatomic particles before and after the exercise.</p>	<p>This should be guided by the teachers. They can emphasize the importance of understanding the processes that govern the world around us and how this has transformed our lives.</p>	<p>The teachers together with the students select few examples in order to make a small exposition for their parents and the public in the form of a science fair</p>
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6 Additional Information

- <http://hypatia.iasa.gr/>
- <http://hypatia.phys.uoa.gr/>



7 Assessment

There are assessment questions embedded in the ISE HYPATIA demonstrator. The students' answers can be collected and provide information about the length of the student's understanding and length of involvement in each phase.

8 Possible Extension

There are several scenarios which can be used as extensions for the demonstrator

A) Calculating masses of parent particles decaying to 2 or 4 daughter ones. HYPATIA has the capability of calculating the invariant mass of particles decaying to one or two pairs of particles. This can be used to extend the exercise beyond the discovery of the Z and Higgs bosons.

B) Measuring the magnetic field of the ATLAS detector. The magnetic field of the central solenoid of the ATLAS detector bends particle tracks as they move through it. The curvature of the tracks can be used through HYPATIA to measure the intensity of the magnetic field.

C) Optimizing the criteria for background suppression in batch even analysis. HYPATIA can perform batch analysis on thousands of events. In this mode two collections of events are selected (signal and background) and a set of parameters determining which events are selected is optimized by the user through the use of a series of graphs for each of them. The goal of the exercise is to select the optimal set of parameters that will remove as much of the background as possible while leaving the signal relatively intact.

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