HST2019

Focus Groups

FINAL REPORTS

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Particle Accelerators

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Key ideas

- Main goal is to accelerate particles or particle-systems as they pass through to a high energy, alter their trajectory (to accommodate for bending through the circular collider), and focus the beam to make collisions more frequent
- The principle underlying this mechanism is the Lorentz force which describes the force that results from the application of an electromagnetic field on a charged particle (this force will apply to any charged particle or particle-system such as leptons, hadrons, or ions)
- The LHC accomplishes this acceleration through large electromagnets that guide two particle beams that travel in opposite directions and collide head-on at the various experiments along the path

Best practice example

Although none of our curricula explicitly introduce particle accelerators to students, there are many opportunities to introduce the concepts that govern the operation of particle accelerators throughout our courses. Throughout kinematics it will be important to emphasize an understanding of accelerated motion and circular motion. The laws of conservation of momentum and conservation of energy give us direction in terms of where we may see energy losses throughout the accelerator and the energies that we need to achieve in order to create the particles that we seek (via $E=mc^2$). An understanding of electromagnetism and, specifically, the Lorentz force (ie. The right-hand rule) are crucial to learning about why and how particle accelerators apply forces to control the particle beams.

To gain a better understanding of these concepts, it is possible to build simple particle accelerators for demonstration in your classroom. A simple linear accelerator would include a linear track made of a non-magnetic material (ie. Plastic or aluminum) with magnets, that have steel balls on the far side, spaced throughout. By introducing a small steel ball (our particle for this experiment) the magnetic force will accelerate it towards the first magnet, transferring energy to the furthest ball, accelerating it into the next magnet, and so on. With each transfer of energy the ball leaving the system will be faster than the ball entering the system, effectively demonstrating the concept of a linear particle accelerator. We can expand on this by replacing the permanent magnets with coils of wire to create small electromagnets and a circuit to coordinate the timing of these. After this, it is recommended to show animations of the operation of the LHC for class discussion.

Animation of CERN's accelerator network – https://videos.cern.ch/record/1610170

Particle Physics & Errors and Uncertainty

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Key ideas

Error – Uncertainty: It is important to give a precise definition of the scientific meaning of error and uncertainty to change the diffuse idea that uncertainty is unscientific and that errors can be completely removed from measuring processes.
Systematic Error - Random Error: It is important for our student to understand the difference between systematic and random error to make them able to address them appropriately.
Absolute Error - Relative Error: The distinction between absolute and relative error is crucial to understand the precision of a measurement.
Accuracy – Precision: it is necessary to clear the difference between these two concepts, one of which is depending on the proximity to the expected true value and the other is completely independent from it and is connected only to the coherence among the data collected.
Models - Experimental data: it is very important for the students to be aware of the distinction from information coming from experimental measurements and the one coming from simulation based on theoretical assumptions. It is also crucial to give our student the instruments to make a decision regarding whether a model is consistent with observations.

Best practice example

Students' imprecise conceptions of the terms used in this topic should be addressed early through simple, formative assessments and a strong vocabulary developed. Examples to illustrate differences for accuracy and precision are suitable for this purpose. However, regular application in other contexts must occur for students to further test and refine their understanding.
Students can model the evidence collected by Millikan to determine the quantum of charge. By measuring the weight of many envelopes, each containing a different number of small sweets of the same mass. The mass of these sweets is intended to be analogous to the charge of an electron and, by repeating the measurement a sufficient number of times, the quantum of mass can be extracted from any noise in the data. This activity can be useful in presenting the concept of quantization as well as statistical methods.

Particle Detectors

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Key ideas

The concept of particle detectors can be quite technical. It is important to keep in mind the level of understanding that students have before deciding how in-depth to discuss the details of particle detectors. We have decided that the most accessible aspects of this topic for students to learn are: the interaction of moving charged particles within an external magnetic field, the relationship between the mass/charge of a particle and its radius of curvature within a magnetic field, how to determine the mass of a particle from the energy of the particles it transforms into, and which parts of the detector are used for making specific measurements.

Best practice example

Start with an engagement activity. Have students fill out a Google Form with identifying information as homework the evening before. When they arrive, play a game in which they guess which "particle" went through the detector based on the identifying information. Tie this to how detectors work. (tracker, calorimeters, etc). Cloud chamber activity to introduce particles (beyond the electron and proton) and their identification. Data-driven activity with ATLAS or CMS- either particle identification or mass calculation (choose your own adventure based on your students' mathematical ability).
Assess student understanding by having students draw a card with a random particle (charge & mass given) and identify how it would be detected in CMS.

Extras!
1) **Curriculum & classroom connections**:This content is featured differently in our various curricula. Some of our curricula feature the concept of particle detectors directly, while others do not. However, the key concepts behind how particle detectors are featured in all our curricula. To identify particle charge, students will need to understand how charged particles behave while moving through an external magnetic field. Students will also need to understand conservation of energy and momentum.

3) **Students' conceptions & challenges**: At this point in the curriculum, we can safely assume that students know the relative size and charge of electrons, neutrons, and protons. They are likely unfamiliar with the concept of positrons, muons, and other particles not featured in the bohr atomic model. If we want students to identify particles, they will first

need to know some basic information about them (mass, charge). Students may also have some difficulty applying the right/left hand rule to identify charges in a variety of situations. In order to determine mass from events, students will need to remember how to use conservation of momentum, 2-D vector addition. Students will need assistance using the $E = p^2 + m^2$. This is likely an equation they have not seen. This will also yield a mass in eV. Students will need help emotionally coming to terms with measuring mass in energy units.

4) **Helpful material and resources**:
https://www.instructables.com/id/Cloud-Chamber-a-Project-to-Detect-Muons/ (in english) website with directions and explanations for cloud chambers in the classroom
https://crayfis.io/about app for using your cell phone as cosmic ray detector
https://quarknet.org/data-portfolio/activity/calculate-top-quark-mass activity for using conservation of momentum to determine the mass of a top quark
https://quarknet.org/data-portfolio/activity/calculate-z-mass very similar to the above activity… except students calculate the Z mass
https://quarknet.org/sites/default/files/cmsde_stdnt_13dec2017.pdf In this activity, students identify events that represent the production of different particles.
https://tap.iop.org/atoms/accelerators/519/page_47183.html Particle detectors activity with detailed instructions
https://www.youtube.com/user/CERNTV CERN videos

Medical Applications of Particle Physics

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Key ideas

Medical applications of particle physics is a great way to introduce the concept to our classes. This is due to many different reasons. First and foremost is that it allows you to discuss how many different basic physics concepts from acceleration to fields to the standard model are applied to our life in a practice method. Three key ideas to examine in medical applications would be to look at the old technology, now technology, and new technology. The old technology is the use of x-rays starting at the beginning of the 20th century. Then now technology takes x-rays to the next level with the CT-Scan that allows us to take a three dimensional picture with slice scans stacked together. We are also using PET scans that uses positrons to help discover diseases. And new technology would be hadron treatment that will allow doctors to pinpoint treat tumors without corresponding damage to the surrounding tissues.

Best practice example

We propose using a “black box” experiment to demonstrate how a CT Scan works. You can do this very simply by placing an object, such as a rectangle, underneath a platform and then place a piece of paper up against the side. You then shine a light from the opposite side and observe the created shadow, observe both size and intensity. Then repeat this from the side, 90° turn. Have students describe the shape and location and density of the object from the shadows. You can then replace the object with one that is slightly translucent to demonstrate different densities. Next add a oval or circular shape and observe the differences, a gradation of light due to the curves. Then have the students observe what both shapes look like when the side paper is moved to 45°. Finally you can then challenge the students to reverse the process and have the students predict what what the shadow would look like from all three angles for a triangle. Then for the final challenge introduce an object that will require additional “scans” from additional angles and dimensions in order to build a better model. This then helps explain how a CT Scan takes scans from multiple layers and then uses a computer to stack them to produce a three dimensional scan of the body.

Computing in Particle Physics

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information, matter manipulation, data storage, analysis, distribution

Universe is computable. Information is physical. Humans are very precise matter manipulators (machines construction). Brains are data processors.

Data is essential in our life. As Plato said, "Numbers are the highest level of knowledge". In Cern each second 1 PB of data is acquired. They store 1 event in a million. After filtering it, the data has to be stored. The storage method used in Cern is only tape drive. Cern can not handle any more such a big amount of data, so they opened a second site in Budapest, which operates at 200 gigabites per second, and is connected to the Geneva CC with 3x100Gb/s links (21 and 24 ms RTT).

In the future another storage place could be located, but maybe new storage technologies would be available.

Students have various conceptions about 'computing' that we need to overcome:

A. Computing is not relevant to students' lives:
B. Devices that students' use everyday are computing devices, e.g. mobile phones, digital cameras, computers, laptops, wii devices, calculators, printers, and so on.
C. Computing is only done by 'computers':
D. Link to the film 'Hidden Figures' - computing was originally done by people.
E. Lack of knowledge about how computing works:
F. We can demonstrate how computers work with simple classroom demonstrations. By collecting data as a class, we are acting in a similar way to computers.
G. The 'cloud' is not a physical entity and students generally lack knowledge about the sheer volume of data and speeds of processing at places at the LHC
H. Lessons on the LHC and the work being done at CERN!

Best practice example

Summarise your findings through a brief outline of an instructional strategy. Explain how to best introduce the topic in your classroom.

Data collection and analysis is done in most classrooms. When computation is involved at CERN, many events are examined, and a common histogram is made.

The class will collect data from a hands-on experiment that simulates the Rutherford gold foil experiment (technically the Geiger–Marsden experiments). The experiment will be performed by many groups, many times. Aggregated data will be analyzed. This simulates distribution of computation among many computers.

Theoretical Physics and Higgs

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Classroom Connections and Key ideas

Key Idea:Theory has a role in the nature, process and goals of science. Two ways that it can be introduced into the classroom is through

I. The History of Physics (which was in many curricula)
II. Model building and Testing (which was in all curricula). For example, model building can be explored in Atomic Theory, Gravity and Light.

Key Idea: Theory involves outside of the box and cricital thinking with a mathematical foundation.

Key Idea: Theories are meant to be tested and nature is the judge. Sometimes these judgements have to wait for the techonology to catch up. For example, Higgs was discovered over 50 years after it was proposed.

Key Idea: Theoretical Physics also relies on collaboration.

Introducing Theoretical Physics in the Process of Science and Higgs

1: In groups have students start with a blackbox activity such as the one from the Perimeter Institute for Theoretical Physics (Process of Science Resource: Activity 4, Making Models).

2: What is a Theory? In groups, have students make a mind map.

3: Theory has a mathematical connection. Have students build a mathematical theory for speed based on a constant velocity cart. Predictions based on that mathematical model. What are the parameters at which this theory breaks down?

4. Introduction to the Standard Model

5: What is Higgs? Students use images and videos (resources)

6: From Theory to testing the Theory: Higgs photon card activity: Achieving the bump.

Outline of Activity: In PresentationVideo

Data Analysis in Particle Physics

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Key ideas

To help students with their understanding of the key concepts within *Data Analysis in Particle Physics* a concept map should be constructed. Students should first identify key concepts, such as particle physics and data analysis etc and then start to develop a hierarchy for these concepts and how they are linked. An exemplar concept map is found below:

Best practice example

The instructional strategy is based on the *Hands-on Particle Physics Masterclasses Program*. At the beginning of the topic a flipped classroom is utilized. Students watch: https://atlas.cern/updates/atlas-news/picturing-particles and http://cms.web.cern.ch/news/how-cms-searching-higgs-boson that contains the basic information about how physicist analyze the tracks created when particles collide to search for new particles. The main idea is to brief the students with the topic that will be discussed at the lesson.

The lesson starts with the introduction, where basic information about the data analysis of the specific experiment is given. There are many resources for the ATLAS, CMS and ALICE experiment available. Student should know which experiment the data set has come from that the goal of the lesson is to analyse the data to determine if there is anything interesting within the data set, and what this interesting things is.

Students need to learn how to work with the software. After that students are divided into the pairs or groups of 3 (depending on the number of the student in the class and the number of computers available). Each group is given a subset of data to be analyzed. At the end of the lesson the results of each group is collated and the overall result for the data set is presented in the form of the graph of *Invariant mass vs Number of events*.

To discuss and interpret the graph students undertake a *Think – Pair – Share* in which they first individually consider the graph, students then share with their group their interpretation of the data. Lastly, groups share with the whole class their interpretation and finding of the graph to come to a common understanding of the data.

Antimatter Research

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Key ideas

Antimatter is not a typical topic found in most physics classrooms. However, this is a subject that fascinates and engages students and is worth tying in with the curriculum you already have. Students will often come to the classroom with many alternative conceptions regarding antimatter. Firstly, antimatter is not an accurate description for what we can actually produce and have remain stable. Antiparticles are a more accurate description. Linguistic accuracy is a very important aspect when discussing science.

Other key ideas that should be covered include symmetry, discussion of sources of antiparticles, current uses of antiparticles, and future engineering and physics challenges with using antiparticles. Most students will find it interesting that after the Big Bang, we think our universe was 50% particles and 50% antiparticles. For the most motivated and curious students, the idea that all matter should have been annihilated might arise. These students should be encouraged to explore this symmetry issue outside of class with the teacher.

Natural source of antiparticles are beta decay and cosmic rays, but can also be created via head on collisions. We use these head-on collisions to create positrons that are already being used for medical imaging. PET scans have an antiparticle in their name: Positron Emission Tomography. The extent of discussion on medical applications can be left to the teachers after gauging interest from students. However, it may be of interest to students that antiparticles could be used as a cancer treatment in the very near future. The production of antiparticles is part of cutting edge physics. To produce antiparticles, such as antihydrogen, elementary particles are collided head on. This was first done in a lab in 2002. Following production, the next challenge is to trap them. This was first done in 2010. The most recent challenge is the next step: cool them so that we can better control their behavior. These steps could allow for antiparticles to be controlled for targeted cancer treatment.

Best practice example

One easy way to introduce antiparticles into your classroom is by going to the source of many of students misconceptions. Show a clip of antimatter usage from the *Angels and Demons* movie or a "Star Trek" episode. Following this, have students work in small groups to answer the following questions:

- How was antimatter presented in the video?
- What do you believe was correct? What do you believe was incorrect?

Have students share their ideas. Alternatively, if you have already introduced antiparticles or students have already been exposed to the ideas, the questions can be changed slightly:

-What is correct with their interpretation?
-What is incorrect with their interpretation?

An extension of this would be for students to create a story in which the characters use antiparticles correctly. The format of this story could be left for students to choose and include: written word, comic strip, short video, music video, a presentation, or a movie storyboard

To extend this to an interdisciplinary project, we recommend working with your ICT teacher. The abstraction of antiparticles opens a channel for developing visual models addressing student misconceptions. Suggestions include a teacher to teacher collaboration or ICT students developing a tool to have other students learn from. Ideas for these projects include: modify a Drag&Drop game with any block-based programming tools such as Kodu, Scratch, Minecraft Education Edition etc., develop an educational software, design an animation, draw a graph, or prepare a video. Students could use a variety of topics to guide their ICT project: hierarchy of matter, explanation of antiparticles, antiparticles in the LHC, principle of antiprotons,and antiparticles in daily use

Engineering & Future Accelerators

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Curriculum & classroom connections

The structure and function of the LHC can be tied into the physics curriculum. Specifically, various elements relate to energy and electromagnetic radiation. As for future accelerators, there are connections to the big questions that our students can ask: What is the universe really made of? How did the universe begin? Future accelerators will operate in our students' lifetimes and help to answer these questions. Our main goal should be to encourage them to pursue STEM degrees in order to target these careers.

Key ideas

Concerning engineering, the key features are superconducting magnets and the cooling mechanisms. An important part is the development of new materials and detectors alongside the computing systems. The key ideas surrounding future colliders are the high energies that they will reach and the deep science questions that they will attempt to answer.

Potential students' conceptions & challenges

In most cases, the main problems we are facing are a lack of time, materials, or resources. Sometimes students also do not have the right interest or motivation in physics, and this can be related to a lack of mathematical skills. Another crucial problem could be the difficulty students have relating abstract concepts with the physical world (i.e., reality).

Helpful material and resources

The main source from which we found this material is here. Information about the lab can be found here. A pre-quiz can be found here. A rubric can be found here. A presentation of the material can be found here.

Best practice example

For the implementation of the curriculum in the classroom, we have agreed that a lab activity is the best and most effective strategy. We have a proposal: BUILD A FRICTION ROLLER COASTER! It is important to make sure that teachers know about the relationship between the physics and engineering principles. For example, students are given a list of materials, but they could change them to make an improvement on the model. Different materials would have different coefficients of friction and could affect the final result. They should be able to minimize the errors in the assembly and optimize the final product.

Before starting we want to inform you that we do not own any of this material. This material was modified from the resources cited above.

How do we do it?

1.Attract the attention of students with a video, a photograph, etc.
2.Check on their previous knowledge with a pre-quiz, open-answered questions, etc.
3.Show them the project (presentation).
4.Make sure that every student knows what we want from them (rubric).
5.Start the project:
- *a.Make calculations.*
- *b.Build and test a prototype.*
- *c.Take and analyse data.*
- *d.Make modifications to improve the prototype.*

1.Make connections between the project and the engineering and physics curriculum.