ITW2018

Study groups

FINAL REPORTS

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SG1 | Medical applications of particle physics

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Curriculum & classroom connections

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17-18 years old	Atom, Nucleus, Proton,X-Ray, Gamma rays, Beta rays. Medical applications of X-rays, Gamma rays and Beta rays.	X-Ray and Its medical applications, Radioactivity and its uses as tracer, diagnostic tool, killing cancerous cells, Harmful effects of radiations, Dose and its Units, PET scan, CAT Scanner, Laser and its medical applications, Photoelectric Effect, Compton Effect.	-Medical applications (X-Ray, PET,CT)	- Mutations and cancer. DNA. Medical applications, Investigation. -Electromagnetic interaction -Quantic physics -Nuclear physics -Antimatter (positron)
Professional training (from 18 to 20 years old)			They learn in depth about the technical aspects of Medical Physics	They learn in depth about the technical aspects of Medical Physics

Key ideas

- Proton, neutron, electron, positron, shell, atomic model, X- Ray, αparticle, βparticle, γ particle, shielding, PET, CT, proton therapy, linear accelerator, cancer, DNA, alzheimer, epilepsy, Parkinson

Potential student conceptions & challenges

Potential student conceptions

- Physics and Medicine are not related.
- Radiation is bad for the health since pupils have heard about Chernobil and Fukushima catastrophes and the nuclear bombs thrown in WW2. Radiation causes deformities.
- As radiation is not visible it is not a concern. In fact, they consider X-ray imaging not harmful; it’s like taking a picture.
- The name of X-Ray was given because its origin was unknown.
- The shape of the X-Ray is like an X, that’s why they expect to see an X.
- X-ray helps us visualise bones (broken or bended)

Challenges

- Antimatter
- Diffraction
- Interdisciplinary teaching of the topic
- How electrons can be isolated from an atom

Helpful material and resources

- For a small group: The Alphabet Game
- For any group: Party(cal)
- On the following link you will find resources related to medical protection, radioactive atom, radiation exposure, vocabulary materials and notes about PET, X-ray imagining and gamma cameras:
    - https://www3.epa.gov/radtown/educational-materials.html
    - http://www.iop.org/education/teacher/resources/teaching-medical-physics/page_54690.html

Best practice example

In order to build up knowledge related to medical physics we propose the following scheme of work throughout the curriculum:

1) Atomic model (electron, shell, proton, neutron)
2) Interdisciplinary teaching (Biology): DNA, mutations and cancer, alzheimer, epilepsy
3) αparticle, βparticle, γparticle, shielding
4) X-Ray, PET, CT, proton therapy, brachytherapy, linear accelerators

SG2 | Particle accelerators

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Curriculum & classroom connections

The topic of particle accelerators is covered differently in the curricula we teach:
*In the Italian curriculum, this is a topic that studied in grade 13th (the last grade of high school). The concept can be introduced at a lower level through the study of kinematics (linear motion) and circular motion.
*In the International Baccalaureate (IB) curriculum the cyclotron is studied and introduced through one of its applications – producing fluorine 19 to be used in PET scans (medical applications).
*In the British curriculum, particle accelerators are covered after the topic on electric fields and most exam boards require students to be able to recall how a cyclotron can accelerate a charged particle.

Obviously, topics such as electricity and magnetism, circular motion, the Standard Model, etc. are directly related to the subject matter and are listed in the key ideas. Further connections to other parts of the curriculum could be made when teaching other topics:

*The focusing of the beam could be related to optical lenses helping the students to visualise the focusing of the beam as light is also focused.
*The structure of the LHC tube could be used to explore methods of loss of heat by radiation & conduction.
*The cooling process could be used to introduce the quantum effects that lead to superconductivity, to phase changes that are not common in daily life and the expansion/contraction of materials under extreme conditions.
*The collisions of particles could be used to explore conservation of momentum & energy.
*The energy of particles inside the accelerator can be used to explore relativistic dynamics.

Key ideas

We organised our key ideas in the same order as the working of the LHC.

INJECTION
*Source of ions
*Ionisation process
*The need for cooling and vacuum
*Particles and antiparticles

ACCELERATION
*Acceleration of charged particles – linear vs. circular.
*The accelerator as a machine that raises energy.
*The concept of the electron volt as a unit of energy.
*Differences between cyclotron, synchrocyclotron and synchrotron (electric field and magnetic field).
*RF resonant cavities
*Order of magnitude of the quantities involved.

FOCUSING
*Deflection of charged particles in a magnetic field.
*Understanding and application of the right-hand rule for the Lorentz force.

COLLISIONS
*Meaning of bunches, luminosity, intensity, energy.

Potential student conceptions & challenges

We have identified a few concepts that in our experience most students will struggle to understand and/or some skills they will not consistently apply. Students will have trouble:
*Recognizing electron volt as a unit of energy
*Recognizing eV/c^2 as a unit of mass
*Fully understanding relativistic dynamics
*Fully understanding that in accelerators and colliders new particles are created and they were not present before the collisions. Colliders do not just smash particles.
*Fully understanding the geometry of the LHC and the relationship with the detecting process
*Explaining the need for a linear accelerator and rings before the LHC
*Making connections with statistics and probability

Helpful material and resources

We have organised materials and resources in four main sections and given a brief description of all of them.

-Books & Articles
https://www.amazon.com/Particle-Odyssey-Journey-Heart-Matter/dp/0198504861/ref=sr_1_59?ie=UTF8&qid=1520930382&sr=8-59&keywords=particle+physics – This book, The Particle Odyssey – A Journey to the heart of matter – tells us of the history of Particle Physics from 1895 until the 21st century talking about the evolution of particle accelerators, detectors and much more. It does answers many of the "how" questions we may still have.
https://www.symmetrymagazine.org/article/april-2014/ten-things-you-might-not-know-about-particle-accelerators - This article published by Symmetry, a joint Fermilab/SLAC publication, is very basic but interesting.
H.Wiedemann, Particle Accelerators Physics, Springer, 2007 (graduate level). An in-depth and comprehensive introduction to the field of high-energy particle acceleration and beam dynamics.
A.Wu Chao et al., Handbook of Accelerator Physics and Engineering 2nd Edition, World Scientific, 2013, Edited by internationally recognised authorities in the field, this expanded and updated new edition of the bestselling Handbook, containing more than 100 new articles, is aimed at the design and operation of modern particle accelerators.
Giuseppe Dattoli, Andrea Doria, Elio Sabia and Marcello Artioli, Charged Beam Dynamics, Particle Accelerators and Free Electron Lasers, IOP Publishing Ltd 2017**.** This book summarises different topics in the field of accelerators and of Free Electron Laser (FEL) devices. It explains how to design both an FEL device and the accelerator providing the driving beam. Covering both theoretical and experimental aspects.
R.Hamm, M.Hammo, Industrial Accelerators and Their Applications, World Scientific, 2012. This unique new book is a comprehensive review of the many current industrial applications of particle accelerators, written by experts in each of these fields. Readers will gain a broad understanding of the principles of these applications, the extent to which they are employed, and the accelerator technology utilised. The book also serves as a thorough introduction to these fields for non-experts and laymen. http://iopscience.iop.org/article/10.1088/0031-9120/51/3/035001 This article provides an overview of the CERN's Large Hadron Collider (LHC) and its operation, highlighting existing education resources, and linking principal components of the LHC to topics in physics curricula, in order to facilitate the introduction of high energy physics in the classroom.

-Interactive apps, animations and simulations
https://www.compadre.org/osp/items/detail.cfm?ID=10527 - This simulation illustrates the operation of a cyclotron, showing a charged particle moving through combined magnetic and electric fields. The particle, started near the centre of the cyclotron, accelerates when passing through the gap between the electric electrodes and is turned by a perpendicular magnetic field. The geometry of the cyclotron, the magnitude of the electric and magnetic fields, and the properties of the charge are all adjustable. This page includes links to information on the operation of cyclotrons.
http://www.particleadventure.org/ - interactive tour from the Particle Data Group of Lawrence Berkeley National Laboratory.
http://www.particleadventure.org/accelerators-and-detectors.html - interactive resources on accelerators.

http://www.lppp.lancs.ac.uk/ - This site gives access to a number of simulations and explanations of particle physics, including a section on the LHC. The content is suitable for AS/A2 16+ students.
http://collider.physics.ox.ac.uk/ Smartphone application – The Higgs Boson in your hand! Collider lets you view high energy particle collisions directly from the Large Hadron Collider, making it simple to understand what's going on at a glance.
https://play.google.com/store/apps/details?id=com.lhsee&hl=en_US Smartphone application - LHSee is an App that allows you to see collisions from the Large Hadron Collider.
http://www.acceleratar.uk/ Smart phone application that uses printed cubes and the camera on your smartphone to help visualize the effects of the quadrupoles, dipoles and rf cavities using virtual reality.

-Other online resources (websites, videos, lab experiments, etc.)
http://lhcathome.web.cern.ch/projects/sixtrack/all-about-accelerators - This video shows the Large Hadron Collider (LHC), a particle accelerator based at CERN, the world's largest particle physics laboratory. The LHC is designed to be the most powerful instrument ever built to investigate the properties of fundamental particles.
http://www.cpepphysics.org/Class_act.html - Packet of classroom activities with worksheets. This packet describes the concepts of the chart, the history of these ideas, and the design and use of particle accelerators and detectors. It brings particle physics to the classroom with meaningful activities.
http://www.particleadventure.org/other/othersites.html - Particle Physics Education and Information webliography.
http://project-physicsteaching.web.cern.ch/project-physicsteaching/english/experiments.htm -focus and defocus, lenses, vacuum within a Cathode ray tube -CERN Teachers Lab 2007.
Defrancesco S, et alii , GEOMAG™; paradoxes *The Phys. Teach.* **45** 542–5 lab on Quadrupole https://videos.cern.ch/search?page=1&size=21&keyword=accelerator Video clips of the LHC project and historical material on the CERN website.
https://stfc.ukri.org/files/educational-publications/big-questions-big-experiments-the-large-hadron-collider/
A full-colour A5 leaflet that opens out into an A2 double-sided wallchart describing the Large Hadron Collider (LHC) at CERN.
https://stfc.ukri.org/files/educational-publications/what-is-next-for-the-lhc/ A full-colour leaflet describing what is next for the Large Hadron Collider (LHC) at CERN.

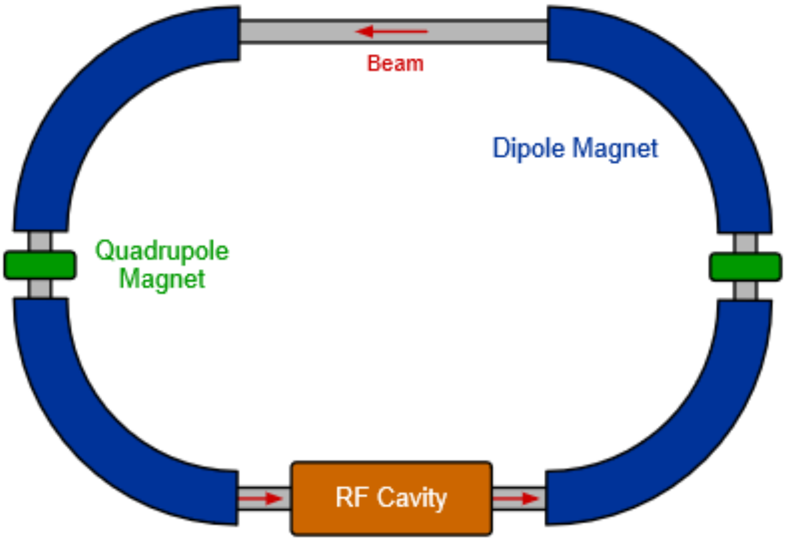
-Simple practical equipment
Dees The cyclotron is explicitly dealt with in many of our exam specifications. The students often struggle with visualisation of how the dees are made up and in particular the fact they are not "solid". A cheap, visual solution to this is shown in the picture below. A biscuit tin can be cut in half. Each half represents one of the dees with centre being hollow in a similar manner to the make up of the dees in an actual cyclotron.
http://ippog.web.cern.ch/resources/2014/salad-bowlaccelerator - salad bowl accelerator lab.

Best practice examples

For most teachers, time management is an issue, especially at the end of high school where students are very concerned about their results and how they might affect their university entrance. The curriculum is many times long and adding extra topics might be a challenge. Our suggestion on how to incorporate the LHC in our classroom will only take one teaching period of about 90 minutes and will be seen by the students as an excellent opportunity to revise almost the whole curriculum.

Since most concepts relating to the functioning of the LHC are present in most physics curricula, the idea is to start building a conceptual map from the beginning of the school year(s). This conceptual map could be, for example, colour coded by the teacher, and kept in a wall to be continuously built.

At the end of the school year it then be time to match all concepts to a general synchrotron like the one in the picture, or to the LHC in particular.



http://operations.fnal.gov/rookie books/concepts.pdf

Looking at our key concepts the ionisation section would be in grey as the can be related to the beam, some of the concepts of the acceleration part would be in orange and some others in blue and the focusing section concepts would be either in blue or green accordingly. In our picture there are no detectors, but these could easily be included and would incorporate the key concepts related to collisions. (We realise that the curvature of the dipoles in the picture is exaggerated, but it could be either corrected or used to productively engage students in discussion).

SG3 | Particle Detectors in the High School Classroom

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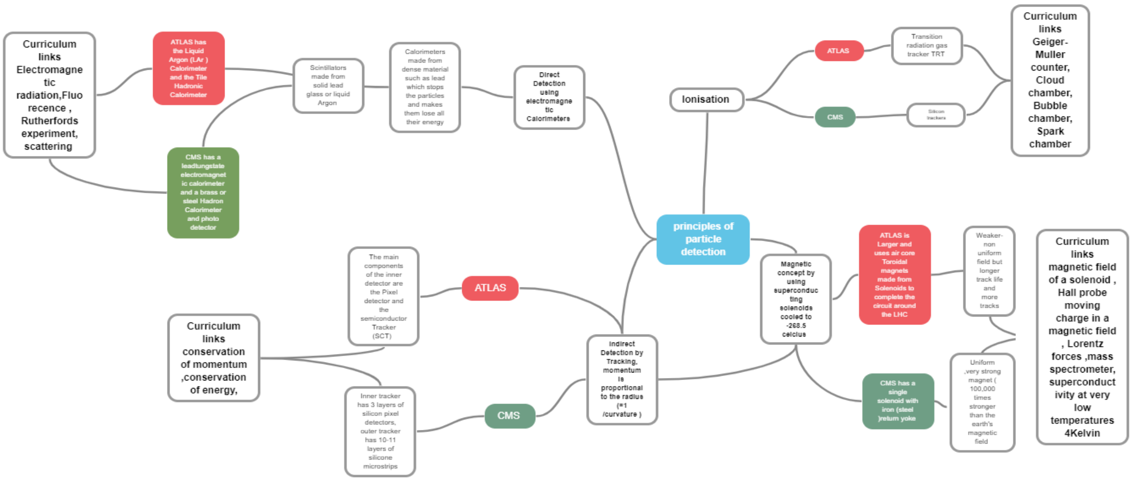
Curriculum & classroom connections

In Level 3 / Scholarship level / Q2 in the Physics Curriculum (university entry) questions may be asked within a variety of appropriate contexts, some of which may be unfamiliar to the candidates. Some questions may involve extended discussion, where the candidate needs to judge what is required. Questions relating to practical work may include discussions of sources of error, reliability of data collected, and validity of conclusions drawn.
In relation to understanding of Modern Physics – the following content knowledge will be required: the Bohr model of the hydrogen atom: the photon; the quantisation of energy; discrete atomic energy levels; electron transition between energy levels; ionisation; atomic line spectra; the electron volt; the photoelectric effect; wave/particle duality; qualitative description of the effects of the strong interaction and Coulomb repulsion; binding energy and mass deficit; conservation of mass-energy for nuclear reactions, $E=mc^2$; conservation of momentum and energy; centripetal- and Lorentz forces.
At lower levels, the atomic and nuclear physics curriculum for years 9-12 (14-18 years old) includes :

1. The development by Thomson and Rutherford of the model for the atom.
2. Nuclear reactions (fission, fusion and radioactive decay/transformations) and their use in today's world.
3. The properties (ionising ability, penetrative ability) of the products of nuclear reactions and the impact they have on today's world.
4. Mass-energy relationship $E=mc^2$

For the students who study particle physics at high school level, they should know about *particle systems* which are made up of *elementary particles*. They should also know the different ways that these elementary particles interact based on their charge which is explained by the *standard model*.
In the context of relativity students calculate the lifetime and time-of-flight and explain, why traces of cosmic muons can be observed in a cloud chamber.
In nuclear physics students learn about detecting with Geiger-Müller-Counter, semiconductor detectors, dosimetry and imaging procedures.

https://www.goconqr.com/p/552258-nuclear-physics-mind_maps



Key ideas

Since matter is concentrated energy $E=mc^2$ then matter can be transformed into energy and back. Since Protons are accelerated in the accelerator which is the energy, then kinetic energy is transformed into matter during the collision and new particles are being produced.
A particle detector measures the outgoing particles and their energy. A perfect detector should reconstruct any interaction of any type with 100% efficiency and unlimited resolution.
High energy colliding detectors consist of

- Tracking detectors (or trackers). This can be a main or central Tracking detector which measures the momentum and the charge of the particles from their curvature in the magnetic field and a Vertex detector both (primary and secondary) which use Silicon pixels .
- Calorimeters which completely stop the particles and measure their energy. This can be an electromagnetic calorimeter for light particles (e^-, e^+, gamma).
  This measures energy of light EM particles (electrons, positrons, photons) based on electromagnetic showers by bremsstrahlung and pair production.
  Two concepts: homogeneous (e.g. CMS) or sampling (e.g. ATLAS)
- Hadron calorimeters (heavy hadronic particles: π, K, p, n) measures energy of heavy (hadronic) particles (pions, kaons, protons, neutrons) based on nuclear showers created by nuclear interactions.
- Muon detector to measure momentum of muons which is the outermost detector layer and is basically a tracking detector.

Detector challenges at LHC include :

- High energy collisions which require sufficiently high momentum resolution up to TeV scale.
- High luminosity (high interaction rate) which require high rate capabilities, fast detectors (25 ns bunch crossing rate).
- High particle density which cause high granularity. So sufficiently small detector cells to resolve particles.
- High radiation (lots of strongly interacting particles) which is radiation mainly due to particles emerging from collisions, not machine background. This requires radiation-hard detectors and electronics (have to survive ~10 years).
- LARGE collaborations!!! ~O(3000) physicists for ATLAS and CMS each which requires good communication.

Basic concepts to understand at high school level are *ionisation*, *movement of charged particles in electric fields* and the *correlation between no of radioactive nuclei and ionisation-rate (measured as current)* in Geiger-Müller counters. The principles of the *cloud chamber* should also be used to explain *ionisation* as well as the different *properties* of cosmic particles which leave their traces in the cloud. Observing different particle traces can be useful in explaining the lifetime of muons at speeds close to the speed of light.
The *bubble chamber* tracks on old photographs can also help in the understanding of the basic concepts of detectors and elementary particles.

Potential student conceptions & challenges

- Students' ideas about the atom and how to interpret Rutherford's model of the atom is always a challenge. They relate Rutherford's model to the Solar System and assume that the electrons are fixed in an orbit. The 3D model is difficult to conceptualize for them.
- They link the idea of a particle as something being observable (e.g. modelled as a small ball) with no relation to charge or being *part of a system*.

- One of the challenges is understanding that human senses act as detectors and what they sense is a result of an interaction.
- Understanding that background radiation is always present. They often link background radiation with the presence of a radioactive source.
- Students conception of mass and charge measurements can be a challenge until they study the effect of magnetic fields on charged particles.
- The students' conception of the reasons behind the four forces/interactions (gravity, electric, magnetic, nuclear forces/interactions). Weak interactions are also a strong challenge because their understanding of forces is always based on a force either being attractive or repulsive.

Helpful material and resources

- **Applets "Geiger Counter" and PhET simulations:**
    - http://www.kcvs.ca/site/projects/physics_files/radioactive/geiger_counter.swf
    - http://www.gigaphysics.com/gmtube_lab.html
    - https://phet.colorado.edu/en/simulations/category/physics/light-and-radiation
    - https://getrevising.co.uk/diagrams/nuclear_physics_2
- **Animations**
  identifying particles by using ATLAS
  https://kjende.web.cern.ch/kjende/en/wpath_teilchenid1.htm
  Latest ATLAS events
  http://atlas-live.cern.ch/
- **Manuals**
  Cloud Chamber (DIY manual)
  http://ippog.org/resources/2016/cloud-chamber-diy-manual
  Any Cooler and you will freeze
  http://ippog.org/resources/2014/any-cooler-and-youll-freeze
- **Student Worksheets**
  Bubble Chamber
    - http://scool.web.cern.ch/sites/scool.web.cern.ch/files/documents/20180811_JW_Student_worksheet_solutions_Bubble_%20chamber_pictures.pdf
    - https://www.geogebra.org/m/VAK3P8ar (German only by now; interactive worksheet)
- **CERN live data for international masterclass**
    - https://kjende.web.cern.ch/kjende/en/wpath.htm (work on W-transformation)
    - https://kjende.web.cern.ch/kjende/en/zpath.htm (work on Z-transformation, includes invariant mass)
- **Videos**
  https://m.youtube.com.watch?v=xky3f1aSkB8
  Discovery of the Standard Model
  https://home.cern/about/physics/standard-model
- **Powerpoint presentations**
  The ATLAS Detector
  https://indico.cern.ch/event/425968/contributions/1913125/attachments/905691/1278148/marc.weber.milano.atlastracker3.pdf
  The CMS Detector
  https://drive.google.com/drive/folders/1Wf-cgXYdmKQmFKLRrd9kbTQ27wiFr61T
  Detectors
  https://indico.cern.ch/event/472440/contributions/1991973/attachments/1252481/1847384/Detectors.pdf
  Characteristics of the ATLAS and CMS detectors
  https://indico.cern.ch/event/140065/contributions/1366408/attachments/121662/172669/ATLAS-CMS_design_Seiden.pdf
- **Games**
  Elementary particles cards to explain their properties (Spanish, English, German)
  http://www.teilchenwelt.de/fileadmin/user_upload/Redaktion/Netzwerk_Teilchenwelt/Downloads/Teilchensteckbriefe_engl.pdf
- **Posters**
  Multilingual poster about elementary particles
  http://ippog.org/resources/2015/multilingual-poster-about-elementary-constituents-matter
- **Publications**
  http://gwiener.web.cern.ch/
  The SKALTA Scintillation detector for detecting Cosmic Rays (project designed for schools)
  http://ippog.org/sites/ippog.web.cern.ch/files/import/ippog2011_mbombara.pdf
  Quarknet for teachers and students
  https://quarknet.org/

- **Songs**
  The ATLAS Boogie song
  https://www.youtube.com/watch?v=WShZVxPZETw
- **Mindmaps and Mindmaps maker**
  https://getrevising.co.uk/resources?q=&sl=a2%2Cphysics&filter_kind=mindmap&go=

Best practice example and new ideas

Our best teaching practices that introduce the basic ideas of detectors which are linked to the various curriculums include:

- *Radioactive Decay-Game:*
  By throwing a batch of tokens (min 100 per group) which are *marked on one side as being active radioactive particles* (or alt. M&Ms). Then removing the tokens which have the coloured side down and re-throwing the remaining ones until we reach nearly zero colored tokens remaining. This is followed by plotting the radioactive decay graph between no. of radioactive particles (coloured tokens) and no. of throws (which corresponds to time). Counting here is the method of *detection using senses*. This also shows the random and spontaneous nature of Radioactive decay.
- Using *Geiger-Müller-Counter* as a method of detecting the three types of nuclear radiation if available at schools.
  The experiments would include: *Detection of Background radiation* (Cosmic rays) and r*adiation from radioactive sources*. This can be used to show the range of radiation in different materials and to test the properties of different types of radiation, also the inverse square law $\frac{1}{r^2}$.
  For schools that don't have a detector *PhET-simulations* can be used.

Our new ideas include:

- Activity: Playing the *ionisation game* for junior students (slide 10 and 11 on powerpoint).
  Pairs of students in the room, one is positive and one is negative, representing neutral atoms. Mark a line using tape in the middle of the room. This represents the positive wire / end of a potential difference. Mark the walls as being the negative end. One single student (radioactive particle) enters the room through the doors. One rule: only negative people may be touched. Once touched, they have to lose contact with their partner. Students then have to think how to move.
  Reinforcement: repetition with Geiger-Müller-applet.
- Using the app *GammaPix* for android which detects gamma radiation using the camera. It can also be used for cosmic ray detection.
- Building a *cloud chamber* (see the manual on cloud chamber). Activity: Students sketch the observed traces, compare them. Perhaps in collaboration with art lessons: draw and color a nice picture.
- *Card game* from "Netzwerk Teilchenwelt" (games):
  The students get to know the basic properties of elementary particles. They have to compare the properties and categorise them in terms of their charge, mass and how they are affected by electric and magnetic fields.
- The principles of the *bubble chamber* can be introduced. Students learn about typical traces, how to determine the charge by right- or left-hand curves (student worksheet).
- To extend students, they can work on real ATLAS/CMS data in class to locate the Higgs boson (International masterclass).

SG4 | Computing in particle physics

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Abstract:

We summarize what computing at CERN consists of and we propose some activities to use in the classroom for different subjects for ages between 14 and 18. We also include some useful resources for the teachers for the classroom and personal understanding of CERN computing..

Introduction:

Computing at CERN is a concept that involves different tasks related with the data, such as storage, processing, event generation, simulation and data reconstruction. It also includes: resource accounting, distributed computing, the concept of Middleware, workload and data management. Another task that is also vital is to monitor the conditions and detectors.

To perform all these task, scientifics use different programming tools and specific software developed at CERN such as Athene-Atlas, CMSSW-CMS and others developed in collaboration, for example Geant4 [1], pythya [2] and sherpa [3].

To understand how data is produced, processed and stored let's start with an example using the CMS experiment. Most process starts with the data acquisition. In the CMS detector there are 100 million channels and 40 million pictures a second that are taken of synchronised signals from all detector parts. Part of those signals corresponds to actual interesting events, while others correspond to background. To distinguish between the signals in this experiment, there is a three level trigger system that filters the data [4]:

• L1: process 40 million events per second - simple information is triggered in a few microseconds and passed on it above certain set thresholds.
• L2: process 100 thousand events per second - it consists of fast algorithms in a local computer farm and takes 1 second to process data.
• Event Filter (EV): It reduces the rate to a few 100 per second recorded for study and reconstructs the events to pass on.

This triggering process is necessary because there is around a Petabyte of data produced per second at L1 level. Only data produced after EV level is stored. Similar processes occur in the other LHC experiments. Experiments at CERN sent 70 Petabytes of data during 2017 year and 40 Petabytes cames from the four LHC experiments.

CERN needs a data center to process the amount of data produced by the several experiments. The hardware is generally based on commodity (market available hardware). Currently it consist of:

~15,000 servers providing 230,000 processor cores
~90,000 disk drives providing 280PB disk space
~30,000 tapes drives, providing 0.4EB capacity (1EB=1024PB)

CERN is the largest scientific repository in the world. The Worldwide LHC Computing Grid (WLCG) was developed at CERN [5]. This is a global collaboration of more than 170 data centres around the world in 42 countries . The CERN data centre distributes the LHC data worldwide to the other WLCG sites. WLCG provides global computing resources to store, distribute and analyse the LHC data. The reason for the resources to be distributed refers to funding and sociological reasons.

The WLCG is used for a community of 10,000 physicists. On average around 250,000 jobs are running concurrently. It has 600,000 processing cores where 15% of the WLCG computing resources are at CERN's data centre. It has 500 petabytes storage available worldwide with 20-40-80-100 Gbit/s optical-fiber dedicated links to connect CERN to each of the 13 institutes.

Since the need for storage and computing power continues to grow, CERN is looking at storage technologies as they evolve such as HDD, SSD, and tapes. CERN-IT is also extremely interested in improving CPU speed and multicore/vector exploitation as well as optimizing energy consumption as well as improvements in software performance and data preservation.

CERN-IT impacts society through the computing grid, it has built it and supports it, but also supports open access to science by people of different programs such as LHC@home and CERN Open Data Portal [6]. They also run a program called CERN openlab [7] that is a public-private partnership that accelerates the development of new solutions for the worldwide LHC community and others scientific communities research.

Fundamental science is vital to society as it pushes boundaries of the cutting-edge technology. For example, the invention of the Web in 1990 contributed to the INTERNET infrastructure as well as capacitive touch screens that has been developed in 1972 for the Super Proton Synchrotron control system because it required complex controls.

Curriculum & classroom connections

In general we want to propose some activities and arguments in order to help other teachers around the world to use them in their classrooms with the goal to present the field of computing at CERN. Since our team has three types of teachers: chemistry, physics, and technology/computing, we want to highlight the ways to connect computing at CERN to these different curriculum areas.

Chemistry/Physics:
Importance of research and how current experiments carried out by collaborations require large of data storage and processing. For example, DNA modelling, astrophysics, model future types of reactions. Information sharing and connectivity is required to tackle these complex projects.

Computing & Technology:
Do to the structure of data collected at CERN it requires a Data Centre to store it, and sends it around the world for analysis [8]**.** In our technology classes we teach networking, programming, data structures, networks digital circuits, etc, we can directly connect the knowledge of the distribution of data and grid to the curricula in this subject.

Key ideas

Computer networks
Processing power
Data storage
Reality is described through models
Computing comprises multiple disciplines
Compare a small simulation with a large simulation at CERN

Potential student conceptions & challenges

Background information students needs to know to understand computing at CERN are units of measurement (metric system) for both transmision velocity of data and time scales for rates of data collection. Also to know how to use scientific notation as math background.

Possible misconceptions students have in this area could be:

- Students believe that computer science is an independent field of study and that it focuses purely on programming activities [9].
- Students do not relate computing with experiments that take place in chemistry and physics.
- Students are users of technology but are not aware of the principles that makes it work.
- Students do not have exposure to units of measurement regarding velocity, bandwidth, and capability.
- Students do not understand the difference between byte and bit therefore MB and Mb.
- Students do not understand the difference between cable connection, fibre optics and WiFi connection rates and bandwidth.

Helpful material and resources:

Computing at CERN presentation - Xavier Espinal - CERN.
https://indico.cern.ch/event/658853/contributions/2995845/attachments/1700030/2737557/ITW-CERN-Computing-2018.pdf

LHC Data Collecting and Storing: Visual of how LHC data is collected, preprocess, distribute and store.
https://www.youtube.com/watch?v=jDC3-QSiLB

Virtual Atom Smasher: An interactive educational game from CERN.
http://test4theory.cern.ch/about/

Cern Computing Center: Information page with links to videos and live information.
http://information-technology.web.cern.ch/about/computer-centre

CERN IT Overview website. Real time information from CERN´s grid.
http://monit-grafana-open.cern.ch/d/000000884/it-overview?orgId=16

CERN, LHC and Particle adventure.
http://ippog.web.cern.ch/sites/ippog.web.cern.ch/files/import/talk_at_bladins_school.pdf

The ISOLDE Radioactive Ion Beam facility|ISOLDE.
http://test-isolde-yields.web.cern.ch/test-isolde-yields/query_tgt.html

LHC@Home.
https://lhcathome.cern.ch/lhcathome/

Best practice examples
Activity #1 (Physics/Chemistry):

Students start with an empty coffee cup and an empty styrofoam cup. Add the same amount of boiling water to each cup. Start taking temperature measurements every 10 seconds for 5 minutes. Collect data in a data table. Place in Excel or Google Sheets to record data. Using the graphing tool determine which insulates the boiled water best. (The type of experiment is not the focus of this task but instead using the data to understand the scalability of data as you collect more.) Since it is over 5 minutes, there are 30 data points for the coffee cup, 30 data points for the styrofoam. Using those 60 pieces of data from each student, we then collect the entire class and look at the data size. Each piece of data will take up 4 bytes (Each student are creates 240 bytes for each complete set of data).

Discussion point for groups: What if we did it this for the next 100 days? What happens when we do this for next 100 days? What impact will it have? If we did these 100 experiments for 25 students each day how much data will we have at the end?

Next up: At the ATLAS experiment in Meyrin, Switzerland, they collect 1Gb/sec. (They actually collect 1 Petabyte / second but most is lost because it does not trigger an event to be stored) If you you took all the students as our school (approximately 600 at Herr Schwarzer aus BRG Reutte) and had them collect this information ONCE daily, how long would it take to have the same amount of data as the ATLAS detector collects in one day?
ATLAS: 1Gb/sec in one day is: 86400 Gb.
Students: 600 students x 240 bytes = 144000 bytes / day
= 140.6kb / day = 0.137 Mb / day = .000134Gb / day
Therefore taking: 7462 days (20.5 years) to create the data generated at ATLAS in 1 sec

Activity #2 (All Subjects):

The idea of this activity is to compare the data stored in book with the data produces in the LHC. Students could google all necessary information without of their own as well as the teacher could help them.
There are roughly 130,000,000 books in existence today [10]
Each book takes roughly 400,000 characters each.[11]
Each character takes 1 byte of storage.
Using this information, calculate the data needed to store all books for all of human history. (Solution is roughly: 47 terabytes of data)
LHC Data per day - 68Tb (from 25Pb/year therefore 25Pb/365 / day = 68Tb)
LHC Produces same amount of data as all of books every written in one day

Article for students to read and explore: [12]

Activity #3 (Chemistry):

The topics of particle physics and the Standard Model are not presented in many high school curricula in different countries. We desire to teach basic concepts of the Standard Model of particle physics. Indeed, the learning unit is strongly focused on conveying the idea that the use of models is essential in science, particularly in particle physics.

The purpose of the activity is that students 1) to learn core fundamental physics concepts, 2) see how to compare a small simulation to a large simulation at CERN to reach results and 3) to show them how much you can do with a small device and the need of a network to combine computer power and capacity.

Step 1: Students use the tool in Minecraft Element Constructor [12-2] to study the atomic structure in a creative way.
Students use the Element Constructor and create elements by moving the sliders to choose the desired number of protons, electrons and neutrons or type the numbers into the fields at the top. By using the Element Constructor students can create 118 elements and over 400 isotopes.
Students drop an element from inventory into output box of element constructor to see the number of protons, electrons and neutrons. Use the Constructor to study atomic structure of the elements.
In table each group will record number of each subatomic particles in each atom;
Conclude with the definition of the atomic mass and atomic number for each .

Step 2: Students investigate Standard Model of particle physics by CERN, LHC and Particle Adventure. It starts with an accurate description of the subatomic structure of the matter showing an atomic model with electron and quarks.
Then students create model of atomic structure by Blender as shown in **Fig. 1** or by some other program.

Step 3: Lectures about particle physics, detectors, accelerations and computing at CERN. Skype -a-scientist.

Step 4: Knowing the computing power to model an atom, discuss the computing bandwidth required to model one second of collisions and the number of particles involved and about computing.

How much is 1 gigabyte? What does 1GB get you? For example, with a data allowance of 1GB you could browse 3.000 webpages or you could send 10.000 e - mail. 10 gigabytes of data may be transferred from Grid servers every second. The Data Centre processes about one petabyte of data every day [8]. How many webpages browse and how e - mail you could send?

Used ISOLDE Yield Database shown in **Fig. 2**, find produced isotopes 5 elements independent on the target. Find production details: target density, ion source on Target and Separators page. This also greatly reinforces the abilities of students of chemistry to think through the immense quantity of data.

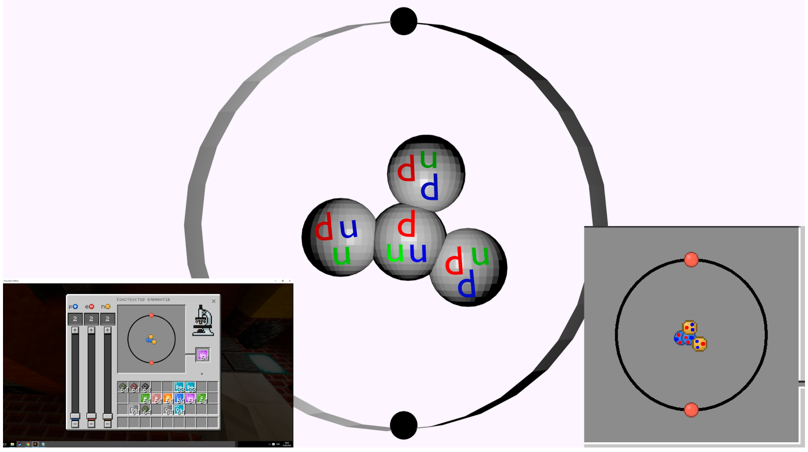

Fig1. Minecraft Element Constructor and models atom substructure by Blender

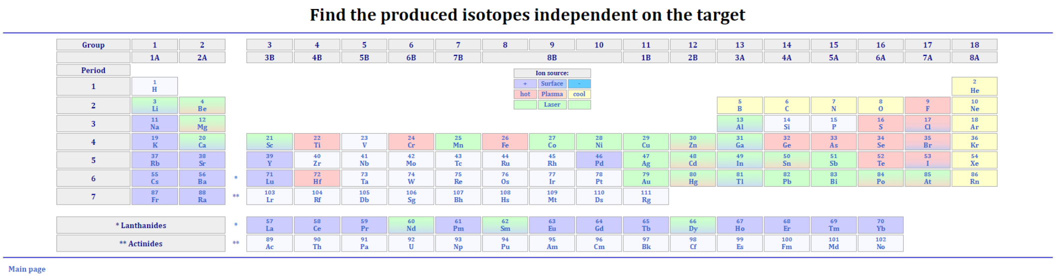

Fig2. ISOLDE Yeild Database.

Activity #4 (Computer Technology/Programming):

Teachers can to start with "Computing at CERN" [13] or teacher can use the above Introduction as reference.

Read carefully and answer the following questions using the above resources.

Network speed transfer:
1) Investigate the transmission velocity of the following devices that you have at home. Please use scientific notation to express all of them in bytes and present the results in a table:

a) LAN Internet connection at home/school.
b) Wifi connection at home.
c) 4G cell phone.
d) Bluetooth device that you have at home (BT speaker, phone, etc.)

2) Compare those values with the Grid peak data transference. [14]

3) The CERN and Wigner Data Centres (Budapest) are connected via three independent and dedicated 100Gb/s lines. How long will take for the information to reach Budapest from CERN data center which are 1,800 km apart? [15].

4) Some simulations at CERN need a lot of processing power and a fast network to deal with the data. For example, engineers need to know how some materials will behave under certain conditions:

- Inside the detectors, where the particles collide, there is high radiation and heat in some moments.
- Inside the LHC´s pipes, there will be high pressure levels because of the vacuum that needs to be higher that in deep space.

The data is processed by the High Performance Computer. This computer is built up using several servers that have to communicate with each other using a superfast network. They use InfiniBand technology for those connections up to 140 GBps.

Compare your LAN Internet connection with the one used in LHP at CERN. [16]

Storage capacity:
5) Investigate the storage capacity of the following devices:

a) The hard disk of your computer/laptop.
b) Internal memory of your cell phone.
c) USB thumb/pendrive.

6) Compare those values with the amount of data stored per day at CERN Data Center.

7) How much is a Petabyte?

8) Why do you think that CERN needs to store such amount of data?

9) Why does CERN have to use Grid Technology in order to archive storage capacity?

10) Try to elaborate a scale with colors to accommodate the values obtained in exercise 1.

Processing power:
The grid at CERN is made of 11,000 servers only in Mayrin, which have to handle all the information coming from the different experiments running at CERN and take all the data to the storage system. These servers have on average 2 processors each. They are no special processors, but just like the one that is inside your computer at home.
Let´s say the most normal processor used in the grid is an Intel i5. But the actual key about the processing needed at CERN is about the cores. Inside a processor you can find different number of cores, each one running one process at the same time.

11) Search the web for the i5-8400 processor and find out how many cores it has. Calculate the number of cores that are in the GRID at Mayrin and compare it with:

a) the cores in your desktop [17]

b) the cores inside an iPhoneX [18]

Conclusions:

In this work and, in particular in the activities above, we explored computing at CERN. We try to explain why a data management center is necessary to manage the data produced in the different experiments and what is the Grid. We proposed four activities based on the different teachers backgrounds, mainly for three teaching subjects and prepared a repository with resources for classroom. We are looking forward to apply these activities in our classes in order to share what we have learned in CERN.

References:

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[3] Sherpa Modelling Software: http://cxc.harvard.edu/sherpa/
[4] The CMS trigger system. CMS Collaboration. https://cds.cern.ch/record/2212926?ln=es
[5] Worldwide LHC Computing Grid: http://wlcg.web.cern.ch/
[6]CERN Open Data program. http://opendata.cern.ch/
[7]CERN Open Lab Program: http://information-technology.web.cern.ch/about/organisation/cern-openlab
[8] CERN Data Centre Website https://home.cern/about/computing
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[10] Google Counts Total Number of Books (Telegraph) https://www.telegraph.co.uk/technology/google/7930273/Google-counts-total-number-of-books-in-the-world.html
[11] Average Book Length (Huffington Post) https://www.huffingtonpost.com/2012/03/09/book-length_n_1334636.html
[12] Science News for Students: Explainer: Understanding the Size of Data https://www.sciencenewsforstudents.org/article/explainer-understanding-size-data

[12-2] Minecraft Education https://education.minecraft.net/chemistry/
[13] https://home.cern/about/computing
[14] https://home.cern/about/computing
[15] http://information-technology.web.cern.ch/about/computer-centre
[16] https://www.infinibandta.org
[17]https://www.intel.com/content/dam/support/us/en/documents/processors/core/intel-core-i5-comparison-chart.pdf
[18] https://www.apple.com/iphone-x/

SG5 | Data Analysis in Particle Physics

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Curriculum & classroom connections

Data analysis in general is an important aspect of experimental physics, and it appears in the physics curriculum of most school systems throughout the world. The students are typically expected to learn how to analyse experimental data by means graphs, evaluate the data in relation to a suitable model, and minimize the sources of errors. Particle physics, on the other hand, is in itself not included in every high school curriculum, and the combination of particle physics and data analysis in a curriculum seems extremely rare.

In our group, the following curricula were represented: Germany (North Rhine-Westphalia), Hong Kong, Israel, Sweden and Turkey. Although all these curricula include data analysis, none of them mention data analysis in relation to particle physics. However, we are aware of some teachers in Israel, Turkey, Germany and Sweden who introduce their upper secondary school students to the analysis of data from CERN as an in-depth activity, often in the format of the International masterclass programmes where visual analysis of particle tracks is performed.

The extent to which particle physics is included in the represented curricula varies: In the German curriculum, it is specified in detail which concepts are to be taught, including the discussion of relativistic effects of particle acceleration in a synchrotron for example. In contrast, the Swedish and Turkish curricula only stipulate a general overview of the standard model and special relativity, including the historical aspects of particle physics. The Hong Kong curriculum requires the study of special relativity, but when it comes to particle physics, only a brief overview of the strong force and the quarks is expected. The Israeli curriculum does not require any particle physics apart from nuclear decay.

The Turkish curriculum for mathematics has been revised and does no longer include statistical analysis. Hence, the students do not have the necessary mathematical background to perform any advanced analysis.

Key ideas [1]

Particle physics experiments are far **less predictable** than the experiments which most students are used to, in that the outcome of a single particle collision will be one single outcome from a large set of possible outcomes. Generally, the outcome of the experiments that the students have previously come across will be predictable, if the experiment is performed correctly. Since there is a large set of possible outcomes of a particle collision, and one often wants to study outcomes with a low probability, a very **large number of collisions is required** in order to perform a meaningful data analysis.

Oftentimes, an experiment searches for a particular particle transformation. A particle transformation is here referred to as an event. The number of collisions required in order to produce a sufficient number of the interesting event is so vast, that **it is not possible to store** all the data generated by the detector. Therefore, the majority of the detected events are discarded already at the beginning. This is true for noise as well as for events which relate to data that is likely to only carry information about already known events. The number of stored events is only approximately 10^{-4} % of the events observed during the collision.

The stored data is then analysed by computer programs in order to **identify which particles have crossed the detector**, as well as their invariant mass. Typically, a **histogram** is then used to illustrate the number of detected events of the studied type as a function of the invariant mass. Hence, such graph “simply” represents **a count of the number of detected events** for different invariant masses.

The background signal is often high compared to the signal from the studied event. Therefore, **simulations of the background** have to be performed, so that it can be understood which part of the detected signal actually originates from the studied event. **Simulations of the studied event**, based on theory, are also performed, in order to compare the measurement data with theory.

In order to increase the reliability of the data, the **results from different experiments, ATLAS and CMS, are compared**. For example, at the LHC, two different experiment designs are used, that both study the same event with different technology. The Higgs boson was detected at the two different experiments at the same time, Since the two experiments independently showed a convincing result, it could be concluded that the Higgs boson had been detected.

Potential student conceptions & challenges

When students enter the classroom, they often hold prior knowledge or conceptions about the natural world. These conceptions will affect how they understand what is taught at school. Some of pre-existing understandings provide a good base, while other, however, are incompatible with the accepted scientific conception. These pre-existing understandings are commonly referred to a misconceptions [2] or “alternative conceptions” [3].

There are a lot of misconceptions in physics particle that have been reported in the scientific literature. Wiener et al. [4] developed a module to avoid overlapping between quark anti-color charge and complementary color from optics. Students conceptions of matter are dominated by a continuum perspective, and the confrontation with a particle model frequently leads to a mixing and overlapping of continuum and discontinuum conceptions, whereby students try to integrate the novel particle model into the framework of the existing continuum model [5]. Gourlay [6] used concept mapping to explore what students in London secondary schools understand regarding particle physics. Some students appeared to have a misconception that everything is made of quarks. Students found it harder to classify tau particles than they did electrons and muons.

Regarding the level of particle physics knowledge in Spanish high schools, Tuzon and Solbes [7] reported that the level is mid-low. However, the variability of answers is high. Ideas from new models appear, meaning that students somehow know updated concepts. Nevertheless, these ideas are very tentative and show confusions with both new and classical models.

Regarding data analysis in general: “Students often ponder that to make a graph they need to connect the data points and that the best-fit function which they will produce will be linear. Students often wonder about the dependent and the independent variable when plotting graphs.

Data analysis in particle physics differs from the data analysis that high school students normally encounter in at least four different ways. The first difference is the visual data, i.e particles’ tracks after collision, see Fig. 1. The student need to be able to recognize and differentiate charge and mass of the particles according to the track curvature.

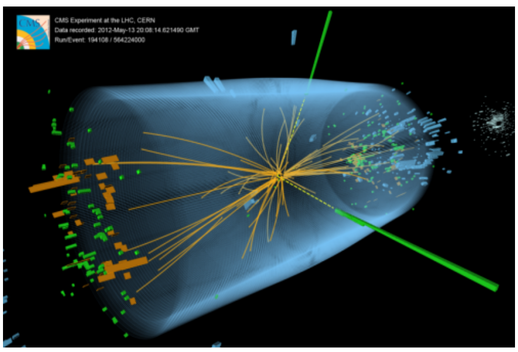

Fig. 1 : A graphic showing particle traces extending from proton-proton collision.

The second difference is the histogram graphs. Students are most likely not very experienced with histograms from previous school experiments. In the data analysis, students will have to plot the number of events against invariant mass and try to connect the peaks in the graph to the new particle. It may be challenging for young minds to relate the peak to a particle, as they have not seen the particle. Cooper and Shore [8] discovered that students may be able to answer basic questions about histograms without fully understanding how the distribution of the data links the frequencies with values on the horizontal axis. The third difference is the huge amount of data that should be managed, compared to the typical school experiment. When we conduct an experiment in high school, 5-10 measurements are often enough for plotting the graph and deducing the relevant information. The fourth difference is the level of the theoretical knowledge required when dealing with particle physics, which is higher than in other high school physics topics.

An awareness of the above differences, difficulties and misconceptions would be helpful in order to close the gap between data analysis in the typical physics school experiments and data analysis in particle physics

Helpful material and resources

EXAMPLE 1: e-Labs	
General introduction to e-Labs	https://quarknet.org/content/about-e-labs
The Cosmic Ray e-Lab	http://www.i2u2.org/elab/cosmic/home/project.jsp
CMS e-Lab	http://www.i2u2.org/elab/cms/home/project.jsp
Gravitational wave e-Lab	http://www.i2u2.org/elab/ligo/home/project.jsp
EXAMPLE 2: International Masterclasses	
Homepage of International Masterclasses	http://physicsmasterclasses.org/index.php?cat=teachers_educators
Instruction for Teachers on Masterclasses using ATLAS data in order to determine the quark content of the proton	http://www.teilchenwelt.de/fileadmin/user_upload/Redaktion/Netzwerk_Teilchenwelt/Material_Vermittler/guide-ATLAS-W-path-2018.pdf
Introduction to the MINERVA data visualization software for the ATLAS detector	http://atlas.physicsmasterclasses.org/en/wpath_teilchenid2.htm
Interactive exercises in particle identification using MINERVA	http://atlas.physicsmasterclasses.org/en/wpath_exercise1.htm#
Flash animation of particle tracks and energy deposits in the ATLAS detector (German website, animation only uses particle names) Can be used as a short stand-alone class activity	http://atlas.physicsmasterclasses.org/de/wpath_teilchenid1.htm
EXAMPLE 3: Jupyter Notebooks	
General Introduction to data analysis and particle physics: developed by Cornell Un. and Siena College. Learning data analysis by using interactive notebook--data provided from the experiments CMS, CLEO, BaBAR. It provides Jupyter notebooks and free to adapt it into your courses.	http://particle-physics-playground.github.io

Interactive Radioactivity Notebook: An interactive Jupyter notebook developed by our group to teach data analysis by using radioactive data on the net. Students get real data measurement from remote experiment and later use this notebook to further explore different projects such as • Is the decay rate constant? • What is the half-live for decay chain?	ITW2018_DataAnalysisGroup.ipynb
Remote Labs: Remotely conduct real (as opposed to virtual) experiments. Those remote labs are very useful for teachers who have time constraint to carry out experiments and for students who have not enough hands-on experience on experimental science. Currently there are some free sites for teachers to use it. We are currently developing a Jupyter notebook for teachers how to use real time radioactivity experiment from remote experiments and then students explore further experiments. ISES (e-Laboratory) Project: We are using this site real online experiment to develop Jupyter Notebook, which will teach data analysis to teachers and students Library of Labs: This site consists of several online remote libraries constituted by different universities and companies. One of them is very suitable performing experiments on modern physics.	. http://www.ises.info/index.php/en/laboratory/experiment/radioactivity/experiment http://www.lila-project.org/content/index.html
HST-2018 Open Data Project: A project prepared by teachers who attended CERN “High School Teacher Program” in June 2018. It provides a basic introduction to Python and provides activities for students in particle physics by Jupyter notebook.	https://github.com/cms-opendata-education/HST-2018
Cern’s database for open data, which can be analysed e.g. by Jupyter notebooks.	http://opendata.cern.ch/

Best practice example

EXAMPLE 1: e-Labs

E-labs is an online platform developed by Fermilab, that the students could use for data analysis. Students reach beyond classroom walls to explore data with other students and experts and share results, publishing original work to a world-wide audience. Students can discover and extend the research of other students. Three types of e-Labs are available:

1a. The Cosmic Ray e-Lab
The Cosmic Ray e-Lab provides an online environment in which students can investigate high-energy cosmic rays. It allows schools that do not have cosmic ray detectors to participate in research by analyzing shared data. Schools with cosmic ray detectors can upload data to be included in the shared data. Students learn what cosmic rays are, where they come from and how they hit the Earth.

1b. CMS e-Lab:
Students can join a scientific collaboration in this series of studies of high-energy collisions from the Large Hadron Collider (LHC) at CERN. Students write a researchable question and analyze data in much the same way as professional scientists. Tools from the e-Lab facilitate collaboration among students as they develop their investigations and report their results.

1c. LIGO e-Lab
The LIGO e-Lab provides an online environment in which students can investigate seismic behavior. Seismic energy from earthquakes, wind, ocean waves and human activity will become visible as students plot data from seismometers at LIGO Hanford Observatory. Students will learn about LIGO's quest to detect gravitational waves as they analyze the vibrations of the ground underneath LIGO's ultra-sensitive interferometers.

In order to access the e-Labs, teachers need to register by sending an e-mail to e-labs@fnal.gov (see the e-Lab webpage for more information).

EXAMPLE 2: International Masterclass
Teachers who can invest a full day in data analysis can take part in an "International Masterclass" at a university in their home country.

A Masterclass includes one or two lectures on particle physics followed by a data analysis session, where students are tutored by PhD students. Finally there is an international video conference to discuss the results. There are Masterclasses on all four LHC experiments.

One of our group members, Anna, took part in a German masterclass which used ATLAS data and did not include the video conference. To profit from the data analysis, students need to know the standard model and understand the transformation of particles. The ATLAS detector is usually covered in the introductory lecture given at the university.

The data analysis is done using the visual analysis software MINERVA, which allows students to identify particles from the tracks and jets in the detector layers.

There are examples and exercises available online (see the section on Helpful links). The simulation of the particle tracks and jets can also be used as a classroom stand-alone activity.

When students have figured out how to identify particles with the MINERVA display, they use a decision tree that takes through the analysis of the event. Each pair of students analyzes fifty events deciding whether they are background events or different branches of the W-path of proton transformation. The statistical analysis of the combined data of all groups gives the composition of the proton of two up quarks and one down quark.

EXAMPLE 3: Jupyter Notebooks
Our schools are overcrowded and many teachers are not keeping up a pace with classroom environment. In today's classrooms, we teachers are more happy if students are occupied by more textbooks and multiple-choice exams. We teachers know that this kind of teaching is not benefit to the students.

We are proposing a way of change to teach how we teach modern physics in the context of particle physics. The students like to see the experiment alive and try to interact with the equipment. But many schools have not enough resources (by means of human or equipment) to carry out modern physics experiments. Even some experiments are possible, withdrawing a meaningful result from this experiment requires students to have some capabilities that many students couldn't have, such as visualizing, doing data analysis and expressing their ideas to their peers.

We propose to use the Jupyter notebook for data analysis. Jupyter notebook is an easy-to-use interactive notebook which allows teachers and students to provide instructions, import data and visualise data by means of programming, for example in Python. Jupyter notebook can for example be used for analysing public data from the CERN detectors, that can be found at http://opendata.cern.ch/. Instructions for using Jupyter notebooks in relation to particle physics have been provided by the High School Teacher programme at CERN in the summer of 2018 [9].

With the e-labs, the International Masterclasses and the remote laboratories with Jupyter notebooks we have presented different approaches for bringing data analysis in particle physics into the classrooms. As the outlined approaches need different amounts of time in classroom, as well as different levels of prior knowledge in detector technology and coding, teachers can choose the appropriate approach for their respective students.

References

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SG6 | Antimatter research

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Curriculum & classroom connections

Even though particle physics has found its way more and more into national curricula, the topic of antimatter is not necessarily included. Below we give a few examples from the countries of the authors of this paper.

Mexico: Particle physics and antimatter are not mentioned in the curriculum.
Turkey and Romania: Antimatter is mentioned in the curriculum, but it requires only theoretical aspects to be taught. There are, however, contests in Romania, where selected students can take part, like the Physics Olympiad, in which students can do extended work on antimatter.
Italy: There is a facultative curriculum for the last year of science high school, which mentions particle physics, cosmology and nuclear energy. Antimatter can be discussed within these topics.
Bavaria: In Germany, the government of each of the 16 countries in the federation sets up their own curricula. "Leptons, quarks and their antiparticles" are mentioned in the curriculum for the final year of high school.

Key ideas

There are different approaches to introduce antimatter research, each emphasizing a different aspect. Each of these approaches should lead to teaching current research results and aims. Depending on the level of students' knowledge, the introduction of antimatter research could start from
- quarks by introducing the concept of antiquarks
- the Standard Model
- science fiction
- students doing their own reading-up on antimatter
- medical applications
- a mathematical approach, i.e. the Dirac equation
- matter-antimatter pairs, as they appear in detectors
- a cosmological view
- experiments at CERN (ALPHA, AMS, ASACUSA, ELENA, AEGIS, GBAR)

Potential student conceptions & challenges

Students' ideas will often reflect what the general public knows or believes to know about antimatter. These are influenced by media reports about research and hypotheses, which often do not distinguish between facts and speculations, but will be taken up by the entertainment industry, which contributes to the spreading of these ideas. These include seeing antimatter as something that
- exists only in theory
- is exotic and somewhat "out of this world"
- is "negative", i.e. "matter is normal, but antimatter is different"

- is a very powerful explosive
- is different from matter only in only electrical charge
- has vanished completely immediately after the Big Bang
- something not worth doing research in, being of no practical use
- something we already know everything about

The following aspects might be challenging for students to understand and challenging for the teacher to teach:

- The Dirac equation
- Colour and flavour charge
- The apparent matter-antimatter symmetry
- The question of antimatter and gravity i.e. the hypothetical concept of antigravity
- How antimatter can be produced and contained for research

Helpful material and resources

Any material on antimatter research to be found on the CERN websites and the websites of the antimatter experiments, CERN being so far the only place where antimatter can be produced and investigated. Selected literature, for example

- Maftei, G. & Popescu, F.F. (2012). Teaching atomic physics in secondary school with the jigsaw technique.Romanian Reports in Physics, 64(4), 1109-1118.
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- www.cernland.net

Best practice example

We cannot tell whether there is such a thing as a best practice example for teaching antimatter research, because what is best depends on the students' previous knowledge and should, if possible, start from a recently taught related topic, like for example the $E=mc^2$ equation, quarks or electrical charge. Ideally, all previous students' concepts should be elicited and addressed, otherwise they might interfere with a realistic understanding of antimatter. Students should then be offered alternative concepts, based on theoretical physics as well as on observations.

Jigsaw strategy: Jigsaw strategy is an interactive physics teaching method. In this method the teacher's role is to facilitate learning. There are two different kinds of groups: Expert groups and jigsaw groups. We thought that there were 25 students in the class. First we divided the topic antimatter into 5 main segments in terms of questions, and then we determined some subquestions for each main question to be answered by students. We divided the class into five groups, which we named "expert groups". Each group was responsible for answering one of the main questions each of which is listed in the first row of Table 1. After that one student of each expert group was chosen to become a member of one jigsaw group. Each member of the jigsaw groups was expected to present her/his segment to her/his group. At the end of this practice the teacher can prepare a quiz including all the topics s/he wants to be covered in the class and apply it individually for all students to be accountable for the whole material.

Table 1. Expert groups' questions

What is antimatter?	What is the research that has been done about antimatter?	How is antimatter used in our daily life?	What is the Standard Model?	Where is antimatter?
Can you define matter and antimatter?	What are the research studies and experiments conducted about antimatter? Please explain.	Find an example from a book or a film in which antimatter is used?	What are the particles and their antiparticles?	Is it possible to find antimatter on the Earth or in space outside of the Earth? Please explain.

What happens when a matter and its antimatter collide?	How and where do physicists investigate about antimatter? Please explain.	What are the medical applications that use antimatter? Please explain.	What is the mathematical explanation for the presence of antimatter?	The theories about what happened to antimatter?
The story of antimatter from the beginning of the world	The discovery of antimatter	What is the place of antimatter in cosmology?		

SG7 | Engineering in Particle Physics

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Curriculum and classroom connections

Engineering is the application of science and mathematics to solve problems. Engineers work in almost every area that affect human life - including building roads, bridges, schools, hospitals, management of our water, gas and electricity supplies among others.
The study of Engineering in particle physics emphasizes the application of basic scientific principles to the designing and building of particle accelerators and detectors for creation of new technological solutions for use in measurements, communications, and data acquisition. The largest accelerator and detectors to be brought into operation are the Large Hadron Collider (LHC) machine and the four large detectors (ALICE, ATLAS, CMS and LHC), which are distributed around the LHC circumference.
The Engineering Design Process is a series of steps engineers use to guide them in problem solving. Engineers must ask a question, imagine a solution, plan a design, create that model, experiment and test that model, then take time to improve the original. However, there is an experience gap between education and engineering skills that can be achieved by the students in classroom. In education, the most important skills are applying basic science and research. On the other hands, engineering skills are needed in the real life when the students get into employment. That is why the teachers need to find a connection between curriculum education and engineering process skills that students need.
Engineering involves many areas, but this paper presents an overview of some physics concepts needed and the engineering competencies that can be applied at the SHS curricular.

<table>
<tr><th>SYLLABUS</th><th>SYLABUS STATEMENTS</th><th>PARTICLE PHYSICS TECHNOLOGY</th><th>ENGINEERING COMPETENCIES</th></tr>
<tr><td>UK syllabus (A level)</td><td>To explain the role of electric and magnetic fields in particle accelerators (linac and cyclotron) and detectors (general principles of ionisation and deflection only)</td><td>Particle accelerators
Particle detectors</td><td rowspan="4">(covered in all syllabus)

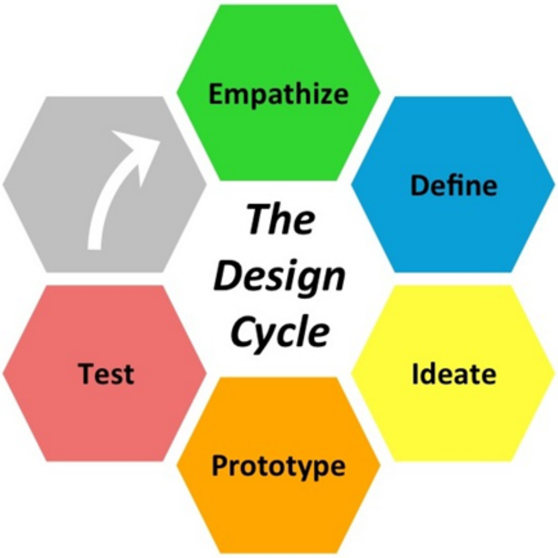
Critical thinking
Creative problem solving
Curiosity
Willingness to try new things
Learning skills
Information searching skills
Leadership
Professional behavior
Communications
Teamwork skills
Project management</td></tr>
<tr><td>Indonesian Syllabus</td><td>Voltage, current and power consumption
To describe the characteristic of atom nuclei, radioactivity and the implementations in technology.</td><td>Electrical power system</td></tr>
<tr><td>France & Ghana Syllabus</td><td>Recognising the relation between the strength of a magnetic field and the intensity of electric current, for a solenoid or a wire</td><td>Magnetic field strength and lines
Make a simple electromagnet
Measure magnetic field strength
Investigate magnetic effect of high currents in straight wires.</td></tr>
<tr><td>US Syllabus</td><td>Not directly covered</td><td></td></tr>
</table>

Key ideas

Electricity and magnetism are core elements of all of the curricula of the members of this group. Electricity in particular is a topic area offering a wealth of opportunities to make reference to particle systems.
Students are taught electricity and magnetism as separate topics at an early age, then links are made as middle school begins (with the introduction of electromagnets). Perhaps this initial separation of the topics is confusing or leads to students failing to adjust their concept model.
Particle Physics has demonstrated unification of fields and forces, and the first unification of fields was electric and magnetic by Maxwell in the 1860's. In terms of key ideas it makes the most sense to focus on electromagnetism, as Maxwell's equations can be introduced to the older students with some explanation.
In particle Physics, Engineering skills and techniques are required to design, construct and test the "microscopes" and the "particle factories". From the beginning of particle Physics practical design skills and construction skills, combined with scientific ideas have been required. For example the first LINAC was part of the cathode ray tube, and careful construction of the vacuum tube was needed.
Engineering at a giant facility like CERN requires many types of engineers to tackle the wide variety of problems that need to be overcome before data from the first collision may be analyzed. For example, the 27 km tunnel required geoengineers and civil engineers to map subterranean strata and design tunnel structures to create a stable environment.
In this report we will focus on magnetism. As current is passed through a wire coil a magnetic field is produced. A greater current or a larger coil will increase the magnetic force, but at the price of increased heat output and resistance in the wire. Using copper wire to generate the 7 TeV required by the Large Hadron collider would result in giant magnets that would separate the beams to an unacceptable level. This problem is overcome by the use of helium cooled superconducting electromagnets. This allows the beam tubes to be close together to allow the deflection of the beams at the collision points. Superconducting magnets allows for a lower energy use for a given field.
So the key ideas regarding engineering in particle physics and their related topics taught in our curricula are;
Providing energy to charged particles using radio frequency electric fields - (voltage, charges, electric fields)
Controlling particle direction - (magnetic fields and the Lorentz force)
Controlling resistive heating in the past or currently limiting it to zero with superconductors - (current and resistance in circuits)
Building big things that have never been built before and making sure they work for the needy scientists - (Practical design, construction and test skills)

Potential student conceptions and challenges

In middle school especially the terms current and voltage are subject to continuous substitution or equivalence errors. For example, references are often made by students to voltages flowing through a component. Students also commonly learn conventional current direction early on in middle school, and are then later presented with the direction of the flow of electrons in metals. This can be confusing for some students who just want to know which is the “correct” direction.
The naming of the North Pole of the earth, and then naming one side of a lodestone “north-seeking” has led to the conventional shortened rules for compasses and magnets contradicting what is for most students a very well established geographical fact. The poles of magnets are often called positive and negative because the simple rules relating attraction and repulsion for electric charges appear similar to the rules relating to the interaction of magnetic poles. The idea that magnetic fields lines are continuous is often not presented until a long time after the introduction of the two poles of a fixed magnet.
Most students are aware that magnets have forces associated with them; either a push or a pull. However, students have many misconceptions and often partial information when it comes to magnetic fields. Most students picture magnets as being either in a bar or horseshoe configuration. Compasses can give students the impression that magnetic force comes from the earth. With the idea that magnets are solid objects, they may be unaware of the properties of electromagnets. Students may be unaware of the problems heat causes when large currents flow in big electromagnets, so they may not appreciate the necessity of superconducting magnets. As we explore electromagnetism students will become aware of the heat produced and can be given guidance to help them understand why that is such a problem and what can be done to overcome it.
With engineering in general, students may equate this only with building and operating equipment. They might not know how engineers work with design and budgetary constraints. Students may also need coaching on the iterative nature of the engineering cycle: design, build, test, evaluate, modify, repeat until a suitable solution is obtained.



Most schools do not have the materials to really explore superconductivity. We will have to rely on videos and other internet resources to demonstrate superconductivity. Other challenges will present themselves as students explore the concepts of magnetism including heat, force, and electrical resistance. The activities we present will introduce the advantages of using superconducting magnets, but unfortunately will not provide a live demonstration.

Helpful material and resources

1 Curriculum
a)http://physics.usask.ca/EP_Pamphlet-2.htm
b)https://www.livescience.com/47499-what-is-engineering.html
c)http://rsta.royalsocietypublishing.org/content/370/1973/3887
2 Key concepts
a)CERN lhc closer website https://www.lhc-closer.es/taking_a_closer_look_at_lhc/0.magnetic_dipoles
b)https://www.lhc-closer.es/taking_a_closer_look_at_lhc/0.electromagnetism_in_linac4
c)https://www.lhc-closer.es/taking_a_closer_look_at_lhc/0.lorentz_force
Stanford Design School - Crash Course in Design Thinking
d)https://dschool.stanford.edu/resources-collections/a-virtual-crash-course-in-design-thinking
e)http://cse.ssl.berkeley.edu/Segwayed/lessons/exploring_magnetism/magnetism_and_electromagnetism/mag_electromag.pdf
Magnetism and electromagnetism activity.
3 Student (mis)conceptions and challenges
a)Wiener, G. J., Schmeling, S. M. & Hopf, M. (2017). Why not start with quarks? Teachers investigate a learning unit on the subatomic structure of matter with 12-year-olds. European Journal of Science and Mathematics Education, 5(2), 134-157 // LINK
b)Wiener, G. J., Schmeling, S. M. & Hopf, M. (2017). Introducing 12-year-olds to elementary particles. Physics Education, 52(4), 1-8 // LINK
c)https://www.physicsclassroom.com/class/circuits/Lesson-2/Common-Misconceptions-Regarding-Electric-Circuits
d)http://cds.cern.ch/record/828008/files/0503132.pdf
e)https://www.asee.org/public/conferences/8/papers/4051/download
f)http://irvinenewleadershipnetwork.org/thinking-about-design-a-framework-for-solving-wicked-problems/
g)S'Cool Lab: Electron Beam - The Basics of Particle Acceleration https://scool.web.cern.ch/experiment/electron-tube
h)Minute Physics - Magnets - How do they Work?
https://youtu.be/hFAOXdXZ5TM
i)Veritasium - How Special Relativity Makes Magnets Work
https://youtu.be/1TKSfAkWWN0
5 Best practice examples
a)Hyper physics website link http://hyperphysics.phy-astr.gsu.edu/hbase/magnetic/solenoid.html#c3
Institute of physics
b)http://practicalphysics.org/simple-electromagnet.html
c)https://www.scienceinschool.org/content/particle-accelerator-your-salad-bowl

d)https://www.tes.com/teaching-resource/fundamental-particles-card-game-a-level-physics-11031595
e)PhET - Magnets and Electromagnets
https://phet.colorado.edu/en/simulations/category/physics/electricity-magnets-and-circuits
f)Exploratorium Snacks Portal - Magnetic Pendulums
https://www.exploratorium.edu/snacks/magnetic-pendulums

Best practice example

There are many activities which can be used to scaffold and construct student knowledge on the engineering challenges of particle physics. We can propose ideas that build-up from a series of problems which students need to find solutions to, and cover our curriculum goals through the process of designing solutions.
For example; How can the LHC dipoles be kept cool?
This is a thermal insulation design challenge - students will be provided with a variety of materials with the challenge of keeping an object thermally isolated from its surroundings. (Ex. The longest time for an ice cube to melt, smallest temperature change in given time, longest time taken for given temperature change, etc.)
Another open design challenge is suggested as a best practice example beginning with simple circuit work, leading to the Lorentz force, with extension possibilities using the same apparatus.
Introductory exercises, dependent on the background knowledge and experience of the students, could be any or all of the following;
A) simple circuit building exercises using ammeters for measuring current and the development of the particle nature of current beginning with calculations for the number of electrons flowing in a copper wire. Use of a van de Graaf, with a discharge sphere and earth cable running through a microammeter to show current flow in an arc. Further calculation for the approximate number of charges flowing in the arc. The arc can be refered to as an unstable, uncontrolled beam of particles. Use resistance wires and high currents to investigate the heating effect of current, up to and including the fuse effect.
B) simple circuit building with voltmeters and ammeters. Investigate increasing voltage effect on current. Reference can be made to charged particles gaining energy from the electric field set up by batteries or a power supply. An extension activity to show this force causing an acceleration of charged particles in electric fields could be the salad bowl accelerator.
C) investigate the magnetic effect of high currents in straight wires with compasses. Build simple electromagnets with low currents and investigate the fields with compasses.
D) combine all of ABC and attempt to build as strong an electromagnet as possible. The temperature of the coils should be monitored, and an indication of the strength of the magnet field could be determined with paper clips challenge or just with low mass slotted masses.

Beam Line Challenge (BLC)
Students must design, build and test an electromagnet system which can be used to adjust the position of a particle beam system.
The particle beam system is set up by the teacher/ supervisor.
Suggested apparatus requirements ; 2 or 4 very sensitive, very low stiffness springs (eg extracted from 0.01N fsd dynamometer sourced from Leybold science equipment, or made with wound thin resistance wire or copper wire eg 32swg)
1 or 2 Short lengths of thin copper wire (mass dependent on spring characteristics). These will be acting as the "particle beams". When they are placed on the two springs in parallel there should be a noticeable extension.
Set up a short circuit for a current flow down one spring, along the beam(s) and back up the second spring - a maximum safe current for the wire being used could be eg 0.5 or 1 amp.
Students need to be shown the particle beam system dimensions and then must design and build an electromagnet system which, when placed surrounding the beam system offers the most stable control of vertical force - both in terms of direction (up and down) and magnitude (change in length of the spring). The electromagnet system must be self-supporting and able to deal with any attractive forces between the poles.
Extension to the challenge – BLC II
Two particle beam systems (two wires on sensitive springs) can be set up by the teacher/ supervisor. Students must adapt, rebuild or add to their existing electromagnet system to control both beams in either parallel or anti-parallel current mode.
Bonus stage;
Use a variable frequency a.c. source (for example from a standard signal generator) to investigate resonance of the 1 or 2 beam system (now just a mass on a spring) under the action of a varying magnetic field.
If this challenge proves too difficult, then with the same student design of electromagnet here is an easy adaptation to determine who has the strongest magnet with the most control -
Place two 10 mg or 1 mg sensitivity scale balances 20cm apart on a bench.

Cut out acetate squares to act as insulating separators.
Lie a long copper wire (eg 50 cm of 16 swg) on top of the insulating acetate sheets.
Carefully complete a short circuit with a 12V supply, pass a current of the order of amps through this copper wire.
Students suspend their electromagnets vertically with the wire between the constructed poles.
The extension task could still be used for an added wire with parallel or anti-parallel currents.
There could be an optional prize for the biggest change in scale balance reading or the best control of the two beam system. This study group suggests chocolate.

SG8 | Astroparticle physics

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INTRODUCTION

The study of the topic "Astroparticles" in the context of the content of the lower secondary school curricula is an important element for students to understand the processes studied in the Earth Science, Life Science, Physics, and Chemistry. The authors consider the possibility of including the topic "Astroparticles" in the curriculum, and give practical recommendations for conducting work in the classroom. The article also discusses potential problems and misconceptions related to the supposed world view of lower secondary school students in the case of some countries in Europe, North Africa and North America.

KEYWORDS

STEM, Astroparticles, Particle Physics, Secondary School Curriculum

1. KEY IDEAS

The report “Principles and big ideas of science education”, edited by Wynne Harlen in 2009 [1] sets out the principles that should underpin the science education of all students throughout their schooling. Students should be helped to develop ‘big ideas’ of science and about science that will enable them to understand the scientific aspects of the world around and make informed decisions about the applications of science. In order to develop this understanding learning experiences must be interesting and engaging. We can mention several ideas, which form the basis of students’ understanding of our place in the cosmic perspective: all material is made of very small particles, the Solar System is a very small part of one of millions of galaxies in the Universe or that the composition of the Earth and its atmosphere and the processes occurring within them shape the Earth’s surface and its climate. Equally important are also the ideas about science, namely: it assumes that for every effect there is one or more causes; scientific explanations, theories and models are those that best fit the facts known at a particular time; the knowledge produced by science is used in some technologies to create products to serve human ends; applications of science often have ethical, social, economic and political implications.

Bringing these particular topic into classroom we should first define what are cosmic particles, how they differ from atoms and how they interact with us and the world around us. Good inspirations supporting the big picture of the subject come from from Go-Lab Big Ideas of Science, The Cosmic Calendar by Carl Sagan and Big History Project. Using right models for describing and scaling is very important throughout the curriculum. We can start introducing students even very early with online applications like The Scales of the Universe or If Moon Were 1 Pixel to give students good tools to enrich their general skills and imagination. The very good idea seems to introduce students to the real sky and celestial phenomena. This is not what we can expect to be included in the typical curriculum, but it is nicely supplementing the school activities (it can be the visit in planetarium or real observations, including ISS transits, for which many applications and internet tools are very useful) usually fulfilling the aim to raise students’ interests in being well educated, open-minded and aware modern world citizens.

2. CURRICULUM AND CLASSROOM CONNECTIONS

As we began this research, we first sought to discover how our curriculums differ in our countries. We were surprised to find that not only did we all teach the same grade levels (middle grades), but that with only a few variations, all of our students learned the same topics throughout their middle school years. All students in our countries (United States, Sri Lanka, Algeria, Poland, and Latvia) learn about Earth/Space, Life Science/Biology, and Physical Science/Chemistry before going on to high school. We took this approach to determine how to best enrich those curriculums with Astroparticle education.

In the subject area of Earth and Space Science, teachers have the opportunity to introduce Astroparticles in many ways. Students will learn about cosmic rays in the form of the suns's radiation and it's effect on Earth's atmosphere. They can also be taught about Astroparticles through the story of the CERN/NASA collaboration of AMS-02, which studies cosmic rays on the International Space Station. Students can also be instructed about Astroparticles when studying natural phenomena like the Aurora Borealis/Australis.

While Life Science and Biology do not often cover the subject of space, teachers in this area can still include Astroparticles in their curriculum. A great way to do this is to include Astroparticles in the area of cells and disease. Students have learned that UV radiation from the sun, and in Biology they can learn how those cosmic rays can cause skin cancer. Finally, they can learn about how Astroparticles affect life on earth through the Carbon Cycle.

In Physical Science and Chemistry have the ability to introduce Astroparticles as part of their atomic theory curriculum. This subject area also can include Astroparticles as part of a lesson on particle physics, as well as modern physics and the search for dark matter. Additionally, teaches in this subject area have the opportunity to show their students Astroparticles by conducting a Cloud Chamber Lab with their students.

3. STUDENTS' CONCEPTIONS AND CHALLENGES

We as teachers should always remember that students never start learning from the school. They are a package full of conceptions which they gather from their surroundings. Here some concepts are error free. Yet some needs a remedy. To have a better lesson on any topic the teacher should figure out the concepts that he/she already has inside the class with respect to the relevant topic.

Regarding the topic of our research, we found the followings main concepts which guide students to look for immediate remedies. They think that sun is the only source of cosmic rays. They do not take the other objects such as dusts, comets, asteroids we have in space into the account. Most of the students think that space is empty where we can find zero gravity. Also they think the only effect on cosmic rays is the sun burns. And they don't yet understand how cosmic rays effect on life in earth such as carbon cycle.

The responsibility of the teacher is to figure out the prior knowledge of the student and make sure it is error free before we start our lesson.

4. MATERIAL AND RESOURCES

An experiment in the classroom is a powerful stimulus for pupils to comprehend the topic of study. Demonstration of the action of the cloud chamber, and preferably, the self-assembly of the chamber by students under the guidance of the teacher, is a time-consuming but rewarded effort of the introduction to the concept. The principles of the cloud chamber experiment and methodological recommendations are given in [2]. As a result of an experiment with a cloud chamber, the pupil gets the idea that in the Earth's atmosphere there are constantly present fast moving high-energy particles, which are evidence of cosmic rays. Further, this phenomenon can be considered in the context of various STEM subjects.

One example of the use of the phenomenon of cosmic rays is radiocarbon analysis. Students get acquainted with the cycle of carbon exchange in nature and come to an idea of how scientists determine the age of the remains or fossils [3]. An experiment can be conducted in a class whose purpose is to determine how long a "frozen man" is in a warm room by the amount of water that has melted. [4]

Another example of the discussion may be the work of computers and other electronic devices. Students learn about the phenomenon of the action of cosmic rays on the memory of computers [5] and discuss the possible consequences of an error in a home computer, satellite, airplane.

5. BEST PRACTICE

As mentioned in 4th part it is highly effective to conduct experiments in addition to theoretical discussions in a classroom. Authors consider using two possible experimental tools to achieve that.
First is the The Cloud Chamber is easy to made detectors which make the tracks of astroparticles visible to us [6]. It is one of the oldest particle detectors. It also led to many discoveries in the history of particle physics . In addition, it was involved in two Nobel Prizes (Charles T.R.Wilson in 1927 / Carl Anderson in 1936).

The other is the CosmicWatch detector [7] which is a simple self-contained apparatus for electronics project for university students and schools which employs plastic scintillator as a detection medium and a silicon photomultiplier for light collection. These detectors can be battery powered and used in conjunction with the provided software to make interesting physics measurements.

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https://www.youtube.com/watch?v=phZeE7Att_s
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SG9 | Exotic physics

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Curriculum & classroom connections

The table below shows the extent of topics included in the curriculum of the members of this study group on the subjects of astronomy, nuclear, and particle physics.

Country	Exotic Physics in the Curriculum	
	Year of Education	Potential Connections to the various curriculums
Iran	10th grade 11th grade 12th grade	Standard Model of particle physics Astronomy Atomic model
Lithuania	7th grade 10th grade 11-12th grade	Introduction to Nuclear physics and Astronomy Model of atoms, Astronomy
Philippines	10th grade 11th grade	Nuclear Science Introduction to the Standard Model
Portugal	7th grade 11th grade 12th grade	General Astronomy Forces of Nature Introducing Standard Model
Serbia	ES 6th grade ES 8th grade HS1 grade HS 3 grade HS 4 grade	State of matter Particle physics Model of Atoms Introduction to Nuclear and Atomic Physics Standard model Astronomy

Given the different curriculum being followed by the members of the study group, there is no specific part of their high school curriculum that includes Exotic Physics. Topics that can be considered as Exotic Physics is only considered in the university and graduate school level. The extent of the curriculum includes discussion only until the Standard Model.
Thus, the group's idea for approaching the subject is to discuss topics found in science fiction to make the students interested in the field in general and to let them explore the possibilities of them happening in the future.

Key ideas

Dark Matter and Dark Energy
There's a force greater than gravity (still unknown) that changes the predicted stars movement around the center of the galaxies.
It's important that students link attraction to dark matter and repulsion and expansion to dark energy. First you need to know that gravity "pulls" on time and space so time passes differently around astral bodies and space "dips" under them. Now you need to imagine that space is a 2D sheet that has been curved but someone has left a gap in between the two halves, now if two bodies are directly opposite of each other on either each half the paper will eventually dip deep enough till each bit is touching. This is how wormholes may form. It looks similar to this

Wormholes
Science fiction is filled with tales of traveling through wormholes. In a nutshell, wormholes are theoretical passages that can create shortcuts for long distance travel across the universe. These are one of the predictions of Einstein's Theory of General Relativity. However, producing a wormhole is not as easy as the theory suggests.
Some problems include the possible size of the wormhole (about 10^{-33} cm) and its stability. It may be possible for the size of a wormhole to increase as the universe continues to expand.
According to Stephen Hsu, a theoretical physicist, a very "exotic" type of matter is needed in order for the wormhole to stabilize. The existence of this exotic matter could help stay the wormhole open and stable for a longer period of time. If it exists, it must contain a negative energy density and a large negative pressure. As of the moment, this has not been the case.

If in the future we found a way to use wormholes, we can send humans to travel outside our solar system or even outside our galaxy!

Time Travel
As the title suggests, time travel means an object could travel either forward or backward in time. According to General Relativity, space time can be distorted due to the effects of massive bodies; it can be bent and warped. Thus, traveling into the future may be possible but traveling into the past is a violation of currently known laws of physics.
For time travel to be possible for humans, a device called time machine, a concept that is very popular in science fiction movies, is needed to take us there. Time machine research often involves bending space-time so far that time lines turn back on themselves to form a loop, technically known as a "closed time-like curve."
To accomplish this, time machines must be composed of exotic form of matter with "negative energy density." Such exotic matter has bizarre properties, including moving in the direction opposite of normal matter when pushed. If this really exists, it might be present only in small quantities; not enough to build a time machine.

Potential student conceptions & challenges

Since these topics are not part of the curriculums, potential misconceptions may arise, like:
- antimatter spaceships,
- antimatter weapons,
- time machines,
- dark matter or dark forces.

Without having full knowledge of what is already known in nature, students will surely gets confused since these topics are difficult to explain even by scientists.

Helpful material and resources

For Dark Matter:
What is dark matter and dark energy? - https://youtu.be/QAa2O_8wBUQ
Dark matter: The matter we can't see - James Gillies - https://youtu.be/HneiEA1B8ks
Dark matter: How does it explain a star's speed - Don Lincoln - https://youtu.be/sI23cwbbNqs
What happened to antimatter? - Rolf Landua - https://youtu.be/CtR5EkvLNfg

For time travel
Interstellar movie
Neil deGrasse Tyson on "Interstellar" - https://youtu.be/l7tV7v71k-I
For Time Travel:Is time travel possible? - Colin Stuart - https://youtu.be/7H3ksmxwpWc
Is Time Travel Possible? https://spaceplace.nasa.gov

For Wormholes:
What is a wormhole? https://spaceplace.nasa.gov

Best Practice example

Activity: Guessing the Unknown
Starting the class with an activity will get the students be interested in the topic.

- Each student will be given a small box with materials inside it.
- Some of the boxes will have magnets inside
- The boxes will feel an attraction (or repulsion) to each other depending on their polarity.
- Here's the best part: The teacher will never reveal to its students what's inside their box.
- This activity will create mysteries and curiosity about the subject

Show an example that demonstrates gravitational force (e.g. an object falling) and ask the students the reason why the object fall. They might answer gravity but we can ask, "Why? I don't see any particle that causes the gravitational force".

After doing the activity and asking some inquiry questions related to the topic, the teacher will listen to the students' conceptions of the subject. Educational videos listed in the resources will then be shown to help the teachers address these conceptions. A healthy class discussion will follow afterwards. The purpose of these practices is to let students be curious so they can in the future try to push the boundaries of what science can explain.