Particle Physics Online Course for High-School Students

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Particle Physics Course for High-School Students

Motivation: high demand for educational offers targeting high-school students

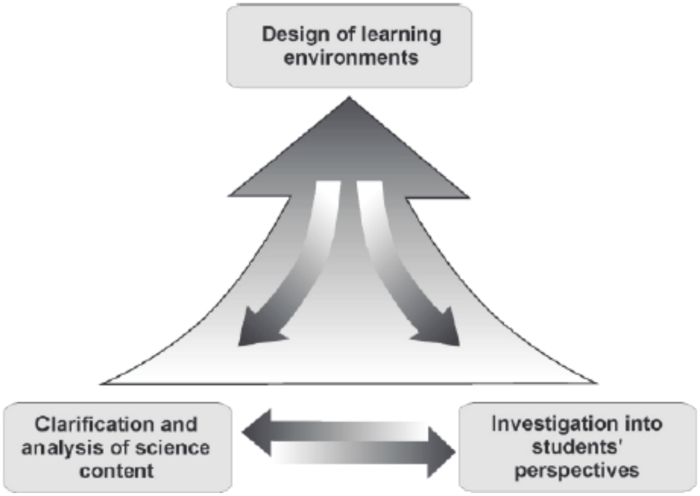
Goals:

- develop online learning offer for high-school students from around the world
- provide teachers with educational ideas and materials for their classroom
- narrow the research-practice gap in particle physics education research

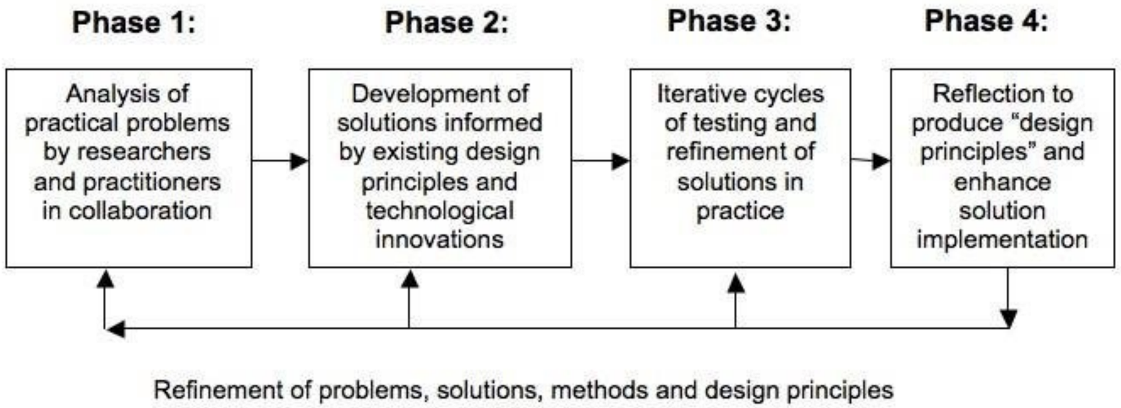
Particle Physics Course for High-School Students

Process: long-term, iterative physics education research project

Methods: educational reconstruction & design-based research



The model of educational reconstruction (Duit et al., 2012)



The design-based research cycle (Reeves, 2006)

Particle Physics Course for High-School Students

Process: long-term, iterative physics education research project

Methods: educational reconstruction & design-based research

Instruments: eye-tracking, questionnaires & think-aloud studies

Particle Physics Course for High-School Students

Target group: high-school students (14-19 years)

Aim: introducing students to central models of particle physics

Structure: key messages and experiments/activities

Pilot: 16 chapters comprising videos/transcripts and quiz questions

Part 1		Part 2	
1 What is a particle?	**5** What are interactions?	**9** What is antimatter?	**13** What is a particle accelerator?
2 What is a model?	**6** What is matter?	**10** What is the SMPP?	**14** What is a particle detector?
3 What is particle physics?	**7** What are conservation laws?	**11** What is the Higgs boson?	**15** What is a cloud chamber?
4 What are charges?	**8** What are particle transformations?	**12** What is beyond the SMPP?	**16** What is CERN?

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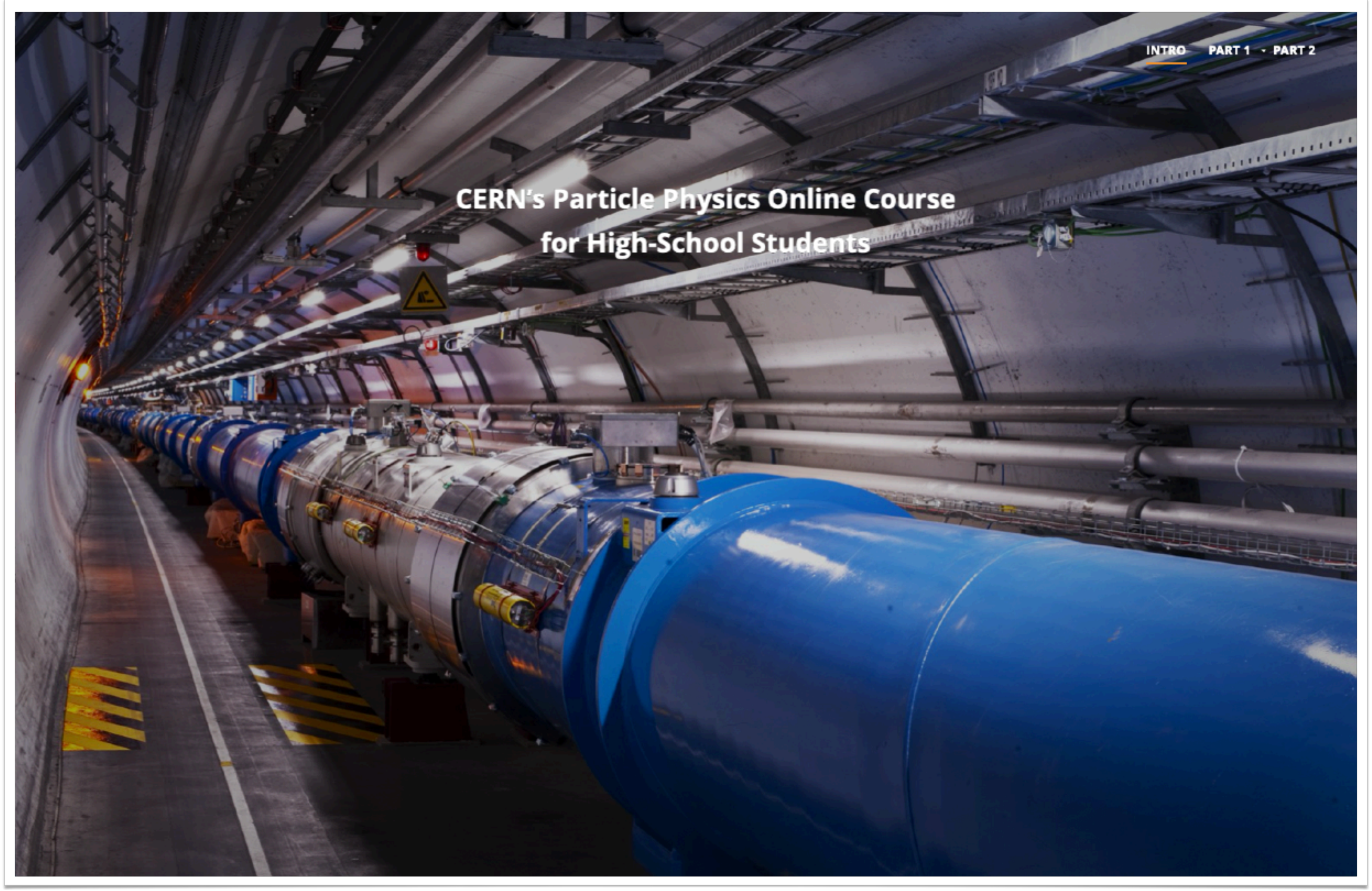

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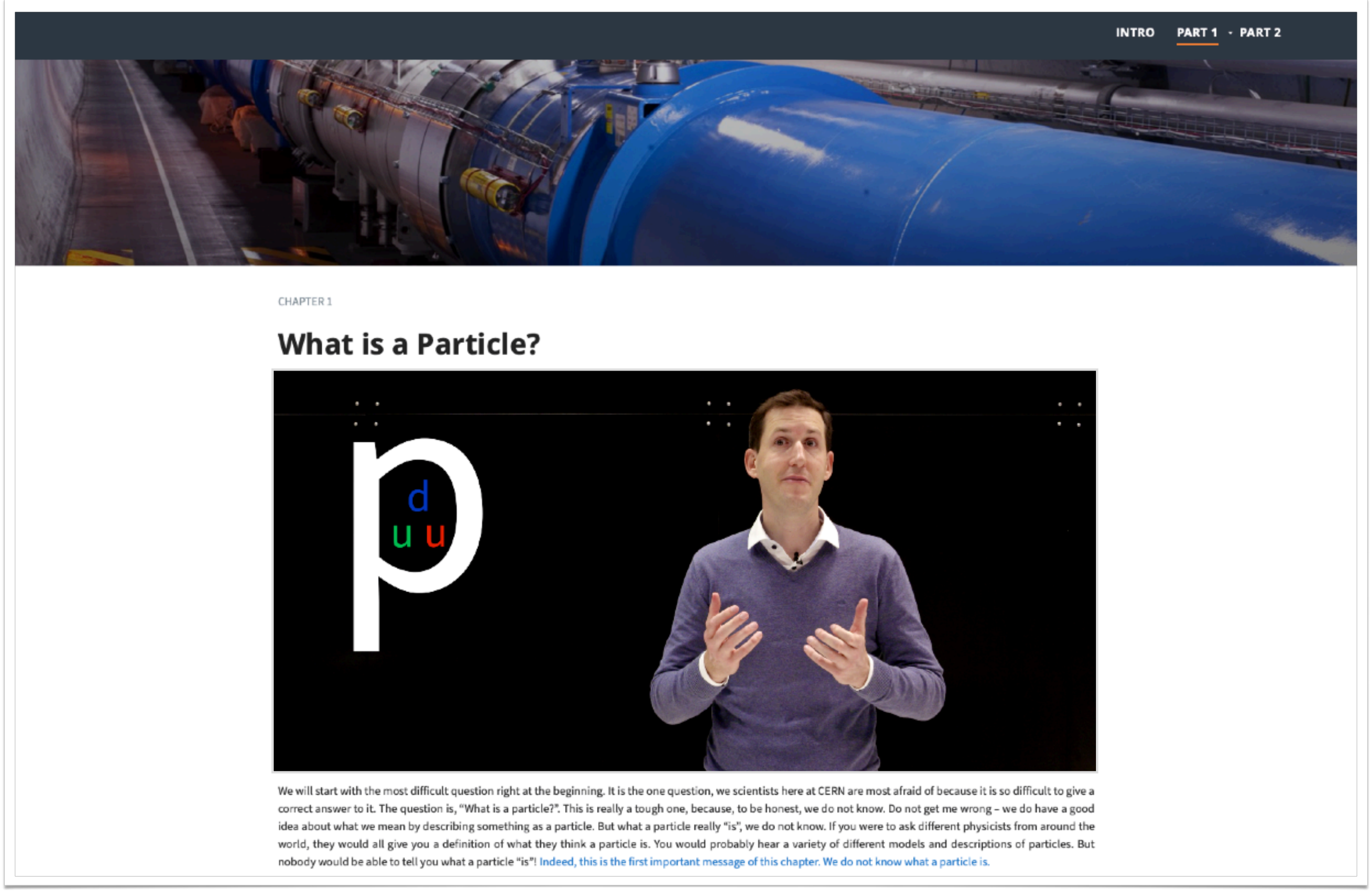

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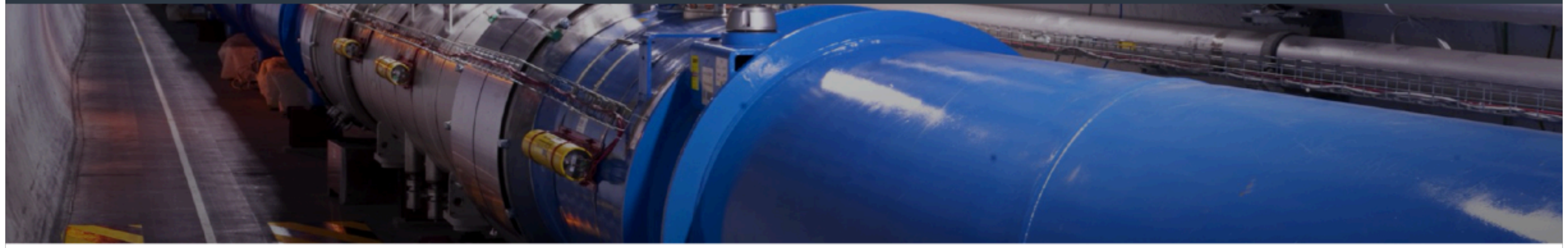
INTRO PART 1 · PART 2



CHAPTER 1

What is a Particle?

We will start with the most difficult question right at the beginning. It is the one question, we scientists here at CERN are most afraid of because it is so difficult to give a correct answer to it. The question is, “What is a particle?”. This is really a tough one, because, to be honest, we do not know. Do not get me wrong – we do have a good idea about what we mean by describing something as a particle. But what a particle really “is”, we do not know. If you were to ask different physicists from around the world, they would all give you a definition of what they think a particle is. You would probably hear a variety of different models and descriptions of particles. But nobody would be able to tell you what a particle “is”! Indeed, this is the first important message of this chapter. We do not know what a particle is.

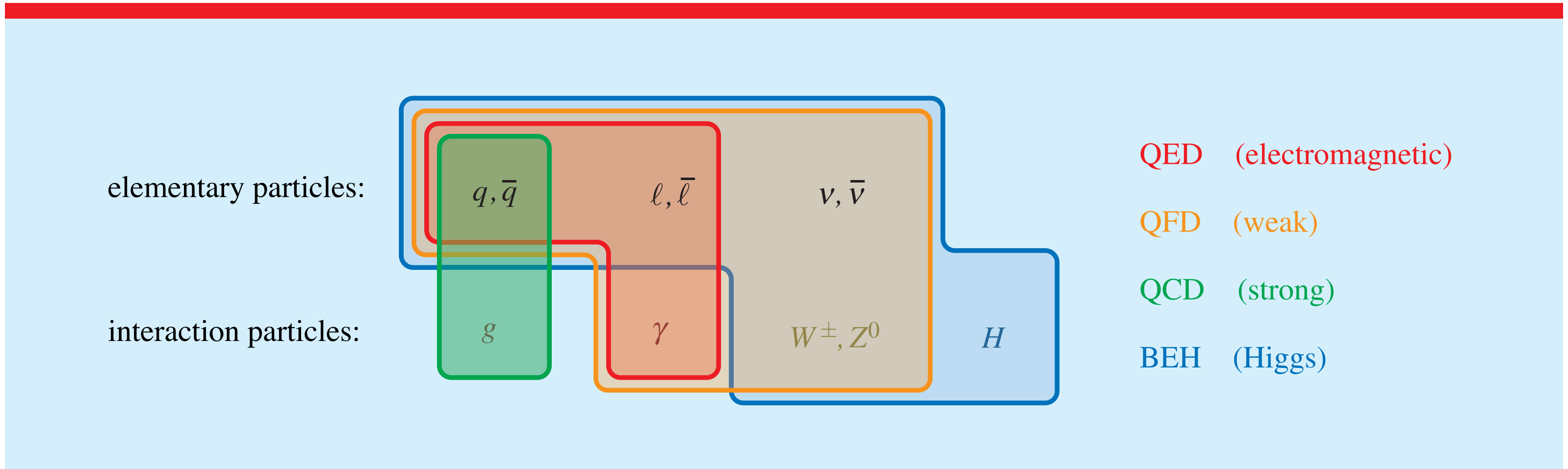
PPC Aims

- Highlighting scientific process & modelling in science
- Representing particle physics & CERN inclusively
- Showcasing connections to general physics curricula
- Demystifying particle physics

- Coherent nomenclature & illustrations throughout the course
- Structure & key messages support students' "learning progression"
- Mix of presentation & activities (quiz questions, DIY experiments)

Important Examples

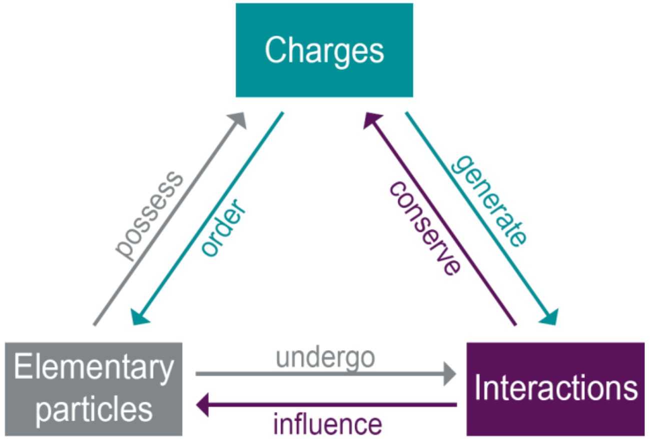
- **Particles:** elementary particles & interaction particles
- **Operationalised:** elementary particles & composite particle systems



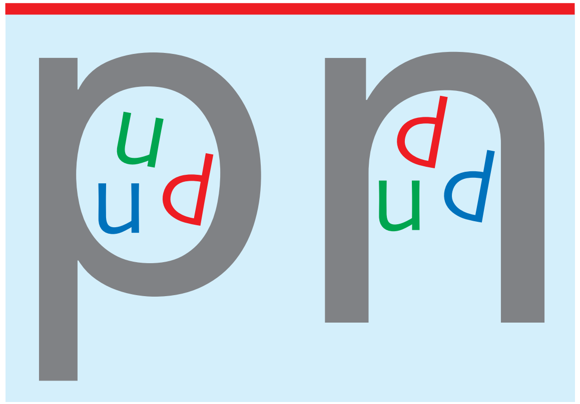
Standard Model overview (Woithe et al., 2017)

Important Examples

- **Fundamental interactions & charges first, particles later**
- **Conservation laws as rulebook of the Universe**
- **Linguistic accuracy & coherence (decay and transformation)**
- **Typographic illustration of particles (link to Feynman diagrams)**



Standard Model triangle (Kobel et al., 2018)



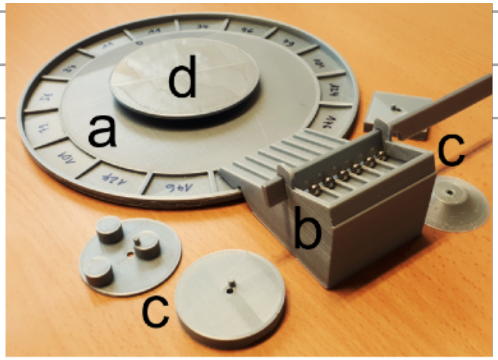
Typographic illustrations of particles (Wiener et al., 2017)

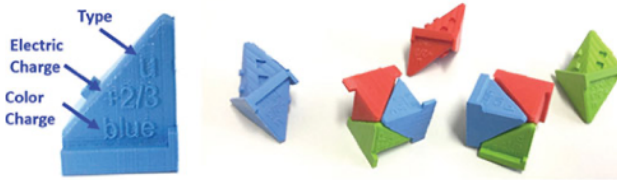
PPC Overview

#	C1	C2	C3
Title	**What is a particle?**	**What is a model?**	**What is particle physics?**
Key messages	1) We do not know what a particle "is". 2) The term "particle" can have different definitions that depend on the context. 3) There are elementary particles that are indivisible, and that can be measured, but we have no idea how they look like. 4) Elementary particles can combine to make up composite particle systems that have particle-like properties.	1) We use scientific models to describe observations of our universe. 2) Different scientific models can describe the same object or phenomenon. 3) Every scientific model allows us to make new predictions. 4) Every scientific model has its limitations.	1) Particle physics is the research field of physics that deals with particles. 2) The field of particle physics can be divided into low-energy particle physics and high-energy particle physics. 3) Quantum physics and high-energy particle physics investigate the same types of particles but at different energies. 4) In particle physics, "electronvolt" is used as the unit of energy.
Activity	Cloud Chamber	Mystery boxes	Laser lab & Electron gun
Particles	up quark, down quark, proton, neutron	electron	photon
Charges			
Interactions			

PPC Overview

#	C4	C5	C6
Title	**What are charges?**	**What are interactions?**	**What is matter?**
Key messages	1) Particles have no size or shape. We describe them as point-like objects. 2) Particles have properties that characterise them, for example, mass and charges.	1) All phenomena in the Universe can be traced back to four fundamental interactions between elementary particles. 2) Apart from the gravitational interaction, all fundamental interactions are described by the Standard Model of particle physics. 3) The electric charge determines if and how a particle can interact with other particles via the electromagnetic interaction. 4) The electromagnetic interaction is mediated by a characteristic interaction particle, the photon. 5) The three fundamental interactions described by the Standard Model of particle physics are each associated with characteristic charges and characteristic interaction particles.	1) Matter is everything that can be touched, practically or theoretically. 2) Matter is made of atoms that can combine to form molecules. 3) Atoms are not indivisible, but they are made of elementary particles that are indivisible. 4) Because of the strong interaction, which is mediated by gluons, quarks are confined in particle systems, such as the proton or the neutron. 5) The charge associated with the strong interaction is described as colour charge.
Activity	Scattering experiment	Scattering experiment	Quark puzzle
Particles		photon	gluon
Charges		electric	strong
Interactions		gravitational, electromagnetic	strong





PPC Overview

#	C7	C8	C9
Title	**What are conservation laws?**	**What are particle transformations?**	**What is antimatter?**
Key messages	1) The total energy of an isolated system, which is the sum of all forms of energy, such as the energy associated with the rest mass of a particle or its kinetic energy, is conserved. 2) The total momentum of an isolated system is conserved. 3) The total electric charge, the total strong charge, and the total weak charge of an isolated system are conserved. 4) The weak interaction allows particles to transform into other particles. 5) The weak interaction is associated with the weak charge, and it is mediated by the W+ boson, the W- boson, or the Z boson.	1) When a particle transforms, it stops existing and new particles are created. 2) Particle transformations are random processes but, on average, particles transform at the end of their characteristic average lifetime. 3) During particle transformations, the total energy, the total momentum, and all charges are conserved. 4) Particle physicists use Feynman diagrams to visualise particle transformations.	1) The evolution of the Universe is best described with the big bang theory. 2) The big bang theory is based on Einstein's famous formula, E=mc2, that describes the equivalence of energy and matter. 3) The transformation of energy into matter is restricted by charge conservation. 4) For every charged particle there is an identical anti-particle with opposite charges. 5) A particle and its anti-particle can cancel each other out and transform into interaction particles. 6) Anti-matter is made of anti-particles that combine to form anti-atoms.
Activity	Cloud chamber	Cloud Chamber	Quadrupole ion trap
Particles	W-, W+, Z	muon, muon neutrino, anti-electron neutrino	positron
Charges	weak		
Interactions	weak		

PPC Overview

#	C10	C11	C12
Title	**What is the SMPP?**	**What is the Higgs boson?**	**What is beyond the SMPP?**
Key messages	1) The Standard Model of particle physics describes the fundamental interactions between elementary particles based on their associated charges. 2) Within the Standard Model of particle physics, elementary particles can be grouped together according to their charges and their mass. 3) The Standard Model of particle physics sorts elementary particles and anti-particles into three generations. 4) Due to their high masses, elementary particles categorised in the second and third generation of the Standard Model of particle physics can only exist in high-energy environments.	1) Composite particle systems made of three quarks are called baryons, and composite particle systems made of one quark and one anti-quark are called mesons. 2) In quantum field theory, elementary particles and interaction particles are considered to be excitations of their associated fields. 3) The Brout-Englert-Higgs mechanism describes how elementary particles and interaction particles can interact with the Brout-Englert-Higgs field, which causes them to acquire mass. 4) The mass of composite particle systems stems from the masses of its quarks and the energy of the strong interaction between them.	Nobel prize ideas 1) Come up with a quantum theory of gravity! 2) Find an explanation of why there are exactly three generations of elementary particles! 3) Find out what dark matter is! 4) Find out what dark energy is!
Activity	SMPP counter	Particle identities	Jar with M&Ms
Particles	all elementary particles and anti-particles	Higgs, mesons, baryons	
Charges			
Interactions			

PPC Overview

#	C13	C14	C15
Title	What is a particle accelerator?	What is a particle detector?	What is a cloud chamber?
Key messages	1) Particle accelerators accelerate electrically charged particles with the help of electric fields. 2) In a linear accelerator, alternating electric fields are used to accelerate particles along a straight path. 3) In a circular accelerator, electric fields increase the energy of particles, and magnetic fields are used to steer them along a circular path. 4) The maximum energy particles can reach in a circular accelerator is limited by the strength of the magnetic fields that steer the particles around the circle, and by the circumference of the circular accelerator. 5) When high-energetic particles collide, their energies can transform, and new particles are created.	1) A particle detector is a device that detects particles and measures their properties. 2) A particle detector can only detect types of particles with a sufficiently long average lifetime. 3) Particle detectors use magnetic fields to determine the electric charge and the momentum of particles. 4) We identify particles based on the unique patterns they produce in different layers of detector components.	
Activity	Electron gun	Cloud Chamber	Cloud Chamber
Particles	hadrons		
Charges			
Interactions			

PPC Overview

#	C16	C17
Title	**What is CERN?**	**PPC Summary**
Key messages	History Organization Life at CERN Job opportunities	
Activity		
Particles		
Charges		
Interactions		

Merci bien!

Questions?

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