You will need:

- A phone or S'Cool LAB laptop to access the internet


WHO WANTS TO BE A
~~MILLIONAIRE~~
Teacher in Residence!
WHO WANTS TO BE A

WHAT IS A TEACHER IN RESIDENCE?

S'COOL LAB

We run workshops for students (and teachers) visiting CERN to support the S'Cool LAB team.

We use it to develop and test our new (low cost, 3d-printable) hands-on activities.

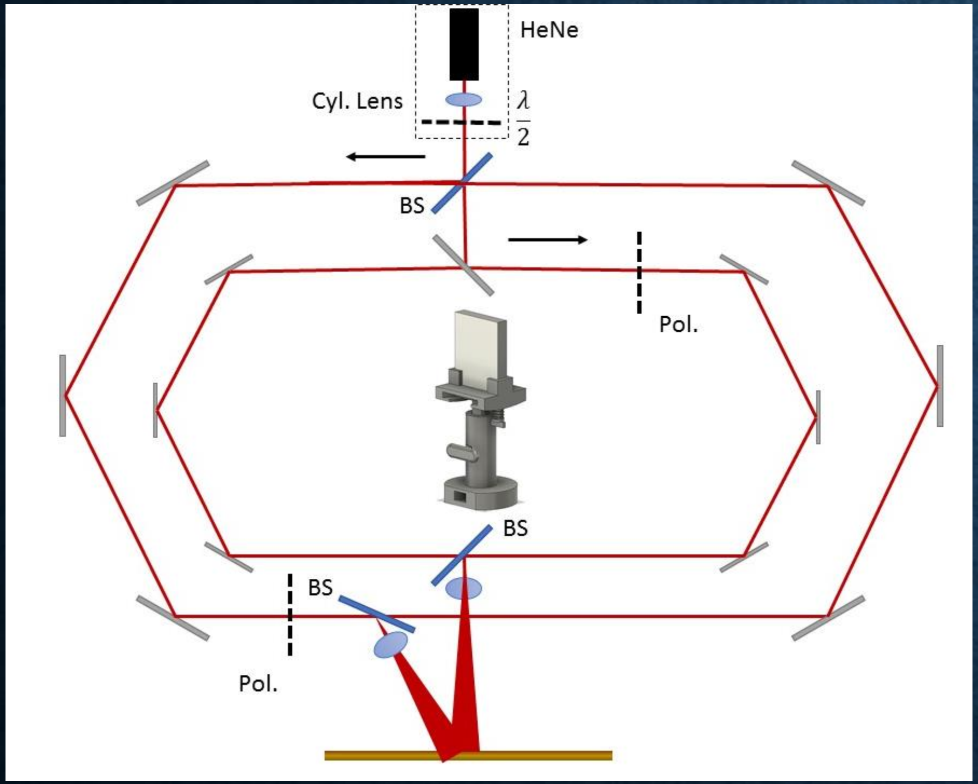
We work as a team.

DATABASE

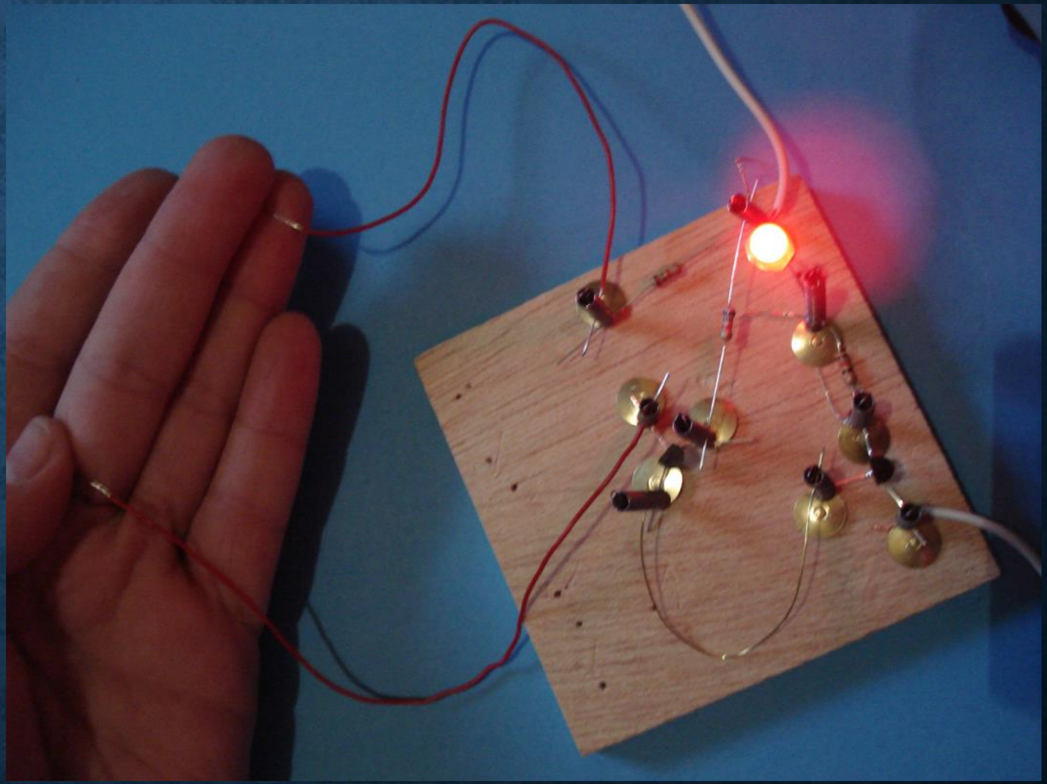
List of Particle Physics Resources and Activities 2 - Excel

	Resource Name	Topic	Type	Language	Age	Supervision Necessary	Required Materials	Website	Author	Description	3D printable	Worth Investigating? (number out of 10)	
2	Cloud Chamber Do-it-yourself manual	Cloud Chamber	Hands on Activity	English	16+	Yes	Dry ice, isopropanol	http://ippog.org/sites/ippog.web.cern.ch/files/SC	Julia Woithe	Instructions for building a cloud chamber from scratch.			
3	International Masterclass	Data Handling	Event - computer based	English	15-19	Yes	Computers, video conferencing, scientists, tutors	http://physicsmasterclasses.org/		Students from a particular area gather and investigate data from the LHC			
4	Be a physicist/dans the skin	Scientific Method	Hands on Activity	English	9-12 years old	yes	Boxes and objects to investigate and test	http://ippog.org/sites/ippog.web.cern.ch/files/livretanglaisfinal.pdf	Saindrine Saison-Marsollier	Students perform an investigation to determine the unknown objects hidden			
5	CMS HEP Tutorial	Data Handling	Computer Activity	English	Under graduates	No	Computer	http://ippog.org/resources/2012/cms-hep-tutorial	Christian Sander and Alexander Schmidt	Students learn programming to handle data from CMS			
6	Mass Calc: Z	Data		English	15-18			Link broken	K cecire	A resource which helps			
7	The Particle Adventure		Computer Activity	English +12 other languages	15-18	No	Computer	http://particleadventure.org/	LBNL	An excellent introduction to particle physics. Note the website itself only contains			
8	Quark-tzee	Standard Model	Game	English	15+	No	Dice, stickers	http://ippog.org/sites/ippog.web.cern.ch/files/i	Helio Takai	A dice game similar to Yahtzee. Students create			
9	The Quark Card Game	Standard Model	Game	English	15+	No	Quark Cards	http://ippog.org/resources/2011/quark-card-	Helio Takai	A modified version of poker. Players are given a hand of 5			
10	Quark Card Dealer	Standard Model	Game	English	12+	No	Cards (Available at website)	https://www.jicfus.jp/en/promotion/pr/quark-					
11	QCD the game	Standard	Game	English	15+	No	Cards (can be viewed	https://tktournament.co		A variety of card games that			
12	The world of particles and their interactions	Standard Model	Game and Activity	English	6-12 years old	Yes	Generic Quark cards	http://creations-project.eu/resources/toolkit/demonstrators-templates/particle-	Dr Maria Pavlidou and Professor Cristina Lazeroni (University of	A game and an activity for primary school children. The game is similar to go fish, but with the standard model. The			
13	Quarkle	Standard Model	Game	English	12+	No	Quarkle Cards (can be bought for $15 at the	https://www.thegamecrafter.com/games/quarkl	Andrew (andrew.huntress	A Quark based game that allows students to become			

WORKGROUPS - HST



Low Cost 3D Printable Experiments

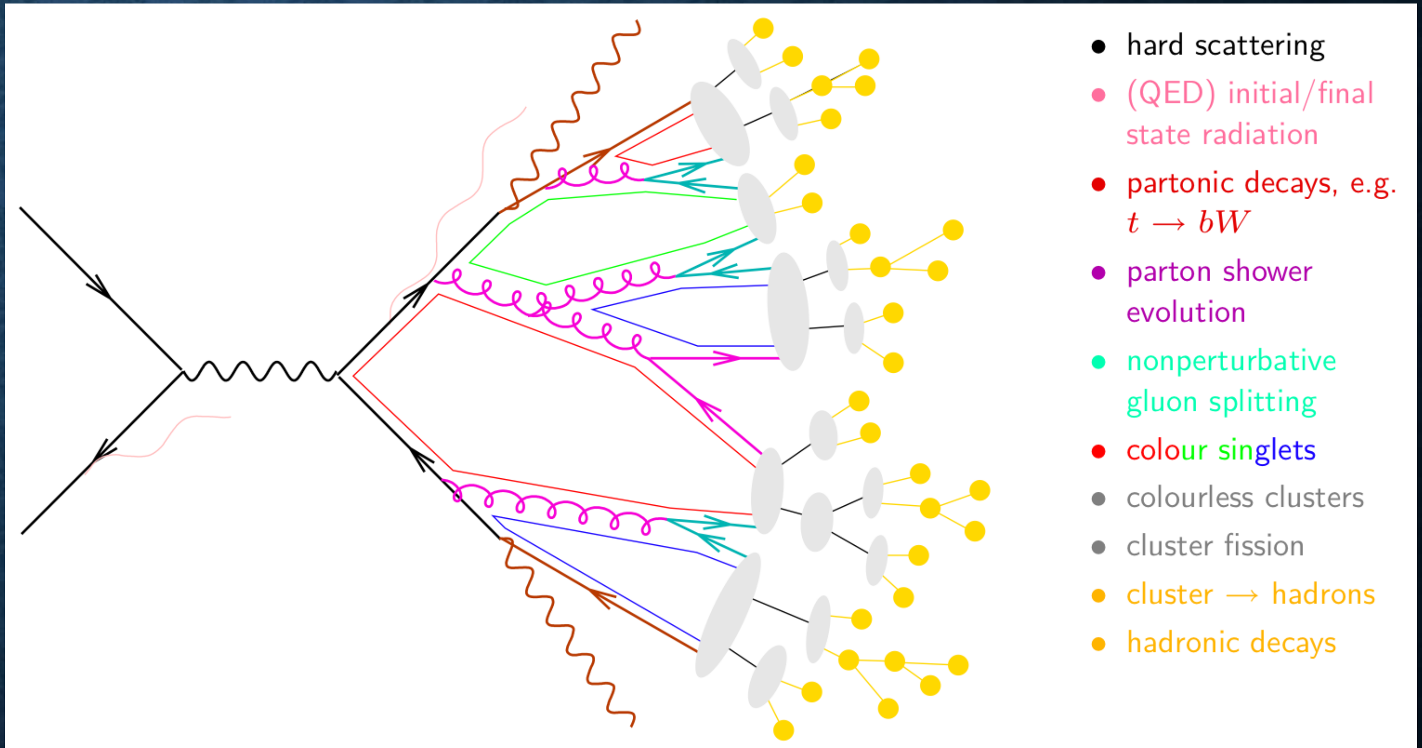


Semiconductors at CERN

WORKGROUPS – SUMMER CAMP

Students will learn:

- *Conceptual knowledge essential to understand Feynman diagrams*
- *Knowledge of particle physics interactions and estimation of the probability of certain processes in particle physics using Feynman diagrams.*



KAHOOT

You will need:

- A phone or S'Cool LAB laptop
- Go to https://kahoot.it/

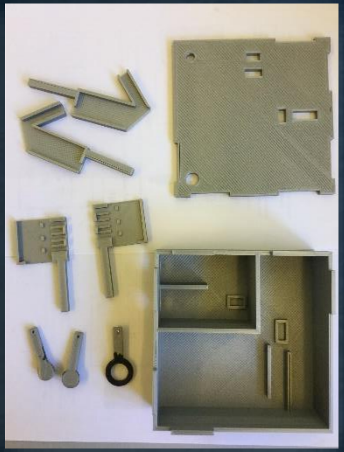
If you would like to use this quiz at home: https://create.kahoot.it/details/hst-anti-matter/67933d98-8699-4f91-b22f-79792aebb9a0

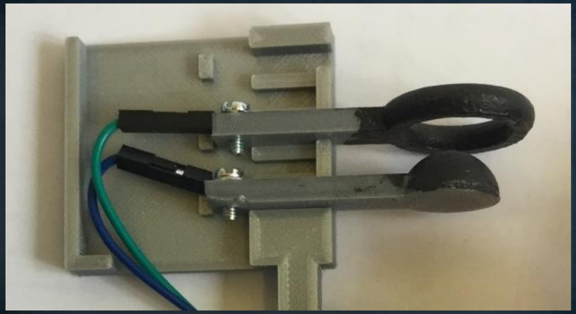
PAUL TRAP

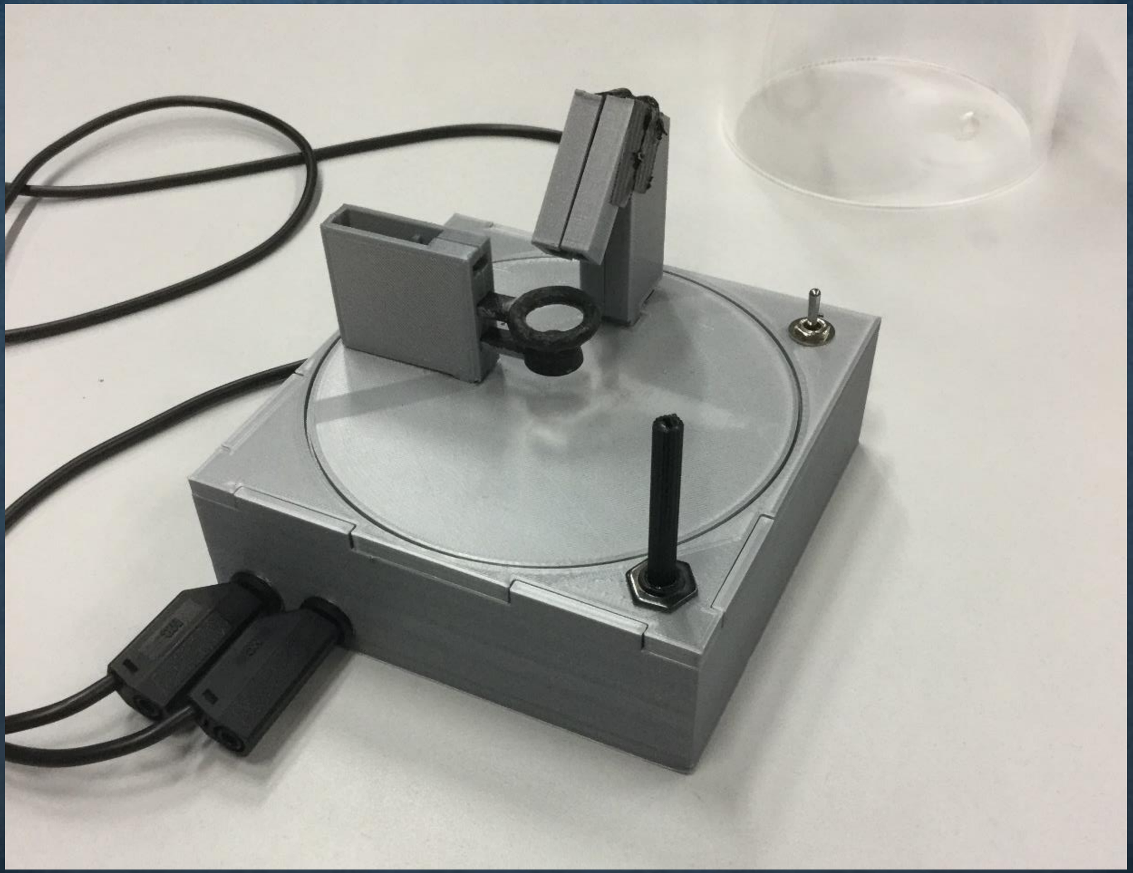
What we worked on:

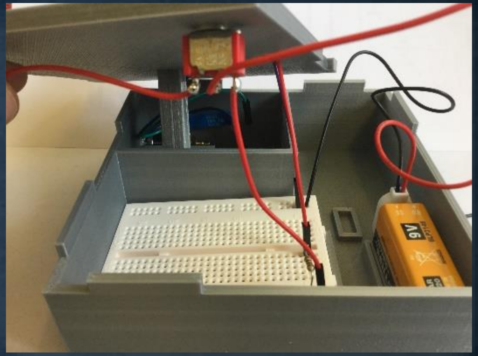
- Refined Trap Design
- Student Worksheets
- Teacher Guidelines and Solutions
- Construction Manual
- Paper

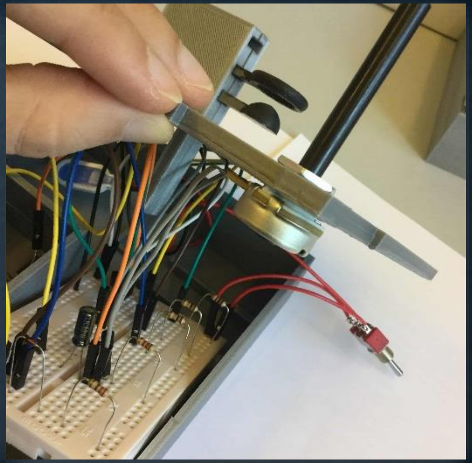
TRAP DESIGN



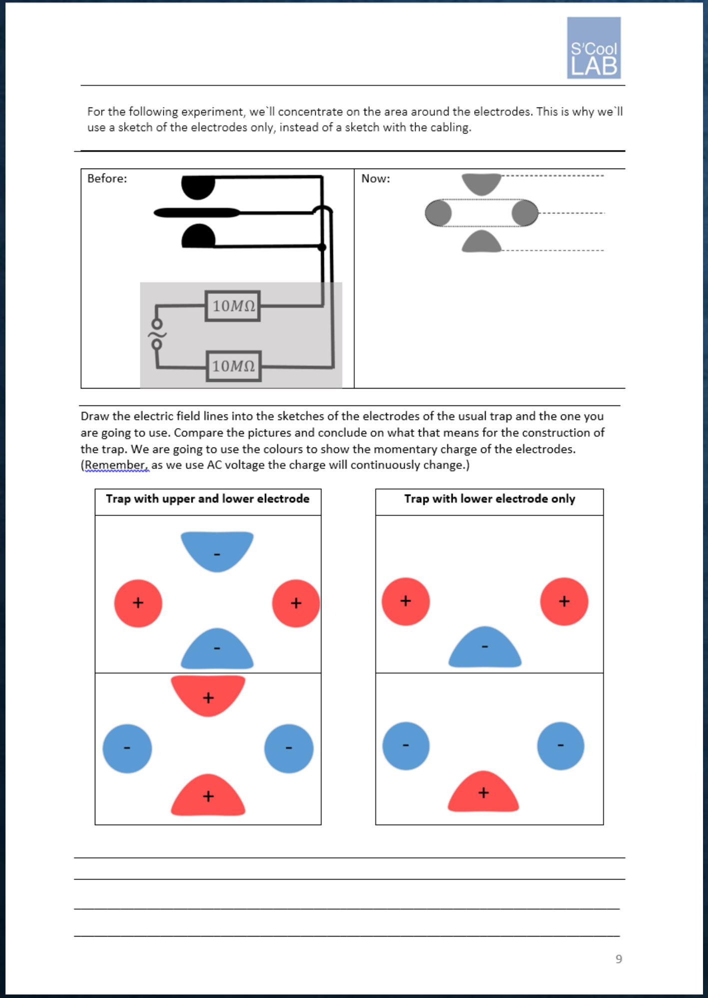








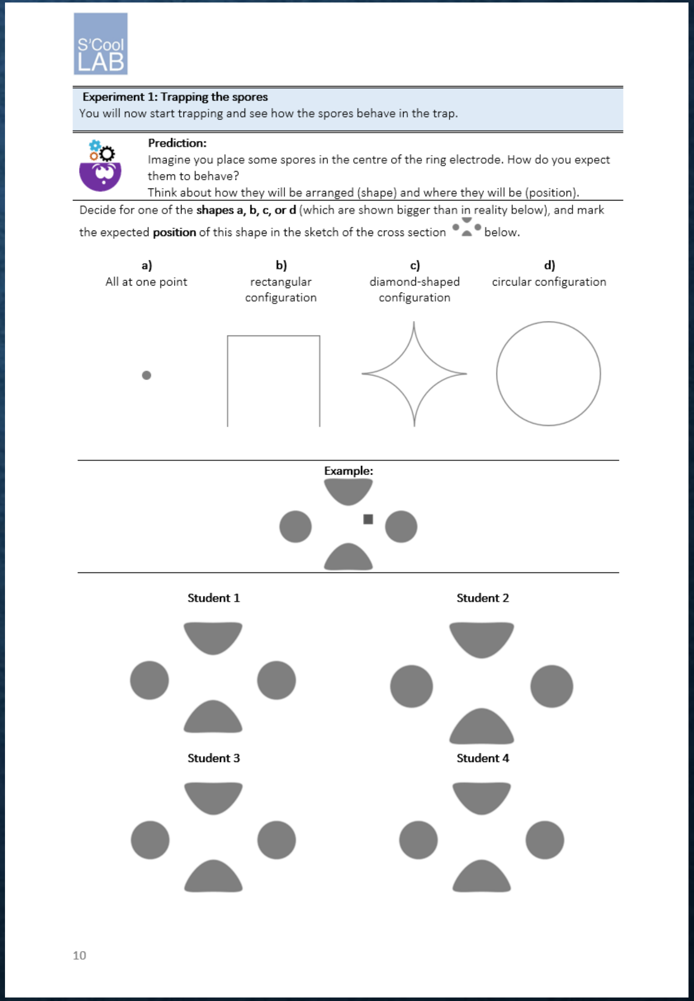
STUDENT WORKSHEETS



S'Cool LAB

For the following experiment, we`ll concentrate on the area around the electrodes. This is why we`ll use a sketch of the electrodes only, instead of a sketch with the cabling.

Draw the electric field lines into the sketches of the electrodes of the usual trap and the one you are going to use. Compare the pictures and conclude on what that means for the construction of the trap. We are going to use the colours to show the momentary charge of the electrodes. (Remember, as we use AC voltage the charge will continuously change.)



S'Cool LAB

Experiment 1: Trapping the spores

You will now start trapping and see how the spores behave in the trap.

Prediction:

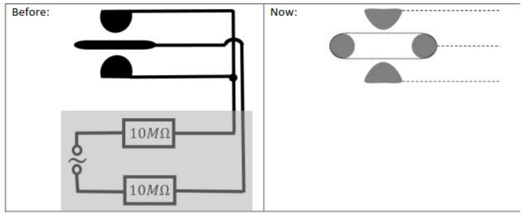
Imagine you place some spores in the centre of the ring electrode. How do you expect them to behave?

Think about how they will be arranged (shape) and where they will be (position).

Decide for one of the **shapes a, b, c, or d** (which are shown bigger than in reality below), and mark the expected **position** of this shape in the sketch of the cross section below.

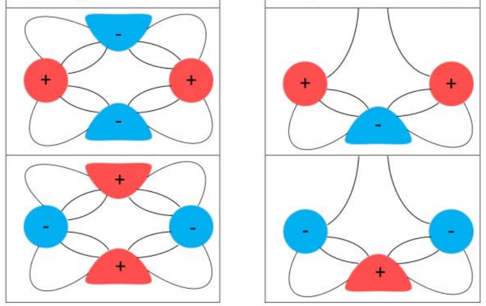
TEACHER GUIDELINES AND SOLUTIONS

For the following experiment, we´ll concentrate on the area around the electrodes. This is why we´ll use a sketch of the electrodes only, instead of a sketch with the cabling.



Draw the electric field lines into the sketches of the electrodes of the usual trap and the one you are going to use. Compare the pictures and conclude on what that means for the construction of the trap. We are going to use the colours to show the momentary charge of the electrodes. (Remember, as we use AC voltage the charge will continuously change.)

Trap with upper and lower electrode	Trap with lower electrode only



In the inner part, between the electrodes, the shape of electric field does not change significantly when the upper electrode is removed. That´s why removing the upper electrode has almost any effect on the experiment.

Appendix:

Further information, you might want to discuss with your students, before performing the workshop

What we will do today:

- You are going to be an antimatter researcher today. Your task is to learn how to trap particles with a quadrupole ion trap.
- Your "particles" today will not be elementary particles like electrons, but very big particle systems, so called lycopodium spores (show container, show picture). Lycopodium spores look like a fine powder; it consists of very small spores (or seeds). Because of friction, these **spores are electrically charged**.

What is antimatter?

- **Ask students first what they think.**
- Every particle has a corresponding antiparticle – a very important symmetry in the Standard Model of particle physics. Most of their properties are identical, for example, they have the same mass. However, their electric charge is opposite.
- One example is the positron, which is the antiparticle of the electron. The positron has a positive electric charge.
- If a particle meets its antiparticle they annihilate, they are converted, for example, into two photons. The process can be reversed: If there is enough energy, a particle-antiparticle pair can be produced.
- Question: How would you make an anti-hydrogen atom? (take antiproton, add positron)

Why is antimatter research interesting?

- We know that during the Big Bang equal amounts of matter and antimatter particles have been produced (charge conservation law). Today, we only see matter around us, the antimatter has disappeared.
- We need to study antimatter, to find out if there are maybe small differences between particle and antiparticles that could explain, why we live in a "matter world". Or maybe there is an antimatter world somewhere far away in the universe?

What kind of antimatter experiments are we doing at CERN?

- One of the many experiments is called GBAR.
- It will try to answer a very simple – but exiting question: Imagine you drop a matter apple on our matter Earth. Everyone agrees, that it will fall down. Now, imagine you drop an antimatter apple on an antimatter Earth. What will happen? Everyone agrees, that the same physics rules would apply, so the apple would fall down. (In fact, if we had a switch that could turn all the matter into antimatter, we wouldn't notice any difference).
- Now the exiting question: If you drop an antimatter apple on our matter Earth, will it fall UP or DOWN? Who thinks it would fall upwards? Who thinks downwards? Who thinks it wouldn't move at all?
- Most physicist believe, it would fall down, but we have never done this experiment!
- Because an antimatter apple is a very complex system, at CERN we use the most simple particle system: an antihydrogen atom
- GBAR will therefore first trap antihydrogen and then do a freefall experiment with it.
  - Question: Why do you we need to trap the antihydrogen atoms first?

CONSTRUCTION MANUAL

3. Required Materials

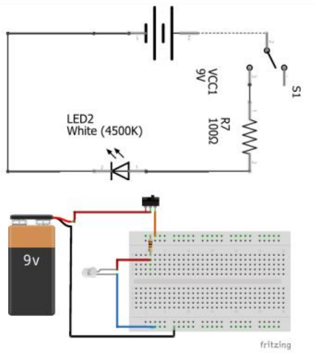
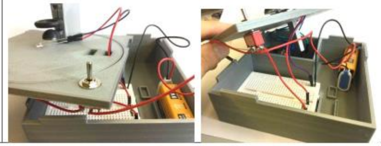
The Table 3.1 below presents all the required materials to build the quadrupole ion trap. Note that the components highlighted in blue are sufficient if you do not intent to build the blinking circuit.

Description	Picture	Price	Online Shop	Stock Number
2 x Resistor (10 $M\Omega$)		8 €	RS Components http://www.rs-components.com *Note any on-off switch will work for the non-strobing circuit however an on-off-on switch is required for flasher circuit.	2960572
Multi Contact 4mm Banana plug sockets		6 € for 2 pieces		404-200
1 × Toggle Switch On-Off-On*		25 € for 5 pieces		448-0753
Male to Male Leads (9 required) Male to Female Leads (6 required)		5 € for packs of 10 (20 € total)		791-6463 791-6454
Electric Paint (Bare Conductive)		20 € for 50 ml		835-2693
Breadboard		18 €		102-9147
Capacitors 1 × 1 μF 1 × 10 μF		Come in packs of 4 for 2 € (4E)		374-910 0571256
Diode		Packs of 10 for 5 €		251-3025
2 × NPN Transistor		Packs of 10 for 3 €		739-0442
Resistors 1 × 100 Ω 2 × 10 Ω 1 × 8.2 kΩ 1 × 10 kΩ		Come in packs of 10 for 3 € (total 12 €)		707-8063 707-8827 707-8902 707-8300
10 kΩ Potentiometer		3 €		468-8705
Battery Strap (Clip)		5 for 4 €		489-021
9V Battery		8 €		841-7002 (or 386-9997)
2 x High power LED		0.12 € per piece	Reichelt Elektronik https://www.reichelt.de	LED 3-6000L GN

Table 3.1) List of required materials

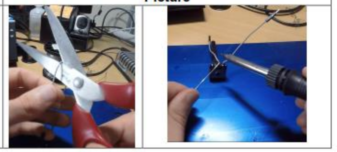
Three M2.5x7 (ISO metric screw thread), and three M2.5 Washer are also required.

To build the trap you will also need a paintbrush, scissors, duct tape, screwdrivers and soldering equipment.

Construct the LED circuit following the circuit diagram and/or breadboard schematic. Attach male to female leads to the LED's before placing on the breadboard. *The diagrams were created using the Fritzing software.* For help identifying resistors please see Section 10: Appendix A – Resistor Bands.	
Place the circuit inside the base. To complete the circuit insert the LED holder and attach the LEDs. Seen final instruction in section 4.2 Strobing Circuit	

4.2. Strobing Circuit

A good extension of the quadrupole ion trap is to observe the charged particles under a strobing light. This section contains instructions for building an 'astable multivibrator', a circuit that causes an LED to turn on and off multiple times per second. This astable multivibrator contains a switch to switch between strobing and continuous LED's and a potentiometer to change the frequency of strobing. The frequency should range between 30Hz and 70Hz.

Description	Picture
Attach leads to the potentiometer. To do this cut a male-to-male (grey in diagrams below) lead in half and strip the ends. Then solder one lead to the middle pin of the potentiometer and solder the second lead to either of the side pins.	

PAPER

Template of Hardware Metapaper

For submission to the *Journal of Open Hardware*

(1) Overview

Title

3D-printable model of a particle trap: development and use in the physics classroom

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Abstract

Quadrupole ion traps are modern and versatile research tools used in mass spectrometers, in atomic frequency and time standards, in trapped ion quantum computing research, and for trapping anti-hydrogen ions at CERN. Despite their educational potential, quadrupole ion traps are seldom introduced into the physics classroom not least because commercial quadrupole ion traps appropriate for classroom use are expensive and difficult to set up. We present an open hardware 3D-printable quadrupole ion trap suitable for the classroom, which is capable of trapping lycopodium spores.

The quadrupole ion trap operates using a 3 kV 50 Hz alternating current power supply and uses an astable multivibrator circuit including high luminosity LEDs to illuminate the spores, using the stroboscopic effect to exhibit their movement.

The trap can be used in teaching laboratories to enhance high school and university students' understanding of electric fields and their applications.

Metadata Overview

Design files & accompanying documents: DOI 10.5281/zenodo.1251787
Link: https://zenodo.org/record/1251787#.Wznxt9IzaUk

Target group: secondary school students, undergraduate students, and their teachers
Skills required: Desktop 3D printing - easy; Point to Point breadboard construction - easy
Replication: For example, a master's thesis on DIY construction of quadrupole ion traps is available in German [3]. Commercial versions of the project can be purchased at Newtonian Labs and LD Didactic [8, 13]. Future versions of designs may be found at DOI 10.5281/zenodo.1251786
See section "Build Details" for more detail.

Keywords

Physics Education; Quadrupole Ion Trap; Paul Trap; Particle Trap.

Introduction

3D printing and 'making' in an educational context has become more prevalent and 3D printers are becoming more widespread in schools and universities throughout Europe, America and Australia [7, 10, 12]. There is also increasing focus on modern physics and particle physics in high school curricula [1, 2, 5]. However, particle physics can be an abstract topic as there are a limited number of hands-on experiments that students can perform.

One type of a 'hands-on' experiment that students can perform is the construction of particle traps such as the quadrupole ion trap. Wolfgang Paul and Hans George Dehmelt developed

PAUL TRAP

Everything is available online at:

https://zenodo.org/record/1251787#.Wz9bHNIzaUk

PARTICLE IDENTITIES

Online Game where you can determine what type of particle fits your personality best:

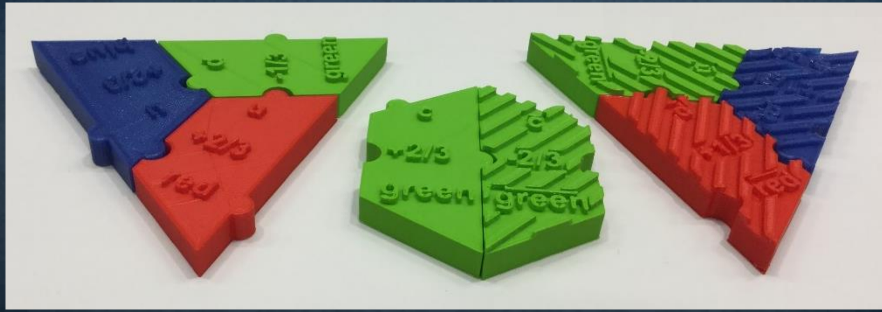
cern.ch/go/fh9J

QUARK PUZZLE

What we worked on:

- Puzzle Design
- Worksheet
- Paper

PUZZLE DESIGN



WORKSHEET

Mission Briefing: Fugitive Particles

Purpose: To discover patterns of various kinds to find a set of rules that govern the mysterious and elusive quarks.

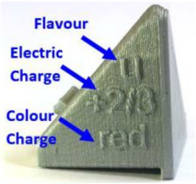
Discussion: It has been trusted to you to discover the rules that the quarks obey. Unfortunately even though the particles make up everything all around you, they are so small there is no way that you are able to see them individually. Luckily, we have obtained a model of puzzle pieces, which obey the same rules as actual quarks.

Your mission ~~should you choose to accept~~ is to use these puzzle pieces to discover the laws that dictate how these particles form groups. You must present your findings as a series of rules that someone else could use to determine possible and impossible combinations of quarks.

For a hint to get started, see guidelines below.

Guide to Quark Puzzle Pieces

Each piece is a model that represents a "**quark**". Every quark has a flavour, an electric charge and a colour charge. You can find these properties printed on the side of the quark.

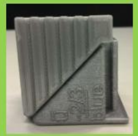


Flavours include up (u), down (d), anti-up ($\overline{u}$) or anti-down ($\overline{d}$).

+2/3 is an example of **electric charge**.

Examples of **colour charge** are red and anti-blue ($\overline{\text{blue}}$).

Some combinations fit together nicely, others ones do not. See diagrams below.

Good Joint	Bad Joint
 Here the pieces fit together nicely.	 Here the pieces do not fit together nicely.

Using groups that fit together nicely to discover the laws and complete the mission.

Hint: If it is difficult to build a group, try dividing sort the quarks by colour charge first and try one from each pile.

Debrief - Comparing the Puzzle to Real Quarks (Research Task)

The puzzle provided is only a model and it does not show what real quarks look like. Do some research and in the table below write down the differences and similarities between the puzzle and real quarks. One row has been completed for you an example:

Category	Quark Puzzle	Real Particles
Shape	In this puzzle, a proton has a cube shape. Pions have a double pyramid shape.	Real protons and pions have no well-defined shape that humans can see or even imagine.
Size		
Empty Space		
Colour Charge		
Electric Charge		
Anti-particles		

PAPER

Quark Puzzle Activities for Open Inquiry into Quarks

Abstract

This short paper responds to the quark puzzle published by Eric Gettrust in The Physics Teacher in 2010. Gettrust calls for a set of three-dimensional objects that fit together in accordance with the color charge symmetries of the Standard Model of particle physics. We provide such a set of puzzle pieces and resources to reduce the barriers of implementing this activity into the classroom.

Introduction

There is an increasing emphasis on fundamental particles, including quarks, in the high school physics classroom. [1,2,3] However, particle physics is an abstract topic and there are few hands on classroom activities. In 2010, Eric Gettrust[4] presented a two-dimensional quark puzzle, a physical manipulative that allowed students to discover the color charge symmetries of quarks through inquiry. His quark puzzle pieces could be joined to form particle systems of three quarks (called baryons) or quark-antiquark pairs (called mesons). The joints of the puzzle pieces color allow only "color charge-neutral" combinations of quark puzzle pieces.

In the paper Gettrust states:[4]

> *"An ideal set of pieces representing quarks would consist of three-dimensional objects that fit nicely together into some basic shape, such as a sphere or some platonic solid, but only for quark combinations allowed by Standard Model rules."*

In 2010, a two-dimensional set of pieces was more accessible to teachers. However since then 3D printing has become widespread in schools throughout Europe, America and Australia[4,5,6] and it is now practical to implement a three-dimensional puzzle into the classroom.

In this short article, we present a 3D printable quark puzzle and give suggestions to implement this activity to the classroom by:

- presenting ready-to-go activities/worksheets for the students
- decreasing the number of pieces required from 36 to 12
- utilising the activity to develop scientific reasoning
- highlighting particle physics misconceptions teachers need to be aware of when implementing this activity

The worksheets also develop students' scientific reasoning, which is key to developing scientific literacy[8]. This gives teachers the opportunity to use this activity even if particle physics is not in the curriculum.

3D Puzzle Pieces

We present an original set of quark puzzles pieces, see Figure 1. These quark pieces can be joined in groups of three to make a cube (Baryon) or two pieces can be put together to make a "double pyramid" (meson). The pieces only fit together if they are consistent with the color charge symmetries of the standard model.

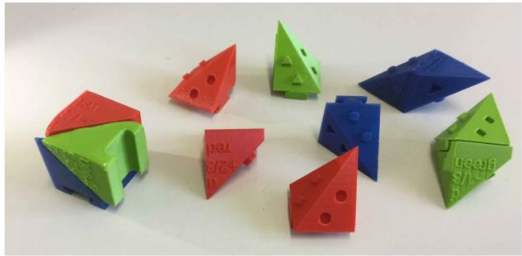


Figure 1: Diagram showing 3D printed puzzle pieces. On the left side a red, green and blue quark are combined to make a baryon. On the right side color and anti-color charge particles create mesons. In the centre are single quark pieces.

Note anti-colors are printed in the same color as the original particles but have a striped texture[9]. It is not necessary to print the pieces in color as the color charge is labelled on the pieces.

2D Puzzle Pieces

We also present a modified version of Gettrust's 2D puzzle pieces, see Figure 2. In light of the work of Wiener et. al. on student's difficulty with the concept of anti-color charge,[9] we have included stripes so students can more easily identify anti-color charge and anti-particles. We also note that the top quark decays so quickly that it does not form hadrons (hadronise).[10] We also provide a 3D printable version of these 2D puzzle pieces.

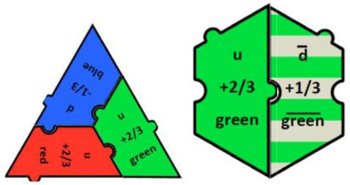


Figure 2: Images of Gettrust's modified quark pieces. The meson shows how anti-color charge is demonstrated using stripes.[9]

The Classroom Activities

QUARK PUZZLE

2D version is available online at:

https://zenodo.org/record/1286989#.Wz-ABNIzaUk

And 3D will be available on Zenodo at DOI:

DOI: 10.5281/zenodo.1252868

GAME HEADS OR TAILS
REAL OR FAKE PARTICLES

Real Particle

Fake Particle

PION

Real Particle

Fake Particle

PION

Real Particle

Fake Particle

FLASHION

Real Particle

Fake Particle

FLASHION

Real Particle

Fake Particle

KAON

Real Particle

Fake Particle

KAON

Real Particle

Fake Particle

STRANGE B MESON

Real Particle

Fake Particle

STRANGE B MESON

Real Particle

Fake Particle

CHARMED SIGMA

Real Particle

Fake Particle

CHARMED SIGMA

Real Particle

Fake Particle

STRANGE KAON

Real Particle

Fake Particle

STRANGE KAON

Real Particle

Fake Particle

CHARMED SIGMA

Real Particle

Fake Particle

CHARMED SIGMA

Real Particle

Fake Particle

BOTTOM LAMDA

Real Particle

Fake Particle

BOTTOM LAMDA

Real Particle

Fake Particle

STRANGE DELTA

Real Particle

Fake Particle

STRANGE DELTA

Real Particle

Fake Particle

BOTTOM SIGMA PRIME

Real Particle

Fake Particle

BOTTOM SIGMA PRIME

Real Particle

Fake Particle

TRIPLE CHARMED XI

Real Particle

Fake Particle

TRIPLE CHARMED XI

Real Particle

Fake Particle

CHARMED DELTA

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CHARMED DELTA

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Fake Particle

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Fake Particle

ETA

Real Particle

Fake Particle

STRANGE D MESON

Real Particle

Fake Particle

STRANGE D MESON

Real Particle

Fake Particle

TOP B MESON

Real Particle

Fake Particle

TOP B MESON

Real Particle

Fake Particle