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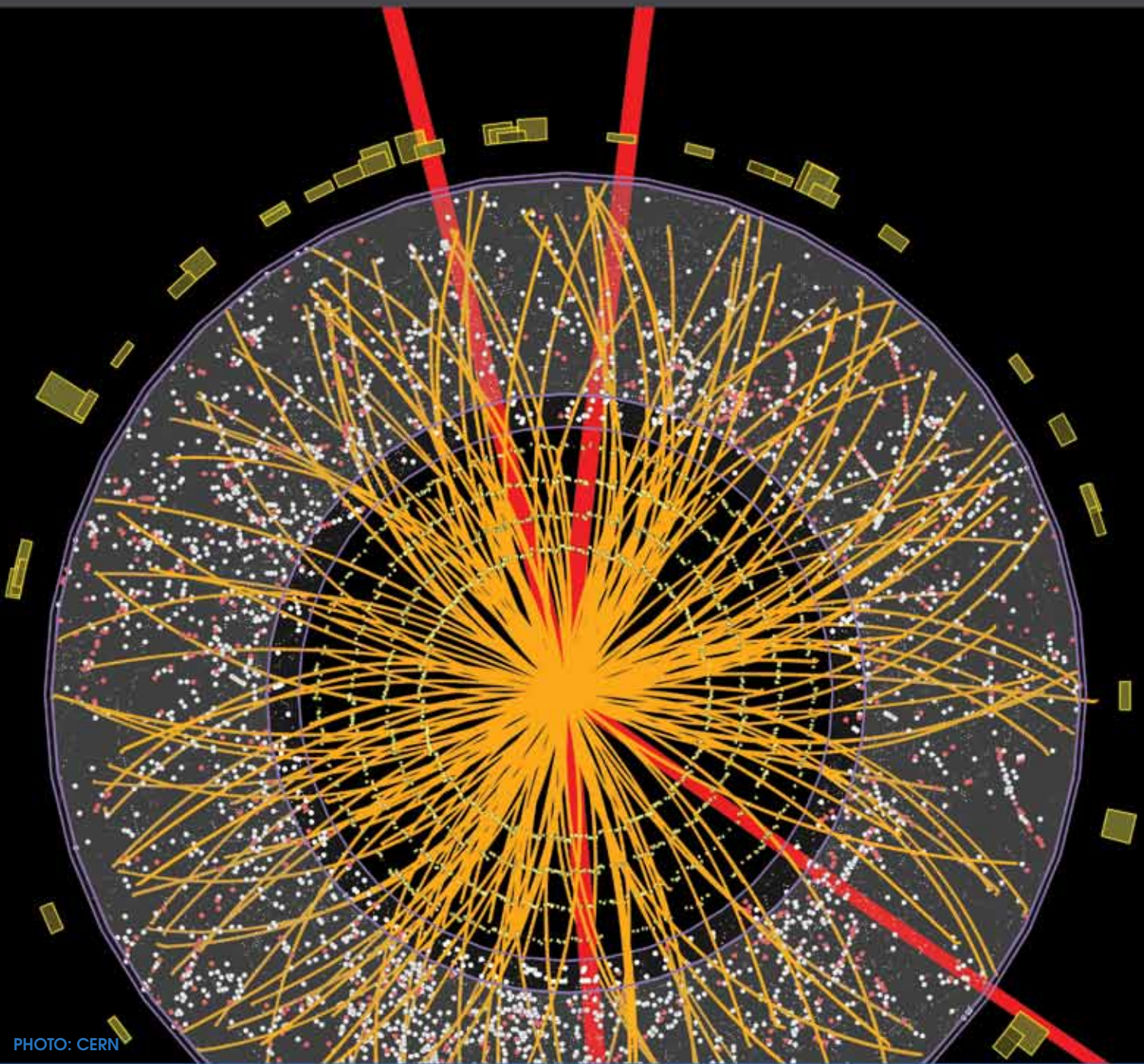


PHOTO: CERN

CERN@school

USERS' GUIDE

CONTENTS

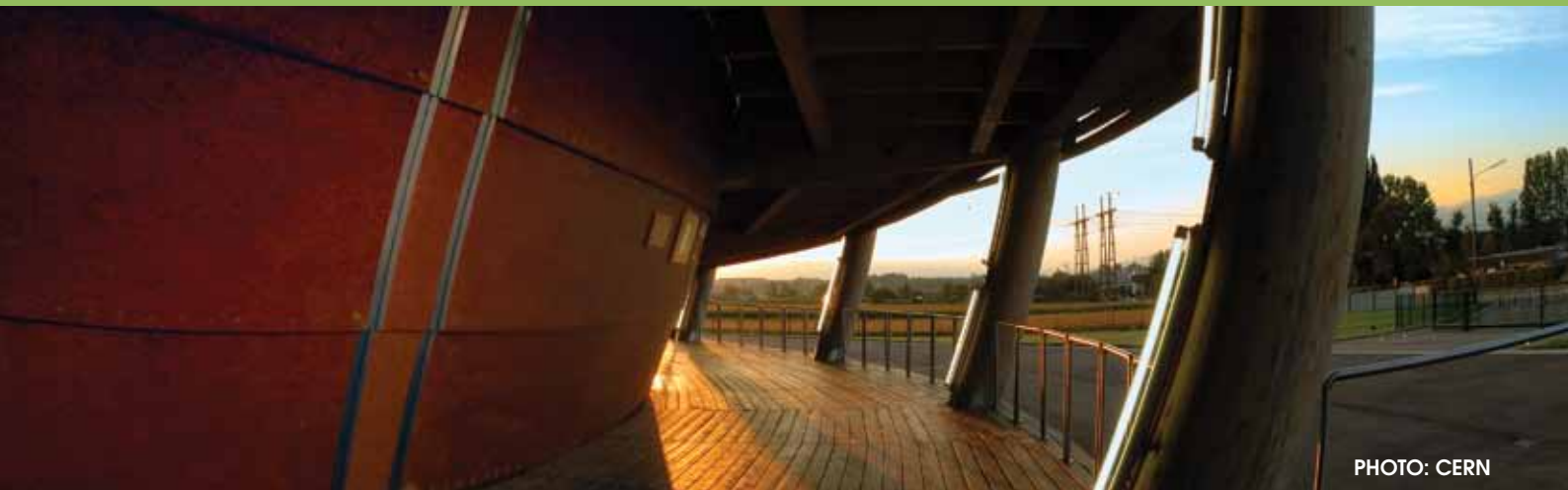


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PAGE

- 1 Introduction
 - 2 Curriculum links
 - 3 The detector
 - 4 School case studies
 - 6 Ionising radiation
 - 7 First measurements
 - 10 Data analysis
 - 11 Troubleshooting
 - 12 Further sources
-

INTRODUCTION

The CERN@school kits contain a Timepix detector based on CERN technology, versions of which are used in current experiments at the Large Hadron Collider. Access to these detectors offers students and teachers an opportunity to explore the workings of CERN firsthand and to build knowledge and experience of how the technology works.

This guide provides information on the CERN@school detector and how to get started using it in class. It is part of a package of resources and the package includes a curriculum guide, a users' guide (this document) and suggested experiments. The curriculum guide covers the relevant aspects of the curriculum. The suggested experiments are there to help you get started using the detector in the classroom and are available to download from our website: www.researchinschools.org



PHOTO: CERN

The CERN@school programme aims to give students an experience of what a research environment is like. This means investigating a theory or question of interest by designing an experiment using the detector. The data gathered is then analysed with results and conclusions shared with other schools in the CERN@school programme, as would be done in any other research collaboration. This could take place at our annual research symposium by presenting a talk or poster or simply by sharing results with others.

The detector widens the scope of investigative work available in class, particularly in the topic of radiation, as it provides data well beyond that which is available from a Geiger Muller (GM) tube. It provides detailed information on the type of radiation, e.g. alpha, beta and gamma.

The detector is not intended as a replacement for a GM tube in school experiments. The experiments where you would normally use a GM tube can be a good starting place to allow familiarisation with the detector. Instead it is offered as a tool to enable students and teachers to take one step beyond set classroom experiments to develop investigations and carry out research based on their own ideas.

CURRICULUM LINKS

STUDENTS AGED 14-16 YEARS

The detector can support learning in various areas of Physics National 5, Physics GCSE (English, Northern Irish and Welsh) and Irish Junior Certificate. This includes:

- identification of ionising radiation, including the exploration of the properties of alpha, beta and gamma
- background radiation, how it varies with location and what its sources are
- the decrease of radioactivity over time leading to further study of half-life and its implications for nuclear waste

Data from the detectors on the International Space Station (ISS) and the LUCID experiment on board TechDemoSat-1 are available for analysis. This is a further opportunity to link to the aspects described but instead of a practical activity or experiment, students can develop their data analysis skills.

STUDENTS AGED 16 YEARS AND OVER

Work with the detector links to different topics within Physics Higher and Advanced Higher, Physics A-level (English, Northern Irish and Welsh) and the Irish Leaving Certificate.

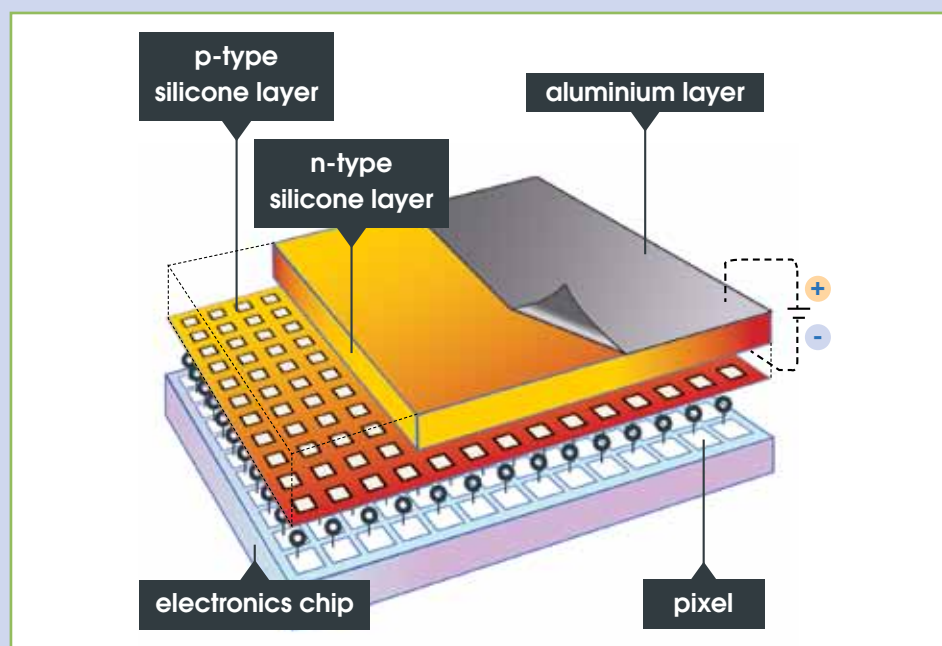
- The detector offers the opportunity for identifying and investigating the properties of alpha, beta and gamma radiation. This includes investigating the range and penetration of these types of radiation and the effects of deflection in a magnetic field.
- The measurements taken with the detector can lead to an understanding of the evidence for the nuclear model of the atom and how our model of the atom has changed over time.
- The detector can be used to provide a demonstration of the inverse square law.
- A study of background radiation, its origins and implications for experimental calculations can be undertaken with the detector.
- The detector can be used as an example of particle detection technology and an investigation into how it works can support students' awareness of particle accelerators and their operation.
- It is possible to capture evidence of a cosmic ray event using the detector. This is in the form of a muon interaction. This can provide context for further study of the particles produced in a cosmic ray event and the source.
- To support the aspects relating to cosmic rays and the properties of alpha, beta and gamma radiation, data from the Timepix detectors onboard the International Space Station and those part of the LUCID experiment on TechDemoSat-1 can be used. In particular students can investigate cosmic rays, their origin and effects. This data can also support investigation of the solar wind as it interacts constantly with our own magnetic field.

Detailed information covering these aspects can be found in our separate CERN@school curriculum guide available to download from our website: <http://www.researchinschools.org/>

THE DETECTOR

Silicon detectors were developed at CERN for the Large Hadron Collider but are now used in a wide range of scientific fields, in medical laboratories and in space as part of satellite experiments.

- The CERN@school detector is a Timepix chip. It is based on a detector designed by the Medipix2 collaboration but has additional modes of operation. The detector is a complementary metal oxide semiconductor (CMOS). The manufacturing technique used to produce them is similar to that used to make microprocessors. This has meant that costs are lower than other types of detectors.
- The detector is described as being “hybrid” as silicon layers are bonded with an electronics layer. When ionising radiation strikes the detector its energy is deposited in the silicon layer. This is then converted into an electrical signal and amplified. The pattern of the energy deposited across numerous pixels allows for identification of alpha, beta, gamma, muon, etc. Please see the Ionising Radiation on page 6 for a description of how these types are identified by the CERN@school detector.



- Each pixel is made up of a reverse biased diode and other electronics including an amplifier. The ionising radiation is able to produce an electrical signal in the detector because as it strikes the silicon it causes electrons and holes to form. Due to the applied voltage these electrons and holes move in opposite directions causing a current to flow. The design of the detector is such that each pixel has its own piece of p-type silicon to allow it to operate independently but then they all share a common n-type layer.
- The small pixel size offers benefits in terms of the type of experiments (those with small movements or deflections) that can be done. For example, Chris Shepherd at the Institute of Physics has designed an experiment that has been used to demonstrate the deflection of an alpha particle in a magnetic field.

- 256 x 256 pixels
- Area of 2cm²
- Pixel size of 55 μm

SCHOOL CASE STUDIES

There are different approaches to using the CERN@school Timepix detector in school. Research projects can be teacher-led or student-led. The case studies below outline the different approaches taken by teachers in schools.



Where project work is completed outside of timetabled classes there is still the opportunity for students to gain a qualification. Schools in England and Wales can submit their sixth form students for an Extended Project Qualification (EPQ). This has been done very successfully by CERN@school participants.

However, regardless of whether a qualification has been gained, students who have mentioned their involvement in CERN@school as part of their UCAS personal statements have had very positive feedback from academics at interviews and open days. The skills developed are highly valued by universities.

TEACHER-LED

Using this approach, teachers use the detector to support various aspects of the curriculum. This can be through a range of investigations and experiments in class before individual students or small groups then use the detector for more in-depth investigations. Often the subsequent report is examined and can contribute to their physics qualification or to an EPQ award. The benefit of the detector being used in class alongside relevant topics, is that students become familiar with it and how it works before developing an idea for investigation.

- Dave Cotton from Cardinal Newman Sixth Form College in Preston uses this approach. The detector goes into each class when they are covering radiation and is used to differentiate between alpha, beta and gamma. By using the detector like this Dave finds that it provides a very visual way of demonstrating the properties of alpha, beta and gamma. Students then go on to investigate other effects, including the inverse square law. Subsequent to the detector being used in class, Dave establishes a smaller group of students who work outside of timetabled hours to complete an experiment. Recently students have been working on alpha deflection. They have made predictions, designed the apparatus (based on an idea first developed by Chris Shepherd of the Institute of Physics), collected data and analysed it. Each student is responsible for a different aspect of the experiment and will be writing this up to submit for an EPQ.

■ Derek Osborne of Llandrindod High School and Tim Browett of Robert Gordon's College in Aberdeen take a similar approach. They use the detector whenever you would normally use a GM tube. This is a way to highlight the differences between the two pieces of equipment and to show the flexibility of the detector.

- Tim Browett's students first come across it in their National 5 course where they look at the types of radiation and have a chance to investigate half-life. At Higher, students can then work in groups of two to three to complete an investigation. Then at Advanced Higher students need to complete a piece of work individually to submit. Areas of investigation at Robert Gordon's have so far included half-value thickness, beta deflection and how the detector itself works.
- Derek Osborne's sixth form students carry out experimental work using the detector. They have taken soil samples from a range of areas to test along with vegetation and water samples. This work has been voluntarily carried out in their own time with evenings and weekends being used to collect data and perform analysis.

PHOTO: CERN



STUDENT-LED

In some instances, teachers have handed the detector directly to students as soon as it was received.


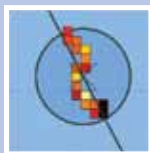
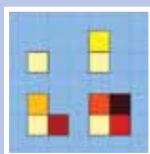
This is the case with Janet McKechnie at Pate's Grammar School. They have a tradition of sixth form students carrying out their own research. This is organised by a student committee that supports students in identifying projects to work on. The research is then normally carried out in their own time. In the past the detector has been used for a project and Pate's Grammar School students have attended and presented at the CERN@school symposium.

This approach is beneficial if the teacher has limited time available and the group of students are motivated and have a goal to work towards.

IONISING RADIATION

Students will need to have some understanding of ionising radiation before work with the detector begins. The curriculum aspects most relevant to CERN@school can be found in the CERN@school Curriculum Guide.

Assuming students have an understanding of the properties of alpha, beta and gamma, the information below provides further description of what happens when one of these types of radiation interacts with the detector.

Type	Description	Track	Comment
Alpha, α	Helium nucleus: high energy, low speed and high mass	Appears as a spot 	On entering the silicon alphas are stopped very quickly, with energy spread uniformly
Beta, β	Electrons or positrons: high energy, high velocity	Wiggly line 	Wiggle is produced as beta moves further through the chip. Energy spread over a larger number of pixels than alpha
Gamma, γ	High frequency electromagnetic radiation	Dot 	Gamma continues to pass through the detector only interacting with a small number of pixels

Potential sources to use with the detector include:

Source	Type of radiation
Cobalt-60	Gamma (low energy betas may need to be filtered out)
Strontium-90	Beta
Americium-241	Alpha and some gamma

When using sources in school you should follow the advice issued by CLEAPSS and SSERC (see the Further Sources section on page 12 for links to their guidance).

FIRST MEASUREMENTS

It is recommended that you follow these steps when first using the detector.

- 1 Take the Timepix chip out of the flight case.
- 2 Connect the device to the laptop using the USB connector provided.



- 3 Power up the laptop. The indicator light on the detector should be green.



- 4 The software package that controls the detector is called Pixelman and is made available by the Czech Technical University, Prague. Open up the Pixelman software.



- 5 Arrange the Timepix chip as required by the experiment or investigation. Uncover the sensor (this action is not necessarily needed if you are recording beta and gamma counts) but do not touch the sensor.



CLOSED



OPEN

- 6 The picture settings tab can be expanded to vary the colours used to display the types of radiation detected. This can be set based on personal preference but to replicate the settings of the measurements shown in this guide and in the experiment guides see the picture opposite.



- 7 Using the Pixelman software prepare the detector for taking measurements by varying the fields identified by the experiment. It is recommended that you start with the "Measuring Background Radiation" experiment, available to download from our website.

There will often be an instruction to set the *Bias*. This is done by selecting *Options* from the menu and choosing *Bias*. A window pops open to allow you to enter the value instructed by the experiment description. The bias restricts the charge from particle interactions diffusing across too many pixels. If the charge was to spread out, then there is the potential for overlap between clusters and this would affect the results.



In addition to this, the two fields *Exp. count* and *Exp. time* are the ones used most ("Exp." stands for exposure). The first sets the number of measurements to be taken and the second the length of each measurement.

- 8 Press "start" and begin collecting data. The indicator light on the detector will be red whilst measurements are being taken. See the Data Analysis section on page 10 for an introduction to Pixelman.

Each measurement taken by Pixelman is referred to as a "frame".



- 9 When data collection is finished, cover up the sensor then save measurements in Pixelman.

There are two options when saving measurements. Select the File menu and then *Save measurement*. This will save two text files for each frame:

- one containing X, Y, C which are the co-ordinates of each pixel (X,Y) registering a hit during the measurement and C is the count
- the second is a text file format that contains the detector settings whilst the measurement was taken.

If required it is also possible to save an image file (PNG format) of each frame. To do this select the Export all frames option in the File menu.

The file window will ask for a destination of the files. Try to name your files and folders so that it is easy to go back to and analyse data at another time.

10 Unfortunately Pixelman does not export the data from the table showing the numbers of alpha, beta and gammas. To record this, as each frame is displayed you need to copy and paste this into a spreadsheet programme.

11 Once you have completed your measurements and saved the results, disconnect the detector from the laptop and pack the items back into the flight case.

12 We would encourage you to share your results with others. This can be done by uploading them to our analysis website:

<http://starserver.thelangton.org.uk/analysis>

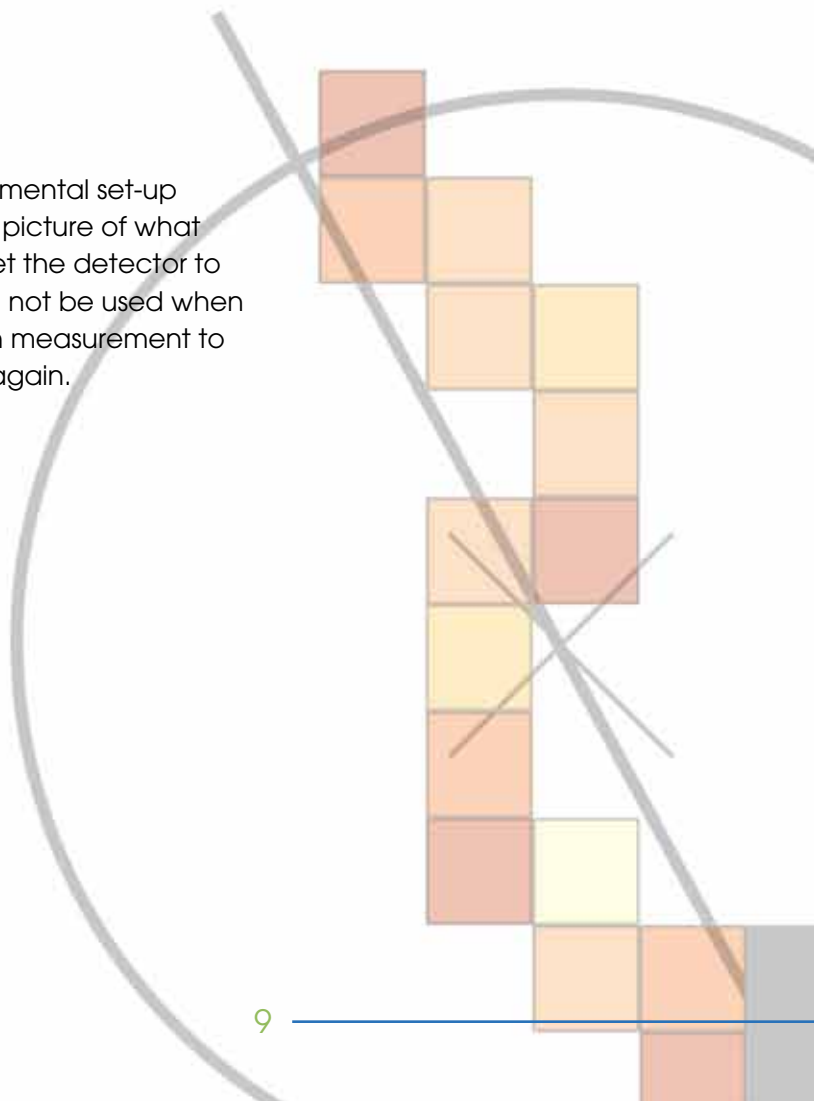
This will also provide a summary of the alpha, beta and gamma counts. Once logged in you will be able to view all of the data uploaded by other schools. Therefore if you are interested in comparing background radiation readings, you will be able to access this information here.

The suggested experiments and investigations are updated regularly so please visit our website to download the most recent versions:

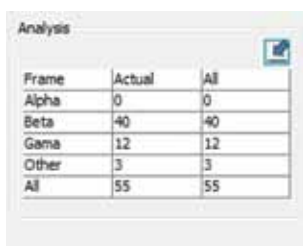
www.researchinschools.org

INTEGRAL MODE

If the detector is being used to demonstrate an experimental set-up then selecting integral mode is a way of building up a picture of what is being detected over time. For example, you could set the detector to take one hundred 3 second measurements. This would not be used when collecting data for analysis as the detector adds each measurement to the same frame and these cannot be separated out again.



DATA ANALYSIS



Frame	Actual	All
Alpha	0	0
Beta	40	40
Gama	12	12
Other	3	3
All	55	55

Pixelman will provide analysis of the frames taken with the detector. A summary of the radiation types is given in the display.

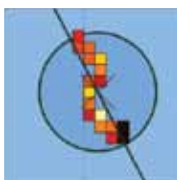
Each type of radiation is recognised as they have their own pattern:

alpha



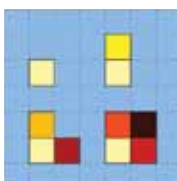
■ Alpha: appears as a blob, as it deposits its energy very quickly

beta



■ Beta: strikes several pixels in a chain as it deposits its energy in the detector

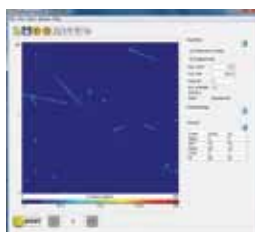
gamma



■ Gamma: can interact with 1-4 pixels, registers high energy

■ Muon:

It is possible to capture the signal of other types of particles, this includes muons. Muons are produced when a cosmic ray interacts with our atmosphere. This event causes a cascade of particles which are detectable at the surface. By placing the detector so that it sits vertically it is possible to capture an image of a Muon. The track will likely appear as a straight line across the chip from the top to the bottom. The track differs from that of a Beta particle as the Muon has a higher mass and is travelling very quickly. The rate at which Muons reach the surface is 1 per square cm per minute.



As mentioned earlier, another option for analysis which does not require the use of Pixelman is an online system called Timepix Analysis Platform At School or TAPAS: <http://starserver.thelangton.org.uk/analysis/> This allows for the review of measurements after the detector has been passed to another school or on other computers than the laptop provided. Students and teachers are able to register for an account by visiting the website.

You can also transfer the data to an Excel spreadsheet or write a program to analyse it. You can access a library of programs written for CERN@school projects here: <https://github.com/CERNatschool>

REVIEWING PREVIOUS MEASUREMENTS

If at any time you want to review previous measurements taken by the detector, you can load these in Pixelman. Open the software, select the *File menu* and *Load file*. You can then select the appropriate frame from your saved measurements.

TROUBLESHOOTING

1 Pixelman won't open.

If you try to open Pixelman without connecting the detector, then you will see this window appear:



To fix this, cancel any open Pixelman windows and connect the detector to the laptop via the USB cable. Pixelman will now open as the license for use is associated to the detector itself. This means that any data analysis done using Pixelman will require the presence of a detector.

2 The Pixelman display looks different to the one featured in this guide.

There are some settings that can be varied with Pixelman. To ensure they are set up in the same way as the software referenced in this guide ensure the following:

- In the *Options* menu under *Measurement* mode the *Spectrometer* setting should be selected.
- In the same menu under *Analysis* type select *Basic*.
- In general the *Layout* option selected is *Normal*. However by selecting *Compact* you can move your cursor over the frame and for the X,Y co-ordinates and the values registered by the detector will be displayed in the table.
- Note that if you are moving between settings Pixelman may have to be restarted and any data waiting will be lost unless you have saved it beforehand.

3 The number of betas and gammas are lower than expected.

It is important to consider the detector settings when designing an experiment. Due to the way in which the software identifies the type of radiation, there can come a point beyond which radiation strikes have overlapped to the extent that the summary table won't give an accurate number. This can be easily fixed by shortening the length of the measurement.

If you have any other queries or questions, please contact CERN@school via info@researchinschools.org and we will be happy to advise.

FURTHER SOURCES

Jablotron (detector manufacturers)

<http://www.particlecamera.com/index.php/about-mx-10>

Pixelman

<http://aladdin.utef.cvut.cz/ofat/others/Pixelman/index.html>

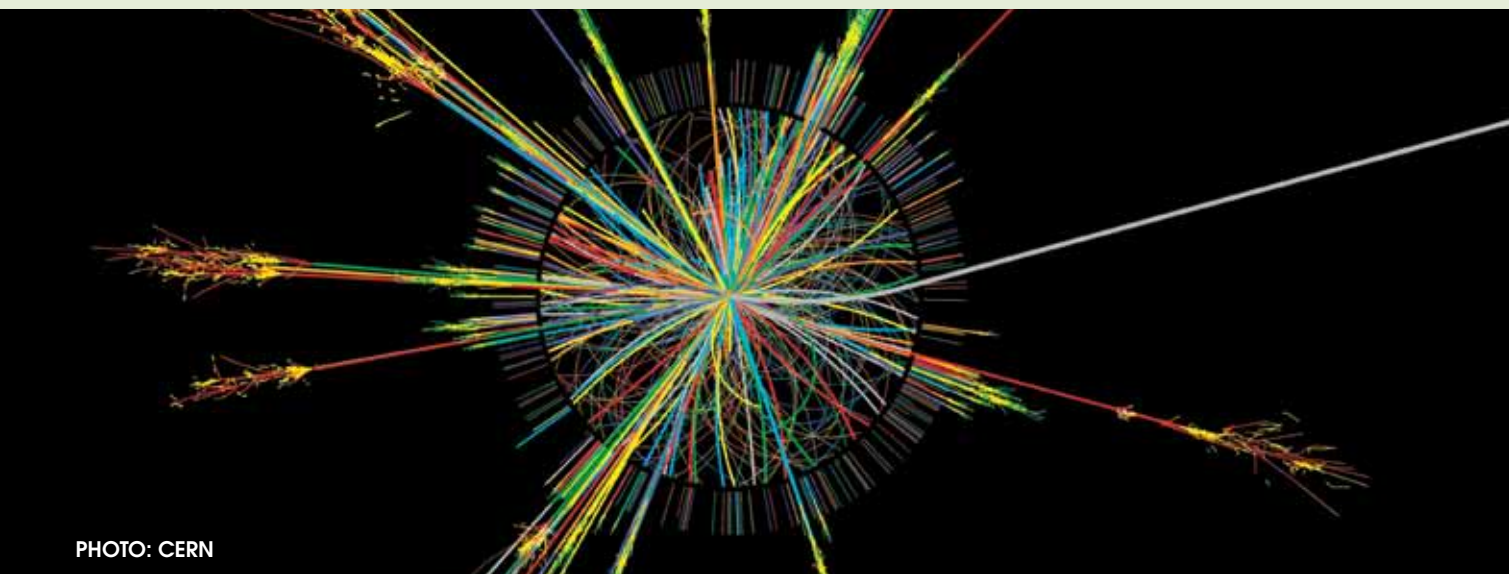


PHOTO: CERN

Radiation Guidance from SSERC (requires log-in)

<http://www.sserc.org.uk/index.php/health-a-safety>

Radiation Guidance from CLEAPSS

<http://www.cleapss.org.uk/secondary/radiation-advice>



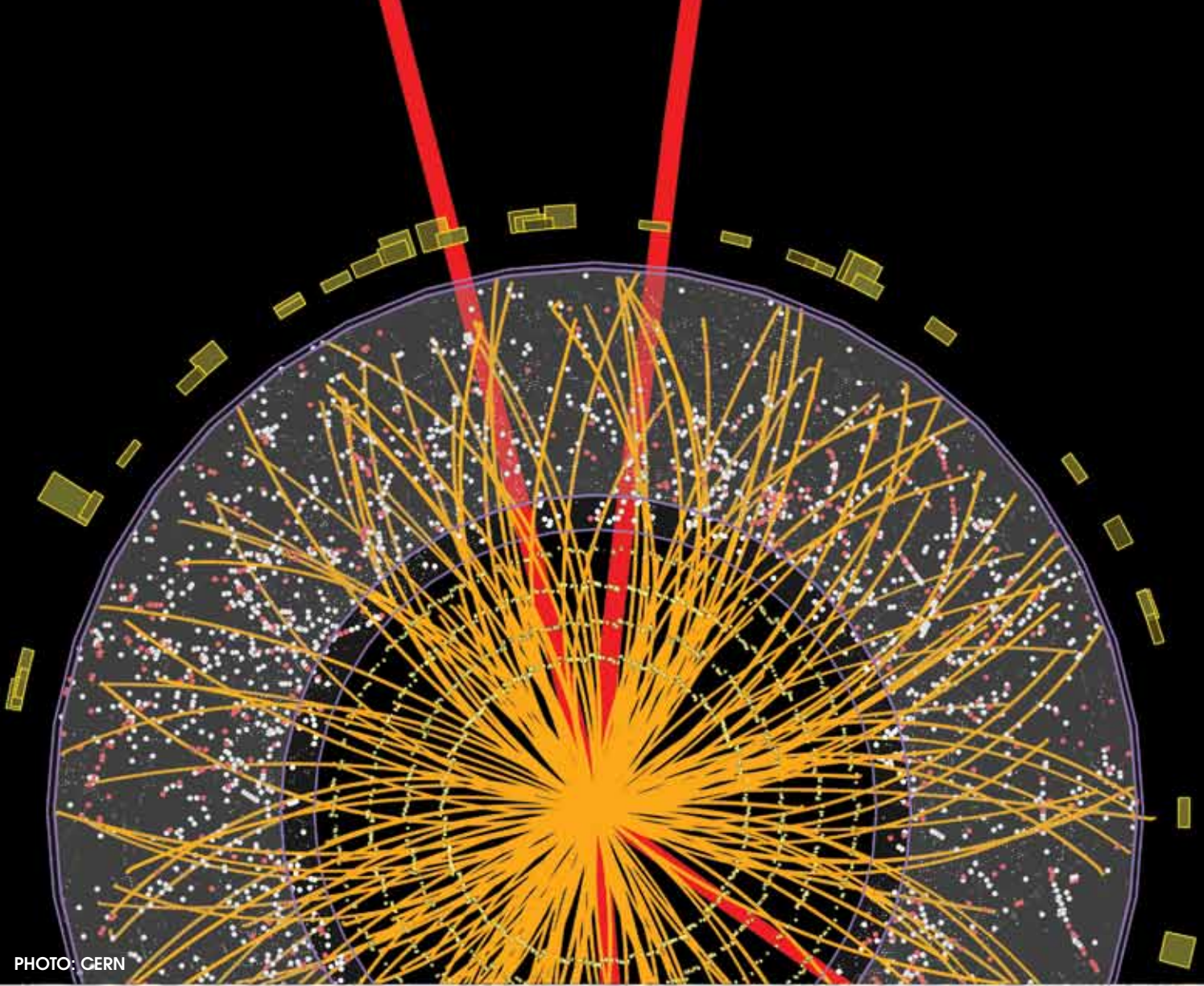


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