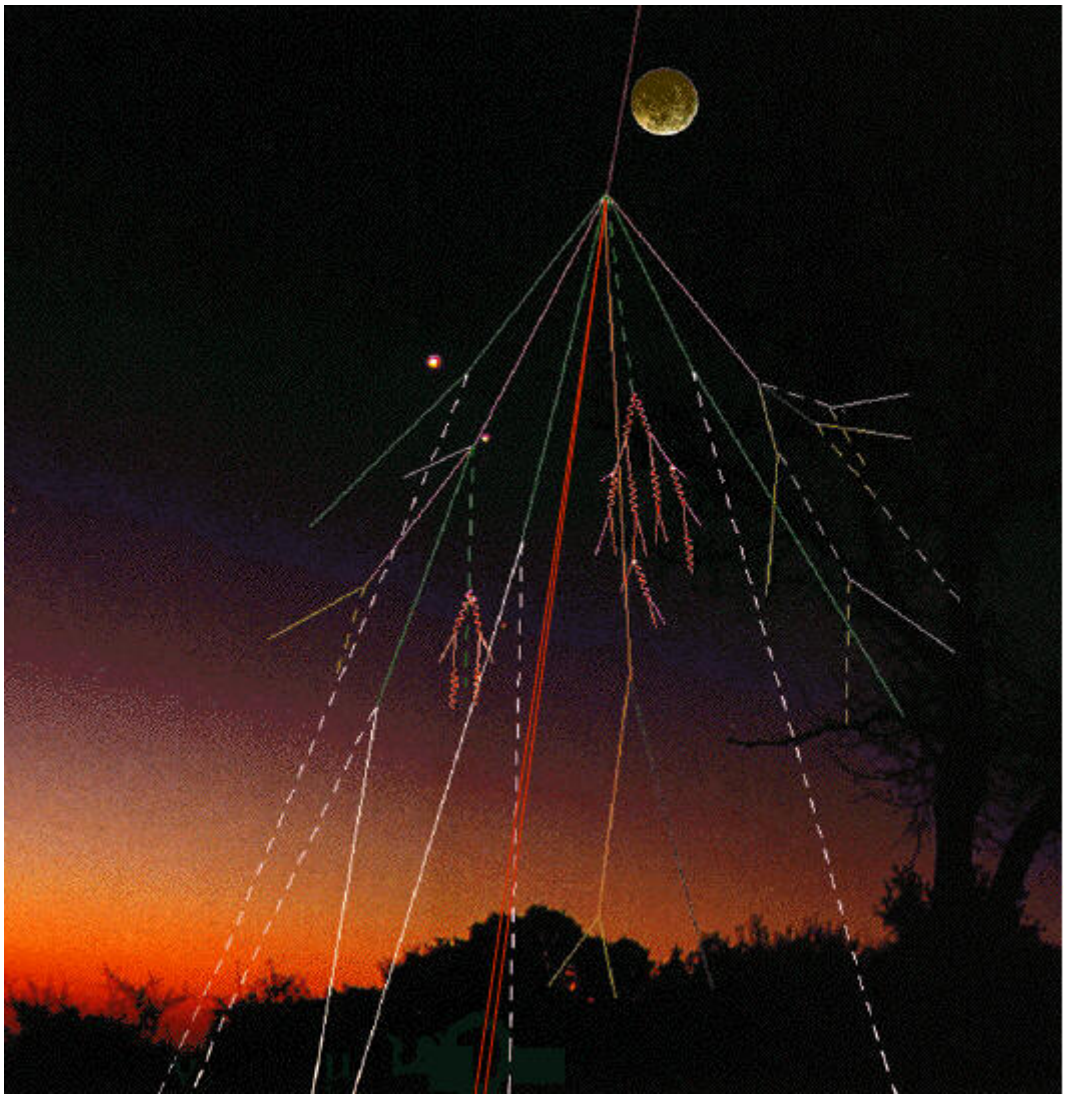


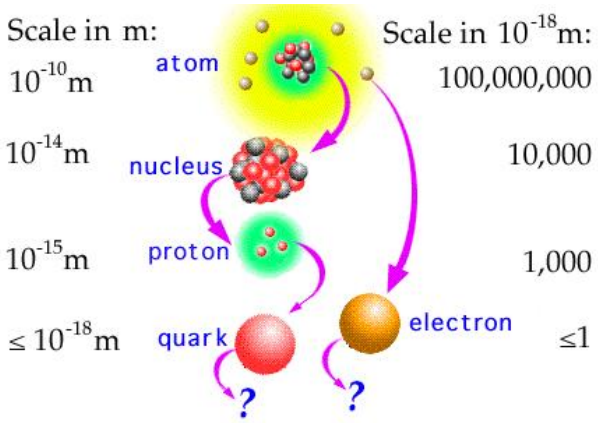
# Searching for Cosmic Rays

## Student Pack

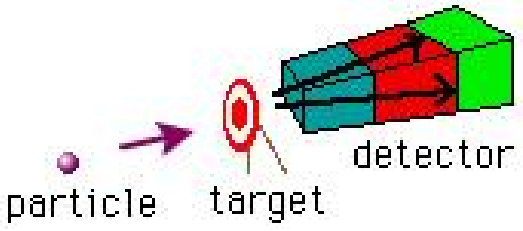
THE UNIVERSITY
OF BIRMINGHAM

Written by James McCarthy for the University of Birmignham. Developed from Quarknet by Fermilab.

# 1 Worksheet 1: Introduction to the Project

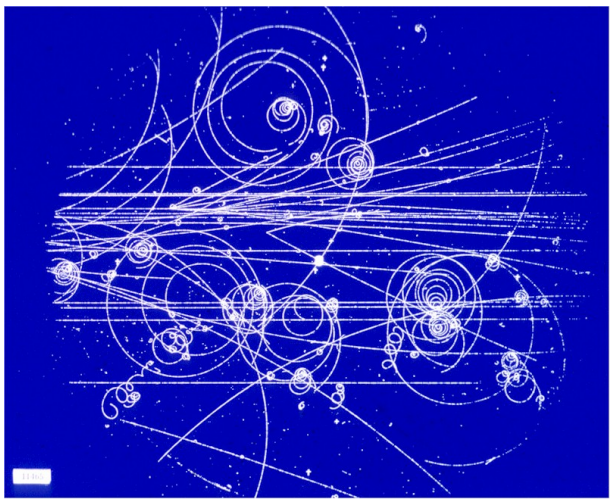



The main aim of this project is to give you some experience of carrying out modern particle physics experiments, and to introduce you to some of the difficulties faced with these experiments. Particle physics is an area of physics which is interested in the universe on a tiny scale. We ultimately want to be able to answer the question *"What are we made up of?"* We know that all organic life is made up of molecules, and that these in turn are made up of complex arrangements of atoms. We can break these up further since we have our picture of the atom as a nucleus being orbited by electrons, and that the nucleus contains a number of protons and neutrons. The number of protons in a nucleus determines which element the atom is, and hence how it behaves chemically. But the important point for particle physicists is that the atom is made up of protons, neutrons and electrons. But can we split these up any further? Well, it turns out that for the electron the answer is no! The electron cannot be broken down into any smaller constituent particles. As far as we know, the electron is not made up of any other particle. In the particle physics jargon we say that it is a *fundamental* or *elementary* particle. However, the story for the proton or neutron is very different indeed. Experiments in particle physics starting in the 1960s have proved beyond any doubt that protons and neutrons are not fundamental, but are made of fundamental particles called *quarks*.




The proton was first discovered in 1919 but quarks were not even proposed until 1964, and not discovered until around 1968. So you might ask "Why did it take 50 years to find out what a proton is made of?" and that is a sensible question. The main difficulty we have when it comes to performing particle physics experiments is the fact that particles are so incredibly small. The proton has a diameter of around $10^{-15}$ m. That's one million billionth of a metre! The most powerful optical microscope in the world can view objects which are no smaller than $10^{-9}$ m, which is incredibly impressive, but the proton is 1 million time smaller than this. Since we have no chance of directly seeing a proton, we require some very clever and very sophisticated techniques in order to show that it is there and to perform experiments on it. In fact, the most common experiment carried out is to fire a beam of particles, for example electrons, at a target made purely of protons, and to investigate the angles at which the electrons are deflected. The distribution of particles after they have been through the target can tell you many things, including the size of the target

particle. This type of experiment, where a beam of particles is fired at a target, is usually called a fixed target experiment.



Particles colliding in a Bubble Chamber

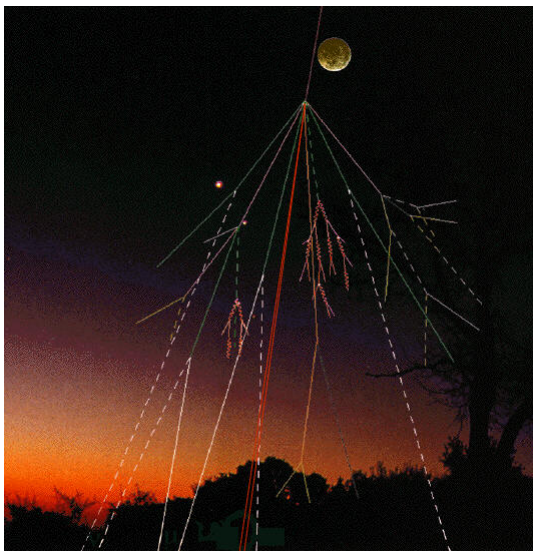
Performing experiments on the quarks inside the proton is much more difficult. In order to observe quarks, the particles in the beams have to be at extremely high energies. If the particles have a high enough energy, then they can break apart the proton and interact with the quarks inside. However, the quarks will never remain separated, and will very quickly form new particles. Particles are created from the energy of the collision. You may have come across Einstein's famous equation: $E = mc^2$. This equation tells us that any particle which has a mass, m, also has an energy associated with that mass which can be calculated from Einstein's equation. This works in the opposite direction as well: if we have some energy (i.e. from our collision between particles) we can create particles which have mass. If the energy of the collision is increased, then we can make particles of higher mass. This is the main goal of particle physics experiments, to collide particles at the highest energies possible in order to create new particles which have never been seen before, but could provide us with the clues we need to answer the big questions in particle physics. However, it gets increasingly difficult to make beams at the highest energies, and so we are constantly looking for new ways to produce high energy collisions.

Many current particle physics experiments, rather than having a beam of particles colliding with a fixed target, collide two beams of particles travelling in opposite directions. This means that the energy of the collision will be much higher. The highest energy collisions are currently being

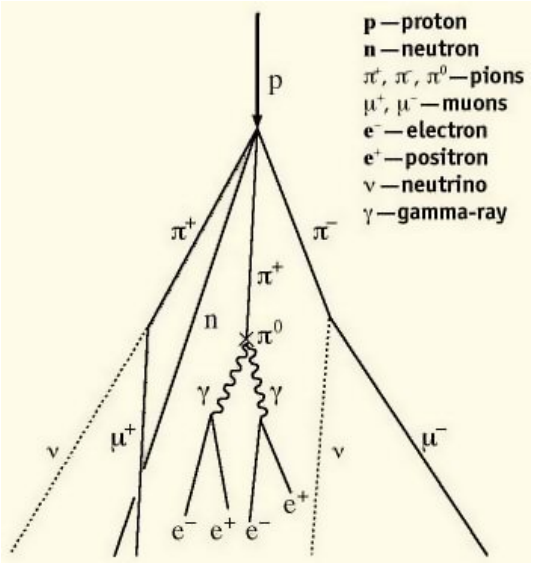
produced at the Large Hadron Collider (LHC). This has two beams of protons travelling in opposite directions around a 27km tunnel 100m underground. The protons collide at an energy of 14 TeV (TeV stands for tera electron-volt; 1 TeV = $10^{12}$ eV). Measuring which particles are produced in these collisions requires sophisticated detectors and extremely fast electronics in order to keep up with the number of particles produced and the rate at which collisions take place. The detectors required are the size of a building and contain millions of electronic readout channels.

Clearly, it is not feasible for a single group to pay for and manage an experiment of this scale. For this reason, particle physics experiments tend to be international collaborations. People from different groups (e.g universities, national laboratories etc.) all contribute to the experiment, designng the detetors and the electronics and then analysing the data which is recorded once the machine is up and running. Experiments record a huge amount of data, which needs to be sent all around the world so that everybody on the experiment can access it from their office in order to run their analysis. Particle physicists have therefore had to develop sophisticated, large scale computing systems which are capable of coping with the enormous flow of data.
Throughout this project, you will experience some of the difficulties we face in detecting particles, collecting and interpreting data and in collaborating with groups from all around the country.

## 1.1 What are cosmic rays?



Cosmic rays are particles which originate in outer space. They are principally protons, with a small fraction of alpha particles and some heavier nuclei. There are many different sources of cosmic rays in the universe: for example, supernovae. When a large star comes to the end of its life, it collapses in on itself, which causes a huge explosion, and a shockwave which accelerates nearby particles to high energies and flings them off in all directions. Cosmic rays which originate from astrophysical sources like this are usually called *primary* cosmic rays. Since the universe is mostly empty, a lot of these particles will just travel through space without ever encountering another particle. Some will actually hit the Earth. Luckily, we are protected by our atmosphere. When the primary cosmic rays approach the Earth, they collide with nuclei in the atmosphere. The energy of these collisions will then make new particles, called *secondary* cosmic rays. These particles will then also interact with the upper atmosphere to produce yet more particles, and so for each primary cosmic ray, a shower of secondary cosmic rays will be produced. Some of these secondary comsic rays will then travel down to ground level where we can detect them.

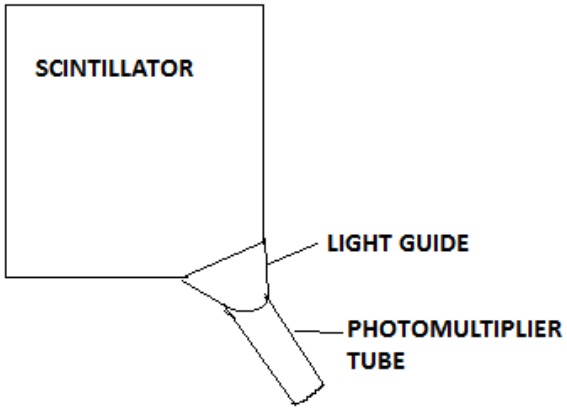



But why are we interested in cosmic rays? Some high energy primary cosmic rays produce collisions in the atmosphere with an energy of 140TeV, 10 times higher than the LHC can produce. Studying

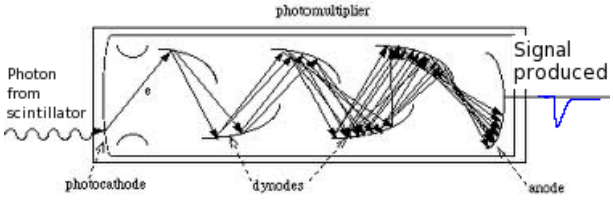
the collisions of these ultra high energy cosmic rays is therefore extremely useful for particle physics. The only problem is that it is impossible to control the collisions, and difficult to put detectors in the atmosphere where the collisions take place. Also, most cosmic rays have a much lower energy than this, and so it is quite rare to see these ultra high energy cosmic rays. However, studying the secondary cosmic rays which reach sea level can give us valuable information about the sources of the primary cosmic rays.

## 1.2 How can we *"see"* cosmic rays?

Within the shower of secondary cosmic rays there will be a lot of muons. These are leptons, like electrons, but much heavier, and we can detect muons using scintillation counters.



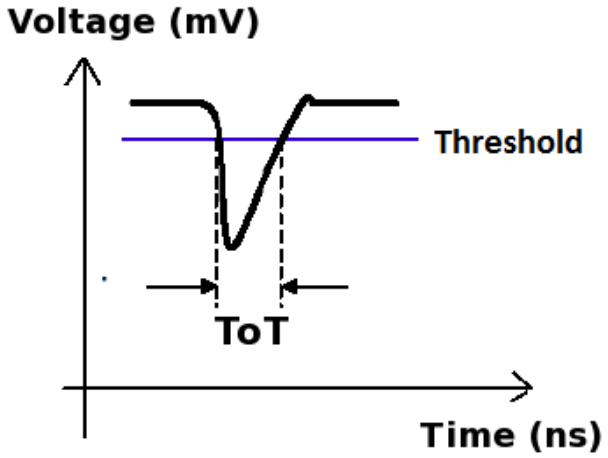

They consist of large squares of a plastic material called scintillator. When a charged particle, like a muon, passes through the plastic, it uses some of its energy to remove electrons from the atoms, or ionises it. The electrons then try to join back up with the atoms, but they can only do this if they give off some of their energy by emitting photons, or a flash of light. The light then bounces around the scintillator until it reaches one corner, where we have placed a photomultiplier tube, or PMT. This can take the tiny flash of light, and convert it into an electrical signal which tells us that a charged particle has passed through.



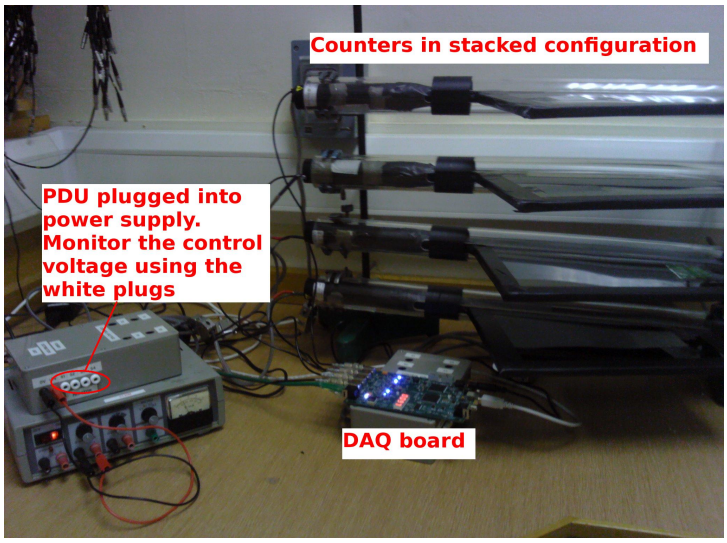

A diagram of the PMT is shown above. When a photon strikes the photocathode surface, it releases an electron. This electron is then attracted to a series of dynodes. A negative high voltage is applied across the dynodes so that the electron is accelerated as it approaches them. This means that when it strikes the dynode, 3 or 4 electrons are then emitted, so that at each stage the signal is amplified. The electrons eventually strike the anode at the end which is held at 0V and produces a negative pulse for a signal. The size of the signal is determined by the high voltage across the dynodes. The PMTs we use do not require a high voltage. We apply a small control voltage using the power distribution unit (PDU), and the base of the PMT converts this into a high voltage to apply across the dynodes.
Four scintillation counters are then placed one on top of the other. Since muons produced by collisions of cosmic rays are travelling at nearly the speed of light, they will pass through all detectors at essentially the same time. So we can look at the electrical signals from all of the

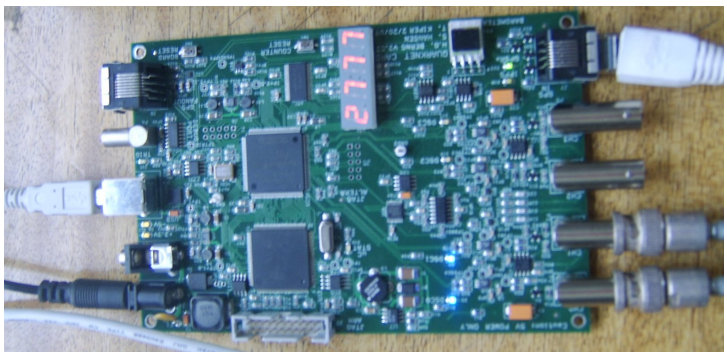
PMTs and use a data aquisition board (DAQ board) to analyse the signals and decide if they arrived at the same time. If all the counters produce a signal at the same time then we call this a coincidence, and that is our evidence that a cosmic ray muon has passed through. We can then use the DAQ board to work out how many muons are passing through the counter each second, or the flux of muons, and move our detectors to investigate what factors affect the flux.

### 1.3 The Signal




The picture above shows a typical signal which comes from the PMT when it detects a cosmic ray muon. The size of the signal depends on both the control voltage, which sets the operating voltage of the PMT and the amount of energy deposited by the muon as it passes through the scintillator. Since every muon deposits approximately the same amount of energy, we expect the signal from cosmic rays to be constant.
In reality, the PMT will not only produce signals which come from cosmic rays. There are some which come from other ionising particles passing through, from light leaking into the counter of from random signals being produced in the PMT itself. These signals, which do not come from cosmic rays, are called noise since we are not interested in them, and they make detecting the cosmic rays harder. The reason we look for a coincidence between more than one counter is that it is unlikely for noise signals to be produced in all the counters at the same time.
But there is another method we use to remove the noise, and that is to set a threshold. Noise signals are usually much smaller than cosmic ray signals, and so we only accept signals which are above a certain level, called the threshold. The higher the threshold, the fewer noise signals get through, but at the same time the possibility of not detecting a genuine cosmic ray is increased. The threshold can be set using a program called Hyperterm, which will be discussed later, and can be found in the appendix.
The figures below show the 4 counters stacked above each other, and the DAQ board which the signals are fed into.



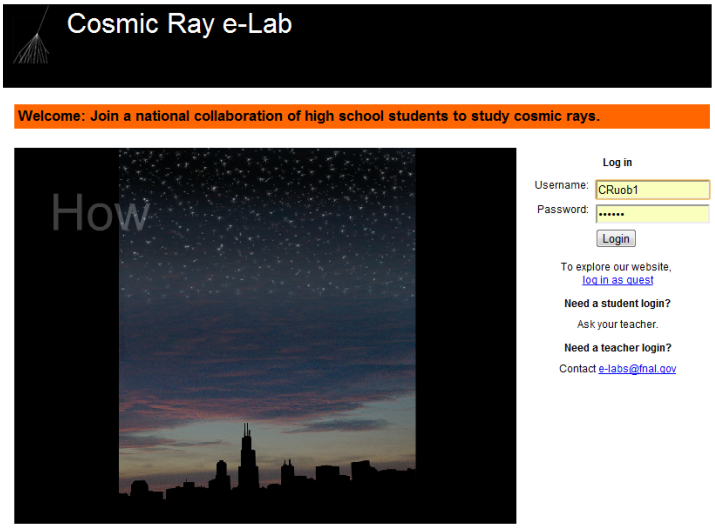
## 1.4 What is recorded?

A program called Hyperterm is used to record the signals from the PMTs, but what is actually measured?
The signals from all four PMTs are fed into the DAQ board. The DAQ board is also connected to a GPS arial, which sends signals to the board about both time and position. Using this method, the board can apply an accurate time stamp, correct to within 10ns, to every signal which comes in from the PMTs. For each signal, you can record the time it goes above the threshold, and the time it goes back below the threshold, so you can calculate the total time the signal spends above the threshold. The board can also check whether or not the signals arrive at the same time and so can be considered a coincidence, and so only record those signals. You are free to choose whichever coincidence level you want. If you set a 4-fold coincidence level, signals are only recorded if there are 4 signals within 100ns of each other. If you set a 1-fold coincidence then all signals are recorded.

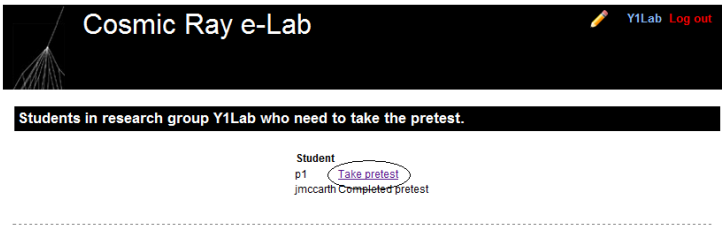
## 1.5 Getting started with the project

### 1.5.1 The Cosmic Ray e-lab

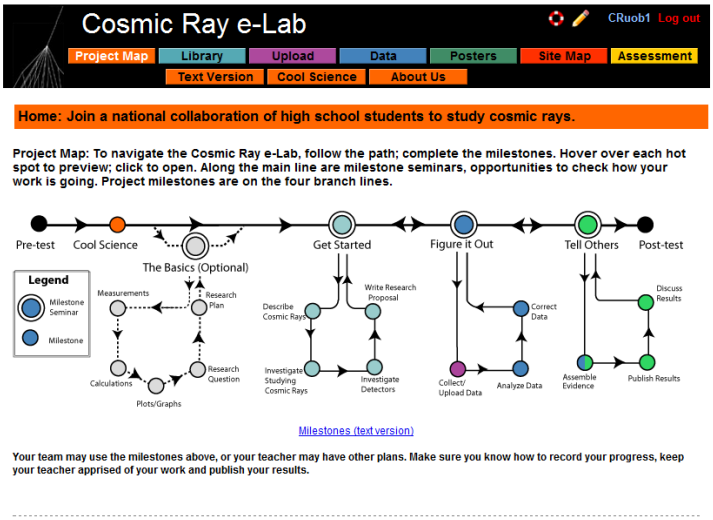
Your most valuable tool for this project is going to be the cosmic ray e-lab website. This contains all the resources you need to understand cosmic rays, and contains the tools to analyse the data you collect. The website is **http://www18.i2u2.org/elab/cosmic/home/**



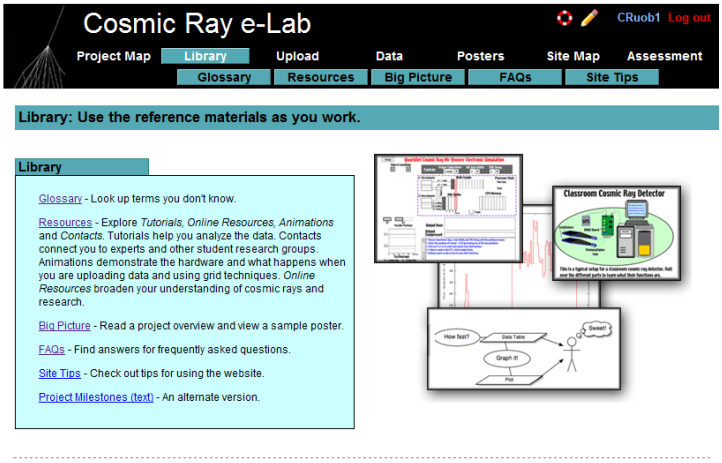

Your teacher will be able to provide you with the details you need to log into the website.




If it is your first time logging on then you will need to complete a short pre-test, just to establish what you already know before you start the project. Everybody in your group will need to complete the test before you can start.




The first page you are presented with is then the project map. This shows you the various milestones you are expected to complete through the project. Clicking on each of the circles will give you more information about that milestone.




By clicking on the "library" tab at the top of the page, you can access all of the learning resources available on the site. The glossary contains a list of technical terms along with what they mean, and the resources page contains useful information about cosmic rays, and step-by-step tutorials about how to use the website. Refer to this section if you ever need help navigating through the site or using the analysis tools, and you cannot find the information in this Student Pack. It would be a good idea to spend some time getting yourself familiar with the website and the tools available to you.

### 1.5.2 Setting up the detectors

The first thing you need to do is set up the detectors so you can measure the flux of cosmic rays. Refer to the sheet entitled "Connecting the muon detector" in the appendix to find out how to connect up the detector.

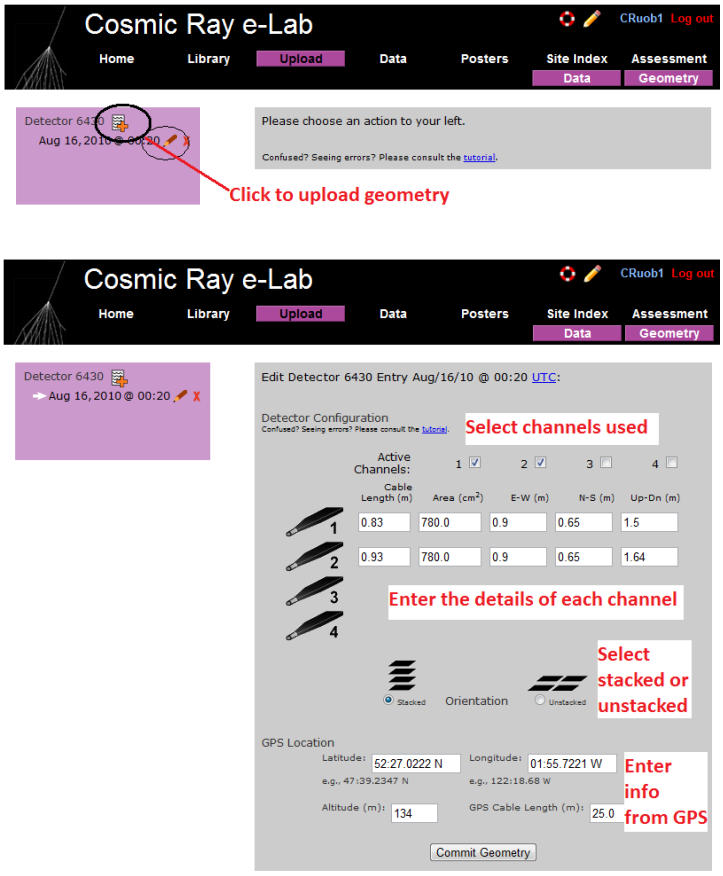
### 1.5.3 Using Hyperterm

Hyperterm is the program which you will be using to collect and record the data being provided by the DAQ board. The sheet entitled "Using hyperterm" in the appendix will give you all the information you need to get started using hyperterm. To check that the counters are working, type the command V1 into Hyperterm. This should bring up information on the counters, including the various settings you are using. You should not need to change these settings from the default, but they can be changed using Hyperterm. Next check that the GPS module is working by typing the command DG. The GPS status should be VALID.

### 1.5.4 Uploading the geometry of the detectors

Once you have the detector set up and working, you need to enter the geometry of the detector into the e-lab website. It is essential that this is correct, since the information is used to calculate the flux of muons from the data you collect.

- To upload the geomtery of the detector click on the upload tab on the e-lab website and then click on the geometry tab.
- Click on "add entry". You should see the following pages.



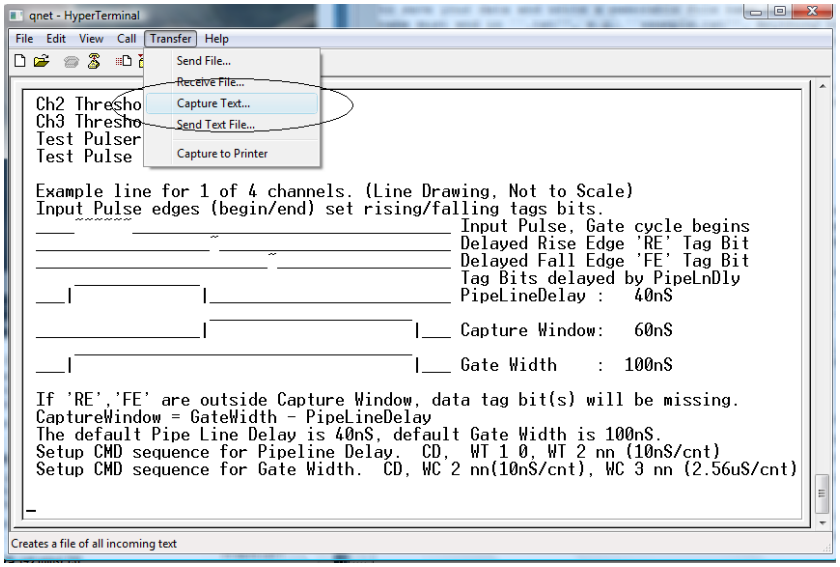

- Fill in the details of the detector setup.
  - First, tick the boxes corresponding to the channels which you are using.
  - Next, enter the required details for each counter.
  - The cable length is the length of cable from the PMT to the DAQ board.
  - The area is the surface area of the counter in units of $cm^2$.
  - The E-W (East-West), N-S (North-South) and Up-Down measurements are the distances of the counters from the GPS antenna.Make sure the difference between the Up-Down measurements of the counters is accurate, as this is vital in calculating the flux.
  - Next you need to select the orientation of the detector. Select stacked if the counters are on top of each other or unstacked if they are all on the same level. To start with, your detector should be stacked.
  - Finally, you need to enter details of the GPS antenna. The longitude, lattitude and altitude measurements can be found by typing the DG command into Hyperterm.
  - The GPS cable length is the length of cable connecting the GPS module to the DAQ board.

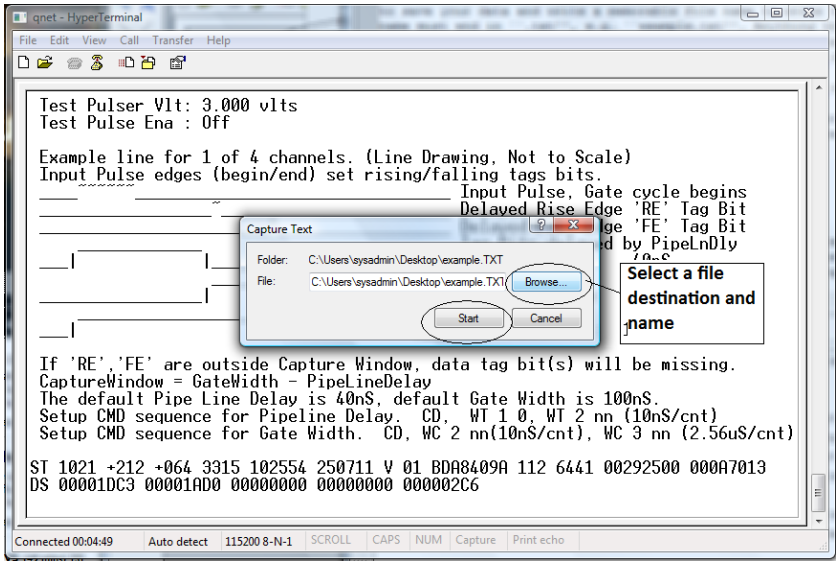
Make sure you always upload the geometry before you start taking data. The website links the data with the current geomtry at the time the data was recorded, not when it was uploaded. To upload a geometry for data already recorded, change the time and date from the upload page to just before you started taking data.

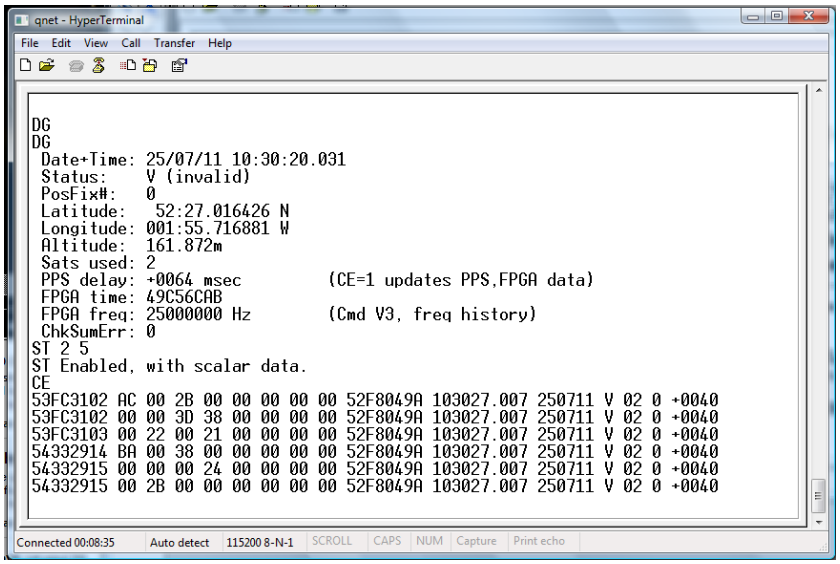
### 1.5.5 Collecting data

Now that the detectors are set up and the geometry has been uploaded to the website, you are ready to start taking data.

- Open up Hyperterm.
- From the "Transfer" menu, select "Capture Text". Choose where you want to save your data and write a memorable file name to write the data to. The file name must end in ".txt", e.g. "example.txt". Anything that now appears on the Hyperterm screen will also be saved to the file you selected.



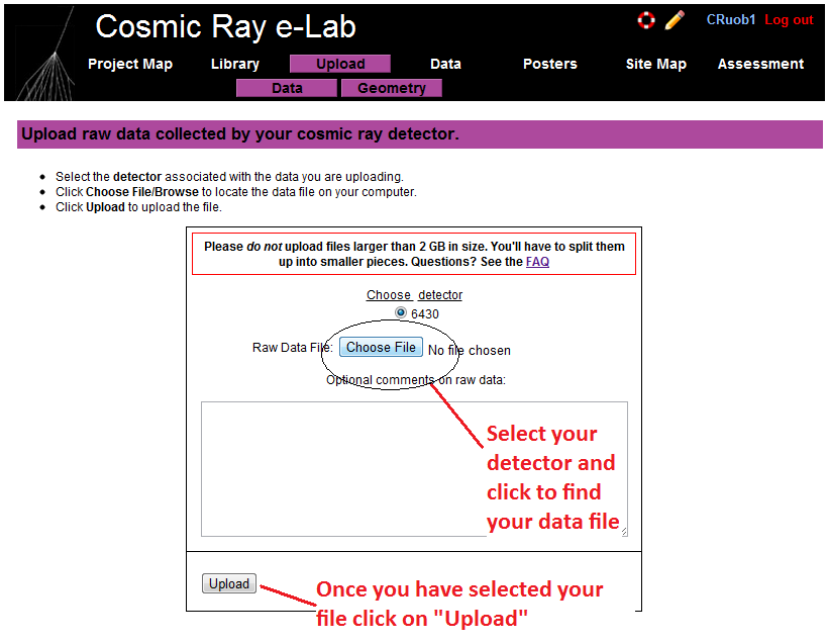



- Before you start taking any data, you need to enter the following commands:
  - V1
  - V2
  - DG
  - TL
  - ST 2 5
- The first 4 commands display information about the status of the detector, which is needed by the website to analyse your data. The last command writes out a status line every 5 minutes, which is also required during analysis of the data you collect.
- You can now start reading out the data from the counters by typing the command CE. Now, everytime the counters detect a cosmic ray muon, data about the signal received will be shown on the screen and recorded in the text file.
- You can then leave the detector running and collecting data for as long as you wish. Just remember that the more data you take, the more accurate your results will be, so there is an advantage to leaving the detector running for as long as you can.
- Once you have collected enough data, tpe the command CD to stop reading the data to the screen.
- Now select "Stop" from the Transfer menu in order to stop recording the data.

### 1.5.6 Analysing data

Now that you have your data recorded on a file, you can upload it to the e-lab website for analysis.

- Click on the upload tab, and then click on data.
- Now select the file that you recorded the data and on click on "upload".



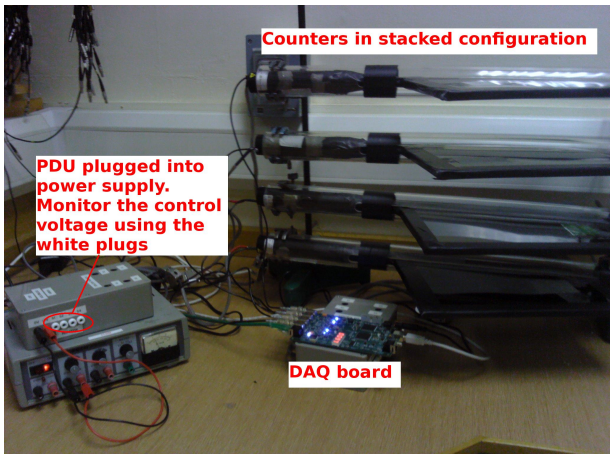

Now that the data are uploaded to the website, you can analyse it using the "Data" tab. We will explore each analysis option in the coming weeks, but first you need to make sure your counters are set up and working correctly. Go to worksheet 2 to find out how to Plateau you counters.

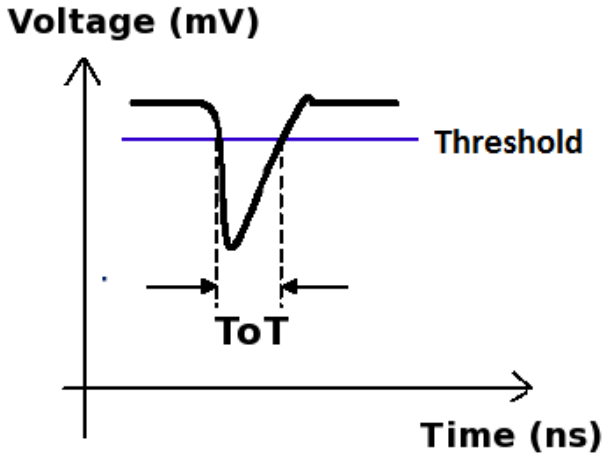
# 2 Worksheet 2: Plateauing the Counters

## 2.1 Aim

Before you use any detector you need to make sure that it is set up properly and working correctly. Otherwise, you cannot trust the data which you are recording. When you come to present your results, nobody will accept them unless you can show that the detector is working as expected. The aim of this worksheet is the find the optimum operating conditions for your detector. For this worksheet you will need a stopwatch.

## 2.2 The Control Voltage



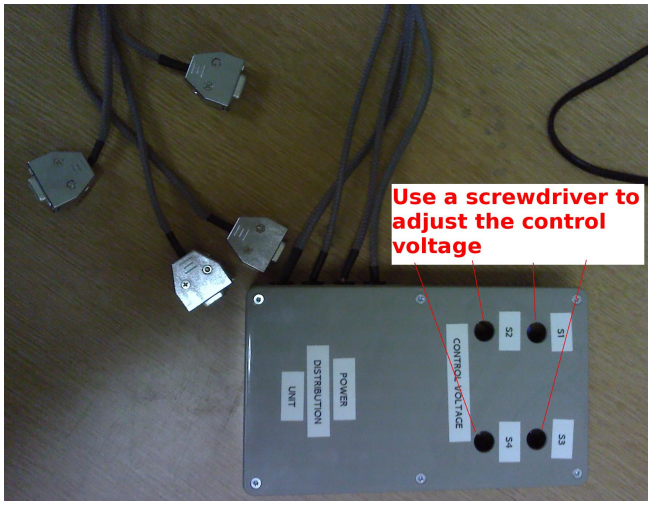




The aim of the Power Distribution Unit (PDU) is to apply a voltage across the photomultiplier tube, called the control voltage. The size of the signal produced by the PMT is determined by the control voltage, the higher the voltage, the larger the signals will be. Usually, signals which are produced when muons pass through the scintillator will be quite large. Signals which are produced by other sources tend to be smaller. Since we are not interested in these types of signals, they are usually called *noise*, and they get in the way of detecting the cosmic rays. We therefore want to ignore these small signals and only count large signals from muons. To do this, the DAQ board only accepts signals above a certain threshold, which is by default set to 300mV. Noise signals will usually be below this, and so will be ignored by the card. However, if the control voltage is set too low, then the signals produced by cosmic rays will be below the threshold, and so we will not detect every particle which passes through. Conversly, if the control voltage is too high then the noise signals will be above the threshold and so will be incorrectly counted as cosmic rays. At

the same time, operating at a high voltage puts a lot of strain on the PMTs, so to extend their lifetime we need to operate at the lowest voltage possible while still detecting as many cosmic rays as we can. To find this optimum control voltage we go through a process called "Plateauing the counters". The reason for calling it this will soon become apparent.

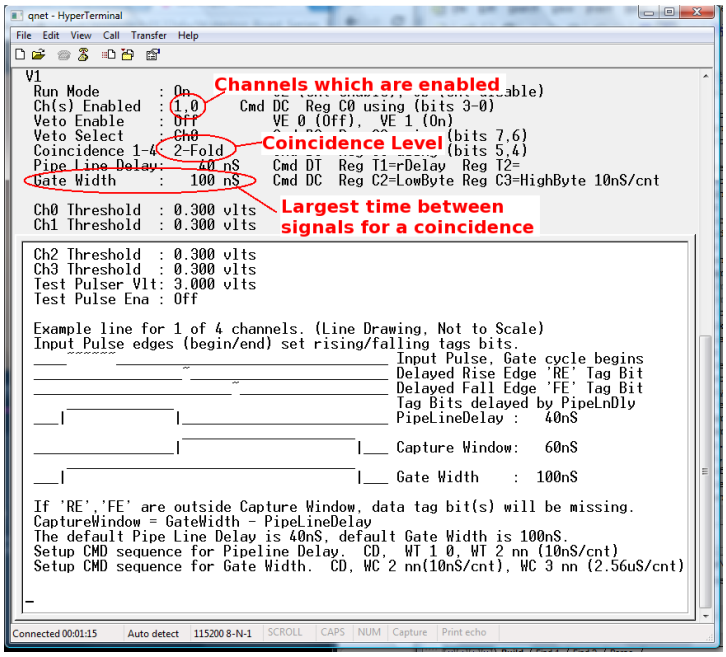
## 2.3 Finding the Plateau

In order to plateau a counter, you need to set up the detector with 2 counters, one on top of the other. One will be the counter which you want to plateau, which we will call Counter 1, and the other will be your reference counter, which we will call Counter 2.



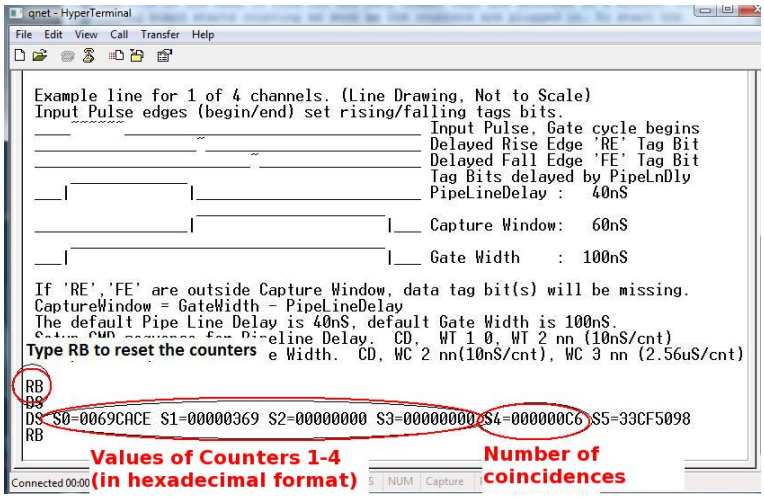

You can test the control voltage on each counter by plugging a digital multimeter (DMM) into the PDU across the 0V (black) and control voltage (white) plugs. Each counter has a separate plug for its control voltage. The control voltage can then be changed by turning the corresponding variable resistor in the PDU.
Follow the steps below to plateau the first counter:

1. Set the control voltage across Counter 2 to 1V.
2. Set the control voltage across Counter 1 to 0.65V
3. Open up hyperterminal. Details of how to use hyperterminal can be found in the appendix to this pack. Type WC 00 13, which will set up the DAQ board to look for coincidences between the two counters.
4. Type TL 4 300 to set the threshold of all 4 counters to 300mV.




5. Type V1 to check that the last two commands worked.

6. We now need to find out how many cosmic rays are detected in a minute. The DAQ board starts counting as soon as the counters are plugged in. To start the counters again you can use the command RB. Type RB and start the stopwatch at the same time.



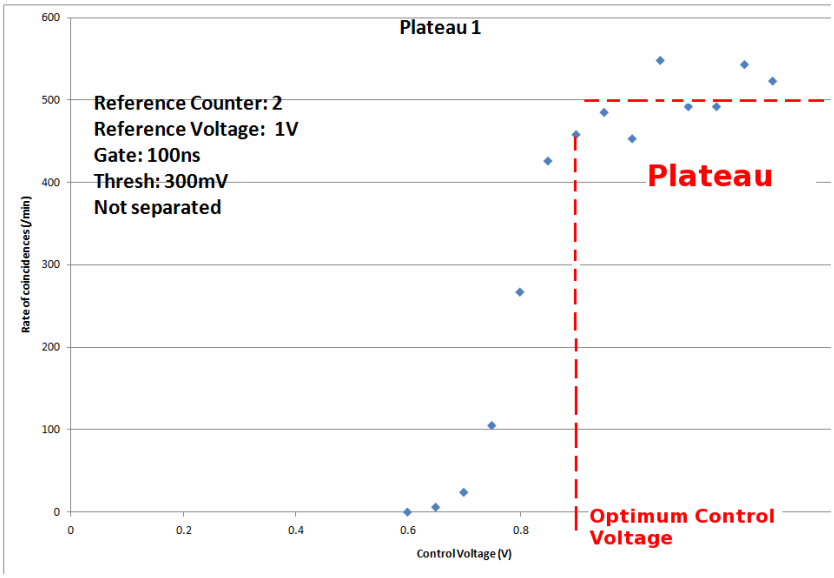

7. After one minute, type the command DS. This displays the counters on the board and tells you how many cosmic rays have been seen. The numbers are all in a hexadecimal format. The value of S4 is the number of coincidences, i.e. the number of comsic rays detected.

8. Type the value of the control voltage and the value of S4 into MS Excel. Use the hex2dec() function to convert the flux into a decimal number.

9. Increase the control voltage across Counter 1 to 0.6V and repeat the process to find out how many coincidences there are in a minute.

10. Repeat this until you reach a control voltage of 1.3V

11. Now use MS Excel to obtain a plot of counts per minute against control voltage.



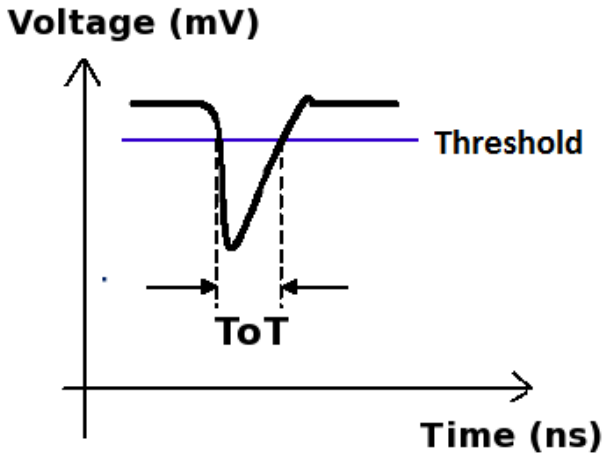

Your plot should look similar to the one above. There should be very few counts below a certain point, and when the control voltage is large enough that the signals are above the threshold, then the counts per minute should increase. The counts per minute should level off when all the cosmic rays are being detected. This levelling off is called the plateau. The operating voltage should be set to the voltage just above where the plateau begins.
You can now plateau the other counters using Counter 1 as a reference counter. Set the control voltage across Counter 1 to the optimum voltage found, and use it to plateau the other counters.

# 3 Worksheet 3: Performance Study

## 3.1 Aim

The aim of this worksheet is to check that the detectors are working and are detecting comsic rays efficiently. We can do this by using the Cosmic Ray e-lab website to analyse the signals being produced by the counters.

## 3.2 Introduction

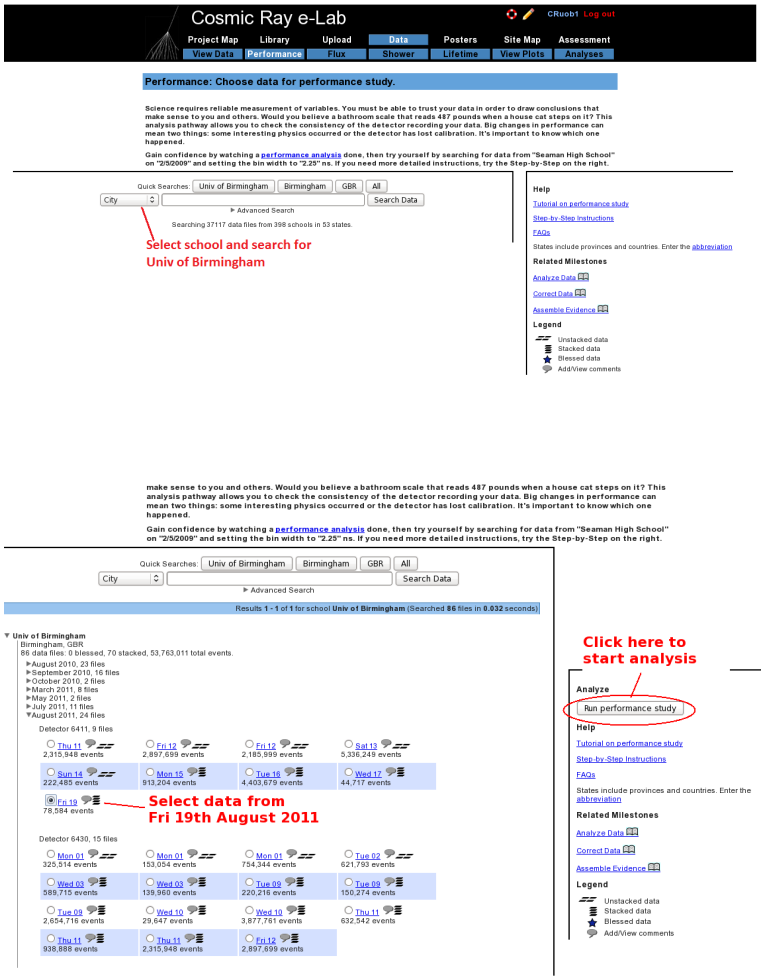



The picture above shows a typical signal which comes from the PMT when it detects a cosmic ray muon. The size of the signal depends on both the control voltage used across the PMT and the amount of energy deposited by the muon as it passes through. Since every muon deposits approximately the same amount of energy, we expect the signal from cosmic rays to be consant.
In reality, the PMT will not only produce signals which come from cosmic rays. There are some which come from other ionising particles passing through or from random flashes of light being emitted. These pulses, which do not come from cosmic rays, are called noise since we are not interested in them, and they make detecting the cosmic rays harder. A single counter will tend to produce more noise pulses than signals. The reason we look for a coincidence between two counters is that it is unlikely for noise to be produced in the two counters at the same time.
But there is another method we use to remove the noise, and that is to set a threshold. Noise pulses are usually much smaller than cosmic ray signals, and so we only accept pulses which are above a certain level, called the threshold. The higher the threshold, the fewer noise pulses get through, but at the same time more cosmic ray signals are missed. The threshold can be set through hyperterm with the command TL n m. n defines the channel which you wish to change, for example counter 1 is channel 0. m is the value of the threshold in mV. I recommend using a threshold of 300mV. So to set the threshold of counter 1 to 300mV, type TL 0 300. To change all 4 counters at once, type TL 4 300.
To test whether the counters are detecting a lot of noise, we want to analyse the pulses which we detect. We do this by measuring the time-over-threshold (ToT) of the pulses. If the height of the pulse is the same, the ToT will also be the same. So we expect all cosmic rays to produce pulses with a ToT of about 20ns. Noise pulses will be much smaller and so will have a smaller ToT. So we will plot a histogram of the time-over-threshold for every pulse we detect from the counter. This will separate the noise from the cosmic ray signals and allow us to check that we shall be able to discriminate between the two sources by imposing an appropriate threshold. We do this by running a Performance Study from the Cosmic e-lab.

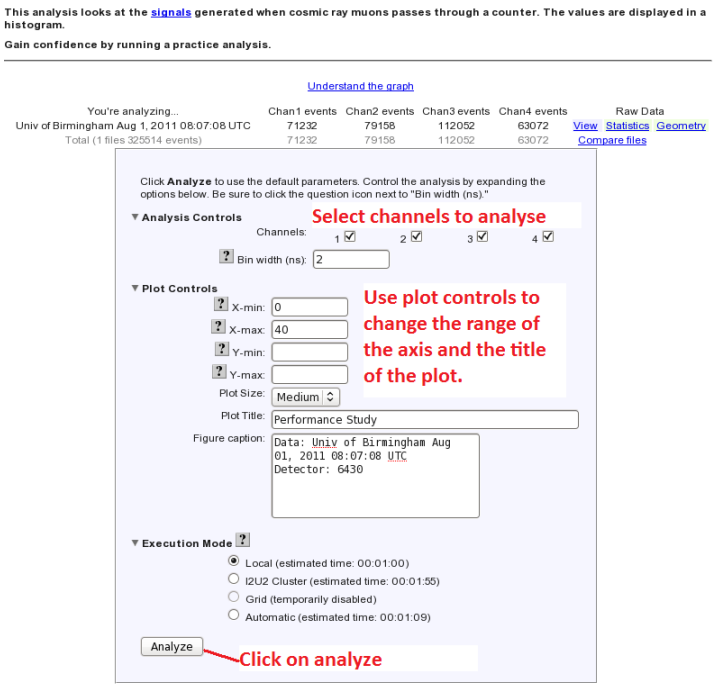
## 3.3 Analysing Data

We will start by running a Performance Study on data which has already been recorded by us at the University of Birmingham. You can analyse the data by logging onto the Cosmic Ray e-lab. The website is **http://www18.i2u2.org/elab/cosmic/home/**

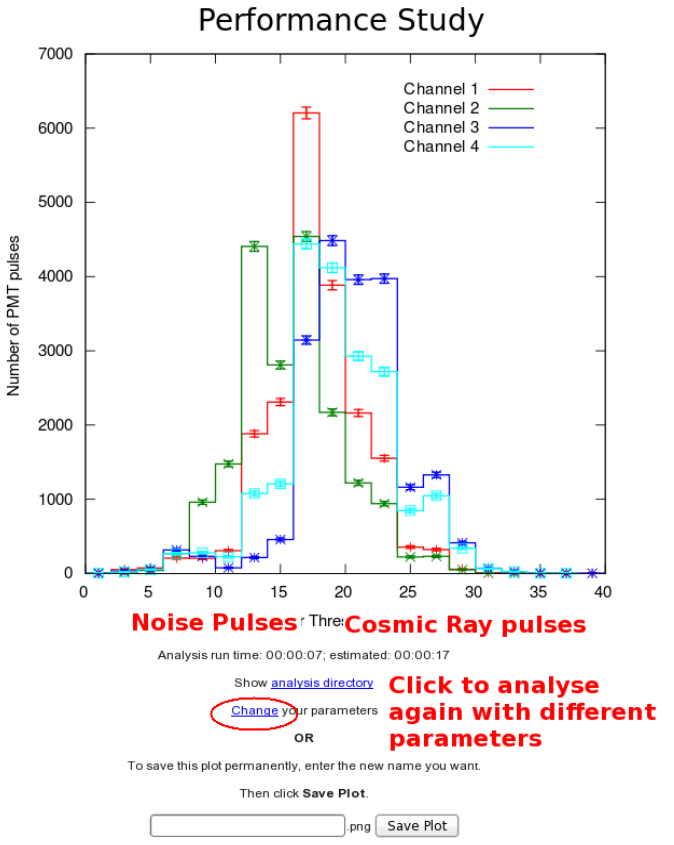
1. Click on the "Data" tab and then "Performance" and you should see the pages below.




2. Search for data from 19/08/2011 from the school "Univ of Birmingham". Select the data from this day to analyse.

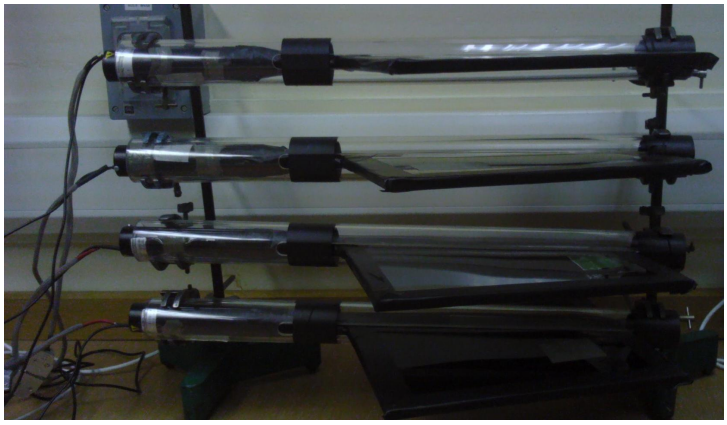



3. You should see the options in the figure above. Select which counters you want to analyse (all of them) and set the bin width to 2ns. Expand the "Plot Controls" tab and you can change the range of the axes and the plot title. Then click on "Analyze".

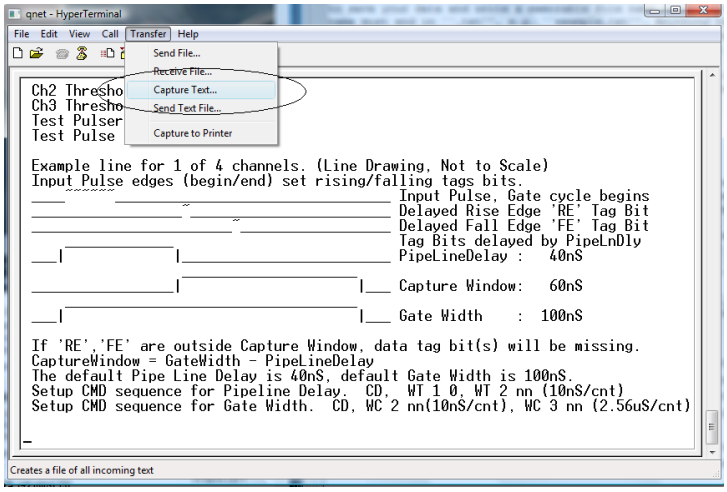


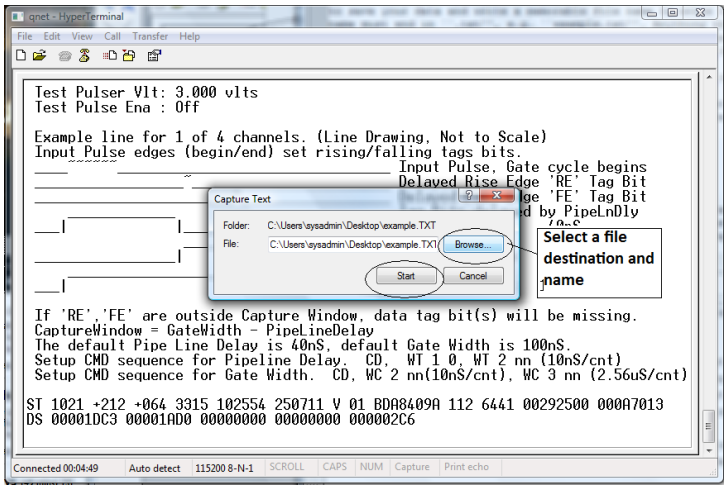
You should get a graph which looks like the one above. The Time over Threshold (ToT) for each pulse is plotted in a histogram. The peak centered on 20ns is due to cosmic rays. The random noise will produce pulses with a lower ToT, and so the smaller peak to the left of the large peak is due to noise. It is nearly impossible to remove the noise altogether, it is just something which we have to learn to live with in particle physics. As long as the noise peak is small, there is nothing to worry about.

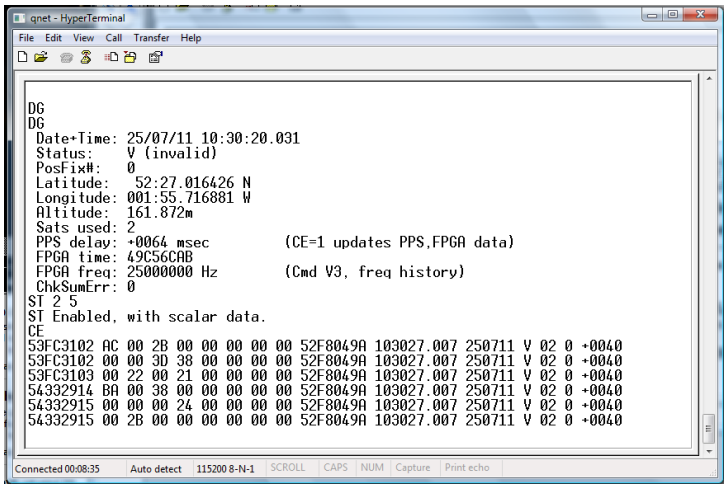
## 3.4 Collecting Data



Now you can collect data from your counters to run your own performance study. Set up your counters in the stacked configuration shown above and set the control voltages to the optimum voltages found by the plateau method. Before you start taking data, upload your geometry to the Cosmic e-lab website. Open Hyperterminal and follow the steps below to collect data:






1. Set up the DAQ board to record coincidences between all 4 counters, i.e. a 4-fold coincidence level, by typing WC 00 3F.

2. From the "Transfer" menu select "Capture Text"

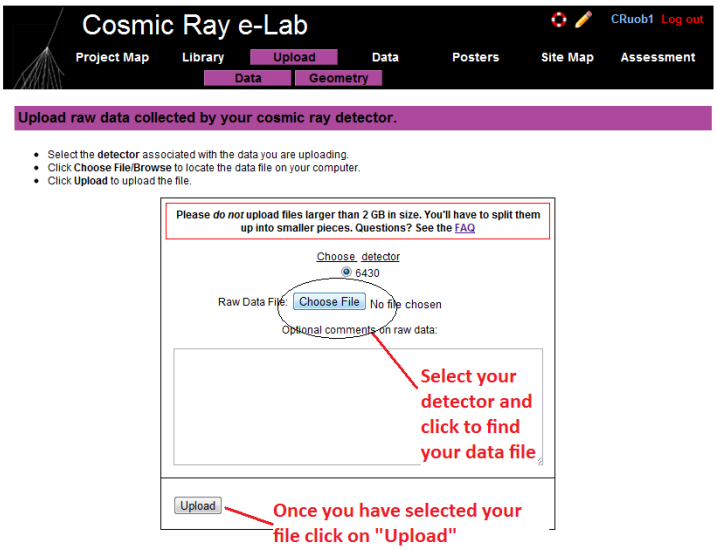
3. Choose a file name ending with ".txt" and save your file somewhere memorable. Then select "Start"

4. Anything which now appears in the Hyperterminal window will also be written to the ".txt" file. Start by typing the commands V1, V2, DG, TL, ST 2 5. This ensures your data file contains the necessary information about the detectors.

5. Type the command CE to enable the counters and start writing data to the ".txt" file. Leave this running for about 2 hours. While you are collecting data you can move onto "Analysing Data" to run a performance study on data we have already taken. Make sure that the computer you are using is set to never sleep, otherwise you will not continue to collect data.

6. Once you have collected enough data type the command CD to stop writing out data.

7. From the "Transfer" menu select "Capture Text" and "Stop".




Once you have collected enough data you can run your own performance study. Upload your data by clicking “Upload” and then “Data”. It is now ready to be analysed. Repeat the steps above with the data you have just taken to obtain your own performance plots. How do they look? Can you trust the detectors to measure the flux of cosmic rays? If the peak of the noise signals is higher than the cosmic ray signal then you have a problem. It could be that your control voltage is too high, so check your plateau again. If that fails then you can increase the threshold slightly to see if that helps.Once you have a detector producing a good performance study, you can have confidence in its ability to observe cosmic rays, and you can prove to other groups that your detector does not have too much noise. Once you are happy with your plot, click on “Save Plot” so that you can easily access it later.

# 4 Worksheet 4: Flux Study

## 4.1 Aim

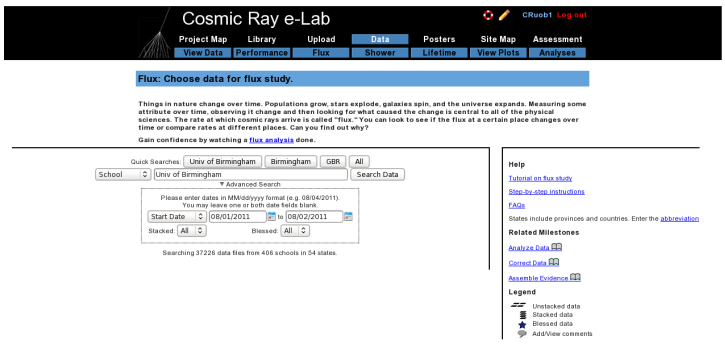
The aim of this worksheet it to find out the flux of cosmic rays and to investigate the different factors which may affect the cosmic ray flux.

## 4.2 Introduction

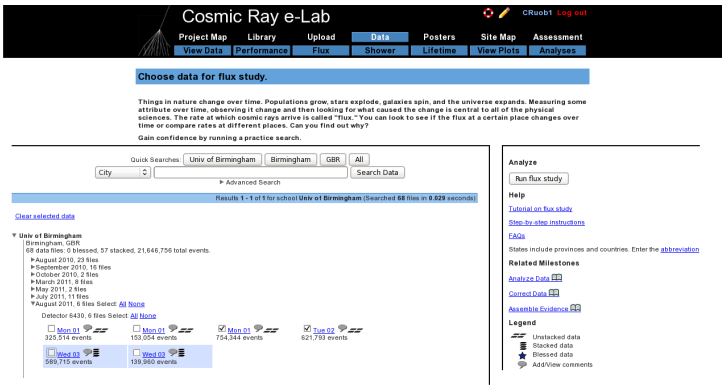
The flux of cosmic rays is the number of cosmic rays passing through a certain area at any given time. It can be measured in different units, but we will measure it in units of $events/m^2/60 - seconds$ . That means we are measuring the number of cosmic rays passing through an area of $1m^2$ in every minute. Using the tools in the Cosmic e-lab website (http://www18.i2u2.org/elab/cosmic/home/) it is possible to measure the cosmic ray flux, and monitor how it changes over time. This is the first thing we will do in the worksheet, and then you will have the opportunity to create your own research question and investigate a factor which affects the cosmic ray flux.

## 4.3 Running a Flux Study

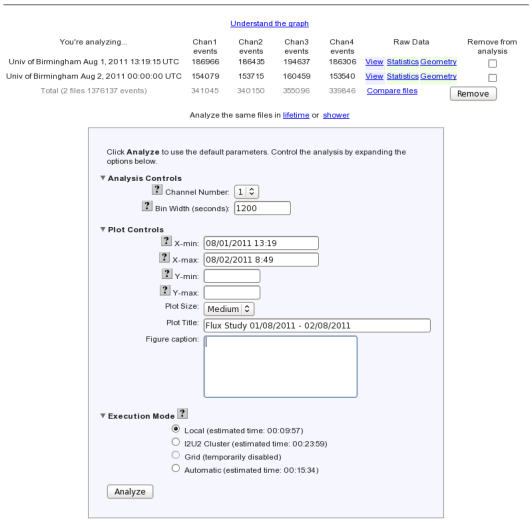
Firstly, we will use some data which has already been uploaded to learn how to perform a flux study. Start by logging onto the e-lab website (http://www18.i2u2.org/elab/cosmic/home/).



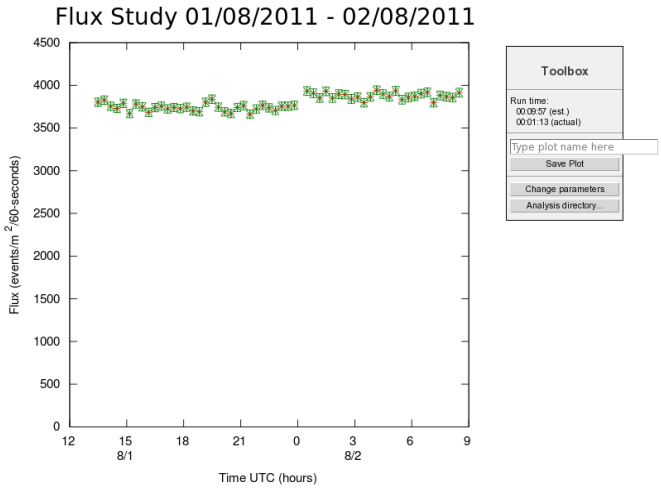

Click on "Data" and then "Flux", and you should see the screen above.




Use the search box to select "School" and find data from the "Univ of Birmingham". Select the data from 19/08/2011 and click on "Run Flux Study".

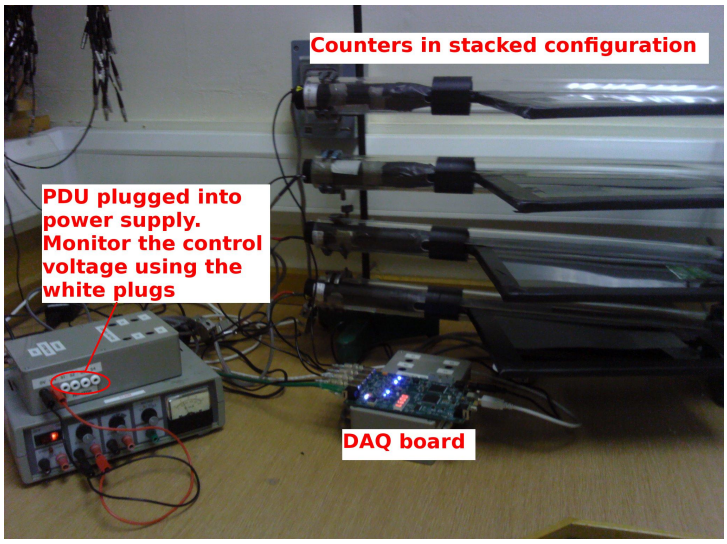



You can change the properties of the plot from the next screen, shown above. If you have collected data over a long period of time, you may want to have a larger bin width, so that the data points are not so cramped. Conversely, if you do not have much data, you may want to use smaller bin widths so that more data points are plotted. Once you have set your own plot title click on "Analyze"

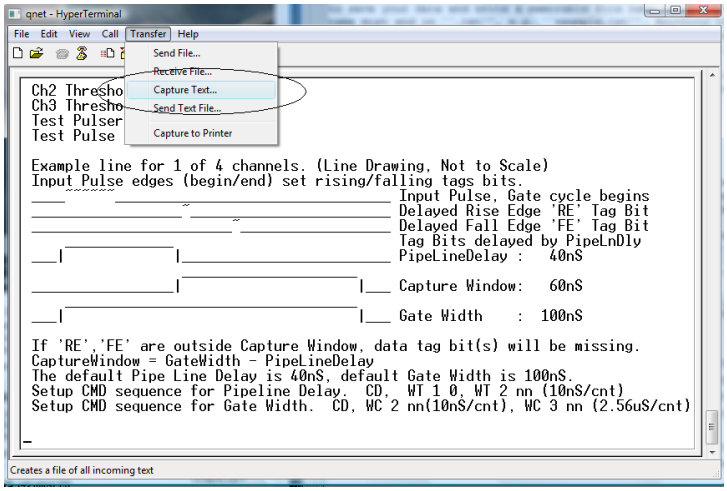


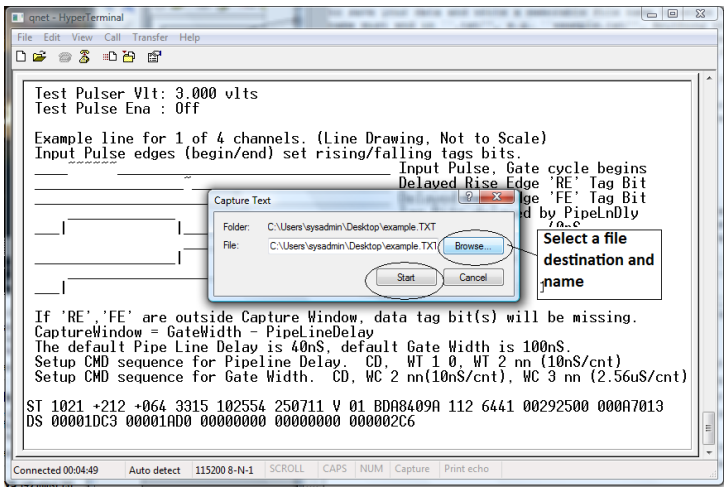

You should obtain a plot which looks like the one above. Click on "Change parameters" to the side if you are not happy with how the graph looks. Now you can take data with your detector to obtain your own flux plot.

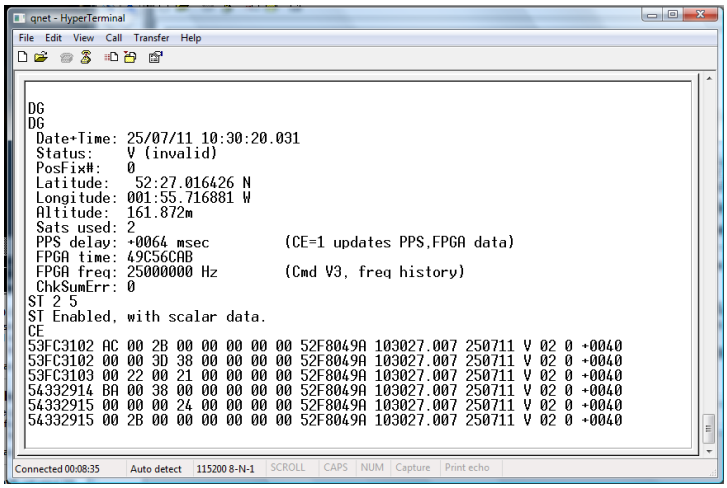
## 4.4 Taking your Own Data




Set up your counters in the stacked configuration shown above and set the control voltages to the optimum voltages found by the plateau method. Open Hyperterminal and follow the steps below to collect data:






1. Set up the DAQ board to record 4-fold coincidence by typing WC 00 3F.

2. From the "Transfer" menu select "Capture Text"

3. Choose a file name ending with ".txt" and save your file somewhere memorable. Then select "Start"

4. Anything which now appears in the Hyperterminal window will also be written to the ".txt" file. Start by typing the commands V1, V2, DG, ST 2 5. This ensures your data file contains the necessary information about the detectors.

5. Type the command CE to enable the counters and start writing data to the ".txt" file. Leave this running for about 2 hours. Make sure that the computer you are using is set to never sleep, otherwise you will not continue to collect data.

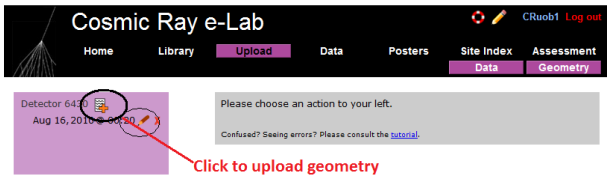
6. Once you have collected enough data type the command CD to stop writing out data.

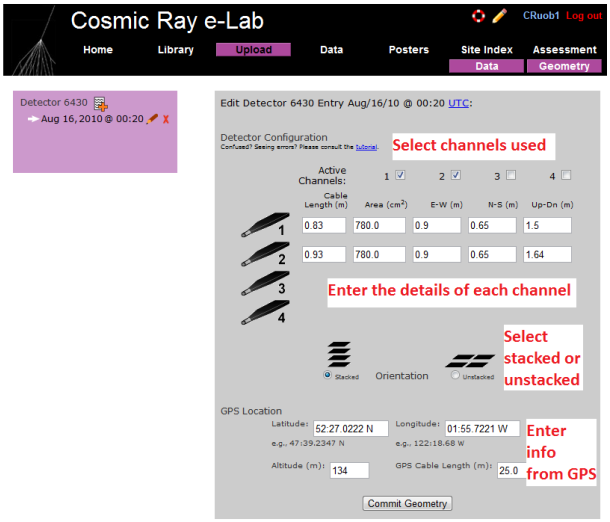
7. From the "Transfer" menu select "Capture Text" and "Stop".

Once you have your data, you can upload it to the Cosmic e-lab website. But before you do that you need to upload the geometry.

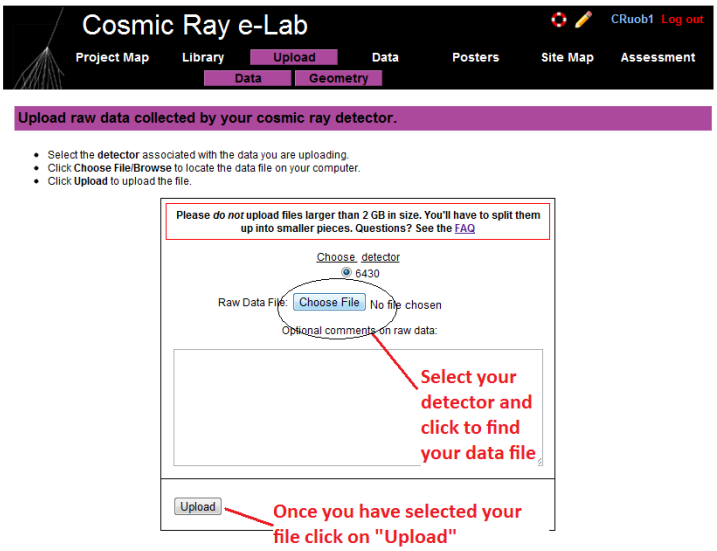
- To upload the geomtery of the detector click on the upload tab on the e-lab website and then click on the geometry tab.

- Click on "add entry".






- Fill in the details of the detector setup. First, tick the boxes corresponding to the channels which you are using.
- Next, enter the required details for each counter.
- The cable length is the length of cable from the PMT to the DAQ board.
- The area is the surface area of the counter in units of $cm^2$.
- The E-W (East-West), N-S (North-South) and Up-Down measurements are the distances of the counters from the GPS antenna. The values do not have to be completely accurate but difference between the Up-Down measurements of your counters should be the distance between the counters, which you can measure quite accurately.
- Next you need to select the orientation of the detector. Select stacked if the counters are on top of each other or unstacked if they are all on the same level. To start with, your detector should be stacked.
- Finally, you need to enter details of the GPS antenna. The longitude, lattitude and altitude measurements can be found by typing the DG command into Hyperterm.
- The GPS cable length is the length of cable connecting the GPS module to the DAQ board.



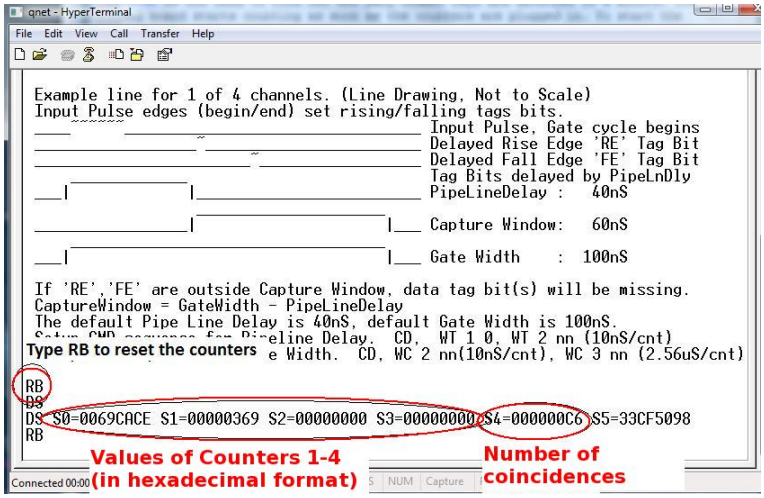
Upload your data by clicking “Upload” and then “Data”. It is now ready to be analysed. Repeat the steps above with the data you have just taken to obtain your own flux studies. How does the flux you measure compare with the flux measured at the University of Birmingham? Does the flux change over the two hours you were collecting data for. Once you are happy with your plot, click on “Save Plot” so that you can easily access it again.

## 4.5 Alternative Flux Measurements

This is not the only way to measure the flux of cosmic rays. If you merely want to find out the rate of cosmic rays detected by your counters, you can use the DAQ board and Hyperterm.

1. Open up hyperterminal and type WC 00 3F. This will set up the DAQ board to look for coincidences between all 4 counters.

2. We now need to find out how many cosmic rays are detected in a minute. The DAQ board starts counting as soon as the counters are plugged in. To start the counters again you can use the command RB. Type RB and start the stopwatch at the same time.




3. After one minute, type the command DS. This displays the counters on the board and tells you how many cosmic rays have been seen, and should look like the screen above. The numbers are all in a hexadecimal format. The value of S4 is the number of coincidences, i.e. the number of comsic rays detected. You can use MS Excel to convert the hexadecimal number into a decimal number using the hex2dec() function. The values of S0-S3 are the number of pulses above the threshold measured in counters 1-4.

This method is not as accurate as the first method and so you may want to repeat the measurement a few times and take an average. It will not allow you to monitor the flux over time and it is dependent on your setup (i.e. how far apart your detectors are etc.) This means it will not give you an absolute flux. However, it is much easier to use if you want to measure the rate and then change your setup and measure the rate again. You will have to decide which method is the best to use for your own investigation.

## 4.6 Choose a Research Topic

You now have free reign to pick a question which you would like to research yourself. You want a question which is something like “How is the comsic ray flux affected by...?” Think about something which you really think would affect the flux of cosmic rays, and see if you can come up with a prediction of exactly how the flux will be affected. This could either be something to do with how the flux is affected by where you are, do you measure a different rate on higher floors

of the building? Does being inside make a difference to the rate you measure? If you want to investigate this type of question you need to be careful to keep the geometry of the detectors the same, they should always be the same distance apart. Or you could investigate whether changing the geometry of the detector affects the rate of cosmic rays which are measured. Does changing the distance between the counters affect the rate? Or the angle of the counters from the vertical? Think about something that you would find interesting to investigate. Ask your teacher if you have an idea but you are not sure how to investigate it.
The most important thing to remember here is to only investigate one variable at a time. If you want to change one thing with the detector, then everything else must be kept exactly the same to make the investigation fair.

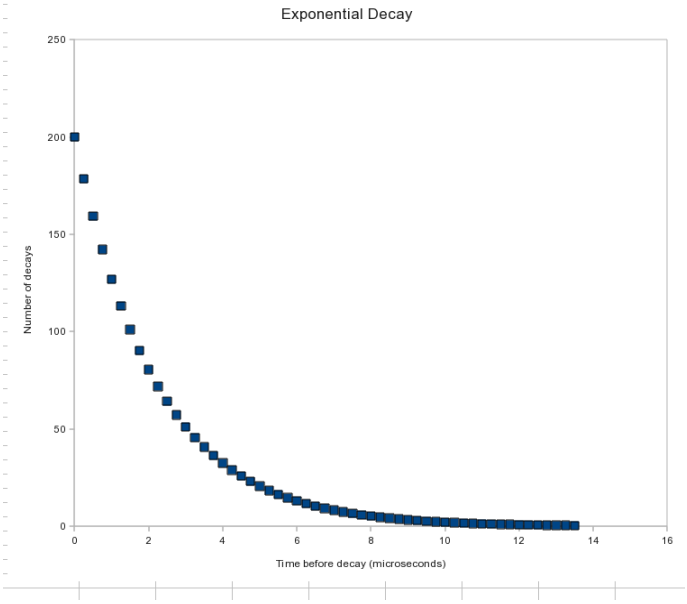
# 5 Worksheet 5: Measuring the Lifetime of a Muon

## 5.1 Aim

The aim of this worksheet is to use your cosmic ray detector to calculate the lifetime of a muon.

## 5.2 Introduction

You have probably come across the idea in nuclear physics of radioactive isotopes. These are nuclei which are not stable, and will decay into different nuclei. A similar concept applies in particle physics. Not all particles are stable, and those which aren't will decay into different, lighter, particles. For example, when primary cosmic rays interact in the atmosphere, pions are created from the energy of the collision. These pions then decay into muons, and we detect the muons with our cosmic ray detectors. The characteristic time that it takes for a particle to decay is known as its lifetime, and the lifetime of a pion is $2.6 \times 10^{-8}$ s. This is an extremely short lifetime, and so the pion will not travel very far towards the Earth before it decays. It is important to remember that this lifetime is only an average time before the pion decays. Some pions will decay well before this time and some will decay well after. However, there is a nice mathematical expression which describes the number of particles which decay in a certain time.

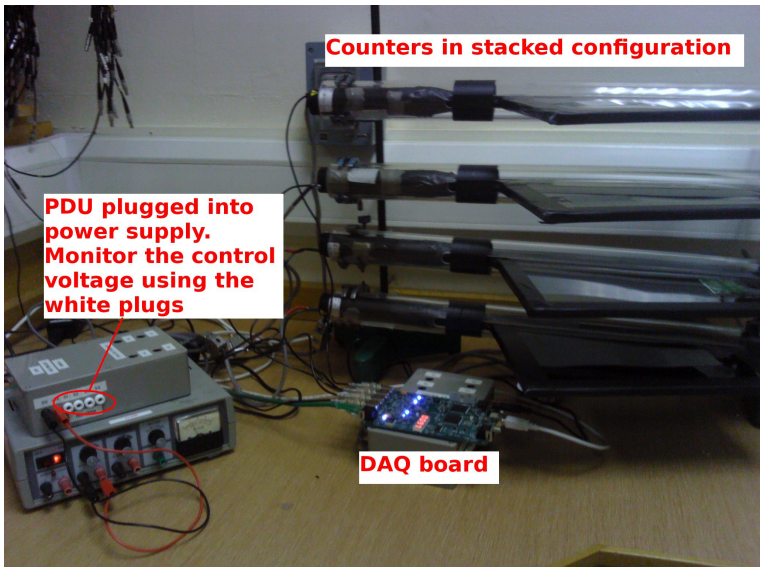



The graph above shows the typical shape we expect from the decay time of particles. The x-axis shows the time before the particle decays, and the y-axis shows the number of particles with this decay time. The general shape, common to all particle decays, is called an exponential decay, and has a very useful mathematical form:

$$N(t) = N_0 e^{-t/\tau} \tag{1}$$

N(t) is what appears on the y-axis, the number of particles with a decay time larger than t, $N_0$ is the total number of particles detected, t is the decay time (the x-axis) and $\tau$ is the lifetime of the particle. Decays with different lifetimes will produce slightly different graphs. Knowing that this is the shape we expect means we can use our detector to draw a graph like this, and use it to work out what lifetime would produce that graph.

## 5.3 Measuring a Lifetime

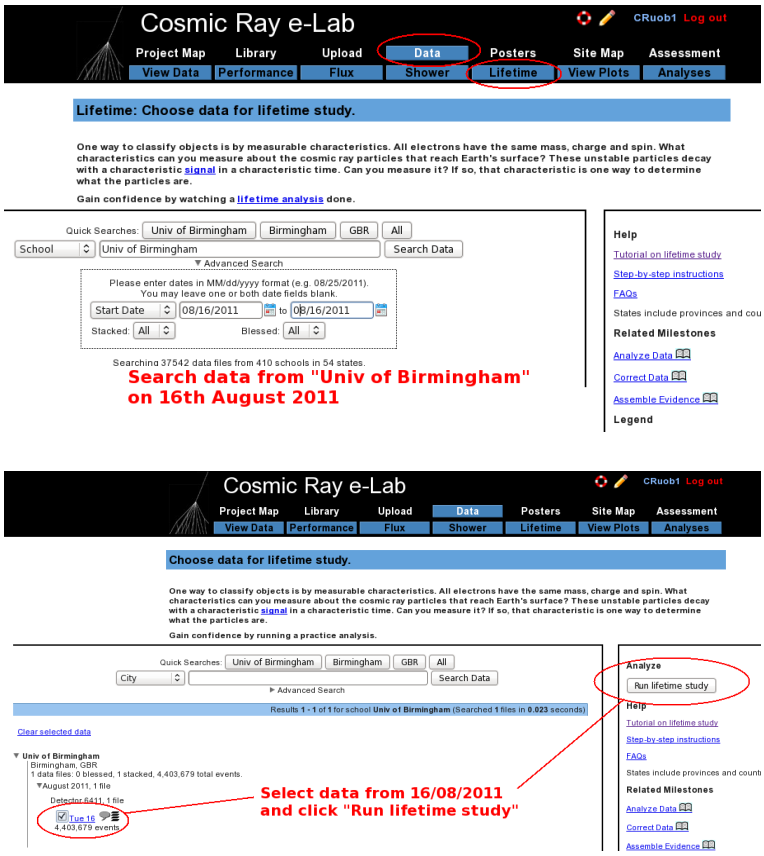



In order to measure the decay time of a muon, we need it to decay actually inside our detector. To do this, set up the counters in the stacked configuration shown above. In order to make sure we have a muon which decays inside the detector, we need a coincidence between the first two or three counters and then no signal in the next counter. This would mean that a muon has passed through the first counters and then stopped within the detector. After a short period of time, the muon will decay into an electron, which will produce a signal in the counter which it stopped in. The time between the original coincidence signal and this second signal is therefore the decay time, which we can plot to see the exponential decay and measure the lifetime.
Of course it is not possible to make a muon stop inside the detector, nature has its own ideas of where the muons will stop. All we can do is look through all the events we record and try to find events which involve a muon stopping in the detector. As with any physics experiment you are likely to come across, the more events we use to make our measurement, the more accurate the measurement will ultimately be. Since it is quite rare to have a muon stop in the detector, we would recommend recording data over about 24 hours to make sure you have enough useful events to make your plot.

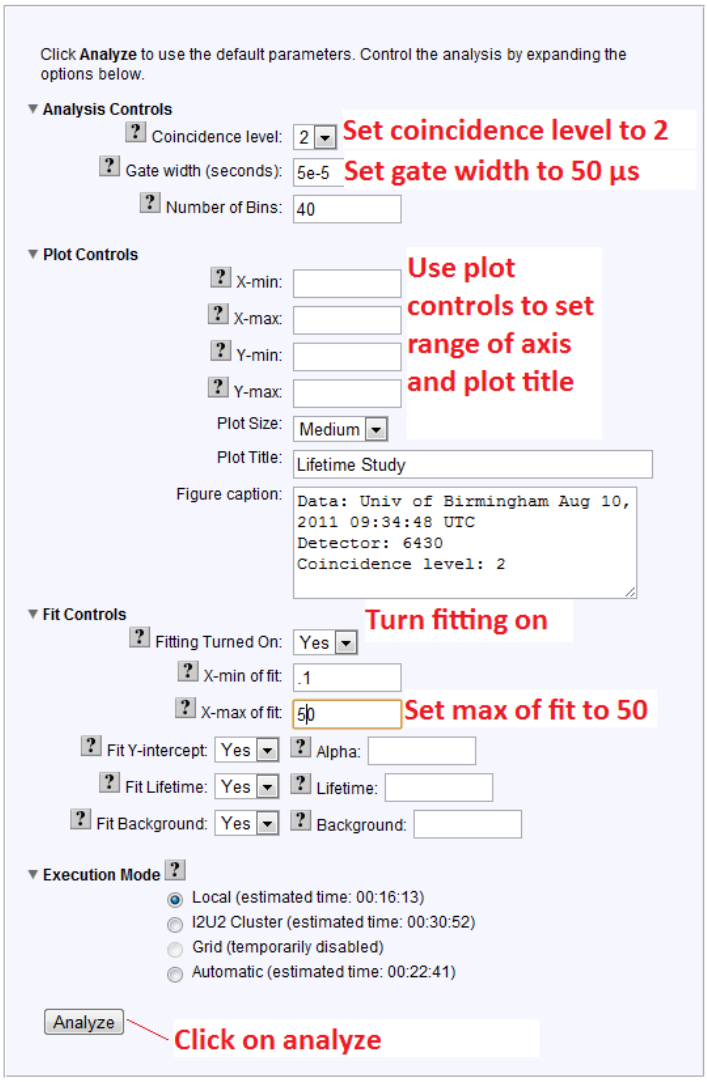
## 5.4 Running a Lifetime Study

We will first run a Lifetime study on data we have already taken so you can get used to using the website. Log onto the Cosmic e-lab webiste at http://www18.i2u2.org/elab/cosmic/home/ The data contains informatation on all pulses produced by each counter. The software then looks for events where 2 adjacent counters produced a coincidence, with no coincidence in the next counter. This is the indication that a muon has stopped in the detector, and the next signal in the second counter gives the decay time.

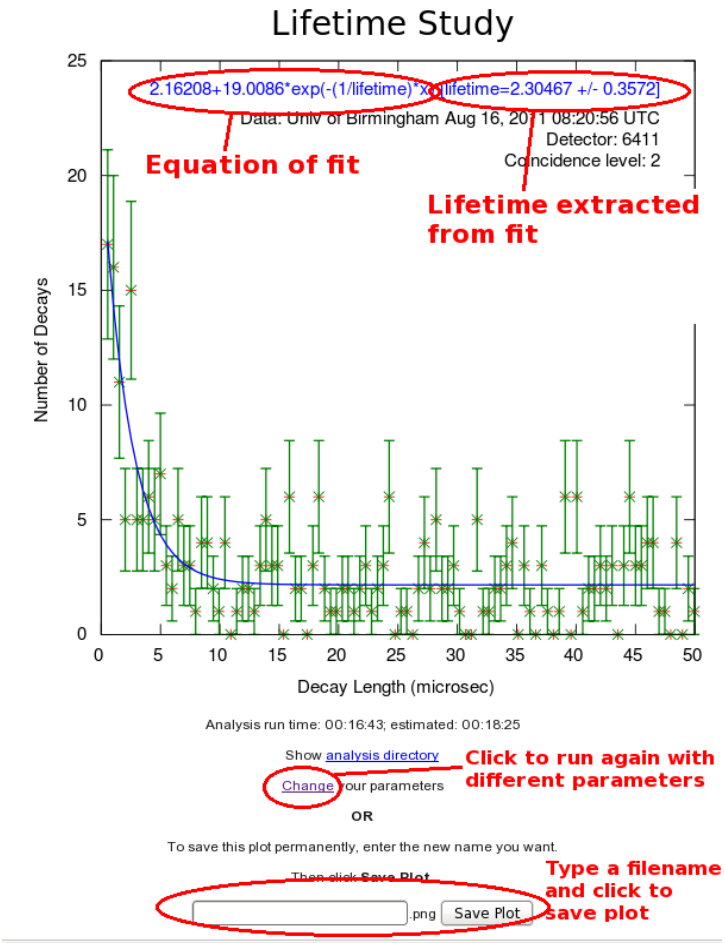
1. Click on the “Data” tab and then “Lifetime”.




2. Search for data from 19/08/2011 from the school “Univ of Birmingham”. Select the data from this day to analyse, as in the figures above.



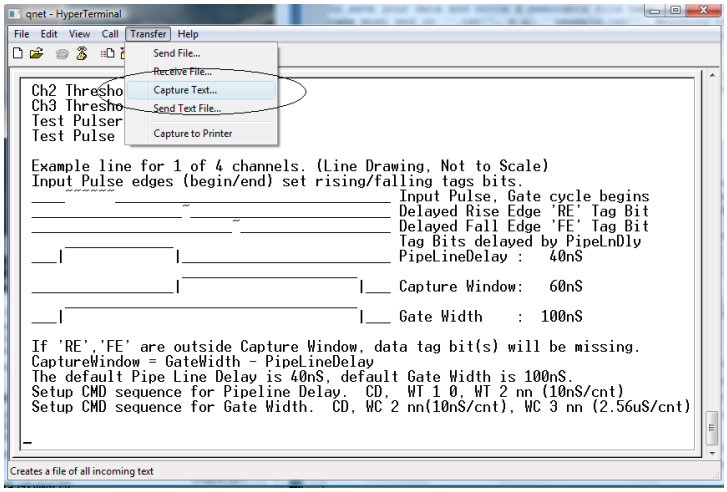

3. Set the coincidence level to 2 so that the software will look for a coincidence in 2 adjacent counters followed by no signal in teh next one. Expand the "Plot Controls" tab to change the range of the axes and the plot title. Expand the "Fit Controls" tab and make sure "Fitting turned on" is set to yes. If you want, you can make an estimate of the y intercept, the lifetime and the background for the plot fit. This could help to make your fit more accurate, but a bad guess could make it completely wrong. I would suggest leaving them blank unless the fit is not giving a sensible result. Once you have done that then click on "Analyze".

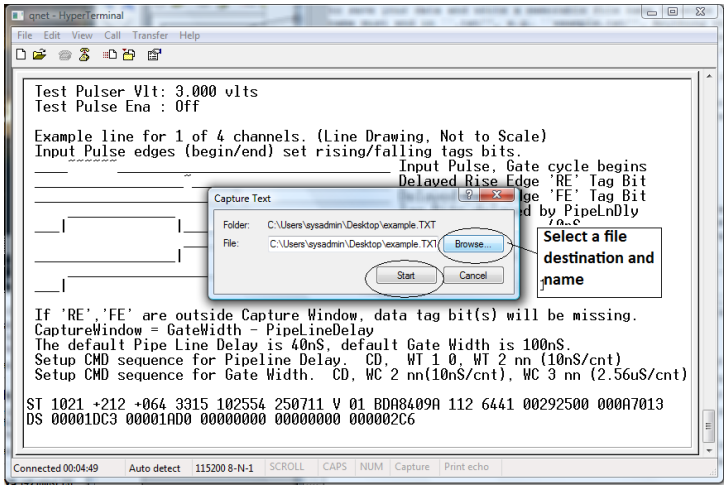


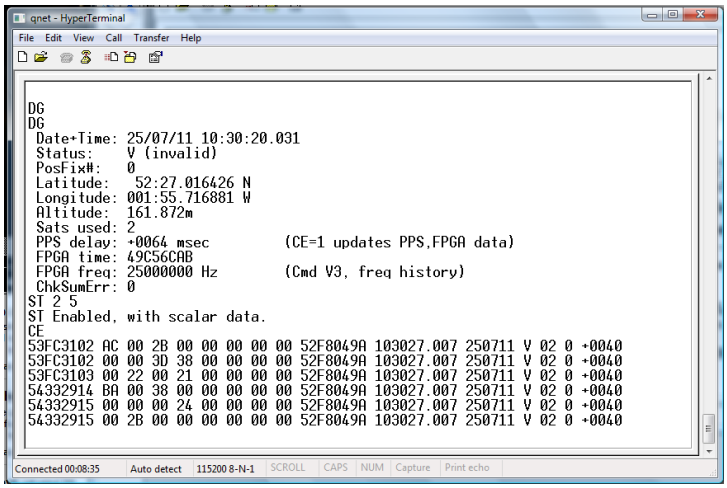

You should obtain a plot similar to the one above. The green points are your plotted data and the blue line is the exponential decay line which has been fitted. The formula for this fit is written at the top of the plot, and tells you the best fit for the lifetime of the muon. This is given in microseconds ($\mu$s, which is 1 millionth of a second.

## 5.5 Collecting Data

Set up your counters in the stacked configuration and set the control voltages to the optimum voltages found by the plateau method. Open Hyperterminal and follow the steps below to collect data:




1. For the muon lifetime study we need all the data that we can get. We want to record all of the signals coming from the counters, not just the ones with coincidences. Type WC 00 0F

to look at 1-fold coincidences from all counters. We will use the analysis page of the website to search the data for coincidences at a later time.

2. From the "Transfer" menu select "Capture Text"

3. Choose a file name ending with ".txt" and save your file somewhere memorable. Then select "Start"

4. Anything which now appears in the Hyperterminal window will also be written to the ".txt" file. Start by typing the commands V1, V2, DG, ST 2 5. This ensures your data file contains the necessary information about the detectors.

5. Type the command CE to enable the counters and start writing data to the ".txt" file. Leave this running for about 24 hours to collect enough data.Make sure that the computer you are using is set to never sleep, otherwise you will not continue to collect data.

6. Once you have collected enough data type the command CD to stop writing out data.

7. From the "Transfer" menu select "Capture Text" and "Stop".

Now you can use your data to repeat the steps above and calculate the lifetime of a muon. How does it compare to the true muon lifetime, which is $2.2\mu$s? If it is wrong then it could be that you have to play about with the plot controls. Try changing the bin width, or using 2.2 as a starting point for the lifetime estimate.

## 5.6 Note on Uncertainties

You will notice that the lifetime is given to you as a number with some uncertainty, for example $2.2 \pm 0.2\mu$s. This uncertainty tells you how accurate the measurement you have made is. No experiment is perfect, and any measurement which you make will have an uncertainty associated with it. The better experiments will have a smaller uncertainty and so the value is more accurate. The technical definition of the uncertainty is that if you repeated the experiment a numer of times, then on average the value you measure will be within these limits 68% of the time. So for the example above, if we repeat the experiment, we expect the value of the lifetime we measure to be within 2 - 2.4 68% of the time. So about a third of the time it will be outside these limits. We can use this to work out if our measurement is correct, and to quantify exactly how close to the true value it is. If it is only 1 or 2 times the uncertainty away from 2.2 then we can say confidently that our measurement is consistent and correct. If teh uncertainty is 0.2 and our measured value is less than about 1.8 then we might start to worry that our measured value doesn't match the true value. Of course if the uncertainty is large then it will probably be consistant with the true value, but isn't very useful to us.
The more data we use, the smaller the uncertainty will be, so if your uncertainty seems particularly large, then try collecting more data.

## 5.7 A little bit of Special Relativity

We have already discussed the fact that muons are produced in the upper atmosphere, which is about 30km above sea level. If we assume that muons are travelling at the speed of light (which they very nearly are) then we can calculate how long they take to reach our detectors.

$$t = \frac{d}{v} = \frac{30 \times 10^3}{3 \times 10^8} = 100\mu\text{s} \tag{2}$$

So it takes $100\mu$s for the muons to reach our detectors. But this is much longer than the lifetime of the muons we jsut calculated, so most muons should decay before they reach us. So how is it we are detecting them? For the answer we need to turn to Einstein's theory of Special Relativity. This theory includes a concept called time dilation which states that when something is travelling

close to the speed of light, time appears to be dilated to an observer who isn't travelling fast. So if we were travelling with the muon, we would measure the time which passes before decay to be $2.2\mu$s. However, since we are a stationary observer, the time that the muons exist for seems to become longer. This is called time dilation. The exact amount that the time is extended by is determined by exactly how fast the muons are travelling, and can be calculated with the following formula:

$$t = \frac{t_0}{\sqrt{1 - \frac{v^2}{c^2}}} \tag{3}$$

Muons are typically travelling at 99.9985% of the speed of light, so the time they actually exist for is:

$$t = \frac{2.2}{\sqrt{1 - 0.999986^2}} = 109 \times 2.2 = 415\mu\text{s} \tag{4}$$

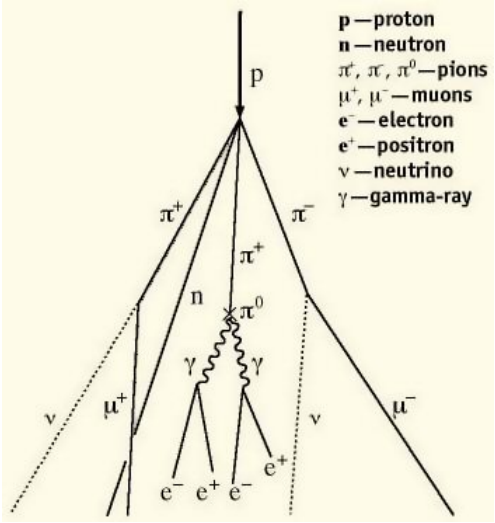
which is plenty of time for the muons to reach our detectors before decaying.
So we need another experiment to prove that the muons are actually produced in the upper atmosphere, but if we assume that is true then my calculating the muons lifetime you can just proved that Einstein was correct in his theory of Special Relativity.

# 6 Worksheet 6: Shower Study

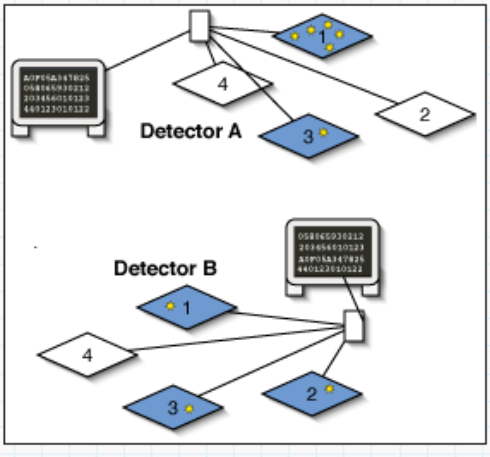
## 6.1 Aim

The aim of this worksheet is to investigate large cosmic ray showers and to find out where they come from and how they are produced.

## 6.2 What are air showers?




We have already discovered that cosmic ray muons are produced when primary cosmic rays interact in the atmosphere. However, there is often more than one particle produced in an interaction. Each of the particles which are produced will then interact with other molecules in the atmosphere to produce even more particles. With each interaction, the particles end up with a lower energy, until eventually there is not enough energy left to create more particles. The particles then decay, and you have a handful of muons produced by a single primary cosmic ray. This is called an Air Shower.

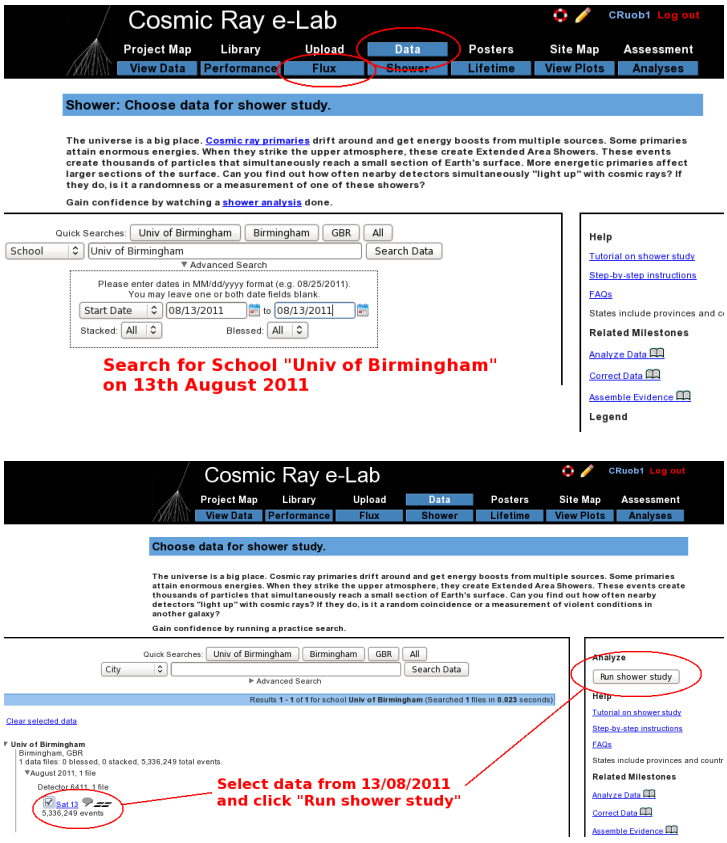



The muons will spread out as they travel towards Earth, but since they are all produced at the same time, they will reach sea level within about 100ns of each other. We can therefore spread our counters out flat, and see if we can detect a handful of muons arriving at the same time. We can then use the Cosmic e-lab website to analyse the data, and it will tell us how many muons were in the shower and what direction the shower came from.

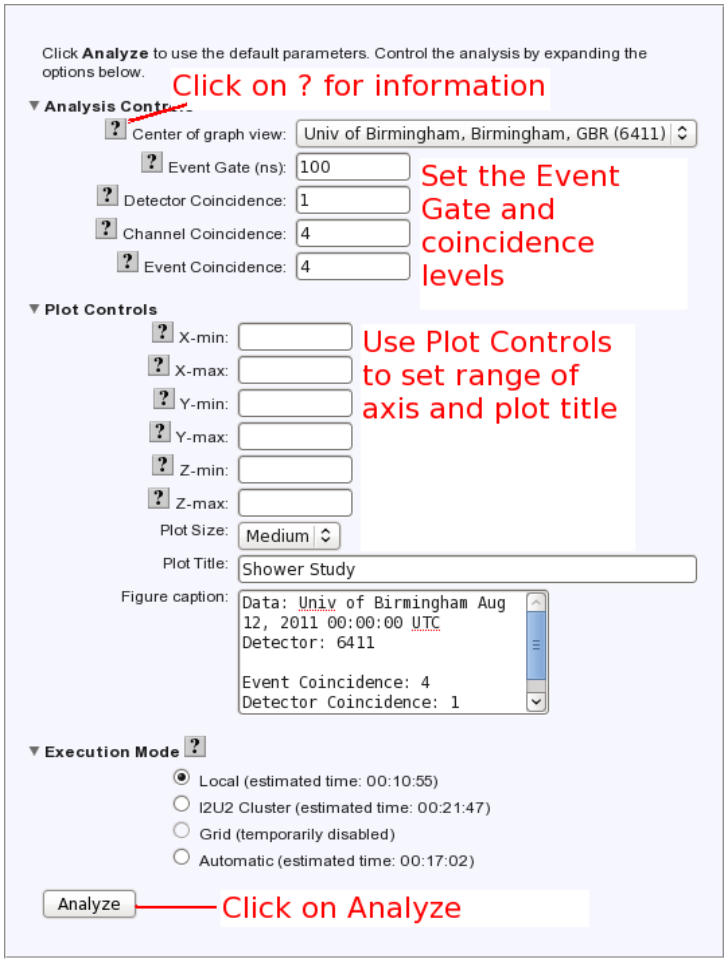
The size of the air shower and the number of particles in the shower are determined by the energy of the primary cosmic ray. The higher the energy of the primary cosmic ray, the more particles there are and the further the shower spreads. There are sources of cosmic rays which produce particles with such high energy that the showers created are the size of a small town. The origin of these ultra high energy cosmic rays are still not fully known to physicists, but you can investigate them. If you know of some schools near you using the cosmic ray muon detector (CRMD) then you can organise yourself to take data at the same time. If you see a coincidence between signals in the detectors from different schools, then it is likely that you are detecting particles which are a part of the same large air shower, produced by an ultra high energy cosmic ray.

## 6.3 Performing a Shower Study

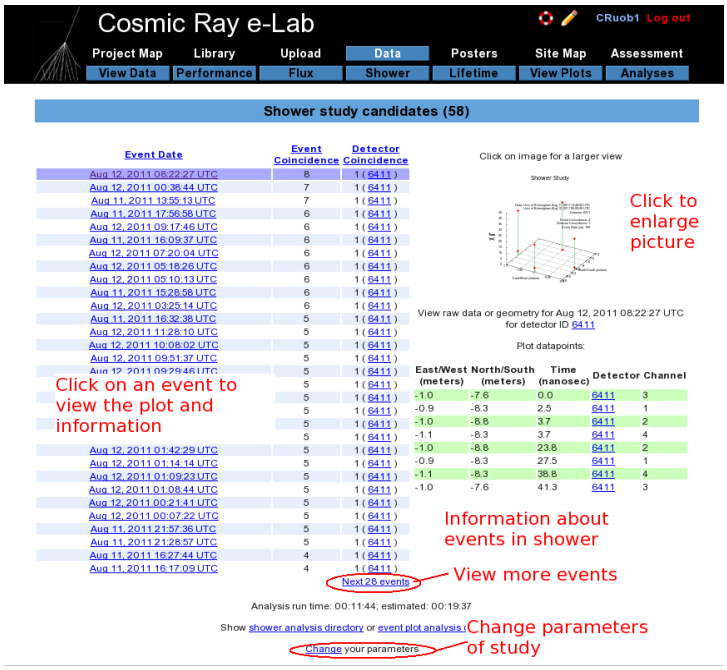
We will first analyse data which has already been recorded by the University of Birmingham to show you how a shower study is done. The counters were unstacked, as in the picture above, and covered an area of about $0.5\text{m}^2$. The data was recorded for about 24hours.



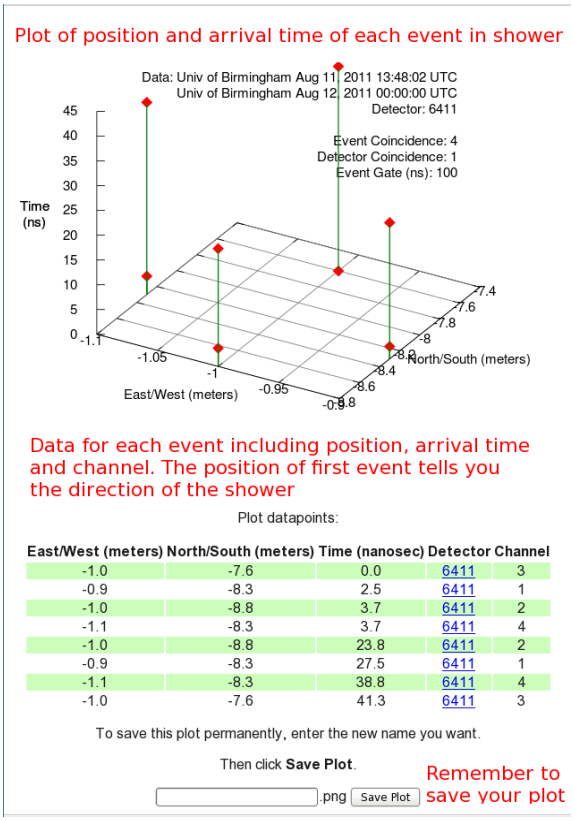
Log into the cosmic e-lab website and select “Shower” from the “Data” tab. Change the dropdown menu to school and search for “Univ of Birmingham”. Select data from 13/08/2011 from detector 6411 and click on “Run shower Study”, as shown in the figures above.




You can then change the coincidence levels. Click on the question mark by each setting for find out what it means. The detector coincidence is the number of different detector (i.e. different schools) you want the shower to have hit. Since we are just looking at one detector, set this to 1. The channel coincidence is the number of counters which need to be hit. Since we want all 4 counters to be hit to define an air shower, set this to 4. The event coincidence is the number of signals which are detected among the 4 counters within the gate width. Set this to 4 also. The value of the gate width should not affect how many particles you see in a shower, since they should all arrive within 100ns. Having a gate width which is too high can mean that you detect particles which are not part of the shower. Set the gate width to 100ns. You should not need to change the plot controls except to change the title of the plot. Once you have set the coincidences, click on “Analyze”.




You will then see a page with all of the events which match your select criteria. They should therefore all be air showers. At the top of the page you will see the number of shower candidates. The list below tells you the date of the shower and the event coincidence, i.e. the number of particles in the shower. By clicking on an event, it will produce a plot of that event on the right hand side of the page. Click on the plot to make it larger.



You will now see a graph and a table of data for that particular study. The graph is a 3-dimensional plot of the shower. For each particle in the shower, the North/Shouth and East/West measurement are plotted on the x- and y-axes and is determined by which channel the event was recorded in, and the geometry which you uploaded for the counter in that channel. The time of arrival is then plotted on the z-axis. This is relative to the time of the first signal, which has a time of 0.0ns. The position of the first signal tells you the direction of the cosmic ray shower. So for the plot above, the shower originated from the north. You can see a plot like this for each of the shower candidates by clicking on them from the page of events.

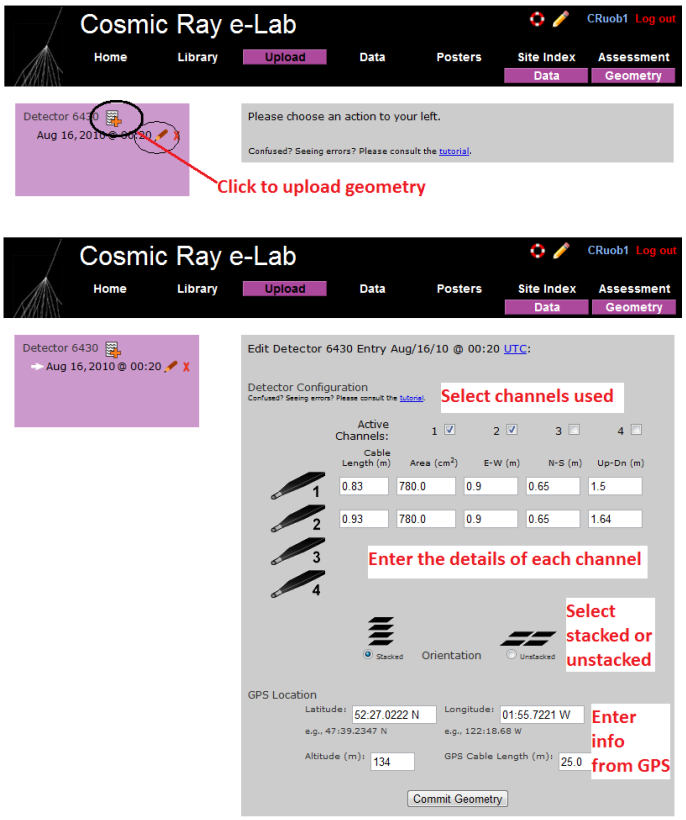
## 6.4 Your Own Investigation

Set up your counters in an unstacked configuration, as shown in section 6.3, and you can start your own shower study. You can be flexible with what it is you really want to investigate. Think about what might affect the air showers, or what properties of air showers you want to investigate, and come up with a research question. For example, what is the average number of particles in a shower? How is the shower affected if you move the counters further apart? Is there one particular direction that the showers tend to originate from? Is there a relationship between the number of particles in a shower and their direction? Try to come up with your own idea and then you are ready to start taking data. Open up Hyperterminal and follow the instructions below:

### 6.4.1 Upload Geometry

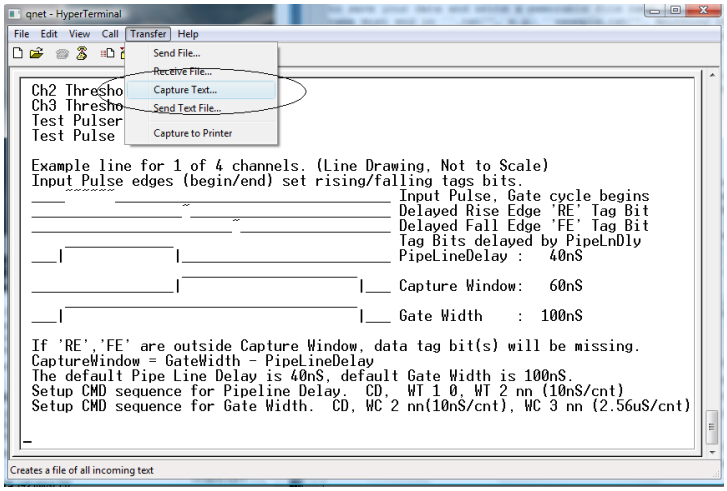
Before you start collecting data, be sure to upload your geometry with the new, unstacked configuration.

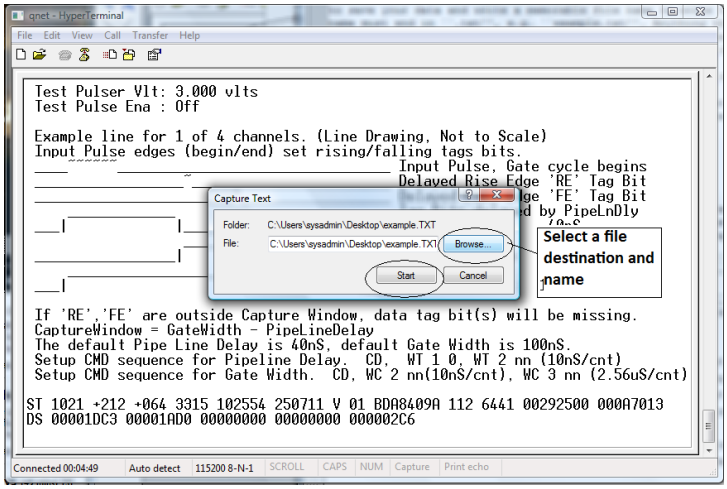
- To upload the geomtery of the detector click on the upload tab on the e-lab website and then click on the geometry tab.
- Click on "add entry". You should see the following pages.

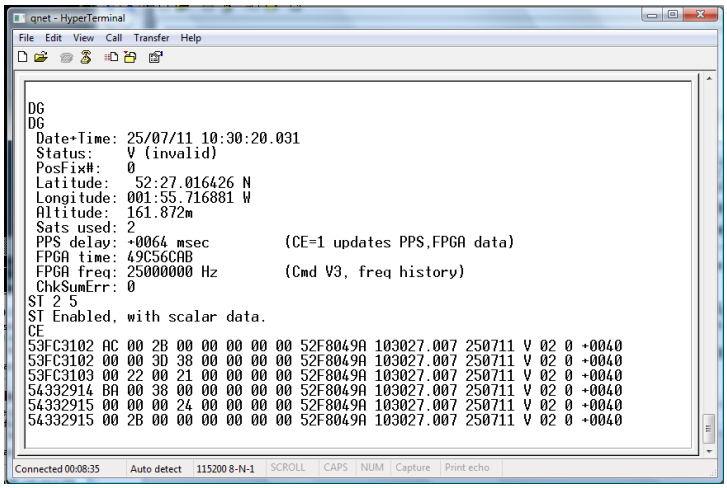


- Fill in the details of the detector setup.
  - First, tick the boxes corresponding to the channels which you are using.
  - Next, enter the required details for each counter.
  - The cable length is the length of cable from the PMT to the DAQ board.
  - The area is the surface area of the counter in units of $cm^2$.
  - The E-W (East-West), N-S (North-South) and Up-Down measurements are the distances of the counters from the GPS antenna. In the stacked configuration, the Up-Down measurements for all counters should be the same.
  - Next you need to select the orientation of the detector. Select unstacked for a shower study.
  - Finally, you need to enter details of the GPS antenna. The longitude, lattitude and altitude measurements can be found by typing the DG command into Hyperterm.
  - The GPS cable length is the length of cable connecting the GPS module to the DAQ board.

### 6.4.2 Collecting Data






1. For a shower study we want to record all of the signals coming from the counters, not just the ones with coincidences. Type WC 00 0F to look at all signals from all counters. We will use the analysis page of the website to search the data for coincidences at a later time.

2. From the "Transfer" menu select "Capture Text"

3. Choose a file name ending with ".txt" and save your file somewhere memorable. Then select "Start"

4. Anything which now appears in the Hyperterminal window will also be written to the ".txt" file. Start by typing the commands V1, V2, DG, TL, ST 2 5. This ensures your data file contains the necessary information about the detectors.

5. Type the command CE to enable the counters and start writing data to the ".txt" file. Leave this running for about 24 hours to collect enough data.Make sure that the computer you are using is set to never sleep, otherwise you will not continue to collect data.

6. Once you have collected enough data type the command CD to stop writing out data.

7. From the "Transfer" menu select "Capture Text" and "Stop".

Now that you have your data recorded on a file, you can upload it to the e-lab website for analysis.

- Click on the upload tab, and then click on data.
- Now select the file that you recorded the data and on click on "upload".

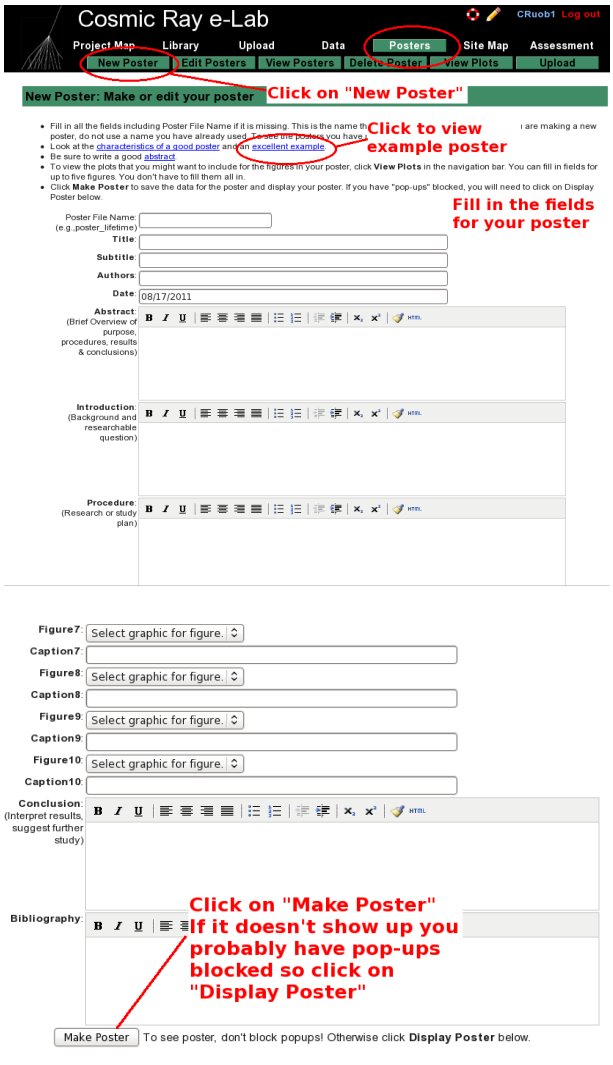
Repeat the steps in section 6.3 and use the data you have collected to answer your research question and write up some conclusions.

# 7 Worksheet 7: Making a Poster

## 7.1 Introduction

With any experiment, when you have finished analysing your results and have come up with a conclusion you will want to share your findings with the world. Science does not progress unless we tell people what we have done and what we found out. There are different ways we can do this. We can write a paper which is published in a journal. This is usually reserved for significant results. As well as this, we may also be lucky enough to be asked to give a presentation about our work at a major conference. This is a great way to tell people about our results as it also gives them an opportunity to ask us questions about our experiment. A much quicker and easier way of presenting our results is to make a poster. This very briefly outlines the experiment, and when small groups come round to look at it, we can discuss with them the procedure and results.You will now be making a poster to present to your fellow classmates. You should then prepare a 5 minute talk about your poster, explaining the experiment and your results. The will then have a question and answer session, where your classmates can ask you about the method and discuss with you your results.

## 7.2 Making your Poster



Making a poster is easy with the Cosmic e-lab. Log in and click on "New Poster" from the "Posters" tab. Now simply fill out all the fields, including a file name, the title and the authors names'. This section will give you advice about exactly what to write in each field. Once you have written everything you need to and uploaded your figures, click on "Make Poster" at the bottom of the screen. It will only appear if you do not have pop-ups blocked. If it does not appear automatically then click on "Display Poster".

### 7.2.1 Abstract

In some ways the Abstract is the most important part of the poster. It is the first thing people read (after the title), and it is what they use to decide whether they are going to read the whole thing or not. It should not be too long, but should very briefly describe the experiment you carried out, and what your most important results and conclusions were. It is often useful to write this after you have written the rest of the poster, so that you can simply summarise the poster in a couple of lines.

### 7.2.2 Introduction

In the introduction you should write about the main physics behind the experiment. You should also discuss what your research question is, and what the ultimate goal of the experiment is.

### 7.2.3 Procedures

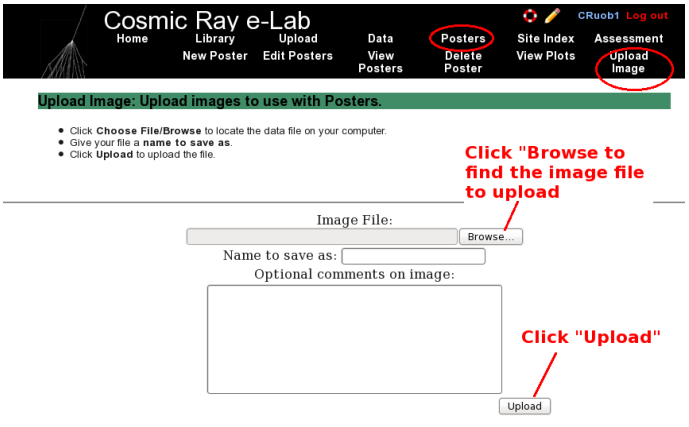
This is where you outline the method you used to carry out your research. It should not be step-by-step instructions, but should be detailed enough that somebody reading the poster will be able to understand how you attempted to answer your research question.

### 7.2.4 Results

This is where you discuss your results. You should state clearly what the data show and how you have interpreted it. You will also have to upload figures and plots after this section. Make sure these plots are relavent and that you refer to them in this section. You should explain your graphs and what the data shows.

### 7.2.5 Figures

You can include up to 10 figures for your poster, but 1 or 2 should be enough. Make sure your graphs are clear and are relavent to the poster. Include a caption to explain what the graph shows. You can inlude any of the graphs which you saved, so select the appropriate graph from the drop down list.



If you want to include a graph which is not saved in the Cosmic e-lab, for example if you used MS Excel to create a graph, then you will need to upload it before you can include it in a poster. You can do this by clicking on "Upload" under the "Posters" tab, as shown in the figure above. Click on "browse" to find the image you want to upload. It has to be saved as an image file, for example with a filename ending ".png" or ".jpg". Once you have uploaded it, it will appear in the drop-down list of figures and you can include it in your poster.

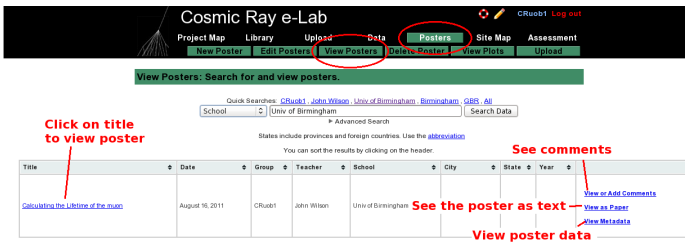
### 7.2.6 Discussions and Conclusions

This is where you interpret your results and give the answer to your research questions. Explain how the data presented in the results section supports these conclusions and why you have interpreted them in that way. What new physics do these conclusions imply? Afterwards you should suggest improvements to the procedure or extensions to the experiment. What can you now investigate knowing what you have learnt from this experiment?

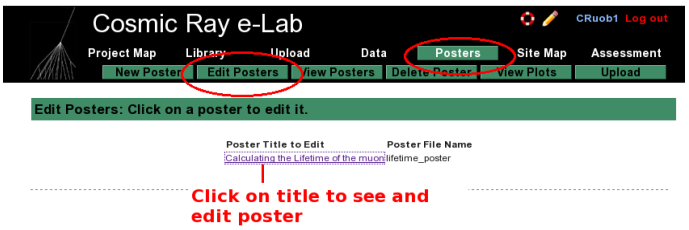
### 7.2.7 Bibliography

Include a list of any books or web pages that you used when researching material for this project.

## 7.3 Editing your poster




Once you have made you poster, you can view it by clicking on "View Posters" in the "Posters" tab. By searching for a school you can also view any other poster uploaded to the website. Just click on the title to view the poster. You can add comments to it by clicking on "View or add comments". If you want to view the poster as a paper, so as plain text and figures, click on "View as paper". If you want to view the data for the poster click on "View as Metadata".



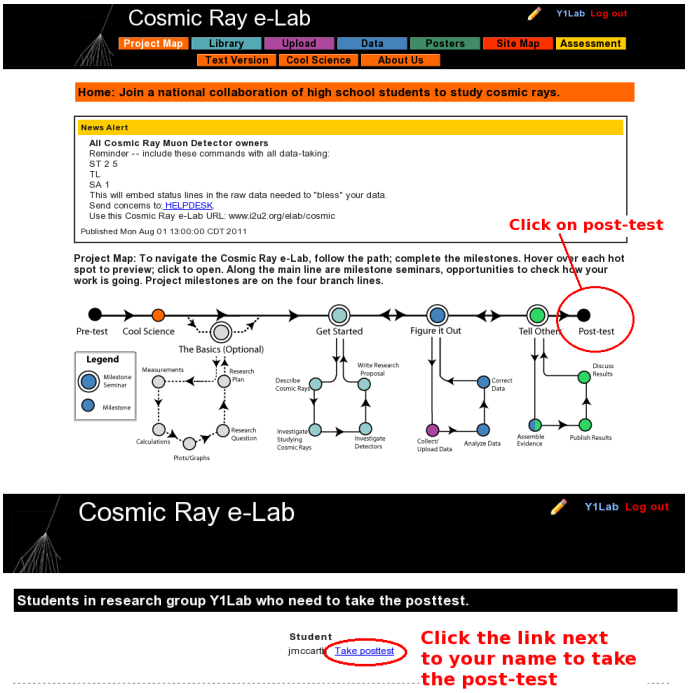

If you want to edit your poster, select "Edit Posters" from the "Posters" tab. Click on the title of the poster you wish to edit and it will bring up the fields for the poster, which you can edit. When you are done click on "Save Changes".

## 7.4 Presenting your poster

When your poster is finished you can present it to the class. Prepare a 5 minute talk about your poster. Summarise each section but don't just read the poster, try and explain it more clearly. When you are finished invite your classmates to ask you questions about the poster, either about the physics behind it, the procedure or the conclusions. They may have some insight which leads

you to interpret the results slightly differently. You can then edit your poster based on their feedback.

## 7.5 Post-test







Finally, to round off the project, you will need to take to post-test. This is designed to test how much your knowledge has imporoved through the project, compared with the pre-test which you took. From the Project Map page, click on the post-test icon at the end. Then click the link next to your name to start the post-test.

# A Connecting the Muon Detector

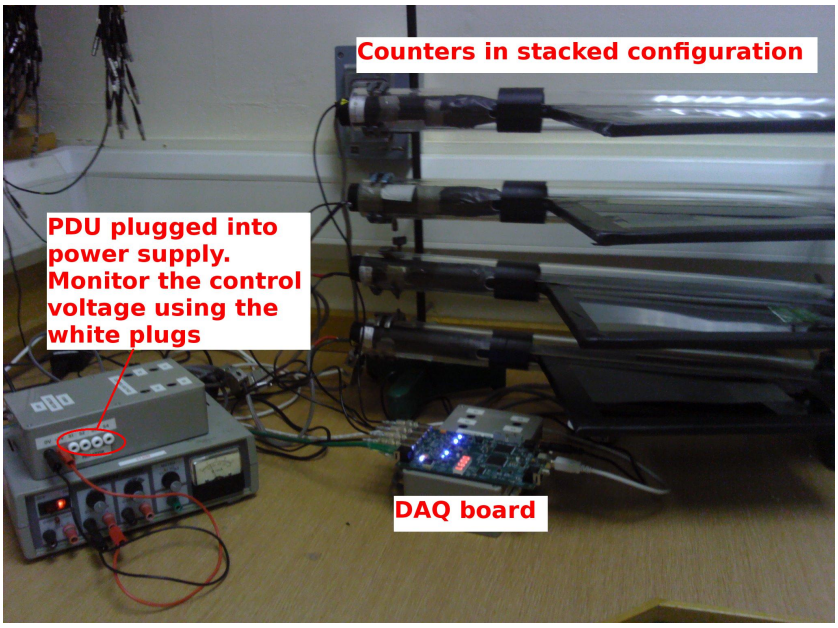



Figure 1: The setup for the muon detector.

## A.1 Downloading Drivers

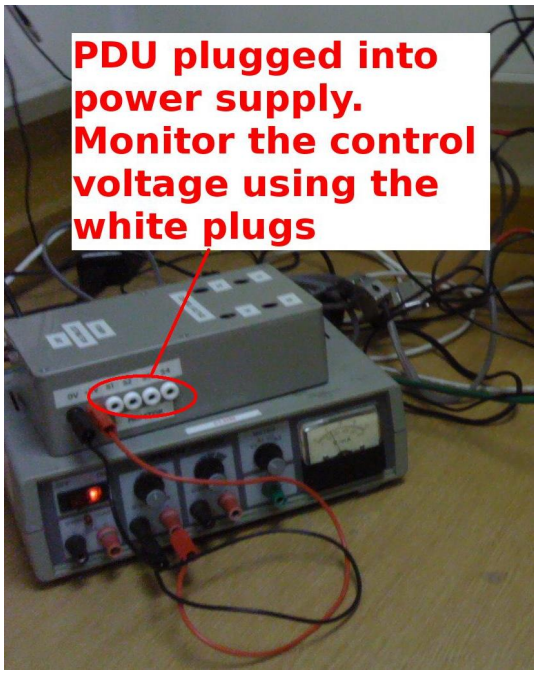
The first thing you need to do is to download the drivers for the Data Aquisition Board (DAQ). The driver can easily be dowloaded from
**https://www.silabs.com/products/mcu/Pages/USBtoUARTBridgeVCPDrivers.aspx**
Select the driver for the operating you are using and click the relevant link. The DAQ can now be used with the Hyperterm program, described in the next Appendix.

## A.2 Positioning the Counters

The counters should first be positioned one on top of the other. This can be done using retort stands. Support the clear tubes at either end, with the scintillators flat and at 90° to the retort

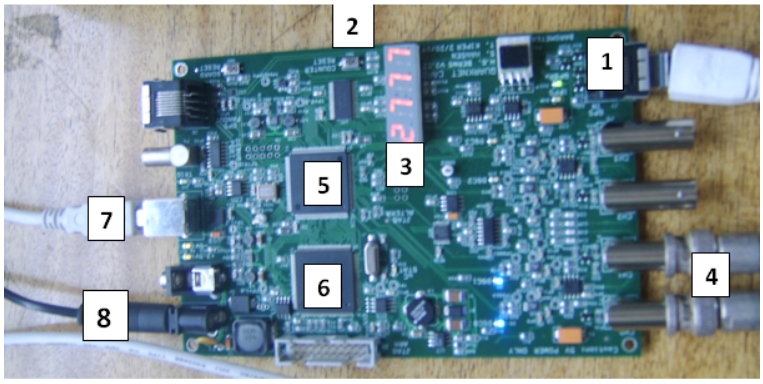
stand. The counters should be around 30cm apart.

## A.3 The Power Distribution Unit (PDU)




Connect the PDU to a power supply, as shown in the figure, and supply it with 5V. Note that supplying more than 5V can damage the PMTs. Connect the PMTs to the PDU via the 9 pin d-type connector. You can change the control voltage across the PMT by changing the variable resistor in the PDU. Use a digital voltmeter in the monitor points to test the control voltage on each counter. This should not go above 1.9V as it may damage the PMT.

## A.4 The DAQ board




The figure above shows the function of each part of the DAQ board. The numbers correspond to the following:

1. GPS Input.
2. Board reset button.
3. Coincidence counter display.

4. Inputs for 4 counters (channels 0-3).
5. CPLD (programmable fast logic).
6. Time-to-digital converter (TMC).
7. USB port (output to PC).
8. 5V Supply Input

- Plug the 5V supply available for the DAQ board into point 8.
- Connect the ethernet cable from the GPS module to point 1, which is the ethernet slot next to the PMT inputs. Place the GPS antenna at a window with a good view of the sky. When the GPS module flashes green with no red night, then it has fixed onto a satellite. This could take up to an hour. While the GPS has not fixed a position, the red LED on the GPS module will flash. Once a position has been fixed, the green LED on the GPS module will flash. In both cases the number of flashes corresponds to the number of sattelites currently being used. You can also check the GPS status with the DG command through Hyperterm (see the worksheet 'Using Hyperterm').
- Plug the signal wires from the counters into inputs at 4.
- Plug the board into a USB port on the computer from point 7.

**Make sure everything is plugged in and you are ready to detect cosmic rays!**

# B Using Hyperterminal

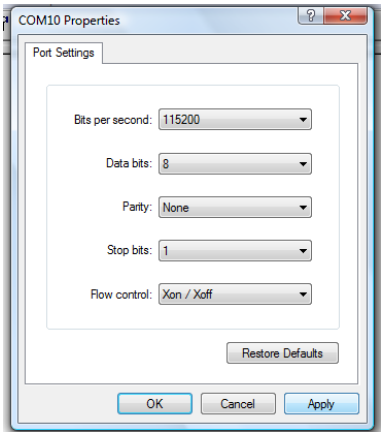
## B.1 Introduction

Hyperterminal is a terminal emulator program which we can use to send commands to the DAQ board. This is our way of interacting with the counters, and allows us to manipulate settings and to record the events we are detecting.

## B.2 Installing Hyperterm

Hyperterm is sometimes installed as standard on windows PCs. If it is then it can be found under "Accessories", "Communications". If it is not already installed, then we have a copy at the University of Birmingham which we can install for you. There may be a shortcut on your desktop for it.

## B.3 Opening Hyperterminal

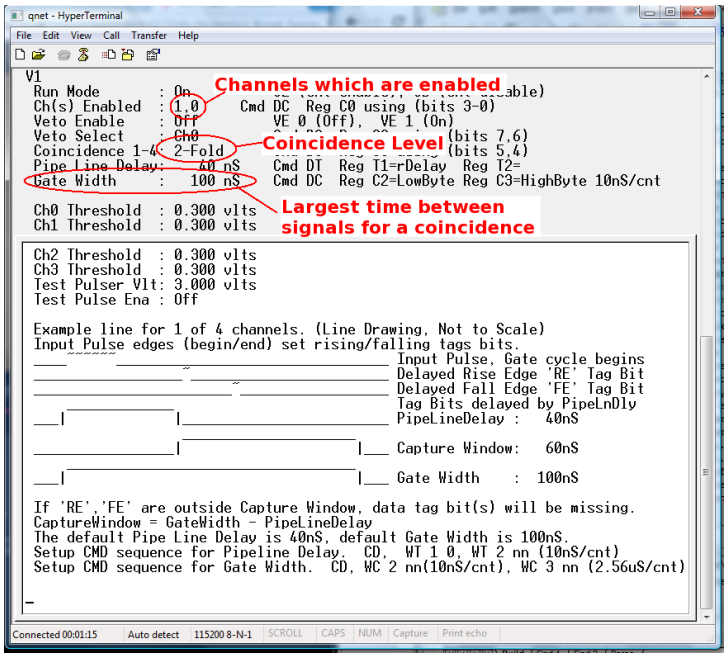



Open hyperterminal and type a name for the connection (for example 'qnet'). When asked to enter a phone number, change "Connect using" to the highest available port (usually COM10), and use the following settings:

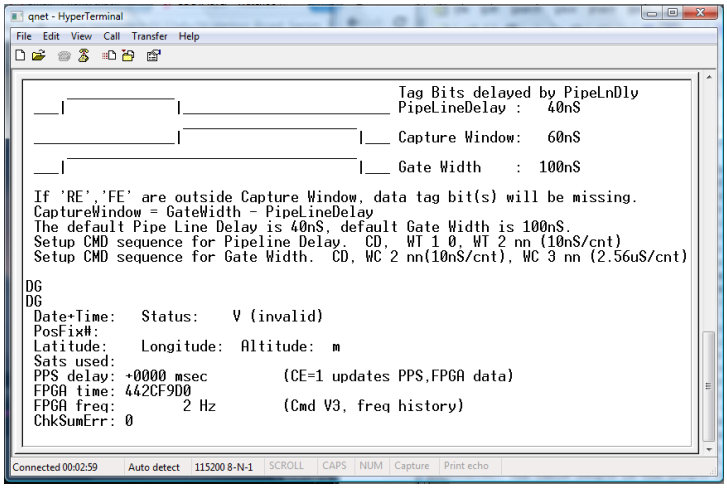
- Bits per second: 115200
- Data bits: 8
- Parity: None
- Stop bits: 1
- Flow control: Xon/ Xoff

You can now send commands to the DAQ board to view and manipulate the settings of the counters.

## B.4 Hyperterminal Commands




You can use the commands V1 and V2 to view the current settings of the detector. This is useful to check whether the commands you used to change settings have had the desired efect.




Using the DG command will display the settings of the GPS unit. You shouldn't start taking data until PosFix# = 1. This means that the GPS module has managed to fix on to a satellite, and this is important to make sure that the data we are recording is valid.
Some useful commands are listed at the end of the sheet, and are also available by using the H1 and H2 commands.

## B.5 Setting up the detector

The detector can be set up differently depending on the number of counters you are using, and the type of experiment you are doing.You can use Hyperterm to change the settings of the DAQ board to suit your experiment.

### B.5.1 Channels and Coincidences

For example, if you are using only two counters, you can set up the board to only use the required channels. In order to detect muons, we want to look for a coincidence between the signals from the two counters, indicating that a particle travelled through them at almost the same time. So for this setup, we say you need a two-fold coincidence between channels 0 and 1. To do this you use the command WC 00 nm. 'n' sets up an n+1-fold coincidence, so for a two-fold coincidence we use n=1.
m is a hexadecimal number representing the channels which are enabled and disabled. The pattern of enabled channels form a 4-bit binary number, with a 1 representing an enabled channel and 0 a disabled channel. So to enable all 4 channels the binary number is 1111, which is 15 in decimal, or F in hexadecimal. To enable channels 0 and 1, the binary number is 0011, which is 3 in hexadecimal. So to set up a two-fold coincidence between channels 0 and 1, we use the command WC 00 13. You can check this has worked with the V1 command.

### B.5.2 Threshold

You can also change the level of the threshold of the DAQ board. The DAQ board will only register signals with a voltage above a certain level, known as the threshold. By default this is set to 300mV, but it can be changed using the TL command. You can also change each channel individually. So TL n 300 set channel n to have a threshold of 300mV. Remember that the channels are labelled 0,1,2,3. Typing TL 4 300 will set the threshold of all 4 counters at once. Just typing TL will display the value of the threshold for each channel.

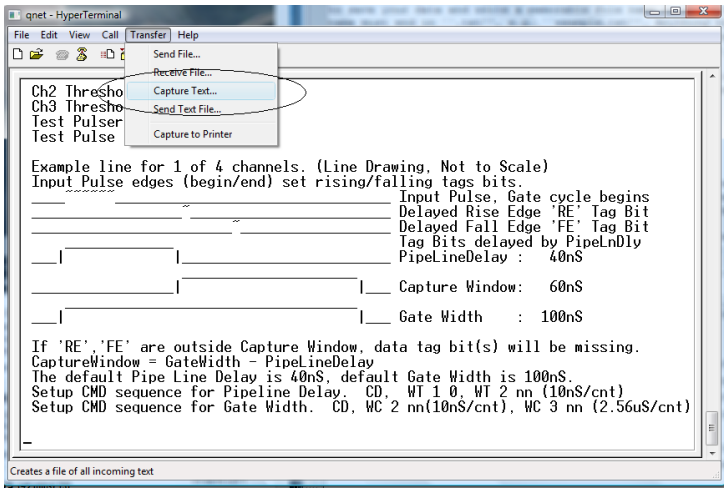
### B.5.3 Gate Width

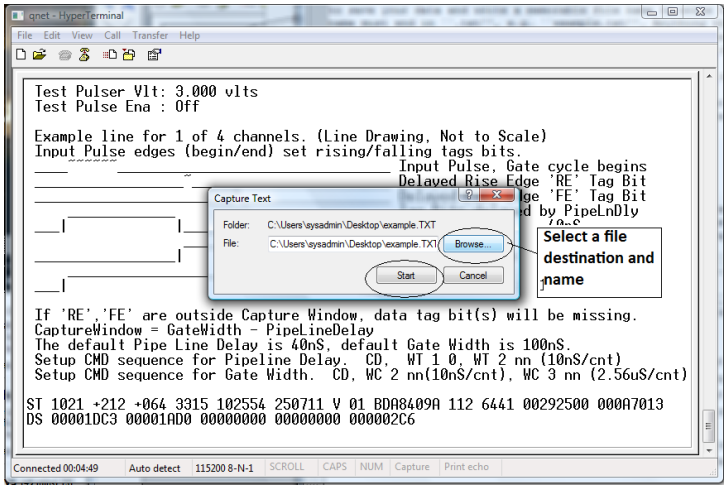
The gate width is the largest time between signals for it to still be considered a coincidence. By default, this is set to 100ns. To change it you need two commands WC 02 cd followed by WC 03 ab. The combination abcd is the number of clock ticks required for the gate width. 1 clock tick is 10ns, so that a 100ns gate width requires 10 clock ticks. In hexadecimal, 10 is 000A, so to set this gate width, you need to type the commands WC 02 00, WC 03 0A.

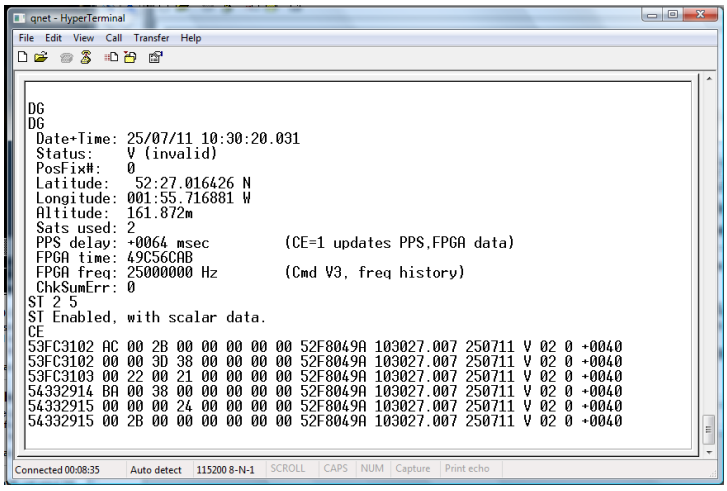
### B.5.4 Save

To save the settings which you are using, typwe the command SA 1.

## B.6 Recording Data




1. From the “Transfer” menu select “Capture Text”

2. Choose a file name ending with “.txt” and save your file somewhere memorable. Then select “Start”

3. Anything which now appears in the Hyperterminal window will also be written to the ".txt" file. Start by typing the commands V1, V2, DG, ST 2 5. This ensures your data file contains the necessary information about the detectors.

4. Type the command CE to enable the counters and start writing data to the ".txt" file. Leave this running for about 24 hours to collect enough data.Make sure that the computer you are using is set to never sleep, otherwise you will not continue to collect data.

5. Once you have collected enough data type the command CD to stop writing out data.

6. From the "Transfer" menu select "Capture Text" and "Stop".

| *Command* | *Description* |
|---|---|
| H1, H2 | **Help commands** |
| CD | **Counters Disabled:** Prevent event lines being written in hyperterm |
| DS | **Display Scalers:** shows the values of the scalers in a hexadecimal format |
| RB | **Reset Board:** resets the scalers |
| RE | **Reset Everything:** resets the whole board |
| TH | Shows values of the thermometer on the GPS module |
| BA | Read and adjust the baromoter on the GPS module |
| DG | Displays information about the GPS modue |
| V1, V2 | View the registers |
| ST 3 5 | Displays the staus line every 5 minutes with counts and resets the counts. Using ST 2 5 doesn't reset the counters |
| SA 1 | Save any changes to the settings. |
| WT 01 00<br>WT 02 nm | **Sets the TMC delay, d:** nm is the value entered in hexadecimal, and this will set the value of d as nm in decimal. (d is actually the difference between register 01 and 02) |
| WC 00 nm | **Sets the coincidece level and enables the desired counters:** n sets an n+1-fold coincidence (i.e. an event is recorded if there is a coincidence in signals between n+1 counters.) m is the hexadecimal number representing the channels on the DAQ board which are enabled. 1 represents an enabled counter and 0 represents a disabled counter. So to have all the channels enabled would be $1111_{bin}$ or $F_{hex}$ |
| WC 02 cd<br>WC 03 ab | Sets the value of the gate width, w. abcd represents the number of clock ticks required for the gate width (1 clock tick is 10ns). For example, a gate width of 100ns requires 10 clock ticks, which is 000A in hexadecimal, so you would use the command WC 02 00 followed by WC 03 0A. |
| TL n 300 | Sets the threshold of channel n to 300mV. Using n=4 changes the threshold of all 4 channels at once. |