Construction and testing of a cosmic ray detector for the House of Science

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June 10, 2009

Master's Thesis for

Master of Science in Engineering and of Education programme

KTH

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TRITA-FYS 2009:29

ISSN 0280-316X

ISRN KTH/FYS/–09:29–SE

Abstract

This Master's Thesis discusses the construction and possible use of a cosmic ray muon detector at the House of Science. A scintillatorbased detector has been developed from the detector used in the Stockholm Educational Air Shower Array (SEASA) project. The SEASA detectors were placed on school roofs inside car ski boxes and were therefore visible to students. The new detector is possible for students to handle by themselves. The new detector consists of three detector plates that are placed on top of each other separated by 33 cm.

The school programme developed for students in the upper secondary school focuses on encouraging students to learn how they could work with data analysis and how a scientific model is developed and changed with time. The main method used is developed by Millar et al. (1999) which studies if a laboratory exercise is effective or not. The task tested in this thesis is shown to be effective on level 1, but can hopefully be effective on level 2 with some changes. It is also shown possible for the students to contribute to the meaning of the task.

Contents

1 Introduction

This project is carried out as a Master's Thesis in the course KTEX4N at the Master of Science in Engineering and of Education program at KTH. The project is a collaboration between KTH, SU and the House of Science, it discuss the installation and possible use of a version of the Stockholm Educational Air Shower Array (SEASA) detector at the House of Science (SEASA, 2009)

The House of Science is a owned by KTH and SU and pursues education activities in natural science and mathematics. Their primary target group is school children between 6 -18 years of age and teachers. In year 2003 House of Science was opened on university area. The aim of the House of Science is to "increase the interest of science and technology" (House of Science, 2009). They also want to enhance contact between schools and the university (House of Science, 2009). The House of Science arranges school visits where laboratory activities requires advanced equipment and/or connected to current research can be performed. Beside this they are involved in other projects with the aim of increasing interest in the natural sciences, for example Explore Space (Explore Space, 2009). A science tour to ten cities in Sweden were upper secondary students get to meet scientists and work with questions related to space.

Stockholm Educational Air Shower Array was founded in 2002 by the Particle and Astroparticle group at KTH. The aim of the project is to bring "intellectual and technical challenge of scientific research to high-school students" (SEASA, 2009). The project gives students possibility to perform their project work[1] at their last year at upper secondary school in contact with KTH and cutting-edge research. The students get opportunity to work with advanced equipment, to collect data and analyze the results. Since September 2007 House of Science is collaborating with KTH in the project.

The Stockholm Educational Air shower Array is a project in the Stockholm region were cosmic ray detectors are installed on school roofs to give upper secondary school students the possibility to execute laboratory work connected to present research. After installation of a new detector it will be possible to evolve new ways of using the detector, i.e. not only annual year project work. When using the old detector only the students at the first year of the project got to work hands-on with the detector. After this the detector is installed on the foof and becomes less accessible. The years after students can only work with data analysis and the detector becomes like a black box they cannot touch, which is planned to change with the new detector.

At present there are six schools participating in the project. The schools that attend the project at present are as follows:

Enskilda Gymnasiet
Nacka Gymnasium
Åva Gymnasium

[1] a 100 hour course in the end of upper secondary school were students plan and perform their own project.

Norra Reals Gymnasium
Thorildsplans Gymnasium
Värmdö Gymnasium

2 Background

2.1 The Swedish curriculum and syllabus

> *The subject of Physics aims at providing such knowledge and skills which are needed for further studies in the natural sciences and technology, but also for studies and activities in other areas. The aim is that pupils should experience the joy and intellectual stimulation, arising from being able to understand and explain phenomena in the surrounding world. (National Agency for Education a)*

This is the first phrase in the physics curriculum in Swedish upper secondary school. This phrase put a lot of demands on the physics teachers, since they should not only teach the students physics. Their teaching also has to organize learning in a way that provides the students intellectual stimulation and they should also feel joy when studying physics. Everyone that has taught knows that this is a hard task. There is always somebody that is hard to reach. "The teachers should also enhance the students ability to plan, perform, interpret and present experiments" (National Agency for Education b). Experimentation in association with models and theories plays a central role in physics education in Swedish upper secondary school (National Agency for Education a). Students following the natural science program should also be able to communicate their knowledge and experiences in speech and writing and be able to acquire new knowledge in natural science (National Agency for Education b). These are some of the goals in the Swedish syllabus for physics and curriculum for the nature of science program.

2.2 Nature of science

In a study by Millar and Abrahams (2008) it is shown that the overwhelming part of experimental lessons that they studied focused on the substantive science content rather than on aspects of experimental design or the collection, analysis, and interpretation of evidence. To understand different aspects of experimental design or/and collection, analysis and interpretation of evidence the teacher need to have knowledge about the nature of science (NOS). In this section we settle with that nature of science is the fundation of science.

There have been a lot of discussions about what nature of science is, if it exists. Herron (1969) claimed that there is no sound and precise description and Lederman (1992) says that nature of science is neither universal nor stable. In 1994 Roberts (1994) wrote that "little more needs to be said about the emphasis itself" (p.13). Because much have been written about it. With the emphasis itself he refers to the «Structure of Science» emphasis which is one of his seven curriculum emphases. These seven emphases are seven different ways of teaching science. This emphasis deal with "how science functions intellectually in its own growth and development" (Roberts 1994, p.13).

Level	Problem	Procedure	Conclusion
0	Given	Given	Given
1	Given	Given	Open
2	Given	Open	Open
3	Open	Open	Open

Table 1: Model for deciding how open or closed an experiment is. (Schwab, 1962)

In a study by McComas et al (1998) eight international science Standard Documents were studied and a consensus view of the nature of science objectives was fond. These statements will be discussed in section 7.2.

2.3 Opened and closed experiments

Fors (2006) shows that upper secondary students that visit a science centre want to make their own interpretations and be able to contribute to the meaning of the activity at the same time as they develop a social identity. She talks about extending or ignoring the meaning of an exhibit, were extending is that the students connect their new experiences with what they knew or things that they have experienced before. In the same text she writes that to achieve this extending of meaning the design of the exhibit cannot be too inflexible and limiting, or be closed.

A practical task can be more or less open-ended. One of the most common ways to show this is as in table 1.

Level zero is when the teacher gives the student both the problem, how to perform the task and that the task has one given answer. The openness increases until everything is up to the student, the student decides what to investigate, how to perform the investigation and draw it is own conclusion. This doesn't say that all tasks should be at a certain level, some things have to be given for example you cannot let student investigate a strong acid without any constraints. A task at level 3 is today more often found at a science centre or museum than in school, or as it is called in informal institutions.

Informal education can according to Salmi (1993) be defined as "education given by different institutes, whose first function is not to educate: newspapers, television, libraries, youth free-time organisations, hobbies, peer groups and family" and that "formal education is given by specialised organisations representing the school system from pre-school to university" (p. 7). Important differences that also can be observed is that the social aspect is more central and that there is more unintended outcomes in the informal institutions. In formal learning the learning is centered around the teacher and not the student. There is a tradition that the teacher decides what to do, how to do it and what conclusions that should be drawn. Salmi (1993) also concludes that one important difference between informal and formal learning is the difference of audience. In an informal situation the audience is inhomogeneous in contrast to the formal learning situations when the audience is more homogeneous. Most of the time in school all children are the same age and also often come from similar background, an informal institution is often used by both young and old and people with different backgrounds. Sometimes the formal education institutes meets the informal education institutes when school groups visits museums and science centres.

3 Aim

The aim of this project is to develop and install a cosmic ray detector at the House of Science and produce a school-programme that agrees with educational science research and the curriculum and syllabus for the Swedish natural-science program at upper secondary school.

3.1 Questions to be addressed

The questions to be addressed in this thesis can formulated by following questions:

- How to construct a cosmic ray detector to make it accessible for the House of Science?
- How to construct a school program that shows how scientists work with data analysis and how theories change with time?
- How to perform this with the limitations that the detector creates in a way were students can do their own interpretations and contribute to the meaning of the task.

4 Method

The main method for this thesis is developed in the research project Labwork in Science Education (LSE) in 1998. The version of the method used in this thesis is the one presented in Mapping the domain - Varieties of practical work written by Milllar, Le Marcéhal and Tiberghien which is included in the book Practical work in Science Education (Millar, 1999).

The method is an instrument to study how effective an experimental task is. At first the experiment is divided into four parts, see figure 1. In A the teacher's intended learning outcome is studied because it is crucial to know what the teachers intentions are with the experiment. In the next step the study looks at what the students are intended to do and what objects they have available. Then the method concentrates on what the students actually do with the objects, and the last step study what the student learn.

A student can in most cases perform the experimental task but the student may not always understand the physics behind the task, the student doesn't learn the intended material. In some cases the students fail in performing the experiment due to different circumstances, as Millar (1999) states it can be that the student doesn't understand the instructions or they may understand them and follow every step of them but due to inadequate or faulty apparatus they don't see what is intended by the teacher. If the student can perform the task and learn the intended material the task is considered to be effective on level 2. If the student can perform the experiment as intended by the teacher the task is effective on level 1.

When formulating and evaluating the experimental task in this thesis this method will be used. Millar et al. (1999) have broken the boxes in figure 1 into smaller parts. This parts can be used to see at what level a task is effective. For example box A is divided into two sub-categories, content and process which then is divided into smaller parts.

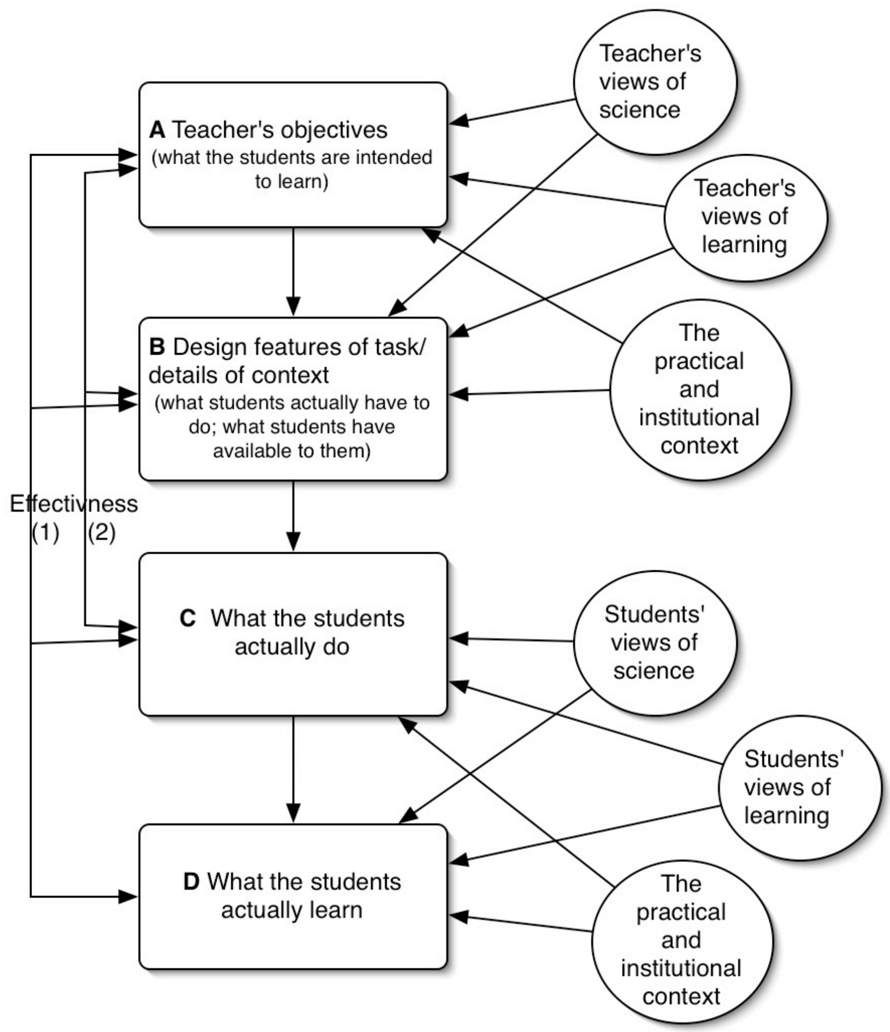


Figure 1: A model of the process of design and evaluation of a teaching and learning task (Miller, 1999)

Content:

a) to help students identify objects and phenomena and become familiar with them

b) to help students learn a fact (or facts)

c) to help students learn a concept

d) to help students learn a relationship

e) to help students learn a theory/model

Process:

f) to help students learn how to use a standard laboratory instrument, or to set up and use a standard piece of apparatus

g) to help students learn how to carry out a standard procedure

h) to help students learn how to plan an investigation to address a specific question or problem

i) to help students learn how to process data

j) to help students learn how to use data to support a conclusions

k) to help students learn how to communicate the results of their work

see appendix A for sub-dimensions of box B

To see if the students do as intended the same tables will be used and thereafter compared to the first tables. The evaluation of the learning outcome is more difficult because the student will only visit the House of science once. The solution is to let the students write what they think they have learnt during the task. Their answers will then be compared with the intended learning goals and evaluated.

4.1 Selection

The school program will be tested at a class at second year on Technology program in upper secondary school. To be a part of the study the students or their parents have to sign an admission. The students can sign by them self if they reached 18 years of age. If they don't sign the form their ten minute writhing will not be collected.

5 Cosmic rays

5.1 History of cosmic rays

The history of cosmic rays starts after the discovery of radioactivity. Scientists saw that the air was ionized constantly no matter how well they shielded their detectors. Their first belief was that the air is ionized due to radioactive material in the bed rock. The calculations done with that assumption showed that the intensity should be half 80 meters up. Theodor Wulf, a German physicist, climbed the 330 meter high Eiffel tower to confirm this statement. He showed that the ionisation fell from 6×10^6 ions m^{-3} to 3.5×10^6 ions m^{-3}, but after 330 meters the ionisation should have decreased further. Wulf hypothesized that the radiation comes from above, this theory was not accepted by other scientists (Wulf 1910).

To further investigate this Victor Hess made a balloon flight in 1912 which reached the altitude of 5 km and during this flight the measurements showed that the ionisation increased with altitude (Hess 1912). His results were later confirmed by Werner Kolhörster, who reached 9 km an altitude. In 1936 Hess received the Nobel prize for the discovery of cosmic rays together with C. Andersson who got the prize for the discovery of the positron. The term cosmic ray was coined by another scientist Robert Millikan, who also was the first to realise that the cosmic rays observed at earth are secondary particles. After C. Anderssons finding of the positron it was realized that it was possible to look for new particles in cosmic rays. C. Andersson and his colleague S. Neddermyer thought they found the pi-meson, but it was the muon. The pi-meson was found in 1947 when C. Powell made measurements in the stratosphere.

In 1934 experiments were done to investigate the east-west effect[2] during these experiments Bruno Rossi noticed that Gieger counters separated with several meters discharged simultaneously. He concluded that "... it seems that once in a while the recording equipment is struck by very extensive showers of particles, which causes coincidences between the counters, even placed at large distances from one another" (Rossi, 1934). Pierre Auger made at the same time independent from Rossi's results the same observation. He concluded that the showers are created by a high energy particle that interacts with air molecules at the top of the atmosphere. The energy distribution and arrival angle of the particles was first studied by a group in Massachusetts Institute of Technology In USA (Clark 1957). They created a 460 m circle of 11 scintillator detectors.

5.2 Physics of Cosmic Rays

Cosmic Rays consist of different particles with energy between $\sim 10^6$ eV and $\sim 10^{20}$ eV. It consists of protons (86 %), helium-nucleons (11 %) and electrons (2 %), heavier nucleons up to uranium (1 %), which is the heaviest natural element,

[2] The effect that low energy cosmic rays from the east are suppressed compared to those from the west because of the influence of the terrestrial magnetic field.

and a small proportion of positrons and antiprotons. The origin of the particles isn't totally known, what is known is that the most of the particles comes from sources in our own galaxy such as the sun (low energy cosmic rays), and supernova remnants (high-energy cosmic ray). Cosmic rays can be divided into three categories, low energy cosmic rays, high-energy cosmic rays and ultra high energy cosmic rays, with following energy ranges below 4×10^{15} eV, between4×10^{15} eV and 5×10^{18} eV and above 5×10^{18} eV. It can be shown that a supernovae remnant can accelerate a particle up to 10^{14} Z eV, were Z is the proton number, for calculations see Perkins (2003). For energies above this it is not known what is accelerating the ultra-high energy cosmic rays. Particles can be primary or secondary particles, primary is those particles that comes directly from the source. A primary cosmic ray particle can interact with the interstellar medium so that other secondary particles are created. For example there is an over abundance of beryllium compared to solar abundance because of primary cosmic ray carbon spallation .

When a cosmic ray particle hits earth's atmosphere the particle collides with the particles in the atmosphere. The original particle collides with air molecules which creates new lighter particles which then collides with new particles. This particles collides with new particles or decays into smaller particles. At earth's surface the original particle has created a shower of particles (see figure 2) mainly consisting of photons, electrons, muons and nucleons. or as it is called the electromagnetic, pionic and hadronic cascade.

If the original particle had the energy of 10^{15} eV, one million particles would reach the ground consisting of 80 % photons, 18 % electrons 1,5 % muons and 0,5 % hadrons. Most of the particles detected by the SEASA detector are muons. The different kind of particles has different lateral distribution. Hadrons is only found close to the centre of the shower which makes them hard to detect because they are only found in a small area. Photons and electrons are distributed over larger areas but muons are the particles that are distributed over the largest areas, which makes them easier to detect.

The Muon is a particle with the same charge as an electron but is approximately 200 times heavier than an electron. A muon that reaches the ground has an mean energy of approximately 4 GeV. During their way through the atmosphere muons lose about 2 GeV of their primary energy (Bartels, 2000). Muons are produced at 15 km altitude in the atmosphere and the overall angular distribution of muons at ground is proportional to approximately $cos^2\theta$ (Bartels 2000), were θ is defined as the zenith angle, see figure 3.

Because of the reason that the particles decays in the atmosphere and the distance to where the muons are created is longer in the vertical direction than the horizontal direction there will be more particles hitting earth surface from the vertical direction than from the horizon.

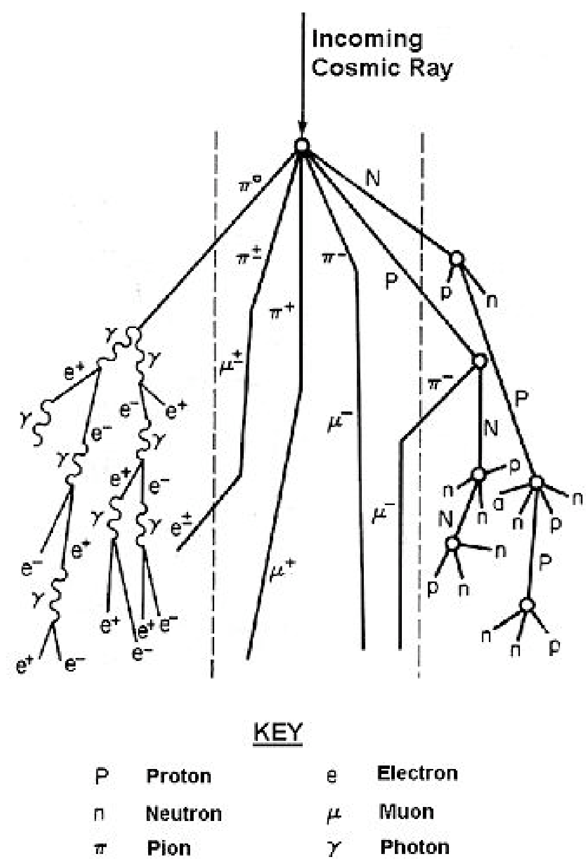


Figure 2: A figure of the shower development, (cosmic rays, 2009)

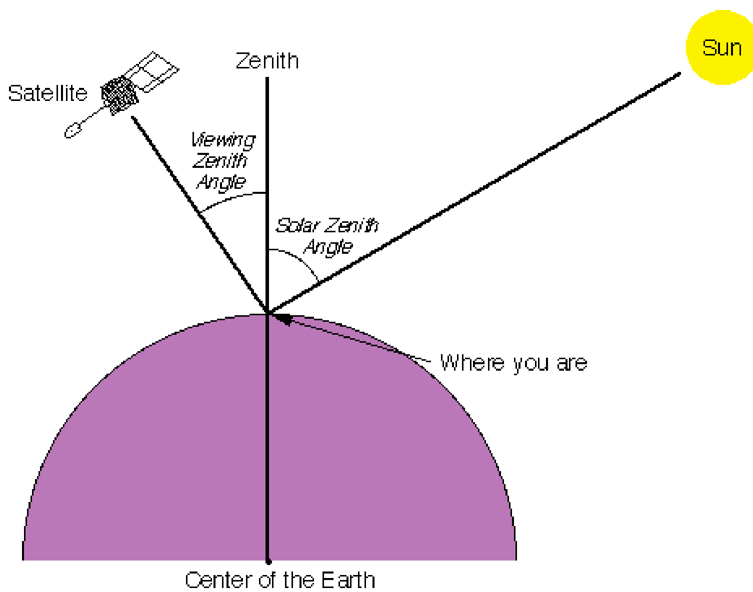


Figure 3: Definition of the zenith angle (Nasa, 2009)

A shower created by a particle with an energy of 10^{17} eV can be detected up till 200 m from the showers axis while a shower with the energy of 5×10^{14} eV is so small that it only can be detected in a very small area. As can be seen in figure 4 less particles are hitting the earth's atmosphere with high energy than with low energy. If the primary particle has the energy of 10^{11} eV, a 1 m^2 surface at the top of the atmosphere will be hit once every second. A particle with energy above 10^{20} eV will strike a 1 km^2 surface only once every century. The energy distribution of cosmic rays follows a power law, $\frac{dN}{dE} \sim E^{-x}$, at first the spectral index x, is 2.7.

At higher energies, between the knee and the ankle the spectral index appears to change from -2.7 to -3.0 and above the ankle it appears to change back to -2.7, but this is discussed and will hopefully be solved with more data. At the lowest energies the solar wind slows the particles down and they lose a significant fraction of their energy, this can be seen in figure 3 through the change in the spectrum for the low energies.

Due to the GZK[3] cut-off, which is due to the interaction between cosmic rays and the cosmic microwave background no particles with the energy above 8×10^{19} eV should reach the atmosphere. Particles with this amount of energy has been detected, but very rarely.

[3]GZK: Greisen, Zatsepin and Kuzmin

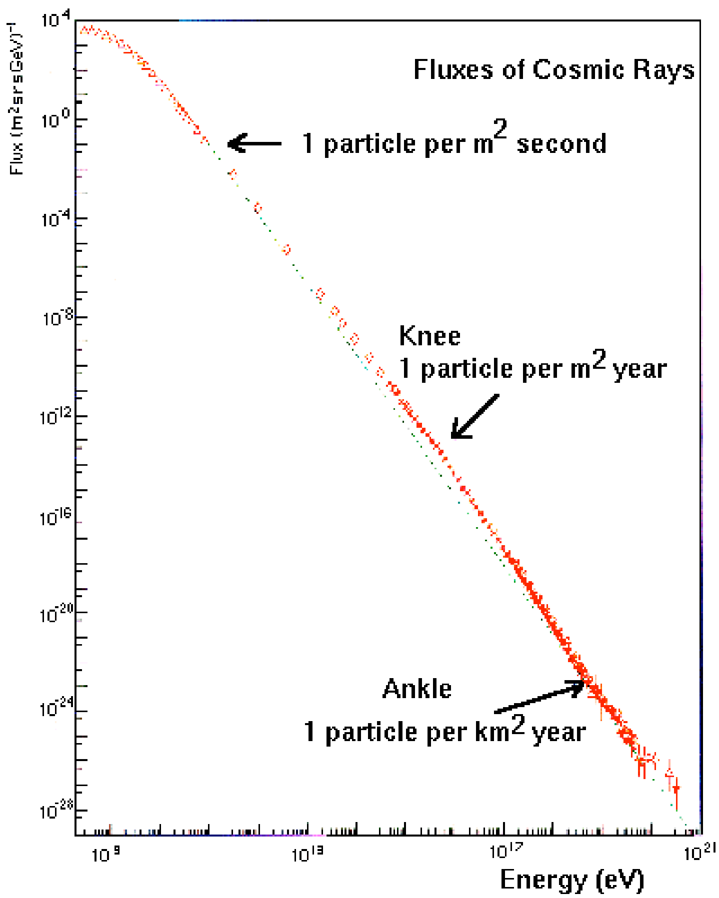


Figure 4: The cosmic ray spectrum at the top of the atmosphere (Cornin, 1997)

Figure 5: The original SEASA detector

6 The detectors

6.1 The original detector

The detector is developed from the SEASA-detector which was a scintillator based detector placed inside of a car roof box as shown figure 5. The detectors were then placed in a triangle 10 meters apart from each other to make it possible to study how often a shower trigger all three detectors. Because of the fact that they are placed on roofs they are as mentioned before like a black box. When constructing the new detector the focus have been of making everything as accessible as possible. It should be possible for the students to look at as many parts as possible and to touch the detector.

6.2 The new detector

The new detector consists mainly of the same parts as the old SEASA detector. The big difference is how the detector plates are placed relative to each other, see figure 6. Instead of placing them in a triangle they are placed on top of each other separated by 33 cm. This changes the physics studied whit the detector, instead of study how often there is a large shower we study number of muons. To be able to move the detector between different rooms and floors at the House of Science the height of the detector cannot excess two meters. It is also supplied with wheels to make it easy to move. The gantry is also possible to tilt to change the detection angle. The detector frame is built of Jokab fencing system (Jokab 2009).

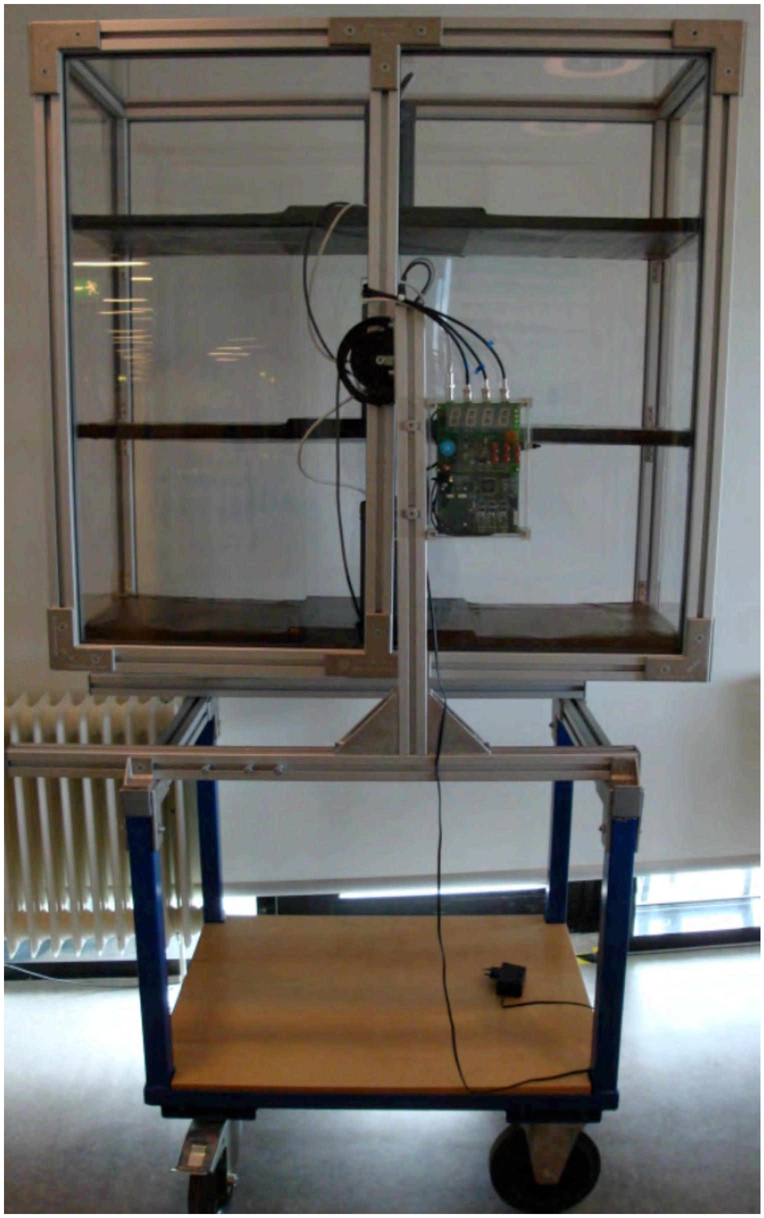


Figure 6: The new detector developed during this Master Thesis project

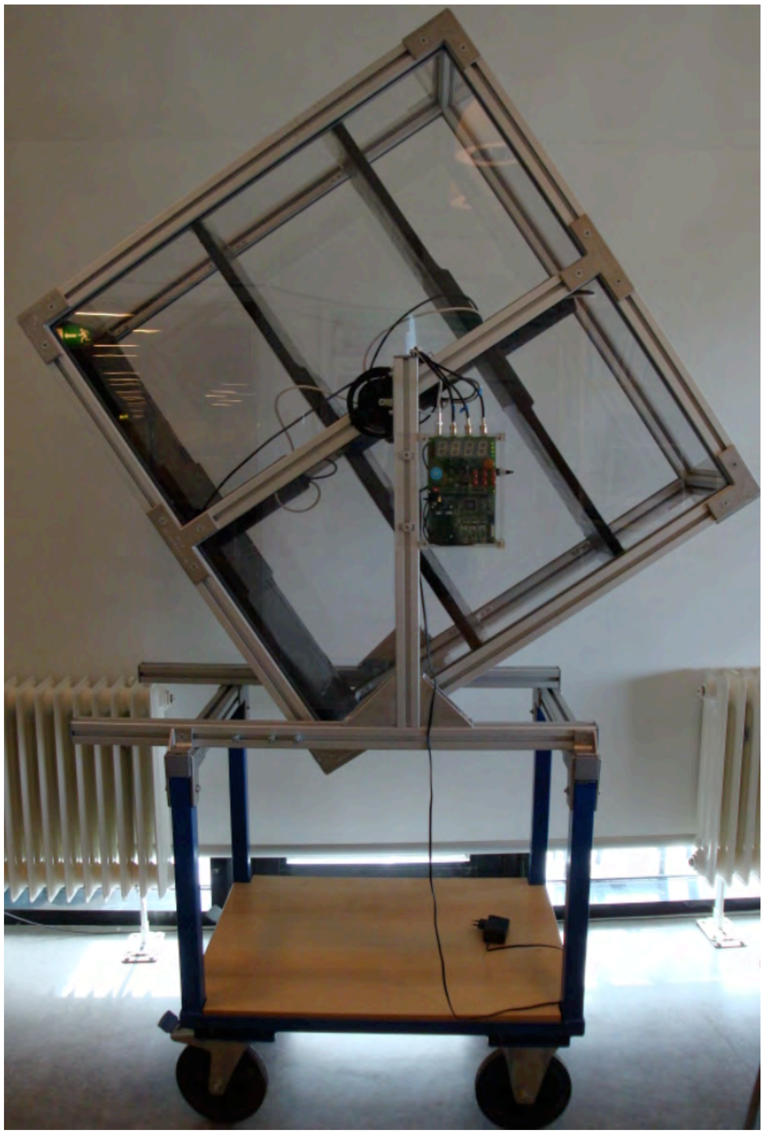


Figure 7: The detector with 45° angle

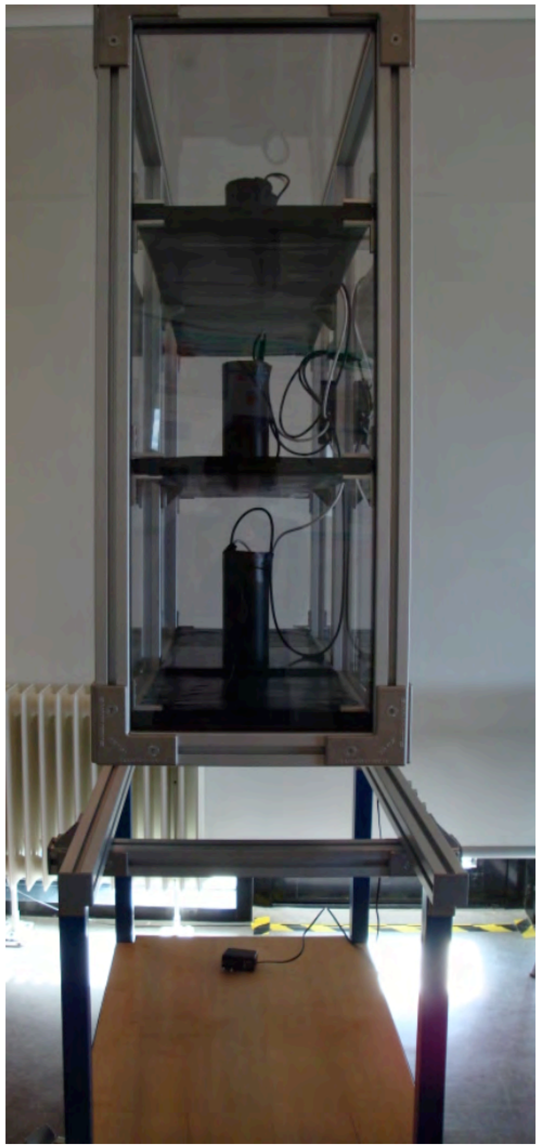


Figure 8: The new detector

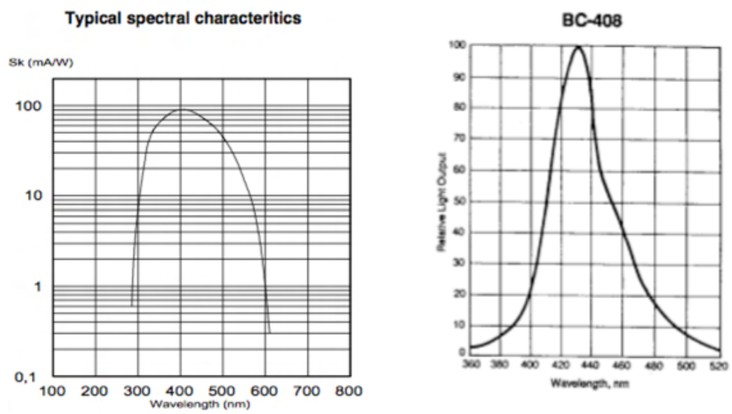


Figure 9: *Right:* The wavelength distribution of the photons from the scintillator (Bicron, 2009). *Left:* The wavelength sensitivity of the PMT (Photonis, 2009)

The detector consists of three detectors plates. Each detector consists of a 1.5 cm × 30 cm × 100 cm plastic scintillator and a photomulitiplier tube (PMT) which is glued to the centre of the scintillator. The plastic scintillator is a BC-408 from Bicron made of polyvinyltoulene (plexiglas) mixed with 1,4-Bis-[2-(5 phenyloxazolyl)]-benzene or $C_{24}H_{16}N_2O_2$ which emits photons at 425 nm, see figure 9. The PMT is a Photonis XP3314B which has its maximum sensitivity at 420 nm, see figure 9, which matches the scintillator.

Due to the fact that 420-425 nm is in the visible part of the electromagnetic spectra the detector must be shielded from visible light. To create this light proof environment for the scintillator it is wrapped in two layers of reflective Dupont Tyvek and a layer of black paper covered in black tape. A plastic tube with a lid shields the PMT. In the lid there is a hole through which the high voltage cable and the signal cable is lead out from the PMT. This plastic tube together with a plate that helps to support the PMT when tilting the detectors.

6.2.1 Photomultiplier

A photomulitiplier converts scintillator photons to an electric signal, see figure 10. In our case a photon is created in the scintillator which is reflected

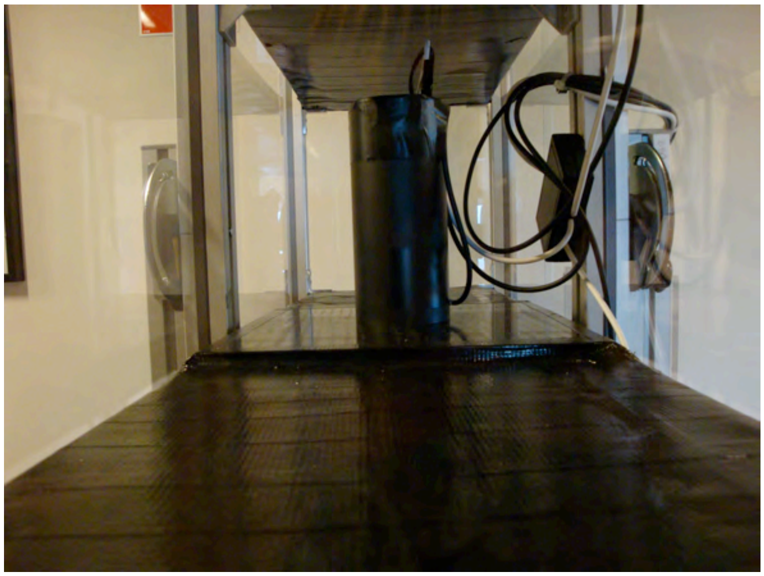


Figure 10: The PMT-protection tube and plate

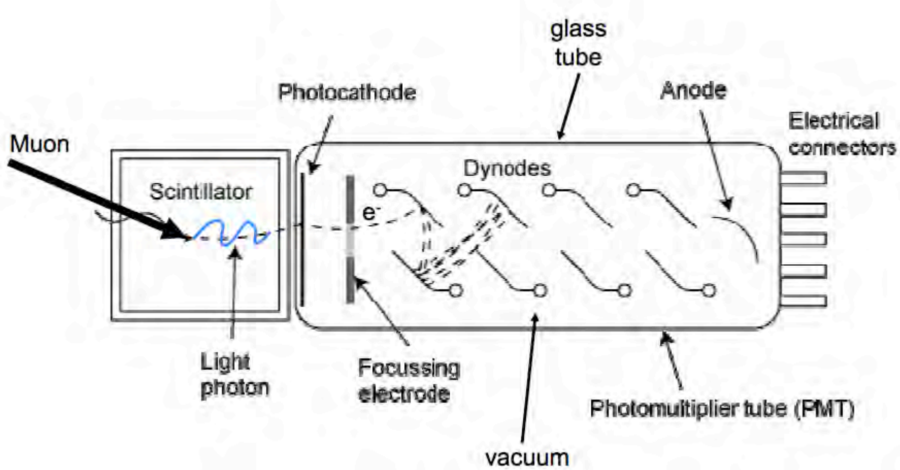


Figure 11: A schematic figure of a photomultiplier (Wikipedia, 2009).

inside the scintillator to the PMT, and the photocathode. When hitting the photocatode an electron is released due to the photoelectric effect.

$$E = h\nu = W + \frac{1}{2}mv^2$$

$$E = \text{Photon energy}$$

$$h = \text{Planch's constant}$$

$$\nu = \text{Photon frequency}$$

$$W = \text{the amount of energy that is needed to free an electron}$$

$\frac{1}{2}mv^2$ is the maximum kinetic energy the electron can have after the strike. The electron is focused by the focusing electrode and then accelerated towards the first dynode due to voltage differences. The total voltage applied to the PMT is -1100 V, which is divided between the dynode chain by resistors. When hitting the first dynode more electrons will be released and accelerated towards the second dynode where more electrons is realised which continues in steps until the electrons reach the anode. A current has been created which we can measure and from that measurement see that we have detected a something, in this case a muon.

6.3 Electronics

To collect and process the signals from the three PMT:s the signal cables are connected to a circuit board. The circuit board registers all combinations of the three detectors, named from the top A, B and C, in total seven combinations. A single is when one of the detector plates get one hit, a coincident when there is a hit in two or all three detector plates at approximately the same time. A hit is when the PMT signal is bigger than a certain value, called V_{ref} It is also possible to set the circuit board to collect data during one, five minutes or continuously. At the circuit board there also is a sensor for air-pressure and it is also possible to turn on sound which makes it possible to hear when a muon is registered.

When a muon hits the PMT a signal looking like the pulse at the top of figure 11 is created. The device called AD8055 between points 1 and 2 inverts the pulse and sends it to the device called AD8561 which have two inputs. One is the signal from the PMT and the other input consists of a voltage level with constant height, called V_{ref}, or later in this thesis the DAC-value. These two signals are compared and if the signal from the PMT is higher than V_{ref} a signal is sent to the Altera chip who saves it. The Altera chip is a Programmable Logic Array (PLA).

The Altera chip is programmable and the logic programmed on the chip creates the different combinations of the detector plates and saves the values.

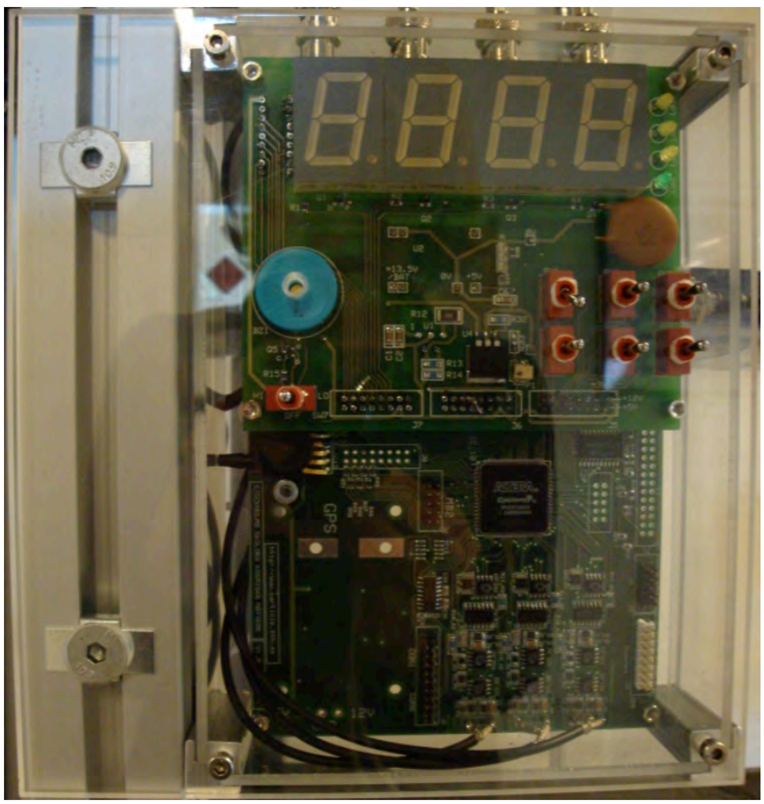


Figure 12: The circuit board

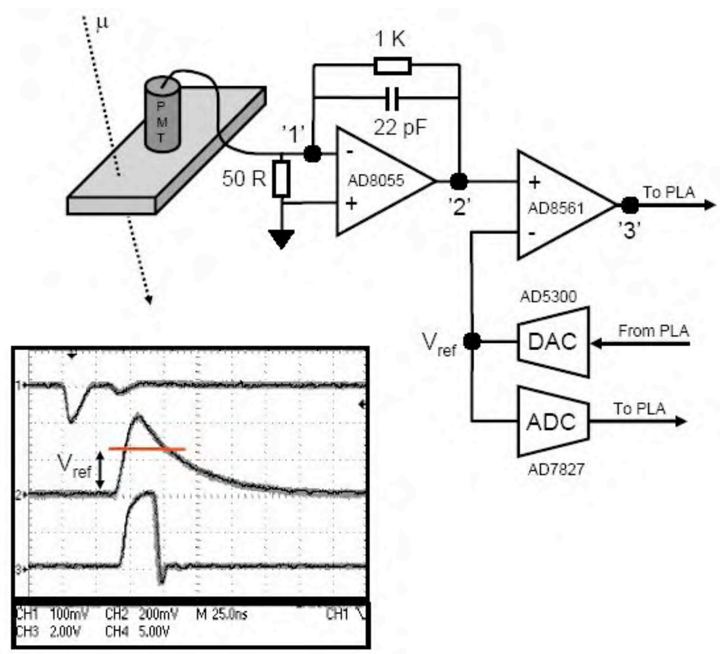


Figure 13: A schematic overview of the electronics which process the PMT-pulses and an inserted screen dump from a oscilloscope showing the pulses at three different locations (Pearce, 2006).

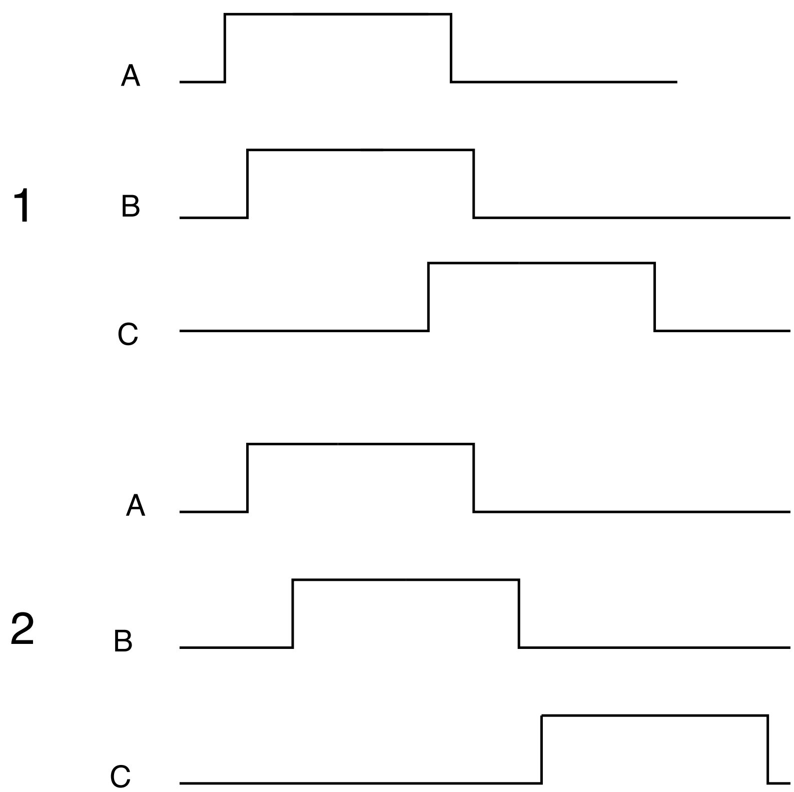


Figure 14: A schematic view of pulses that are sent to the PLA from the AD8561 device, all pulses are 100 ns.

The V_{ref} -value is set by the user of the detector, see section 6.4. The device called DAC or a digital to analog converter, in figure 11 generates the V_{ref}-signal. ADC, the analog to digital converter sends the signal back to the Altera chip and checks that it is the correct value.

All pulses are processed so that they last 100 ns. To get an coincidence all three of the pulses needs to be high at the same time. If all three detector plates have a signal at the same time, as in case 1 in figure 12, all combinations will register one muon. If the case is as case 2 in figure 12 it will register hits in all detectors separately and the combination A&B but not in A&B&C, B&C or A&C.

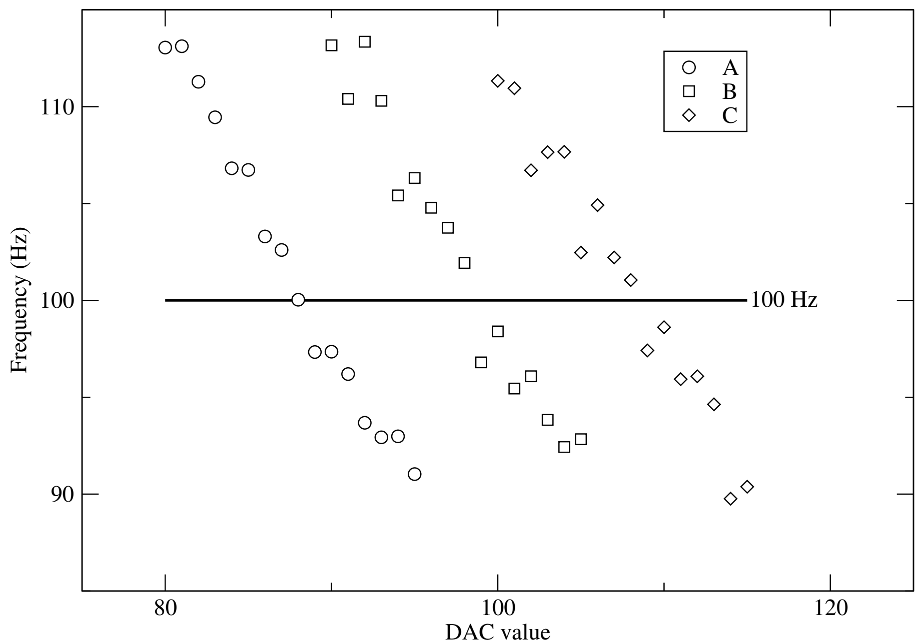


Figure 15: A graph of number of singles for each detector plate, from the left A, B and C against DAC-value

6.4 DAC-value

At the circuit board the PMT signal is read out and if the signal exceeds the DAC-value it saves it as a hit. The DAC-value is set to approximately reproduce the singles rate used for the original SEASA-detector, 100 Hz (Hofverberg, 2006). The intensity of vertical muons is approximately 70 $m^{-2}s^{-1}sr^{-1}$, assuming a 2π acceptance, which gives 130 Hz (De Pascal 1993, Allkofer 1984). The DAC-value is by testing known to be somewhere between 80 and 95 for detector A, 90 and 105 for detector B and between 100 and 115 for detector C. A plot of how the number of singles vary with the DAC-value is measured, see plot 13. The three detectors does not have the same efficiency due to differences in the PMT and the connection between the PMT and the scintillator.

To decide the DAC value more precisely, values close to the desired singles rates is tested further. A is tested further between 89 and 91, B between 99 and 101 and C between 109 and 111.

A,B,C	A [Hz]	B [Hz]	C [Hz]
89,99,109	99,37	99,56	98,84
90,100,110	97,37	98,30	96,90
91,101,111	95,37	97,85	95,52

Table 2: The results of the measurements of the chosen DAC-values from the figure 13

	A&B [1/min]	B&C [1/min]	difference
89,99,109	1407	1375	32
90,101,110	1412	1396	14

Table 3: Comparing the two combinations that gave the most similar results in the measurement done in table 2 to determine which gives the smallest difference between A&B and B&C

The measurements in table 2 and 3 is an mean of five one minute long measurements. There is two combinations were the difference between the values is less than one, (89,99,109) and (90,101,110) and the singler ates is close to 100 Hz. To evaluate this two options further measurements on coincidences of plates A&B and B&C will be done. A&B and B&C should theoretically get the same number of coincidences. These two combinations is not possible to distinguish with statistics but one has to be chosen so (90,101,110) is chosen because difference seems to be lower, the values chosen may have to be adjusted in the future.

6.5 Angle dependence

According to Bartels (2000) the angular distribution of muons at ground proportional to $cos^2\theta$. When measuring the angular dependence with the new SEASA detector, figure 14 is obtained. In the plot to the left intensity is plotted against angle, were the angle is the zenith-angle, or how much the detector is tilted, zero degrees is when the detector plates are horizontal. In the plot of the right the intensity is plotted against $cos^2\theta$. The χ^2 value for the $cos^2\theta$ fit is one order of magnitude higher than for the linjear fit, this supports that the theory of a $cos^2\theta$ dependence.

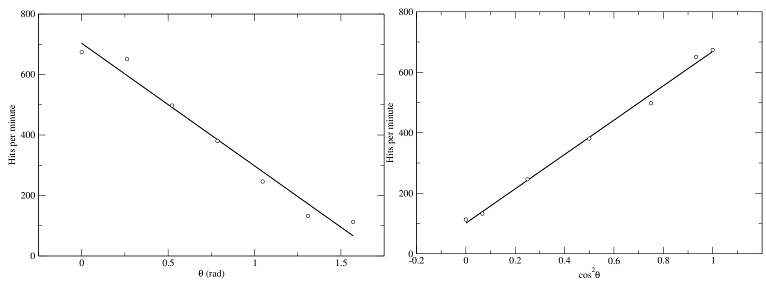


Figure 16: *Left:* A linear plot of intensity vs. degrees *right:* a linear plot of intensity vs. $cos^2(\theta)$, error bars are smaller than symbol.

7 Description of the school programme

7.1 The students' prior knowledge

This program is constructed for students in the second or third year at upper secondary level in Swedish schools. The students are about 17-18 years of age and study their eleventh or twelfth year. They are at a natural science or technology program and they have studied physics for approximately one or two years (end of Physics A or Physics B). Physics A gives the student's basic knowledge about physics and it is basic laws. It is not very mathematically advanced, most calculations contain only linear relationships like Ohm's law and Newton's first law in the form of F=ma. In the second physics course (Physics B) the mathematics has a more central role than in the first course, and many students think this is a difficult course, many even think this is the most difficult course. The students have just learnt to integrate and differentiate which sometimes is used in the second physics course. In both courses experimental work has a central role and usually the students perform an experiment every second week, but this can differ between different schools and different teachers. For more details of the courses see The Swedish National Agency for Educations homepage (National agency for Education c&d, 2000).

7.2 Experimental work

In Sweden as in many other countries schools have their own cultures and people tend to behave a certain way in a certain situation. The House of Science is not a school but their laboratory tasks are more similar to those performed in school than those at a science centre. The tasks often have a printed instruction and are performed in a classroom that looks much like an ordinary science classroom, the big difference is that they have more advanced equipment. Reigosa & Jiménez-Aleixandre (2007) have stated seven dimensions on stereotyped school culture in connection with experimental work. This may not be the case in all schools but it can be seen as the overall the tradition.

1. Laboratory activities as closed unique sequence of steps
2. Viewing searching for a solution, collecting data or clarifying concepts in inappropriate or not useful
3. Interpreting the teacher's questions as criticisms
4. Assuming each piece of equipment and resource to have only a single and predefined use
5. A tendency for confirmation bias
6. Reluctance to challenge the teacher's authority
7. Imitating the behavior of other students, even when it is not justified.

They also stat that it is usual that students who are more high performing than their classmates doesn't always share their knowledge with their group members. Which during a experimental session can result in that only some of the students in a group will learn.

Millar (2000) states that the European project LSE showed that most physics teachers in all countries uses labsheets and labsheets therefore play an important role in laboratory education in physics. The labsheet also conditions the activities occurring during an experimental lesson. After studying labsheets Millar concludes that students at both upper secondary school and at universities only rarely have to present, display or make something but they are at many times asked to perform activities mentioned in the list below.

- Use a laboratory device in physics or a laboratory procedure in chemistry and (to a lesser extent) in biology
- Make an event occur, in all three disciplines
- Observe an event, in all tree disciplines, and also, mainly in physics and in chemistry to observe a quantity (i.e., to read a measurement apparatus).

In another study by Abrahams and Miller (2008) it is shown that the overwhelming part of the experimental lessons that they studied "was on the substantive science content rather than on aspects of experimental design or the collection, analysis, and interpretation of evidence". They also suggest that it is possible to improve practical work in science if teachers realized that explanations of a phenomena doesn't emerge from a observation. The role of practical according to Abrahams et al. (2008) is to create a bond between observations and ideas. The ideas should also be "in play" when the practical task is performed. (Millar & Abrahams 2008).

Of those fourteen statements stated by McComas et al (1998), see the list below, about nature of science five of them is connected to the question formulation of the school programs. Students will hopefully during their visit get new insights in these statements. The most important for this thesis is number 2,3,4 and 8 in the list below. This can be summarized in that science results can change with more data and that scientists work together and togeheter drive the research forward through peer review and different collaborations.

1. Scientific knowledge while durable, has a tentative character
2. Scientific knowledge relies heavily, but not entirely, on observation, experimental evidence, rational arguments and skepticism
3. There is no one way to do science (therefore, there is no universal step-by-step scientific method)
4. Science is an attempt to explain natural phenomena
5. Laws and theories serve different roles in science, therefore students should note that theories do not become laws even with additional evidence
6. People from all cultures contribute to science
7. New knowledge must be reported clearly and openly
8. Scientists require accurate record keeping, peer review and replicability
9. Observations are theory-laden
10. Scientists are creative
11. The history of science reveals both an evolutionary and revolutionary character
12. Science is part of social and cultural traditions
13. Science and technology impact each other
14. Scientific ideas are affected by their social and historical milieu

This can be summarized in that scientists work together to drive the research forward through peer review and different collaborations and that results are obtained through creative ideas together with observations, experimental evidence, rational arguments and skepticism. But if digging deeper into the nature of science all science branches have differences but this can be seen as a foundation when teaching about nature of science.

It is also important to organize learning in a way that is wanted by the students. Kisiel (2006) studied a group of inner city upper secondary school students during a off school science activity where they got to do different things related to science. During the study Kisiel concluded in a list of strategies to use for positive science learning.

- Providing unique “hands-on” experiences
- Utilizing different learning environments (labs, museum hall, outdoors)
- Providing new or unique experiences (whale-watching, squid dissection, sushi-making)
- Recognizing student autonomy and choice
- Avoiding a “classroom atmosphere” and teacher-centered lectures
- Providing a variety of activities to appeal to varied interests
- Allowing for social interactions
- Incorporating projects with real outcomes (such as assisting researchers in generating new knowledge or assisting education staff in disseminating information)

All these things is important to keep in mind when constructing and carrying out the class program. This is because when the students come and visit the House of science they will have their own view of science and experimental work and it is hard to change this during only one session. To even get close to change students view of science it has to be more fun than school or othervise they may not want to participating at all. The goal with the school program is as mentioned before that the students should get insight in how scientists work with data analysis and how theories changes with time.

7.3 Lecture and planning of the experiment

When the students come to classroom the first they will meet is the question:

> How do we know that cosmic rays exist?

This will hopefully make them think about how we actually know that something we cannot see exists. When all is settled there will be a presentation of what cosmic rays are and how they behave. During the lecture it will be explained why the rate of cosmic rays will depend on the angle. All parts of the detector will also be explained and showed to the students. Some of the parts will also be available for the students to touch and look at, for example there will be a piece of scintillator to look at and touch and all the circuit boards are visible to the eye. In the middle of the lecture the students will be asked to plan how they would like to perform the experiment. This will give them a chance to think of what they think will give the best result. If they like to measure at a lot of angles but during a short time or few angles during longer or something in between. Everybody has to agree on how to perform the experiment because there only is one experimental set- up. This can be compared to how a large research project is conducted when a lot of scientists have to agree on what to build and what to measure or how to measure.

	Interactive	Non-Interactive
Dialogic	**A** Interactive/dialogic	**B** Non-interactive/dialogic
Authoriative	**C** Interactive/ authoriative	**D** Non-interactive/authoriative

Table 4: Four classes of communicative approach (Mortimer, 2003).

When doing this, the students have to be asked why they want to do things in an certain way, sometimes they might not thought about why the choose as they do. During the test session described in next section one student answered the question why they chose to measure at 0, 45 and 90 degrees with that is what they usually do. For the teachers it is important to let the students find out for themselves how they would like to do the experiment. The teachers are only allowed to lead the discussion and ask questions about the students' own thinking and own ideas. As Mortimer and Scott (2003) discusses in their four communicative approaches where they have divides school communications into four different parts, see table 4. A teacher could allow different views or not, the communication is dialogic or authoriative and the teacher could allow students to be part of the communication or not, the communication is interactive or non-interactive.

During the experimental session the teacher has to adopt different communicative approaches. In some parts of the lecture the teacher has to be the one that decides the boundaries for example when facts about cosmic rays are presented. But it is important for the teacher to let the students ask questions, and give the students answers. Some parts in the presentation is very suitable for discussion for example when Northern lights is discussed due to the fact that many students have seen it and many of them also know why the phenomena occur. This can then lead the students into how earth is protected from cosmic rays. This puts demands on the teacher to be able to shift between the Non-interactive/authoriative and the Interactive dialogic approach during the lecture.

7.4 Analysis of Measurements

After deciding what measurements should be done it is time to measure. During the measurements there will be some time were nothing special happens. This is an ideal time to respond or discuss questions asked by students or study the randomness of cosmic rays. In the beginning of the measuring period it can be good to propose the students to prepare some kind of table so they keep track of their data. When all measurements are done it is time for the data analysis which is the most difficult part of the session. All students will have different pre-knowledge and there will be big differences depending on if their physics teachers introduced it to the students and if the students are used to working with their calculators. As help during the analysis the students will have a manual for the calculator and some tips on how to perform the data analysis,

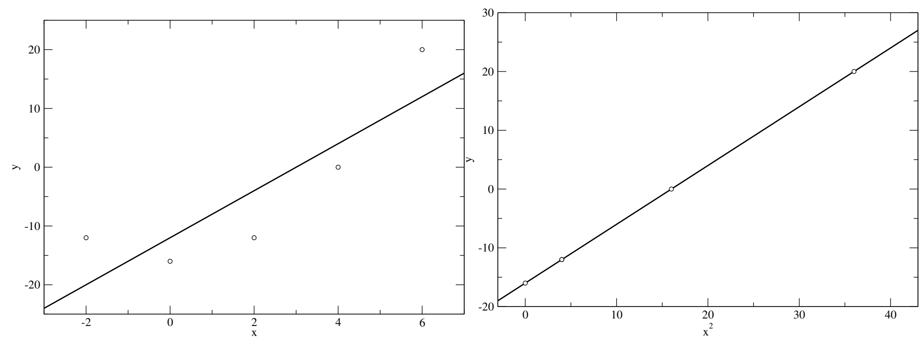


Figure 17: Both figures show data points chosen from a second degree function, these two plots is used when explaining a method for data analysis. *Left:* A linear fit to the data points. *Right:* A second degree fit to the data points.

this document is found in Appendix B. In Appendix C guidelines for teachers attached.

After that the lecture will conclude with a short presentation about how to analyze data with help of linearization on their calculator. A plot with five points chosen from a second degree function is used and a linear fit to the points, see figure 15. Beside this curve another plot is showed where the x-values is squared and a new straight line is fitted and it can be seen that the points now lies on a straight line.

When they then are doing the analysis on their measured data they should, if time allows, also try to calculate some kind of error, for this task a simplified method is presented to the students. They should use the absolute value of the difference between the measured value and the function value.

The data analysis will hopefully make them understand that it is possible to use y=kx+m in the data analysis. Linear functions is something that they seen many times earlier during their education. Together with this explanations the students is asked about how they think it is possible to substitute data. Hopefully they will realize that it is possible to use a lot of functions for example x^n, e^{nx}, $sin^n(x)$ and so on.

The purpose is to learn how to find relationships between variables using data-analysis. By testing some main ideas they might get hold on the problems in analyzing data. They will not be fully trained in analyzing data but they will have tested some of the main ideas. For example will they not learn anything about statistical methods to separate different regression lines. This may cause an issue that the students think that they have found the correct relationship between the angle and number of counts. The teacher thereby needs tell the students that this is a model for how number of counts depend on the angle but it doesn't have to be the only one, for example our detector have a very big detection angle and number of measurements is small. The detection angle is the maximum angel from where a muon can hit all three detectors.

7.5 According to Millar

In this section the school program will be studied with help of Millar et al. (1999). All the tables discussed below can be found in appendix A. In this section there will be references to tables in appendix A marked in the end of the sentences. The first letter and the two following numbers refers to a table in the appendix, the ending letter refer to a certain statement in that table.

The overall goal for the experimental session is the students should get insight in how scientists work with data analysis and how theories change with time, which according to Millar et. al. is mainly i and j in dimension A but the students will also plan their measurements so also statement j is applicable. It is not the main purpose that students learn about cosmic rays but this is inevitable due to the fact that the experimental set-up measure cosmic rays. Cosmic rays are an aid for the students to learn how to work with data-analysis. During the experimental session the students with help of the teacher will use a measuring instrument (B1.1.a). Because there only is one detector the whole class needs to do the measurements together. This leads to that the teacher directs the measurements and the students perform as much as possible of the practical work. If there is a large group the teacher might have to do the most of the work so that all students can get involved in some way, otherwise it will probably only be a small group of students that do everything (B1.5.b). When doing the measurement the main task for the students is to observe how the number of counts decrease with increasing angle (B1.1.k).

After the measurements the students should explore the collected data and explore the relationship between the angle and number of counts and try to invent a new concept (B1.2.d and f). Another thing that the students do is to test an prediction, that the counts should decrease with increasing angle due to the fact that the cosmic rays travel a further path in the atmosphere (B1.2.j). The presentation about cosmic rays and how to work with data-analysis creates ideas for which the students can create new ideas concerning how cosmic rays behaves (B1.3.a).

According to Schwab (1962) this task can be interpreted as open at level two. The arguments are that the students choose how many angles and for how long time, and that the method of data-analysis is not totally given. Millar et al. (1999) discusses openness/closure in a different way than Schwab (1962) instead of levels they talk about if a certain statement is specified by the teacher, decided through teacher-student discussion or chosen by the student itself. Instead of just looking at the problem, procedure and the conclusion Miller et .al. looks at five different statements, question to be addressed, equipment to be used, procedure to be followed, methods of handling data collected and interpretation of results. For the evaluation of with help of Millar's method see table XX.

Aspect of practical task	Specified by teacher	Devided through teacher student discussion	Chosen by students
Question to be addressed	x		
Equipment to be used	x		
Procedure to be followed			x
Methods of handling data collected	x		
Interpretation of results		x	

Table 5: Millars et. al. (1999) version of judging if an laboratory is open or closed

In the table 5 it can be observed that a lot of things is specified by the teacher in advance. But the student is deciding how to perform the measurement, if there will be measurements done at a lot of angles or at few angles but during a long time. The equipment does only allow one way to do the measurement and therefore parts of the procedure are closed. The method of handling data is nearly fully decided by the teacher, the students do the data handling and thereby choose which functions will be tested for the linearization. The time for the visit at the House of Science is planned to last for 1.5 hour, this is a medium long experiment according to Millar et. al. (1999) (B2.1.c). During the experiment the students get instructions from a Powerpoint presentation and on the whiteboard (B2.3.b) and for the data analysis they will have a short manual that guides them through the task (B2.3.e). The students are supposed to collaborate in groups of approximately 3-4 students (B2.2.a), but it is also possible to interact with the teacher (B2.2.c). After the data analysis the students will tell each other their results and compare their analysis (B3.3.b and c) to do this it demands that the students have taken notes during their analysis (B3.1.b). When all groups have shared their results it is time to discuss why they have got different equations so that they learn more about how natural science work (B3.2.a).

8 Test visit by a technology class

8.1 The Students

The program was tested on a second grade technology program class. When participating in the test the students were studying the last parts of their first physics course and approximately 75 % of the students was in the last parts of mathematics D, the forth math course in upper-secondary school in Sweden. The rest of the students had finished different parts of the courses before, all students had passed the first course in mathematics. In the test session the students divided themselves into three groups, in this thesis called group 1,2 and 3.

8.2 Course of events

The students did not come to the House of Science at the same time, the first ones came approximately 10 minutes before scheduled time and the last students came 10 minutes after scheduled time. This made it possible for the first students to think about the initial question, but they did not pay a lot of interest in the question. They read it but then they started talking about other things. In the beginning of the lecture not much happened, no questions were asked and questions asked to them were answered unwillingly. This proceeded during the better part of the theoretical part of the presentation.

When discussing the technical parts of the detector they got more engaged and asked questions. When they were asked to plan their own investigation of the angle dependence two of the three groups chose 0°, 45° and 90°. One of them wanted to do measurements each minute and the other group wanted three measurements at each angle. The third group wanted to measure at 0°, 30°, 60° and 90° and to do each measurement for two minutes. When asking the first group why they have chosen as they had done they answered that 0°, 45° and 90° is the usual angles that they use in school and it is straight up and down and something in between. The third group said that it gives more accurate results if you measure at more angles. This started a discussion were somebody thought that 0°, 30°, 60° and 90° was really stupid because then you miss the one in the middle and that 0° and 30° and 60° and 90° almost covered the same solid angle. This was probably the reason for that one of the students during the analysis section looked closer to the detector and studied the solid angle. There were also one group that sketched the detector to determine the solid angle. They did not pay a attention to how many measurements that should be done at every angle.

During the time data were collected there were some questions about if there is any difference if the detector is placed inside or outside a building and if you put mirrors around the detector would that affect the result. There were also questions about how the detector would react if it were placed in space instead of on earth, would the PMT manage the particles with higher energy.

When all the data were collected and the analysis started some problems were identified. There had been a mistake in the communication, only one of the students had brought his calculator. This changed the plan and two of the groups got calculators and the third got to use a lap-top. In the two groups using calculators there were only at maximum two students working intensive with the problem, this two groups was the same that proposed the 0, 45 and 90 degrees measurements. In the third group all students were involved in the problem solving.

All groups manage to do a linear fit to the data, with help of the teacher and the student manual for the calculator. The group using a Excel got time to try other kinds of functions and got more involved in the problem solving than the other groups, they worked concentrated and focused and discussed with each other. They also discussed intensely how to convert between degrees and radians. The time for the visit was planned to last about 1.5 hours, but due to late start there were only approximately 1 hour 15 minutes for the program and evaluation. After 1 hour and 15 minutes it felt like more time was needed. The ending of the session became very hasty and there were only a short ending were all groups presented their equations and a short summation from the teacher regarding how to interpret the results, but there was no time for discussion.

8.3 Student comments

In this sections comments given by the students will be presented, both positive and negative. I will start with the most negative, which speaks for itself.

> *Due to the fact that this research is totally worthless and doesn't help anyone/anything so this machine is totally worthless and waste of money. (authors translation)*

This type of comments was also delivered from one student during the lecture, the student asked for the purpose of the task and why this detector were interesting. The most of the students wrote in their comments that they thought that the lecture about cosmic rays were interesting. One student wrote that he thinks that the length of the Power-point slides were perfect and that there were interesting information that he didn't know before, for example why nothern lights occur. Another student thought that it was interesting when talking about the atmosphere and the nucleus and one thought that the most interesting thing was how the detector worked. Nobody thought that the same thing was the most interesting. There is also one student that thought that the task contributed to a lot of own thinking. There is also comments about the ending of the lecture that there it could have been more clear what about the conclusions.

8.4 Evaluation according to Millar et. al.

The intended learning outcome, dimension A was as stated earlier that students should get insight in how scientists work with data analysis, how theories change with time and also how to plan a measurement. To evaluate if the experimental task helped the student to evolve this knowledge areas the tables from Millar et al. will be reviewed and compared to the original plan.

8.4.1 Sub-dimension B1.1

In the plan for the experiment the thought was that the students should with use a detector to be able to observe the quantity of muons that hit the detector during a certain time. This occurred during the experiment with the students but there was less hands-on work than planned from the beginning.

8.4.2 Sub-dimensions B.1.2- B1.5:

When doing the experiment all students observed that the number of coincidences decreased with angle and all of them tried to explore the relationship between the physical quantities. The time for exploring the relationship was too short, this resulted in that two groups only did a linear fit and not trying different approaches. The third group which worked faster than the other two groups got time to try more than one approach to the problem.

There is nothing to comment on the sub-dimensions B1.3 and B1.4, since they turned out as planned. In sub-dimension B1.5 there were a difference from the plan, there were not the level of student involvement that had been planned for. Instead of that the students told the teacher what to do, the teacher directed everything and told the students what to do.

8.4.3 Sub-dimensions 2.1-2.4

The time for the lecture became shorter than planned instead of being 90 minutes it became about 75 minutes effective time. It had been better if there had been 90 minutes effective time so that the evaluation of the results could have gotten more time. For sub-dimensions B2.2-2.4 there is not any divergence.

8.4.4 Sub-dimensions 3.1-3.3

The students did make notes of the data and their thinking. Something that had been observed is that most of the students think about the detection-angle and how that can affected the result. As mentioned before there were a very short ending of the lecture, this got the consequence that the audience for the record more or less became the teacher instead of both the students and the teacher.

8.5 Result

All of the students were able to perform the task, they followed the instructions and manage to get an result. In the comments from what they think they have learnt nobody commented on the method for analyzing data and because of that there is doubt about that the task was effective on level 2. The students did not get insight in how scientists work with data analysis and how theories changes with time. There is only one student that commented their own work and thought that it was fun with a lot of own thinking. This student may have reached the intended learning goals and got new insight in how scientists performs data analysis. Because of this reason it can with certainty be said that the exercise were effective on level 1, they were able to perform the task, but it is undetermined that the task were effective on level 2 for some students.

9 Discussion

9.1 The detector

There is no problem with the detector when using it in this exercise but there is some possibilities to changes to make it useful in other situations. For example it is possible to make a connection to a computer. The circuit board is prepared for this but a program for saving the data has to be created. This would make it possible to collect data for a longer period and create opportunities for student project work at upper secondary school. It would then be possible for them to both touch the detector and analyze data from a longer period.

Another thing that would be possible to change if there is a new detector built is to increase the distance between the detector plates. This would decrease the solid angle. It would be interesting to see if that changed the angular dependence and if so in what way.

9.2 This experiment

During the test session the exercise were observed not to be effective on level 2. The goal is that it should be and therefore changes have to be done. In this section possible changes will be discussed and proposed. Those changes will hopefully improve the exercise and make it effective on level 2.

9.2.1 Initial question

The first feeling that I got at the part where the students plan the experiment was that the initial question of the task was not inspiring enough for the students. One of them asked why this kind of research is interesting and why he should engage himself into the laboratory-exercise and those who came first did only give the questions seconds of attention. He didn't do much during the following parts of the laboratory. The start of the lecture is the most important, the students have to feel that the subject is interesting so they want to learn more about the topic. Therefore I think that the most important thing to change is the initial question. It should be something that interests the students and starts their thinking. The question doesn't have to be the same as the one that is answered in the end but the question have to be answered and lead to new questions. Something that students often say when I talk to them about what they are interested in, in physics they often answer the space and space-travels, this give rise to the new question:

Can a human being travel to Mars?

This question will hopefully lead to new questions for example, how are we protected from cosmic rays, what happens in the atmosphere and how could we measure muons. If human can travel to Mars is probably a question that upper secondary students sometimes have thought about and answered with "it is too far". During the initial lecture it can be discussed why it is too far and then lead the discussion towards cosmic rays and the difference between earth and space. With to far I mean for human beings not to get damages that lead to death. This will hopefully make them interested in knowing how we can survive on earth and many muons that hits us and how well the particles is stopped in the atmosphere. Other things that can make the students more interesting is to provide something unique and not the same as in school (Kisiel, 2006). During their visit at the House of Science and this laboratory task the experimental equipment is unique.

9.2.2 Students interests

Some of the statements by Kisel (2006) is more easy to use in this experimental session than others, for example the House of Science is a new environment. Something that is hard to avoid is the classroom atmosphere and that the teacher has an centred role when there only is one experimental set-up. What can be kept in mind is that the activity has to appeal different interests and therefore both talk about how the detector is constructed, the physics behind and how the particles can affect the human body and let the students lead the experimental part instead of the teacher, the students tell the teacher what to do. This was something that succeeded during the test session. Most of the students found something that they thought was interesting and nobody thought that the same thing was the most interesting. Another of Kisiel's (2006) statements that also is included is that social interaction is allowed and encouraged.

When they are interested in the subject it probably will be easier to engage them in the intended data-analysis. During the data-analysis the teacher have to think of that there is no answer that is faulty, or all answers is correct. Most of the students is used to that all questions have an exact and correct answer. For the teacher it could be very tempting at the end give the students the best fit but this might give the students a feeling of that they did something wrong because they didn't found the "correct" regression line. This will hopefully increase the students belief in their own ability (National agency for Education e, 1994). A thing that would be interesting to test in the ending part where the conclusions are drawn is to show all functions graphs that the students calculated with the data and then discuss and draw conclusions with help of the graphs.

9.2.3 Nature of science

All three of the statements made by Millar (2000) of what students usually are asked to do during an experiment is included in the task, but in the end the focus is not on the result it self. It is focused on that different groups got different results from the same data and how an model in physics is developed and that physics is an attempt to explain physics. This can be referred to the fourteen different NOS statements that McComas et al. (1998) has found in their research.

When performing the task some of the students used and discussed knowledge and ideas that they had from before, for example that some students would like to shield the detector with mirrors to be able to compare muons to photons. There were also a lot of ideas about what could be tested with the detector to investigate muons further. From this the conclusion can be drawn that the students could contribute to the meaning of the task even if the detector is inflexible and limiting but it would be preferable if it was possible to test their ideas so they could be evolved.

I think the students during the planning of the experiment started to think about why they always uses certain angles and that there is more than one way to perform an experiment with the same result. Because the discussion got very intense and that different groups supported different views. What I did hope was that they should think more about that science is an attempt to explain nature, not all research is the correct answer to an certain question. This didn't get the attention it needed. It would be preferable to have 20 minutes in the end of the lecture for discussions. It would need more attention in the end when discussing the different results from different groups. This will hopefully even give the students the insight that scientists needs to be creative and try to find new solutions or new ways of performing different experiments.

The increased focus on those statements and the changes mentioned above will hopefully make the task effective on level 2.

9.2.4 Technical resources

As mentioned before there was one group where all students were involved in solving the problem, the group who had a computer instead of a calculator. The reason for this could be that it is easier for all students in a group to look together at a big screen than a small. I think that more students would have been involved in the problem if there had been computers instead.

9.2.5 Difficulty level

The problem might even have been to hard for some of the students in the test group, they have not the knowledge in mathematics that the task demands and therefore they do not do anything. It could be said that the task is outside of the students zone of proximal development, ZPD. The term ZPD is introduced by Vygotsky who introduces it as following.

> *"It is the distance between the actual developmental level as determined by independent problem solving and the level of potential development at determined through problem solving under adult guidance or in collaboration with more capable peers." (Vygotsky, 1974)*

This can be interpreted as following, a student is able to do certain things when performing tasks by him/herself but with help from an adult the student will be able to perform more advanced tasks. This doesn't say that the student with help will be able to solve all tasks some tasks will be to difficult and is therefore outside of the students ZPD. According to Säljö (2000) you can help the student by structuring the problem or helping the student to understand the problem or question. Maybe this students would have performed better with more support and encouragement or maybe the task was outside of their ZPD. Perhaps the program only should be recommended for students in the second physics course due to the abstract-nature of the task or maybe dedicate more time for the program if the students are at their first physics course. This have to be tested further and is hard to say after only one test session.

9.3 In the future

9.3.1 Openness

The experimental task is today not as opened as wished for due to the fact that there only is one experimental set-up. An opportunity is to have this detector together with the smaller detectors used during the explore space tour [4] and/or a muonoscope[5]. This would make it possible to let all students formulate their own experiment, not only plan an experiment for an certain question. The small ones is easy to carry to different places, even the big one is possible to move to different levels in the building. The angular dependence can be studied and perhaps how much different materials stop mouns. What maybe will be lost here is the focus on the NOS, this is not certain but an risk that needs to be considered. This is a possible 4,5 hp project for a student at the course DH2605, Science, Technology and Learning, part II.

9.3.2 Another program

Another opportunity is to use the detector in a mathematics-experiment in the second mathematics-course. In this course probability and statistics are studied. It would be possible to do measurements with the detector and work with different statistical terms. In school the usual task on statistics and probability is to work with dies, problems where data already is collected or at most formulate an question which they ask friends, family or other persons. When doing this kind of experiment with a detector it is possible to join together the mathematics and physics and also discuss how physicists work with measurements and statistical data.

[4] A small handheld detector for cosmic rays with diodes that blinks when it is hit. http://www.nasa.gov/mission_pages/station/science/experiments/Particle_Flux.html

[5] A small portable detector for cosmic rays, more like the new SEASA detector, but a lot smaller, see http://www.particle.kth.se/~pearce/CRT/

10 Conclusion

The school program was when tested shown to be effective on level 1 according to Miller et al., all students were able to perform the task (Millar 1999). With small changes it can hopefully become effective on level 2, that all students will learn how scientists can work with data analysis and how theories changes with time . The laboratory also gives the students chance to contribute to the meaning of the task even if the laboratory device and the task is fairly closed.

A Appendix

A Intended learning outcome

a) to help students identify objects and phenomena and become familiar with them	
b) to help students learn a fact (or facts)	
c) to help students learn a concept	
d) to help students learn a relationship	
e) to help students learn a theory/model	

f) to help students learn how to use a standard laboratory instrument, or to set up and use a standard piece of apparatus	
g) to help students learn how to carry out a standard procedure	
h) to help students learn how to plan an investigation to address a specific question or problem	
i) To help students learn how to process data	
j) to help students how to use data to support a conclusion	
k) to help students learn how to communicate the results or their work	

B1.1 What students are intended to do with objects and observables

use	an observaton or measuring instrument	a
	a laboratory device or arrangement	b
	a laboratory procedure	c
present or display	an object	d
make	an object	e
	a material	f
	an event occur	g
observe	an object	h
	a material	i
	an event	j
	a quantity	k

B1.2 What students are intended to do with ideas

<table>
<tr><td colspan="2">report observations</td><td>a</td></tr>
<tr><td colspan="2">identify a pattern</td><td>b</td></tr>
<tr><td></td><td>objects</td><td>c</td></tr>
<tr><td>explore relation between</td><td>physical quantities (variables)</td><td>d</td></tr>
<tr><td></td><td>objects and physical quantities</td><td>e</td></tr>
<tr><td colspan="2">invent' (or 'discover') a new concept (physical quantity, or entity</td><td>f</td></tr>
<tr><td colspan="2">determine the value of a quantity wich is not measured directly</td><td>g</td></tr>
<tr><td rowspan="3">test a prediction</td><td>from a guess</td><td>h</td></tr>
<tr><td>from a law</td><td>i</td></tr>
<tr><td>fram a theory (or model based on a theoretical framework)</td><td>j</td></tr>
<tr><td rowspan="4">accont for observations</td><td>in terms of a given explanaton</td><td>k</td></tr>
<tr><td>by choosing between to (or more) given</td><td>l</td></tr>
<tr><td>explanations</td><td></td></tr>
<tr><td>by proposing an exlanation</td><td>m</td></tr>
</table>

B1.3 Objects- or Ideas-driven?

a) What the students are intended to do with ideas arises from what they are intended to do with objects	
b) What the students are intended to do with objects arises from what they are intended to do with ideas	
c) There is no clear relationship between what the students are intended to do with objects and with ideas	

B1.4 Degree of openness/closure

Aspect of practical task	Specified by teacher	Devided through teacher student discussion	Chosen by students
Question to be addressed	x		
Equipment to be used	x		
Procedure to be followed			x
Methods of handling data collected	x		
Interpretation of results		x	

B1.5 Nature of student involvement

a) demonstrated by teacher; student observe	
b) demonstrated by teacher; student observe and assist as directed	
c) carried out by students in small groups	
d) carried out by individual students	

B2.1 Duration

a) very short (less than 20 minutes	
b) short (one science lesson, say upp to 80 minutes)	
c) medium (2-3 science lessons)	
d) long (2 weeks or more)	

B2.2 People with whom student interacts

a) other students carrying out the same practical task	
b) other students who have already compleated the task	
c) teacher	
d) more advanced students (demonstrators, ect.)	
others (technician, ect.)	

B2.3 Information given to the student on the task

a) oral instructions	
instructions on blackboard/witheboard/OHP	
c) guiding worksheet	
d) textbook(s)	
e) other (e.g. data book, data base, instruction manual, etc.)	

B2.3 Type of apparatus involved

a) standard laboratory equipment	
b) standard laboratory equipment + interface to computer	
c) everyday equipment (kitchen scales, domestic materials...)	

B3.1 Nature of student's record of work on task

a) no written record	
b) notes	
c) completion of printed worksheet	
d) written account (using given structure and format)	
e) written account (free format)	

B3.2 Purpose of record

a) to assist students in learning science content or process	
b) to provide evidence that the task has been carried out	
c) as a basis for assessing the student's performance	
d) as a record which the student can use to revise for tests or examinations	
e) to help students learn how to write a scientific report	

B3.3 Audience for record

a) the student	
b) the teacher	
c) other students	
d) other	

B Appendix

Student instruction manual

At next page the follows the student instruction manual that will be used during the laboratory exercises, the manual is written in Swedish.

Uppgiften

Syfte: Syftet med uppgiften är dels att ni skall lära er om kosmisk strålning och hur den beter sig och dels att ni skall få inblick i hur en forskare arbetar med att samla in data och bearbeta data.

Frågeställning: Kan vi resa till Mars?

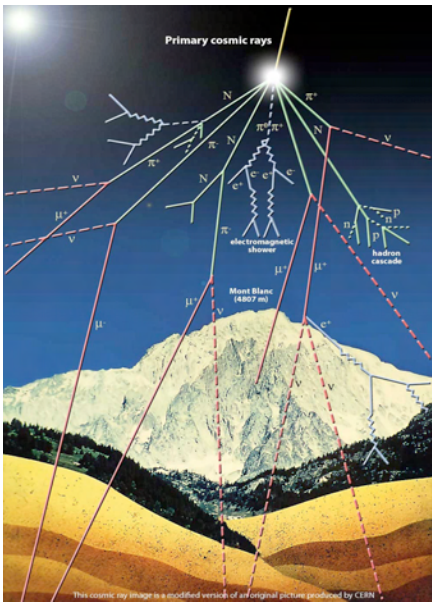
Genomförande:

- ✓ Genomgång av upplägget av passet
- ✓ Teorigenomgång
- ✓ Planera för att göra mätningarna. Hur många mätningar bör göras och i vilka vinklar?
- ✓ Mätningar i storgrupp
- ✓ Leta efter ett samband mellan antalet träffar och vinkeln med hjälp av beskrivningen för hur man anpassar kurvor efter data.

Till er hjälp har ni nedanstående beskrivning av kosmisk strålning och hur man gör för att anpassa data. Ni kanske inte behöver använda den men den finns där för att hjälpa er om ni kör fast.

Kosmisk strålning

Kosmisk partikel strålning består av partikelkärnor från våra naturligt förekommande grundämnen. De flesta partiklar vi detekterar på jorden kommer ursprungligen från väte (86 %) och helium (11%). När vi detekterar dem på jorden har de slagits sönder och sönderfallit till bland annat fotoner, elektroner och myoner.



(Cern, 2009)

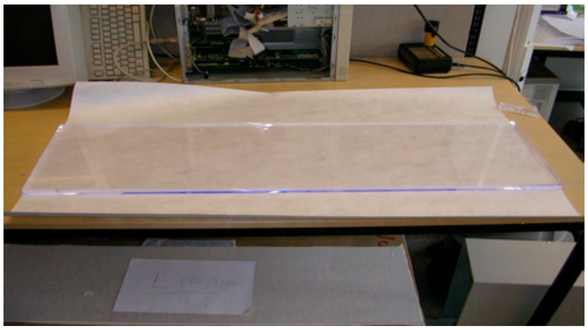
När en partikel träffar atmosfären kommer den krocka med andra partiklar. Detta gör att ursprungspartikeln slås sönder och bildar mindre partiklar. Dessa partiklar sönderfaller för att tillsist sluta med att en partikel bildat en skur av andra partiklar. Denna skur består av fotoner, elektroner, myoner och så kallade hadroner till exempel neutroner och protoner. Av alla dessa partiklar är de flesta fotoner. Fotonerna har dock för låg energi för att kunna detekteras av vår detektor, så de partiklar vi detekterar är framförallt myoner.

Kosmisk partikelstrålning kommer från olika platser. De partiklar som träffar oss kommer framförallt från vår egen galax. Partiklarna kommer dels från supernovor men även från stjärnor. En mindre del av partiklarna bör komma från andra galaxer eftersom vi inte funnit något i vår egen galax som skulle kunna accelerera partiklar till så pass höga energier som vi mätt upp här på jorden.

crab nebula (wikipedia, 2009)

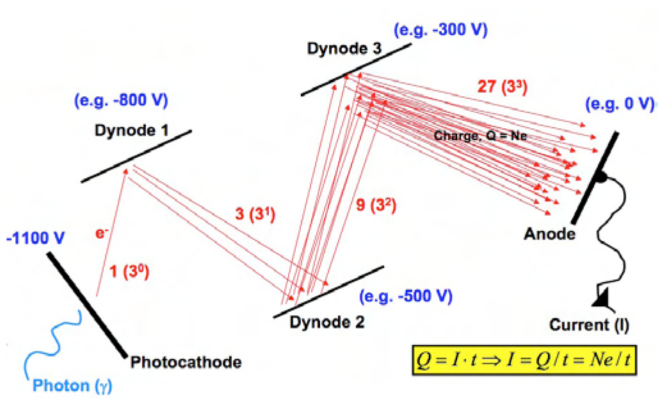
Detektorn

Den del som detekterar de partiklar som bildas i atmosfären är den så kallade scintillatorskivan, vilken ser ut som en helt vanlig plastskiva men har en speciell egenskap, molekylerna i plasten skickar ut fotoner (ljuspartiklar) när den träffas av partiklar.



(Pearce, 2009)

Detta sker genom att elektroner i molekylen exciteras till en högre energinivå när plasten blir träffad av en inkommande partikel. Elektronerna vill sedan tillbaka till sin grundnivå och då sänds en foton ut. De fotoner som skapas i scintillatorn studsar runt inuti scintillatorn tills de fångas upp av fotomultiplikatorn, se bild. I vilken signalen förstärks med hjälp av fotoelektrisk effekt och högspänning. Signalen går sedan igenom elektroniken vilken sedan visar att vi fått en träff.

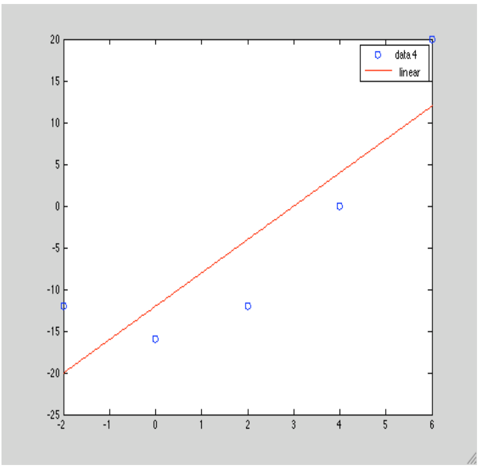


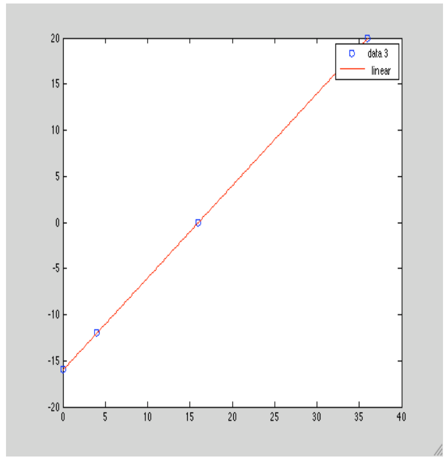
(Pearce, 2

(Pearce, 2009)

Elektroniken kan ställas in så att man tittar på en platta, två plattor eller alla plattor och man kan välja att räkna under en minut eller fem minuter. Själva detektorn går dessutom att vinkla, den är markerad med vinklarna 0, 15, 30, 45, 60, 75, 90 grader.

Anpassning av kurvor





För att anpassa en kurva efter sina mätningar kan man rita upp mätpunkterna med hjälp av en grafritande miniräknare eller excel och sedan låta datorn räkna ut den bästa linjära anpassningen. Det är dock inte alla kurvor som är linjära (y=kx+m) utan ofta har kurvorna någon annan form. I exemplet ovan har punkter på kurvan $y=x^2-16$ valts ut. Om vi då försöker anpassa en rät linje efter dessa punkter kommer linjen inte att gå genom alla punkter. I det andra fallet har vi använt samma punkter, men istället för att ha x-värdena på x-axeln har vi kvadrerat dessa och plottat de nya punkterna, vi har plottat x^2 mot y. Vad vi ser då är att vi kan anpassa en rät linje genom alla punkterna.

x	y	x^2
-2	-12	4
0	-16	0
2	-12	4
4	0	16
6	20	36

Metoden som miniräknaren eller datorn använder kallas för minsta kvadratmetoden. Denna metod minimerar summan av avstånden mellan punkterna och kurvan i kvadrat. Kvadraten används för att undvika att positiva och negativa värden uppstår vilka i så fall skulle kunna göra att felet blir noll även om kurvan inte går genom någon av punkterna.

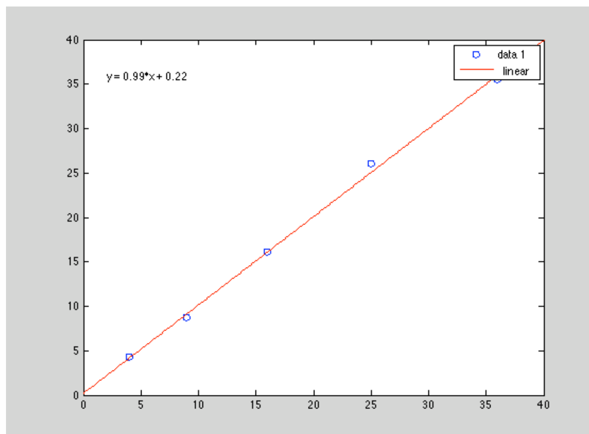
När man gör en mätning av en fysikaliskt fenomen kommer punkterna inte ligga precis på en kurva. Detta beror både dels på att vi inte kan mäta exakt men även att vissa fysikaliska fenomen är slumpmässiga, vi vet ungefär hur ofta det händer men inte exakt när. Detta leder till att vi måste göra många likadana mätningar eller mäta under en lång tid för att få ett bra närmevärde. När man gjort mätningarna får man analysera dessa data med hjälp av olika matematiska metoder, där minsta kvadratmetoden är en av metoderna. Ibland kan det vara svårt att avgöra viken av anpassningarna man har gjort som är den bästa. Då måste man ha en metod för att jämföra dessa, den metod vi skall använda oss av idag är summan av absolutbeloppet av uppmätt värde minus värde på den anpassade kurvan. Vi kallar denna summa för fel-summa.

Vad som dock är viktigt att komma ihåg är det att även om man har en låg fel-summa är det inte helt säkert att den anpassningen är bättre än en anpassning som har något högre felsumma. För att avgöra detta måste man använda sig av mer avancerade statistiska metoder, men felsumman är ett tecken på att en viss anpassning är bättre än en annan

Exempel:

Mätvärden:

x	y
2	4,3
3	8,7
4	16,1
5	26
6	35,5



Anpassningen ger följande värden på kurvan

x	y-kurva
2	4,18
3	9,13
4	16,06
5	24,97
6	35,86

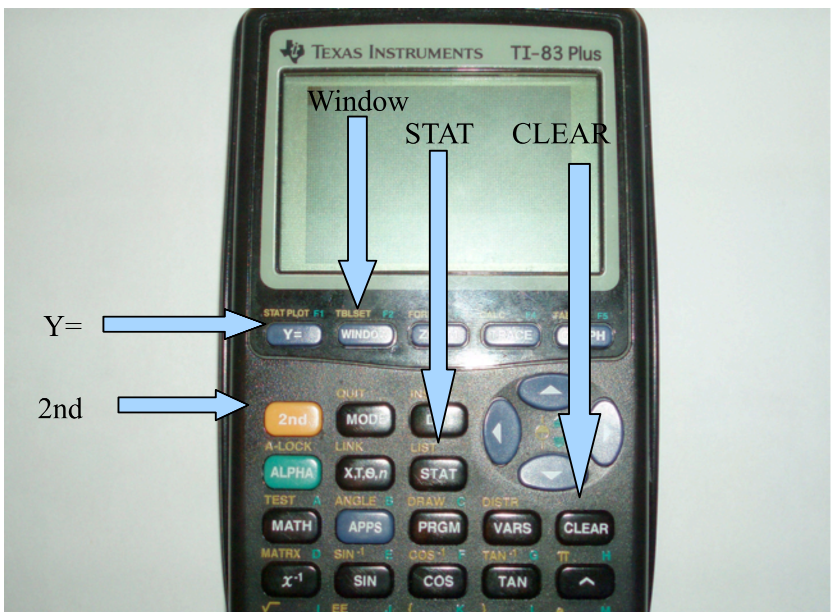
Fel-summa = |4,3 - 4,18|+|8,7 - 9,13|+|16,1 - 16,06|+|26 - 24,97|+|35,5 - 35,86|=1,98

Grafritande miniräknare

Här följer en kort redogörelse för hur du kan använda din grafritande miniräknare för att anpassa en kurva till uppmätta data. Detta görs lite olika beroende på vad du har för märke på din miniräknare, här kommer jag utgå ifrån de två mest vanligt förekommande tillverkarna, Texas Instruments och Casio.

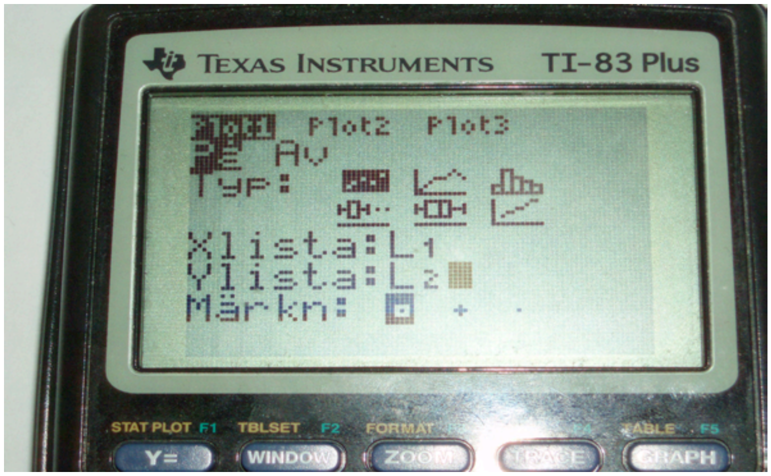
Texas Instruments TI83-TI84 Plus
För att lägga in de uppmätta datapunkterna och rita dem i ett koordinatsystem.

- Tryck STAT och välj 1: Edit
- Om L1 och L2 ej är tomma rensa listan genom att markera L1 och tryck CLEAR, gör samma sak för L2.
- I L1 skriver du nu in vid vilka värden du har mätt, t.ex. 90º
- I L2 skriver du in de uppmätta värdena



När du lagt in alla datapunkter är det dags att göra de inställningar som behövs för att titta på datapunkterna i ett koordinatsystem.

- Trycker du 2nd och Y= (start plot)
- Välj en av siffrorna genom att markera den och trycka Enter. Fönstret kommer då se ut enligt bilden nedan.



- Välj hur du vill att punkterna ska se ut och lägg in vilken lista du vill ha på x och y axeln. Detta gör du genom att trycka 2^{nd} och knappen för någon av siffrorna 1-6 beroende på vilken lista dina värden ligger i.
- Tryck WINDOW och lägg in lämpliga värden för fönstret.
- Titta på dina punkter genom att trycka GRAPH

I den här uppgiften kommer vi använda oss av att miniräknaren kan anpassa räta linjer till datapunkter. Denna funktion kallas för LinReg. Denna funktion ligger under CALC-menyn som finns under STAT-knappen

- Tryck STAT och gå ett steg åt höger (CALC-menyn), välj sedan punkt fyra LinReg (ax+b)

I fönstret kommer då följande upp:

LinReg(ax+b)

- Skriv in de listor du har dina x- och y-värden i, exempelvis L1,L2,Y1. Y1 skriver du för att spara funktionen så att du kan rita upp den senare.
- Y1 hittas genom att trycka VARS, Y-VARS, Function och sedan välja vilken du vill använda

Ett exempel på hur det kan se ut är:

- LinReg(ax+b) L1,L2,Y1
-

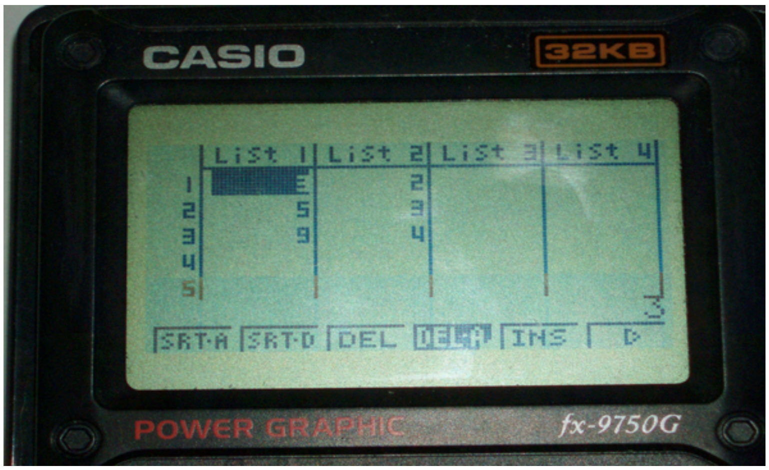
eller mer allmänt

- LinReg(ax+b) x-lista,y-lista, vart funktionen skall sparas.

- Titta på dina data och på funktionen genom att trycka på GRAPH
- För att ta reda på y-värdena på kurvan tryck TRACE och för vilken x-värde du vill ta reda på Y-värdet.

Casio
För att lägga in de uppmätta datapunkterna och rita dem i ett koordinatsystem.

- Starta miniräknaren och välj STAT.
- Om lista 1 och lista 2 ej är tomma tryck F6, fönstret kommer se ut som bilden nedan.
- välj sedan DEL A och tillsist trycker du YES.
- I L1 skriver du nu in vid vilka värden du har mätt, t.ex. 90°.
- I L2 skriver du in de uppmätta värdena



När alla datapunkter är inmatade är det dags att rita dessa

- Tryck F6 igen om du raderade tidigare inlagda data.
- Tryck F1 (GRPH)
- Välj GPH1 (eller annan om du vill)

Du kan nu se dina datapunkter, för att hitta den linjära anpassningen tryck F1. Du kan då se ekvationen för den anpassade funktionen.

- Spara den genom att trycka F5 (COPY)
- Välj vart du vill spara den avsluta med EXE.

Funktionen sparas och du kommer tillbaka till bilden med ekvationen, om du vill titta på grafen och dina datapunkter trycker du F6 (DRAW)

För att räkna ut felsumman måste vi hitta vilka y-värden på kurvan som motsvarar de x-värden vi mätt vid.

- Tryck MENU
- Välj GRAPH (nummer 5)
- Välj F6 (DRAW)
- Tryck SHIFT – F5
- Tryck F6 och välj sedan Y-CAL
- Mata in det x-värde du vill ta reda på y-värdet för, gör sedan om från SHIFT – F5 för att ta reda på övriga punkter.

C Appendix

Teacher guidelines

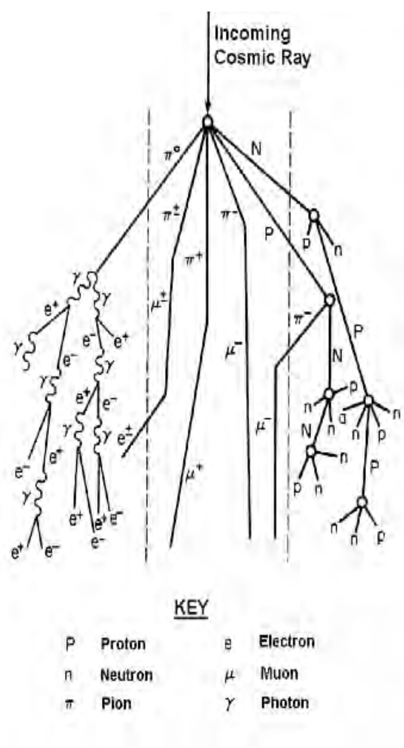
Uppgiften

Eleverna skall genomföra en uppgift där de skall bestämma ett möjligt samband för hur antalet träffar beror av vinkeln. Målet med uppgiften är givetvis att de skall lära sig om kosmisk strålning men det övergripande målet är att de skall lära sig något om hur man bedriver forskning och hur man inom fysiken försöker hitta olika samband. Något som därför kan vara viktigt att poängtera är att det samband de kommer fram till i slutet inte behöver vara det som är det bästa sambandet som kan hittas men att det kan ses som en förenklad modell för hur den kosmiska strålningen beter sig.

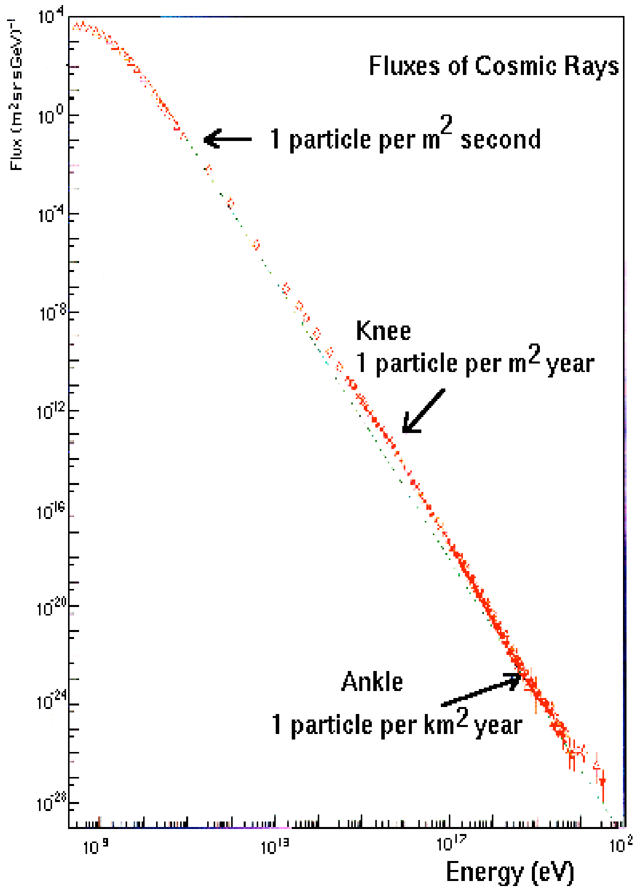
Eleverna skall i så stor utsträckning som möjlig själva lägga upp mätningen, både vad gäller antalet mätningar och vid hur många vinklar det skall mätas. Det är upp till dig som lärare eller laborationsassistent att ge dem råd och kring hur lång tid de har till de olika momenten och hur utrustningen fungerar, men du skall inte säga hur de skall göra vad gäller upplägg av mätningarna.

Kosmisk strålning

Kosmisk partikel strålning består av partikelkärnor från våra naturligt förekommande grundämnen, alla ämnen upp till Uran. De flesta partiklar vi detekterar på jorden kommer ursprungligen från väte (86 %) och helium (11 %). När vi detekterar dem på jorden har de slagits sönder och sönderfallit till bland annat fotoner, elektroner och myoner. En del av väte och helium partiklarna kommer från vår egen sol. Dessa partiklar har dock en ursprungsenergi som gör att de inte kan detekteras av vår detektor. För att vår detektor skall detektera en partikel i en av sina plattor krävs att partikeln har en energi över $5x10^{14}$ eV (Hofverberg 2006). Partiklar från solen har vanligtvis en energi som inte överstiger 10 GeV (Grieder) .



När en partikel träffar atmosfären (40 km över jordytan) kommer den krocka med andra partiklar, för ursprungspartikeln är det som att köra in i en vägg. Detta gör att ursprungspartikeln slås sönder och bildar mindre partiklar som i sin tur sönderfaller. Partiklarna sönderfaller i flera steg för att tillsist sluta med att en partikel bildat en skur av andra partiklar. Denna skur består av fotoner, elektroner, pioner, myoner och så kallade hadroner till exempel neutroner och protoner. Av dessa partiklar är de flesta fotoner. Fotonerna har dock för låg energi för att kunna detekteras av vår detektor, så de partiklar vi detekterar är framförallt myoner. De flesta partiklarna som bildas når aldrig jordytan utan sönderfaller och stoppas upp av atmosfären innan de når jorden. För en partikel med ursprungsenergin 10^{15} eV kommer ca en miljon partiklar att nå jordytan. Av dessa en miljon partiklar är 80 % fotoner, 18 % elektroner, 1,5 % myoner och 0,5 % hadroner. En av anledningarna till att man studerar myoner när man tittar på kosmisk strålning är att det är dessa partiklar som sprids över störst yta. En annan anledning är att myonerna jämfört med elektroner och fotoner har betydligt högre energi (O(GeV) mot O(MeV)).



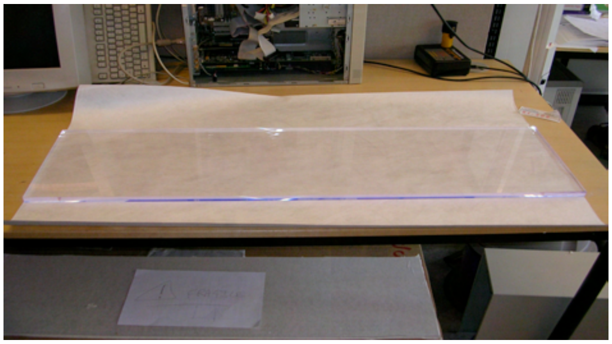
(Bartels, 2000)

crab nebula (wikipedia,2009)

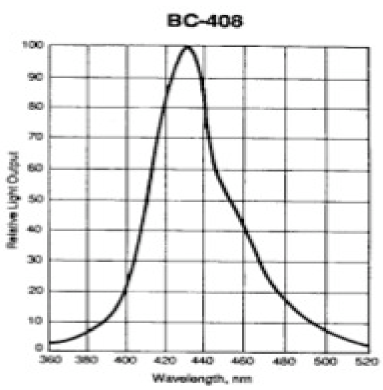
Kosmisk partikelstrålning kommer från många olika platser olika platser. I figuren ovan kan ses att jorden träffas av fler partiklar med låg energi än med hög energi. De flesta partiklarna kommer från källor i vår egen galax till exempel från rester av supernova explosioner. Partiklar med energier över ankeln kommer med stor säkerhet från andra galaxer då inget i vår egen galax klarar av att accelerera partiklar till dessa energier. Gränsen för partiklarnas energi går vid 10^{20} eV, detta beror på att dessa partiklar interagerar med mikrovågsbakgrunden och därmed förlorar energi. Efter ungefär 100 Mpc kan man visa att partikelns energi är oberoende av dess ursprungliga energi.

Detektorn

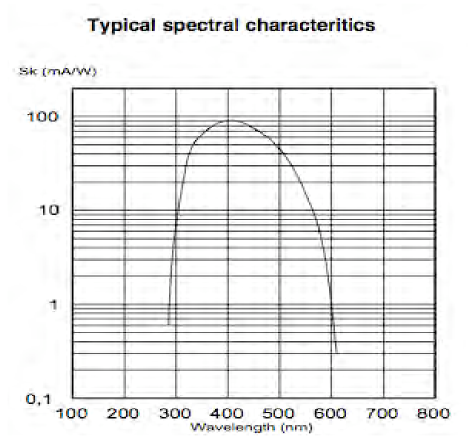
Den del som detekterar de partiklar som bildas i atmosfären är den så kallade scintillatorskivan, vilken ser ut som en helt vanlig plastskiva men har en speciell egenskap, molekylerna i plasten skickar ut fotoner när den träffas av partiklar. Genom att molekylen exciteras till en högre energinivå när plasten blir träffad av en inkommande partikel vilken sedan återgår till sitt ursprungsläge. Anledningen till att alla delar av detektorn är övertäckta är den att den våglängd som scintillatorskivan (ca 425 nm) skickar ut är inom våglängderna för synligt ljus. Om solljus eller annat ljus inom de synliga våglängderna skulle träffa PM-röret skulle mätningarna bli helt fel och PM-röret gå sönder efter en relativt kort tid. PM-röret är som mest känslig för strålning med våglängden 420 nm.



(Pearce, 2009)

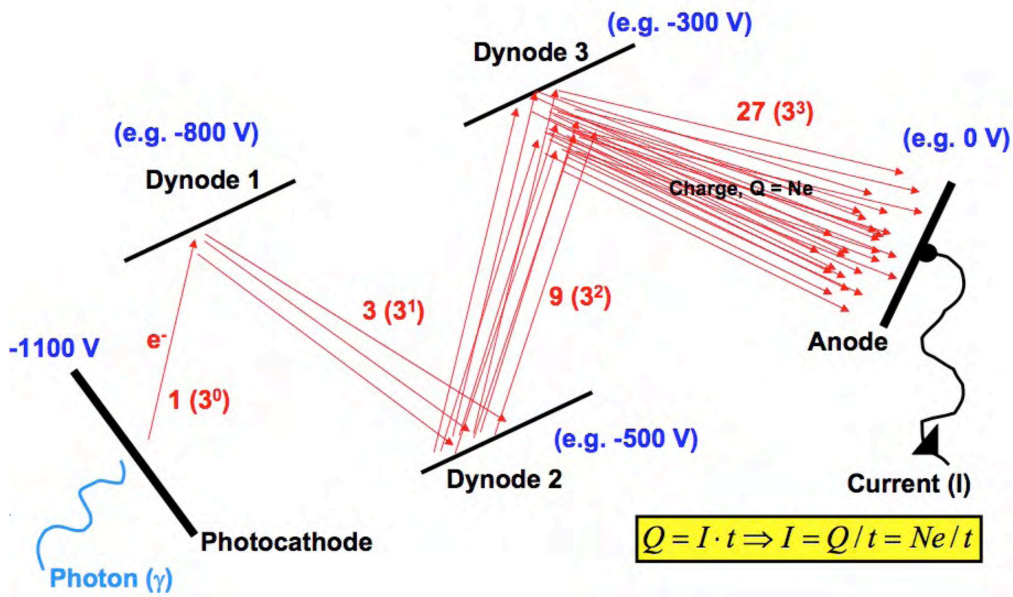


(Photonis, 2009)



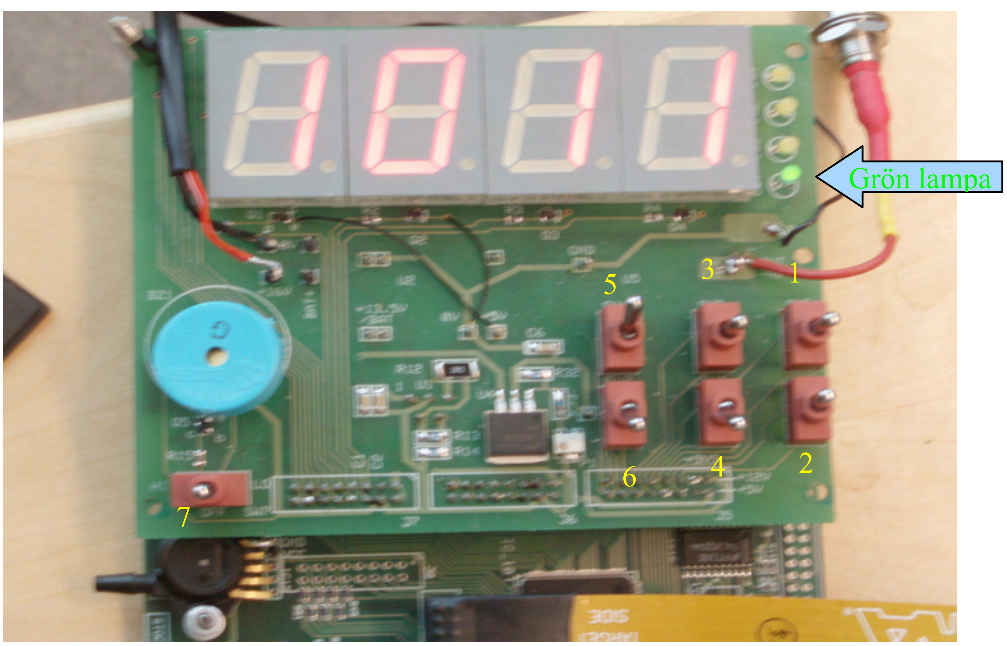
(Bicron, 2009)

Fotonerna reflekteras sedan inuti plasten tills de når PM-röret. I vilken signalen förstärks genom att elektroner accelereras och slår ut fler och fler elektroner (fotoelektrisk effekt, se bild). Signalen går sedan igenom elektroniken vilken sedan visar att vi fått en träff.



(Pearce, 2007)

Elektroniken
Elektroniken kan ställas in så att man tittar på en platta, två plattor eller alla plattor och man kan välja att räkna under en minut eller fem minuter. Själva detektorn går dessutom att vinkla, den är markerad med vinklarna 0, 15, 30, 45, 60, 75, 90 grader. Elektroniken räknar och lagrar all data från den senaste körningen, så oavsett om man under körningen visade en platta så kan man få fram data för övriga kombinationer i efterhand genom att ändra inställningarna.



Det finns ett antal olika inställningar som kan göras av detektorn, för detta ändamål finns sju stycken switchar, här numrerade 1-7. De switchar som kan behöva kommenteras är framförallt 1-4. Switch 1 och 2 har med inställningar av tiden och räkneverket att göra och switch 3 och 4 med vilka plattor som studeras. Förenklat kan switch fyra beskrivas med att den bestämmer om platta C skall vara med eller ej och om vi enbart ska titta på C eller om C skall kombineras med vad switch 2 har för inställning.

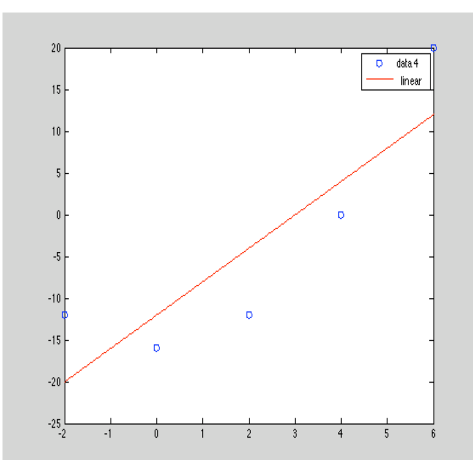
3	4	Upp (enbart C)	Mitten (sw 3+C)	Ned (C avstängd)
Upp		C	A+C	A
Mitten		C	A+B+C	A+B
Ned		C	B+C	B

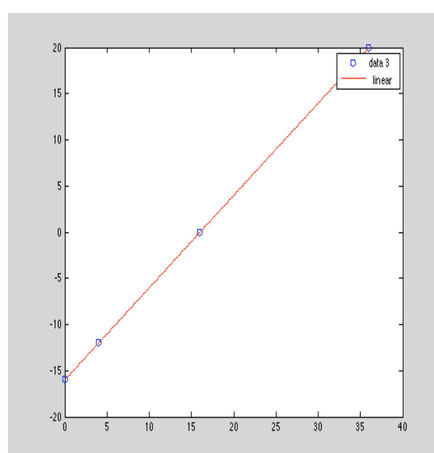
Övriga switchar har med olika funktioner vilka sammanfattas nedan.

	1	2	5	6	7
Uppåt	räkna	1 minut	Starkt ljussken	Tid kvar	Högt ljud
Mitten	håll	Ingen tidtagning	Av	Normalläge	Ljud av
Nedåt	rensa	5 minuter	Svagt ljussken	Lufttryck	Lågt ljud

Switch 2 bestämmer om vi skall ha någon tidtagning. När denna slås på raderas tidigare körning ur minnet och den börjar räkna, även om switch 1 står i uppåt eller mitten läge. När detektorn räknar och tidtagning sker kommer den gröna lampan att slockna, när den räknat färdigt tänds lampan igen. För att se när den räknar eller sedan se antalet träffar måste switch 1 vara i uppåt läge.

Anpassning av kurvor





För att anpassa en kurva efter sina mätningar kan man rita upp mätpunkterna med hjälp av en grafritande miniräknare eller excel och sedan låta datorn räkna ut den bästa linjära anpassningen. Det är dock inte alla kurvor som är linjära (y=kx+m) utan ofta har kurvorna någon annan form. I exemplet ovan har punkter på kurvan $y=x^2-16$ valts ut. Om vi då försöker anpassa en rät linje efter dessa punkter kommer linjen inte att gå genom alla punkter. I det andra fallet har vi använt samma punkter, men istället för att ha x-värdena på x-axeln har vi kvadrerat dessa och plottat de nya punkterna, vi har plottat x^2 mot y. Vad vi ser då är att vi kan anpassa en rät linje genom alla punkterna.

x	y	x^2
-2	-12	4
0	-16	0
2	-12	4
4	0	16
6	20	36

Metoden som miniräknaren eller datorn använder kallas för minsta kvadratmetoden. Denna metod minimerar summan av avstånden mellan punkterna och kurvan i kvadrat. Kvadraten används för att undvika att positiva och negativa värden uppstår vilka i så fall skulle kunna göra att felet blir noll även om kurvan inte går genom någon av punkterna. Mer om minsta kvadratmetoden kan läsas på http://en.wikipedia.org/wiki/Least_squares

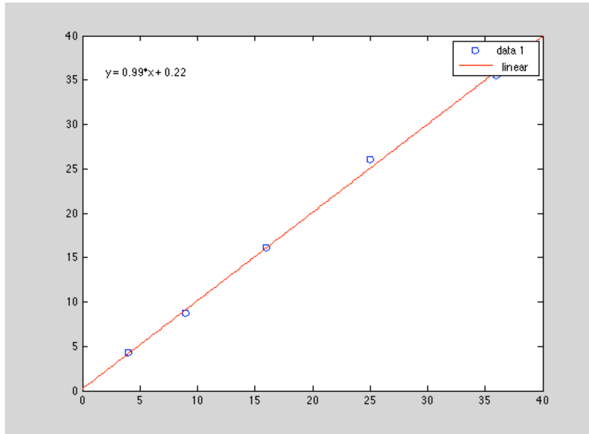
När man gör en mätning av en fysikaliskt fenomen kommer punkterna inte ligga precis på en kurva. Detta beror både på att vi inte kan mäta exakt men även att vissa fysikaliska fenomen är slumpmässiga, vi vet ungefär hur ofta det händer men inte exakt när. Detta leder till att vi måste göra många likadana mätningar eller mäta under en lång tid för att få ett bra närmevärde. När man gjort mätningarna får man analysera dessa data med hjälp av olika matematiska metoder, där minsta kvadratmetoden är en av metoderna. Ibland kan det vara svårt att avgöra viken av anpassningarna man har gjort som är den bästa. Då måste man ha en metod för att jämföra dessa, den metod vi skall använda oss av idag är summan av absolutbeloppet av uppmätt värde minus värde på den anpassade kurvan. Vi kallar denna summa för fel-summa. Detta är inte den metod som används inom vardaglig forskning, utan en förenkling som endast ger tecken på om en anpassning är bra eller inte. Detta kan vara bra att nämna i samband med genomgången.

Vad som dock är viktigt att komma ihåg är det att även om man har en låg fel-summa är det inte helt säkert att den anpassningen är bättre än en anpassning som har något högre felsumma. För att avgöra detta måste man använda sig av mer avancerade statistiska metoder, så som att titta på korrelations koefficienten r^2. Detta skulle för den här laborationen ta för lång tid och kräva djupare genomgångar än vad tiden ger möjlighet till.

Exempel:

Mätvärden:

x	y
2	4,3
3	8,7
4	16,1
5	26
6	35,5



Anpassningen ger följande värden på kurvan

x	y-kurva
2	4,18
3	9,13
4	16,06
5	24,97
6	35,86

Fel-summa = |4,3 - 4,18|+|8,7 - 9,13|+|16,1 - 16,06|+|26 - 24,97|+|35,5 - 35,86|=1,98

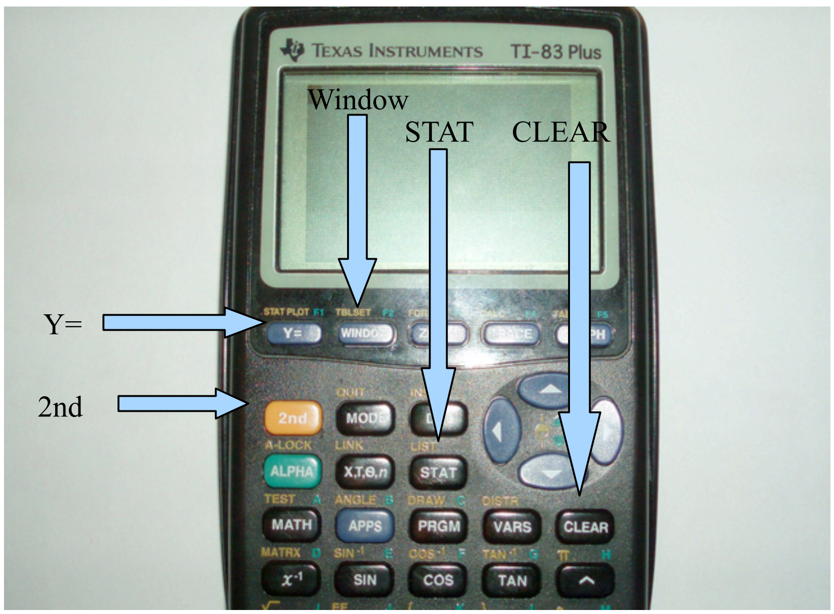
Anpassning av kurvor

Här följer en kort redogörelse för hur du kan använda din grafritande miniräknare för att anpassa en kurva till uppmätta data. Detta görs lite olika beroende på vad du har för märke på din miniräknare, här kommer jag utgå ifrån de två mest vanligt förekommande tillverkarna, Texas Instruments och Casio.

Texas Instruments TI83-TI84 Plus

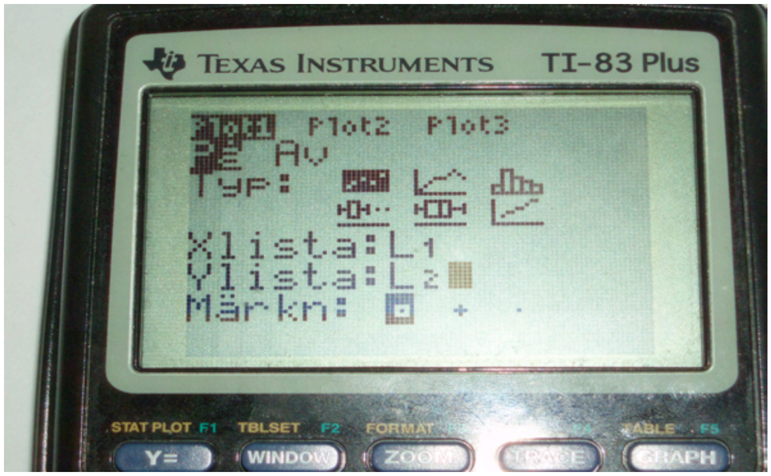
För att lägga in de uppmätta datapunkterna och rita dem i ett koordinatsystem.

- Tryck STAT och välj 1: Edit
- Om L1 och L2 ej är tomma rensa listan genom att markera L1 och tryck CLEAR, gör samma sak för L2.
- I L1 skriver du nu in vid vilka värden du har mätt, t.ex. 90°
- I L2 skriver du in de uppmätta värdena



När du lagt in alla datapunkter är det dags att göra de inställningar som behövs för att titta på datapunkterna i ett koordinatsystem.

- Trycker du 2nd och Y= (start plot)
- Välj en av siffrorna genom att markera den och trycka Enter. Fönstret kommer då se ut enligt bilden nedan.



- Välj hur du vill att punkterna ska se ut och lägg in vilken lista du vill ha på x och y axeln. Detta gör du genom att trycka 2nd och knappen för någon av siffrorna 1-6 beroende på vilken lista dina värden ligger i.
- Tryck WINDOW och lägg in lämpliga värden för fönstret.
- Titta på dina punkter genom att trycka GRAPH

I den här uppgiften kommer vi använda oss av att miniräknaren kan anpassa räta linjer till datapunkter. Denna funktion kallas för LinReg. Denna funktion ligger under CALC-menyn som finns under STAT-knappen

- Tryck STAT och gå ett steg åt höger (CALC-menyn), välj sedan punkt fyra LinReg (ax+b)

I fönstret kommer då följande upp:

LinReg(ax+b)

- Skriv in de listor du har dina x- och y-värden i, exempelvis L1,L2,Y1. Y1 skriver du för att spara funktionen så att du kan rita upp den senare.
- Y1 hittas genom att trycka VARS, Y-VARS, Function och sedan välja vilken du vill använda

Ett exempel på hur det kan se ut är:

- LinReg(ax+b) L1,L2,Y1
-

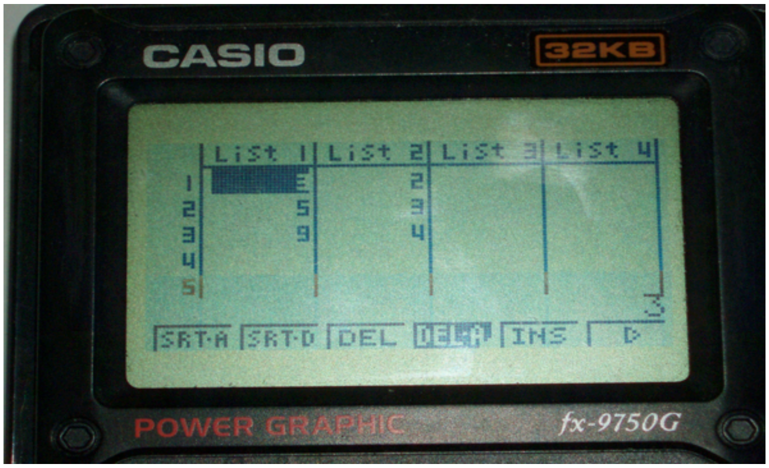
eller mer allmänt

- LinReg(ax+b) x-lista,y-lista, vart funktionen skall sparas.

- Titta på dina data och på funktionen genom att trycka på GRAPH
- För att ta reda på y-värdena på kurvan tryck TRACE och för vilken x-värde du vill ta reda på Y-värdet.

Casio
För att lägga in de uppmätta datapunkterna och rita dem i ett koordinatsystem.

- Starta miniräknaren och välj STAT.
- Om lista 1 och lista 2 ej är tomma tryck F6, fönstret kommer se ut som bilden nedan.
- välj sedan DEL A och tillsist trycker du YES.
- I L1 skriver du nu in vid vilka värden du har mätt, t.ex. 90°.
- I L2 skriver du in de uppmätta värdena



När alla datapunkter är inmatade är det dags att rita dessa

- Tryck F6 igen om du raderade tidigare inlagda data.
- Tryck F1 (GRPH)
- Välj GPH1 (eller annan om du vill)

Du kan nu se dina datapunkter, för att hitta den linjära anpassningen tryck F1. Du kan då se ekvationen för den anpassade funktionen.

- Spara den genom att trycka F5 (COPY)
- Välj vart du vill spara den avsluta med EXE.

Funktionen sparas och du kommer tillbaka till bilden med ekvationen, om du vill titta på grafen och dina datapunkter trycker du F6 (DRAW)

För att räkna ut felsumman måste vi hitta vilka y-värden på kurvan som motsvarar de x-värden vi mätt vid.

- Tryck MENU
- Välj GRAPH (nummer 5)
- Välj F6 (DRAW)
- Tryck SHIFT – F5
- Tryck F6 och välj sedan Y-CAL
- Mata in det x-värde du vill ta reda på y-värdet för, gör sedan om från SHIFT – F5 för att ta reda på övriga punkter.

Acknowledgments

I especially want to thank my supervisors Mark Pearce at the Royal Institute of Technology, Carolina Svensson-Hulth at Stockholm University and Cecilia Kozma at the House of Science for their support.

I also want to thank Stefan Rydström for always taking time to answer all my questions and supporting me in my work and other technician-personnel that helped me with my detector. The third thank goes the rest of the astro- and particle-physics group for all tips and company during lunches.

At last I want to thank my boyfriend, Erik, for believing in me when I have doubted in myself.

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