Buiding a HiSPARC detector
&
Signal Processing

H.J. Bulten (NIKHEF)

Adjusted by C.T. Herbschleb

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1 Building a HiSPARC Detector

This section describes, guided by pictures, the building process of a HiSPARC detector station. Wrapping the detector in aluminium foil and pond foil, gluing parts together and making the detector light tight is a very precise job to do, so you have to work decently and careful, that is the fastest way to accomplish a working system.

The plan is to glue the scintillation plate, light guide and Photon Multiplier Tube (PMT) together, wrap them in highly reflecting aluminium foil and after that in light tight pond foil.

There will be loss of photons (and thus signal) when there are scratches or impurities on the scintillation plate, light guide or PMT-window, so be careful, use as few tools in the neighborhood of the different parts of the detector as possible and use gloves where possible.

The PMT can detect a single photon. To compare: every second 10 billion photons per square micrometer arrive on earth only from the sun. So a very tiny hole in the foils means an useless detector.

1.1 Aluminium foil

You start with cleaning a table with methanol and put a sheet of hard aluminium foil on it. This kind of foil reflects in the best way, but it easily tears at the edges. The sheet should be a little longer and wider than the scintillation plate, i.e. 60 cm wide and 105 cm long. **Use gloves to avoid fingerprints on the plate**. Clean the aluminium sheet with an anti-statical tissue (see figure 1). If there are bumps, make them flat; if there are stains, remove them with methanol. If necessary, make the sheet dry and clean it again with the anti-statical tissue.

1.2 Scintillation plate

Be aware: the scintillation material is a soft material and can get scratches easily. Do not touch them with your bare hands, only with gloves, and if moving them, be very careful. The scintillation plates have already been polished, so we do not have to do that anymore.

First the protecting layer of paper has to be removed from the plate (see figure 2). Make sure to make a note of the serial number of the scintillation

Figure 1: Cleaning the aluminium sheet with an anti-statical tissue

plate, this is necessary for the detector data sheet. Later on one can trace the scintillation plate if necessary.

When the protecting paper is removed, you can clean the scintillation plate with the anti-statical tissue (it repels dust; see figure 3). If there are remnants of glue from the protecting paper on the scintillation plate, you can remove them using Permacel tape. This kind of tape takes the glue-remnant with it and does not leave any glue remnants of itself on the scintillation plate. When cleaning, do not push too firm on the plate, it is soft, so you can make easily bumps in it. When both the sheet of aluminium foil and scintillation plate are clean, you can put the scintillation plate on top of the sheet of aluminium foil.

1.3 Wrap the scintillation plate

The side on which the light guide will be glued, should stretch out a little bit (few cm.) above the aluminium sheet (see figure 4. It is clever to let the scintillation plate stretch out a little from the table surface, so that you can turn it and put it down easily. Now, fold the aluminium foil around the sides of the scintillation plate. Try to fold it as tight as possible. In case the aluminium tears at the corners, there should be put some soft aluminium foil around them later on.

Figure 2: Remove the protecting paper

1.4 Second sheet of aluminium foil

Create a new sheet of hard aluminium foil and use the same cleaning process as described in the section *Aluminium foil*. This sheet should be a little smaller in area than the scintillation plate and is being taped to the folded edges of the underlying sheet of aluminium foil (see figure 5). If necessary, clean the scintillation plate again before putting the second sheet on top of it.

To acquire the dimensions of the second sheet, you can put the foil against the edge of the underlying foil at one side and fold it around the detector to the other side (see figure 6). After that you can cut or clip the foil to its dimensions.

Before taping the second sheet to the underlying one, make sure that its dimensions are right. If it is peeling out a little, you can use a sharp pair of

Figure 3: Cleaning the scintillation plate

scissors to remove that. After that you can tape the sheets together.

1.5 Taping the foils

If the second foil is ready (for our kind of scintillation plate that will be approximately 47 cm x 97 cm), it can be taped on top of the folded edges of the underlying foil. Use Permacel tape and try to tape the foil as tight as possible. First use little pieces of Permacel tape, after that tape the foils together along the whole sides (see figure 7).

If the aluminium foil teared at the corners, then there should be put some soft aluminium foil around the foil. Also make sure that there is no Permacel tape directly put around a tear. We use soft aluminium foil for it, because it can be shaped easily. When put over the tear, tape it tight to the earlier sheets. If tears are too big, you have to make a new sheet of aluminium foil.

Figure 4: Technical layout of the detector

Sometimes the tape is not deployed in the right way. In that case, you have to remove it. To remove it, pull it to yourself and to the edge of the aluminium foil. In this way the chance to tear the foil is lowest.

The upper edge of the foil will now be attached to the scintillation plate with Permacel tape. These pieces of tape have to be removed later on, when the light guide is glued on to of the scintillation plate and the glue is dry. At this moment, the foil has to be wrapped tight around the scintillation plate and be attached to the scintillation plate all around; this because during the gluing process you do not want to have the glue leaking between the foil and the scintillation plate. The Permacel tape should be put around half a centimeter from the edge of the scintillation plate.

1.6 Light tight pond foil

Now that the scintillation plate is packed in aluminium foil, the plate will be packed in light tight pond foil to make the system light tight and for protection of the plate and the aluminium foil. Because this pond foil has to stay around the plate, make sure that you do not attach the pond foil to the upper layer of Permacel tape that attaches the aluminium foil to the scintillation plate (because this will be removed later on). Therefor the pond foil should be a little shorter then the aluminium foil. The eventual result is shown in figure 8.

First, cut or clip the pond foil in the right dimensions (around 94 cm x 48 cm). Attach it to the aluminium foil with tiny pieces of Permacel tape. Turn the scintillation plate. The best way to turn it around is let the plate support itself on its edge to avoid bumps and damages (see figure 9).

Now also attach a piece of light tight foil to the other side of the plate.

Figure 5: Technical layout of the detector

Create pieces of pond foil for the edges of the scintillation plate, also attach them to the plate. Now tape the detector in light tight tape around the edges; all the pieces of pond foil should become connected by this tape. The light tight tape is elastic. To avoid tension you first have to clip the pieces of tape, hang them somewhere and wait for a while, until the tension is gone. While taping, you can let the plate support itself on its edge and tape both of the other edges at the same time.

Now tape every edge again with an extra strip of tape. Also here make sure that you do not put light tight tape on the Permacel tape at the edge of the scintillation plate, this will be removed later on (see figure 8).

In the end on all bald edges of the scintillation plate should be put Permacel tape in such a way, that only the surface that has to be glued is bald.

Figure 6: Measure the dimensions of the second foil

These pieces of tape cannot stretch out along the to be glued edge, but also must not be too low (few tenths of millimeters max). If the Permacel tape stretches out, remove it and try again.

1.7 Light guide

Now the light guide (a fish tail form Perspex plate) has to be wrapped in aluminium foil and pond foil. This happens in exactly the same way as the wrapping of the scintillation plate; only now two edges will be left open; on one side the scintillation plate will be glued, on the other side a second light guide attached to the PMT will be glued.

The Perspex has been made by cutting and routing. All sides of the Perspex have been polished alongside the two edges which have to be glued. Before the Perspex can be wrapped it has to be in an oven for some hours to remove the tensions, which are being created during the routing. Ask if this is done. If it is done, you can start wrapping.

First you have to remove the protecting plastic from the Perspex and clean the Perspex. Also do not rub to firm, because of possible scratching. Sometimes there are remnants of the glue of the protection plastic on the Perspex, remove them with Permacel tape. Now:

- Take a sheet of hard aluminium foil and clean it the usual way

Figure 7: Taping the foils

- Put the Perspex on top of it
- Fold the aluminium around the edges to take the dimensions
- Cut the aluminium foil; it has to be 2 or 3 centimeters shorter then the length of the Perspex; this because of the gluing later on. It should be longer then the other edges, so that it can be folded around them. The folded edge should be cut off a little oblique, else the aluminum foil will advance to the to-be-glued-edges too close.

Now make a second aluminium sheet and make it fit. This second sheet will be put on top of the Perspex and attached to the folded edges of the underlying sheet. To take the dimensions, you can again fold it along the Perspex and clip or cut it along the edges. Clean it and attach it as tight as possible to the underlying sheet. Now tape along along the whole edges a strip of Permacel tape, just like the process used at the scintillation plate. The Permacel tape at the to-be-glued-edges should be removable! Is some tape is not attached in the right way, remove it (pull to yourself and the edge of the Perspex) and try again. If the aluminium foil is tearing, you should replace it.

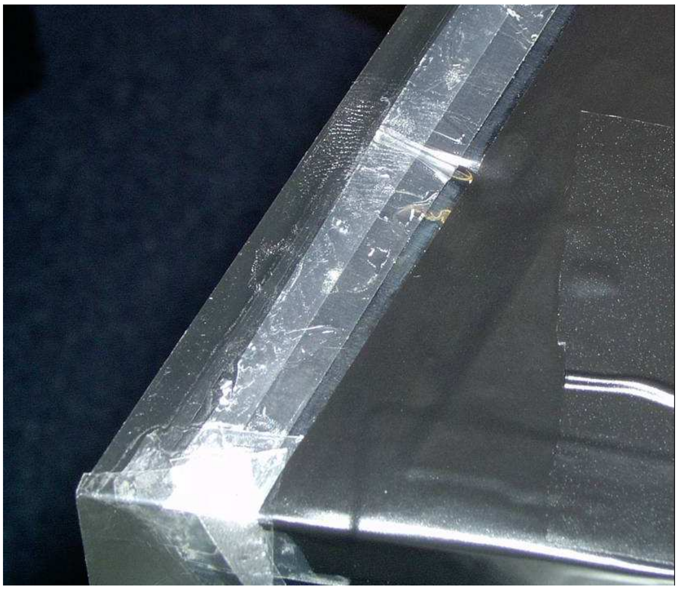

Figure 8: The edge of scintillation plate, aluminium and pond foil

After the layer of aluminium foil a layer of pond foil is wrapped around the Perspex. This is done by:

- Make the pond foil fit. It should be a little less high then the aluminium foil, because of the Permacel tape at the edges that has to stay removable. At the other edges the pond foil should be a little more narrow then the Perspex.
- Attach the foil with Permacel tape to the Perspex.
- Turn it around and make another sheet of pond foil; also make some strips of pond foil that can be put along the edges.
- Now tape with the light tight tape (first let it hang for some time to remove the tension) along the edges. Be aware: the Permacel tape at the to-be-glued-edges should stay removable.

When the light guide is all packed in the two different foils, there has to be put a strip of Permacel tape around the edges, which have to be glued in such a way, that only the to-be-glued surfaces stay bald. After this, the light guide can be polished on the to-be-glued-edges. The light guide has to be flat, a tolerance of 0.02 millimeters is max. If you look under a certain angle in the Perspex, before polishing is, you can see a circular ditch-pattern that was created during the production. After polishing you will only see little

Figure 9: Turn the plate around

stripes along the polishing direction. The polishing has to be done with wet polishing paper. First you polish with 1200 grains paper (use Brasso), after that with 2400 grains paper (use water). The polishing papers can be put on a flat mould.

1.8 Polishing the light guide

When you polish, make sure that the surface you polish and the polishing paper stay wet. Also put always the mould with the polishing paper on it straight on the surface you polish (see figure 10; when the corners are polished roundish, the light guide has to be routed again (and to be unwrapped, put in the oven again and wrapped back). Polish carefully and calmly. Start with the 1200 grains paper. You can feel and hear (from the peeping sound that is caused by polishing) whether the surface is already flat enough.

Figure 10: Polishing

When you think the surface is smooth (after some minutes of polishing), you can clean it with an optical tissue and look if it looks right. If it is; then polish with the 2400 grains paper. If all things worked out well, the surfaces can be made dry and cleaned with methanol.

1.9 Gluing - theory

There are different kinds of glue that can be used. At this moment, for gluing the Perspex on top of the scintillation plate, the glue "EJ 500" is used; it consists of two components which have to be mixed. This glue fills the little stripes created by polishing and creates a transparent connection between the two plates. This glue has to dry for at least 24 hours, it takes even more time for the glue to become fully transparent. To glue the light guide on top of the scintillation plate real careful, there has been made a mould (see figure 11).

The mould is secured to a standard table (78 cm. high) and contains 2 supporting wooden plates, one on which the scintillation plate is leaning (it also stands on the ground) and one on which the Perspex can lean. The Perspex has got a bigger surface then the scintillation plate, so the supporting plate for the Perspex is put a little backwards in such a way that the Perspex will be put nicely on top of the scintillation plate. The space between the two supporting wooden plates is made because then the overflowing glue can leak away.

Figure 11: Mould for gluing

First, create gutters around the to-be-glued surface, so that the overflowing glue that leaks away is collected in here. To do this, fold pieces of paper tape in a V-form and attach them to the scintillation plate (see figure 12).

Place the scintillation plate vertically, exactly along its supporting plate, on the ground. Use clamps to secure the scintillation plate to its supporting plate. They must be attached **very loosely**, there must be no pressure on the plate, otherwise there will be fractures caused by stress in the material in the scintillation plate (also counts for the Perspex). Before using glue, first practise lowering the Perspex plate on top of the scintillation plate. Take the Perspex; hold it high with the right hand and fetch it low, on the left side, with the left hand. Put it vertically along the supporting plate of the mould; your right hand should stick out above the mould. Now lower it easily. With your left hand, make sure that the left corner of the Perspex stretches out max 1 millimeter from the left corner of the scintillation plate (see figures 13). When these two corners catch each other, tilt the plate slowly along its support; in this way the two surfaces reach each other slowly and the glue is spread out uniformly. Do everything carefully, do not damage one of the surfaces.

Figure 12: The V-formed gutters

1.10 The glue

If you have the feeling that you can lower the Perspex real smooth on top of the scintillation plate, you can start to make the glue. The glue we use is “EJ 500” and the two components should be mixed in proportion 4 : 1 (optical cement : hardener).

To make the glue, put a clean beaker (glass) on top of a Libra (see figure 14) and recalibrate it. Wait for the Libra to be stable.

Now we will make 12.5 grams of glue; this should be sufficient to glue two scintillation plates. Pull out of the can of optical cement a certain amount of it with an injection tube (see figure 15). Now let that pour into the beaker until you have got 10 grams. Now easily pour 2.5 grams of the hardener in the beaker. If you are close to the 2.5 grams you can use Perspex stirring bars to put droplets of hardener in the beaker, so that you eventually get 2.5 grams.

When the two components are mixed, stir with the Perspex stirring bar for at least 3 minutes. The glue is transparent, but you still have to mix the two components real accurately. If the glue is not mixed well, and in that condition is used to glue the two plates together, it will not be good. Then the two plates have to be separated again, which means at least a week of full time work to get things right again. When the stirring is done, put the

Figure 13: Lowering the Perspex

glue into a vacuum pump. Now we will use the vacuum pump to remove the bubbles of air from the glue (see figure 16).

When using the vacuum pump (to make it work, first switch the air valve open, turn on the pump, then close the air valve), the glue will be bubbling. After some time, bubbles of air will stay into the glue; now easily let in some air and make the system vacuum again. After doing this three times, the glue should be bubble free.

1.11 Gluing - practical

When the glue is ready, take a new injection tube and fill it with glue. Now clean the surface of the Perspex and the scintillation plate with methanol (see figure 17); be careful, methanol is transferred by the skin.

Wait for a while, until the surfaces are real dry; otherwise bubbles will be created in the glue while gluing and you have to start all over again. Fill the tube with little more then 4 milliliters. Push the air out of the tube (see figure 18).

Now equally spread the glue on the surface of the scintillation plate. Smear it with a plastic card; make sure that the whole surface of the scintillation plate is covered with glue. See figures 19 and 20.

When the scintillation plate was not dry or was filthy, you can see bubbles being created in the glue (see figure 21). This means that you have to clean the surface again and put on new glue. In figure 21 there were little amounts of methanol still on the surface of the scintillation plate. The bubbles appear

Figure 14: Beaker on Libra

right away after smoothing the glue.

When the glue is equally distributed, you can lower the Perspex plate on top of the scintillation plate as practised. If you see that the glue is still nice and smoothly distributed with the Perspex on top, you can fix the Perspex to the mould with clamps (easy, no pressure) and tape (see figure 22). Remove leaking glue with optical tissues and leave the system drying for at least 24 hours before doing anything else with it.

Later on, the second light guides will be put on top of the Perspex plate in the same way as the Perspex was attached to the scintillation plate (after polishing), with the same glue; on top of the second light guide the PMT will be glued; this with the soft glue. Firstly there have to be done some calibration experiments with the PMT, this will be described in chapter 2. After that the connections between the plates have to be made light tight and a detector plate is finished (when checked whether the system is light tight).

2 Signal Processing

In this chapter some aspects with respect to the signal processing of the HiSPARC detectors will be discussed. Firstly the operation of the scintillation material and a PMT is described shortly. The PMT's create pulses with a width of about 5 nanoseconds. With such high-frequently signals, you cannot use ordinary cables, the electronics have to be adjusted for high-frequent signals. This will be described next. The last part will describe the operation system of the oscilloscope and the adjustment of the detector.

Figure 15: Making the glue

2.1 Scintillation

Scintillation is the emission of photons by atoms, which are brought in an excited state. A scintillation plate consists of a material (usually some kind of plastic) which contains a doping with atoms, which emit that kind of photons. If a charged particle passes the scintillation material, it excites electrons. Usually these electrons have energies of about 50 eV, but rarely much higher energies can be seen. Those "free" electrons excite electrons from the scintillation atoms; when those electrons fall back into the ground state, a photon is emitted (blue light in our case). The amount of energy lost by a charged particle when passing through matter, is dependent on the mass and energy of the incoming particle and the kind of matter it is passing. Relativistic muons, pions and protons loose typically about 2 MeV. Because the loss of energy is a statistical process, you measure a distribution of pulse heights for the incoming particles at given energy, this is a Landau-distribution (see figure 23). In figure 23 (which comes from the Particle Data Group at NIKHEF), is displayed what the chance for 500 MeV pions is to loose a certain amount of energy in silicon plates of different thickness. The maximum of the graph is the most probable energy loss per square micrometer; the average energy loss is higher.

In figure 24 (also from the Particle Data Group), the most probable energy loss of a charged particle, which is heavier then an electron is put against the energy of the incoming particle (actually it is against the ratio of the

Figure 16: Using the vacuum pump

momentum and rest mass of the particle 10 on the x-axis corresponds with e.g. a proton of 10 GeV or a muon of roughly 1 GeV).

Averagely the amount of photons that is created in a scintillation material is a good quantity to determine the energy loss that a charged particle experienced in the scintillation material. Particles with low energy (< 5 MeV) will be stopped in the scintillation material and loose all of their energy. High-energetic particles (in our case usually muons from cosmic rays) loose only part of their energy. In air showers we want to measure will be electrons with an average energy of 1.5 MeV and muons, which typically loose an average energy of 4 MeV in the plate. But in the Landau-distribution can be seen, that efrom event to event there can be a wide spread in energy loss.

2.2 Photon Multiplier Tubes (PMT's)

The photons, which are being created in the scintillation plate, will be transferred to the PMT, attached to the light guides. A PMT is being used to make an electronic signal out of a photon. It consists of a tube, which is vacuum; on one side there is a transparent (quartz or glass) window. At the inside of this window is put an anode, on which is put a negative voltage (depending on the tube and the usage of it, it is about -0.5 – -3 kV). The anode contains a material, which is appropriate to arouse the photo-electric effect (Einstein): a photon can free an electron in such a material. The quantum-efficiency of the tube describes how many times that happens as a function of the wavelength of the photon. The freed electron will create a

Figure 17: Cleaning the surfaces

signal, but it is way to weak, so it has to be amplified. That is why the tube contains an amount of dynodes. A dynode is a metal disk with a coating, which easily loose some electrons when an electron with enough energy hits it. Typically, a PMT contains 10 − 14 dynodes. They are placed behind each other, and each dynode is put at a little higher positive voltage. The electron of the anode will be attracted to the field of the first dynode (e.g. +100 V with regard to the anode) and will crash into the first dynode with almost an energy equal to the potential difference between the anode and the first dynode (the photon has an energy of about 2 eV, the binding energy of the electron to the anode material is also in that order of magnitude). This electron frees more electrons from the anode material (e.g. 3 per 100 V). The amount of freed electrons from a dynode is roughly proportional to the kinetic energy of the incoming electron. The freed electrons will hit the next dynode, which has a potential difference of 100 V with respect of the first dynode, and more electrons are created. This will go through until the cathode at the end. In this example, eventually there will be $3^{10} \simeq 59000$ electrons (for 10 dynodes). Would the potential difference put on the tube be twice as big, then the amplification factor will be roughly 6^{10} and the resulting pulse will be a factor 1000 higher. A schematically picture of a

Figure 18: The glue in the tube

PMT is put in figure 25.

2.3 Impedance matching

The PMT creates deposits fast signals. The tubes we use deposit pulses of 5 nanoseconds without scintillation plate attached to it. With the plate it becomes about 20 nanoseconds. When such fast signals are in play, you need special cables and electronics to suppress noise and conserve the form of the pulse. This is done by impedance matching; you take care that the impedance at the entrance of an apparatus that receives a pulse, is equal to the impedance at the exit of an apparatus that delivers the pulse. Impedance is the sam as resistance, but then with AC in stead of DC. At DC $V = I \cdot R$, but at AC besides resistance also capacities and inductions are in play. To preserve your pulse form from the PMT, you have to use RG-58 BNC cables or RG-174 lemo cables. The signals pass through an inner cylinder of copper (see figure 26). Earth is connected to the outer cylinder, which consists of copper wires. Between the inner and outer cylinder there is a dielectric material (of plastic). The capacity and induction of this kind of cable is adjusted for 50 Ω impedance. This impedance depends on the ratio of the diameters of the inner and outer cylinder and on the properties of the dielectric material. Radio and TV also need impedance matching; for the cable of the TV 75 Ω impedance matching is used. If you do not put a 50 Ω impedance lock on the ends of the cable, the signal will reflect in the cable

Figure 19: Glue on scintillation plate

and the signal will transform.

2.4 The oscilloscope

With an oscilloscope you can measure electric signals. An oscilloscope has two channels A and B plus an external one. If connecting a cable to A or B, the voltage will be put on screen as a function of time. You can alter the x– and y–axis. The most important part is the trigger. The trigger is the condition that starts data acquisition; a signal higher then the trigger will be seen as a real signal. Because oscilloscopes usually have memory cards, you can mostly choose which time interval you want to see with regard to the trigger. At the trigger-part of the oscilloscope you can choose on which channel you trigger (A, B or extern), on which level the trigger condition is set; this is called the threshold. Also you can choose whether to work with rising or falling edge (rising means that the signal was smaller and is growing; falling works vice versa). Furthermore you can choose to generate triggers automatically or not. Line or auto means that you do not (always) wait for your trigger condition, but display the signals on the entrance of the channel continuously. Norm is the normal setting, which only displays data if a trigger is given. It is also important that yoy can set the impedance at the entrance of the channels. Put them on 50 Ω, DC.

The Picotech (Picoscope) is a digital oscilloscope card, which can be connected to the PC. It has not the opportunity to set the impedance, so you

Figure 20: Spread the glue with a plastic card

have to put a 50 Ω impedance lock as hardware parallel to your signal (see figure 27). This is done by putting a T-junction between the Picotech and the coaxial cable and putting the 50 Ω impedance lock on the loose end of the T-junction.

In figure 28 you see the screen of the oscilloscope, on which a signal is displayed from a HiSPARC-detector (1 PMT) with 80 meters of cable between detector and oscilloscope.

In figure 29 you see a few events, which are taken by the Picotech; these signals are created by smaller detectors. The threshold is put that low, that the electronically noise band (∼10 mV) is still visible. The most probable energy loss of cosmic muons causes the band at ∼120 mV.

2.5 Calibration of the PMT

Every PMT has its own characteristics: how many power it uses in dark conditions ("dark current"), its amplification factor, its quantum efficiency, its noise level and so on. To quantitatively interpret data from a detector, the characteristics of the PMT should be recorded. Later on we can see how many energy a shower lost in a detector plate and how stable the detector is in time. **It is important to make a journal, in which everything that**

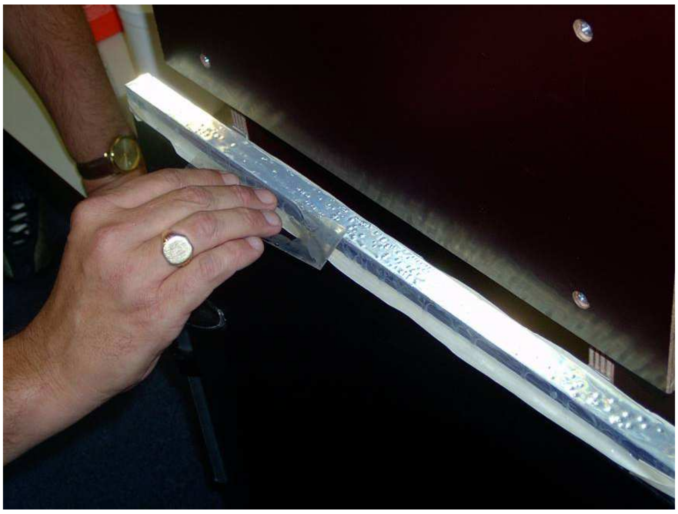

Figure 21: Bubbles during gluing

happens and is being measured is recorded. In a few years you want to repeat all relevant measurements, so you need it.

In the first place you need to record the noise of a PMT when it is packed light tight (no external photons must get the chance to get in), without the detector glued to it yet. There is electronic noise; you can study that with the oscilloscope by putting the trigger condition “line” on it. You have to see a constant baseline in order of magnitude of a few millivolts. If you see the baseline oscillating or see pulses come by, then the PMT is not light tight. If you put a black sheet on top of the PMT and the signal on the oscilloscope does not change, then the PMT is packed light tight (if that does not seem to be the problem, the soldered connections might be wrong).

The next step is to determine the noise of the PMT. This noise is the single-photon noise. The PMT will create a pulse regularly, even when it is packed light tight. This pulse can be created by a cosmic ray, or by electrons, which coincidentally are excited from the anode or one of the early dynodes (by e.g. thermic effects). This noise is a function of the high voltage; you want to know how many events you record as a function of the high voltage and threshold. A real event, caused by a cosmic ray, can occur with a frequency of e.g. 0.1 Hz. Dependent on the threshold you can measure noise with a rate of a few kilohertz. What should be done:

Firstly, make a table for 700, 750, 800, 850n and 900 V potential differ-

Figure 22: Fixing the Perspex plate

ence set on the PMT. Scan the threshold from 1 – 500 mV and measure the amount of coincidences with the electronics. Eventually, what you want to see in a graph, is the flank of the steep peak in which the frequency is varying from 100 – 1 Hz and the area in which the count rate is almost zero. Per threshold you can measure for instance 30 seconds and record the amount of counts in a table. Dependent on a PMT you scan different values for the threshold, you can do for instance 1, 2, 3, 4, 5, 10, 20, 30, 50, 100, 150, 200, 300, 500 and 700 mV. But if the counting rate at 5 mV is above the 100 Hz, you do not have to measure 1 – 4 mV. If the rate is falling from 10 to 1 Hz between 10 and 20 mV, you also have to measure 15 mV. Shortly: you want to see the flank, the plateau and the area where the rate is going to zero. You can see [3], section 3 for an example.

Secondly, if the PMT is working properly, and all of the measurements are

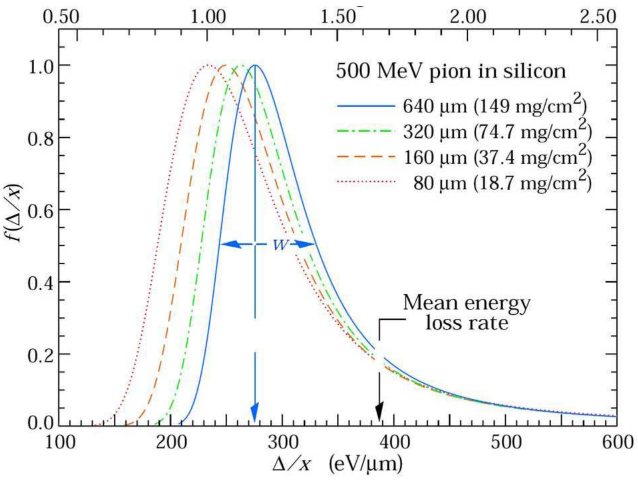

Figure 26.6: Straggling functions in silicon for 500 MeV pions, normalized to unity at the most probable value Δ_p/x. The width w is the full width at half maximum.

Figure 23: Landau-distribution

recorded properly (there should be some log, which describes who did when which measurement, the type and serial number of the PMT and the data), the PMT can be glued on top of the detector. Now you want to repeat the same measurements, but now you will encounter about 200 Hz single rate of cosmic rays that pass through the detector. The noise peak will also be much higher; regularly photons will be emitted by the detector, which have nothing to do with cosmic rays.

Thirdly, you want to measure the Landau-distribution, as described in section 2.1; this also has to be done for 700 – 900 V. For this, you have to make a setup with two extra scintillation plates. This setup is pictured in figure 30.

In figure 30 you see two little detector plates being installed above and beneath the HiSPARC detector plates. You can use the Scintillation Signal Follower (hardware electronics with which you can set threshold, high voltage, etc.) for setting the thresholds in such a way, that you only get triggers when there is a coincidence between the two little detectors caused bu a cosmic muon (almost 100 % of the cases). You have to organize this by checking signals of both the HiSPARC and the little detectors. If the threshold is set, use the Picotech to trigger (externally) on the little detector, and connect the signals from the HiSPARC detectors to the channels A and B of the Picotech.

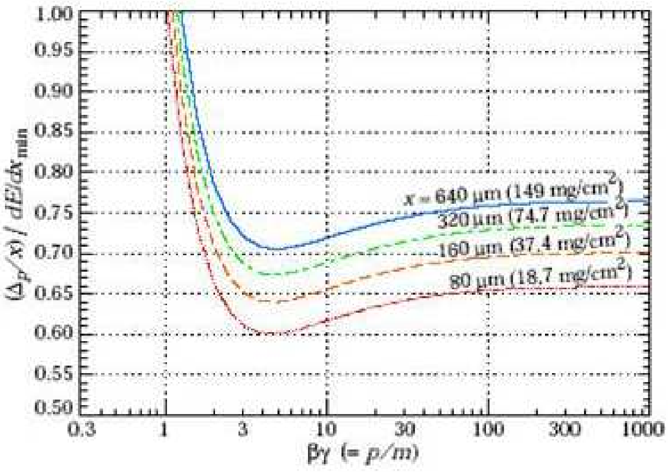

Figure 26.7: Most probable energy loss in silicon, scaled to the mean loss of a minimum ionizing particle, 388 eV/μm (1.66 MeV g^{-1}cm^2).

Figure 24: Energy loss as function of momentum

Now you can measure the Landau-distribution. You measure signals from the HiSPARC detector, with the condition that a muon passed by (because you trigger on the little detector). Download the program “adc.vi” or “kalibratie.vi” to measure the distribution. In these programs you see the individual events and two distributions, which record the difference between maximum and minimum of every event and adds them. After the measurement you can write a file in which are two columns of data. The x-axis describes the central value of the bin in x (= the difference between maximum and minimum of an event in mV) and the y-axis contains the amount of times an event had this difference between max and min. In the end you get a Landau-distribution. An example you can find in section 3 of [3].

2.6 Calibrations - schedules

A schedule is shown for calibration of the detector. Firstly you want to know, whether the detector is light tight. This can be determined the following way:

- Connect the signal cable of the PMT to the oscilloscope
- Put settings of the oscilloscope on “auto” or “line”; scale on minimum

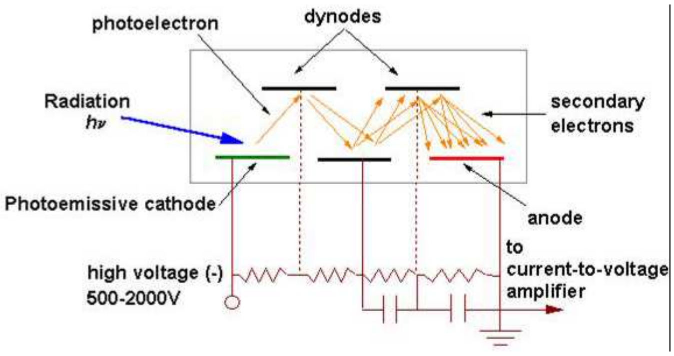

Figure 25: Schematically drawing of a PMT

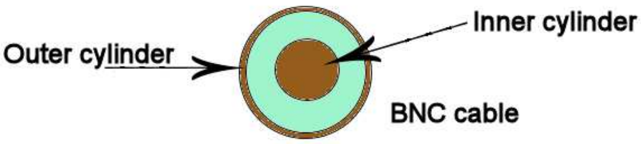

Figure 26: The coaxial cables

(1 or 2 mV)

- Check if the baseline is at zero (when there is a light leak, the PMT uses power continuously)
- Check the noise level of the electronic noise ($<\sim$ 1 mV is good)
- Check whether you see little peaks at the baseline (single-photon peaks); they must not be there.
- Now set the trigger on “norm” and look whether the shape of the pulse is reasonable
- If things are right, you do not see any loose photon peaks before the pulse, but after the pulse there will be some.

If the detector is light tight, you can start expiring the following list:

- Put the two detector plates on top of each other. Trigger on coincidences; now you will see a lot of muons in any case.
- Use “kalibratie.vi” to make a spectrum

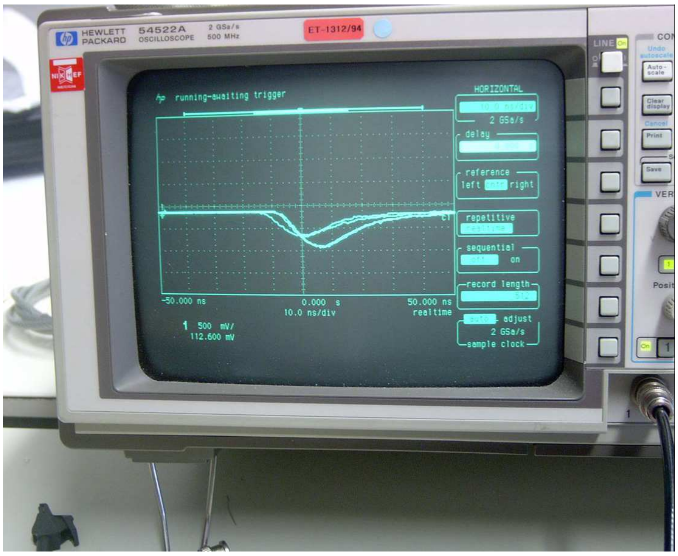

Figure 27: The Picotech with 50 Ω impedance locks

- Now organize the high voltage of the PMT's in such a way that the muon peak (highest of the two) will be somewhere around 200 mV
- Now measure a spectrum with "kalibratie.vi" again and save this one
- Now measure the same spectrum, but now trigger on channel A respectively B in stead of external. The threshold now should be negative, because the shape of the pulse also is.
- Now repeat these steps with high voltages on the PMT's that are respectively 50 V higher and lower (in total you get 9 measurements)

Furthermore you can examine where the two peaks are coming from; you can measure what happens when yo vary the mutual distance between two detector plates. The electronics have also to be calibrated. Next things should be checked:

- What is the width of the pulse at the exit of the monitor. It should be 2 microseconds, no matter the threshold setting.
- Is the threshold setting correct. Check with a pulse generator with pulses of 20, 100 and 300 mV at which threshold setting the electronics still accepts the pulses (or not) (see section 2.6.1)
- What is the amplification factor. You can also measure this with the pulse generator.

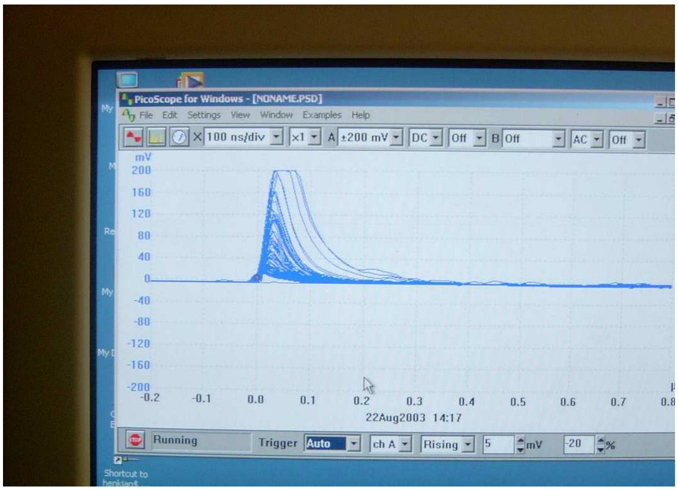

Figure 28: Screen of oscilloscope

2.6.1 The pulse generator

Set the generator in such a way that it generates negative block pulses with widths of 10, 20, 30, 40, 80 and 160 nanoseconds. The pulse heights should vary from ∼40 mV to 1–2, varying in steps of ∼2 (40, 80, 150, 300, 600, 1200 mV). What we want to know is what happens to the height and width of the peak after it is processed by the electronics. So first we have to measure the shape of the pulse with the oscilloscope (the generator can create different pulses on different gates). These pulse shapes should be recorded in the log. Now connect the pulses on channel A and B of the electronics and start the HiSPARC measuring program. Write down, at which second the measurement starts (using the GPS). Measure about 500 events with a rate of ∼5 Hz (otherwise the GPS cannot catch up). Then change channel A and B and measure 500 events again. Write down the starting and ending points of the GPS. Do not close the HiSPARC-program, but only disconnect the cables between the generator and the electronics. Now change the shape of the pulse (using the oscilloscope), describe the shape of the pulse in the log and carry on by connecting the cables again and do all the steps in this section again; this until you measured all the pulse shapes. The data can be worked on later off line.

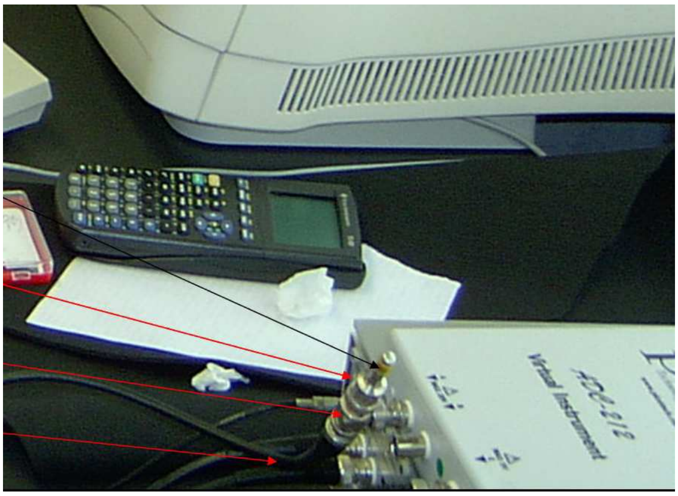

Figure 29: Screen of the Picotech

3 References

1. Signaalverwerking – H.J. Bulten (NIKHEF, Amsterdam)
2. Bouw detector – H.J. Bulten (NIKHEF, Amsterdam)
3. HiSPARC in general – C.T. Herbschleb (Kamerlingh Onnes Laboratory, Leiden)

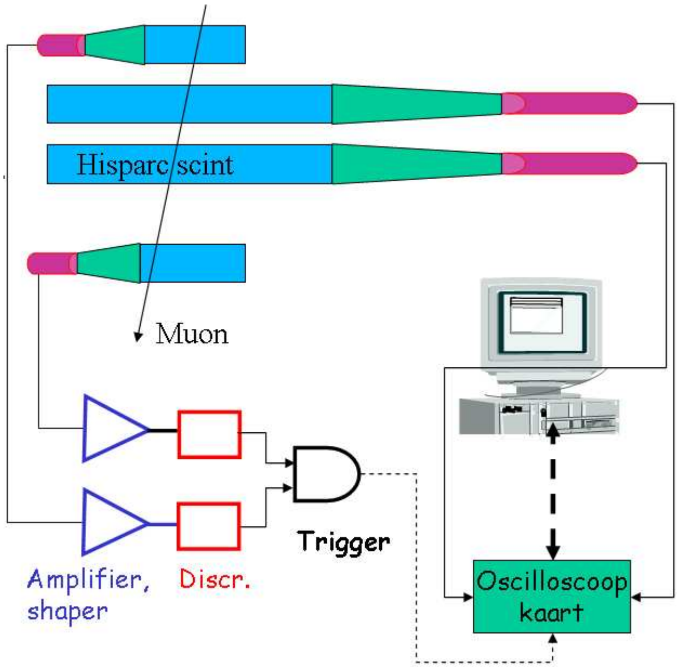

Figure 30: The setup for measuring the Landau distribution