Computing muons trajectories through the acoustic spark chamber

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Abstract

This report first describes the spark chamber developed here at the McGill's physics department as a mean to detect cosmic charged particles striking the earth's surface and explains how it can be used to compute the trajectory of a particle passing through the spark chamber using the sound wave produced by the sparks, thus leading direct information about the incoming particle rate's angular dependence. Then, the data acquisition system developed to compute the trajectories is described in details.

1 Introduction

When cosmic rays protons strike the earth's upper atmosphere, a lot of pions are produced which decay in highly energetic neutrinos and muons. The muons mean lifetime is about 2.2 μs which, on a relativistic point of view, is long enough to allow them to reach the earth's surface. Because the muons are charged particles, they do, contrary to the neutrinos, interact easily with matter and are therefore detectable.

The spark chamber of McGill physics department was built[1] in the optic of detecting these muons. The general idea is that when a muon passes through a gas such as helium or neon, it ionises a lot of atoms along it's trajectory. Applying a big electric field between separated plates immediately after the passage of the particle in a box full of helium, the ionised electrons acquire enough energy to ionise other atoms. The newly free electrons ionise other atoms and so on. This avalanche effect produces sparks between each plate along the particle's trajectory. Thus the track of ionisation left by the particle in the gas can be observed directly.

Now, the physical quantity that can be extracted from such an apparatus is the angular dependence of the flux of incident muons. To do so, one must design an acquisition system that computes the trajectory for each incident particle. This can be done directly by taking digital pictures of the sparks, but it requires a lot of computer memory and processing time. A more suitable way is to locate the position of two distant sparks. This gives enough information to trace the path because the incident muon's energy is so high compared to the helium's ionising energy that the muon experiences little scattering so the muon travels in a straight line through the chamber. This report explains the method used to locate the a spark using the sound wave it produced.

Section 2 describes the spark chamber used. Section 3 deals with the acoustic method for locating a spark. Section 4 explains the data acquisition system developed to compute sparks location. Section 5 shows how to use the system. Section **??** shows how the trajectories can be retrieved using the data acquired by the system. In section 7, the possibility of adding more transducers is addresses and we explain how it can be done. 10.1contains the

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[1] See Pascale Sevigny, Anne-Elizabeth Granier and Thierry Guizouarn work reports for details about the construction and the parameterisation of the spark chamber.

hardware data sheet.

Useful and detail information is contains in the logbook. If any part remains unclear, please feel free to contact me.

2 The spark chamber

This section describes how the spark chamber works. Technical aspects of the hardware is presented in section 10.1. Section 5.1 explains how to get the spark chamber working.

2.1 General principle

Figure 1 shows the spark chamber and it's associated electronics. When a muon passes through the plexiglass box which is full of helium, it ionises atoms along its trajectory. A triggering system (explained in the section below) then applies a high electric potential difference between each of the 15 pairs of metal plates. A strong electric field is created between the plates, with a typical value of 10 keV/cm. At this time, the ionised electrons accelerate and ionise other helium atoms, generating an avalanche effect. This amplifying process causes sparks to be formed along the particle's trajectory. One can then see the muon's trajectory. Neat! Helium is used because of it's high ionisation energy, making sure that the ions in the gas come from the interaction with an high energetic particle. In addition, a clearing field can be applied to wash away tracks produced by older events.

2.2 The triggering electronics

Because it is a very bad idea to apply a constant electric field between the plates and wait for muons to come, it is essential to use a triggering system (see figure 1) which generates the field for a short time only after a muon passes through the chamber. When a muon passes through scintillator A, he interacts with the atom of the plastic and a bunch of photons are produced. The photons are then guided through the photomultiplier A which produces a largely amplified electric signals. This is an analog signal that has to be converted into a digital signal using a discriminator. The discriminator output is a logic NIM pulse with adjustable width each time the voltage of

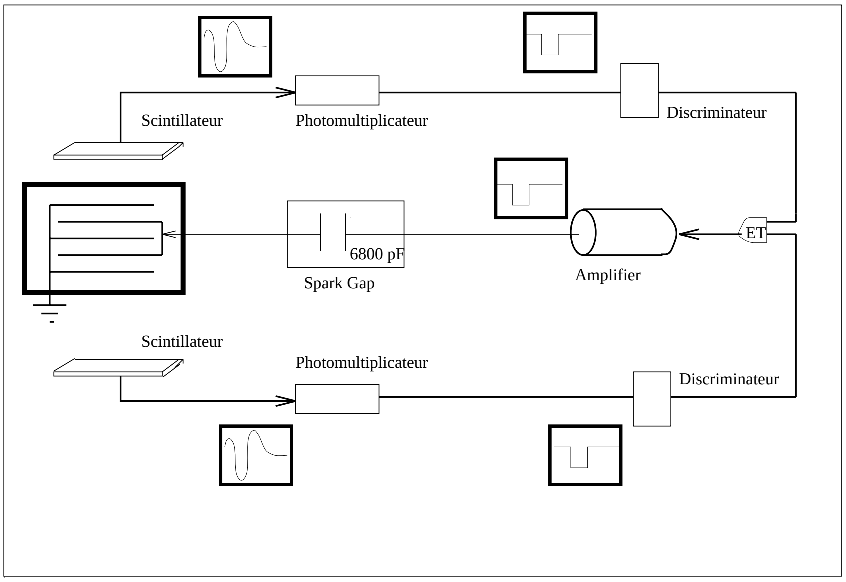

Figure 1: Spark chamber and associated electronics

it's input signal crosses an adjustable threshold voltage. The two sets of scintillator, photomultiplicator and discriminator form detectors A and B. The two outputs of the discriminators are fed to a logic NIM AND gate. If a muon passes only in one of the detectors, the output of the AND gate will be held in the logic state 0. If however a muon passes through both detectors, two logic pulse are produced almost instantly, the time elapsed corresponds to the time it took the muon to go from detector A to B and the output of the AND gate will be a logic pulse 1 identifying that the muon went through the chamber. This triggering pulse is then amplified by a spark gap amplifier to a value of about 6 keV. The amplified pulse then triggers the spark gap which switches the desired tension to the plates.

An important point is that the logic unit can respond very fast to the passage of muons with a response time in the nanoseconds while the spark gap amplifier and the spark gap are slower with a response time in the order of the milliseconds due to big RC constant. This means that the triggering system cannot detect all the muons passing through the chamber if the rate is lower then say one muon per 10 milliseconds.

2.3 The electromagnetic pick-up?

Figure 2 shows the electromotive force and it's Fourier transform induced in a loop antenna 5 cm in radius located at 10 feet from the spark chamber when the spark chamber is triggered and sparks are produced. The pick amplitude depends on the antenna's geometry and distance. We can see that the em pickup is quite important: a peak voltage of almost 1 volt at 10 feet! The main harmonic of the pickup is found to be always around 70 MHz and must be a signature of the desexcitation of the helium gaz causing the spark. The pickup represents a big source of noise which can disturb and damage unprotected electronics.

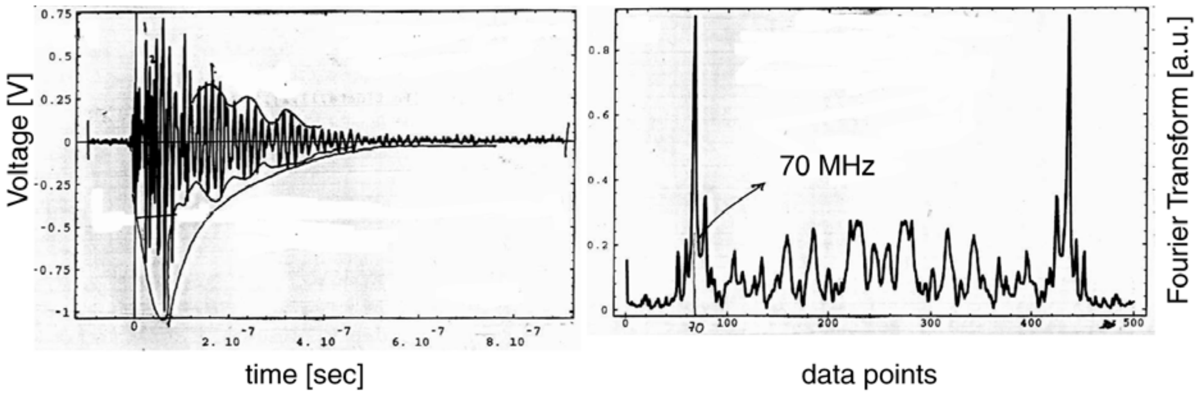

Figure 2: Pickup

3 Measuring muons trajectories: an acoustic method

By itself, the spark chamber can only be used as a display device for looking at muons. In order to make quantitative measurements about rate of incoming muons and their angular distribution, it is necessary to design an acquisition system that keeps track of the trajectories for each muon passing through the spark chamber. This can be done in several ways.

3.1 The photographic method

The obvious one is to take three digital pictures (one for the xy projection of the trajectory, one for the xz and the other for the zy) for each events. After the acquisition, we have enough information to retrieve all trajectories. This method has the advantage of being easily implemented but has the disadvantages of being expensive and of requiring a lot of computer memory and processing time.

3.2 Trajectories are straight lines

Because the energy of an incident muon is very high compared to the ionising energy of the helium atoms (10^8 greater!), the muon experiences little scattering and it's trajectory can be considered as a straight line in the chamber. This reduces the information to be processed and stored because only two points in space are needed to keep track of a straight line! A more suitable method for computing the trajectories is then to locate the position of two distant sparks along the muon's trajectory and store it on disk each time a muon passes through the chamber.

3.3 How can a spark be located?

A spark is the source of an electromagnetic wave as well as a sound wave. Knowing the speed of propagation of any of them, the spark can be located by knowing the time it takes for the wave to travel from the source to a bunch of suitable detectors. Because the em waves travel near the speed of light, the working frequency of the electronics needed to compute the time intervals would have to be in the GHz for light detectors located at 1 meter from the source!

The sound waves work fine however. The typical speed of sound in helium is about 300 m/s. For a detector located at a 0.5 meter (a typical dimension from the spark chamber used), the time interval to be computed by the electronics is 1.6 msec. Using a counting frequency of 1 MHz gives a resolution of 1microsecs.

3.4 The acoustic method

Lets first define the co-ordinate system. Referring to figure 3, we set the origin to be one inside corner of the plexiglass box. The x, y and z axis are then parallel to the edges of the box.The xy plane is parallel with the metal plates and the z axis corresponds to the height.

Now, for each muon passing through the chamber, the location of two separate sparks has to be measured in order to recover the trajectory. We choose the sparks occurring in the first and last gap between the first two plates and the last two plates) at height z_1 and z_2.

This reduce the problem to two dimensions. To locate the x and y co-ordinates of sparks i, a set of at least three sound detectors in the xy plane at height z_i is needed. If the helium in the box is homogeneous, it means that the speed of sound in helium is a constant. It is then easily seen that only three probes are required to single out a unique solution for the spark position. Otherwise, more probes have to be used to reduce the set of solution to an area as small as possible.

When the spark i is produced, the time intervals Δt_i taken for the sound wave to reach each detectors of the corresponding set have to be computed. Let v be speed of sound in helium, the distance of the spark to detector i is then $v\Delta t_i$. For the probe, this distance represents the radius of a position circle along which the spark can be. The position of the spark is then the intersection of the three circle. In practice, we won't get a single solution but rather a set of solution in the area common to the three circle. That is the essence of the acoustic method we used.

In section **??**, we will describe the acquisition system that compute, for each muon passing through the spark chamber, the time intervals Δt_i using piezzo-electrics transducers and proper electronics, a data acquisition card and a computer.

In section **??**, we will describe the program used to recover the trajectory.

4 The acquisition system

4.1 Specification

The whole system is base on an acquisition card installed on a computer. This card, called **labtender** from **Scientific Solution**, contains an ana-

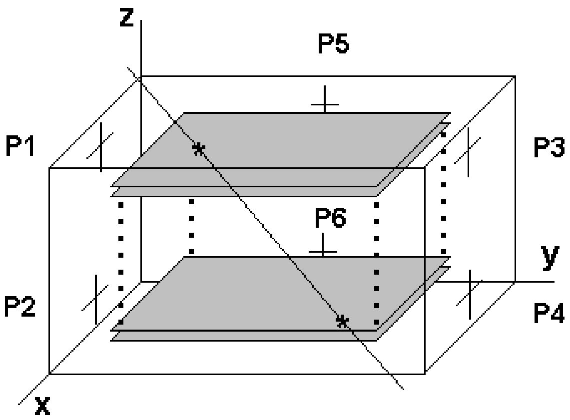

Figure 3: Location of the 5 piezzos

log to digital converter, a digital to analog converter, a parallel port and a $AM9513$, a timing and counting devices working with a frequency up to 1 MHz. The $AM9513$ contains 5 16 bits counters. All the modules are fully programmable. The important point here is that each counters of the $AM9513$ can be programmed to count at a selected frequency only when a TTL signal at its input is set **high**. We call this signal a gate. This is what is needed to measure the time intervals.

The idea is then to design a TTL interface that sends to each counter a gate signal that is set high when the spark is produced and set low when the sound wave reaches the corresponding detector.

Because the $AM9513$ contains only 5 counters, we use only 5 sound detectors (we will address the question of adding more detectors in7). We use piezzo-electric transducers as sound probes. These detectors basically transform a mechanical vibration into an analog electric signal. The transducers respond to sound in the 4 to 8 KHz range. For a spark produced in our chamber, the output voltage is in the order of mV so each piezzo signal has to be amplified before sending it through a coaxial cable. We defines the amplified piezzo-electric transducers output signals as P_1, P_2, P_3, P_4 and P_5.

We also need a signal to know when the sparks are produced. We could use the coincidence signal which trigs the spark chamber but the problem is that the signal is produced by a NIM module and it's definition of logical 0 and 1 is not the same as the TTL family. The high level for NIM is between -1 and -0.8 volt and the low level is 0 volts where the high level for TTL is everything higher then 1.5 and smaller then 5 volts and the low level is anything below 0.7 volt and greater then 0 volt. So the NIM signal as to be treated as an analog signal to be converted into a TTL signal. The pulse of the coincidence at the output of the NIM AND gate is about 50 ns. Because the response time of the analogue to TTL converter designed is about 300 ns, the coincidence pulse width has to be lengthened to at least 500 μs. We will call this lengthened coincidence signal T_0.

The inputs signals of the TTL interface are therefore the T_0 pulse wich tells when a muon has triggered the spark chamber and the 5 amplified transducers signals P_1 to P_5 which tell when the sound waves has reached the probes. All the 6 signals are analog and have to be converted in TTL signals.

We must also take care of the electromagnetic pickup. First, all inputs of the labtender and the TTL interface must be protected against over voltage and current spike. All used labtender's TTL inputs must be clamped between 0 and 5 volts. All the analog inputs of the TTL interface must be clamp between -15 and $+15$ volts. Secondly, because the P_1 to P_5 signals tell the TTL interface when to close the gates, an appropriate delay after the arrival of T_0 must be applied before setting high each gate signal. Otherwise, the electromagnetic pickup in the cables of the P_1 to P_5 signals could tell the TTL interface to close the gates! To minimise the effect of the pickup, all lead longer then 6 inches as to be coaxial (RG 58). The TTL interface has to be in an enclosed metal box and be located as far as possible from the sparks. Because the signals sent to the labtender can only be sent via twisted pairs flat cable, we make use of differential line drivers and receivers which basically subtracts the noise and the pickup induced in the flat cable.

We also need a signal that tells when the computer can read the values computed by the counters and rearms them for another event. This can be done by sending to the parallel port of the labtender, a TTL signal which is set LOW by the TTL interface when the chamber is triggered and set HIGH after an appropriate delay telling the computer that all counters are ready to be read. This delay has to be long enough to allow the sound wave to reach any transducer and short enough to allow the computer to read and rearm the counters before the next muon passes through the chamber. We will call this signal the READ signal.

In the case that no spark is produced, the TTL interface must close the gate signals. Otherwise, the counters will continue counting indefinitely. This is done by gating each TTL converted piezzo signals with the READ signal.

4.2 The amplified sound probes

The 5 piezzo-electric transducers are located at position $P_1[7''^{1/16}, 0, 1'0''^{3/4}]$, $P_2[7''^{1/16}, 0, 1''^{3/4}]$, $P_3[7''^{1/16}, 2'8''^{1/2}, 1'0''^{3/4}]$, $P_4[7''^{1/16}, 2'8''^{1/2}, 1''^{3/4}]$, $P_5[0, 1'4''^{1/4}, 1'0''^{3/4}]$ in the spark chamber (crosses on figure 3). This setting allows the system to locate the two sparks occurring in the second gap from the top and the second gap from the bottom. For each transducer, there is a shielded amplification module on the exterior side of the box. The transducer output leads connecetd to the amplifier module are made as short as possible to minimise the em pickup . Figure shows the electronics of the amplifier module. It is made of an high pass RC filter and an operational amplifier LF411. The gain can be adjusted from 1 to 100 via the trim resistance. The formula for the gain is $G = 1 + \frac{R_2}{R_1}$. All modules are powered from the acquisition box +15 and -15 volts outputs via coaxial cables[2]. We use bypass capacitors between the supply pins of the operational amplifier and the ground. Because capacitor's impedance gets smaller and smaller with increasing frequency, any ac signal induced in the power line by the sparks and other noise sources is led to the ground instead of going in the amplifier. It's a necessary protection to prevent damage of the chip. The output of the five modules are the P_1 to P_5 signals.

4.3 The T_0 signal

To make the coincidence pulse larger, we feed the output of the NIM AND gate in the input of a voltage attenuator set to 50%. The output of the attenuator is then fed into the input of a LECROY discriminator like the one used for the photomultipliers with a threshold voltage set to -0.5 volt. The output pulse width is then set to it's maximum value of $1\mu s$. The complemented output of the discriminator is the T_0 signal needed. Figure 5 shows the coincidence pulse after a muon has triggered the spark chamber and the corresponding T_0 signal.

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[2] Never apply an input signal if the operational amplifier is not powered.

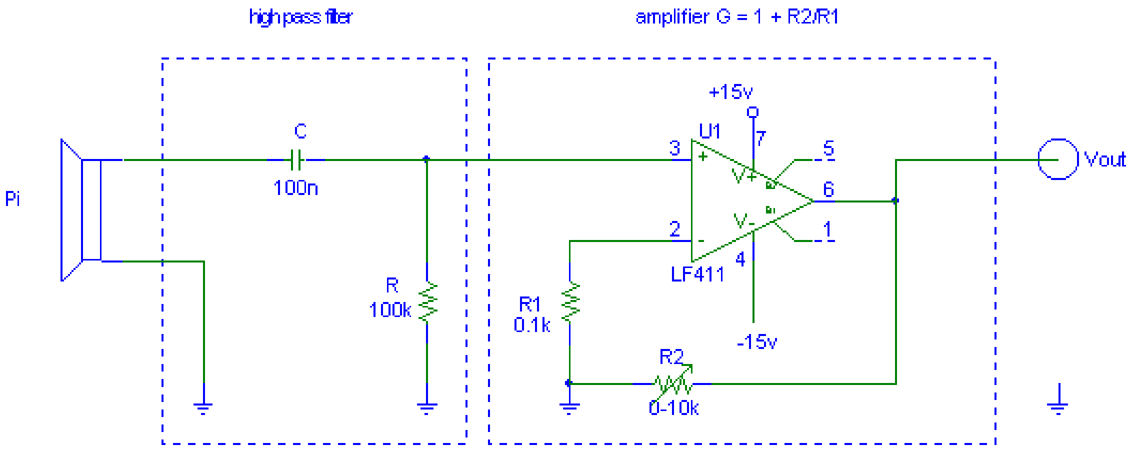

Figure 4: Piezzo amplifier circuit

4.4 The TTL interface

Figure 6 presents the functional diagram of the TTL interface. The inputs are the T_0, P_1, P_2, P_3, P_4 and P_5 signals. The electronics is protected from the pickup induced in the inputs coaxial cables using a protection module. Each input is then converted into a TTL signal with an analog to digital module. The TTL converted T0 signal then sets LOW the output of two delay modules, the first one is used to open the gates and the second one is used to generate the READ signal. The output of the first delay module remains LOW during a time intervals that last longer the em pickup after which the output goes HIGH again.

The transition from LOW to HIGH of the first delay‘s output sets HIGH all gates outputs thus bypassing the unwanted closure of the gates by the em pickup.Thesecond delay’soutputremainsLOWforatimeintervallongenoughtoallowallsonicpulsetobede
again. The output of the second delay thus generate the READ signal. The TTL converted Pi signals is OR gated with the READ signal. The output of the gate is used to close the corresponding gate. This allows the system to close all gates if no sound waves were detected by the probes. The READ and all 5 gates’output are then fed to 6 differential line drivers. The 12 outputs of these drivers are sent to a receiving card plugged in the pc bus next to the

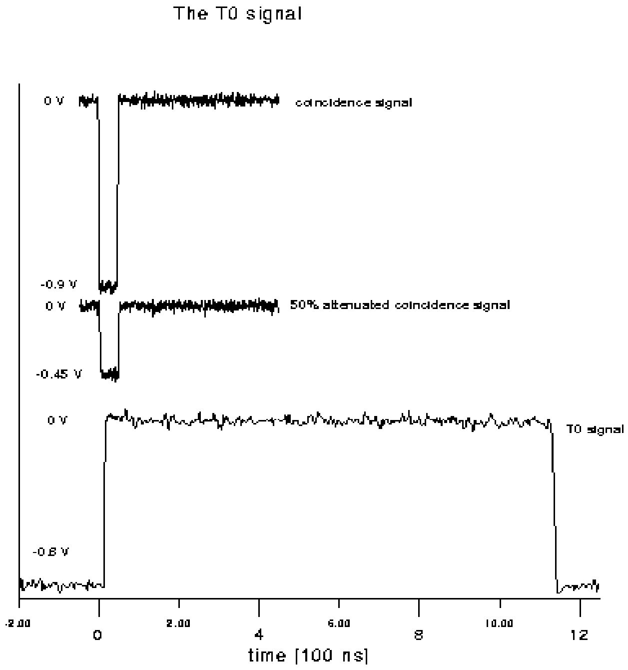

Figure 5: T_0 signals

labtender via a 34 lead twisted pair flat cable. The receiving card contains a protection module and a 6 differential line receivers. The 6 outputs of the receivers are then connected to the labtender's inputs (READ signal to the parallel port A bit 0, and the gates signals to the AM9513's gate inputs) using a flat cable made as short as possible. Figure 8 shows the signals. The hardware used for each modules is describes in the following sections.

4.4.1 Inputs protection circuit

We use a SP720 from HARRIS Semiconductors as a protection circuit for inputs TO through P5. It is an integrated circuits which clamps its 14 inputs between V+ and V-. We set V+ = 15 volts and V- = -15 volts. Figure 7 shows the connections.

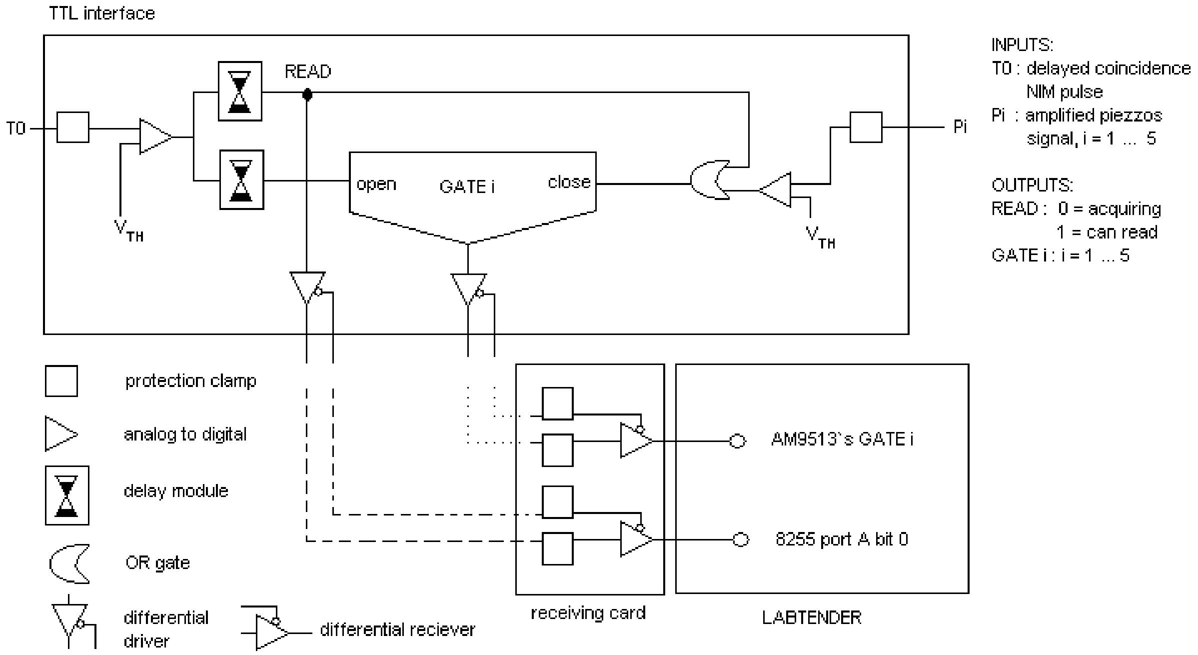

Figure 6: TTL interface

4.4.2 Analog to TTL modules for signal T_0

We use a LM311 comparator from MOTOROLA with one input being the T_0 signal and the other being a threshold voltage. The threshold voltage is produced by a unity gain follower with it's input being a voltage divider which can be varied from -10 volts to 0 volt via a trim resistance of 20 KOhm. The unity gain follower is made with an operational amplifier LM411 or MC1741. The output of the comparator is fully TTL compatible via the pull-up resistor. The module works as follow. When T_0 is lower then the threshold voltage, the output is kept HIGH. When the voltage is higher then the threshold, the output is pull low. This is why we need to use the complemented output of the discriminator. The time needed for the comparator to switch from HIGH to LOW is about 300 ns and that is why the input pulse has to be greater then 500 ns. The output of the comparator is then fed to the input of a TTL inverter 74LS04 to get a clean TTL signal

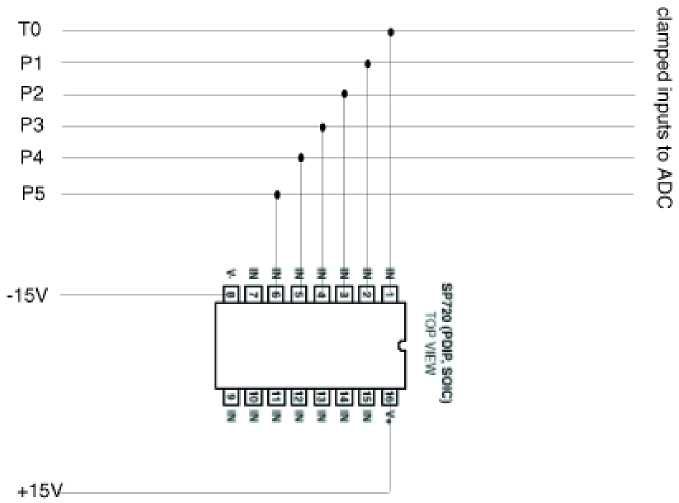

Figure 7: SP720

with positive logic (HIGH meaning TRUE and LOW meaning FALSE). The figure 8 shows the circuit.

4.4.3 Analog to TTL modules for signals P_1 to P_5

We use again LM311 comparator but with negative feedback. This configuration is called a Schmitt trigger and allows to put hysterisis which prevents from transition due to noise. We refers to page ??? of Horowitz for the explanation of the circuit. We use the same threshold voltage for each of the Schmitt trigger. The threshold voltage is (like the preceeding section) produced by a unity gain follower with a voltage divider which can be varied between 0 to 5 volts via a trim resistance of 10 KOhm. The output of each comparator is fed to the input of a TTL inverter 74LS04 inverter to buffer the signal and make it logical positive. Figure 9 shows the circuit.

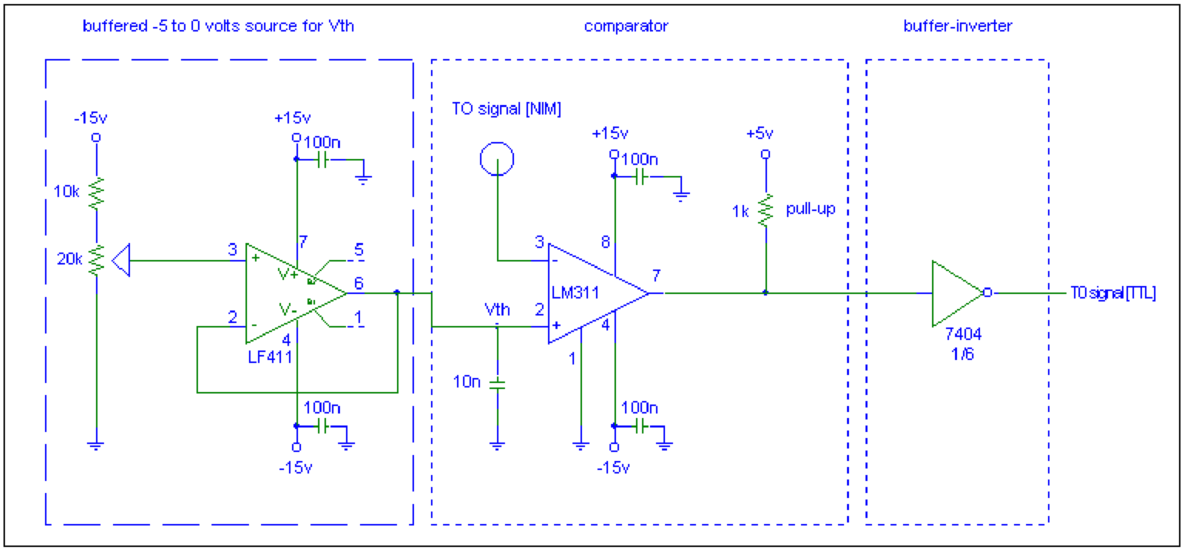

Figure 8: NIM to TTL

4.4.4 Delay units

We use the timing chip MC1455 in monostable mode for each delay module. Figure 10 shows the circuit. The circuit works as follow. We invert ,using a 74LS00, the output of the analog to TTL module and use it as the trigger input of the MC1455. When the trigger inputs falls below 1/3 of Vcc (Vcc = 5 volts), the output is set HIGH for a time of $1.1 * RC$ and then is reset to LOW. The output cannot be retriggered until the present timing period has been completed. The trigger pulse must be less than the timing period. We refer to the application sheet of the devices given in annexe for more details. Note that the reset inputs is not used and must be set HIGH. It is important to use a bypass capacitor to prevent bad reset from the pickup in the power line.

The timing period is therefore programmable by changing value of R and C. For the first delay, $R = 10 \pm 1\%\ \Omega$ and $C = 0.002\ \mu F$ The corresponding time period is 24.1 μs (see fig??). The output of the fist delay units is defined as ΔT For the second delay, $R = 49.9 + / - 1\%\ \Omega$ and $C = 0.1\ \mu F$ for a time period of 4.76 ms. The READ signal is obtained by inverting the output of the second module using the same 74LS00.

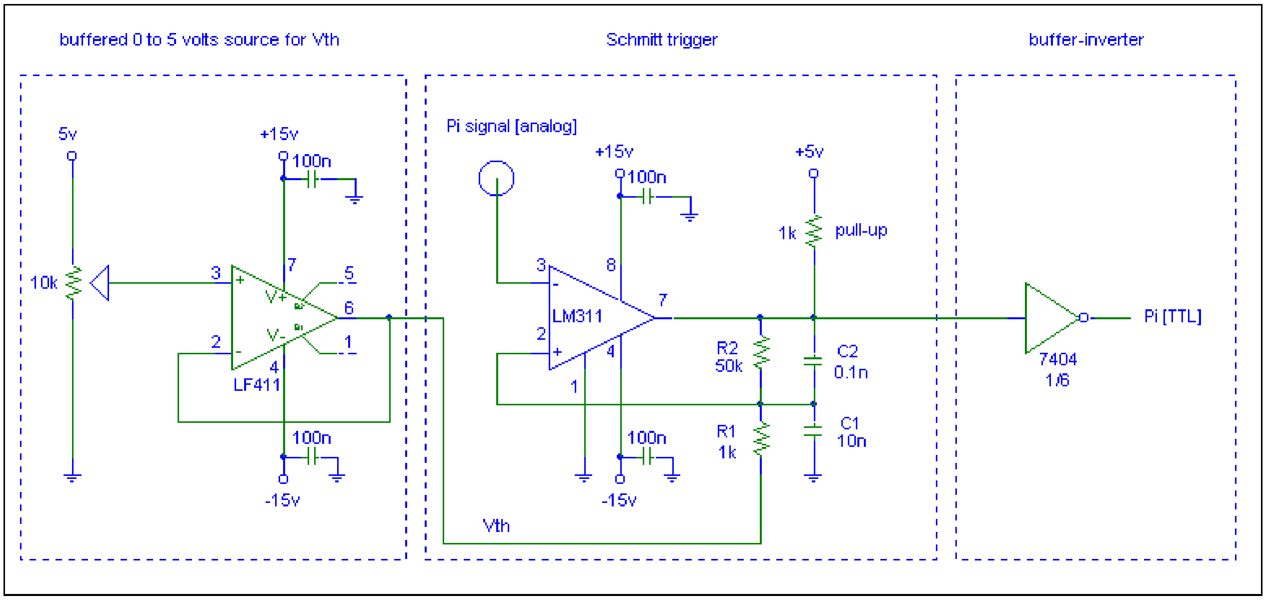

Figure 9: Piezzo TTL

4.4.5 Gates

We use the 74LS74 as a gate generator. It's an IC with two D positive edge triggered flip-flops. Figure 11 shows the circuit for one gate generator. We first invert the first delay signal ΔT (output of the first MC1455) using one NOR gate of the 74LS02. The output of this gate is fed to the clock input of one flip-flop The output Q of this flip-flop is set HIGH when its clock input goes from LOW to HIGH, i.e. after the first delay has elapsed. The output is reset to low when it's reset input is set LOW, i.e. when the analogue to TTL output of the corresponding piezzos is set to HIGH or when the READ signal is set to HIGH. This is to ensure that the gate is close after the second delay if no soundwave have been detected. We define the output Q of the flipflop i as the GATE_i signal.

4.4.6 Differential drivers

The five gate signals and the read signal have to be sent to the labtender via a twisted pair flat cable. To reduce the pickup and the noise in the cable, we sent those signals differentially using the differential line drivers

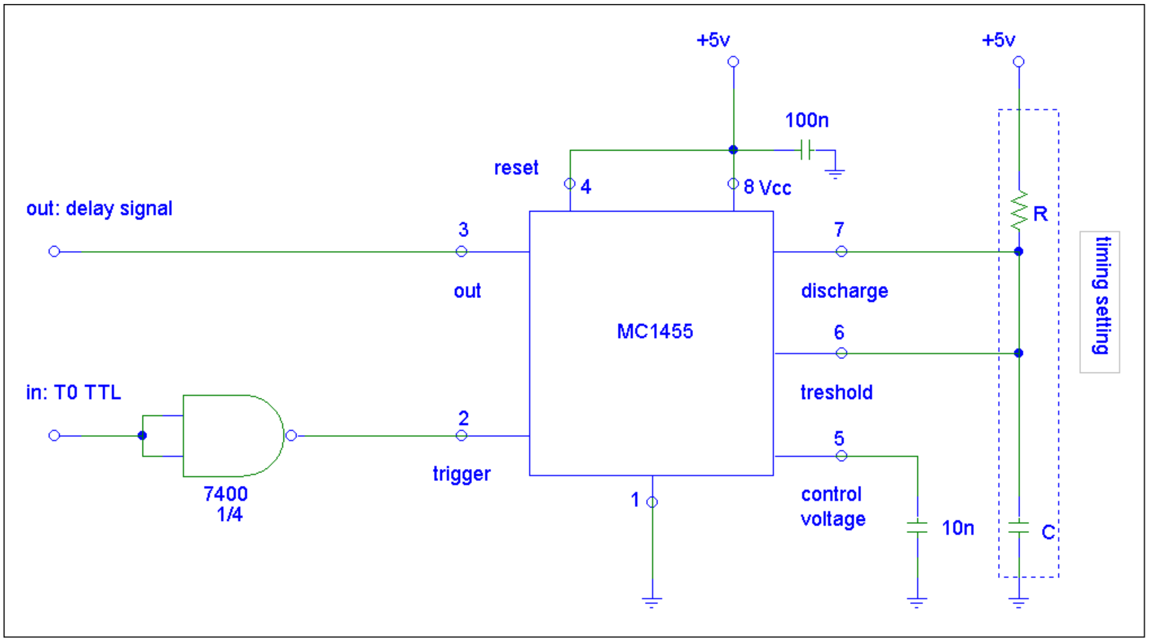

Figure 10: Delay

MC75174BDW. The idea is that for each logic signal A to be sent, the driver sends in one of the lead of the pair A and in the other it's complement $\overline{A}$. At the receiving end, a differential receiver substracts $\overline{A}$ from A. The resulting output is signal A without the noise and the pickup induced in the cable. Figure 12 shows the driving circuit. The resistance of 120 Ohm is used to match the driver's output impedance with the twisted pair impedance to avoid reflection and the enable input is set high ($En = 1$).

4.4.7 Power supply

We use an AC to DC converter with a regulated +15 volt, a -15 volt and a + 5 volt outputs capable of sourcing up to 1 A. The AC input is protected with a slow glow 1A fuse. Each output is fine adjustable via a trim resistor. A connector as been installed to allow easy connection with the TTL interface.

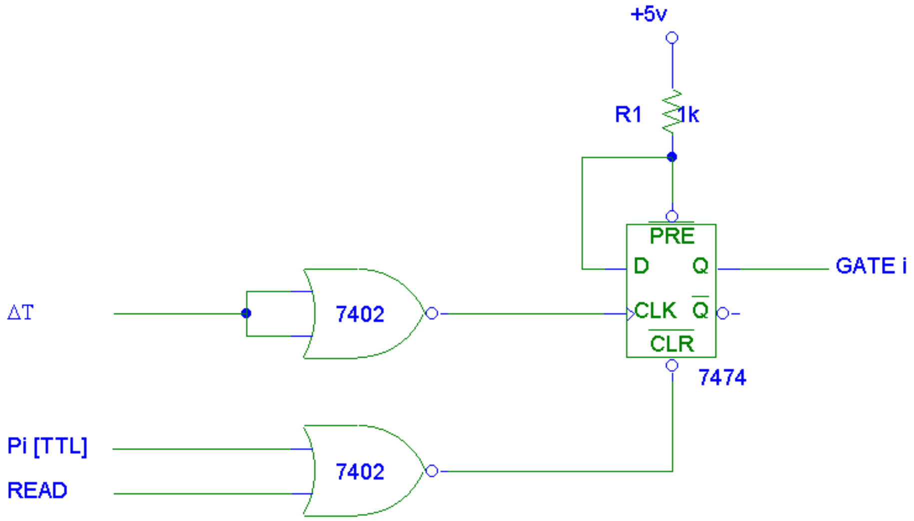

Figure 11: Gate

4.4.8 The acquisition box

The TTL interface was built on a wire-wraping card with ground plane and power leads. All IC's, resistor and capacitor (except some by-pass capacitor) are mounted on wire-wrapping pins to allow easy replacement. The connections have been made using wire-wrapping insulated leads and a wire-wrapping tool. All the connections has been logged in the logbook and every supply pins has a bypass capacitor.

Figure 13 shows the physical aspect of the card with corresponding modules and power line. The input of the card are connected via connector C1. Pin 1 is for T_0, pin 2 to 6 are for P_1 to P_5. The output are accessible via connector C2. Pin 2, 4, 6, 8 and 10 are the gates 1 to 5 output. Pin 33, 31,29, 27, 25 are the complemented output of gate 1 to 5. Pin 12 is the READ output and pin 23 is the READ complemented output.

The power leads are connected to the power supply connector via connector C3. The blue lead is for the -15 volts, the yellow one is for +15 volt and the orange one is for the +5V.

The card and the power supply is mounted in an metal enclosed box that fits on a 17 inches rack.

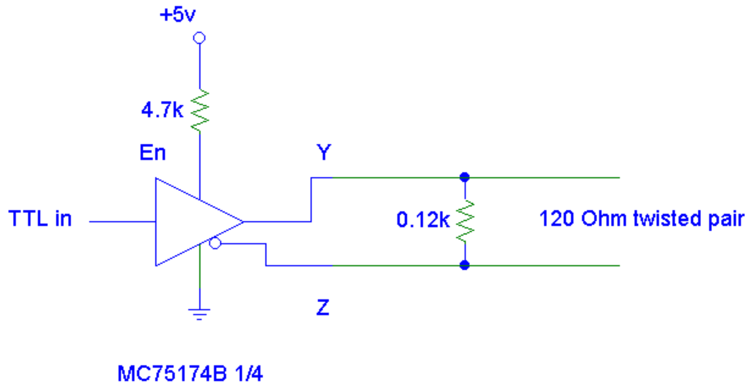

Figure 12: Driver

The front panel has 6 input BNC connectors for receiving the T_0 to P_5 signals and 2 output BNC connectors as +15 and -15 volts output BNC connectors directly connected to the power supply. These outputs are used to power the 5 amplifier modules installed one the spark chamber.

The front panel input connectors are connected to C1 using 6 coax cables with one end soldered to the BNC connector solder cup and the other to a 10 pins flat cable female connector which fit in C1.

All ground leads are connected to the same location in the box to prevent ground loops and ground current flowing from device to device.

4.5 The differential receivers and connection to the labtender

Another card installed in the pc is used to receive the differential signals send by the acquisition box. The card contains two SN75175 quad differential line receivers from MOTOROLA and a SP720 circuit protection. The IC's are powered using the +5 volt power lead of the motherboard bus. The input are connected to C4 and the output are accessible via C5. We then connect the gate output of C5 (pin to the gates input of the AM9513 of the labtender AM9513 gates inputs(connector P5, pin 1 to 5). The READ output of C5 is connected to the bit 0 of port A of the parallel port of the labtender(connector

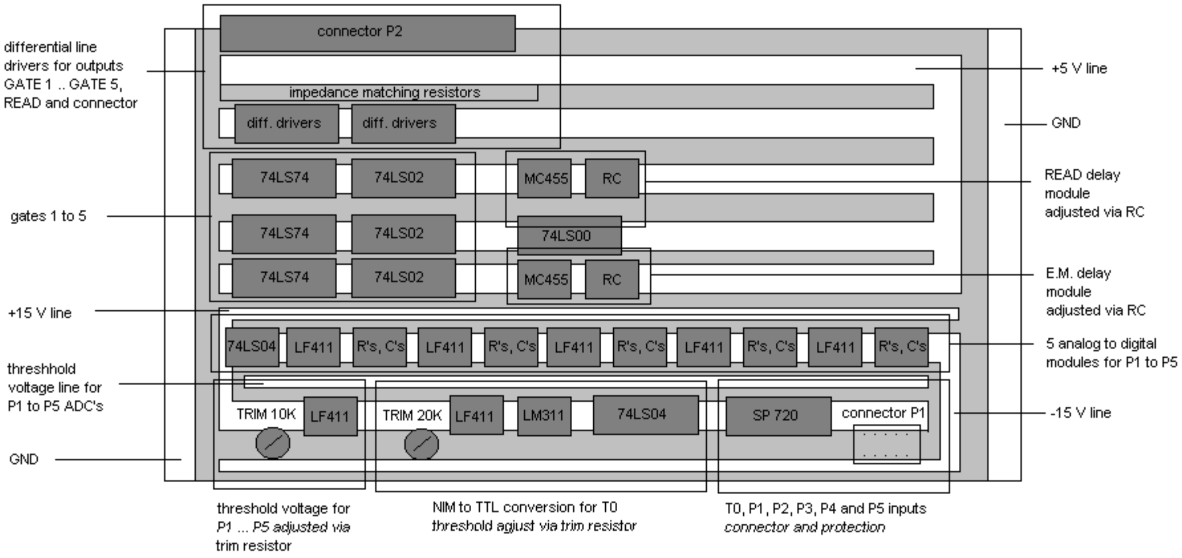

Figure 13: TTL card

P4, pin 17).

4.6 Connecting things together

The amplifer module are alimented using the + and - 15 volt output on the front panel of the acquisition box mounted on a rack located 15 feet aways using two 25 feet RG-58 coax cables.

The inputs signals T_0 to P_5 produced by the discriminator and the 5 amplifiers are sent to the acquisition box input using 20 feet RG-58 cable connected to the front panel input connectors T0, P1, P2, P3, P4 and P5.

The pc is installed on the rack where sits the acquisition box. Connector C2 of the TTL interface is connected to connector C4 of the receiving card with a 34 connections twisted pair flat cable made as short as possible.

4.7 Programming the labtender

The labtender is fully programmable via the pc bus. We refer to the labtender user's manual for the way the card can be programmed. Page ? of the logbook summarises the key programming points. In refacquire.c presents the acquisition program used.

5 The acoustic spark chamber at work

We explain in this section how to set the spark chamber to get spark tracks of muons and how to adjust the parameters of the acquisition box and program. We also present a trace of all the significant signals from the photomultiplier signals to the gates signals send to the labtender. This is some importance for trouble shooting of the system.

5.1 Setting the spark chamber

This section explains how to set the spark chamber to get sparks tracks of muon trajectories.

5.1.1 Purge of the chamber

The first thing to do is to take the air out of the chamber and fill it with helium. This is done by applying an important flow of helium for about an hour. The procedure is the following. Open the helium bottle and set the output pressure to 15-20 psi. Adjust the helium flow so you can feel with your hand the gas going out from the evacuation hole located on the left bottom side of the chamber. Purge for about 30 minutes and reduce the flow so that the ball of the indicator rest at the 80 graduation.

5.1.2 Triggering

We first look at each photomultiplier output signal with respect to its alimentation voltage. We first set the alimentation voltage to it's minimum value of 1 kV. The idea then is to get a signal well above the background noise by increasing the voltage. The voltage has not to be so high because the minimum threshold voltage of the discriminator is -30 mV. We found 1.8 kV to be an appropriate voltage. Fig 14 shows a corresponding output pulse observed at a digital scope. It is important to realise that the amplitude of the pulse depends not only on the applied voltage but on how many photons strike the phototube. This number depends on the muon energy, the incident angle of penetration, the attenuation of the plastic and so on. The important point is that the tension has to be high enough so that all signals of different amplitude are well above the noise. The discriminator will be set so that only high energy muons are filtered out.

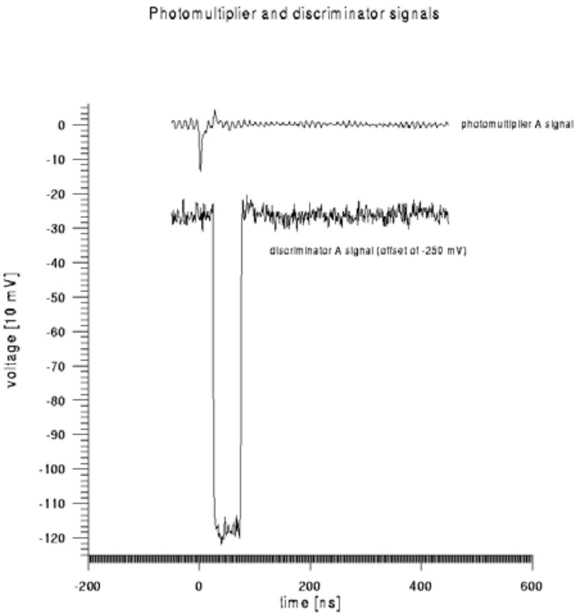

Figure 14: Photomultiplier discriminator

The integral intensity of muons with vertical incidence with energy above 1 GeV is about 1 cm-2min-1 for horizontal detectors(ref? in cosmic rays). The area of the plastic scintillator is about 60 cm x 20 cm. This give a rate of incident muon of 72 000 muons per second! Clearly, the discriminator threshold voltage as to be high enough to detect muons with higher energy to reduce this rate. For a tension of 1.8 kV applied at each photomultiplier, a threshold voltage of -50 mV was used. This give a rate of about 2 or 3 pulse per second at the output of both discriminator. The output pulse width are set to 50 ns. Figure 16 shows the input and output of one discriminator We observe a delay of ? between the input and output. Note: the threshold voltage can be measure directly by measuring the voltage between the white pin near the input connector and ground.

We set the output pulse of the AND gate to 50 ns. With this setting, the rate of coincidence is about 1 to 2 pulse/s.

We then set the alimentation voltage of the spark gap driver amplifier to 200 volts and the amplification voltage to 6.3 kV. The distance between the electrodes of the driver can be varied but we use the setting given in the logbook. The response time of the driver being about 1 sec, no more than one coincidence pulse per second can trigger the spark chamber.

At this point, we make sure that all the electronics including the piezzo amplifiers, the acquisition box and the computer are all under tension. Otherwise, a triggering of the spark chamber may damage all the electronics inputs!

We then set the voltage to be delivered by the spark gap to the plates when triggered. We set it to about 12 kV. [3]

We then look at the sparks in the chamber and adjust the helium flow to a minimal value. Table ? summarises the setting used.

5.1.3 Adjusting the parameters of the acquisition box

The gain of the amplifiers The amplified sound wave signal outputted by the amplifier must be in the volt range to ensure proper operation of the analogue to TTL converter. With the spark chamber working, we simply look at each piezzos signals outputted at the end of their 20 feet coax cable. A gain of 50 is found to do just good for each piezzos.To adjust the gain, we simply choose the value needed for R2 from formula ? and then turn the

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[3] the power supply used is adjust via a trim resistor and the output voltage can be monitored via pin 3 and 6 of the white connector. The voltage reading as to be multiplied by a factor of 3000 to get the actual output voltage.

trim's screw until an ohmmeter reads the appropriate value between pin 2 and 6 of the operational amplifier. [4]

Figure 15 shows the amplified piezzos signal after the triggering of the spark chamber.

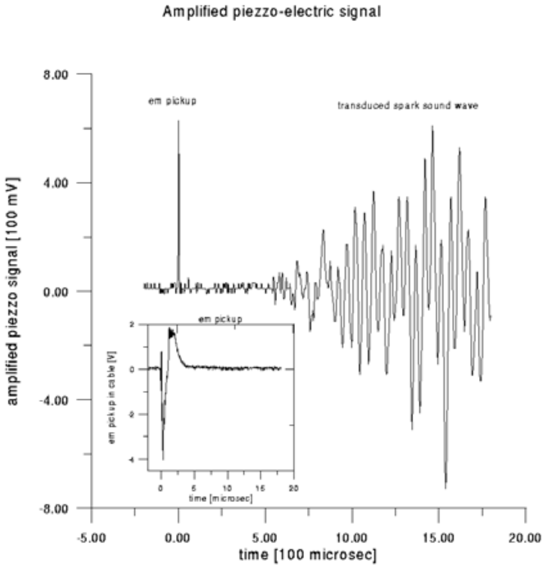

Figure 15: Piezzo signal

The threshold voltage of the T0 analog to TTL module Figure 16 shows the lengthened coincidence pulse at the end of its 20 feet coax cable. This is the input of the T_0 analog to TTL converter. A threshold voltage of -0.6 volt has to be set. To adjust the threshold, turn the 20 k\$omega$ resistor on the TTL interface card and look at the voltage with respect to ground at pin 2 of the LF311 comparator of the module until the voltmeter reads the proper value.

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[4] Turn off the all voltage source before adjusting the gain.

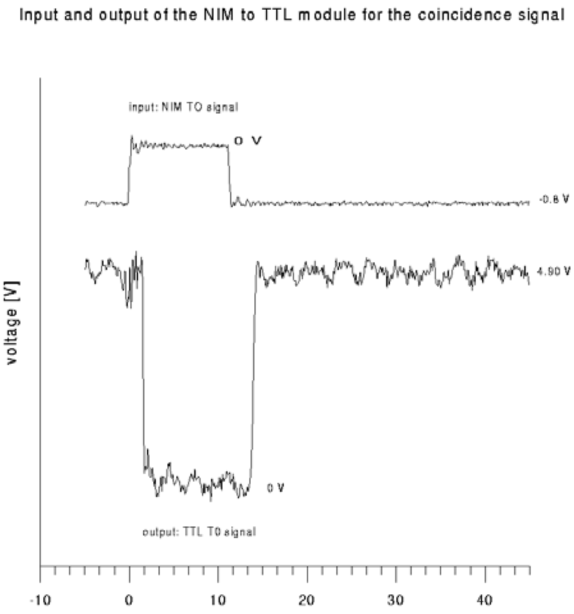

Figure 16: NIM to TTL signal

To test the module, input a coincidence pulse. Trace the voltage at pin 1 of the SP720 protection circuit or pin 3 of the LF311 comparator. This is the protected analog input of the module. You will notice that it is deformed compared to the pulse outputted by the discriminator. This is because of the impedance mismatch between the coax cable and the input. But it doesn't matter as long as the signal is longer then 500 ns and crosses the threshold voltage. Then, look at the output of the module which is pin 12 of the 74LS04 inverter. If the threshold is properly adjust and the length of the input signal is greater then 500 ns, you should observe a neat TTL output with little delay with respect to it's input. It may happen that the comparator fall into an oscillation mode (the LF311 has the tendency of doing that). If this happens, turn off and on the power supply making sure that no signals is inputted while the system is off.

The threshold voltage of the P1 to P5 signals The threshold voltage for the 5 Schmidt triggers is adjustable via the 10 k\$Omega$trim resistor located in the threshold voltage source module. To value of the threshold can be read using a voltmeter with one lead at ground and the other touching the threshold voltage line on the board. This line is located between the +15 and -15 power line. A threshold as low as possible must be use in order to minimise the error on the arrival of the sonic pulse. For a gain of 50\QCOM{00030}{ for the amplifier, we use a value of 0.2 volt for the threshold.

To test the 5 analog to TTL module, a trace of the incident piezzos signal vs output signal must be obtained with a digital scope. To measure the input signal of P_i, scope the signal at pin $i + 1$ on the SP720 protection ic. All output signals can be traced using the output pins of the 74LS04 inverter located at the very left of the 5 comparators. Pin 2 is for the TTL converted signal of P_1, Pin 4 for P_2, Pin 6 for P_3, pin 8 for P_4 and pin 10 for P_5.

The delay module's RC constant The time constant for each module is $1.1RC$ where R is the resistance of the resistor on the wirewrapping dip located at the right of the MC1455 timing IC and C the capacity of the capacitor that sits next to the resistor. The two are easily replaced if you need two.

The electromagnetic pickup dies out in about 5 \$mu$s. We therefore set the first delay to be about 25 \$mu$s. Choosing R = 10 K\$Omega$ and C = 0.02 \$mu$F, this sets the expected value of de delay to be 1.1*RC=22 \$mu$s.

For the second delay, we choose R = 49.9 k$Omega andC=0.1$muF. This sets the time constant to about 5 ms.

To measure exactly each delay, we sent a coincidence pulse and look at the signal on pin 3 of each MC1455 (the output of the timing device) and measure with the scope the time the output is set HIGH. We have measure the first delay to be 24.1 \$mu$s and the second one to be 4.76 m. See figure 17.

Update of the acquisition program It is important to set the acquisition program variables ? and ? with the delays'RC time constant measured with the scope.

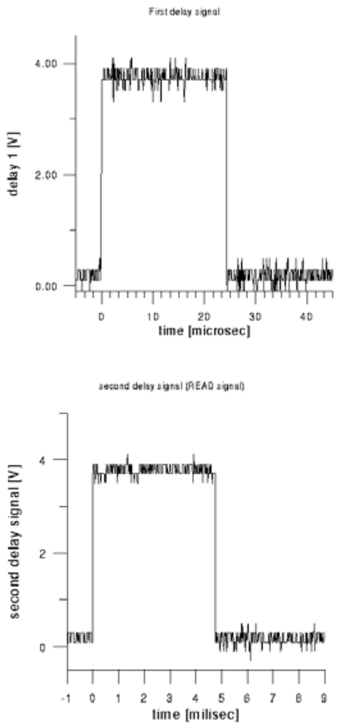

Figure 17: Delay signals

5.2 Looking at the input to output signals

This section is intended to prove that the acquisition box works properly and is useful for debugging in case something doesn't work.

We use the parameters given in the last section and trace the signals from the photomultipliers to the inputs of the labtender.

Figures 14,5 and 16show the photomultipliers signals to the T0 TTL converted signals after a muon passed through the chamber. We can see the effect of the em pickup. We also notice a delay of ?.

Figure 16 shows the T0 signals and the NIM to TTL output. T0 is measure at pin 1 of the SP720 and the TTL output is measured at pin 12 of the 74LS00 inverter of the module.

First three traces of figure 18 shows the T0 signals, the P1 signals measured at pin 2 of the SP720, the analog to TTL output of P1 measured at pin 2 of the 74LS00 of the analogue to TTL modules.

Figure **??** shows the T_0 signals and the two delays output signals measured at pin 3 of both MC1455

Figure 18 show the T_0 signals, P_1 signals, the CLK input of the first flip-flop (pin 3 of the top row 74LS74), it's reset input which is the TTL P1 signals OR gated with the READ signal (pin 1 of the same 74LS74), it's output Q (pin 5, which is gate 1 signals), the two output of the corresponding line driver (pin 2 and 3 of the MC75172 on the right) and the output to the labtender (pin 3 of the first line receiver SN75175 on the pc receiving card). The logbook contains all pin locations for inputs and outputs of each IC's in case you want to monitor signals for P2 to P5.

In the last figure we see that the time elapsed between the emission of the spark and the receiving of the sound wave at piezzo 1 is ?. Adding the 24.1 \$mu$s to the time gate 1 is high gives the same value. The time computed by the labtender counter was ?? too!

6 Recovering the trajectories

6.1 First run of acquisition

6.2 The data file

6.3 Measuring the speed of sound in helium

6.4 Locating the two sparks

7 Adding more transducers and multiplexing

The system has been designed to use 5 probes but it is possible to use more probes using a multiplexing technique. Suppose we want to add 5 probes and still use the same system. The idea is to let the system think that all 5 subsequent probes signals come from a second event by shifting probe i+5 's signal by \$dela$t in time and adding it to probe iˆ{\prime}s signal. Mathematically, make Pi(t) = Pi(t) + Pi+5(t - \$delat$t) with \$delat$t greater than the duration of the sonic pulse. To make thing simple, this operation should be done in an analog way but I have not find a way of delaying an analog signal. It can also be done digitally using 2 analog to TTL converters, delay module and voltage adder.

8 Conclusion

9 Acknowledgement

10 Appendices

10.1 hardware data sheet

10.2 acquisition program aqcuire.c

Typical signal traces of the acquisition electronics