Deutsches Elektronen Synhchroton

Forschung mit Lepton Collidern Time Projection Chamber

Summer Student Program
2007

Report of my work at DESY

REPORT

by

Georgios I.Laskaris

Supervisor: Klaus Dehmelt
Post Doctorate Researcher

Hamburg,September 2007

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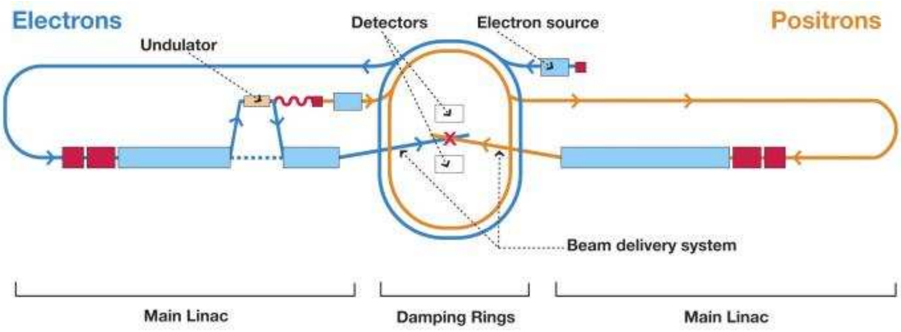

Figure 1: A schematic layout of the International Linear Collider. This diagram reflects the recommendations of the Reference Design Report, a report published in February 2007 that provides the first detailed technical snapshot of the machine. (Credit ILC Global Design Effort)

1 International Linear Collider ILC

The International Linear Collider (ILC) is a planned electron-positron linear collider, which will operate at energies from 91 GeV up to about 500 GeV range (with the possibility to upgrade to 1 TeV). This machine will allow us to explore a new frontier of high energies in electron-positron collisions, complementary to what is planned at the LHC at CERN. The main physics motivation of this machine is the detailed investigation of the mechanism, by which the electroweak symmetry breaking is realised in nature. The as yet undiscovered HIGGS particle, the TOP quark and the electroweak gauge bosons and their interactions play a central role in this. The detector and the physics at the ILC machines are studied by an international workshop chartered by ECFA to study the physics potential of a 500-1000 GeV linear accelerator. More generally understandable information on the ILC machine, physics and detector can be found at the DESY public relation web pages.

Currently, this project is in its planning phase and much development work is being done all over the world. Besides the work on the accelerator, this work includes research and development for four different detector concepts, which are in their planning status. These four concepts will later on be amalgamated to two remaining ones. The FLC group at DESY is involved in the R&D work for the Large Detector Concept (LDC).

The LDC detector concept includes a Time Projection Chamber (TPC) as the main particle tracker. The TPC allows a three-dimensional reconstruction of tra-

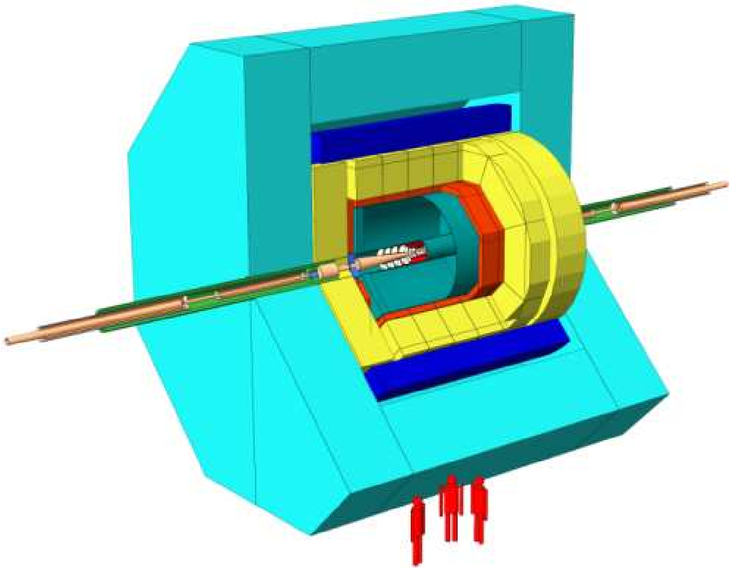

Figure 2: A schematic view of the Large Detector Concept (the TPC is the dark-turquoise cylinder inside the red electromagnetic calorimeter).

jectories of charged particles in a high track density environment. Our subgroup (FLC-TPC) is involved in various topics of the R&D being done for the LDC-TPC. This includes testing and studies of gas amplification structures with Gas Electron Multipliers (GEM), the construction of prototypes for the TPC field cage, the development of reconstruction and analysis software as well as the construction and testing of the read-out electronics.

1.1 Time Projection Chamber

The Time Projection Chamber has been introduced in 1976 by D.R. Nygren. It consists of a gas filled sensitive volume, usually with a central cathode that divides the volume into two identical halves. Each side has an anode with a readout system. The cathode is at a potential that results in a field strength of some 100 V/cm while the anode is at ground potential (typically, this leads to a potential of some 10 kV at the cathode. In 4-detectors (detectors that cover nearly the whole solid angle) at high energy experiments, the drift volume is usually cylindrical and the beam pipe goes through the rotation axis of the TPC with the interaction point being at the center.

1.1.1 Measurement Principle

A charged particle traversing the gas volume of the TPC will ionize the atoms of the gas mixture (usually around 90% noble gas and 10% quencher) along its trajectory, see point 1 in Figure. A high electric field is applied between the endplates of the chamber. The released electrons drift in this field towards the anode, see point 2 in Figure. To be able to measure the position of the particle trajectory as accurately as possible, the electric field has to be very homogenous. This can be achieved by a field cage, which usually consists of conducting rings around the cylinder. These rings divide the potential from the cathode stepwise down to the anode. Additionally, a high magnetic field parallel to the electric field is used to "bend" the trajectory of the particle on a spiral track due to the Lorentz force. This gives the possibility to calculate the momentum of the particle from the knowledge of the curvature and the B-field.

At the anode plane, the electrons can be detected on the readout plane which is segmented in the directions perpendicular to the drift direction, see point 3 in Figure. As the electron signal from the primary ionization process is only of the order of 100 electrons per centimeter, the signal needs to be amplified before being detectable. Traditionally this has been done within high electric field in vicinity of thin wires.

The $r\phi$ position (coordinates perpendicular to the cylinder axis) of the trajectory can be reconstructed directly from the coordinates of its projection on the pad plane. The z position (coordinate along the cylinder axis) is reconstructed from the drift time (time between particle passing the TPC volume and measured signal on the pads). Therefore an external timing information, e.g. from a silicon detector, is needed.

1.2 Gas Electron Multipliers (GEMs)

As mentioned before, up to now proportional wires have been used in TPCs as standard device for gas amplification. In this technique, tense parallel wires are mounted in front of the pad plane. These wires are on a pontential, such that the arriving electrons are accelerated in their field, gaining an energy to the magnitude where ionization happens.

The produced ions drift back into the TPC volume and induce a (very broad) signal on the pad plane behind the wires. So the signal is measured at the wires and (to improve the resolution) also at a pad plane. Since ions in the TPC volume should be avoided, a second layer of wires (which is called the gate) is necessary. When the gate is open the gating wires are at the same potential as the field in this region. In this state, drifting electrons (and ions) pass this grid without disturbance. To close the grid (which is the normal state) and collect the ions, the potential of neighbouring wires is set alternating to 50-100 V. At this setting, the drifting ions and electrons are collected on the wires.

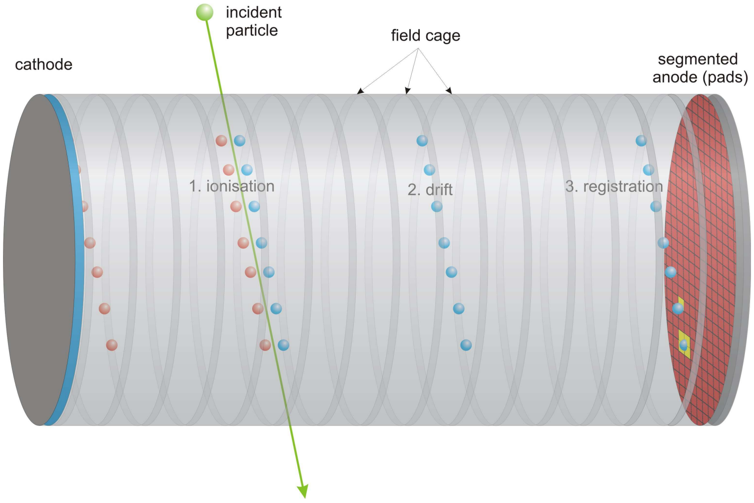

Figure 3: Working principle of a TPC.

Some drawbacks of this technique have led to the development of new amplification structures, the so-called micro-pattern gas detectors (MPGDs). Two different technologies of micro-pattern devices are under investigation for their use in a TPC at the ILC: the Micro Mesh Gaseous Detectors (MICROMEGAS) and Gas Electron Multipliers (GEMs). We at the FLC-TPC group work with the GEM technology.

1.2.1 Disadvantages of Proportional Wires

With proportional wires, the signal is very broad and the distance between two wires is mechanically limited. This makes it difficult to separate two nearby tracks and set limits to the possible r and time resolution. A second disadvantage is the high material budget of the support structures that hold the wires. To provide a perfectly parallel alignment the wires have to be mounted under very high tension. This demands for a very solid mounting system with a high material budget. Third, the gating is problematic in experiments with a high event rate, where the time between two events is too short for the gating and measurement cycle. If the events do overlap, which means the drift needs longer than the time between two events, gating becomes impossible.

In the case of the ILC all these three problems are realized. A good two-track separation and precise time resolution is needed to achieve the physics goal of the project. To be able to make a very precise energy measurement in the calorimeter, the material budget is very limited. Furthermore, the collision rate is so high that the gating with a grid would not work anymore. Therefore a new amplification technique is needed, that will be described in the next section.

1.2.2 Gas Electron Multipliers

The GEM technology, which has been introduced by F. Sauli in 1996 and is in use in high energy and medical physics, provides the possibility to avoid the problems mentioned in the previous section. GEMs consist of a thin Kapton foil (about 50 m) which is coated on both sides with copper layers (about 5 m). This structure is perforated with holes that typically have a diameter of 70 m and a pitch of 140 m. The holes are arranged in a hexagonal pattern. Due to an etching production process they have a double conical shape with an inner diameter of about 55 m. Figure 4a shows a picture of a GEM that has been taken with an electron microscope.

The working principle of the GEMs is shown in Figure 4b. Between the two copper coatings a voltage of a few 100 V is applied. Since the field lines are focused in the holes, there the resulting electric field strength is in the order of some 10 kV/cm which is high enough for the gas amplification. It is possible to achieve an amplification up to ten thousand, but usually a setup consists of two or three successive GEMs which are operated at a lower voltage and therefore run more stable.

Most electric field lines end on the side towards the cathode while on the other side most lines go into the direction of the anode. The ions from the gas amplification are pulled to and collected on the GEM surface while most of the electrons are extracted out of the GEM holes. The electron extraction is intensified if additionally a magnetic field is applied perpendicular to the GEM plane. The electrons tend to follow the magnetic field lines. The intrinsic ion back-drift suppression is one of the main advantages of the GEMs and makes a gating grid unnecessary.

Another advantage of the GEM amplification is the fast signal: the electron signal is measured directly on the pad plane, which leads to a better time (respectively Z) resolution. Furthermore, the GEMs do require less mounting structures as proportional wires do.

The GEM signal on the pad plane is narrower than in the case of proportional wires. This is an advantage in the two-track separation, but poses new problems in the r resolution. The pads have to be smaller, so that a narrow signal still hits enough pads for a good reconstruction in the r plane (see the Pad Responce Correction page). However, the number of pads is limited by the feasible number of readout channels and the signal height (smaller pads result in a smaller signal per pad), so a compromise has to be found.

Overall GEMs are a very promising technique for the gas amplification in a TPC and many of their advantages already have been proven.

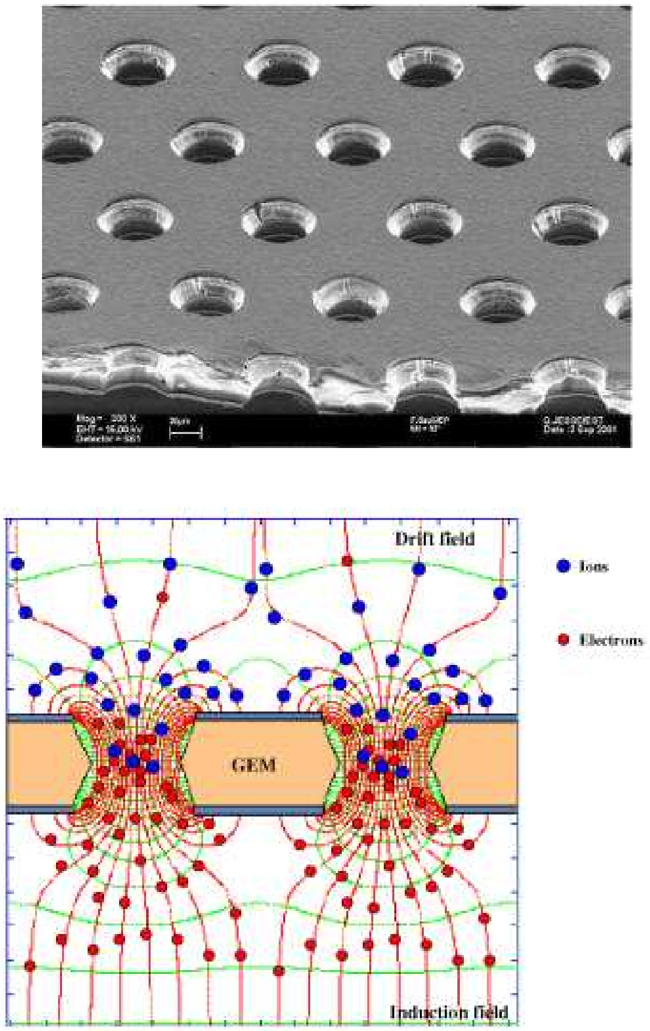

Figure 4: (from left to right): a) Image of the GEM structure taken with an electron microscope (image from CERN GDD group) b) Sketch of the working principle of a GEM (click on a picture to see larger version)

2 A manual for the test setup for the operation of a TPC

2.1 What are the modules that we use for the operation of the TPC

The modules that we use for the operation of the TPC are below:

1. Discriminator
2. coincidence unit
3. Scaler/counter
4. Gate Generator in other words timer
5. Quad Fan out Model F304/NL
6. ECL-NIM-ECL Model 4616
7. LRS Model 428 Linear Fan In Fan out
8. Controller
9. HV power supply for the TPC
10. NIM Crate
11. VME Crate
12. TPD Fast bus
13. scintillators
14. power supply for the TPD
15. preammplifiers up to the TPC
16. pulser
17. PC for the collection of our data

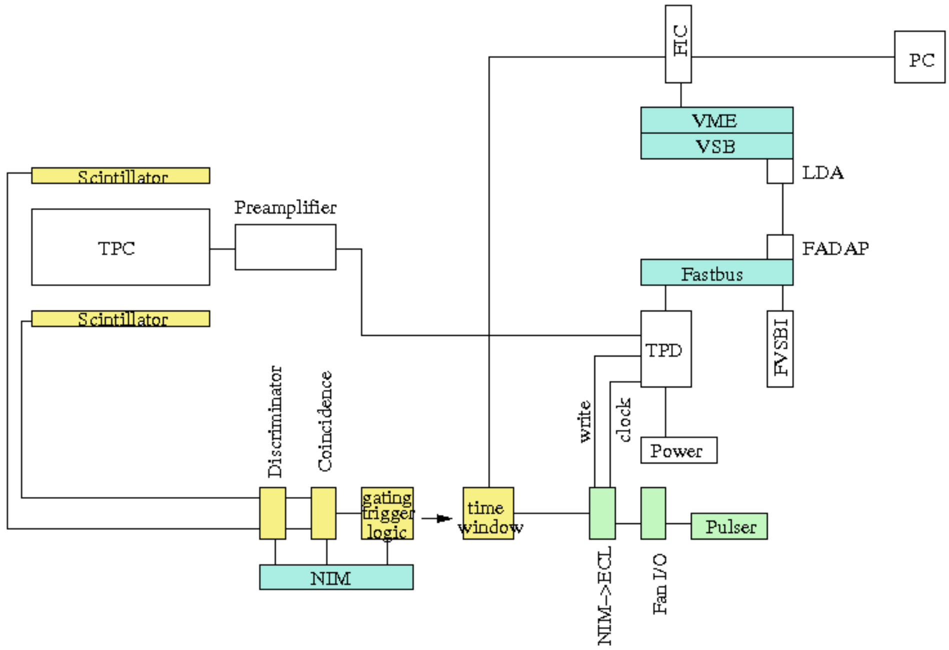

Figure 5: At this sketch we can see the setup

2.1.1 What do we connect where and why ?

First of all ,since a picture is thousands of words , we can give a small sketch of the DAQ which we use and after that we can explain what do we connect and of course why .

The output signal of our scintillators goes to **discriminator unit**. What does it do a discriminator you may ask .Here is the answer. The discriminator is a device which responds only to input signals with a pulse height greater than a certain threshold value . If this criterion is satisfied , the discriminator responds by issuing a standard logic signal; if not , no responce is made . The value of the threshold can usually be adjusted by a helipot or screw on the front panel . As well , an adjustment of the width logic unit of the logic signal is usually possible via similar controls .

The most common use of the discriminator is for blocking out low amplitude noise pulses from photomultipliers or other detectors . Good pulses , which should in principle be large enough to trigger the discriminator , are then transformed into logic pulses for further processing. In this role , the discriminator is essentially a simple analog to digital converter. An important aspect of the discriminator is the method of triggering . Because of its use in timing , it is important that the time relation between the arrival of the input pulse and the moment the pulse crosses the threshold level. This is known as leading edge (LE)triggering . A more precise method is constant fraction (CF) triggering . Two important parameters measuring the speed of the discriminator are the double pulse resolution and the continuous pulse train or cw rate . The double pulse resolution is the smallest time seperation between two input pulses for which two separate output pulses will be produced . For fast discriminators , this is usually on the order of a few nanoseconds . The continuous pulse train rate is the highest frequency of equally spaced pulses which can be accepted by the discriminator . This rate can be as high as 200 MHz in fast discriminators.

Then the signal from the discriminator goes to the **coincidence unit**. What does it do this strange thing you may ask .Here is the answer again. The coincidence unit determines if two or more logic signals are coincident in time and generates a logic signal if true and no if signal if false . The electronic determination of a coincidence between two pulses may be made in a number of ways .A simple method is to sum the two input pulses and to pass the summed pulse through a discriminator set a height just below the sum of two logic pulses . Obviously , the sum pulse will only be great enough to trigger the discriminator when the input pulses are sufficiently close in time to overlap. The definition of coincidence , here , actually means coincident within a time such that the pulses overlap . This time period determines the resolving time of the coincidence and depends on the widths of the signals and the minimum overlap required by the electronics .

The coincidence unit is one example of a more general class of units known as the logic gate . These are units which perform the equivalent of Boolean logic operations on the input signals. The coincidence unit , for example , essentially , performs the logical AND, OR, NOT and combinations of the above , operations .

Then we take the signal from the output of the coincidence unit and we go to the **Scaler** and to the **Gate Generator** . WE use the scaler in order to measure the number of coincidences . The Gate generator or timer plays an other role . This module takes as input the logic output of the coincidence unit at the slot Start and gives pulses which triggers the system. In other words it opens a time window in which the data of the TPC and only these data are valid . Then ,we connect the Gate generator to the module Quad FAN OUT Model F304/NL at the input slot .Since we need more output slots we interconnect the input of the Quad FAN OUT Model F304/NL to an other input of the same module .

But what does it mean FAN OUT you make thing and here is the answer again! . Fan-out is a term that defines the maximum number of digital inputs that the output of a single logic gate can feed. It is an active circuit which allow the distribution of the signal to several parts by dividing the input signal into several identical signals of the same height and shape .This should be distinguished from the passive pulse splitter which divides both the signal and its amplitude . The signal after the Fan Out unit goes to the module **ECL-NIM-ECL MODEL 4616** Lecroy . But what does it mean you may wonder again ECL-NIM-ECL ? . A NIM signal has the following definition of a digital "1" and a digital "0":

When a signal voltage is between -0.8 V and -1 V, it's a digital "1". When a signal voltage is exactly 0 V, it's a digital "0". NIM is an acronym for Nuclear Instrument Modules since it has been developed for this kind of experiment.In electronics, emitter-coupled logic, or ECL, is a logic family in which current is steered through bipolar transistors to compute logical functions. ECL is sometimes called 'current mode logic'.The chief characteristic of ECL is that the transistors are always in the active region and can thus change states at very high speed. Its major disadvantage is that the transistors are continuously drawing current, which means the circuits require a lot of power. Most of this power is wasted as heat.ECL gates use differential amplifier configurations at the input stage. A bias configuration supplies a constant voltage at the midrange of the low and high logic levels to the differential amplifier, so that the appropriate logical function of the input voltages will control the amplifier and the base of the output transistor (this output transistor is used in common collector configuration). The propagation time for this arrangement can be less than a nanosecond, making it for many years the fastest logic family. After the transformation of the signal from NIM to ECL the signal goes to **TPD FAST BUS**. In order to have a clock for the Fast Bus we connect the module ECL-NIM-ECL MODEL 4616 with the module **LRS Model 428 Linear Fan In Fan out**which take as an input the pulse of a pulser . (Fan-in is a term that defines the maximum number of digital inputs that a single logic gate can accept.Fan-in is the number of inputs of an electronic logic gate. For instance the 'fan-in' for the AND gate shown below is 3. Logic gates with a large fan-in tend to be slower than those with a small fan-in, because the complexity of the input circuitry increases the input capacitance of the device.).So this module takes a certain number of digital inputs and produce identical pulses for output. And Linear gate means that it is essentially a pulse signal switch allows linear signals as its inputs to pass through only if there is a second coincident signal present as input. At all other times the input signal is blocked . The gate signal is usually a logic signal the width of which determines the time the gate stays open. In our case the two signals are the signal from the ECl-NIM-ECL module and the signal from the pulser . Then we have a clock for the TPD . The TPD need a power on its own so we need a power supply.

The TPD is connected to different modules. First , it is connected to the ECL-NIM-ECL MODEL 4616 , secondly, it is connected to the power supply, thirdly to the TPC thought these long blue wires and fourthly to the **Controller**. Controller is responsible for the good operation of our system , it collects the data , which then sends to the PC and then at the Net .Controller is based on a VME Crate but all other units needs a NIM Crate .

The TPD is connected to the preamplifiers of the TPC through these long wires. The basic function of a preamplifier is to amplify weak signals from a detector and to drive it through the cable that connects the preamplifier with the rest of equipment . At the same time , it must add the least amount of noise possible. Since the input signal at the preamplifier is generally weak , preamplifiers are normally mounted as close as possible to the detector so as to minimize cable length . In this way , pick up of stray electromagnetic fields is reduced and cable capacitance , which decreases the signal-to-noise ratio , minimized . Three basic types of preamplifiers exist :

- voltage sensitive
- current sensitive
- charge sensitive

The current sensitive is not important for our case . Of the remaining two types the voltage sensitive preamplifier is more conventional. This device amplifies any voltage which appears as its input. Since radiation detectors are essentially charge producing devices , this voltage appears through the intrinsic capacitance of the detector plus any other stray capacitances which may be in the input circuit .

$$V = \frac{Q}{C_{tot}} \tag{2.1}$$

It is therefore important that the capacitance of the detector remain stable during operation. For preamplifiers , proportional counters and Geiger-Muller tubes , this is the case. The shortcomings of the voltage-sensitive preamplifier can be avoided by using a charge sensitive one .The basic idea is to integrate the charge carried by the incoming pulse on the capacitor C_f . It can be seen that the output voltage is always proportional to

$$V \simeq -\frac{Q}{C_f} \tag{2.2}$$

After all, we must mention that the TPC is connected to its own power supply ,and of course the data are available on the Net.

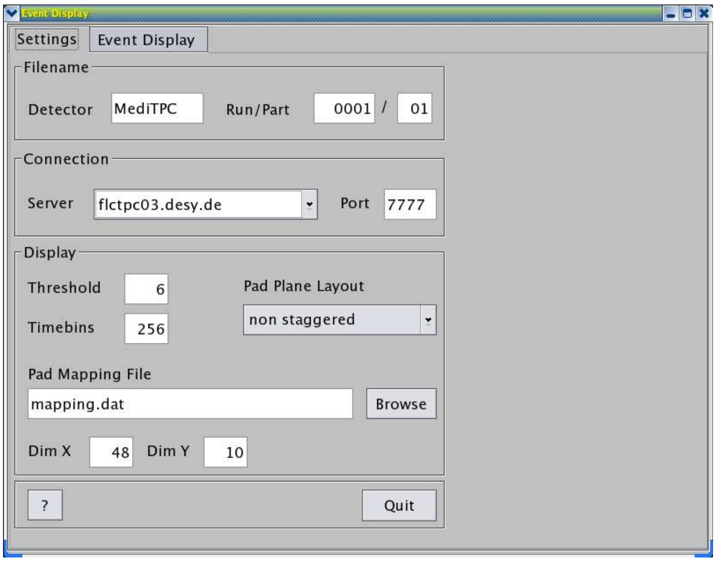

Figure 6: The control panel of a new Event Display

3 A new Event Display

The Event Display is a typical way to represent the Raw data in order to :

- see if what you get is meaningful
- put some parameters in your system for example thresholds , time bins etc.

An Event Display in order to be useful must have the characteristics below:

- It must provide a reliable method of tracking reconstruction
- It must have a control panel in order to control the parameters of the system
- It must use a package in order to Display the Events in a meaningful way

I participate in the construction of a new Event Display . This Event Display uses the Multi-Fit tracking reconstruction method.Furthermore , it is uses the **tQWidget** for the creation of the control panel. Last but not at all least, it uses the scientific package **Root** for the visualization of the raw Data.We can see the control panel of the new Event Display above Figure 5.

This control panel has some options . We can set :

- the name of the TPC from which we take the data.

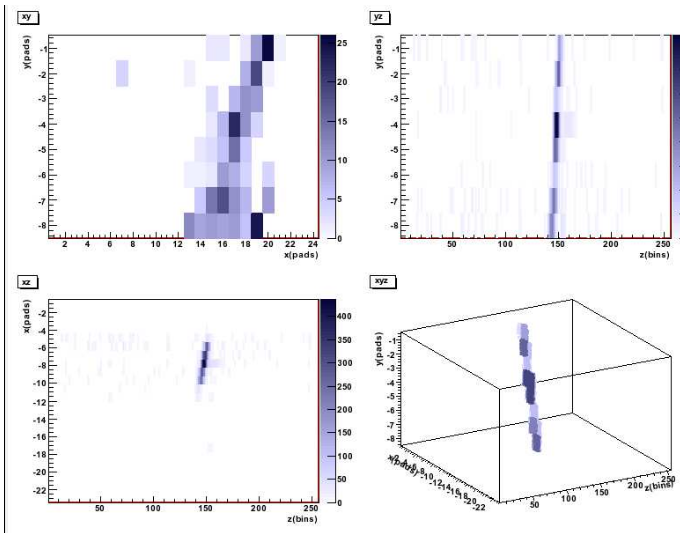

Figure 7: We can see a projection to XY , XZ, YZ and a 3D display of a real track of a TPC chamber

- the that we must connect in order to take them
- the threshold that we must set in order to cut most of the noise
- the time bins that our system has.
- some other parameters of the system

The final picture that we take of our visualized data is above Figure 6.

Here , we can see the projection of the track at the xy coordinates in other words at the end plate of the TPC , the projection to the xz and yz coordinates , after the calculation of the coordinate by the equation

$$z = \upsilon_{drift} t \tag{3.1}$$

where υ_{drift} of course is constant. Finally, we can mention that since the projection at the yz coordinates is big in length , the projection at xz coordinates is small in length something which normal .The color code is random and the only thing that represents, is the amount of charge that we collect. If we collect a bigger amount of charge the color will be darker . But there is no analogy .

4 Testing materials for the construction of a new fieldcage for the TPC

The third part of my work here at DESY is to check some samples of fieldcage which may be used in the future for the construction of the wall for the TPC. We have five samples which they have different combinations of the below materials : Kapton, GFP(Glass fiber Reenforced Plastic), and Nomex which has a structure of honeycomb.

We test these samples under High Voltage of 24 kV. The fieldcage in general must have same characteristics such as :

- We need this material because it is light so as to have least multiple-scattering to the TPC fieldcage in front of the calorimeter
- It has to be mechanically and electrically stable

The fieldcage must be electrically stable for the following reason. In order to keep the Homogeneity of the electric field between the end plates we need some strips. These strips helps us to keep homogenous the electric field which is very important in order at last to keep the drift velocity constant . The fieldcage which its length is 2 cm has to stand a potential of 25 kV on the one side and zero on the other . So it has to stands 25 kV . We test different types of samples and the results are below.

Number	No.1	No.2	No.3	No.4	No.5
Layer 1	GFK	GFK	GFK	GFK	GFK
Layer 2	Nomex	Nomex	Nomex	Nomex	Nomex
Layer 3	GFK	Kapton	GFK	GFK	GFK
Layer 4	Kapton	GFK	Kapton	Kapton	Kapton
Layer 5	Kapton	Kapton	GFK	-	-
Layer 6	Kapton	-	Kapton	-	-
Test Duration/hrs	24	24	24	24	24
Voltage/kV	24	24	24	24	24
Current/mA	0.001	0.001	0.001	0.001	0.001

We can see in the Figure 8 a fieldcage.

Last but not least, the circuit that we use in order to test the samples is below. This circuit uses a HV power supply at 24 kV!!! Furthermore , we use a small resistance around 100 Ω in order to measure the floating current . We have a multi-meter for the measurement of the voltage at the resistance and then since we know the resistance we can easily estimate the floating current. Finally, we can say that the resistance of our sample is at least $R = \frac{I}{V} = \frac{24kV}{1\mu A} = 24G\Omega$.Below you can see(Figure 9) the circuit that we have.

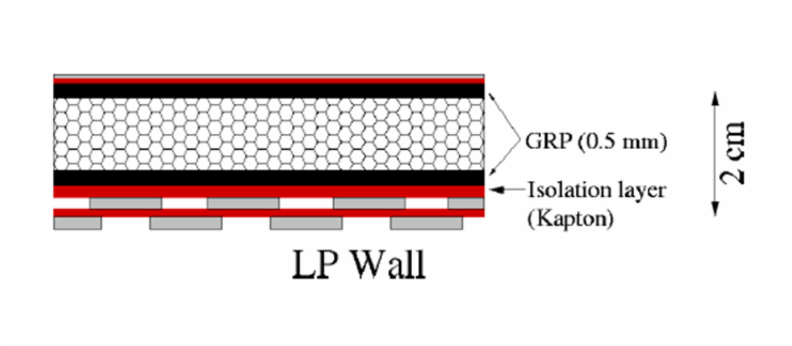

Figure 8: We can see a Fieldcage

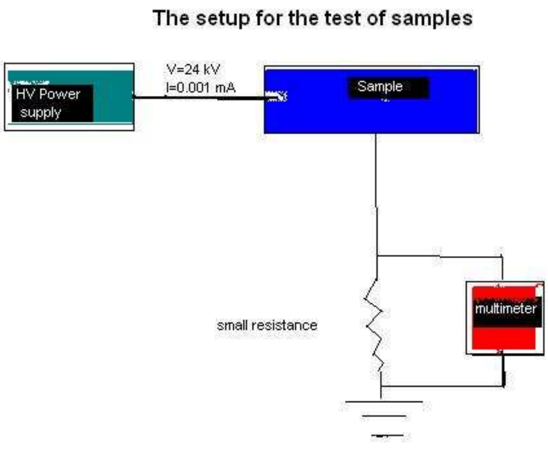

Figure 9: The circuit that we use for the Test of our samples

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[2] W.Blum,L.Ronald,Particle Detection with Drift Chambers, Spinger-Verlag,First edition, 1993.

[3] 688AL DUAL, 8 INPUT NIM/TTL,TTL/NIM 4616 16 INPUT ECL/NIM/ECL

[4] 428F QUAD LINEAR FAN-IN/FAN-OUT 429A QUAD LOGIC FAN-IN/FAN-OUT

[5] Web