

PRODUCTION OF RESISTIVE PLATE CHAMBERS FOR CMS EXPERIMENT AT CERN GENEVA

V. K. Bhandari

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Baljinder Singh, Sumit Saluja, Rakesh Kumar Syal, Shiv Kumar, Amit Saini
EHEP Group, Department of Physics, Panjab University Chandigarh

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The Experimental High Energy Physics group at Panjab University, Chandigarh is going to produce 40 numbers of large Area Resistive Plate Chambers (RPC) for end-cap region of CMS, in collaboration with BARC Mumbai. These detectors shall be assembled in Physics Department with the imported gas gaps, mechanics and front end electronics. The RPC's after assembly shall be tested for their performance and sent to CERN for integrating them into the CMS detector main frame. Here is a report on establishing infrastructure for undertaking various jobs for assembly and testing of RPC's. The entire infrastructure consists of a dust free lab, air conditioning, gas handling and mixing system, high voltage power supply, cosmic stand, data acquisition system with associated electronics and efficiency measurement of RPC.

1. Resistive Plate Chamber

The Resistive Plate Chamber (RPC) or counter is a fast detector which is able to cover large area economically. It is variant of widespread parallel plate such as glass or Bakelite (phenol-formaldehyde polymers) and spark chamber in which homogenous electric field is applied across two parallel resistive plates enclosing a gas gap. Particle passing through, lead to ionization and avalanching in the gas towards the electrode and hence to a detectable signal. Because of various properties RPC's are viable for use as muon detectors, especially for use as muon trigger for large Hadron Collider (LHC) at CERN Geneva.

- Large – scale area detector coverage.
- Built from simple and common material.
- The cost of RPC is much smaller as compared to other Scintillators.
- It is easy to construct and operate.
- Simple signal pick up and readout system.
- High efficiency of the order of >90% and the time resolution of the order of ~1ns.
- Two dimensional (x and y) particle tracking readout from same chambers is possible.
- Long term stability.

2. Design and Operation

2.1 Basic Design:

The basic design of a RPC is shown in figure1. It consists of two parallel resistive plates such as glass or Bakelite (phenol-formaldehyde polymers) about 3mm thick, separated by a gas gap whose width is maintained by spacers. The gas is kept at atmospheric pressure and DC voltage is applied to the plates via a layer of graphite paint on their external surface. The graphite electrodes are covered with insulating layer on which is etched a thin layers of copper which acts as a pickup pad to detect any movement of charge within the chamber.

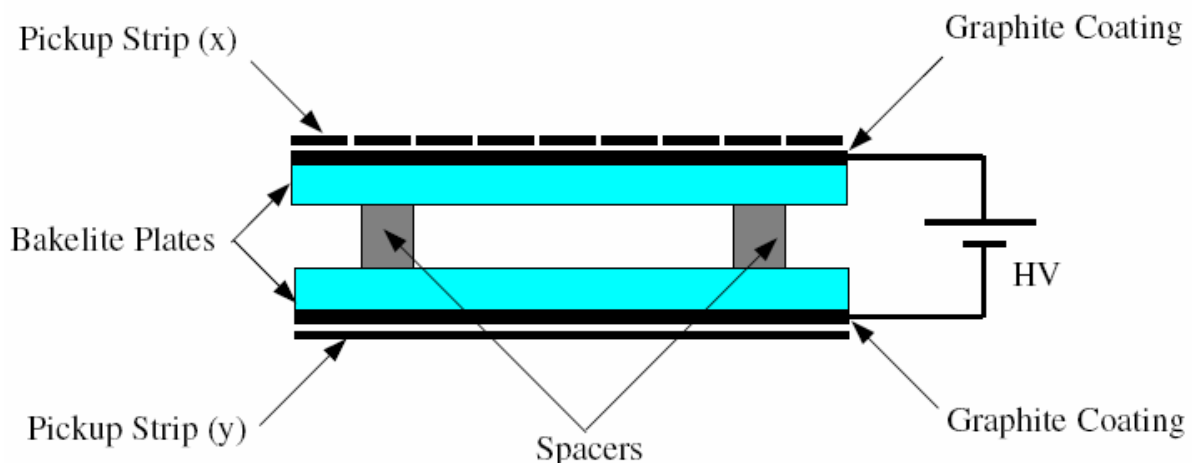


Figure 1: Basic Design of a RPC

- They are special type of ionization detectors made up of high resistive plates having resistivity of the order of 2×10^{12} ohm cm.
- Gas gap of 2mm between the two Bakelite plates, having width of 3mm of each plate with graphite coating on their outer surfaces.
- High resistive plate chambers help us to contain the discharge by the passage of the charged particle or an ionizing radiation in gas volume.
- Pick up strips are used to collect the signal.
- Typical time resolution is of the order of 1-2 ns.

2.2 Basic principle of gaseous ionization detectors.

The Ionization Detector is a device for radiation detection. The device is based on the direct collection of the ionization electrons and ions produced in a gas by passing radiation. Because of mobility of electrons and ions, a gas is the obvious medium to use for collection of ionization from radiation. The Gas devices are ionization chambers, the proportional counter, Geiger –Muller Counter (GM Counter) and Resistive plate Chambers (RPC).

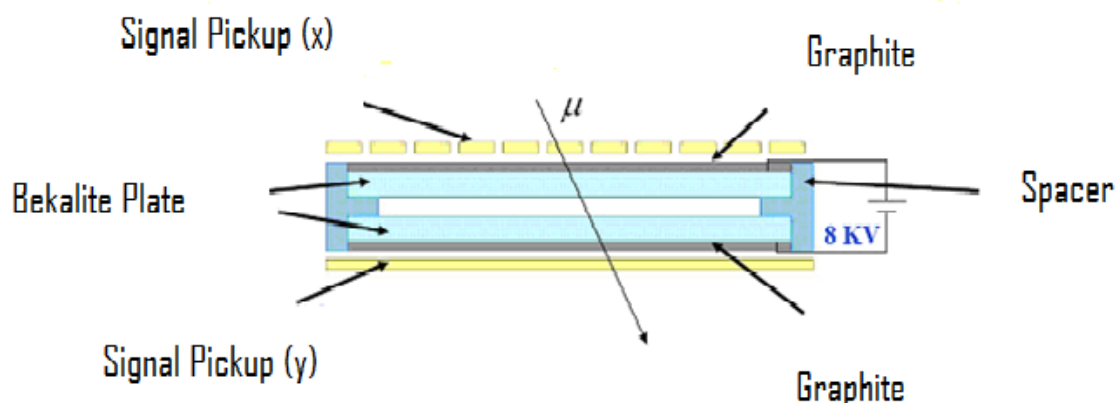


Figure 2: The gas ionization detector

The gaseous ionization detector consists of one gaseous chamber whose two opposite faces are having conducting material (figure 2). The two Bakelite plates are applied with a high voltage HV. When a sufficiently energetic radiation passes through the chamber, it ionizes the gas molecules and produces a certain number of electron ion pairs. The mean number of electron ion pairs created is proportional to the energy deposited on the chamber. With the application of strong electric field, the electrons are drawn towards the anode and ions are drawn towards the cathode and gets collected.

If the electric field is strong enough, the free electrons are accelerated to enough high energy where they are capable of ionizing the gas molecules in the chamber. The electrons liberated in this secondary ionization then accelerated to produce still more ionization and so on. This results in an ionization avalanche or cascade. This is known as **avalanche mode** of Resistive Plate Chamber.

The avalanche has the form of a liquid drop with electrons grouped near the head and slower ions tailing behind.

When such an avalanche increases in number, they form a streamline of continuous flow of charges from one electrode to the other. This forms a **streamer pulses** which are collected by the front end electronics.

2.3 Modes of Operation in Gases

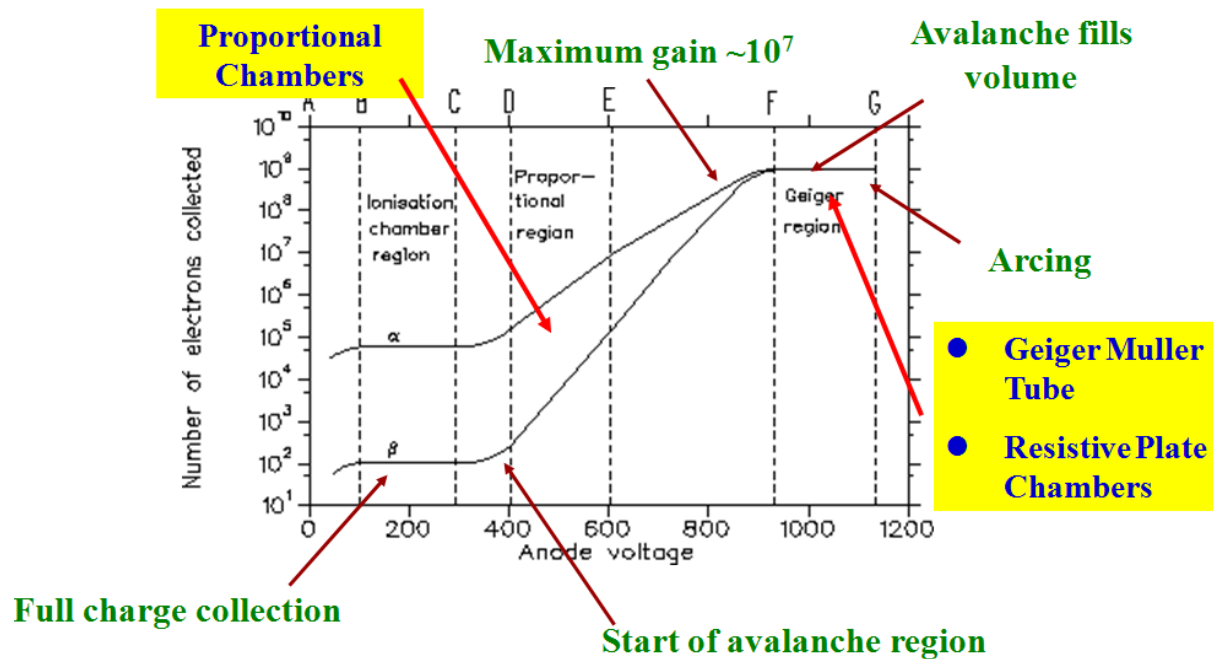


Figure 3: Mode of operation in gases

As the voltage on anode is increased from zero, various modes of operation of chambers are encountered. Zone I is recombination mode where the field is not high enough for the primary electrons to drift to anode, and they are lost by recombination to the positive ions. The second region is ionization mode where the field is enough for the electrons to reach anode, but still not enough to multiply, nevertheless, all of them are collected.

Region III is called the proportional mode region; here above the critical or threshold voltage multiplication starts and the detector signal is proportional to the original ionization, thus the chamber can be used for energy measurement. However secondary avalanches have to be quenched since gain can reach up to 10^7 in the proportional mode.

Increasing the voltage further one encounters the region of limited proportionality (IV) where multiplication reaches saturation. Thus gain no longer increases with the voltage but avalanche transits into Streamer as shown in figure 3. In this region of operation there is a strong probability of photoemission from avalanches where secondary avalanches merge with original avalanche creating a streamer (V). This mode of operation has advantage of very large gains, hence simple electronics. Nevertheless, the gas mixture requires a strong quencher as one of its components.

Increasing voltage further still more one reaches the Geiger or discharge mode which is dominated by tremendous amount of photoemission where the full length of anode is arrested by avalanche. To operate in this mode the HV needs to be pulsed and very strong quenchers are needed.

2.4 Gas system requirements for testing of RPS's

The choice of filling the gas system is governed by several factors: low working voltage, high gain, good proportionality and high rate capability. For minimum working voltage, the noble gases are usually chosen, as they require low electric field intensities for avalanche formation.

Hence the role taken by the gas mixture is very important, as the first ionization potential, the first Townsend co-efficient and the electronegative attachment co-efficient determines the avalanche multiplication. The gas mixture fixes the working mode of the RPC in avalanche mode or in streamer mode.

To work in a **streamer mode**, the main components should provide a robust first ionization signal and a large avalanche multiplication for a low electric field. One typical element can be Argon.

To work in an **avalanche mode** the main components could be an electronegative gas, with high primary ionization but with small free path for electron capture. The high electronegative attachment co-efficient limits the avalanche electron number. **Tetrafluorethane** (known as Freon), is widely used. But here we use **R134A** (as **Freon**) which is eco-friendly.

The other gas is **Iso-butane** which is having high probability for absorbing ultra violet photons. This is known as quenching gas.

Finally **SF6** is used to control the excess number of electrons.

Hence gases for the Gas Mixture we procured for use over here in the RPC lab are:

1. **Argon**: To provide the efficient gas amplification
2. **Iso-butane**: To absorb UV photons. It is the 'Photon quench gas'
3. **Freon (R134a)**: To Control charge and physical size of streamer. It is the 'Electron quench gas.'

These gases are separately procured in gas cylinders. Quantity of gas is measured by weight for **Iso-butane** and **Freon** and by pressure for **Argon**

We shall be using a gas mixture which is environment friendly and non-combustible that provides high detection efficiency and stable RPC operation. We shall be investigating the RPC operation with following option of gas mixture:

1. **R134 (Freon)** = 62%, **Argon** = 30% and **Iso-butane** = 8%
2. **Argon** = 70% and **Iso-butane** = 30%
3. **R134 (Freon)** = 96%, and **Iso-butane** = 4%

2.5 Design and Construction of Prototpye RPC and Signal Formation:

The 30 cm X 30 cm prototype RPC is made of 2mm thick float Glass. Special type of PVT material is used for the insulator spacers for maintaining precise and electrically isolated gap between the two electrode plates. Also T-shaped frames are used for supporting the electrodes and for forming an enclosed gas volume. The spacers between the electrodes are arranged in staggered manner in order to make the gas flow inside the chamber uniform. The gas plates, spacers, frames, gas inlet and outlet nozzles are assembled using special 3M Scotch-Weld 2216 or DP-190 epoxy.

A semi-resistive coating is applied to establish electrodes for applying high voltage. A mixed graphite powder (of grade 40019) and industrial lacquer in ratio 1:8 is sprayed uniformly on glass surface using paint spray gun. The signal pick-up panels are made up of poly-isocyanurate foam board with reinforced poly-aluminum foil facers on both sides. While on side of this material, strips of required pitch were milled, the other side is used as the ground reference for pickup signal. Mylar sheet is placed between the RPC electrodes surfaces for achieving the necessary isolation between RPC electrodes and pickup strip. Special nozzles are implemented as gas inlet and outlet for the RPC. A photograph of the prototype RPC is shown in figure 5.

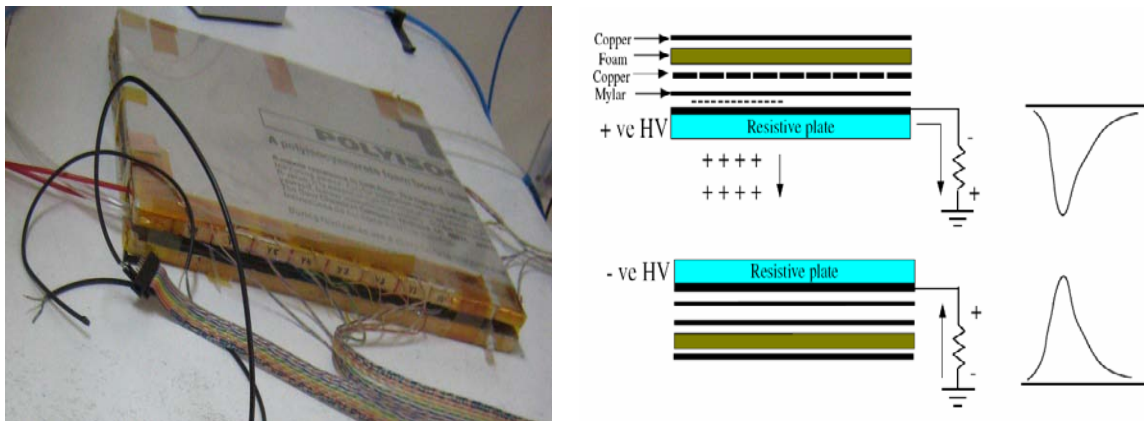


Figure 5: The prototype RPC and signal formation

While circulating gas in prototype RPC and applying high voltage to the two electrodes, we can observe following signal (see figure 5):

- In the (+ve) plate induced pulse is negative
- in the (-ve) plate induced pulse is positive

2.6. Expression of Capacitance in RPC

A Planar detector with resistive electrodes can be modeled as set of discharge cells. From the simple expression of a capacitance of a planar condenser area of such cell is proportional to the total average charge Q that is produced in RPC gas gap.

$$A \approx \frac{Q d}{\epsilon_0 V}$$

Where d = gap thickness

V = voltage applied to electrodes

ϵ_0 = dielectric constant of the gas

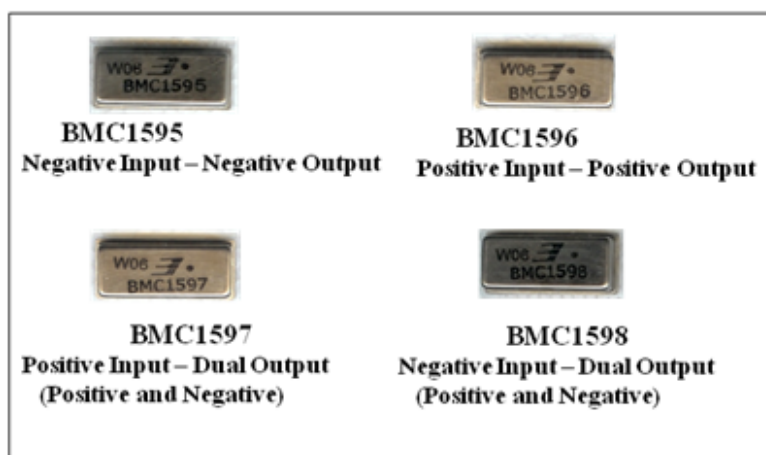
The expression explains the important role played by parameter Q in maximum detection rate that RPC is capable to sustain efficiently. Lower the Q , lower the area of the cell, and hence higher is the rate handling capability of RPC. The charge produced in Avalanche mode is about 1 pC and in streamer mode it is about 100 pC.

2.7 Fast Preamplifiers for RPC



Figure 6: An 8-in-1 cascaded preamplifier board

RPC produces a negative polarity signal at its anode and positive polarity signal at its cathode. RPC can be operated at streamer or avalanche modes. In streamer mode RPC can produce large enough signals and therefore not require any external amplification. While in avalanche mode, typical pulse height and rise time of these signals across 150 Ω load are 0.5mV - 2mV and 1 nS respectively. Since we want to operate the RPC in avalanche mode we need a fast (rise time under 2nS), high gain (more than 100) and low noise (a few mV) preamplifiers to process these signals. The signals are extracted by terminating the far end of the strip by a 50 Ω resistor and connecting the near end to a 1-in-8 cascaded preamplifier board is shown in figure 6.



- Rise Time < 2 nsec
- Gain : 10
- Input/Output Impedance : 50 ohm
- Package : 22-pin DIP (29.718 X 14.478mm)
- Power Supply : +/- 6V
- Power Consumption ~ **110mW**
- Bandwidth : 350 MHz

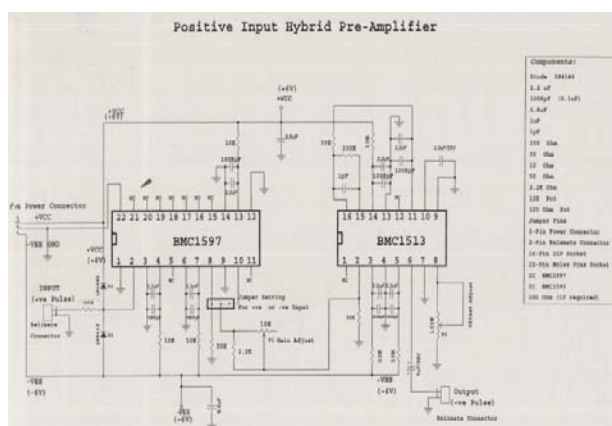
Figure 7: Four Variants of Voltage Sensitive Fast Pre-Amplifier HMC

Two types of Preamplifier boards one each for +ve and -ve signals are used which are designed and developed by BARC and produced at BEL Bangalore as Hybrid Micro Circuits (HMC). Figure 7 shows the specifications of these HMC's.

1. Negative Input and Negative Output (BMC 1595).
2. Positive Input and dual Output (BMC 1597).

We use inverted output of BMC 1597.

Since we need a preamplifier with a gain of 100 or more, BMC 1595 or BMC 1597 are cascaded with BMC 1513 to achieve a desirable gain. Figure 8 shows the circuit diagram of cascaded preamplifier. The Preamplifier board is fitted inside a galvanized iron mounting case before installing in the RPC chassis in order to improve the EMI shielding as well as grounding especially at the input side of the board. ± 6 Volts regulated powersupply is needed for operating this preamplifier circuit board.



We use these pre amplifier boards for checking the signal formation and efficiency of the prototype RPC detector. The RPC signals from pickup strips are fed to the preamplifier board with the help of twisted cables. The output signals from this board are fed to the DAQ for converting into logic signals and further processing, via coaxial cables and lemo connectors.

Figure 8: Cascaded preamplifier circuit

3. RPC Laboratory at Physics Department Panjab University Chandigarh

For the production of RPC new dust free air-conditioned laboratory having area of 8mX8m has been made. Various infrastructure facilities like gas handling and mixing, high voltage power supply, cosmic ray stand for efficiency measurement, data acquisition system consisting of various NIM and CAMAC modules has been built over the past about two years (See figure 9).



Figure 9: A view of RPC Lab in Physics Department Panjab University, Chandigarh consisting of Cosmic Ray Test Stand, Gas mixing unit and Data Acquisition

3.1 Cosmic Ray Test Stand And Experimental Setup

Setting up of Cosmic Ray Test Stand is the first step being taken up to test the prototype RPC (size 30cmX30cm) in the lab at Panjab University Chandigarh where we are going to produce a number of actual RPC's for integrating them into the main CMS Detector at CERN. Cosmic rays are high energy particles. About 90% of cosmic rays are protons, which come in contact with the earth's atmosphere and interact with it forming kaons and pions which decay into muons, with energies ranging from 100MeV to 10GeV. These are then detected by our test stand, which contain prototype RPCs. We measure the efficiency of RPC by making the experimental setup in such a way to ensure that the trigger pulse is solely due to atmospheric muons, to do that we have to exclude all other cosmic rays which forms the noise. A **scintillator paddle** based **Cosmic Ray Muon Telescope** is made for this purpose which is found to exhibit excellent stability. Schematic of cosmic ray test stand and experimental set up is shown in the block diagram figure 10.

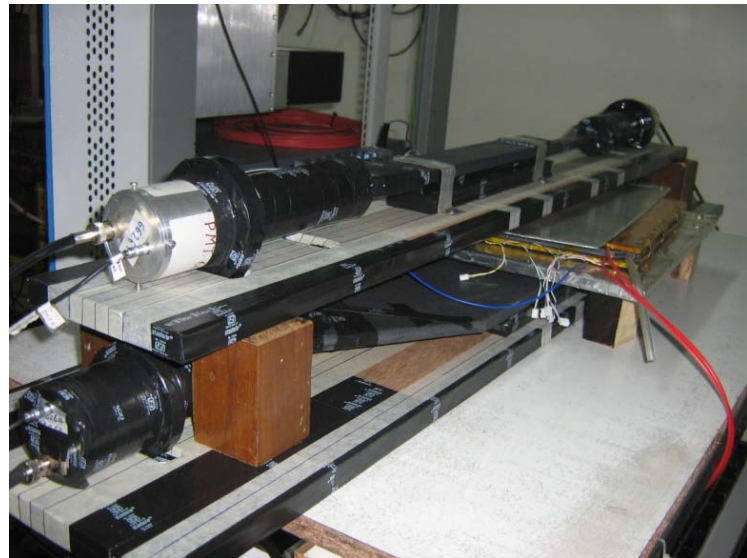
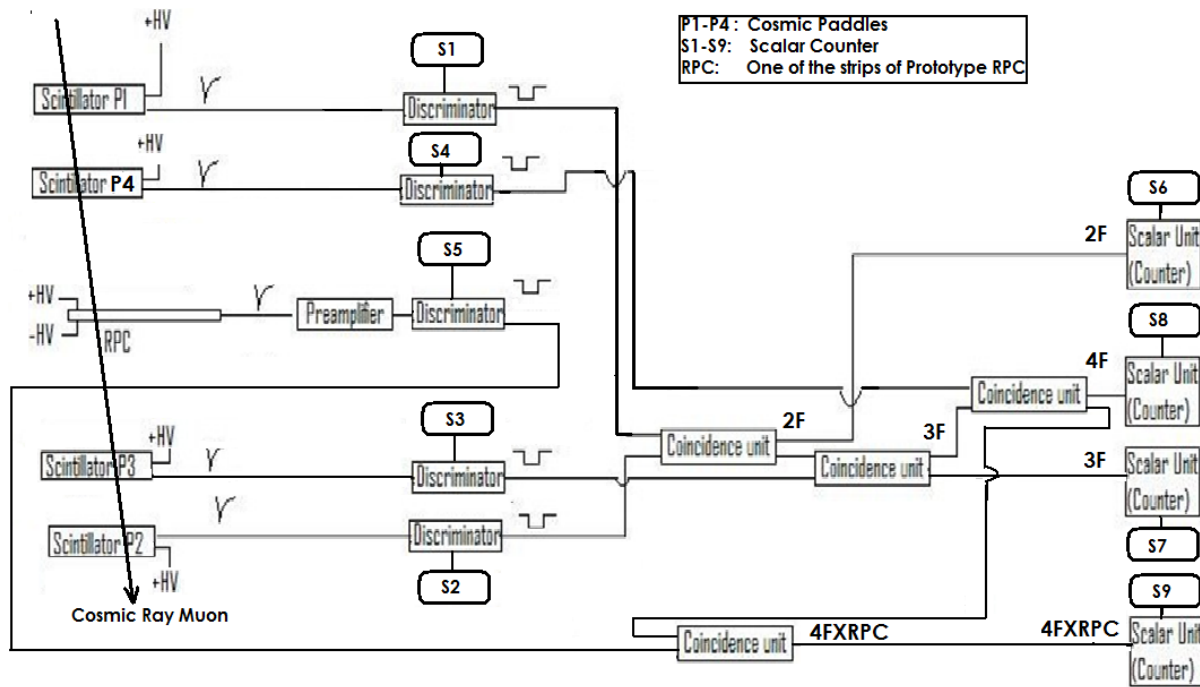


Figure 10: Schematic and photographic view of Cosmic Ray and Experimental Setup

Here we use 4 scintillator paddles P1 to P4 to set a **coincidence circuit**. Area of P1 and P2 is 20cmX35cm, P3 is 5cmX30cm where as the area of the forth paddle is taken as the area of the prototype RPC strip i.e. 2cmX30cm (pencil paddle). We keep peddle P4 along the strip and paddle P1above and P2and P3 below the RPC respectively. All paddles are made up of scintillator material of 1cm thickness. These scintillator paddles are optically coupled to **photomultiplier** (PMT) for converting light into electrical signal. Figure 11 shows the scintillator master paddle P1 and pencil paddle P4. When PMT is operated with high voltage (HV), the paddle gives a signal indicating the passage of a cosmic ray muon. The geometry of the four paddles is arranged in such a way that we define a window of about 15cmX2cm for

the cosmic muon to pass through paddles P1, P2, P3, P4 and one of the pickup strips of RPC under test. Pencil paddle P4 is used to define the geometry precisely. This ensures us that muon trigger is generated when we have four paddles in coincidence. We record data from RPC pickup strip whenever a cosmic muon particle has passed through all the four paddles. This is indicated by a trigger signal, which is generated according to the following equation:

$$\text{Trigger} = P1.P2.P3.P4$$



Figure 11: Scintillator Paddle P1 and Pencil Paddle P3

For establishing the geometrical arrangement described above a suitable mechanical structure is being designed and built using aluminum channels. The arrangement is quite reliable and accurate to do measurements on RPC performance. To find out the stability of the cosmic ray muon telescope we monitor individual count rates of paddles as well as various coincidence logic signals rates. This is achieved by a dedicated Data Acquisition Systems being setup in the lab. Figure 12 shows various graphs plotted for stability monitoring of the telescope paddles.

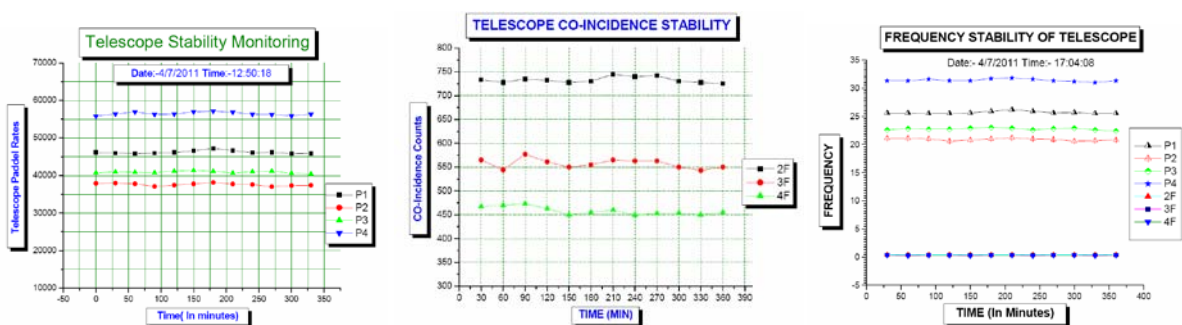


Figure 12: Stability monitoring of telescope paddles

3.2 Data Acquisition System and Efficiency of RPC:

We have designed and developed a Data Acquisition System (DAQ) for testing of RPC using NIM and CAMAC Standard Electronics. A photographic View is shown in Figure 13 below.

The scintillator paddle signals (analog pulses) are converted to NIM level Logic signals (Digital Pulses) by feeding them into **discriminator modules** operating with threshold of -30 mV and producing a pulse of 50 ns width. The cosmic ray trigger signal is formed by using **NIM logic circuits**. A, 2 fold (2F) Coincidence consists of 2-input AND of P1 and P2. The Output of this first stage is ANDed again to generate the 3 fold coincidence (3F). The output of 3F is ANDed again to get a final trigger (4F). **Scalars** are added in every stage to monitor counting rates of these signals.



Figure 13: Photographic view of NIM and CAMAC based Data Acquisition System for RPC Lab

The RPC pickup strips acts as transmission lines of Characteristic impedance of about 110Ω . We match this to standard 50Ω coaxial cable impedance by placing suitable impedance circuit on the signal lines. Pickup strips of RPC are connected to **preamplifiers** by twisted pair cables and to discriminators by coaxial cables and then to different channels of TDC with some delay. Analog signals are also fed in as inputs to CAMAC Charge **ADC module**. The NIM Logic-output of RPC is again fed in as input to a **CAMAC TDC module**. The Efficiency of the RPC is determined by the ratio of its coincidence with the triggers (4F) and triggers themselves (4F) both of which are counted simultaneously with the help of Scalar module.

$$\text{Efficiency} = \frac{\text{RPC Count with Signal in coincidence with trigger (4F)}}{\text{Trigger count (4F)}}$$

The trigger signal is also used as a common START for TDC module and as a GATE signal for ADC Module. A dedicated PC host controls the data acquisition system of RPC and Cosmic Ray setup. The PC based data acquisition system is built using CAMAC standard modules in

the back end which is connected to the front end with a fast serial link. In this PC we have installed on-line data acquisition software. While the scintillator paddle monitor system, collects, displays and stores all scalar counter's data at chosen intervals continuously, the RPC system waits for the cosmic ray muon trigger, to initiate data acquisition for the event. On trigger, the timing (TDC), charge (ADC) and rates (scalars) data are acquired, displayed and stored. The stored data of RPC is used for its characterization by finding the efficiency, time resolution and other parameters. The data collected by the online system is analysed using standard physics analysis software package such as **PAW** and **ROOT**. The software package is described in chapter 5.

3.3 Gas system and Mixing Unit

For proper and efficient working of RPCs, it is required to premix individual gases in appropriate proportion and also control the flow in the detector. This is done with the help of **gas mixing and distribution system**. A gas mixing unit capable of mixing four individual gas components and control the mixing gas flow through the detector has been designed and developed with the help of local industry.

We procure gases for our RPC's in cylinders. Freon (134A) and Iso-butane are in liquid form for which we low pressure input regulators of 0 to 5 Kg/cm² range are used, while 2000 kg/cm² pressure regulators are used for Argon and SF₆. Input range of these regulators is 0 to 5 kg/cm². Depending upon the mode of operation, appropriate optimum gases pressure is allowed to flow into the purifier. A schematic diagram and a photograph of Gas mixing unit and distribution system are shown in figure 14 & 15 respectively. The pressure of the gases to be mixed, are controlled by at the output of the cylinder itself by using two stage pressure regulators.

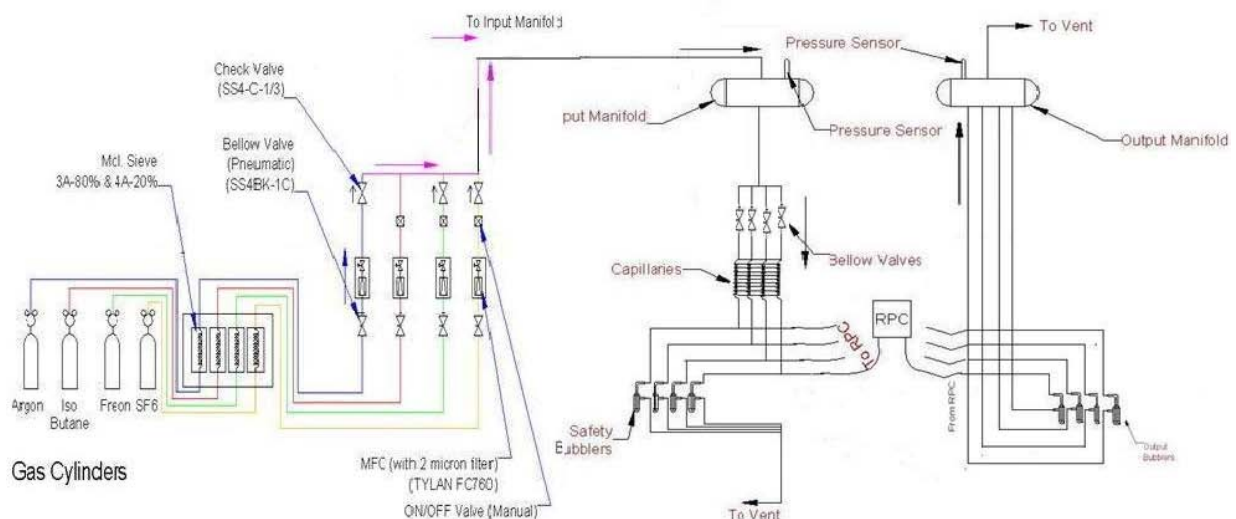


Figure 14: Block Diagram of Gas Mixing System



Figure 15: Photographic View of Gas mixing unit and distribution System

The gas Mixing Unit consists of following components:

1. **Purifying Column:** Though gases are 99% pure, moisture and other impurities may have diffused through valves and other accessories due to long transit time and storage. This calls the need of purifying the gases being used. Molecular sieve is used here, to absorb moisture and purify the gas flowing through it. The system is provided with four molecular sieve based columns mounted on the input gas lines. Heaters are built in these stainless steel Columns.
2. **Mixing Unit:** From purifier column the gas enters mixing unit which consists of pneumatic valves, Mass Flow Controllers (MFC), mixing lines, check valves and the flow of gas is displayed in Standard Cubic Centimeter per Minute (SCCM). MFC ensures controlled flow of gas. The pneumatic valves are activated by pressure of about 4 mbar, and a compressor is used for the purpose. (See Photo)
3. **Mass flow controllers:** Following the pneumatic valves, are Tylan-made (model FC-760) mass flow controllers, which are used to measure and control the flow of gases. The unit has four mass flow controllers to control flow of **Argon**, **Iso-butane**, **Freon** and **SF6**. Selection of each gas is done from the front panel through lighted selector switch. (See figure 18) These switches are located in the uppermost section of the mixing unit cabinet. The mass flow is set by adjusting the 10 turn potentiometers below the LED display. The DPDT switch sets the above the display to either flow value or set point. The display displays the value in SCCM (Standard Cubic Centimeters per minute) unit.
4. **Mixer Manifold:** From MFC's the gas enter manifold and mixes in it. This manifold feeds the mixed gas to four selectable channels, each isolated through a pneumatic valves. The mixer manifold is connected to a pressure transducer to monitor the



pressure at which gas is dispensed. LED display is provided on the front panel to monitor the mixed gas flow. (see Figure 16)

5. **Distribution Panel:** 4 RPC's can be connected in parallel, which is achieved by "Flow resistors" (Capillaries which are 2 meters long and 200 μ in diameter) and pressure transducers. These offers a resistance of 1/14th of a bar to the gas flow when a flow is of 6SCCM. Uniform Flow of gases in RPC's is maintained by these Flow resistors.
6. **Safety bubbler's:** These bubblers take care of the back pressure exerted and protect the RPC's from over pressurizing. They are made of borosilicate glass (see figure 17). In case of over pressure, the same is relieved through bubbling of excess gases to vent. All safety bubblers are connected to a common vent.
7. **Isolation Bubbler's:** It prevents back diffusion of air into the RPC and also indicates the flow of gas. There are 4 such bubblers in the system. The gas mixture is flowing out from each RPC through theses isolation bubblers. The output of all bubblers is fed into a output/exhaust manifold and then vented out.
8. **Exhaust Manifold:** All the gases to be vented are collected in this manifold and a single output is provided to vent the used gas into the atmosphere. This manifold has a pressure sensor to indicate the pressure with respect to the room pressure.

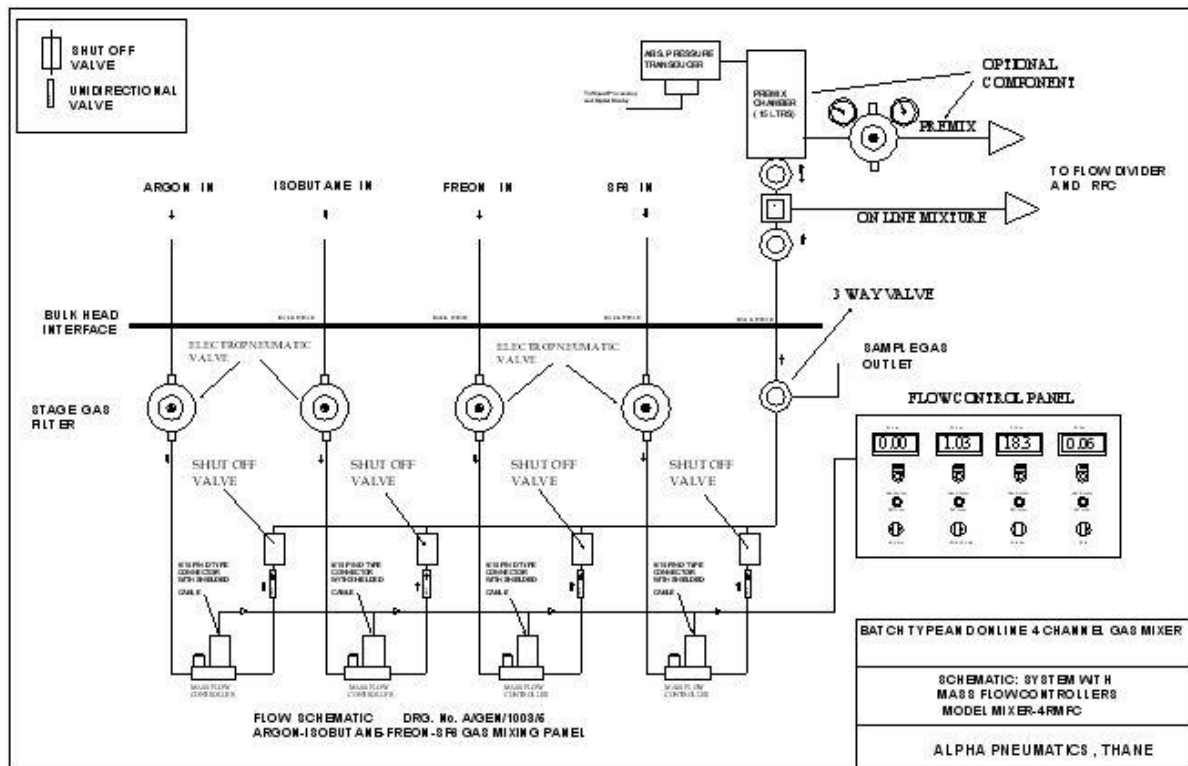


Figure 16: Front panel view of the mixing unit showing Led Display's, Switches and Bubblers

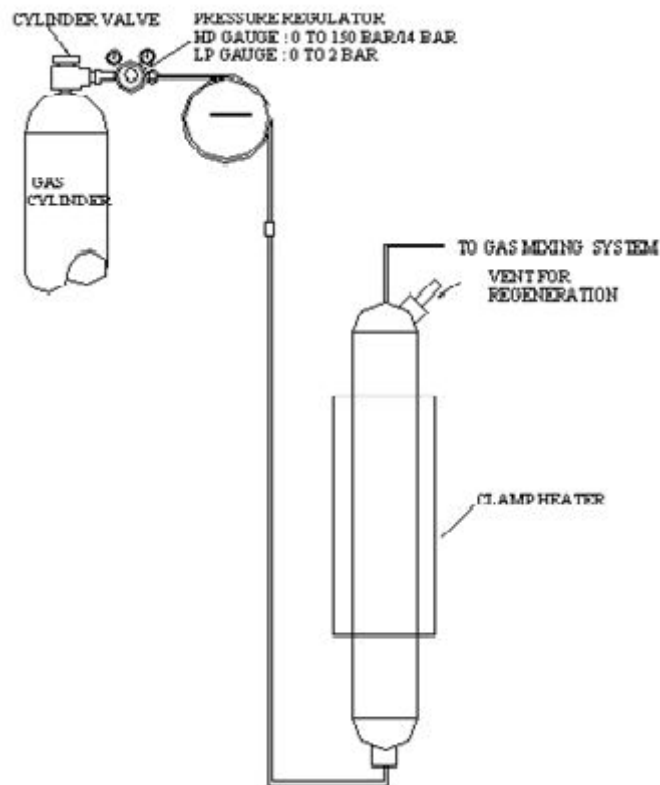
There is also a provision of monitoring the gas pressure together with possibility of setting and monitoring the gas flow through MFCs. This is displayed in standard cubic centimeters per minute (**SCCM**). Flow rate of individual gases calibrated in SCCM are settable and are displayed on the front panel. Steel tubing is used to for individual gas supply from gas cylinders to the mixing unit as well as from gas mixing unit to the RPC test stand. Standard Norton Tygon flexible plastic tubes are used for short connections within the test stand.

The gas mixing system is an open circuit system in which no gas recirculation is done. We shall however be using this system only for all the RPC's we are going to produce including the prototype RPC described above.

Schematic of mixing console



Schematic of Gas Purifier system



3.4 Calculation of gas flow rate

In the front panel of our gas mixing unit, all the flow rates are displayed in SCCM (Standard Cubic Centimeter per Minute). Here is the calculation of the gas flow in SCCM for 1-4 RPC's. We shall calculate the flow rate in SCCM for the End Cap RPC we are going to produce as follows:

Actual size of a Bakelite RPC for CMS End Cap = 1.2mX1.67mX2mm

Area of the RPC is taken as 1mX2m=2m² and thickness = 2mm

Volume of the gas gap = Length X Breadth X Height

$$= 1\text{m} \times 2\text{m} \times 2 \times 10^{-3}\text{m}$$

$$= 2 \times 2 \times 10^{-3}\text{m}^3$$

$$= 4 \times 10^{-3}\text{m}^3$$

$$= 4 \times 10^{-3} \times 10^6 \text{Xcm}^3$$

Volume of one gas gap = 4X10³cm³

The calculated volume is to be multiplied with the number of RPC's we want to let the gas flow in. The unit is capable of supplying mixed gas to four RPC's simultaneously. Hence the Volume of one RPC shall be multiplied by four RPC we want to let the gas flow in

$$4 \text{ RPC} = 4 \times 4 \times 10^3 \text{Xcm}^3 = 1600 \text{ cm}^3$$

We further multiply by a number of volumes we want to circulate the gas.

Let there be 3 volume change per day.

Then the total volume required for the number of RPC shall be:

$$= 3 \times 1600 \text{cm}^3 = 4800 \text{cm}^3/\text{day}$$

$$\text{Flow Rate} = \frac{4800 \text{ cm}^3 \times \text{cm}^3}{24 \times 60 \text{ min}} = \underline{\underline{33.3 \text{ SCCM/min}}}$$

This is total gas flow rate. However on mixture unit the display is for individual gases to be mixed. For proper functioning of the RPC we let a mixed gas to flow into RPC in some proportion. The volume of gas calculated above is divided into one two or more gases to be mixed. We divide the total flow rate into some %age as follows:

Let us say we want to mix 96% of Freon and 4 % of **Iso-butane**. So we take the %age of the total SCCM volume calculated above to make the mixed gas 100%.

96% of 33.3 = SCCM of **Freon** to be set on the front panel

4% of 33.3 = SCCM of **Iso-butane** to be set in the front panel

For the prototype RPC gap of size 30cmX30cm and thickness 2mm are as follows:

$$\text{Volume of gap of 1 Glass RPC} = 30 \times 30 \times 2 \times 10^{-1} \text{ cm}^3 = 9 \times 2 \times 10 \text{ cm}^3 = 180 \text{ cm}^3$$

For 2 Volume change in a day the total volume shall be: 2X180 cm³/day

$$\text{Flow Rate} = \frac{2 \times 180 \text{Xcm}^3 \times \text{cm}^3}{24 \times 60} = \frac{1}{4} = \underline{\underline{0.25 \text{ SCCM /min}}}$$

96% of 0.25 for Freon and 4 % of 0.25 for **Iso-butane** is to be set on the front panel of the mixing unit.

3.5 Power Supply and Monitor System

For RPC we need to setup an electric field across the electrodes by applying differential high voltage of $\pm 4.9\text{KV}$. The base RPC is wired for applying high voltage and picking up the signals as charged particles pass through. The voltage is applied to the graphite layer by sticking on a copper tape and leads are then soldered on to the copper. Positive voltage is applied to one side and roughly equal and negative voltage to the other side, using a bipolar high voltage DC supply, so that both see a common ground. The bipolar connection is better than the unipolar one, since each glass surface sees only half the total voltage, thus decreasing the chance of HV leaks.

The essential features of the high voltage power supply need to be a multichannel monitoring of output voltage and load currents. We also need DC power supply like $\pm 6\text{ Volts}$ and $\pm 8\text{ Volts}$ for the front-end electronics comprising of preamplifiers, analog and digital frontend systems. Fine control of supply at the load input and monitoring of the supply voltages and load currents is the essential requirement of low voltage power supply system. We have designed the power supply system using commercially available components from CAEN shown in figure 17.



Figure 17: Universal Power supply System Model 2527 From CAEN

The High Voltage system consists of two 6-channels High Voltage Supply Modules (1526P & 1526N shown in figure 20) - one each for either polarity, plugged into SY 2527 power supply the main frame (Shown in figure 19). The SY 2527 main frame is housed in 19" wide, 4U high euro-mechanics rack (refer to figure 19). The main frame is divided into main sections:

- *The board section with 6 slots to house boards*
- *The Power Supply Section*
- *The CPU and Front Panel Section with interface facilities.*
- *7.7" Color LCD*



Board section is located in the mainframe's rear part and hosts the 6 slots for High Voltage and Low Voltage (HV/LV) boards (See figure 20) insertion. The 6 slots are numbered starting from bottom (**Slot 0**) to top (**Slot 5**). They are completely equivalent, i.e. the user can insert in each slot either a HV/LV board or a distributor, indifferently. At Power-On the processor will scan all the slots to find out where the boards are plugged in and what kind of boards they are.

The **Power Supply unit** furnishes the +/-12 V and +5 V at 320 W for the system logic circuitry and +48 V at 750 W for the system boards. On the SY2527 front panel there is the **power-ON key** to turn the system on (the main switch on the rear panel just enables the system to be powered, but the system is not powered until the power-ON key is turned on).

The turn-ON key has three different positions:

- *The central position corresponds to the system OFF;*
- *The right position turns the system ON locally;*
- *The left position enables the system to be turned ON remotely.*

Above the **turn-ON** key an orange LED (**MAIN**) warns, when it lights up, that the system is connected to the mains and the switch on the rear panel is on (i.e. in position 1).

This unit contains the **system's intelligent core** that divided into the following parts:

Interface Bus Backplane; CPU Board; Interface Board; Ethernet board.

The **CPU board** houses a microprocessor which has direct control on the crate operation. It fulfils the basic functions like, *direct control and monitoring of the channels; manual and remote interfaces; power supply control; temperature monitoring; fan tray monitoring.*

The Interface board is the system's communication core and controls the following internal connections:

- *Status/control signals between the front panel and channel boards;*
- *Status/control signals and bidirectional communications between CPU and channel boards;*
- *Bidirectional communications between the CPU and the external peripherals;*
- *Monitoring of power supply section and fan tray unit.*

The components on the **Front Panel** are:

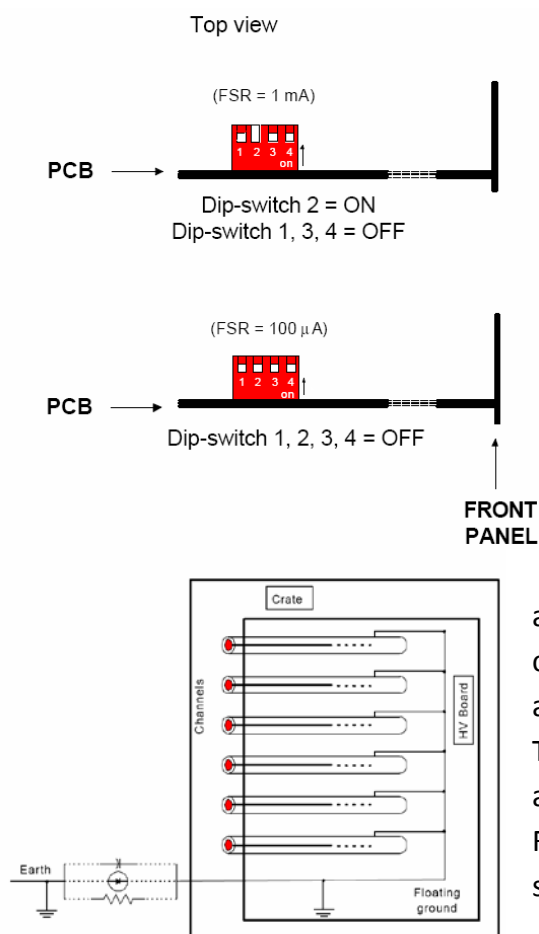
- 7.7" colour LCD monitor with a 15-key keypad and a compact switch;
- The Interface Bus section with three slots containing a RS232 interface, a VGA port, one PS/2 connector, a 10/100baseT Ethernet connector and additional peripherals;
- The I/O Control section which hosts I/O connectors and several displays and switches.
- Other front panel signals and relevant LEDs are foreseen to signal the channel status, such as OVERVOLTAGE, UNDERVOLTAGE, CHANNEL ON and TRIP. Another set of LEDs warn about possible fault conditions in the system operation (OVER TEMPERATURE, FAN FAILURE, POWER FAILURE).

The software interface provided in the system helps in controlling external devices.

The supply system is connected to a PC via Ethernet port to support, control and monitor various parameters and values. Comprehensive software is developed to interface the system to PC. The required voltages are set at various output channels using this PC.

3.5.1 Some Comments on HV 1526P or 1526N Boards

High Voltage Boards which are inserted into the Main Frame need to be set as per our requirements i.e to 1mA or 100µA maximum current. This is done as described below. Also the board need to be enabled to get the channels on. Once the board is enabled we get the channels selected from the front panel. This is indicated by the LED's on the 1526 HV System



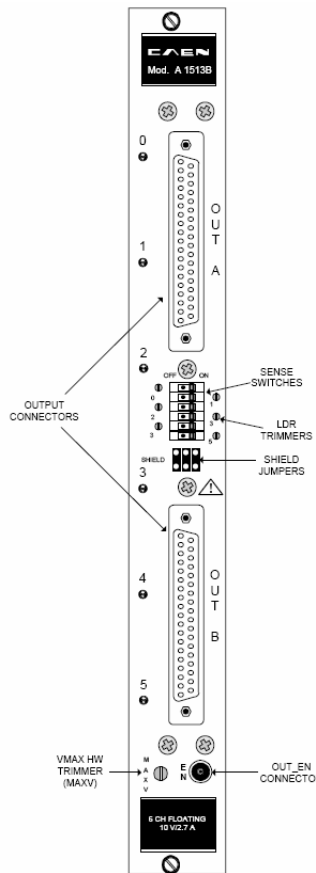
- To change or manipulate boards, shut everything down. Log out, put the key on **OFF** position, and put the main switch (on the back of the PS) in **O** position.

- On the back of the board, on the **HVEN** (HV Enable) lemo connector must be a 50Ohm Resistor. (50 Ohm Lemo Terminator).

- To switch between 100uA (All Dip-switch OFF) and 1mA (Dip-switch 2 = ON) maximum current, pull out the board (make sure the PS is turned off and disconnected) and change the Dip-switch #2 on the switch.

- The HV Module board 1526 channels share a common floating ground, which does not coincide with the crate ground, which is available as earth connector on the front panel of the board. This feature allows on detector grounding, thus avoiding loops which may increase noise level. Floating ground and earth may be coupled in several ways as shown.

3.5.2 Low Voltage (LV) Power Supply Board A1513B



The single width board is housing **6 LV floating Channels**. The voltage range at the connector output is 1-10V (2.7 A maximum output current). The LV is provided with two **DB37 female type connectors** (OUT A & OUT B). 3 Output channels each i.e. 0, 1, 2 are in connector A and 3, 4, 5 in connector B. **The board need to be enabled for functioning with the help of OO-type LEMO Connector 50 Ohm terminator**. 6 LED's are provided on the front panel of the board which gives indication to presence of voltage at each output channels. 6 numbers of **SENSE** Switches allow enable/disable the automatic Line Drop Recovery system. The system is provided with three front panel jumpers **JP1, JP2, JP3** for grounding of the DB 37 connectors. Maximum output voltage can be set with the help of **MAXV trimmer** (Common to all channels). With **LDR trimmer** automatic Line Drop Recovery system can be calibrated.

LV 1513B board can be controlled, either locally or remotely, through the SY 2527 software interface. For each output channel, following operations can be performed through SY 2527 system:

- Channel can be assigned a symbolic name
- Set output voltage (VSET)
- Set output current (ISET)
- Set output voltage software limit (SVMAX)
- Set voltage ramp-up & ramp-down speed (RAMP-UP, RAMP-DOWN)
- Set Trip parameter
- Enable/disable POWER ON option
- Switch channel ON/OFF
- Monitor output voltage (VMON) and current (IMON)
- Monitor Channel Status
- While monitoring the channel status messages like OFF (channel turned OFF), RUP (channel ramping up, RDWN (channel ramping down), OVC (channel in OVERCURRENT), OVV (channel in OVER VOLTAGE condition), INTTRIP (channel OFF due to over current position), EXT_DIS (channel disabled by board INTERLOCK protection).

3.5.3 Operating Power Supply SY 2527 System using TCP/IP protocol via Ethernet (Telnet Client)

The Ethernet interface can be used to connect one SY2527 system to a standard PC running a terminal emulator program (Telnet Client). To operate via TCP/IP protocol, follow this procedure (the example refers to Telnet Client in Windows; Telnet Clients are available in almost all operating systems):

1. Connect system via the Ethernet interface and configure TCP/IP protocol correctly.
2. Run Telnet Client software;
3. Type the **Host name** of the system you want connect to
4. Type the **Port: 1527**;
5. Type the **Terminal type: VT100**;
6. Select **Connect** and press ENTER.

At this point you are connected to the SY2527 system via Telnet protocol.

3.5.4 Operation of HV Power Supply SY 2527 Control

1. Plug in the supply to mains
2. Turn the main switch on back of the power supply on (Switch on I)
3. Turn the key on the front to the position **Local**
4. The switches are to be **local enabled**
5. Connect a standard PC keyboard to the power supply (socket **KBD** on the front)
6. Press any key, then login as admin (password admin)
7. Go to **Setup** menu, select the submenu **Communications** and choose **TCP/IP settings**
8. Enter 192.168.0.90 for **IP address** and 255.255.0.0 for **IP NetMask**.
9. Select **Ok** to confirm the settings.
10. Use the arrow keys to navigate, the **Tab** key to change back to main menu and **Enter** key to select something.
11. In the main menu you will find the **channels** submenu, where you can set voltages and current limits and see the status.
12. After you have changed the value confirm it with **Enter or Space Key**
13. To toggle between yes/no or on/off, use **Space**.
14. When a channel is turned "on" the LED **CH-ON** on the top right corner of power supply is on.
15. Make sure that the trip time **Trip** is set to 0.0s and software maximum voltage **SVMax** is set to 1560V (or another value slightly above your used maximum)
16. Usually **VOSET** and **IOSET** are used to values (Indicated by **VO IO** in the status line at the bottom of the window).
17. Use **Tab** to go back to the menu and on the main menu select **Logout**

4. Experimental set-up for preliminary study of prototype RPC and Results

4.1 Signal Formation

We started our study on a prototype RPC of size 30cmX30cm (Procured from TIFR Mumbai) and operated in Avalanche mode. We study some basic operating characteristics like RPC pulse profile, voltage current relationship and individual count rates of RPC.

The Characteristic impedance of the RPC strip is 50Ω . The signal range on these strips across 50Ω load is 0.5-2mV and rise time of about 1ns. We therefore need to pre-amplify the strip signal before it can be further processed.

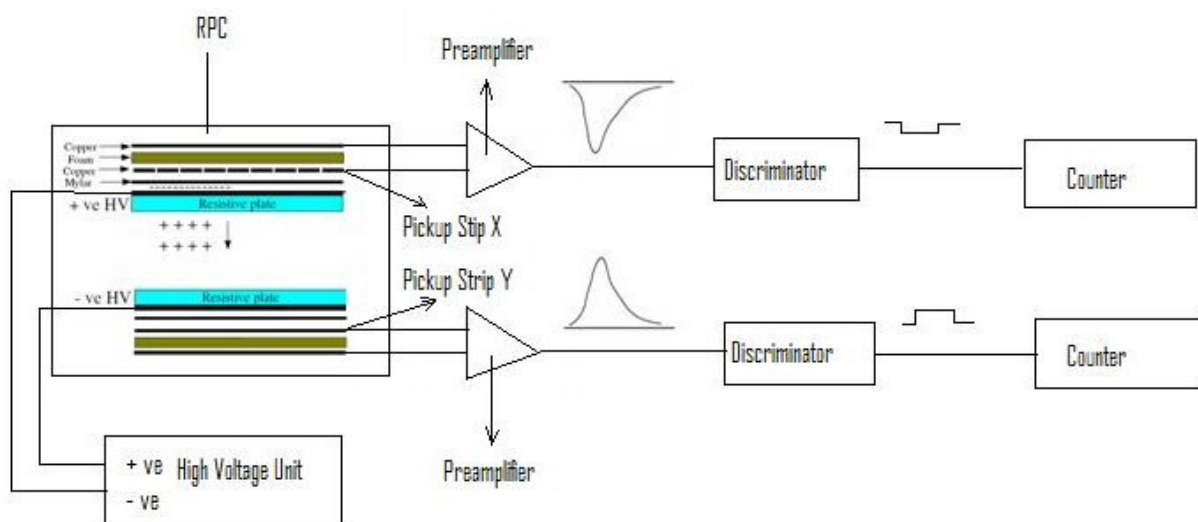


Figure 18: Experimental setup for preliminary study of prototype RPC

The block diagram in figure 18 represents the experimental setup we use to test RPC for signal formation and observation on oscilloscope. Signal from one of the strip is observed on oscilloscope after the same is passed through preamplifier. Oscilloscope Trace of the formed signal is shown in figure 19.

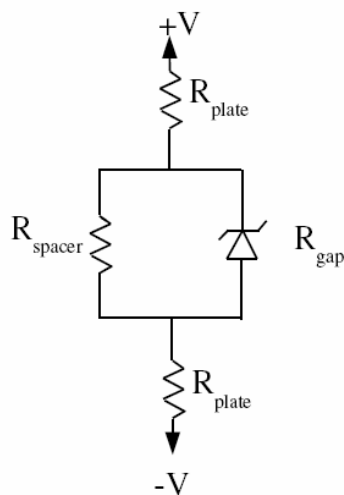


Figure 19: Oscilloscope trace of RPC signal

Signal of RPC strip is fed to Discriminator for converting the signal into NIM signal. These signals are produced by cosmic ray charged particles of all energies, due to surrounding stray activity as well as due to dark current of the chamber. Discriminator converts the signal above certain threshold value and count rates are taken on a scalar.

4.2 V-I Characteristics of the Prototype Glass RPC

Figure 19 below is the electrical equivalent circuit of the RPC and characteristics of prototype glass RPC. The lower portion of the figure 20 represents the V-I Characteristics of RPC. RPC gas Gap is represented by a parallel combination of spacer (Ohmic) resistance and gas ionization volume of gas (represented by a Zener diode). At Lower applied voltage, no ionization or avalanche takes place in the gas gap. Therefore, the gas gap offers infinite resistance (Equation 1). The current flowing through the chamber then is entirely determined by the spacer resistance Equation 2. Starting from the chamber's turn on point the slop of the curve changes drastically as the ionization volume almost seizes to offer any resistance (Equation 3). The current flowing through the chamber in this case is determined by the glass resistance (Equation 4).



At Lower Voltage:

$$R_{\text{Gap}} \approx \infty \quad \dots\dots\dots (1)$$

$$\frac{dV}{dI} = R_{\text{Spacer}} \quad \dots\dots\dots (2)$$

At Higher Voltage:

$$R_{\text{Gap}} \approx 0 \quad \dots\dots\dots (3)$$

$$\frac{dV}{dI} = R_{\text{plate}} \quad \dots\dots\dots (4)$$

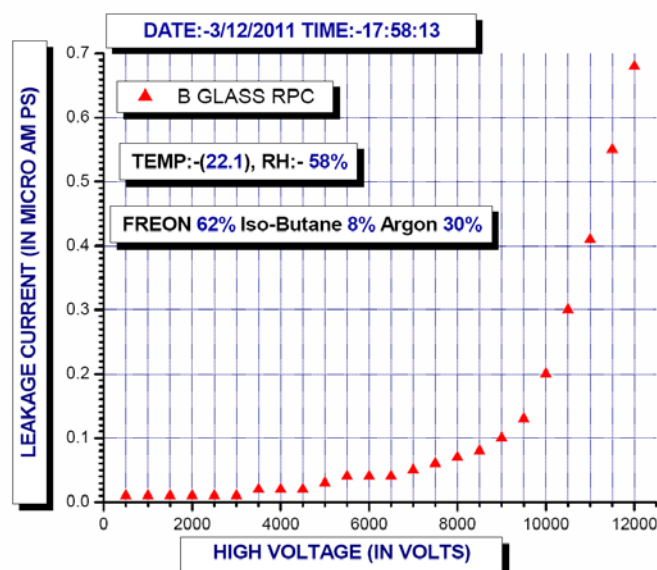


Figure 20: Electrical Circuit Representation of RPC

4.3 Voltage verses individual counting rates of a RPC

Counting rate (noise rate) of a RPC is the total counting rates of all signals above certain discriminator threshold. These are signals produced by cosmic ray charged particles of all energies, due to the surrounding stray radio activities as well as due to the dark current of the chamber [1]. Figure 21 shows the graph plotted of the noise rate on applied high voltage. We can see that there is linear dependence of noise rate on the applied voltage to the two electrodes of the RPC.

To be followed

Figure21: Noise rate as a function of applied voltage

4.3 Efficiency Plot of a Prototype Glass RPC

Efficiency of a detector means its ability to respond to external radiations by producing a fast and well discriminated signal. That means that RPC with good efficiency can detect the track of a particle passing through it accurately and efficiently. The cosmic ray setup using scintillator paddles as described earlier is used to find the efficiency of the RPC detector. Figure 22 shows the plot of efficiency as a function of high voltage applied using a gas mixture.

To be followed

Figure 22: Efficiency as a function of applied voltage

5. Introduction to ROOT and PAW

5.1 PAW

PAW is an interactive utility for visualizing experimental data on a computer graphics display. It may be run in batch mode if desired for very large and time consuming data analyses; typically, however, the user will decide on an analysis procedure interactively before running a batch job.

PAW combines a handful of CERN High Energy Physics Library systems that may also be used individually in software that processes and displays data. The purpose of PAW is to provide many common analysis and display procedures that would be duplicated needlessly by individual programmers, to supply a flexible way to invoke these common procedures, and yet also to allow user customization where necessary.

PAW can do a wide variety of tasks relevant to analyzing and understanding physical data, which are typically statistical distributions of measured events. Below we list what are probably the most frequent and best-adapted applications of PAW; the list is not intended to be exhaustive, for it is obviously possible to use PAW's flexibility to do a huge number of things, some more difficult to achieve than others within the given structure.

5.1.1 Typical PAW Applications:

1. **Plot a Vector of Data Fields for a List of Events.** A set of raw data is typically processed by the user's own software to give a set of physical quantities, such as momenta, energies, particle identities, and so on, for each event. When this digested data is saved on a file as an Ntuple, it may be read and manipulated directly from PAW.

Options for plotting Ntuples include the following:

- *One Variable.* If a plot of a one variable from the data set is requested, a histogram showing the statistical distribution of the values from all the events is automatically created. Individual events are not plotted, but appear only as a contribution to the corresponding histogram bin.

- *Two or Three Variables.* If a plot of two or three variables from the data set is requested, no histogram is created, but a 2D or 3D scatter plot showing a point or marker for each distinct event is produced.
 - *Four Variables.* If a plot of four variables is requested, a 3D scatter plot of the first three variables is produced, and a color map is assigned to the fourth variable; the displayed color of the individual data points in the 3D scatter plot indicates the approximate value of the fourth variable.
 - *More than Four Variables.* More than four variables can be plotted but it is up to the user to customize the system in order to assign the additional variables to graphics attributes like the size or the shape (type) of the markers.
 - *Vector Functions of Variables.* PAW allows the user to define arbitrary vector functions of the original variables in an Ntuple, and to plot those instead of the bare variables. Thus one can easily plot something like $\sqrt{P_{2x}^2 + P_{2y}^2}$ if P_x and P_y are original variables in the data without having to add a new data field to the Ntuple at the time of its creation.
 - *Selection Functions (Cuts).* PAW does not require you to use every event in your data set. Several methods are provided to define Boolean functions of the variables themselves that pick out subsets of the events to be included in a plot.
 - *Plot presentation options.* The PAW user can set a variety of options to customize the format and appearance of the plots.
2. **Histogram of a Vector of Variables for a List of Events.** Often one is more interested in the statistical distribution of a vector of variables (or vector functions of the variables) than in the variables themselves. PAW provides utilities for defining the desired limits and bin characteristics of a histogram and accumulating the bin counts by scanning through a list of events. The following are some of the features available for the creation of histograms:

- *One Dimensional Histograms.* Any single variable can be analyzed using a one-dimensional histogram that shows how many events lie in each bin. This is basically equivalent to the single-variable data plotting application except that it is easier to specify personalized features of the display format. A variety of features allow the user to slice and project a 2D scatter plot and make a 1D histogram from the resulting projection.
 - *Two-Dimensional Histograms.* The distribution of any pair of variables for a set of events can be accumulated into a 2D histogram and plotted in a various of ways to show the resulting surface.
 - *Vector Functions of Variables.* User-defined functions of variables in each event can be used to define the histogram, just as for an Ntuple plot.
 - *Selection Functions (Cuts).* Events may also be included or excluded by invoking Boolean selection functions that are arbitrary functions of the variables of a given event.
 - *Event Weights.* PAW allows the user to include a multiplicative statistical bias for each event which is a scalar function of the available variables. This permits the user to correct for known statistical biases in the data when making histograms of event distributions.
 - *Histogram Presentation Options.* Virtually every aspect of the appearance of a histogram can be controlled by the user. Axis labels, tick marks, titles, colors, fonts, and so on, are specified by a large family of options.
3. **Fit a Function to a Histogram.** Once a histogram is defined, the user may fit the resulting shape with one of a family of standard functions, or with a custom-designed function. The parameters of the fit are returned in user-accessible form. Fitted functions of one variable may be attached to a 1D histogram and plotted with it. The capability of associating fits to higher dimensional histograms and overlaying their representations on the

histogram is in the process of being added to PAW. The fitting process in PAW is normally carried out by the MINUIT library. To use this package effectively, users must typically supply data with reasonable numerical ranges and give reasonable initial conditions for the fit before passing the task to the automated procedure.

4. **Annotate and Print Graphics.** A typical objective of a PAW user is to examine, manipulate, and display the properties of a body of experimental data, and then to prepare a graph of the results for use in a report, presentation, or publication. PAW includes for convenience a family of graphics primitives and procedures that may be used to annotate and customize graphics for such purposes. In addition, any graphics display presented on the screen can be converted to a PostScript file for black-and-white or color printing, or for direct inclusion in a manuscript.

5.1.2 Basic Principle

1. Paw is an Interactive System.
2. Paw provides a set of COMMANDS acting on specific objects.
3. The Commands structure of PAW is a TREE Structure.
4. The general Structure of the tree is

OBJECT/ACTION

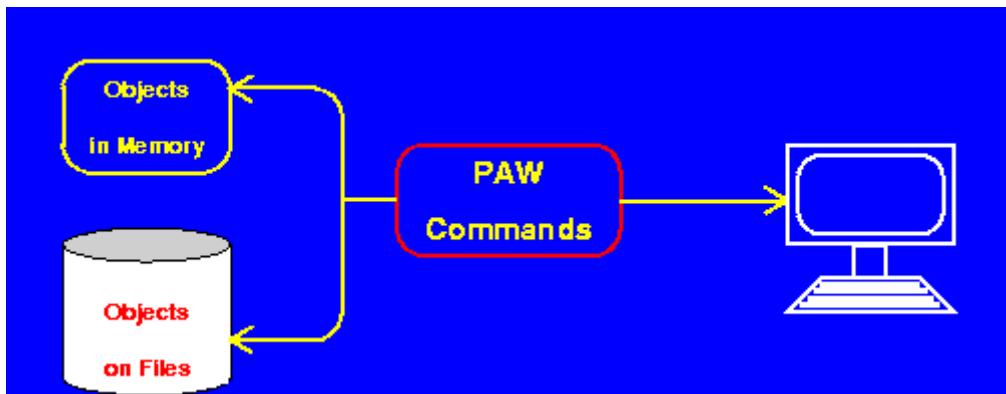
Example:

NTUPLE/PLOT

HISTOGRAM/PROJECT

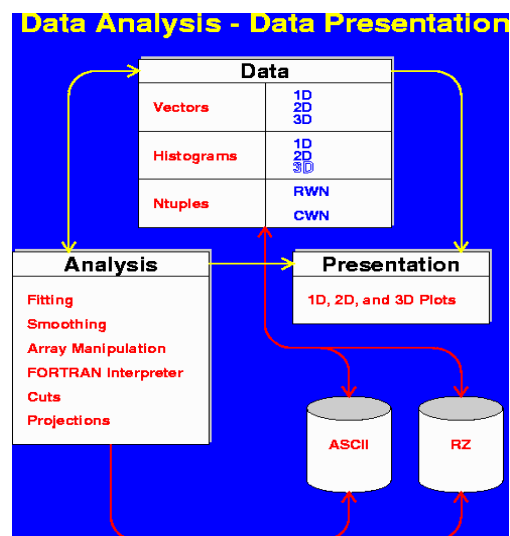
VECTOR/DRAW

5. PAW Commands can be grouped into Macros



5.1.3 Data Analysis

PAW is implicitly based on a family of fundamental objects. Each PAW command performs an action that either produces another object or produces a “side-effect” such as a printed message or graphics display that is not saved anywhere as a data structure. Some commands do both and some may or may not produce a PAW data structure depending on the settings of global PAW parameters.



5.1.4 Basic Structure of PAW



5.2 ROOT

ROOT is a framework for data processing, born at CERN, at the heart of the research on high-energy physics. ROOT is a system for large scale data analysis and data mining. It is being developed for the analysis of Particle Physics data, but it can be equally well used in other fields where large amounts of data need to be processed. ROOT is currently being used in many different fields: physics, astronomy, biology, genetics, finance, insurance, pharmaceuticals, etc.

Like PAW, it is a general-purpose program to fit arbitrary functions to your data via the method of Chi-square minimization (or maximum likelihood), and offers a variety of plotting options. The main advantage over a program like Microsoft Excel is that it can fit nonlinear functions, and it returns the errors on the fitted parameters. Also, it is distributed free of charge

The source and binaries for many different platforms can be downloaded from the ROOT web site (<http://root.cern.ch/>).

Root differs from PAW in that it is based on the modern C++ programming language rather than FORTRAN or the KUMAC scripting language. So you don't have to learn a new syntax. It can run compiled programs, so it is faster, and it has a nice GUI for manipulating plots. On the other hand, you have to learn the many class names that are available, which in a sense is like learning new commands. Also, I find that you have to write more code to accomplish the same thing as in PAW.

5.2.1 Main Features of ROOT

The main components of the ROOT system are:

- A hierarchical object-oriented database (machine independent, highly compressed, supporting schema evolution and object versioning)
- A C++ interpreter
- Advanced statistical analysis tools (classes for multi-dimensional histogramming, fitting and minimization)
- Visualization tools (classes for 2D and 3D graphics including an OpenGL interface)
- A rich set of container classes that are fully I/O aware (list, sorted list, map, btree, hash table, object array, etc.)

- An extensive set of GUI classes (windows, buttons, combo-box, tabs, menus, item lists, icon box, tool bar, status bar and many more)
- An automatic HTML documentation generation facility
- Run-time object inspection capabilities
- Client/server networking classes
- Shared memory support
- Remote database access either via a special daemon or via the Apache web server
- Ported to all known UNIX and Linux systems and also to Windows 95 and NT.

The complete system consists of about 450,000 lines of C++ and 80,000 lines of C code. There are about 310 classes grouped in 24 different frameworks (each represented by their own shared library).

5.2.2 The CINT C/C++ Interpreter

One of the key components of the ROOT system is the CINT C/C++ interpreter. CINT, written by Masaharu Goto of Hewlett Packard Japan, covers 95% of ANSI C and about 85% of C++ (template support is being worked on, exceptions are still missing). CINT is complete enough to be able to interpret its own 70,000 lines of C and to let the interpreted interpreter interpret a small program. The advantage of a C/C++ interpreter is that it allows for fast prototyping since it eliminates the typical time consuming edit/compile/link cycle. Once a script or program is finished, you can compile it with a standard C/C++ compiler (gcc) to machine code and enjoy full machine performance. Since CINT is very efficient (for example, for/while loops are byte-code compiled on the fly), it is quite possible to run small programs in the interpreter. In most cases, CINT out performs other interpreters like Perl and Python.

Existing C and C++ libraries can easily be interfaced to the interpreter. This is done by generating a dictionary from the function and class definitions. The dictionary provides CINT with all necessary information to be able to call functions, to create objects and to call member functions. A dictionary is easily generated by the program root cint that uses as input the library header files and produces as output a C++ file containing the dictionary. You compile the dictionary and link it with the library code into a single shared library. At

run time you dynamically link the shared library, and then you can call the library code via the interpreter. This can be a very convenient way to quickly test some specific library functions. Instead of having to write a small, test program, you just call the functions directly from the interpreter prompt.

5.2.3 Architectural Overview

The backbone of the ROOT architecture is a layered class hierarchy with currently around classes grouped in about frameworks divided in categories. This hierarchy is organized in a mostly single rooted class library that is most of the classes inherit from a common base class TObject.

1. **The Class Categories:** The basic ROOT classes contain the most low level building blocks of ROOT. For example the TObject class which implements common behaviour for all ROOT classes. The class TClass and its helper classes that provide support for extended runtime type information. The storage manager TStorage which handles all memory allocation and de allocation operations and performs basic error checking memory overwrites etc. The class TFile which provides a hierarchical sequential and direct access persistent object store. The operating system abstraction layer TSystem and the concrete OS interfaces TUnixSystem, TWinSystem and TMacSystem concentrate all OS dependent behavior like file system access, dynamic loading and interprocess communication (IPC) for the three main platforms supported by ROOT. The container classes provide general purpose data structure classes like arrays, lists, sets, Btrees, maps, etc. which are heavily used in the implementation of ROOT itself.
2. **The TObject Class:** Most ROOT classes are derived from TObject. TObject defines protocols, abstract methods for comparing objects, for object I/O, for graphics hit detection and for notification between objects to name the most important ones.
3. The ROOT object I/O facility supports the transfer of arbitrarily complex polymorphic data structures from memory to a ROOT file and vice versa. This functionality is based on the abstract method Streamer, which is overridden in subclasses to stream an object's instance variables. Circular structures are liberalized and multiple references to the same object are restored properly. Storing pointers is implemented by an object table, which assigns a unique identifier to each

transmitted object This identifier can be transferred to other address spaces or to permanent storage.

Conclusions:

The lab is successfully set and equipped with *gas mixing unit*, *data acquisition system* for signal processing or monitoring and *cosmic ray muon telescope* with *test stand* for the prototype RPC procured from TIFR and the *high voltage power supply system 2527* from CAEN. All the systems are operational and we had been able to successfully test the prototype RPC operating in avalanche mode. Various characteristic like V-I, noise ration etc of RPC are studied. We have made various size scinillator paddles and have monitored the stability of the cosmic ray muon telescope for stability using various NIM and CAMAC modules like discriminators, fan in fan out, coincidence logic unit, scalars etc. RPC signals are monitored on CRO. *Efforts are continued to add on more instrumentation to the lab which can be required to fabricate and test the large area resistive plate chambers for CMS experiment.*

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