Analysis of RPC Performance with Different Gas Mixture

Cern Summer Student Programme Report

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1 Introduction

1.1 LHC and RPC detector

The Large Hadron Collider, LHC, is a proton-proton collider installed at CERN in the LEP tunnel 100m underground in Geneva. Four experiments − ALICE, ATLAS, CMS, and LHCb − are installed at four interaction points where proton-proton collisions occur. Resistive Plate Chambers, RPCs, are used in ALICE, ATLAS, and CMS in the muon stations. As we will discuss in the next section, RPCs have fast time response, so they are widely used in LHC experiment for trigger. For example, CMS uses RPCs to provide muon trigger system combined with DTs and CSCs. The aim of our test is to find new gas mixture used in RPCs.

1.2 Principle of RPC detector

Fig. 1 shows the overview of RPC detector. It is mainly composed of two high resistive plate (usually bakelite), separated about 2mm. Electrode are placed outside the plates to apply high voltage. The pickup strips are placed outside the plates with insulator between them to read out the induced signals. Spacers are inserted between two plates to maintain the right distance between the plates and proper gas mixture fill the gap region. By applying high voltage about 5kV/mm between the two plates, RPC can be operated as an ionization detector.

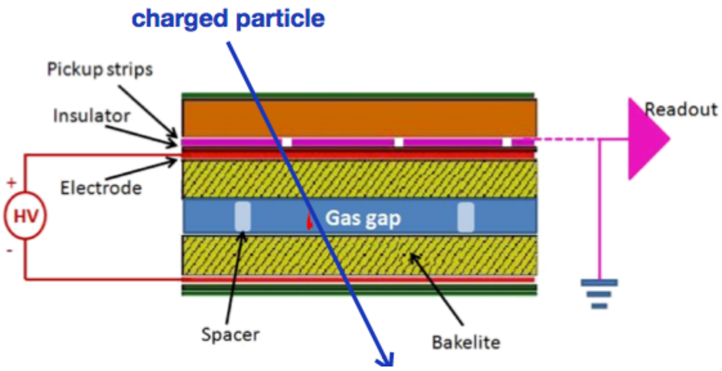

Figure 1: overview of RPC detector

When a charged particle passes through the gap region, it can ionize the gas molecule, creates electrons and ions, which accelerated by electric field. When the electrons become fast enough, they can generate secondary ionisation. The secondary ionised electrons can also generate another ionization again. This process repeats many times and finally the multiplication factor can be 10^7. One of the biggest feature of RPC is that since the plates are highly resistive, by choosing proper voltage, cascade multiplication decrease down by itself and it does not expand all over the ditector. Due to this localization mechanism, RPCs can be operated at high rate such as $1\mathrm{kHz/cm^2}$. This operation mode is called avalanche mode. In addition since the electric field is constant between two plates, cascade multiplication occur in all the gas volume. RPCs don't have drift volume, which is main contribution to low time resolution in other gaseous detectors.

However, if the multiplication factor is higher than Geather limit, ionization of gas molecule can be occurred outside the avalanche region and the signal can expand to all the gas gap. This type of operation mode is called streamer mode. Since the multiplication is not localised and the multiplication process takes much longer time, time resolution and flux tolerance of streamer mode can be much worse than avalanche mode.

RPCs in ATLAS and CMS are operated in avalanche mode for having high rate capability.

1.3 Gas mixture of RPC

The ATLAS and CMS RPCs gas mixture is composed of 95.2% $C_2H_2F_4$, 4.5% i-C_4H_{10}, and 0.3% SF_6. $C_2H_2F_4$ is to be ionised by incident particle, i-C_4H_{10} is quencher gas to absorb soft X-ray which can induce streamer mode, and SF_6 is an electronegative gas to prevent too high multiplication process which will

result in streamer mode.
Though this gas mixture is widely used, $C_2H_2F_4$ and SF_6 are not environmentally friendly gases. Global Warming Potential, which is defined as potential for ozone layer distraction compared to CO_2, of $C_2H_2F_4$ and SF_6 are 1430 and 23900. The goal of this test is to find good substitution for standard gas mixture. The requirements are:

- A voltage range lower than 10 kV where RPCs can be operated with about 100 % detection efficiency.
- The streamer mode probability is not high where the detector is efficient.
- Time resolution is not worse than about 10 ns.
- The gas mixture is not environmentally bad.

During this summer student programme, we tested several gas mixtures containing R1234yf, and R1234ze. In this report, we discuss about standard gas mixture with SF6 variation as an example.

2 Set-up

Fig. 3 shows our set-up for RPC gas measurement. The RPC gap is 2 mm, surface area is 80×100 cm^2. Signals are read from 7 read-out strips of 2.1 cm wide. Two scintillators are placed above and under the RPCs to generate trigger signal. We used CAEN Digitizers V1730 and CAEN WaveDump to record signal from RPCs and scintillators. Gas flow was controlled by Mass Flow Controller, and monitored during measurement. Temperature and pressure in the laboratory are also monitored using Picolog.

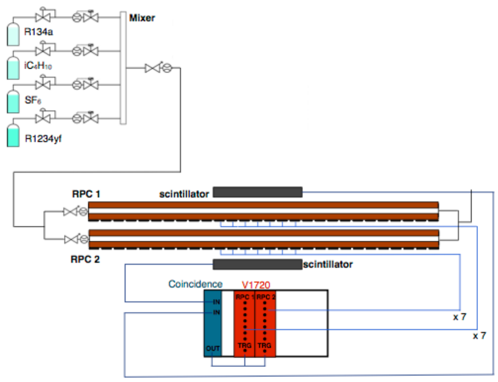

Figure 2: Schematic view of our RPC set-up

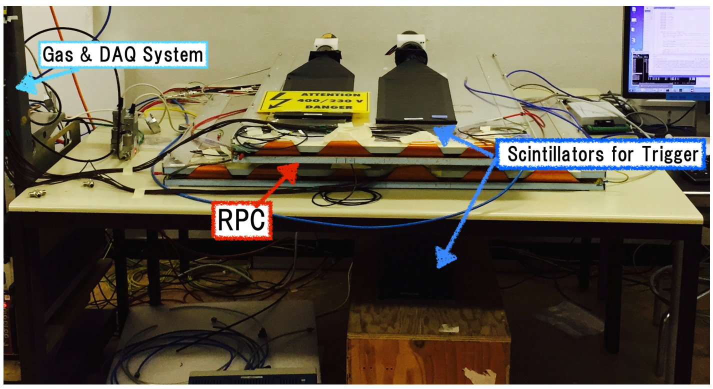

Figure 3: Picture of our RPC set-up

Measurements were performed using cosmic rays. The trigger rate was about 2 Hz, and we acquired about 10 minutes data for each mixture and high voltage to obtain enough statistics. During the measurement, the temperature of the laboratory is kept between 21 and 23 degrees, and pressure was kept between 960 and 975 mbar.

3 Data and analysis

Analysis method and results are described in this section using standard gas mixture as a example.

3.1 Typical waveform and definition of several values

Fig. 5 is a typical wave form when avalanche and streamer mode come together. As it can be seen, the pulse height of avalanche signal is small, less than 10mV, and the time scale is very short. On the other hand, streamer signal is higher, usually more than 20mV, but the time scale is much longer than that of avalanche.

In order to distinguish avalanche and streamer signals, we calculated pulse height, integrated charge, and timing of the two signals. The method is as follows (Fig. 6).

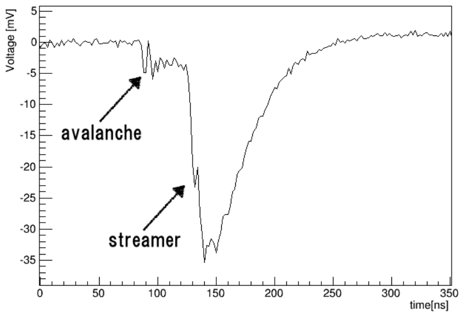

Figure 4: Typical wave form of RPC

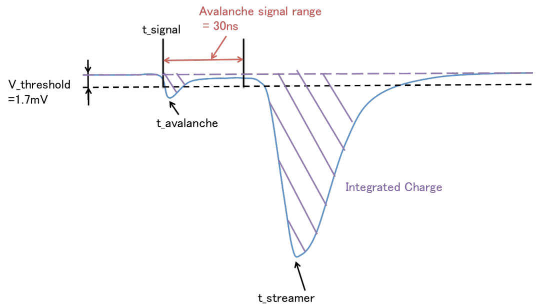

Figure 5: schematic description of analysis method

1. Take average of the voltage height for 6 us before signal comes, and call the mean value as “baseline”.
2. Find the timing the voltage passes “V_threshold”, (= 1.7mV) and call this timing “t_threshold”.
3. Search the highest voltage timing in “avalanche signal range” which is predefined 20 ns after “t_threshold”, and defined the timing as “t_avalanche”. In addition, we imposed some cuts to enhance data quality which is explained in 3.3.
4. Search the highest voltage timing and height in whole region, and defined them as “t_streamer” and “pulse height”.
5. Calculate “integrated charge” by integrating height of signal.

Finally, we defined avalanche signal as signal whose integrated charge is less than 3 pC, and streamer signal as signal whose integrated charge is more than 3 pC. Fig. 7 shows histograms of integrated charge. It can be seen as applied voltage becomes higher, we can see more streamer signals around 10 pC.

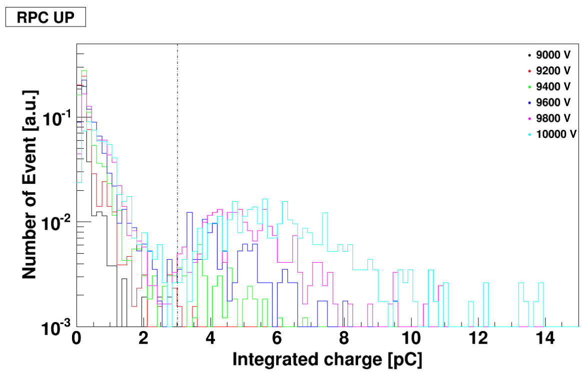

Figure 6: Integrated charge distribution for standard gas mixture

3.2 Voltage dependence of Detection Efficiency and streamer mode probability

As mentioned before, our goal is to operate RPC in avalanche mode. The ideal operation voltage is when detection efficiency is near to 1 while streamer probability is almost 0. In addition, wider ideal range is preferred to maintain RPC operation stability. We changed voltage applied to the RPC and measured detection efficiency and streamer mode probability.

Fig. 8 shows detection efficiency and streamer probability of standard gas mixture with different SF6 concentration. It can be seen that without SF6, the voltages when efficiency of RPC and streamer probability rise are not so separated, and we cannot find ideal voltage to operate. By adding SF6 we can suppress streamer signal and we can find a voltage range where detection efficiency is high while streamer probability is low. However, we cannot use high SF6 percentage because the operation voltage is more than 10 kV. It can be seen that with standard gas mixture, the RPC can be operated stably at about 9.8 kV.

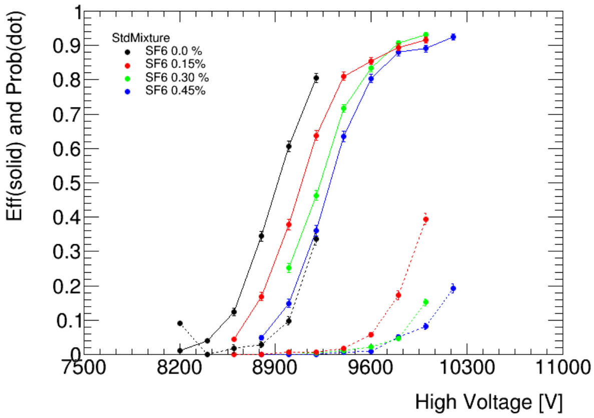

Figure 7: Detection Efficiency and streamer mode probability as a function of voltage

3.3 Time resolution of RPC

Time resolution is one of the biggest advantages of RPC. The intrinsic time resolution of RPC is about 1 ns, but due to several reasons such as electronics, incompleteness of plates, uniformity of gas mixture, the effective resolution can be worse. We changed voltage applied to the RPC and measured time resolution. Here, we used "avalanche signal timing" as the timing of RPC and calculated RMS of that.

In order to increase data quality, we imposed two cuts for analysis. The cut conditions are as below.

- The minimum value in "avalanche signal region" should be separated less than 8.5mV from baseline.
- The timing of "t_avalanche" is neither the final timing nor the timing before final in avalanche region.

The first condition is to assure that the minimum value is not from streamer but from avalanche. Since the impedance of our circuit was 50 Ω and one record step of digitiser was 2 ns, 8.5 mV corresponds to $8.5\times2/50 = 2$pC. This value is close to the threshold for streamer signal, 3 pC. Therefore, it is reasonable to set cuts to 2pC. The second condition is to reject recording rising slope of streamer signal. There are many streamer signals which is too close to avalanche and indistinguishable from avalanche signal. Without the condition above, it is possible that rising slope of streamer mode is recorded as "avalanche signal timing".

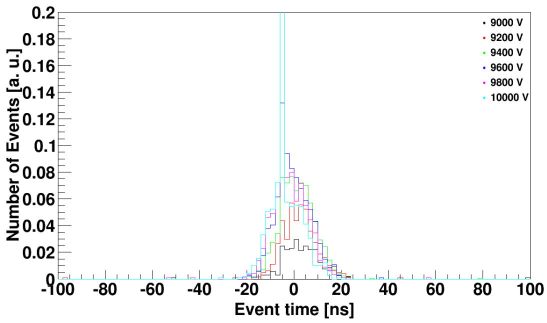

Figure 8: "t_signal" distribution of our RPC

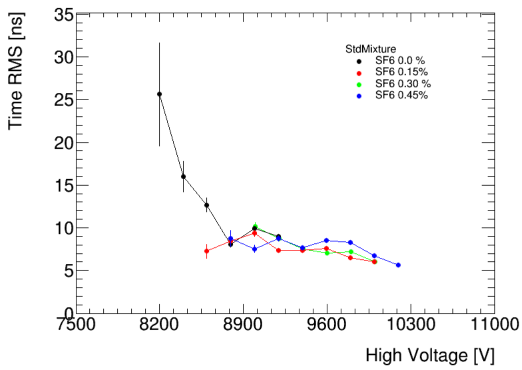

Figure 9: Time resolution of standard gas mixture RPC

Fig. 9 shows the time distribution for standard gas mixture and Fig. 10 shows the RMS of timing distribution as a function of applied voltage. Time resolution for our RPC is about 5 ns with standard gas mixture and as the applied voltage becomes higher, time resolution becomes better. Indeed as electric field becomes strong, the length of time required to create signal becomes shorter, and the RMS of timing distribution becomes better.

3.4 Timing difference distribution of avalanche and streamer signal

Timing difference of avalanche and streamer signal can affect the performance of RPC. We changed voltage applied to the RPC and measured the behaviour of timing difference. Here, we took the deference of "t_avalanche" and "t_streamer". Also, we imposed same cut condition as described in section 3.4.
Fig. 11, 12 shows obtained timing difference histograms for standard gas mixture.

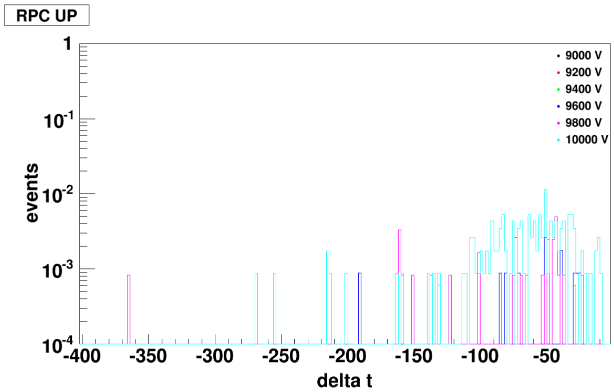

Figure 10: timing deference distribution of our RPC

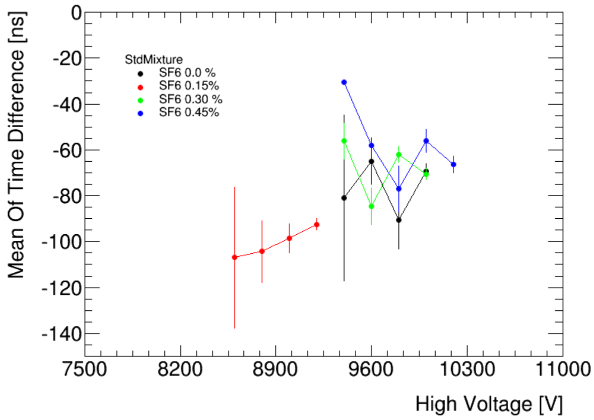

Figure 11: Timng deference as a function of HV

Timing diference of avalanche signal and streamer signal is about 60 ns. We can see slightly that as the applied high voltage becomes higher, time difference of avalanche and streamer signal becomes shorter. One possible explanation is that in high electric field, streamer signal grows faster and the difference can becomes shorter.

4 Conclusion

During this summer student program, I established analysis method to analyse performance of RPC with different gas mixtures. It includes recording temperature and pressure, monitoring applied high voltage and current, creating warning signal when voltage or current have strange behaviour, accessing to mass flow controller file to record gas flow, and extracting desired values from signals as described in this report. These analysis methods have also been applied to several gas mixtures tested in the laboratory and must be helpful in general RPC tests.