Resistive Plate Chamber Detector Efficiency Curve

Summer Student Report

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ABSTRACT

In the ATLAS detector, the resistive plate chambers (RPCs) provide the first-level muon trigger and the measurement of the coordinate in the muon spectrometer. RPCs which have high time resolution, are installed parallel to the muon drift tubes (MDTs), which have high spacial resolution. This summer project revolves around plotting the efficiency curve of the newly developed RPC-like cylindrical detector, which is called resistive cylindrical chambers (RCCs).

I. INTRODUCTION

RPCs are made of 2 oppositely charged high resistivity plates, separated by a thin layer of gas. The gas is currently composed of 94.7% of $C_2H_2F_4$, 5% of C_4H_{10}, and 0.3% of SF_6 [1]. When there is a muon passing through the gas chamber, electrons are knocked out of the atoms of the gas. These electrons will then hit other atoms creating an avalanche of electrons. There is a layer of graphite on the resistive plate, which is carefully chosen to allow high frequency signal to pass through, the external metallic strips will then pick up the signal from the electrons only, but not the positively charged ion. The time delay between the trigger and the signal is also precise, giving it a billionth of a second time resolution[2]. However, the spacial resolution is limited by the width of the metallic strips, which is in the order of centimeter. Also, there is a small chance for the muon to pass through the thin layer of gas without knocking out any electrons. As the gas chamber is not pressurised, for 1 mm gas gap, it is about 1.5%. To ensure the gas gap is 1 mm across the entire RPC, separators of height 1 mm are placed in the RPC plate, as shown in Fig. 1, which essentially added dead area to the detector and further decrease the efficiency.

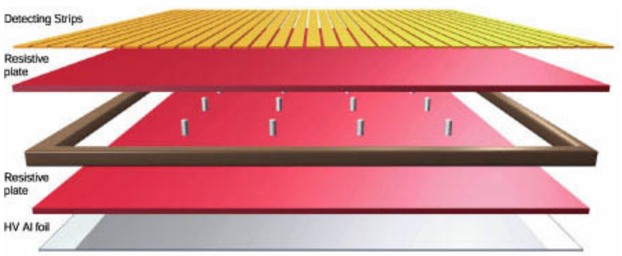

Fig. 1: Diagram of the structure of the resistive plate chamber[2].

A new generation of detector, RCC is therefore created to overcome the limitations. As shown in Fig. 2, the RCCs are made up of two concentric cylindrical electrodes of high resistivity material where the gas gap has a negligible thickness with respect to the cylinders radii. With the cylindrical geometry, the forces are balanced and the electrodes can be held in place[1]. The side walls can be reinforced using metal pipes to contain gas pressure up to order of 10 bars, and to keep the cylinders in position[3]. This removes the need of separators in RPCs and increases the efficiency of the detector. With higher gas pressure, the probability of muon passing through the gas gap without ionising any atom is also reduced. On the other hand, the cylindrical geometry made track reconstruction possible with only one gas gap. The field inside the gas gap can also be controlled to be radial geometry, where the gap is much larger than the radius, or uniform field, where the gap is much smaller than the radius[1].

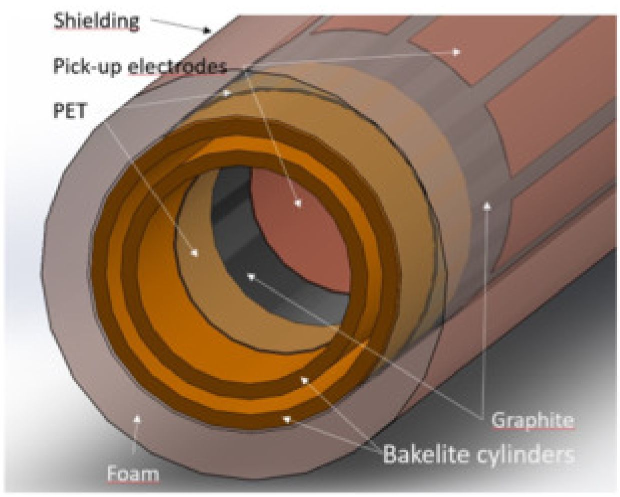

Fig. 2: Diagram of the structure of the resistive cylindrical chamber[3].

Another important apparatus used in this summer project is the scintillator. When struck by an muon, it will absorb energy and re-emit the absorbed energy as light. The scintillator is connected to a photomultiplier tube (PMT) at one end, which can absorb the light emitted by the scintillator and convert it into electron and amplify the signal. Scintillators are used to confirm the signals from RPC/RCC are triggered by muon, instead of random noises.

II. METHOD

The experimental setup is shown in Fig. 3. The two golden rectangular boxes contain scintillator, which are connected to the oscilloscope as trigger. When two scintillators are triggered at the same time, it is highly improbable that the signal is from random noise, thus confirming there is a muon passing through.

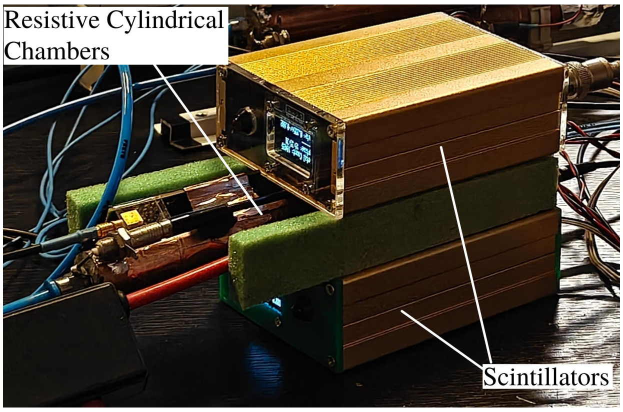

Fig. 3: Experimental setup of a RCC sandwiched between two scintillators for finding efficiency curve.

Voltage ranging from 2000 V to 5400 V with 200 V separation was applied to the RCC with 300 μm gas gap by the high voltage supply. The RCC was connected to the oscilloscope through an amplifier to read the signal, which the data can then be analysed to find the efficiency. However, the scintillator spans a wider planar area than the RCC. The calculated acceptance, which is the total number of signals divided by the total number of triggers, will be an underestimation to the efficiency of RCC, as some muon may pass through the scintillators but not the RCC. The setup was then upgraded to the configuration shown in Fig. 4. The overlapped area between three scintillators is then similar to the diameter of the RCC. The acceptance calculated will then be a closer estimation to the efficiency of the RCC.

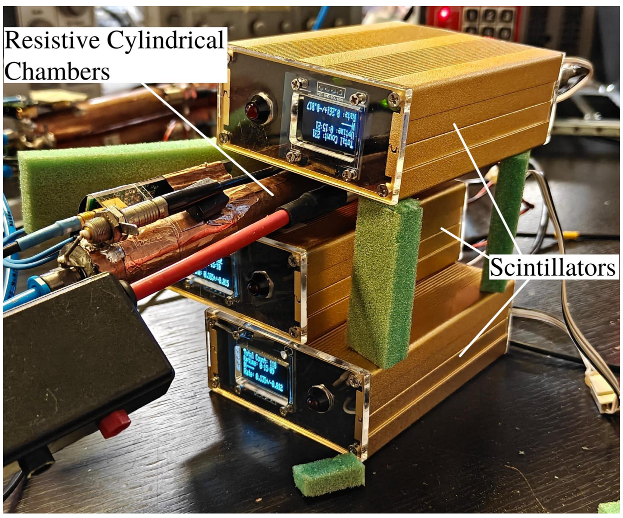

Fig. 4: Experimental setup of a RCC sandwiched between three scintillators for finding efficiency curve.

The oscilloscope was set to use the three scintillators as trigger, it will save the waveform from the RCC, and scintillators as CSV files. These files will then be converted to a single ROOT file for storage and ease of access. The structure of the ROOT file is shown in Fig. 5. The root file contains folders from 2000 V to 5400 V with 200 V separation, each folder contains events recorded at the corresponding voltage applied, each events contain data from the four channels of the oscilloscope, namely the waveform from RCC, and the three scintillators.

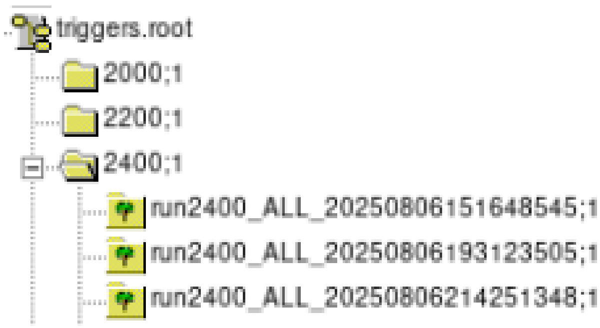

Fig. 5: Data structure of the ROOT file.

III. DATA ANALYSIS

Then, a computer programme was used to eliminate events which contains noise and to find the number of signals. Events that contained data of infinite magnitude, and false trigger were eliminated. To filter signals from background noise, moving average with 5 ns selection was performed on the RCC waveform for each event. This can smooth out the waveform for further analysis. Then, the data points of the waveform before the trigger was used to plot histogram and Gaussian curve fitting was performed. Using the standard deviation (sigma) from the Gaussian curve fitting, the signal peaks from RCC near the trigger which have magnitude larger than 5 sigma threshold away from the mean value of noise were classified as a signal. This process was performed on each event, and the efficiency can be estimated by total number signals divided by the total number of triggers. By repeating these calculations for all voltages measured, efficiency curve can be plotted. The plot is shown in Fig. 6, and the data is tabulated in Table. I. For some of the voltages applied, we took more data to have a more accurate efficiencies.

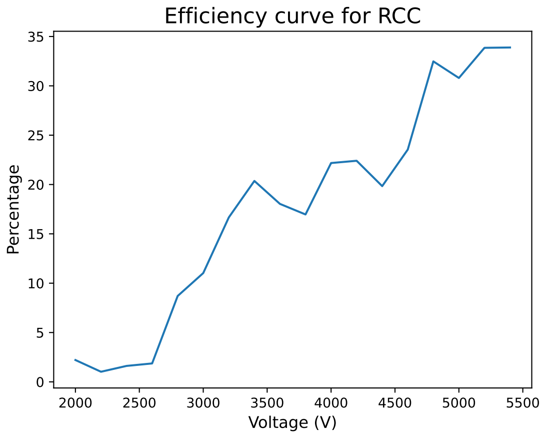

Fig. 6: Experimental setup of a RCC sandwiched between three scintillators for finding efficiency curve.

Applied voltage (V)	Number of signals	Number of triggers	Efficiencies
2000	11	497	2.2
2200	5	488	1.0
2400	8	495	1.6
2600	9	482	1.9
2800	43	494	8.7
3000	57	517	11.0
3200	82	492	16.7
3400	101	496	20.4
3600	90	499	18.0
3800	85	501	17.0
4000	220	992	22.2
4200	108	482	22.4
4400	97	489	19.8
4600	117	497	23.5
4800	165	508	32.5
5000	607	1971	30.8
5200	325	960	33.9
5400	326	962	33.9

Table I: Number of signals, triggers, and the efficiencies for different voltage applied across RCC gas gap.

As one can observe, the efficiency increases from nearly zero at below 2600 V applied, to the plateau after 4800 V, which is around 32% to 34%. The RCC used in this experiment has a gas gap of 300 μm, the calculated efficiency is in a reasonable range.

IV. CONCLUSION

For this summer project, the efficiency for the RCC was calculated at different voltages applied across the gas gap. It was found that the efficiency is around zero below 2600 V. It increases to and plateaus around 32% to 34% after 4800 V, which is consistent with the expectation for RCC with 300 μm gas gap.

V. ACKNOWLEDGEMENT

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[2] Anonymous, "Resistive cylindrical chambers," (n.d.), `https://cms.cern/detector/detecting-muons/resistive-plate-chambers`.
[3] R. Cardarelli, A. Rocchi, G. Aielli, P. Camarri, A. Di Ciaccio, L. Di Stante, B. Liberti, E. Pastori, and G. Proto, Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment **1058**, 168822 (2024).