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INVESTIGATION OF RESISTIVE PARALLEL PLATE CHAMBERS

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Abstract

The resistive parallel plate chamber (RPC) has been developed during the last 10 years. We have investigated two versions of these chambers, one with cellulose and the other with phenolic plates. We present a comparison between these two for various gas mixtures and the dependence on particle flux.

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1. INTRODUCTION

The detection of muons at future super colliders is very important. Coupled to this there is a need for a trigger that selects a muon above a given P_t . The identification of muons relies on charged particles penetrating many interaction lengths of absorber, this implies that for the muon trigger we need a detector that is cheap to build (as many m^2 will be needed). It also needs to have good time resolution (bunch crossing every 15 nsec) and good spatial resolution (1 cm or better). During the last 10 years a detector known as the resistive plate chamber (RPC) has been developed by Santonico et al.[1,2] which seems to satisfy these requirements. We have constructed chambers of this type in our laboratory. Our goal was to investigate the operational characteristics of this device and possibly to find a better gas mixture or alternative materials for the resistive plates. However the dominant finding of our investigation was that these chambers do not operate well at very modest rates.

The cross section of a chamber similar to that described in [1,2] is shown in figure 1. Essentially it is two plates of phenolic composite separated by 2 mm. Voltage is applied to a carbon film painted onto the outer sides of these phenolic plates; this produces a high electric field across the gap between the plates. The gap between the plates is sealed and a suitable gas flowed. The ionisation from a through going charged particle initiates a spark discharge in the gas. The high resistivity ($\rho = 10^{11} \Omega \text{ cm}$) of the phenolic plates quenches this discharge. After this discharge the phenolic plates will be charged with electrons and positive ions. This charge is slowly dissipated by conduction through the plates.

The phenolic plate is made from laminated paper impregnated in a phenolic resin; we were concerned that there may be problems associated with local non-uniformity of these plates. Pol.hi.tech.# found that cellulose film has a similar resistivity to phenolic and built a test chamber for us using this material. A cross section is shown in figure 2.

In this paper we will report on the comparison of operation between these two chambers (phenolic and cellulose). We also will present our findings concerning the rate dependence of these chambers.

2. The Phenolic and Cellulose Test Chambers

2.1 Construction

The cross section of the two chambers is shown in figures 1 and 2. The chamber with phenolic plates was an attempt to reproduce the chambers described in [1,2]. The phenolic plates are 2 mm thick paper based phenolic available in the CERN stores. We measure the

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resistivity to be $3 \times 10^{11} \Omega \text{ cm}$ over the full test range of 0 to 8000 volts across the plate. The plates are $30 \times 35 \text{ cm}^2$ in size. On one side we cover an area of $25 \times 30 \text{ cm}^2$ with carbon paint that has a resistivity of $5 \text{ k}\Omega/\square$. We cover this with a thin sheet of glass-epoxy board (0.2 mm thick) also painted with carbon paint on one side; the carbon paint is connected to a copper electrode on the glass-epoxy foil. The layers of carbon paint are in contact, thus a voltage can be applied to phenolic plate by applying the voltage to the copper electrode on the glass epoxy foil. This is covered with a $200 \mu\text{m}$ thick foil of mylar, and finally we place the signal pickup board. This is a standard printed circuit board, 1 mm thick, on which we have etched just one pickup pad of $22 \times 26 \text{ cm}^2$. The same procedure is used for both phenolic plates making the chamber. The two plates are held apart by a PVC spacer 2 mm thick. This spacer is glued to the edges of the phenolic plates making a gas tight envelope. Gas is fed into this gap with small pipes through this 2 mm spacer. Finally this test chamber is held together and rigid by clamping it between two sheets of 1 cm thick Plexiglas. One difference between our test chamber and those built by Santonico et al. is that they apply a layer of oil to the surface of the phenolic. This is required to remove finger prints and fill scratches created in the construction of the chamber. Since our test chamber is small we could ensure that the surface was not scratched. We cleaned the phenolic plates just before sealing the chamber.

The chamber shown in figure 2 has been constructed by Pol.hi.tech. This chamber has an active area of $26 \times 26 \text{ cm}^2$. The cellulose foil is painted with carbon paint in a similar way as the phenolic boards. The cellulose is then glued to a polycarbonate support board 6 mm thick with tubular cross section. The pickup strips are glued to this support board, followed by another support board with the tubes running orthogonal to the first. Finally a ground plane forms the outer surface. We measure the resistivity to be $0.9 \times 10^{12} \Omega \text{ cm}$ at 22°C and $3.6 \times 10^{12} \Omega \text{ cm}$ at 11°C . For our tests we have connected all strips to form one pad. Typical pulses obtained from this chamber in a test beam are shown in figure 3.

2.2 Test with Cosmics

We mounted the chambers horizontally and tested the response to cosmic rays. In figure 4 we show the detection efficiency versus high voltage for various gas mixtures. The curves are to guide the eye; one can observe with the data from the phenolic chamber that there is a large shift in the plateau for small changes in the gas mixture. The cellulose chamber appears to have a higher value for the efficiency, but the efficiency drops with increasing high voltage; however with 6% freon the plateau appears flat. For these tests the signal from the chamber was amplified by a $\times 10$ amplifier and then discriminated by a standard discriminator. The threshold was set to be just above the noise and was typically between 50 and 100 mV (i.e. between 5 and 10 mV of the chamber signal). The same scheme was used in the test beam.

2.3 Test with Test Beam

2.3.1 Efficiency measurements

We have mounted the chambers in a test beam in the East Hall at CERN. The beam was defocused (by turning off the last two quadruple magnets) so that the particle flux was largely contained in a 10 cm diameter spot. We selected the central $10 \times 10 \text{ cm}^2$ of the chambers with a scintillator. We measure the efficiency by counting the number of particles in our scintillator telescope and also the number in coincidence with a signal from the chamber under test. The telescope signal width was 150 ns and the chamber signal width was 50 ns. The timing was set so that a coincidence would be registered if the chamber produced a signal within 100 ns of the average time of the signal from the chamber. With this arrangement we feel confident that our results have not been affected by (a) changes in the timing of the chamber signal at high rates and (b) effects due to two particles not being resolved at high rates. We show the efficiency versus high voltage for various incident particle rates (figures 5 and 6) for the two chambers with two gas mixtures. The particles arrived in a spill of 350 ms every 15 seconds. The efficiency was calculated by integrating over several spills, and the flux is the average flux during a spill. The maximum efficiency versus flux is shown in figure 7. We observe a large drop of 45% in the efficiency with an increase in flux from 0 to 100 Hz/cm^2 . Bertino et al [3] have measured the rate dependence of the phenolic chambers described in [1] and [2]; they have measured a drop from 97% to 86% for the same increase in flux (0 to 100 Hz/cm^2).

What is the cause of this large discrepancy between these two measurements? A possible explanation is as follows. These chambers operate in a quenched spark mode. Through-going ionising particles initiate a discharge. This discharge deposits charge on the surface of the resistive plates. This charge reduces the electric field making this particular region less efficient. This charge on the surface is removed by conduction through the resistive plates. However, on a shorter time scale the charge can diffuse laterally, thus reducing the voltage by a small amount over the whole plate. Bertino et al. tested a chamber with an active surface of $2\text{m} \times 1\text{m}$ and the test beam was concentrated in a spot ($3 \times 3 \text{ cm}^2$ or maybe a bit bigger). In comparison our chamber is much smaller and we used a beam that covers a large part of the chamber. Thus for the test performed by Bertino et al. lateral diffusion can play a role.

To check this hypothesis we tested the chambers with a beam spot of (a) $4 \times 5 \text{ cm}^2$ and (b) totally defocused, thus completely covering the chamber. The efficiencies as a function of the beam intensity for these two conditions are shown in figure 8. One can see that when the beam is confined to a small area of the chamber (the beam spot of $4 \times 5 \text{ cm}^2$ is 3.5% of the phenolic chamber area of $22 \times 26 \text{ cm}$) a rate of 1kHz/cm^2 (in this spot) will

reduce the efficiency to 25%. A similar drop in efficiency can be obtained by having a rate of 100 Hz/cm² over the whole chamber area. One should also note that if we extrapolate the focused beam results to 90% at 0 Hz (the smooth curve), the slope of this curve for the focused beam data is very similar to the result published by Bertino et al.

The efficiencies presented above are those obtained by integrating over the whole spill. If we measured the efficiency for the first 1000 beam particles of each spill we have an efficiency that is much higher and that does not show a large rate dependence. Figure 9 shows for different particle rates the efficiency measured over the first 1000 particles of each spill and measured by integrating over the whole spill (~ 350 ms). One can also do a similar thing for the first 100 particles and obtain an efficiency of around 90%. In figure 10 we show the efficiency measured over the first, second, third and fourth 100 ms of the beam spill for a defocused beam with a rate of 60Hz/cm² in the beam spot for the phenolic chamber. One can see that the efficiency drops during the spill, thus our measured efficiencies are somewhat optimistic. From the above results one concludes that the operation of the chamber must be dominated by lateral diffusion, and the drop in efficiency is caused by the whole surface of the resistive plate becoming charged. The measurement of Bertino et al. was performed by exposing only 0.05% of the chamber area to the beam. Their drop of 11% results from a rate of 100 Hz/cm² in the beam spot; this is equivalent to exposing the whole chamber surface to a rate of 4 Hz/cm² (see figure 8).

2.3.2 Timing measurements

The time response of these chambers when exposed to cosmic rays is very good. The time spectrum is essentially gaussian with a FWHH of 10 nsec. However there is a long tail towards later times, 0.2% of cosmic triggers produce a late time of between 45 and 60 nsec. During our beam test the situation is not so clear as we could not work at these very low rates of 1 or 2 Hz/cm². In figure 11 we show the time spectrum measured by using the first 100 or the first 1000 events of each spill. This measurement was with a focused beam spot of 4 x 5 cm², with a rate of 500 Hz/cm² in this spot. Even though the FWHH is 10 nsec for each case, there is a large tail towards late times.

In figure 12 we show the time spectrum with a defocused beam with rates of 20, 35 and 65 Hz/cm². This data is obtained by integrating over the whole spill, one assumes that the tail of late times is produced by events towards the end of the spill, where the chamber is only 25% efficient.

3. Discussion

It appears to us that the drop in the efficiency is dominated by the charging of the plates. We have measured the capacitance of the 2mm thick phenolic plates and find a value of 16 pF/cm². Using a value for the resistivity of $\rho = 3 \times 10^{11} \Omega \text{ cm}$, then one obtains a value of $6 \times 10^{10} \Omega$ for the resistance per cm². This gives a decay time of $\tau = 1 \text{ sec}$. It is interesting to note that the value of τ does not depend on area, R decreases and C increases with area. The average charge in a discharge has been estimated by Cardarelli et al.[2] to be 0.1 nC. However this is only a measure of the fast component. The charging of the resistive surface will be dominated by the residual positive ions and electrons left after the discharge. This quite easily can be 100 time larger than the fast component. However even if we use this average charge of 0.1 nC and consider 50 discharges per cm² together with a capacitance of 16pF, we obtain a voltage of 300 volts. Since this happens on both plates it appears that we can reduce the voltage across the gap by 600 volts. This is balanced by the conductivity through the plate with $\tau = 1 \text{ sec}$. Obviously the time between spills (15 sec) is enough to discharge the phenolic plate and the also the cellulose plate, which has a resistivity 5 times higher. Given these figures our measured drop in efficiency is not so extraordinary.

As previously stated, our measurement of efficiency is by integrating over the whole spill. However the spill is only 350 ms compared with the time constant of 1 s. Thus our measurements are somewhat higher than the efficiency that will be obtained with a continuous flux. Our results also indicate that the charge of the surface of the resistive plate does not stay localised but spreads out; this leads support to the idea that maybe some of the efficiency can be recovered by increasing the applied voltage when faced with a continuous flux of particles.

4. Conclusion

It appears that cellulose can be used instead of phenolic, however the plateau is shorter and more freon is needed in the gas mixture. With an increase of particle flux both these chambers have a similar drop in detection efficiency. This drop would severely limit their use. The good timing resolution is also destroyed with increasing rate. We have tried using plates of materials with lower resistivity ($10^9 \Omega \text{ cm}$); however with these plates the chamber would enter a mode of continuous discharge.

It is possible that these chambers can be made to operate in a continuous flux better than our results indicate simply by increasing the applied voltage. In fact one can imagine a feed back system controlling the applied voltage.

There is also question of the single counting rate. If these chambers are to be used as large area trigger devices then the single counting rate has to be low. We have not concerned ourselves with this problem yet.

References

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3. M. Bertino et al., Nucl. Instr. and Meth. A283 (1989) 654.

FIGURE CAPTIONS

1. Cross Section of 'phenolic' type Resistive Plate Chamber.
2. Cross section of 'cellulose' type Resistive Plate Chamber.
3. Typical pulses observed on the pickup strips of a 'cellulose' type chamber.
4. Efficiency versus voltage for cosmic rays using different gas mixtures
5. Efficiency versus voltage in a test beam for a 'cellulose' type chamber.
6. Efficiency versus voltage in a test beam for a 'phenolic' type chamber.
7. Efficiency versus particle flux, beam confined to $10 \times 10 \text{ cm}^2$ region in centre of chamber.
8. Efficiency versus particle flux for two conditions; focused refers to a beam spot of $4 \times 5 \text{ cm}^2$, while defocused refers to a uniform beam illuminating the whole chamber.
9. Efficiency versus particle flux; the upper plot uses the first 1000 particles of each spill, the lower integrated over the whole spill.
10. Efficiency of a phenolic chamber measured at 4 points within a spill, the beam was defocused with a flux of 65 Hz / cm^2 .
11. Time spectrum using the first 100 or the first 1000 events in each spill. The beam spot was $4 \times 5 \text{ cm}^2$, with a flux of 500 Hz/cm^2 .
12. Time spectrum as produced for 3 particle rates. The beam was defocused.

FIGURE 2

CELLULOSE CHAMBER

Figure 3

FIGURE 4

FIGURE 5

FIGURE 6

FIGURE 7

FIGURE 8

Figure 9

Figure 10

FIGURE 11

FIGURE 12