An Affordable Particle Detector For Education – Interim Report

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Introduction

We are investigating a particle detector for use in schools which is inexpensive, safe, robust, compact, easy to use and maintain. Past investigations have looked into cloud chambers and scintillation detectors but we chose to open a new avenue and investigate Resistive Plate Chambers (RPCs). We chose to do this because of the apparent low cost of the materials required for the chamber and because research shows that less than half of schools have access to dry ice necessary for cloud chambers. A colleague is continuing research into scintillation based detectors.

An RPC is closely related to the spark chamber in that it registers charge freed from ionising particles. The key difference is that they do not need to be triggered and so do not need expensive coincidence detectors. An RPC comprises of two plates of highly resistive material which lie between the anode and the cathode, these plates in turn are separated by a small (2mm) gap filled with a gas mix. A particle event is registered by readout strips of conducting material which lie outside the electrodes. Figure 1 shows this skeleton setup.

A passing ionising particle ionises the gas locally along its path in the gas gap. The resulting electrons and ions move towards opposite electrodes and are 'slowed' by the two inner resistive layers. Since directly above and below the particle's path there is briefly a concentration of either positive or negative charge, an opposite charge is induced in the readout strips in accordance to the laws of electrostatics. The readout strips are isolated from the electrodes by another resistive layer.

The resistive plates between the electrodes also serve another purpose in that they lower the voltage in the gas gap thus greatly reducing the chances of a sustained spark, which is why they do not need triggering.

These types of detectors are generally designed to detect high energy muons from secondary cosmic rays. These particles are highly ionising and highly penetrating and so are detectible in the lower atmosphere. In practice it should detect any particle which has enough energy to ionise a noble gas. Although almost all schools have sources of radiation it was thought that cosmic rays would prove more interesting to investigate for schoolchildren and also allow for the possibility of a collaborative array of detectors such as the NALTA[1] and the SEASA[2].

Project Challenges

Typically these detectors are made for large scale industrial and research applications and so various modifications need to be made in order to make them suitable for classrooms. Most RPCs use flammable gases in the gas mix such as isobutane as well as strongly greenhouse gases such as freon and sulphur

[1] http://csr.phys.ualberta.ca/nalta/
[2] http://www.particle.kth.se/SEASA/

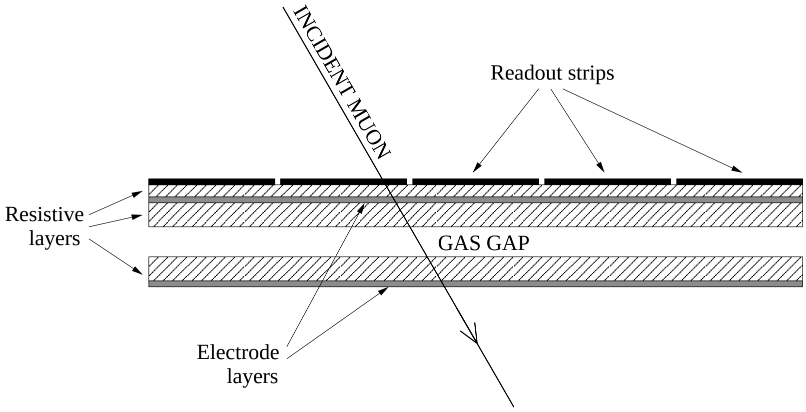

Figure 1: Schematics of a basic RPC

hexafluoride however research has been done into non-flammable, environmentally friendly mixes[1][2].

The high voltages used is another health and safety concern. Industrial RPCs use supplies which range from 4kV to 10kV whereas it has been suggested that schools are restricted to 5kV supplies by safety regulations. This may prove difficult to reconcile with the modified gas mixture and restricts us to streamer mode operation although this should not be a problem in our low rate application.

Although in the final product we envisage sealing the optimum gas mixture into the chamber, for testing purposes we need to develop a system where we can experiment with different gas mixes. This system needs to include a method of mixing the gases in correct proportions, it also needs to meet health and safety requirements in that any dangerous gases need to be vented properly and gas cylinders dealt with properly.

As always with this project we have to be vigilant with respect to costs. Our questionnaire has placed the available funds for candidate schools between a huge range of £30 to £1000, with the mode being £50! A more realistic figure is the median of around £125 (perhaps subsidies could be provided for less well-off schools). Ideally, the school could construct its own detector and so specialist skills in construction should be kept to a minimum.

Water has detrimental effects on the resistivity properties of glass and can also erode glass over time[4]. We need to figure out a way to ensure that the gas mixture is not only safe, green and effective but also free of water vapour.

Progress

A questionnaire was placed online[3] and advertised on the IOP mailing list and the Times Educational Supplement forums. We received around thirty responses from physics teachers nationwide. Information from this survey has been referred to throughout this report.

A prototype was designed and is in the process of being built. The design is illustrated in figure 2.

In order to create the gas gap we inserted a glass frame between the glass plates rather than plastic spacers. We did this because we are already working in glass for the resistive

[3] http://brendan.sdf-eu.org/misc/detector_survey.php

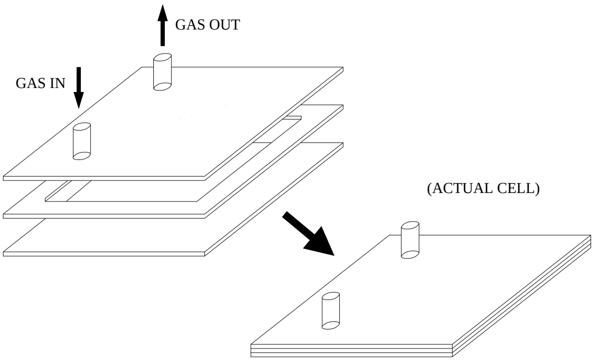

Figure 2: Our prototype RPC

plates and because it is a relatively cheap and widely available. Since we submitted the prototype design we found out that when working with glass it is a much easier process to cut a large circular hole in the frame rather than a rectangle. Future designs in glass will most likely feature a circular chamber.

Another novel feature is that the gas is introduced through two pipes in the top plate. This is easier to engineer and allows a continuous glass frame which make for a better gas seal. When it comes to applying the graphite paint for the electrodes we must take care paint around these stubs and leave a similar area unpainted on the bottom plate in order to ensure a linear field.

We have so far assembled a practice model on a smaller scale to get used to using the epoxy and handling the glass which, in the case of the rectangular separator frame, is very fragile. We also applied the graphite paint to the practice RPC also to get a feel of what to expect. We hope to have assembled the first working prototype chamber by the end of this week.

We have devised a system for the delivery of gas which uses as few valves as possible and yet will satisfy the previously mentioned requirements. We shall be working in a fume cupboard so waste gas can be vented properly. The setup is as shown in figure 3.

This setup was dictated largely by available equipment with the only components we still need to find being various sundries such as rubber tubes and bungs. Another important feature of the setup is its modularity, connections will be via rubber tubes for ease of replacement of components. Items such as the drier, for example, will occasionally need taking out and treating when it becomes saturated. The whole gas system should not take much time to realise.

This leaves the readout strips and the electronics left to construct.

Future Work

Although we have some ideas for the electronics and readout strips much still needs to be done. For the readout strips we came up with the idea of using printed circuit board (PCB), this way we can easily make whatever strip configuration we like using the standard etching technique and we have an insulator built in. Using PCBs also has the benefit of being separate from the chamber so we can use one set of readout strips on many test chambers so long as we decide on a standard chamber area. However we need to investigate the resistive properties of PCBs since they are normally designed for low voltage applications as well as maximum sizes that can be etched easily.

We plan to place the readout strips over the ground electrode so that chances of a spark are minimal with the two sets of readout strips placed perpendicular to each other. We can then obtain a two dimensional position measurement of resolution N with $2\sqrt{N}$ sets of electronics rather than N sets for a single PCB with a chessboard type arrangement. However this configuration means that one of the sets of strips is twice as far from the electrode as

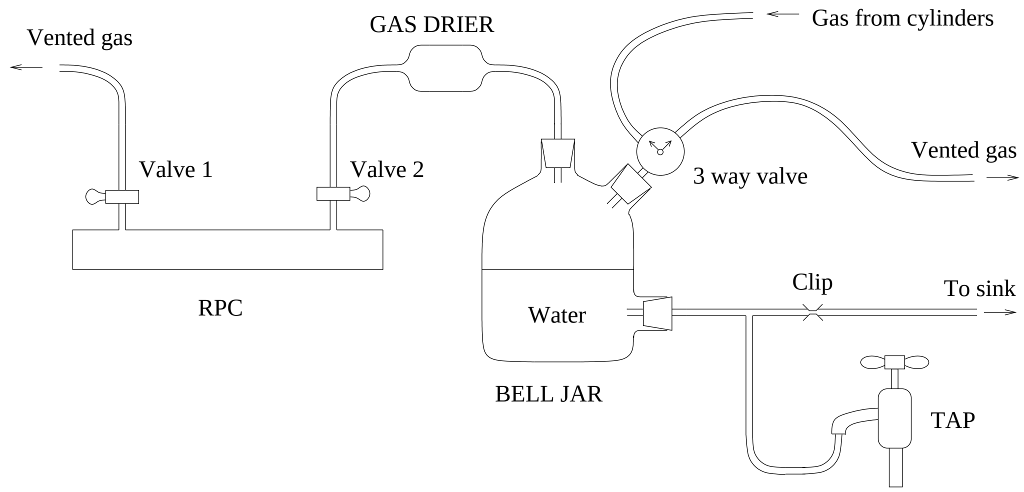

Figure 3: Planned schematic of gas system

the other. With the law of electrostatics being dependent on $1/r^2$ this means that the outer set of strips will be subject to a quarter of the electrostatic effect of the inner strips which in turn mean that we will have to devise different electronics or at least a different configurations for each set. An alternative is to place one set of readout strips on the lower surface and seeing if we can adjust the HV supply so that the 5kV goes from -2.5kV to $+2.5$kV rather than from ground to $+5$kV. This way, if the PCBs have a high enough resistance, we can use the same electronic configuration for both sets of readout strips. We shall decide which method to use once we work out the scale of currents involved.

The problem of being restricted to a relatively low 5kV means that we may have to reduce the gas gap to less than 2mm to increase the electric field strength. We will have to discover the optimum width of gap since reducing the gap also means less scope for ionised particles and therefore less detectible charge. Research has been done into this and a gas gap of 0.75mm at 5kV seemed to give a good efficiency[3], however glass is not available cheaply in this thickness, we would have to look at other high resistance materials such as plastics to act as the spacer frame. *RS* supplies sheets of Copolyester and PVC which are 1mm thick, however the resistivity properties are not available on the website which could cause problems in determining charge flow in the RPC necessary when it comes to developing electronics.

Determining resistivities of high resistance material is a problem. We do not know the precise resistivity of the glass we are using since it is standard Pilkingtons float glass designed for glazing. In addition we should not use other manufacturers values since different techniques of manufacture are used worldwide depending on the climate. Simply taking the voltage across a sample is not practical (a voltmeter's internal resistance is $\sim 10^6\Omega$ compared to the resistivity of glass which is $\sim 10^{14}\Omega m$) we would have to use something like a Wheatstone bridge although we need to do this in a vacuum since the flow of charge through the air becomes significant! This is obviously a procedure that we would like to avoid at all costs and we may be forced to use an approximate value.

Should we get the time we would also like to investigate a Cerenkov light detector design that was brought to our attention[4]. The detector is constructed from a commercially available Thermos flask and a photomultiplier tube using little specialist skills. It appears relatively inexpensive to build and quite practical for classroom use.

References

[1] S. Narita et al, Transac. on Nucl. Sci. Vol 48, No. 3 (June 2001) 893 – 899

[2] H. Sakaue, E. Nakano, T. Takhashi, Y. Teramoto, Nucl. Instr. and Meth. A 482 (2002) 216 – 225

[3] T. Kubo, E. Nakano, Y. Teramoto, Nucl. Instr. and Meth. A 516 (2004) 50 – 57

[4] T. Kubo, E. Nakano, Y. Teramoto, arXiv:hep-ex/0211020 v1 8 Nov 2002

[4] http://cosmicray.bnl.gov/bottle2.html