Development of Novel Designs of Resistive Plate Chambers

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On behalf of the CALICE Collaboration

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Abstract. A novel design of Resistive Plate Chambers (RPCs), using only a single resistive plate, was developed and tested. Based on this design, prototype chambers of size ranging from 10 cm × 10 cm to 32 cm × 48 cm were constructed and tested with cosmic rays and particle beams. The tests confirmed the viability of this new approach for calorimetric applications where the particle rates do not exceed 1 kHz/cm^2, such as CALICE digital calorimeters. The chambers also have improved single-particle response, such as a pad multiplicity close to unity. In addition to this development, we probed a new technique to mitigate limitations associated with common RPC gases compatible with the environment. The technique is based on electron multiplication in a thin layer of high secondary electron yield material coating on the anode plane. Here we report on the construction of various different glass RPC designs, and their performance measurements in laboratory tests and with particle beams.

1. Introduction

Resistive Plate Chambers (RPCs) are widely used particle detectors in High Energy Physics experiments. They were introduced in the 1980's [1] and the experimental implementations are mostly on triggering and precision timing. They consist of two or more resistive plates of high resistance that are separated by thin gas gaps. The resistive plates are made of glass or Bakelite. The readout is provided either by strips or pads, which are placed on the outside of the chambers.

Under high particle fluxes, the RPCs exhibit a significant loss of efficiency due to the high resistance of the resistive plates. Lower resistivity glass samples are produced and purchased, and various size RPCs were constructed with them. As expected, lower resistivity glasses offer higher rate capability.

We developed a novel design of RPC based on a single resistive plate. This work was performed in the context of studies of imaging calorimetry for a future lepton collider, as carried out by the CALICE collaboration [2]. The novel design was read out using the standard Digital Hadron Calorimeter (DHCAL) [3] electronic readout system featuring 1 × 1 cm^2 signal pads. Tests were performed with both cosmic rays and particle beams.

Recently, we probed a new technique to mitigate the limitations associated with common RPC gases compatible with the environment. The technique is based on electron multiplication in a thin

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layer of high secondary electron yield material coating on the anode plane. A number of 1-glass RPC samples were produced and are under operational tests as of this writing.

Here we report on the construction of various different glass RPC designs, and their performance measurements in laboratory tests and with particle beams.

2. Development of Semi-Conductive Glass

The RPCs exhibit a significant loss of efficiency with increasing particle flux. The rate effects in the RPCs are local to the area of high beam intensities and do not affect the entire chamber surface uniformly [4]. The mechanism behind the drop of efficiency is that the charge build up on the inner surface of the glass electrode becomes faster than the speed the glass plate can dissipate the charge via bulk conductivity in addition to the space charge effects. As a result, the voltage between the glass electrodes drops, which causes the signal charge to decrease and efficiency to drop. A simple approach to handle this problem is to increase the electrical conductivity of the glass to allow the resistive plates to restabilize faster. Soda lime silicate glasses in current RPCs are well known, inexpensive, and easily manufactured. However, they are not conductive enough for this application, which requires a bulk electrical conductivity range from 10^{-10} to 10^{-13} S/cm. Compared to the conductivity of the soda lime silicate glass of 10^{-15} S/cm, the target conductivity resides two to five orders of magnitude higher. In addition to the conductivity requirements, the RPC glass must be homogenous, radiation-hard and it must be easily manufactured and must not be ionically conductive to provide long term stability.

In this context, we developed low resistivity vanadate based glasses, probing lead vanadates first. The final conductivity of the glasses was 10^{-10} S/cm and the samples ended up not being able to hold the high voltage with sparking across the plates.

The tellurium vanadates were probed next as they have the advantage of being comprised entirely of glass formers with multiple oxidation states which are known well. The binary tellurium vanadate had a conductivity nearly three orders of magnitude higher than that of the binary lead vanadate. In order to reduce the conductivity to within the target range, the tellurium vanadates were doped with zinc oxide (ZnO) which proved to be an economical modifier. From 25 % to 55 % ZnO, conductivity ranged four orders of magnitude from around 10^{-11} to around 10^{-15} S/cm. The glass composition of $0.40ZnO - 0.40TeO_2 - 0.20V_2O_5$ was used to make three 5 cm ´ 5 cm two-glass RPCs. The RPCs were tested at the Fermilab Test Beam Facility (FTBF) [5] with 120 GeV proton beam. Figure 1 shows the efficiency vs. particle rate for the RPC made with soda lime silicate glasses (denoted as SLS), and the three RPCs made with the zinc tellurium vanadate glasses (denoted ZTV1, ZTV2 and ZTV3). The improvement in the rate capability of the RPCs at a given efficiency is more than an order of magnitude. The key point in this R&D is that there is full control over the conductivity of the glass. In addition to the conductivity, the mechanical properties can also be tuned for large size production [6].

3. Development of 1- Glass RPC

The chambers with a single soda-lime float glass plate were built. The thickness of the resistive plates was 1.15 mm and the gas gap was 1.15 mm. The lateral size of the chambers was 32×48 cm^2. The gas volume was defined by the glass plate and the readout board with the readout pads located directly in the gas volume. Figure 2 shows a sketch of the 1-glass RPC. Figure 3 shows the readout (left) and front side (right) pictures of the 1-glass RPC with standard soda-lime float glass [7].

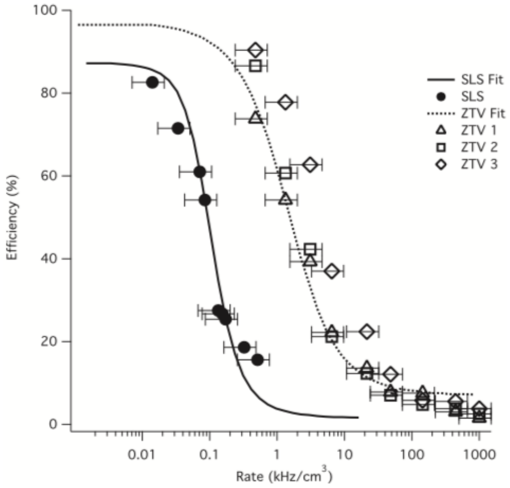

Figure 1. Efficiency vs. particle rate for the RPC made with soda lime silicate glasses (denoted as SLS), and the three RPCs made with the zinc tellurium vanadate glasses (denoted ZTV1, ZTV2 and ZTV3) [6].

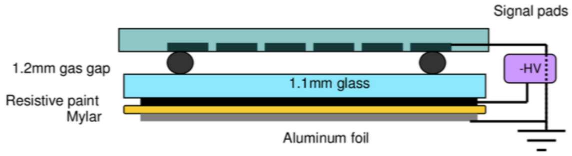

Figure 2. A sketch of the 1-glass RPC.

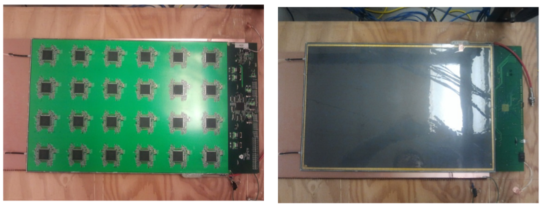

Figure 3. Pictures of the readout (left) and front (right) side of the 1-glass RPC.

The novel 1-glass RPC design offers a number of distinct advantages:

- The average pad multiplicity is close to unity. This also includes the case where the particle detection efficiencies are approaching 100%. The calorimetric measurements depend critically on both the efficiency and the average pad multiplicity. With close to unity average pad multiplicities, the calibration procedure is also significantly simplified.
- The resistive coating is applied to the outside of the anode and cathode resistive plates. The surface resistivity of the cathode plate has a minor effect on the pad multiplicity, however, the coating on the anode plate has a significant effect. With the elimination of the anode plate, the strict requirement on the uniformity and the value of this resistivity becomes immaterial.
- The overall thickness of the RPC and the readout board is reduced to approximately 3 mm, with obvious advantages for calorimetry.
- Since the overall bulk resistivity of the chamber is lower as a result of the removal of the anode plate, the rate capability of the RPC is enhanced approximately by a factor of two.

Figure 4 shows the efficiency (left) and pad multiplicity (right) of the 1-glass RPC as measured with cosmic ray tracks. There were seven standard 2-glass design RPCs and the two novel 1-glass RPCs were interleaved in the stack. The cosmic muon tracks traversing the stack were reconstructed using the standard 2-glass RPCs, and the intersection point of these tracks with the novel 1-glass RPCs under test were determined. The efficiency is defined as the probability of finding a cluster of hits in the 1-glass RPC within 2 cm of the track impact point. The hits are clustered so that any two hits sharing a common edge belong to the same cluster. If the RPC under test is efficient for a given cosmic muon track, the pad multiplicity is defined as the number of hits in the cluster found. Figure 4 shows the result for one of the chambers. The average efficiency of the chamber is 95% and the average pad multiplicity is close to unity (apart from the bottom left corner where there is an increased number of accidental noise hits in the vicinity of the ground connection). Similar results were obtained with the other prototype chamber [7].

4. Measurement of Rate Capability

Three different RPC designs were tested for rate capability at FTBF [8]:

1. *2-glass RPCs with standard glass:* The chambers were built with two standard soda-lime float glass plates with a thickness of 1.1 mm each. The gas gap was 1.2 mm. The chambers were 20 × 20 cm^2 in size.
2. *1-glass RPCs with standard glass:* The chambers were built with one standard soda-lime float glass plate with a thickness of 1.15 mm. The gas gap was also 1.15 mm. The size of the chamber was dictated by the size of the readout board, i.e. 32 × 48 cm^2.
3. *2-glass RPCs with semi-conductive glass:* These chambers utilize semi-conductive glass with a bulk resistivity several orders of magnitude smaller than standard soda-lime float glass. The glass, *model S8900*, is available from Schott Glass Technologies Inc. [9]. The gas gap of these chambers was also 1.15 mm and the area of the chambers measured 20 × 20 cm^2. With 1.4 mm thickness, the glass plates were somewhat thicker than for the other designs.

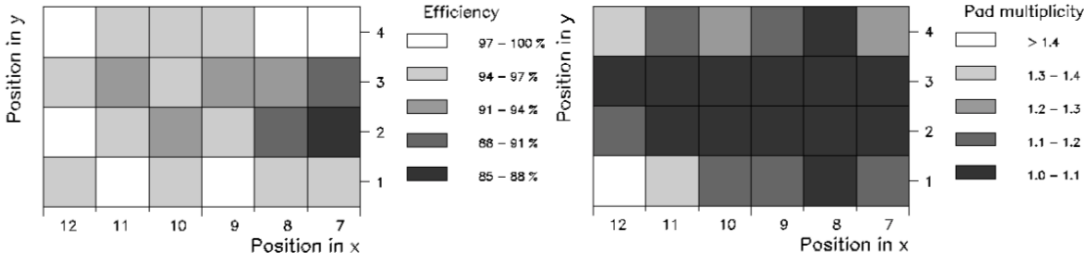

Figure 4. The efficiency (left) and pad multiplicity (right) of the 1-glass RPC as measured with cosmic ray tracks [7].

The measurement of the rate capability in units of [Hz/cm^2] requires the knowledge of the size of the beam spot. In order to achieve a more accurate measurement of the beam spot, the usually pencil-like 120 GeV primary proton beam was defocused upstream of the experimental hall. The resulting beam profile was Gaussian in both horizontal and vertical direction with a width σ, as measured by the wire chambers, of approximately 1.0 (0.8) cm in the horizontal (vertical) direction. In the calculation of the beam intensity, in units of [Hz/cm^2], the size of the beam spot was taken to be $2\sigma_x \times 2\sigma_y$, with an error derived from the measurement error of the widths of the Gaussians.

Figure 5 shows the efficiency (left) and average pad multiplicity (right) as function of beam rate for six different RPCs. All three sets of chambers exhibit a drop in the efficiency as the rate increases. However, for the chambers with lower overall resistance, the loss of efficiency is shifted to higher particle rates. The average pad multiplicity is close to unity for the entire range of particle rates for the 1-glass chambers. For the 2-glass chambers, the average pad multiplicity remains below two.

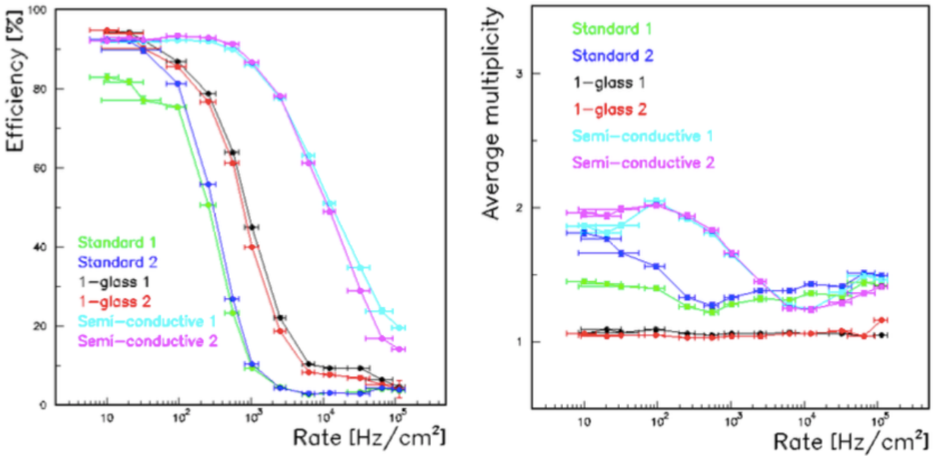

Figure 5. The efficiency (left) and average pad multiplicity (right) as function of beam rate for six different RPCs [8].

Figure 6 shows the rate $I_{50\%}$ at which the RPC performs with a 50 % efficiency as a function of the conductance per area of the glass plates. The red curve shows the result of the fit function $I_{50\%} = (1.7\times10^5) + (3.2\times10^6)H + (-1.7\times10^8)H^3$, where $H = 1/\log_{10}(G)$, G being the conductance per unit area of the glass plates.

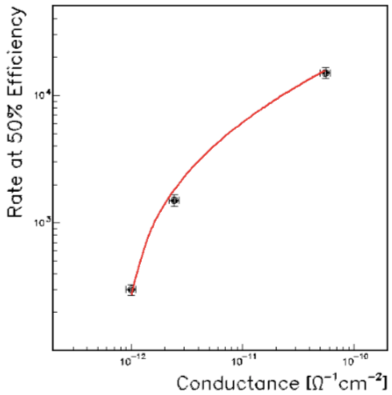

Figure 6. The rate at 50% efficiency as a function of conductance per area of the glass plates [8].

5. Conclusions

Novel design Resistive Plate Chambers utilizing a single resistive glass plate has been tested with cosmic rays and particle beams. This novel design of RPCs offers numerous advantages over the traditional 2-plate design such as simplified construction procedure, reduced overall thickness of the detector, average pad multiplicity close to unity and increased rate capability.

Several RPCs were tested for their rate capabilities in 120 GeV proton beam. Among these were the 1-glass and 2-glass RPCs made with the standard soda lime float glass, and 2-glass RPCs made with semiconductive glasses. The results indicate that with increasing conductance per area of the glass plates, the rate capability of the RPCs increases. In addition, the range of particle rates for which the chambers retain their full particle detection efficiency also increases. A functional description of the dependence of the rate at 50 % efficiency was obtained.

A dedicated R&D was performed to develop semi-conductive glasses with flexible design parameters. It was found that the $0.40ZnO - 0.40TeO_2 - 0.20V_2O_5$ glass provides an outperforming starting point with unbound options of constituents and processes to pursue further R&D.

One major complication about the future RPC-based detector systems is that the majority of the RPC gases will be limited use if not forbidden. We probe solutions that implement electron multiplication in a thin layer of high secondary electron yield material coating on the anode plane, overall reducing the gas flow. A number of 1-glass RPC samples were produced and are under operational tests. The results will be reported at a later time.

6. Acknowledgements

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