Snowmass2021 - Letter of Interest

[Novel Designs of Resistive Plate Chambers]

Instrumentation Frontier Topical Groups: (check all that apply □/■)

□ (IF1) Quantum Sensors
□ (IF2) Photon Detectors
□ (IF3) Solid State Detectors and Tracking
□ (IF4) Trigger and DAQ
□ (IF5) Micro Pattern Gas Detectors (MPGDs)
■ (IF6) Calorimetry
□ (IF7) Electronics/ASICs
□ (IF8) Noble Elements
□ (IF9) Cross Cutting and Systems Integration

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Abstract: Resistive Plate Chambers (RPCs) exhibit a significant loss of efficiency for the detection of particles, when subjected to high particle fluxes. This rate limitation is related to the usually high resistivity of the resistive plates used in their construction. In this Letter of Interest, we report on the measurements of the performance of various different glass RPC designs featuring a different total resistance of the resistive plates.

In parallel, a novel design of RPC, using only a single resistive plate, was developed and tested. Based on this design, large size prototype chambers were constructed and were tested with cosmic rays and in particle beams. The tests confirmed the viability of this new approach.

Resistive Plate Chambers (RPCs) are used in a wide spectrum of 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 boards are placed on the outside of the chambers. The readout is provided either by strips or pads. Under high particle fluxes, the RPCs exhibit a significant loss of efficiency due to the high resistance of the resistive plates. Here we report on the rate capability of various glass RPCs featuring different conductance per area of the glass plates. In parallel, 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 x 1 cm^2 signal pads. Tests were performed with both cosmic rays and particle beams.

In order to validate the improved performance of the new RPCs, we studied three different chamber designs: 2-glass RPCs with standard glass, 2-glass RPCs with semiconductive glass and the novel 1-glass RPC with standard glass. The 2-glass RPCs with standard soda-lime glass design is based on the DHCAL RPCs [3]. For easier handling, smaller chambers with two standard soda-lime float glass plates with a thickness of 1.1 mm each and a gas gap of 1.2 mm were also built. The chambers were 20 x 20 cm^2 in size. The bulk resistivity of the soda-lime glass was 4.7 x 10^{12} Ωcm. For more details on the chambers see [4].

The 2-glass RPCs with semi-conductive glass design was constructed using the low-resistivity vanadate glasses, developed in collaboration with the COE College, Iowa [5]. In order to utilize good glass-forming ability and to start with well-known conductive properties, lead vanadates were probed first. The conductivity was proportional to the vanadium content and was enhanced 5 orders of magnitude by increasing x in $0.20Fe_2O_3$-(0.80-x)PbO-xV_2O_5 from x = 0.32 to x = 0.64. With a target conductivity of 10^{-10} S/cm, $0.20Fe_2O_3$-0.40PbO-$0.40V_2O_5$ was chosen as the best option. However, the chamber resulted in sparking across the plates when the high voltage was applied due to much higher conductivity than anticipated. Further studies were concentrated on tellurium vanadates which also resulted in more homogenous glasses compared to the lead vanadates. The tellurium vanadates 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. The glass composition of 0.40ZnO-$0.40TeO_2$-$0.20V_2O_5$ was used to build RPC prototypes. The samples of this composition were investigated under FEG-SEM and no visible inclusions or microscopic inhomogeneities were observed. The 5 x 5 cm^2 prototypes did not show any sparking in long term tests and they were tested at the Fermilab Test Beam Facility (FTBF) with 120 GeV proton beam.

In addition, we tested a commercially available semi-conductive glass. The glass had several orders of magnitude smaller bulk resistivity compared to the standard soda-lime float glass. The glass sample used in these tests is available from Schott Glass Technologies Inc. [6], model S8900. The glass plates were 1.4 mm thick, the chambers measured 20 x 20 cm^2 and the gas gap was 1.15 mm.

In the 1-glass RPCs with standard soda-lime glass design, 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 x 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 [7]. 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 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 1 shows the efficiency (left) and average pad multiplicity (right) as function of beam rate for six different RPCs. The semi-conductive glasses used in this test were Schott glasses. 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.

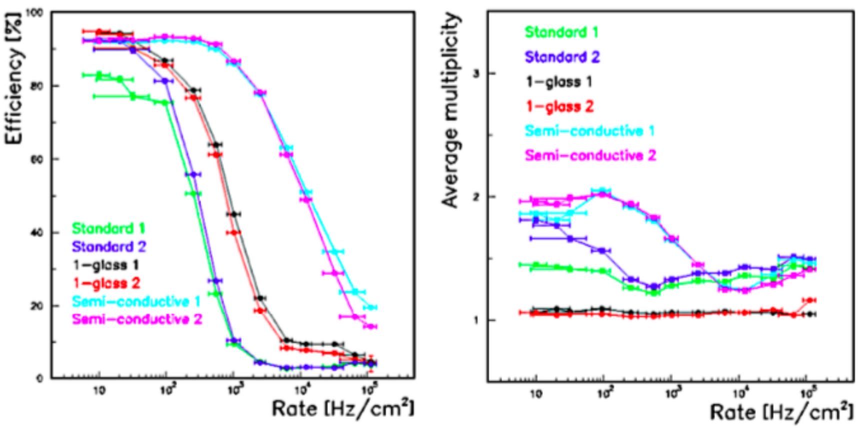

Figure 1. Efficiency (left) and average pad multiplicity (right) as function of beam rate for six different RPCs. Lines connecting the points are drawn for better visibility [8].

Novel design Resistive Plate Chambers utilizing a single resistive glass plate have been tested with cosmic rays and particle beams. The chambers were read out with the CALICE Digital Hadron Calorimeter electronics. The readout boards consisted of 1 x 1 cm^2 pads. The average detection efficiency of the chambers was approximately 95 % and the average pad multiplicities were close to unity. This novel design of RPCs offers numerous advantages over the traditional 2-plate design: simplified construction procedure, reduced overall thickness of the detector, average pad multiplicity close to unity, increased rate capability. Several RPCs were tested for their rate capabilities in 120 GeV proton beam. The results indicate that with increasing conductance per area of the glass plates, the rate capability of the RPCs increases as well as the range of particle rates for which the chambers retain their full particle detection efficiency. A functional description of this dependence was obtained. In a dedicated development, it was found that the $0.40ZnO\text{-}0.40TeO_2\text{-}0.20V_2O_5$ glass provides an outperforming starting point with unbound options of constituents and processes to proceed further R&D.

References: (hyperlinks welcome)

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