Development of Novel Designs of Resistive Plate Chambers

B. Bilki[1,2,3,*], Y. Onel[2], J. Repond[2] , K.K. Sahbaz[1,3,4,*], M. Tosun[1,3,4,*], L. Xia[5]

[1] Beykent University, Istanbul, Turkey
[2] University of Iowa, Iowa City, USA
[3] Turkish Accelerator and Radiation Laboratory, Ankara, Turkey
[4] Ankara University, Ankara, Turkey
[5] Argonne National Laboratory, Argonne, USA

On behalf of the CALICE Collaboration

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The CALICE DHCAL Prototype

Description

Hadronic sampling calorimeter

Designed for future electron-positron collider (ILC)

54 active layers (~1 m^2)

Resistive Plate Chambers with 1 x 1 cm^2 pads

→ ~500,000 readout channels

Electronic readout

1 – bit (digital)

Tests at FNAL

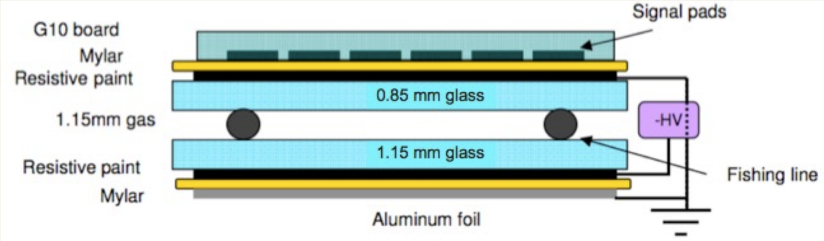
with Iron absorber in 2010 – 2011

with no absorber in 2011

Tests at CERN

with Tungsten absorber in 2012

Resistive Plate Chambers (RPCs)



Gas: Tetrafluorethane (R134A) : Isobutane : Sulfurhexafluoride (SF_6) with the following ratios 94.5 : 5.0 : 0.5

High Voltage: 6.3 kV (nominal)

Average efficiency: 96 %

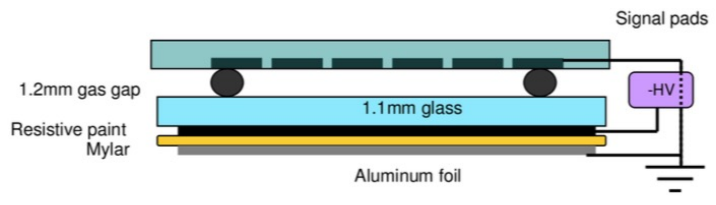
Average pad multiplicity: 1.6

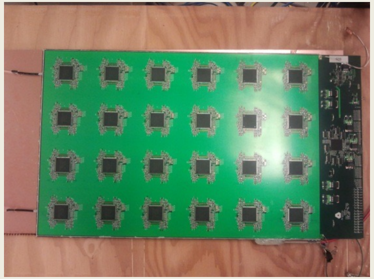
This talk presents further R&D performed on the Resistive Plate Cambers.

1-glass RPCs

Offers many advantages

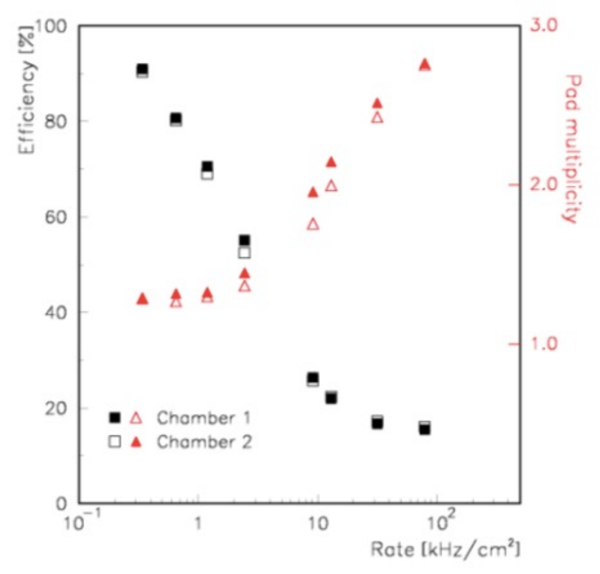
Pad multiplicity close to one
→ easier to calibrate
Better position resolution
→ if smaller pads are desired
Thinner
→ $t = t_{chamber} + t_{readout}$ = 2.4 + ~1.5 mm
→ saves on cost
Higher rate capability
→ roughly a factor of 2

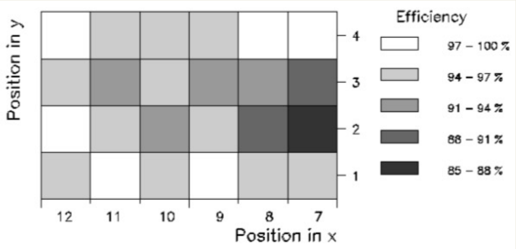


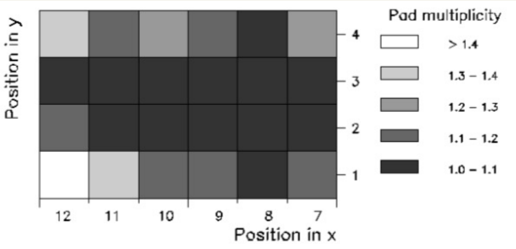


Status

Built several large chambers
Tests with cosmic rays very successful
→ chambers ran for months without problems
Both efficiency and pad multiplicity look good
Good performance in the test beam







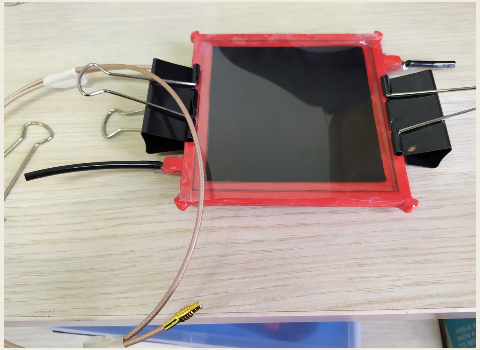
Further Development of 1-glass RPCs

Probing a hybrid readout where part of the electron multiplication is transferred to a thin film of high secondary emission yield material coated on the readout pad with the purpose of reducing/removing gas flow and enabling the utilization of alternative gases.

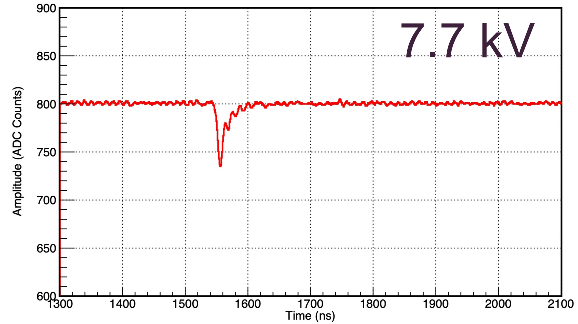
Built several 10 cm x 10 cm chambers with single pad readout.

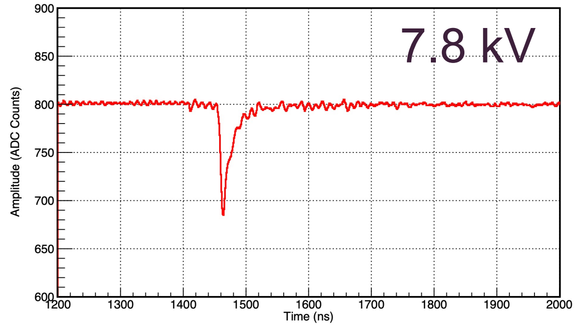
Coating of Al_2O_3 made with magnetron sputtering at Gazi University Photonics Application and Research Center (https://fotonik.gazi.edu.tr/).

Coating of TiO_2 made with airbrushing after dissolving TiO_2 in ethanol.



Cosmic muon response



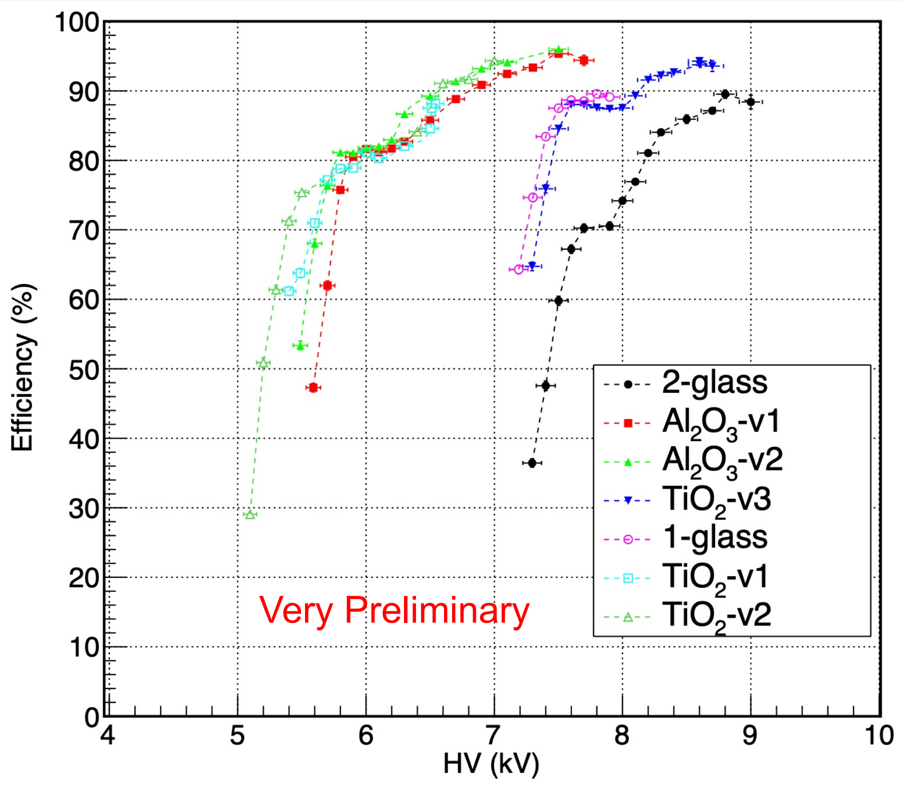


First-Generation Hybrid RPCs

We tested the first-generation hybrid RPCs as well as the standard 1-glass and 2-glass RPCs at Fermilab test beam. The lateral size of the chambers was 10 cm x 10 cm, the gas gap was 1.3 mm and the gas mixture was the DHCAL RPC gas mixture R134A : Isobutane : SF_6 ; 94.5 : 5.0 : 0.5 at 2-3 cc/min flow rate (lower than the nominal 5 cc/min).

The chambers tested:

1. 2-glass RPC
2. 1-glass RPC
3. 500 nm Al_2O_3 (v1)
4. 350 nm Al_2O_3 (v2)
5. 1 mg/cm² TiO_2 (v1)
6. 0.5 mg/cm² TiO_2 (v2)
7. 0.15 mg/cm² TiO_2 (v3)



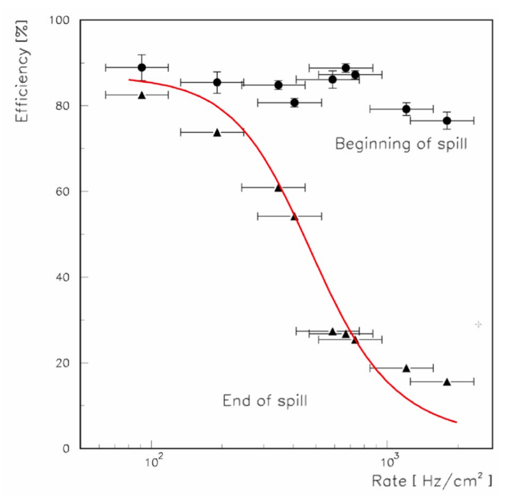
The charge multiplication in the secondary emission layer is qualitatively validated.

Efficient if charge > 300 fC

Rate capability of RPCs

Measurements of efficiency

With 120 GeV protons
In Fermilab test beam

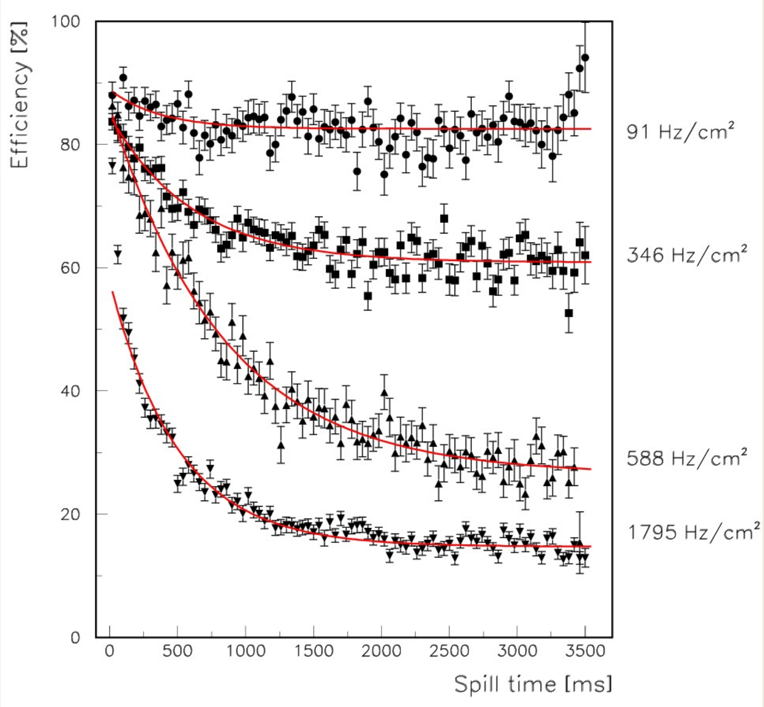


Rate limitation

NOT a dead time
But a loss of efficiency

Theoretical curves

Excellent description of effect



Rate capability depends on

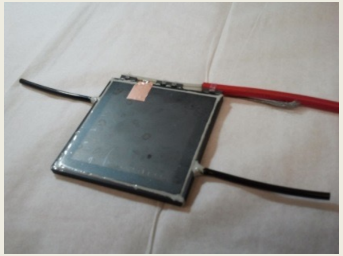
The bulk resistivity R_{bulk} of the resistive plates

Lower bulk resistivity → higher rate capability

B.Bilki et al., JINST 4 P06003, 2009

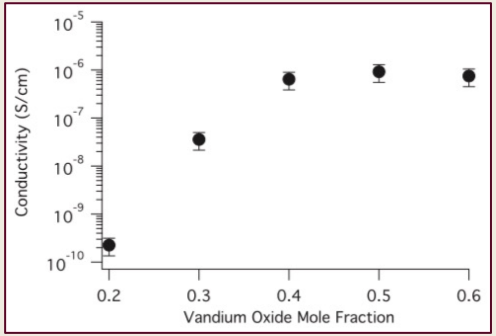
Development of semi-conductive glass

Co-operation with **COE college** (Iowa)

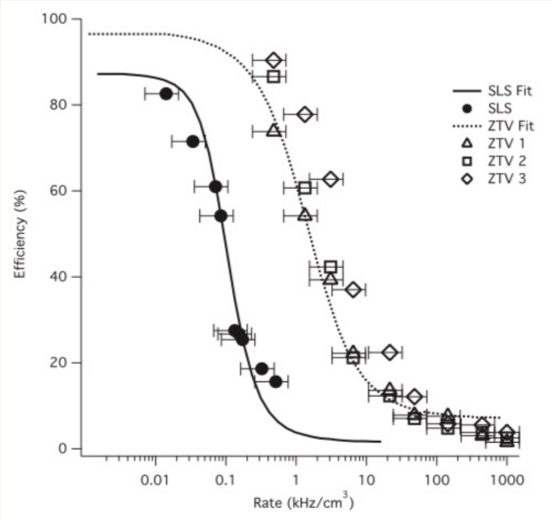


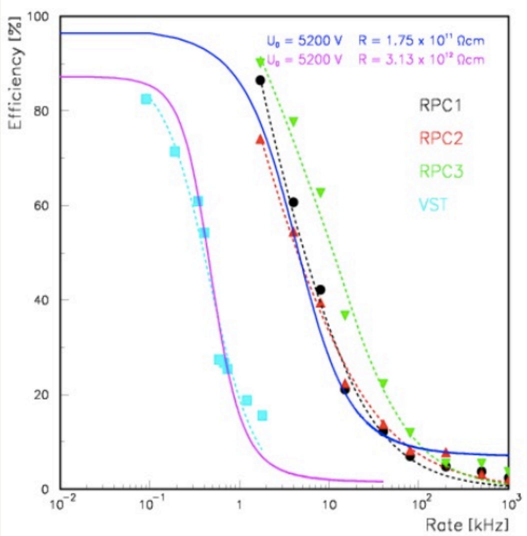
Vanadium based glass

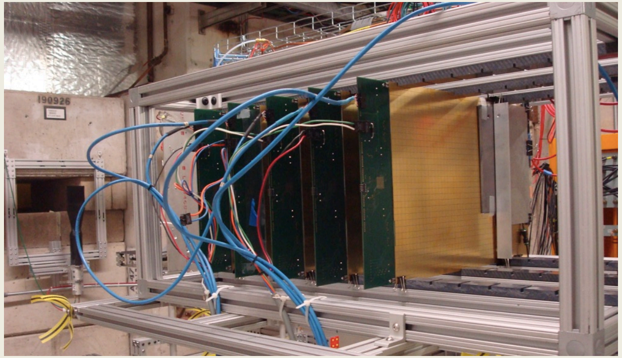
Resistivity tunable



SLS: Soda lime silicate
ZTV: Zinc tellurium vanadate







N. Johnson et al., Int. J. Appl. Glass Sci. 6, 26, 2015

Further Development of High-Rate RPCs

RPC design	Number of glass plates	Area A [cm^2]	Bulk resistivity ρ [Ωcm]	Total thickness t of the glass [cm]	Conductance per area of the glass $G = (\rho \cdot t)^{-1}$ [$\Omega^{-1}cm^{-2}$]	Rate at 50% efficiency [Hz/cm^2]	
1	2	400	4.7×10^{12}	0.22	1.0×10^{-12}	300	Soda-lime
2	1	1536	3.7×10^{12}	0.11	2.4×10^{-12}	1500	Soda-lime
3	2	400	6.3×10^{10}	0.28	5.6×10^{-11}	15,000	Schott

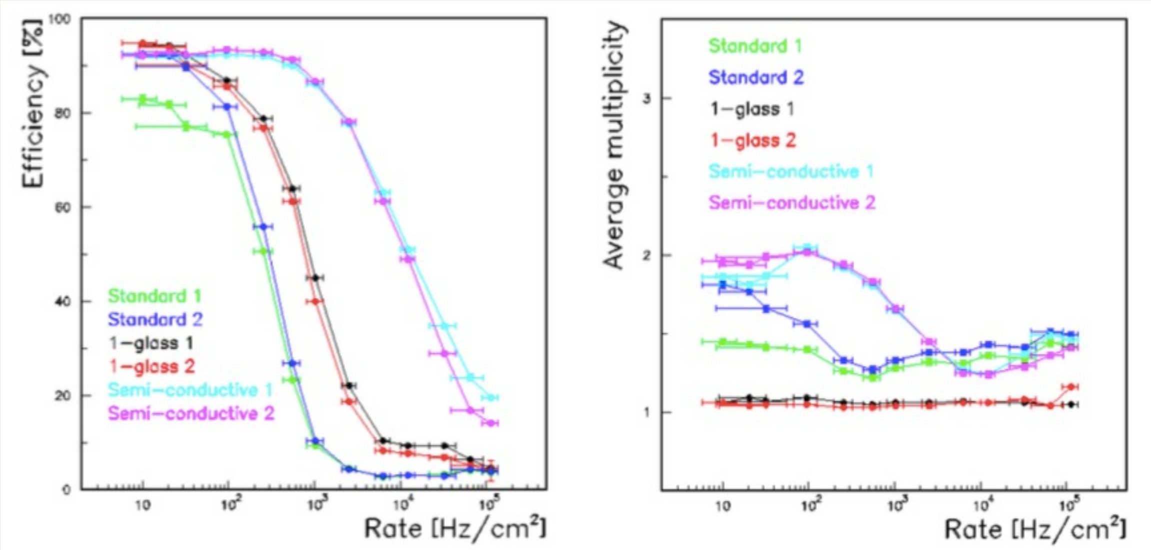
M. Affatigato et al., JINST 10 P10037, 2015

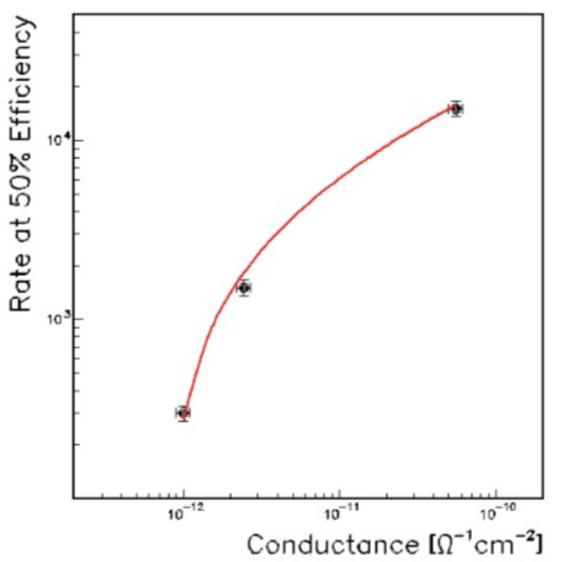
1. *2-glass RPCs with standard glass*
   The chambers were built with two standard soda-lime float glass plates with a thickness of 1.1 mm each. The gas gap was 1.2 mm. The chambers were 20 x 20 cm^2 in size.

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 x 48 cm^2. With only one glass plate the gas volume is defined by the glass plate and the anode board. Thus, the readout pads are located directly in the gas volume.

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. The gas gap of these chambers was also 1.15 mm and the area of the chambers measured 20 x 20 cm^2. With 1.4 mm thickness, the glass plates were somewhat thicker than for the other designs.

Further Development of High-Rate RPCs





$I_{50\%}$=a+bH+cH^3

where H = 1/ log$_{10}$(G), where G is the conductance per area of the glass plates; and *a*, *b*, and *c* are free parameters.

a = 1.7x10^5, *b* = 3.2x10^6 and *c*=-1.7x10^8.

Conclusions

- Raising the overall conductance per area of the glass plates will enhance the rate capability and increase the range of particle rates for which the chambers retain their full particle detection efficiency.

- $0.40ZnO-0.40TeO_2-0.20V_2O_5$ glass is an optimized starting point for further R&D to fine-tune the ideal RPC glass parameters. It is as efficient as soda lime silicate glasses at 100 times the rate.

- The novel 1-glass chamber design offers a number of advantages over the traditional two-plate design: an average pad multiplicity close to unity, a reduced overall thickness, a simplified construction procedure and an improvement in rate capability by a factor of 2. The latter is mostly due to the relaxed requirement for a specific surface resistivity of the resistive layer and the omission of one glass plate.

- R&D in progress to introduce an additional layer of solid-state secondary electron multiplication on the anode plane in the gas gap of one-glass RPC. Plans include measuring the shape of the charge distributions, testing with alternative gases and probing sealed chambers.