Development of Novel Designs of Resistive Plate Chambers

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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 m²)
Resistive Plate Chambers with 1 x 1 cm² 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 (SF₆) 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 Chambers.
1-glass RPCs

**Offers many advantages**

- Pad multiplicity close to one → easier to calibrate
- Better position resolution → if smaller pads are desired
- Thinner → $t = t_{\text{chamber}} + t_{\text{readout}} = 2.4 + \sim 1.5$ 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 Al₂O₃ made with magnetron sputtering at Gazi University Photonics Application and Research Center (https://fotonik.gazi.edu.tr/).

Coating of TiO₂ made with airbrushing after dissolving TiO₂ in ethanol.

Cosmic muon response

7.7 kV

7.8 kV
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$_2$O$_3$ (v1)
4. 350 nm Al$_2$O$_3$ (v2)
5. 1 mg/cm$^2$ TiO$_2$ (v1)
6. 0.5 mg/cm$^2$ TiO$_2$ (v2)
7. 0.15 mg/cm$^2$ TiO$_2$ (v3)

The charge multiplication in the secondary emission layer is qualitatively validated.
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 $R_{\text{bulk}}$ of the resistive plates

Lower bulk resistivity $\rightarrow$ 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

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 cm² 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 cm². 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 cm². With 1.4 mm thickness, the glass plates were somewhat thicker than for the other designs.

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### Table: RPC Design Specifications

| RPC design | Number of glass plates | Area $A$ [cm²] | Bulk resistivity $\rho$ [Ωcm] | Total thickness $t$ of the glass [cm] | Conductance per area of the glass $G = (\rho \cdot t)^{-1}$ [Ω⁻¹cm⁻²] | Rate at 50% efficiency [Hz/cm²] |
|------------|------------------------|----------------|-------------------------------|--------------------------------------|-------------------------------------------------|----------------------------------|
| 1          | 2                      | 400            | $4.7 \times 10^{12}$          | 0.22                                 | $1.0 \times 10^{-12}$                          | 300                               |
| 2          | 1                      | 1536           | $3.7 \times 10^{12}$          | 0.11                                 | $2.4 \times 10^{-12}$                          | 1500                              |
| 3          | 2                      | 400            | $6.3 \times 10^{10}$          | 0.28                                 | $5.6 \times 10^{-11}$                          | 15,000                            |

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

\( a = 1.7 \times 10^5, \ b = 3.2 \times 10^6 \) and \( c = -1.7 \times 10^8 \).
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-0.40TeO₂-0.20V₂O₅ 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.