# Development of Novel Designs of Resistive Plate Chambers

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**On behalf of the CALICE Collaboration**

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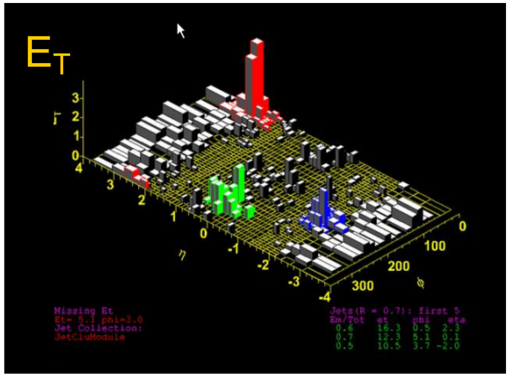
# Trend in Calorimetry

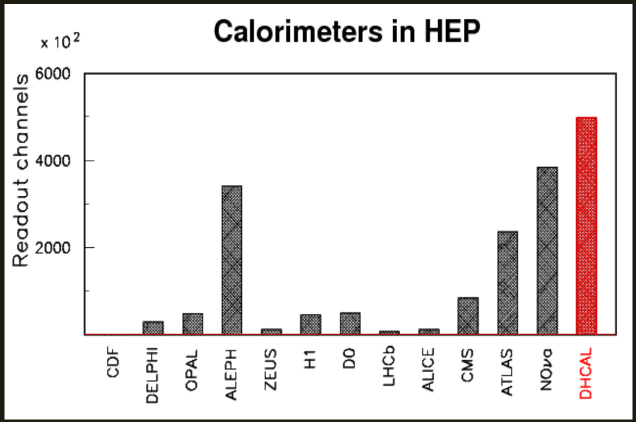
## Tower geometry

Energy is integrated over large volumes into single channels

Readout typically with high resolution

Individual particles in a hadronic jet not resolved



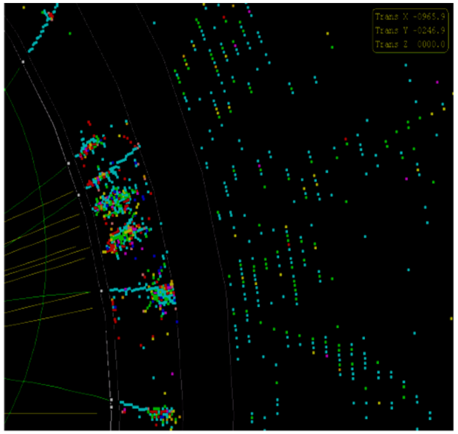




## Imaging calorimetry

Large number of calorimeter readout channels (~$10^7$)

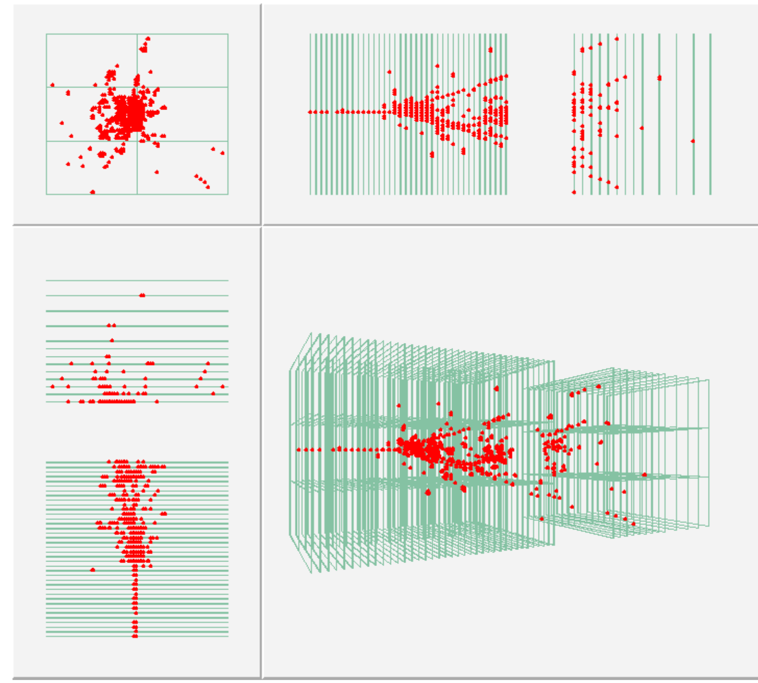
Option to minimize resolution on individual channels

Particles in a jet are measured individually



# The DHCAL prototype

60 GeV $\pi$+



**Description**

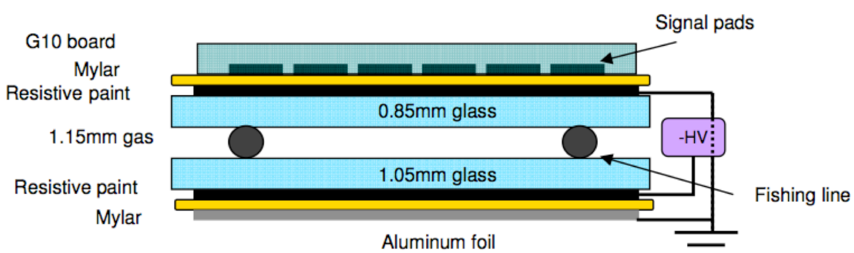
Hadronic sampling calorimeter

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**

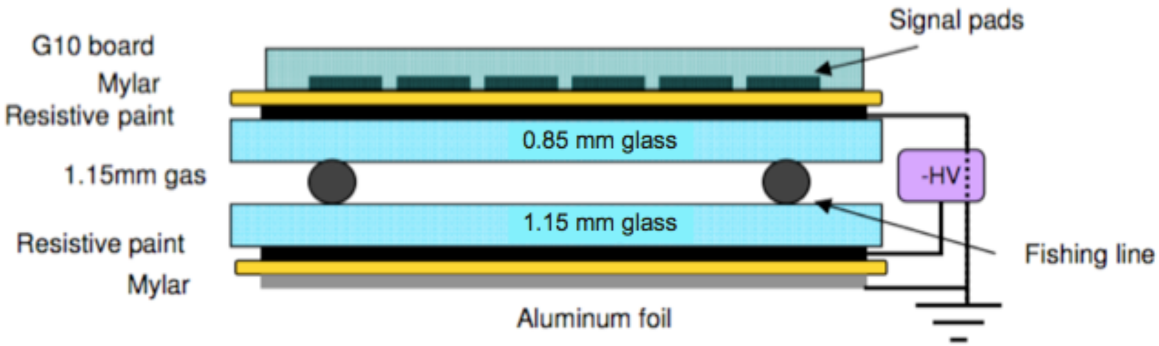
with Iron absorber in 2010 – 2011

with no absorber in 2011

**Tests at CERN**

with Tungsten absorber in 2012

# Resistive Plate Chambers (RPCs)



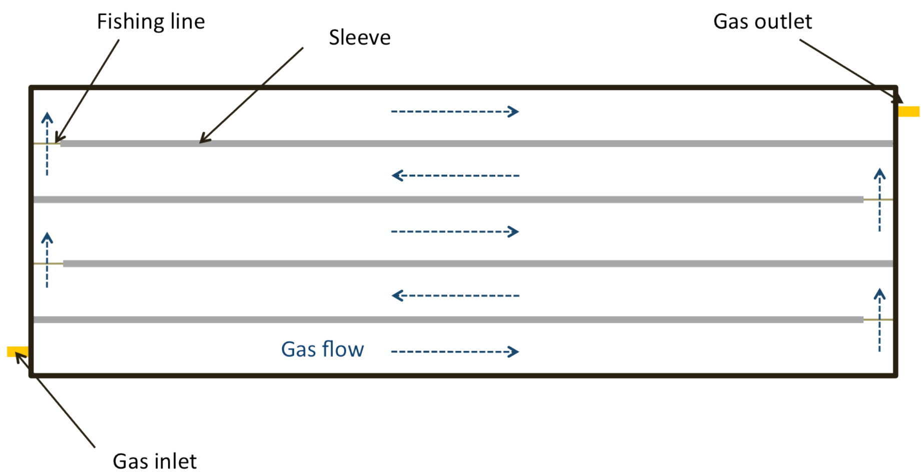

Gas: Tetrafluorethane (R134A) : Isobutane : Sulfurhexafluoride ($SF_6$) with the following ratios 94.5 : 5.0 : 0.5

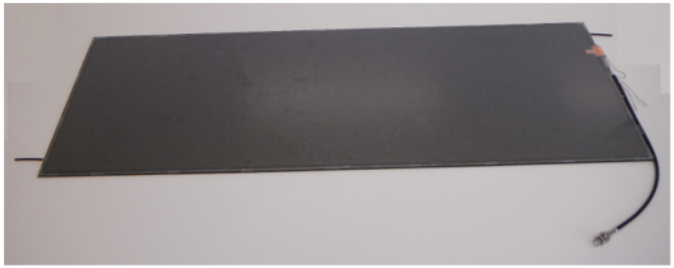
High Voltage: 6.3 kV (nominal)

Average efficiency: 96 %

Average pad multiplicity: 1.6

Gap size and gas flow uniformity is maintained via fishing line channels

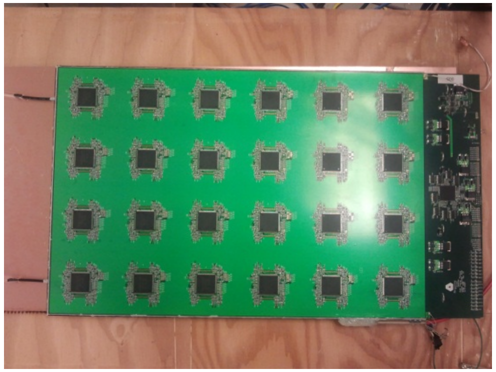


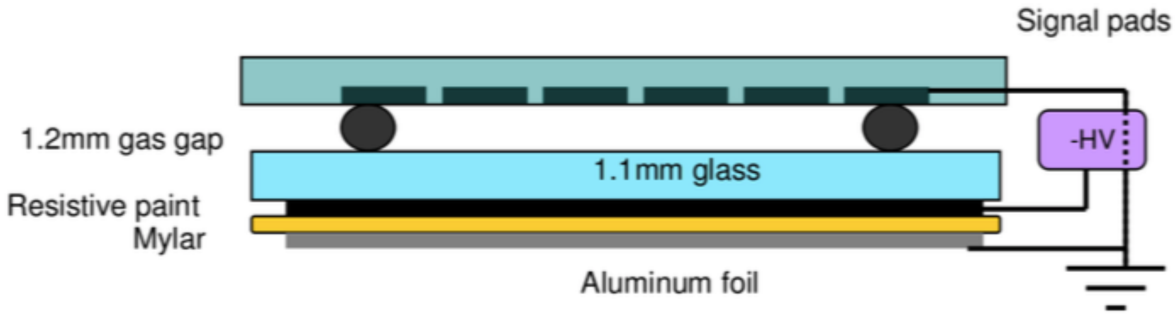



# 1-glass RPCs

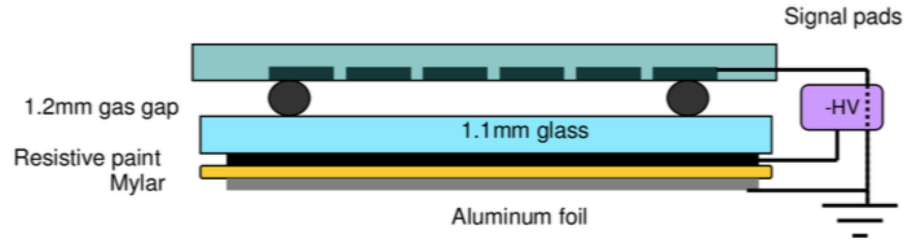
**Offers many advantages**

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



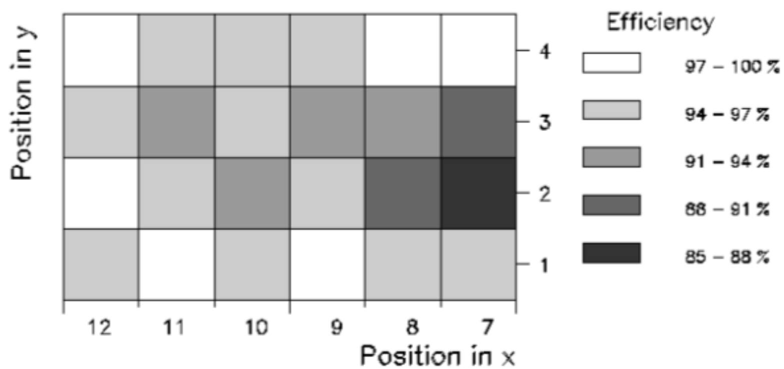


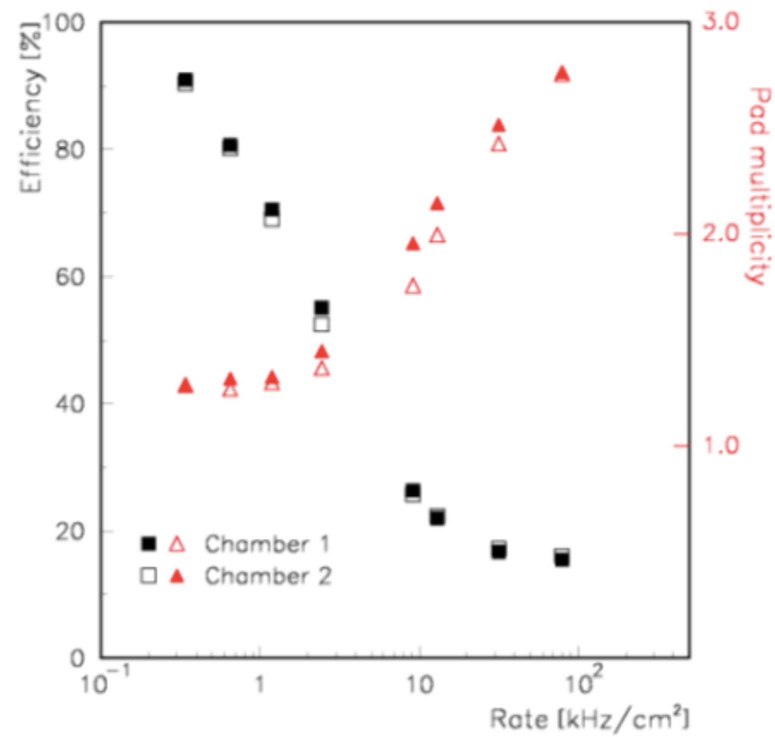
# 1-glass RPCs

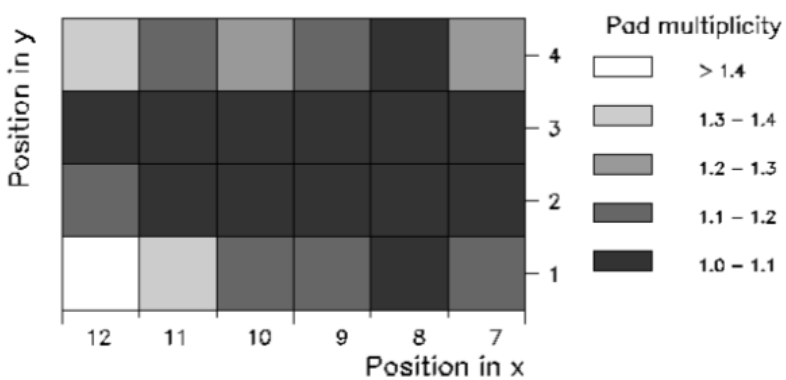



## Status

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




B.Bilki et al., JINST 10 P05003, 2015

# Rate capability of RPCs

**Measurements of efficiency**

With 120 GeV protons
In Fermilab test beam

**Rate limitation**

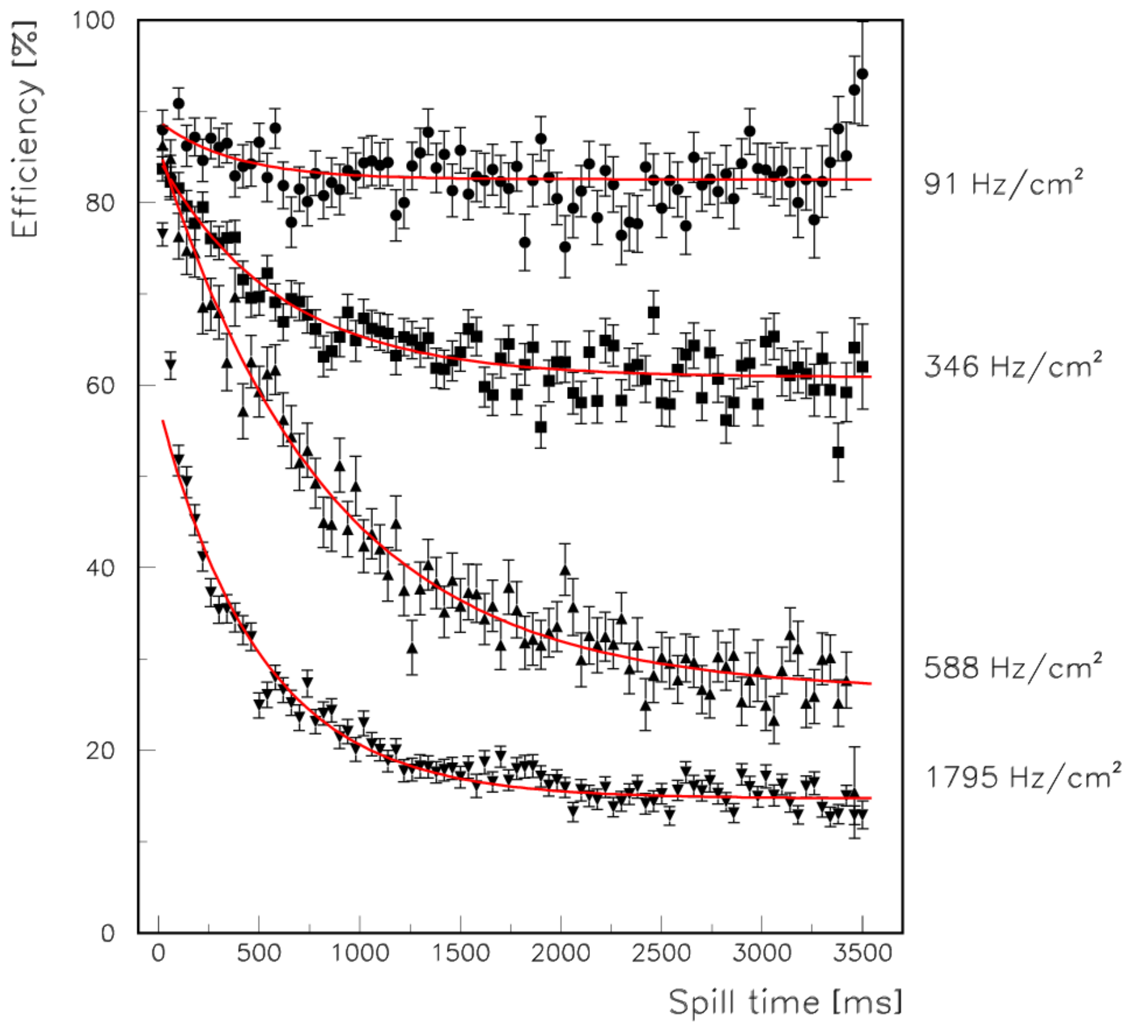
**NOT** a dead time
But a loss of efficiency

**Theoretical curves**

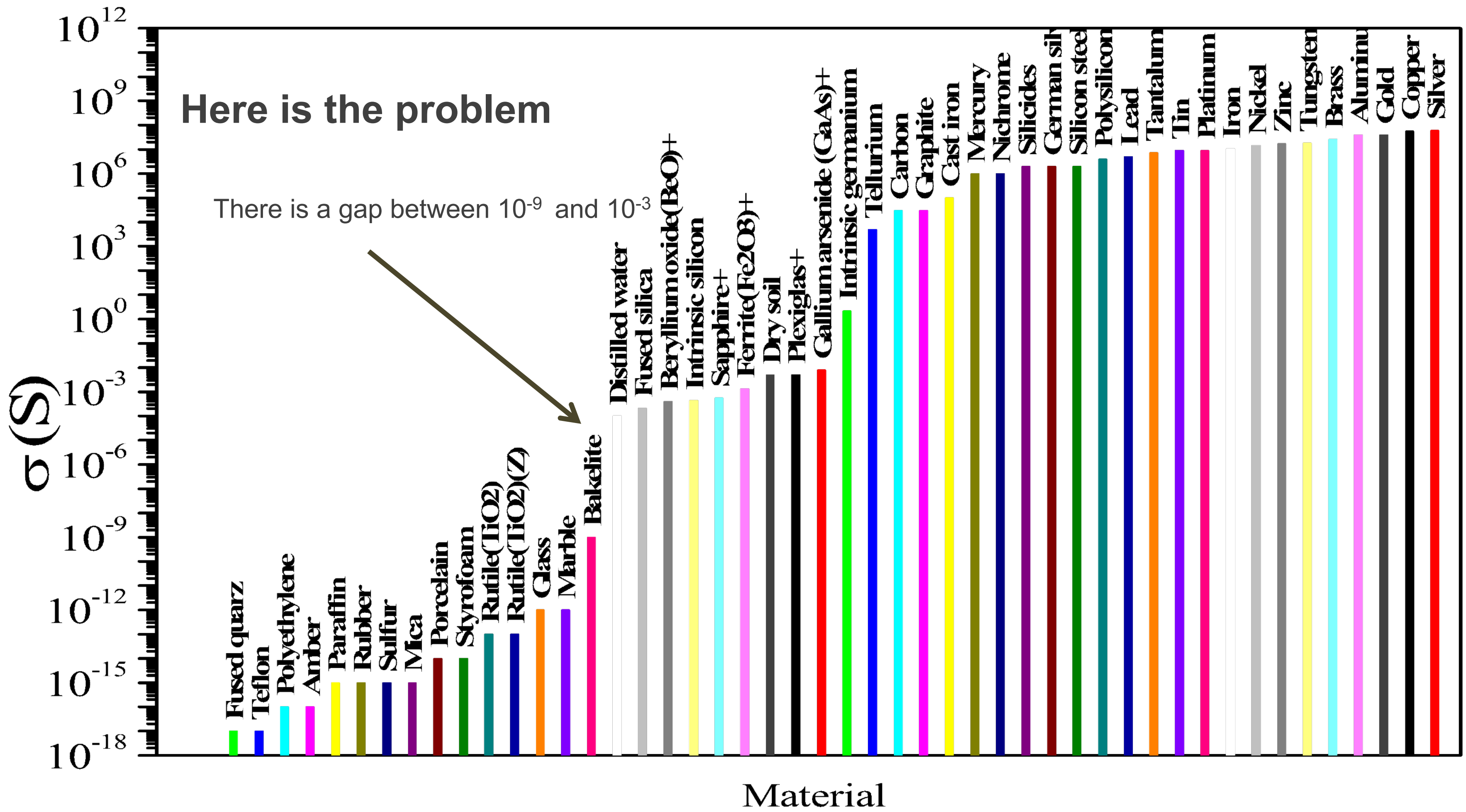
Excellent description of effect

**Rate capability depends**

Bulk resistivity $R_{bulk}$ of resistive p
(Resistivity of resistive coat)




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



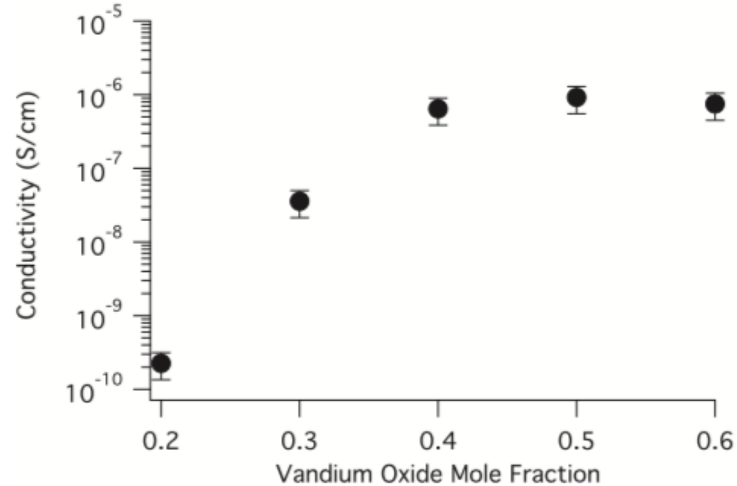

C. Pecharromán *X. Workshop on RPC and related Detectors* (Darmstadt)

# Development of semi-conductive glass

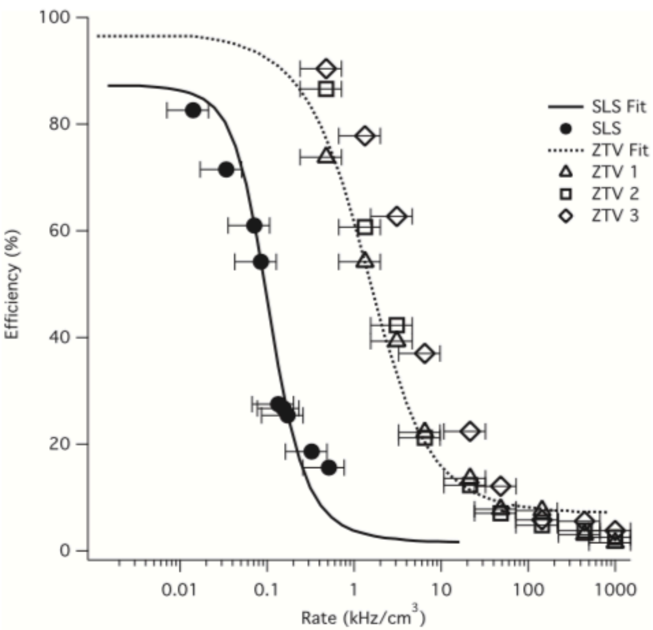
Co-operation with **COE college** (Iowa)

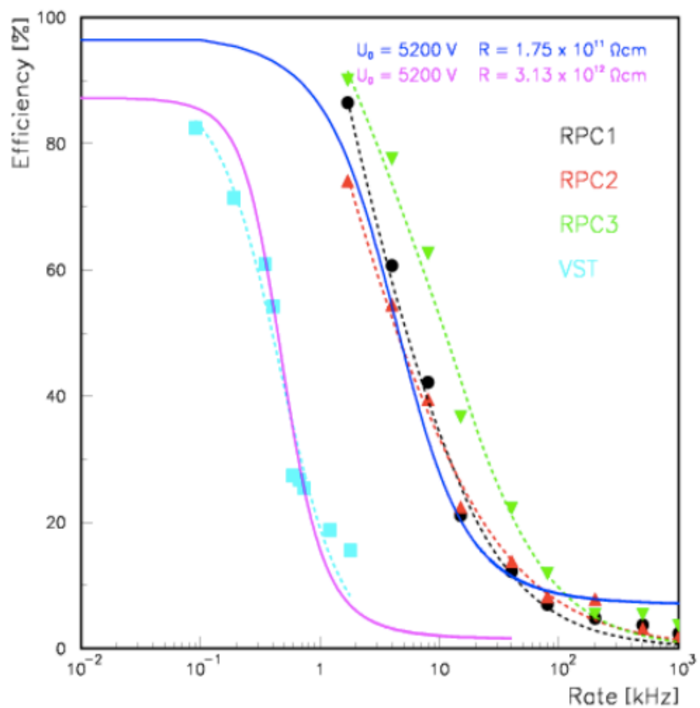
**Vanadium based glass**

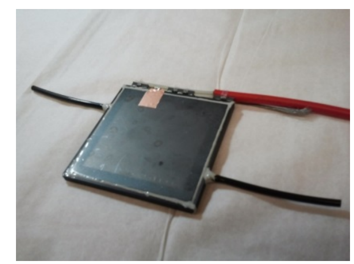
Resistivity tunable
Procedure aimed at industrial manufacture

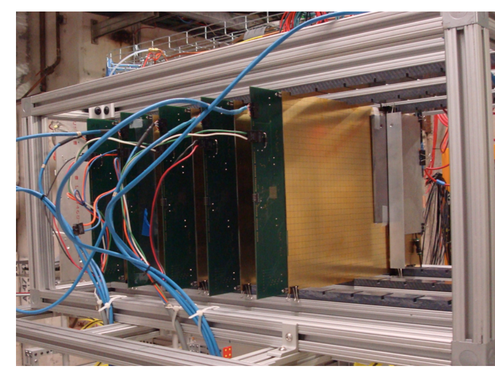



SLS: Soda lime silicate
ZTV: Zinc tellurium vanadate





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 $\rho$ [$\Omega$cm] | 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 | $4.7 \times 10^{12}$ | 0.22 | $1.0 \times 10^{-12}$ | 300 | Soda-lime |
| 2 | 1 | 1536 | $3.7 \times 10^{12}$ | 0.11 | $2.4 \times 10^{-12}$ | 1500 | Soda-lime |
| 3 | 2 | 400 | $6.3 \times 10^{10}$ | 0.28 | $5.6 \times 10^{-11}$ | 15,000 | Schott |

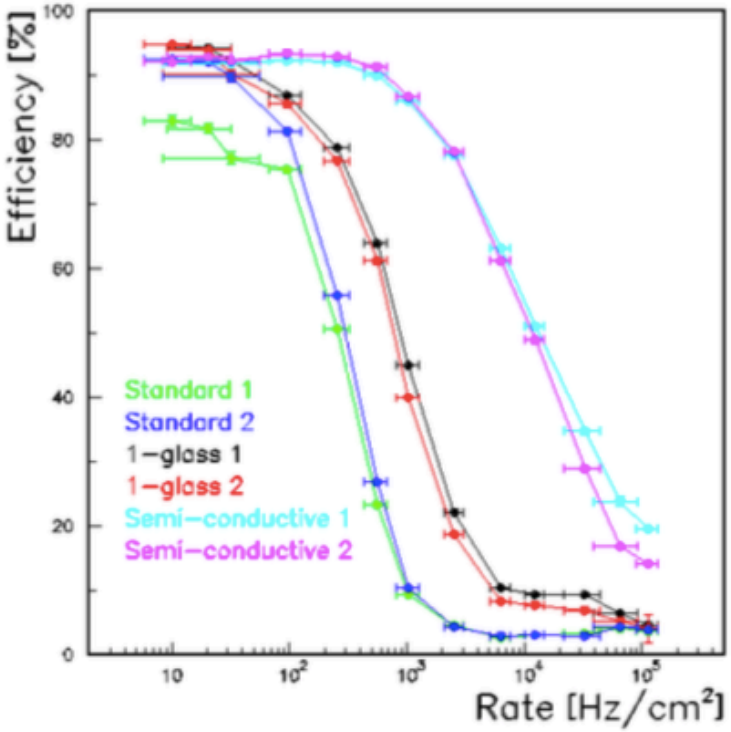
1. *2-glass RPCs with standard glass*
   The chambers were built with two standard soda-lime float glass plates with a thickness of 1.1 mm each. The gas gap was 1.2 mm. The chambers were 20 x 20 cm$^2$ in size.

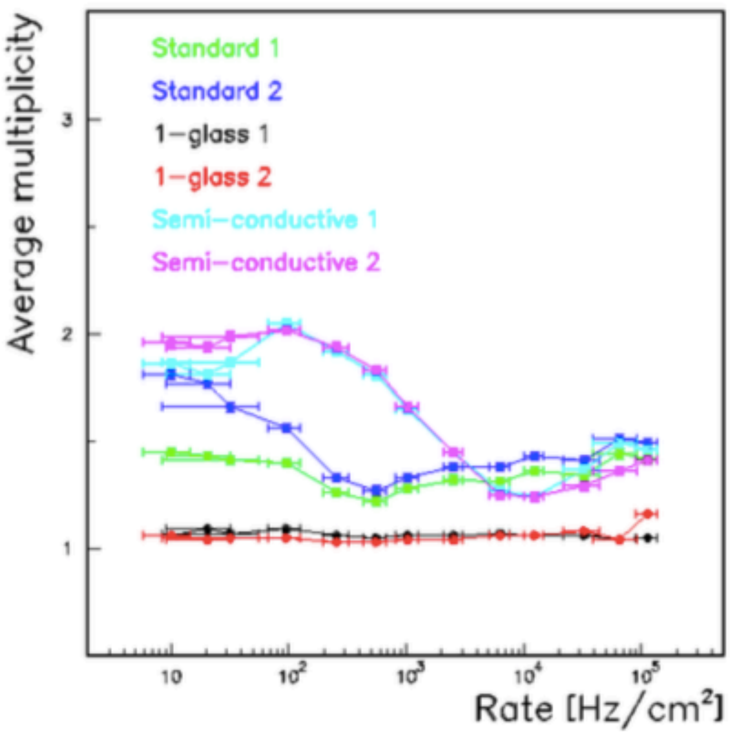
2. *1-glass RPCs with standard glass*
   The chambers were built with one standard soda-lime float glass plate with a thickness of 1.15 mm. The gas gap was also 1.15 mm. The size of the chamber was dictated by the size of the readout board, i.e. 32 x 48 cm$^2$. With only one glass plate the gas volume 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.

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

# Further Development of High-Rate RPCs

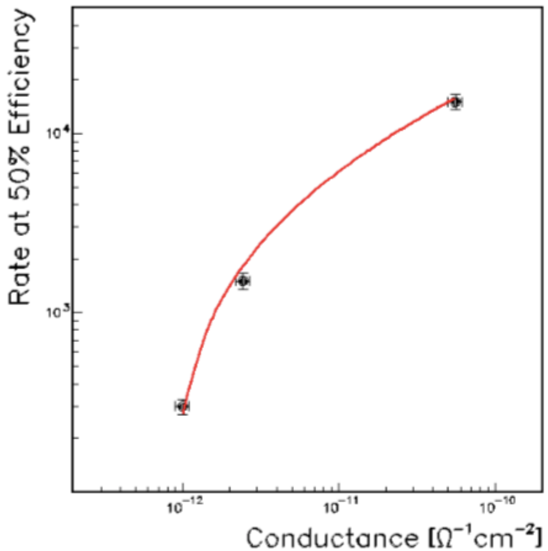



$I_{50\%}=a+bH+cH^3$

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.

$a = 1.7\text{x}10^5$, $b = 3.2\text{x}10^6$ and $c=-1.7\text{x}10^8$.



# 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.

- $0.40ZnO-0.40TeO_2-0.20V_2O_5$ 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.