Fundamentals of Resistive Plate Chamber (RPC)

Varchaswi K S Kashyap
SCHOOL OF PHYSICAL SCIENCES
NATIONAL INSTITUTE OF SCIENCE EDUCATION AND RESEARCH

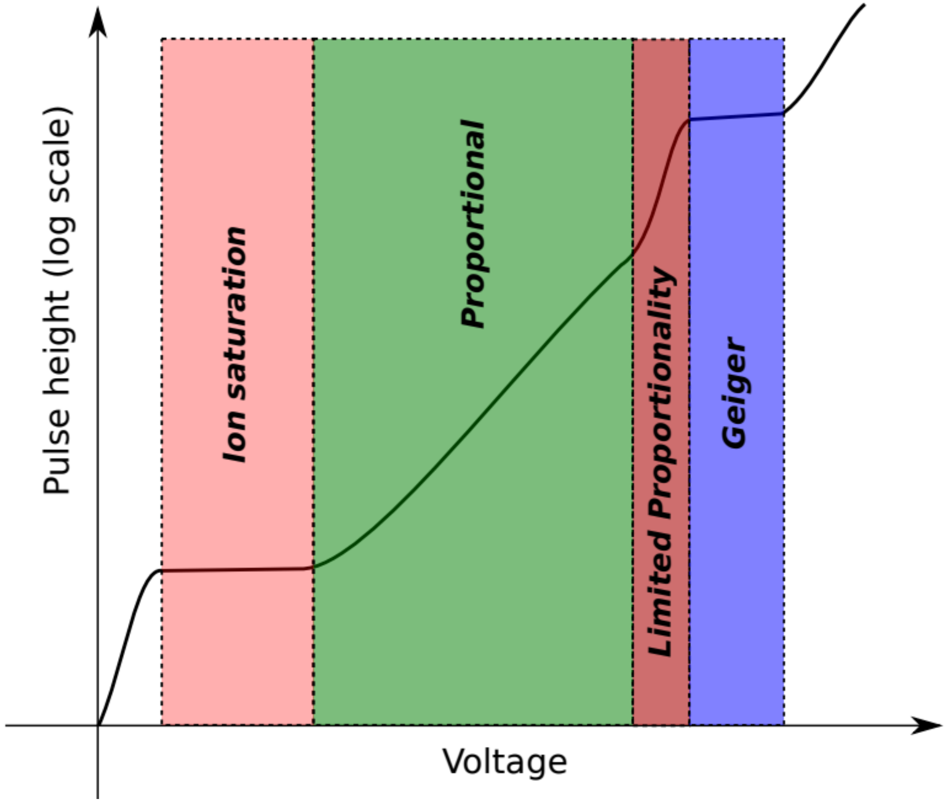
Gas detectors

Geometry

- Cylindrical – Eg. GM counter, proportional counter, straw tube
- Planar – Eg. RPC, PPAC

Features

- Energy
- Timing
- Position

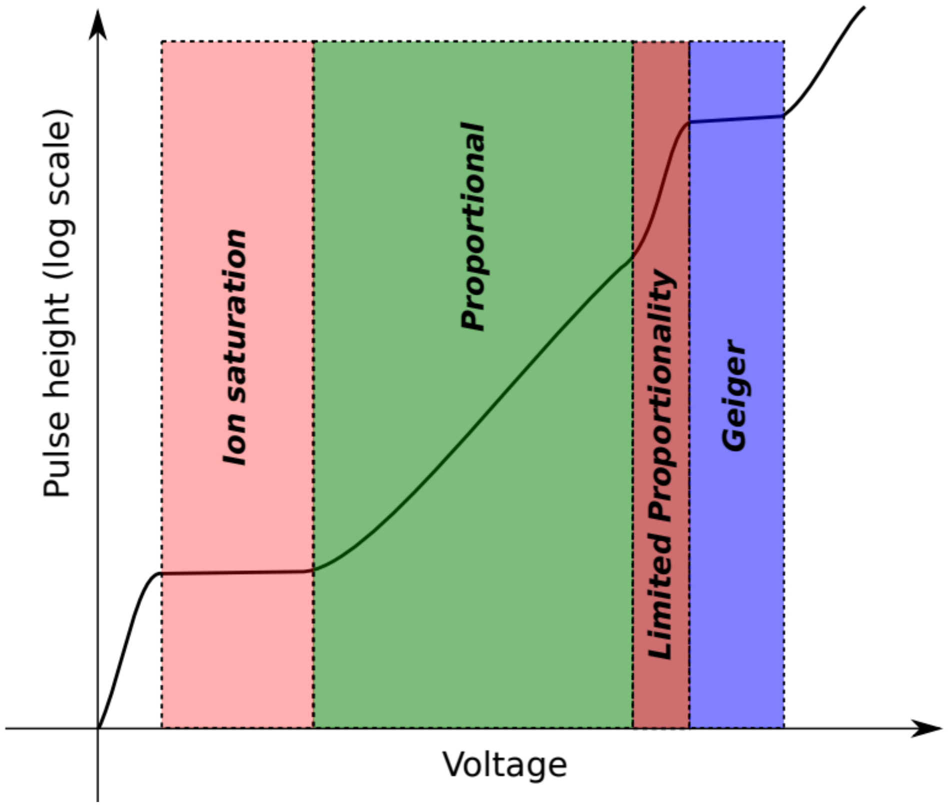


Gas detectors

Geometry

- Cylindrical – E.g. GM counter, proportional counter, straw tube
- Planar – E.g. RPC, PPAC

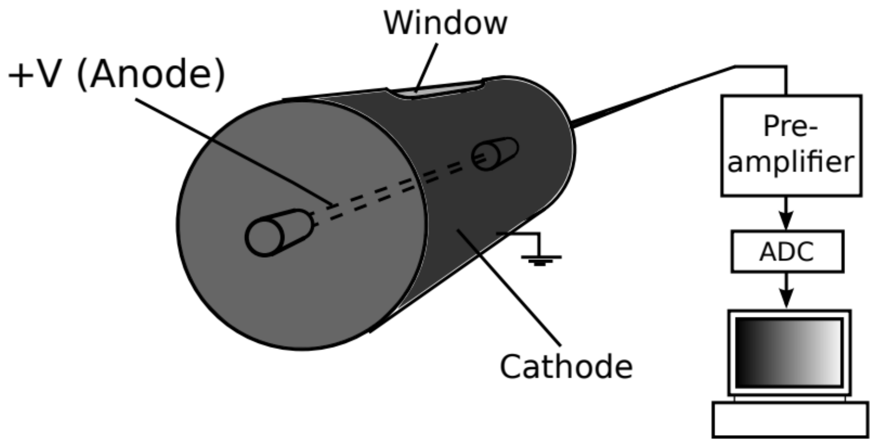
Features	**RPC**
• Energy	**NO**
• Timing	**YES**
• Position	**YES**



Features of RPC

- Simple in construction. Can be made from relatively inexpensive materials like glass and Bakelite
- Can cover large area
- Provide excellent time resolution and reasonable position resolution
- Can be used for triggering and tracking
- When stacked and place in magnetic field of sufficient strength, RPCs can be used to obtain energy of incoming particles
- Very efficient for detecting minimum ionizing particles such as muons

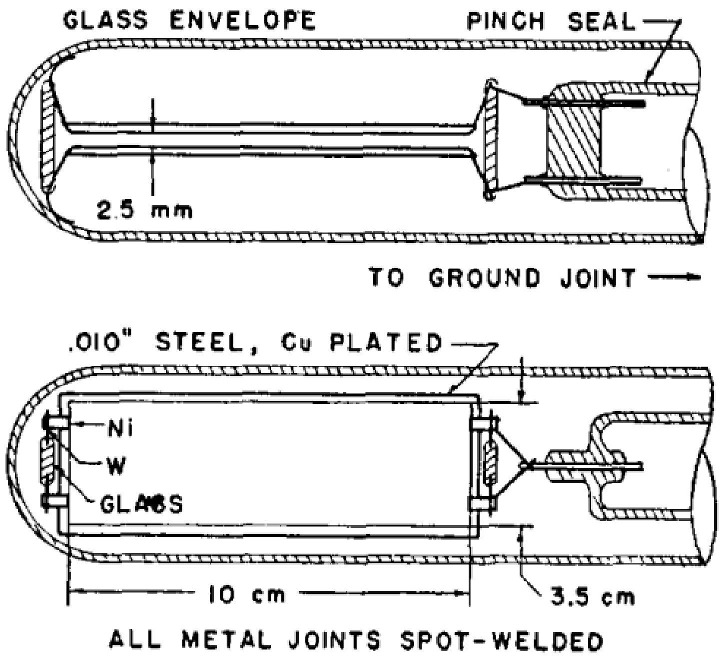
Cylindrical gas detectors



Proportional counter

- Non-uniform electric field
- Avalanche multiplication happens near the wires
- Average time resolution
- Good signal proportionality for energy measurements

Planar gas detectors
(A little bit of history)



J. W. Keuffel, Rev. Sci. Instruments 20.3 (1949)

Parallel Plate Counter

- Designed to provide time resolution better than GM counters
- Excellent time resolutions of the order of ns.
- Small size and large recovery time
- External electronics circuit required for quenching

Planar gas detectors
(A little bit of history)

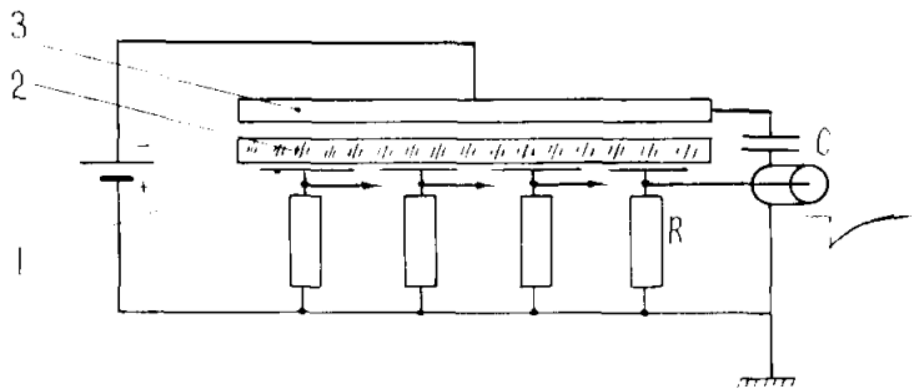


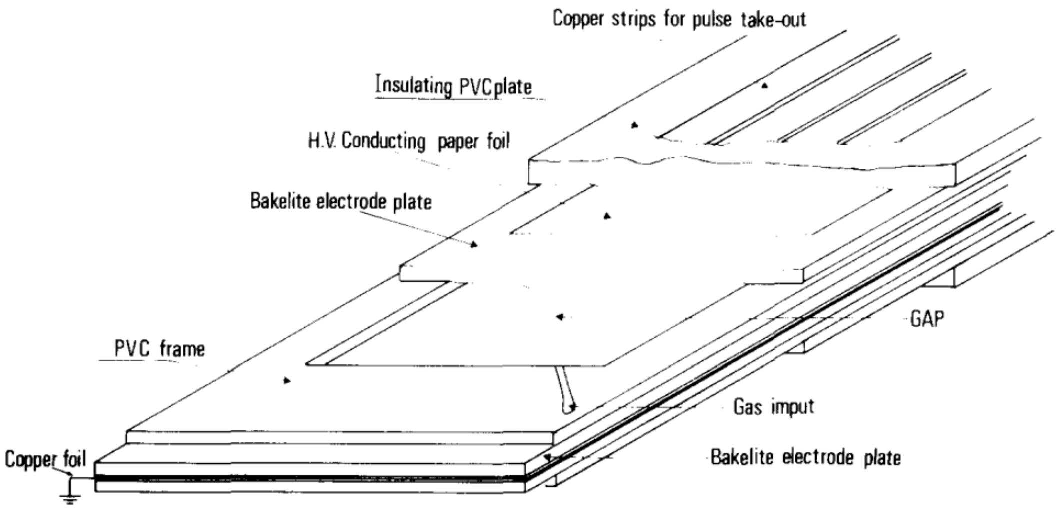
Fig. 1. The principal experimental lay-out. 1. Conductive layer; 2. electrode of semiconductive glass; 3. copper electrode.

V.V. Parkhomchuck, Yu.N. Pestov, and N.V. Petrovykh, NIM 93.2 (1971)

Planar Spark Chamber (Pestov Counter)

- Semi-resistive **glass** electrode
- Self quenching property and localization of discharge
- Excellent time resolutions of the order of ns.
- Large area detector construction possible

Planar gas detectors
(Enter **RPC**)



R. Santonico and R. Cardarelli, NIM 187 (1981)

Resistive Plate Chamber

- Usage of inexpensive materials like **bakelite**
- Simplified construction
- Readout with capacitative coupling and reasonable position resolution
- Large area particle detection

The resistive electrode

The time evolution of charge deposited on an electrode can be described by

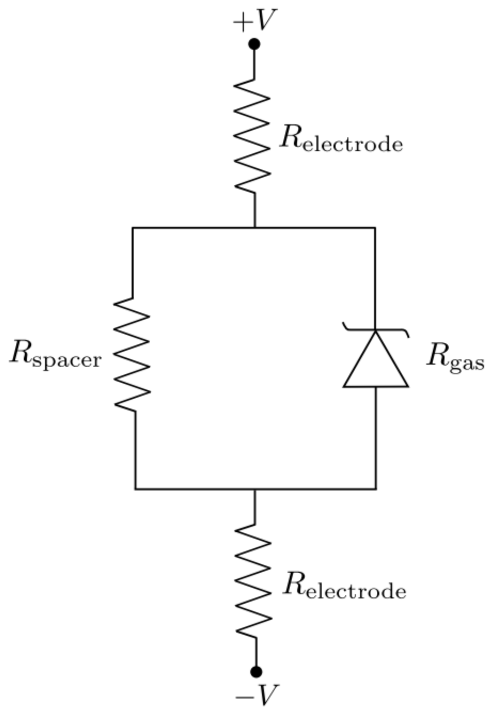
$$Q(t) = Q_0(t)\exp(-t/\tau)$$

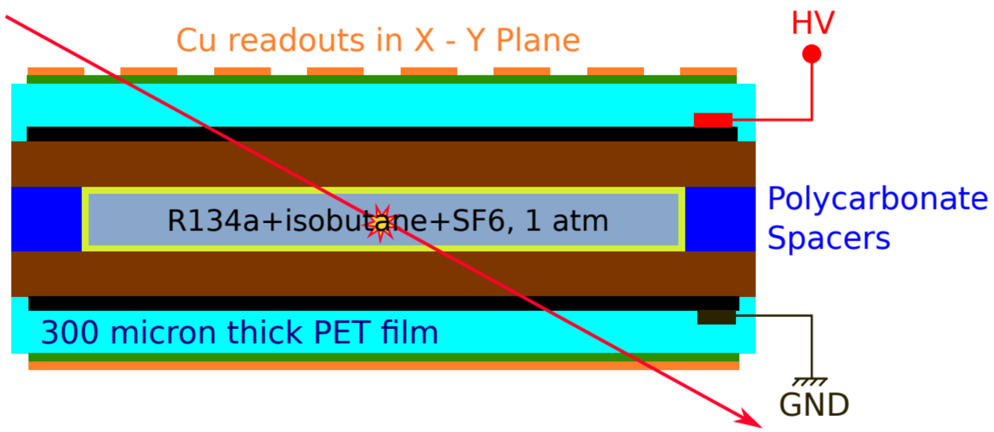
$$\tau = \rho\epsilon_0\epsilon_r$$

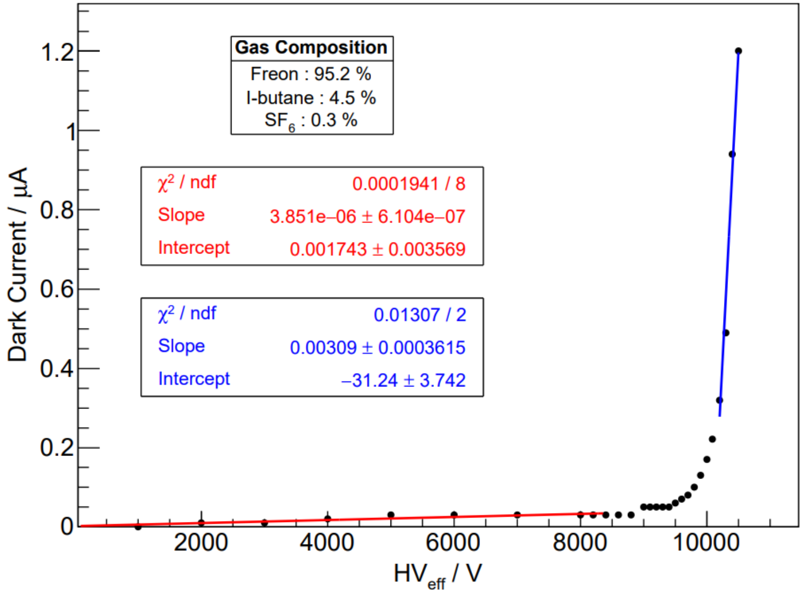
where Q is the charge deposited and τ is the relaxation time

- Allows localization of the discharge making only small part of the detector inactive
- Localization of charge can be exploited to obtain reasonable position information
- Provides inbuilt protection to electronics from sparks and discharges

Basic construction and working principle of RPC

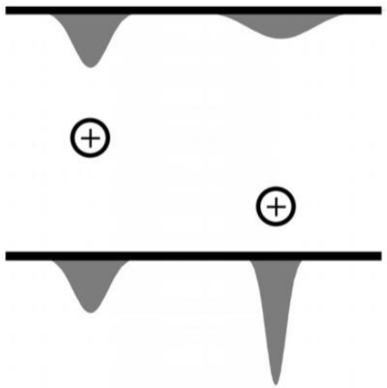






- Lower voltages: gas is insulating
- Higher voltages: gas becomes conducting

Signal induction by motion of charge



F. Sauli, Gaseous Radiation Detectors, Cambridge University Press

The Shockley-Ramo theorem is given by

$$i = E_v e v$$

where i is the instantaneous current flowing in the electrode due to the motion of a single electron, E_v is the electric field and v is the velocity of the electron

- The signal is generated on the readout as soon as ions and electrons start moving in the gas due to the electric field
- Since the electrons have higher mobility compared to ions, electron component is mostly used.

Electrodes materials

Glass

- Hard and rigid
- Surface smoothness excellent
- Typical resistivity $\sim 10^{12} - 10^{13}\ \Omega\text{cm}$
- Semiconductive glasses can be produced with $\sim 10^{10}\ \Omega\text{cm}$ resistivity but are expensive
- Suitable mostly for low count rate or cosmic ray experiments

Bakelite

- Comparatively flexible
- Surface finish above average. Requires oil coating for better performance
- Typical resistivity $\sim 10^{10} - 10^{12}\ \Omega\text{cm}$
- Suitable for collider experiments
- Requires humidified gas mixture
- Needs R & D on rate capability for use in future collider facilities with increased luminosity and particle flux

Modes of operation

Avalanche Mode

- After ionization, charge multiplication reaches to an extent that its own field prevent further multiplication
- This is also known as the saturated avalanche
- Charge induced is ~1 pC
- Requires low-noise preamplification electronics
- Higher count rates are possible
- Better time resolution

Streamer Mode

- When the applied voltage is increased beyond the saturated avalanche regime a streamer or mild spark is created.
- A conductive channel is formed across the electrodes and the small discharge area remains inactive for a larger amount of time.
- Charge induced is ~10-100 pC
- Requires no preamplification electronics
- Cannot be operated in high count rate environment

Modes of operation (Gas mixtures)

Avalanche Mode

- **Freon**: Main medium of interaction
- **Isobutane**: Recombination photon quencher
- **SF_6**: Arrests the development of avalanche

Typical gas composition:

Freon	i-butane	SF_6
95	~5	0.3

Streamer Mode

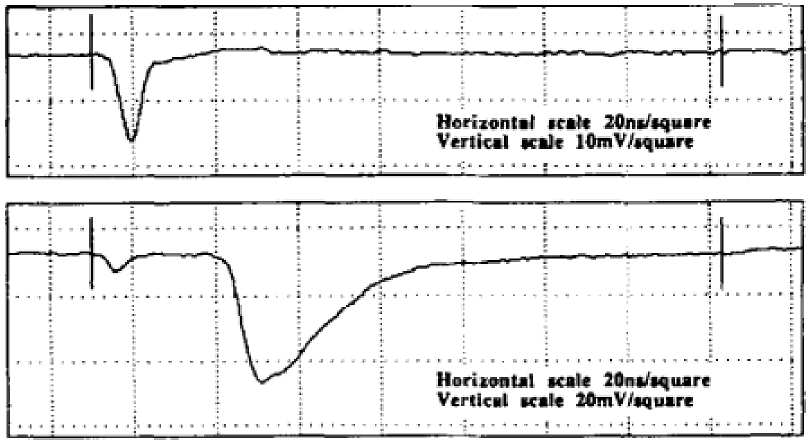
- **Argon**: Medium of interaction
- **Freon**: Slightly electronegative gas that controls avalanche development
- **Isobutane**: Recombination photon quencher
- **SF_6**: Arrests the development of avalanche

Typical gas composition:

Ar	Freon	i-butane	SF_6
48	48	4	Very little or NA

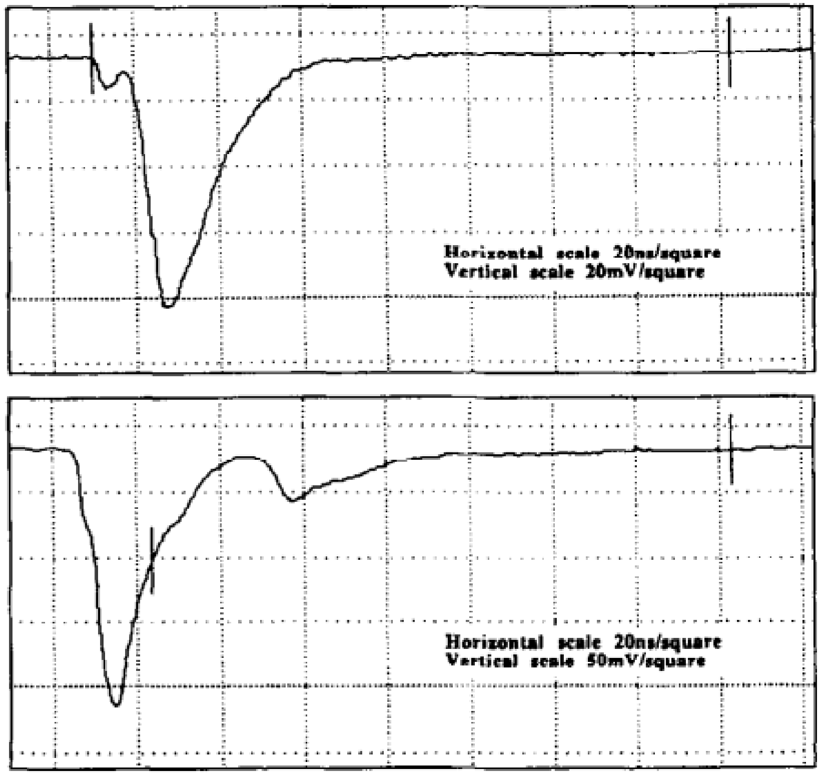
Modes of operation (pulses)

Avalanche Mode

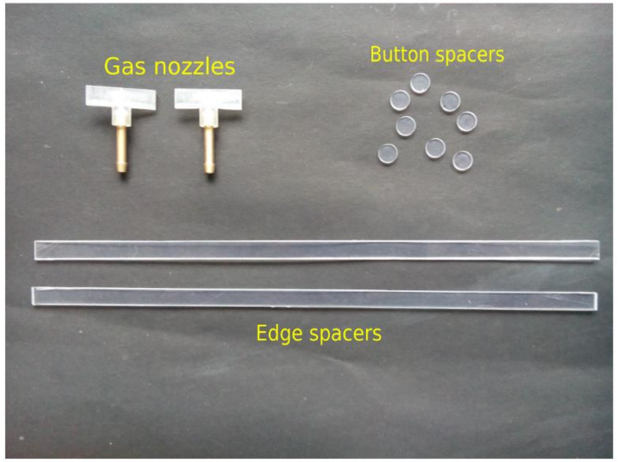


R. Cardarelli et al, NIM A 382 (1996)

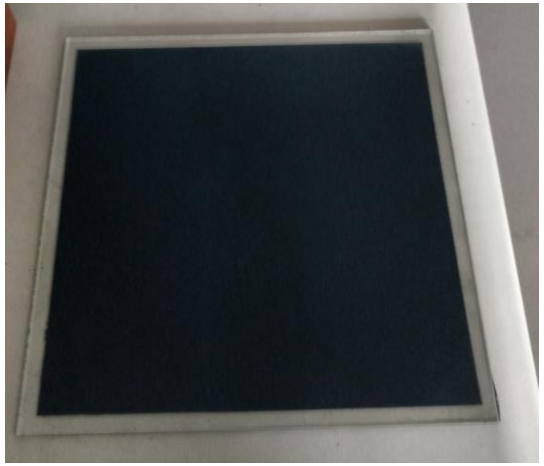
Streamer Mode



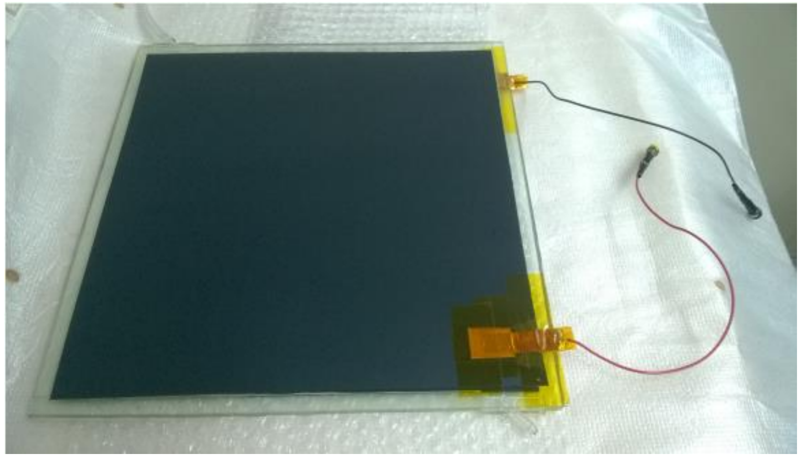
Fabrication of RPC



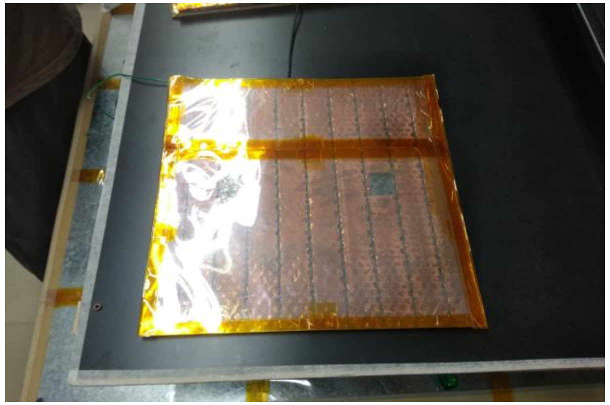
Spacers



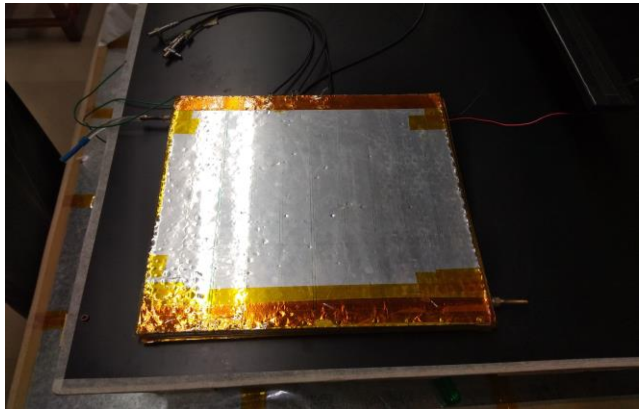
Conductive paint coated electrode



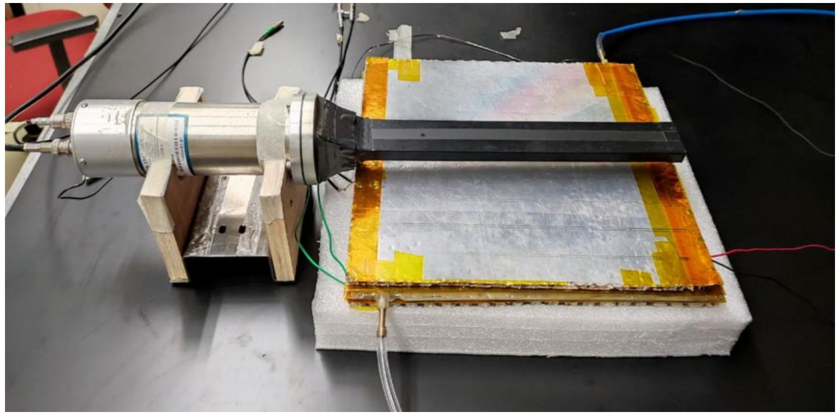
RPC gas gap



Readout panel



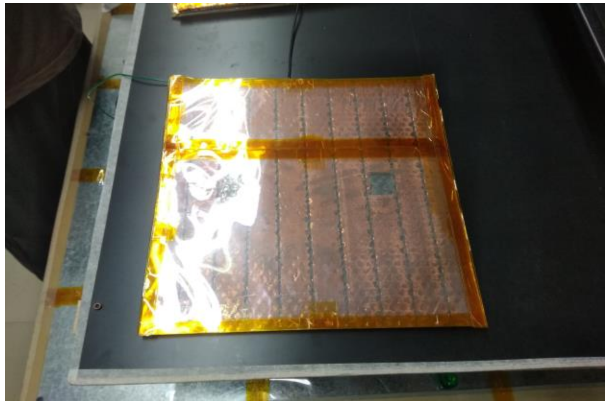
Gap sandwiched between readouts



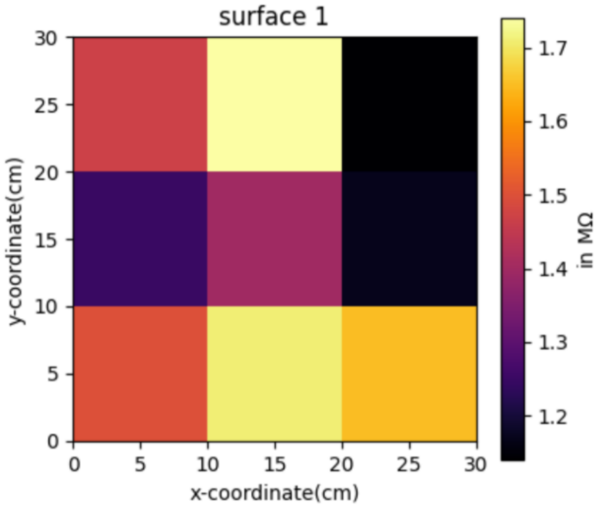
RPC under characterization

Surface resistivity and readout

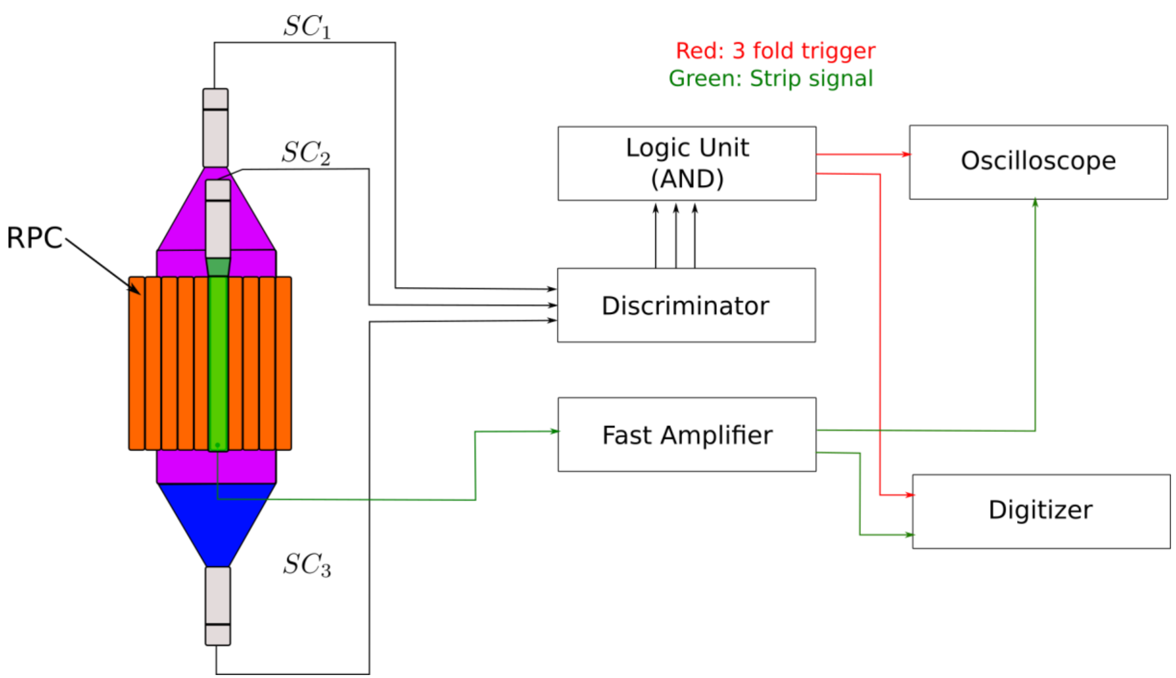
- The surface resistivity of the conductive coating on the RPCs is $\sim 100 - 250\ \mathrm{k\Omega}/\square$ for bakelite and $\sim 1\ \mathrm{M\Omega}/\square$ for glass electrodes
- Surface resistance needs to be uniform
- The readout strips act as transmission lines and their characteristic impedances need to be matched with cables connecting frontend electronics.
- The impedance depends on the dielectric material of the readout



Readout panel



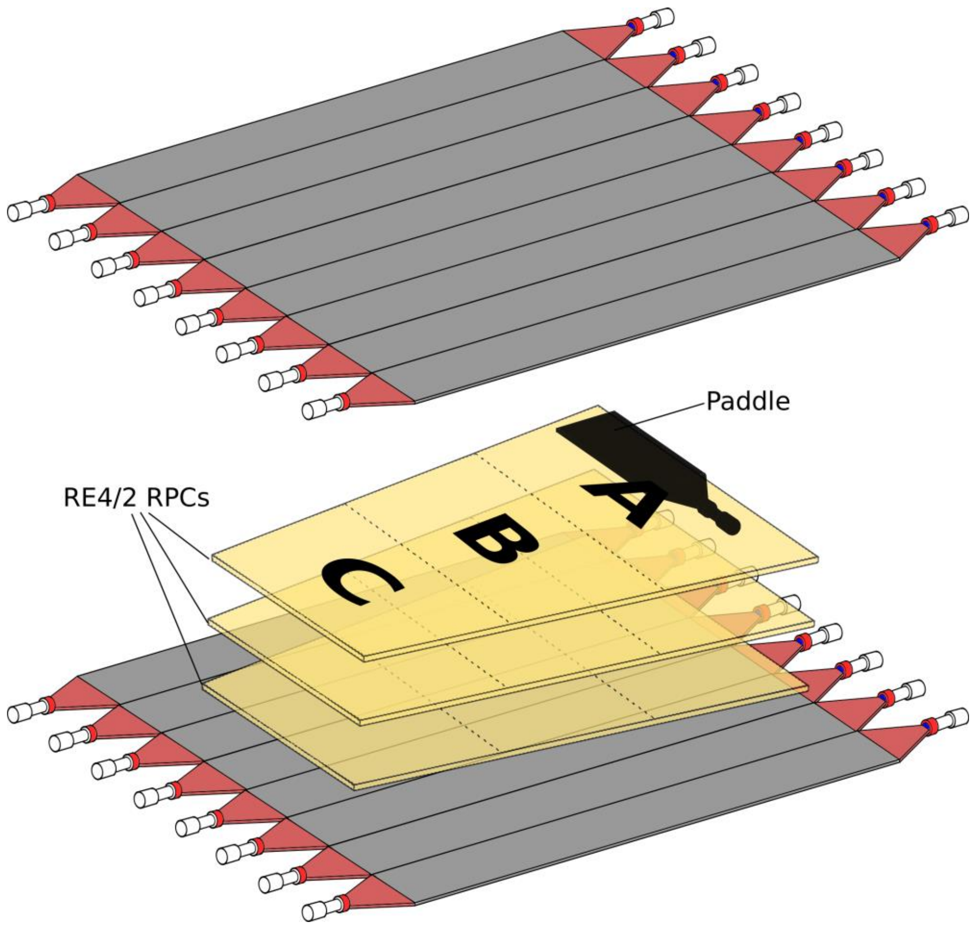
Characterization of RPC



- RPC is sandwiched between scintillator paddles
- 3-fold logical coincidence of paddles constitutes a trigger
- No. of signals detected by the RPC in the presence of 3-fold trigger gives the efficiency

Quality control during production

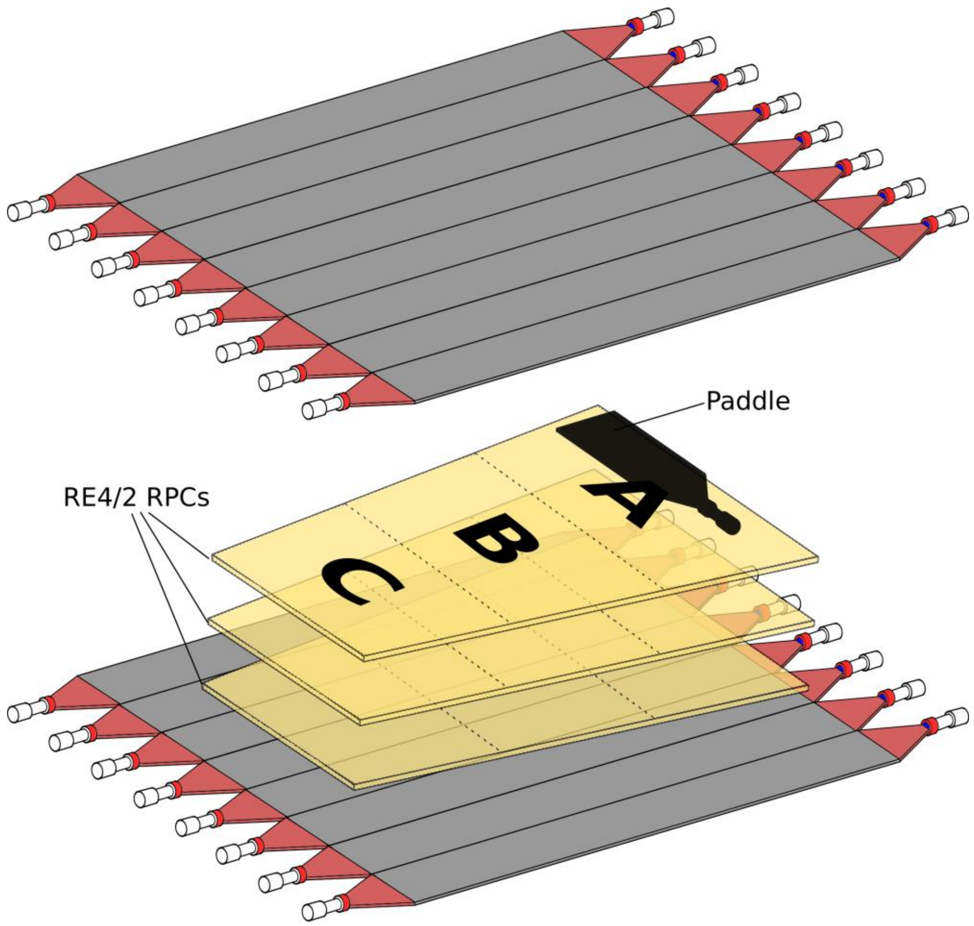
- **Visual inspection** of gap and components
- **Mechanical tests** – leak tests of the gas gaps and pressure test of the spacers. Test of cooling systems for electronics
- **Electrical tests** – I-V characteristics of the RPC. Connectivity tests of readouts and FE electronics after integration with RPCs.
- **Uniformity and performance tests**- Cosmic muon characterization using hodoscope



V. K. S. Kashyap et al, Pramana – J Phys. 88.79 (2017)

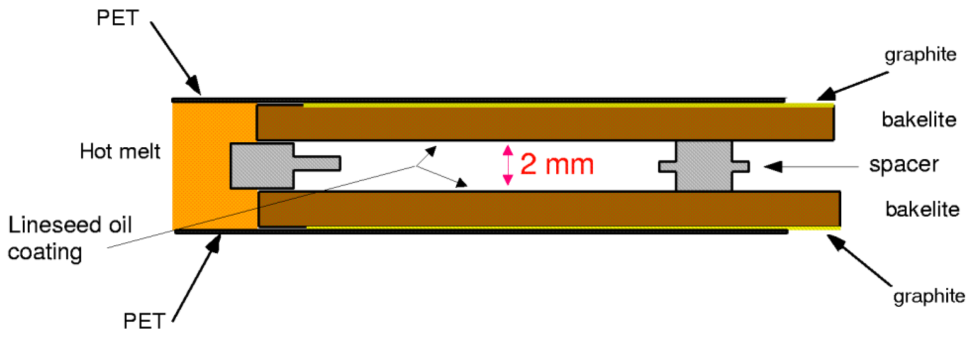
Characterization of RPC (Production)

- Large area characterization is required at the stage of production
- Hodoscope setups are a good choice to characterize RPCs using cosmic rays
- Obtain important parameters such as efficiency, time resolution and clustersize
- Characterized RPCs themselves can be used to characterize other RPCs



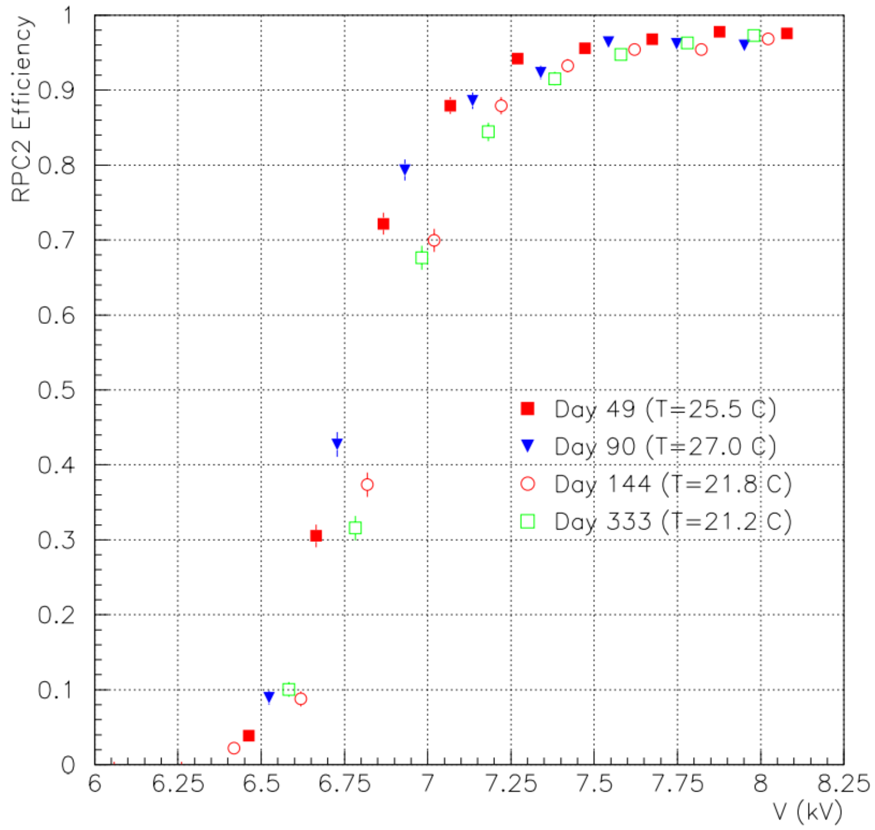
V. K. S. Kashyap et al, Pramana – J Phys. 88.79 (2017)

Streamer RPCs in experiments (OPERA)



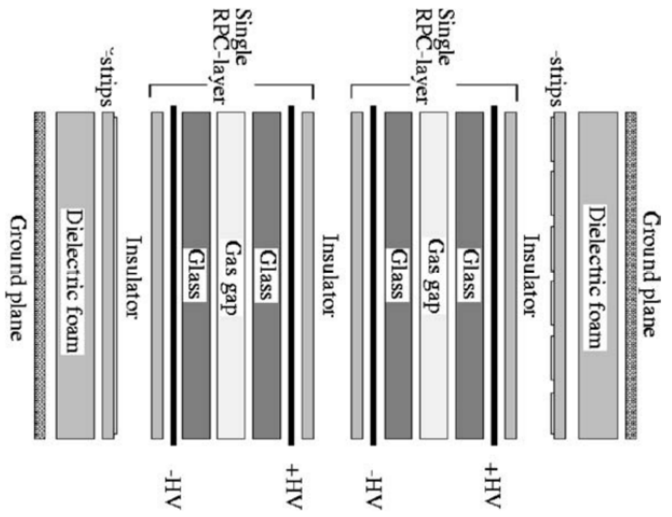
Electrode material	Gap thickness	Electrode thickness
Bakelite	2 mm	2 mm

- Argon (76%), Freon (20%) and i-butane (4+0.7%)
- Bulk resistivity $\rho > 5 \times 10^{11}\ \Omega\mathrm{cm}$
- Dimension: 2.91 x 1.14 m^2



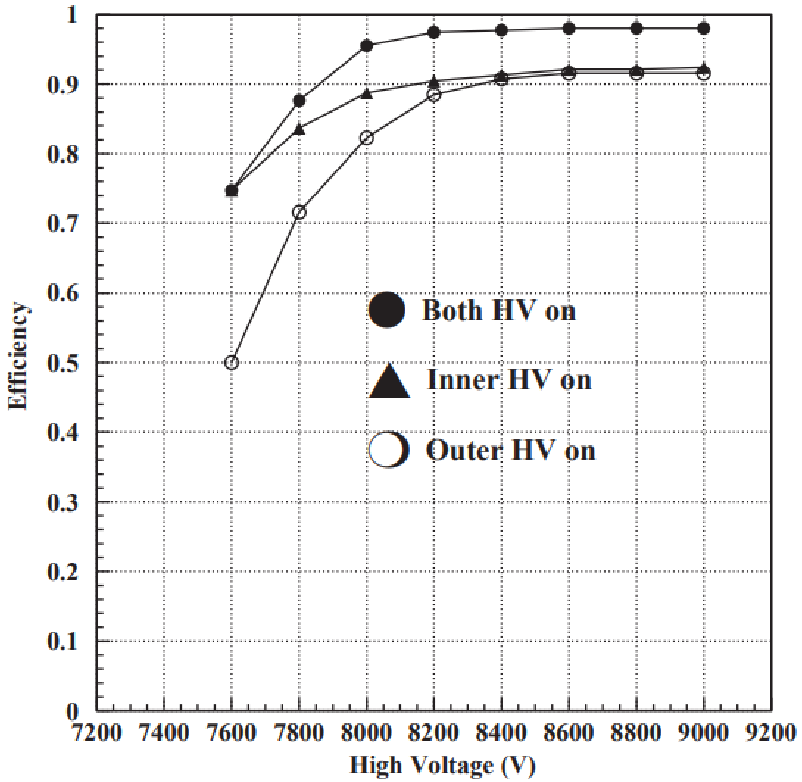
A. Paoloni, "The OPERA spectrometer RPC system," *IEEE Symp. Conf. Rec. Nuc. Sci. 2004.*, 2004, pp. 502-506 Vol. 1

Streamer RPCs in experiments - Double gap (BELLE)



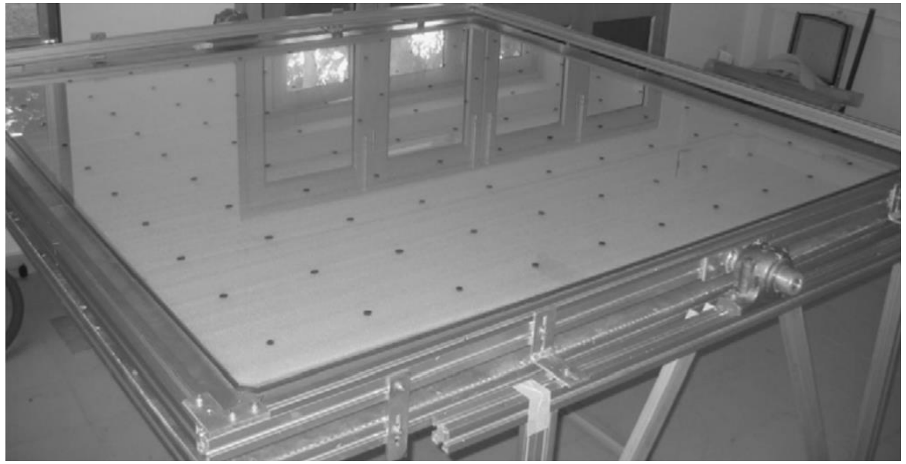
Electrode material	Gap thickness	Electrode thickness
Glass	2.4 mm	2 mm

- Argon (30%), Freon(62%) and Butane silver(8%)
- Bulk resistivity $\rho \sim 10^{12}\ \ \Omega\text{cm}$
- Dimension: $2.2 \times 2.7\ \text{m}^2$

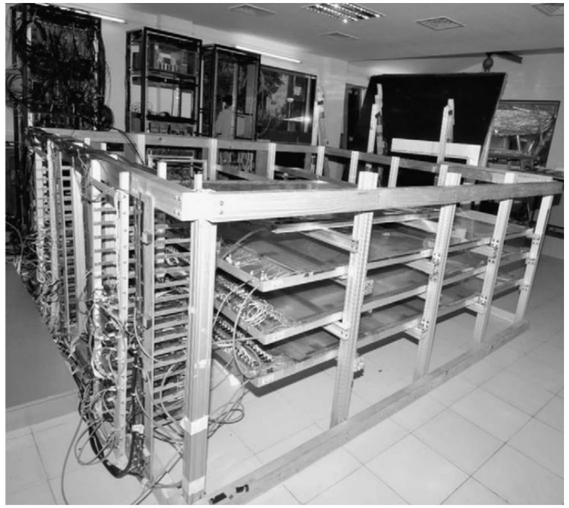


Jian Gui Wang, NIM A 508 (2003)

Avalanche RPCs in experiments (INO)



V. M. Datar et al, NIM A 602 (2009)

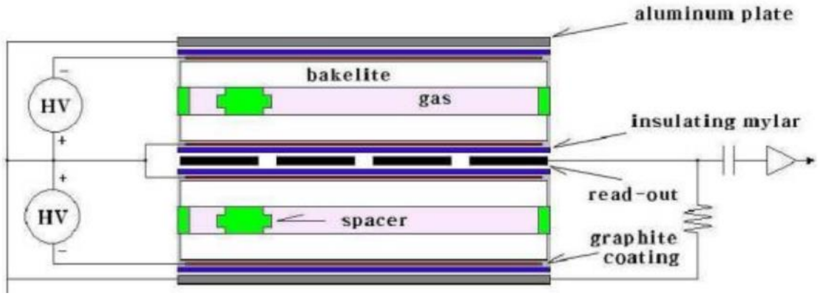


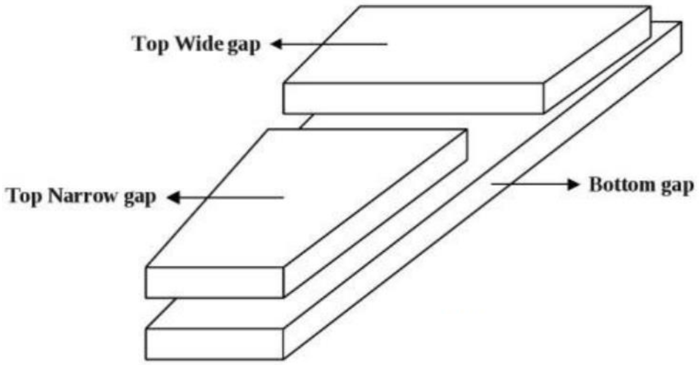
Electrode material	Gap thickness	Electrode thickness
Glass	2 mm	3 mm

- Bulk resistivity $\rho \sim 10^{12}\ \Omega\text{cm}$
- Dimension/area: 2 x 2 m^2

More details in the talk by Dr. B. Satyanarayana

Avalanche RPCs in experiments – Double gap (CMS Endcap)





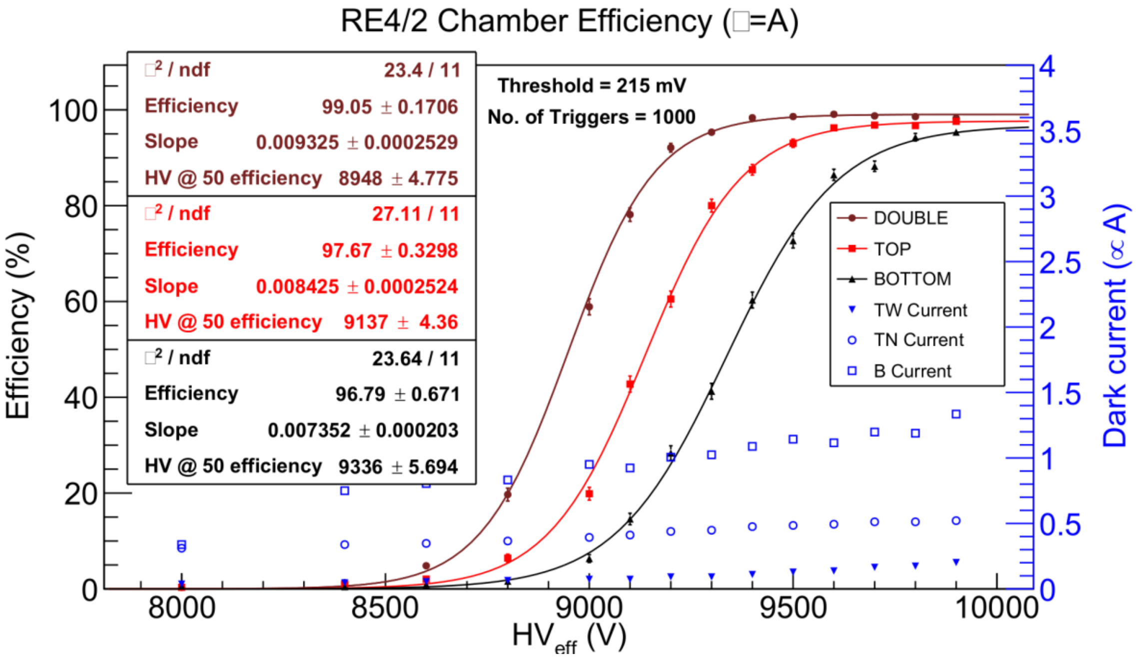
Mariana Shopova, ArXiv: arXiv:1605.06798v1

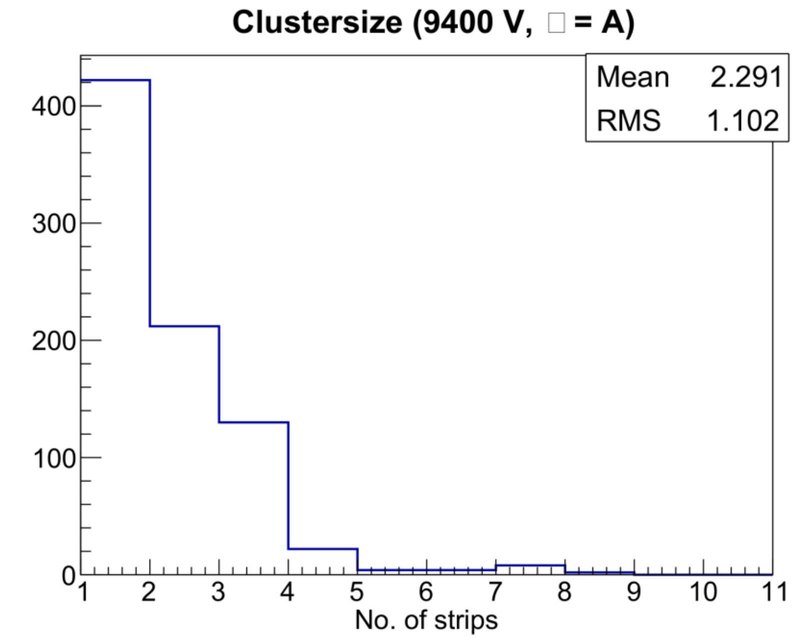
- Usage of double gap improves the efficiency of the RPC
- The efficiency of 1 gap would compensate for the inefficiency of the other per event
- Readout only on one side of the RPC

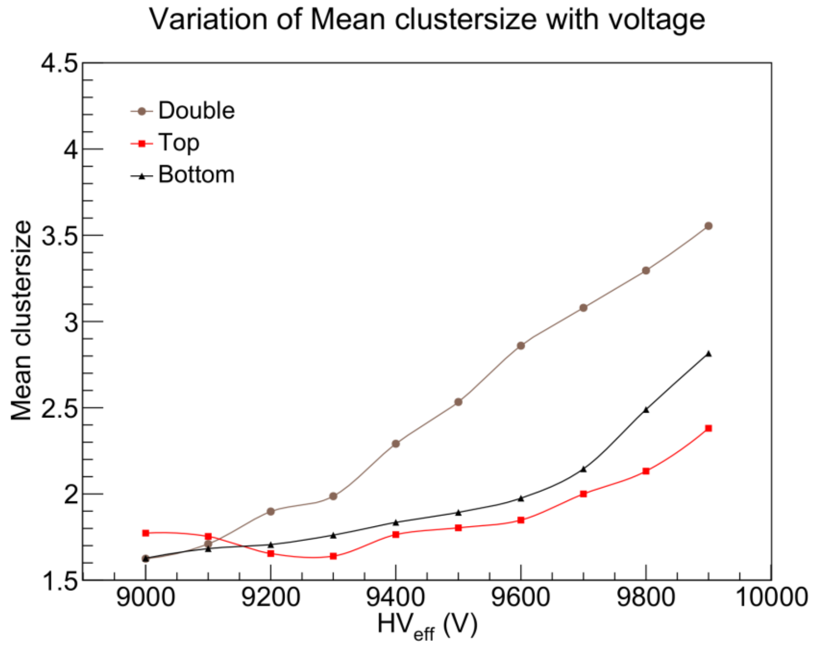
Electrode material	Gap thickness	Electrode thickness
Bakelite	2 mm	2 mm

- Freon (95.2%), i-butane (4.5%) and SF_6(0.3%)
- Bulk resistivity $\rho \sim 1 - 6 \times 10^{10}\ \Omega\text{cm}$
- Dimension/area : ~2 mm^2

RPCs in experiments – Double gap (CMS)







$$HV_{\text{eff}} = HV_{\text{app}} \frac{P_0}{T_0} \frac{T}{P}$$

$$P_0 = 990 \text{ mbar}$$

$$\eta = \frac{\epsilon_{\max}}{1 + e^{-\lambda(HV_{\text{eff}} - HV_{50\%})}}$$

$$T_0 = 293 \text{ K}$$

V. K. S. Kashyap et al, Pramana – J Phys. 88.79 (2017)
S. Colafranceschi et al 2014 JINST 9 C10033

RPC rate capability

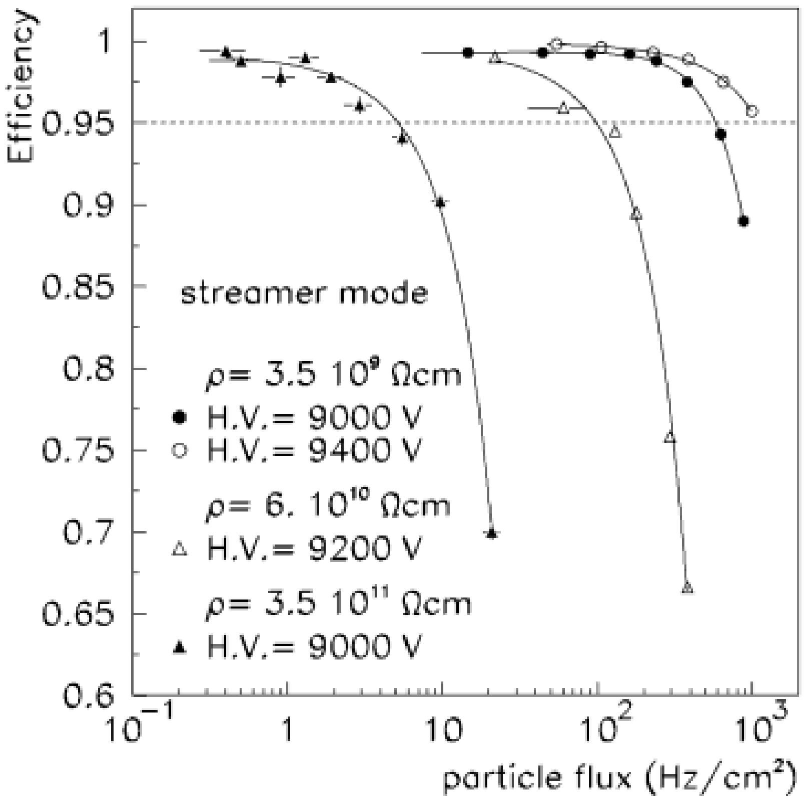
With colliders reaching unprecedented luminosities the demand for high rate capable detectors Is increasing.

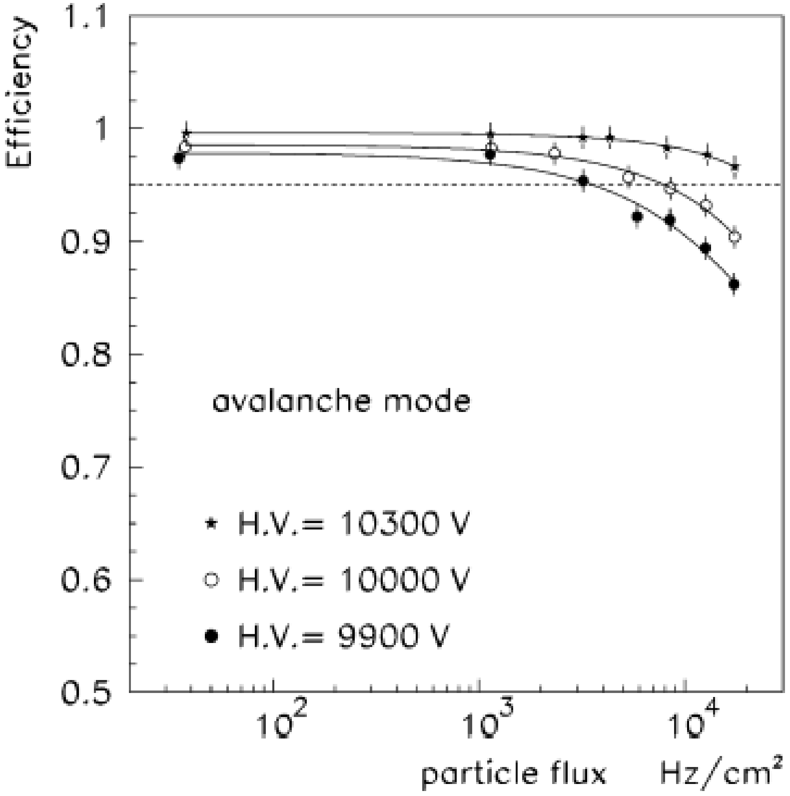
The rate capability of RPC is defined as

$$r_C = \frac{r}{V} = \frac{1}{\rho t\langle Q\rangle}$$

where $r_C = r/V$ is the rate per unit voltage drop, r is the particle (counting) rate, V is the voltage drop across the electrodes, ρ is the bulk resistivity of the electrodes, t is the total thickness of the electrodes and $\langle Q\rangle$ is the average charge produced in the gas for each count

RPC rate capability

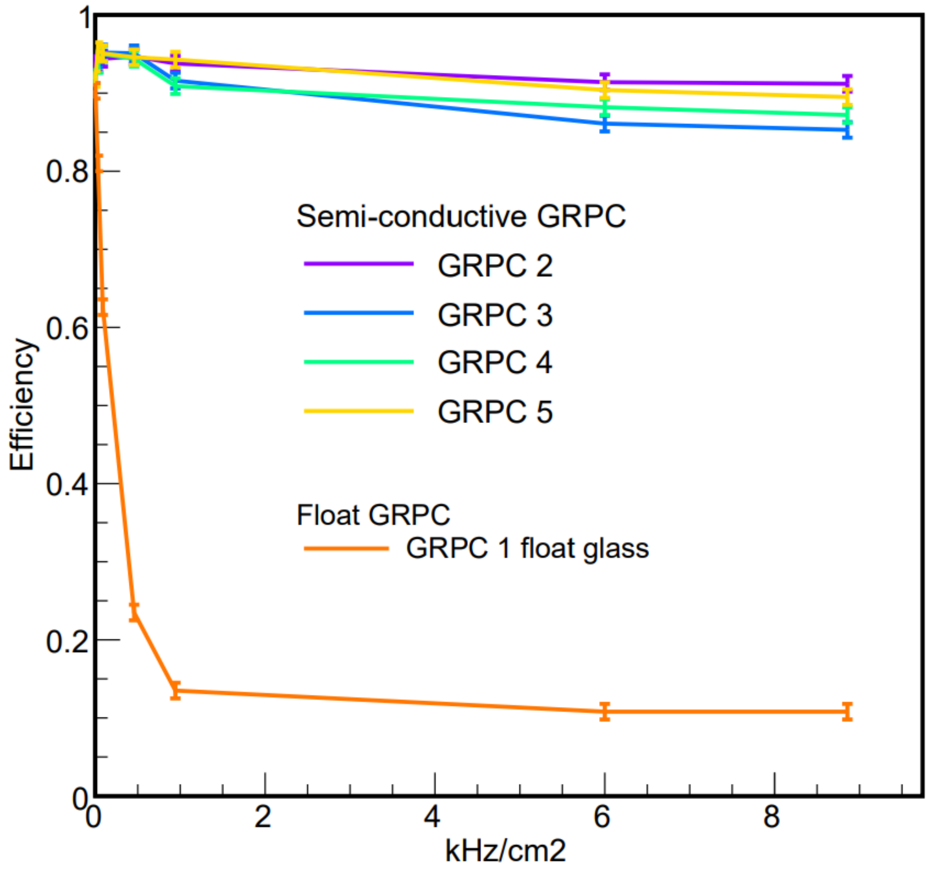


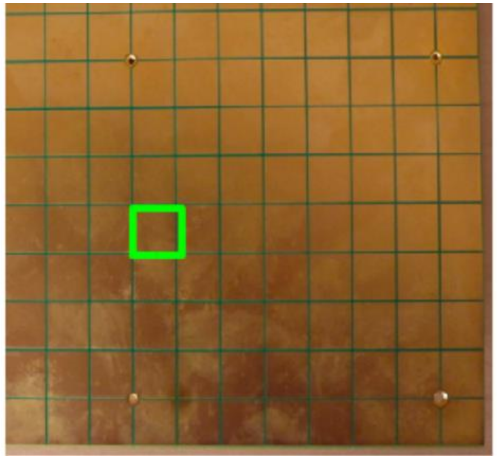


- 50x50 cm^2 RPC
- 2 mm gas gap with 2 mm thick electrodes
- Streamer gas composition: Ar/i-C_4H_{10}/$C_2H_2F_4$/SF_6 = 49/7/40/4
- Avalanche gas composition: $C_2H_2F_4$/i-C_4H_{10}/SF_6= 95/3/2

Arnaldi et al, NIM A 451 (2000)

RPC rate capability





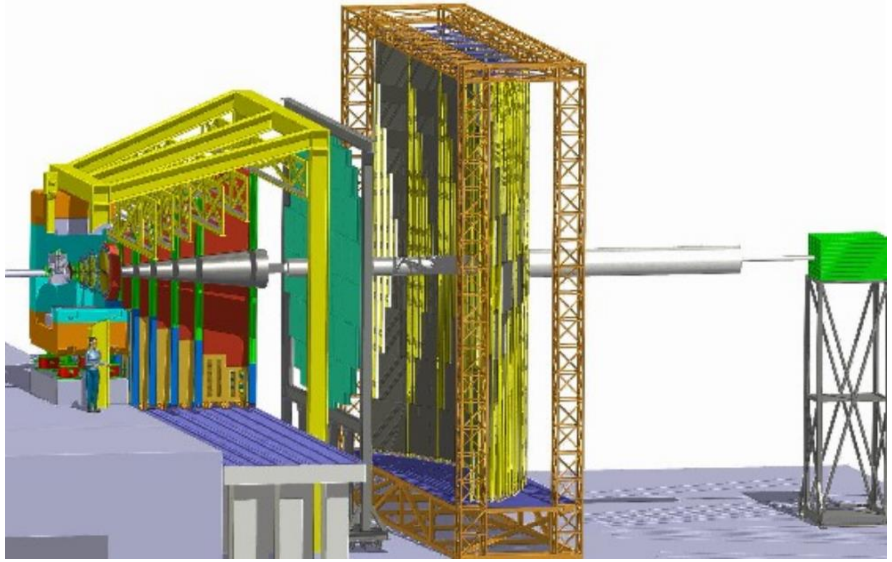
Haddad et al, NIM A 718 (2013)

- 1.1 mm thick doped silicate glass electrodes developed by Tsinghua university
- Glass bulk resistivity

  $$\rho \sim 10^{10}\ \Omega\text{cm}$$

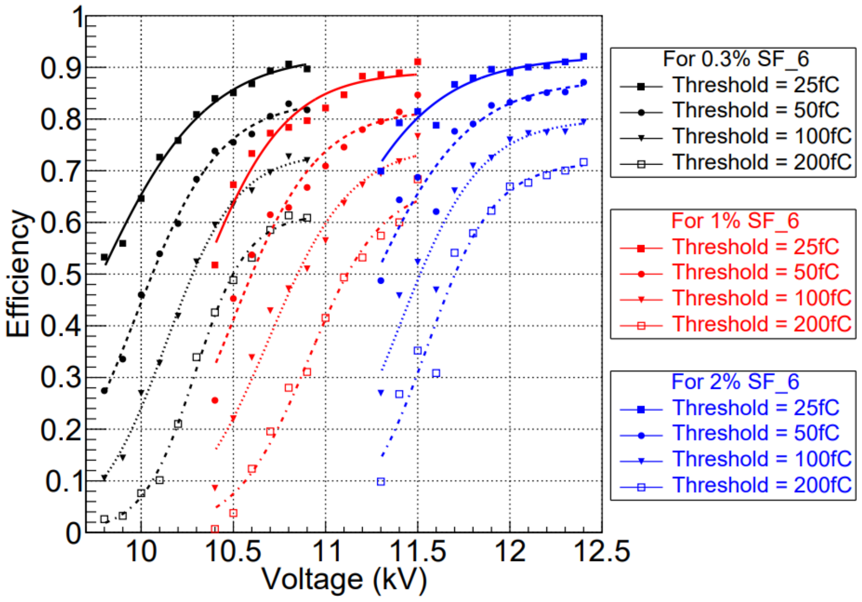
- 1.2 mm thick gas gap
- 1 cm x 1 cm pad based readout
- Glass currently very expensive

RPC rate capability (CBM 3rd and 4th stations)



Picture from CBM-MUCH-TDR

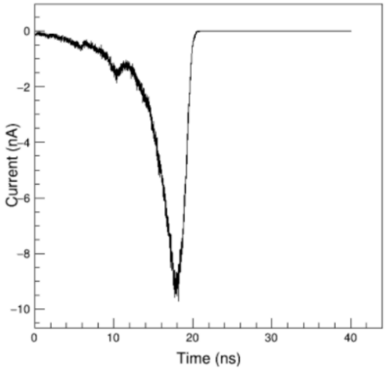
- Proposal to use RPCs for CBM 3rd and 4th stations
- 15 kHz.cm^{-2} and 5.6 kHz.cm^{-2} rate capability needed for 3rd and 4th stations respectively
- RPC operation at 25 fC to 100 fC level needed

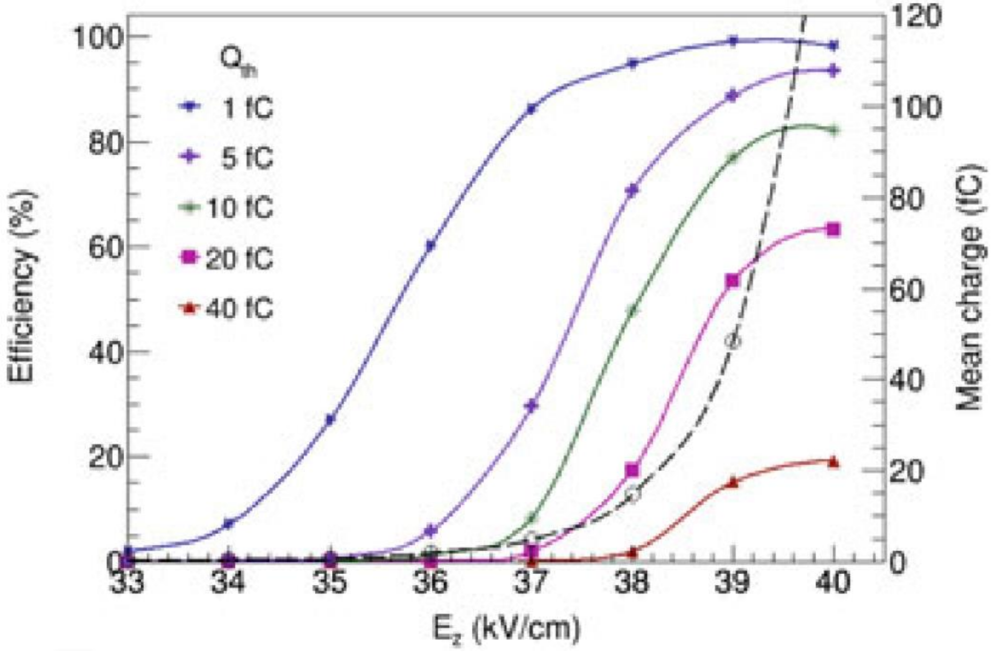


V K S Kashyap et al, CBM progress report 2019

- R & D at NISER in progress with low resistivity glass (previous slide)
- Parallel R & D progress at VECC, Kolkata with bakelite RPCs

Rate capability (Simulation)





- One can model avalanche mode RPCs and estimate the amount of charge induced on the readout per event using tools like GARFIELD++, HEED and MAGBOLTZ
- Only electron signals
- Simulation predicts it may be possible to get signals even at low thresholds
- Noise level in real conditions - deciding factor

A Jash et al, XXIII DAE High Energy Physics Symposium. Springer Proceedings in Physics, vol 261.

Gas mixture and GWP

Gases used in RPC and Global Warming Potential (GWP)

Gas	Freon-r134a	i-butane	SF_6
GWP	1430	3	23900

- Freon r134a and SF_6 have high GWP
- Alternative gas candidates are:

Gas	HFO-1234ze	HFO-1234yf
GWP	6	4

- These gases currently do not show performance similar top that of r134a mixtures in the avalanche mode and can be used as additional components to reduce overall gas mixture GWP
- More R & D ongoing to find good alternatives

1. M. Capeans et al, *2015 IEEE Nuc. Sci. Symp.and Med. Imag. Conf. (NSS/MIC)*, 2015, pp. 1-4
2. R. Guida et al, https://doi.org/10.1016/j.nima.2019.04.027

RPC descendant (Multi-gap RPC)

- Built to improve the time resolution of RPCs drastically while still retaining good efficiency
- Very fine division of gas gap in the order of 100s of microns
- Electrostatic division of voltage
- Time resolution ~50 ps
- With optimized designs, they can be good candidates for PET imaging

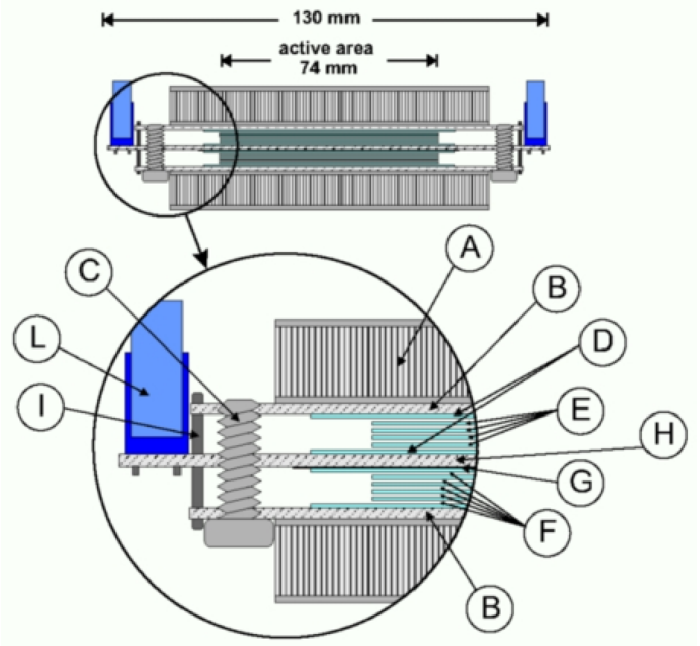
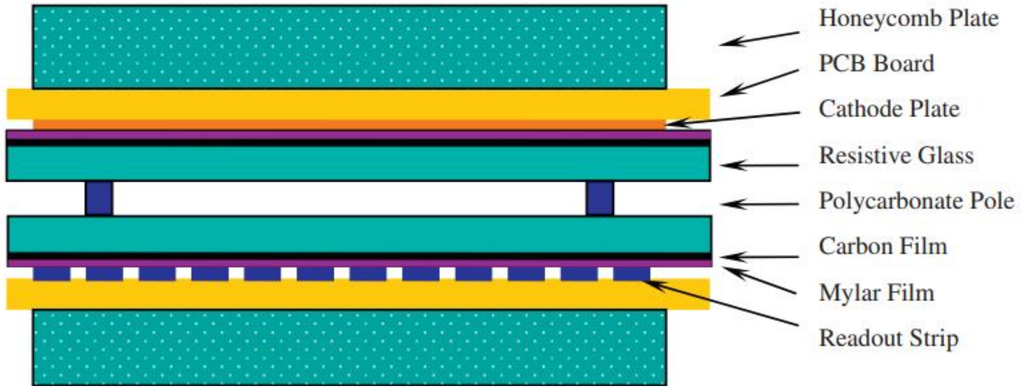


Figure 3. Cross-section of the double-stack MRPC of the ALICE-TOF system. A: 10 mm thick honeycomb panel; B: PCB with cathode pick-up pads; C: M5 nylon screw to hold the fishing-line spacer; D: 550 μm thick external glass plates; E: four 400 μm thick internal glass plates; F: five gas gaps of 250 μm; G: 250 μm thick mylar film; H: central PCB with anode pick-up pads; I: pin to bring cathode signals to central read-out PCB; L: flat-cable connector (for MRPC signal transmission to the front-end electronics).

A. Akindinov et al, Nuclear Physics B (Proc. Suppl.) 158 (2006) 60–65

Improved position resolution

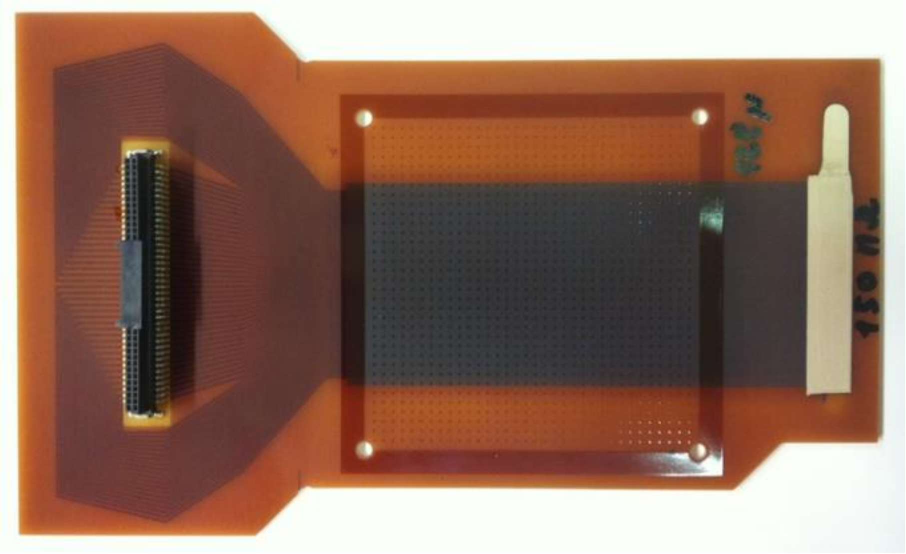
RPCs with 1 mm strips



Ye et al, NIM A 591 (2008)

- Position resolution ~500 micron
- Spark protection

Microgap-Microstrip RPC (MMRPC)



P Fonte et al 2012 JINST 7 P12003

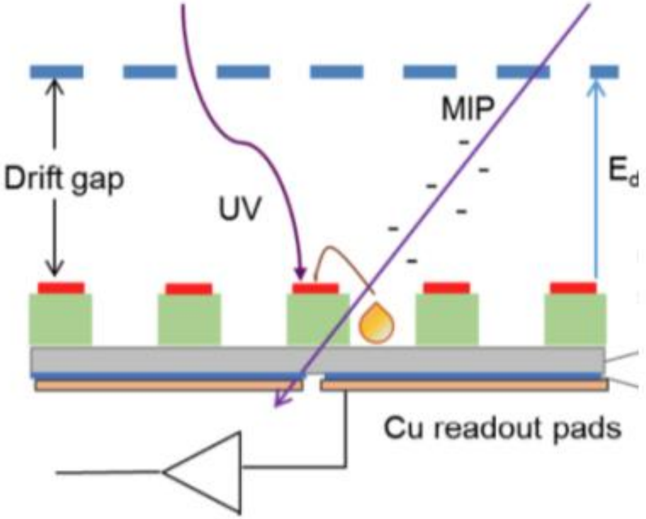
- Micron level position resolution
- Spark protection
- High rate capability

Applications
(Muongraphy)

- RPCs being able to cover large area are excellent candidates for muography studies like surveys of geological structures and isolated ore bodies or weak zones in mines, detecting a reservoir or boulders during tunnelling etc.
- They could be a cheaper alternative to large scintillation detector based setups
- Compactness and portability of muography setups with RPCs can be explored
- The muon tomography technique can be used to identify contraband materials in large shipping containers

P. Baesso *et al* 2014 *JINST* **9** C10041
J. Wang *et al* 2016 *JINST* **11** C11008

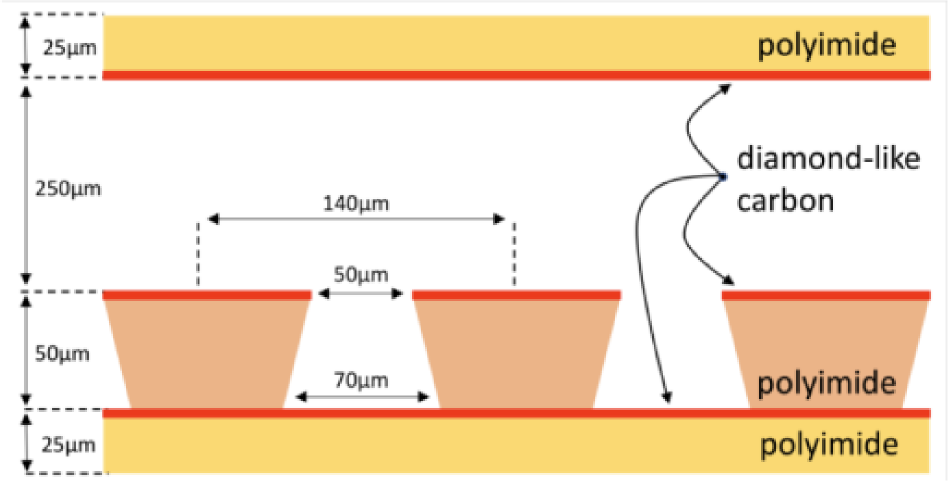
When RPC married an MPGD



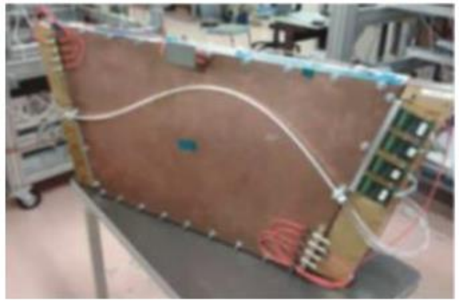
RPWELL

High rate μRWELL

Pictures taken from slides of Florian in this symposium



FTMPGD



ATLAS resistive MICROMEGAS

“Where there is resistance there is potential”

Thank you