Cost Effective Large Area Gaseous Detectors for Detection of Charged Particles

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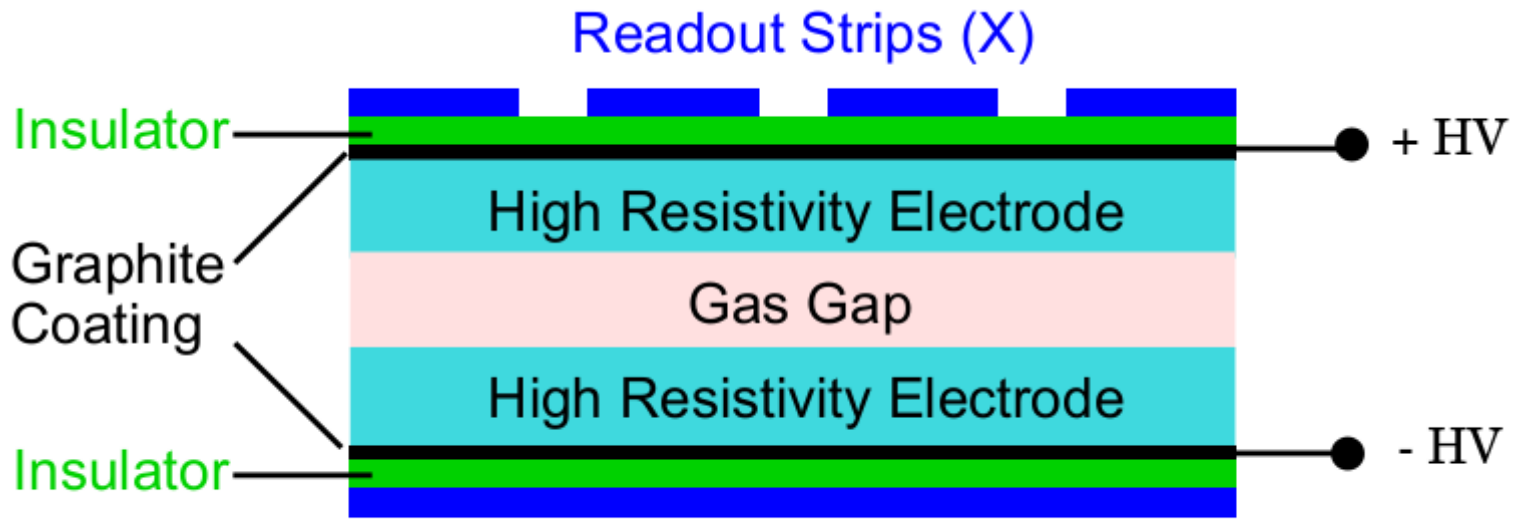
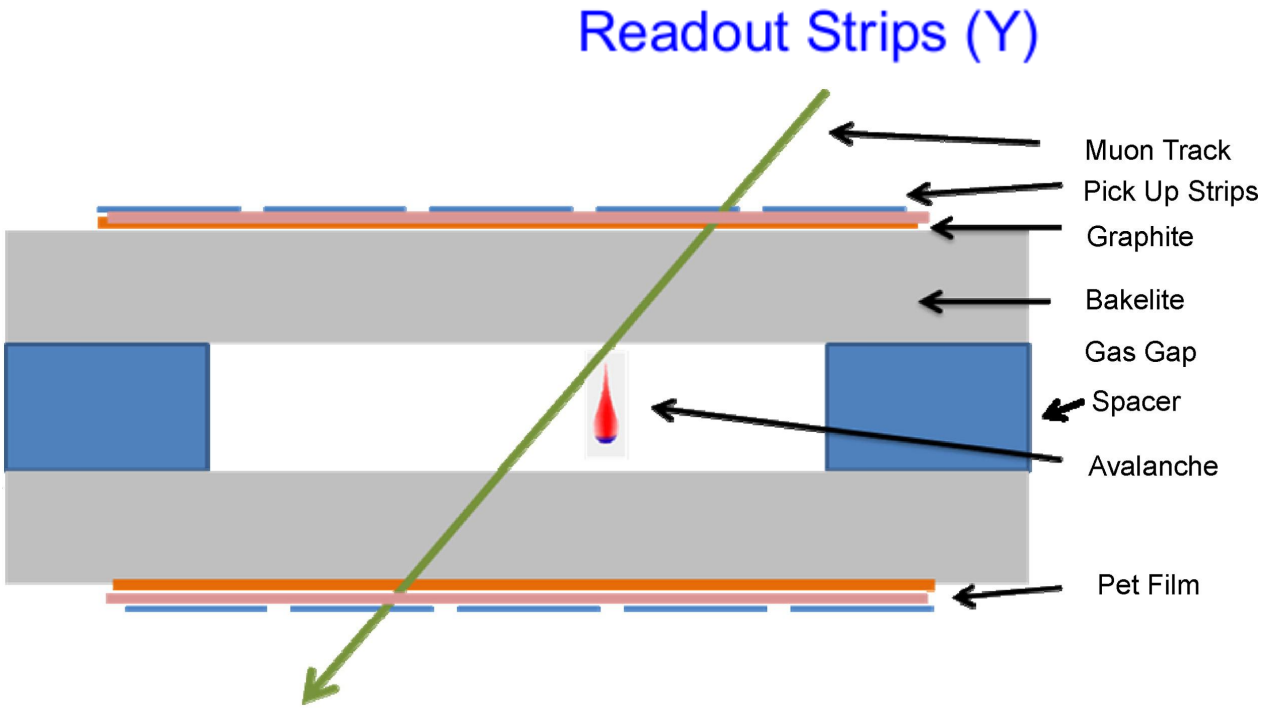
Overview

1. Resistive Plate Chambers
2. Journey towards the deevelopment of oil-free bakelite-RPC
   - Failures
   - Development of small Oil-free Bakelite RPC
   - Development of large Oil-free Bakelite RPC
   - Summary
3. Multi-gap Resistive Plate Chamber
   - Development of oil-free MRPCs
   - Summary

Resistive Plate Chamber - RPC





Operation

Two modes of operation:

Avalanche mode

- Low gas gain mode ($\sim 10^6$)
- Low average charge per signal ($\sim$1 pC).
- Pre-amplifier and amplifier are needed.
- Large number of electronic channels.
- Gas mixture is $R134a : i-butane : SF_6 :: 95 : 4.5 : 0.5$

Streamer mode

- High gas gain mode ($>>10^6$)
- High average charge per signal ($\sim$100's pC).
- No need of pre-amplifier and amplifier.
- Limited number of electronic channels.
- Gas mixture is $Ar : R134a : i-butane :: 55 : 40 : 5$

Electrodes

Mainly two kinds of electrode material used (till date):

Bakelite

- Less fragile than glass.
- Can be operated in streamer mode.
- High prone to impurities.
- Higher cost due to **Oil** coating on the inner surface of the electrodes.

Glass

- Less prone to impurities.
- Thinner plates can be manufactured $\longrightarrow$ MRPC
- No oil-coating needed.
- Very fragile.

Development of oil-free Bakelite-RPC

- All experiments using bakelite RPCs uses **oiled** bakelite electrodes.
- Significant increase in the per-RPC production cost.
- What if bakelite RPCs can be produced without oil-coating?
- No oil coating $\Longrightarrow$ Bare bakelite surfaces exposed to impurities in gas in high electric field ($\sim$50 kV/cm).
- Will streamer mode operation be possible?
- If *NO* $\rightarrow$ The advantage of bakelite RPC over any other electrode material *fails*.

We tried and tried and tried and ..... for more than 3 years

Finally succeded.

Failure is the pillar of success - some failed results

P-301 sample : No oil-coating

I-V characteristics

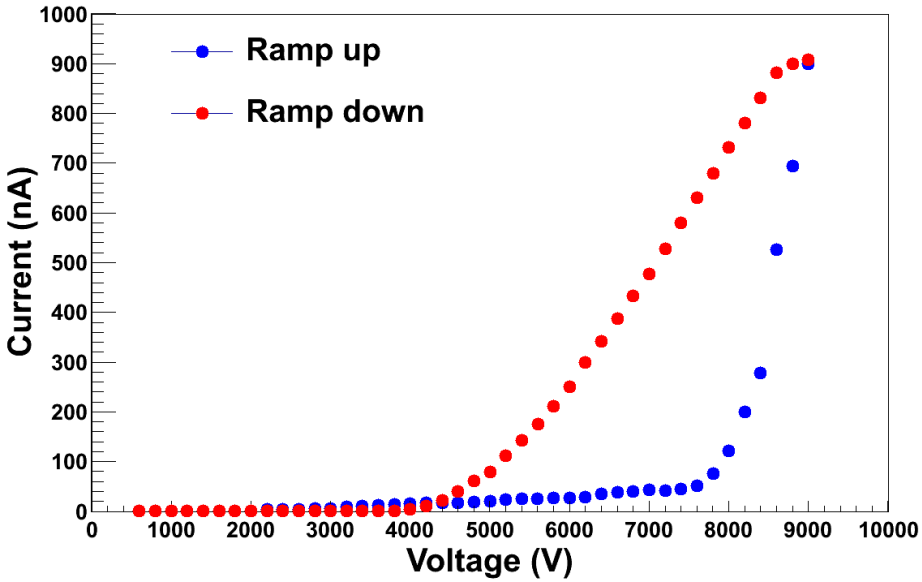


Figure 1: Avalanche mode

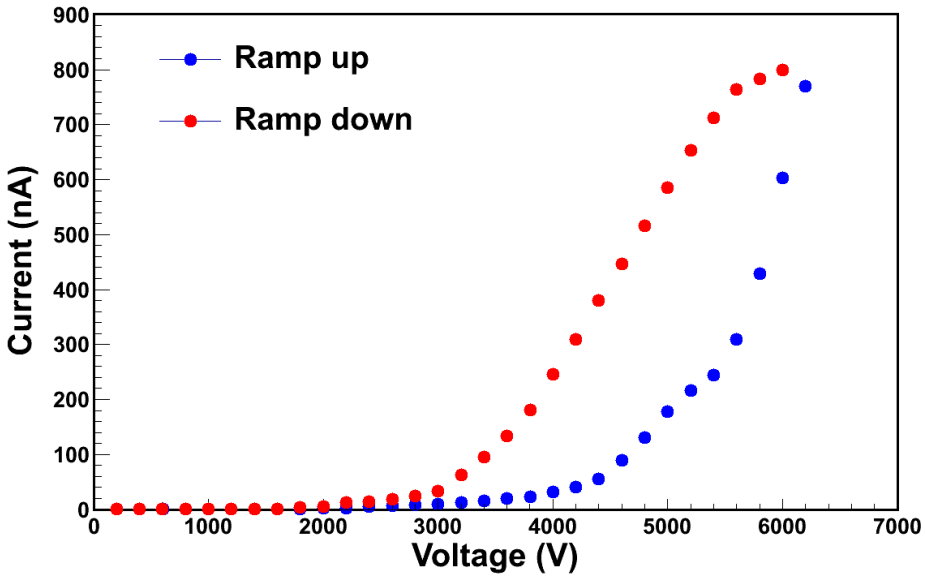


Figure 2: Streamer mode

Reason

Figure 3: Inner coated electrode under microscope

Figure 4: Inner coated electrode under microscope

Development of 30 cm × 30 cm Oil-free Bakelite RPC

- Tested with 3 scintillator cosmic ray test bench.
- Operation mode : Streamer
- Gas gap : 0.2 cm.
- Gas mixture → Argon:R134a:i-butane::55:40:5
- Gas flow rate : 12 SCCM
- Gas breakdown voltage : ∼7000 V (±3500 V).
- Current stability monitored at ∼12000 V (±6000 V)

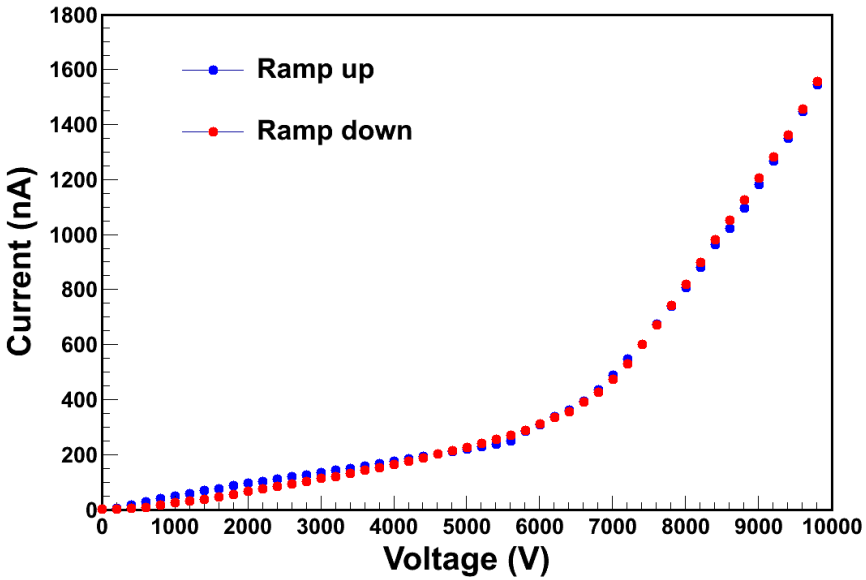


Figure 5: I-V characteristics

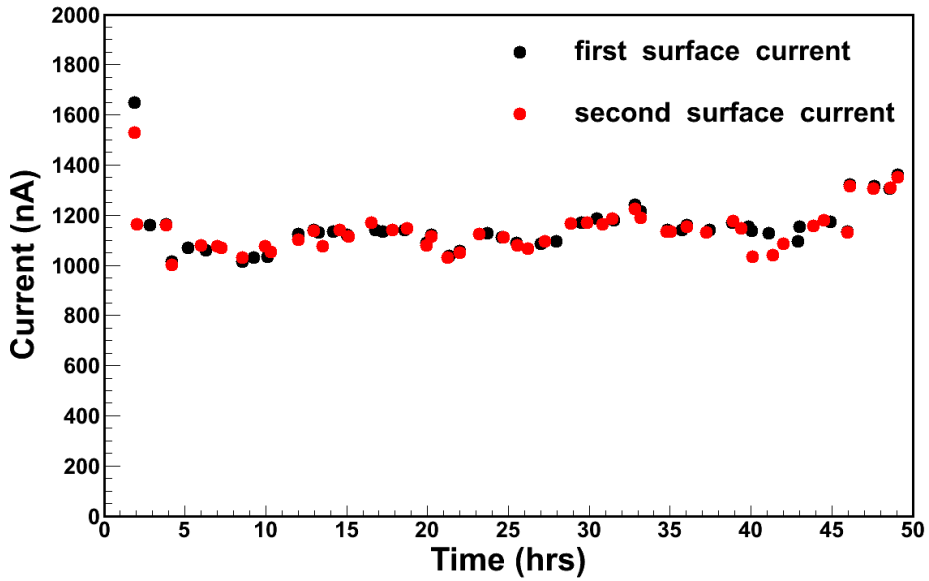


Figure 6: Current stability

Development of 30 cm × 30 cm Oil-free Bakelite RPC

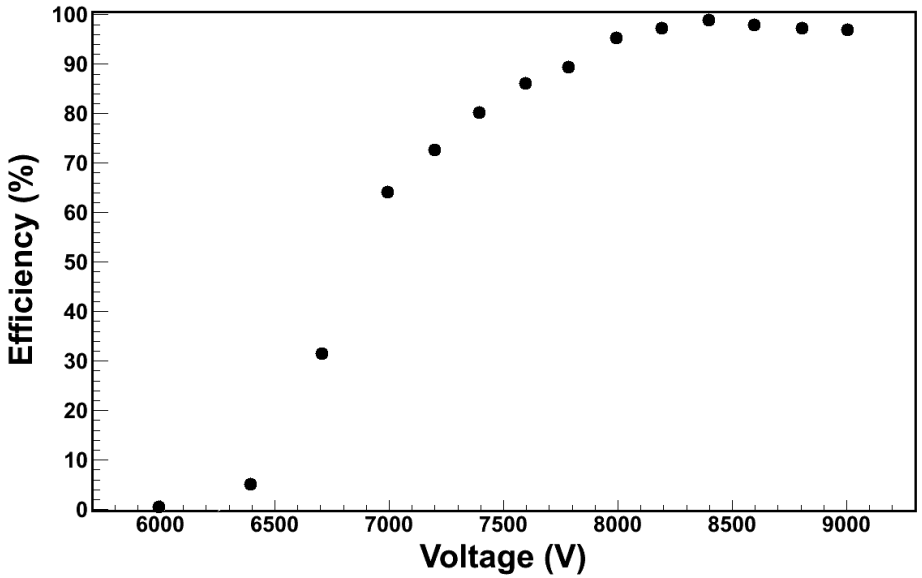


Figure 7: Efficiency

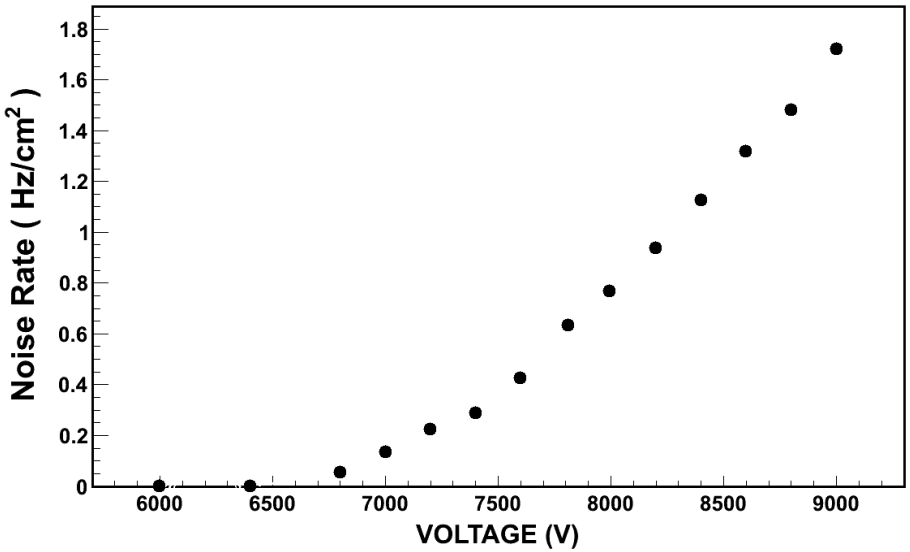


Figure 8: Noise rate

- Signal threshold : -20 mV.
- Efficiency plateau was obtained beyond 8000 V.
- Cosmic muon detection efficiency : ∼98%.
- Measured noise rate : ∼1.7 Hz/cm^2 at 9000 V.
- Successfull result $\Longrightarrow$ Development of (240 cm× 120 cm) RPC.

Development of 240 cm × 120 cm Oil-free Bakelite RPC

Glue testing

Problem faced with glue.

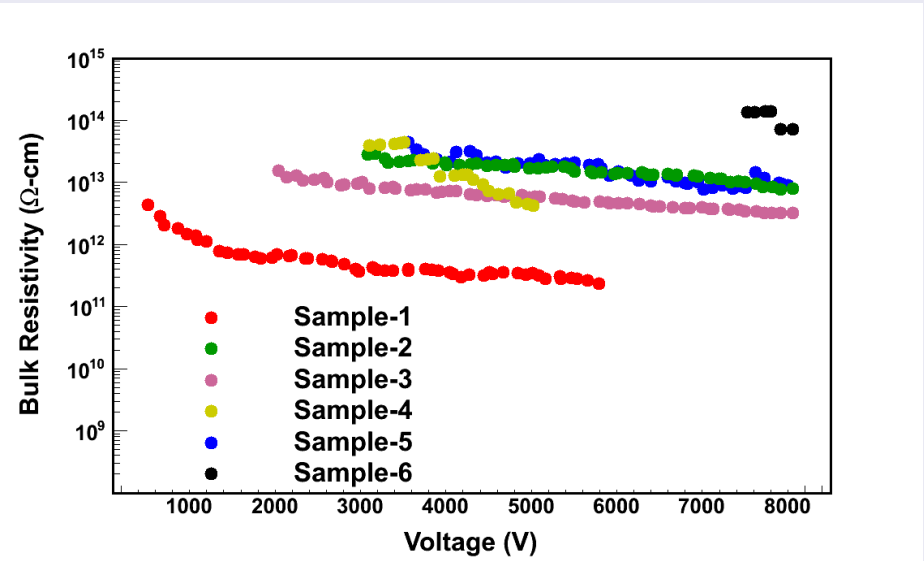


Figure 9: Bulk resistivity of different glue samples

- Glue samples were tested for their mechanical strengths and bulk resistivity.

Figure 10: Large RPC

Cosmic ray test results

- Operation mode : Streamer
- Gas gap : 0.2 cm.
- Gas mixture $\rightarrow$ Argon:R134a:i-butane::34:57:9
- Gas flow rate : $\sim$0.75 litres/hour

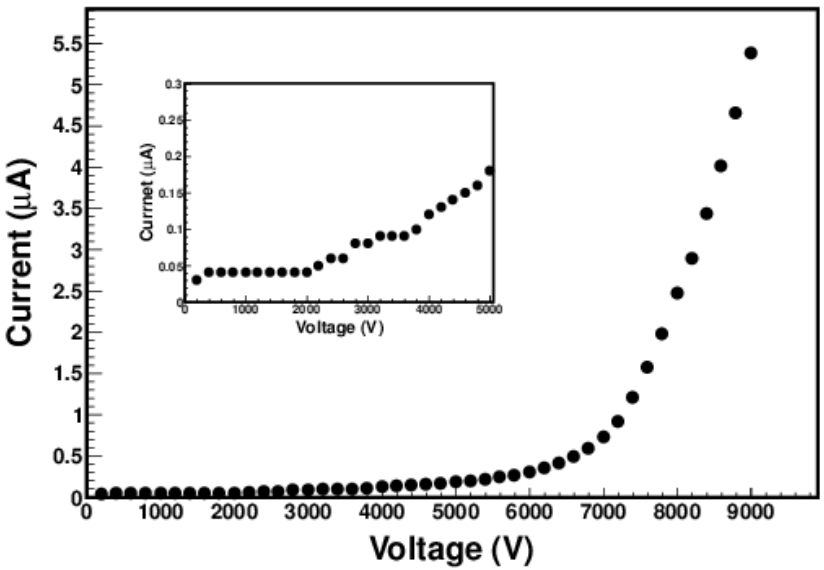


Figure 11: I-V characteristics

- Breakdown voltage : $\sim$7000 V.
- From the Ohmic part, the calculated bulk resistivity of the chamber was fond to be 1.72×10^{13} Ωcm.

Efficiency and Noise Rate

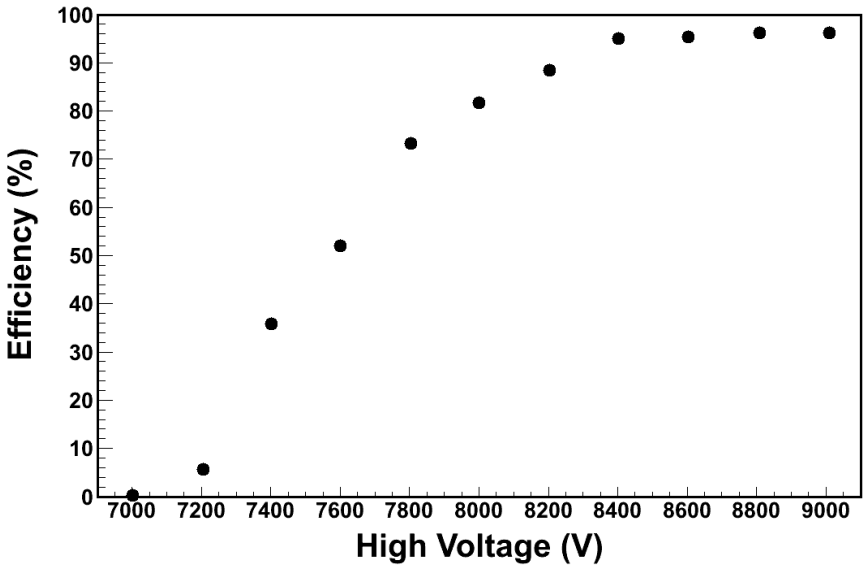


Figure 12: Efficiency

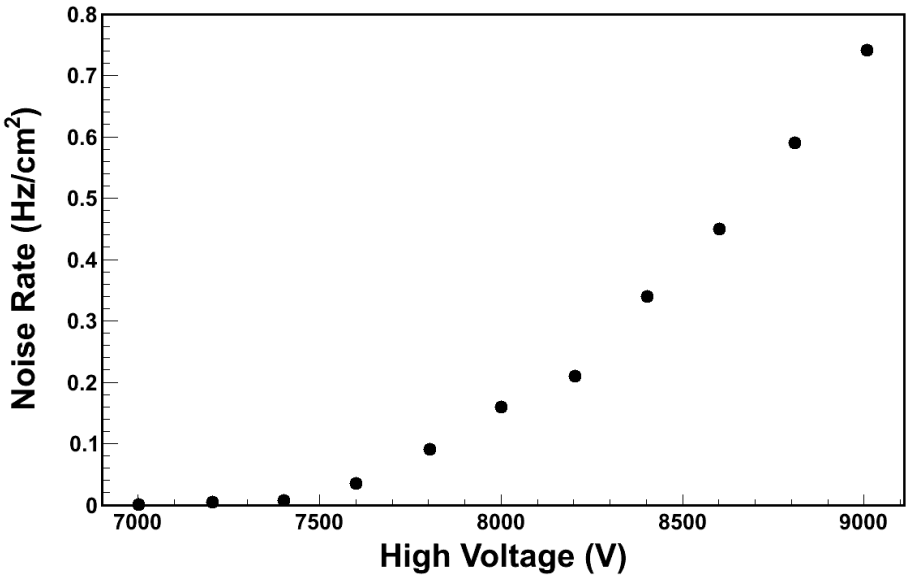


Figure 13: Noise rate

- Signal threshold : -20 mV.
- Efficiency plateau was obtained beyond 8400 V.
- Cosmic muon detection efficiency : >95%.
- Measured noise rate : $\sim$0.75 Hz/cm^2 at 9000 V.

Efficiency at Different Locations

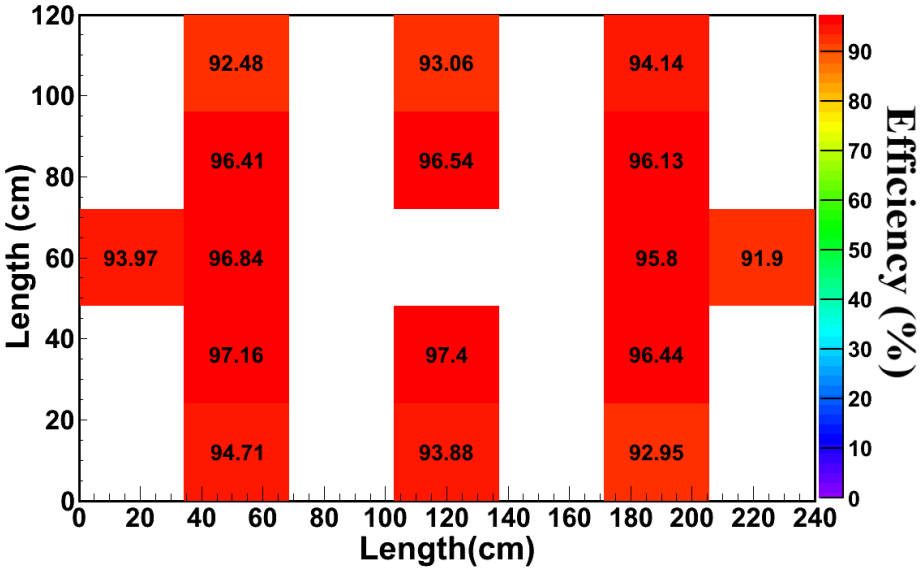


Figure 14: Regional efficiency

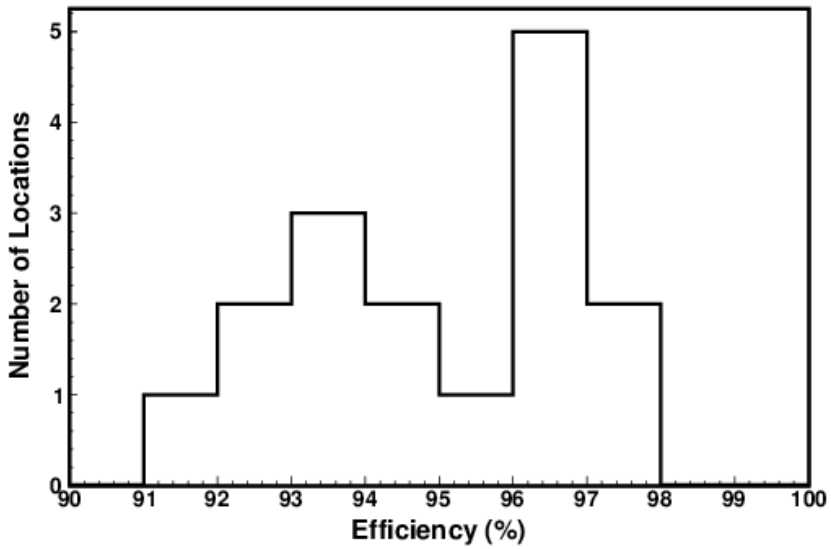


Figure 15: Regional efficiency distribution

- Efficiency measured at 16 different locations - 8 at the edges and 8 away from the edges.
- Efficiency measured at 9000 V.
- Two distinct groups were observed.
- Edges relatively low efficienct than the central part $\Longrightarrow$ Edge Effect.

Time resolution measurement

- Time resolution measured at central location.
- It is measured with 16 channel Philiphs Scientific 7186 TDC module.

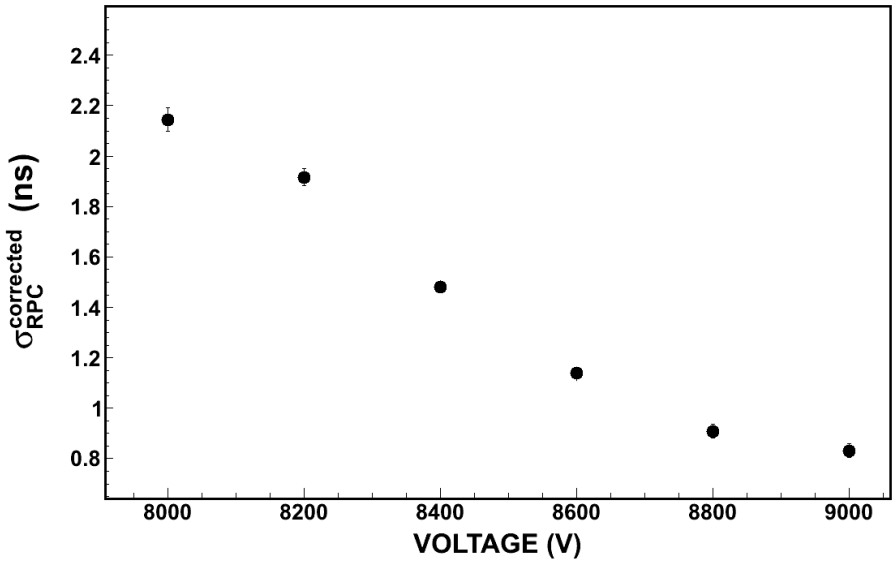


Figure 16: Time resolution as a function of applied voltage.

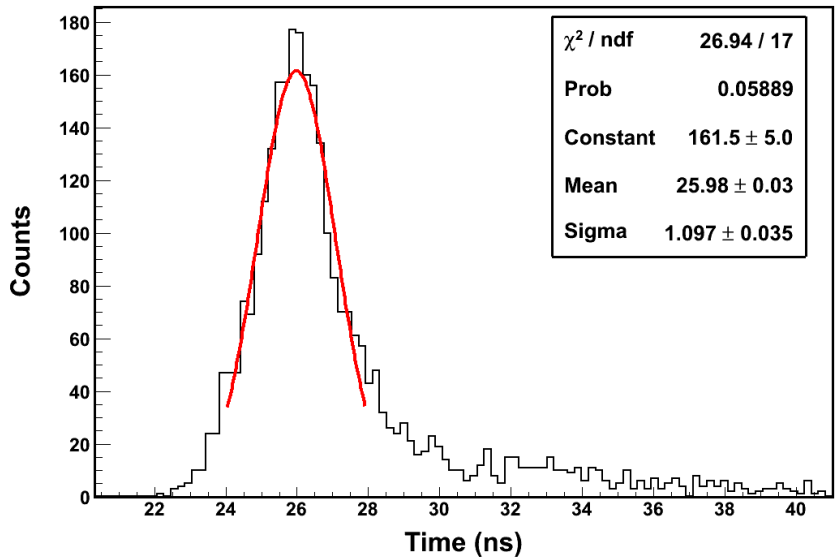


Figure 17: TDC spectra at 9000 V.

- The best value of scintillator corrected time resolution measured to be ∼0.83 ns at 9000 V.

Long term test results - Current and Efficiency.

- The detector was kept in continuous gas flow and HV for more than 10 months.
- Various detector performance parameters were measured and monitored continuously over a period of 60 days.

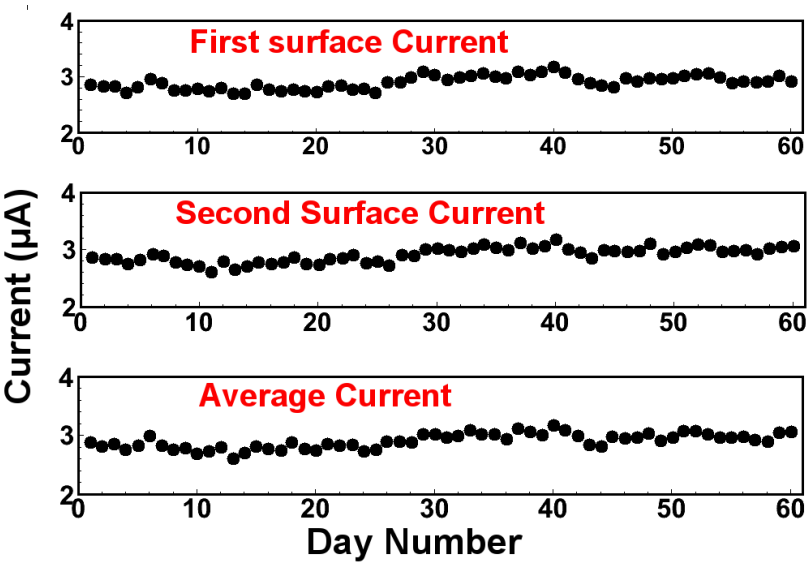


Figure 18: Long term current stability.

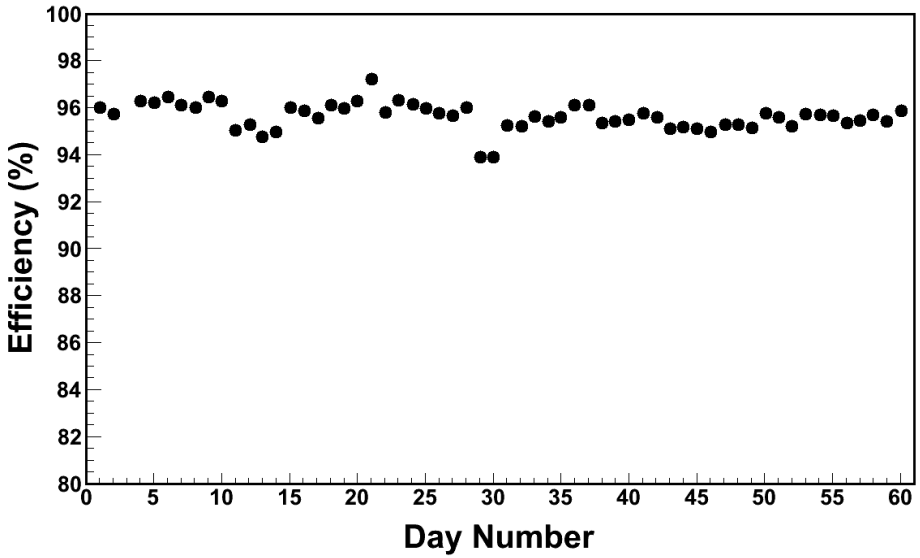


Figure 19: Efficiency measured after 10 months.

- Current was found to be stable at 9000 V.
- Efficiency was found to be >95% and stable at 9000 V.

Long term test results: Noise Rate and Time Resolution

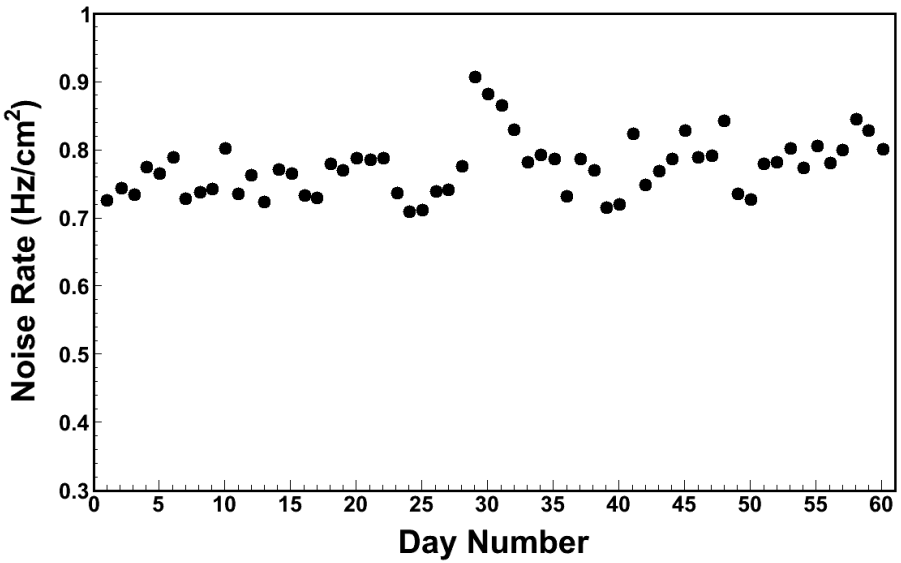


Figure 20: Long-term noise rate.

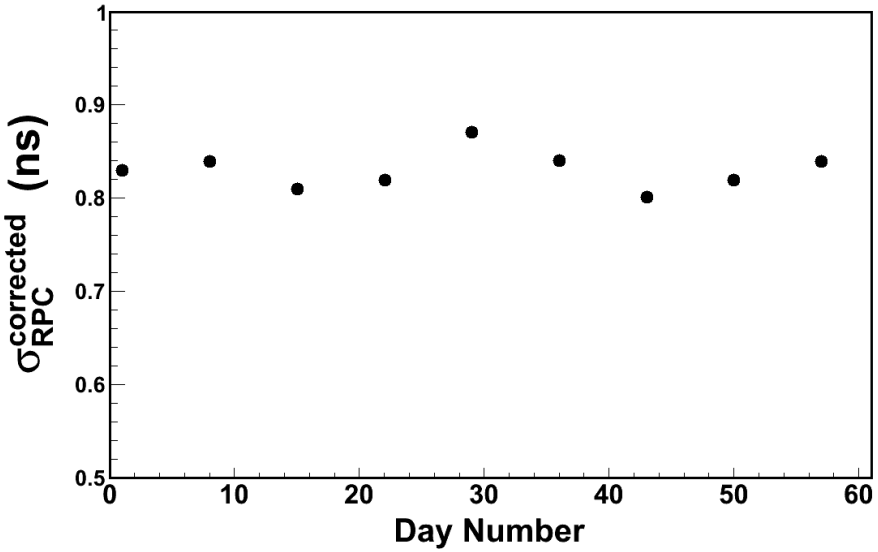


Figure 21: Long-term time resolution.

- The noise rate of the detector was stable at $\sim$0.75 Hz/cm^2 at 9000 V.
- The time resolution of the chamber was stable with an average corrected value of $\sim$0.83 ns.

Summary of Large Oil-free Bakelite RPC

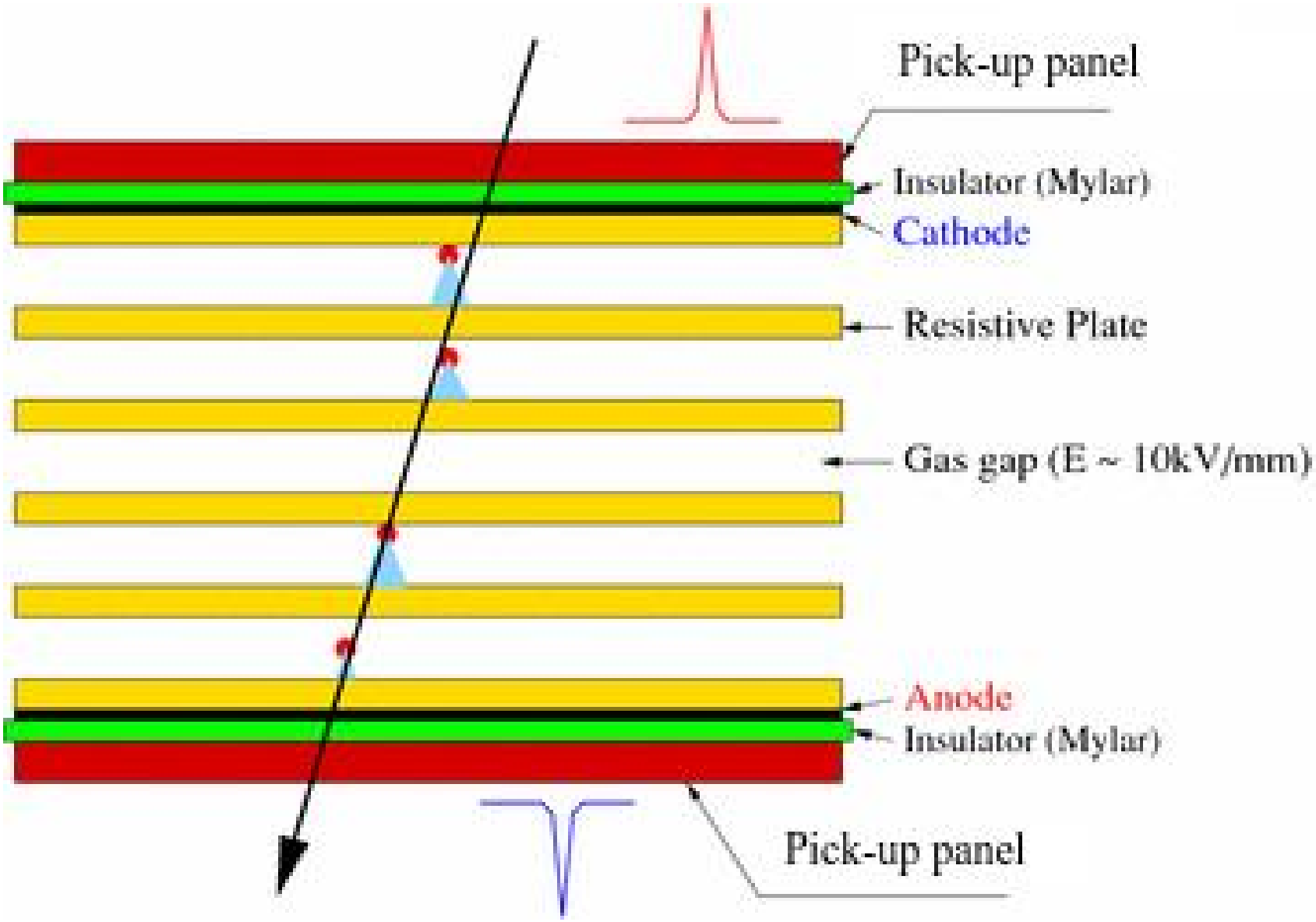
- Successfully developed large ($\sim$2.9 m^2 area) **oil-free** bakelite RPC
- Very stable performance towards the detection of cosmic muons.
- Happy with long term performance.

Advantages

- Complicated industrial steps to coat the inner surface of bakelite sheets can be eliminated $\Longrightarrow$ Significant cost reduction.
- Streamer mode operation possible $\Longrightarrow$ Significant reduction in electronics channel $\Longrightarrow$ Significant cost reduction.
- Happy with long term performance.
- Fabrication of the large detector cost $\sim$100 USD.

Grade of the bakelite: P302- OLTC.

Multi-gap Resistive Plate Chamber - MRPC



Development of Oil-Free bakelite MRPC

- One of the toughest challenge →Manufacture thin bakelite sheets.
- Regular communication with the company $\Longrightarrow$ Successfully manufactured $\sim$500 μm think bakelite sheets.
- Developed a couple of MRPCs with dimensions of 15 cm$\times$ 15 cm $\times$ 1 cm were developed.

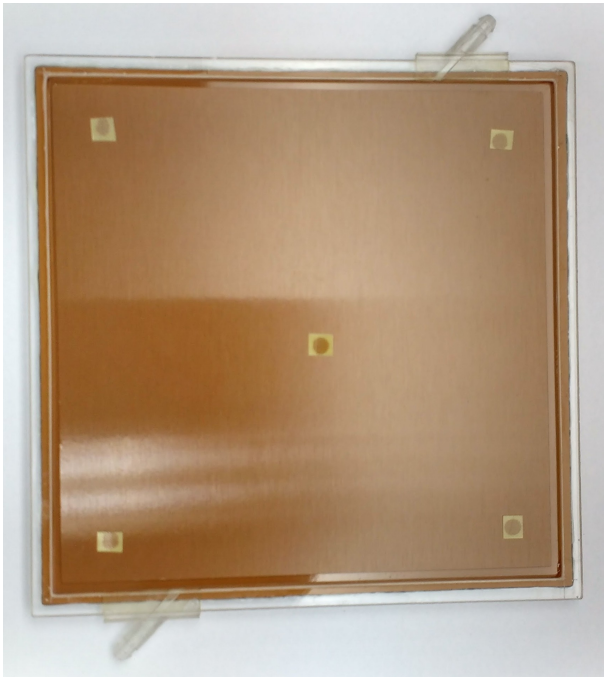


Figure 22: Base plate with frame, gas nozzles and spacers.

Figure 23: Thin inner plates - 5 nos.

Specifications of the MRPC

Total area of the MRPC	$\sim$ 15 cm $\times$ 15 cm
Active area of the MRPC	$\sim$ 14 cm $\times$ 14 cm
Number of outer electrodes	2
Number of inner electrodes	5
Dimensions of the outer electrodes	$\sim$ 15 cm $\times$ 15 cm $\times$ 0.30 cm
Dimensions of the inner electrodes	$\sim$ 14 cm $\times$ 14 cm $\times$ 0.050 cm
Thickness of each button spacer	$\sim$ 0.024 cm
Thickness of the side spacer frame	0.40 cm
Total number of gas nozzles	2
Total number of gas gaps	6
Thickness of each gas gap	$\sim$ 0.025 cm

Test Results of Bakelite MRPC- Efficiency and Noise Rate

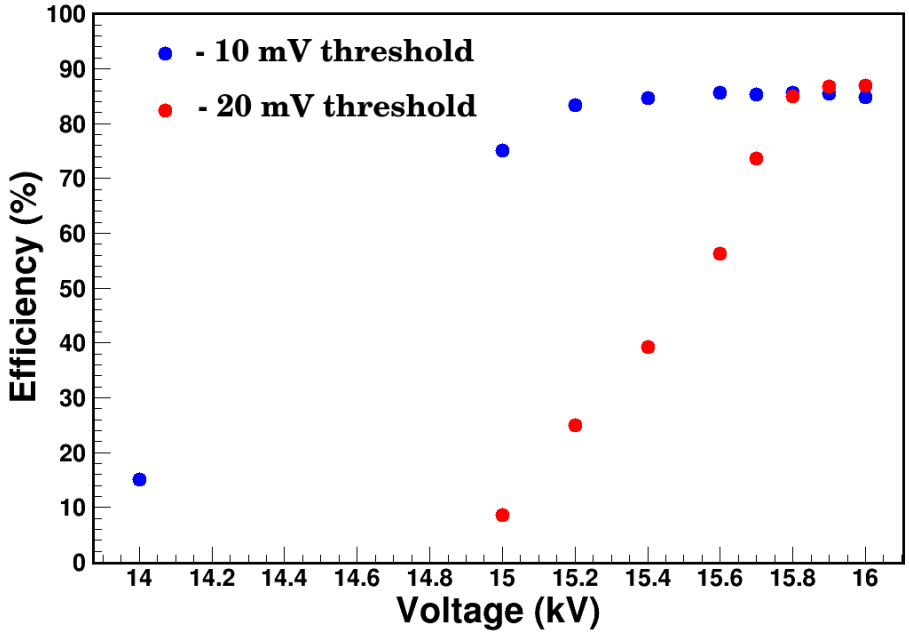


Figure 24: Efficiency of oil-free bakelite MRPC.

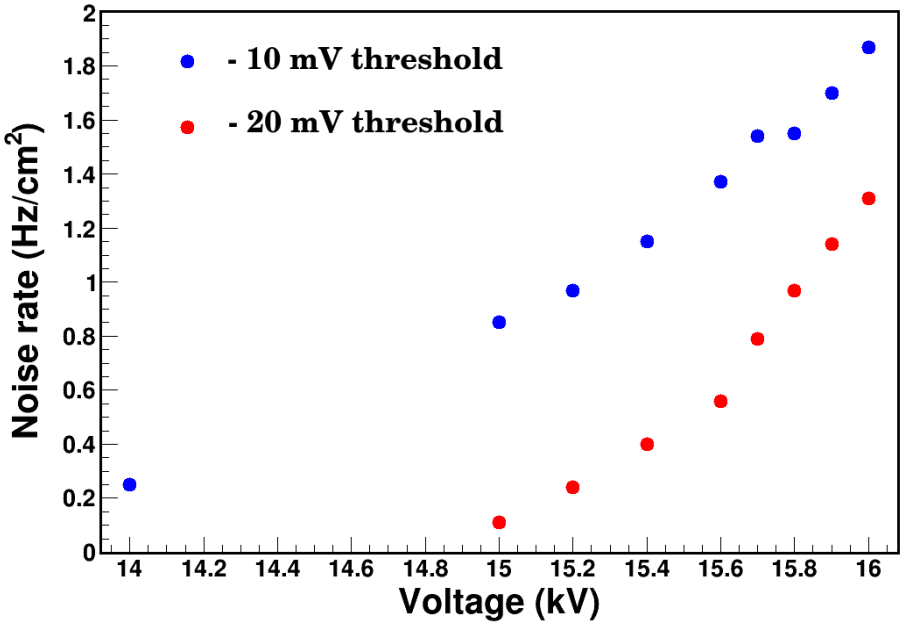


Figure 25: Noise rate of oil-free bakelite MRPC.

- The efficiency of the detector was obtained to be $\sim$85%.
- The maximum noise rate of the detector was found to be $\sim$1.85 Hz/cm^2 at 16 kV of applied voltage and -10 mV of signal threshold.

Test Results of Bakelite MRPC- Time Resolution

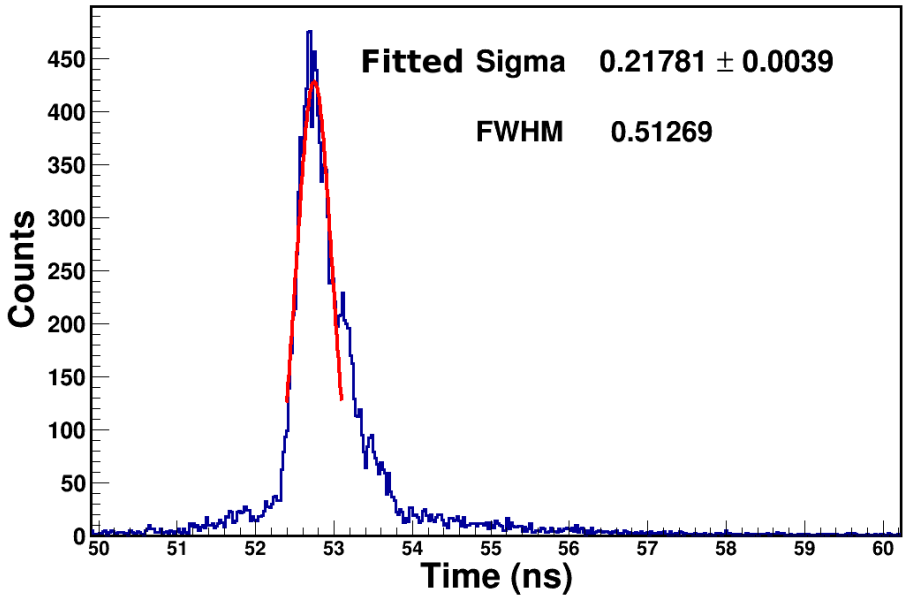


Figure 26: TDC spectraof oil-free bakelite MRPC.

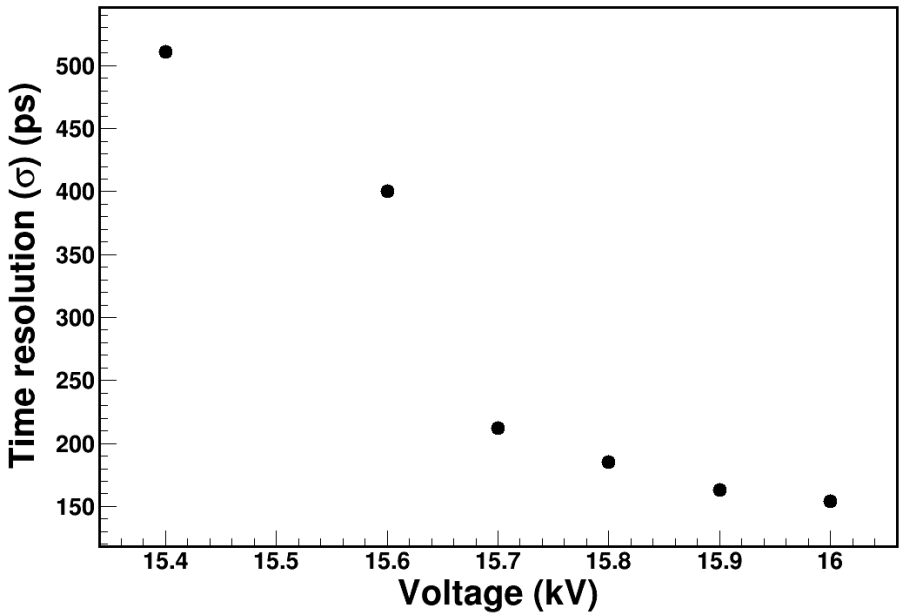


Figure 27: Time resolution of oil-free bakelite MRPC.

- The best time resolution of the detectors obtained was **∼154 ps** at an applied voltage of **16 kV**.

Summary of Oil-free Bakelite MRPC

- Difficult goal but achieved successfully.
- New idea to develope MRPCs with $\sim$500 μm thin bakelite sheets without any coating.
- Happy with the performance of the detector.
- The time resolution can be improved further. Work is in progress.

Societal applications

- Successfully proved the basic working principle of ToF-PET imaging using MRPCs.
- A fully functional MRPC-ToF-PET scanner will reduce per scan cost significantly with much improved results.
- A couple of problems to be addressed first.

References

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THANK YOU