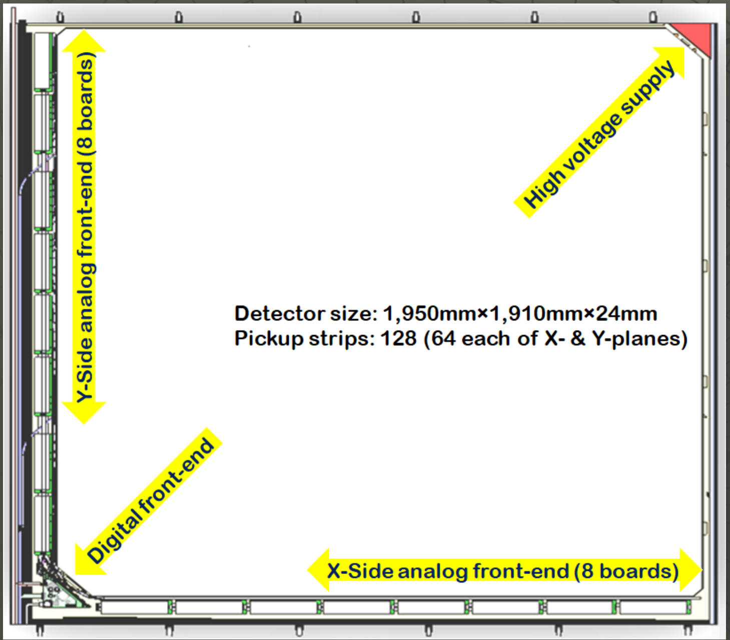
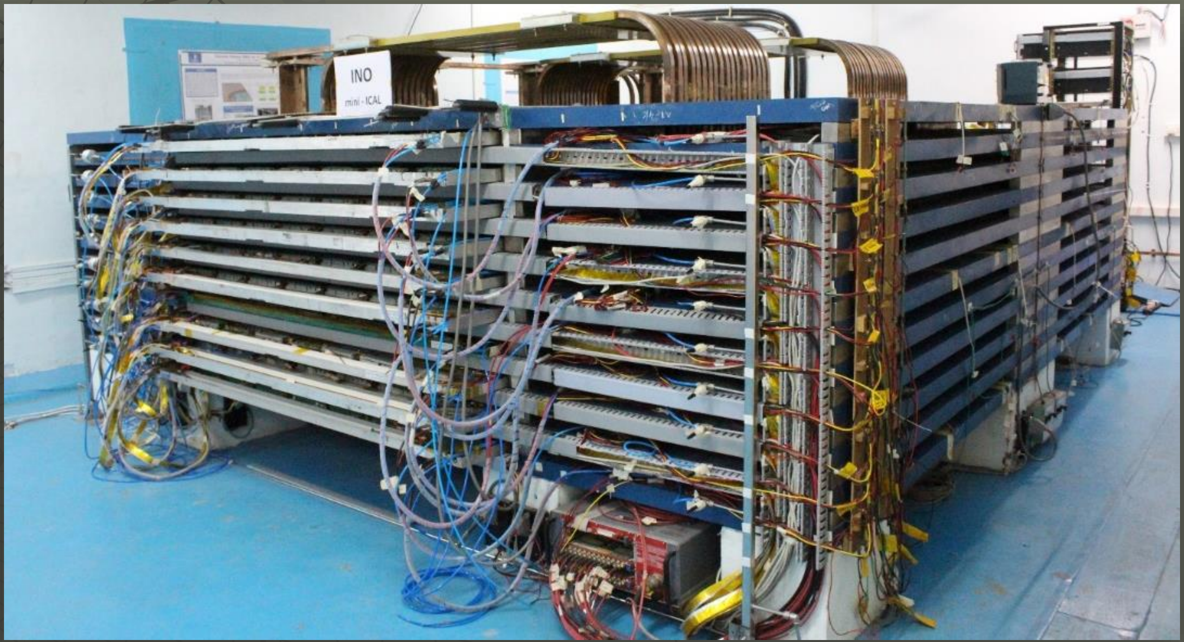
Highlights of development and deployment of RPC detectors in India





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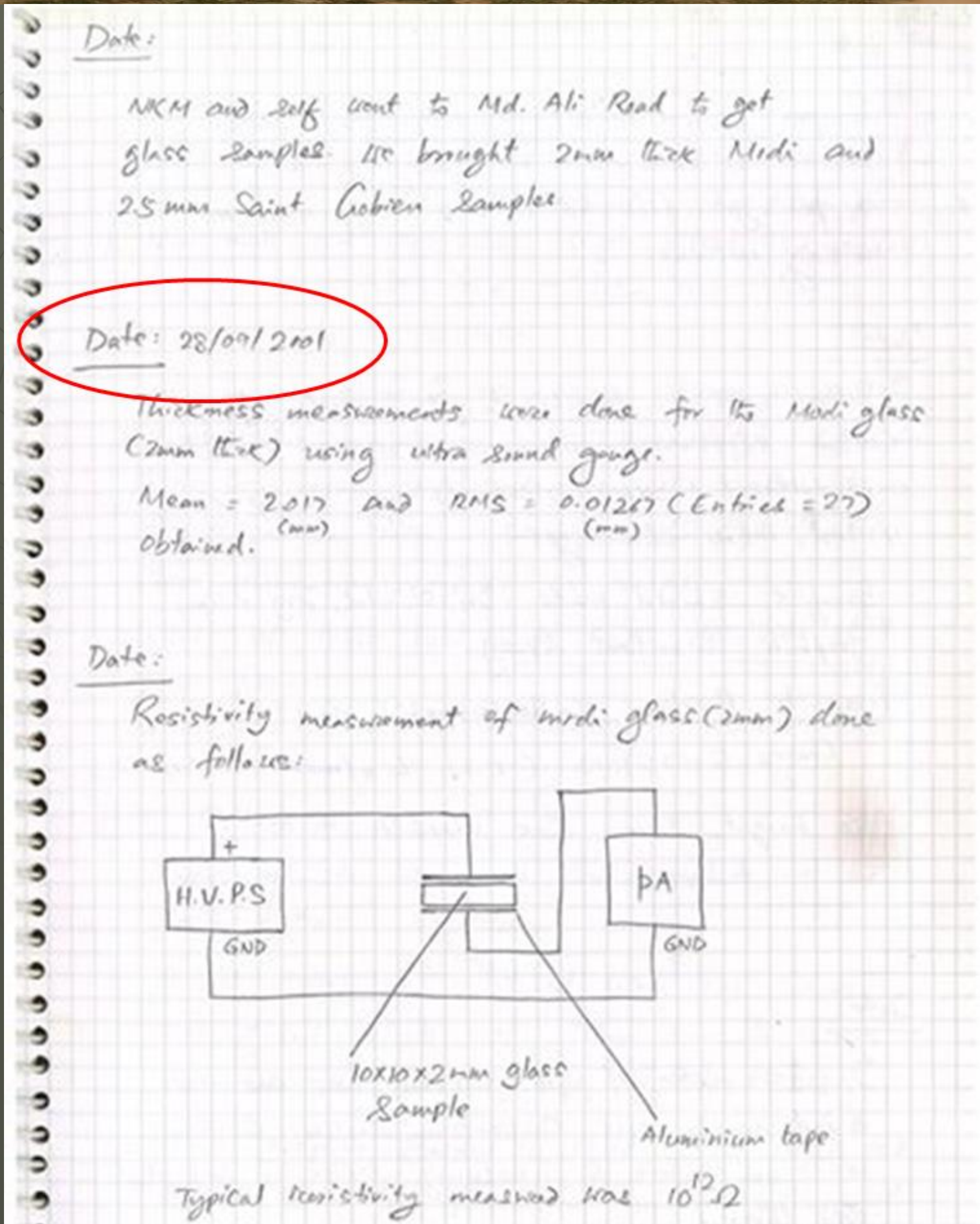
RPC development centres in India


Date:

NKM and self went to Md. Ali Road to get glass samples. We brought 2mm thick Modi and 2.5 mm Saint Gobien samples

Date: 28/09/2001

Thickness measurements were done for the Modi glass (2mm thick) using ultra sound gauge.

Mean = 2.017 (mm) and RMS = 0.01267 (mm) (Entries = 27) obtained.

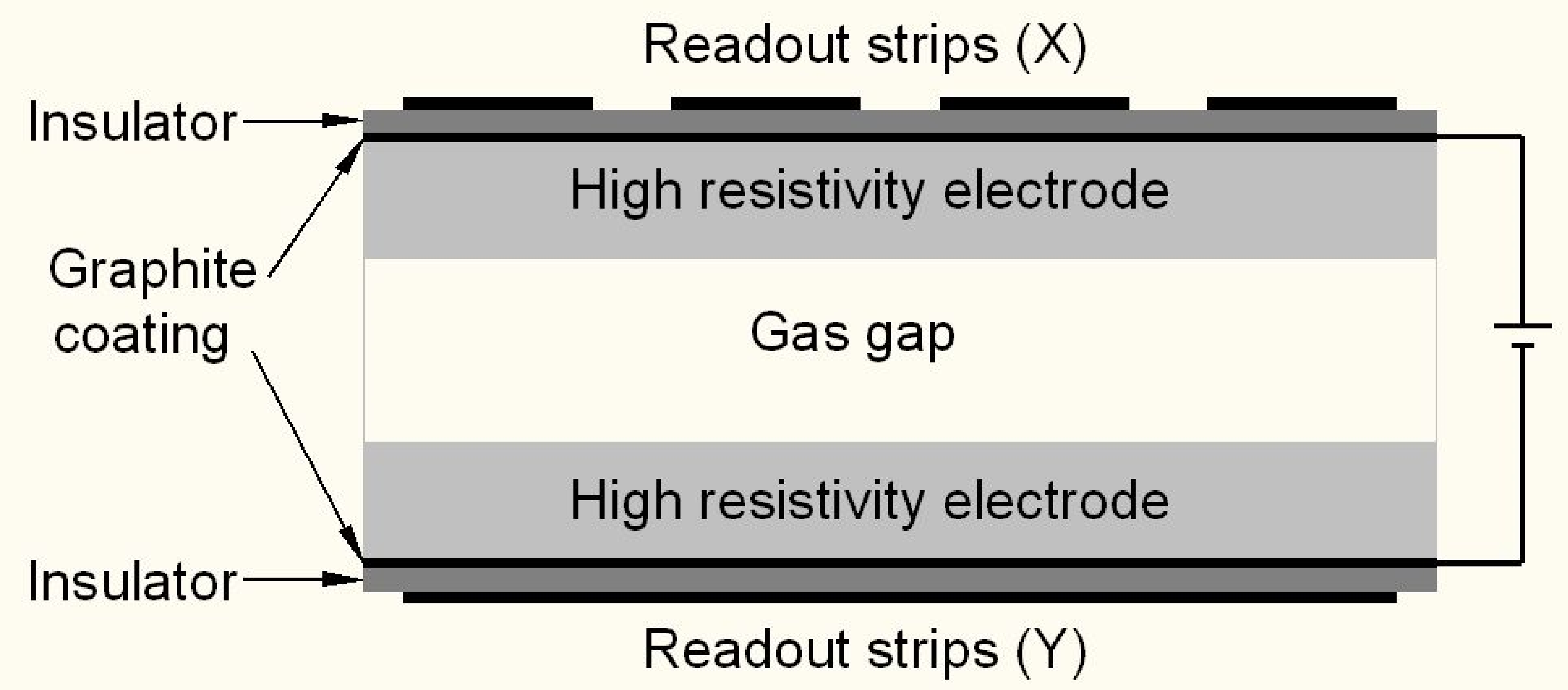
Date:

Resistivity measurement of modi glass (2mm) done as follows:

Typical resistivity measured was $10^{12}\Omega$

AMU	Aligarh
BARC	Mumbai
BHU	Varanasi
Bose Institute	**Kolkata**
CUK	**Kalaburagi**
DU	Delhi
IISER	**Mohali**
IITB	Mumbai
IITM	Chennai
KU	**Kashmir**
NISER	**Bhubaneshwar**
PU	Chandigarh
SINP	Kolkata
TIFR	Mumbai
TKMCAS	**Kollam**
TU	**Tejpur**
VECC	Kolkata

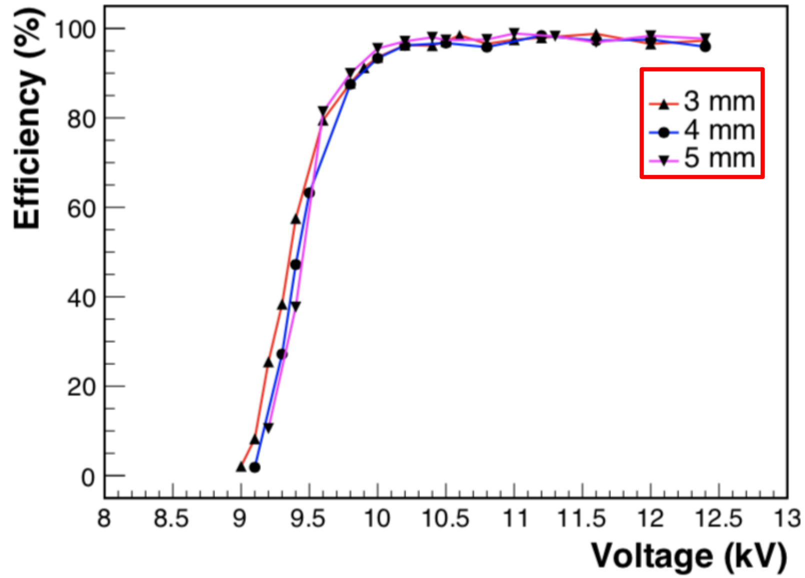
Schematic of a basic SRPC

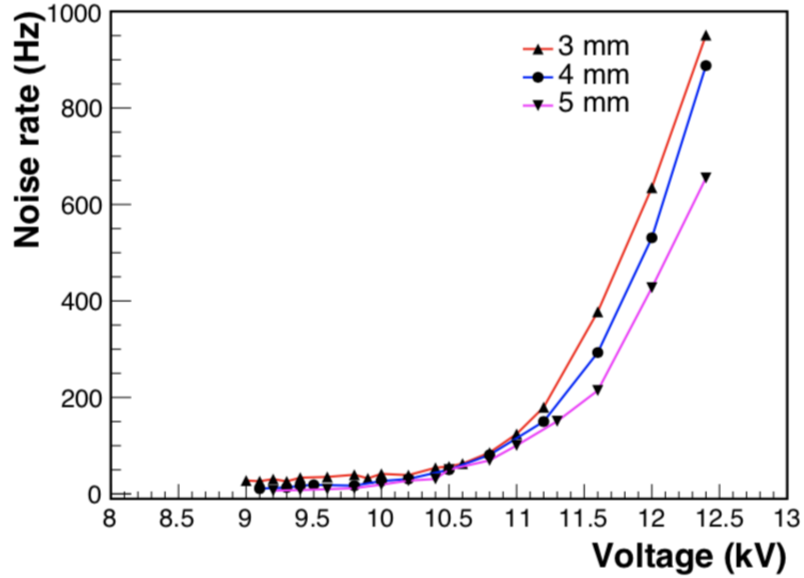


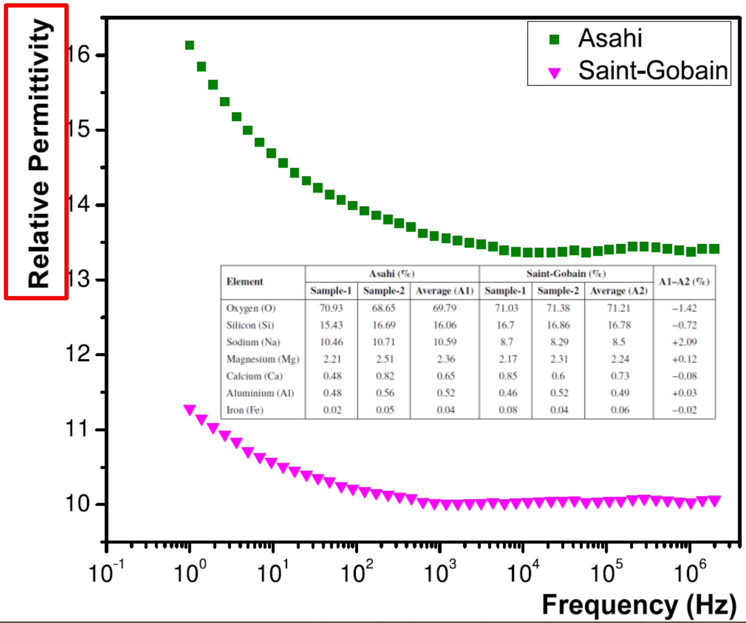
- Resistive materials like glass or bakelite for electrodes
- Special paint mixture (developed locally) for semi-resistive coating
- Plastic honey-comb laminations used as readout panel
- Special plastic films for insulating the readout panels from high voltages
- Two modes of operation: Avalanche (R134a:Isobutane:SF_6 ::95.5:4.2:0.3) and Streamer (R134a:Isobutane:Ar::56:7:37)

Studies on electrode characteristics

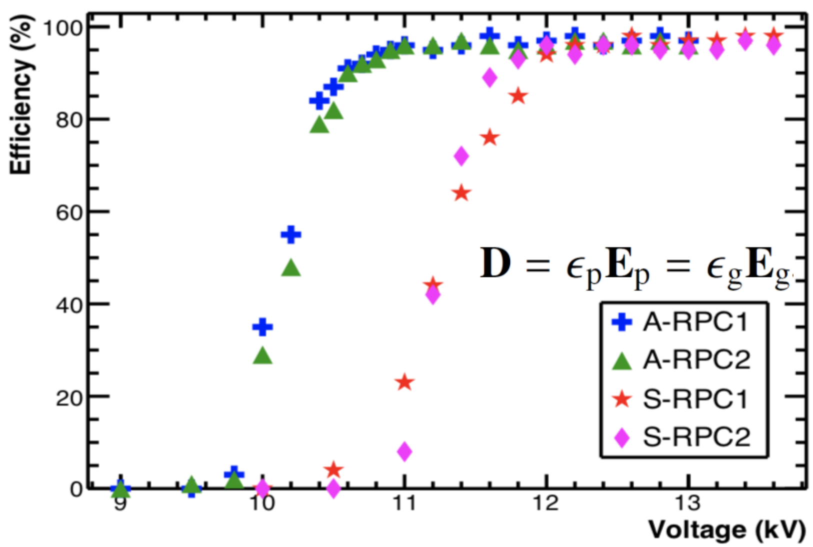
30cm×30cm, 3mm thick float glass



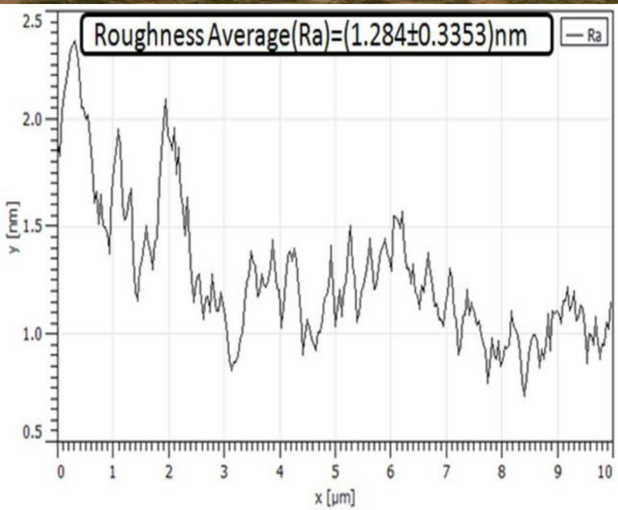


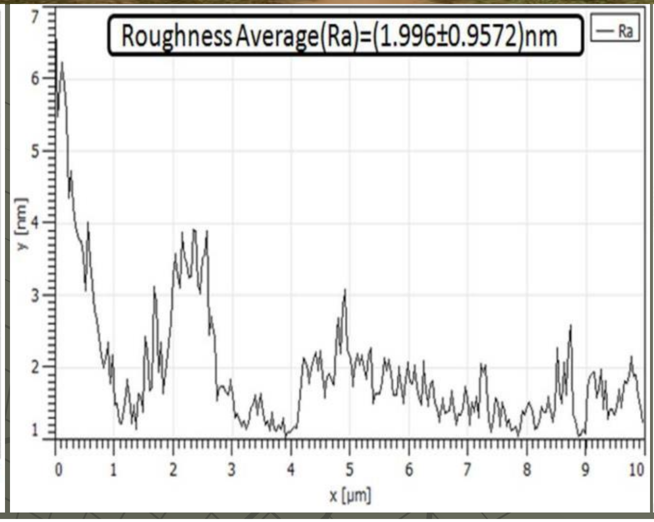


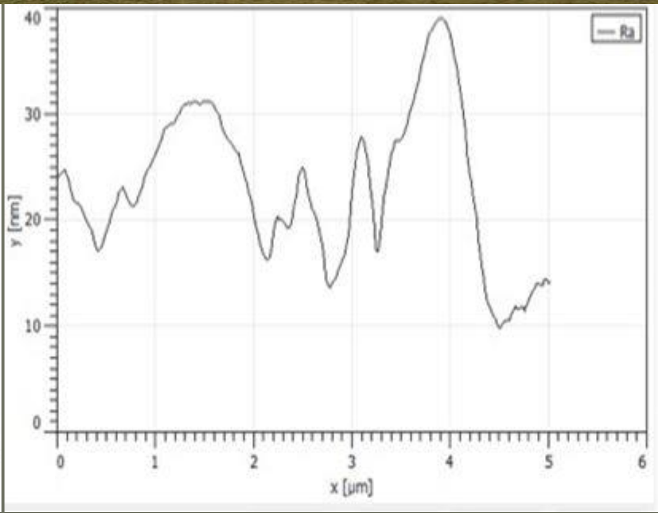
Element	Asahi (%)			Saint-Gobain (%)			A1–A2 (%)
	Sample-1	Sample-2	Average (A1)	Sample-1	Sample-2	Average (A2)	
Oxygen (O)	70.93	68.65	69.79	71.03	71.38	71.21	−1.42
Silicon (Si)	15.43	16.69	16.06	16.7	16.86	16.78	−0.72
Sodium (Na)	10.46	10.71	10.59	8.7	8.29	8.5	+2.09
Magnesium (Mg)	2.21	2.51	2.36	2.17	2.31	2.24	+0.12
Calcium (Ca)	0.48	0.82	0.65	0.85	0.6	0.73	−0.08
Aluminium (Al)	0.48	0.56	0.52	0.46	0.52	0.49	+0.03
Iron (Fe)	0.02	0.05	0.04	0.08	0.04	0.06	−0.02

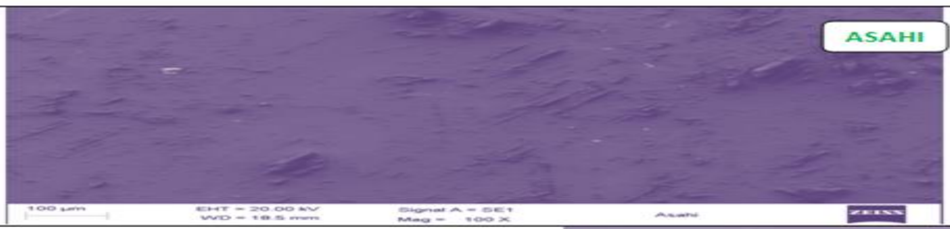


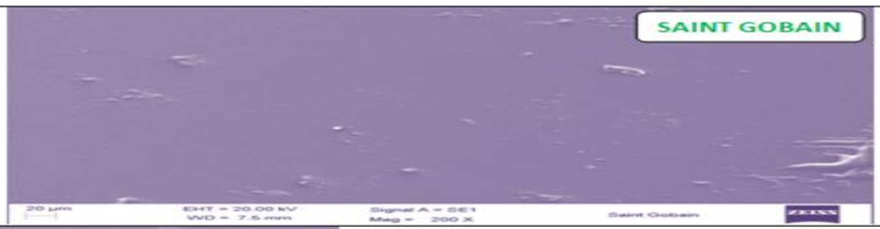
Electrode surface quality

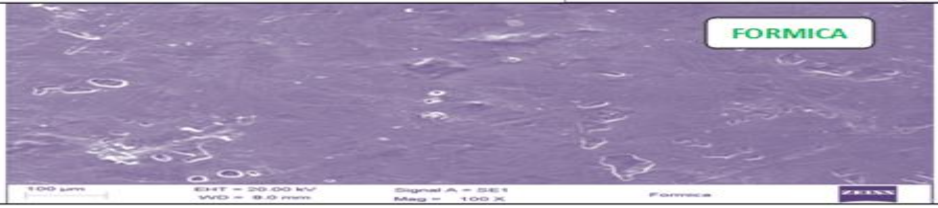


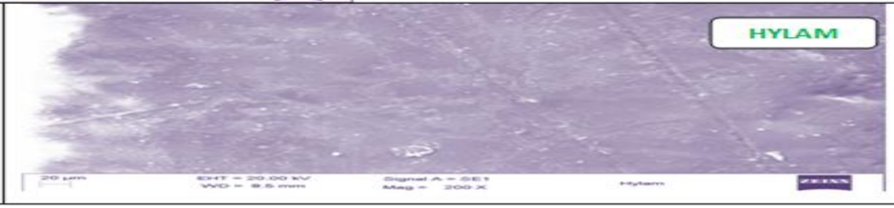






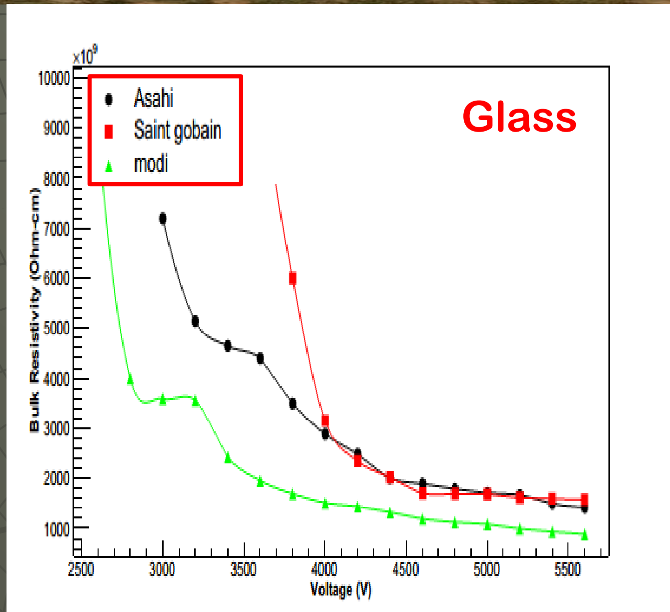


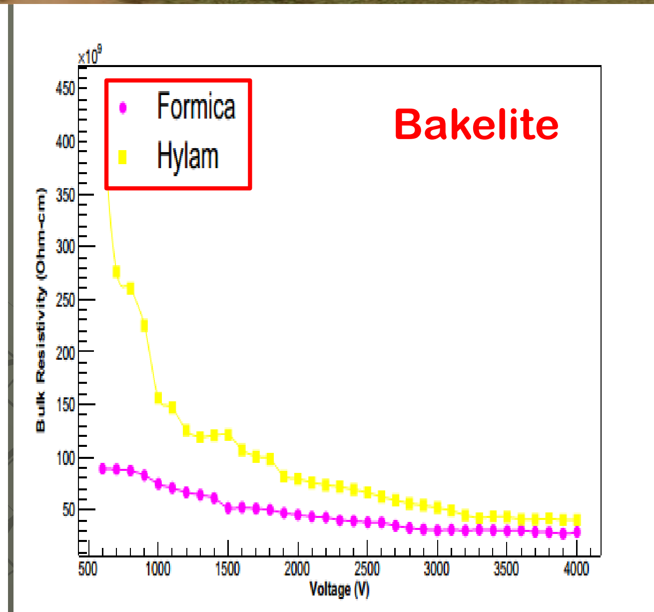


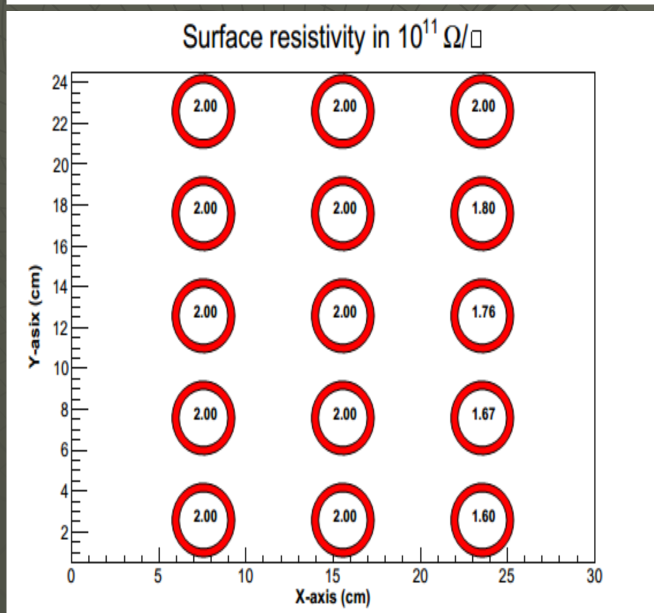


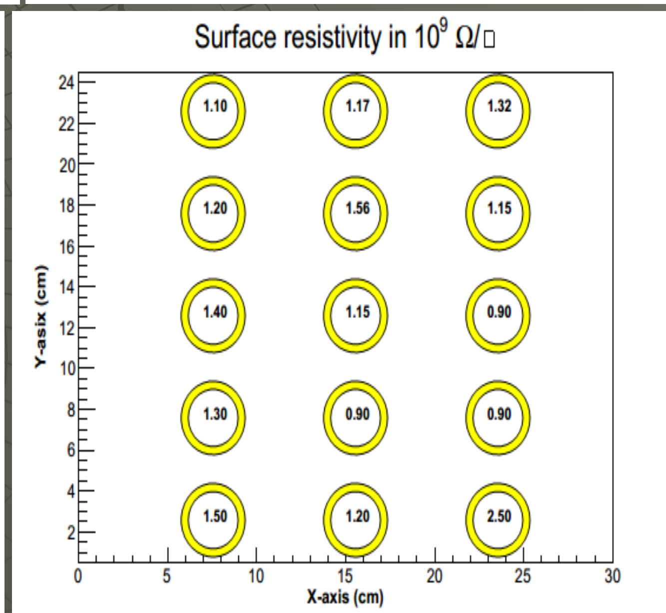
Due to manufacturing process, glass surfaces are lot smoother compared to that of bakelite.

Bulk and surface resistivities

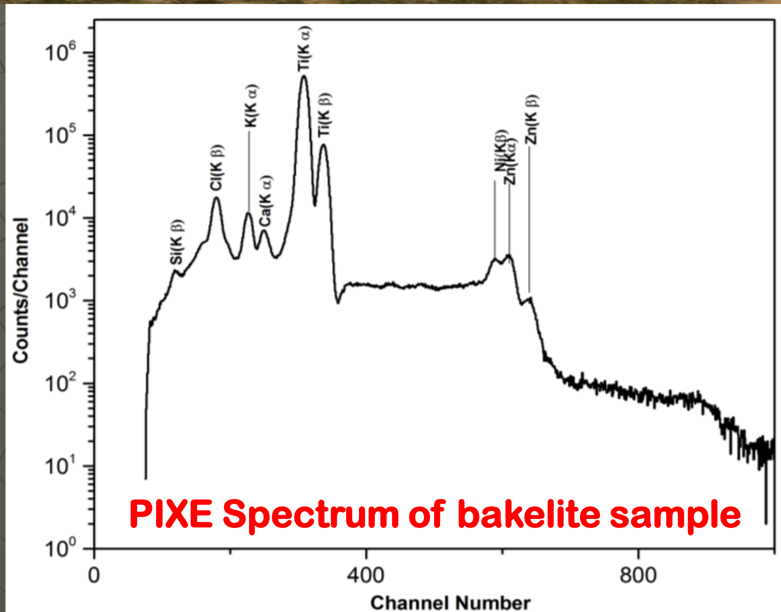


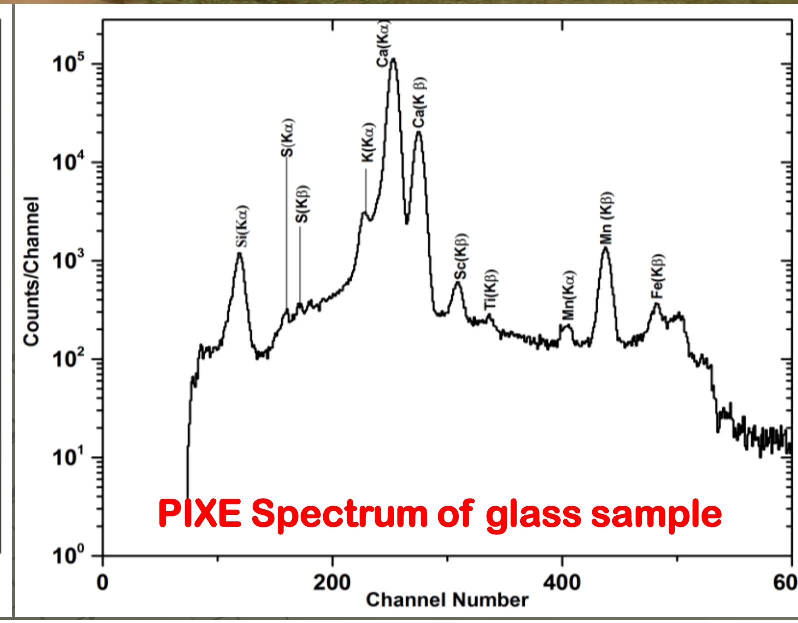


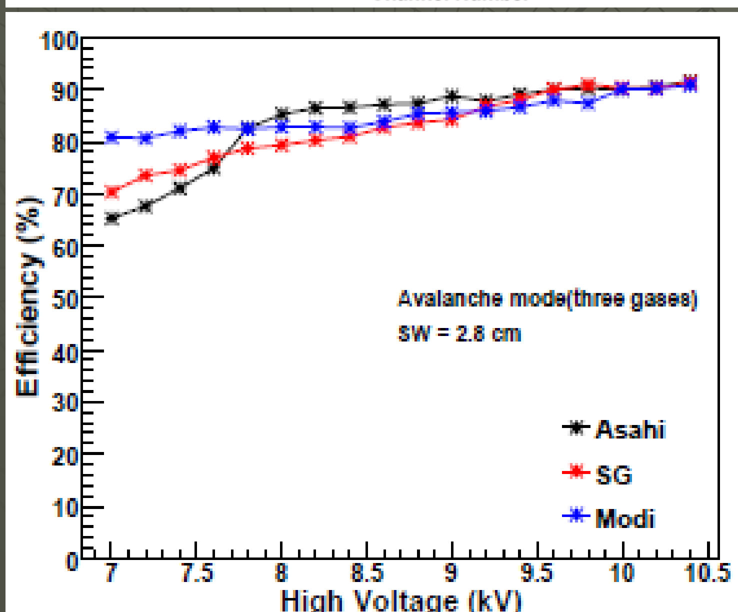


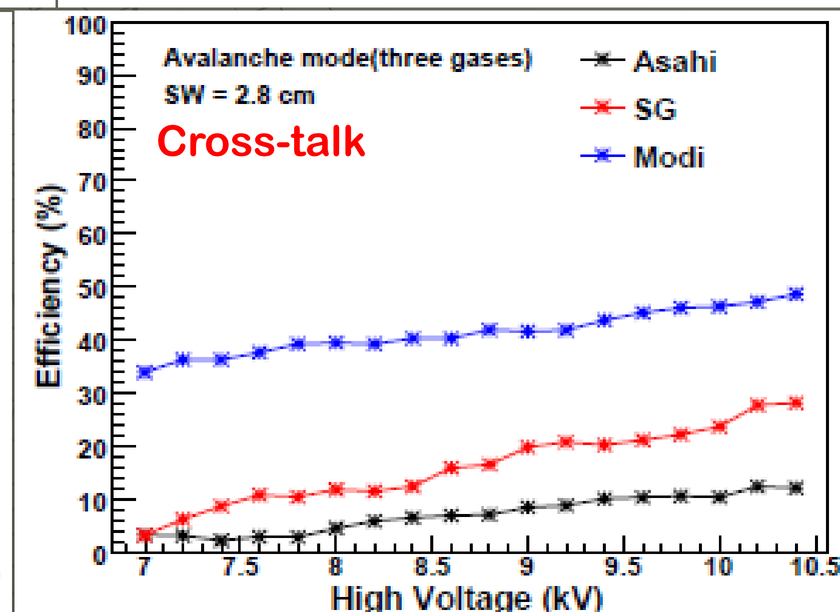


Glass characterisation studies

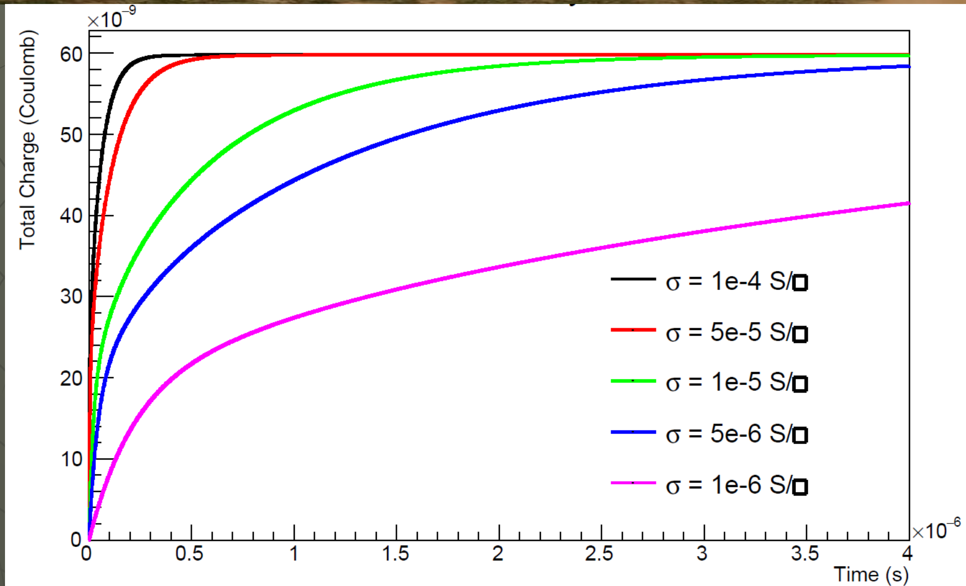


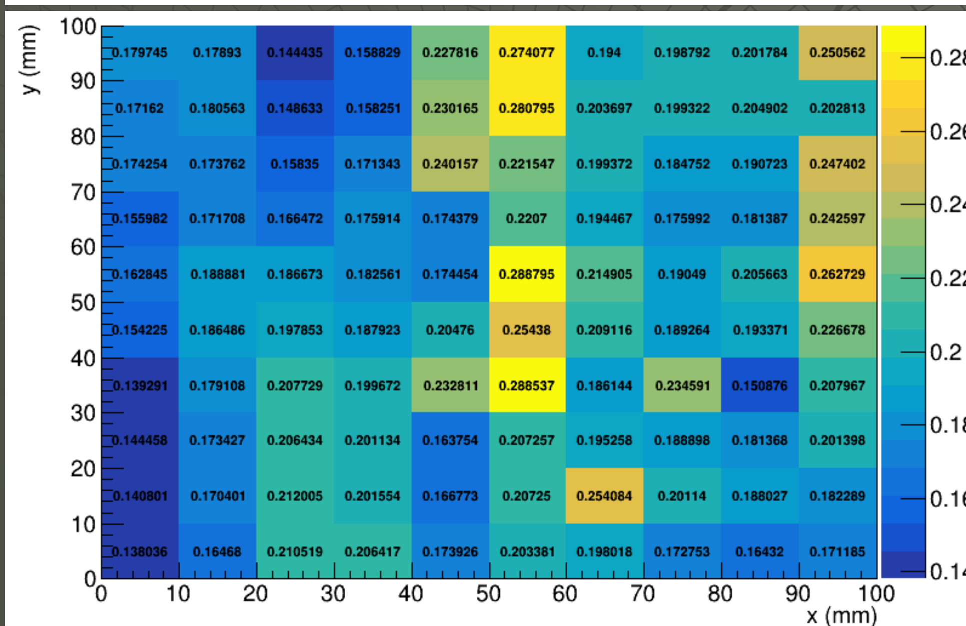


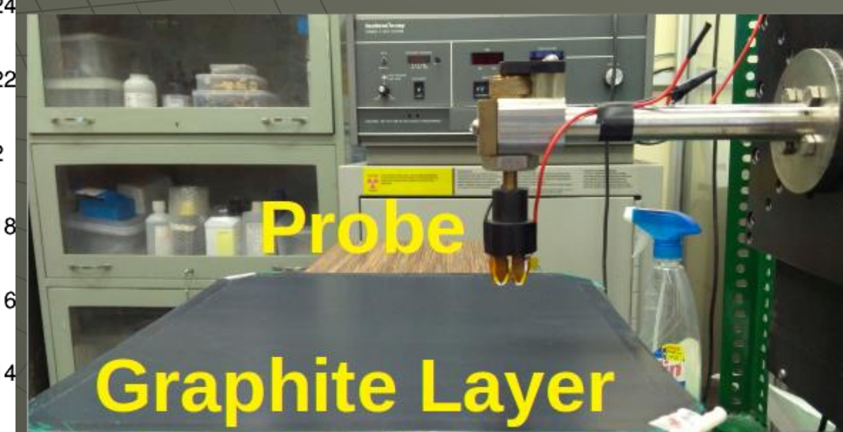




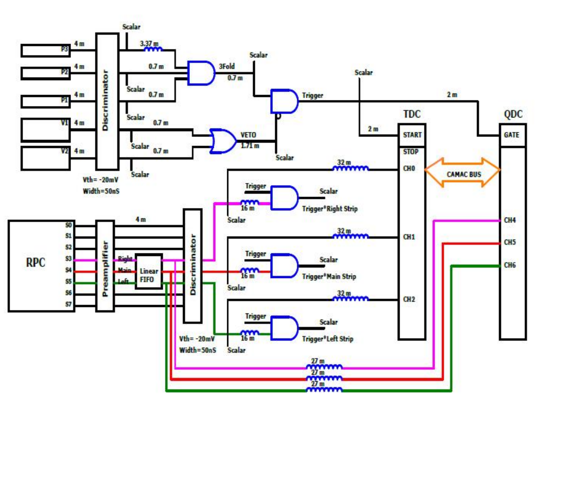
Paint conductivity and charge profile

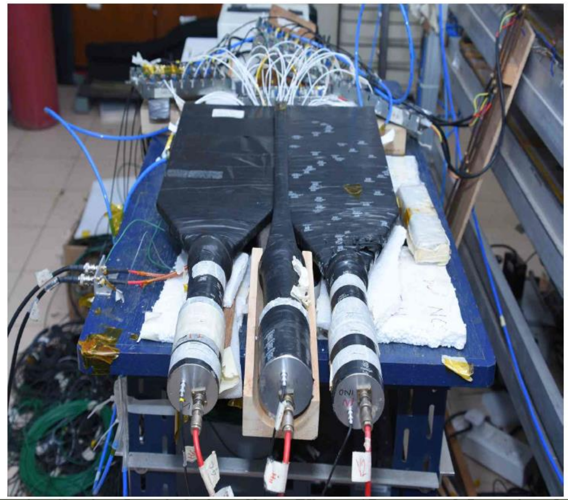


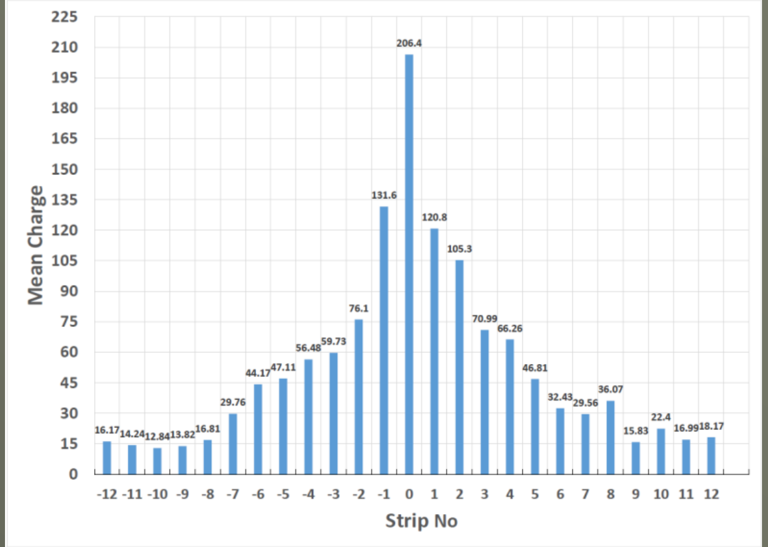


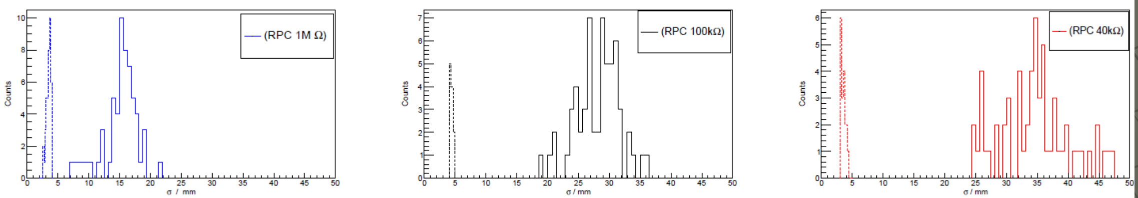


Precision studies on coat resistance

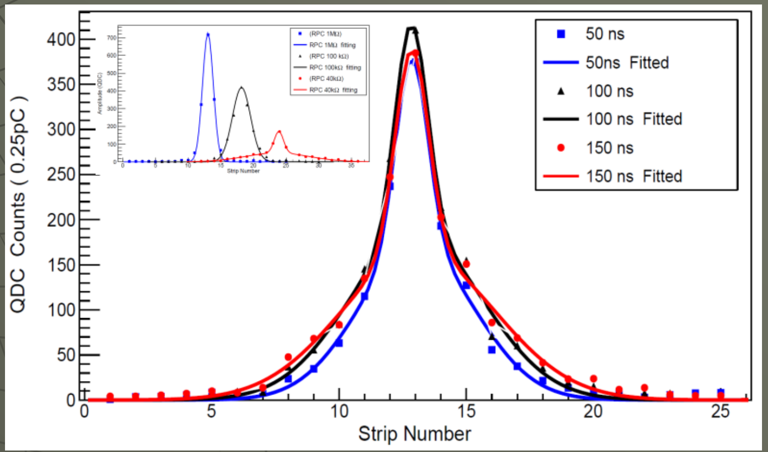






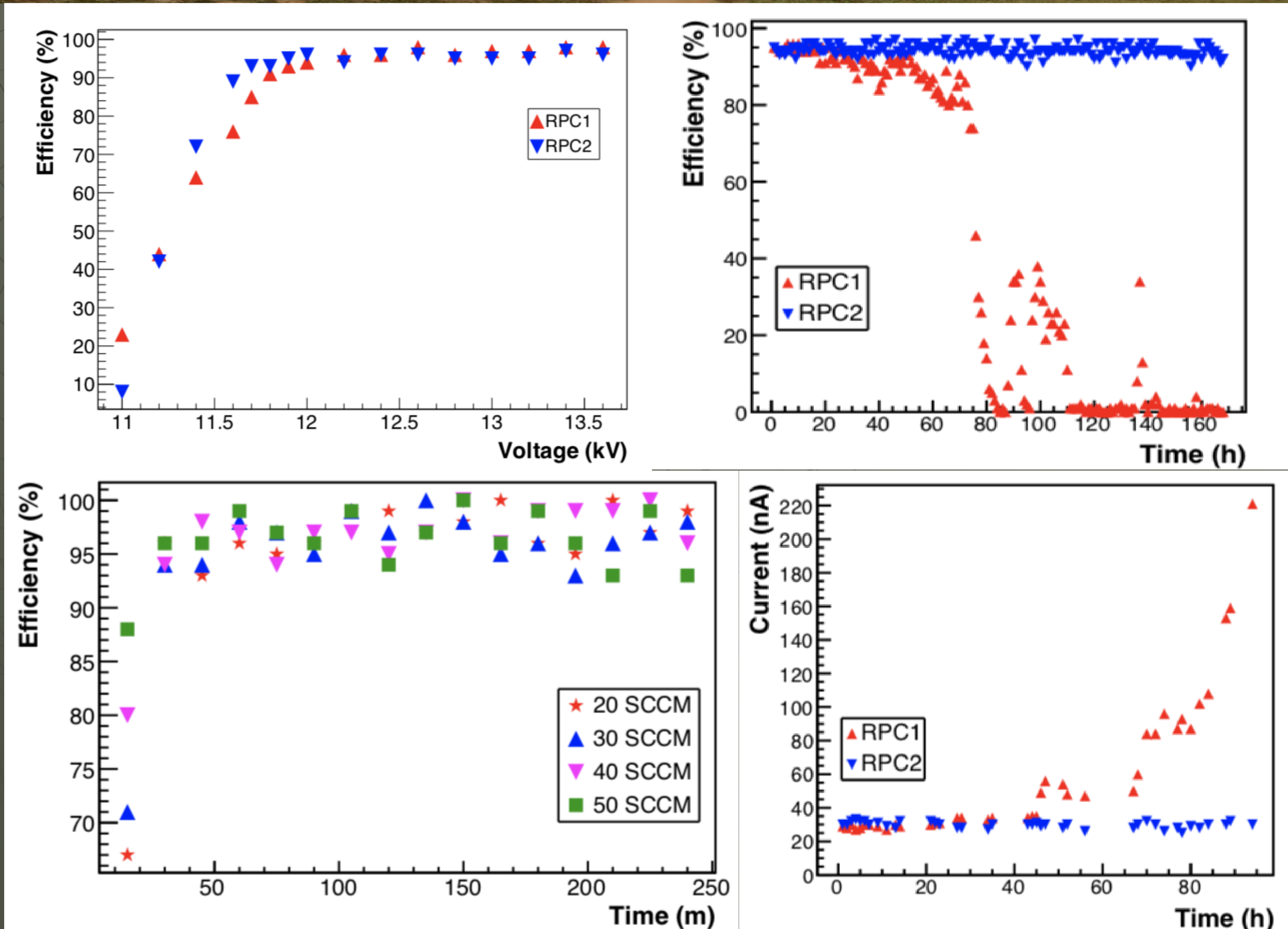


Experimental		
Integration time	$\sigma_1(mm)$	$\sigma_2(mm)$
$50ns$	5.66 ± 0.12	37.28 ± 2.13
$100ns$	5.77 ± 0.13	43.94 ± 2.11
$150ns$	5.76 ± 0.12	51.23 ± 2.41

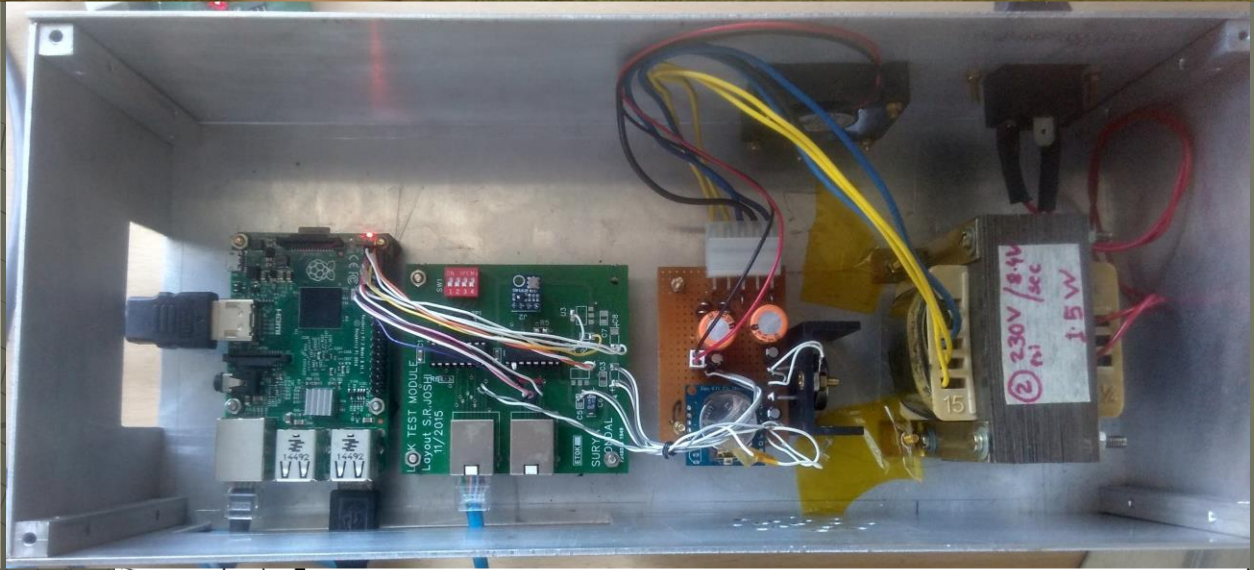


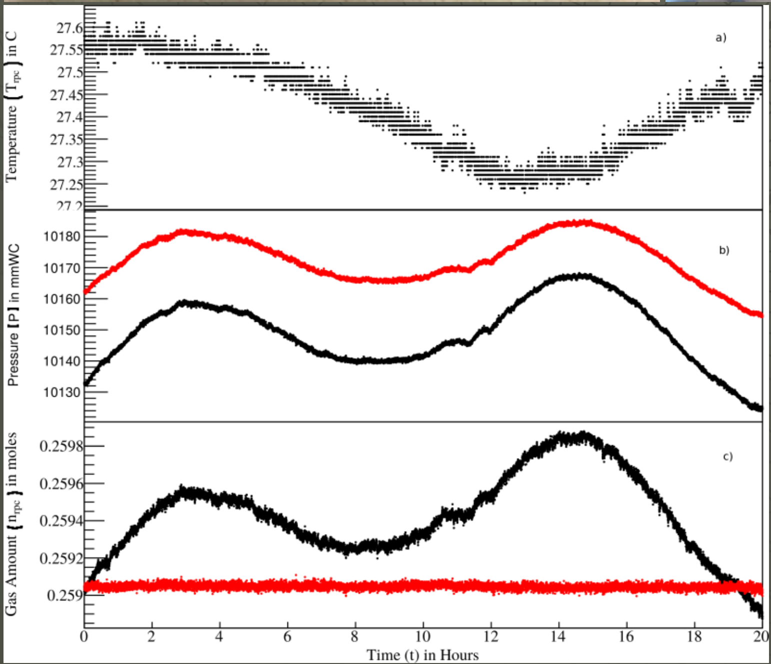
We obtained a position resolution of (0.98±0.11)mm using panels made of 5mm wide strips while it was (0.57±0.21)mm with panels made of 3mm wide strips.

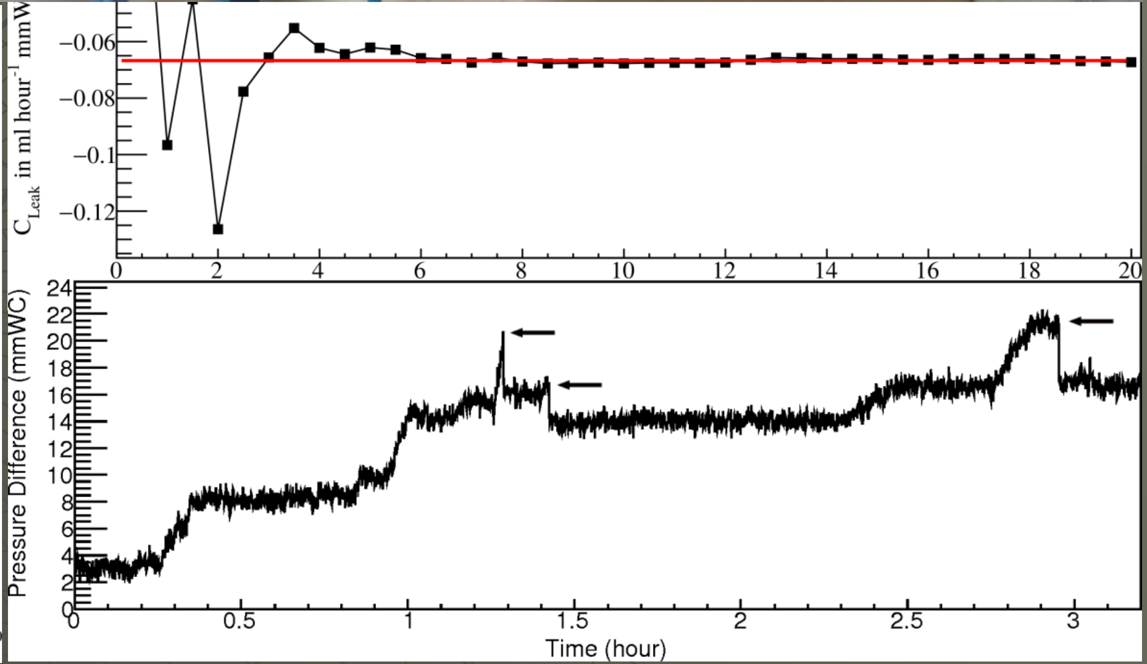
Studies on moister contamination



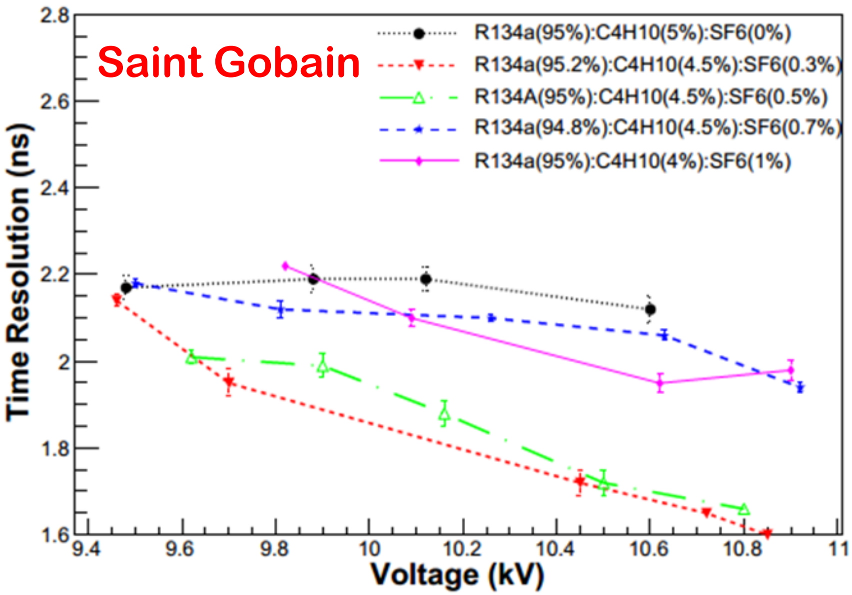
Automated leak test system

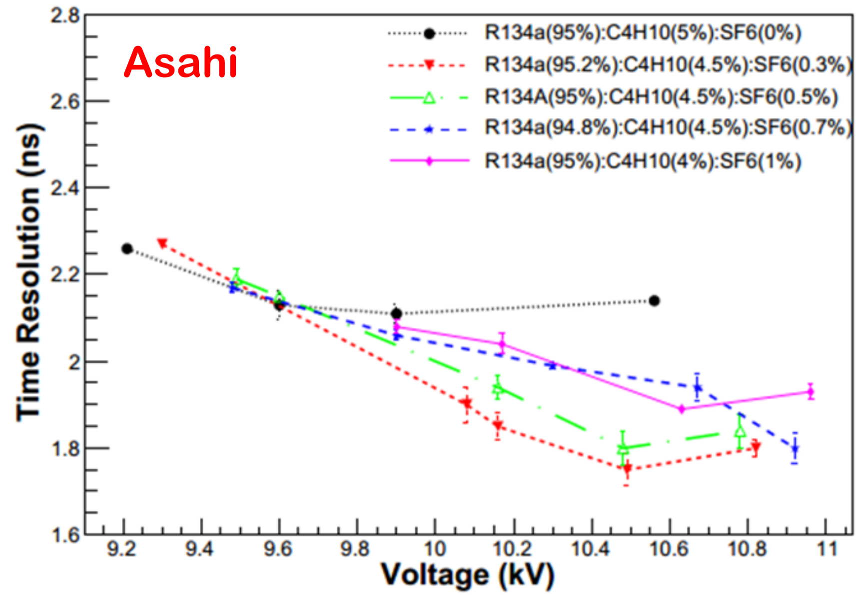


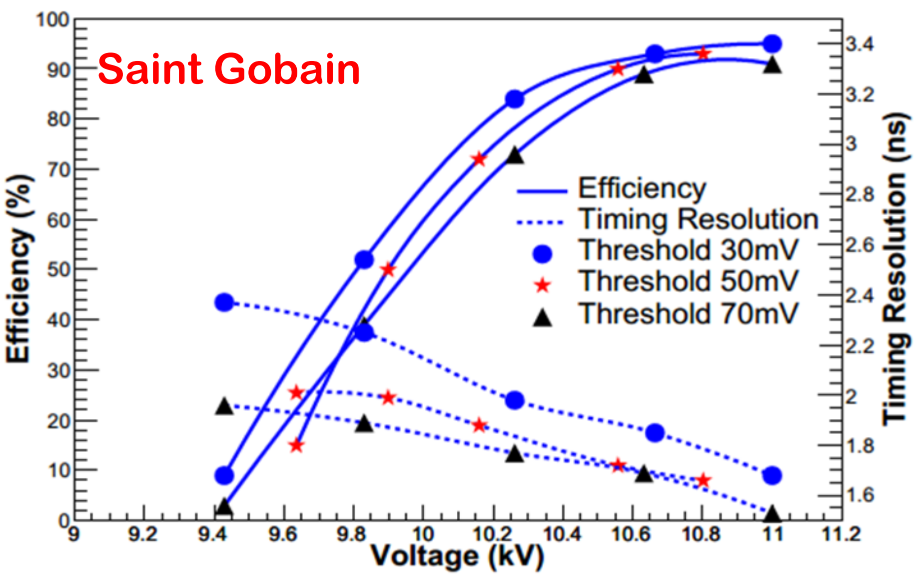


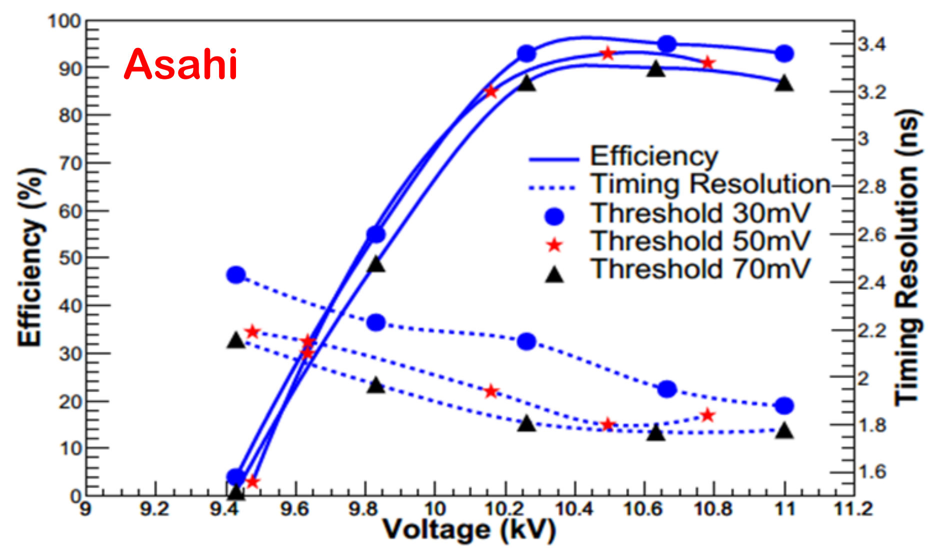


Optimising operating gas mixtures

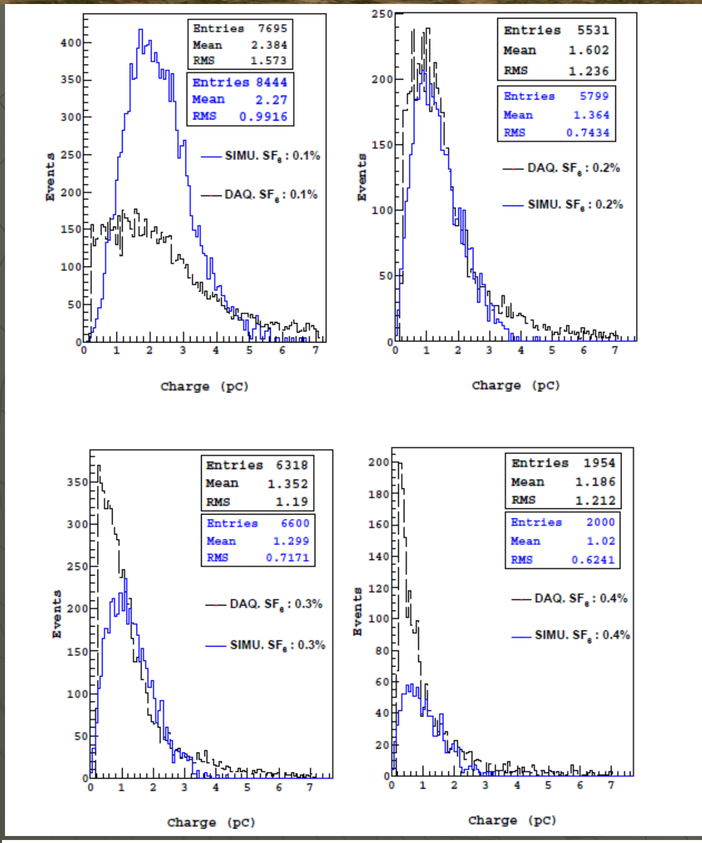


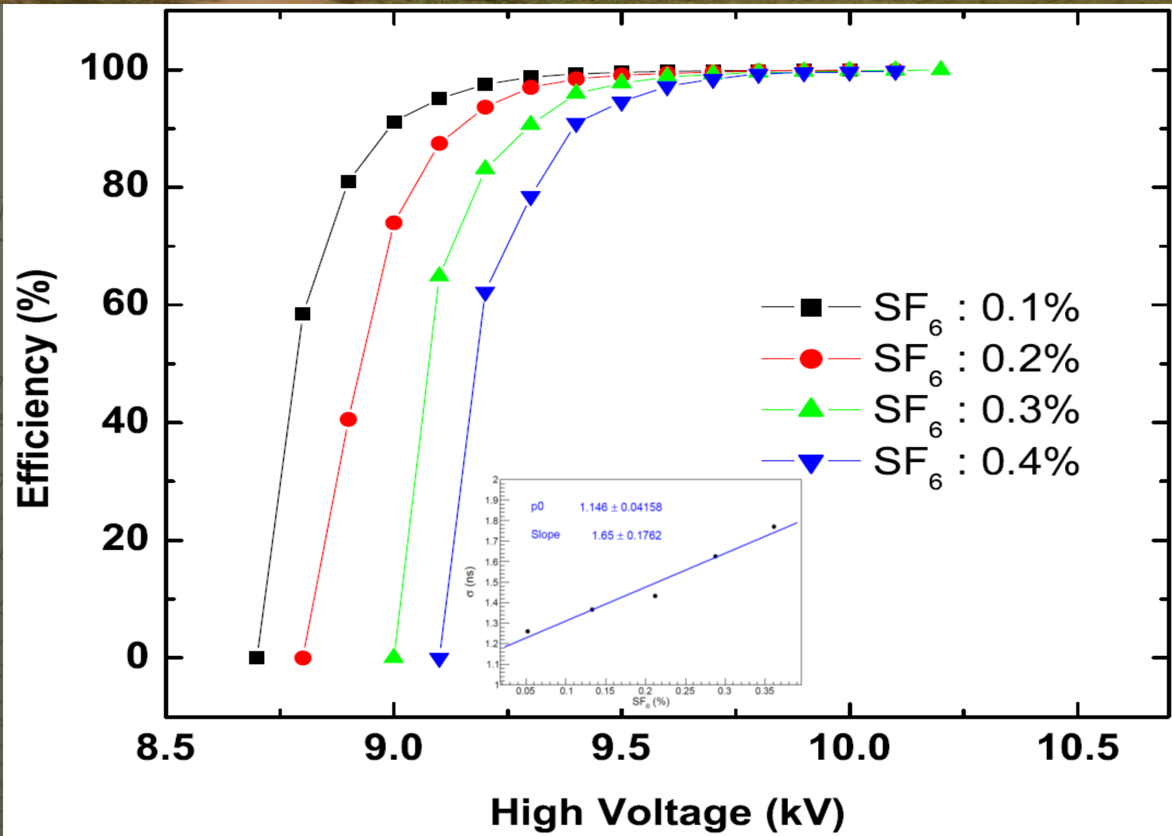






Role of SF_6 in the RPC gas mixture

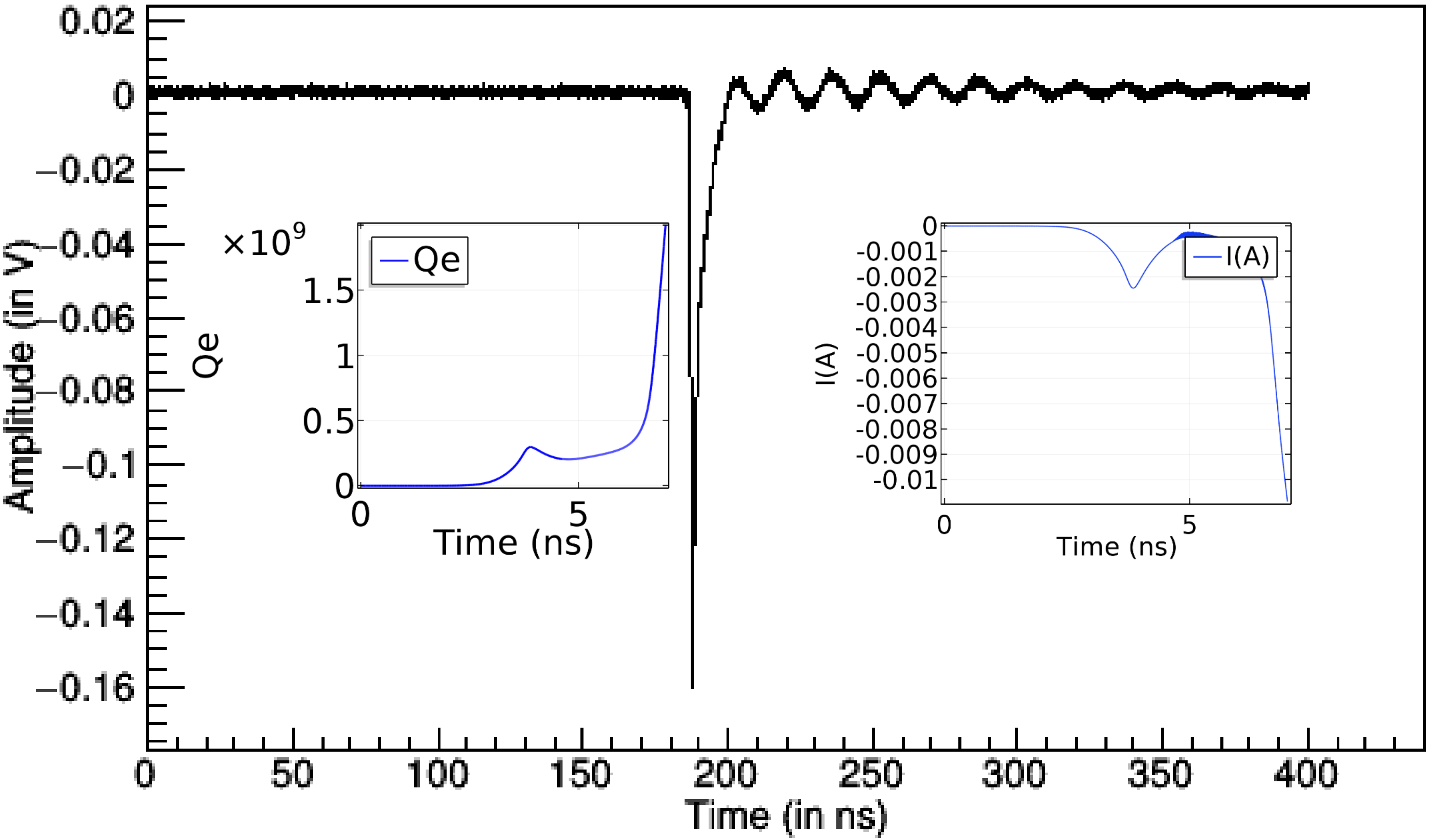




SF_6 (%)	DAQ		Simulated		CRO		Simulated		Simulated	
	Mean	Events	Mean	Events	Mean	Events	Mean	Events	Mean	Events
0.1	2.38	7695	2.27	8444	1.91	2161	2.28	2500	2.24	100000
0.2	1.60	5531	1.36	5799	1.37	2119	1.37	2500	1.37	100000
0.3	1.35	6318	1.30	6600	1.08	2297	1.30	2500	1.30	100000
0.4	1.18	1954	1.02	2000	0.79	2191	1.00	2500	1.01	100000

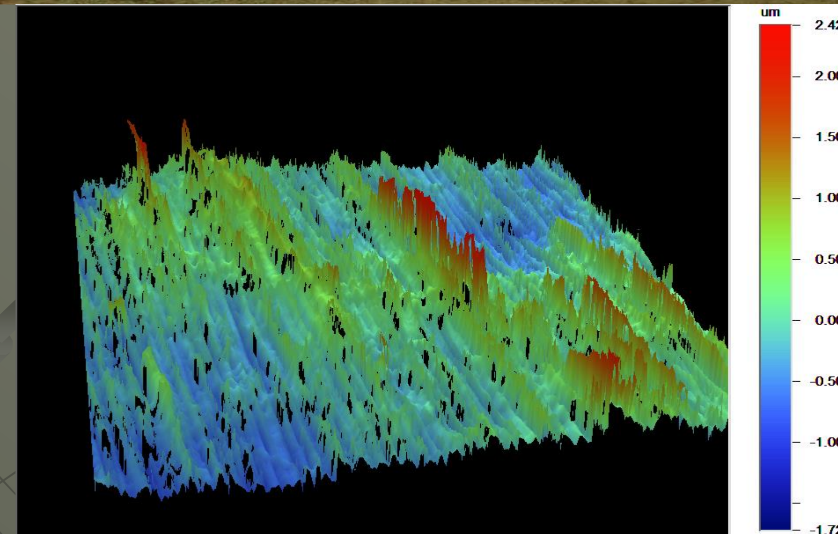
Studies on alternate gas mixtures

Electric field: 50 KV/cm and gas mixture Ar:CO_2:N_2 :: 5:65:30

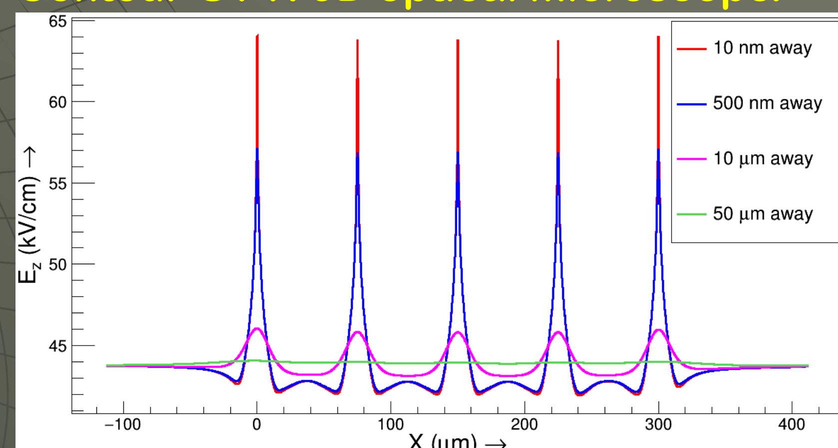


RPC timing properties for ICAL

- Charge identification efficiency (distinguishing up-going/down-going μ^+/μ^-) of proposed ICAL setup depends on timing properties of RPC.
- Experimental and numerical studies on a RPC and calculation of timing properties and efficiency of the detector at various operating conditions.
- In this connection, the electric field map of RPC was studied in detail as it is one of the crucial factors for RPC operation. Effect of design components and imperfections (surface roughness) on the detector properties.



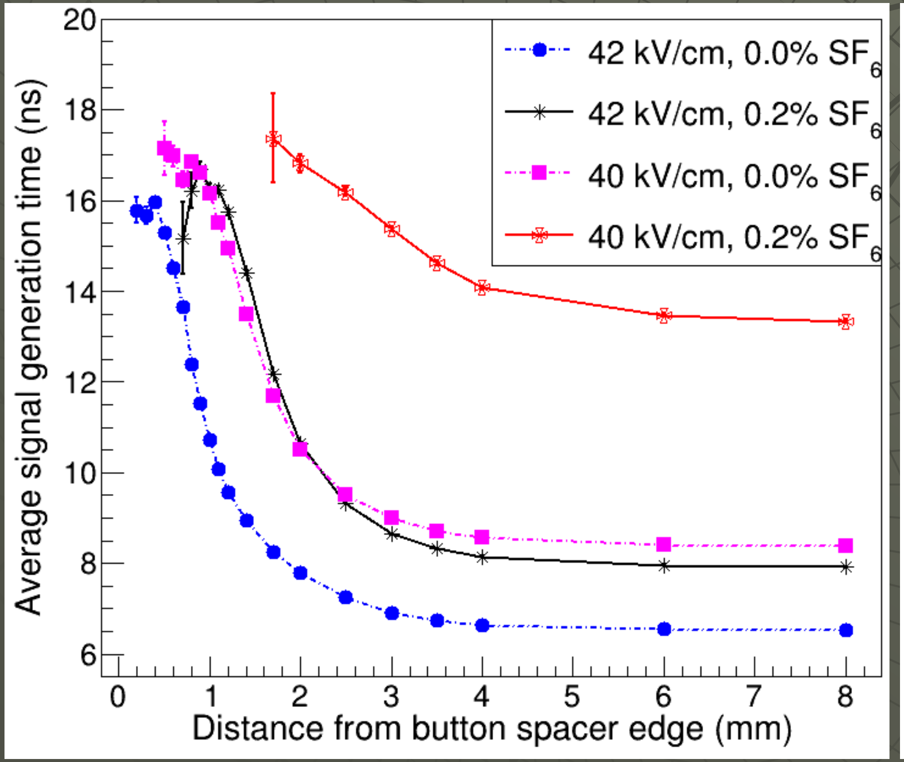
3D surface profile of P-120 Bakelite from Contour GT-K 3D optical microscope.

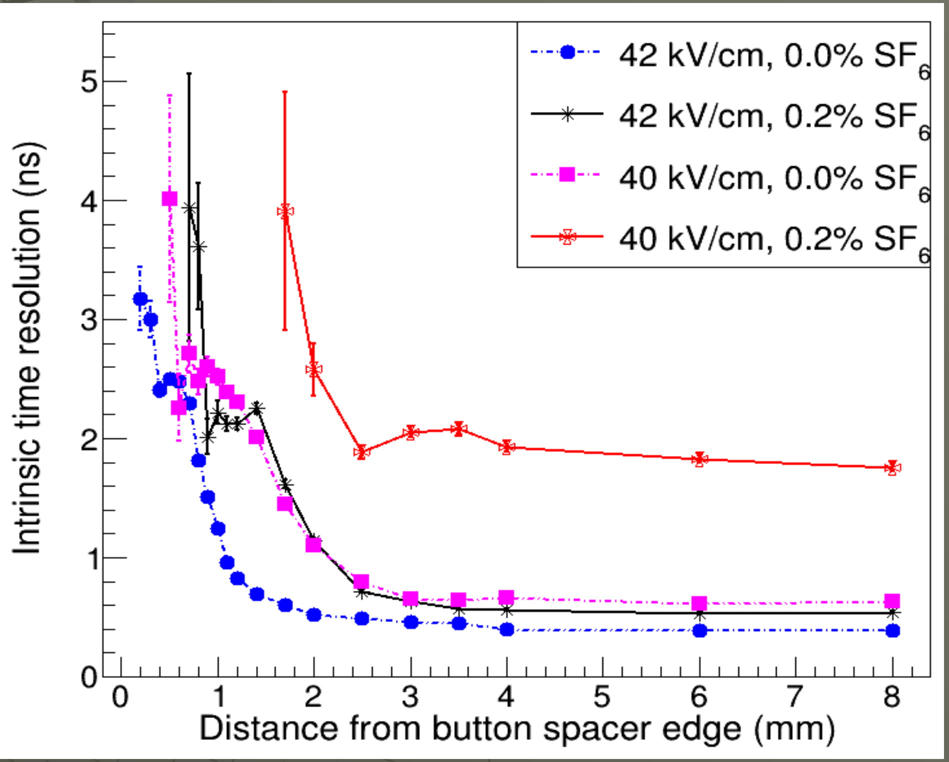


Variation of E_z along the lines at various distances from the tip of ridge-like rough structures on RPC electrode.

RPC timing properties for ICAL

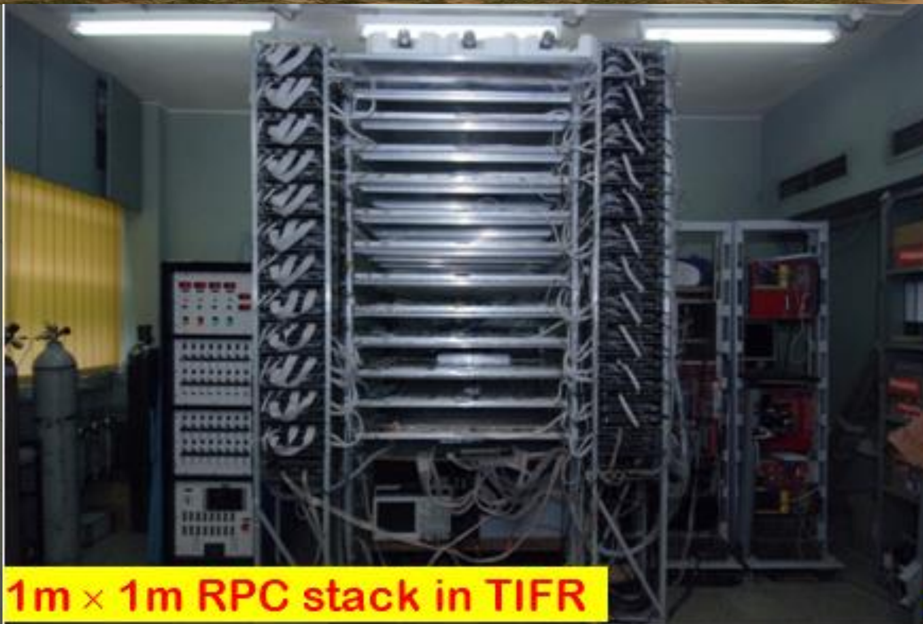
- The RPC is slower near its edge and button spacer (affected region is ~6 mm).
- Reduction of RPC gas gap and using more than one gas gap (Multi-gap RPC configuration) were found to improve timing properties significantly (1ns → 50ps).





Variation of (left) average signal generation time and (right) intrinsic time resolution of RPC with distance from a button spacer for different applied fields and gas mixtures.

Bench marking of RPC detectors



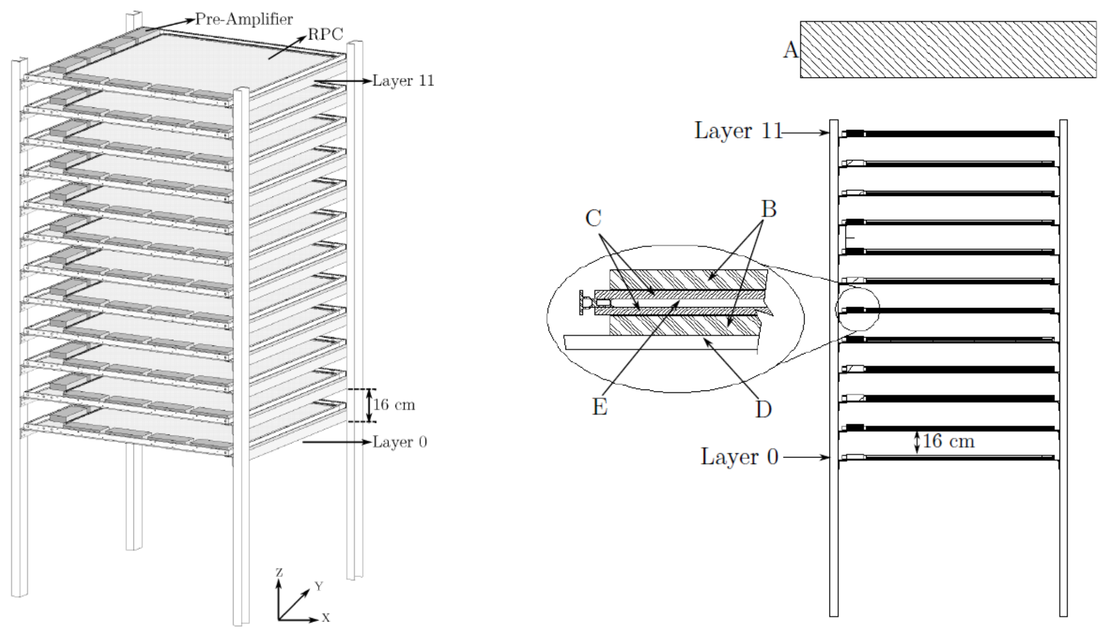
1m × 1m RPC stack in TIFR

2m × 2m RPC test stand in TIFR

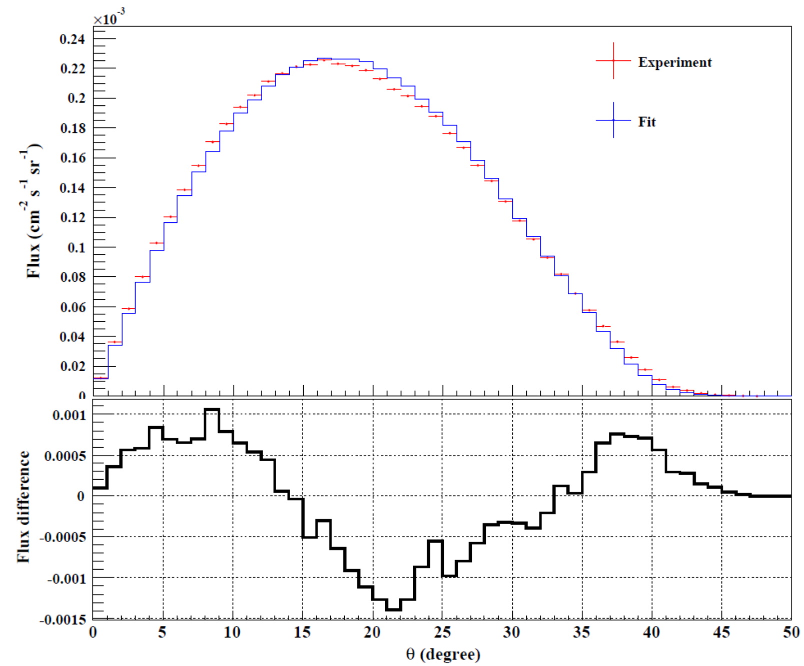
2m × 2m RPC stack in Madurai

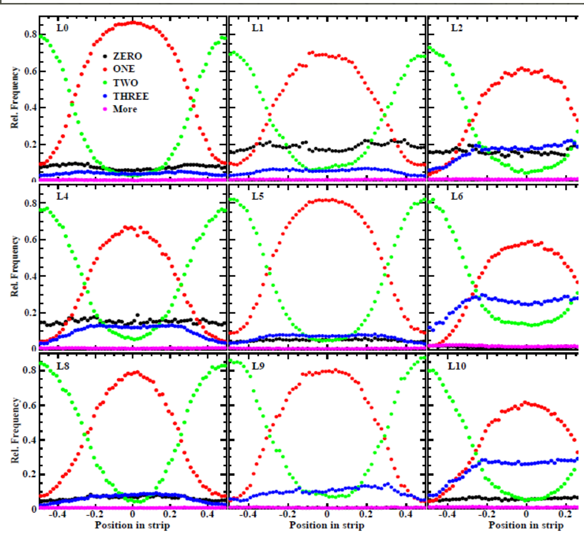
1m × 1m RPC stack in VECC

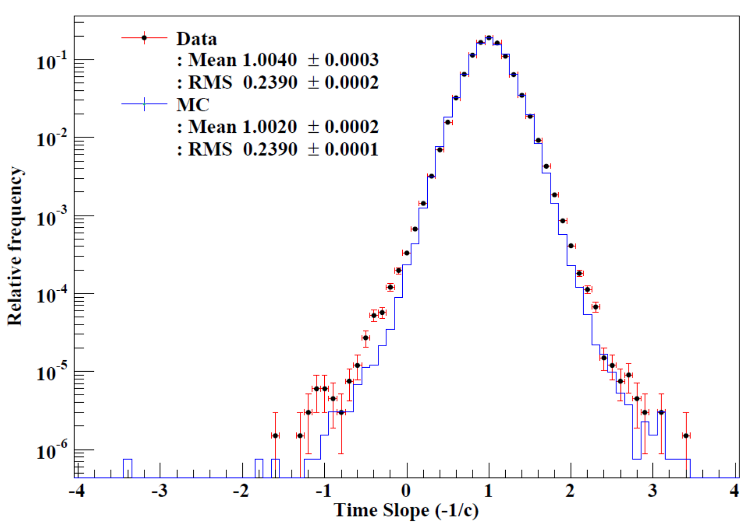
A few results from an RPC stand

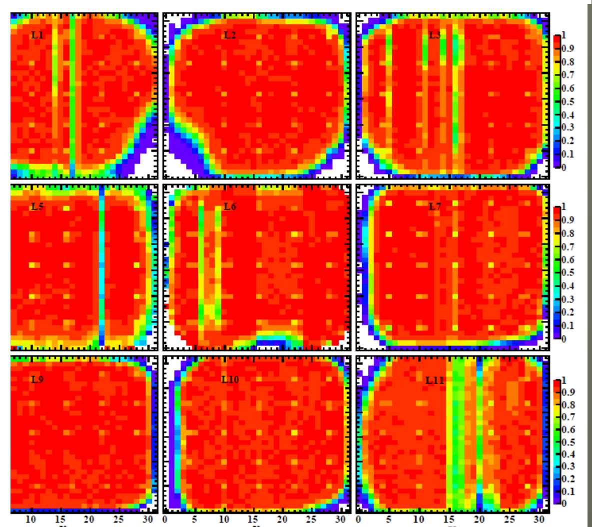


(a) 3D-view (b) 2D-view

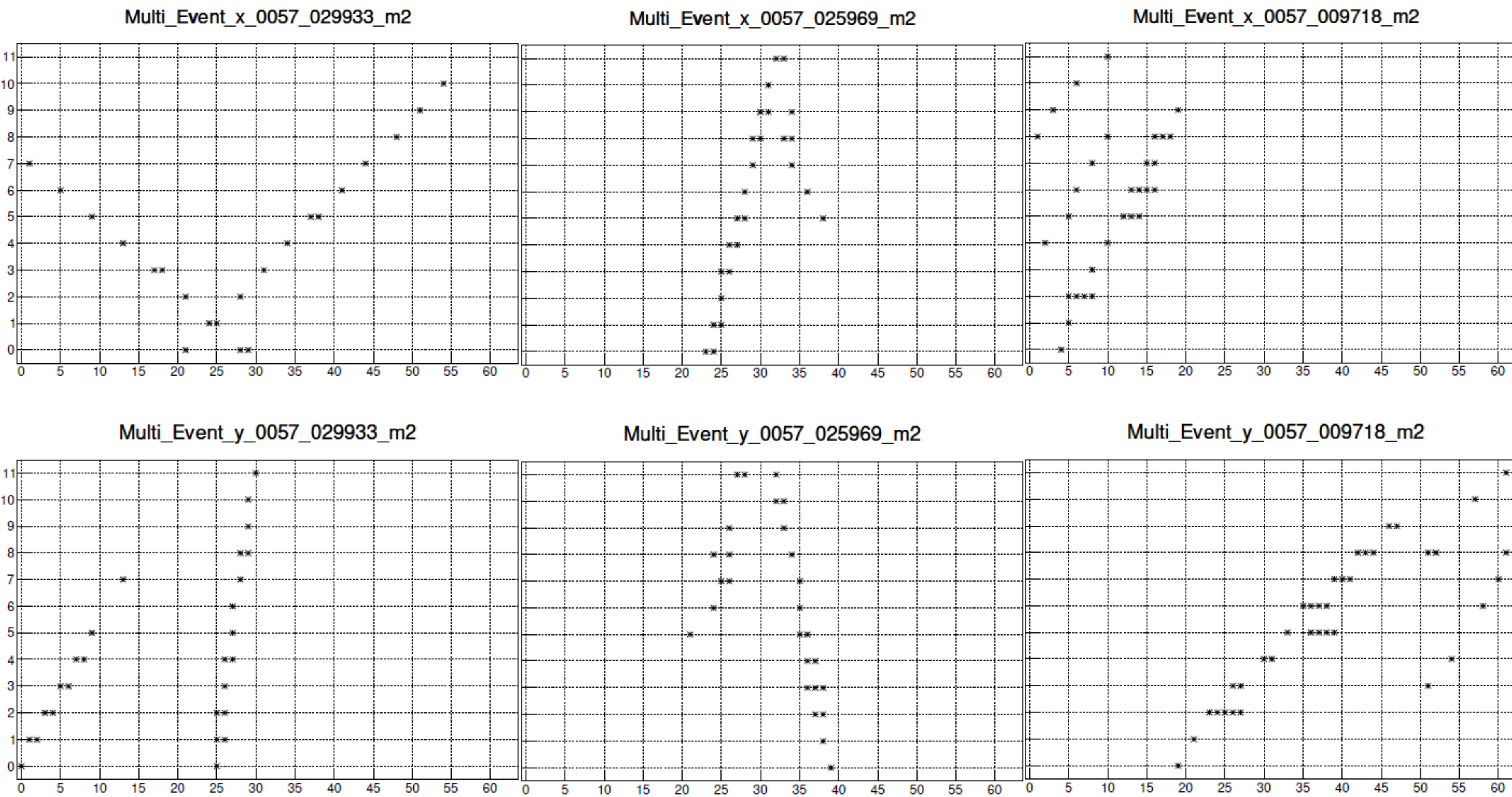








Multiple muons in RPC stands



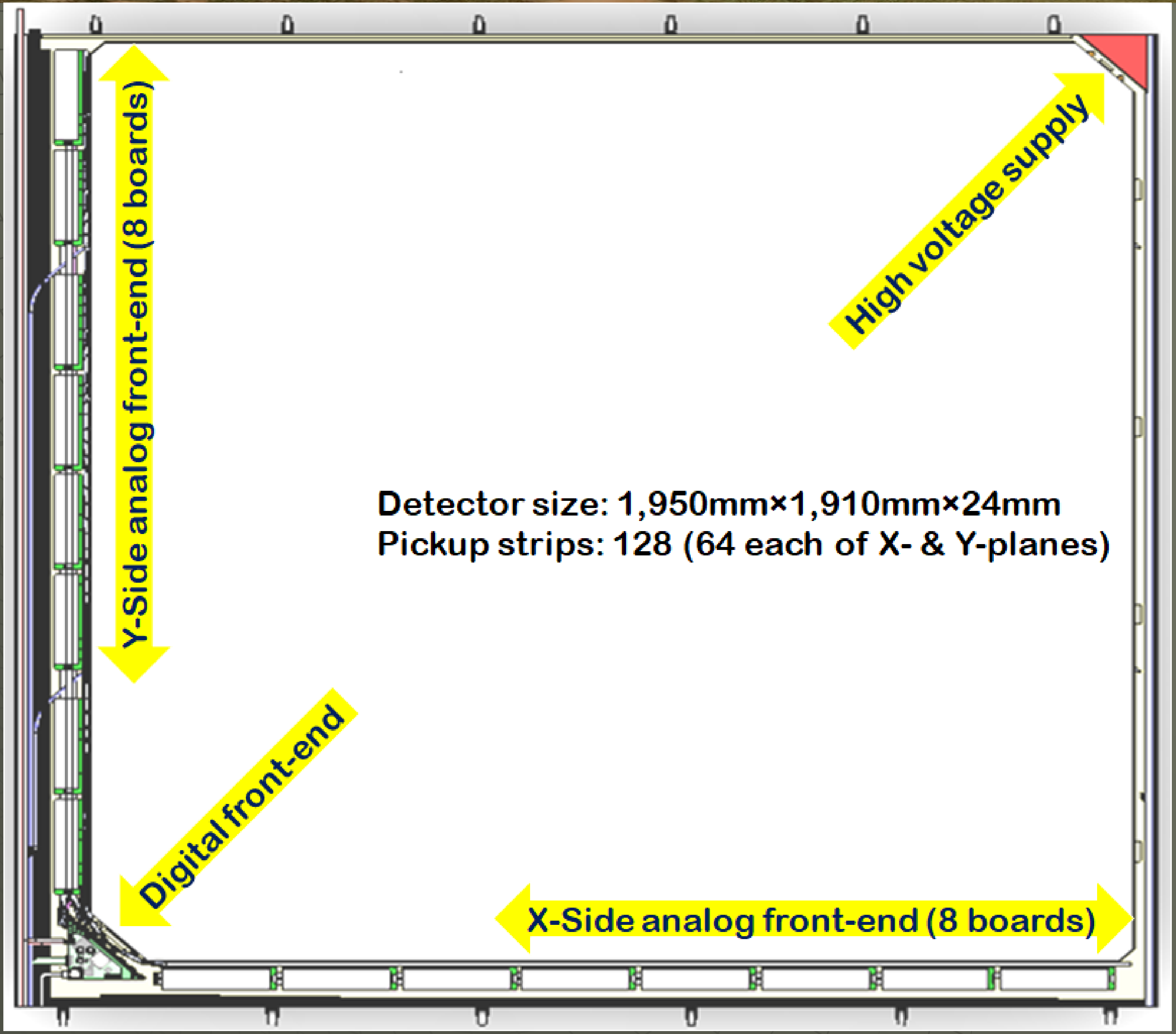
ICAL, e-ICAL and m-ICAL

Parameter	ICAL	e-ICAL	m-ICAL
No. of modules	3	1	1
Module dimensions	16.2m×16m×14.5m	8m×8mx2m (90:1)	4m×4mx1m (720:1)
Detector dimensions	49m×16m×14.5m	8m×8mx2m	4m×4mx1m
No. of layers	150	20	10
Iron plate thickness	56mm	56mm	56mm
Gap for RPC trays	40mm	40mm	45mm
Magnetic field	1.3Tesla	1.3Tesla	1.3Tesla
RPC dimensions	1,950mm×1,910mm×24mm	1,950mm×1,910mm×24mm	1,950mm×1,910mm×24mm
Readout strip pitch	30mm	30mm	30mm
No. of RPCs/Road/Layer	8	4	2
No. of Roads/Layer/Module	8	4	1
No. of RPC units/Layer	192	16	2
No. of RPC units	28,800 (107,266m^2)	320 (1,192m^2) (90:1)	20 (74.5m^2) (1440:1)
No. of readout strips	3,686,400	40,960 (90:1)	2,560 (1440:1)

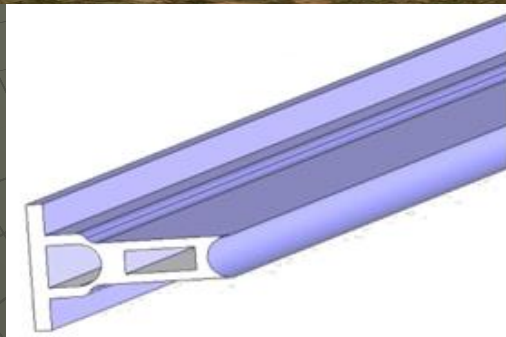
Deployment scenario of RPCs

Experiment	Area (m^2)	Electrodes	Gap(mm)	Gaps	Mode	Type
PHENIX	?	Bakelite	2	2	Avalanche	Trigger
NeuLAND	4	Glass	0.6	8	Avalanche	Timing
FOPI	6	Glass	0.3	4	Avalanche	Timing
HADES	8	Glass	0.3	4	Avalanche	Timing
HARP	10	Glass	0.3	4	Avalanche	Timing
COVER-PLASTEX	16	Bakelite	2	1	Streamer	Timing
EAS-TOP	40	Bakelite	2	1	Streamer	Trigger
STAR	50	Glass	0.22	6	Avalanche	Timing
CBM TOF	120	Glass	0.25	10	Avalanche	Timing
ALICE Muon	140	Bakelite	2	1	Streamer	Trigger
ALICE TOF	150	Glass	0.25	10	Avalanche	Timing
L3	300	Bakelite	2	2	Streamer	Trigger
BESIII	1200	Bakelite	2	1	Streamer	Trigger
BaBar	2000	Bakelite	2	1	Streamer	Trigger
Belle	2200	Glass	2	2	Streamer	Trigger
CMS	2953	Bakelite	2	2	Avalanche	Trigger
OPERA	3200	Bakelite	2	1	Streamer	Trigger
YBJ-ARGO	5630	Bakelite	2	1	Streamer	Trigger
ATLAS	6550	Bakelite	2	1	Avalanche	Trigger
ICAL	97,505	Both	2	1	Avalanche	Trigger

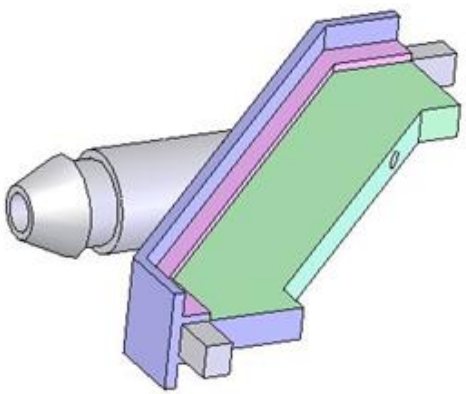
Profile of an ICAL RPC detector



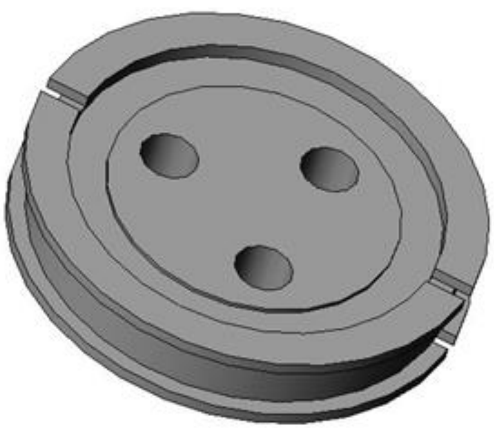
Materials for gas gap fabrication



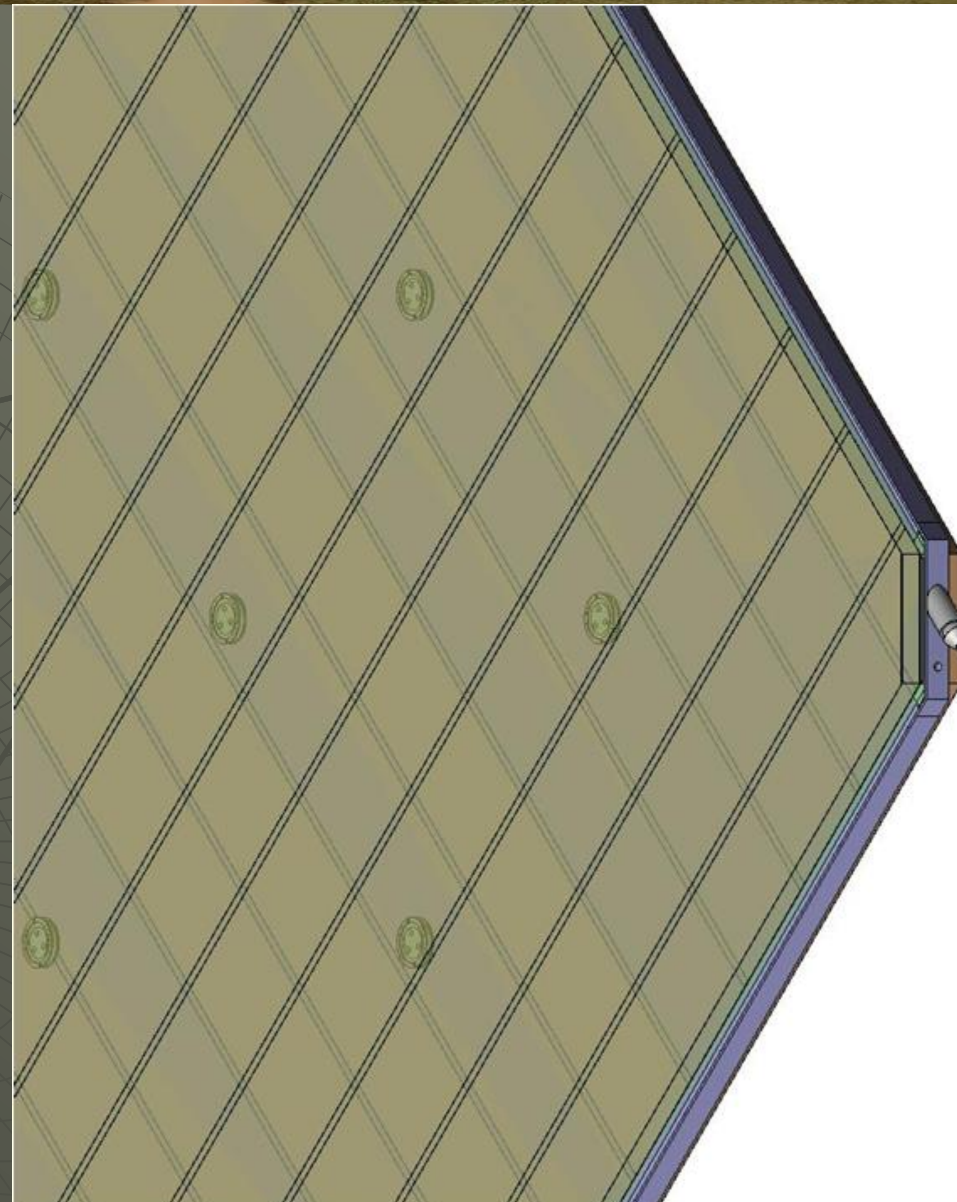
Edge spacer



Gas nozzle



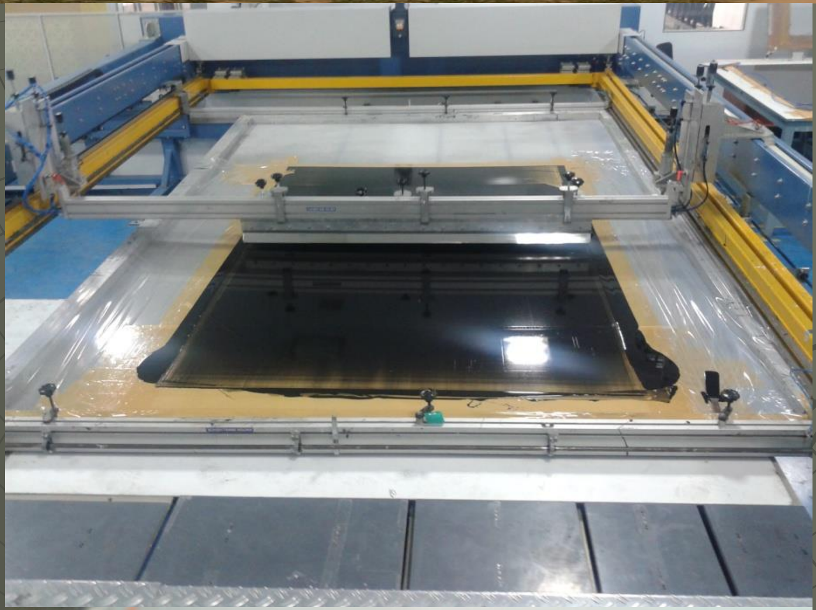
Glass spacer

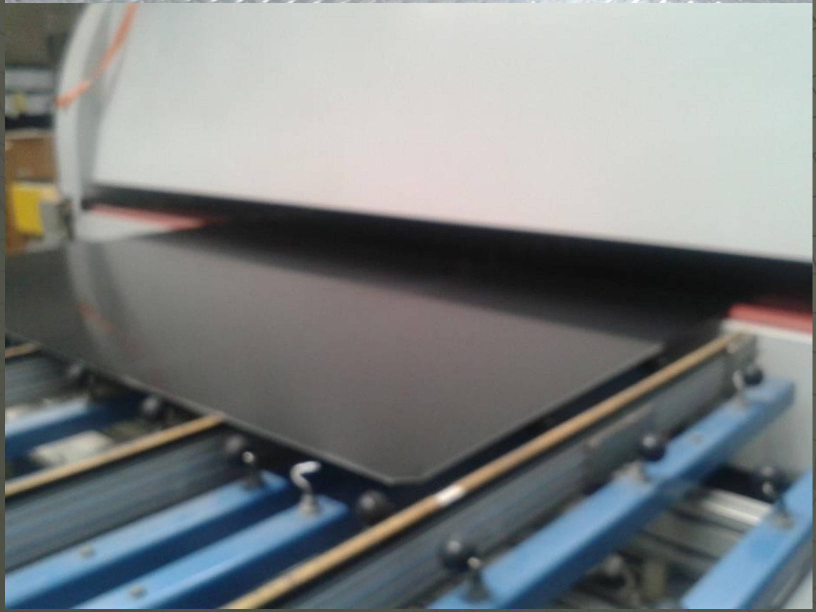


Schematic of an assembled gas volume

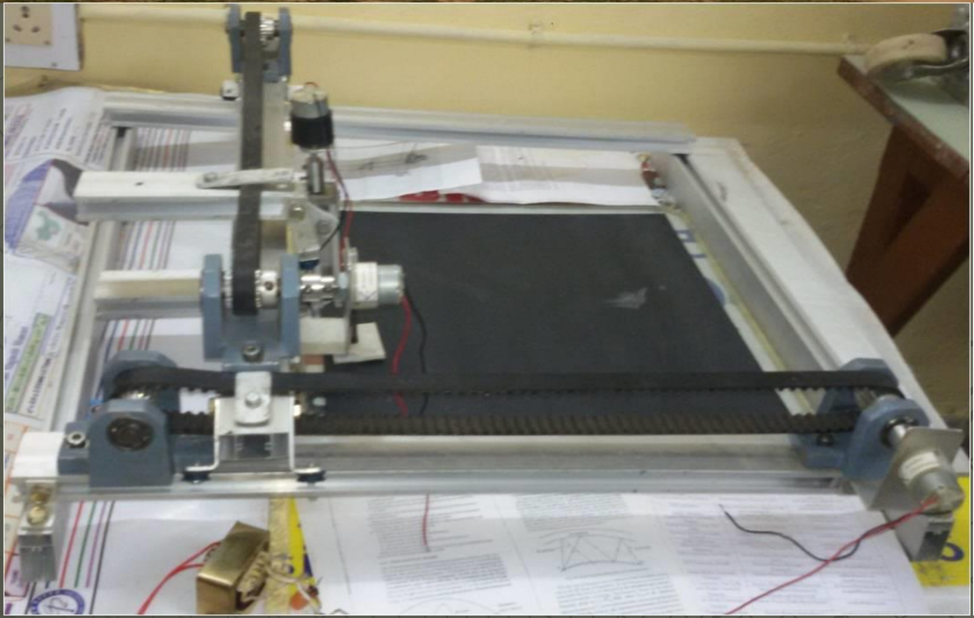
Glass spray painting robot

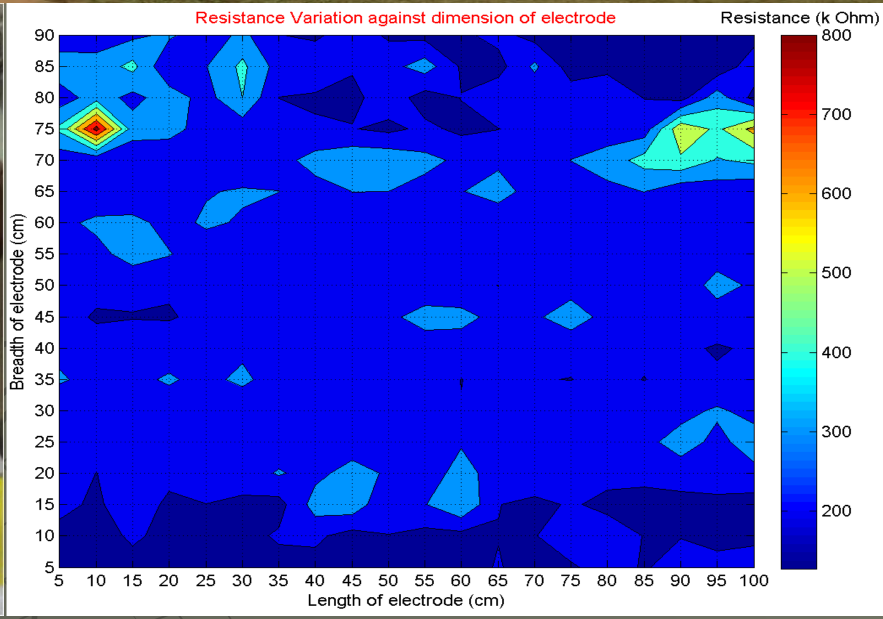
Screen printing on electrodes

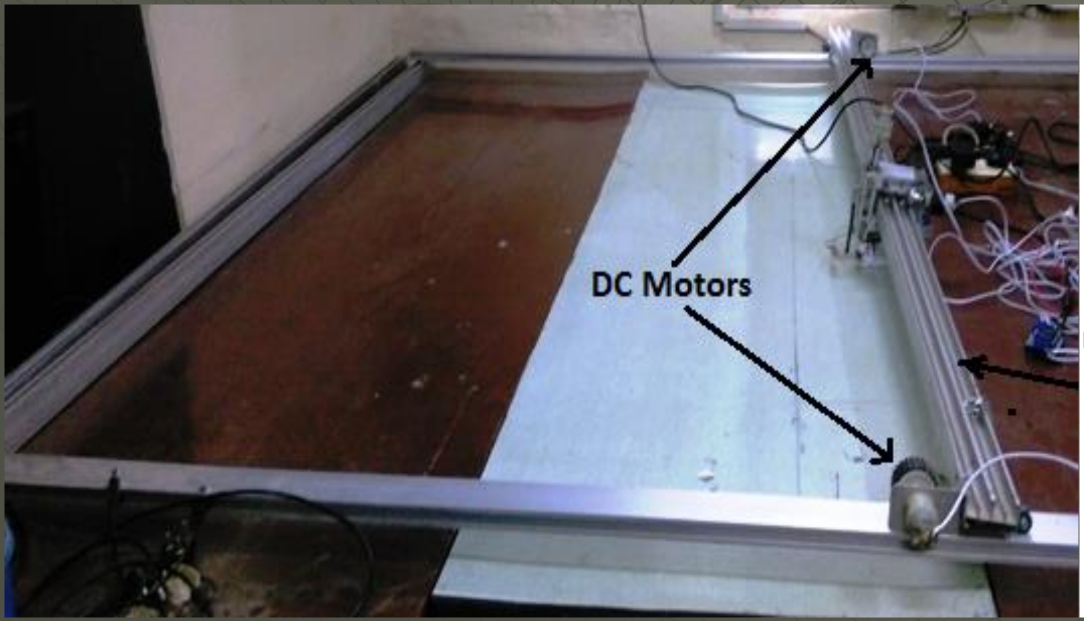


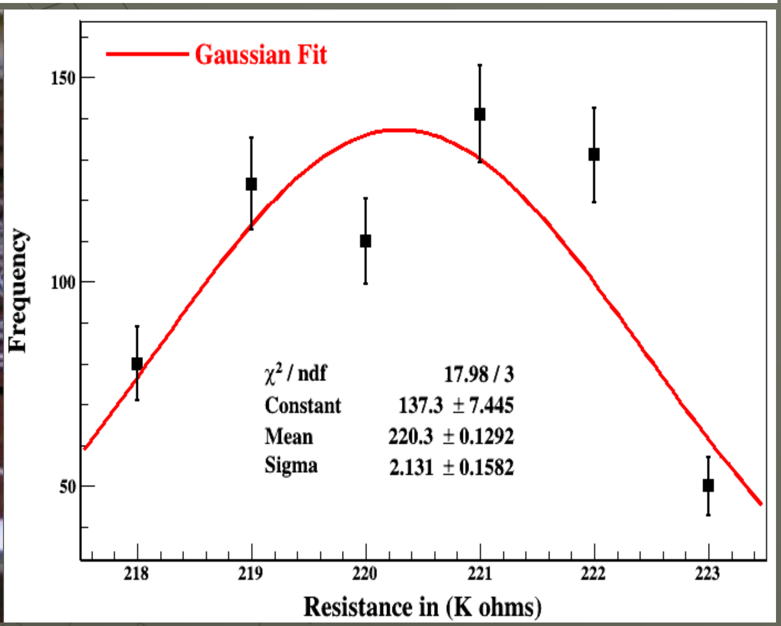


Automated resistivity measurement



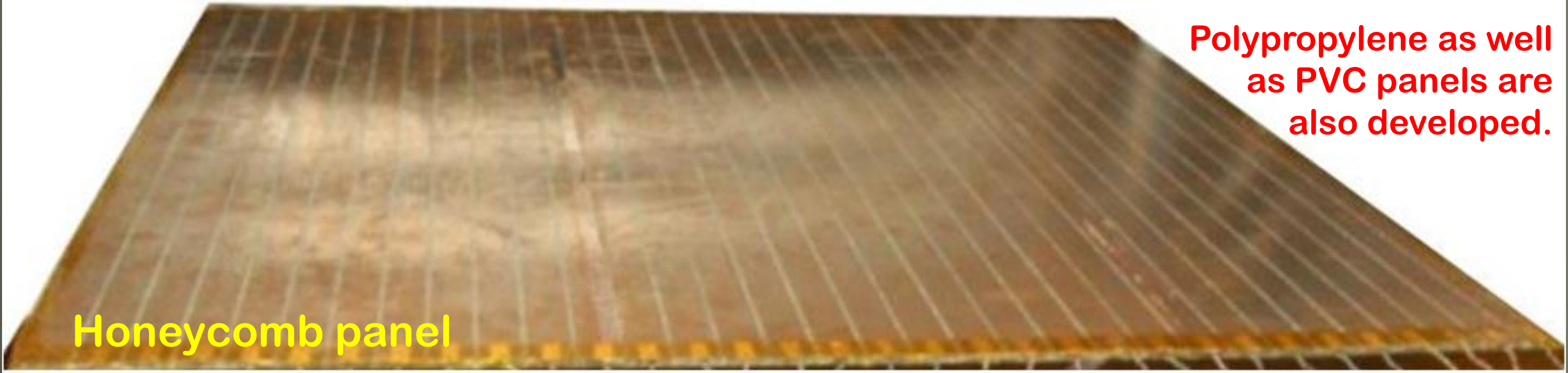




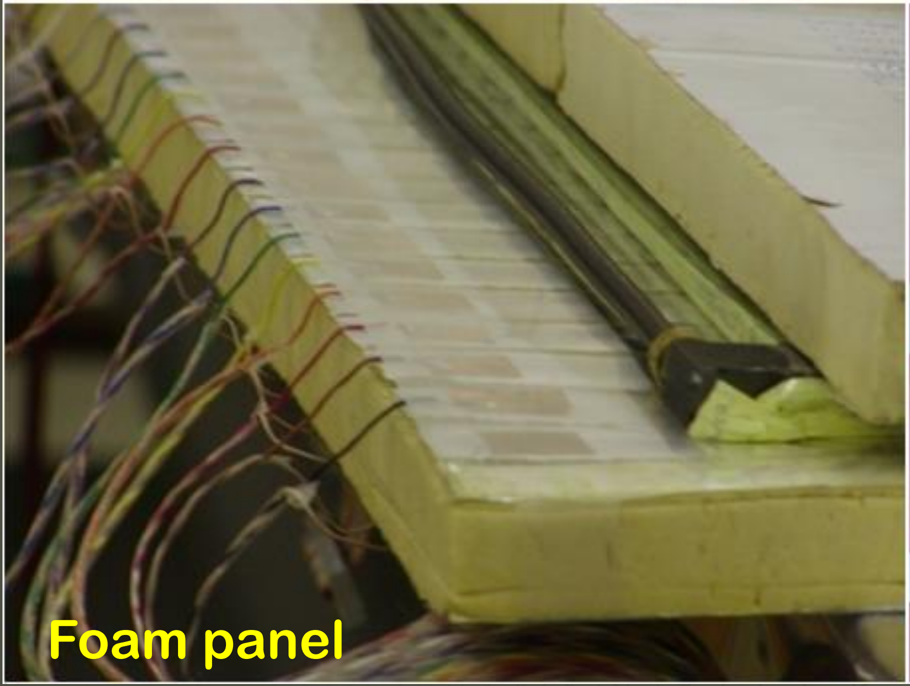


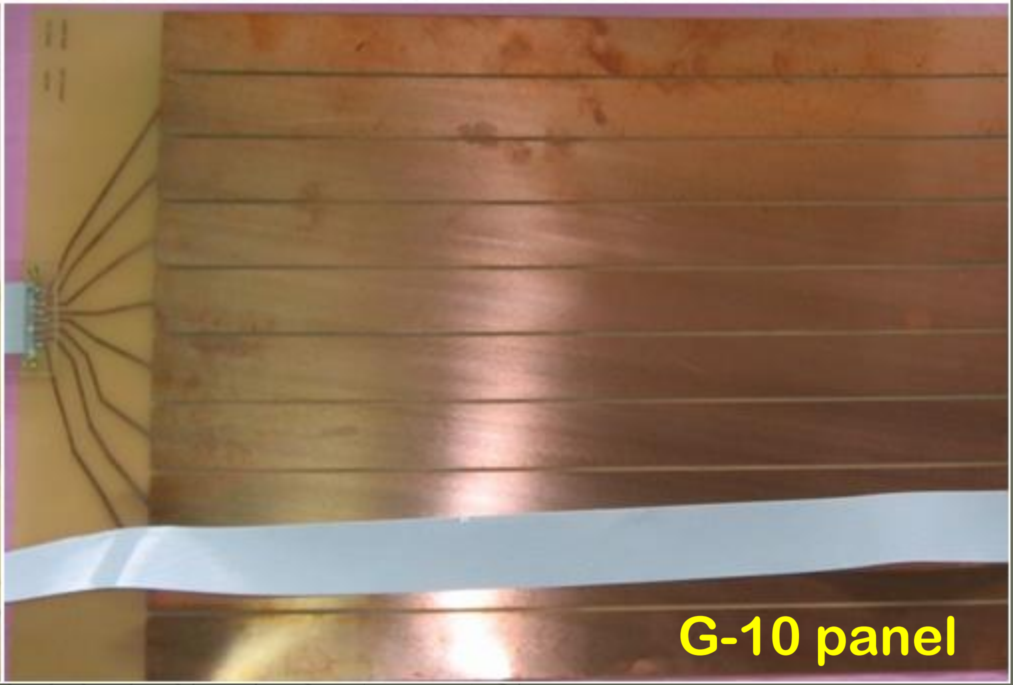
Automatic RPC gap making

Development of Pickup panels



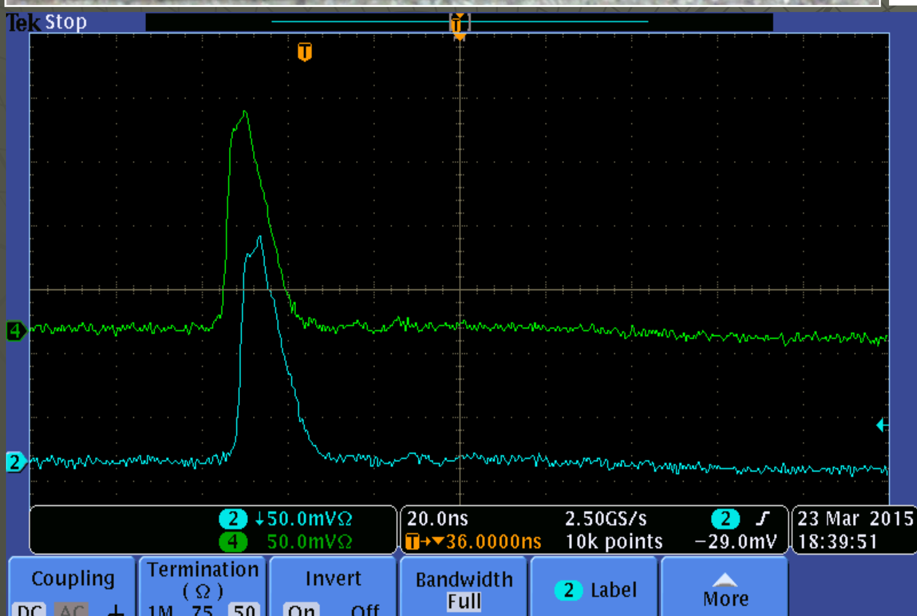
Polypropylene as well as PVC panels are also developed.

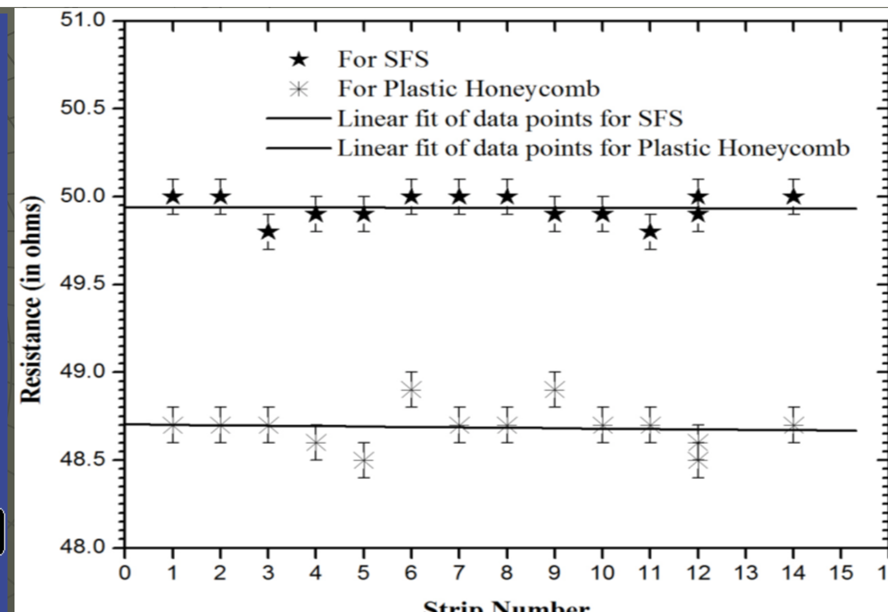




Development of SFS pickup panel

- Fire proof
- Water proof
- Flexible
- Light weight
- Cost effective
- Strip impedance
- Locally available
- Density (ρ): 0.3 - 0.6 g/cm^3
- Flexibility: Strong
- Radiation resistance: High
- Melting temperature (T_m) 2100 ^{0}C

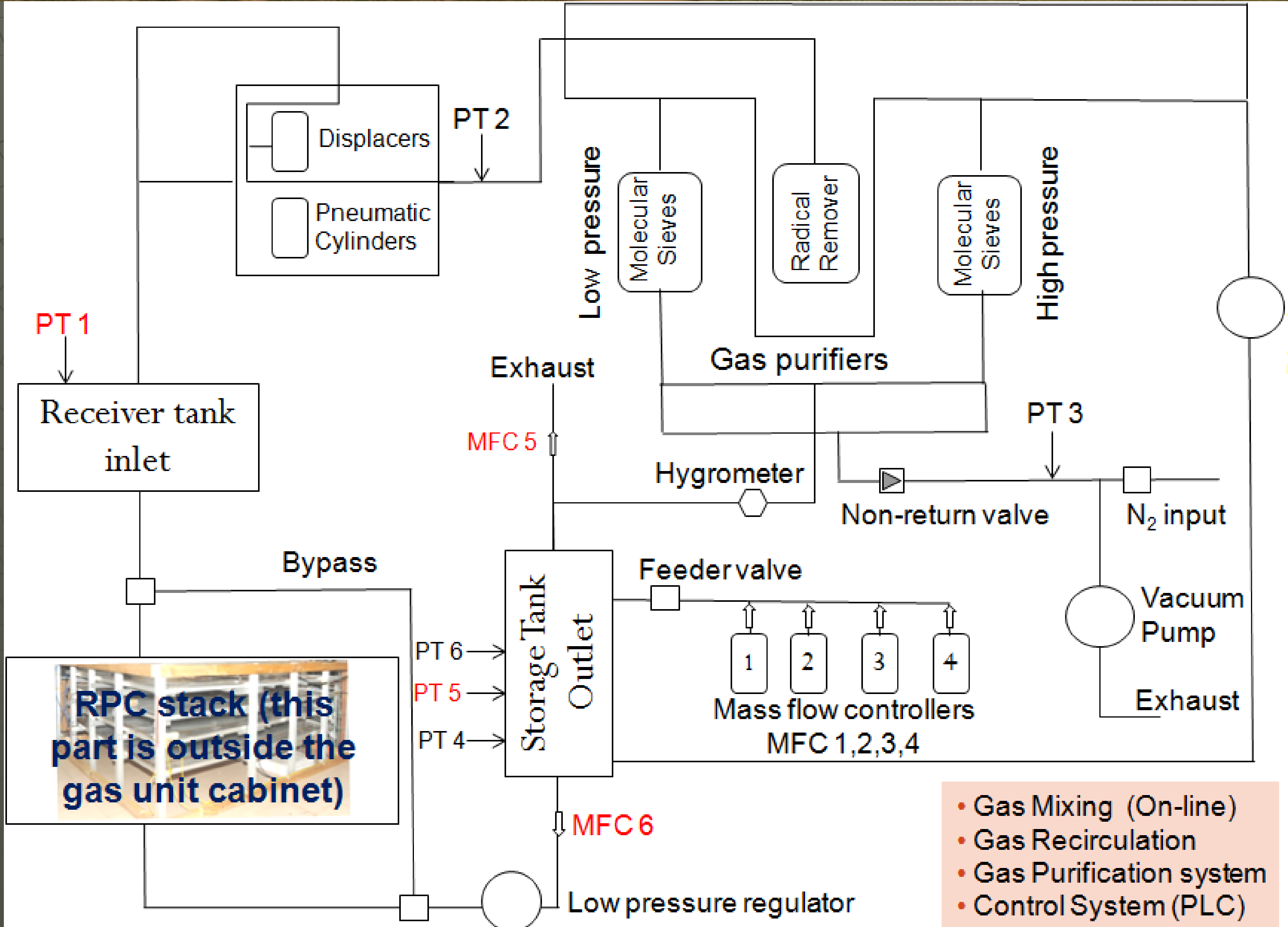




Closed loop gas system

About 200,000 litres (60 LPG cylinders) of gas will be circulating in the ICAL detector all the time.

Regenerate, Recycle and Reuse

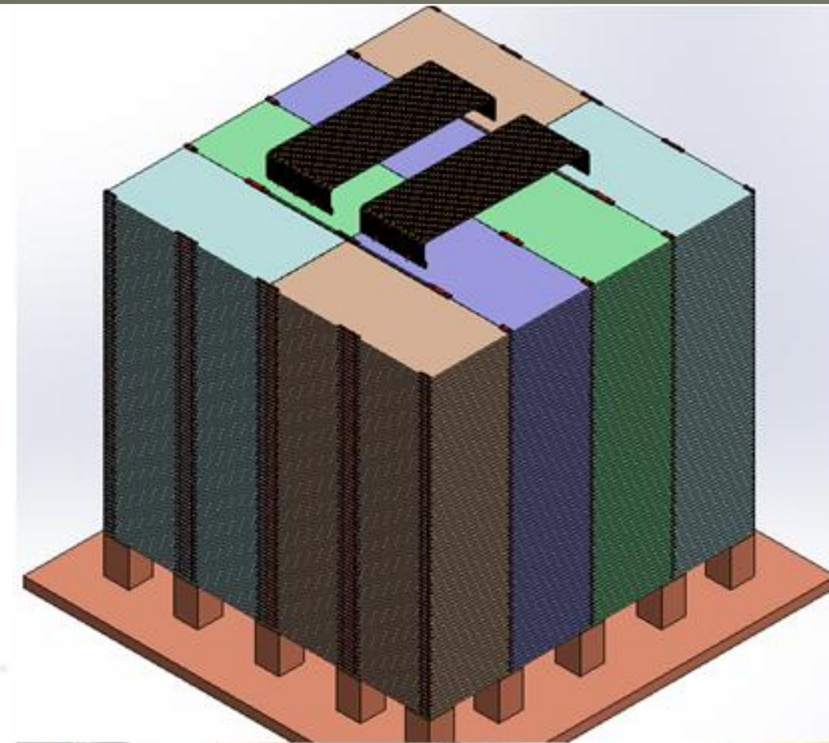


- Gas Mixing (On-line)
- Gas Recirculation
- Gas Purification system
- Control System (PLC)

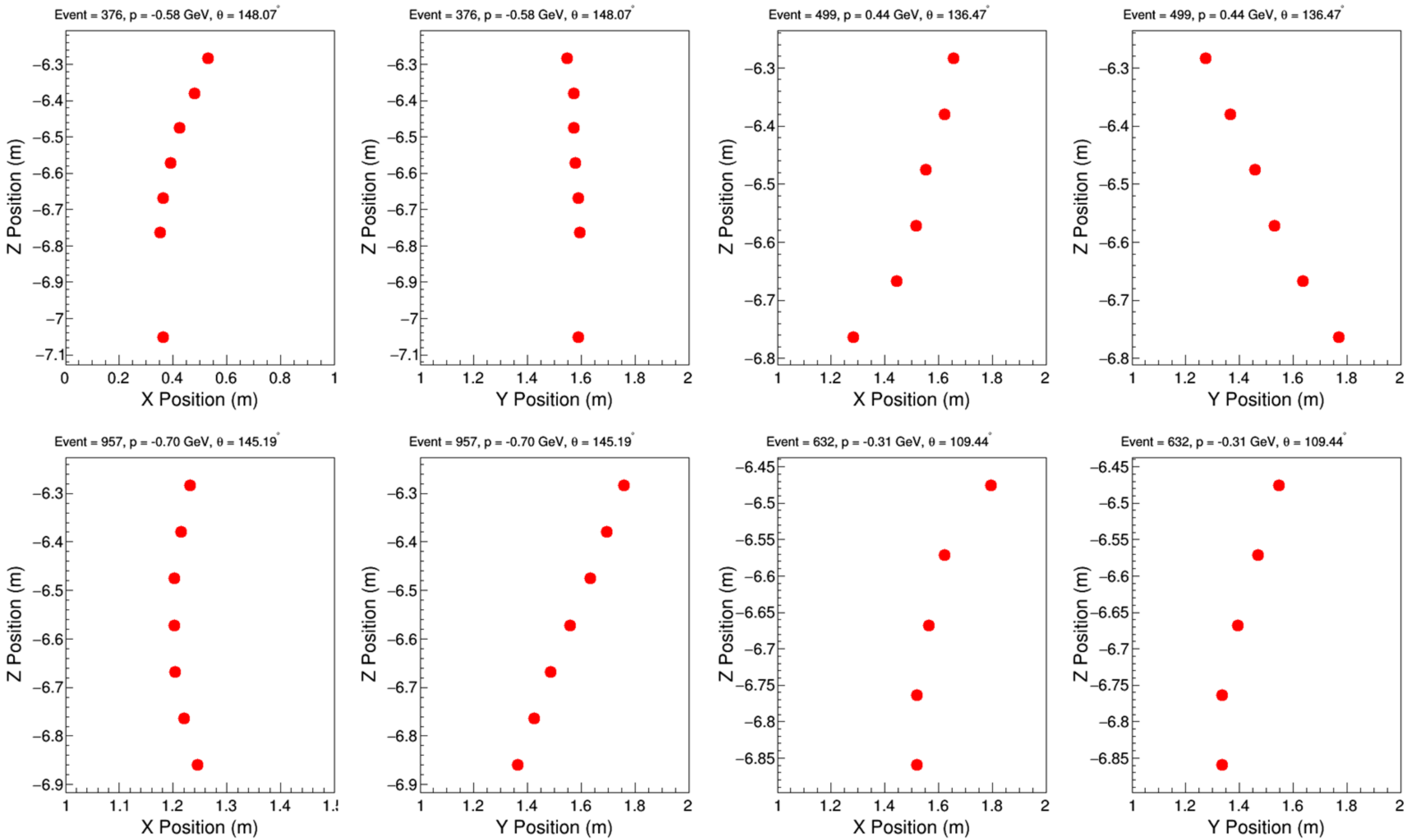
Development of Gas systems

ICAL detector holds about 200,000 litres of gas all the time.
Gas recycling system ensures that almost no gas is wasted.

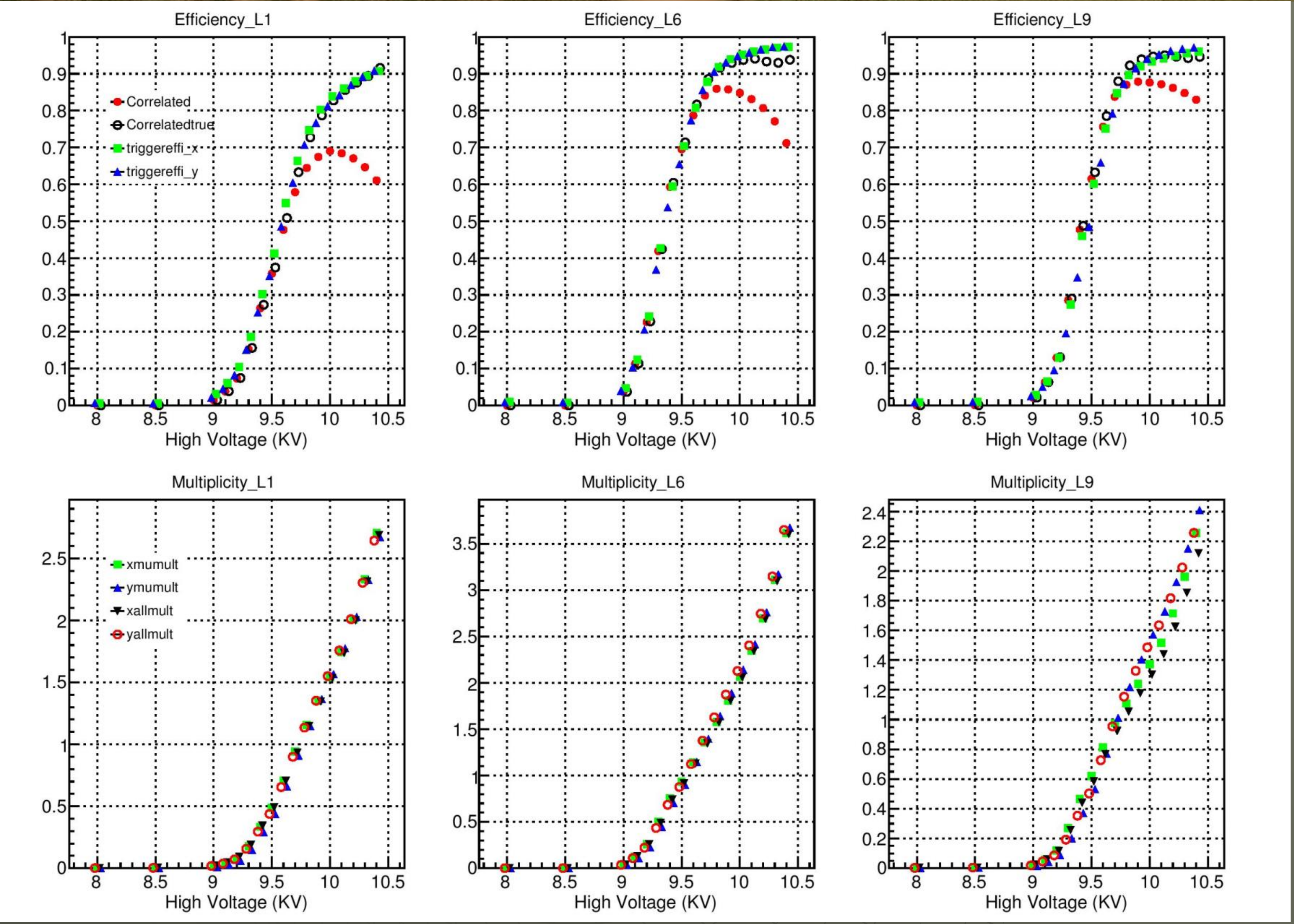
ICAL, e-ICAL and m-ICAL



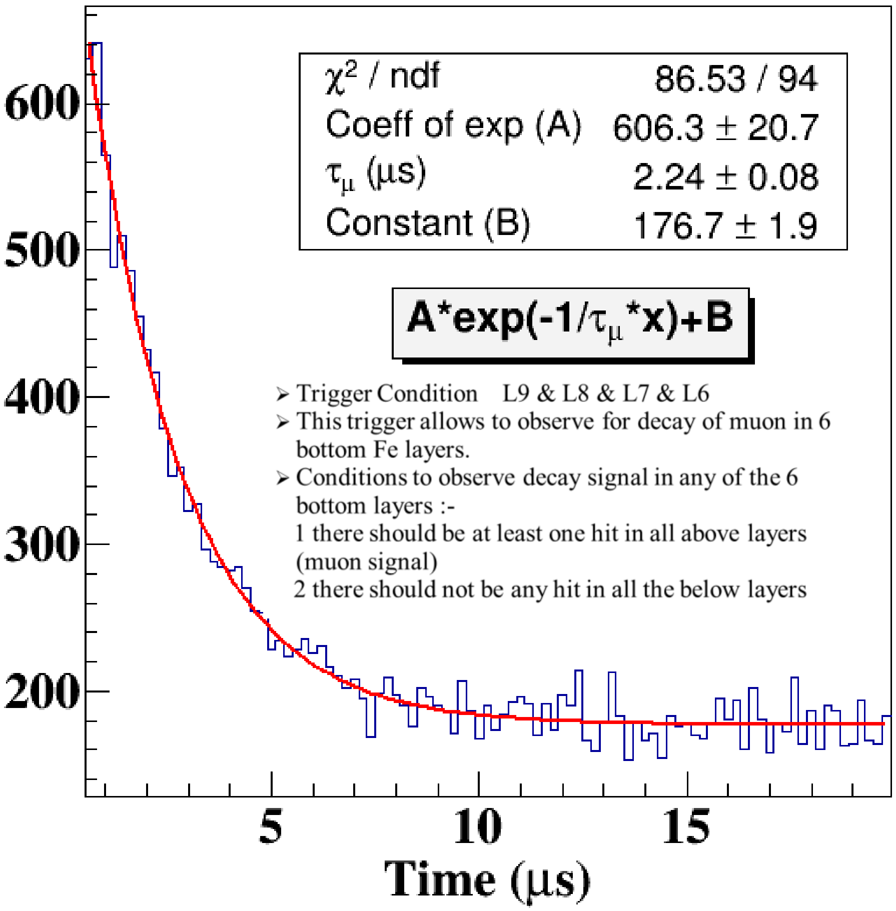
A collage of muon tracks in m-ICAL

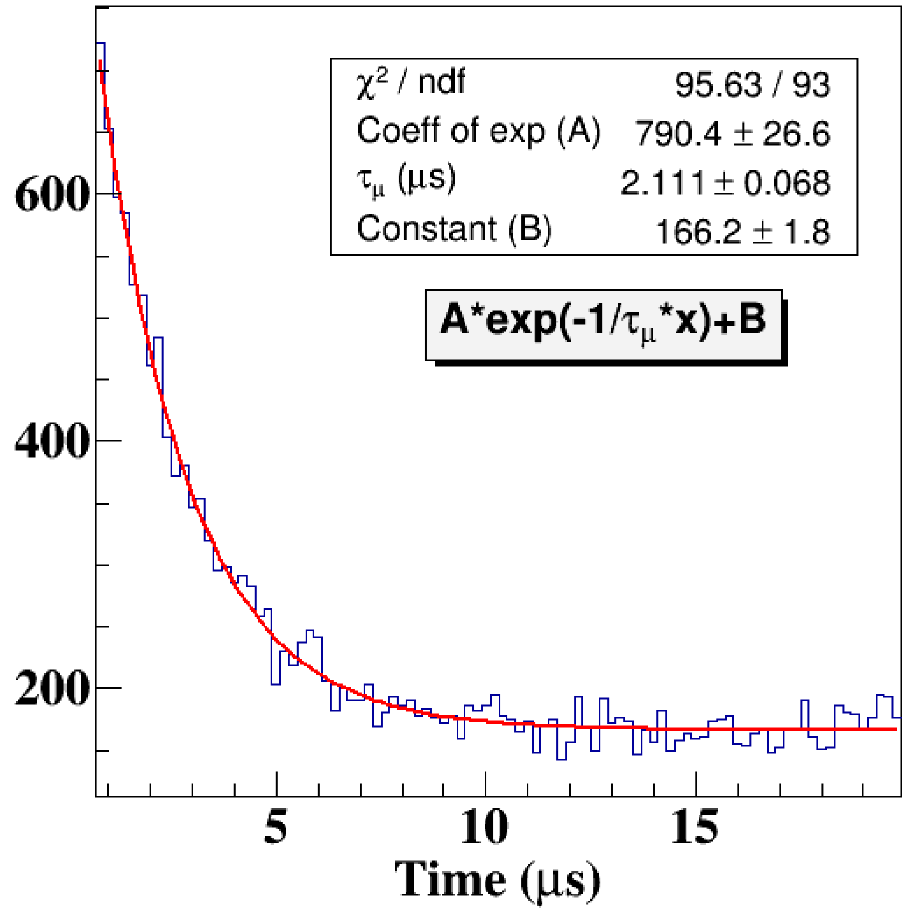


Fine tuning RPC operating conditions

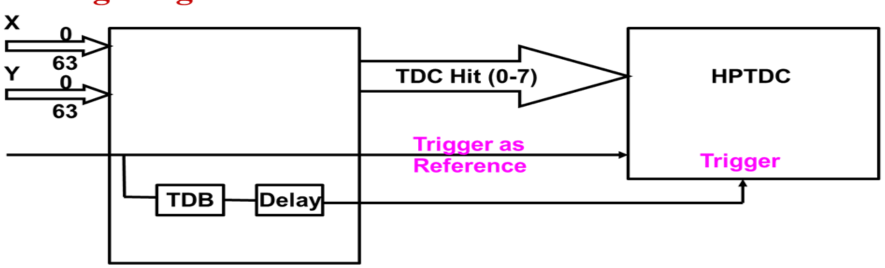


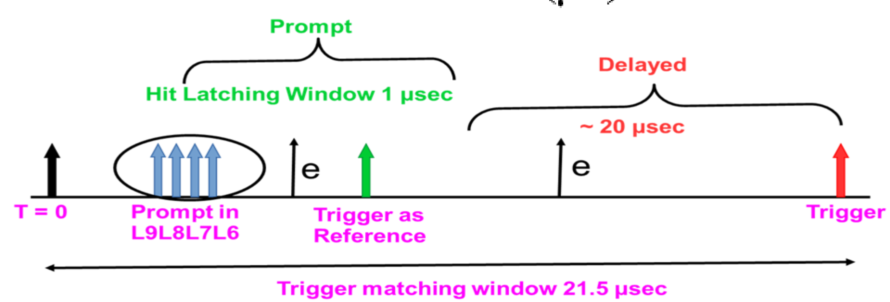
Muon life time measurement





Timing Diagram





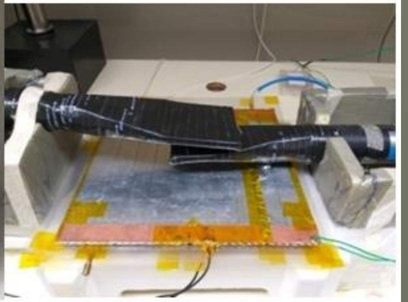
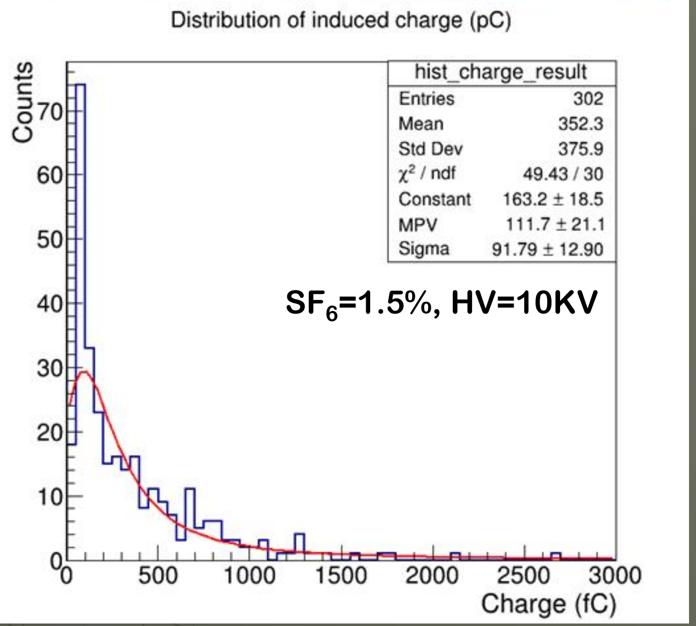
High rate (low gain) RPCs

- The rate handling capability (RC) of the RPC per unit voltage drop is given by:

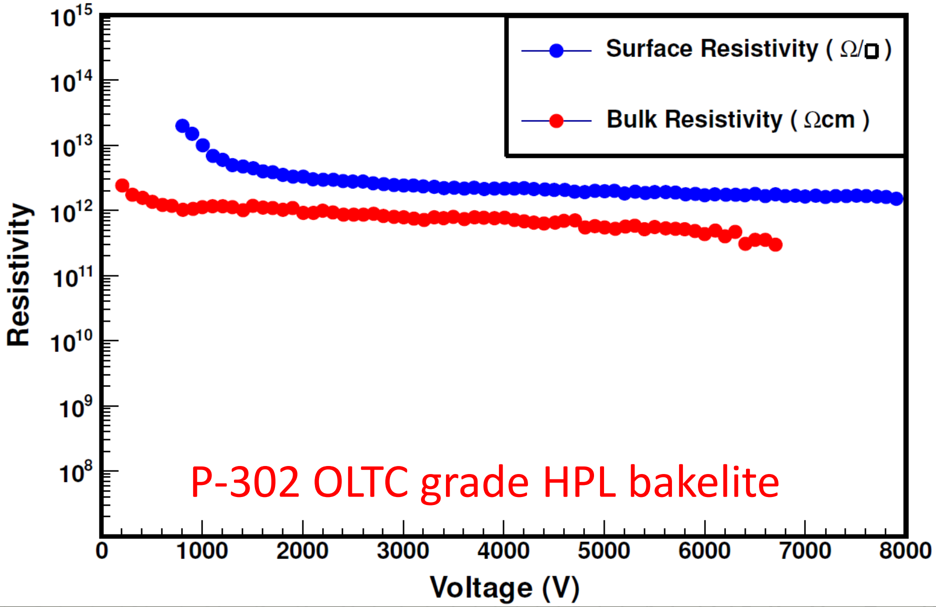
$$S = \frac{Qd}{\epsilon_0 V} \quad \ldots \quad \mathrm{RC} = \frac{1}{\rho t q_m}$$

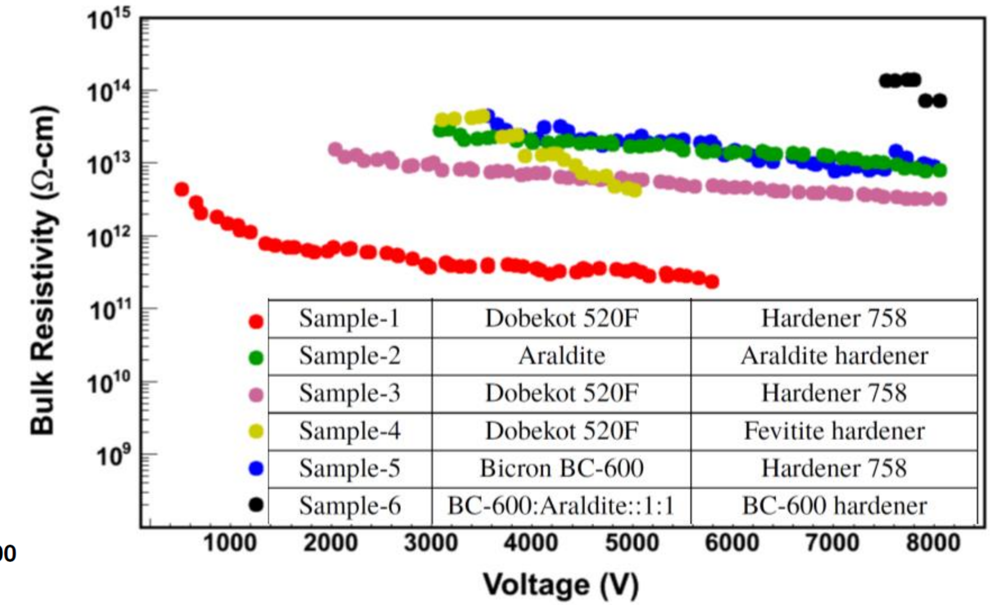
  where *S* is the dead area, *Q* is the total charge, d is gap thickness, ε_0 is the dielectric constant of the gas, *V* is the applied voltage, ρ is the electrode resistivity, *t* is the electrode thickness and q_m is the average charge produced per event.
- Next generation collider experiments like HL-LHC-ATLAS, HL-LHC-CMS and CBM-FAIR require detectors with rate capability of ~20KHz/cm^2.
- If q_m can be reduced to 50fC, rate capability can be increased to 25KHz/cm^2.
- Experimental and simulation studies on RPC are in progress using cosmic muons to optimize gas mixture, noise threshold, and applied voltage to achieve required rate capability with reasonable efficiency.

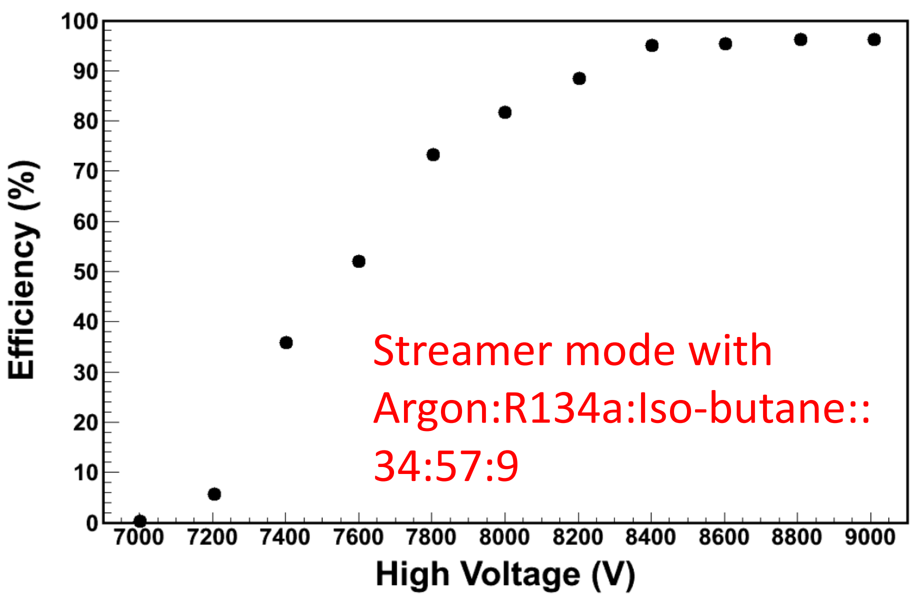


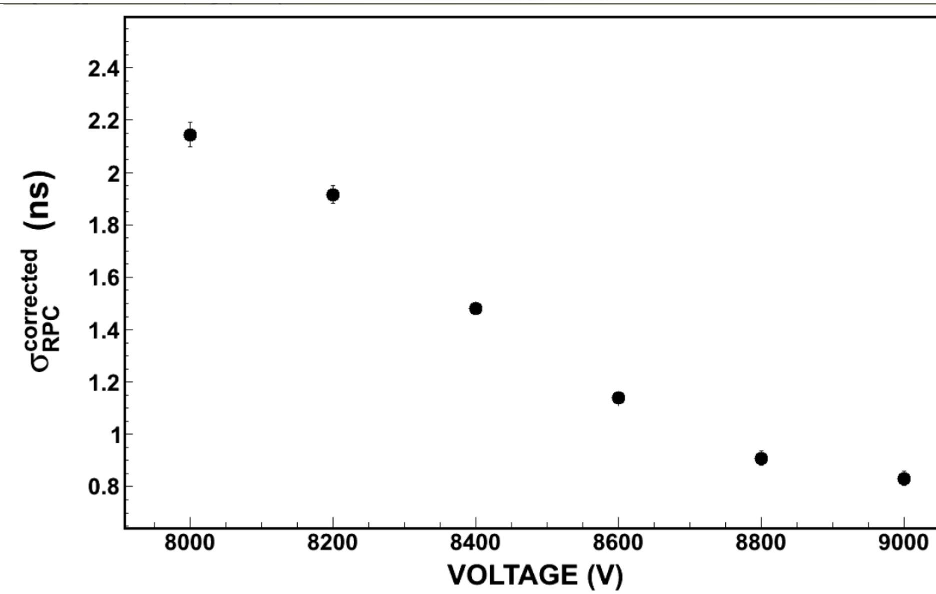



R&D with bakelite electrodes

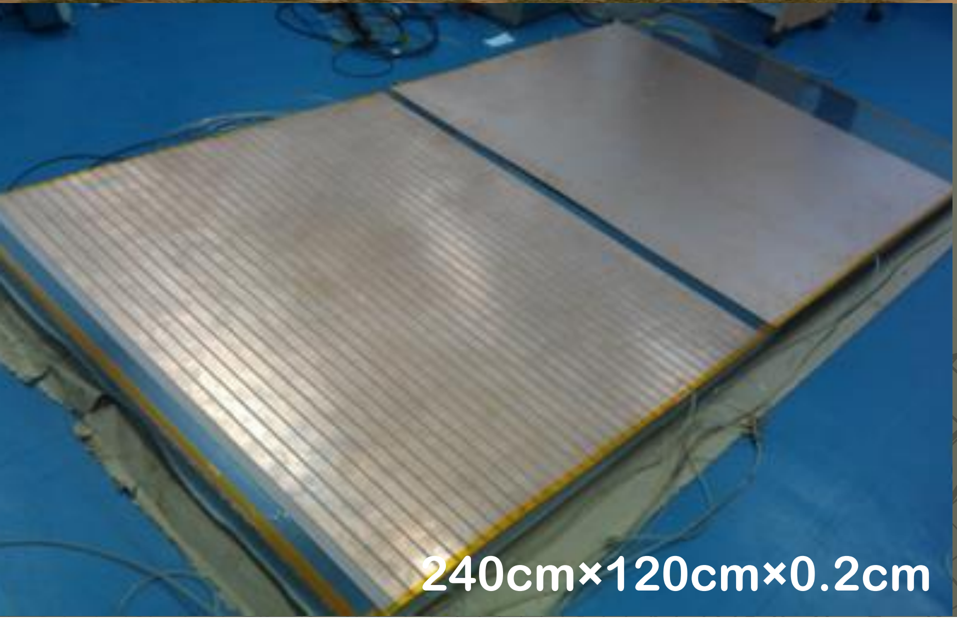


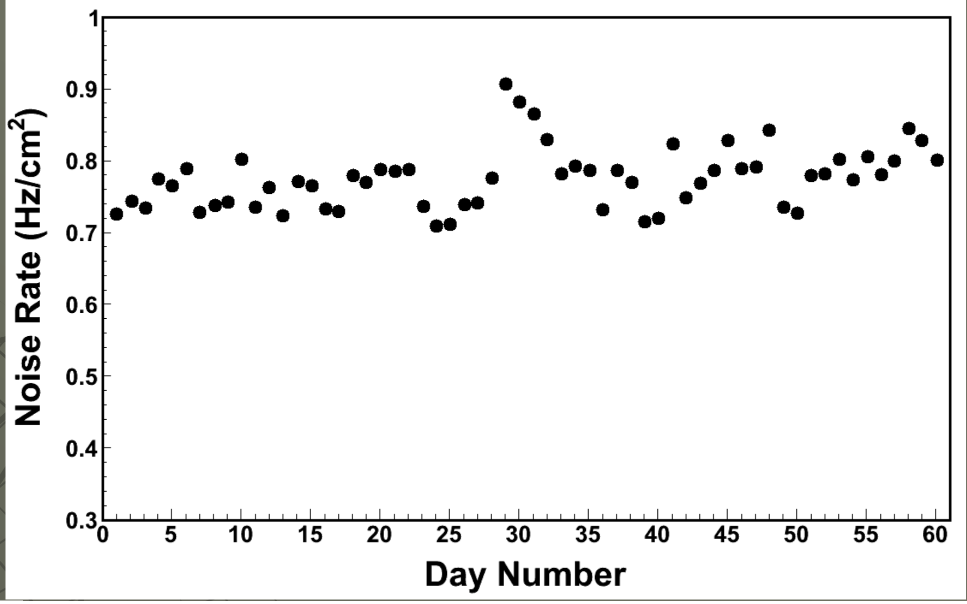


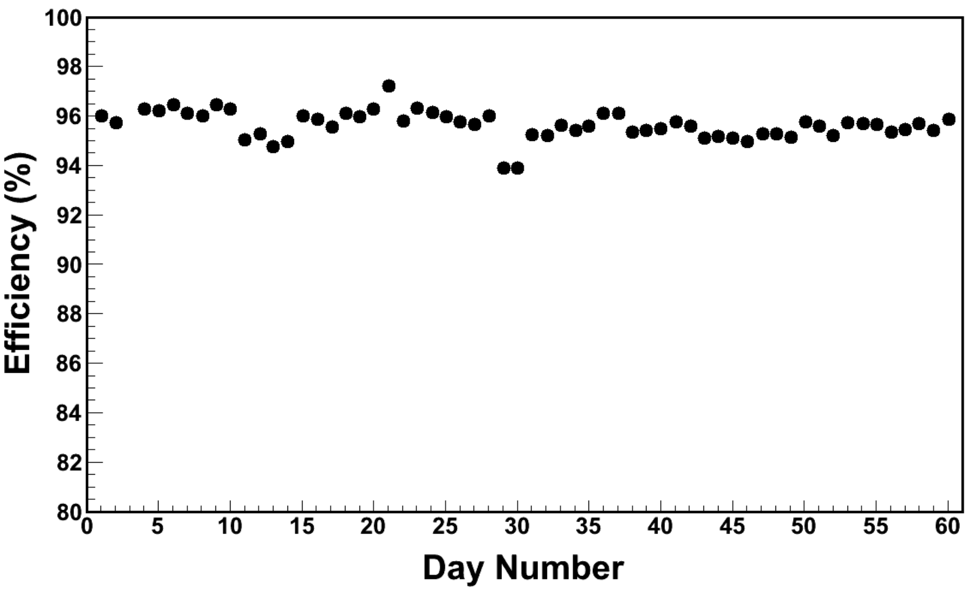


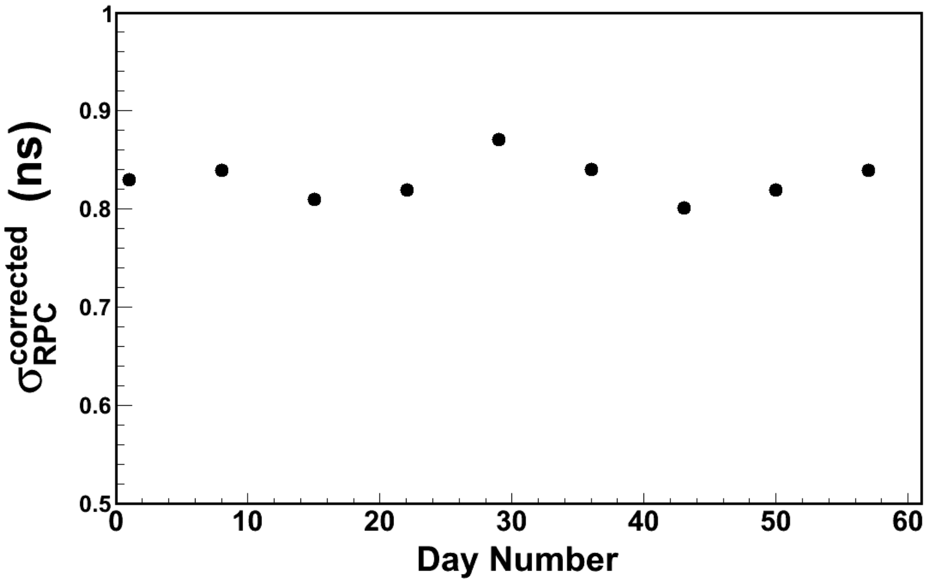


Long time operation of bakelite RPC

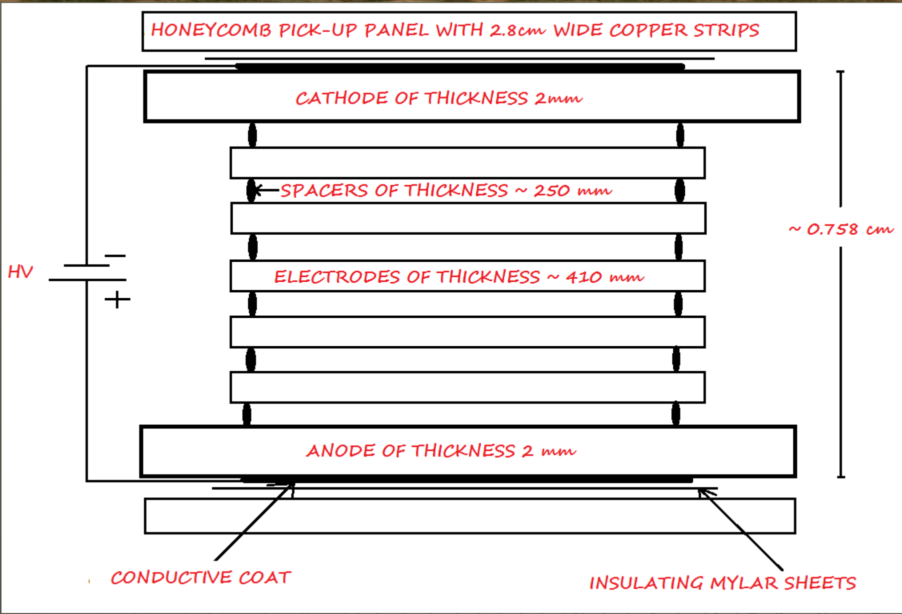


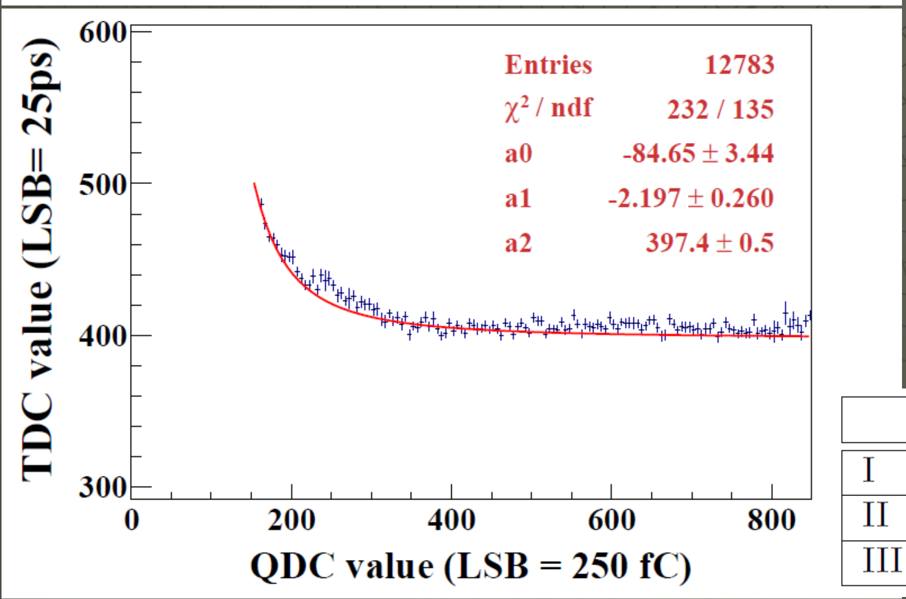


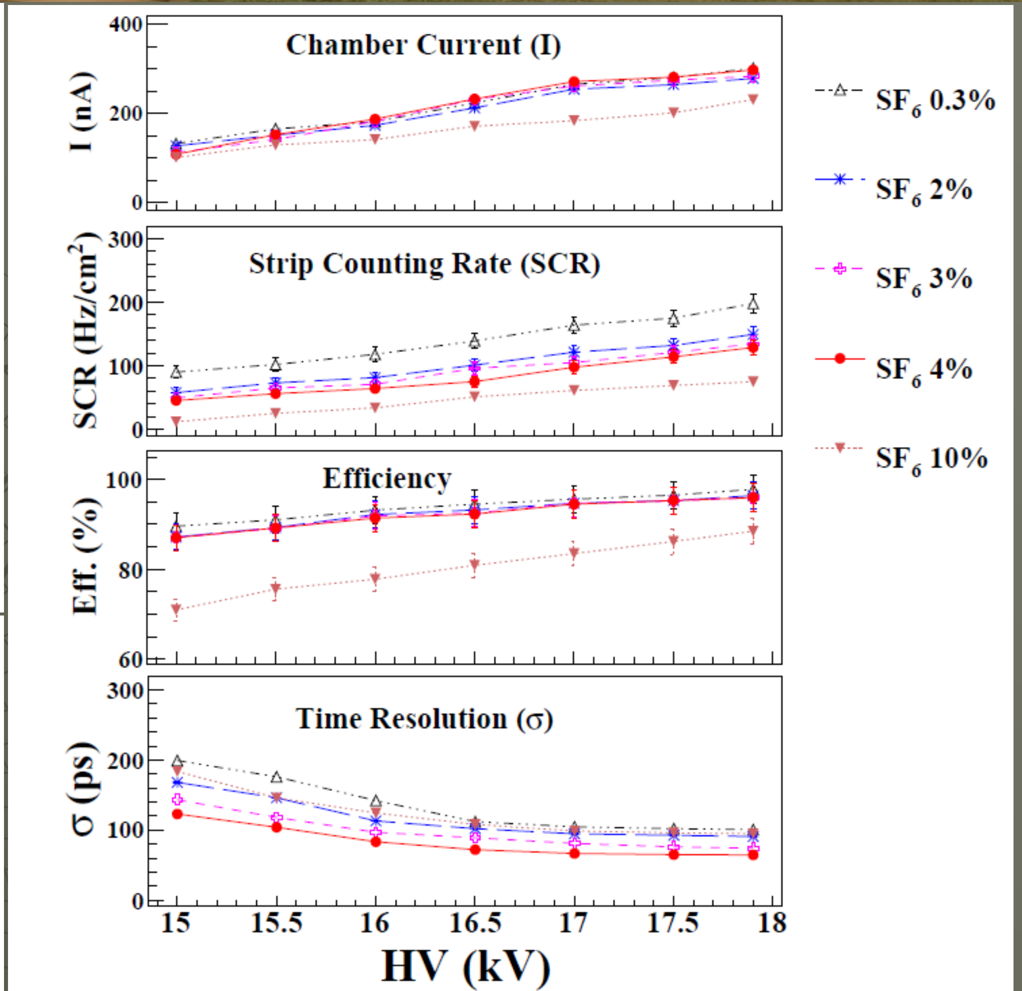




Multi-gap Resistive Plate Chamber

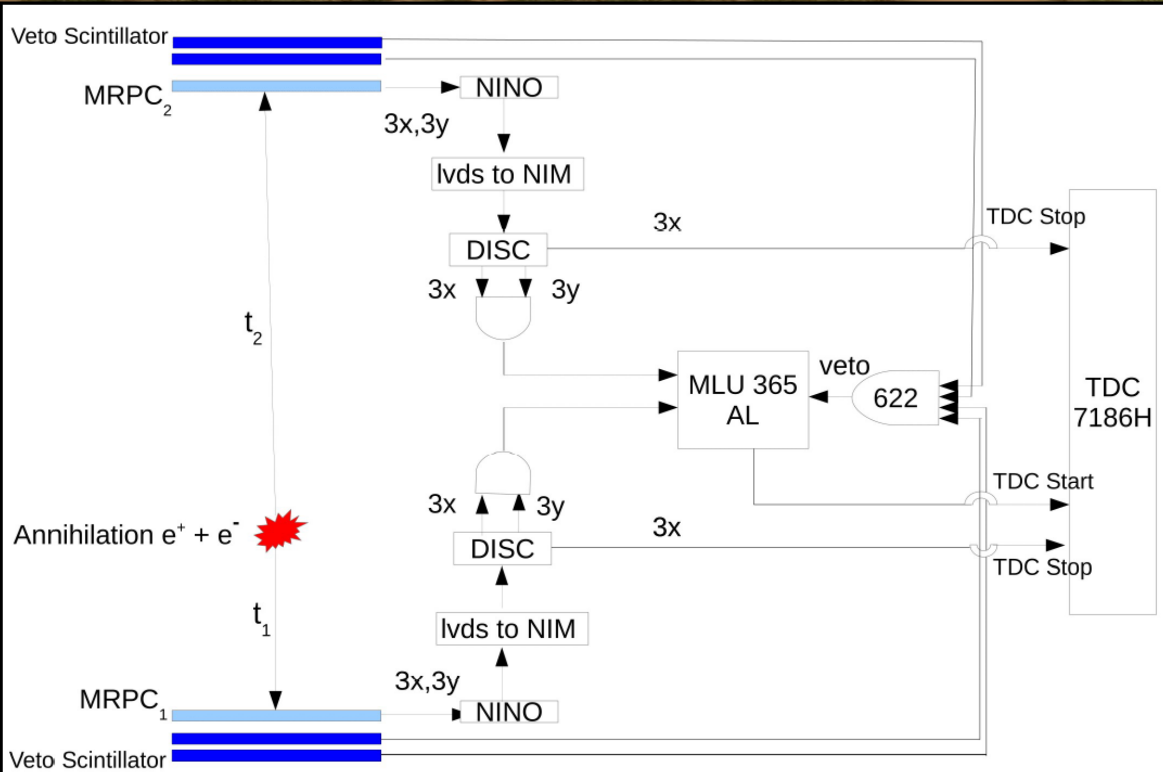


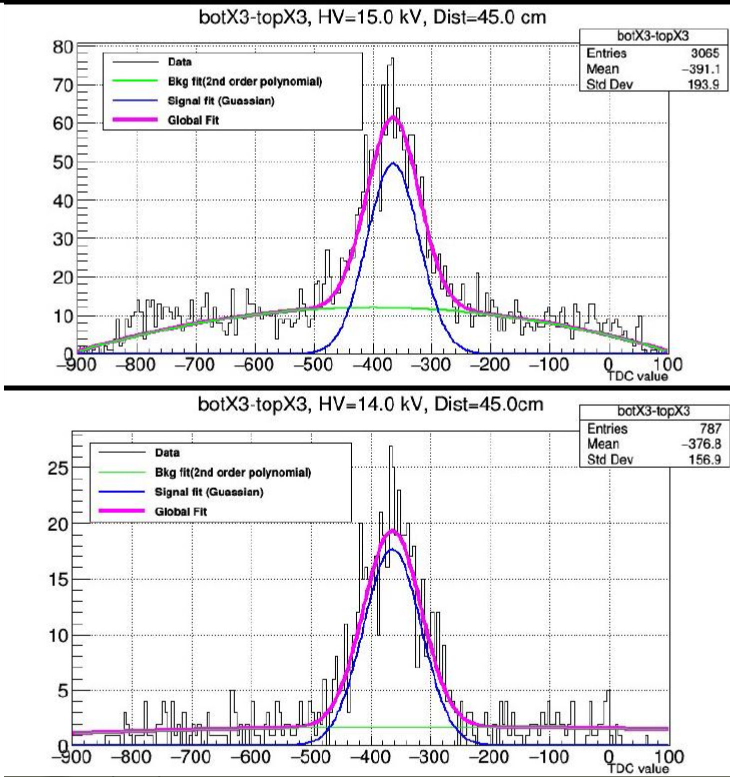


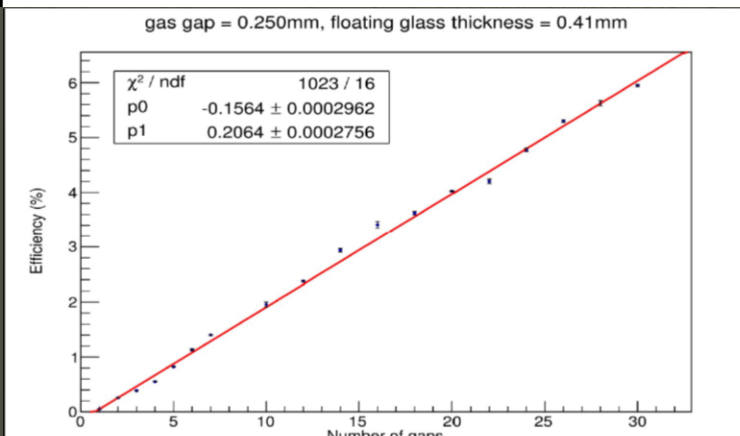


	Trigger	Eff.(%)	Time res.(ns)	Noise($\frac{Hz}{cm^2}$)	I(nA)
I	P1, P2	85	1.42	1.5	305
II	P1, P2, MRPC	85.9	0.87	2.85	312
III	P1, P2, MRPC	87.8	0.85	1.87	311

Feasibility of MRPC for PET







Distance b/w MRPCs	Source at bottom MRPC Δt_1	Source at top MRPC Δt_2	diff=$\lvert\Delta t_1 - \Delta t_2\rvert/2$	Time of flight(TOF) = diff x 25 ps	Actual TOF
30 cm	Mean= -335.8 ± 2.1 Sigma= 54.76 ± 2.4	Mean=-248.4 ± 2.8 Sigma=82.13 ± 3.5	43.7 ± 2.4	1.09 ± 0.06 ns	1.0 ns
45 cm	Mean= -369.4 ± 2.3 Sigma= 61.57 ± 2.7	Mean=-256.8 ± 2.1 Sigma=59.56 ± 2.1	56.3 ± 2.2	1.41 ± 0.05 ns	1.5 ns
60 cm	Mean=-385.8 ± 2.8 Sigma=63.36 ± 3.6	Mean=-223.5 ± 2.4 Sigma= -53.2 ± 2.4	81.2 ± 2.6	2.03 ± 0.07 ns	2.0 ns
75 cm	Mean=-404.9 ± 3.0 Sigma=77.72 ± 4.5	Mean=-204.0 ± 2.7 Sigma=63.85 ± 3.6	100.5 ± 2.8	2.51 ± 0.07 ns	2.5 ns

Stay tuned for …

- High quality, but low cost RPC detector production by industries for e-ICAL and ICAL.
- Alternate gas mixtures for RPCs
- 3D simulation of multi-component, viscous gas flow through RPC
- Pixel readout techniques for RPCs
- Neural networks and machine learning techniques for efficient track reconstruction
- Muon tomography and cargo scanners
- Prototypes of MRPC based PET devices
- RPC detector technologies for contributing to accelerator and other futuristic experiments

For more details …

- Effect of the surface resistivity of electrode coating on the space dispersion of induced charge in Resistive Plate Chambers (Shamsul Haque Thoker et al)
- Study of Multigap Resistive Plate Chambers as a potential candidate for development of a PET device (M. Nizam et al)
- A portable Cosmic Muon Tracker using Resistive Plate Chambers (RPCs) for outreach activities (Yuvaraj E. et al)
- Manufacturing, installation commissioning of mini-ICAL magnet: INO project (S. P. Prabhakar et al)
- Mini-ICAL, INO Project: Magnetic field simulation & development of magnetic measurement set up (N. S. Dalal et al)
- Design and assembly of water-cooled coil for prototype mini ICAL magnet at Madurai for INO project (S. K. Thakur et al)
- Electronics and DAQ for the magnetized mini-ICAL detector at IICHEP (Mandar Saraf et al)
- Trigger generation system architecture for INO mini-ICAL system (Shib Shankar Sikder et al)
- RPC and CLS for mini-ICAL detector - Ravindra (R. Shinde et al)
- Optical Communication for RPCDAQ (Abinaya et al)
- RPC-DAQ V3 module for INO's ICAL detector (Abinaya et al)
- A multi-hit TDC for INO experiment (Chithra et al)
- Database management system for RPC production QC (Pavan Kumar Vengala et al)
- μSR with mini-ICAL (Neha Panchal et al)
- Measurement of azimuthal dependence of Cosmic ray muon flux using 2m x 2m RPC stack at IICHEP Madurai (Pethuraj S et al)
- Muon multiplicity in 2m x 2m RPC and comparison with Corsika simulation (Suryanarayan Mondal et al)
- Update on muon reconstruction for INO-ICAL (A.D.Bhatt et al)
- Muon momentum spectra with mini-ICAL (A.D.Bhatt et al)
- Reconstruction of muon track in presence of noise in ICAL (Moon Moon Devi et al)
- Studies on deep learning technique for track reconstruction for INO (Deepak Samuel et al)
- Simulation studies for a shallow depth ICAL and planned cosmic muon veto detector for mini-ICAL (Neha Panchal et al)