Design and Simulation Studies of Resistive Plate Chambers

(Ph.D Progress Seminar)

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Plan of the this presentation

- Introduction
- Review of our earlier work
- Long term stability tests of INO RPCs
- Characterisation of electrode glass samples
- Development of 16-channel gas system
- Tracking of cosmic ray muons using small size RPCs
- Development and study of electrode coatings
- RPC materials and assembly procedures' development
- Construction of INO prototype detector
- Future work plan
- Presentations and papers
- Acknowledgements

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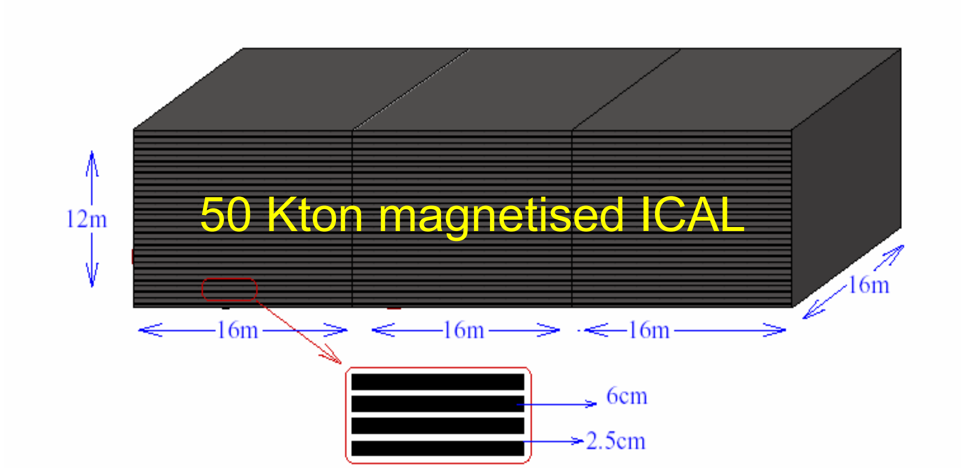
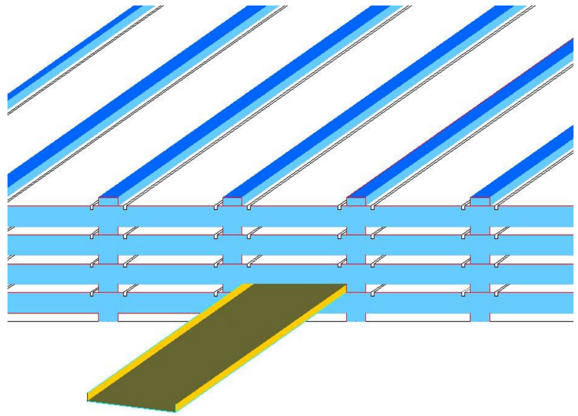
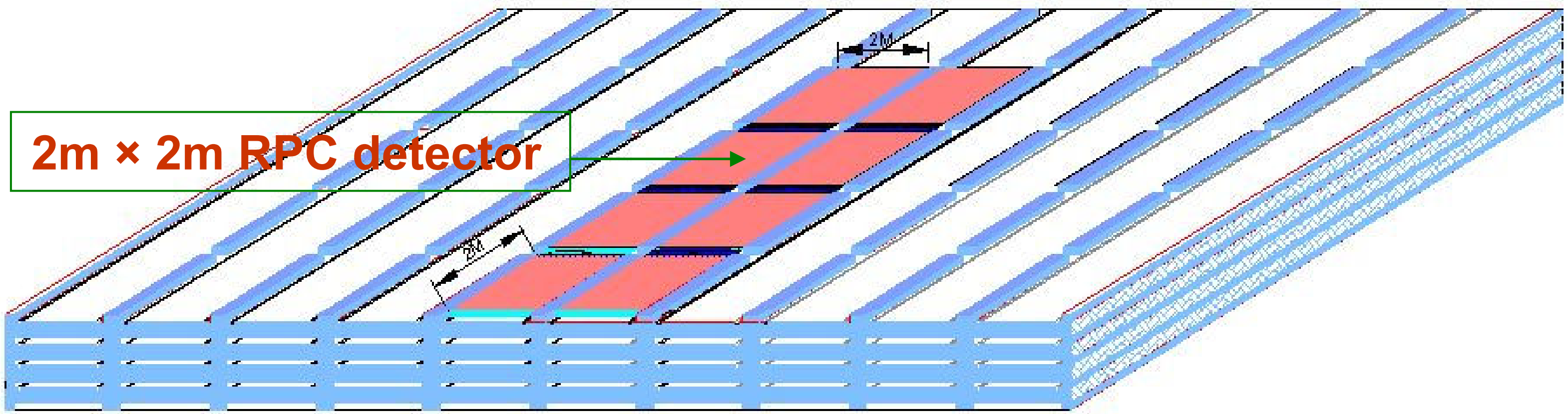
INO detector concept



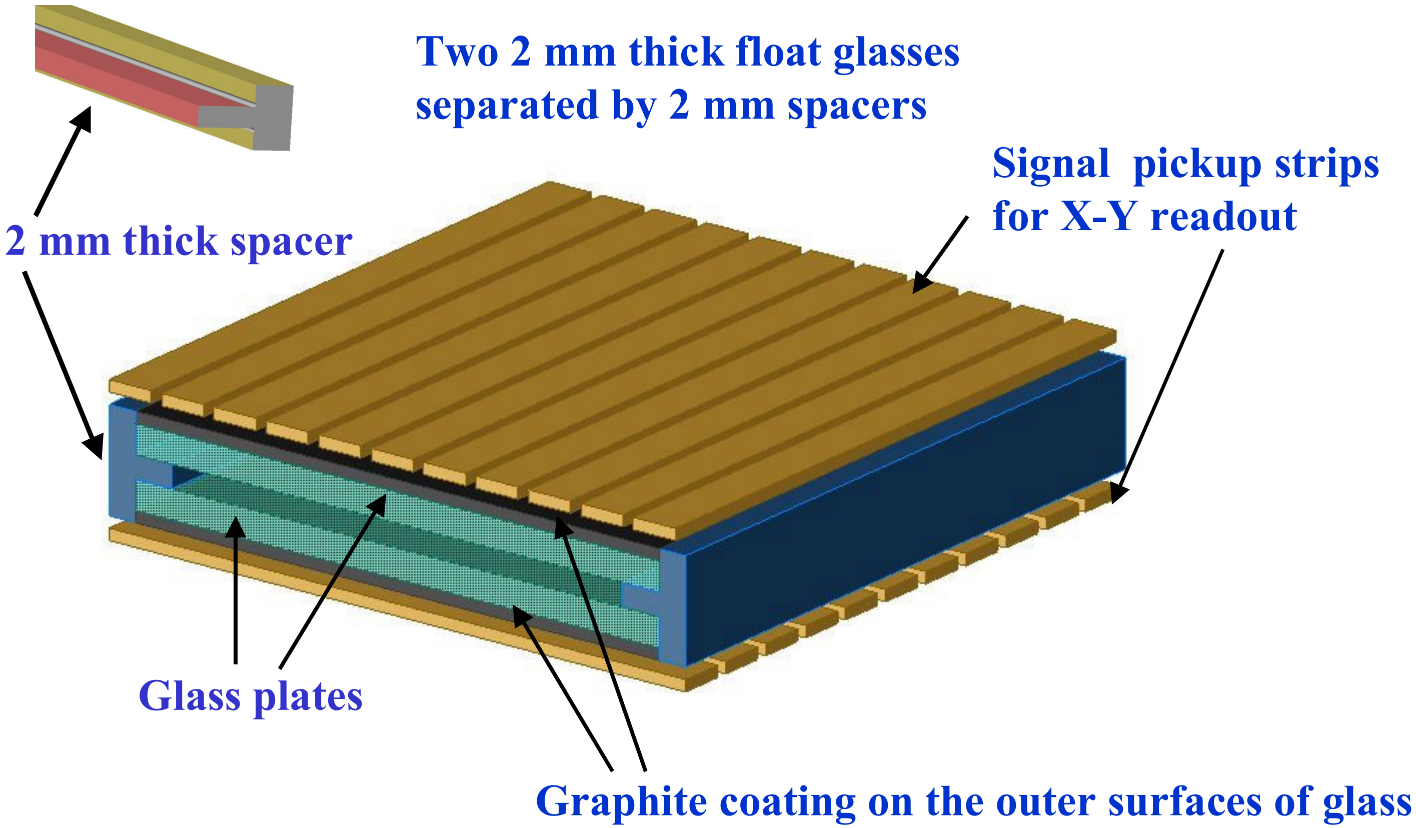




INO detector specifications

No. of modules	3
Module dimension	16 m X 16 m X 12 m
Detector dimension	48 m X 16 m X 12 m
No. of layers	140
Iron plate thickness	6 cm
Gap for RPC trays	2.5 cm
Magnetic field	1.3 Tesla
RPC unit dimension	2 m X 2 m
Readout strip width	3 cm
No. of RPCs/Road/Layer	8
No. of Roads/Layer/Module	8
No. of RPC units/Layer	192
No. of RPC units	27000
No. of Electronic channels	3.6×10^6

A typical RPC construction



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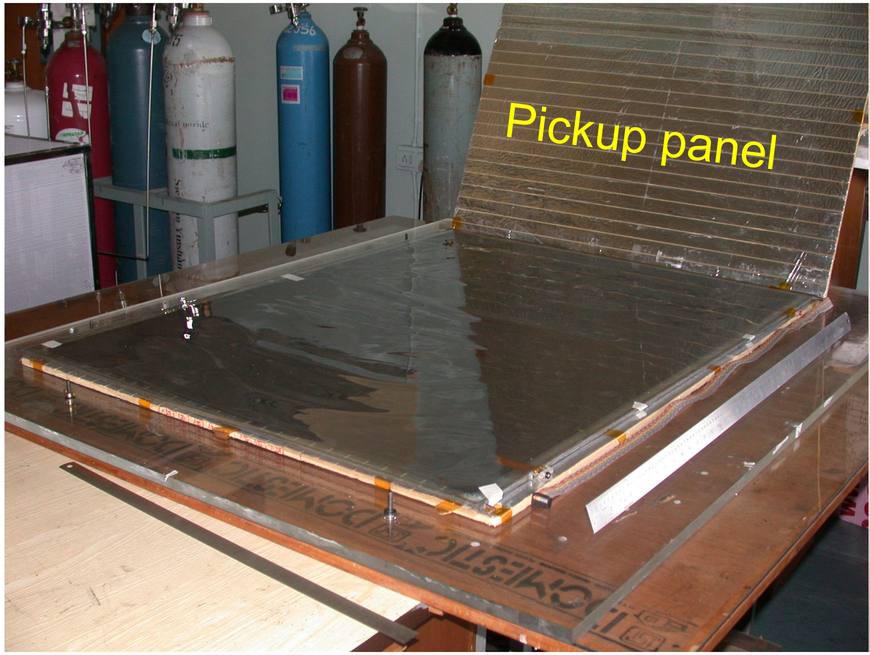
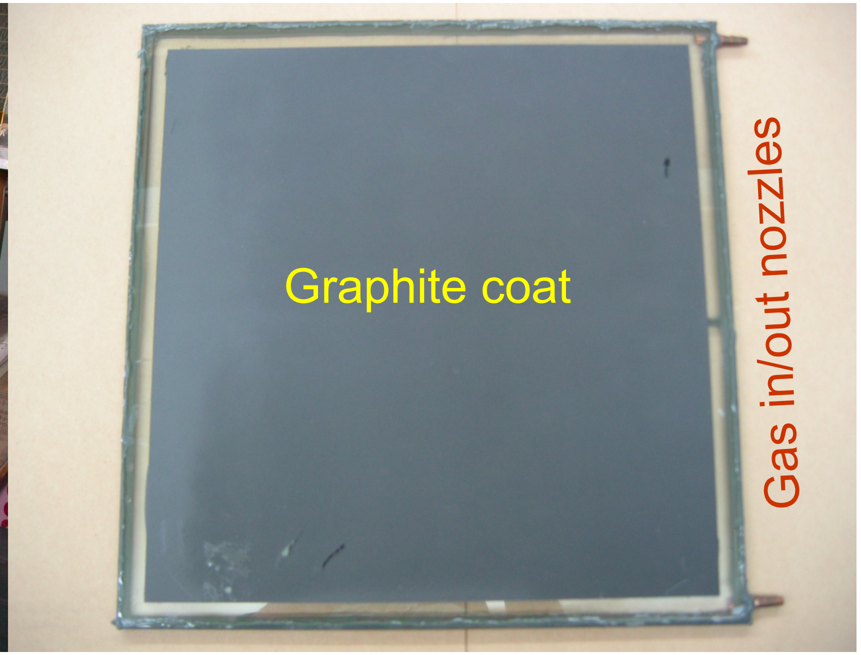
INO prototype RPCs



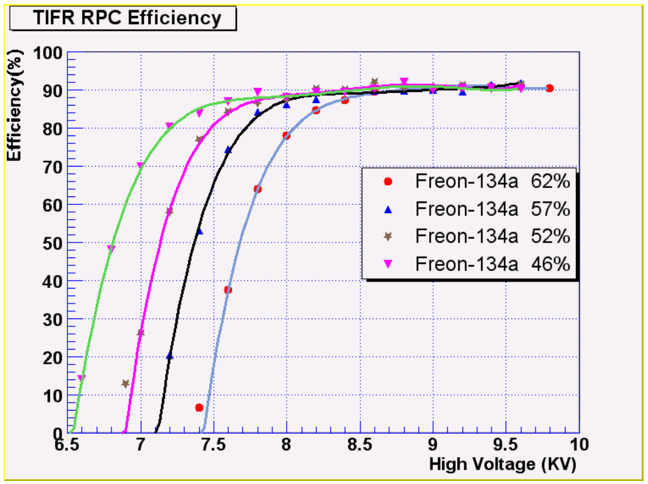


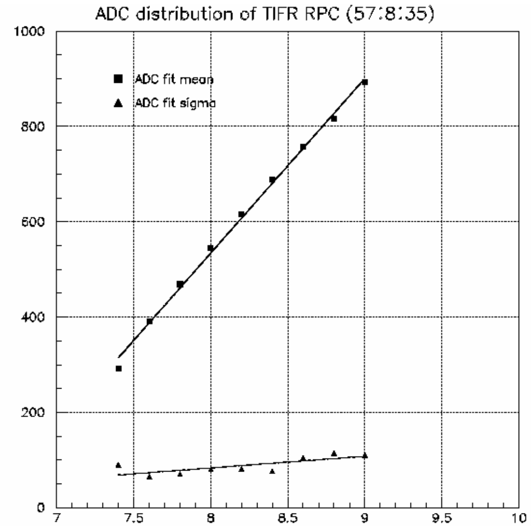
1200 X 900 mm

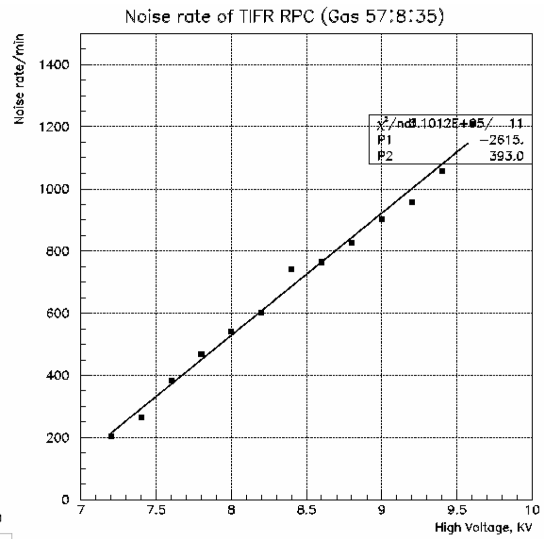
400 X 300 mm

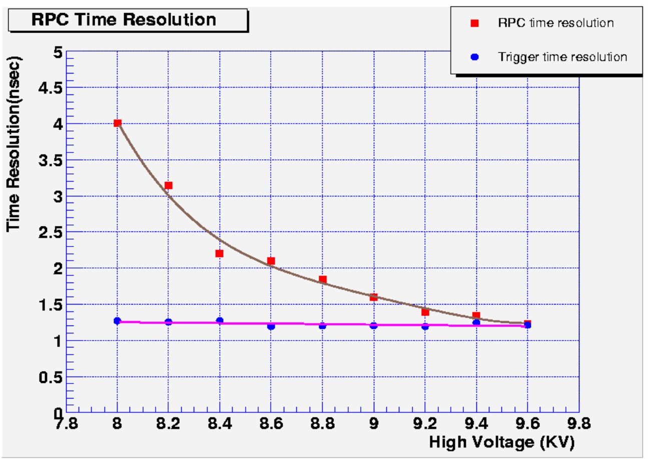
- 2mm thick local float glass
- 2mm single gas gap using Noryl spacers

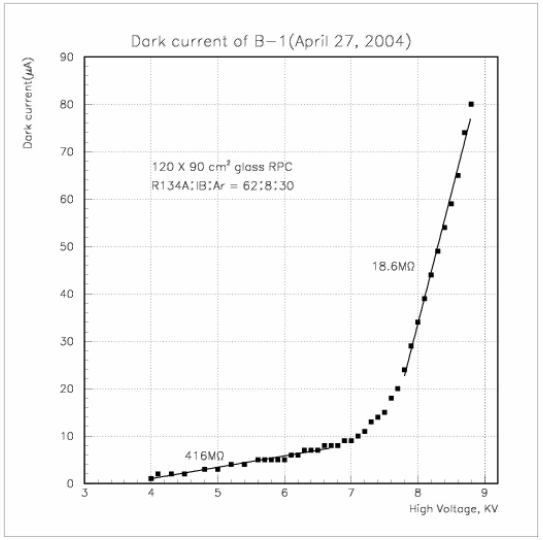
A few of our earlier results

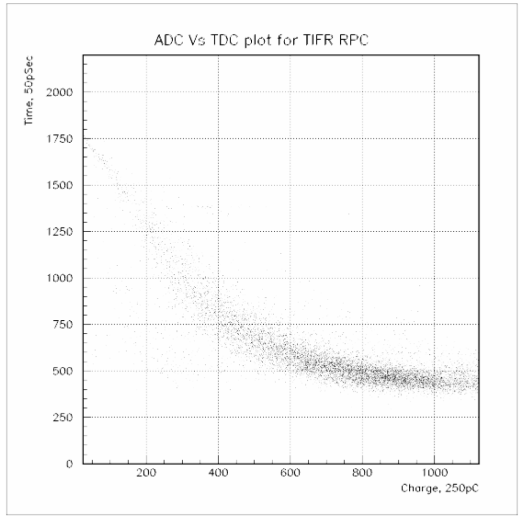




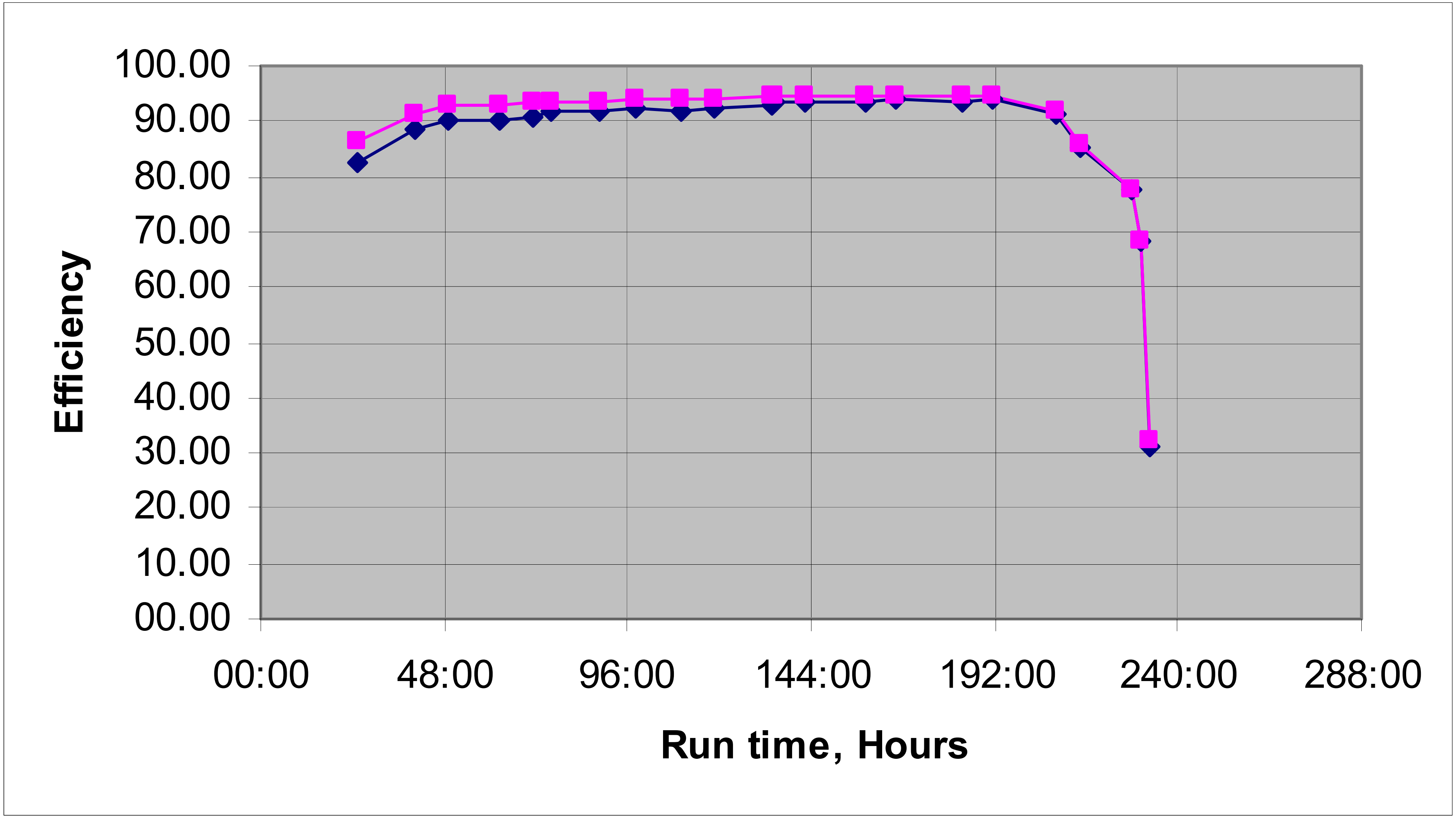








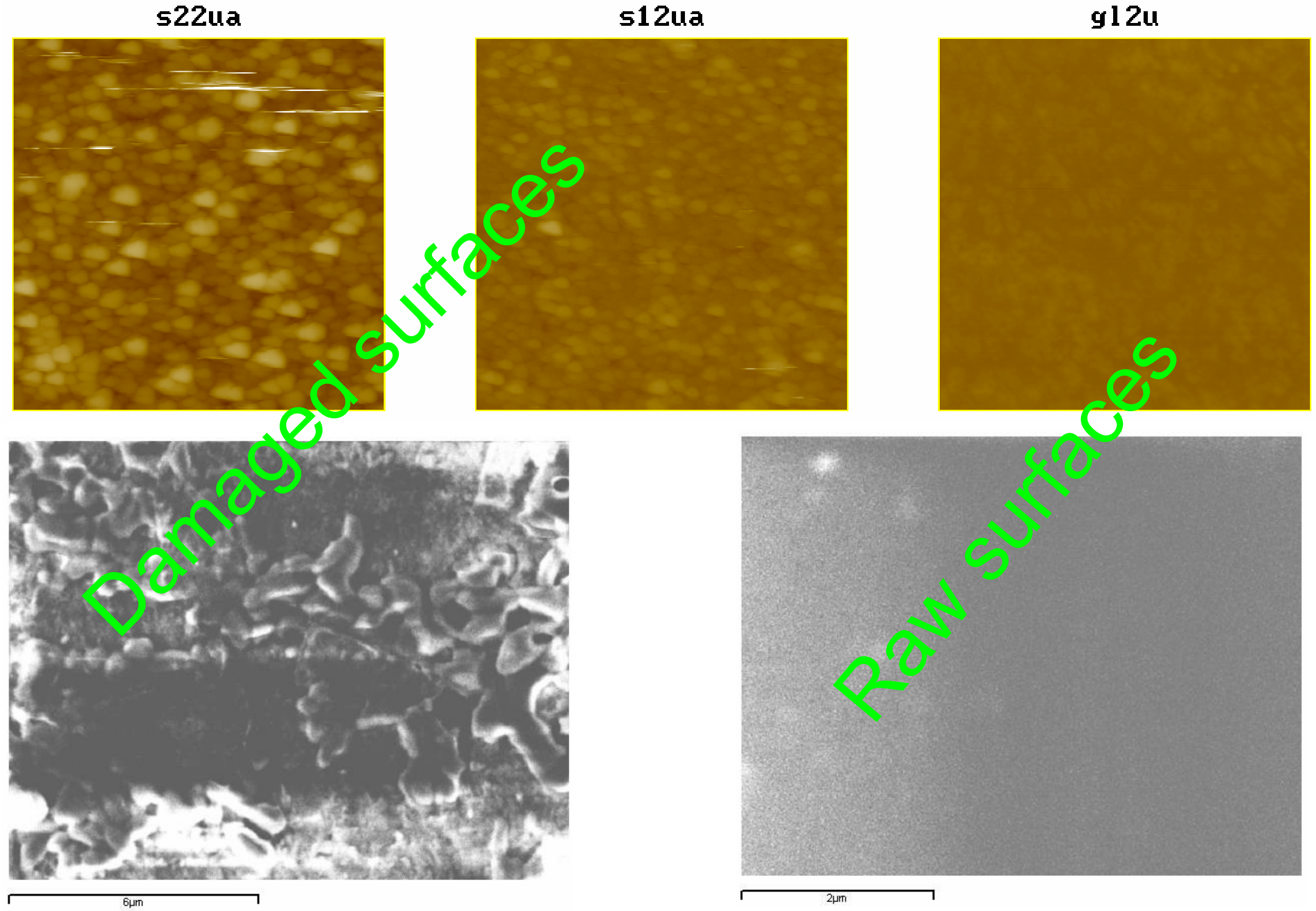
Efficiency drop of an aging RPC detector



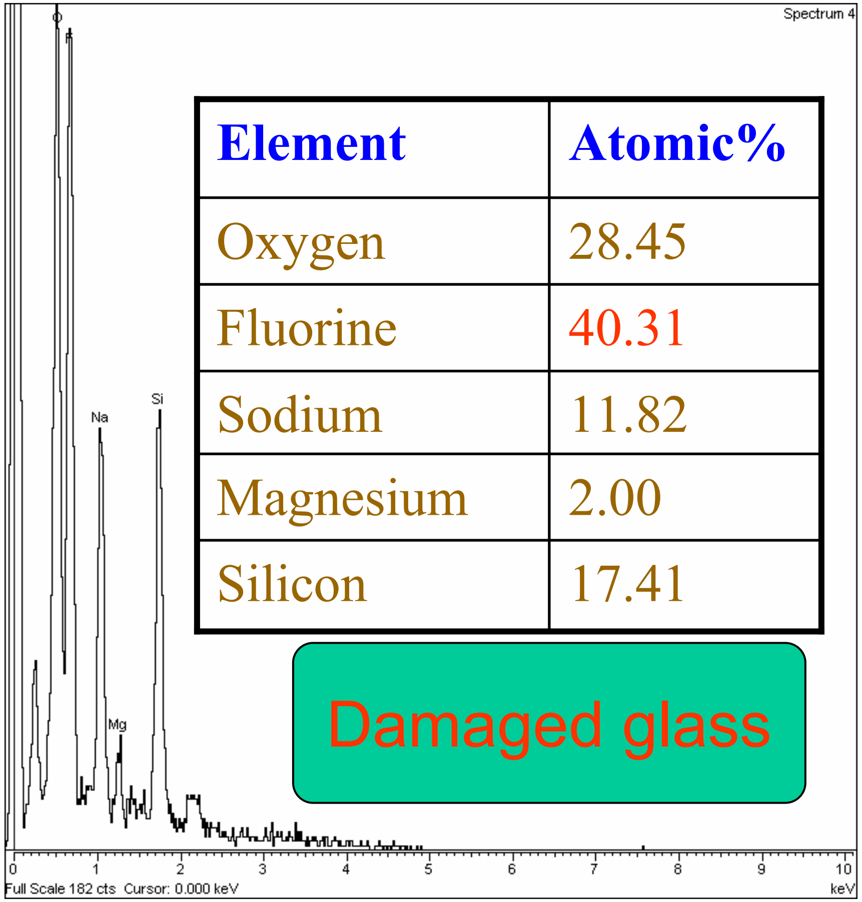
AFM & SEM scans of electrode surfaces

AFM

SEM

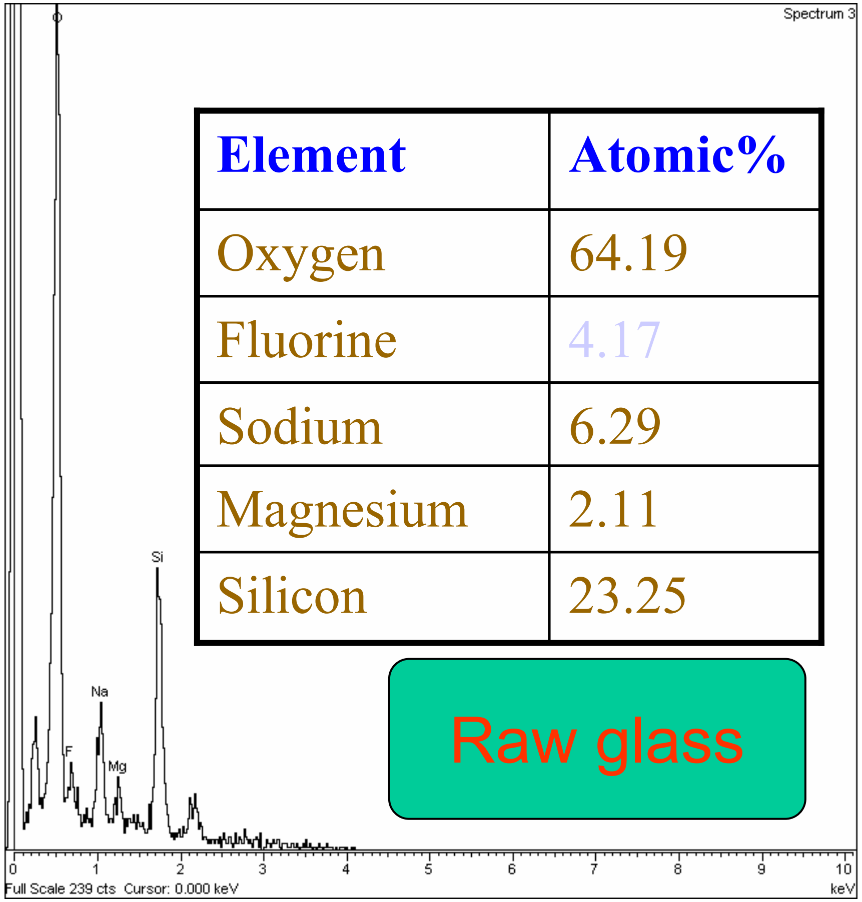


Element analysis glass samples



Element	Atomic%
Oxygen	28.45
Fluorine	40.31
Sodium	11.82
Magnesium	2.00
Silicon	17.41

Damaged glass



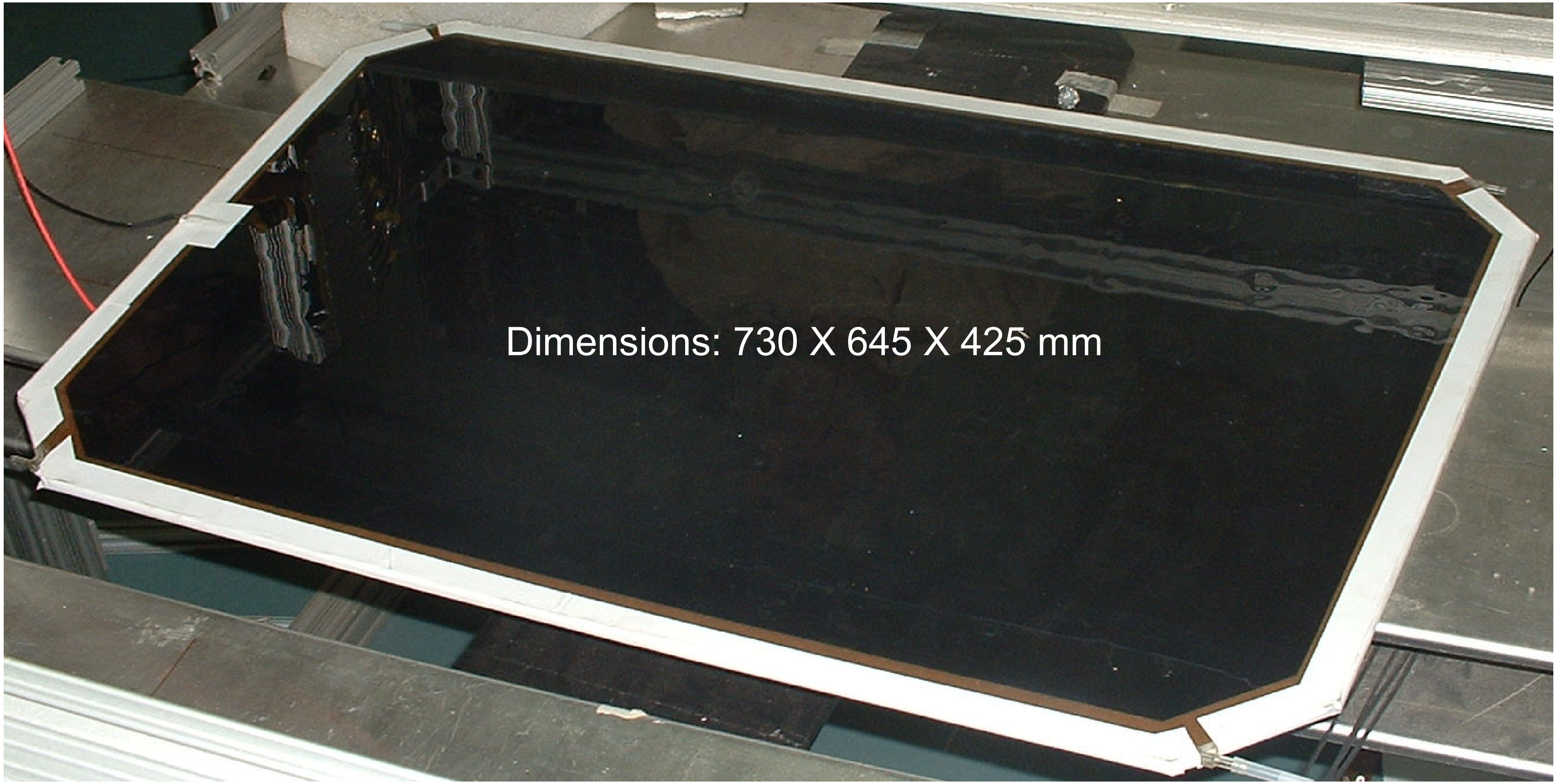
Element	Atomic%
Oxygen	64.19
Fluorine	4.17
Sodium	6.29
Magnesium	2.11
Silicon	23.25

Raw glass

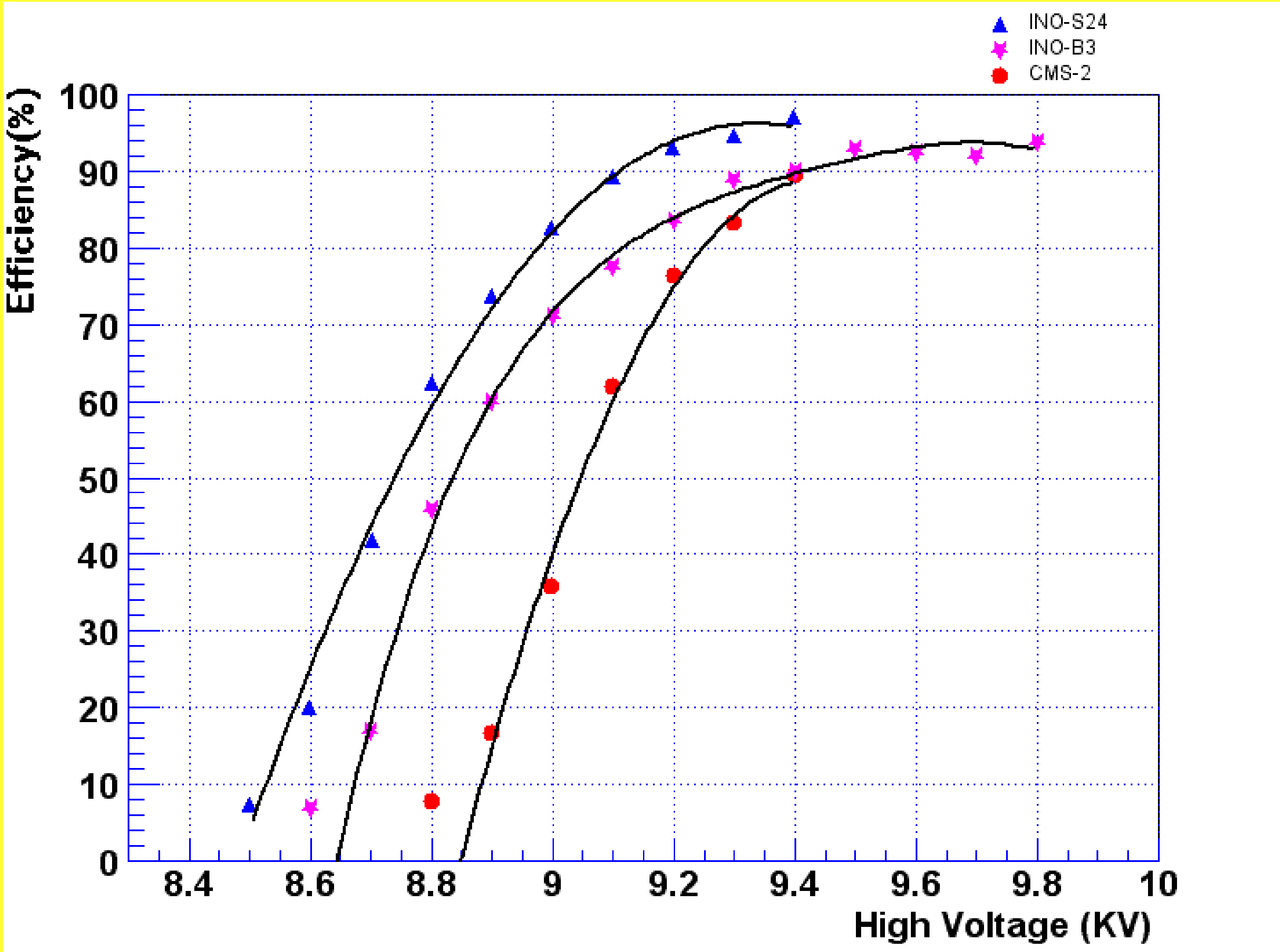
One possible reason for aging

- The RPCs make large use of electronegative gases to control and limit the discharge process. Fluorine compound gases such as $C_2H_2F_4$ and SF_6 were introduced for their effectiveness and industrial common use.
- The decomposition of such a gases under electrical discharge produces a significant concentration of fluoride radicals that can be detected in the RPC exhausted gas.
- The fluoride radicals may easily produce HF. Due to its high chemical reactivity, this represents a possible cause of the inner surface damaging if it is not quickly removed by the gas flow.
  - HF film on inner electrode surface increases ohmic current.
  - HF is an aggressive acid. It can harm the inner surface, finding the eventual weak points of the oil protective coating.
  - The effect is self sustaining HF damage → rate increase → more HF
- Systematic measurements of this process can help to understand many ageing processes and can be also a new probe to investigate the discharge phenomena.

CMS RE bakelite RPC



Comparative study of INO & CMS RPCs



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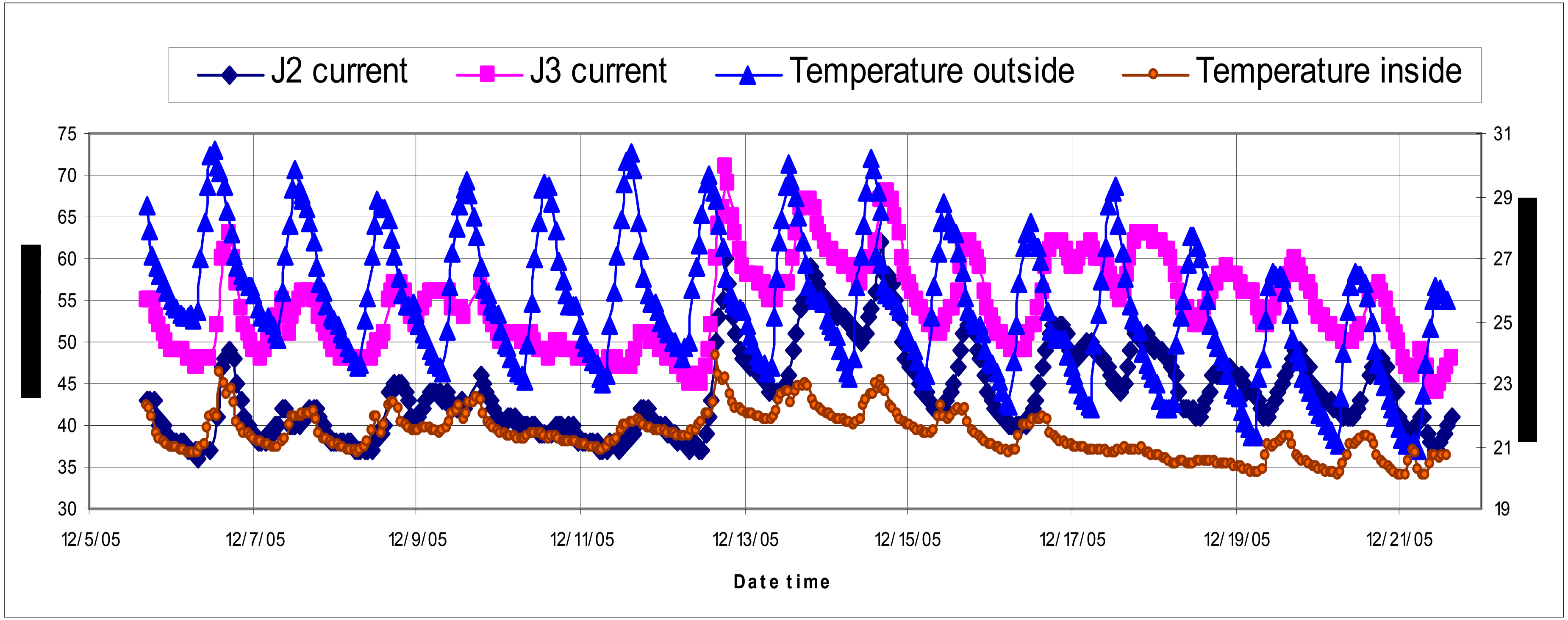
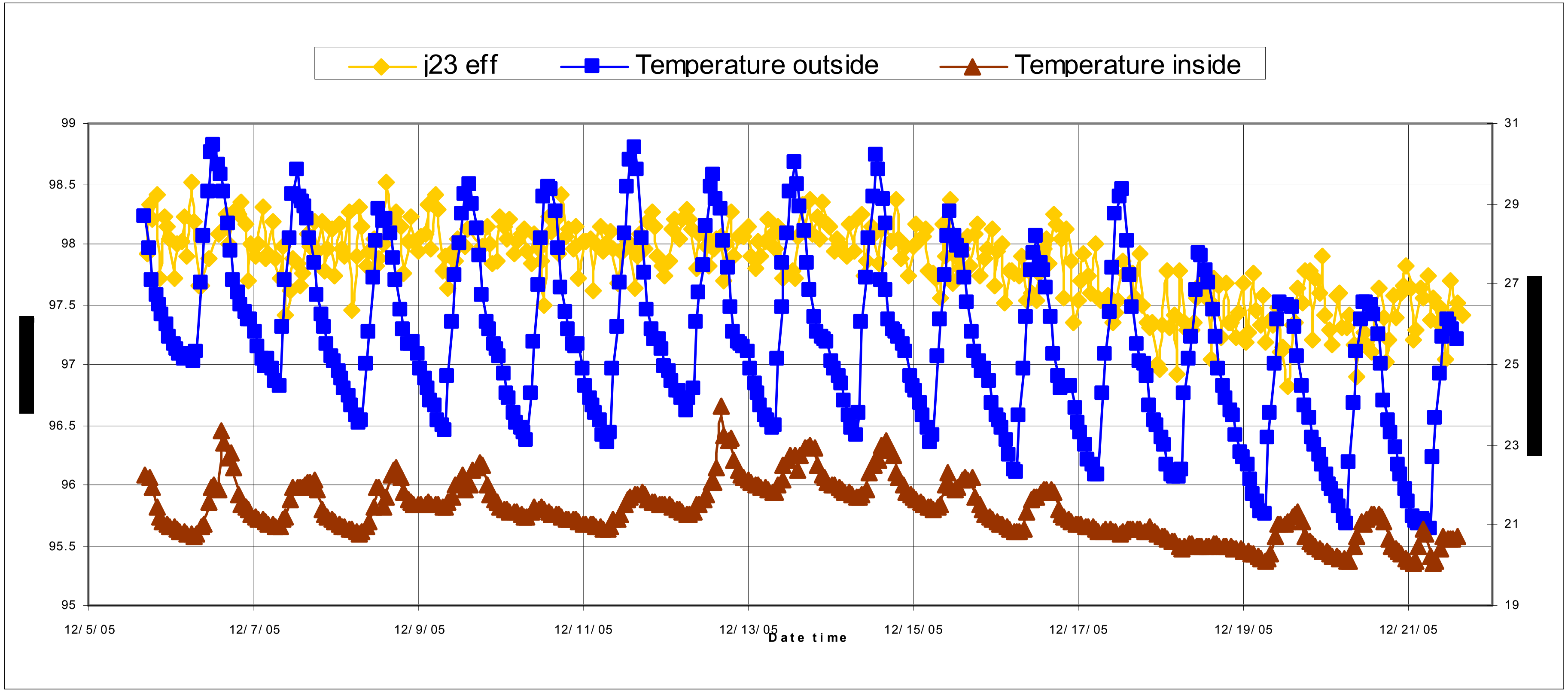
RPC with Japanese glass

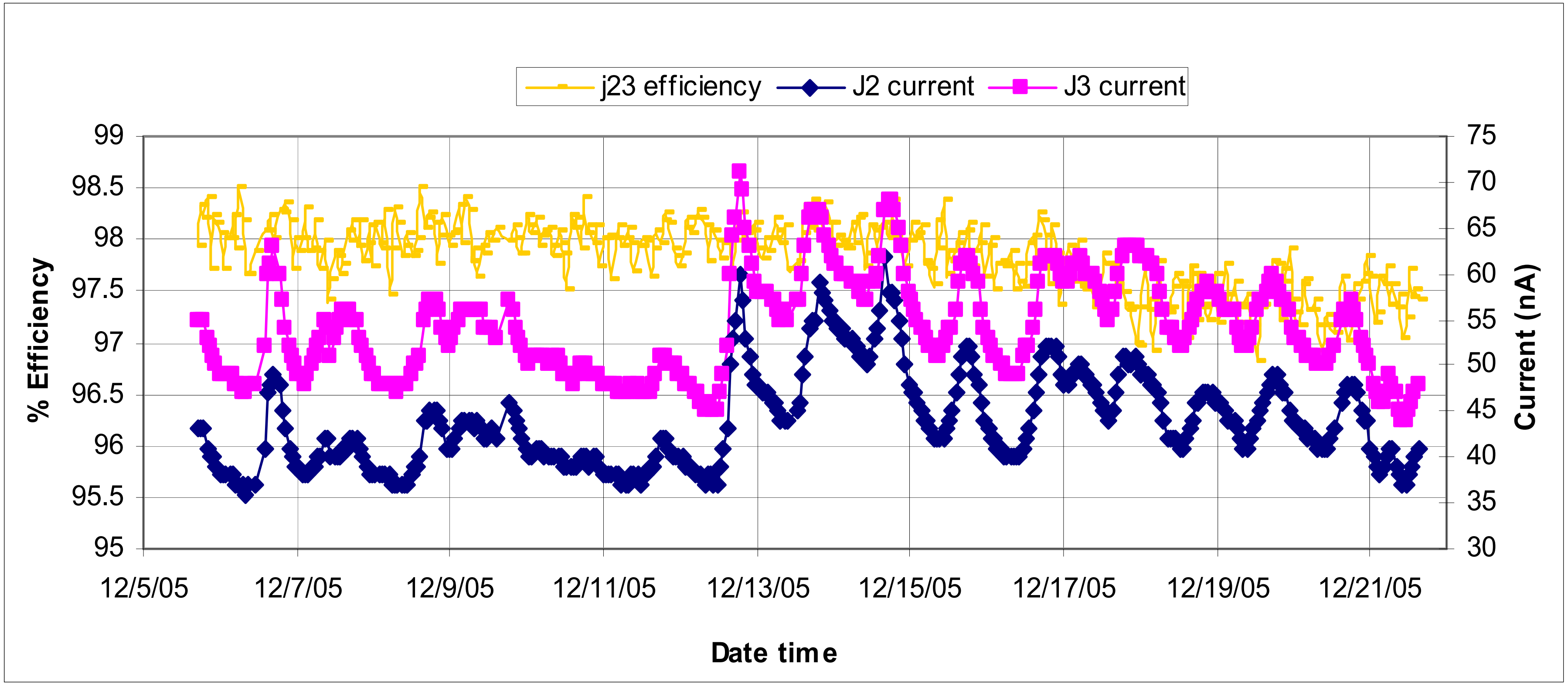
J2+J3 currents Vs Temperature



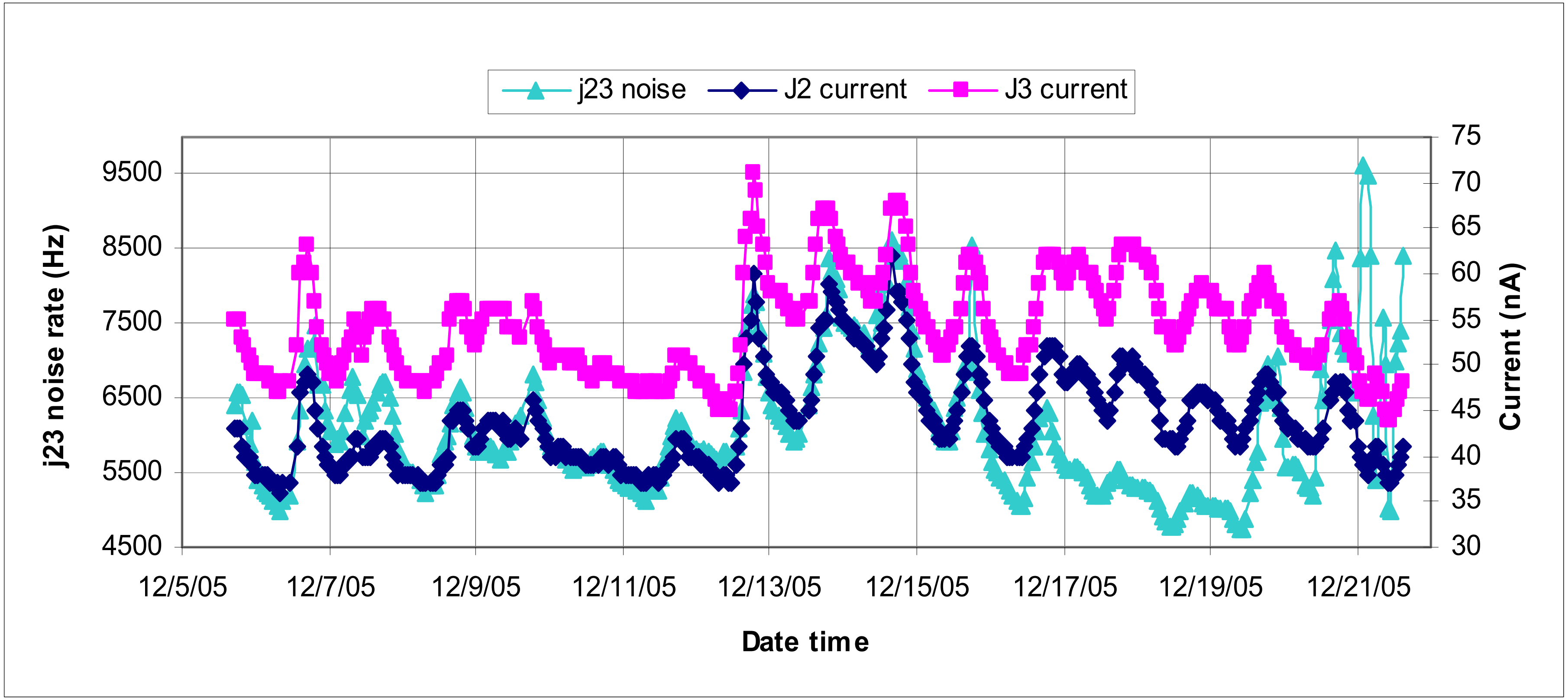
J2+J3 efficiency Vs Temperature



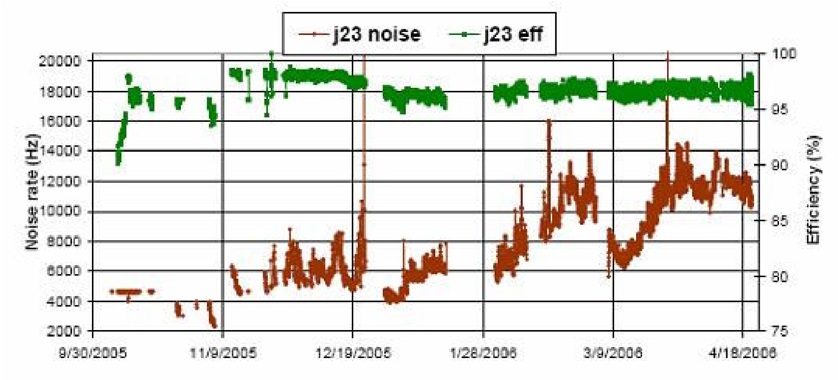
J2+J3 efficiency Vs Currents

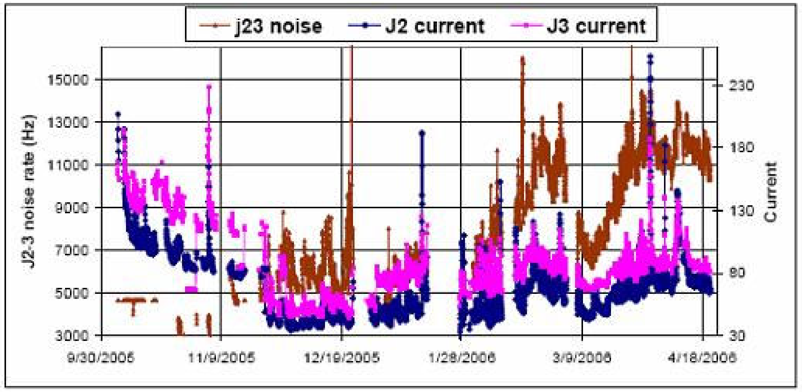


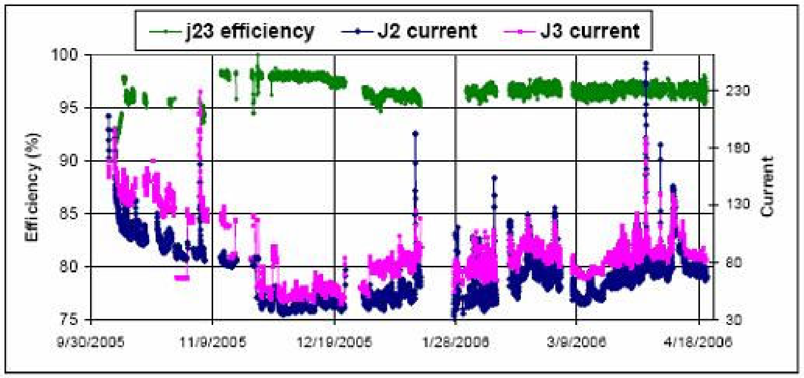
J2+J3 Noise Vs Currents



Long term monitoring of J2 & J3







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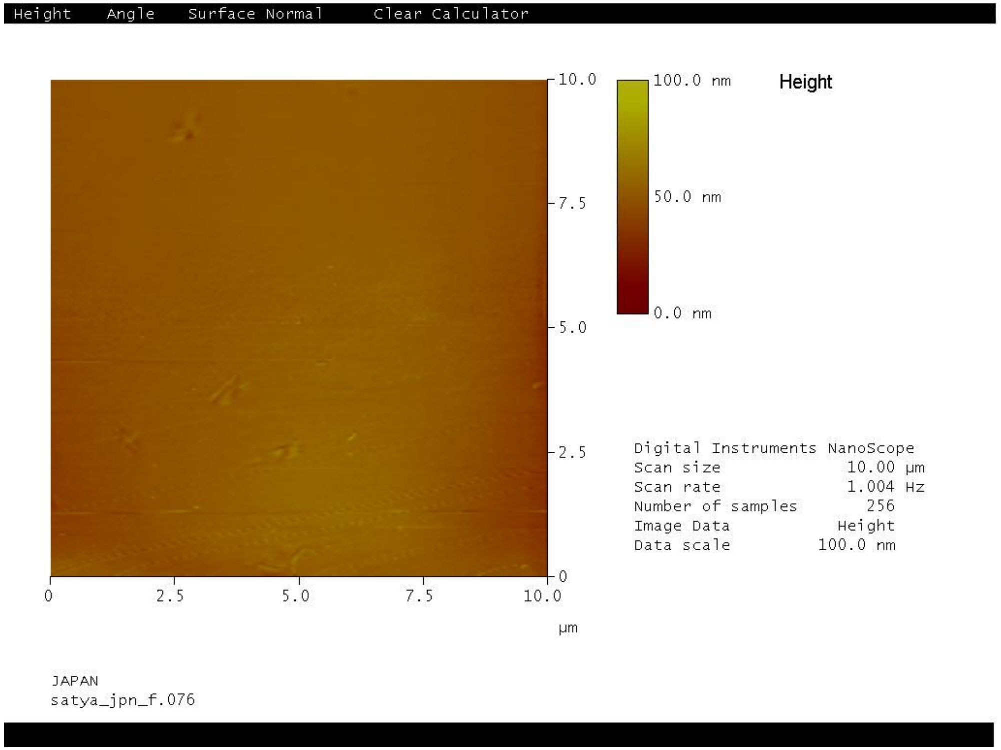
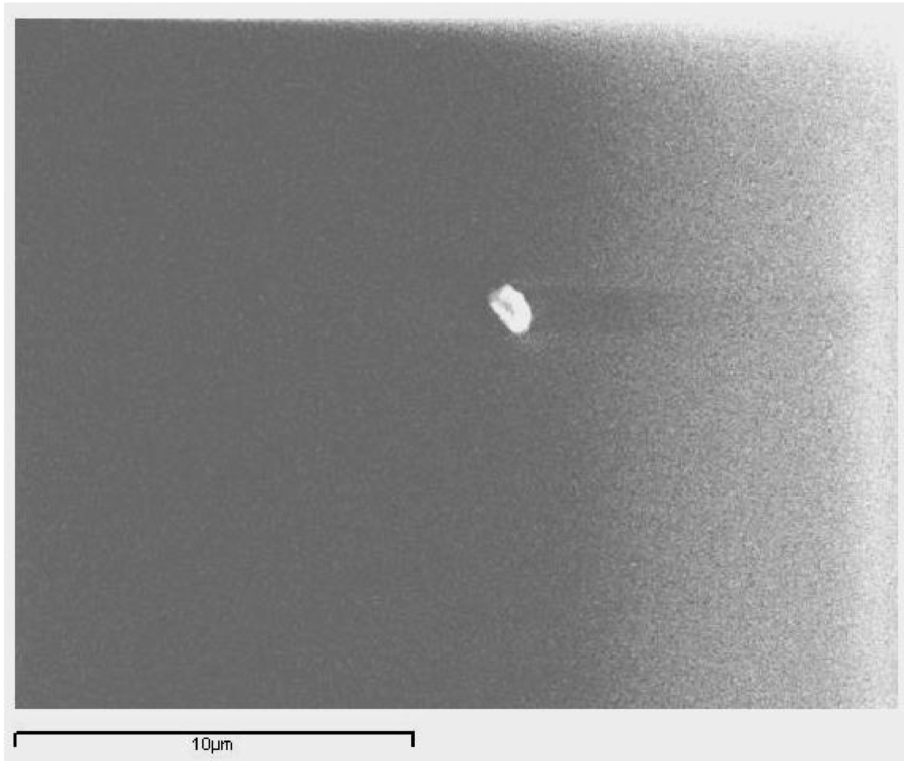
Japanese glass

AFM image



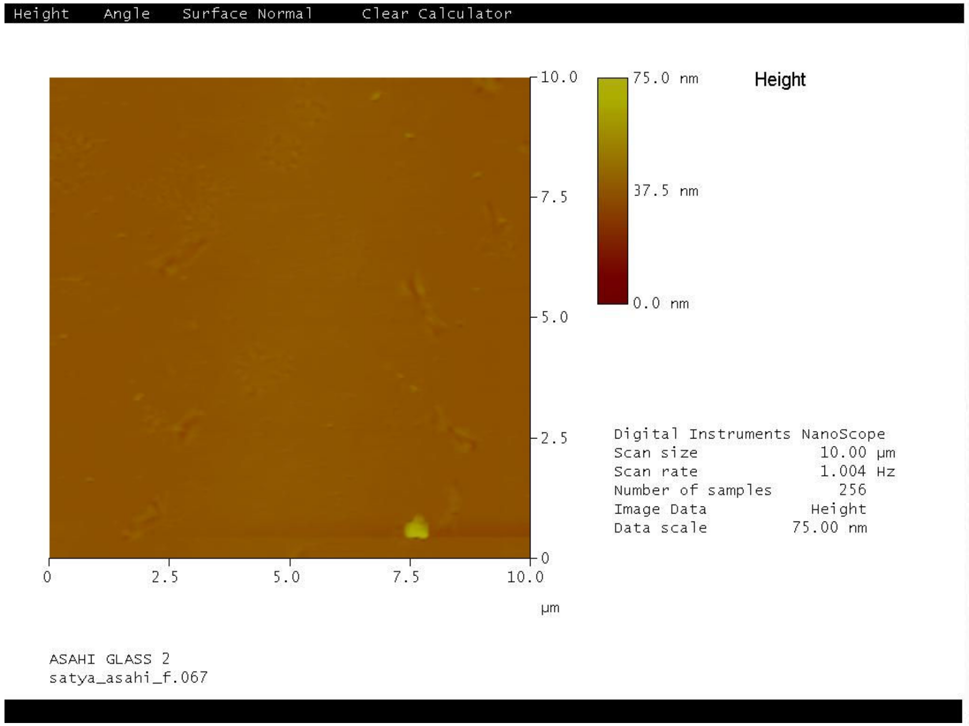
SEM image



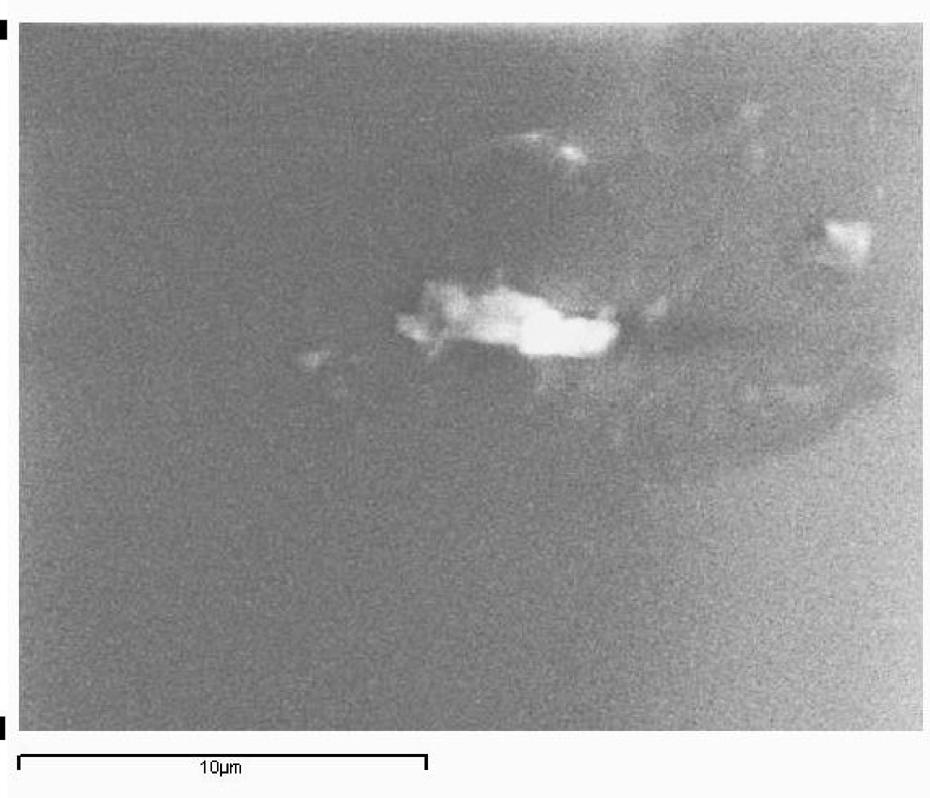
Japanese glass surface quality is relatively the best

Asahi glass

AFM image



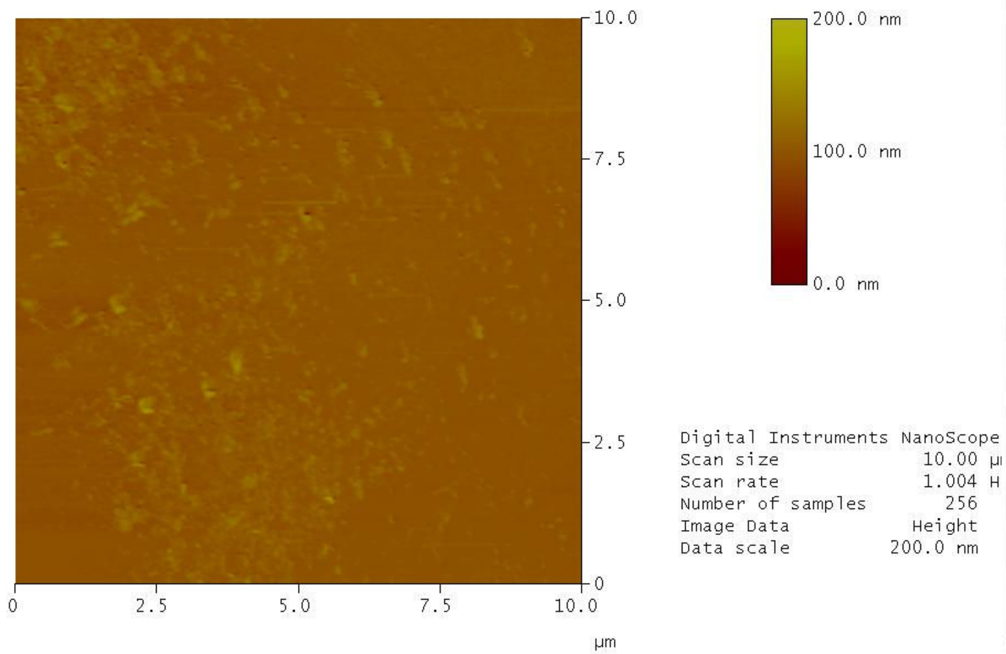
SEM image



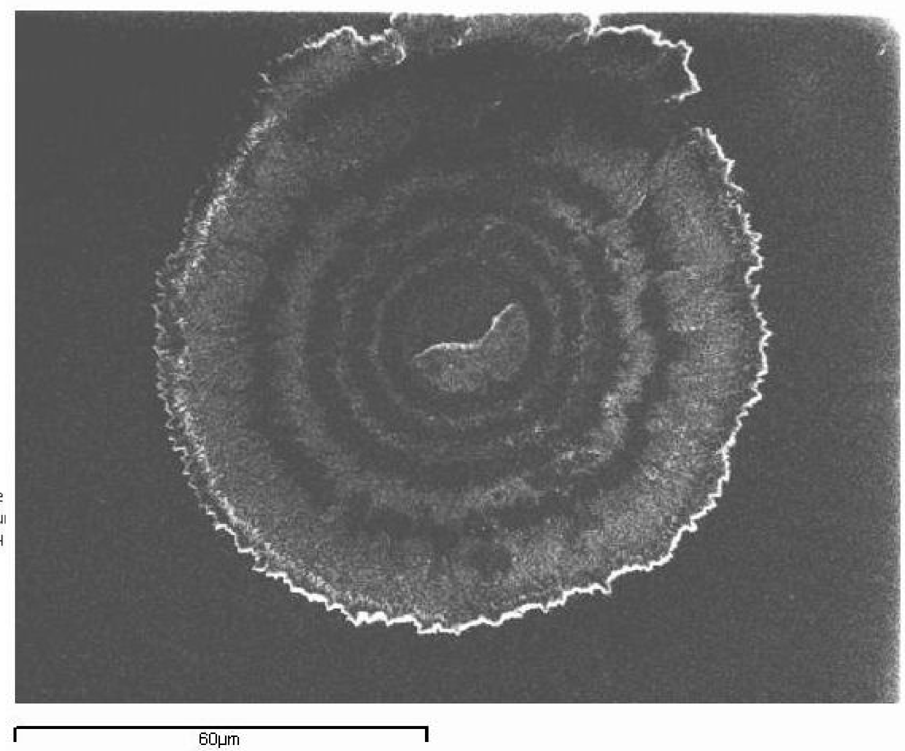
Asahi surface quality is comparable to Japanese glass

Modi glass

AFM image



SEM image



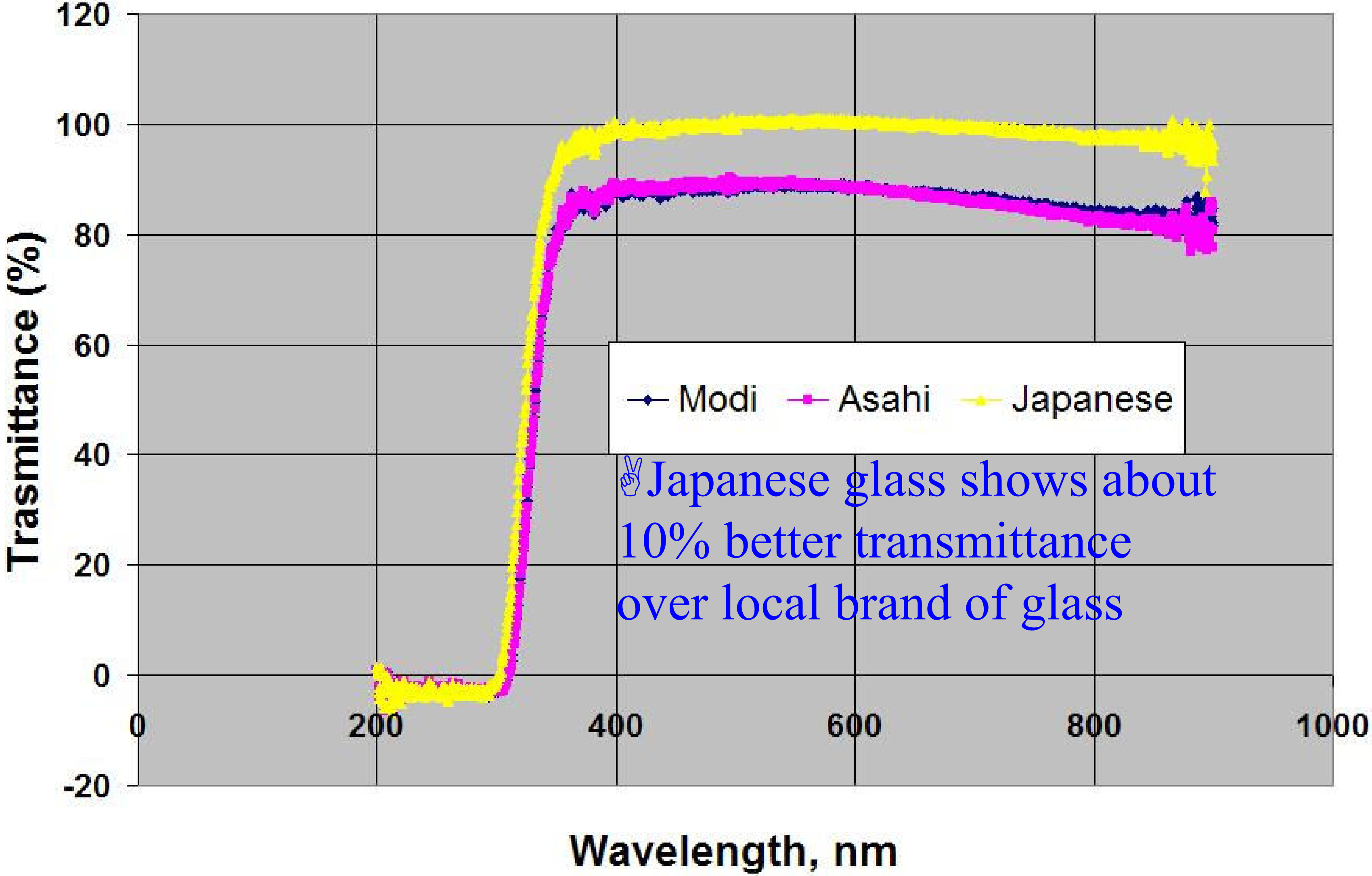
Modi surface quality is comparatively unsatisfactory

EDS study summary of glass samples

Element	Modi		Asahi		Japanese	
	Sample 1	Sample 2	Sample 1	Sample 2	Sample 1	Sample 2
Oxygen	71.0	72.6	69.9	70.1	72.9	73.4
Sodium	8.6	3.3	7.7	7.8	7.6	7.2
Magnesium	1.8	1.8	2.3	2.4	1.9	1.5
Silicon	17.8	15.7	19.0	18.6	16.9	17.1
Calcium	0.9	-	0.7	0.7	-	0.4
Carbon	6.7	-	-	-	-	-
Aluminium	-	-	0.5	0.4	0.7	0.5

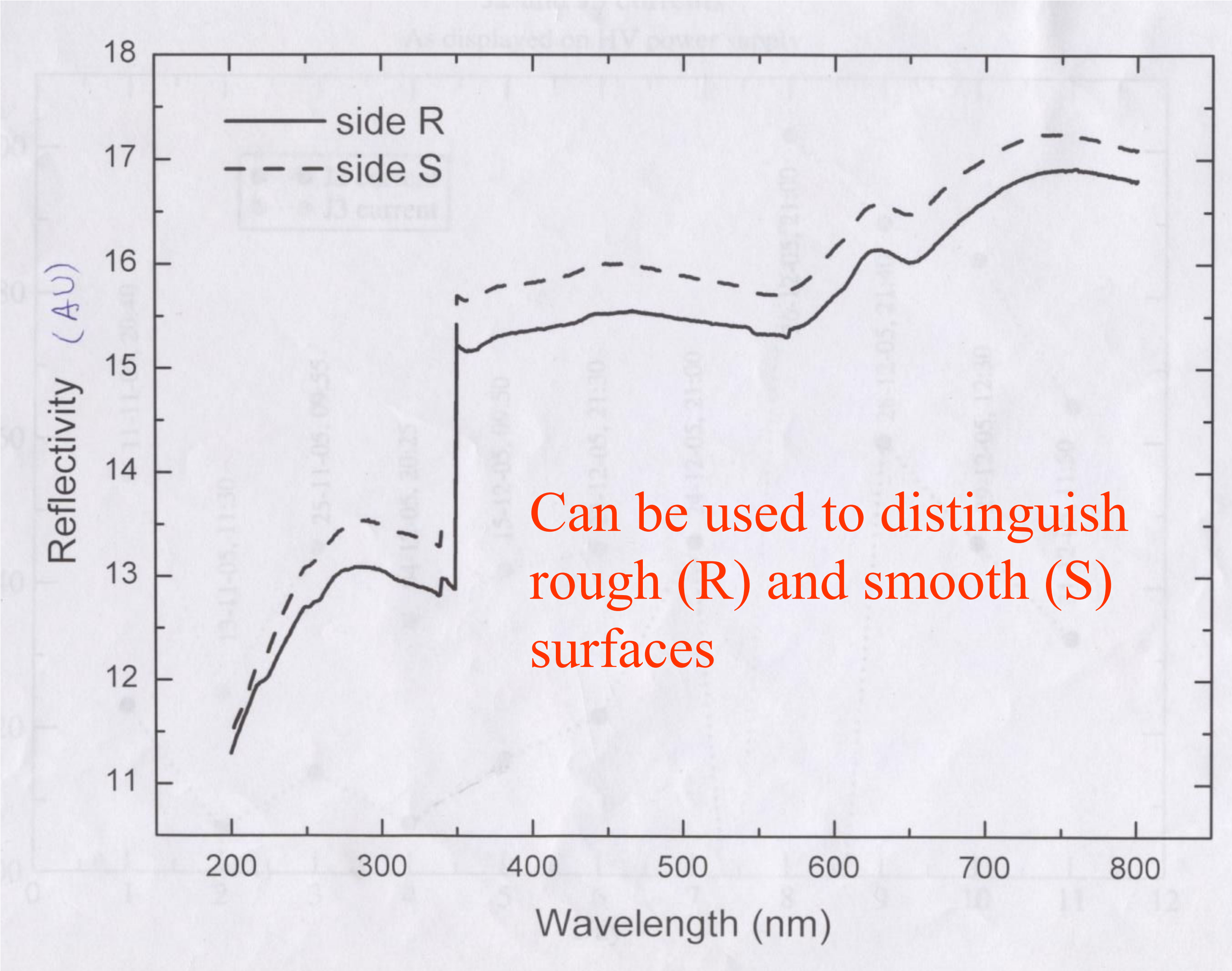
Conclusion: Within the sensitivity of measurement technique, all three glass samples show similar fractional weights of various constituent elements.

Transmittance test of glass samples



✌Japanese glass shows about 10% better transmittance over local brand of glass

Reflectance test of a glass sample



Can be used to distinguish rough (R) and smooth (S) surfaces

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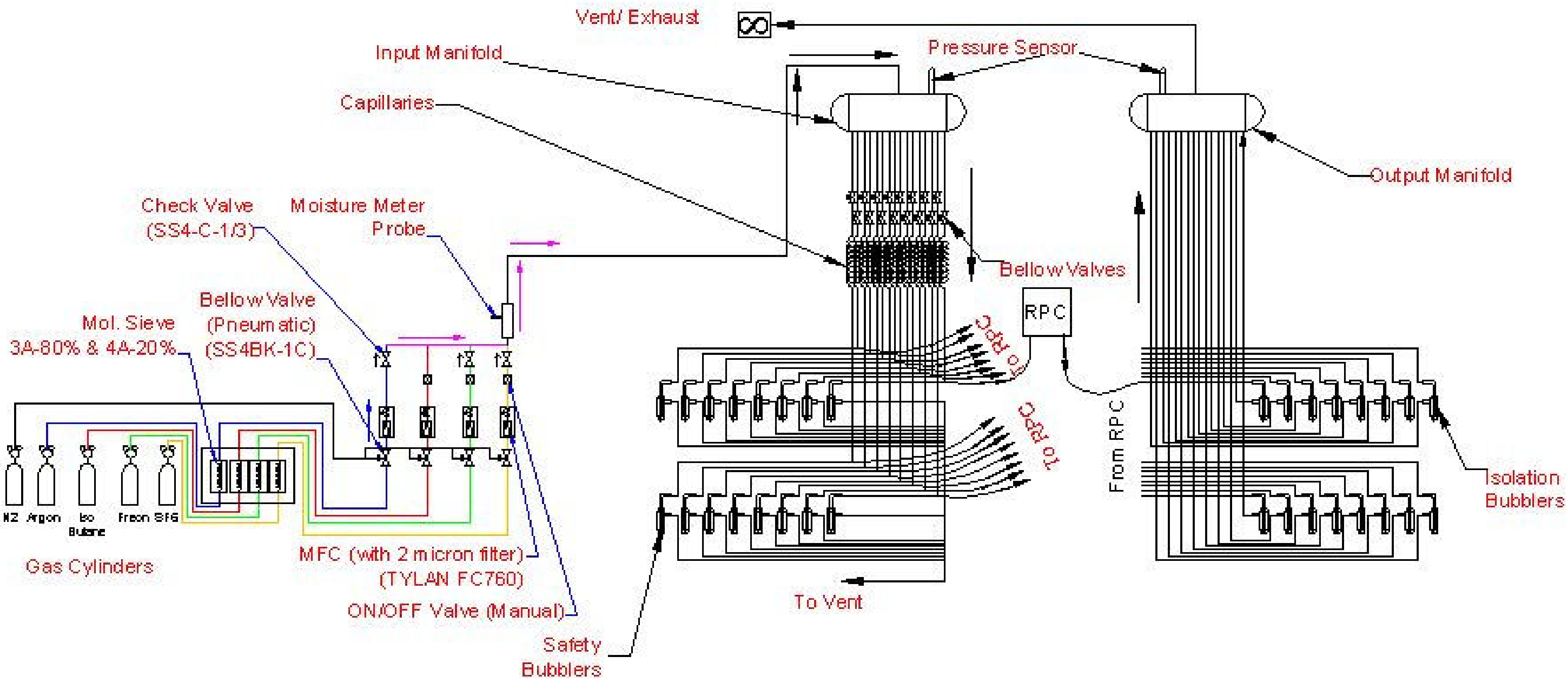
New gas system features

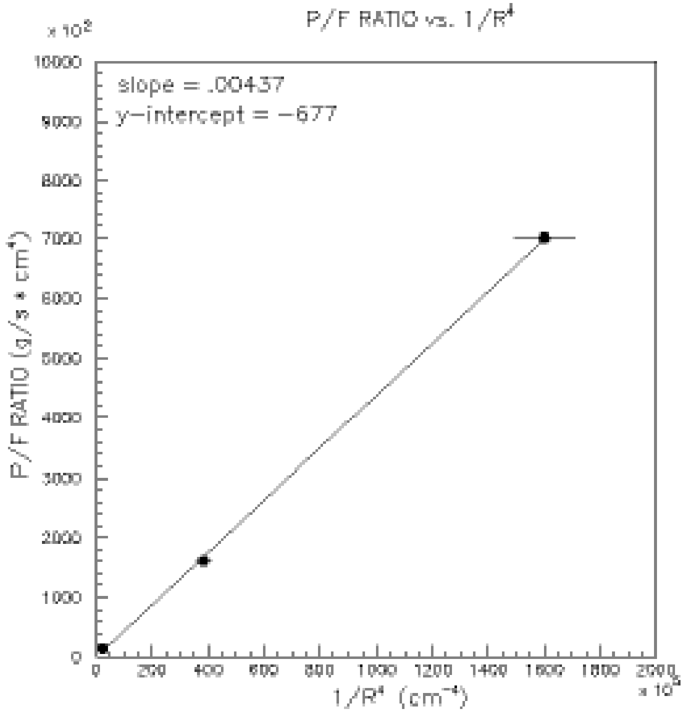
- 16 pneumatically controlled outputs
- Molecular sieve based input filter columns
- Nippon Tylan made model FC-760 MFCs
- Parker made fine filters on the mixed gas
- On-line moister readout on mixed gas
- Output flow control by SS 0.3mm capillaries
- Bleeder bubblers for RPC protection
- Facility to add controlled moister into the mixture
- Computer interface for control and monitoring

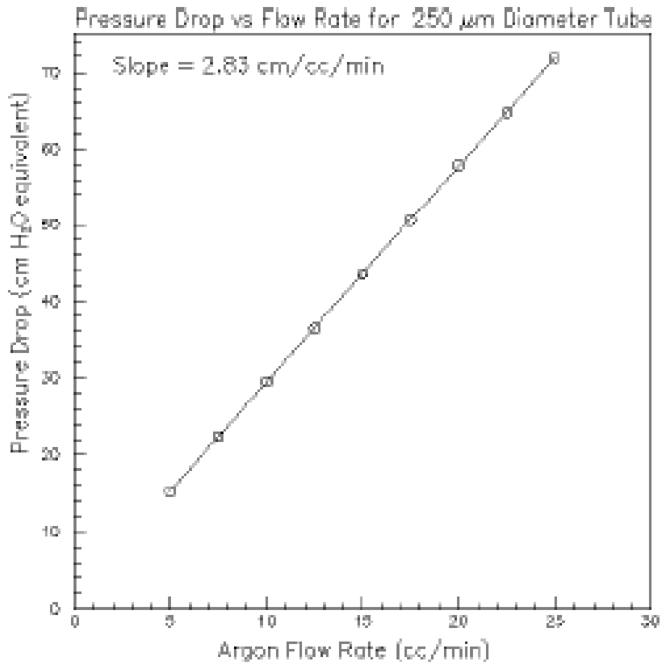
New gas system layout



Gas flow resistors

The flow resistors are quite linear and show quantitative agreement with Poiseuille's Law, including the expected R^4 dependence.





$$F = \frac{\pi}{8}\frac{R^4}{\eta}\frac{\Delta p}{L}$$

Front-view of the new gas system

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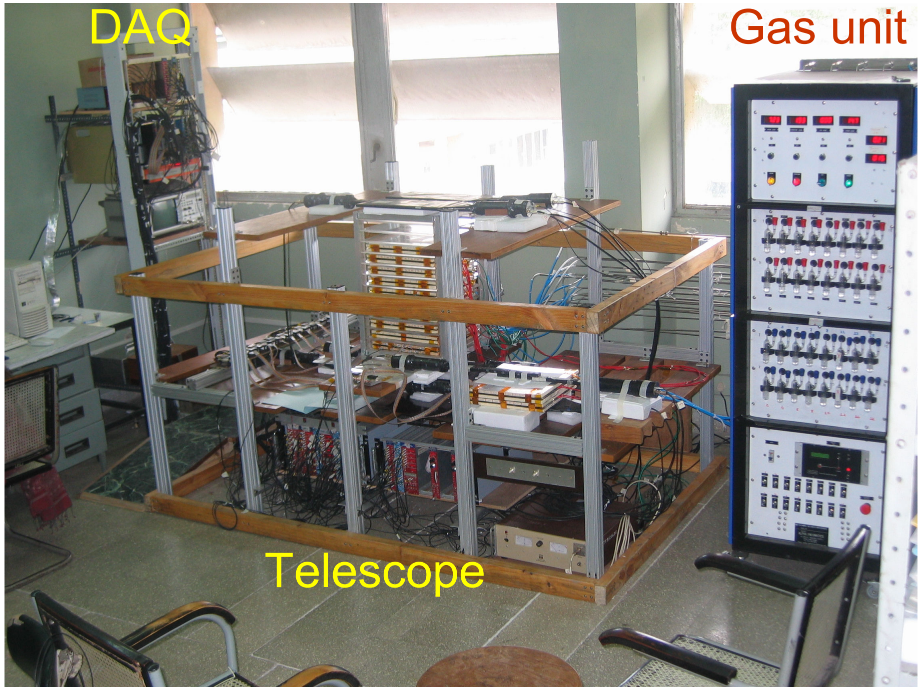
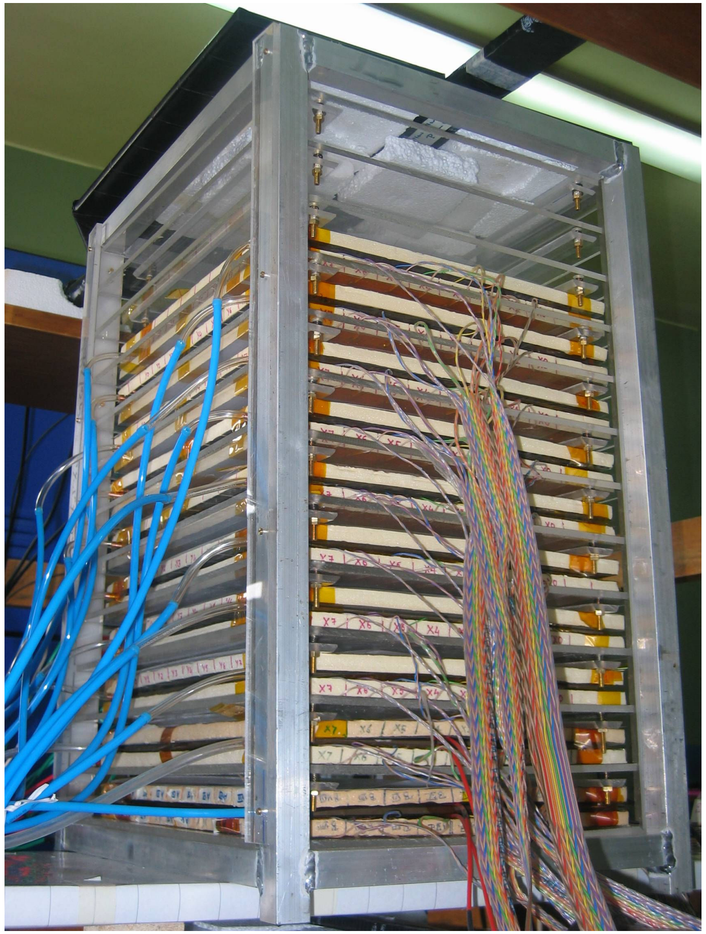
New RPC laboratory at TIFR

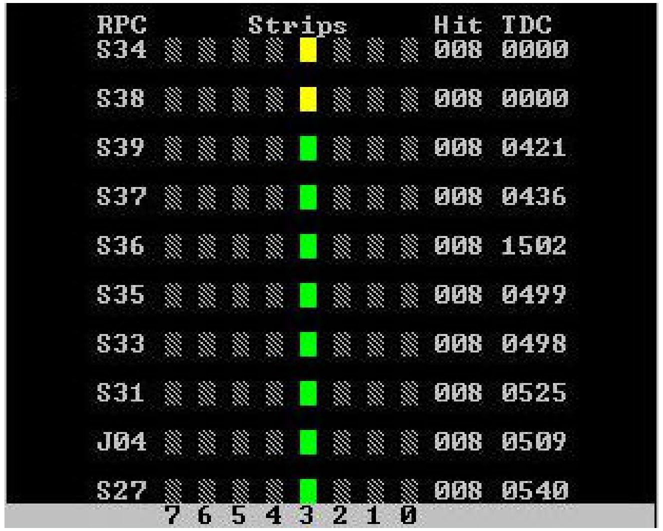


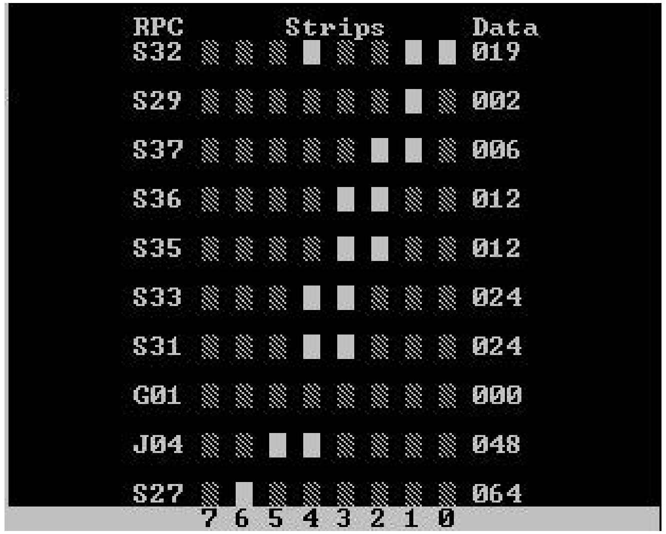


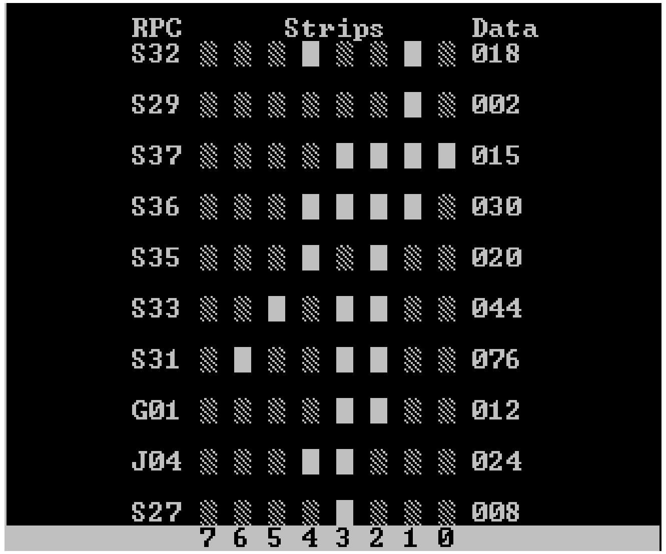
Stack of 10 RPCs

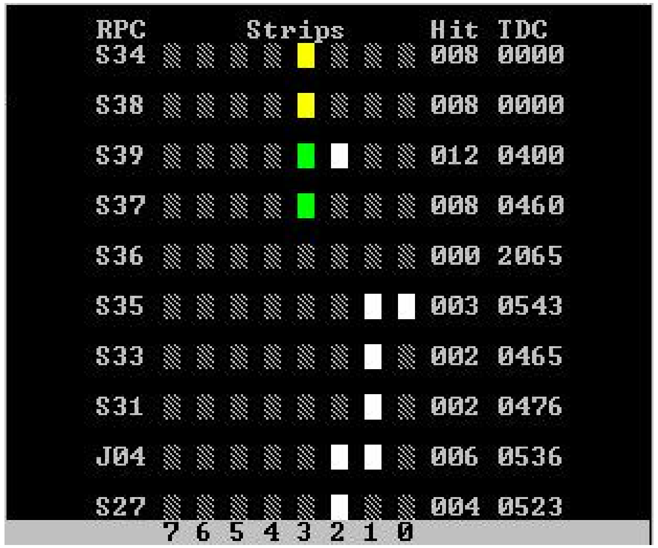
- Streamer mode (R134a=62%, Argon=30% and the rest Iso-Butane)
- Recording hits, timing, noise rates etc

Some interesting events tracked



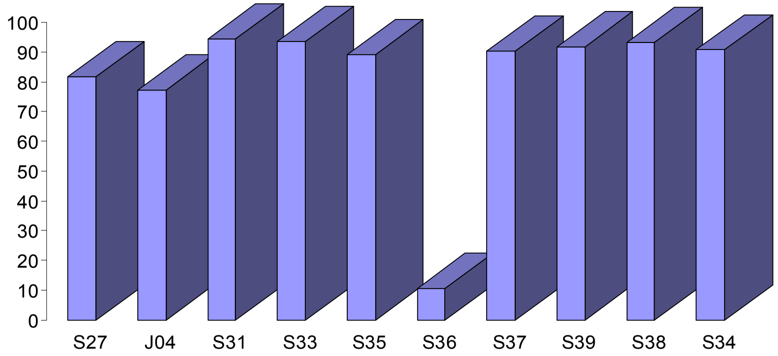




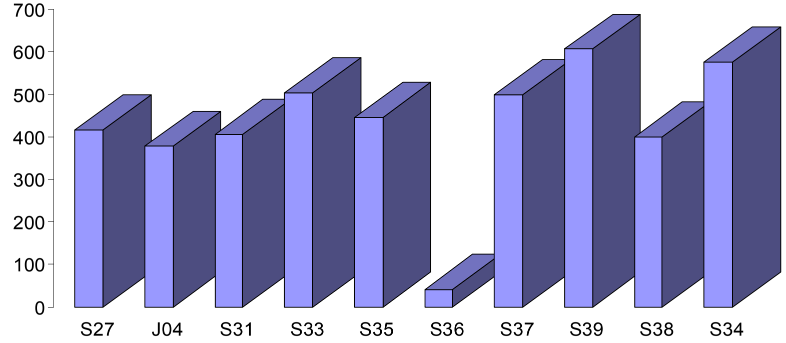


Some extracted parameters

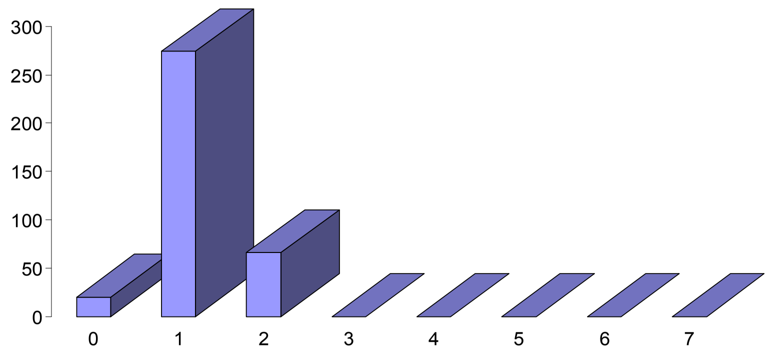
RPC efficiencies



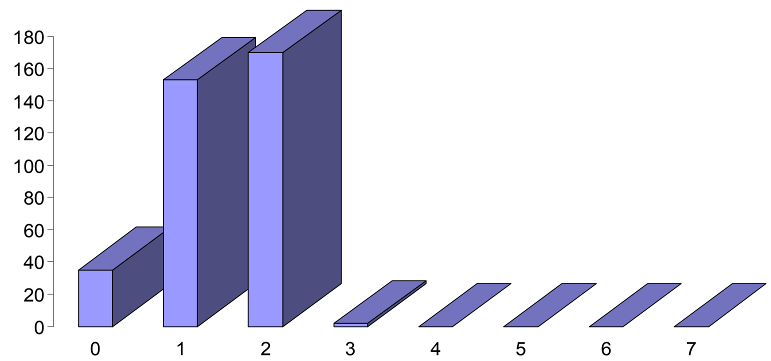
Total hits of RPCs



Strip hit distribution of S-31



Strip hit distribution of S-37



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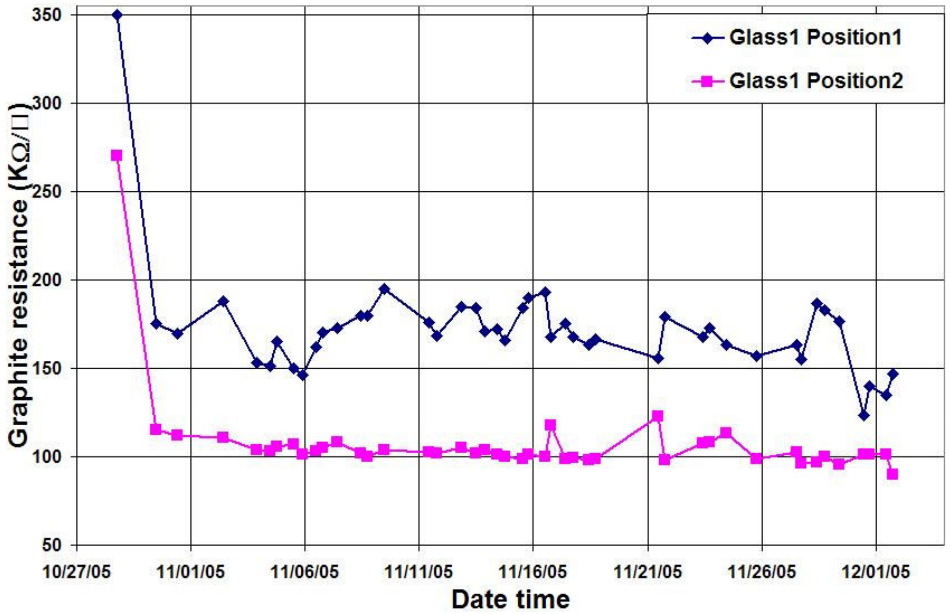
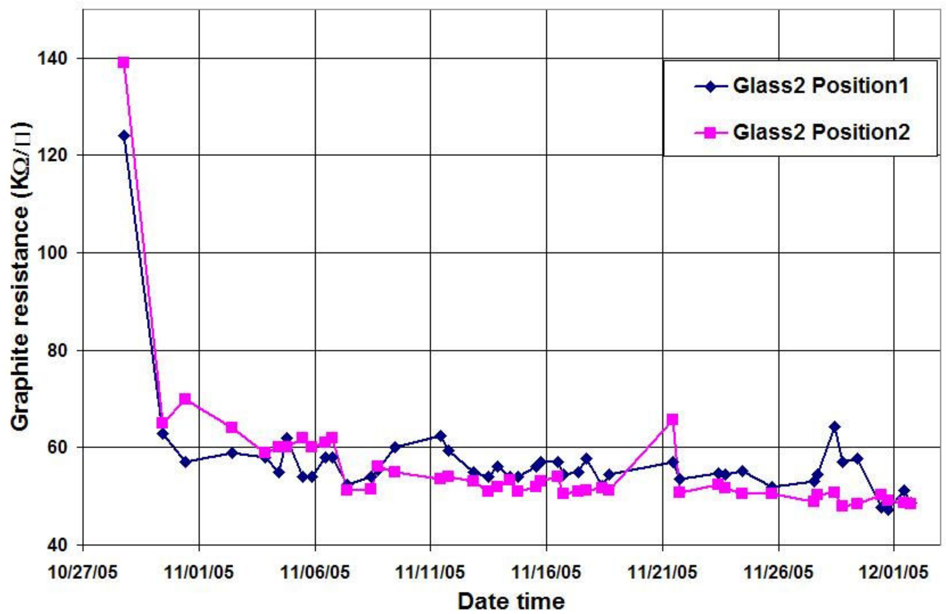
Electrode coating technique

Graphite paint prepared using colloidal grade graphite powder(3.4gm), lacquer(25gm) and thinner(40ml) is sprayed on the glass electrodes using an automobile spray gun. A uniform, stable graphite coat of desired surface resistivity (100-200KΩ/□) can be obtained by this method.





Technique of surface resistance measurement

- Resistance of a film,

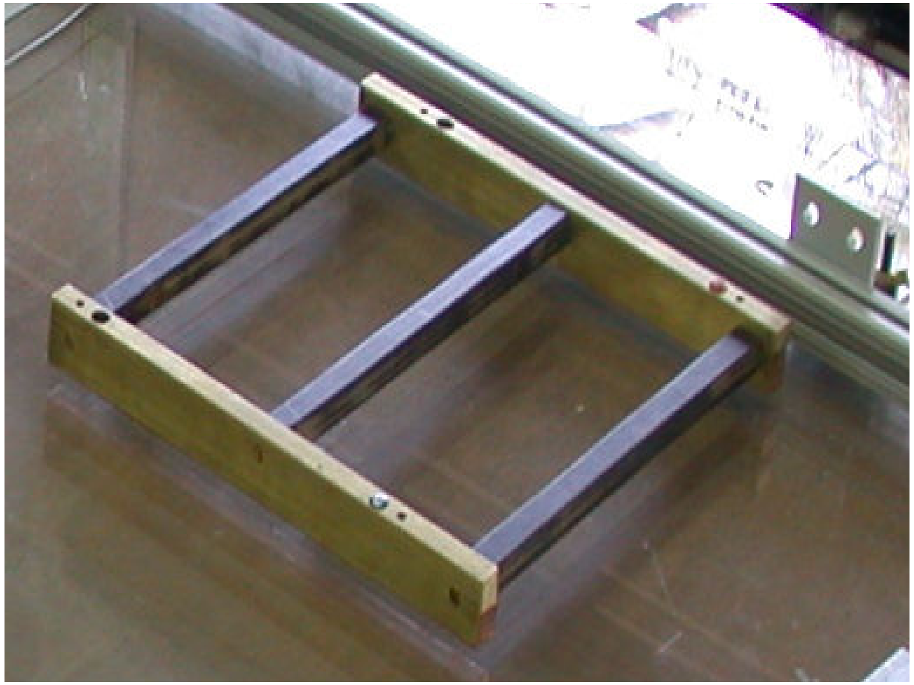
  $$R \propto L \div (W \times t)$$

  - L = Length of two parallel conductors
  - W = Separation of the conductors
  - t = Thickness of the film
- For a square of side, L (= w),

  $$R \propto 1/t$$

- Resistance is expressed as

  $$\Omega/\Box$$



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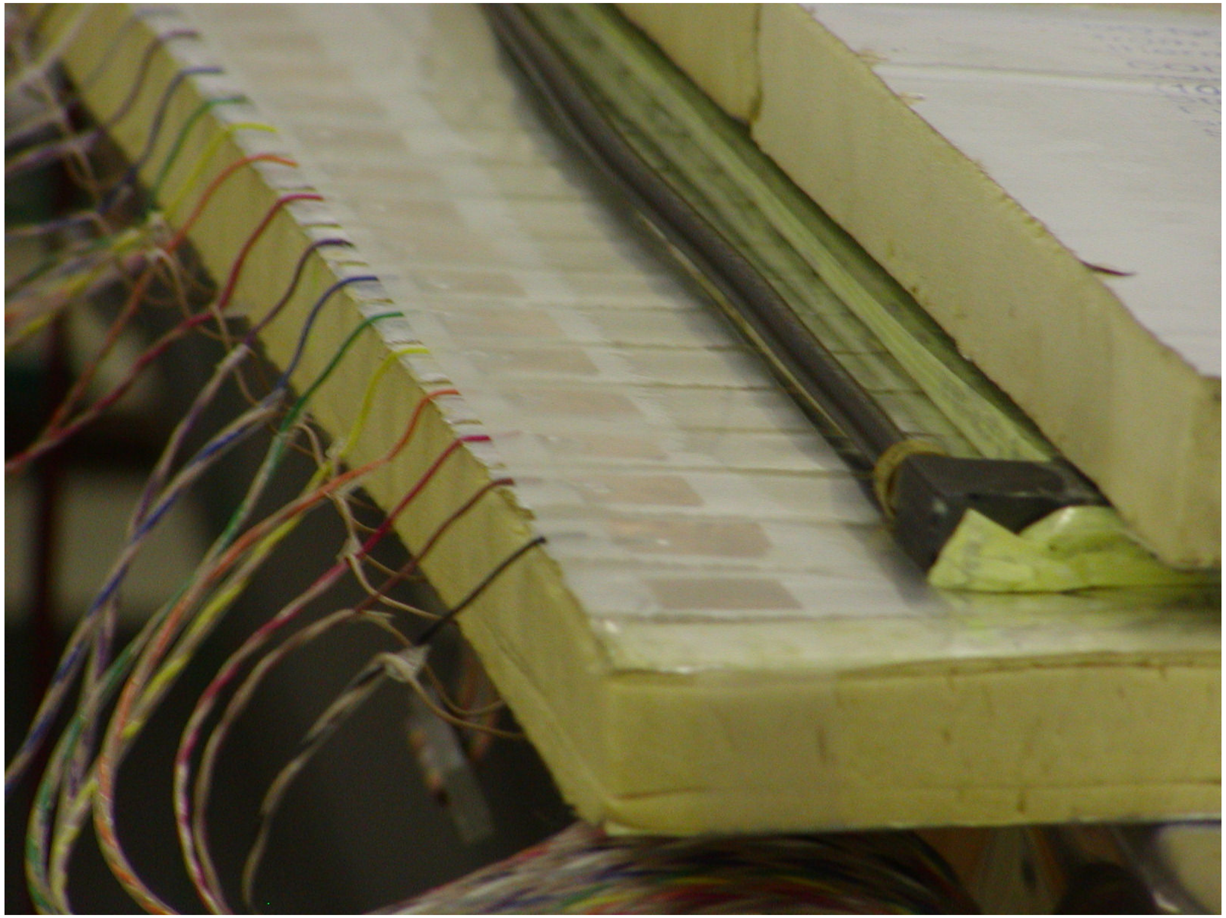
Development of RPC materials and procedures

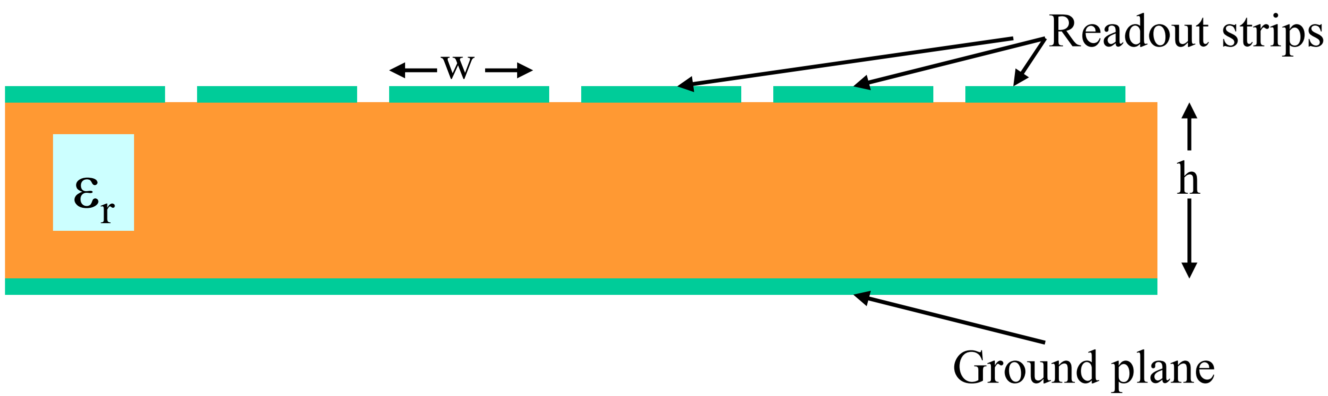
- Electrode glass and characterisation
- Frames, spacers, buttons, gas nozzles etc
- Gases and gas proportions
- High Voltage insulating Mylar sheets
- Adhesives, cleaning agents etc
- Pickup panel designs and characterisation
- Electrode coating & resistance measurement techniques
- Spark free high voltage contacts
- Gas leak and assembly testing of RPCs
- High voltage holding tests etc
- Quality control parameters and procedures

Pickup electrode design



- Large area glass RPC sandwiched between two readout boards.
- X and Y coordinates from a single chamber.
- Strip readout: transmission line using insulation board.

Transmission line impedance



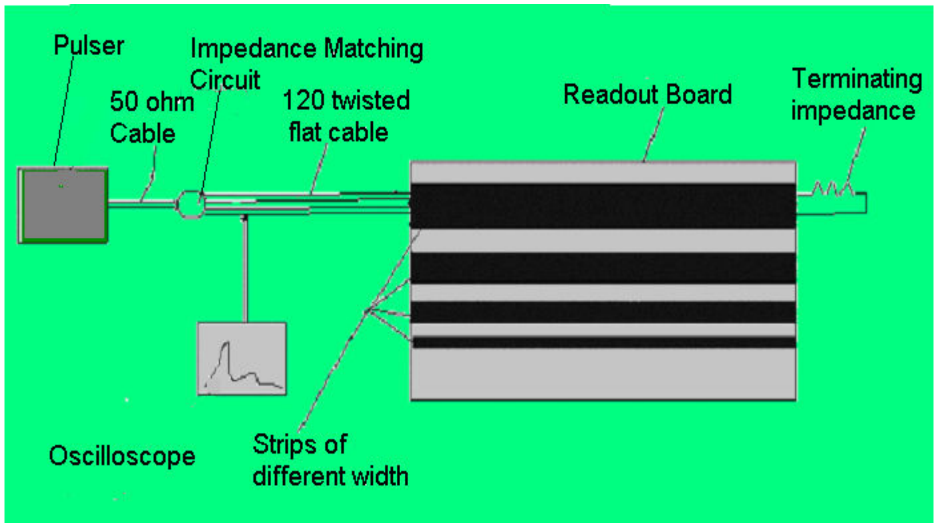
$$x \equiv w/h \qquad \varepsilon_r' = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}(1+10x)^{-\frac{1}{2}}$$

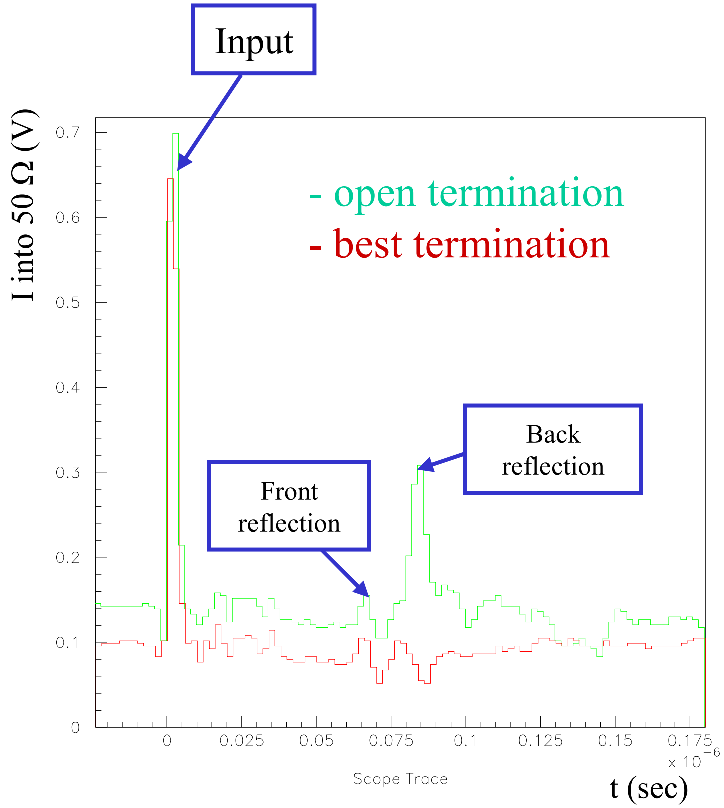
$$Z = \frac{60 \text{ x } \ln(8/x + x/4)}{\sqrt{\varepsilon_r'}} \quad : \ x < 1$$

$$Z = \frac{377}{\sqrt{\varepsilon_r'}\,(x + 1.393 + 0.667\ln(x + 1.444))} \ : \ x \geq 1$$

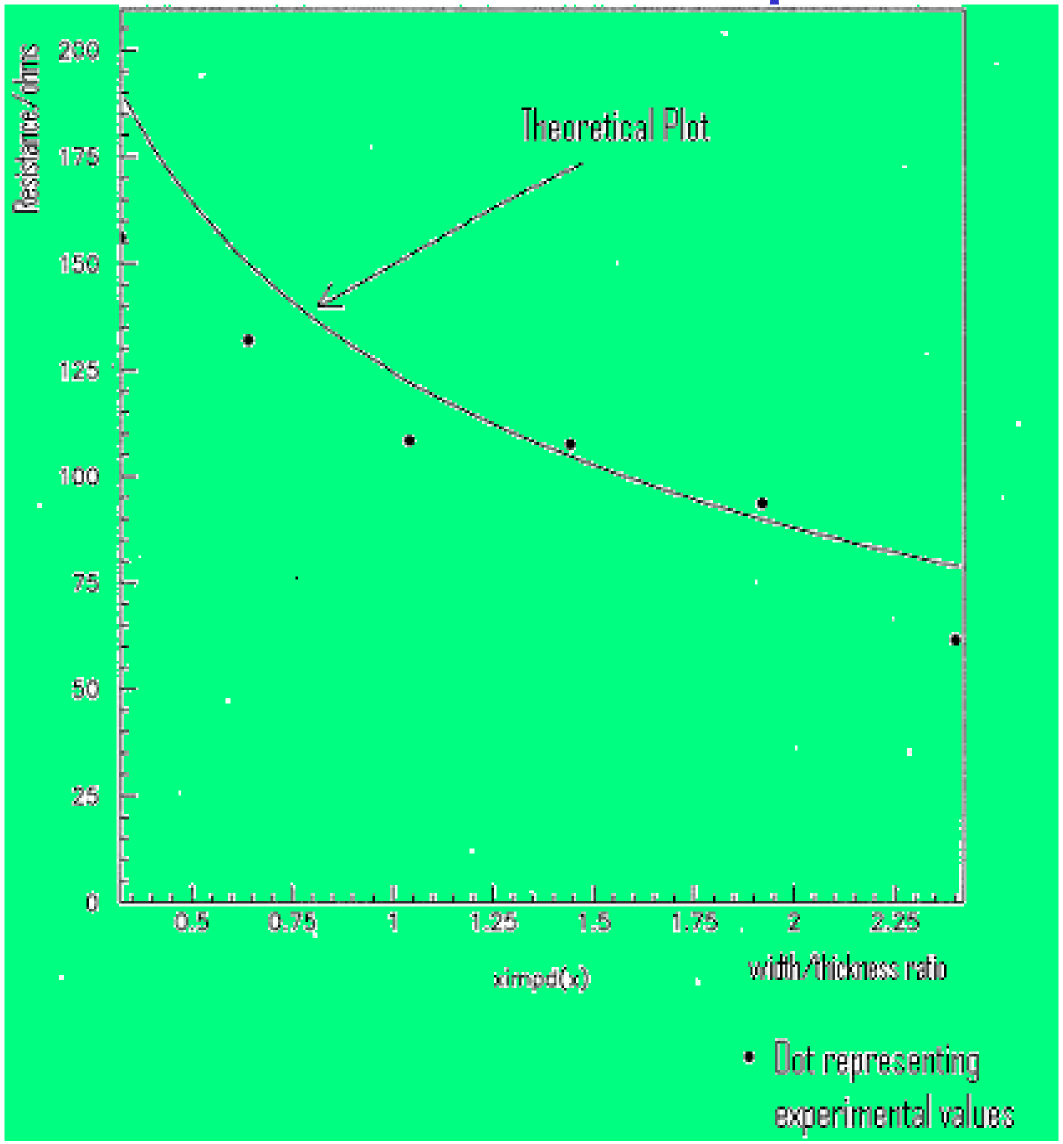
Characteristic impedance measurement of pickup strips

Tune termination for each strip width to get 0 reflected signal for injected charge pulse





Impedance versus strip width



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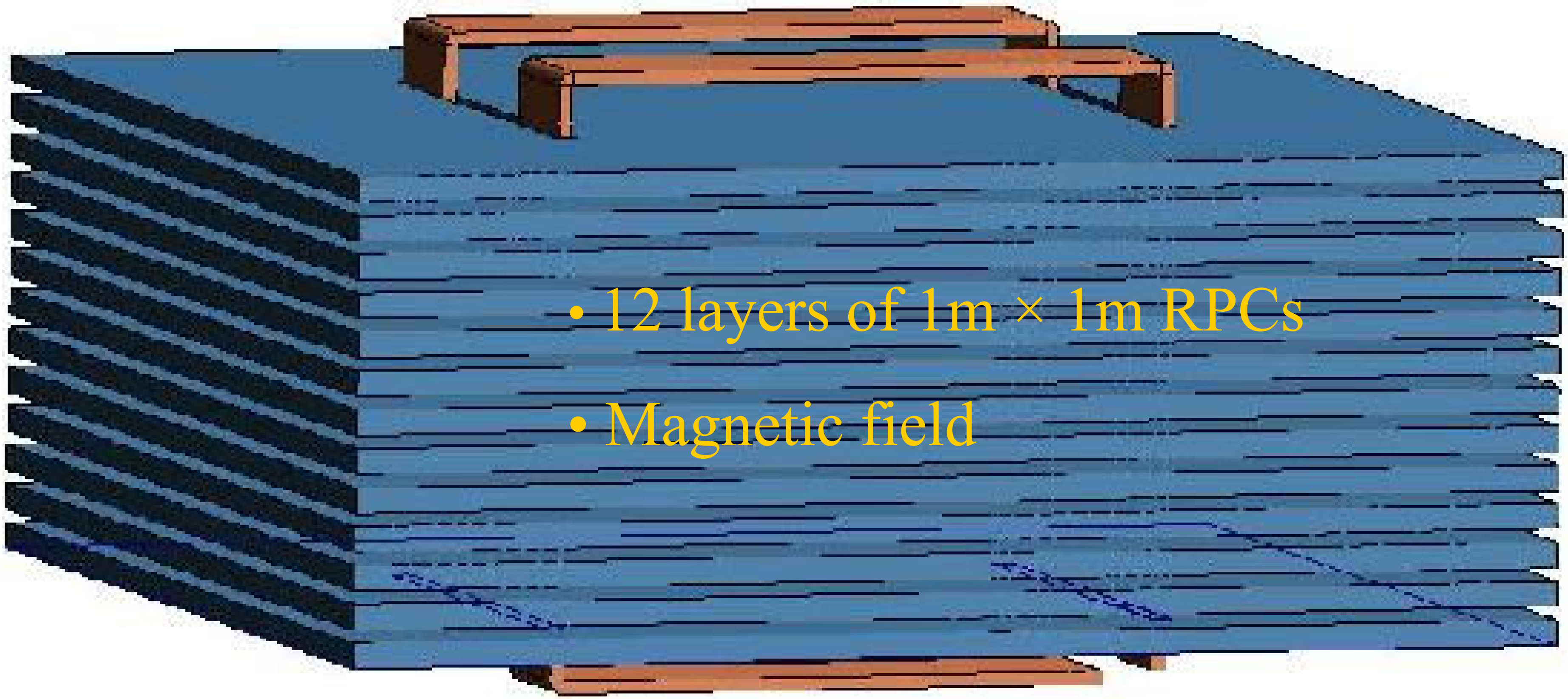
- Introduction
- Review of our earlier work
- Long term stability tests of INO RPCs
- Characterisation of electrode glass samples
- Development of 16-channel gas system
- Tracking of cosmic ray muons using small size RPCs
- Development and study of electrode coatings
- RPC materials and assembly procedures' development
- ✓ Construction of INO prototype detector
- Future work plan
- Presentations and papers
- Acknowledgements

INO prototype detector



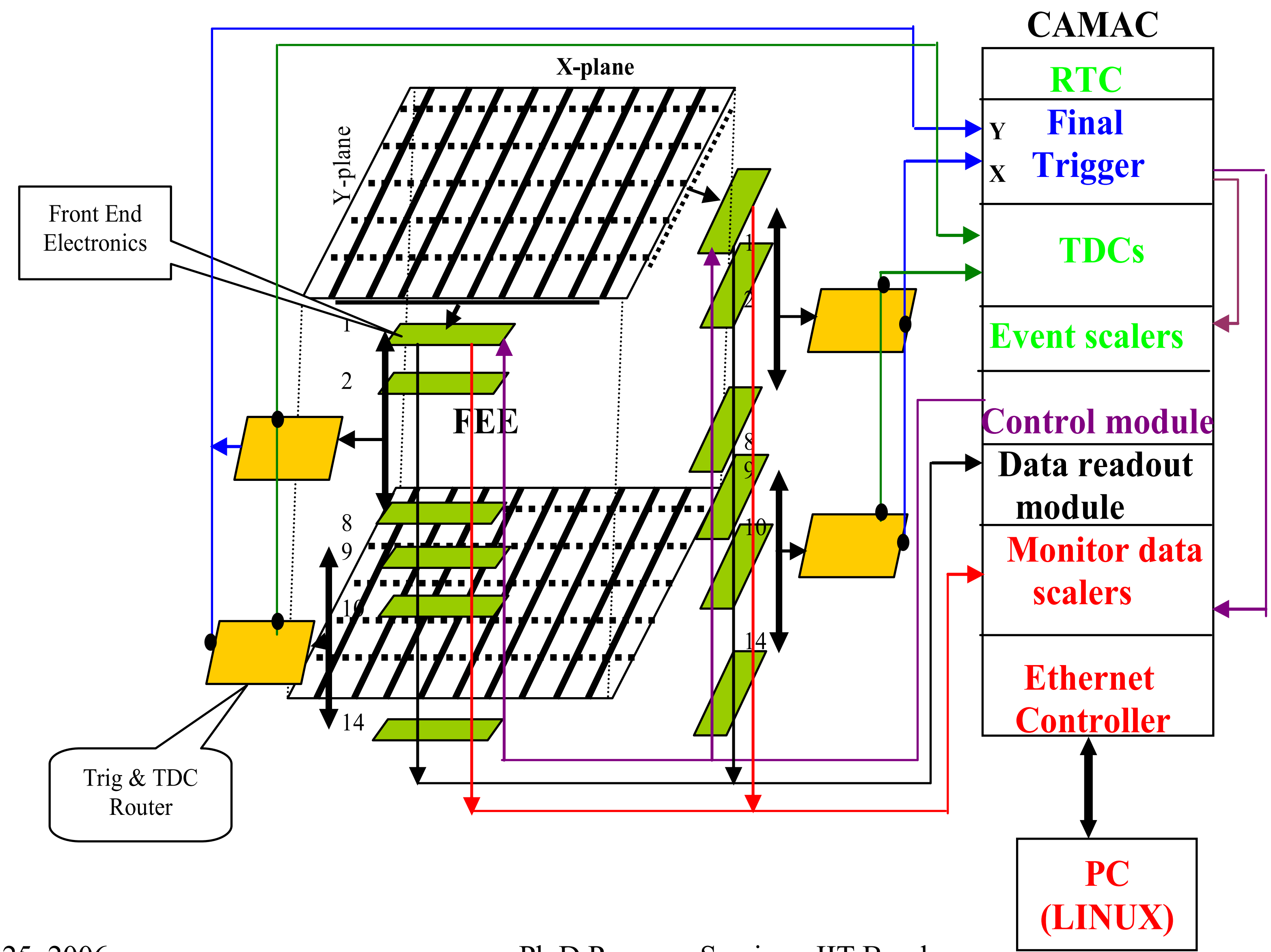
INO prototype specifications

- **Detector and signal specifications**
  - Detector dimensions: 1m X 1m X 1m (approx.)
  - 12 layers (max) of RPCs with 6cm iron plates interleaved.
  - Two signal planes orthogonal to each other and each having 32 pick-up strips
  - Total channels = 32 X 12 X 2 = 768
  - Pulse height = 100 to 300mV; Rise time = < 1 ns
  - Pulse width = ~50ns; Rate ~ 1KHz

- **Trigger information**
  - Expected trigger rate is few Hz
  - Required (in situ) trigger logic is **m X n** fold, where
  - m = 1 to 4; no. of consecutive channels in a layer
  - n = 5 to 1; no. of consecutive layers with **m** fold in each layer
  - i.e. m x n = (1 x 5) OR (2 x 4) OR (3 x 3) OR (4 x 2)
  - External scintillate paddle based trigger

- **Information to be recorded on a trigger**
  - Absolute arrival time of the trigger
  - Track identification (XYZ points in RPC layers)
  - Direction of track (TDC information)
  - Miscellaneous information and calibration data
- **Monitoring health of the detector**

Readout scheme for prototype



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Future work plan

- Confirmation of role of glass on RPC aging
- Continuing glass characterisation studies
- Building and detailed characterisation of large area RPCs
- Device simulation and modeling of:
  - RPC fields
  - Particle interaction
  - Gas modes and charge production
  - Signal pickup, transmission and readout
  - Gas contamination (especially moisture)
- Building and data analysis of INO prototype detector
- Material and industrial process development for large scale RPC production

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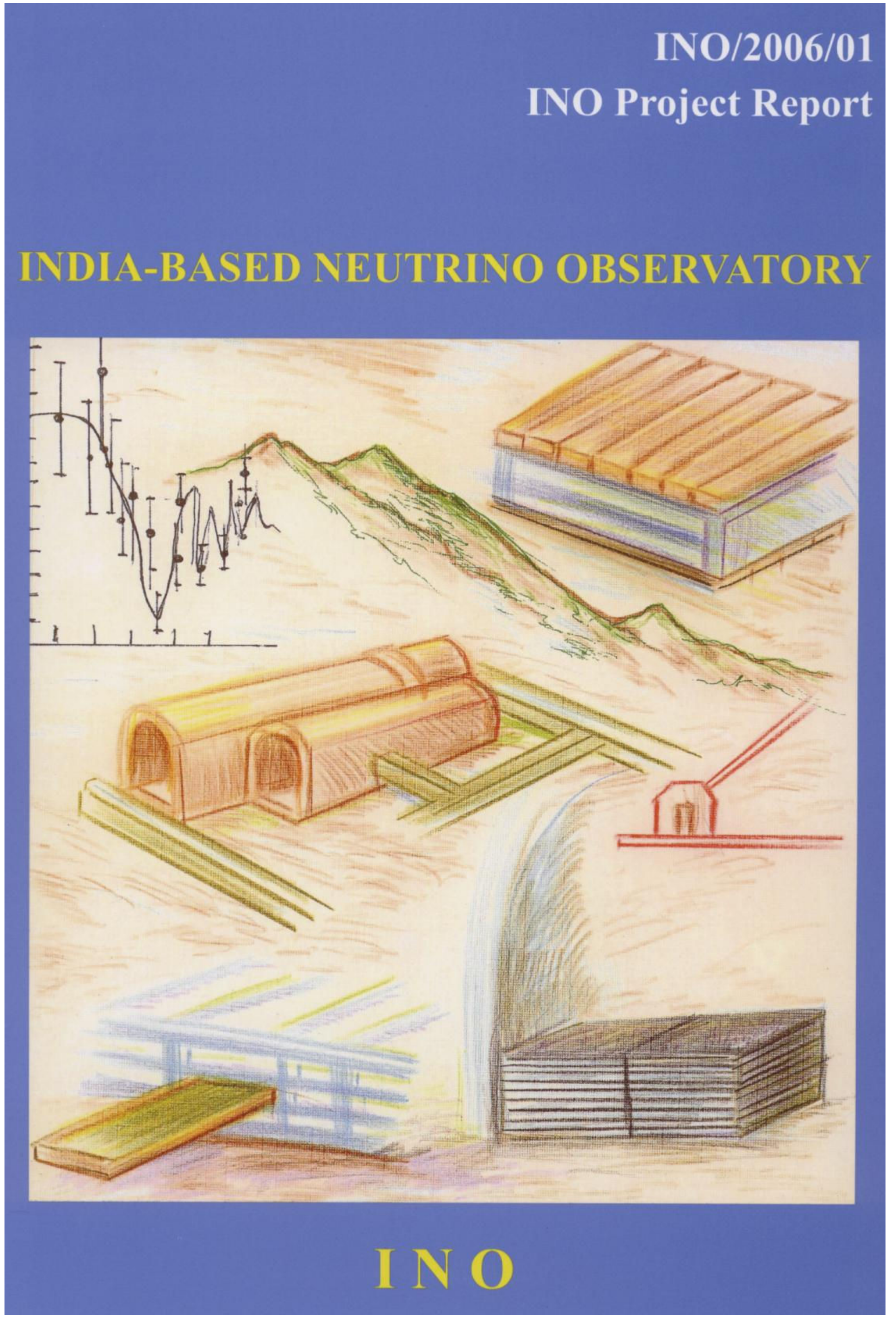
Presentations and papers

1. On aging problem of glass Resistive Plate Chambers, The VIII Workshop on Resistive Plate Chambers and Related Detectors, Korea University, Seoul, October 10-12, 2005, Nuclear Physics B, In press
2. Development of Resistive Plate Chambers for the INO detector, 50th DAE-BRNS Symposium on Nuclear Physics, BARC, Mumbai, December 12-16, 2005
3. Status report on RPC R & D at TIFR, INO detector meeting, VECC, Kolkata, December 24, 2005
4. Status report on electronics, trigger and data acquisition systems for the INO prototype detector, INO detector meeting, VECC, Kolkata, December 24, 2005
5. Electronics, trigger and DAQ system for INO prototype detector and A few thoughts for ICAL detector, INO Interaction meeting, IMSc, Chennai, February 22-24, 2006
6. Preliminary results from INO detector R&D programme, Linear Collider Workshop 2006, IISc, Bangalore, March 9-13, 2006, Pramana, In press
7. Course on Resistive Plate Chambers, INO School, VECC/SINP, Kolkata, May 1-13, 2006
8. Course on Data Acquisition Systems, INO School, VECC/SINP, Kolkata, May 1-13, 2006
9. Experiences of using float glass as electrodes for radiation detectors, National Symposium on Science & Technology of Glass/Glass-Ceramics (NSGC-06), BARC, Mumbai, September 15-16, 2006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INDIA-BASED NEUTRINO OBSERVATORY
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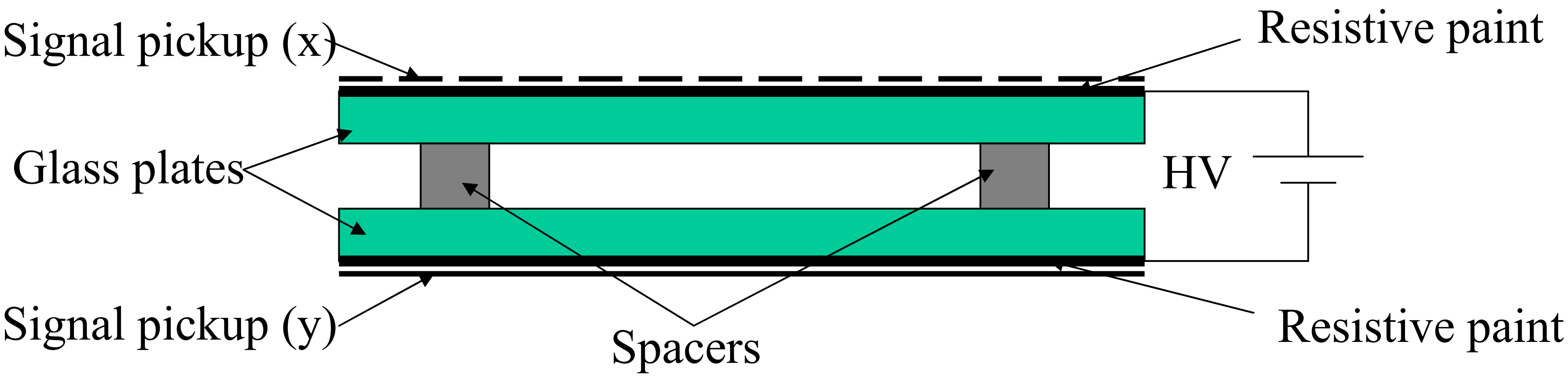
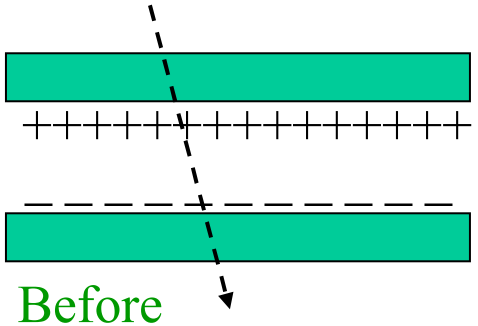
Acknowledgements

- Prof Raghava Varma, IIT Bombay
- Prof Naba Mondal, TIFR, Mumbai
- Prof Basant Nandi, IIT Bombay
- Prof S.Uma Sankar, IIT Bombay
- INO detector development & electronics design teams’ colleagues

Backup slides

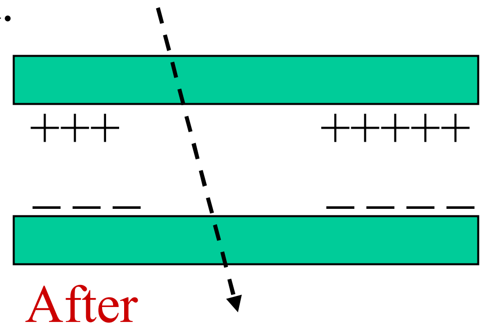
Principle of operation (Streamer)





Before

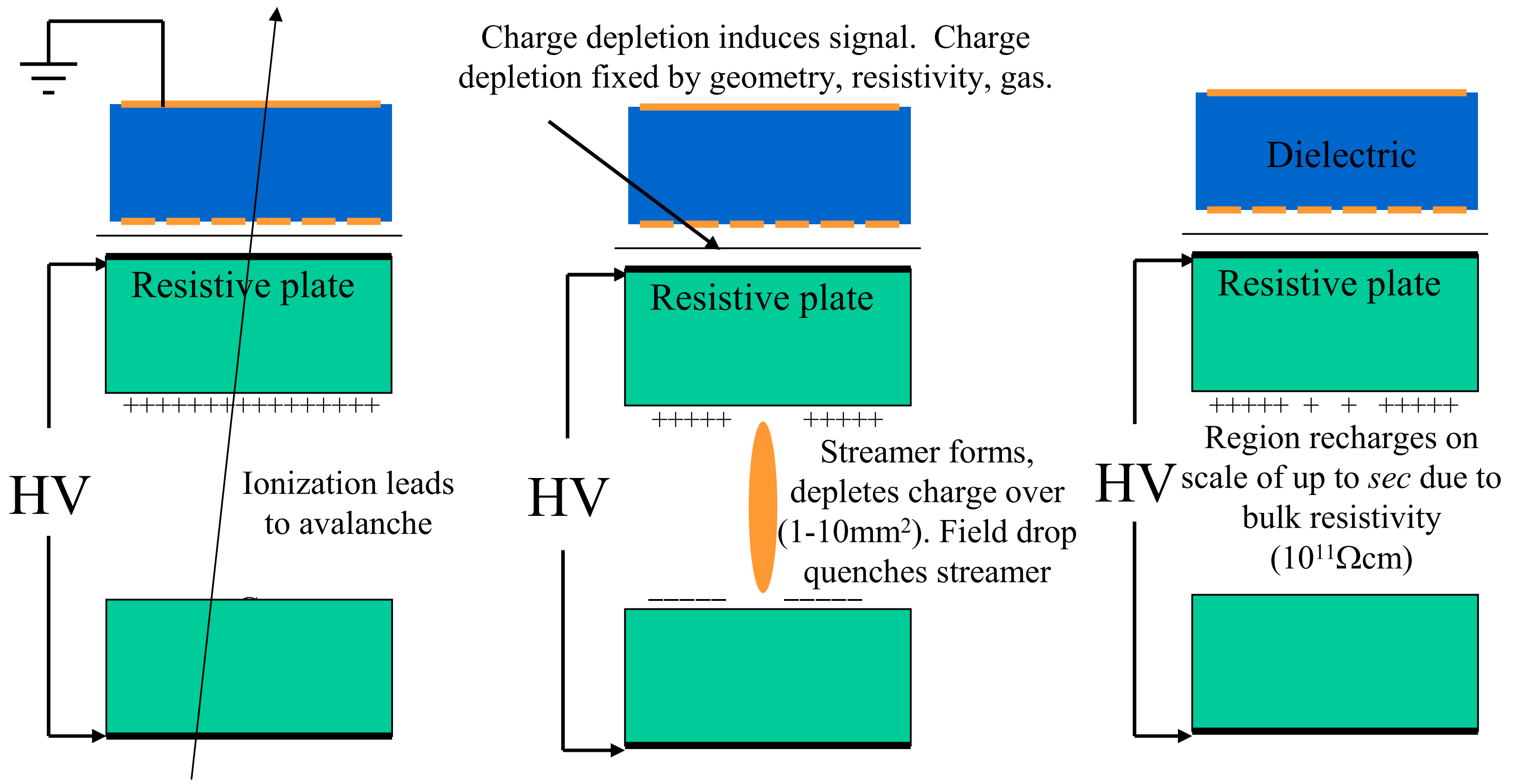
A passing charged particle induces an avalanche, which develops into a spark. The discharge is quenched when all of the locally $(r \approx 0.1\,\mathrm{cm}^2)$ available charge is consumed.



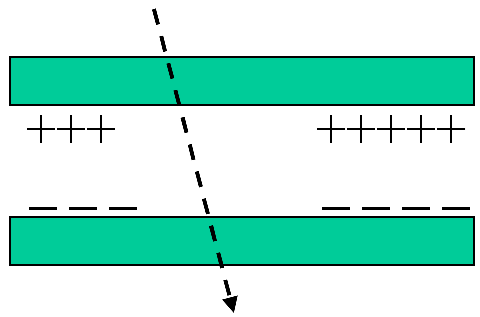
After

The electric field drops only around the streamer location, for a time proportional to the electrode resistivity. The discharged area recharges slowly through the high-resistivity glass plates.

Principle of operation (Signal pickup)



Rate handling capability



As noted, each discharge locally deadens the RPC. The recovery time is approximately

$$\tau = RC \cong \left(\frac{\rho\, l}{A}\right)\left(\frac{\kappa\varepsilon_0 A}{l}\right) = \rho\kappa\varepsilon_0$$

Numerically this is (MKS units)

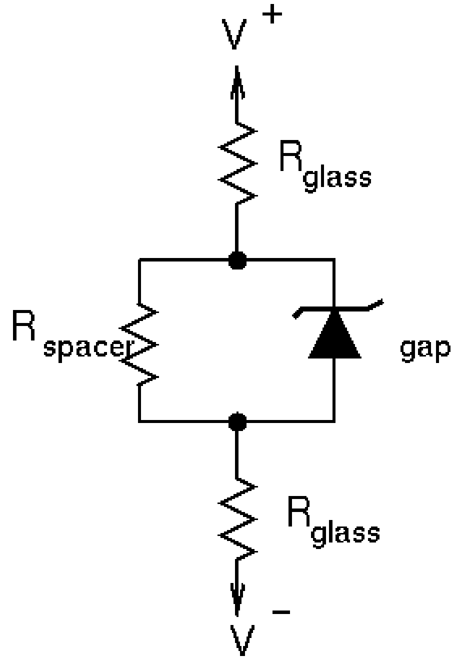
$$\tau = (5 \text{ x } 10^{10}) \text{ x } 4 \text{ x } (8.85 \text{ x } 10^{-12}) = 2 \text{ s}$$

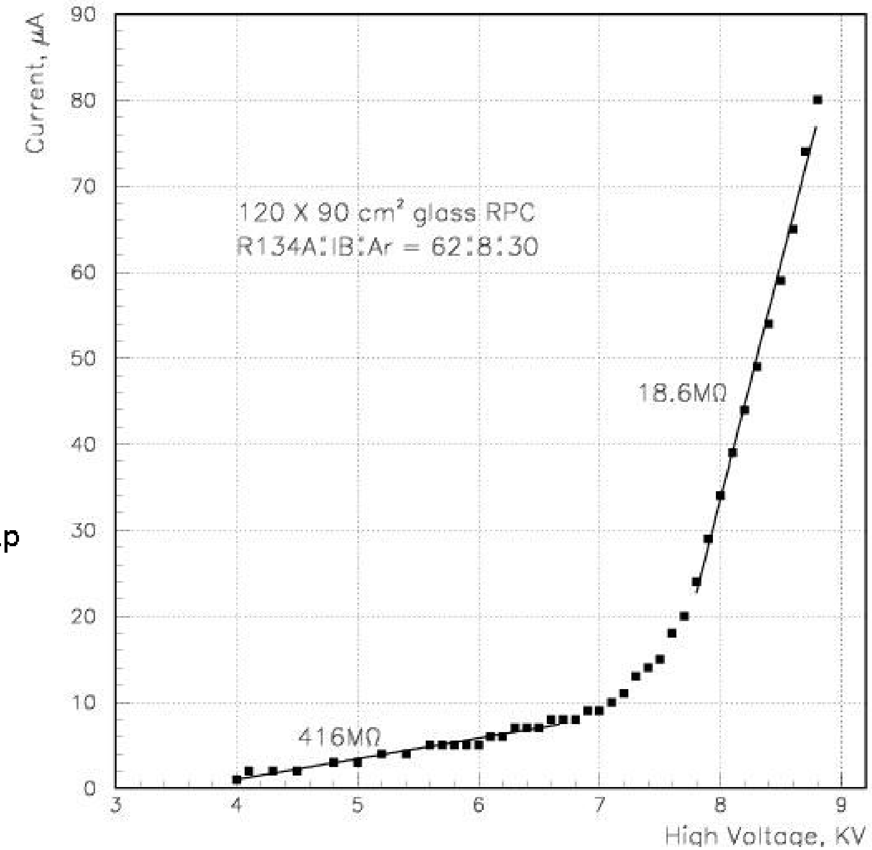
Assuming each discharge deadens an area of $0.1\ \mathrm{cm}^2$, rates of up to $500\ \mathrm{Hz/m}^2$ can be handled with 1% deadtime or less. This is well below what is expected in most of the detector applications.

Voltage-Current characteristics

Glass RPCs have a distinctive and readily understandable current versus voltage relationship.

- Low voltage
  - $R_{gap} \approx \infty$
  - $\frac{dV}{dI} = R_{spacer}$
- High voltage
  - $R_{gap} \approx 0$
  - $\frac{dV}{dI} = R_{glass}$





RPC mode definitions

Let, n_0 = No. of electrons in a cluster

α = Townsend coefficient (No. of ionisations per unit length

β = Attachment coefficient (No. of electrons captured by the gas per unit length

Then, the no. of electrons reaching the anode,

$$n = n_0 e^{(\alpha - \beta)x}$$

Where x = Distance between anode and the point where the cluster is produced

- Gain of the detector, $M = n / n_0$
- M decides the mode of RPC operation
- $M > 10^8 \rightarrow$ Streamer mode;
- $M << 10^8 \rightarrow$ Avalanche (Proportional mode)

RPC mode definitions

- A planar detector with resistive electrodes
  - ≈ Set of independent discharge cells
- Expression for the capacitance of a planar condenser
  - → Area of such cells is proportional to the total average charge, Q that is produced in the gas gap.

$$S = \frac{Qd}{\varepsilon_0 V}$$

Where, d = gap thickness
V = Voltage applied to the electrodes
ε_0 = Dielectric constant of the gas

Lower the Q, Lower the area of the cell (that is 'dead' during a hit) and hence higher the rate handling capability of the RPC

Q ~ 100pC = Streamer mode
Q ~ 1pC = Proportional (Avalanche) mode