Resistive Plate Chambers

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Outline

- History and introduction to RPC
- Characteristics and merits of RPC
- Basic principles of operation
- Operating modes
- Types of RPCs
- Construction of RPCs
- Gas mixture issues
- RPC detector signal conditioning
- Test stands and characterisation procedures
- Problem of RPC aging
- RPCs for INO ICAL detector
- Course module summary
- Acknowledgements and References

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History

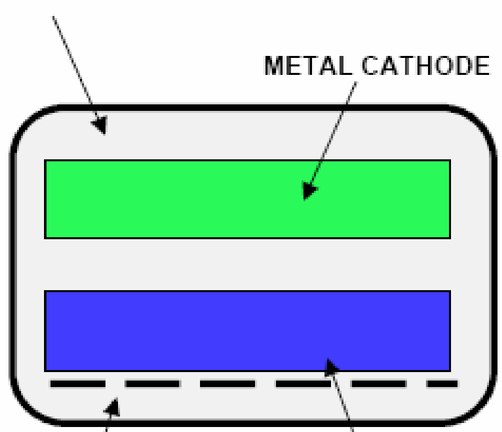
- Introduced by R.Santonico & R.Cardarelli (NIM 187, 1981 & NIM 263, 1988)
- Practical alternative to the *Localised discharge spark counters* (NIM 93, 1971)

Spark (Pestov) counters

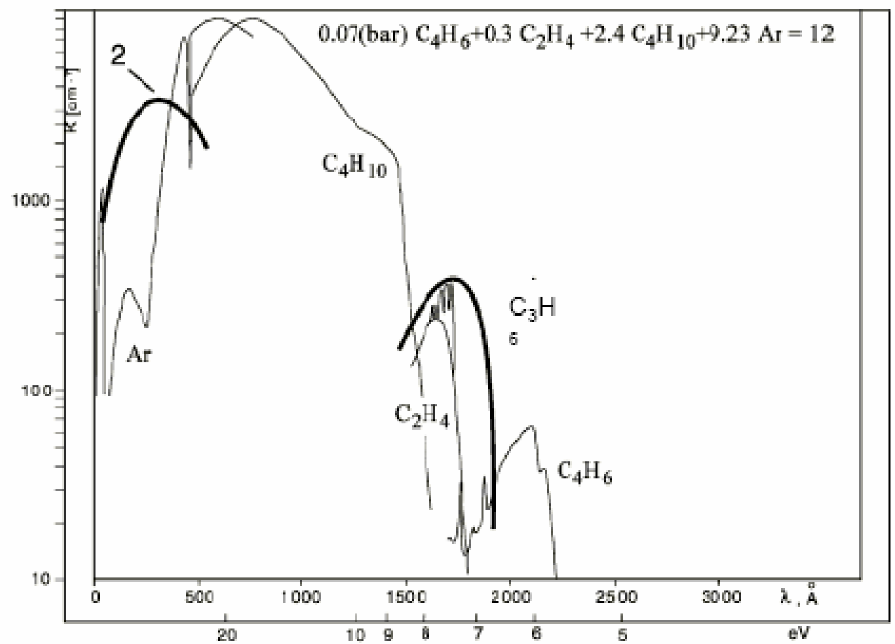
GOOD TIME RESOLUTION ---> THN GAP
GOOD EFFICIENCY---> THICK GAS LAYER

THIN GAP (100 µm) AND HIGH PRESSURES (~10 bar)
HIGH RESISTIVITY ELECTRODE
(PESTOV GLASS, $10^9\ \Omega$ cm

Yu. Pestov
Nucl. Instr. and Meth. 196(1982)45



DESIGNER'S GAS MIXTURE FOR WIDE SPECTRUM PHOTON ABSORPTION:

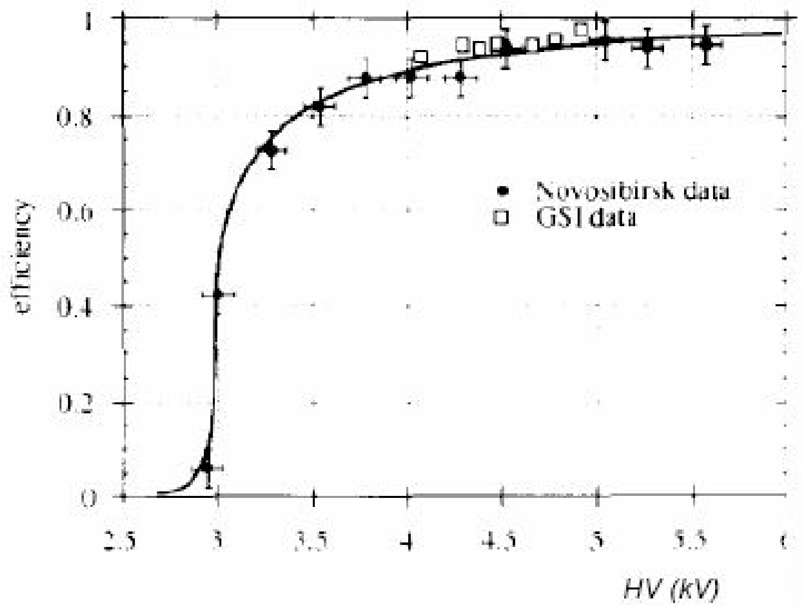


Yu. Pestov et al, Nucl. Instr. and Meth. A456(2000)11
H. R. Schmidt, Nucl. Phys. B (Proc. Suppl.) 78 (1999) 372

Spark counter performance

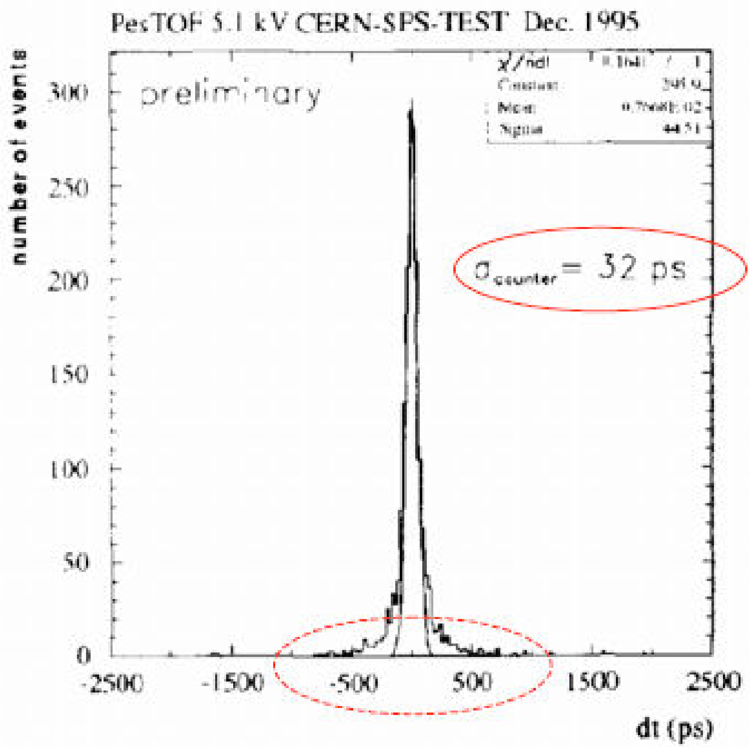
100 µm GAP 12 BAR PRESSURE

EFFICIENCY



E. Badura et al, Nucl. Instr. and Meth. A379(1996)

TIME RESOLUTION



PHYSICAL ORIGIN OF TAILS IN THE TIME RESPONSE OF SPARK COUNTERS:

A. Mangiarotti and A. Gobbi, Nucl. Instr. and Meth. A482(2002)192

What is an RPC?

- HV/Gas device using resistive plates as parallel electrodes
- High electrode bulk resistivity
- HV distribution surface
- Self quenching of streamer through charge depletion
- Capacitive signal readout; no HV blocking!
- High enough surface resistivity to prevent signal shielding

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Characteristics and merits

- Large detector area coverage, thin (~10mm)
- Flexible detector and readout geometry designs
- Solution for tracking, calorimeter, muon detectors
- Trigger, timing and special purpose design versions
- Built from simple/common materials; low fabrication cost
- Ease of construction and operation
- Highly suitable for industrial production
- Detector bias and signal pickup isolation
- Simple signal pickup and front-end electronics; digital information acquisition
- High single particle efficiency (>95%) and time resolution (~1nSec)
- Particle tracking capability; 2-dimensional readout from the same chamber
- Scalable rate capability (Low to very high); Cosmic ray to collider detectors
- Good reliability, long term stability
- Under laying Physics mostly understood!

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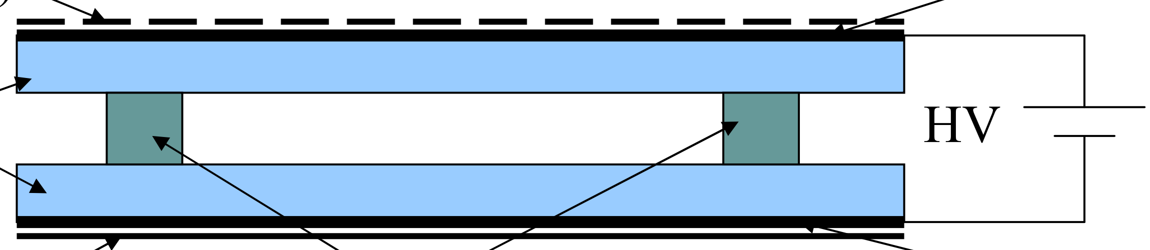
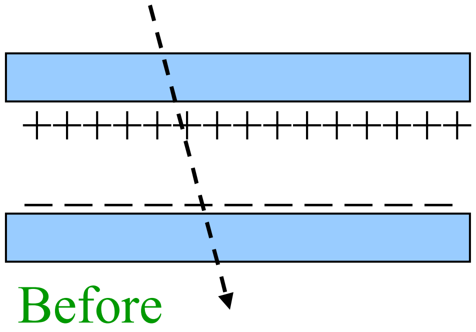
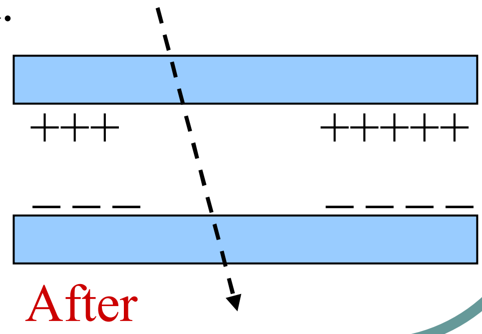
Principle of operation (Streamer)



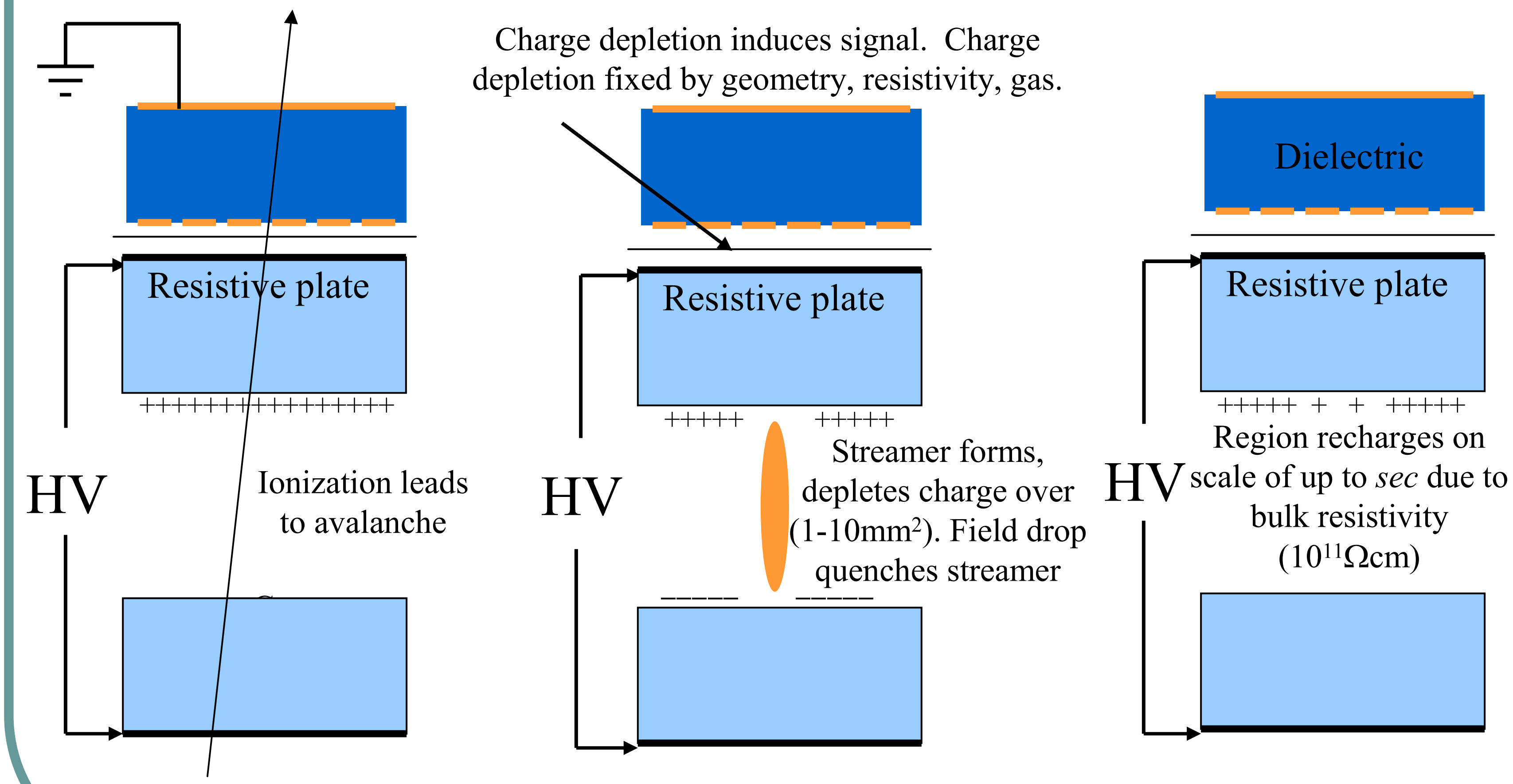


A passing charged particle induces an avalanche, which develops into a spark. The discharge is quenched when all of the locally $(r \approx 0.1\,\mathrm{cm}^2)$ available charge is consumed.



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)



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

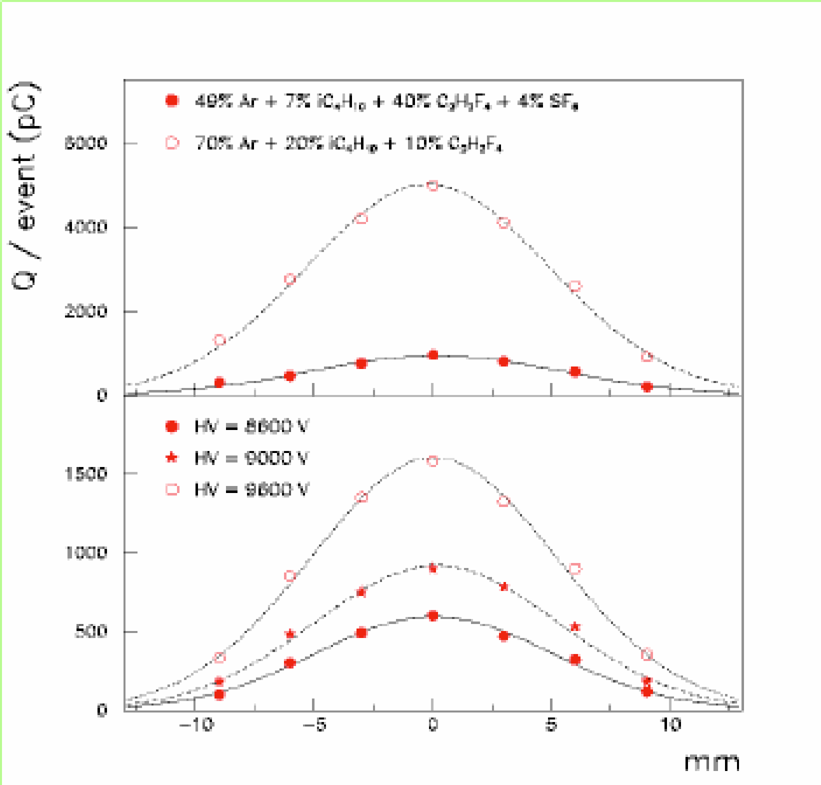
Lower the Q, Lower the area of the cell (that is 'dead' during a hit) and hence higher the rate handling capability of the RPC

Q ~ 100pC = Streamer mode

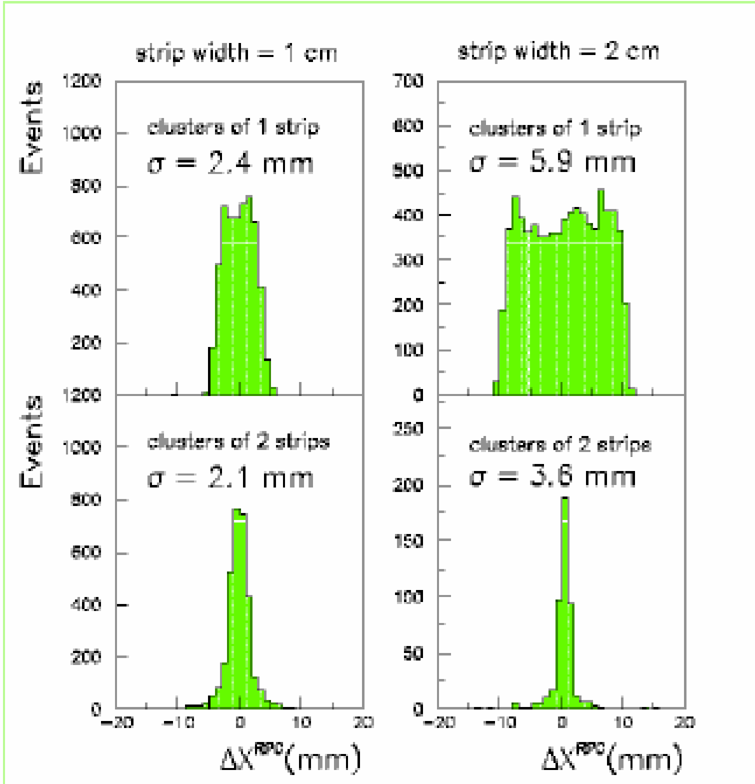
Q ~ 1pC = Proportional (Avalanche) mode

Induced charge distribution

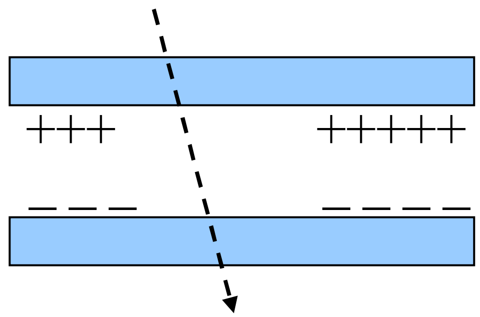
2 mm gap
STREAMER MODE



Induced charge is only ~5% of the total charge collected by the anode



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)

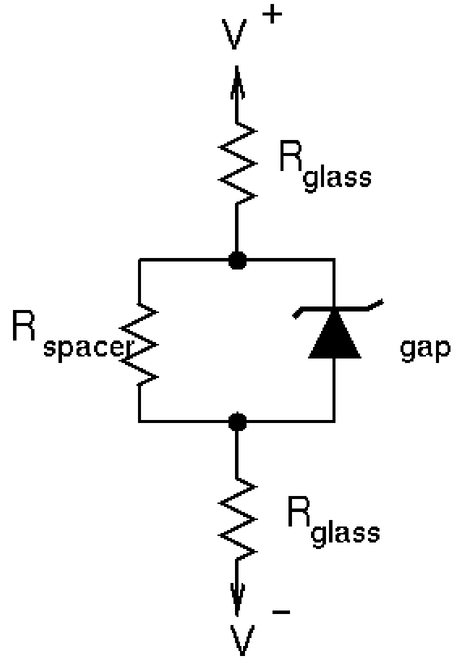
$$\tau = (5 \times 10^{10}) \times 4 \times (8.85 \times 10^{-12}) = 2\ \mathrm{s}$$

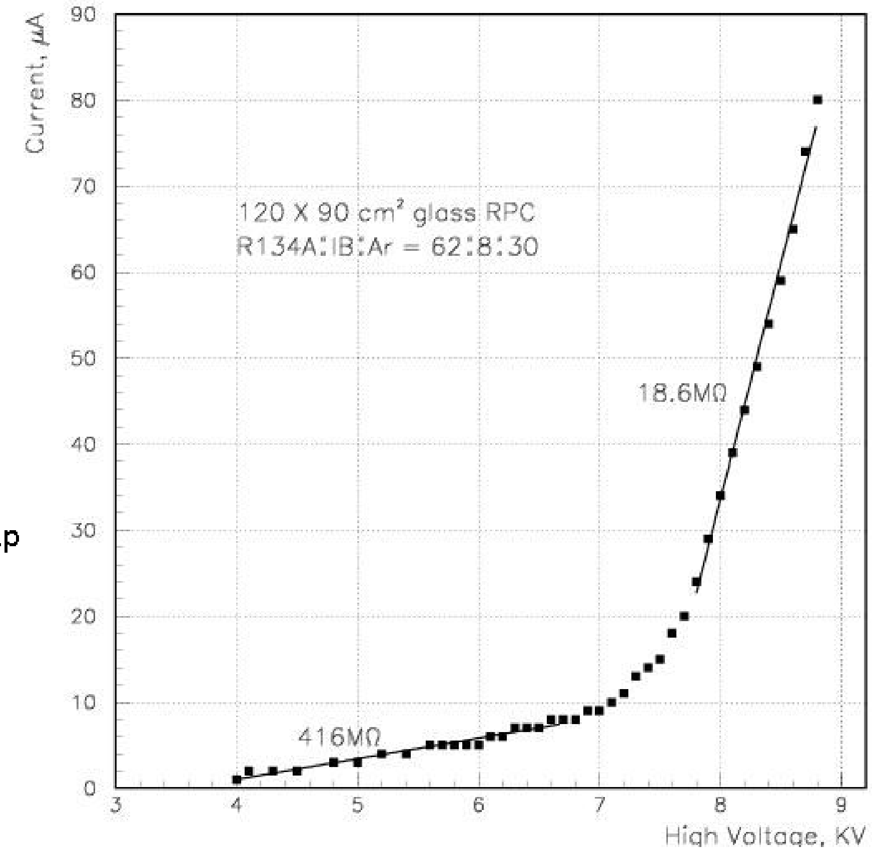
Assuming each discharge deadens an area of $0.1\ \mathrm{cm}^2$, rates of up to $500\ \mathrm{Hz/m}^2$ can be handled with 1% deadtime or less. This is well below what is expected in most of the detector applications.

Voltage-Current characteristics

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

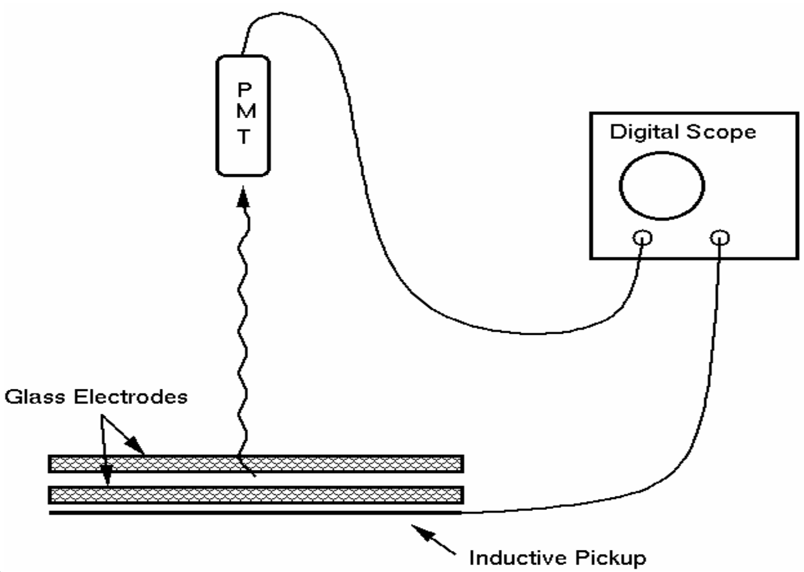
- Low voltage
  - $R_{gap} \approx \infty$
  - $\frac{dV}{dI} = R_{spacer}$
- High voltage
  - $R_{gap} \approx 0$
  - $\frac{dV}{dI} = R_{glass}$

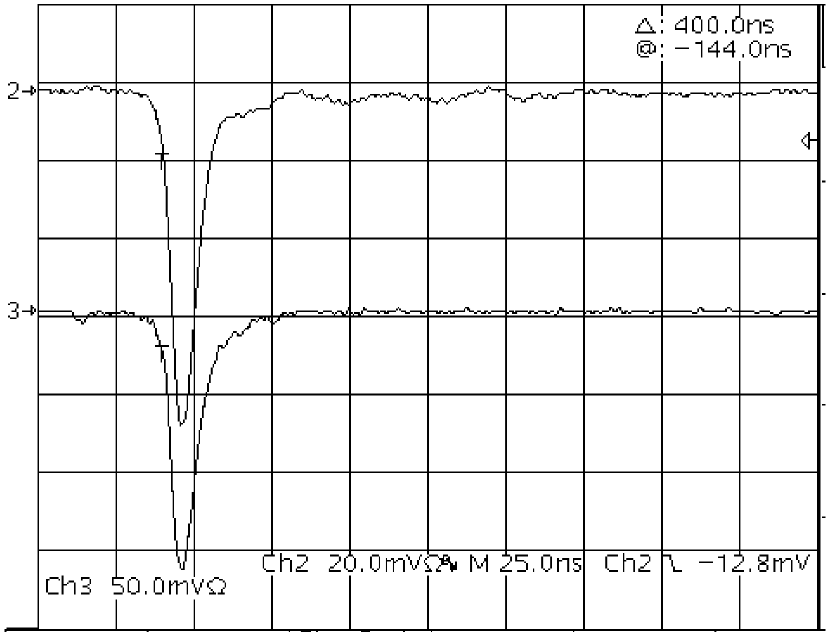




Typical signal shape

One interesting feature of RPCs is that the signal can be observed both using a pickup electrode and by viewing the light signal using a PMT.





The pulses are large (~100 mV into 50 ohms) and fast (FWHM ~ 15ns)

There is a very good correlation between the electronic and the light signal.

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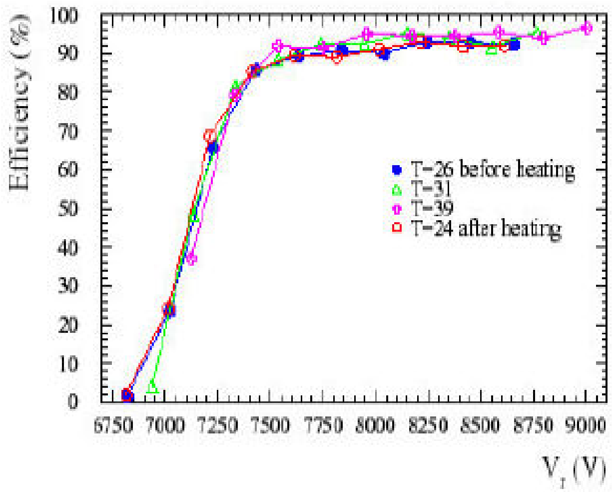
RPC modes of operation

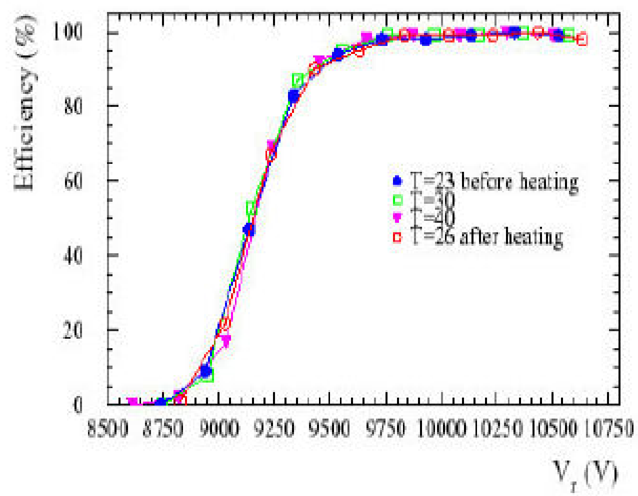


Streamer mode

$Ar/TFE/C_4H_{10}/SF_6$= 48/47/4/1

Efficiency @ working point ~ 97%

- Big signals
- Very low H_2O contamination is needed



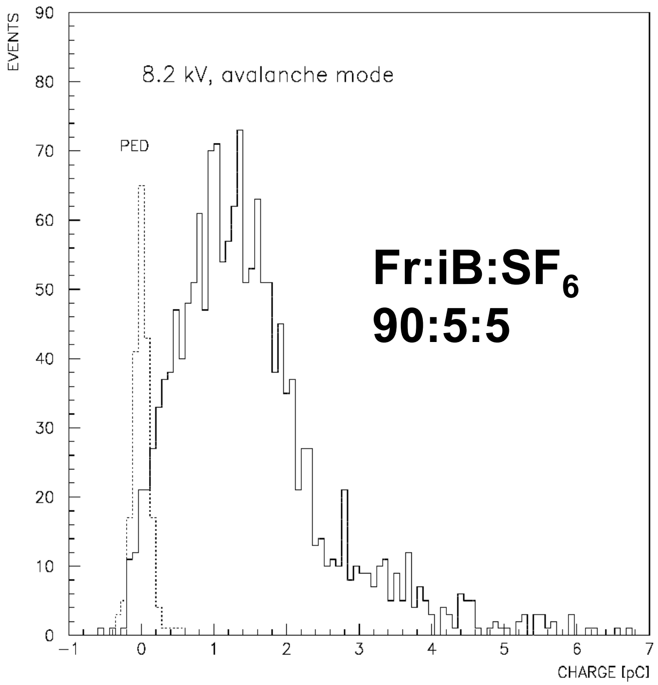
Avalanche mode

$TFE/C_4H_{10}/SF_6$= 95/4/1

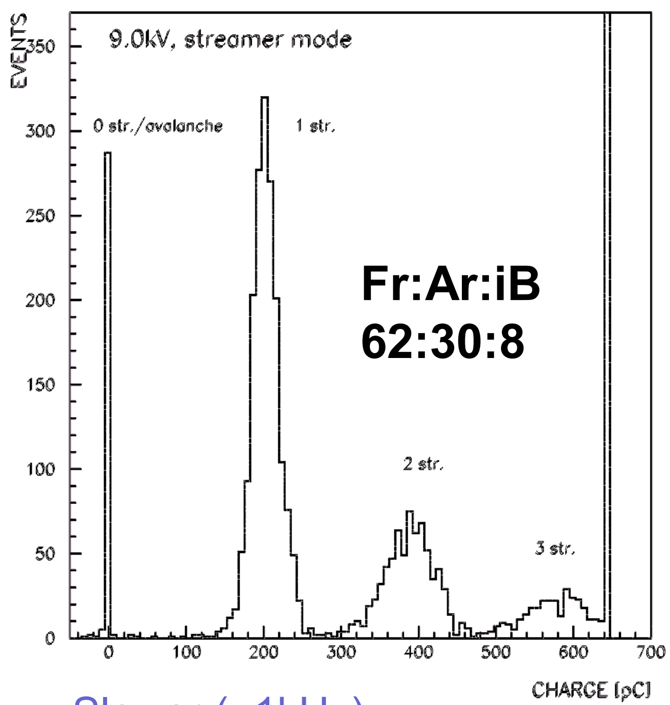
Efficiency @ working point ~ 99%

- Smoother operation.
- Higher efficiency value with respect to the streamer mode.
- Small signals

Comparison of RPC modes



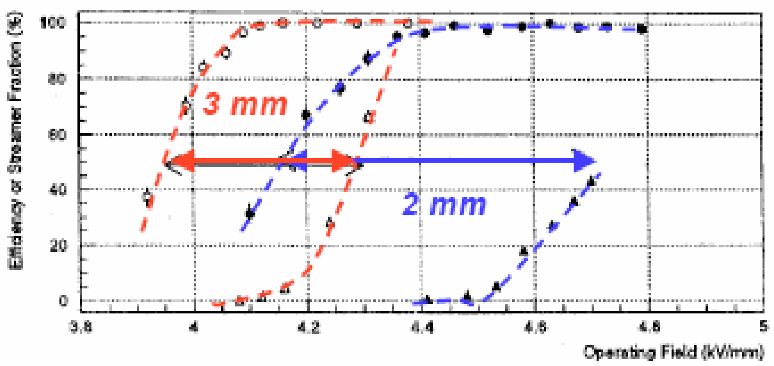
Faster (~10kHz)
Lower HV (Insulation issues)
Smaller signal (~1pC)
Needs pre-amplifier
Better long-term prognosis
No multiple streamers



Slower (~1kHz)
Higher HV
Large signals(~100pC)
Sharp signal
Multiple streamers

Gap dependence

THE SEPARATION AVALANCHE-STREAMER DEPENDS ON THE GAP:



○ 3 mm EFFICIENCY (Threshold = 30 mV)

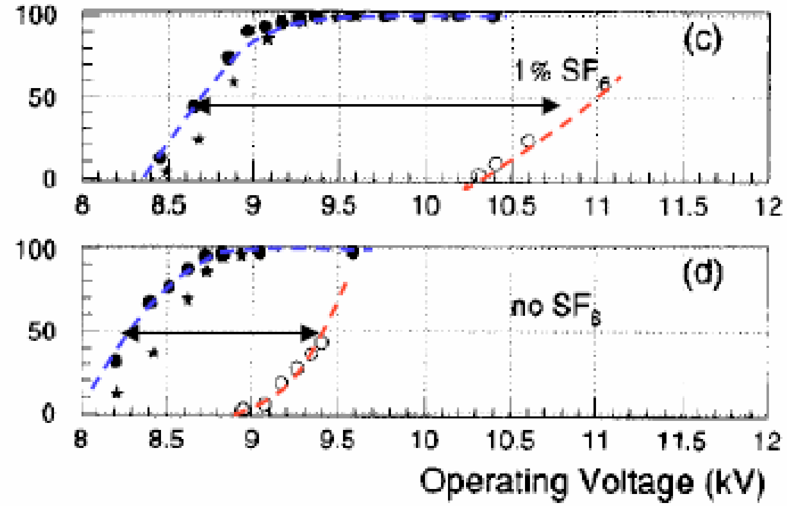
△ 3 mm STREAMER FRACTION

● 2 mm EFFICIENCY (Threshold = 30 mV)

▲ 2 mm STREAMER FRACTION

R. Santonico, Scient. Acta XII N2(1997)1

SMALL ADDITIONS OF ELECTRO-NEGATIVE GASES EXTEND THE SEPARATION:

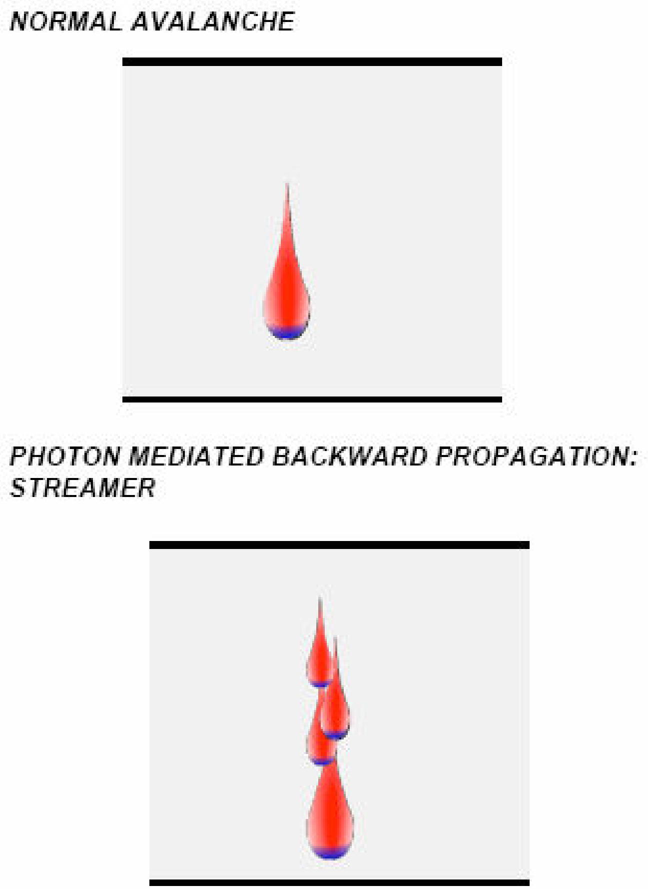


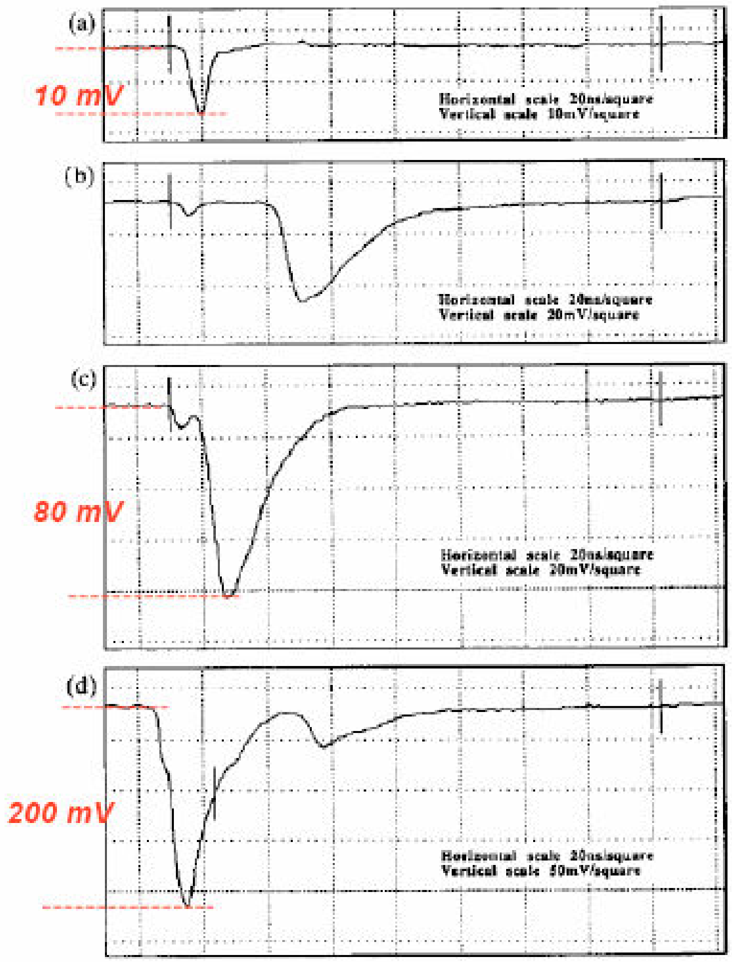
● EFFICIENCY (threshold = 30 mV)

★ EFFICIENCY (threshold = 100 mV)

○ STREAMER FRACTION

Avalanche to streamer transition





Parameters controlling the modes

- Gases (especially the *quenchers*) and their proportions
  - Special role of SF_6
- Applied high voltage
- Gas gap

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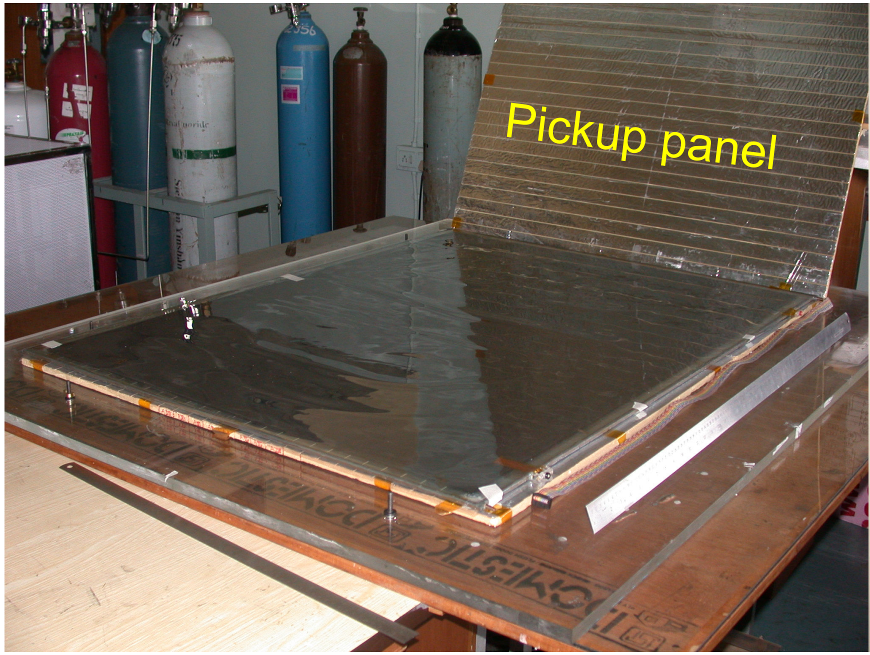
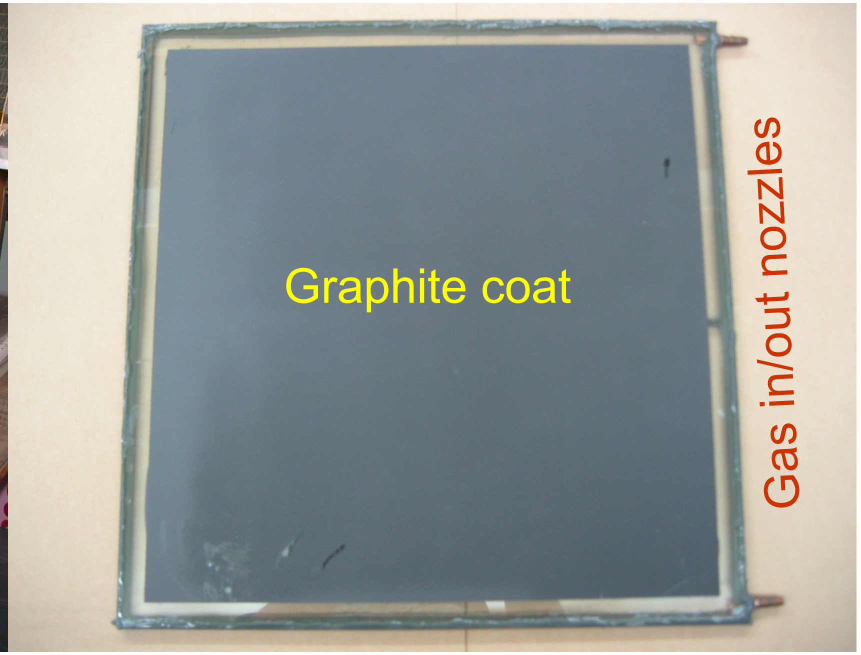
Single gap chambers (Glass)



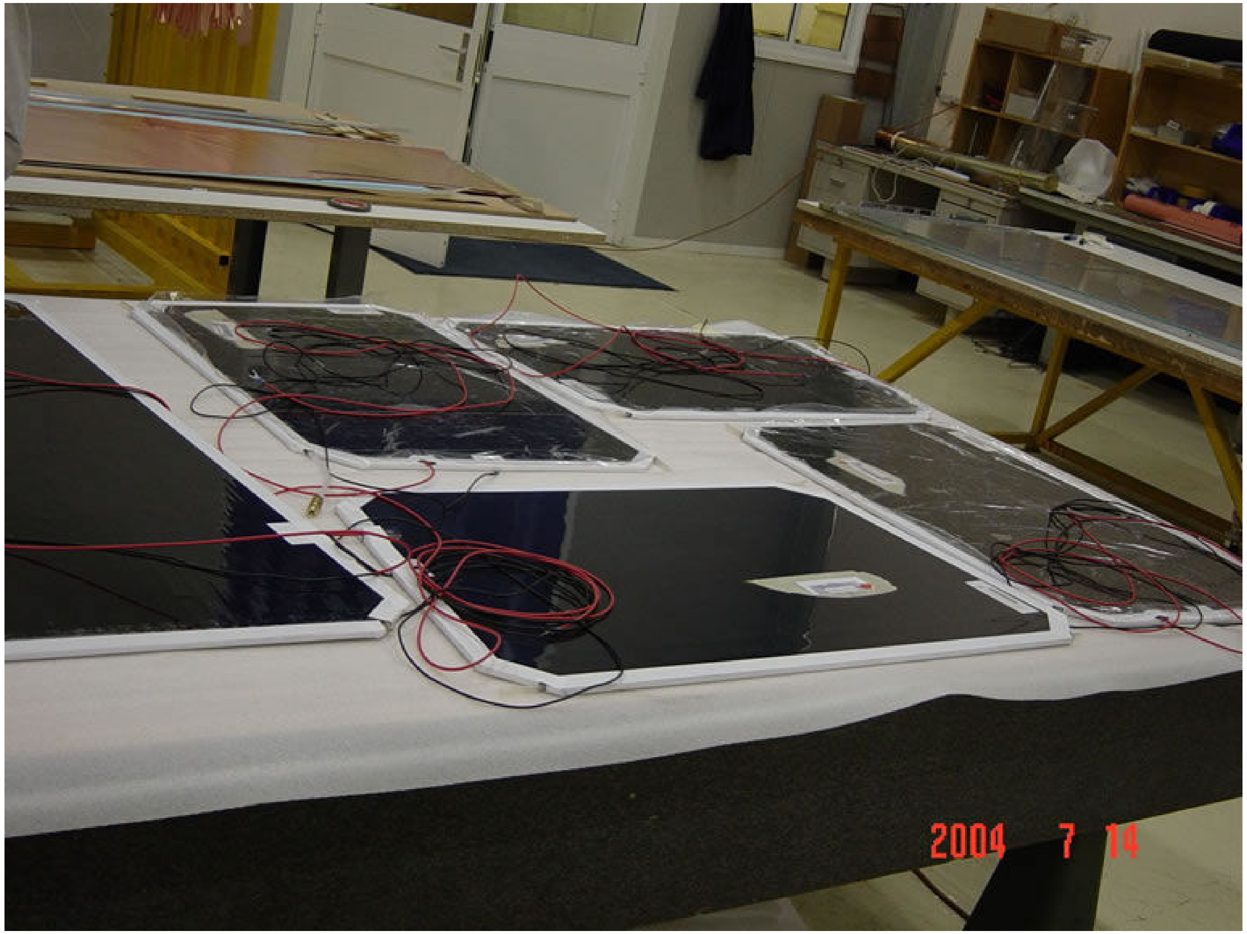
1200 X 900 mm



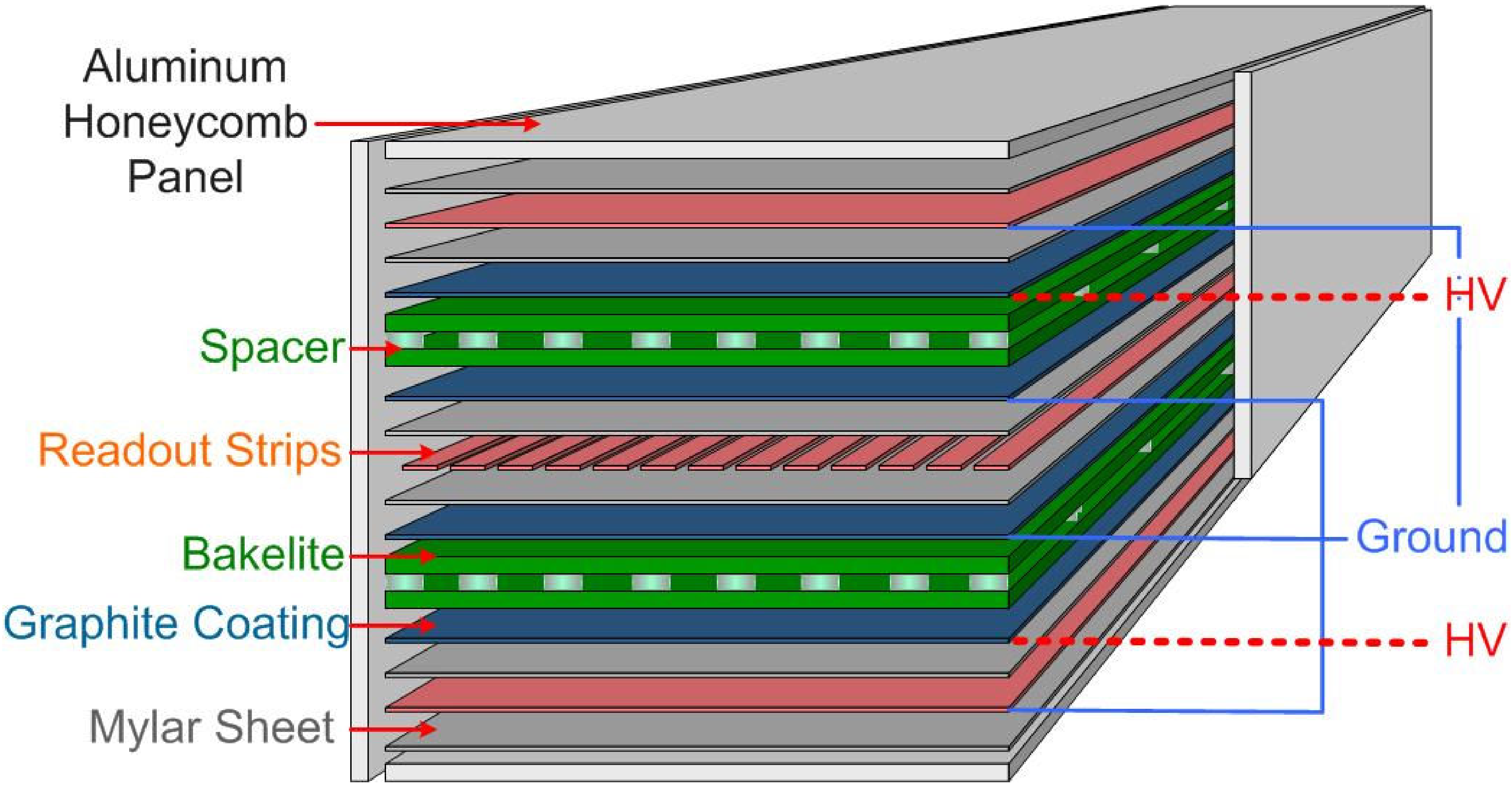
400 X 300 mm

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

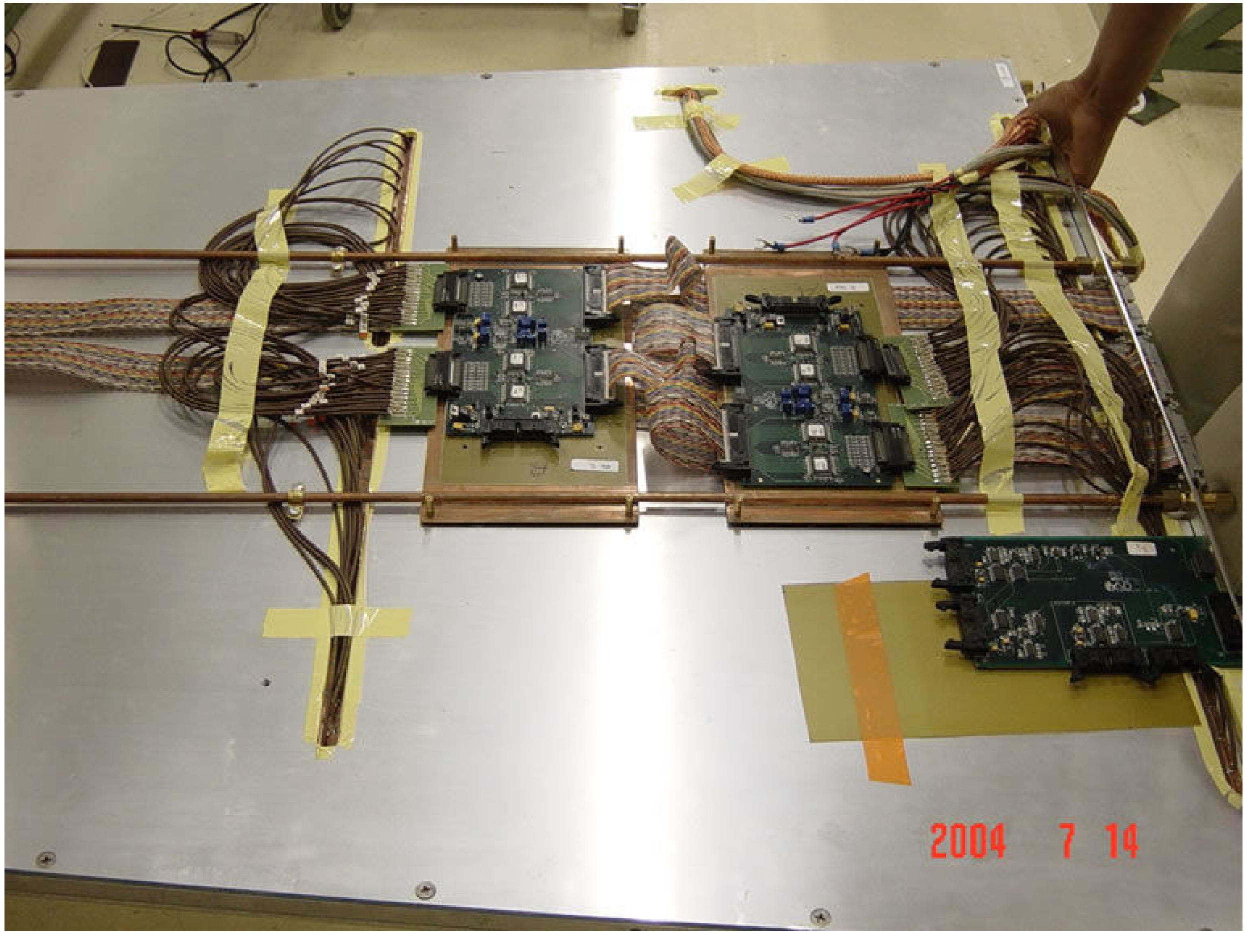
Single gap chambers (Bakelite)



CMS RPC module concept



An assembled RPC module

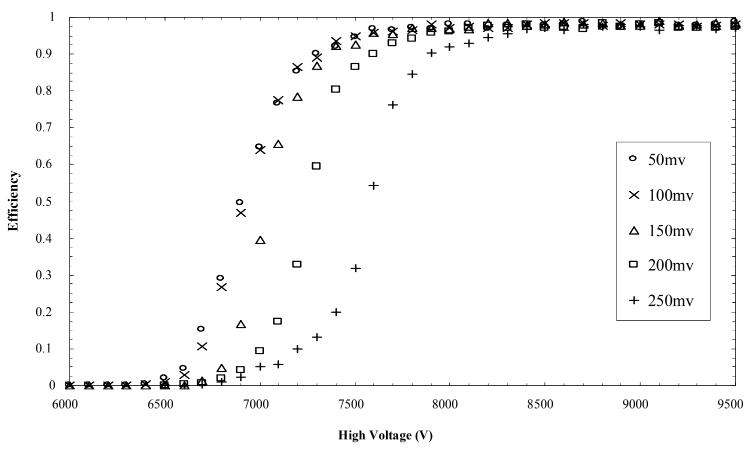


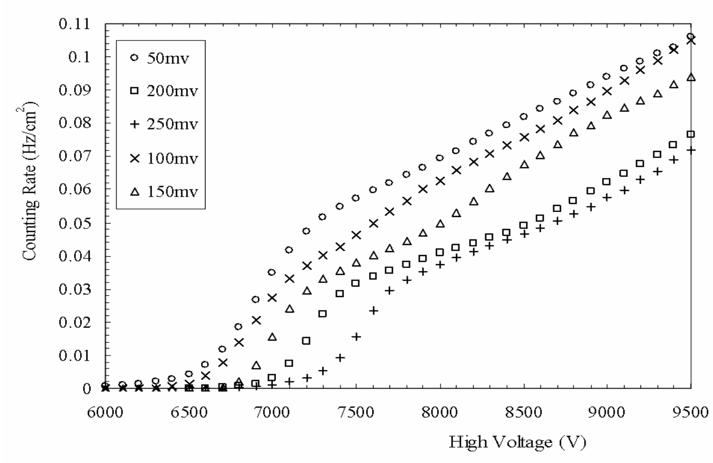
Facility for bakelite RPC oiling

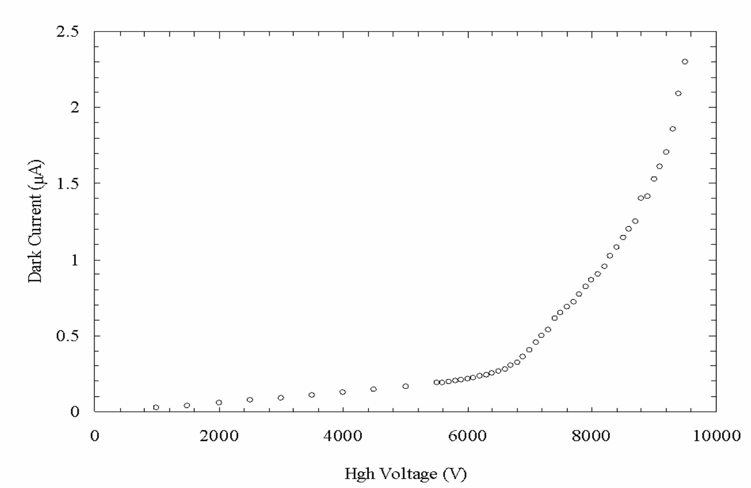
Oil-less bakelite resistive plates

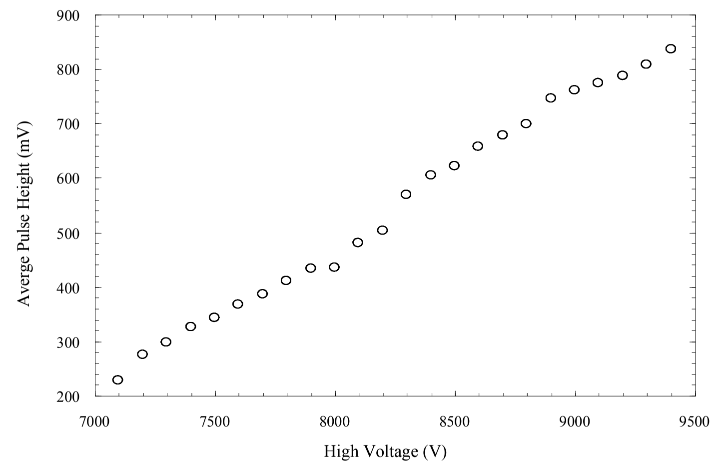
- The most important innovation is a method to improve the surface smoothness(~200nm) and control resistivity(10^9 -10^{14} $\Omega \cdot cm$) when the resistive plates are produced in the factory.
- The surfaces of the resistive plates are covered by a layer of specially formulated plastic film. The prefabricated film laminated onto the surface of the phenolic paper plate during the high pressure lamination process can reduce the surface defects caused by the steel plates used in the lamination process. The thickness of the film is 50 μm and the resistivity of the resistive plates can be adjusted to optimize the performance of RPCs.

Results of oil-less bakelite RPCs

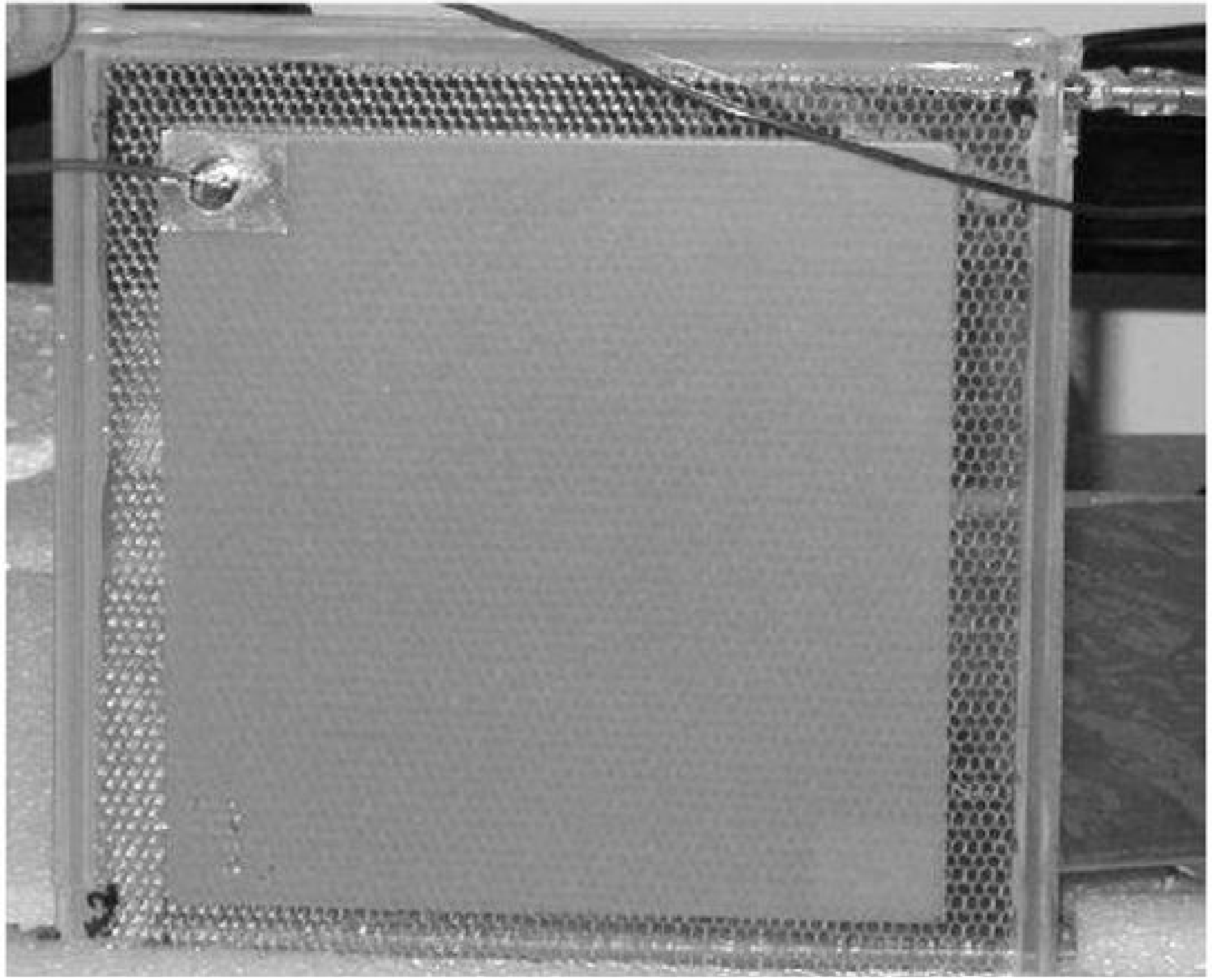








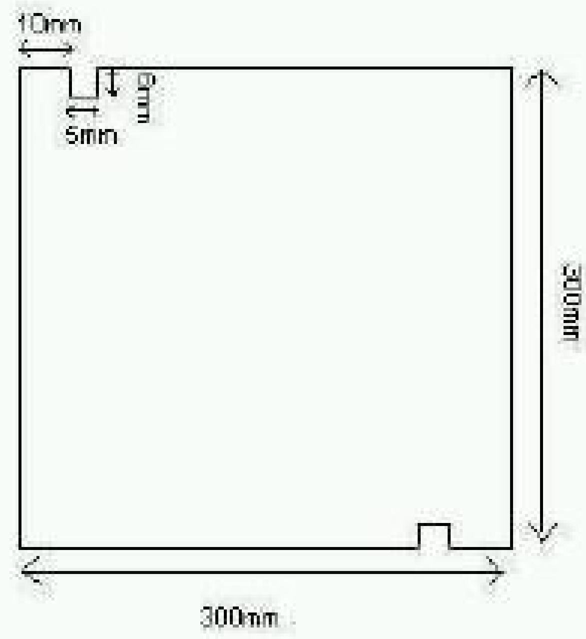
A honeycomb based quencher



Why multi gap RPCs?

- There is only one merged avalanche in a single gap leading to avalanche fluctuations
- We need a finite distance close to cathode in order that clusters of ionisation are produced; smaller the gap, better the timing

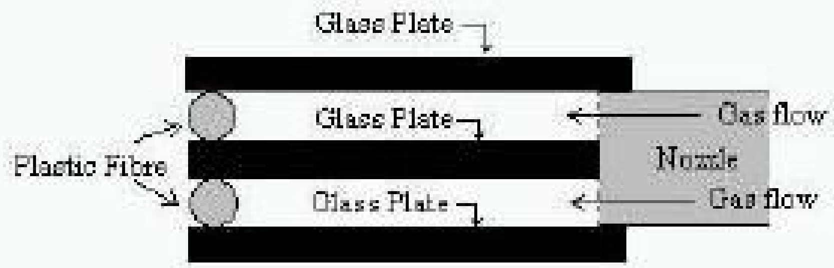
Double gap chambers



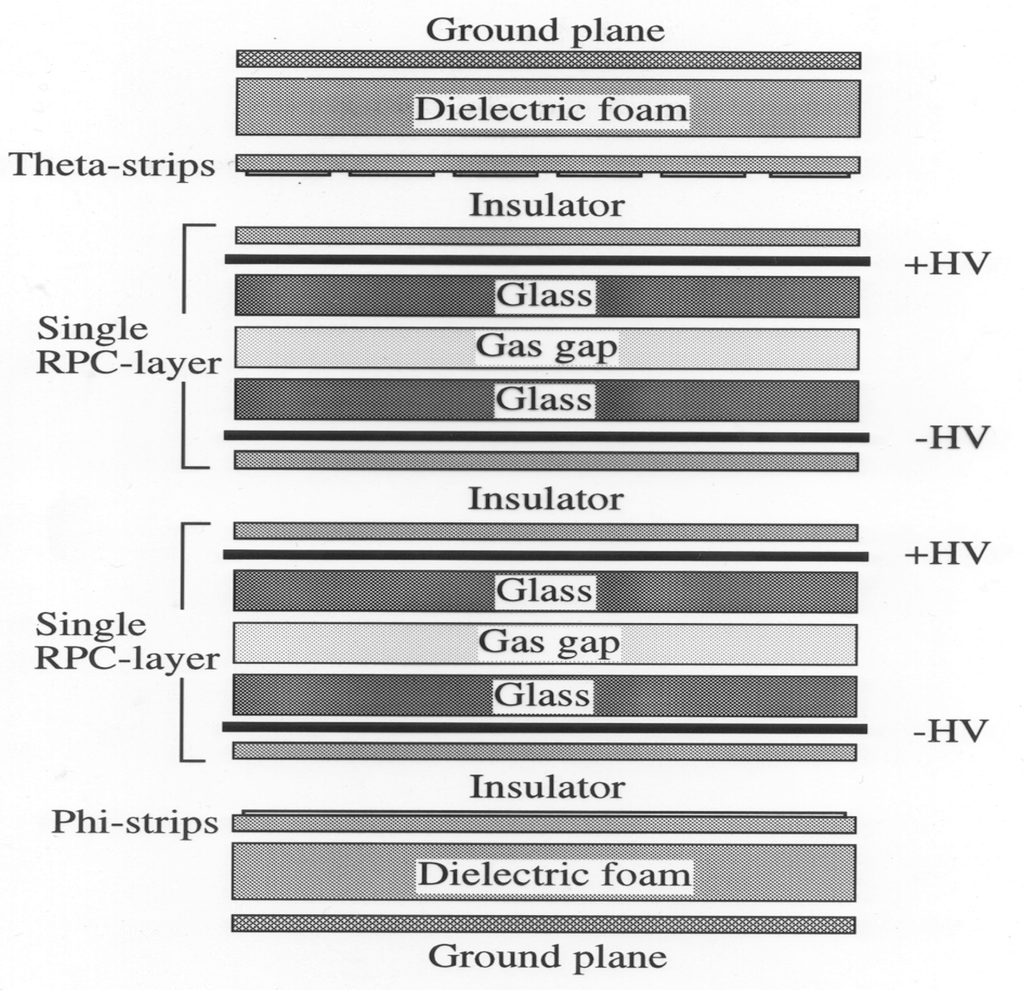
Double gap RPCs for better detection efficiencies

$$Efficiency \approx (1 - effi)^n$$

Where n = Number of gas gaps,
$effi$ = Efficiency of individual gaps

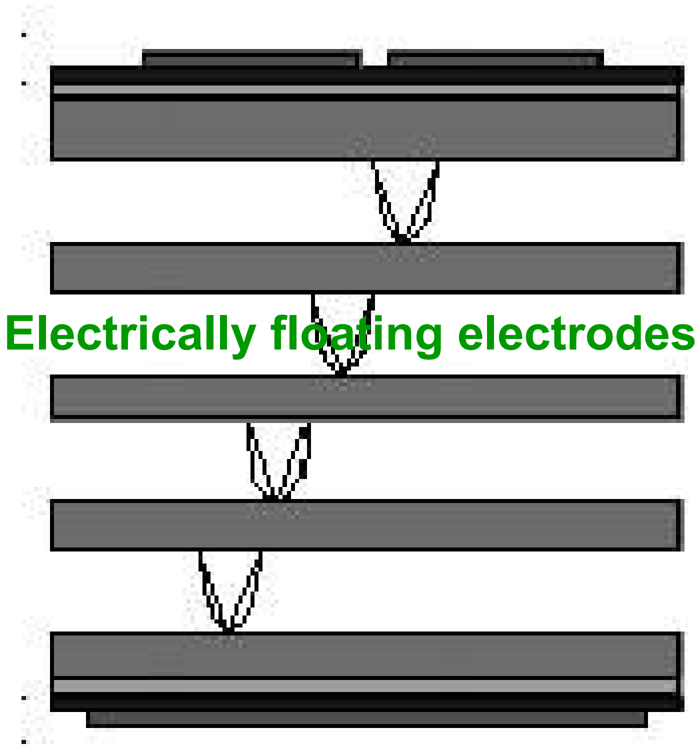


Double gap RPC (Belle design)



Multi-gap RPC designs

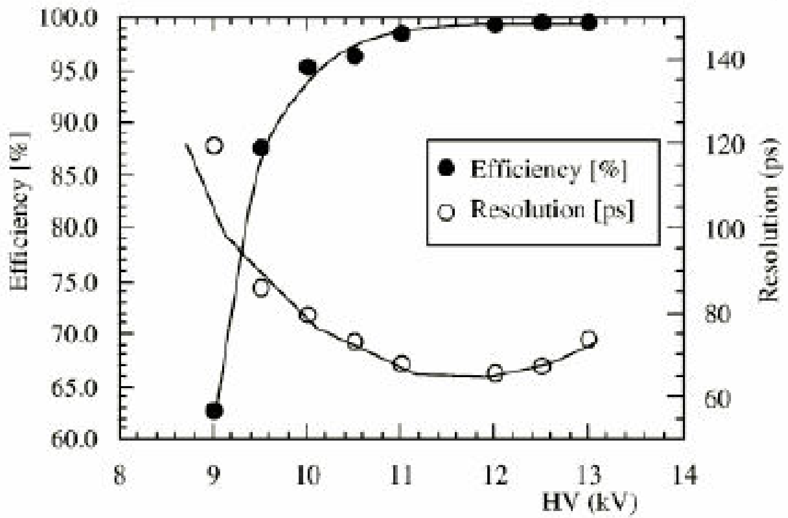
- *Timing RPCs*
- Time-of-flight applications
- Ex: ALICE, STAR etc
- Division of gas volume
- Division of bias voltage
- Small charges/gap
- Improvement of time resolution
- Ageing issue



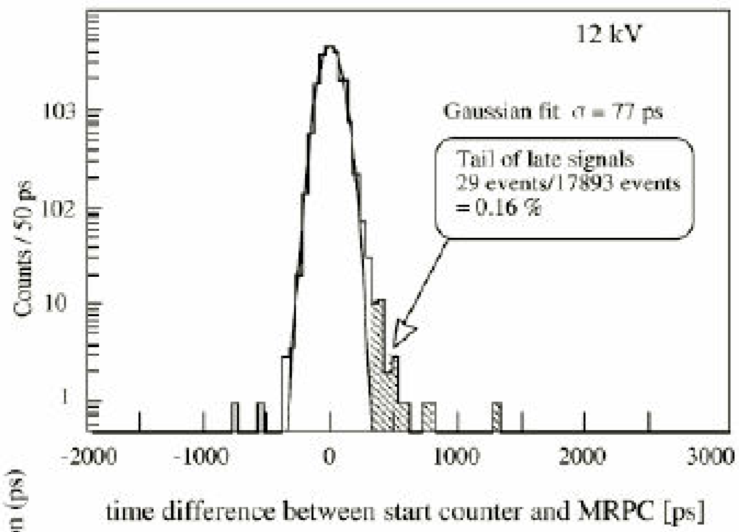
MULTIGAP RPC

SEVERAL RESISTIVE ELECTRODE PLATES WITH NARROW GAPS
ALL INTERNAL PLATES ARE FLOATING (SET AT PROPER VOLTAGE BY ELECTROSTATICS)

E. Cerron Zeballos et al, Nucl. Instr. and Meth. A 374(1996)132

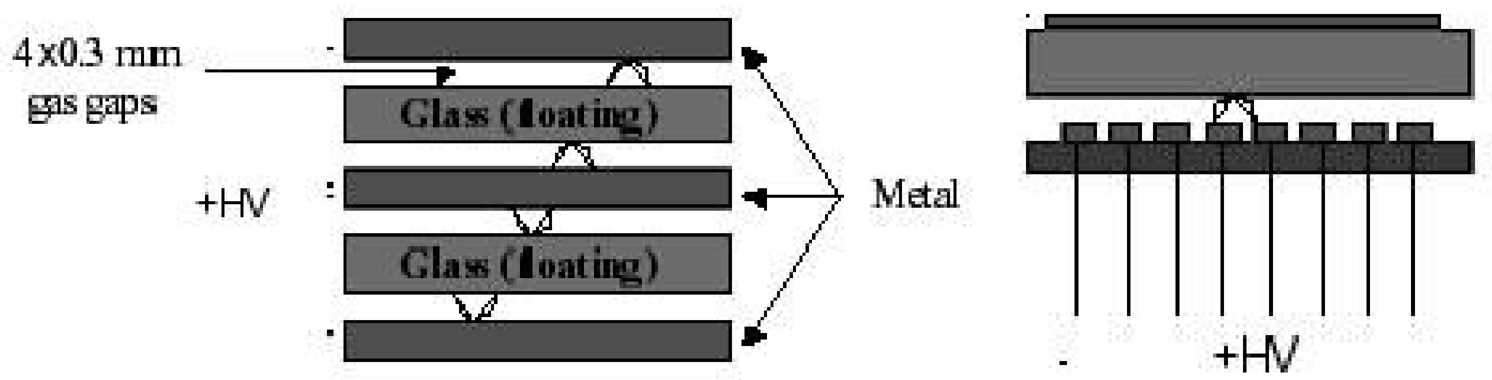


Typical time spectrum from 5 gap MRPC



A. Akindinov et al,
Nucl. Instr. and Meth. A456(2000)16

Hybrid and micro RPC designs



- Useful in very high counting rate areas
- Special RPCs for very fine spatial resolution
- Equipped with solid X-ray converters
- Medical imaging applications

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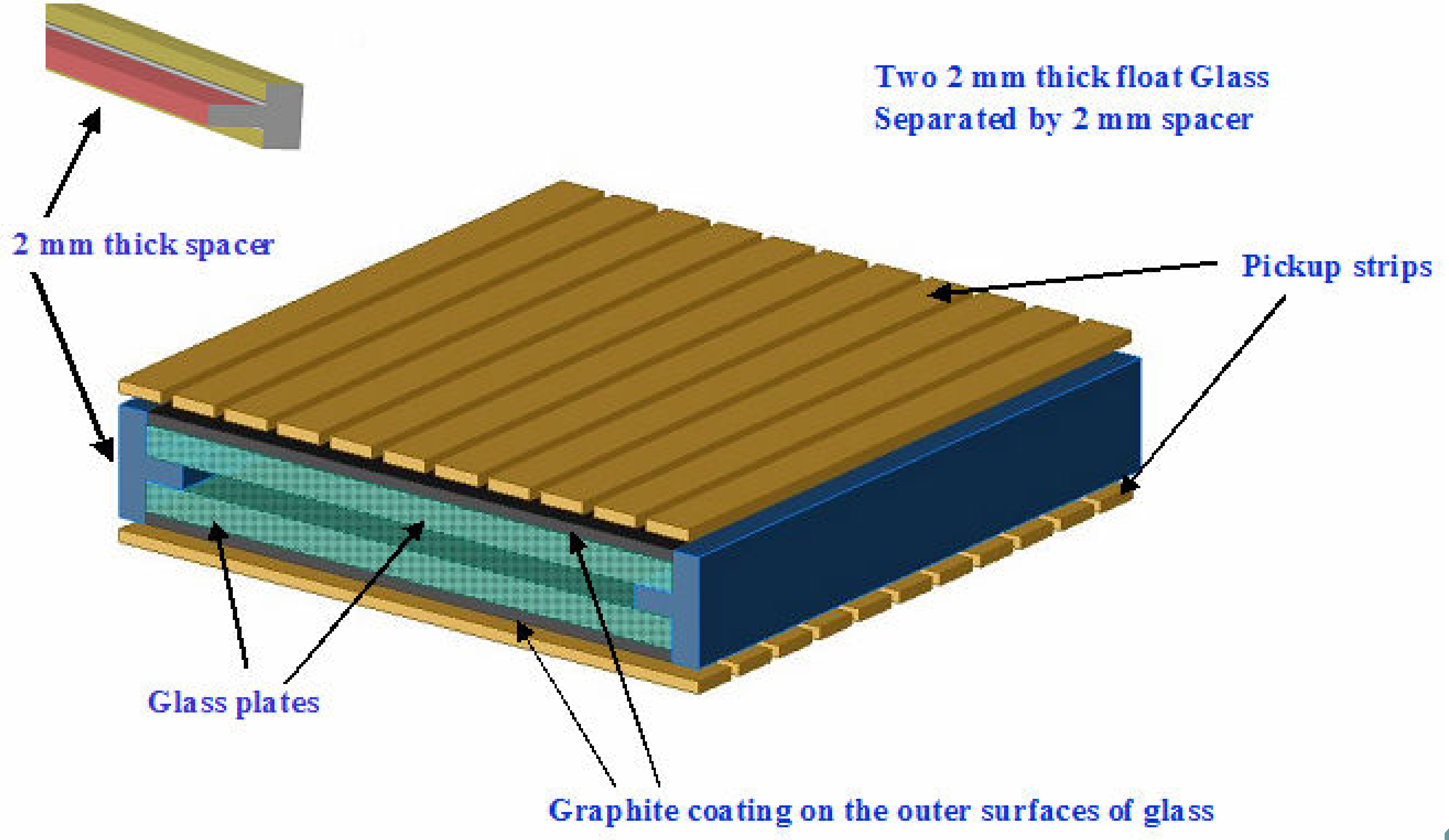
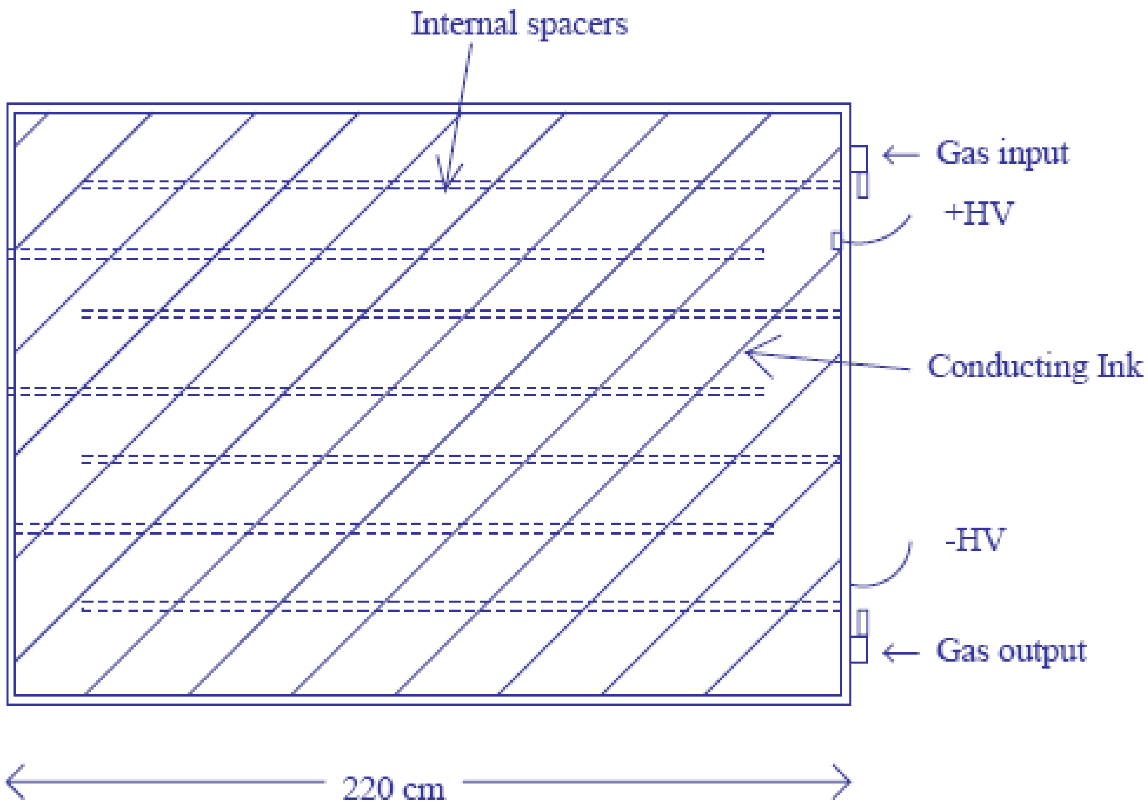
RPC construction

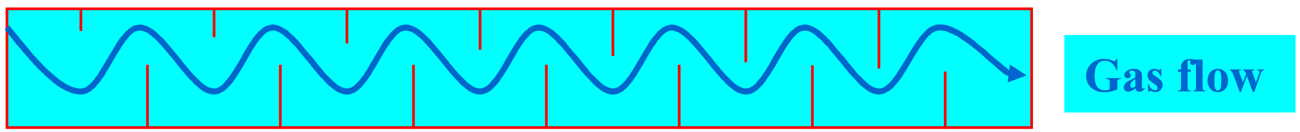


RPC fabrication procedure

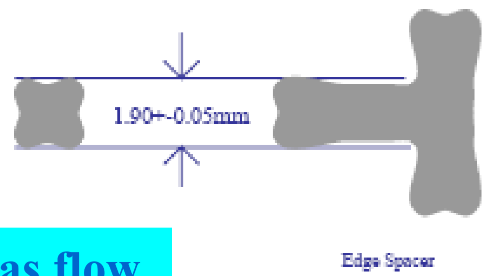
- Electrode preparation, material QC
- Electrode cleaning
- Spacers, frames, gas nozzles preparation
- Gluing of the RPC, QC (leak and flow tests)
- Electrode coating, QC (resistivity)
- Mylar preparation, high voltage contacts
- Pickup panel preparation
- HV holding and V-I tests
- RPC signal, signal readout chain checks
- Efficiency plateauing of the chamber
- Long term stability tests
- QC sheets and database

RPC construction

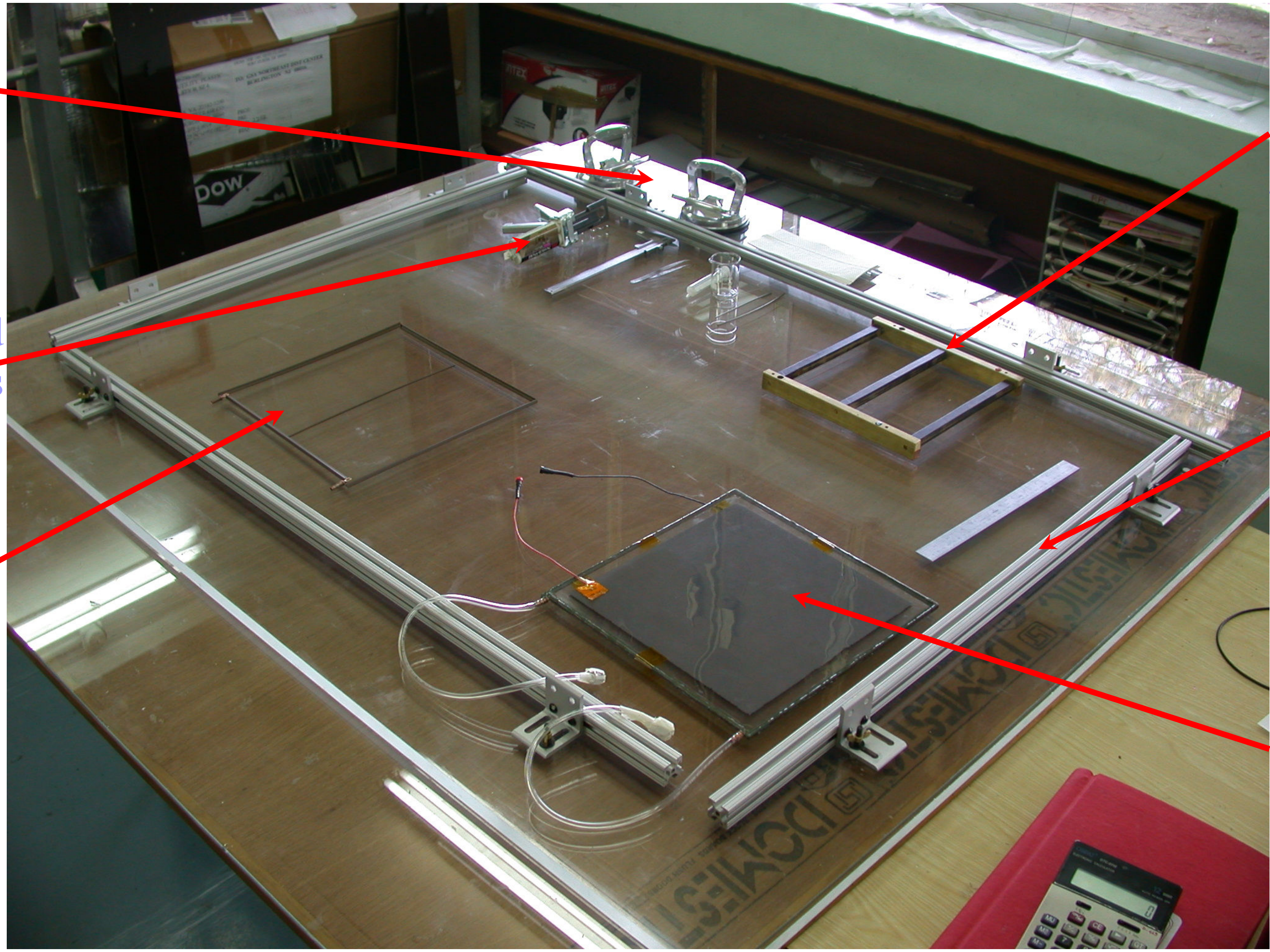




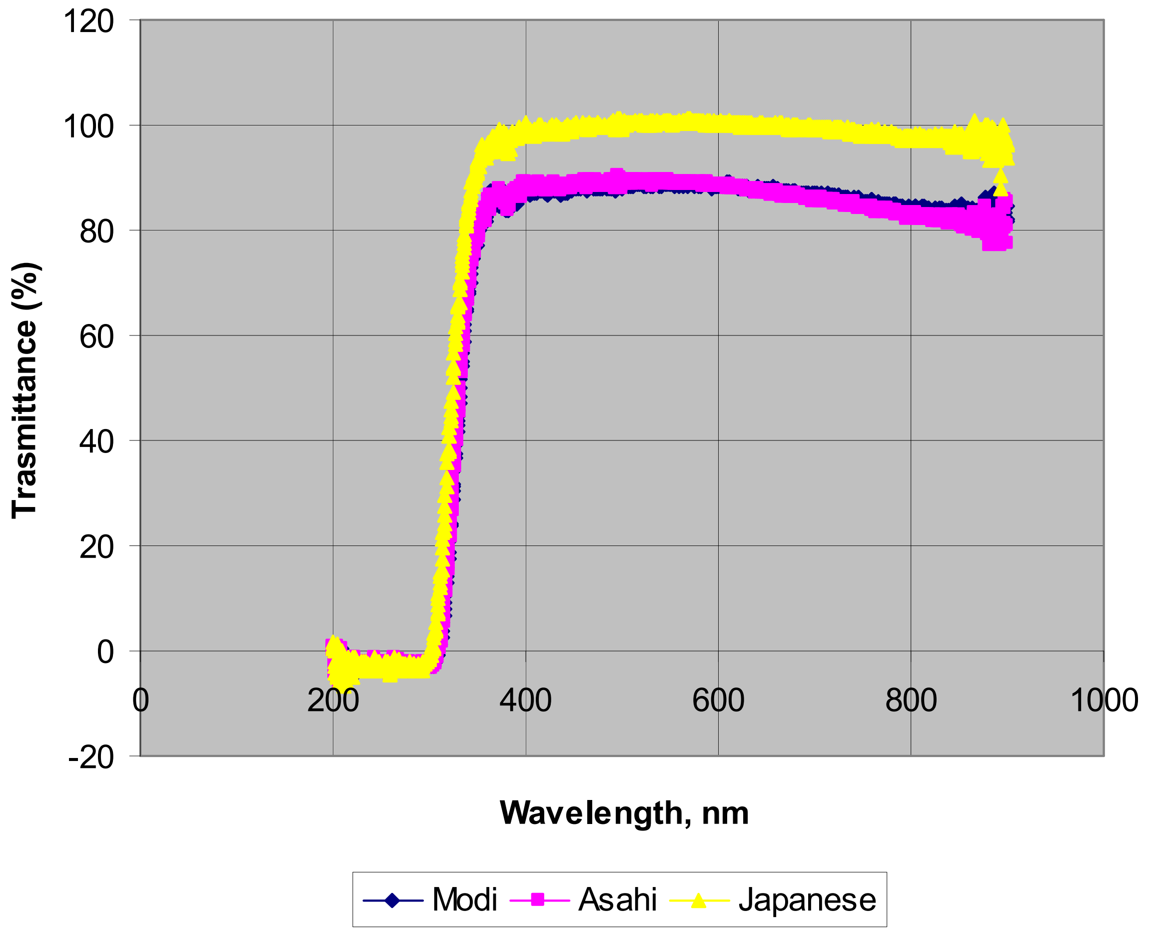
- Two float glass sheets, 2 mm thick
- Noryl spacers
- Epoxy 3M 2216
- India ink (30%black + 70%white)
- Gas connectors



Jigs for RPC fabrication



Transmittance test of glass

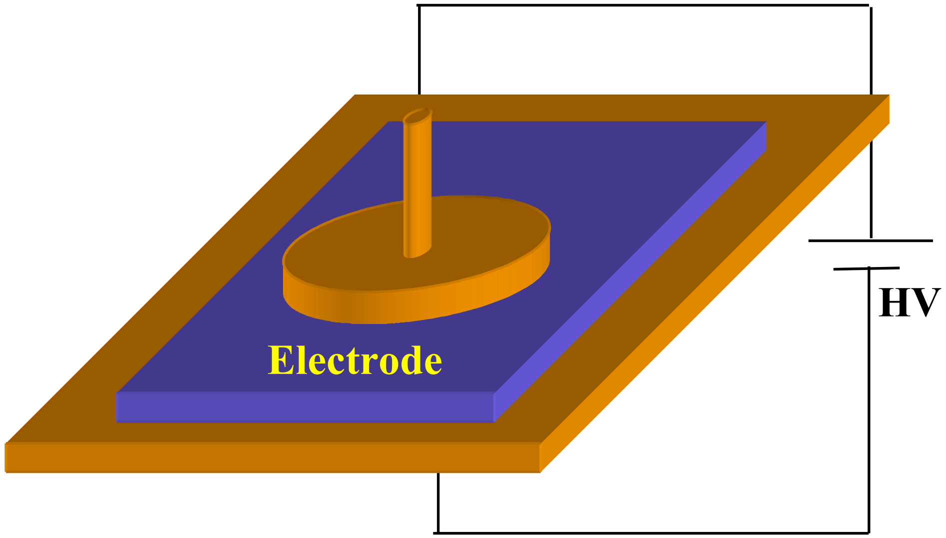


Bakelite processing

Raw bakelite sheets

Bakelite sheets being cut to sizes using a CNC machine

Bulk resistivity of electrodes



Float Glass

Stable resistivity (hopping conductivity)
$\rho=10^{12}-10^{13}\ \Omega cm$ at normal temperature
Resistivity depends only on temperature

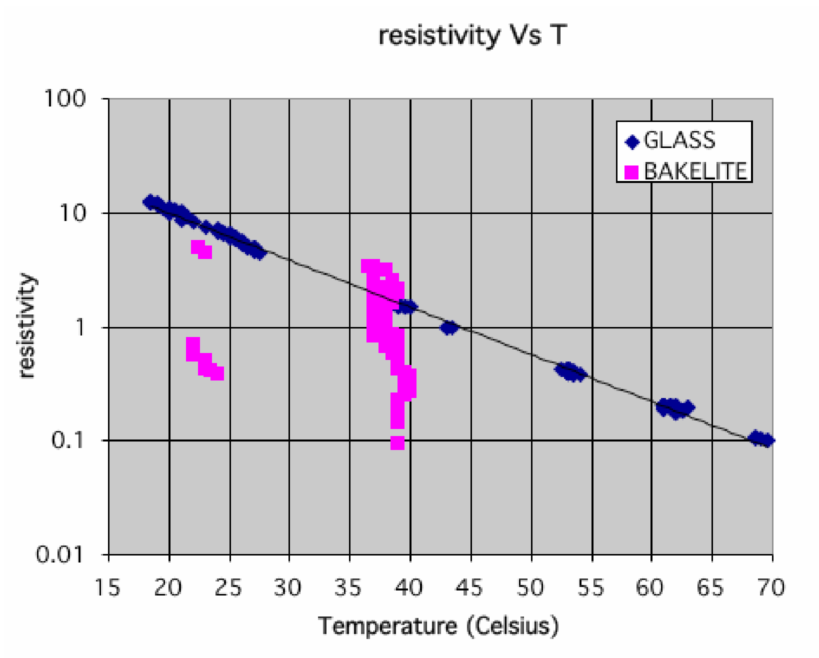
$$\rho=\rho_0 10^{(T-20)/25}$$

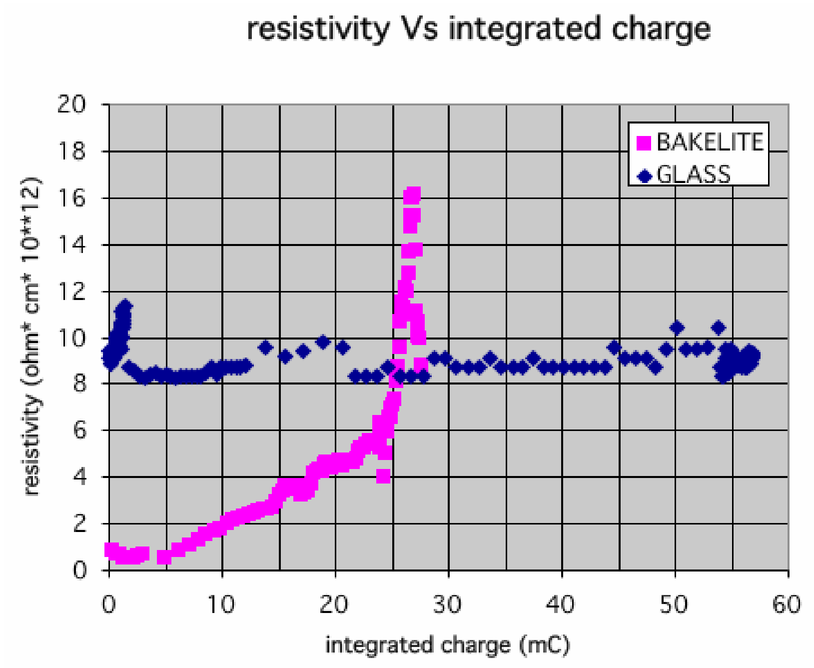
Well known industrial technology

Bakelite

$\rho=10^{10}-10^{12}\ \Omega cm$ at normal temperature
Resistivity increases with the integrated charge (ionic conductivity)
Need a surface treatment with linseed oil

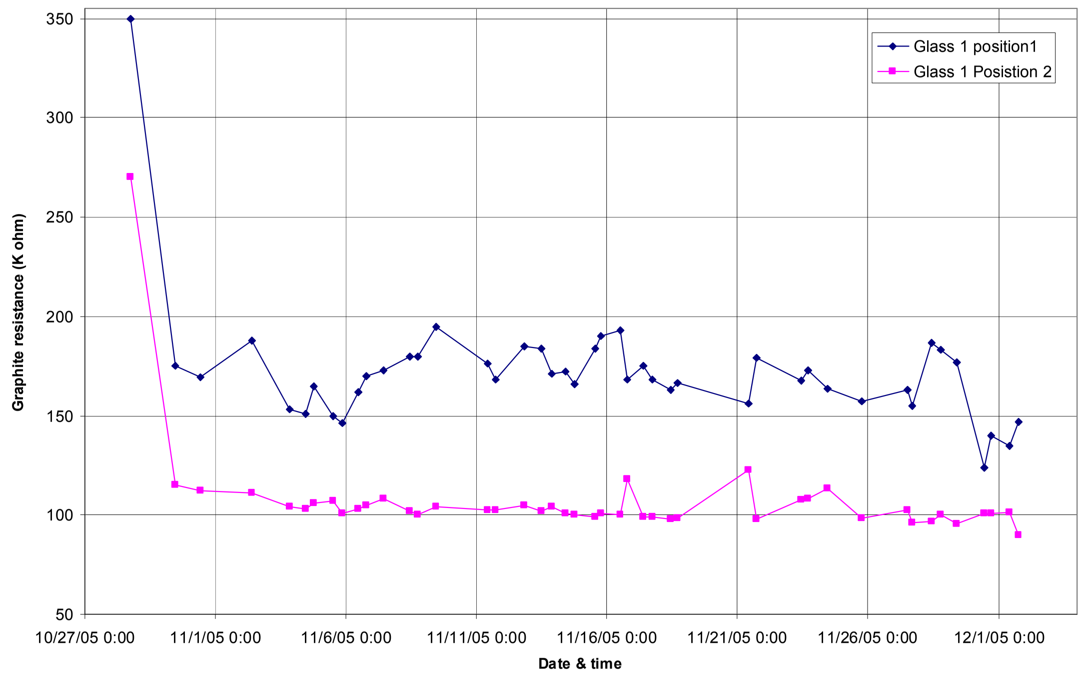
Bulk resistivity of electrodes





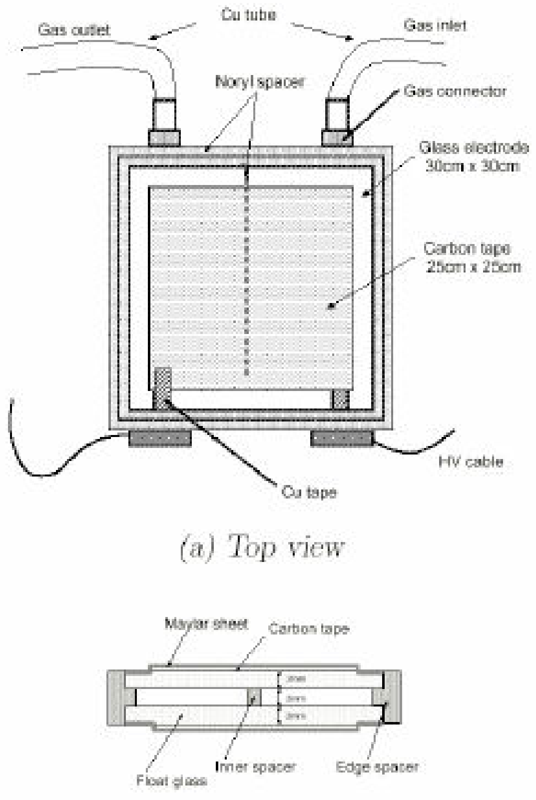
An electrode coating technique

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.



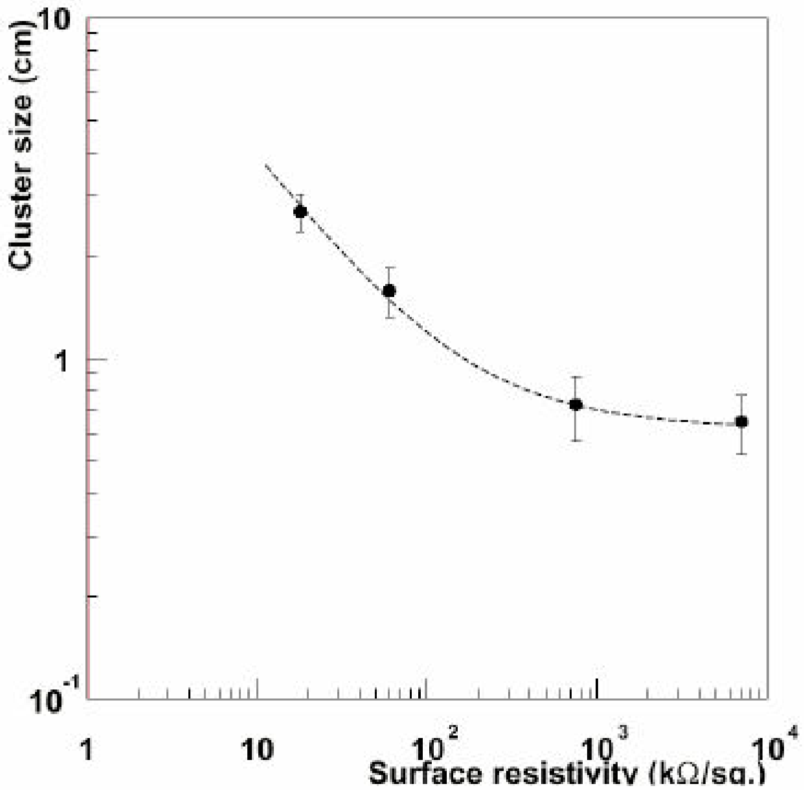
RPC: INDUCED SIGNAL CLUSTER SIZE

EFFECT OF ELECTRODE SURFACE RESISTIVITY



(a) Top view

(b) Side view

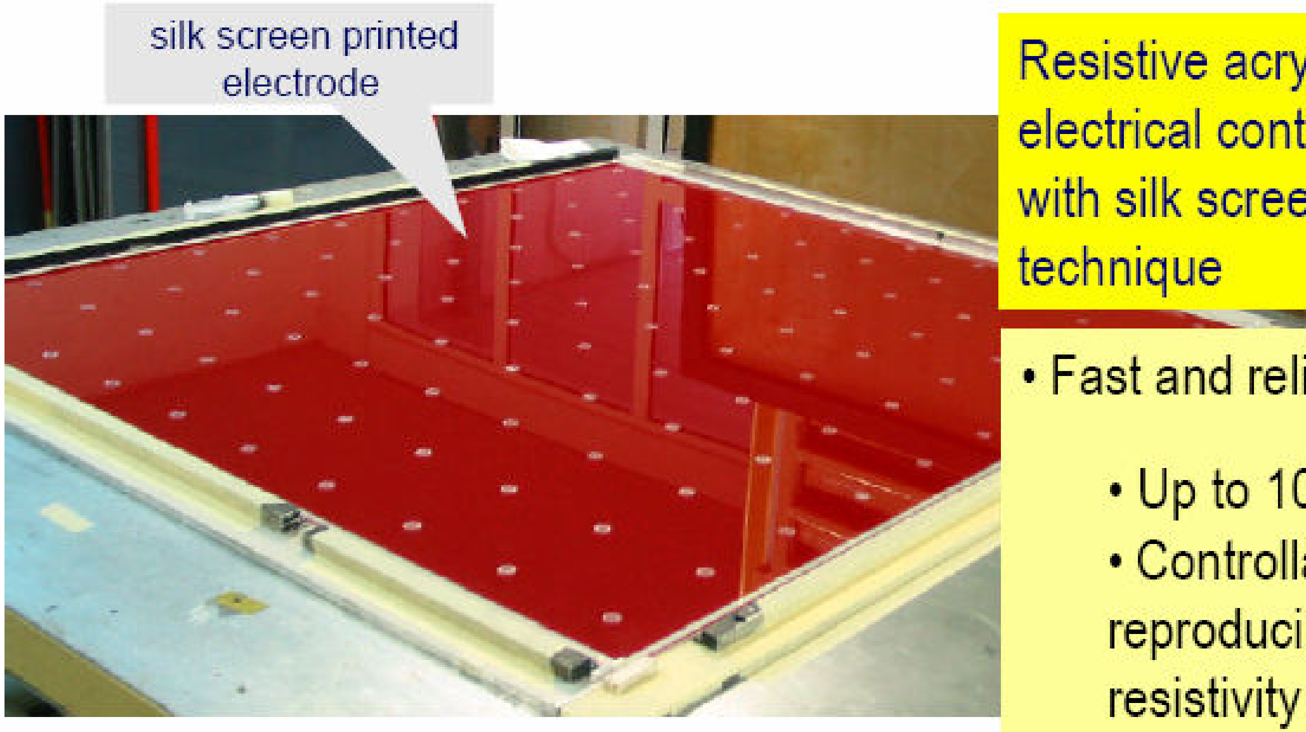


Y. Hoshi et al, RPC Workshop, Coimbra 2001

SIGNAL PROPAGATION IN RESISTIVE PLATE CHAMBERS:
W. Riegler and D. Burgarth, Nucl. Instr. and Meth. A481(2002)130

14

Another electrode coating technique

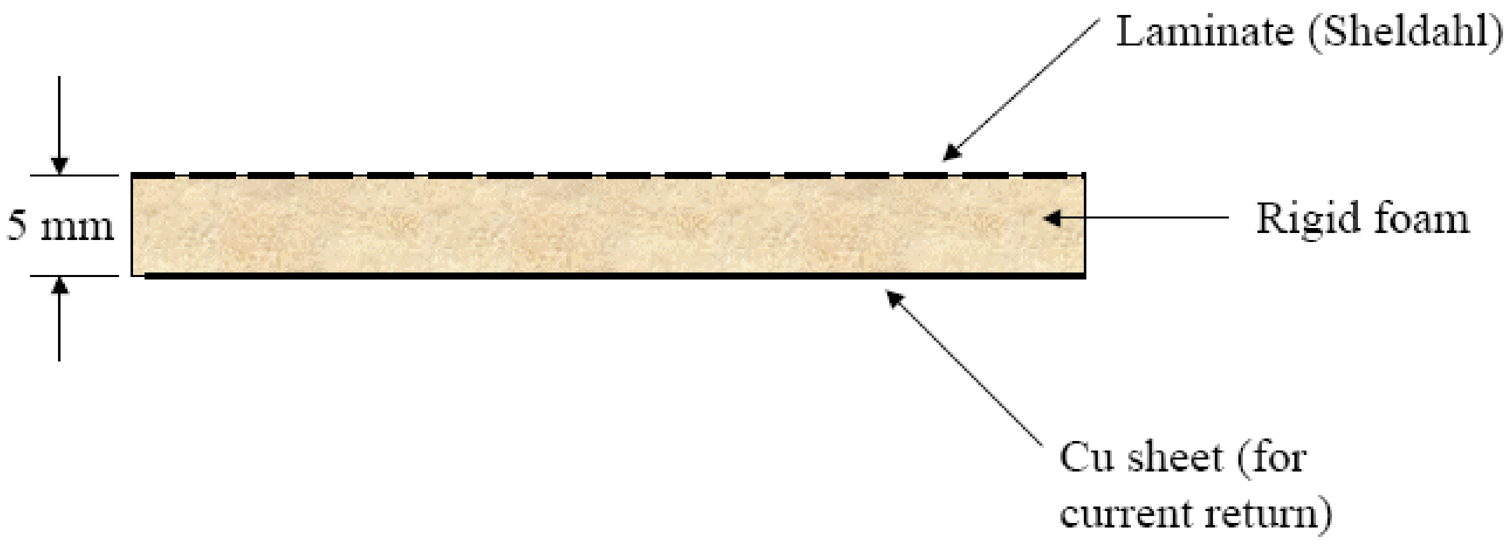


Resistive acrylic paint for electrical contacts deposited with silk screen printing technique

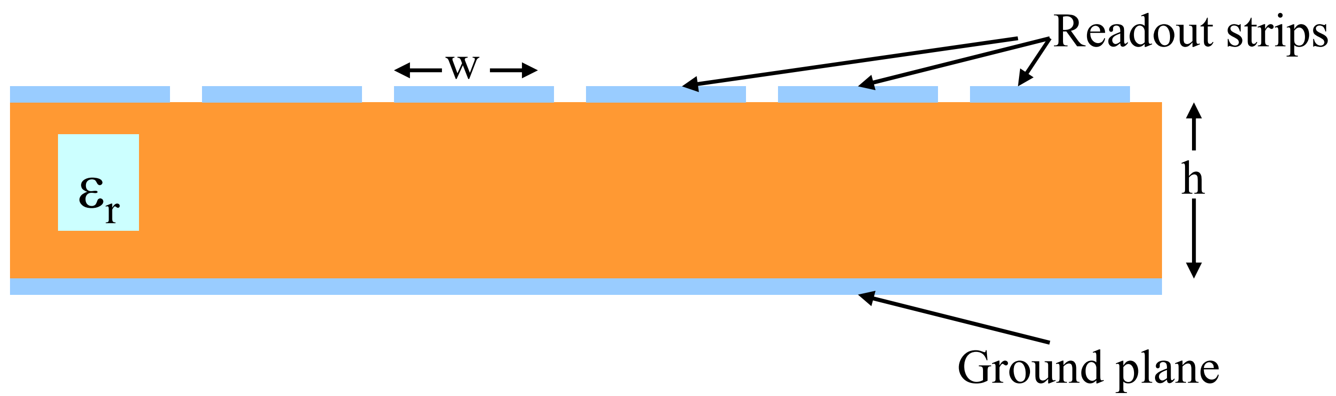
- Fast and reliable:
  - Up to 1000 m^2/day
  - Controllable and reproducible surface resistivity

Pickup electrode design example

The 5-cm-wide readout strips form a ~50 ohm transmission line.



Transmission line impedance



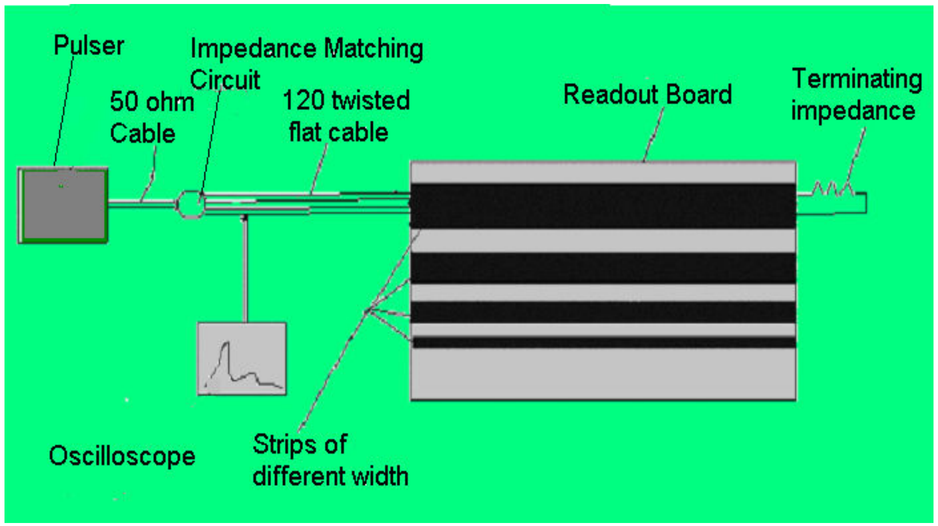
$$x \equiv w/h \qquad \varepsilon_r' = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}(1 + 10x)^{-\frac{1}{2}}$$

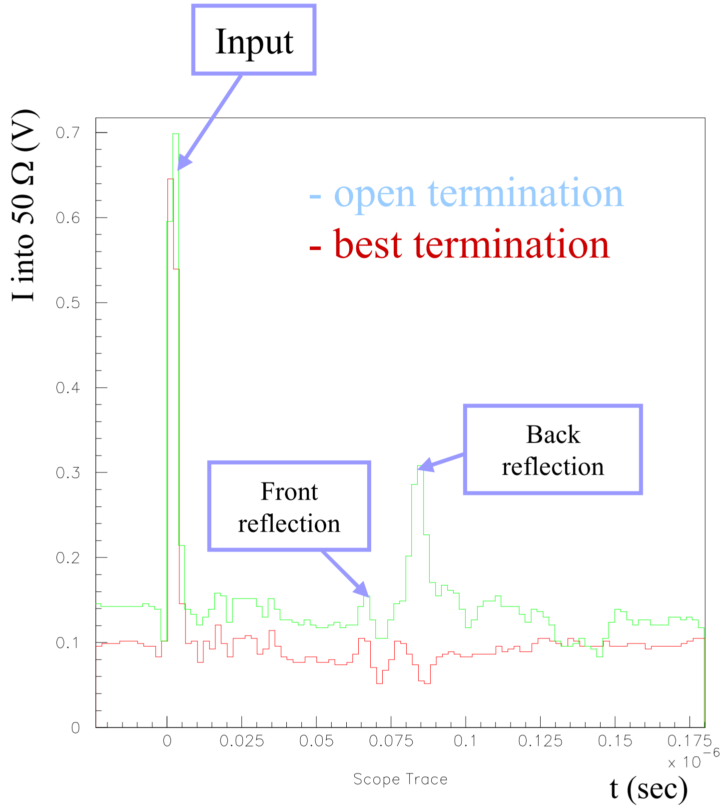
$$Z = \frac{60 \text{ x } \ln(8/x + x/4)}{\sqrt{\varepsilon_r'}} \quad : \; x < 1$$

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

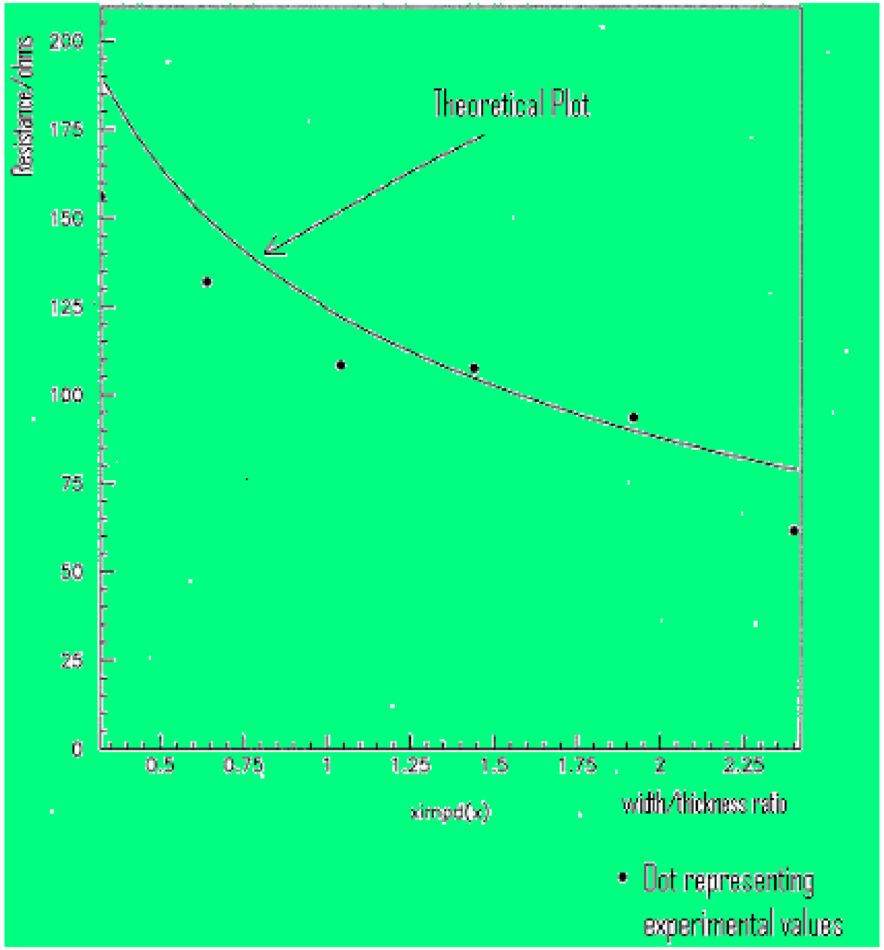
Impedance measurement

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

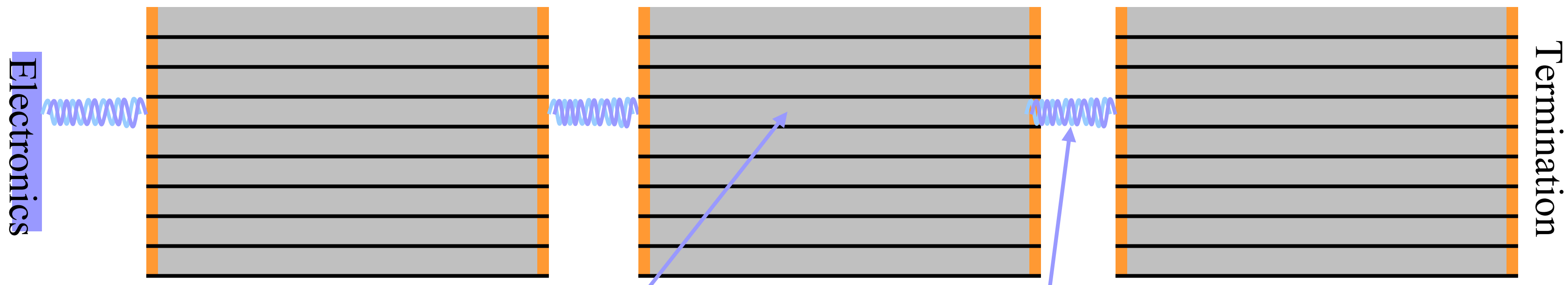


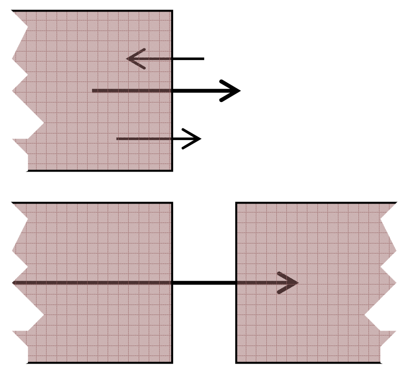


Impedance versus strip width



Chained readout boards

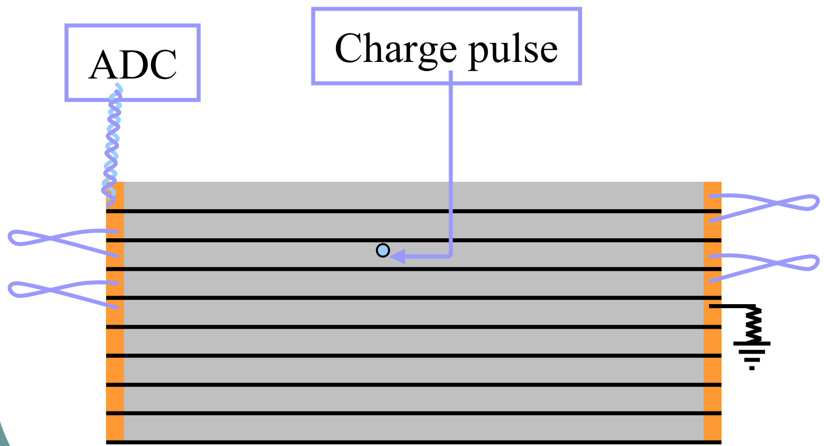


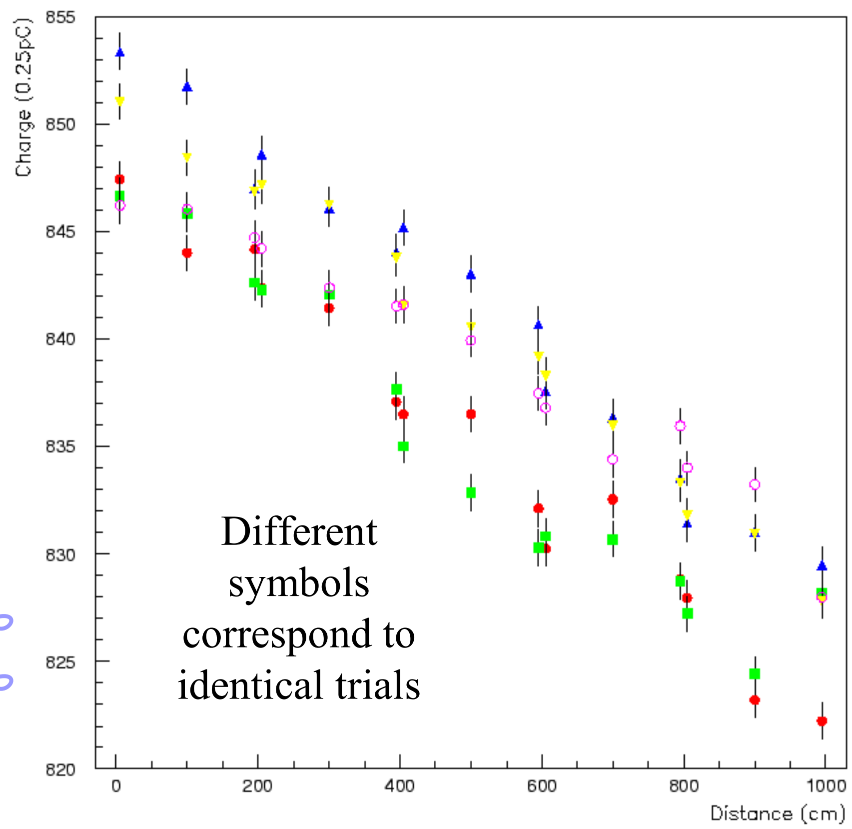


- Won't hurt if propagation across gap is faster than rise time of the signal
- Allows up to 0.5m or so for interconnections

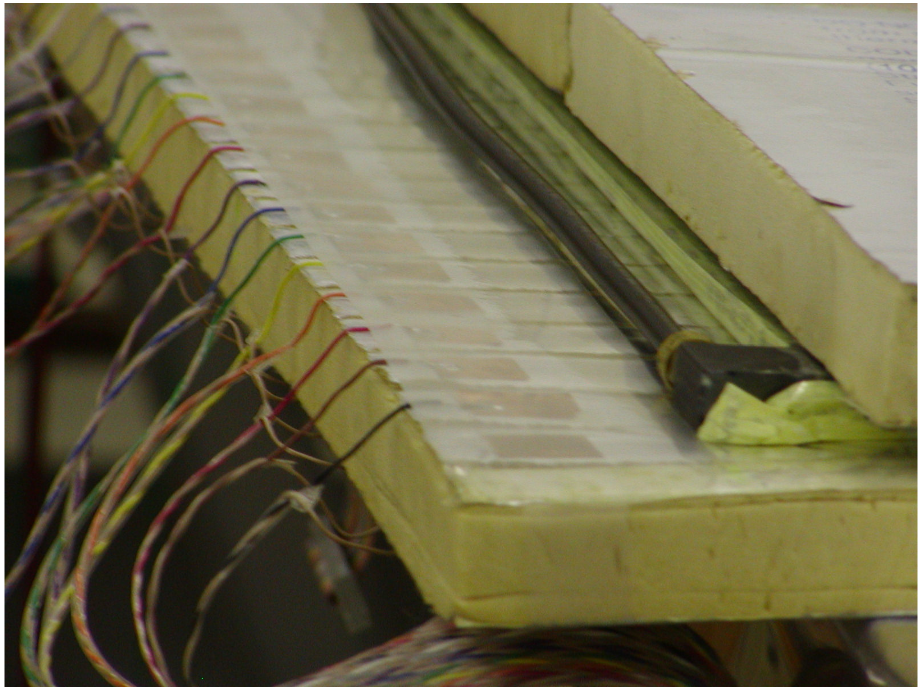
Transmission measurement

- Charge collected from injected pulse as a function of distance from readout end
- Less than 3% loss over 10 meters



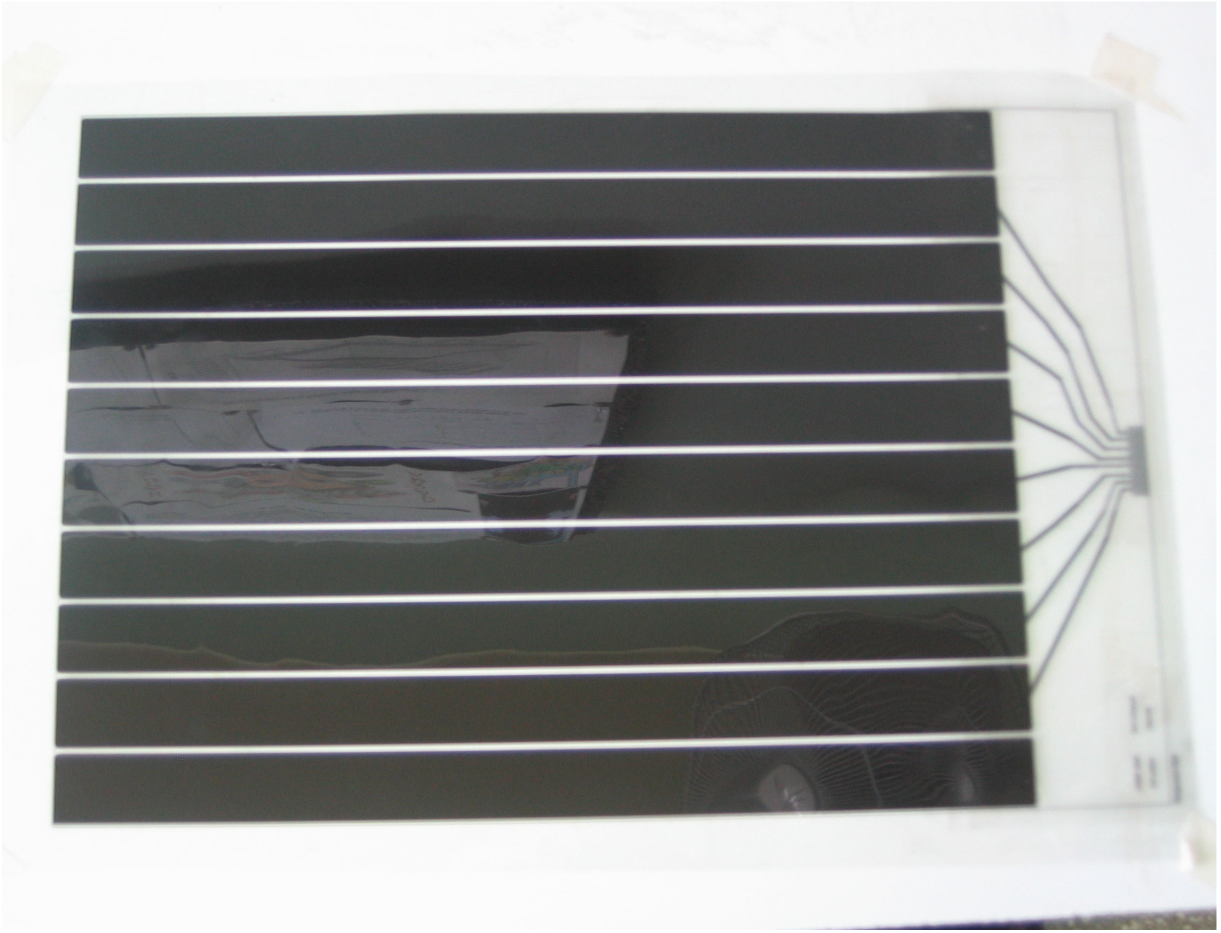


Pickup electrode design

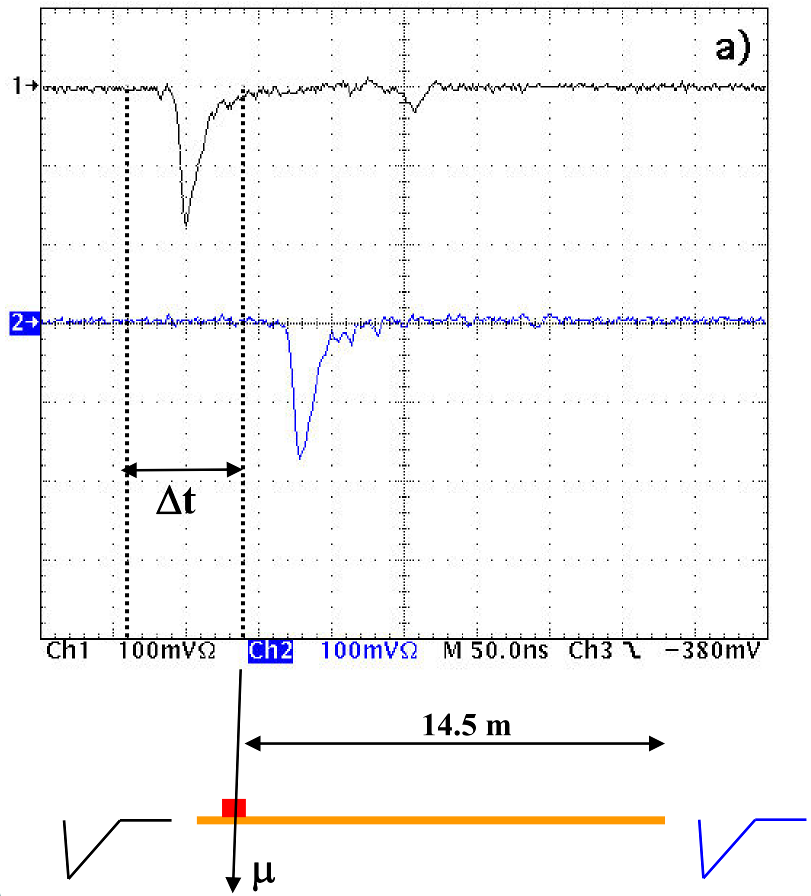


- Large area glass RPC sandwiched between two readout boards.
- X and Y coordinates from a single chamber.
- Strip readout: transmission line using insulation board.

G-10 based pickup plane

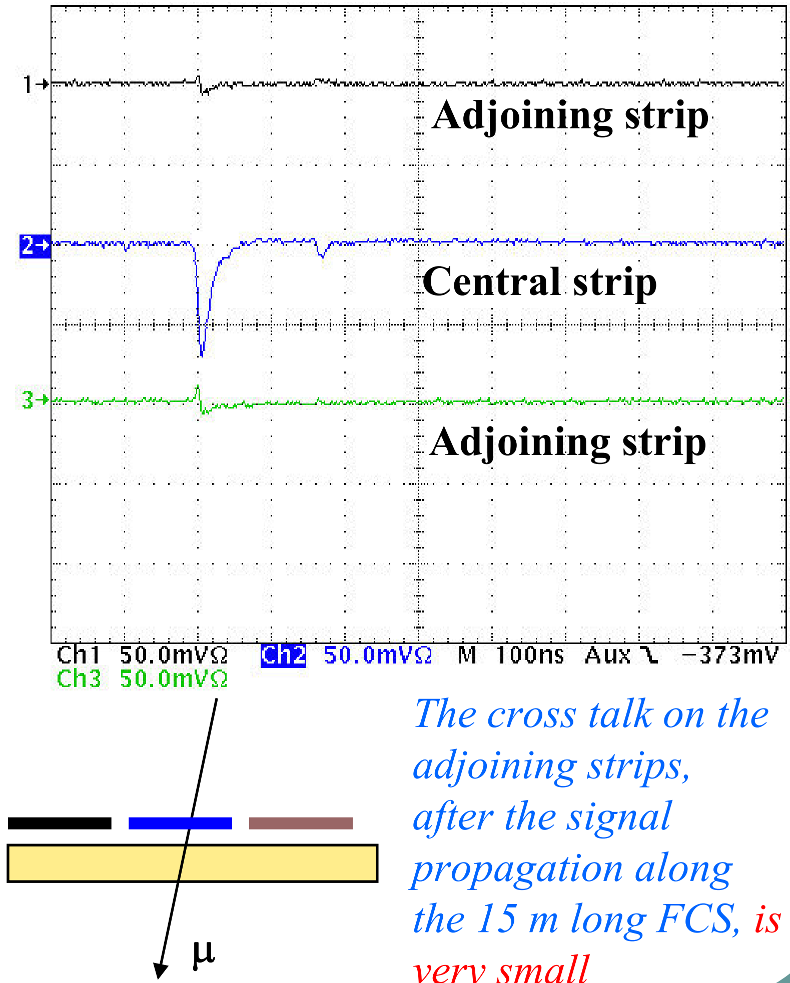


Tests on signal pickup schemes



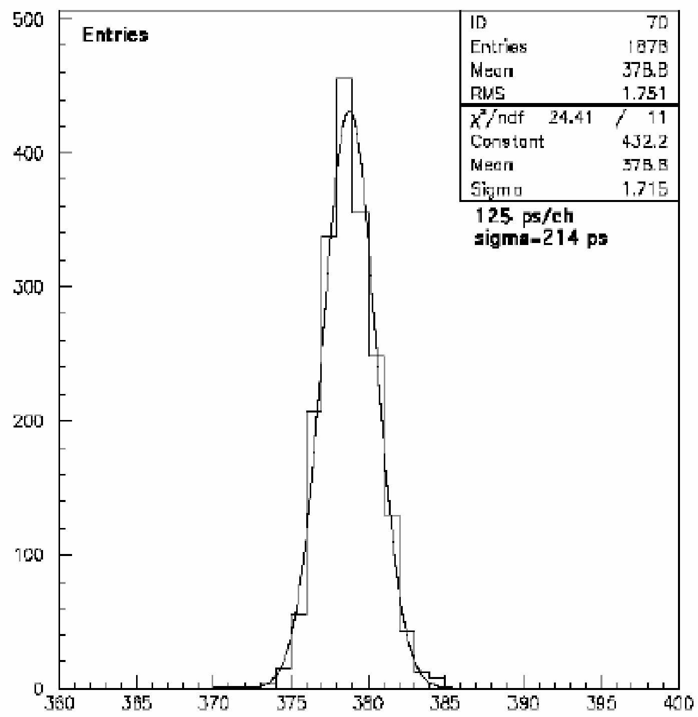
Attenuation = 0.052 db/m

τ = Propagation constant = 5.6 ns/m



The cross talk on the adjoining strips, after the signal propagation along the 15 m long FCS, is very small

Test on readout system



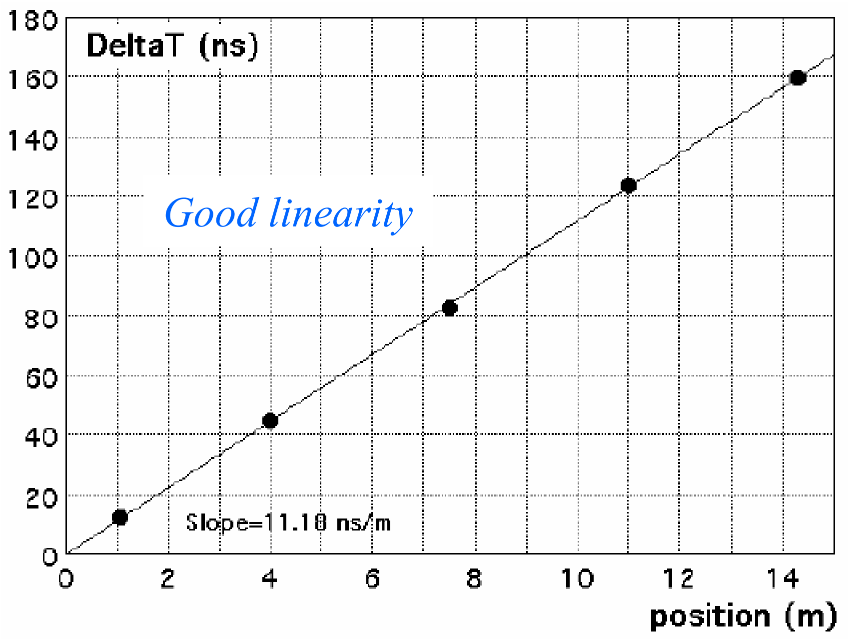
The time performance of the X-system, of the order of 100 ps, shows that 15 m long FCS can be used without a worsening of the intrinsic time resolution of the Glass RPC (~1 ns).

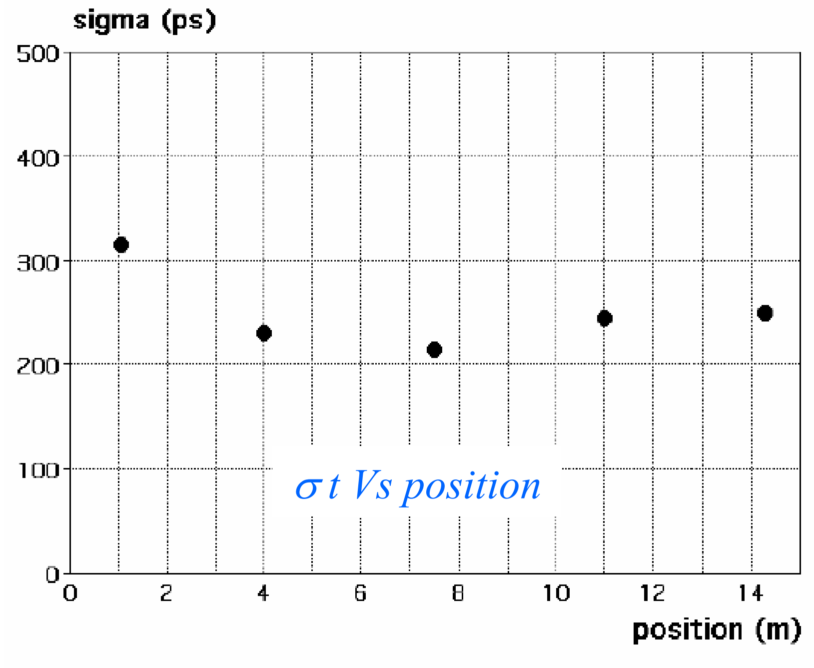
Even the Y-coordinate can be measured with a resolution of the order of 1 cm by a Δt measurement

Raw data resolution = 2.4 cm.

After subtracting quadratically the broadening due to the scintillator width σX (cm) = 1.23 cm

Test on readout system

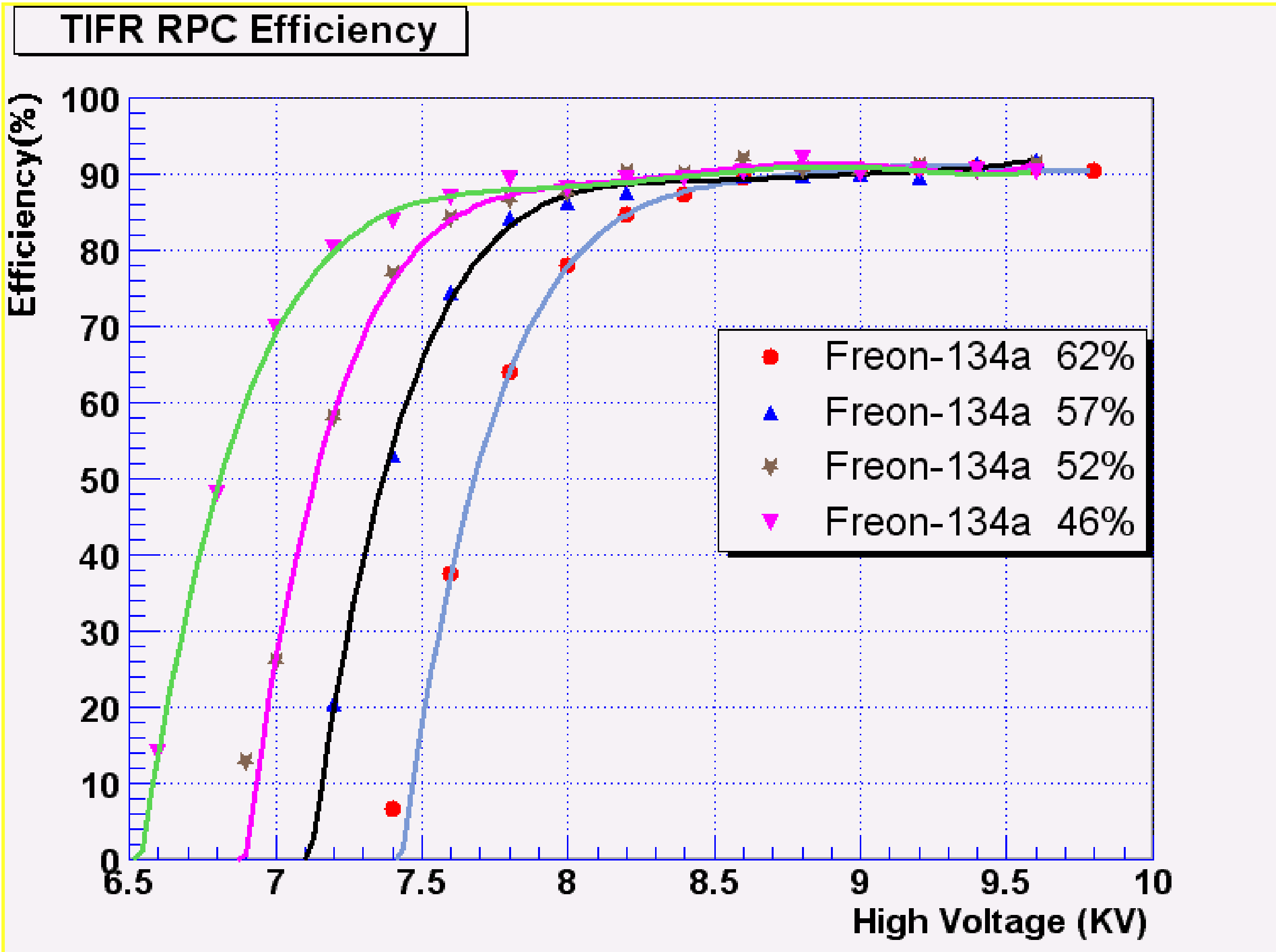




Outline

- History and introduction to RPC
- Characteristics and merits of RPC
- Basic principles of operation
- Operating modes
- Types of RPCs
- Construction of RPCs
- Gas mixture issues
- RPC detector signal conditioning
- Test stands and characterisation procedures
- Problem of RPC aging
- RPCs for INO ICAL detector
- Course module summary
- Acknowledgements and References

RPC gas mixtures' study plots



Freon-less mixtures

- Aging issue
- Global warming potentials
- O_2(0), CO_2(1), R134a(1300), SF_6(24900)
- O_2 and SF_6 both have high electron affinity; O_2 with butane is flammable
- Narrower efficiency plateau
- Lower pulse height
- Higher multi-pulse rate

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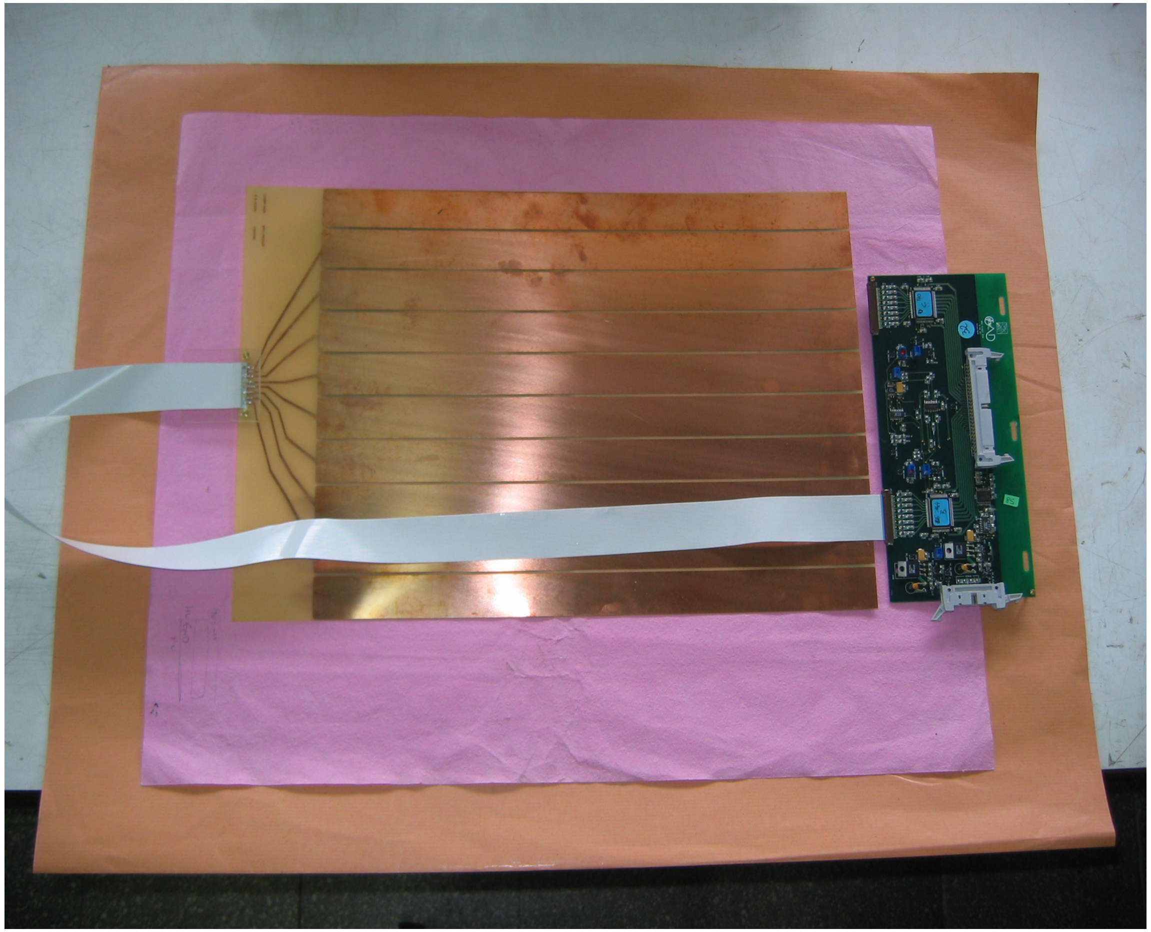
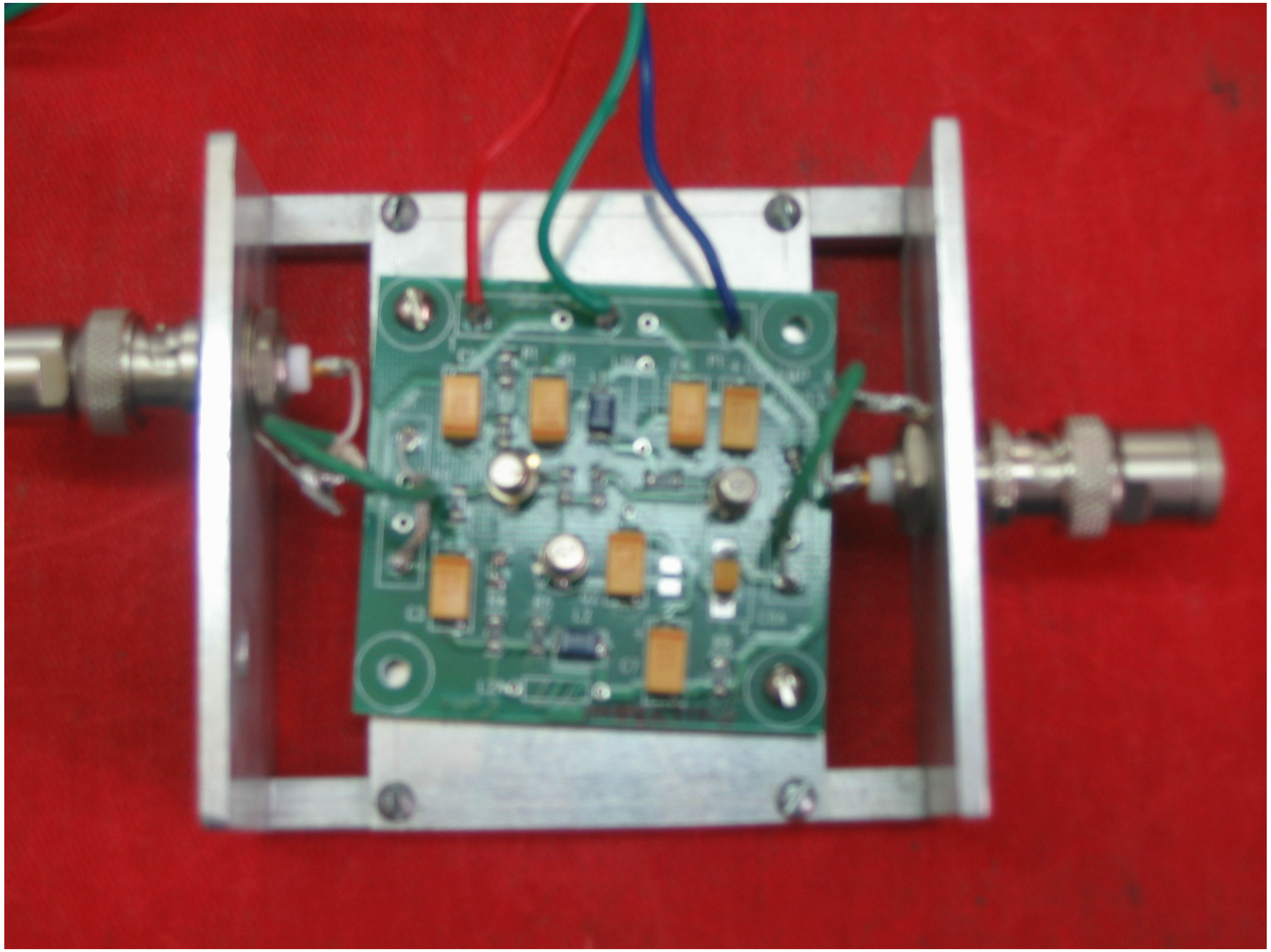
G-10 based RPC pickup plane



Low noise preamplifier



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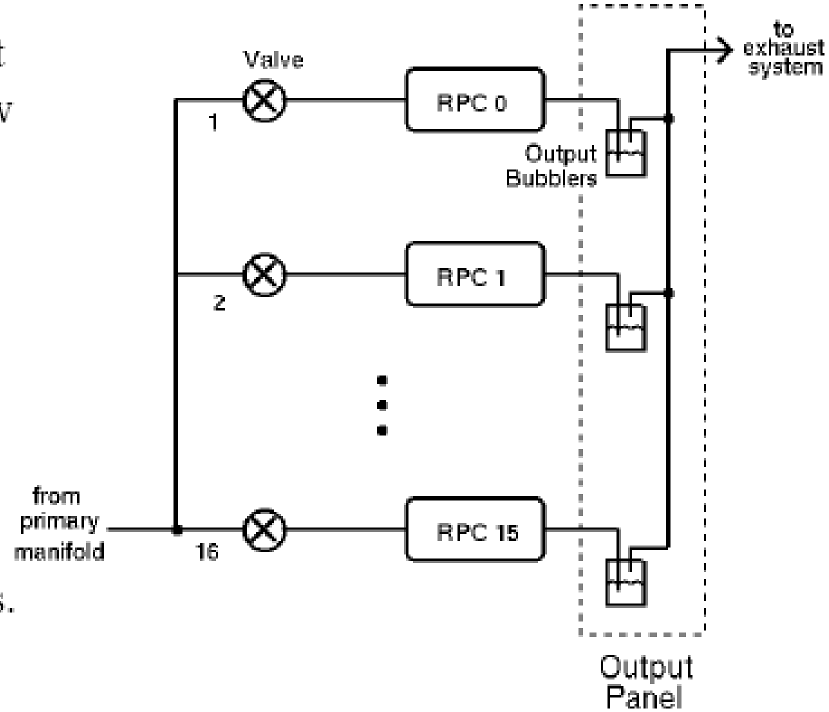
A simple gas system

In early versions of the system we found that with inexpensive valves it was very difficult to balance the flow if several chambers were connected to a single manifold.

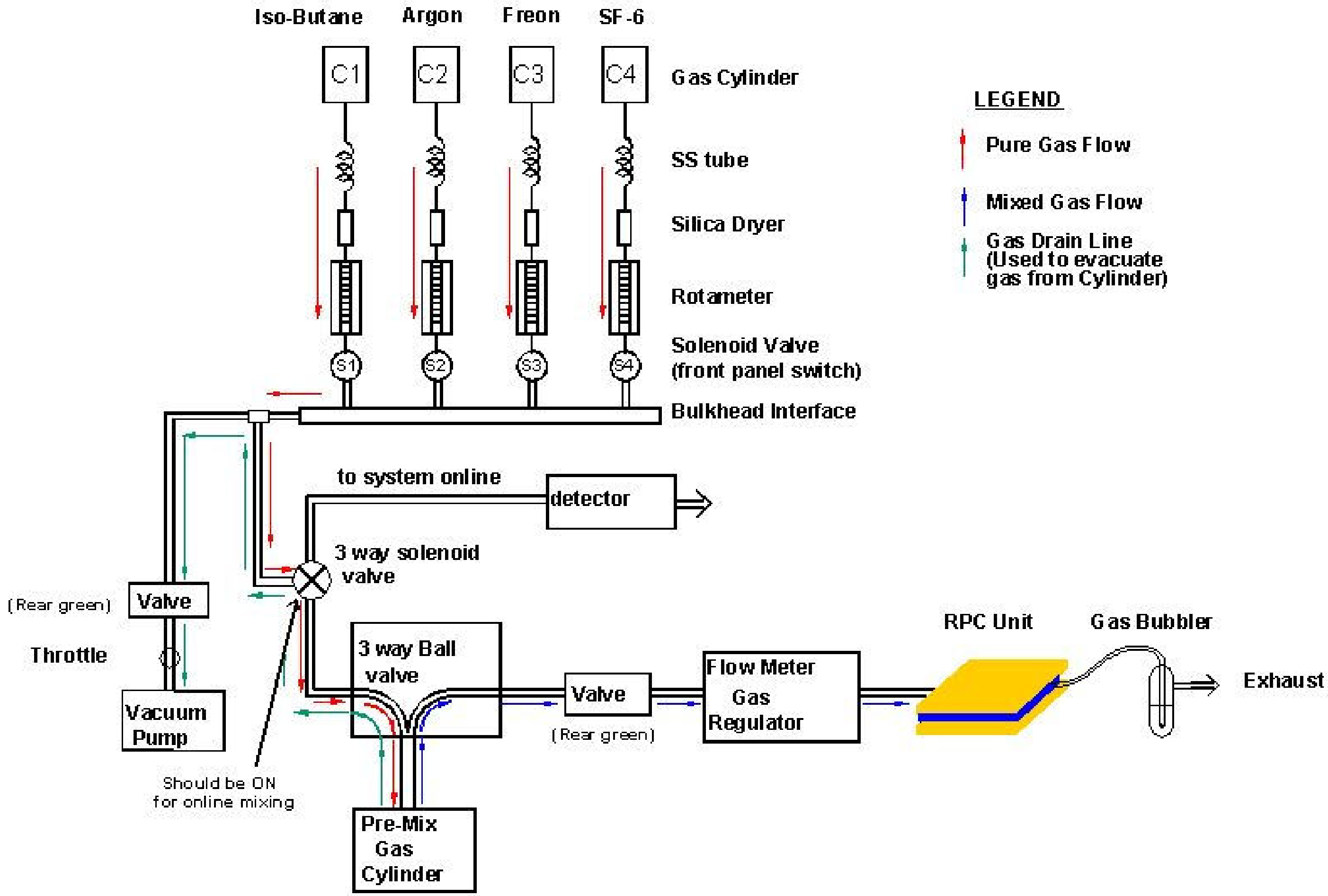
The basic problem was that the pressure drop across the control valves was not so different from the pressure drop across the RPCs.

As a result adjusting one channel caused changes in the other channels.

Given that all we wanted was approximately equal flows, it seemed that there must be a better way.



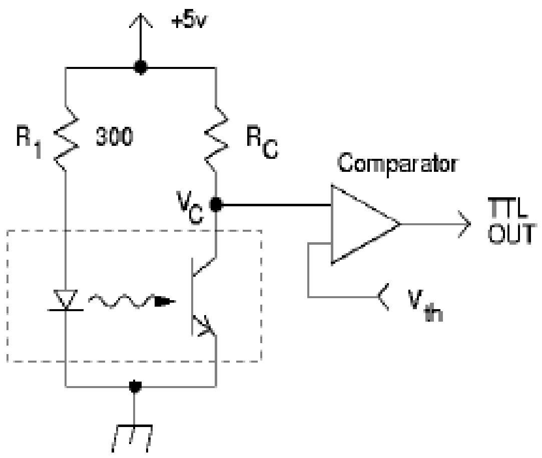
Schematic of gas mixing unit

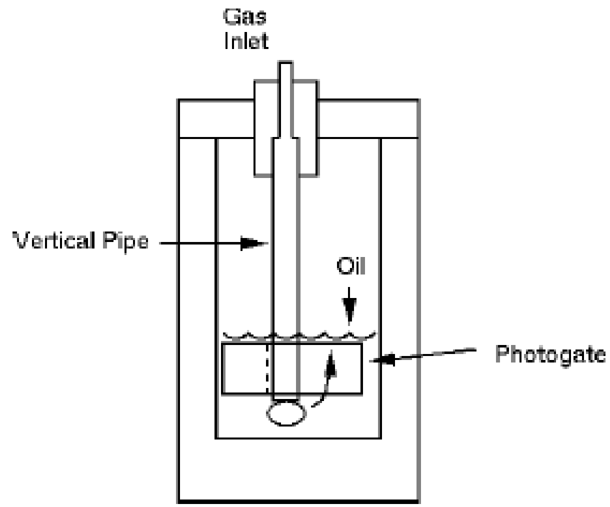


Gas mixing unit

Digital gas bubblers

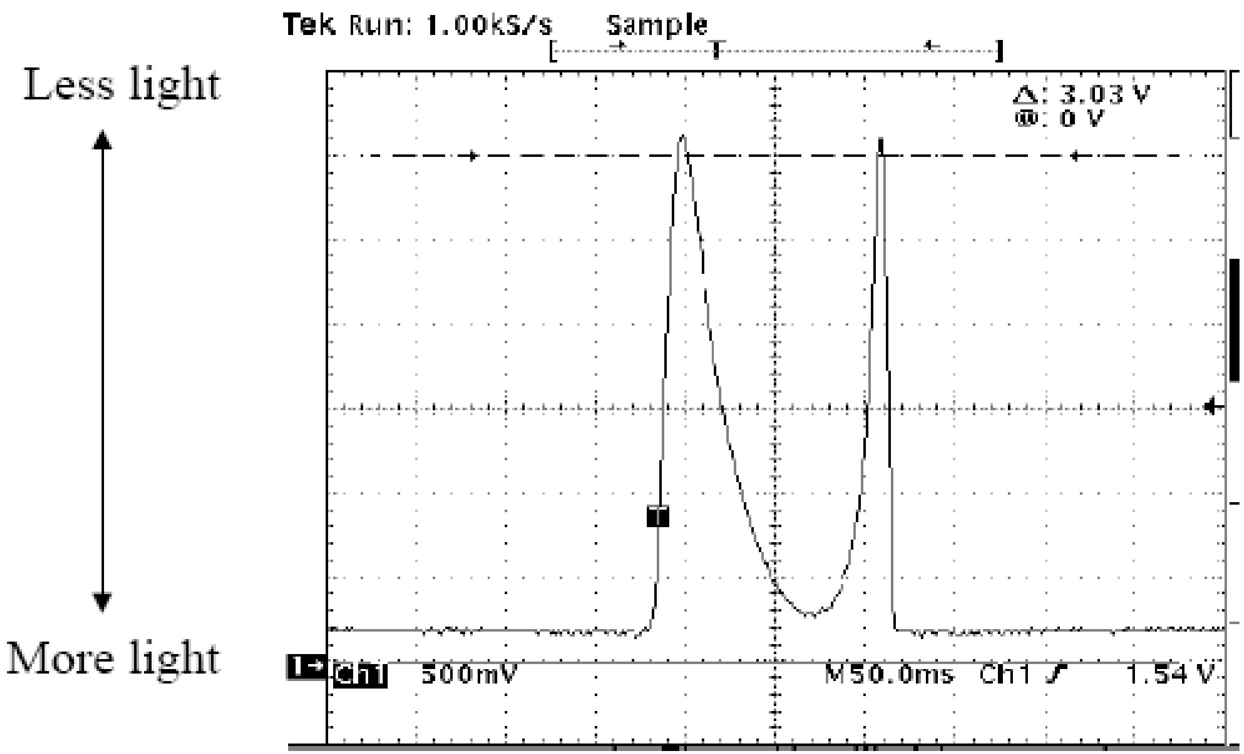
To eliminate the tedium of checking all 750 output bubblers (and the corresponding safety-relief bubblers) we have developed a "digital bubbler" that monitors the flow by electronically counting bubbles as they pass through inexpensive photogates.





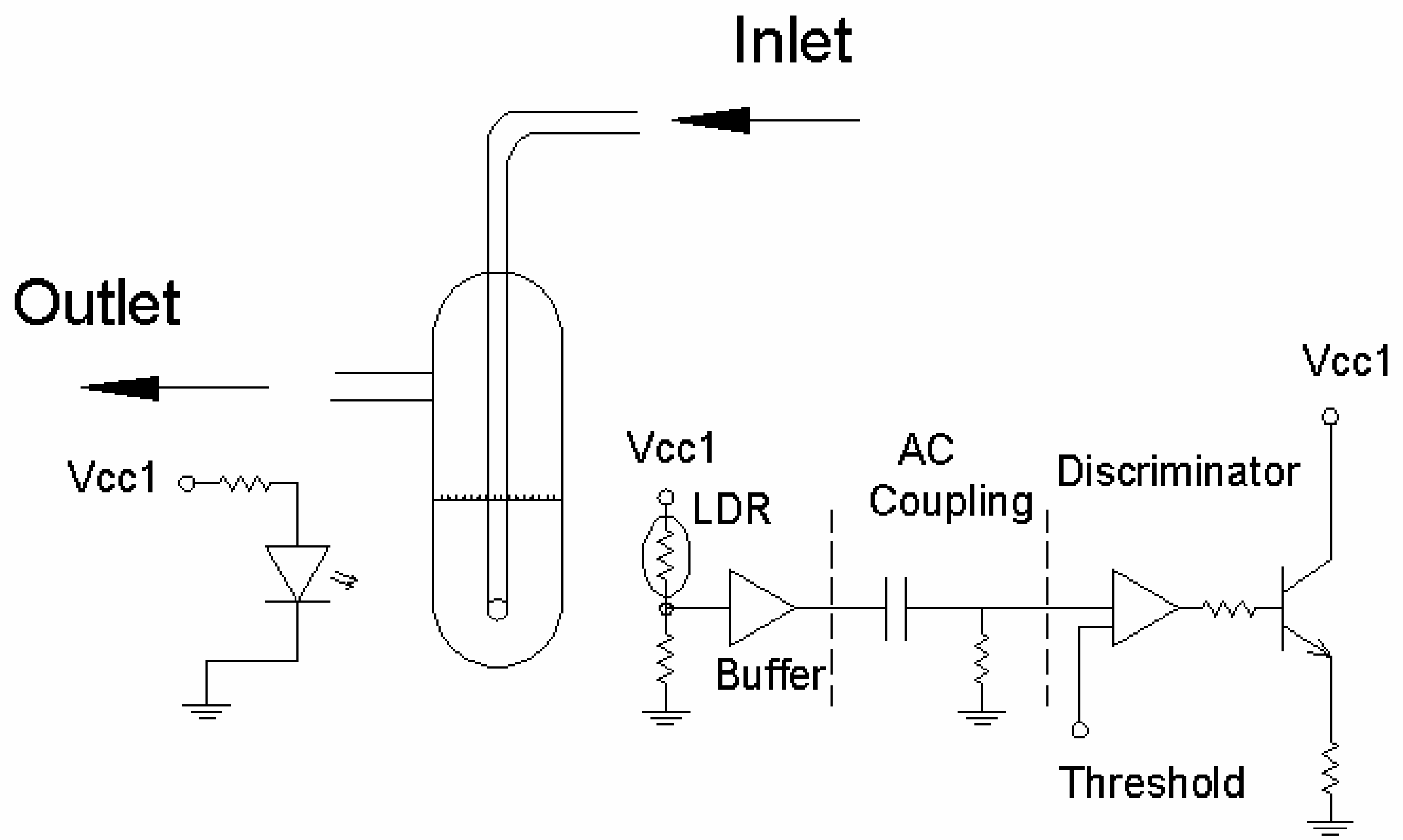
The circuit shown is a functional equivalent. The actual circuit is somewhat more complex. To reduce cost and to maintain flexibility, a custom multiplexing (64:1) ADC system was developed.

Digital bubblers: CRO trace



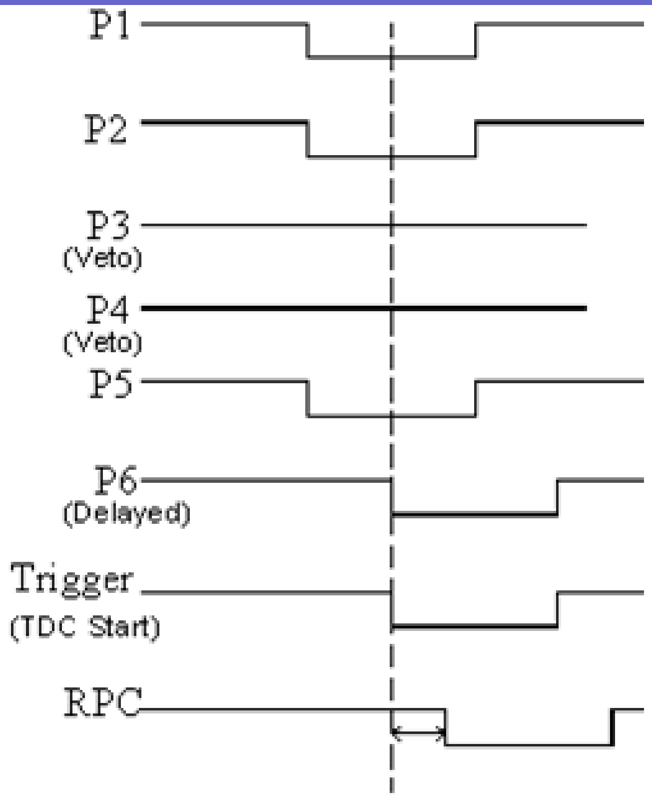
As the edges of the bubble pass through the photogates, they refract the light, causing a decrease in intensity.

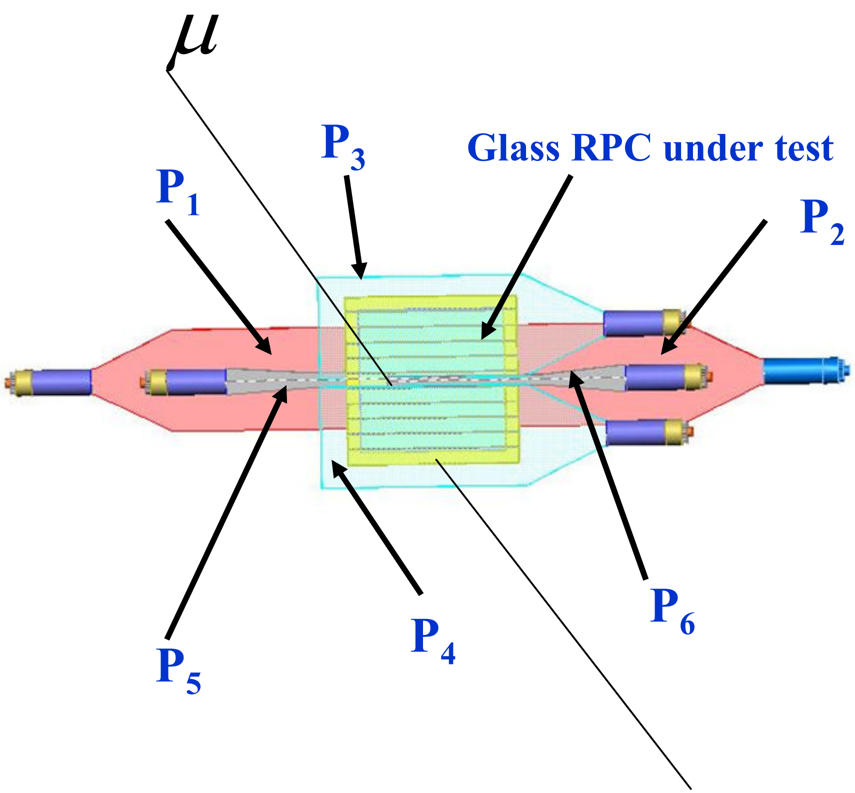
Schematic of digital gas bubble counter



Digital gas bubble counter

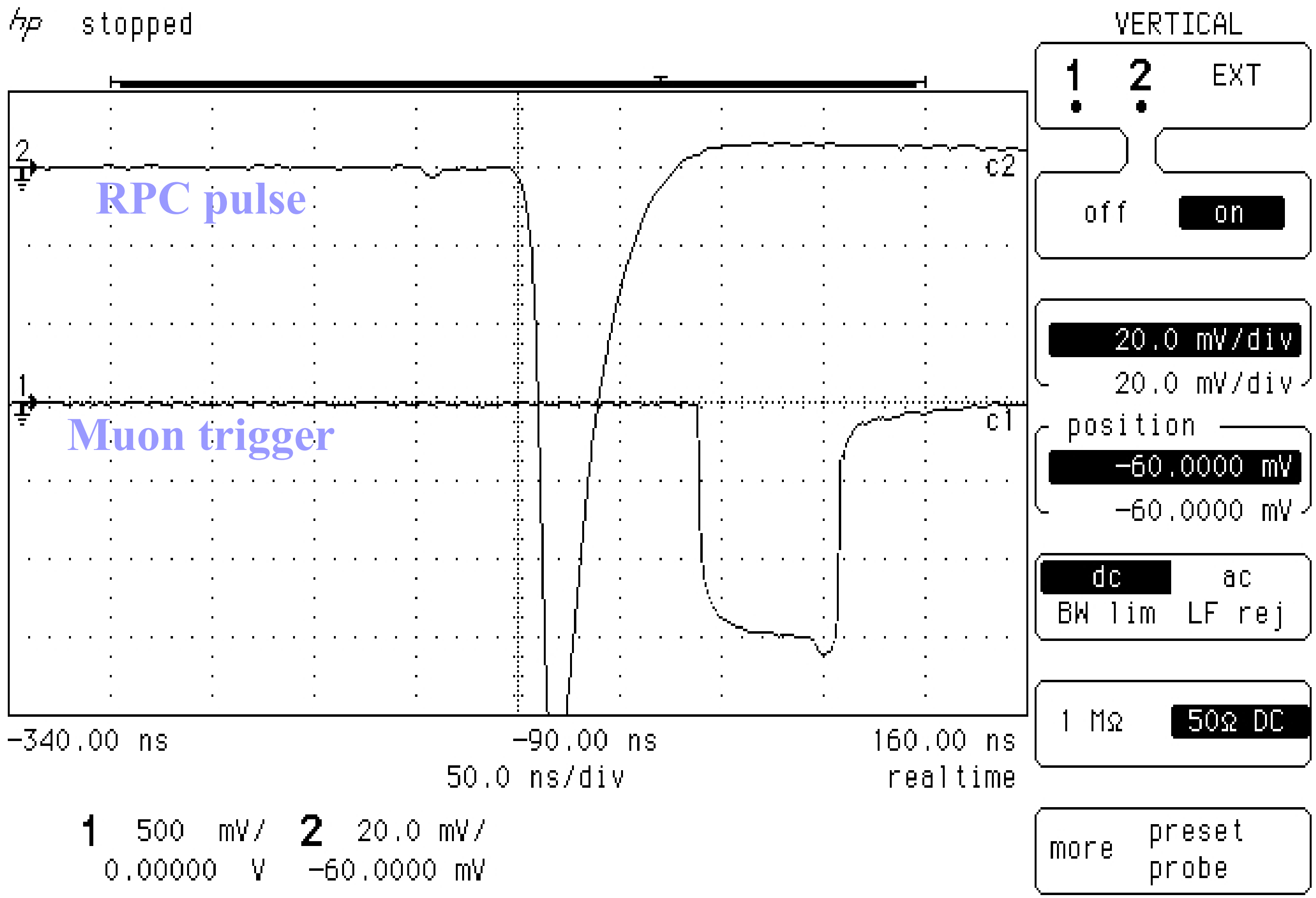
Schematic of Cosmic trigger



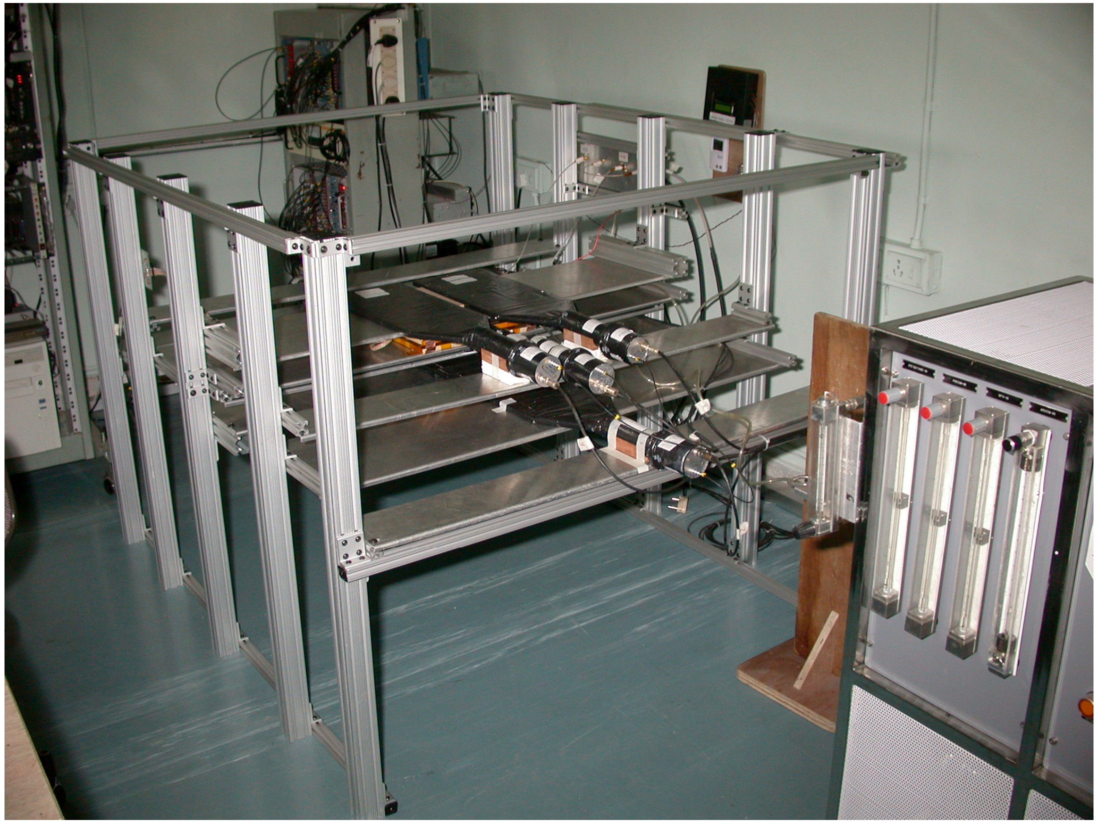


Muon Trigger = $P_1 \bullet P_2 \bullet \overline{P_3} \bullet \overline{P_4} \bullet P_5 \bullet P_6$

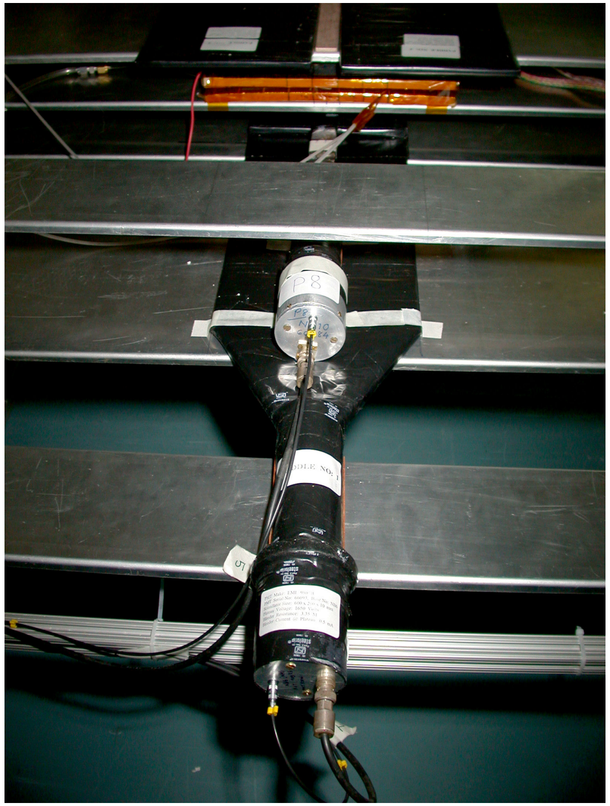
Typical RPC pulse profile



Cosmic ray muon telescope setup

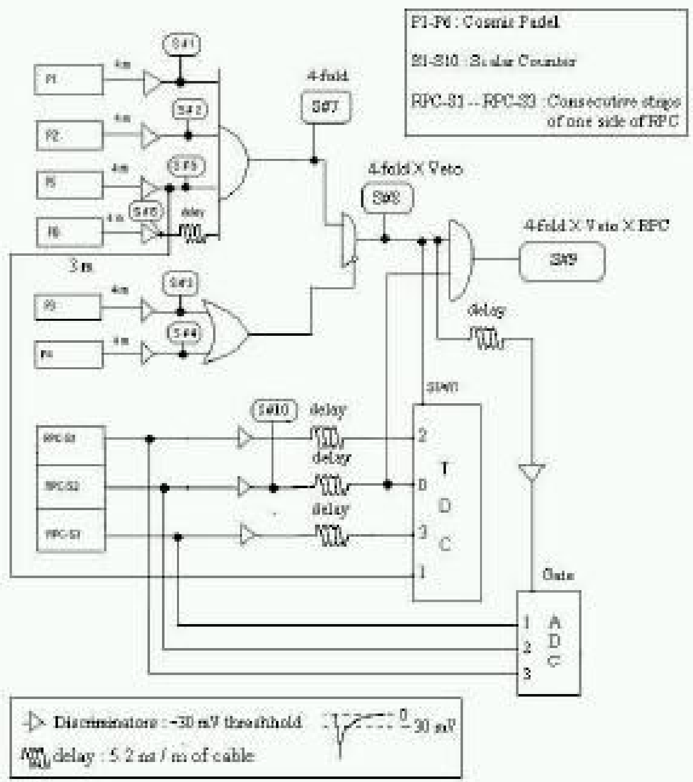


Mounting structure for flexible
and precise telescope alignment



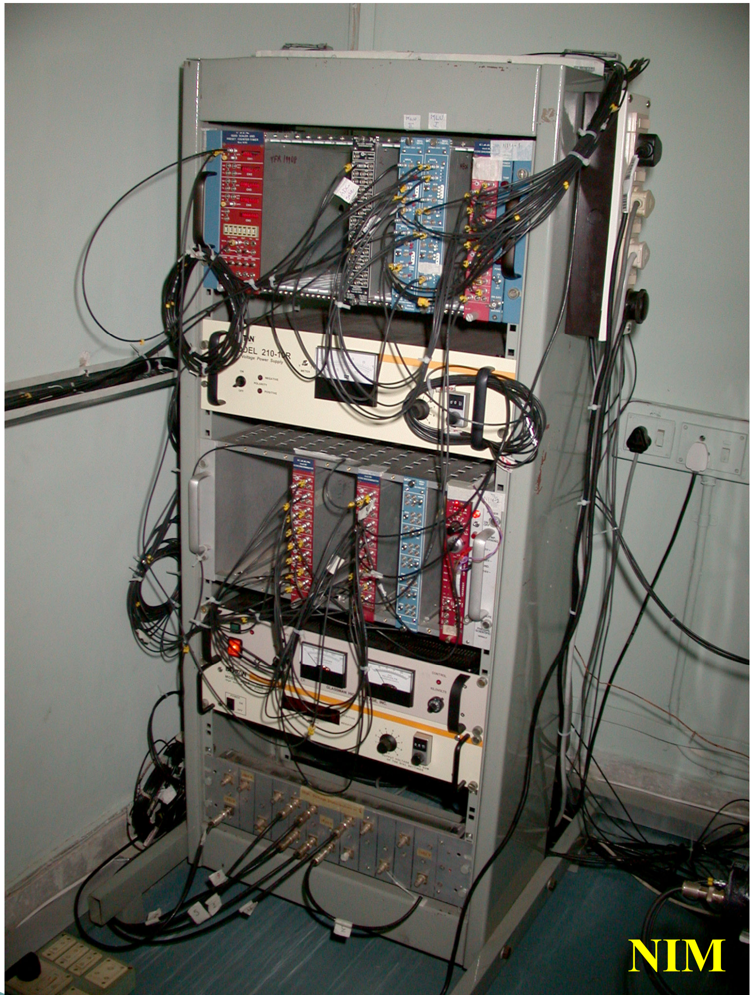
Paddle alignment detail

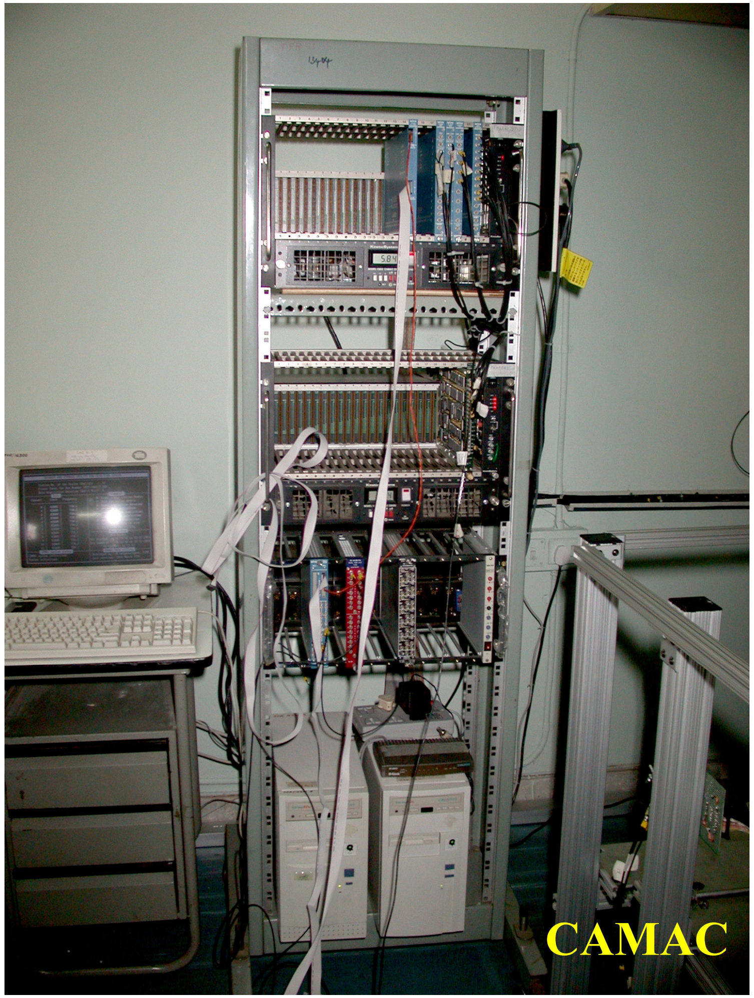
Schematic of data acquisition system



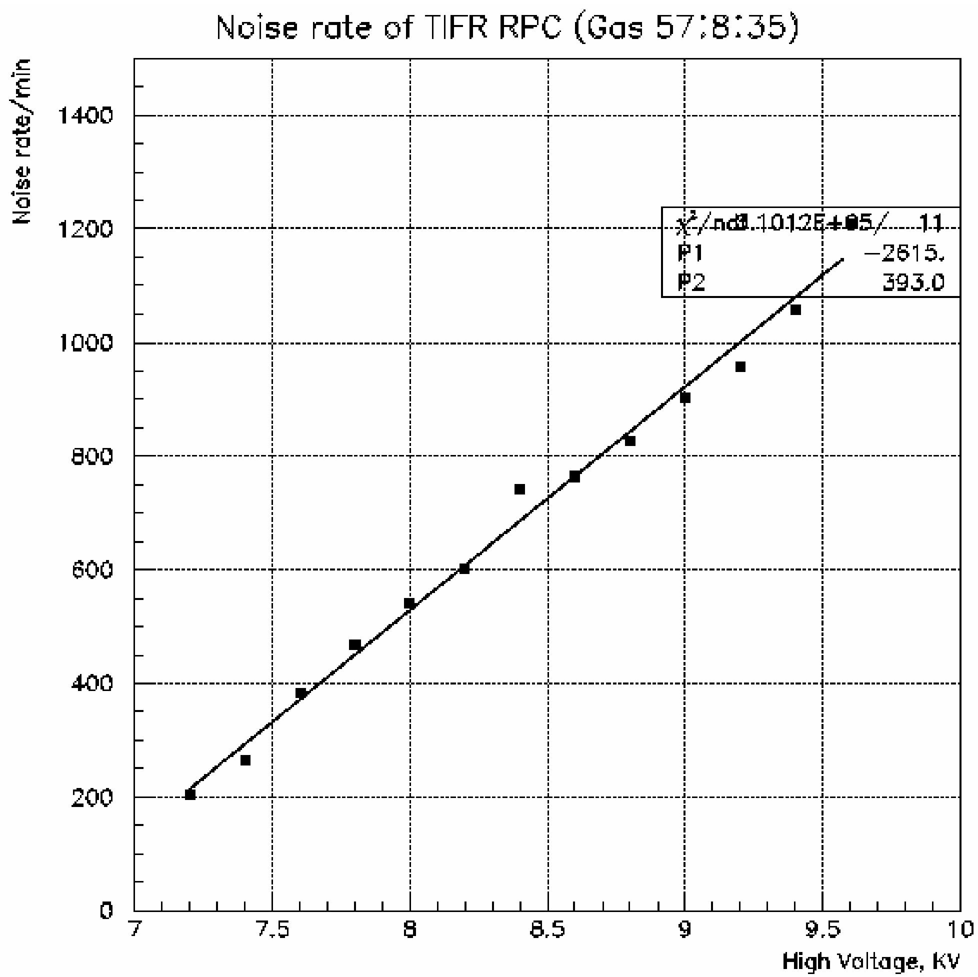
$$\text{Efficiency of RPC} = \frac{(4\text{-fold} \times \text{Veto} \times \text{RPC})}{(4\text{-fold} \times \text{Veto})}$$

Data acquisition system electronics

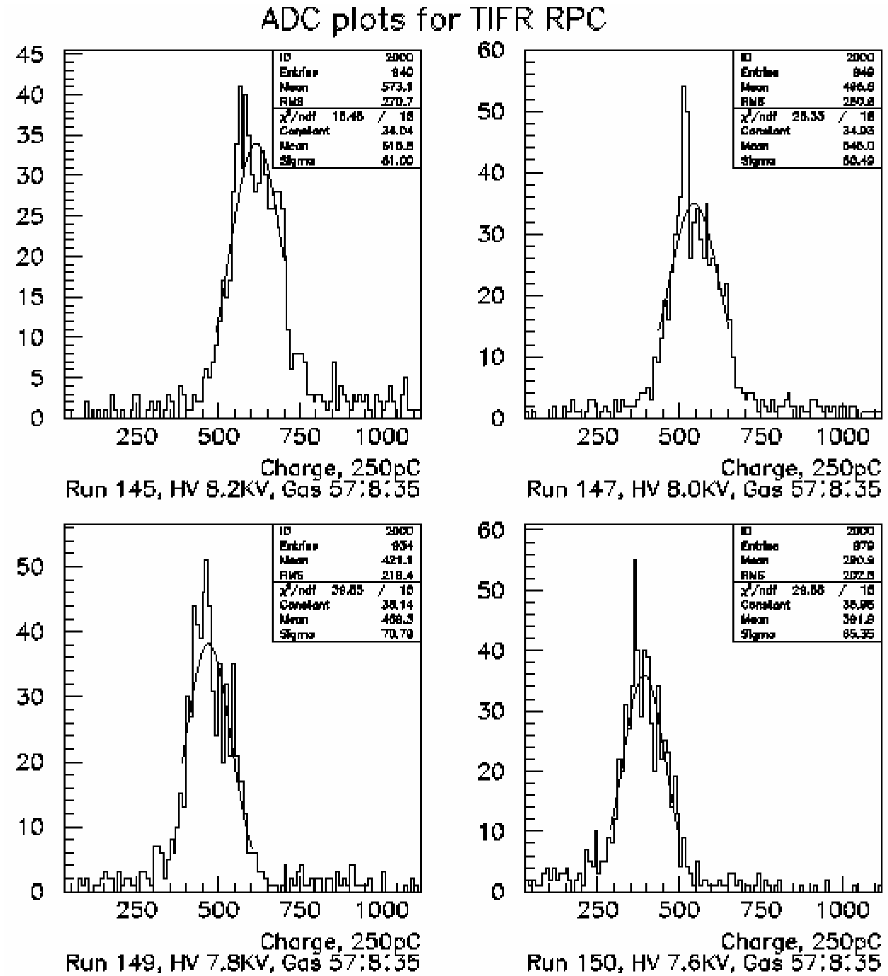




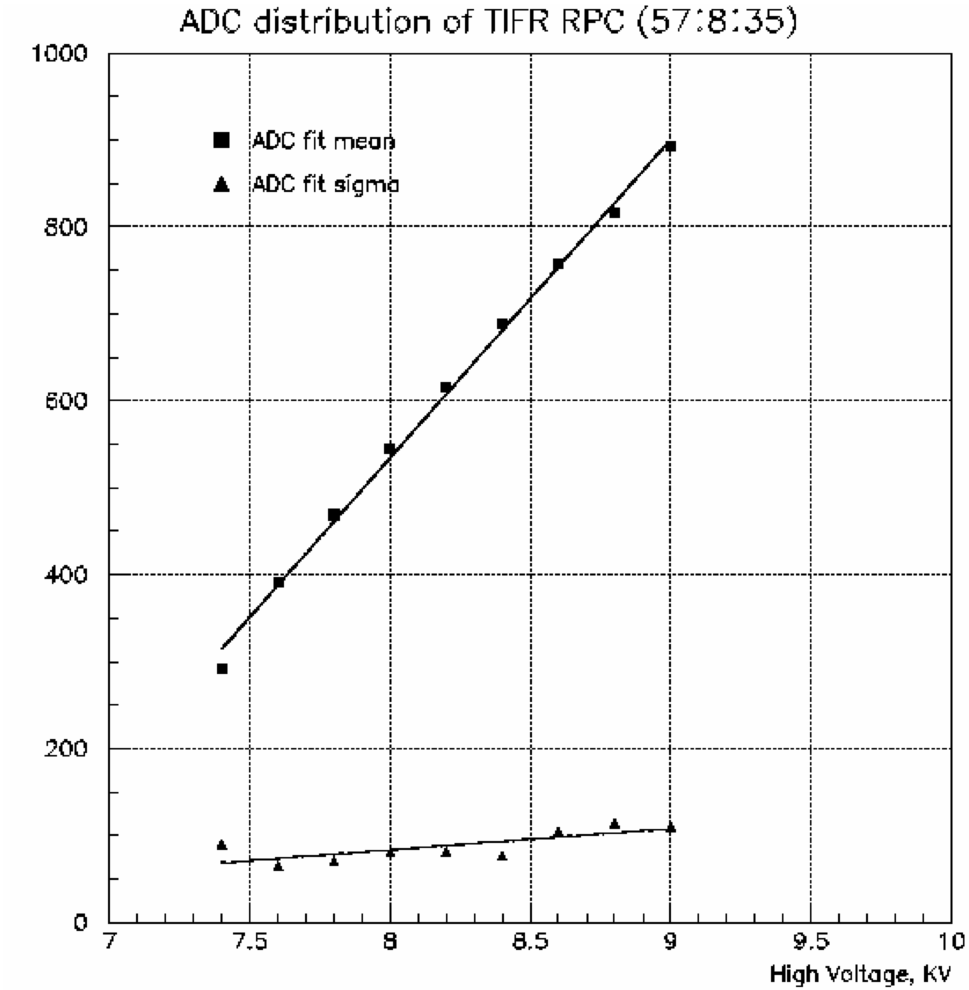
RPC typical noise rate plot



RPC typical charge distributions



RPC typical mean charge plot



Charge resolution plot

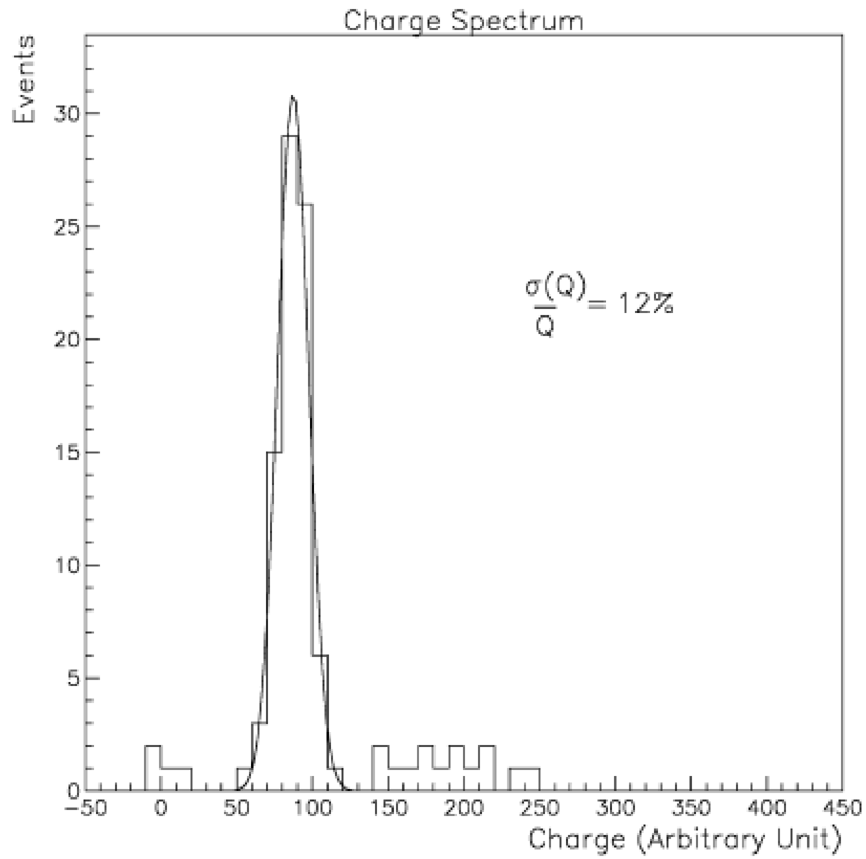
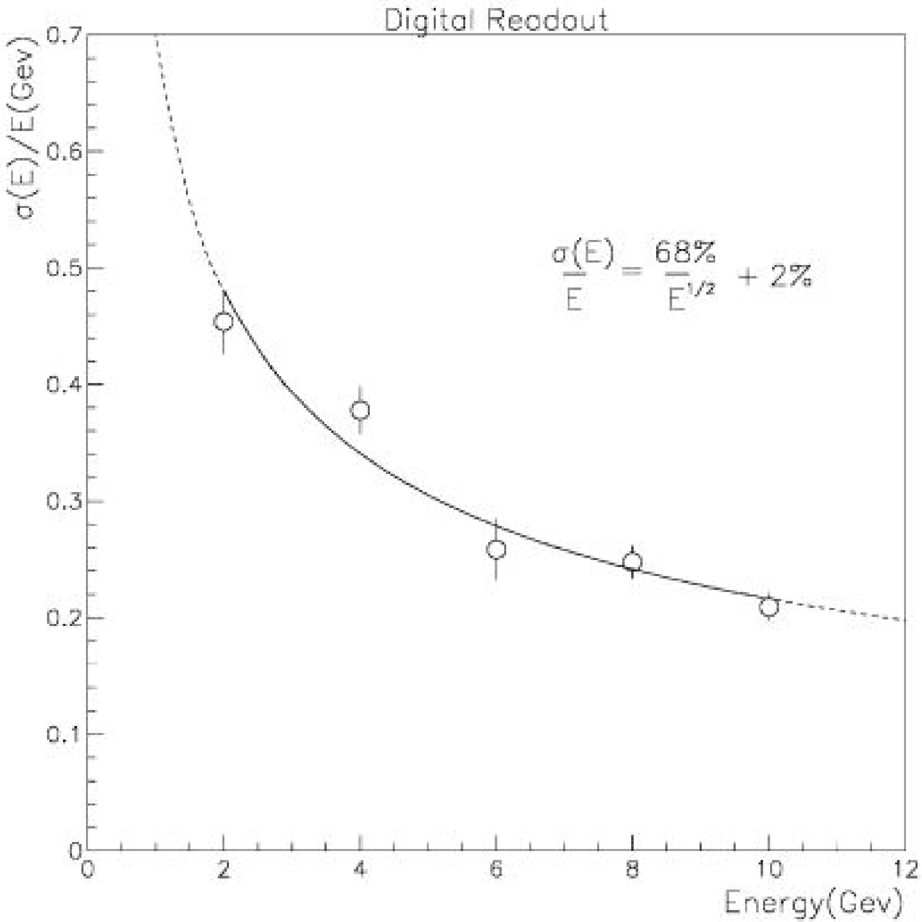
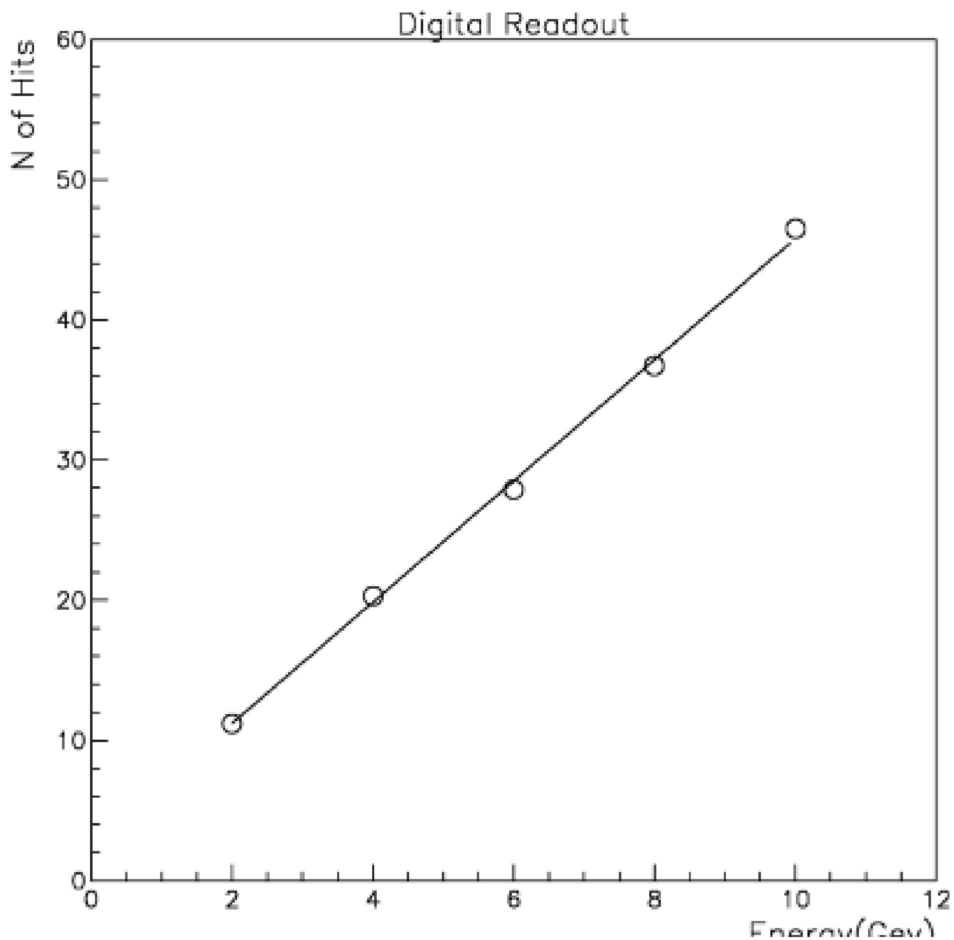


Fig. 3. Induced charge distribution for 10 GeV muons crossing

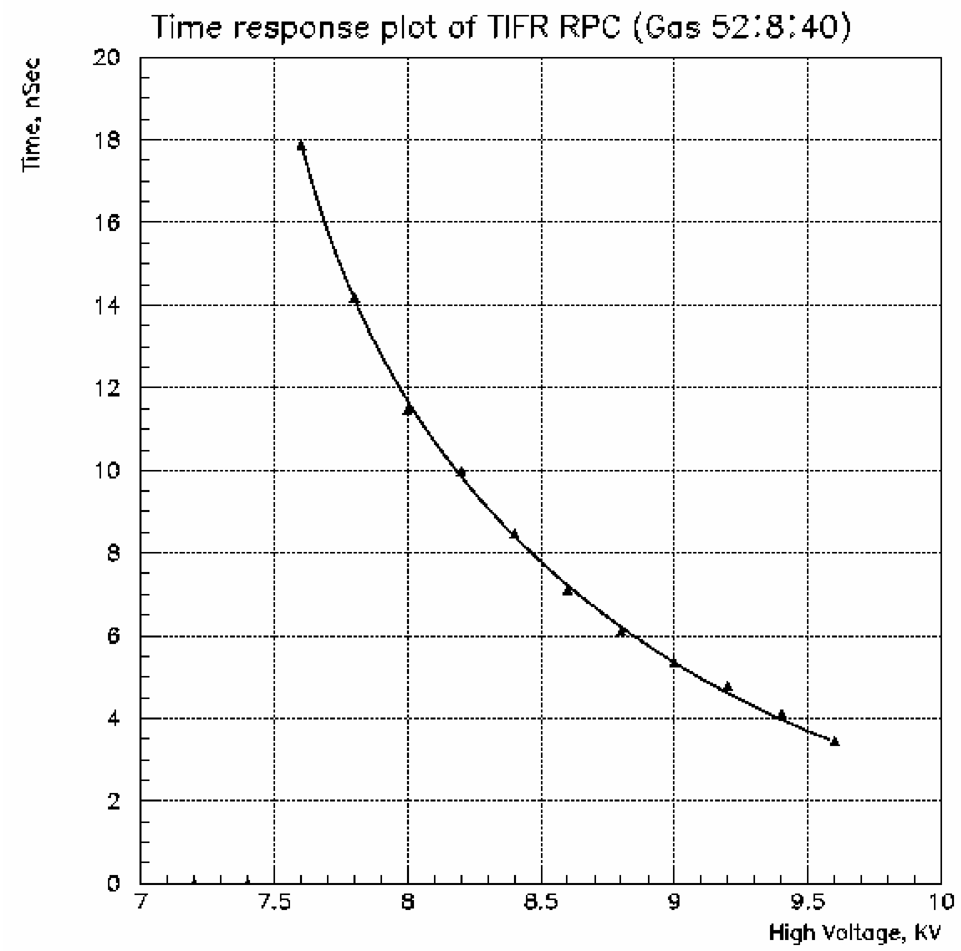
Energy resolution plot



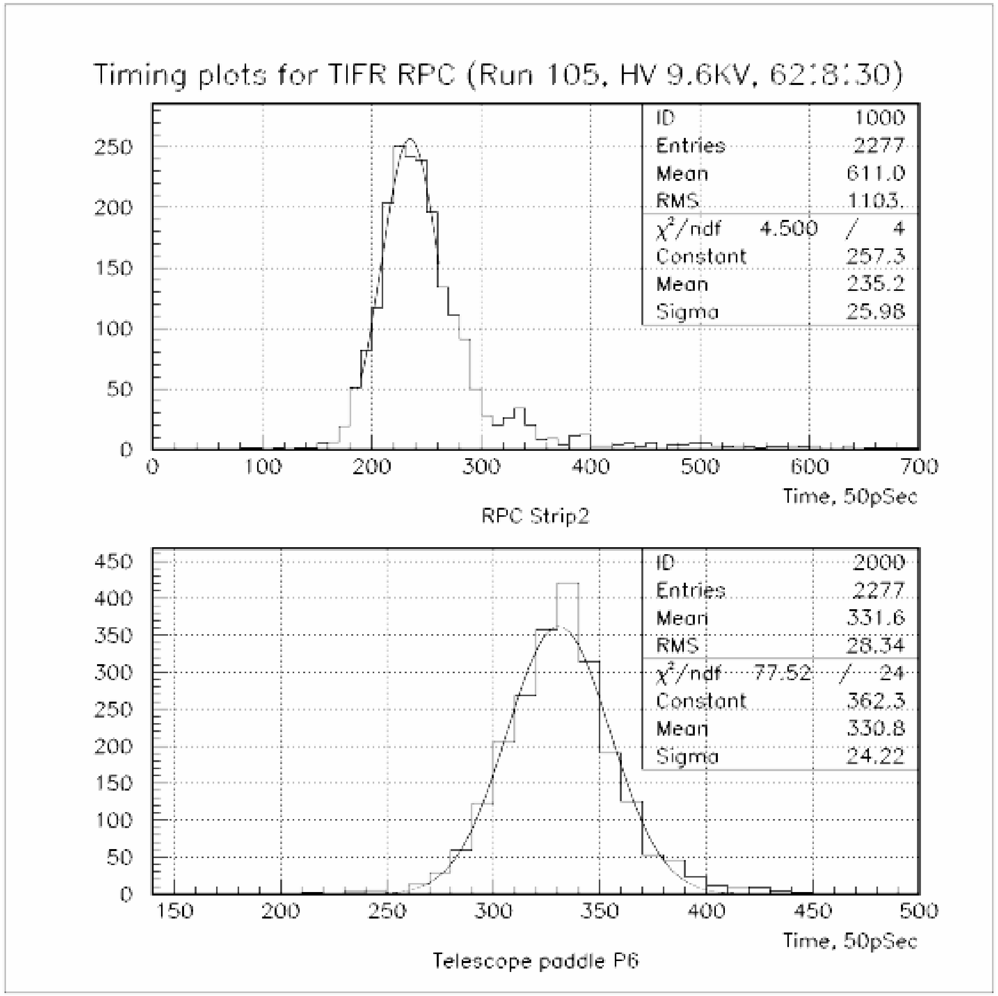
Digital calorimetry using RPC



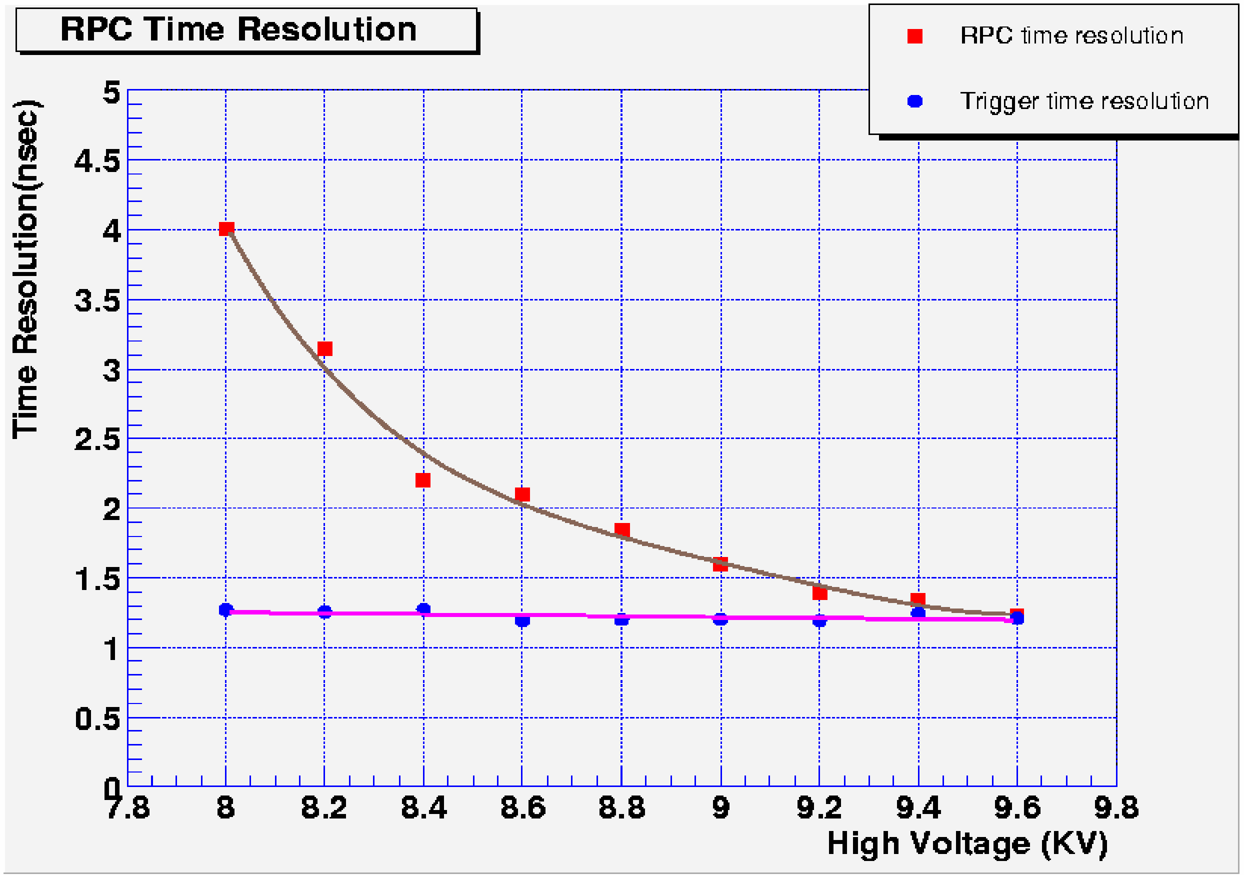
Typical time response plot



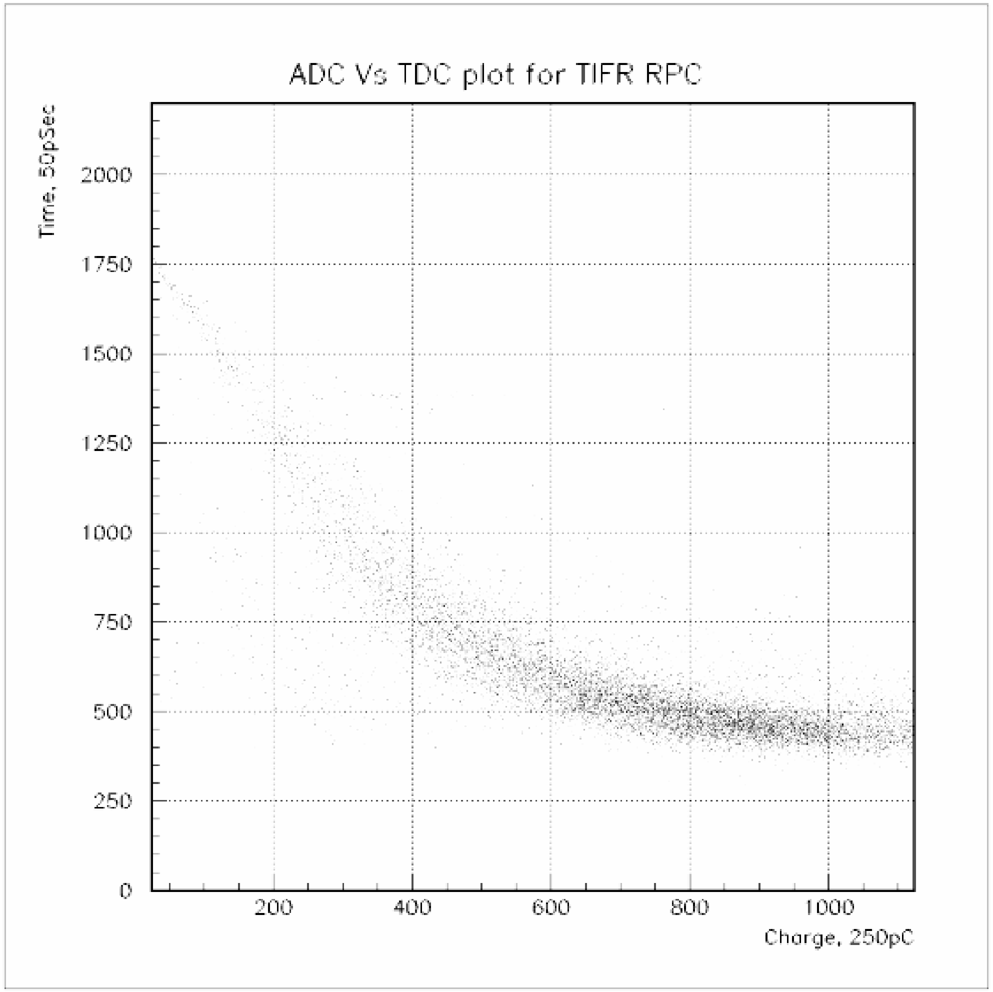
Typical timing distribution plot



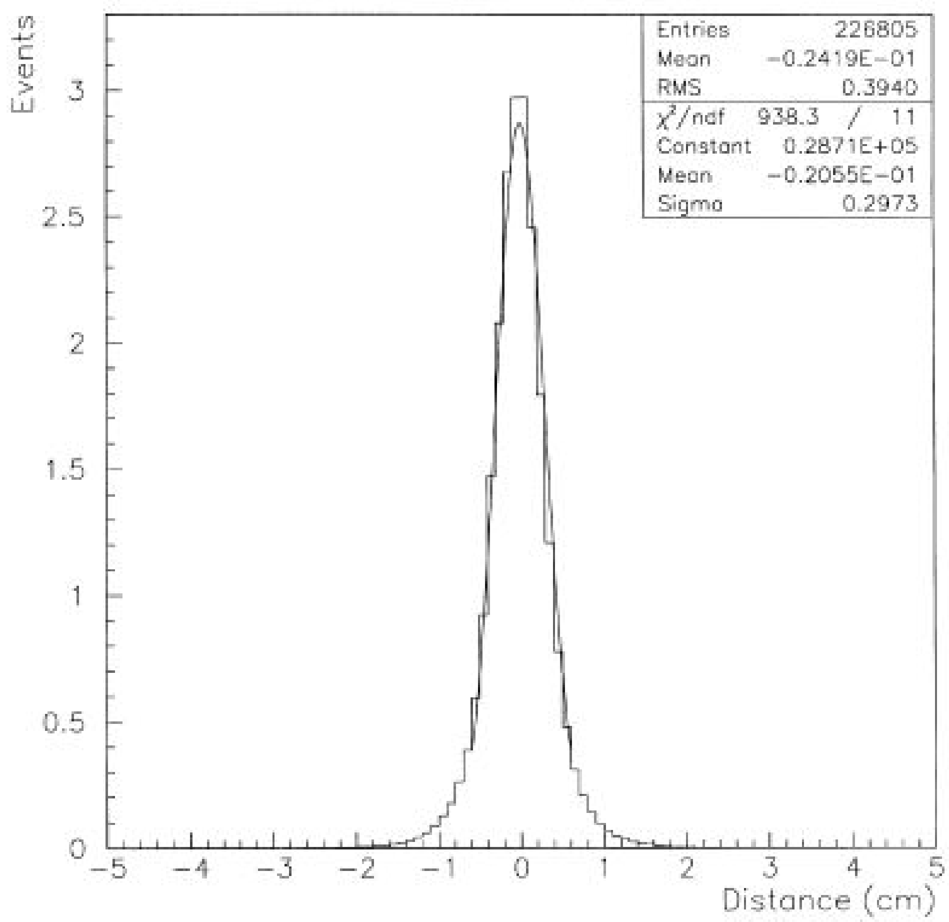
RPC timing resolution plot



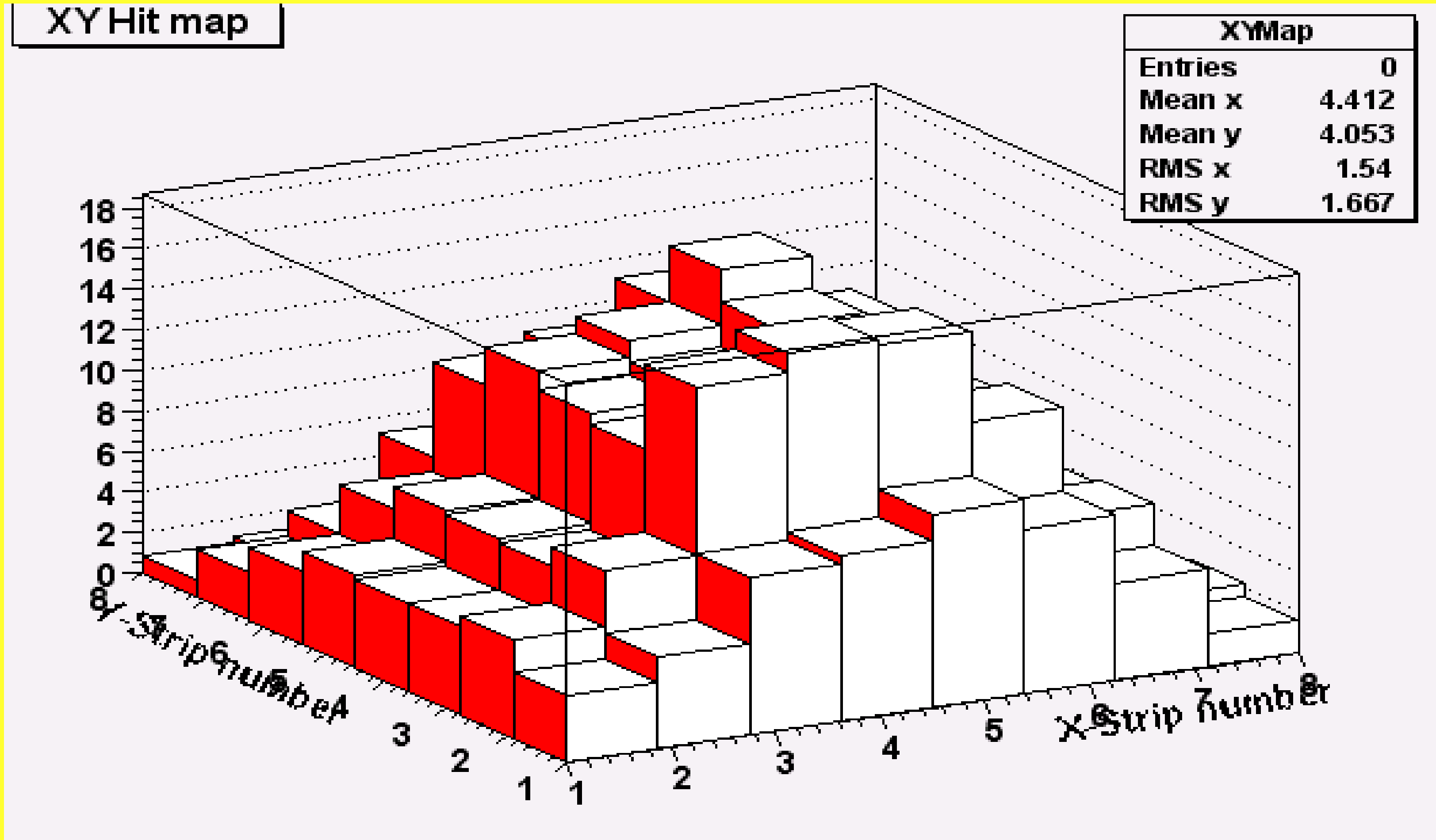
RPC pulse height Vs timing plot



Spatial resolution plot



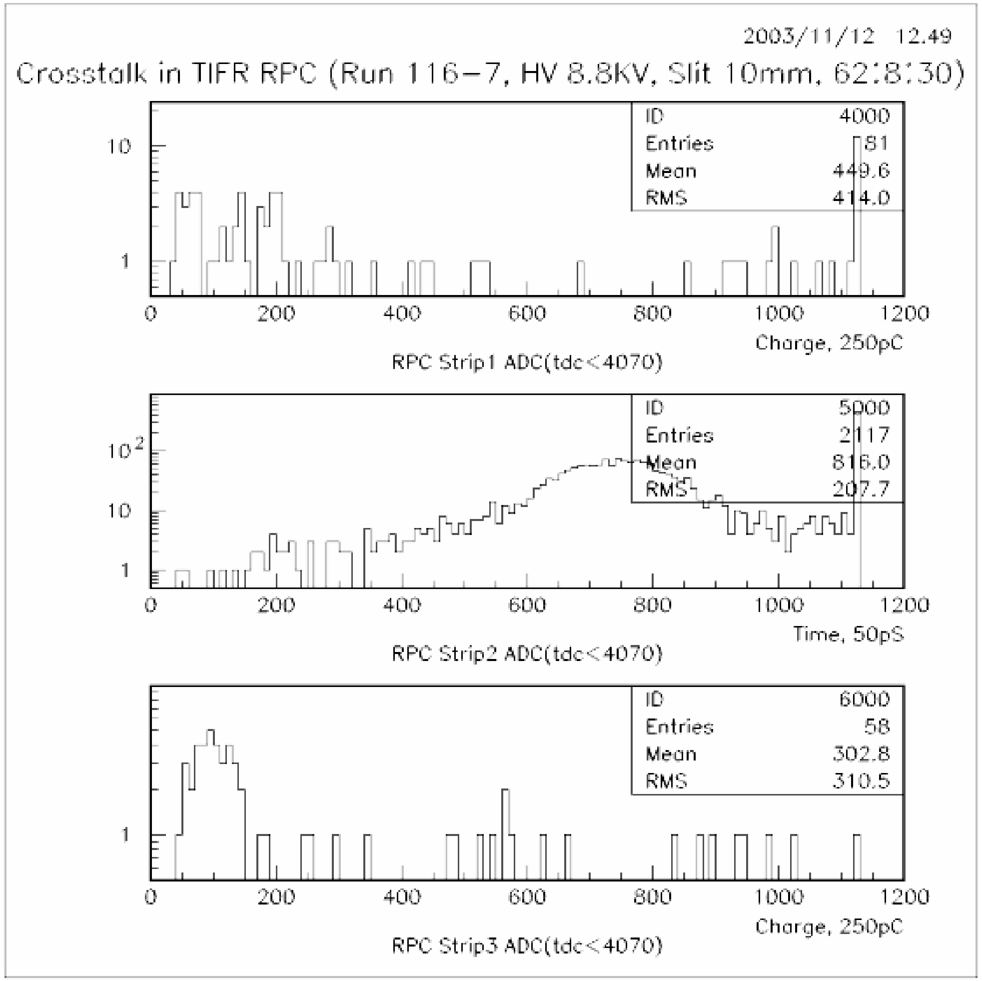
X-Y strip readout plot



Cross-talk issues

- **Reduced with higher resistivity graphite layer**
- 40kΩ/□ → 200kΩ/□ → 1MΩ/أ
- Easy to discriminate: cross talk at 1- 4% level

Typical cross-talk plots



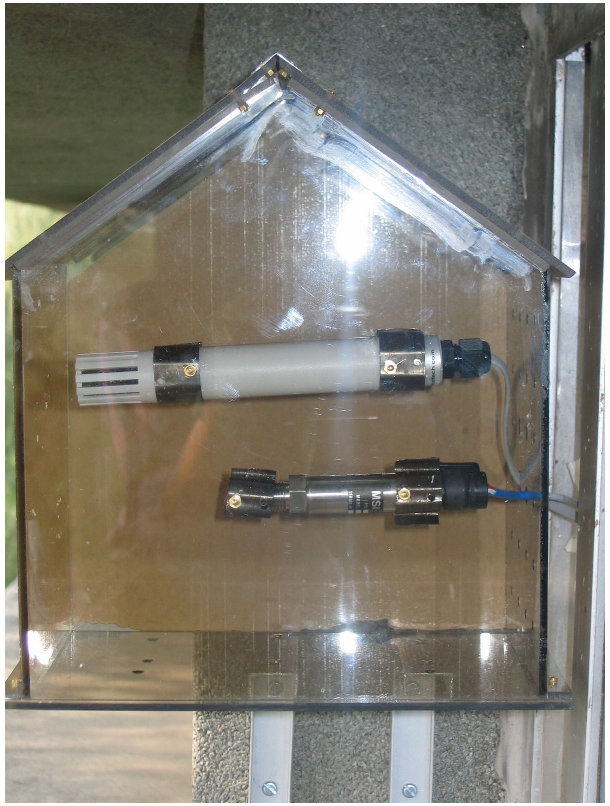
RPC cross-talk measurements

Gas Mixture	Slit Size (mm)	Cross talk (%)
62:8:30	10	6.8
62:8:30	15	6.7
62:8:30	20	6.2
57:8:35	20	6.5
52:8:40	20	5.9
46:8:46	20	6.3

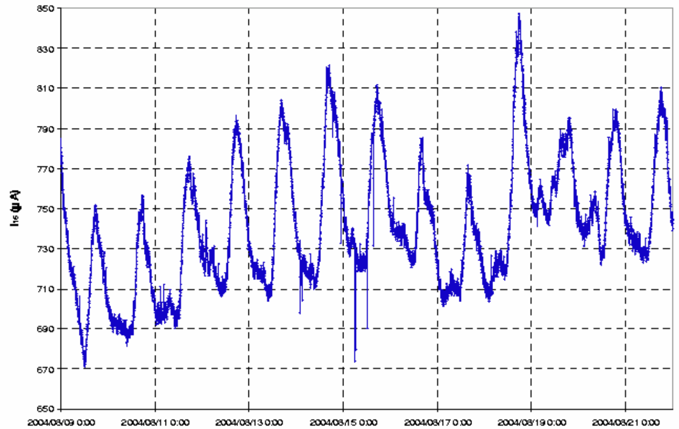
Slow monitoring of parameters

Long term monitoring of:

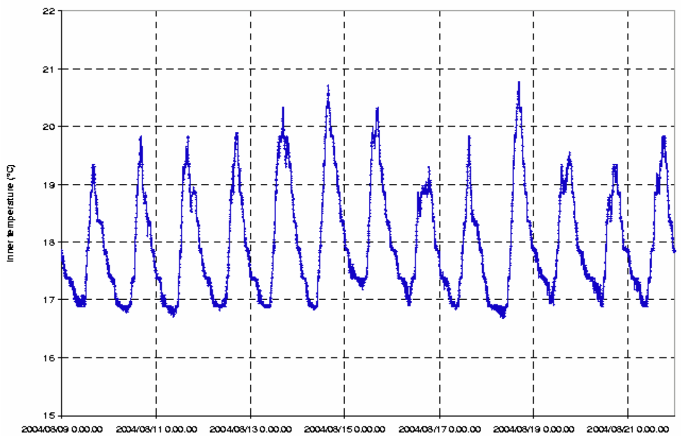
- efficiency
- dark current
- noise rate
- temperature
- relative humidity
- barometric pressure



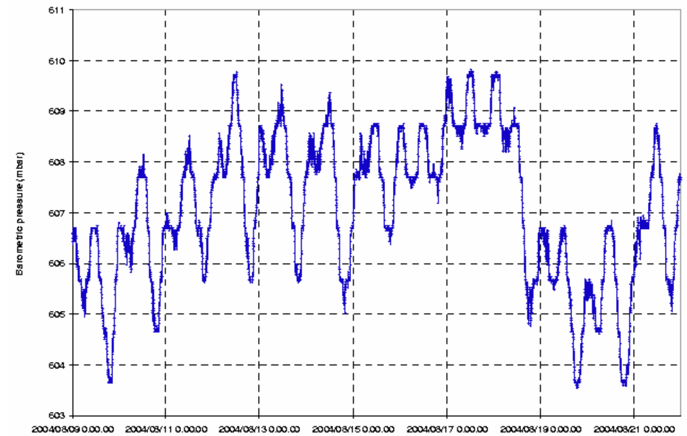
Effect of ambient parameters



RPC current

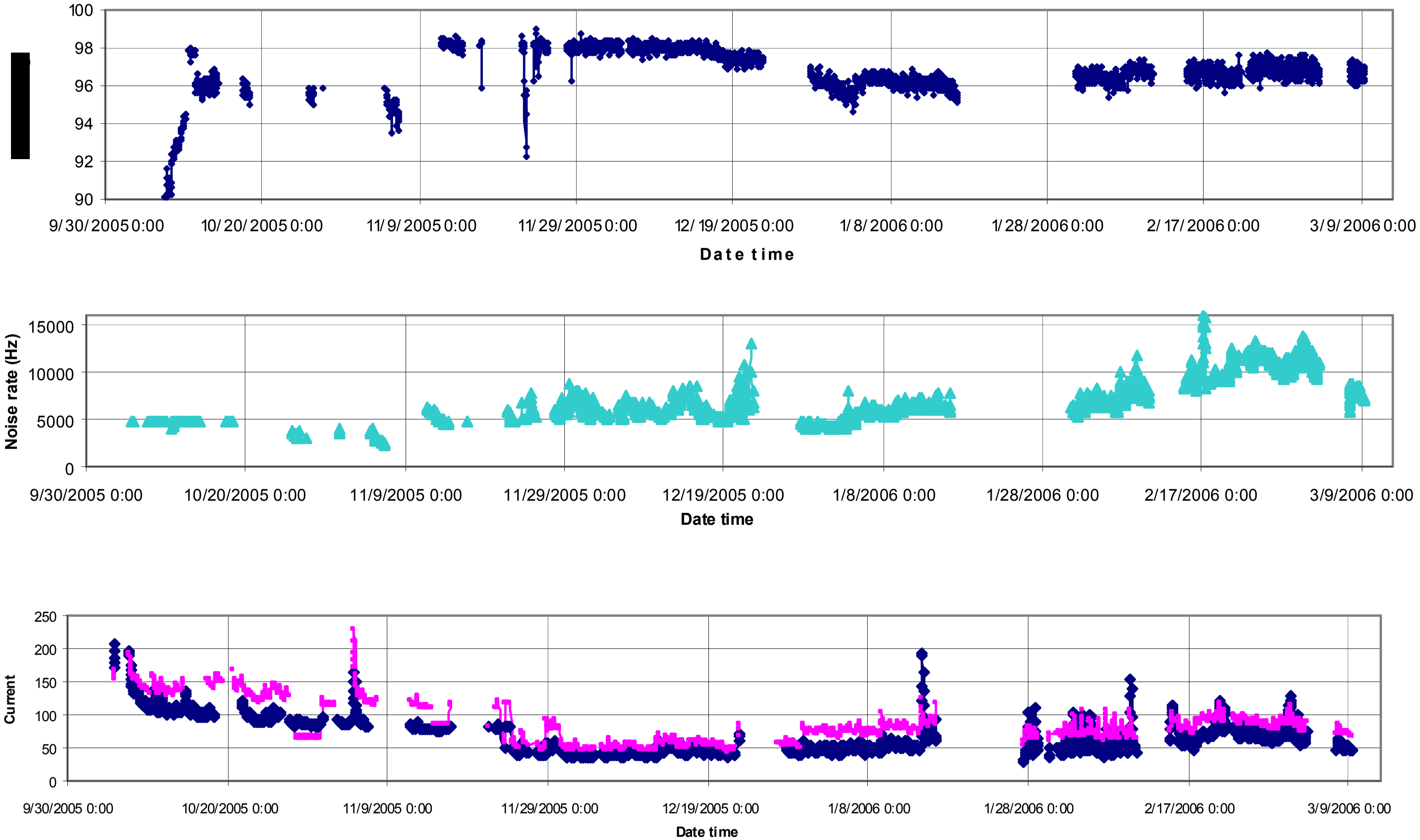


Lab temperature



Barometric pressure

Long term stability of RPCs



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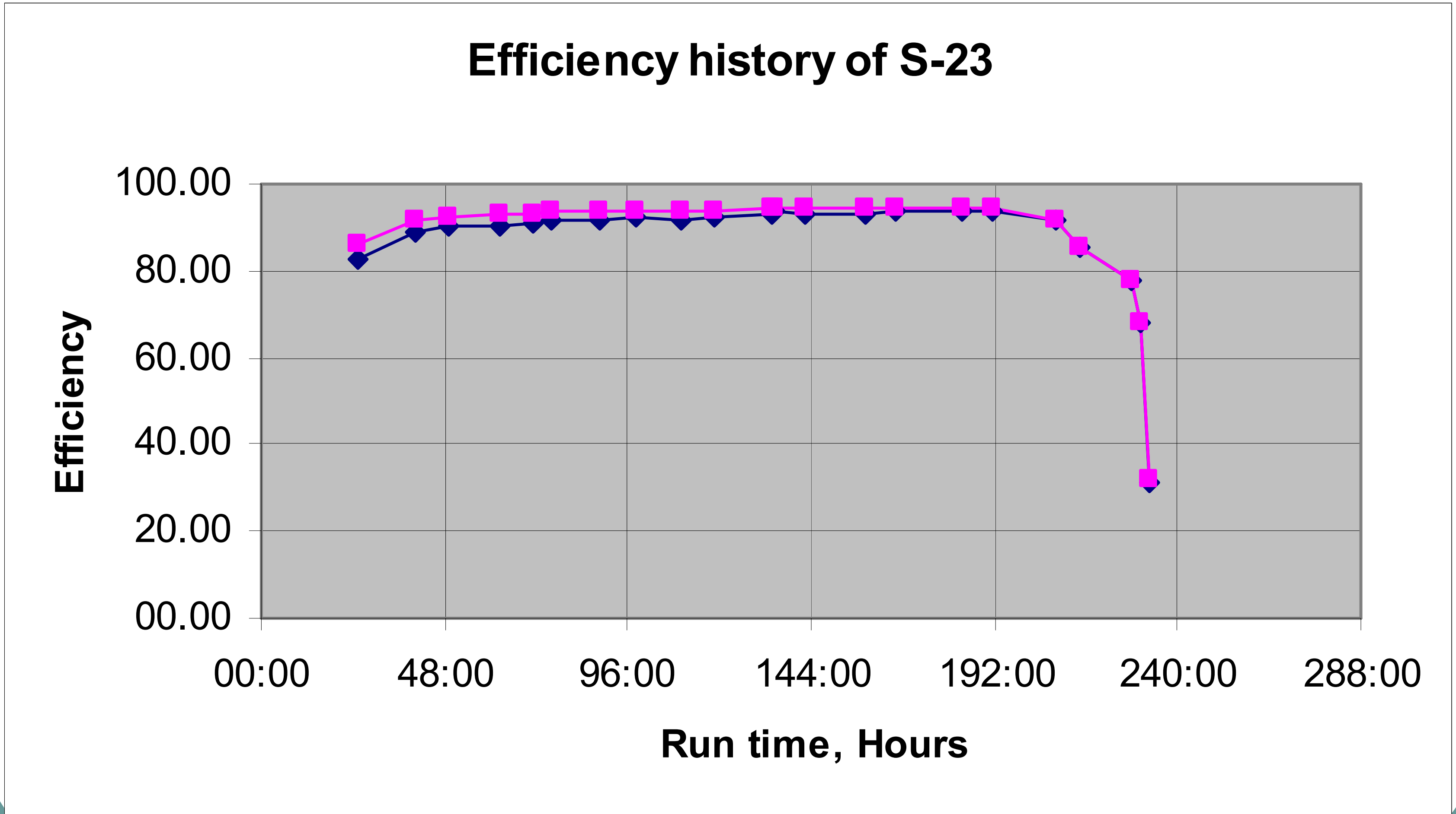
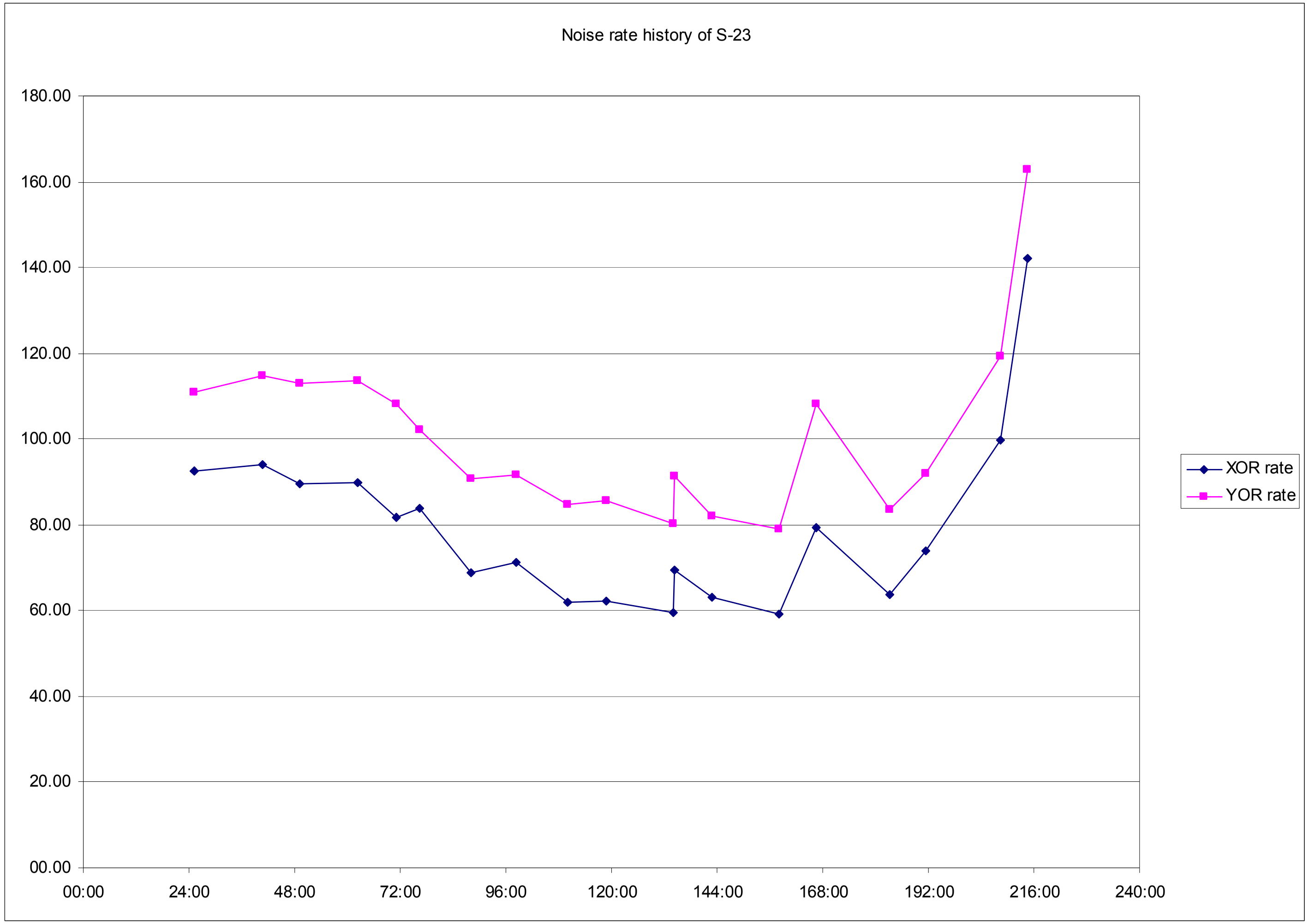
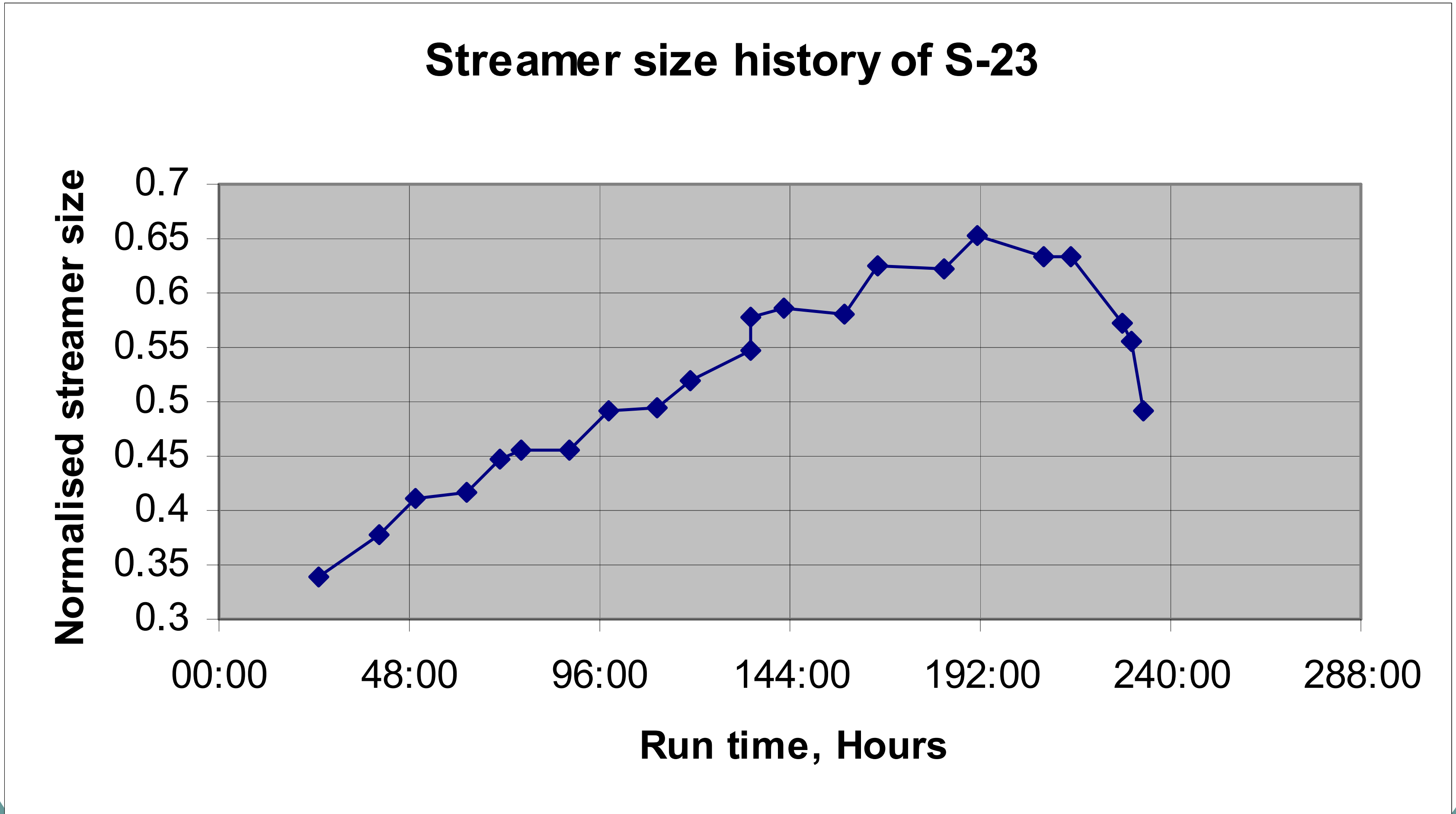
Aging: RPC S-23 efficiency history



RPC-S23 noise rate monitoring

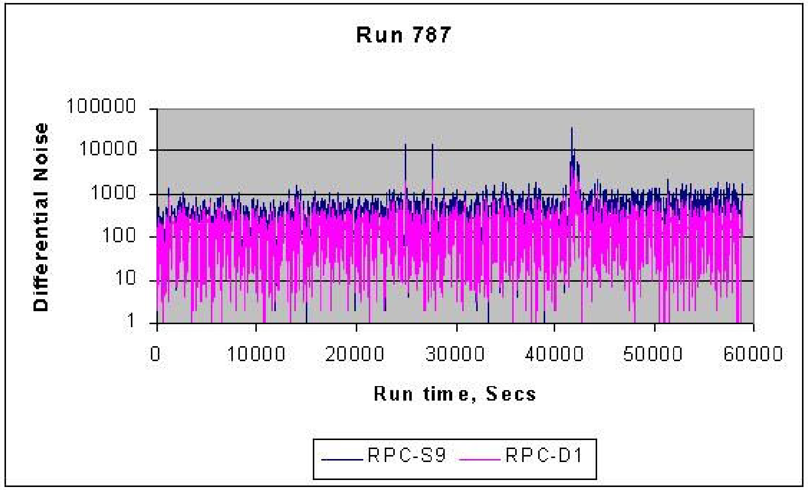


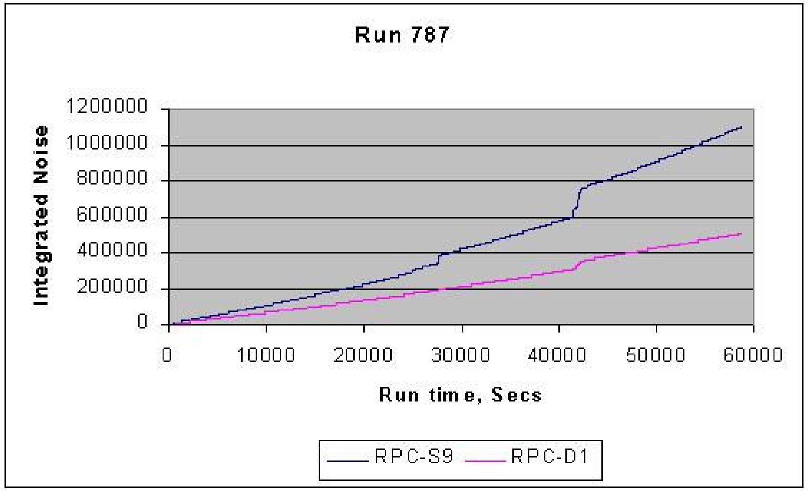
RPC-S23 streamer size



RPC aging problem

- ✓ Drop in efficiency, increase in noise rate and chamber current seen after a few weeks of continuous operation
- ✓ Reports in the literature (Monolith, Belle etc)
- ✓ Moister contamination in Freon gas, the culprit?
- ✓ Use of SF_6 instead of Freon preferred



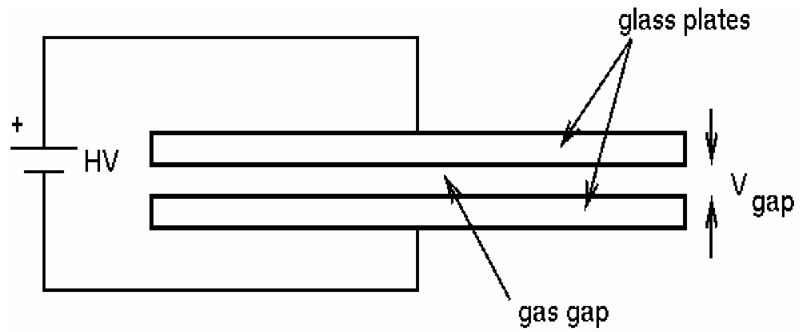


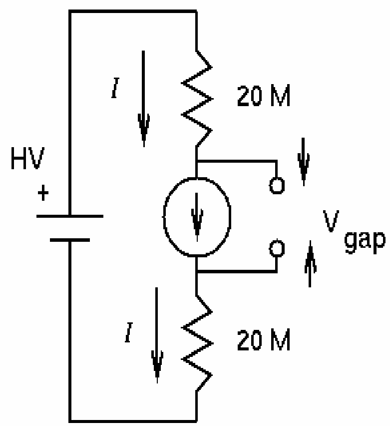
Symptom of a dieing RPC

High dark currents induce a significant IR voltage drop across the glass plates, which lowers the voltage across the gap, causing the chamber to slide off the efficiency plateau.

Increasing the applied voltage doesn't help since it merely results in increased dark current.

This is termed as RPC Death Spiral.

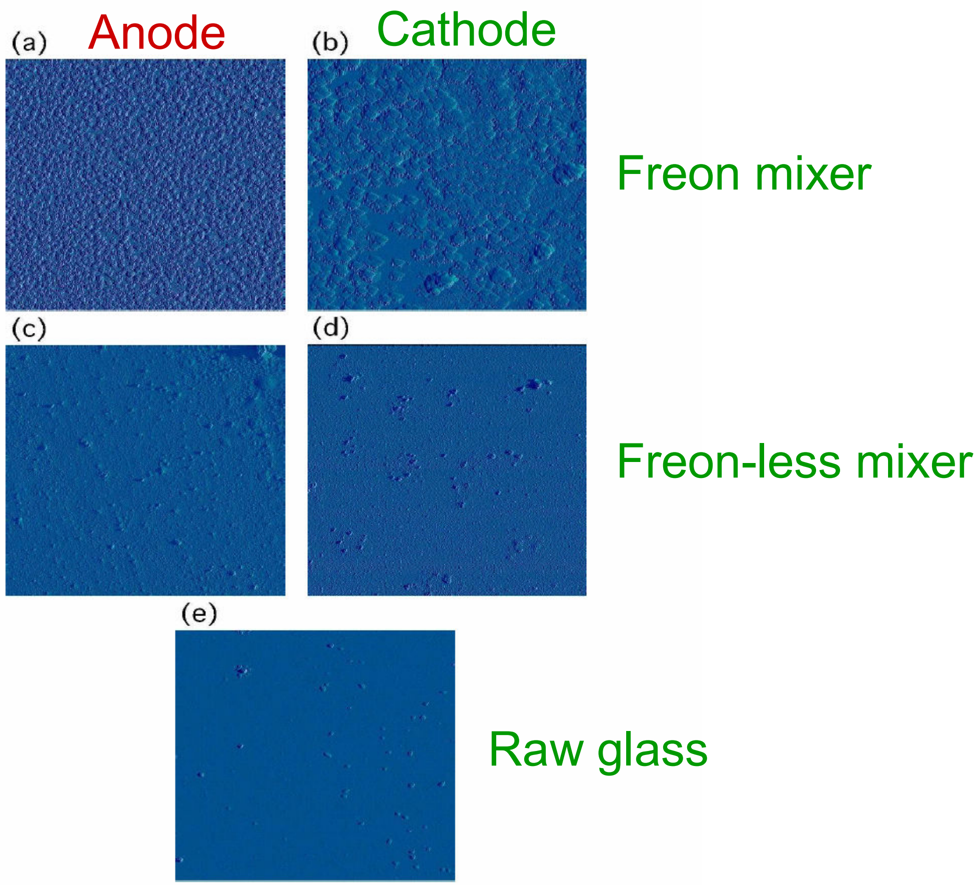




V_{gap} = HV − IR = HV − 10 uA x 40 M

= HV − 400V

AFM images of electrode surfaces



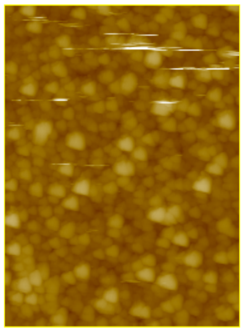
- Cathode and anode of RPC operated with Freon mixer show deposits.
- Makes it conductive?
- Reduces glass work function?

AFM images of damaged electrodes

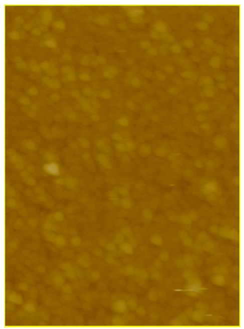
2μ scans

10μ scans

s22ua



s12ua

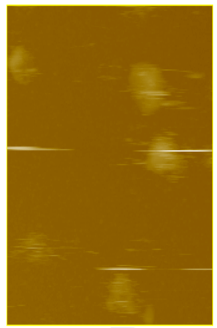


Damaged electrodes

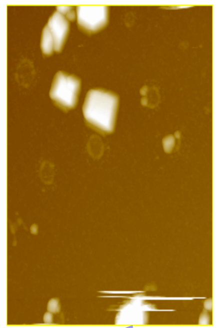
g12u

Raw glass

s210ua

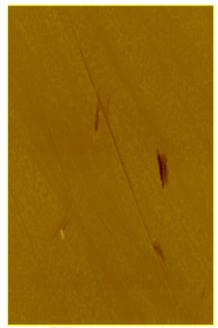


s110ua



Damaged electrodes

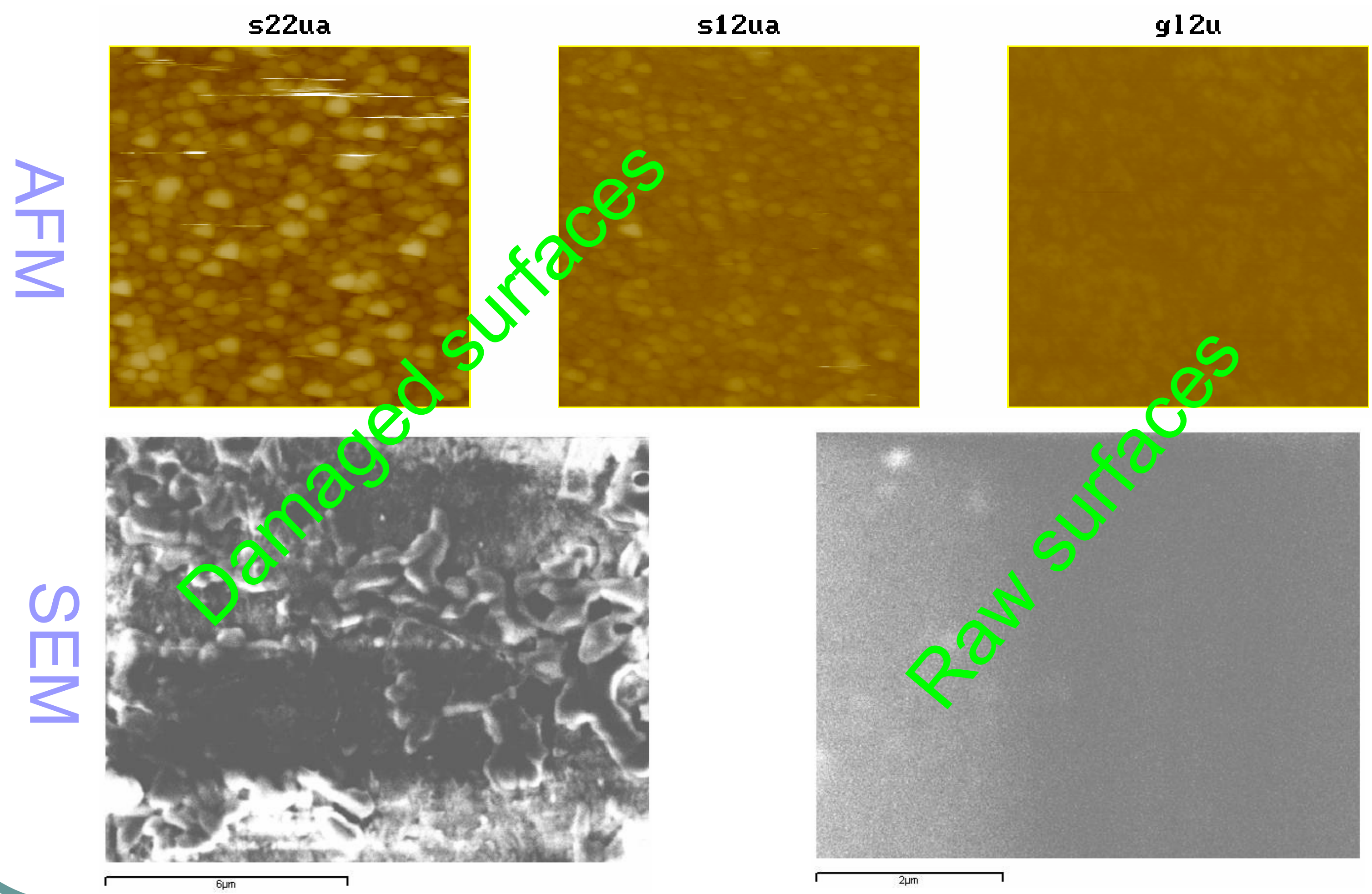
g110u100



Raw glass

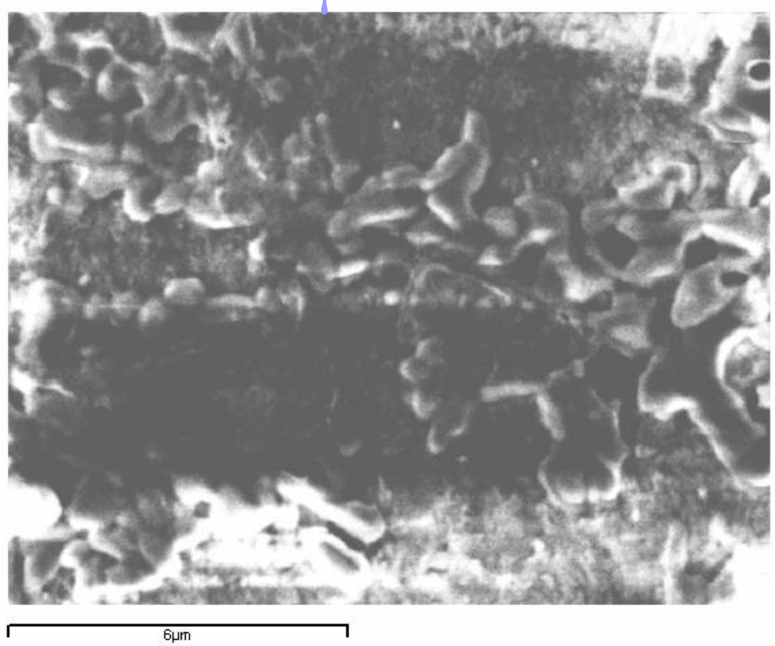
- 500nm structures of 100nm thick seen in the images

Aging: AFM and SEM scans



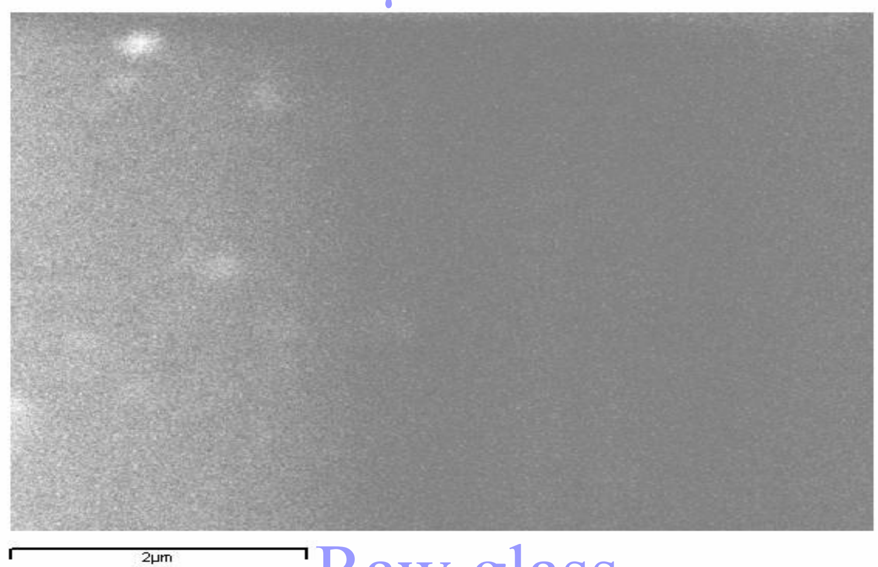
SEM image of damaged electrode

6μ scan



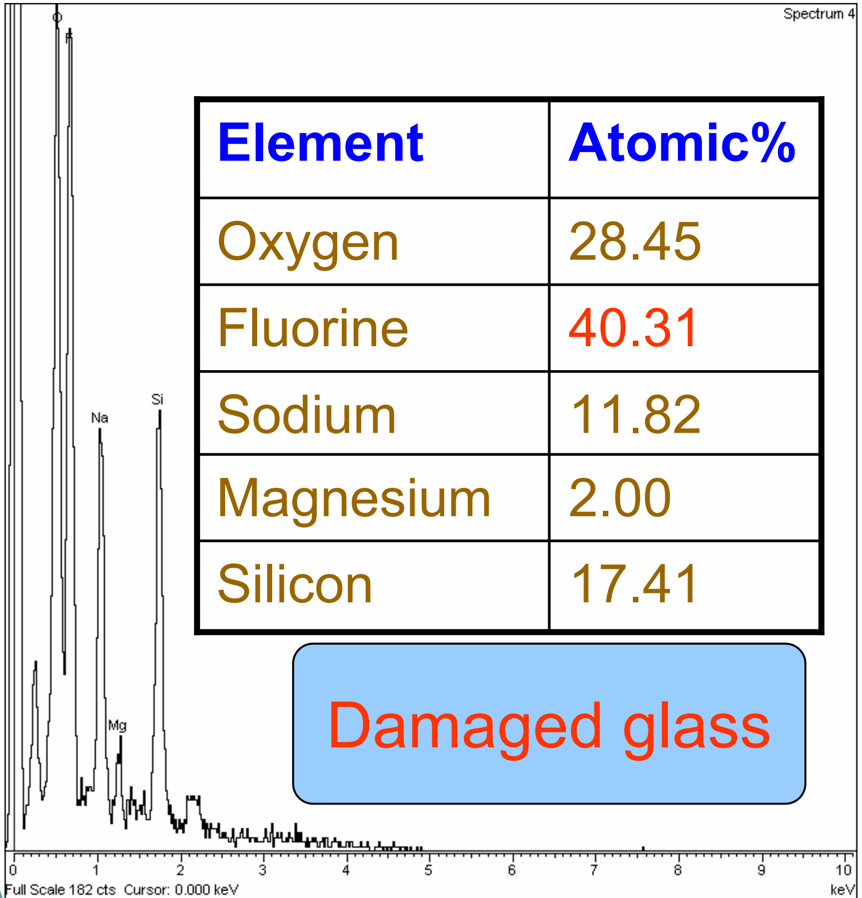
Damaged electrode
Fluorine: 38%

2μ scan



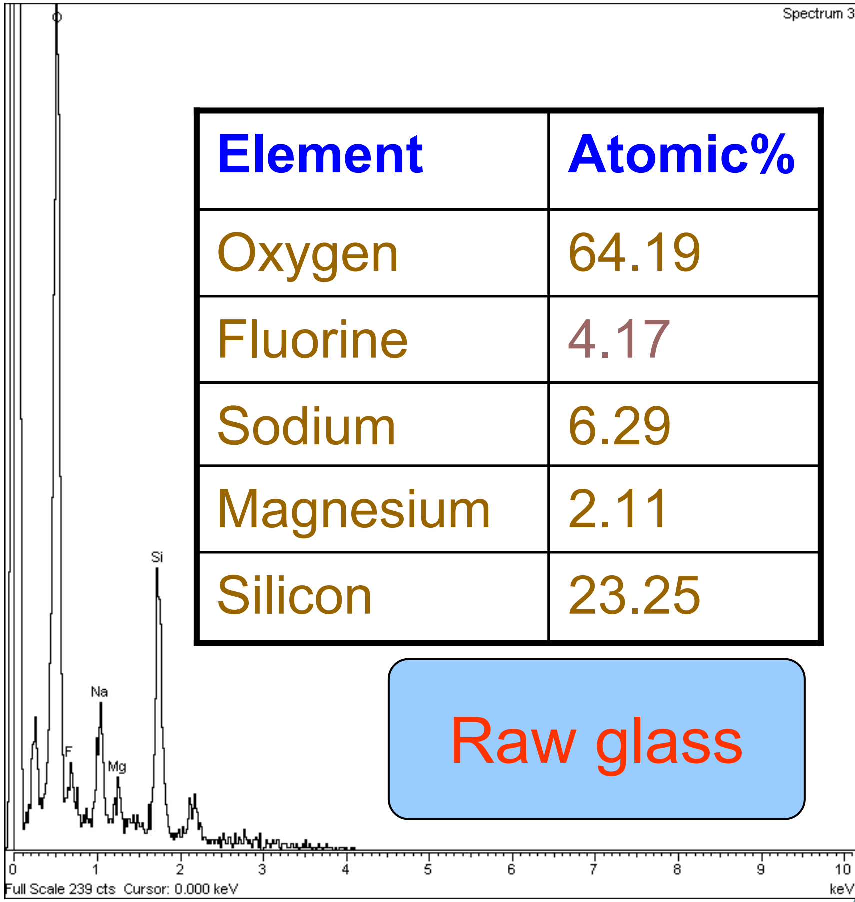
Raw glass
Fluorine: 4%

Aging: Element analysis



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

Damaged glass



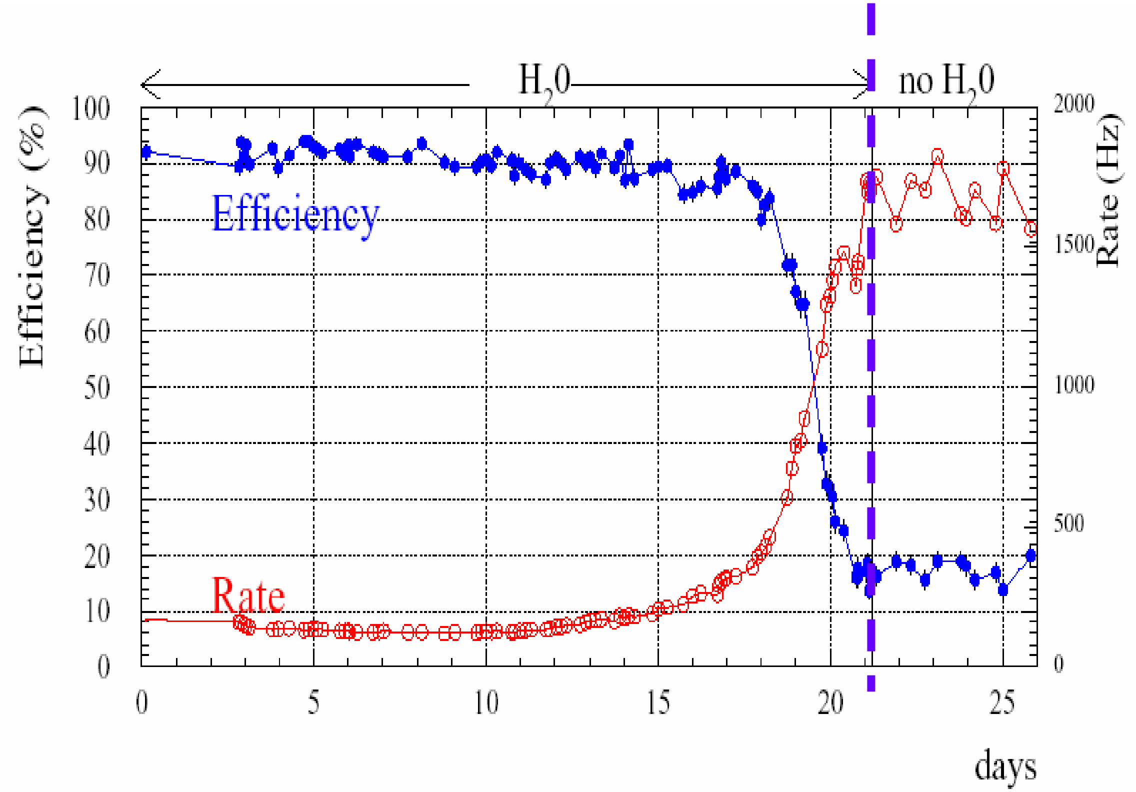
Element	Atomic%
Oxygen	64.19
Fluorine	4.17
Sodium	6.29
Magnesium	2.11
Silicon	23.25

Raw glass

Element analysis of the surfaces

Element	A (orange glow)	B (white glow)	C (RPC #1 anode)	D (RPC #1 cathode)	E (RPC #2 anode)	F (RPC #2 cathode)
Carbon	51.09%	51.71%	25.05%	42.60%	16.09%	24.53%
Oxygen	31.84	31.22	33.28	36.57	19.64	35.41
Nitrogen	1.27	1.74	0.82	1.44	0.17	0.53
Silicon	13.98	12.62	15.01	13.18	13.59	6.88
Fluorine	0.28	0.26	14.77	2.37	34.44	18.71
Chlorine	0.19	0.21	0.45	0.09	0.28	0.21
Tin	0.18	1.06	0.25	0.37	0.05	6.80
Calcium	0.50	0.61	1.62	0.77	1.91	4.58
Sodium	0.67	0.57	8.74	2.60	13.83	2.36

Aging: humidity test

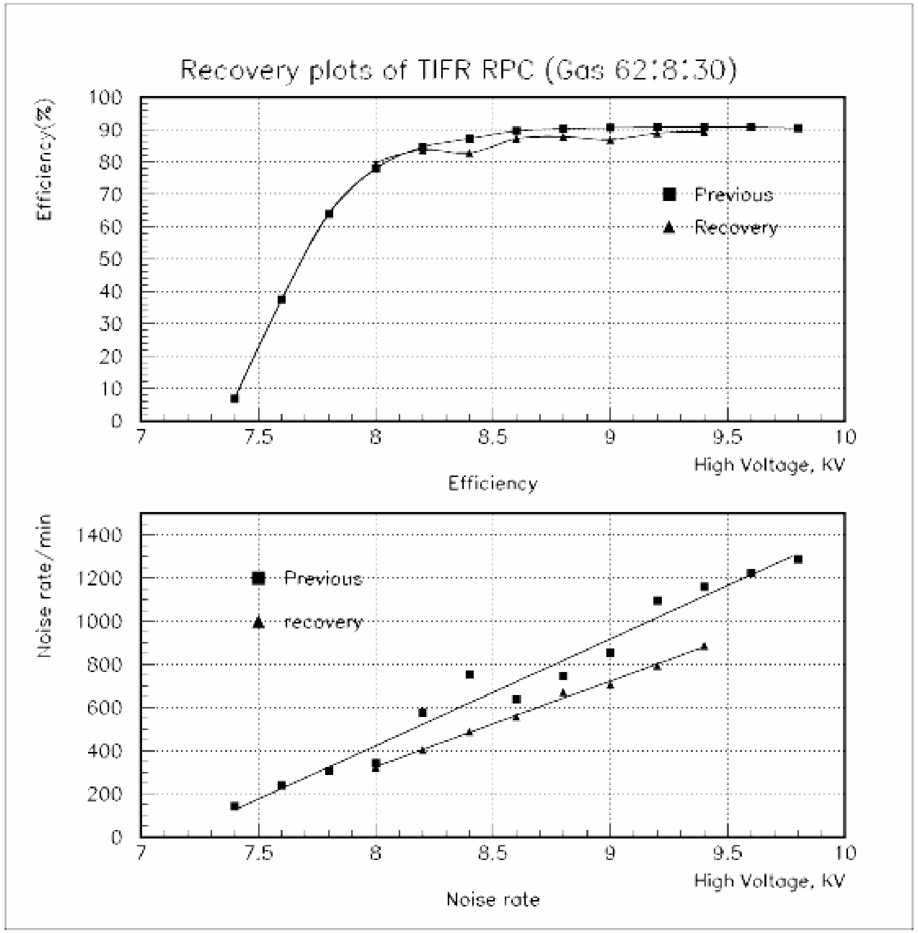


Water vapour seriously damages the Glass RPC

It is a threshold effect

Recovery of a damaged RPC

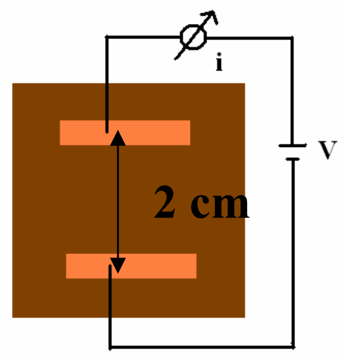
Bubbling Argon through 25% Ammonia solution for 24 hours without electric field



Alumina gas filter

HF and surface resistivity

Surface resistivity measured on three samples cut from one RPC electrode, before and after different treatments

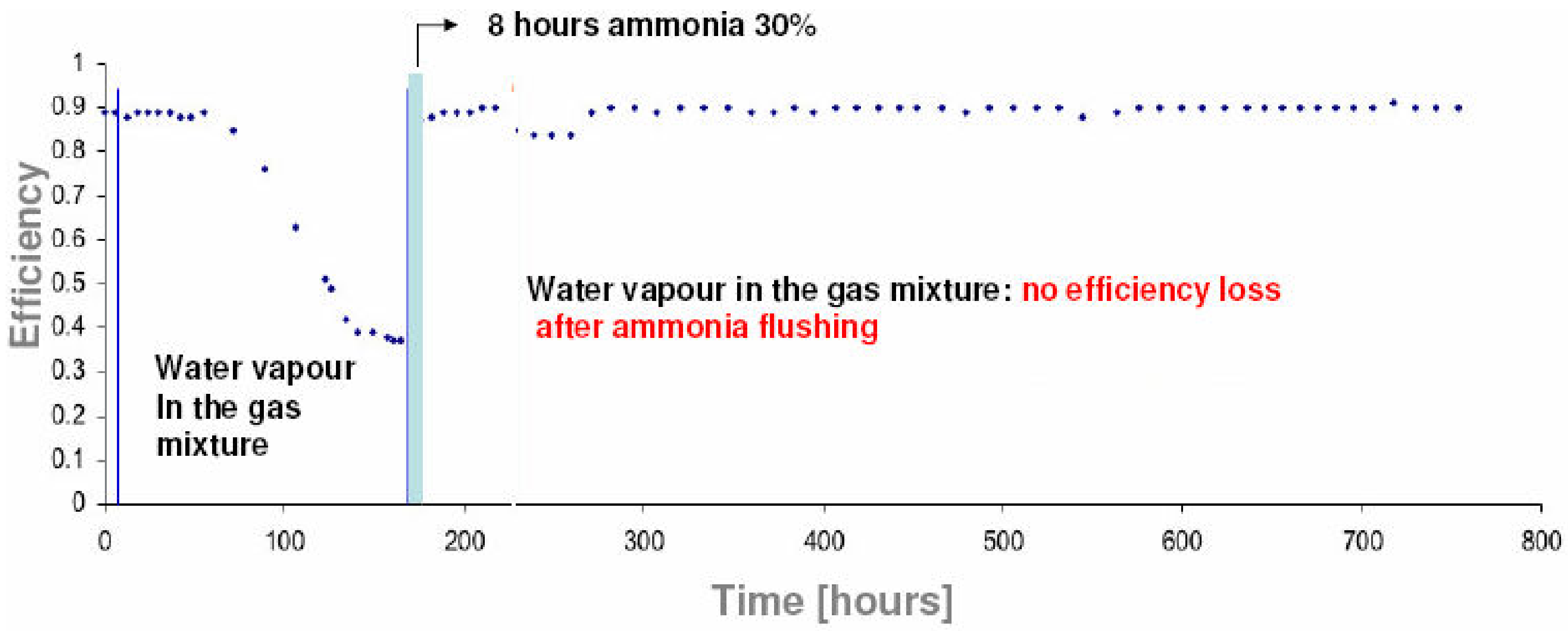


Sample n.	Treatment	σ_i (GΩ/■)	σ_f (GΩ/■)	σ_f/σ_i
1	No treatment	35.1 ± 0.4	39.2 ± 0.5	1.12
2	Water	61 ± 1	77 ± 2	1.26
3	Water/HF=60/40	40.5 ± 0.4	11.56 ± .05	0.285

HF seems to lower the electrode surface resistivity and explain:

1. The high ohmic current of damaged RPC1
2. The increase of the local discharge rate?

Simulated aging: Recovery



Why electrode damages matter?

Eight combinations of exchanged electrodes[a]

	Anode	Cathode	Efficiency
1	D anode	D cathode	Low (high singles rate)
2	D cathode	D anode	Low (no signal)
3	N anode	D cathode	Low (high singles rate)
4	D cathode	N anode	High
5	D anode	N cathode	High
6	N cathode	D anode	Low (no signal)
7	N anode	N cathode	High
8	N cathode	N anode	High

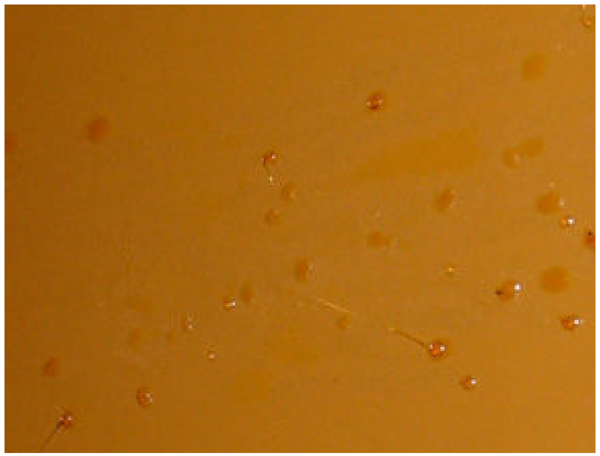
[a] N: normal chamber, D: damaged chamber.

Chamber functions properly if it has *good* cathode; anode doesn't matter!

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 F 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 bakelite 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.

Linseed oil stalagmites



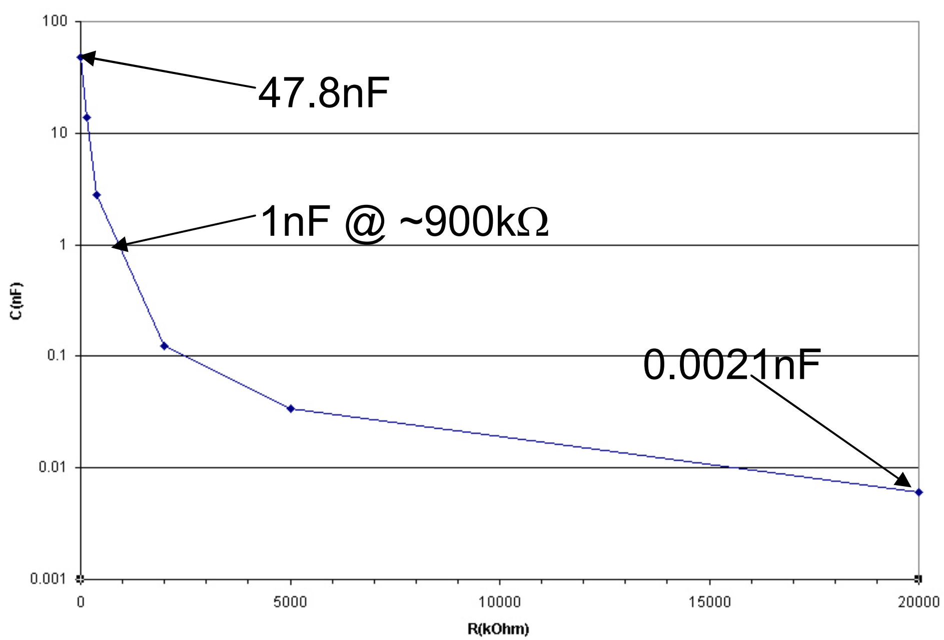
Three basic conditions for forming linseed oil droplets on the inner surfaces of RPC:

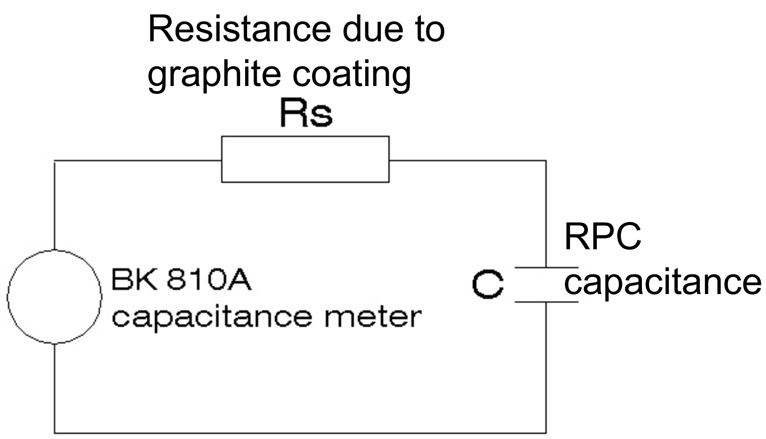
- ❖ Excess linseed oil existing on the surface which is the source of the droplets;
- ❖ Elevated temperature softens the oil film, and makes the oil molecules movable;
- ❖ High electric field to help pull the soften oil layer away from the Bakelite sheet. Electric force could be 70 times stronger than the gravity force!

Disappearance of graphite

The explanation: Graphite paint film developed discontinuity region

While using a simple handheld capacitance meter the resistance of the graphite paint can seriously pervert the capacitance measurement.





Increase in Rs will reduce capacitance reading. A 900kΩ resistor can let a 47.8nF capacitance be read as 1nF with a BK 810A meter!

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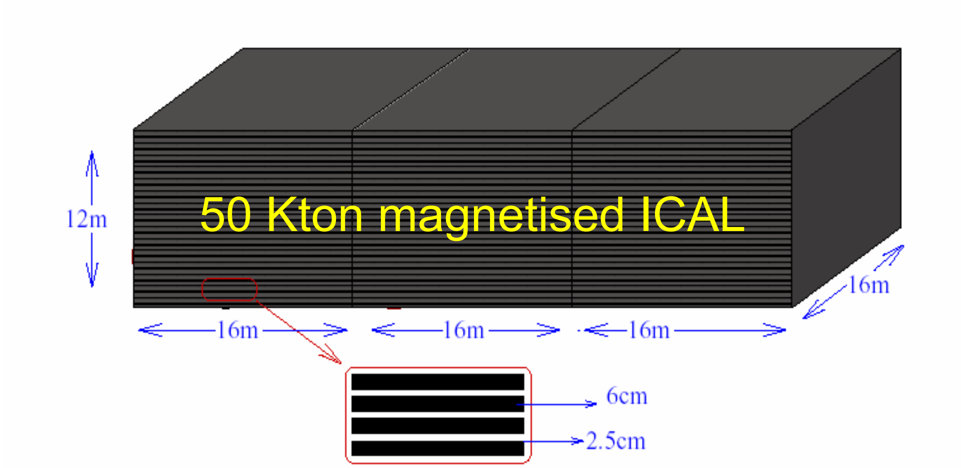
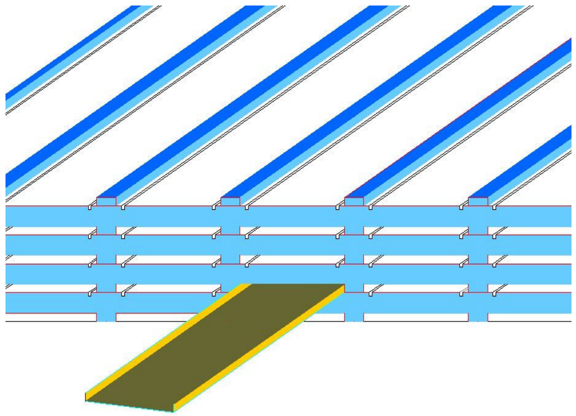
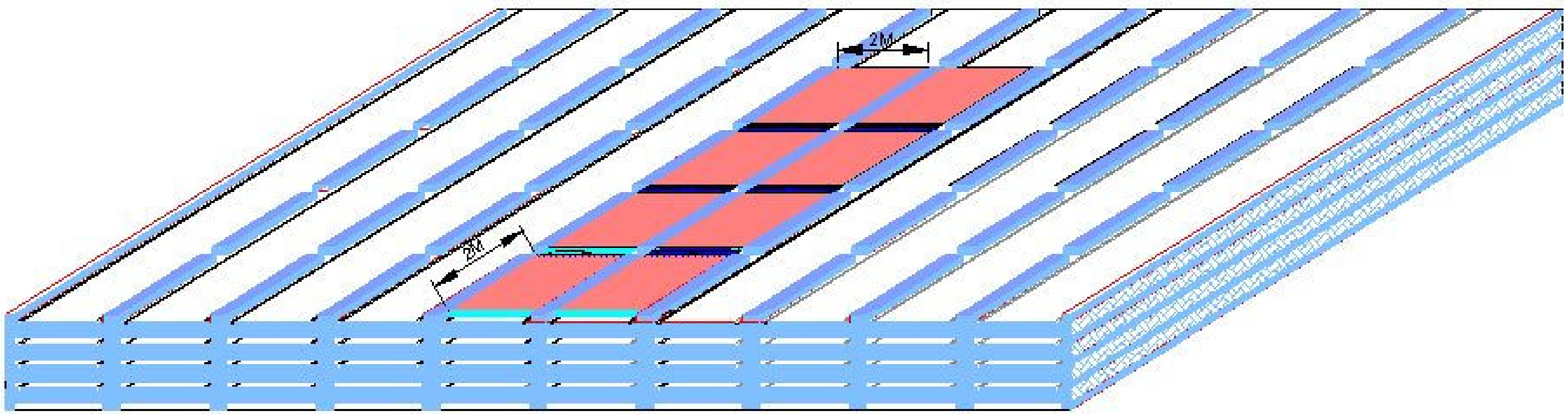
INO detector concept







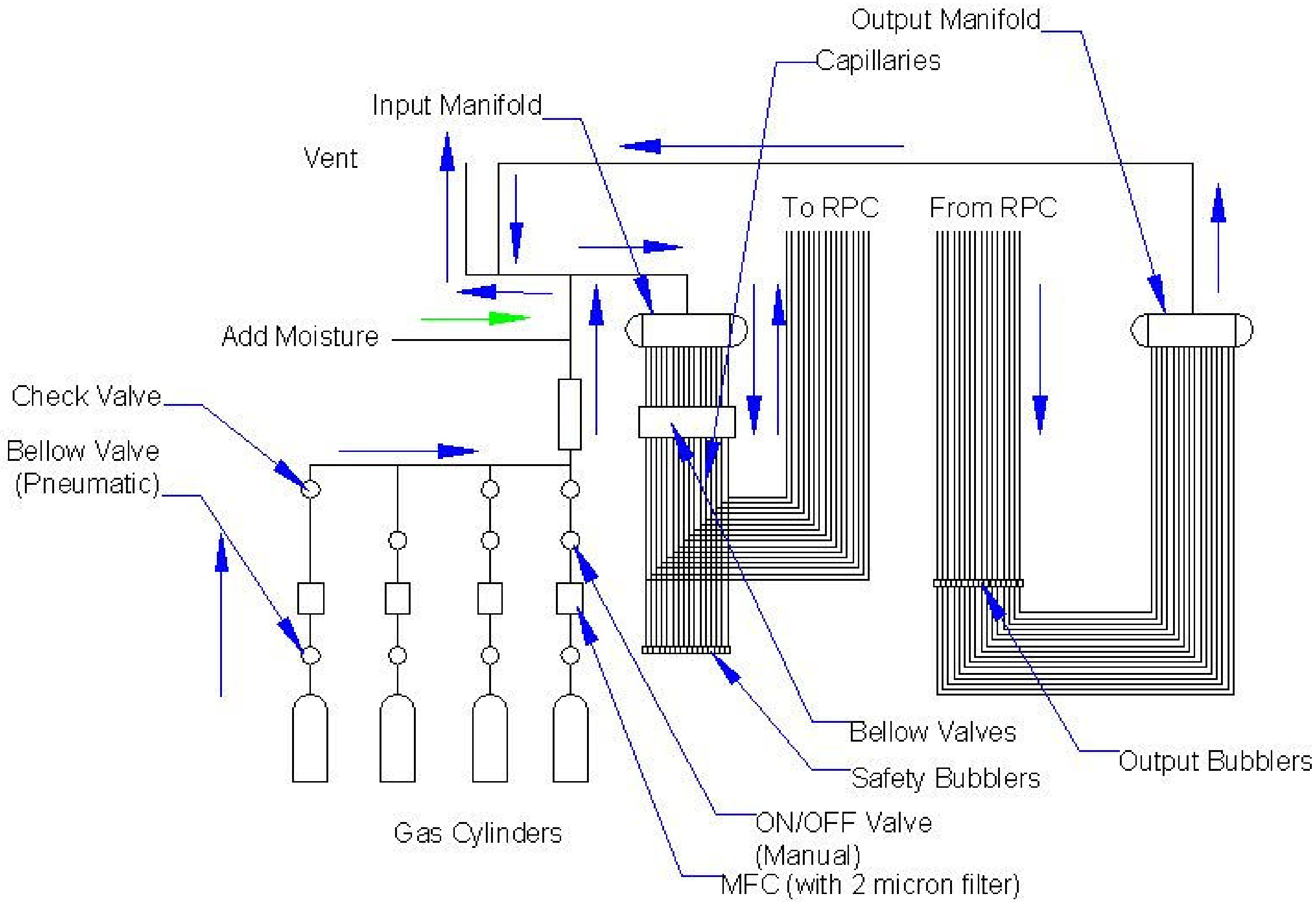
INO detector specifications

Number of modules	3
Module dimensions	16 m X 16 m X 12 m
Detector dimensions	48 m X 16 m X 12 m
Number of layers	140
Iron plate thickness	~6 cm
Gap for RPC trays	2.5 cm
Magnetic field	1.3 Tesla
RPC unit dimensions	2 m X 2 m
Readout strip width	3 cm
Number of RPCs/Road/Layer	8
Number of Roads/Layer/Module	8
Number of RPC units/Layer	192
Total number of RPC units	27000
Number of electronic channels	3.6×10^6

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

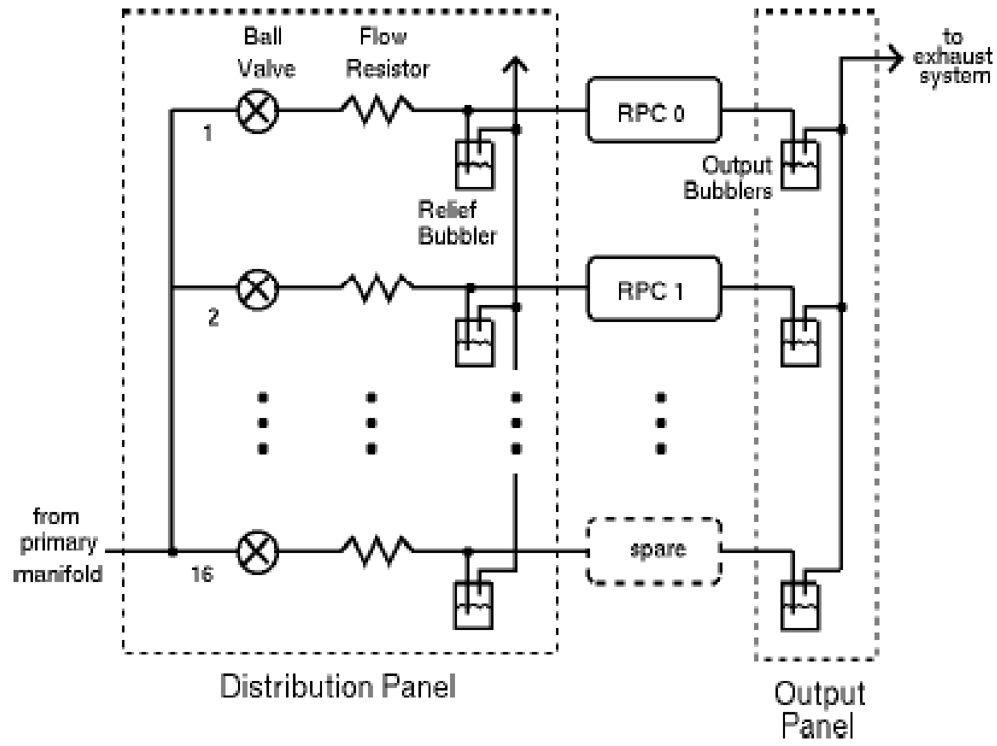
New gas system layout



Gas flow resistors

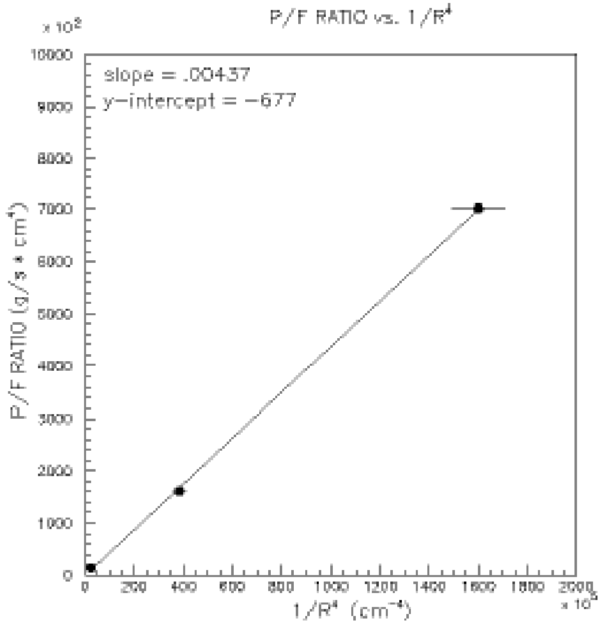
The solution turned out to be a simple device that we call a "flow resistor". These are simply 10-cm-long SS tubes with 250 um diameter bores.

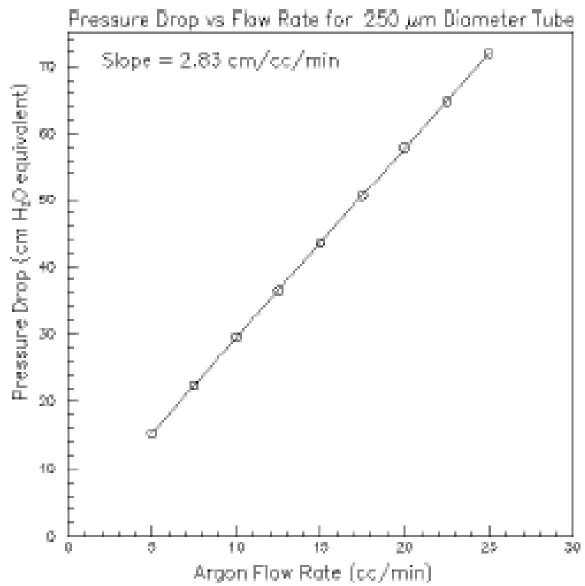
They are available from Fischer Scientific for ~$2.00 each.



Gas flow resistors

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

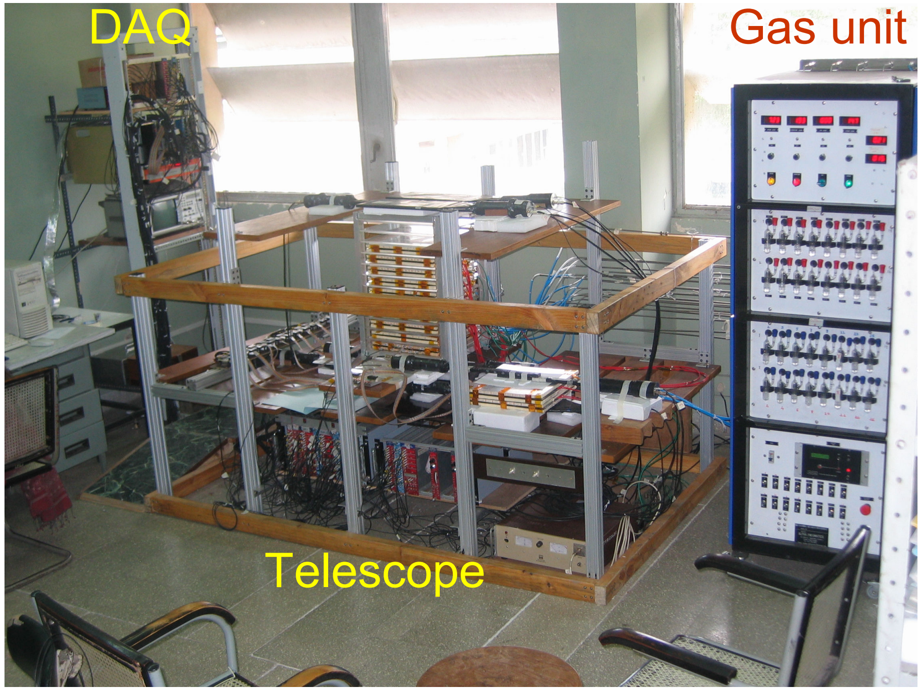


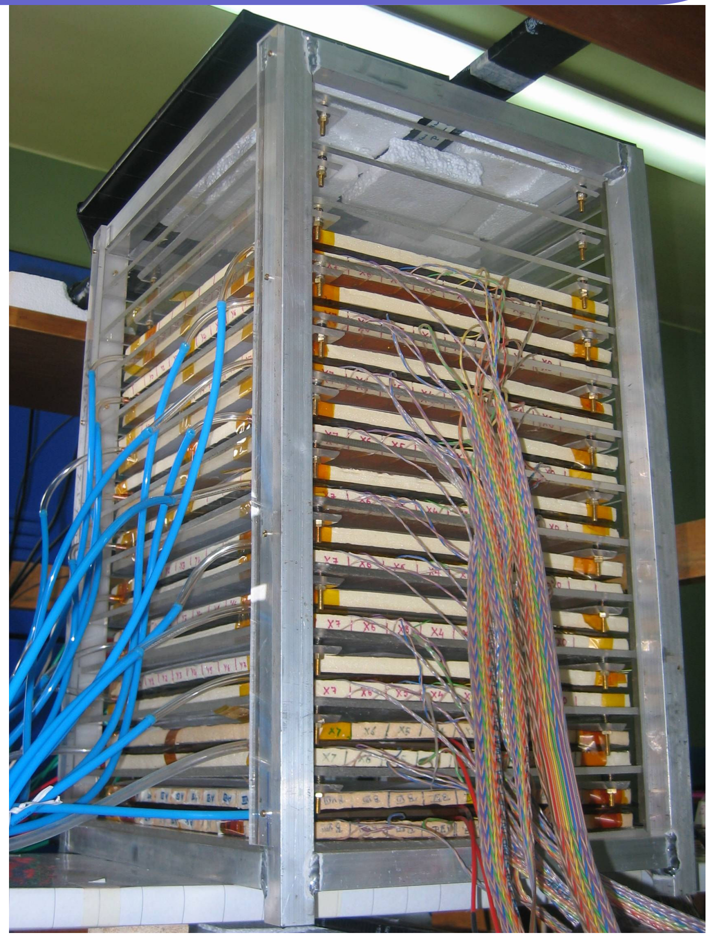


$$F = \frac{\pi}{8}\frac{R^4}{\eta}\frac{\Delta p}{L}$$

A sophisticated gas system

New RPC laboratory at TIFR

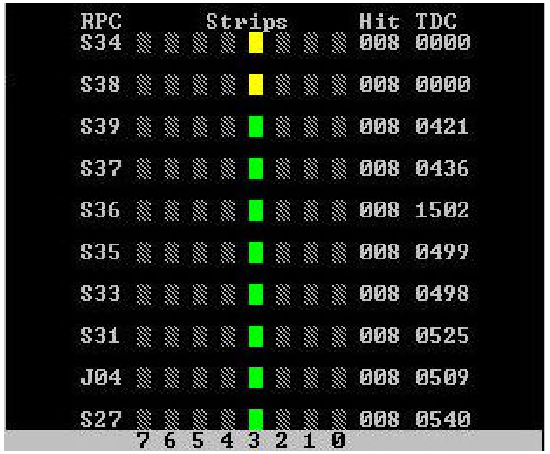


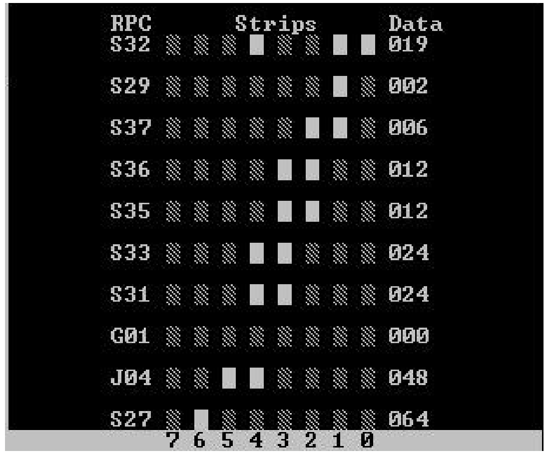


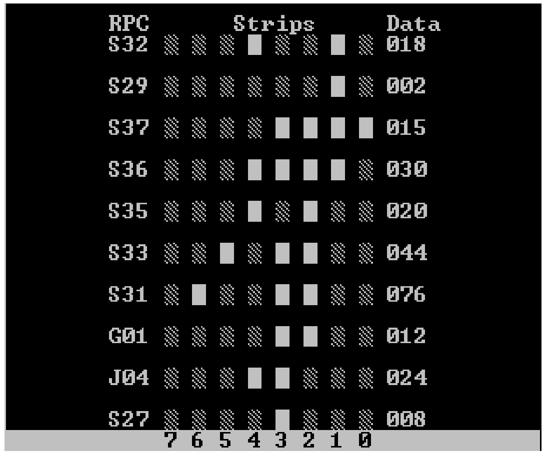
Stack of 10 RPCs

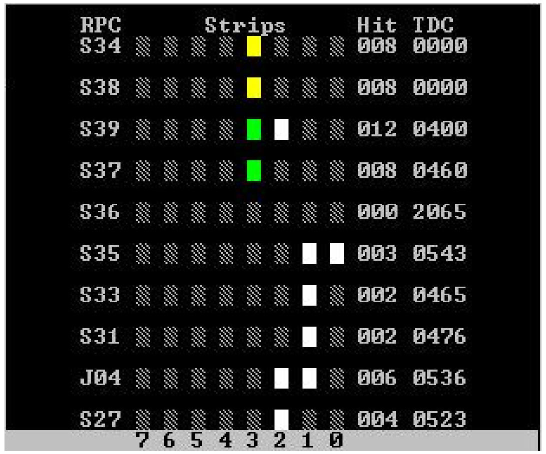
- Streamer mode (R134a=62%, Argon=30% and the rest Iso-Butane)
- Recording hits, timing, noise rates etc

Some interesting events tracked



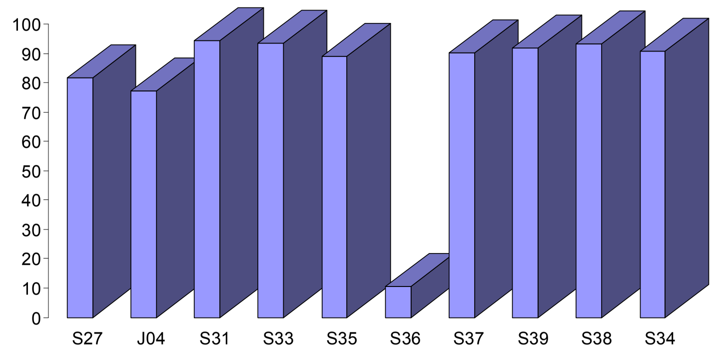




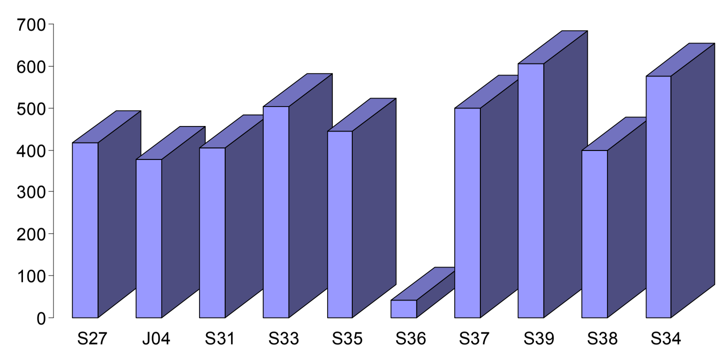


Some extracted parameters

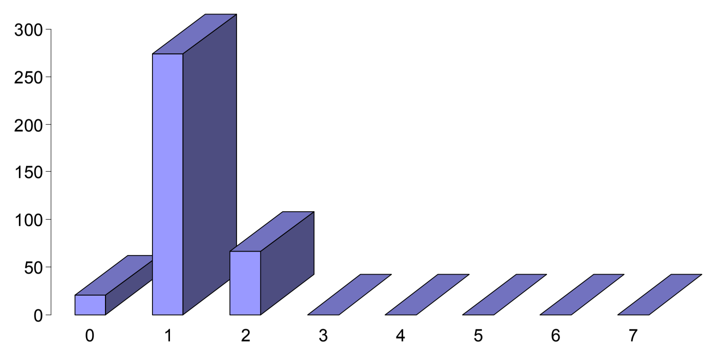
RPC efficiencies



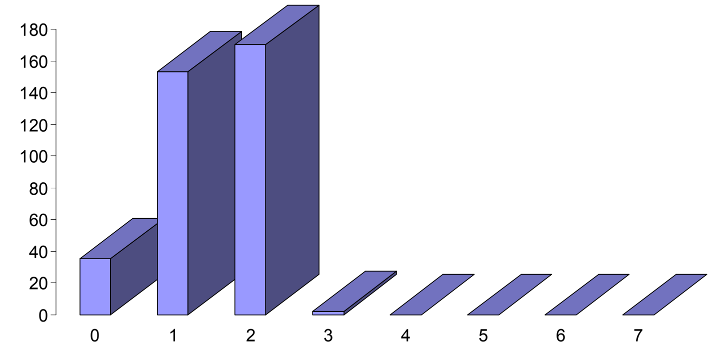
Total hits of RPCs



Strip hit distribution of S-31



Strip hit distribution of S-37



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Open questions and challenges

- Streamer mode simulation
- Space charge affects
- Ionisation density, charge, efficiency issues
- RPC aging problem
- Surface physics
- Complicated organic chemistry
- Device simulations
  - Analytical
  - Monte Carlo

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Acknowledgements

- All the authors from whose publications, some pictures were picked up
- INO collaboration
- Colleagues from TIFR INO group

References

- Various on going or future experiments which use RPC detectors:
  - Belle
  - BaBar
  - CMS, ALICE, ATLAS
  - Monolith, Opera
  - BESIII
  - STAR
  - ARGO
  - MINOS, Off-Axis
  - INO
  - ILC