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Detector and Electronics R&D for INO's ICAL Experiment

Plan of the talk

- Introduction
- The INO Iron Calorimeter (ICAL)
- Principle of operation of RPC
- Review of RPC detector developments
- Design and studies of small RPC prototypes
- Development of RPC materials and procedures
- Large area RPC development
- Construction of ICAL prototype detector
- Data analysis and results
- Summary and future outlook
- RPC aging (May be during lunch/dinner!)

The INO Iron Calorimeter (ICAL)

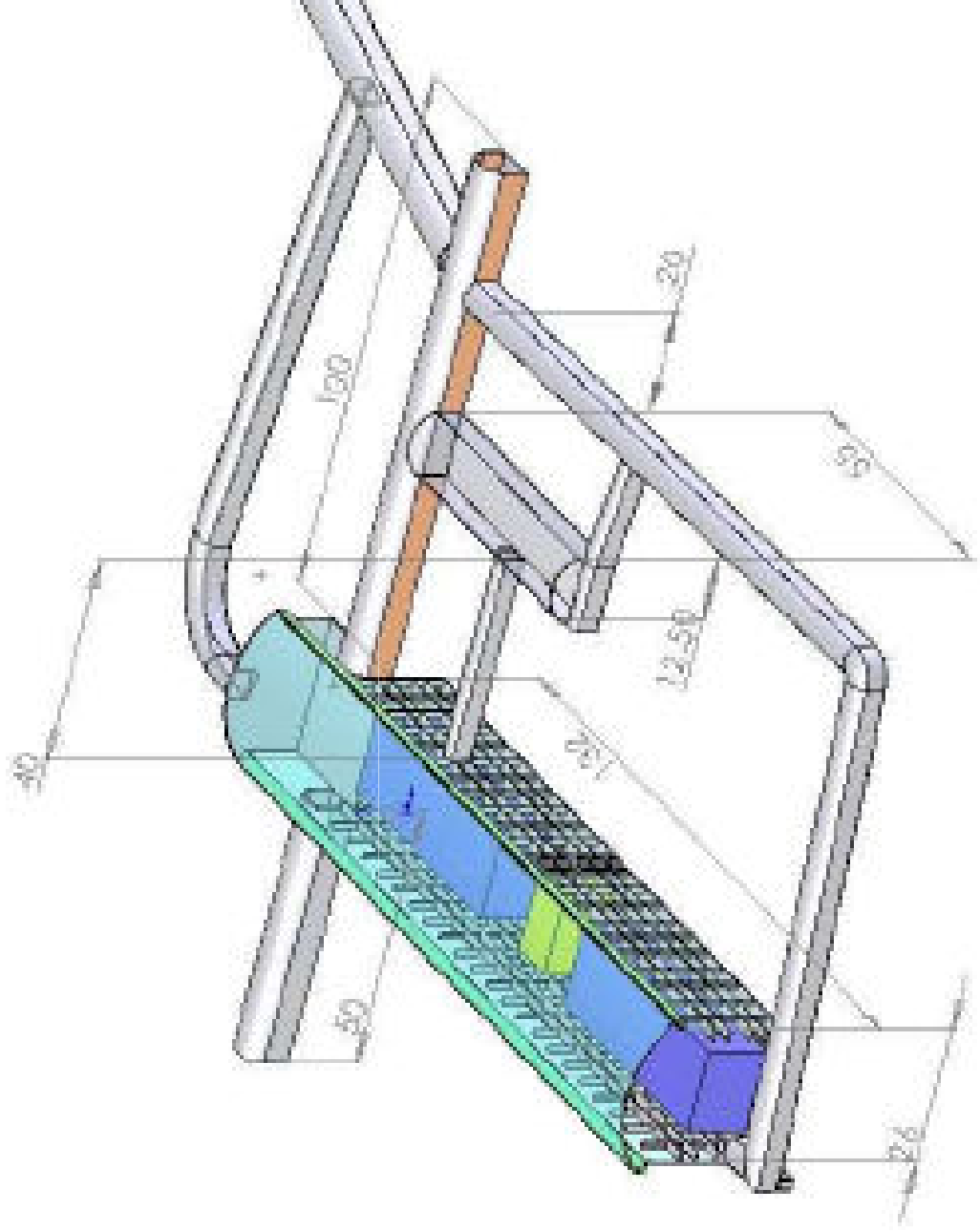
India-based Neutrino Observatory (INO) is a consortium of a large number of research centres and universities.

Neutrino sources and detector choice

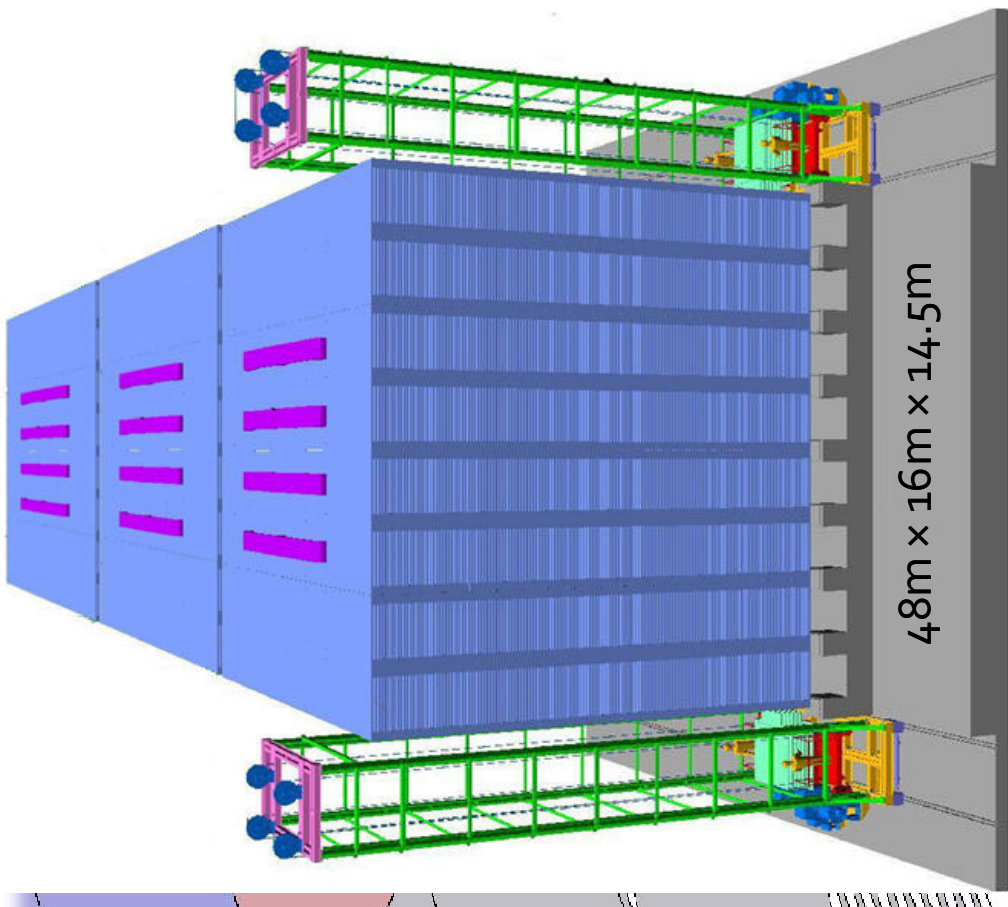
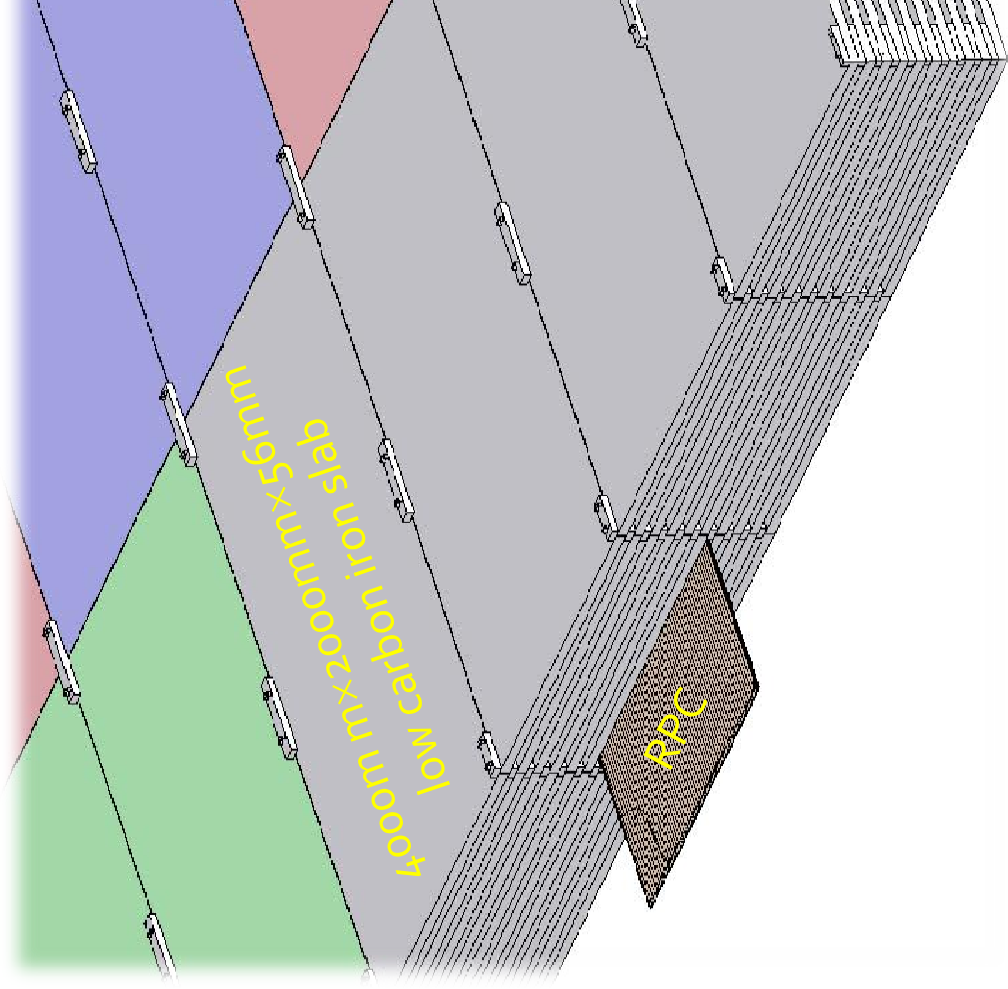
- Source of neutrinos
 - Use atmospheric neutrinos as source
 - Need to cover a large L/E range
 - From neutrino factory in long base-line detector configuration
- Physics driven detector requirements
 - Should have large target mass (50-100 kT)
 - Good tracking and energy resolution (tracking calorimeter)
 - Good directionality (< 1 nSec time resolution)
 - Charge identification capability (magnetic field)
 - Modularity and ease of construction
 - Compliment capabilities of existing and proposed detectors
- Use magnetised iron as target mass and Resistive Plate Chambers (RPCs) as active detector medium

$$\nu_{\mu} + n \rightarrow \mu^{-} + p^{+}$$
$$\bar{\nu}_{\mu} + p \rightarrow \mu^{+} + n$$

Design of the INO cavern



Assembly of ICAL detector



Factsheet of ICAL detector

No. of modules	3
Module dimensions	16m x 16m x 14.5m
Detector dimensions	48.4m x 16m x 14.5m
No. of layers	150
Iron plate thickness	56mm
Gap for RPC trays	40mm
Magnetic field	1.3 Tesla
RPC dimensions	1,840mm x 1,840mm x 24mm
Readout strip pitch	3 0mm
No. of RPCs/Road/Layer	8
No. of Roads/Layer/Module	8
No. of RPC units/Layer	192
No. of RPC units	28,800 (97,505m ²)
No. of readout strips	3,686,400

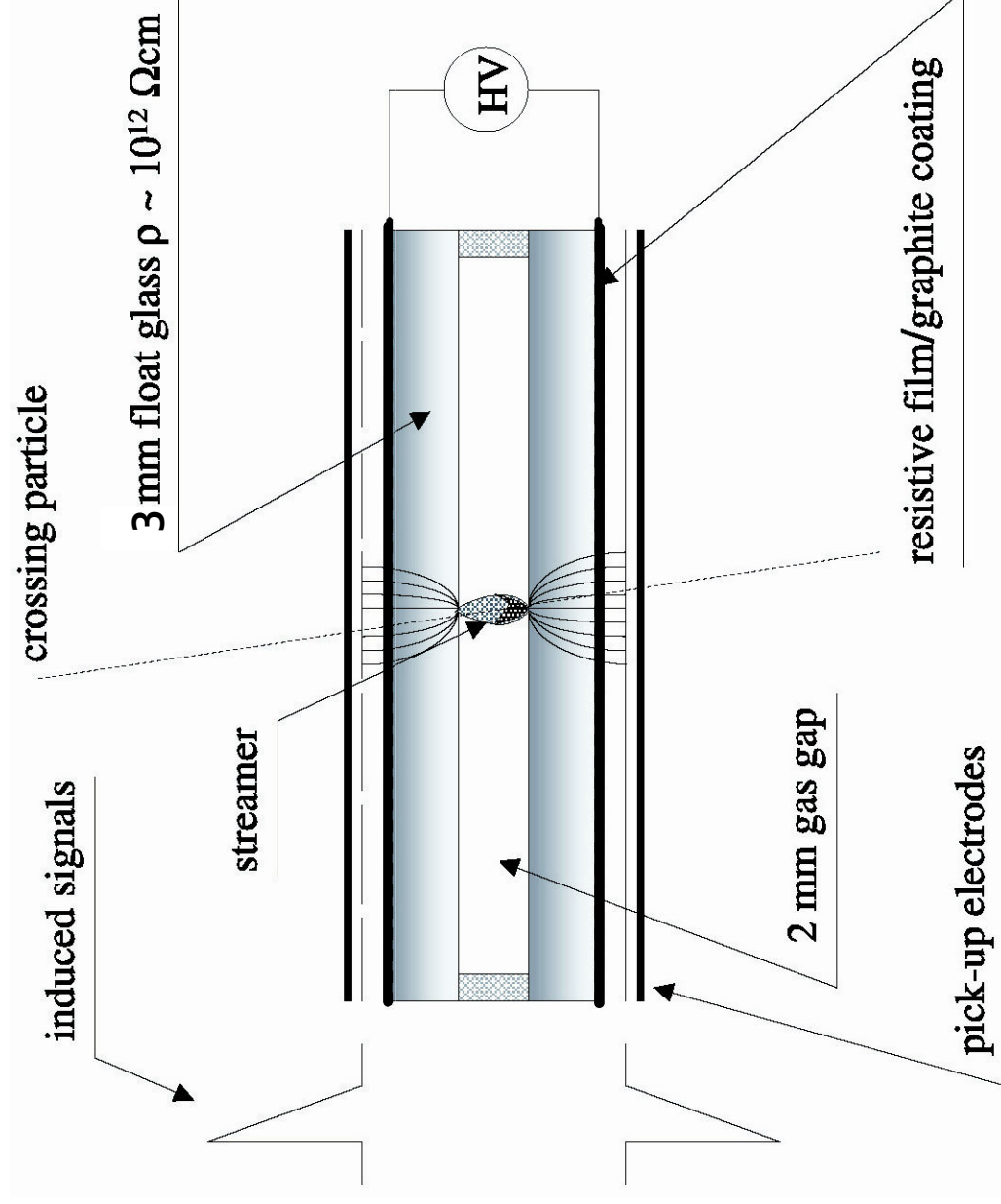
Why ICAL chose RPC?

- Large detector area coverage, thin (~10mm), small mass thickness
- 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!

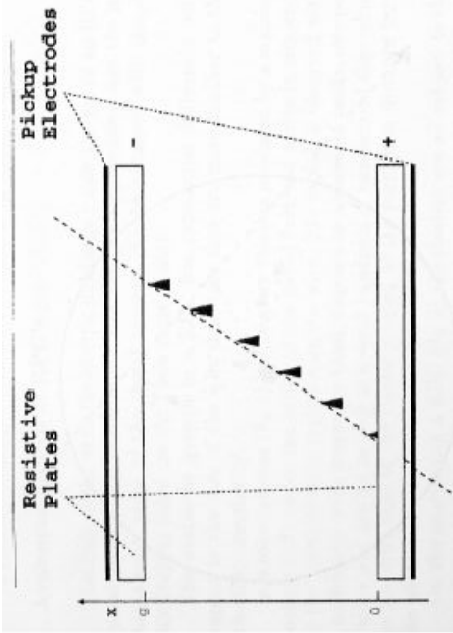
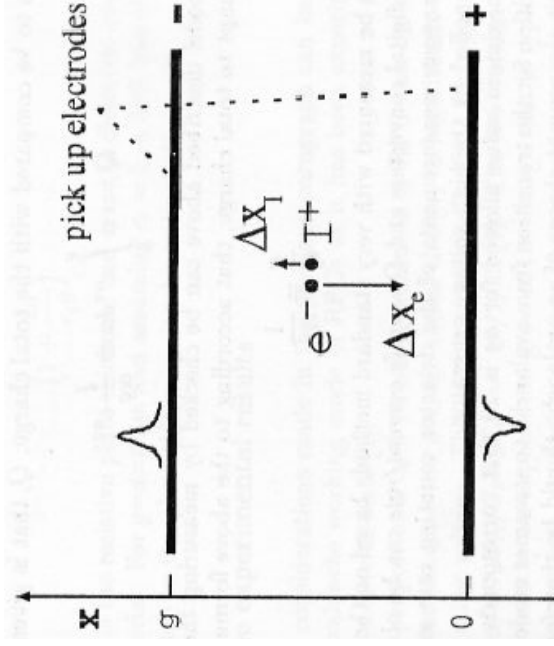
Principle of operation of RPC

Gaseous detector of planar geometry, high resistive electrodes,
wire-less signal pickup

Schematic of a basic RPC

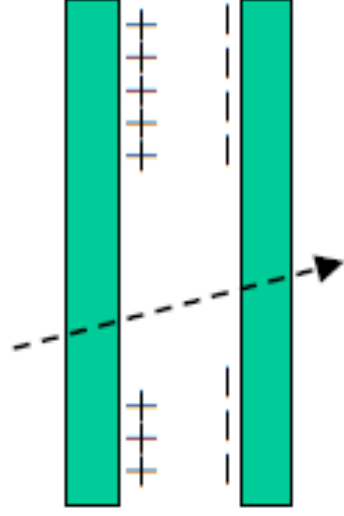


Principle of operation



- Electron-ion pairs produced in the ionisation process drift in the opposite directions.
- All primary electron clusters drift towards the anode plate with velocity v and simultaneously originate avalanches
- A cluster is eliminated as soon as it reaches the anode plate
- The charge induced on the pickup strips is $q = (-e\Delta x_e + e\Delta x_i)/g$
- The induced current due to a single pair is $i = dq/dt = e(v + V)/g \approx ev/g, V \ll v$
- Prompt charge in RPC is dominated by the electron drift

Rate capability of a streamer RPC



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

$$\tau = RC \cong \left(\frac{\rho l}{A} \right) \left(\frac{\kappa \epsilon_0 A}{l} \right) = \rho \kappa \epsilon_0$$

Numerically this is (MKS units)

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

Assuming each discharge deadens an area of 0.1 cm^2 , rates of up to 500 Hz/m^2 can be handled with 1% deadtime or less. This is well below what is expected in our application.

RPC operating mode definitions

Let, n_o = No. of electrons in a cluster
 α = Townsend coefficient (No. of ionisations/unit length)
 β = Attachment coefficient (No. of electrons captured by the gas/unit length)

Then, the no. of electrons reaching the anode,

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

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

Gain of the detector, $M = n / n_o$

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

$$S = \frac{Qd}{\epsilon_0 V}$$

Where, d = gap thickness

V = Applied voltage

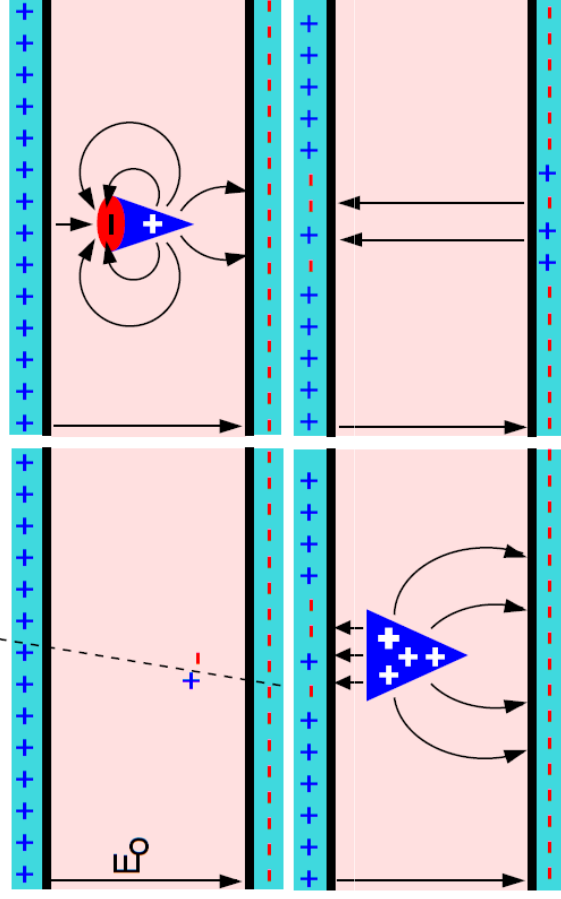
- ϵ_o = Dielectric constant of the gas
 Lower the Q ; lower the area of the cell (that is 'dead' during a hit) and hence higher the rate handling capability of the RPC

Control of avalanche process

- Role of RPC gases in avalanche control
 - Argon is the ionising gas
 - R134a to capture free electrons and localise avalanche
 - $e^- + X \rightarrow X^- + h\nu$ (Electron attachment)
 - $X^+ + e^- \rightarrow X + h\nu$ (Recombination)
 - Isobutane to stop photon induced streamers
 - SF_6 for preventing streamer transitions
- Growth of the avalanche is governed by $dN/dx = \alpha N$
- The space charge produced by the avalanche shields (at about $\alpha x = 20$) the applied field and avoids exponential divergence
- Townsend equation should be $dN/dx = \alpha(E)N$

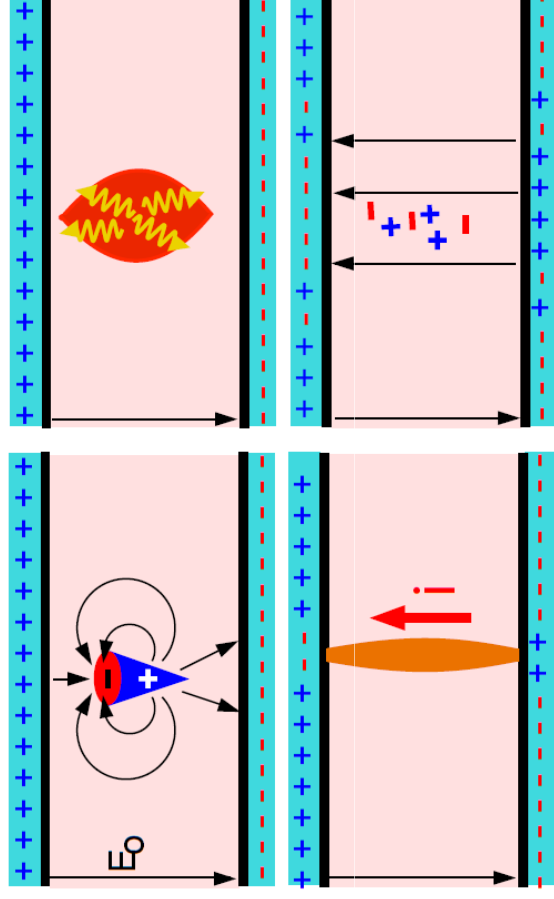
Two modes of RPC operation

Avalanche mode



- Gain of the detector $\ll 10^8$
- Charge developed $\sim 1\text{pC}$
- Needs a preamplifier
- Longer life
- Typical gas mixture Fr:iB:SF₆::94.5:4:0.5
- Moderate purity of gases
- Higher counting rate capability

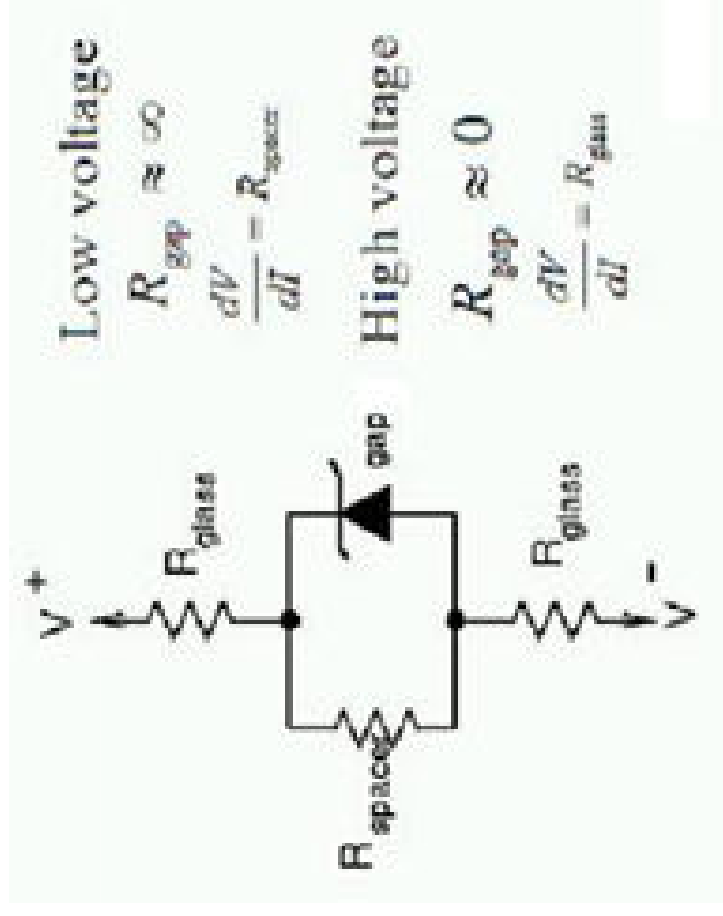
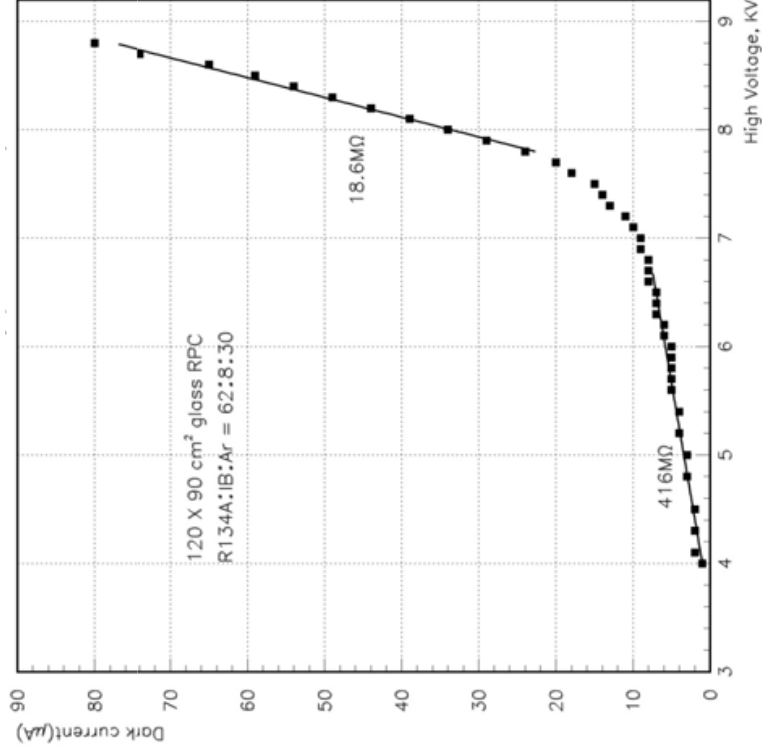
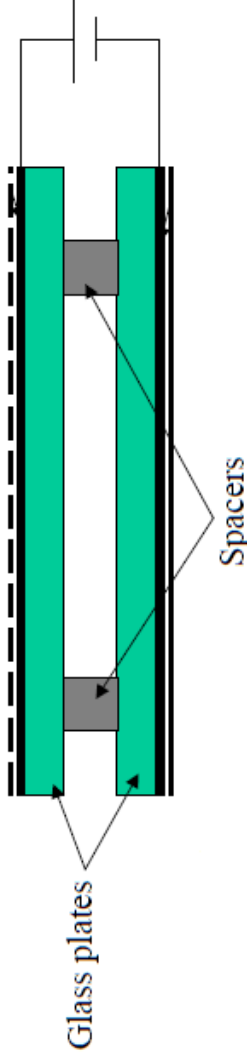
Streamer mode



- Gain of the detector $> 10^8$
- Charge developed $\sim 100\text{pC}$
- No need for a preamplifier
- Relatively shorter life
- Typical gas mixture Fr:iB:Ar::62.8:30
- High purity of gases
- Low counting rate capability

V-I characteristics of RPC

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



Typical expected parameters

- No. of clusters in a distance g follows Poisson distribution with an average of $\bar{n} = g/\lambda$
- Probability to have n clusters $p(n) = \frac{1}{n!} \left(\frac{g}{\lambda}\right)^n e^{-\frac{g}{\lambda}}$
- Intrinsic efficiency $\epsilon_{\max} = 1 - e^{-\bar{n}}$
- $\epsilon_{\max}$ depends only on gas and gap
- Intrinsic time resolution $\sigma_t = 1.28/(\alpha - \eta)v_D$
- σ_t doesn't depend on the threshold

- ❖ Gas: 96.7/3/0.3
- ❖ Electrode thickness: 2mm
- ❖ Gas gap: 2mm
- ❖ Relative permittivity: 10
- ❖ Mean free path: 0.104mm
- ❖ Avg. no. of electrons/cluster: 2.8
- ❖ Charge threshold: 0.1pC

- ❖ HV: 10.0kV
- ❖ Townsend coefficient: 13.3/mm
- ❖ Attachment coefficient: 3.5/mm
- ❖ Efficiency: 90%
- ❖ Time resolution: 950ps
- ❖ Total charge: 200pC
- ❖ Induced charge: 6pC

Review of RPC detector developments

Creativity aided by intrinsic tunability of the RPC device

Birth of the RPC

DEVELOPMENT OF RESISTIVE PLATE COUNTERS

R. SANTONICO and R. CARDARELLI

Istituto di Fisica dell'Università di Roma, Roma, Italy; Istituto Nazionale di Fisica Nucleare, Sezione di Roma, Italy

Received 12 January 1981

A dc operated particle detector has been developed and tested, whose constituent elements are two parallel electrode bakelite plates between which, in a 1.5 mm gap, a gas mixture of argon and butane at ordinary pressure is circulated. The counter has 97% efficiency and ~ 1 ns time resolution at an operating voltage of about 10 kV. The output pulse needs no amplification, being typically 300 mV over 25 Ω .

The detector presented in this paper, which will be called "Resistive Plate Counter" (RPC) is based on essentially the same principle as that recently developed by Pestov and Fedotov [1]. Nevertheless the

wire chambers or limited streamer tubes [2]. This is an obvious advantage...

The detector presented in this paper, which will be called "Resistive Plate Counter" (RPC) is based on essentially the same principle as that recently developed by Pestov and Fedotov [1]. Nevertheless the drastic simplifications introduced in its realization, such as the absence of high pressure gas, the low requirements of mechanical precision, and the use of plastic materials instead of glass, makes it of potential interest in a different and possibly wider range of applications. In particular it could replace with great economic advantages plastic scintillators, whenever large detecting areas are needed under not exceedingly high fluxes of particles.

...may be used a small amount of graph...

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

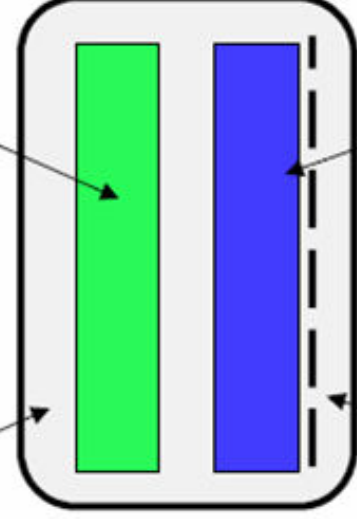


THIN GAP (100 μm) AND HIGH PRESSURES (~ 10 bar)
HIGH RESISTIVITY ELECTRODE
(PESTOV GLASS, $10^9 \Omega \text{ cm}$)

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

HIGH-PRESSURE GAS VESSEL

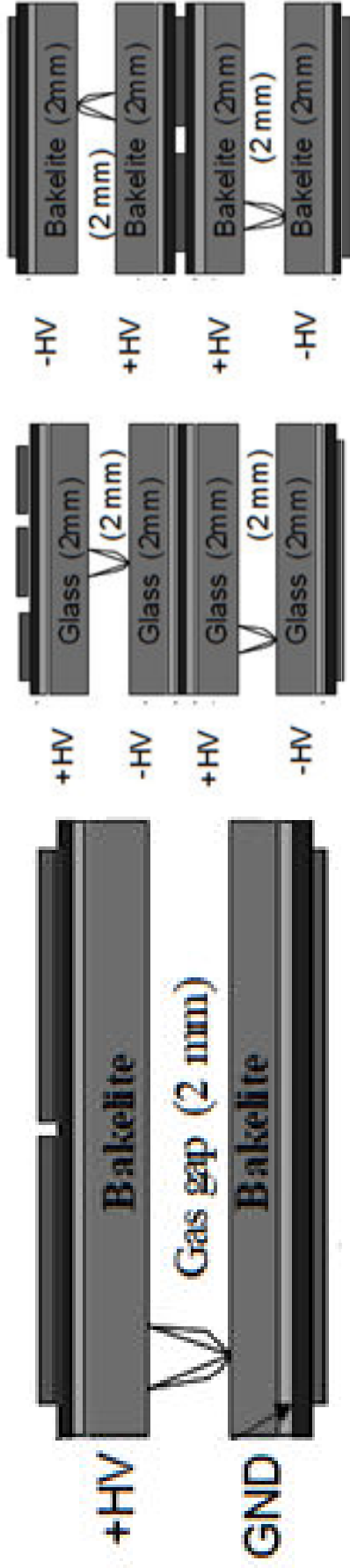
METAL CATHODE



SEMI-CONDUCTING GLASS ANODE

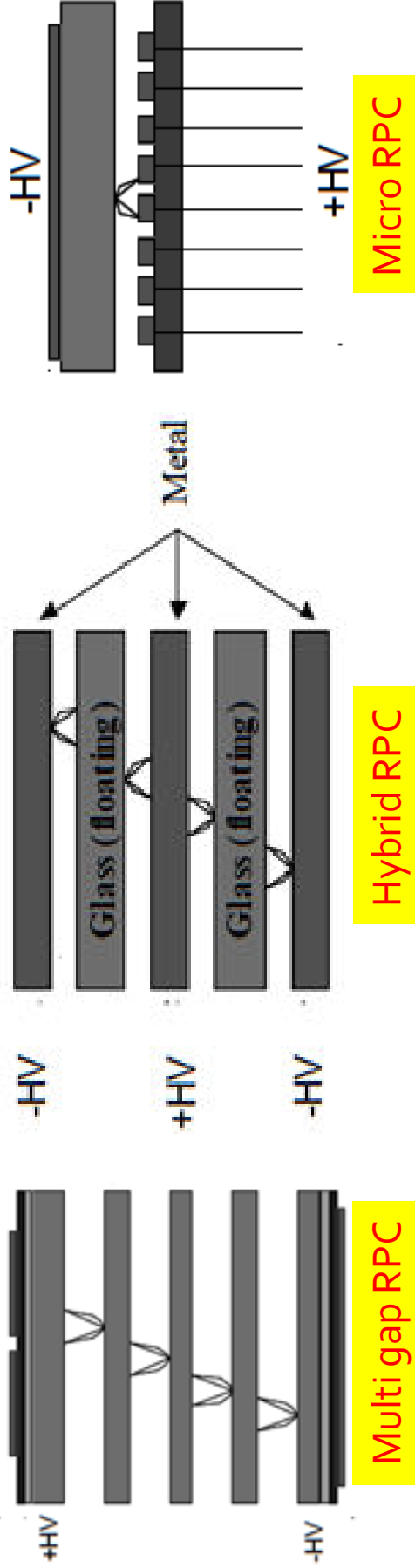
SIGNAL PICK-UP STRIPS

Application driven RPC designs



Single gap RPC

Double gap RPC



Multi gap RPC

Hybrid RPC

Micro RPC

Deployment of RPCs in running experiments

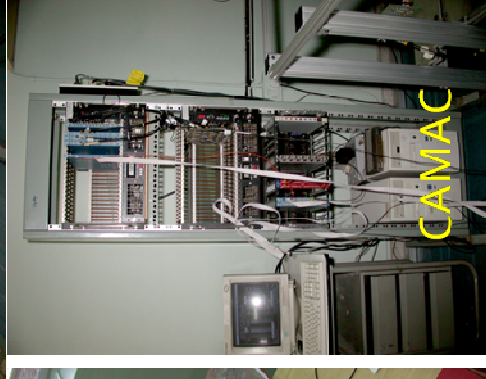
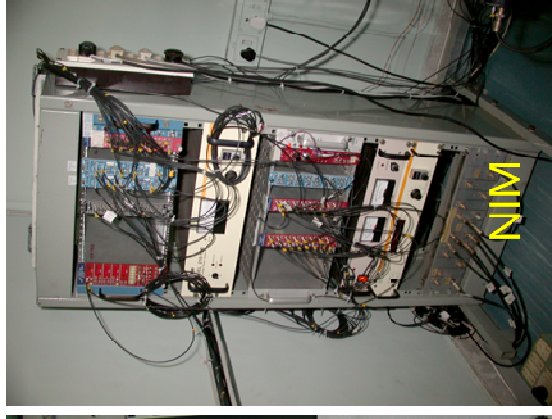
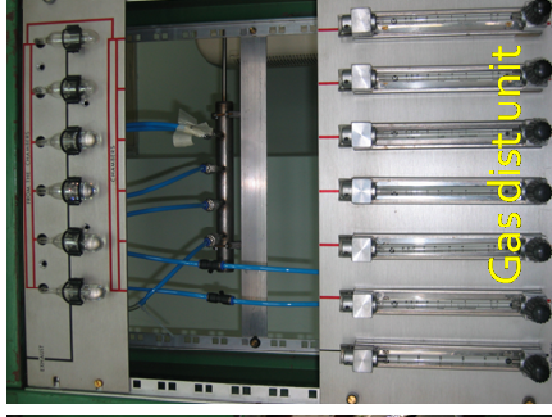
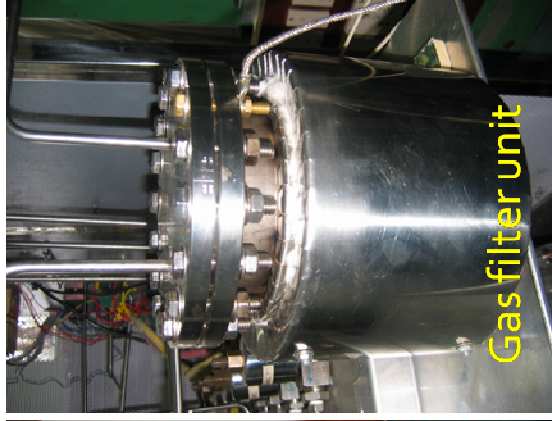
Experiment	Coverage(m ²)	Electrodes	Gap(mm)	Gaps	Mode
BaBar	2000	Bakelite	2	1	Streamer
Belle	4000	Glass	2	2	Streamer
ALICE Muon	140	Bakelite	2	1	Streamer
ATLAS	6550	Bakelite	2	1	Avalanche
CMS	6000	Bakelite	2	2	Avalanche
STAR	60	Glass	0.22	5	Avalanche
ALICE TOF	150	Glass	0.25	10	Avalanche
OPERA	4600	Bakelite	2	1	Streamer
YBJ-ARGO	5600	Bakelite	2	1	Streamer
BESIII	1200	Bakelite	2	1	Streamer
HARP	10	Glass	0.3	4	Avalanche

Also deployed in COVER_PLASTEX,EAS-TOP, L3, HADES, PHENIX, POPI experiments

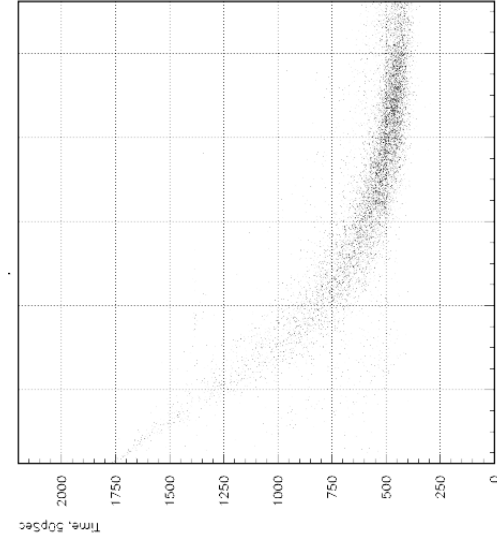
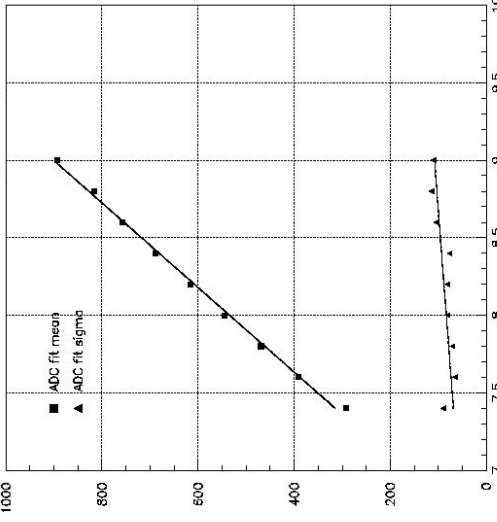
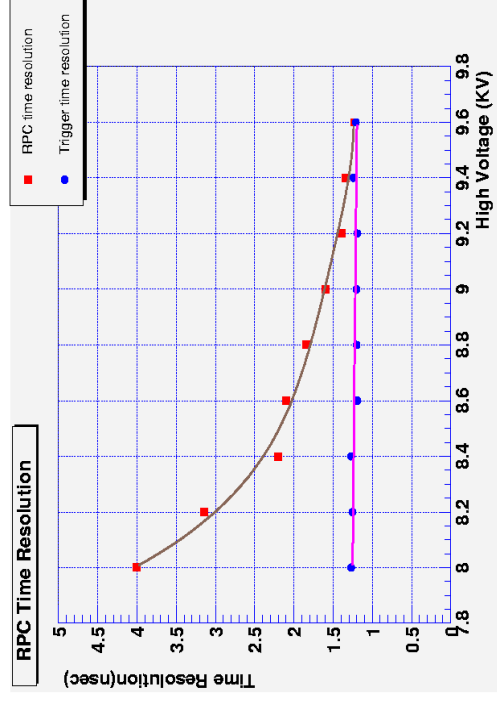
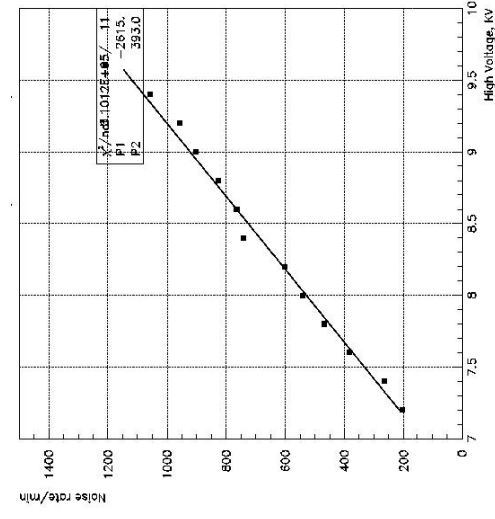
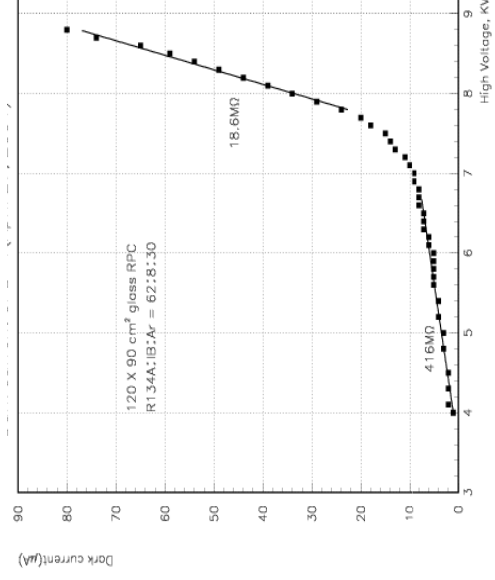
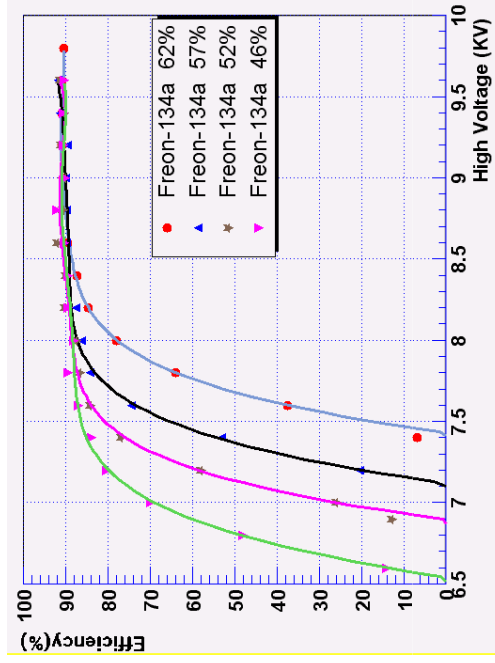
Design and studies of small RPC prototypes

The first RPC built at TIFR was 30cm × 10cm!

Initial infrastructure for RPC R&D

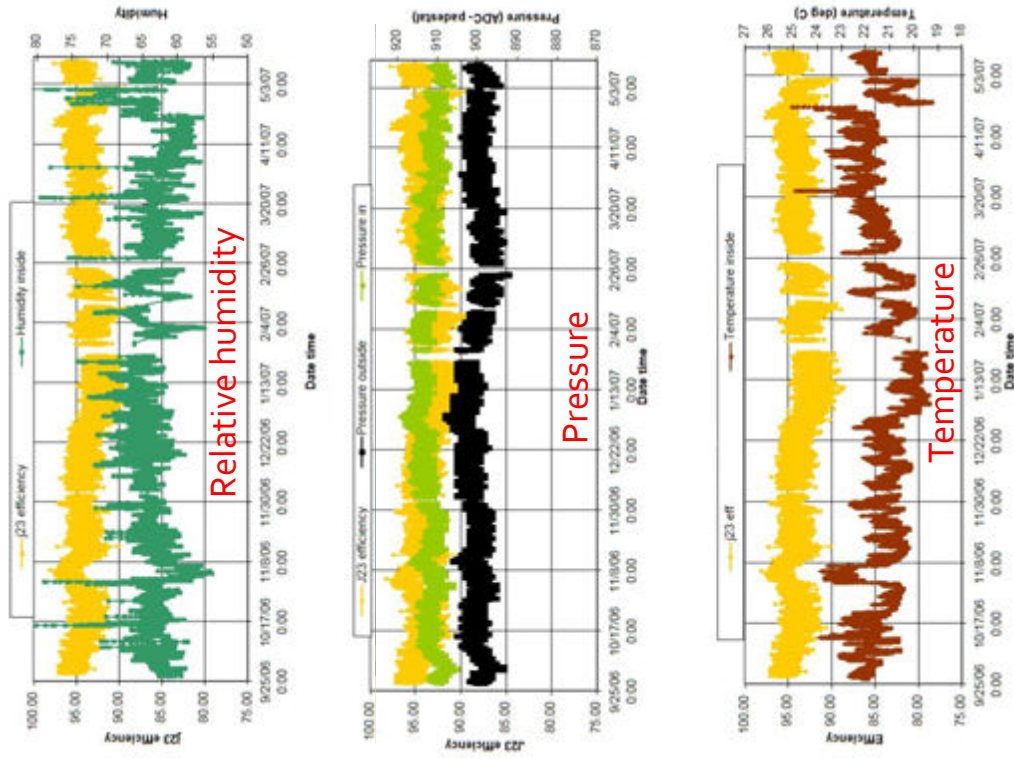


Some early encouraging results



Long-term stability study of RPC

- Two RPCs of 40cm x 30cm in size were built using 2mm glass for electrodes
- Readout by a common G-10 based signal pickup panel sandwiched between the RPCs
- Operated in avalanche mode (R134a: 95.5% and the rest Isobutane) at a high voltage of 9.3KV
- Round the clock monitoring of RPC and ambient parameters – temperature, relative humidity and barometric pressure
- Were under continuous operation for more than three years
- Chamber currents, noise rate, combined efficiencies etc. were stable
- Long-term stability of RPCs is thus established



Development of RPC materials and procedures

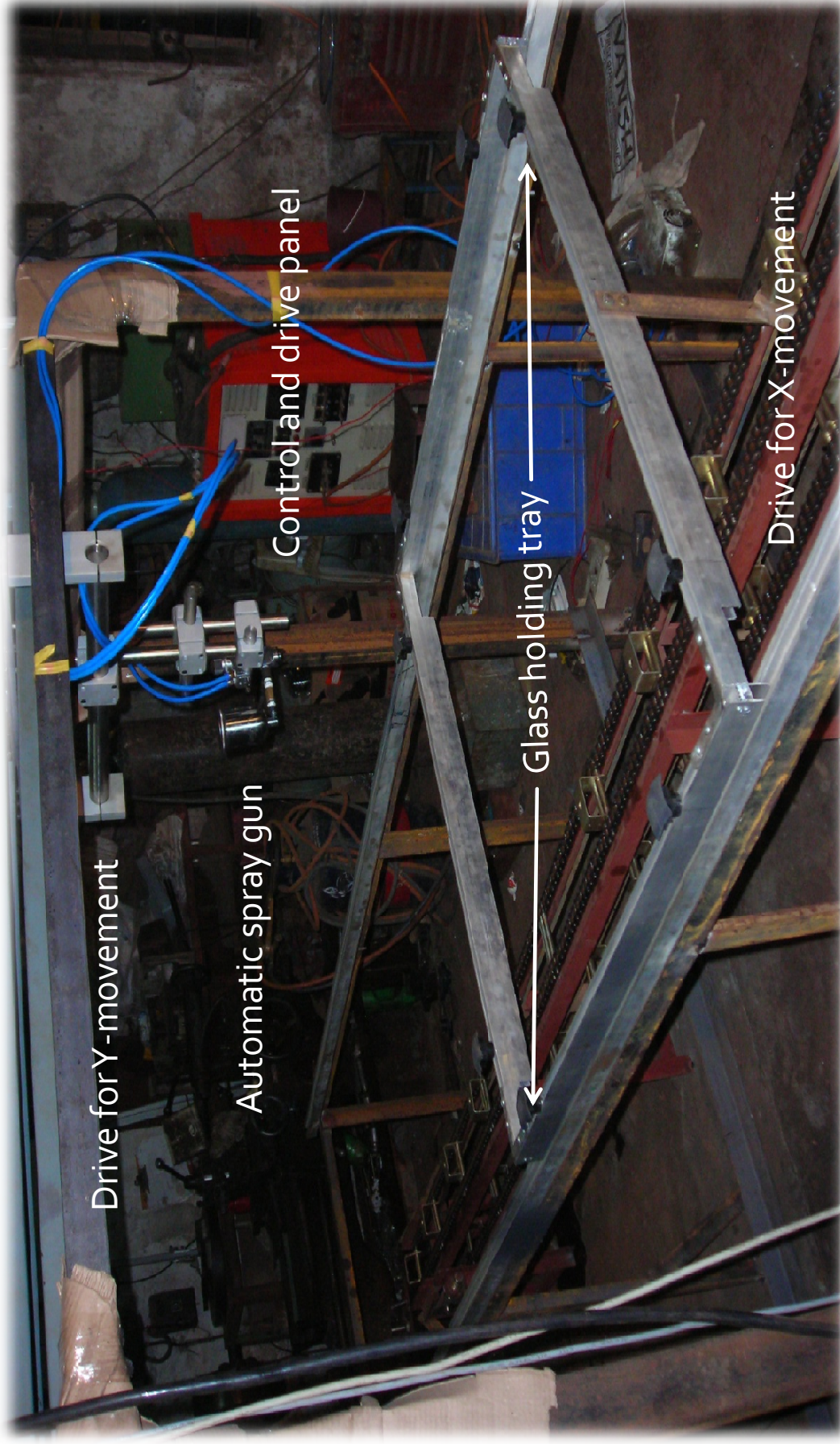
Continuous interaction with local industry and quality control standards

Electrode coating techniques

- Graphite paint prepared using colloidal grade graphite powder(3.4gm), lacquer(25gm) and thinner(40ml)
- Sprayed on the glass electrodes using an automobile spray gun.
- A uniform and stable graphite coat of desired surface resistivity ($1\text{M}\Omega/\square$) was obtained by this method.



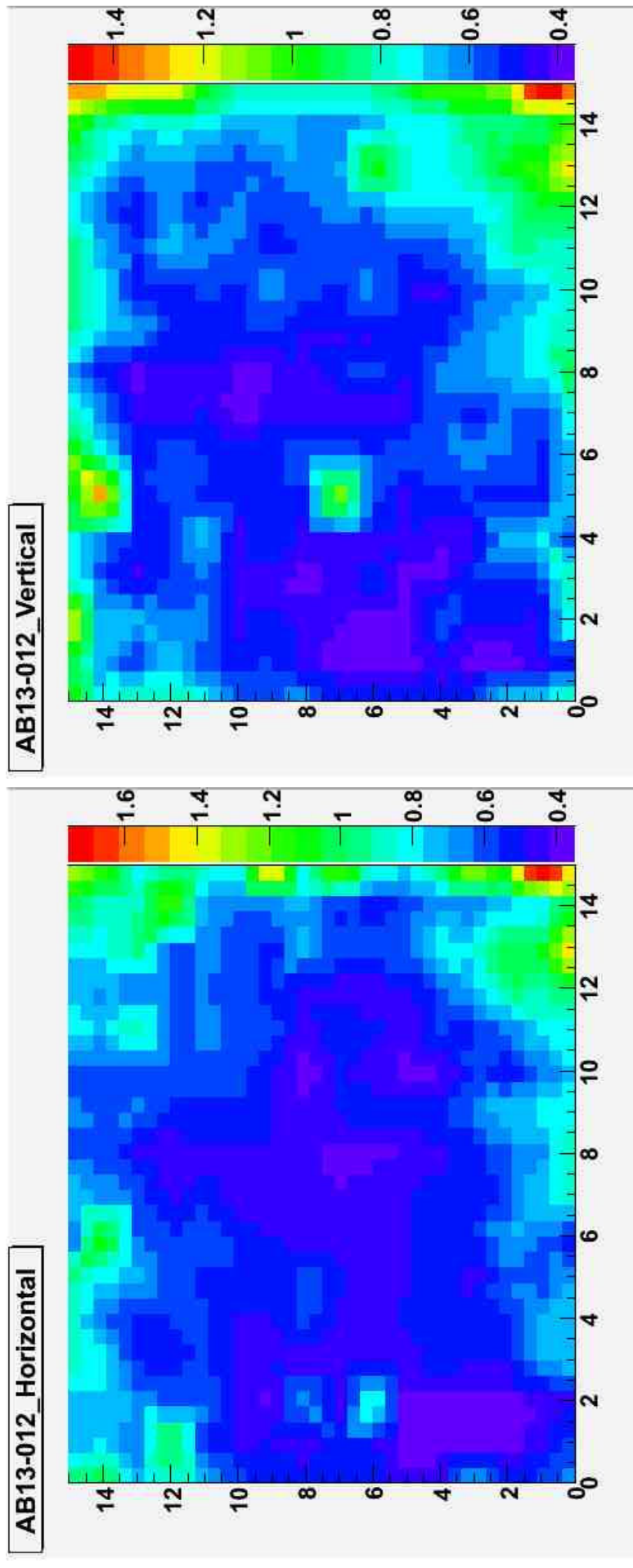
Automatic spray paint plant



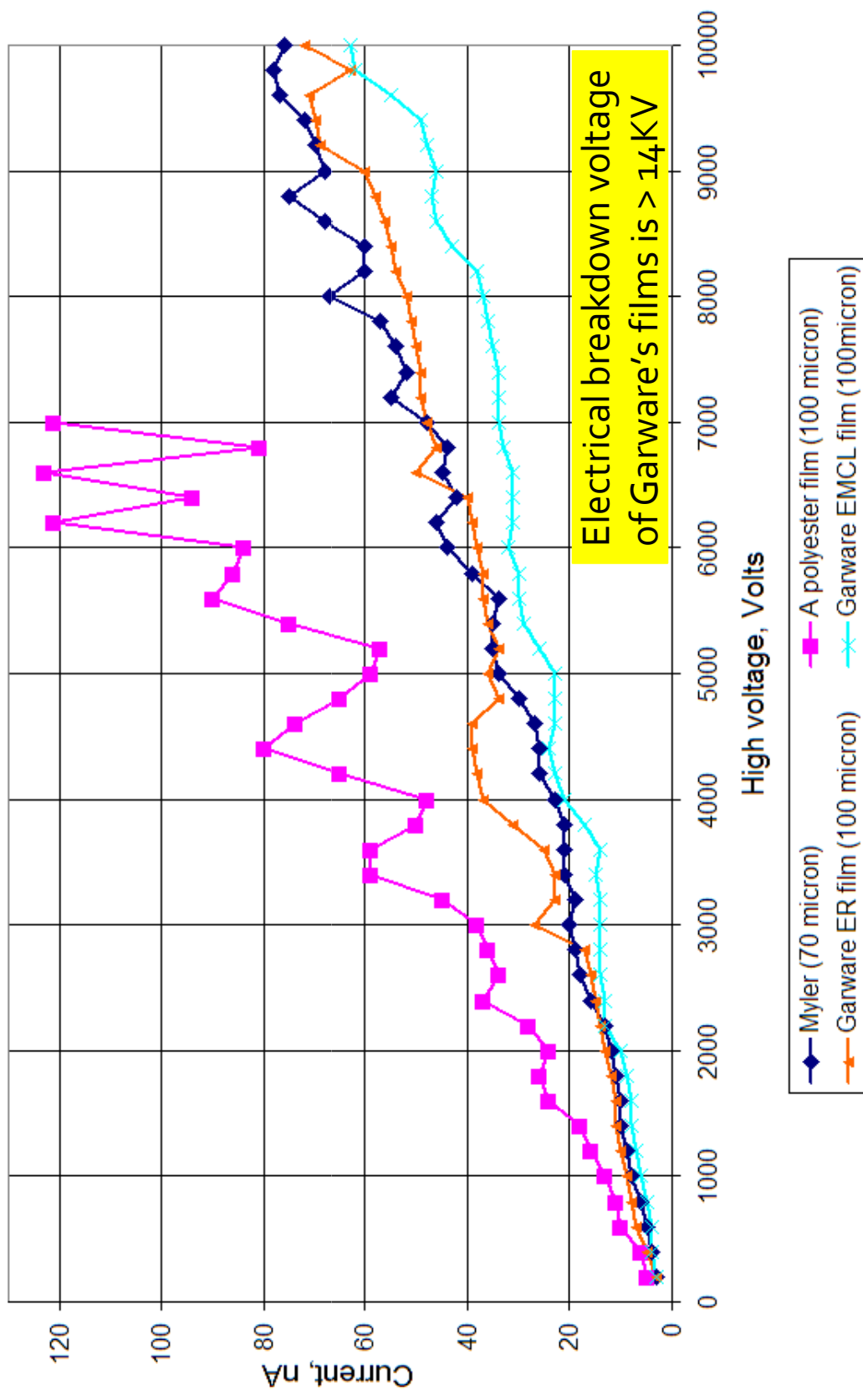
Screen printing techniques



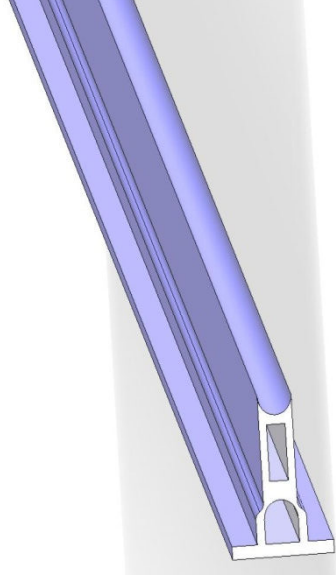
Glass electrode coating results



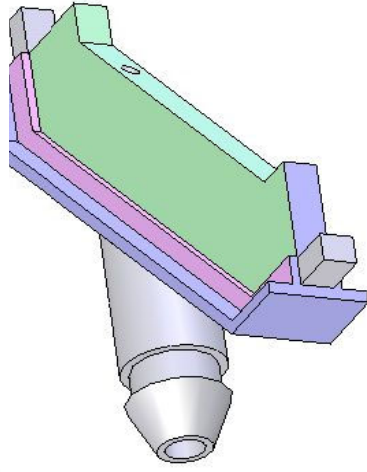
Characterisation of Mylar sheet



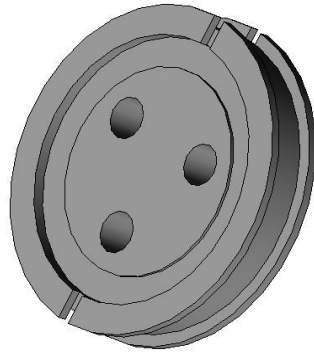
Materials for gas volume fabrication



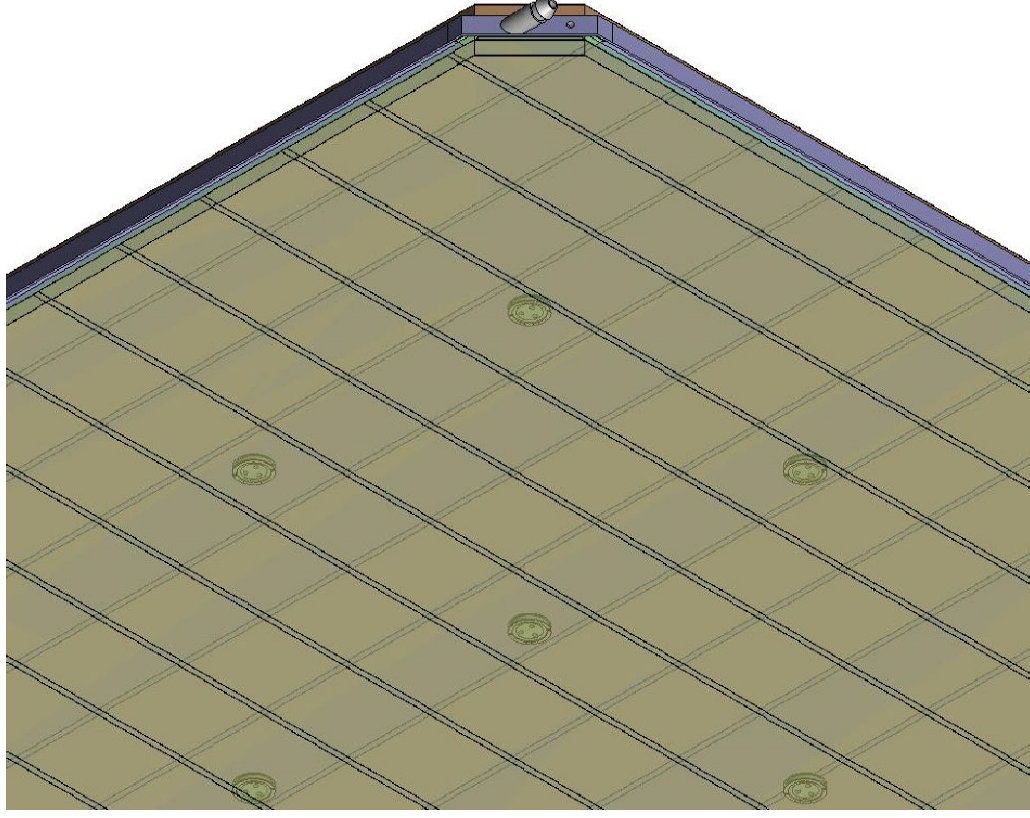
Edge spacer



Gas nozzle

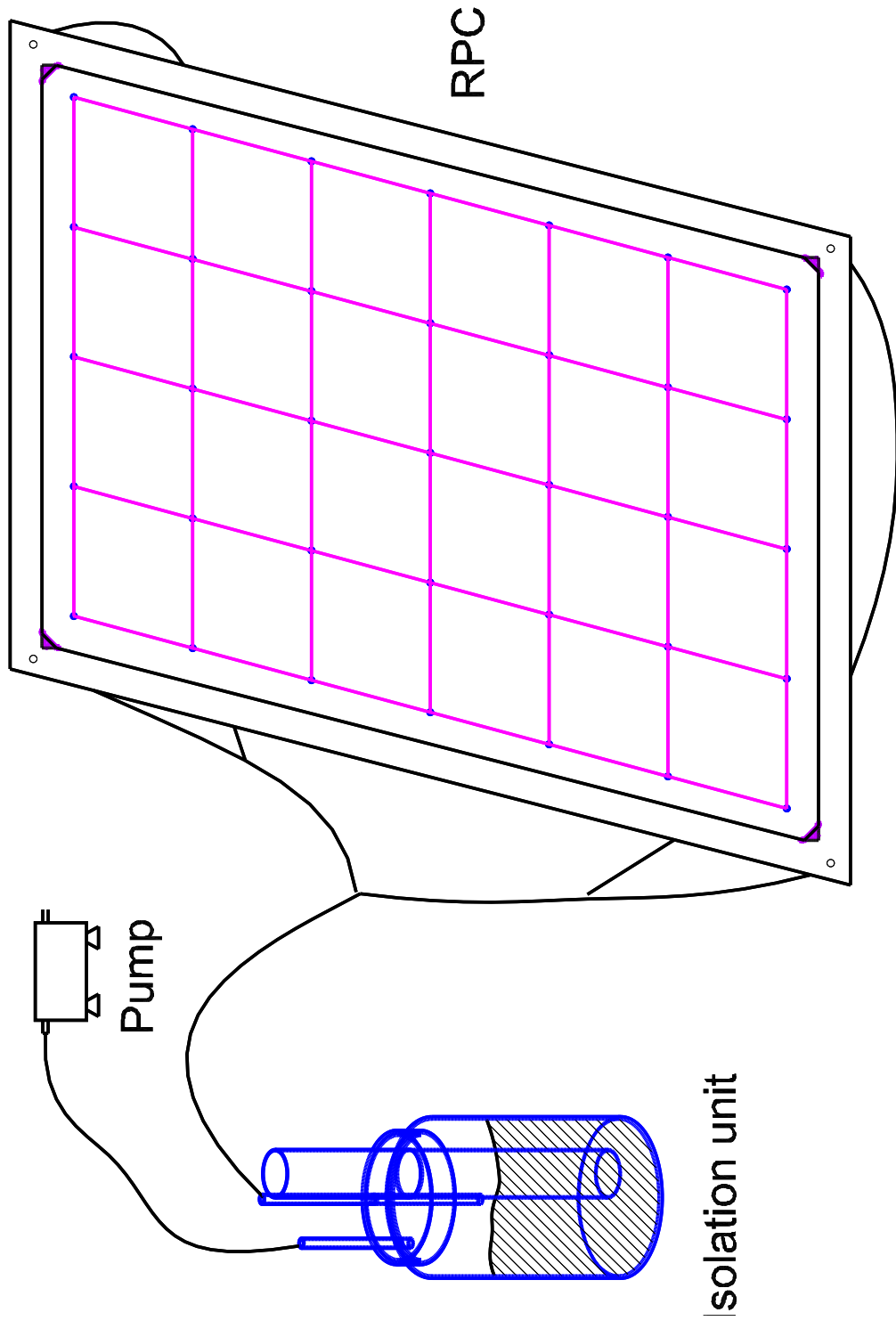


Glass spacer



Schematic of an assembled gas volume

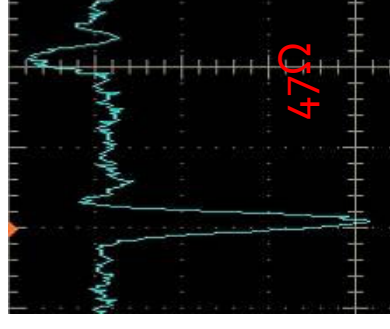
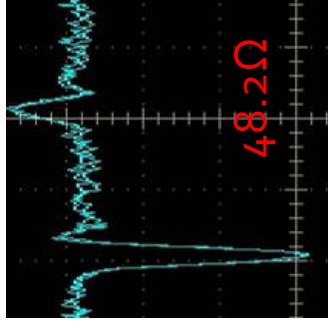
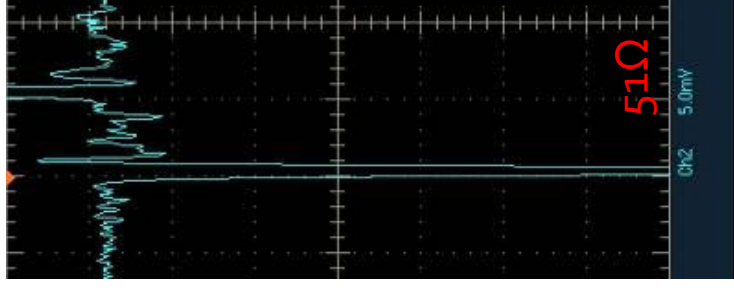
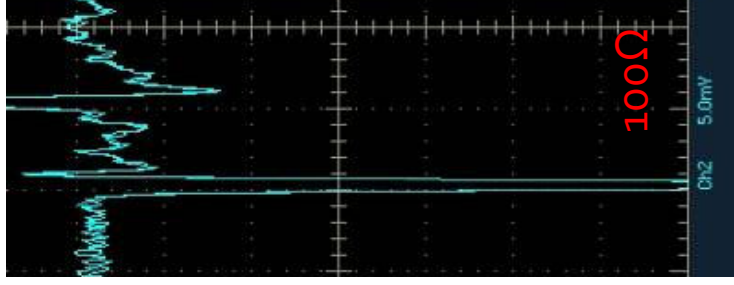
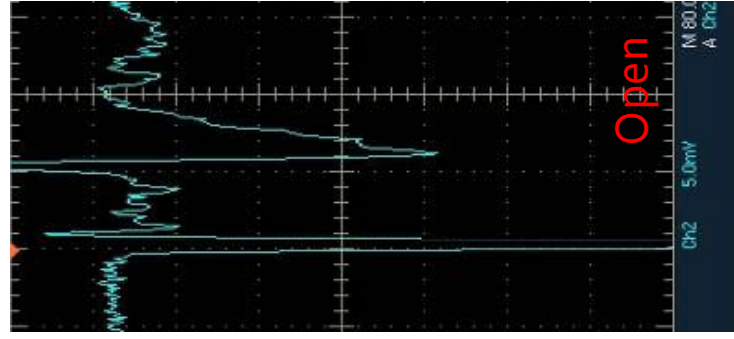
Schematic of RPC assembly jig



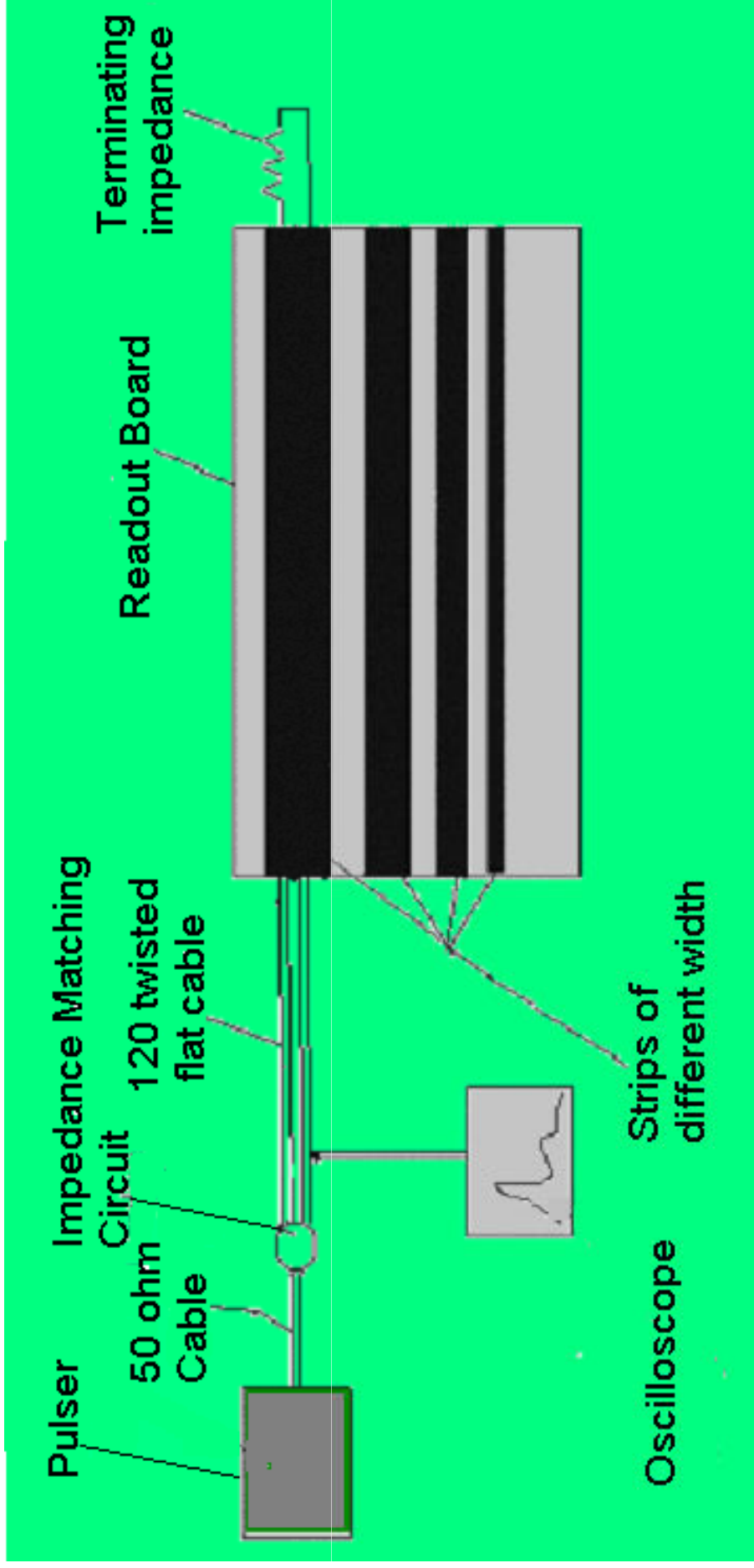
Development and characterisation of signal pickup panels



Z_0 : Inject a pulse into the strip; tune the terminating resistance at the far end, until its reflection disappears.



Measurement of characteristic impedance



Recipe: Tune terminating impedance for each strip width until the reflected signal for injected charge pulse disappear.

Requirement of gases in ICAL

Total number of RPCs in ICAL = $3 \times 150 \times 64 = 28,800$

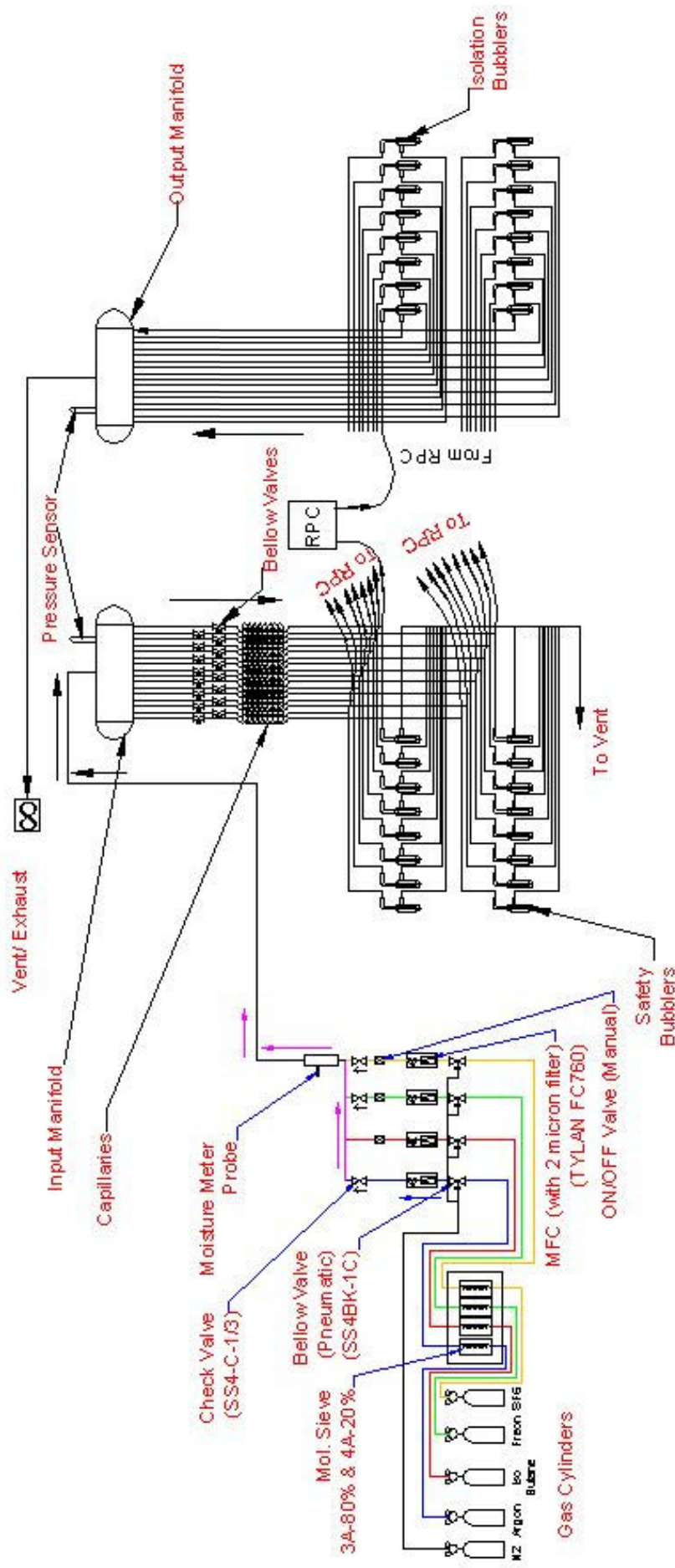
Total gas volume = $28,800 \times 184\text{cm} \times 184\text{cm} \times 0.2\text{cm} = 195,010$ litres

For ex: One volume change/day with 10% gas top-up in a re-circulating scheme

Approximate running gas cost = Rs 30,000/day (Using cheaper R134a)

Gas	Avalanche (%)	Streamer (%)	Maximum (%)	Volume (L)	Density (g/L)	Weight (Kg)	Cost (Rs/Kg)
Argon	0.0	30.0	30.0	58,503	1.784	104.4	
R134a	95.5	62.0	95.5	186,234.6	4.25	791.5	
Isobutane	4.3	8.0	8.0	15,600.8	2.51	39.16	
SF ₆	0.2	0.0	0.2	390	6.164	2.40	

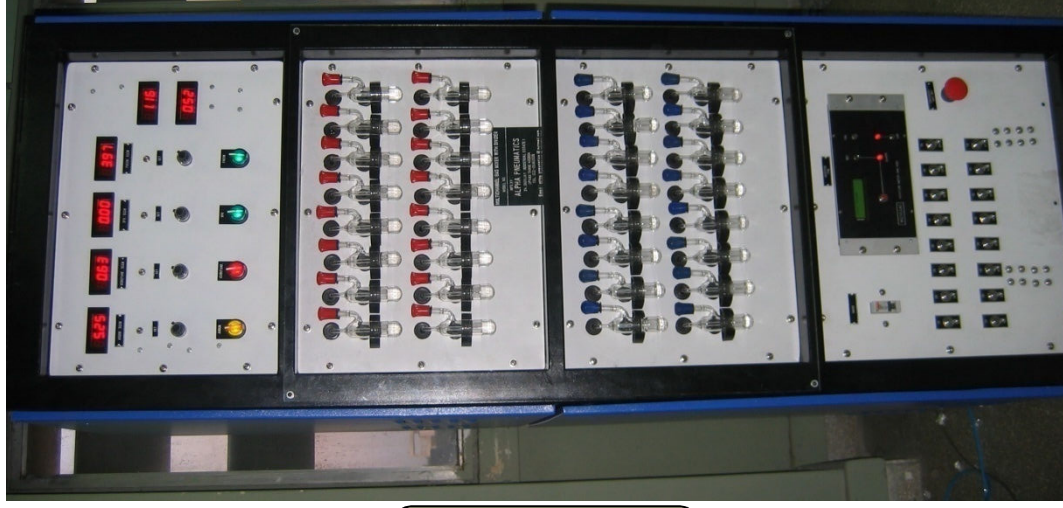
Schematic of gas system



Features of the gas system

- ❖ 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 moisture readout on mixed gas
- ❖ Output flow control by SS 0.3mm capillaries
- ❖ Bleeder bubblers for RPC protection
- ❖ Facility to add controlled moisture into the mixture
- ❖ Computer interface for control and monitoring

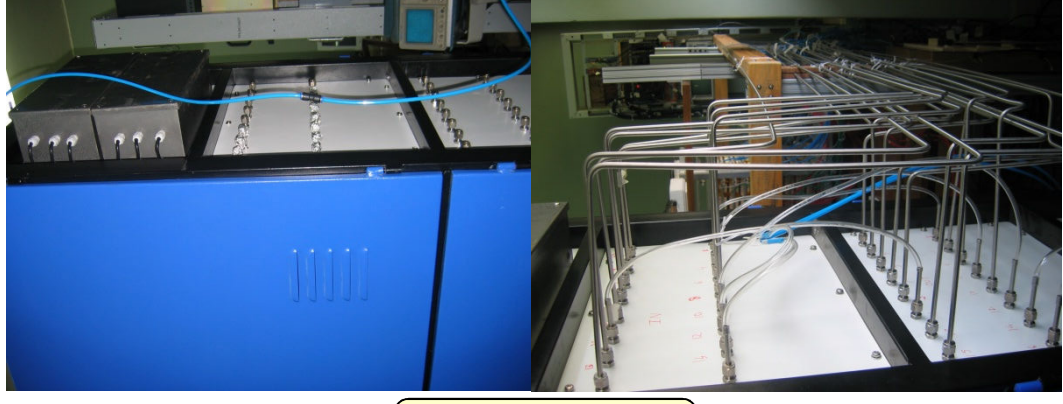
Constructional details of the gas system



Front view

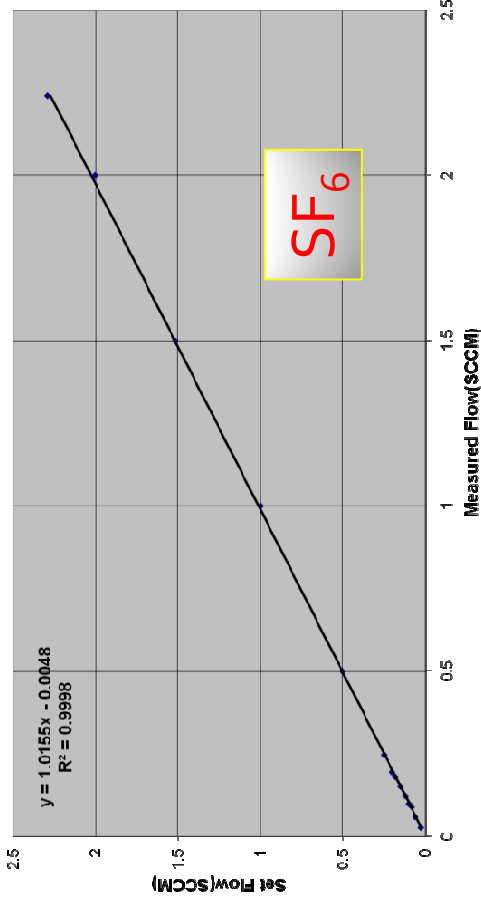
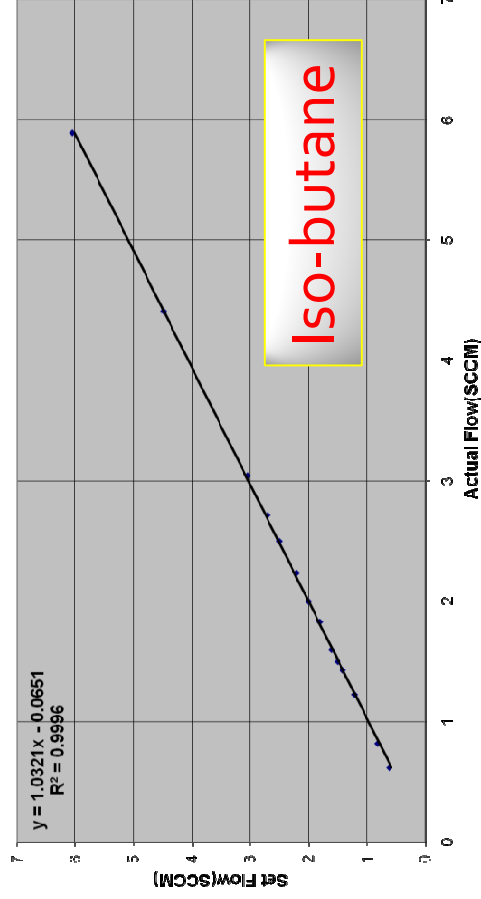
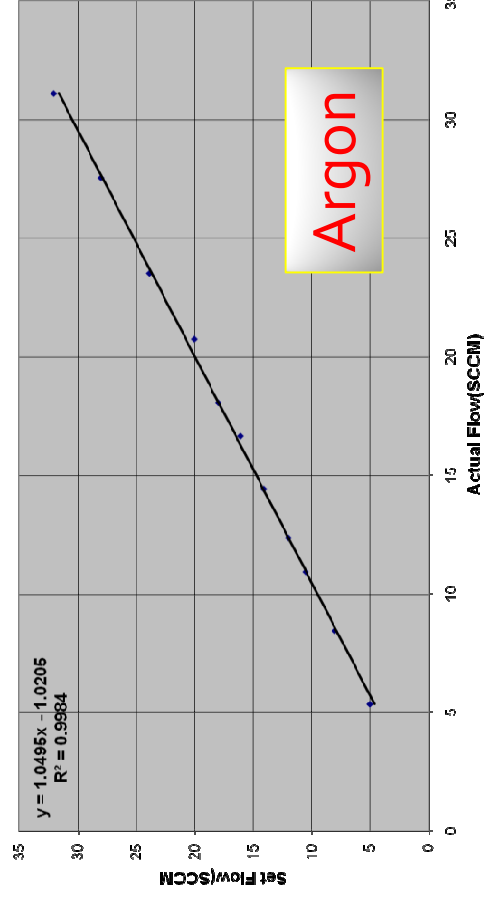
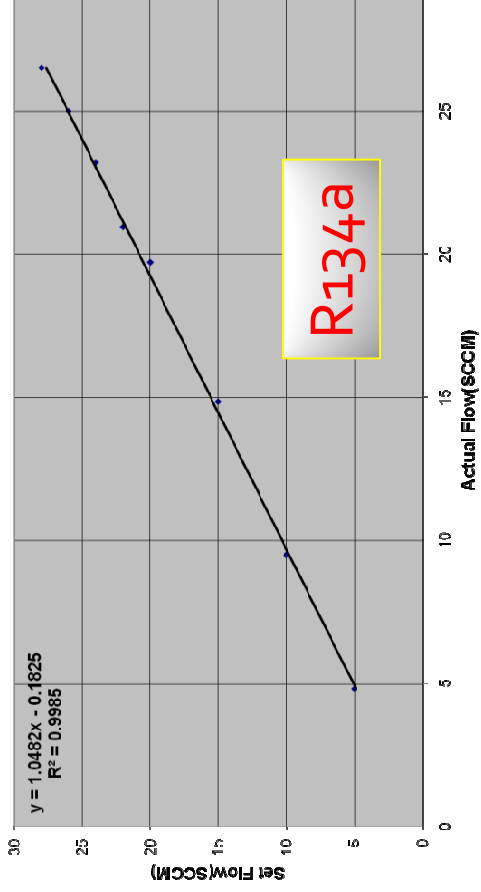


Internal view



Rear view

Calibration of gas system



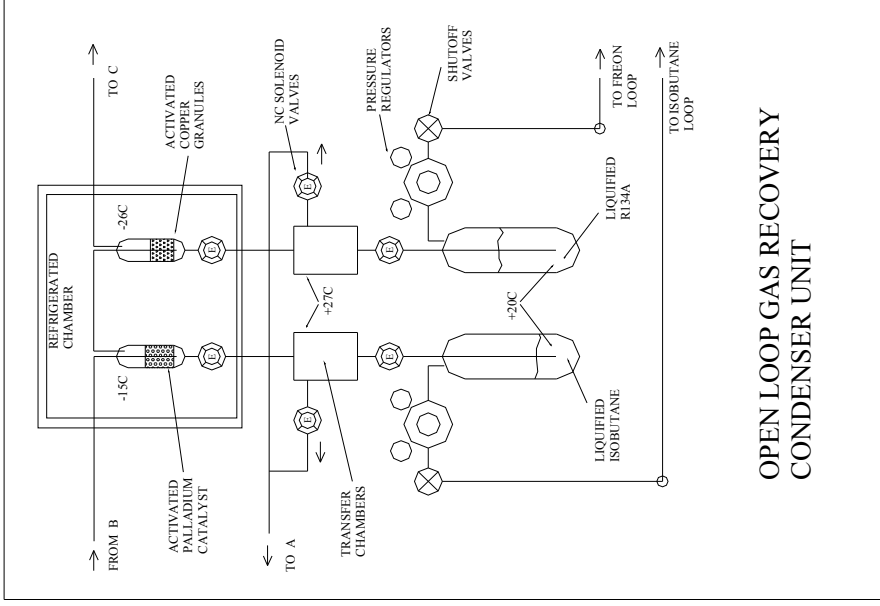
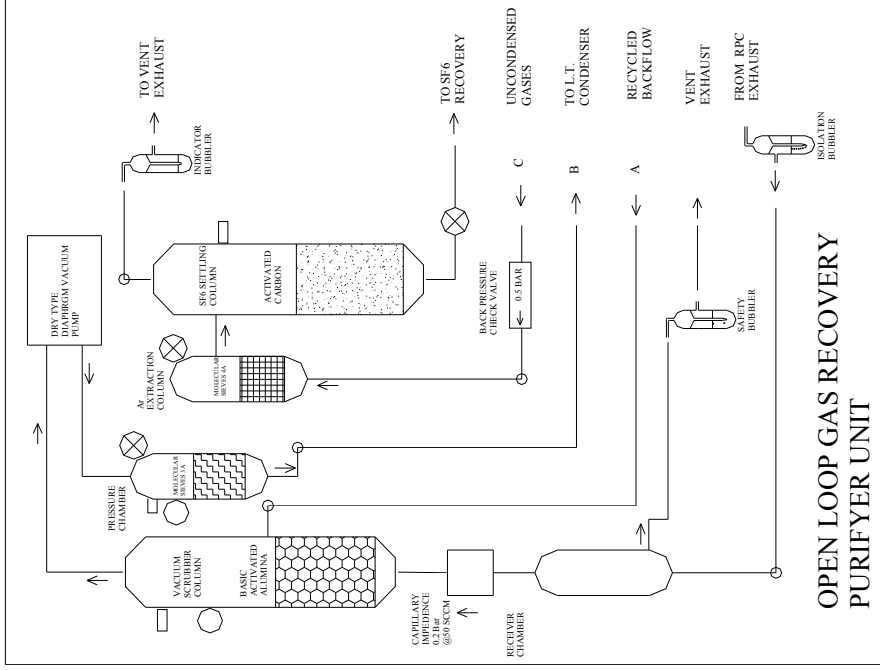
Cross-calibration of the gas system

- Calibration done using water displacement method
- Calibrated against the MFC monitor voltage
- Cross-calibration procedure
 - Glass/hard plastic tube with precise inner diameter chosen. Placed on a perfectly horizontal surface.
 - Water droplet introduced through an opening on one end of the tube
 - Gas connected to this end
 - Gas moves the water droplet forward $\propto$ gas flow
 - Distance, time intervals measured
 - Gas volume computed and compared with displayed value

Gas	Calibration equation
Argon	$y = 1.0886x - 0.1782$
Iso-butane	$y = 1.06x - 0.2315$
SF ₆	$y = 1.539x + 0.0578$
R134a	$y = 1.0541x - 0.6054$

x = Actual flow, y = Set flow

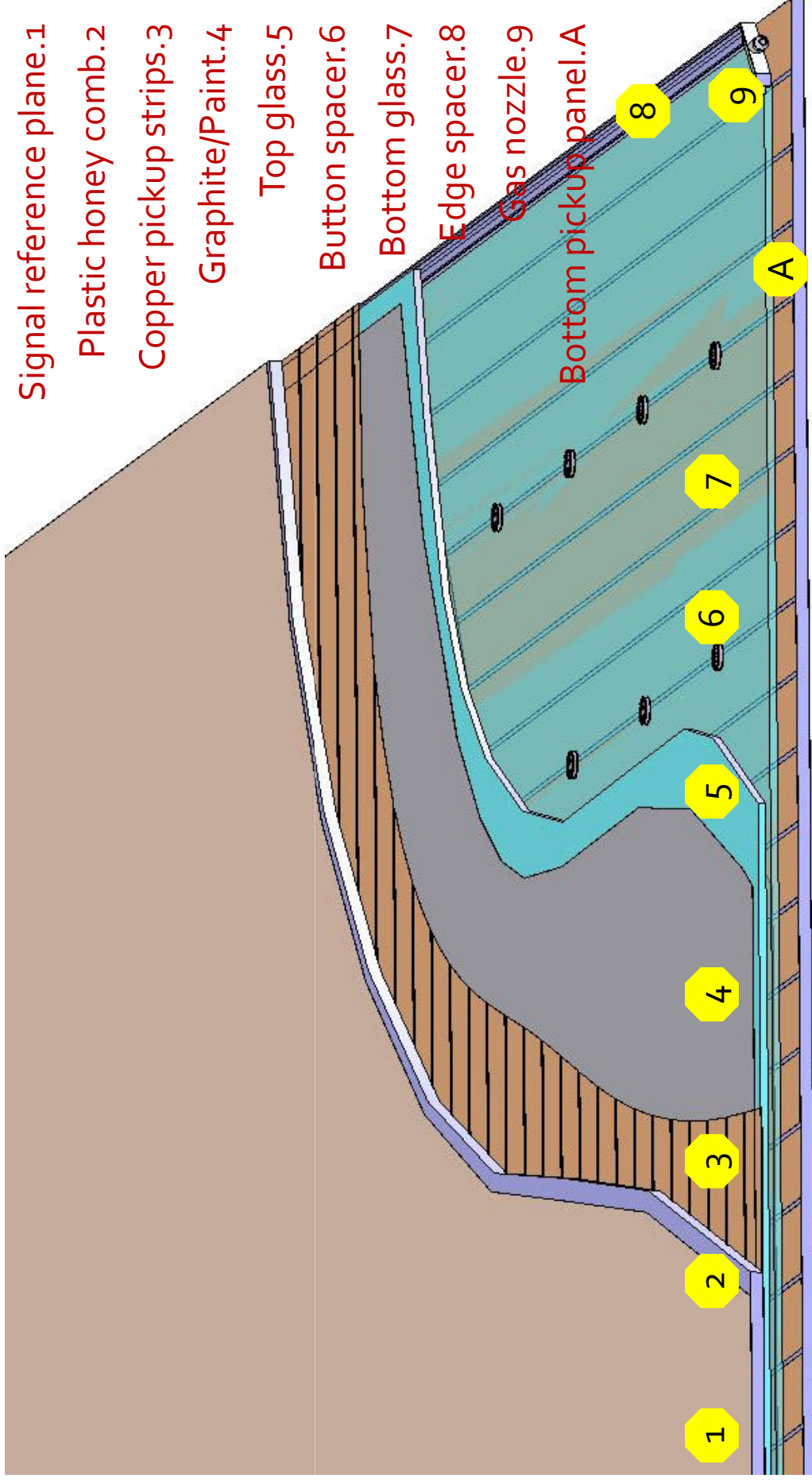
Open loop gas recovery system



Large area RPC development

Scaling up dimensions without deterioration of characteristics

Basic construction of an RPC



Fully assembled large area RPC



Final Frontier: Making of 2m x 2m RPCs

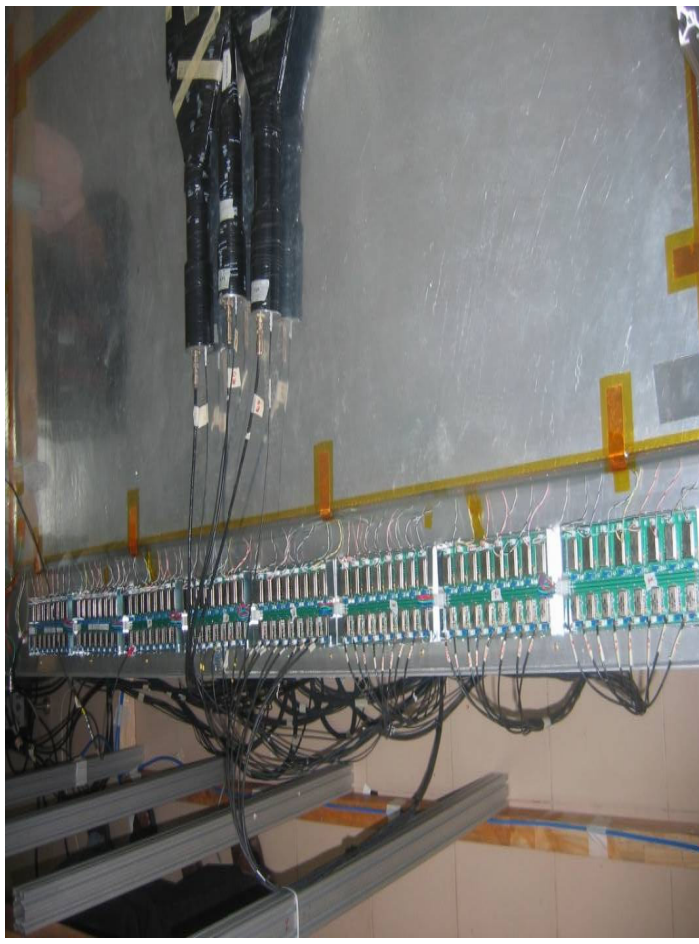


2m x 2m RPC in the Cosmic test stand

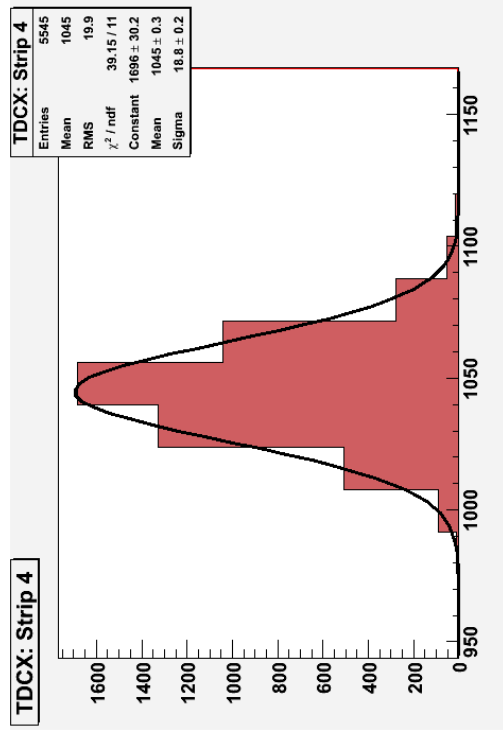
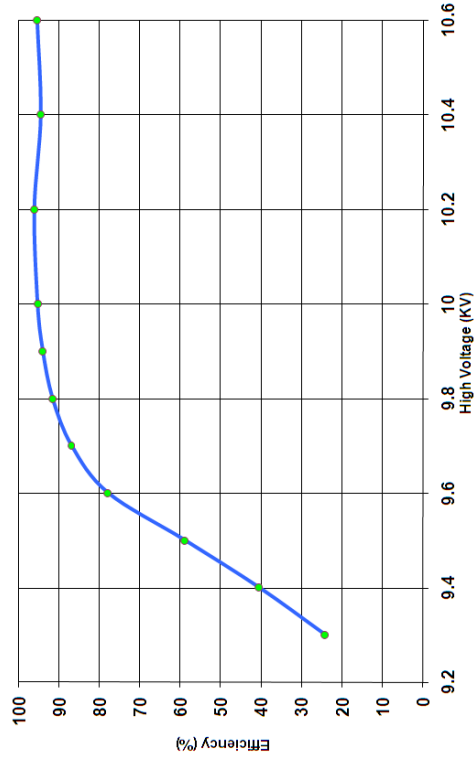
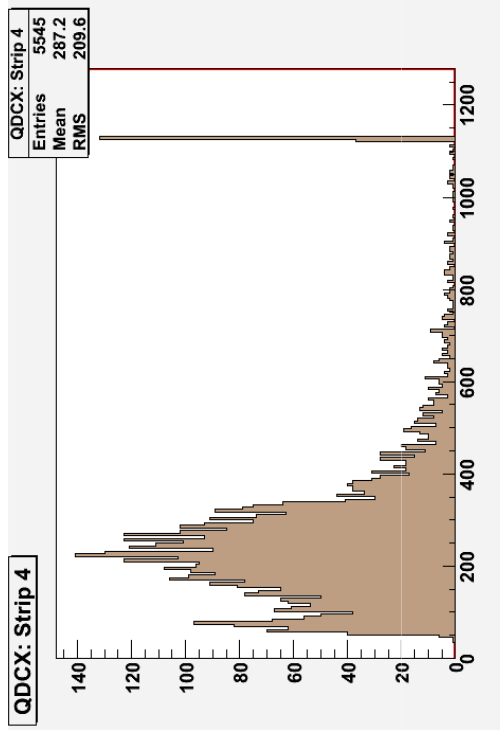
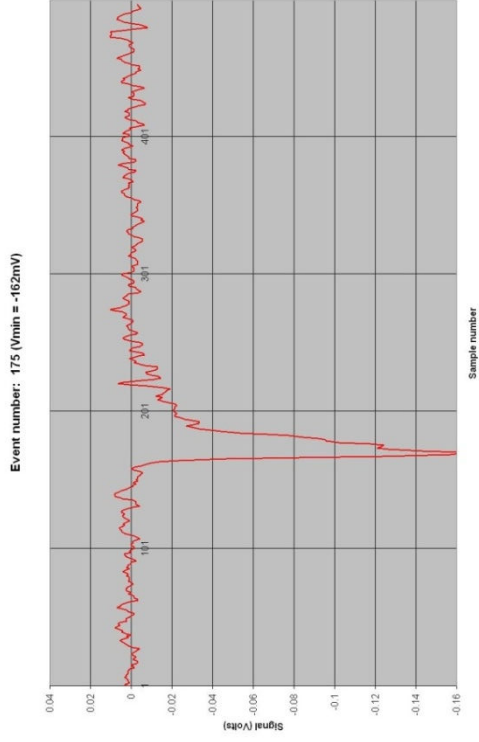
Cosmic test stand



Front-end electronics

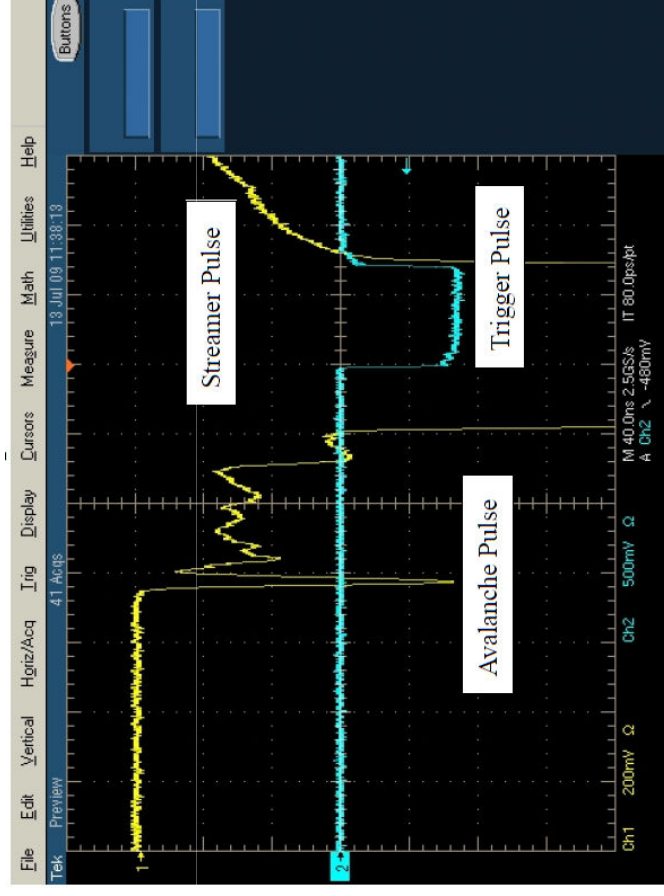


RPC parameter characterisation

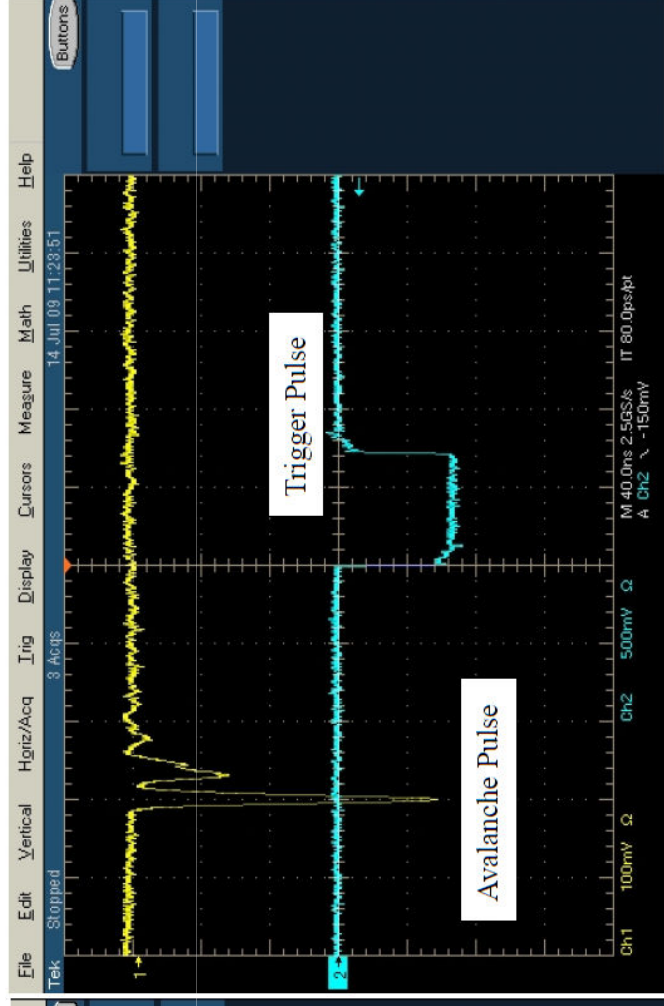


SF₆ studies: RPC pulse profile

SF₆ = 0%

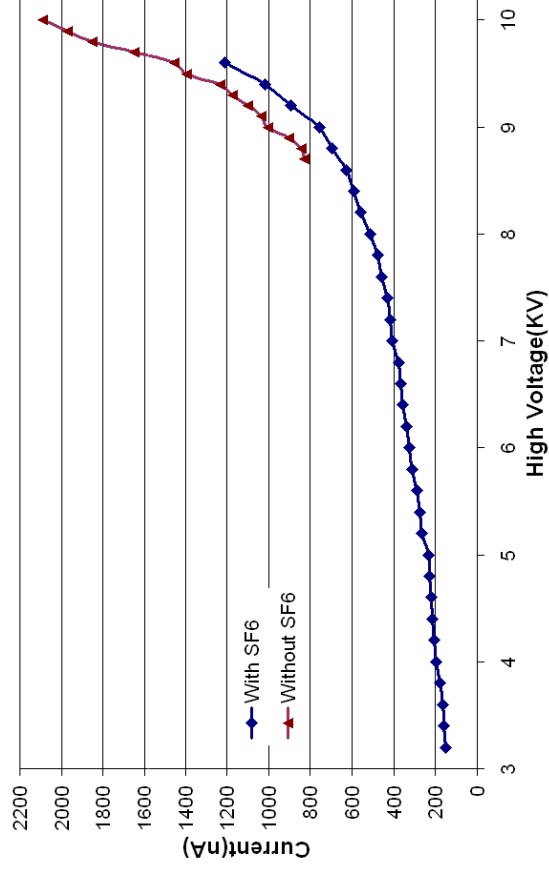


SF₆ = 0.32%

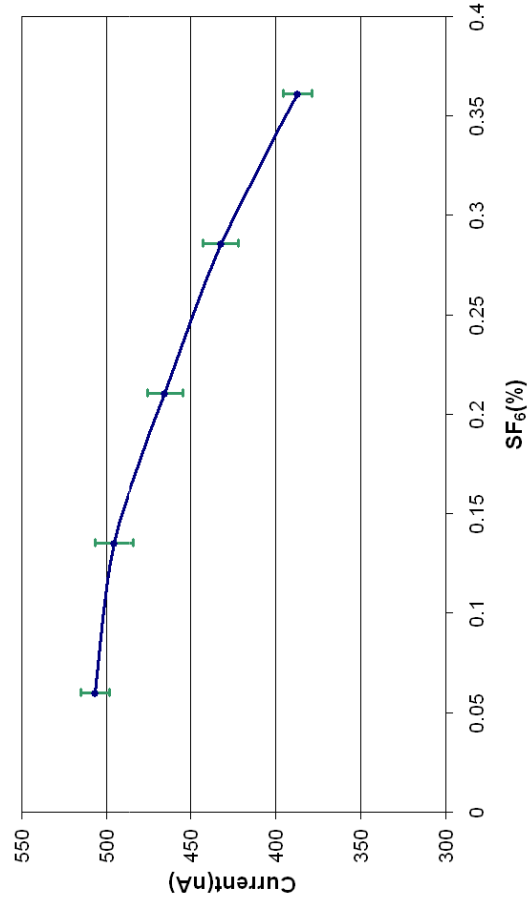


SF₆ studies: Chamber current

V-I characteristics

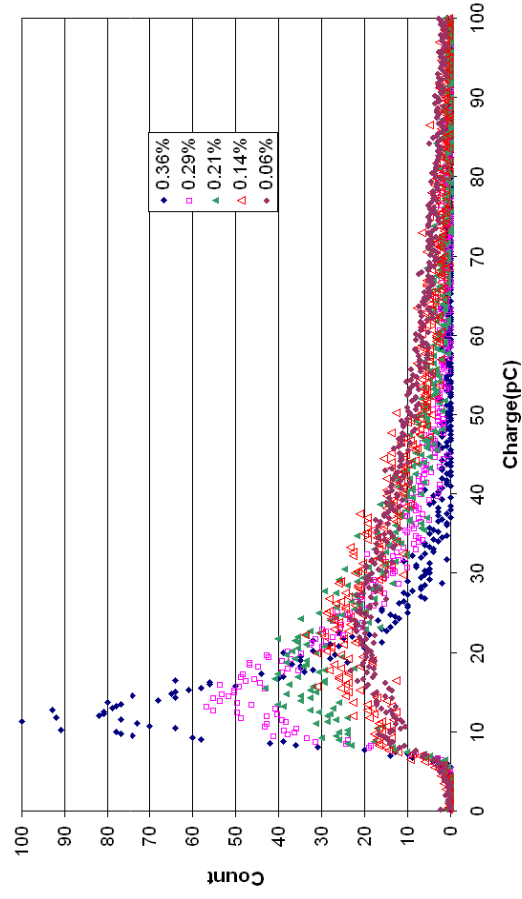


Chamber current

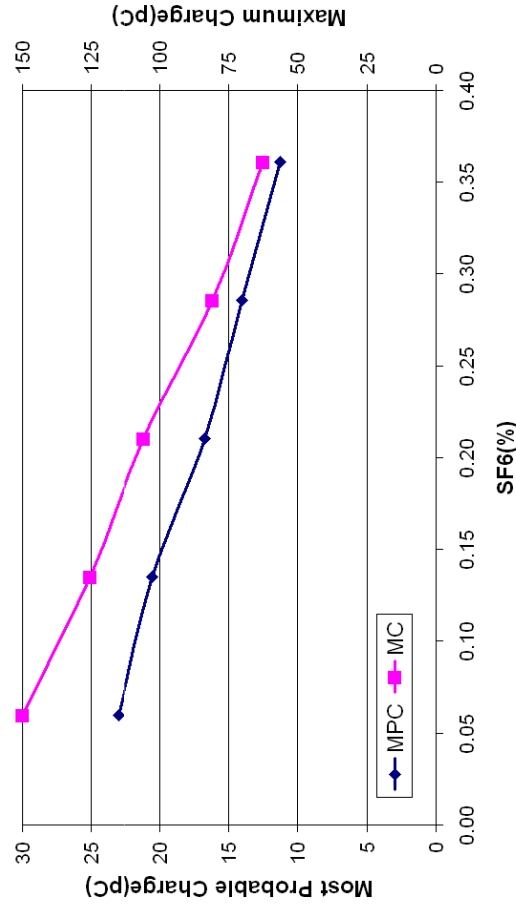


SF₆ studies: Collected signal charge

Charge distributions

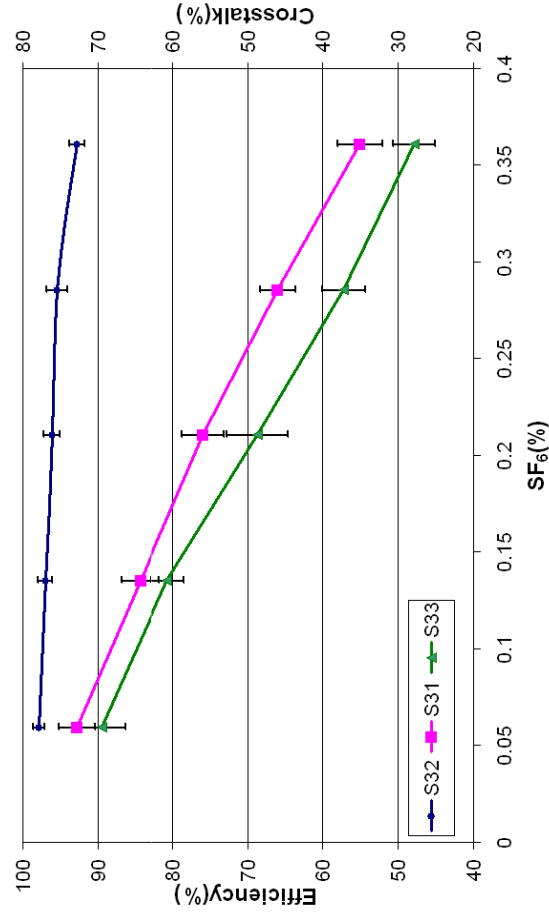


Charge parameters

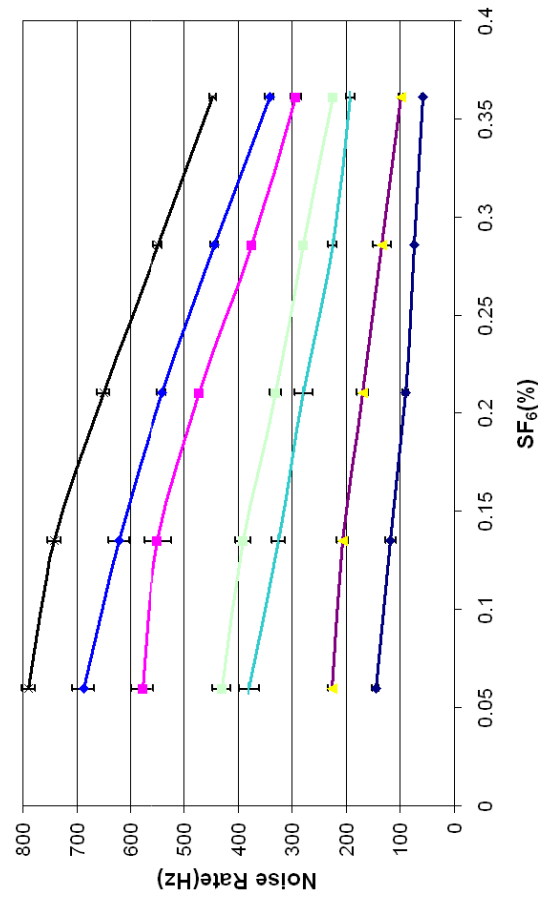


SF₆ studies: Important operating parameters

Efficiency

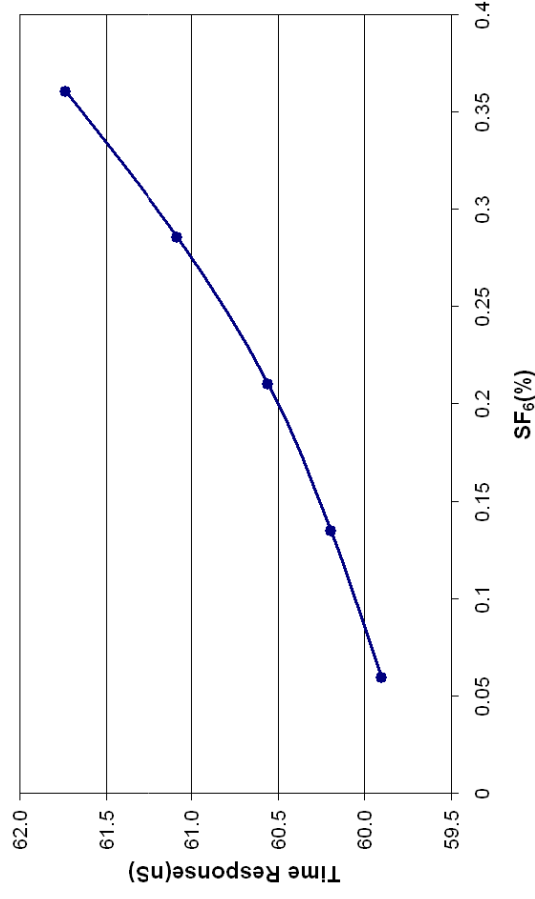


Noise rate

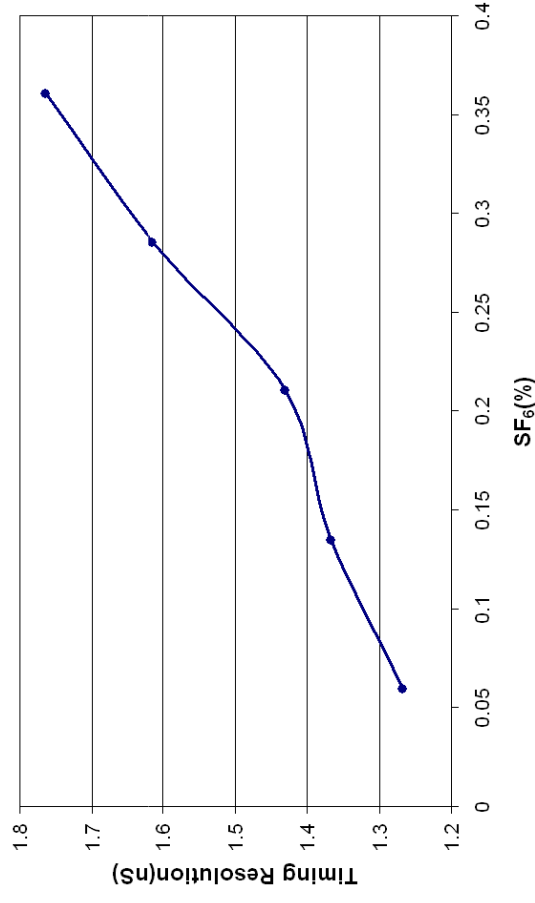


SF₆ studies: Timing characteristics

Time response



Time resolution

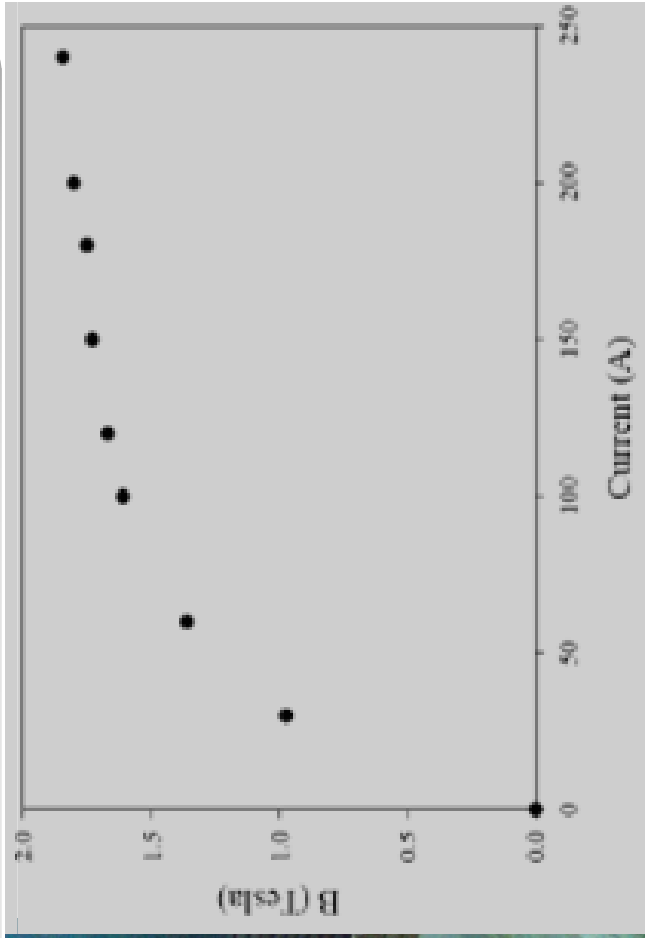


Construction of ICAL prototype detector

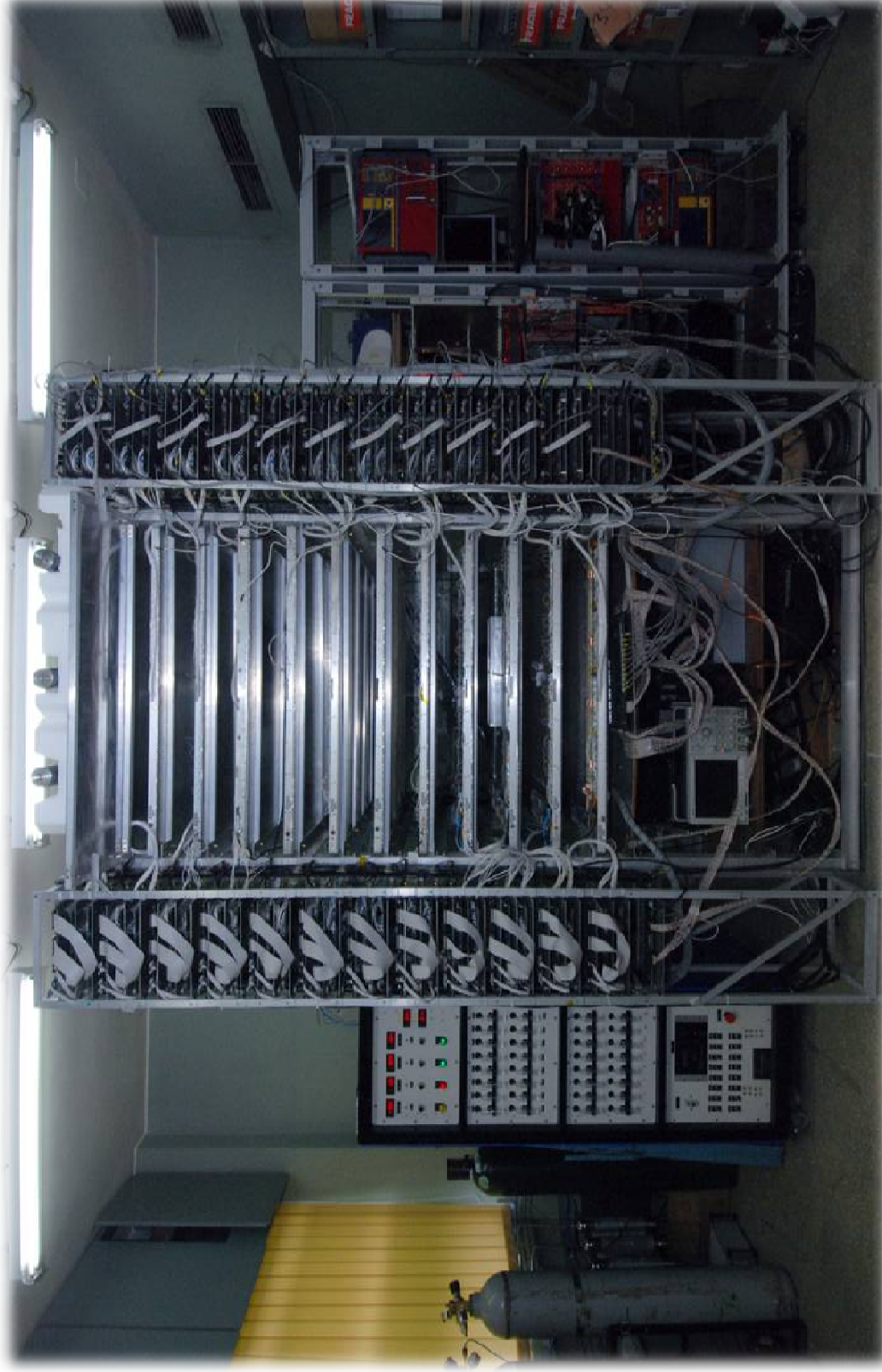
Want to check if everything works as per design!

Prototype detector magnet

- ❖ 13 layer sandwich of 50mm thick low carbon iron (*Tata A-grade*) plates (35ton absorber)
- ❖ Each layer assembled by joining a 'T' and a 'C' shaped iron plates.
- ❖ Detector is magnetised to 1.5Tesla, enabling momentum measurement of 1-10Gev muons produced by ν_μ interactions in the detector.
- ❖ 4 sets of copper coils of 5 turns each, made from electrolytic copper conductor tubing.
- ❖ Central bore in coils for flowing low conductivity water.
- ❖ Thyristor controlled three phase low voltage constant current type power supply.



Prototype RPC stack



Schematic of prototype detector segmentation

T3	T2	T1
NC 31	30	29
28	27	26
25	24	23
22	21	20
19	18	17
16	15	14
13	12	11
10	9	8
7	6	5
4	3	2
1	0	
NC 31	30	29
28	27	26
25	24	23
22	21	20
19	18	17
16	15	14
13	12	11
10	9	8
7	6	5
4	3	2
1	0	
NC 31	30	29
28	27	26
25	24	23
22	21	20
19	18	17
16	15	14
13	12	11
10	9	8
7	6	5
4	3	2
1	0	
NC 31	30	29
28	27	26
25	24	23
22	21	20
19	18	17
16	15	14
13	12	11
10	9	8
7	6	5
4	3	2
1	0	
NC 31	30	29
28	27	26
25	24	23
22	21	20
19	18	17
16	15	14
13	12	11
10	9	8
7	6	5
4	3	2
1	0	
M3	M2	M1
NC 31	30	29
28	27	26
25	24	23
22	21	20
19	18	17
16	15	14
13	12	11
10	9	8
7	6	5
4	3	2
1	0	
NC 31	30	29
28	27	26
25	24	23
22	21	20
19	18	17
16	15	14
13	12	11
10	9	8
7	6	5
4	3	2
1	0	
NC 31	30	29
28	27	26
25	24	23
22	21	20
19	18	17
16	15	14
13	12	11
10	9	8
7	6	5
4	3	2
1	0	
B3	B2	B1

$$\text{Trigger} = (T1+T2+T3)*(M1+M2+M3)*(B1+B2+B3)$$

B.Satyanarayana, TIFR, Mumbai

Kodai Winter School

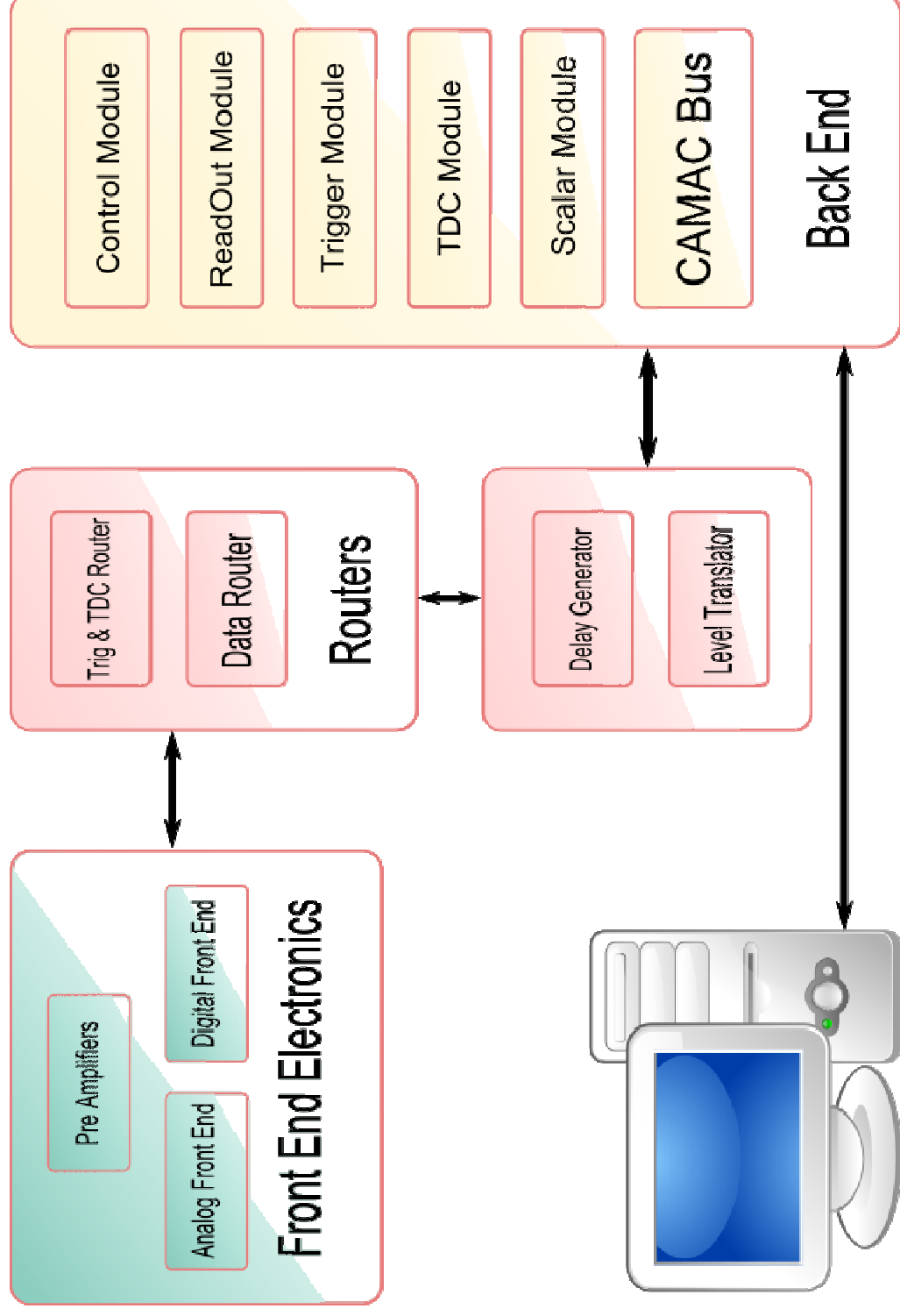
December 7, 2009

57

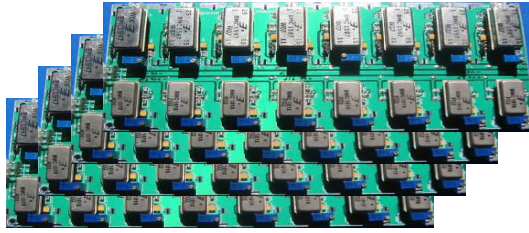
Layer Number	RPC	Gas Channel
Layer 11	AB08	16
Layer 10	AB07	03
Layer 9	AB04	05
Layer 8	AB03	07
Layer 7	AB01	13
Layer 6	AB02	09
Layer 5	IB02	15
Layer 4	JB03	06
Layer 3	JB01	08
Layer 2	AB10	12
Layer 1	JB00	14
Layer 0	AB06	10

- 12, 1m² RPC layers
- Two readout planes (X & Y)
- 32 channels/plane
- Total 768 readout channels
- Trigger on muons using:
 - Scintillator paddle layers
 - RPC strip signals
- Recorded information:
 - Strip hits
 - Timing
- Monitoring data:
 - Chamber parameters
 - High voltage and current
 - Strip noise rates
 - Cosmic muon efficiency
 - Ambient parameters
 - Temperature
 - Relative humidity
 - Barometric pressure
- Magnet control and monitor
- Gas system control & monitor

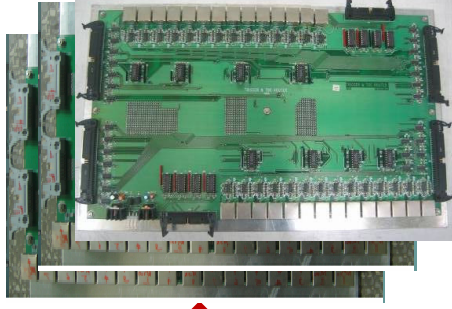
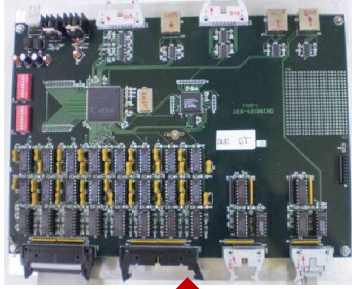
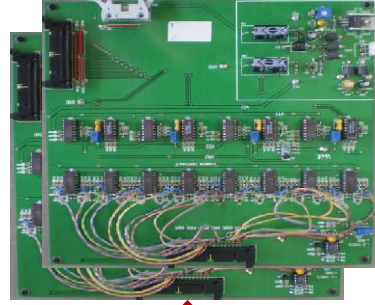
Schematic of prototype detector DAQ system



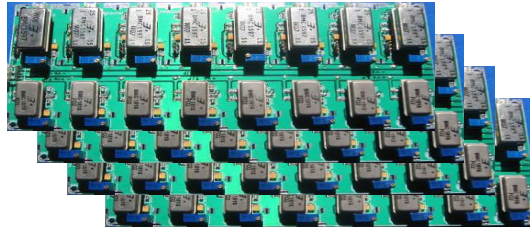
Design and implementation of the data acquisition system



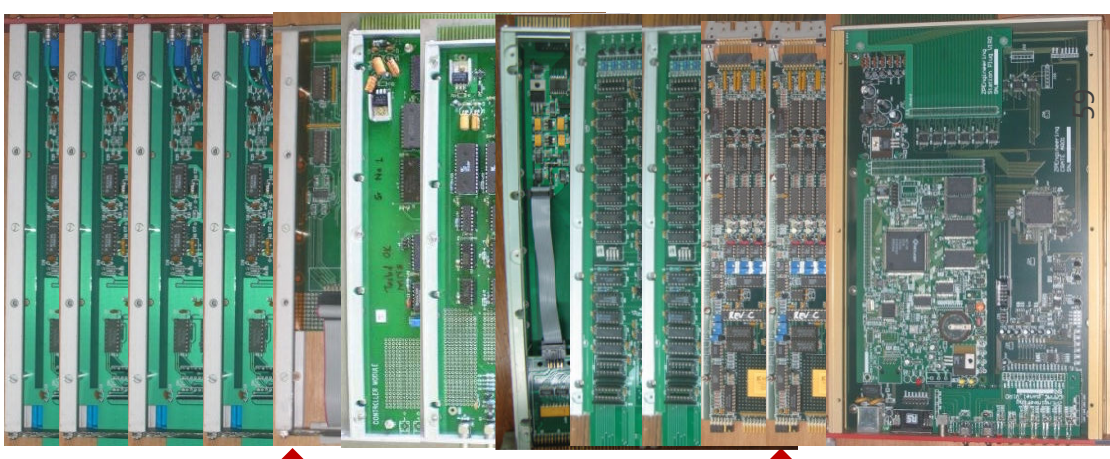
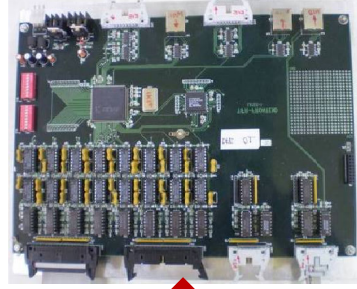
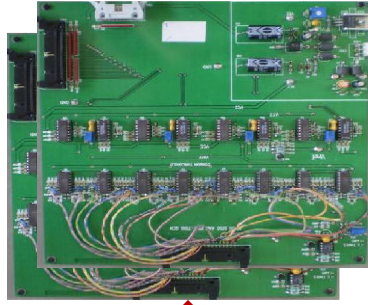
200 boards of 13 types



Custom designed using



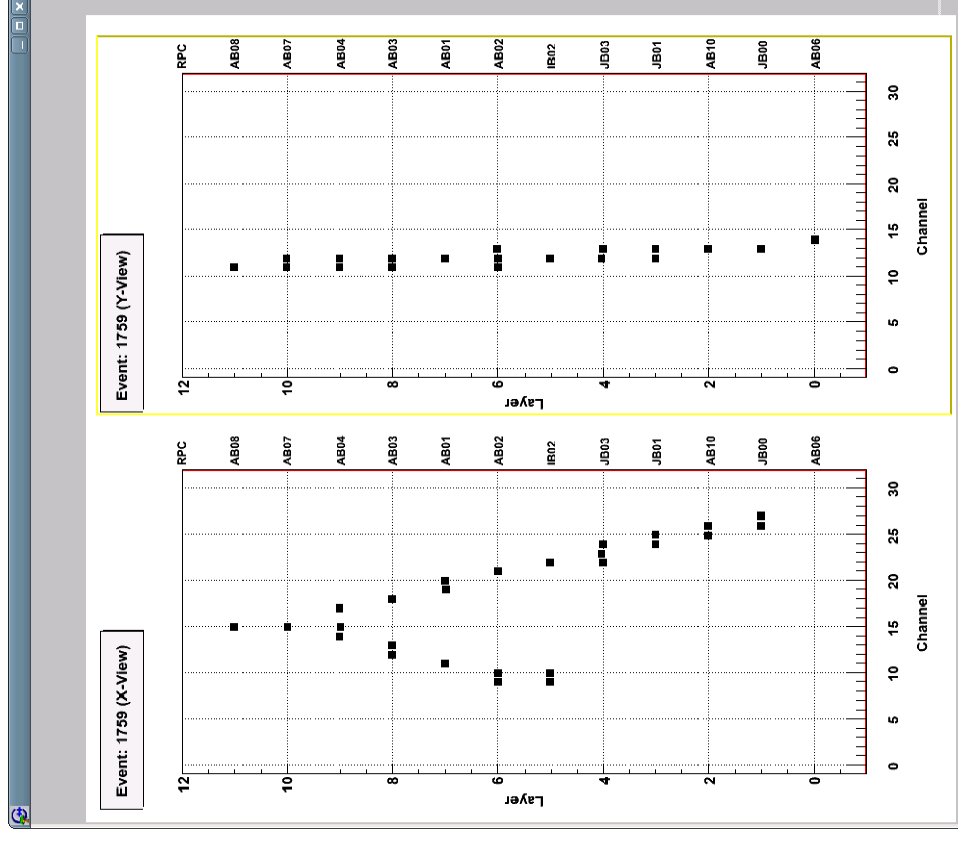
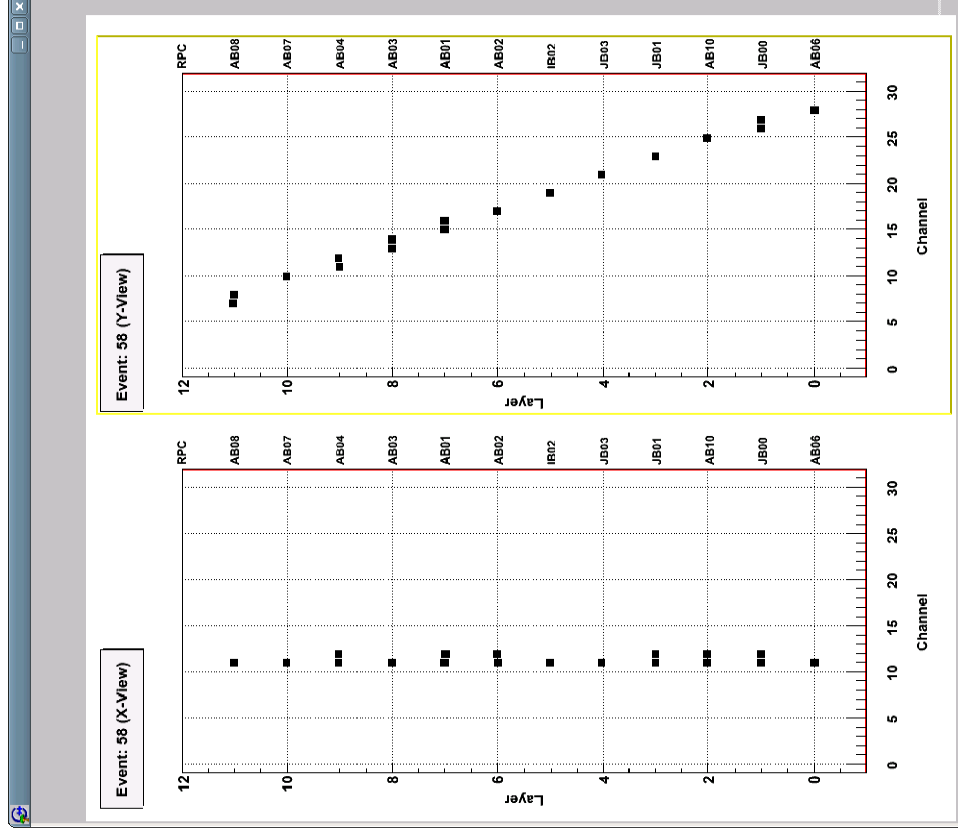
FPGA,CPLD,HMC,FIFO,SMD



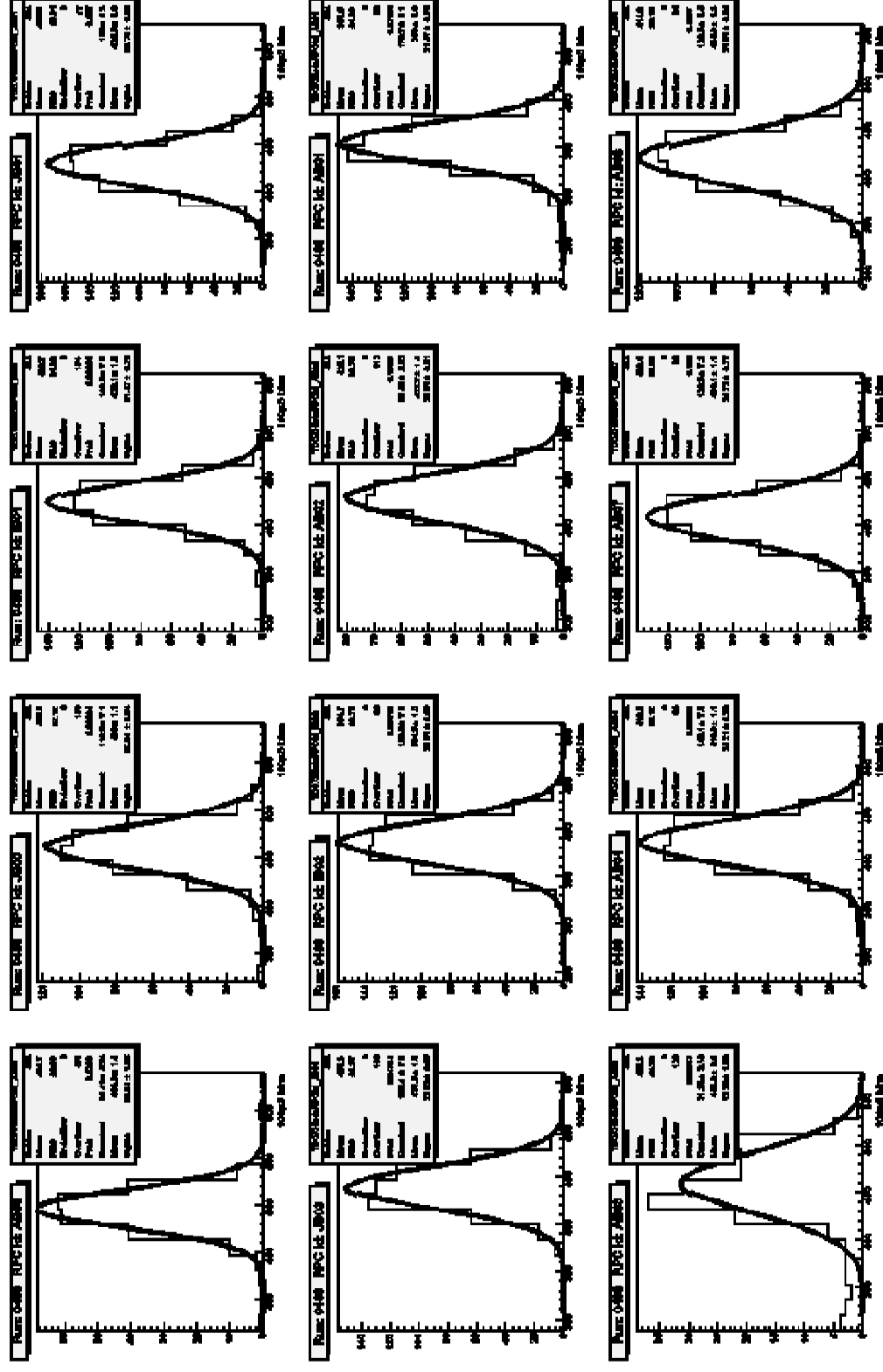
Data analysis and results

Using a ROOT based package *BigStackV3.8*

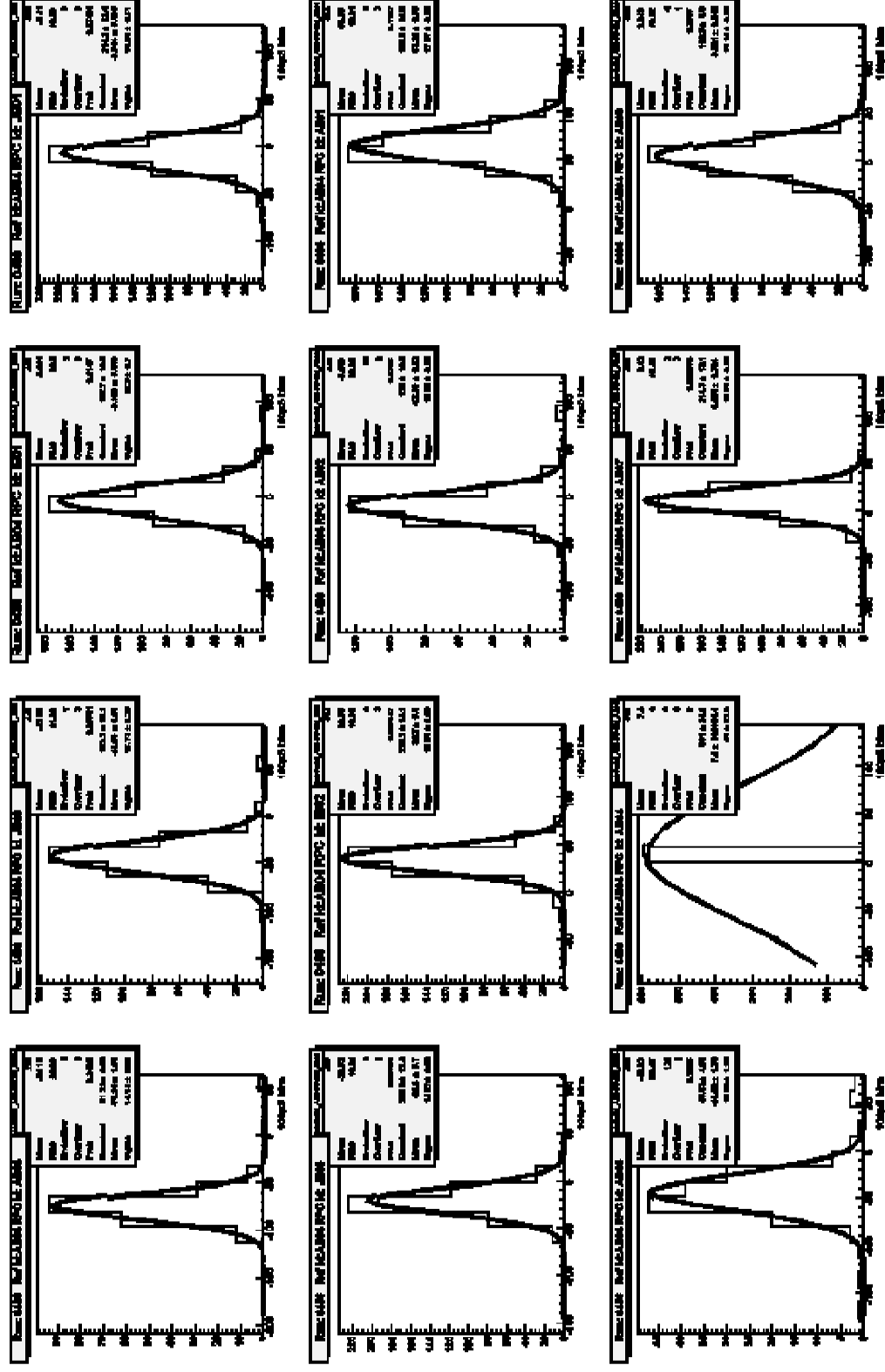
A couple of interesting events



RPC absolute time resolution plots



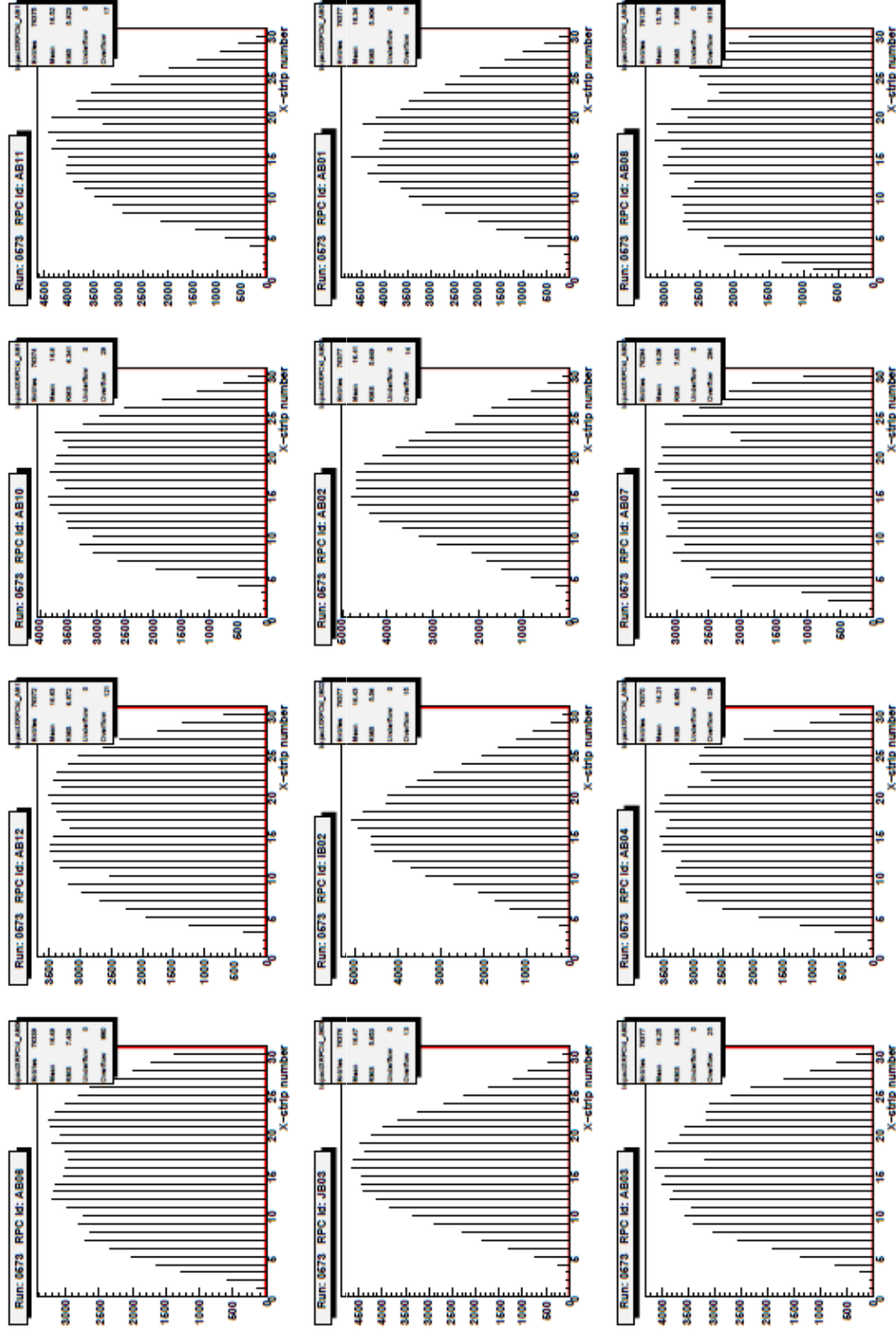
RPC relative time resolution plots



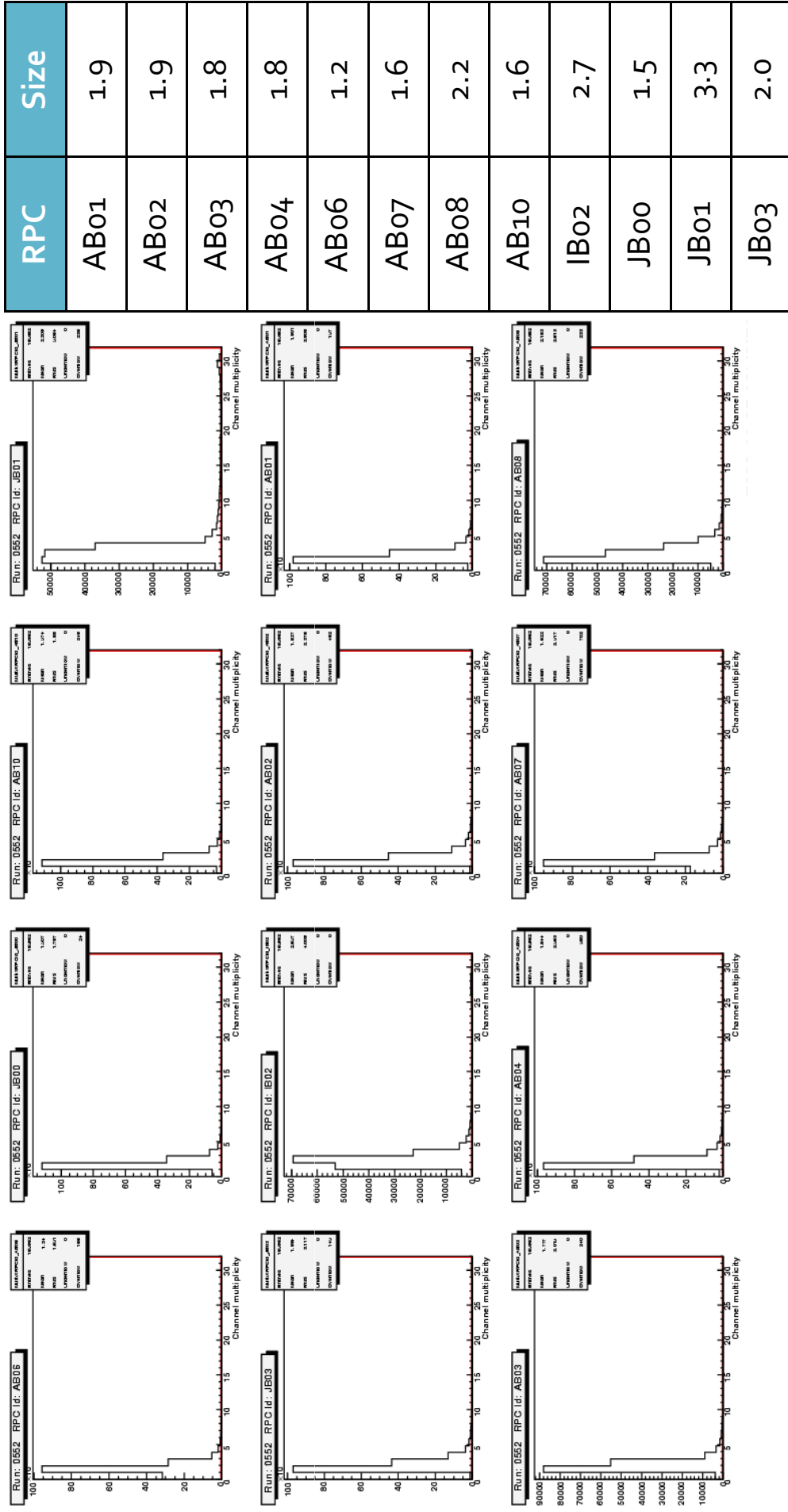
Summary of timing resolutions

RPC Id	HV(KV)	Mean(ns)	Sigma(ns)	Re1Mean(ns)	Re1Sigma(ns)
AB06	09.8	49.53	2.06	-7.64	1.41
JB00	09.6	46.00	2.32	-4.47	1.67
IB01	09.8	42.31	2.15	-0.64	1.63
JB01	09.6	42.55	2.28	-0.87	1.58
JB03	09.8	43.75	2.26	-2.18	1.44
IB02	09.8	38.49	2.31	3.27	1.38
AB02	09.8	42.77	2.53	-1.21	1.51
AB01	09.8	35.30	2.16	6.33	1.71
AB03	09.8	45.82	3.23	-4.55	1.99
AB04	09.8	41.66	2.42	Reference RPC	
AB07	09.8	40.61	2.47	0.96	1.35
AB08	09.8	41.56	2.80	0.31	1.82

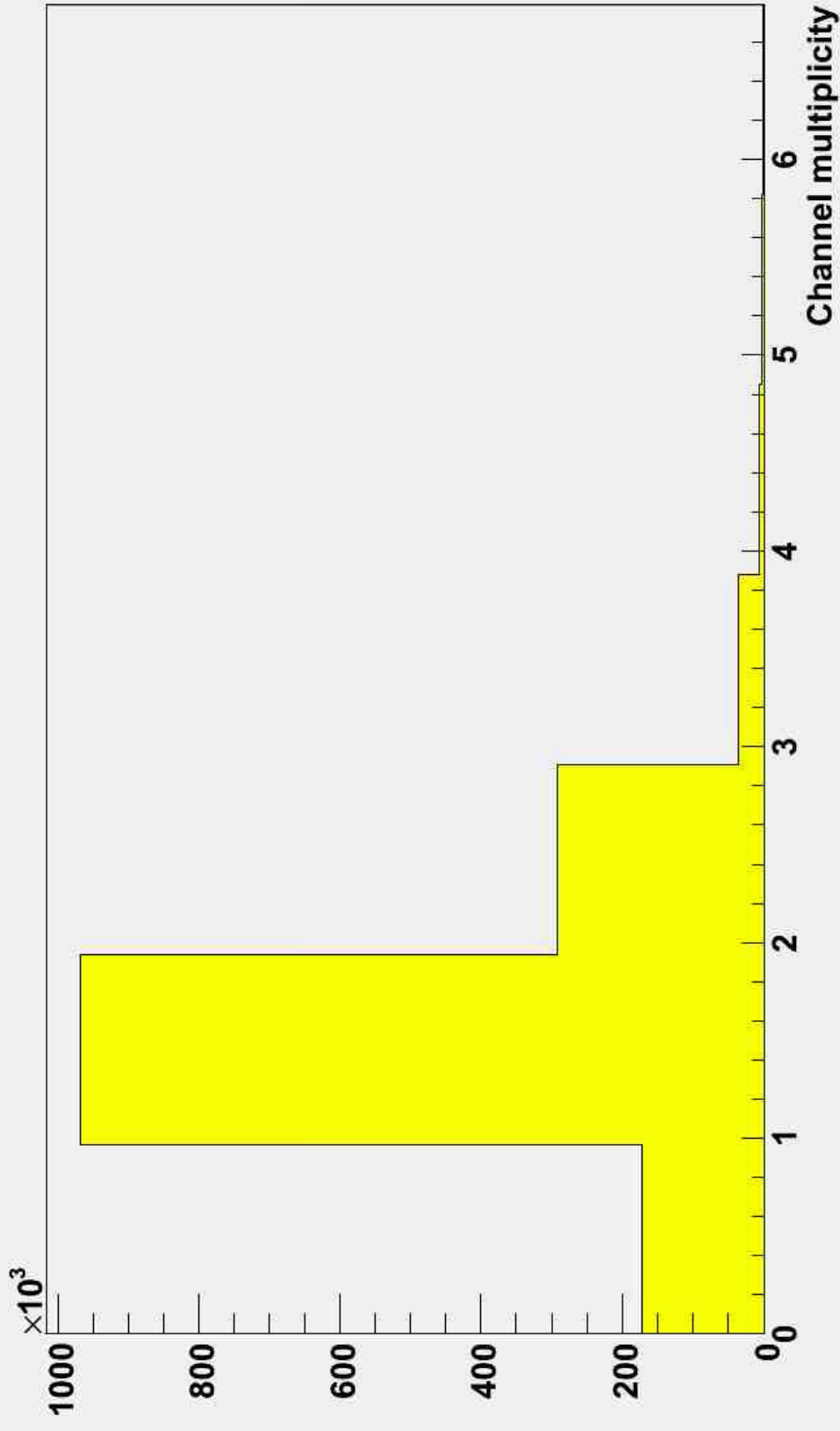
Impact position plots



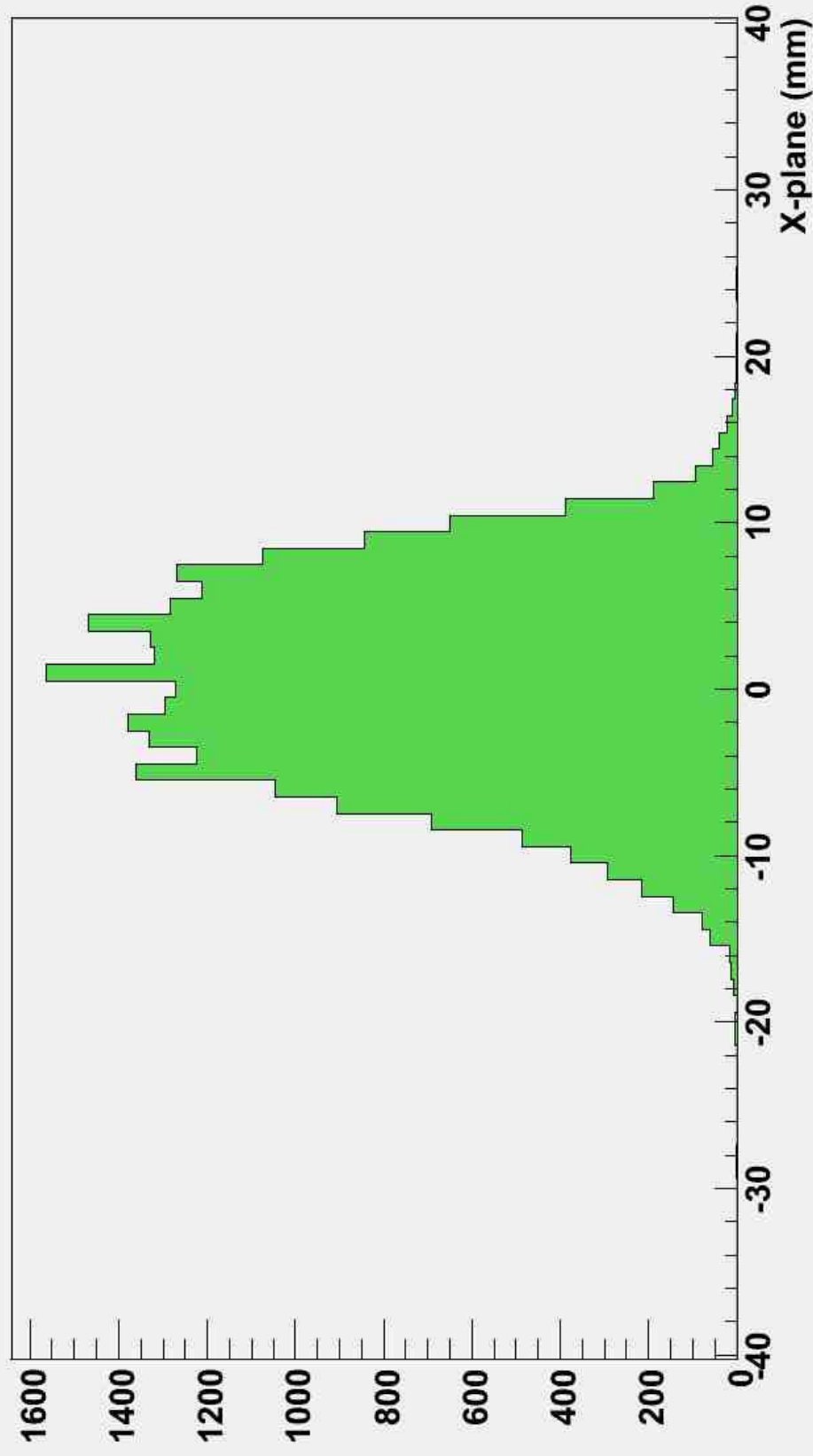
Cluster size distributions



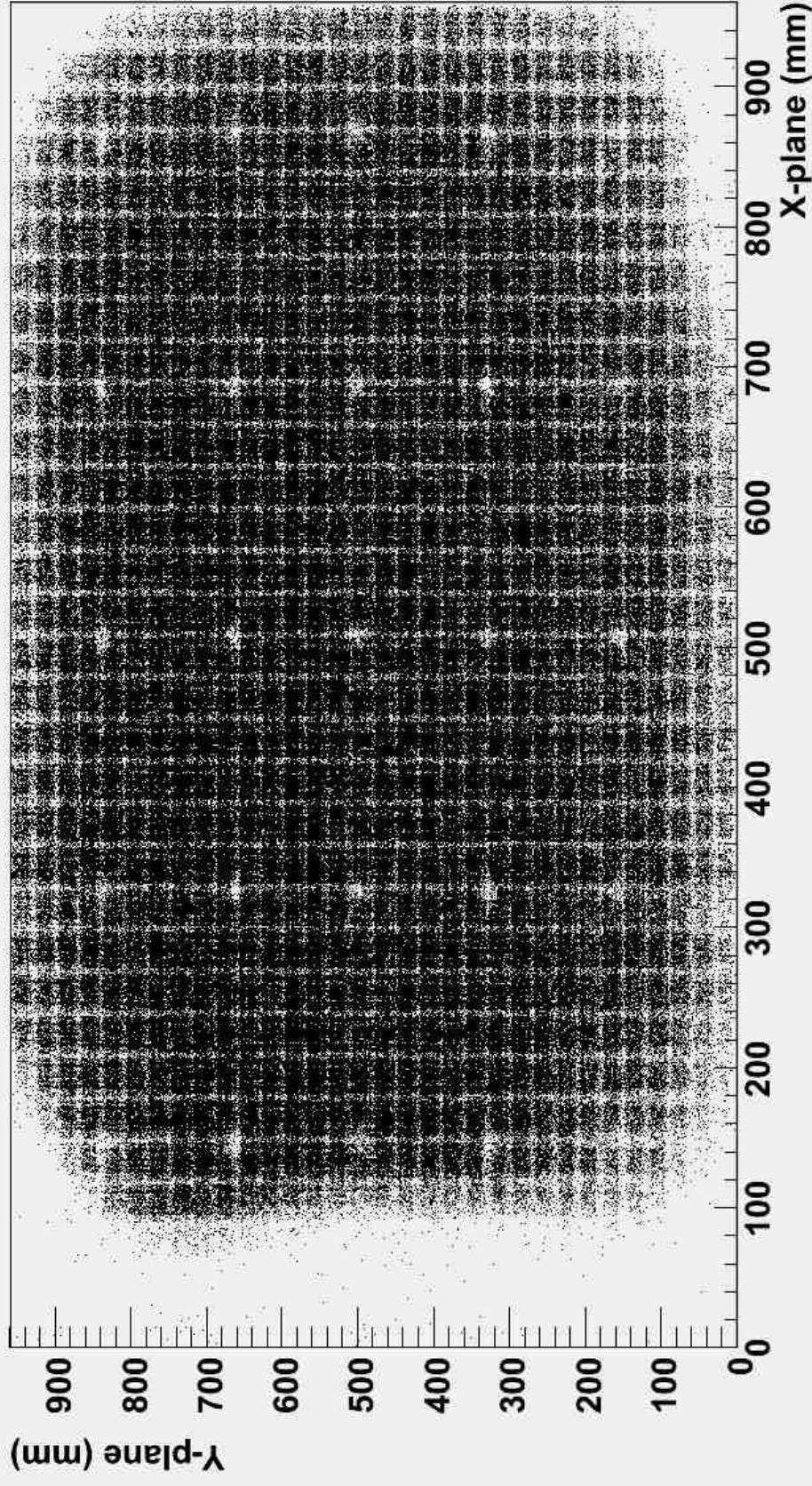
Strip multiplicity



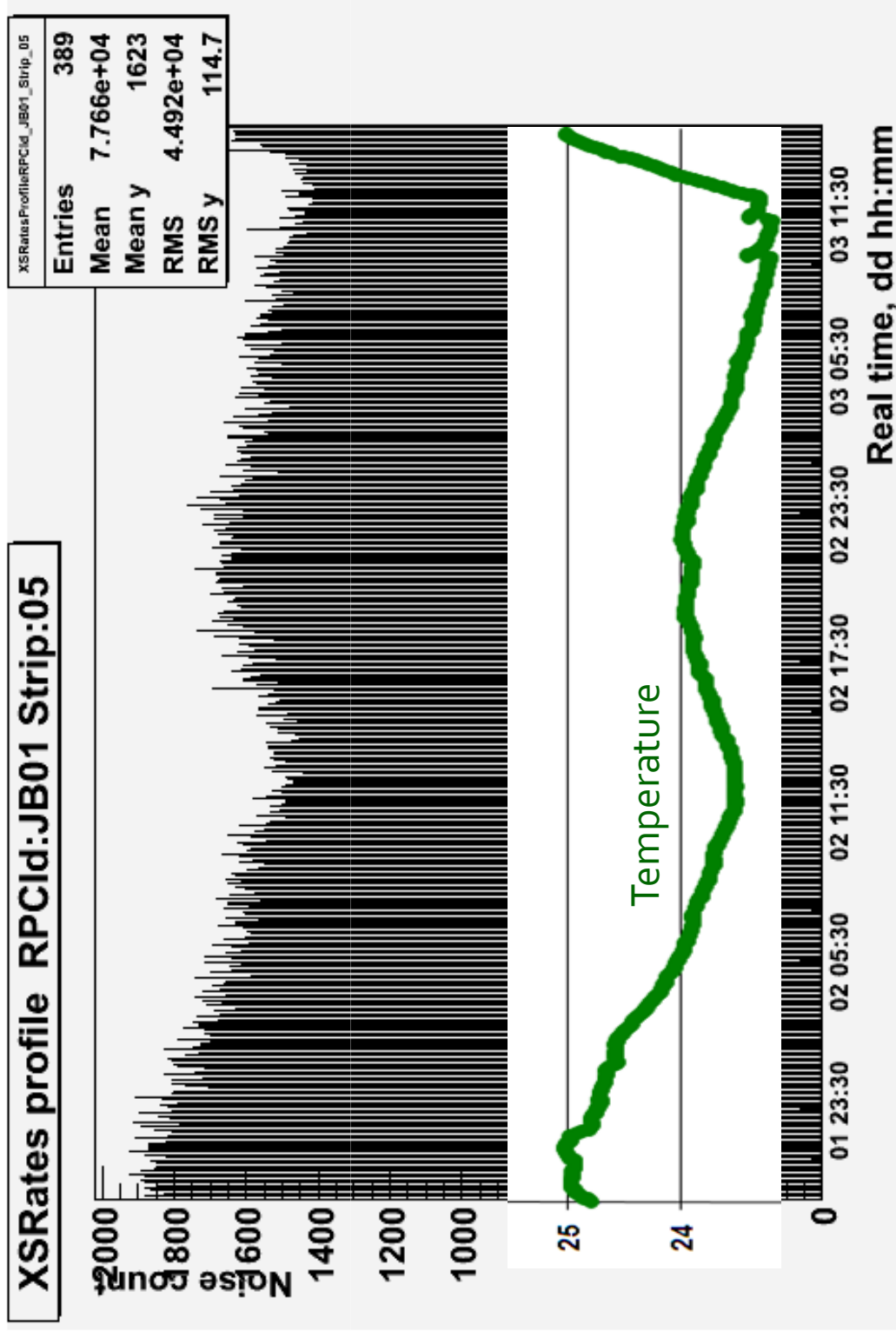
Track residue plot



Tomography of RPC using muons



RPC strip rate time profile



On-line monitoring utilities

lamps@ino06:~/i27/ItoHVControl

File Edit View Terminal Tabs Help

Date	Time	SlotNo	ChNo	ChName	V Set	V Mon	I Set	I Mon
27/10/2008	12:21:36	0	0	AB06-ve	4800.00	4808.00	1500	0
27/10/2008	12:21:36	1	0	AB06-ve	4800.00	4801.00	2000	20
27/10/2008	12:21:36	0	1	JB00-ve	4800.00	4806.50	1500	40
27/10/2008	12:21:36	1	1	JB00-ve	4800.00	4800.50	2000	40
27/10/2008	12:21:36	0	2	AB10-ve	4800.00	4807.00	2000	20
27/10/2008	12:21:36	1	2	AB10-ve	4800.00	4807.00	2000	40
27/10/2008	12:21:36	0	3	JB01-ve	4800.00	4807.50	2000	40
27/10/2008	12:21:36	1	3	JB01-ve	4800.00	4800.00	2000	40
27/10/2008	12:21:36	0	4	JB03-ve	4800.00	4808.50	4000	60
27/10/2008	12:21:36	1	4	JB03-ve	4800.00	4801.00	2000	40
27/10/2008	12:21:36	0	5	JB02-ve	4800.00	4811.50	4000	120
27/10/2008	12:21:36	1	5	JB02-ve	4800.00	4800.50	1500	80
27/10/2008	12:21:36	0	6	AB01-ve	4800.00	4810.00	1500	60
27/10/2008	12:21:36	1	6	AB01-ve	4800.00	4811.50	1500	60
27/10/2008	12:21:36	0	7	AB02-ve	4800.00	4806.50	1500	40
27/10/2008	12:21:36	1	7	AB02-ve	4800.00	4806.50	1500	40
27/10/2008	12:21:36	0	8	AB03-ve	4800.00	4808.50	1500	0
27/10/2008	12:21:36	1	8	AB03-ve	4800.00	4808.50	1500	0
27/10/2008	12:21:36	0	9	AB04-ve	4800.00	4809.00	4000	0
27/10/2008	12:21:36	1	9	AB04-ve	4800.00	4805.50	1500	0
27/10/2008	12:21:36	0	10	AB07-ve	4800.00	4806.50	2000	20
27/10/2008	12:21:36	1	10	AB07-ve	4800.00	4806.50	2000	20
27/10/2008	12:21:36	0	11	AB08-ve	4800.00	4801.00	2000	0
27/10/2008	12:21:36	1	11	AB08-ve	4800.00	4801.00	2000	0

Run Started : 27/10/2008 12:18:26 Total Samples : 8 Samples
Current Run File : 200810271218.DAT Sample Rate : 1/50Sec
Press 'q' to exit

lamps@ino06:~/RH02

File Edit View Terminal Tabs Help

lamps@ino06:~/RH02

31:10:2008 18:07:35

Position : Temperature(C)

Humidity(%)

In Side Room: 25.65 42.73

Out Side Room: not Available

lamps@ino06:~/i27/ItoHVControl

File Edit View Terminal Tabs Help

Date	Time	SlotNo	ChNo	ChName	V Set	V Mon	I Set	I Mon
20081031	180928	13	1	DFEX-	8.00	7.98	15000	7200
20081031	180928	13	2	DFEX-	8.00	8.01	15000	5800
20081031	180928	13	3	PAMP-	7.17	7.18	25000	16100
20081031	180928	13	4	PREFMP	7.16	7.16	15000	100
20081031	180928	13	6	DFEX+	8.00	7.99	16000	10700
20081031	180928	13	7	DFEX+	8.00	8.01	16000	10000
20081031	180928	13	8	PAMP+	7.16	7.16	25000	16100
20081031	180928	13	9	CH3	2.00	2.00	26000	100
20081031	180928	13	11	AFEX6-	7.00	7.01	8000	6150
20081031	180928	13	12	AFEX5-	6.86	6.86	8000	6140
20081031	180928	13	13	AFEX4-	6.81	6.82	8000	6070
20081031	180928	13	14	AFEX3-	6.75	6.74	8000	6020
20081031	180928	13	15	AFEX2-	6.70	6.70	8000	5980
20081031	180928	13	16	AFEX1-	6.70	6.70	8000	6130
20081031	180928	13	17	AFEX6	7.43	7.41	8000	6080
20081031	180928	13	18	AFEX5-	7.20	7.20	8000	6180
20081031	180928	13	19	AFEX4-	7.10	7.11	8000	6080
20081031	180928	13	20	AFEX3-	7.00	7.00	8000	5900
20081031	180928	13	21	AFEX2-	6.90	6.91	8000	5960
20081031	180928	13	22	AFEX1-	6.93	6.94	8000	6090
20081031	180928	13	24	AFEX6+	6.10	6.10	1000	520
20081031	180928	13	25	AFEX5+	6.10	6.10	1000	530
20081031	180928	13	26	AFEX4+	6.10	6.11	1000	540
20081031	180928	13	27	AFEX3+	6.10	6.11	1000	550
20081031	180928	13	28	AFEX2+	6.10	6.12	1000	540
20081031	180928	13	29	AFEX1+	6.10	6.11	1000	540
20081031	180928	13	30	AFEX6+	6.10	6.11	1000	550
20081031	180928	13	31	AFEX5+	6.10	6.11	1000	550
20081031	180928	13	32	AFEX4+	6.10	6.10	1000	500
20081031	180928	13	33	AFEX3+	6.10	6.09	1000	510
20081031	180928	13	34	AFEX2+	6.07	6.07	1000	520
20081031	180928	13	35	AFEX1+	6.07	6.06	2000	530

Run Started : Total Sample(s) : 37 Samples
Current Run File : 200810311806.DAT Sample Rate : 1/50Sec
Press 'q' to exit
Press 'q' to exit

INO electronic logbook

INO-TIFR-RPC-ELOG - Maki... x

INO-TIFR-RPC-ELOG - Maki... x

https://www.ino.tifr.res.in:8080/TIFR_RPC/154

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TIFR_BARC IITB SIMP-VECC IMSc General TIFR_RPC TIFR_DAQ TIFR_Gas-Systems TIFR_Electronics TIFR_Inventory TIFR_Documentation TIFR_IndustryInterface TIFR_Others TIFR_Inventory_Log Computing Systems and Software

TIFR_RPC

INO Logo

Not logged in

Message ID: 154 Entry time: Wed Oct 22 18:38:36 2008

Author: M. R. Bhuyan

Category: Other

Subject: Making of RPC AB10

Button gluing done for making of RPC "AB10", after dry run setup followed by resistance measurement of GAB028 and GAB030, which is as below. After that Vacuum setup started at 15:15 Hours, 18-9-2008.

Date :18/09/2008 11:30 P.M

Resistance measurement :

Painted on 23th May '2008 at TIFR

a) Glass ID# GAB031;

For first measurement Zig is Vertical while second it is Horizontal with painting direction.

665/612 587/850 710/693

498/591 619/830 773/735

523/573 677/973 982/1180 =====> all in Kilo ohms (ZIG used is smaller)

b) Glass ID# GAB039;

For first measurement Zig is Vertical while second it is Horizontal with painting direction.

630/704 638/777 621/641

953/793 652/785 871/773

822/951 681/812 620/692 =====> all in Kilo ohms (ZIG used is smaller)

1. The resistance measurement was done by Dr Pant(BARC)/Mr Manas R.Bhuyan.

2. Vacuum Pump stopped at 19:20 Hours, 18-9-2008 by Mr Suresh D Kalmani.

3. First side Glueing done by Santosh S Chavan, Manas R Bhuyan and Suresh D Kalmani on 10:30AM 19-9-2008.

4. Second side Glueing done by Santosh S Chavan and Suresh D Kalmani on 10:30AM 22-9-2008.

ELOG V2.7.42111

start

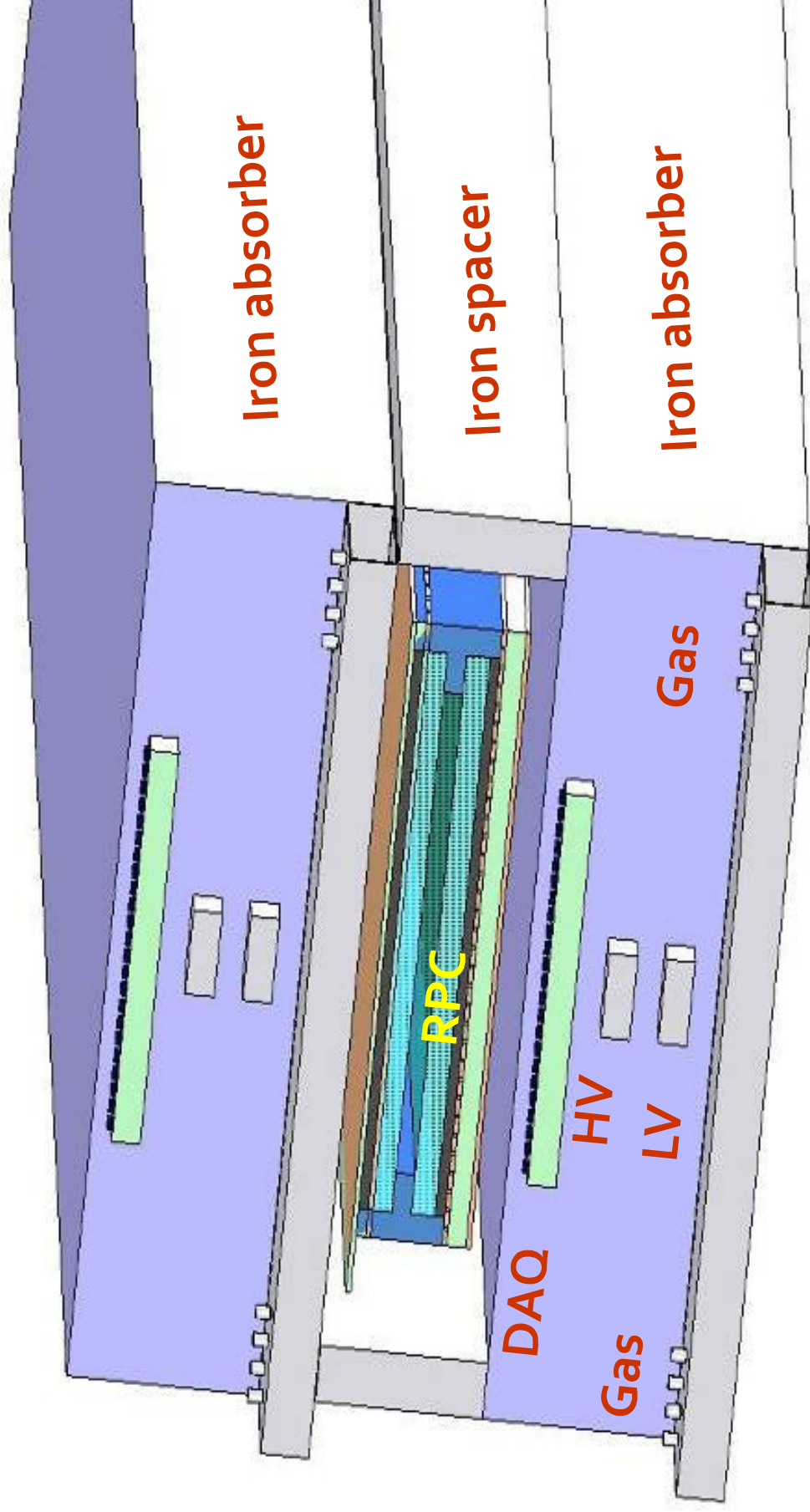
2 Microsoft O... tifr

bsn - Inx5 - Wi... INO-TIFR-RPC... bsn (Es) 7:41 PM

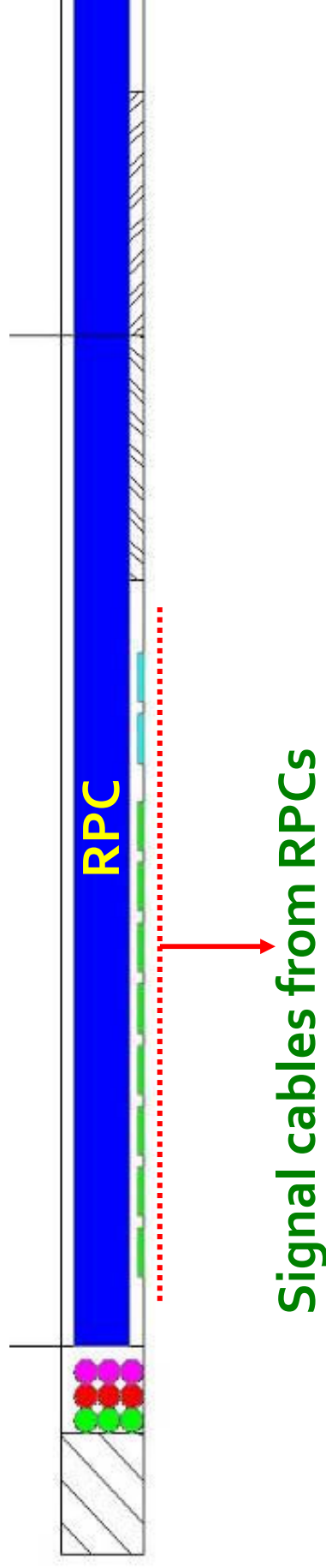
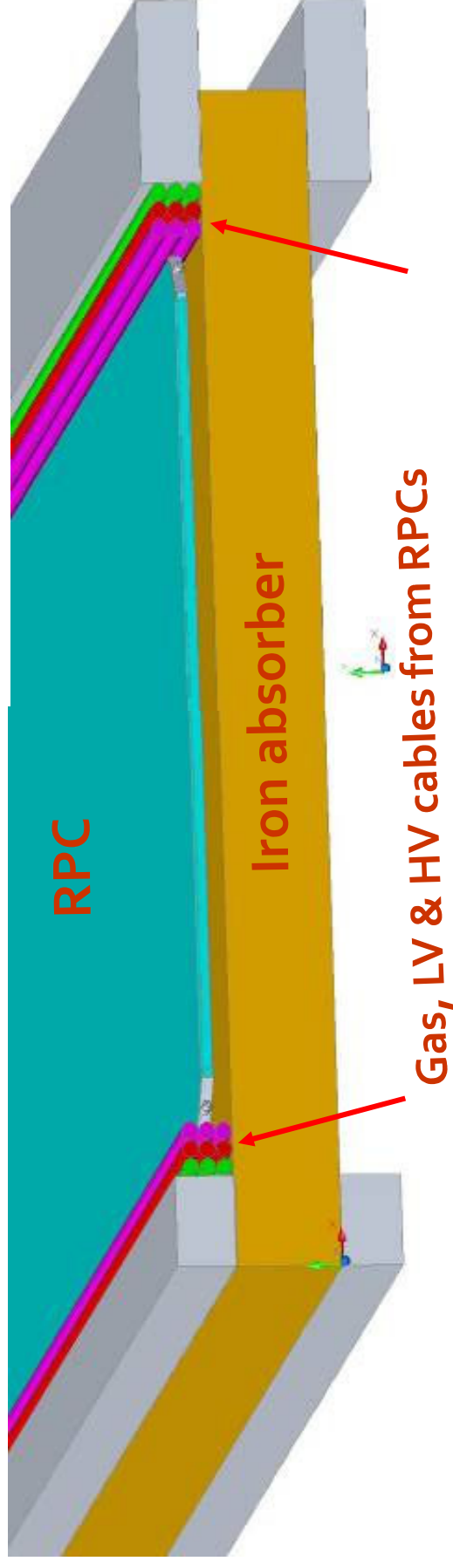
Challenges of ICALElectronics

- Huge number of electronic data readout channels. This necessitates large scale integration and/or multiplexing of electronics. The low to moderate rates of individual channels allow this integration/multiplexing.
- Large dimensions of one unit of RPC. This has bearing on the way the signals from the detector are routed to the front-end electronic units and matching the track lengths of the signals, irrespective of the geographical position of the signal source. We need to do this in order to maintain equal timing of signals from individual channels.
- Large dimensions of the entire detector. This will pose constraints on the cable routing, signal driving and related considerations.
- Road structure for the mounting of RPCs. This necessarily imposes constraint that signals from both X & Y planes of the RPC unit, along with other service and power supply lines are brought out only from the transverse direction of the detector.
- Eight RPC units are going to be installed in a road. We can at best bring out signal cables from four of them from one side of the detector and the other four from other direction.
- About 25cms gap is available between the faces of the detector and the trolleys. Any installations on the face of the detector have to be designed with this consideration.
- About 40mm gap between iron layers is available for the RPC detector, out of which thickness of the RPC unit is expected to at least 24mm. Leaving another 5-6mm for various tolerances, realistically about 10mm is the available free space in the RPC slot for routing out cables etc.
- On the sides adjacent to the RPC unit in the gap, free space is available for routing out power supply cables, gas lines etc.
- The gap between three modules is about 20cms. It is not advisable plan any installations on these faces.

DAQ & services' sub-stations



Cables & services routing



More design inputs

- RPC signal's rise time is of the order of 500-800nSec. Therefore, we will need a resolution of about 200nSec for the timing devices used for recording RPC signal arrival times w.r.t to ICAL trigger.
- The opening width of the amplified signals is of the order of 25nSecs. The minimum width of the RPC pulse over the threshold in the avalanche mode is as low as a few nSecs. This is an important input for the front-end electronics design.
- The amplifier in the avalanche mode preferably should have a fixed gain in the range 100-200 depending on the noise levels obtainable and hence the minimum discriminator levels settable.
- Discriminator overhead (ratio of average peak pulse height to discriminator level) of 3-4 is preferable for reliable performance. Variable (but common) threshold in the range of ± 10 to ± 50 mV for the discriminators should be supported.
- The pulse shaping of the discriminator output pulse should be in the range of 50-100nSec (but fixed). However, if the facility of pulse width monitoring has to be supported, this specification has to be relooked.

Important considerations

- Information to record on trigger
 - Strip hit
 - Timing
- Rates
 - Individual strip background rates $\sim 100\text{Hz}$
 - Event rate $\sim 10\text{Hz}$
- On-line monitor
 - RPC parameters
 - Ambient parameters
 - Services, supplies

RPC strip rate considerations

- RPC strip signal rates mainly contributed by the surrounding low energy activities such as stray radioactivity, local electrical discharges, dark currents of the detector and other electrical/electronic disturbances.
- For a given RPC, installed at particular location, operating at a particular high voltage, and a gas mixture, the average counting rate or *noise rate* is fairly constant and is in fact commonly used to monitor the stability of the above mentioned RPC operating parameters.
- One of the main background tasks (while not collecting event data) of the ICAL DAQ system is to sequentially monitor individual strip rates of all the RPCs in the detector, with a reasonable (of the order of 1 hour cycle time for a strip) frequency.
- The noise rate has consequences on the design of trigger system. The threshold of the trigger system is such that it shouldn't generate triggers due to chance coincidence of noise rates.

Sub-systems

- Front-ends
- Latch and timing units
- Pipelines and fiber
- Backend (VME) data collectors
- Trigger system
- Central clock
- Slow control and monitoring
 - Gas, magnet, power supplies
 - Ambient parameters
 - Safety and interlocks
- Computer, networking and security issues
- On-line data quality monitors
- Voice and video communications
- Remote access to detector sub-systems and data

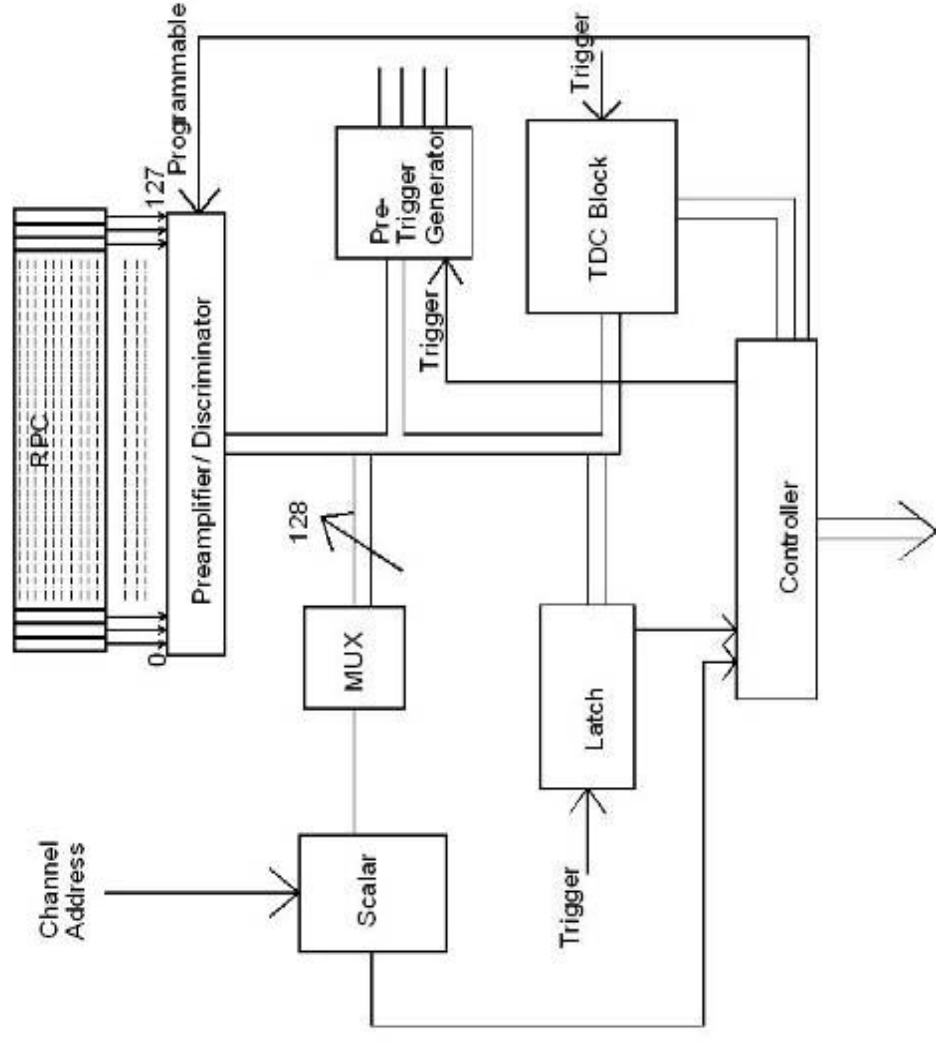
Front-end considerations

- RPC strip pitch versus front-end packaging
 - n-in-1 ASIC or PCB: Routing of tracks
 - 1-in-1 ASIC: Mounted on pickup panels
- Low voltage distribution
- DC-DC converters, one per RPC to generate high voltage supply
- Output signal routing

Triggered scheme

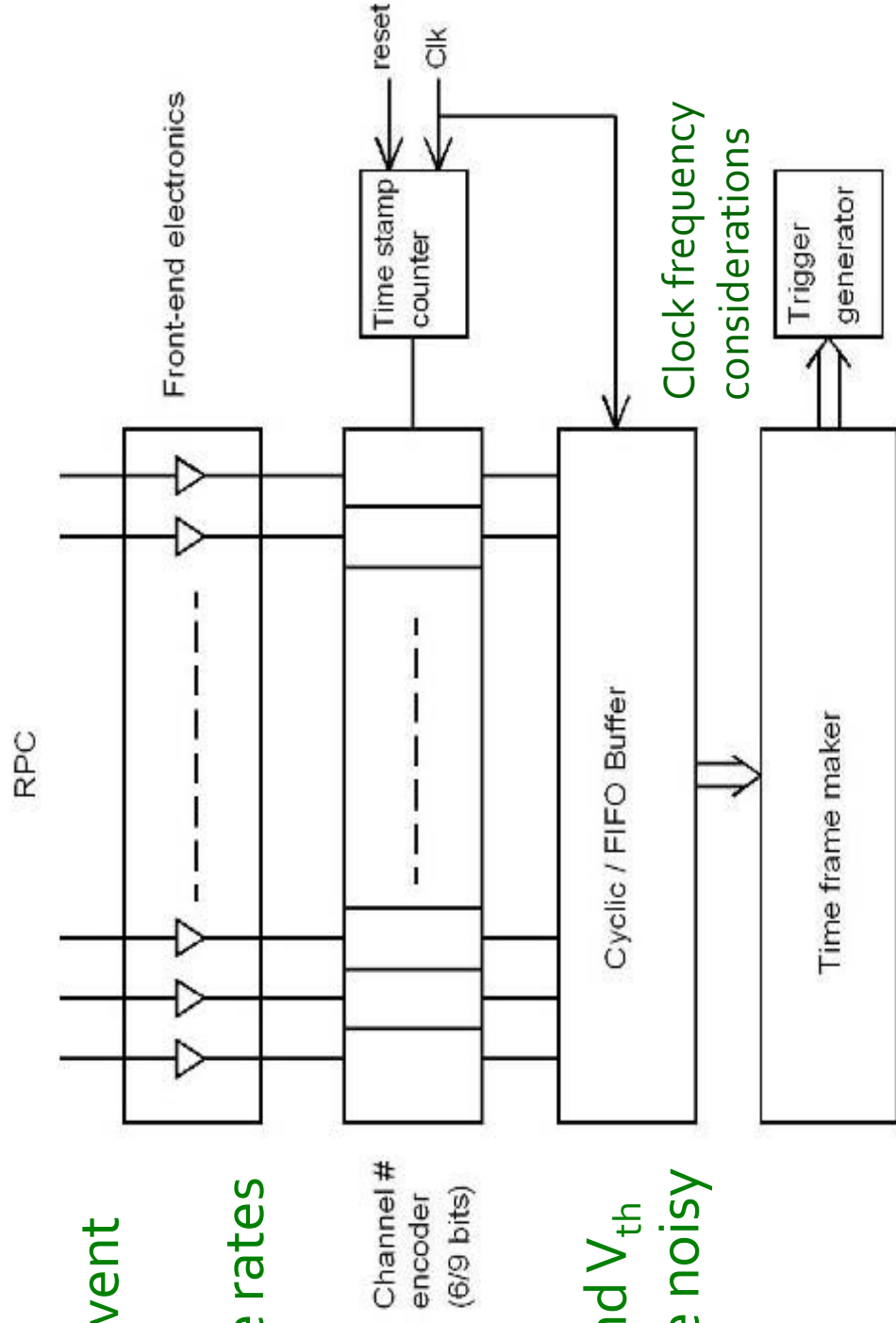
RPC , a unit for front-end processing

- ❖ Conventional architecture
- ❖ Dedicated sub-system blocks for performing various data readout tasks
- ❖ Need for *Hardware* based *on-line* trigger system
- ❖ Trigger latency issues and how do we take care in implementation
- ❖ Synchronisation of trigger/global clock signals



Trigger-less scheme

Suitable for low event rate and low background/noise rates



On-off control and V_{th} control to disable noisy channels

Trigger system segmentation

- Pre-trigger signals (1F, 2F, 3F, ...) generated on the RPC unit (**Level-0**)
- *Signal driving issues permitting*, eight local trigger generating stations (**Level-1**). Could be more; trade-off with segment overlapping issues.
- Level-1 trigger used for data acquisition
- Final data validating using **Level-2** global trigger

Event rates and event data sizes

- Event rates:
 - Input from simulations: 1.5Hz for full ICAL
 - Comparable chance coincidence rates if the current trigger scheme is used
- Event data sizes:
 - Very low occupancy
 - Number of channels grouped for timing, essentially decides the data size
 - Data reduction at the front-end

Other critical issues

- Power requirement and thermal management
 - 25mW/channel → 100kW/detector
 - Magnet power
 - Front-end positioning; use absorber to good use!
 - Do we need forced, water cooled ventilation?
- Suggested cavern conditions
 - Temperature: $20 \pm 2^\circ\text{C}$
 - Relative humidity: $50 \pm 5\%$

Summary and future outlook

RPC: Is it the best thing happened after MWPC?

Summary and future R&D plans

- Starting from modest $30\text{cm} \times 30\text{cm}$ chambers ...
- Now, $200\text{cm} \times 200\text{cm}$ RPCs are being routinely fabricated and characterised in detail
- Long-term stability of these chambers is established
- ICAL prototype detector is being assembled
- All the required materials and procedures designed and optimised for production
- Detailed studies using the prototype detector stack will continue
- Design and optimisation of gas recirculation system
- Device level simulations of the RPC will begin
- Design of ICAL electronics in progress

Deployment of RPCs in ICAL

- Incorporating and optimisation of ICAL specific parameters and constraints in the production designs
- Large scale production of RPCs is being thought about
- EDR preparation for RPC production is in progress
- Parallel production of chambers at multiple assembly centres with common quality control standards

Acknowledgements

Growth is necessarily built around people ...

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Belle Experiment, Japan

Jianxin Cai
Peking University, China

Rinaldo Santonico
University of Roma, Italy

For further information

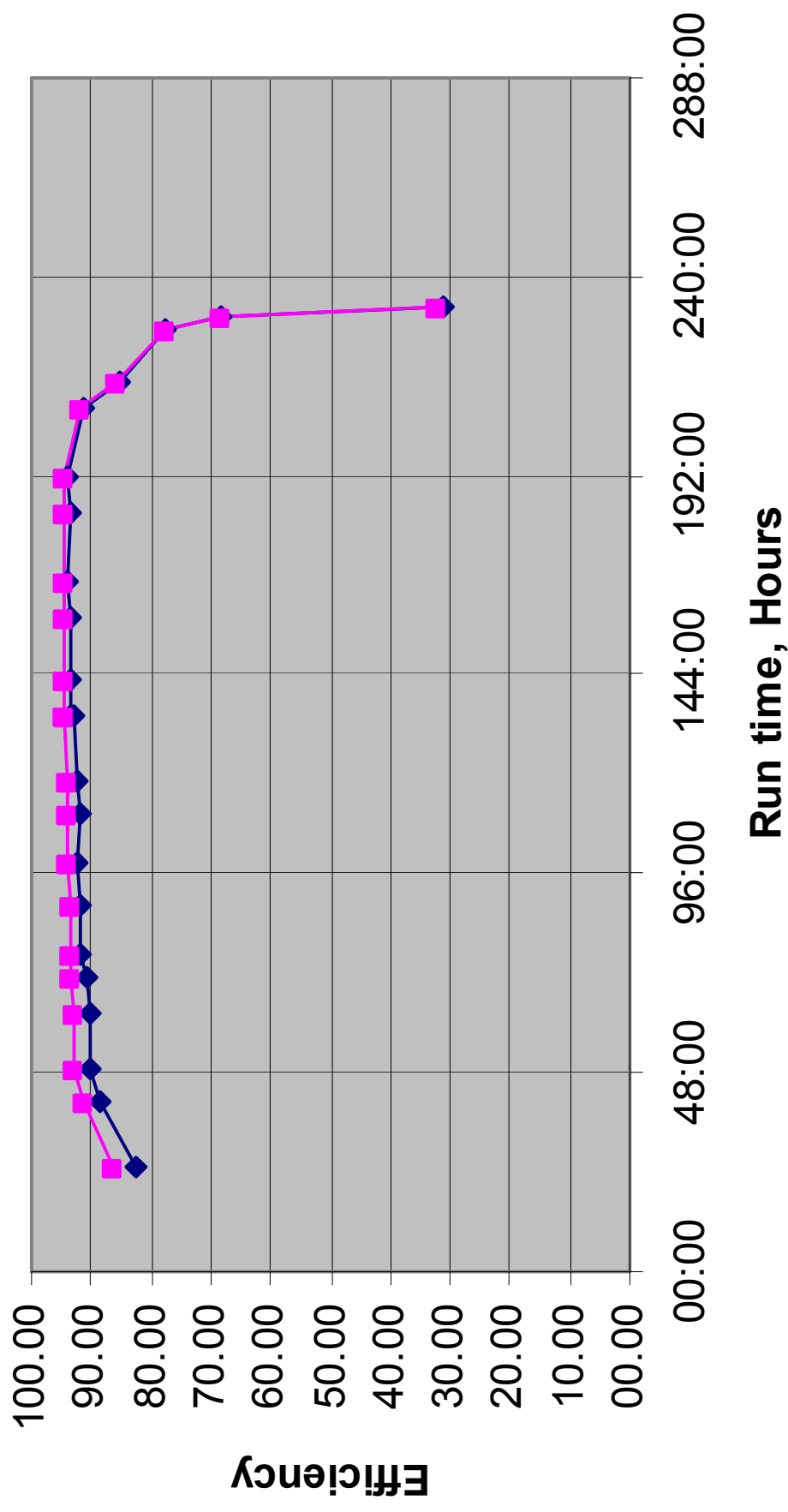
INO homepage: <http://www.imsc.res.in/~ino>
TIFR INO homepage: <http://www.ino.tifr.res.in>
My INO homepage: <http://www.hecr.tifr.res.in/~bsn/ino>

Thank you

RPC aging

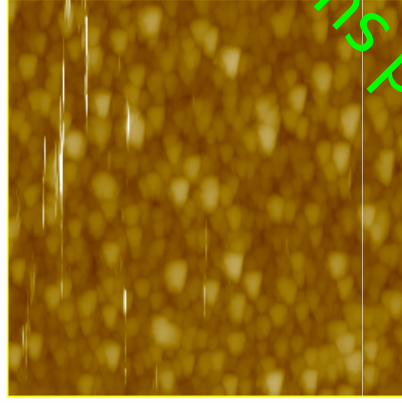
You can't get away without it!

Aging: Efficiency drop of a RPC

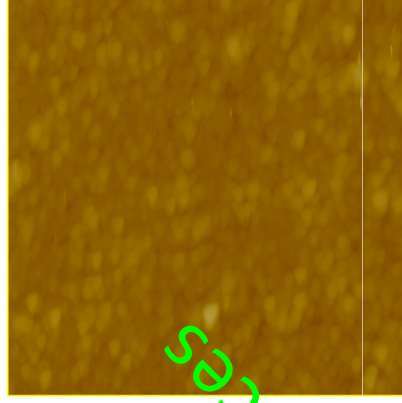


Aging: AFM and SEM scans

s22ua



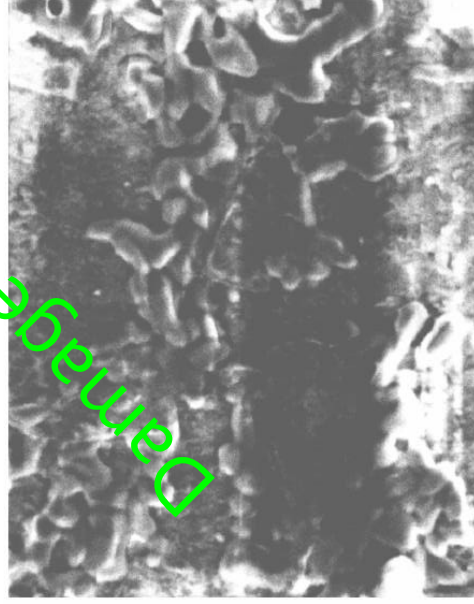
s12ua



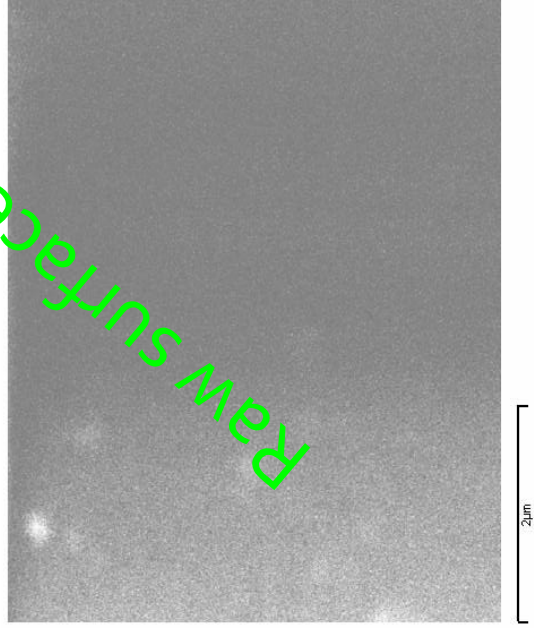
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AFM



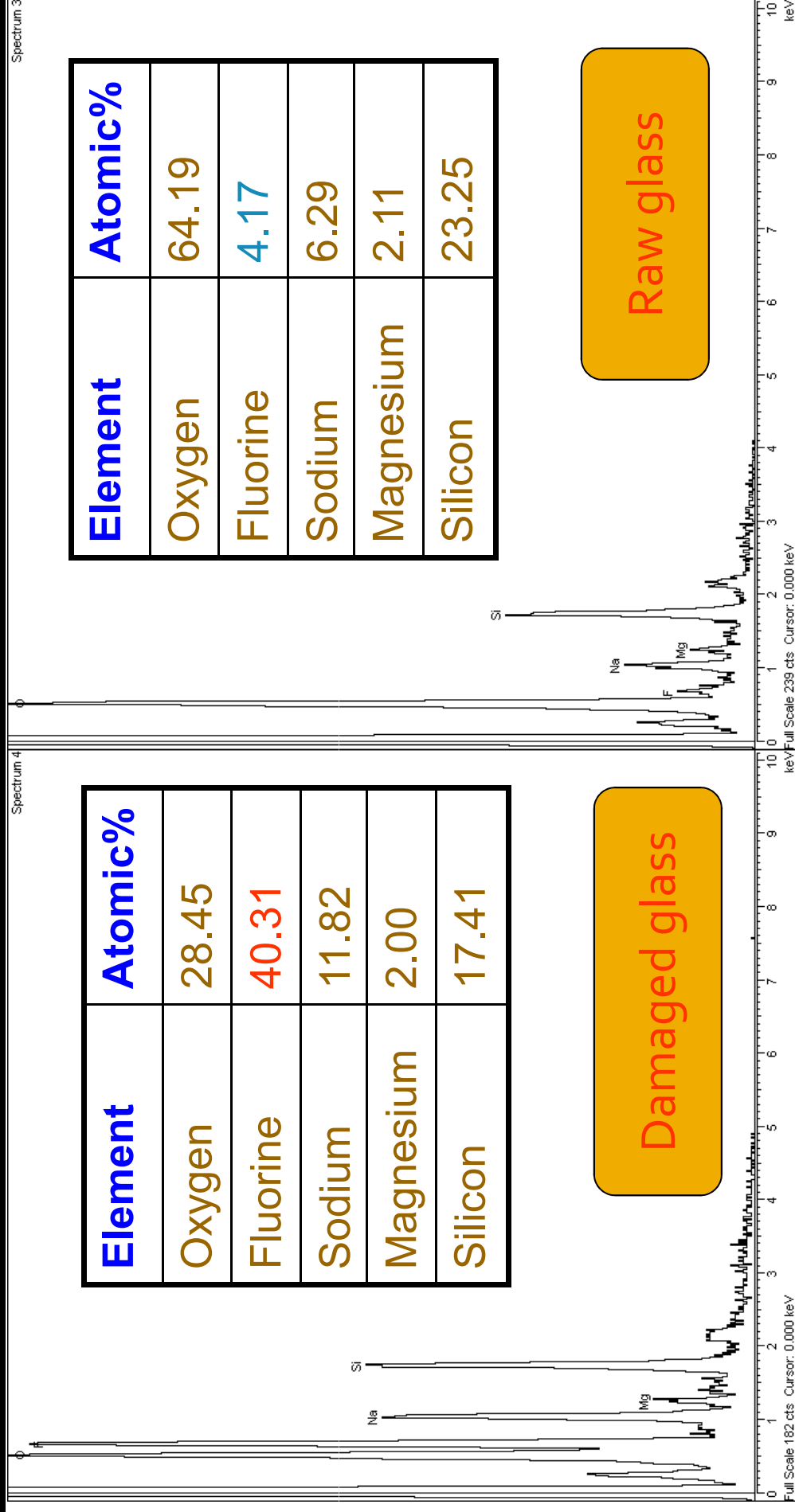
SEM



Raw surfaces

Damaged surfaces

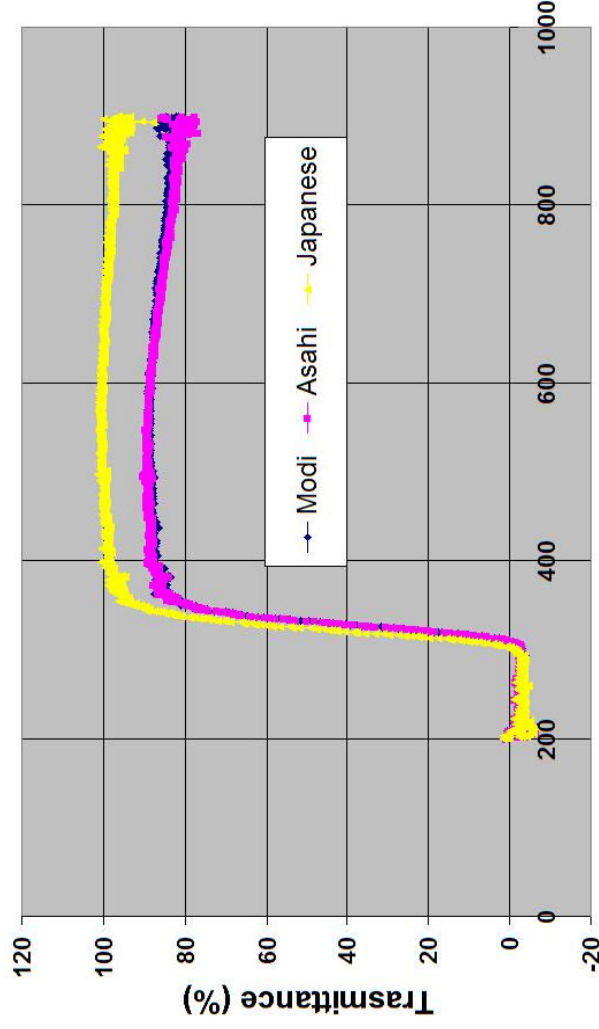
Aging: Element analysis



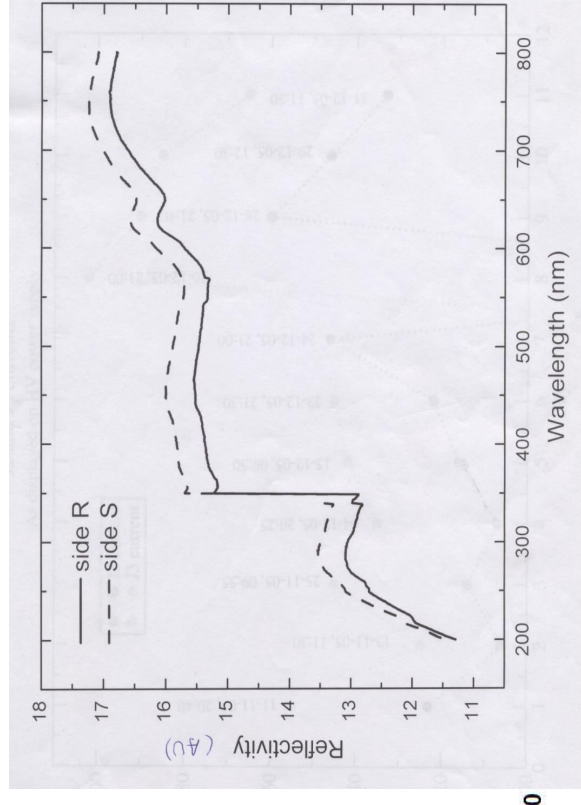
Density measurements of glass samples

Saint Gobian				German				Japanese			
Sample no.	Volume	Weight	Density	Sample no	Volume	Weight	Density	Sample no	Volume	Weight	Density
SG1	5.100883	12.8276	2.51478	G1	4.807928	10.6978	2.225033	J1	4.282649	10.7103	2.500859
SG2	5.010955	12.5467	2.503854	G2	4.828185	10.7368	2.223776	J2	4.29113	10.6816	2.489228
SG3	4.962828	12.4893	2.516569	G3	4.9211	10.9445	2.223995	J3	4.214357	10.4389	2.476985
SG4	5.078969	12.7575	2.511829	G4	4.802715	10.6503	2.217558	J4	4.187715	10.3865	2.480231
SG5	5.065868	12.7342	2.513725	G5	4.929372	10.96	2.223407	J5	4.175192	10.392	2.488987
Average			2.512151	Average			2.22754	Average			2.487258
Modi				Asahi				New Japanese			
Sample no.	Volume	Weight	Density	Sample no	Volume	Weight	Density	Sample no	Volume	Weight	Density
M1	4.690323	11.8039	2.51665	A1	5.497301	13.7945	2.509322	JN1	4.72466	11.7209	2.480792
M2	4.633623	11.6363	2.511275	A2	5.247131	13.1615	2.508323	JN2	4.6282	11.5423	2.4939
M3	4.570981	11.4635	2.507886	A3	5.223292	13.0981	2.507633	Average			2.487346
M4	4.580165	11.471	2.504495	A4	5.253931	13.153	2.503459	All volumes are in cc			
M5	4.608432	11.5331	2.502608	A5	5.242139	13.1274	2.504207	Weight in gm			
Average			2.508583	Average			2.506589	Density in gm /cc			

Characterisation of electrode glass samples



Wavelength, nm
Transmittance test



Reflectance test

EDS measurements on glass samples

New Japanese Glass 1

Side 1			Side 2		
Element	Weight%	Atomic%	Element	Weight%	Atomic%
O K	54.93	67.60	O K	60.41	71.97
Na K	9.23	7.91	Na K	8.83	7.32
Mg K	1.83	1.48	Mg K	2.21	1.73
Si K	30.06	21.07	Si K	26.57	18.04
Ca K	3.96	1.94	Ca K	1.98	0.94
Totals	100.00		Totals	100.00	

New Japanese Glass 2

Side 1			Side 2		
Element	Weight%	Atomic%	Element	Weight%	Atomic%
O K	59.81	71.64	O K	56.52	68.29
Na K	8.84	7.37	Na K	9.68	8.14
Mg K	2.03	1.60	Mg K	2.88	2.29
Si K	26.32	17.96	Si K	30.92	21.28
Ca K	3.01	1.44	Totals	100.00	
Totals	100.00				

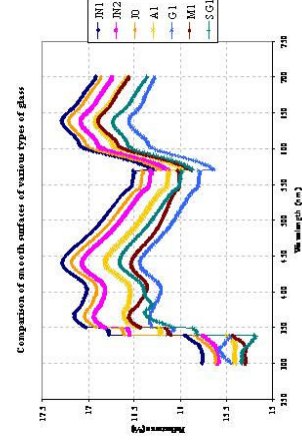
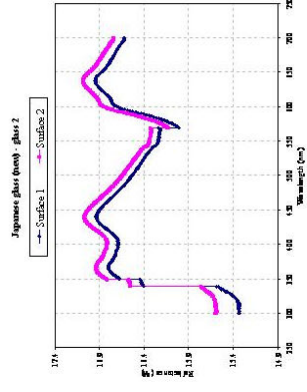
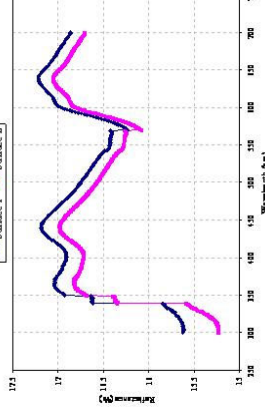
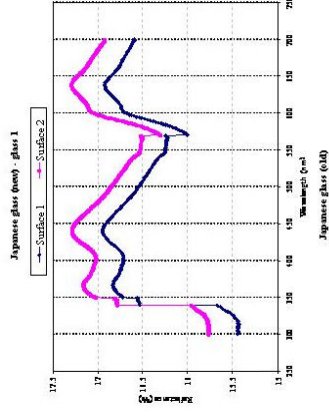
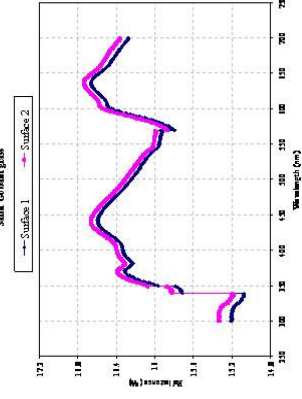
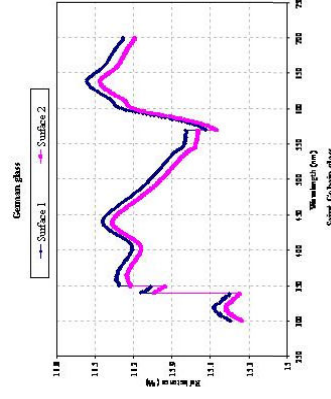
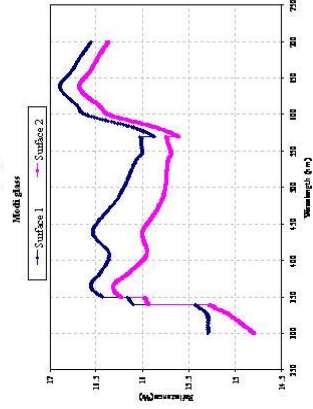
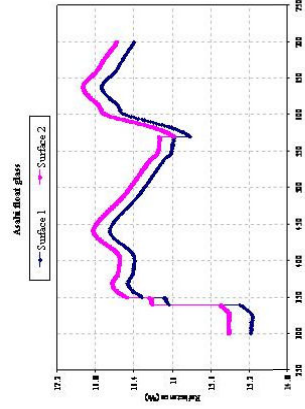
German

Old Japanese		
Element	Weight%	Atomic%
O K	78.16	86.05
Na K	1.86	1.43
Si K	19.98	12.53
Totals	100.00	

Modi

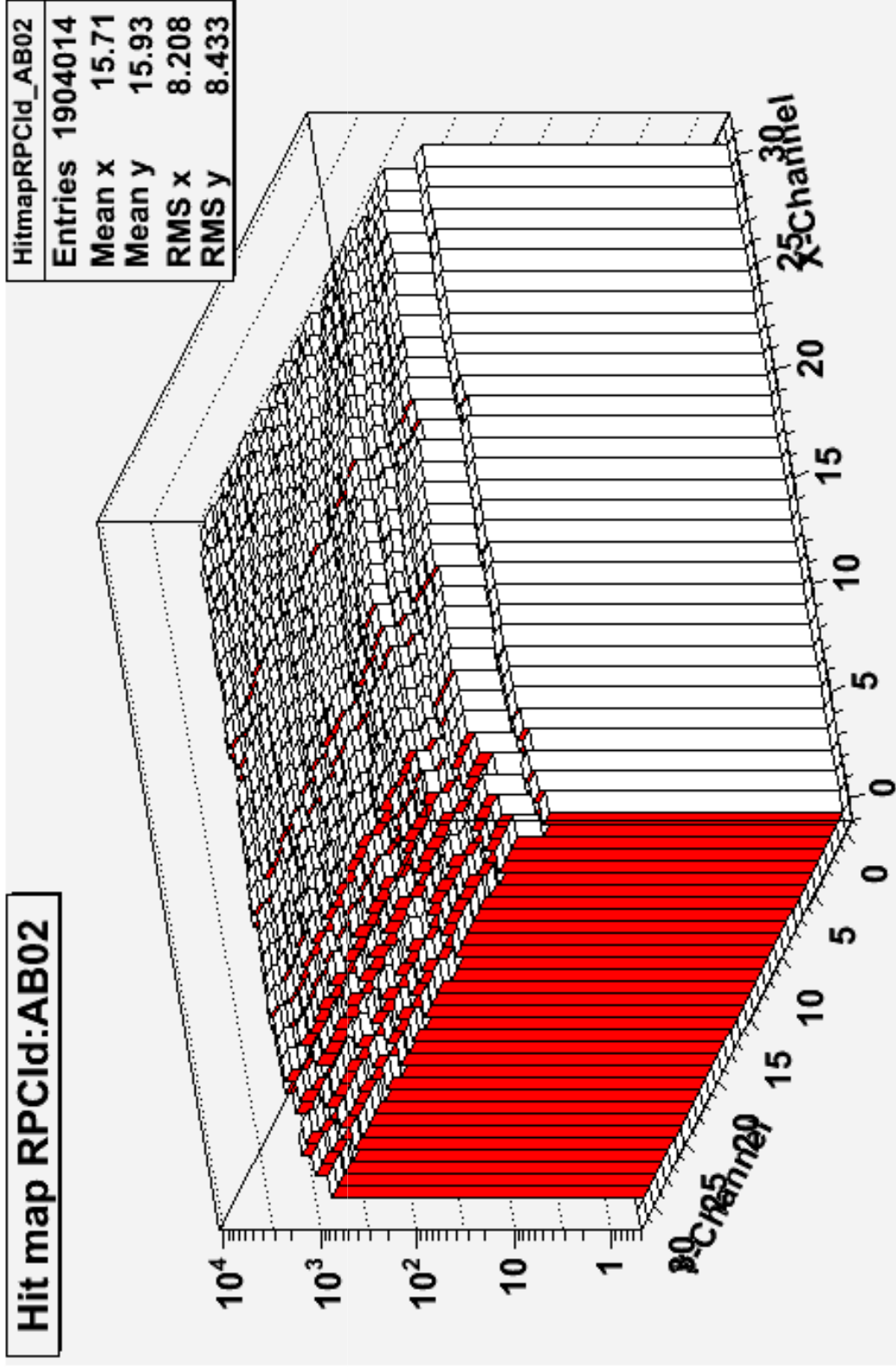
Saint Gobian		
Element	Weight%	Atomic%
O K	60.88	71.90
Na K	10.33	8.49
Mg K	2.27	1.76
Si K	26.52	17.84
Totals	100.00	

Reflectance study of glass samples

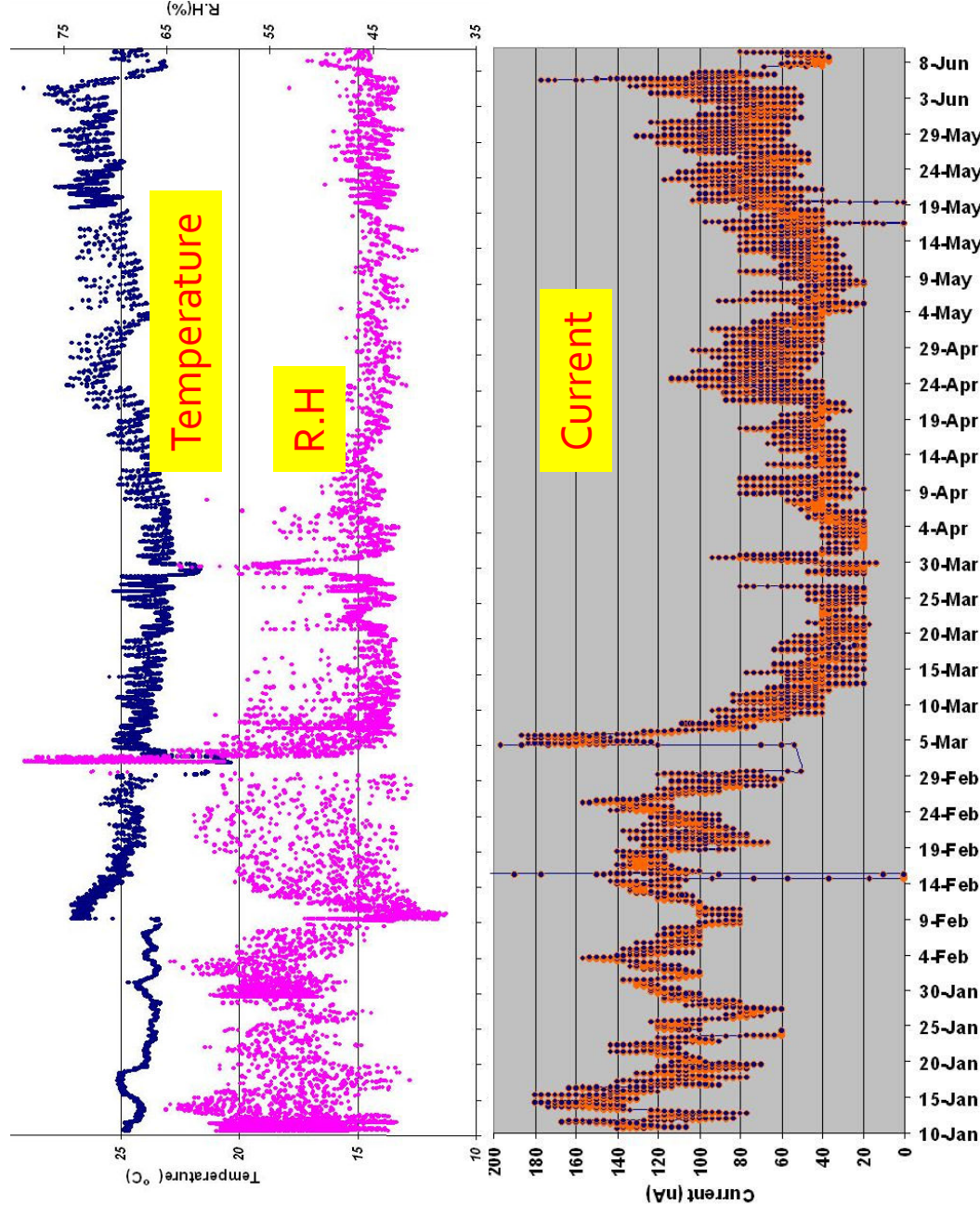


Backup/reference slides

Strip hit map of an RPC



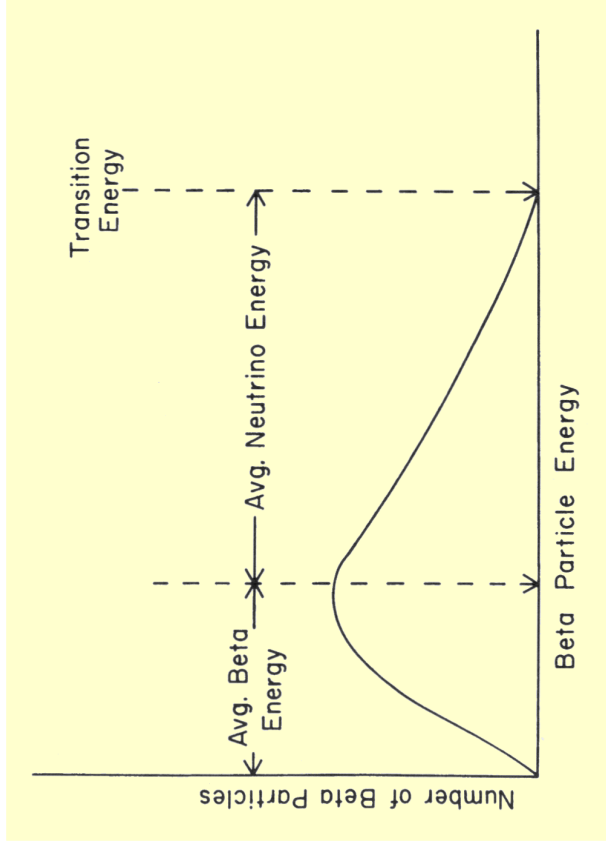
On-line monitoring of ambient parameters



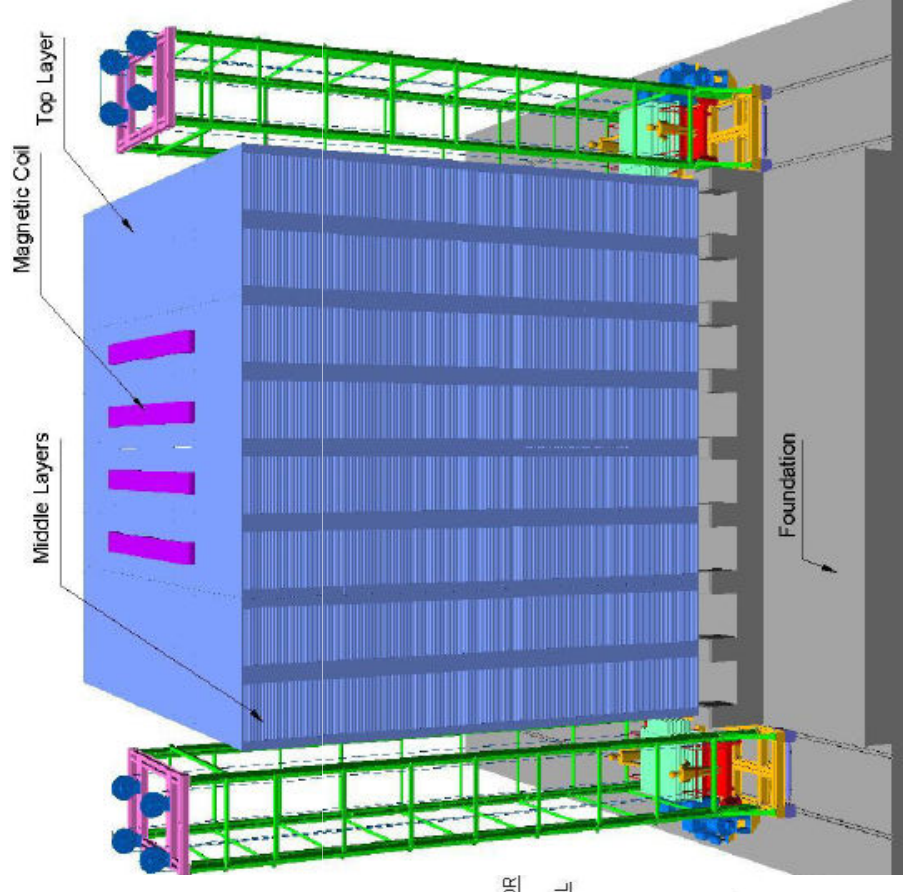
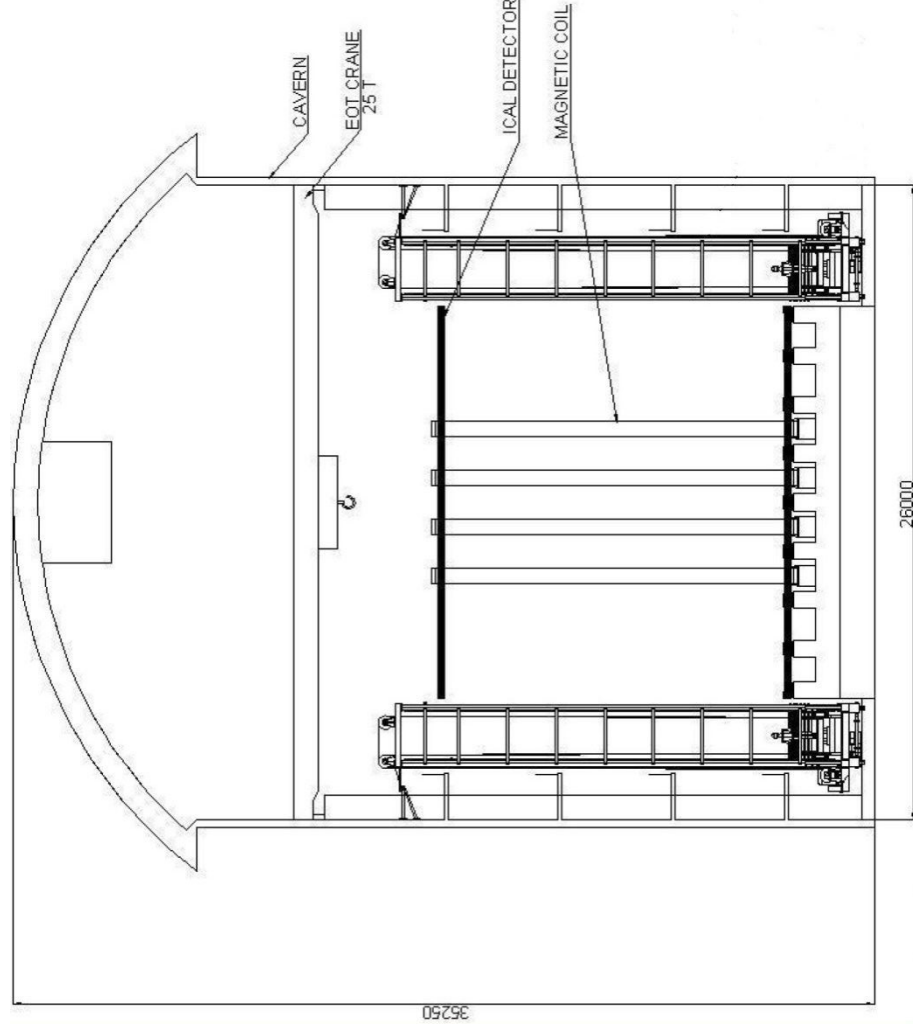
Beta decay



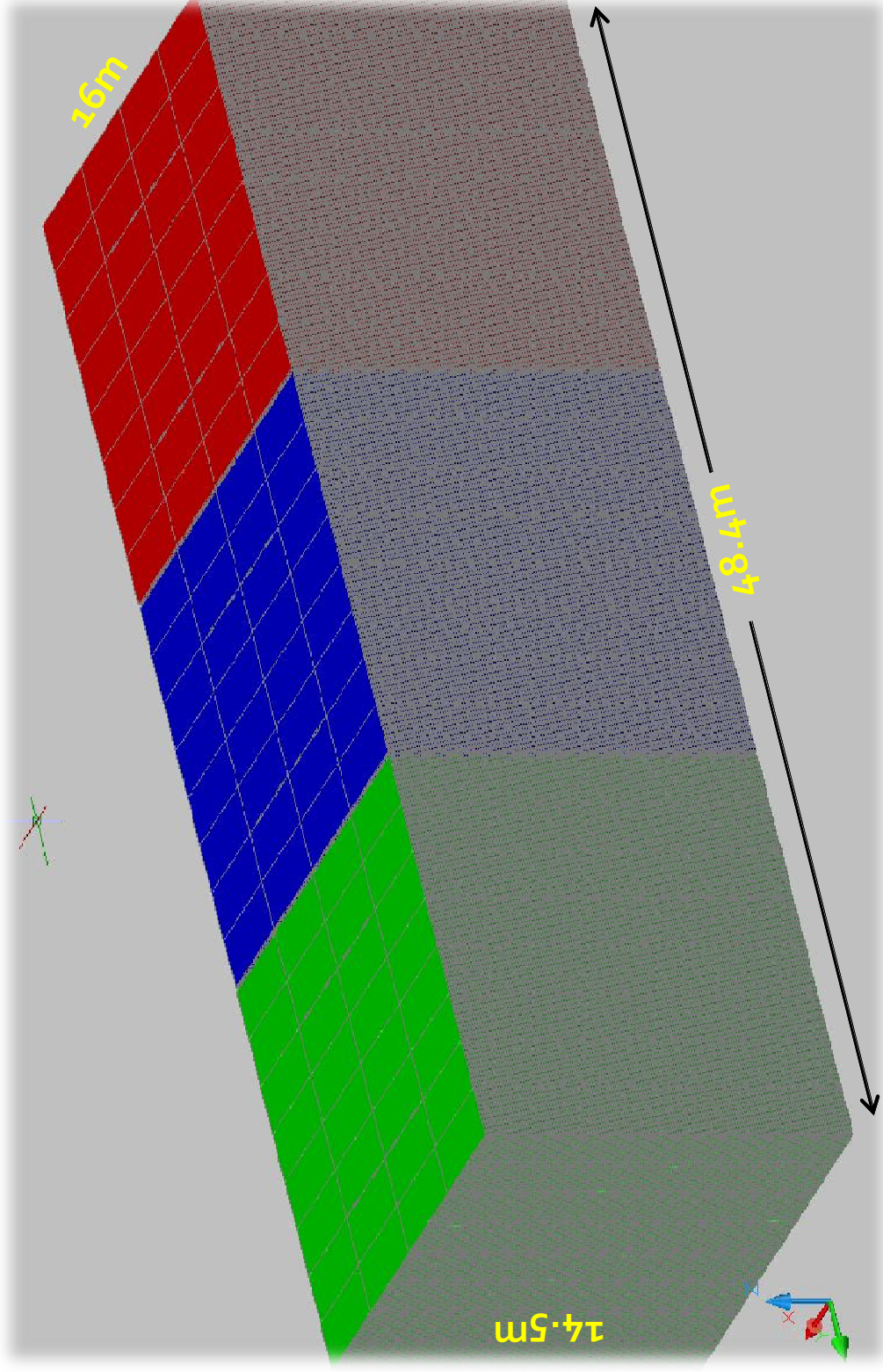
- Continuous energy spectrum of the β -particle
- Available energy for the decay is shared between the β -particle and the (anti-)neutrino which goes undetected



ICAL detector in the cavern



ICAL detector dimensions



Avalanche development in RPC

- **RPC volume**
 - 2mm glass resistive plates
 - 2mm gap
- **Gas mixture**
 - $C_2F_4H_2$ (97%)
 - iC_4H_{10} (2.5%)
 - SF_6 (0.5%)
- **HV applied**
 - 10.0kV

Particle legend

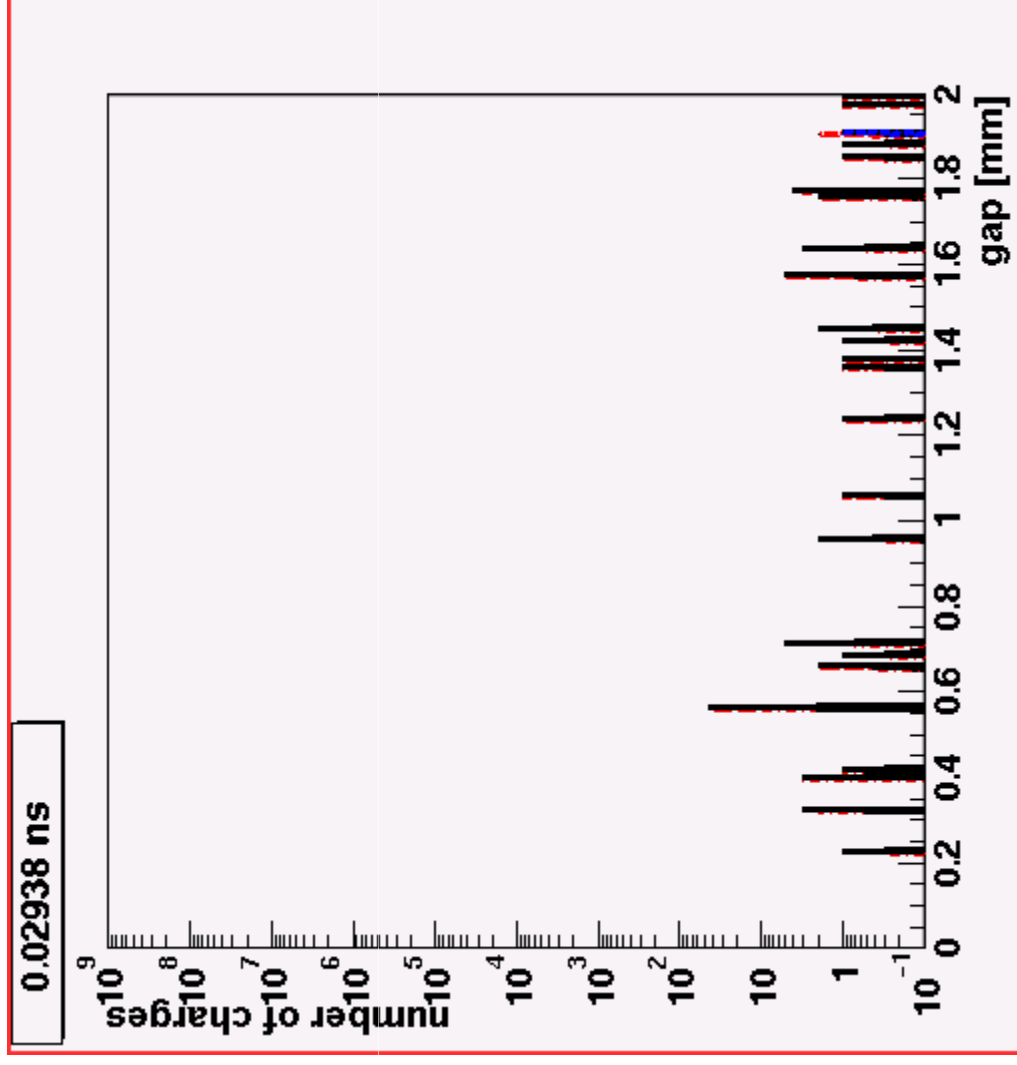
Red: Positive ions

Blue: Negative ions

Black: Electrons

Credit: Christian Lippmann

B.Satyanarayana, TIFR, Mumbai

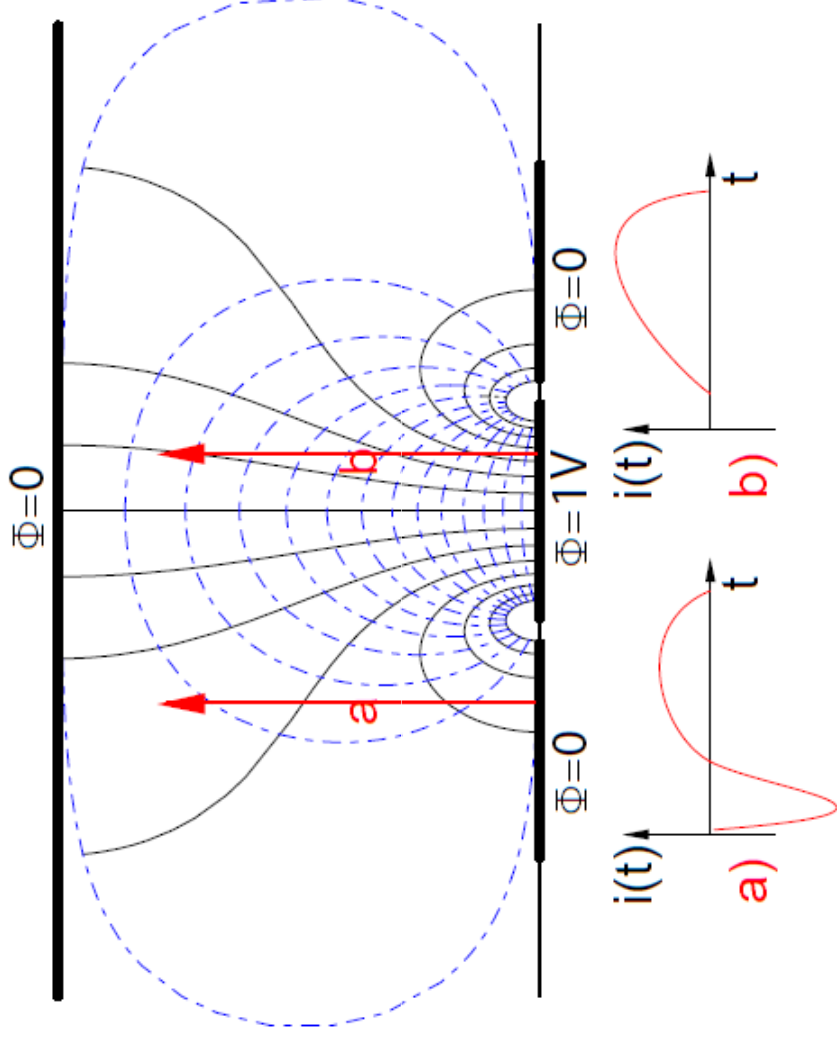


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December 7, 2009

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Signal induction process

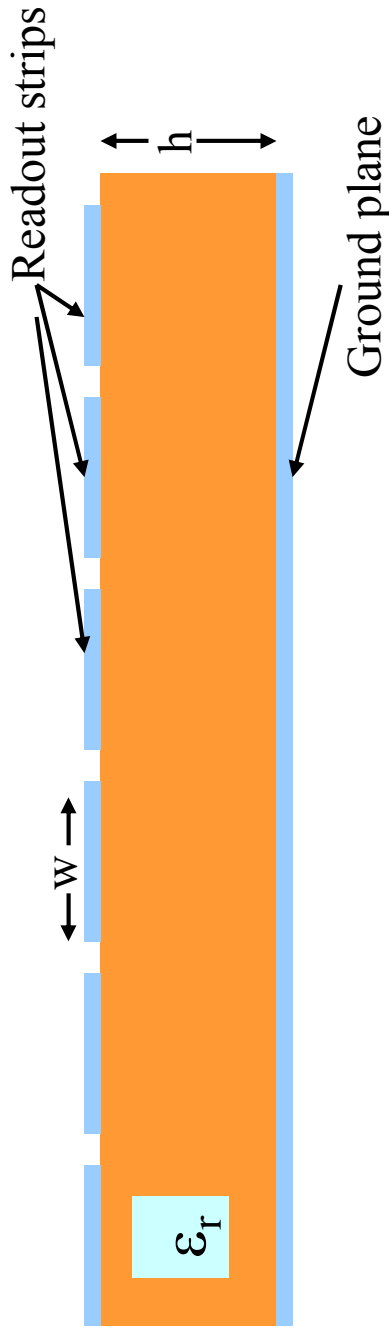


$$i(t) = \sum_{j=1}^{n_{cl}} \vec{E}_w(\vec{x}_j(t)) \cdot \vec{v}_{Dj}(t) e_0 N_j(t)$$

Specifications of polycarbonate

	QUALITY ASSURANCE GIE India Industrial Private Limited Plastics Division, Plastics Avenue, P.O. Jawaharnagar, Vadodra - 391328 Ind.				
GIE India Industrial Private Limited		LEXAN THERMOPLASTIC RESINS			
Grade-Color	:	EX5GF-7315108			
Lot No.	:	69947			
Date	:	01-DEC-06			
Property	Units	Test Reference	Min Spec.	Max Spec.	Lot Avg.
FLEXURAL MODULUS	MPa	ISO-178	2000	3500	2922
MM 300 Deg C/1.2 Kgs	cc/10 minutes	ISO-1133	5	8	6
FLEXURAL STRENGTH	MPa	ISO-178	70	90	85

Transmission line impedance



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

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

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

Properties of gases used in ICAL

Gas	Mol. Wt. (g/mol)	Density (g/L)	Specific Ht. (Cal/g °C)	Ion. Pot. (eV)	Viscosity (Poise)	GWP
Argon	39.95	1.784	0.125	15.75	2.099×10^{-4}	
R134a	102.0	4.25	0.20			1300
Isobutane	58.12	2.51	0.389		6.89×10^{-5}	
SF ₆	146.05	6.164			1.42×10^{-4}	24900

Operating principle of a gas MFC

The heart of a mass flow controller is a thermal sensor. It consists of a small bore tube with two resistance-thermometer elements wound around the outside of the tube. The sensor tube is heated by applying an electric current to the elements. A constant proportion of gas flows through the sensor tube, and the cooling effect creates a temperature differential between the two elements. The change in the resistance due to the temperature differential is measured as an electrical signal.

The temperature differential created between the elements is dependent on the mass flow of the gas and is a function of its density, specific heat, and flow rate. Mass flow is normally displayed in terms of volume of the gas either in standard cubic centimeters per minute (sccm) or in standard liters per minute (slm). The electronics of a mass flow controller convert mass flow into volume flow at standard conditions of 0°C (32°F) and 1 atmosphere. Because the volume of 1 mole of an ideal gas at 0°C (32°F) and 1 atmosphere occupies 22.4 liters, a set point of 22.4 slm will cause 1 mole of gas to flow during 1 minute.

The bypass forces a constant proportion of the incoming gas to be fed into the sensor. The gas flow through the sensor tube causes heat to be transferred from the upstream resistance-thermometer element to the downstream resistance-thermometer element. This temperature differential is linearized and amplified into a 0 to 5 V flow output signal by means of a bridge circuit. The output signal is compared with the external set point signal to the mass flow controller. The error signal that results from comparing the output signal with the set point signal directs the control valve to open or close to maintain a constant flow at the set point level.

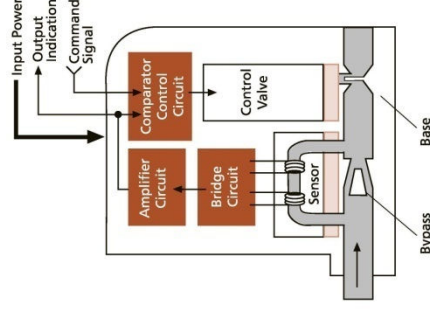


Figure 2. Operational diagram
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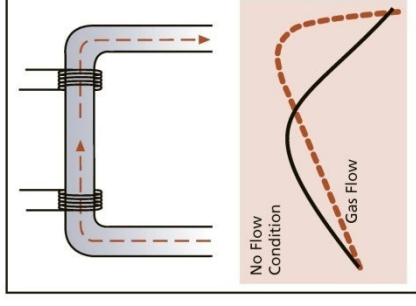


Figure 3. Sensor temperature profile

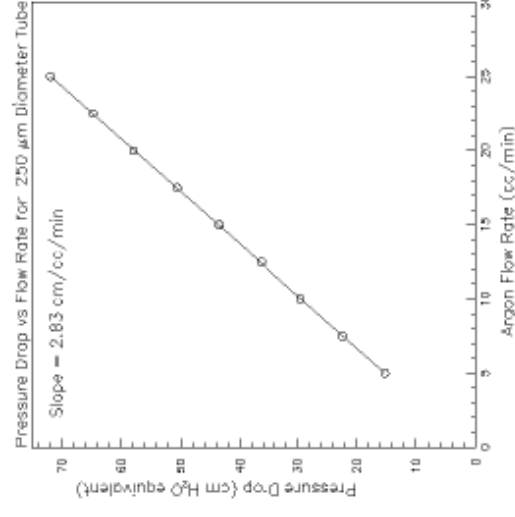
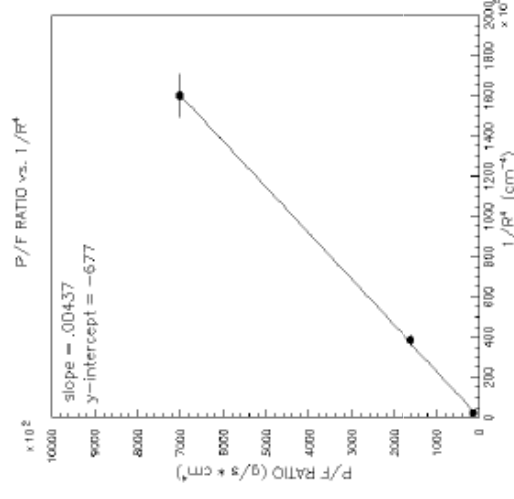
Credit:
Advanced
Energy
Industries,
Inc.

Working principle of flow resistors

- The capillaries allow the gas to mix thoroughly by providing long residence time. The flow rate through the capillary is calculated using Hagen-Poiseuille equation given by

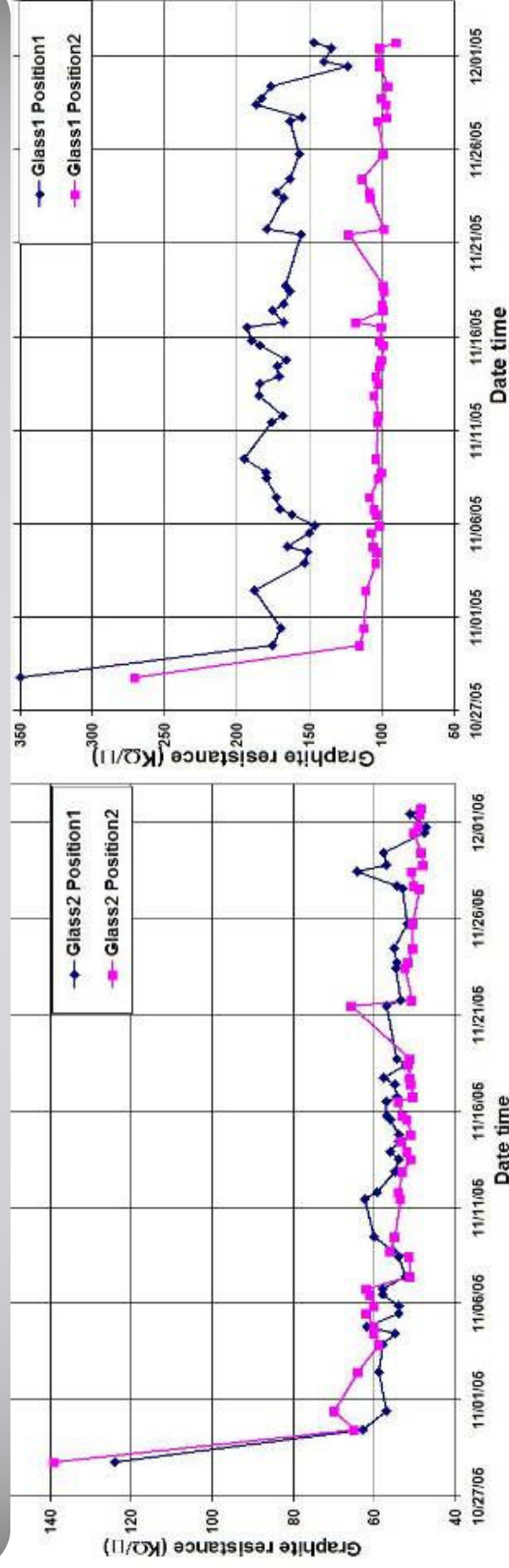
$$\Phi = \pi R^4 \Delta P / 8 \eta L,$$

- Where, Φ is the voluminal gas flow rate (cu-meters/second), R is the capillary radius (meters), ΔP is the differential pressure (Pascal), η is the dynamic fluid viscosity of gas (Pascal-Second) and L is the total length of the capillary tube in the x-direction (meters).



Electrode coating techniques

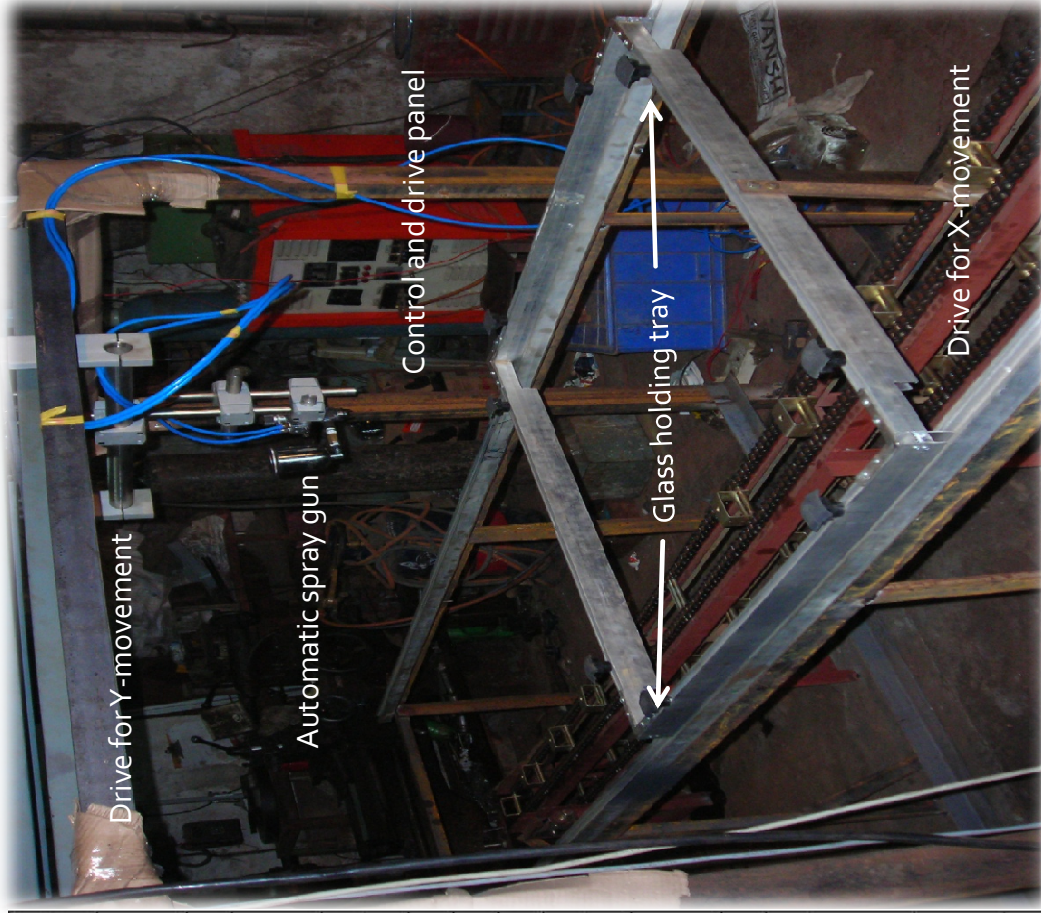
Graphite paint prepared using colloidal grade graphite powder(3.4gm), lacquer(25gm) and thinner(40ml) is sprayed on the glass electrodes using an automobile spray gun. A uniform, stable graphite coat of desired surface resistivity ($100\text{--}200\text{K}\Omega/\square$) was obtained by this method.



Development of a new spray paint and application plant

M/s Kansai-Nerolac Paints Limited

No	Test	Specifications	Result
(A) Liquid Paint Properties :-			
1)	Supply Viscosity	35 ± 5 Sec by Ford Cup B4 at 30°C.	32 Sec.
2)	WT/10 Ltr.	9.50 ± 3% Kgs	9.45 kgs
3)	% Solids	28 ± 3 % at @ 105°C/3 Hrs.	27.50%
4)	% Thinner intake	100 ± 20 % by Vol.	100 % by vol.
5)	Hegman Gauge	< / = 35µ	30µ
6)	Recommended Thinner	1000053	Satisfactory
7)	Color / Shade	Black	Black
8)	Drying characteristics	Surface dry :- 10 Min	Satisfactory
		Tack free :- 30 Min	Satisfactory
		Hard dry :- 18 Hrs.	Satisfactory
9)	Application Viscosity	16 ± 2 Sec by FCB4 @ 30°C.	15 Sec.
(B) Dry Film Properties :-			
10)	Finish	Smooth & Matt	Satisfactory
11)	Adhesion on glass	2 x 2x 10mm, Should pass 0/100 with Panfix Adhesive Cellotape.	Passes 0/100.
12)	Dry Film Resistivity	1500 ± 5 00 K Ωs at 2.5 Inches apart.	1350-1500 K Ω.
13)	Recommended DFT	16 ± 2	15 µ



Development of paint and screen printing technique

M/s Dozen Tech, Korea

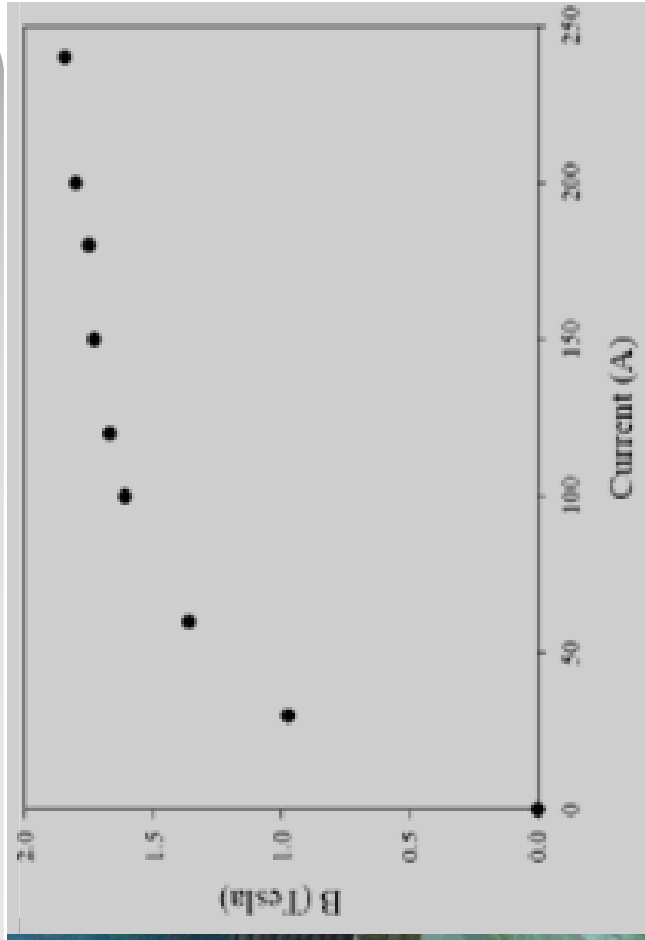
DC-20	DC-1000M	Resistance/Square	Remarks
(% by weight)	(% by weight)		
0	100	> 50 M?	+ 10% Sericol Vionyl
10	90	> 50 M?	
20	80	5 to 10 M?	After drying
50	50	4.8 K?	
100	0	160 ?	
40	60	5-7 K ?	Single coat
		3.1 to 4.3 K ?	Double coat
30	70	40 K? on paper	No reducer
30	70	30 K? On polyester	

M/s Dozen Tech, Korea

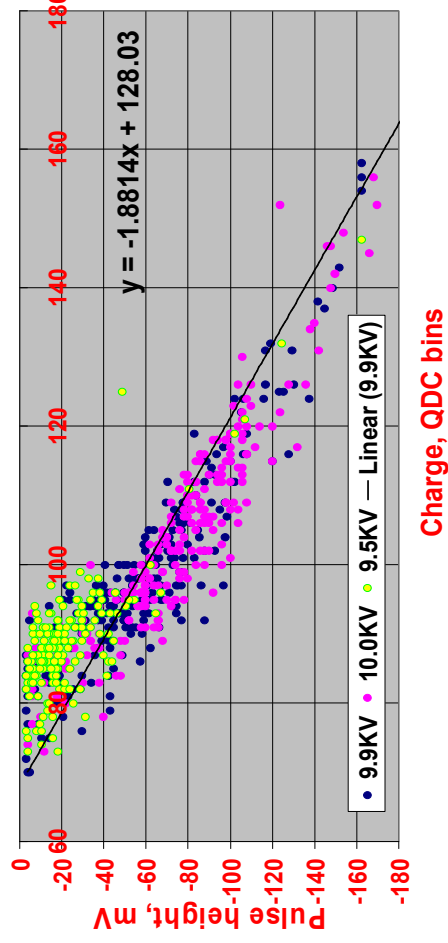
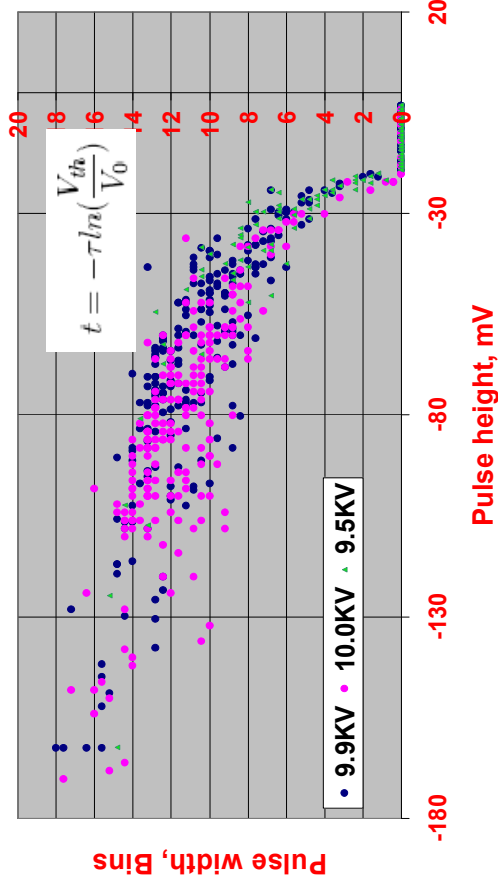
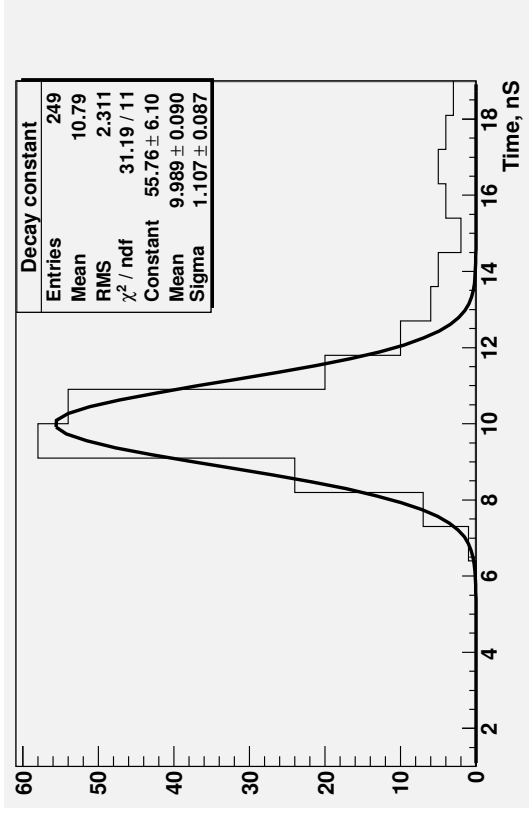
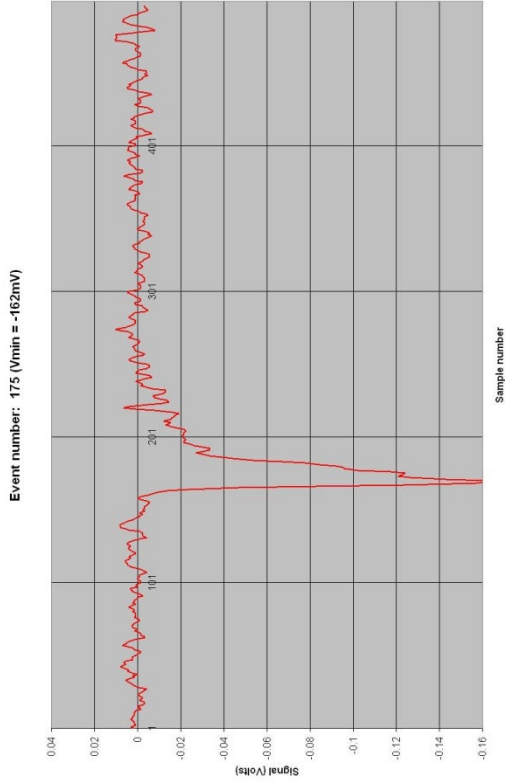


Prototype detector magnet

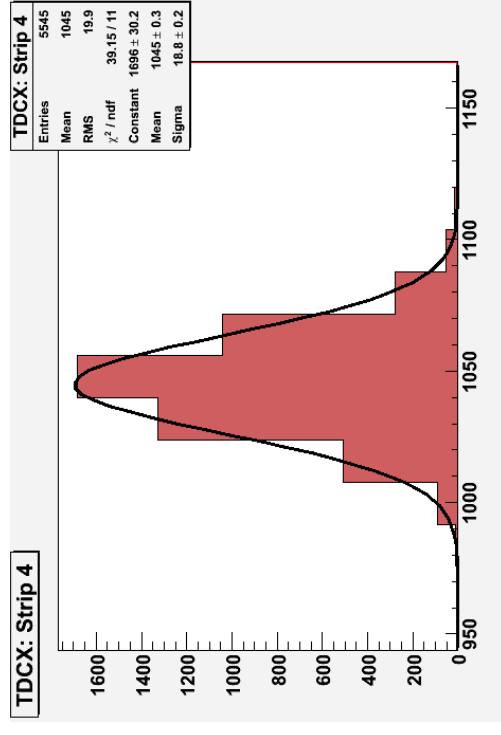
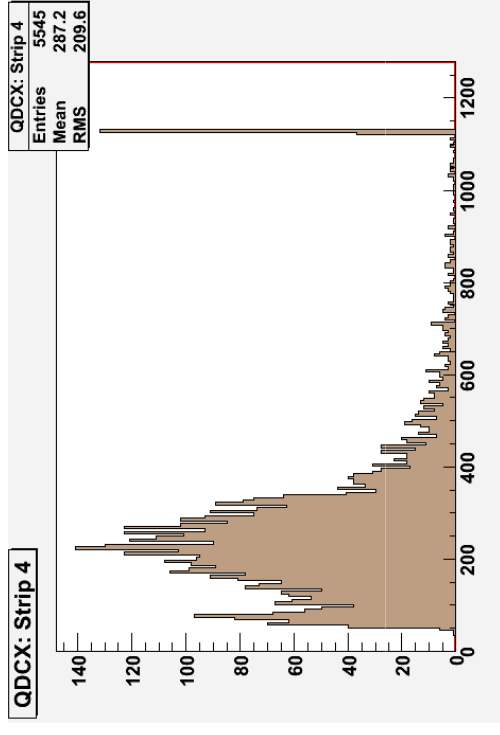
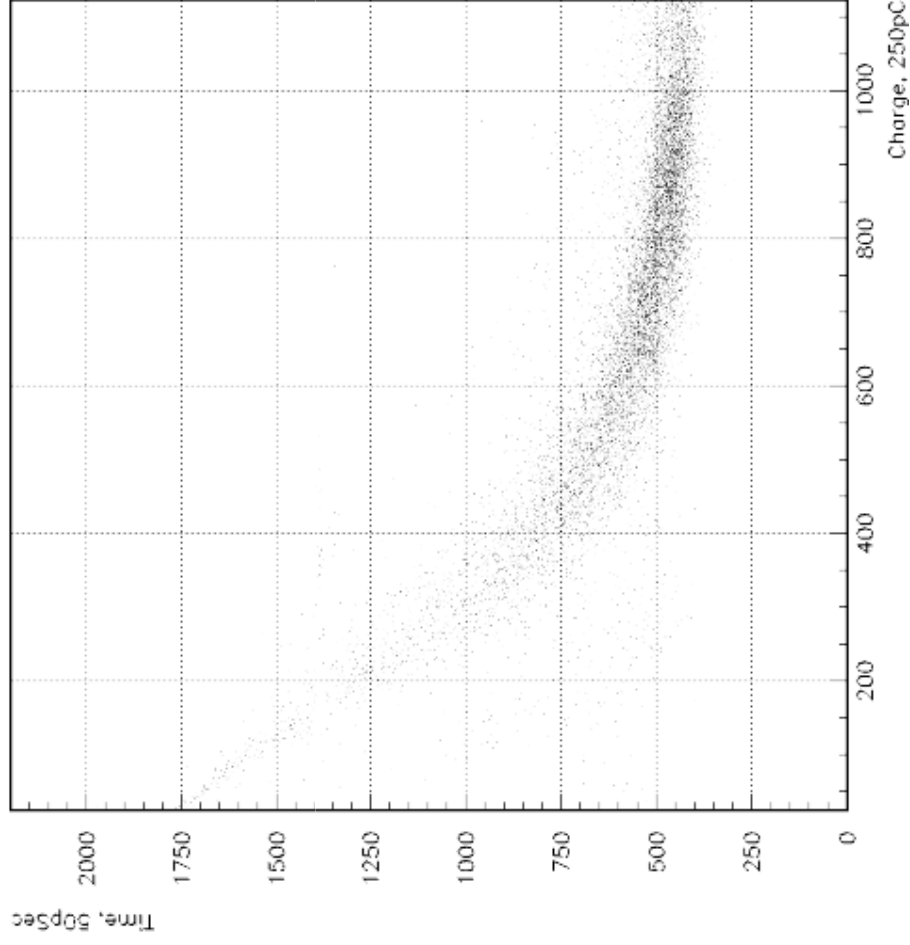
- ❖ 13 layer sandwich of 50mm thick low carbon iron (*Tata A-grade*) plates (35ton absorber)
- ❖ Detector is magnetised to 1.5Tesla, enabling momentum measurement of 1-10Gev muons produced by ν_μ interactions in the detector.



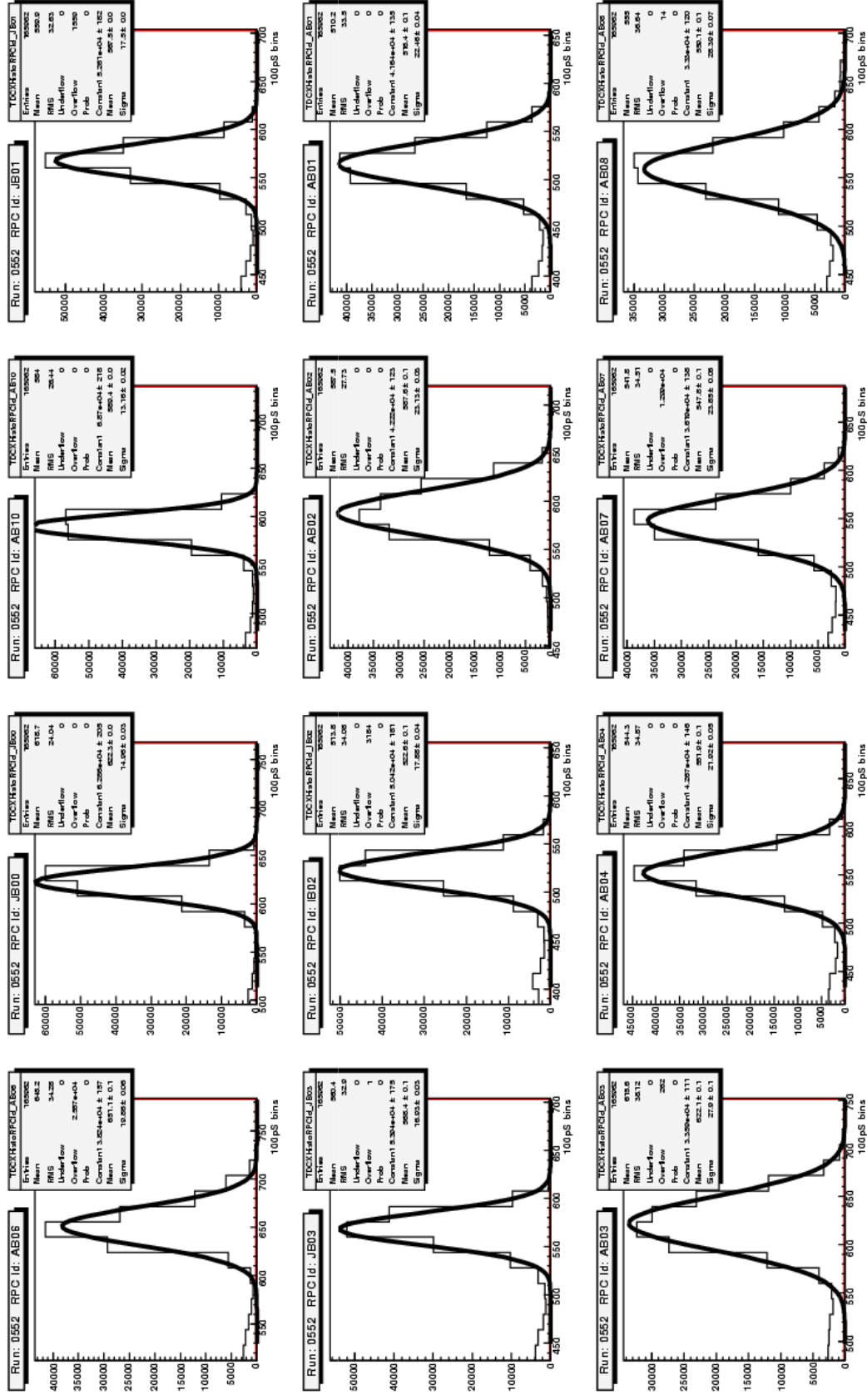
RPC signal characterisation



RPC parameter characterisation



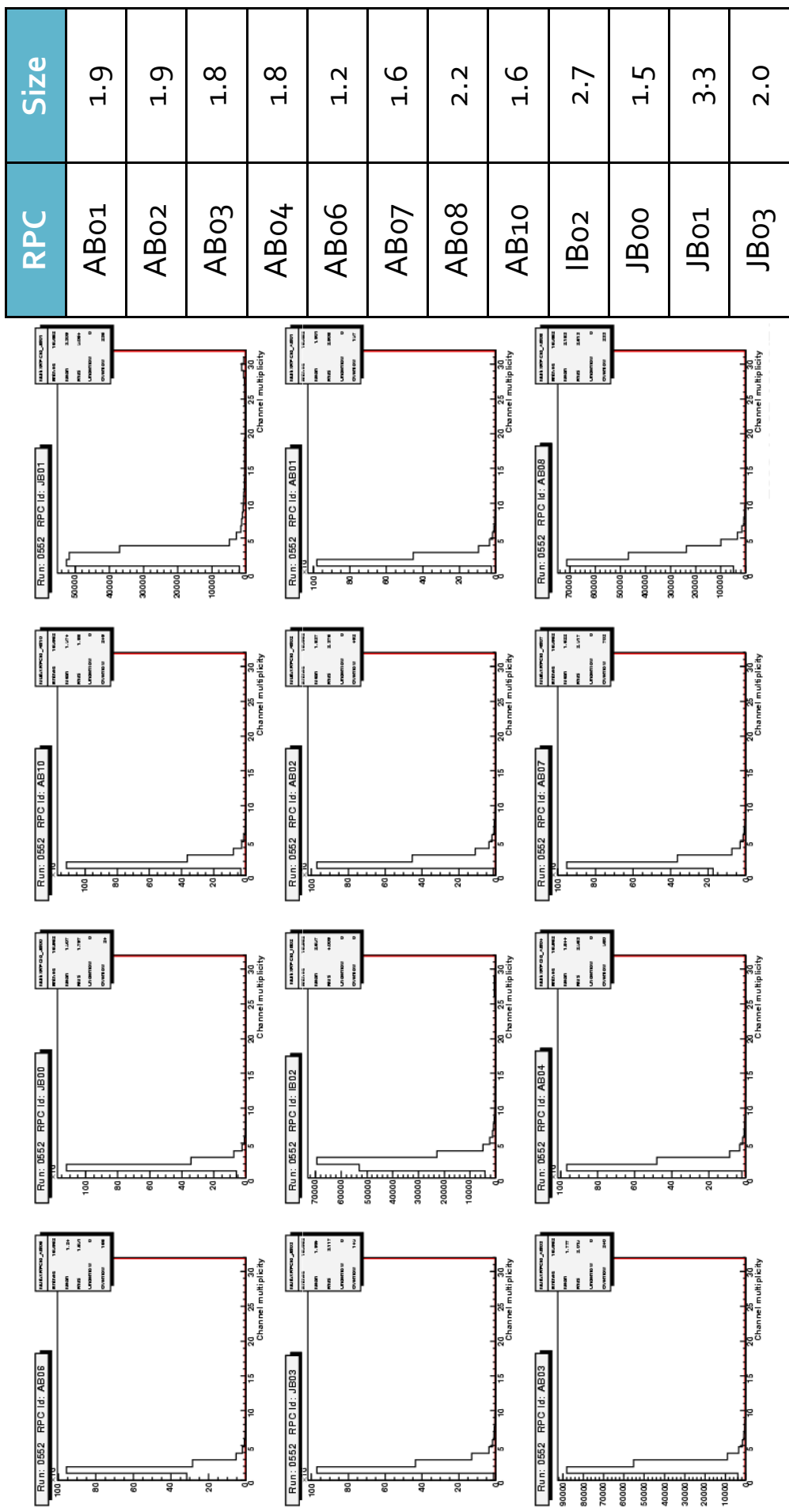
RPC time resolution plots



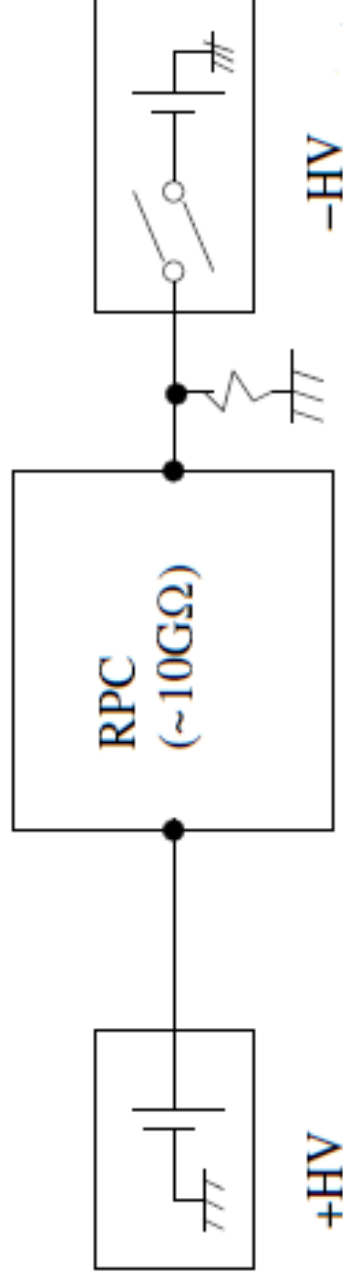
RPC-wise timing parameters

RPC Id	HV (KV)	Mean (nS)	Sigma (nS)	RelMean (nS)	RelSigma (nS)
AB06	09.8	49.53	2.06	-7.64	1.41
JB00	09.6	46.00	2.32	-4.47	1.67
IB01	09.8	42.31	2.15	-0.64	1.63
JB01	09.6	42.55	2.28	-0.87	1.58
JB03	09.8	43.75	2.26	-2.18	1.44
IB02	09.8	38.49	2.31	3.27	1.38
AB02	09.8	42.77	2.53	-1.21	1.51
AB01	09.8	35.30	2.16	6.33	1.71
AB03	09.8	45.82	3.23	-4.55	1.99
AB04	09.8	41.66	2.42	Reference RPC	
AB07	09.8	40.61	2.47	0.96	1.35
AB08	09.8	41.56	2.80	0.31	1.82

Cluster size distributions

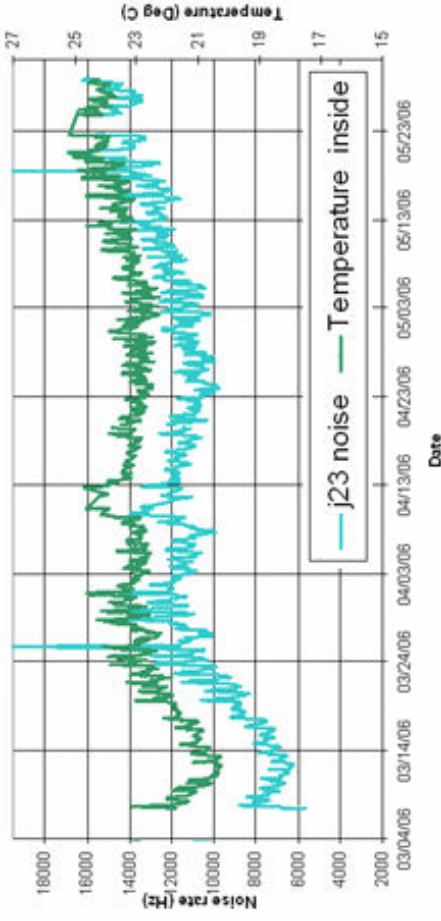


RPC dark current measurement

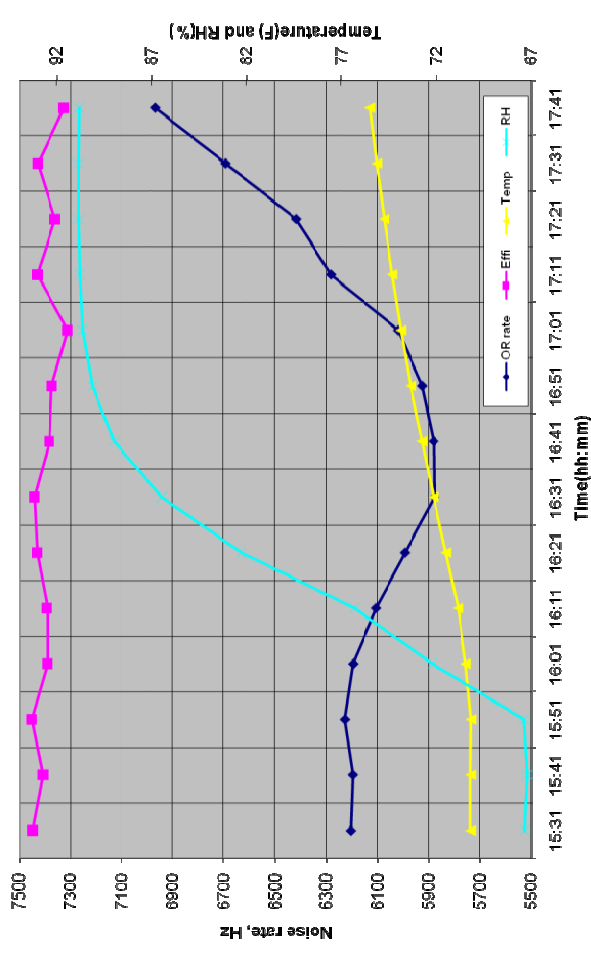
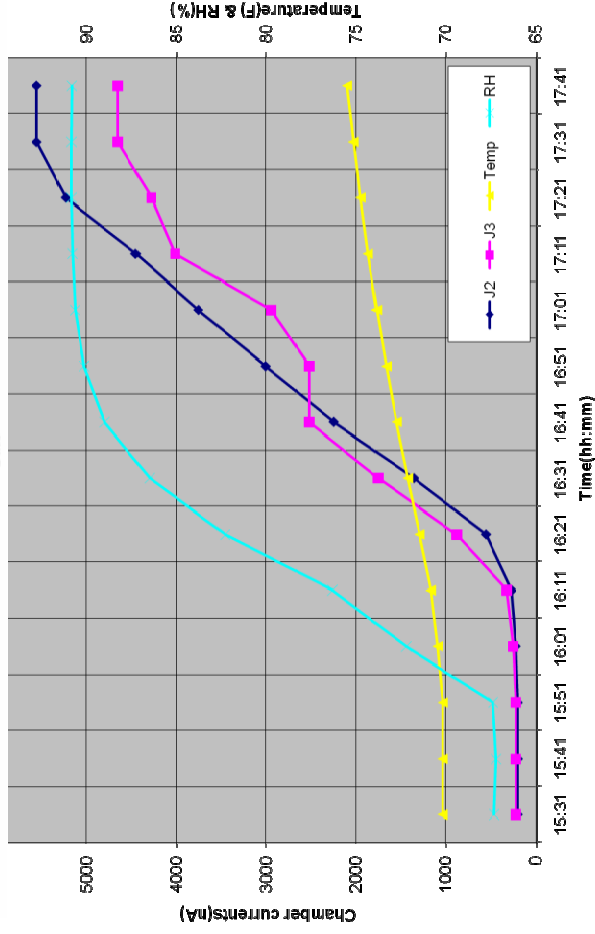


Dark current = Current drawn from the negative supply – Current through the shunt

Effect of ambient parameters on RPC characteristics



If the applied voltage at room temperature T_0 and barometric pressure P_0 is V_0 , then the voltage V to be applied at any temperature T and pressure $P = V_0 \times \left(\frac{T_0}{T}\right) \times \left(\frac{P}{P_0}\right)$ Or what is the effective applied voltage? N.B: This accounts for gas behaviour only.

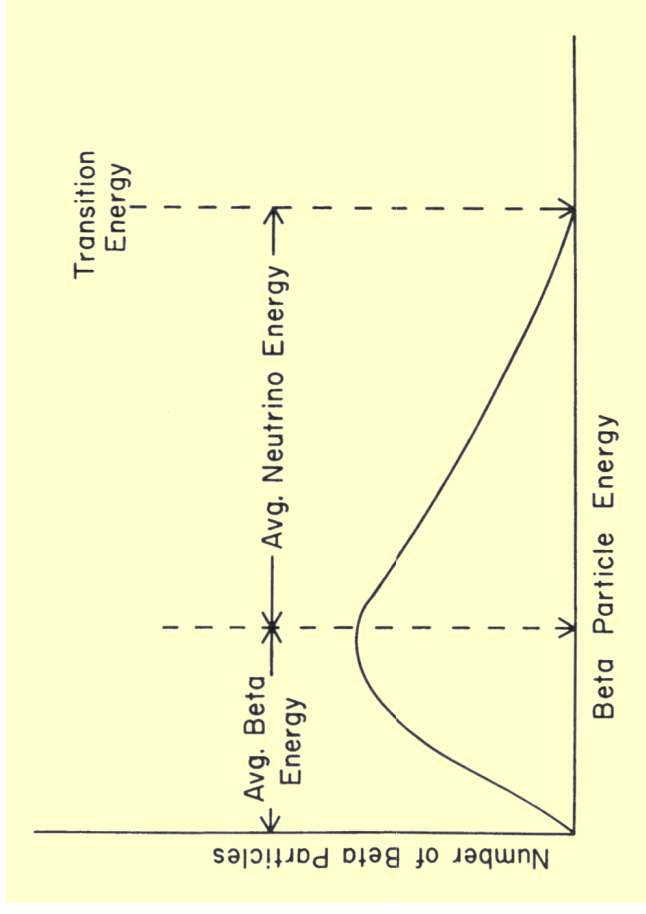


Introduction

RPC R&D was motivated by its choice for INO's neutrino experiment.

Neutrino (ν)

- Proposed by Wolfgang Pauli in 1930 to explain beta decay.
- Named by Enrico Fermi in 1931.
- Discovered by F.Reines and C.L.Cowan in 1956.
- Created during the Big Bang, Supernova, in the Sun , from cosmic rays, in nuclear reactors, in particle accelerators etc.
- Interactions involving neutrinos are mediated by the weak force.



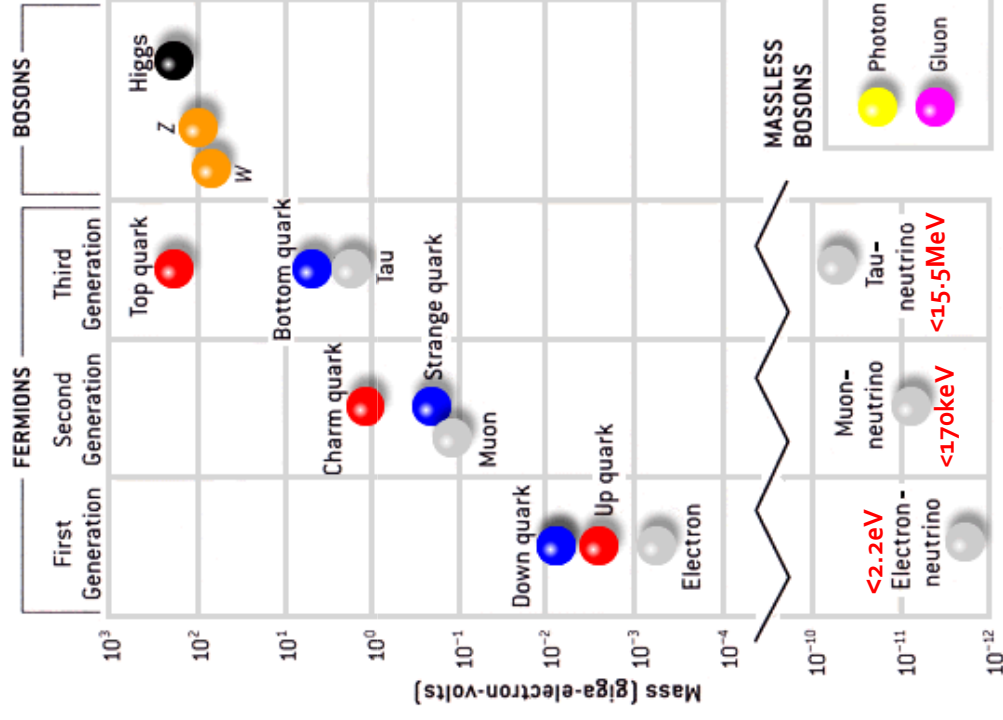
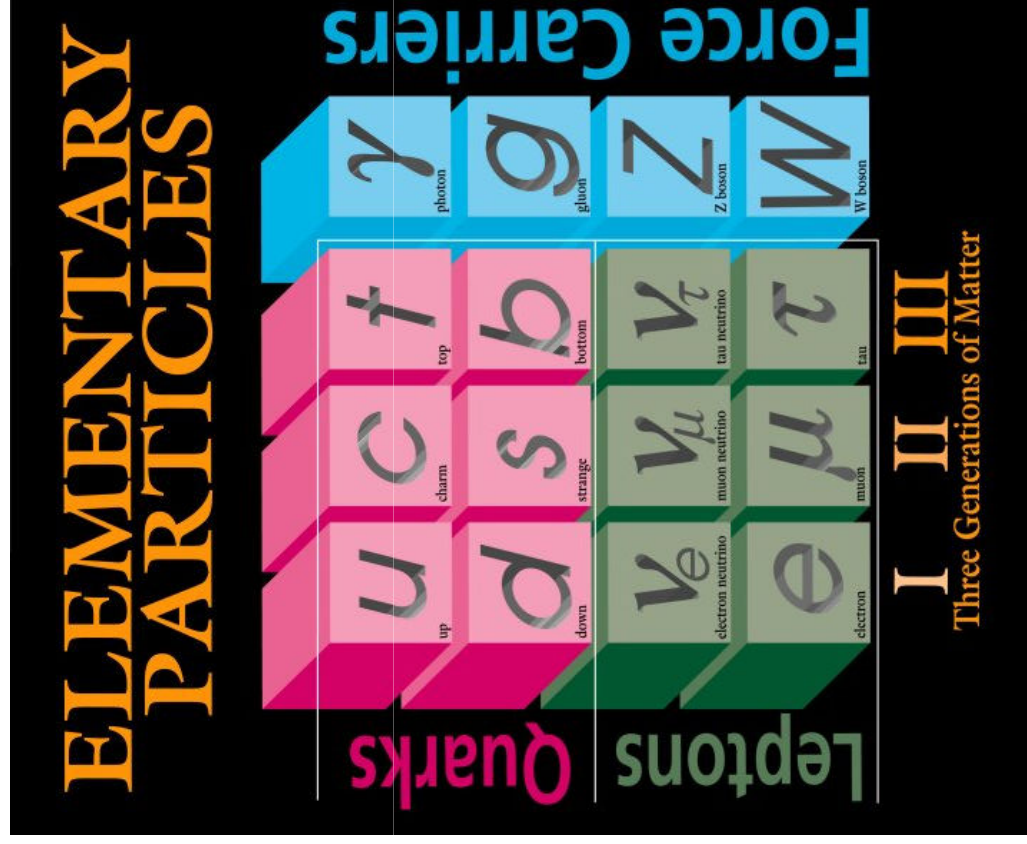
$$n \rightarrow p + e^{-} + \bar{\nu}$$

$$p \rightarrow n + e^{+} + \nu$$

$$4p \rightarrow \alpha + 2e^{+} + 2\nu_e + 25MeV$$

$$\pi^{+} \rightarrow \mu^{+} + \nu_{\mu} \quad \pi^{-} \rightarrow \mu^{-} + \bar{\nu}_{\mu} + \nu_e + \nu_{\mu}$$

Standard model of particle physics



Neutrino oscillations

- It is now known that neutrinos of one flavour oscillate to those of another flavour.
- The oscillation mechanism is possible only if the neutrinos are massive.
- Neutrino experiments are setting the stage for extension of Standard Model itself.
- Massive neutrinos have ramifications on nuclear physics, astro physics cosmology, geo physics apart from particle physics

- Electron and muon neutrinos (ν_e and ν_μ) are the flavour eigen states. They are super positions of the mass eigen states (ν_1 and ν_2)..

$$\begin{aligned}\nu_e &= \nu_1 \cos \theta + \nu_2 \sin \theta \\ \nu_\mu &= -\nu_1 \sin \theta + \nu_2 \cos \theta\end{aligned}$$

- If at $t = 0$, an eigen state $\nu(0) = \nu_e$, then any time t

$$\nu(t) = \nu_1 e^{-iE_1 t} \cos \theta + \nu_2 e^{-iE_2 t} \sin \theta$$

- Then the oscillation probability is

$$P(\nu_e \rightarrow \nu_f; L) = \sin^2 2\theta \sin^2 1.27 \Delta m^2 L/E$$

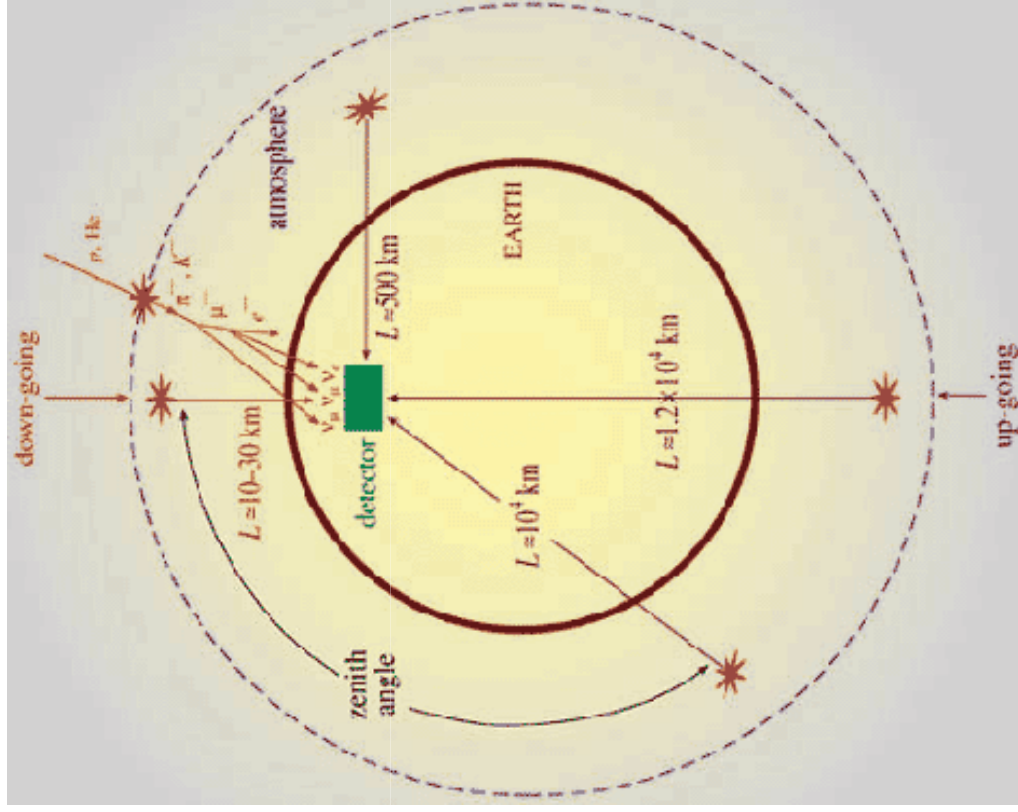
- And the oscillation length is

$$\lambda = 2.47 m(E/\text{MeV}) (eV^2 / \Delta m^2)$$

Neutrino physics using ICAL

- Reconfirm atmospheric neutrino oscillation
- Improved measurement of oscillation parameters
- Search for potential matter effect in neutrino oscillation
- Determining the mass hierarchy using matter effect
- Study of ultra high energy neutrinos and muons
- Long baseline target for neutrino factories

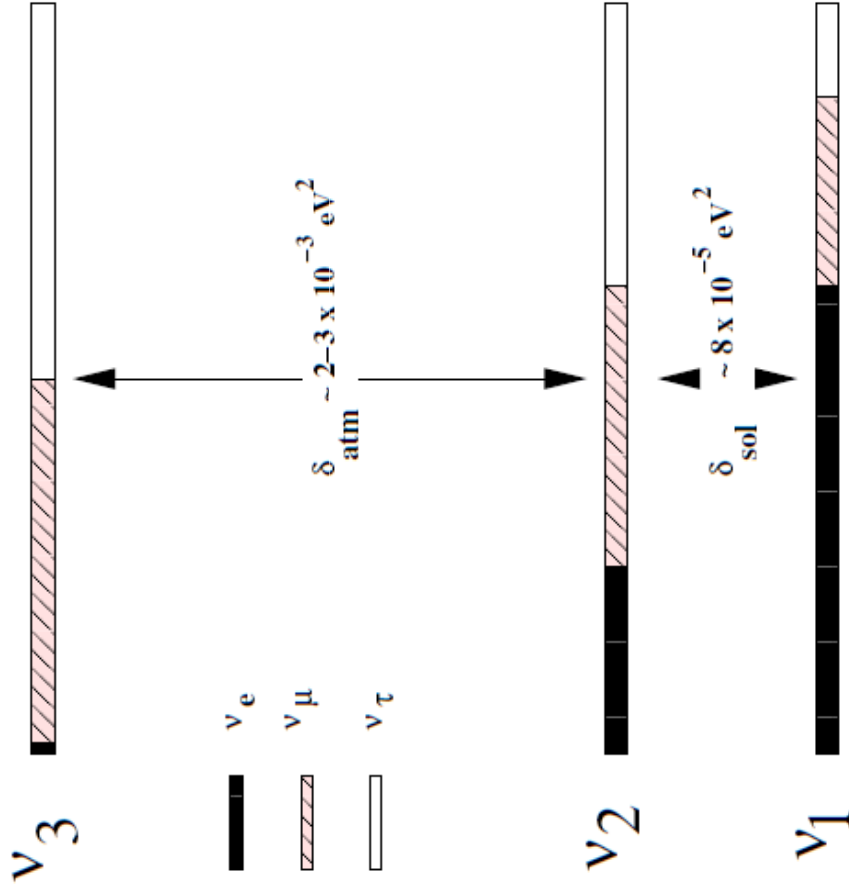
Up-Down asymmetry measurement



- Atmospheric neutrino energy $> 1.3 \text{ GeV}$
 $\Delta m^2 \sim 2\text{--}3 \times 10^{-3} \text{ eV}^2$
- Downward muon neutrino are not affected by oscillation
- They may constitute a *near* reference source
- Upward neutrino are instead affected by oscillation since the L/E ratio ranges up to 10^4 Km/GeV
- They may constitute a *far* source
- Thus, oscillation studies with a single detector and two sources

$$\frac{N_{Up}(L/E)}{N_{Down}(L'/E)} = P(L/E) = 1 - \sin^2(2\Theta) \sin^2(1.27 \Delta m^2 L/E)$$

Matter effects and neutrino mass hierarchy



- Matter effects help to cleanly determine the sign of the Δm^2
- Neutrinos and anti-neutrinos interact differently with matter
- ICAL can distinguish this by detecting charge of the produced muons, due to its magnetic field
- Helps in model building for neutrino oscillations