Assembly and Testing of RPCs in Pakistan

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Layout

- Introduction
- RPCs in CMS
- RPC: From Lab to Detector
- Assembly
- Testing
- QA & QC
- Installation and Commissioning

Resistive Plate Chambers

PAST

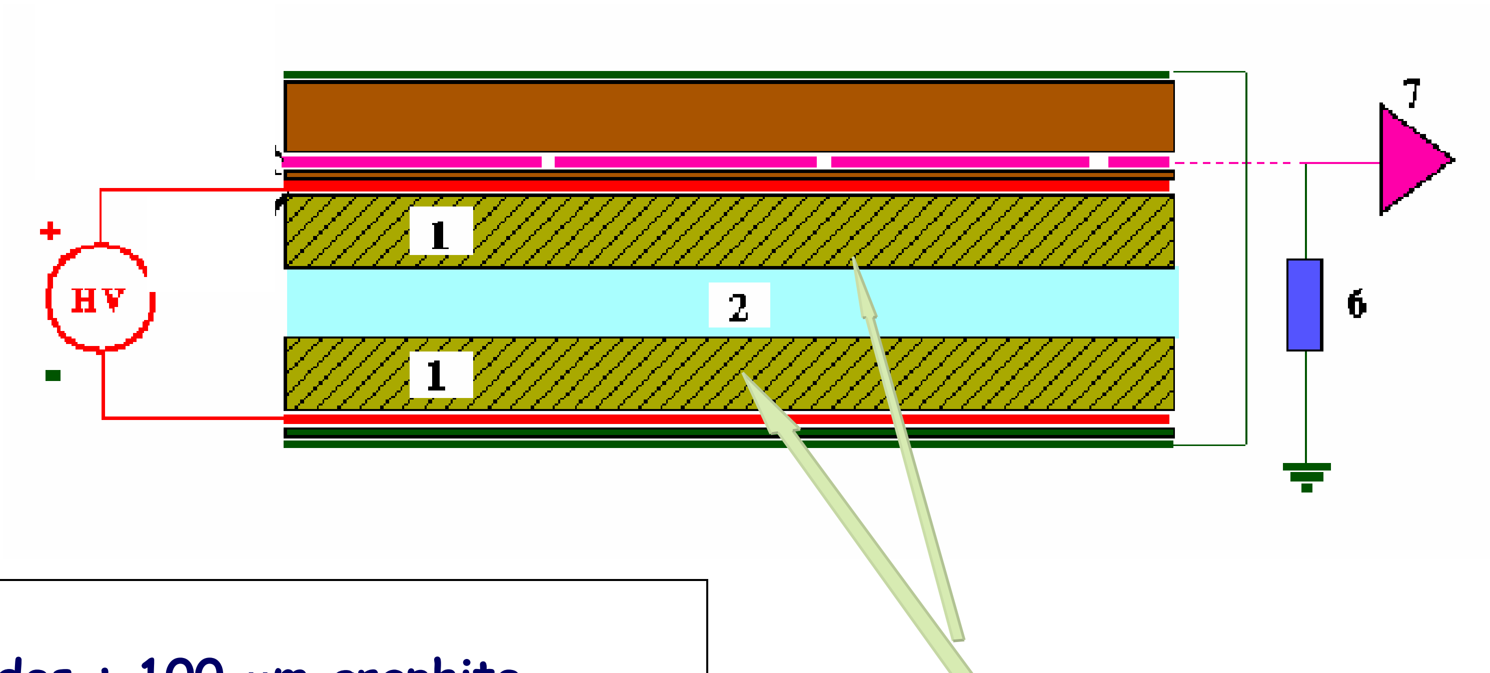
- Used in several HEP experiments: **L3, BaBar, Belle**
- No wires
- High efficiency
- Fast response
- Position measurement
- Low production cost
- Large surfaces

PRESENT

- LHC experiments: **ATLAS, CMS, ALICE, LHCb**
- Cosmic rays experiments: (ARGO)
- High rate capability
- Low gas gain operation
- Long term performance

Resistive Plate Chambers

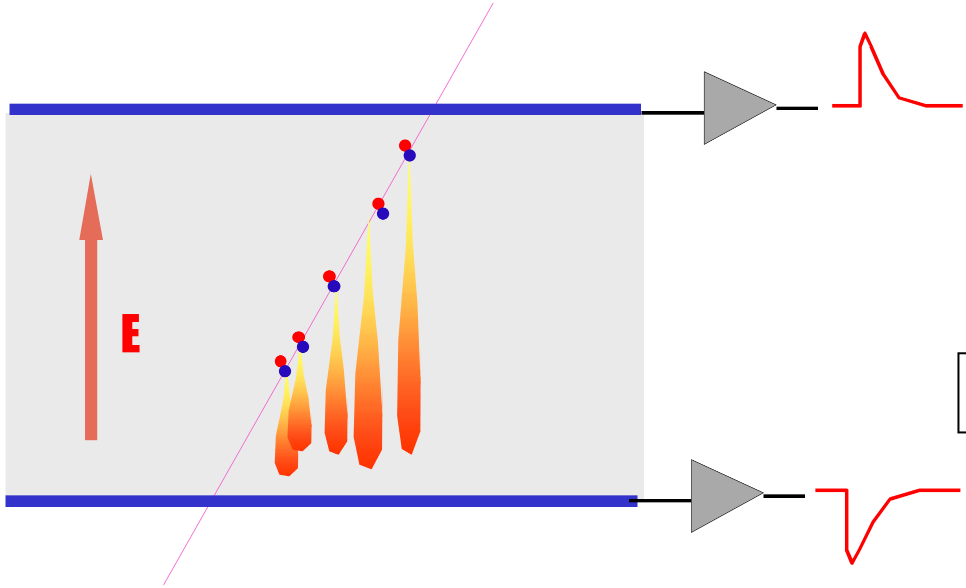
Developed by R. Santonico (Roma) in the early 80'



- Gap: 2 mm
- HV electrodes : 100 μm graphite
- Gas pressure : ~ 1 Atm
- Gas mixture: 70% Ar, 29% iso-Butane, 1% Freon
- Gas flow: 0.1 vol/hour

bakelite resistivity 10^{10}- 10^{12} Ωcm
Coated with linseed oil

Operating Regimes



The avalanche size depends on the anode distance

RPC is not a proportional counter

The signal is induced on the read-out electrodes

SPARK COUNTER

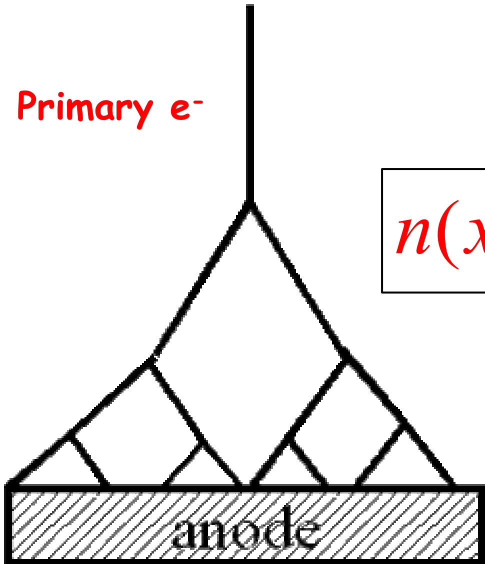
RESISTIVE PLATE CHAMBERS

AVALANCHE CHAMBERS

Different regimes with different HV

The Avalanche Regime

Primary e⁻



α = first Townsend coefficient

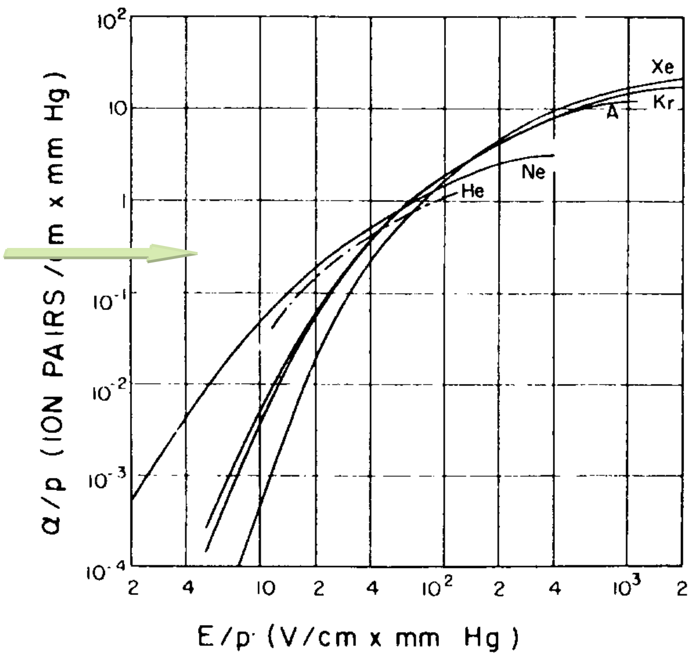
$$n(x) = n_0 e^{\alpha(E)x}$$

$$\alpha = \frac{1}{\lambda}$$

λ: free mean path

Korff approximation

$$\frac{\alpha}{p} = Ae^{-\frac{Bp}{E}}$$



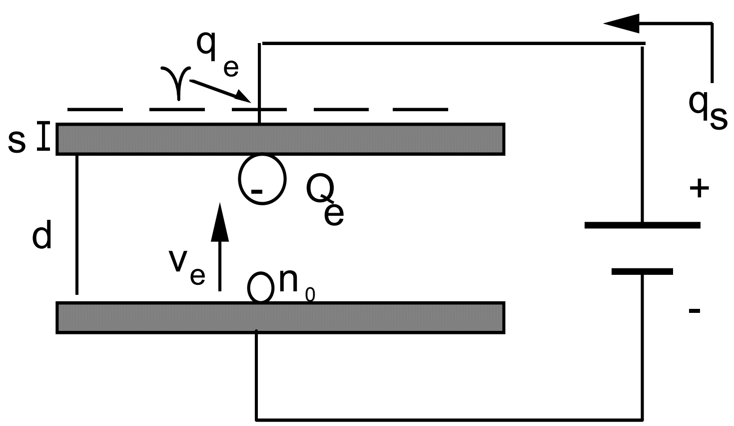
Gain

$$M = \frac{n}{n_0} = \exp\left[\int_0^d \alpha(x)dx\right]$$

The Avalanche Regime

High rate environment require low gas gain (avalanche operation)

$$< q_e > = \frac{k}{\eta d} < Q_e(d) > = q_{el} n_0 \frac{k}{\eta d} \frac{\lambda}{\eta + \lambda} e^{\eta d}$$



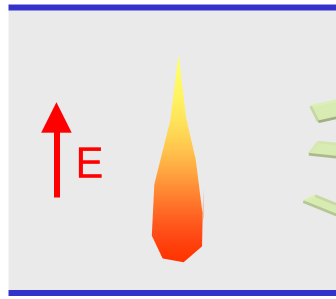
- $k = (\varepsilon_r d/s)/(\varepsilon_r d/s + 2)$
- q_{el} is the electron charge
- n_o is the average size of the primary cluster
- λ is the cluster density in the gas mixture
- ε_r is the relative dielectric constant
- d is the gap width
- s is the electrode thickness

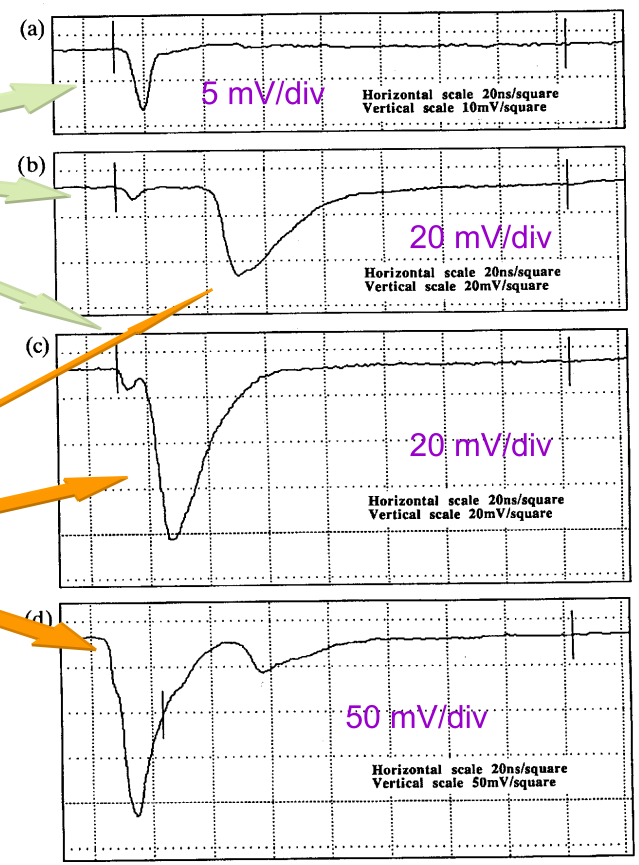
λ should be large to achieve high efficiency-------> $C_2H_2F_4$ gas mixtures

The Streamer Regime

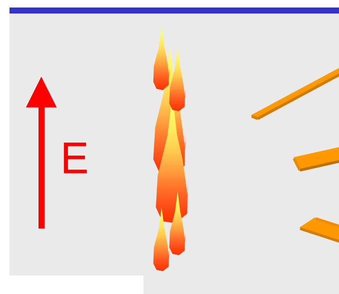
Avalanche:

The electric field is such that the electron energy is larger than the ionising potential

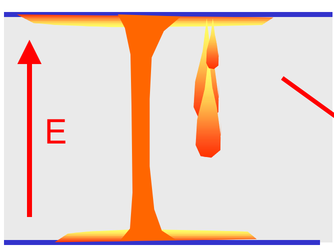


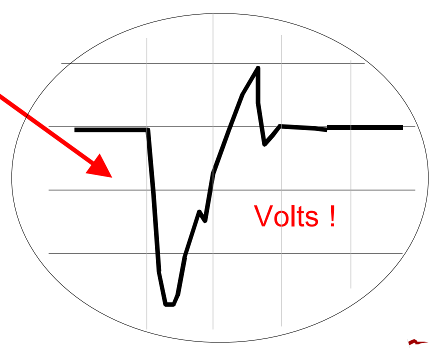


Streamer



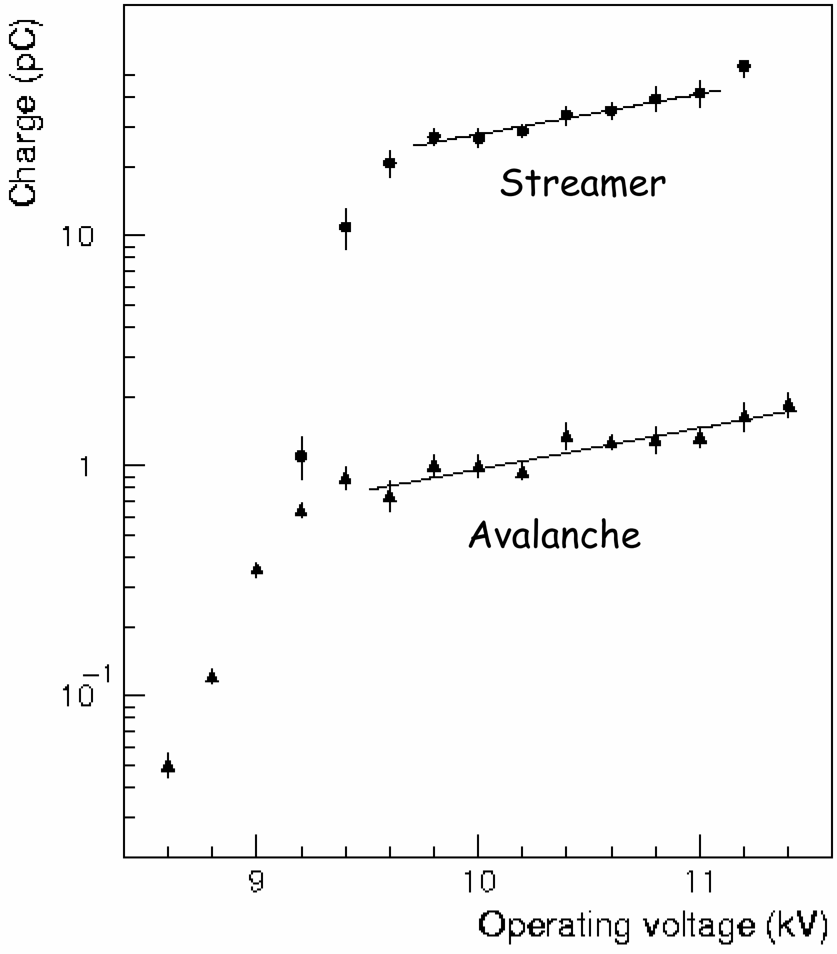
Spark



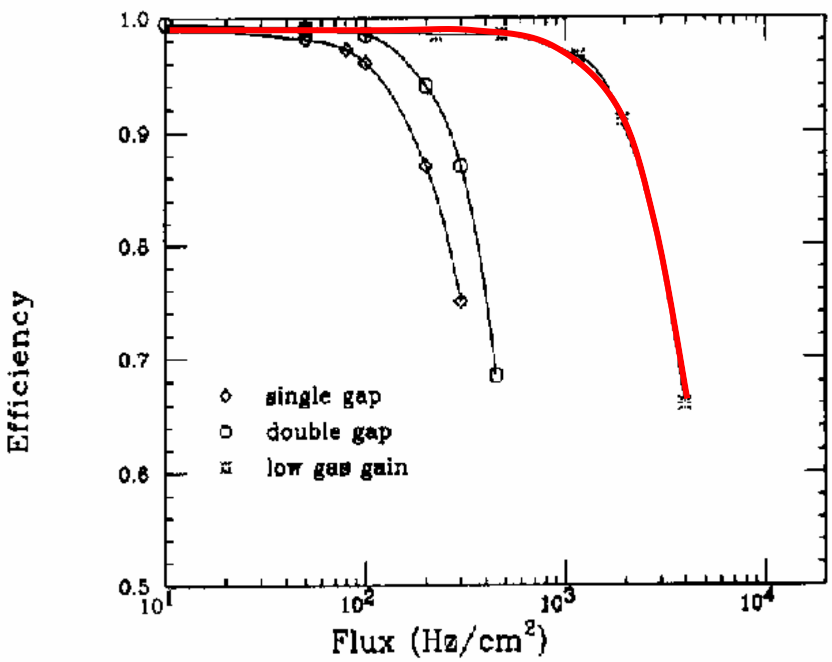


The separation avalanche-streamer decreases with increasing HV

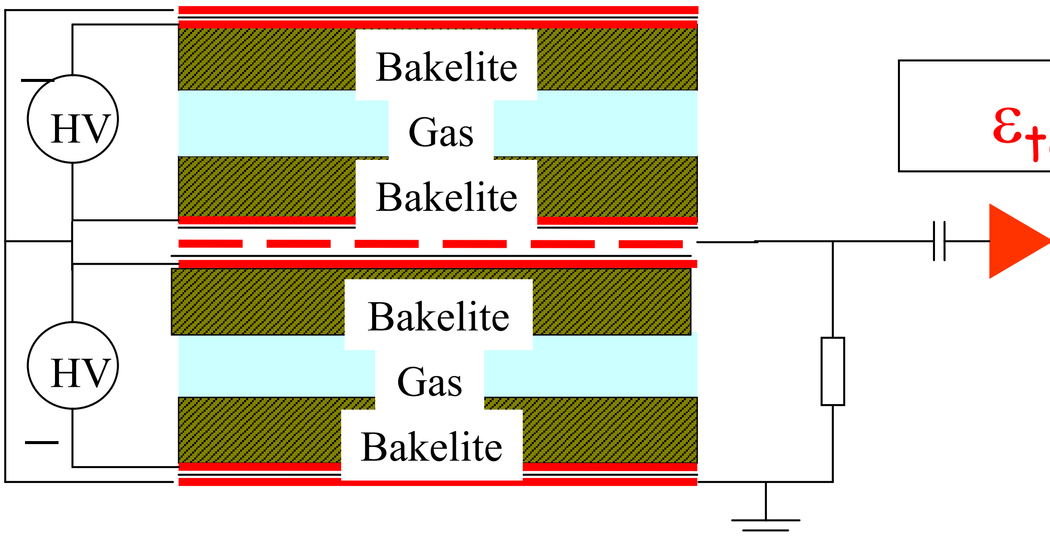
RPC in Avalanche



Rate capability increases by a factor 10!

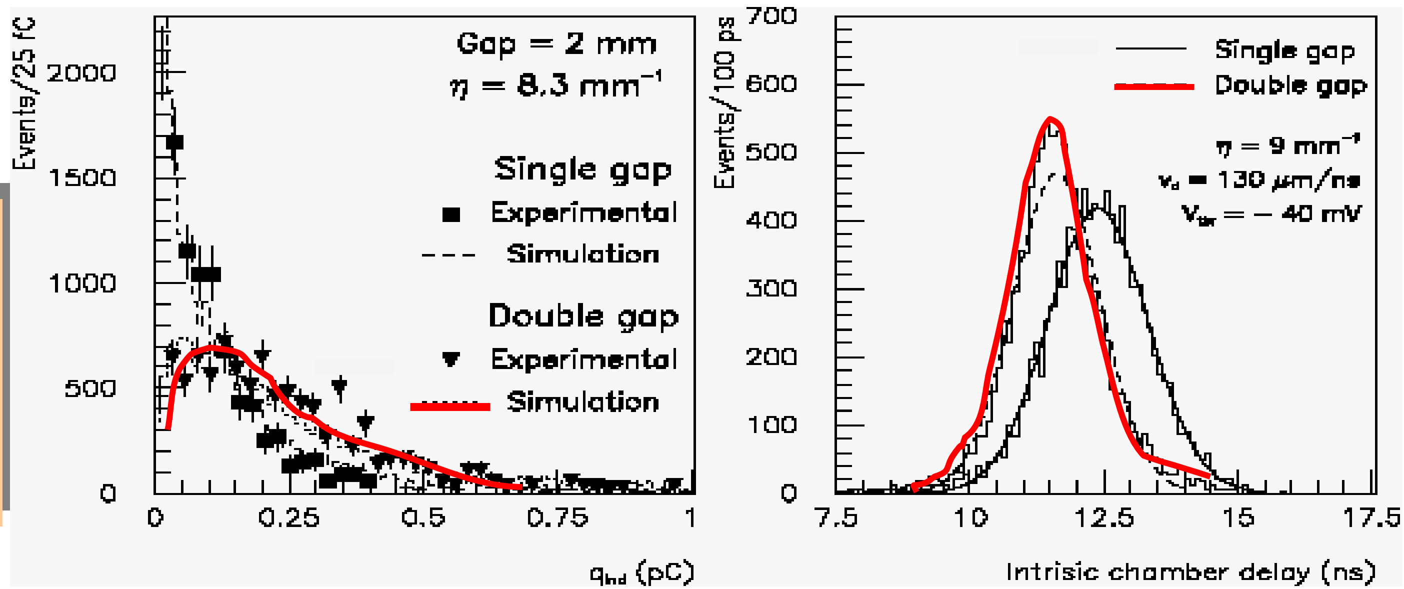


Double Gaps



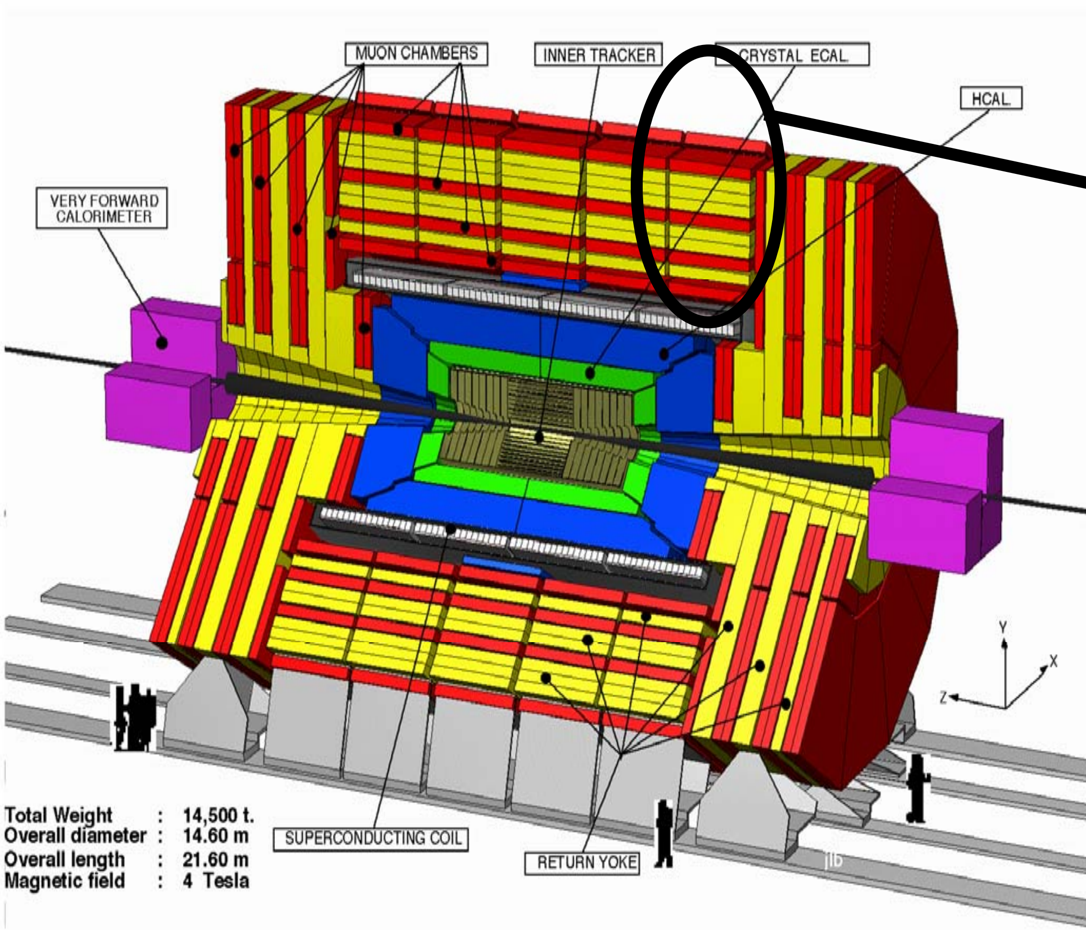
$$\varepsilon_{tot} = \varepsilon_1 + \varepsilon_2 - \varepsilon_1\varepsilon_2$$

Double gap geometry improves the efficiency and allows safer operation at higher threshold. Also the time resolution improves.



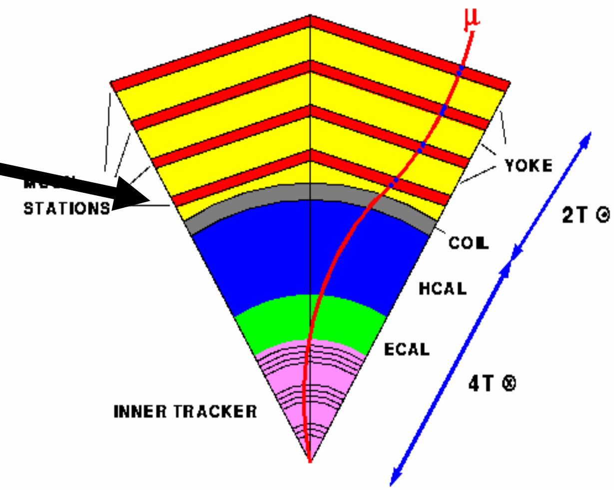
Compact Muon Solenoid

A Compact Solenoidal Detector for LHC



CMS. LHCC Meeting, 19 January 1995 Overview 2

CMS Muon Trigger



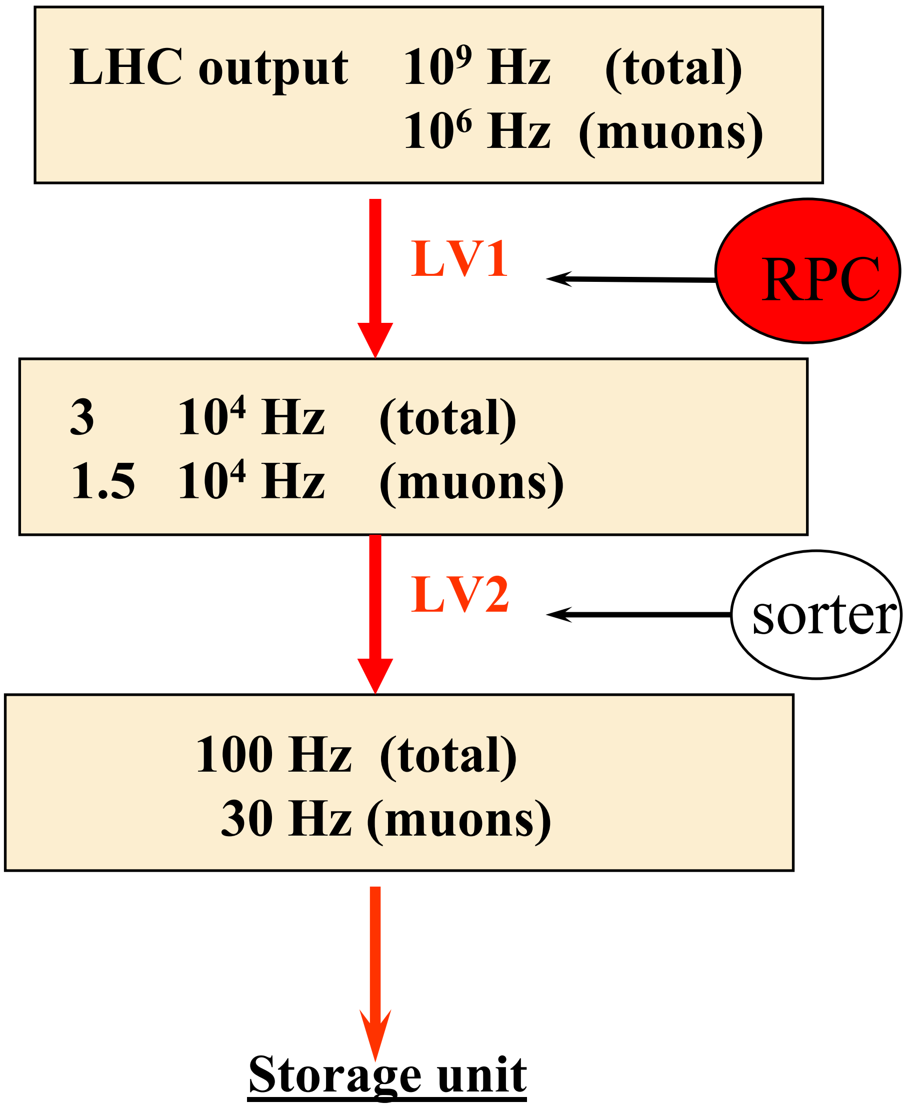
The CMS Muon Trigger is based on:

dedicated trigger detectors (RPC)
- precise timing
- unambigous position
- crude momentum measurement

muon chambers (Drift Tubes, CSC)
- vector per station
- more precise momentum measurement

Two component trigger provides
- sure bunch crossing identification
- sharp p_t cut
- powerful background rejection
- large flexibility: p_t cut = 3–100 GeV
  $L = 10^{32}–10^{34}\ cm^{-2}s^{-1}$

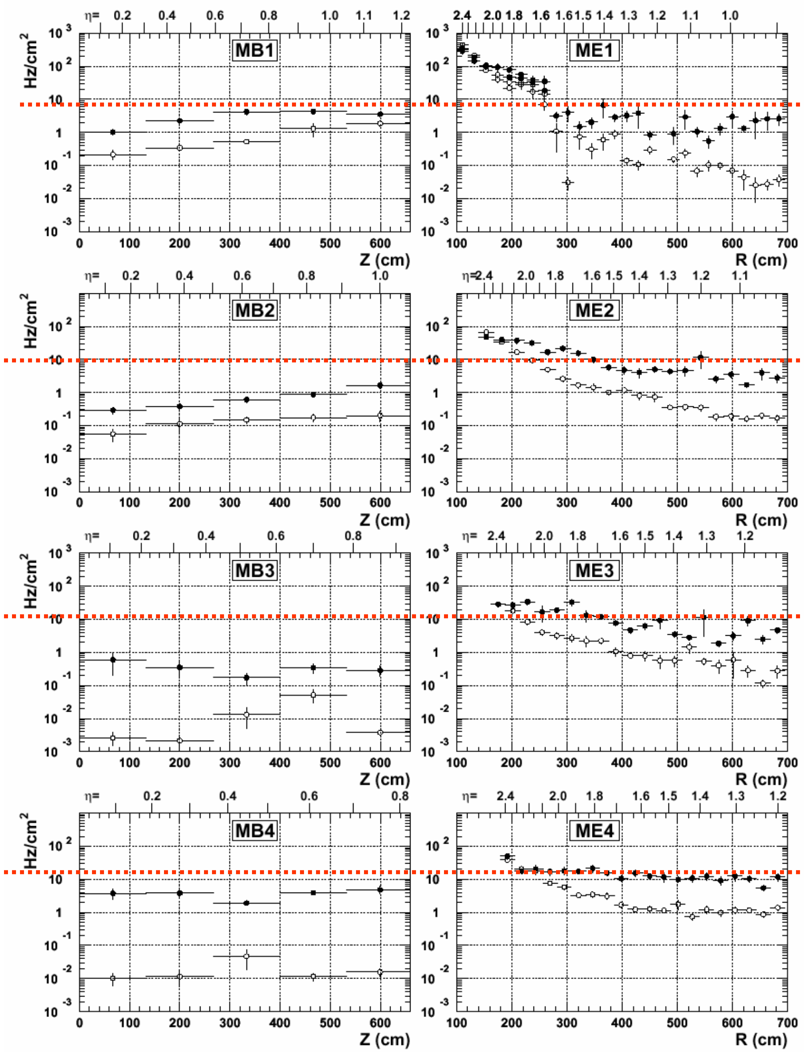
Dedicated Trigger



CMS environment

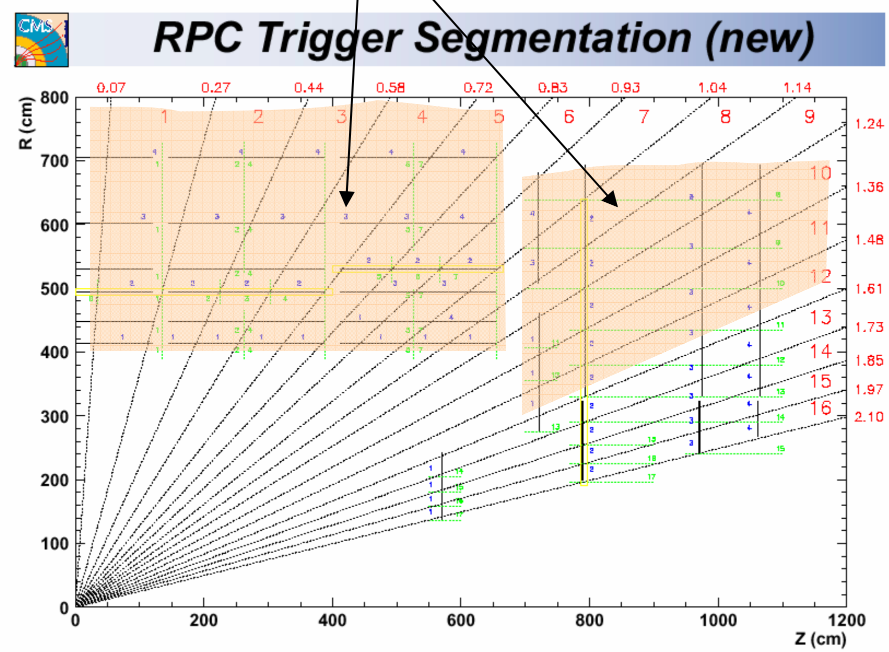
- bunch separation of 25 ns
- high background of n and γ
- long term operation with high irradiation

Background



Hits due to neutrons (full circles) and charged particles (open circles).

Rate in the shadow region (η ≤1.6) is ≤ 10 Hz/cm²



Red dashed line is at 10 Hz/cm²

Endcap Overview

Korea

Pakistan

China

Gap production

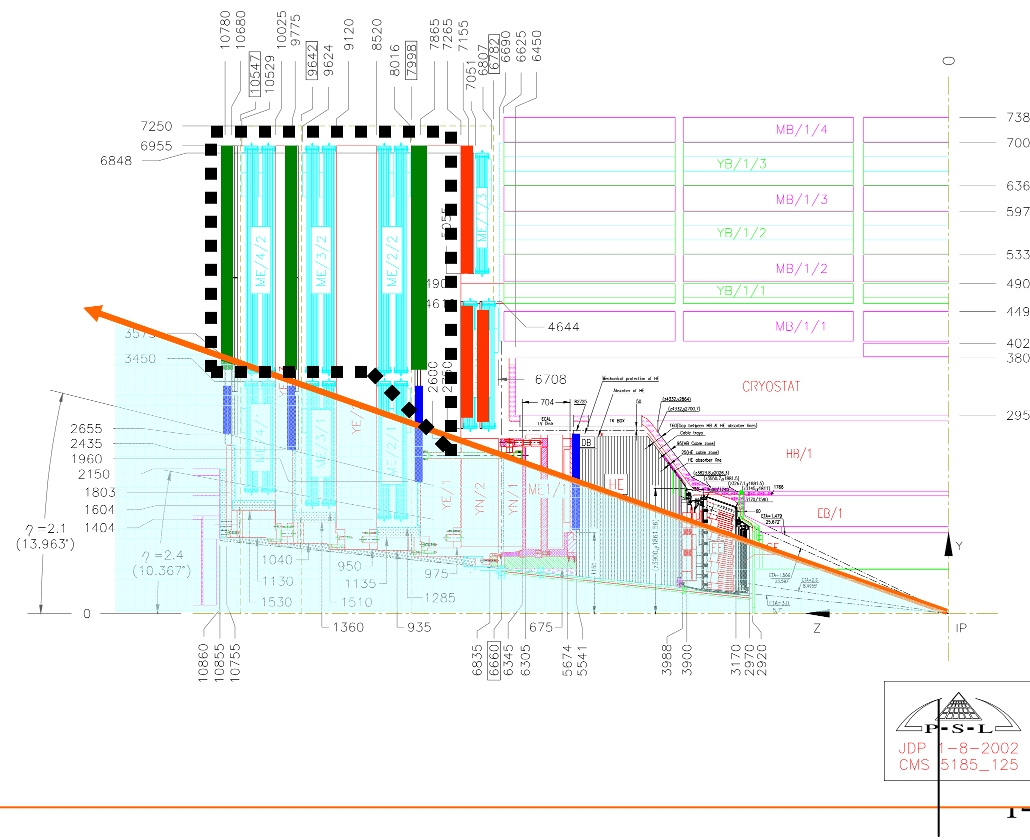
Korea

Front-end electronics

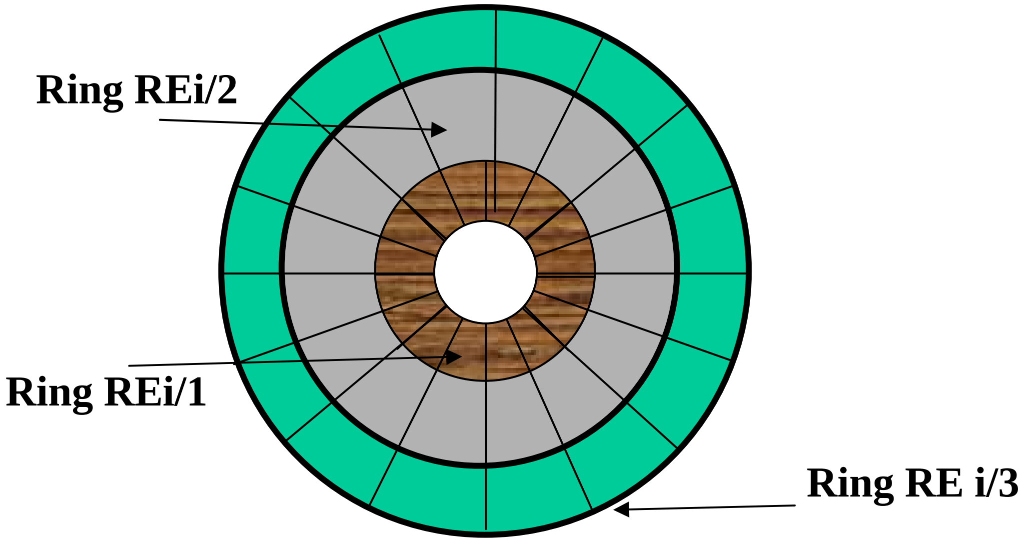
Pakistan

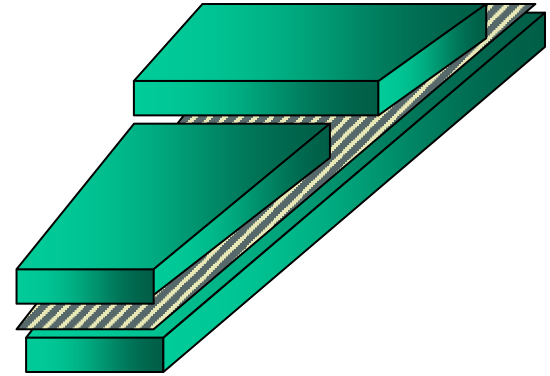
HV/LV system

Pakistan



Endcap Overview





RE1/1 Staged
RE1/2 and RE1/3 in production at CERN

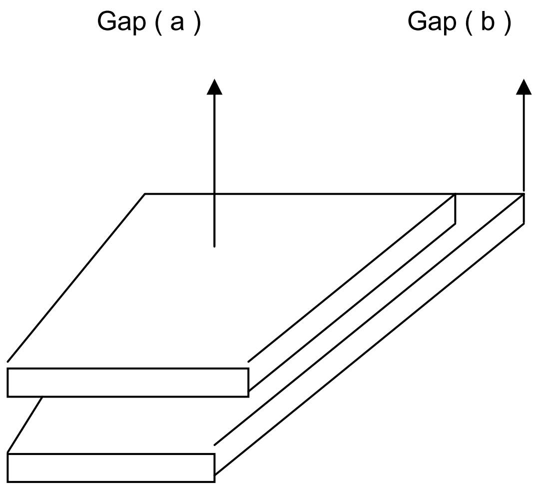
RE2/2 and RE2/3 under production in Pakistan

RE3/2 and RE3/3 to be produced in Pakistan

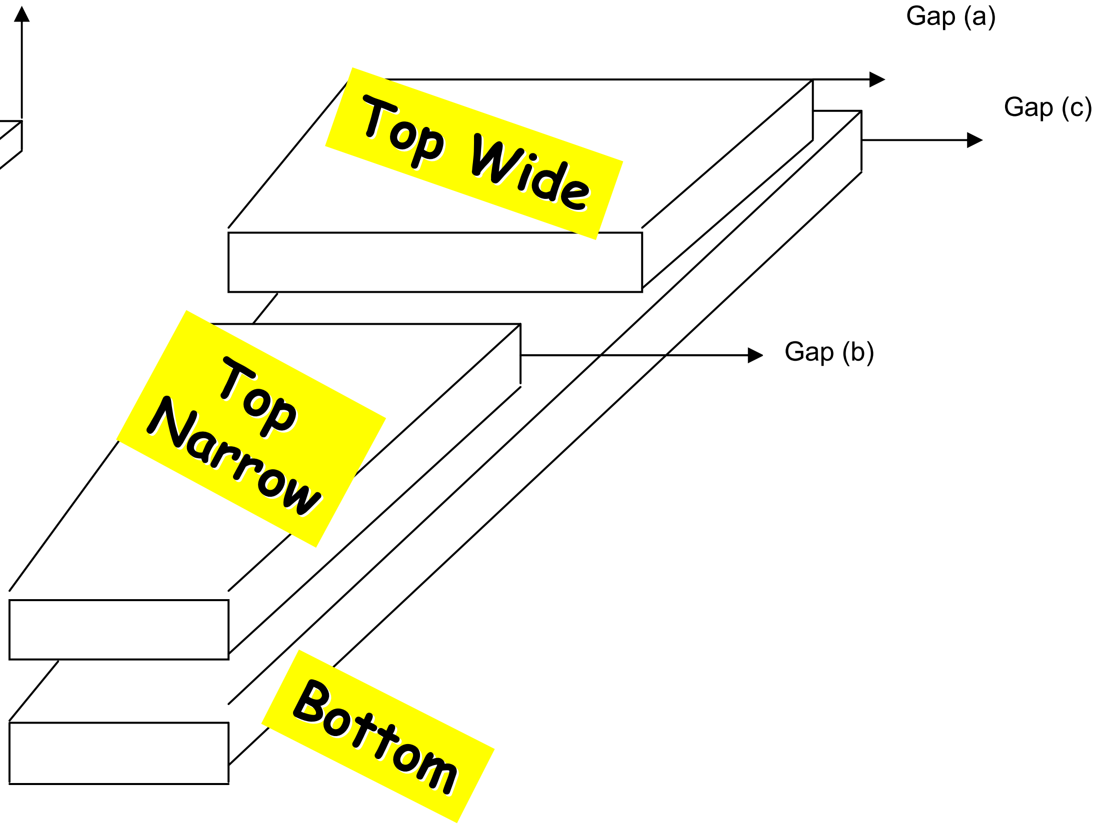
	RE 1/1	RE 1/2	RE 1/3	RE 2/1	RE 2/2	RE 2/3	RE 3/1	RE 3/2	RE 3/3	RE 4/1	RE 4/2	RE 4/3
No. of chambers	36*2	36*2	36*2	18*2	36*2	36*2	18*2	36*2	36*2	18*2	36*2	36*

Endcap Overview

RE3/1, RE4/1



All other chambers



Sensitive Volume (Gaps) made in Korea

Endcap Organization

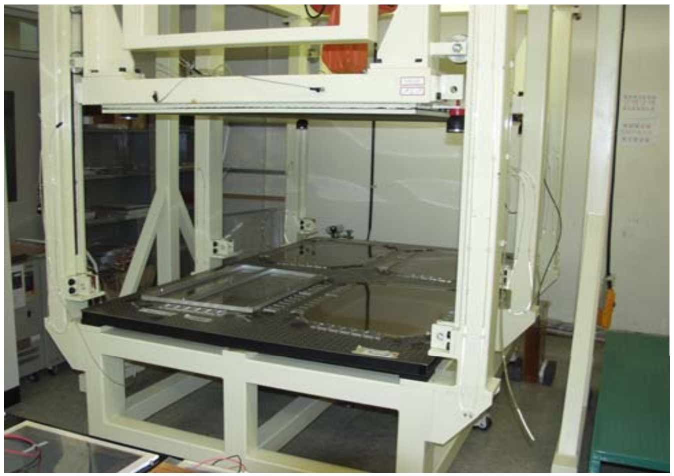
Bakelite Purchase Italy	Cut 	Clean 	Ship to S. Korea
Gaps	Built in Seoul	QC	Ship to CERN Pakistan
Mechanics	Kit prep in China Pakistan	Procurement Cables and pieces	Assembly at CERN Pakistan
FEBs, Adaptor Boards	Procured from Italy	Ordered by Pakistan	Ship to Pakistan CERN
Chamber Assembly	CERN/Pakistan	QC	Construction Database
Storage	Point 5	Installation	Production Database

Organizational Structure

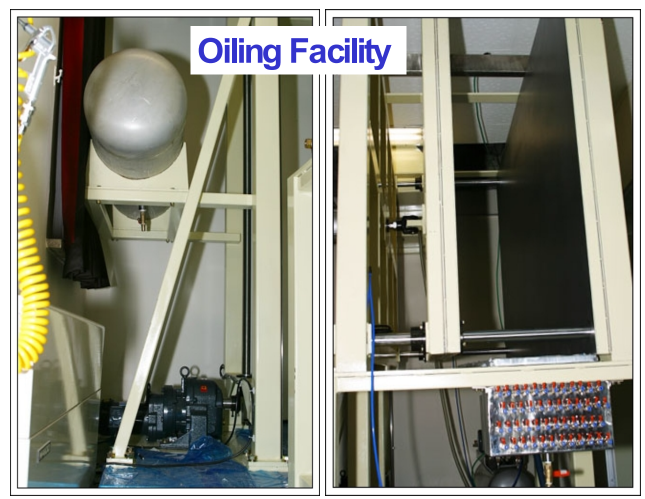
Project Managers	**Tariq Solaija/Hafeez Hoorani**
Technical Coordination	Zia Aftab
Mechanics	M. Shariq Khan
Design & Fabrication	Javed A. Jan
Assembly	M. Iftikhar/M. Saleh
Installation	M. Shariq Khan
Cosmic Testing	Waqar Ahmed
DAQ Software	Sajjad Asghar/Hassan Shahzad
Analysis	M. Irfan/M. Saleh
QA & QC	Imran M. Awan/Hafeez Hoorani

Gap Production

Oiling procedure successfully transferred to Korea 2003



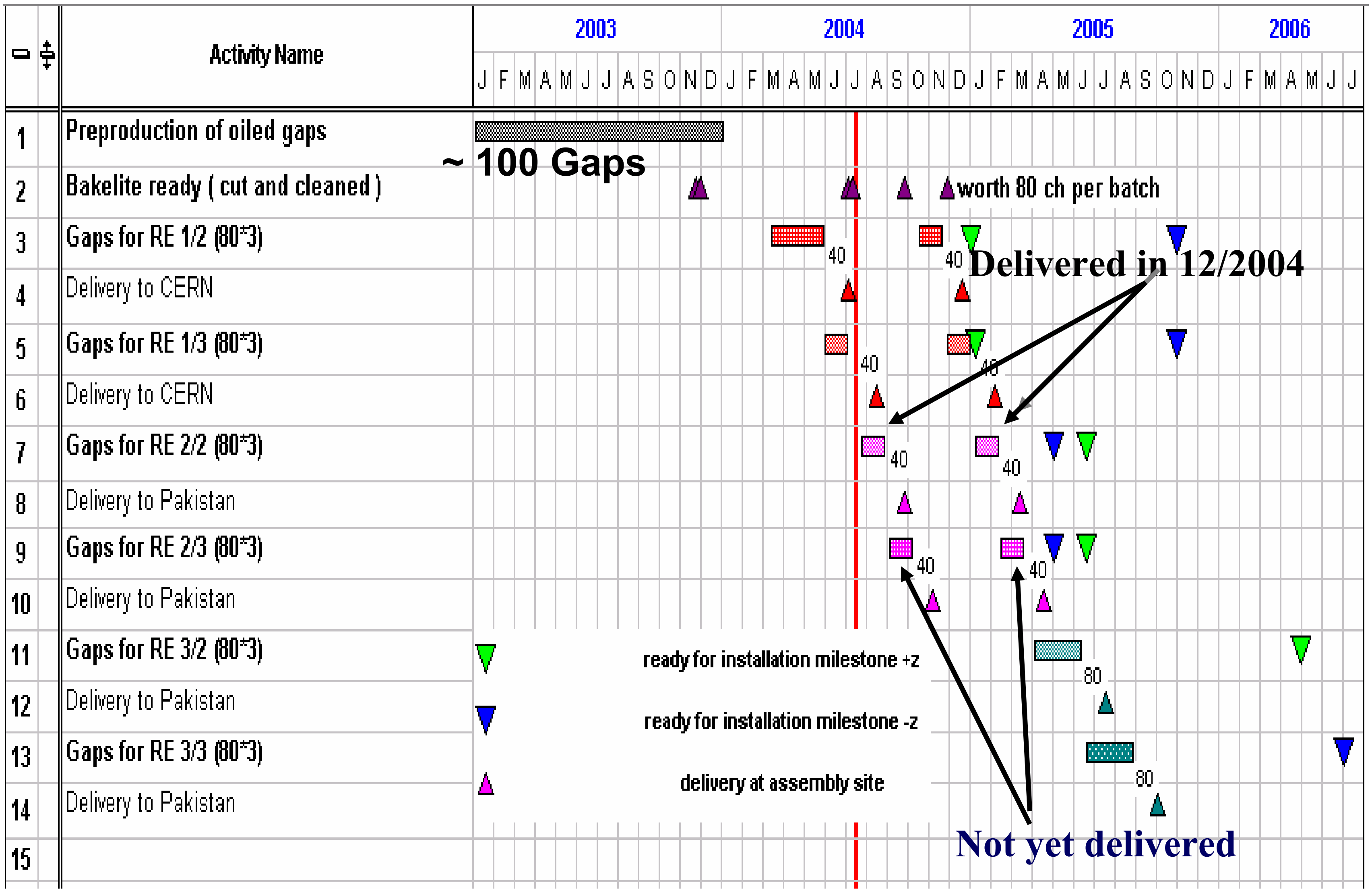
Hot melt of PET film



Oiling Facility

KODEL

Schedule for Gap Delivery



RPCs from Lab to Detector

- Research & Development
- Prototyping
- Pre-Production
  - Mockups, Retrofitting
- Production
  - Quality Assurance
- On-site Installation
- Commissioning
- Maintenance

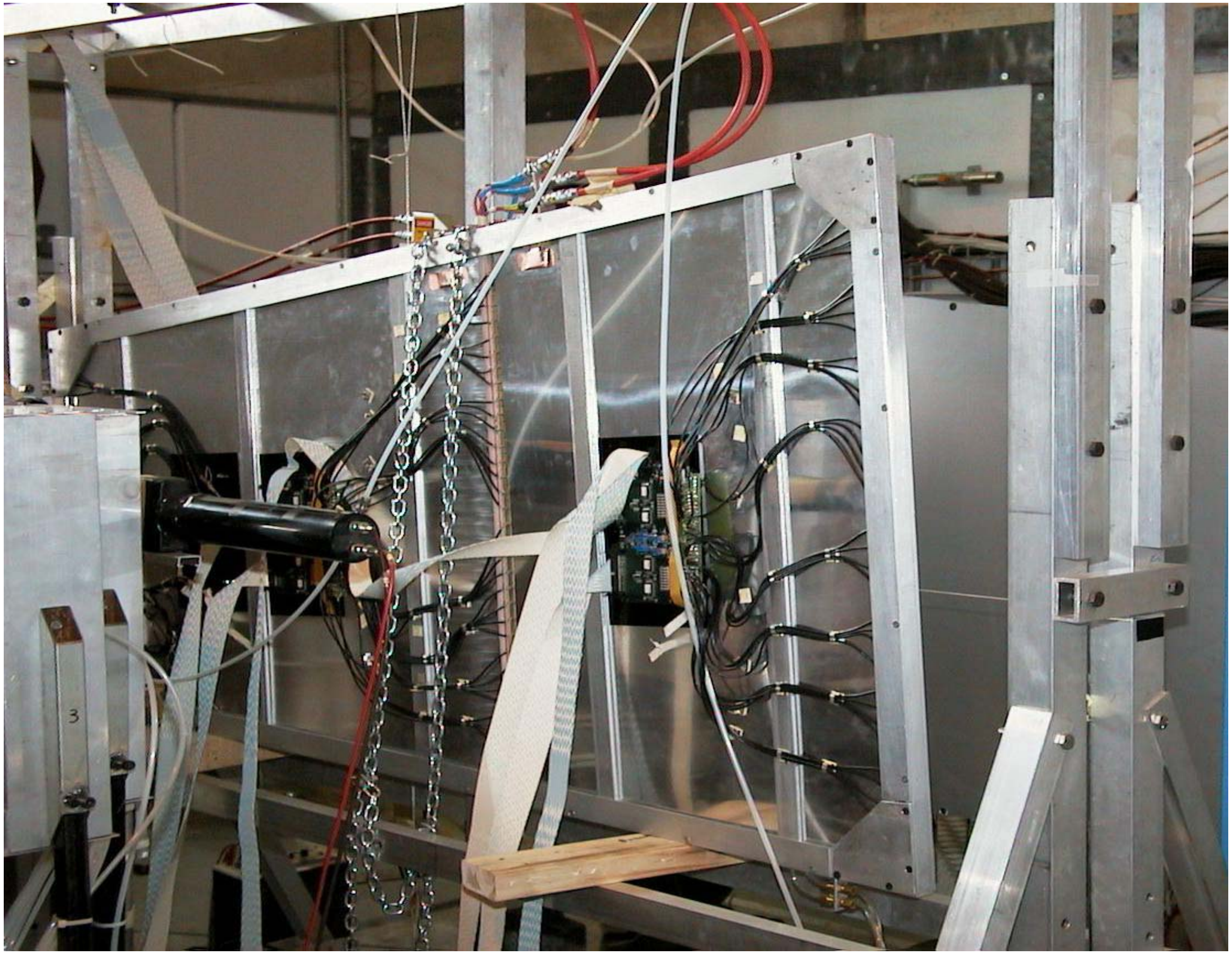
Prototyping

- **PK-01/99** 400*400 mm^2 double gap RPC, Italian bakelite 1999. (non-oiled)
- **PK-02/00** Full-size RE 2/2 chamber, tested at GIF in 2000, phenolic bakelite gaps fabricated in Italy ($\rho \cong 10^9\ \Omega$ cm). (non-oiled)
- **PK-03/01** Full-size RE 2/2 chamber, tested at GIF in 2001, melaminic bakelite gaps ($\rho \cong 10^{10}\ \Omega$ cm). (non-oiled)
- **PK-04/02** Full-size RE 2/2, tested at GIF in 2002, gaps supplied from Korea ($\rho \cong$ 10 10 Ω cm) (non-oiled)
- **PK–05/03** Full-size RE 2/2, tested at GIF in 2003, gaps supplied from Korea ($\rho \cong$ 10 10 Ω cm) (Oiled)

Good results were achieved in all beam tests.

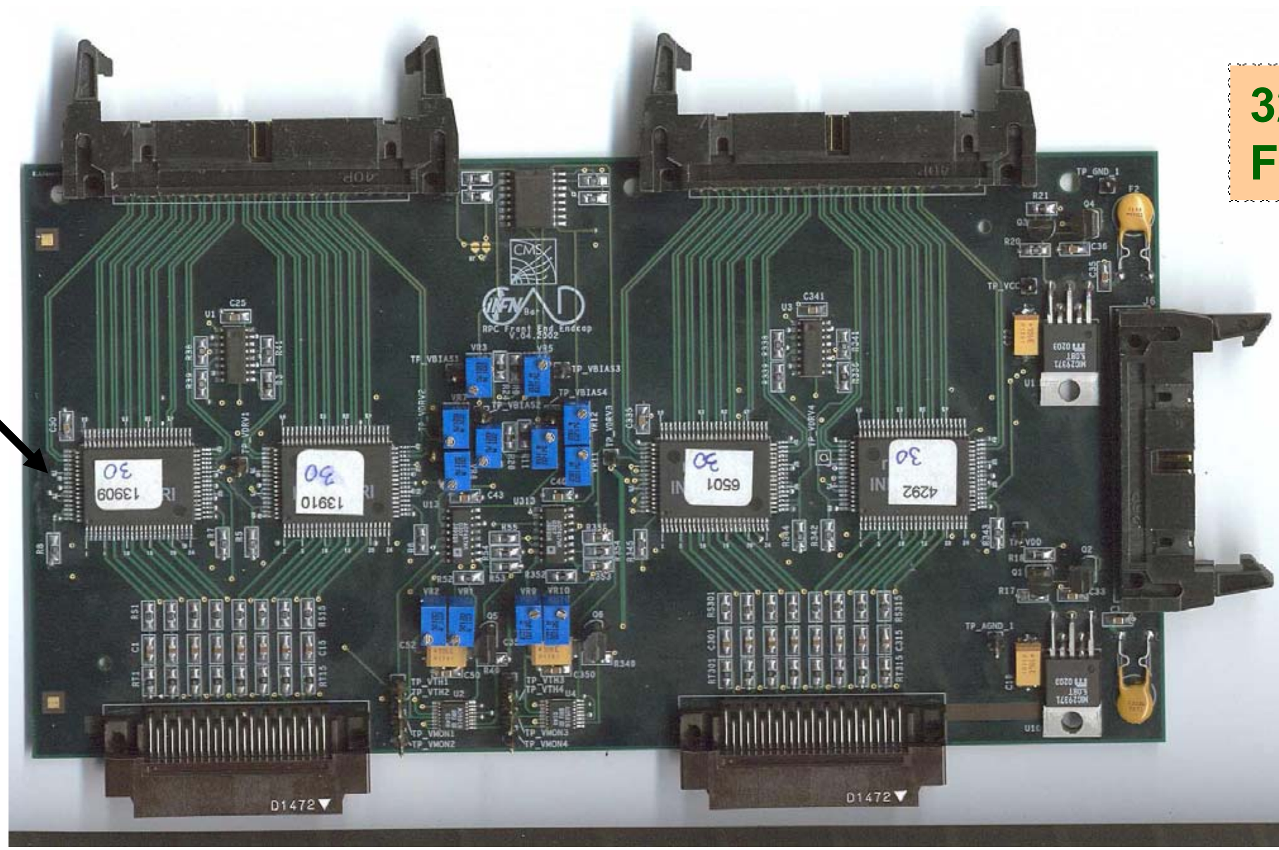
First Prototype RPC

RPC Prototype in 2002



Front End Board for RPC

ASIC
0.14 μ
Bi CMOS

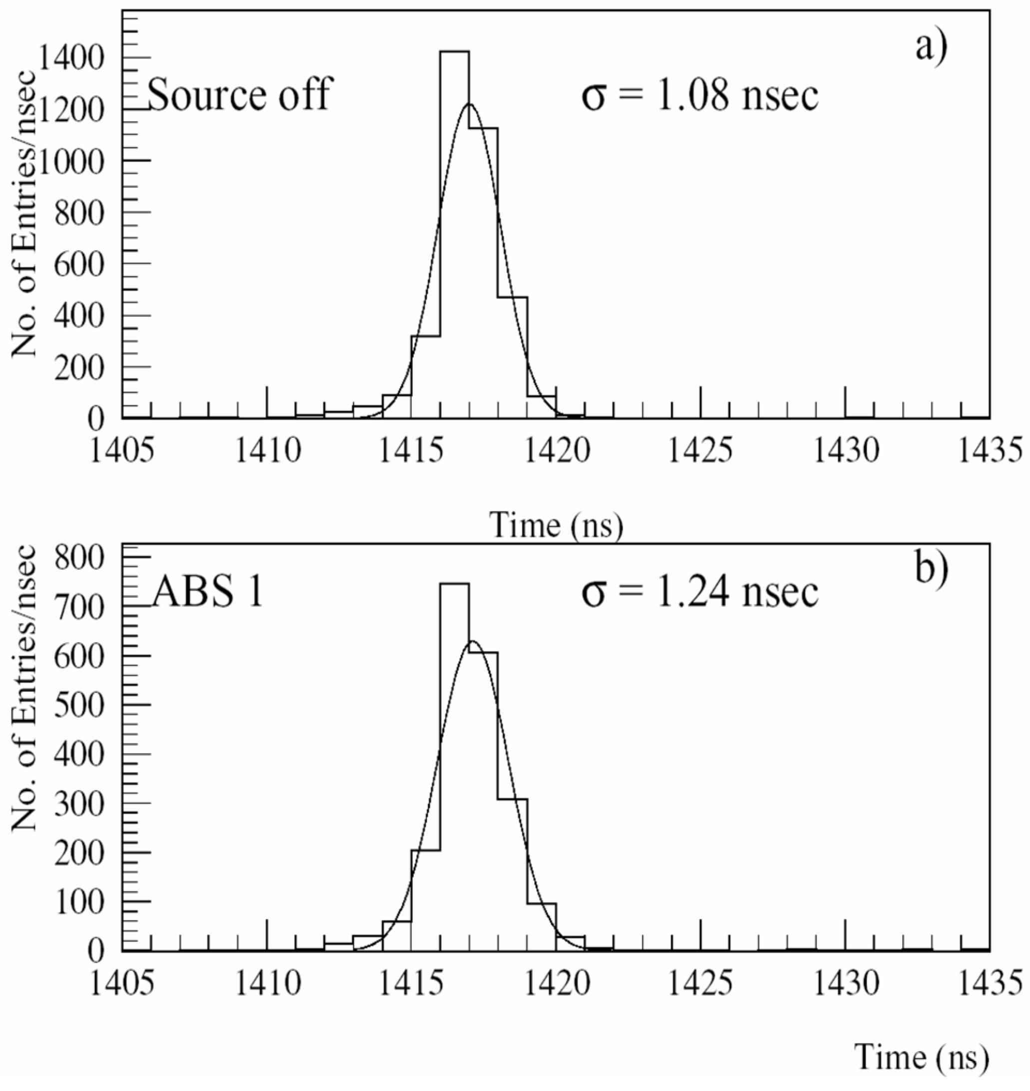


32 Channels
FEB

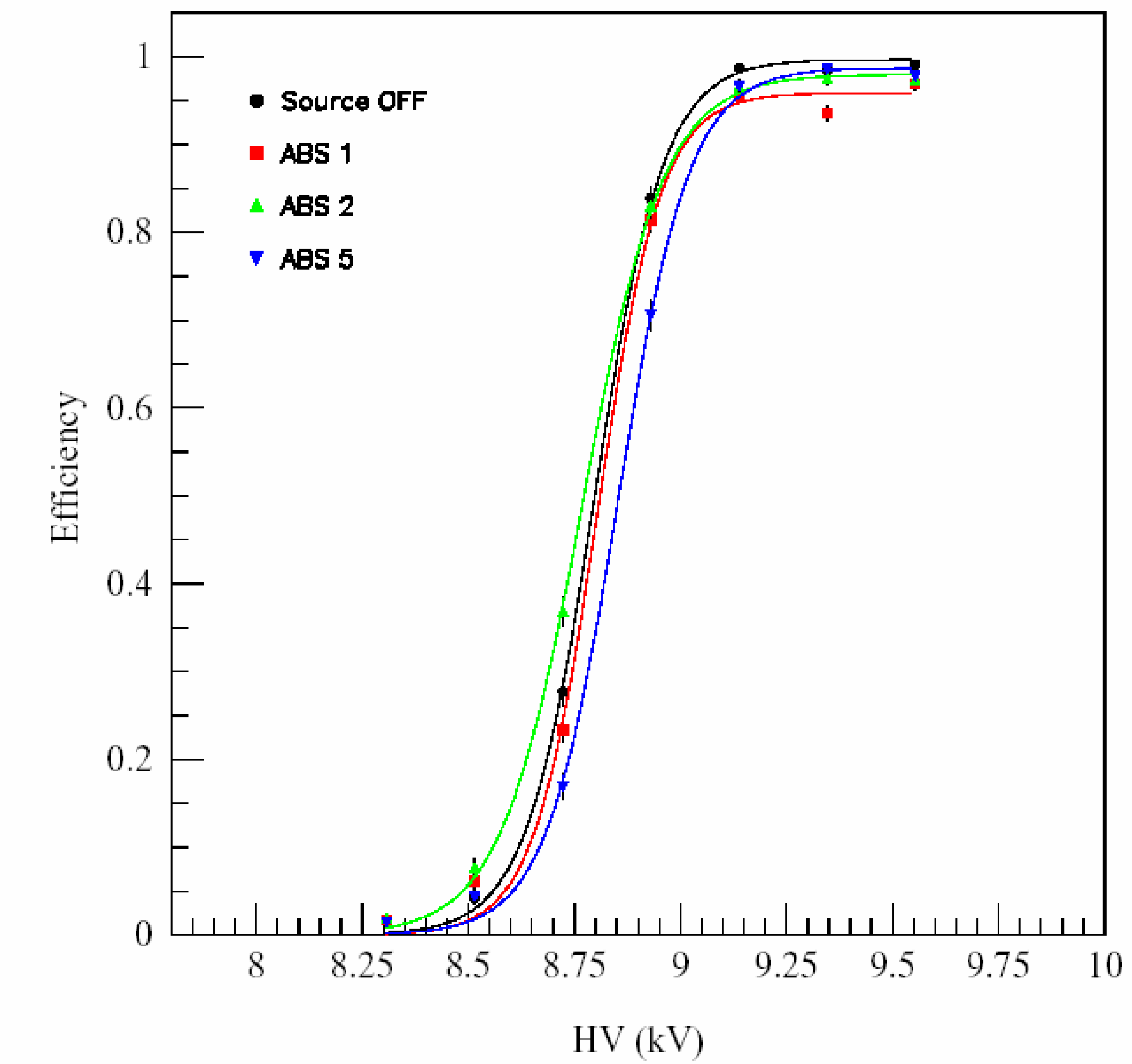
CMS Criteria for good RPC

• Good Rate Capability	> 1 KHz/cm^2
• Efficiency	> 95%
• Good Time Resolution	< 3 ns
• Small Cluster Size	< 3
• Operational Plateau	> 300 V
• Streamer Probability	< 10%

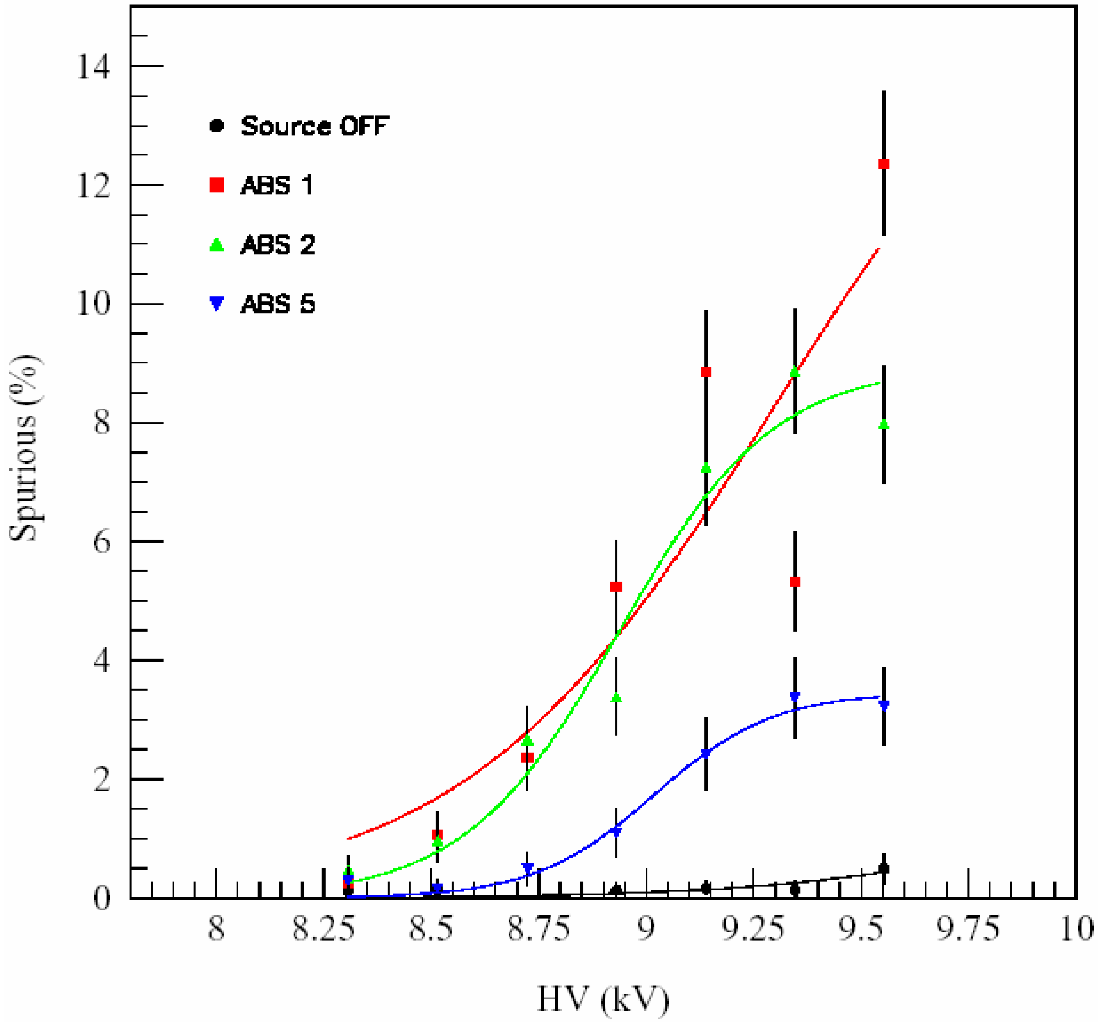
Beam Test Results -I



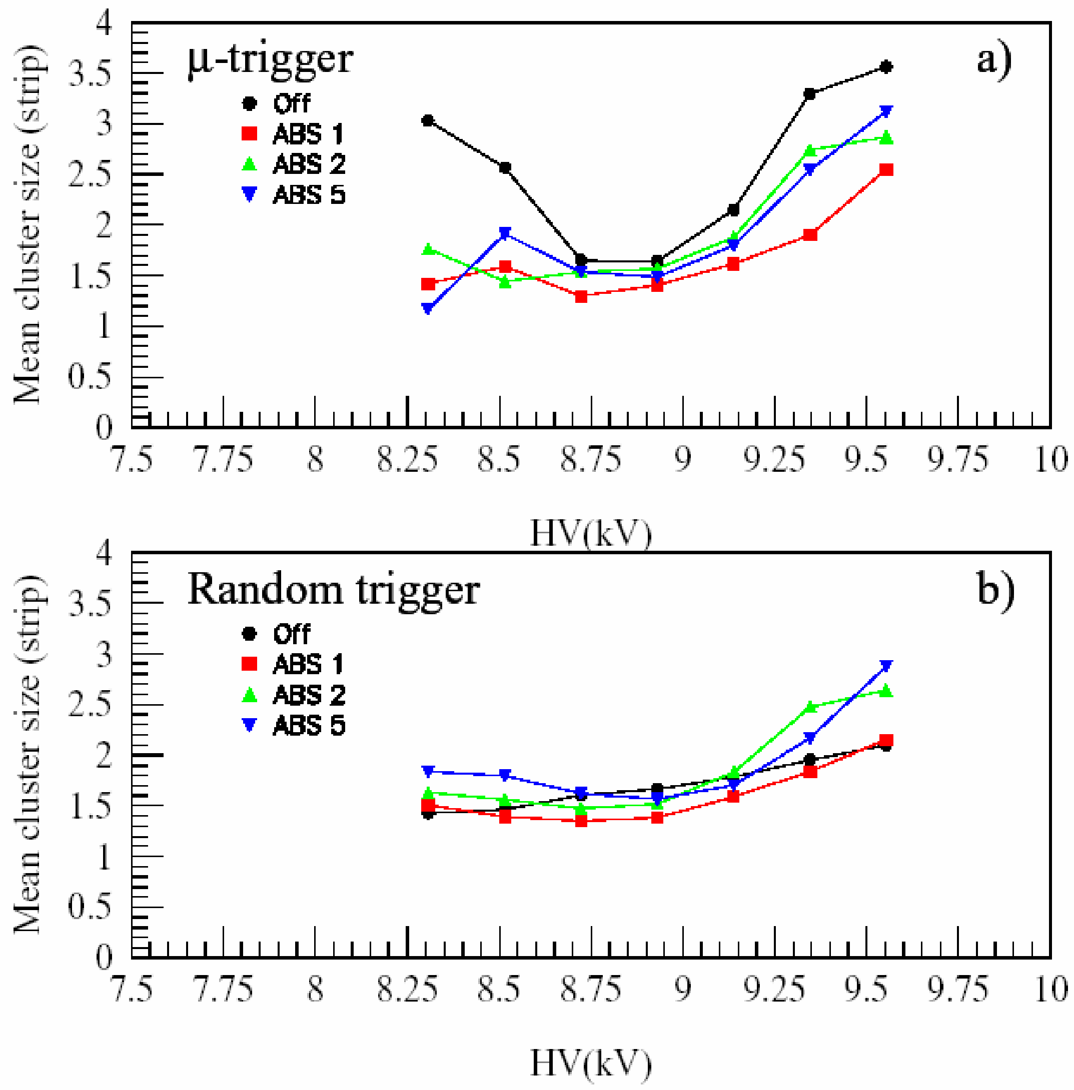
Beam Test results-II



Beam Test Results-III



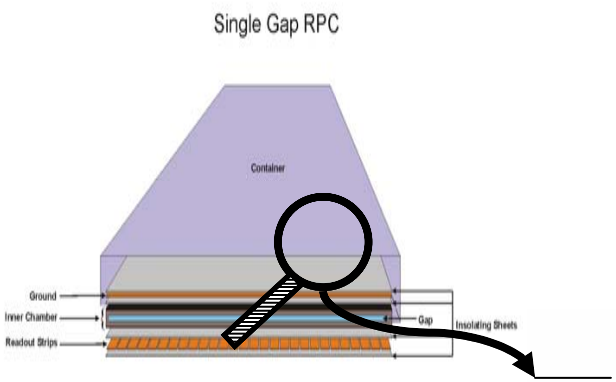
Beam Test Results-IV



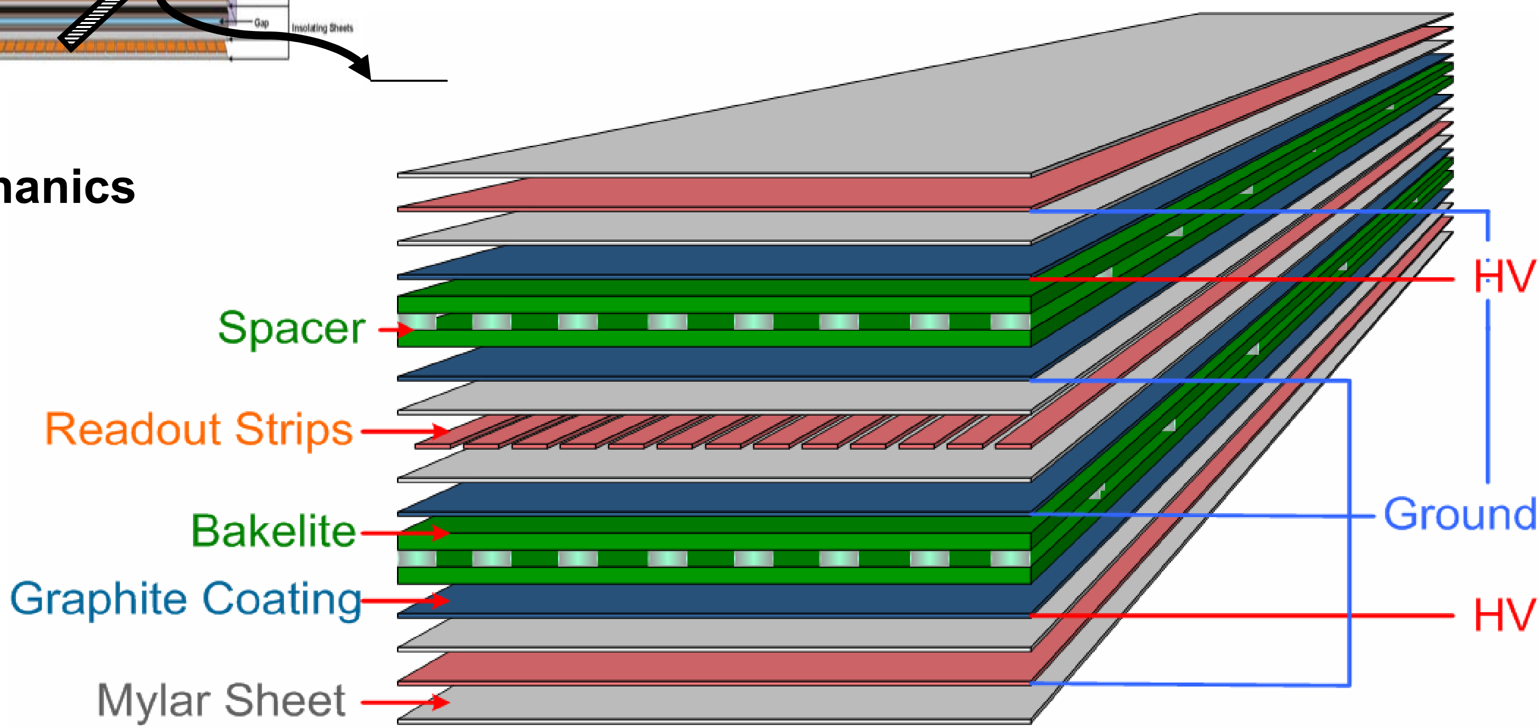
RPC Layout

Final Gas mixture used in all tests

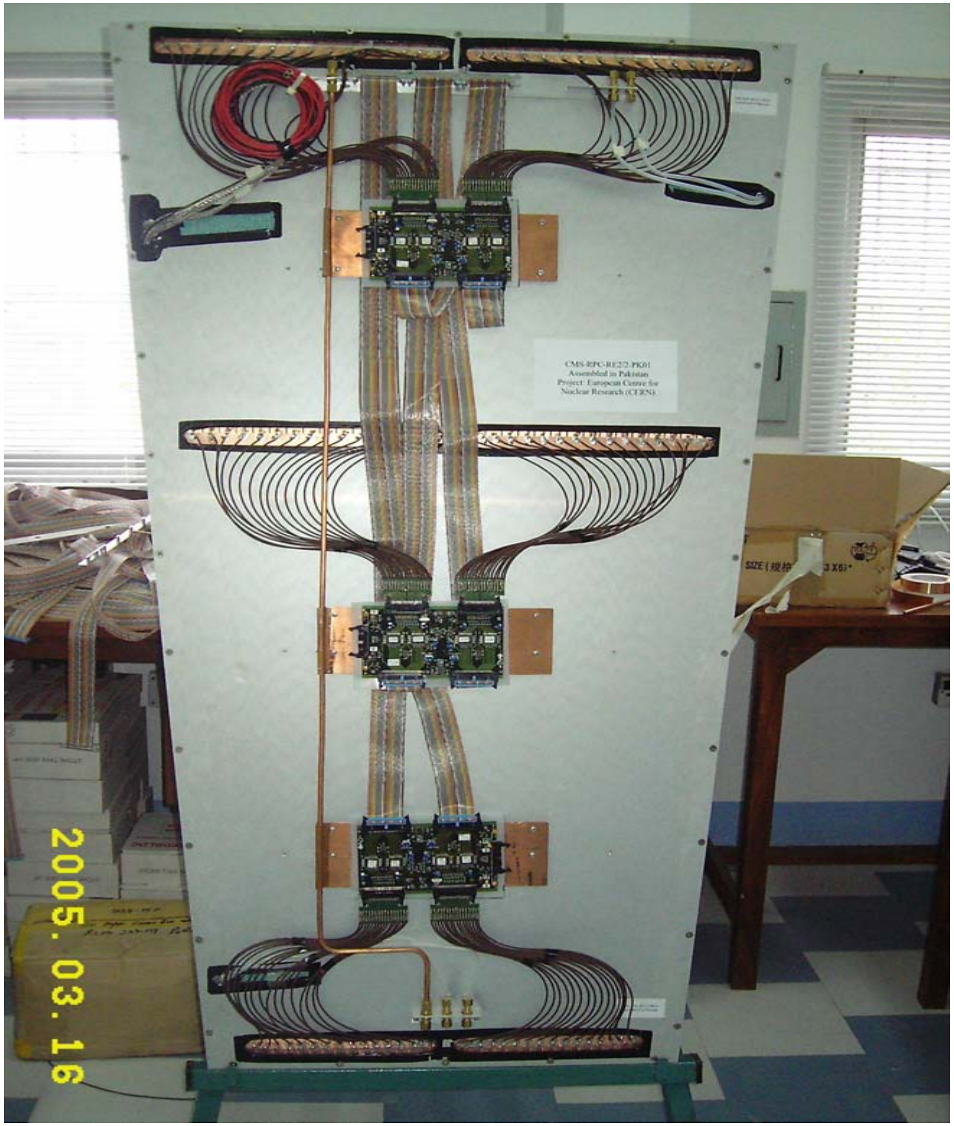
95.5 Freon 3.5 Isob 0.3 SF6 + RH 50% = 5000 ppm



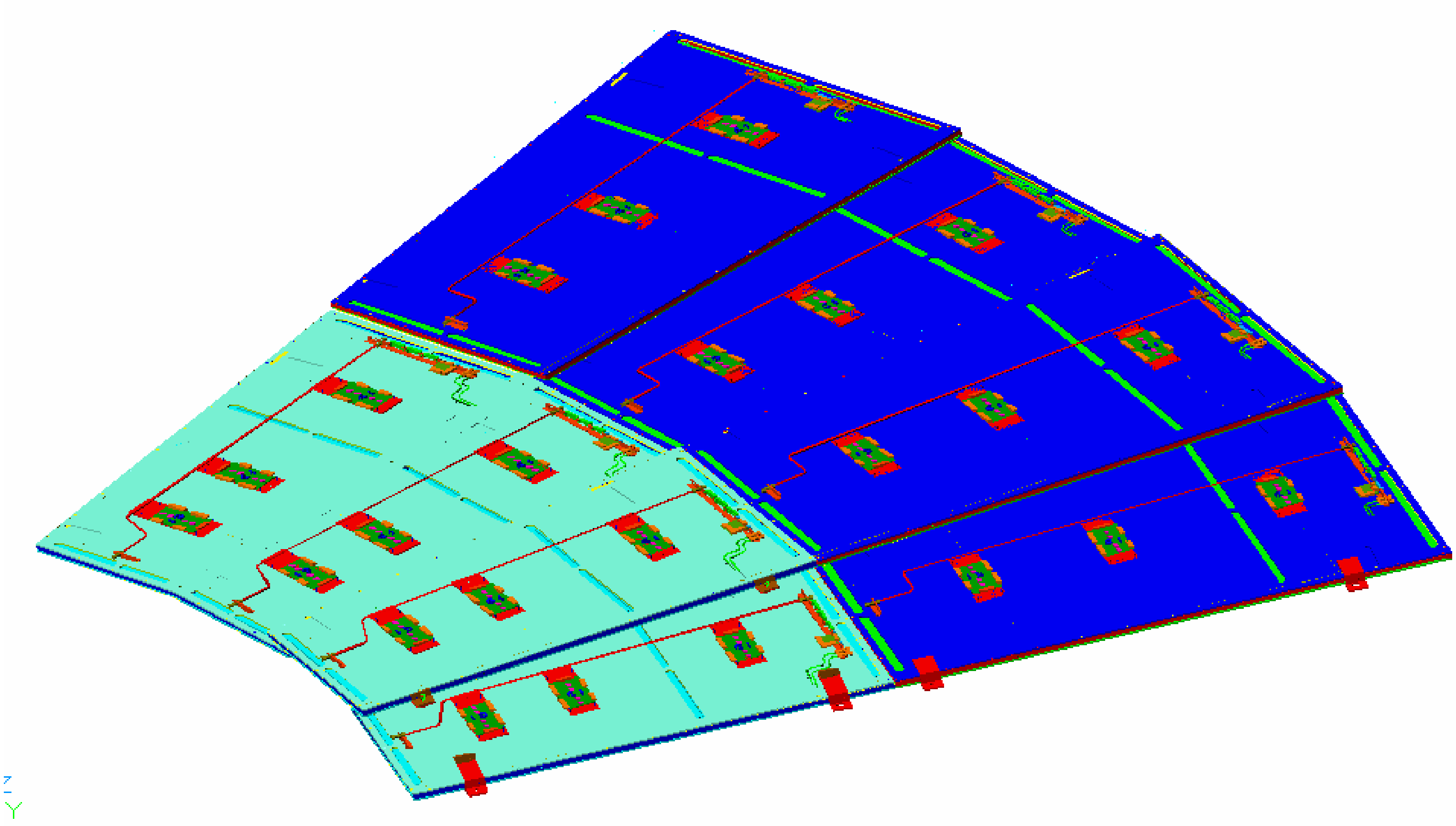
GAP Mechanics



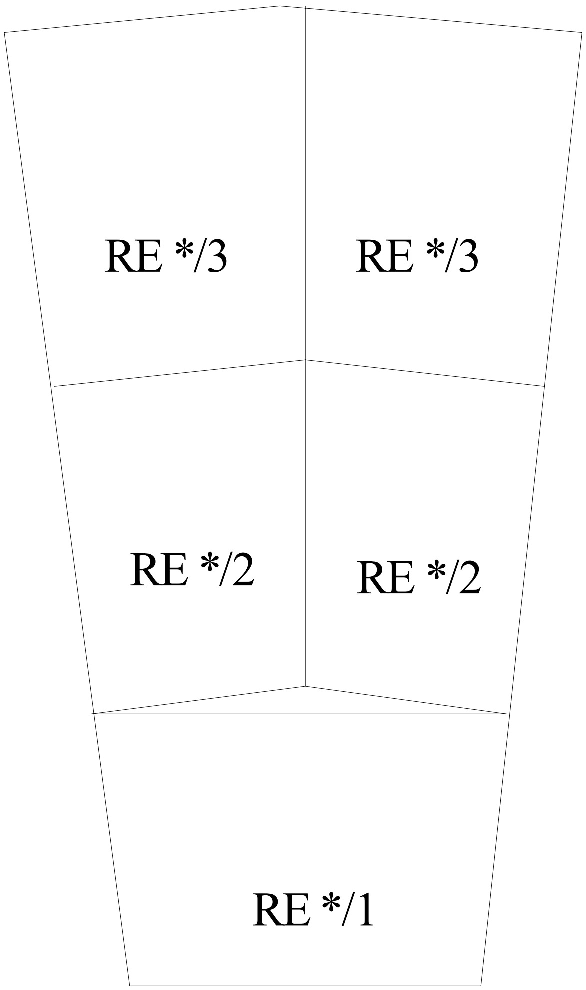
Full-Scale RPC



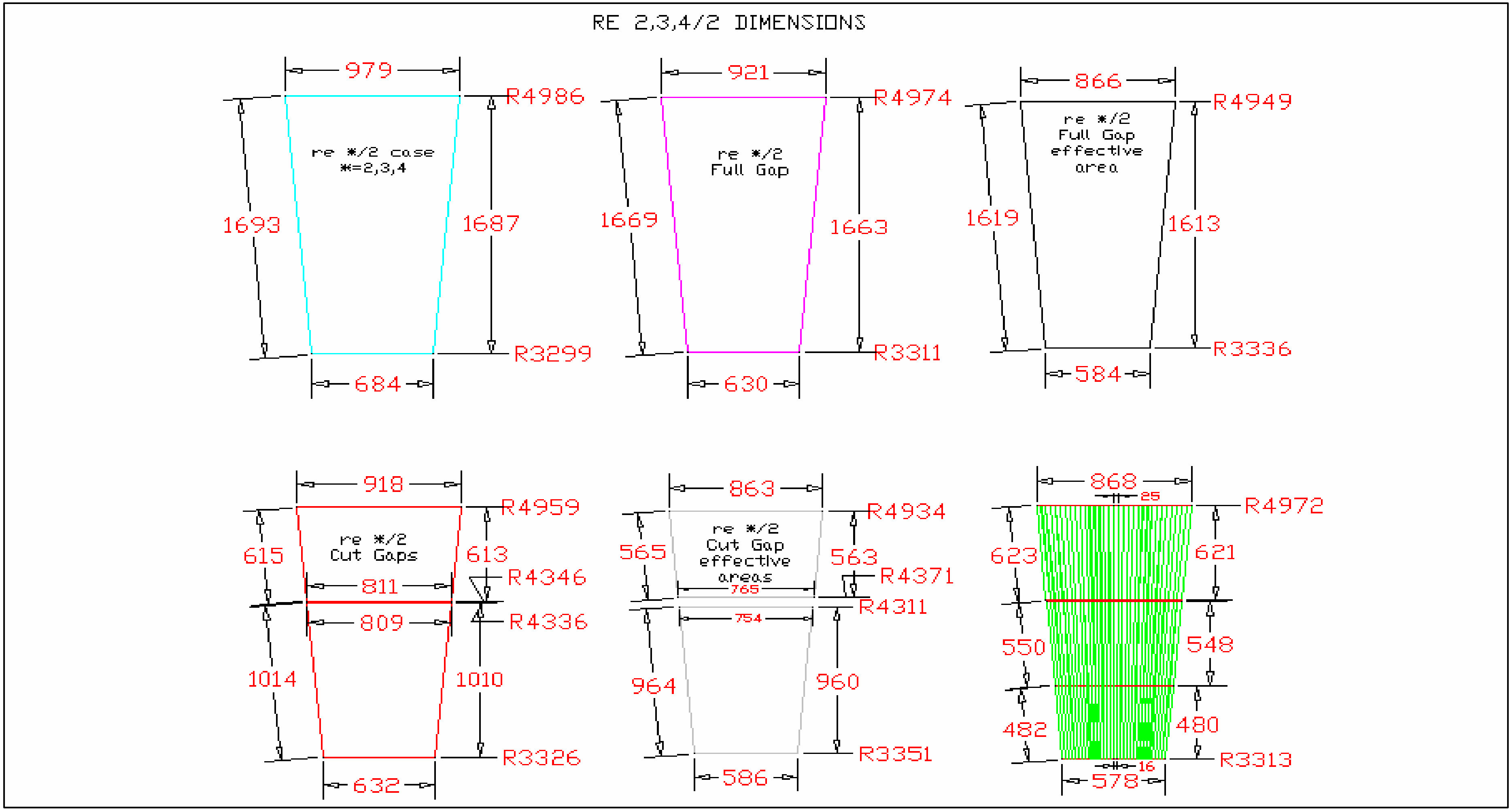
40 ° Sector with Services



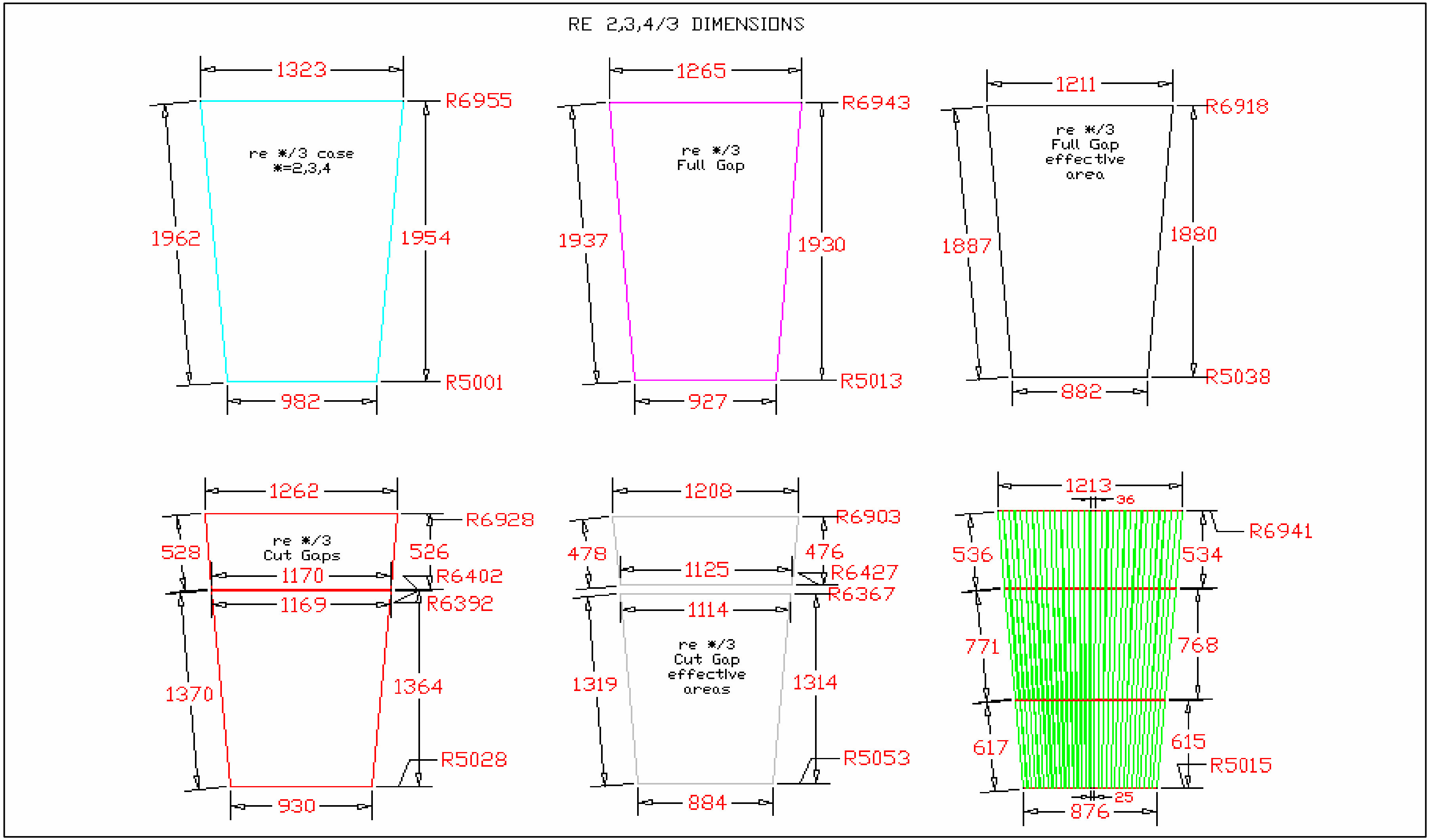
20 ° Sector of Station 2, 3 & 4



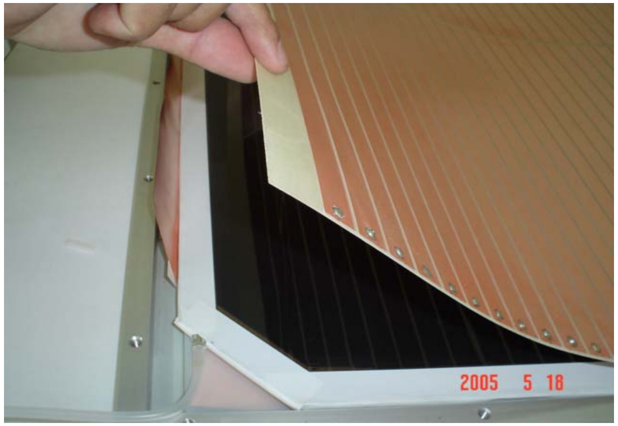
RE */2 dimensions

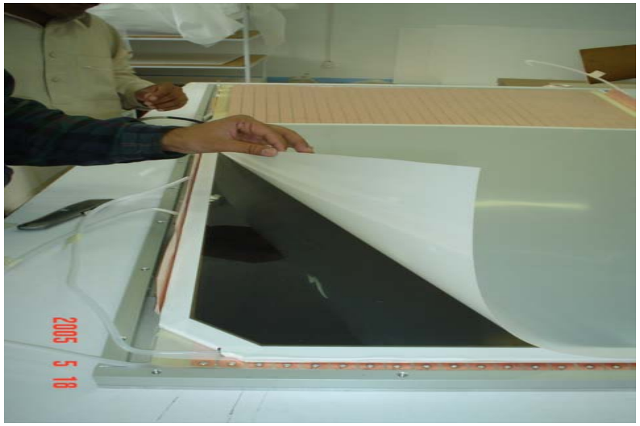


RE */3 dimensions

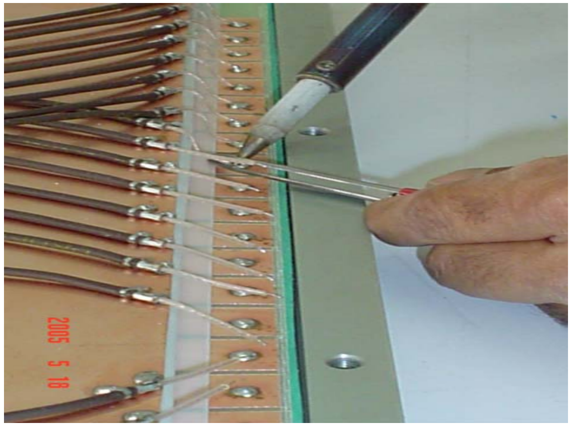


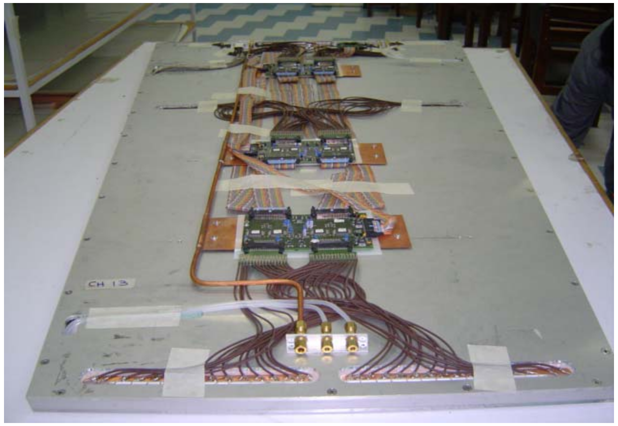
Assembly Procedure





Assembly Procedure





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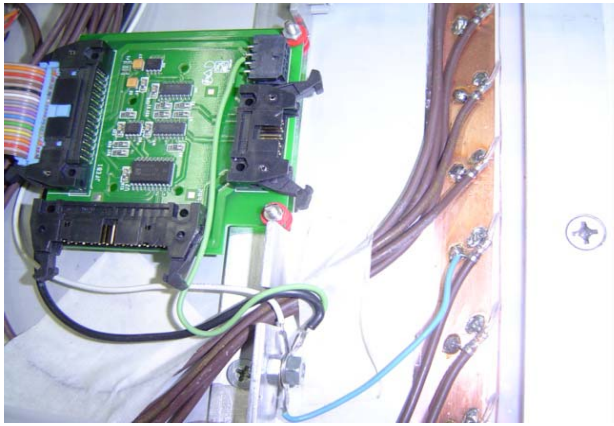
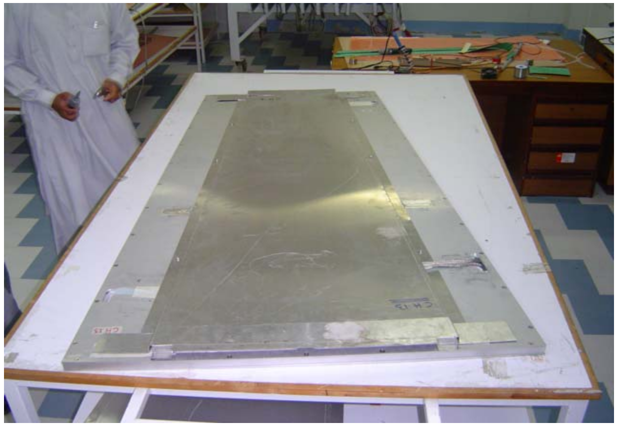
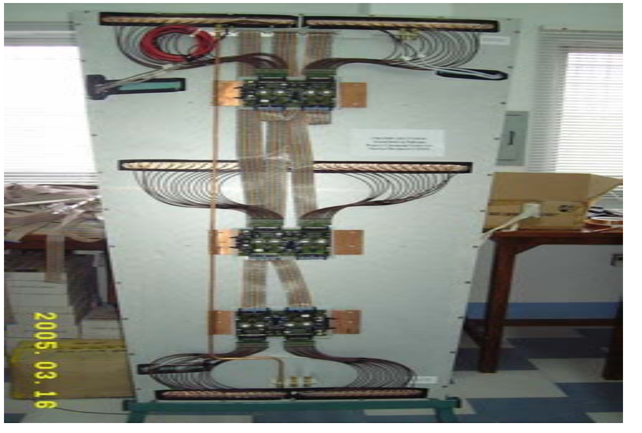
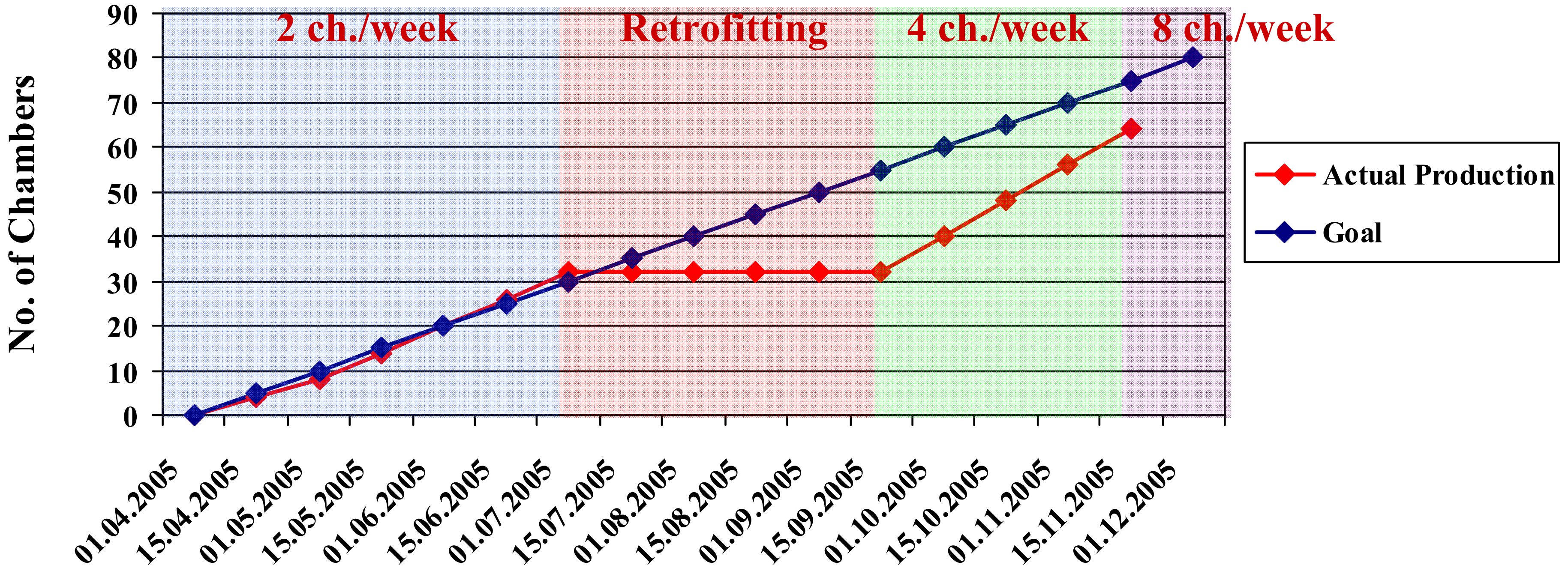




Storage



Chamber Production in Pakistan



Quality Assurance & Control

- Gas flow & leakage test
- Dark current test
- Cosmic ray test

Cosmic Test Facility

- Testing of chamber done using Cosmic Rays
- VME based Data Acquisition System used:
  - **64 Channels TDC**
  - **NI Crate Controller**
- Trigger is generated using scintillators
  - Top & Bottom Layer consist of 8 scintillator each
  - **Scintillators are ORed in a layer**
  - **Trigger is the AND of two ORed top & bottom layers**
- Events are read automatically, stored and analyzed for chamber performance

Cosmic Test Facility

Each chamber consist of 96 readout channels

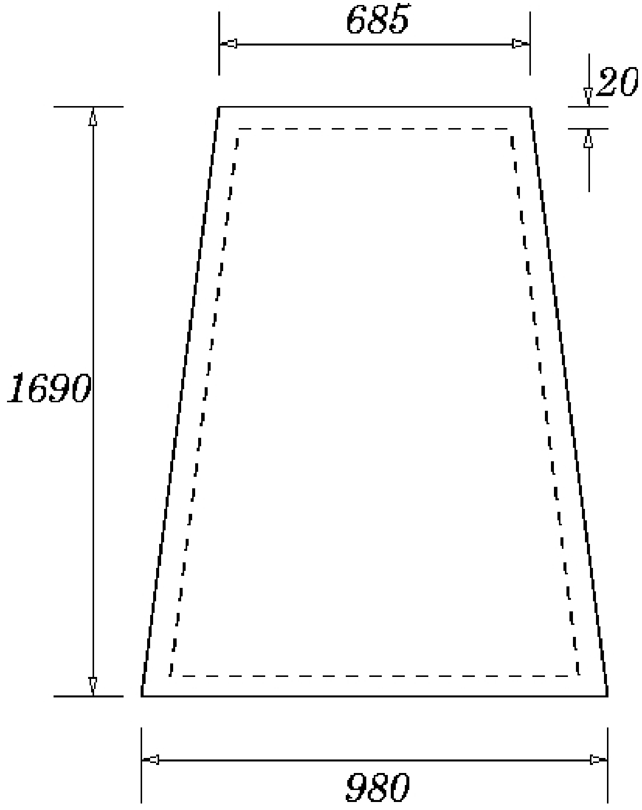
10 Chambers are tested in parallel

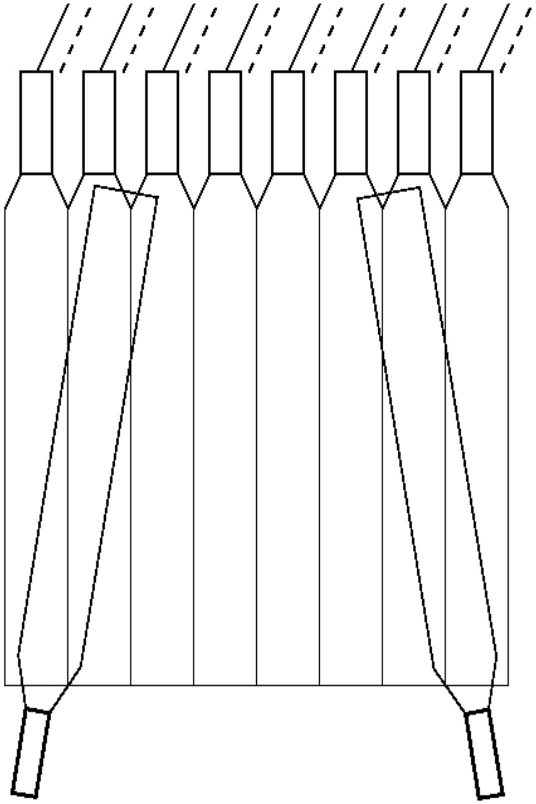
- Gas System is working (10 Chambers can be connected)
  - Gas Mixture (96% Freon, 3.5% Iso-butane, 0.5% SF6)
- HV Available for Chamber (5 modules CAEN, 1526N)
- LV is available for 30 FEBs
- 15 TDCs are available, each can read 64 channels
- Two Layers of scintillators, each layer consist of 8 scint.
- Most Scintillators have efficiency great than 90% Scint. trigger is working properly

Scintillators

- Dimension – 195x20x1 cm
- Can work up to 180 cm
- 18 scintillators
- For the trigger we need 18 scintillators + some spare
- 2 layers – 8 scint. each + 2 additional scint.

Trigger set-up





- **Two movable scintillators to match the chamber's dimension**

Timing

- **Trigger**
  - Cable 52 ns
  - Amplifier 26 ns
  - Discriminator 12 ns
  - Coincidence 16 ns
  - PMT 40 ns
  - **Total Delay Trigger 146 ns**
- **RPC**
  - RPC + FEE 16 ns
  - Cable 25 ns
  - **Total Delay RPC 41 ns**

Scintillator trigger is late by 100 ns compare to signal from RPC


COSMIC
RAY MUON
TELESCOPE


wiener
wiener


113
-000
-001
090

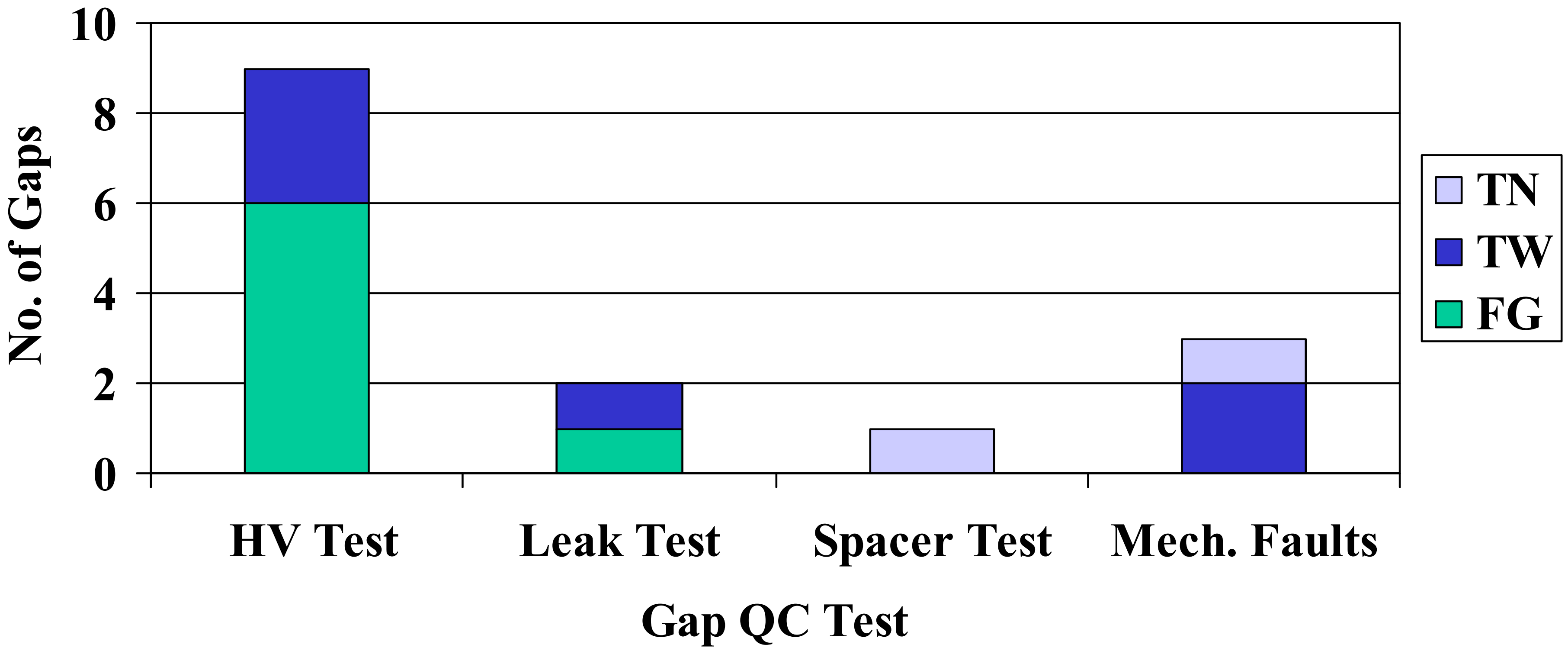
Quality Assurance

- Each component has a unique identifier
- All information is stored in a central database "**Construction Database**"
- For each step of movement a traveler's sheet is filled and signed by the person responsible for QA
- All test results are stored in the database

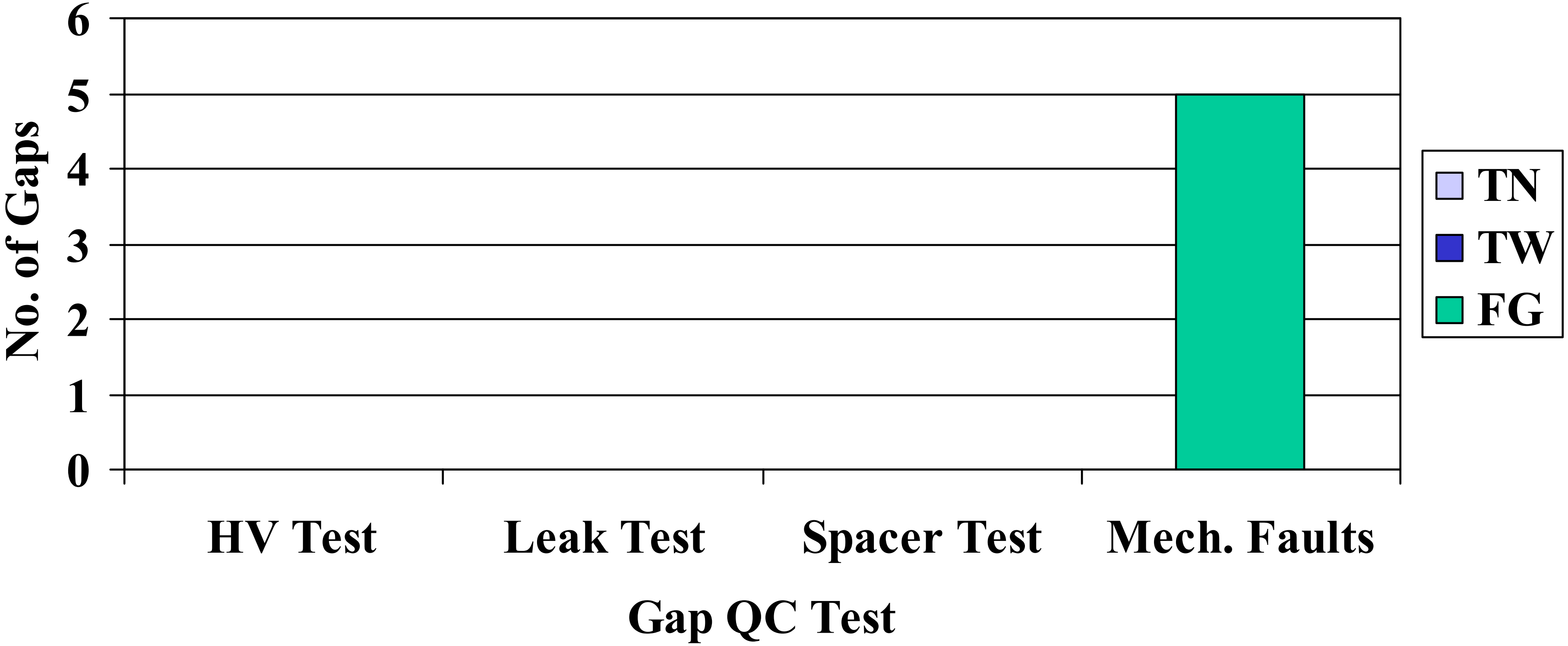
Quality Assurance (Gaps)

- **Visual Test**
  - Random check of dimensions
  - HV connectors and gas inlet/outlet
- **Leakage Test**
  - Checked with 20 mbar over pressure
- **Spacer Test**
  - Template sheet is used, 5 N pressure is applied
- **Dark Current (V vs I)**
  - Gaps with current more than 5 μA are rejected

RE-2/2 Gaps QC (Total 120 Gaps)



RE-2/3 Gaps QC (Total 120 Gaps)



Quality Assurance (Chambers)

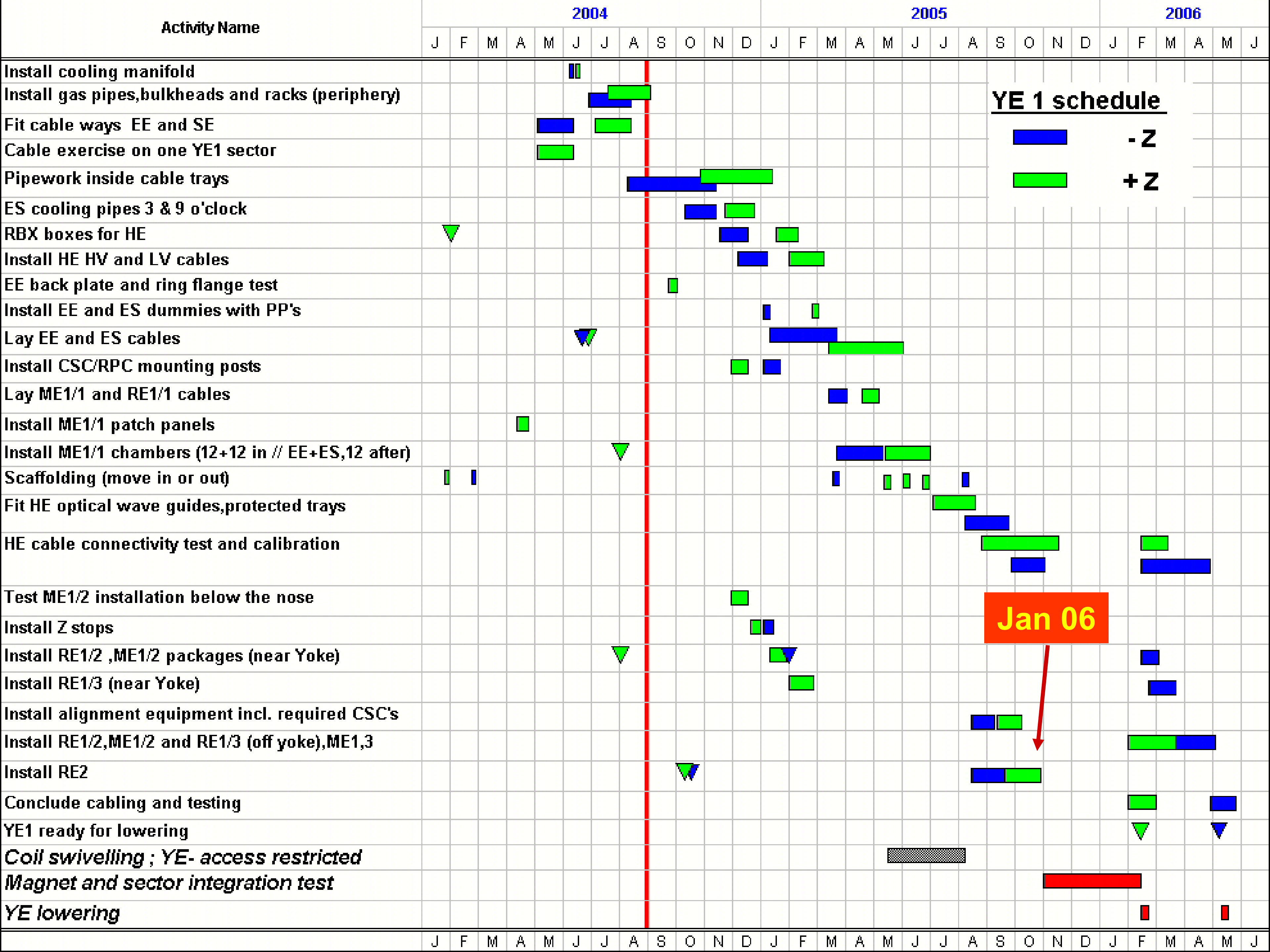
- All chambers are **inspected visually** after assembly
- Chambers are conditioned using the gas mixture, **8 volume changes**
- HV of **8.6 kV** is applied for 6 hours and the behavior of dark current is observed. More than 0.5 μA variation chamber is rejected

Quality Assurance (Chambers)

- HV is varied:
  - **8.6, 8.8, 9.0, 9.2, 9.3, 9.4, 9.5 & 9.6 kV**
- For each HV point 20,000 events are taken
- Using the data following parameters are obtained:
  - **Strip Occupancy**
  - **Efficiency**
  - **Cluster Size**

Quality Assurance (Chambers)

- **Strip Occupancy**
  - Noisy and/or dead channels are identified
  - More than **2** noisy or dead channels, chamber is rejected
- **Efficiency**
  - Chamber is rejected if $\varepsilon < 95\%$
- **Cluster Size**
  - Chamber is rejected if cluster size is greater than **3.0**


Activity Name
2004
2005
2006
J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J
Install cooling manifold
Install gas pipes,bulkheads and racks (periphery)
Fit cable ways EE and SE
Cable exercise on one YE1 sector
Pipework inside cable trays
ES cooling pipes 3 & 9 o'clock
RBX boxes for HE
Install HE HV and LV cables
EE back plate and ring flange test
Install EE and ES dummies with PP's
Lay EE and ES cables
Install CSC/RPC mounting posts
Lay ME1/1 and RE1/1 cables
Install ME1/1 patch panels
Install ME1/1 chambers (12+12 in // EE+ES,12 after)
Scaffolding (move in or out)
Fit HE optical wave guides,protected trays
HE cable connectivity test and calibration
Test ME1/2 installation below the nose
Install Z stops
Install RE1/2 ,ME1/2 packages (near Yoke)
Install RE1/3 (near Yoke)
Install alignment equipment incl. required CSC's
Install RE1/2,ME1/2 and RE1/3 (off yoke),ME1,3
Install RE2
Conclude cabling and testing
YE1 ready for lowering
Coil swivelling ; YE- access restricted
Magnet and sector integration test
YE lowering
YE 1 schedule
- Z
+ Z
Jan 06
J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J

Summary

- We started in 1999 with the notion, RPCs are cheap and easy to make. *None is correct.*
- Chambers are now produced at a constant rate.
- For assembly we have gone over the learning curve.
- For the testing (QA/QC), still some problems but situation is under control and improving.
- Testing of 70 chambers in 6 weeks.