Resistive Plate Chambers

History

Resistive Plate Chambers Detectors have been employed in many HEP experiments:

L3 BaBar Belle

- No wires
- High efficiency
- Fast response
- Position measurement
- Low production cost
- Large surfaces

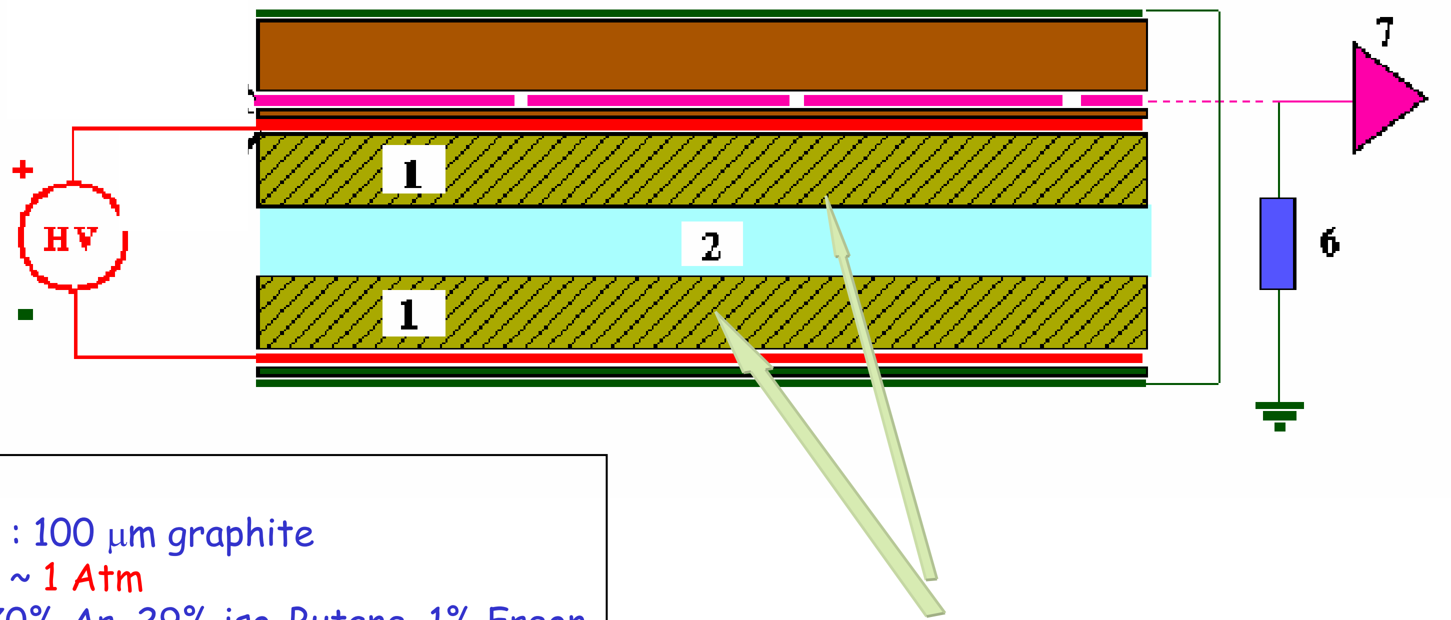
Future

- **LHC experiments (ATLAS CMS ALICE LHCB)**
- **Cosmic rays experiments** (ARGO)

- High rate capability
- Low gas gain operation
- ToF measurement
- Long term performances

The Resistive Plate Chamber (RPC)

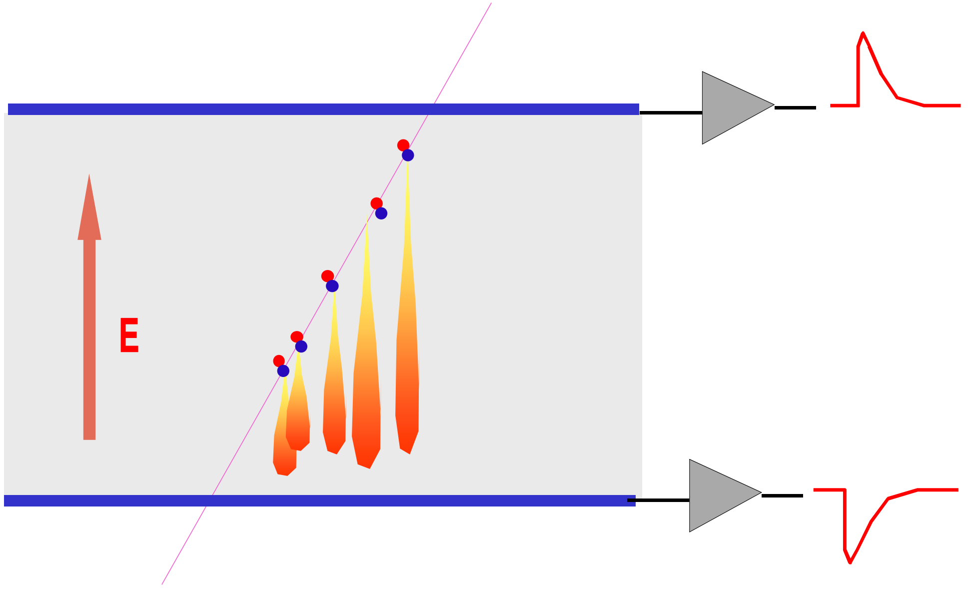
Developed by R. Santonico (Roma) in the early 80'



- 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

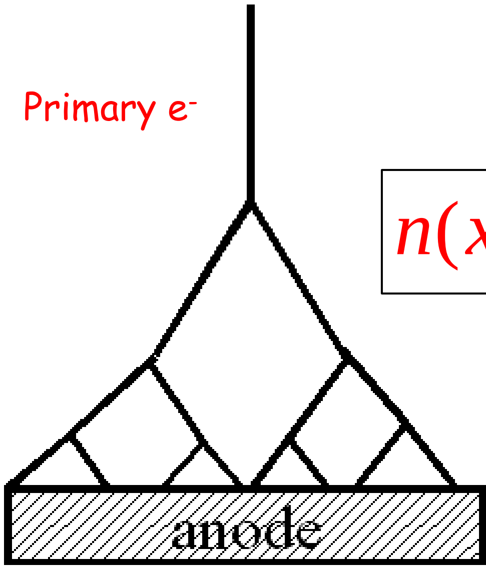
RESISTIVE PLATE CHAMBERS

AVALANCHE CHAMBERS

Different regimes with different HV

The "avalanche" regime

Primary e⁻



α = first Townsend coefficient

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

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

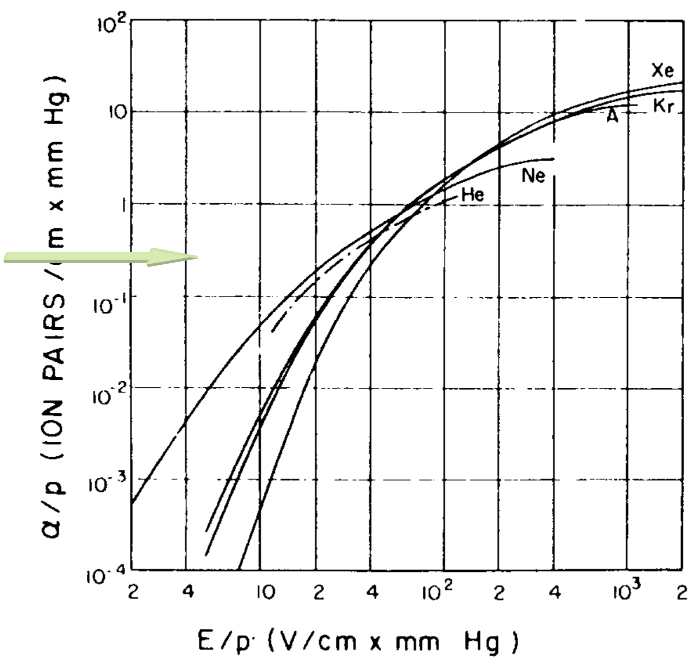
λ: free mean path

Gain

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

Korff approximation

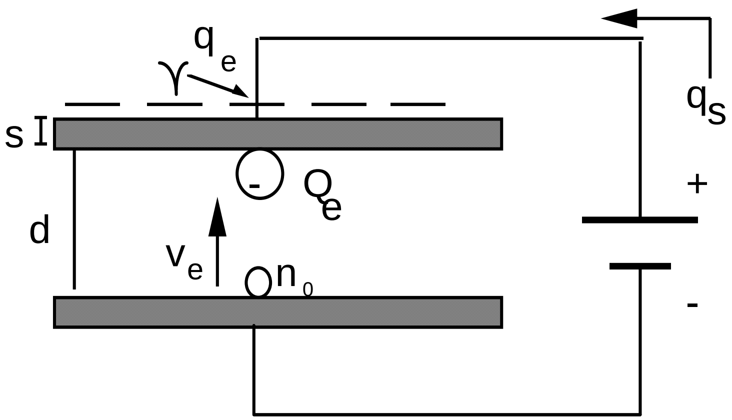
$$\frac{\alpha}{p} = Ae^{-\frac{Bp}{E}}$$



The “avalanche” regime

High rate environment require low gas gain (avalanche operation)

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

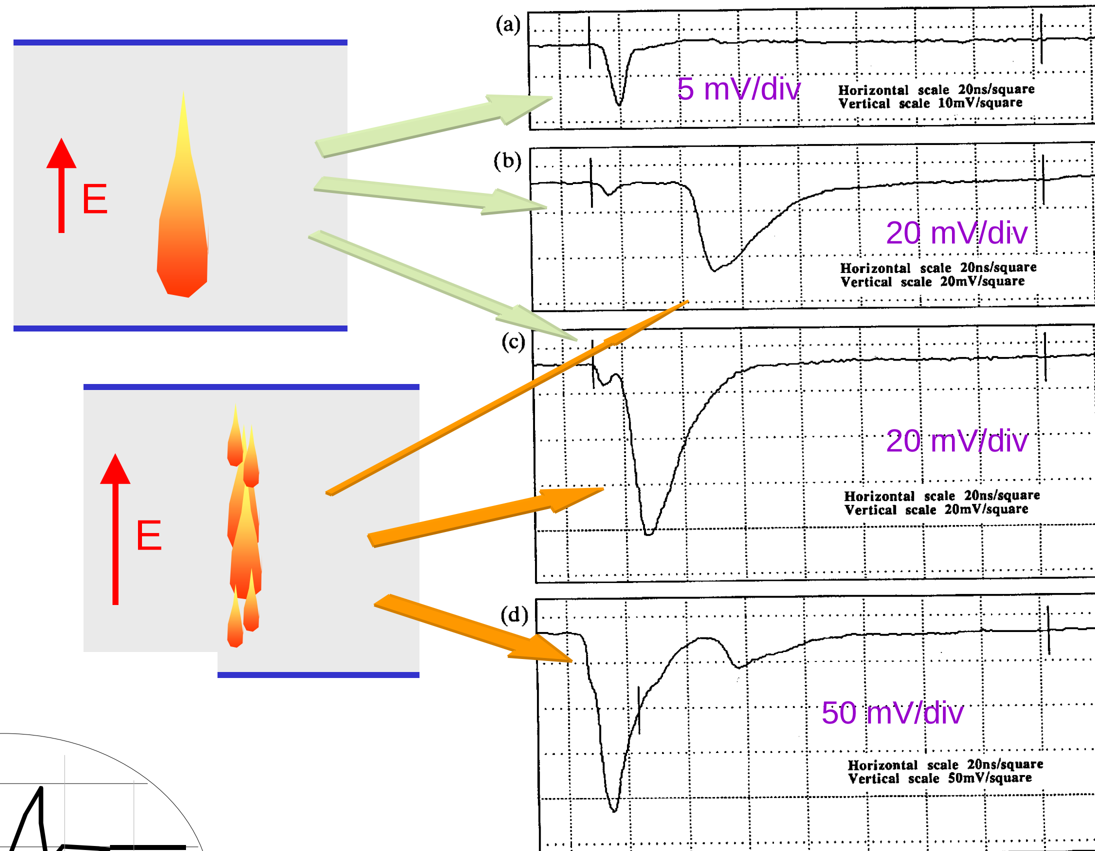


- $k = (\varepsilon_r d/s)/(\varepsilon_r d/s + 2)$
- q_{el} is the electron charge
- n_o is the average size of the primary cluster
- λ is the cluster density in the gas mixture
- ε_r is the relative dielectric constant
- d is the gap width
- s is the electrode thickness

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

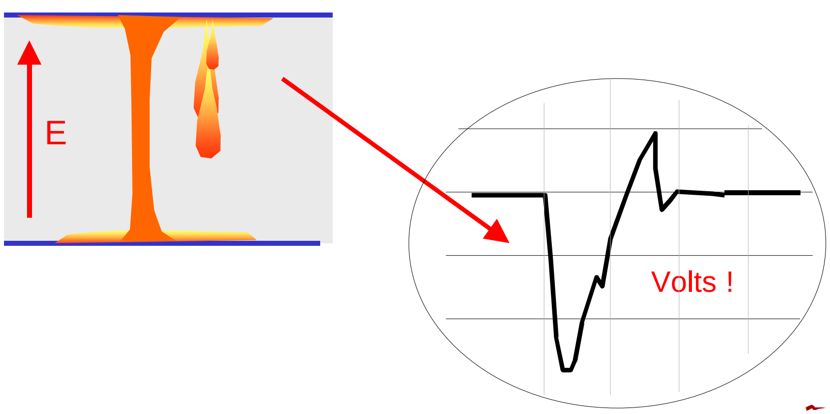
The “streamer” regime

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



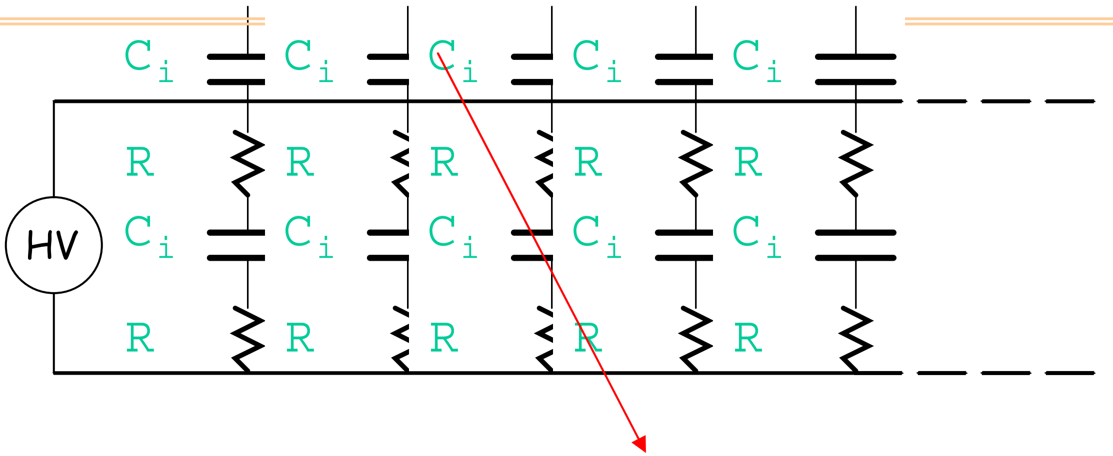
Streamer

Spark



The separation avalanche-streamer decreases with increasing HV

Why resistive electrodes?



The discharge time is defined by the electron drift velocity and the multiplication mechanism

$\tau_{scar} = 1/\eta v_d \sim 10$ ns

The circuit re-charge time is defined by the RC:

$\tau_{circ} = \rho\varepsilon \sim 10$ ms

$\tau_{dis} \ll \tau_{circ}$

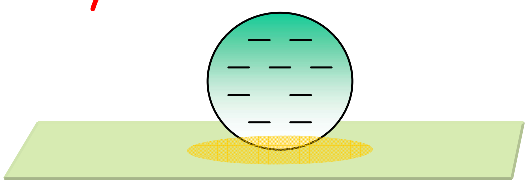
Since τ_{circ} is large ,the electron on the anode will reduce the electric field inside the gas and the discharge will be quenched

During the discharge the bakelite electrodes can be considered perfect dielectrics

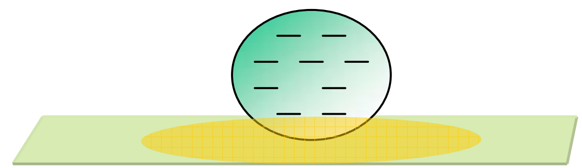
Why resistive electrodes?

Only a small region ~ few mm^2 around the discharge becomes inefficient for a time $\tau \sim 10$ ms

The inefficiency region increases with the decrease of the electrode surface resistivity



$\frac{\rho_{sup}}{\rho_{vol}}$ "large"



$\frac{\rho_{sup}}{\rho_{vol}}$ "small"

The electrode re-charge time increase with increasing volume resistivity

- ρ_{vol} "large" → The deposited charge is collected at low rate → **RPC more "stable"**
- ρ_{vol} "small" → The deposited charge is collected at high rate → **RPC less "stable"**

RPC in avalanche

AT high flux of particles, the rate capability can be improved by:

Decreasing the electrode re-charge time → ...so we need to decrease the bakelite resistivity

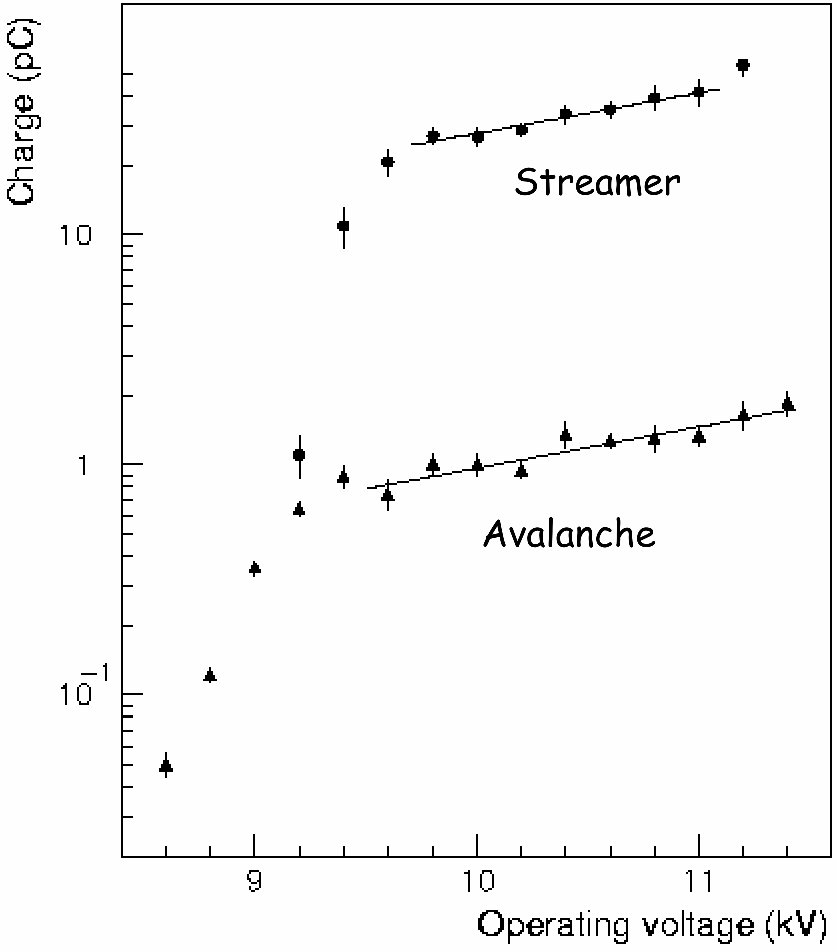
$$\tau = \rho\varepsilon_0\left(\varepsilon_r + \frac{2d}{g}\right)$$

Lowering the discharge intensity and decreasing the electrode region interested by the discharge → ..so we need to make ρ_{sup}/ρ_{vol} large and we need low electric field

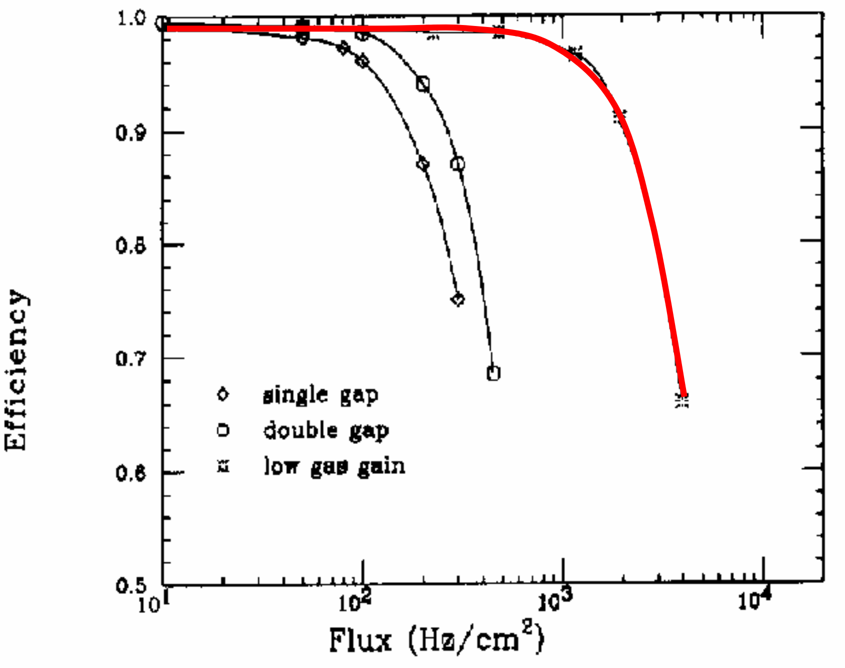
→ **Move the amplification from gap to front-end electronics**

Use electronegative gas (C2H2F4) to stop streamers

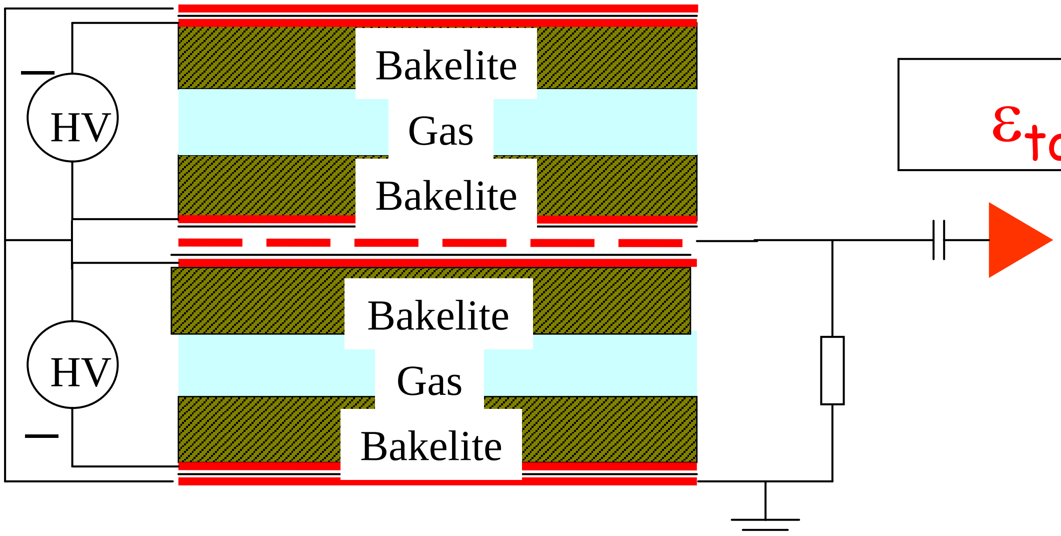
RPC in avalanche



Rate capability increases by a factor 10!

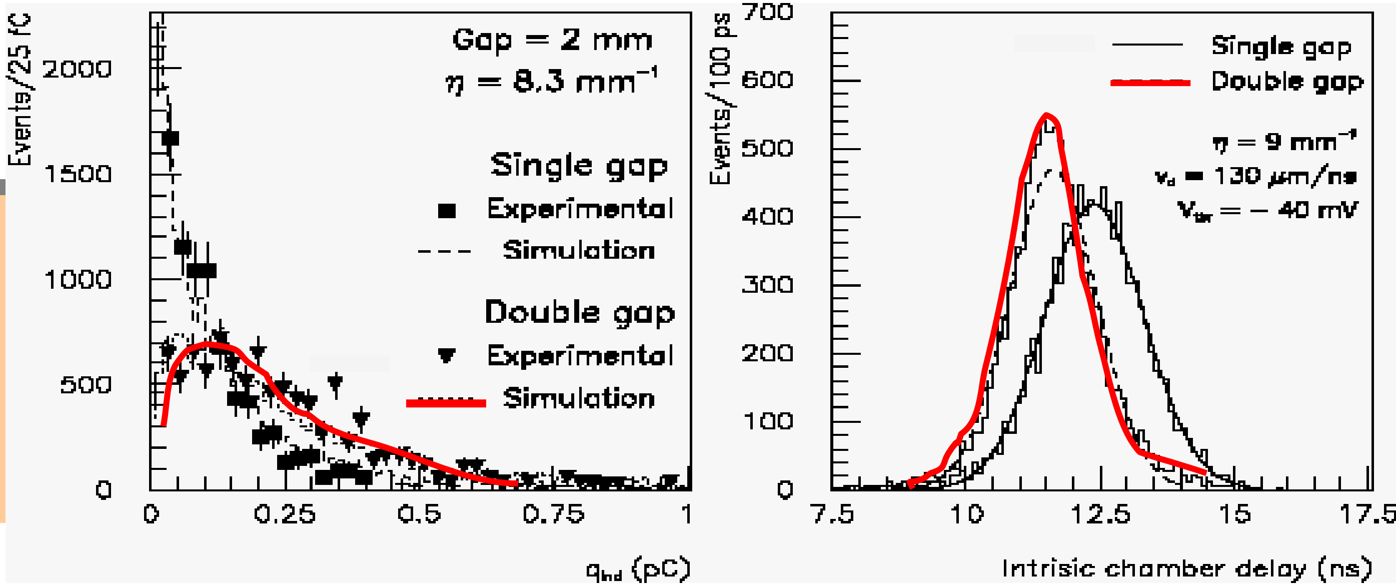


Double gaps……multigaps

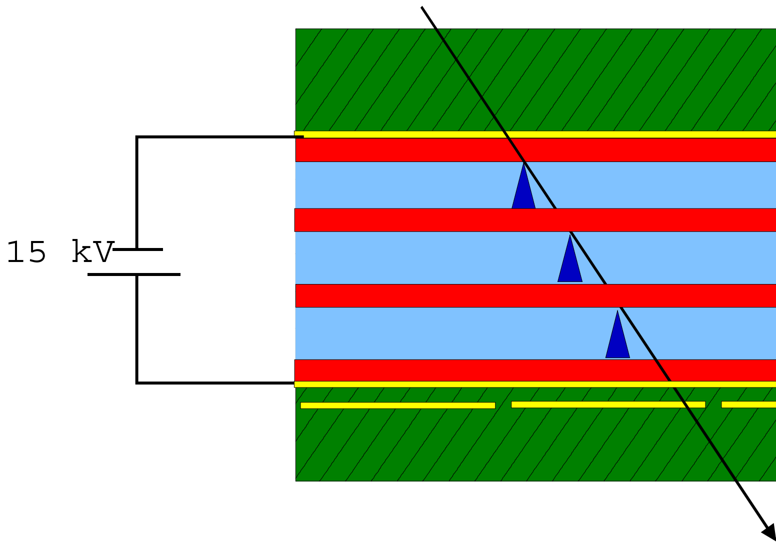


$$\varepsilon_{tot} = \varepsilon_1 + \varepsilon_2 - \varepsilon_1\varepsilon_2$$

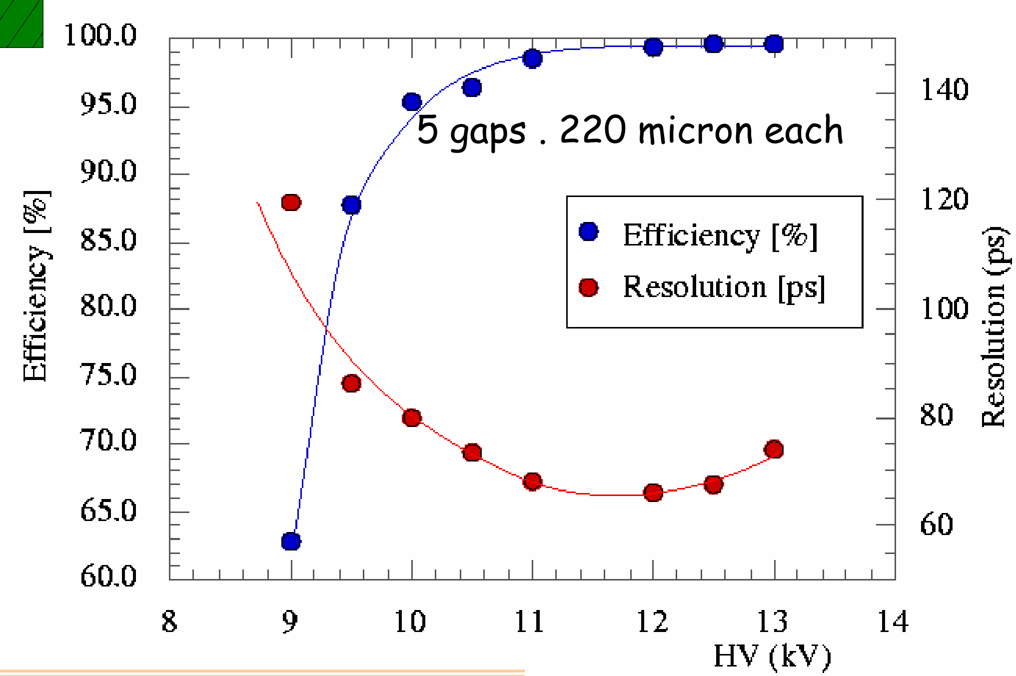
Double gap geometry improves the efficiency and allows safer operation at higher threshold. Also the time resolution improves.



Multigap



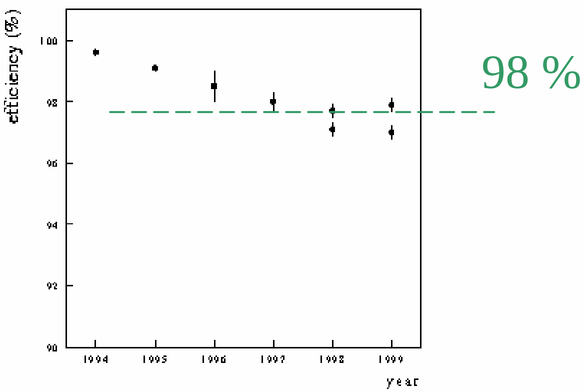
ALICE Multigaps



The L3 experiment

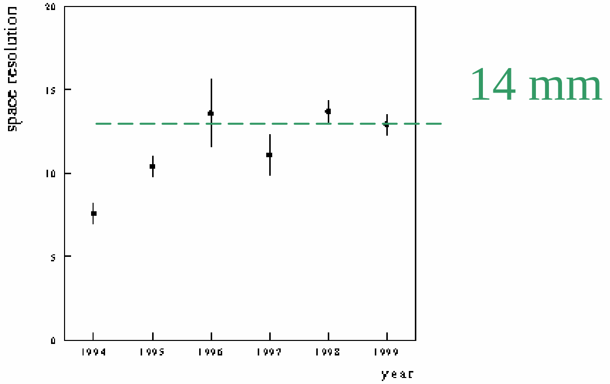
Streamer

- 600 m^2 (single gap)
- 6000 electronics channels
- Double gap geometry
- Streamer mode operation

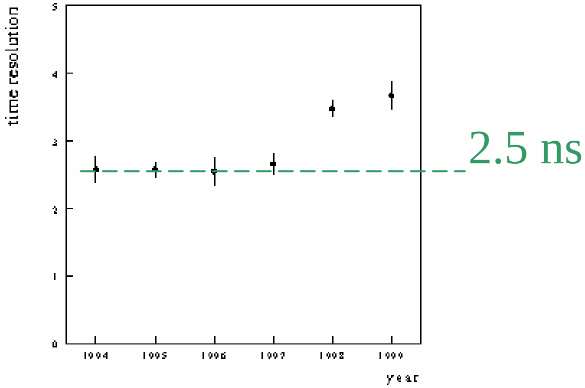


Detector efficiency

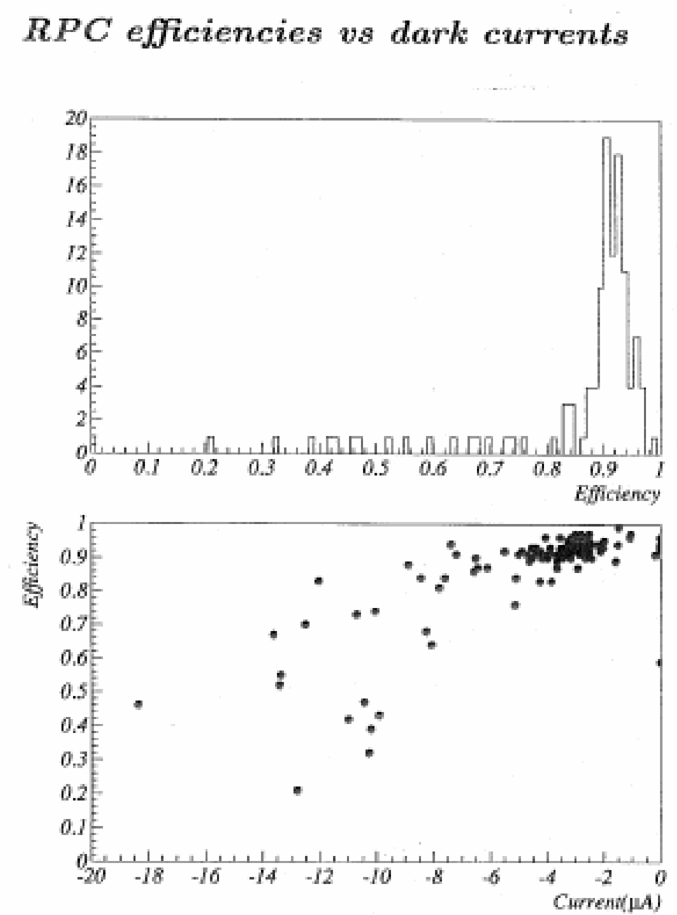
Space resolution



Time resolution



The Belle RPC system



- 2000 m^2 coverage
- Glass electrodes $10^{12}\ \Omega$ cm
- Single gap geometry
- Quasi-avalanche mode operation
- X-Y read-out with independent gaps

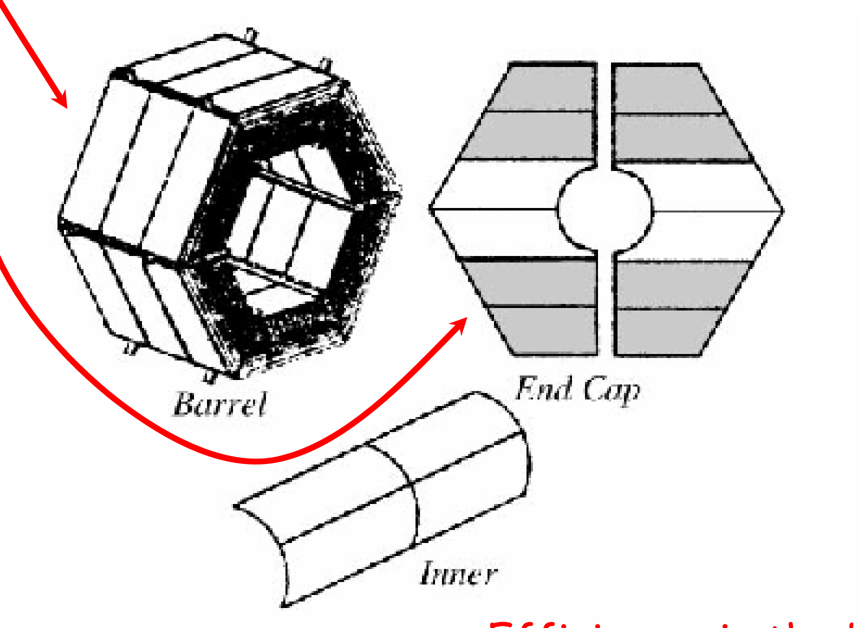
BaBar

streamer

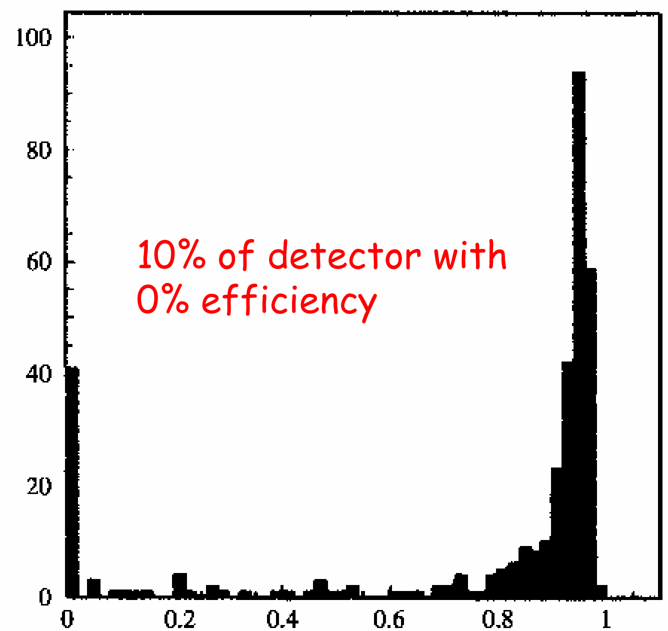
1 barrel and 2 end-cap → total surface : ~ 2300 m^2
56.000 front-end channels in total

about 800 RPCs

Streamer mode:
Argon/tetrafluoroethane/isobutene 48/48/4



Efficiency in the barrel:

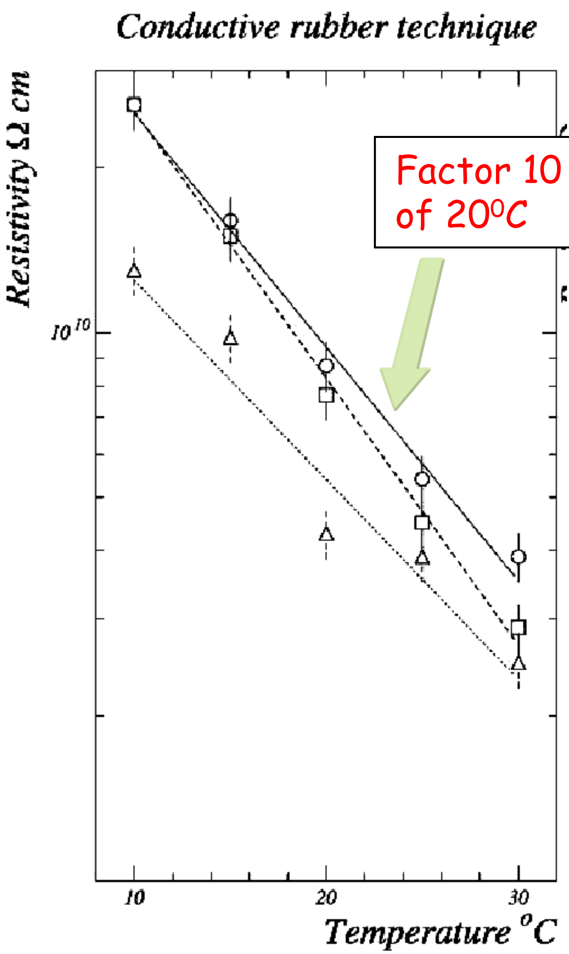


BaBar

streamer

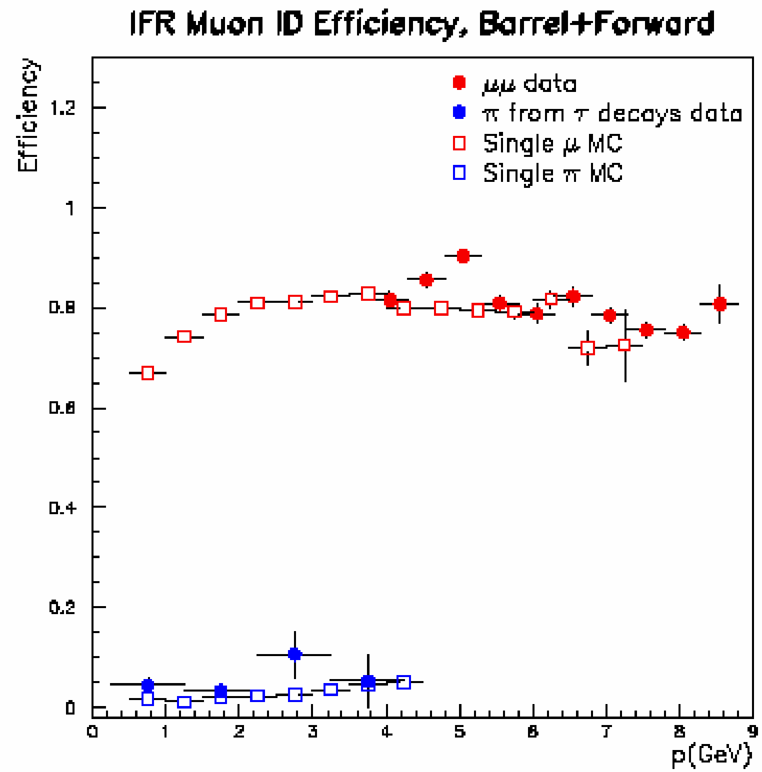
Gap temperature > 35⁰C (Sepyember 1999) → Currents up to ~ 500 μA

The bakelite resistivity decrease with increasing tempera



Factor 10 ina range of 20⁰C

Muon Id. Efficiency



What happened?

Streamer

BAD OIL COATING!!!!

An improved oil coating technic is now used

The gap assembly procedure has been completely revised

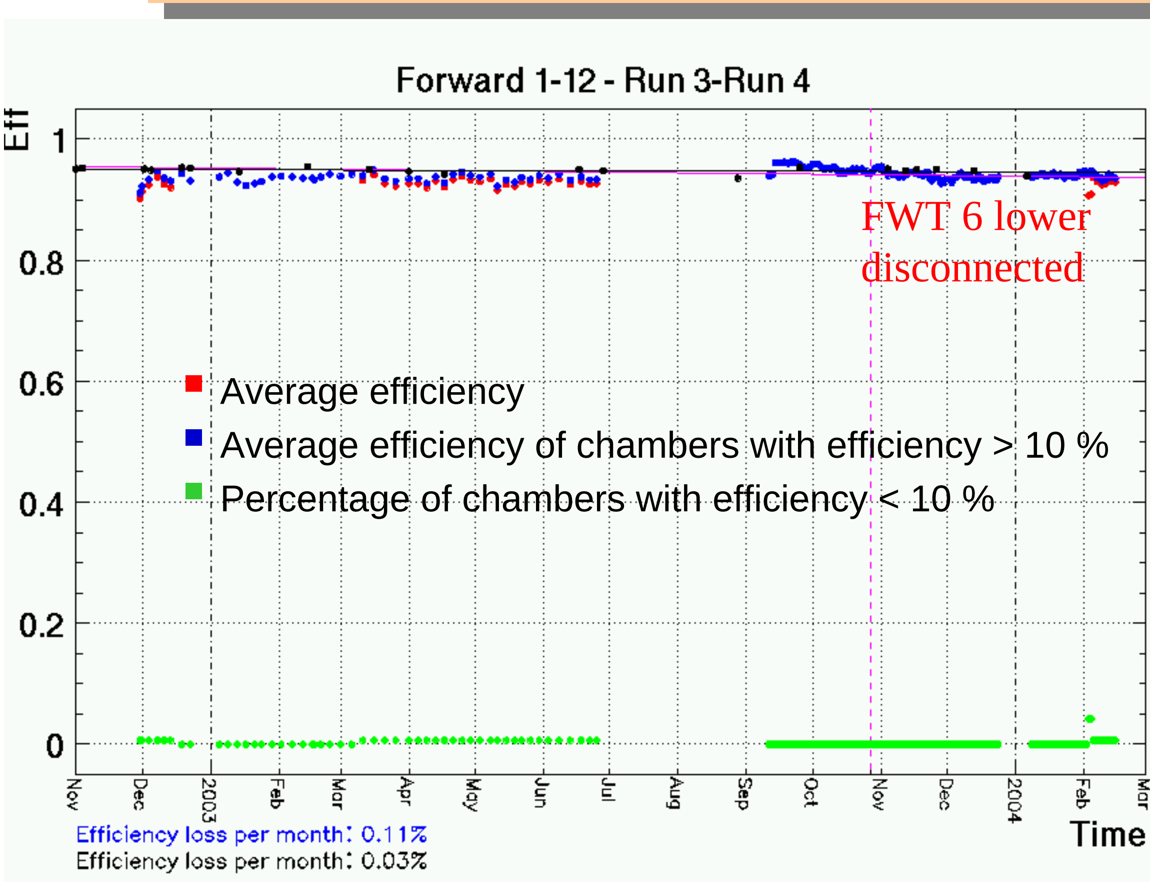
The quality control is more accurate (20% drop rate!!)

New BaBar chambers

streamer

Evaluated with collision data ($e^+e^- \rightarrow \mu^+\mu^-$ events)

Layer 1-12



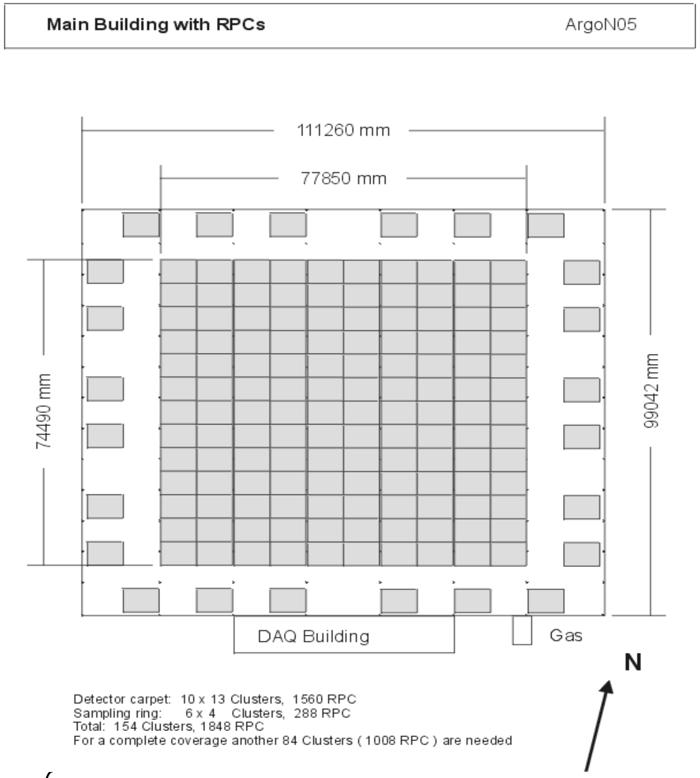
No drop with cosmics (black dots)

Efficiency in Collisions for ***outer layers*** suffers from high background (*voltage divider effect*)

No substantial decrease since installation

ARGO-YBJ

ARGO-YBJ
(Astrophysical Radiation with Ground based Observatory at YangBaJiing, Tibet)

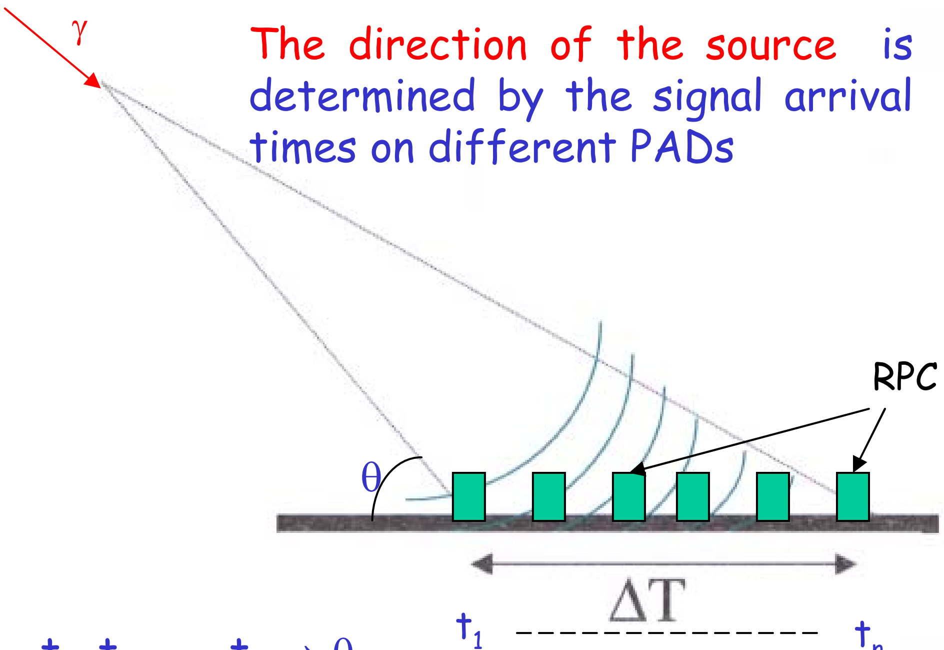


Detection of atmospheric shower with energy > 100 GeV →

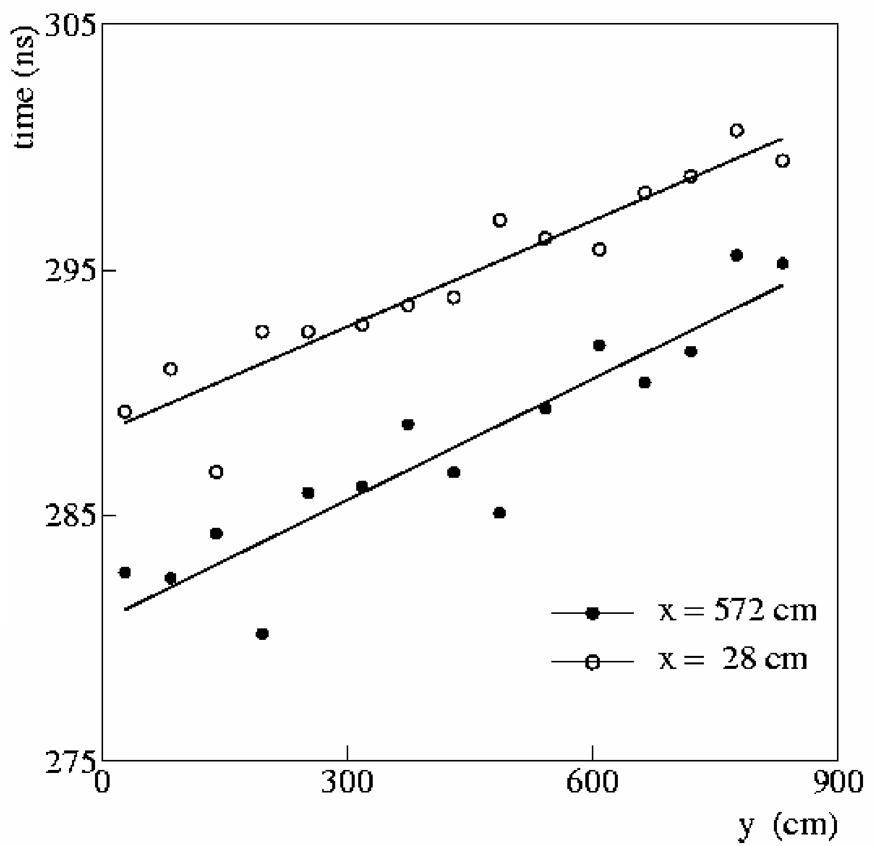
- γ Astronomy with a threshold of ~ 100 GeV
- Diffuse γ rays
- γ-Burst
- Ratio anti p/p
- Spectrum of primary protons

ARGO-YBJ

The direction of the source is determined by the signal arrival times on different PADs



$t_1, t_2, \ldots, t_n \rightarrow \theta$



Good time resolution is needed!!

Δt_{RPC} ~ 1-2 ns $\rightarrow \Delta\theta$ = 1 mrad

$$\frac{Signal}{Background} \propto \frac{1}{(\Delta\theta)^2}$$

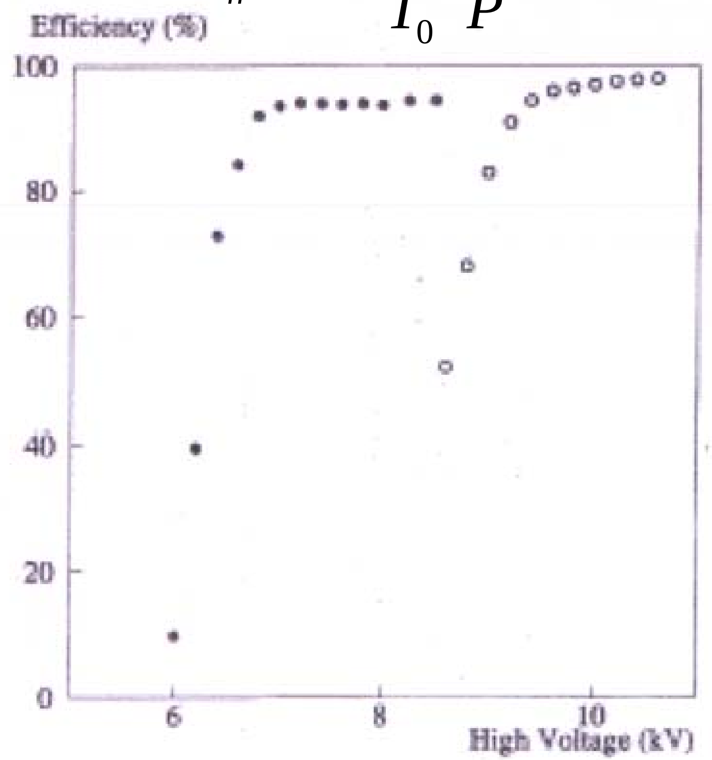
ARGO-YBJ

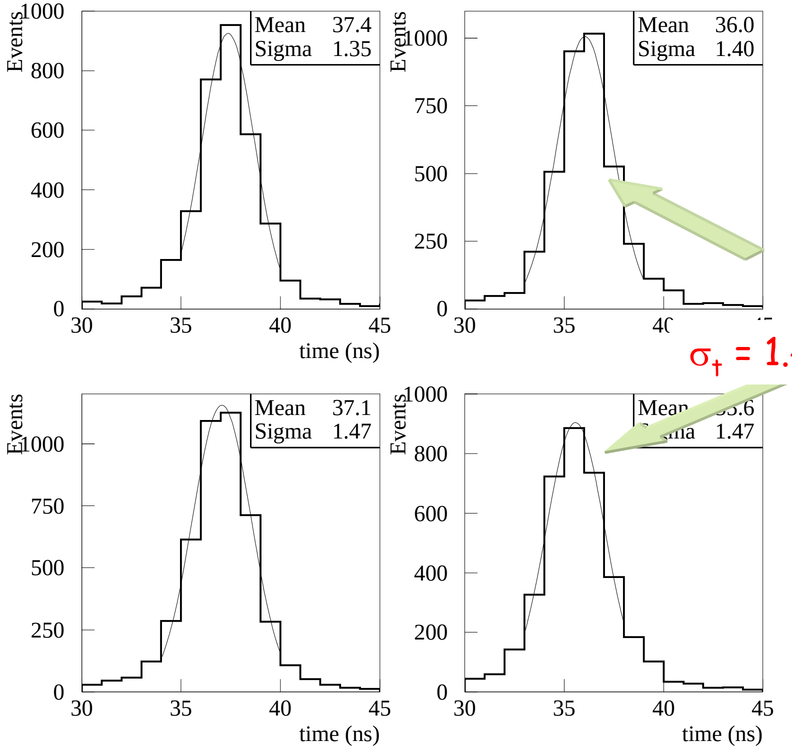
streamer

Detector at 4300 m on the see level

Low pressure ~ 600 mbar

$$V_{eff} = V_0 \frac{T}{T_0} \frac{P_0}{P}$$

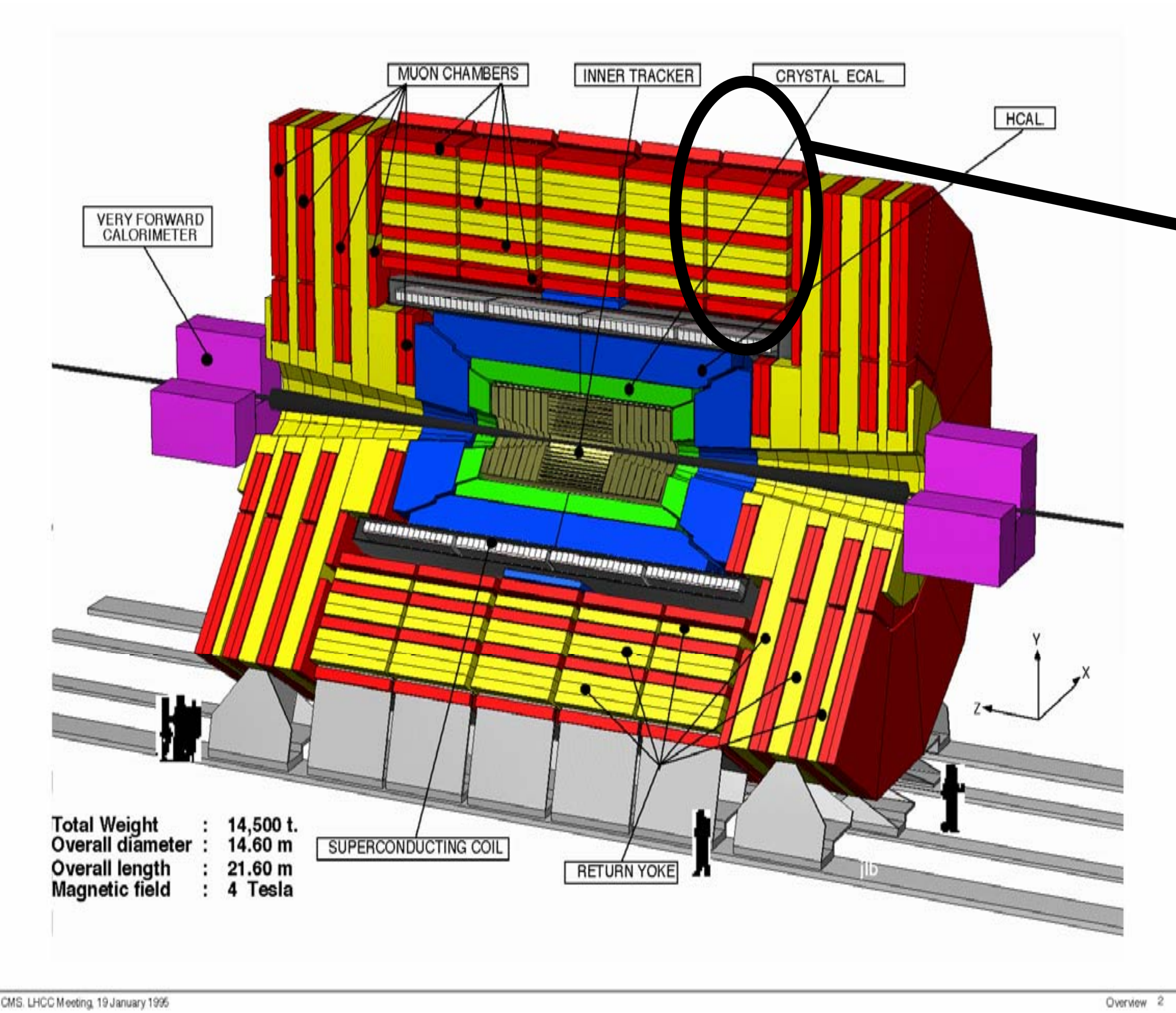


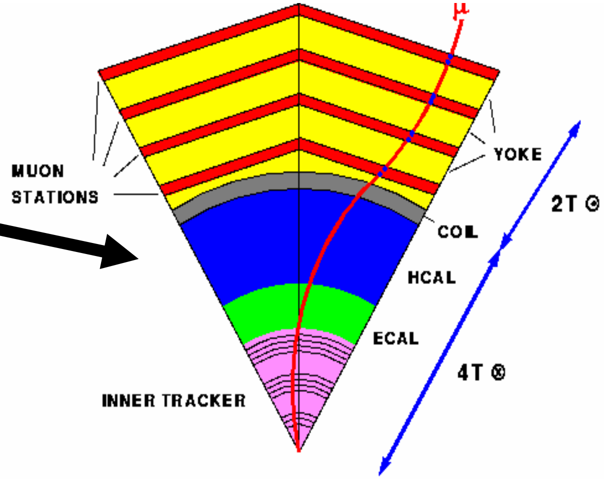


σ_t = 1.45 ns

Time resolution of 4 PADs

CMS





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

LHC output 10^9 Hz (total)
10^6 Hz (muons)

↓ **LV1** ← RPC

3 10^4 Hz (total)
1.5 10^4 Hz (muons)

↓ **LV2** ← sorter

100 Hz (total)
30 Hz (muons)

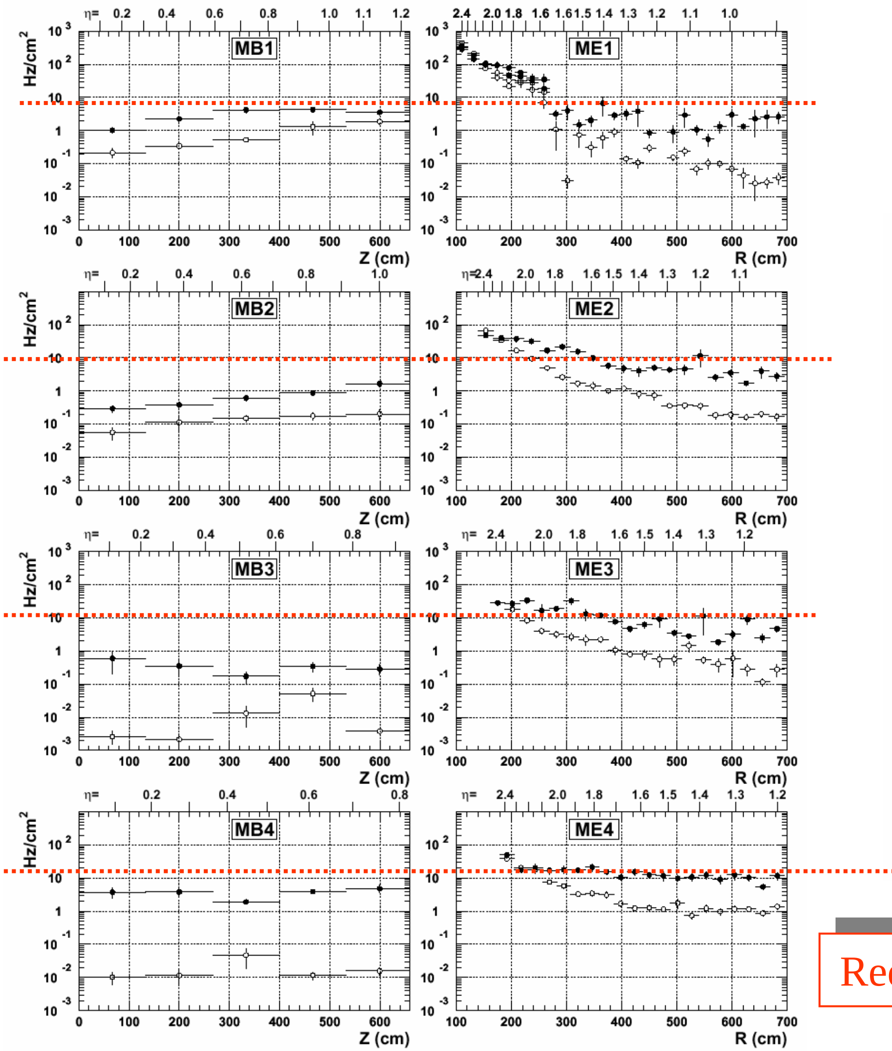
↓

<u>Storage unit</u>

CMS environment

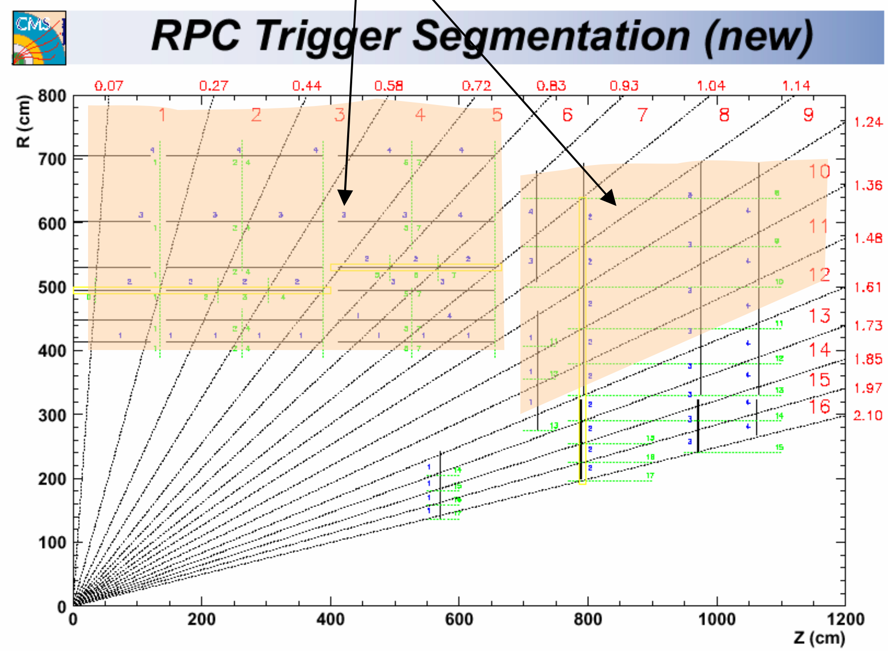
- bunch separation of 25 ns
- high background of n and γ
- long term operation with high irradiation

Background



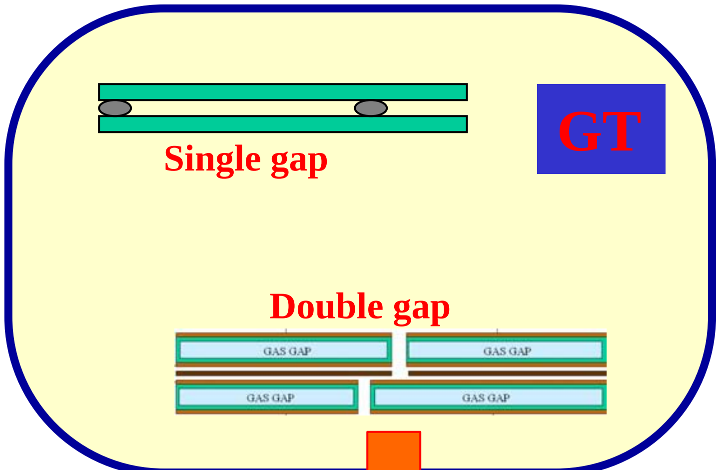
Hits due to neutrons (full circles) and charged particles (open circles).

Rate in the shadow region ($\eta \leq 1.6$) is ≤ 10 Hz/cm^2



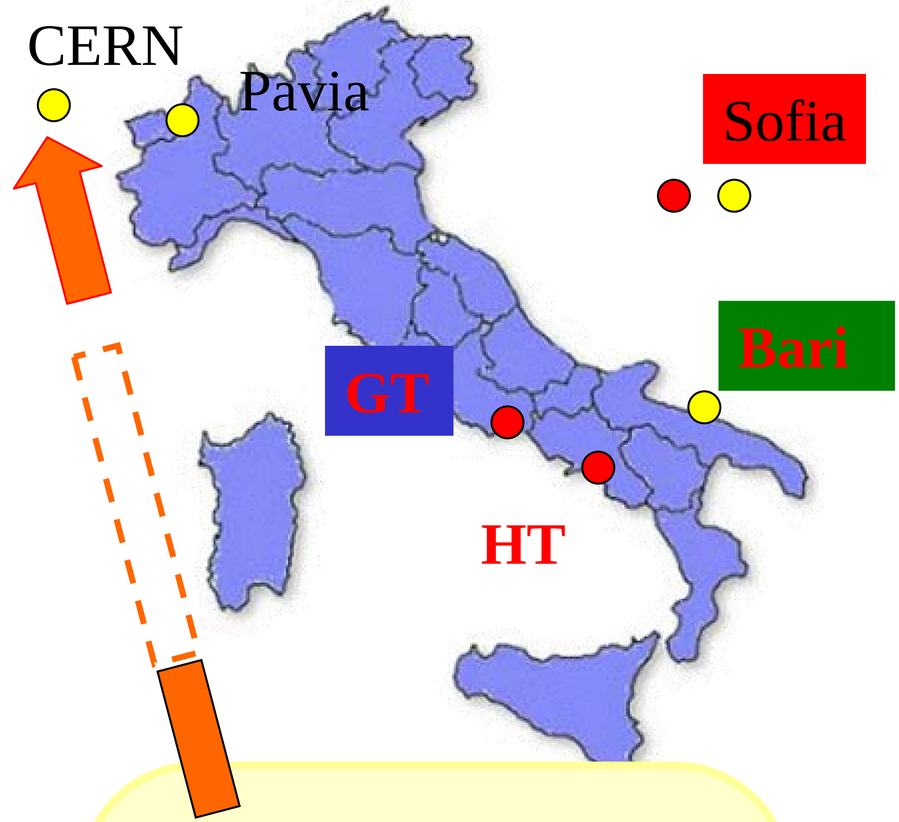
Red dashed line at 10 Hz/cm^2

The barrel organisation



Chamber assembling sites

120 RB1 at HT
240 RB2 and RB4 at GT
120 RB3 in Sofia (& Bari)



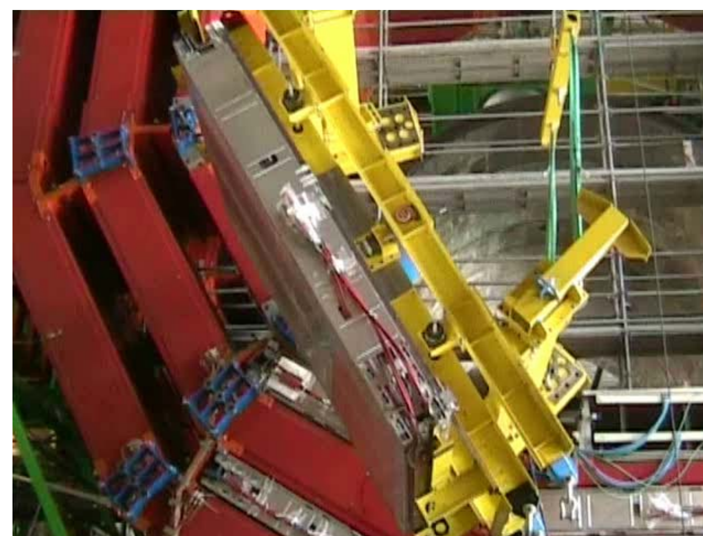
Chamber test sites

RB1 in Pavia
RB2 & RB4 in Bari
RB3 in Sofia (& Bari)

Barrel

Summary

- 164 chambers are at ISR
- 60 chambers installed in wheel W+2



Endcap overview

Korea

Pakistan

China

Gap production

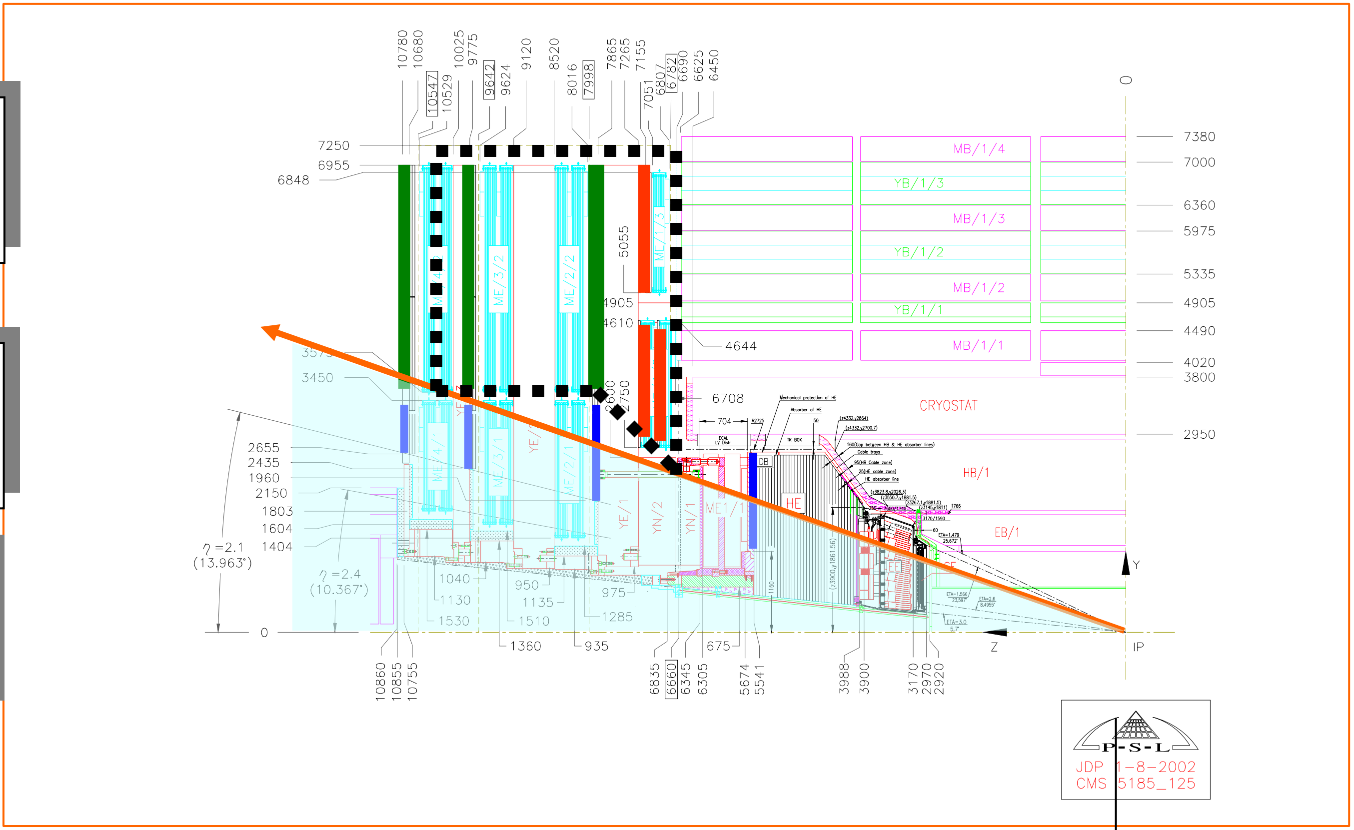
Korea

Front-end electronics

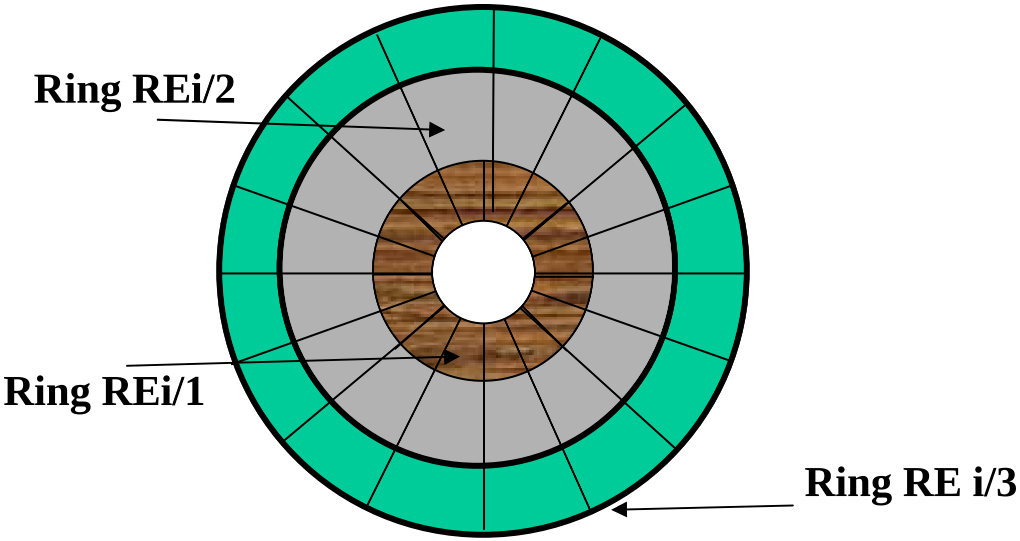
Pakistan

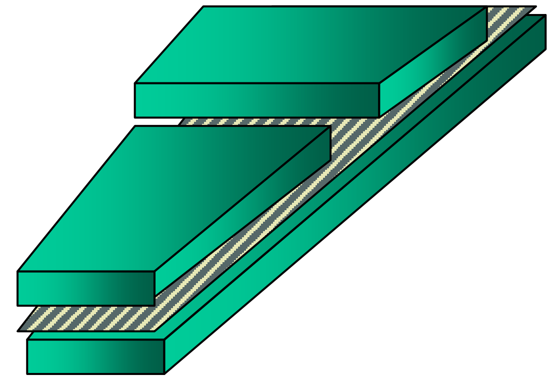
HV/LV system

Pakistan



Endcap overview





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

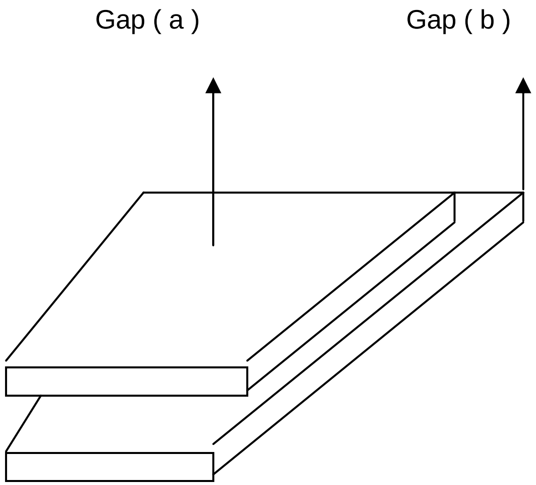
RE2/2 and RE2/3 under production in Pakistan

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

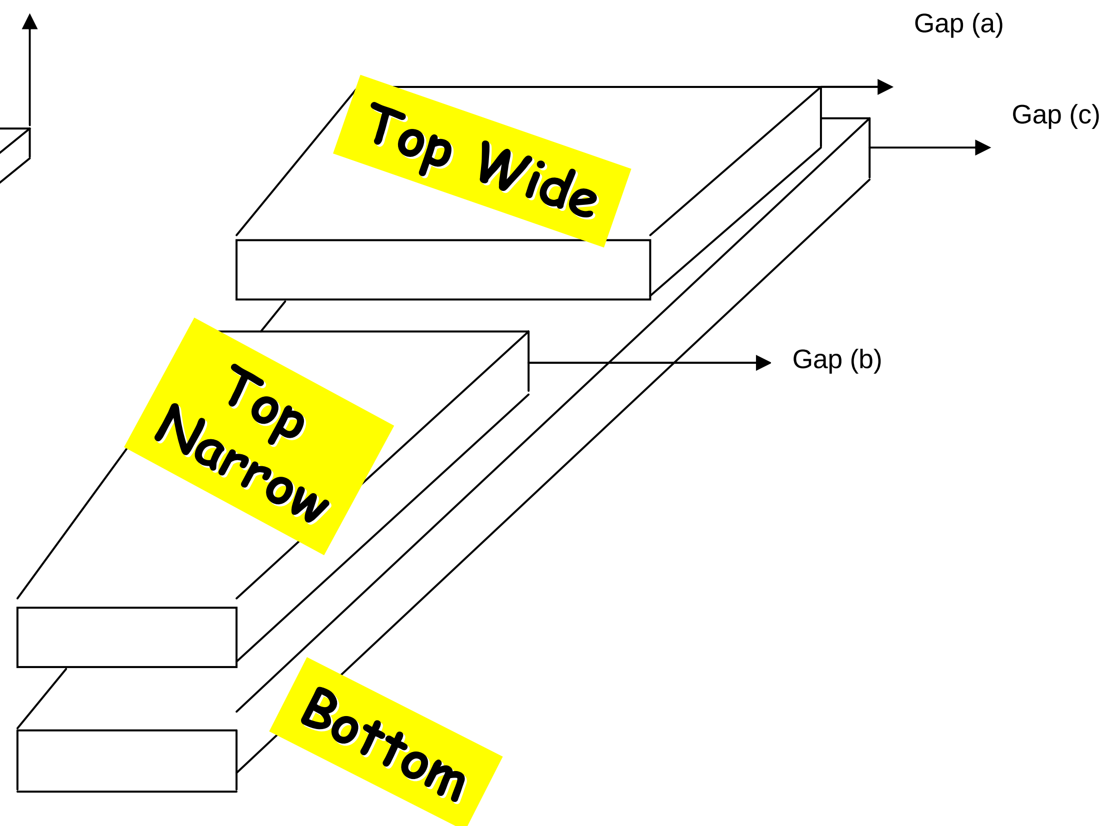
	RE 1/1	RE 1/2	RE 1/3	RE 2/1	RE 2/2	RE 2/3	RE 3/1	RE 3/2	RE 3/3	RE 4/1	RE 4/2	RE 4/3
No. of chambers	36*2	36*2	36*2	18*2	36*2	36*2	18*2	36*2	36*2	18*2	36*2	36*

Endcap overview

RE3/1, RE4/1



All other chambers



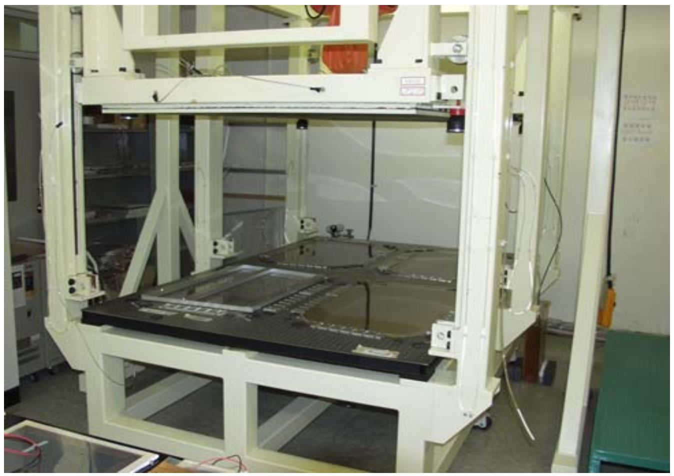
Sensitive Volume (Gaps) made in Korea

Endcap organisation

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 from Pakista	Ship to Pakistan CERN
Chamber Assembly	CERN/Pakistan	QC	Construction Database
Storage	Point 5	Installation	Production Database

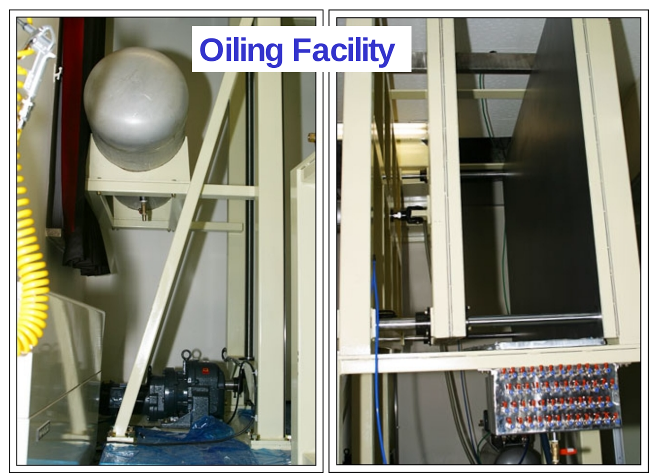
Gap production

Oiling procedure successfully transferred to Korea 2003



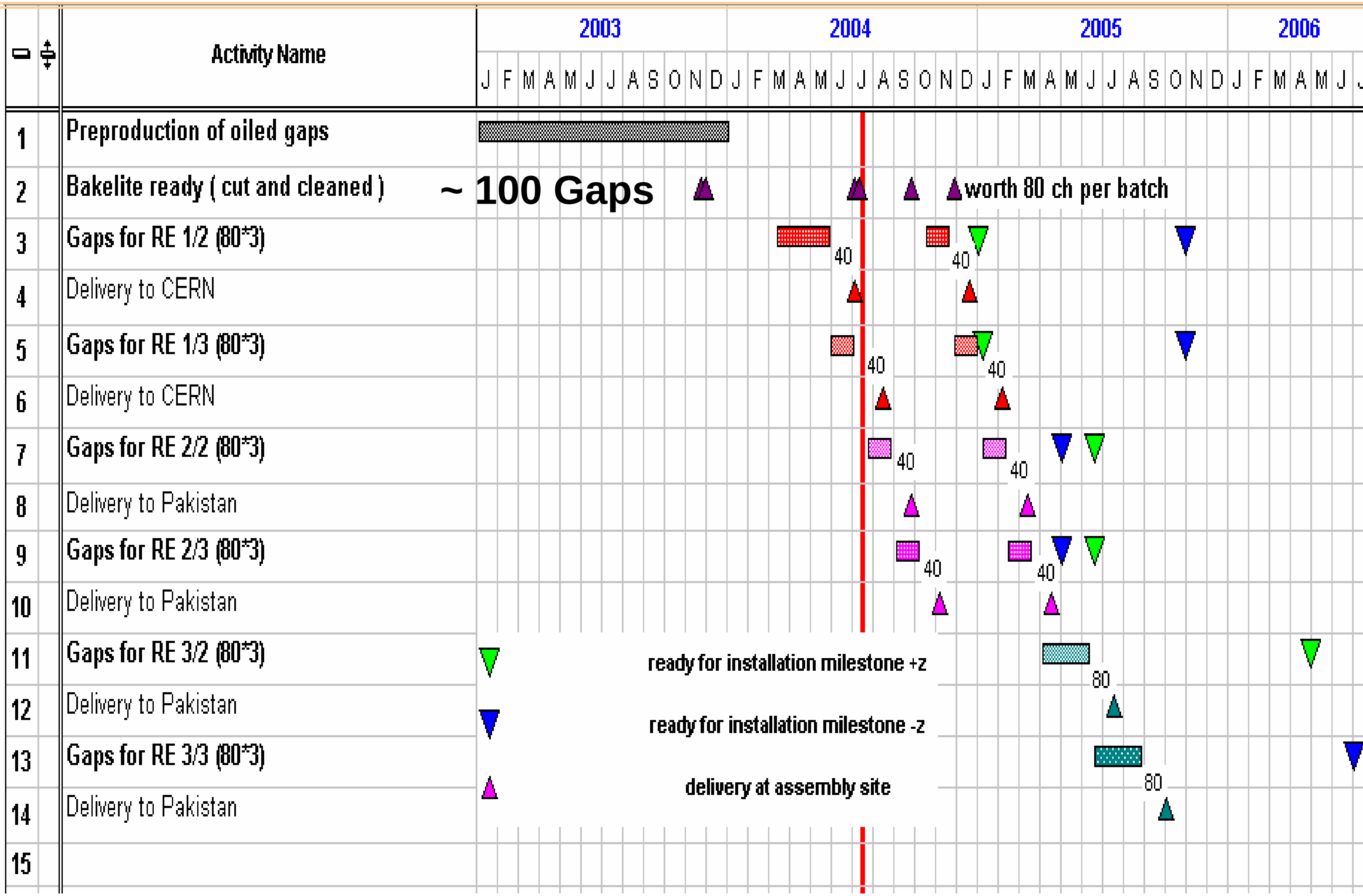
Hot melt of PET film

Oiling Facility

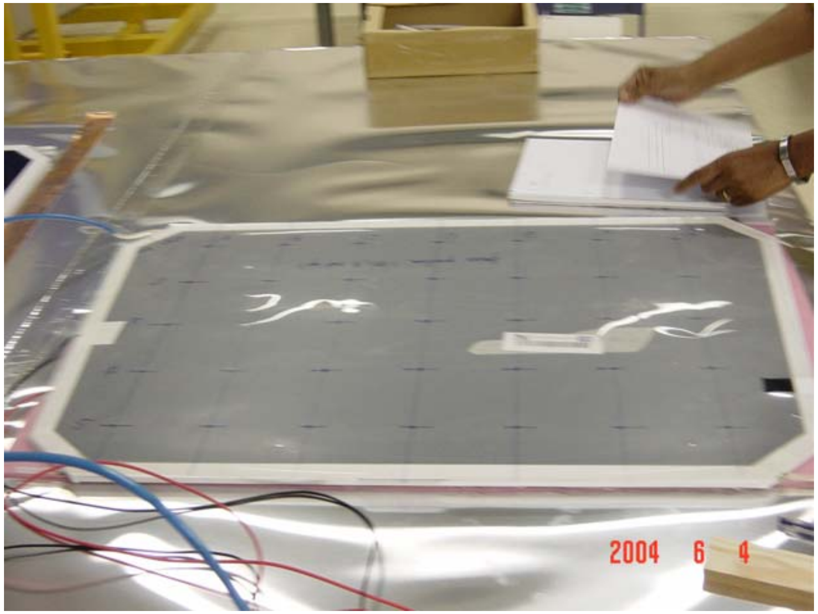


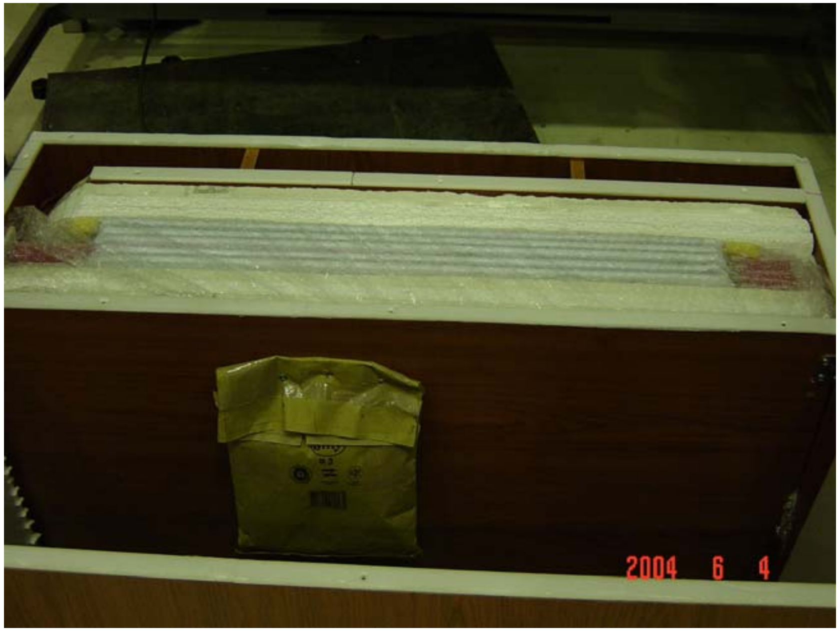
KODEL

Schedule for gap delivery



Gap QC at CERN@ISR



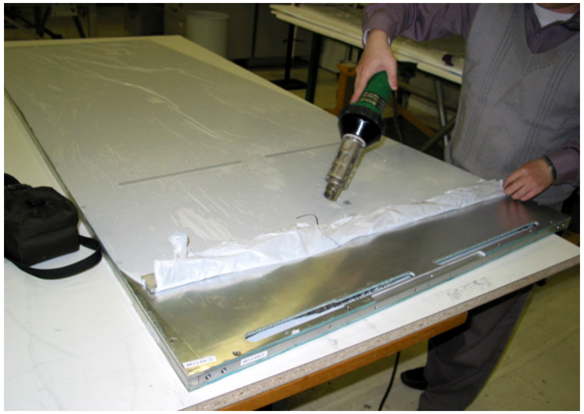


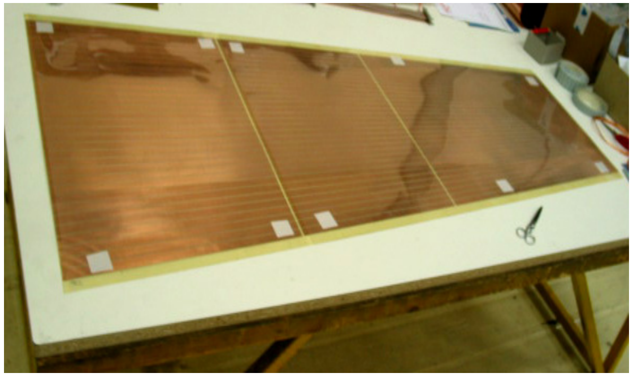
Quality Good and equal to Gap produced from GT

Passed polymerization tests
Gas and HV QC

RE1 assembly at CERN@ISR

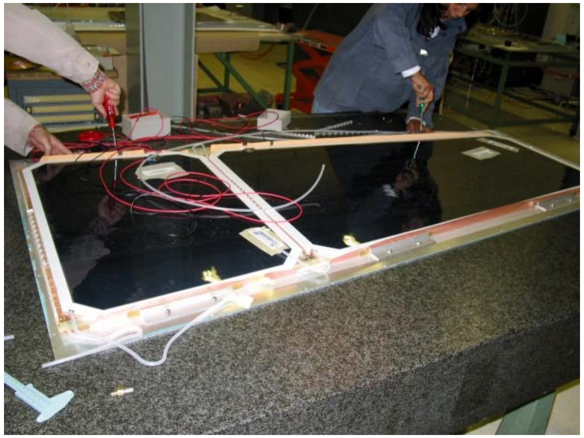
RE1 assembly at CERN@ISR

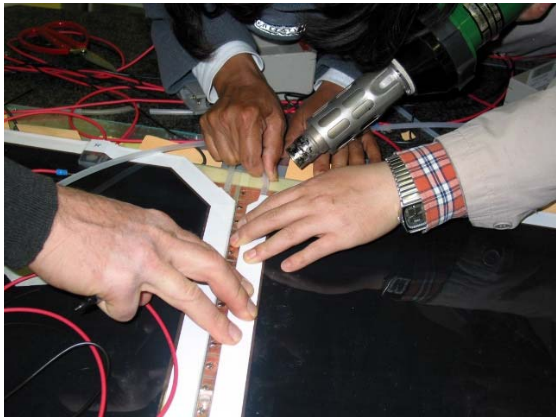




http://cms-isr-endcap-rpc.web.cern.ch/cms-isr-endcap-rpc/

RE1 assembly at CERN@ISR



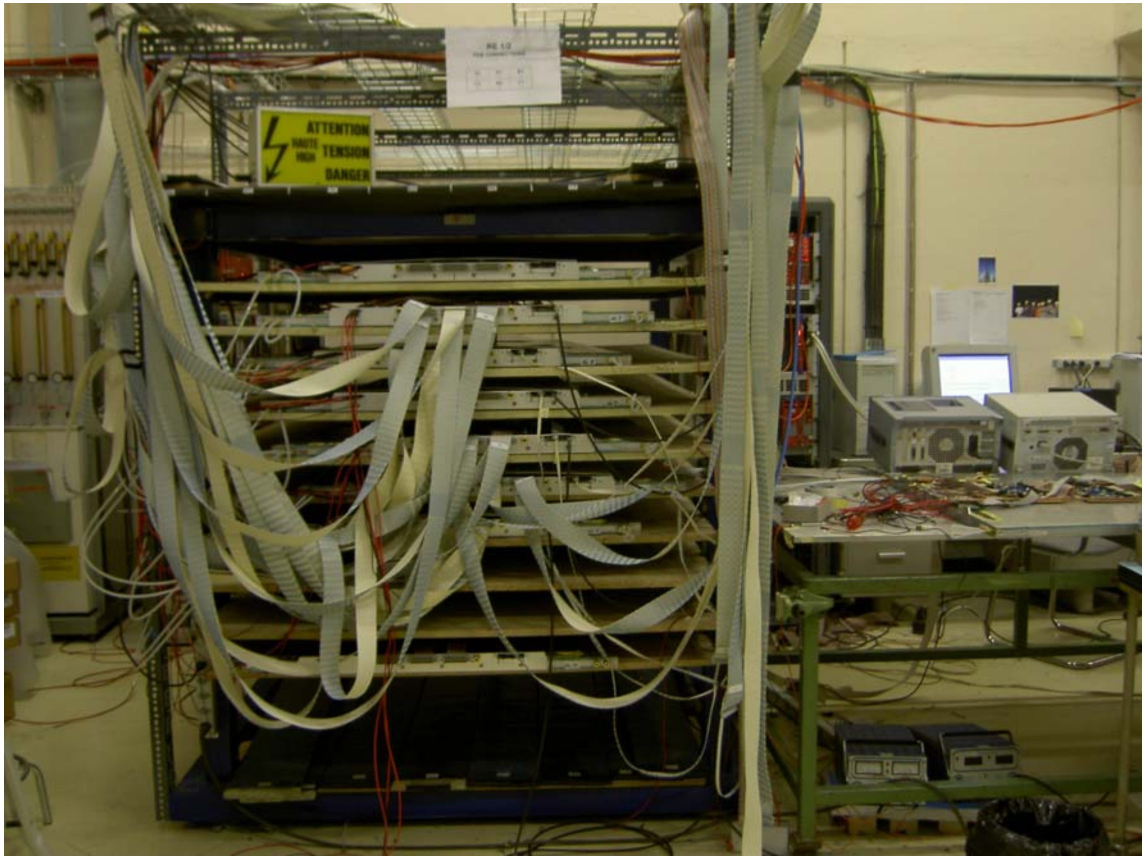


RE1 production schedule

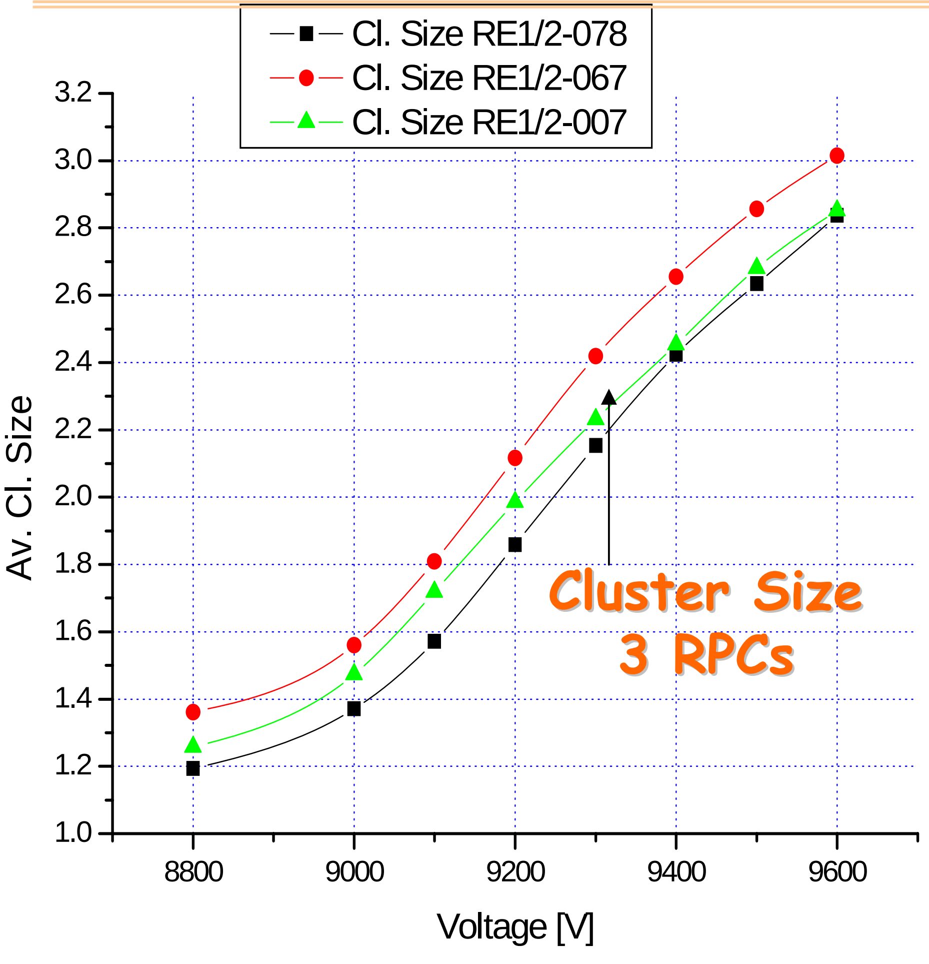
	RE1/2	RE1/3
Should be installed	72	72
Shall be built	80	80
Target of 2004	20	20
Accomplished so far	23	20
Target of 2005	57	60

Cosmics QC

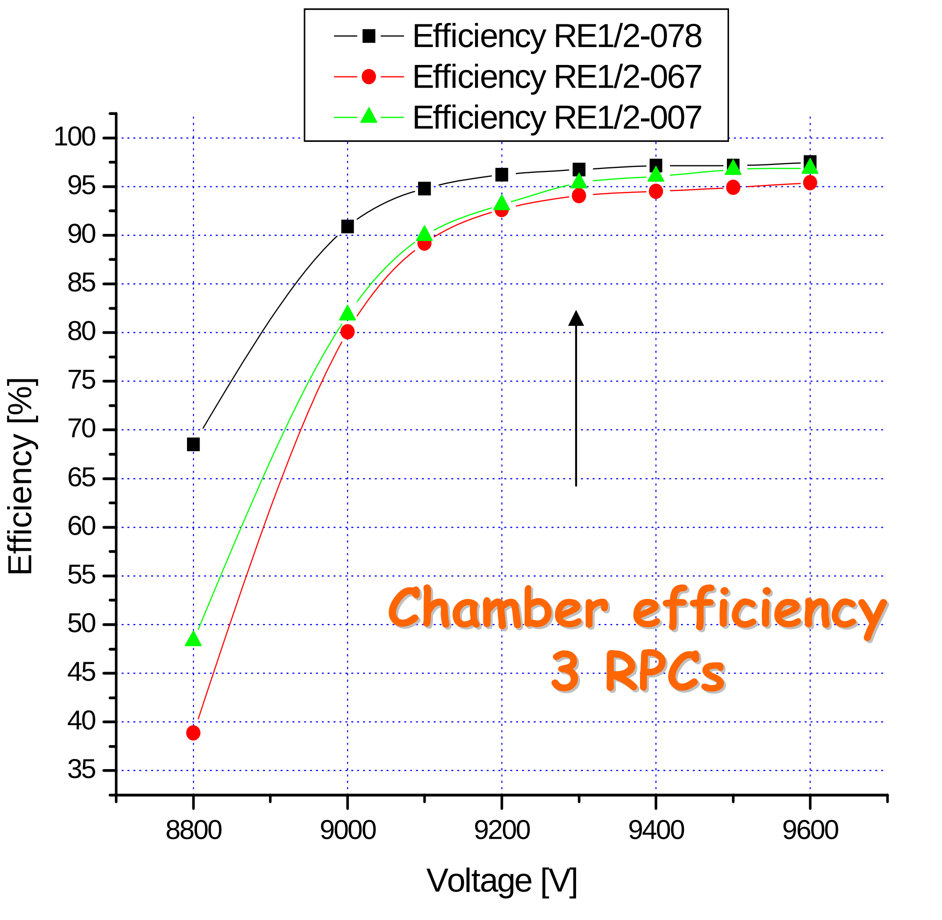
Cosmic stand and DAQ



Cosmics QC

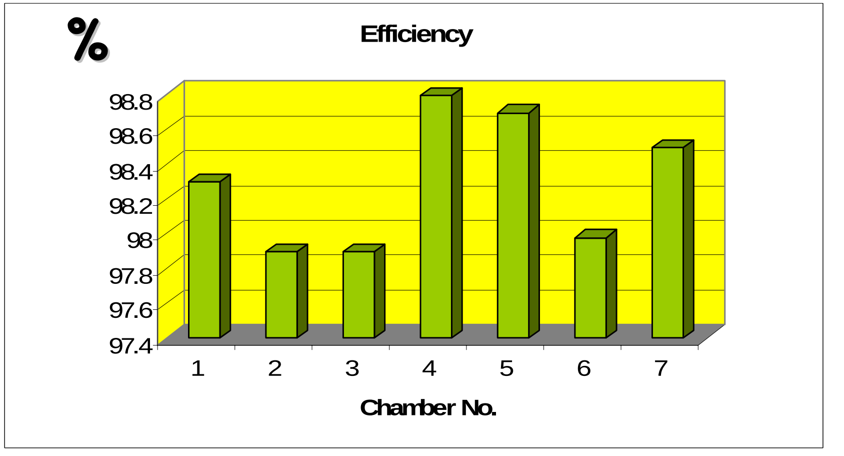


Cl. Size RE1/2-078
Cl. Size RE1/2-067
Cl. Size RE1/2-007
Av. Cl. Size
Voltage [V]
Cluster Size
3 RPCs

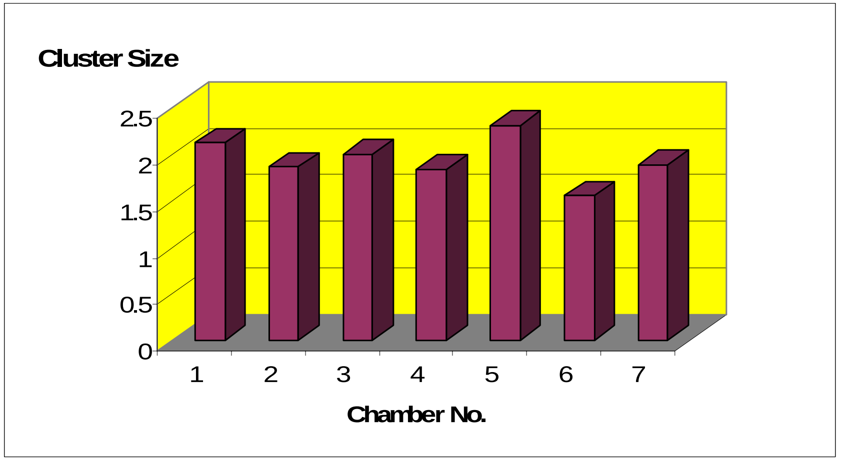


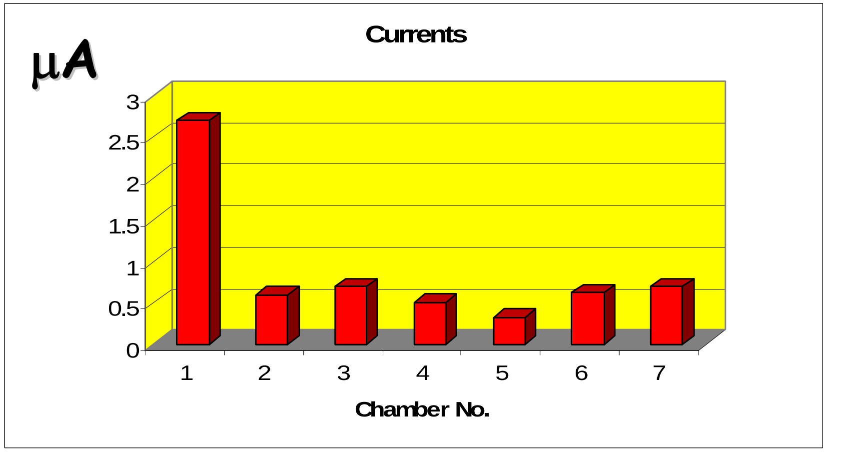
Efficiency RE1/2-078
Efficiency RE1/2-067
Efficiency RE1/2-007
Efficiency [%]
Voltage [V]
Chamber efficiency
3 RPCs

Cosmics QC



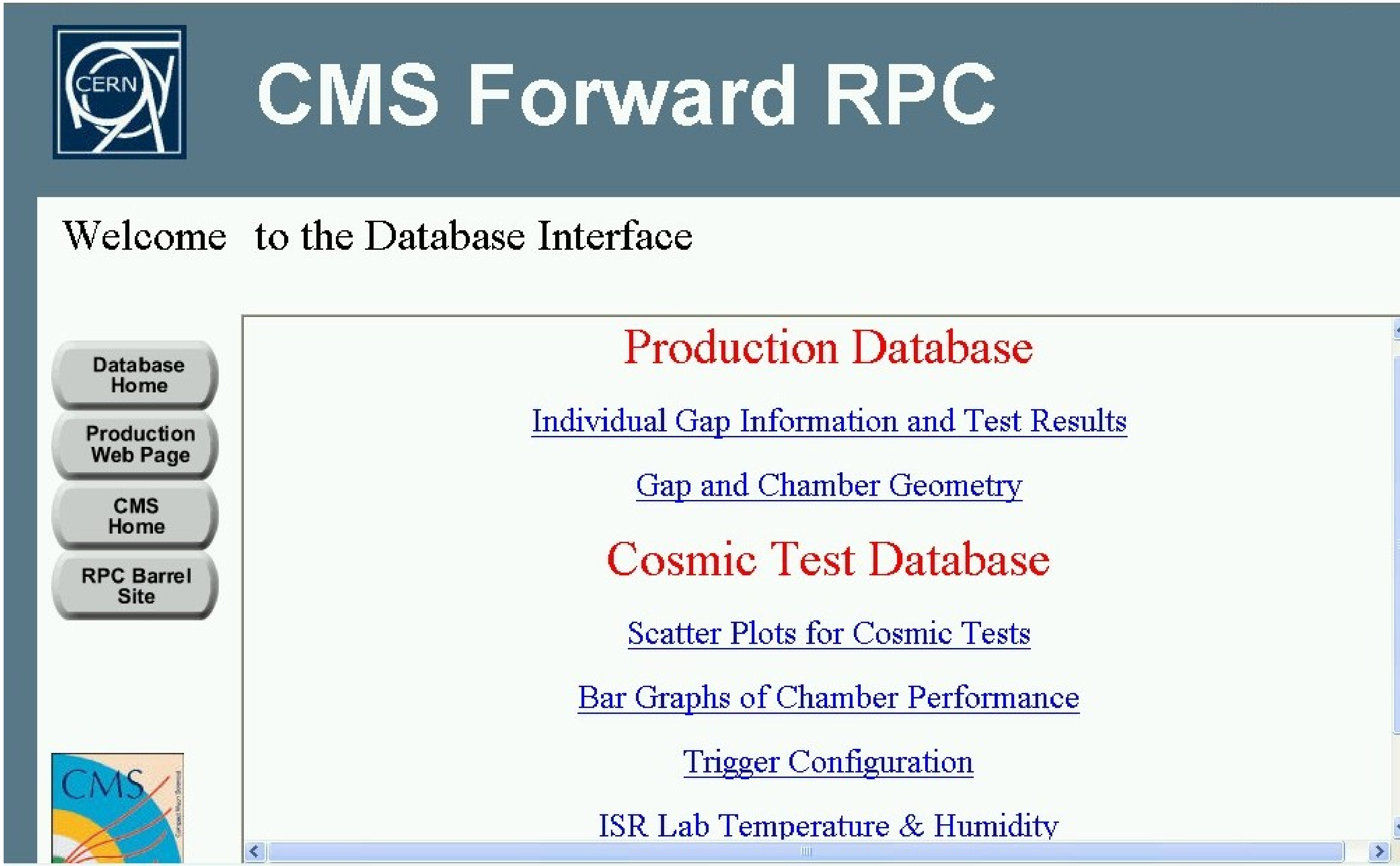
HV 9.2kV





Noise < $10 Hz/cm^2$

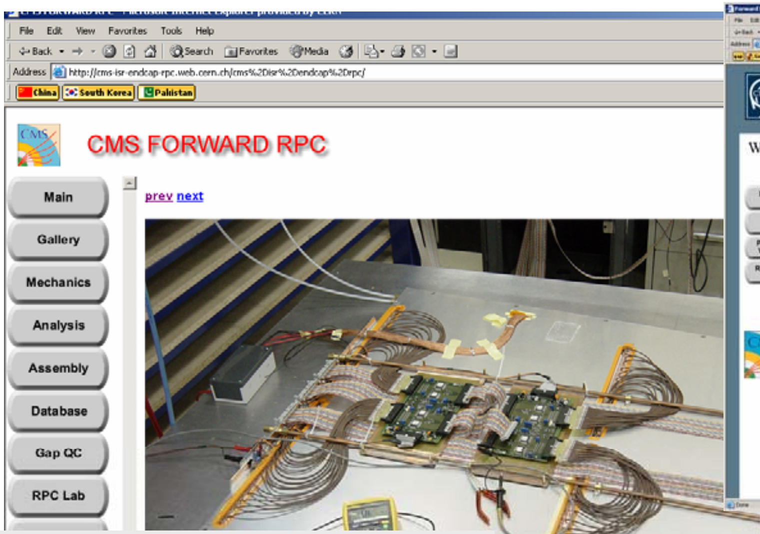
Data Base

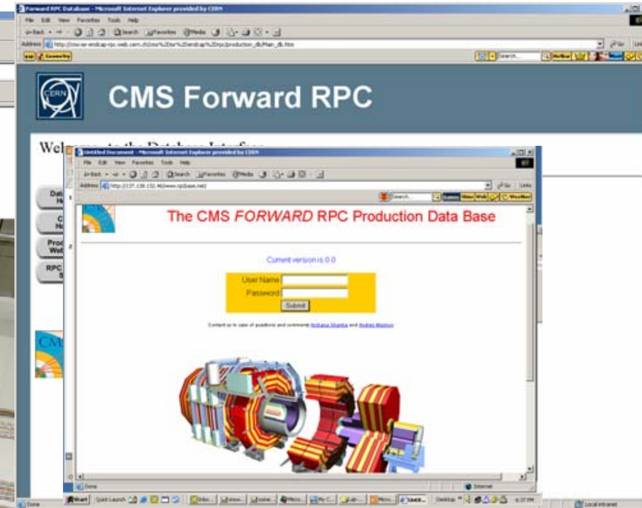


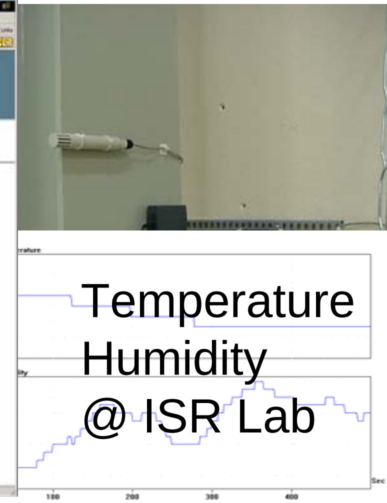
Database developed to store RPC production information

http://forwardrpc/cms_forward_rpc/production_db/Main_db.htm

Data Base

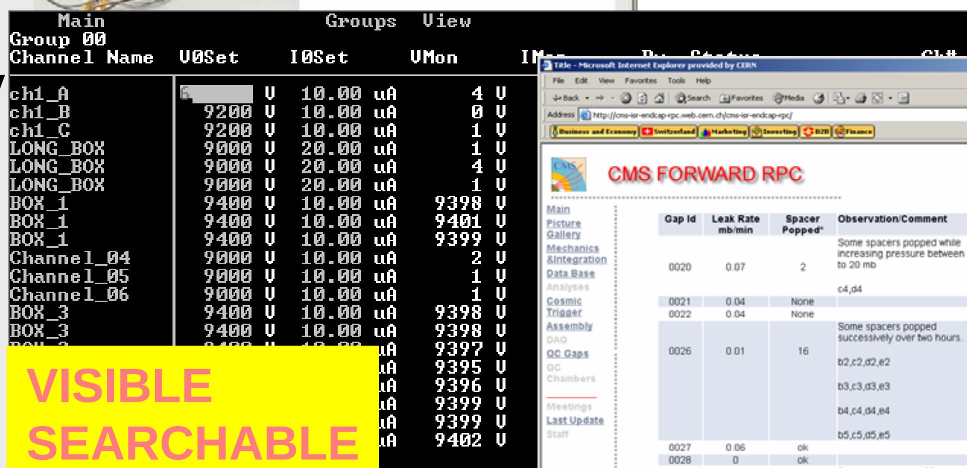


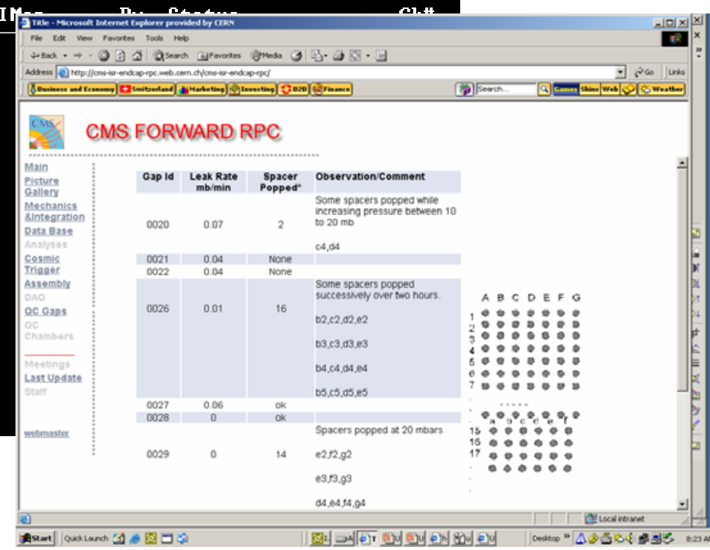




Online

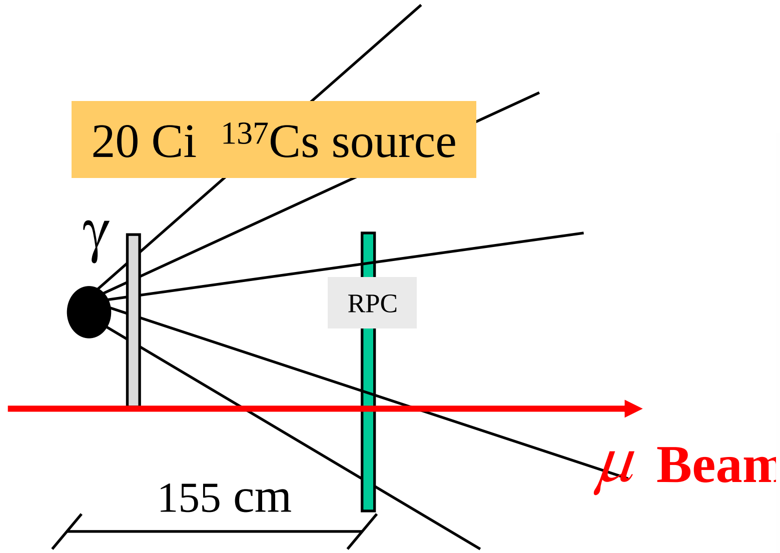
- **HV monitoring and QC IV data storage**
- **Searchable tracking for individual Gaps / Chambers**
- **Production QC procedures**
- **Mechanics**
- **Cosmic Tests**





Irradiation tests

Gamma Irradiation Facility

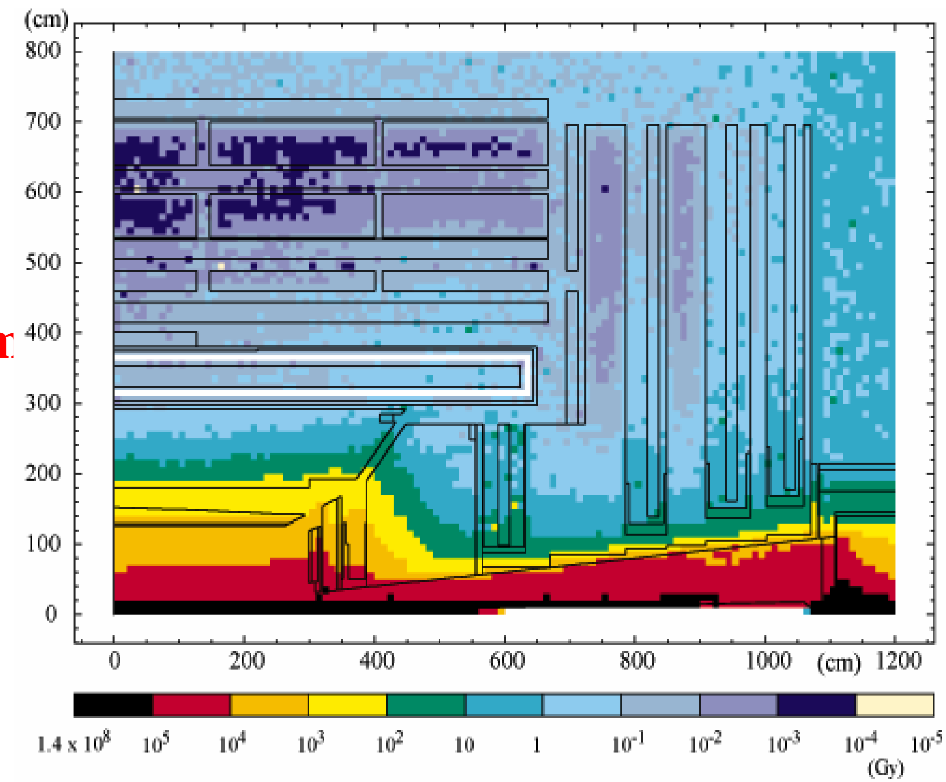


Filters can be positioned in front of the source:

•Absorption 1 (no filters)	ABS 1
•Absorption 5	ABS 5
•Absorption 10	ABS 10
•Absorption 100	ABS 100

CMS R&D

Absorbed dose during the test: ~23 Gy

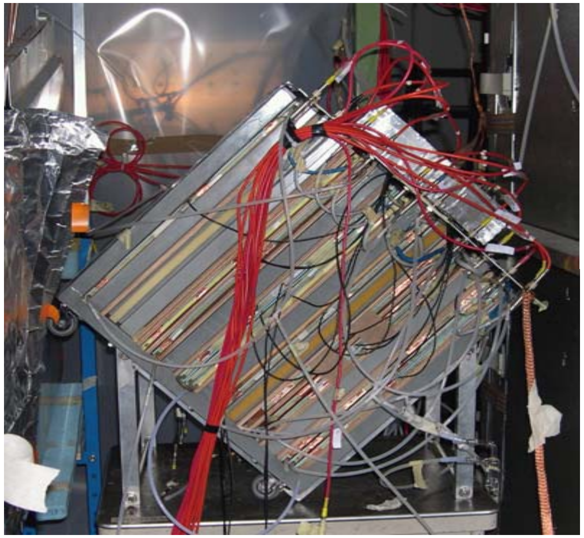


Irradiation tests

Aim

- Check the RPC performance after a working period equivalent to 10 CMS years
- Check possible long term effects of the close loop gas system on the chambers performance
- Study the HF and/or others pollutants production and their effects on the chambers performance

11 gaps



Dimensions: 50 x 50 cm^2, equipped with 10 x 10 cm^2 pads
Entered in the GIF during May 2002
Integrated charge up to now: 70 mC/cm^2
Equivalent to ~ 15 CMS years (safety factor included)

2 final chambers (RB1)

At the beginning in open loop mode;
Until December 2003 integrated 15 mC/cm2 ~ 3 CMS eq. years

Later with the with the closed loop gas system
Integrated about 25 mC/cm2 ~ 5 CMS eq. years

Performance of small gaps

Many problems

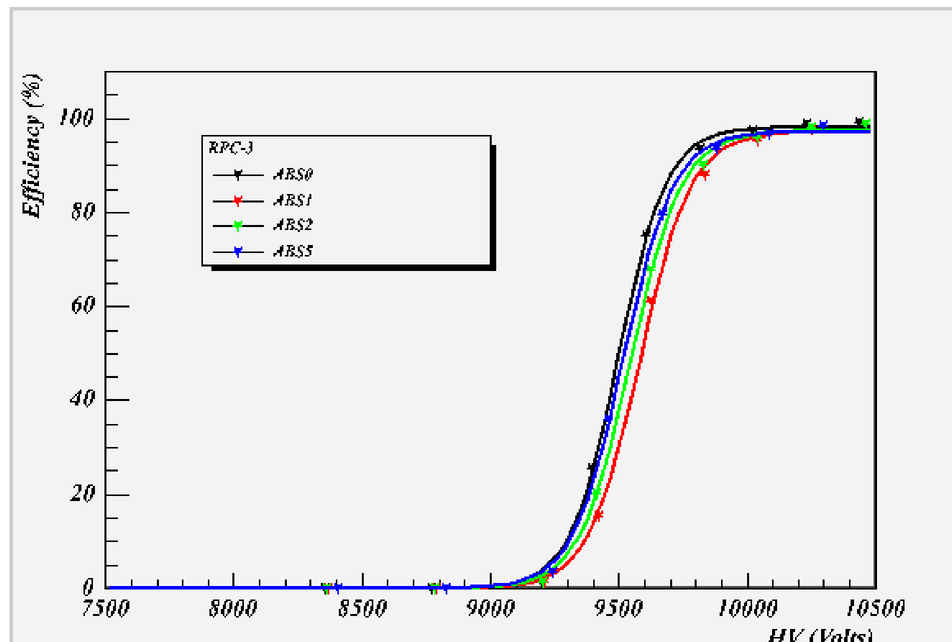
Major problem with some chemical reaction on the copper springs used in gas pipe followed by a strong increase in current and counting rate

T-connectors in the gas circuit badly damaged by HF in exhaust

Chambers found not bubbling (sometimes with HV on) (also due to frequent detector displacements in GIF)

Present performance RPC - 3 (example)

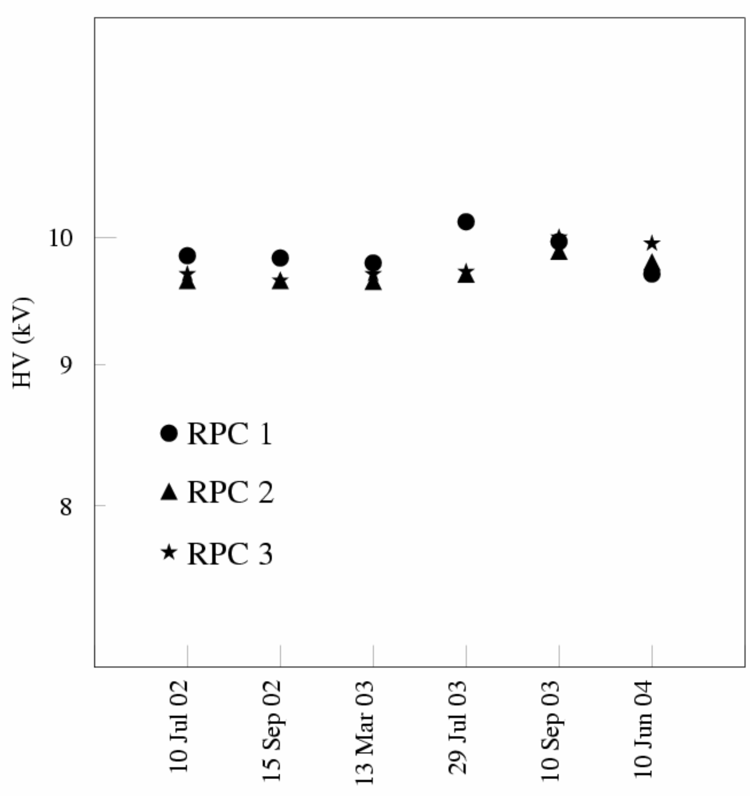
Efficiency at ABS 0 (Source Off),
ABS 1 (Full source),
ABS 2
ABS 5

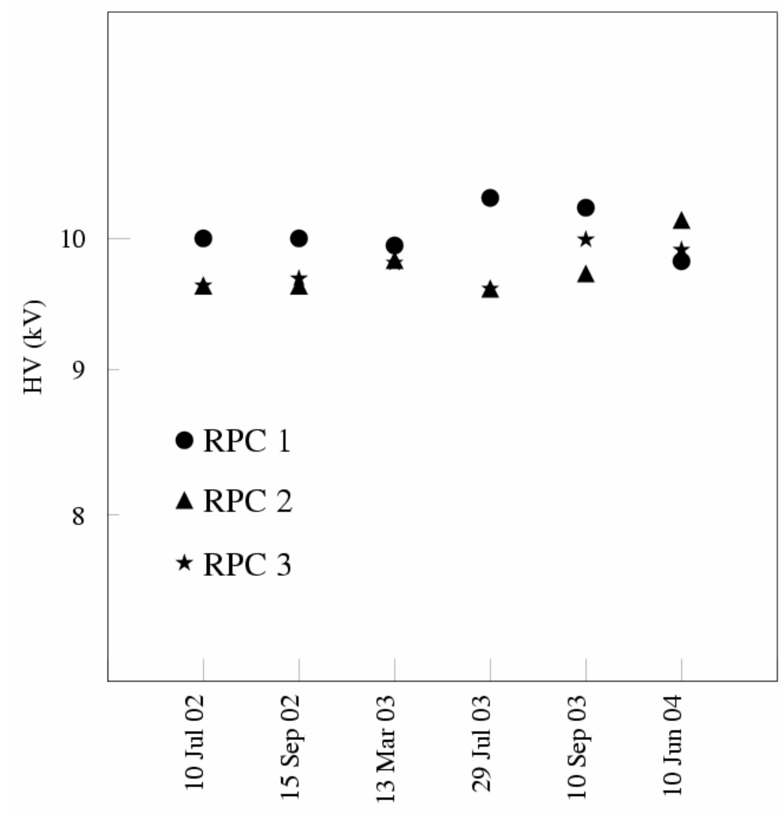


Performance of small gaps

Working voltage at 90% efficiency as a function of the time

ABS0 (Source Off) ABS1

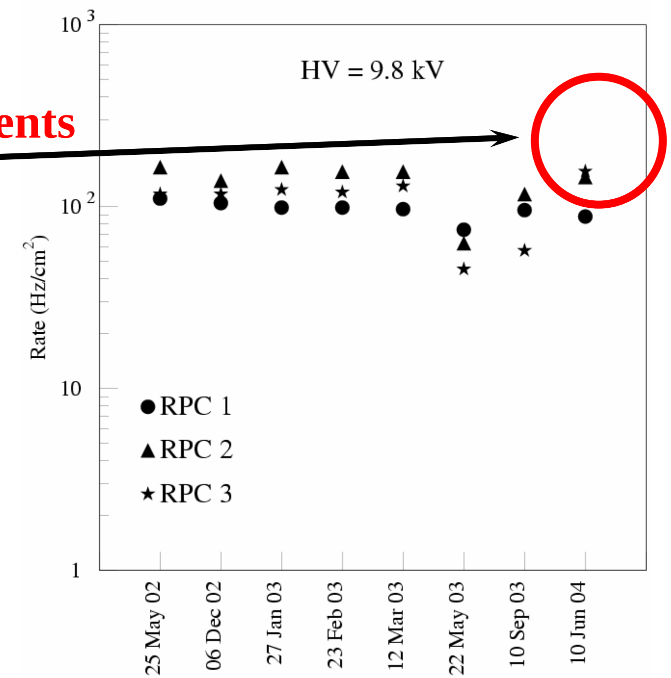


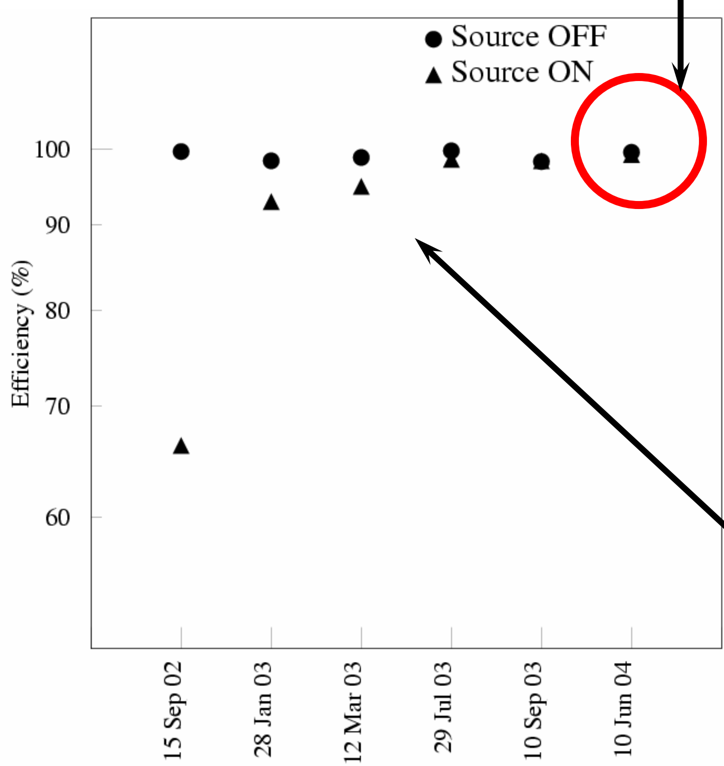


Performance of small gaps

Rates at 9.8 kV and ABS 1

Last measurements

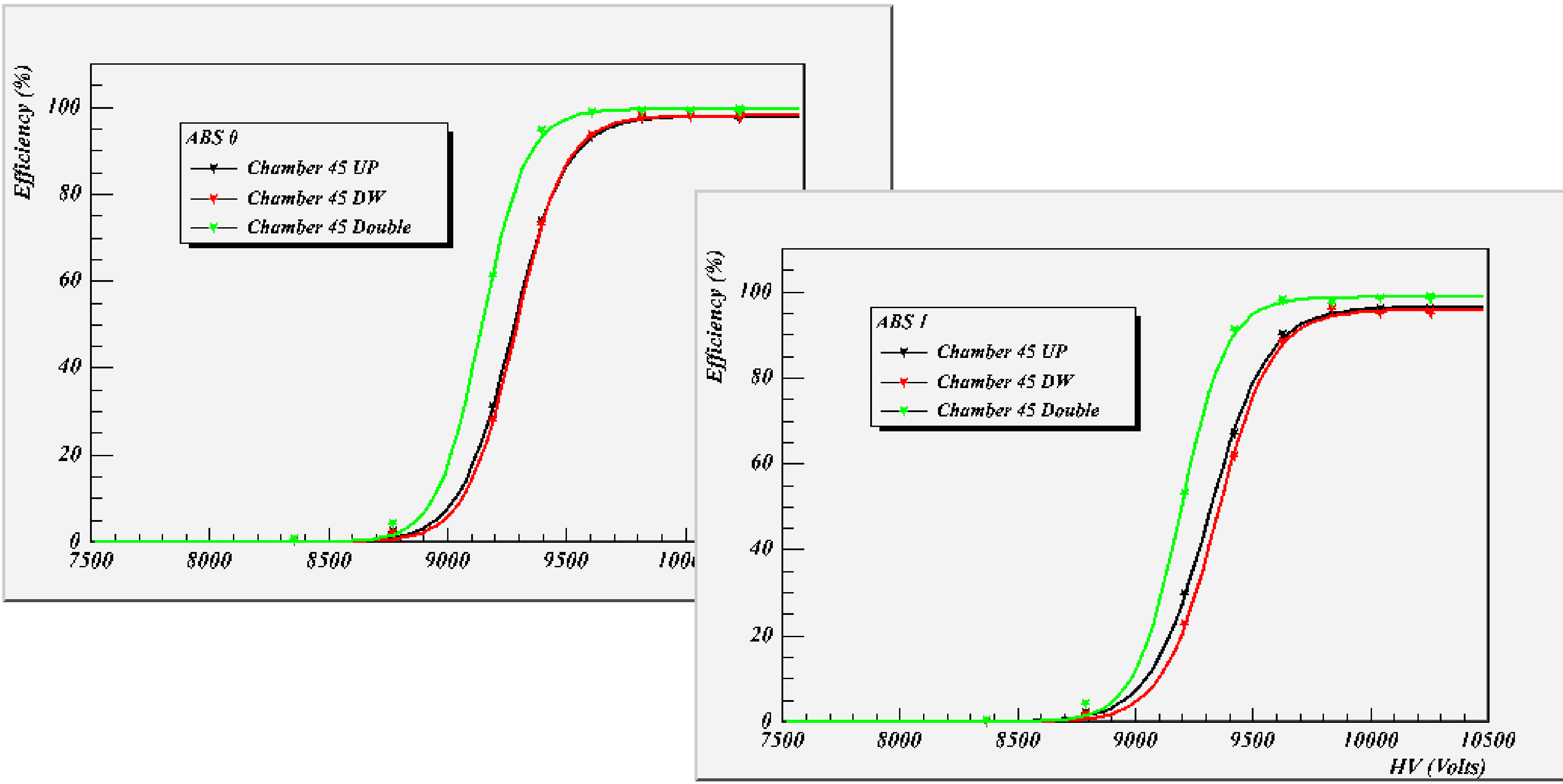




Recovery of RPC#9 with the moist mixture:
maximum efficiency vs time at source Off and ABS1

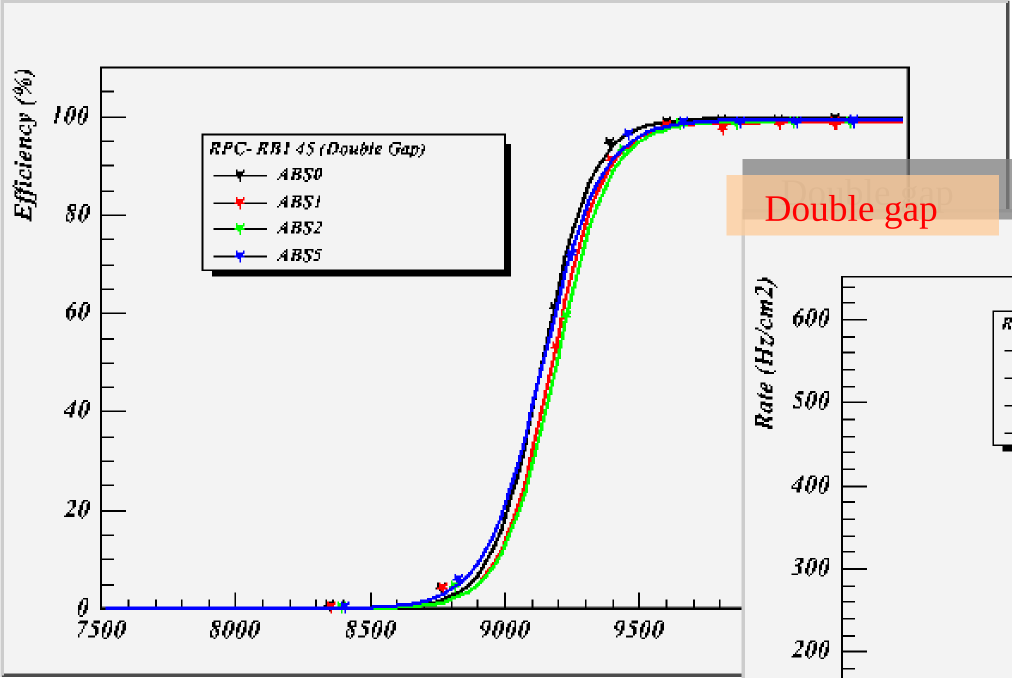
Performance of RB1s

efficiency of chamber 45 at ABS0 and ABS1 (single gap and double gap)

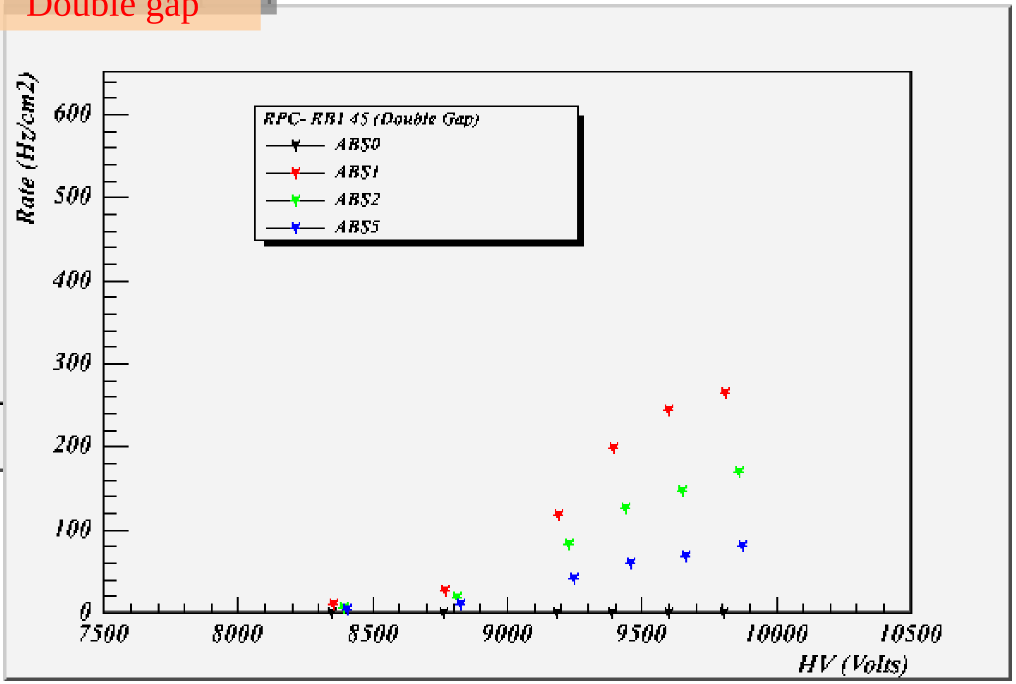


Performance of RB1s

Efficiency and cluster rate of chamber 45 at ABS0, ABS1, ABS2 and ABS5



Double gap

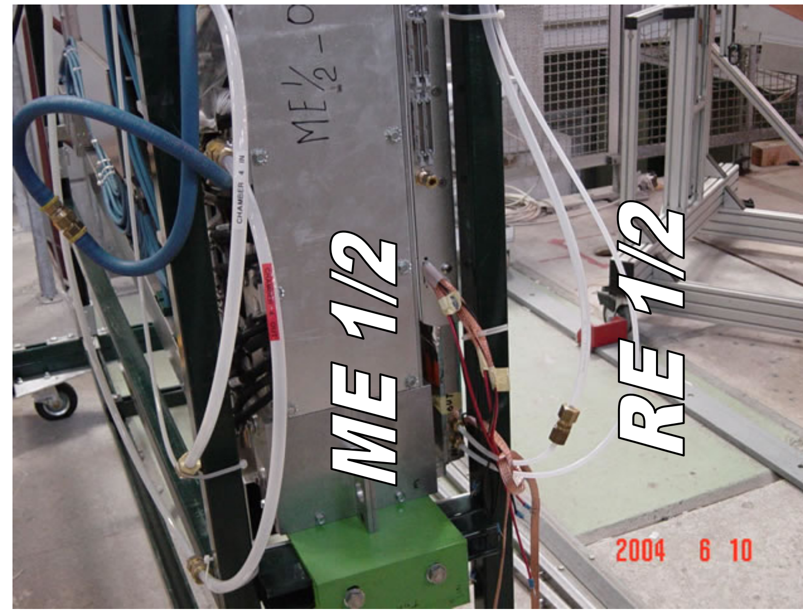


RPC-CSC

First RE 1/2 production chamber assembled @ ISR lab coupled to one ME 1/2 CSC and tested in X5A (25 ns beam)

GOALS:

•Validation of Link Board system
•Link to Link Board and data flow (Warsaw)
•RE 1/2 performance
•Link Board monitoring capability
•Mechanical Compatibility
•Grounding and electronic compatibility
•Possibly Trigger ambiguity resolution

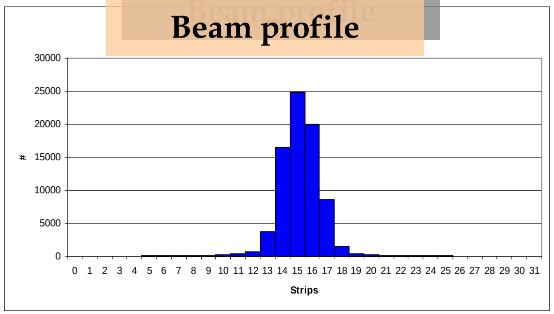


The team

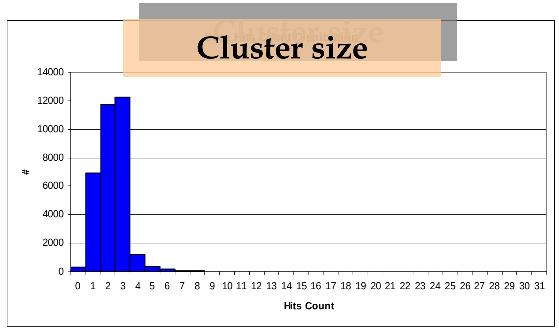
RPC-CSC

LB monitoring HV = 9.1 kV

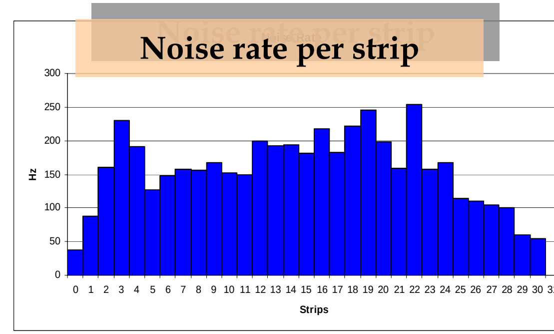
Beam profile

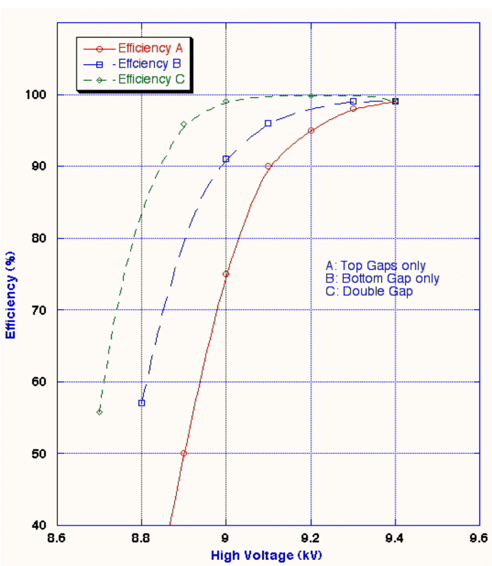


Cluster size



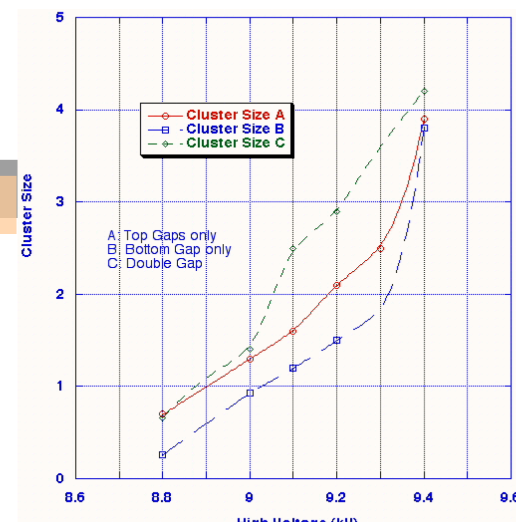
Noise rate per strip





Muon detection efficiency

RE 1/2 performance



Average cluster size

Conclusion

Endcap project on the way..

- Gap production at regime
- Assembly and test site at ISR ok
- 40 RE1 expected by the end of the year
- Pakistan site ready to go
- Most of the chamber components available

But..

- Endcap resources (manpower and budget) are limited
- Follow the start up of RE2, RE3 production
- Signal cable procurement
- HV/LV procurement

GIF

- Satisfactory long performance at GIF
- HF production and removal under study
- Close loop system operation is understood
- RPC/CSC test with 25 ns beam ok

	RE1/2	RE1/3
Should be installed	72	72
Shall be built	80	80
Target of 2004	20	20
Accomplished so far	23*	21**
Target of 2005	57	60