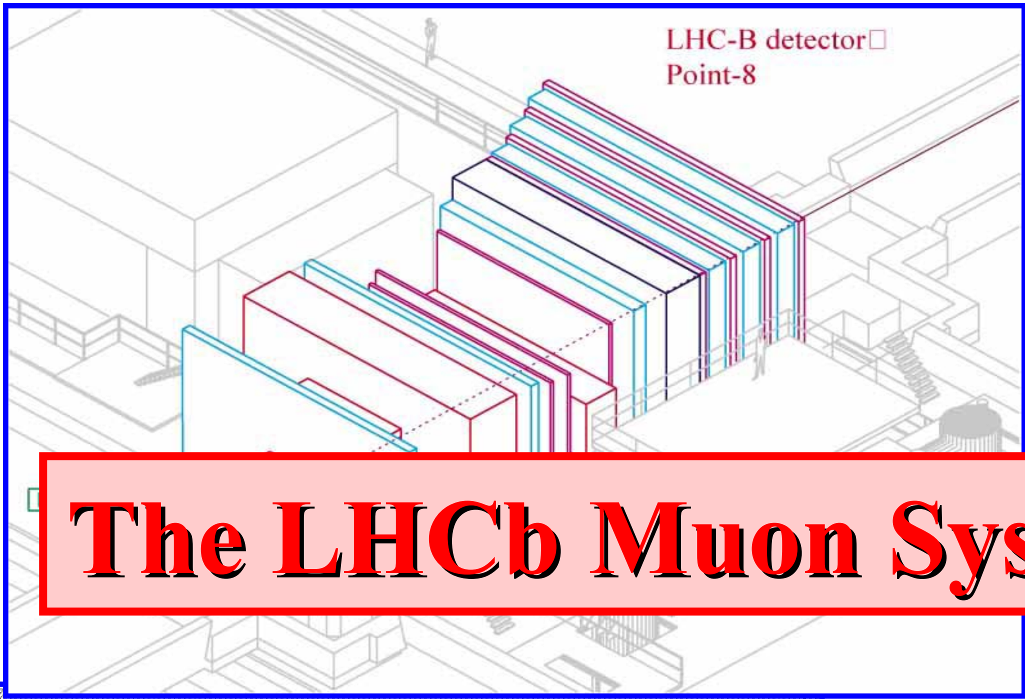
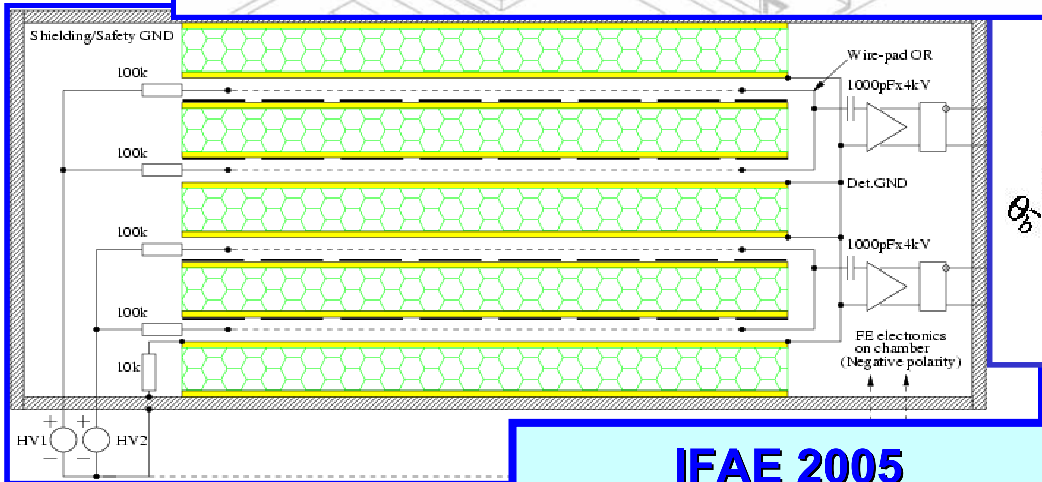
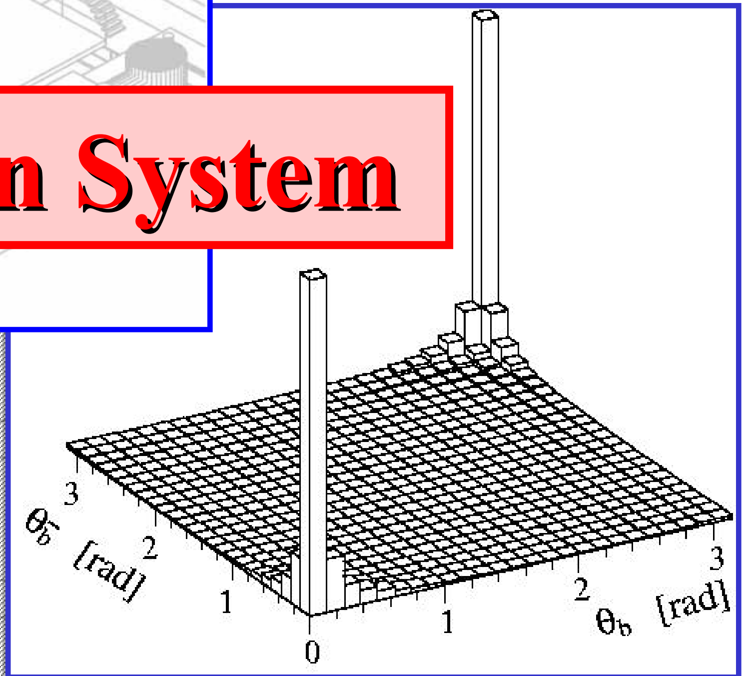
The LHCb Muon System







IFAE 2005

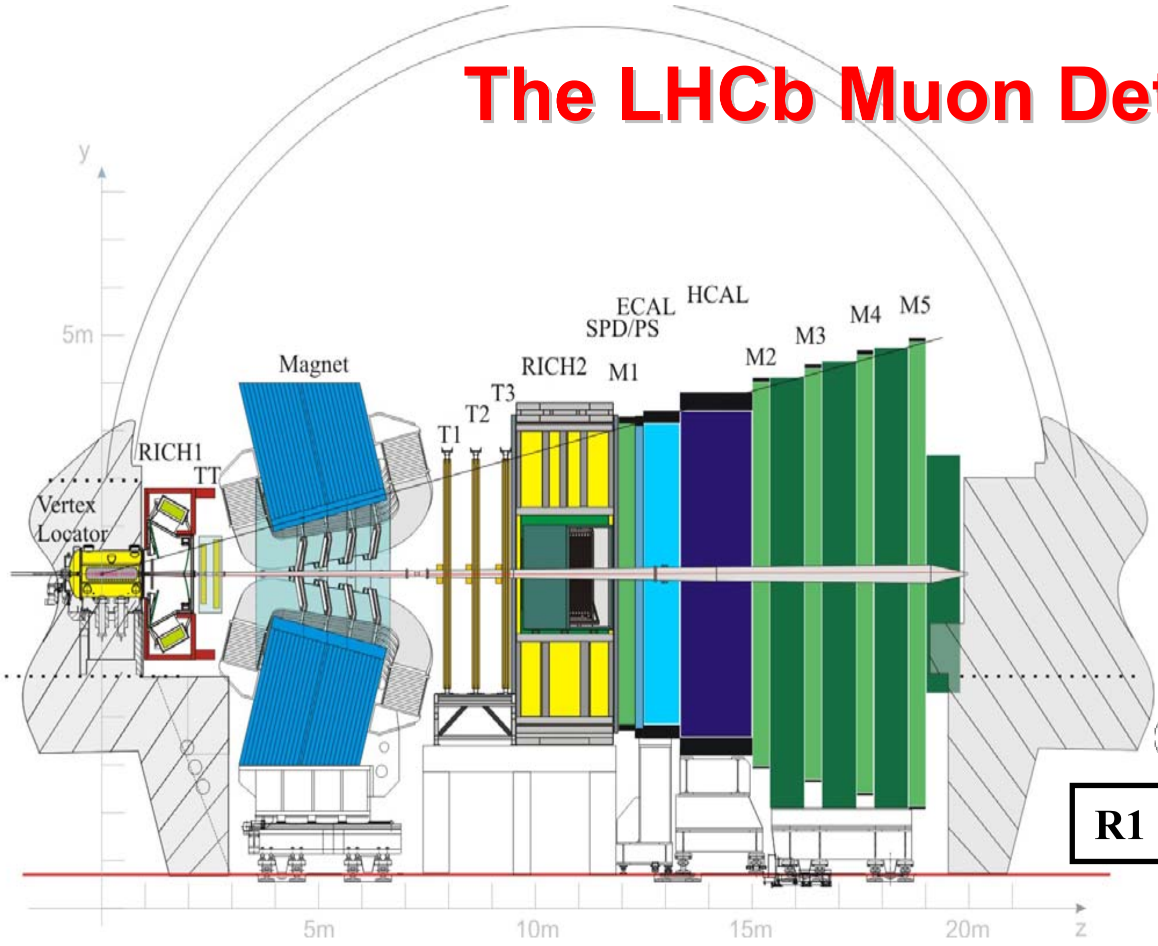
Catania, March 30 – April 02

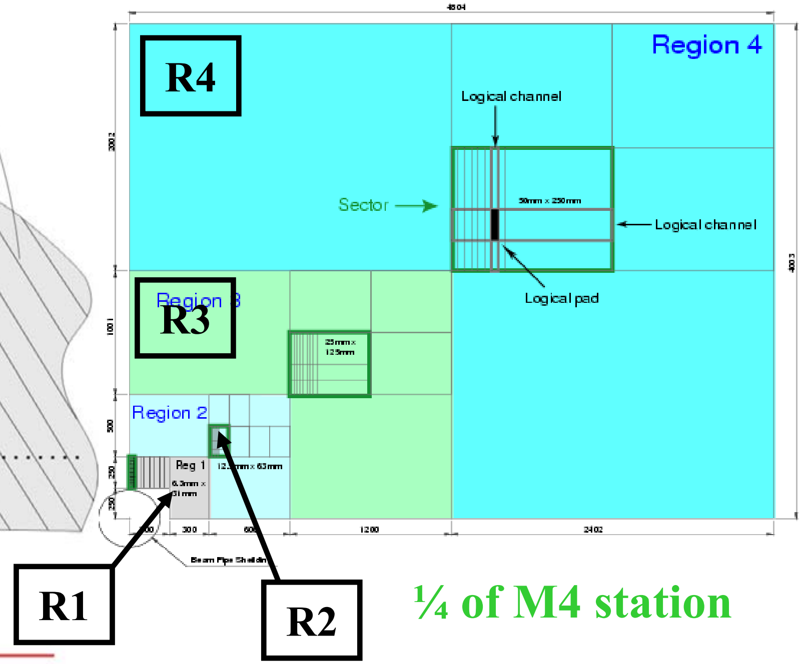
Wander Baldini INFN – Ferrara, on behalf of the LHCb Muon Group

Overview

- **The LHCb Muon Detector**
- **Requirements**
- **Performances:**
  - Detection Efficiency and time resolution
  - Ageing studies
- **Production status**
- **Conclusions**

The LHCb Muon Detector

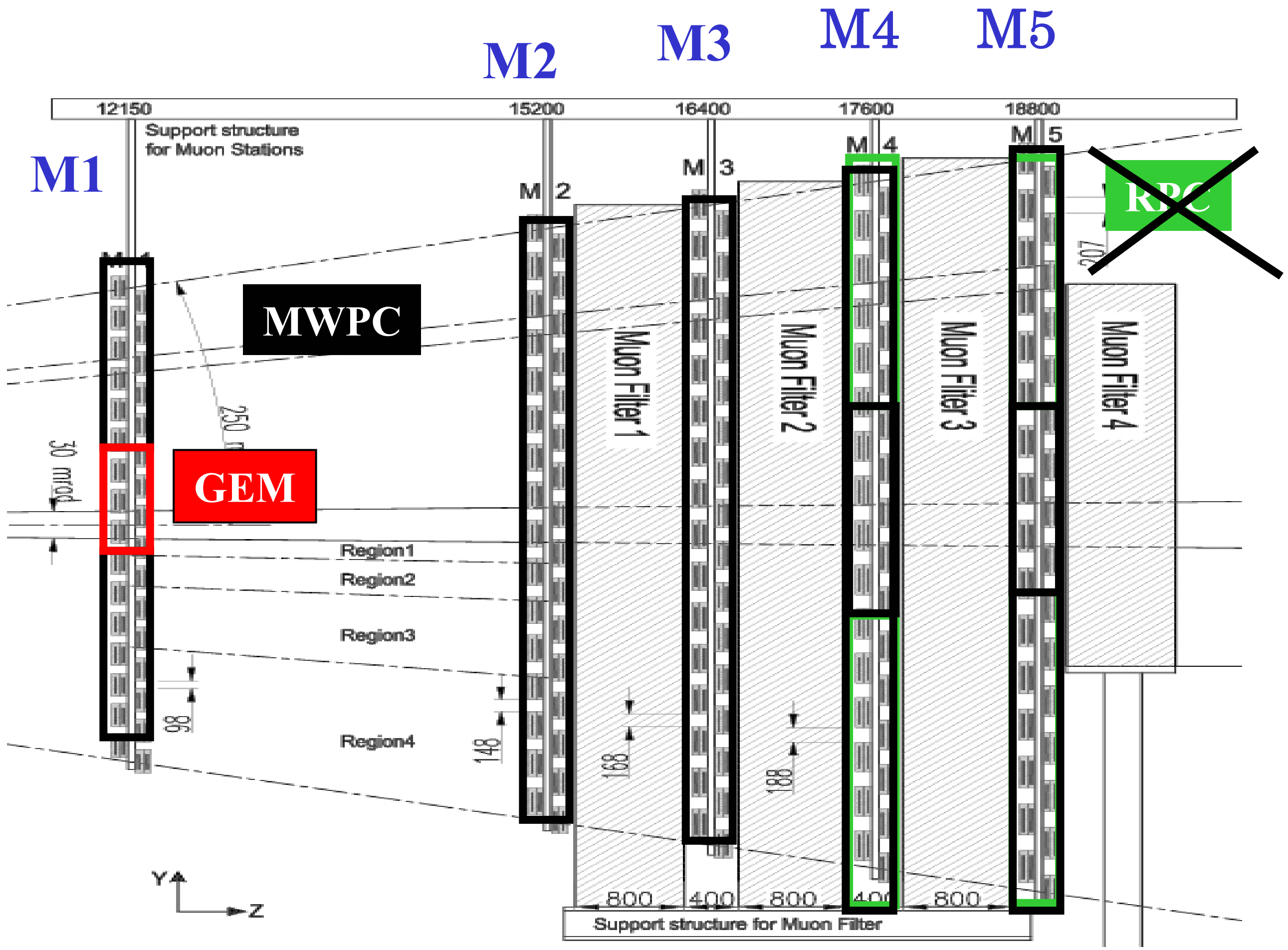




¼ of M4 station

- **5 muon stations, one upstream (M1), 4 downstream (M2-M5) the calorimeters.**
- **Each station is divided in 4 Radial Regions R1,R2,R3,R4**
- **The muon detector must provide high-pt information to the Level-0 muon trigger through a coincidence of hits in all five stations within the bunch crossing time of 25 ns**
- **The muon momentum must be measured with $\delta p_t / p_t \sim 20\%$ accuracy.**

The LHCb muon detector



- **1380 MWPC chambers, total surface: 435 m^2**
- **12 triple GEM detectors for the highest rate region**
- **Dimensions scales according to a pointing geometry**
- **M2-M5: 4-gaps, M1: 2-gap**

Rates and Readout

	M1	M2	M3	M4	M5	
R1	460 GEM	37.5 MWPC mixed r/o	10 MWPC mixed r/o	6.5 MWPC cathode r/o	4.4 MWPC cathode r/o	Rates (KHz) Detector type Readout
R2	186 MWPC	26.5 MWPC mixed r/o	3.3 MWPC mixed r/o	2.2 MWPC cathode r/o	1.8 MWPC cathode r/o	
R3	80 MWPC cathode r/o	6.5 MWPC cathode r/o	1.0 MWPC cathode r/o	0.75 MWPC cathode r/o	0.65 MWPC cathode r/o	
R4	25 MWPC wires r/o	1.2 MWPC wires r/o	0.4 MWPC wires r/o	0.25 MWPC wires r/o	0.23 MWPC wires r/o	

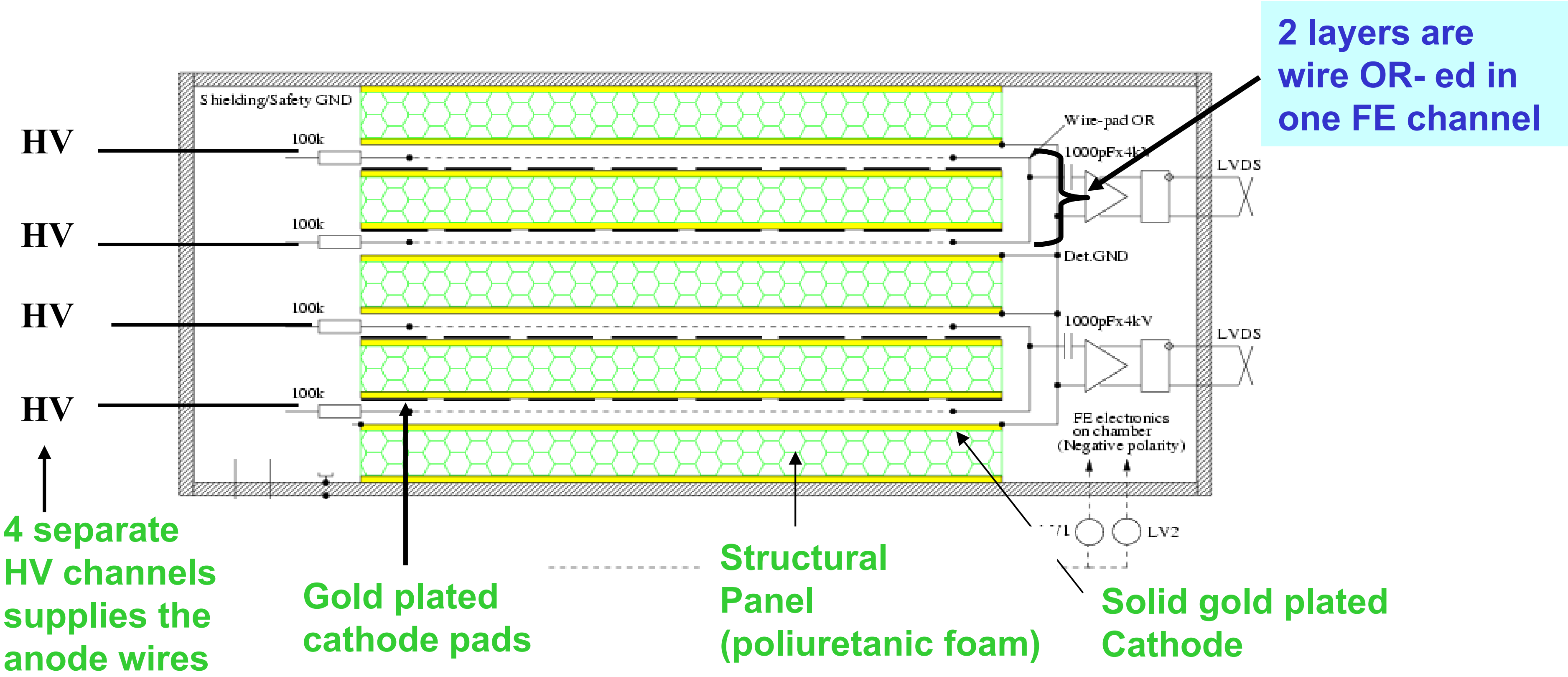
Expected rates considering σ_{pp}= 102.4 mb including safety factors

Requirements

- High detection efficiency (> 99%) per station in a 20 ns time window:
  - → good time resolution
- Good rate capability:
  up to ~460 kHz/cm^2 @ L = 5•10^{32} cm^{-2} s^{-1} in hottest region;
  - → fast
- Aging resistant: up to an integrated charge ~ 1 C/cm
  for safe operation in 10 years @ <L> = 2•10^{32} cm^{-2} s^{-1}
  - → robust

MWPC design

- **4 wire layers (High detection efficiency + redundancy)**
- **5 mm symmetric gas gap**
- **2 mm wire pitch (gold plated tungsten wires, 30 μm diameter)**
- **Wire tension: > 50 g**



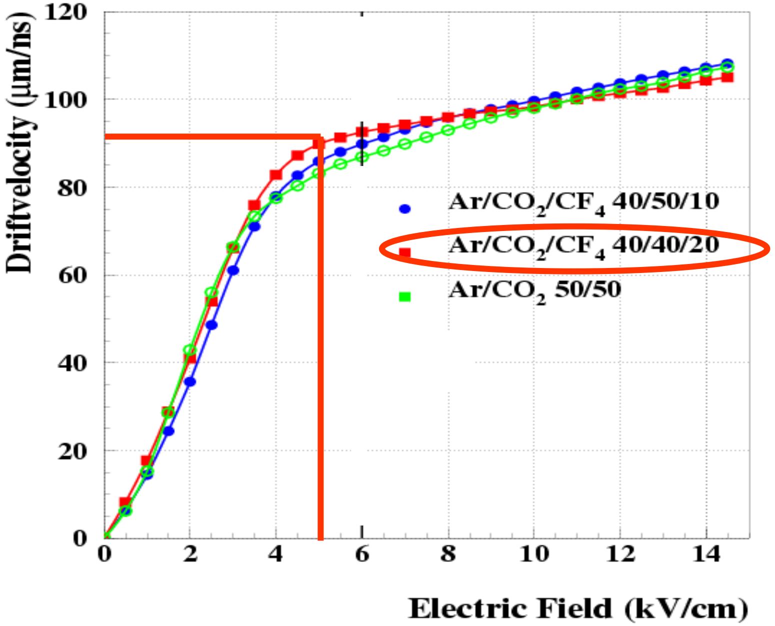
MWPC operating parameters:

- Gas mixture: Ar / $C0_2$ / CF_4 (40:40:20)
- Working point: Gain~ $5 \cdot 10^4$
- total charge per gap: 53 e^- (gap 5.0 mm)

→ Total charge per mip: 0.4 pC (for cathode pads readout)

- Field on wires: 212 kV/cm, field on cathodes: ~ 5 kV/cm
- Drift velocity: ~ 90 µm/ ns → collecting time @ half wire pitch: ~ 10 ns

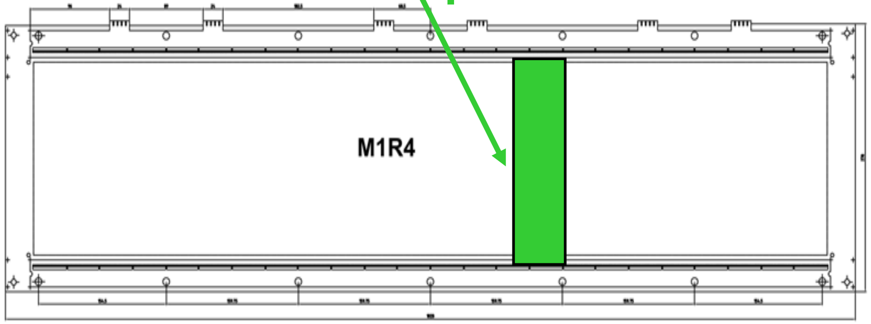
Drift velocity:



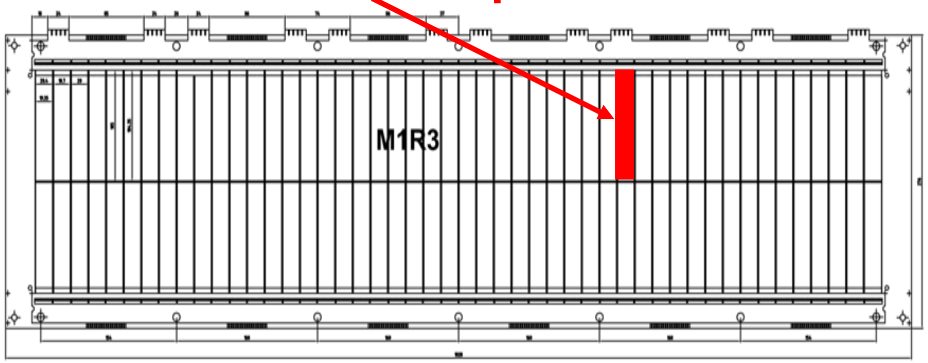
MWPC readout schemes

- The readout scheme depends on the granularity requested by: trigger, offline and particle rate
- We have: anode wire readout, cathode pads readout and combined readout (anode wire + cathode pads)

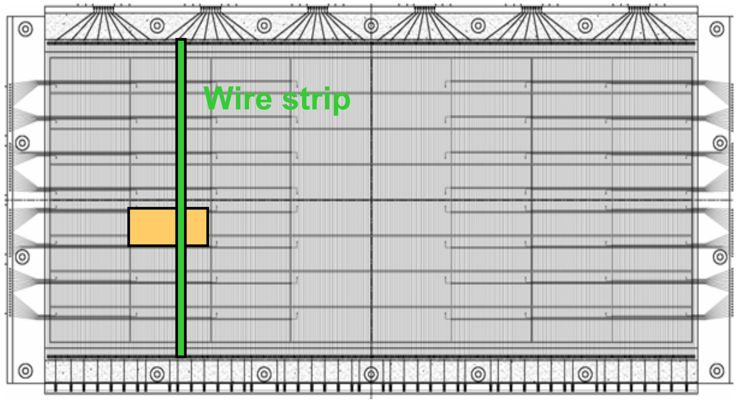
R4: wire pad readout



R3: cathode pad readout



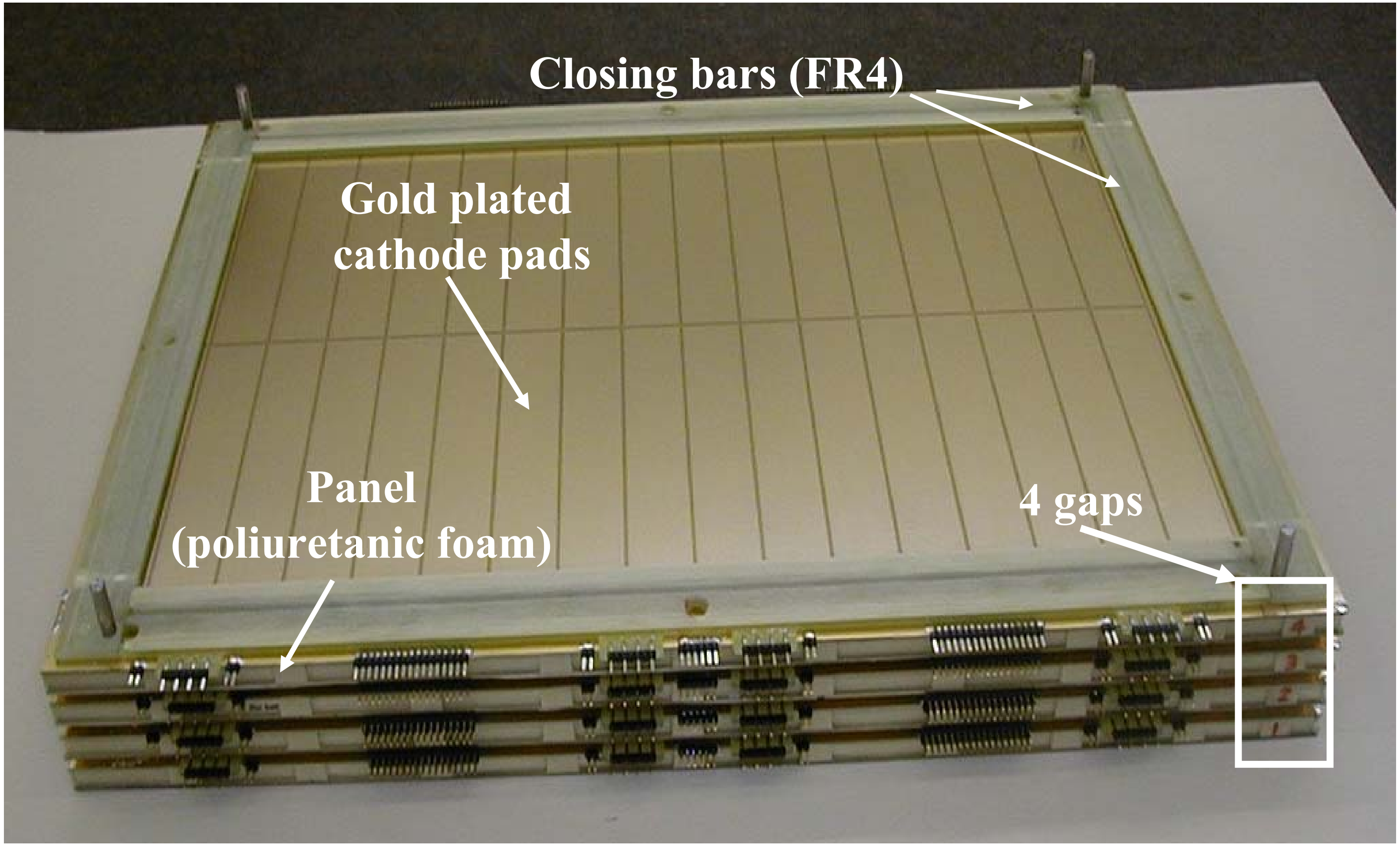
R1/R2-M2/M3: mixed readout

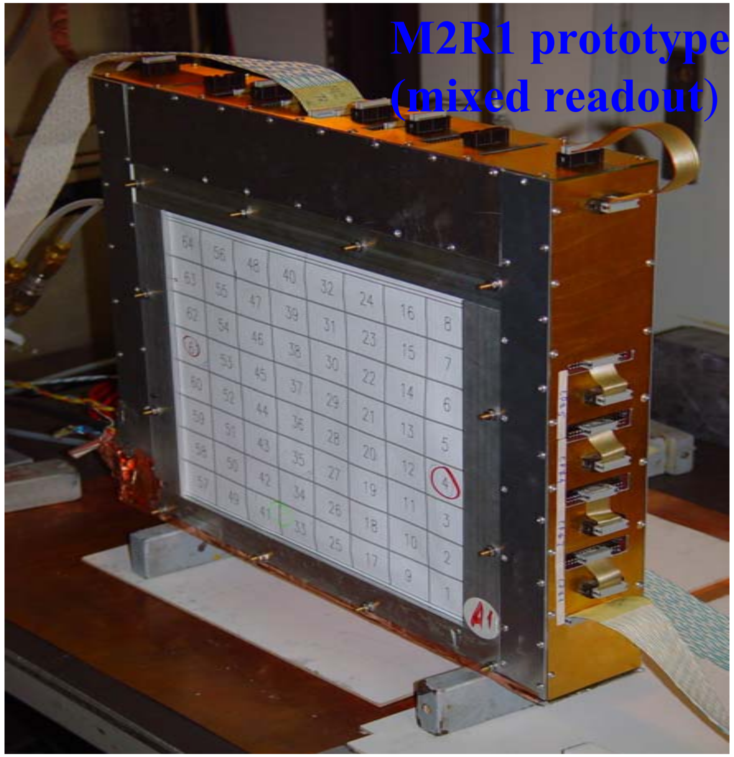


Granularity goes from (1x2.5)cm^2 to (25x30) cm^2

MWPC dimensions from (48x20)cm^2 to (149x31)cm^2

A small MWPC prototype:



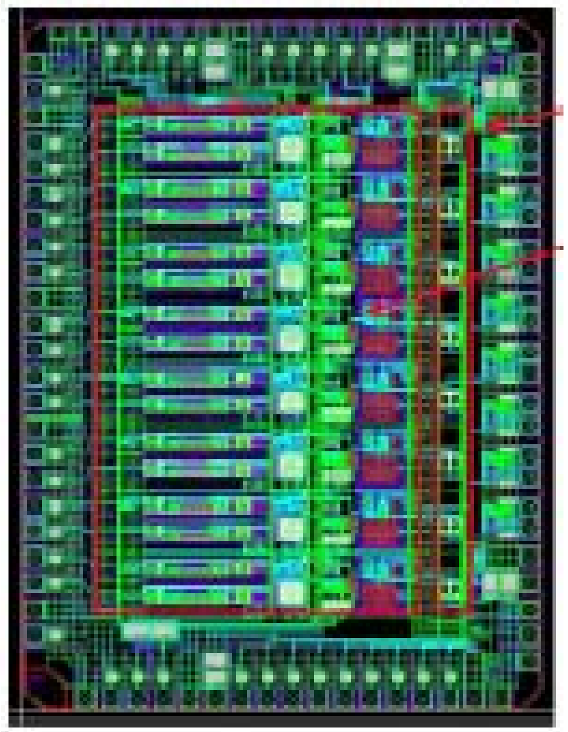


~ 15 prototypes built and tested with (almost) final front-end electronics at the T11 test beam area at CERN.

The Front-End Electronics: the CARIOCA chip

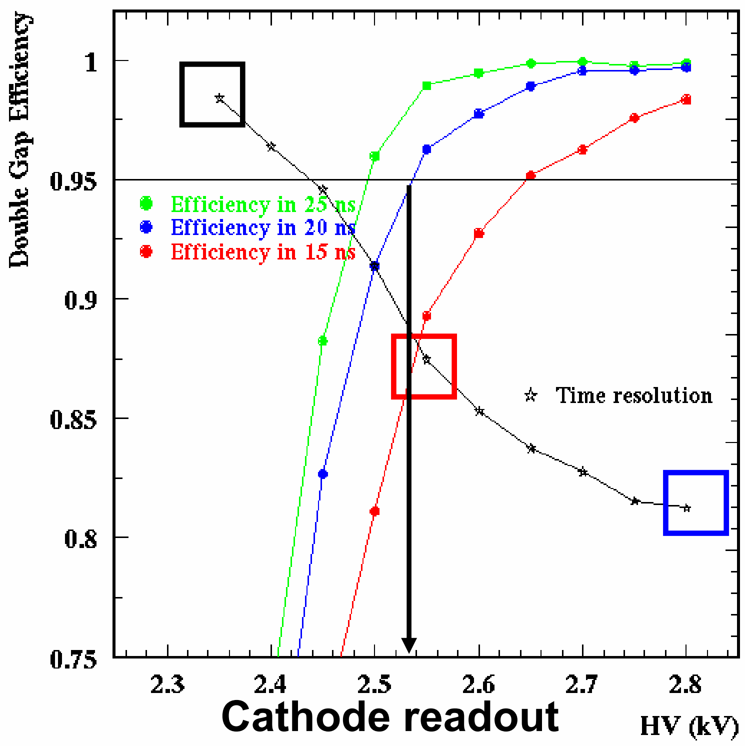
Carioca is the Amplifier-Shaper-Discriminator front-end chip developed for the MWPCs of LHCb

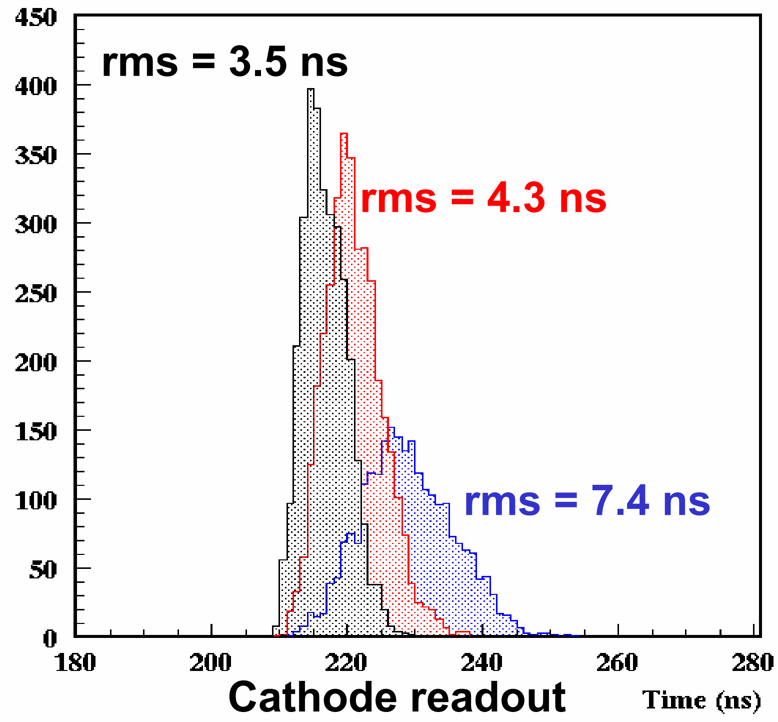
Specifications important for time resolution and rate capability:



- **Sensitivity: 15mV/fC**
- **Short peaking time:**
  tp ~ 10 ns for Cdet = (40÷220) pF
- **Low noise:**
  ENC ~ 2000 e-/pF
- **High rate capability:**
  pulse width ~ 50 ns, signal tail cancellation and baseline restoration circuits.
- **8 amplifiers per chip – 2 chips per board**

Efficiency and time resolution





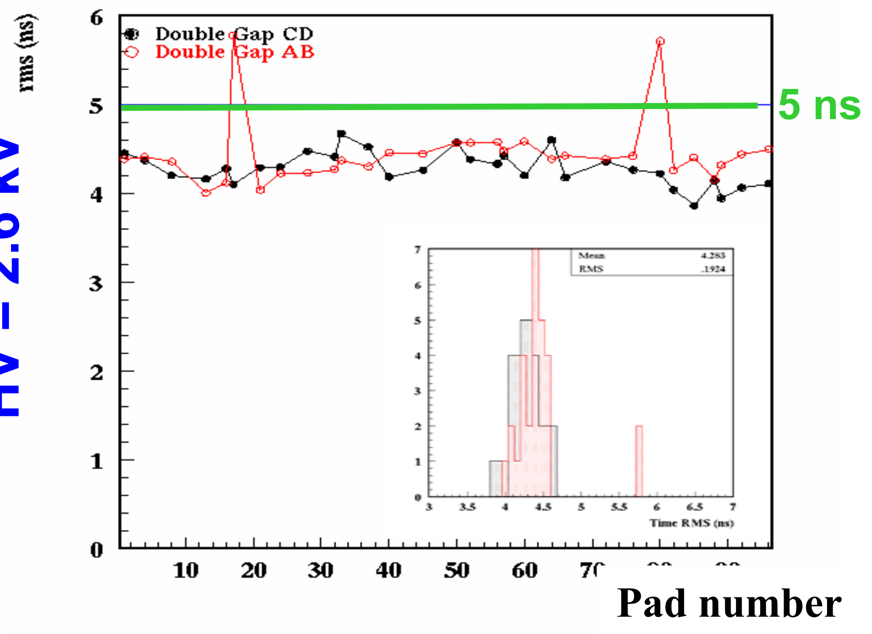
- ε(double gap) ≈ 95% in 20 ns ⟺ rms (double gap) ≤ 5 ns
- HV(ε=95%) = 2.45 kV for wire readout
- HV(ε=95%) = 2.55 kV for cathodes/mixed readout

Time Resolution and Efficiency Uniformity:

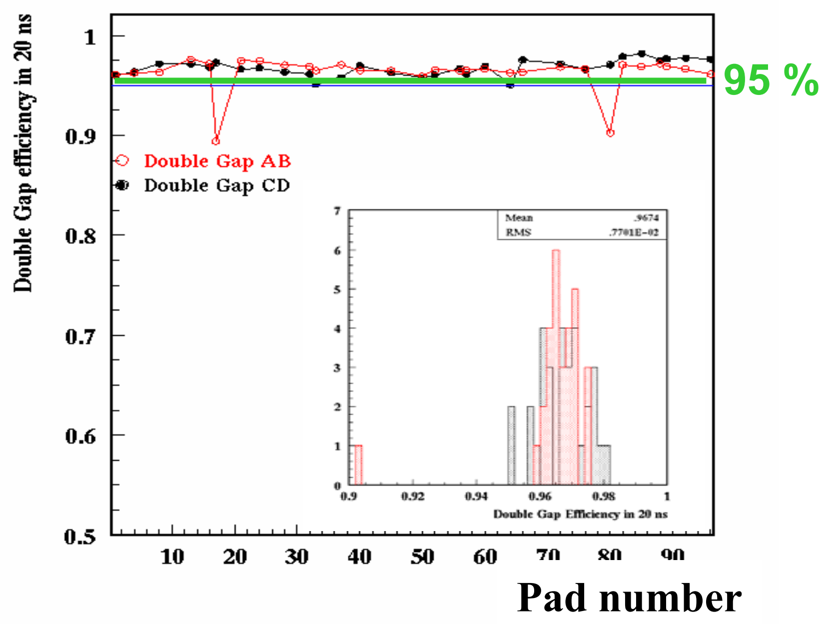
Example of uniformity measurements on a M3R3 prototype with cathode pad readout

HV = 2.6 kV

Time resolution:



Double Gap Efficiency in 20 ns:



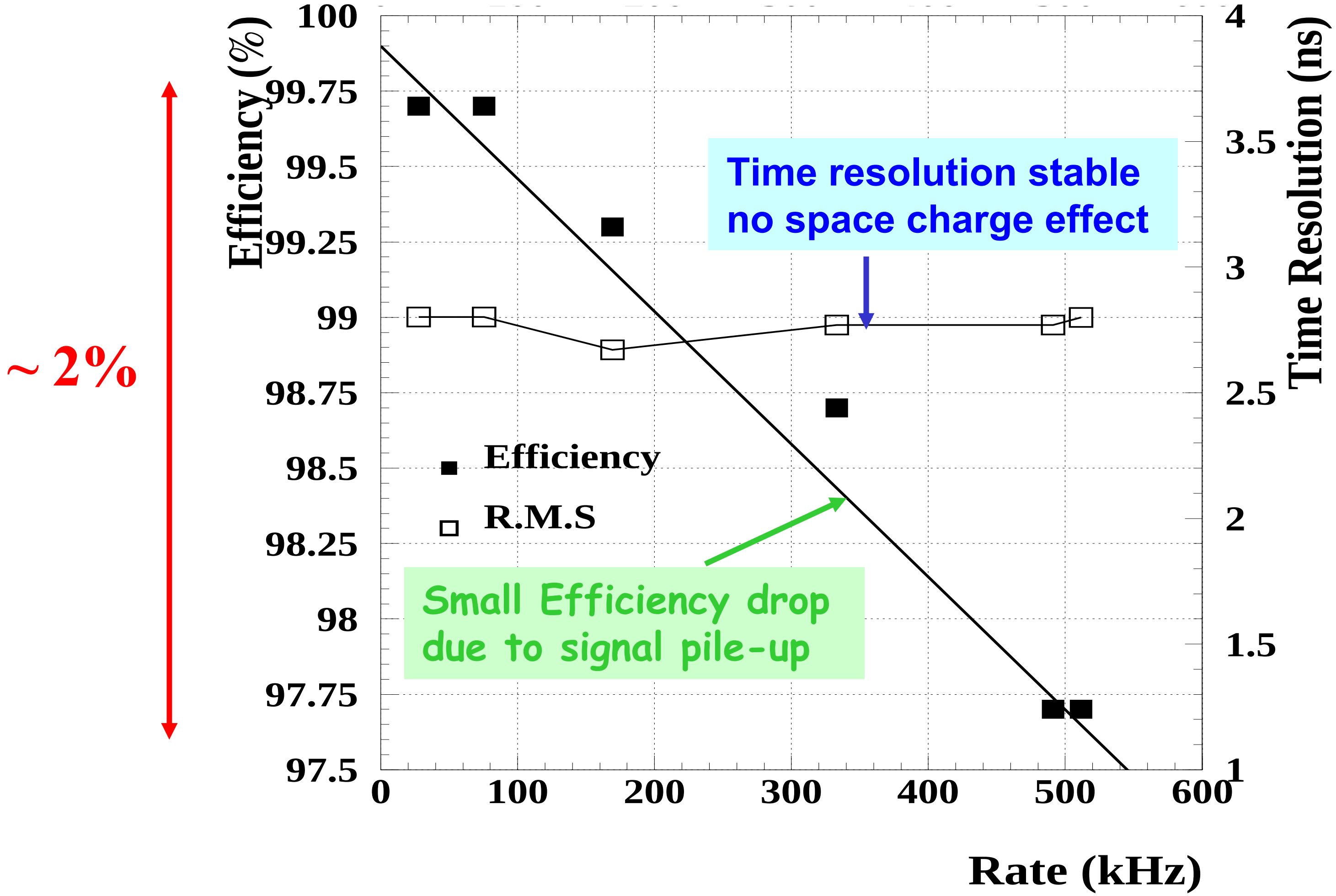
Average time = (4.3±0.2) ns

Average ε = (96.7 ±0.1) %

> 99% pads are inside the specifications

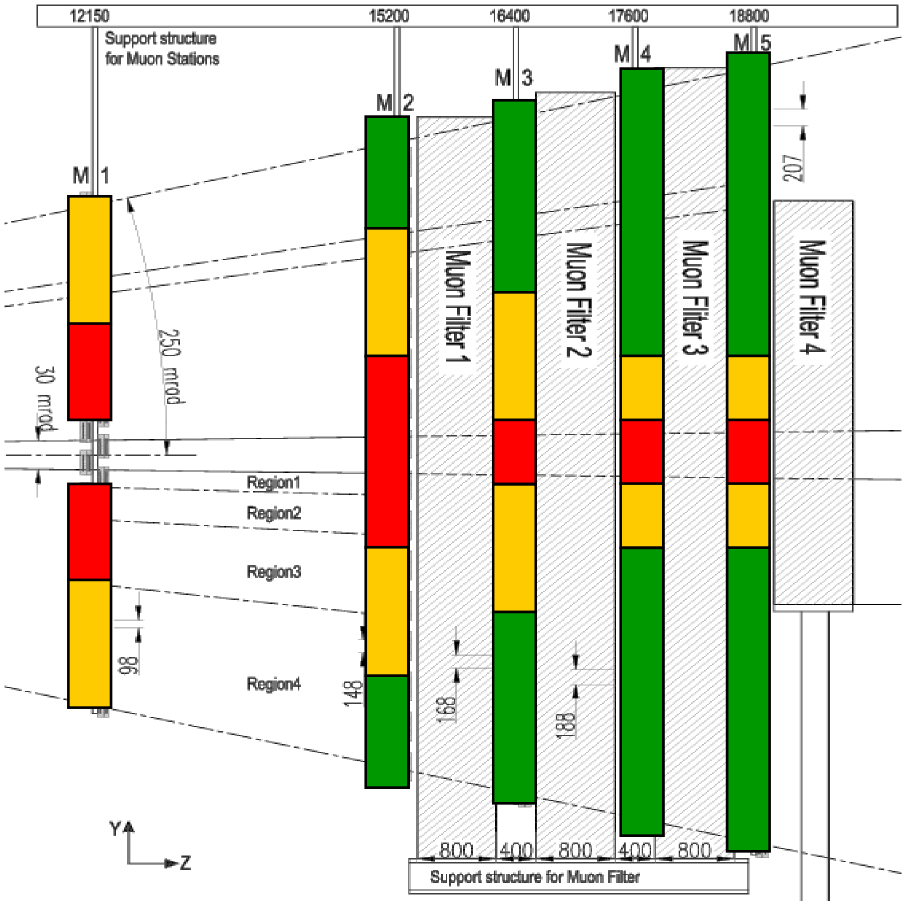
High Rate behavior

Test @ GIF up to 500 kHz/FEE channel



Aging Test of MWPCs

Expected Integrated charge in
10 years @ $2 \cdot 10^{32}$ cm^{-2} s^{-1}



- **Q < 10 mC/cm**
  for 76% of area
- **10 mC/cm <Q < 100 mC/cm**
  for 19% of area
- **100 mC/cm < Q < 1 C/cm**
  for 5% of area

Particle rates are from LHCb-Muon TDR2001.
Safety factors of have been included to take into account the deposited charge of low energy background hits.

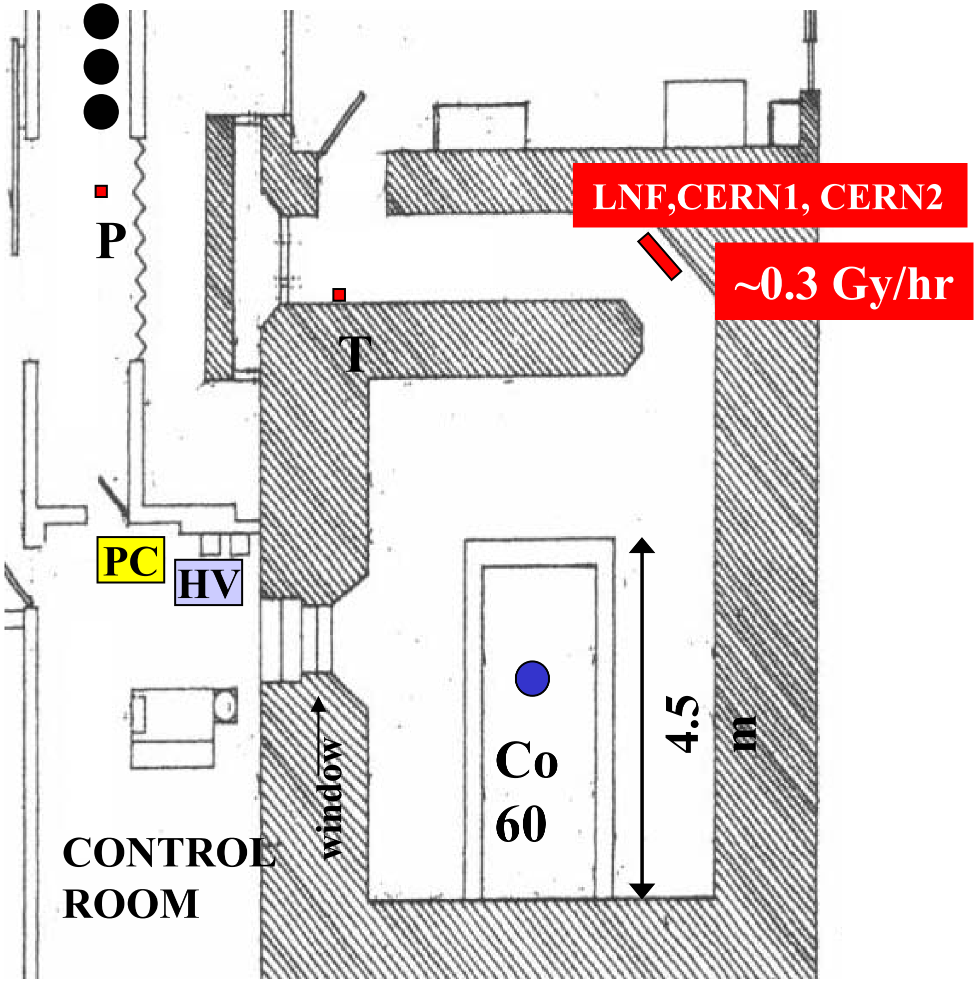
Aging tests @ ENEA Casaccia Calliope Facility:

- Source: ^{60}Co (~ 10^{15} Bq)
  <Eγ> ~ 1.25 MeV

- 3 MWPC irradiated with dose rates up to ~ 0.3 Gy/hr and different gas flows (vented and re-circulating gas system)

- Standard mixture:
  $Ar / CO_2 / CF_4$ = 40:40:20

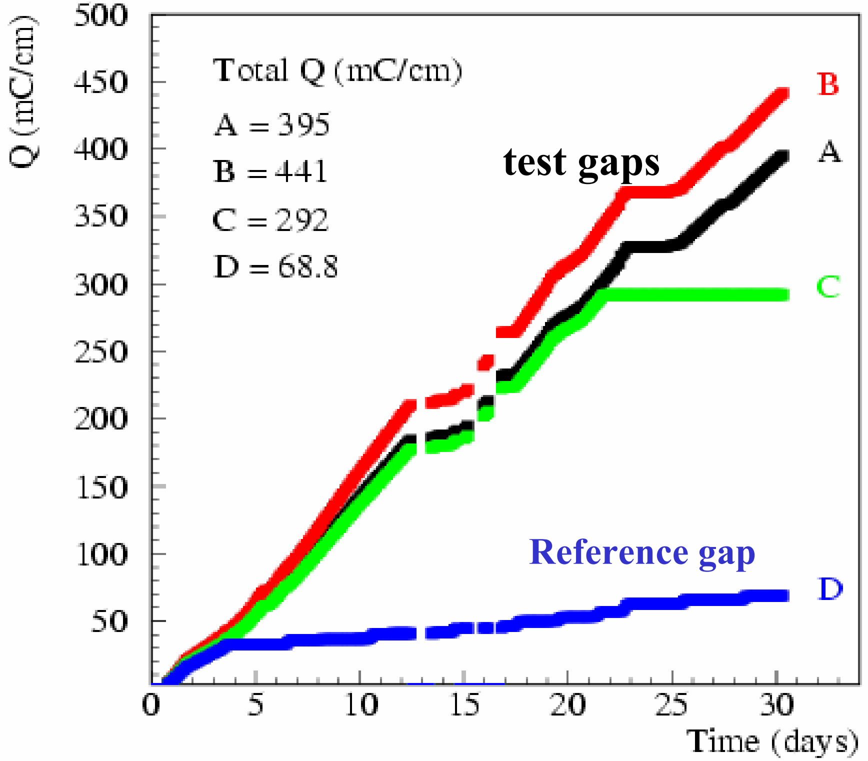
- Gas gain ~ (1÷1.5) 10^5 (~double wrt to the nominal one).



Aging tests @ ENEA Casaccia Calliope Facility

- 32 days of tests
- Integrated charge per cm of wire:
  Q ~ (440÷480) mC/cm $\Rightarrow$ (5÷10) years depending on the rate evaluation.
- Typical current density: I ~ (1÷1.4) μA/cm^2 (active areas = 500÷1200 cm^2);
- In each chamber, one gap (out of 4) was switched on only for short periods to be used as reference

Integrated Charge:

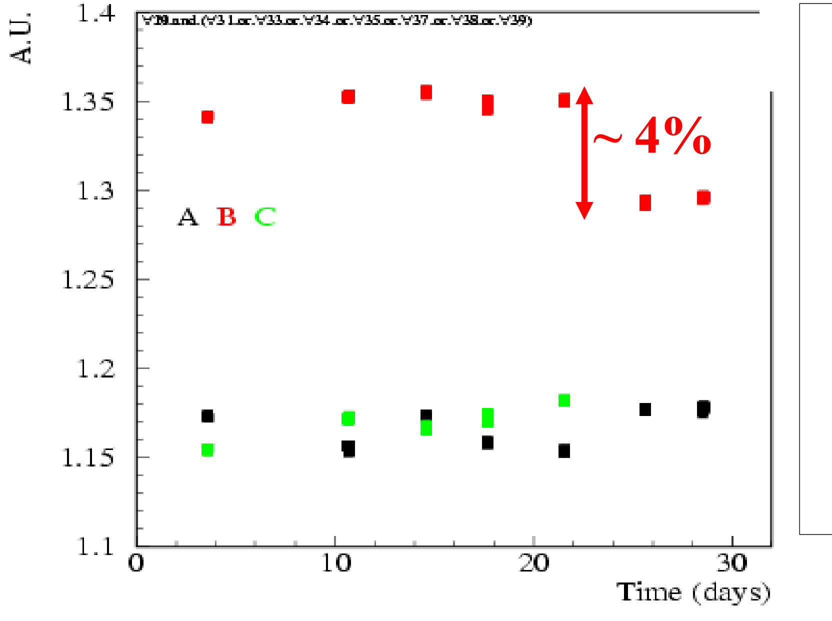


Aging tests @ ENEA Casaccia Calliope Facility

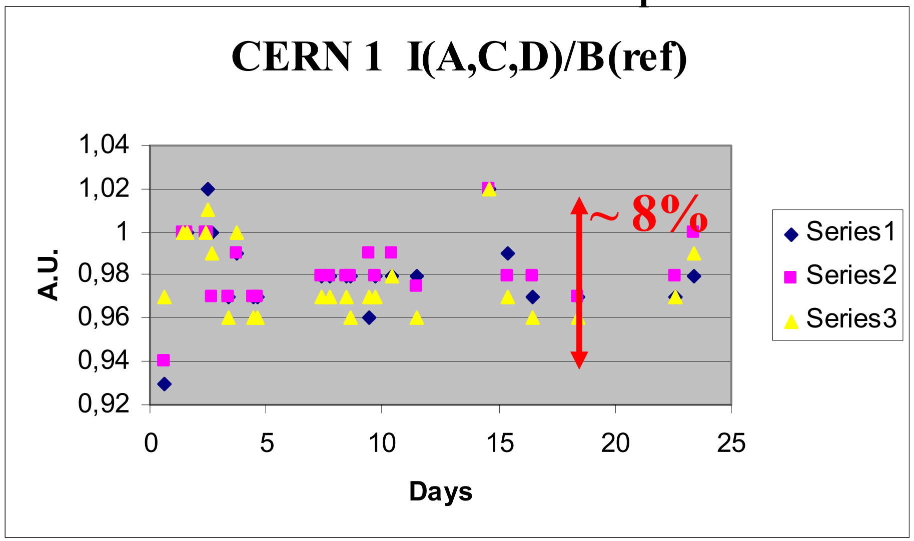
We normalized the currents of tested gaps respect to the reference gap in order to remove T and P dependence and accidental gas mixture changes.

⇒ Current ratios are constant within ~10% for all chambers.

Current ratios – vented mode



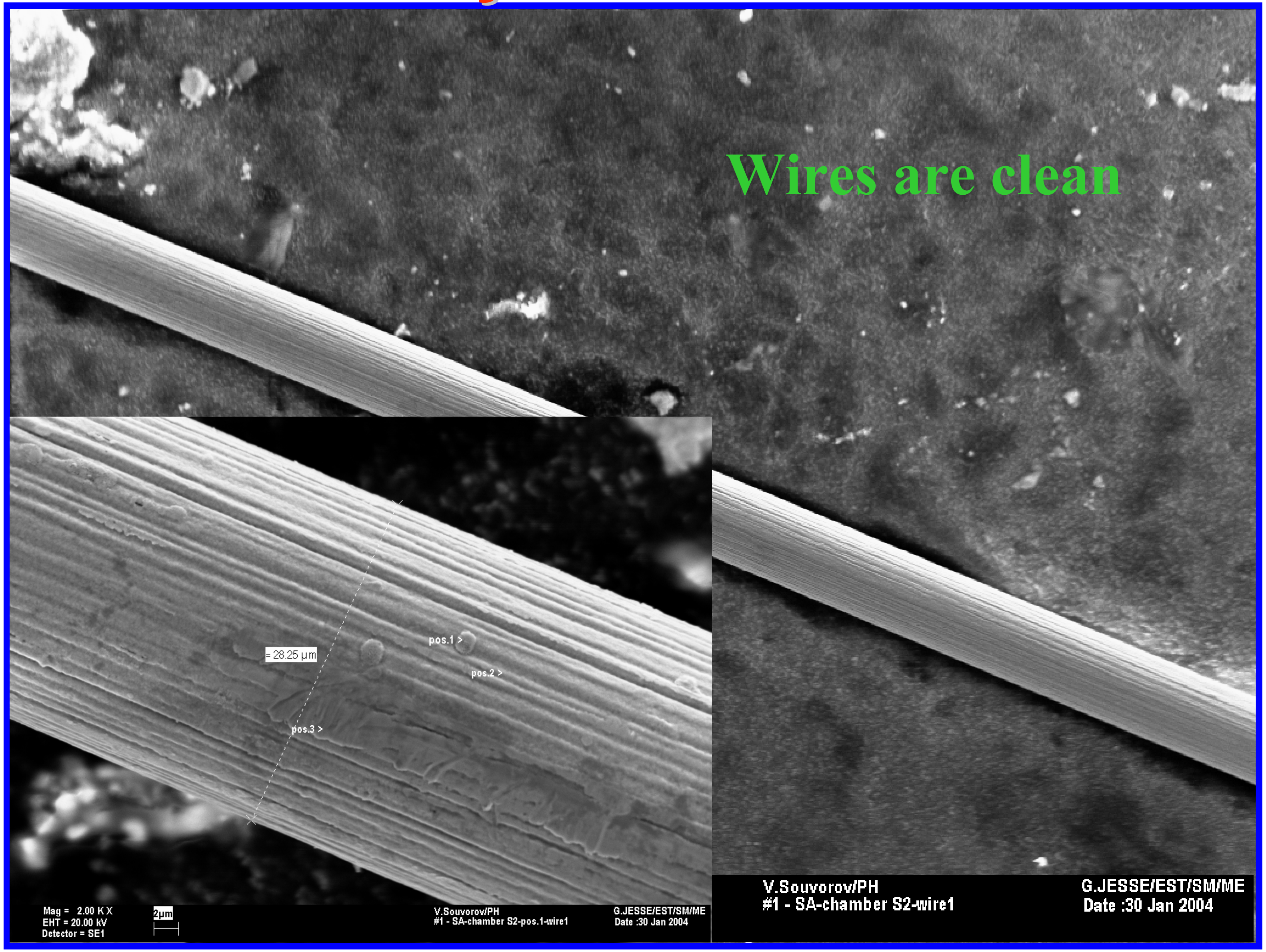
Current ratios - closed loop

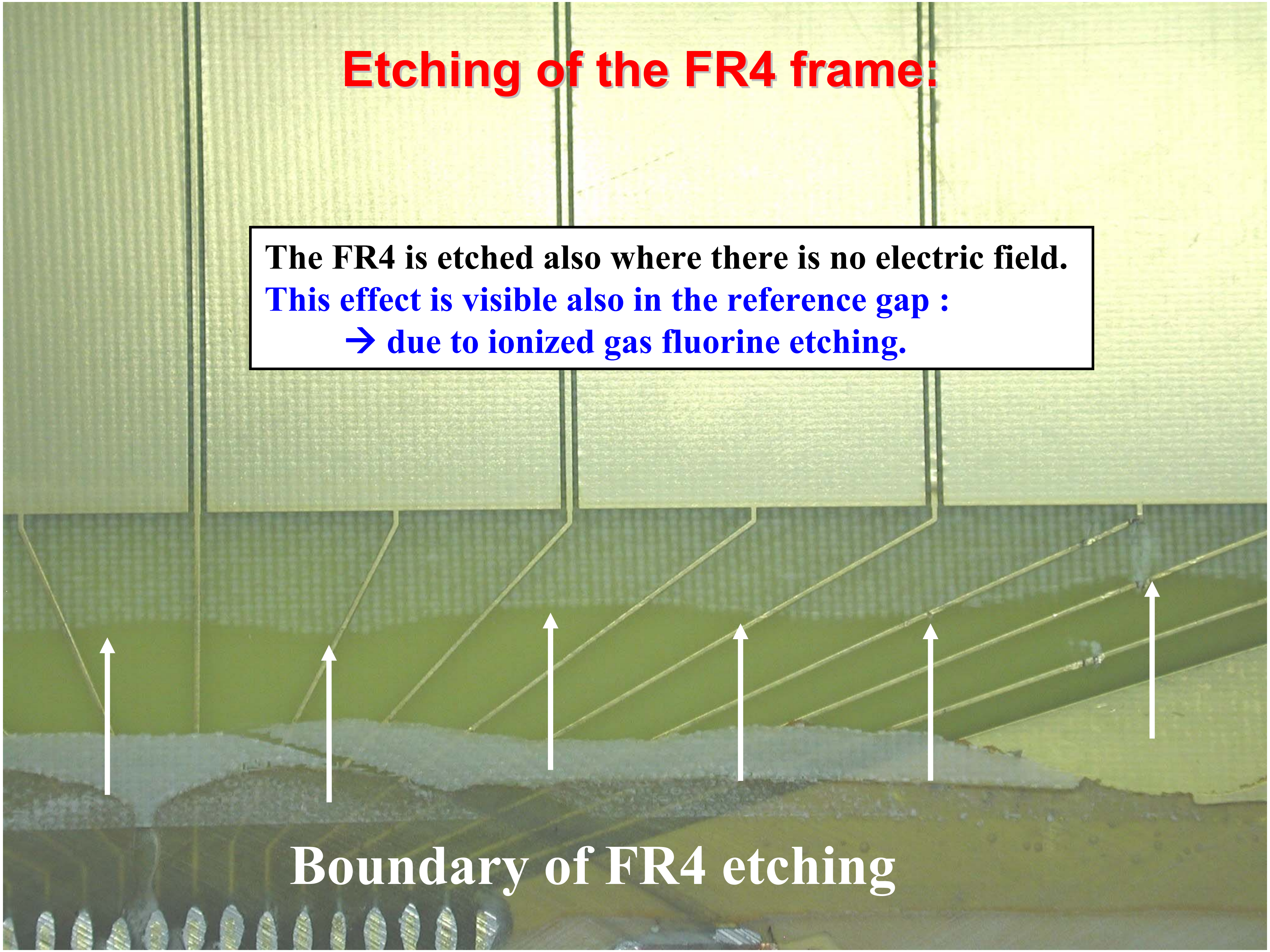


Malter currents: **The self-sustaining rest currents were measured with the source off, using current monitors with a resolution of 1 nA.**

⇒ All gaps of all chambers drew currents of the order of few tens of nA or smaller with a decreasing trend.

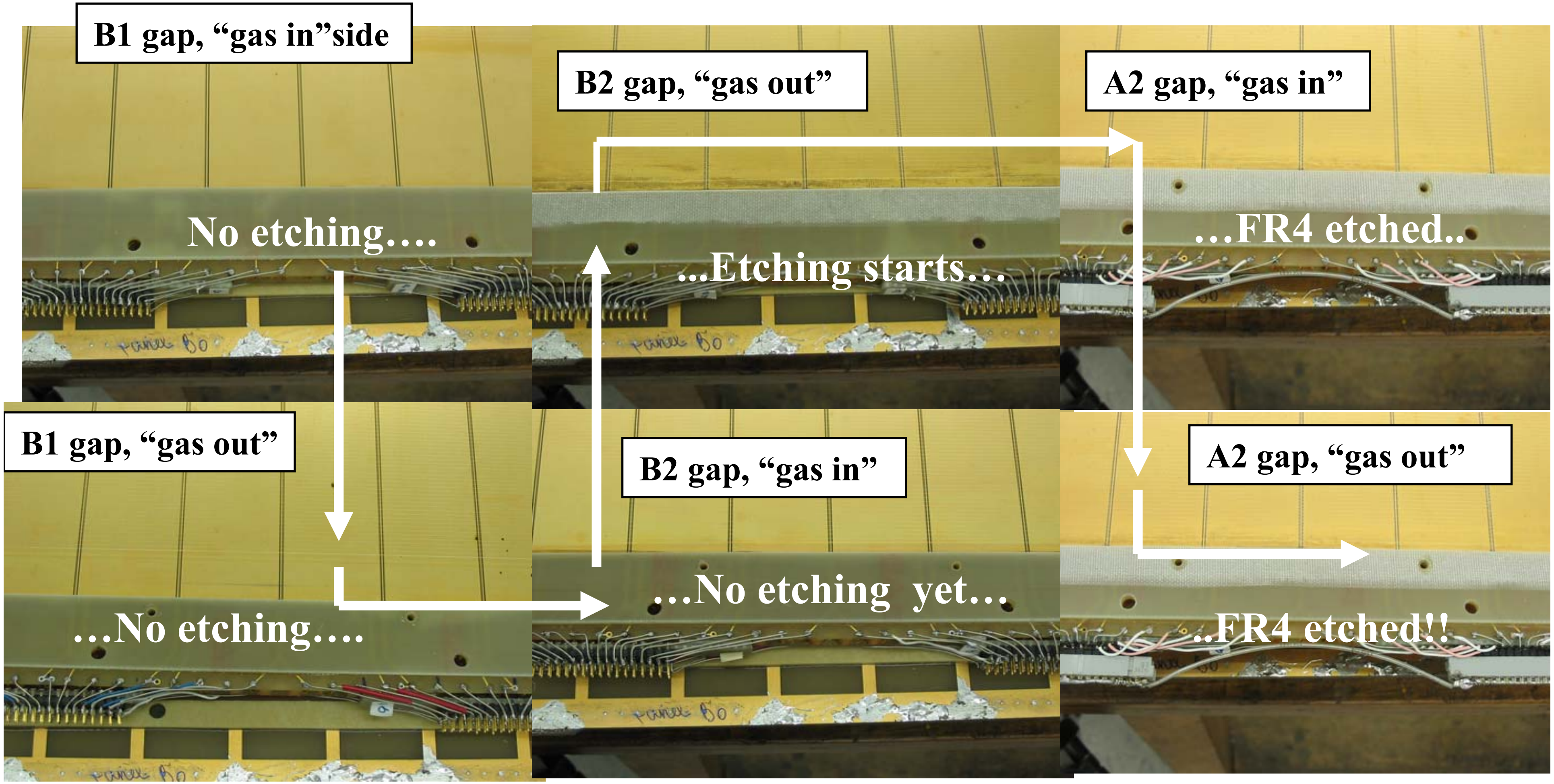
Analysis of Wires




Etching of the FR4 frame:
The FR4 is etched also where there is no electric field.
This effect is visible also in the reference gap :
→ due to ionized gas fluorine etching.
Boundary of FR4 etching

The etching of the FR4 frame goes with the gas flow :

Gas flow direction: B1 ⇒ B2 ⇒ A2 ⇒ A1, B1=reference gap



Conclusions on the MWPC ageing test

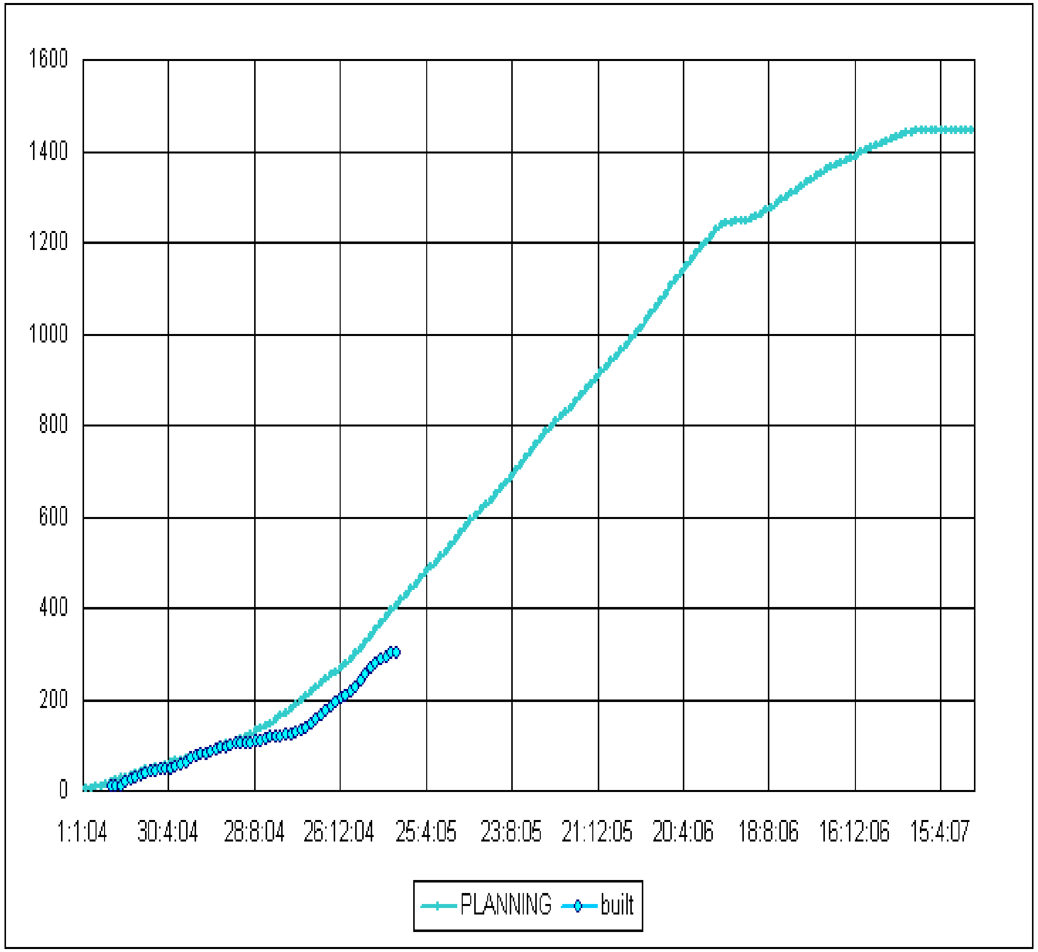
- In **32 days** we integrated up to **Q~480 mC/cm** corresponding to **5÷10 years** (depending on the rates foreseen) of LHCb **@ 2 x 10^{32} cm^{-2} s^{-1}**

- Materials exposed to CF_4 under irradiation **show a surface etching BUT no drop in gas gain** observed within 10%:

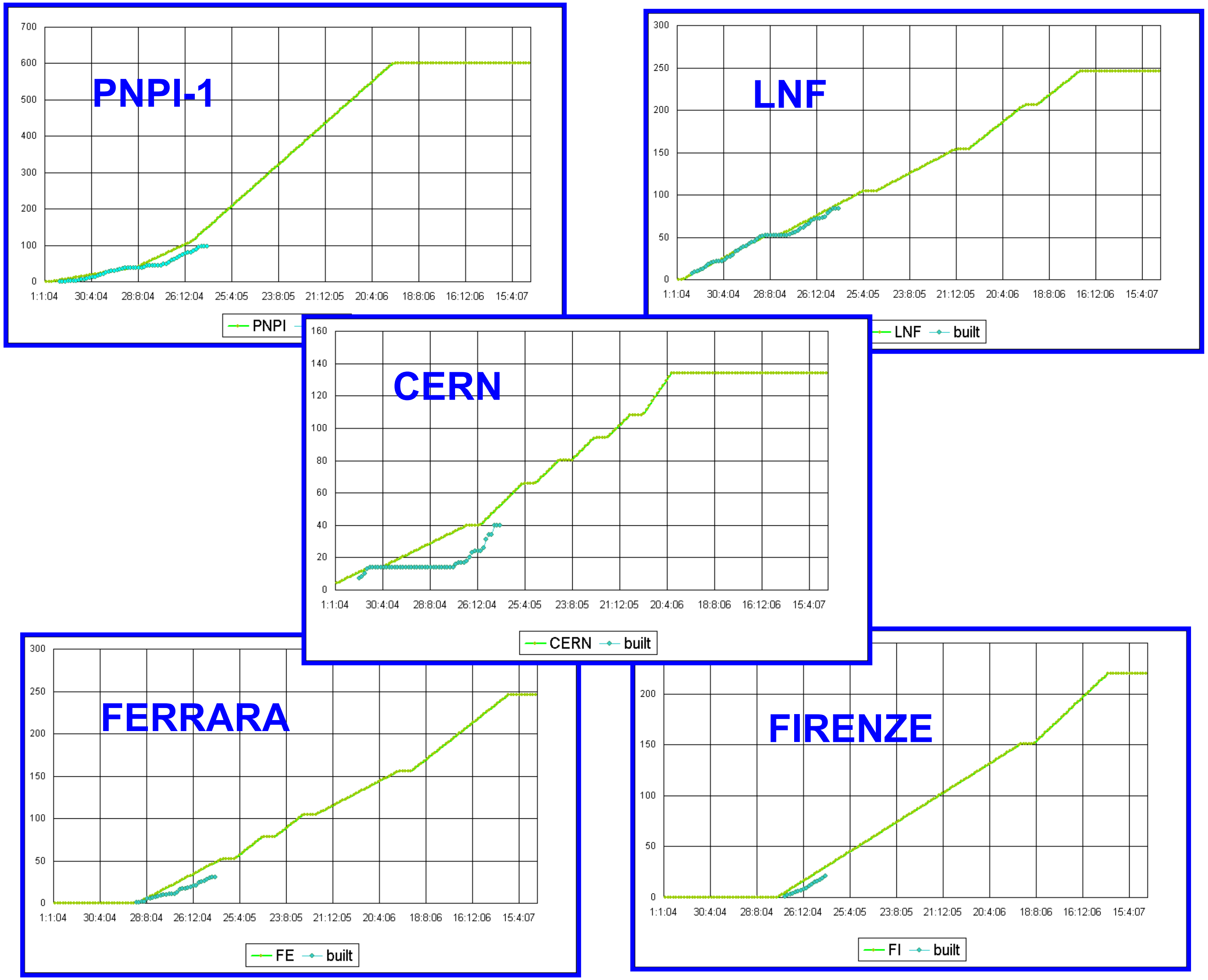
  ⇒ **we decided do not change chamber design and materials**

MWPC Chamber Production

- A total of **1380 MWPC** (+ 10% spare) have to be produced
- The MWPC are produced in 6 productions centers:
  - LNF, Ferrara, Firenze, CERN, PNPI-1,PNPI-2
- LNF,PNPI-1,CERN started in January 2004, Ferrara and Firenze in August 2004, PNPI-2 is starting now



Production status



Conclusions

- Three years of extensive tests showed that our design of MWPCs of operating with CF_4 based gas mixture satisfies all the requirements for the LHCb Muon System

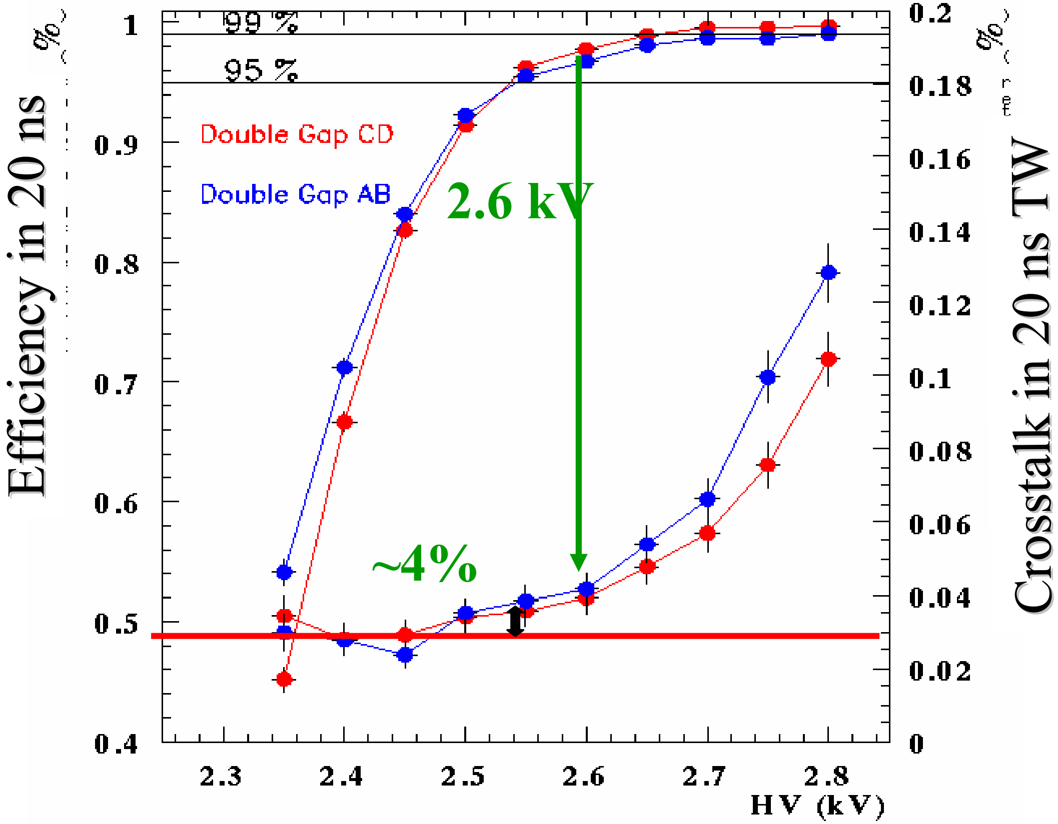
- We built a fast detector, with good time resolution and aging resistant

- It will cover an area of ~ 435 m^2 with 1380 chambers and ~126000 readout channels

- The production is started and the detector should be ready for the 1st LHC beams

Spares:

Efficiency and crosstalk



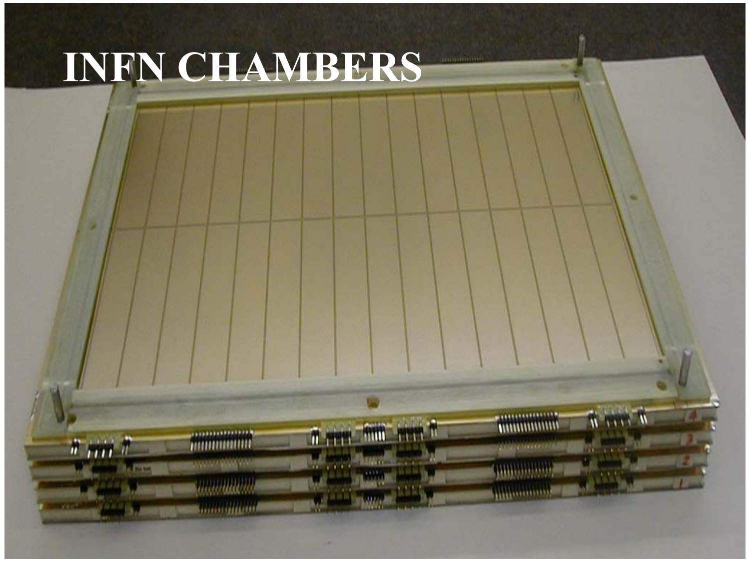
Crosstalk: probability of firing the neighboring pad

Pt accuracy measurement requires: Crosstalk < 5%

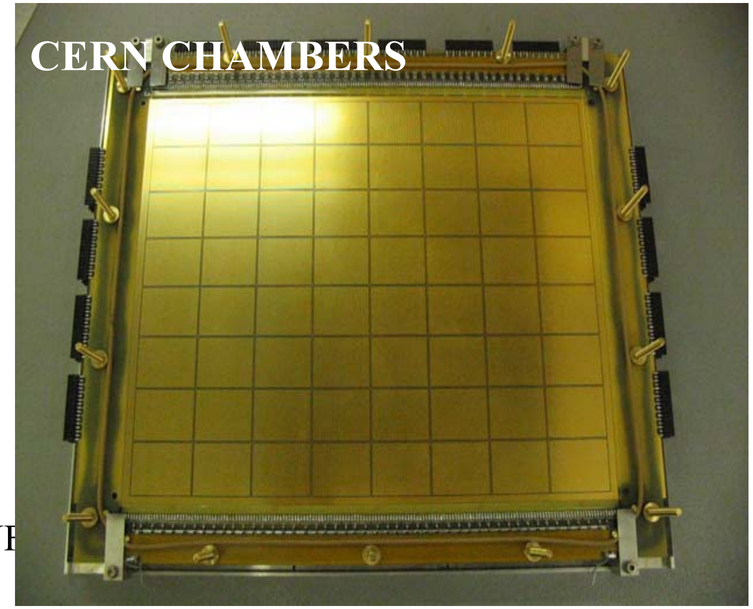
Main source is the pad-to-pad capacitive coupling

Chambers materials

Common Materials:
Gold plated 30 µm tungsten wires.
Gold plated cathode pads.
Adekit 145/450 epoxy for wire glueing.



INFN chamber:
- **Adekit 140 for chamber closing.**



CERN chambers:
- **Natural rubber O-rings.**
- **Kapton foils to protect HV-traces and glued with epoxy.**
- **Low temperature soldering, carbon film resistors and SMD capacitors.**

RPC for LHCB Muon System

Historical review

1998: RPC were proposed for LHCb Muon detector in regions with rates < 1 kHz/cm^2.

1999: 2 prototypes built with identical characteristics:

- bakelite electrodes ($\rho \sim 10^{10}\ \Omega$ cm);
- linseed oil;
- graphite (100 kΩ/□) ;
- 50 x 50 cm^2 area.
- 2 mm gas gap ($C_2H_2F_4 : iC_4H_{10} : SF_6 =$ 95:4:1)
- avalanche mode (HV ~10.6 kV).

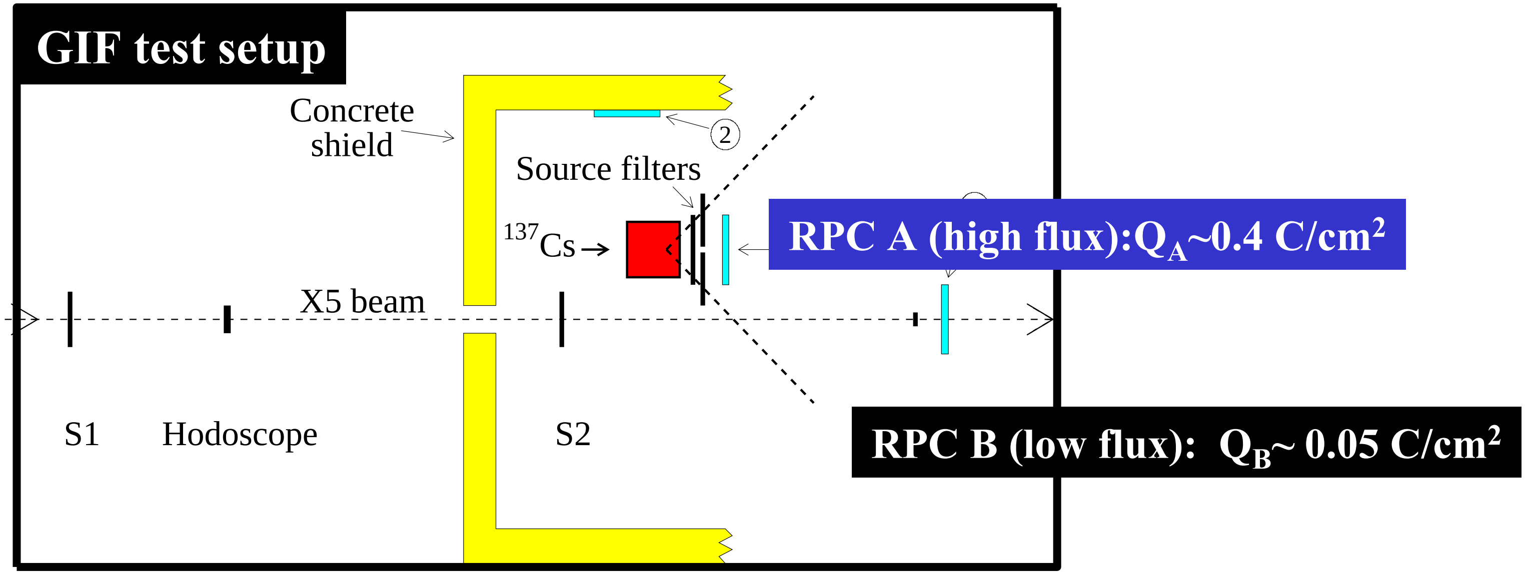
2000: rate capability was measured to be ≥ 3 kHz/cm^2 (NIM A 456 (2000) 95.)

2001: an extensive test for study the aging properties started at GIF…

Rates (kHz/cm^2) and integrated charge (C/cm^2) for $L = 5 \cdot 10^{32}$ cm^{-2} s^{-1}

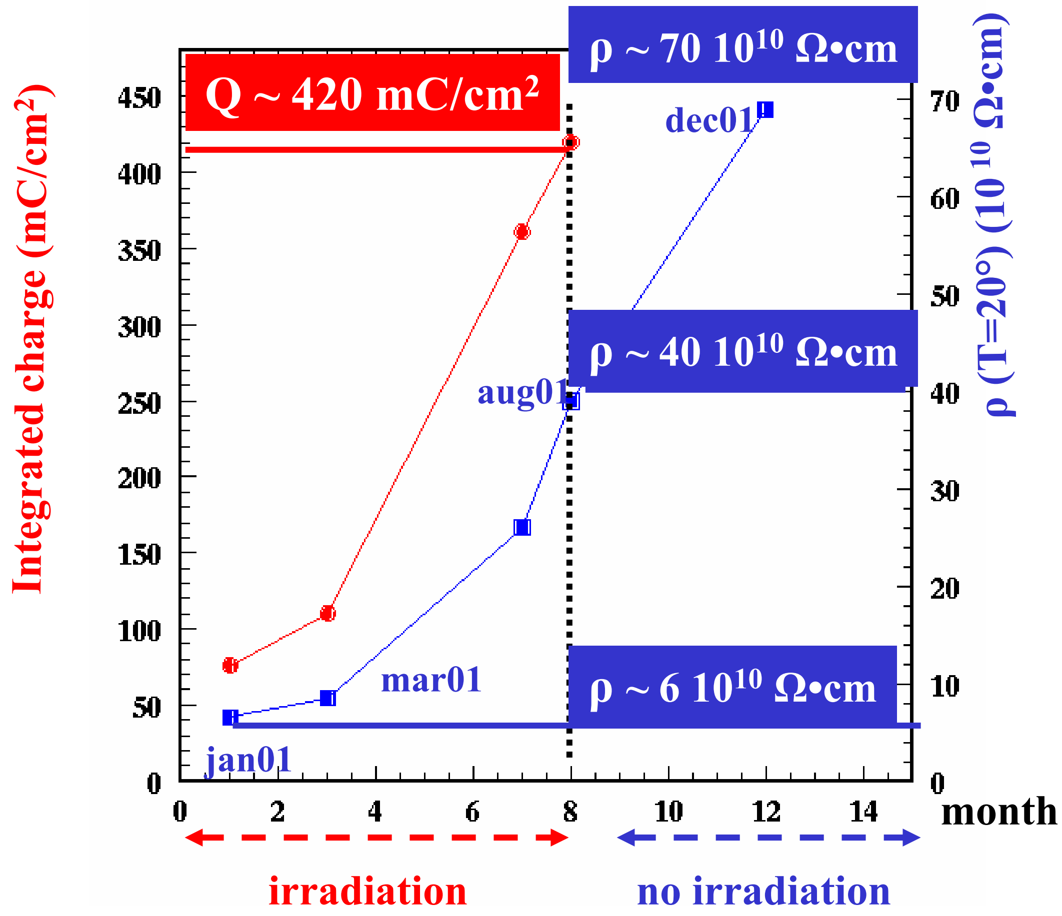
	M1	M2	M3	M4	M5
R1					
R2				RPC	
R3				0.75 1.1	0.65 1.0
R4				0.25 0.4	0.23 0.3

Aging test in 2001 @ GIF



- RPC A irradiated at GIF during 7 months up to Q~ 0.4 C/cm^2 .
- RPC B not irradiated, used as reference.
- I, V_0 and T continuously monitored.
- Bakelite resistivity ρ extracted from (I,V_0) curve using a model for RPC operating under high flux conditions (NIMA 498 (2003) 135) and corrected for T dependence.

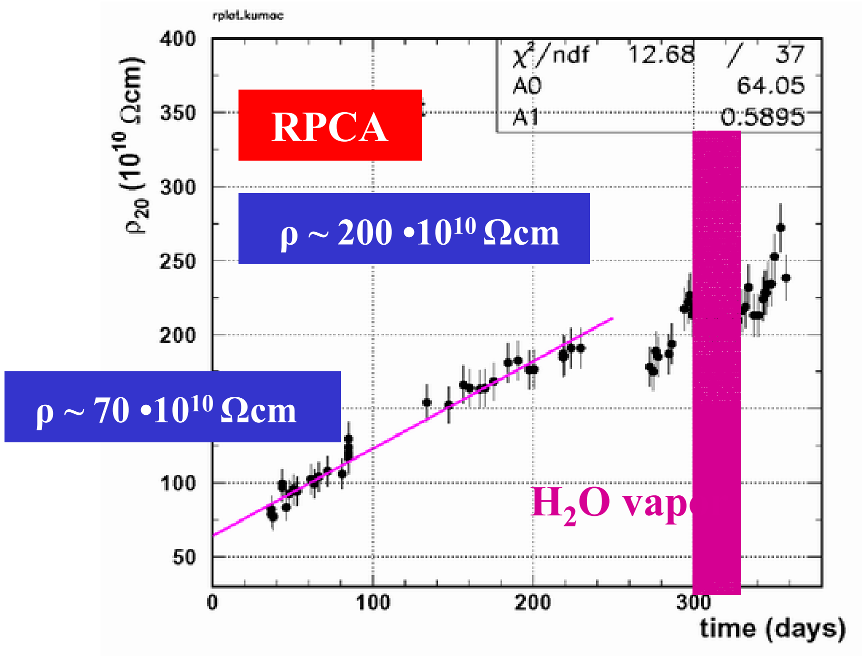
Aging test in 2001 @ GIF: RPC A results

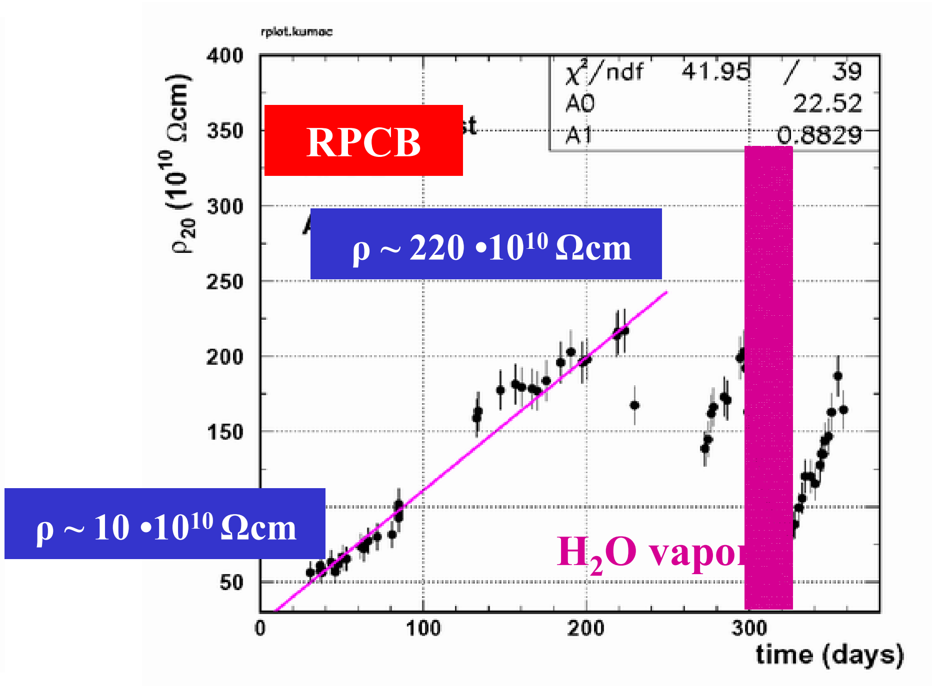


Observed a steady increase of ρ with and without irradiation.

Aging test in 2002 @ GIF

- ❖ Both detectors slowly irradiated (Q~0.05 C/cm^2 accumulated charge).
- ❖ Resistivity continuously measured during ~ 350 days.
- ❖ Observed a steady increase of ρ with time for both deterctors probably due to drying up of bakelite.
- ❖ Addition of 1.2% of H_2O vapor to the nominal gas mixture produced a decrease of resistivity. This effect in any case disappeared as soon as dry gas was flowed.





Mechanical Tolerances:

- The specifications for a single gap were defined such as the gas gain is within :
  - $0.8*G_0$ and $1.25*G_0$ in 95% of the chamber area;
  - $G_0/1.5$ and $1.5*G_0$ in 5% of the chamber area.

- What chamber imperfections are allowed in order to keep the gain within specifications?

SPECIFICATIONS:

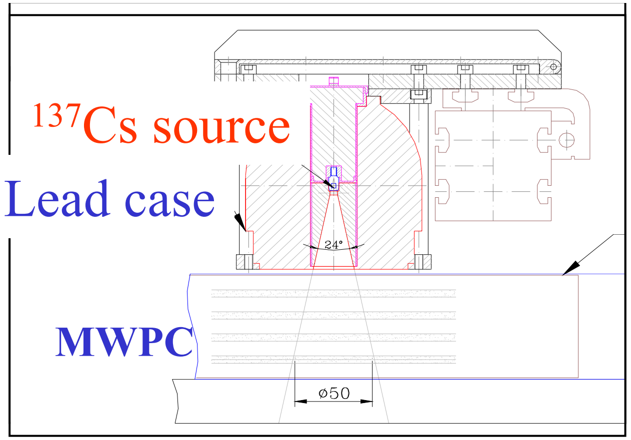
• Gap:	95% in ± 90 μm	5% in ± 180 μm
• Wire pitch:	95% in ± 50 μm	5% in ±100 μm
• Wire y-offset:	95% in ± 100 μm	5% in ±200 μm
• Wire plane y-offset:	95% in ± 100 μm	5% in ± 200 μm

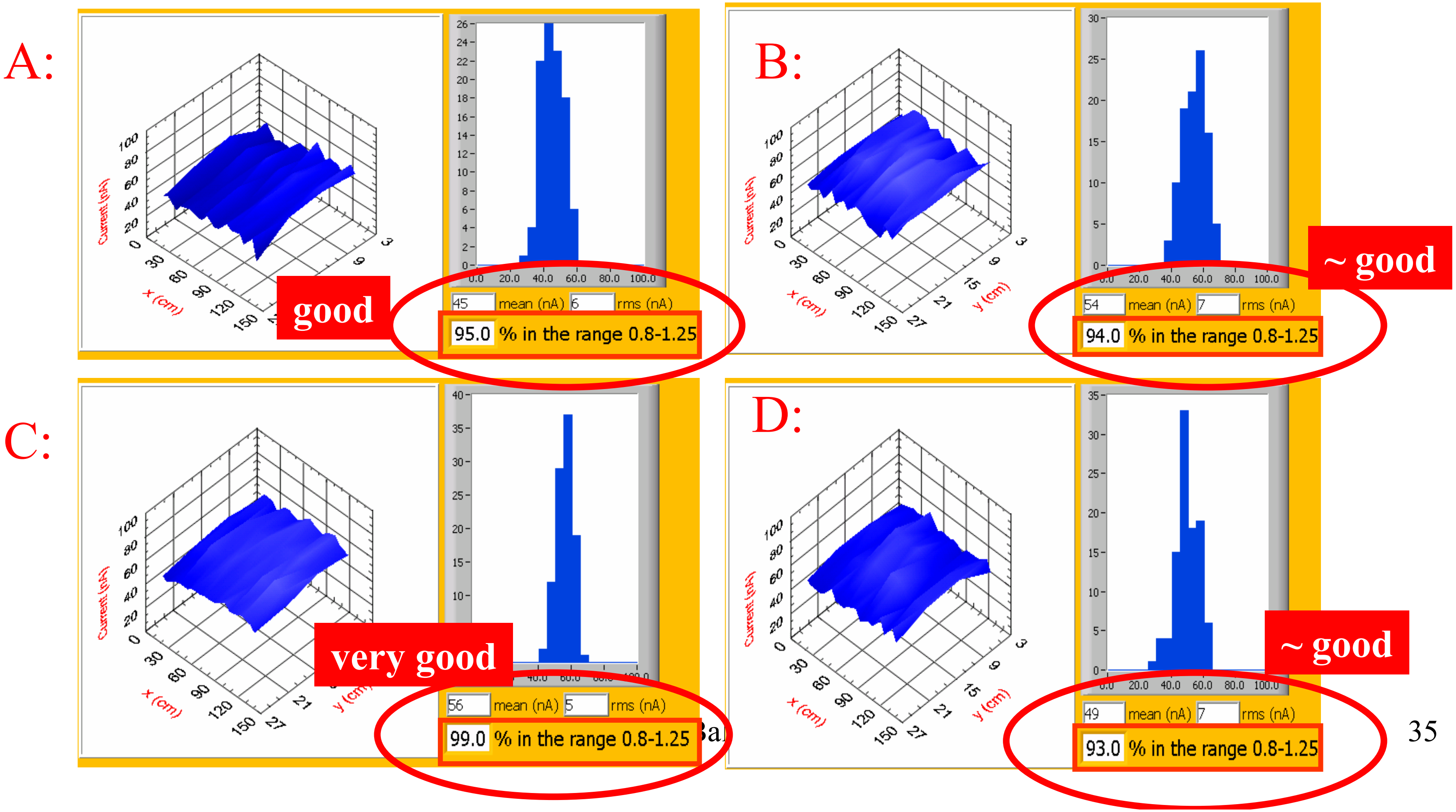
- **The most critical parameter for our chambers is the gap dimension !!**

Measurement of gain uniformity:

-We scan each gap using a radioactive source (^{137}Cs, 40 mCi, 0.66 MeV photons).

-The current drawn by group of wires is measured by a nano-amperometer with 1 nA resolution.





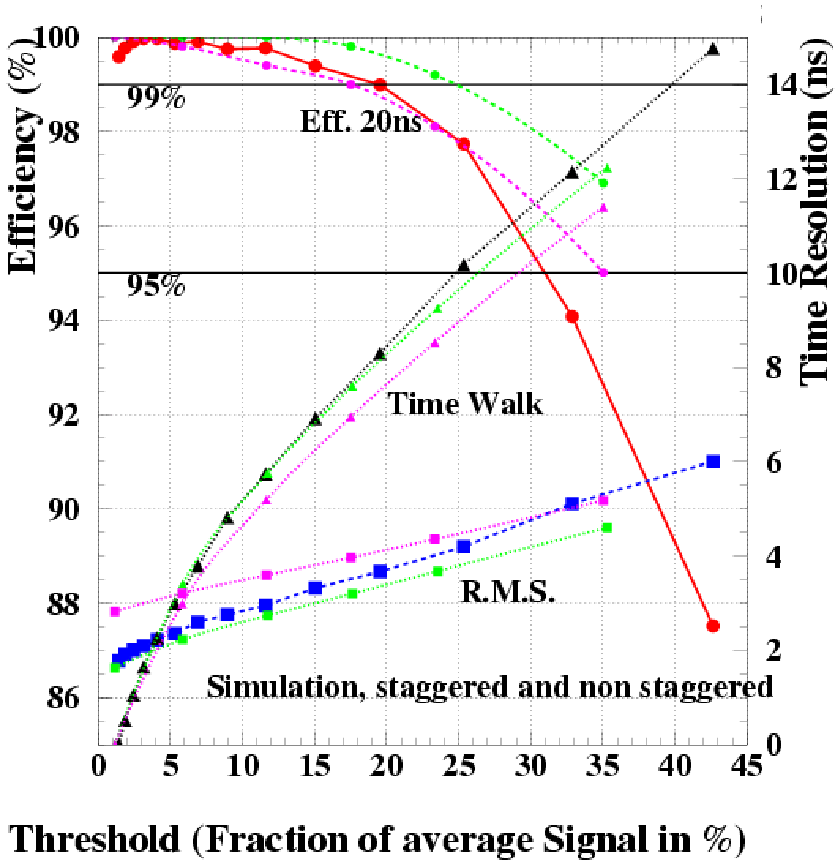
Average rates and Integrated Charges:

	M1	M2	M3	M4	M5
R1	184 GEM	15 132 MWPC	4 35 MWPC	2.6 46 MWPC	1.76 31 MWPC
R2	74.4 328 GEM or MWPC	10.6 185 MWPC	1.32 25 MWPC	0.88 16 MWPC	0.72 13 MWPC
R3	32 141 MWPC	2.6 46 MWPC	0.4 7 MWPC	0.3 6 MWPC	0.26 5 MWPC
R4	10 44 MWPC	0.48 4.3 MWPC	0.17 1.5 MWPC	0.1 1 MWPC	0.09 0.8 MWPC

kHz/cm^2
mC/cm

- Rates (TDR2000) and integrated charges in 10 equivalent (~ 10^8 s) years for average luminosity $\langle L \rangle = 2 \cdot 10^{32}$ cm^{-2} s^{-1} ,
- Safety factors (2 in M1 and 5 in M2-M5) are included.

Comparison with simulations



- ❖Comparison with simulations has been done by plotting double gap efficiency and time resolution as a function of threshold.
- ❖ The threshold is expressed as a fraction of the average signal in order to be independent from the gain.
- ❖ Full simulation:
  - primary ionization (HEED);
  - drift, diffusion (MAGBOLTZ);
  - induced signals (GARFIELD).

Good agreement between data and simulations

Comparison with ATLAS/CMS

The ATLAS Cathode Strip Chambers are intended for position resolution. Amplifier peaking time 80ns, bipolar shaping, 'crosstalk intended' on cathode strips for center of gravity.

The CMS Cathode Strip Chambers are intended for position resolution (cathodes strips) and timing (wires). Cathode amplifier peaking time 100ns, wire amplifier peaking time 30ns.

The LHCb MWPCs are intended for highly efficient timing within a certain spatial granularity at the LVL0 trigger. Amplifier peaking time of 10ns, pulse width<50ns, unipolar shaping, low crosstalk.

Since crosstalk is ✪ ◆$R_{in}C_{pp}$ and since ◆ (🕓20 MHz) is high we have to minimize the pad-pad capacitance C_{pp} and amplifier input impedance R_{in}. Because we want unipolar shaping we need a baseline restorer in the front end.