

Aging measurements on triple-GEM detectors operated with CF_4 based gas mixtures

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OUTLINE $\Rightarrow$ 1) introduction

2) local aging tests (hadrons at PSI and X-ray)

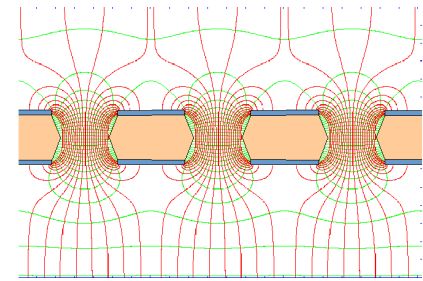
3) global aging test at Casaccia (^{60}Co source)

4) understanding of the aging process

5) conclusions

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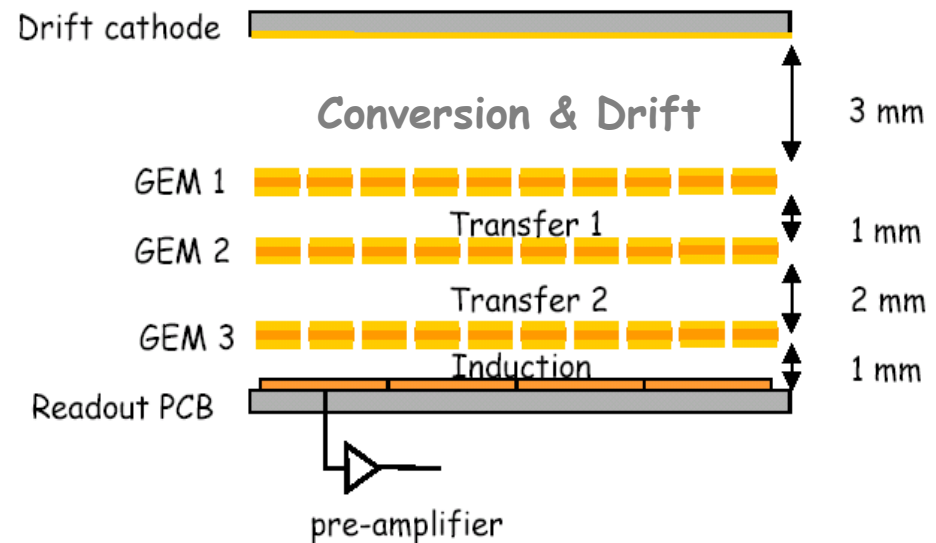
Triple-GEM detector



a Gas Electron Multiplier (F.Sauli, NIM A386 531 1997) is made of 50 μm thick kapton foil, copper clad on each side

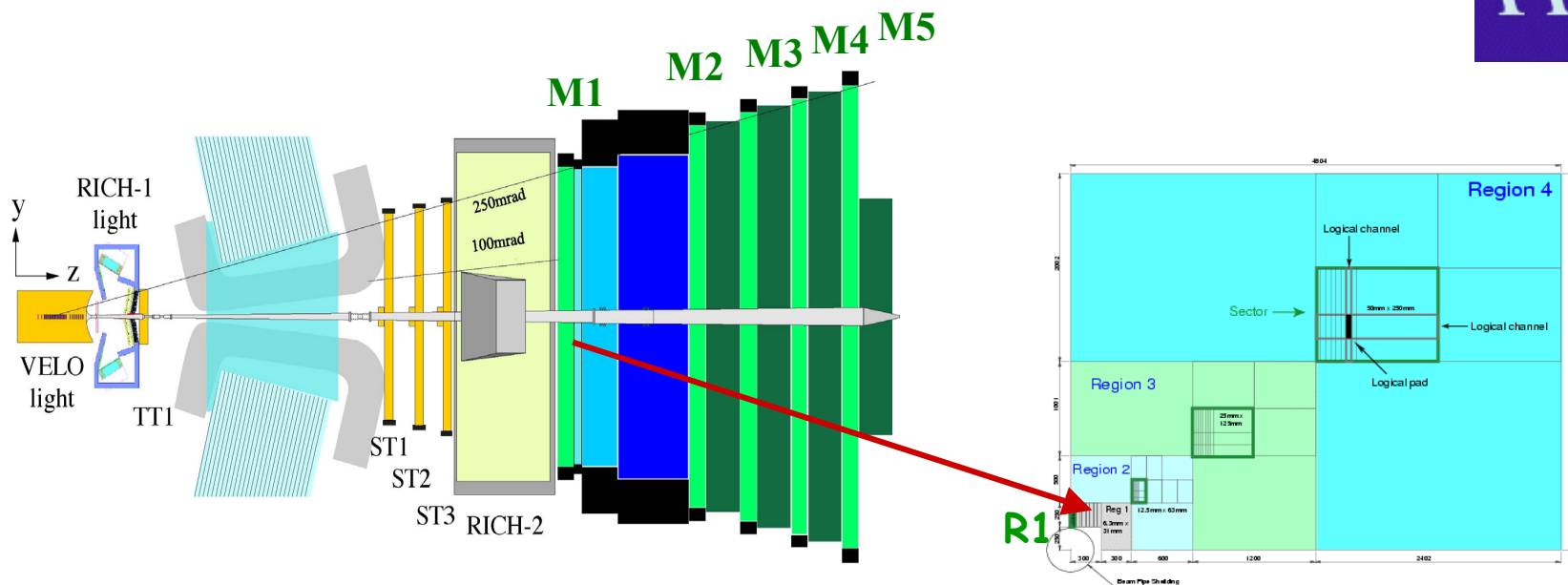
by applying a potential difference (300 - 500 V) between the two copper sides, an electric field as high as 100 kV/cm is produced in the holes acting as multiplication channels for gaseous detectors ($G \cong 10^3$)

a Triple-GEM detector is built by inserting three GEM foils between two planar electrodes which act as the drift cathode and the anode pad



ionisation electrons drift through the four gaps towards the anode, they are multiplied passing through the three GEM foils and they induce signal on the readout PCB as they leave the third GEM ($G \cong 10^4 - 10^5$)

GEM detectors in LHCb*

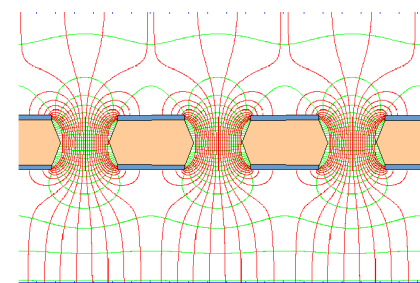


in the innermost region of the first muon station (M1R1) of LHCb, the highest particle rate region of the Muon Subsystem, the experiment requires:

Rate Capability
Station Efficiency
fired pads/particle
Radiation Hardness
Chamber active area

up to 0.5 MHz/cm^2 (average $\sim 0.2 \text{ MHz/cm}^2$)
 $>96\%$ in a 20 ns time window
 <1.2 for a $10 \times 25 \text{ mm}^2$ pad size
 1.8 C/cm^2 in 10 years
 $20 \times 24 \text{ cm}^2$

Why CF₄ based gas mixture ?

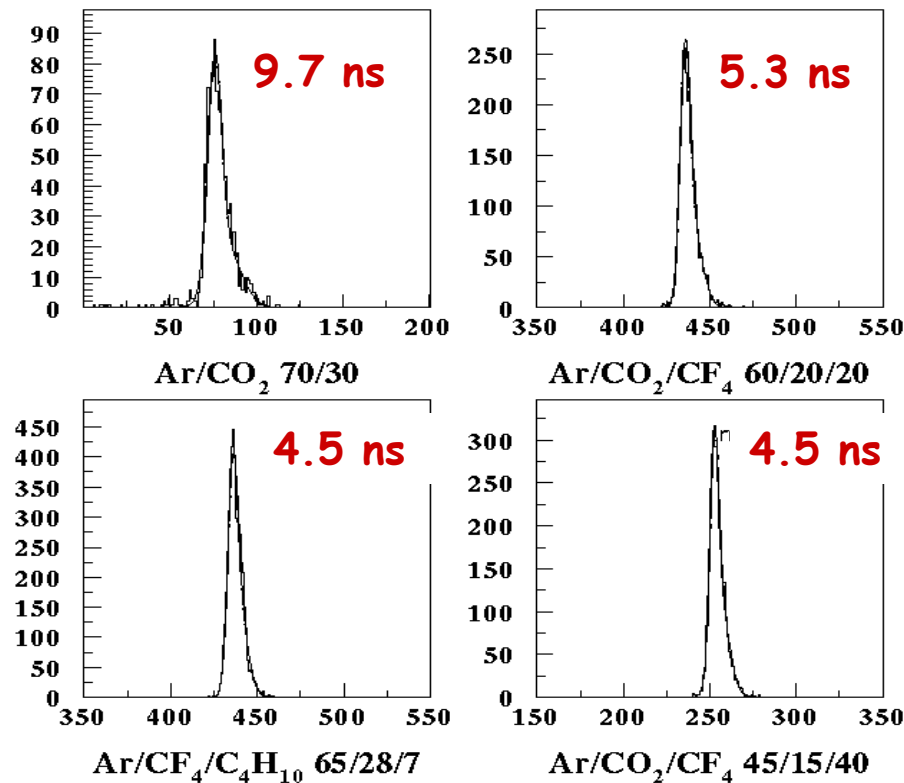


the **intrinsic time spread** of a GEM detector is $\sigma(t) = 1/nv_{\text{drift}}$, where **n** is the number of primary clusters per unit length and **v_{drift}** is the electron drift velocity in the ionization gap

Ar/CO₂/CF₄(45/15/40)
Fast & Non-flammable

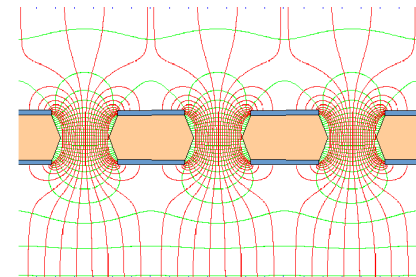
96% in 20 ns time window for the muon detection efficiency is achieved with 2 detectors logically OR-ed pad by pad

performance of the triple-GEM detector already presented in session N1-4 by W. Bonivento



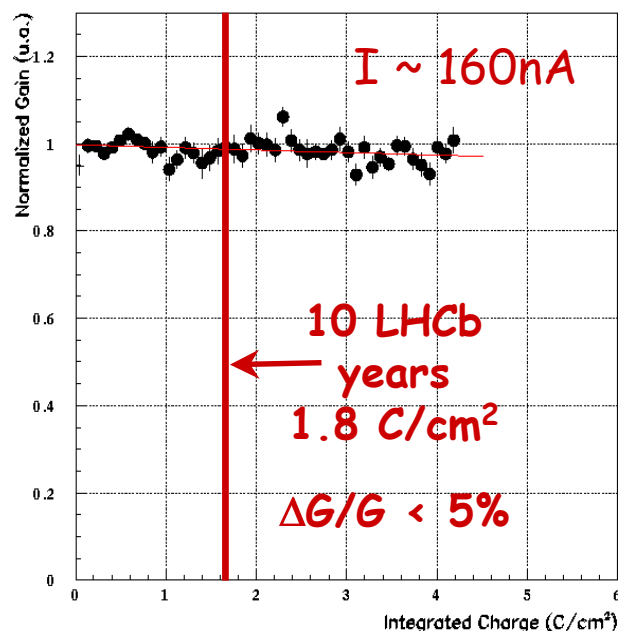
Single Chamber Time Spectra

Local & large area aging measurements



aging tests has been performed on small size ($10 \times 10 \text{ cm}^2$) prototypes of the triple GEM detectors, with the $\text{Ar}/\text{CO}_2/\text{CF}_4$ (45/15/40) gas mixture, $G = 6 \cdot 10^3$, $\Phi_{\text{gas}} = 200 \text{ cc/min}$

local aging $\Rightarrow$ an high intensity 5.9 keV X-ray beam, $\sim 50 \text{ MHz/cm}^2$ on 1 mm^2 (about 50 GEM holes)



large area aging $\Rightarrow$ an high intensity $\pi^+ + \sim 7\% p$ (350 MeV) beam up to $\sim 300 \text{ MHz}$ on 15 cm^2 at PSI

during the test we measured a constant current on the anode of $\sim 10 \mu\text{A}$

integrated charge $\sim 0.5 \text{ C/cm}^2 \Leftrightarrow 3 \text{ LHCb years}$

new measurements have been performed on these detector at T11/PS at CERN $\Rightarrow$ NO LOSSES in performances (time resolution, working region width) have been observed

presented at

"Frontier Detectors for Frontier Physics - 9th Pisa Meeting on Advanced Detectors", La Biodola, May 2003

Global aging test: set-up

⇒ to check the compatibility between the construction materials (detector and gas system) and the gas mixture

⇒ large amount of CF_4 (40%) ⇒ Global Aging Test

a full size ($20 \times 24 \text{ cm}^2$) prototype (C) in low irradiation position $\sim 1 \text{ MHz/cm}^2$, and 2 full size prototypes in high irradiation position, $\sim 15 \text{ MHz/cm}^2$ (chamber A) and $\sim 20 \text{ MHz/cm}^2$ (chamber B)

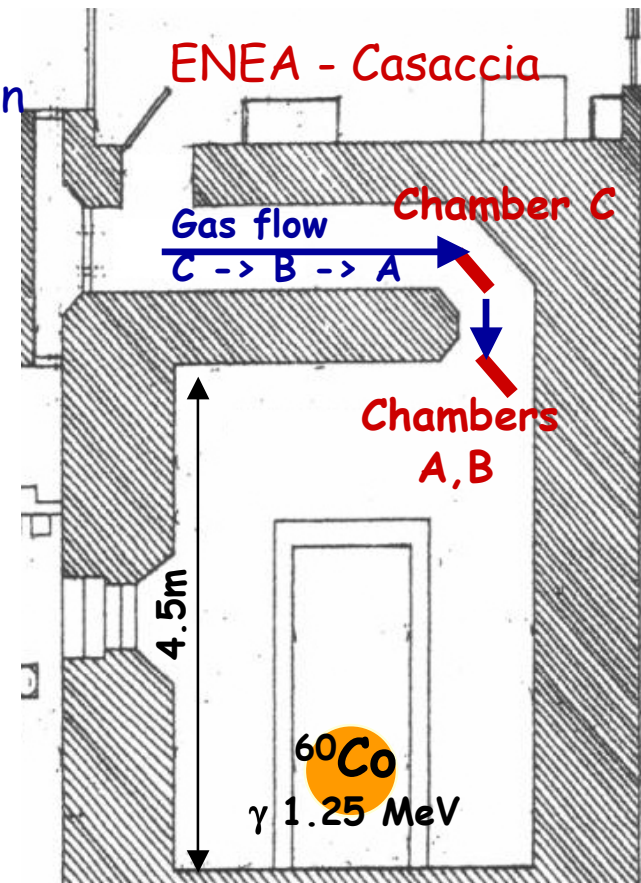
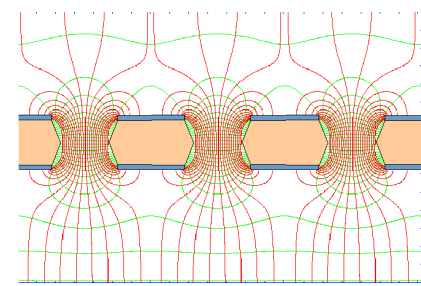
$\text{Ar}/\text{CO}_2/\text{CF}_4$ (45/15/40) at reference Gain $\sim 6 \times 10^3$

monitored H_2O ($\pm 1 \text{ ppm}$), T ($\pm 0.1^\circ \text{K}$), and external P ($\pm 0.1 \text{ mbar}$)

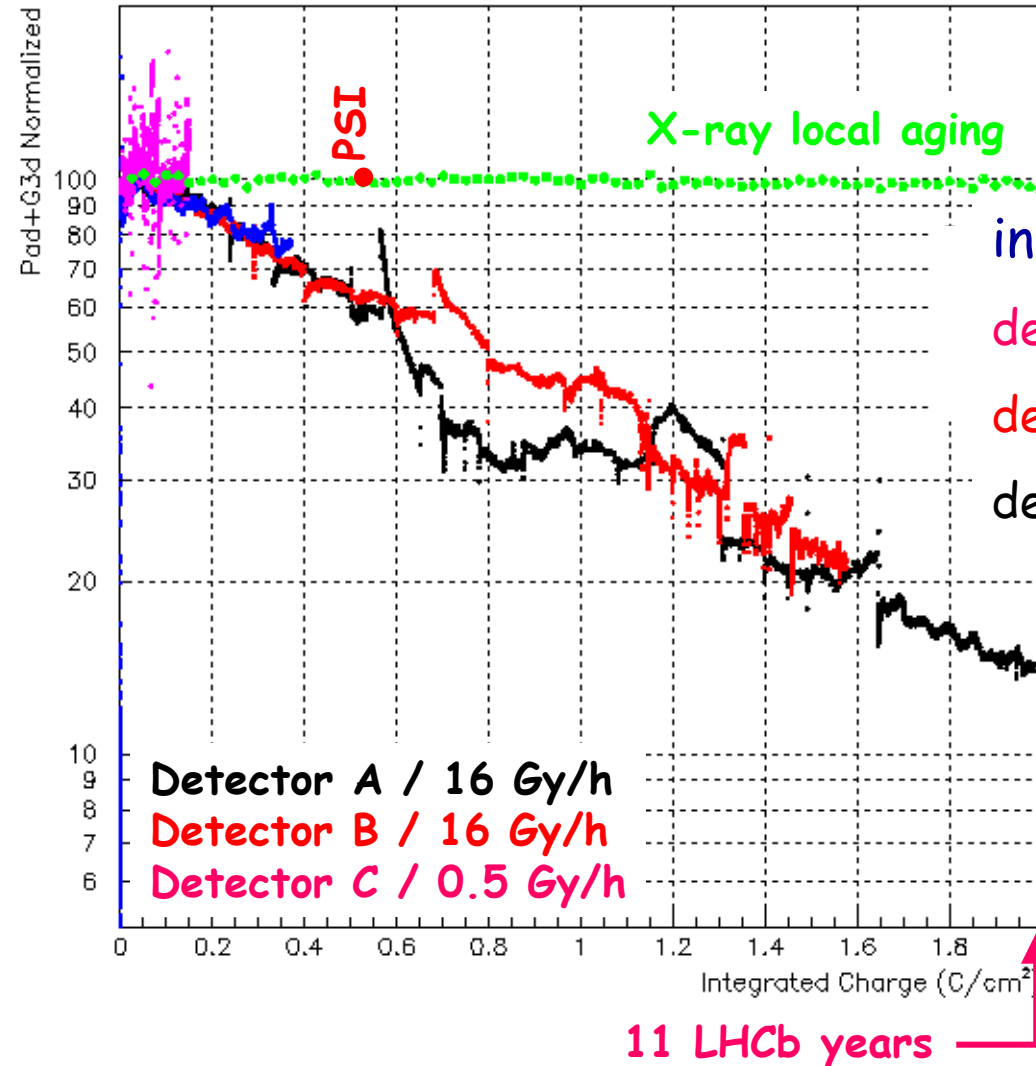
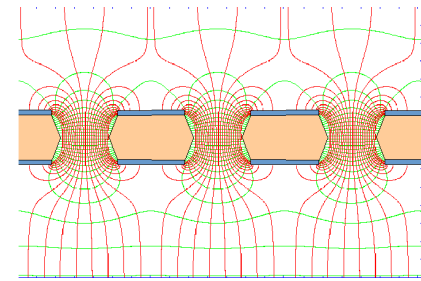
gas flows: $C \rightarrow B \rightarrow A \rightarrow T/\text{H}_2\text{O}$ Probe $\rightarrow$ Out initially
 $\Phi_{\text{gas}} = 200 \text{ cc/min}$, then $\Phi_{\text{gas}} = 350 \text{ cc/min}$

gas inlet line ⇒ stainless-steel tubes

exhaust gas line ⇒ polypropilene tubes (not hygroscopic)



Global aging test: results (I)



integrated charge

detector C $\sim 0.16 C/cm^2 \Leftrightarrow 1$ LHCb y

detector B $\sim 1.6 C/cm^2 \Leftrightarrow 8.5$ LHCb y

detector A $\sim 2.2 C/cm^2 \Leftrightarrow 11.5$ LHCb y

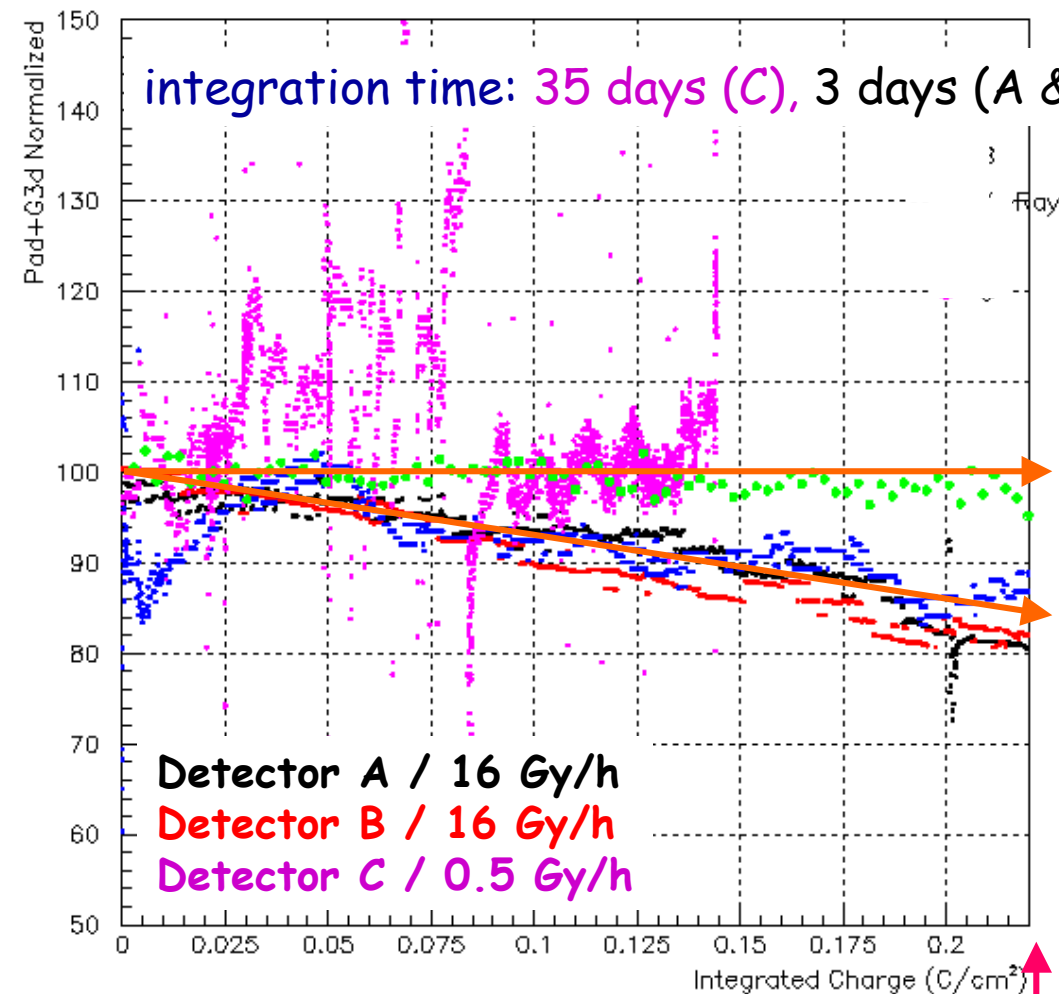
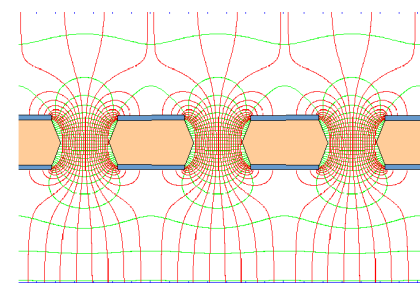
high-irradiated chambers
exhibit a drastic current
drop during the test

A $\rightarrow -89\%$

B $\rightarrow -80\%$

** no increase on the discharge
rate has been observed**

Global aging test: results (II)

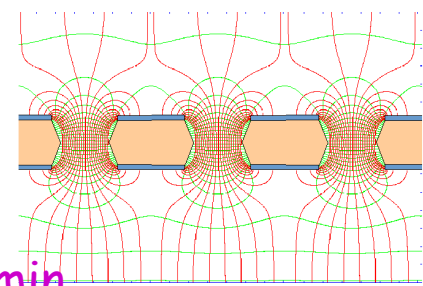


chamber C as well as
X-ray and PSI test results
show no current drops
after an integrated charge
of $0.15 \text{ C}/\text{cm}^2$

$\Delta G/G \sim -10\%$
after the same integrated
charge !

1.25 LHCb years

Preliminary conclusions



we attribute the obtained result to the gas flow rate (350 cc/min, the maximum flow reachable with our mass-flowmeters) $\Rightarrow$ LOW with respect to the very high γ rate ($\sim 15\text{-}20 \text{ MHz/cm}^2$ equivalent m.i.p. on the whole detector area $\Leftrightarrow 400\text{-}500 \mu\text{A}$)

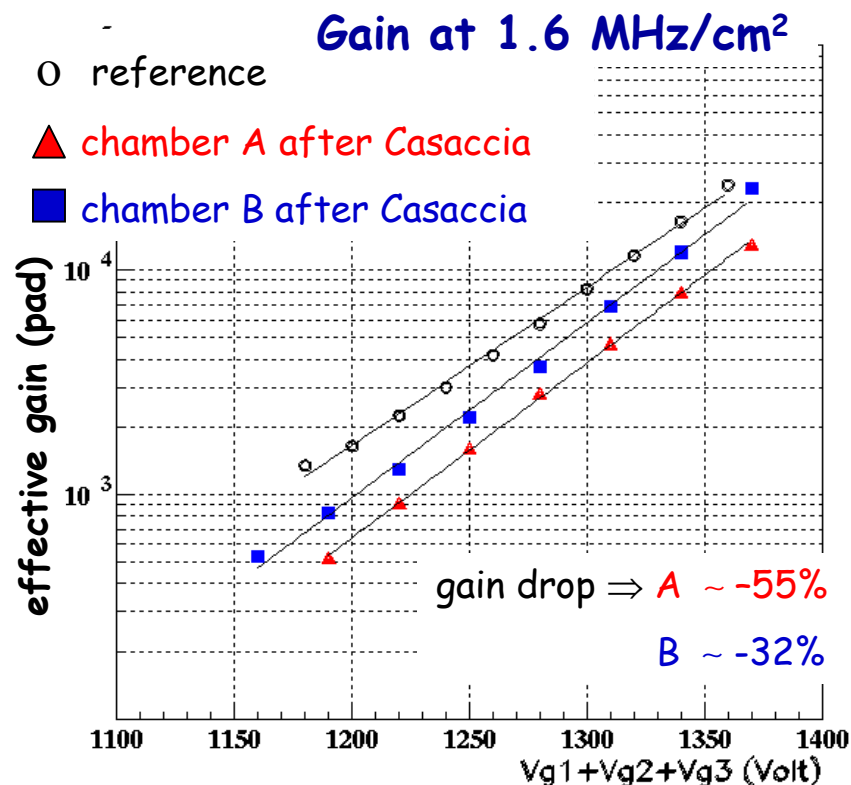
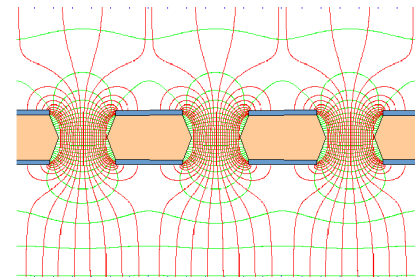
on the contrary local and large area aging tests $\Rightarrow$ gas flow rate of 100 cc/min for a global detector current of 0.2-0.4 μA

⇒ high-irradiated chambers suffered of gas mixture pollution $\Leftrightarrow$ submitted to a strong plasma etching due to F (CF_4 fragmentation) not quickly removed by the gas flow

... several tests and checks on aged chambers to understand the aging process have been performed:

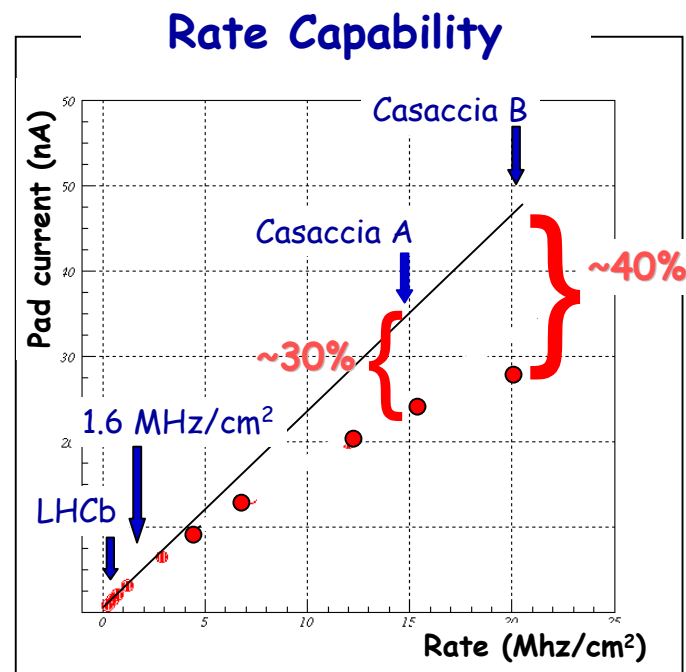
- gain and rate capability measurements with X-rays
- performance at beam test
- electron microscope analysis (SEM)
- reproducing the low gas flow effect observed at Casaccia

Gain & rate capability on aged chambers



aged chambers exhibit **NO** rate capability loss up to $\sim 3\text{MHz/cm}^2$
 (expected LHCb rate $\sim 0.5\text{MHz/cm}^2$)

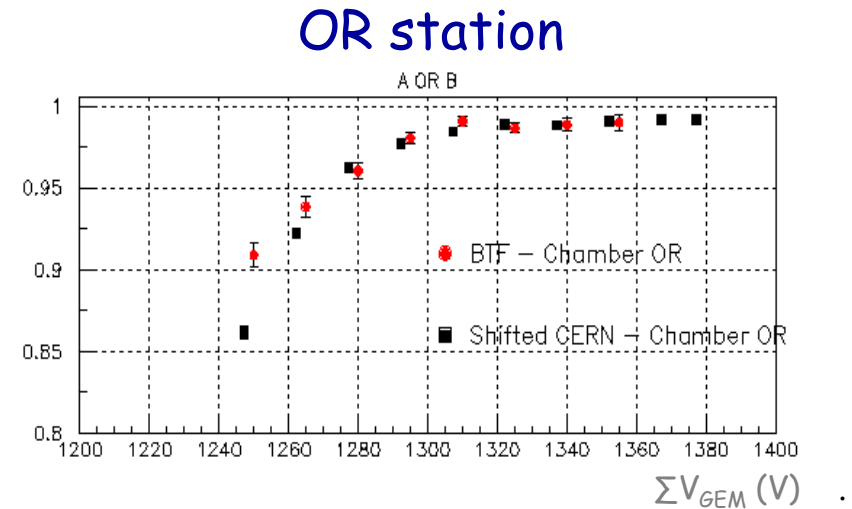
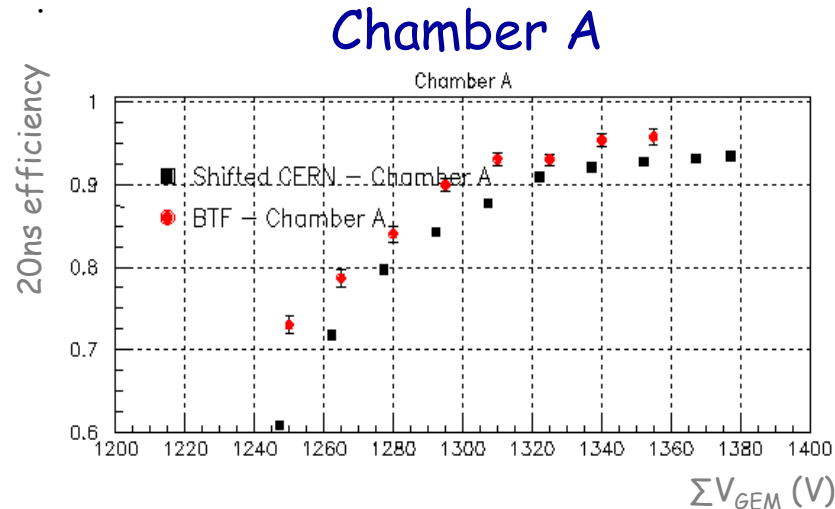
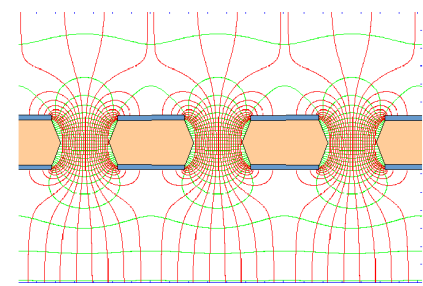
Chamber A current drop ($\sim 89\%$)
 $\approx$ gain drop ($\sim 55\%$)
 + rate cap. loss at 15 MHz/cm^2 ($\sim 30\%$)



Test beam results on aged chambers

before irradiation, performance of these detectors were measured at BTF-LNF Facility (500 MeV e^- beam)

new measurements have been performed after aging, at T11-PS at CERN(*)
@ 100 KHz/cm²



chamber A (with the larger gain loss) shows **ONLY** a shift of the working point of $\sim 15V$, without affecting the working region width
the shift for chamber B is negligible, so performances of the "OR station" is practically unaffected

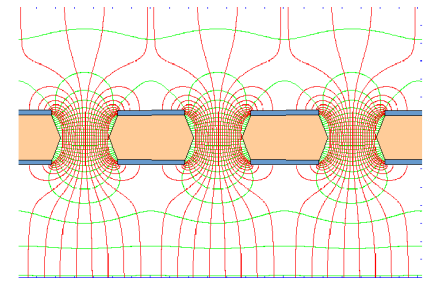
(*) Different T, p of the two tests has been taken into account

SEM analysis & X-ray spectroscopy on aged chambers

1) no damage observed on gold plated cathode and readout anode, and no damage on exposed FR4

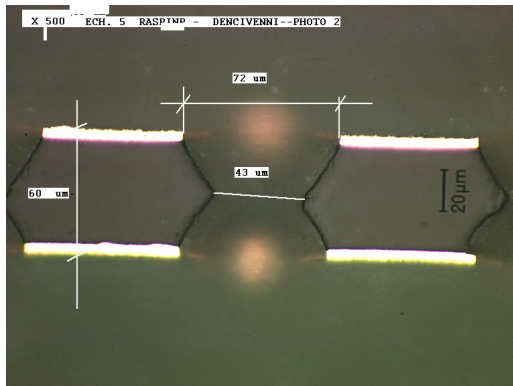
2) no carbon deposits

3) flourine found only on the bottom side of G2 and G3 $\Rightarrow$ Cu-F compound forming a thin insulating layer

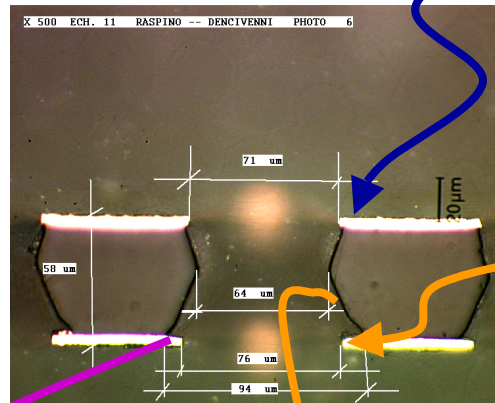


no fluorine on top side of GEM

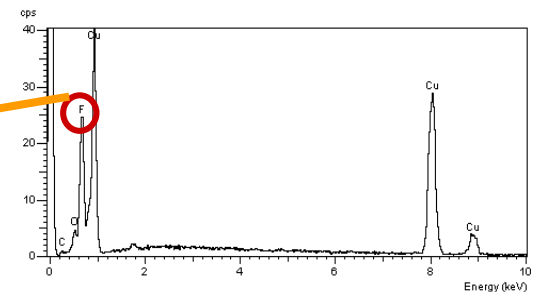
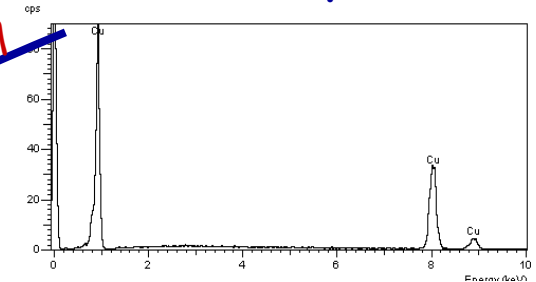
cross section of the first GEM foil of the aged chamber A $\Rightarrow$ GEM is as new
cross section of the third GEM foil of the aged chamber A



fluorine etching not only widens the copper hole ...

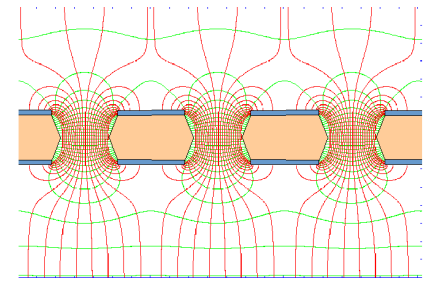


... but also removes the kapton inside the hole



Cu-F thin insulating layer on bottom side of GEM

Fluorine etching explains observed effects



the effects of fluorine etching is twofold:

1) widening of copper holes

➡ gain reduction (*)

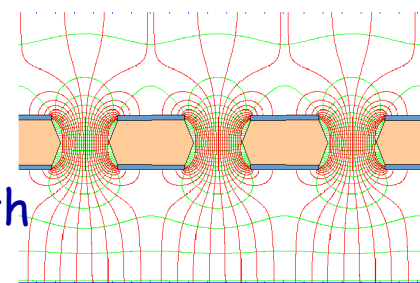
2) Cu-F compound forming an insulating layer near the hole

➡ enhanced charging-up effects

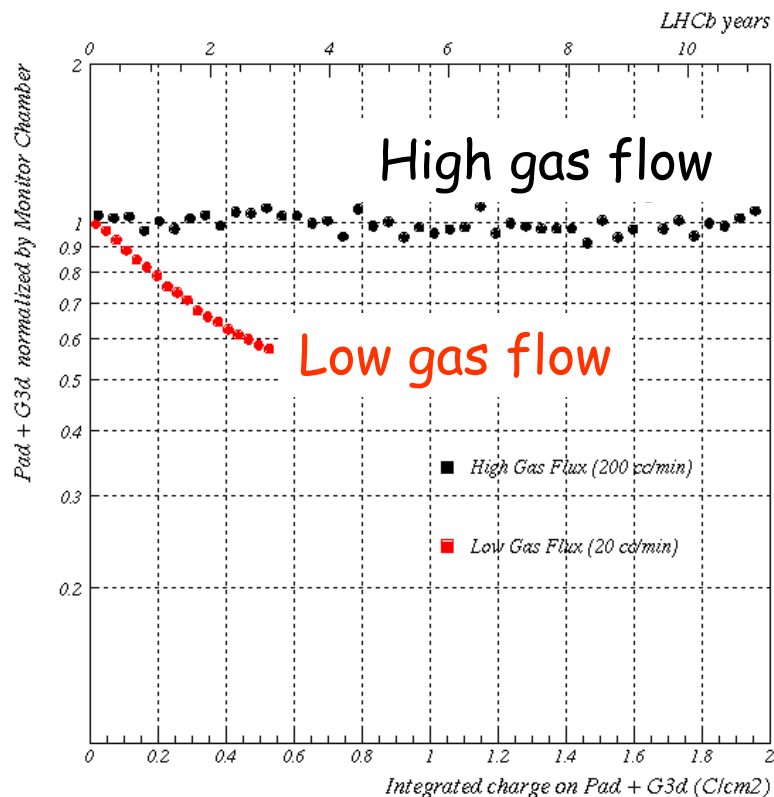
➡ rate capability reduction

(*) S.Bachmann et al., NIM A 438(1999),376-408

Aging induced by low gas flow



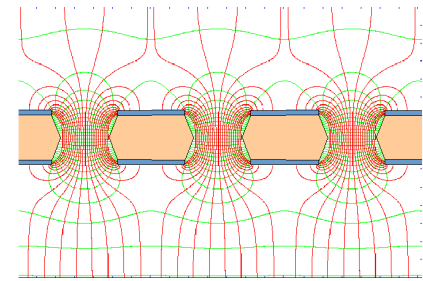
we tried to reproduce the Casaccia test results, irradiating with X-rays a $10 \times 10 \text{ cm}^2$ chamber (total current $\cong 2 \mu\text{A}$ on $\cong 1 \text{ cm}^2$ irradiated spot) flushed with a low gas flow rate (20 cc/cm)



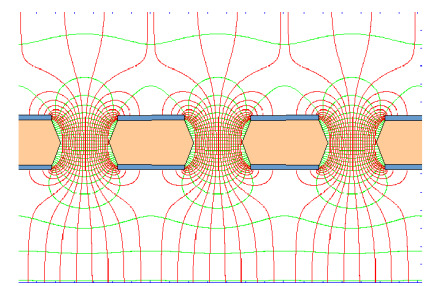
a current drop of $\sim 40\%$ for a 0.55 C/cm^2 integrated charge (~ 3 LHCb years) is found on the low gas flow measurement

NO current drop is observed on the high gas flow measurement

Conclusions

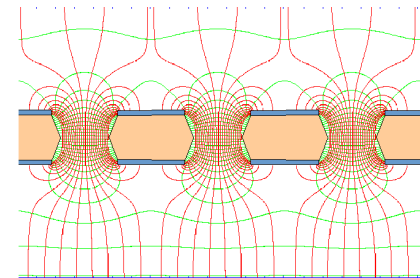


1. Casaccia results are understood $\Rightarrow$ the **etching** observed is correlated with **bad gas flow rate condition**
2. **no corrosion** effects observed on the **cathode** and **anode**
3. etching effects mainly on the **third GEM** with fluorine deposits near the copper holes edges
4. **no etching** occurs if the gas flow is properly set, as in the **LHCb running condition**
5. **detectors, even after a severe irradiation in bad conditions, exhibit good time and efficiency performance**



Spare slides

Large area aging measurements



at PSI ($\pi M1$) we exposed small size prototypes to a high intensity hadron beam (up to ~ 300 MHz on a spot size of about 15 cm^2)

the beam was composed by low momentum ($350 \text{ MeV}/c$) π^+ + $\sim 7\%$ p contamination

gas mixture used $\Rightarrow$ Ar/ CO_2 / CF_4 (60/20/20), Ar/ CO_2 / CF_4 (45/15/40),
Ar/ CF_4 /iso- C_4H_{10} (65/28/7), with a $\Phi_{\text{gas}} = 200 \text{ cc/min}$

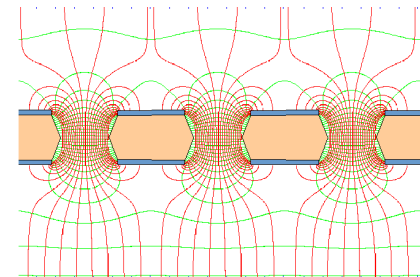
during the test we measured a constant current on the anode of $\sim 10 \mu\text{A}$

with the chosen gas mixture, Ar/ CO_2 / CF_4 (45/15/40), detectors integrated a charge of $\sim 0.5 \text{ C/cm}^2$, equivalent to about 3 years of operation at LHCb

new measurements have been performed on these detectors at T11/PS at CERN $\Rightarrow$ NO LOSSES in performances (time resolution, working region width ..) have been observed

Local aging measurements

performed with an high intensity 5.9 keV X-ray beam on 1 mm²
(about 50 GEM holes) of small size (active area 10x10 cm²)
prototypes of the detector



Ar/CO₂/CF₄ (60/20/20)

$G = 2.5 \cdot 10^4$ $I \sim 270$ nA

$\Phi_{\text{gas}} = 166.6$ cc/min

Ar/CO₂/CF₄ (45/15/40)

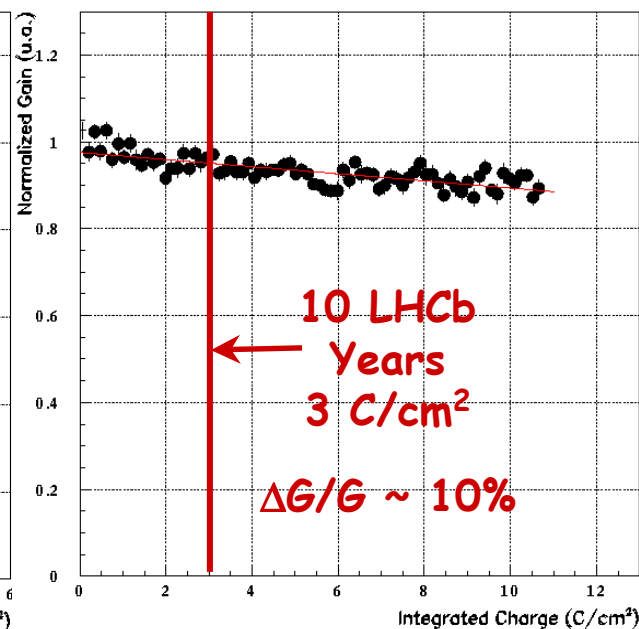
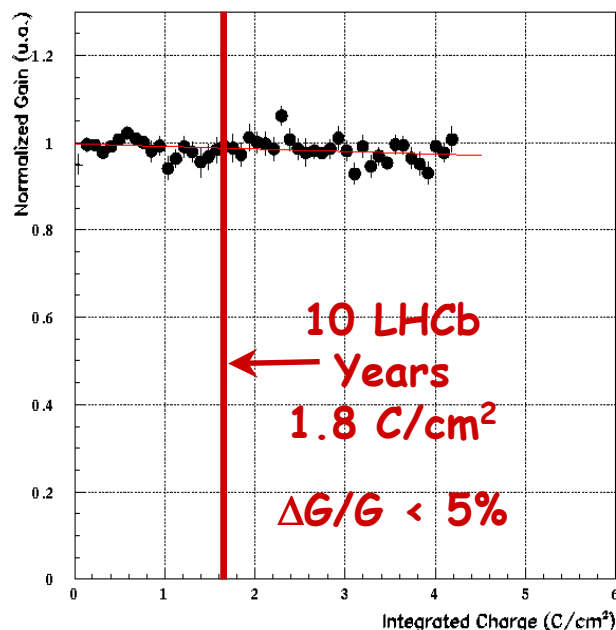
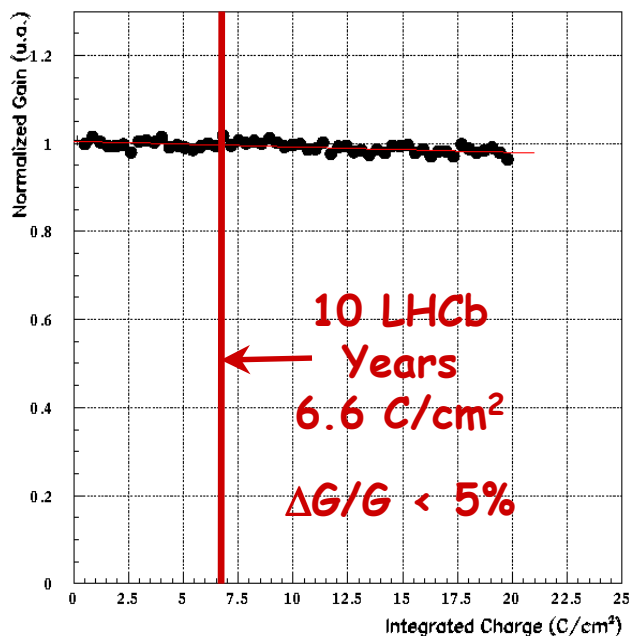
$G = 6 \cdot 10^3$ $I \sim 160$ nA

$\Phi_{\text{gas}} = 200$ cc/min

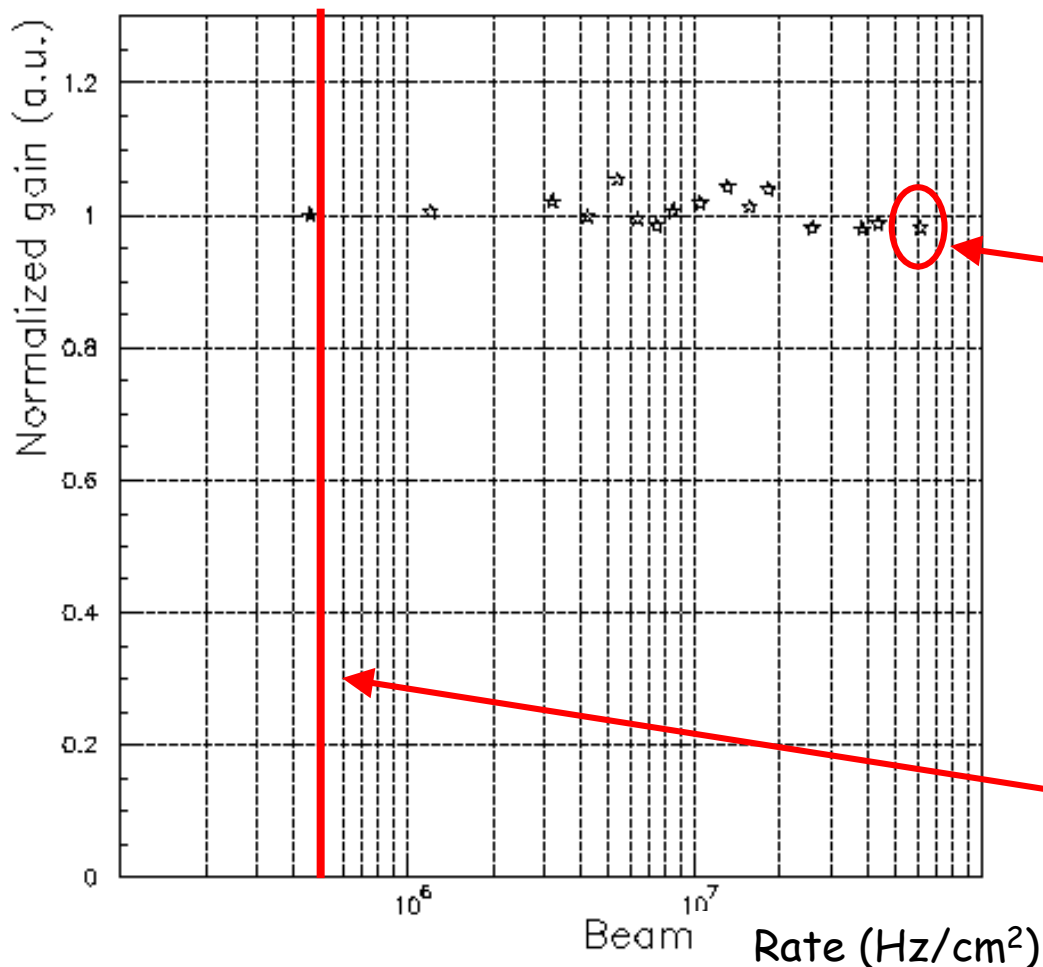
Ar/CF₄/C₄H₁₀ (68/25/7)

$G = 10^4$ $I \sim 160$ nA

$\Phi_{\text{gas}} = 154$ cc/min



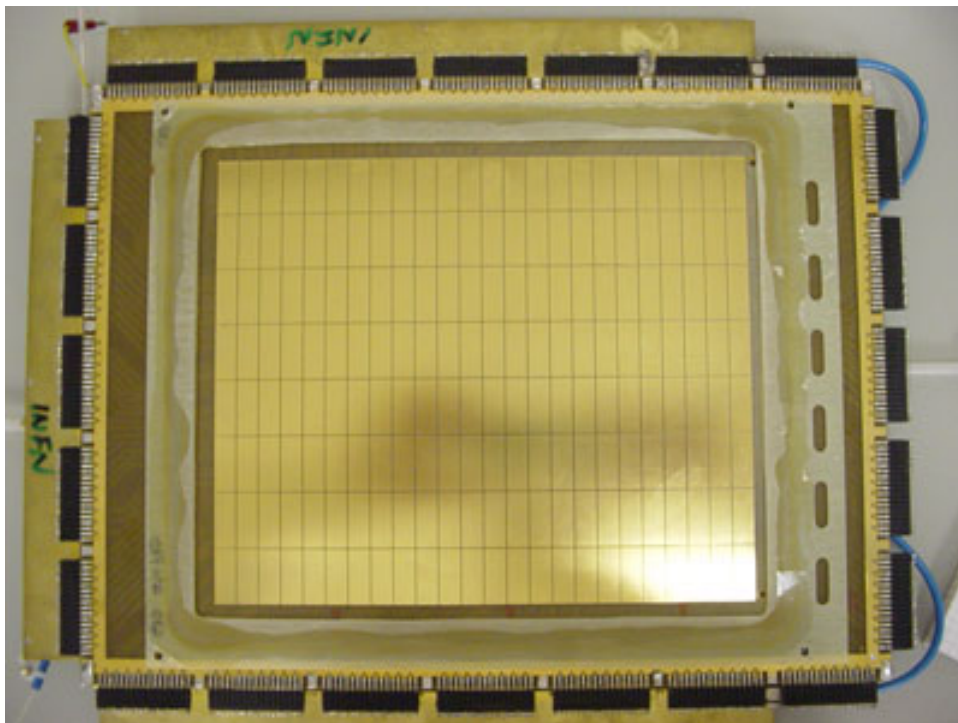
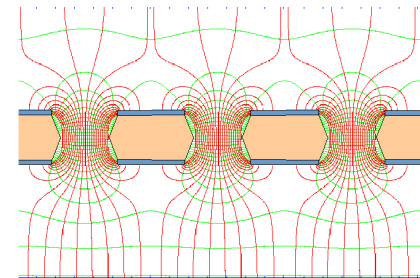
- The rate capability was measured with an X-ray (5.9 keV) tube over a spot of $\sim 1 \text{ mm}^2$
- The detector was operated at a gain of $\sim 2 \times 10^4$



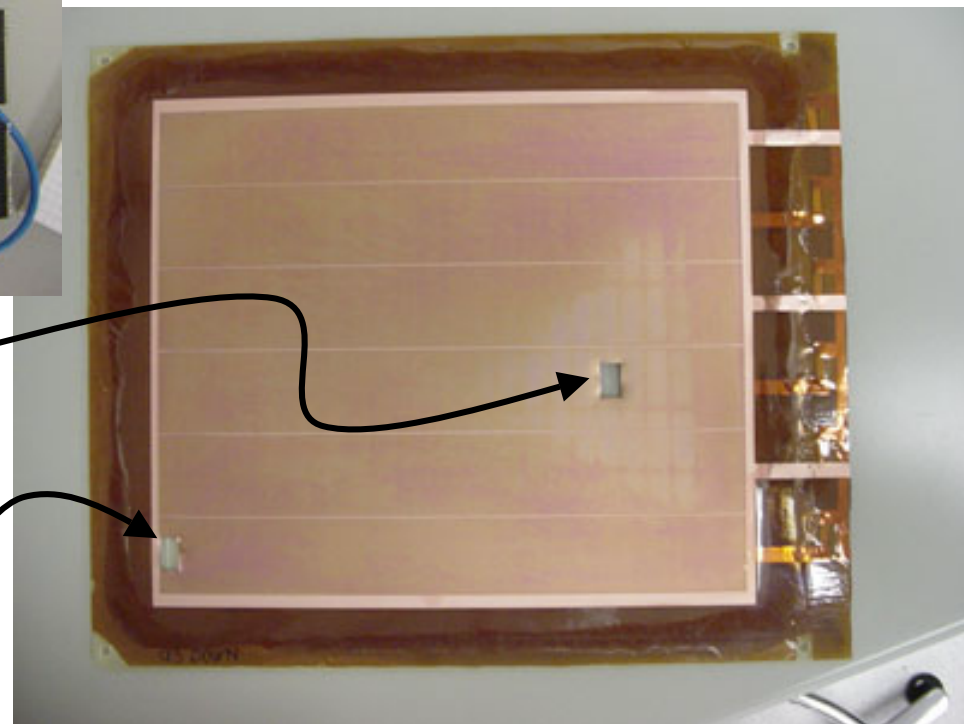
A very good gain stability was found up to a photon counting rate of 50 MHz/cm^2

LHCb M1R1
maximum rate
(460 kHz/cm^2)

SEM analysis on aged chambers

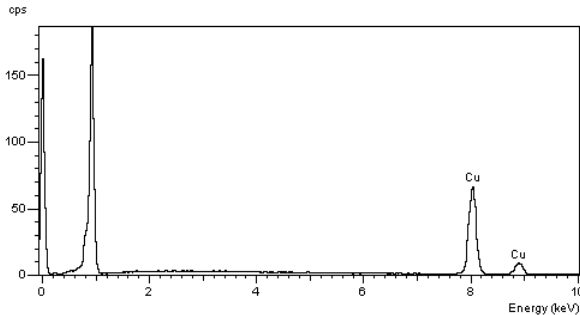
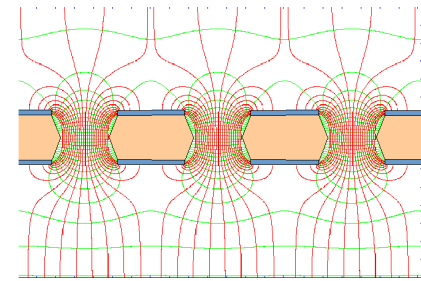


GEM 3 down sampling

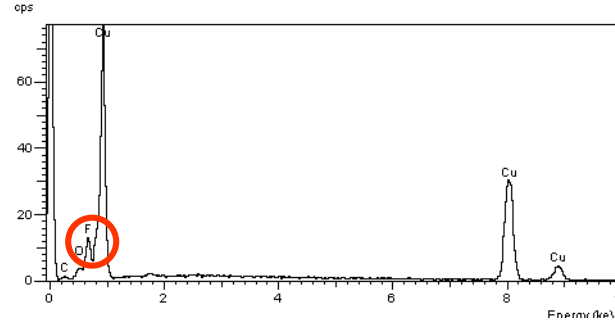


SEM analysis & X-ray spectroscopy on aged chambers

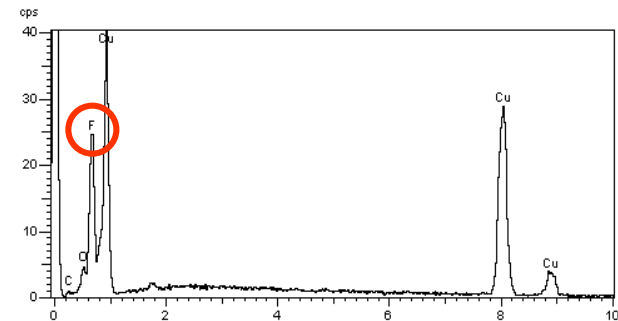
fluorine found on the bottom side of G2 and G3 $\Rightarrow$ Cu-F compound forming a thin insulating layer



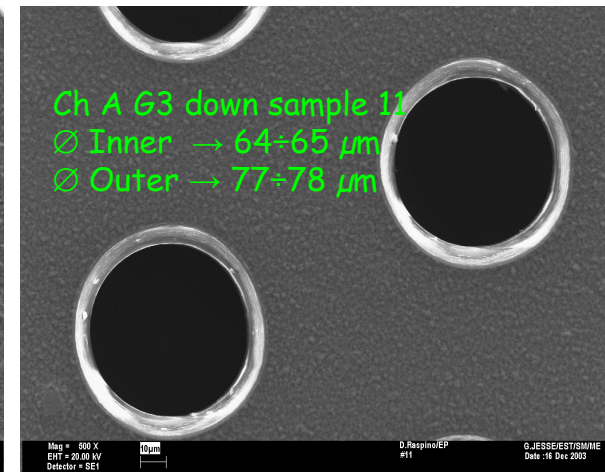
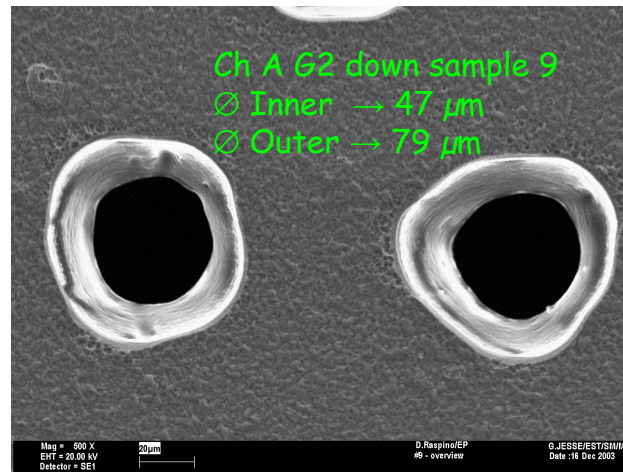
G1: No fluorine No etching



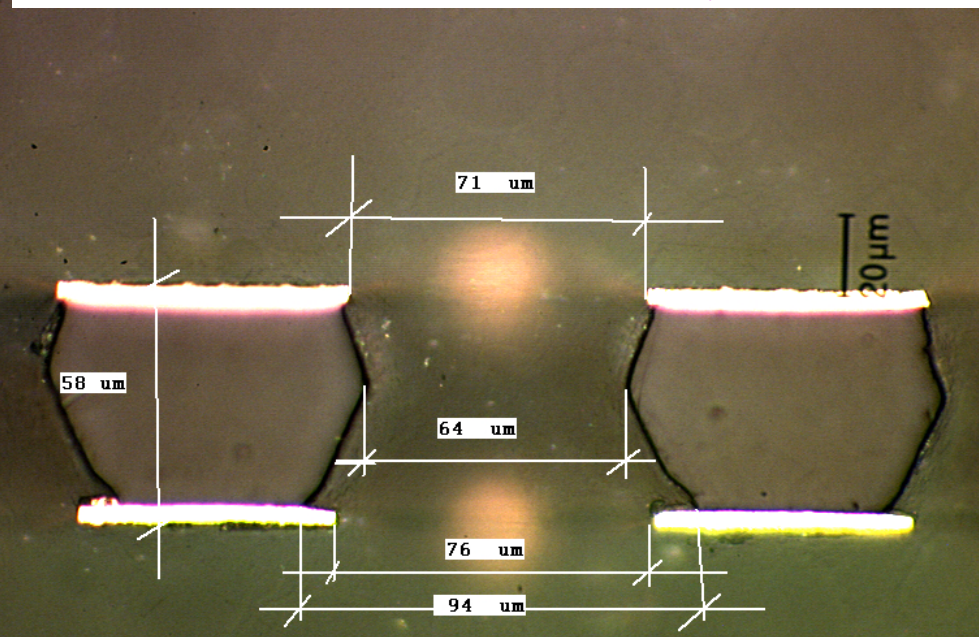
G2: Small fluorine, etching started



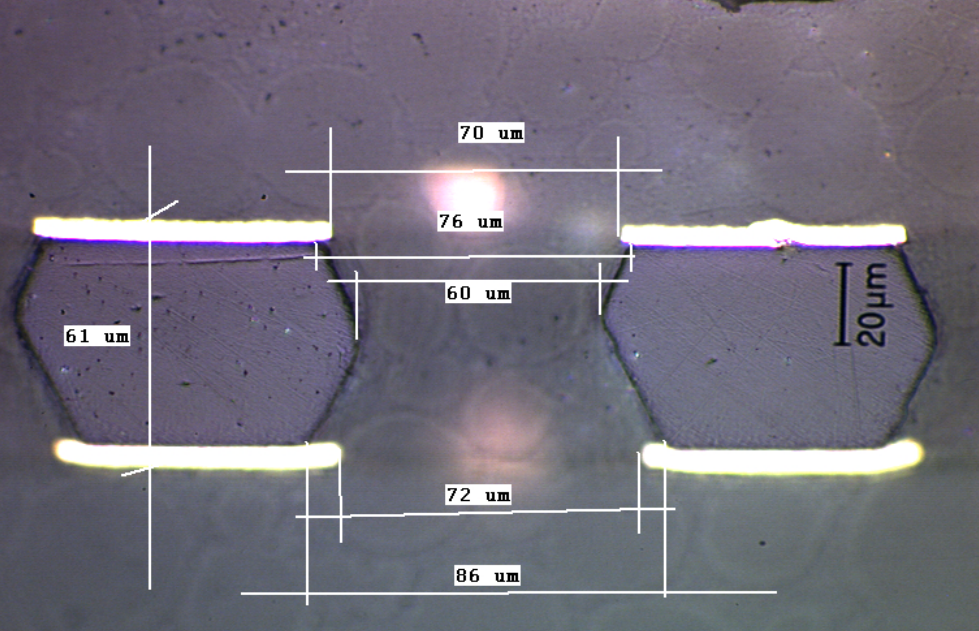
G3: Large fluorine etching enhanced



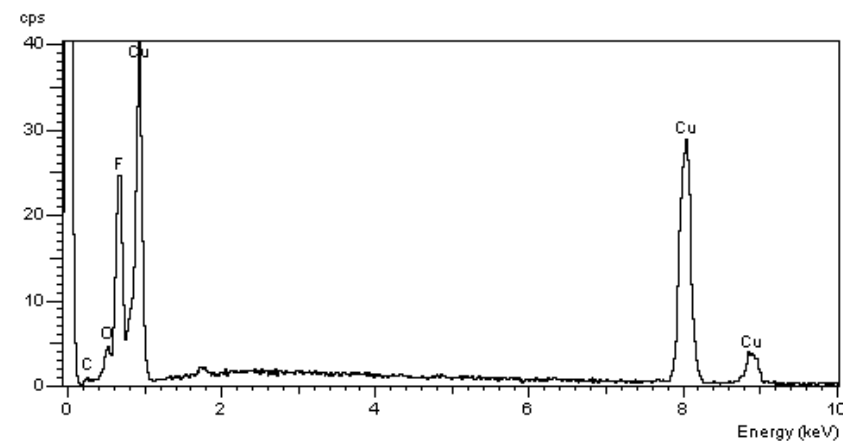
Fluorine etching comparison chambers A & B



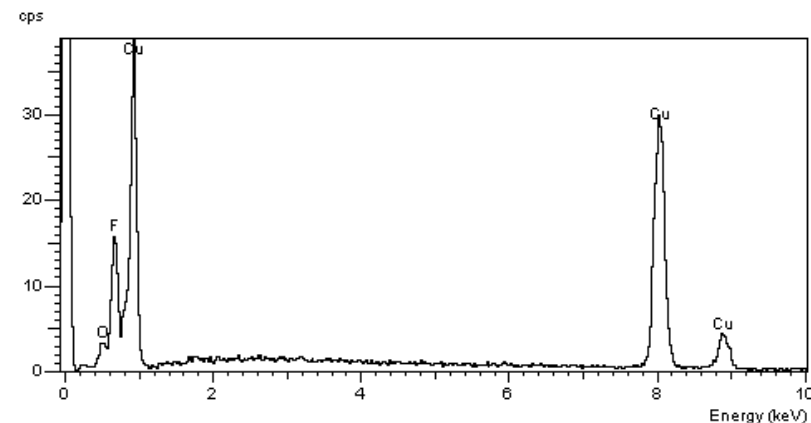
X 500 ECH. 7 B RASPINO -- BENCIVENNI PHOTO 16



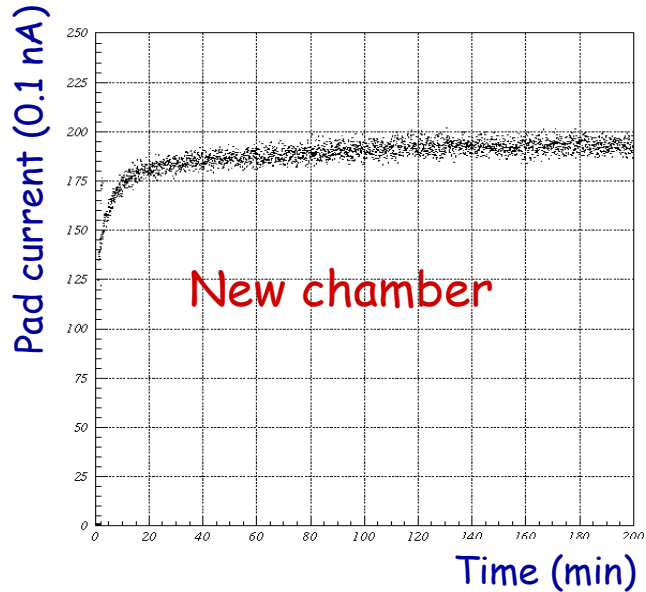
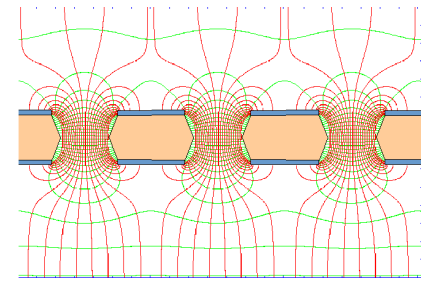
third GEM of detector A



third GEM of detector B



GEM charging - up



the charging-up of the kapton surface (due to both electrons and ions), a typical effect of micro-pattern detectors using insulating material as support

rate capability loss of aged chambers can be explained by the new internal shape of the hole and the presence of an insulating Cu-F compound layer around the hole

