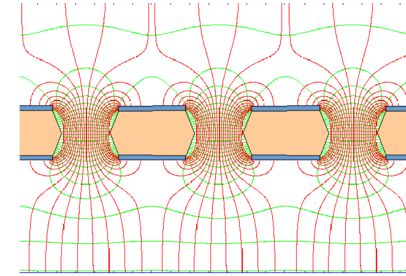
IEEE, Roma, October 2004



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

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OUTLINE ⇒ 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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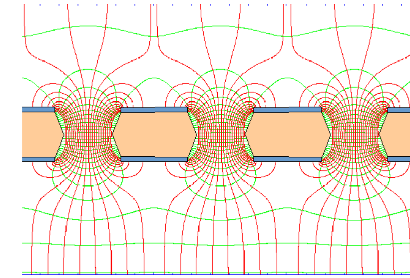
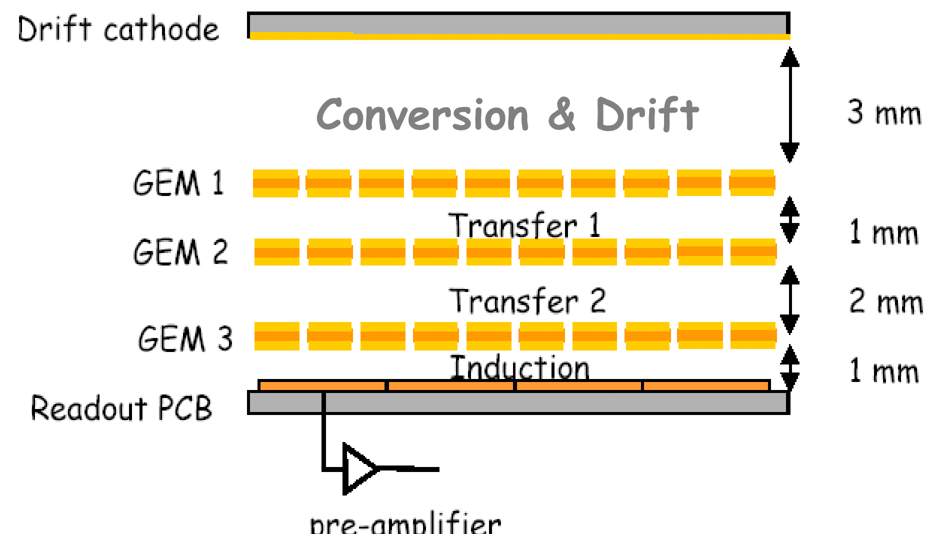
Triple-GEM detector



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

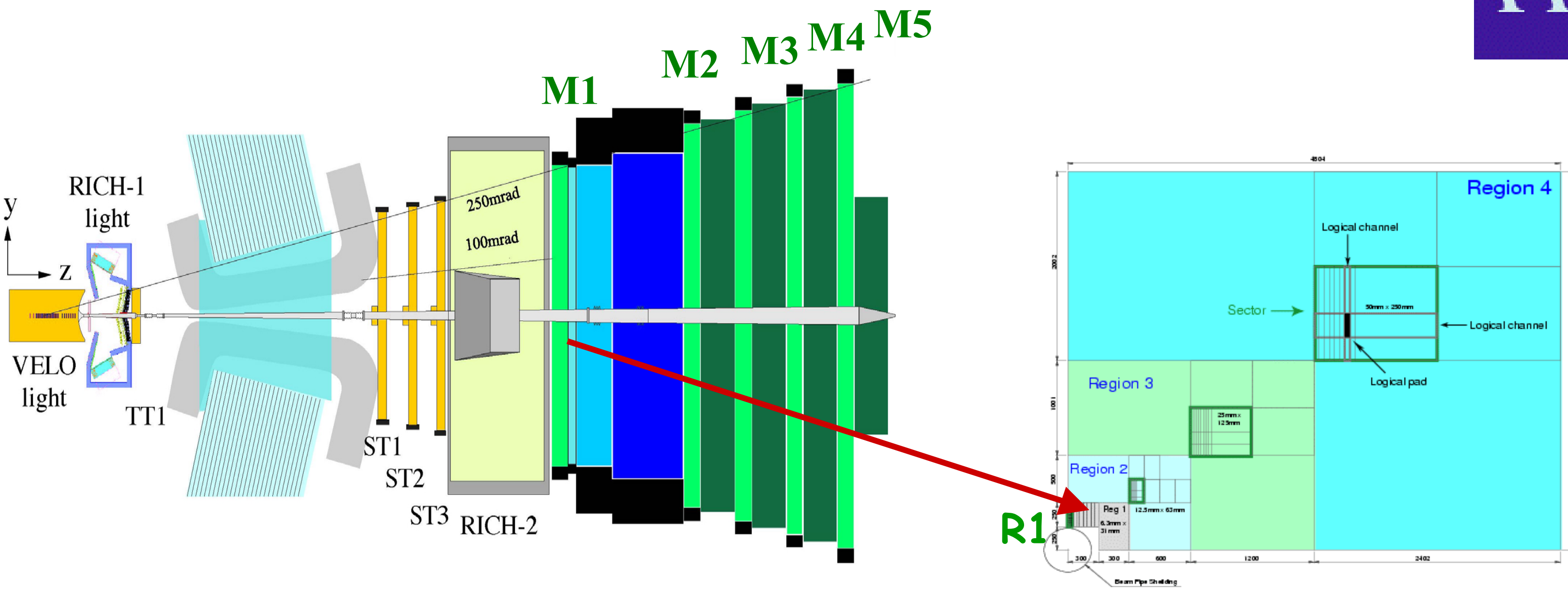
by applying a potential difference (300 - 500 V) between the two copper sides, an electric field as high as 100 kV/cm is produced in the holes acting as multiplication channels for gaseous detectors ($G \cong 10^3$)

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*

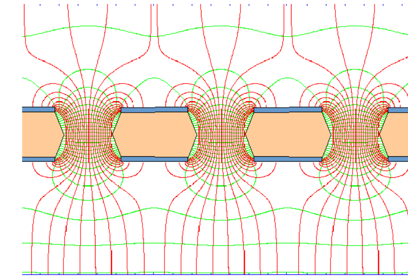


in the innermost region of the first muon station (M1R1) of LHCb, the highest particle rate region of the Muon Subsystem, the experiment requires:

Rate Capability	up to 0.5 MHz/cm^2 (average ~0.2 MHz/cm^2)
Station Efficiency	>96% in a 20 ns time window
# fired pads/particle	<1.2 for a 10x25 mm^2 pad size
Radiation Hardness	1.8 C/cm^2 in 10 years
Chamber active area	20x24 cm^2

* approved by LHCC on February 2004

Why CF_4 based gas mixture ?

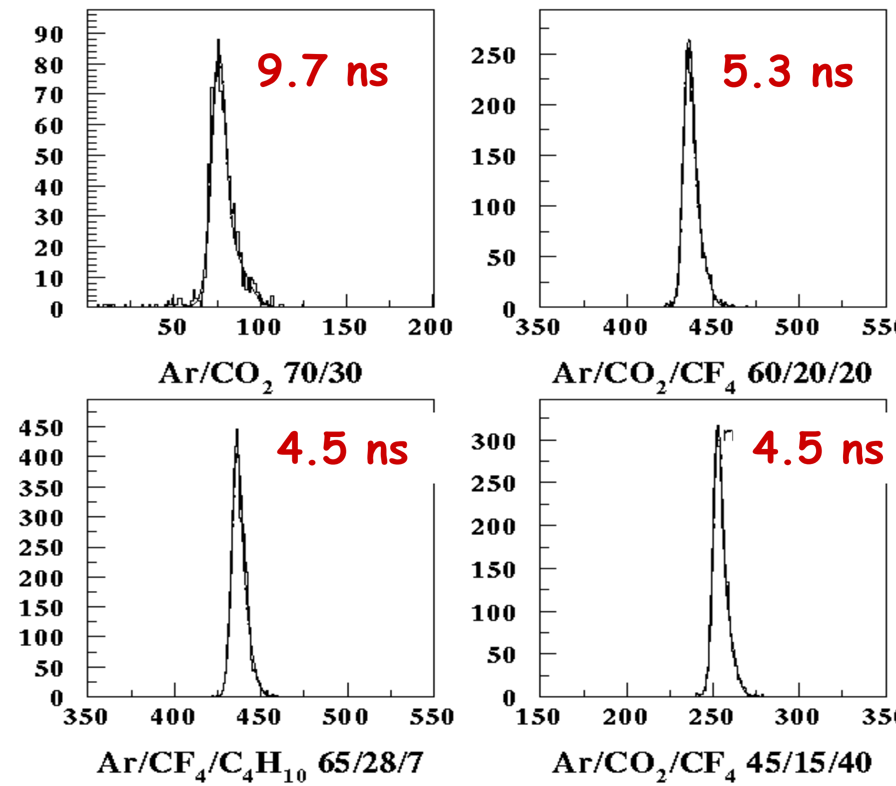


the intrinsic time spread of a GEM detector is $\sigma(t) = 1/nv_{drift}$, where n is the number of primary clusters per unit length and v_{drift} is the electron drift velocity in the ionization gap

$Ar/CO_2/CF_4$(45/15/40)
Fast & Non-flammable

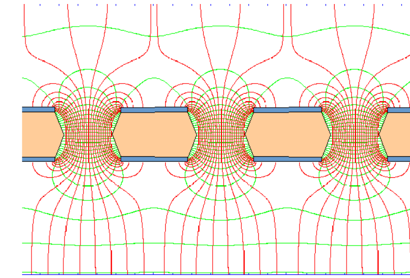
96% in 20 ns time window for the muon detection efficiency is achieved with 2 detectors logically OR-ed pad by pad

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



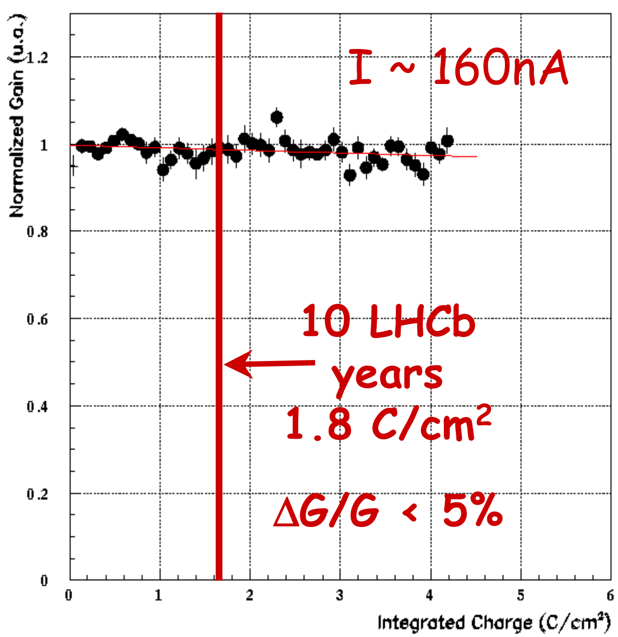
Single Chamber Time Spectra

Local & large area aging measurements



aging tests has been performed on small size (10x10 cm^2) prototypes of the triple GEM detectors, with the $Ar/CO_2/CF_4$ (45/15/40) gas mixture, $G = 6 \cdot 10^3$, Φ_{gas}= 200 cc/min

local aging ⇒ an high intensity 5.9 keV X-ray beam, ~ 50 MHz/cm^2 on 1 mm^2 (about 50 GEM holes)



large area aging ⇒ an high intensity π^+ + ~7%p (350 MeV) beam up to ~300 MHz on 15 cm^2 at PSI

during the test we measured a constant current on the anode of ~10 μA

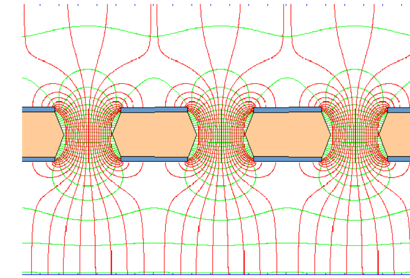
integrated charge ~ 0.5 C/cm^2 ⇔ 3 LHCb years

new measurements have been performed on these detector at T11/PS at CERN ⇒ 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

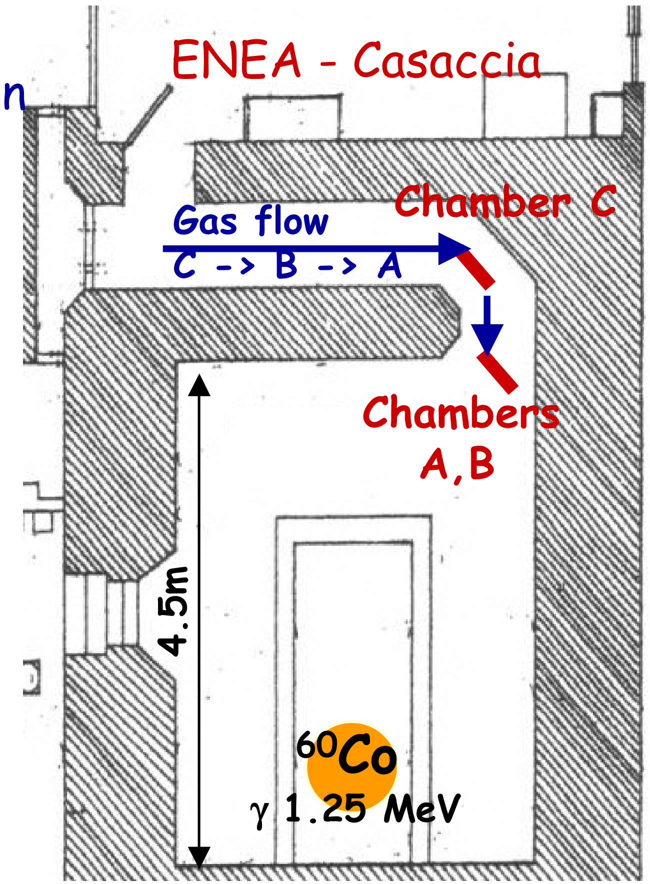
a full size (20x24 cm^2) prototype (C) in low irradiation position ~ 1 MHz/cm^2, and 2 full size prototypes in high irradiation position, ~ 15 MHz/cm^2 (chamber A) and ~ 20 MHz/cm^2 (chamber B)

$Ar/CO_2/CF_4$ (45/15/40) at reference Gain ~ 6x10^3

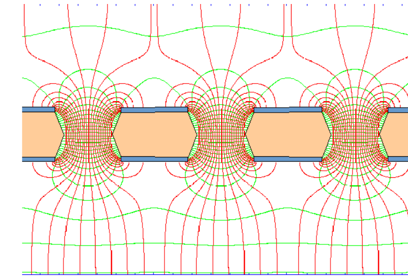
monitored H_2O (± 1ppm), T (± 0.1°K), and external P (± 0.1mbar)

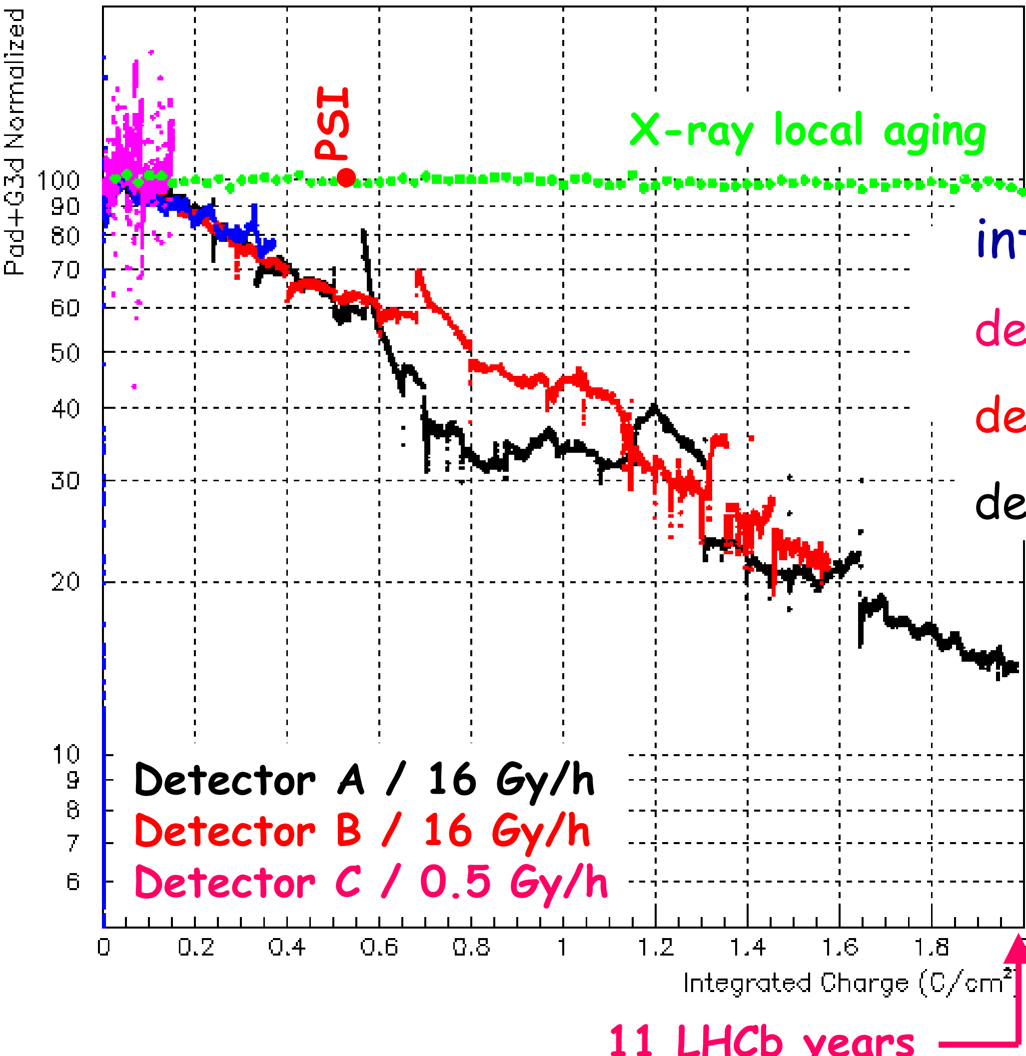
gas flows: C -> B -> A -> T/H_2O Probe -> Out initially Φ_{gas}= 200 cc/min, then Φ_{gas}= 350 cc/min

gas inlet line ⇒ stainless-steel tubes
exhaust gas line ⇒ polypropilene tubes (not hygroscopic)



Global aging test: results (I)





integrated charge

detector C ~ 0.16 C/cm² ⇔ 1 LHCb y

detector B ~ 1.6 C/cm² ⇔ 8.5 LHCb y

detector A ~ 2.2 C/cm² ⇔ 11.5 LHCb y

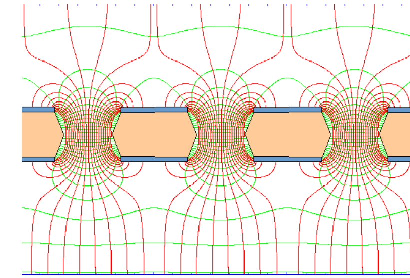
high-irradiated chambers exhibit a drastic current drop during the test

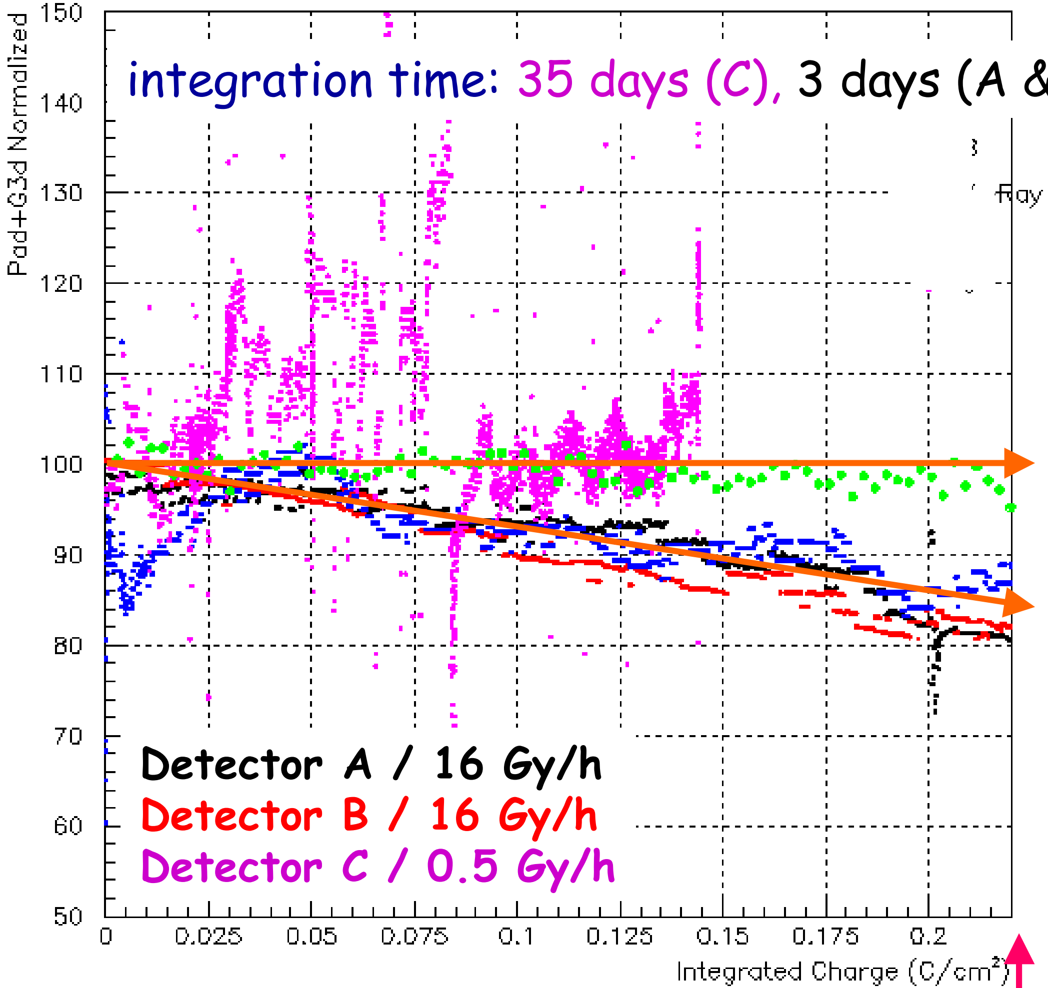
A → -89%

B → -80%

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

Global aging test: results (II)



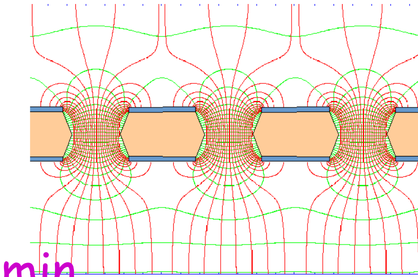


chamber C as well as X-ray and PSI test results show no current drops after an integrated charge of 0.15 C/cm^2

$\Delta G/G \sim -10\%$ 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) ⇒ LOW with respect to the very high γ rate (~ 15-20 MHz/cm² equivalent m.i.p. on the whole detector area ⇔ 400-500 μA)

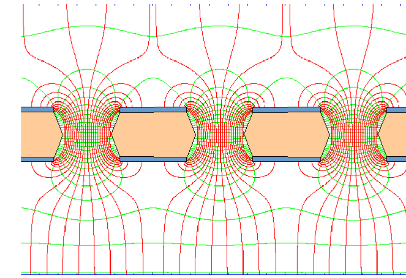
on the contrary local and large area aging tests ⇒ gas flow rate of 100 cc/min for a global detector current of 0.2-0.4 μA

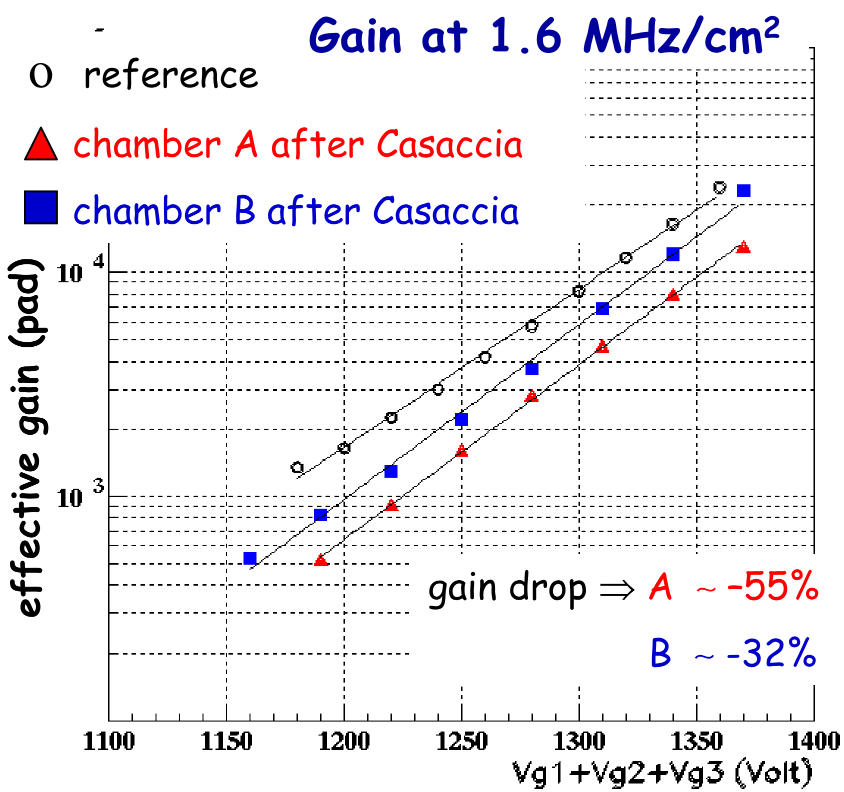
high-irradiated chambers suffered of gas mixture pollution ⇔ submitted to a strong plasma etching due to F (CF_4 fragmentation) not quickly removed by the gas flow

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

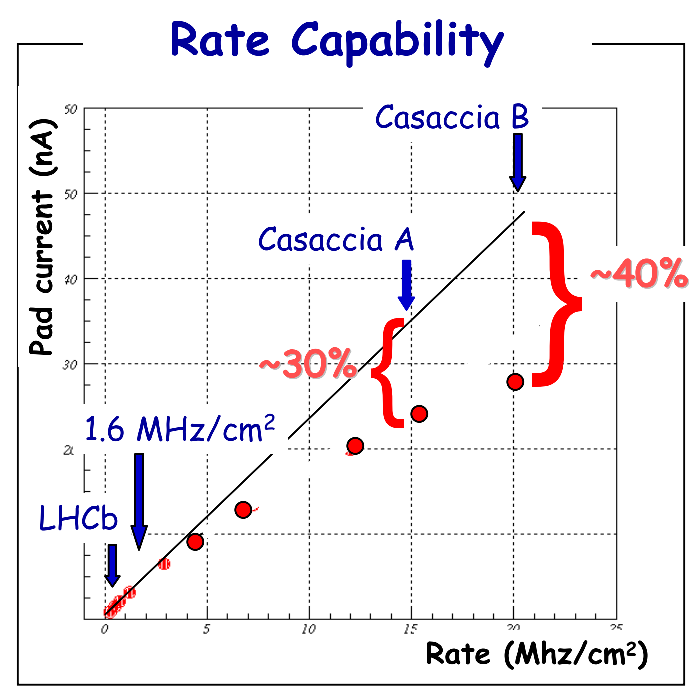
- gain and rate capability measurements with X-rays
- performance at beam test
- electron microscope analysis (SEM)
- reproducing the low gas flow effect observed at Casaccia

Gain & rate capability on aged chambers



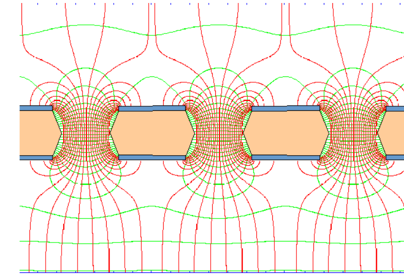


aged chambers exhibit NO rate capability loss up to ~ 3MHz/cm² (expected LHCb rate ~ 0.5MHz/cm²)



Chamber A current drop (~89%)
≈ gain drop (~55%)
+ rate cap. loss at 15 MHz/cm² (~30%)

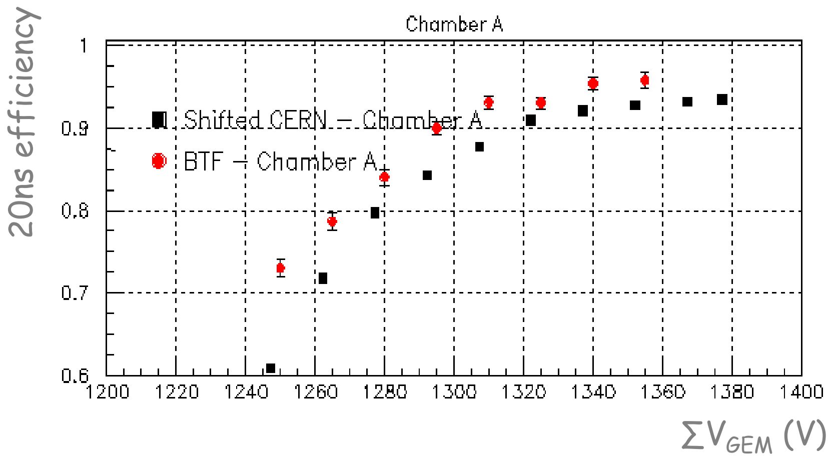
Test beam results on aged chambers



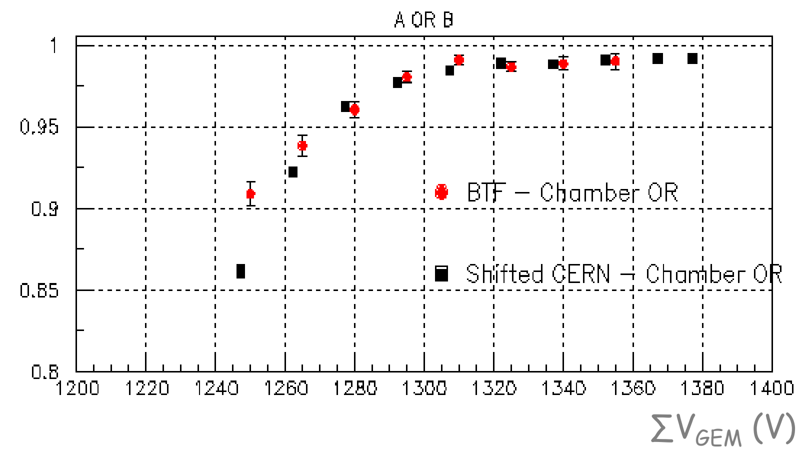
before irradiation, performance of these detectors were measured at BTF-LNF Facility (500 MeV e^- beam)

new measurements have been performed after aging, at T11-PS at CERN(*) @ 100 KHz/cm^2

Chamber A



OR station

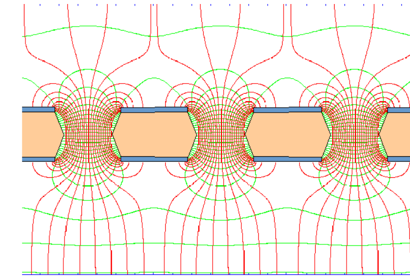


chamber A (with the larger gain loss) shows ONLY a shift of the working point of ~ 15V, without affecting the working region width

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

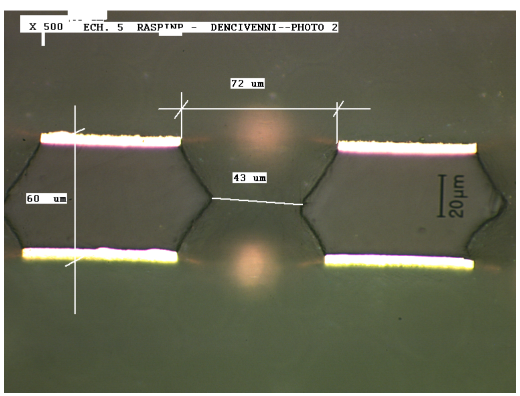


1) no damage observed on gold plated cathode and readout anode, and no damage on exposed FR4

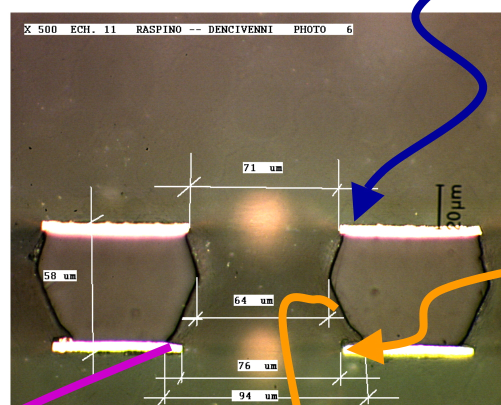
2) no carbon deposits

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

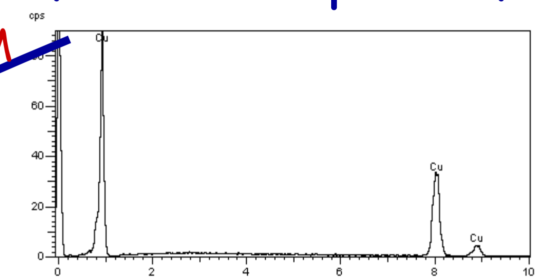
cross section of the first GEM foil of the aged chamber A ⇒ GEM is as new

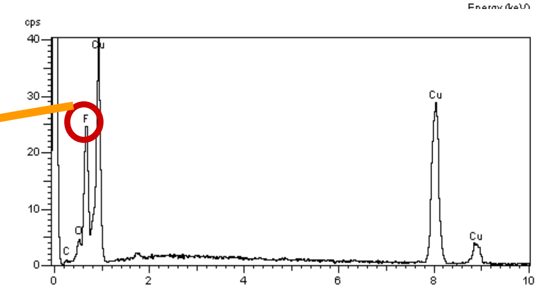


cross section of the third GEM foil of the aged chamber A



no fluorine on top side of GEM



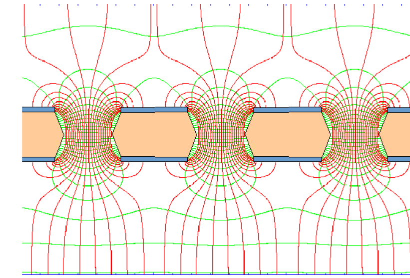


Cu-F thin insulating layer on bottom side of GEM

fluorine etching not only widens the copper hole ...

... but also removes the kapton inside the hole

Fluorine etching explains observed effects



the effects of fluorine etching is twofold:

1) widening of copper holes

→ gain reduction (*)

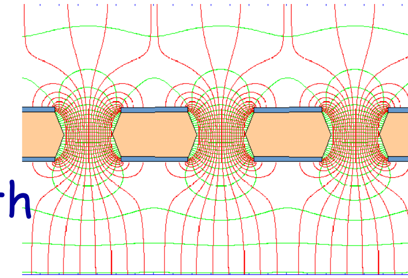
2) Cu-F compound forming an insulating layer near the hole

→ enhanced charging-up effects

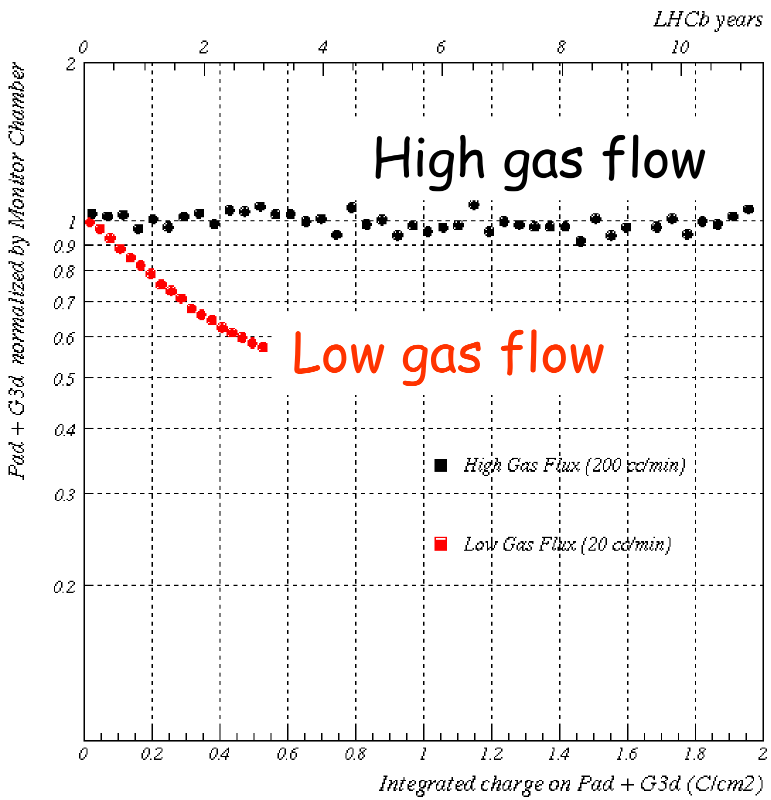
→ rate capability reduction

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

Aging induced by low gas flow



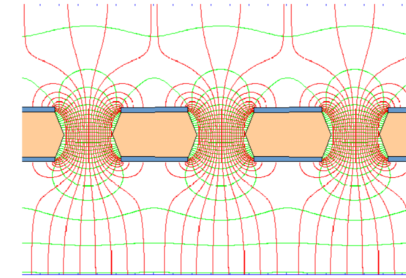
we tried to reproduce the Casaccia test results, irradiating with X-rays a 10x10 cm^2 chamber (total current ≅ 2 μA on ≅ 1 cm^2 irradiated spot) flushed with a low gas flow rate (20 cc/cm)



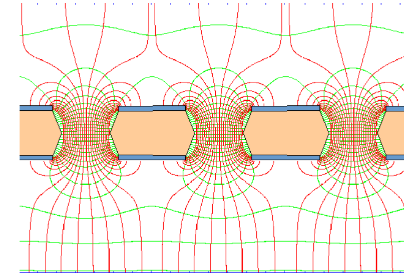
a current drop of ~ 40% for a 0.55 C/cm^2 integrated charge (~3 LHCb years) is found on the low gas flow measurement

NO current drop is observed on the high gas flow measurement

Conclusions

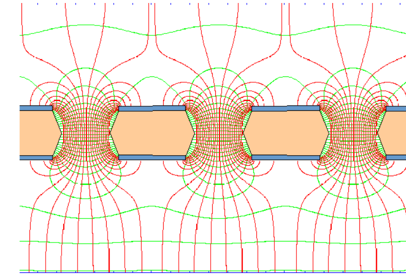


1. Casaccia results are understood ⇒ the etching observed is correlated with bad gas flow rate condition
2. no corrosion effects observed on the cathode and anode
3. etching effects mainly on the third GEM with fluorine deposits near the copper holes edges
4. no etching occurs if the gas flow is properly 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 (πM1) 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 MeV/c) π^+ + ~7% p contamination

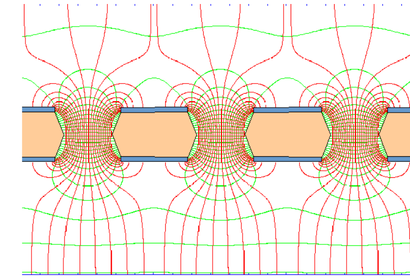
gas mixture used $\Rightarrow$ $Ar/CO_2/CF_4$ (60/20/20), $Ar/CO_2/CF_4$ (45/15/40), $Ar/CF_4/iso\text{-}C_4H_{10}$ (65/28/7), with a Φ_{gas}= 200 cc/min

during the test we measured a constant current on the anode of ~ 10 μA

with the chosen gas mixture, $Ar/CO_2/CF_4$ (45/15/40), detectors integrated a charge of ~ 0.5 C/cm^2, equilavent 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

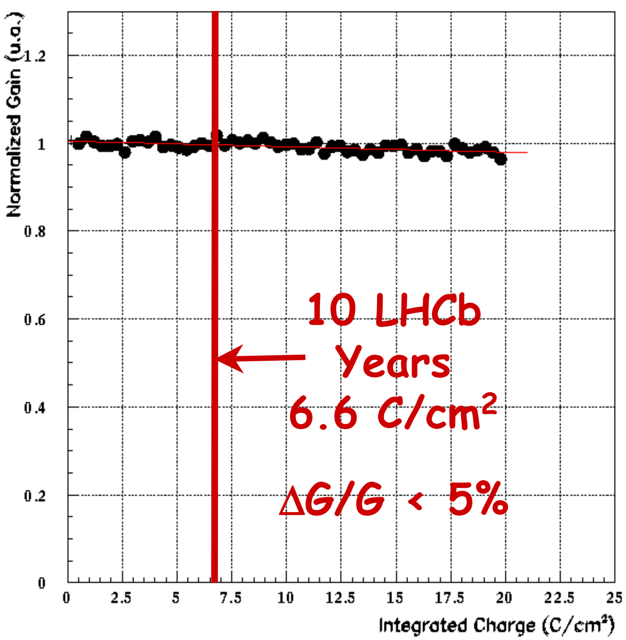


performed with an high intensity 5.9 keV X-ray beam on 1 mm^2 (about 50 GEM holes) of small size (active area 10x10 cm^2) prototypes of the detector

$Ar/CO_2/CF_4$ (60/20/20)

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

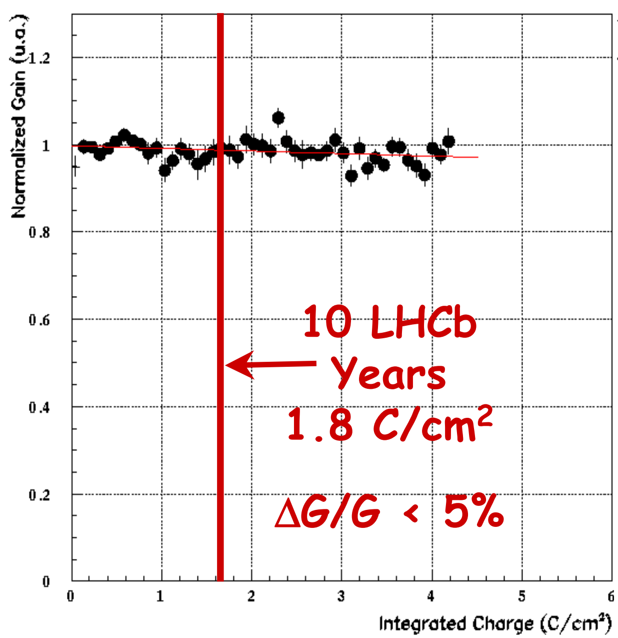
Φ_{gas}= 166.6 cc/min



$Ar/CO_2/CF_4$ (45/15/40)

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

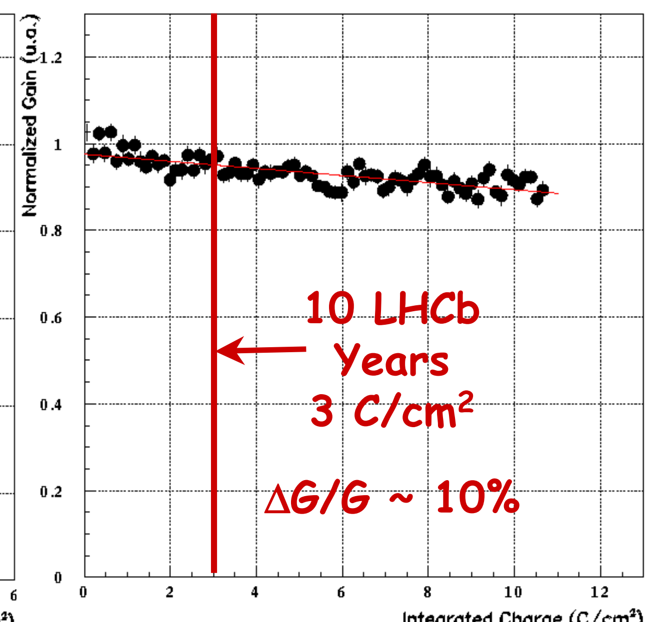
Φ_{gas}= 200 cc/min



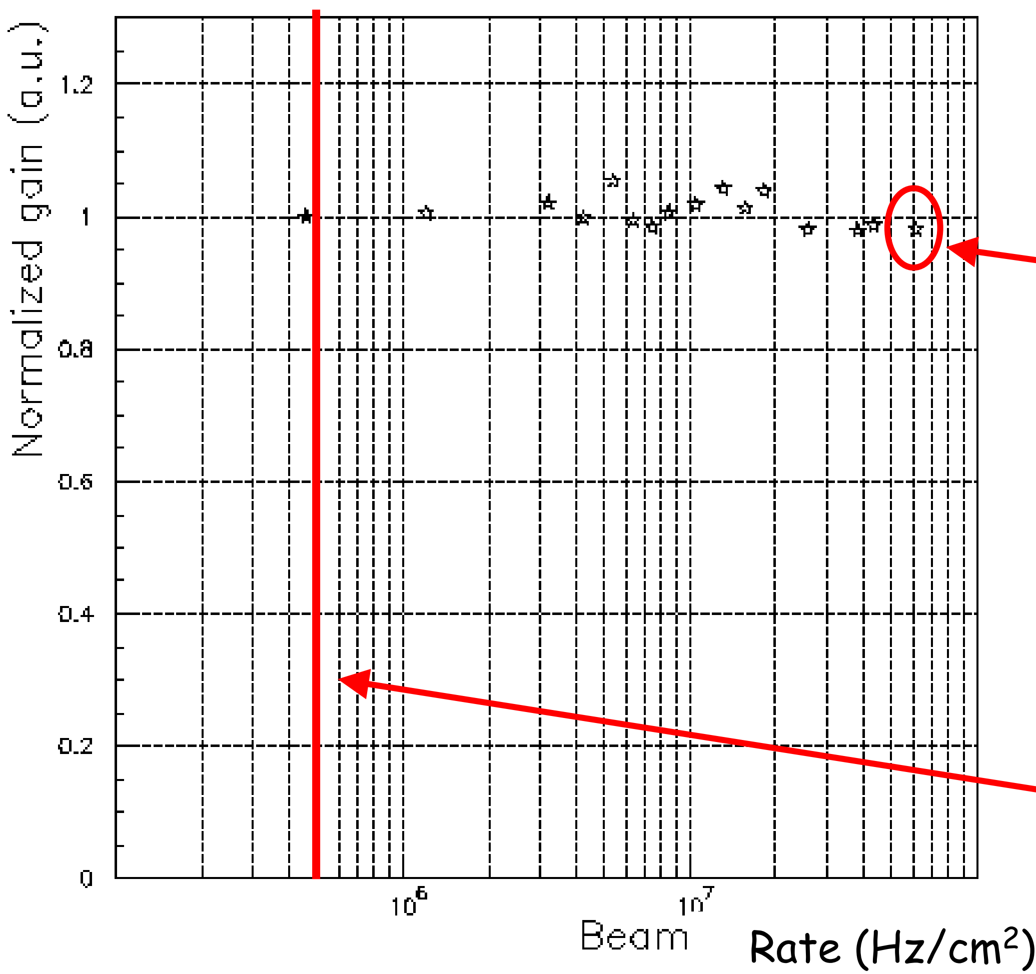
$Ar/CF_4/C_4H_{10}$ (68/25/7)

$G = 10^4$ I ~ 160nA

Φ_{gas}= 154 cc/min



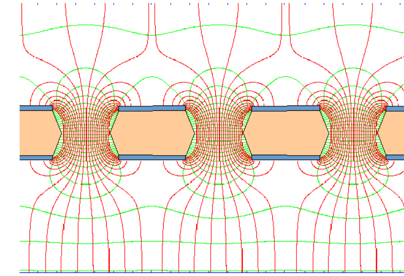
- The rate capability was measured with an X-ray (5.9 keV) tube over a spot of ~ 1 mm^2
- The detector was operated at a gain of ~ $2x10^4$

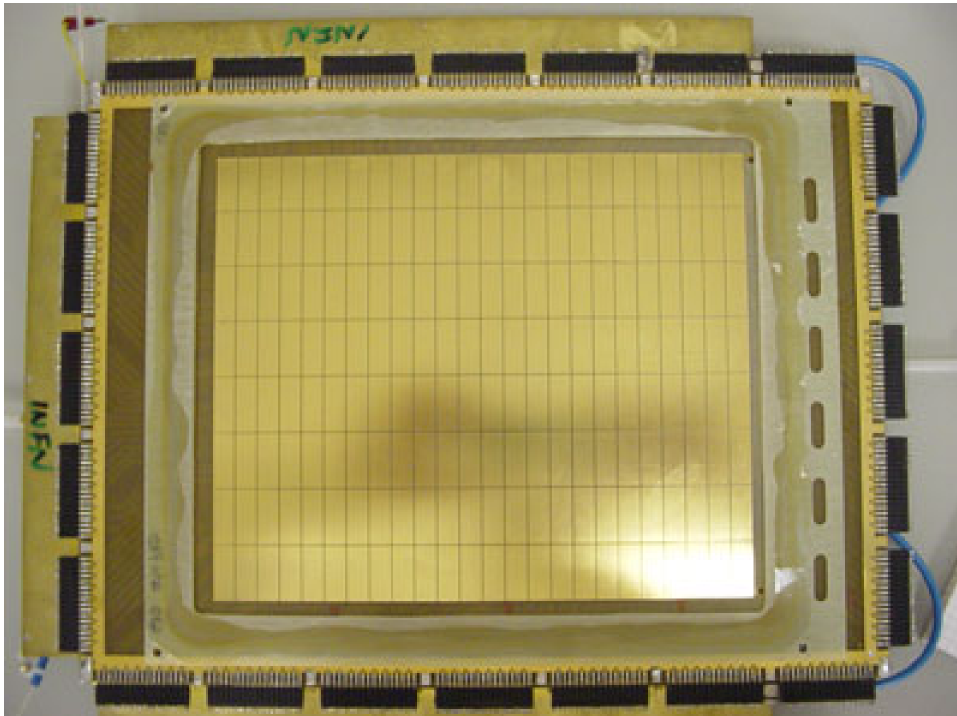


A very good gain stability was found up to a photon counting rate of 50 MHz/cm²

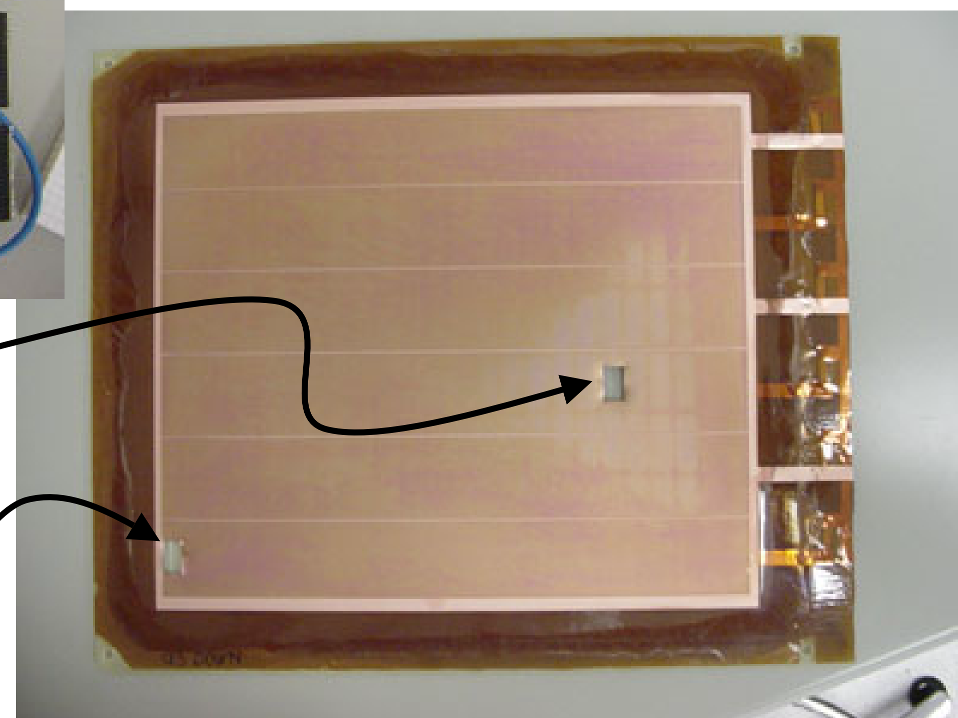
LHCb M1R1 maximum rate (460 kHz /cm²)

SEM analysis on aged chambers

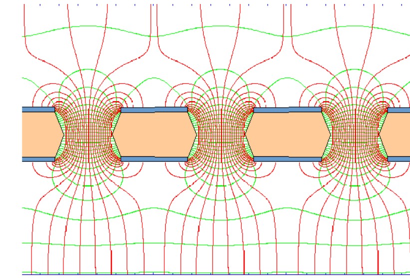




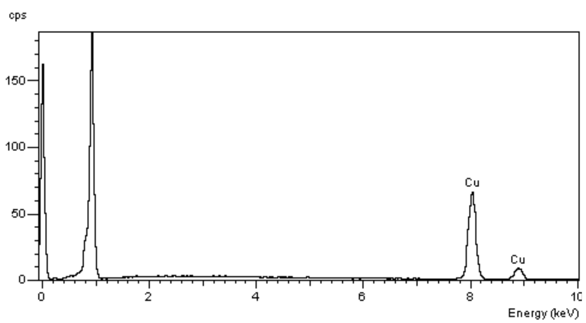
GEM 3 down sampling



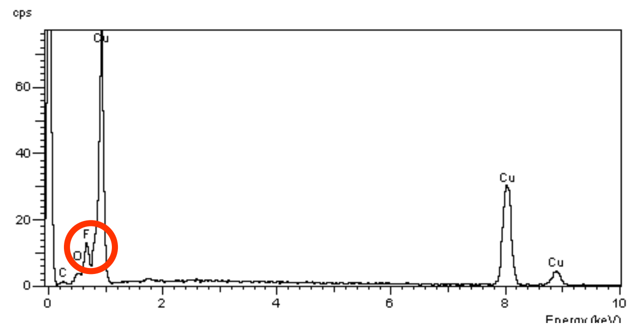
SEM analysis & X-ray spectroscopy on aged chambers



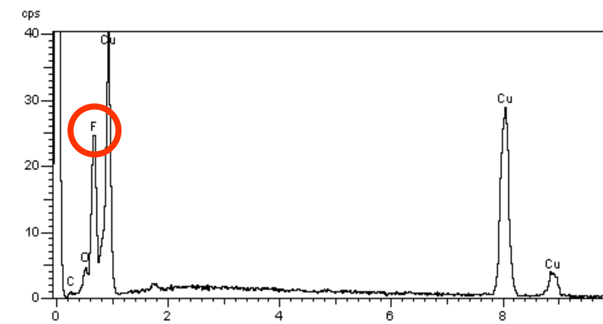
flourine found on the bottom side of G2 and G3 ⇒ Cu-F compound forming a thin insulating layer



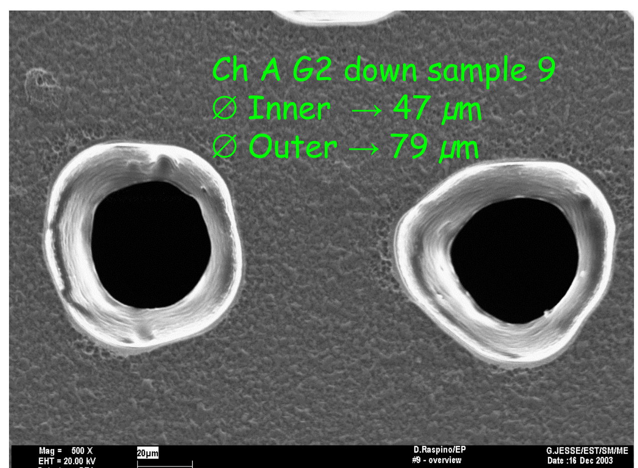
G1: No fluorine No etching

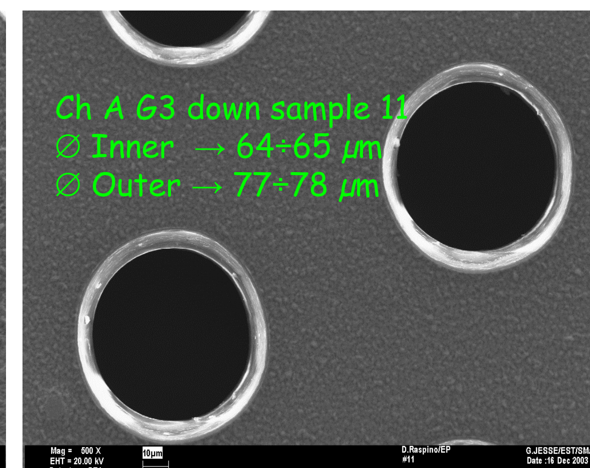


G2: Small fluorine, etching started

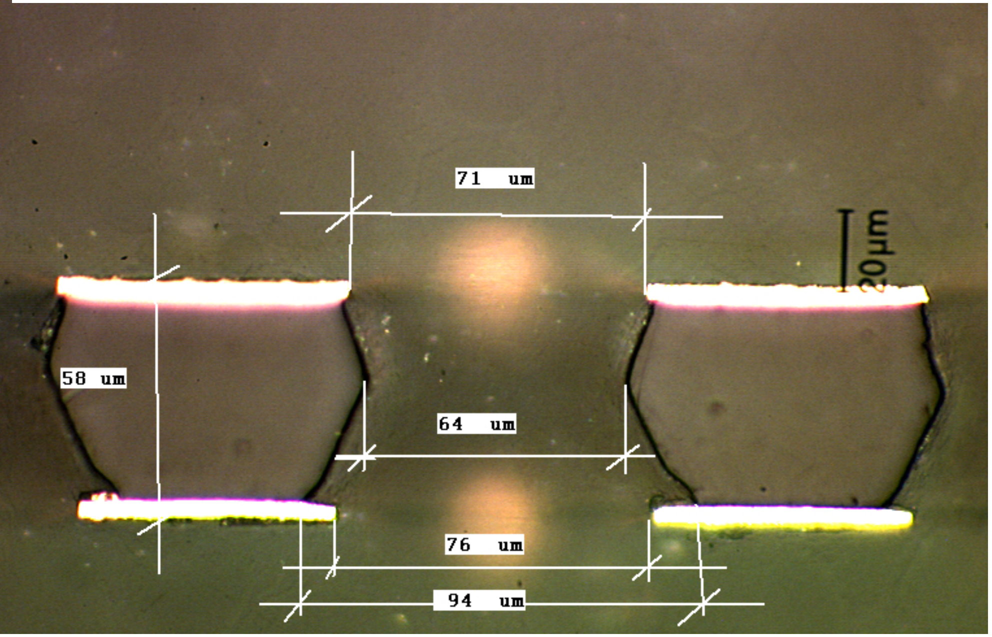


G3: Large fluorine etching enhanced

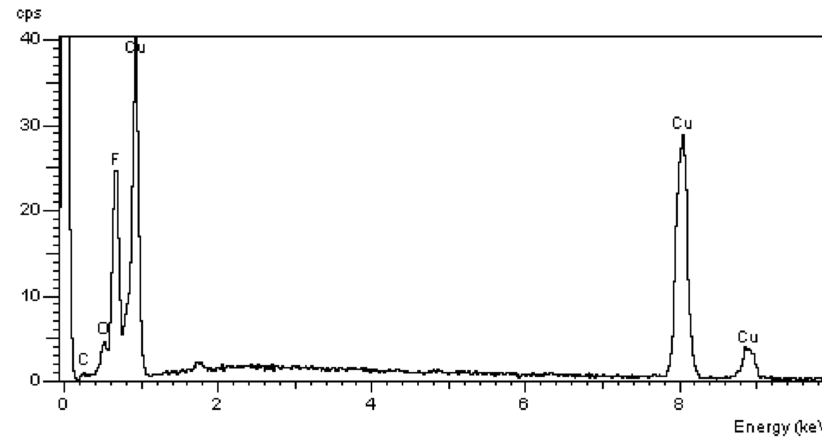


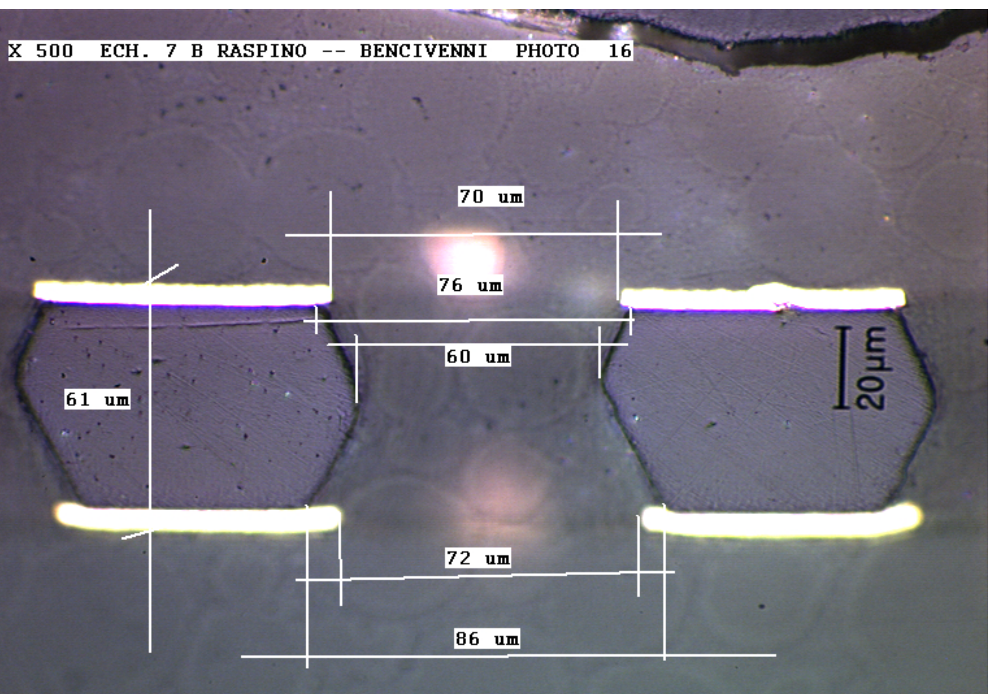


Fluorine etching comparison chambers A & B

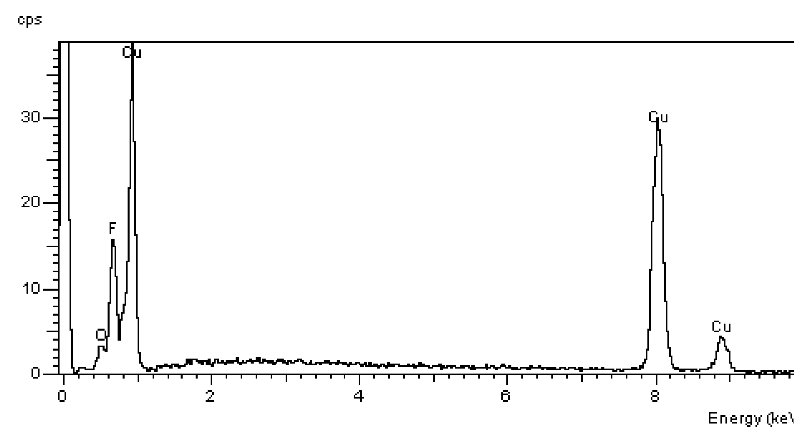


third GEM of detector A

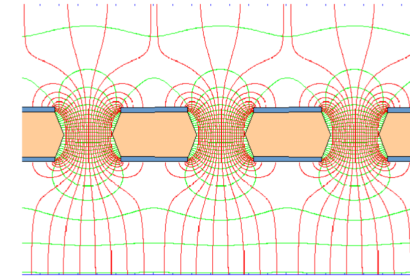


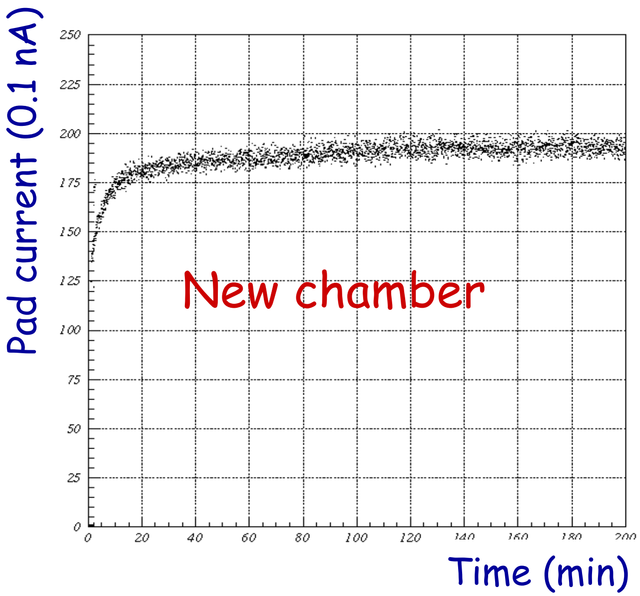


third GEM of detector B



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