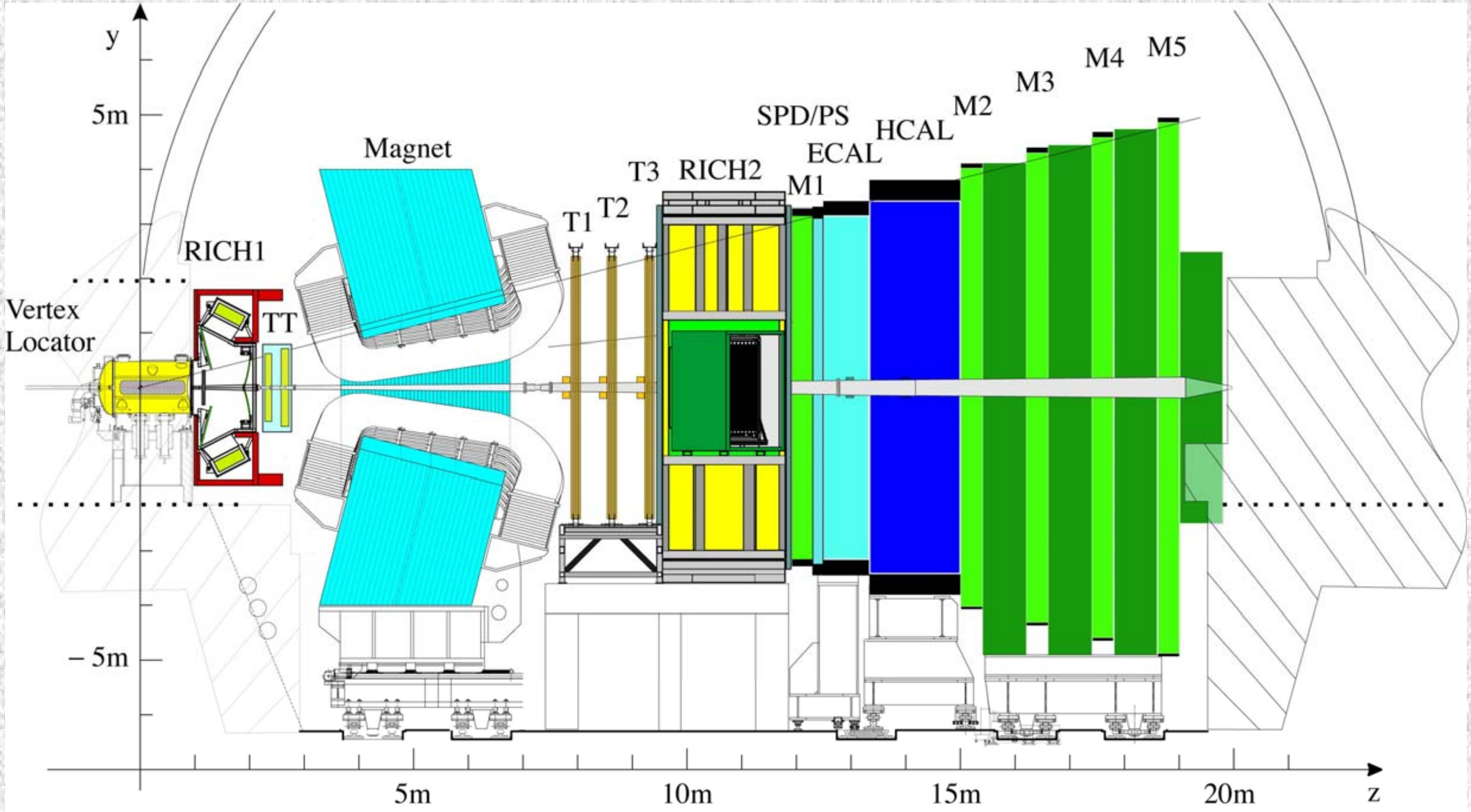
The 3GEM detector for the inner region of the first station (M1-R1) of the LHCb muon system

M.Alfonsi[1], G. Bencivenni[1], W. Bonivento[2], A.Cardini[2], P. de Simone[1], F.Murtas[1], D.Pinci[4], M. Poli-Lener[1] ,D. Raspino[2] and B.Saitta[3,2]

- 1 - Laboratori Nazionali di Frascati - INFN, Frascati , Italy
- 2 - Sezione INFN di Cagliari – Cagliari, Italy
- 3 – Universita' di Cagliari - Italy
- 4 – Sezione INFN di Roma 1, Roma, Italy

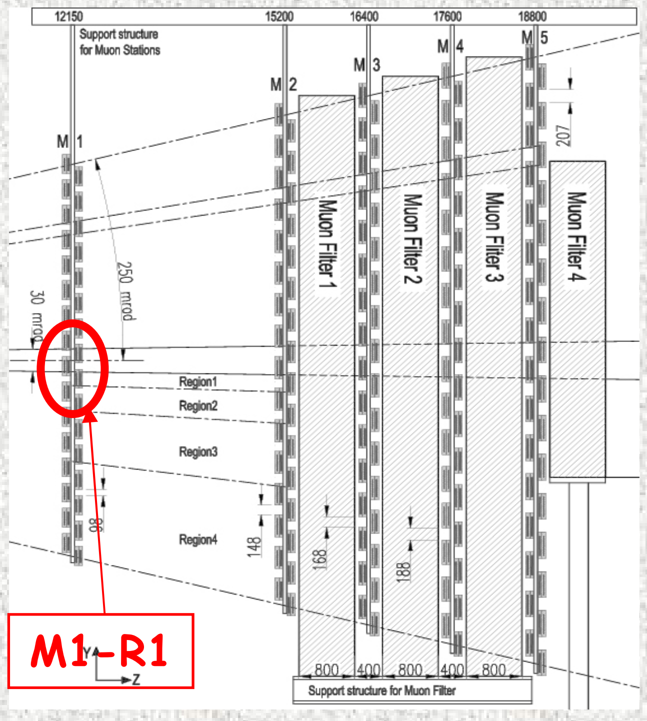
The LHCb detector



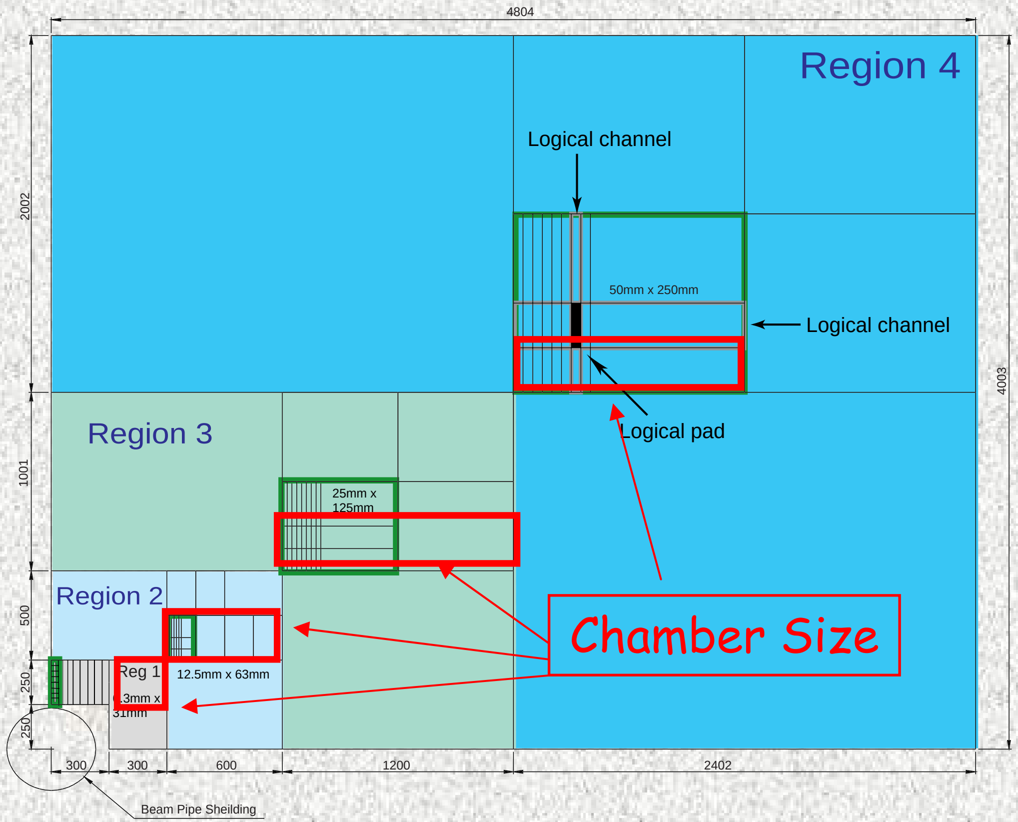
Muon detector: L0 high pT trigger + offline muon ID

The LHCb muon chambers

Side view:



Front view of a quadrant:



Muon trigger: AND of 5 stations + BCID

Layout by logical pads of different size
→four regions R1 to R4

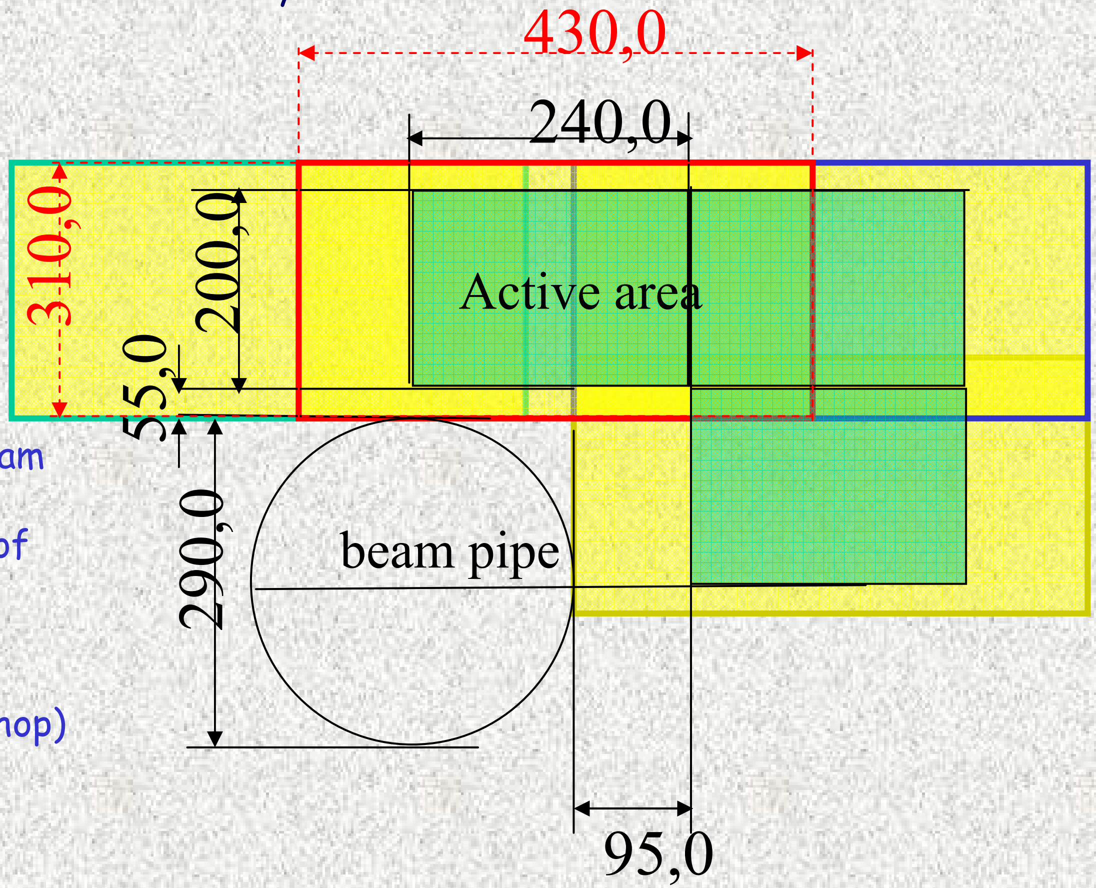
All equipped with wire chambers but for
station M1-Region 1 → **triple-GEM**
Main reasons of the choice:
ageing and cluster size (pad size 10x25mm²)

S=0.6 m² but about 20% of the triggered muons need it!

The M1R1 detector

Requirements for the station

- Rate capability (mostly hadrons) — up to 0.5 MHz/cm^2 , average 0.2MHz/cm^2
- Efficiency on muons — >96% in a 20 ns window
- Pad multiplicity or cluster size (<# >of hit pads/muon) — <1.2
- Signal width (to limit trigger dead time) — <50ns
- Radiation hardness — 10 years of LHCb



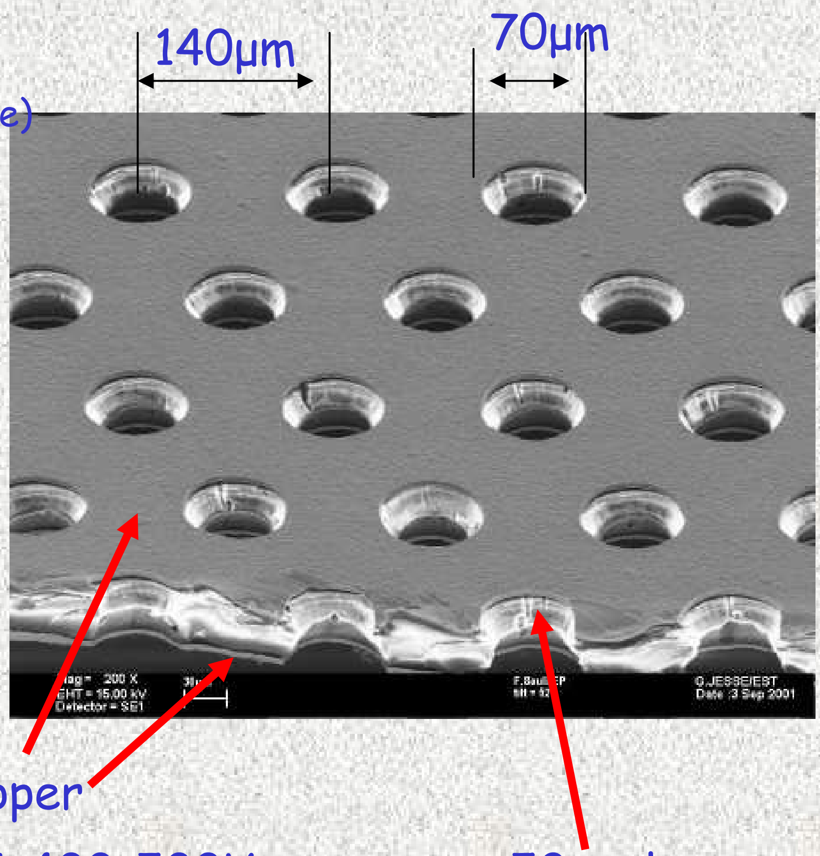
The M1R1 station

12 double detectors surrounding the beam pipe:
each detector is a triple-GEM chamber of 20x24cm^2 active area

→24 triple-GEM chambers
(GEM foils from CERN-EST-DEM workshop)

How to make a charged particle detector with GEM

(picture from CERN-GDD site)



ΔV=400-500V

E_{hole}=50-100kV/cm

GEM as charge amplifier in a parallel plate detector.
Fast readout: O(5ns) rise-time, ENC=3000e$^-$ (C_{det}=20pF), leading-edge time pick-off, threshold/ENC=5

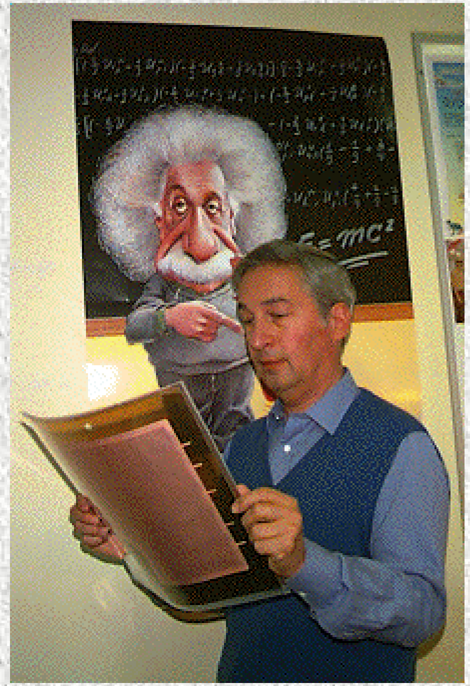
➡ 1e- triggered with G=15,000

With one GEM ➡ discharges at high incident particle rate.

Reduced with multi-GEM structures (voltage dependence of Reather limit, diffusion…) →3GEM

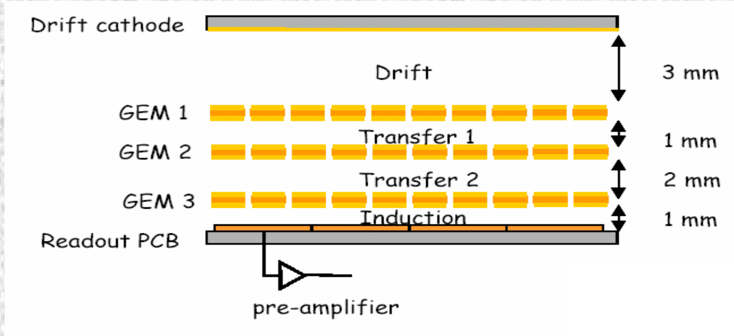
Starting point for our group: Ar/CO_2 70/30 (year 2000): time resolution (measured by Sauli's group) not good enough for the LHCb application

The inventor of GEMs



A new idea: an optimal gas mixture

Time resolution (with leading-edge time pick-off) depends mainly on the intrinsic time resolution on the arrival of the first ionisation clusters on GEM 1



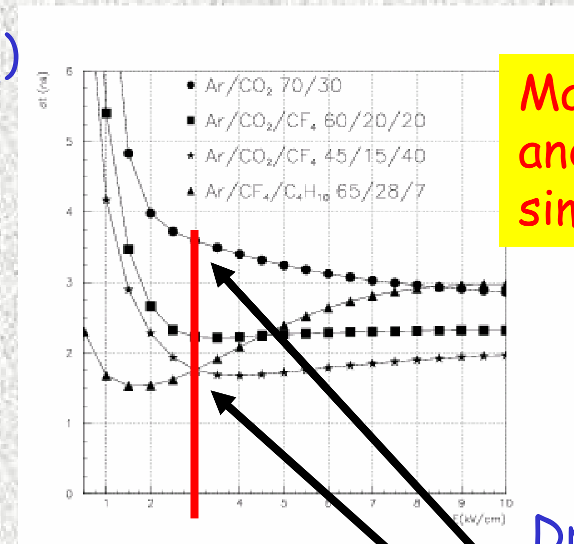
$\sigma(t_1) = 1/(n_{clu}\ v_{drift})$
$\sigma(t_i) = f(i)/(n_{clu}\ v_{drift}),\ f(i)>1$

Choice of the gas mixture

High yield and fast
Also good quenching properties and radiation hardness

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

$\sigma(t_1)$



Magbolz and Heed simulation

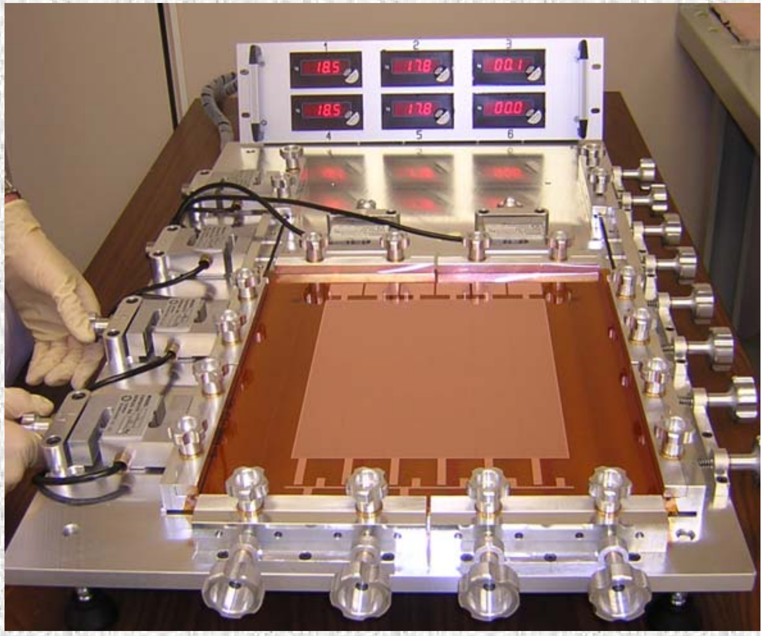
Drift field

3kV/cm

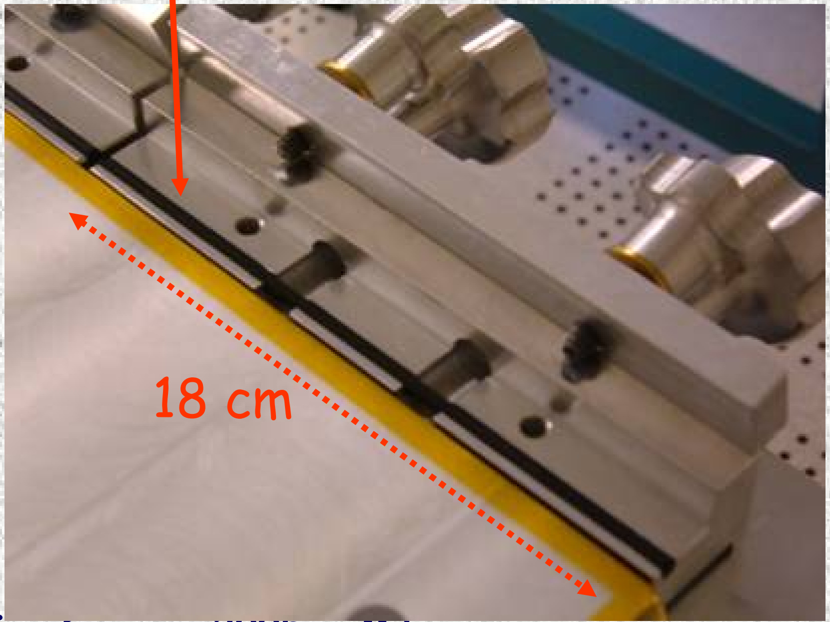
More than a factor 2 of improvement w.r.t. Ar/CO_2 (70/30)

Detector assembly: GEM stretching

20x24 cm2 GEM foils produced at CERN



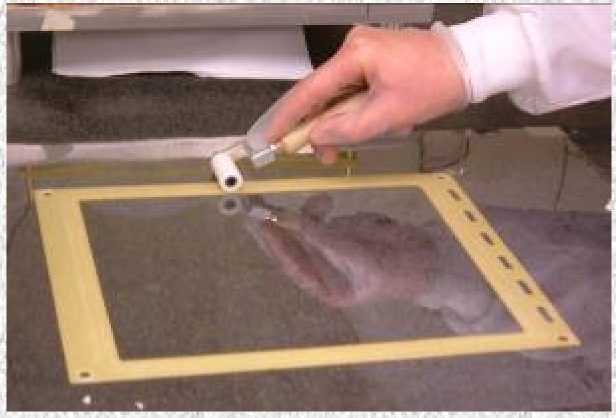
GEMs that pass the HV test are stretched with a specific tool.
The foil is clamped with jaws equipped with plastic O-ring.



Mechanical tension (18kg/jaw → 20 MPa) applied to the edge of the foil is monitored with gauge meters.

Kapton creep is negligible for this mechanical tension

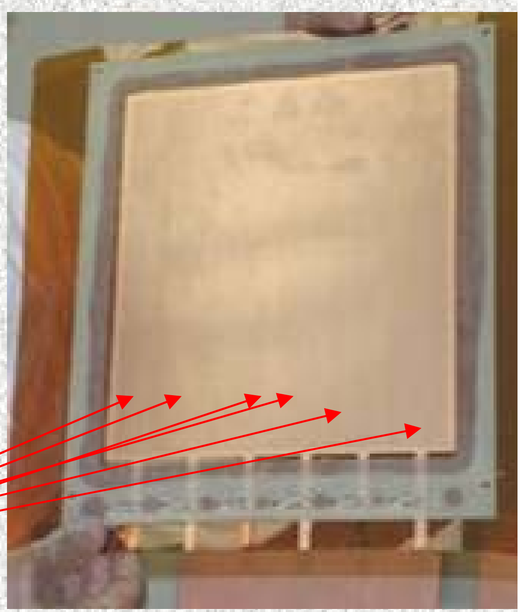
Detector assembly: glueing on frames



Araldite 2012 epoxy resin (good electrical behavior, suitable handling properties & aging tested(*)) is applied with a rolling wheel tool on the frame.

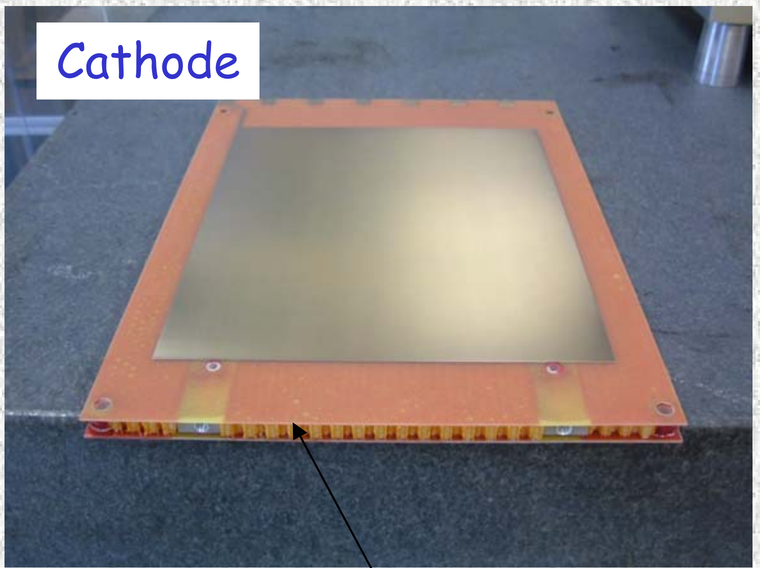
Epoxy work life: 4 minutes; curing time: 2 hours.

Then the frame is coupled with the stretched GEM foil, with a load of 40 kg.



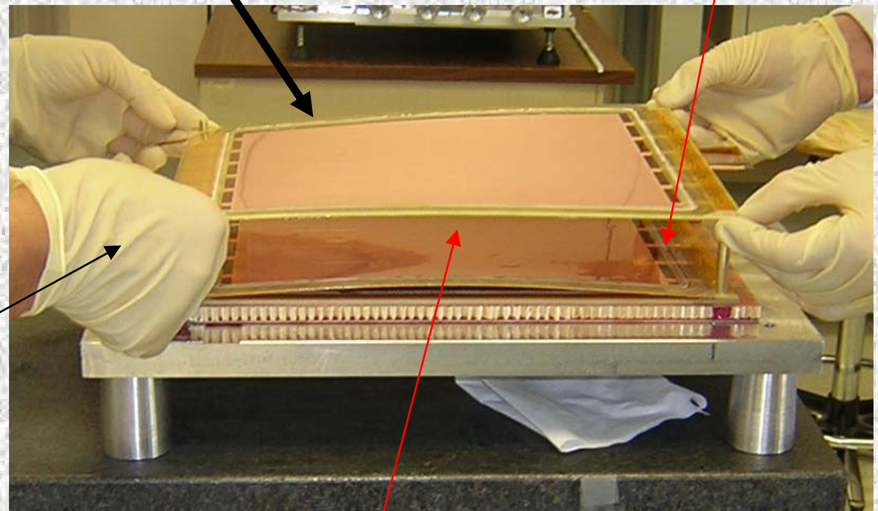
The GEM foil is divided in 6 sectors
to reduce the energy released in case of discharge

Detector assembly: GEM piling-up



GEM foils are assembled without internal spacers, thus avoiding geometrical dead zone.

The G10 frames glued on the GEM

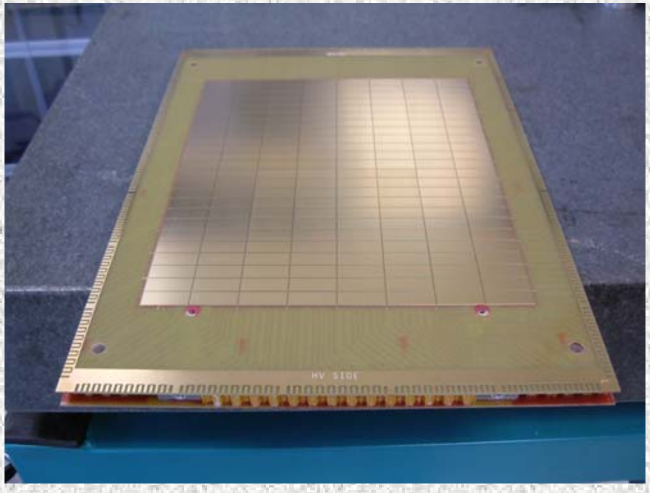


honeycomb structure
(in front of EM calorimeter!)

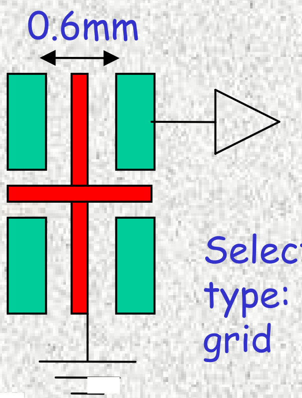
The three GEM frames are glued one on top of the other and tested with HV

In the frame 6 holes house 0.1-1 MΩ SMD resistors for HV decoupling

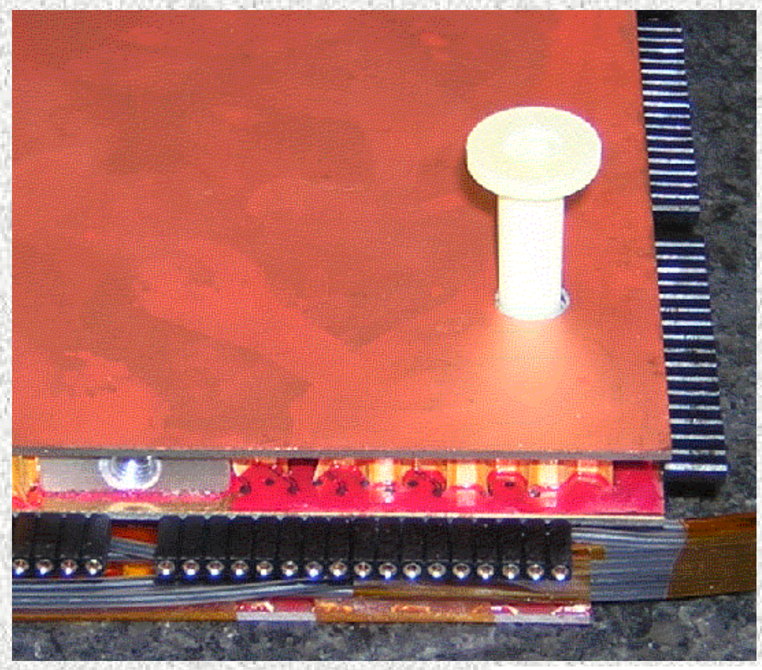
Detector assembly: anode plane as top cover



Stesalite bushings are inserted and glued with the CIBA 2012 epoxy.
Bushings prevent gas leaks from the corners of the chamber and are used to hang-up the chamber on the muon wall.



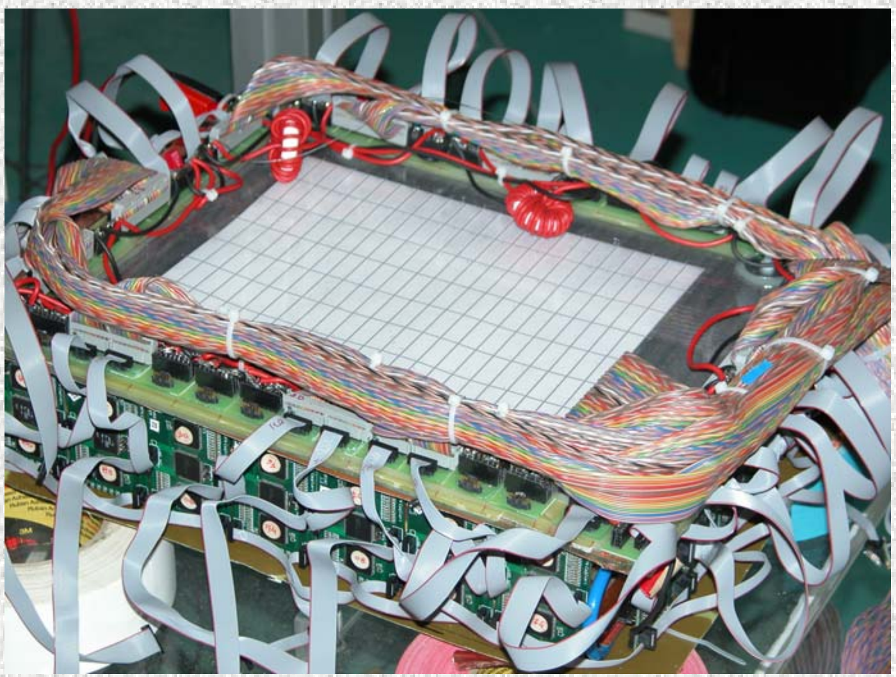
Selected pad type: with ground grid

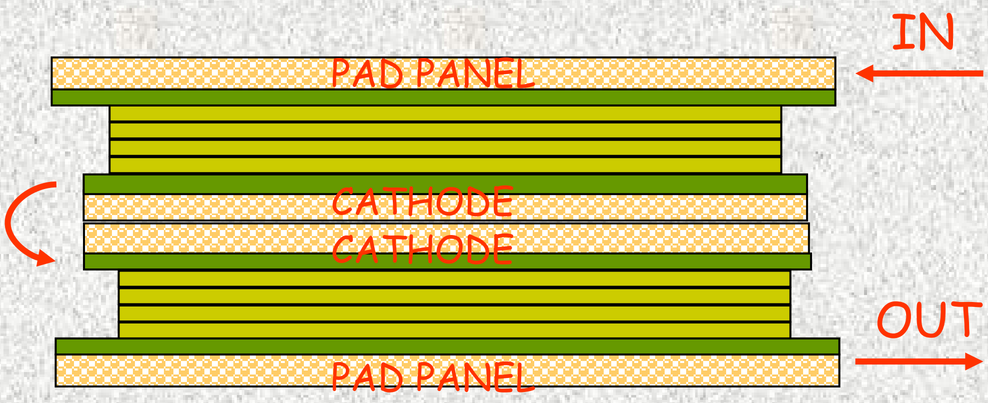


Detector assembly: coupling of two detectors

Two detectors are coupled through the 4 pin holes with cathodes faced one to each other→build a station

FEE boards are installed along the detector perimeter and closed with the Faraday cage (not in the picture!!)

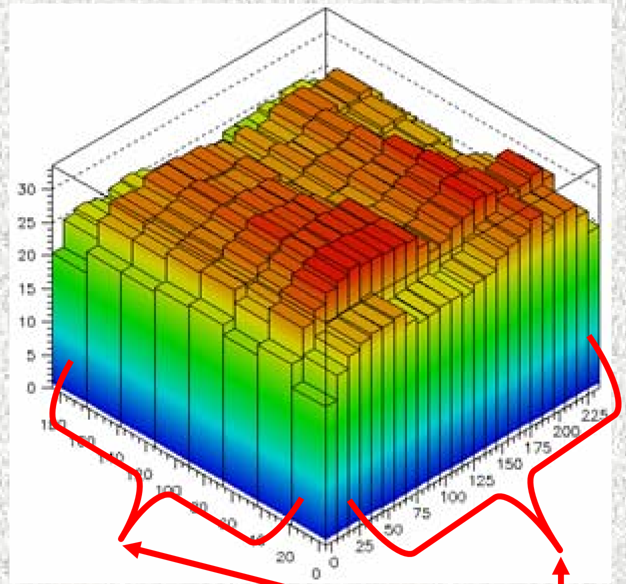


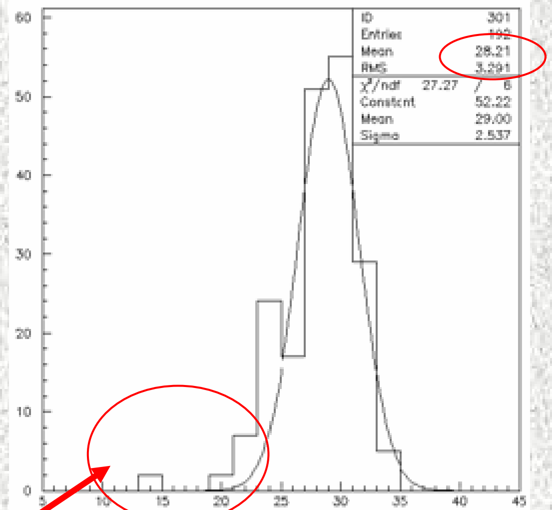


The gas flows through the two chambers in serial mode.

X-ray test: gain uniformity measurment

The current signal induced on the single pad is read-out with a current-meter (nA sensibility) and it is corrected for T and p variations





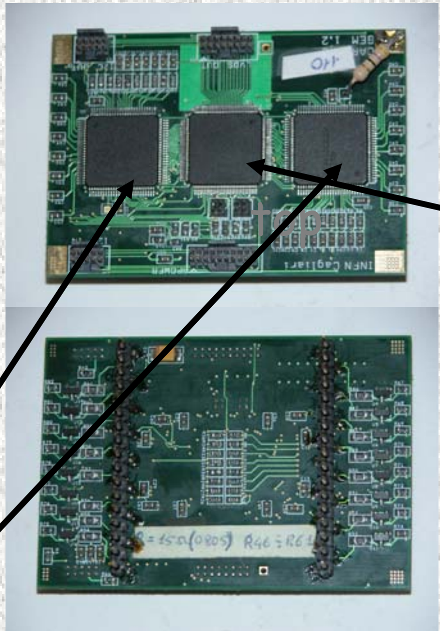
Due to effective beam spot in the border pads

A gain uniformity < 12%

(with edge effects, 6% without)

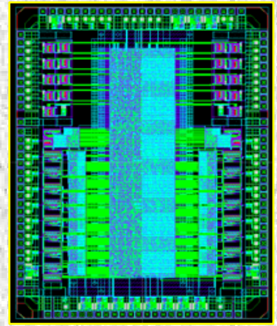
Front-end electronics

Front-end boards



bottom

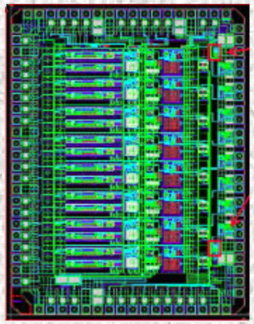
IBM 0.25 μm radiation
tolerant technology
16 LVDS input channels
8 LVDS output channels



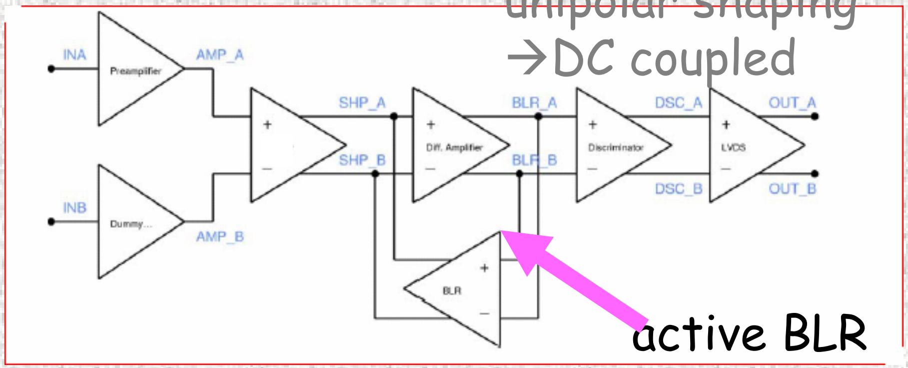
DIALOG chip

All differential
circuitry,
unipolar shaping
→DC coupled

CARIOCA-GEM chip

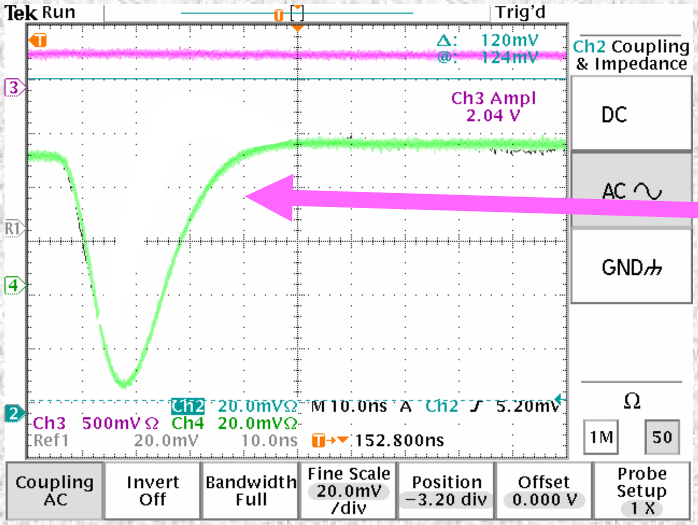


IBM 0.25 μm radiation
tolerant technology
8 analog input channels
8 LVDS output channels



Zin=50Ω, tr<10ns, pw(delta)<30ns,linear up 130fC,
ENC=0.5fC@Cdet=30pF → working threshold ~2.5fC

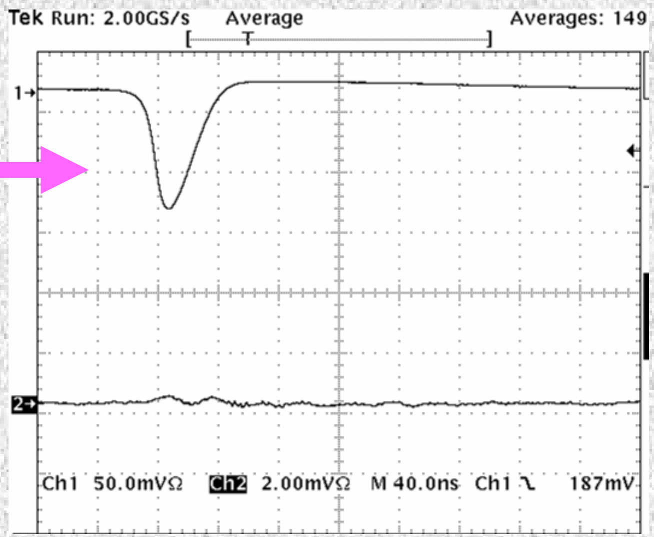
Analog signal response



delta response

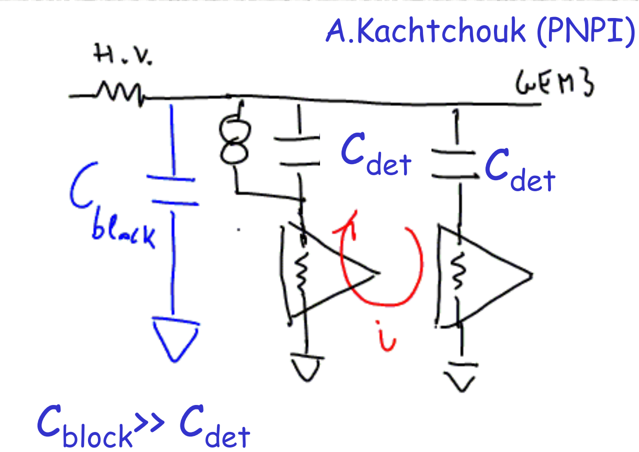
Cdet=15pF

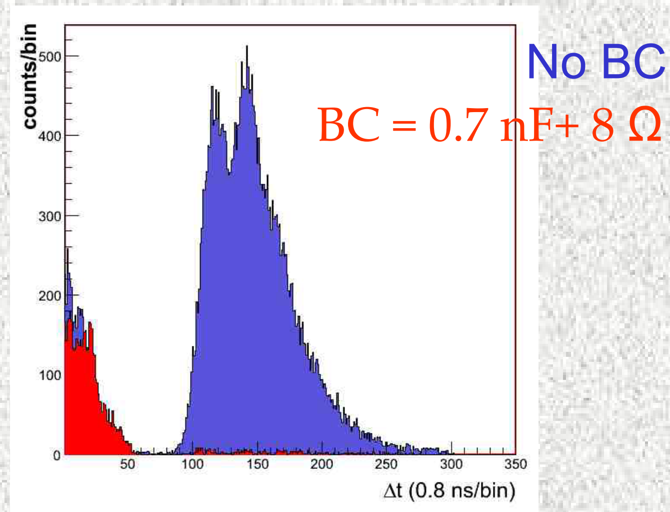
average response to detector signals



- ✓ ^{90}Sr 100 μCi
- ✓ Low energy electrons (~2 MeV)
- ✓ Detector Gain = $2 \cdot 10^4$ (plateau end)

A new idea: the blocking capacitor





Cross-talk from capacitive coupling through the common GEM3 foil → it is long-distance → at high rate gives additional noise in the chamber

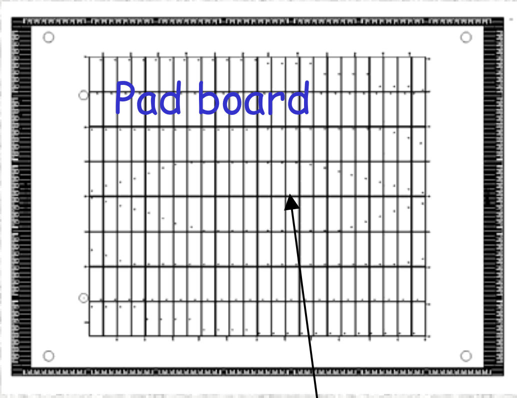
Solved with discrete capacitor (plus dumping resistor)

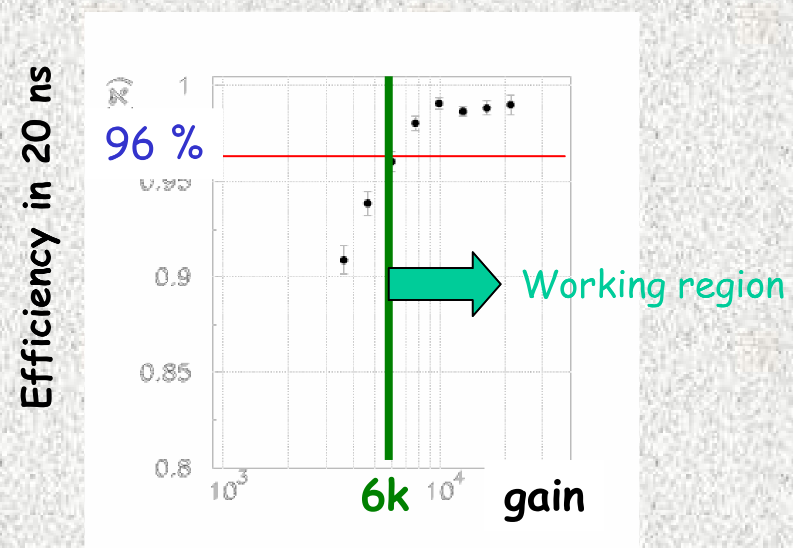
→ the idea is similar to wire grounding of WPC in cathode readout

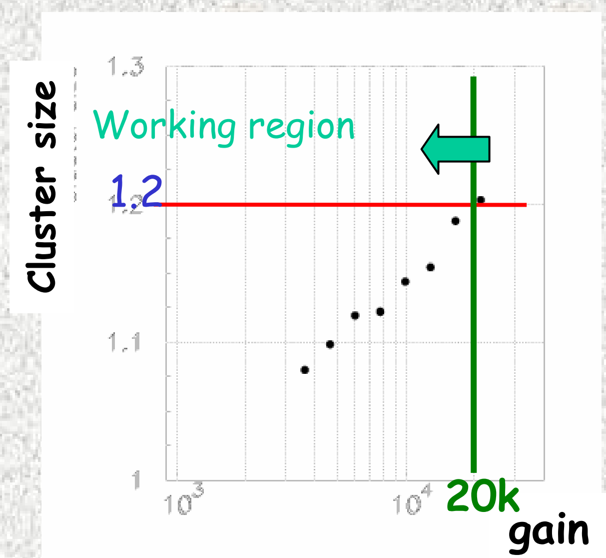
Prototype performance: efficiency and cl.size

A protorype detector:

2 triple-GEM chambers OR-ed



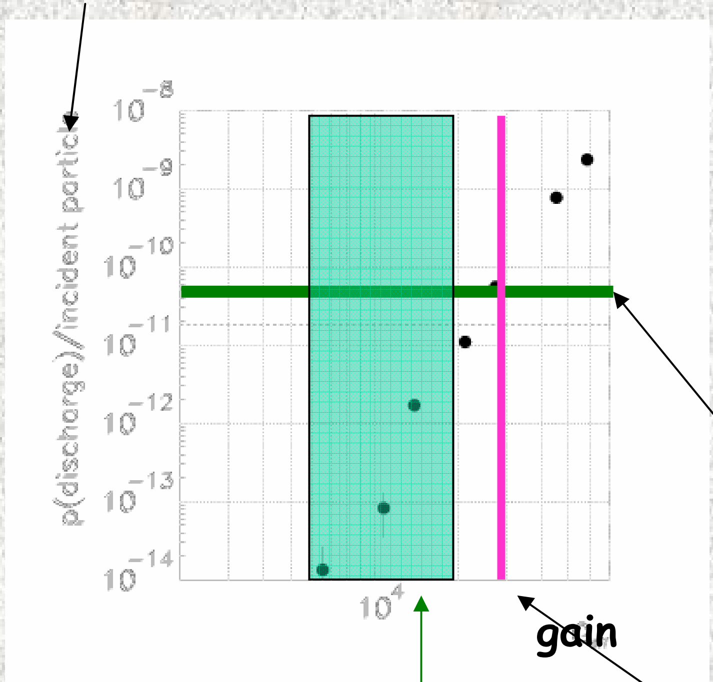




Working region about 70V (a gain range of more than 200%) → it allows for
a) gain non uniformities over the surface (10-15% measured with the prototype)
b) P variations (-1.5%/mbar) c) gain variations with rate

Prototype performance: discharge rate

Measurement done at π-M1 beam
350MeV/c π (7% p) of PSI (CH)
300Mhz beam



Working region

+ **measurement of maximum number of discharges leading to detector death:**

With ^{241}Am source on $0.5cm^2$ area
To speed-up the test → Geff=40k (conservative result)
Three detectors killed after 500, 700 and 800 discharges

→ We derived a maximum safe value (10 y of operation of the detector at the nominal luminosity) for the discharge probability per incident particle

→ We obtain a maximum safe gain value → OK well compatible with the working region

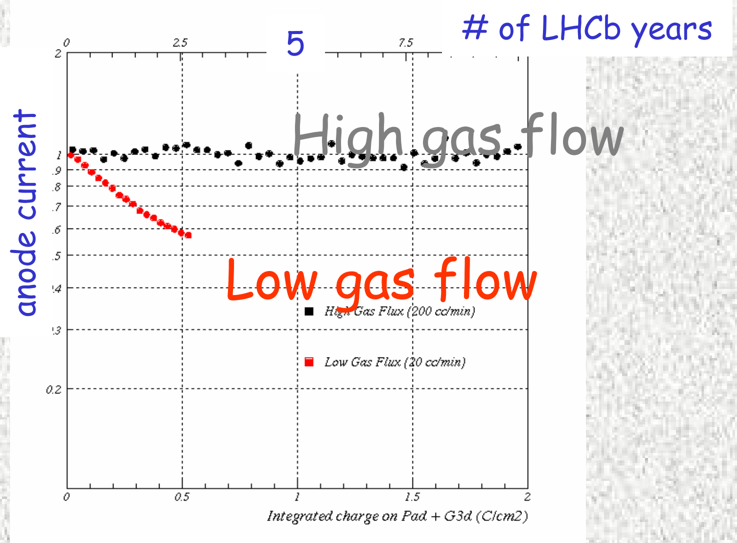
Ageing studies(i)

Local Aging: performed with a high intensity iron-target X-ray tube, irradiated area of about 1 cm^2 (~ 5000 GEM holes). Integrated charge 4 C/cm^2 ⇔ 25 LHCb years.

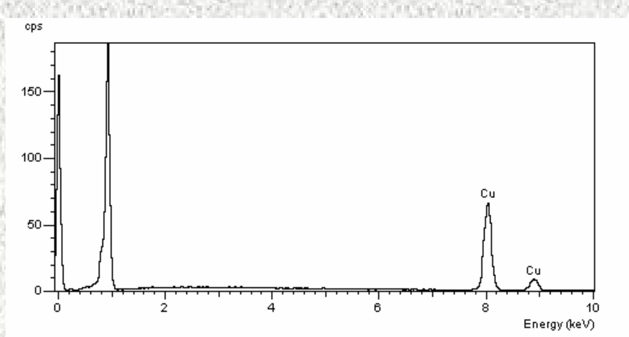
Large Area Aging: performed at the PSI πM1 hadron beam, with an intensity up to 300 MHz and an irradiated area of about 15 cm^2. Integrated charge 0.5 C/cm^2 ⇔ 3 LHCb years.

Global Aging: performed with a 25 kCi ^{60}Co source. Detectors were irradiated at 0.5 ÷ 16 Gray/h. Integrated charge up to 2 C/cm^2 ⇔ 12.5 LHCb years.

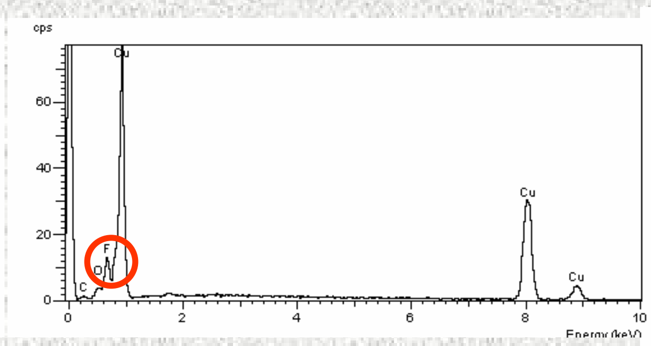
→ No ageing if appropriate gas flow is used:



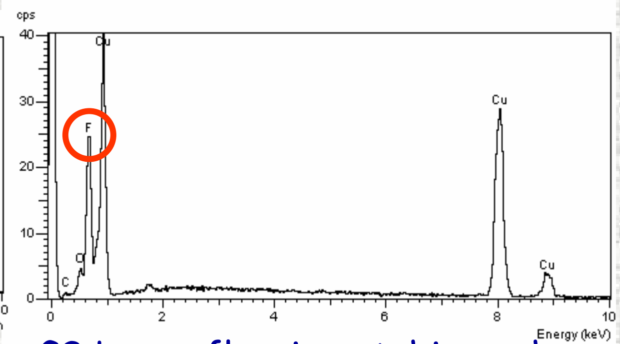
A curiosity: SEM on aged GEM foils



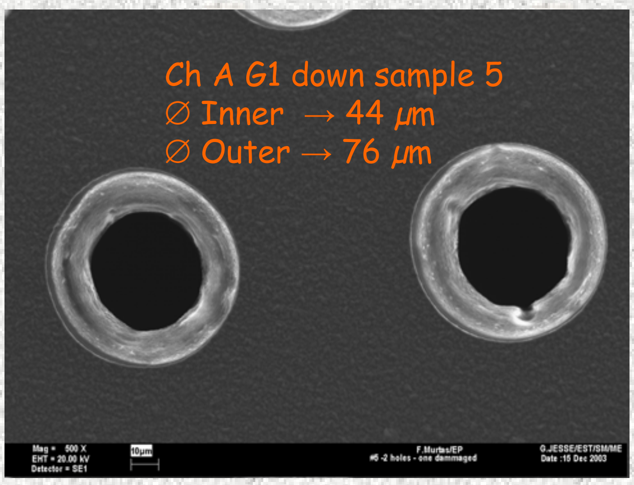
G1: No fluorine No etching

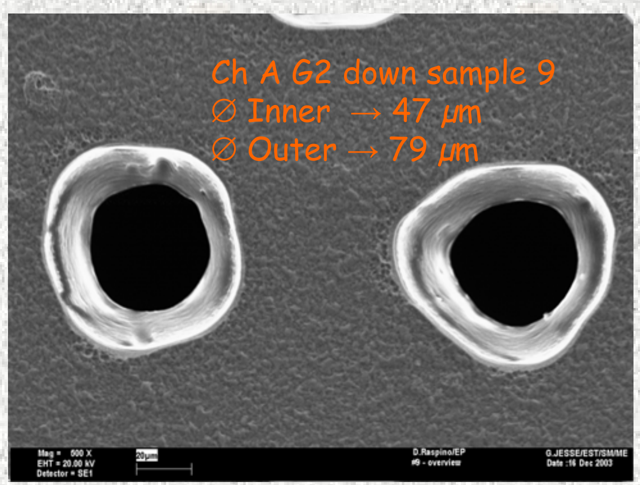


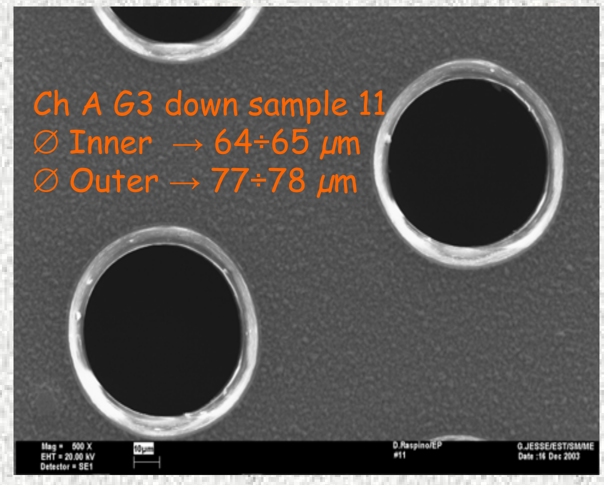
G2:Small fluorine,etching started



G3:Large fluorine etching enhanced







Hole diameter increased ➔ gain reduction→negative feedback →the opposite of wire chambers!!!!

Conclusions

The triple GEM detector is part of the LHCb muon detector in the M1R1 region

The system consists of 12 double chambers, built by INFN Cagliari and LNF.

Two chambers bulit so far, one fully equipped with electronics, the second one in 2 weeks.

Construction is going to end during the first half of 2006

THE END

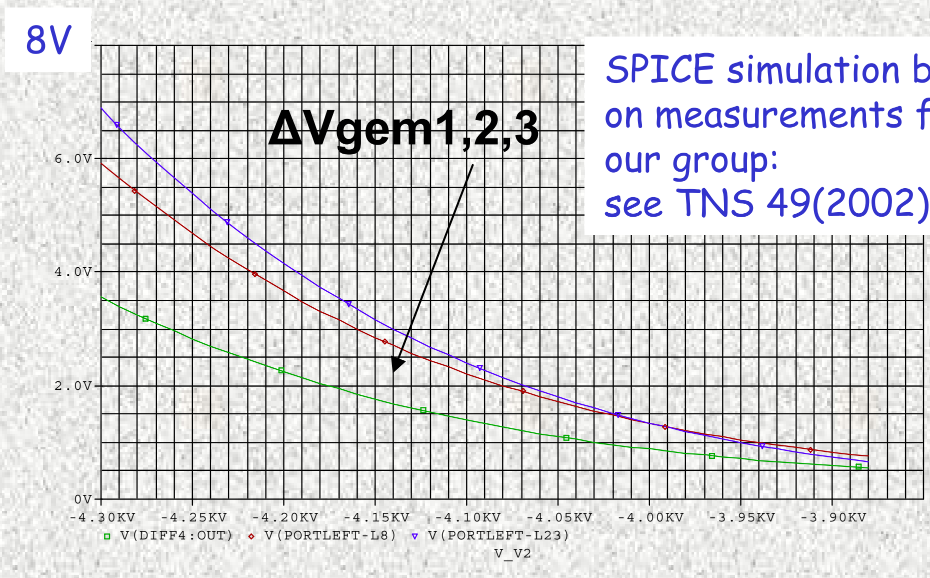
Back-up slides

High voltage distribution

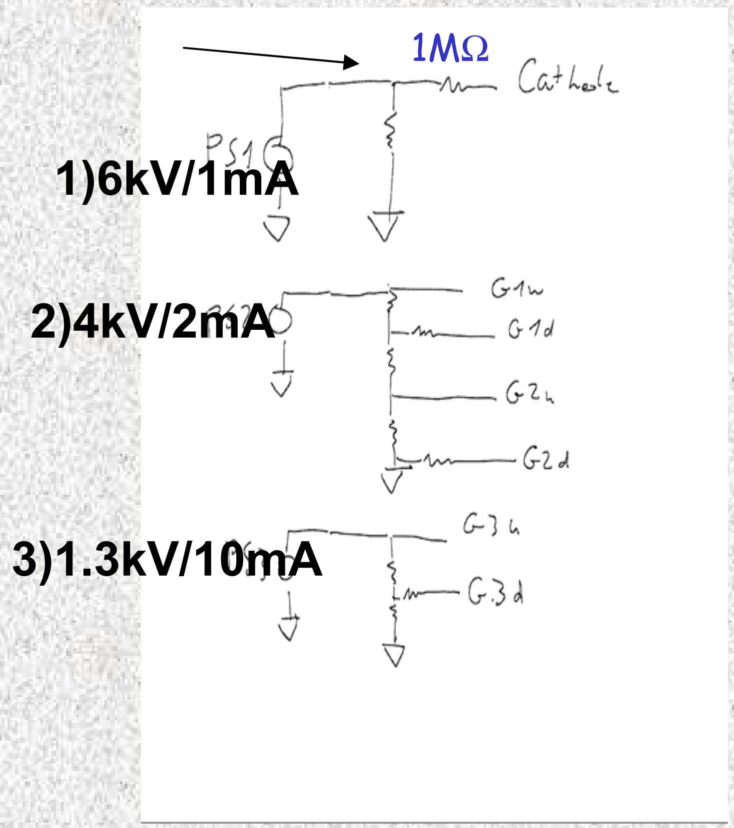
High voltage: Solution not easy → large currents→ need to stay within working region
→ a candidate solution with 3 dividers and 3 commercial power supplies

monitor of GEM current !

SPICE simulation based on measurements from our group:
see TNS 49(2002)1638



plateau 1280V to 1350V



$G = A\exp(B\,U_{tot})$ $B = 0.017/V$

total Power consumption
15 W at plateau end