THE LHCb EXPERIENCE WITH THE ASSEMBLY OF THE GEM (*)

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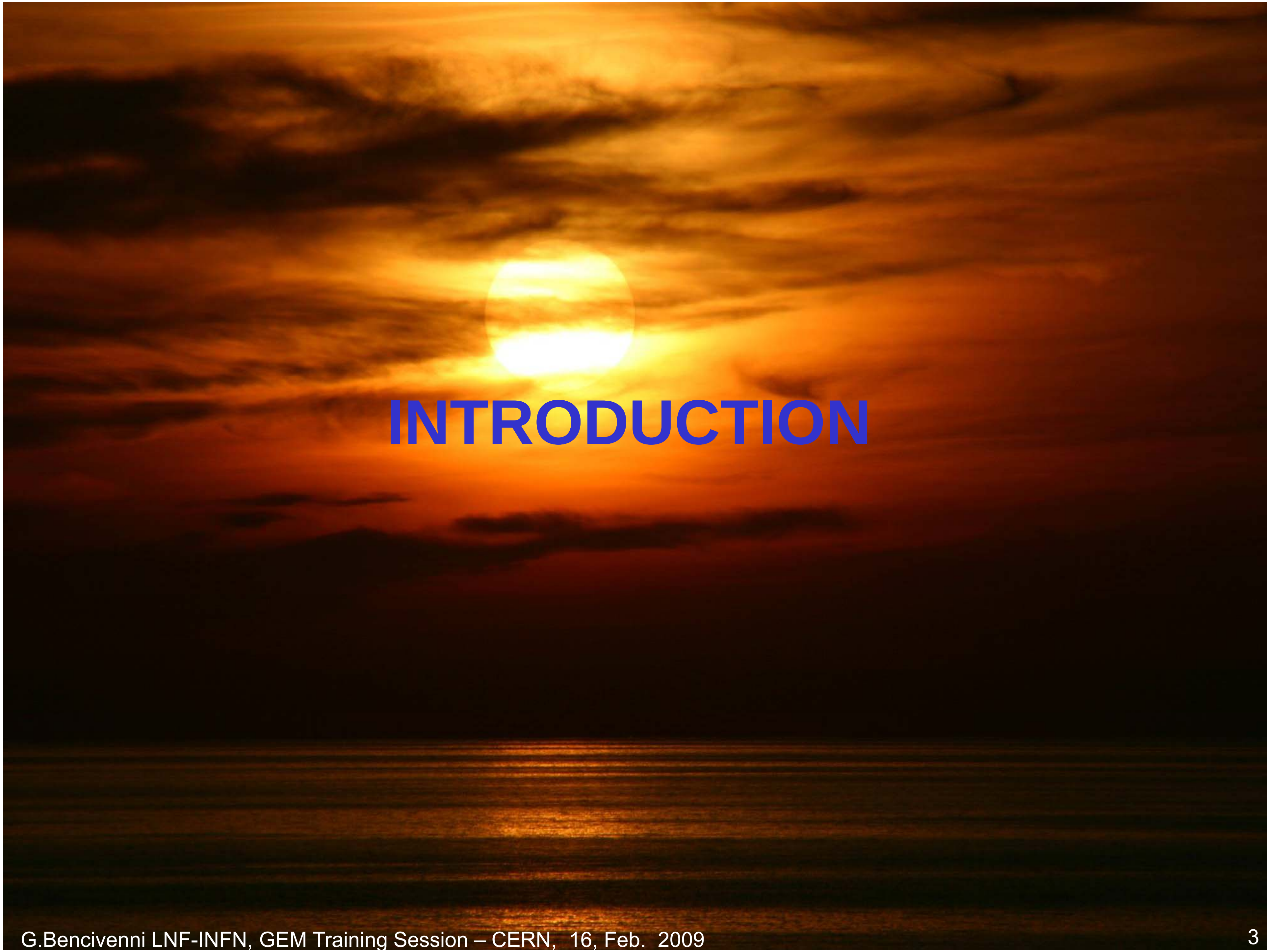
(*) Work done in collaboration with the INFN-Cagliari

OUTLINE

- Introduction
- Construction of GEMs in LHCb
- Quality Controls in LHCb
- Beyond LHCb: large area GEMs
- Assembly training session schedule

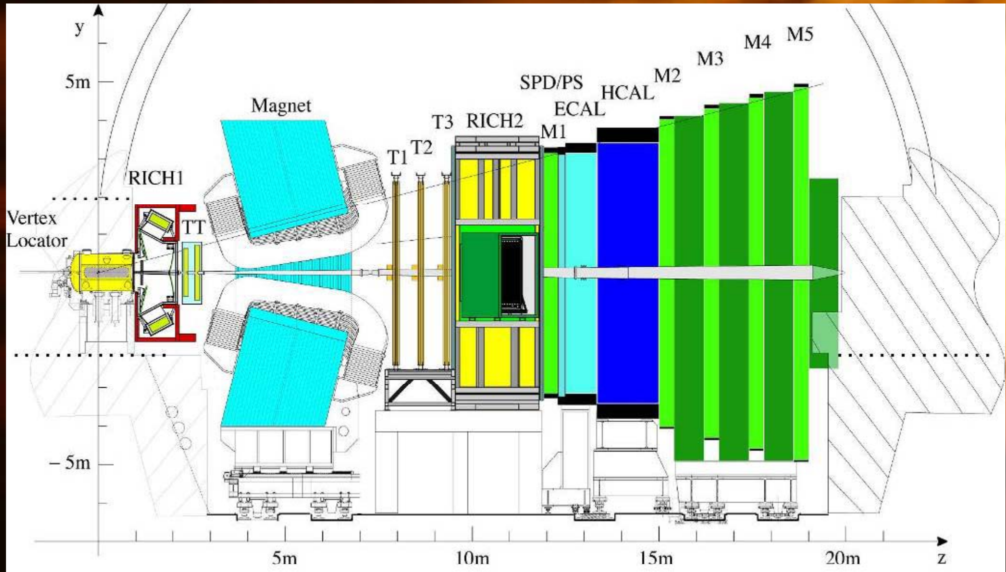


INTRODUCTION

The LHCb GEM detector in M1R1

LHCb apparatus

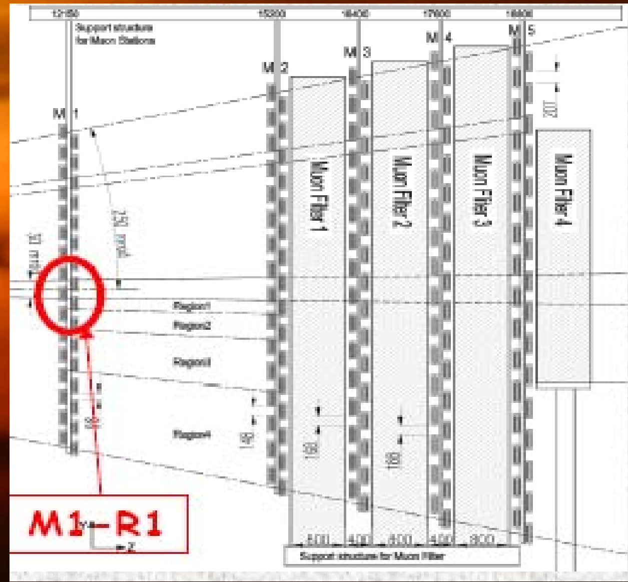
~~CP~~ in B-meson system | $B^0_d \rightarrow J/\Psi + K^0_S$ | $B^0_s \rightarrow \mu^+\mu^-$



$B^0_s \rightarrow J/\Psi + \phi$

Muon system:

L0 high p_T trigger + offline μ -ID



All stations are equipped with small gap MWPCs with the exception of M1R1 sector (area ~ 1 m^2), that is instrumented with triple-GEM detectors.
About 20% of triggered muons will come from M1R1.
M1R1 is placed in front of the calorimeters and very close to the beam pipe, so that low material budget, high rate capability and radiation tolerant detectors are required.

LHCb GEM detectors in M1R1: requirements (1)

Rate Capability	up to ~ 1 MHz/cm^2
Station Efficiency	> 96% in a 20 ns time window **(*)**
Cluster Size	< 1.2 for a 10x25 mm^2 pad size
Radiation Hardness	1.6 C/cm^2 in 10 years **(**)**
Chamber active area	20x24 cm^2

(*) A station is made of two detectors "in OR". This improves **time resolution** and provides some redundancy

(**) Estimated with 50 e$^-$/particle at 184 kHz/cm^2 with a gain of ~ 6000

LHCb GEM detectors in M1R1: requirements (2)

Main tasks & solutions found (R&D):

- improvement of the time resolution:
  - gas mixture: $Ar/CO_2/CF_4$ =45/15/40, 10.5 cm/µs @ 3.5 kV/cm, 5.5 i.p./mm;
  - detector geometry: 3/1/2/1 mm gap size;
    - first transfer gap smaller to reduce bi-GEM effect;
    - Induction gap smaller to increase signal current ($I =- q/ t =- q\ w_d /x$)

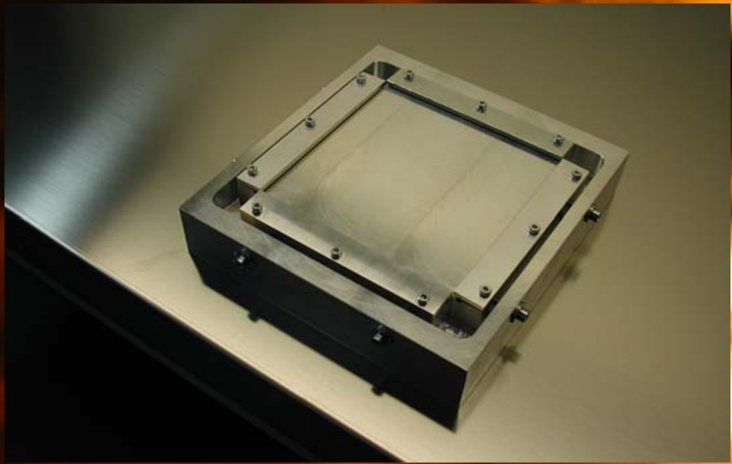
- good gain uniformity and safe operation mode:
  - detector mechanical tolerances (*): δgap($\leq$100 µm) → $\delta E_{gap}(E)$ → δG_{eff} ($\leq$ 6%)
  - choice of the material (**): aging/etching (CF_4) → epoxy glue, gas inserts …
  - GEMs voltage choice(***): $V_{G1} > V_{G2} \geq V_{G3}$ to reduce discharge probability (but also bi-GEM effect)
  - GEM segmentation: 80cm^2/sector to reduce damages in case of discharge

(*) M.Poli Lener, "The Triple-GEM detectors for M1R1 at the LHCb experiment", PHd thesis, http://www.lnf.infn.it

(**) P. de Simone et al., "Studies of etching effects on triple-GEM detectors operated with CF4-based gas mixtures", IEEE Trans. Nucl. Sci. 52 (2005) 2872

(***) Bencivenni et al., "Performance of a triple-GEM detector for high rate charged particle triggering", NIM A 494 (2002) 156

Triple-Gem R&D for LHCb (2000 – 2002)

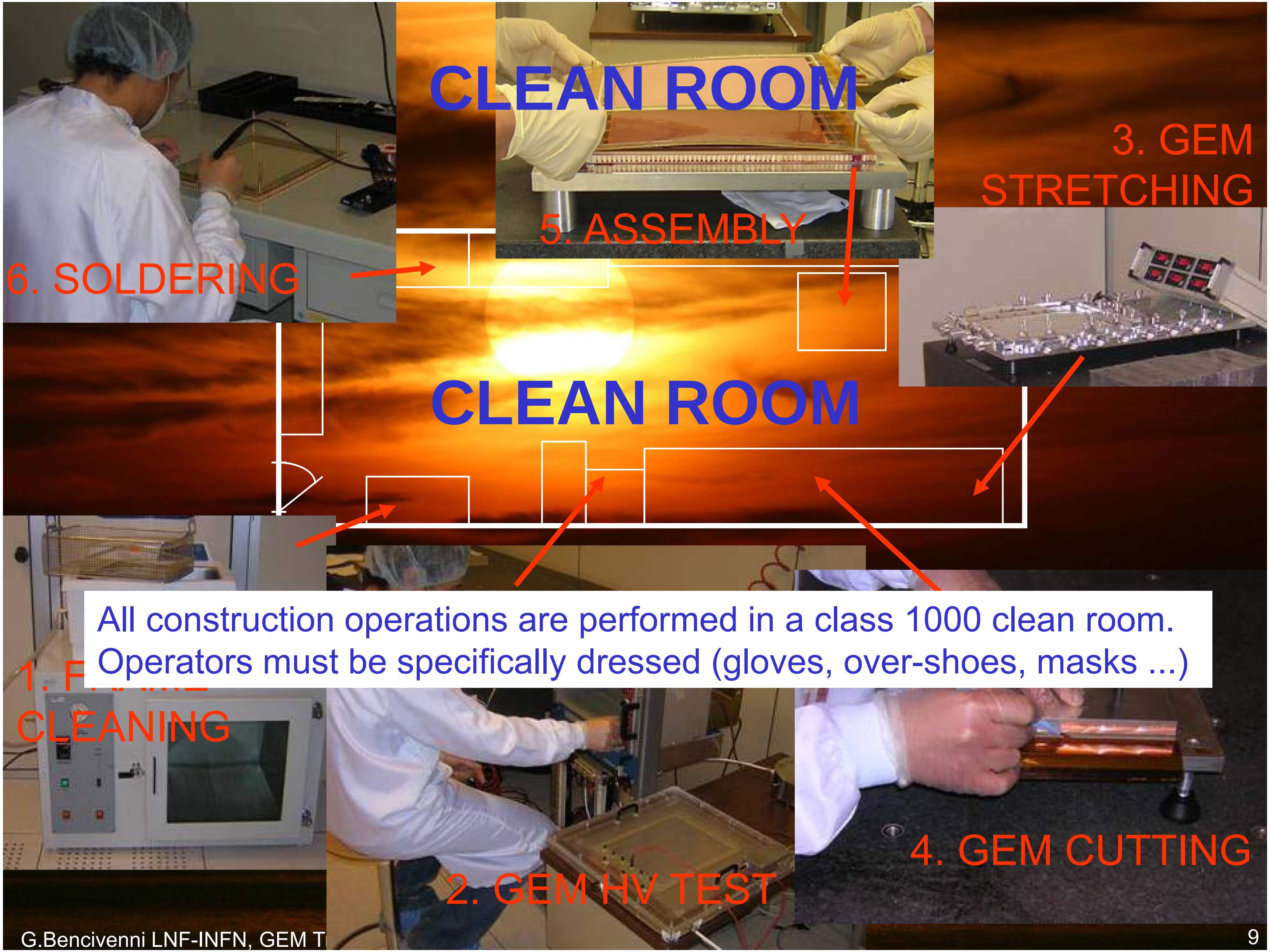


The first GEM stretcher for $10x10cm^2$ GEM foil (2000)

$10x10\ cm^2$ GEM foil stretched and glued on frames.

The triple-GEM prototype is assembled inside a gas tight box.
Prototypes were equipped with FEE based on VTX-KLOE chip.

Construction of GEMs in LHCb



All construction operations are performed in a class 1000 clean room.
Operators must be specifically dressed (gloves, over-shoes, masks ...)

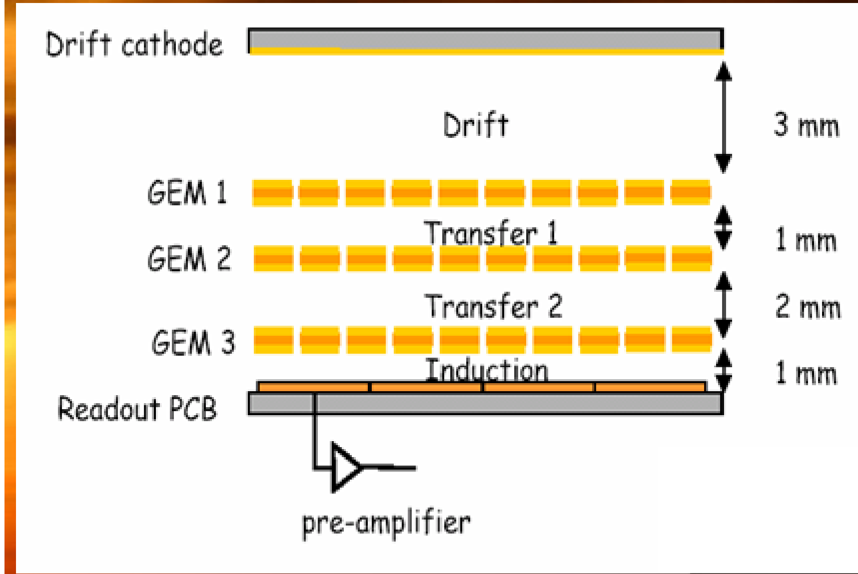
A remind of the chamber structure

The detector is composed by:
- 3 GEM foils glued on FR4 frames, defining the gaps

  and then sandwiched between

- cathode and anode PCBs, glued on honeycomb structure panels.

A M1R1 detector is realized coupling two of such chambers.



The main construction steps are:

- GEM framing
- Chamber assembly
- Coupling of the two chambers

GEM FRAMING: frame preparation

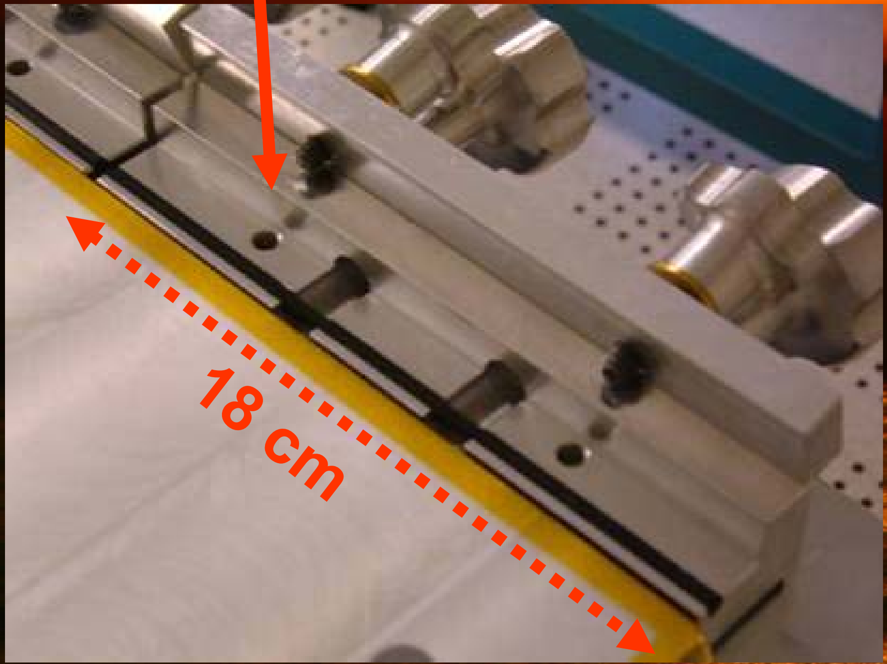
The internal edge of the frame is preliminary sanded (outside the clean room). The frame is cleaned before entering in the clean room, and finally checked for broken fibers.

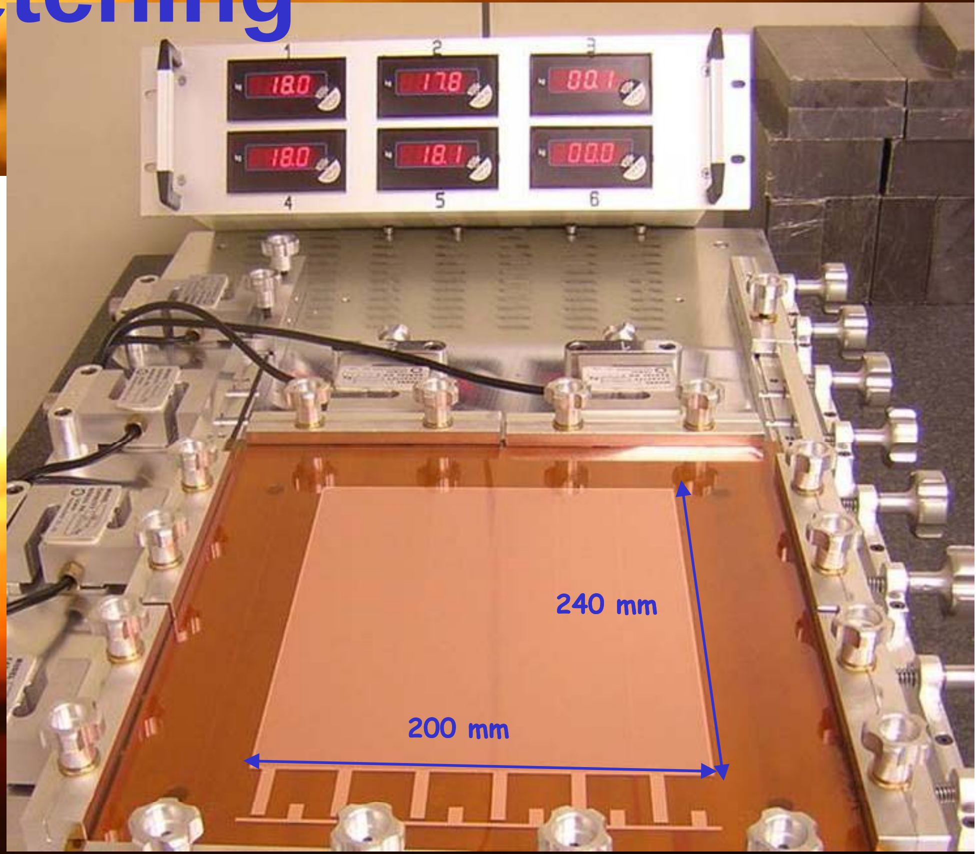
In the clean room further cleaning is performed by means of an ultrasonic bath.
Then frames are dried in a oven at 40°C for about 24 h.

A clean cabinet is used for the storage of frames.

GEM FRAMING: stretching

GEMs that pass the HV test (see quality controls) are stretched with a specific tool. The foil is clamped with jaws equipped with plastic O-rings.





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

Kapton creep is negligible for this mechanical tension (see http://www.dupont.com)

GEM FRAMING: glueing

Before glueing the frame is checked again for broken fibers, cleaned with isopropyl-alchool and dried with nitrogen flow.

Araldite 2012 epoxy resin (good electrical behavior, suitable handling properties & aging/etching tested(*)) is applied with a dispenser and distributed 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 at least 60 kg.
All gluing operations have been performed at a controlled temperature of about 35-40 ºC .
Stretching and glueing require for two operators and last about 15 - 20 minutes to be accomplished.

(*) P. de Simone et al., “Studies of etching effects on triple-GEM detectors operated with CF4-based gas mixtures”, IEEE Trans. Nucl. Sci. 52 (2005) 2872

GEM FRAMING: refining

Exceeding Kapton is cut to size. During this operation the HV connections of the GEM foil are suitable masked.

HV connection to sectors, of the segmented side of the GEM foil, is provided through SMD limiting resistors (1MΩ). These are soldered inside the slots machined in the frame.
During this operation the active area of the GEM is protected.

HV test (see quality controls) is performed again at this stage.

CHAMBER ASSEMBLY (I)

For the chamber assembly we use the epoxy araldite **AY103 + HD991** (good electrical behaviour, convenient handling properties & well-known aging properties (*))

(*) C. Altunbas et al., CERN-EP/2002-008; CERN **PH-TA1-GS,** http://detector-gas-systems.web.cern.ch

One after the other the 3mm, 1mm, 2mm framed GEMs, plus an additional bare 1mm-frame (defining the induction gap), are positioned and glued on the cathode PCB panel.

The assembly operation is performed on a machined ALCOA reference plane, equipped with 4 reference pins.

CHAMBER ASSEMBLY (II)

Finally readout anode pad panel is glued, and over the whole structure a load of 80-100 kg is "uniformly" applied for 24h, as required for epoxy polymerization.

Globally the assembly procedure requires for two operators and last about 2 working hours.

All gluing operations have been performed at a controlled temperature of about 35-40 ºC, to avoid humidity trapping problems.

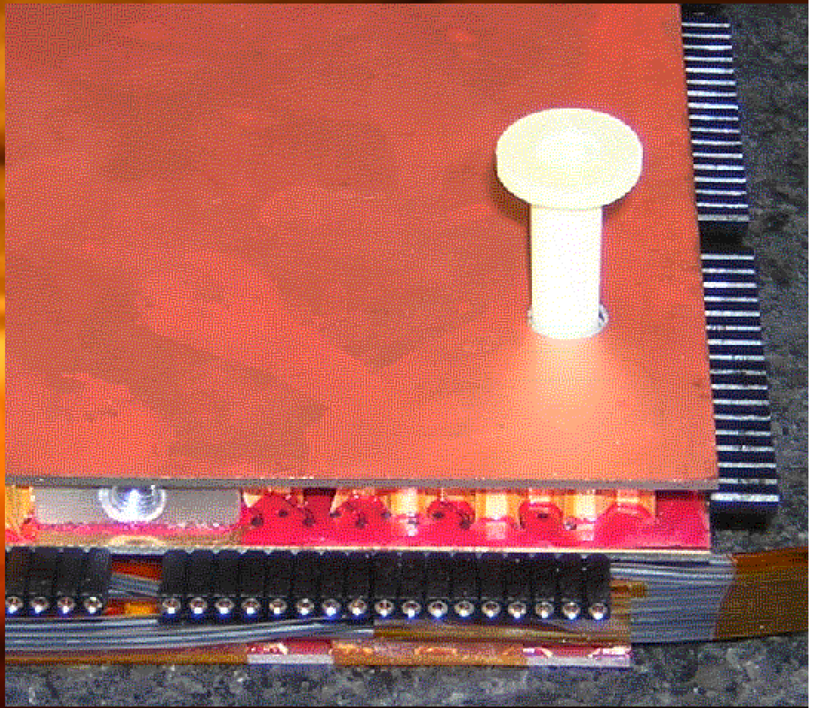
At the end HV connections of GEM foils are soldered on the cathode PCB .

The 7 HV cables will be successively soldered on the internal side of the PCB

CHAMBER SEALING

Inside the four reference holes, used for the positioning of the various components during the assembly, 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.

Small leaks (see quality control) can be fixed with additional glue (AY103 + HD991).



Dow Corning 3-1953 conformal coating (very good dielectric rigidity), is used for the passivation of the HV connections on the cathode. Curing time: 24h

Chamber is then ready for the X-ray test (see quality controls)

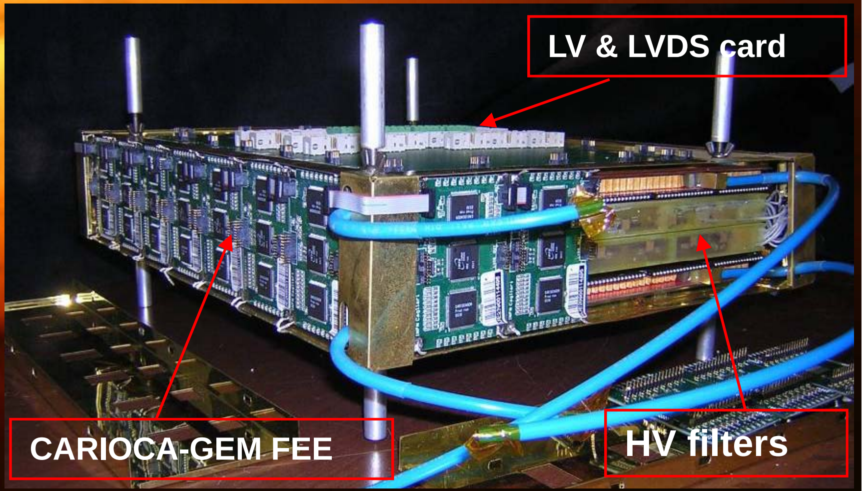
DETECTOR INTEGRATION

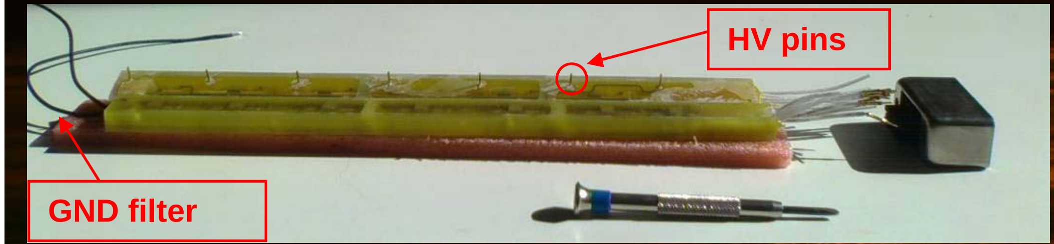
Two chambers, passing the QCs, are coupled with the cathodes faced one to each other

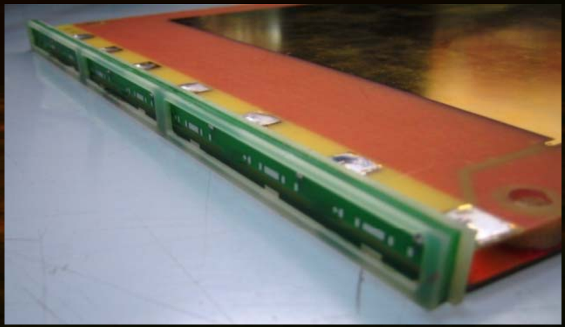
- ❑ Low voltage and LVDS signal distribution board is laid on the detector back-plane

- ❑ CARDIAC-GEM boards are installed along the detector perimeter.

- ❑ On the HV side, HV filters together with a rad-hard Radiall® HV connector are plugged on the corresponding cathode panel through the 7 HV pins, in the space located behind the FEE boards

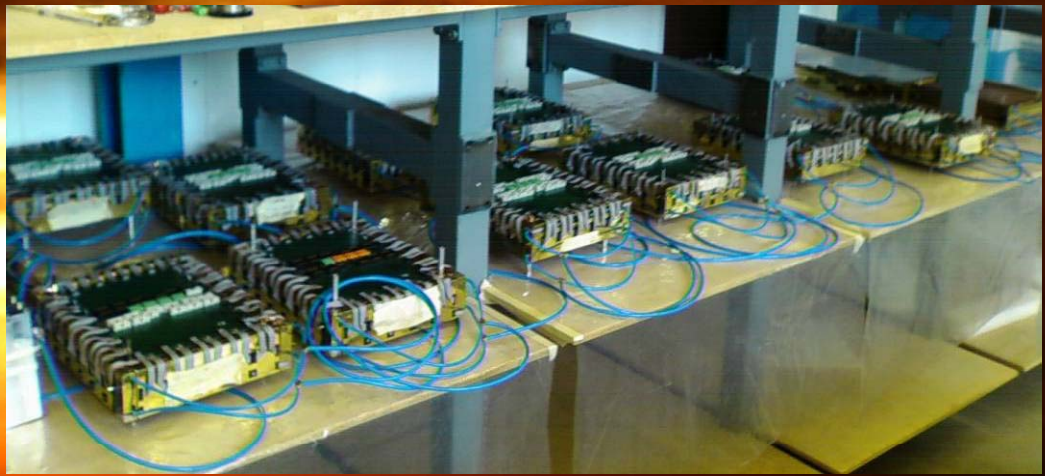


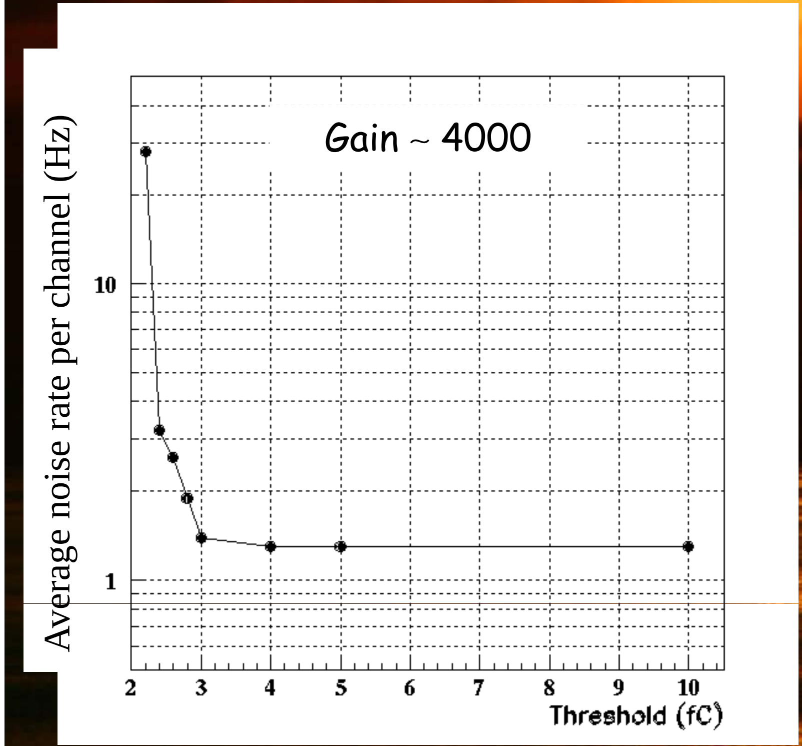




Fully integrated detectors at CERN

All detectors have been moved to CERN in July 2007. In the storage site they are kept under nitrogen flux, waiting for the installation on the apparatus, foreseen in spring 2009





FEE boards installed on the detectors have been selected on the basis of noise rate.

The resulting average noise rate per channel is few Hz, even at threshold as low as 2.5 fC.

Chamber Quality Controls

Checks before the chamber construction:

- ❑ Panels (cathode and pad PCB)
- ❑ GEM foils visual inspection
- ❑ GEM foil HV test

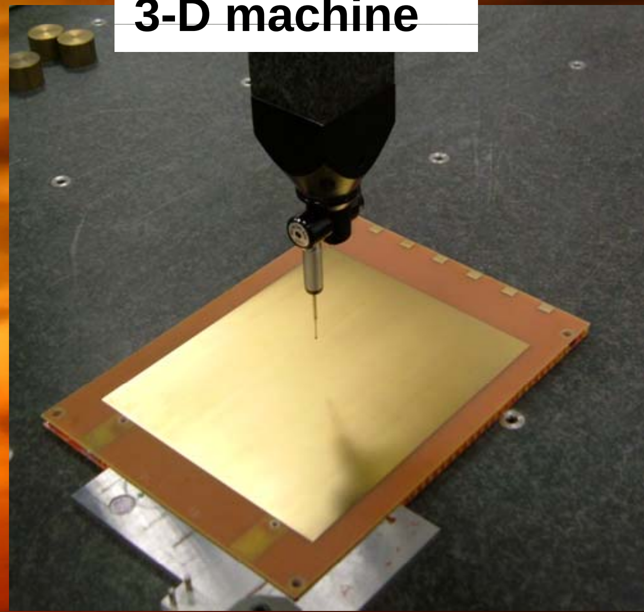
Tests on assembled detector:

- ❑ Gas chamber leakage
- ❑ Gain uniformity with X-ray

Checks on panels

5	10	15	20	25	30	35
4	9	14	19	24	29	34
3	8	13	18	23	28	33
2	7	12	17	22	27	32
1	6	11	16	21	26	31

3-D machine



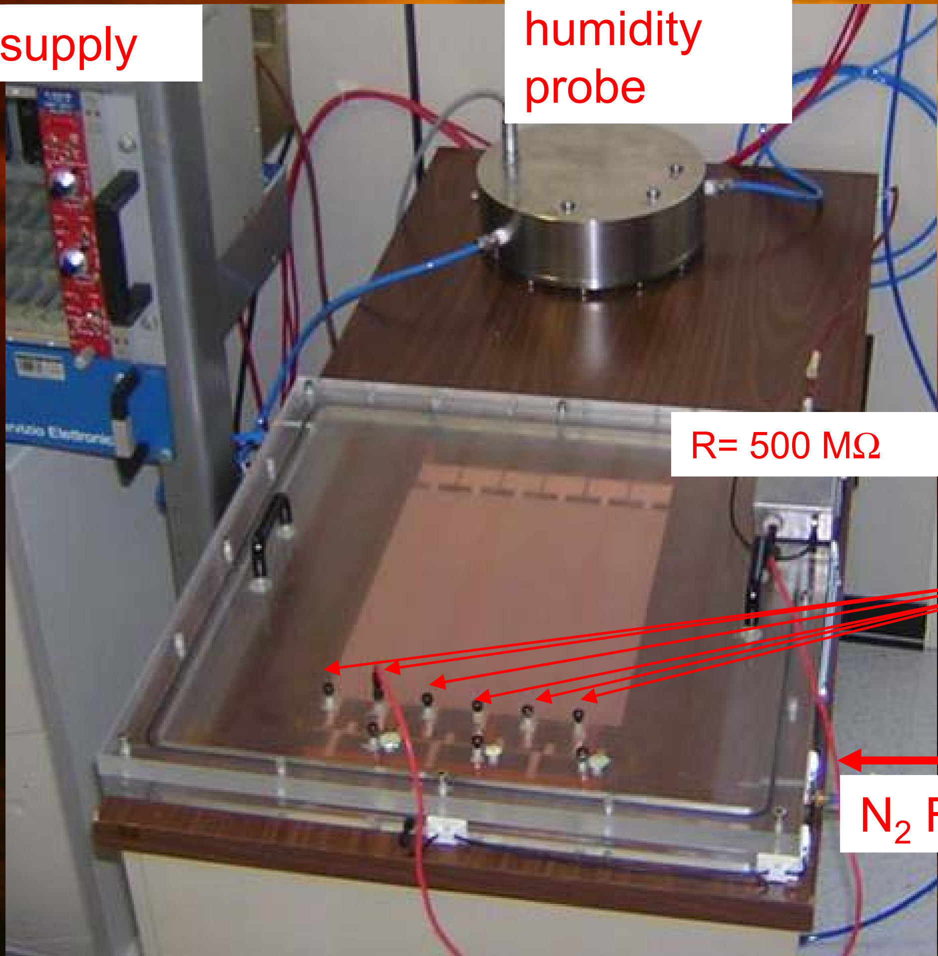
Preliminary measurements have been done on the panel pre-production resulting better than 30 μm

All panels were checked for planarity with a 3-D machine at LNF.
The measure was performed on a grid of 35 points.

The planarity requirement ≤ 50 μm

GEM foil HV test: conditioning (I)

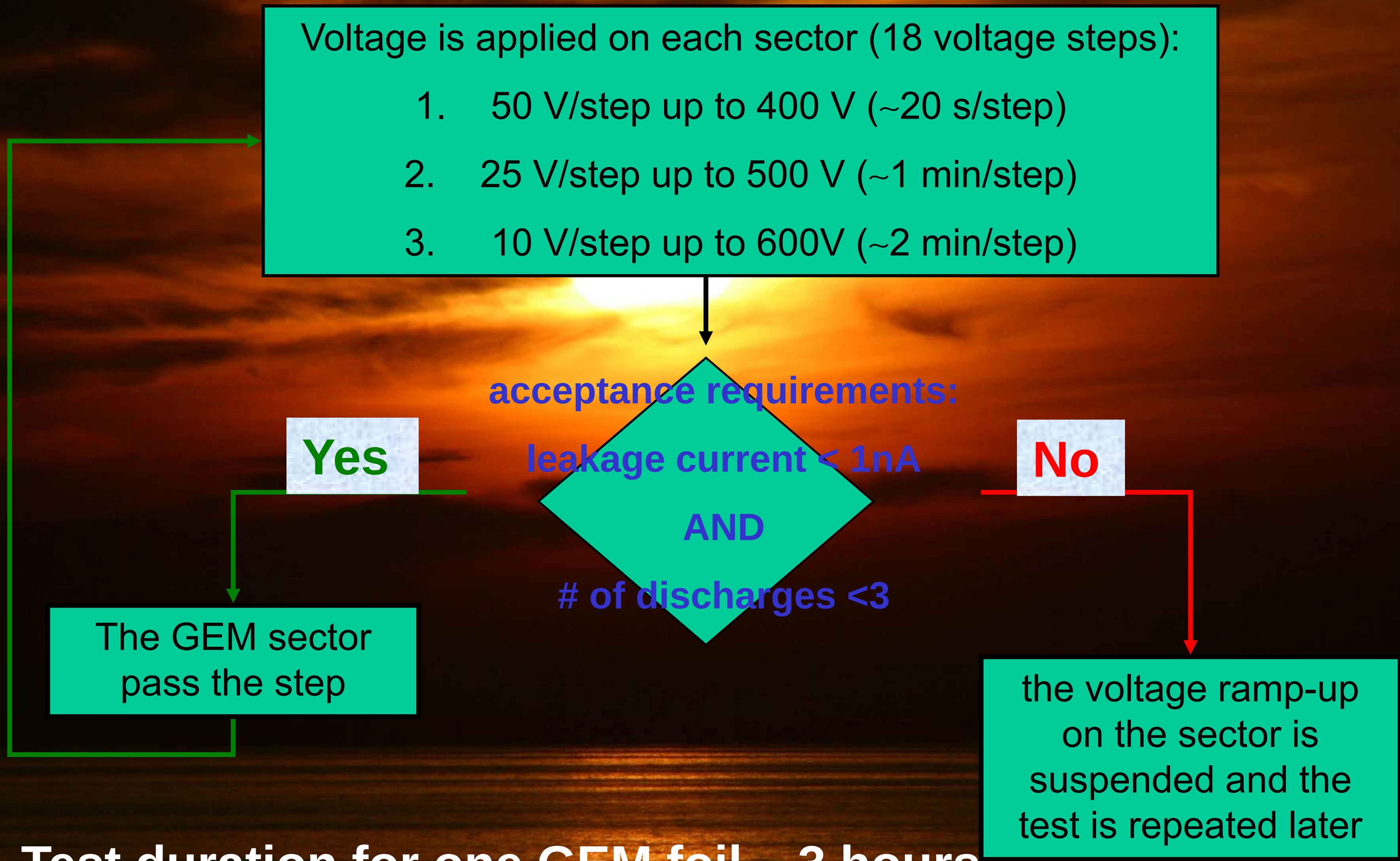
All GEM foils have been tested before the frame gluing in order to check their quality. The test, sector by sector, was performed in a gas tight box.



The gas tight plexiglass box is flushed for about 1 hour with nitrogen in order to reduce the humidity level @ < 5%, before the GEM test

The voltage to each GEM sector is applied through a 500 MΩ limiting resistor in order to avoid GEM damages in case of discharges.

GEM foil HV test: conditioning (II)



Test duration for one GEM foil ~ 3 hours (30' per sector)

GEM foil HV test: conditioning (III)

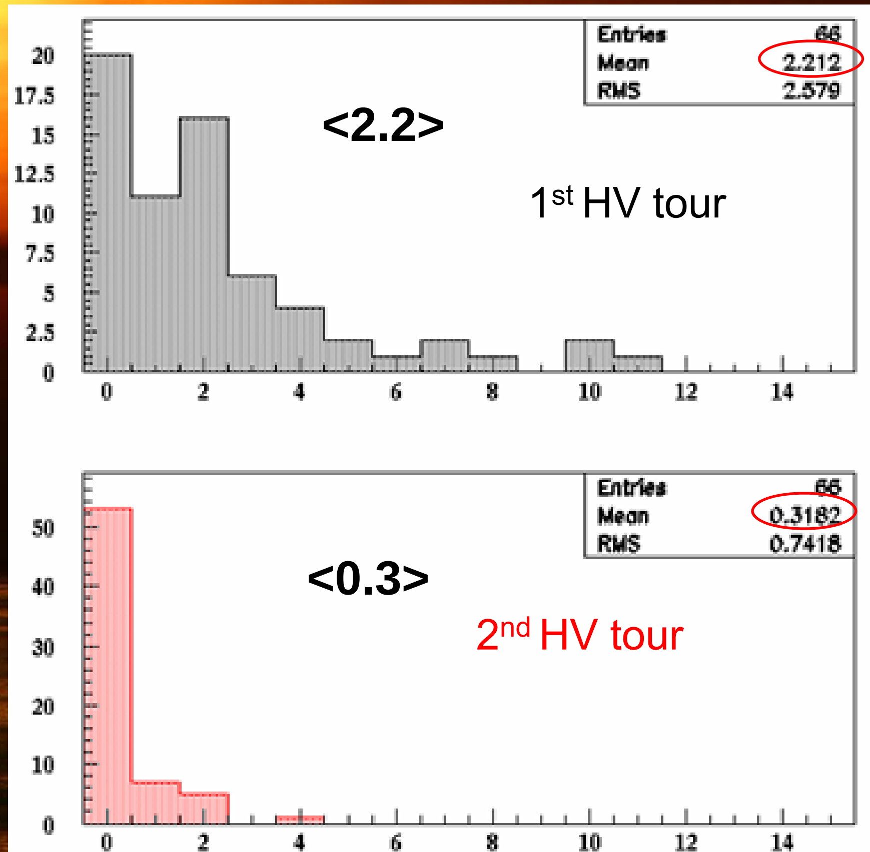
This procedure has been tuned on a pre-production of 11 GEM foils

Histograms are filled with the total number of discharges occurred in each sector during ramp-up (18 HV steps).

The average number of **discharges per sector** on the whole procedure comes out to be **<2.2>.**

If the test is repeated a second time, the total number of discharges goes down to **<0.3>.**

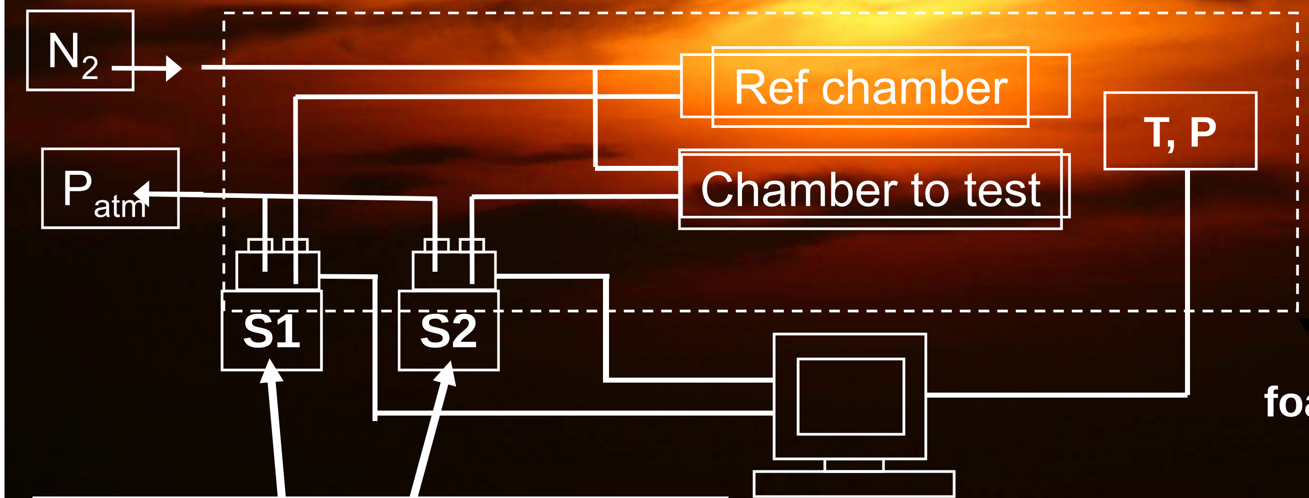
This behaviour could be due to microscopic dust softly burned with high voltage and then removed from the GEM surfaces by N_2 flow.

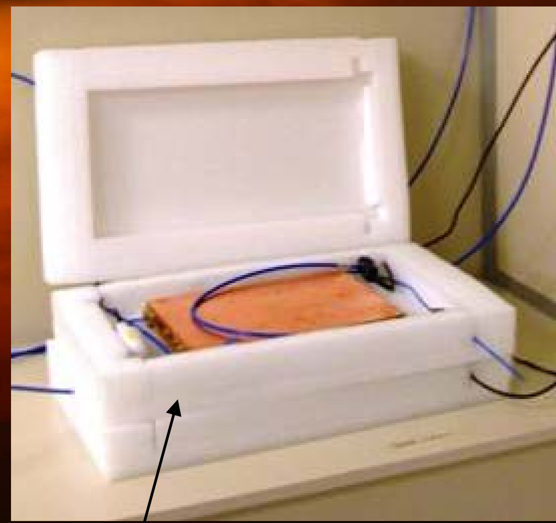


Gas leak test (I): system set-up

The gas leak rate measurement of a chamber is generally referred to that one of a reference chamber (same volume, “no leak” defined as <<1mbar/day) in order to take into account for atmospheric pressure and temperature variations.

Both test and reference chambers are inflated in parallel, up to an overpressure of ~ 5 mbar.





foam box for thermal insulation

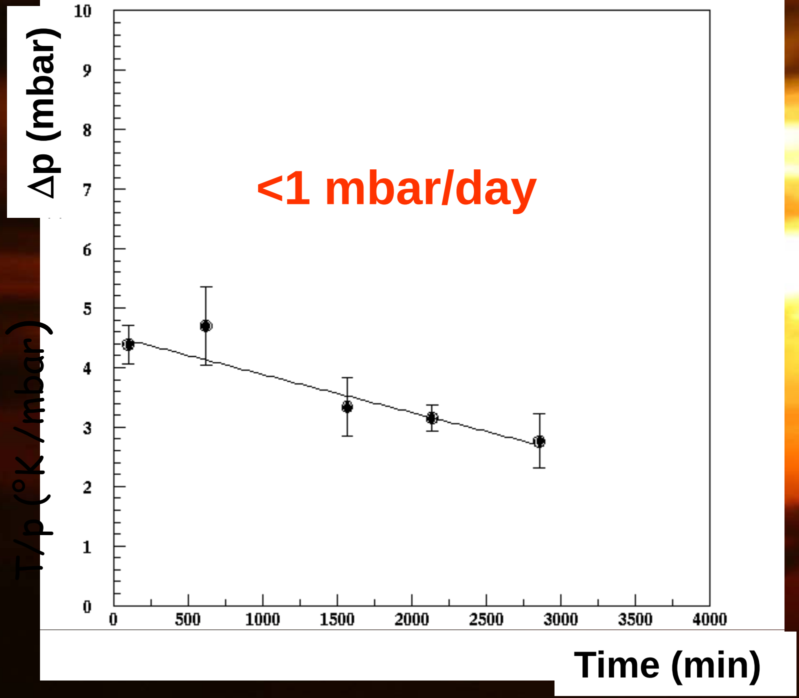
The difference between ΔP(S1) e ΔP(S2) measures the **gas leak rate** of the test chamber

Ambient parameters (T and P) are monitored with additional sensors

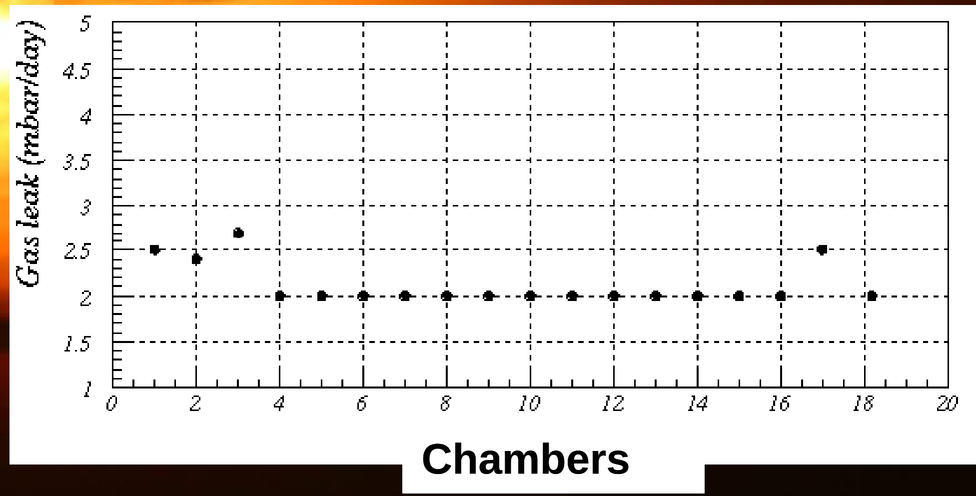
Test duration ~ 2 hours

Gas leak test (II)

"reference chamber"



All chambers exhibit a gas leak of the order of few mbar/day

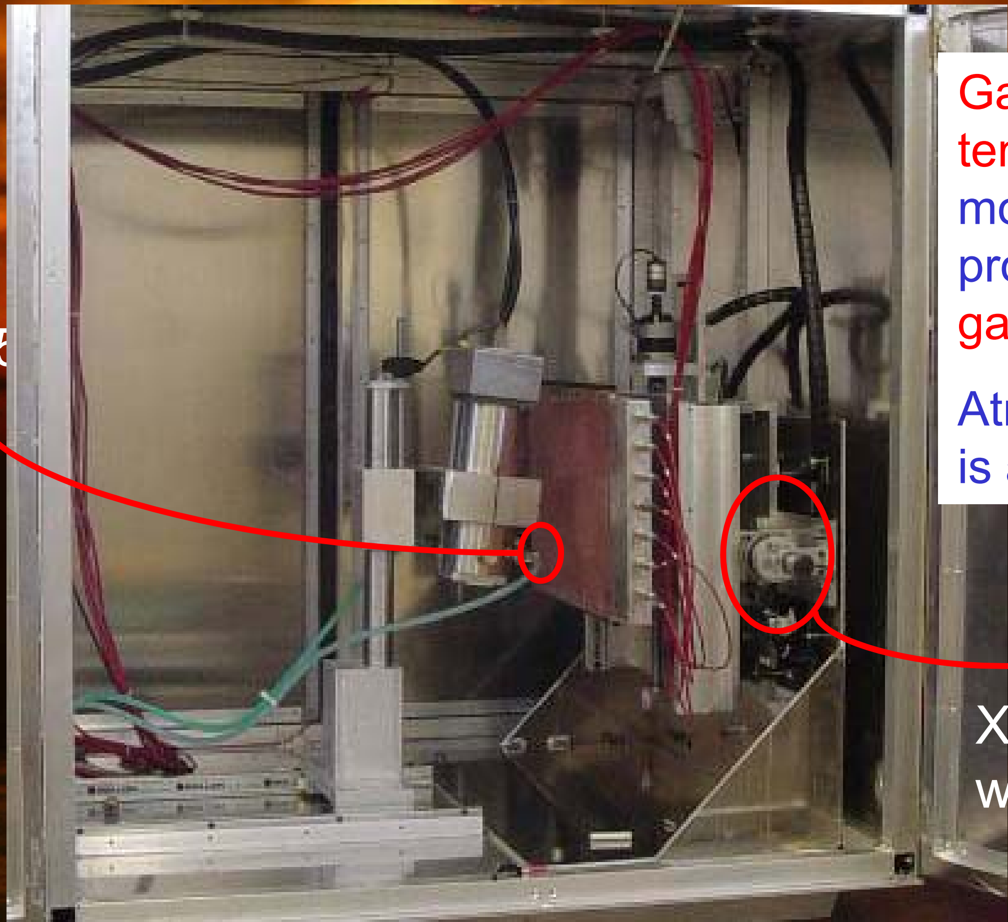


A gas leak rate of ~1 mbar/day corresponds to a residual humidity ~ 50 ppm$_V$ for a 80 cc/min gas flow.

X-ray test(I): system setup

The mapping of the gain, pad by pad, was performed with a high intensity X-ray tube

Collimator with 5 mm diameter



Gas humidity and temperature are monitored with a probe mounted on the gas line outlet.

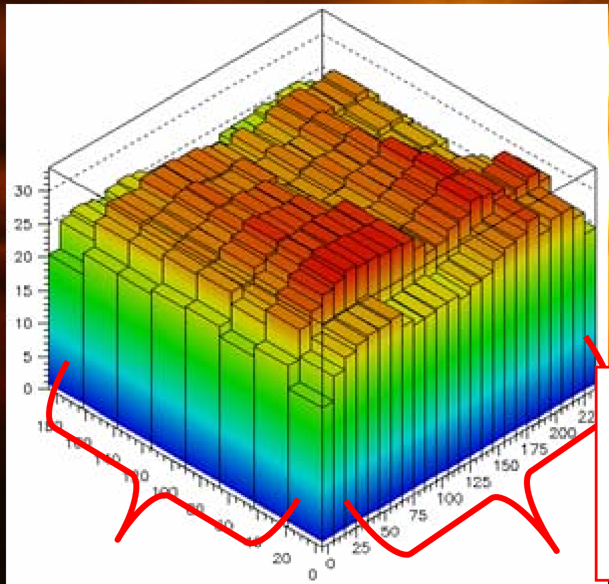
Atmospheric pressure is also recorded.

X-Y plane moved with step-motors

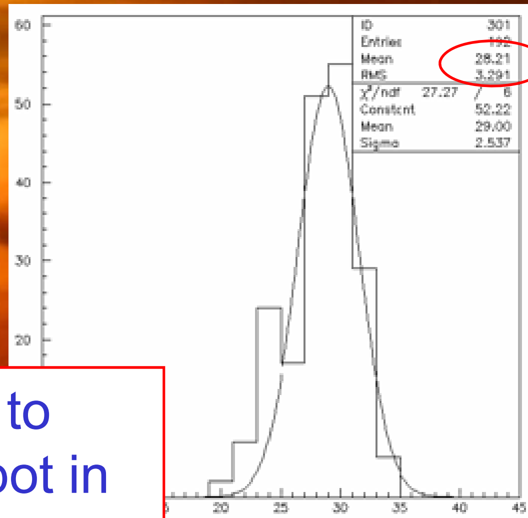
Test duration: 16 hours

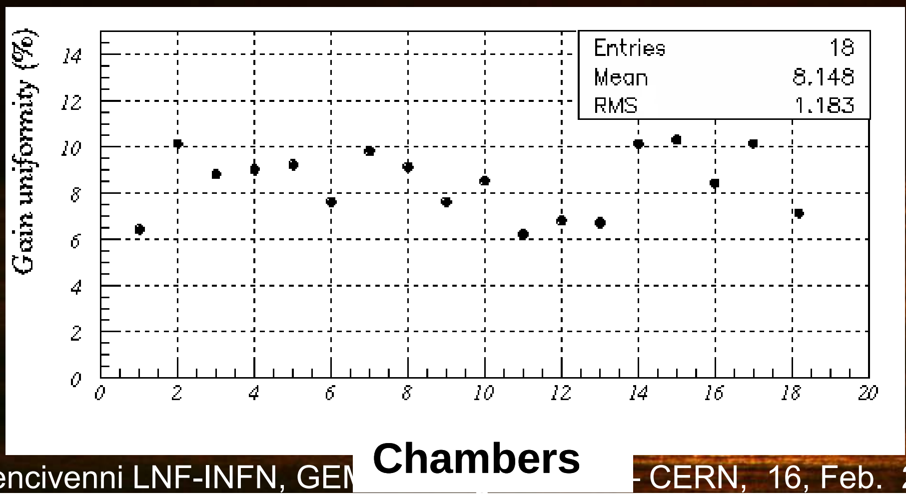
X-ray test(II): measurements

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.



Edge effects due to effective beam spot in the border pads

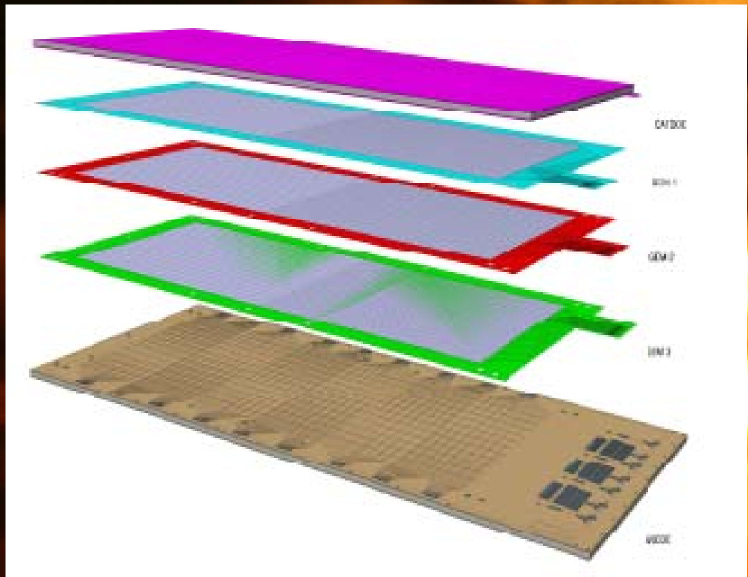




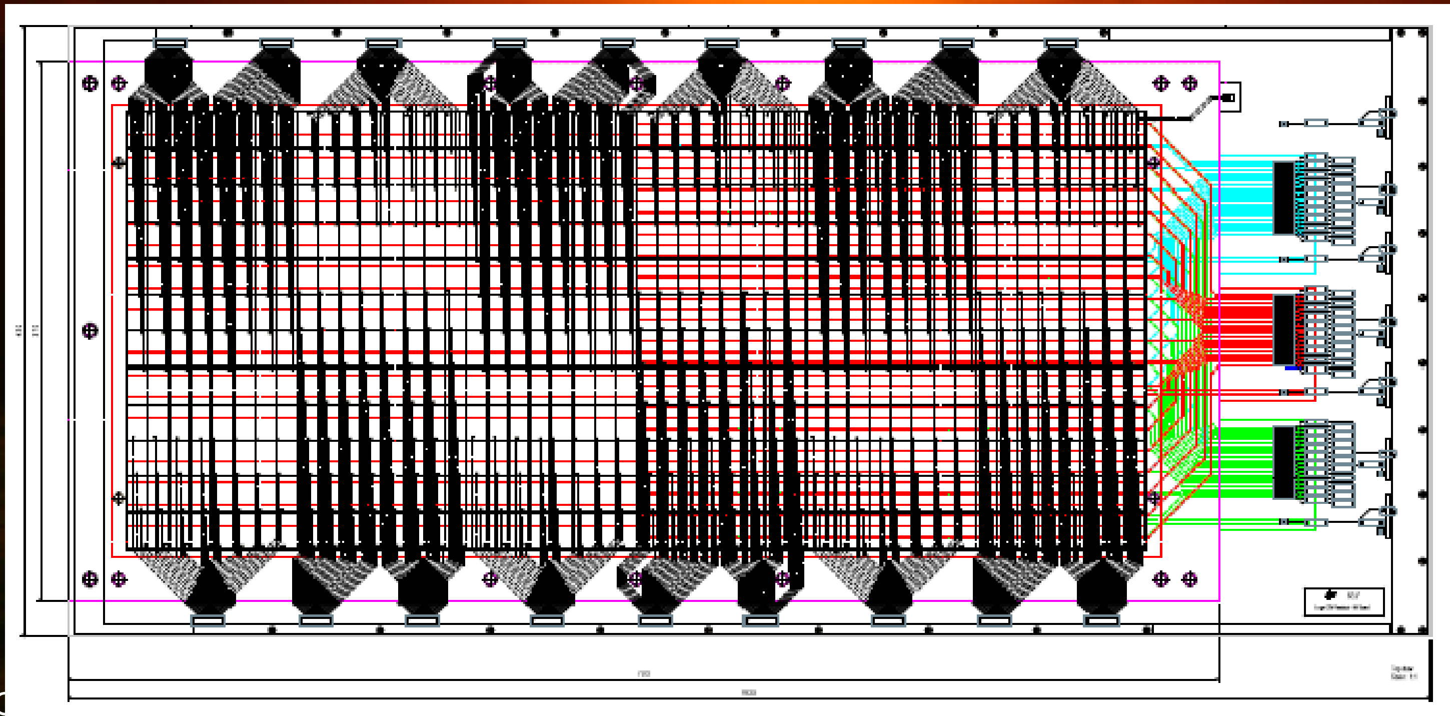
gain uniformity < 10%

(without edge effects ~ 6%)

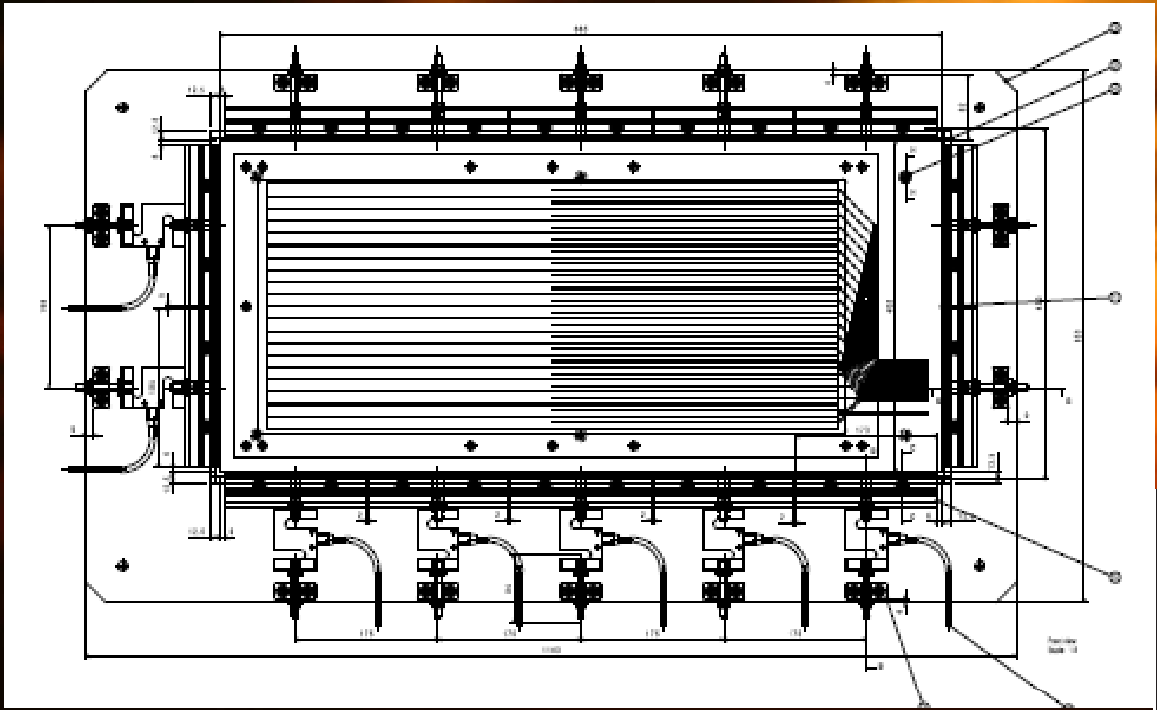
Beyond LHCb: design of a large area GEM



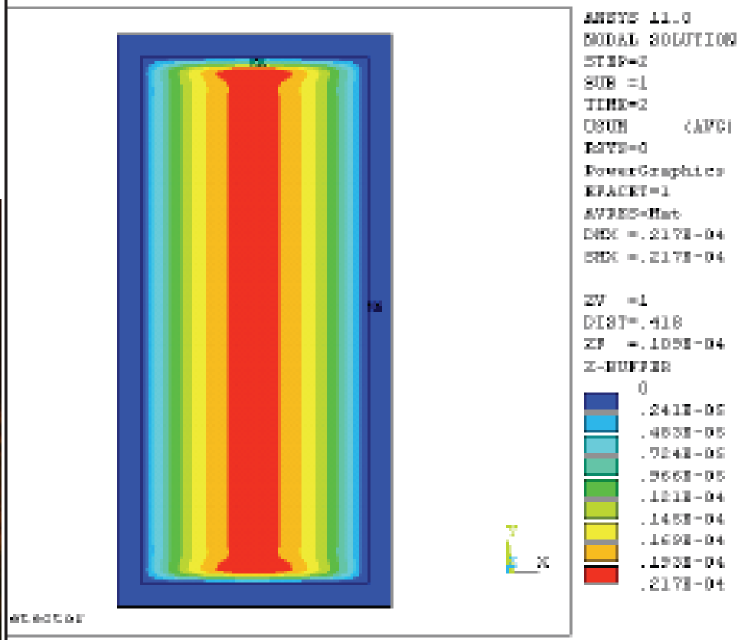
In the framework of the R&D on the Cylindrical-GEM (CGEM) for the KLOE experiment upgrade we are going to build a large area planar GEM (30x70 cm^2 active area), with the aim to test the quality/ homogenity of the large GEM produced with the new single mask technique (by Rui)



Beyond LHCb: the large stretching tool



With the usual 1 kg/cm, finite element simulation indicates a maximum gravitational/electrostatic sag of the order of 20 μm



Stato di deformazione [m]

A very large stretching tool has been designed.
The frame gluing will be performed by using the "*vacuum bag*" technique, tested in the construction of the CGEM

GEM detector assembly training session

Under the supervision of our technician, Marco PISTILLI, who built all the LNF GEM chambers for the LHCb experiment, we will show the main construction phases of a Triple-GEM.
All the operations will be not done in a clean room due to logistics problems.

TUESDAY 17th FEBRUARY

9:00 – 10:30 Frascati/Cagliari GEM 1 stretching and glueing
15:30 – 17:00 Frascati/Cagliari GEM 2 stretching and glueing

WEDNESDAY 18th FEBRUARY

10:30 – 12:00 Frascati/Cagliari GEM 3 stretching and glueing
15:30 – 18:00 Frascati/Cagliari detector final assembly