Construction features of the KLOE Cylindrical-GEM detector

Danilo Domenici

CGEM.Workshop@LNF

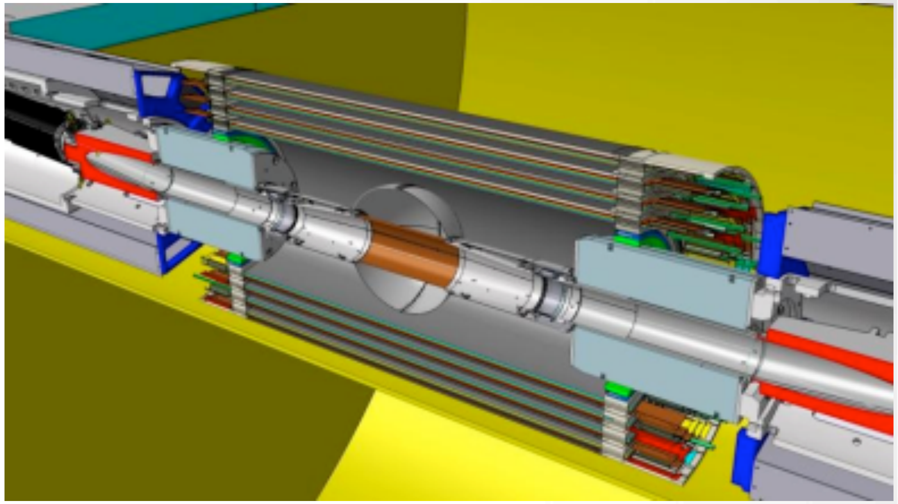
Overview

- Physics requirements and detector choice
- Mechanical parts
- Dimension and Quality control
- Manufacturing a cylindrical GEM
- Manufacturing a cylindrical Cathode
- Manufacturing a cylindrical Readout
- Assembling a cylindrical triple-GEM
- The temperature issue and the choice of grid
- Last minute adjustments: grid and blocking capacitor
- Material budget

A new Inner Tracker in KLOE-2

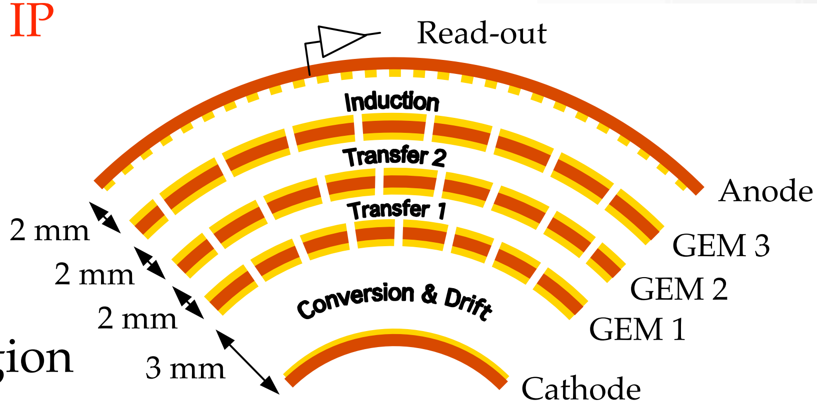
To improve vertex reconstruction of $K_s/\eta/\eta'$ and K_s- K_L interference measurements:

1. $\sigma_{r\phi} \sim 200\ \mu m$ and $\sigma_z \sim 500 \mu m$
2. low material budget: < 2%
3. 5 kHz/cm^2 rate capability



Detector choice: Cylindrical triple-GEM

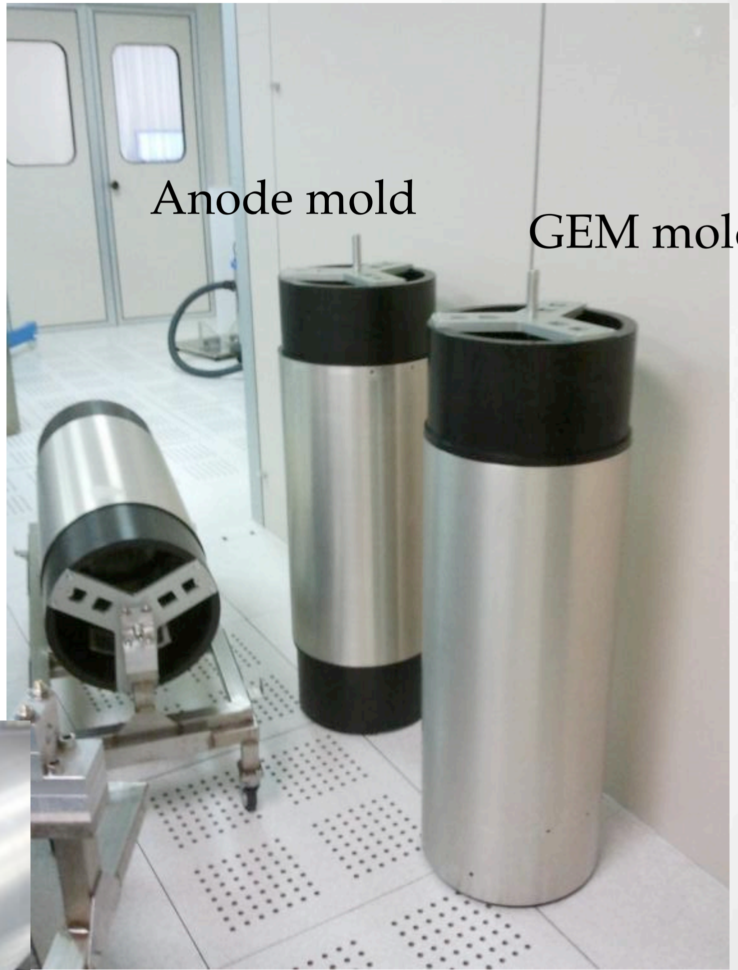
- 4 CGEM layers at 13/15.5/18/20.5 cm from IP inside outer Drift Chamber
- 700 mm active length
- XV strips-pads readout (25°÷30° stereo angle)
- 2% X_0 total radiation length in the active region including Carbon Fiber shield

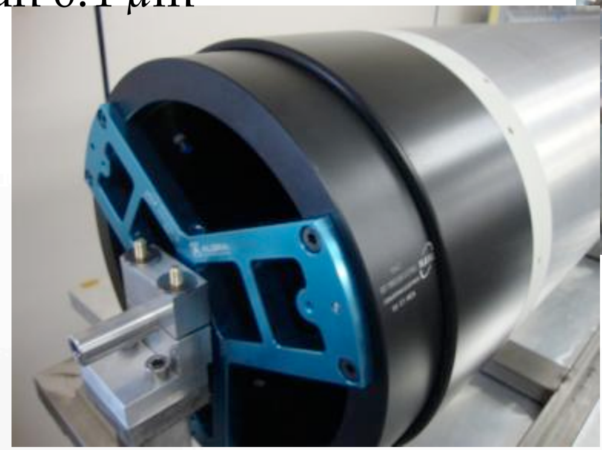


Cylindrical Molds

- To obtain cylindrical electrodes we wrap the foils around molds
- There is one mold for each of the 5 electrodes needed in a triple-GEM (cathode/3 GEM/readout): 20 different molds

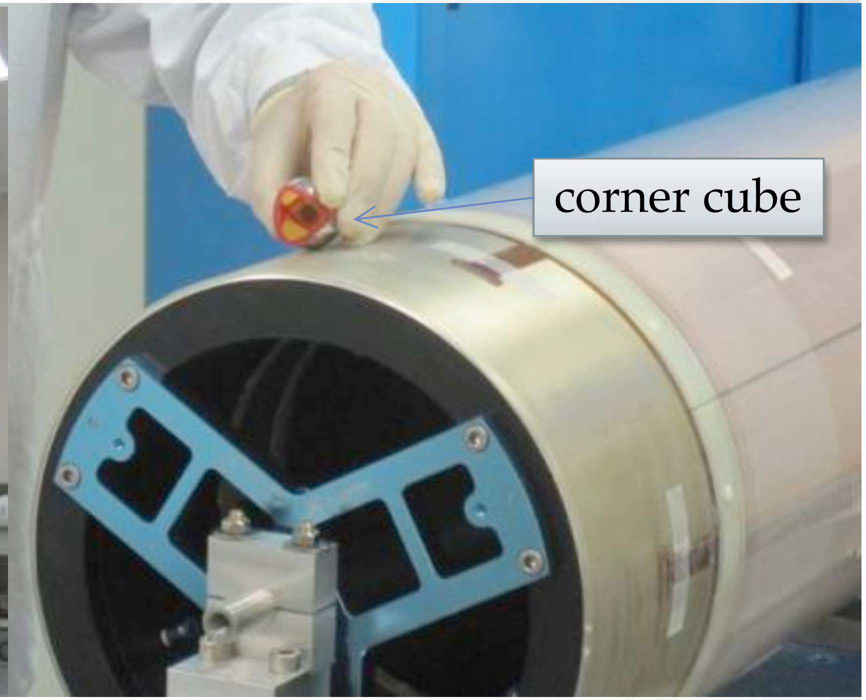
- Molds are realized in Aluminum with precision machined surface
- A Teflon (HST-FEP-HT) cladding 0.5 mm thick provides a low-friction and non-sticking surface.
- Tolerance on the final diameter is 0.02 mm
- Roughness is less than 0.4 μm

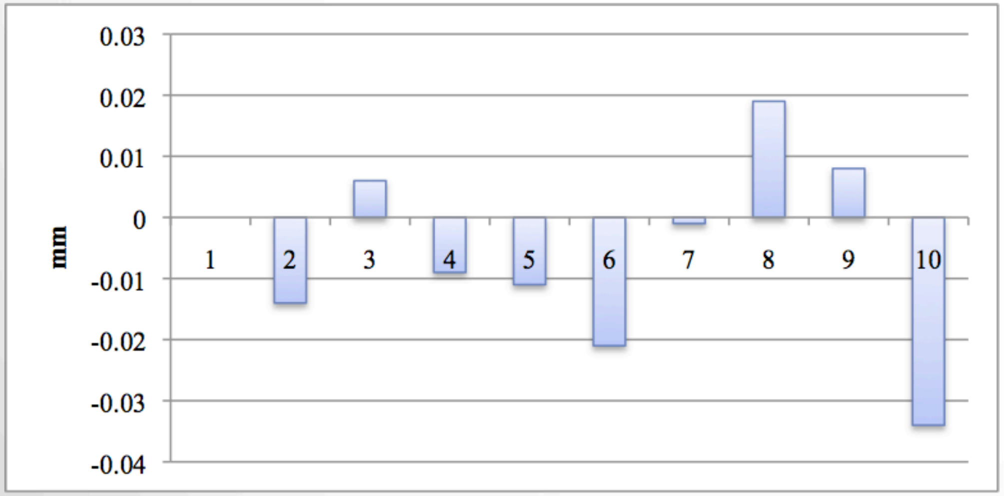




Algra, Bergamo, IT
Cecom, Rome, IT

Cylindrical Molds



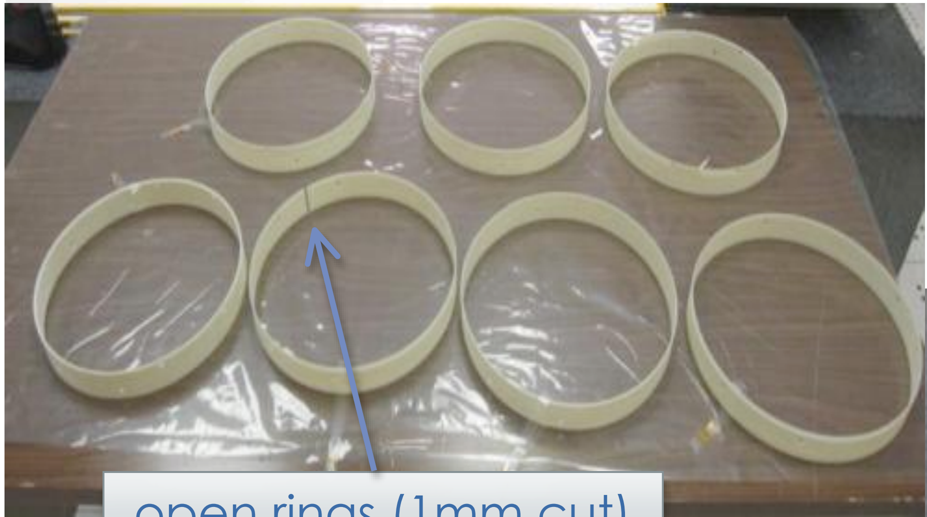


Molds have been 3D checked with a Laser Tracker

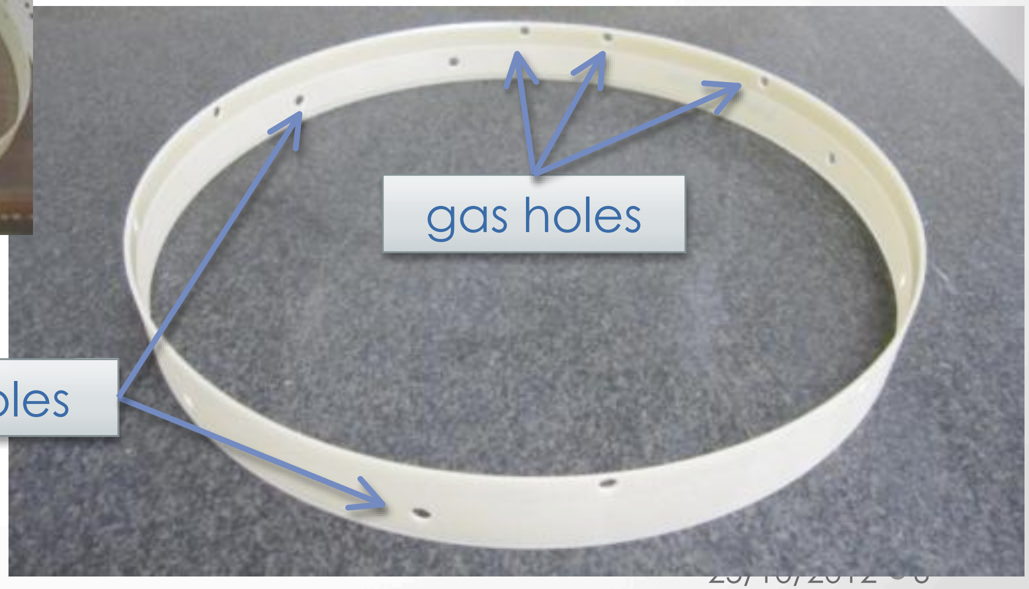
Outer diameter
<Meas – Nom> = -6 ± 15 μm

Fiberglass rings

- At the far ends of the cylinder we place annular rings to provide mechanical support and spacing between the gaps (3/2/2/2)
- They also allow the sealing of the detector and hosts the pinholes for the positioning of the electrodes
- The material is Durostone, a stratified glass epoxy composite (EPGC22)



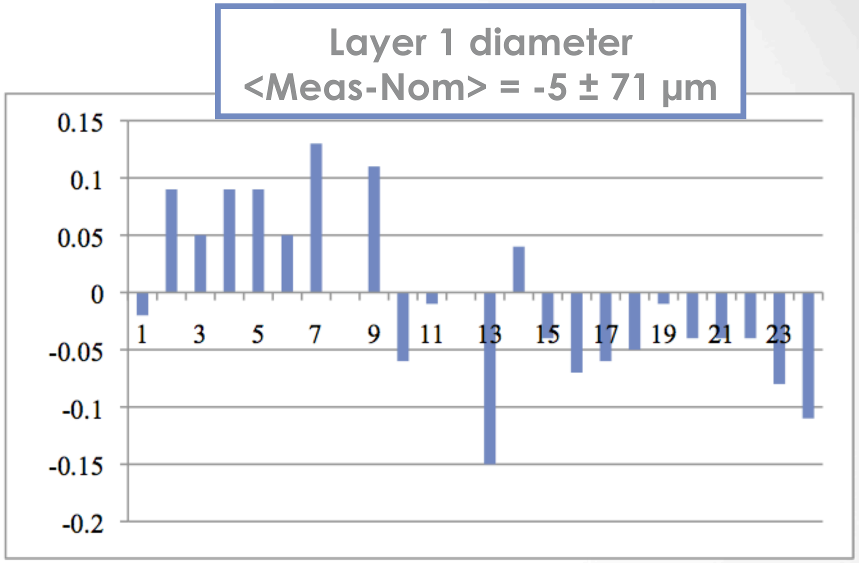
- The preparation procedure foresees: dimensional check, brushing, US cleaning w/DI water, passivation w/Araldite 2011

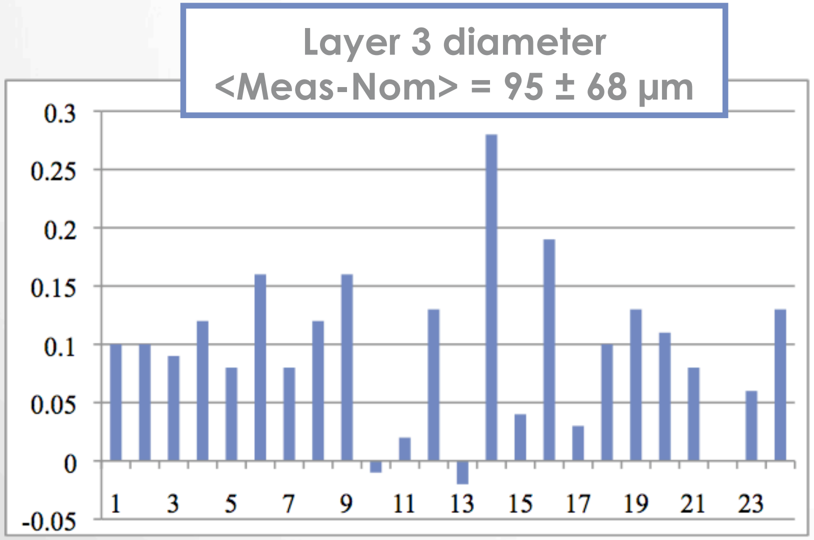


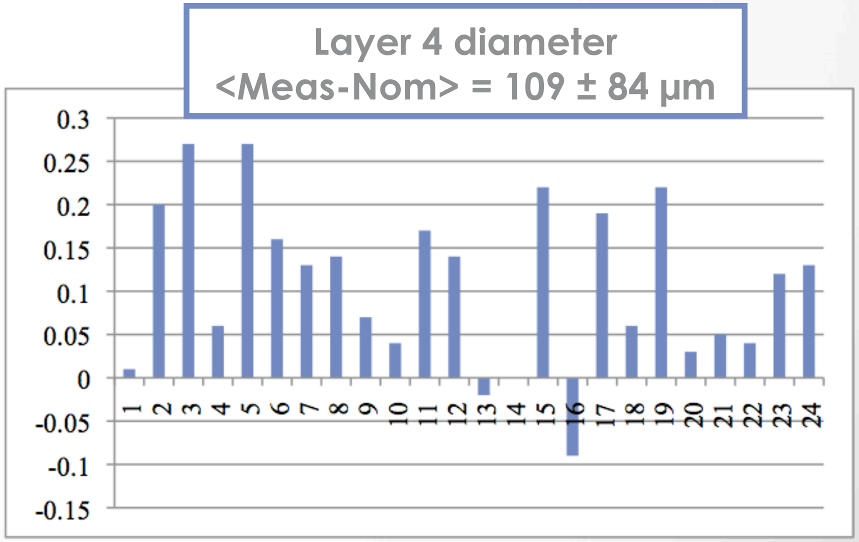
Resarm Engineering Plastics, Barchon, B

Fiberglass Rings

Summary of 3D dimensional measurements

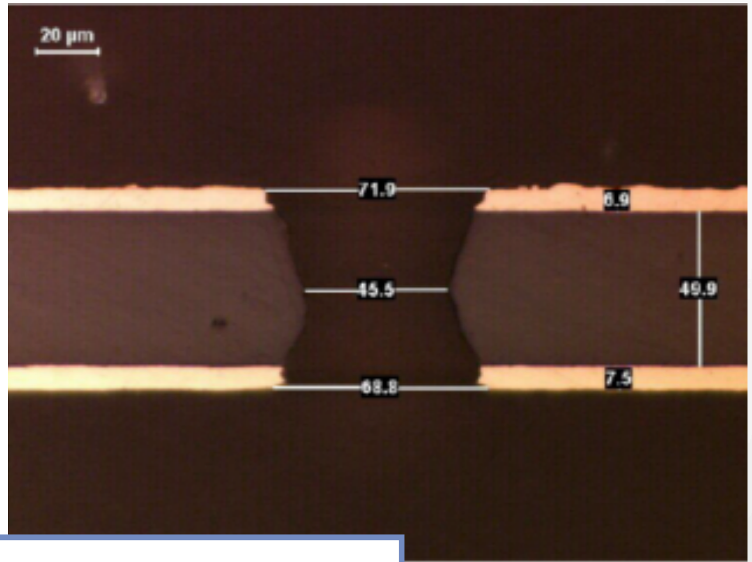






GEM Foils

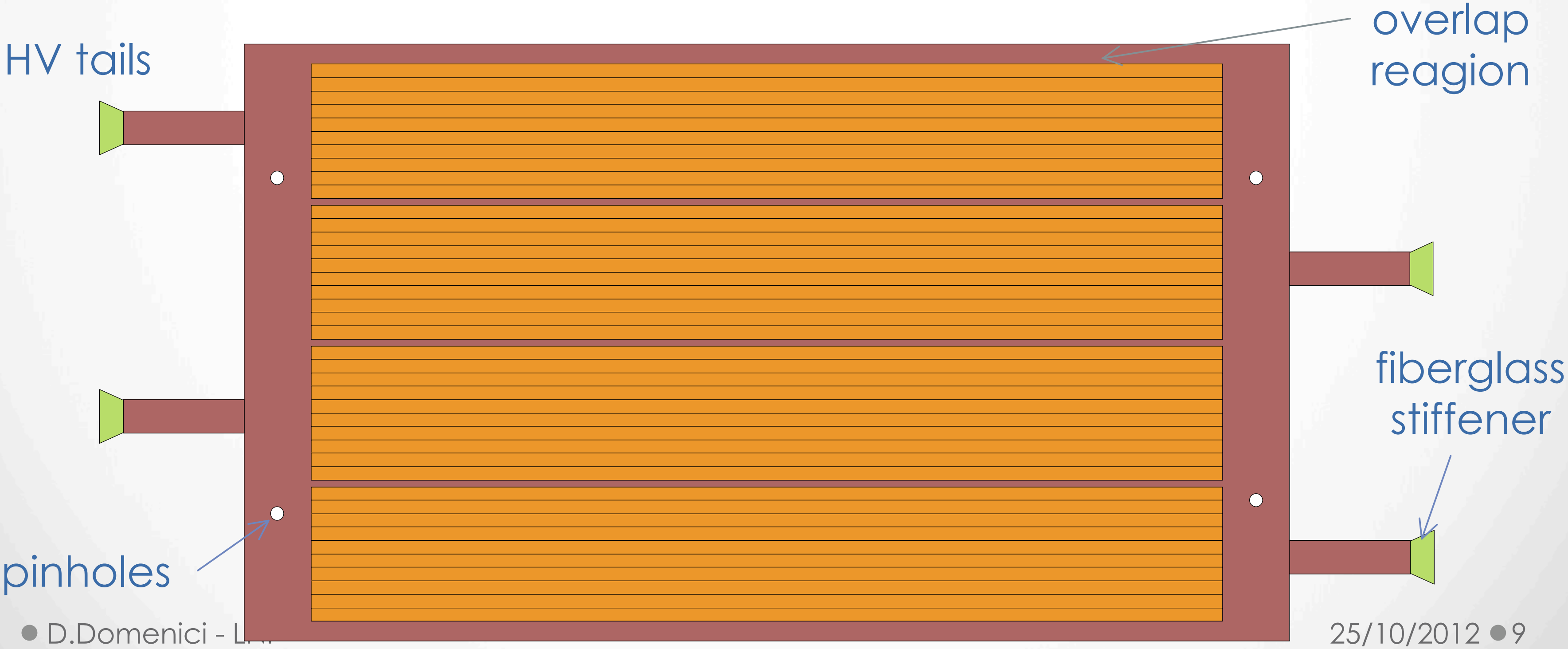
- GEM foils are manufactured at CERN TE-MPE-EM with a single-mask chemical etching technique expressly tuned to produce large-size GEM
- The hole shape is double-conical (70-50-70) with a slight asymmetry
- Length is 780 mm
- Width are in the range 282 – 447 mm



hole cross section

Layout of a GEM

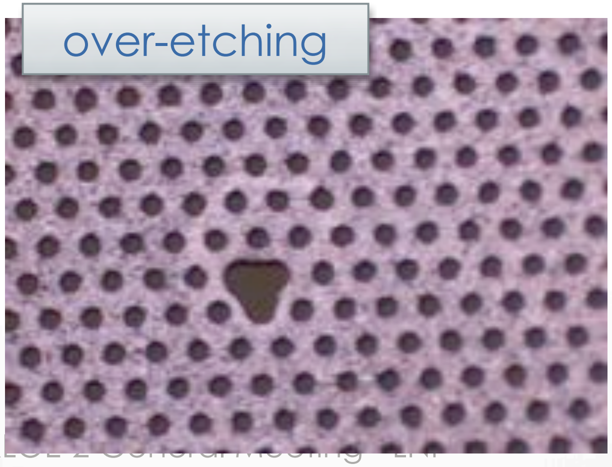
- Bottom side of the active area is divided in 4 Macro-Sectors (MS), each with its own HV connection tail
- Top side of MS is furthermore divided in 10 Sectors, all independentely supplied
- HV tails have 11 connections (1 bottom MS + 10 top S) ending on 0.8 mm fiberglass stiffener
- Sectorization is for minimizing damage in case of discharge
- Sector HV independance is for minimizing loss in case of damage: just a single Sector can be turned off



GEM Quality Control

GEM foils are visually inspected with a microscope to find dangerous defects

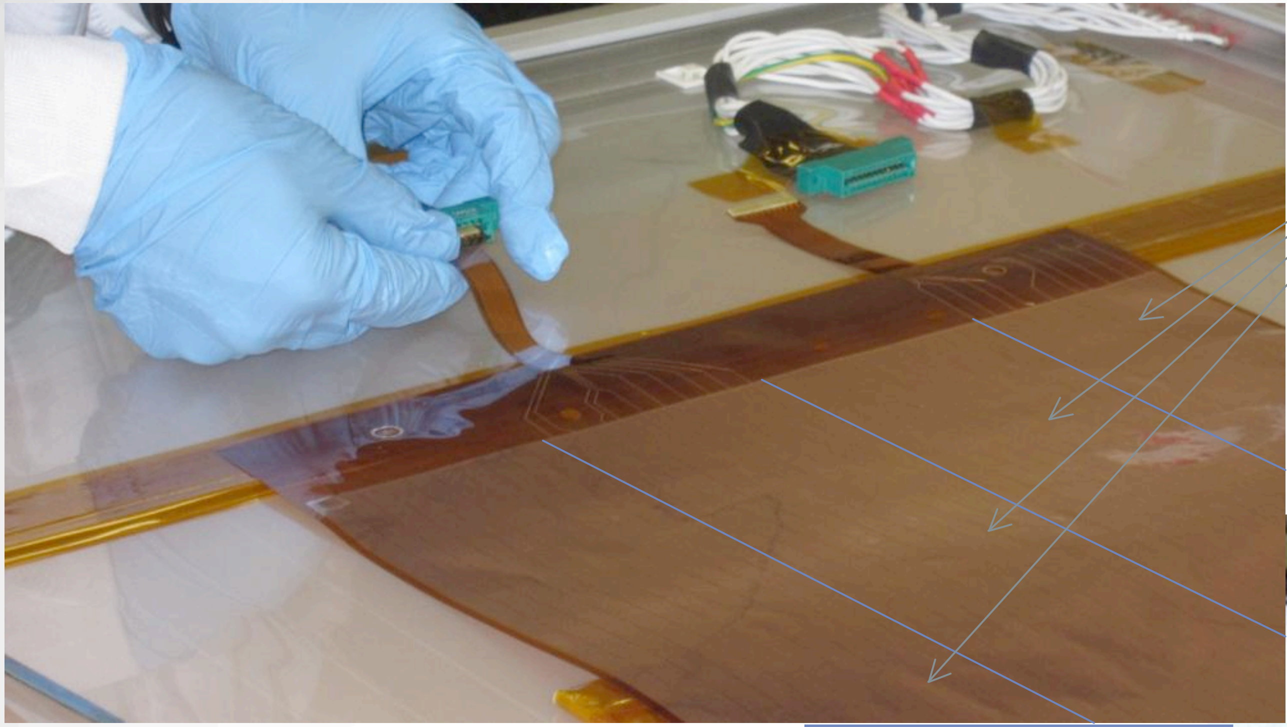
missing holes



over-etching

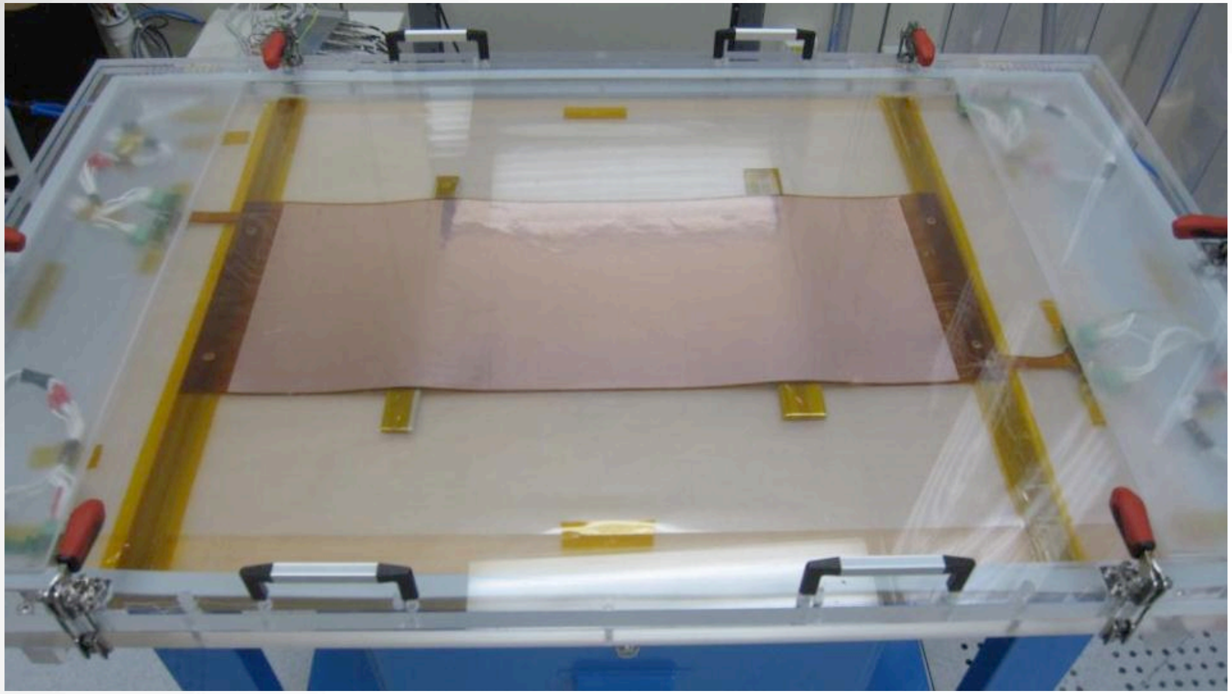
scrathes

GEM HV Test



- HV tails have 10 conductive through-holes to bring lines on the connector side
- Resistance of the conductive glue is checked with Ohmeter (must be < 3Ω)

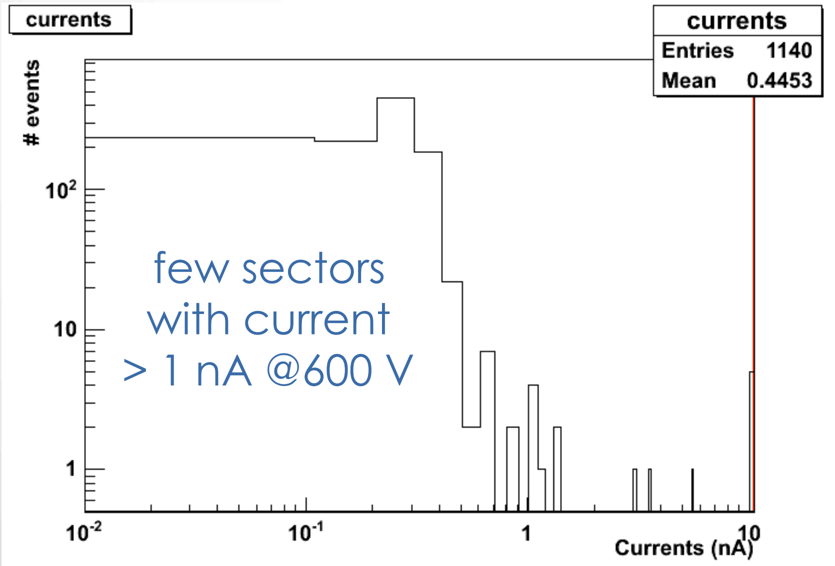
GEM HV Test

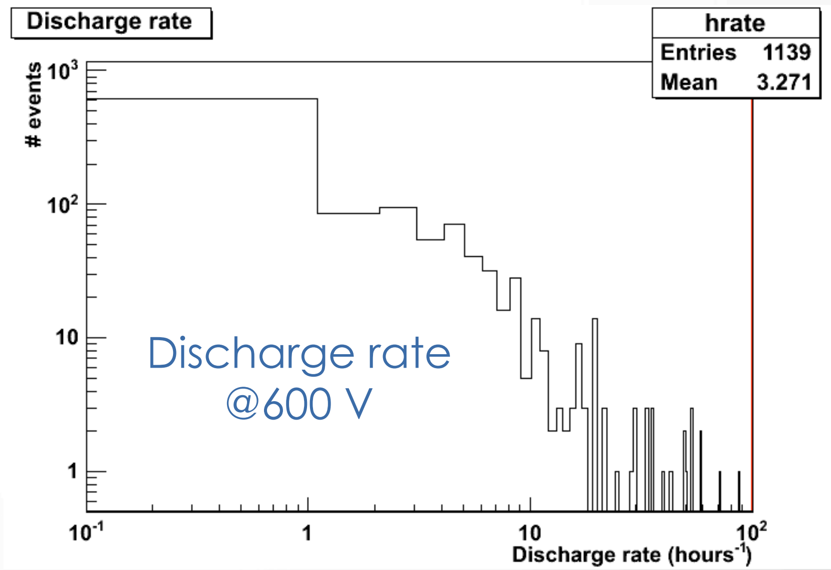


GEM is tested in a N_2 flushed plexiglass box to reduce RH below 10%

Each Sector must draw a current < 1nA @ 600V

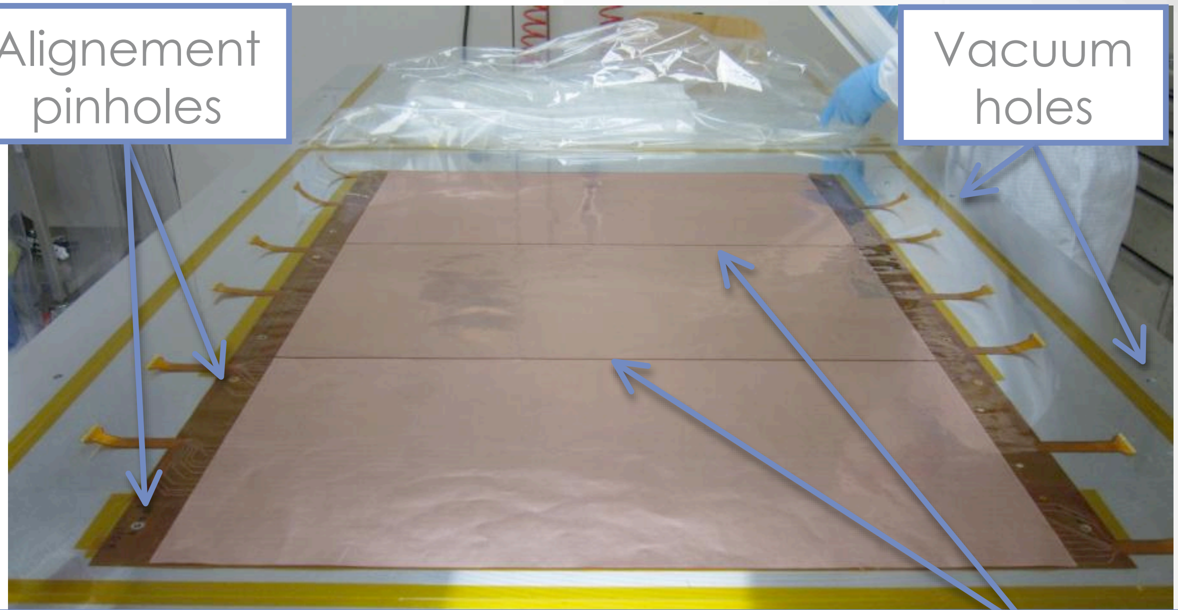
Discharge rate is measured over a period of ~1h





Manufacturing a C-GEM

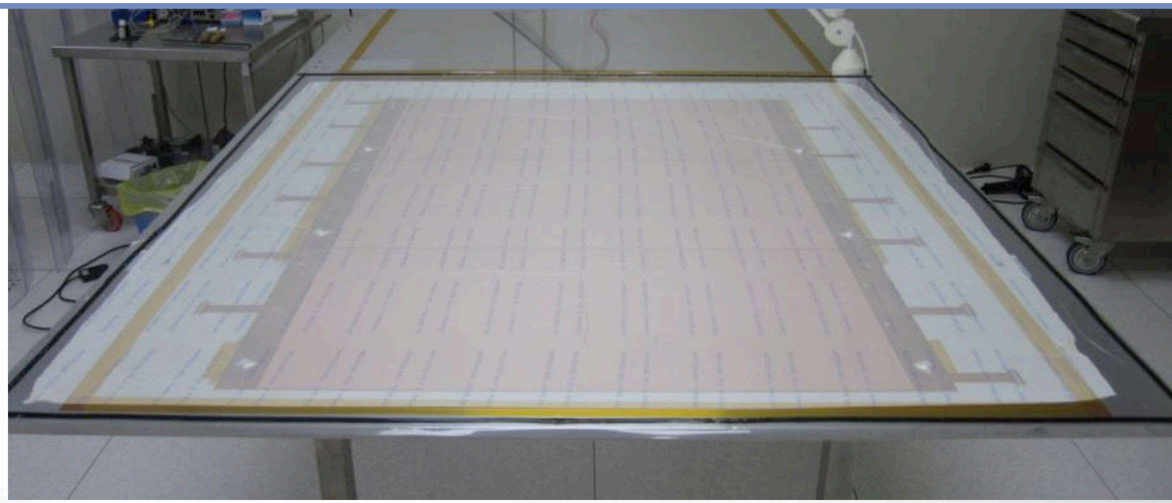
Epoxy glue (Araldite 2011) is distributed by hand on a 2 mm wide line



Alignement pinholes

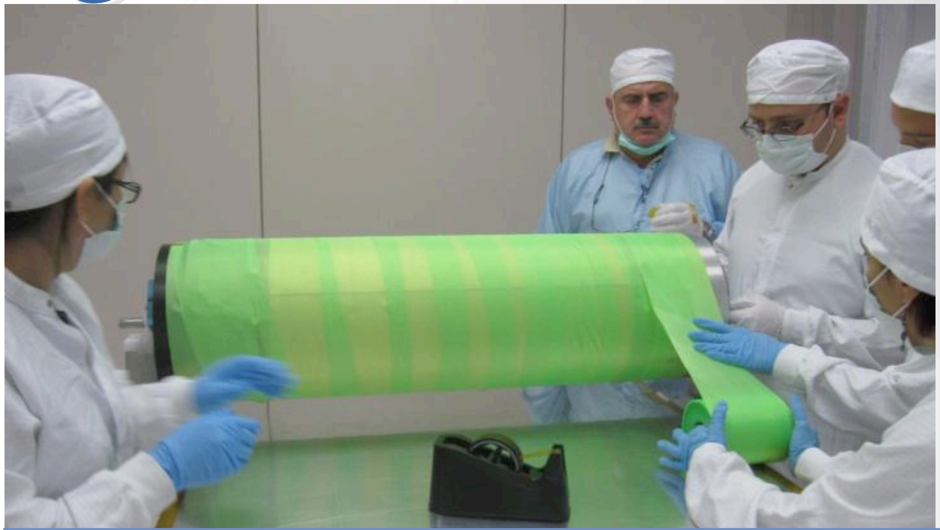
Vacuum holes

3 GEM foils are spliced together with a 3 mm overlap and closed in a vacuum bag (0.9 bar)



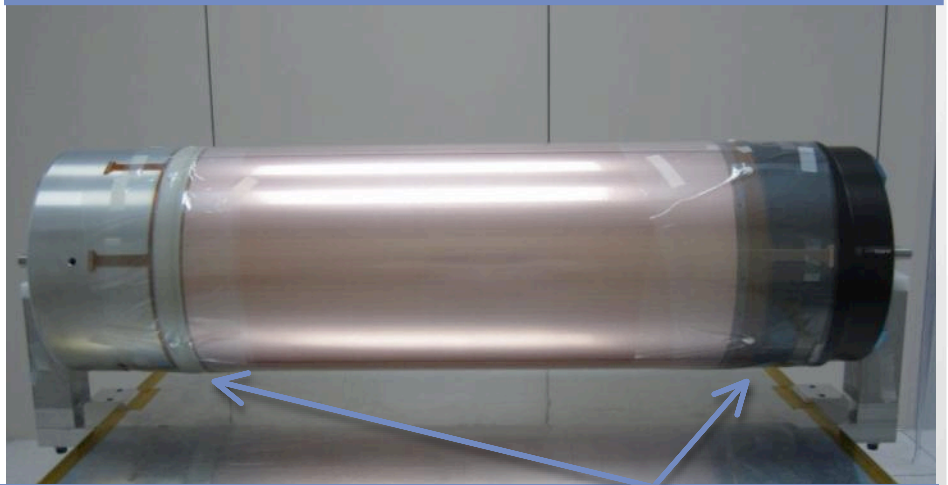
Manufacturing a C-GEM

GEM is protected with a Mylar sheet and wrapped on the cylindrical mold



Transpirant tissue (PeelPly from RiBa) is placed around to distribute vacuum

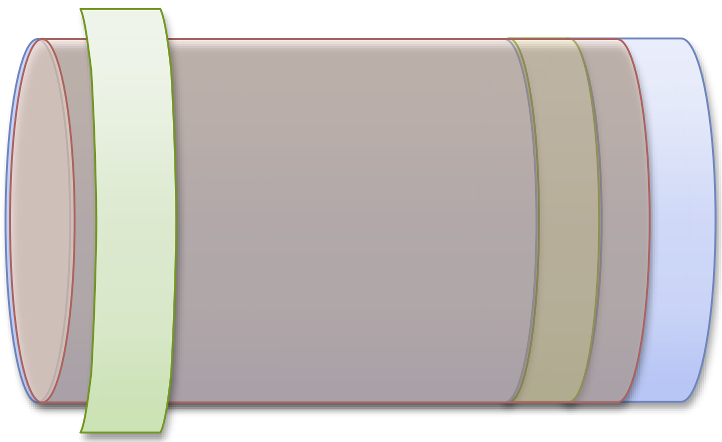
Vacuum bag envelope



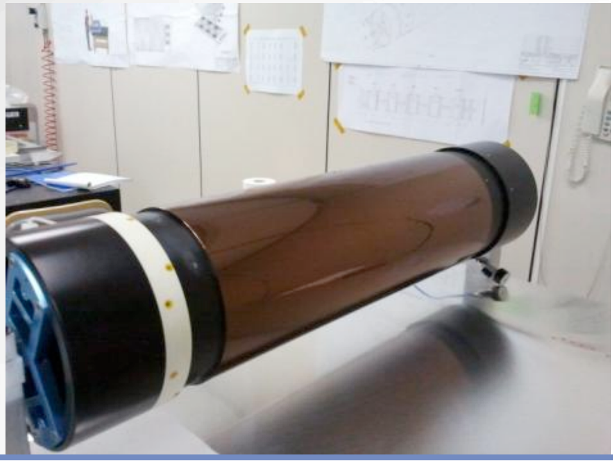
Final cylindrical GEM with internal and external rings

Position of the Rings

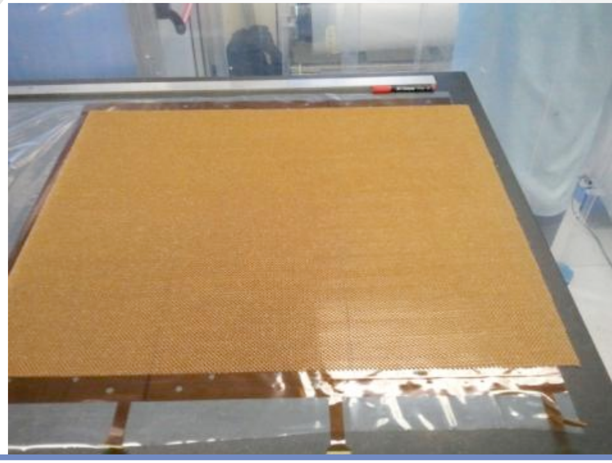
- Place the fiberglass internal ring with glue on the mold
- Close the mold with an Al ring
- Wrap the GEM on the mold and on the internal ring
- Place the open external ring



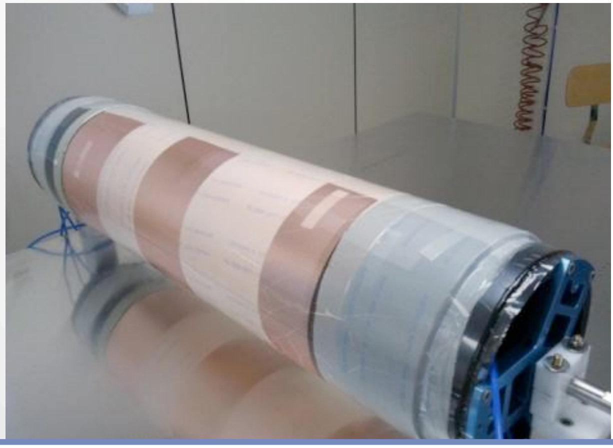
Manufacturing a Cathode



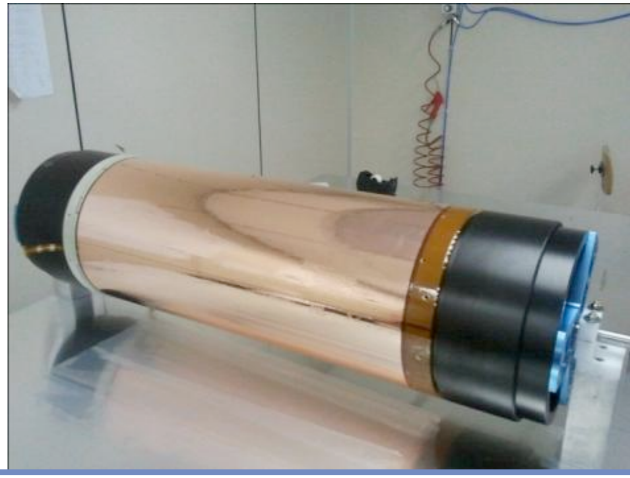
We place an inner cylindrical kapton layer on the mold



Nomex honeycomb 3 mm thick is glued on the back of the cathode

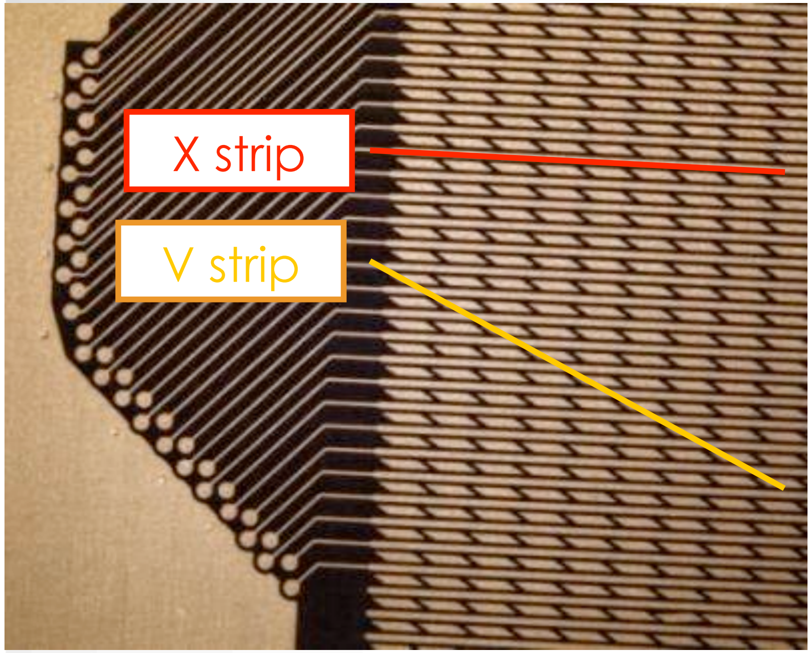


Cathode (made by 3 foils) is wrapped around the mold and closed with a vacuum bag

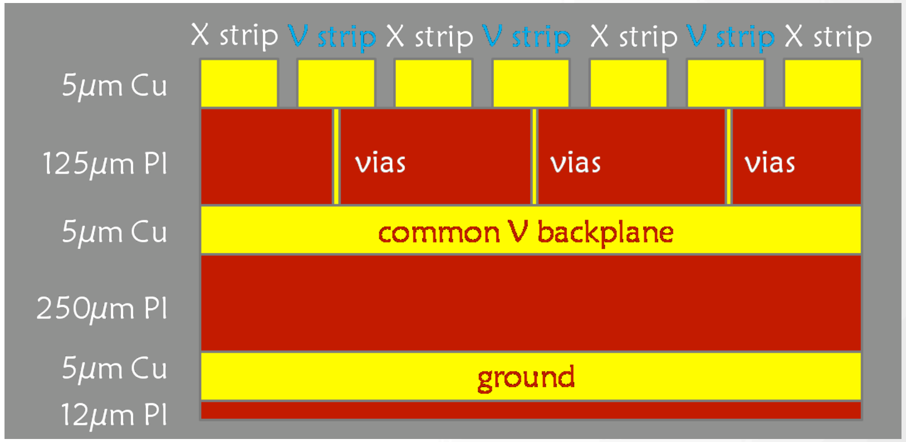


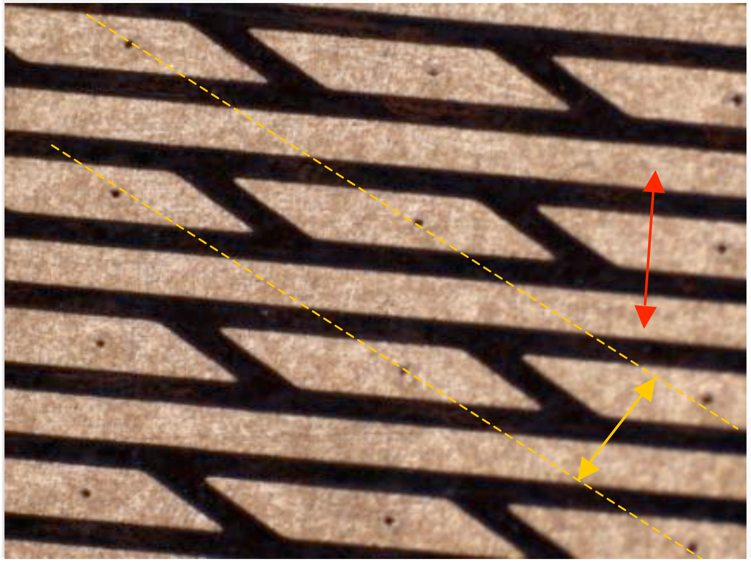
Final cathode is ready with both internal and external rings

Readout Plane



Readout plane is realized at CERN TE-MPE-EM
It is a kapton/copper multilayer flexible circuit
Provides 2-dimensional readout with XV strips on the same plane
•X are realized as longitudinal strips
•V are realized by connection of pad through conductive holes and a common backplane
•Pitch is 650 μm for both

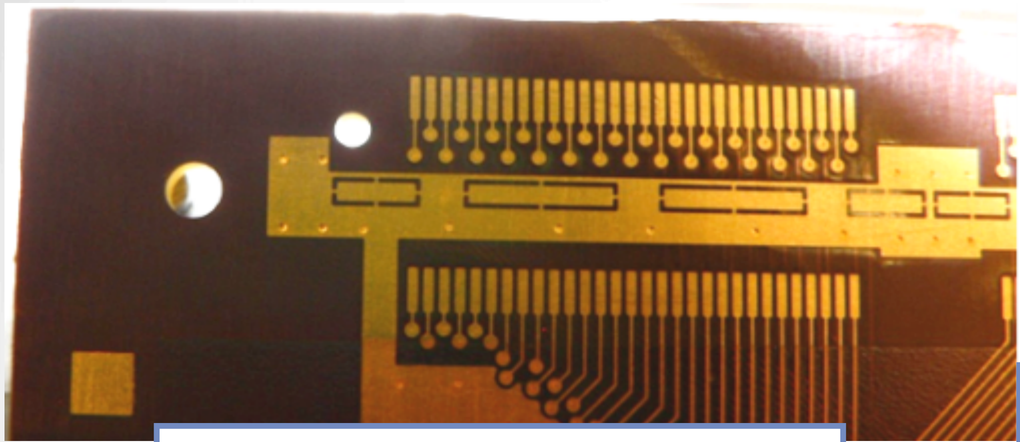




X pitch 650µm → X res 190µm

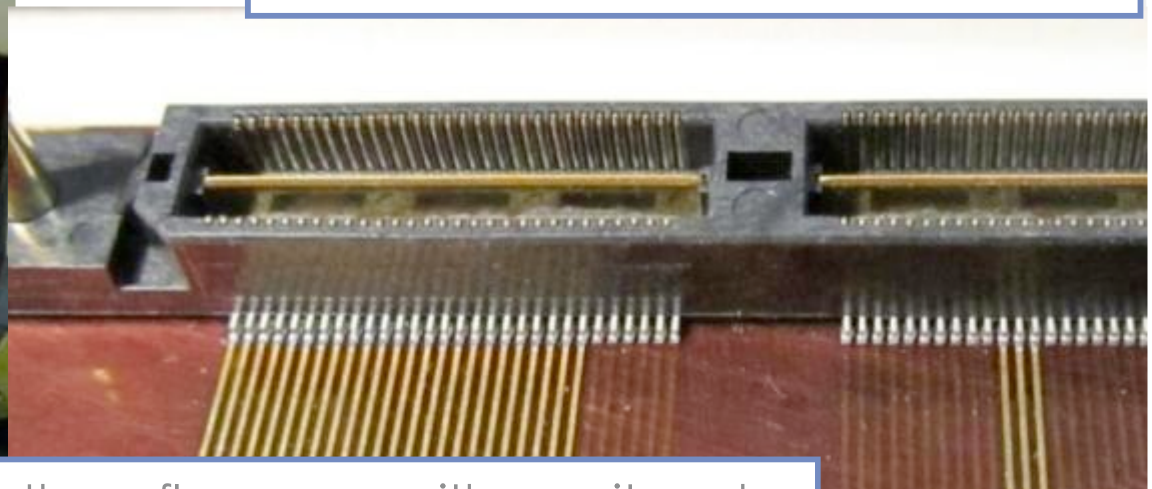
V pitch 650µm → Y res 350µm

Readout Connector Soldering



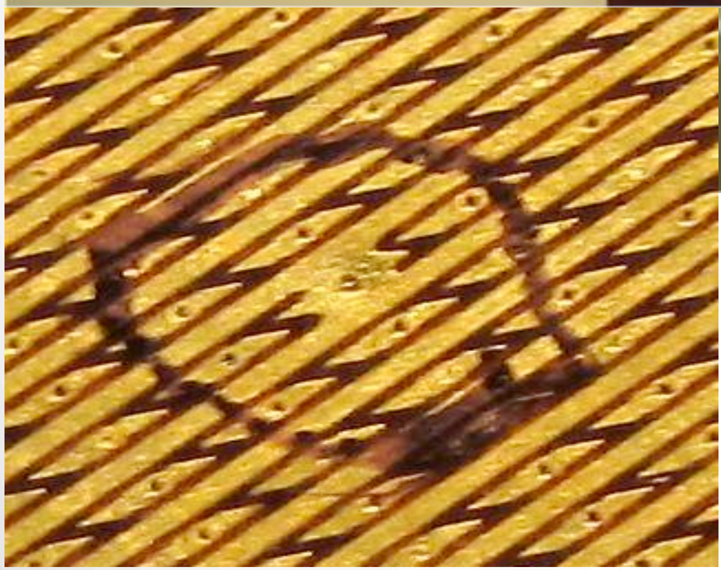
Connector soldering pads

Connectors are placed and fixed on the circuit after the deposition of the solder paste with a serigraphy machine



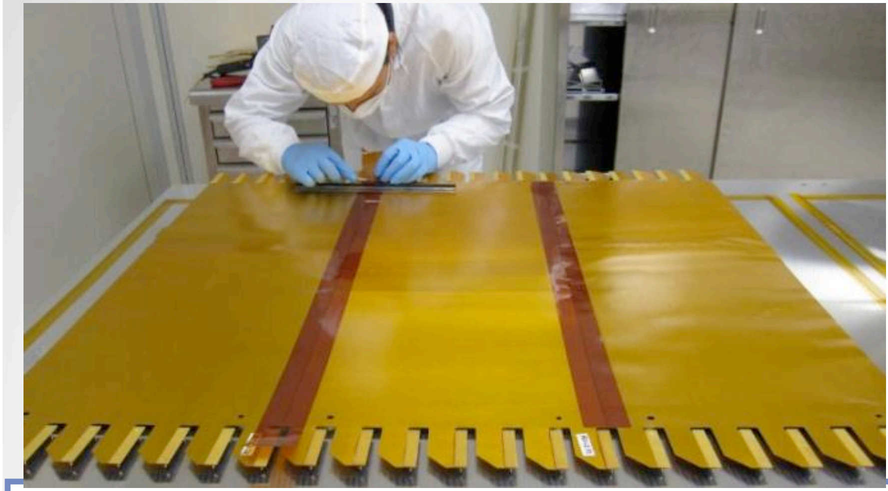
Circuit are put in the reflow oven with monitored temperature cycle , for connectors soldering

Readout Test

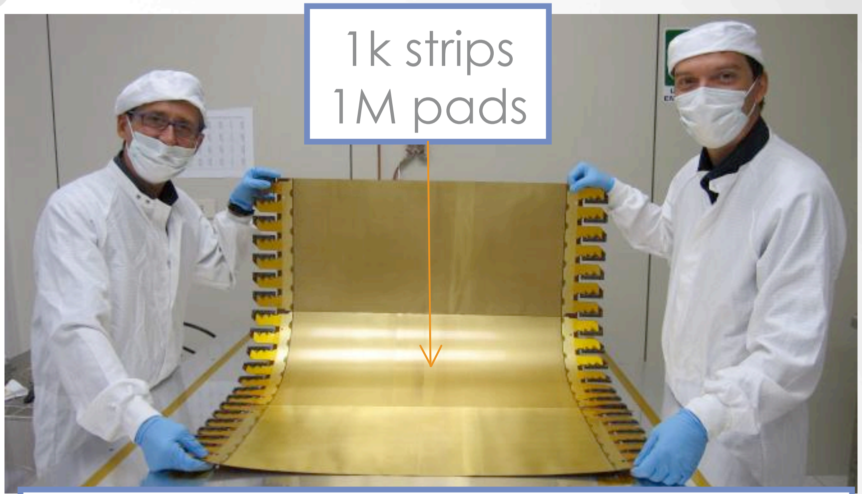


See dedicated talk by Giampiero Fanizzi

Manufacturing the Readout



3 foils are spliced <u>without overlap</u>: kapton strips (6 cm) are glued on the back of head-to-head joints



Final foil is ~1m long with three ~1mm wide dead zones

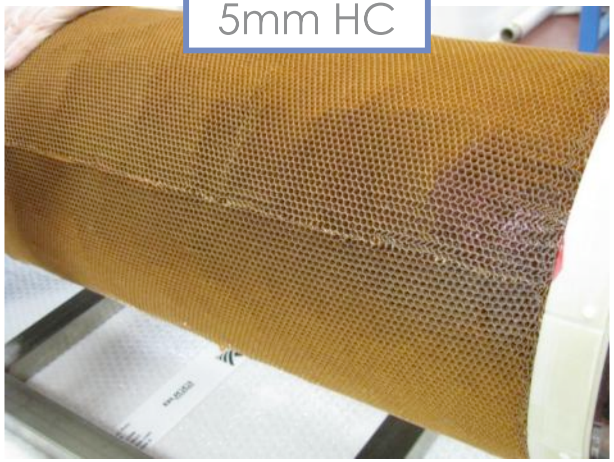
Foil is wrapped on the mold

...to obtain cylindrical electrode

Readout CF Lamination

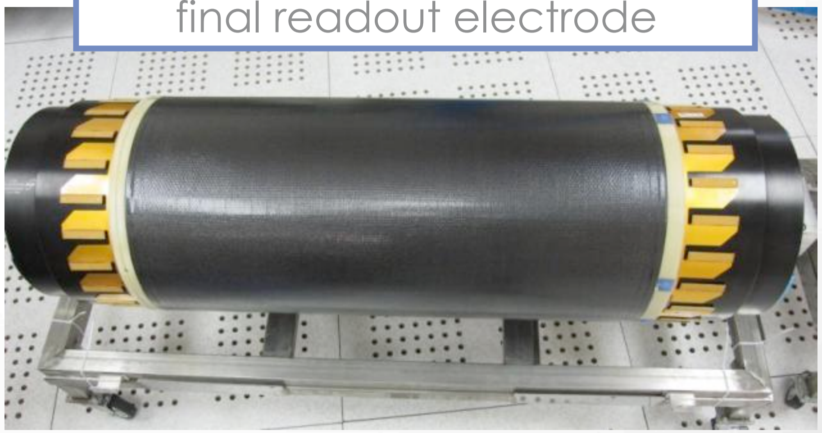
- The readout is shielded with a very ligth Carbon fiber composite structure realized by RiBa Composites, Faenza, IT
- The shield is composed by a sandwich of two 90 μm thick carbon foils prepreg with epoxy (Carbon-Epoxy 90g/m2 58% Fibra T300) spaced by a 5 mm thick Nomex honeycomb (ECA-I 4.8-48 3/16-3.0)


first 90µm CF skin


5mm HC

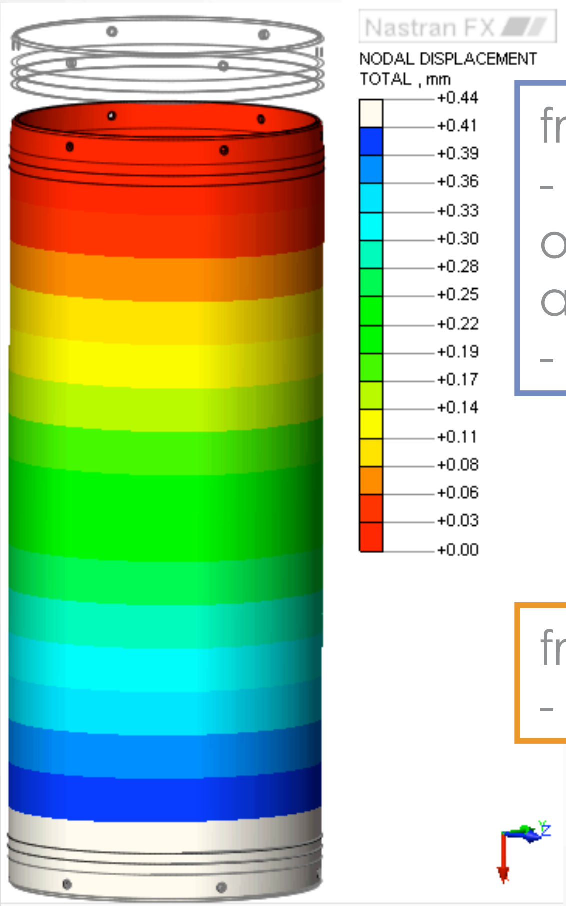

second 90µm CF skin


curing 24h in autoclave


final readout electrode

Readout Load Test

- At the beginning of the project the idea was to stretch the foils and to release the load (about 1kN) on the Carbon Fiber structure.
- For this reason we have performed both simulation with a finite element model software (FEM) and load tests on a full scale prototype structure
- Despite the test was successful, the idea has been abandoned (see Lina Q. talk)
- An alternative would be the honeycomb/kapton structure of the cathode



from FEM analysis:
- axial deformation of 0.44 mm with 6kN applied
- break load = 96 kN

from load test:
- break load = 39 kN

Assembling a triple-GEM

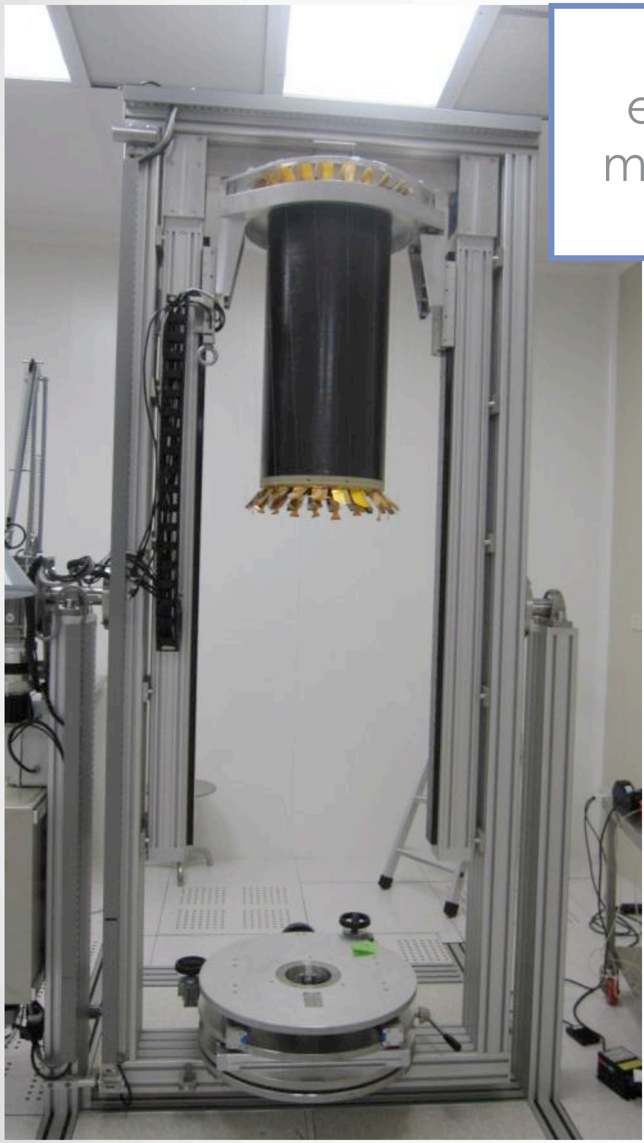
- A dedicated assembling machine has been designed and realized to perform the insertion of the electrodes one into the other
- It is an Aluminum structure with a bottom plate and a top flange running vertically on linear bearings
- Axial alignment has a precision of 0.1mm/1.5m
- The structure can rotate by 180° around its central horizontal axis

The first electrode (the readout) is fixed with its mold on the bottom plate

The top ring is grabbed with pins by the top flange

Assembling a triple-GEM

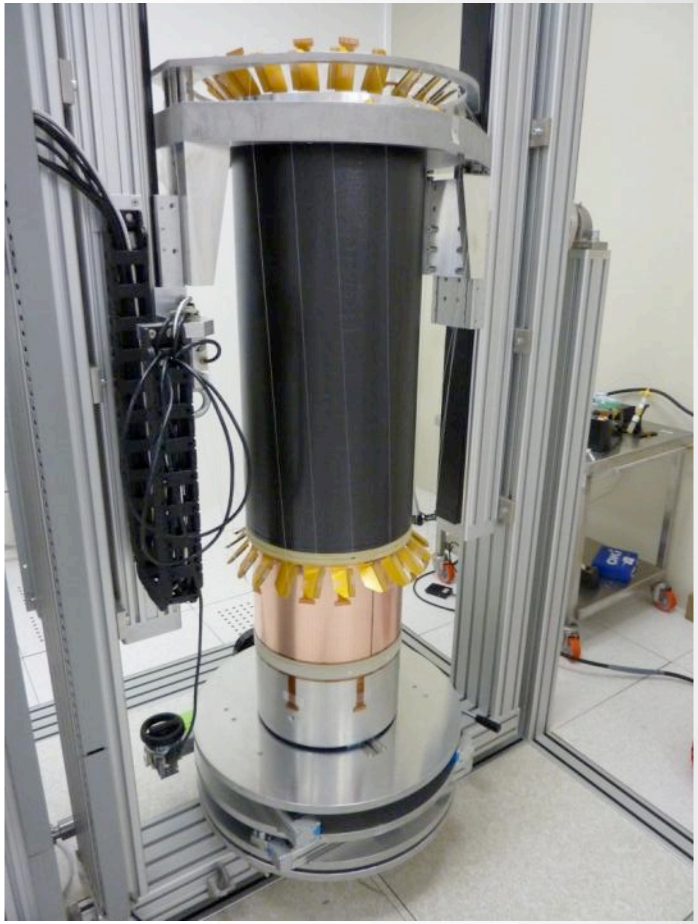
The electrode is extracted from its mold by moving up the flange



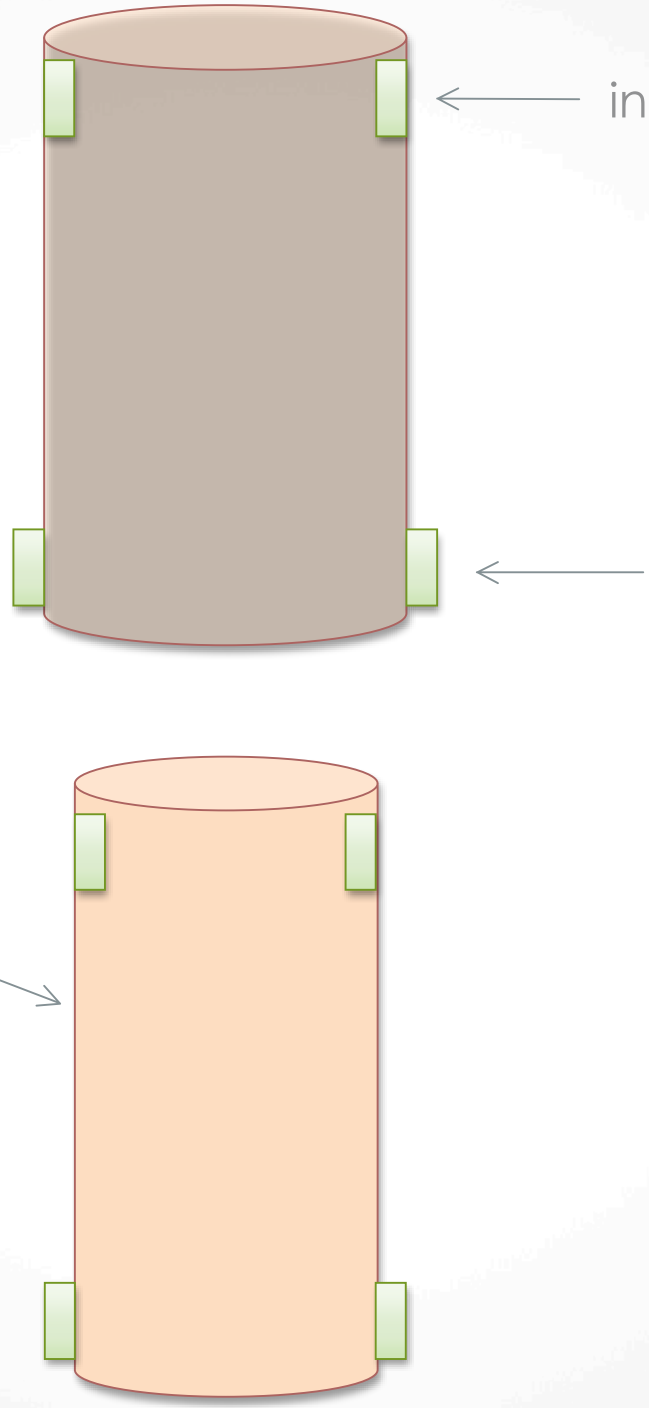
internal readout surface

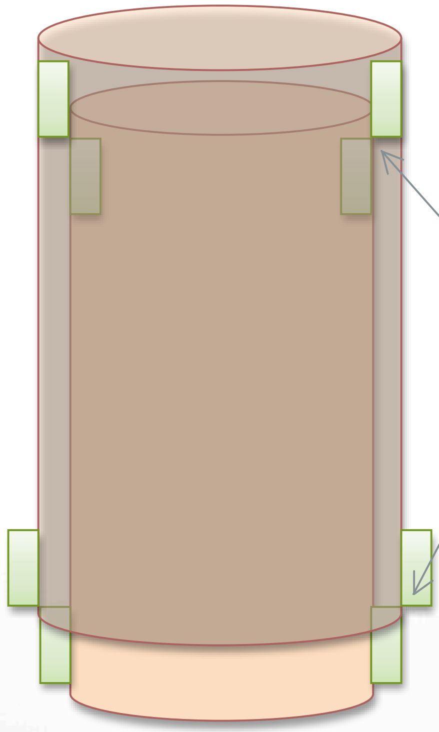
● D.Domenici - LNF

Assembling a triple-GEM



1. The second electrode (GEM3) is placed on the machine with its mold and
2. Fixed to the bottom plate
3. The top flange with Readout is moved down around the GEM


internal ring on the top
external ring on the bottom
During most of the ride the clearance is given by the gap (2 mm)

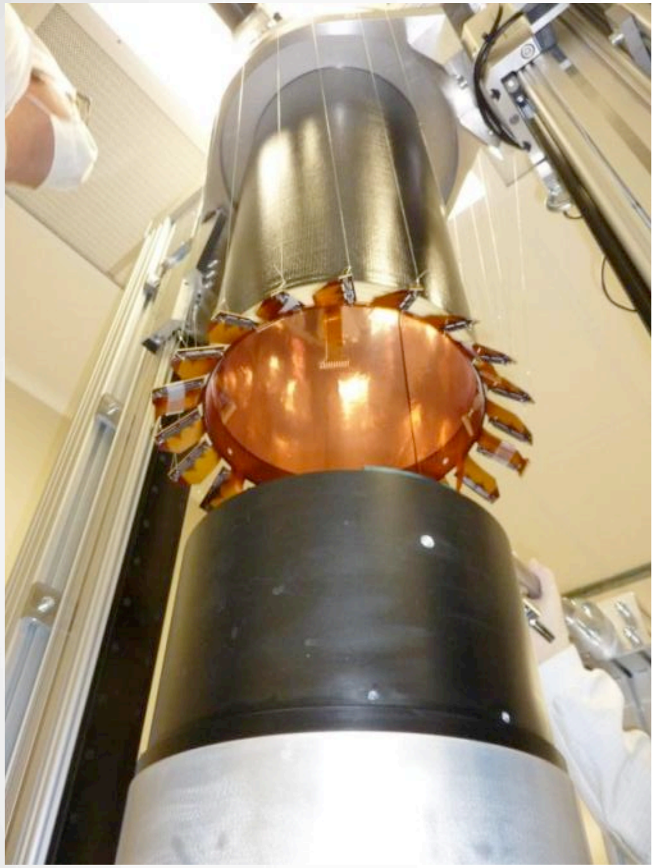


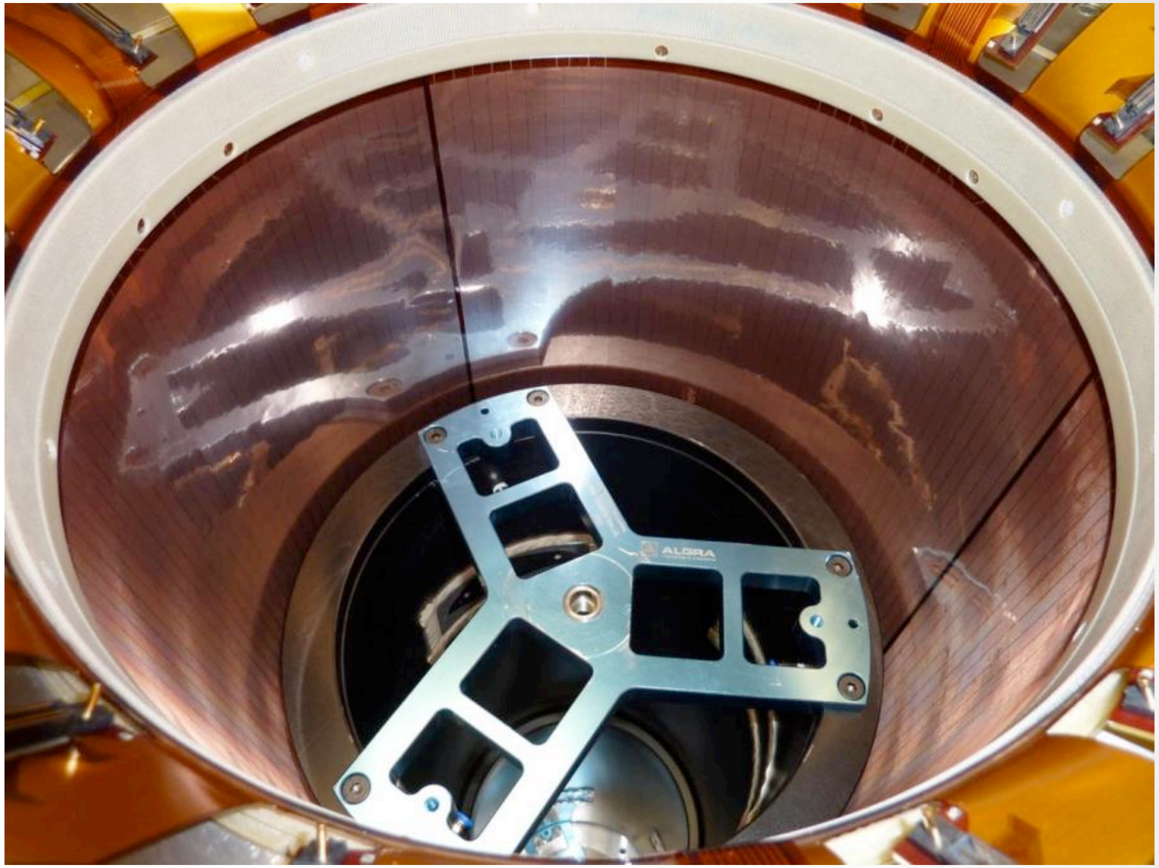
In the last 35 mm
(when the rings are
faced) the clearance
is 0.25 mm

Sealing of the Detector

The top side of the detector is sealed with epoxy adhesive (Araldite 2011) flowed into the 0.35 mm reservoir with a dispencer.
Curing cycle lasts 24h

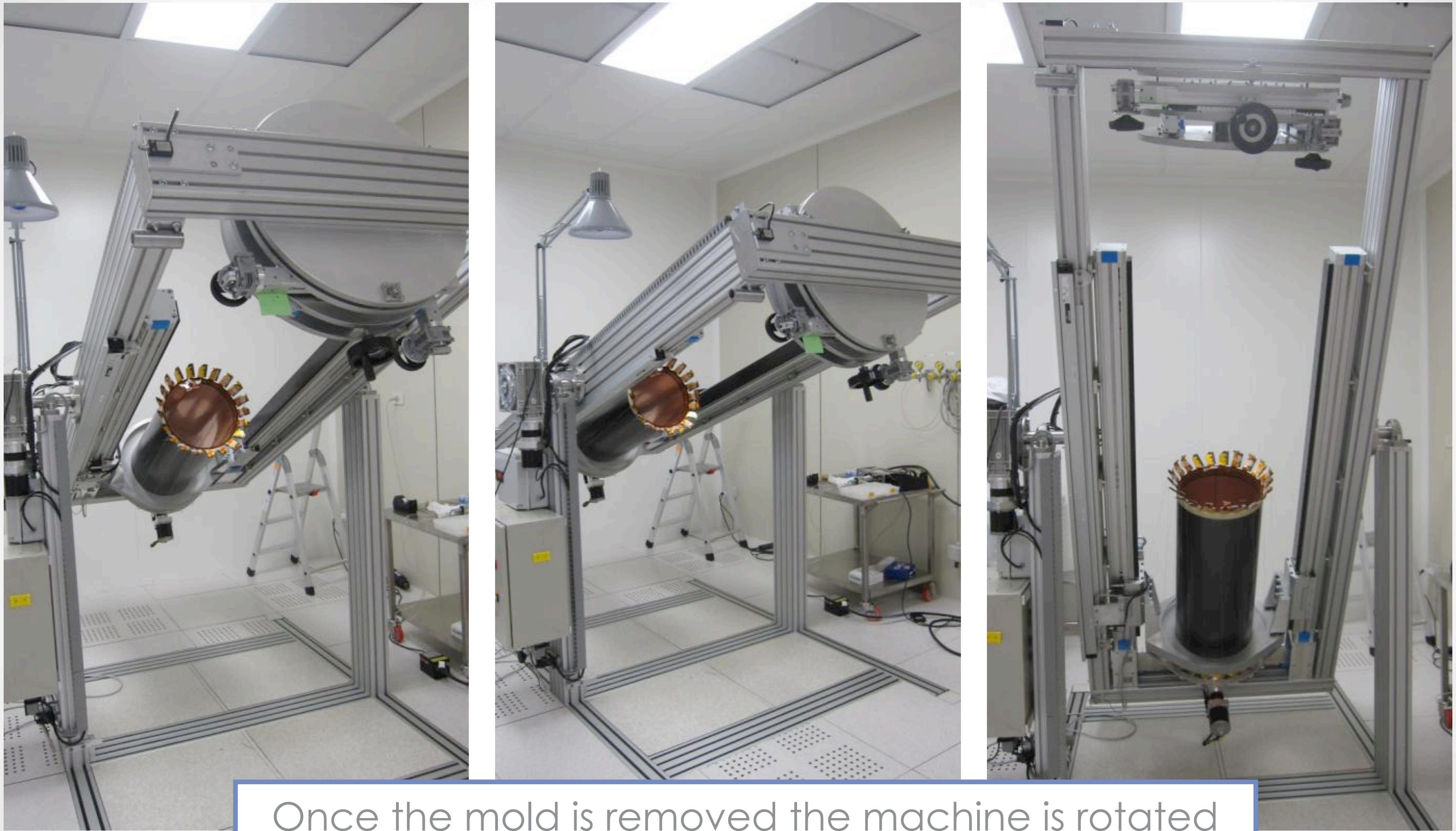
Assembling a triple-GEM





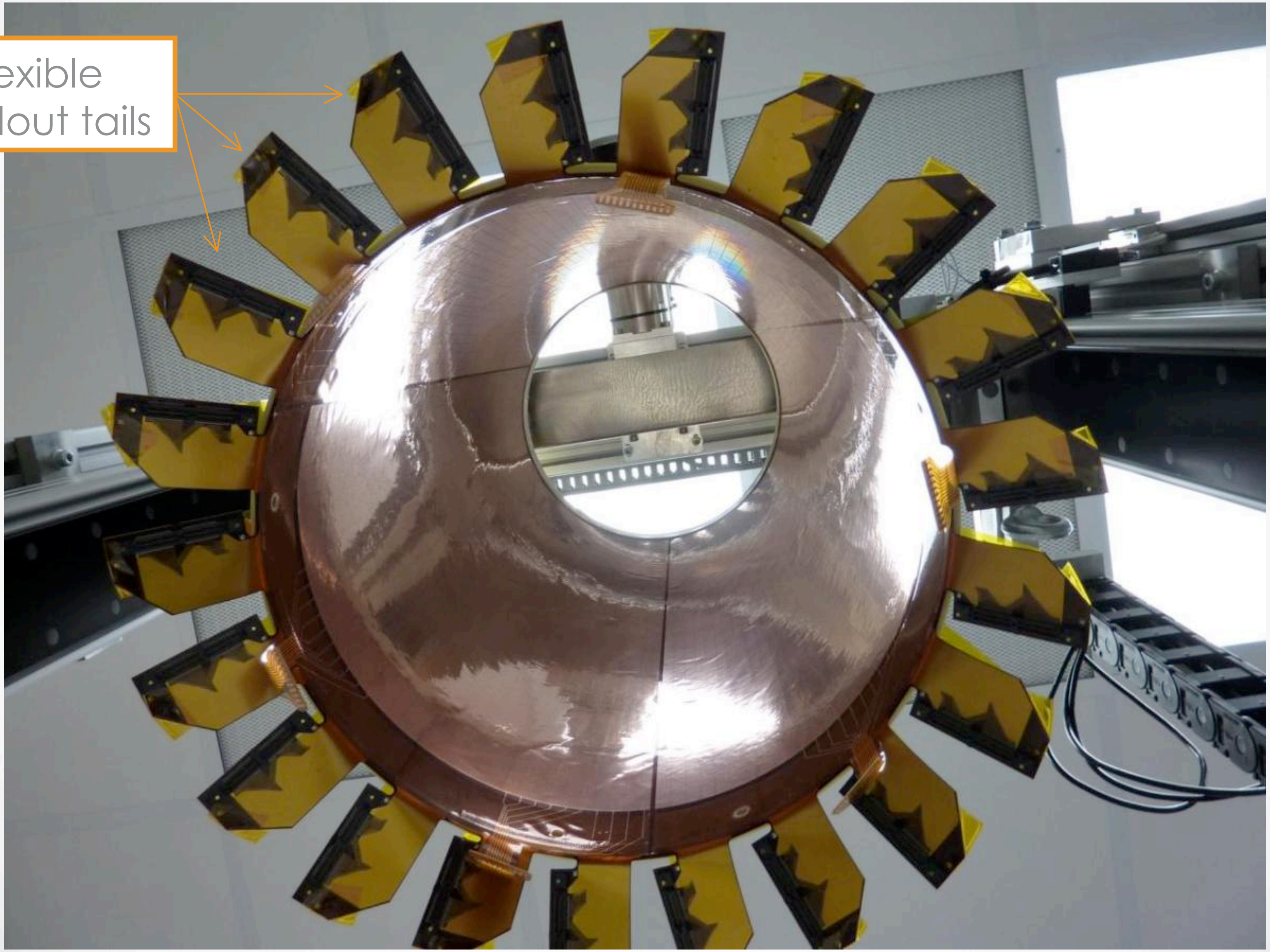
The top flange with both Readout and GEM3 is moved up
The naked mold is left downside

Assembling a triple-GEM



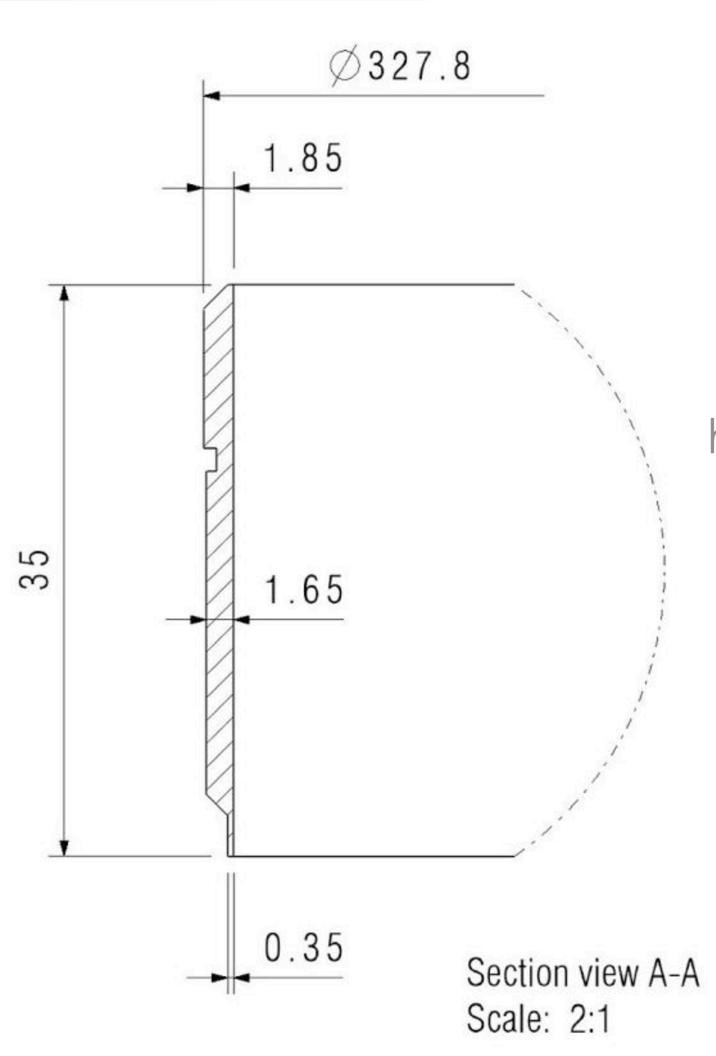
Once the mold is removed the machine is rotated by 180° so that the bottom side becomes accessible and can be sealed

Assembling a triple-GEM



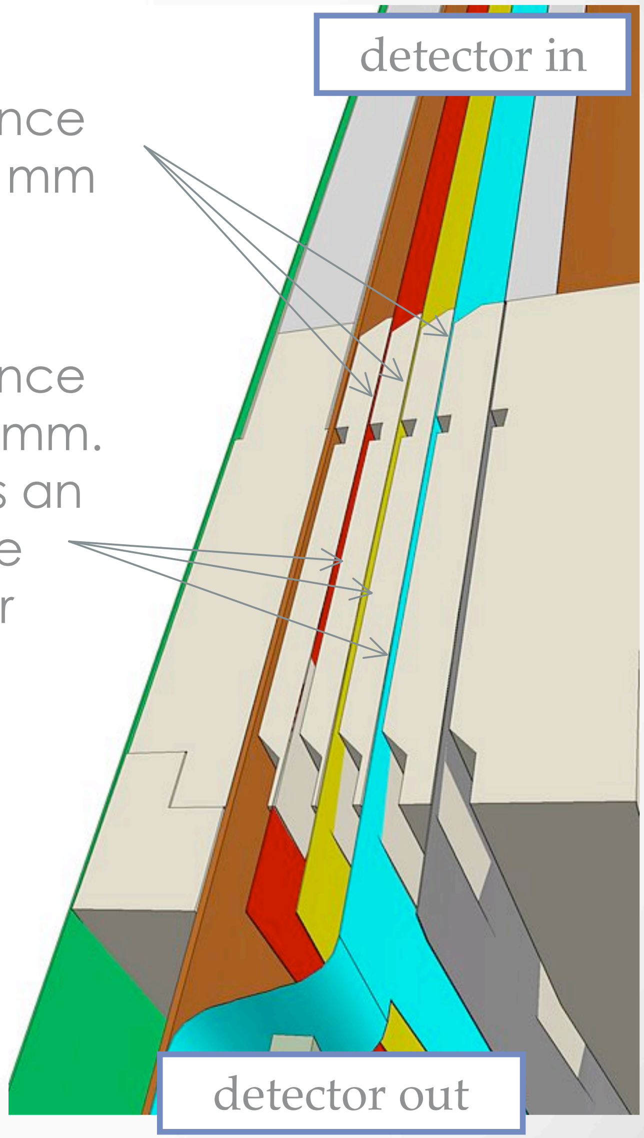
Flexible readout tails

Details of the Rings

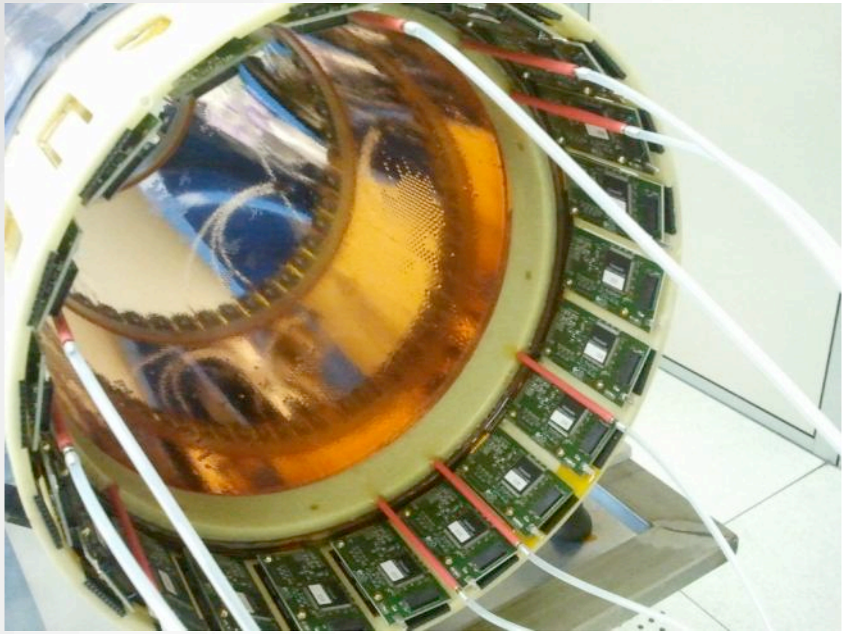


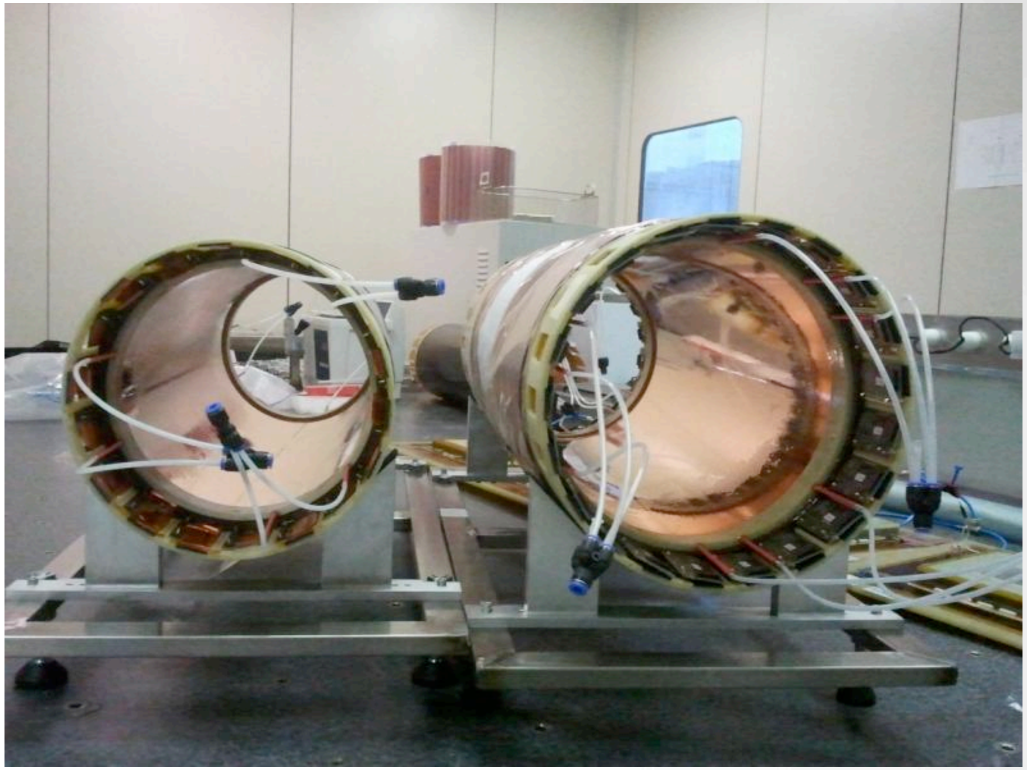
The clearance here is 0.15 mm

The clearance here is 0.35 mm. This acts as an adhesive reservoir

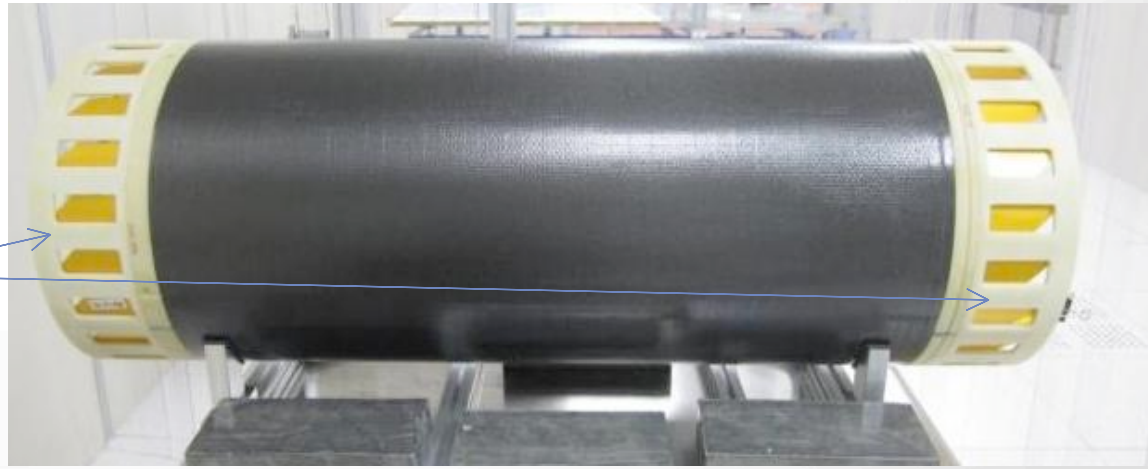


Completed Detector





Layer2 equipped with FEE



FEE is supported by 2 fiberglass outer rings

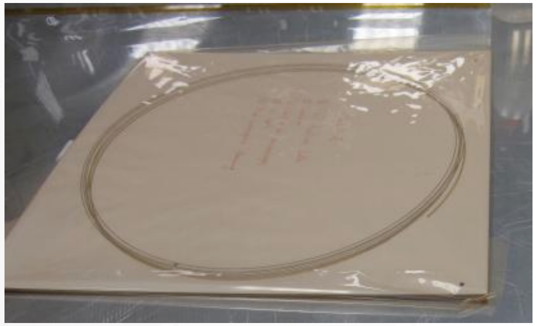
The Temperature Issue

- DAFNE beam pipe temperatures are higher than those foreseen (up to 50 °C)
- Temperature tests on Layer2 showed some instability for T > 35-40 °C, due to the mechanical "relaxing" of the GEM electrodes

To cope with this problem:

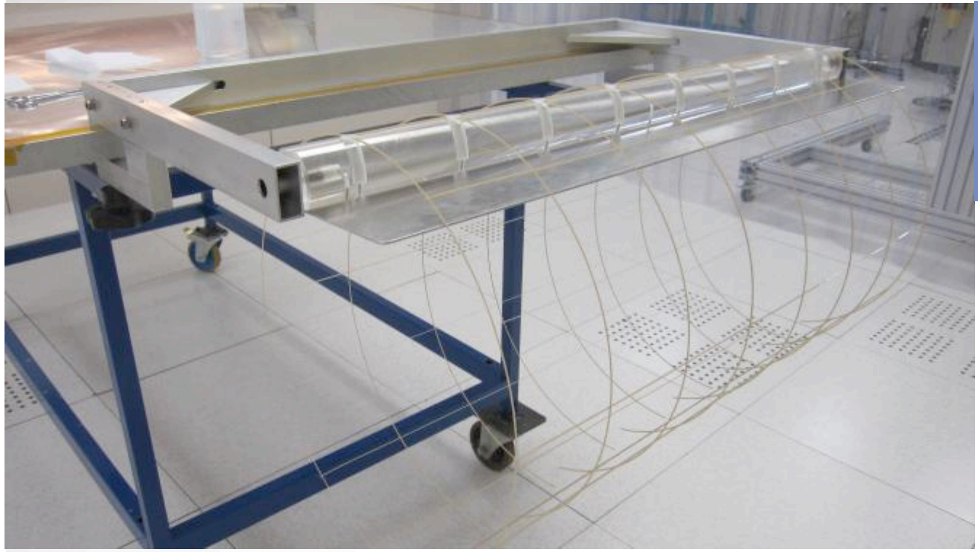
1. A cooling system of the DAFNE Interaction Point is foreseen: mock-up tests indicate that the operation temperature can be kept under 30 °C
2. A 300 μm thick spacing grid is introduced between GEM electrodes for Layer3 and Layer4. The material is PEEK, an organic polymer thermoplastic we bought at VICTREX, UK and has been machined at CERN TE-MPE-EM

rings



rods

Assembling a PEEK Grid



8 rings and 12 rods are assembled with a dedicated tool

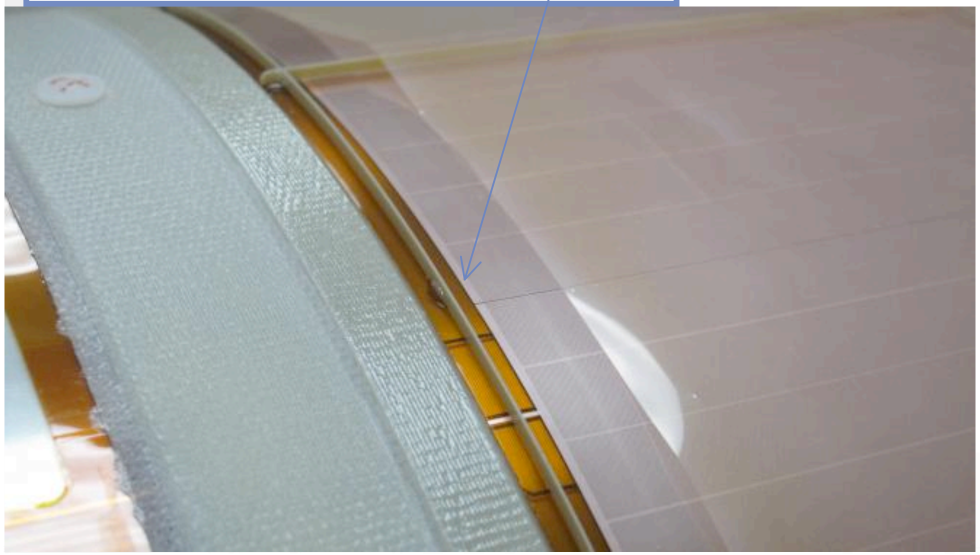
the final grid is self-consistent and can be safely handled

a tiny drop of fast epoxy (Araldite2012, 2h curing cycle) is dispensed at the crossing points

Assembling a PEEK Grid

the grid is placed around the GEM on its mold

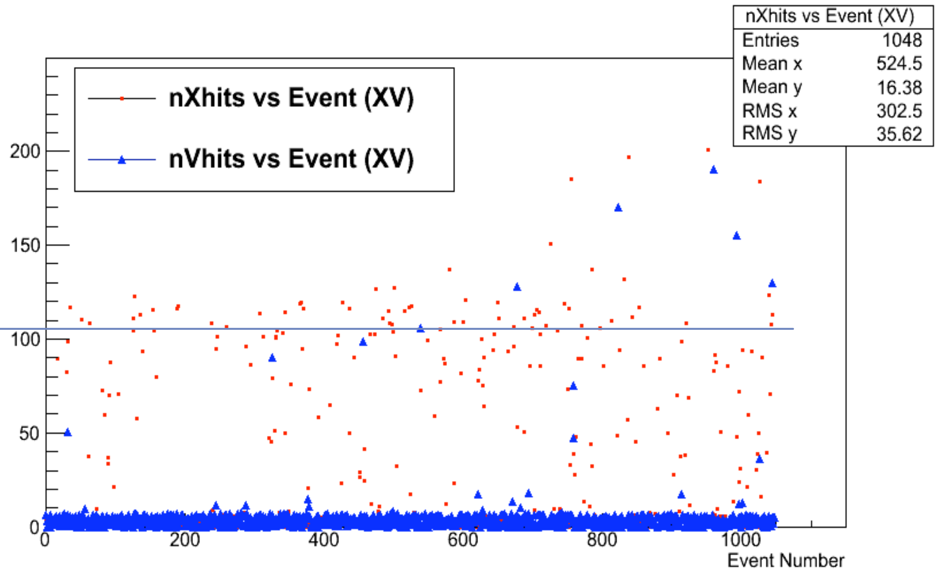
and it's fixed on the kapton with epoxy drops



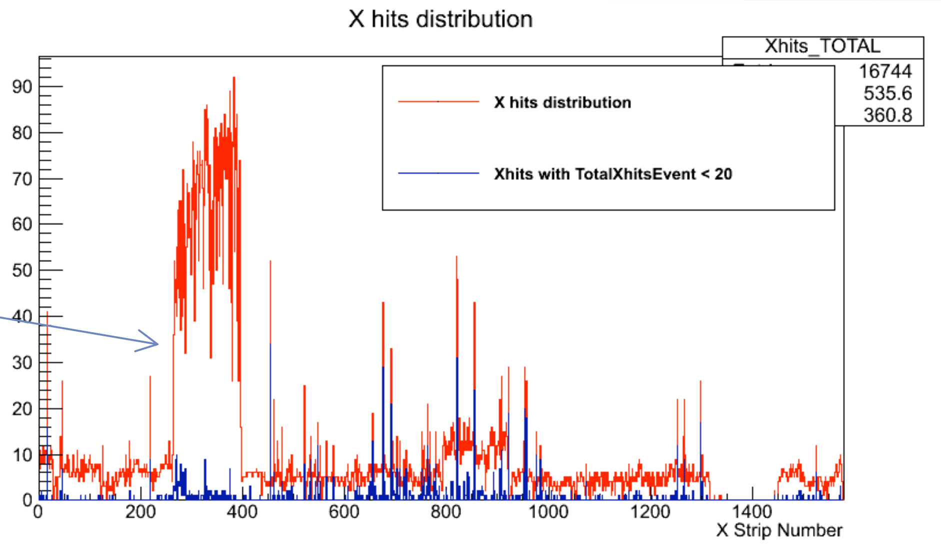
the GEM with grid can be assembled

Splash Events

- During the β source tests we have observed «splash events» with large hit multiplicity, in particular on the X strips
- The average number of X hits (~100) corresponds to the number X of strips facing a HV Macro Sector



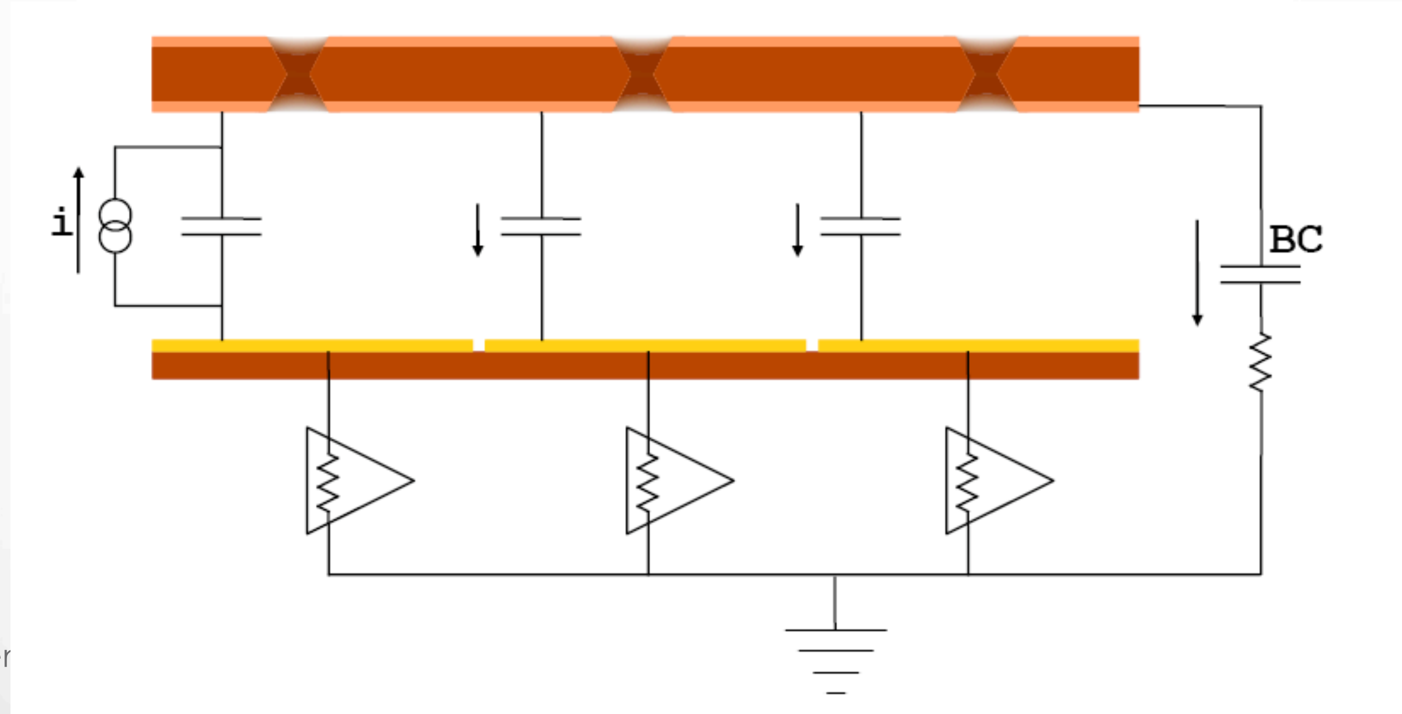
- The effect is clearly visible in the X hits distribution, with a whole HV Sector fired



- A similar effect had been already seen in the LHCb triple-GEM

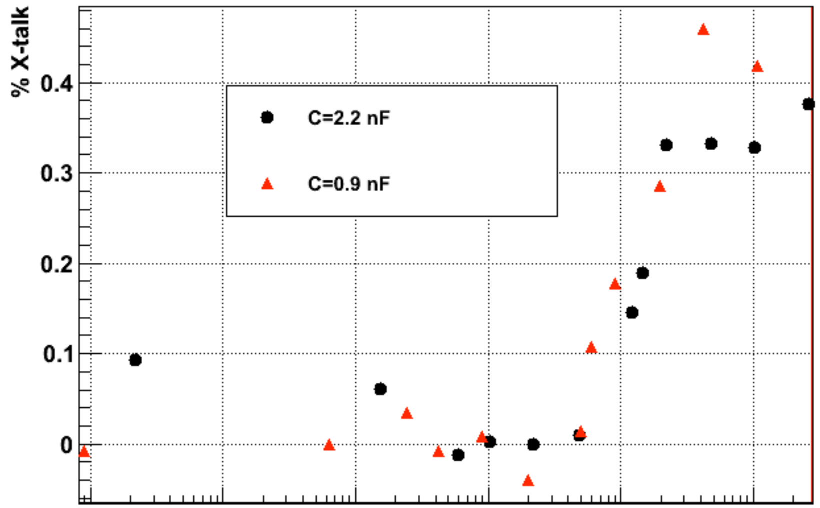
Blocking Capacitor

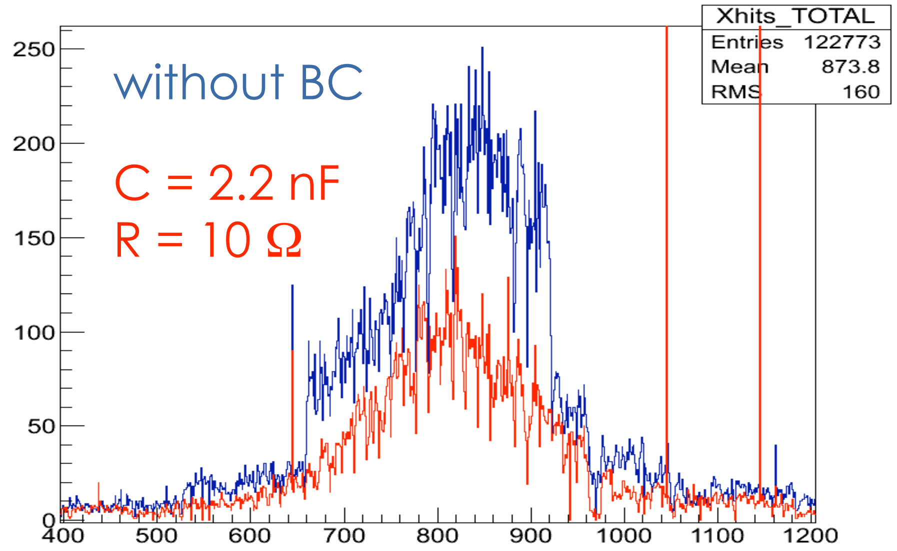
- Such effect can be explained as X-talk due to capacitive coupling between GEM3_Bottom and the Readout plane
- Currents on the GEM3_Bottom can induce signals on all the strips facing the GEM3 Macro Sector
- If the charge deposit is large enough this can triggers the discriminators, creating X-talk hits and splash events
- Splash events are strongly suppressed by the insertion of a Blocking Capacitor circuit (BC): the current induced on G3_Bottom flows to ground rather than into the detector



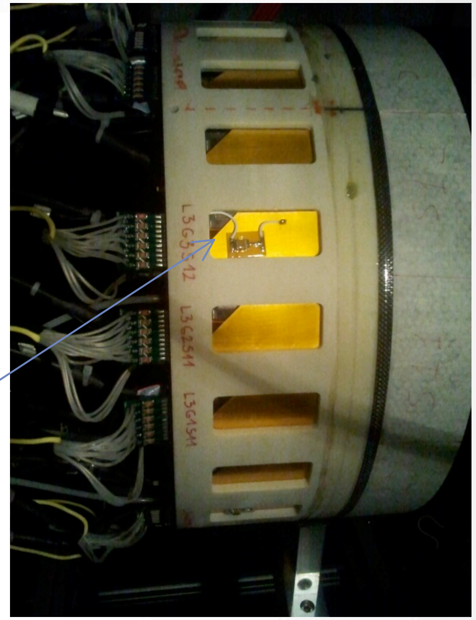
Blocking Capacitor

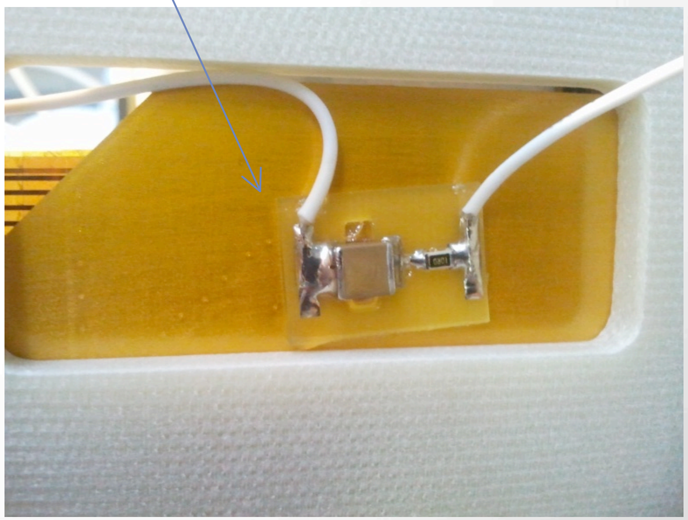
We have performed a scan to find suitable values of RC





And we also found an elegant way to place the BC





Material Budget

Material	Radiation Length (cm)
Copper	1,43
Polyimide - Kapton	28,6
Carbon fiber	28
Argon	14000
Isobuthane	17000
Epoxy - Araldite 2011	33,5
Honeycomb - Nomex	1250
Fiberglass - FR4	16
Air	30500
Aluminum	8
Gold	0,33

The KLOE-2 requirement of X0 < 2% is fulfilled

	Thickness (µm)	Radiation Length (%)
Copper	3	1,68E-04
Polyimide	50	1,40E-04
Copper	3	1,68E-04
GEM foil	**56**	**4,76E-04**
Copper	3	2,10E-04
Polyimide	50	1,75E-04
Honeycomb	3000	2,40E-04
Polyimide	50	1,75E-04
Copper	3	2,10E-04
Cathode foil	**3106**	**1,01E-03**
Gold	0,1	3,03E-05
Copper	5	2,45E-04
Polyimide	50	1,75E-04
Copper	5	1,05E-04
Epoxy	12,5	3,73E-05
Polyimide	125	4,37E-04
Epoxy	12,5	3,73E-05
Polyimide	50	1,75E-04
Copper	3	2,10E-04
Gold	0,1	3,03E-05
Anode Foil	**263**	**1,48E-03**
Carbon fiber	90	3,21E-04
Honeycomb	5000	2,40E-04
Carbon fiber	90	3,21E-04
CF Shield	**3200**	**9,54E-04**
Total 1 Layer		**4,87E-03**
Total 4 Layers		**1,95E-02**

Project Remarks

- The design, planning and realization of the Inner Tracker project has been a huge challenge
- GEM of unprecedented size have been assembled in an unprecedented fashion
- Material budget has been a strong constraint that forced us to use peculiar materials
- Very fine Sector power supply complicates HV system but is mandatory for a recoverable operation
- The choice of different solutions for a C-GEM are strongly driven by overall dimensions
  - E.g.: grid is only needed above a certain diameter

Project Criticalities

- The option chosen for the molds is too much money/time consuming
- Mechanical tolerances of the rings and clearances in the assembly should have been more permissive
- The design of the GEM foil had some criticality:
  - precise cuts and reference holes
  - fragile tails
  - weak through holes with conductive glue
- The CF shield of the Readout could have been replaced by a simpler honeycomb/kapton structure
- For the issues about the realization of the Readout foil see the dedicated Rui de Oliveira's talk