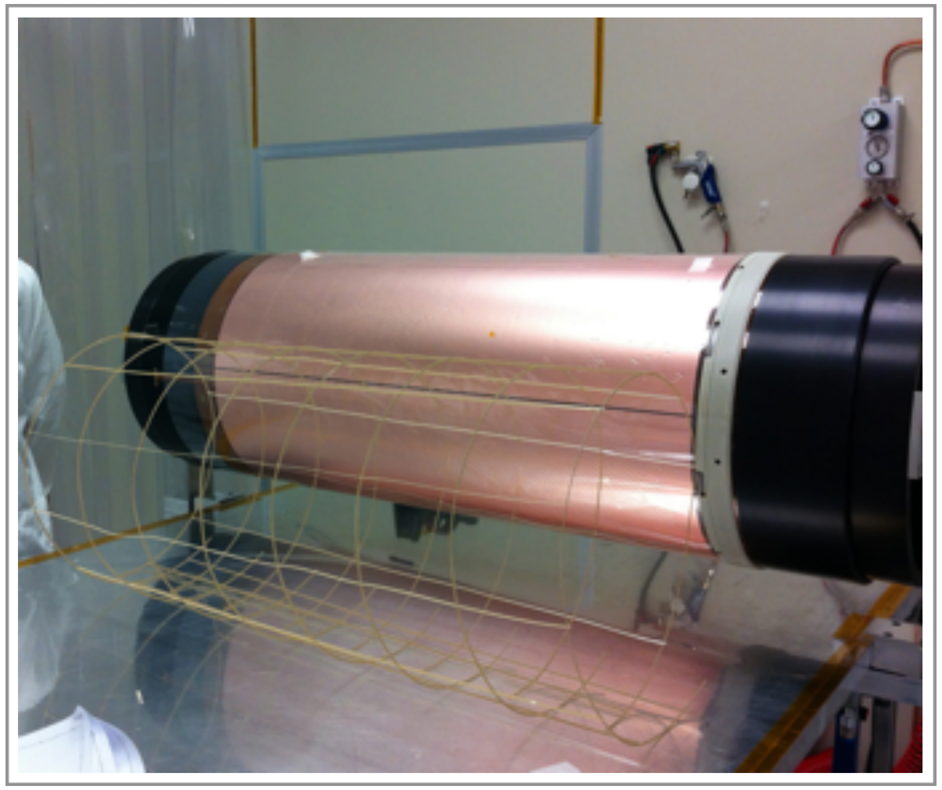
CGem
Thermo-Mechanical characteristics and F.E.Model



L.Quintieri, S.Cerioni, G. Morello

Cylindrical Gem Miniworkshop

Frascati, 25-26 Ottobre

What's the point...

- The CGEM detector has several peculiarities that make it an interesting object from the mechanical point of view (materials, assembling and so and so forth)

- It is made of materials that are not well characterised from the mechanical point of view (very few literature). We could define these materials as "non conventional" from the structural point of view. This is why we needed to carry out some tests in workshop (mainly tensile and thermal tests)

- The assembling phase has demonstrated to be the most critical one: many technical solutions have been studied and applied...But I do not talk about this aspect (Technical Services of LNF, Bari, Roma1)..

- I will focus on the work done to perform a finite element model of the detector

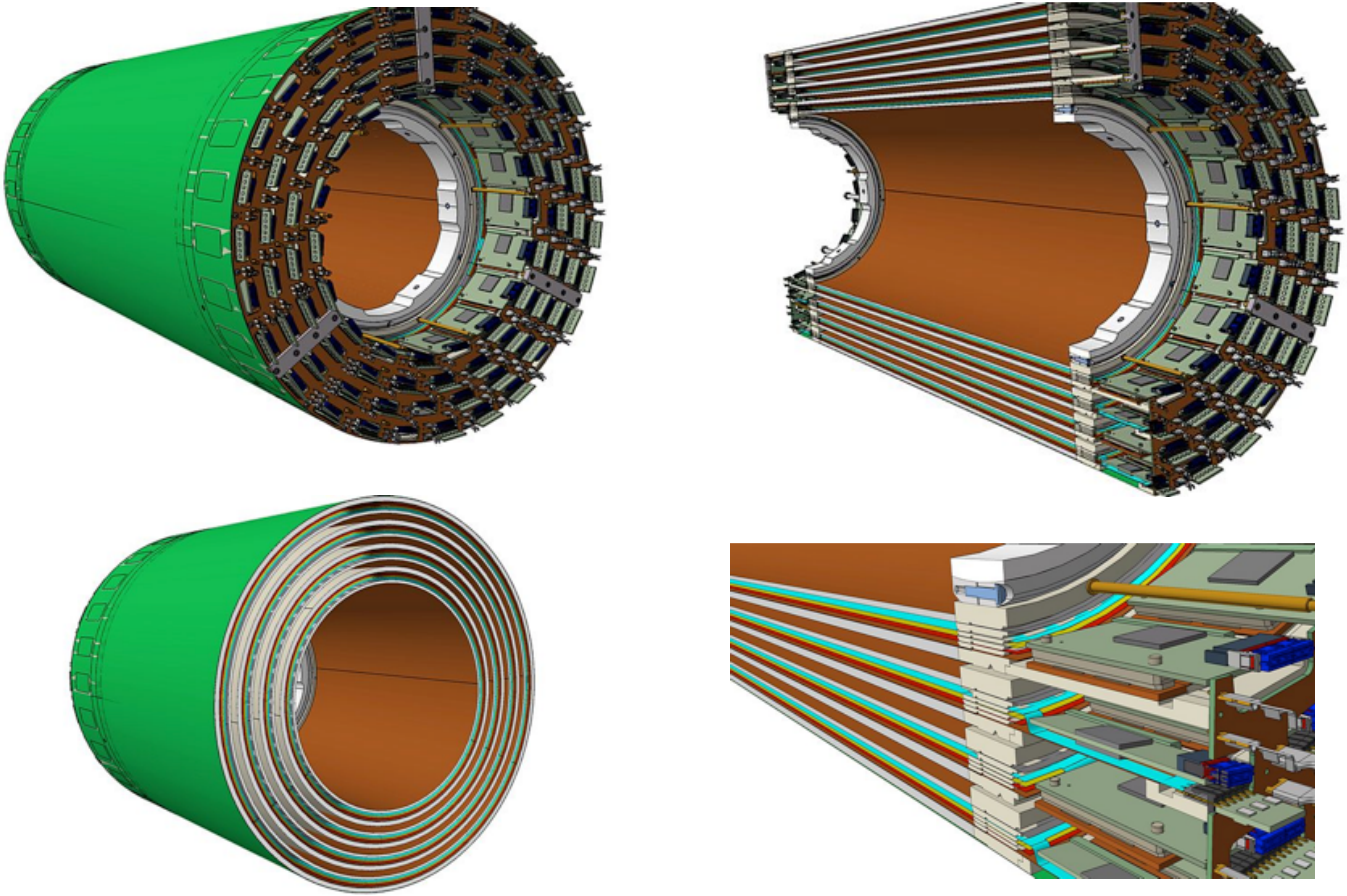
- In particular I will take care of the thermo-mechanical specifications that have to be introduced in the "Ansys" code, in order to realize a finite element model of the detector as much reliable as possible

Why a finite element Model? What we expect from?

- We can have predictions about the entity of deformations due to different loads (this could adress to the best mechanical solutions during the detector design and construction or individuate some critical points under severe scenarios that we do not want to reproduce experimentally).
- In this frame, it is important to dispose of a code able to perform multi-physics calculations (so that we can develop thermo-mechanical or elect-mechanical or thermo-electro-mechanical analys....)
- We use the "Ansys" code since it offers a lot of important options (calculation in different physics domain) and different kind of anlysis (static, transient, modal, etc)...
- .....

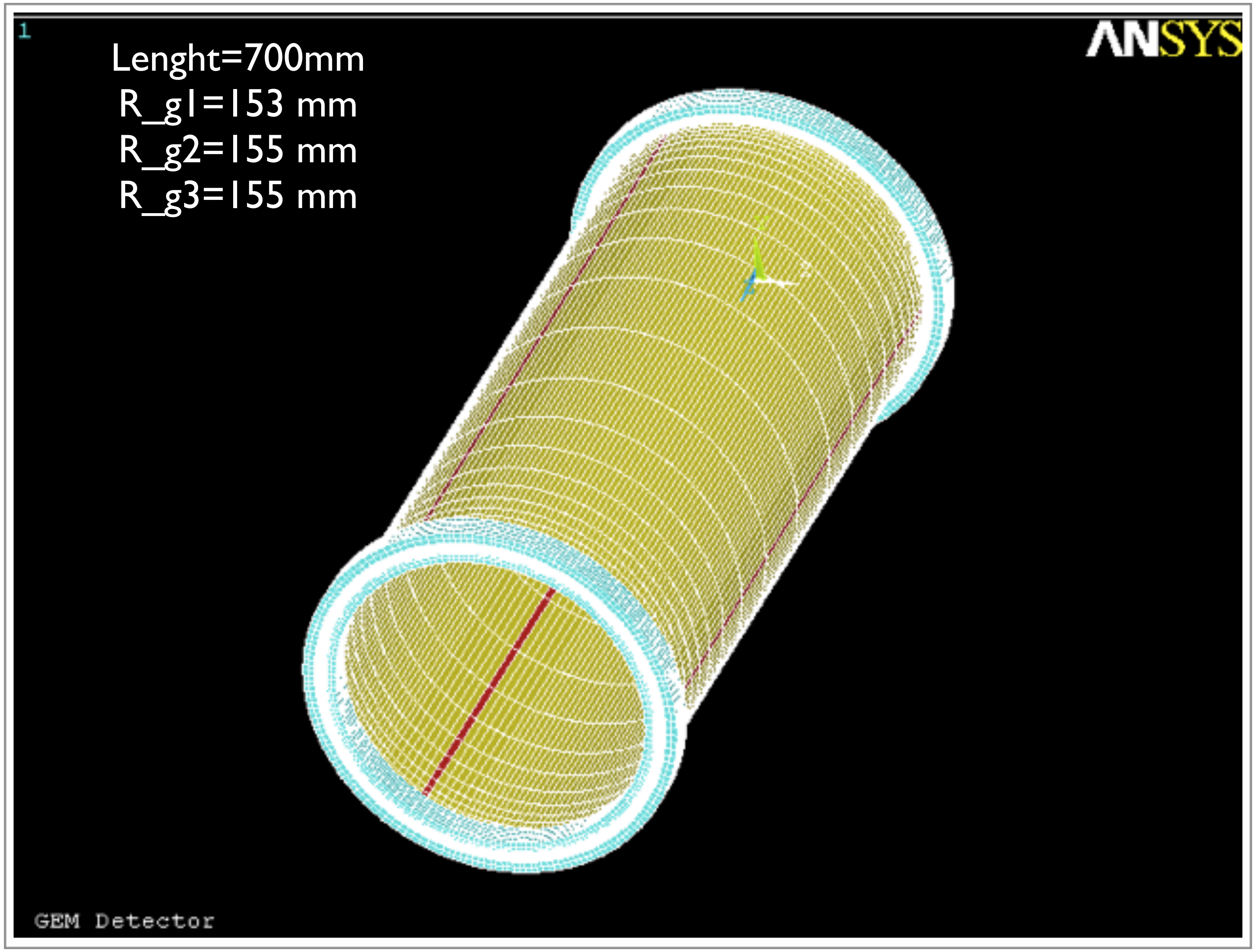
Outline

- CGem: brief description of geometry and material as introduced in the Finite Element model
- Mechanical characterisation: tensile tests for Young Modulus measurements in elastic domain
- Thermal characterisation: thermal tests for the linear expansion coefficient measurements
- Simulation results:
  - Validation phase (trough the prototype)
  - Some results from simulations



Courtesy INFN Bari

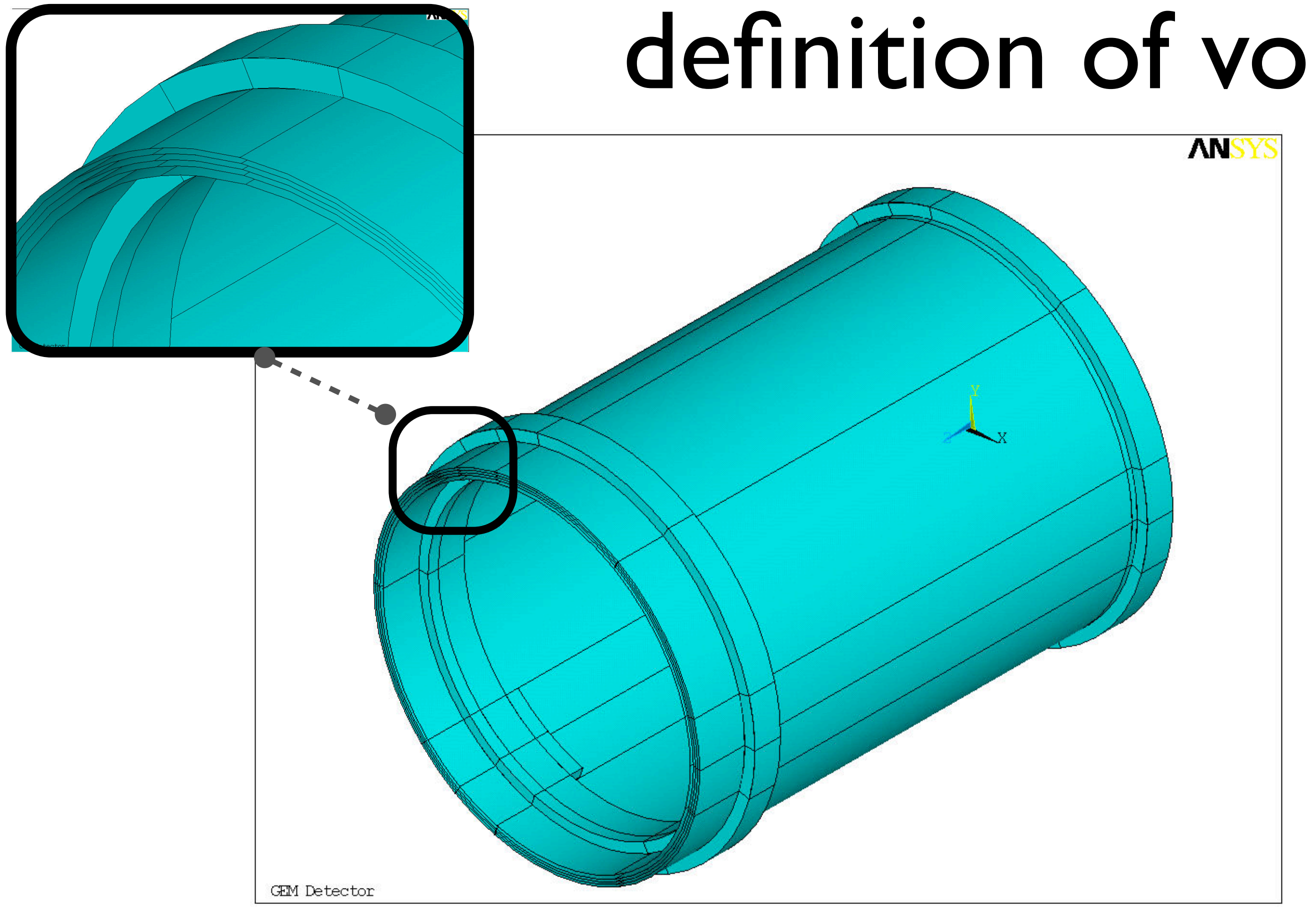
The mechanical design



The finite element model:

simplified but representative enough to reproduce in accurate and reliable way the mechanical behaviour

First step in constructing the model: definition of volumes and areas



	R[m]	s[micron]
Gem-1	**0.153**	**50(Kap)+10(Cu)**
Gem-2	**0.155**	**50(Kap)+10(Cu)**
Gem-3	**0.157**	**50(Kap)+10(Cu)**
Anodo	0.159	100(Kap)+10(Cu)
Catodo	0.150	100(Kap)+5(Cu)

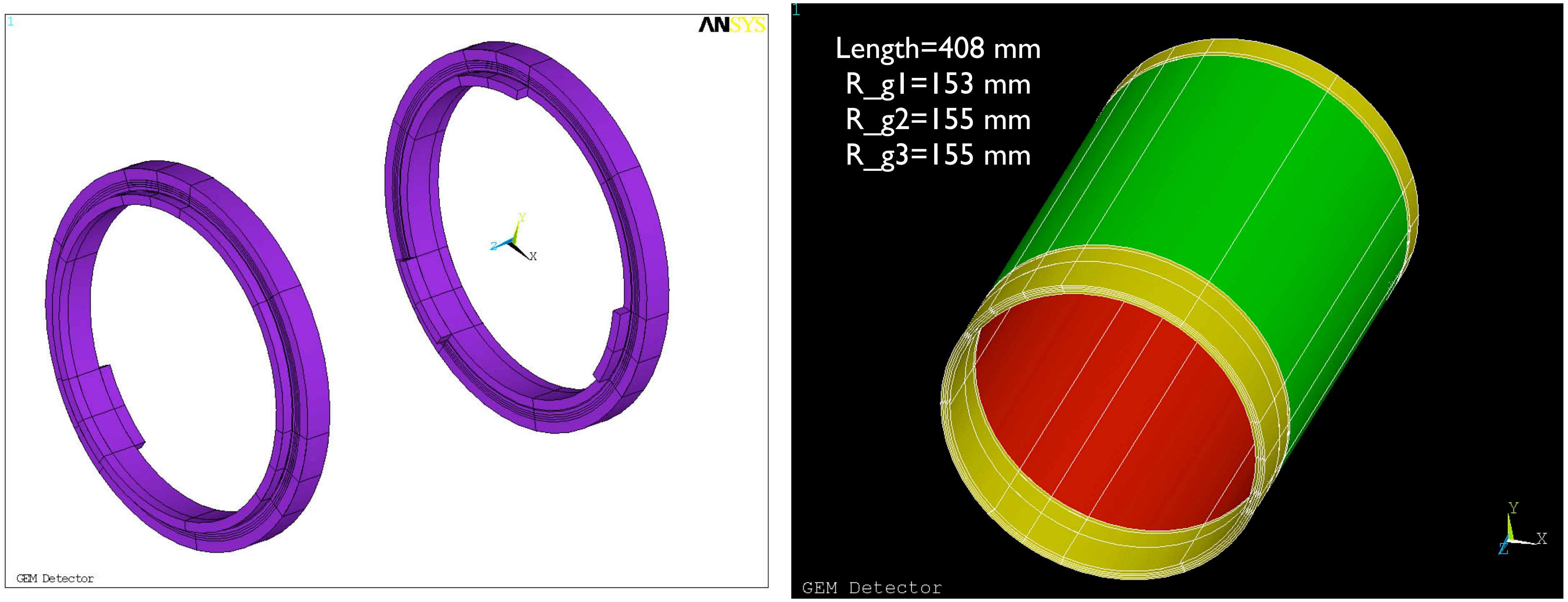
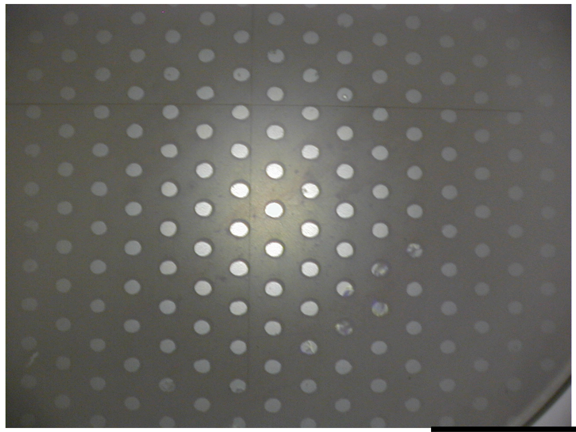
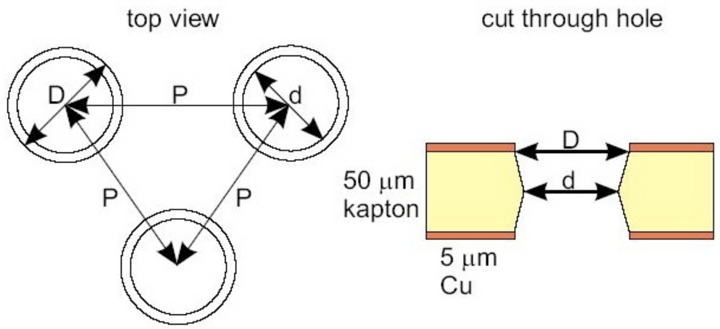


Figure 16: Volume entities in the model on the left (permaglass ring and brass plates); area entities on the right (different colors stay for different material)..

Gem: Ansys material model

The gem foil are represented as uniform thin shell: mass distributed all over the cylindrical surface





$$GEM \quad : \quad \rho_{GEM} = \left(\frac{2h_{cu-rid}\rho_{kap-rid} + h_{kap}\rho_{kap-rid}}{2h_{cu-rid} + h_{kap-rid}} \right)$$

gem-3 of prototype	Ansys Estimated Mass(g)	Measured Mass(g)	error
R=0.157 m L= 408 mm	68.5	68	0.7%

In such a way the inertial effect due to mass are preserved

GEM Detector Ansys Model

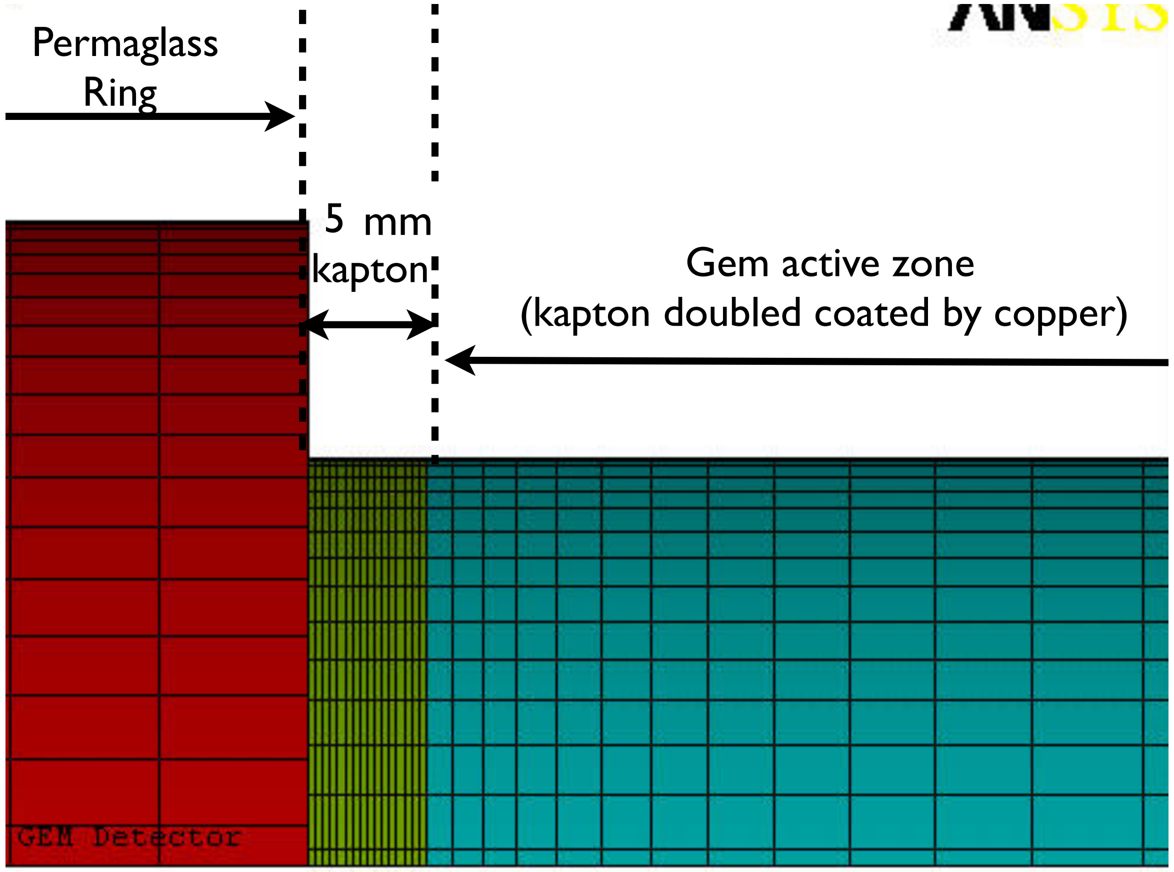
Component	Inner Radius [m]	Thikness [μm]	Equivalent density[kg/m3]	Linear El. Modulus [GPa]	Poisson Coefficient
Catode	0.150	100(Kap)+5(Cu)	1779	5.29	0.34
GEM-1	0.153	50(Kap)+10(Cu)	2291	4.8	0.335
GEM-2	0.155	50(Kap)+10(Cu)	2291	4.8	0.335
GEM-3	0.157	50(Kap)+10(Cu)	2291	4.8	0.335
Anode	0.159	100(Kap)+10(Cu)	2105	3.735	0.34

Table 3: Main geometric and material parameters

Gem Material and mesh in the F.E.Model

Volumes are meshed by solid 45/solid95

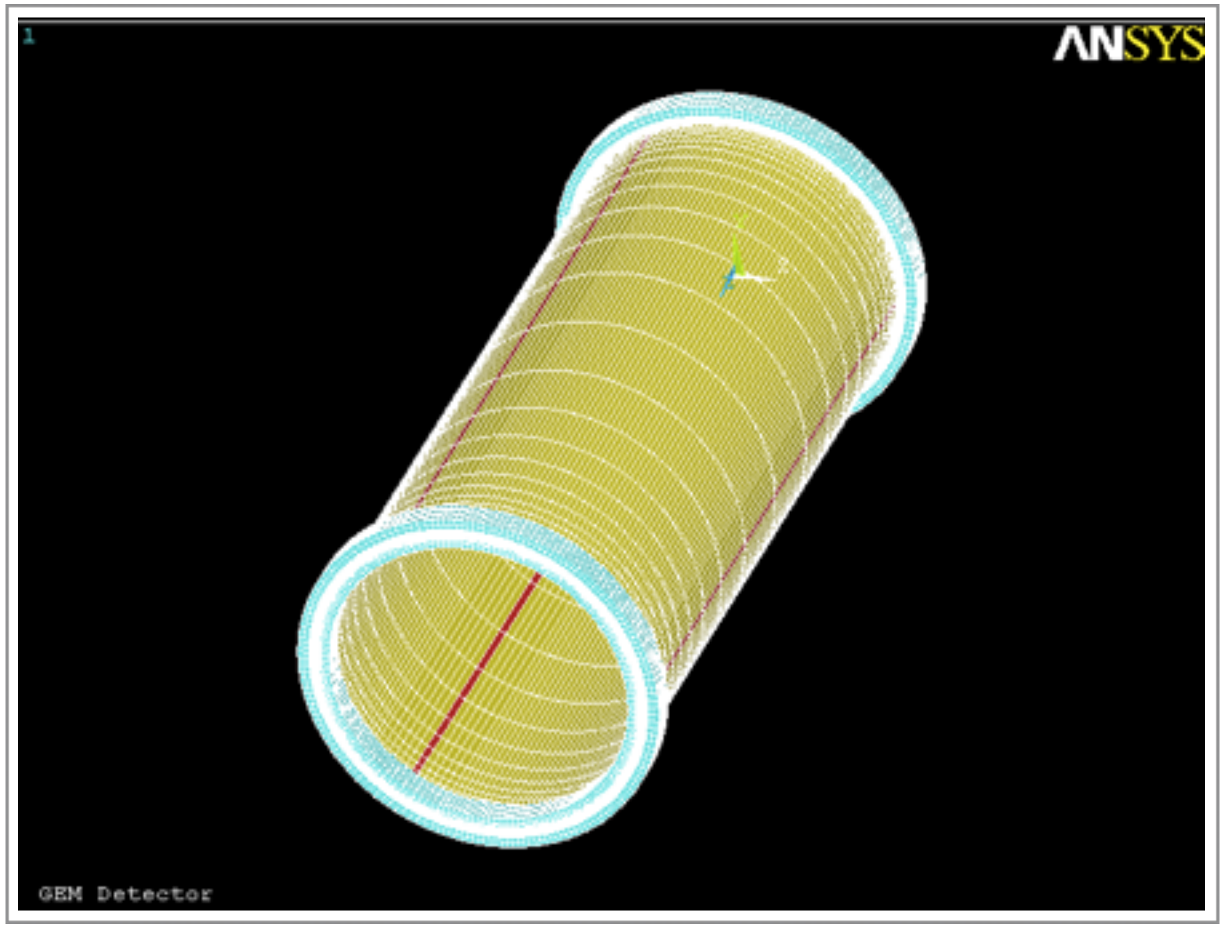
Areas are meshed by shell43/shell63/shell93



Permaglass Ring

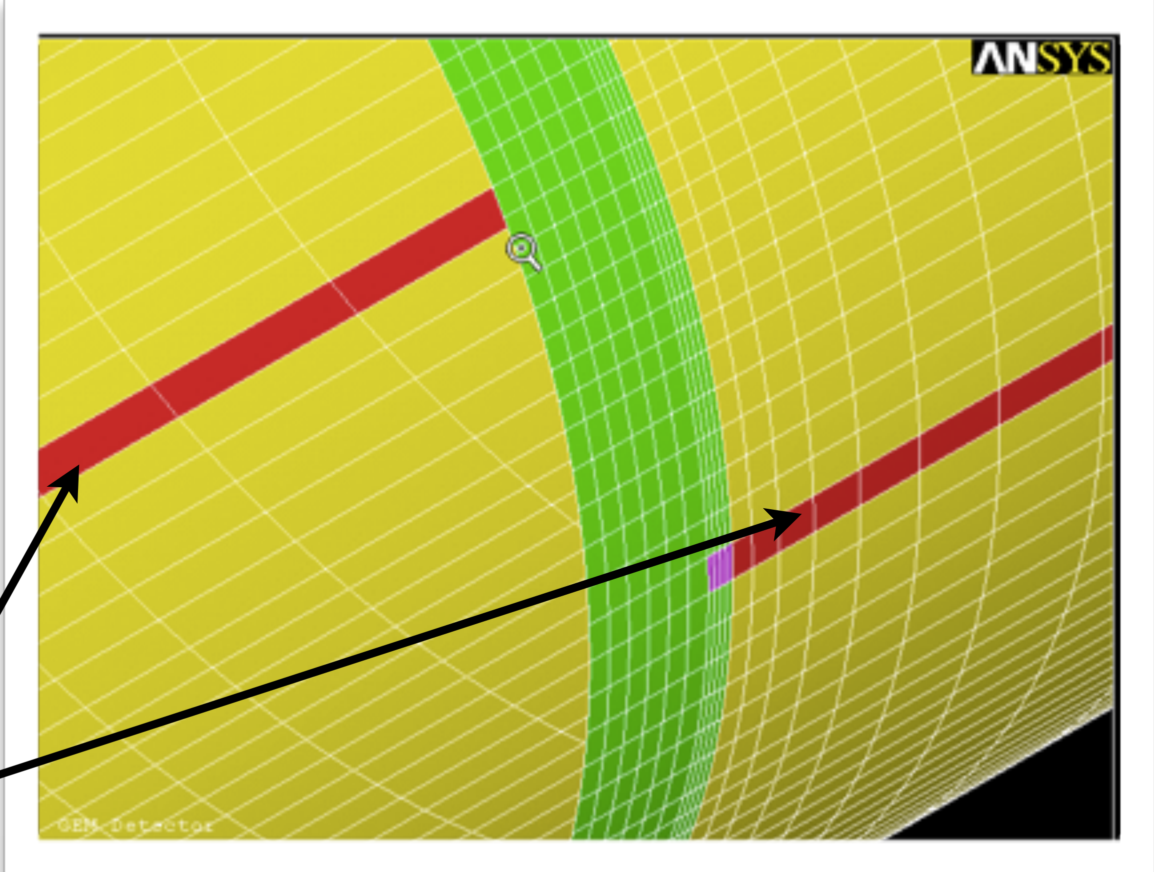
5 mm kapton

Gem active zone
(kapton doubled coated by copper)



h_glu = 2 · 50E-6 +10E-6 Glue thickness

yo_glu = 3.1E+9 +0.7E+9 Glue Shear Modulus

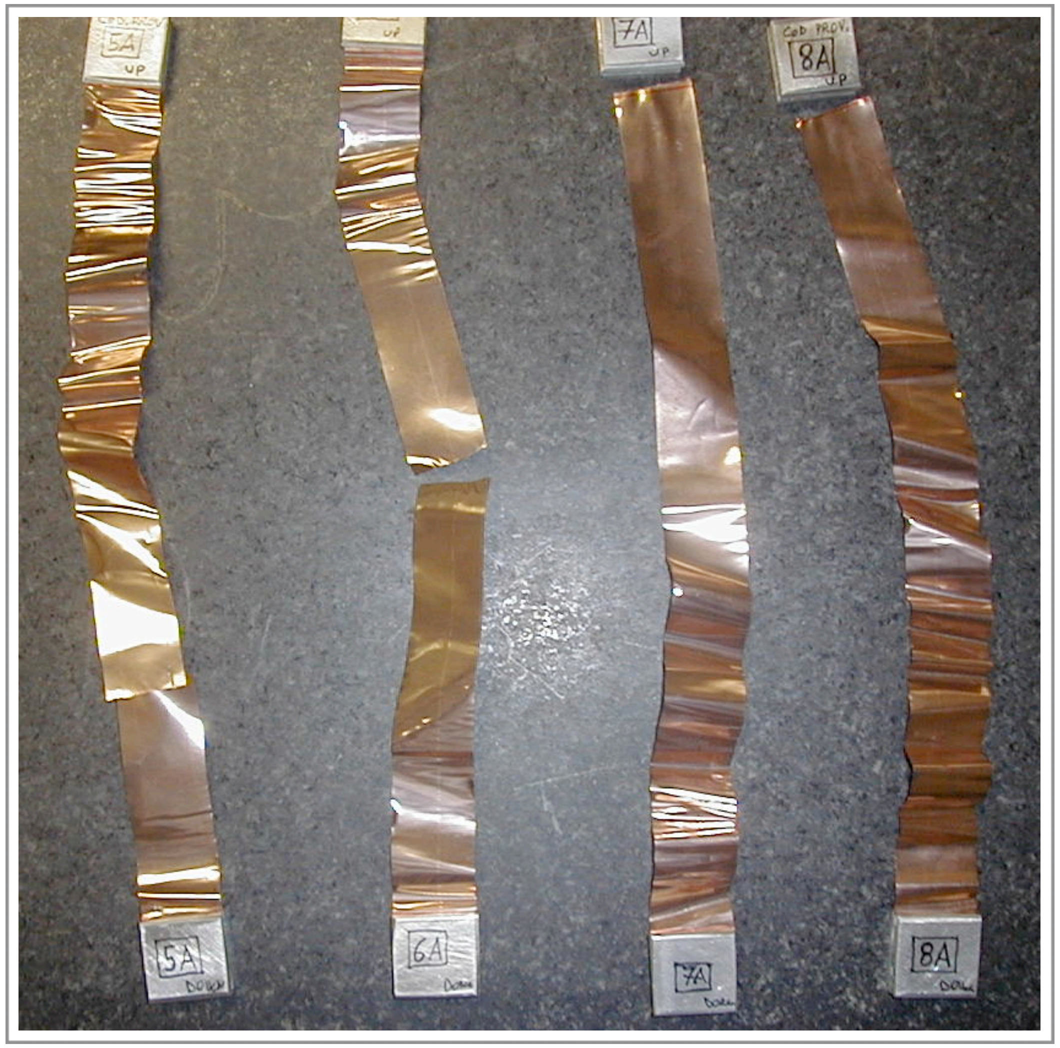


Gem glued foils:
kapton+epoxy+kapton

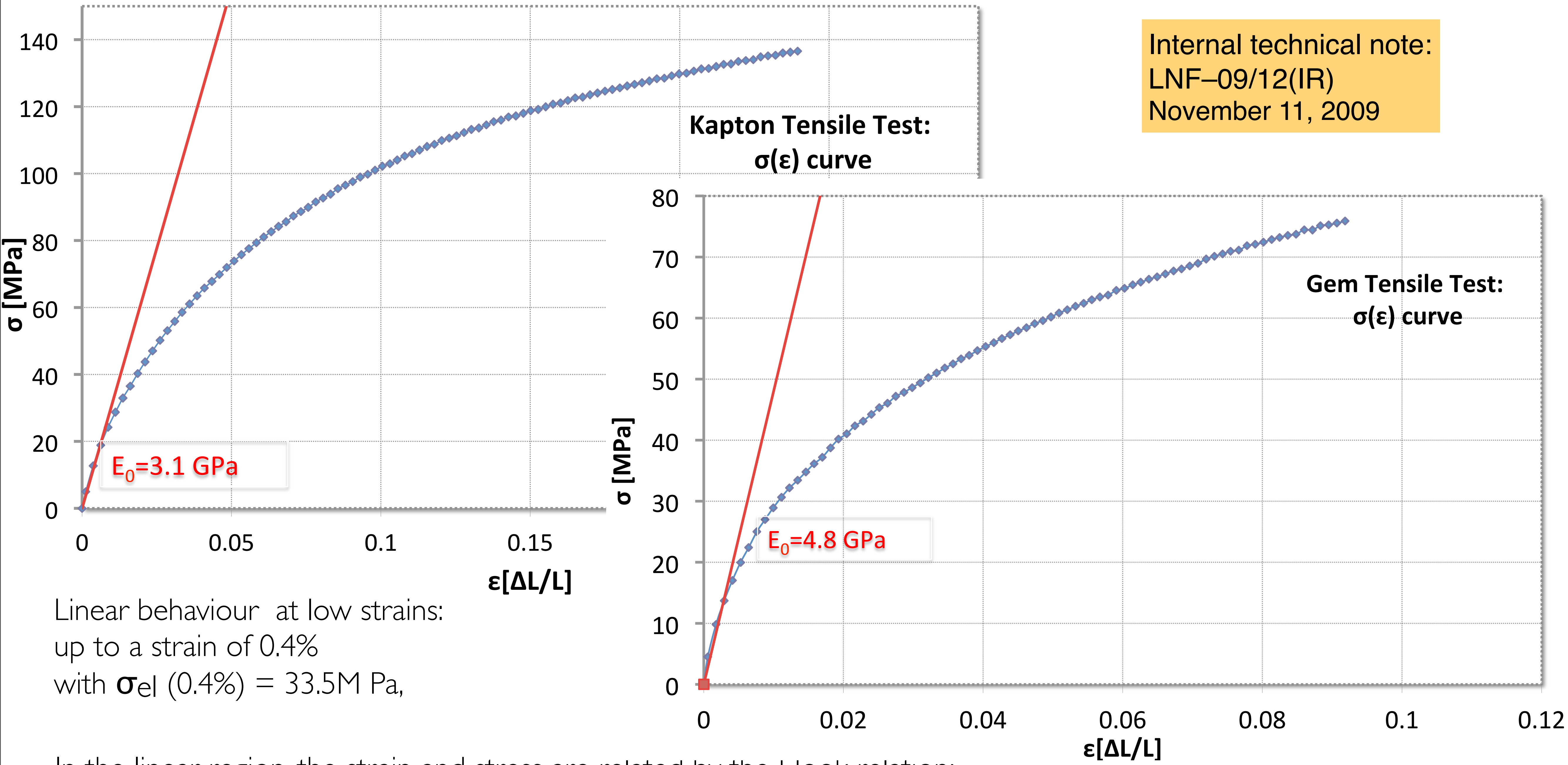
Tensile tests

LNF SSCR

- Gem foils are made of “non conventional” materials from the structural point of view.
- Limited documentations in literature for structural data (Young Modulus, yield stress, rupture stress...)



ε-σ curves



Internal technical note:
LNF–09/12(IR)
November 11, 2009

Linear behaviour at low strains:
up to a strain of 0.4%
with σ_{el} (0.4%) = 33.5M Pa,

In the linear region, the strain and stress are related by the Hook relation:

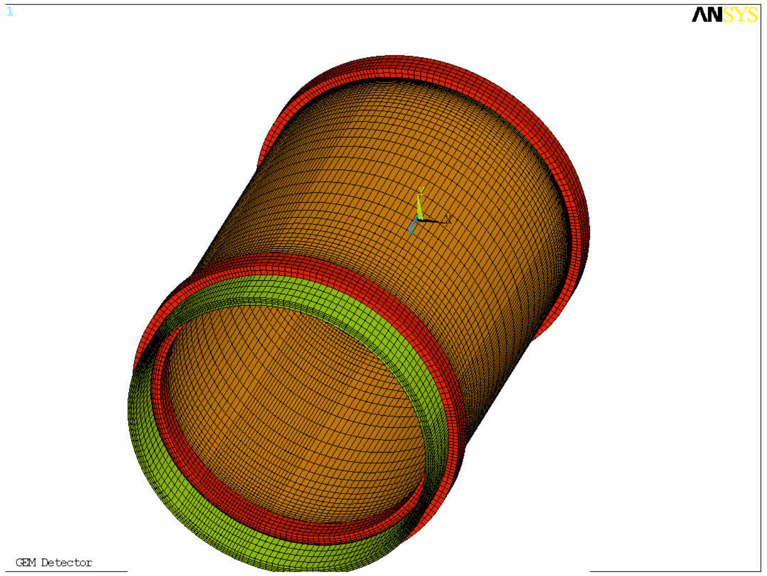
$\sigma = E_0 \varepsilon$, with **E_0 = 4.8 GPa** for the "gem".

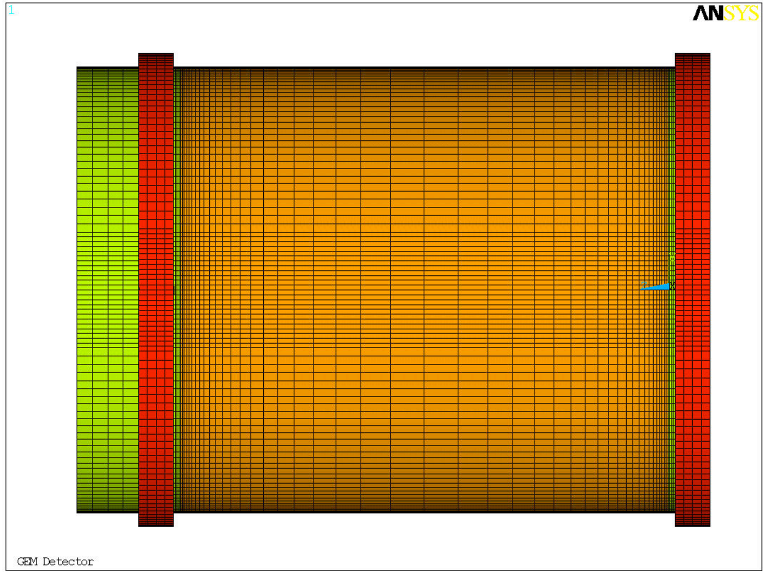
These experimental results imply that the GEM cylinders of Layer-2 (R_g1,2,3=0.153/0.155/0.157) are expected to exhibit elastic behaviour when the applied tensile load is below **1** kN

The ultimate tensile stress for the GEM material has been estimated to be σ_{ult} = 76 MPa with an expected elongation at breakdown of 9.2 %.

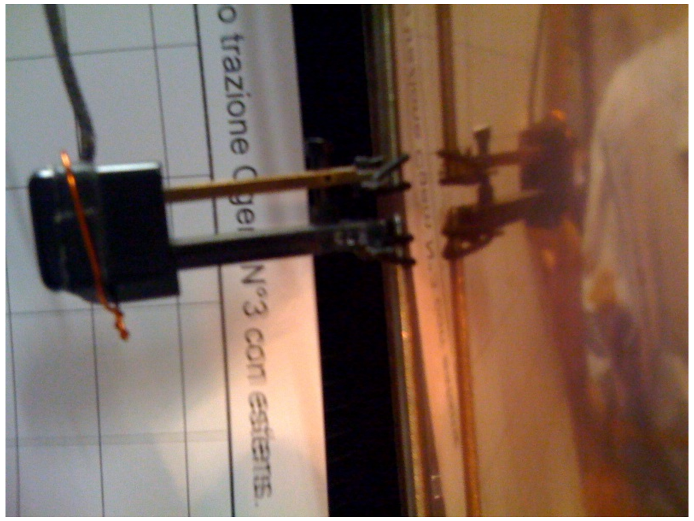
The mechanical failure of the GEM cylinders of Layer-2 is expected for tensile load greater than 4 kN

Validation of the model with the cylindrical prototype

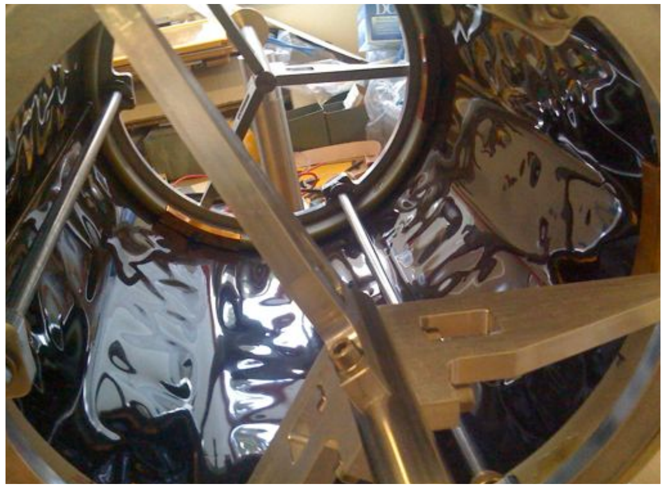




Enea Material Test Laboratory



Load N	Measured U_z by extensometer $[\mu m]$	Calculated U_z by Ansys $[\mu m]$
100	11.58	20.24
500	57.91	101.
1000	115.82	202.4
1500	173.73	303.6
2000	231.63	404.8
2500	289.54	506
3000	347.45	607.2



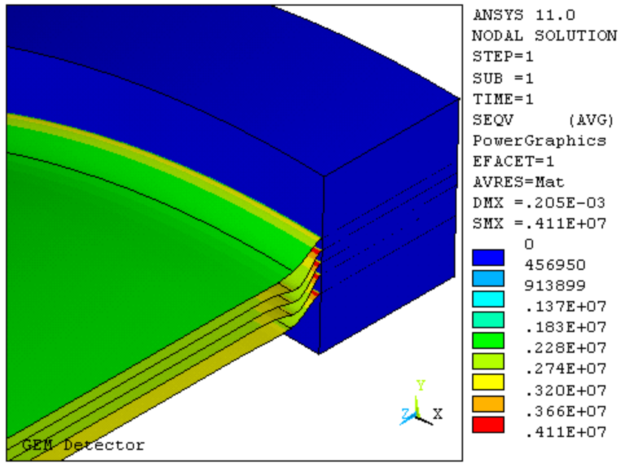
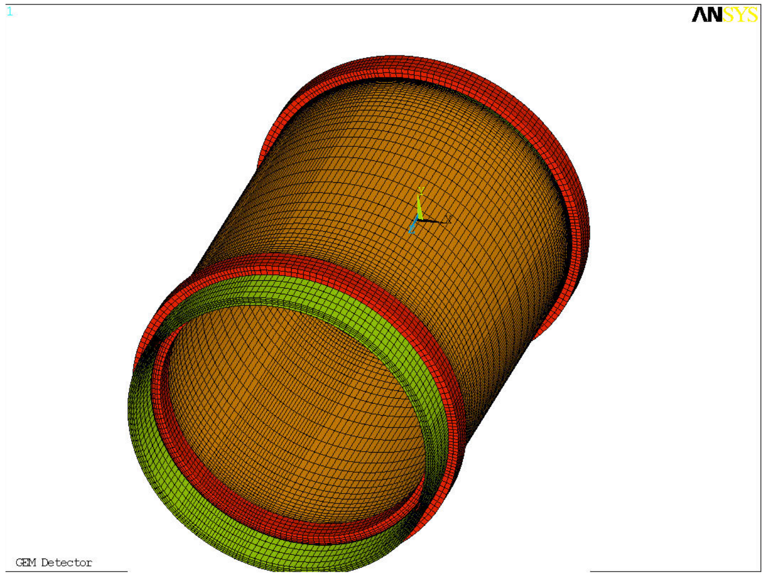
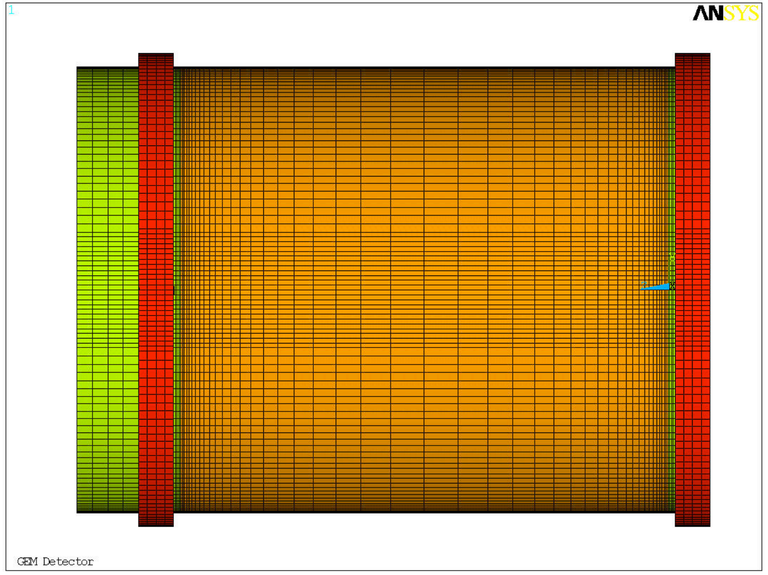


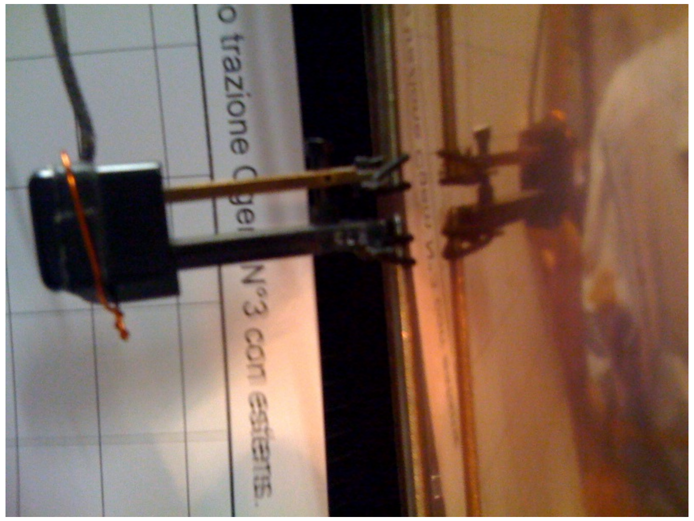
Figure 34: Maximum stress location in the GEM detector

Validation of the model with the cylindrical prototype



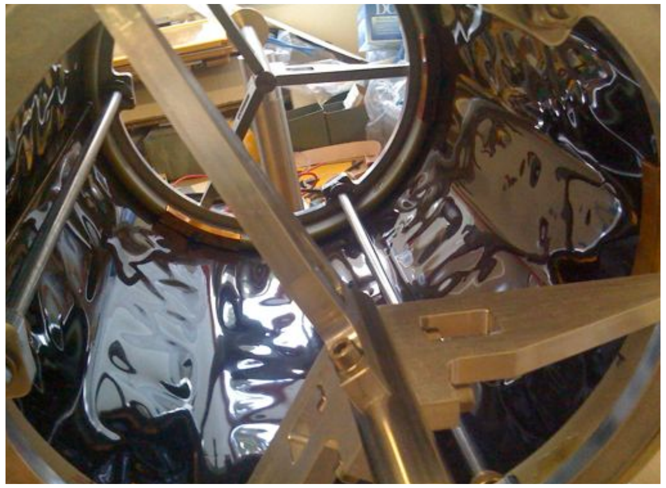


Enea Material Test Laboratory



Load N	Measured U_z by extensometer $[\mu m]$	Calculated U_z by Ansys $[\mu m]$
100	11.58	20.24
500	[illegible]	101.[illegible]
1000	11[illegible]	[illegible].4
1500	173.73	[illegible]
2000	231.63	404.8
2500	289.54	506
3000	347.45	607.2

There is a factor 1.7 ?



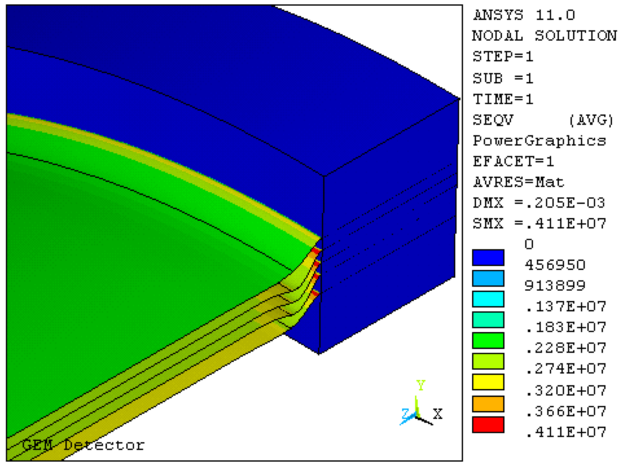
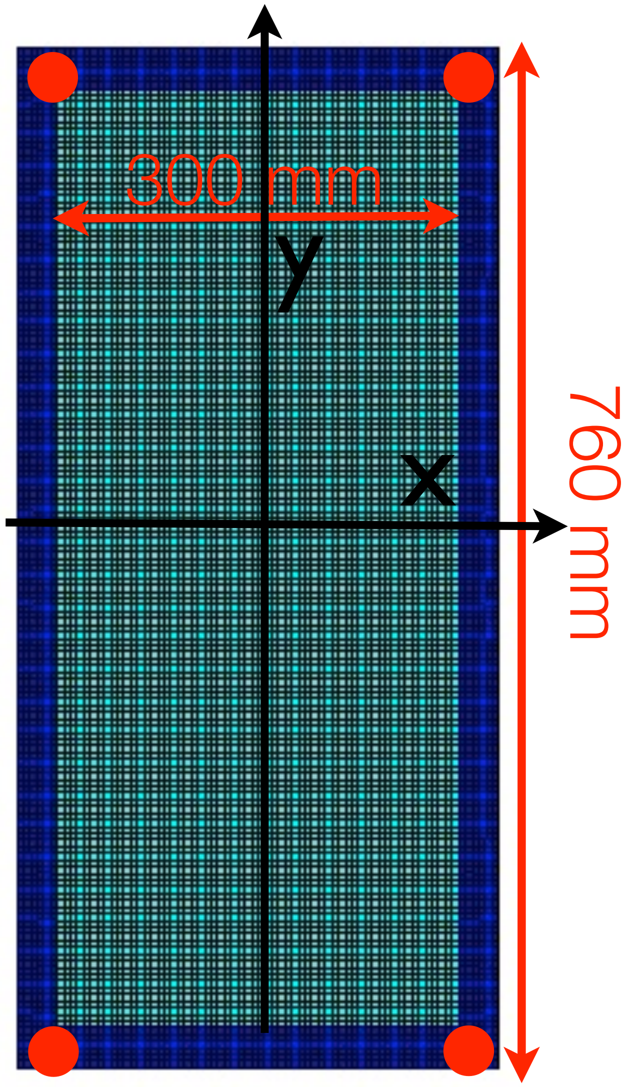
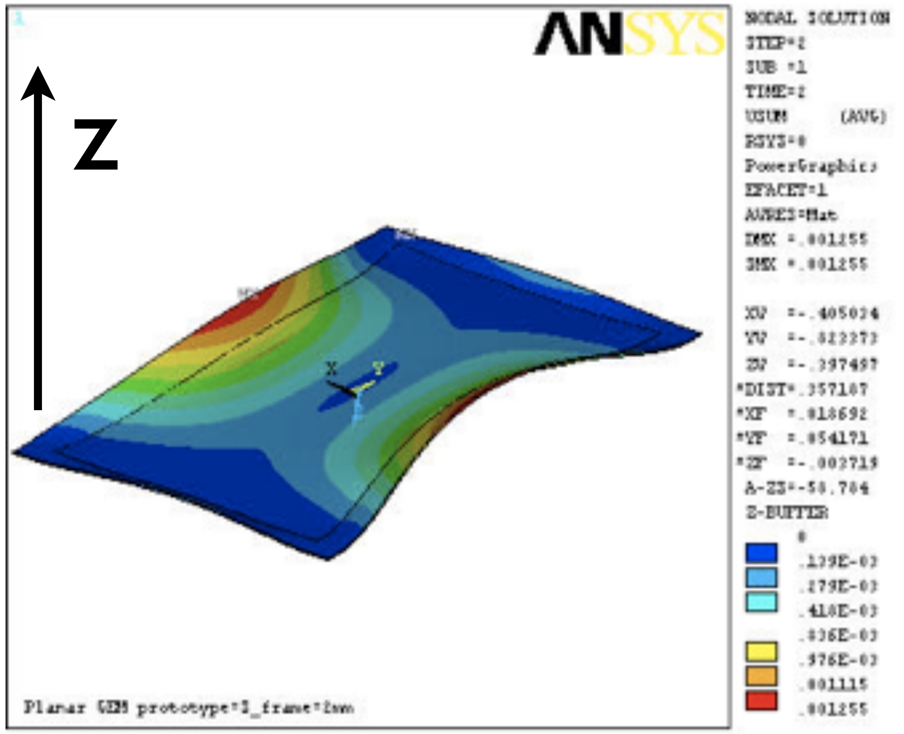
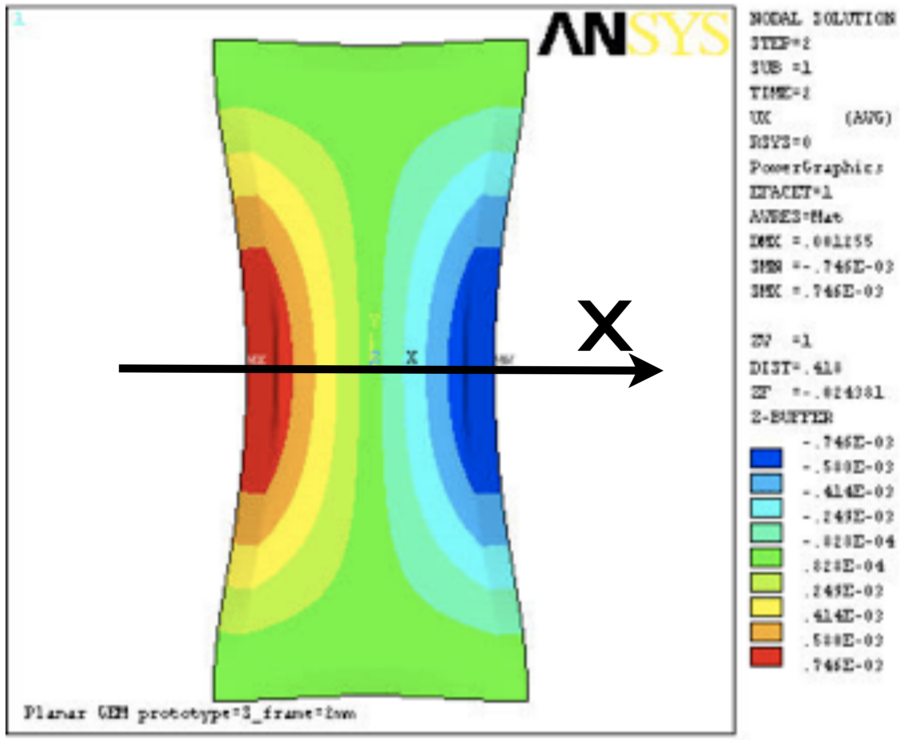


Figure 34: Maximum stress location in the GEM detector

The planar case:
excellent agreement between predictions and measurements







Planar Gem

•1) First pretensioned (sigma=1.638E+7 Pa)

•2) Glued on the permaglass frame.

•3) final configuration to which calculations refers is frame pinned only 4 at corners against a table

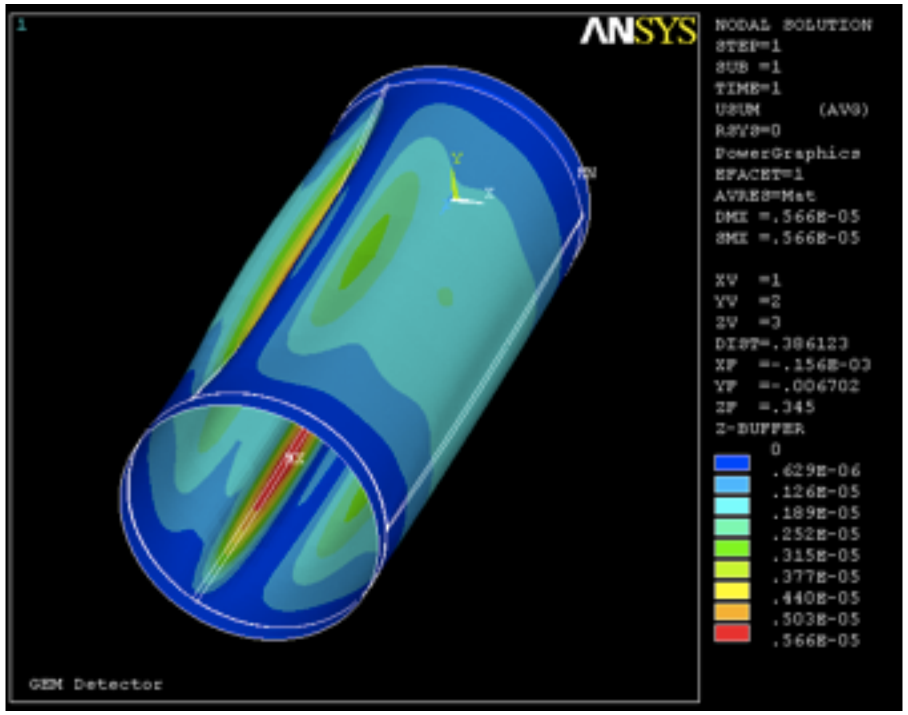
Calculated: Uz max (outside) = 1.009 mm (symmetric)	**Calculated:** UX= 0.746 mm (symmetric)
Measured: Uz max (outside) = 1.1 mm on both sides	**Measured:** UX= 0.7 mm on both sides

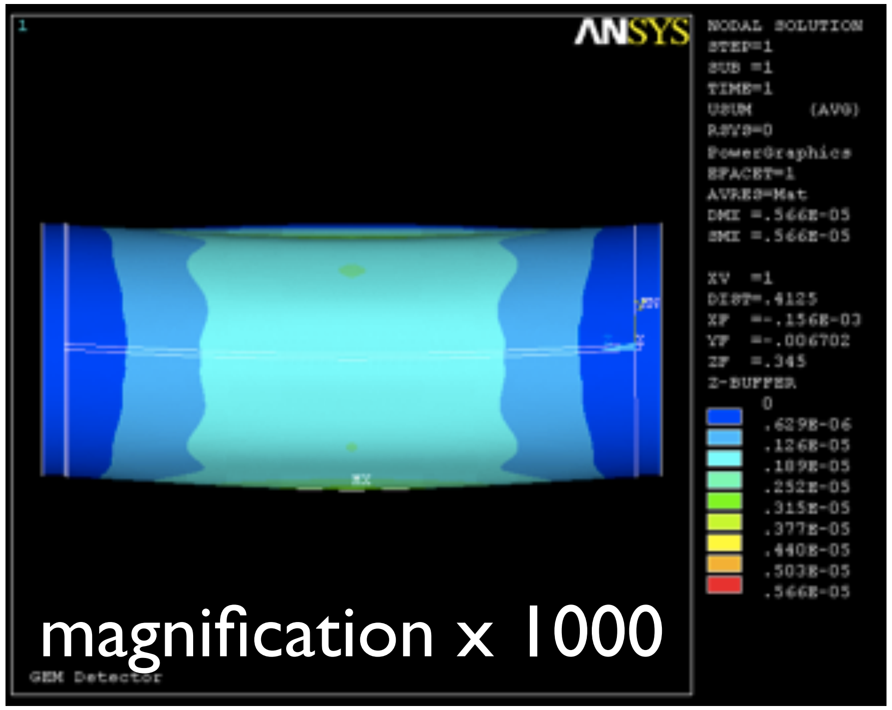
Difference(Meas-Calculated) < 6.5%

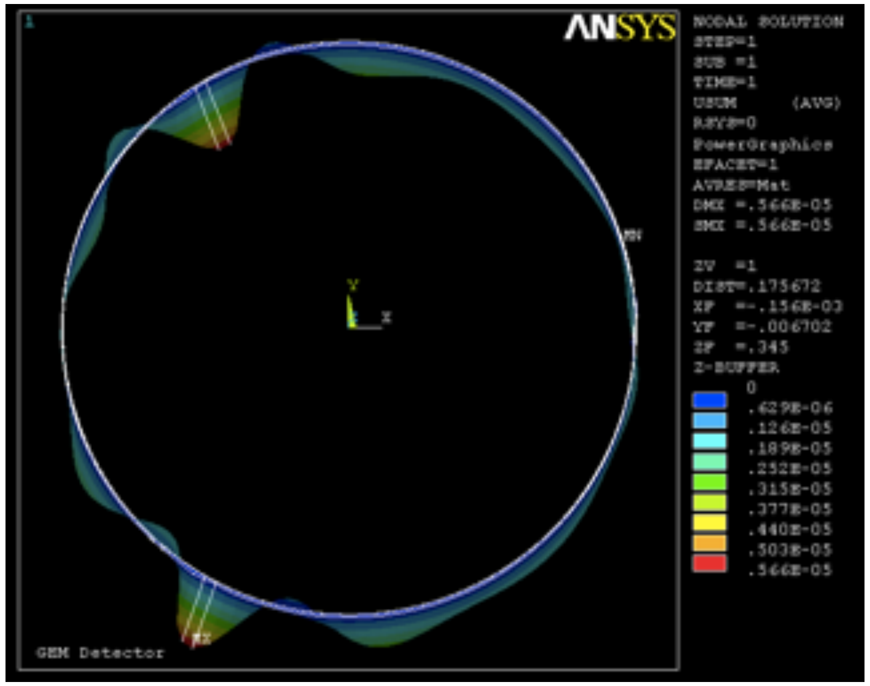
Some simulation results

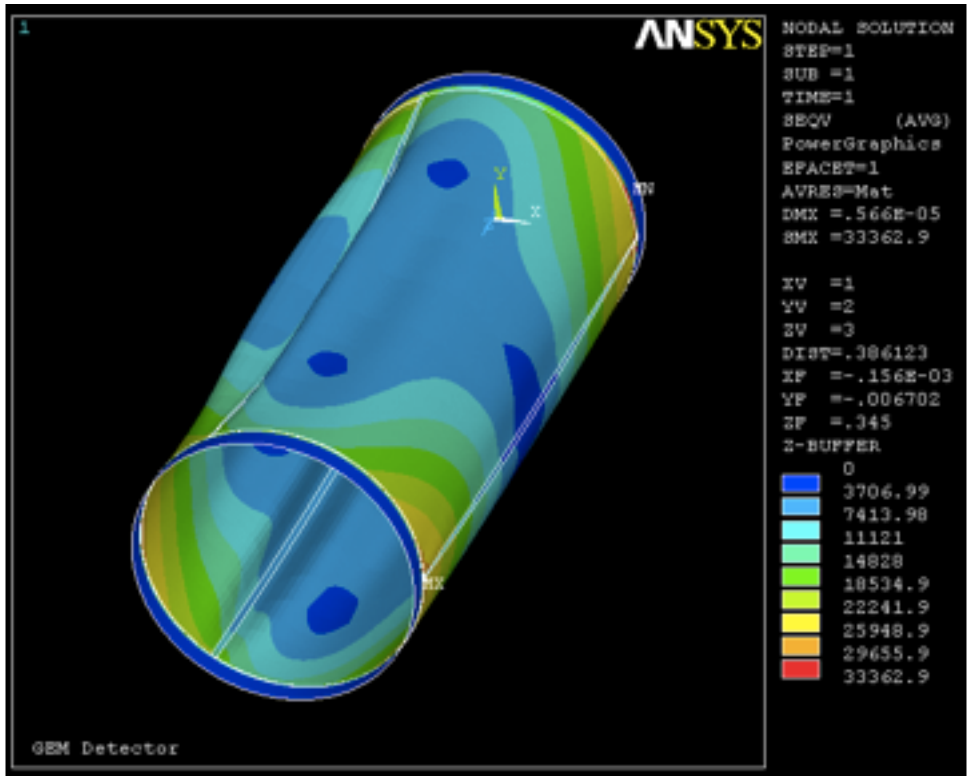
(static linear and non linear analysis)

Static under gravity: Gem1 of Cgem
(clumped at 1 end and free to move in axial direction at the other end)







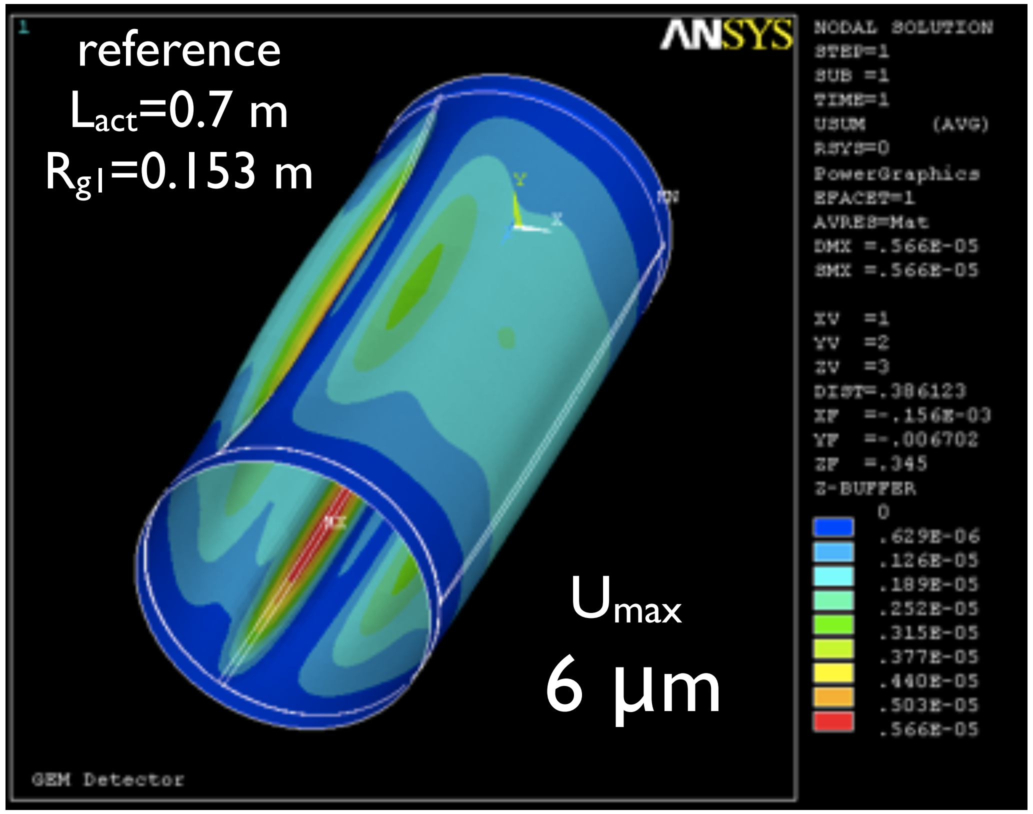


$L\_act=0.7$ m ; $R\_g1=0.153$ m

$U_{sum}\_$ max $=5.7$ E-6 m

$\sigma\_max= 0.3$ MPa

Gravity deformation versus gem linear dimension



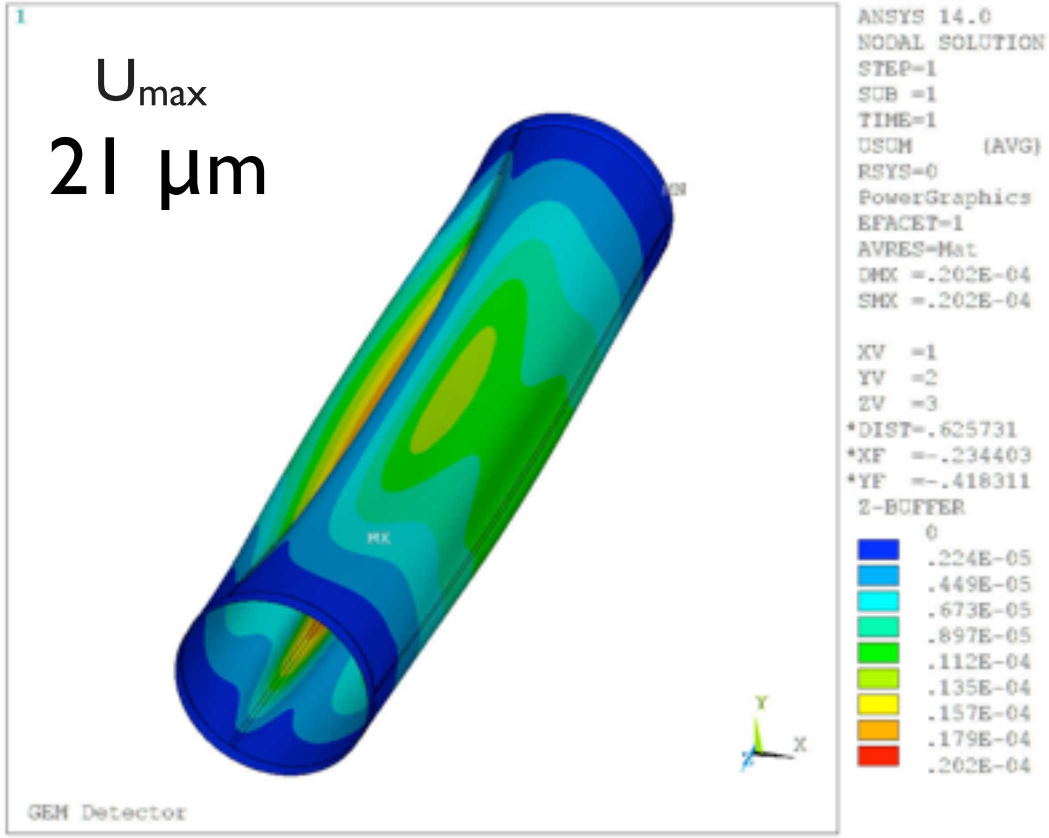
reference
L_{act}=0.7 m
R_{g1}=0.153 m

U_{max}
6 µm

```
NODAL SOLUTION
STEP=1
SUB =1
TIME=1
USUM       (AVG)
RSYS=0
PowerGraphics
EFACET=1
AVRES=Mat
DMX =.566E-05
SMX =.566E-05

XV  =1
YV  =2
ZV  =3
DIST=.386123
XF  =-.156E-03
YF  =-.006702
ZF  =.345
Z-BUFFER
     0
     .629E-06
     .126E-05
     .189E-05
     .252E-05
     .315E-05
     .377E-05
     .440E-05
     .503E-05
     .566E-05
```

R_{g1}=0.153 m $2 \cdot L_{act}$

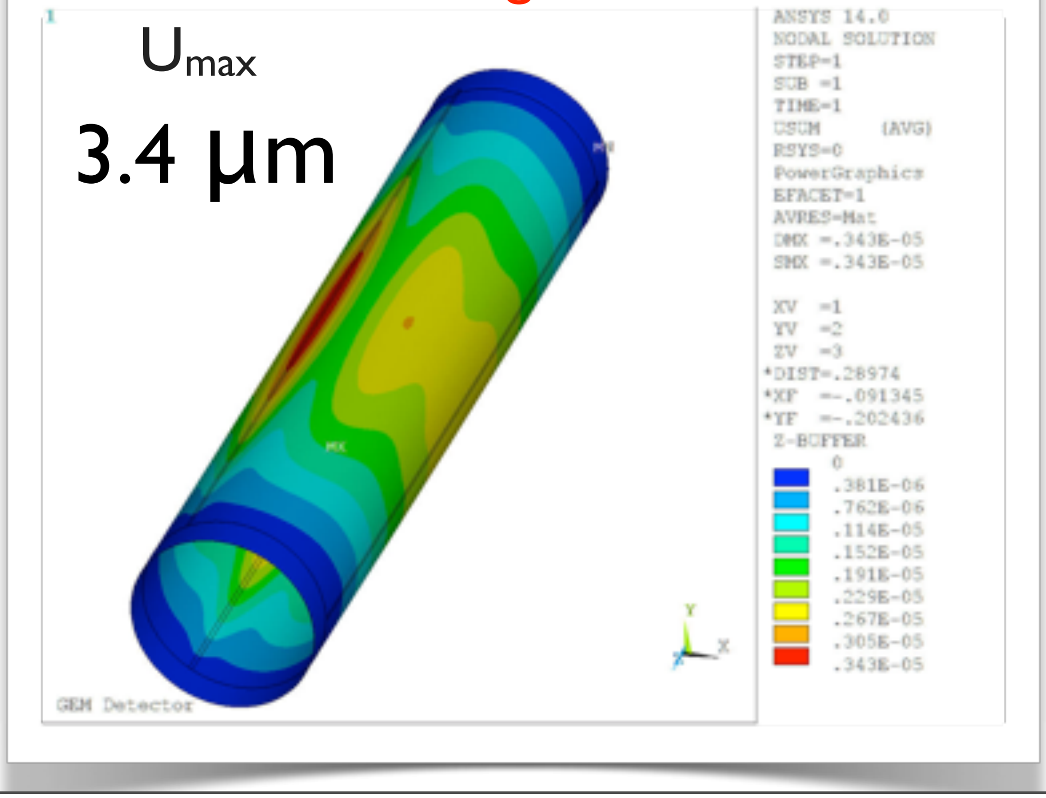


U_{max}
21 µm

```
ANSYS 14.0
NODAL SOLUTION
STEP=1
SUB =1
TIME=1
USUM       (AVG)
RSYS=0
PowerGraphics
EFACET=1
AVRES=Mat
DMX =.202E-04
SMX =.202E-04

XV  =1
YV  =2
ZV  =3
*DIST=.625731
*XF  =-.234403
*YF  =-.418311
Z-BUFFER
     0
     .224E-05
     .449E-05
     .673E-05
     .897E-05
     .112E-04
     .135E-04
     .157E-04
     .179E-04
     .202E-04
```

L_{act}=0.7 $R_{g1}/2$=0.076

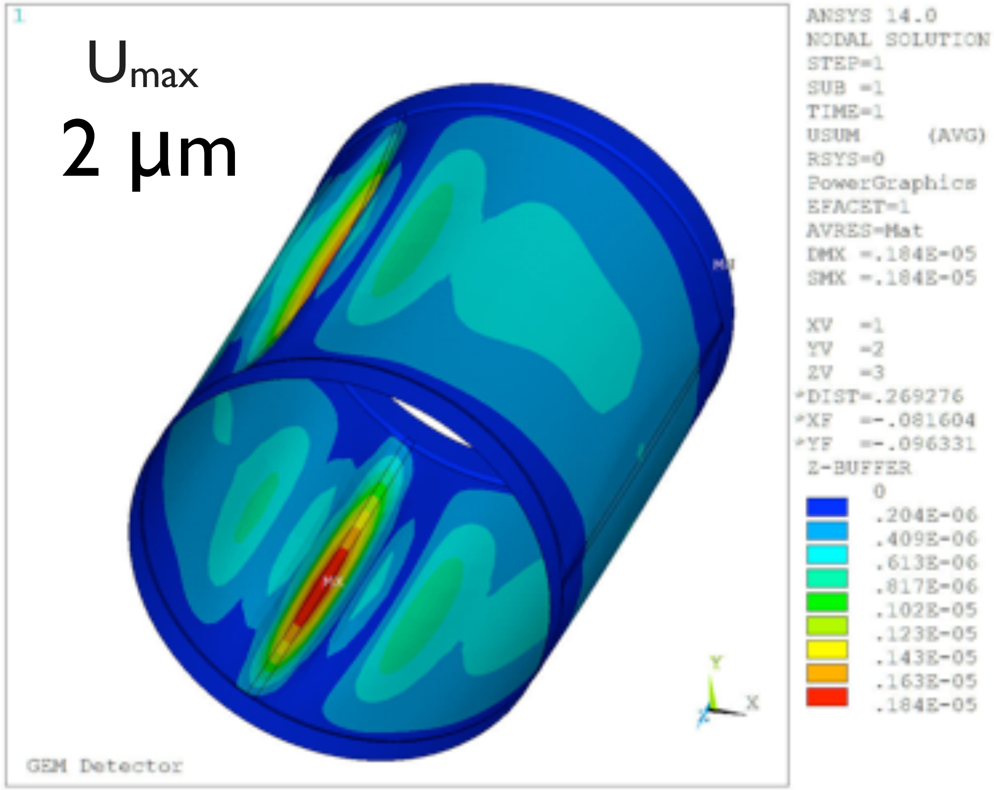


U_{max}
3.4 µm

```
ANSYS 14.0
NODAL SOLUTION
STEP=1
SUB =1
TIME=1
USUM       (AVG)
RSYS=0
PowerGraphics
EFACET=1
AVRES=Mat
DMX =.343E-05
SMX =.343E-05

XV  =1
YV  =2
ZV  =3
*DIST=.28974
*XF  =-.091345
*YF  =-.202436
Z-BUFFER
     0
     .381E-06
     .762E-06
     .114E-05
     .152E-05
     .191E-05
     .229E-05
     .267E-05
     .305E-05
     .343E-05
```

R_{g1}=0.153 $L_{act}/2$



U_{max}
2 µm

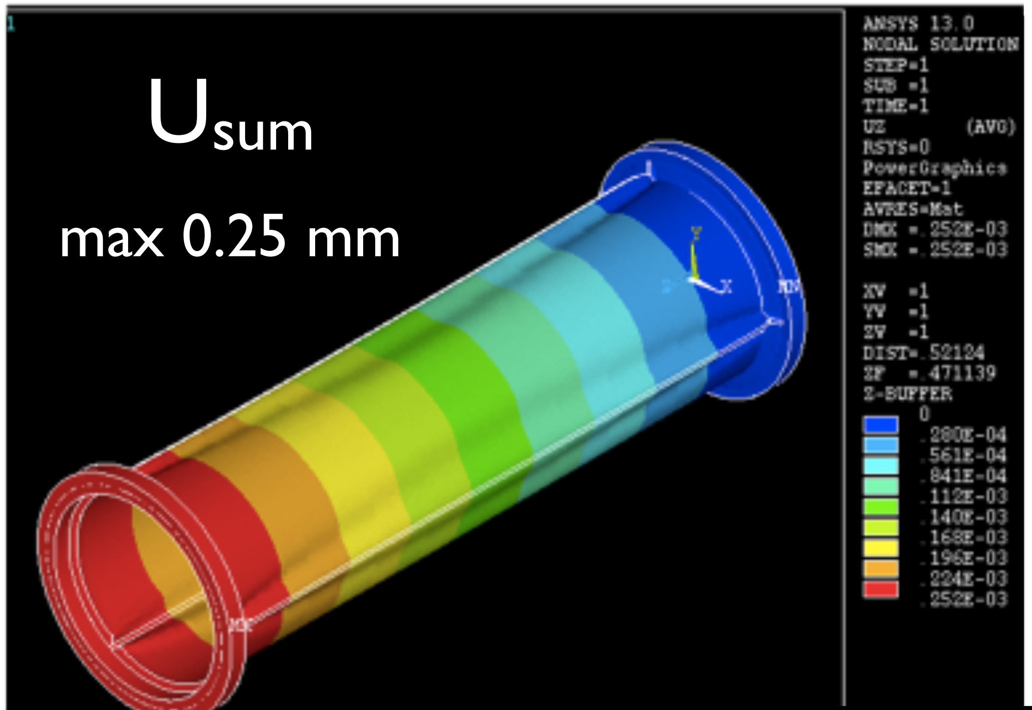
```
ANSYS 14.0
NODAL SOLUTION
STEP=1
SUB =1
TIME=1
USUM       (AVG)
RSYS=0
PowerGraphics
EFACET=1
AVRES=Mat
DMX =.184E-05
SMX =.184E-05

XV  =1
YV  =2
ZV  =3
*DIST=.269276
*XF  =-.081604
*YF  =-.096331
Z-BUFFER
     0
     .204E-06
     .409E-06
     .613E-06
     .817E-06
     .102E-05
     .123E-05
     .143E-05
     .163E-05
     .184E-05
```

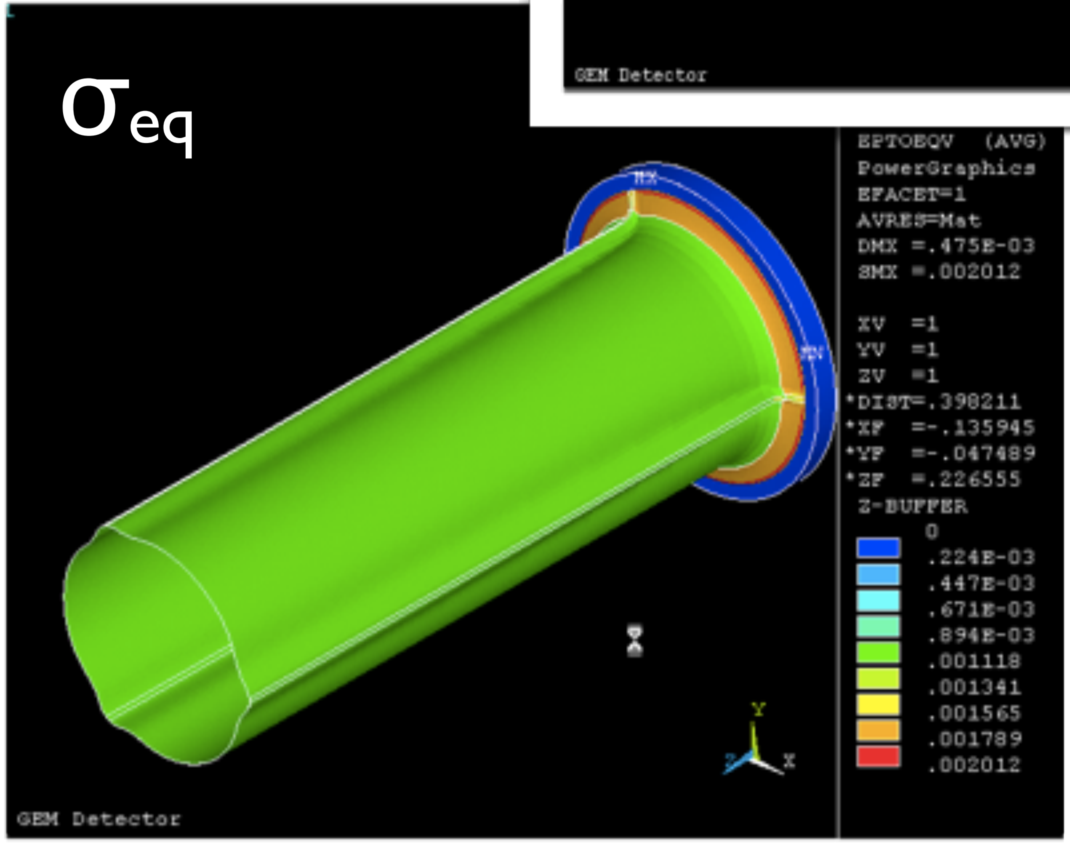
Stretching or not stretching? this is the problem...

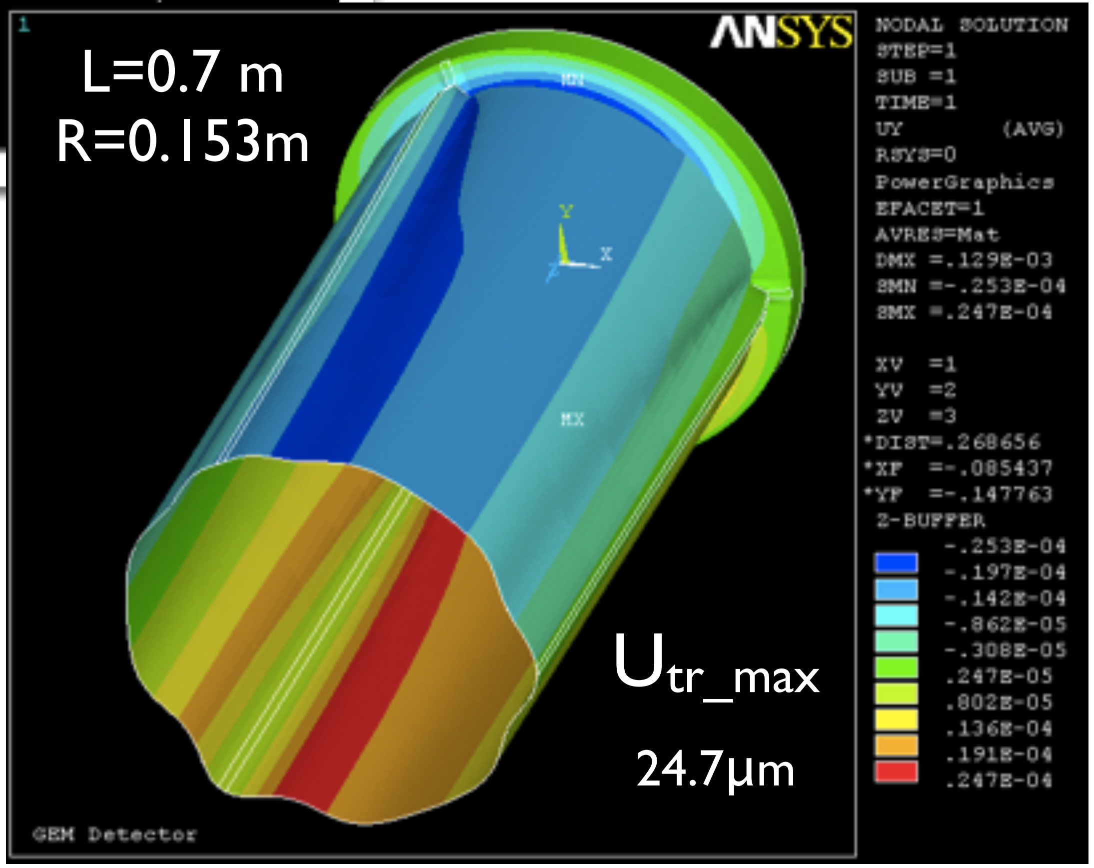
The elongation of a single cylindrical gem for Layer-2 in linear regime (that is tensile load < 1000N) is: **DL/L/F = 3.57 micron/m/N**

- Deformation under tensile load (picture refers to P=100 N)
- ripples around glued strips: transversal deformation increases with the tensile load
- the main drawback is the lost of homogeneity in azimuthal sense



- G1: L_{act}=0.7m, R_{g1}=0.153
- Tensile load: 100 N, distributed uniformly on the flat surface of the left side permaglass ring .





Thermal Simulation

Linear expansion coefficient

$$\alpha_{eq} = \frac{2\alpha_{cu}E_{cu}\delta_{cu} + \alpha_{kap}E_{kap}\delta_{kap}}{2E_{cu}\delta_{cu} + E_{kap}\delta_{kap}}$$

α_cu=1.6E-5/K
δ_cu=5.E-6m

α_kap= 2.E-5/K
δ_kap=50.E-6m

For copper, values for bulk have been used, but we know these could be different from those of the same materials worked as film

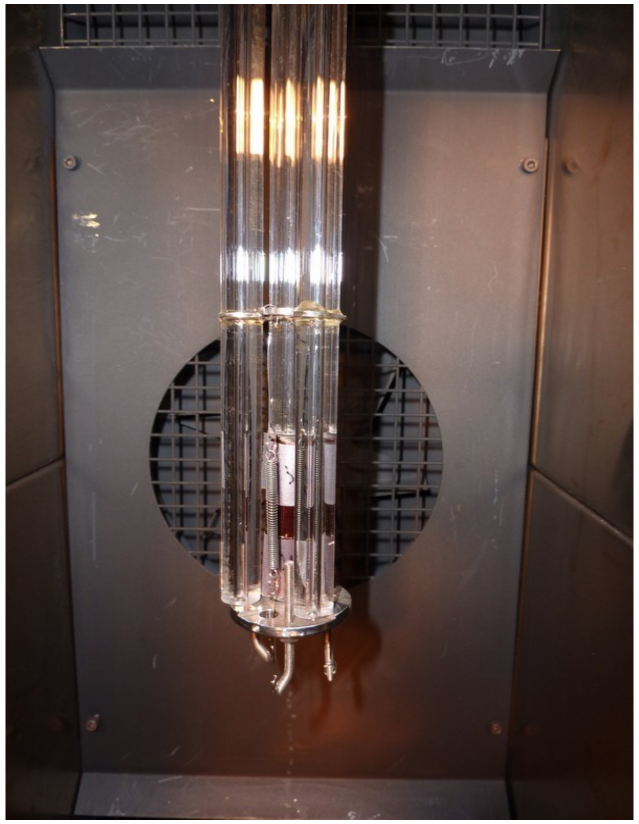
DuPoint catalog for polyamide films

Theoretical estimation: 16.9 μm/m °C for T∈ (22- 100 ° C)

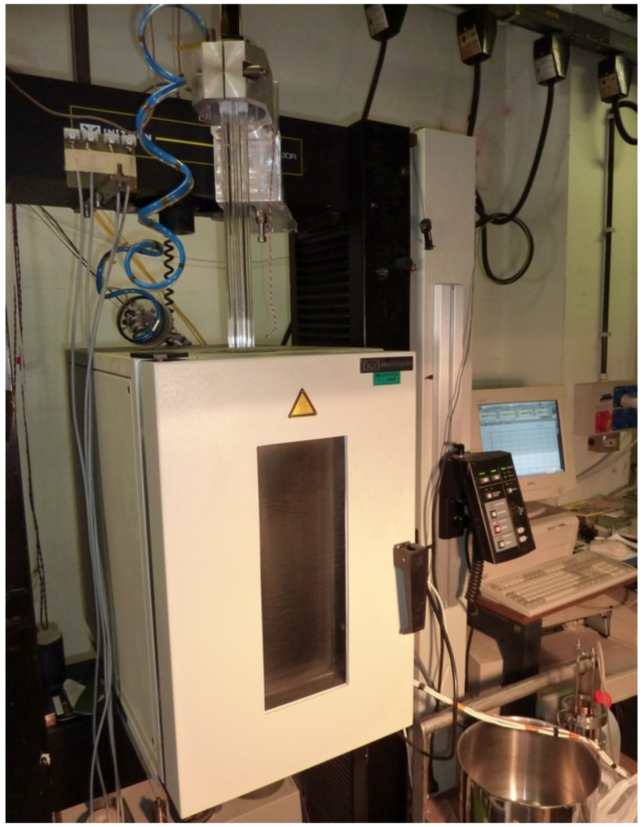
Specimens for thermal tests and experimental apparatus

Kapton Specimens Gem Specimens

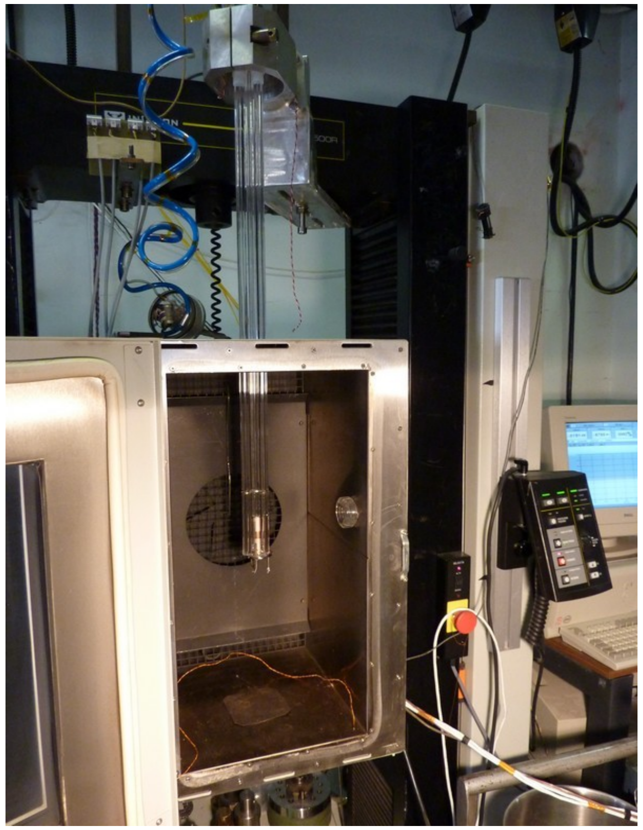
Preparation of specimens



Specimen in the quartz gauge



Gauge in the oven 1



Gauge in the oven 2

INFN - LNF
S.Cerioni - G.Morello 25/11/2011
Test presso ENEA Frascati
Laboratorio Sig. L.Bettinali

Thermal tests

Measurement of the linear expansion coefficient of Gem

	Specimen height	Initial Temperature	Temp 1 ΔL (μm) α (μm/m/°C)	Temp 2 ΔL (μm) α (μm/m/°C)	Temp 3 ΔL (μm) α (μm/m/°C)
Kapton Specimen n.1	52.2 mm	23.9 °C	100 °C 99 micron **24.9**	78 °C 83 micron **29.4**	75 °C 77 micron **28.9**
Kapton Specimen n.2	52.5 mm	21.8 °C	100 °C 120 micron **29.2**	40°C 26 micron **27.2**	
Gem Specimen n.1	53.8 mm	22 °C	100 °C 75 micron **17.9**		
Gem Specimen n.2	52.3 mm	23.5 °C	100 °C 67 micron **16.7**		
		20.8 °C	100 °C 69 micron **16.6**		

Data Sheet Kapton
Coefficente Dilatazione Termica Lineare da 14 a 38 °C = 20 μm/m-°C
" " " da 100 a 200 °C = 32 μm/m-°C

Data Sheet Rame
Coefficente Dilatazione Termica Lineare da 20 a 100 °C = 16.4 μm/m-°C

- Kapton and Copper have almost the same thermal expansion coefficient. This makes negligible the interface stress at higher temperature
- The measured value of α for gem is 17 μm/m/°C, in agreement with the theoretical estimation
- The thermal stress have to be considered if the anode and cathode are made of almost rigid material

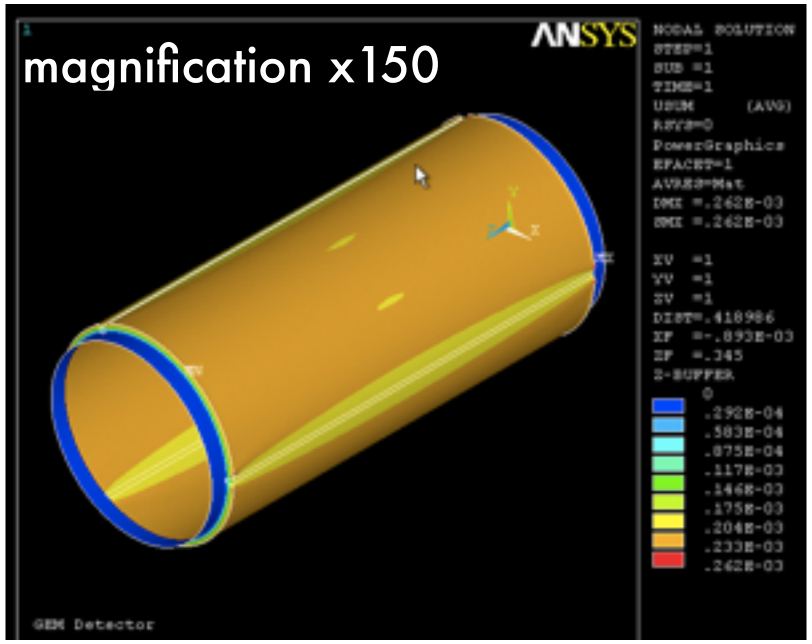
pg1

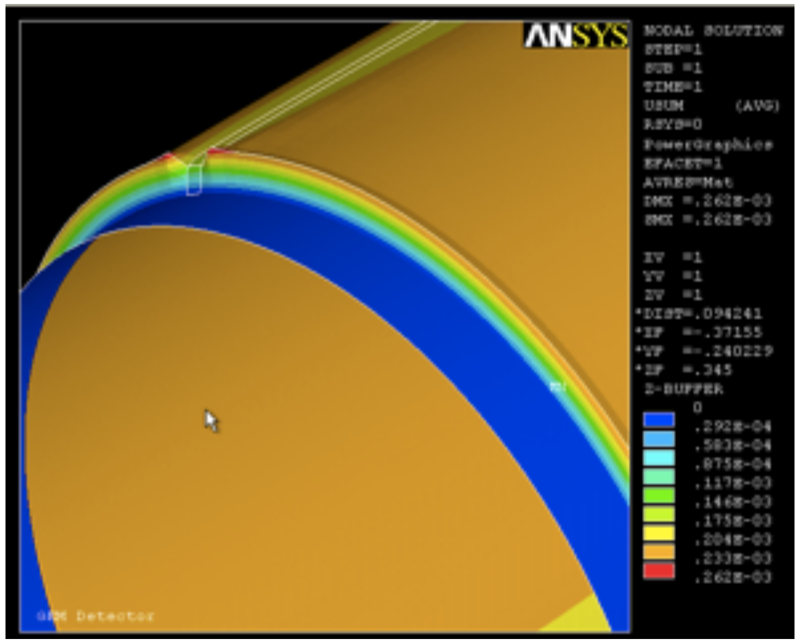
Thermal load: dT (uniform and equal distribution) Real Length Cgem clumped (on both ends)

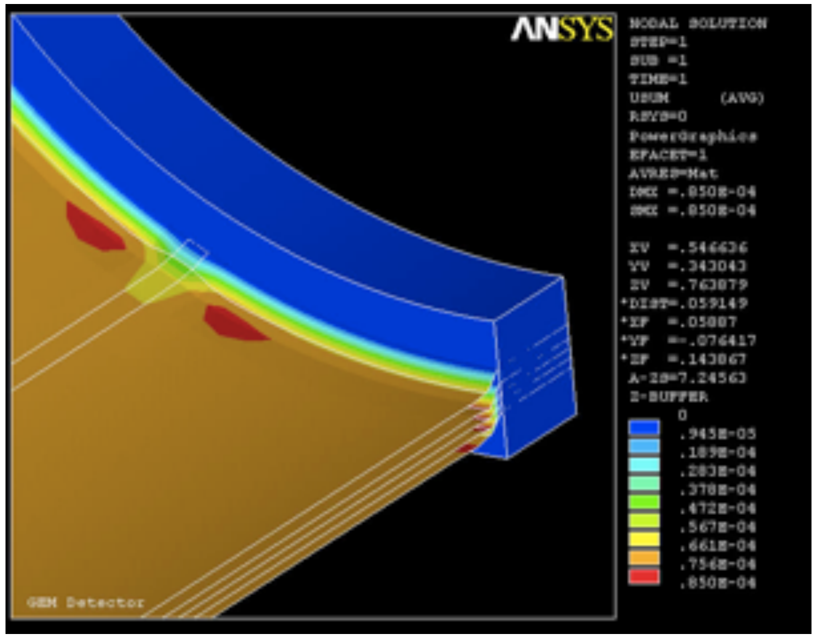
Thermal deformation and stress have been calculated for both ends clumped: actually the carrbon fiber of anode is much more rigid than gem foil reproducing a similar boundary condition

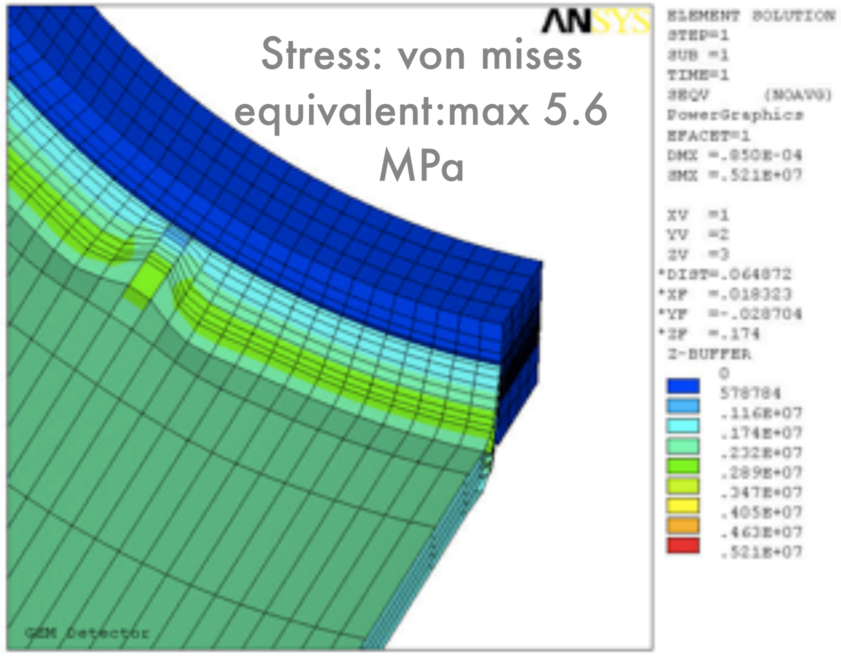
Results for G1 (inner gem) L=0.7 m R_0.153 mm

ΔT	uz [E-6 m]	u_rad [E-6 m]
20	0	71
40	0	141
60	0	248









Stress: von mises equivalent:max 5.6 MPa

Conclusions

- The Cgem is a complex object from the mechanical point of view
- Some important tests of important thermo-mechanical parmaters have been performed
- There can be issues related to the dimensions of the detector: some critical deformations can have different weight depending on the final dimensions, so that different strategy could be necessary to fix them
- A finite element model with Ansys has been realised and validated. It is an important predictive and analysis tool (predictions well in agreement with observations).
- This model can be used also to study the detector behaviour under electrostatic force (multiphysics analysis on the same model is more effective than using different codes)