Validation of the Mechanical Design of the BESIII Cylindrical GEM Tracker against Buckling-induced Deformation

Presented by Stefano Gramigna on behalf of the CGEM-IT Group

Forum on Tracking Detector Mechanics 2023, 31st of May 2023, Tübingen

Università degli Studi di Ferrara

Contact information: gramigna@fe.infn.it

Outline

- Introduction
  Scientific context, principle of functioning, mechanical design
- Drop test of a CGEM detector mockup with PEEK spacer grids
  Mockup construction, characterization of the accelerometers, results
- Conclusions

Introduction

Beijing Spectrometer III

Standard configuration general purpose detector

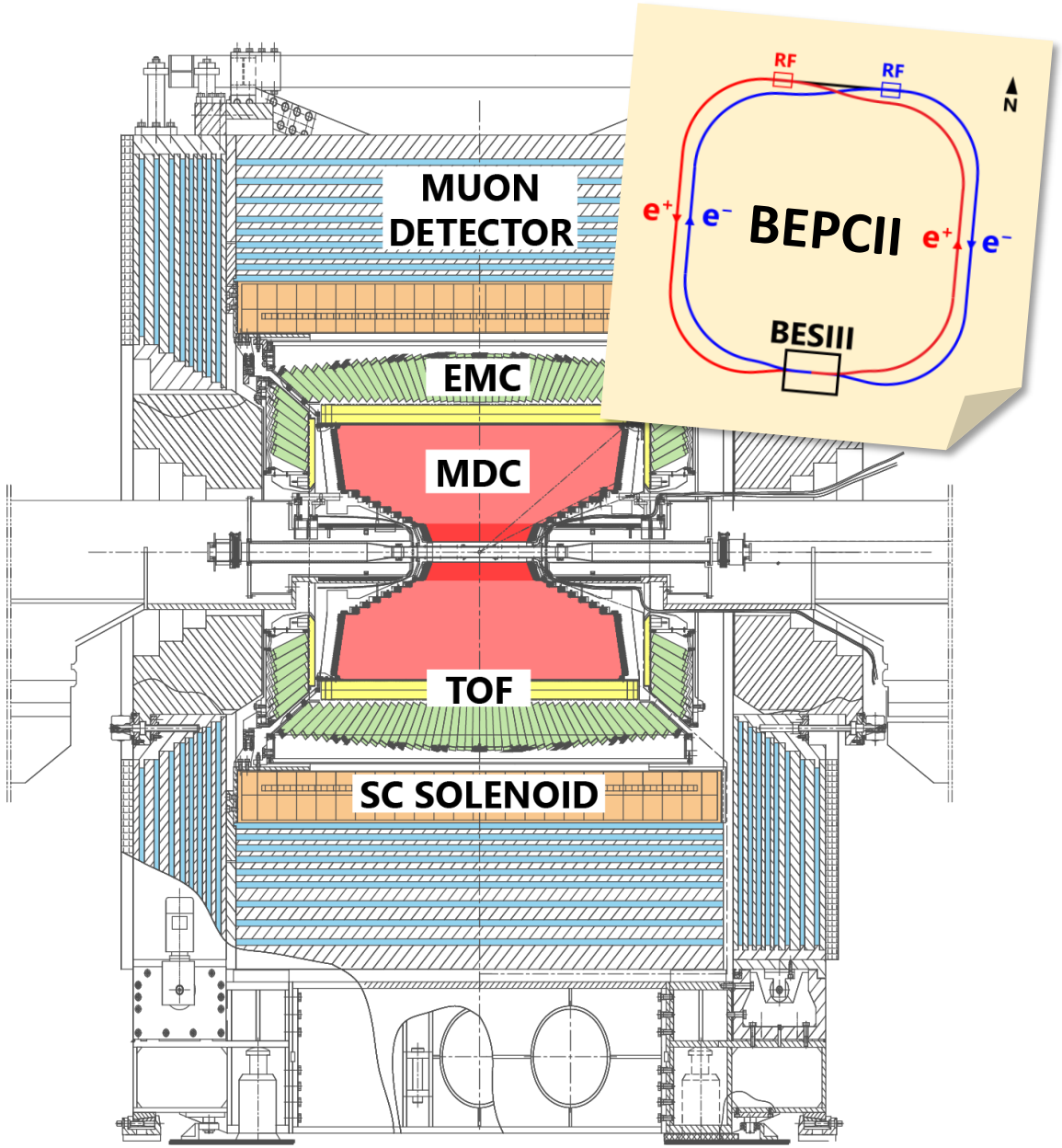
Energy range: 2.00 ÷ 4.96 GeV

Peak luminosity of the IP: 10^{33} cm^{-2} s^{-1}

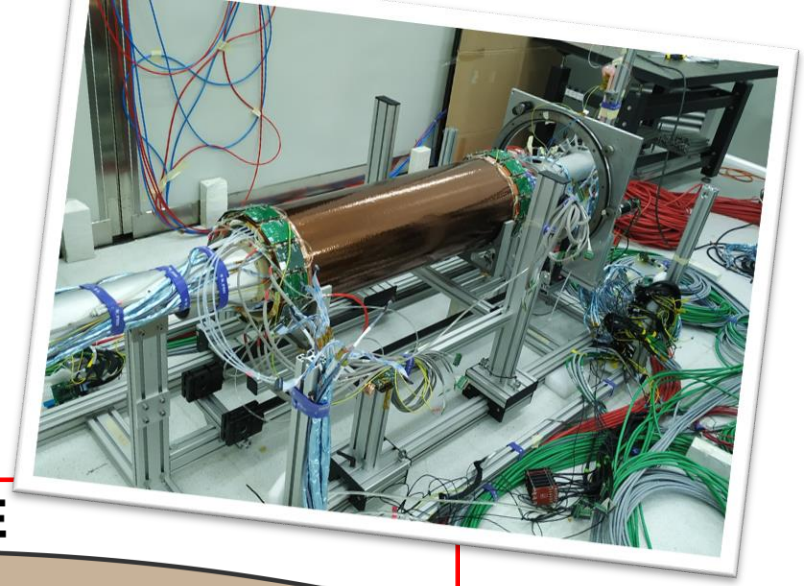
Physics program:
- Charmonium physics
- XYZ searches
- QCD studies
- Precision SM measurements

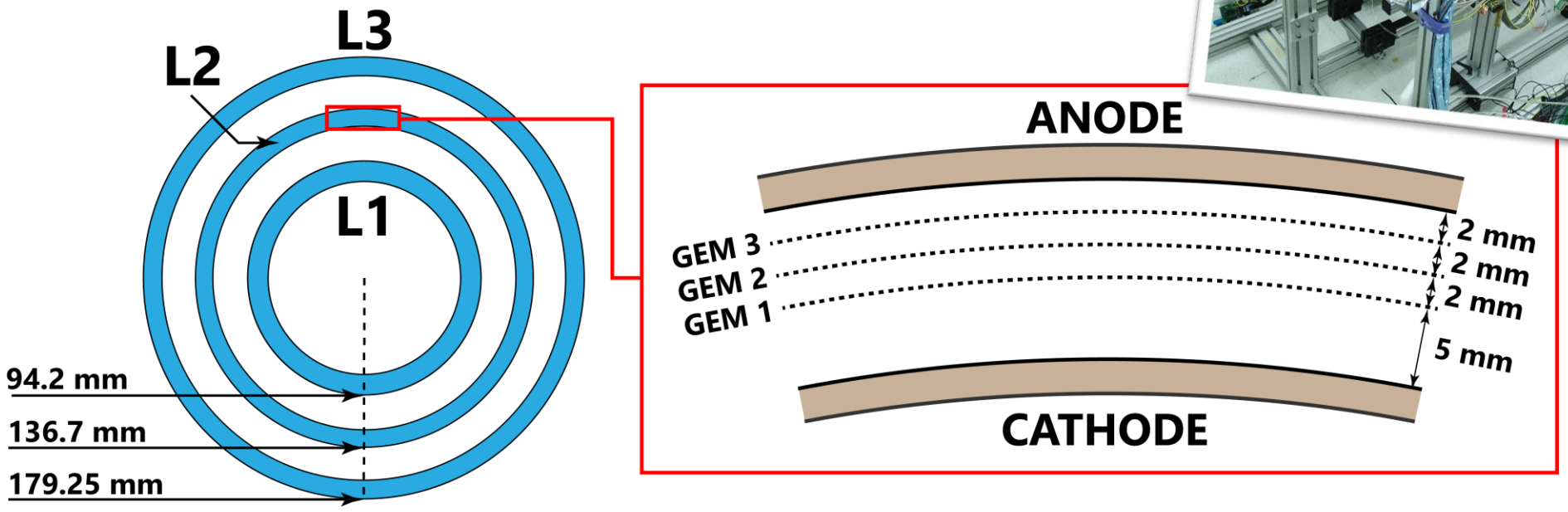
Data taking extended up to 2030

Aging inner multilayer drift chamber to be upgraded with a new CGEM-based inner tracker in 2024



Cylindrical GEM Inner Tracker

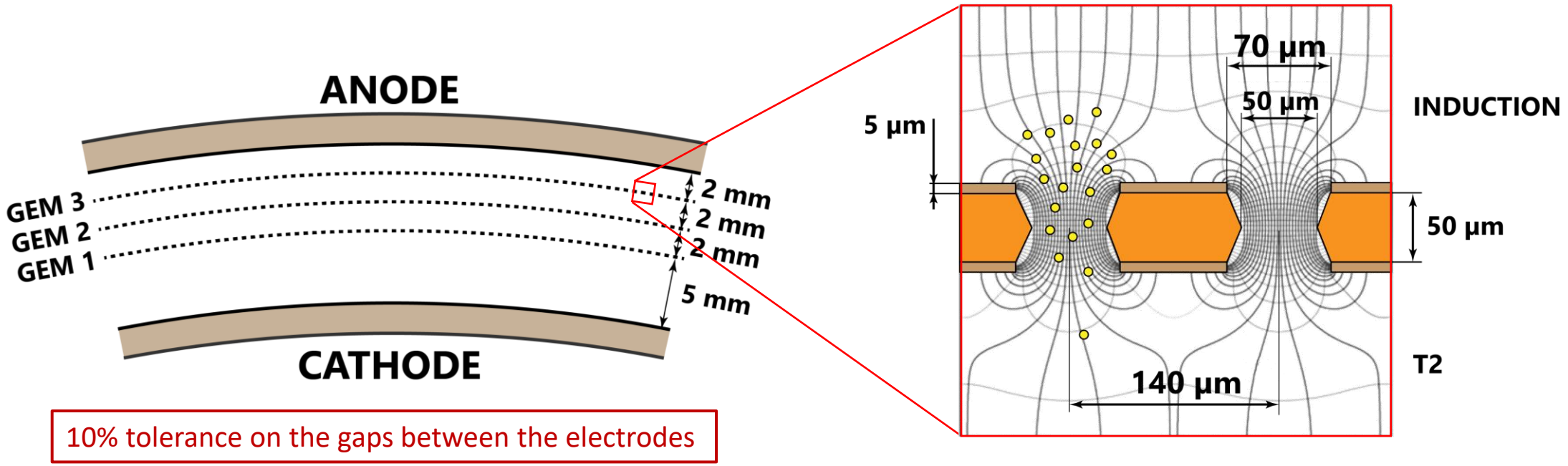




Three tracking layers, three multiplication stages for each layer

Layers 1 and 2 already collecting data in Beijing, **Layer 3 under re-construction**

Gas Electron Multiplier



10% tolerance on the gaps between the electrodes

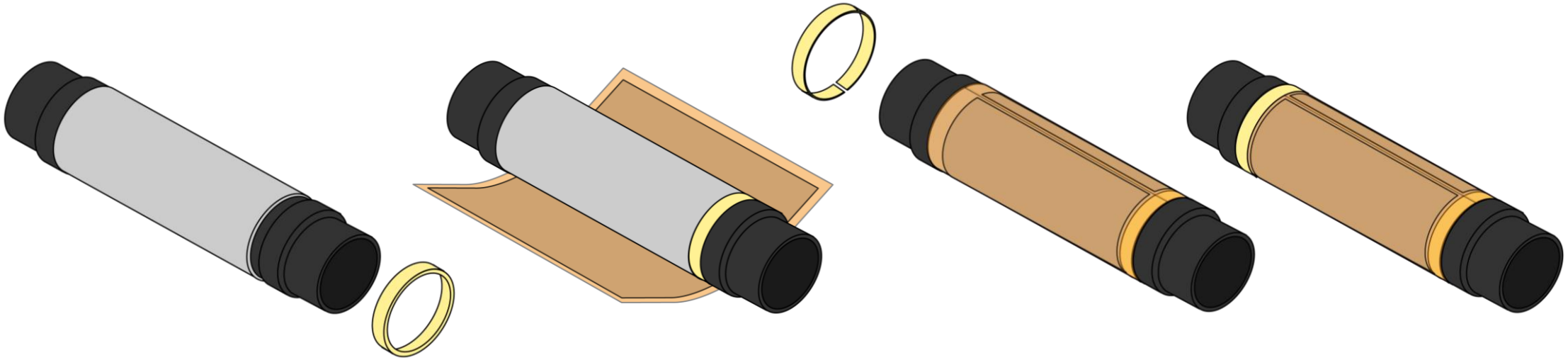
GEMs are thin copper-clad Kapton foils with a dense matrix of holes

The strong electric field inside each hole serves to multiply the electrons, thus amplifying the signal

CGEM Construction Technique

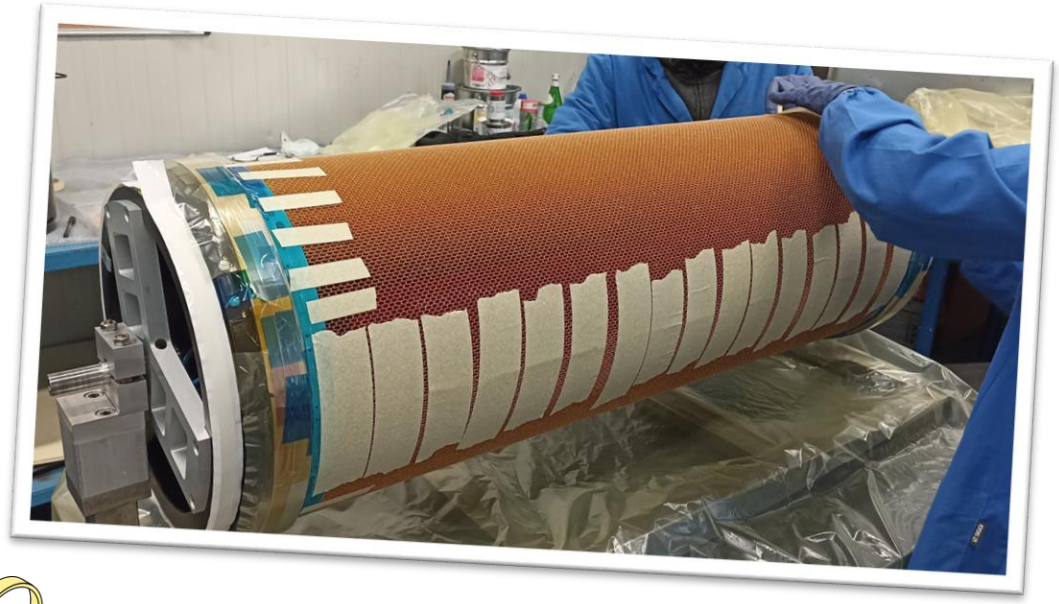
The GEM Electrodes are floating, only supported by Permaglass rings glued at the two extremities

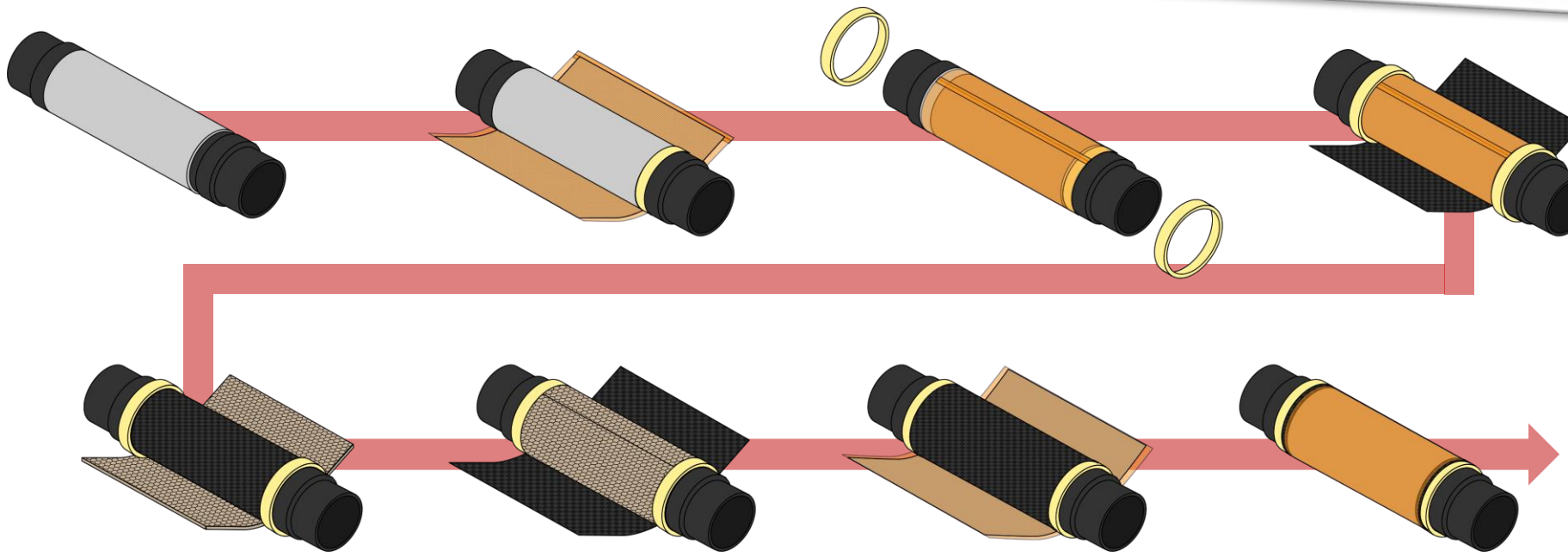
GEM foils are wrapped around a cylindrical mold, **a 3 mm wide overlap keeps the cylinder closed**



Support Structures

Anodes and cathodes are supported by sandwich-structured composites that are built layer by layer around the cylindrical molds



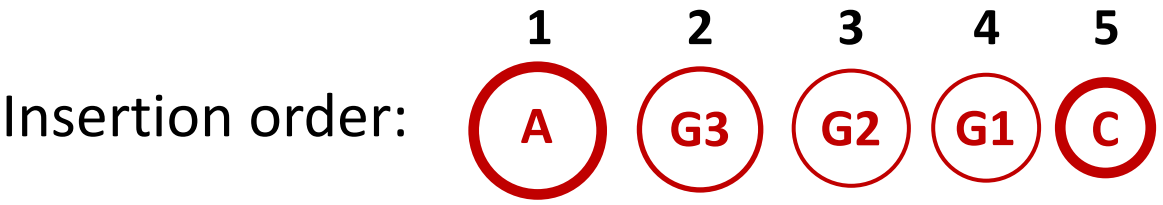


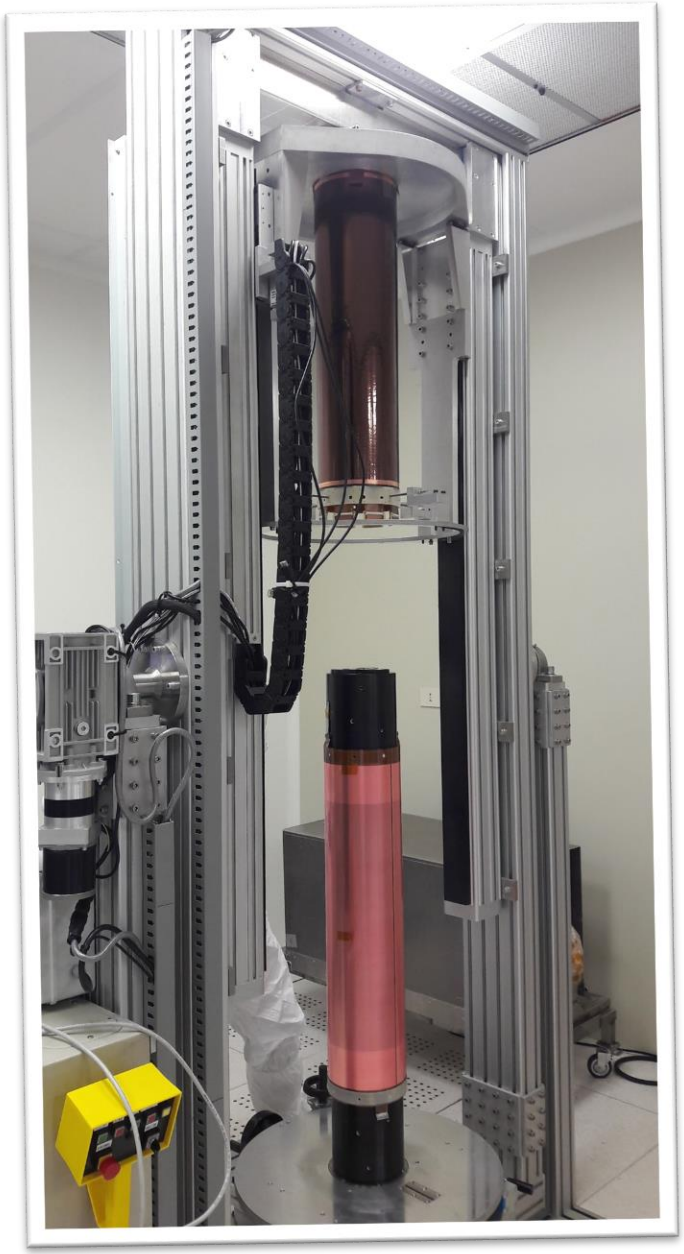
Detector Assembly

The electrodes are extracted and assembled using the Vertical Insertion Machine (VIM)

The VIM can also rotate to allow access to both ends of the detector for gluing

The detector is assembled by inserting each electrode inside the previous one, starting from the largest



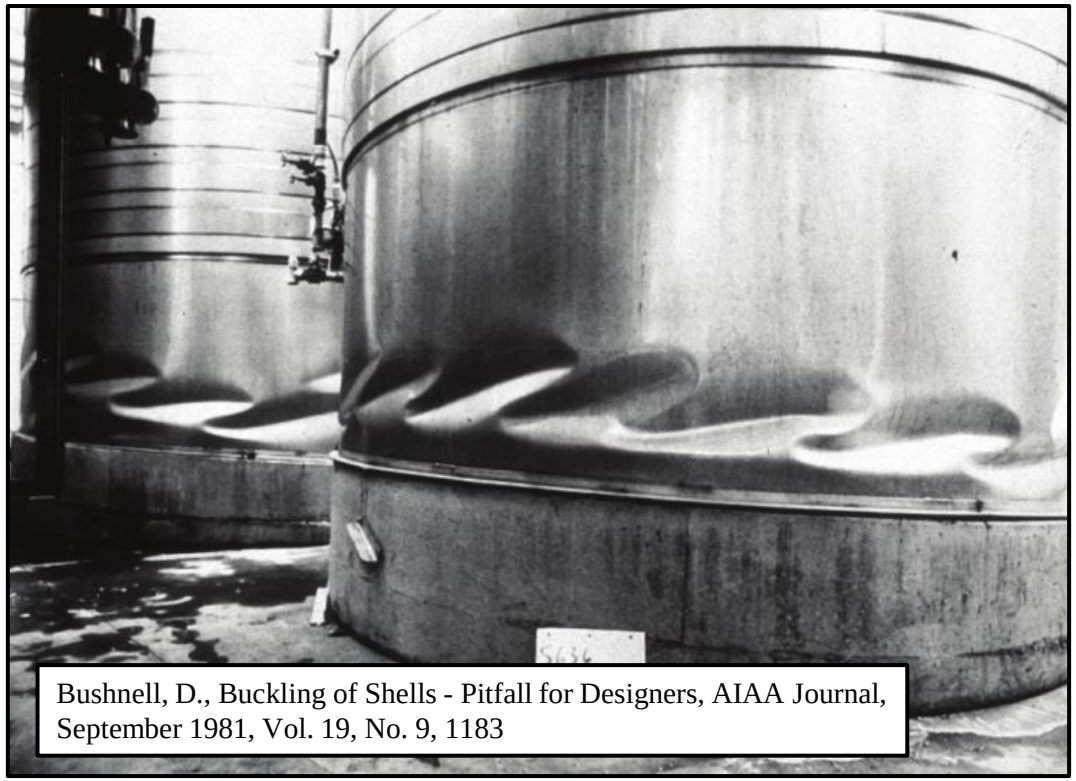


Drop Test of a CGEM Detector Mockup with PEEK Spacer Grids

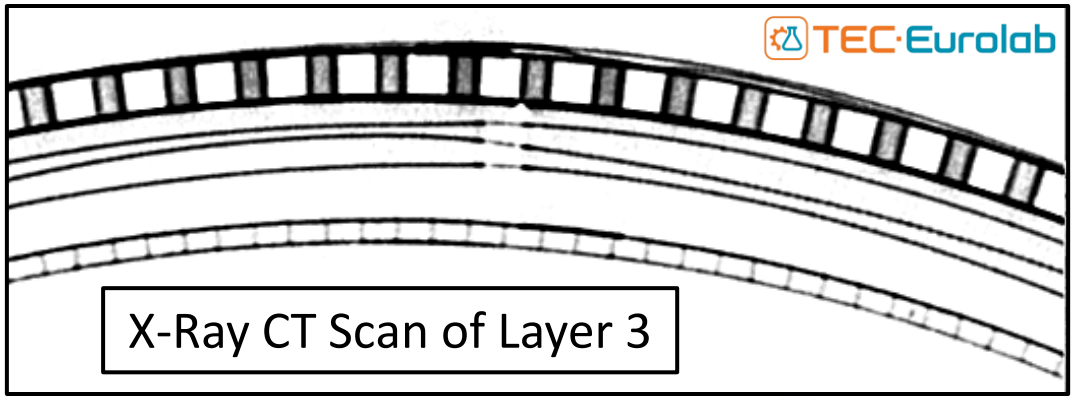
Buckling in CGEM Detectors

To know more check
Dr. Ilaria Balossino's contribution at
Forum on Tracking Detector Mechanics 2021
https://indico.cern.ch/event/1017981/contributions/4348788/

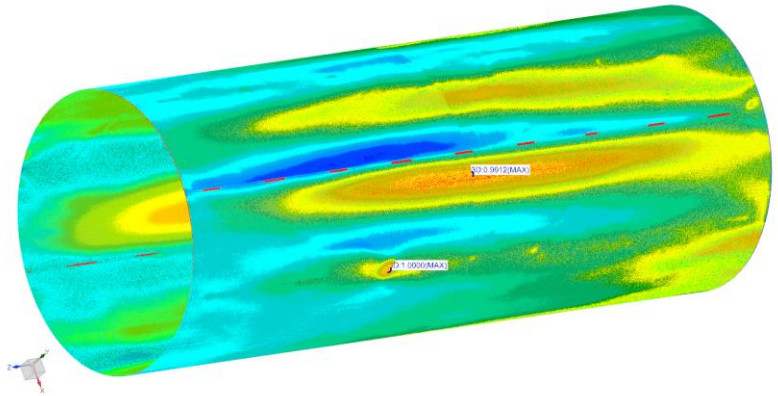
A CGEM is a long, thin-walled shell with a large radius, therefore **particularly prone to buckling**



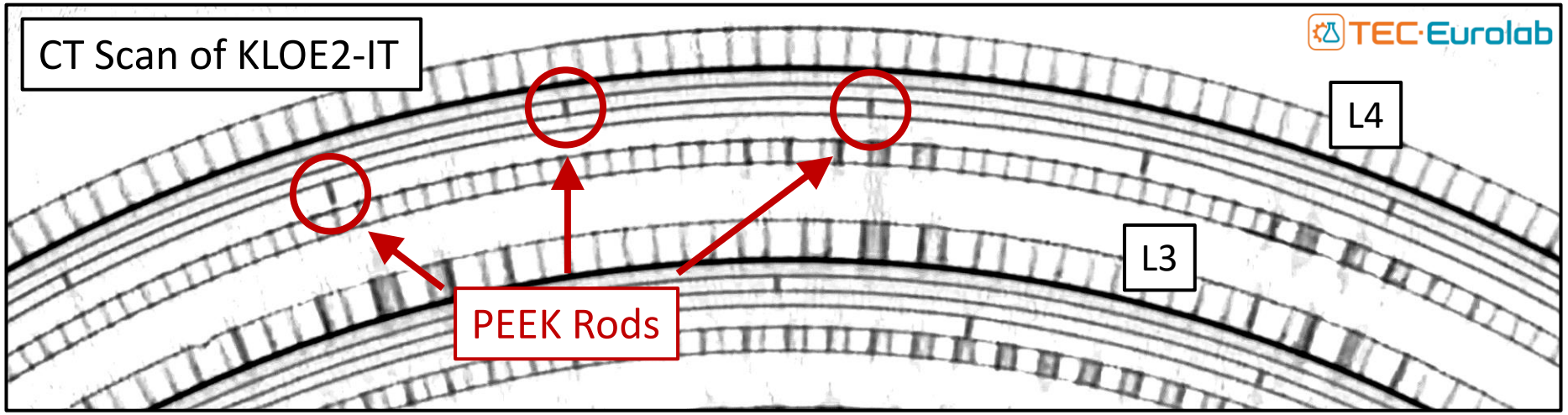
Bushnell, D., Buckling of Shells - Pitfall for Designers, AIAA Journal, September 1981, Vol. 19, No. 9, 1183



X-Ray CT Scan of Layer 3



The KLOE2-IT Approach



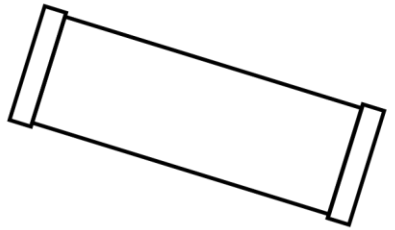
SOLUTION

Add cylindrical PEEK spacer grids to contain buckling induced deformations

PEEK is clean, mechanically stable, and radiation resistant

How to Test the Spacer Grids

Build a representative mockup of the detector with PEEK grids



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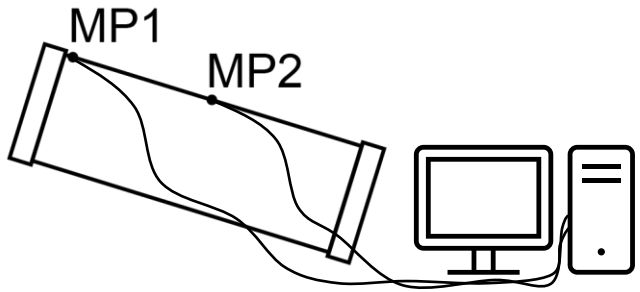
Build a representative mockup of the detector with PEEK grids

Equip it with accelerometers to measure acceleration during handling and test falls



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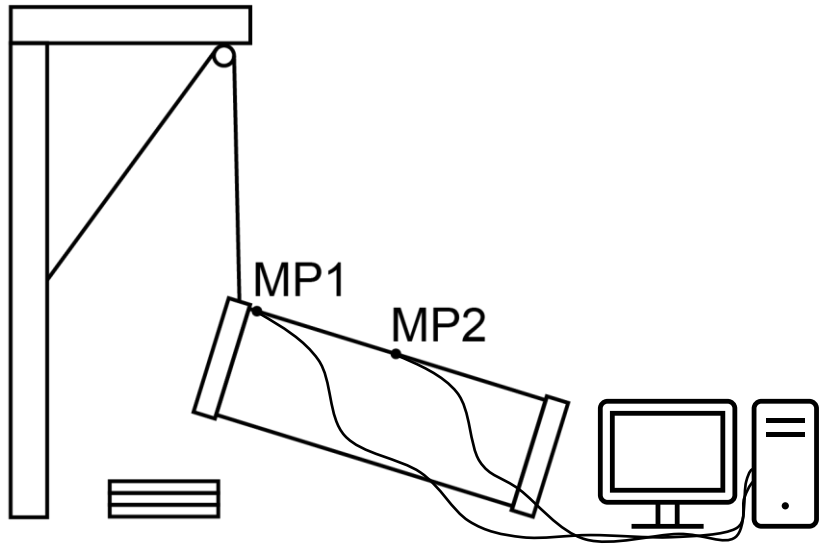
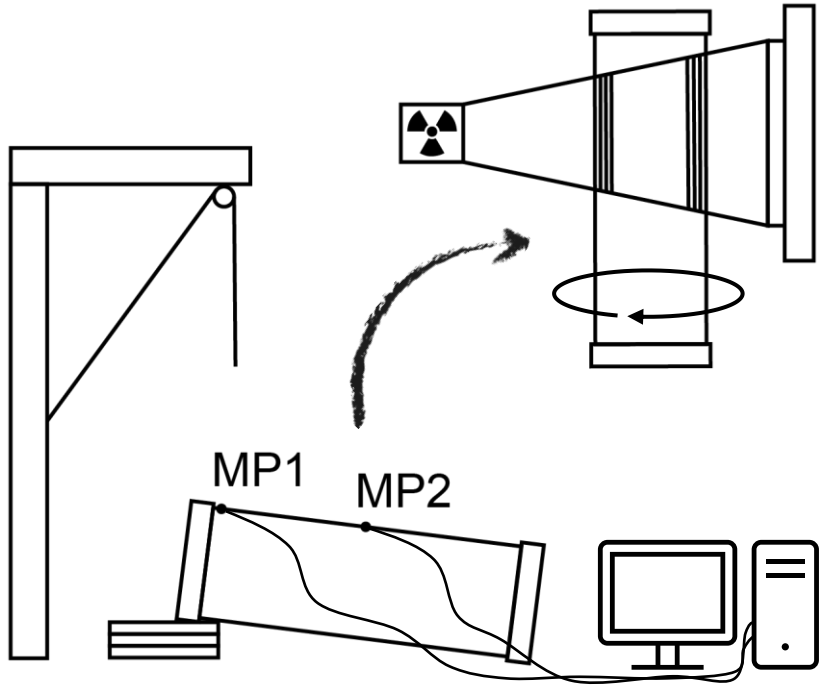
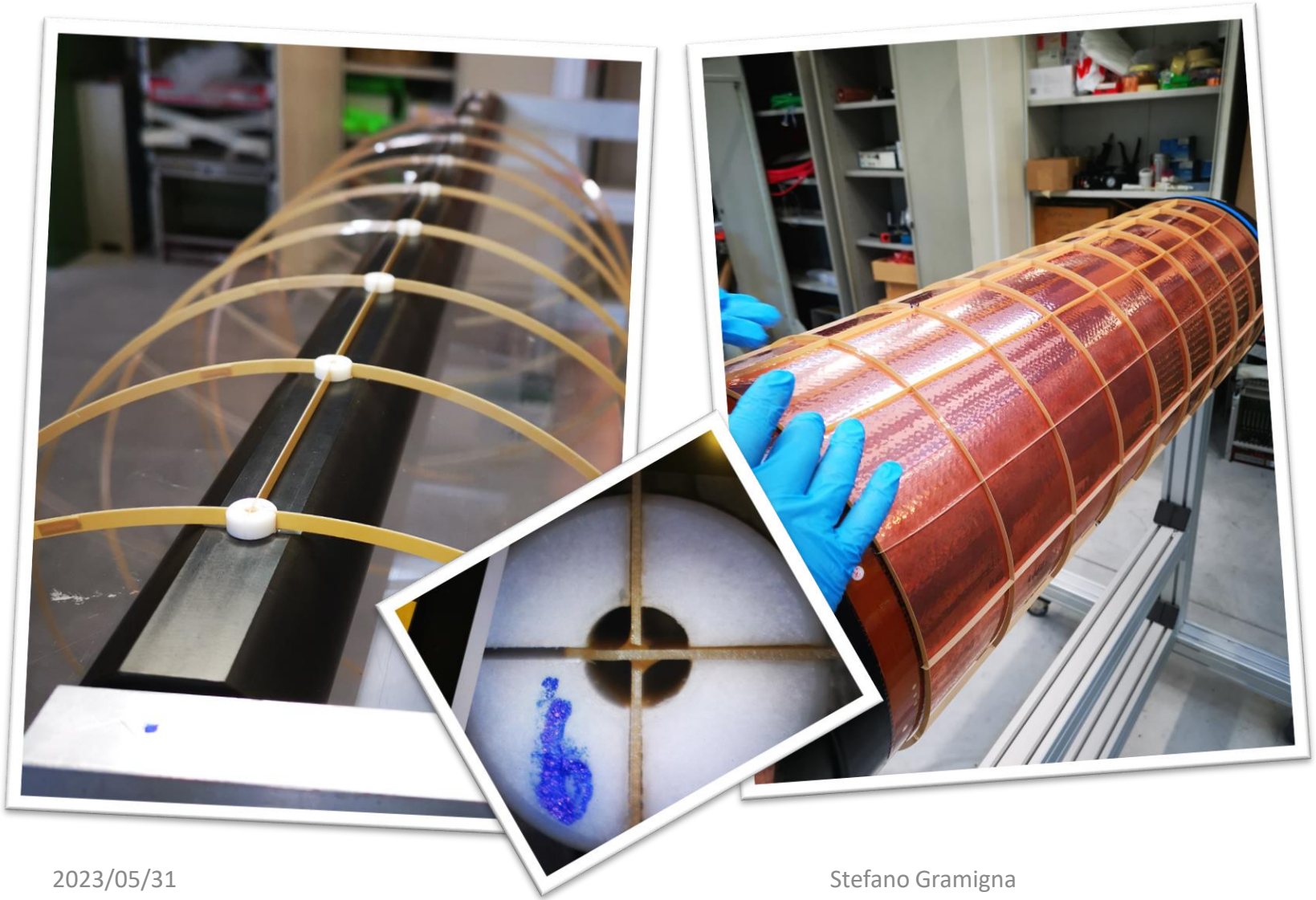


How to Test the Spacer Grids

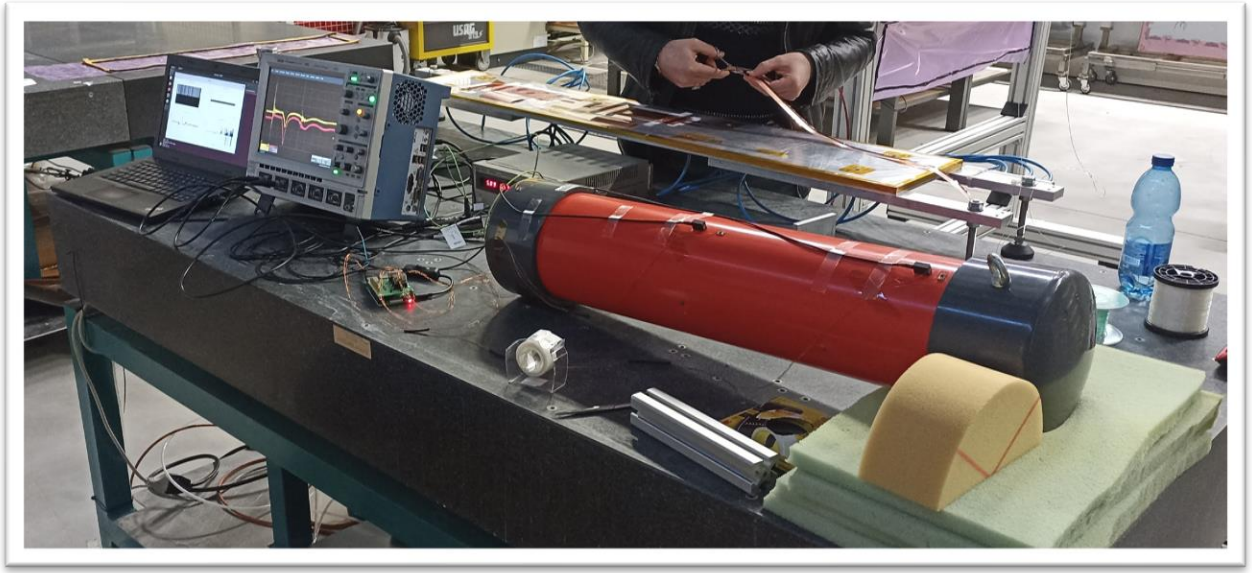
- Build a representative mockup of the detector with PEEK grids
- Equip it with accelerometers to measure acceleration during handling and test falls
- Let it fall at known peak acceleration values on layers of shock absorbing material
- Perform a full CT scan after each fall



Grid and Mockup Construction



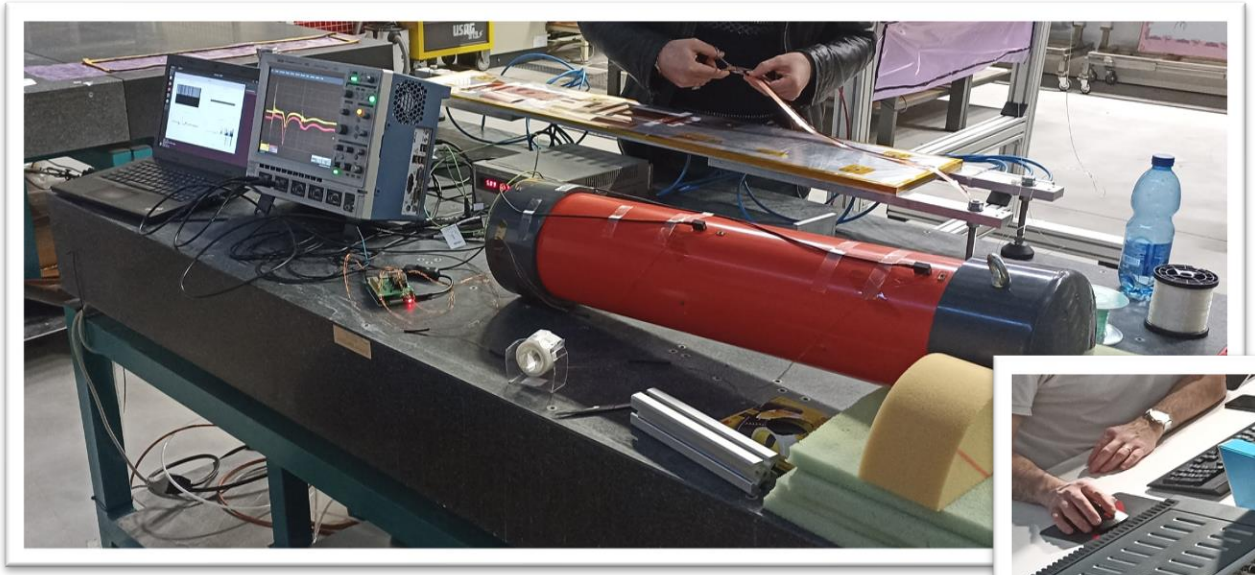
Characterization of the Accelerometers



Homemade characterization:

- Repeatability studies
- Prediction of the fall parameters
- Setup development

Characterization of the Accelerometers



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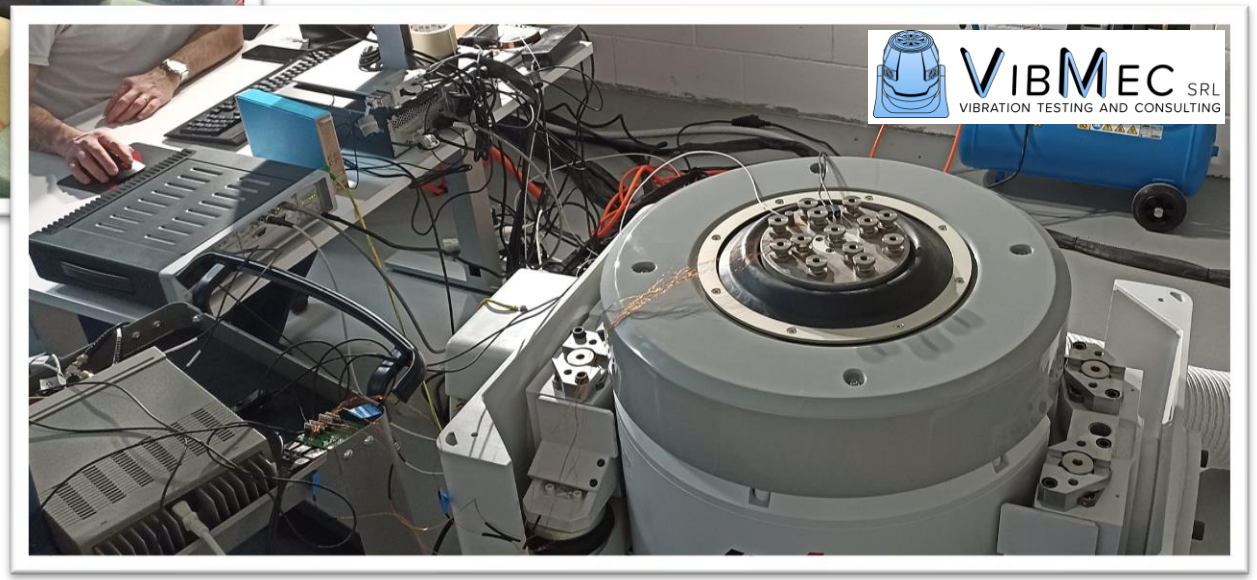
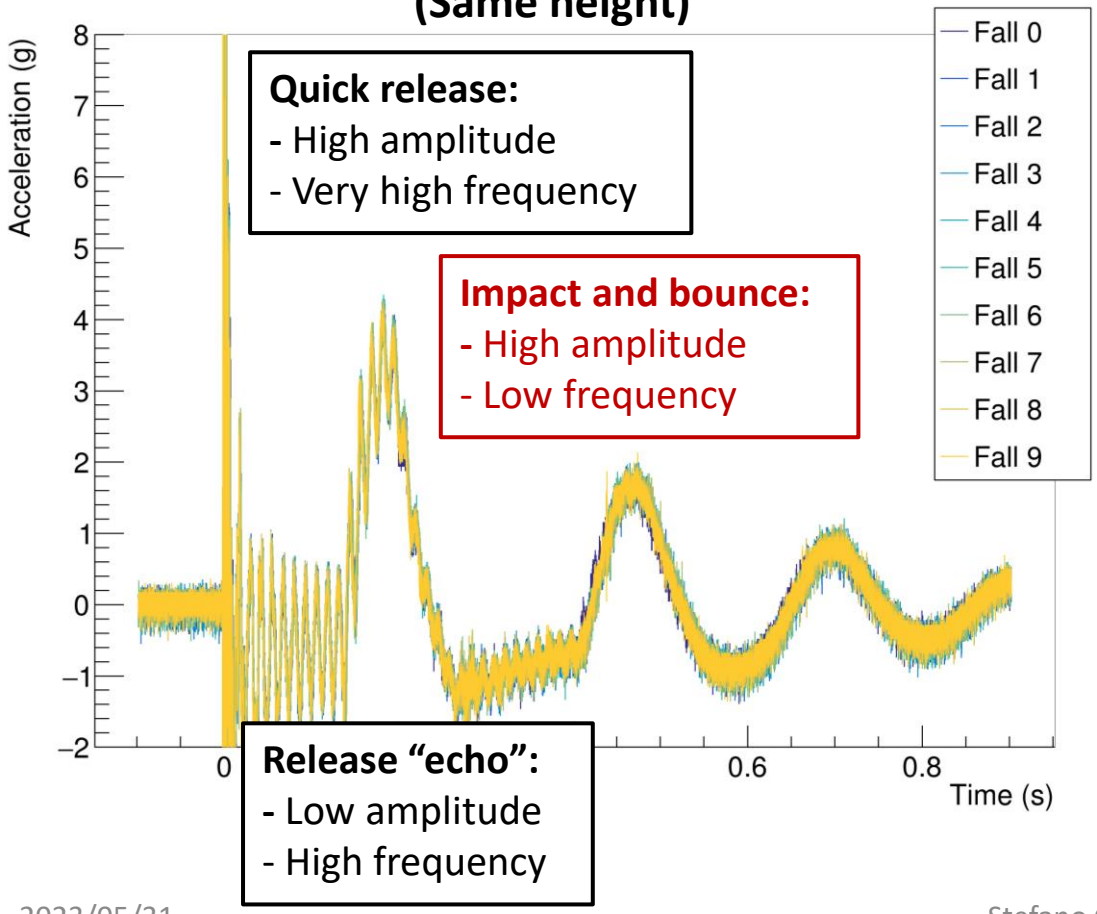


Professional characterization:

- Sensitivity assessment
- Frequency response
- Ranges of measurement

Preliminary Studies and Fall Spectra

Repeatability (Same height)

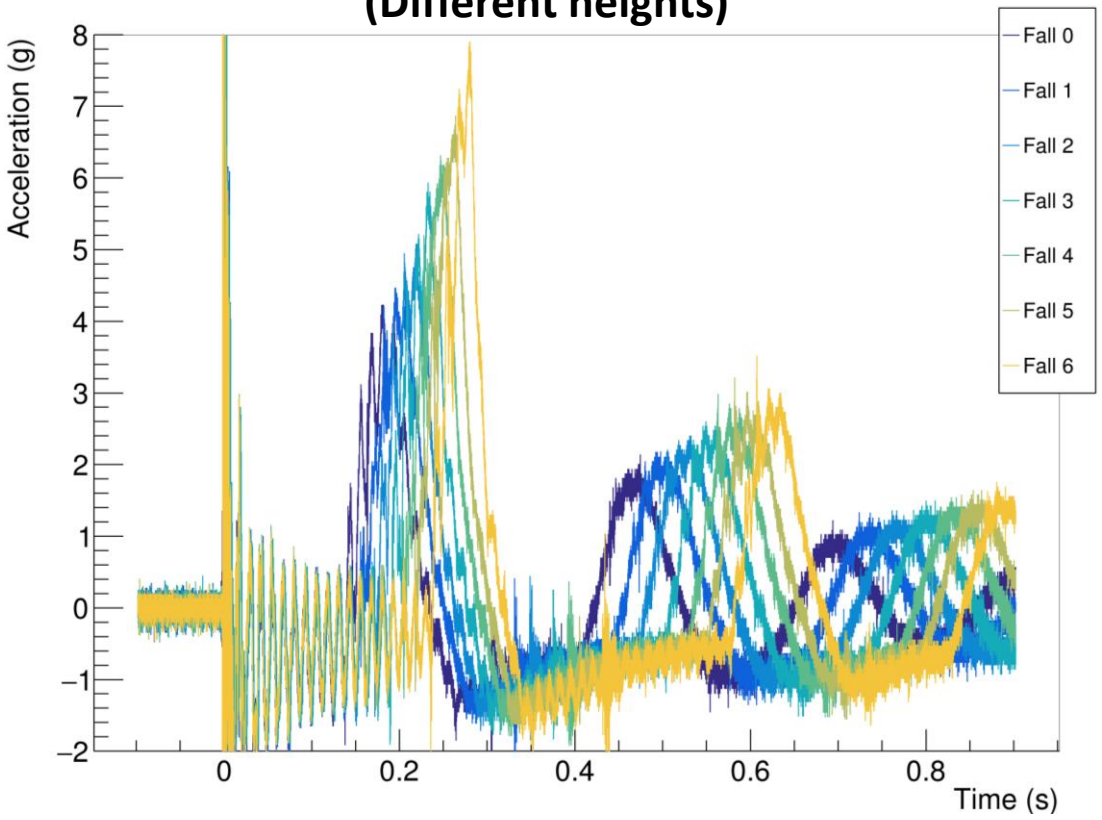


Quick release:
- High amplitude
- Very high frequency

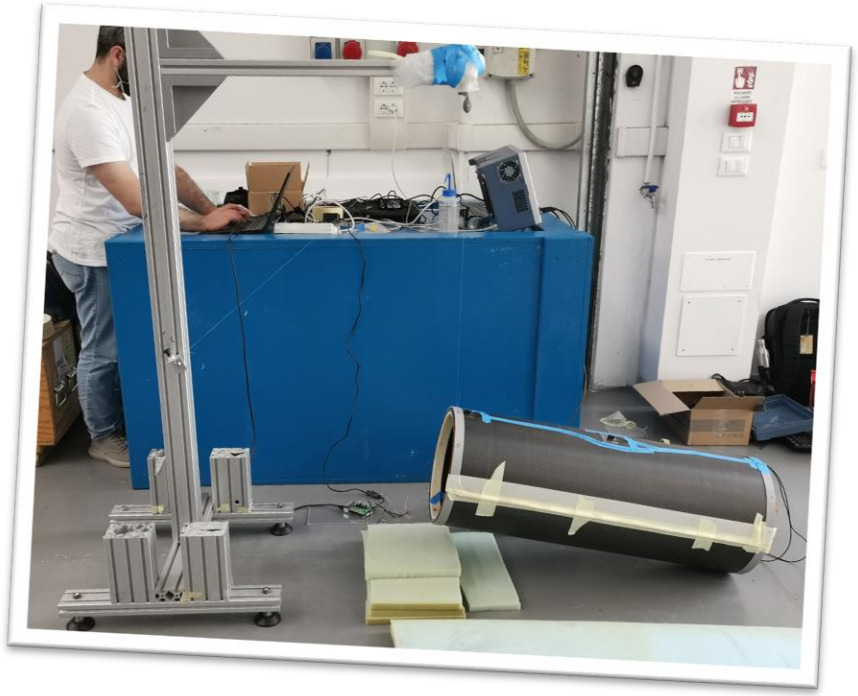
Impact and bounce:
- High amplitude
- Low frequency

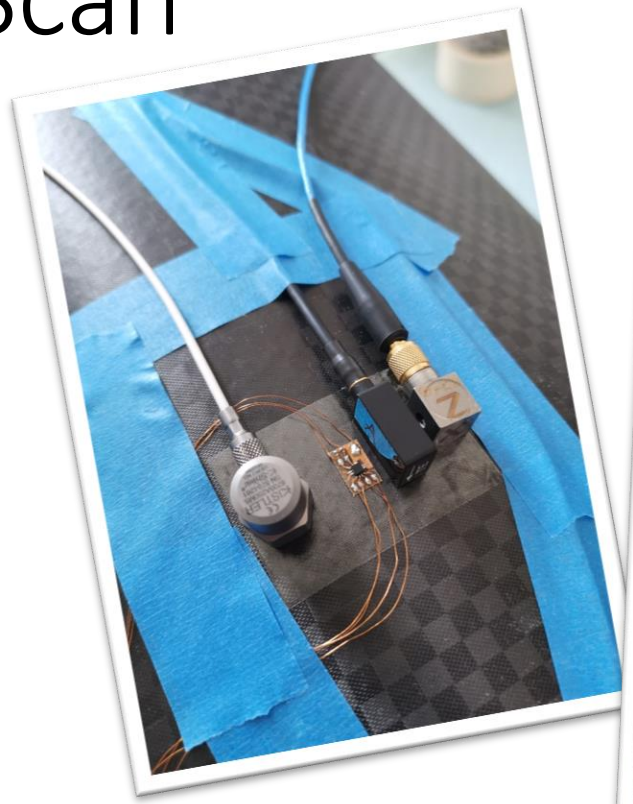
Release "echo":
- Low amplitude
- High frequency

Prediction of fall parameters and setup development (Different heights)



Drop Test and CT Scan





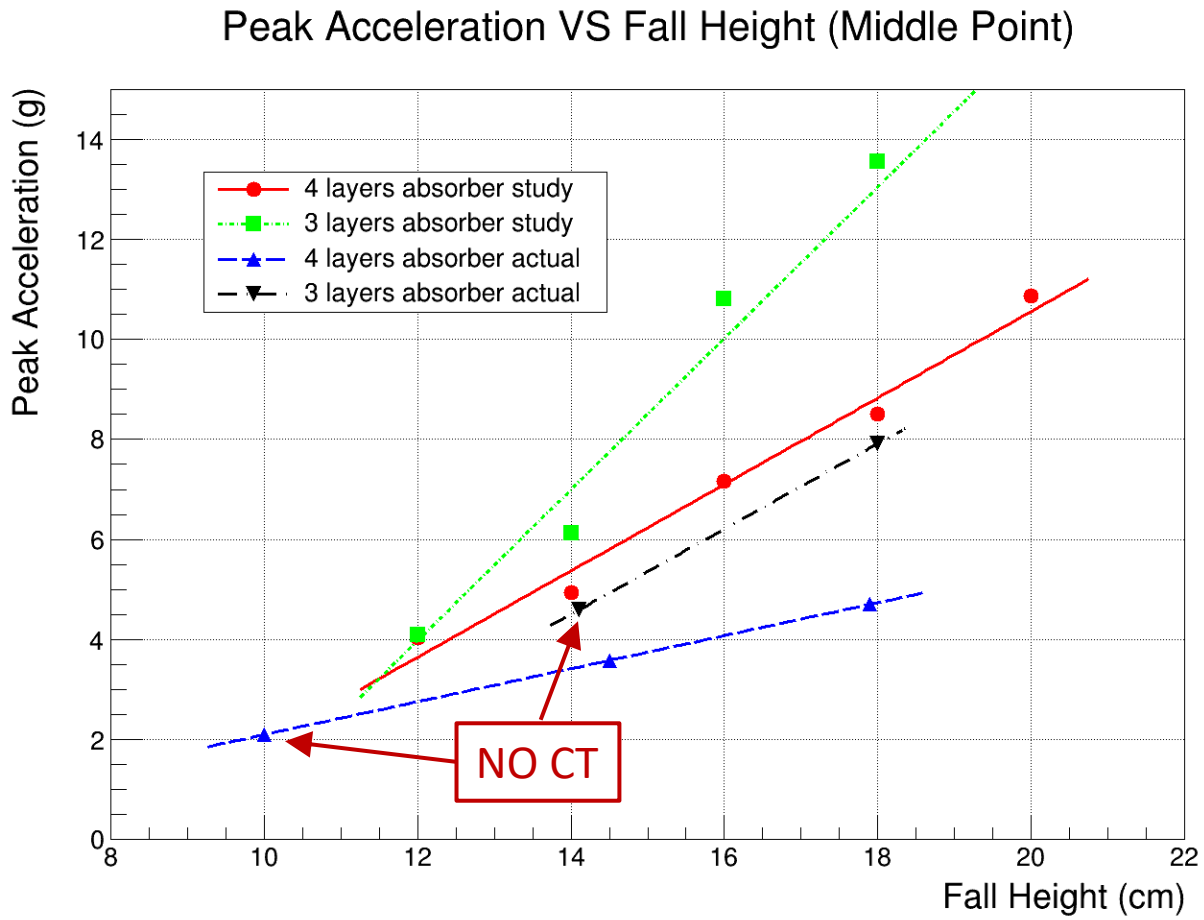
Months of preparation -> two full days of testing

CT Scan on arrival to be used as reference

3 controlled falls, each followed by a complete CT scan

Real-time correction of the predicted fall parameters

Real-time Correction of the Fall Parameters



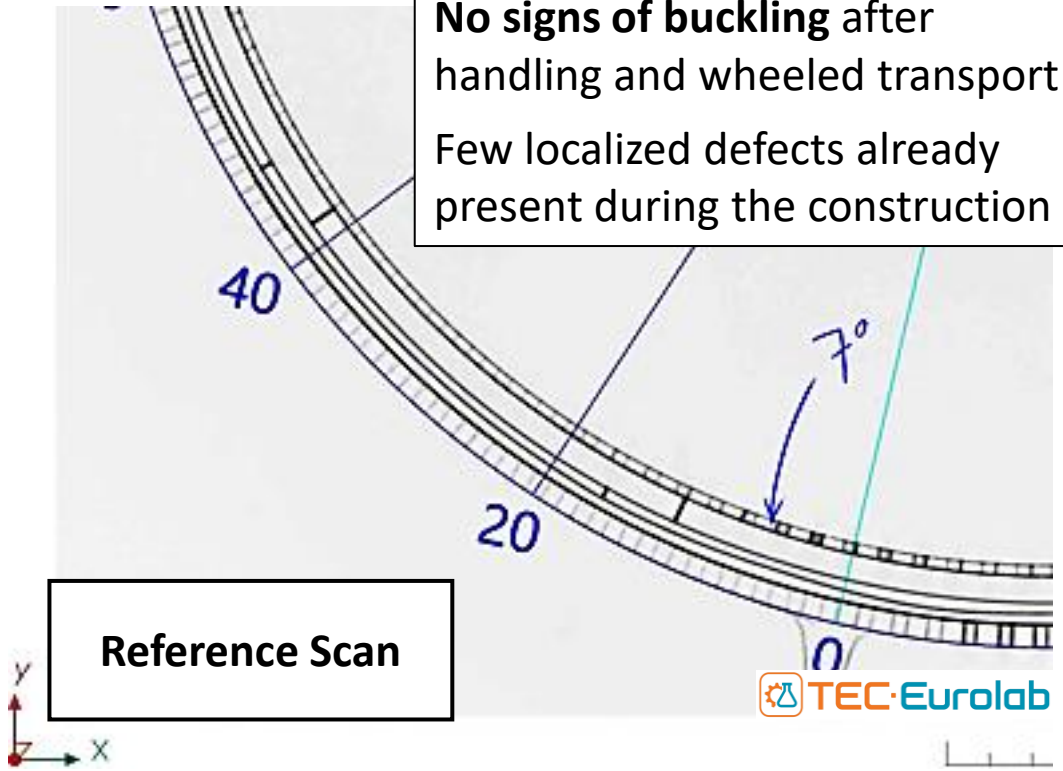
Absorber thickness and fall height control the impact force

Several test campaigns conducted with spare components weighted to match the mockup

A fall too weak (<2g) would not have been significative

A fall too strong (>10g) would have meant a ruined mockup and several months of work wasted

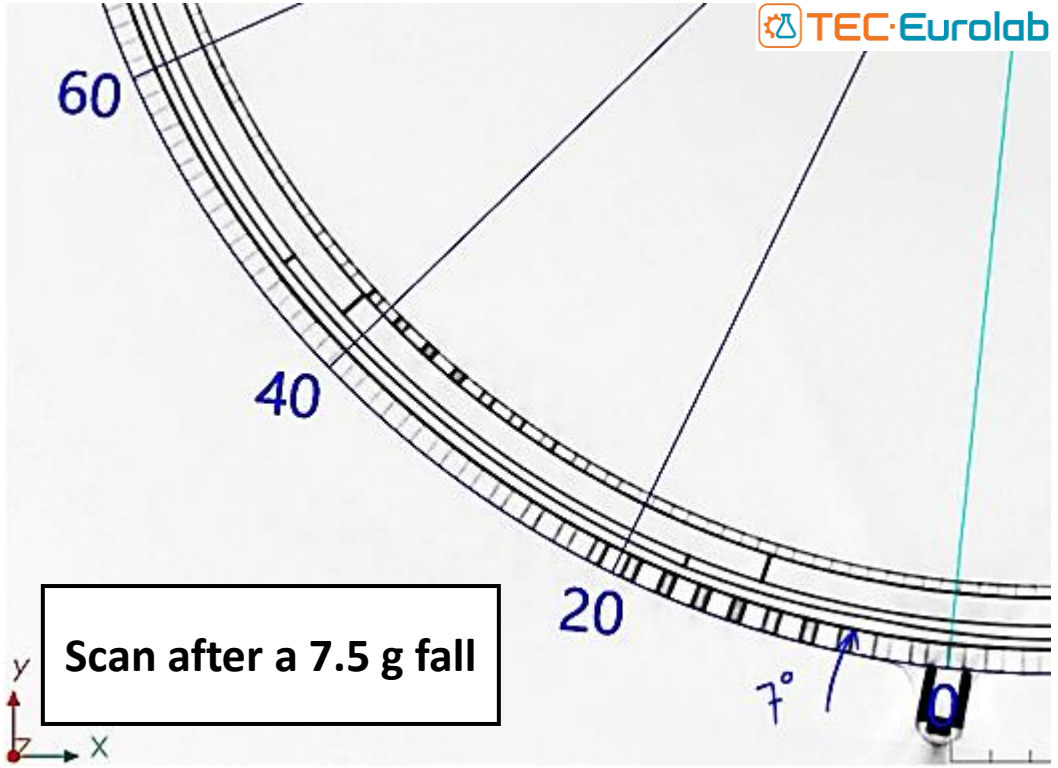
Results of the Test



Reference Scan

No signs of buckling after handling and wheeled transport

Few localized defects already present during the construction



Scan after a 7.5 g fall

Mockup subjected to **accelerations largely above the expected operability range**

No noticeable differences with respect to the reference scan

All clear for the construction of Layer 3 with PEEK grids

Lack of acceleration data on cargo planes landing still mandates a split construction between Italy and China

Conclusions

Final Remarks

The Cylindrical GEM Inner Tracker (CGEM-IT) is the detector meant to replace the aging innermost layers of the multilayer drift chamber of the BESIII experiment in its 2024 upgrade

Deformation due to **buckling prevented the ignition of the CGEM-IT's largest layer**

A CT scan of the KLOE2-IT shows the PEEK grids in the two largest layers, where no signs of buckling-related damage are found

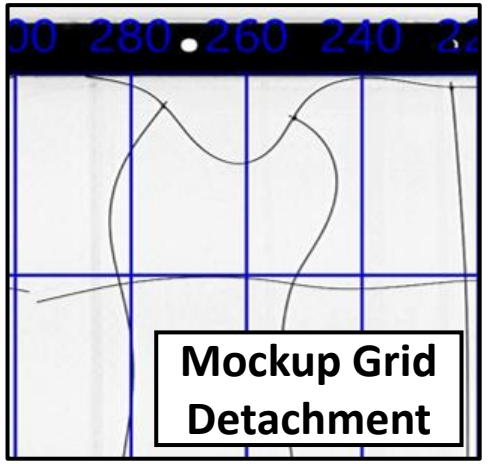
A series of drop tests followed by CT scans was performed on a mockup of the CGEM-IT to assess the grids effectiveness and operability range

The proposed technique may be applied to investigate similar mechanical issues in lightweight detectors

Additional Lessons Learned

First time anyone in the CGEM-IT group had to build PEEK spacer grids

-> Tools and techniques have been improved for Layer 3 construction

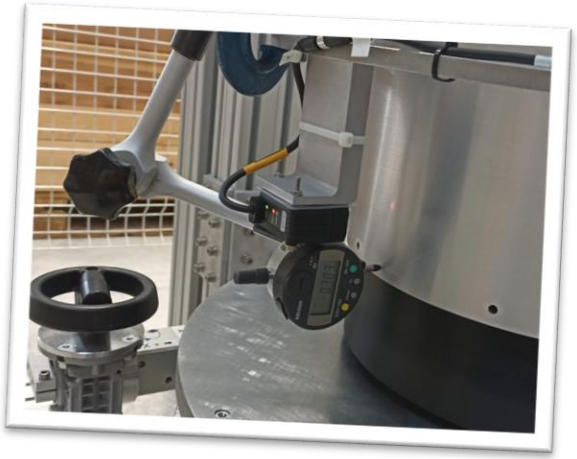


Reduced clearance due to grids led to issues during the mockup assembly

-> Grid design and mounting modified to ease electrode insertion

A split construction will require contactless alignment of the production molds

-> Development of a laser alignment system for the Vertical Assembly Machine



Training of the new team for the construction of Layer 3

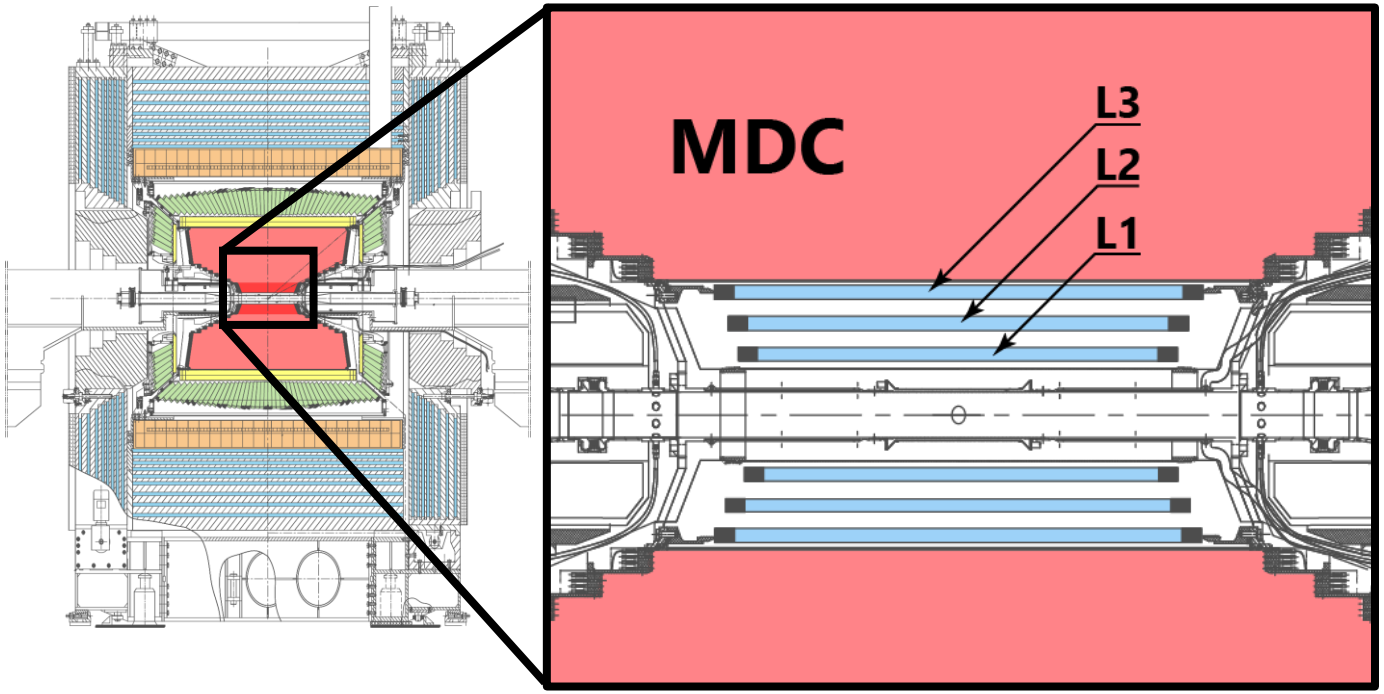
Thanks for your attention

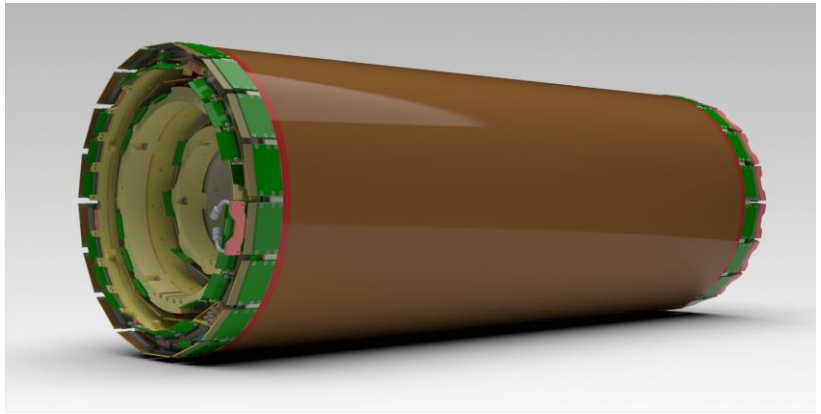
European Commission
Horizon 2020
European Union funding
for Research & Innovation

The research leading to these results has been performed within the BESIIICGEM Project (645664), funded by the European Commission within the call H2020-MSCA-RISE-2014, and within the FEST Project (872901), funded by the European Commission within the call H2020-MSCA-RISE-2019.

Backup

CGEM-IT Collocation





CGEM-IT Upgrade Requirements

$\sigma_{r\varphi}$	**≤130 μm**
Rate capability	**10^4 Hz/cm^2**
σ_z	**≤1 mm**
Angular coverage	**93% 4π**
Material budget	**≤1.5% X_0**

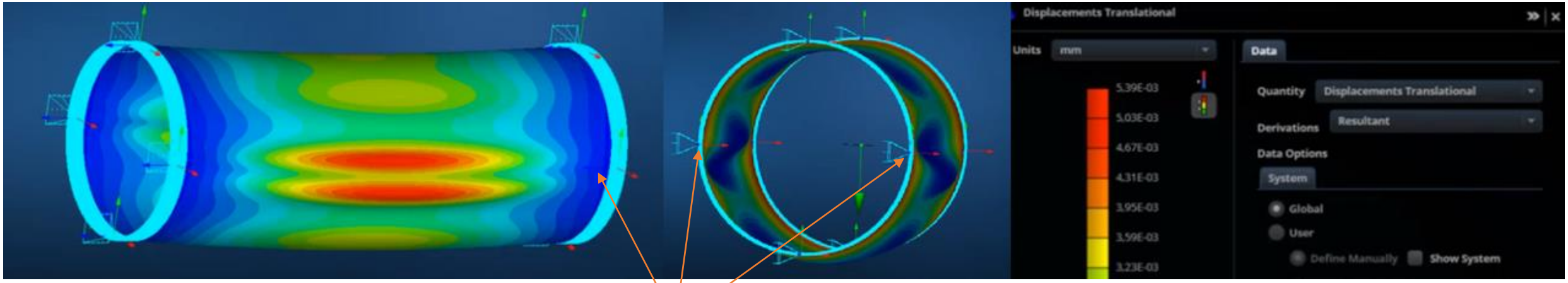
Radiation Length

LAYER 3	material	thickness	fill factor	rad length			tot	
cathode	kapton	25	1,00000	0,000087489	1,28E-03	1	1,28E-03	
	epoxy	15	1,00000	0,000044170				
	carbonfiber	60	1,00000	0,000214286				
	epoxy	15	1,00000	0,000044170				
	honeycomb	1900	1,00000	0,000144773				
	epoxy	15	1,00000	0,000044170				
	kapton	50	1,00000	0,000174978				
	epoxy	15	1,00000	0,000044170				
	kapton	50	1,00000	0,000174978				circuito catodico
	copper	3	1,00000	0,000208914				
	peek	4750	0,00634	0,000098886				
gem	copper	5	0,66000	0,000229805	0,00639643	3	0,002028224	
	kapton	50	0,81000	0,000141732				
×3	copper	5	0,77000	0,000268106				
	peek	1750	0,00634	0,000036432				
		1750	0,00634	0,000036432				
		1750	0,00634	0,000036432				
anode	copper	5	0,88000	0,000306407	5,72E-04	1	0,002744	circuito anodico
	kapton	50	0,20000	0,000034996				
	copper	5	0,20000	0,000069638				
	epoxy	25	1,00000	0,000073616				
	kapton	25	1,00000	0,000087489				
	epoxy	15	1,00000	0,000044170	0,001125575	1		
	kapton	125	1,00000	0,000437445				
	epoxy	15	1,00000	0,000044170				
	honeycomb	3900	1,00000	0,000297165				
	epoxy	15	1,00000	0,000044170				
	carbonfiber	60	1,00000	0,000214286				
	epoxy	15	1,00000	0,000044170				
	copper	5	1,00000	0,000348189	0,000523168	1		ground plane
	kapton	50	1,00000	0,000174978				
	kapton	50	1,00000	0,000174978	0,000523168	1		faraday cage
	copper	5	1,00000	0,000348189				
							TOT	
							0,0060533	

No grids	No ff	Only cath. grid
0.0058451	0.038	~ 0.02

Courtesy of Dr. Isabella Garzia

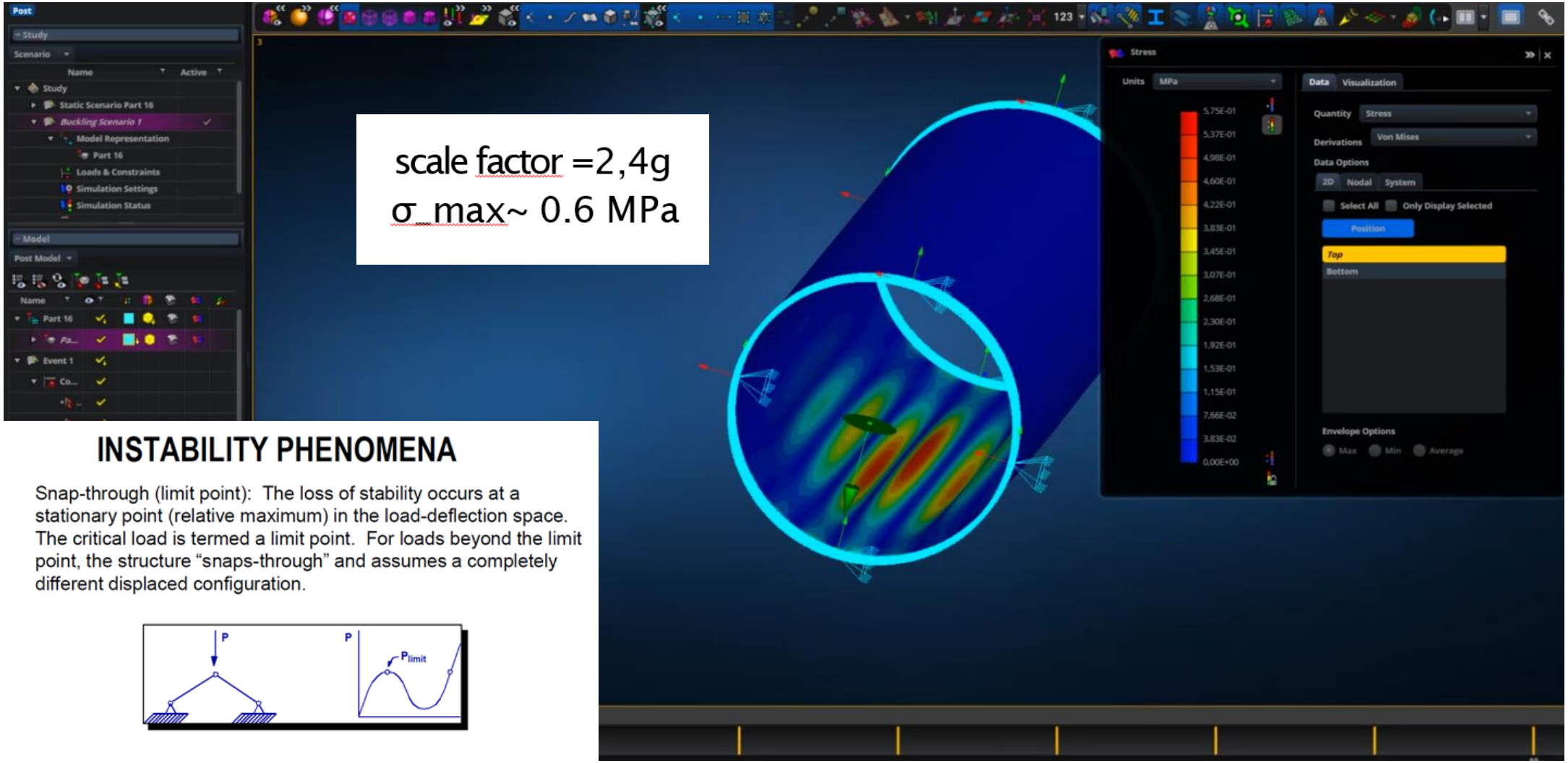
Layer 3 GEM 3 1g Check



overlap

Courtesy of Eng. Michele Melchiorri

Buckling FEM Simulation



scale factor =2,4g

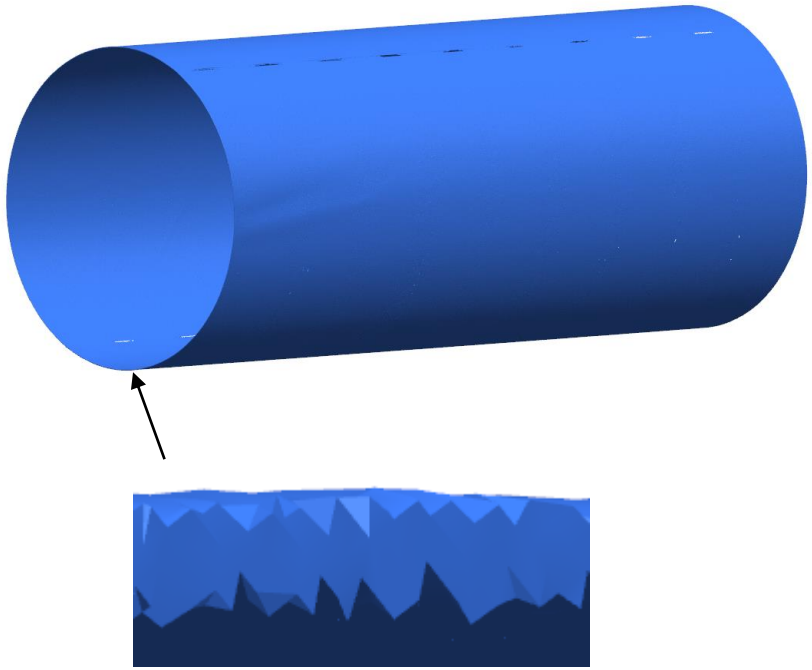
$\sigma_{max} \sim 0.6$ MPa

INSTABILITY PHENOMENA

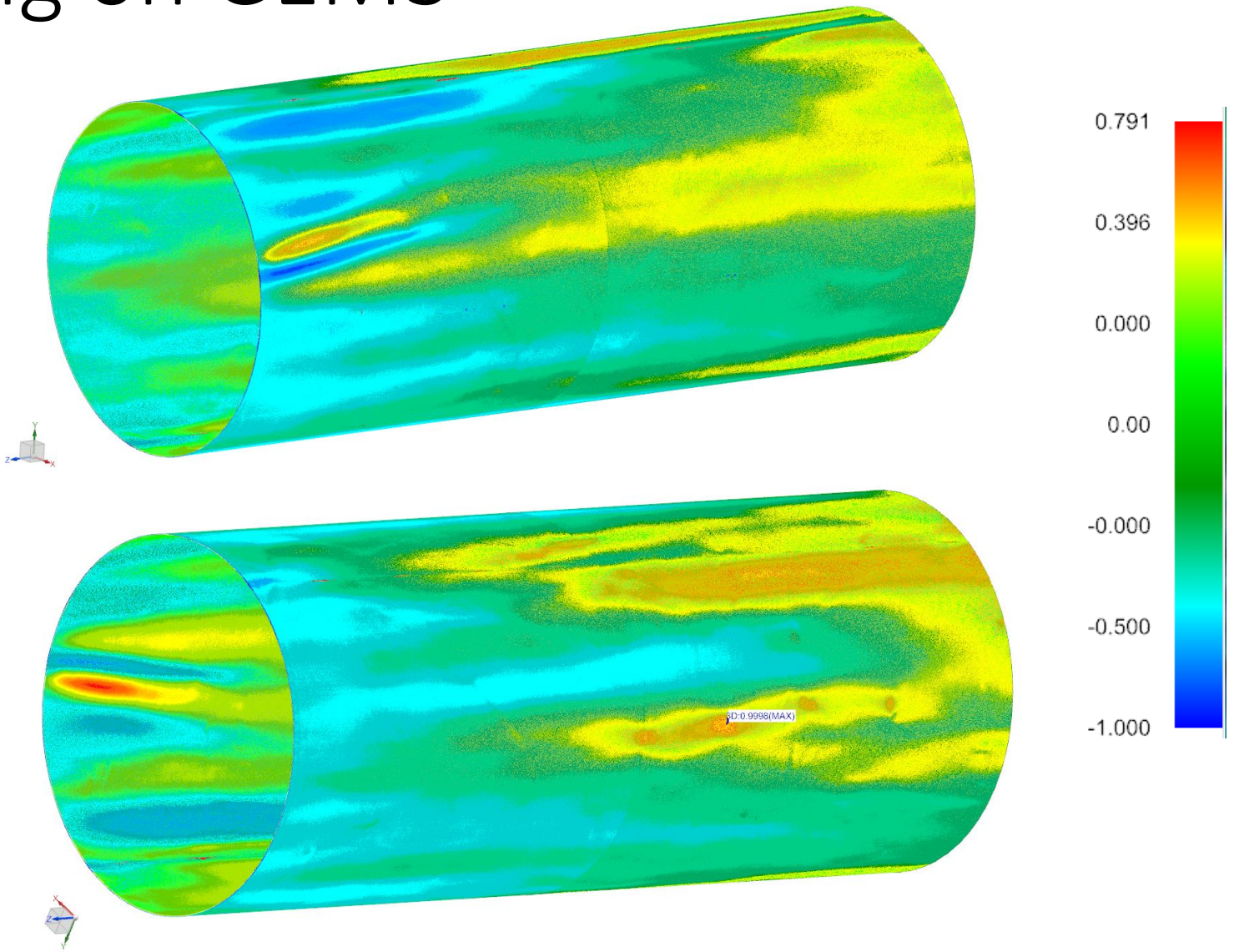
Snap-through (limit point): The loss of stability occurs at a stationary point (relative maximum) in the load-deflection space. The critical load is termed a limit point. For loads beyond the limit point, the structure "snaps-through" and assumes a completely different displaced configuration.

Courtesy of Eng. Michele Melchiorri

Reverse Engineering on GEM3



The reconstructed cylinder from the CT scan is overlapped to the nominal one and the displacement is evaluated



Courtesy of Eng. Michele Melchiorri

PEEK Datasheet

BIEGLO High Performance

PEEK-shop.de

DEXNYL©

Dexnyl© PEEK-SF Film_22 **Technical Datasheet**

BIEGLO PEEK-Film is a semi-crystalline thermoplastic film with high crystallinity made of Polyetheretherketone.

Main characteristics:

excellent radiation resistance
excellent chemical and hydrolysis resistance
excellent mechanical properties
high thermostability
opaque
stress crack resistant
FDA Food contact compliant

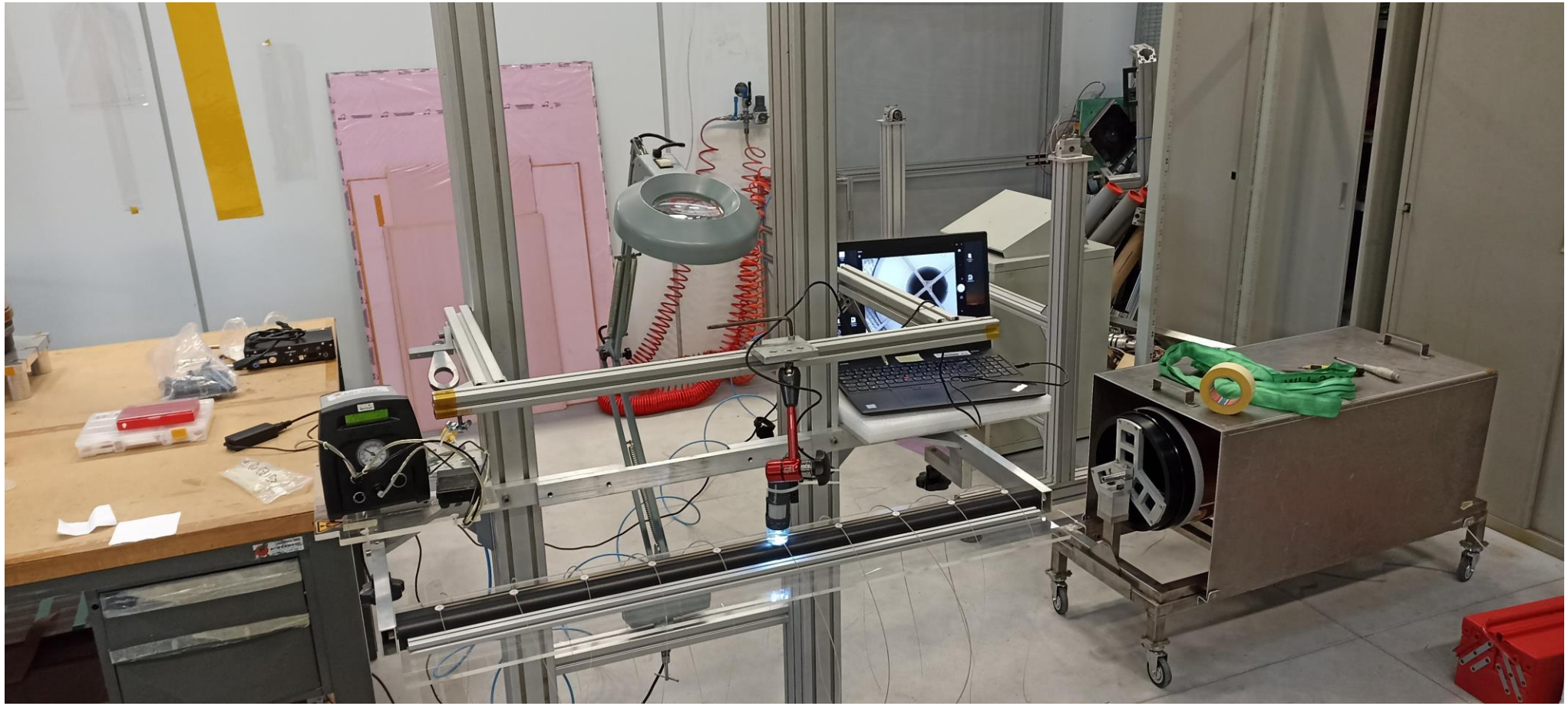
Physical Properties:			
Density	ISO 1183	g/cm³	1,30
Glass Transition Temperature	ISO 11357	°C	143
Crystalline Melting Point	-	°C	343
Mechanical Properties			
Yield Tensile Strength at 23°C	ISO 527	N/mm²	90
Yield Tensile Elongation at 150°C	ISO 527	N/mm²	35
Tensile Strength at 23°C	ISO 527	N/mm²	130
Tensile Strength at 150°C	ISO 527	N/mm²	80
Tensile Elongation at 23°C	ISO 527	%	170
Tensile Elongation at 150°C	ISO 527	%	300
Tensile Modulus	ISO 527	N/mm²	3200
Initial Tear Resistance	EN 60674	N	140
Tear Propagation Resistance	ISO 8296	N/mm	240
Electrical Properties			
Dielectric Constant at 1kHz/23°C	IEC 250	-	3,3
Dissipation Factor 1kHZ 23°C	IEC 250	-	0,0013
Volume Resistivity	IEC 93	Ohm.cm	10^{17}
Surface Resistivity	IEC 93	Ohm	10^{15}
Dielectric Strength	IEC 243	kv/mm	180
Thermal Properties			
Long-term service temperature	UL746B	°C	22 0
Flammability	UL94	VTM/µ	0/25
Thermal expansion coefficient x10^6	E831	1/°K	46
Thermal conductivity x10^2	DIN 52612	W/mK	25

BIEGLO GmbH
Bahrenfelder Straße 242
22765 Hamburg
Telefon: +49 40 4011 30000
E-Mail:
info@bieglo.com
Web:
www.bieglo.com

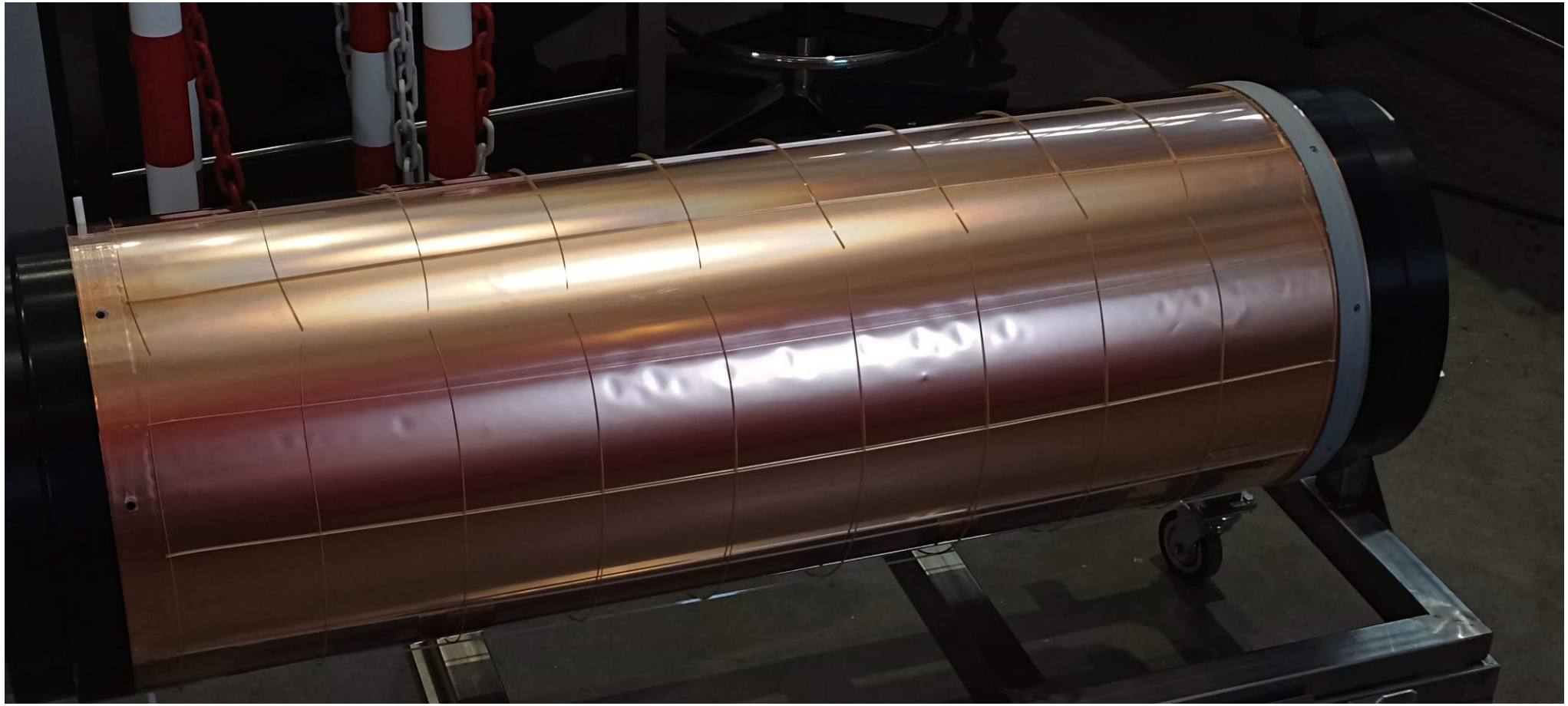
All the tests have been conducted with a standard conditioning atmosphere of 23° C (at the moment no other temperature is available). All the test specimens were made through extrusion process. The specified values are established from average values of several tests and they correspond to our today's knowledge. They are only to be used as information about our products and as help for the material selection. With these values, BIEGLO does not ensure specific properties, or the suitability for certain application, therefore BIEGLO does not assume any legal responsibility for an improper usage. Since the plastics' properties depend on the manufacturing process (extrusion, injection moulding), on the dimensions of the semi-finished material and on the degree of crystallinity, the actual properties of a specific product may slightly deviate from the tested ones. For information about divergent properties do not hesitate to contact us. On request we advise you regarding the most appropriate component design and the definition of material specifications more suitable to your application data. Notwithstanding, the customer bears all the responsibility for the thorough examination of suitability, efficiency, efficacy and safety of the chosen products in pharmaceutical applications, medical devices or other end uses.
Status: September 2020

Courtesy of BIEGLO

First Grid Gluing Machine

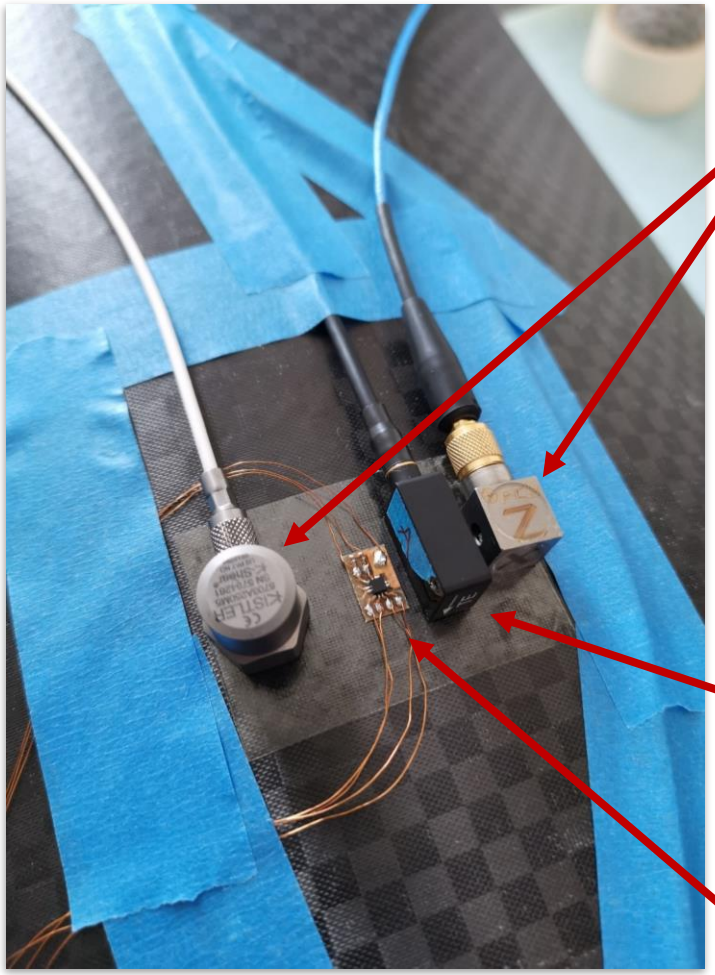


Mockup Construction Defects



Insertion

Accelerometers

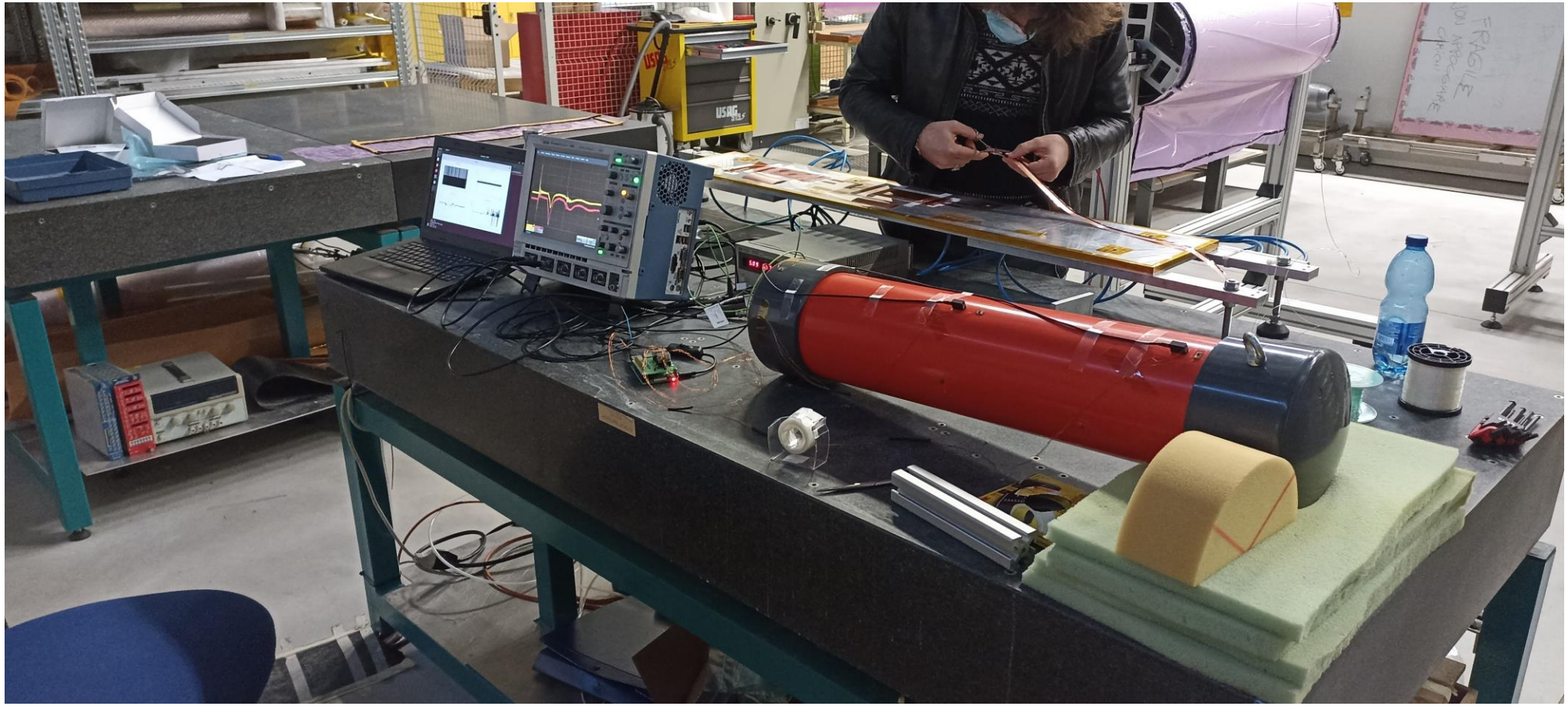


VibMec Accelerometers

TE Connectivity model 8201-0025-125
one-axis analog piezoelectric accelerometer

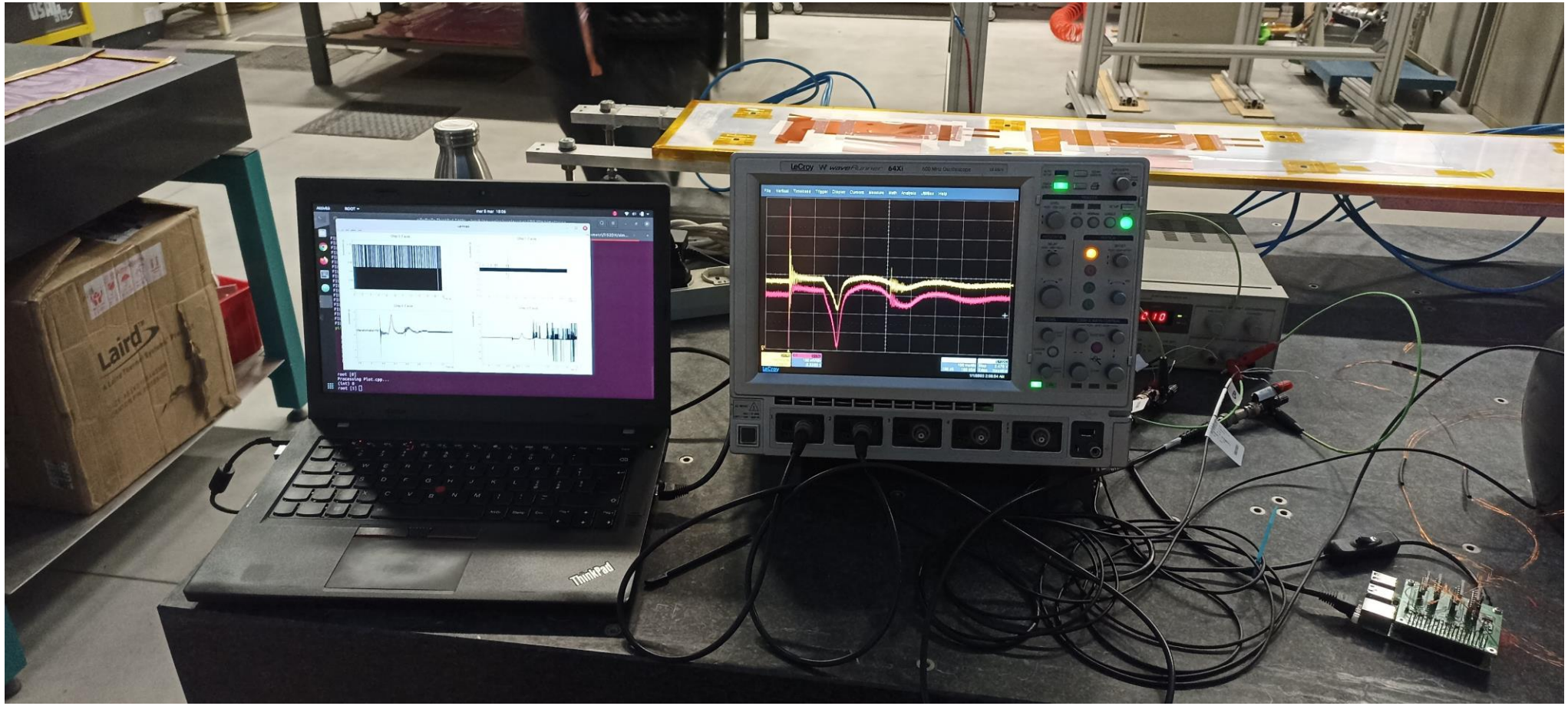
STMicroelectronics IIS2DH
three-axis digital MEMS accelerometer

Setup for Preliminary Studies



Spare Component for Preliminary Studies

Digital and Analog Acquisition



Laser Alignment System