3x1x1 implications to the protoDUNE prototype

Performance of the 3x1x1

The 3x1x1 m3 was constructed with the goal to test many aspects of the dual phase on large scale.

- The cryostat and cryogenics (purity, piston purge, cryogenic system, stability of LAr level)
- The functionality of the CRP (charge extraction, amplification and readout sandwich) on meter squared area
- …
- The detector response with 3 m strips (final DUNE design):
    - hardware (FE electronics, digital electronics, anode design, detector capacitance, noise, uniformity…). Is there room for improvement?
    - software: hit finding, noise filtering, reconstruction (track, shower, etc..). Here there is always room for improvement! We now have real DP data to use.

- <u>**Many of those aspects have been tested with success (as pointed out in previous talks)**</u>

Performance of the 3x1x1

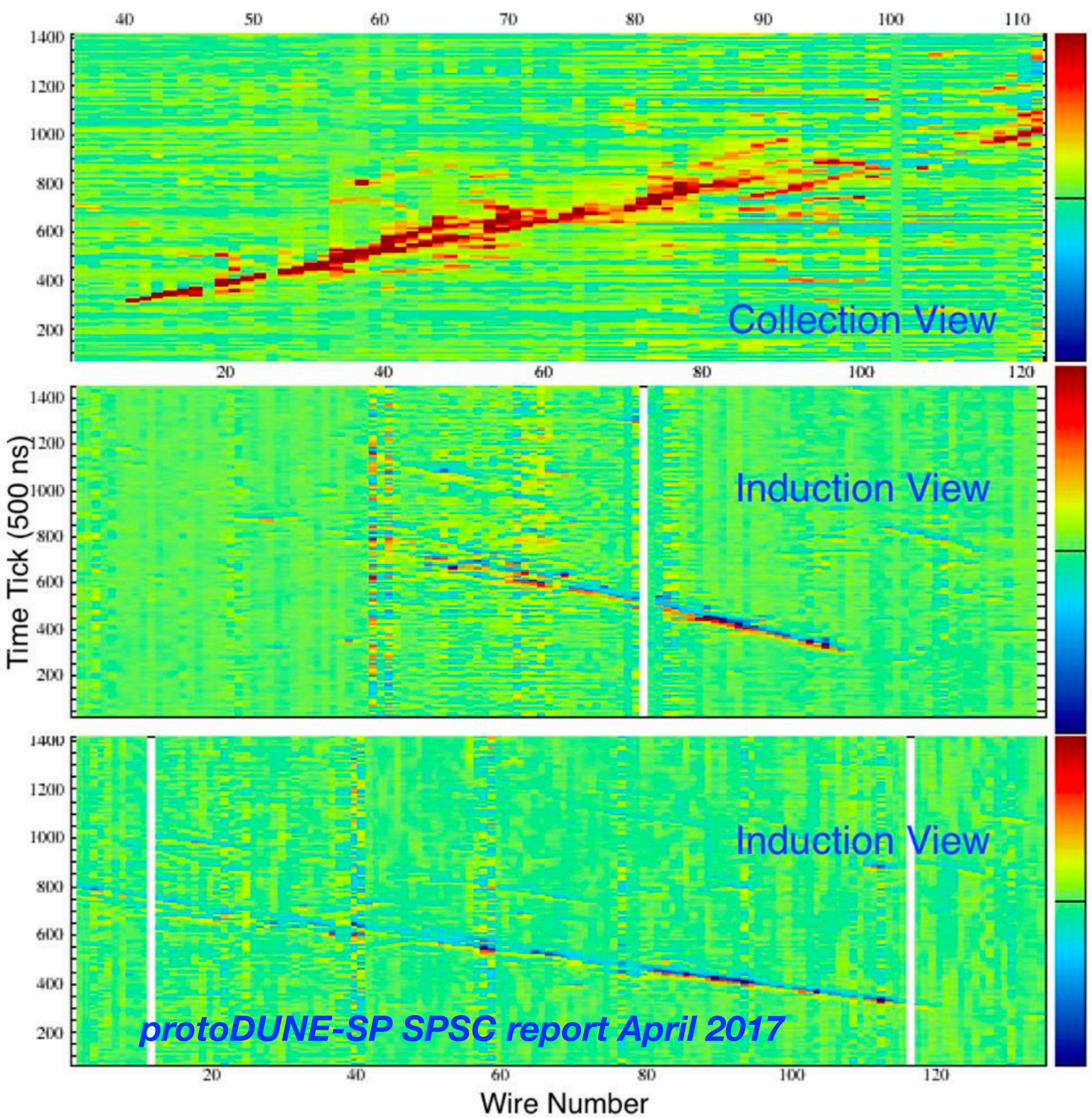
Main (hardware) issues immediately relevant for protoDUNE construction:

- an unforeseen problem on the grid: HV discharges at ~5 kV whereas the nominal should be around 7 kV.
- This issue prevented us to operate the entire CRP at the required voltages and to demonstrate the dual phase operation at nominal fields (extraction, amplification and induction).

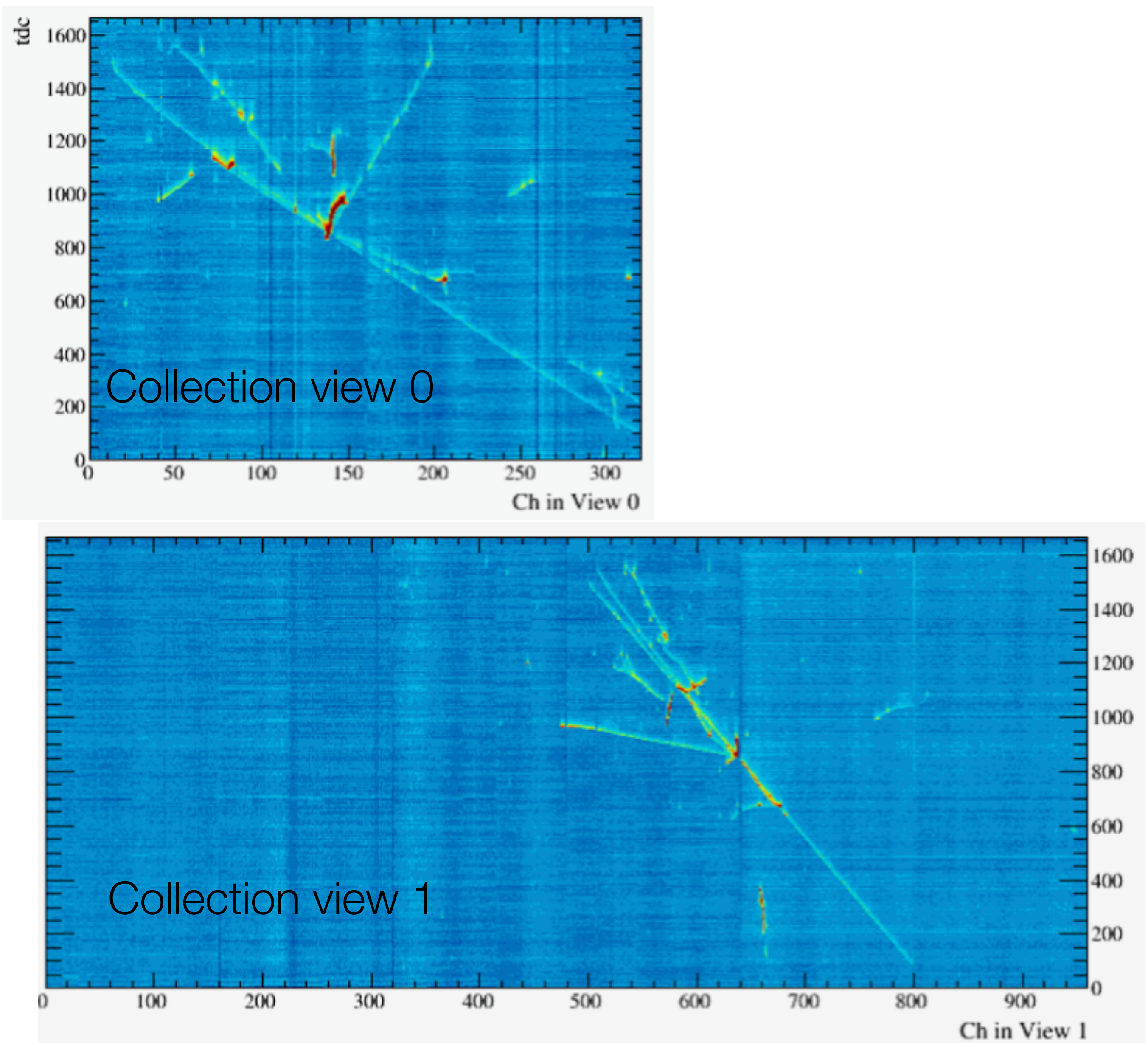
Performance of the 3x1x1

- We have nonetheless demonstrated that the concept is sound. Even without optimal field settings we have shown the powerful imaging capabilities of the detector with two collection views of 1 meter and 3 meter length.

35 ton (with noise filtering)



3x1x1 dual phase (raw no noise filtering)



Impact on protoDUNE-DP

The possible explanations on the issues with the extraction grid HV have been discussed this morning. They point to a broken or loose wire and a potential issue with the HV connection on the grid. These are problems that can be “easily” mitigated for protoDUNE-DP by 1. design improvement 2. specific QA/QC on separate elements and on the entire CRP.

➡1. special care on the protoDUNE-DP CRP has been taken during design phase (1.5 years of engineering and test of elements in cold condition). Described in detail in the DUNE project readiness review in April 2017. Also reported in detail in the 50 backup slides.

➡1. Electrostatic simulations of the entire protoDUNE-DP detector have been performed with great detail DUNE project readiness review in April 2017 and Master thesis CERN 2017-150 . This was not the case (at least with this level of detail) for the 3x1x1.

➡2. targeted QA on sensitive elements (HV contact, LEMs, grid wires,..) QA and “global” QA of an entire CRP in cold conditions.

Proposed plan of action

3x1x1

- stop the operations of the 3x1x1 in ~2 weeks (the necessary time to finalise the last tests we want to do, see this morning and TBD now).
- Empty warm up and make the tank accessible fo an investigation of the grid and detector in general.
- If we see something obvious and repairable (without having to lift the top-cap), propose to repair and perform a second run in optimal conditions.
- The estimated time of this entire activity (warm up, repair + 2nd run) would take us to ~next summer. Will require support from CERN for cryogenic operations.

protoDUNE-DP

- In parallel for the next ~6 months we will focus on the following activities for protoDUNE-DP:

1. Drift cage in EHN1:

- partial assembly of the drift cage end in the cryostat in November/December. On our side all material will be available at CERN mid-november.
- QA and electrical test of the drift cage, details to be understood.

Proposed plan of action

protoDUNE-DP

2. CRP assembly and testing in clean room b. 185:

- Assembly of the 1st CRP and proceed to test as much as possible this entire CRP and in parallel dedicated tests to validate HV on LEM and grid should go on.
- We may think about a possible cold box for testing the full CRP (box similar to that done for protoDUNE-SP but with a greatly simplified design (smaller and horizontal)).
- This would be a complementary step to the studies and tests needed for the stable HV operation of the grid and LEMs.
- Put on hold the orders of the subsequent CRP material LEMs etc.. until we are satisfied with the functionally of CRP#1 in this cold box.
- Continue smaller test and optimisation of individual elements such as HV contacts (already been performed for the grid), LEMs (in process, see talk from Eddy), …

BACKUP

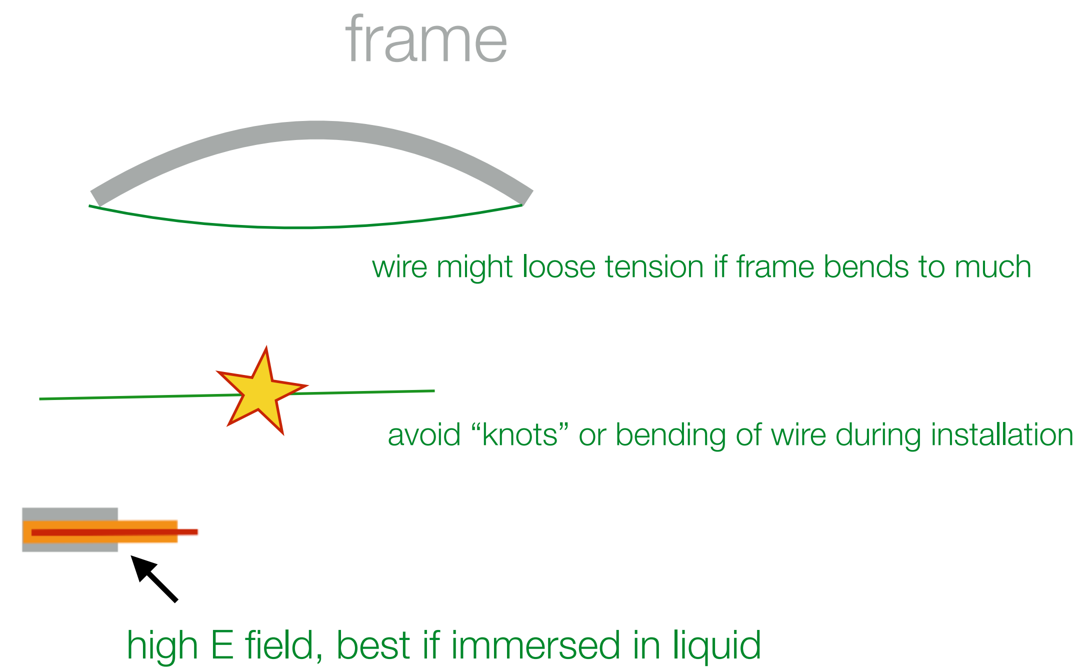
The subsequent slides describe all the technical aspects related to the CRP design and the tests which have been performed so far

possible explanations of the grid issues on the 3x1x1 m3

1. CRP frame deformation (planarity)

2. Grid wire robustness

3. Grid HV connection

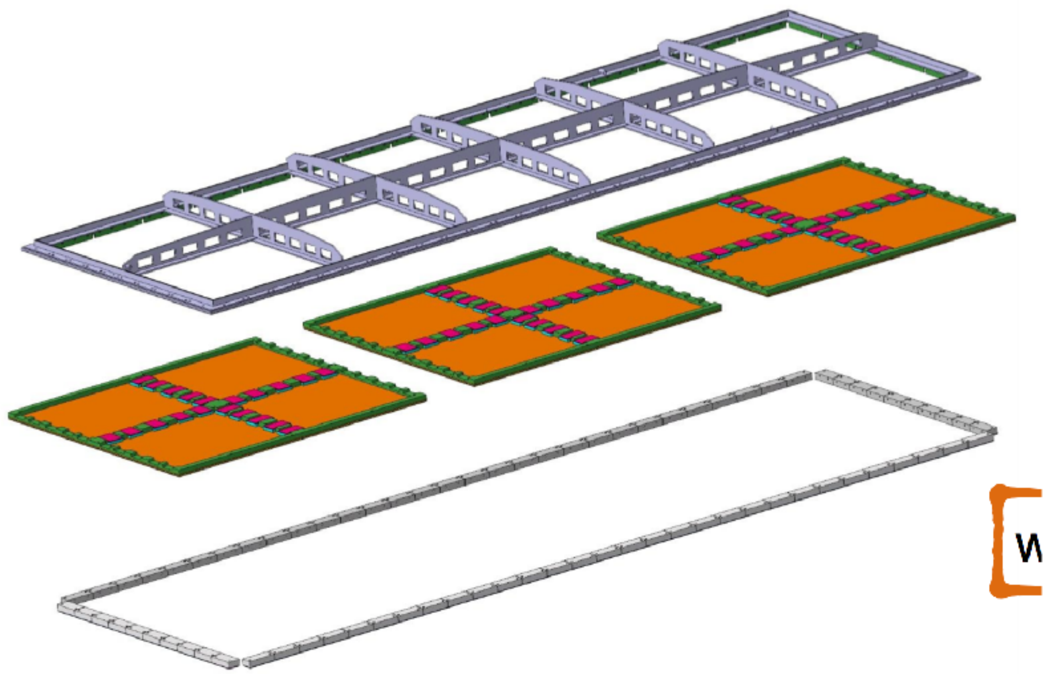


Why the 3x3 m2 CRP would behave differently than that of the 3x1 m2 and how to avoid those potential problems:

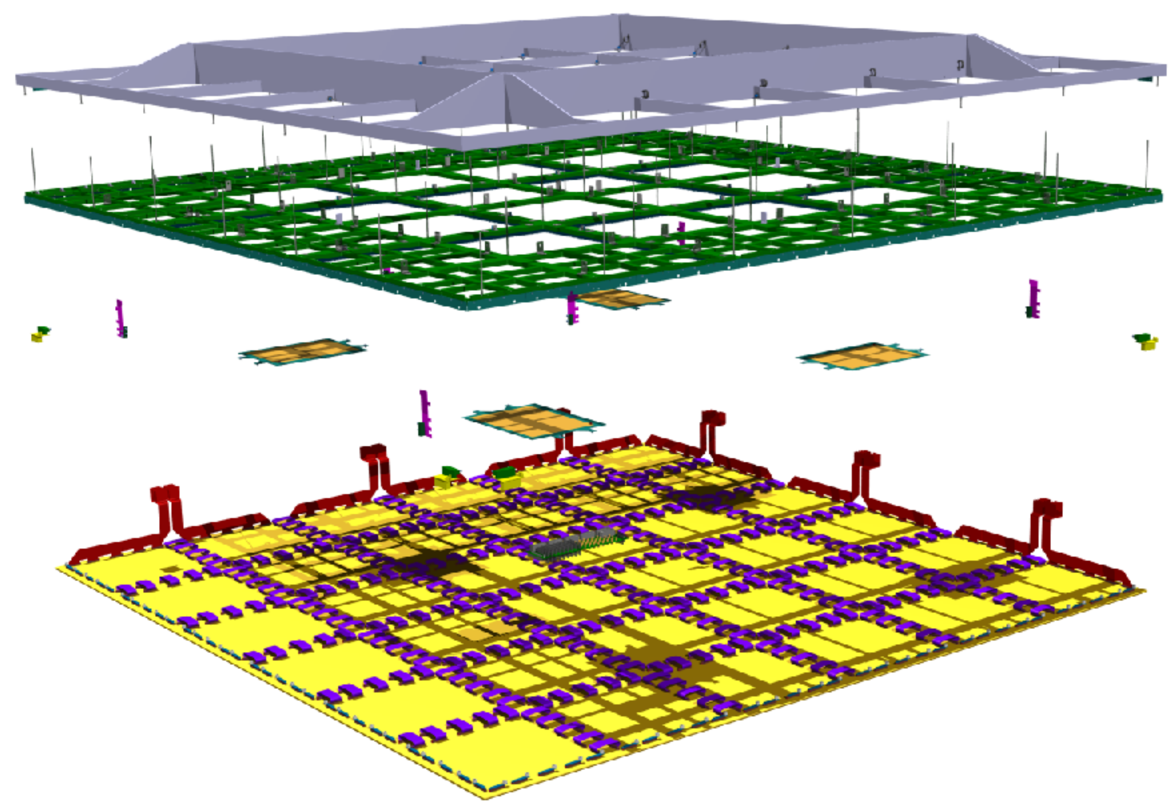
- Different approach on the design of the main structure based on very strict criteria
- Grid wire modules built differently
- Systematics tests on grid parts
- Specific HV tests for the HV connections to the grid

All are described in detail in the backup

CRP frame deformation (planarity)



- Frame:
  - Stainless steel top plate (CTE ~3 mm per m at 87K)
  - G10 structure holding LEM & anode modules screwed to SS frame (i.e follow the shape of the SS frame)
  - deformations measured in cold bath test
- **Grid:** 100 um SS wire carefully soldered with 100 g weight per wire. Tension maybe released during installation fixation on the frame.
- **HV contact of the grid:** no prior test in gas argon. Cable shield terminated in gas



- Frame
  - INVAR top plate (CTE ten times less than SS)
  - G10 structure holding LEM & anode mechanically decoupled from the INVAR frame.
  - 1.5 years of design and test in cold of subcomponents
- **Grid**: 100 um SS wire specific tooling developed to guarantee that the the wires always remain in tension.
- **HV contact of grid:** to be tested on small scale setup (pure argon)

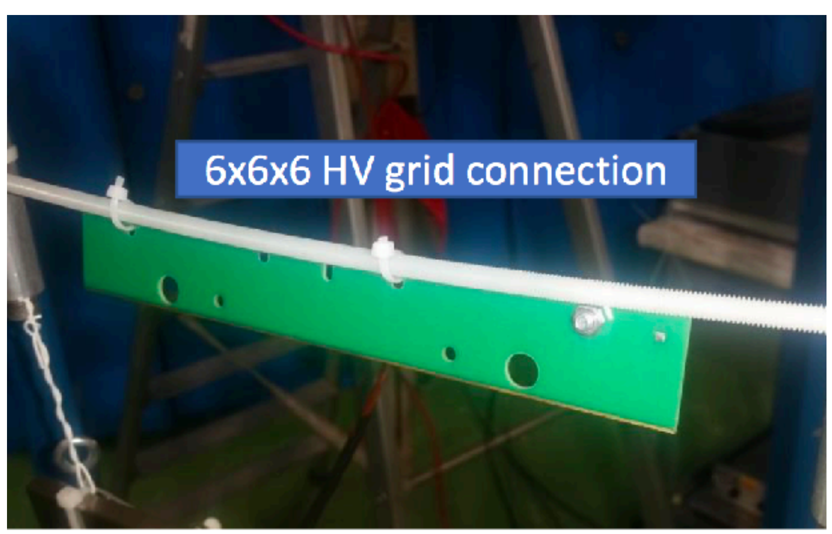
CRP: extraction grid robustness

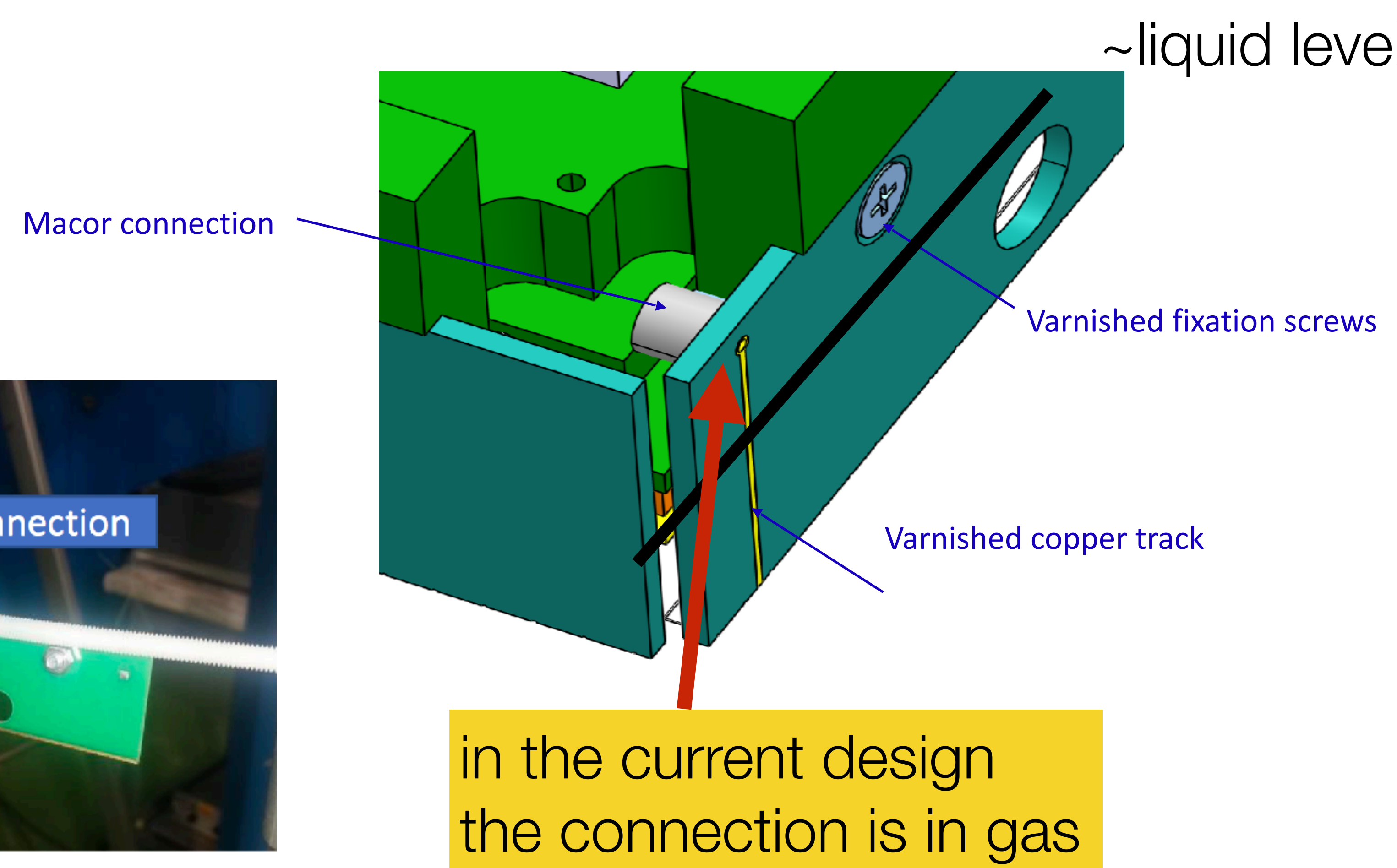
- Compared to the 3x1x1 a large number of precautions have been taken for the grid wire assembly. In addition systematic QA checks are foreseen.

  Precautions:
- system of pulleys to guarantee that a) the wire is not twisted during installation b) the tension is uniform at 0.4 N (factor 35 below the rupture limit).
- the soldering has been stress tested in the lab
- Foresee non destructive quality control test:
  - Visual inspection of wire regularity and surface quality
  - visual of soldering quality
  - Tension of the wires using a cylindrical weight put on the wires

CRP: Extraction grid HV contact

- The grid needs to be powered at about 7 kV. The HV contact on the grid is a critical part.
- The grid itself is in liquid but for the 3x1x1 the contact is in gas (see previous talk).
- For protoDUNE-DP the current design also foresees contact in gas.
- Being tested in pure cold Argon. Investigation ways to have the cable fully immersed in liquid
- Will test the final assembled CRP in a box filled with dry air (or N2)

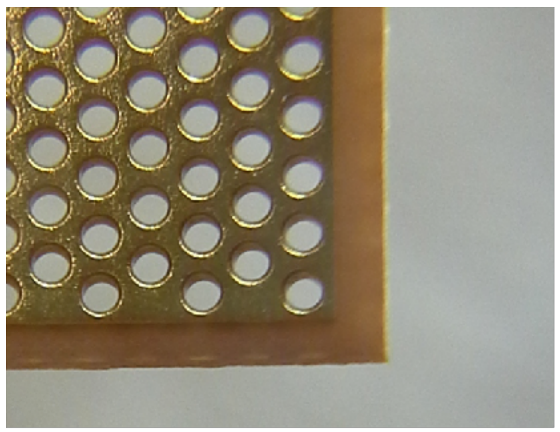


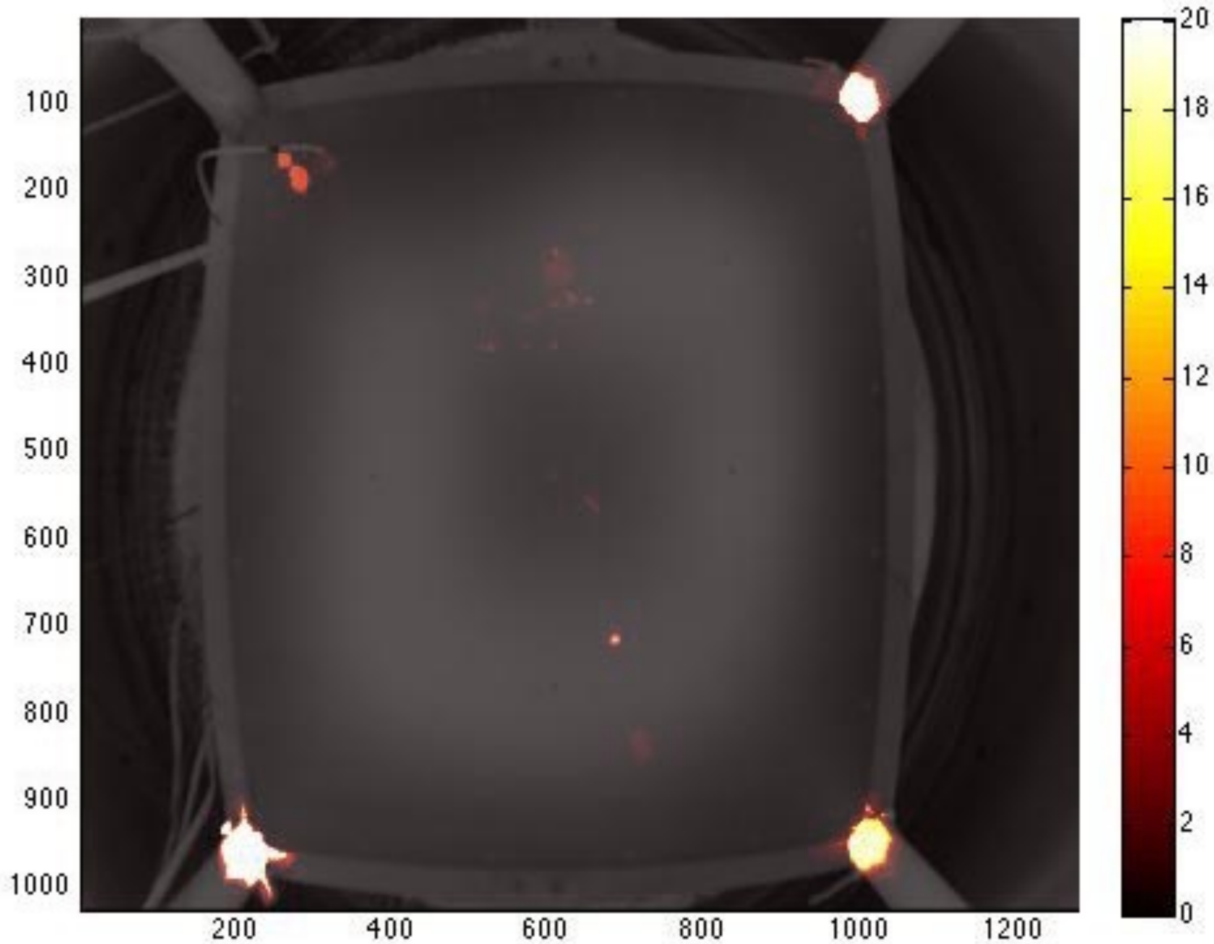


LEMs-what we understood during 3x1x1 construction

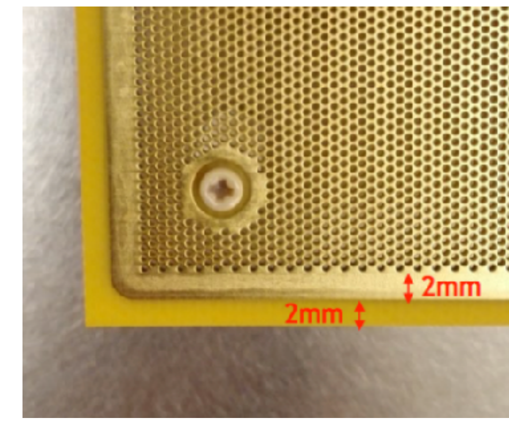
at P=0.989 bar, **T=88 K** and purity ~ 5 ppm **in year 2015**

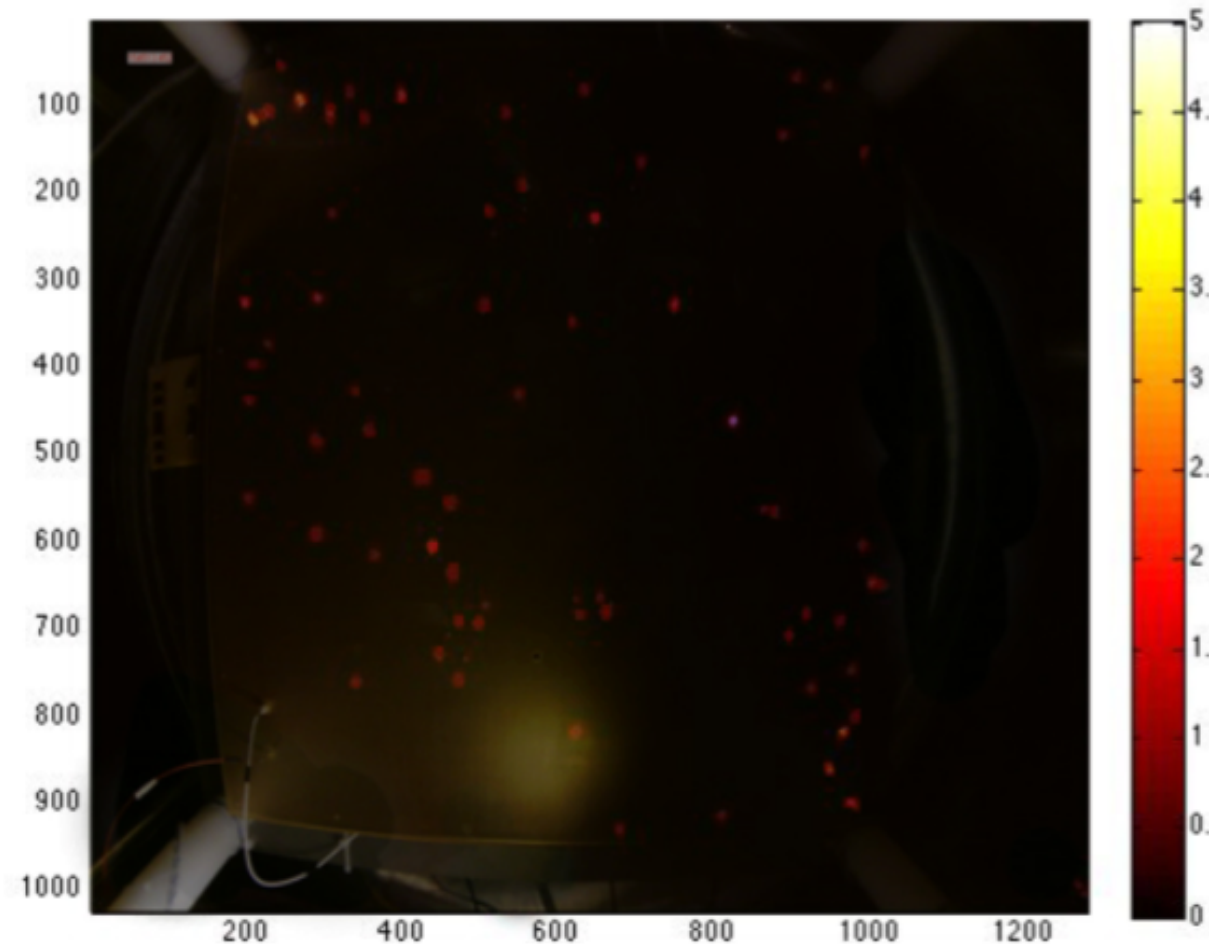
- sparks at 4 corners at 2750 V.





- uniform sparks at 3150 V





CRP frame details

CRP for protoDUNE-DP

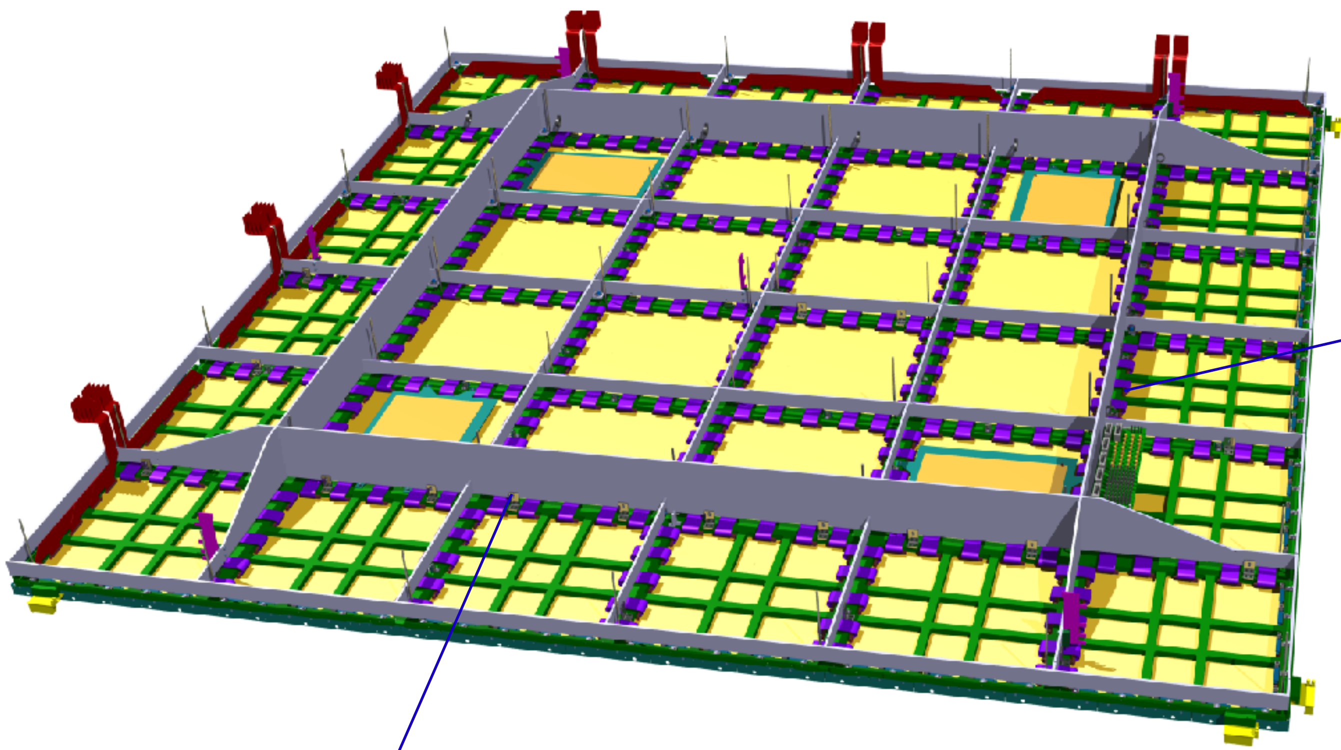
- Mechanical specifications of the plane :
  - In planarity
    - Specified planarity tolerance on the LEM plane is **+/-0,5mm**
  - In positioning
    - Specified altitude tolerance is **+/-0,05mm**
  - In detection surface
    - Minimise inter-space between module **max. 10mm**
  - Be transportable and installable…
- Design of WA105 must be scalable and usable for DUNE

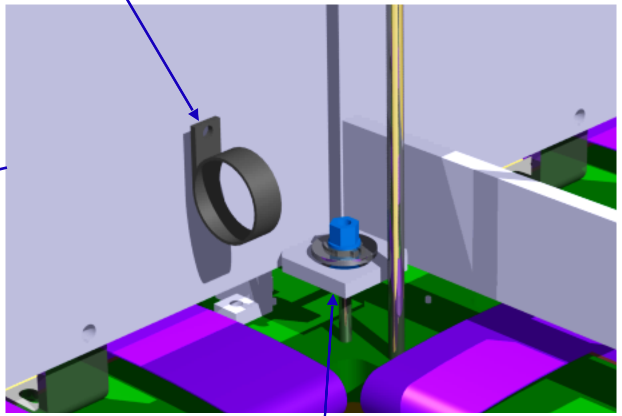
The frame

- Invar frame is the skeleton of the module
- All the frames are identical

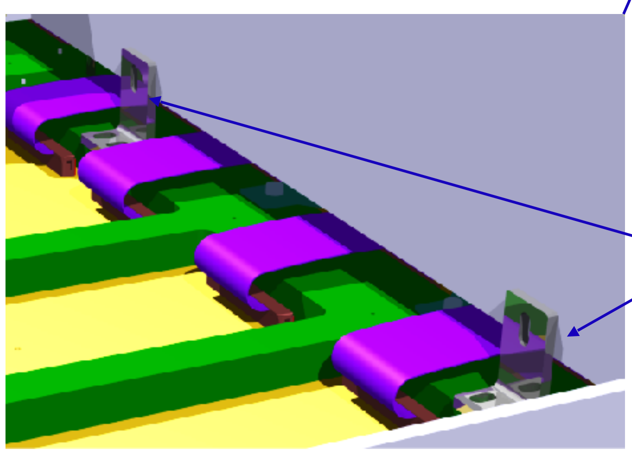
Nickel-iron alloy $^{64}FeNi$

Stainless steel adaptable Cable fixations all around the frame



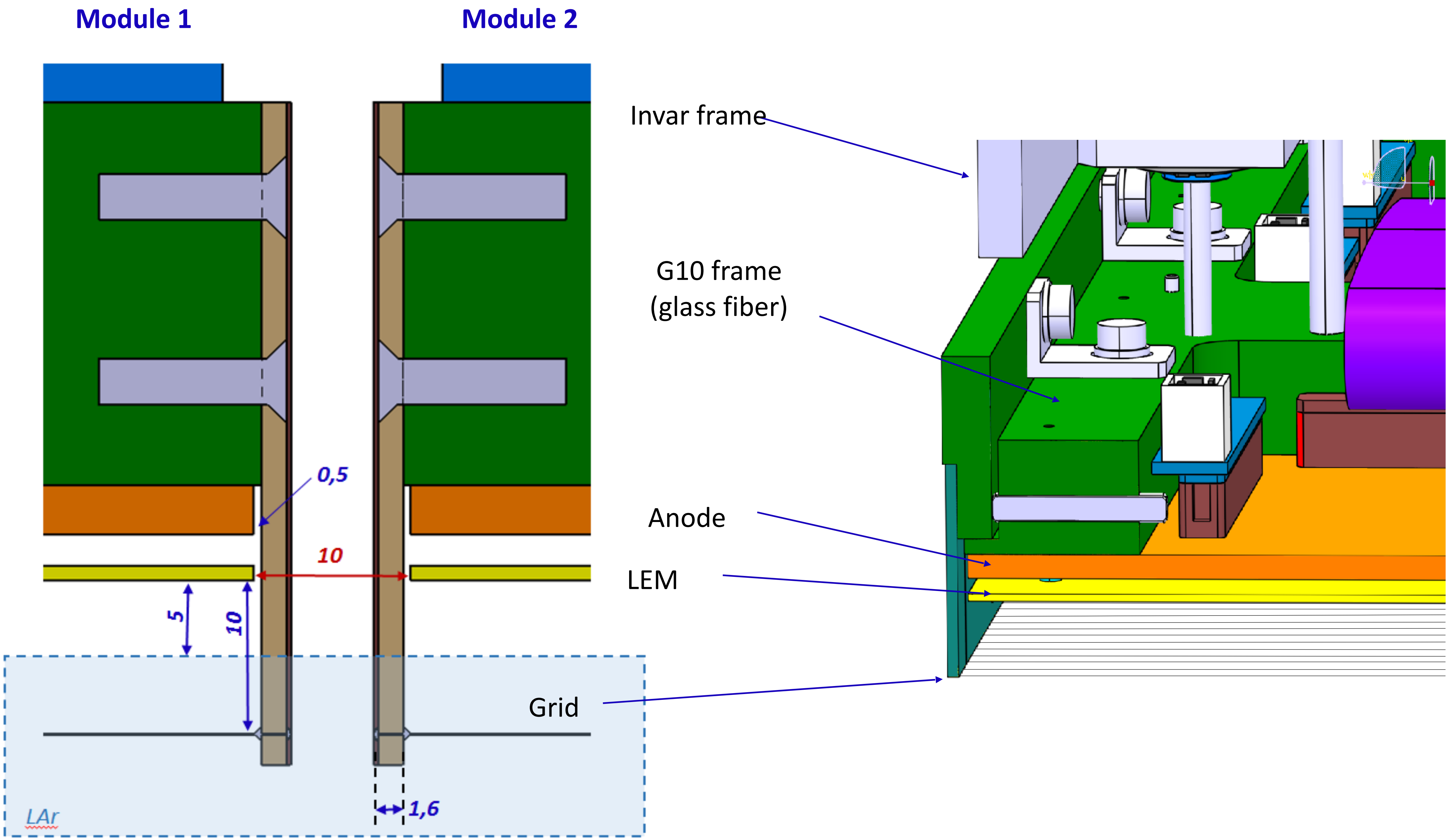


Supporting plates for thermal decoupling and planarity tuning welded on the frame



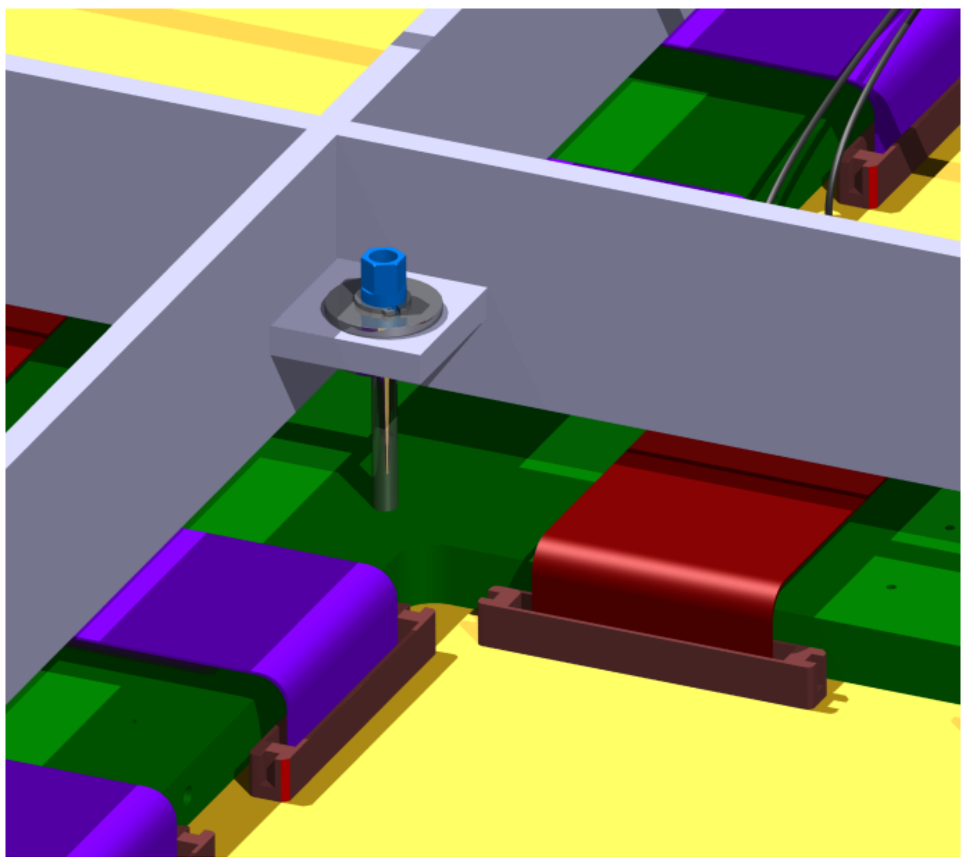
Square supports between invar and G10 for final assembly transportation

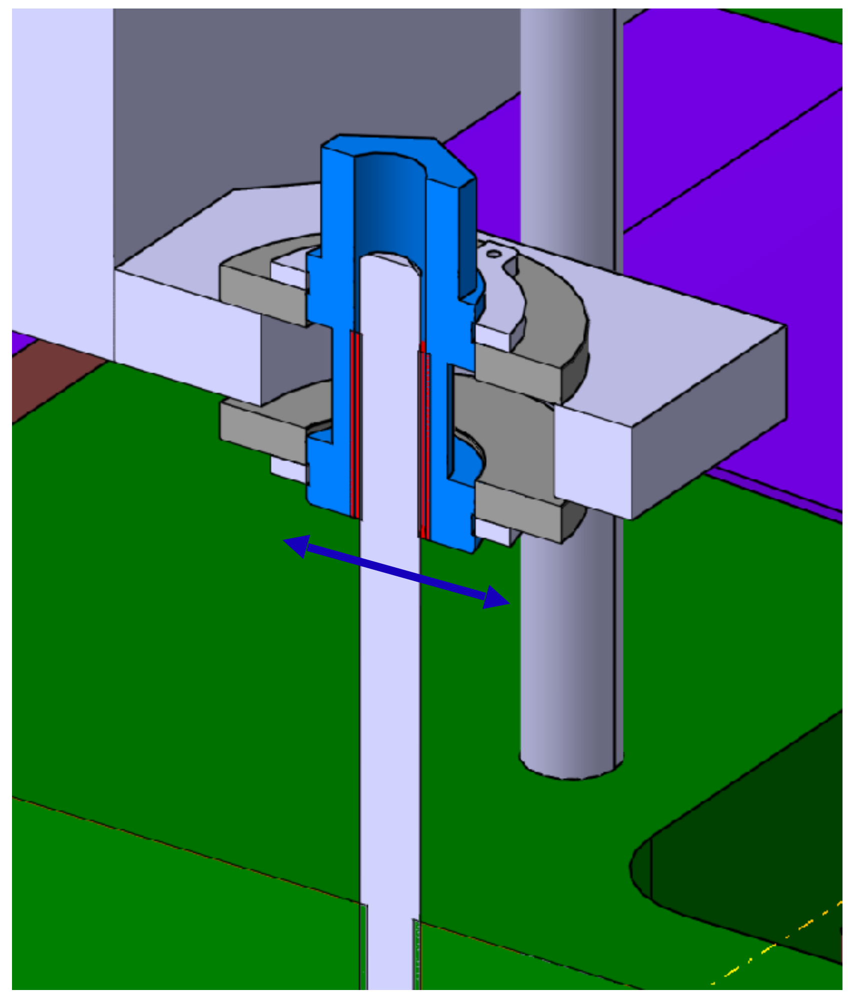
CRP Overview and composition

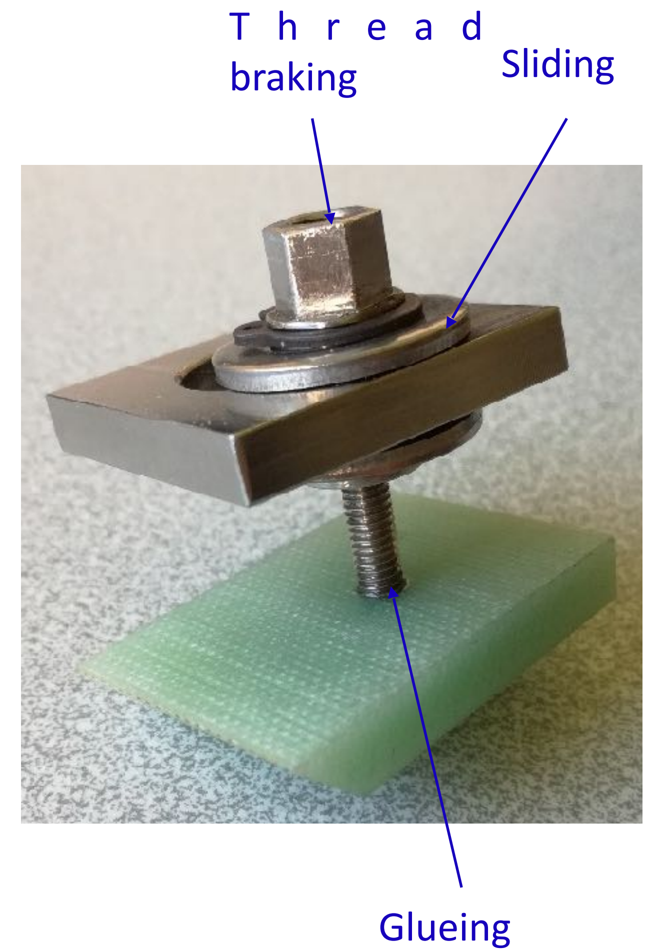


Thermal Decoupling between Invar and G10 frames

- During cooling, Invar is keeping its dimensions while G10 frame and LEMs/Anodes are contracting
- Thermal decoupling allows a lateral sliding of the G10 frame, without changing the altitude
- Decoupling systems are installed at each corner of the invar frame (50 systems by 3x3m module)



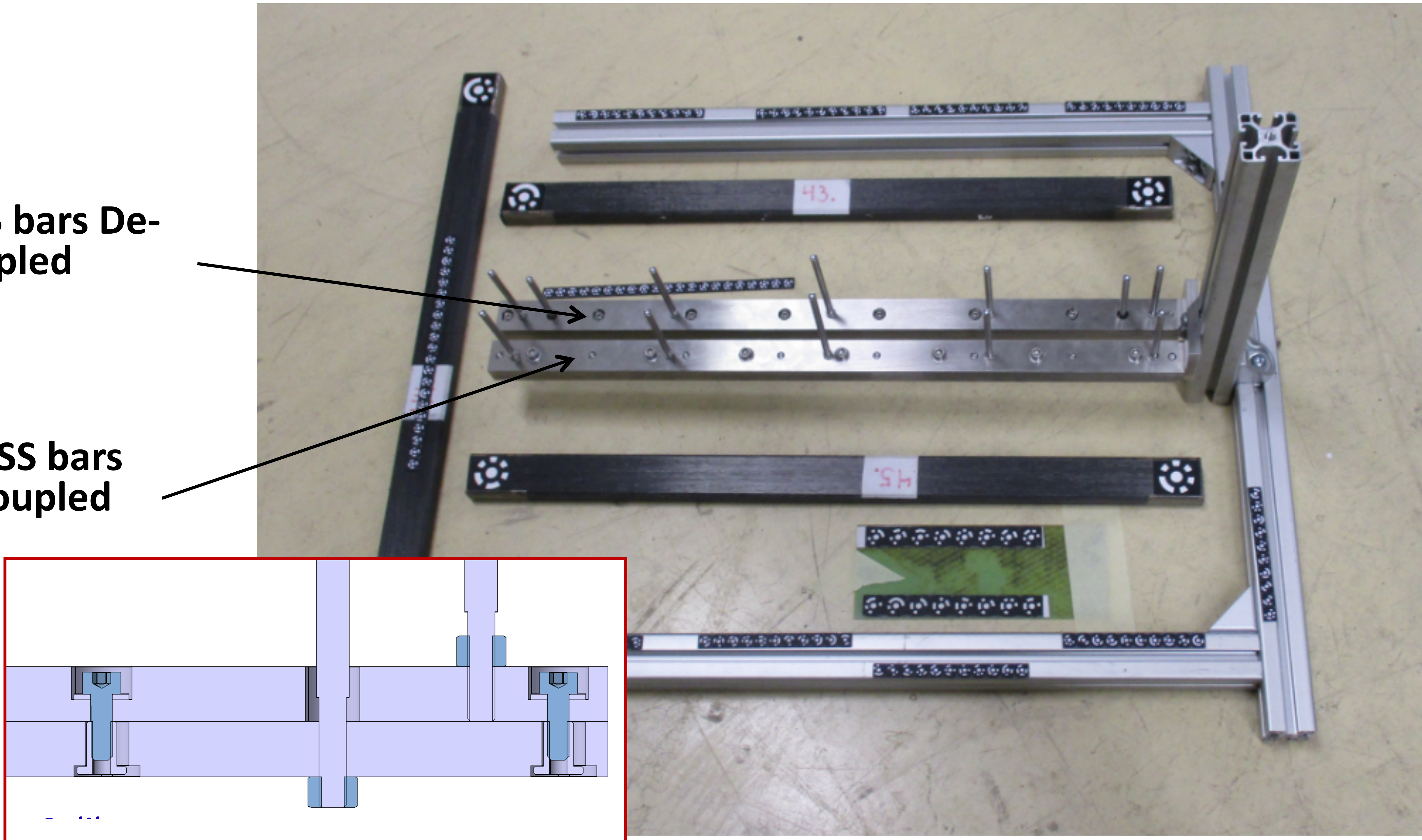




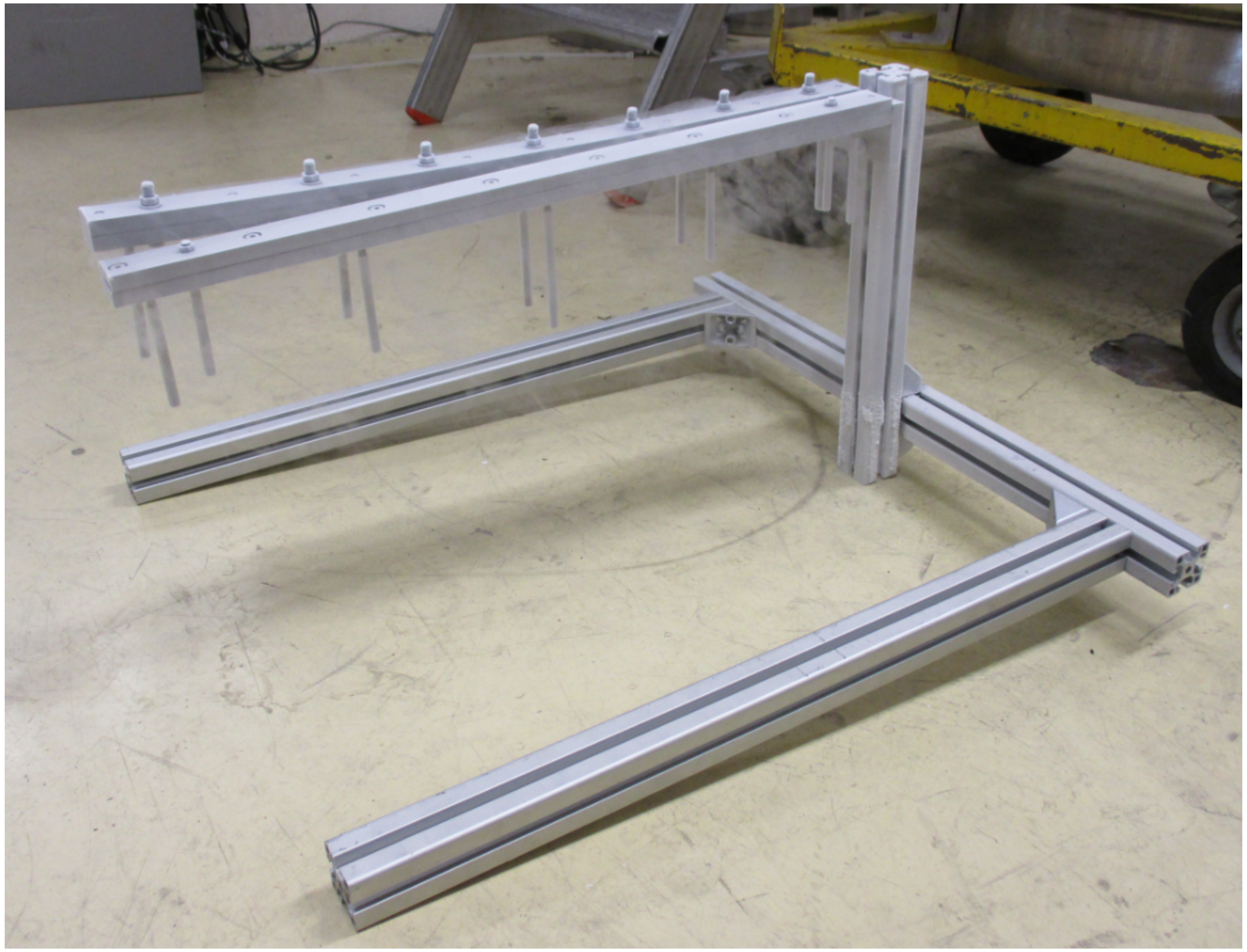
Test of decoupling system

2 SS bars De-coupled

2 SS bars Coupled

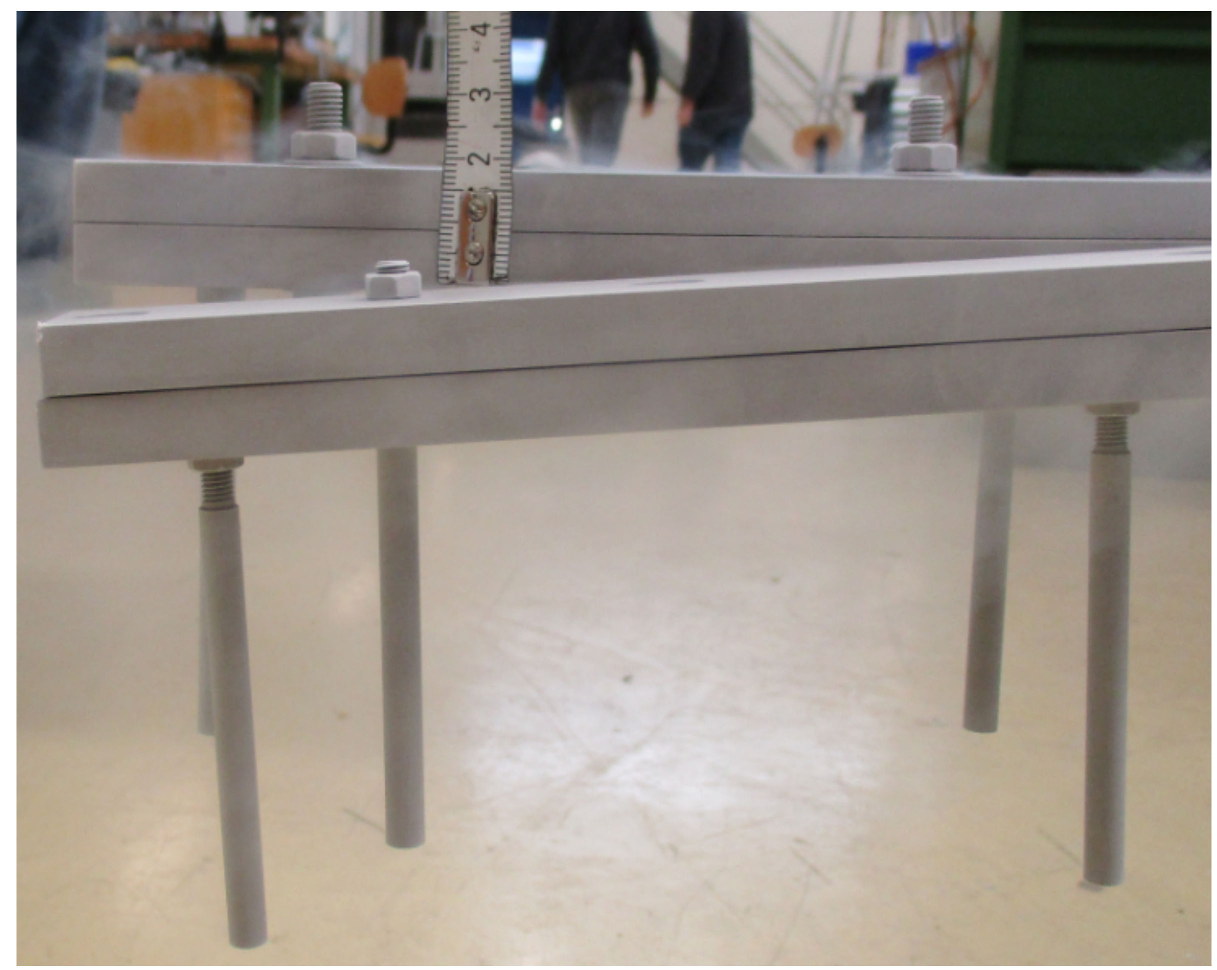


Decoupling system – Cryogenic tests

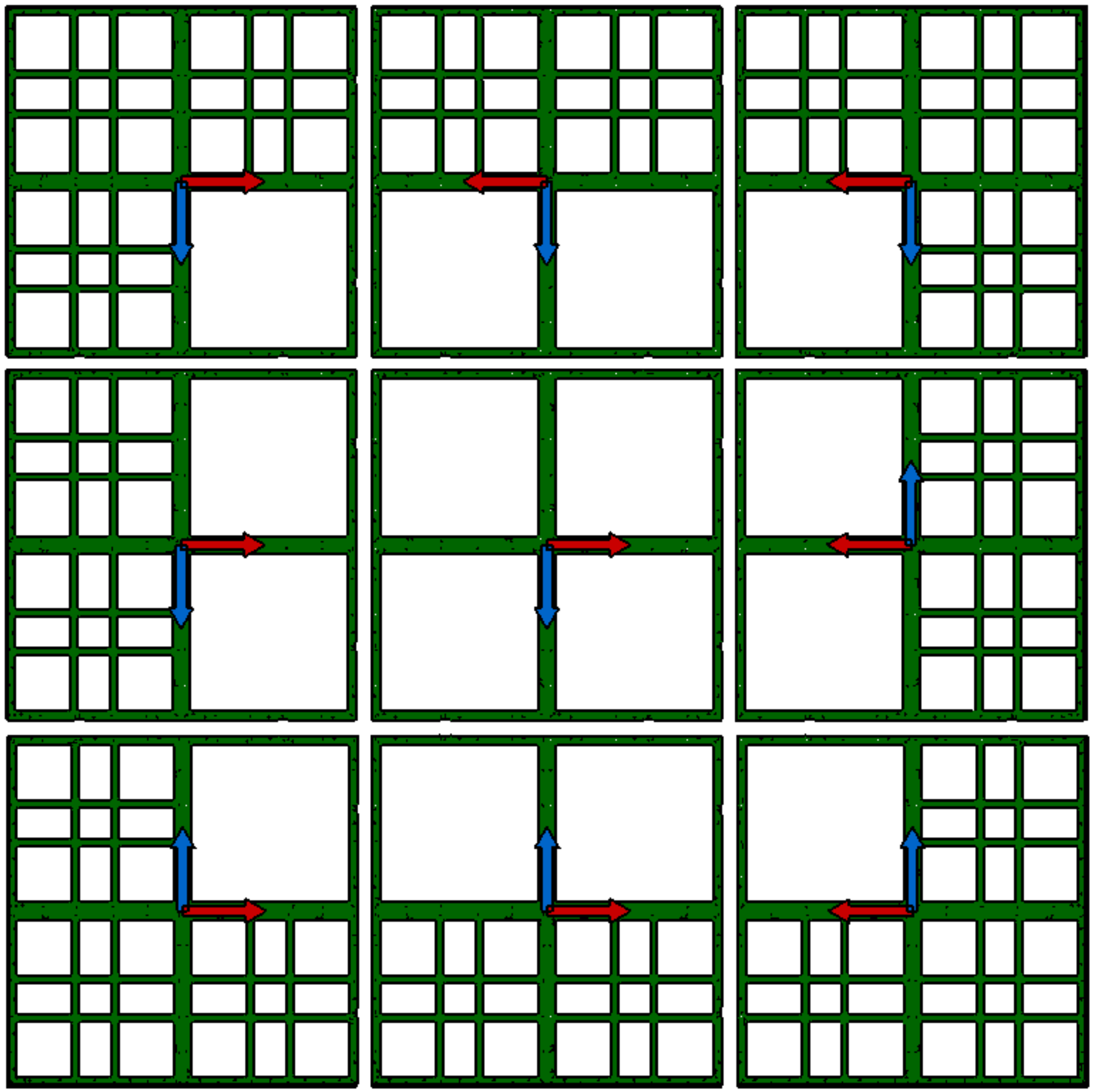


Warming after cold bath

Important behavior difference between 2 assemblies



Nine 1x1m² sub-frames are composing final structure



Three different patterns :

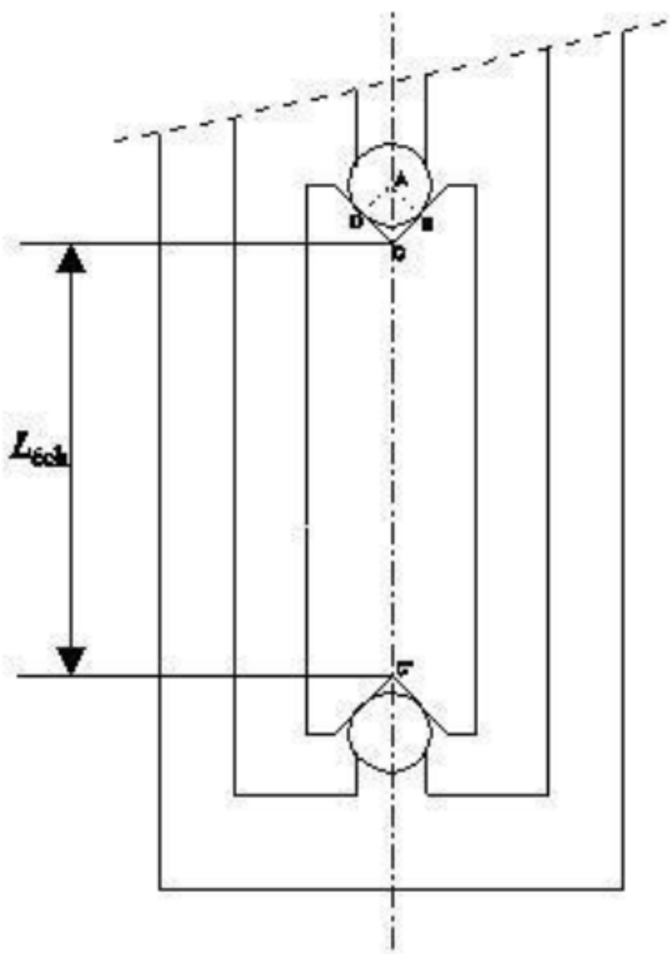
- « Cadre_G10_T1 » for angles
- « Cadre_G10_T2 » for face centers
- « Cadre_G10_T3 » for center

- Fibers directions are matched to insure harmony in thermal shrinkage
  - ➢ Two versions of each pattern
  - ➢ Supporting bars and combs follow same rule

Thermal shrinkage measurements

- Study has been performed by Cryolab at CERN to know contraction coefficients

  https://edms.cern.ch/ui/file/1557852/1/LAPP_G10_rapport.pdf



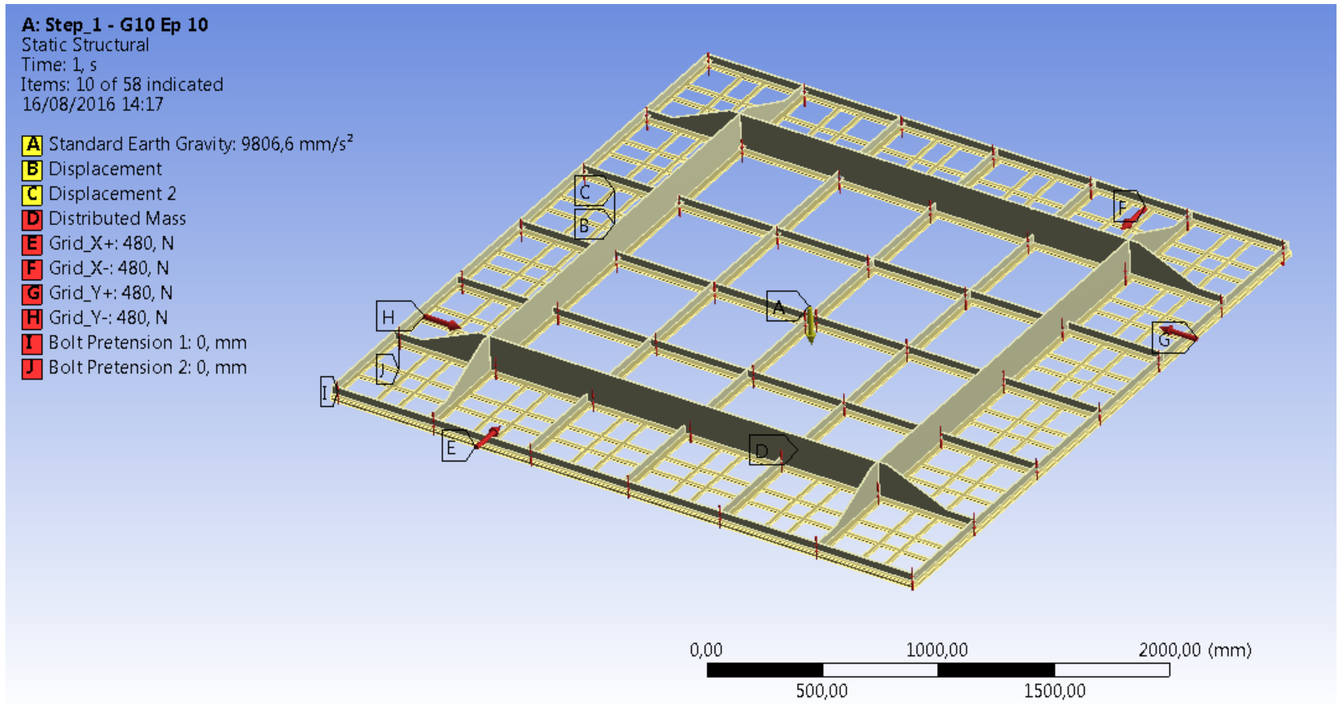
Tests from ***CRYOLAB*** on G10
(Vetronit EGS 102 from Von Roll)

α_1 = 7,2.10^{-6} K^{-1}
α_2 = 9,3.10^{-6} K^{-1}
α_3 = 33,5.10^{-6} K^{-1}

Thoses values are supposed to be close to the LEM-Anode sandwich (LAS) one,

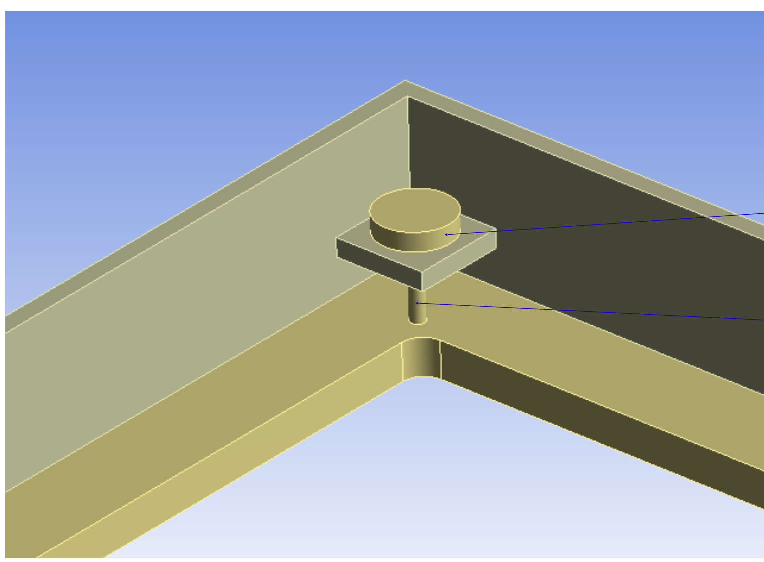
so G10 thermal behavior is similar to LAS

Initial geometry



INVAR Frame :

- ***H = 150 mm***
- ***h = 40 mm***
- ***Ep = 5 mm***
- ***Frame mass : 112,3 kg***



Contact

Adjustable length for planarity tuning

G10 Frame :

- ***Thickness = 15 mm***
- ***Frame mass : 67,7 kg***

Added Mass (for LEMs and electronic) : **150 kg**

Material properties

➢ Invar properties :

- E = 139.000 MPa minimum (around -150°C)
- ν = 0,228
- ρ = 8125 kg/m^3
- α = 1,5.10^{-6} K^{-1} between 22°C and -186°C

➢ G10 properties :

- Isostatic
- E = 24.000 MPa minimum (around -150°C)
- ν = 0,11
- ρ = 1850 kg/m^3
- α = 8.10^{-6} K^{-1} between 22°C and -186°C

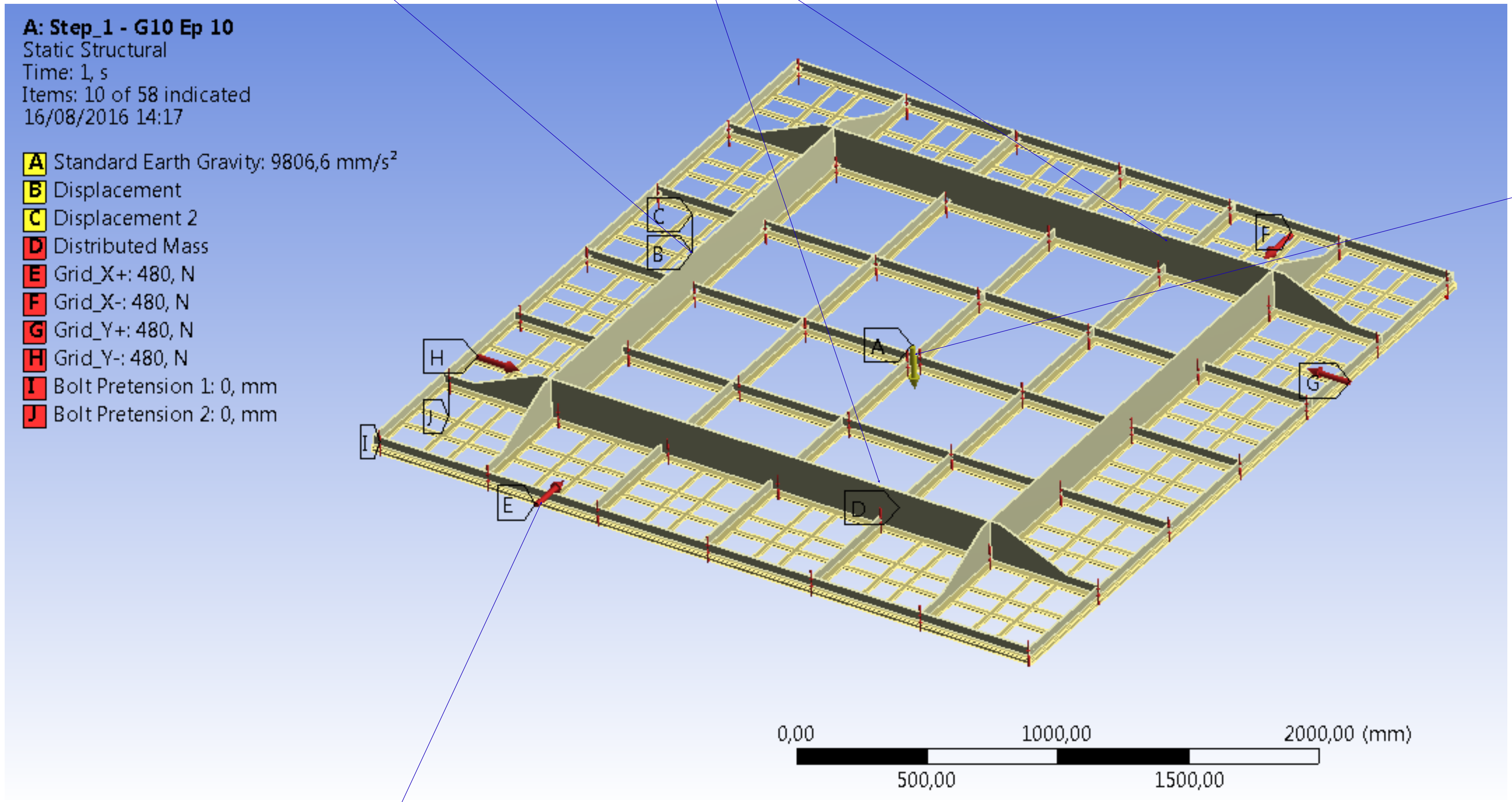
➢ Stainless Steel properties (Extraction grid) :

- E = 210.000 MPa minimum (around -150°C)
- α = 1,36.10^{-5} K^{-1} between 22°C and -186°C
- Cables diameter : 0,1mm
- Cable stiffness : 0,5498 N/mm

Initial geometry

X, Y and Z locking

Z locking



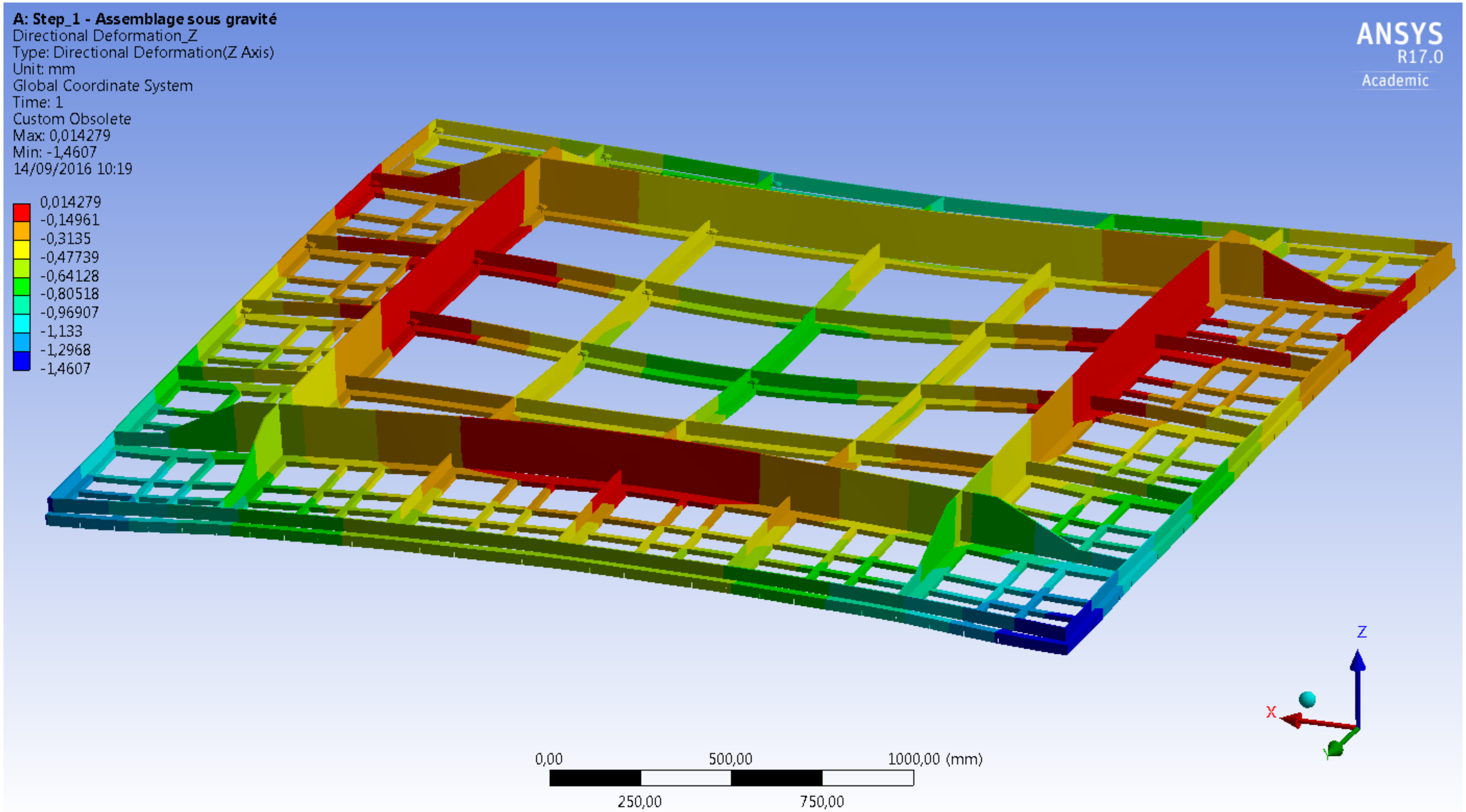
G10 and Invar locked on this point

All other links are only locking Z relative displacements

All link length can be adjusted for planarity tuning

Grid wires as springs (along each side of the module)

Step 1 : Module assembled, warm conditions, no tuning



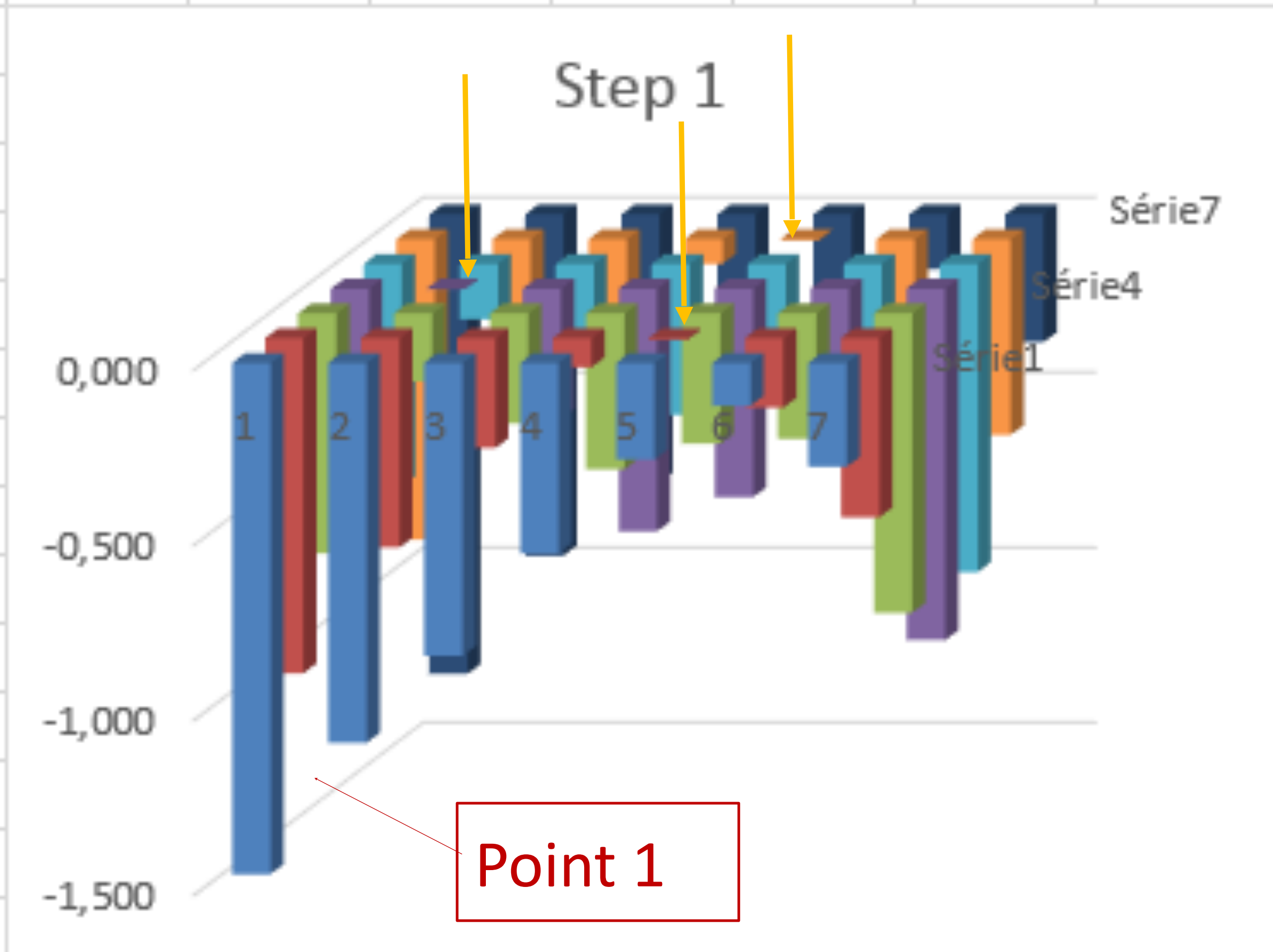
Loading case :

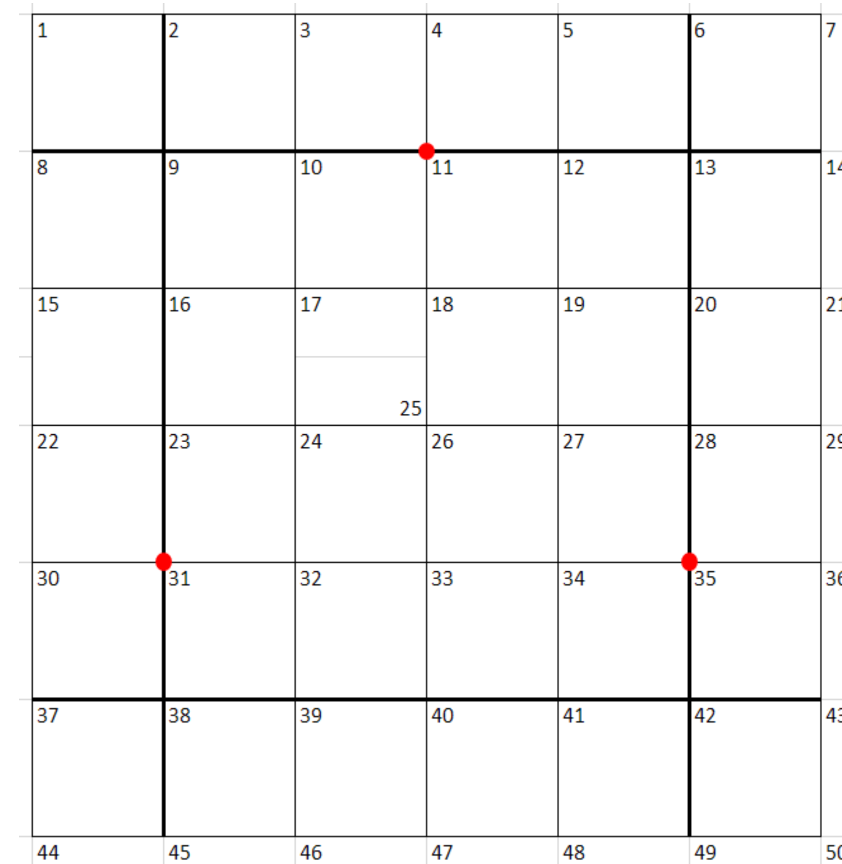
- Gravity
- No Grid tension : grid installed but not tightened

G10 Planarity results for step 1 – Tension init 1 mm

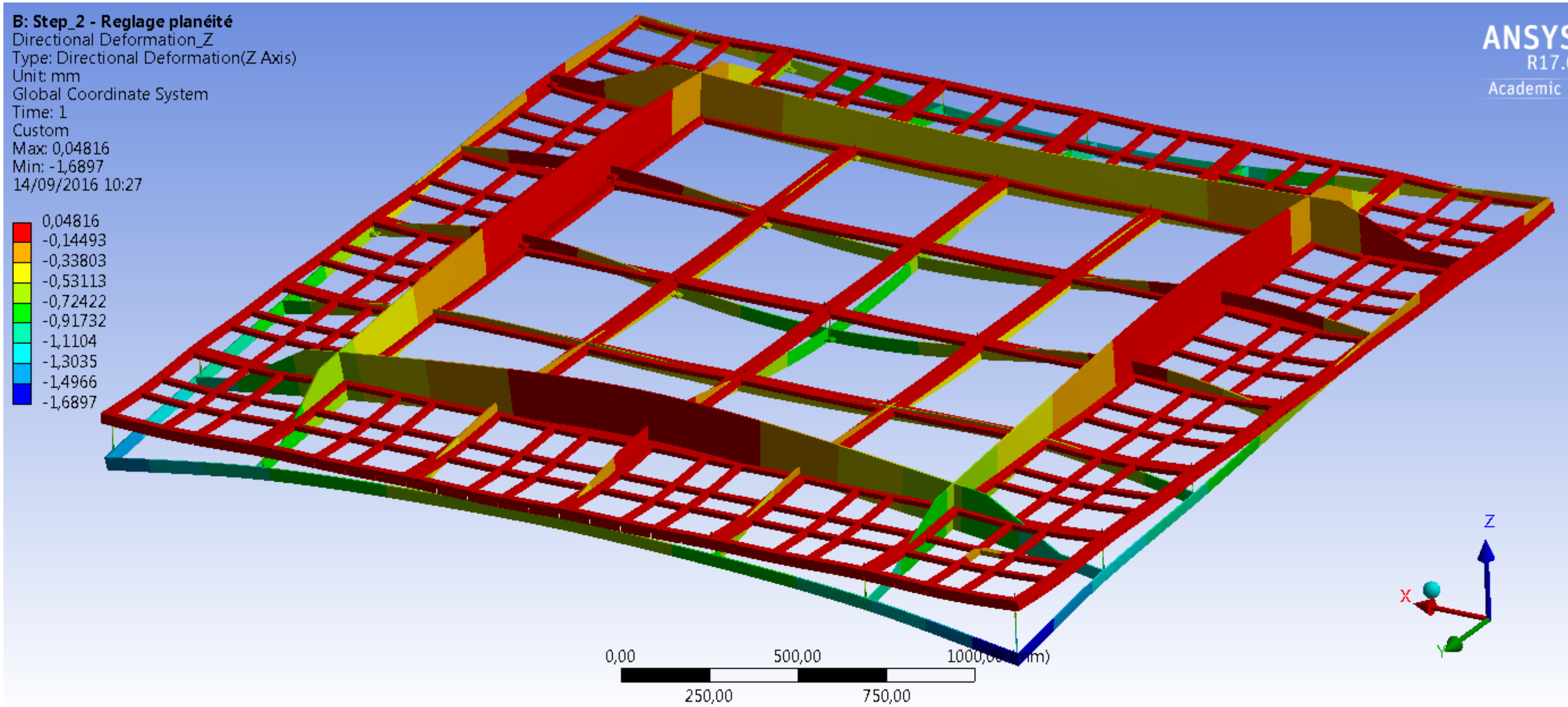
-1,460	-1,086	-0,837	-0,544	-0,276	-0,122	-0,297
-0,957	-0,598	-0,314	-0,083	-0,005	-0,198	-0,512
-0,685	-0,194	-0,315	-0,445	-0,372	-0,358	-0,855
-0,570	-0,002	-0,370	-0,693	-0,596	-0,433	-1,004
-0,635	-0,158	-0,291	-0,432	-0,372	-0,370	-0,880
-0,858	-0,524	-0,265	-0,070	-0,004	-0,221	-0,559
-1,312	-0,975	-0,764	-0,525	-0,273	-0,156	-0,365

Mini	-1,460
Maxi	-0,002
Delta	1,458





Step 2 : Module assembled, warm conditions, Planarity tuned

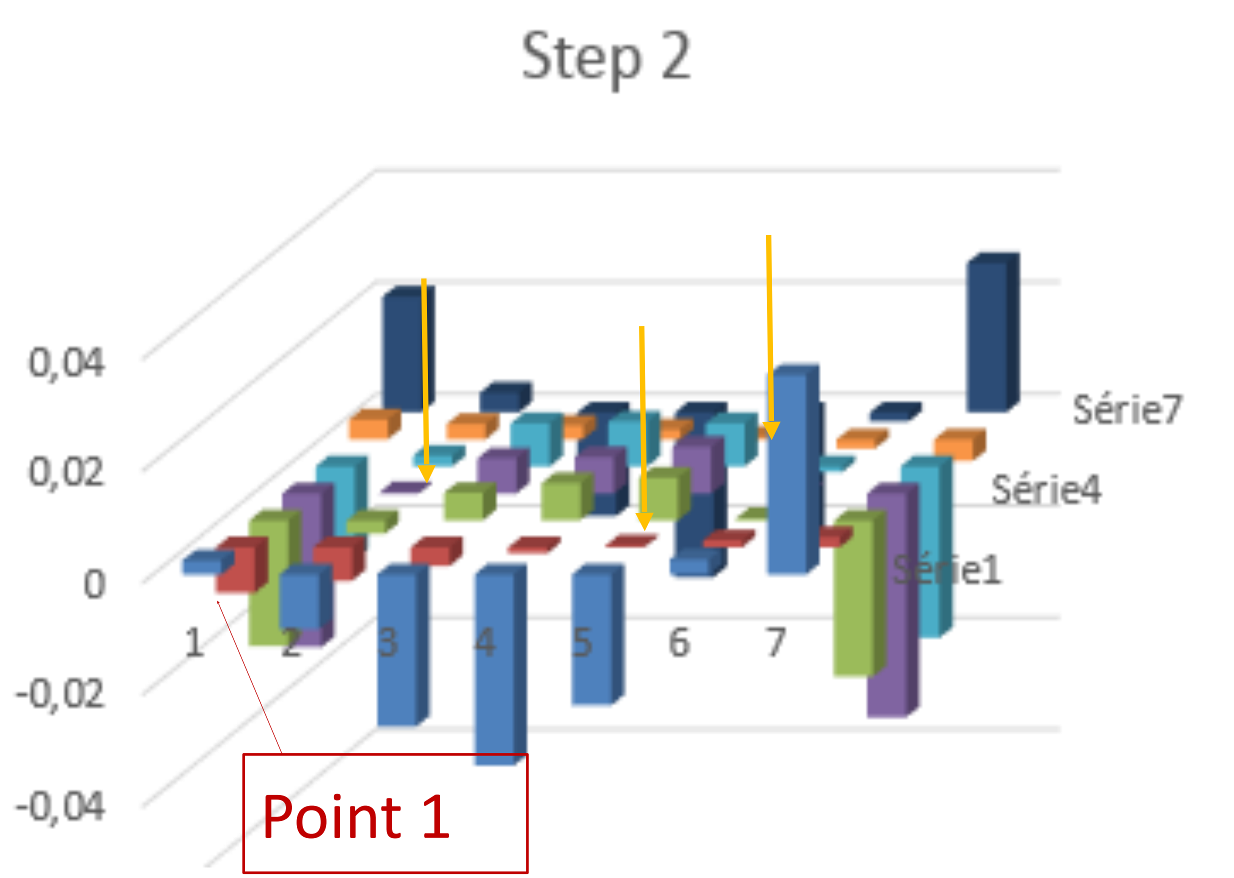


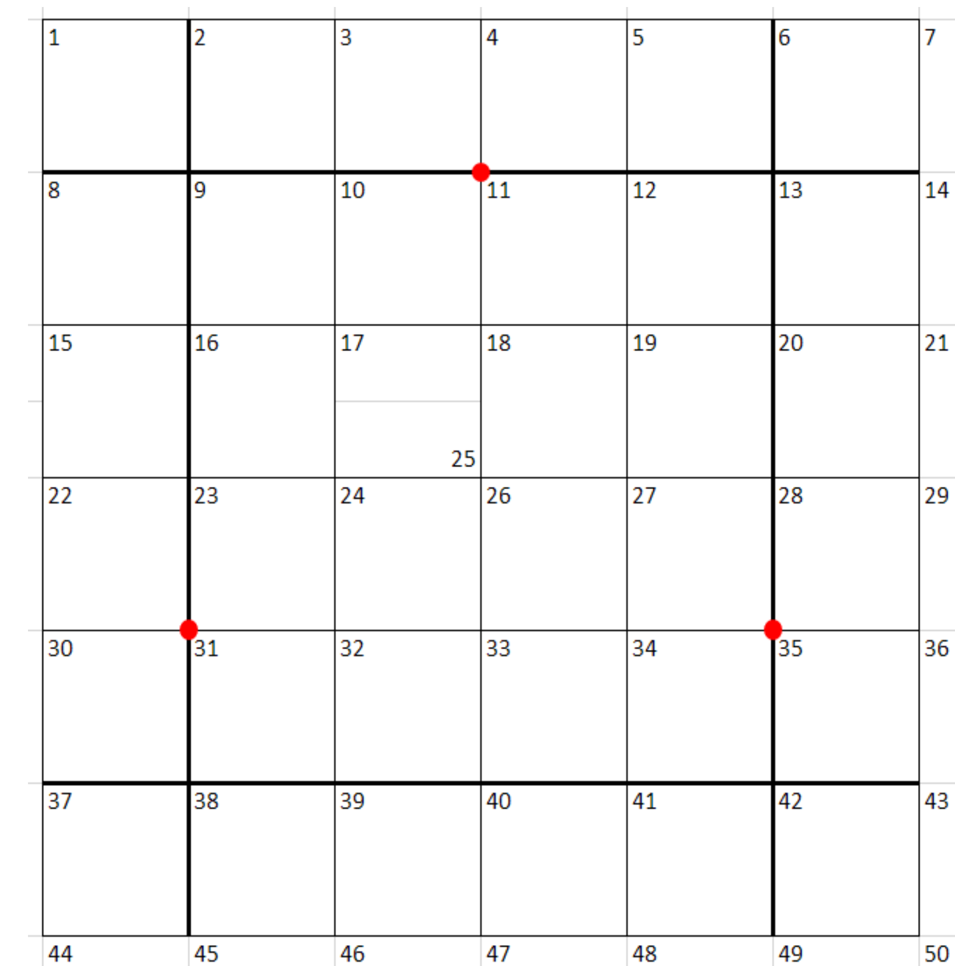
Loading case :

- Gravity
- No Grid tension : grid installed but not tightened
- Planarity tuning

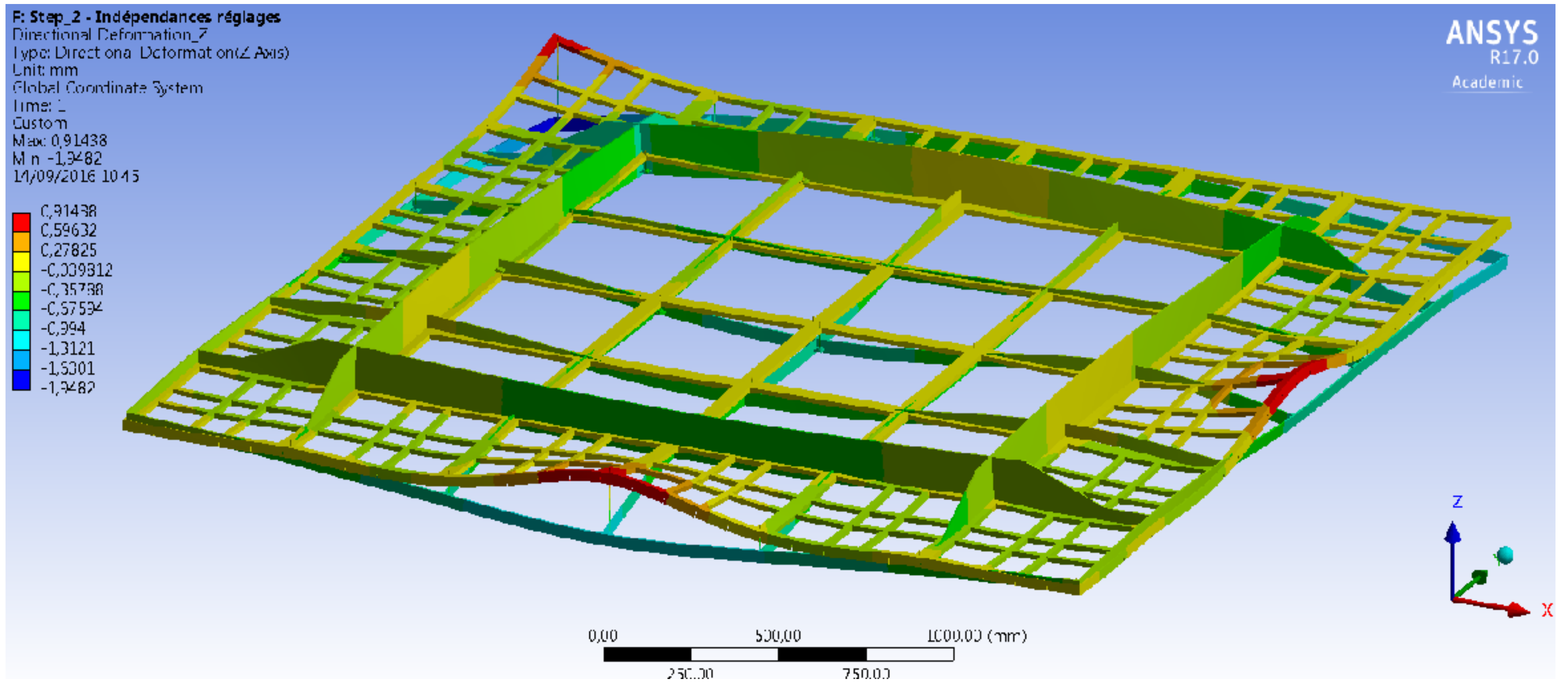
0,0025	-0,01	-0,027	-0,034	-0,023	0,0027	0,0357
-0,008	-0,006	-0,003	-0,001	0,0004	0,0013	0,0018
-0,022	-0,002	0,0049	0,0067	0,0076	0,0004	-0,028
-0,027	0,0003	0,0063	0,0065	0,0083	-3E-04	-0,04
-0,017	0,0019	0,0077	0,008	0,0077	-0,001	-0,031
0,0036	0,0028	0,0025	0,0018	0,0005	-0,002	-0,004
0,0207	0,0035	-0,018	-0,029	-0,023	-0,002	0,0267

Mini	**-0,040**
Maxi	**0,036**
Delta	**0,076**

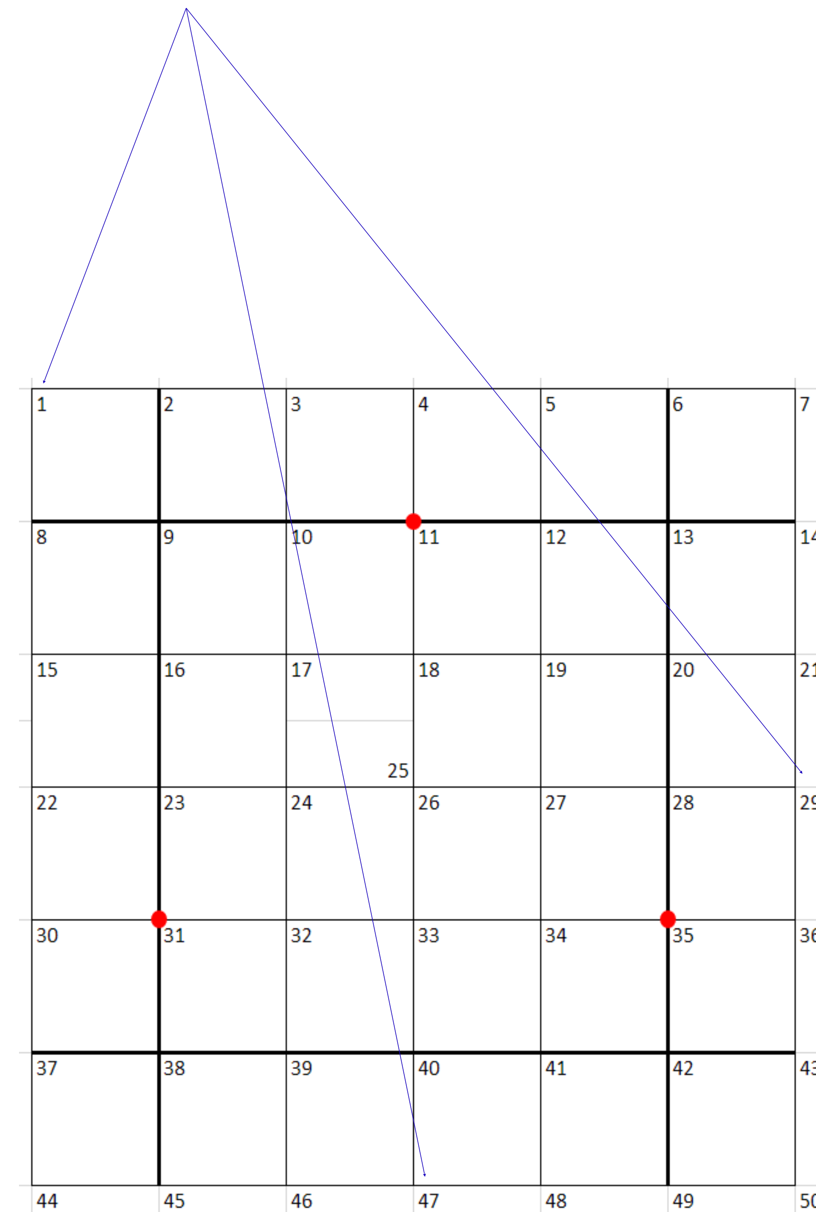




Planarity tuning independency



+1mm on those points



Loading case :

- Gravity
- No Grid tension : grid installed but not tightened
- Planarity tuning

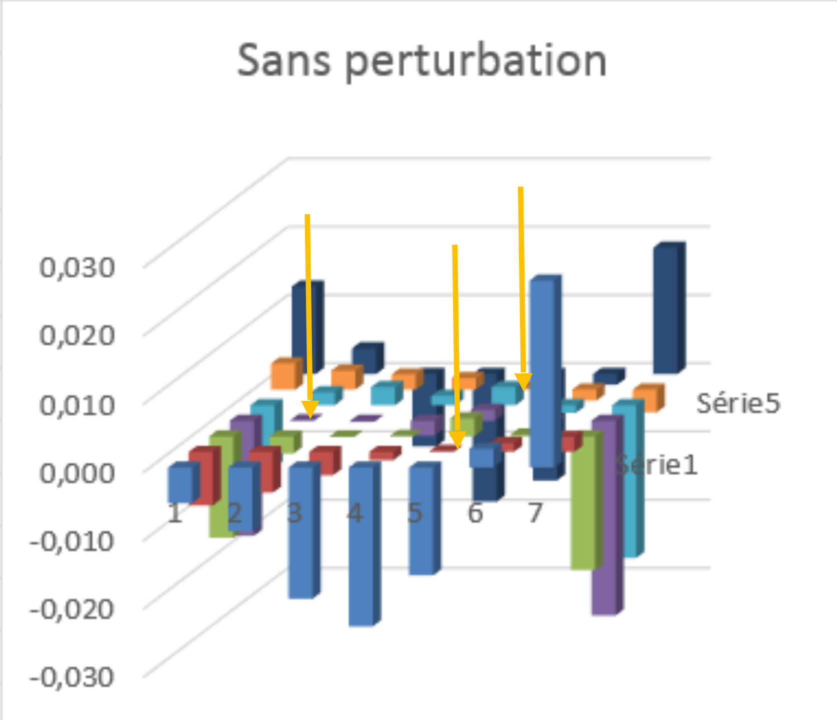
- +1mm perturbations on points 1 - 29 - 47

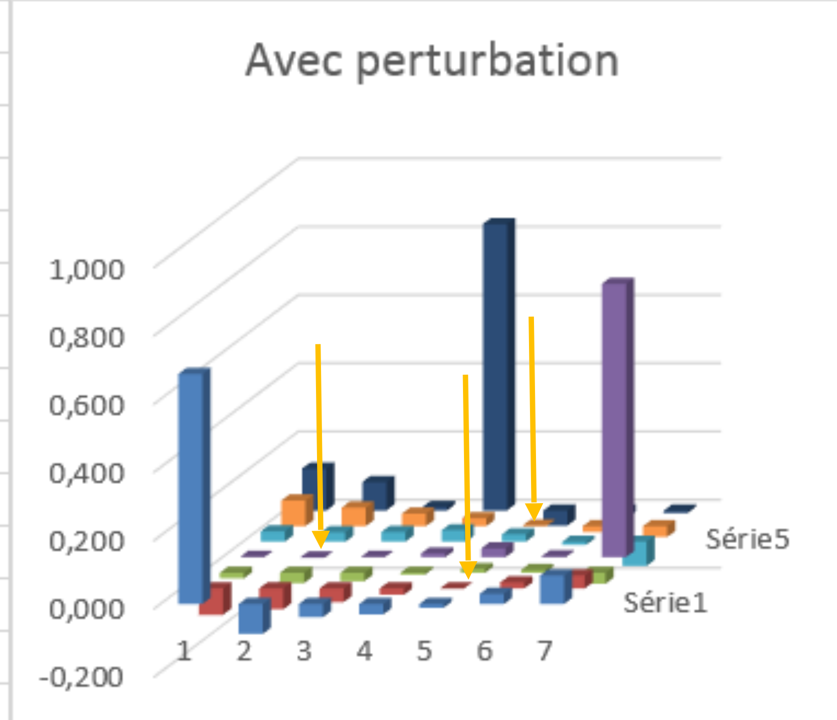
Planarity tuning independency

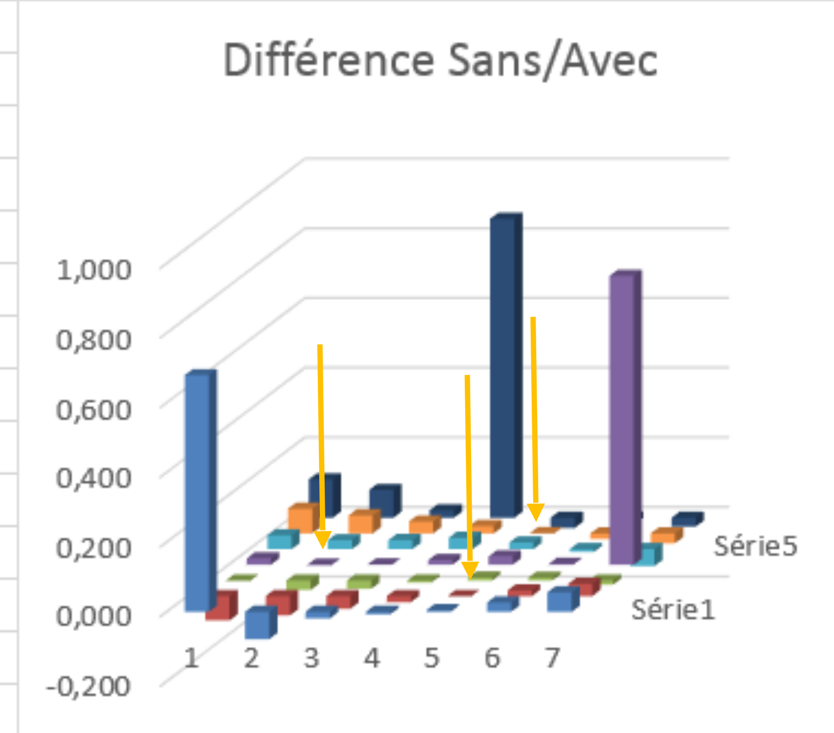
-0,005	-0,009	-0,019	-0,023	-0,016	0,003	0,027
-0,008	-0,006	-0,003	-0,001	0,000	0,001	0,002
-0,015	-0,003	0,000	0,000	0,003	0,000	-0,020
-0,017	0,000	0,000	-0,002	0,002	-0,001	-0,029
-0,009	0,002	0,003	0,001	0,003	-0,001	-0,022
0,004	0,003	0,002	0,002	0,000	-0,002	-0,003
0,013	0,004	-0,011	-0,019	-0,016	-0,002	0,019

0,674	-0,088	-0,038	-0,030	-0,011	0,029	0,083
-0,078	-0,061	-0,040	-0,018	0,000	0,018	0,038
-0,016	-0,030	-0,024	-0,006	0,011	0,008	-0,032
0,001	-0,001	0,001	0,011	0,026	0,003	0,801
0,030	0,028	0,028	0,034	0,022	-0,009	-0,071
0,075	0,054	0,036	0,023	0,001	-0,017	-0,032
0,123	0,083	0,011	0,839	-0,045	-0,021	-0,007

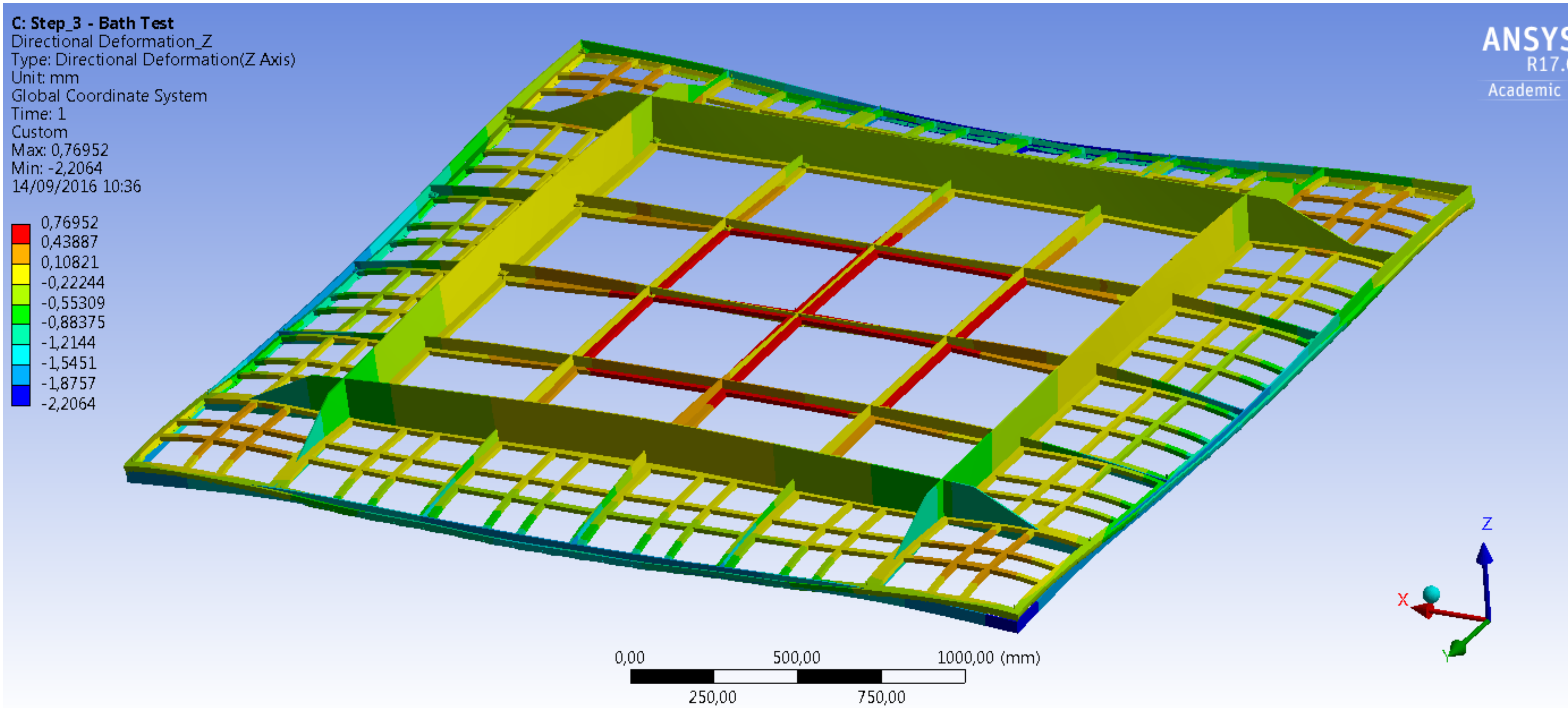
0,679	-0,078	-0,019	-0,007	0,005	0,027	0,056
-0,070	-0,055	-0,036	-0,017	-0,001	0,016	0,035
-0,001	-0,027	-0,024	-0,006	0,009	0,008	-0,013
0,018	-0,001	0,001	0,013	0,024	0,003	0,829
0,040	0,026	0,026	0,032	0,019	-0,008	-0,049
0,071	0,052	0,034	0,022	0,001	-0,016	-0,028
0,110	0,080	0,021	0,858	-0,029	-0,019	-0,026







Step 3 : Module assembled, warm conditions, maxi grid tension



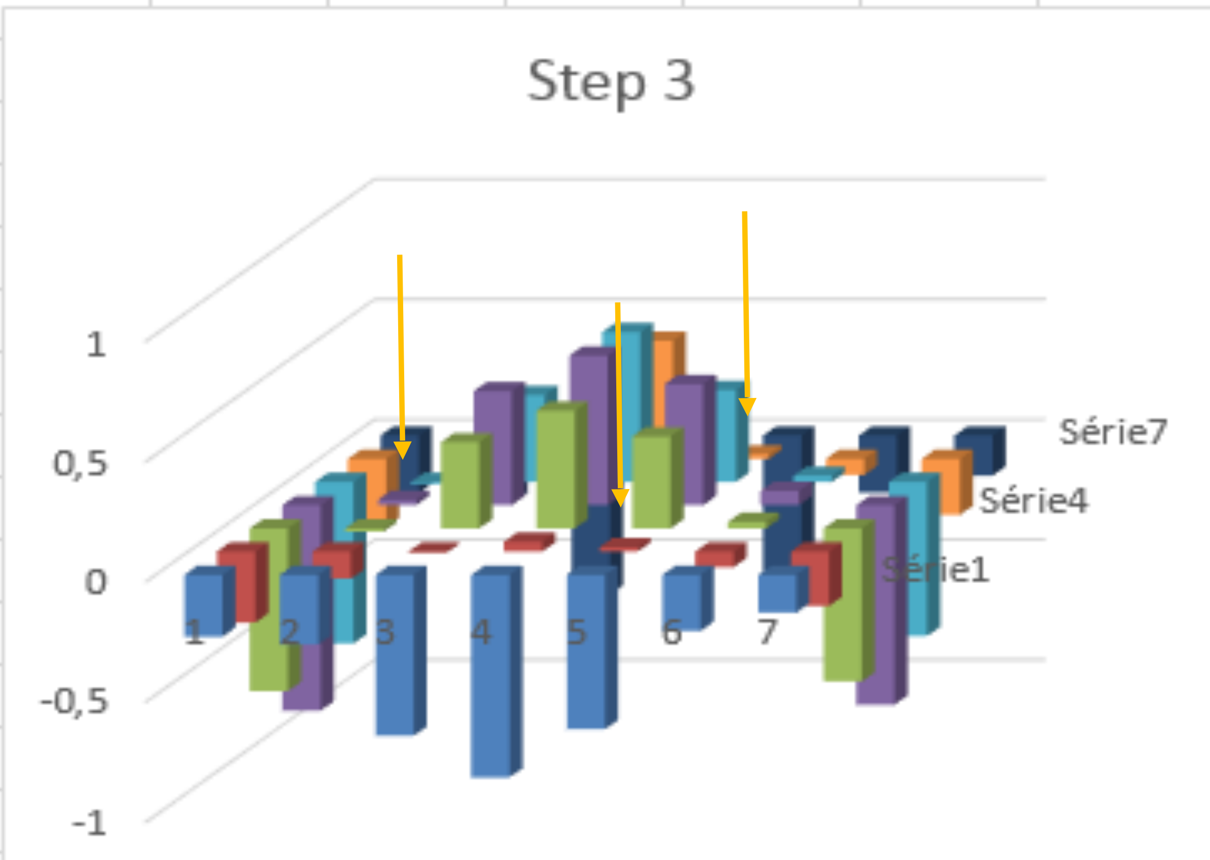
Loading case :

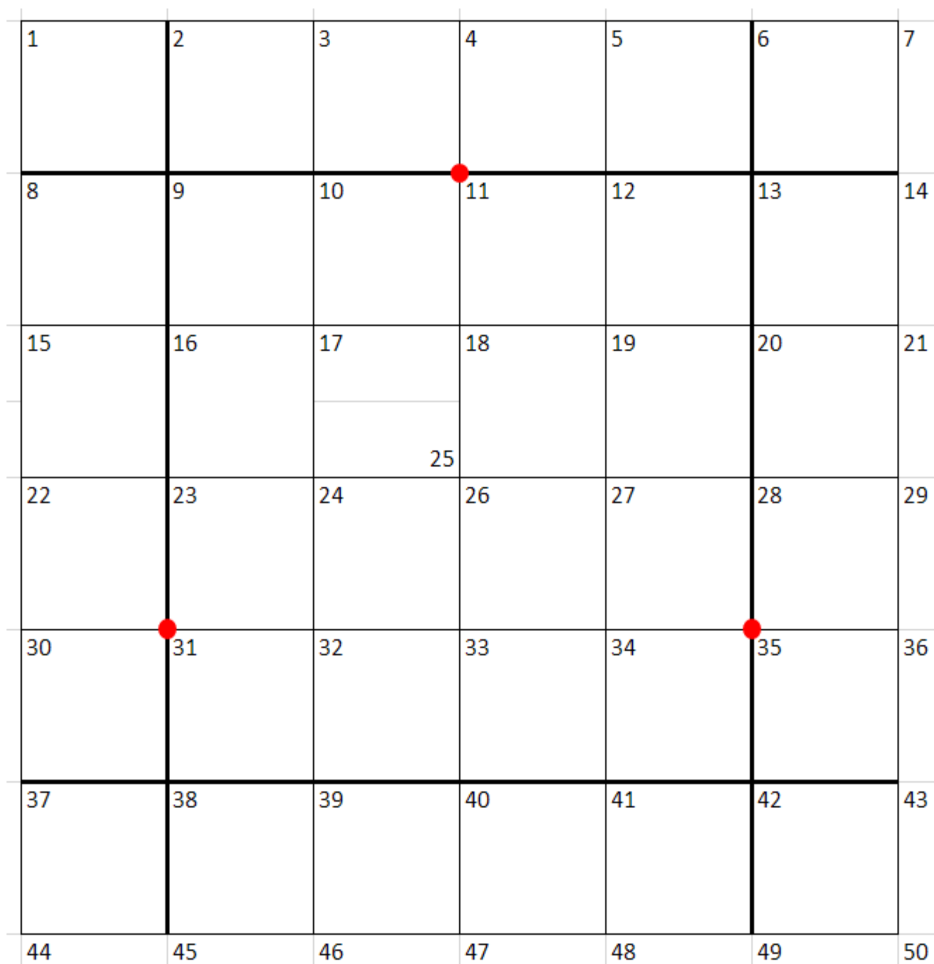
- Gravity
- Grid tension : -10,51mm (thermal contraction with alpha=1,7e-5) – tension measured ~ 5,3N/cable
- Planarity tuning from Step 2

G10 Planarity results for step 3 – Tension Init 1 mm

-0,257	-0,289	-0,67	-0,843	-0,642	-0,233	-0,157
-0,296	-0,113	-0,005	0,0411	0,0182	-0,064	-0,226
-0,677	-0,014	0,3588	0,49	0,3826	0,0273	-0,636
-0,855	0,0221	0,4745	0,622	0,5042	0,0599	-0,831
-0,671	-0,009	0,3619	0,6229	0,3828	0,0258	-0,641
-0,284	-0,103	0,0009	0,491	0,0183	-0,068	-0,233
-0,238	-0,276	-0,662	0,0435	-0,642	-0,238	-0,166

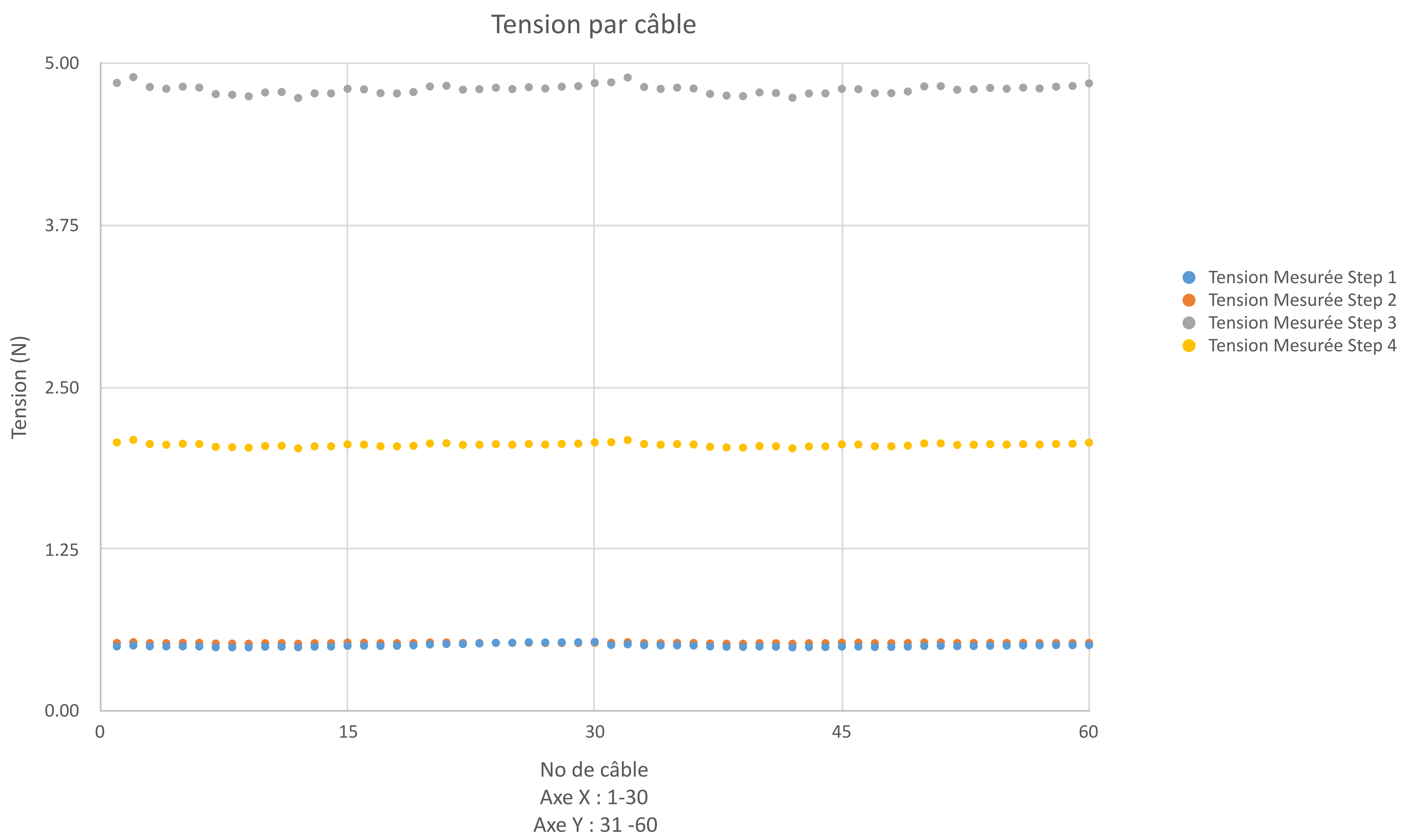
Mini	**-0,855**
Maxi	**0,623**
Delta	**1,478**



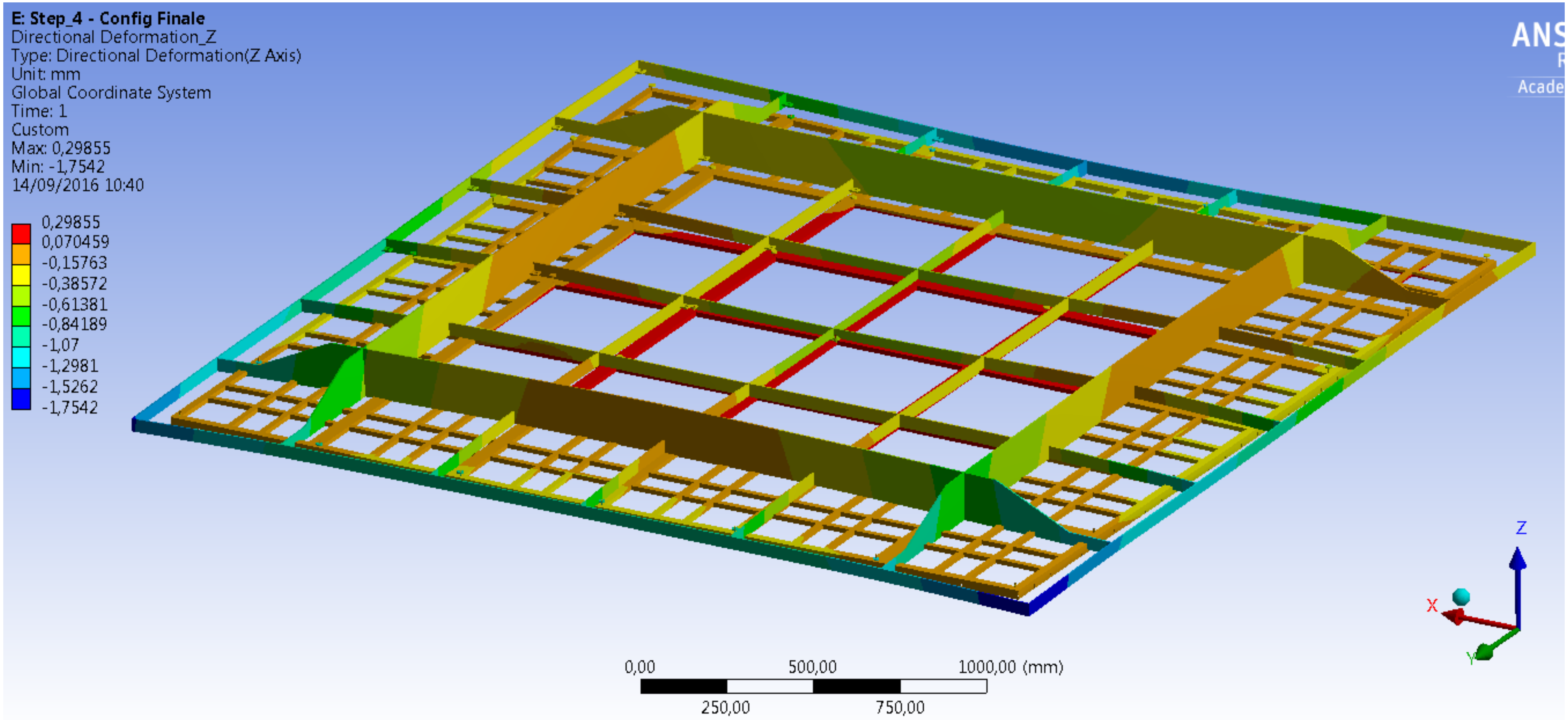


Tension in the extraction grid – Tension Init 1 mm

ETH LAPP WA105



Step 4 : Module assembled, Cold conditions, final grid tension



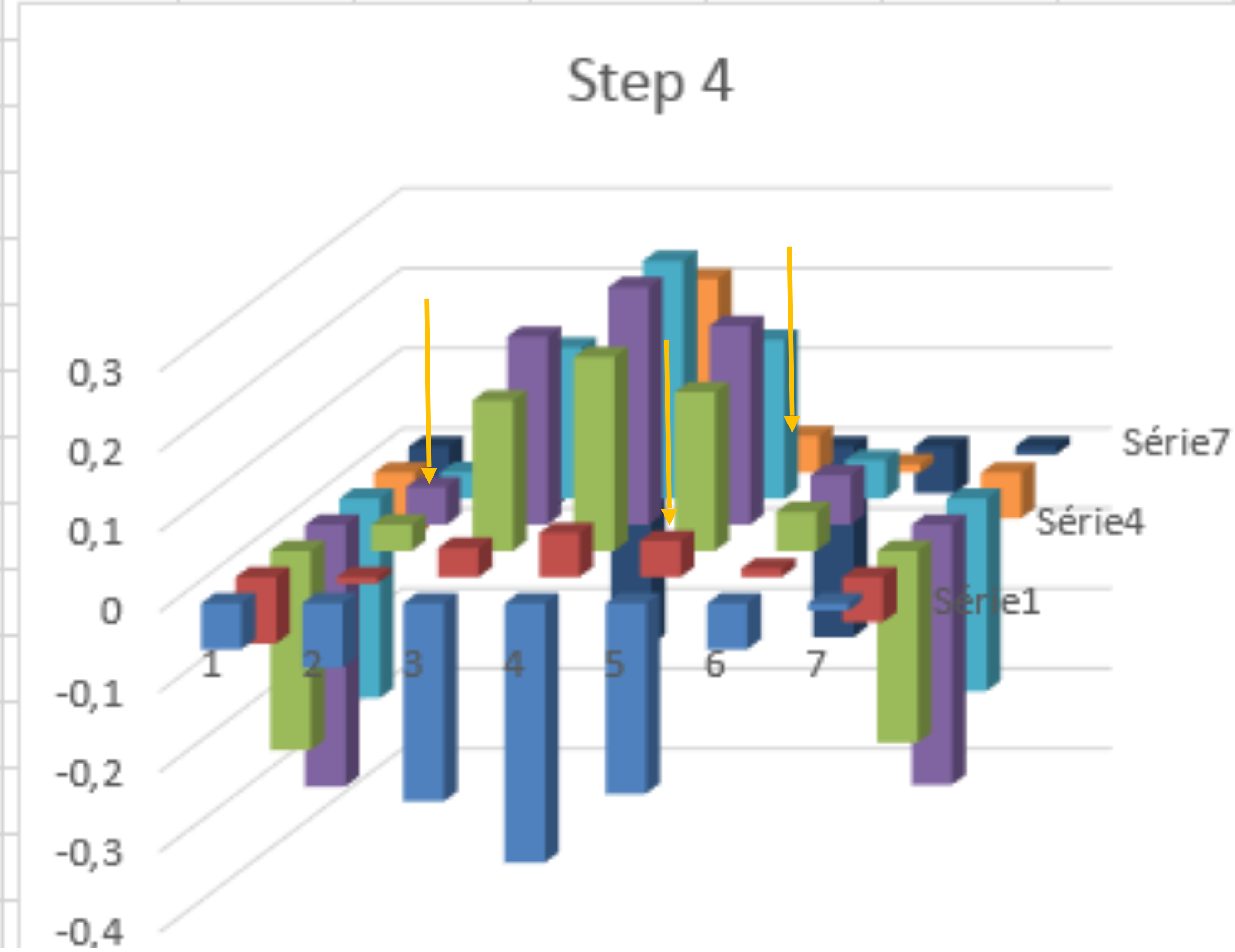
Loading case :

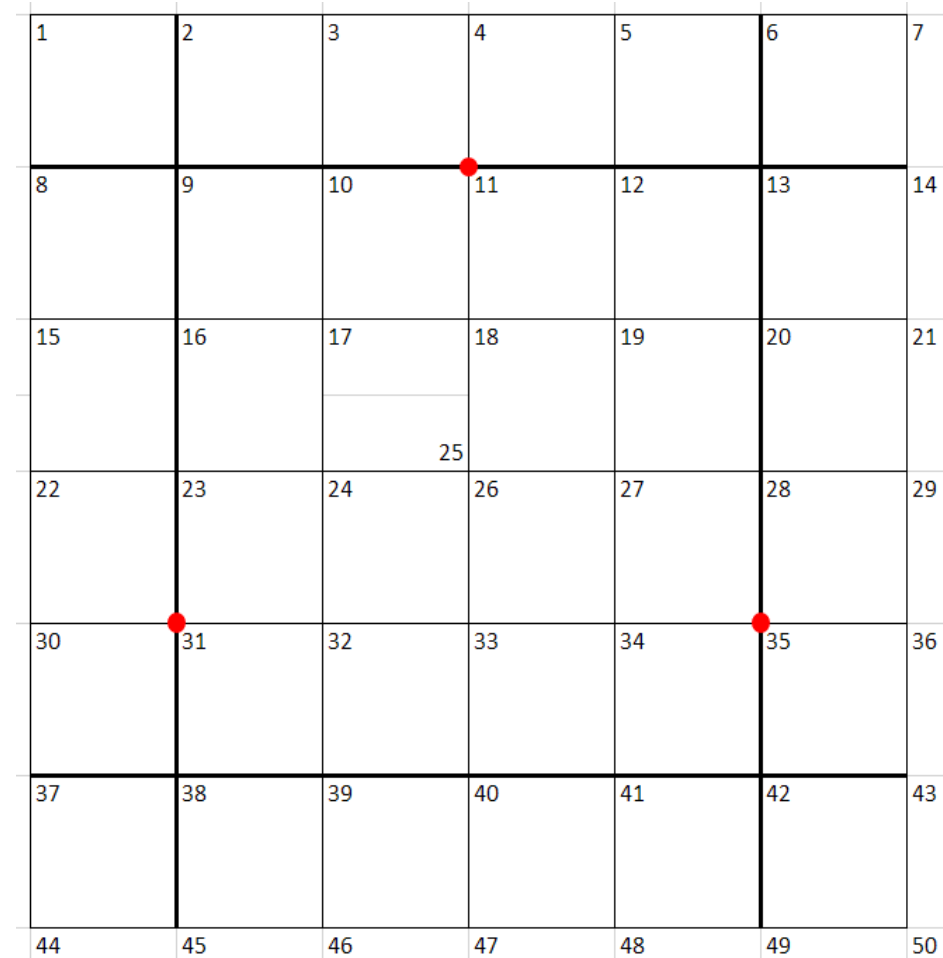
- Gravity
- Grid tension : -10,51mm (thermal contraction with alpha=1,7e-5) – final tension measured ~ 1,5 - 1,6 N/cable
- Planarity tuning from Step 2
- Temperature : -186°C

G10 Planarity results for step 4 – Tension Init 1 mm

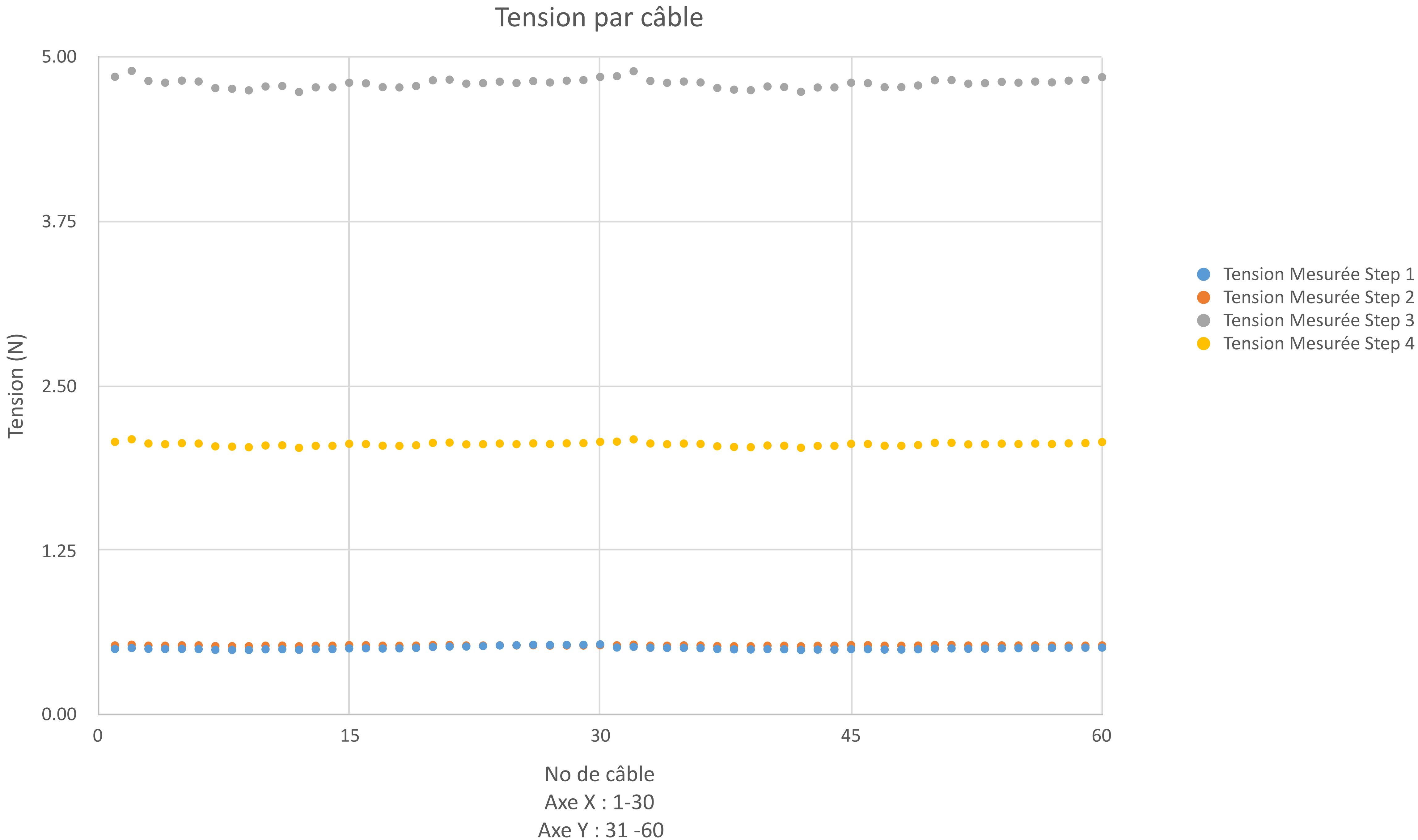
-0,058	-0,08	-0,248	-0,324	-0,238	-0,058	-0,009
-0,083	-0,008	0,0362	0,055	0,0453	0,0107	-0,056
-0,249	0,0326	0,1878	0,2422	0,1982	0,0486	-0,239
-0,327	0,047	0,2349	0,2965	0,2484	0,062	-0,325
-0,249	0,0333	0,1885	0,2969	0,1982	0,0483	-0,24
-0,082	-0,007	0,0366	0,242	0,0455	0,0103	-0,057
-0,056	-0,08	-0,248	0,0548	-0,238	-0,058	-0,01

Mini	**-0,327**
Maxi	**0,297**
Delta	**0,624**



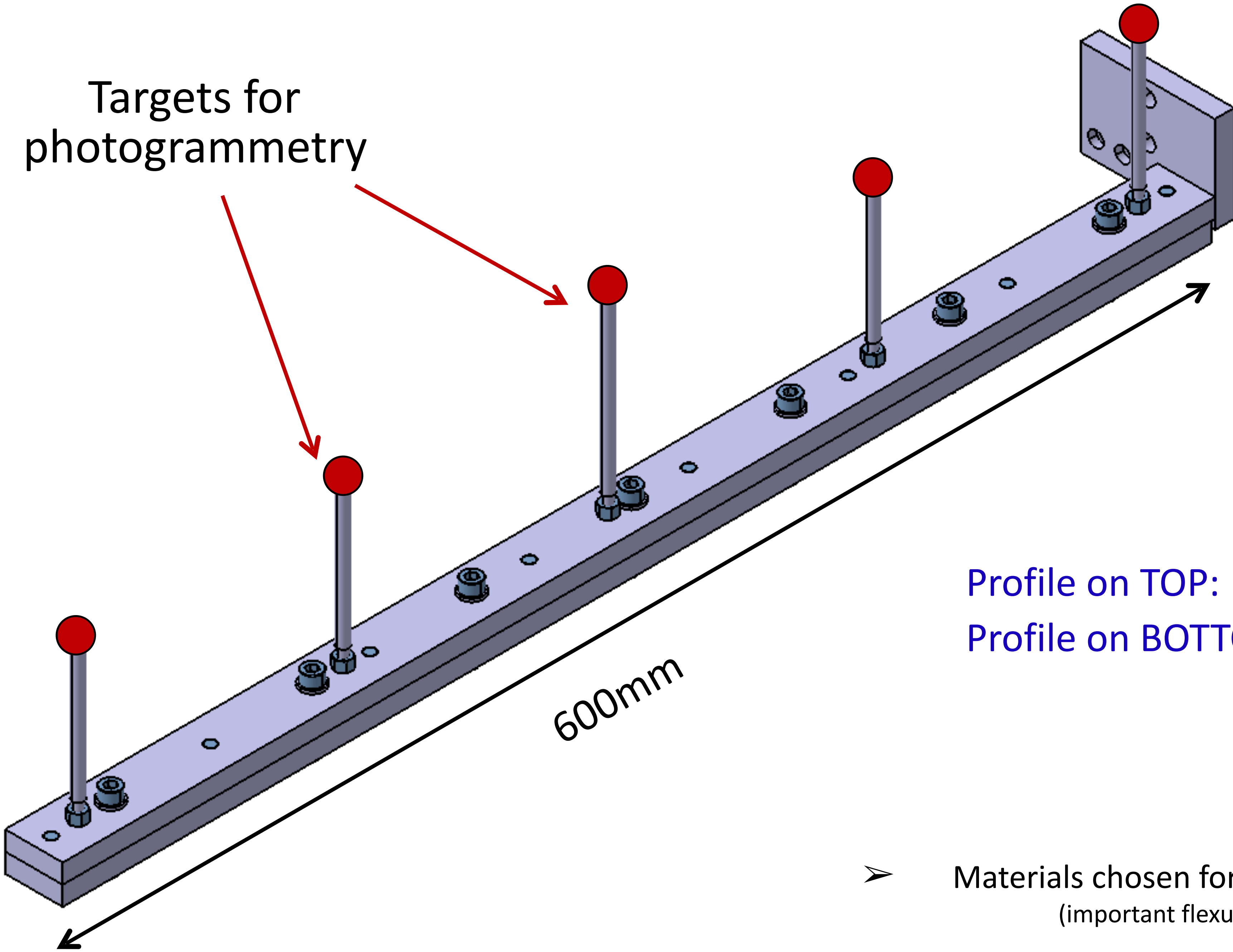


Tension in the extraction grid for Step 3 & 4



Wires are breaking at 15 N

Decoupling system



Clamping

(system to immerse not shown)

α =Thermal shrinkage coefficient

Profile on TOP:	**Invar**	$\alpha = 1{,}9.10^{-6}\ K^{-1}$
Profile on BOTTOM:	**SSteel**	$\alpha = 13.10^{-6}\ K^{-1}$

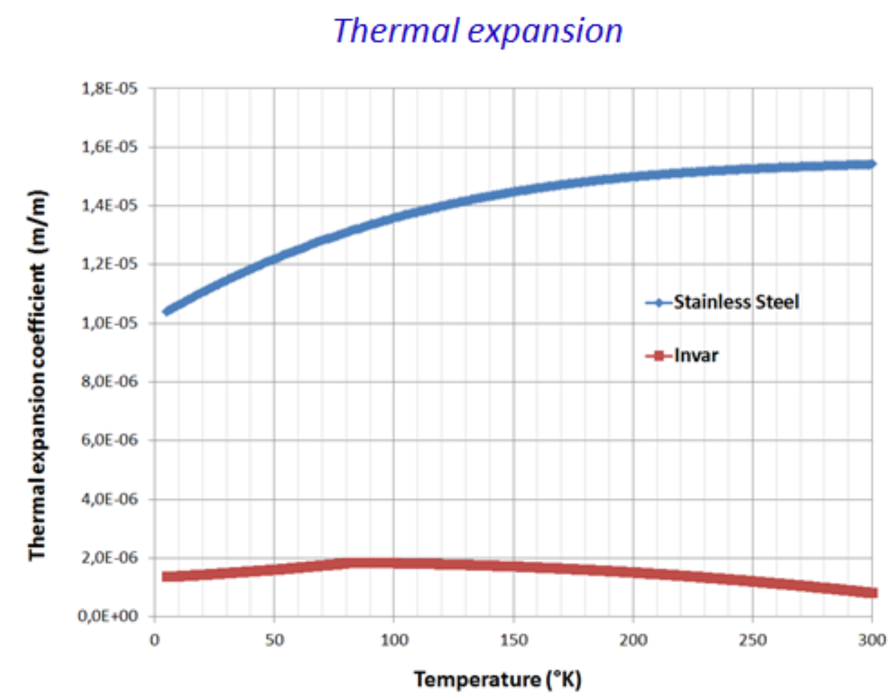
- Materials chosen for *big α differences*
  (important flexural behavior when coupled)
- Screws and shears pins ensure a good coupling
- Invar rods to ensure measurements
  above LAr surface (once fog dissipated)

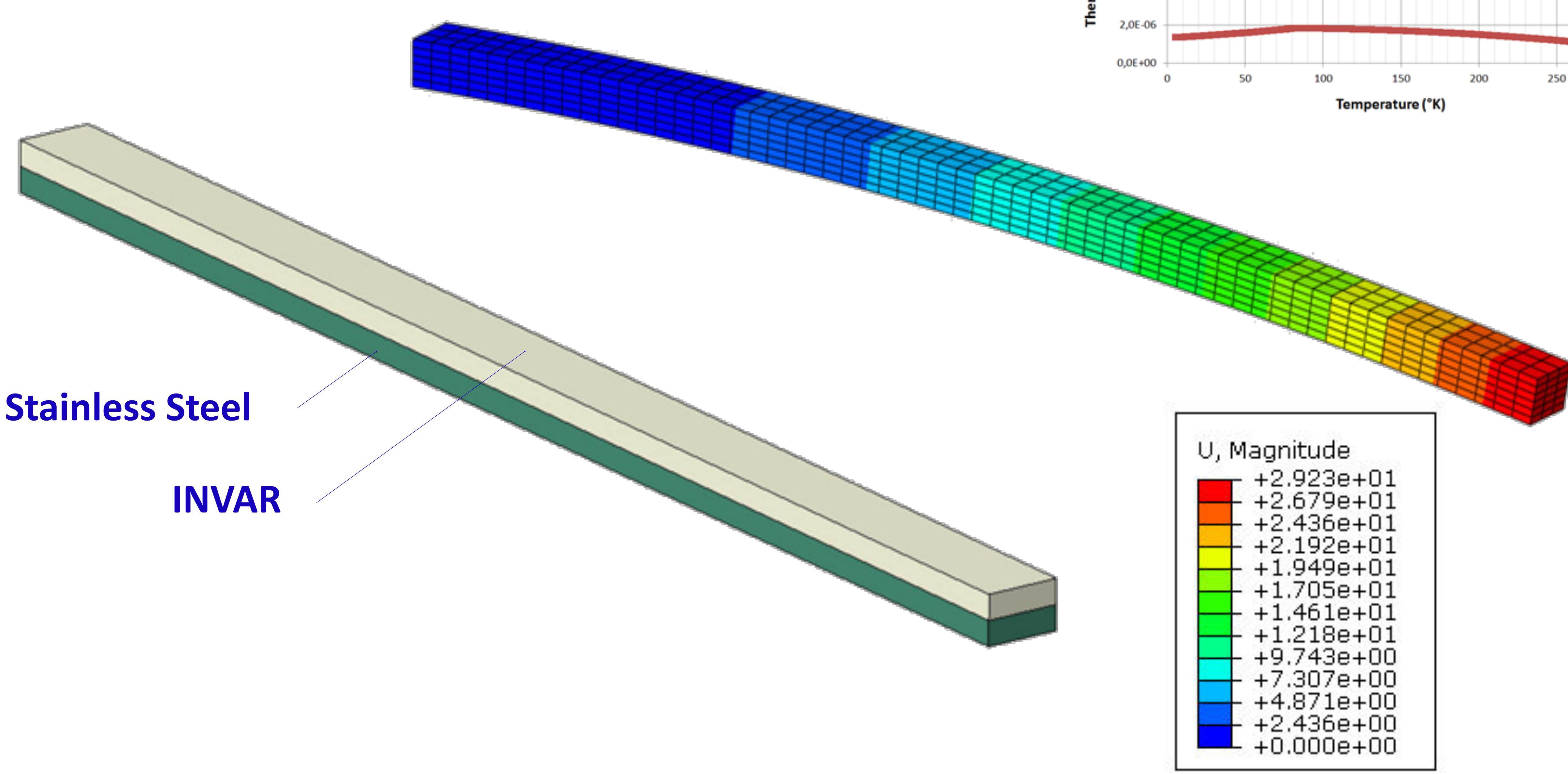
Decoupling system – Simulation warm & cold conditions

- For a coupled system, expected vertical displacement is : **29,2 mm**

*(Taking in account the variation of **α** with the temperature)*

- For decoupled system, **no vertical displacement** is expected

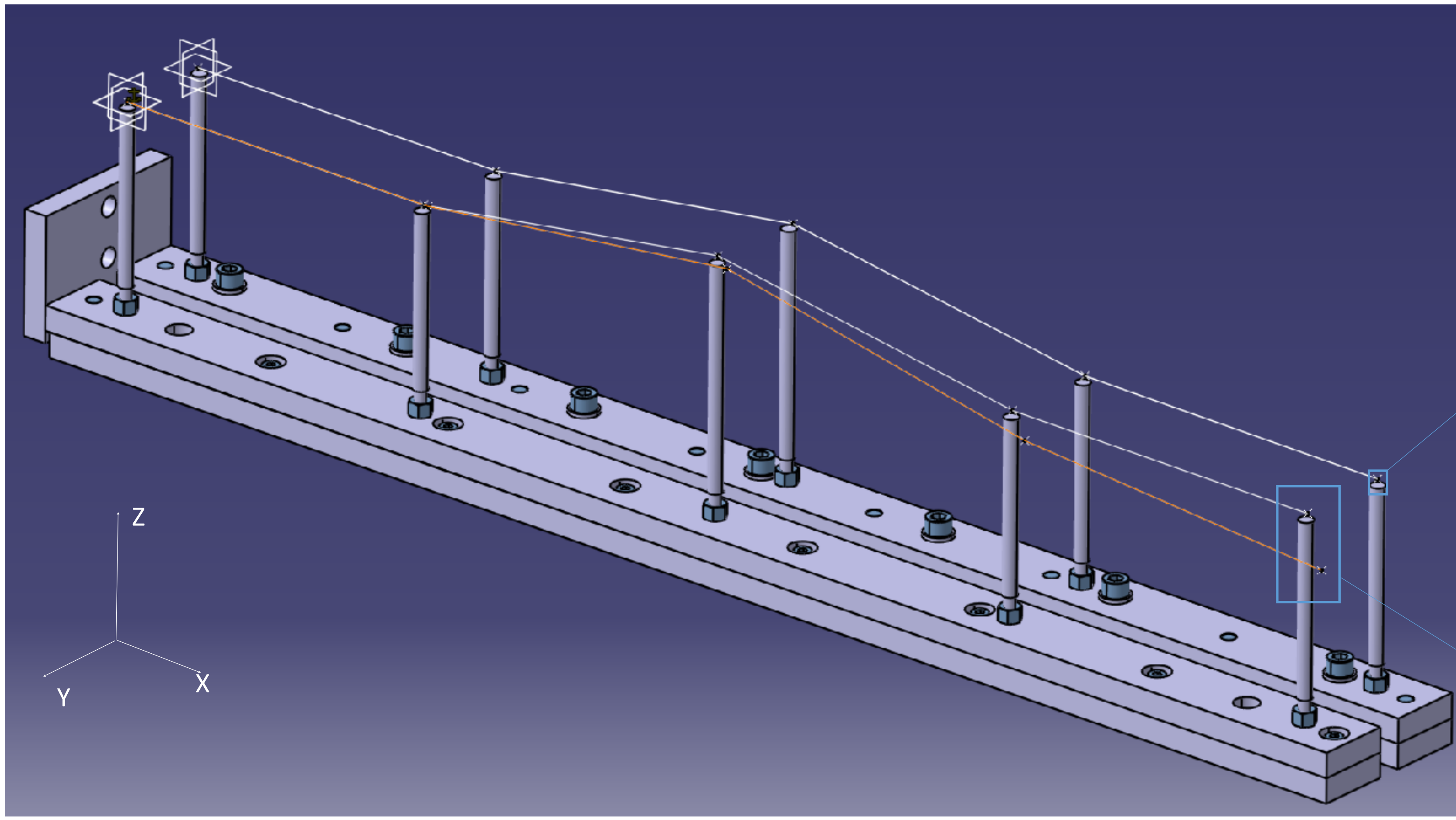




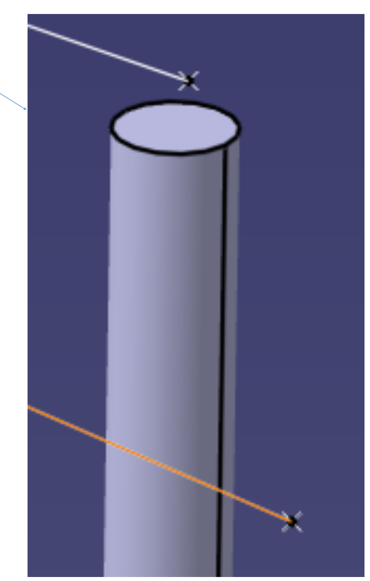
Decoupling system - Results

Measurements on **warm and cold condition**

Accuracy of photogrammetry measurements : 0,02 mm @ 1 sigma



Decoupled :
Δx= - 0,1 mm
Δy= 0 mm
Δz= **0 mm**

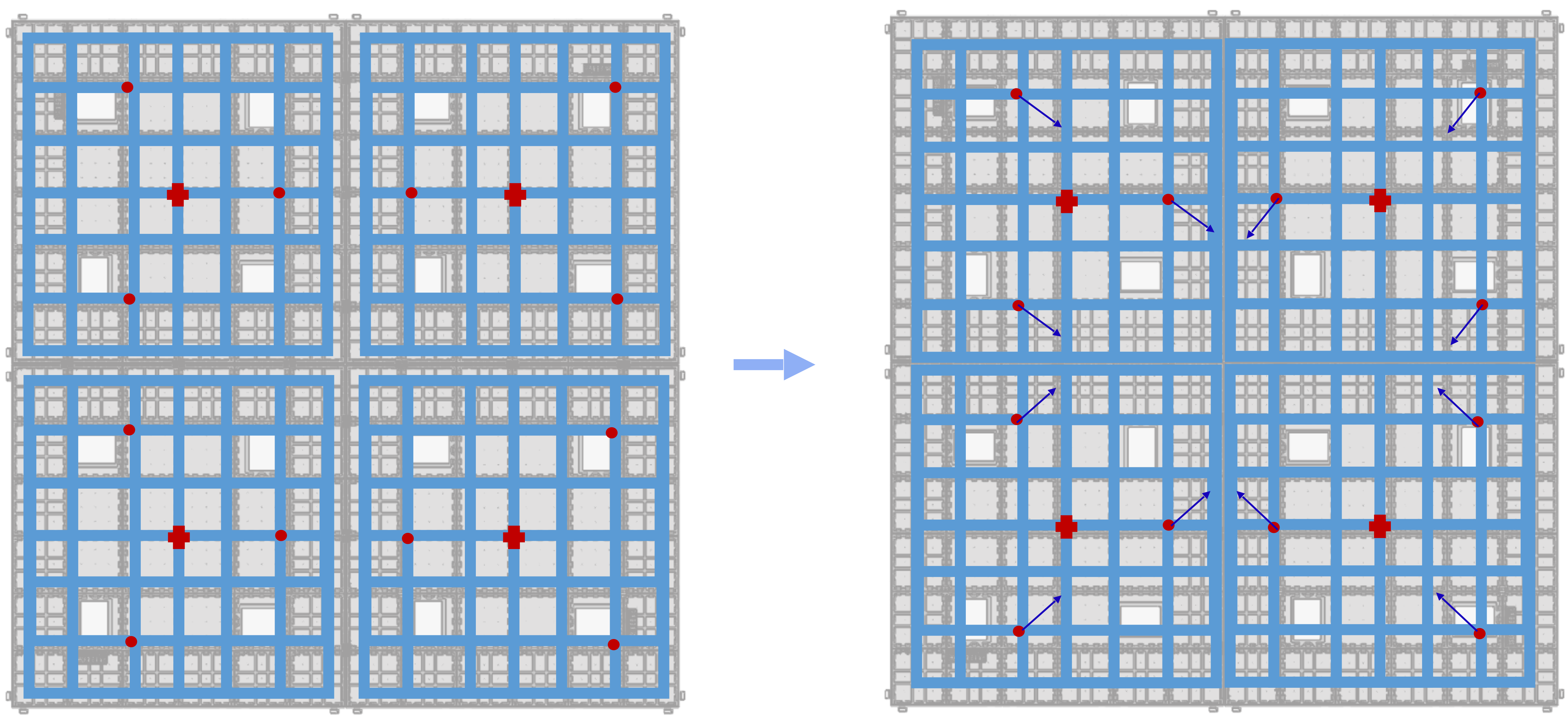


Coupled:
Δx= -5,9 mm
Δy= -0,9 mm
Δz= -24,6 mm

Decoupling system avoid any vertical shrinking due to thermal load.

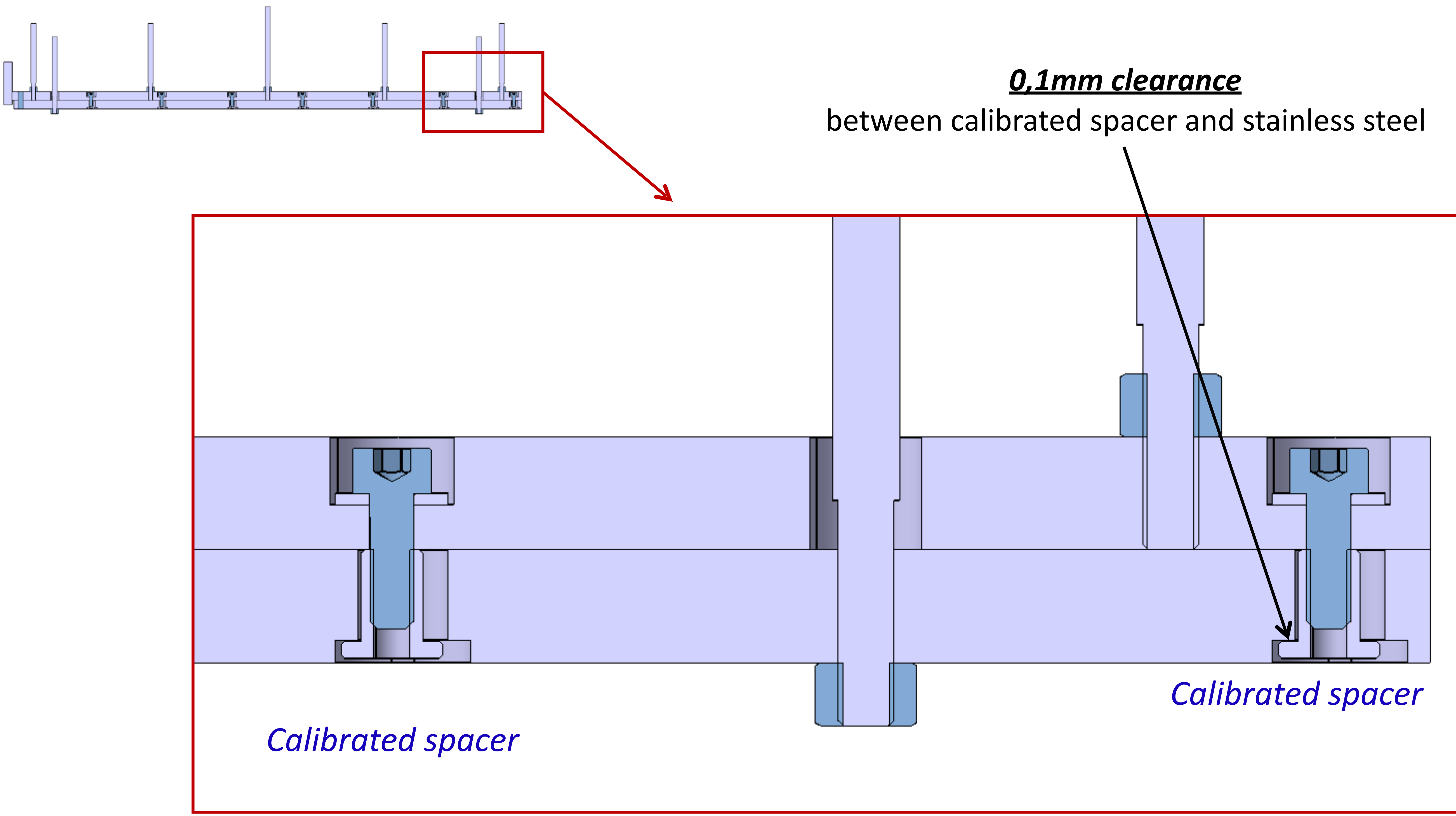
Zero inter-space thermal contraction pattern

- The contraction of each 3x3m detection plane is fixed at each modules' center
  - G10 is contracting about seven times more than invar in cold conditions
- Once in cold condition, modules are moved thanks to SPFT lateral movement and Distance-Meters measurements
- Final Interspaces between LEMs in cold condition :
  - 0,5-0,8mm inside a 3x3m module
  - < 10mm between two 3x3m detection area

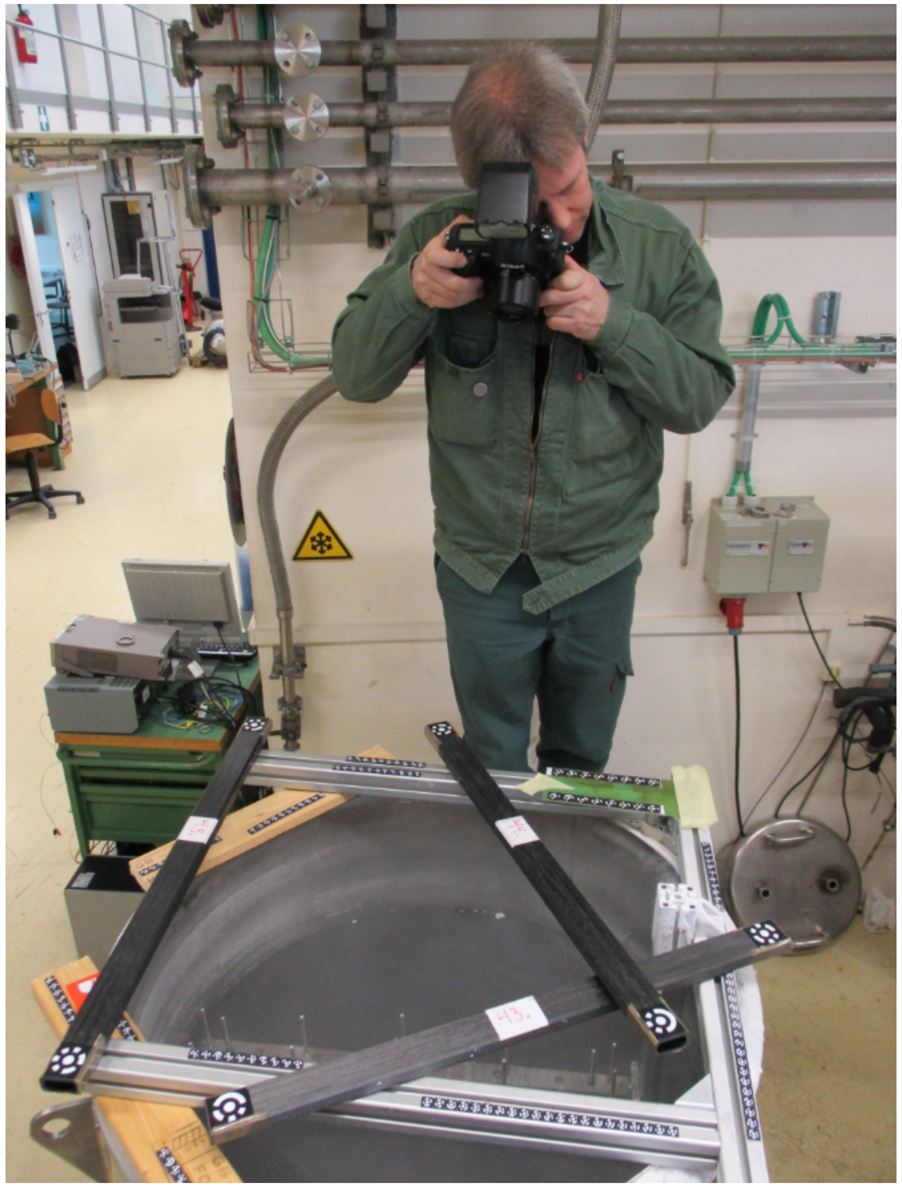


Decoupling system

Same 2 materials assembly *with decoupling parts* instead of shear pins



Decoupling system – *Cryogenic tests*

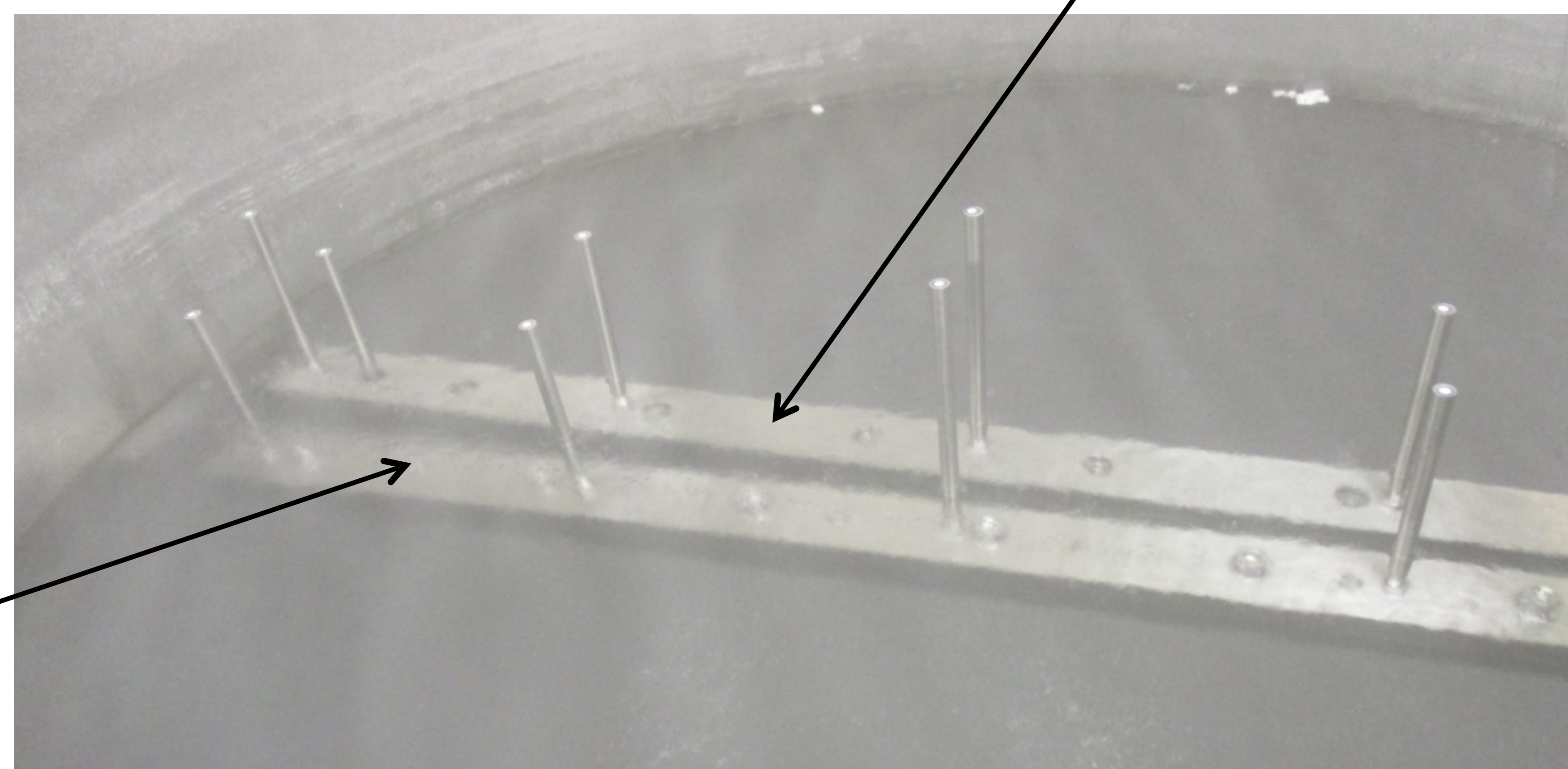


Dirk Mergelkuhl taking measurement at Cryolab

Cold measurement with photogrammetry targets

(targets on top of rods as well)

De-coupled

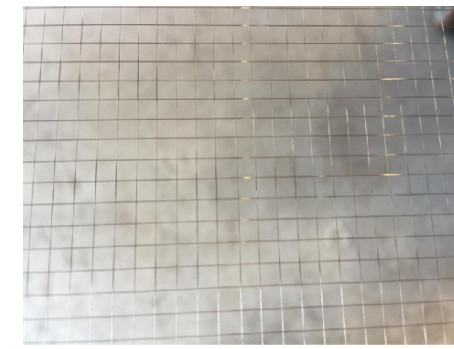


Coupled

EXTRACTION GRID details

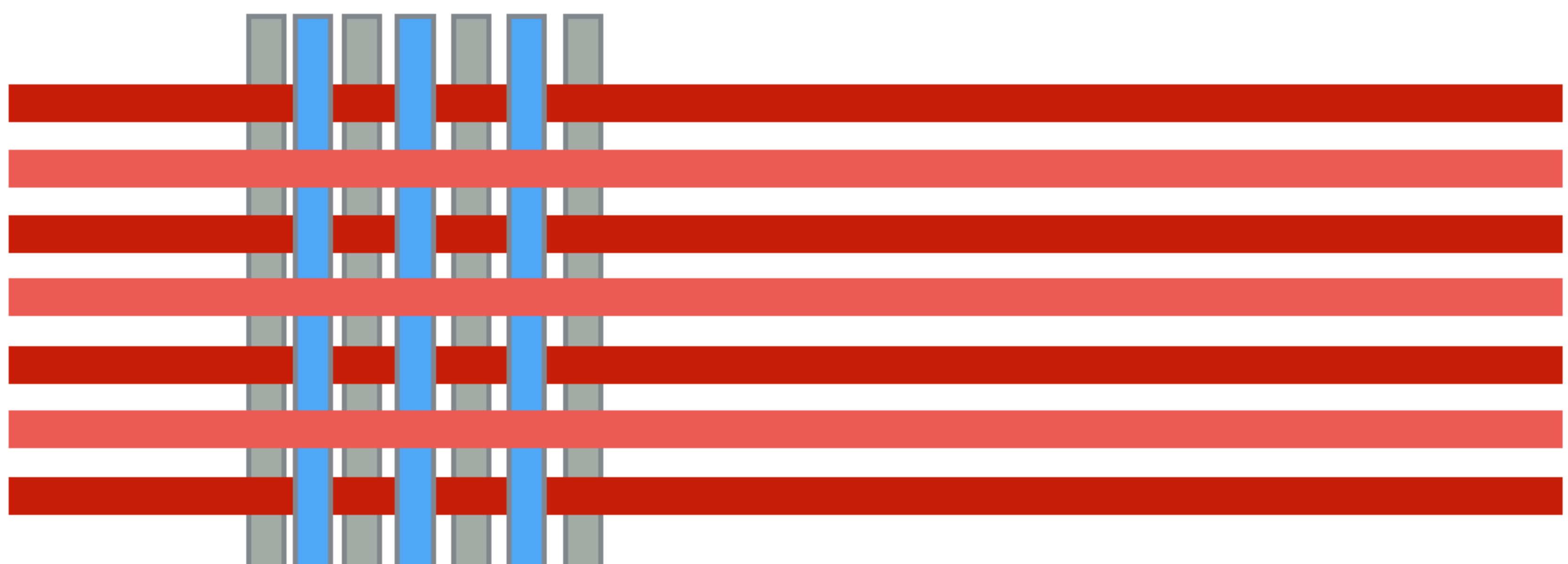
The grid for the 3x1x1

AISI 316L Stainless Steel wire
Temper : Hard
Diameter : 0.10mm
Supplier: Goodfellow

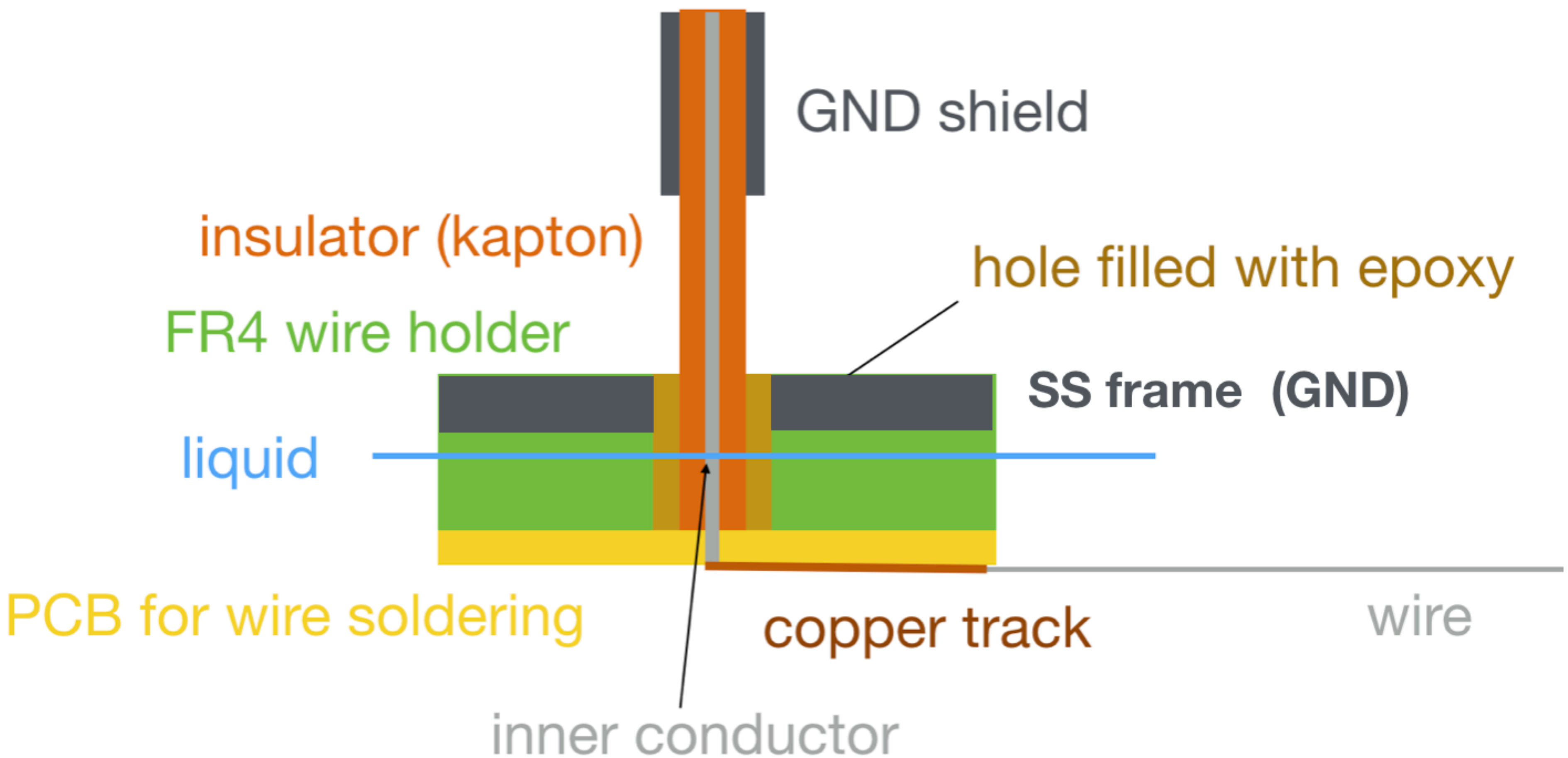


order of mounting:

1st 3rd
2nd 4th

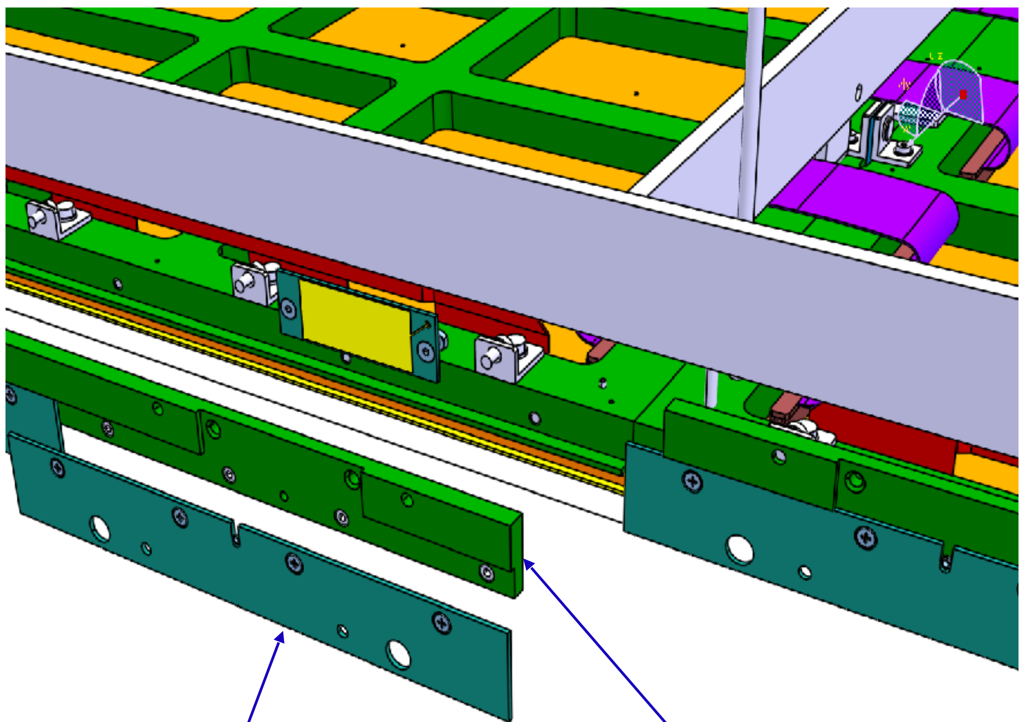


The grid for the 3x1x1 - HV contact

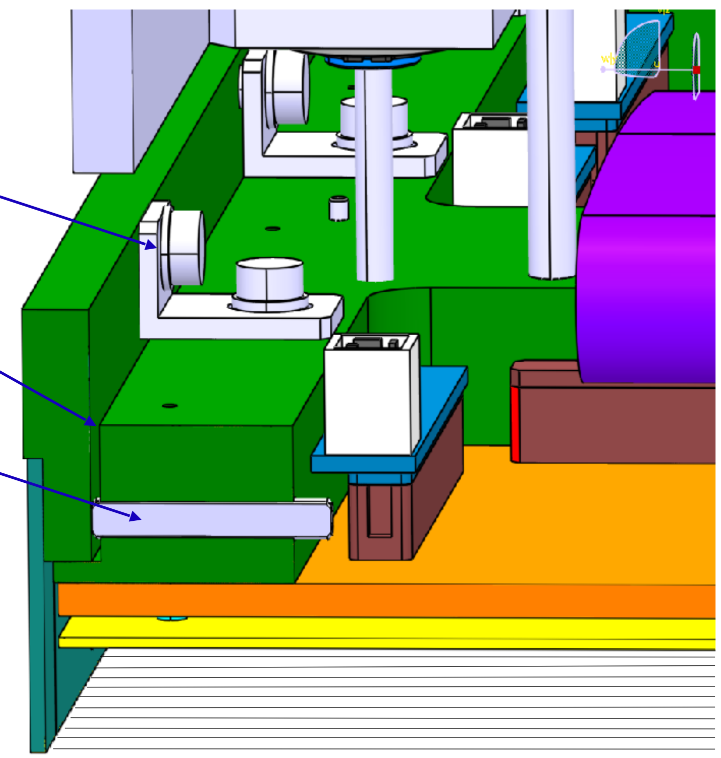


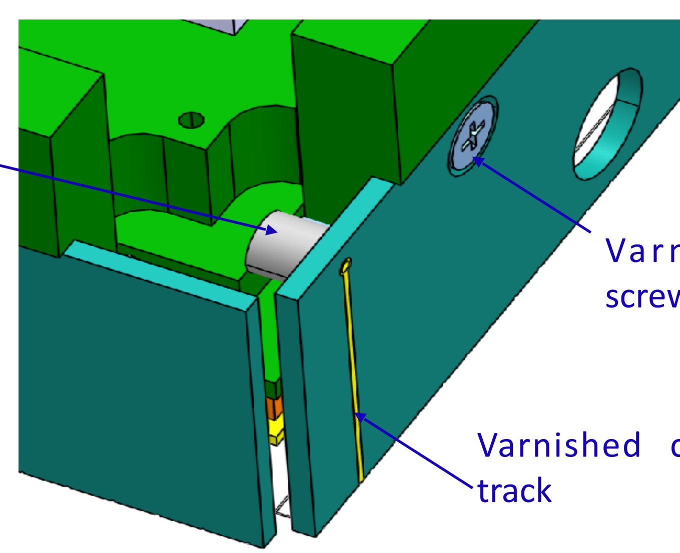
Extraction Grid for protoDUNE-DP

- Extraction grid's wires are soldered on supporting PCB plates, assembled on a supporting beam



- Grid tensionning is performed by tightening « pushing screws », adding a calibrated wedge, and locking the supporting square



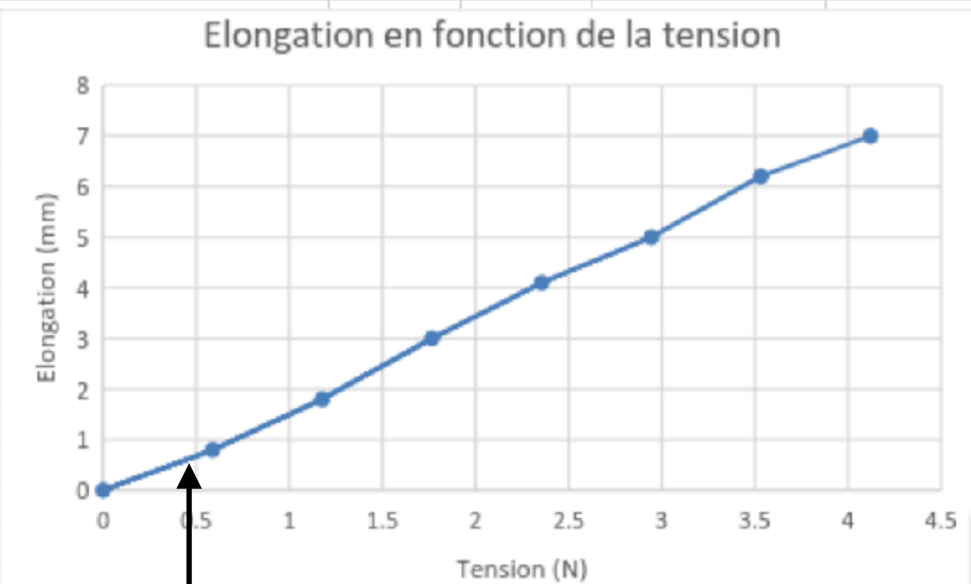


Grid wire

Tests d'élasticité fil inox

		Volume d'eau (ml)	Tension	Elongation (mm)	Coef d'élasticité
Longueur du fil (mm)	2775				
Masse initiale récipient (g)	73	0	0	0	
		60	0,5886	0,8	0,589
		120	1,1772	1,8	0,491
		180	1,7658	3	0,535
		240	2,3544	4,1	0,654
		300	2,943	5	0,491
		360	3,5316	6,2	0,736
		420	4,1202	7	0,589
				Moyenne :	**0,583**
				Valeur théorique :	**0,5944**

test in lab

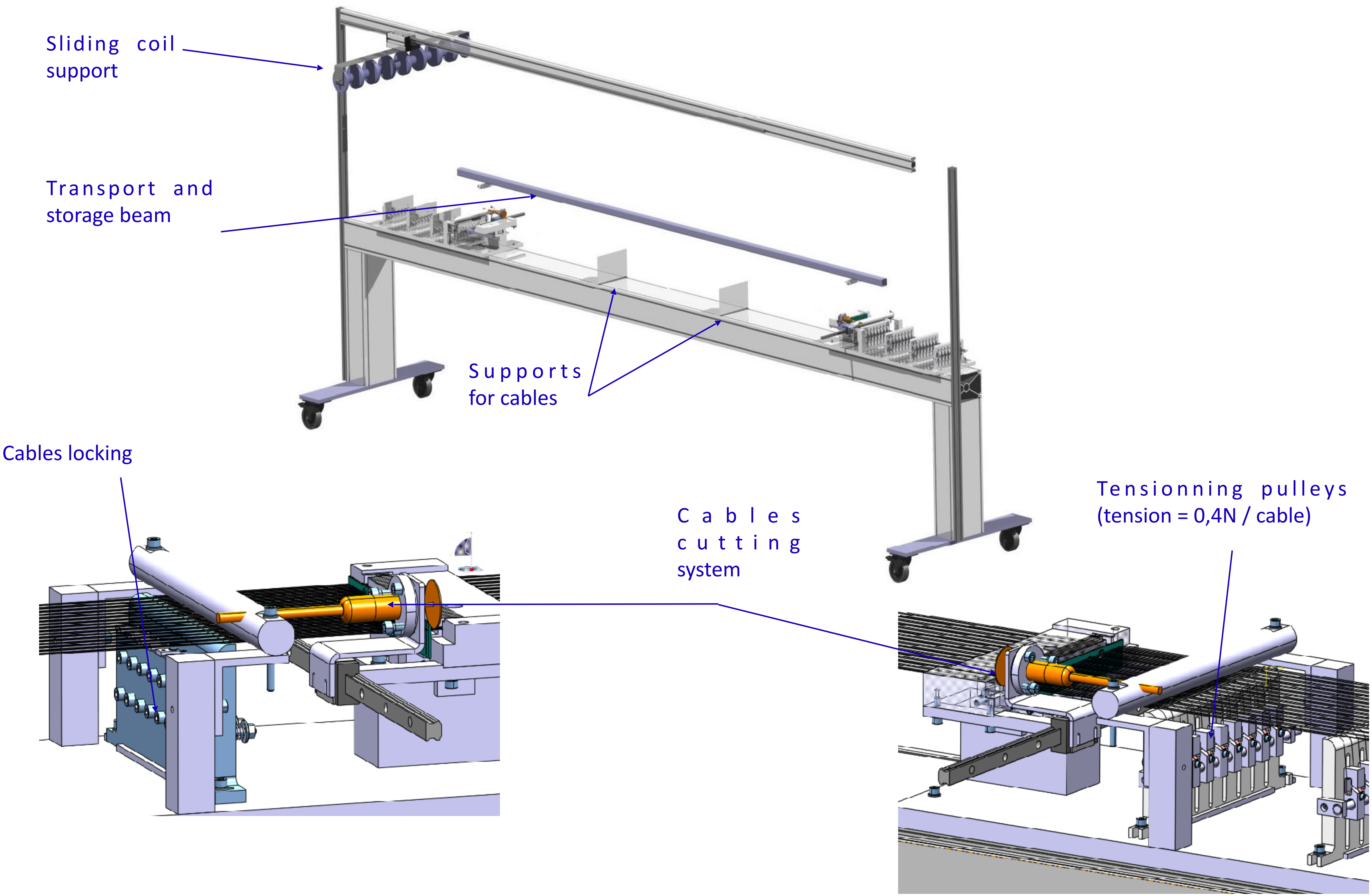


tension during assembly 0.4 N

Rupture at 15 N (from supplier)

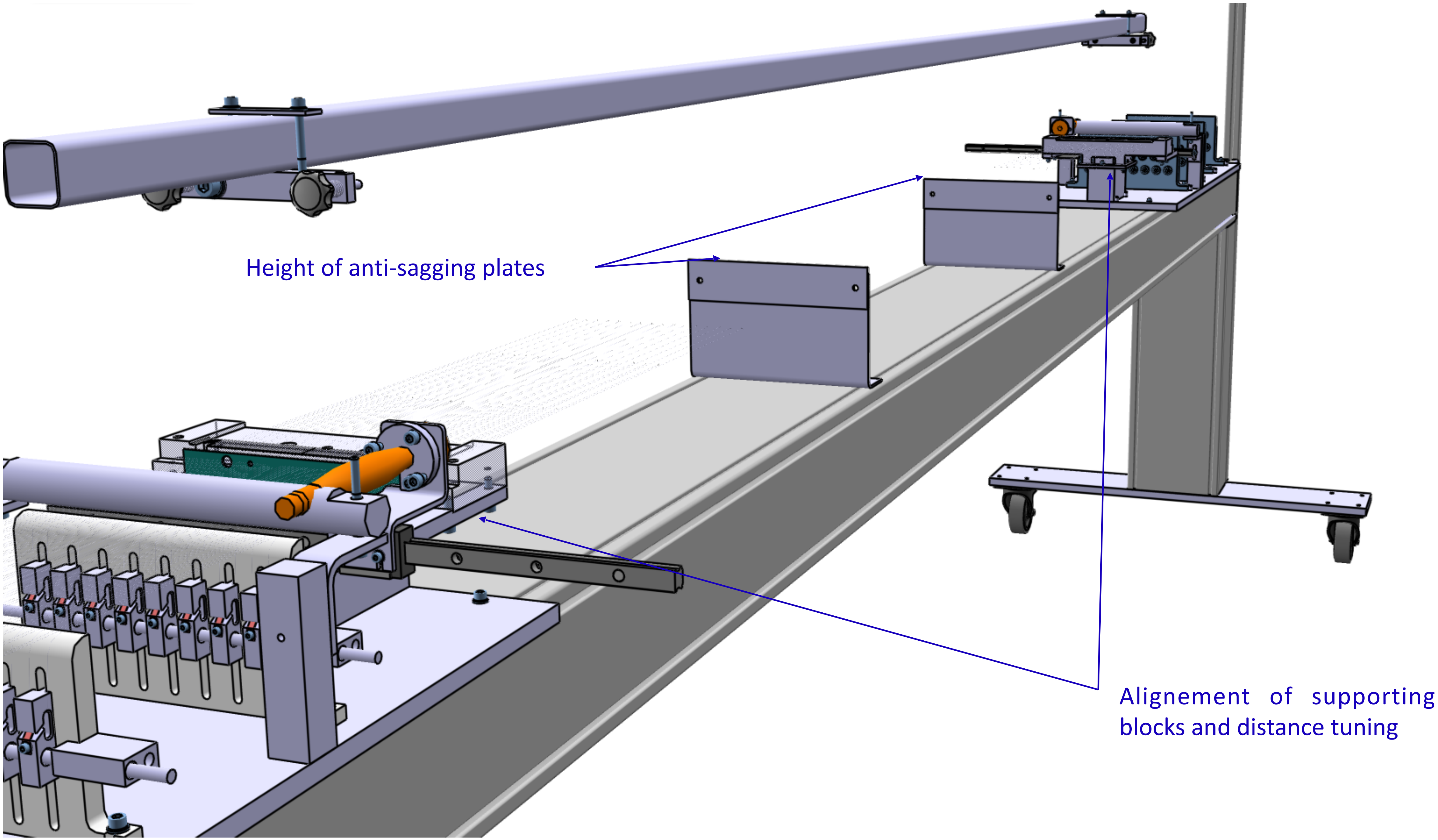
AISI 316L Stainless Steel wire
Temper : Hard
Diameter : 0.10mm
Supplier: Goodfellow

Tooling for Grid production



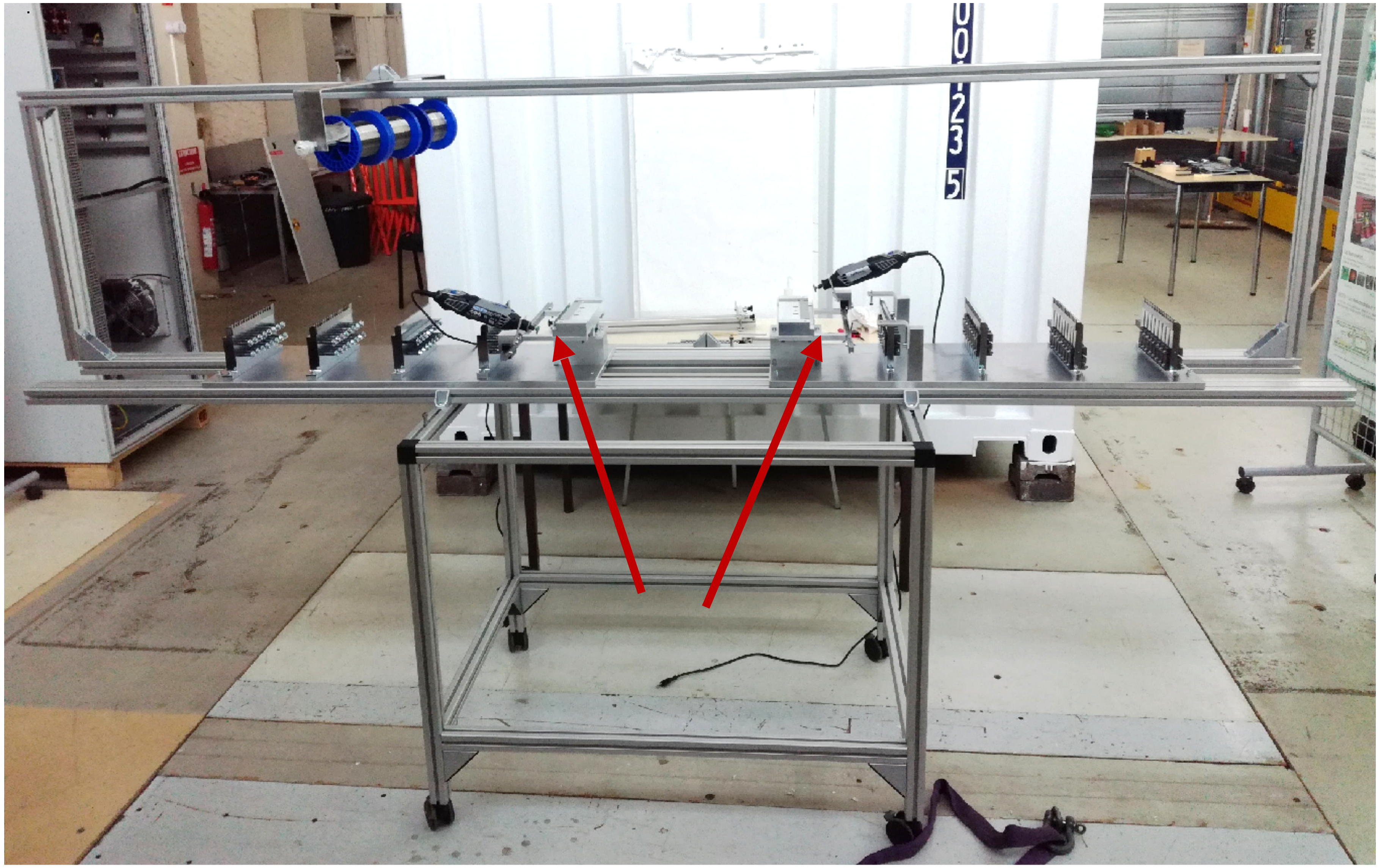
Tooling for Grid production – Metrology operations

ETH LAPP WA105



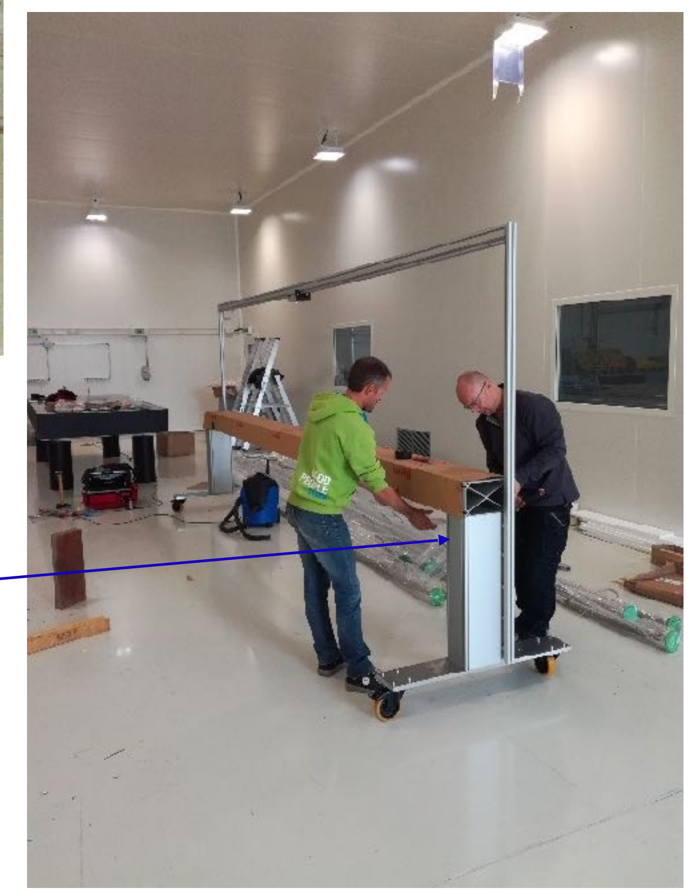
Each G10 frame is measured, then tooling dimension is adapted.

Grid production



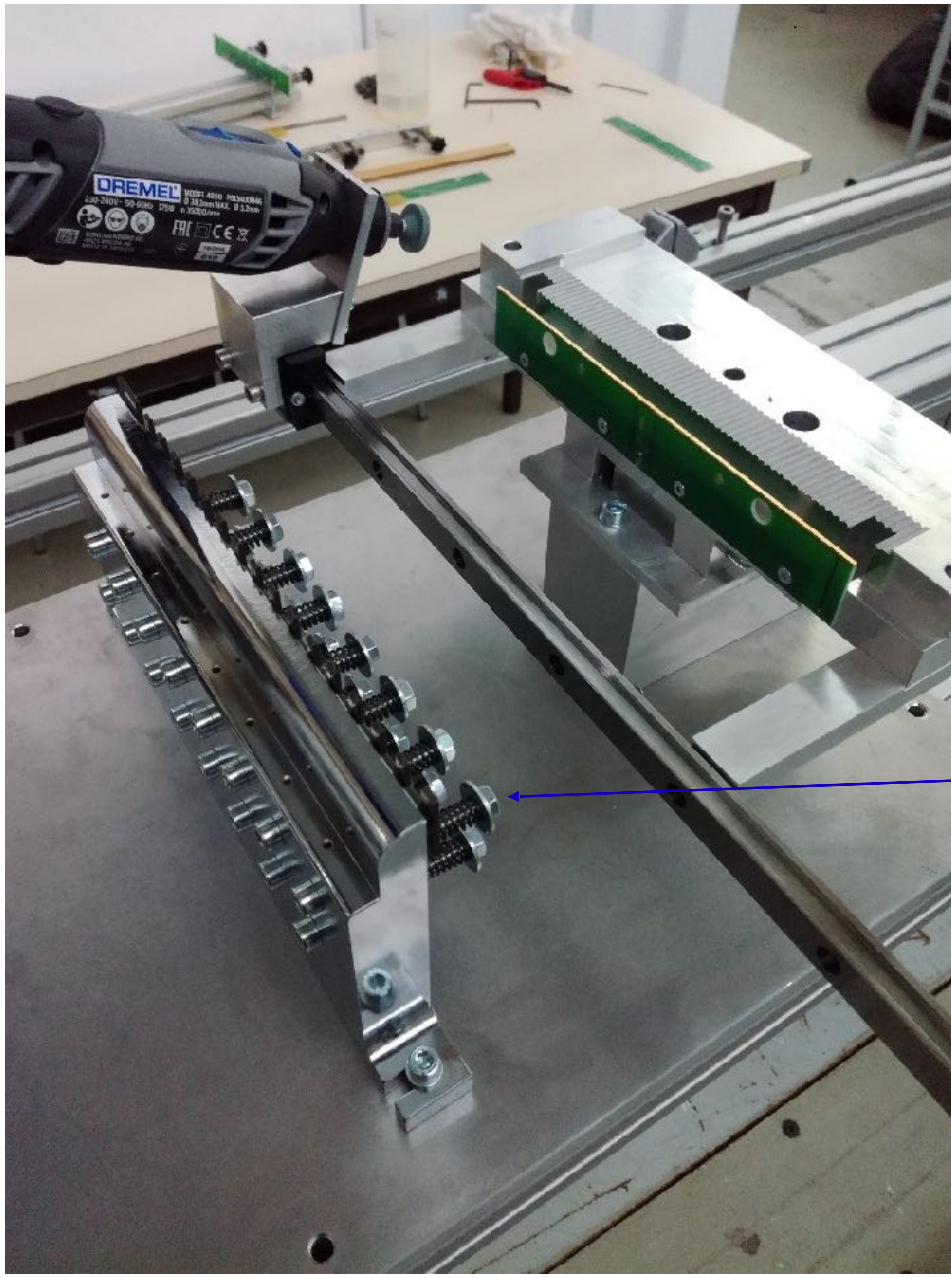
First, the two PCB plates are set on the tooling

The assembly above is a test performed at LAPP with 70cm wires, the real structure has been installed in CR185, CERN, for 3 meters wires



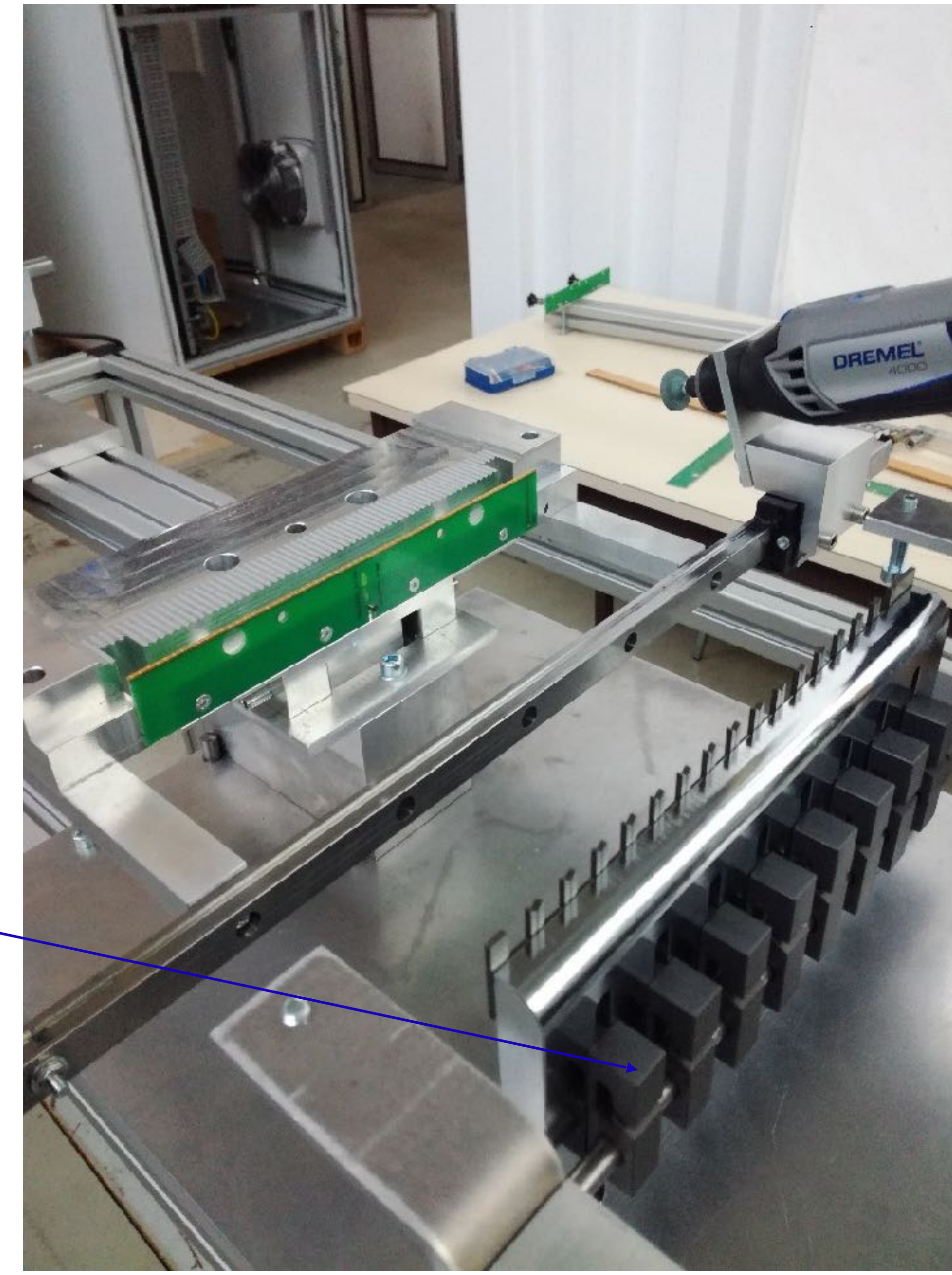
The final assembly will be completed soon

Grid production



Locking system

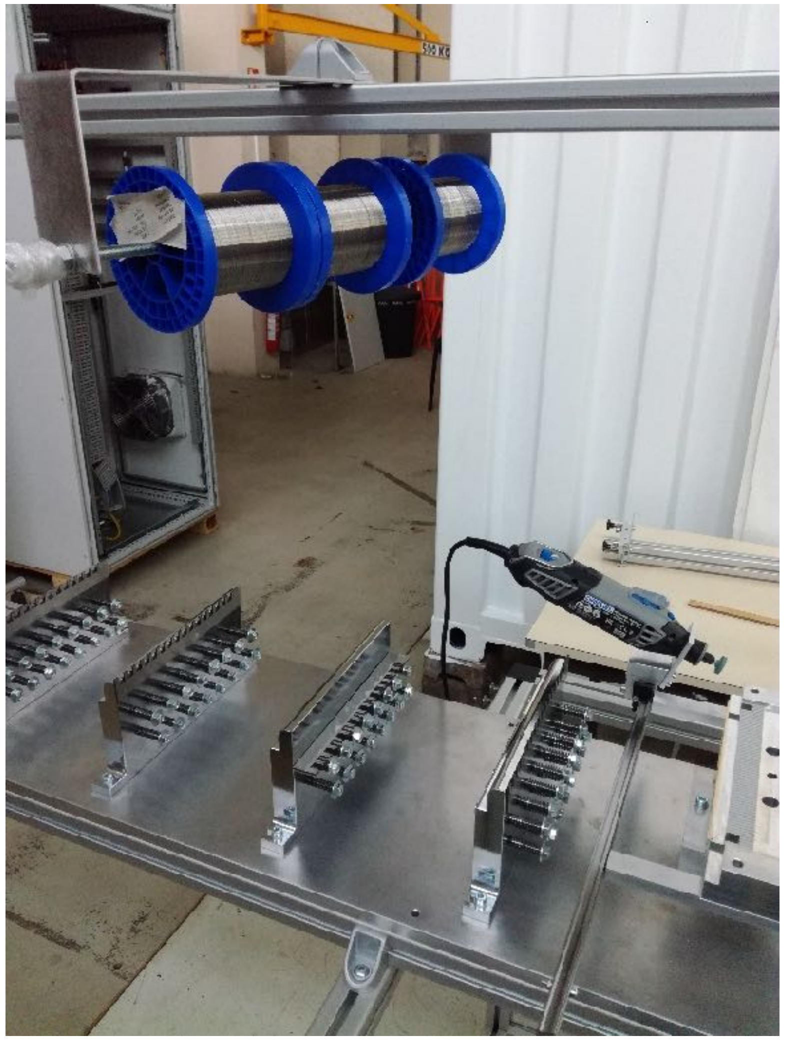
Pulley

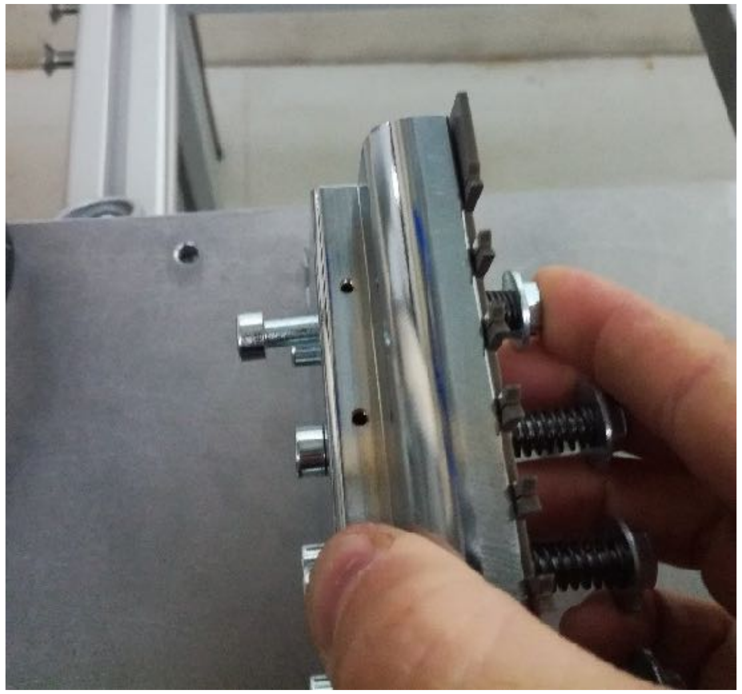


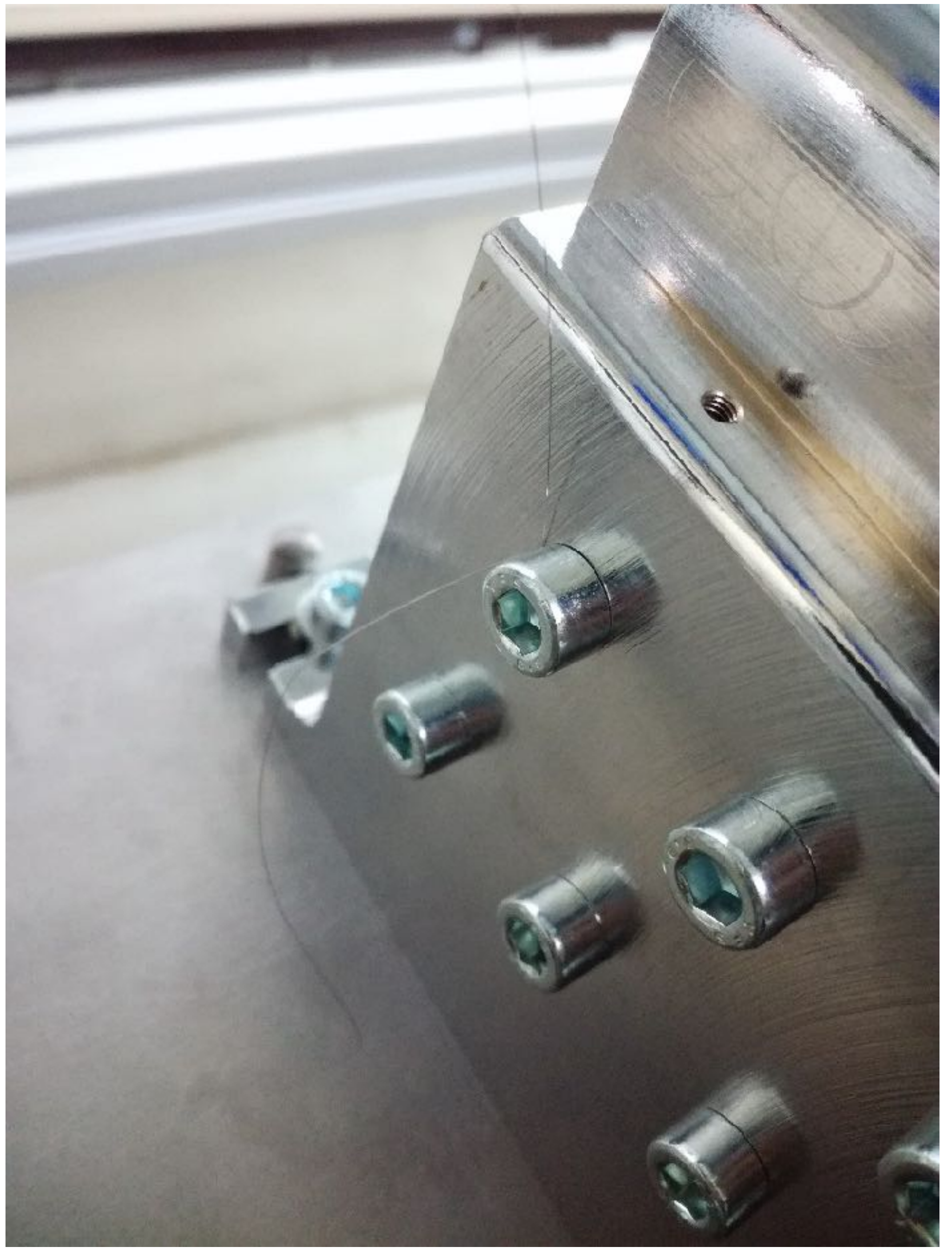
View from the "locking" side

View from the "pulley" side

Grid production

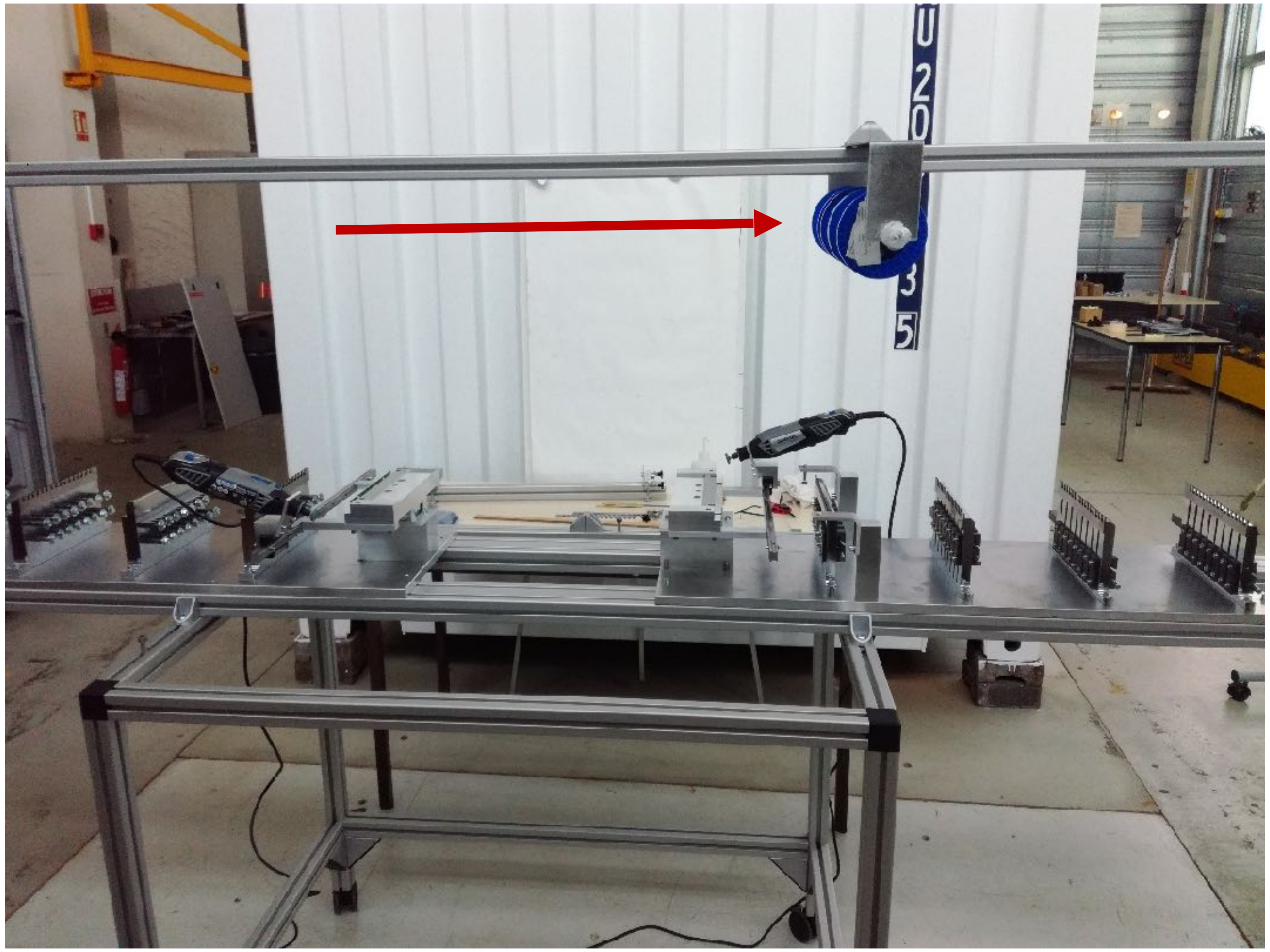


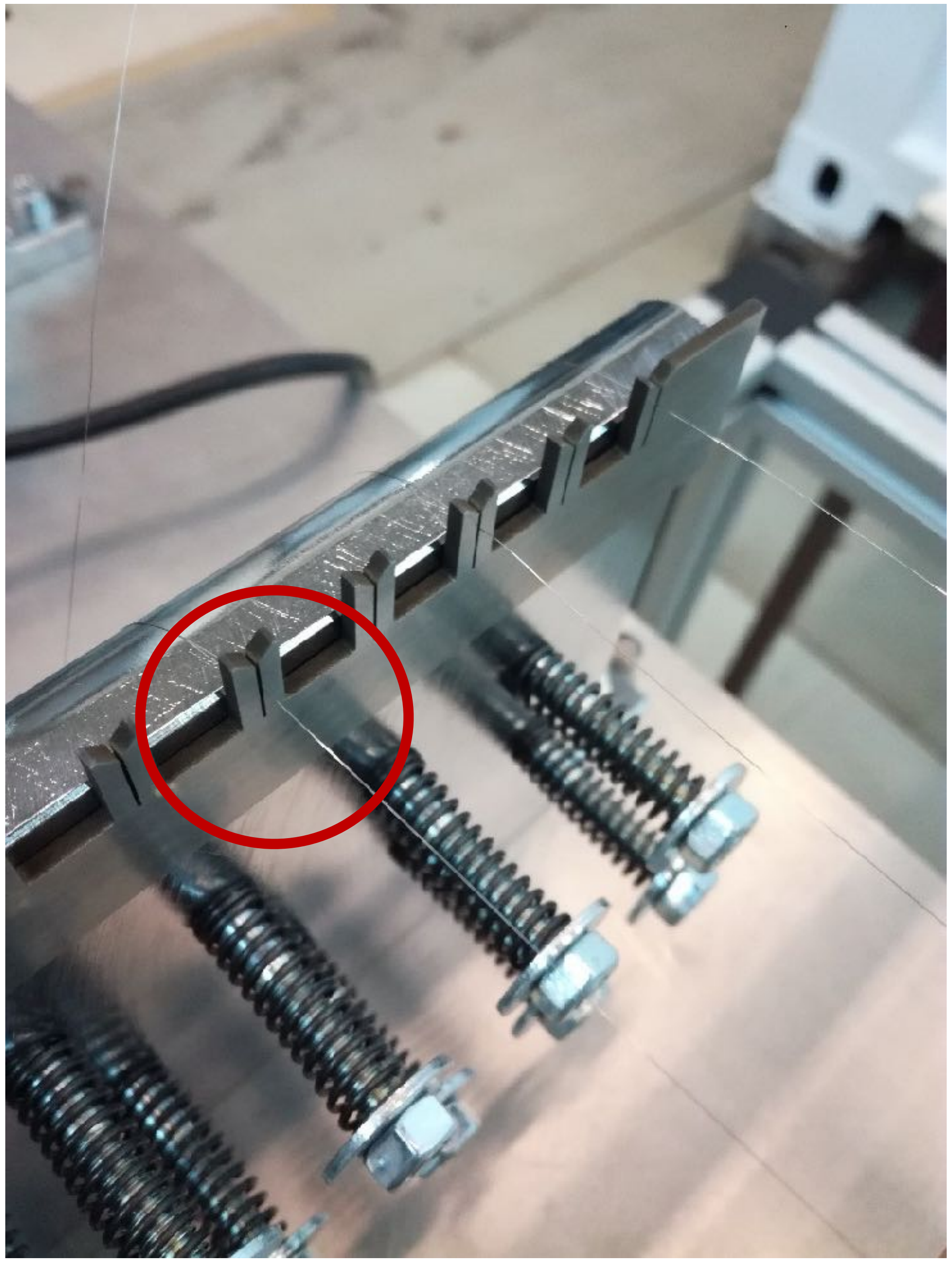




The wire from the coil is locked in the locking system
This operation is repeated for each coil

Grid production

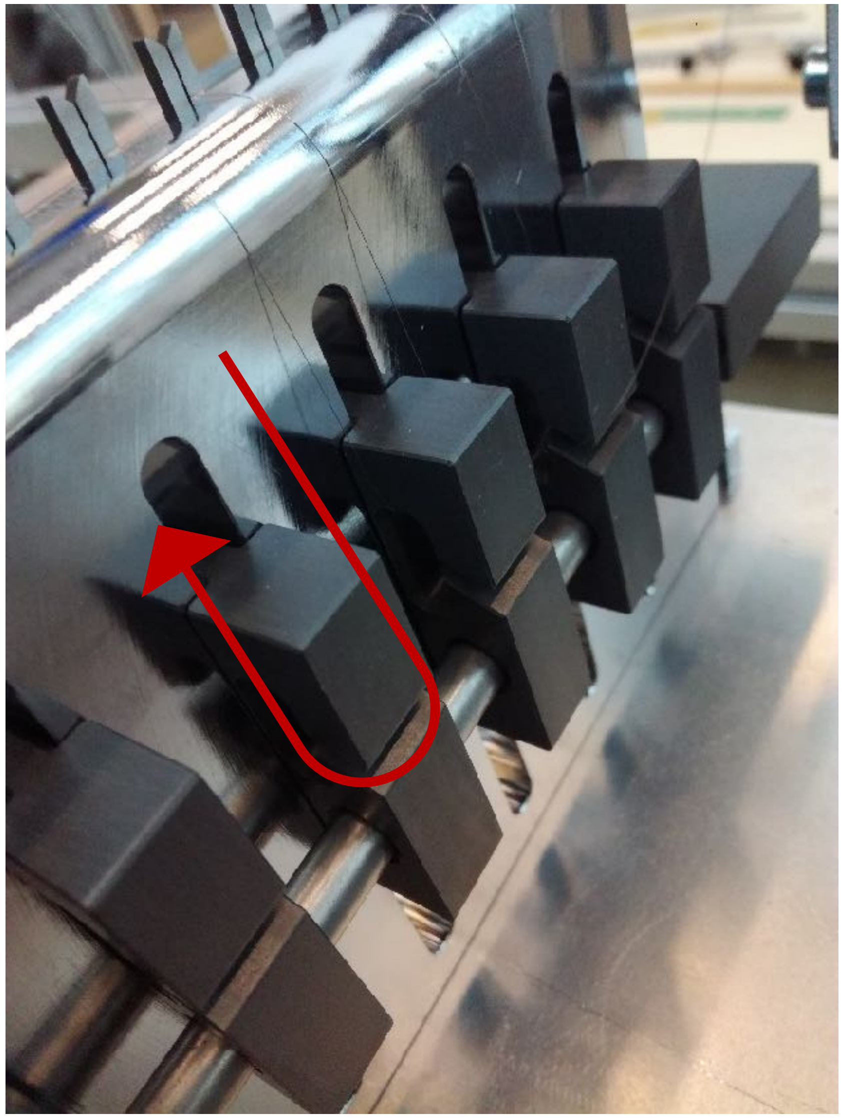


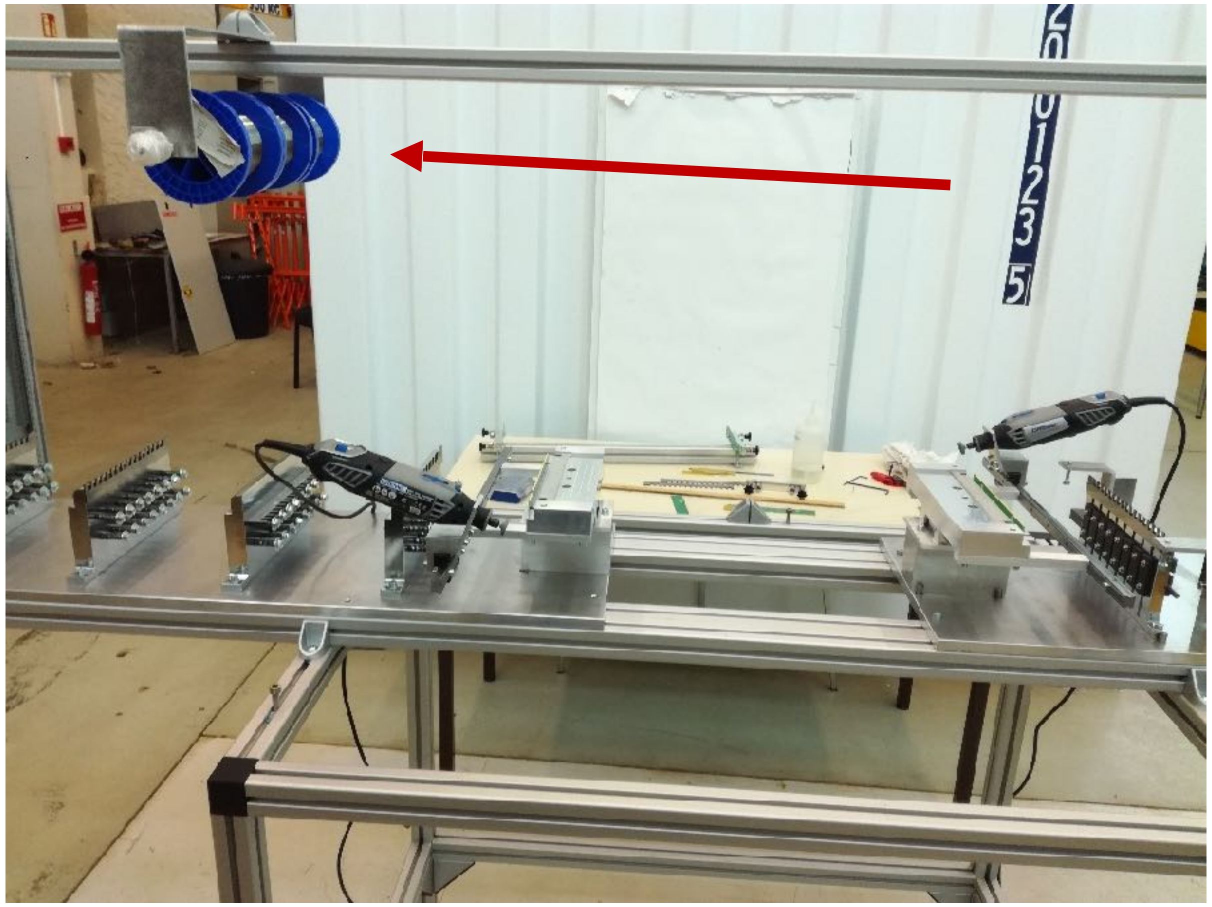


The coils are moved to the pulley side, taking care that the wires stay in the guides

➢ The coil chariot avoid to touch the wire with finger between the PCB plates.

Grid production

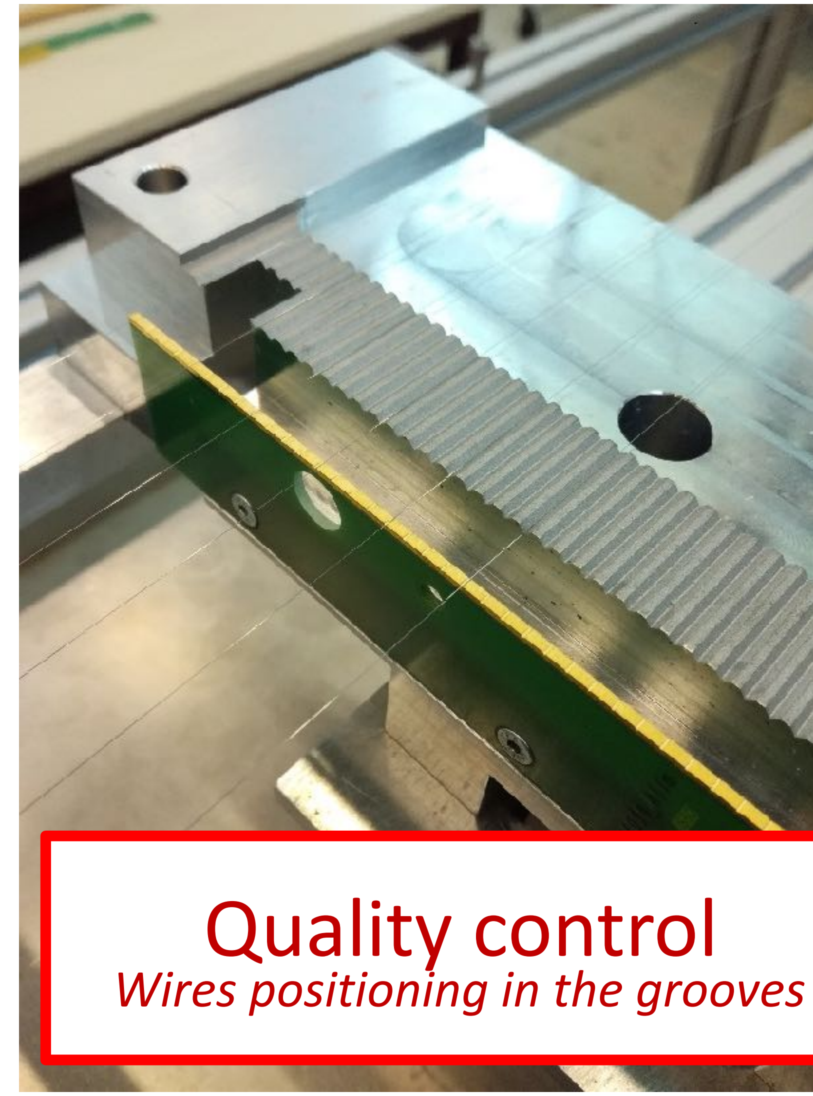




The wires are guided through the slots of the pulleys and the coil chariot is sent back, taking care of the wires position, in the guides

Grid production

Quality control
Wires positioning in the guides

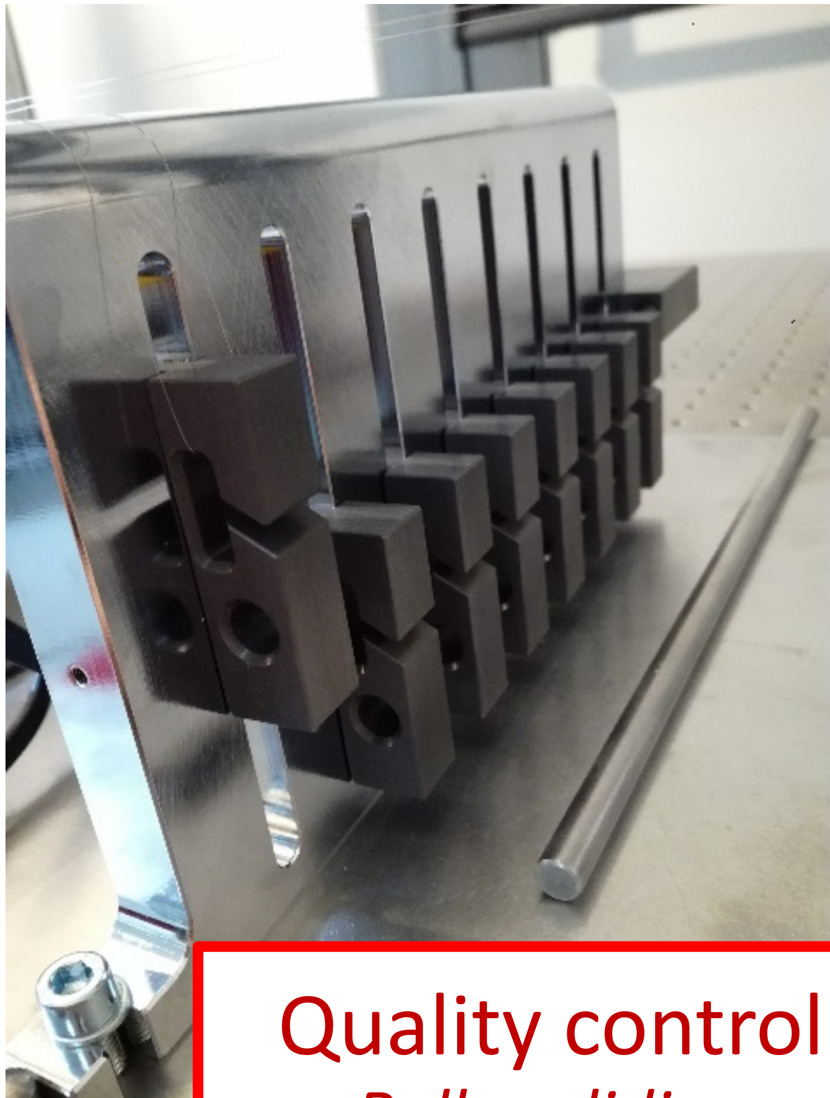


Quality control
Wires positioning in the grooves

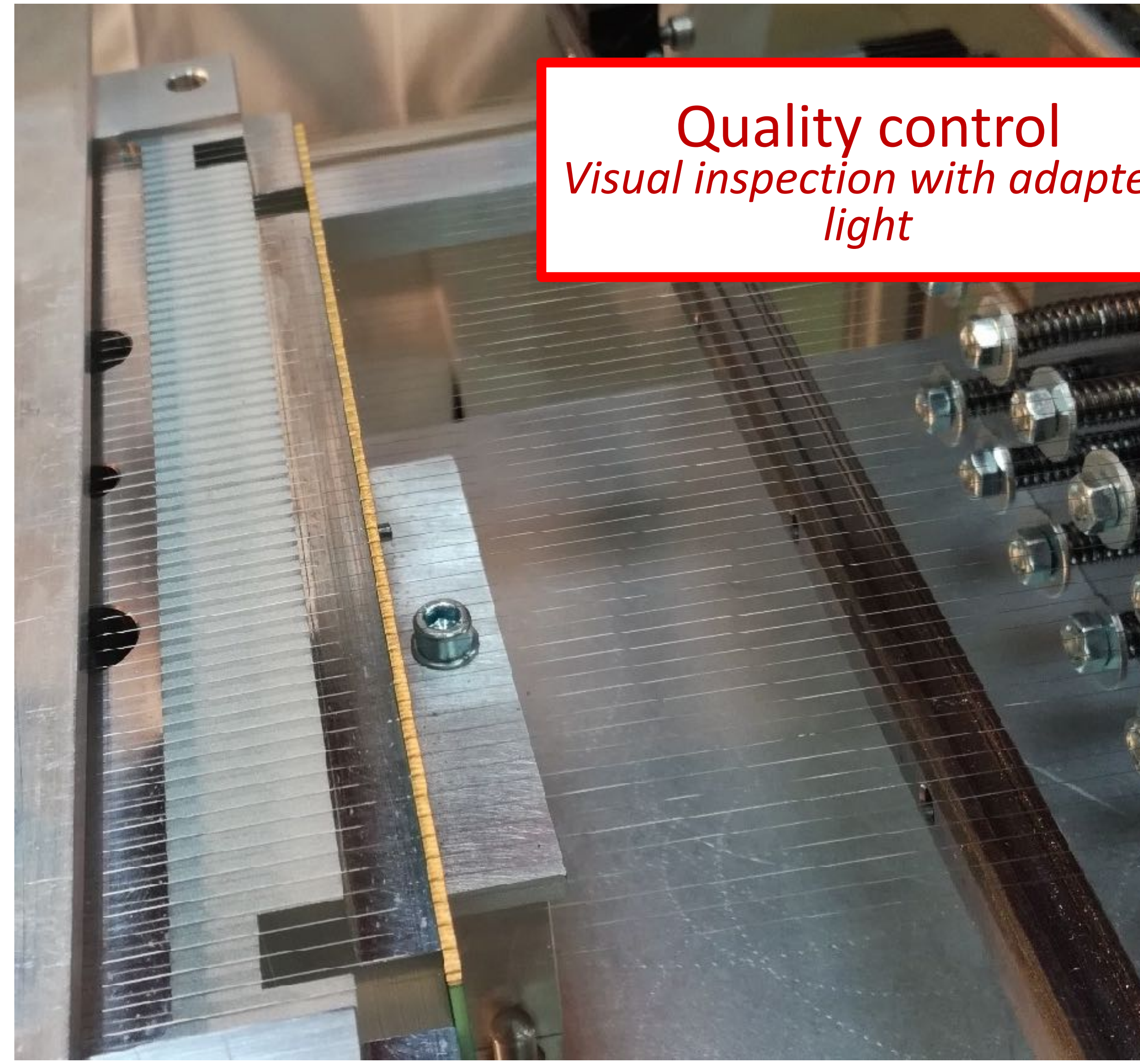
The wires are then guided through the guides on the locking side, and locked
The position of the wires inside of the PCBs grooves is also checked

Those operations are repeated until all the wires are placed

Grid production



Quality control
Pulley sliding

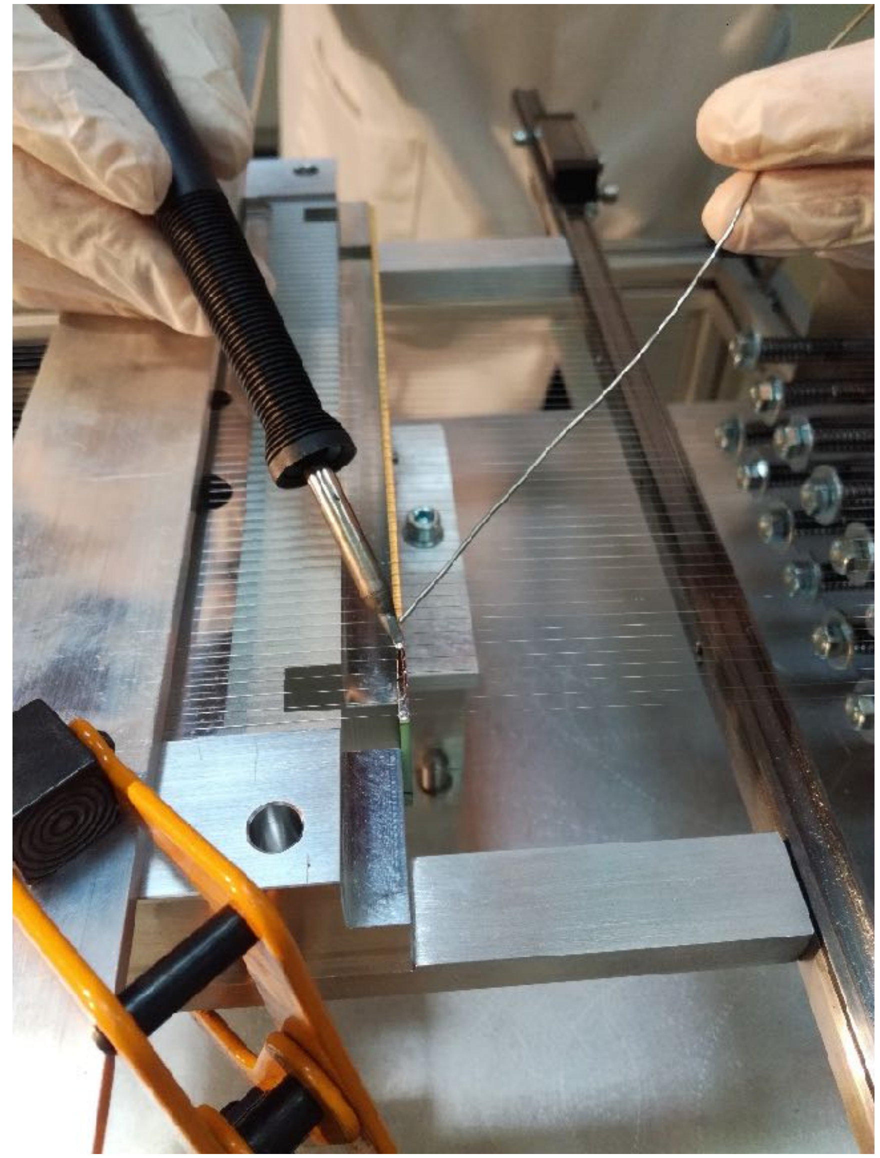


Quality control
Visual inspection with adapted light

Then the pulleys are unlocked, insuring the calibrated tension in the wires, due to calibrated weight of the pulley and wire friction control

The position of the wires in the grooves of the PCBs is also carefully checked

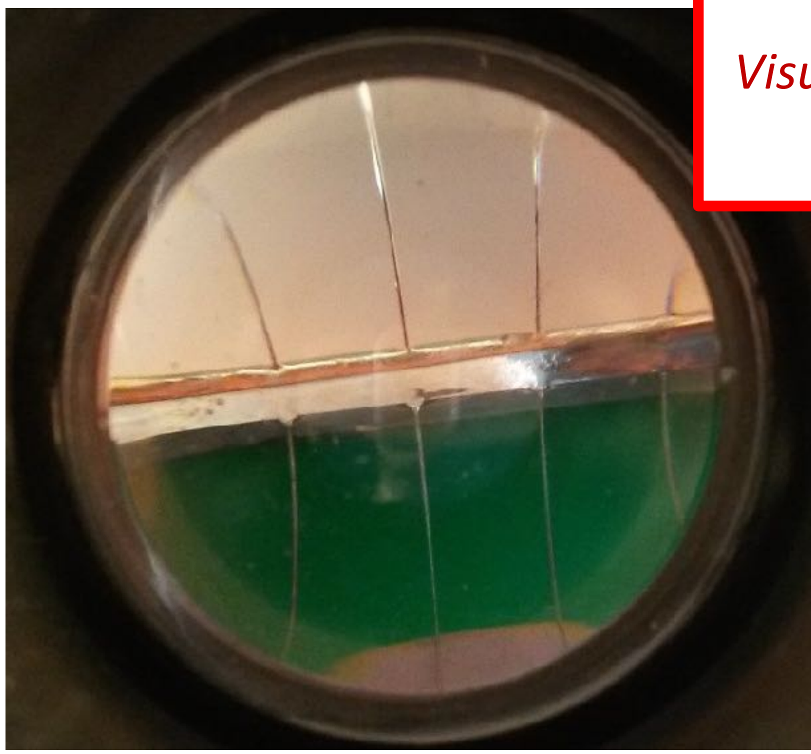
Grid production



Phosphoric acid is applied on the wires to improve soldering properties
Then the soldering is processed

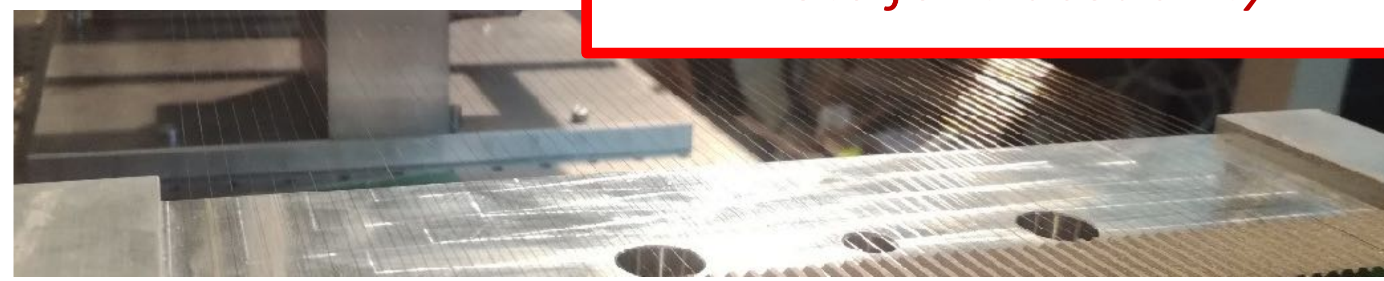
Those two operations are done under smoke extraction hood

Grid production



Quality control
Visual inspection of the soldering +
Photo for traceability

Quality control
Visual inspection of the grid +
Photo for traceability



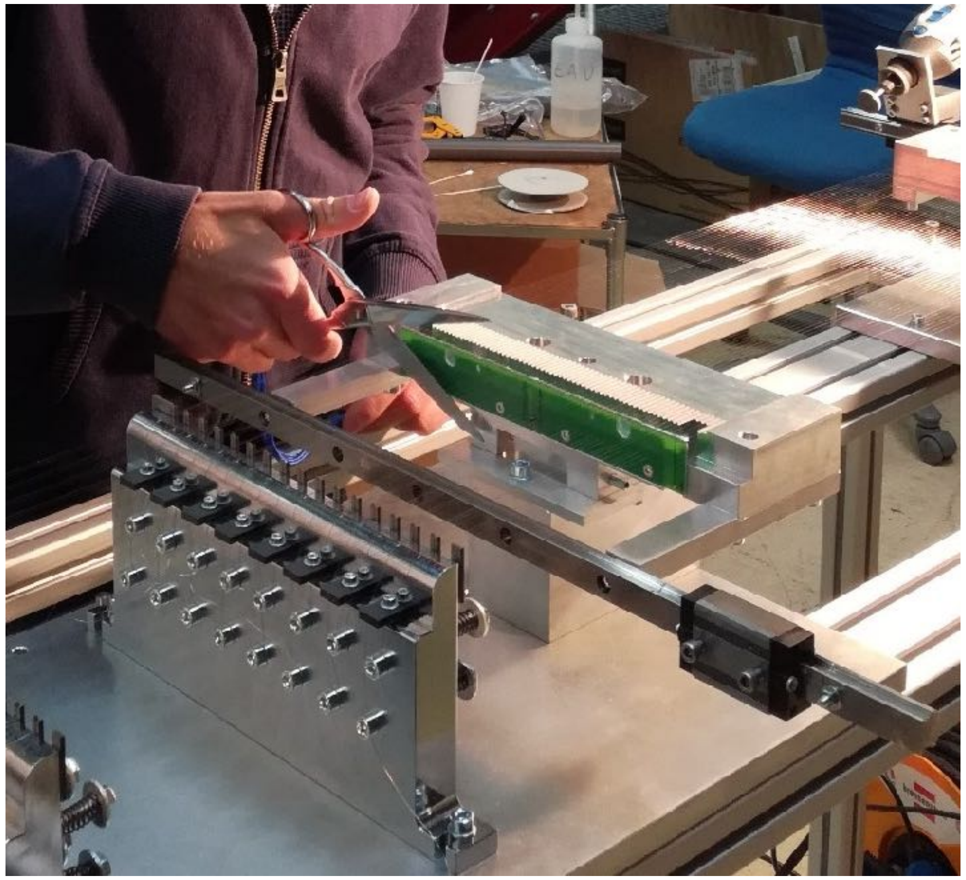
Quality control
Slight over-tensioning to
break defective wires

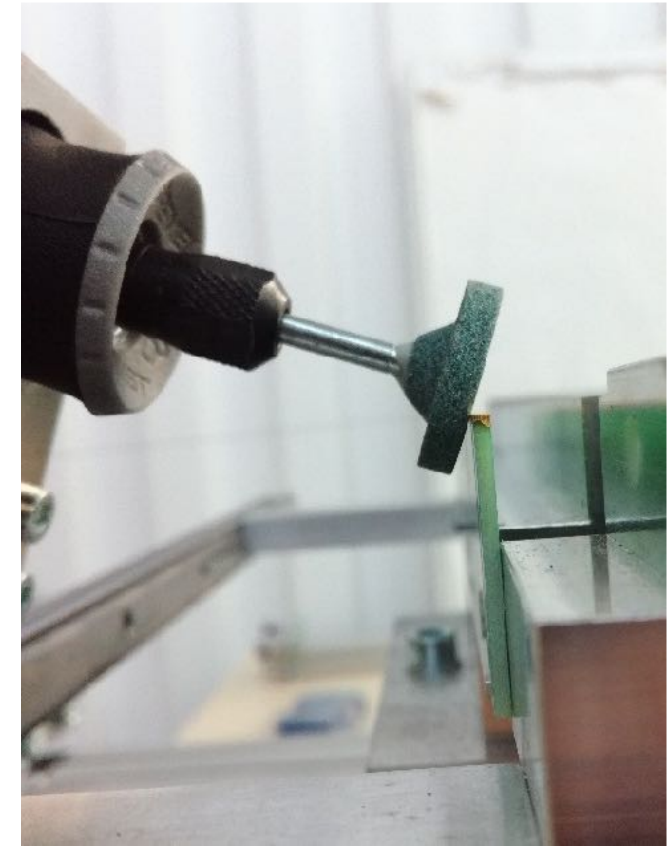
At this point, several quality controls are done, including :

- The soldering quality, to prevent rupture
- The grid aspect, to spot wires defects, wire bending or bad wire positioning
- Tension control, to break eventual defective wires without damage a sane assembly

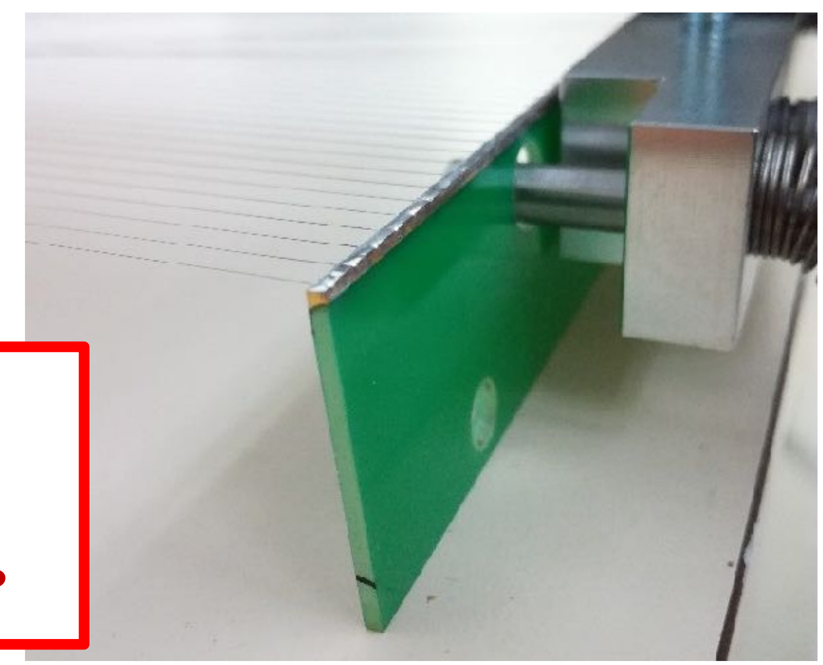
Photographies of each set and traceability is foreseen for the installation

Grid production





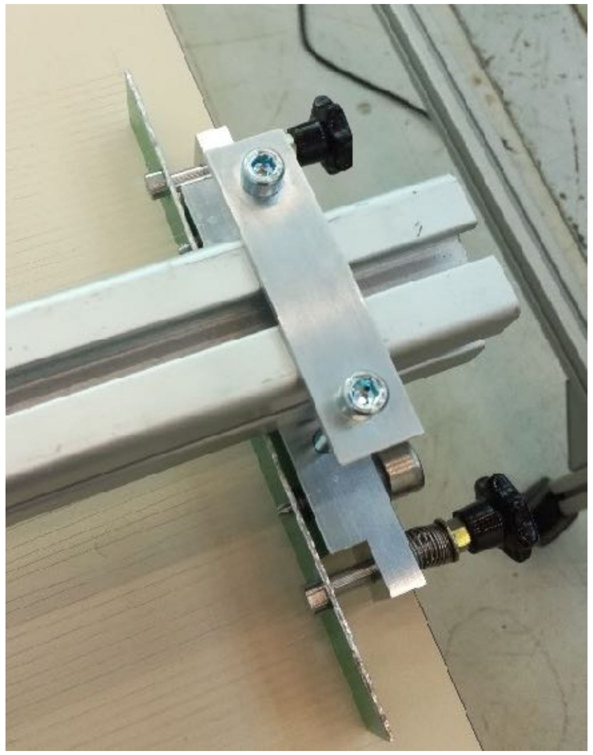
Wires are then cut roughly on the external side with scissors, an cut with the rotative tool, which provide a smooth and clean finishing of the edge

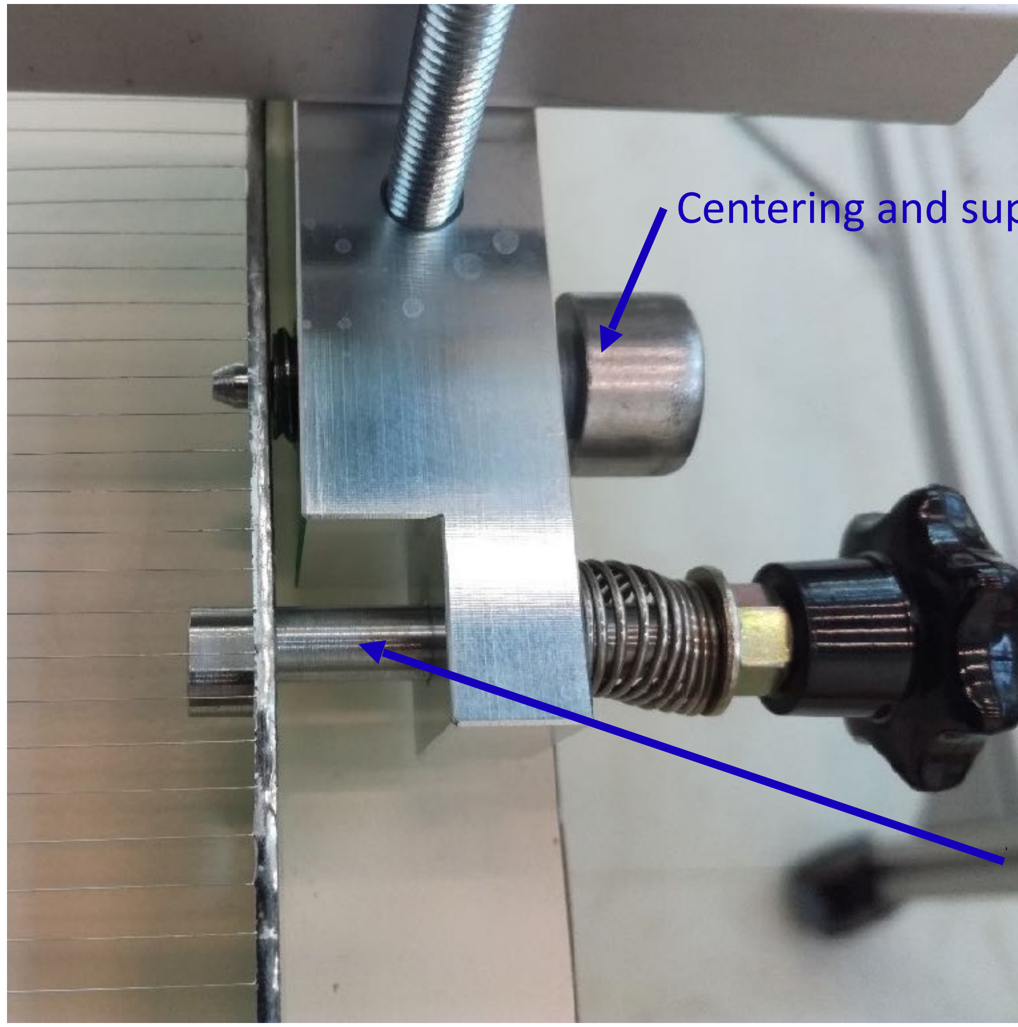


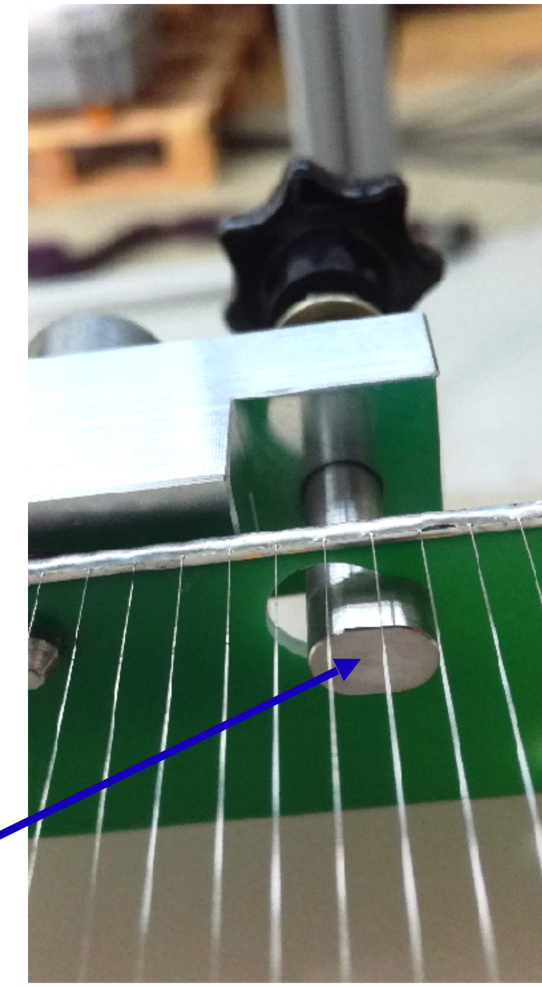
Quality control

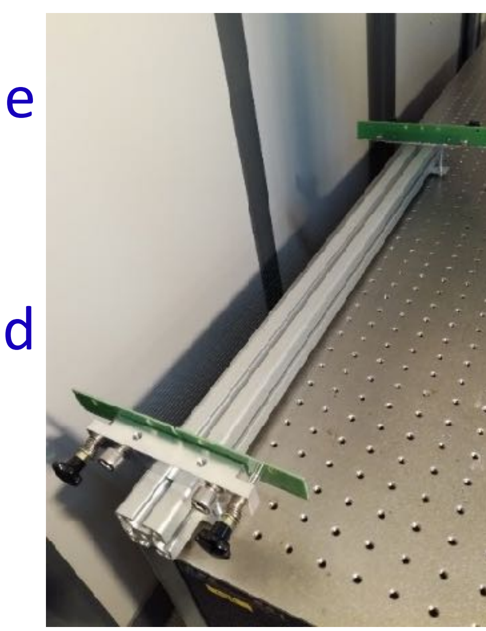
Visual & sensitive inspection of the edge

Grid production









Storage bar is finally placed on the validated grid subset and the transfer from the tooling to the storage bar is made, without touching it with hand.

Since the storage bar does not insure a flat support of the PCBs, it is normal and non-problematic to loose tension in some wires at this point

The bar is then stored before installation on CRP

Grid production

Quality control
Aging test of a grid subset with over-tensioning (3 months in October)

Large parts have been received at CERN in the clean room.

40 km / 25 miles of certificated high quality stainless steel wire.

Prototype of a woven grid set, stored with extra tension to test soldering quality along time.

Extraction grid supporting plates (standard and high voltage supply versions received).
Will be tested soon.

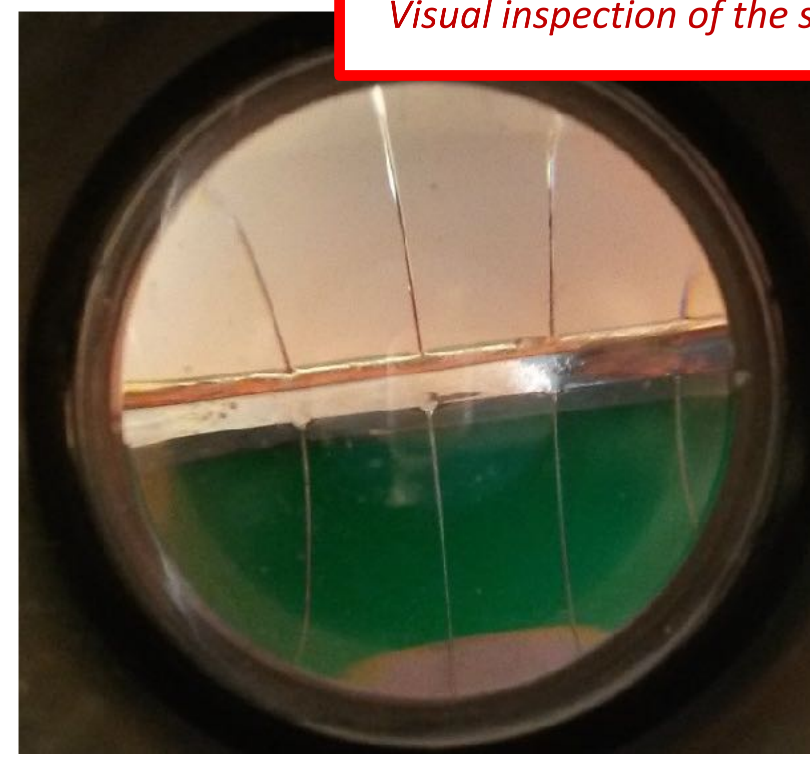
Grid production

Test of grid brazing

Quality control
Test of the soldering in cold condition

Grid prototype in liquid nitrogen, for cold test of the brazing

Quality control
Visual inspection of the soldering



Test of grid brazing

- Zero defect soldering process validated (use of phosphoric acid to improve brazing).
  - Tests with « low brazing skill » operators --> OK