WA105/ProtoDUNE-DP

Charge Readout Plane Design

WA105 – protoDune-DP Technical Review – 24th of April 2017

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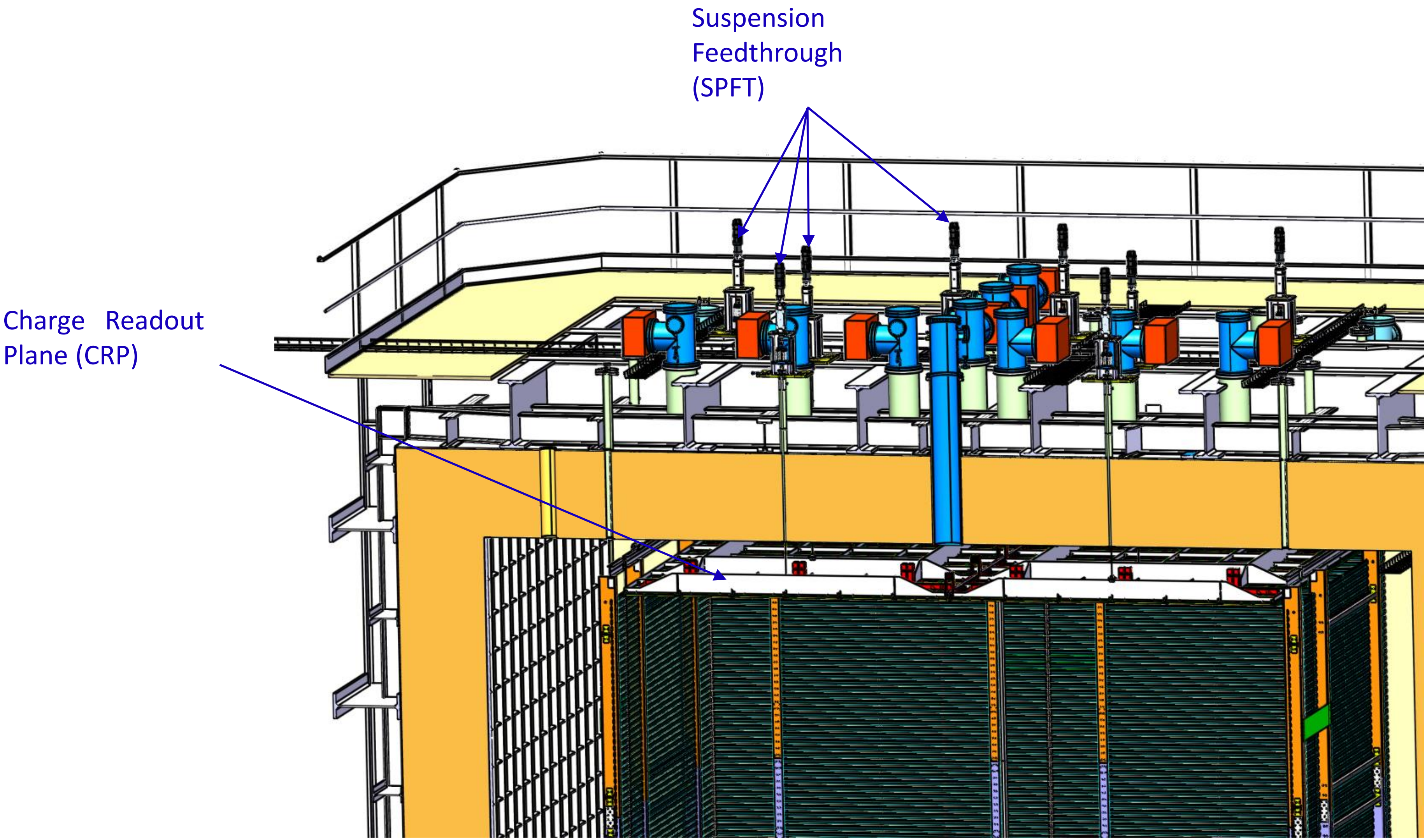
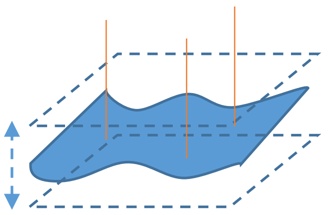
Detector Overview



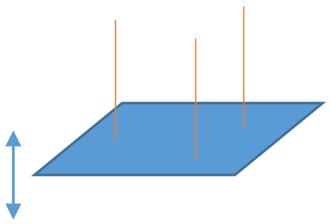
Assumptions on 6x6 anode deck design and assembly :

- *Mechanical specifications of the plane :*

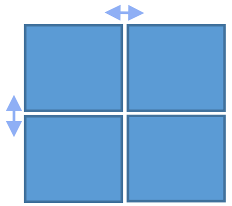
  - ***In planarity***
    - *Specified planarity tolerance on the LEM plane is **+/-0,5mm***



  - ***In positioning***
    - *Specified altitude tolerance is **+/-0,05mm***

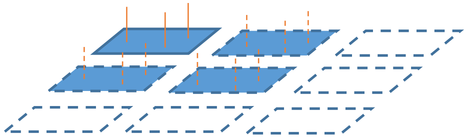


  - ***In detection surface***
    - *Minimize inter-space into 6x6m, **max. 10mm***

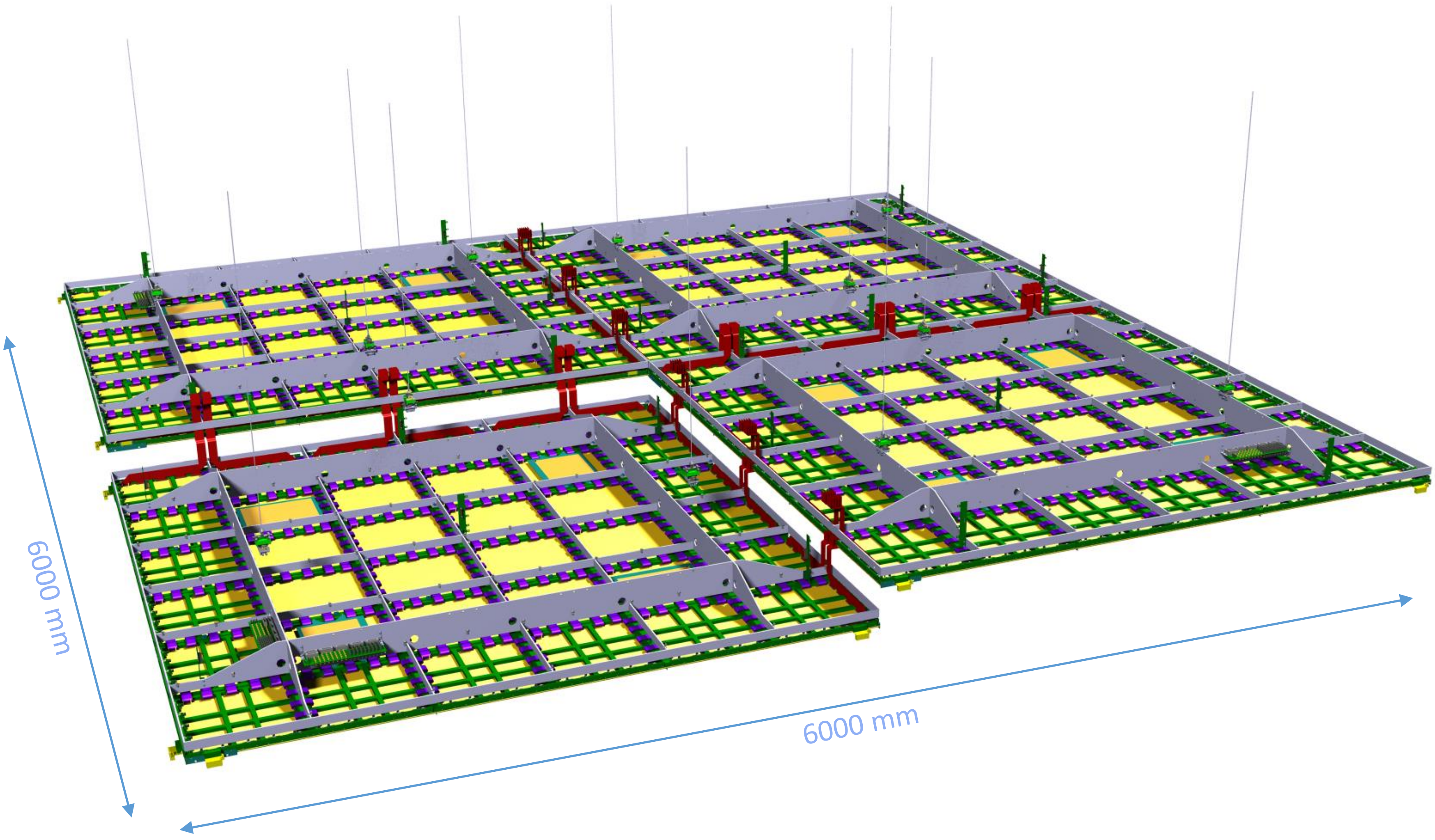


  - ***Be transportable and installable…***

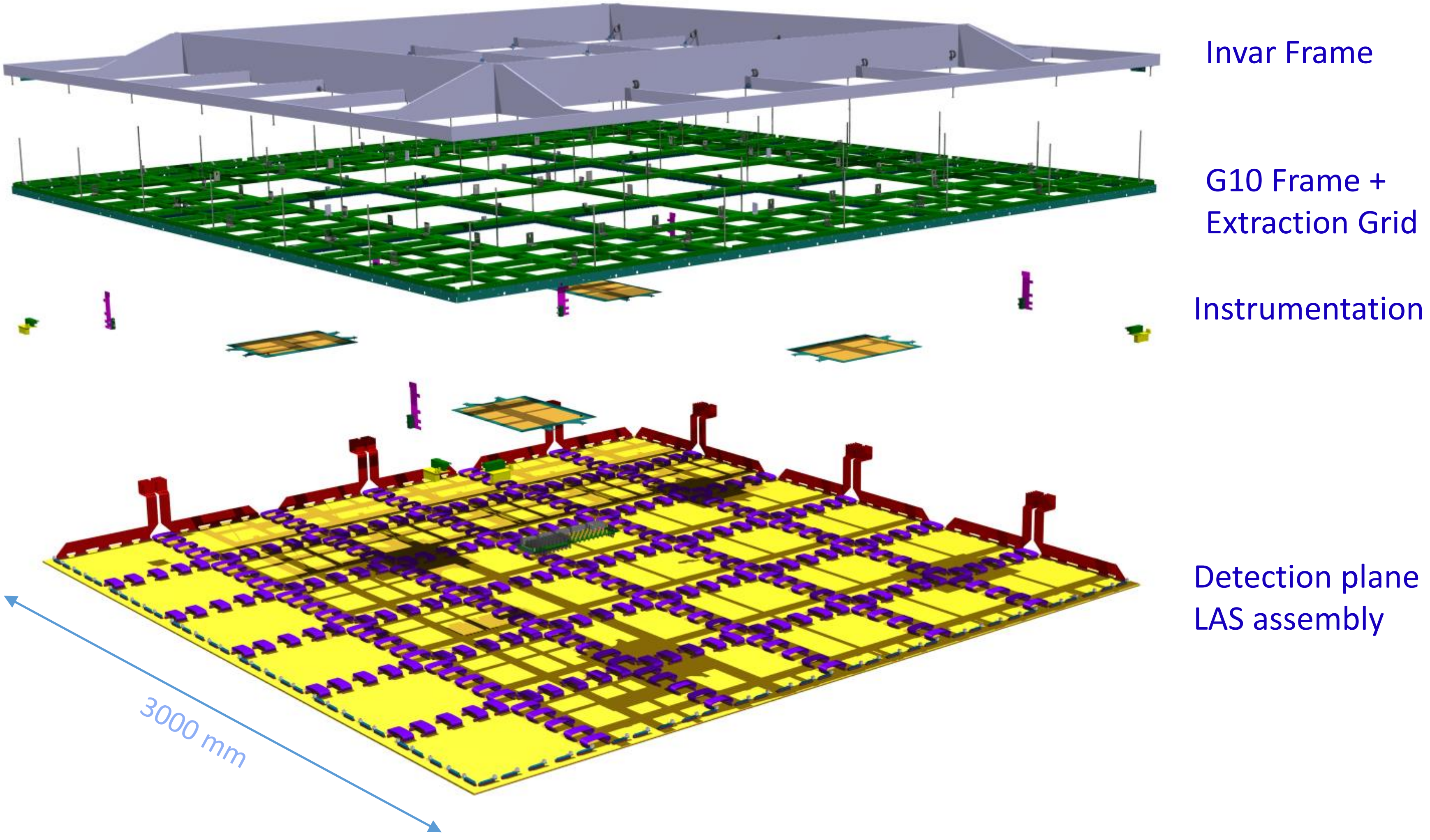
- *Design of WA105 must be scalable and re-usable for DUNE*



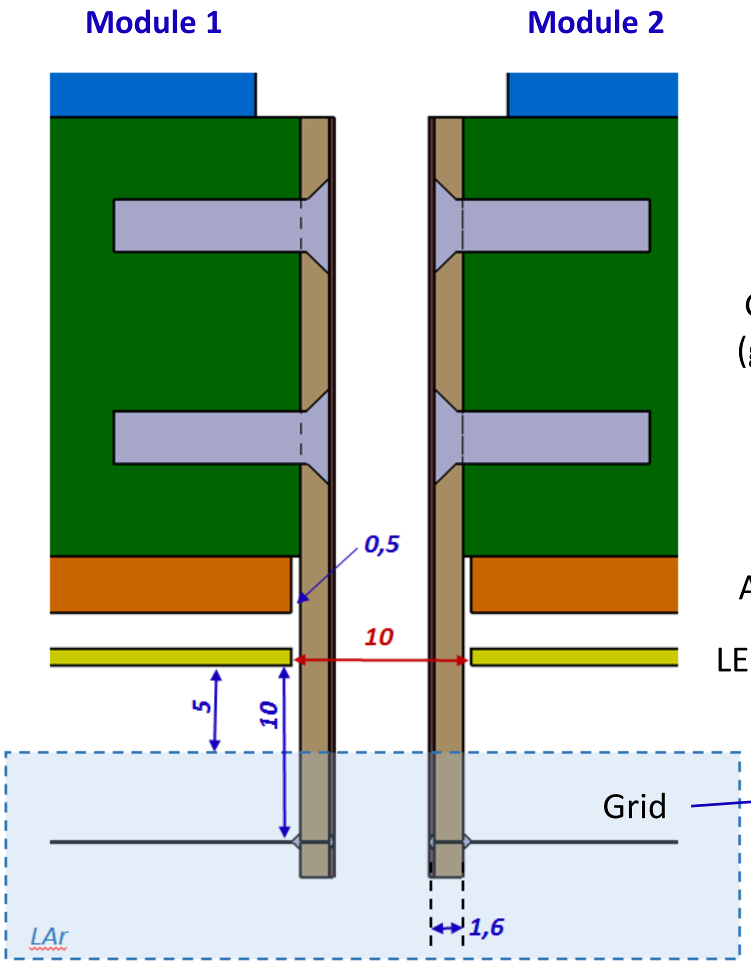
CRP Design

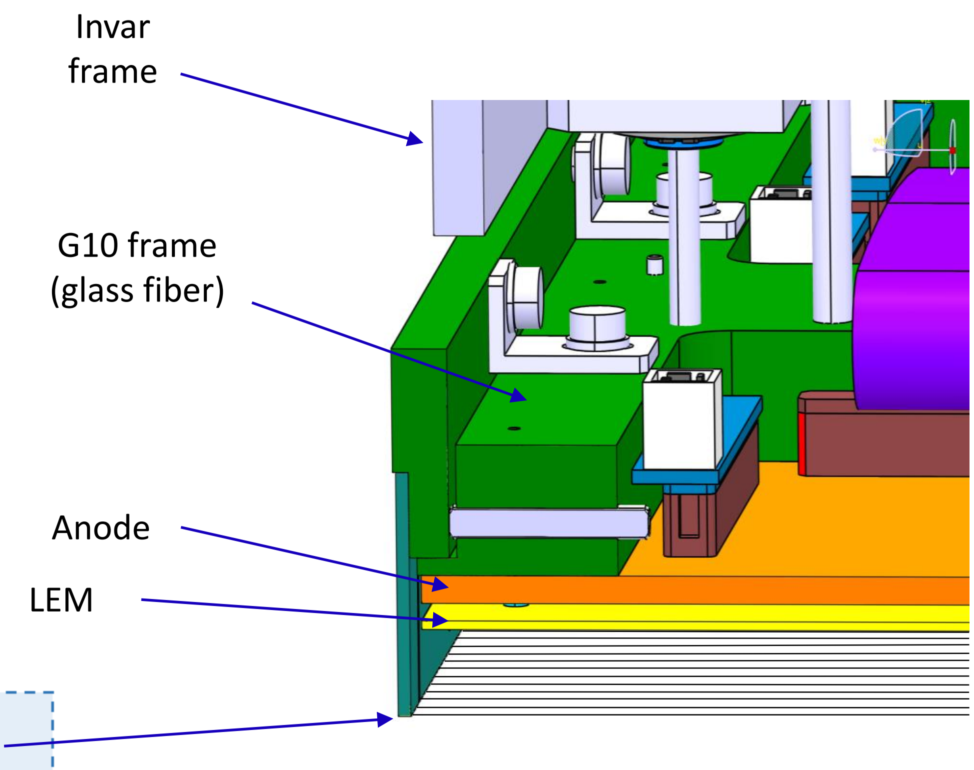


CRP Overview and composition



CRP Overview and composition

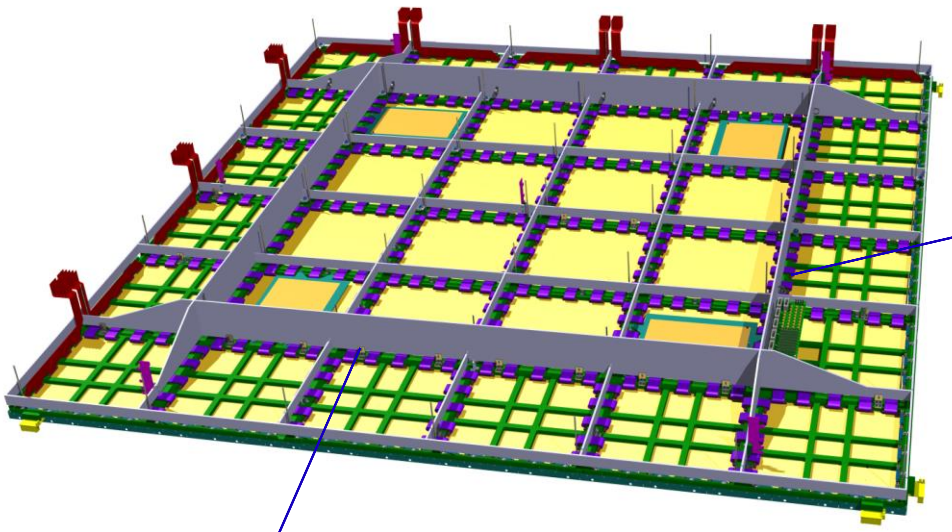


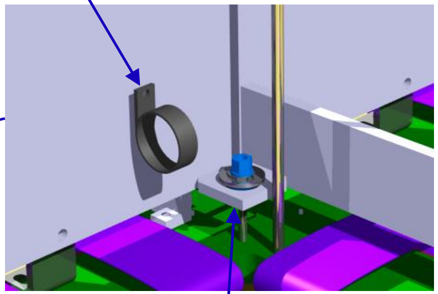


Invar Frame

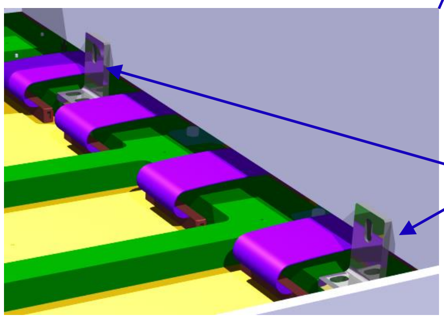
- Invar frame is the skeleton of the module
- All the frames are identical

Stainless steel adaptable Cable fixations all around the frame





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

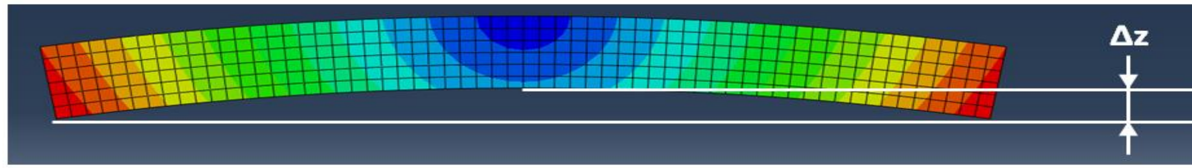


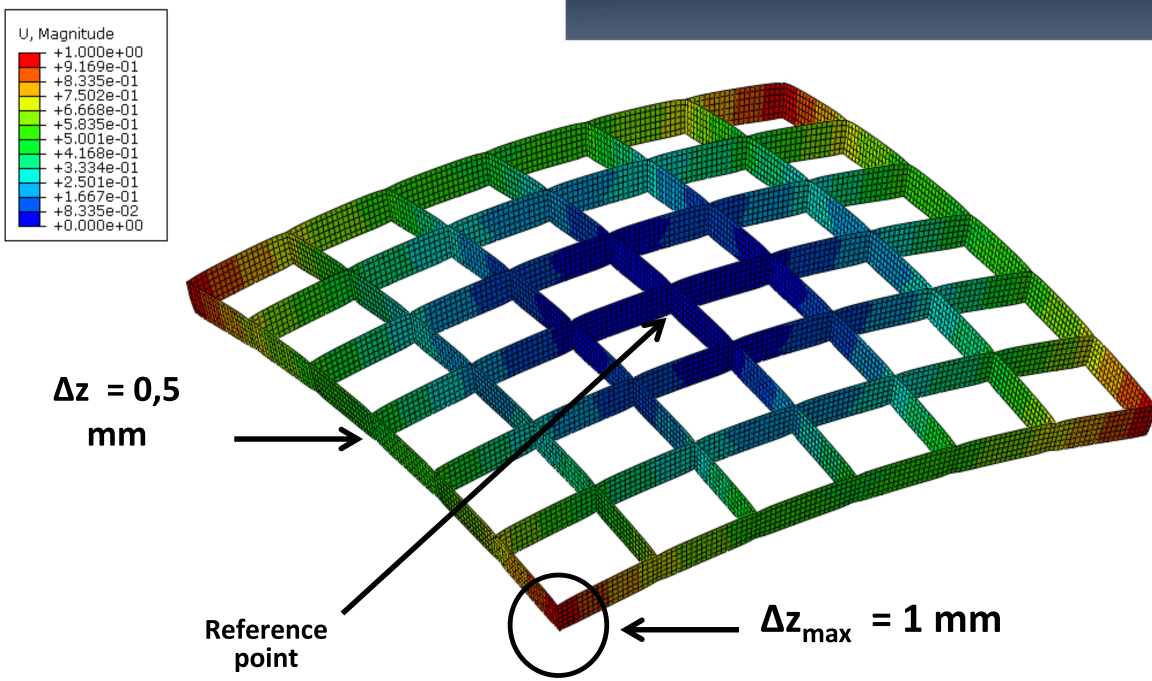
Square supports between invar and G10 for final assembly transportation

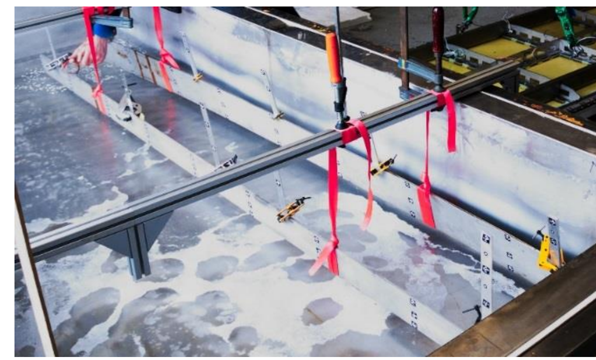
Why Invar?

More details are given in spares slides

- Bending of a stainless steel frame due to temperature gradient in GAr.







Thermal Δz_{max} allowed per plate = 0,5 mm

Measured with a cold bath test Δz_{max} on a real 150mm plate = <u>2,1 mm</u>

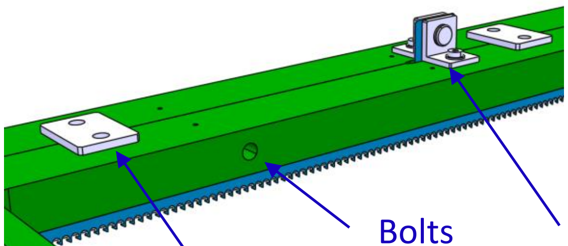
→ **INVAR for WA105,**

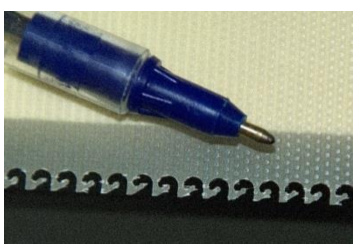
→ **ProtoDUNE feedback (Temp. gradient measurements) will help for final DUNE design**

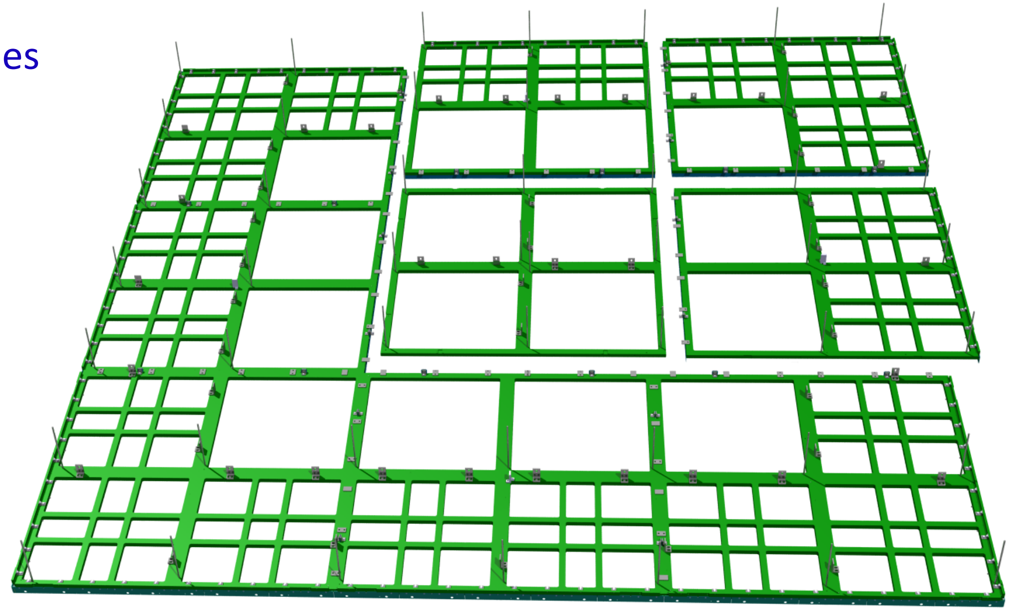
G10 (fiberglass) Frame

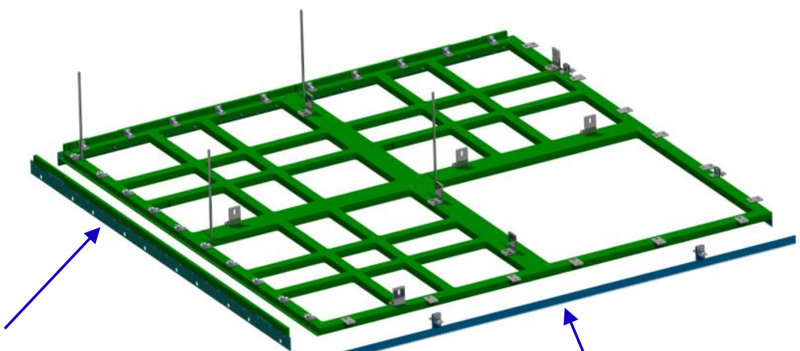
- 3x3m frame is an assembly of 1x1m frames
- Only 3 types of 1x1m frames

Junction between 1x1m frames :





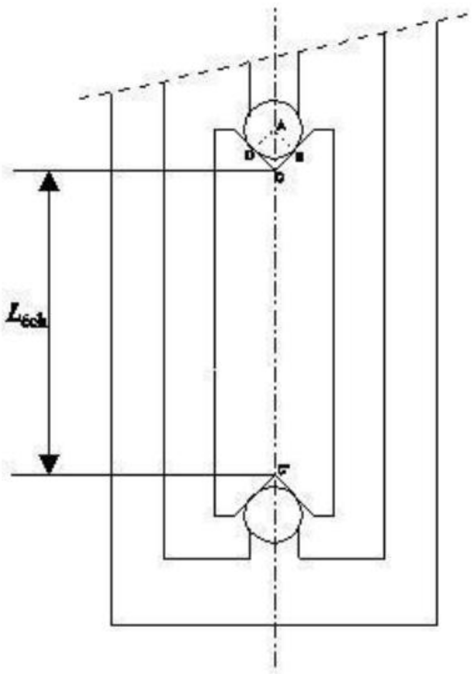




Thermal shrinkage measurements

- Study has been performed by Cryolab to know contraction coefficients

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



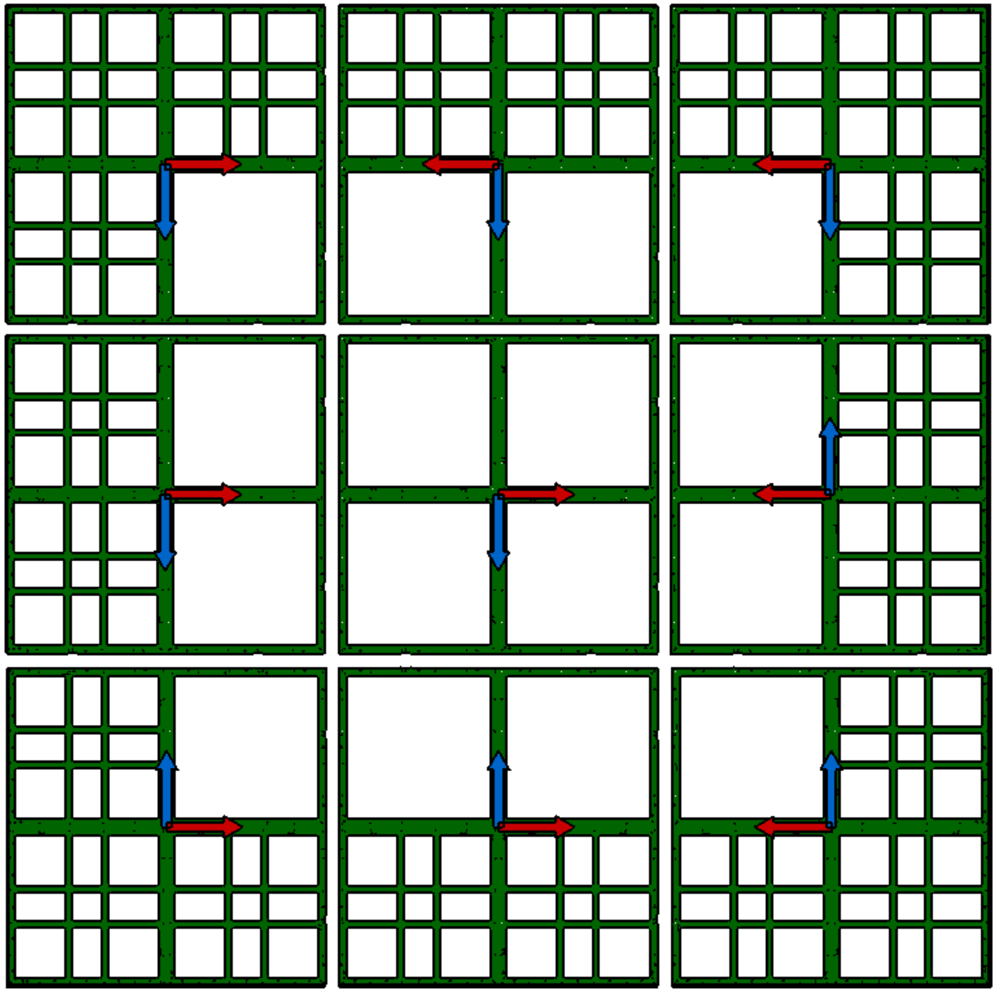
Tests from ***CRYOLAB*** on G10
(Vetronit EGS 102 from Von Roll)

$\alpha_1 = 7{,}2.10^{-6}\ K^{-1}$
$\alpha_2 = 9{,}3.10^{-6}\ K^{-1}$
$\alpha_3 = 33{,}5.10^{-6}\ K^{-1}$

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

so G10 thermal behavior is similar to LAS

Nine 1x1m² sub-frames are composing final structure

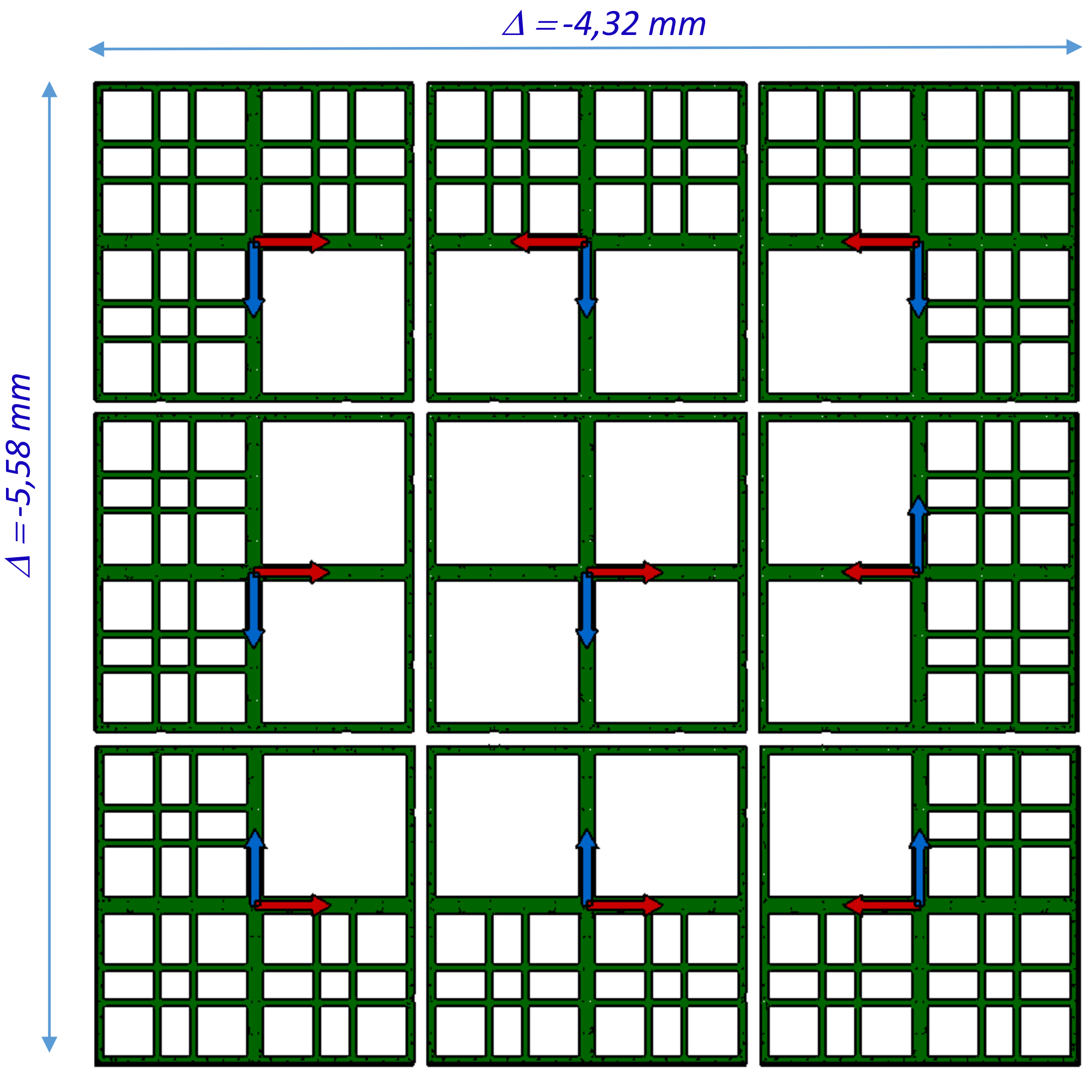


Three different patterns :

- « 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

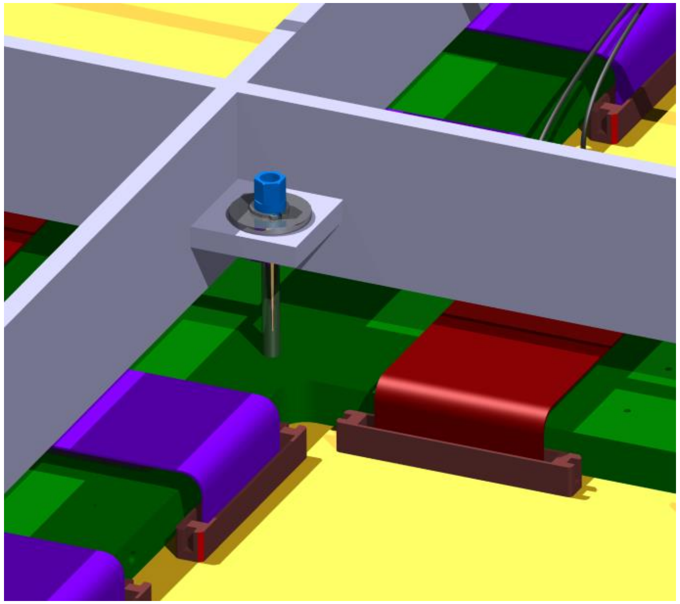
Thermal contraction values on G10 *(between +20°C and -186°C)*

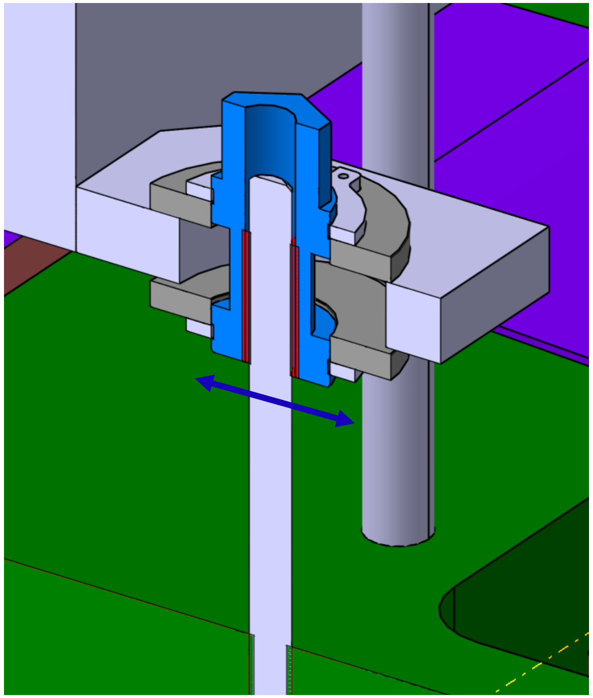


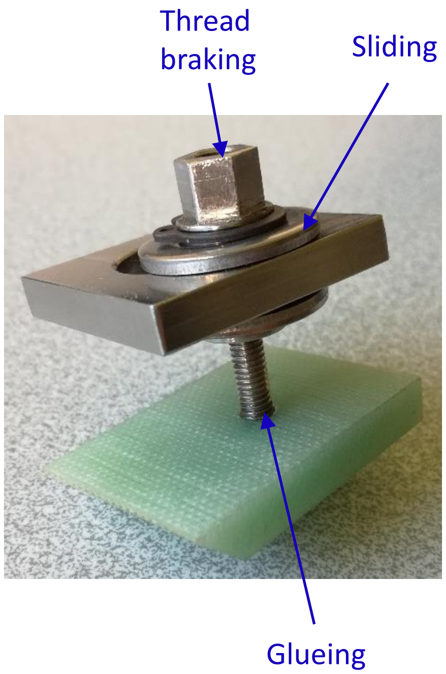
- Fiberglass is used to stick with LAS thermo-mechanical behavior and avoid over-stress due to differential thermal contraction.
- At cold, whole plane will be a slight rectangle.
- Differential thermal contraction occurs between G10 and Invar frames.

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)

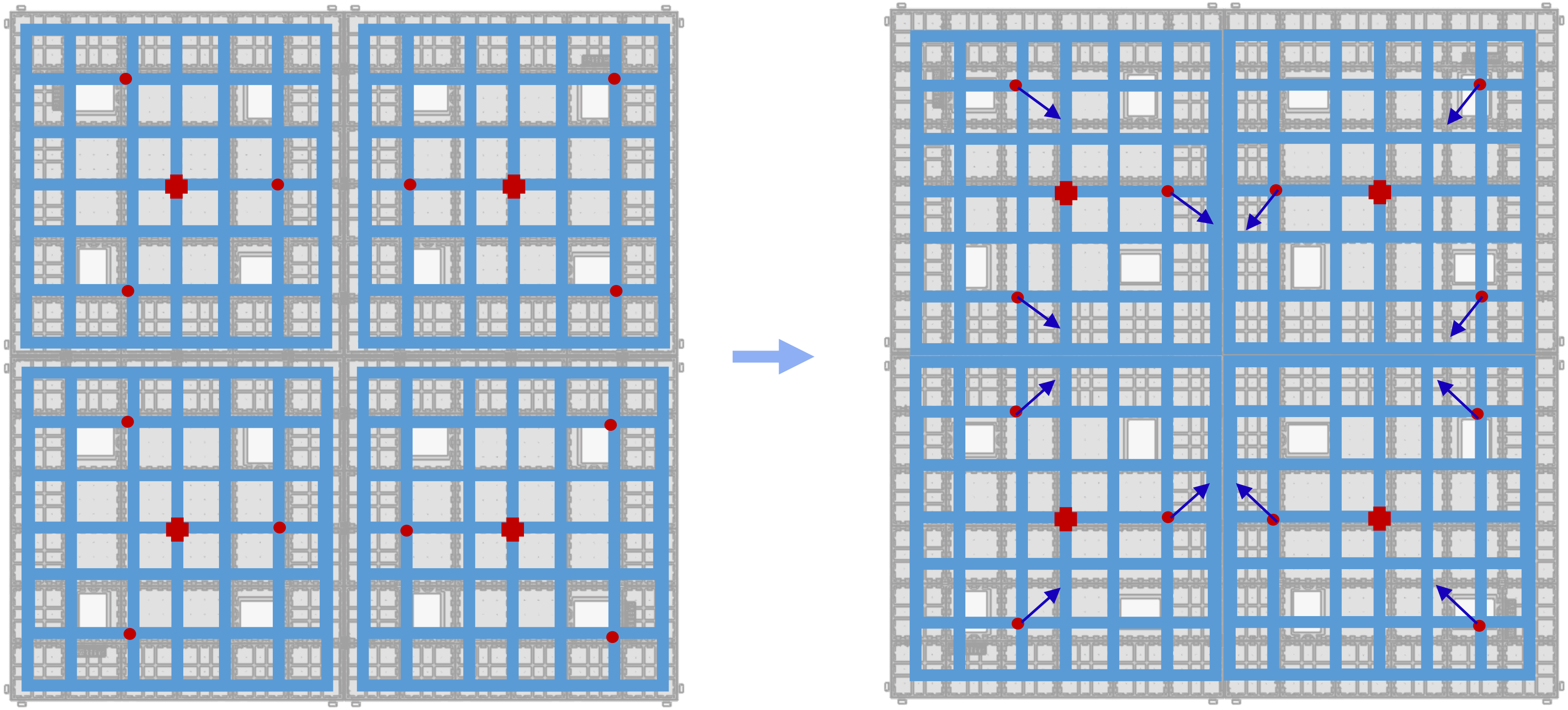






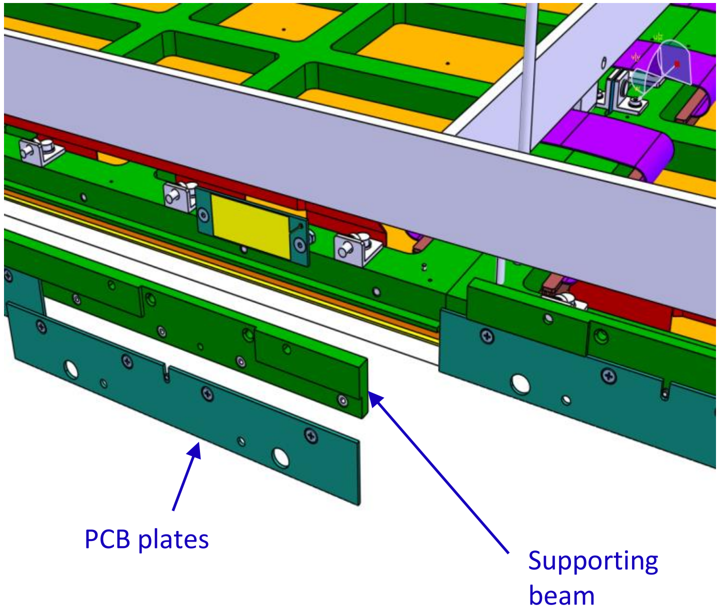
Zero inter-space thermal contraction pattern

- 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 (see next slides)
- Final Interspaces between LEMs in cold condition :
    - *0,5-0,8mm inside a 3x3m module*
    - *< 10mm between two 3x3m detection area*

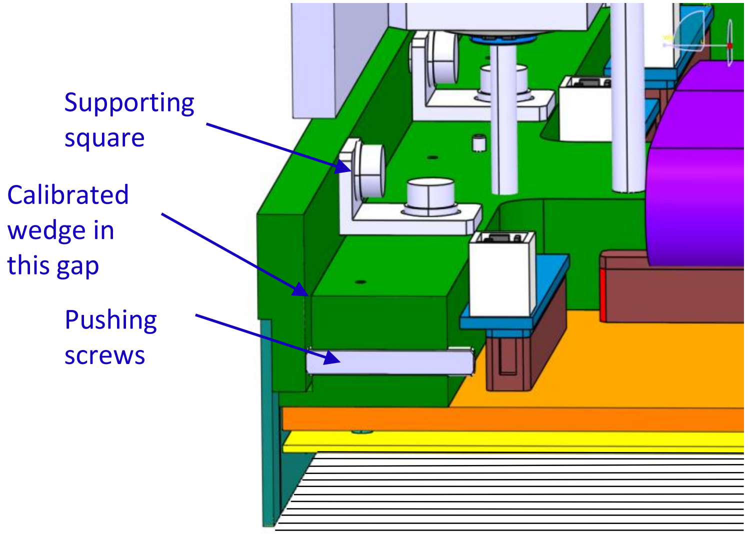


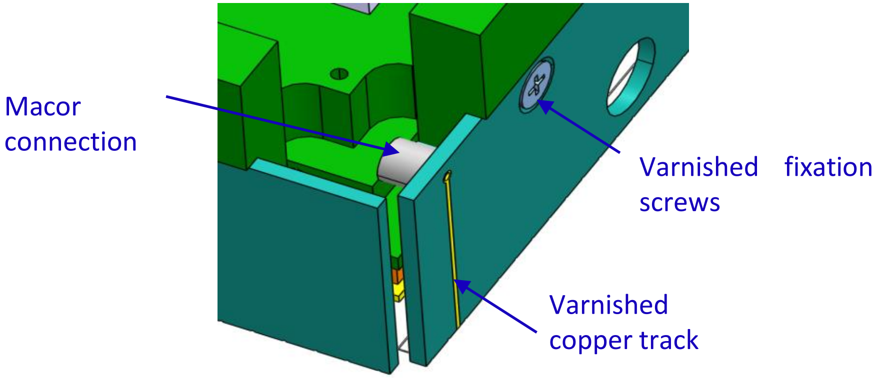
Extraction Grid

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



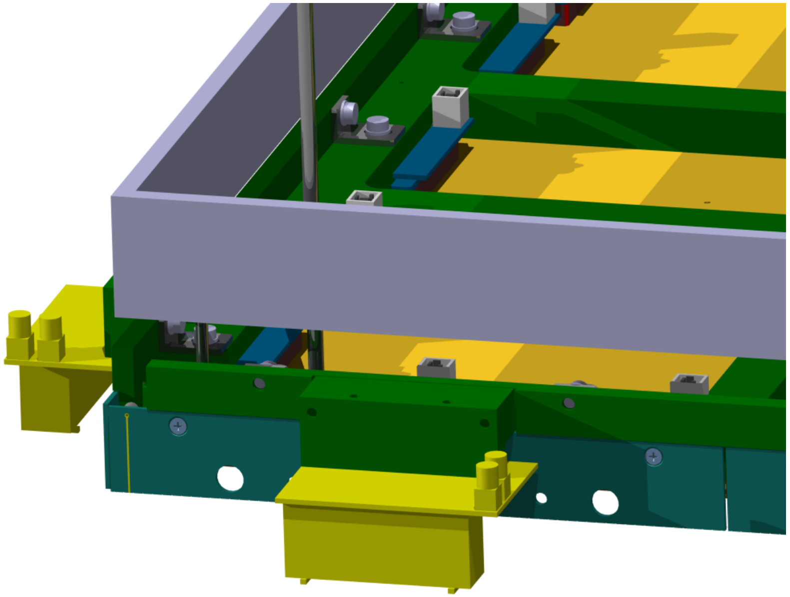
- Grid tensionning is performed by tightening « pushing screws », adding a calibrated wedge, and locking the supporting square



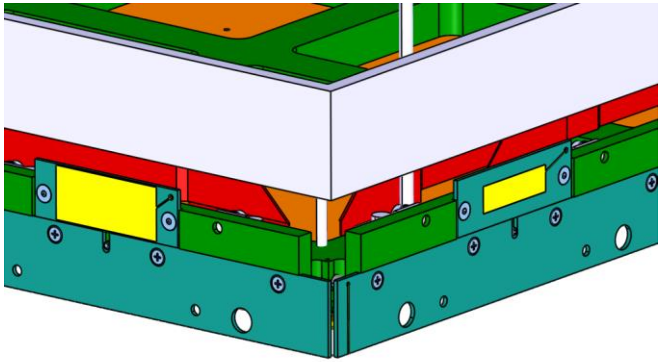


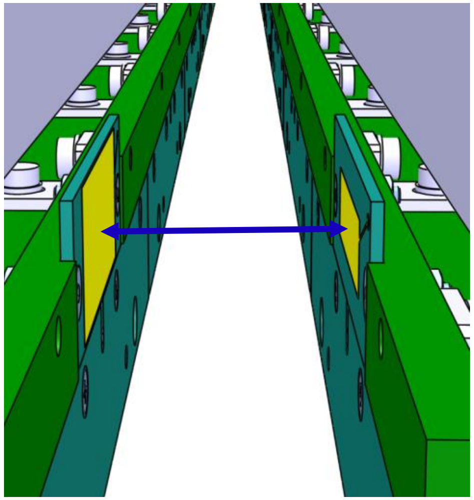
CRP position Instrumentation

- Capacitive Level Meters (same as 3x1x1)
  - *4 devices by external side of the 6x6m*
  - *Fixed on a very stiff G10 support*



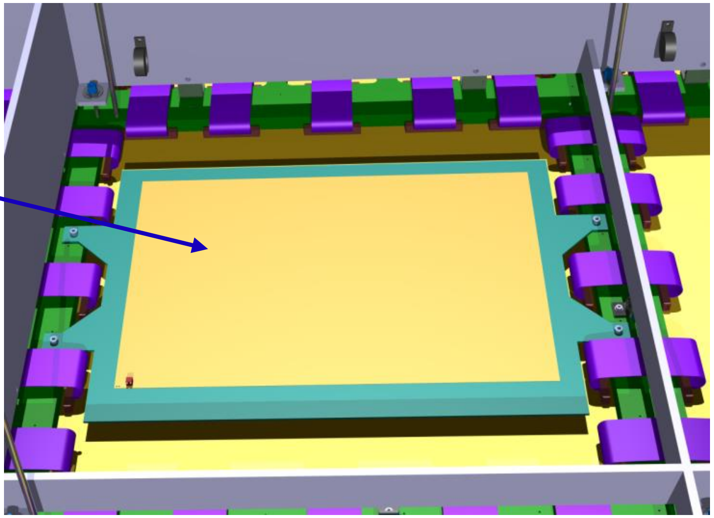
- Distance Meters
  - *Gives informations on module's relative positions*
  - *Capacitive measurement, no contact*
  - *4 devices by 3x3m side (internal side)*

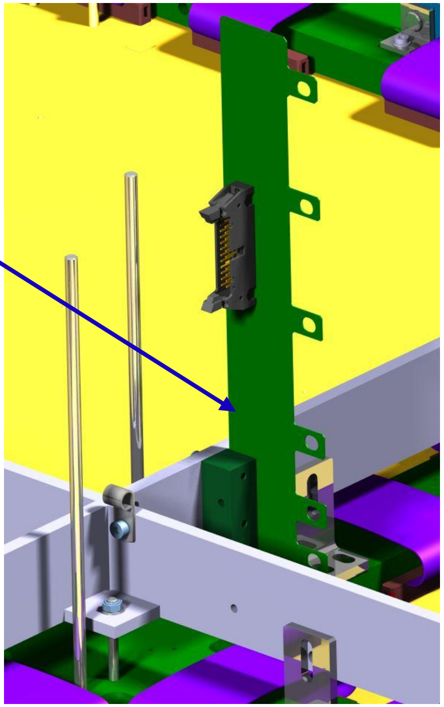


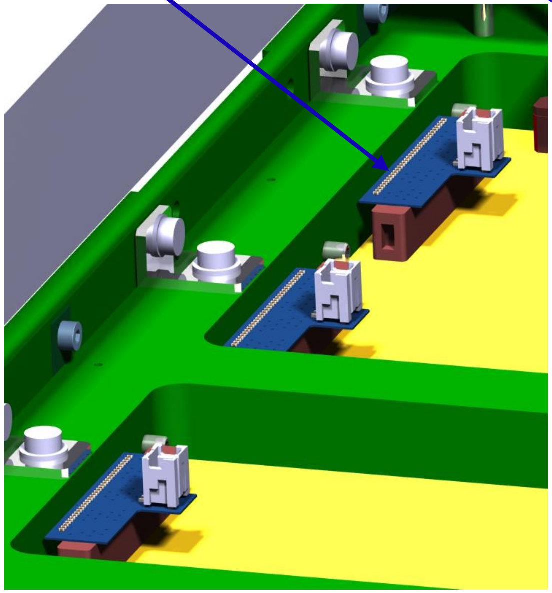


Other Instrumentation

- Heaters
  - *Fixed on a dedicated G10 plate*
- Thermometers
  - *Fixed on G10 blocs*
- Calibration boards



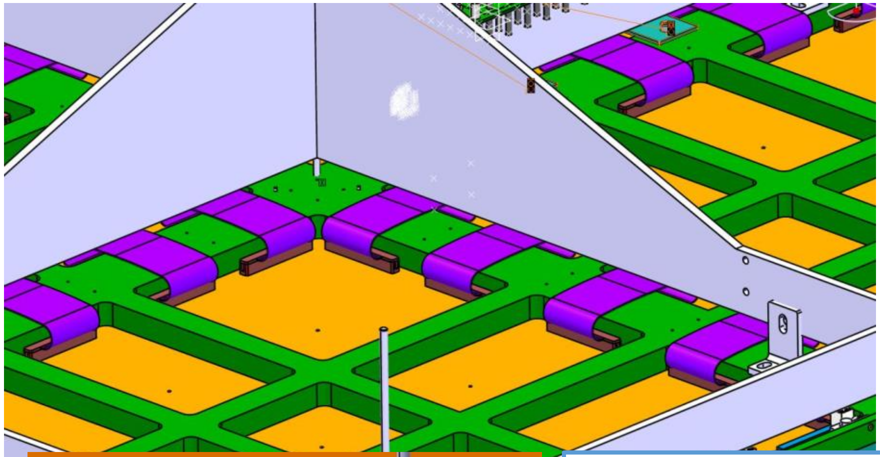


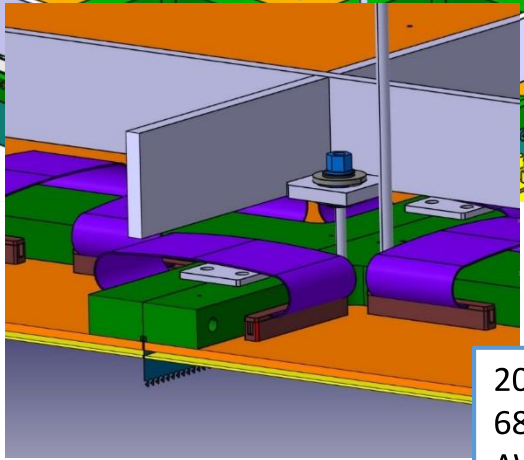


Jumpers between LAS

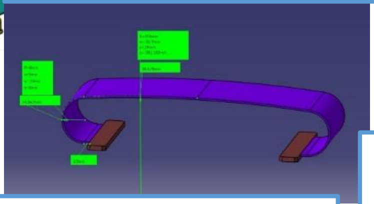
More details in spare slides

Independent Charge Readout Plane 3x3 m2 module





Bridge needed to electrically connect adjacent 50x50 cm2 anodes



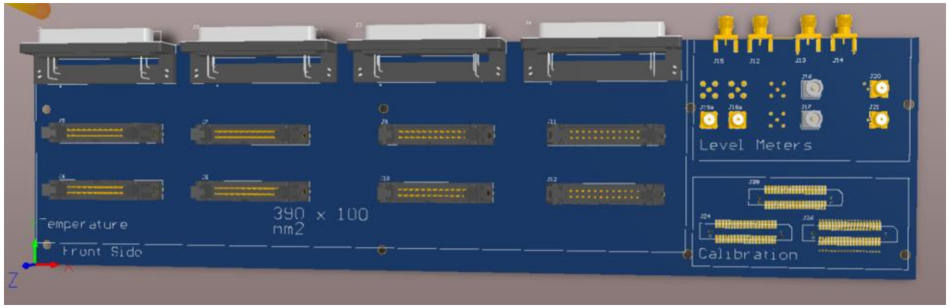
20 cm long flat cable 68c, 0.635 mm pitch, 30 AWG

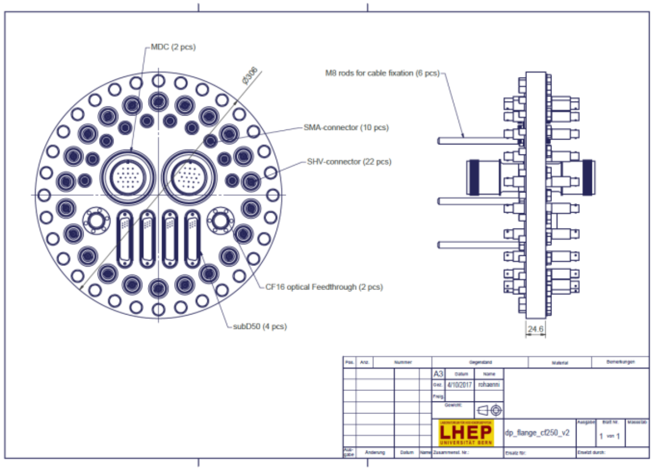
Sample to be tested for continuity in cold and outgassing

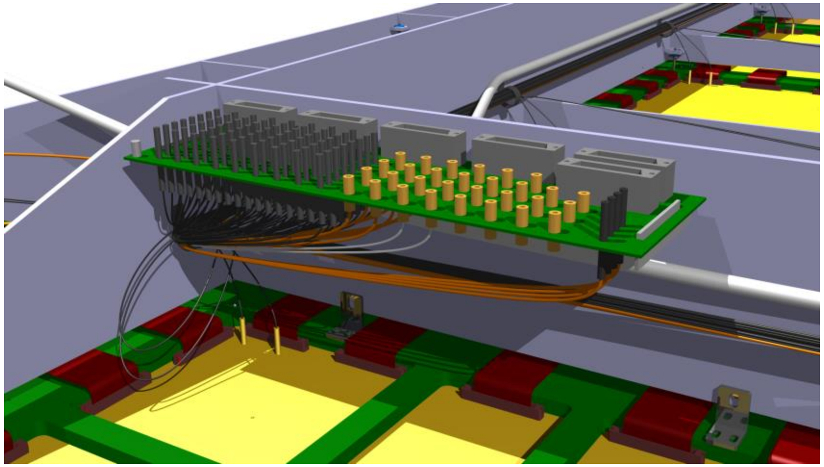
- 300 bridge per 9m2 module needed
  - Several options under consideration – see backup
- 600 KEL 8925E-068-179-F (receptacles to be crimped on cable)
- 720 KEL 8913-068E/R-178MS-A-F (smd connectors for anode)

Instrumentation - Patch Panels

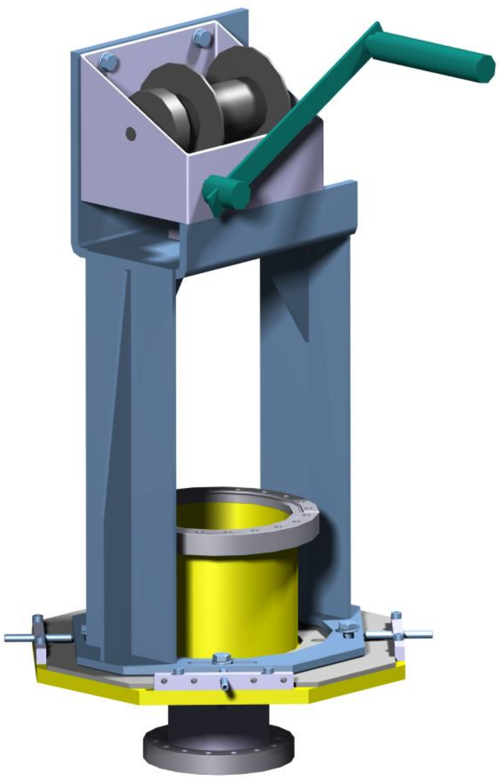
- 2 patch panels per 3x3m module
- Instrumentation from the module is connected first to Patch-Panel, then Patch-Panel to Cryostat
- Designed in collaboration with Confectronics
  - *Signal and HV panels separated*
  - *Special Macor connector for HV*



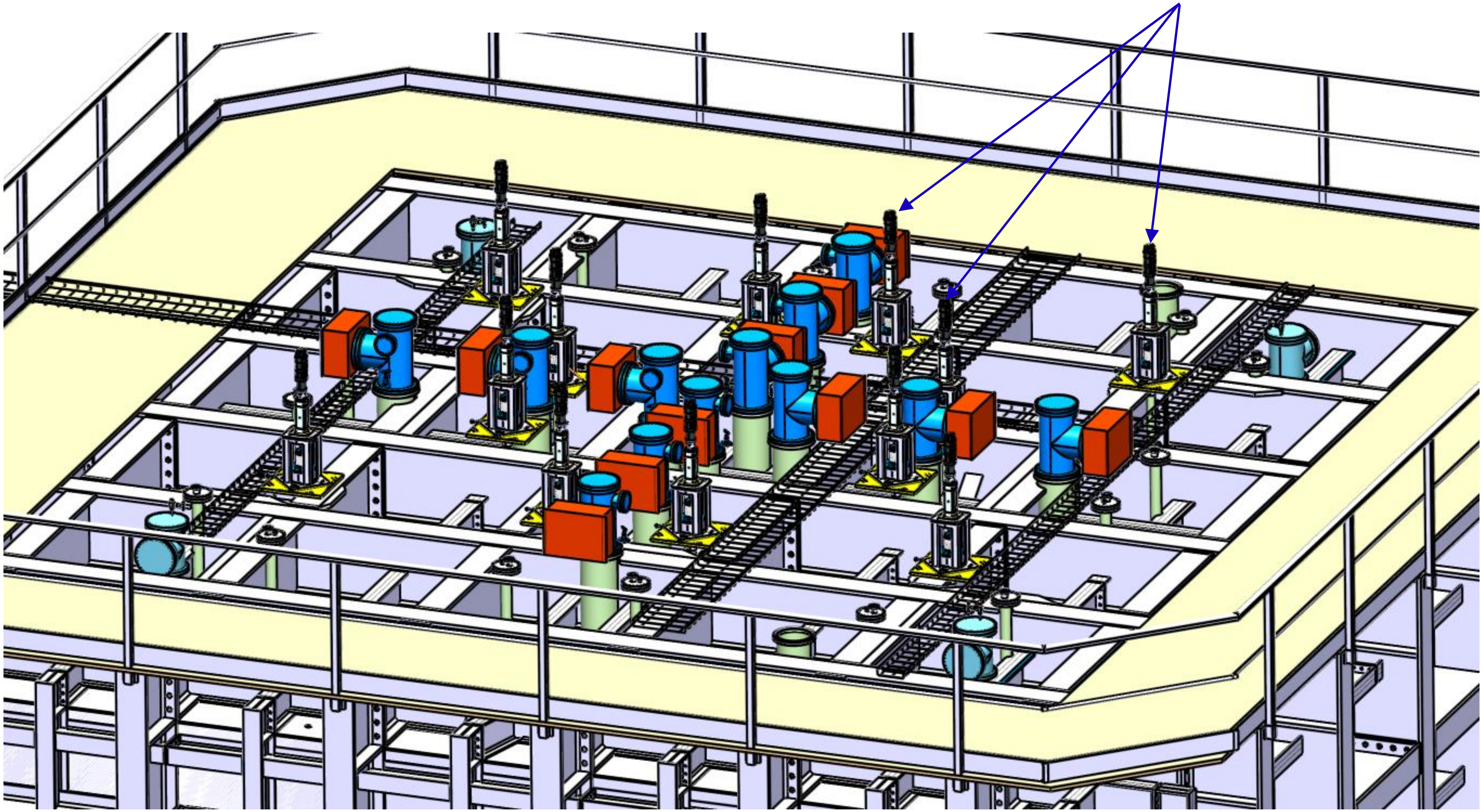




Suspension Feedthrough

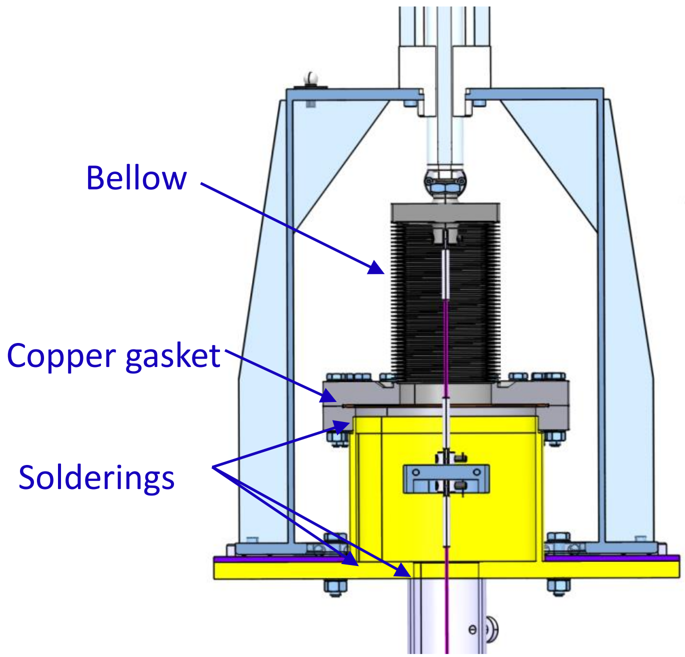


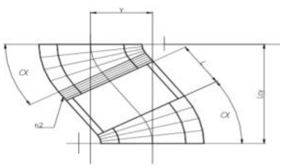
SPFTs on detector's roof

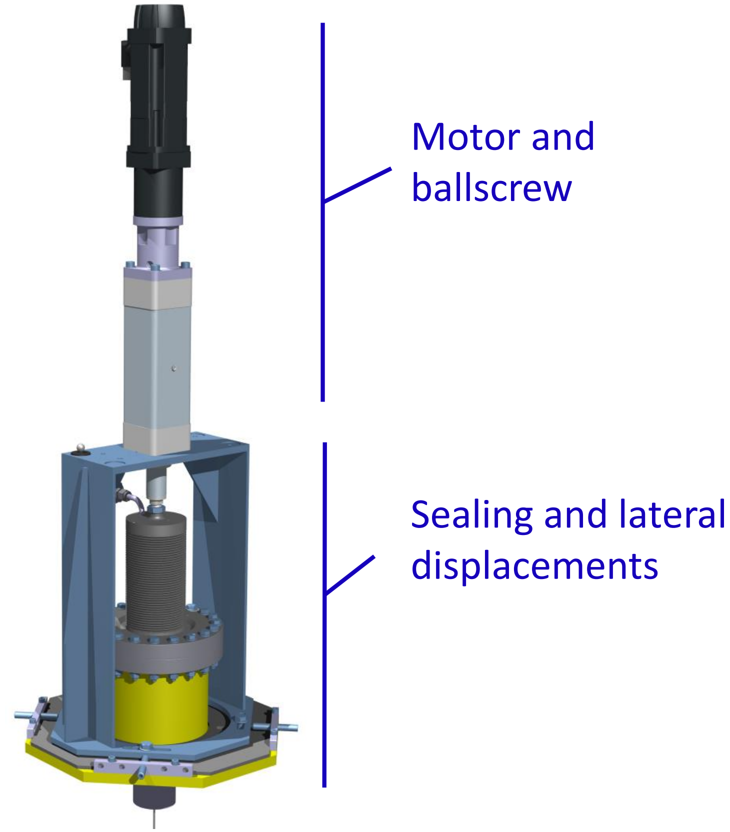


Design & features – Overview

- GAr volume completely closed
  - *no sliding parts,*
  - *no moving sealing*
- Movement absorbed by lateral deformation of the bellow







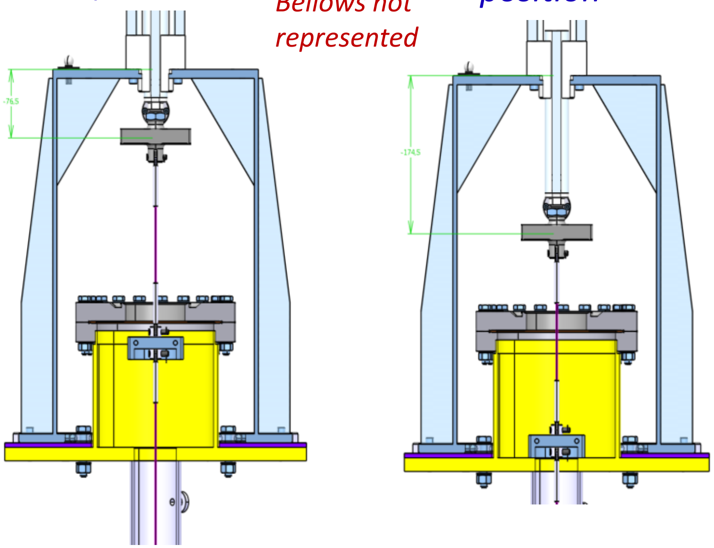
Design & Features – Vertical displacements

- Vertical stroke : **98mm**
  - *Even with max lateral displacement*
- Lateral stroke : **+/- 26mm**
  - *Displacement in a circle Ø52mm*

« High » position

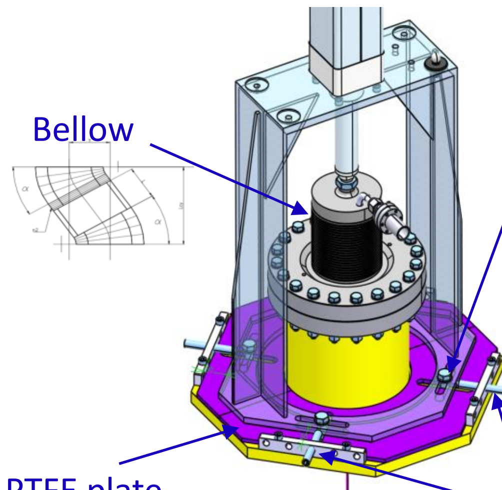
Bellows not represented

« Low » position



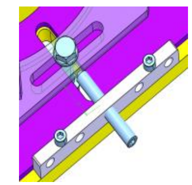
Bellow

Fixation screws

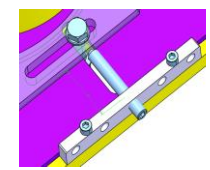


PTFE plate
(good sliding)

Screws for lateral displacements
(used hole can be changed to push in the right axis)



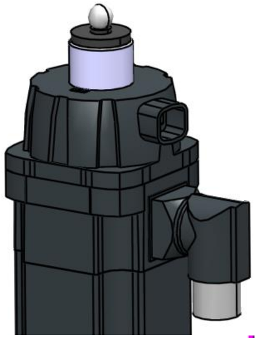
Centered



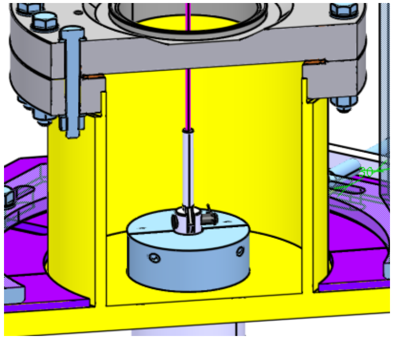
Off-centered

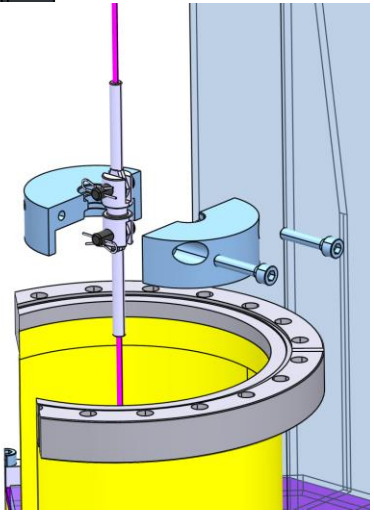
Design & Features – Additionnal features

- Special slot for Laser Tracker target
  - *SPFT position monitoring during installation*

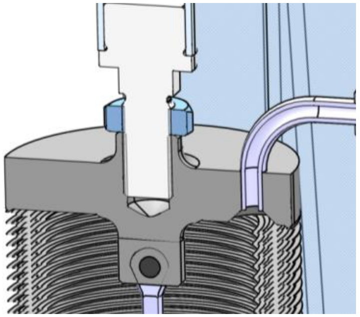


- Mechanical stop and chimney simple obstruction for maintenance or bellow replacement



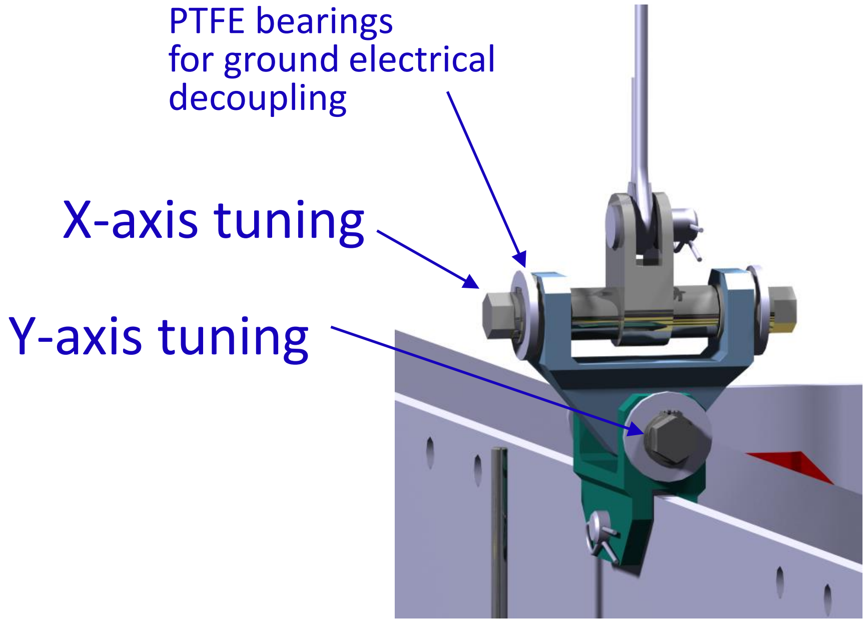


- Air purge at the highest point for best GAr purity



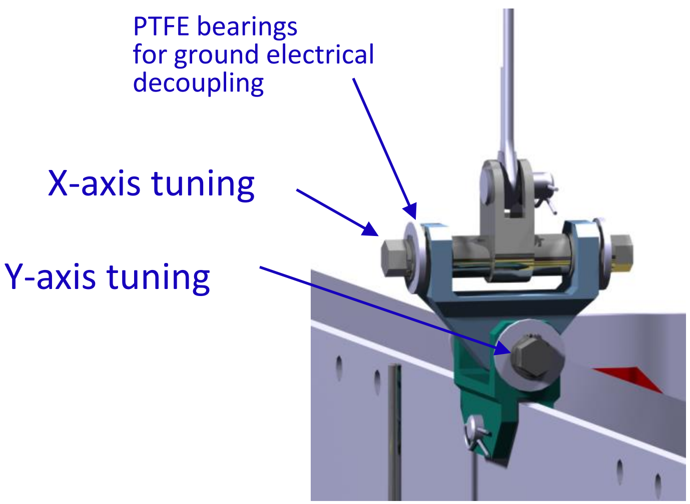
Suspension cables anchoring system

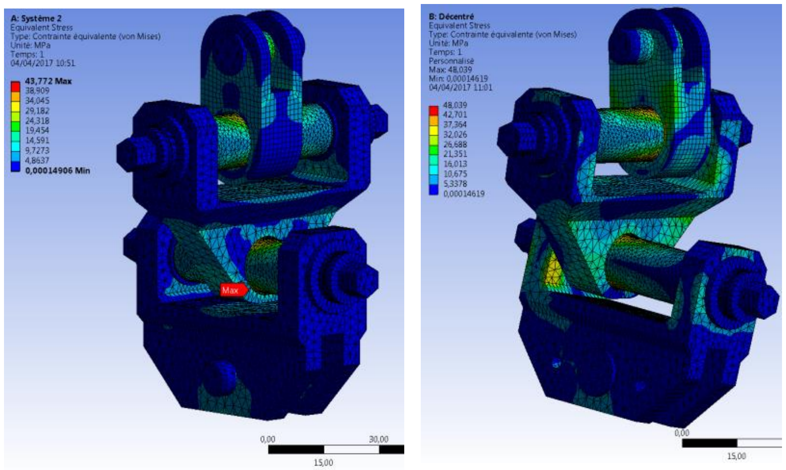
- In case of variation of the cryostat pipes verticality, this system allows to change anchoring point on module, in warm conditions
- In cold condition, this is done with SPFTs positions
- Those devices have been validated by FEA, and suspension cables are certified by manufacturer (see HSE report for more details)



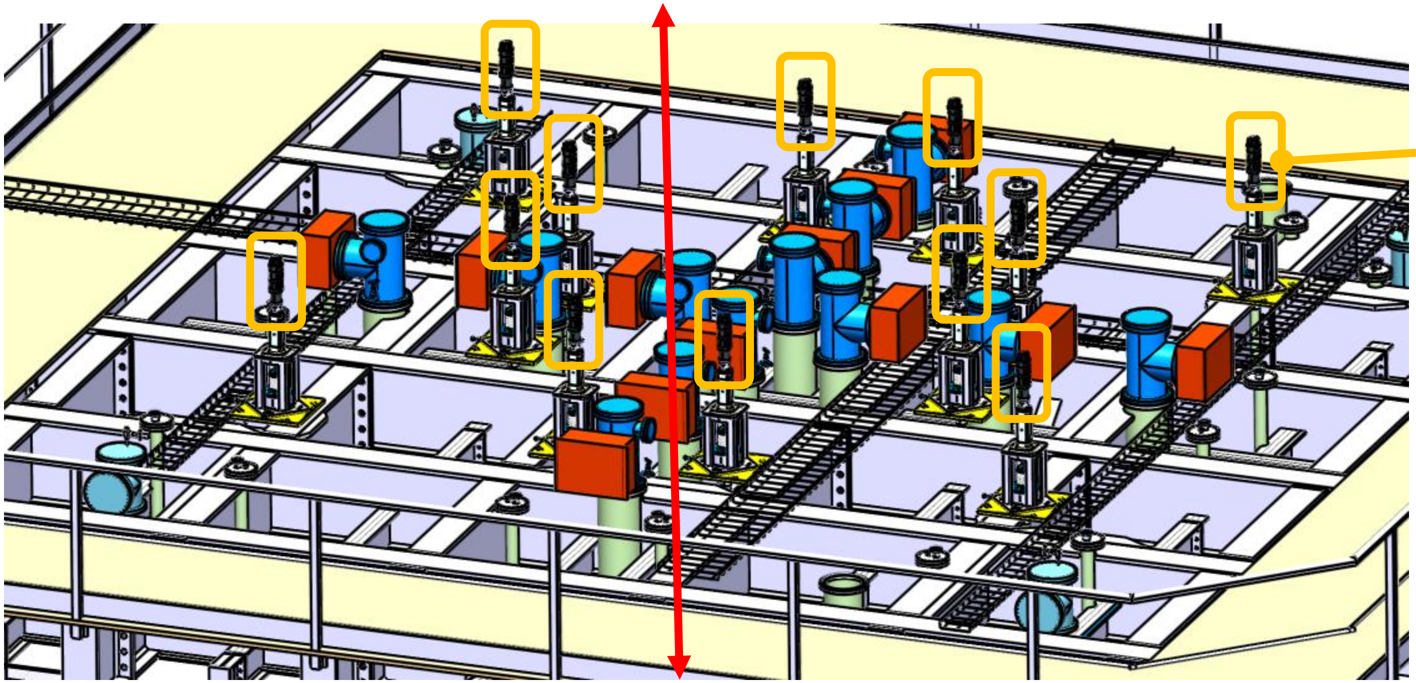
FEA Calculation Procedure

- Each non-standard device is validated by FEA calculation
  - Material properties from trusted sources
    - *Use of Rp0,2*
  - Boundary conditions :
    - *for suspended loads, (total mass+10%) is taken in account*
  - Operation configuration / Worst configuration
    - *Design is validated if the max stress is less than Rp0,2 with a safety factor of 5*
  - Details on FEA calculations are given in the HSE document





CRP Position Control : principle

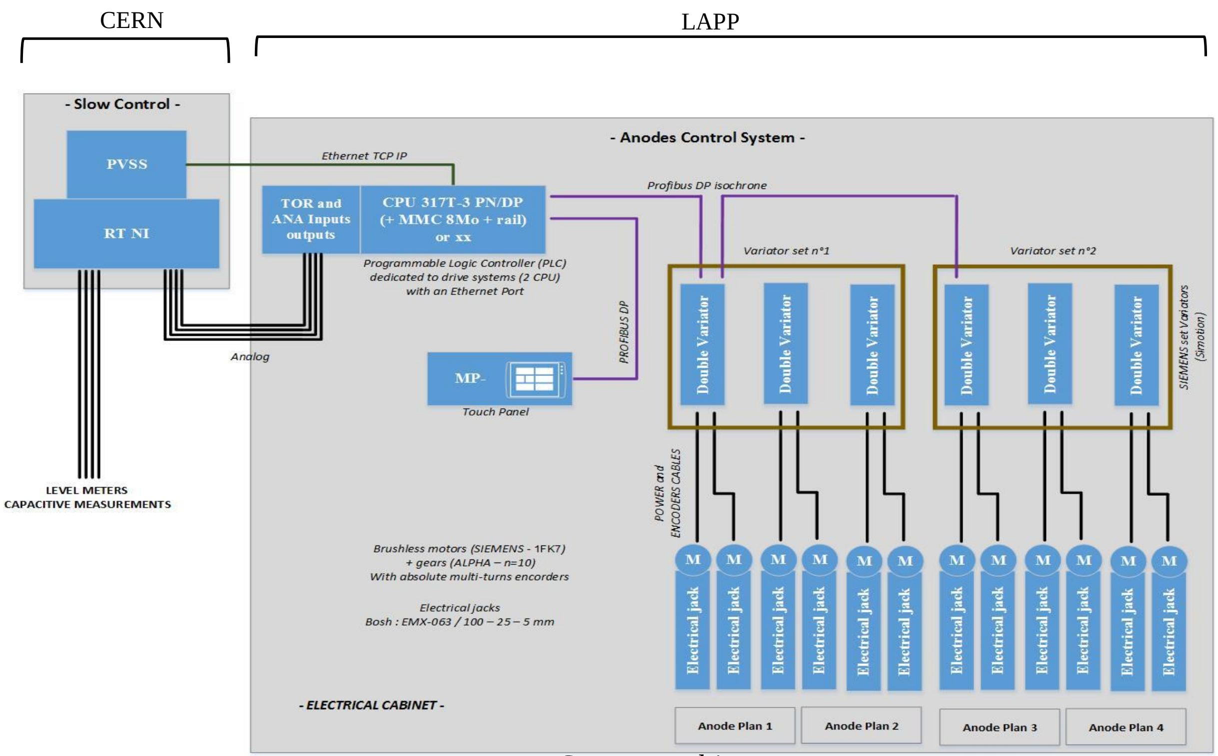


- Tuning:
  - Each motor could be controlled independently
- Process:
  - **Command of a virtual master axis : 1 command / whole system**
  - **The 12 motors (real axes) are the slaves of the virtual one**

- *Position of the CRP is measured by the motors encoders, the levels meters and the LEM capacitive measurements*
- *Nominal displacement of +/- 20 mm*

CRP Position control : integration

- Control architecture
  - *Extension of the 3x1m configuration / cabinet*



- System architecture -

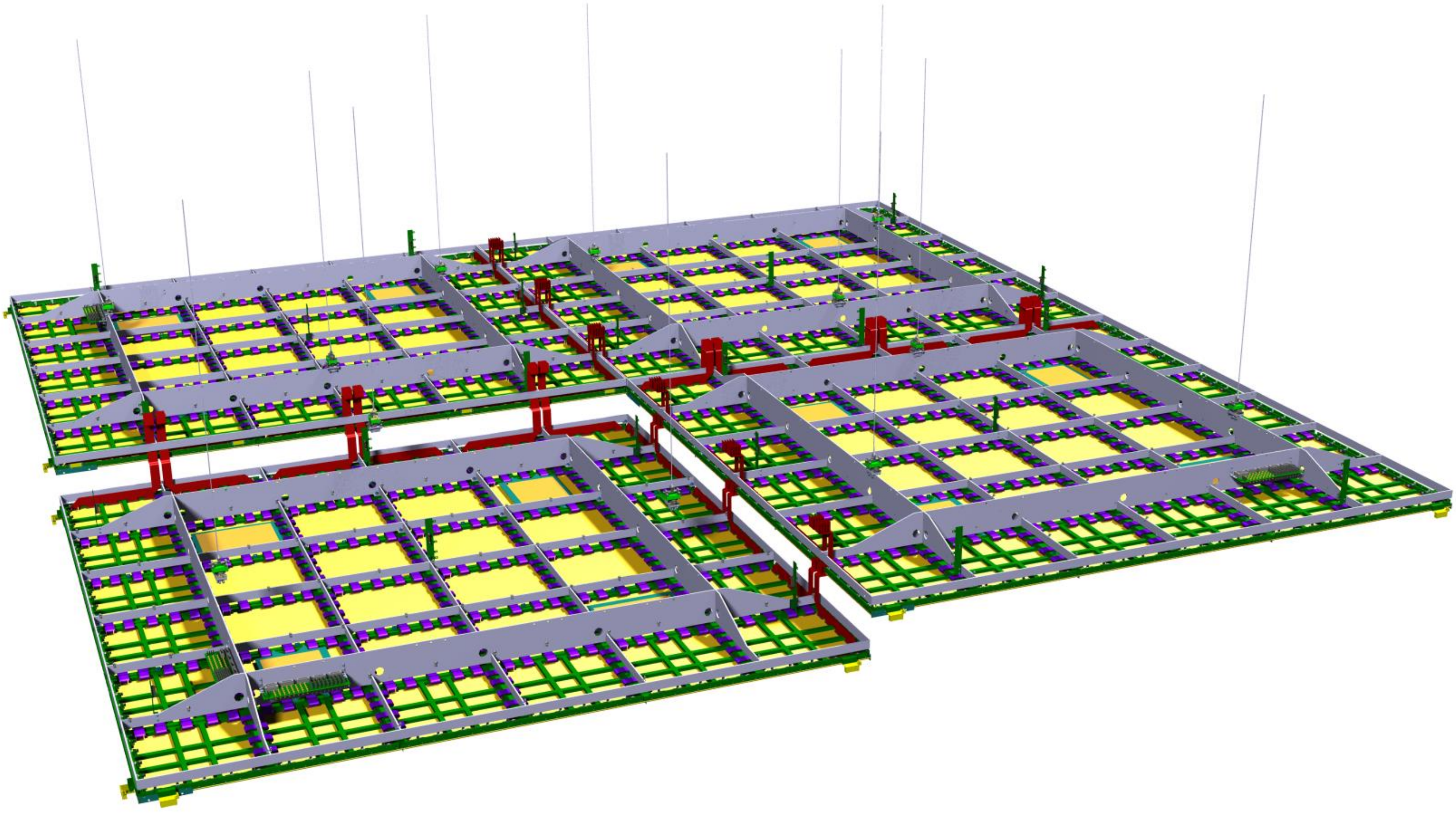
- Current 3x1m cabinet -

- ***Extension of PLC configuration vs the I/O quantity***
- ***Extension of variators configuration vs the additional motors***
- ***New Power supply processing***

- The 3x1m devices are kept and completed

- The rack will be extended (cabling on the two sides of the cabinet)

Thanks for your attention



Spare slides

Jumpers between LAS *- Alternative 1 for bridge*

ETH zürich WA105

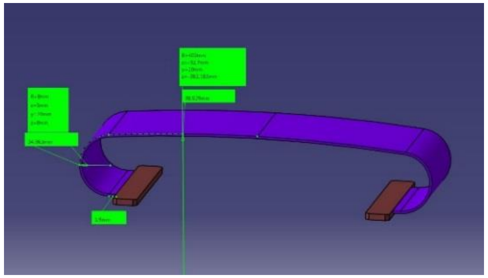
L03 FLAT RIBBON CABLE

PITCH: 0.635mm

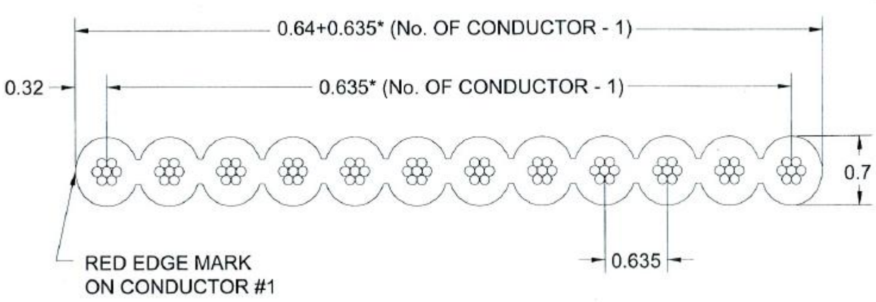
SPECIFICATIONS
UL File No. : E162690
UL Style : 2678
Operating Temperature : -20˚C to +105˚C
Flammability Rating : UL-VW-1
Voltage Rating : 150V

Physical
Insulation Material : Polyvinyl Chloride (PVC)
Conductor : #30AWG (7*0.102) Stranded Tinned Copper
Color : Grey With Red Edge

Electrical
Impedance : 75Ω (Unbalanced)
Capacitance : 22.5 pF/ft. 70 pF/m
Inductance: .317 uH/ft
Propagation Delay : 1.7 ns/ft.
Insulation Resistance : 1GΩ /M min.



+ CONNECTOR KEL 8925E-179F
2 CHF piece / 6-12 weeks delivery



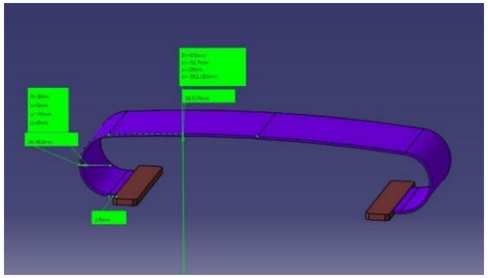
3.85 CHF/m / 12-14 weeks delivery

Assembly and electrical test possible here at CERN

LAPP

Jumpers between LAS *- Alternative 2 for bridge*

RADIATION SIGN : 5.3
CONDUCTOR : Tinned copper - 30 AWG multi. 7 x 0.102 mm (KLASING)
CROSS-SECTION 0.057 mm2
DISTANCE BETWEEN CONDUCTOR AXES : 0.635 mm
INSULATION : Polyolefine
SPECIFICATIONS : TEST VOLTAGE 250 V a.c.
OPERATING TEMPERATURE -50 to +105°C
RESISTANCE (D.C.) 354 Ohm/km
IMPEDANCE 110 Ohm
CAPACITANCE 60pF/m
RATED PROPAGATION TIME 4.10 ns/m
INDUCTANCE 0.85 µH/m
FIRE RESISTANCE : IEC 60332-1



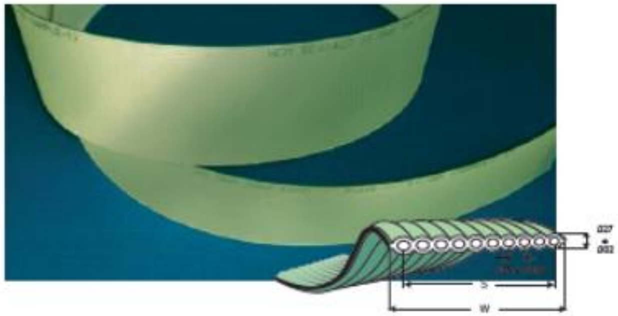
+ CONNECTOR KEL 8925E-179F
2 CHF piece / 6-12 weeks delivery

CERN Catalogue 04.21.21.068.4
8.1 CHF/m
Assembly and electrical test possible here at CERN

Sample to be tested for continuity in cold and outgassing

Jumpers between LAS - *Alternative 3 for bridge*

Solid Microzip Low Smoke Zero Halogen (LSZH) 0.025 inch (0.635 mm)



UL Style: 20930 (Pending)	CSA Style: AWM I A/B FT- 1
UL Voltage Rating: 30V	CSA Voltage Rating: 30V
UL Temp: 105°C	CSA Temp: 105°C

Pitch 025 (0.635 mm) ± 0.0016"
Low smoke zero halogen polyolefin thermoplastic
ECO friendly
APPLICATIONS Ultra ATA 33, 66, 100 and 133. Internal wiring of electronic equipment
REACH and RoHS 2 compliant

PHYSICAL CONSTRUCTION DESCRIPTION This Microzip consists of 30 AWG solid bare copper. Each leg of copper is pulled in parallel and fully extruded. A polarity stripe is co-extruded into position number one for easy identification. Color is green with black polarity.

Pitch: 0.025 in (0.635 mm)

- XX - P - 00YYY
- Conductor AWG: 30 1/30 AWG BC
- Insulation: LSZH
- Conductor Resistance ohms/1000 ft (ohms/Km): 104 (341.12)
- Capacitance Ground-Signal (G-S) pF/ft (pF/m): 12.5 (41.01)
  - (G-S-G) pF/ft (pF/m): 22.0 (72.17)
- Impedance (G-S-G) SE - Single End: 80 ohms
  - (G-S) Differential: 130 ohms
- Propagation Delay Nanoseconds/ft (ns/m): 1.60 (5.25)
  Maximum Skew ns/ft (ns/m): 0.060 (0.196)

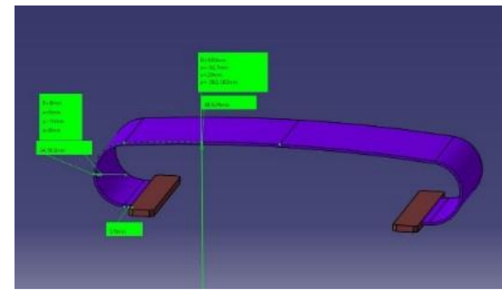
Other conductor counts and put-ups available upon request. All data is for reference only and is subject to change.

	Part Number	# of Conductors	Put-Up	Width "W" Span "S"
Example 1	68 - P - 00400	68	400 ft 121.92 m	Width: 1.700 in (43.18 mm) Span" 1.675 in (42.54 mm)
Example 2	80 - P - 00400	60	400 ft 121.92 m	Width: 1.500 in (38.10 mm) Span: 1.475 in (37.46 mm)

Building a Part Number

Part Number Format	XX - P - 00YYY	XX	00YYY	Width: XX * .050 in Span: XX* .050 in - .050

XX= No. of conductors: other conductor counts available upon request
YYY = Put-Up (ft): 400



+ CONNECTOR KEL 8925E-179F
2 CHF piece / 6-12 weeks delivery

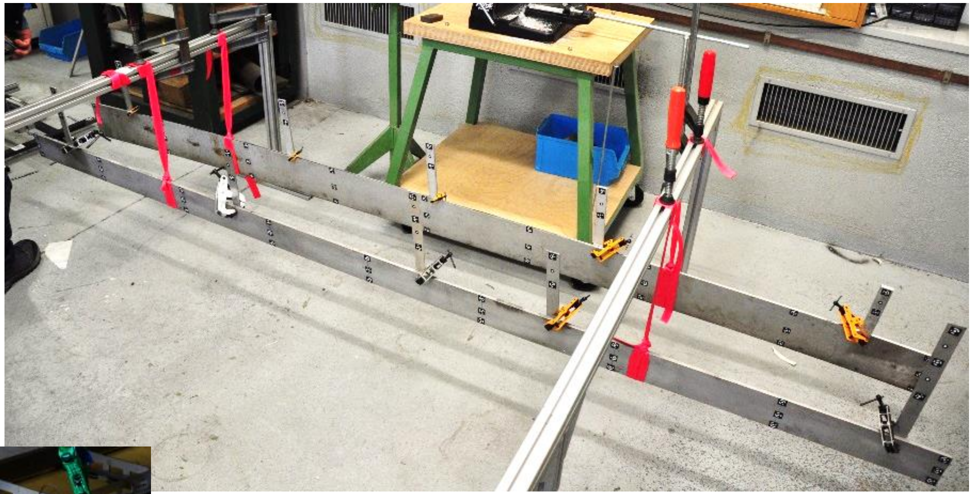
Minimum order 2 Km , 12.7 CHF/m / 12-14 weeks delivery

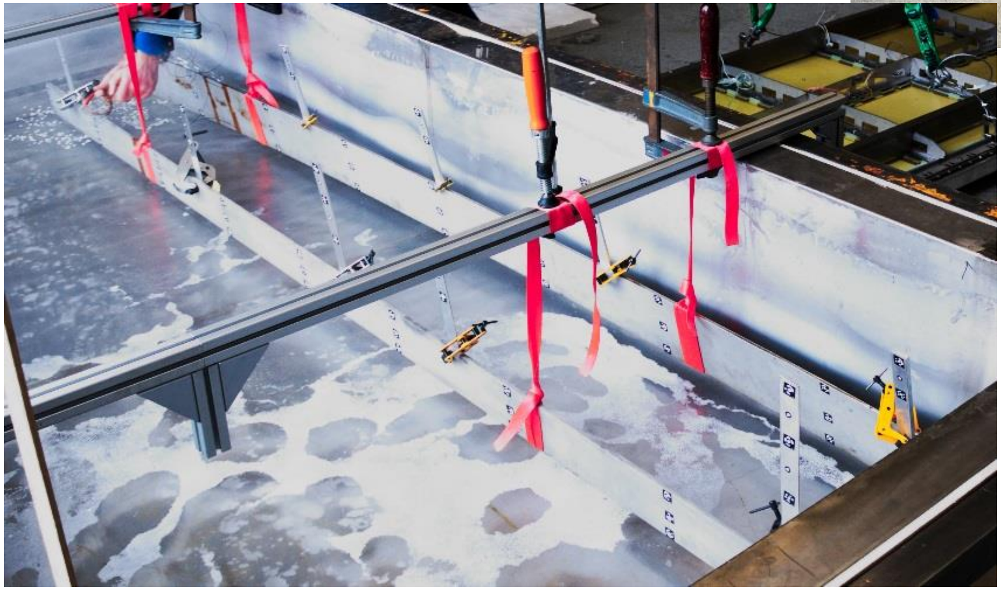
Why invar?

Thermal shrinkage Real tests on Stainless Steel plates

Stainless Steel plates above the 3x1 Argon bath

(Measurements by Dirk in photogrammetry)

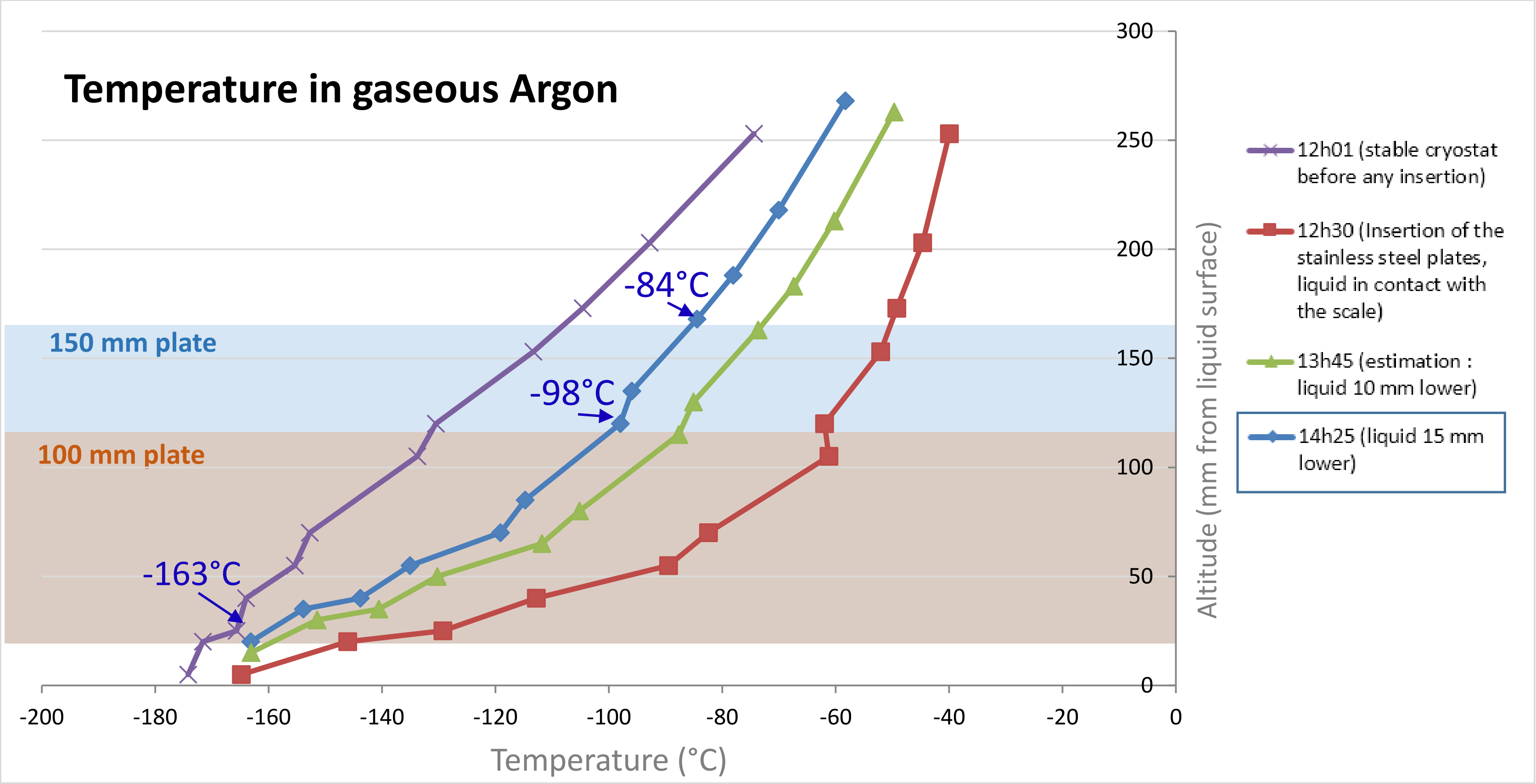




Thermal shrinkage *Temperatures in gaseous Argon*

Temperatures **in gaseous Argon** around the plates (@ 14h25) :

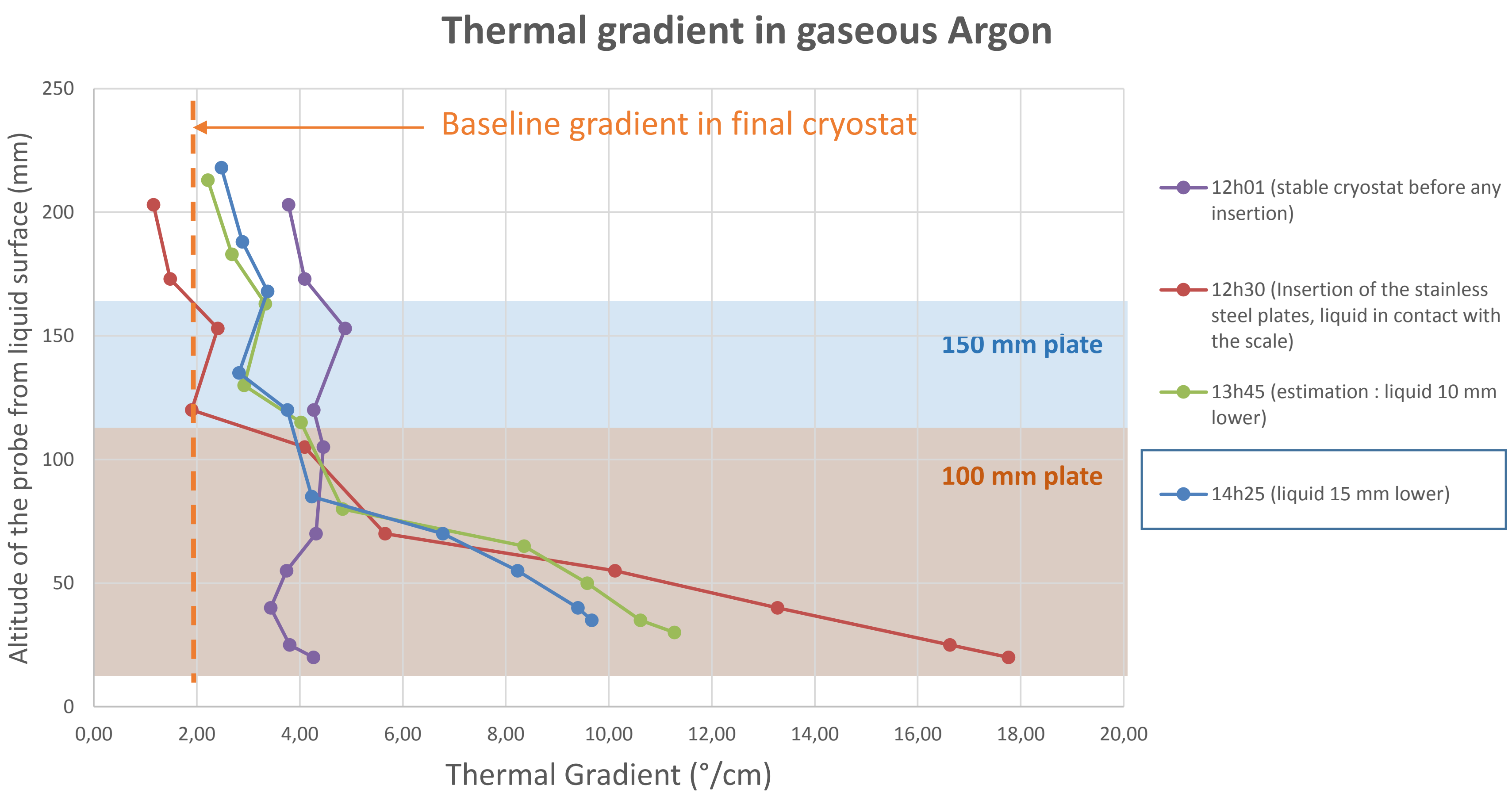
- ***100 mm plate*** **:** *Bottom = -163°C, Top = -98°C , ΔT : 65° (GAr)*
- ***150 mm plate :*** *Bottom = -163°C, Top = -84°C , ΔT : 79° (GAr)*



Thermal shrinkage *Thermal gradient in gaseous Argon*

Thermal gradient **in gaseous Argon** around the plates (@14h25):

- ***100 mm plate :*** *4 - 10 °/cm (in GAr)*
- ***150 mm plate :*** *3 - 10 °/cm (in GAr)*

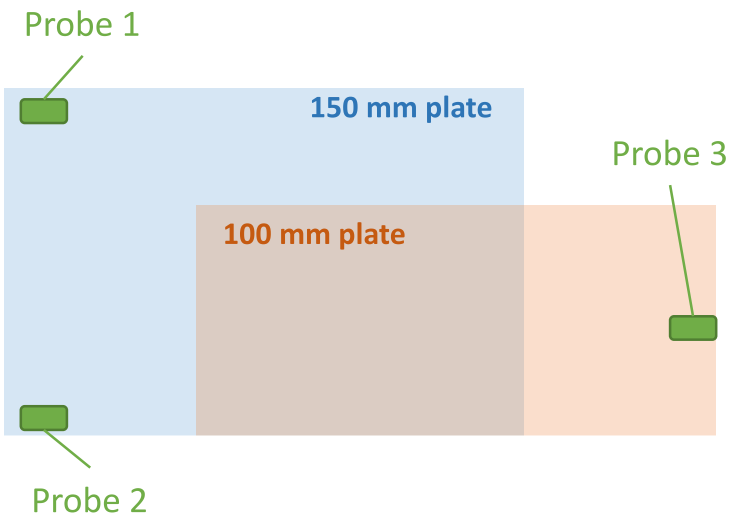


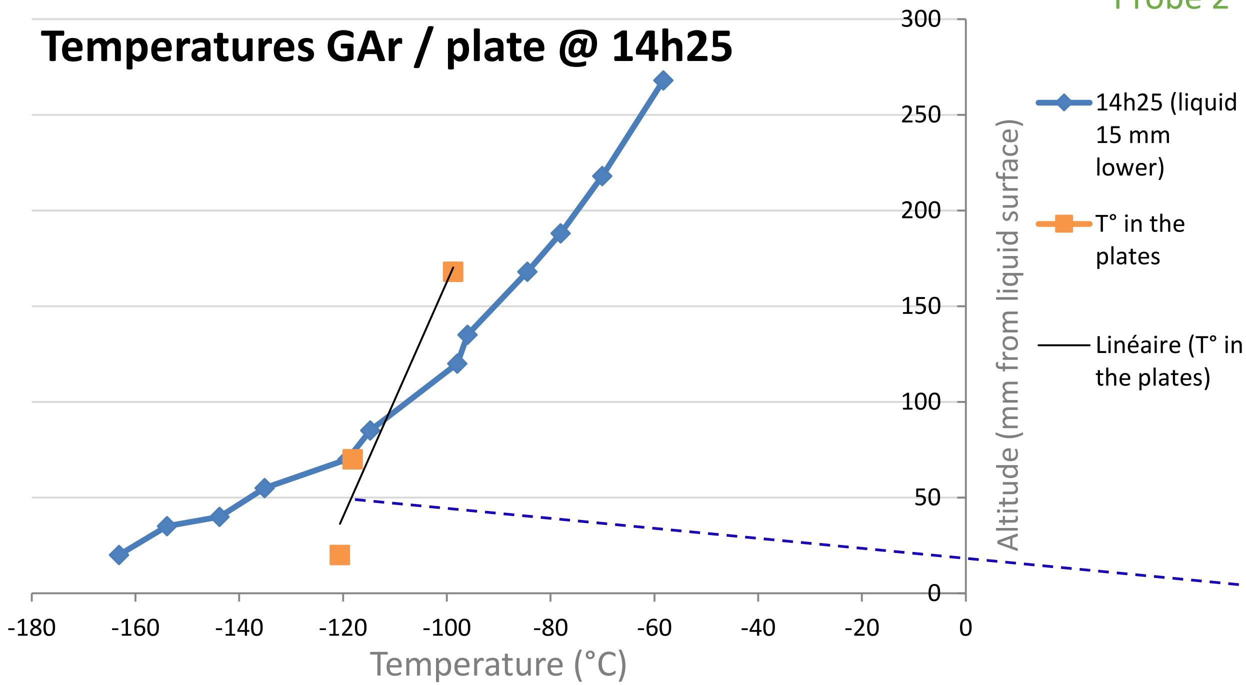
Thermal gradient in the plates

Temperatures **in the plates** (@14h25) :

(*With three PT100 probes)*

- ***Probe 1 :*** *-98,75°C*
- ***Probe 2 :*** *-120,6°C*
- ***Probe 3 :*** *-118,10°C*



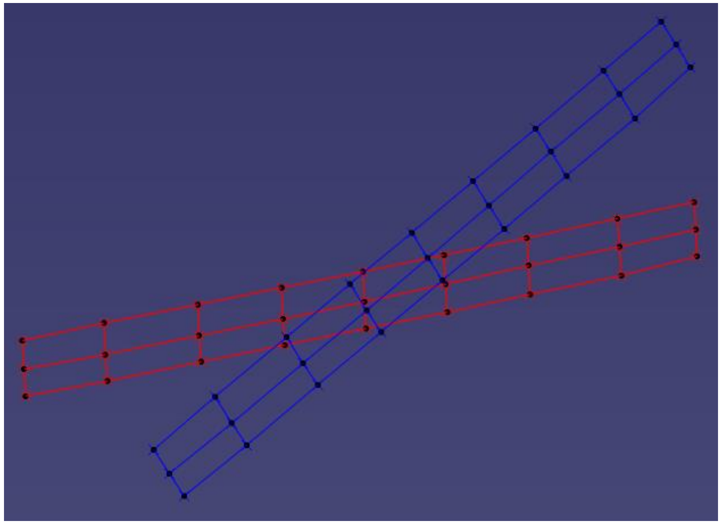


Remarks :

- Temperatures measured **on the surface of the plate**
- No special care taken to insure probe quality measurements (glueing?)

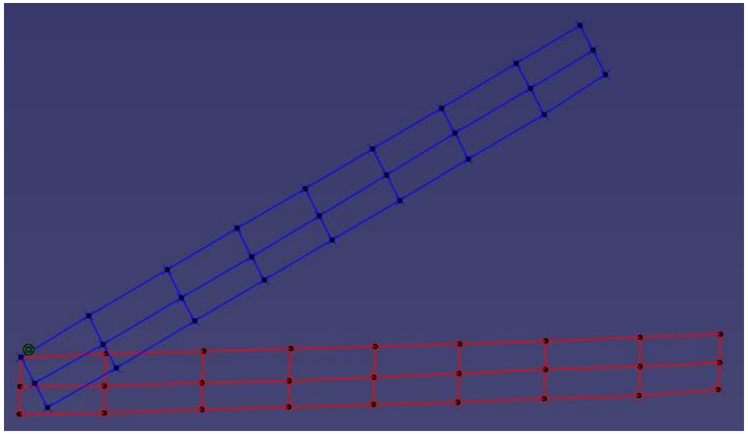
- *Average gradient in the plate : ~ 1,5°/cm*

Thermal shrinking : Photogrammetry results – Model constraints



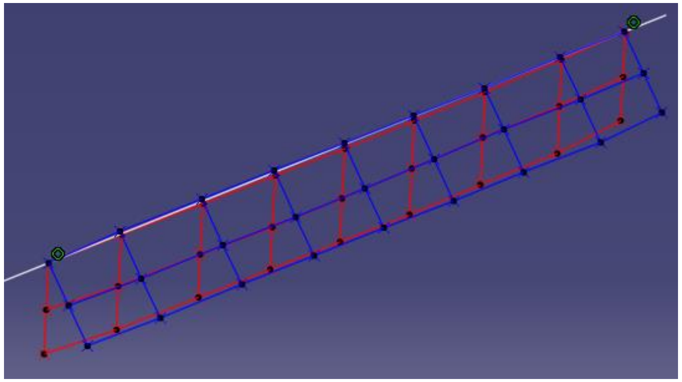
- Photogrammetry provides two clouds of points
- How to superpose clouds for measurements ?

➢ Red (warm measurement) is the reference.

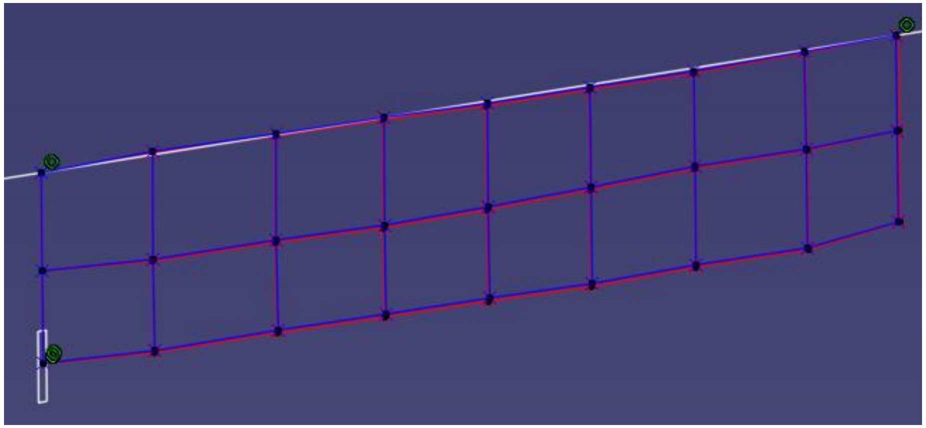


- First, a corner is fixed.

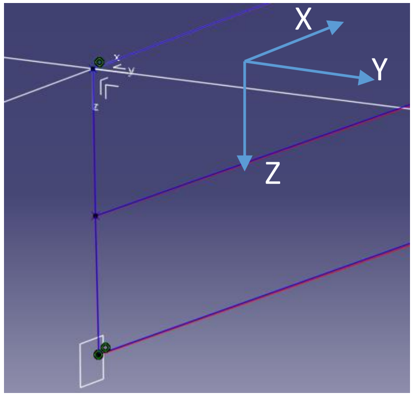
Thermal shrinking : Photogrammetry results – Model constraints



- Then, a line between upper corners

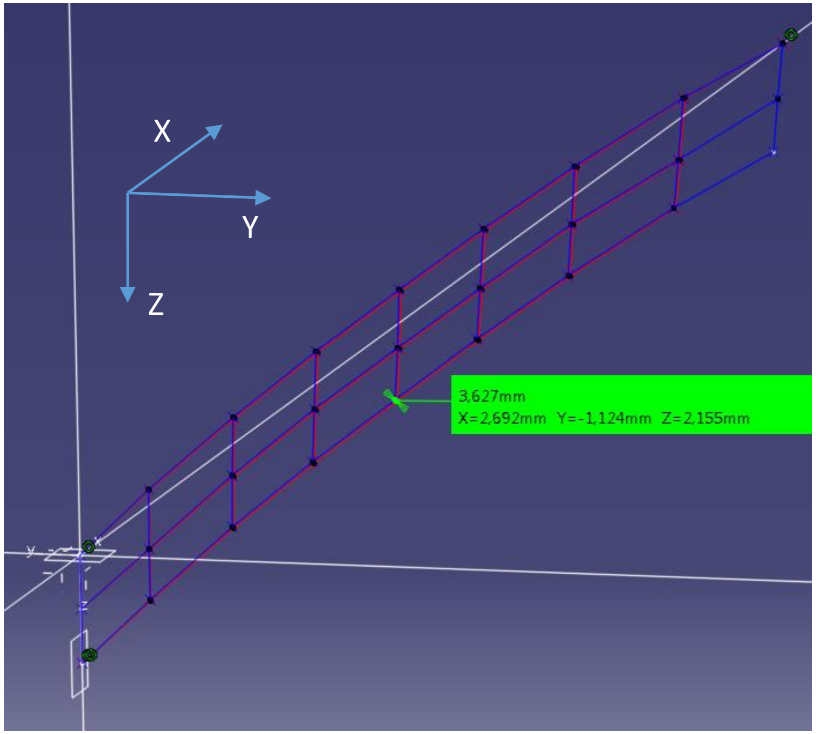


- Finally, the rotation is locked by a third point on a plane
  - *(plane defined by previous line + bottom corner point)*



- Results are given in this coordinate system

Thermal shrinking : Photogrammetry results – Large plate 150 mm



- First : The plate is bended
- Displacements from warm to cold, (at the middle bottom point) :
  - *ΔX = 2,69 mm*
  - *ΔY = - 1,124 mm*
  - *ΔZ = 2,155 mm*

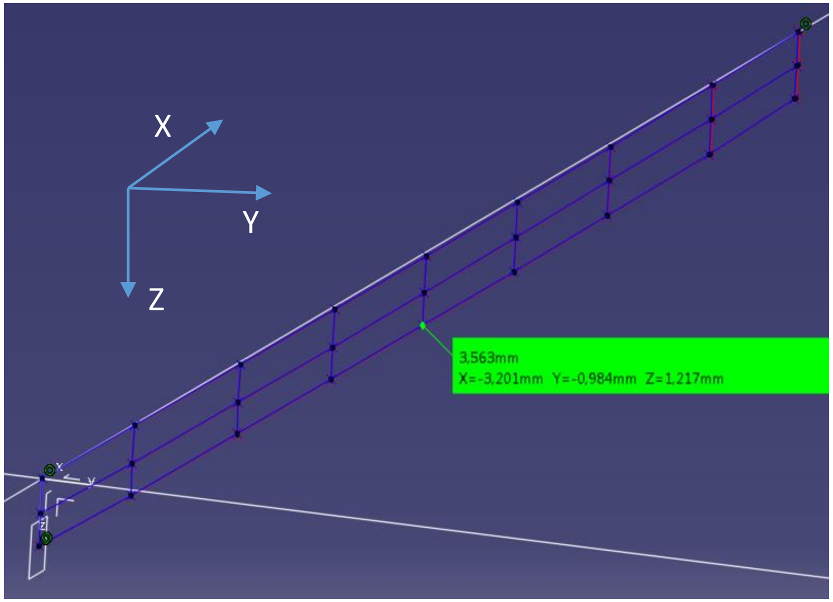
More than 4x the spec

Photogrammetry precision :
+/-0,1 @ one sigma along X
+/-0,05 @ one sigma along YZ

- *ΔX comes from the longitudinal contraction of Stainless Steel => OK **with NIST***
- *ΔY comes from a bending amplification => Unknown gas flow? radiation?*
- *ΔZ comes from thermal gradient in the structure => Ok but less than expected*

⚠

Thermal shrinking : Photogrammetry results – Small plate 100 mm



- The plate is slightly bended
- Displacements from warm to cold, (at the middle bottom point) :
  - *ΔX = 3,201 mm*
  - *ΔY = - 0,98 mm*
  - *ΔZ = 1,217 mm*

More than 2x the spec

Photogrammetry precision :
+/-0,1 @ one sigma along X
+/-0,05 @ one sigma along YZ

- *ΔX comes from the longitudinal contraction of Stainless Steel => OK **with NIST***
- *ΔY comes from a bending amplification => Unknown gas flow? radiation?*
- *ΔZ comes from thermal gradient in the structure => Ok but less than expected*

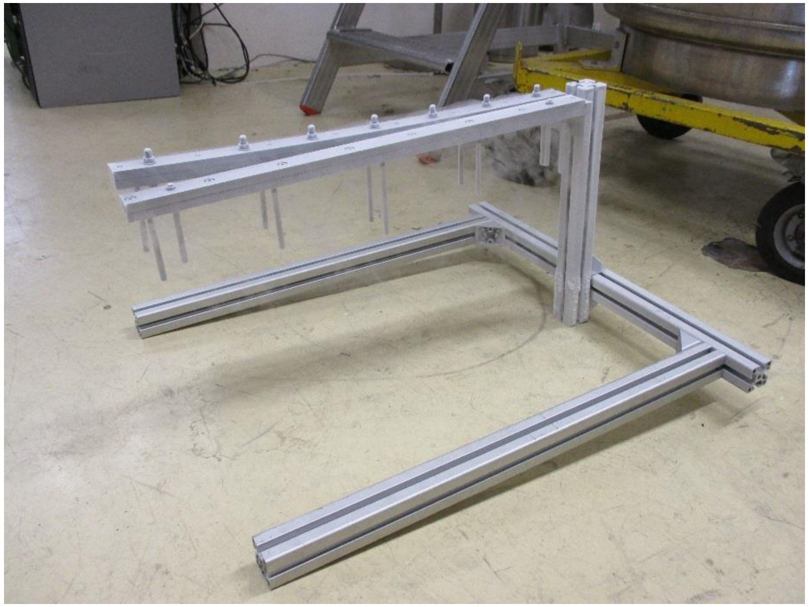
⚠

Invar oxydation studies

INVAR part

INVAR part from cryo decoupling test

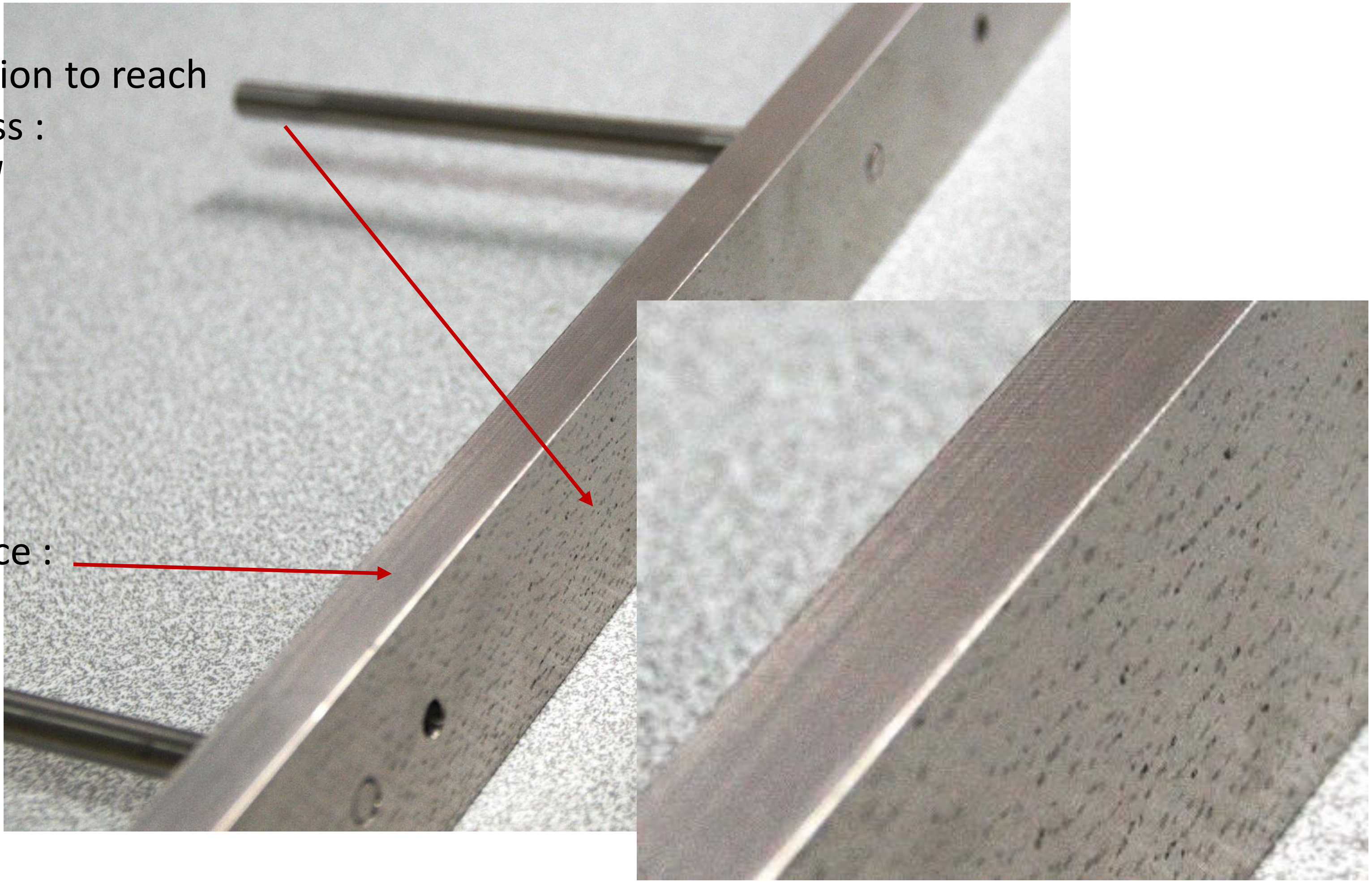
- *Two thermal cycles in liquid Argon/Nitrogen*
- *No storage precaution*
- *Stored for 6 months*



Design overview

Slight rectification to reach 10mm thickness :

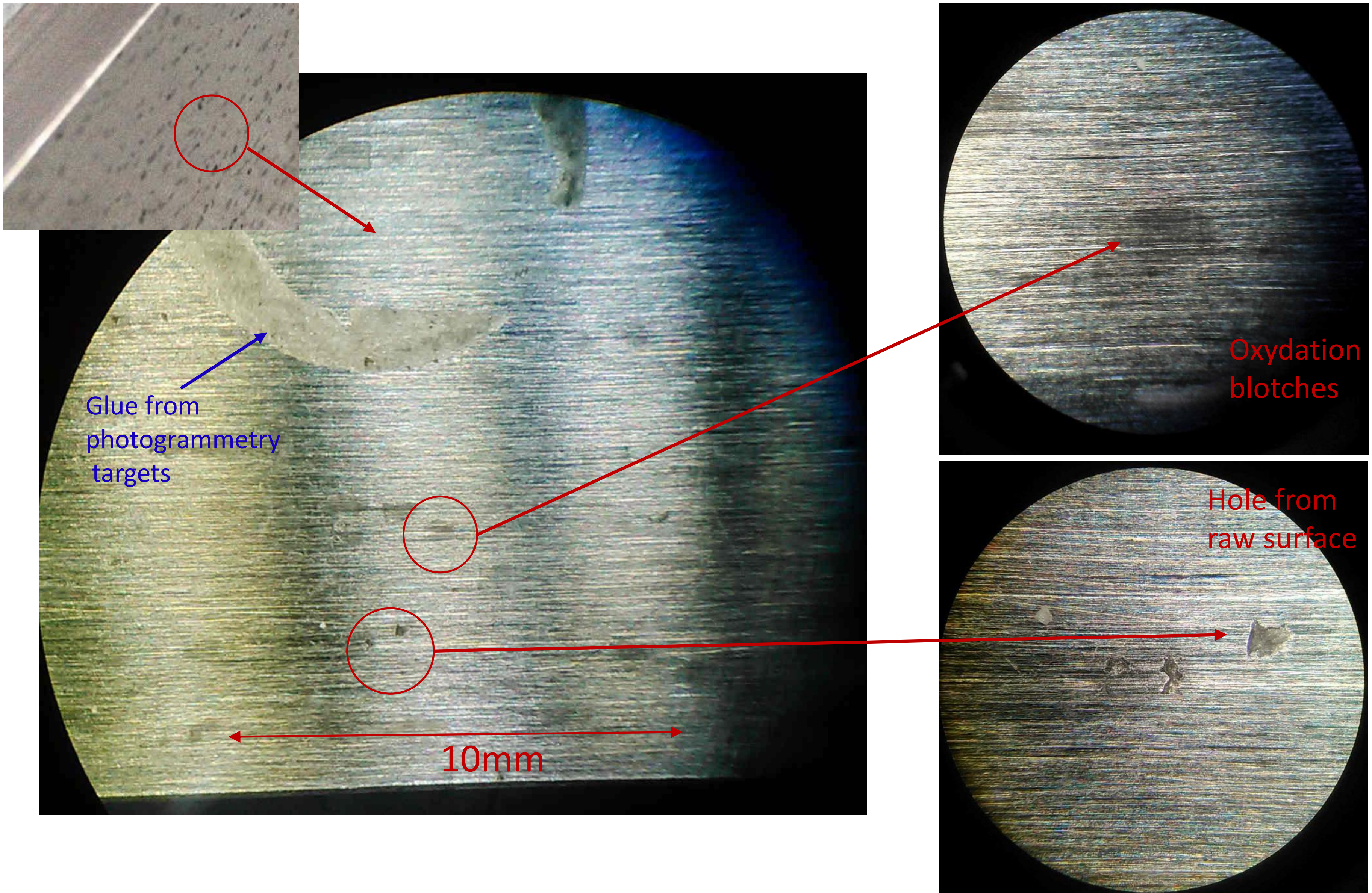
Slightly oxydated



Machined face :

No oxydation

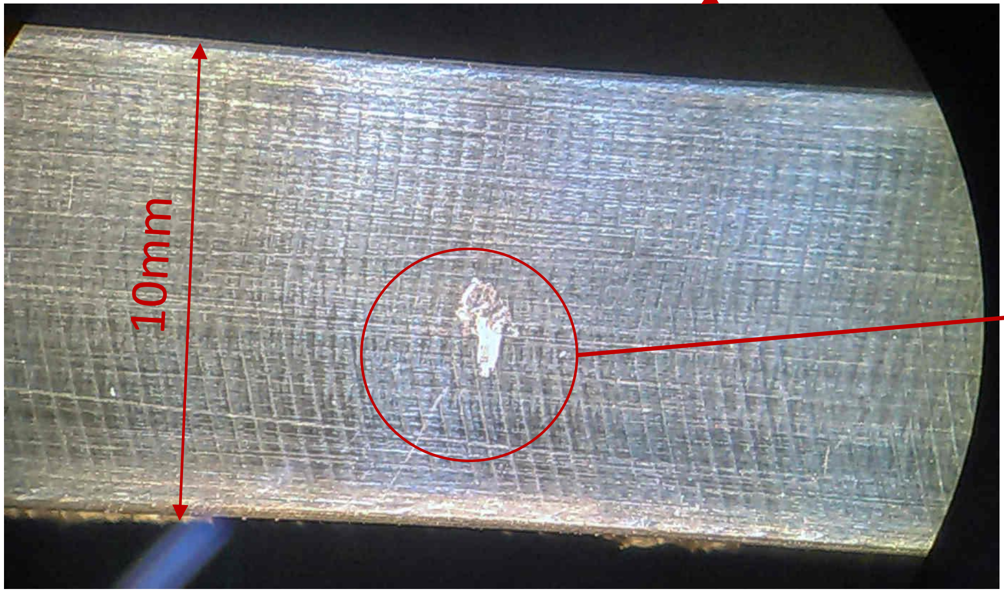
Rectified face (from a block, not from a plate)

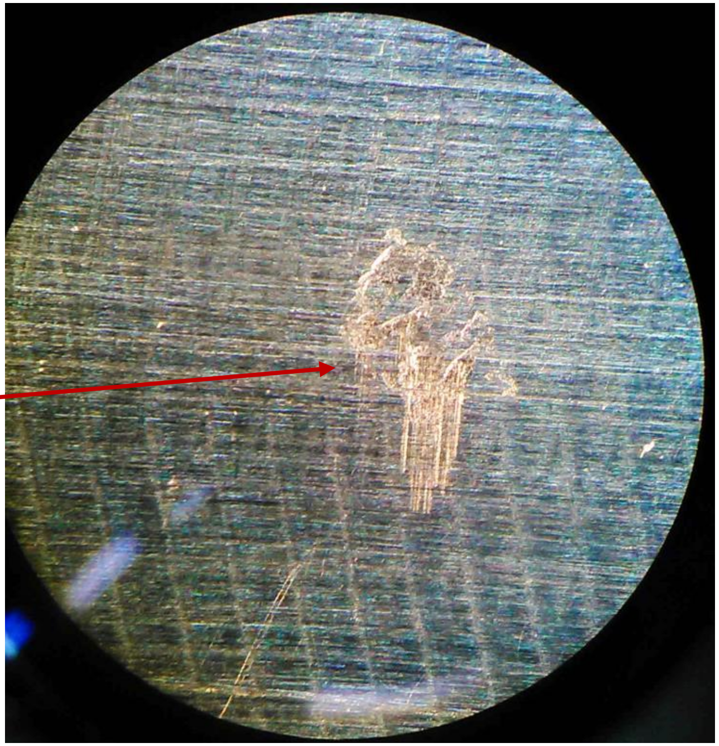


Machined face (from a block, not from a plate)

No trace of oxydation noticed on the machined face

➢ *Even no oxydation in the scratches*





Machined face (from a block, not from a plate)

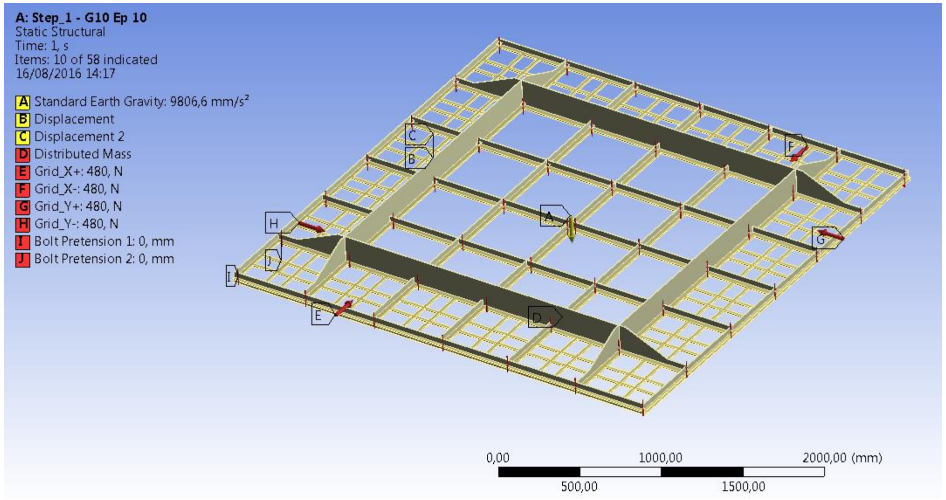
- Invar frame will be made from rectified plates
  - shallower « holes » on the surface, and deeper rectifying than previous test

- Even with no precaution storage, no special oxydation observed.

- Final frame will be rectified, assembled, welded, washed and stored in special plastic cover with dessicant to absorb humidity and avoid oxydation.

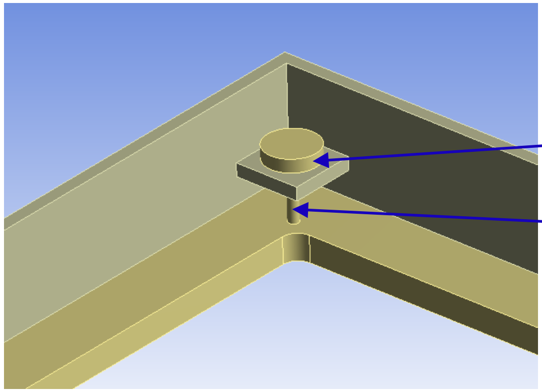
CRP Planarity and wires tension modeling

Initial geometry



INVAR Frame :

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



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

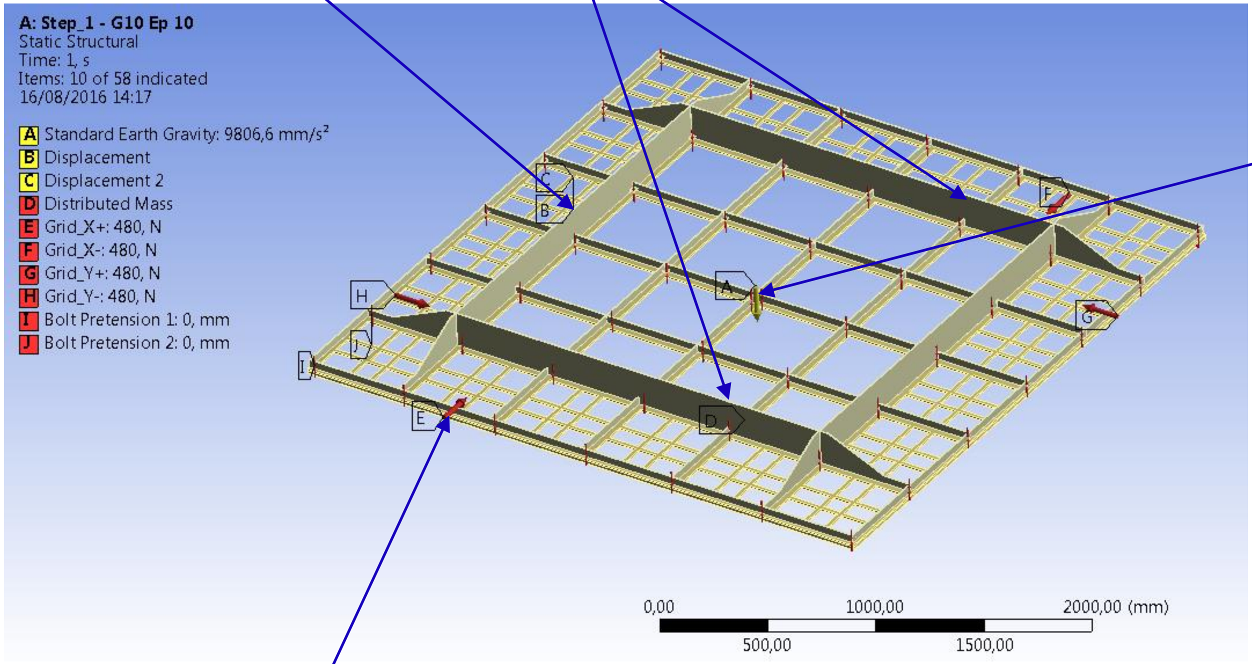
➢ Stainless Steel properties (Extraction grid) :

- 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



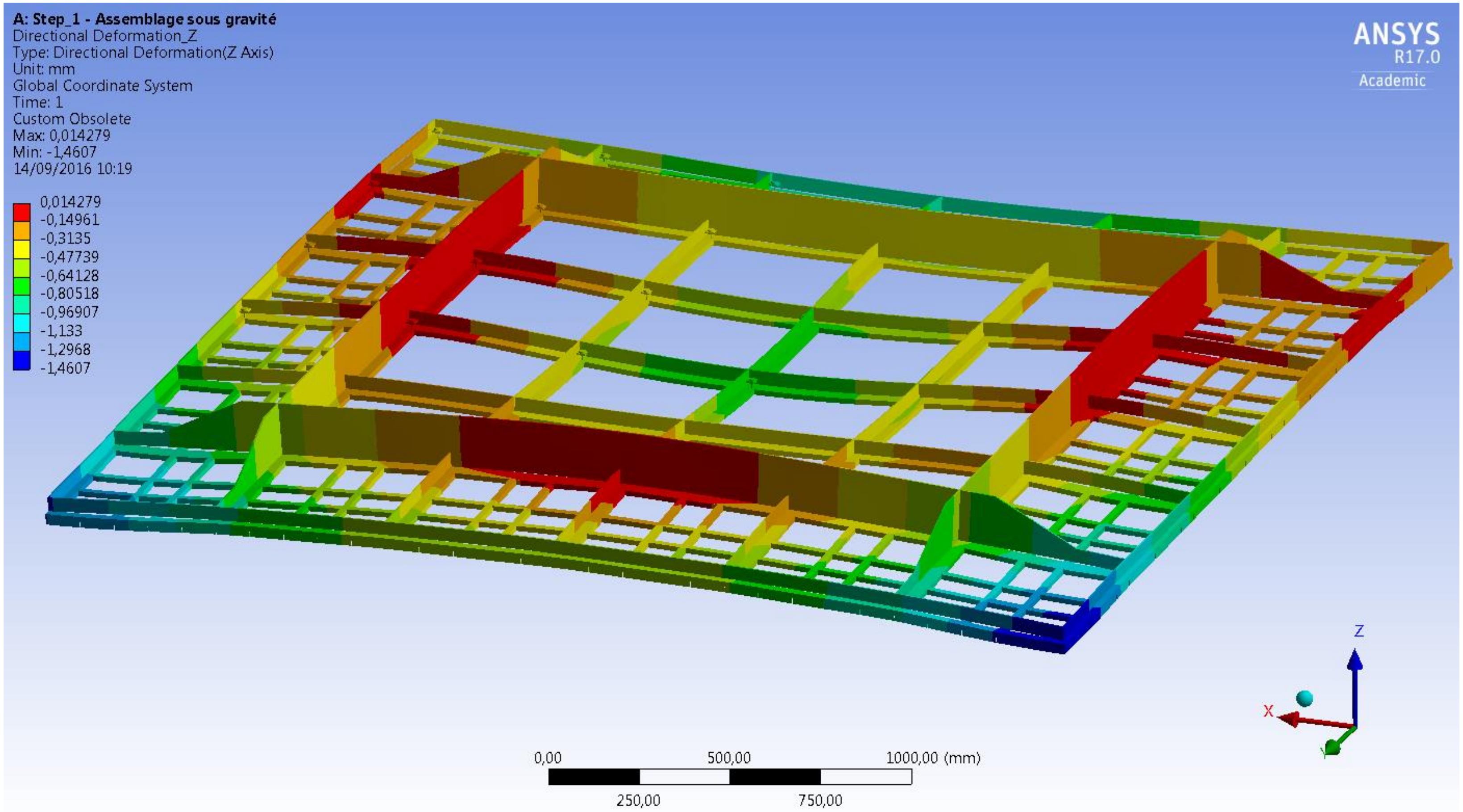
G10 and Invar locked on this point

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



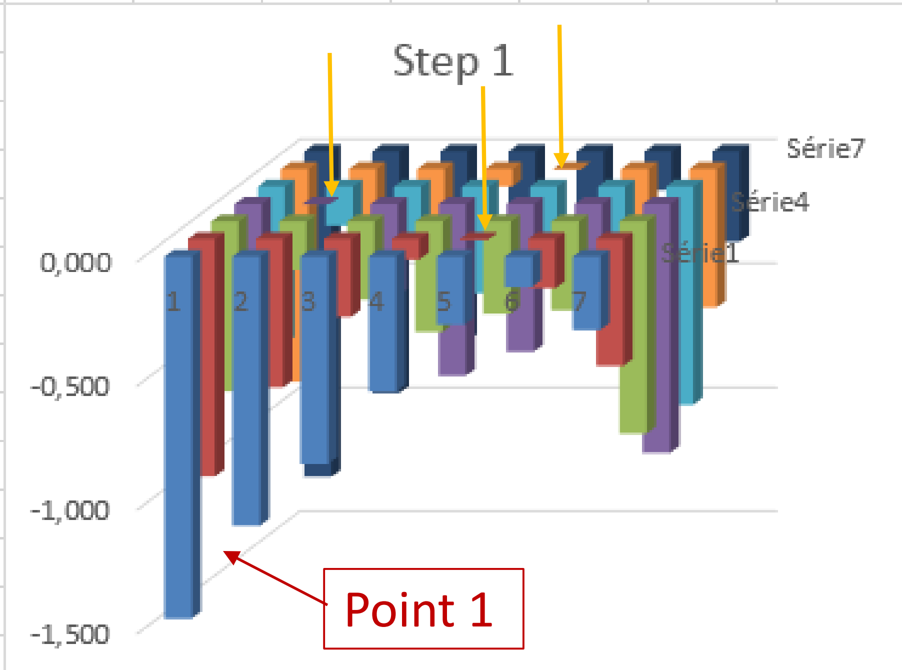
Loading case :

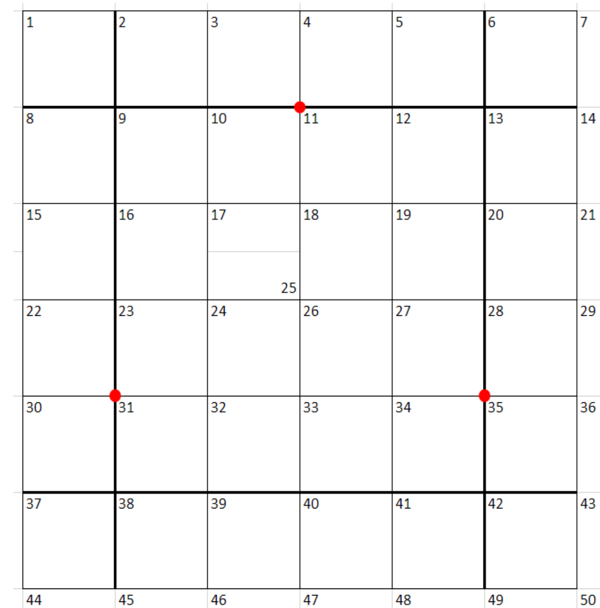
- Gravity
- No Grid tension : grid installed but not tightened

G10 Planarity results for step 1 – Tension init 1 mm

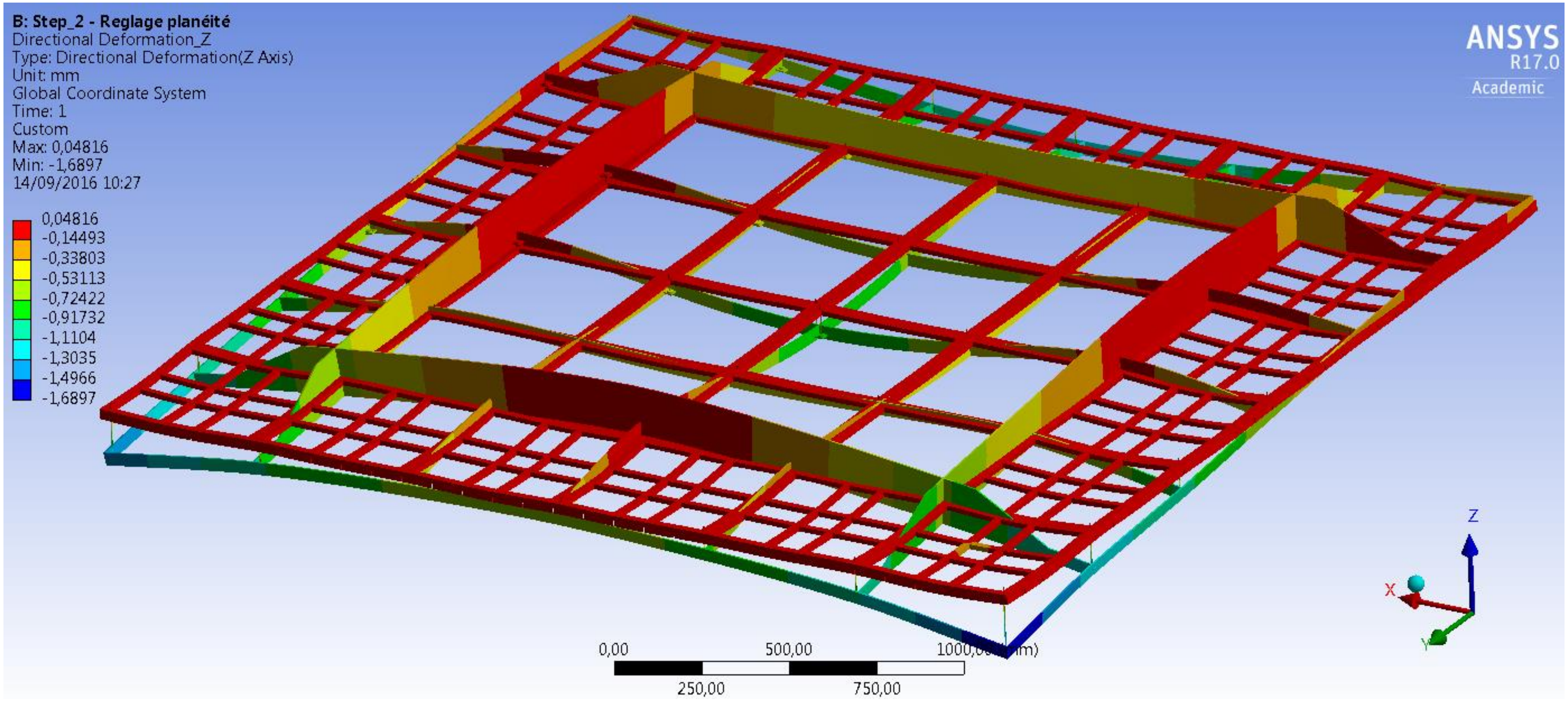
-1,460	-1,086	-0,837	-0,544	-0,276	-0,122	-0,297
-0,957	-0,598	-0,314	-0,083	-0,005	-0,198	-0,512
-0,685	-0,194	-0,315	-0,445	-0,372	-0,358	-0,855
-0,570	-0,002	-0,370	-0,693	-0,596	-0,433	-1,004
-0,635	-0,158	-0,291	-0,432	-0,372	-0,370	-0,880
-0,858	-0,524	-0,265	-0,070	-0,004	-0,221	-0,559
-1,312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



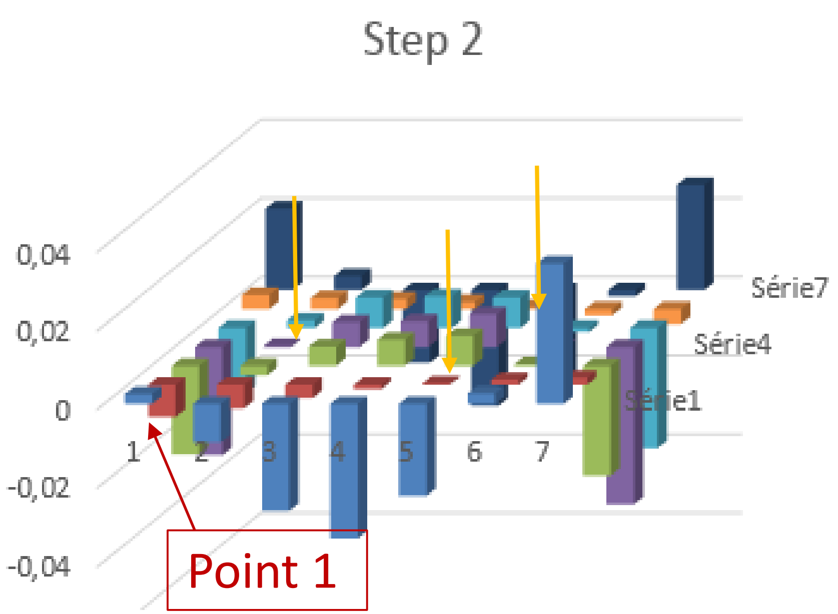
Loading case :

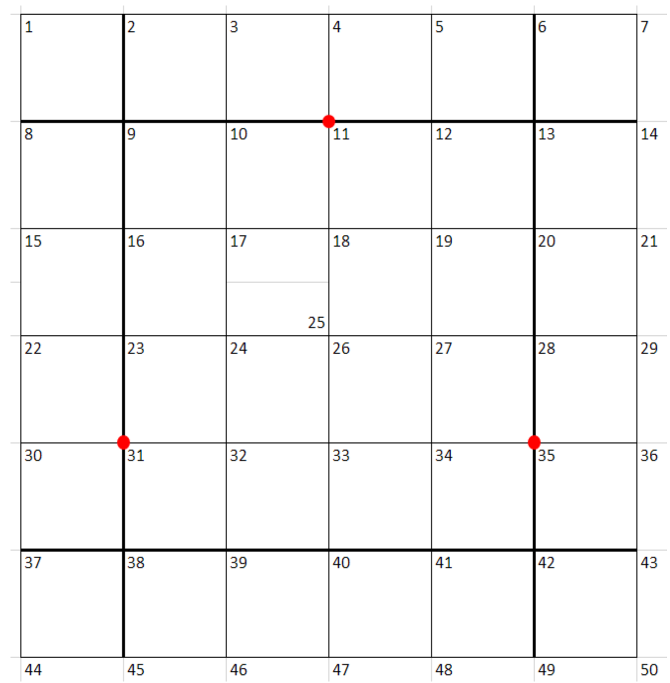
- Gravity
- No Grid tension : grid installed but not tightened
- Planarity tuning

G10 Planarity results for step 2 (2nd tuning iteration) – Tension init 1 mm

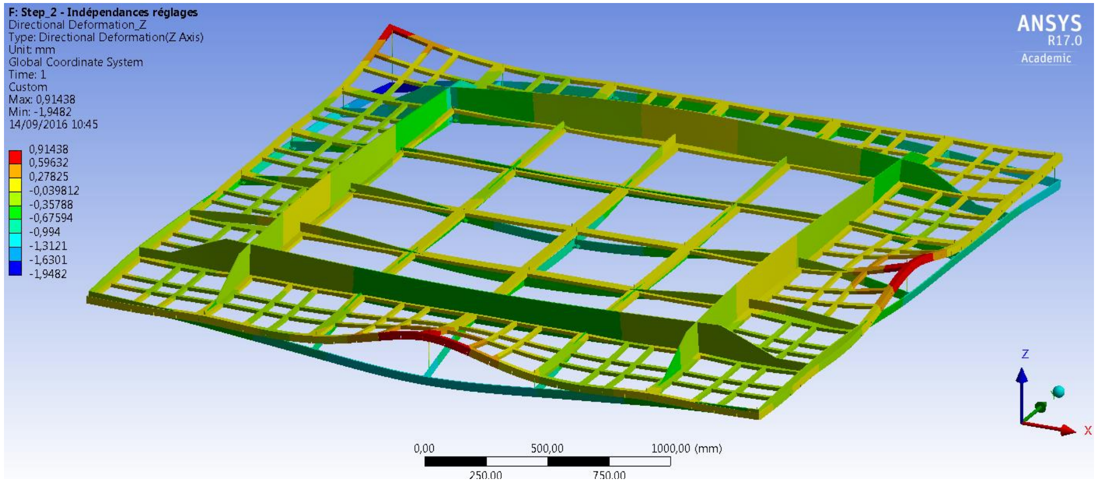
0,0025	-0,01	-0,027	-0,034	-0,023	0,0027	0,0357
-0,008	-0,006	-0,003	-0,001	0,0004	0,0013	0,0018
-0,022	-0,002	0,0049	0,0067	0,0076	0,0004	-0,028
-0,027	0,0003	0,0063	0,0065	0,0083	-3E-04	-0,04
-0,017	0,0019	0,0077	0,008	0,0077	-0,001	-0,031
0,0036	0,0028	0,0025	0,0018	0,0005	-0,002	-0,004
0,0207	0,0035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

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

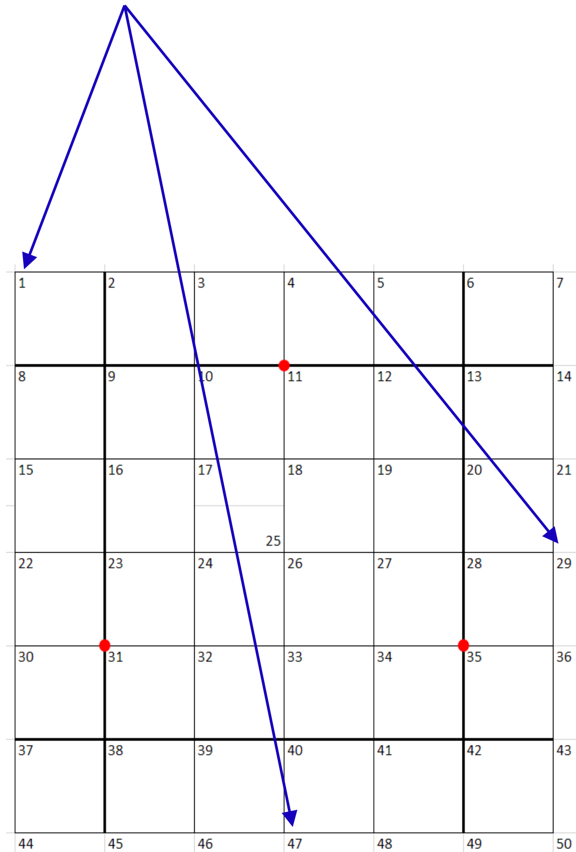




Planarity tuning independency



+1mm on those points



Loading case :

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

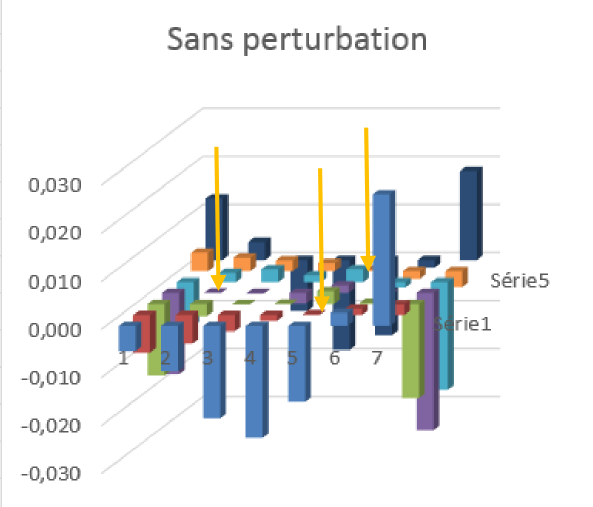
- +1mm perturbations on points 1 - 29 - 47

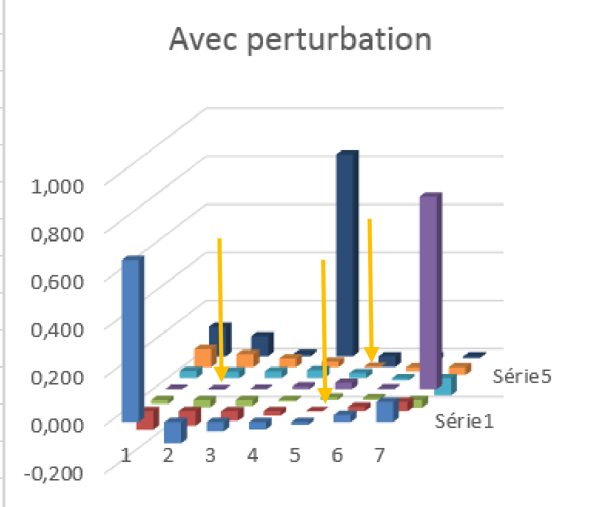
Planarity tuning independency

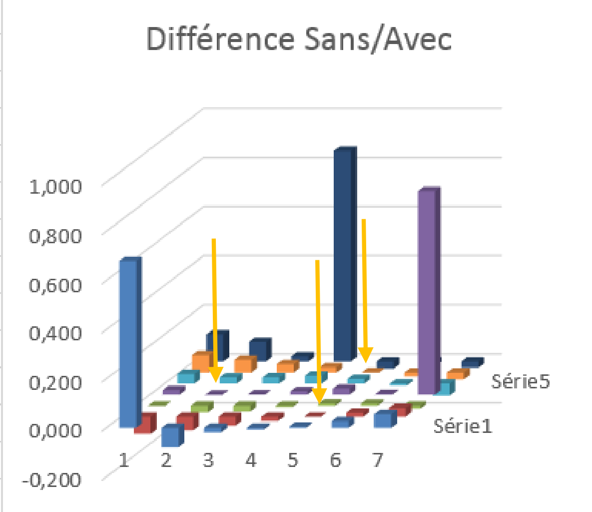
-0,005	-0,009	-0,019	-0,023	-0,016	0,003	0,027
-0,008	-0,006	-0,003	-0,001	0,000	0,001	0,002
-0,015	-0,003	0,000	0,000	0,003	0,000	-0,020
-0,017	0,000	0,000	-0,002	0,002	-0,001	-0,029
-0,009	0,002	0,003	0,001	0,003	-0,001	-0,022
0,004	0,003	0,002	0,002	0,000	-0,002	-0,003
0,013	0,004	-0,011	-0,019	-0,016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

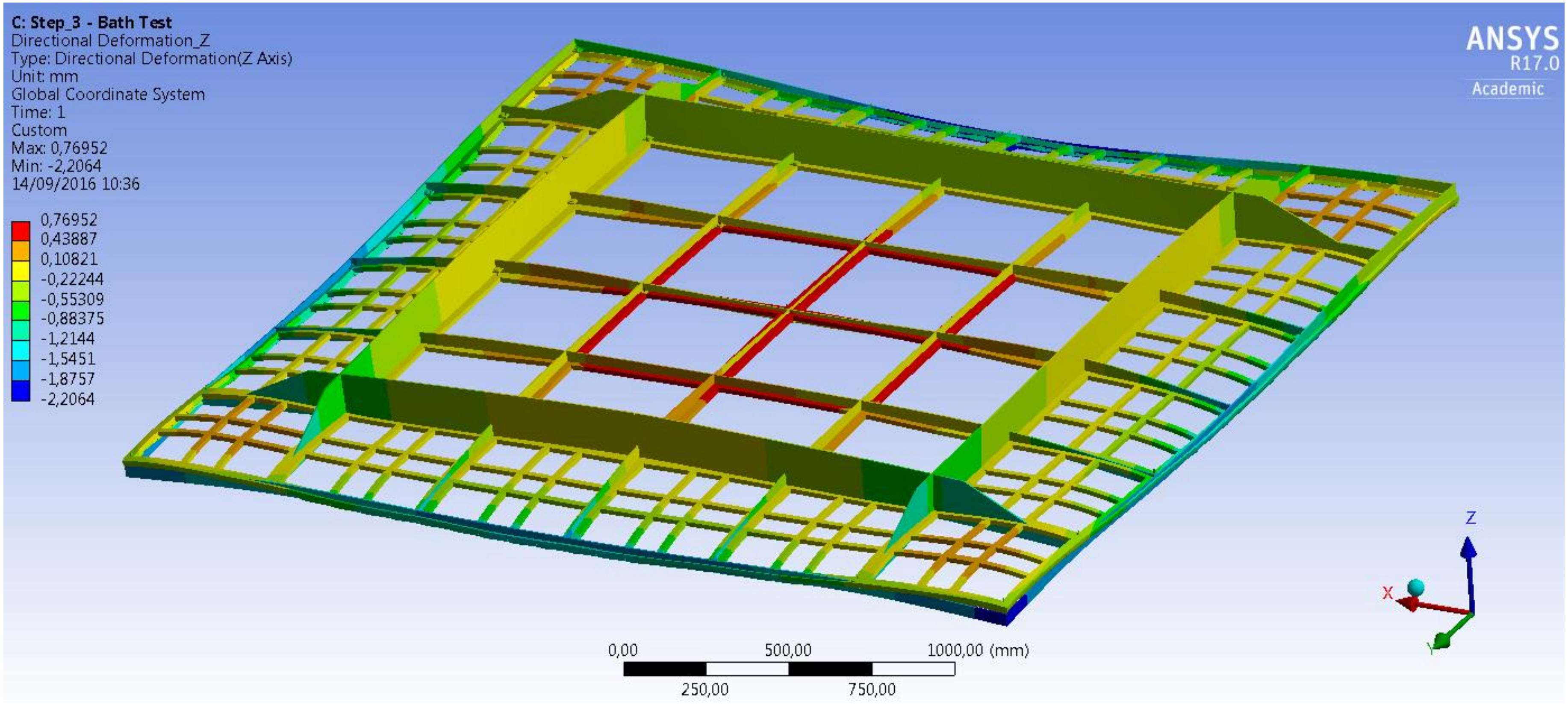
0,679	-0,078	-0,019	-0,007	0,005	0,027	0,056
-0,070	-0,055	-0,036	-0,017	-0,001	0,016	0,035
-0,001	-0,027	-0,024	-0,006	0,009	0,008	-0,013
0,018	-0,001	0,001	0,013	0,024	0,003	0,829
0,040	0,026	0,026	0,032	0,019	-0,008	-0,049
0,071	0,052	0,034	0,022	0,001	-0,016	-0,028
0,110	0,080	0,021	0,858	-0,029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







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



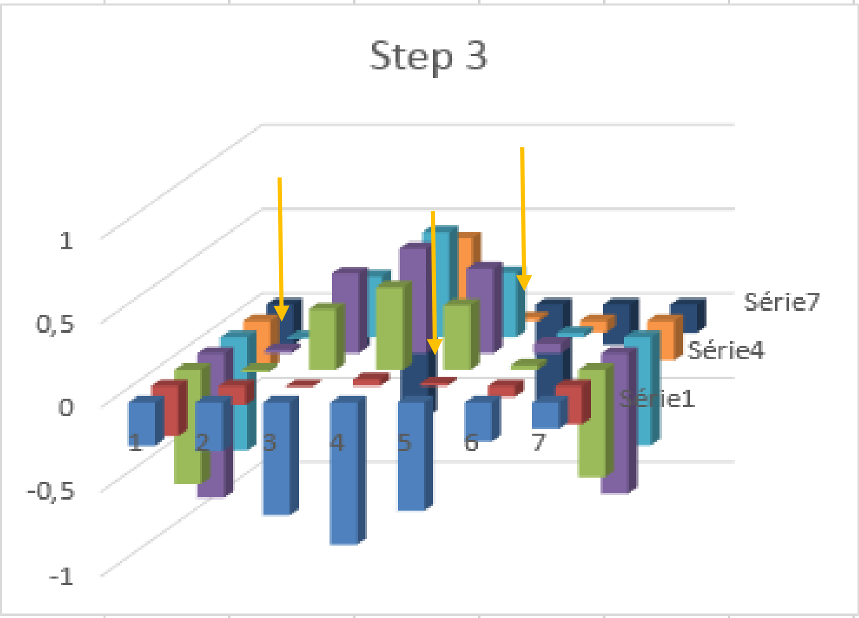
Loading case :

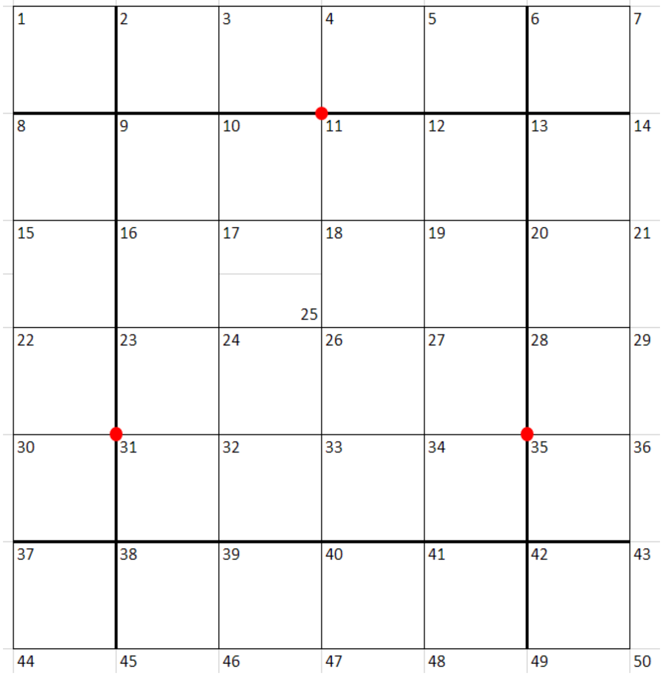
- Gravity
- Grid tension : -10,51mm (thermal contraction with alpha=1,7e-5) – tension measured ~ 5,3N/cable
- Planarity tuning from Step 2

G10 Planarity results for step 3 – Tension Init 1 mm

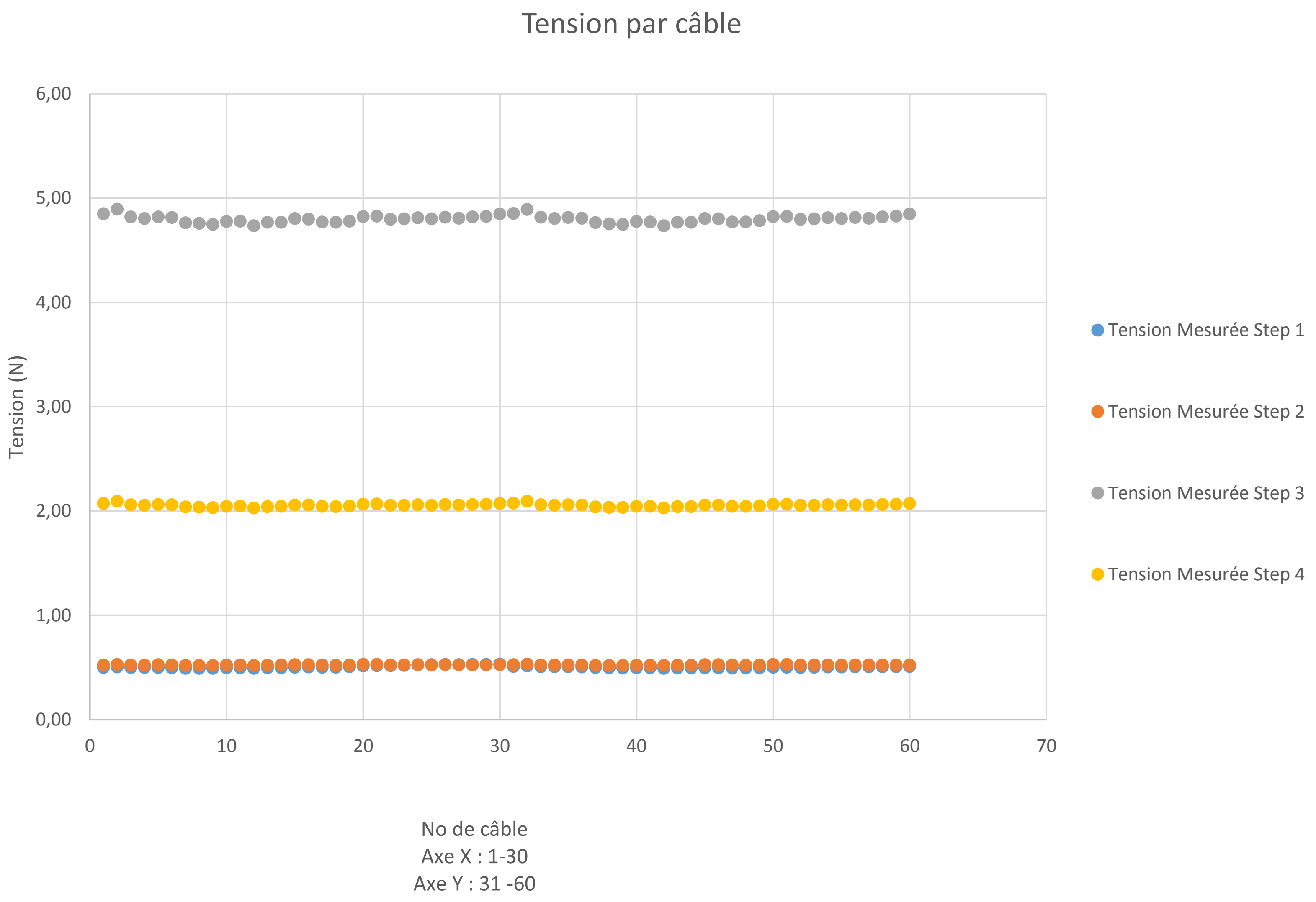
-0,257	-0,289	-0,67	-0,843	-0,642	-0,233	-0,157
-0,296	-0,113	-0,005	0,0411	0,0182	-0,064	-0,226
-0,677	-0,014	0,3588	0,49	0,3826	0,0273	-0,636
-0,855	0,0221	0,4745	0,622	0,5042	0,0599	-0,831
-0,671	-0,009	0,3619	0,6229	0,3828	0,0258	-0,641
-0,284	-0,103	0,0009	0,491	0,0183	-0,068	-0,233
-0,238	-0,276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

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

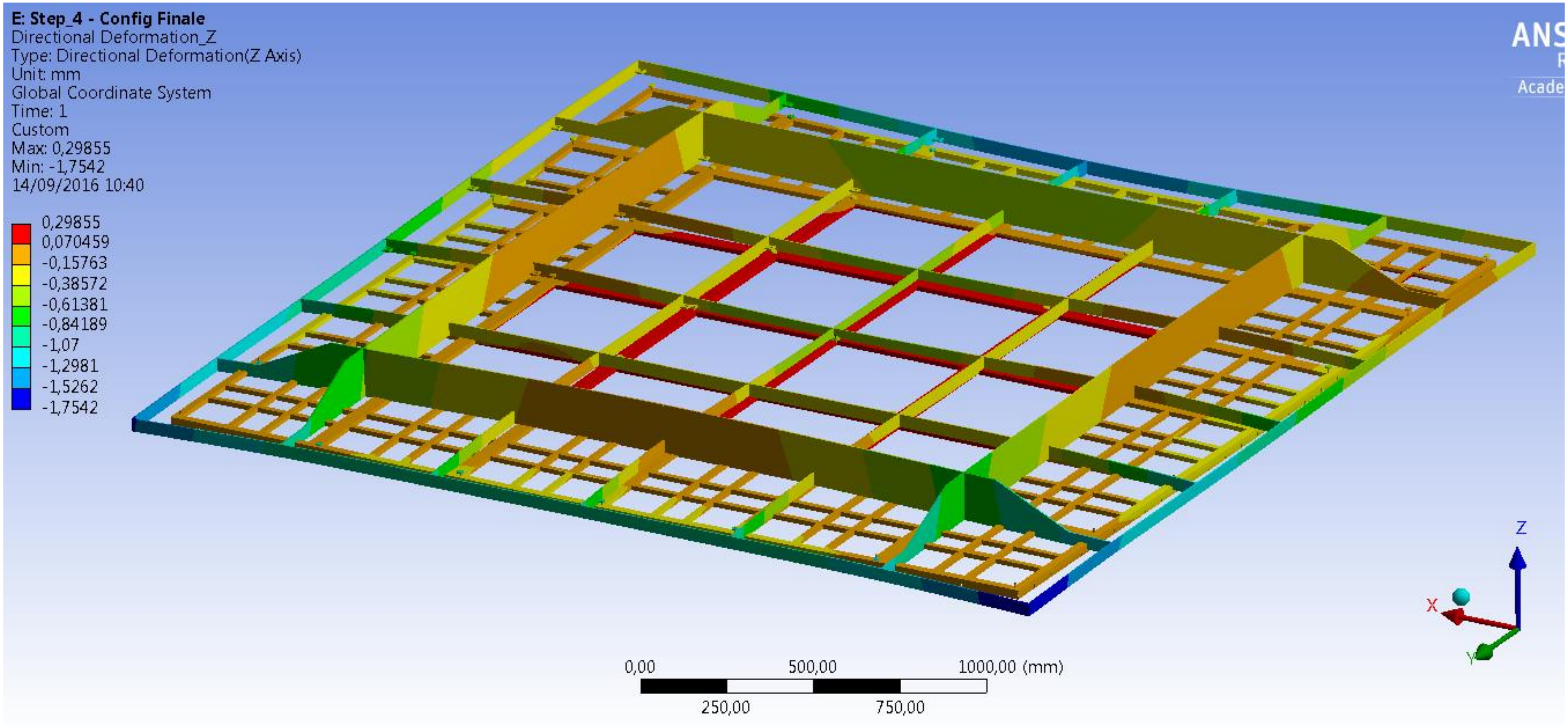




Tension in the extraction grid – Tension Init 1 mm



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



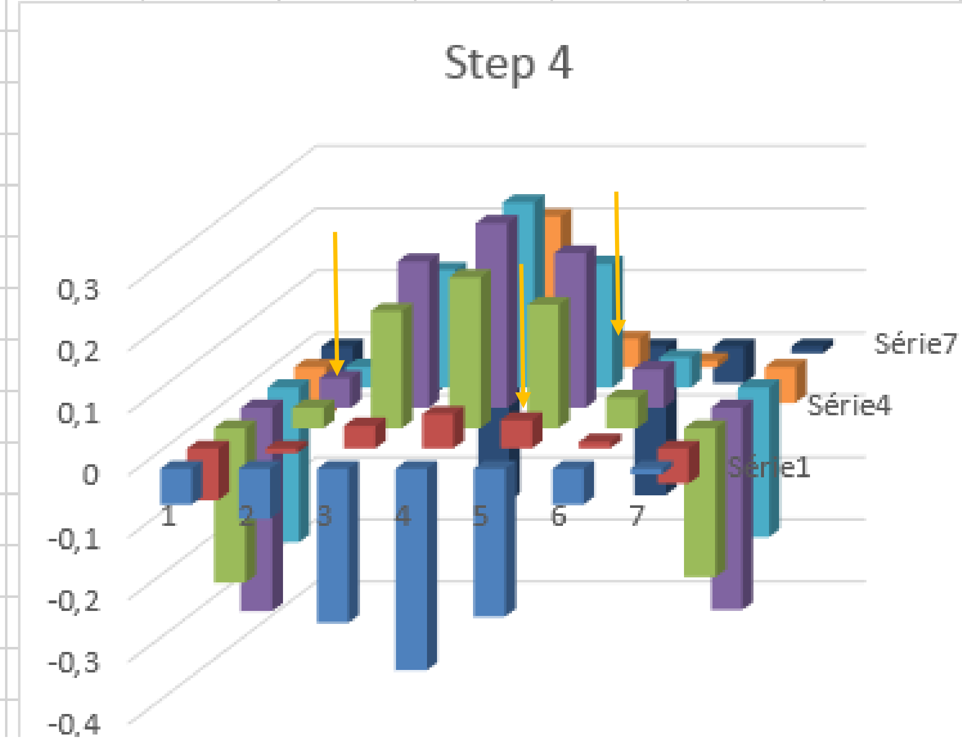
Loading case :

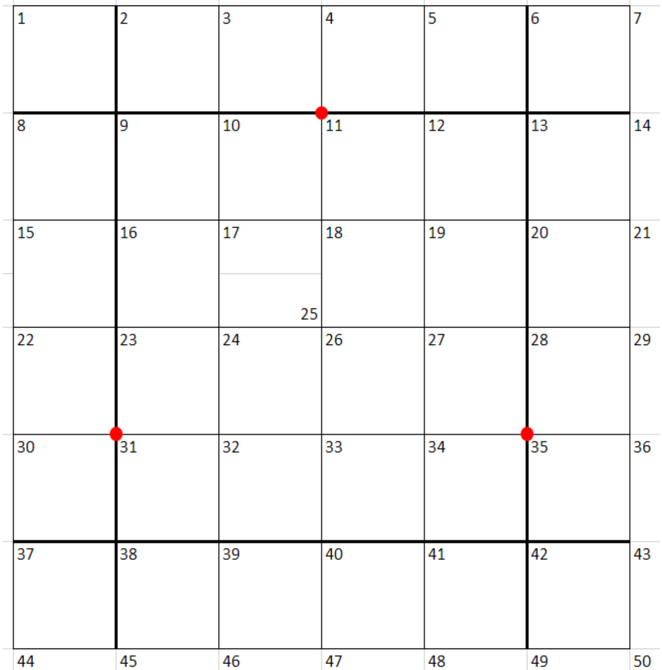
- Gravity
- Grid tension : -10,51mm (thermal contraction with alpha=1,7e-5) – final tension measured ~ 1,5 - 1,6 N/cable
- Planarity tuning from Step 2
- Temperature : -186°C

G10 Planarity results for step 4 – Tension Init 1 mm

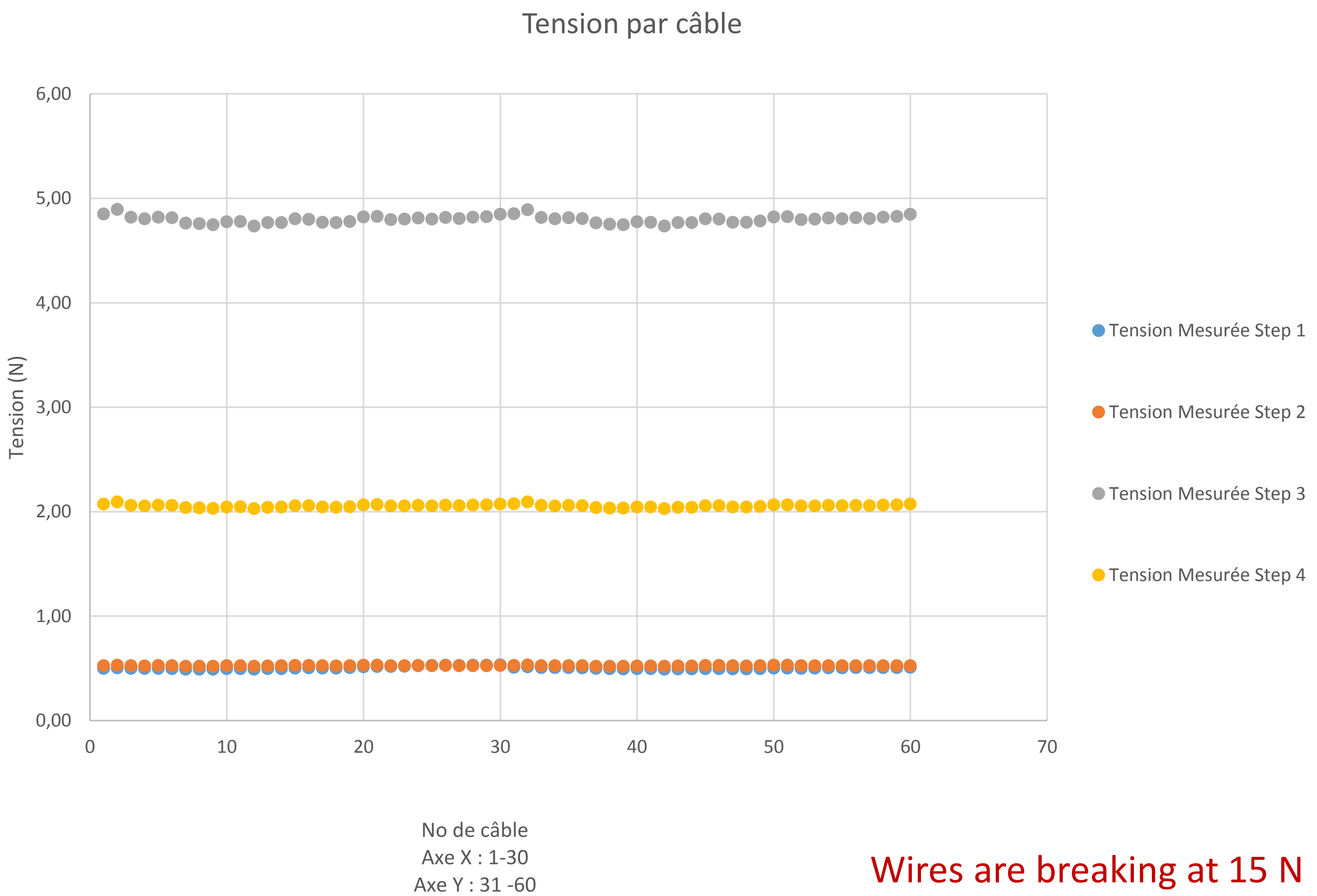
-0,058	-0,08	-0,248	-0,324	-0,238	-0,058	-0,009
-0,083	-0,008	0,0362	0,055	0,0453	0,0107	-0,056
-0,249	0,0326	0,1878	0,2422	0,1982	0,0486	-0,239
-0,327	0,047	0,2349	0,2965	0,2484	0,062	-0,325
-0,249	0,0333	0,1885	0,2969	0,1982	0,0483	-0,24
-0,082	-0,007	0,0366	0,242	0,0455	0,0103	-0,057
-0,056	-0,08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