LHCb SciFi Upgrade Tracker;

Technical overview of the scintillating fiber tracker for the upgrade of the LHCb Experiment (CERN)

Forum on Tracking Detector Mechanics 2017, Marseille

By R.Walet,
On behalf of the SciFi Collaboration

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NWO

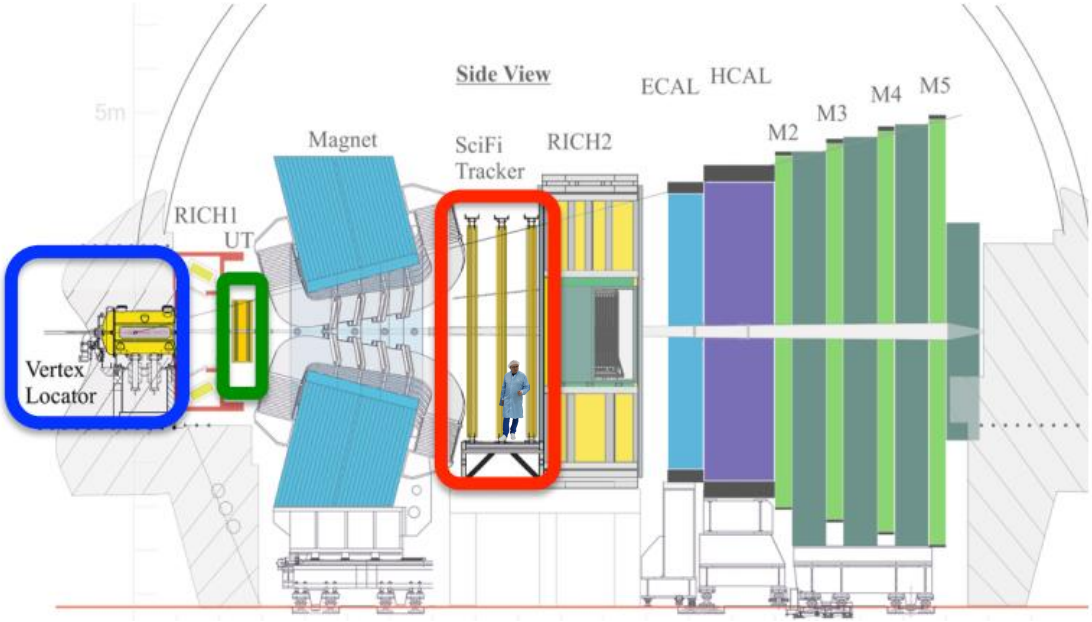
The LHCb Upgrade

During Long Shutdown 2 (2019) LHCb will be prepared for operation at Higher Luminosity (50 fb^{-1})

1. **Improve trigger efficiency**
2. **Replace Hardware triggers (1MHz) by software triggers (40MHz)**
3. **New sub detectors with improved granularity and 40 MHz read-out compatibility**

LHCb Tracking upgrade:

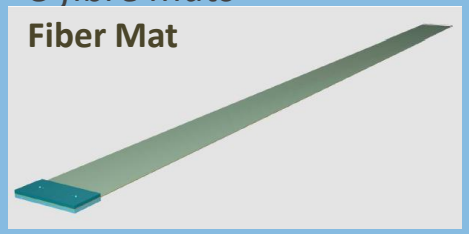
- New VELO, Si-pixel
- New Upstream tracker (UT), Si-strip
- SciFi Tracker, scintillating fibres

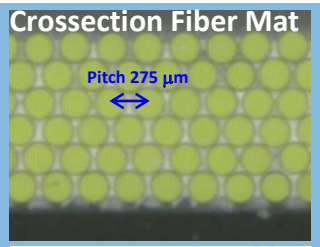


The LHCb SciFi Tracker

1 module *(0.5 x 5 m²)*

- *8 fibre mats*



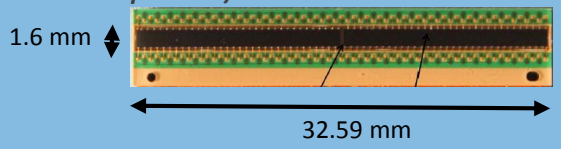


Total active surface ~ 340 m²
~ 11,000 km of fibres

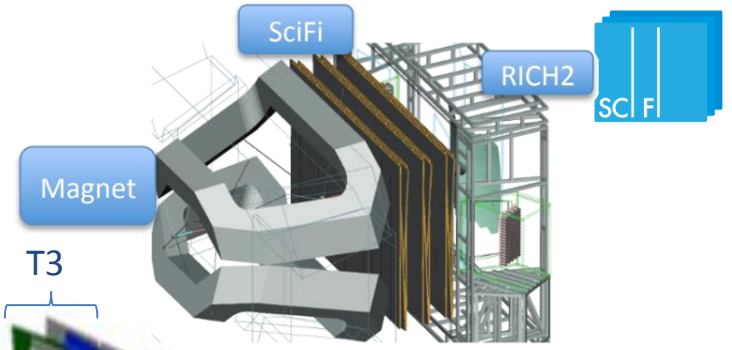
Read-out Box *on each side of the module*

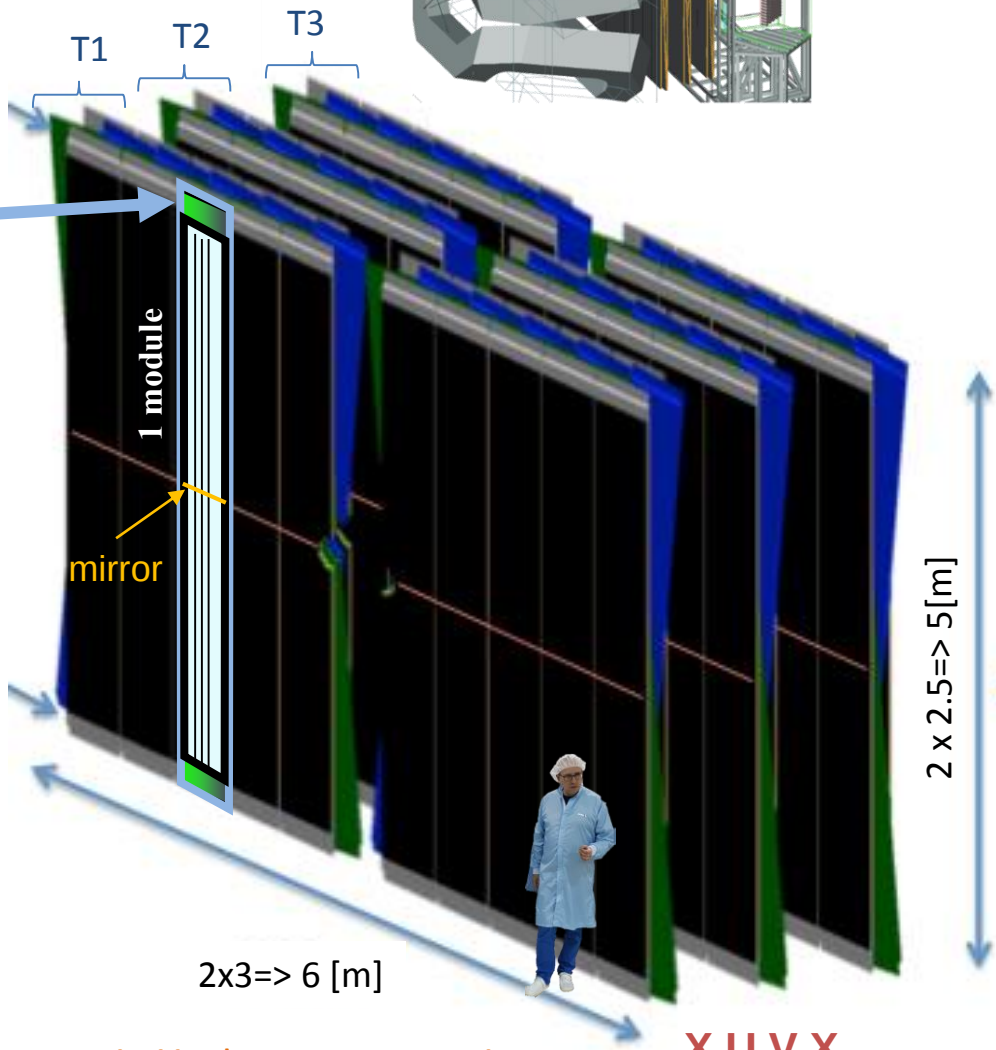
- *Each Read-out Box contains 16x SiPM**

*(*Silicon photon multipliers)*



SiPM Electronics *one RoB contains 32x Pacific ASICs*



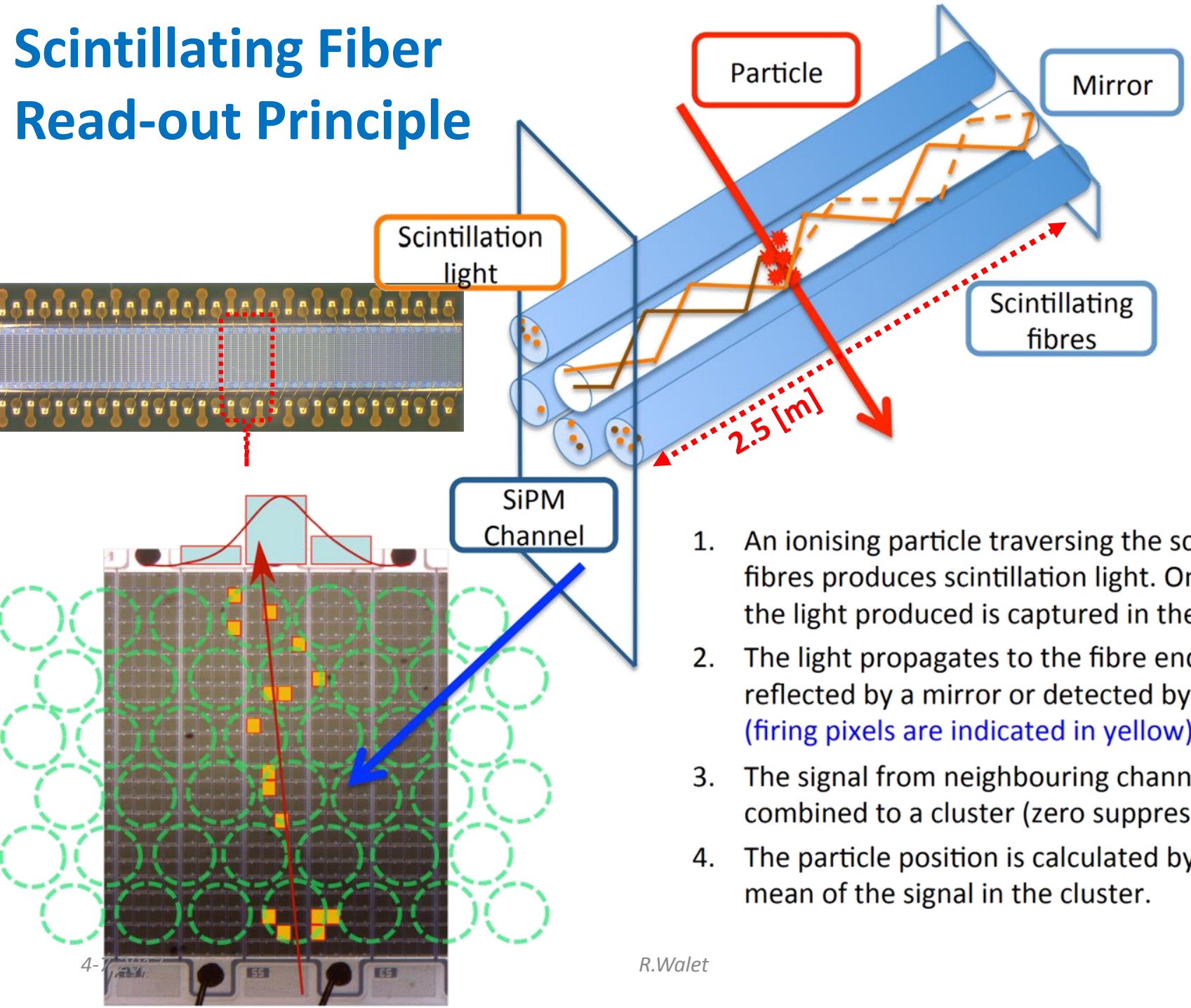


Requirements :

- **Hit detection efficiency** *higher than 98%*
- **Spatial resolution** *better than 100µm*
- **40MHz readout** *without dead time*
- **Operation in radiation environment**
  - *Fibres 35 kGy and SiPMs 6x1011 1MeV neq/cm2 (with neutron shielding) + 100 Gy ionising dose*
- **Low material** *with X/X0≤1% per detection layer*

X U V X
stereo angle ± 5°

Scintillating Fiber Read-out Principle

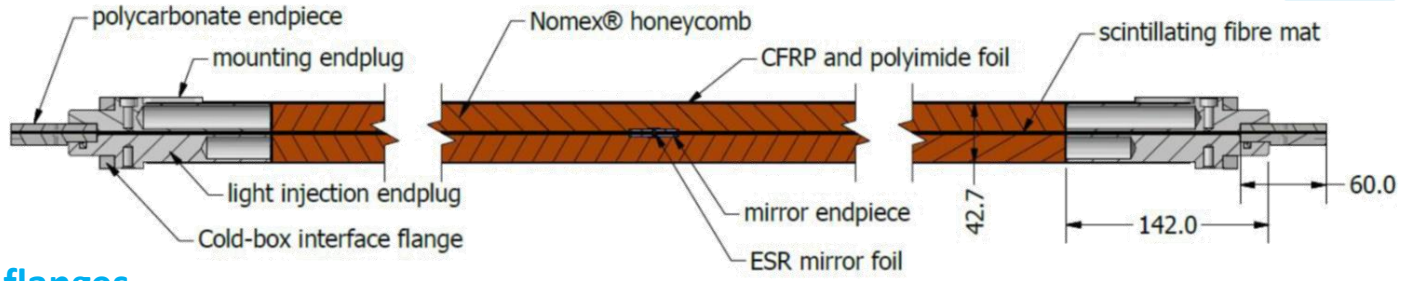


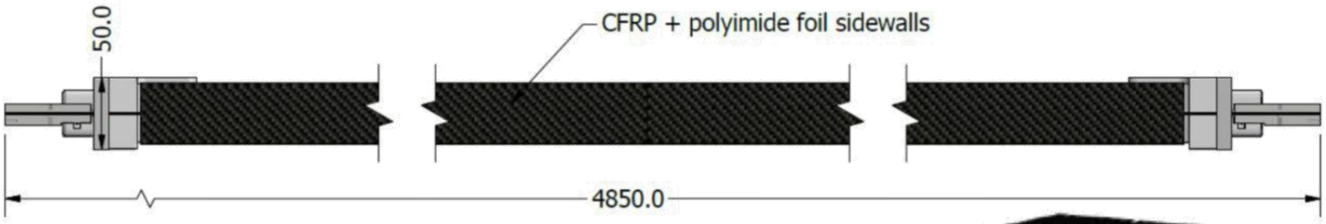
1. An ionising particle traversing the scintillating fibres produces scintillation light. Only 10% of the light produced is captured in the fibres.
2. The light propagates to the fibre end is either reflected by a mirror or detected by the SiPMs (firing pixels are indicated in yellow).
3. The signal from neighbouring channels is combined to a cluster (zero suppression)
4. The particle position is calculated by a weighted mean of the signal in the cluster.

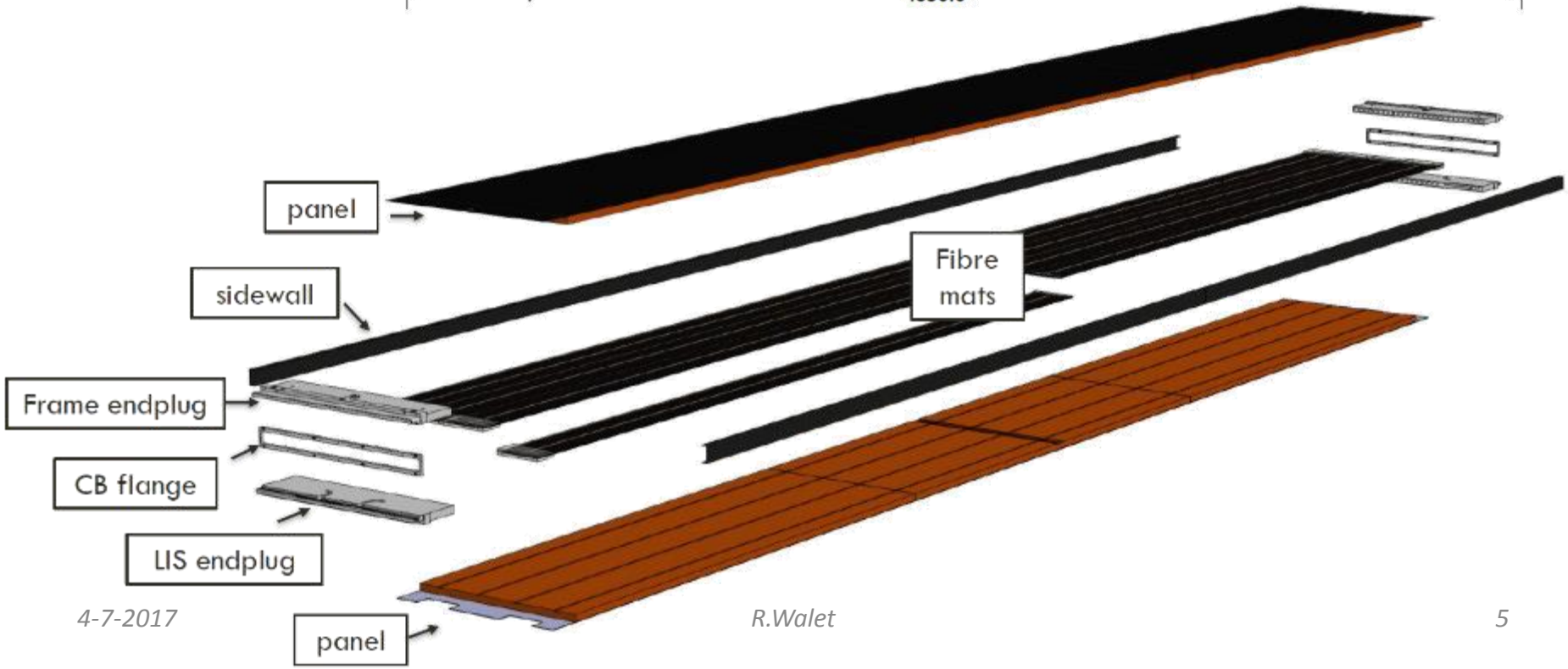
Modules

Remarks;

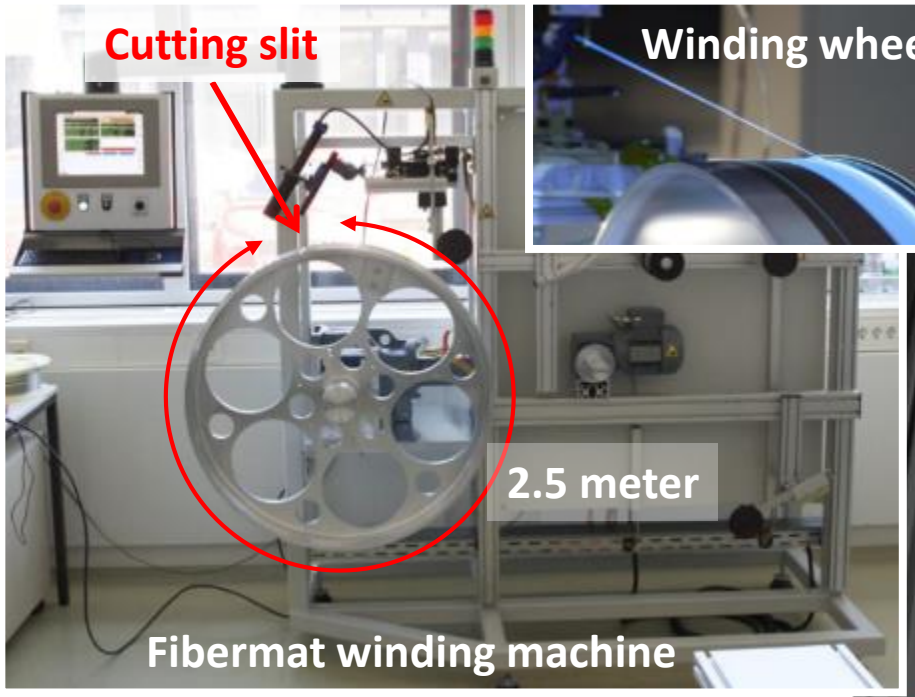
- Eight fiber mats
- Endplugs include
  - Light injection
  - RoB mounting flanges
- Honeycomb Sandwich
- Carbon Fiber Wrapping







Modules – Fibre Mat Production

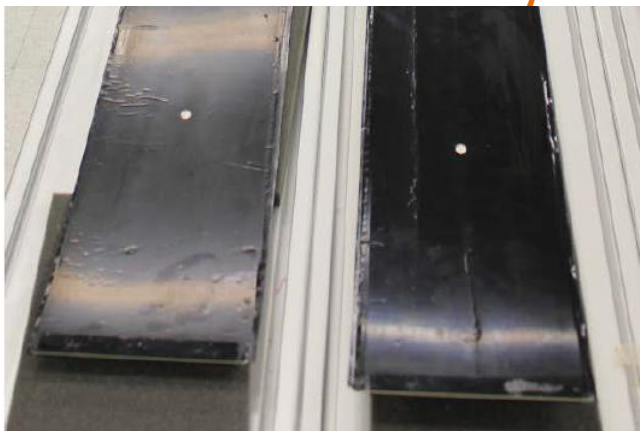


Alignment holes for module assembly

Casted Fiber mat

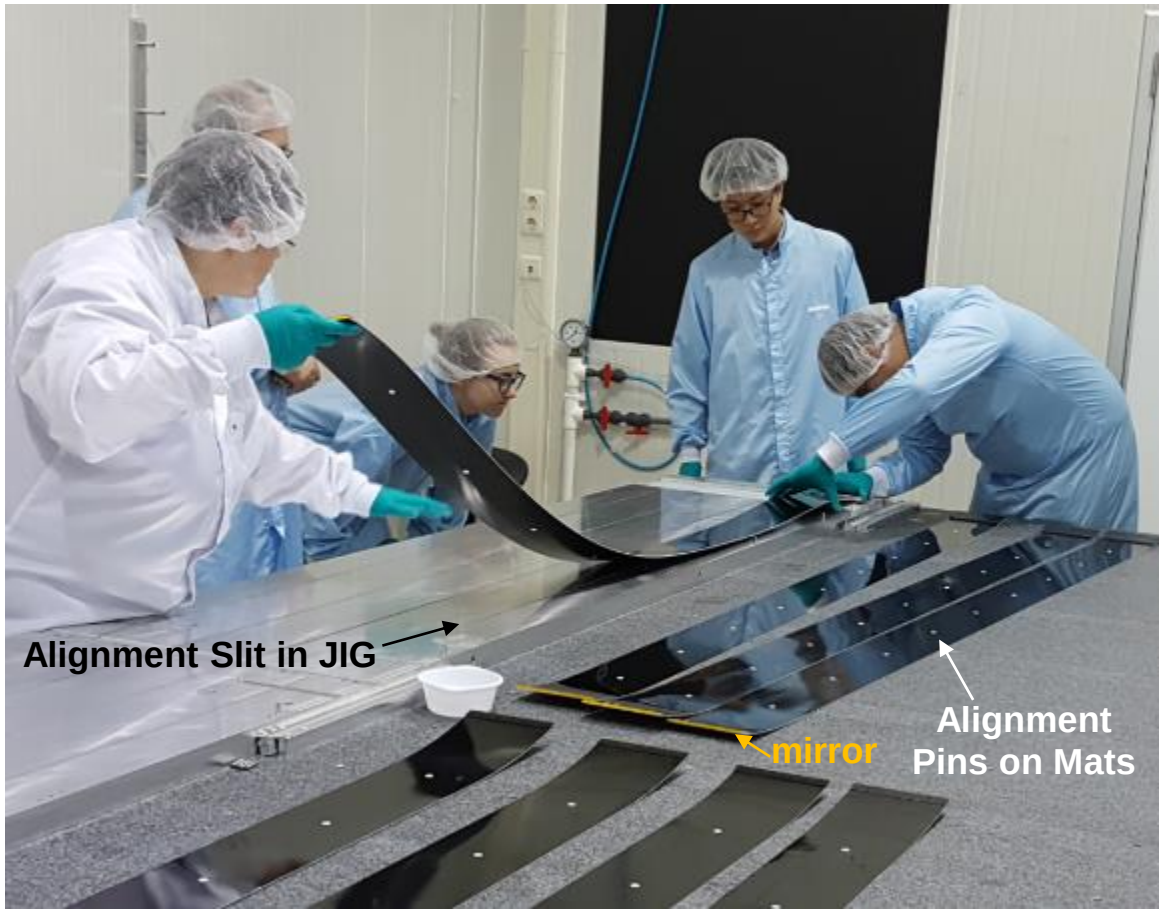
Remarks

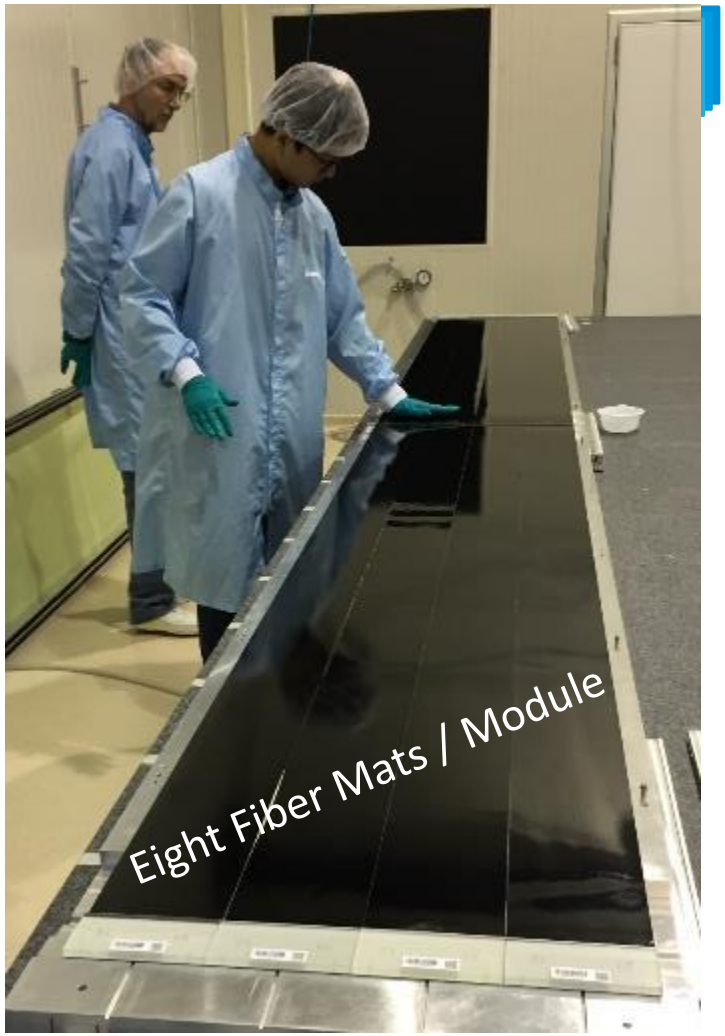
- Initial quality control on fiber diameter → bumps >350µm will be removed
- Four winding centers
- 1024 good mats needed → Produce 1200 + spares
- Lateral bending controlled by fiber winding pre-tension variation
- Mirror glued on one side
- Read-out side polished
- Sides cut to 0.1mm accuracy

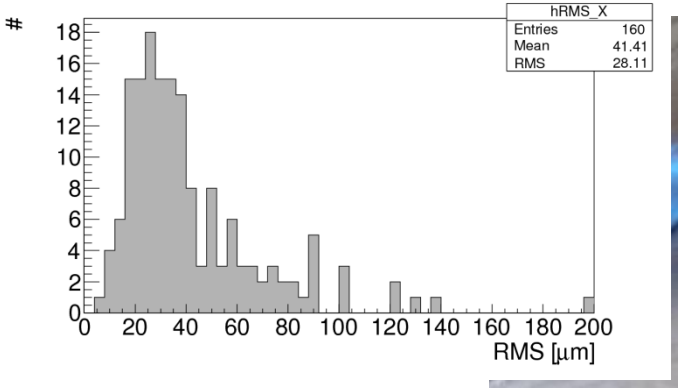


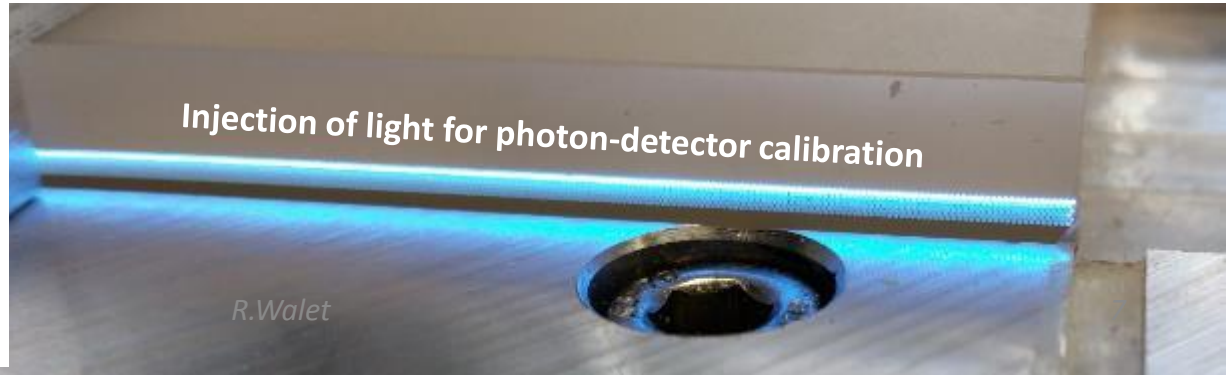
Fiber mat foil cladding

Modules-Fiber mats core

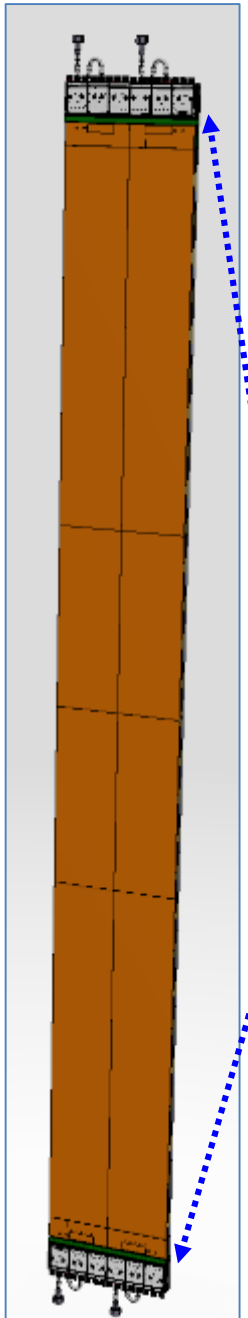






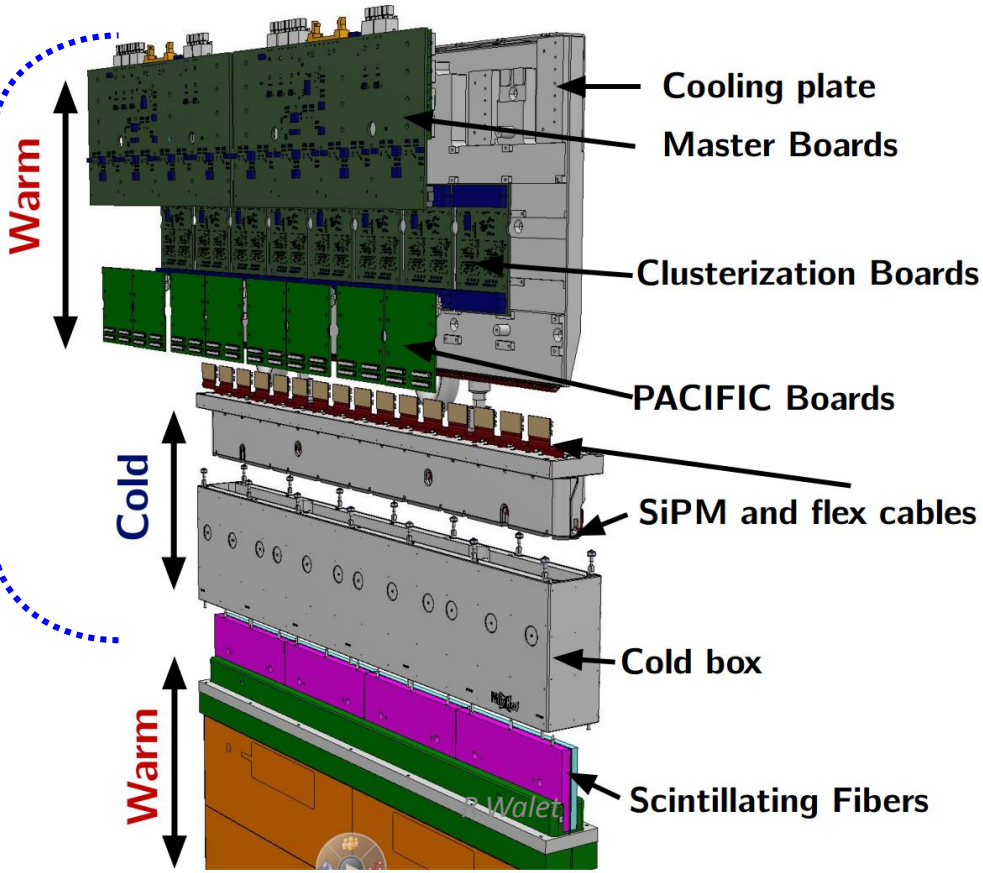


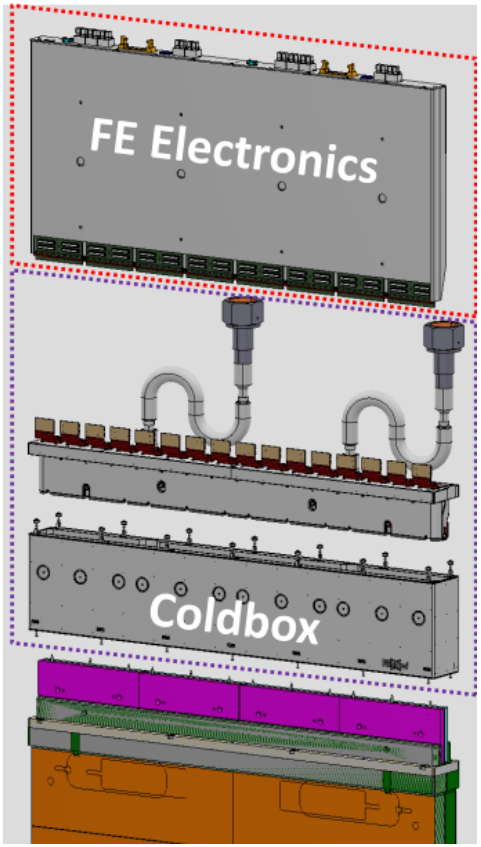
Read-out Box;



Very schematically a ROB is:

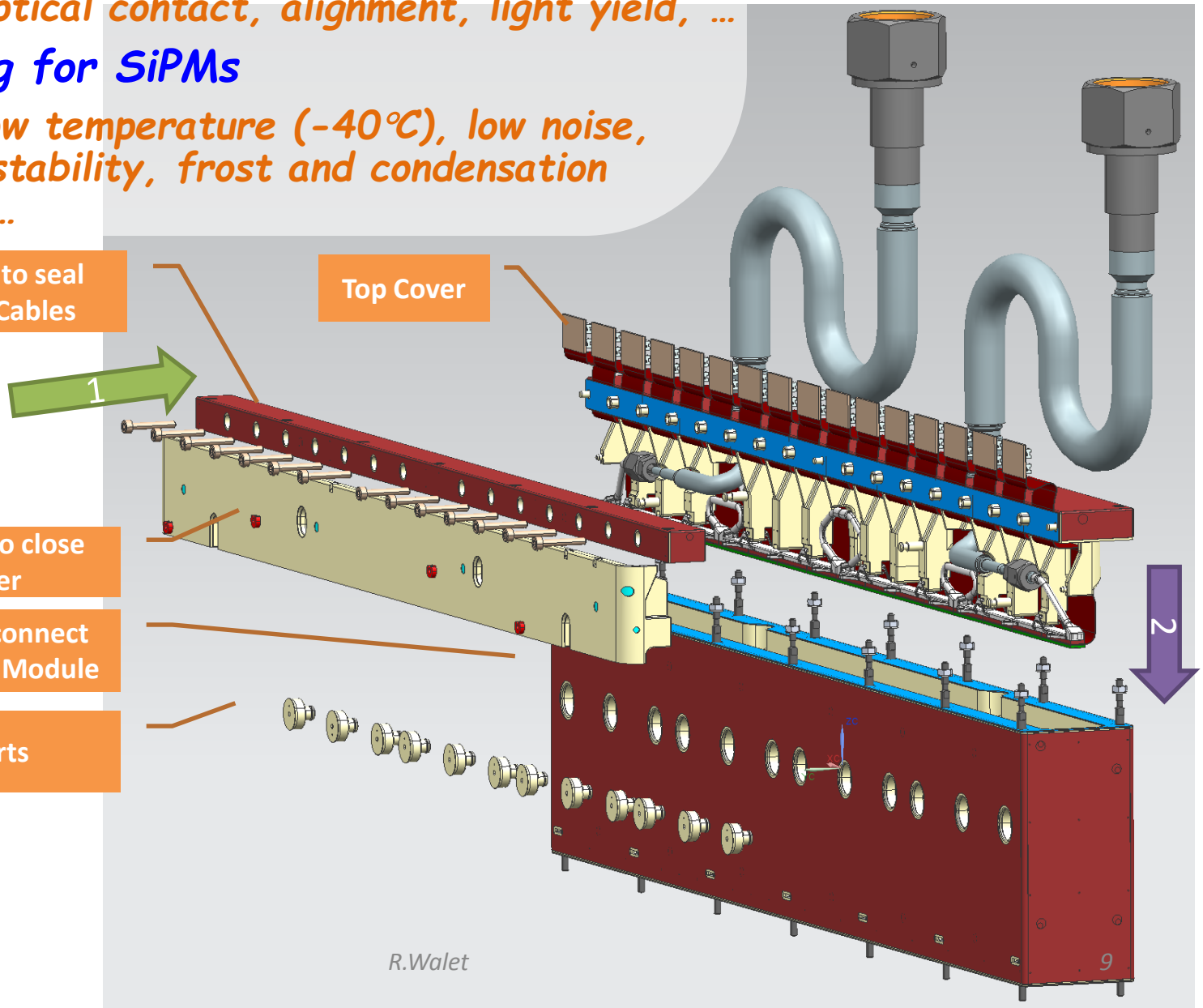
1. **FE electronics boards, cables, etc.**
   → **"FE ELECTRONICS"**
2. **SiPMs, SiPM cables, SiPM cooling, etc.**
   → **"COLDBOX"**





Cold Box

- *supports and positions SiPMs w.r.t. fibers*
  - *keywords: optical contact, alignment, light yield, …*
- *provides cooling for SiPMs*
  - *keywords: low temperature (-40°C), low noise, uniformity, stability, frost and condensation prevention, …*



Enclosure

3D printed Shells;

- Hollow structure
- Wall thickness 0.7-1mm
- Good geometrical tolerances
- PA3200GF impregnated with black paint

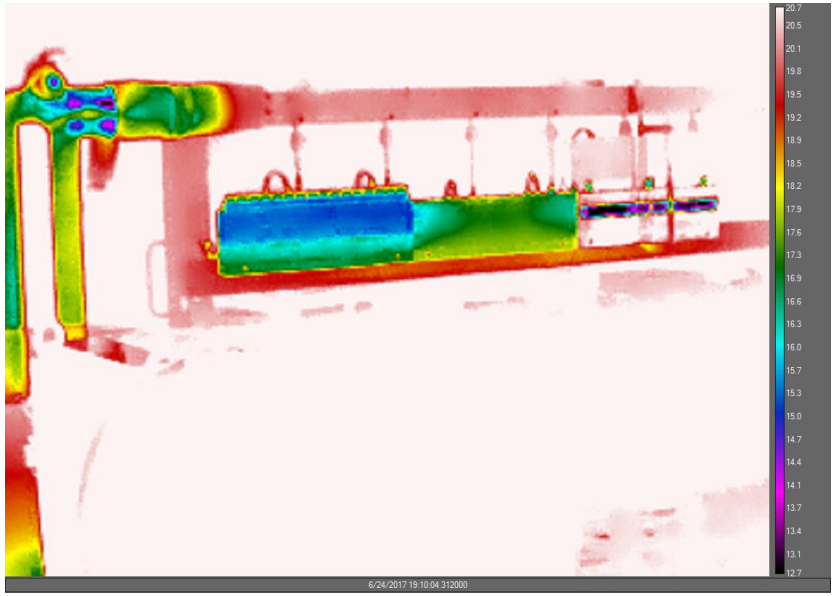
Filling by 2K PUR Foam;

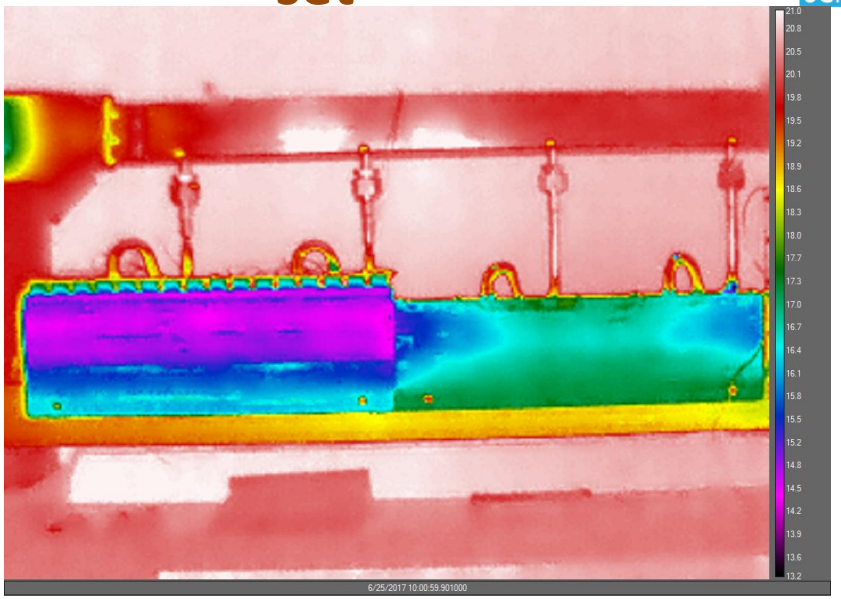
- Pigmented Foam
- Parts placed in reference JIGs during foam expansion to guaranty geometric tolerances

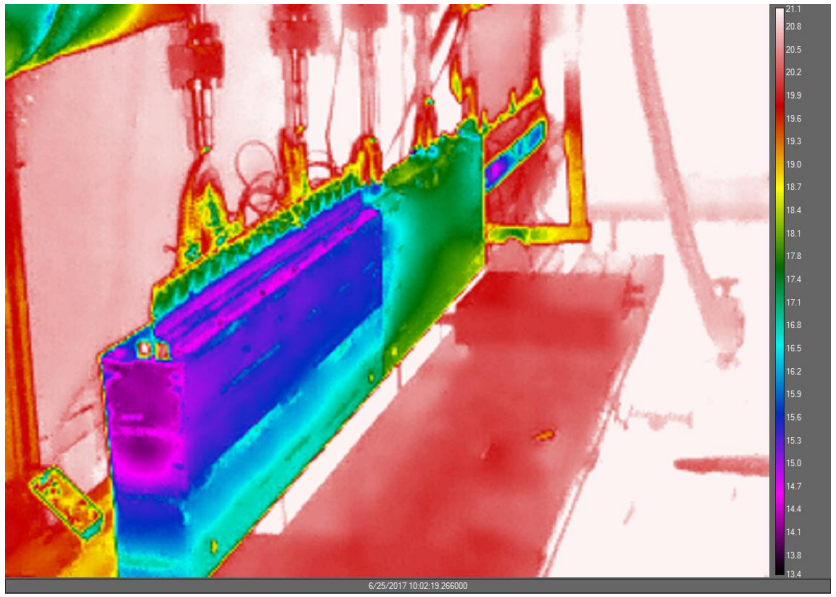
Outer surfaces are cladded with 0.2[mm] CU Foils

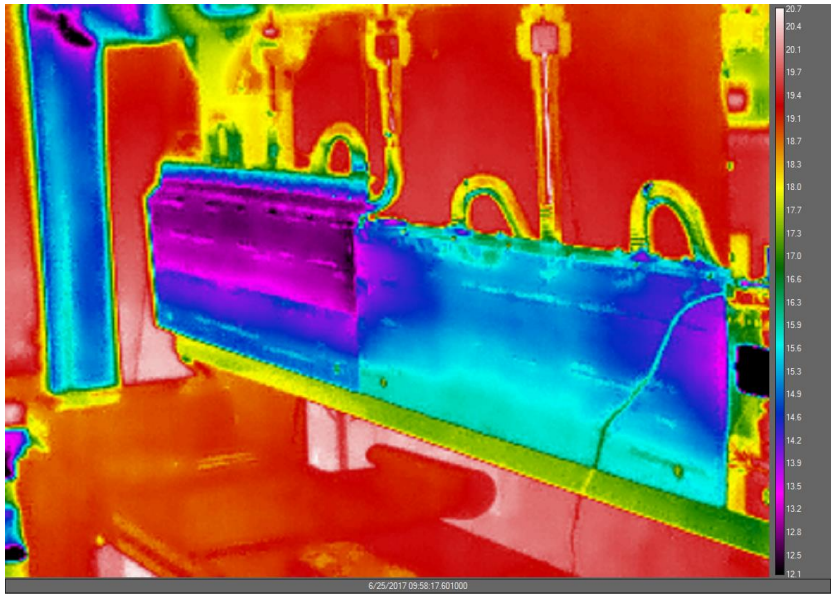
All materials are tested for degradation by irradiation

Enclosure – Heat Spreading (T_{set} = -50°C)



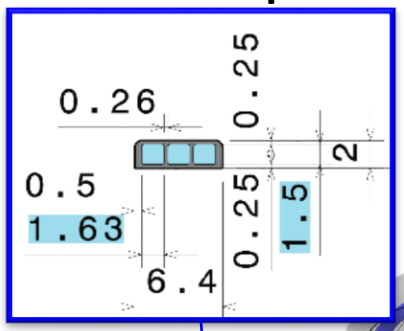






Coolbar – Feedthrough Overview

Titanium 3D printed Coolbar



Outside 3/4" VCR Vacuum Insulation
Open vacuum pipe to Manifold

Inside 1/8"VCR
Corrugated Novec Lines

End vacuum insulation

Feedthrough topcover

Inside Coldbox

Cooling Blocks
<-40°C

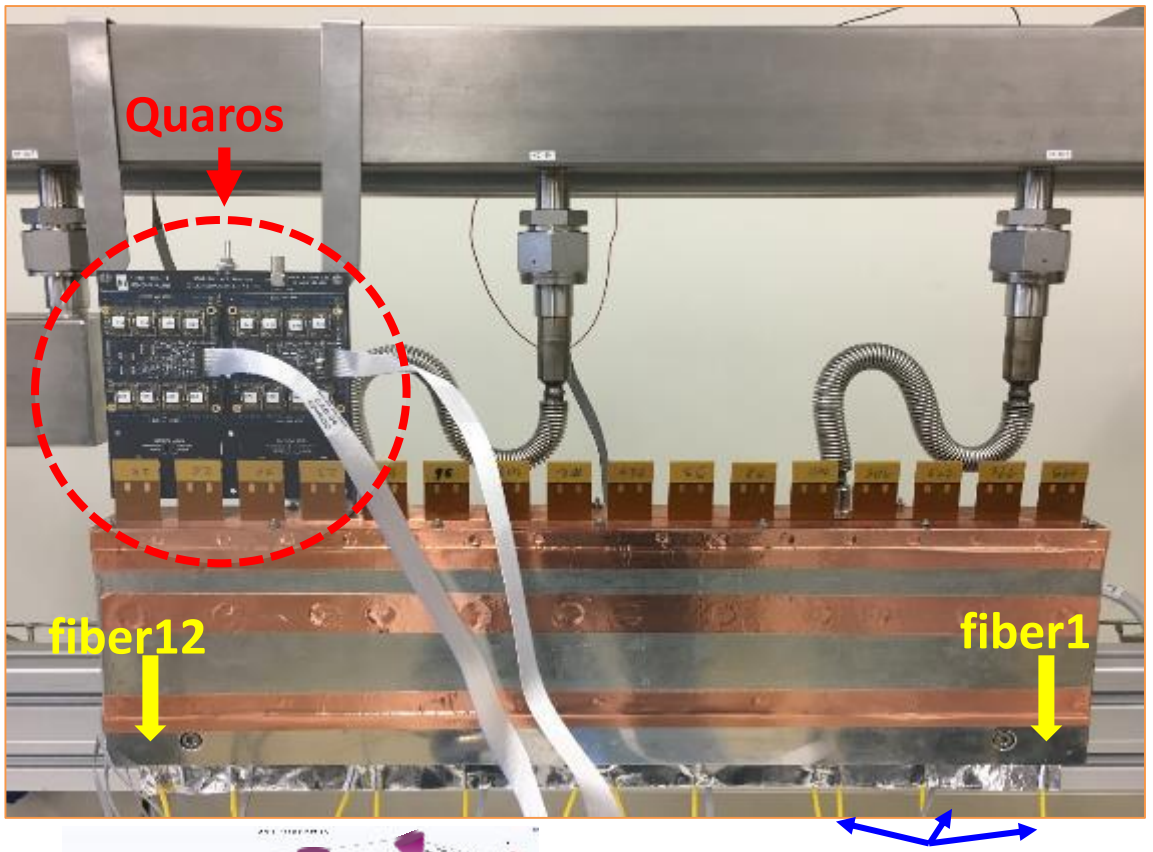
End Pieces Deformation

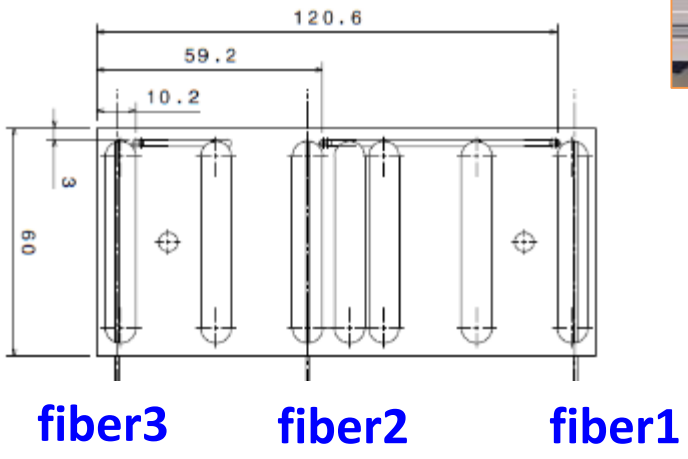
Remarks:

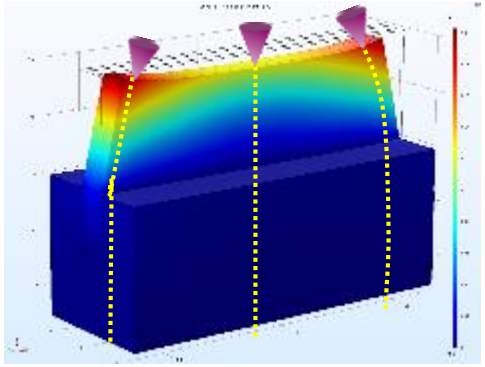
- *pulsed light and SiPM readout with QUAROS (DAQ)*
- *repeat at different temperatures and check for variations*

Results:

- *Measured deformations 87.5-200 [µm]*
- *Check impact on light yield*



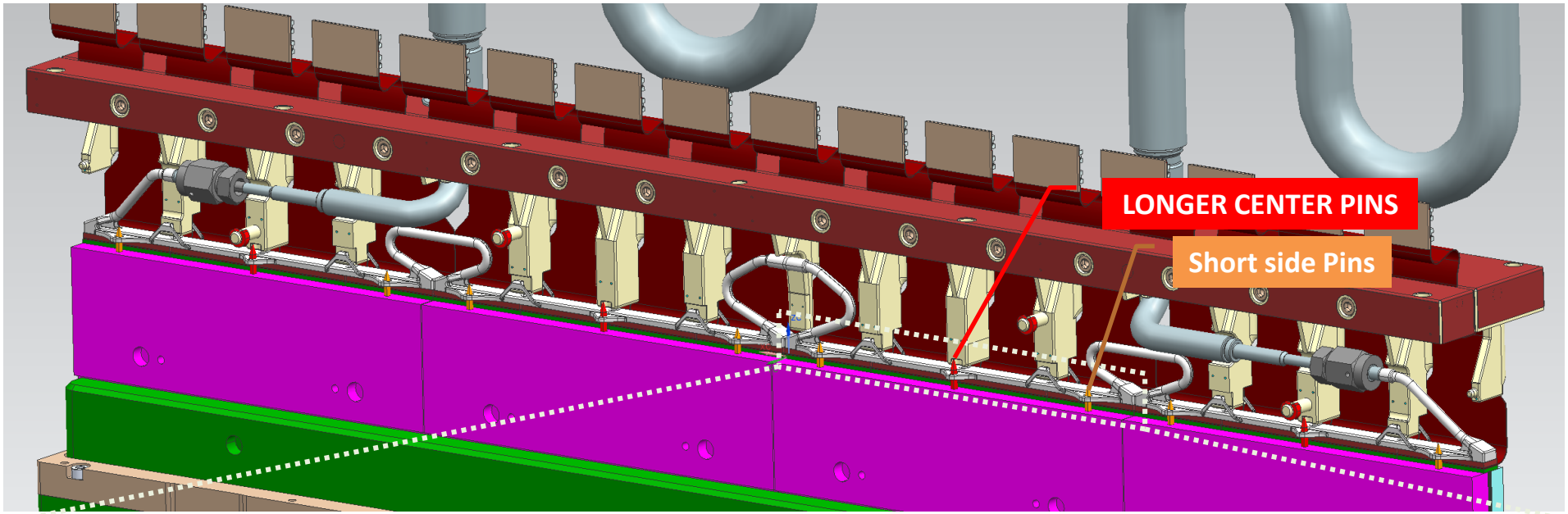


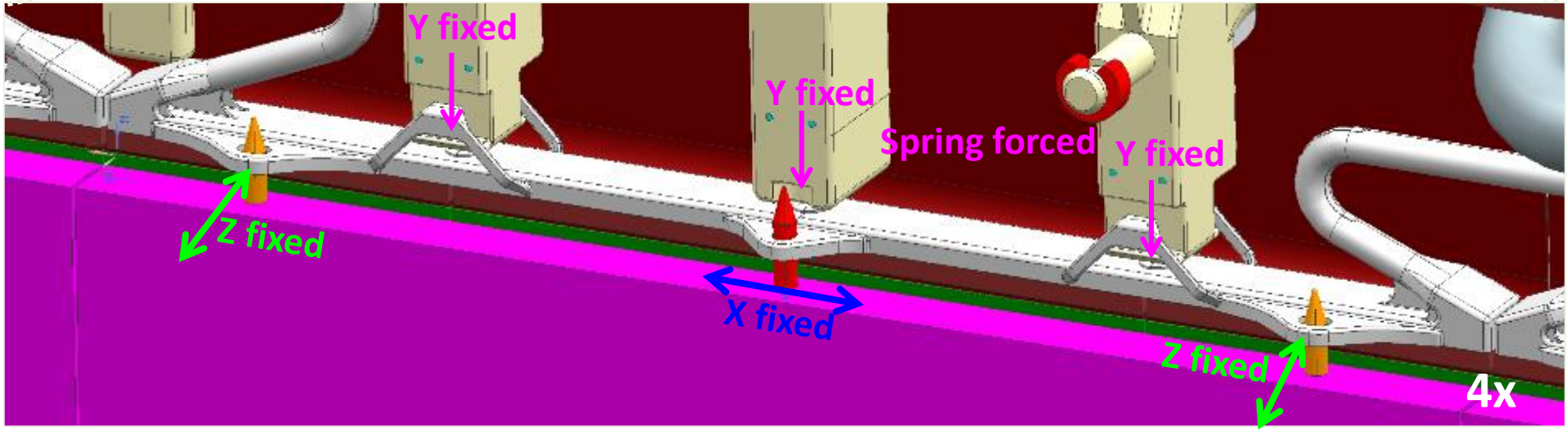


Fibers for Light Injection

(3 mono-mode 9/125 fibers per end-piece)

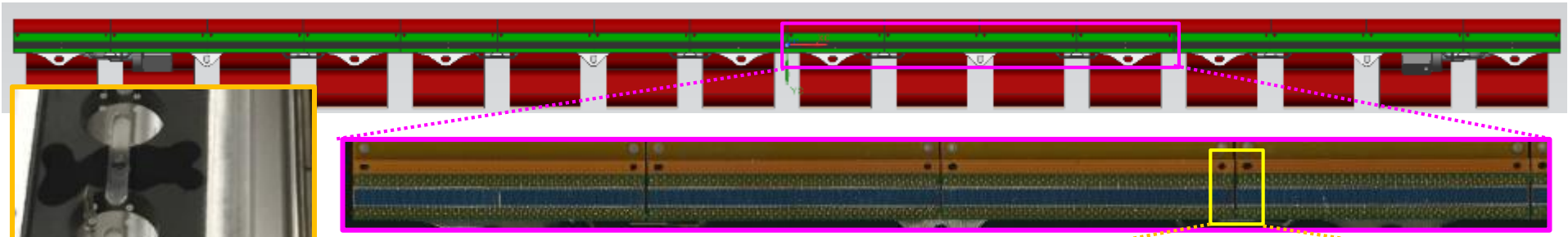
Coolbar; Alignment Principle

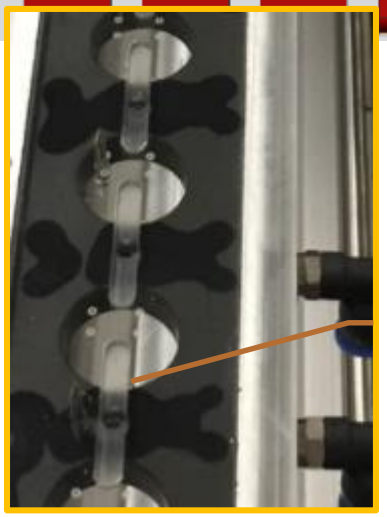




EACH INDIVIDUAL COOLING SUBSTRATE POSITIONED AND ALIGNED WITH RESPECT TO SINGLE FIBER MAT

Alignment; Coolbar <-> SiPM





Vacuum slots glass plate

Alignment markers on glass plate

SiPM channels Pattern recognition

16x SiPMs

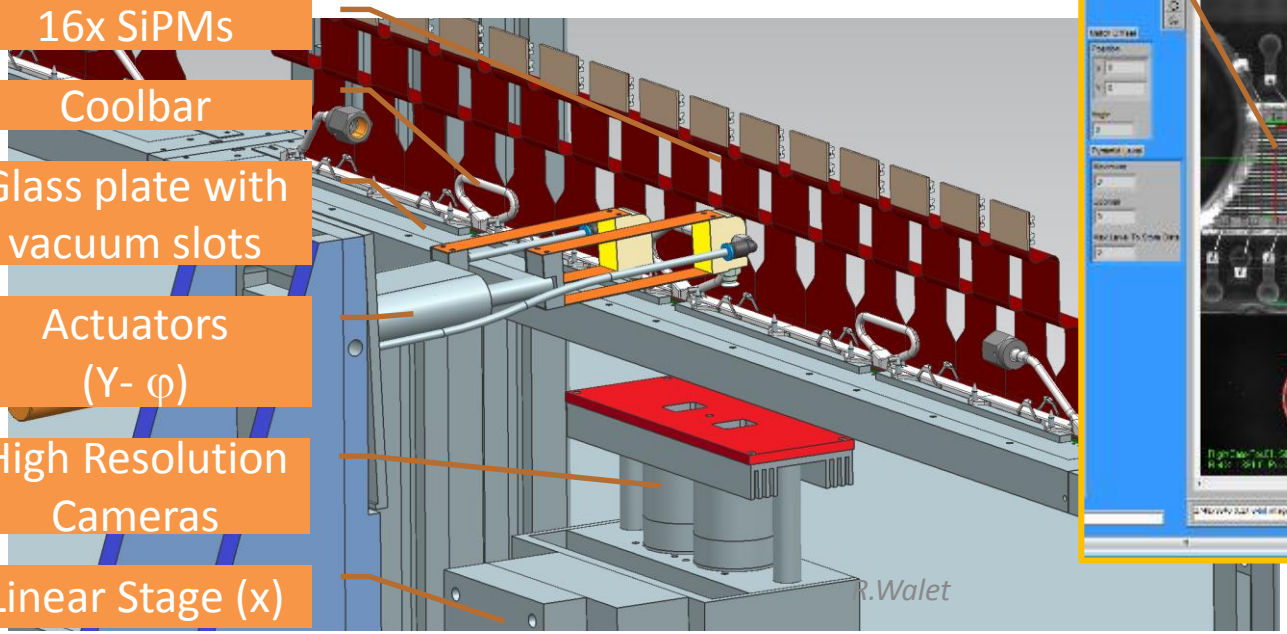
Coolbar

Glass plate with vacuum slots

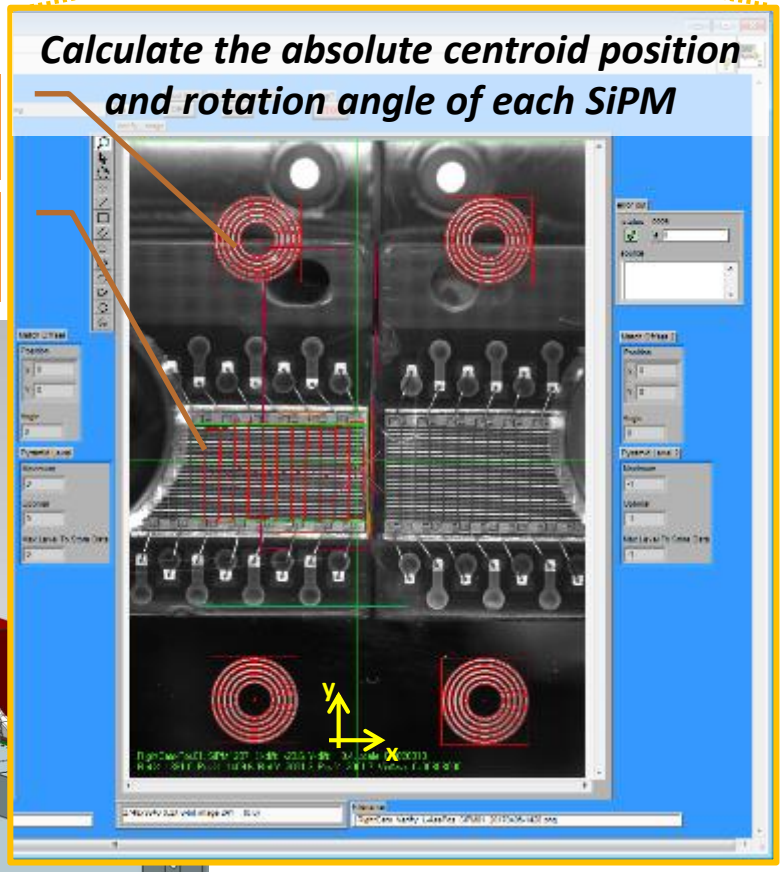
Actuators (Y- φ)

High Resolution Cameras

Linear Stage (x)

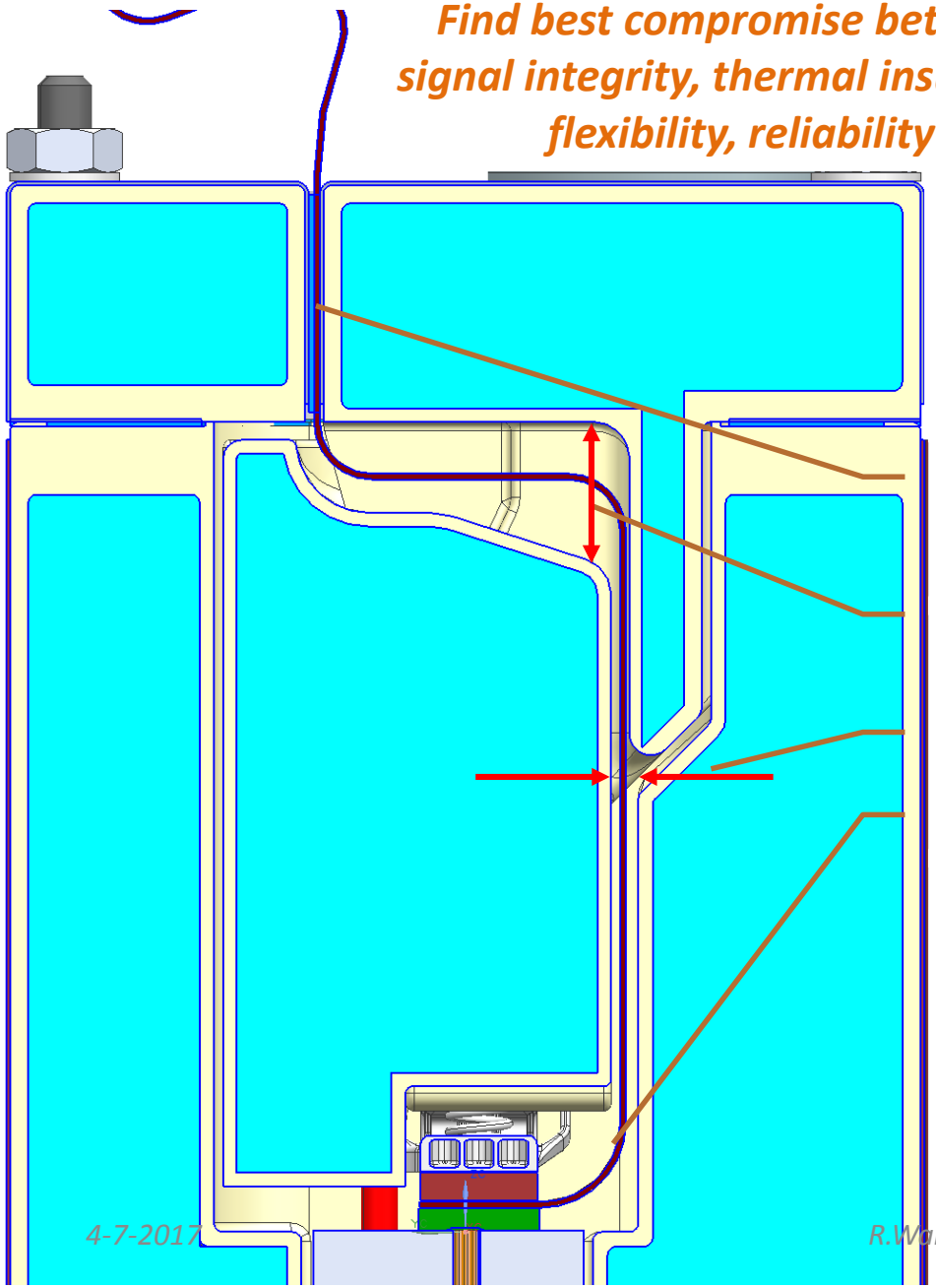


Calculate the absolute centroid position and rotation angle of each SiPM



SiPM Flex Cable

Find best compromise between signal integrity, thermal insulation, flexibility, reliability

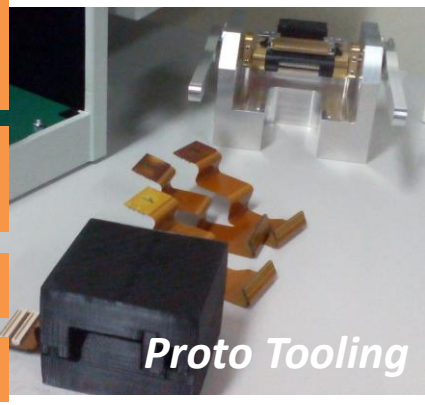


Clamped and sealed flex cable feedthrough
(By PEEK bolts and nuts)

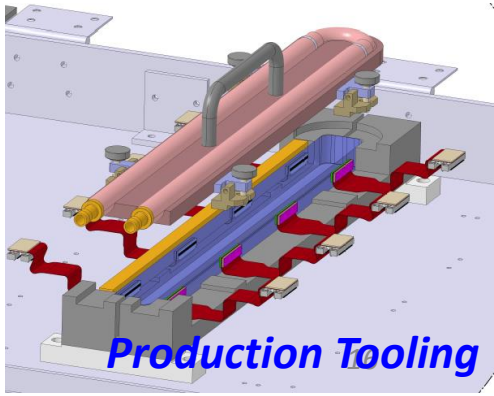
Thermal/Tolerances Compensation area

Free Space

Optimized Bending Radius



In detector, flex must compensate non-perfect alignment of cold box and FEE as well as rel. movements (mm-scale)

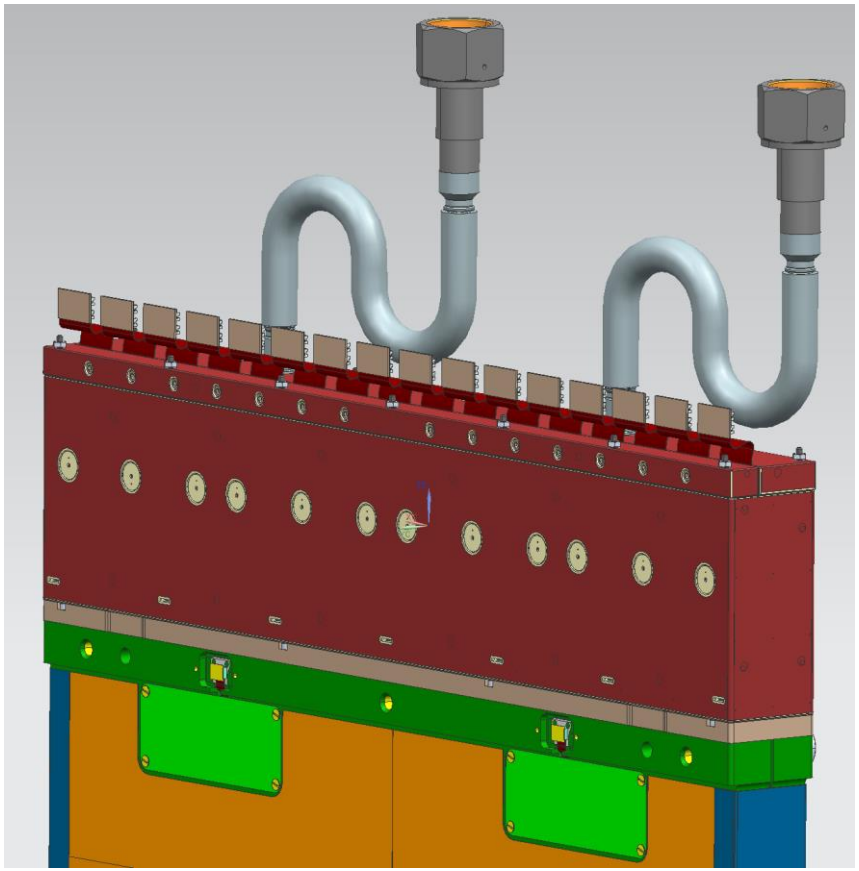


Heat loss

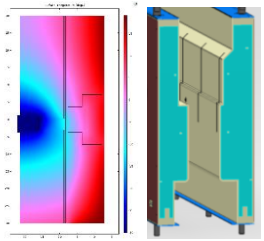
Conditions:

Environment	*+20 ℃*
Coolant	*-45 ℃*
Enclosure outside	*>13.5 ℃*

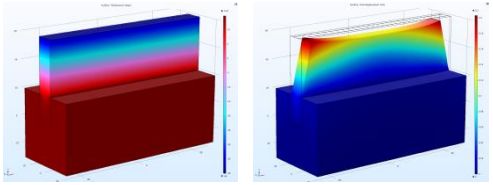
Overall



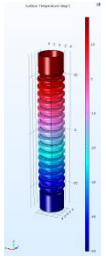
Insulation
7 W



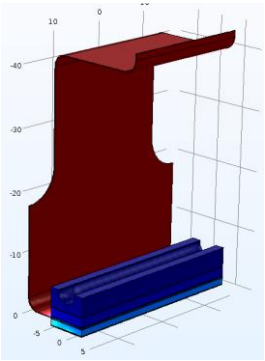
Module/End Pieces
± 1.5-4.5* W



Novec. Feedthr.
1 W



Elec. Feedthr.
± 2,5 W



Total 12-15* W

(*Additional heat loss by sensor cabling)

SiPM – Overview

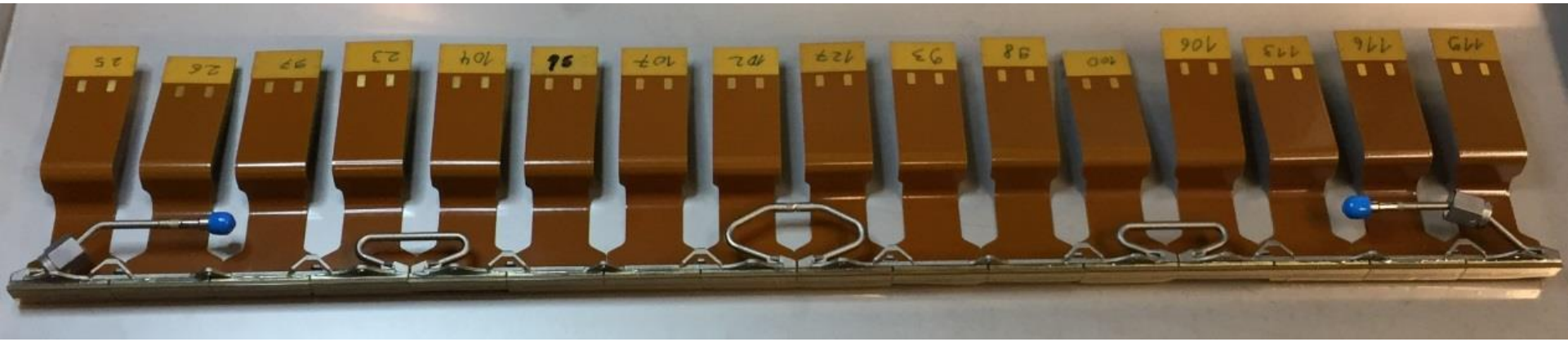
Hamamatsu, model H2016-HRQ (high quench resistor)

Fully adequate performance for SciFi:

- peak PDE 48% (at 3.5 V)
- direct cross-talk 3.3%,
- delayed cross-talk 2.7%
- after pulses 0.1%
- DCR = Φ=6·10^{11} n_{eq}/cm^2 = 14.3 MHz at -40C, halved every -10 K

For more details see Axel Talk
https://cds.cern.ch/record/2270146/files/Tipp2017_Axel_Kuonen.pdf

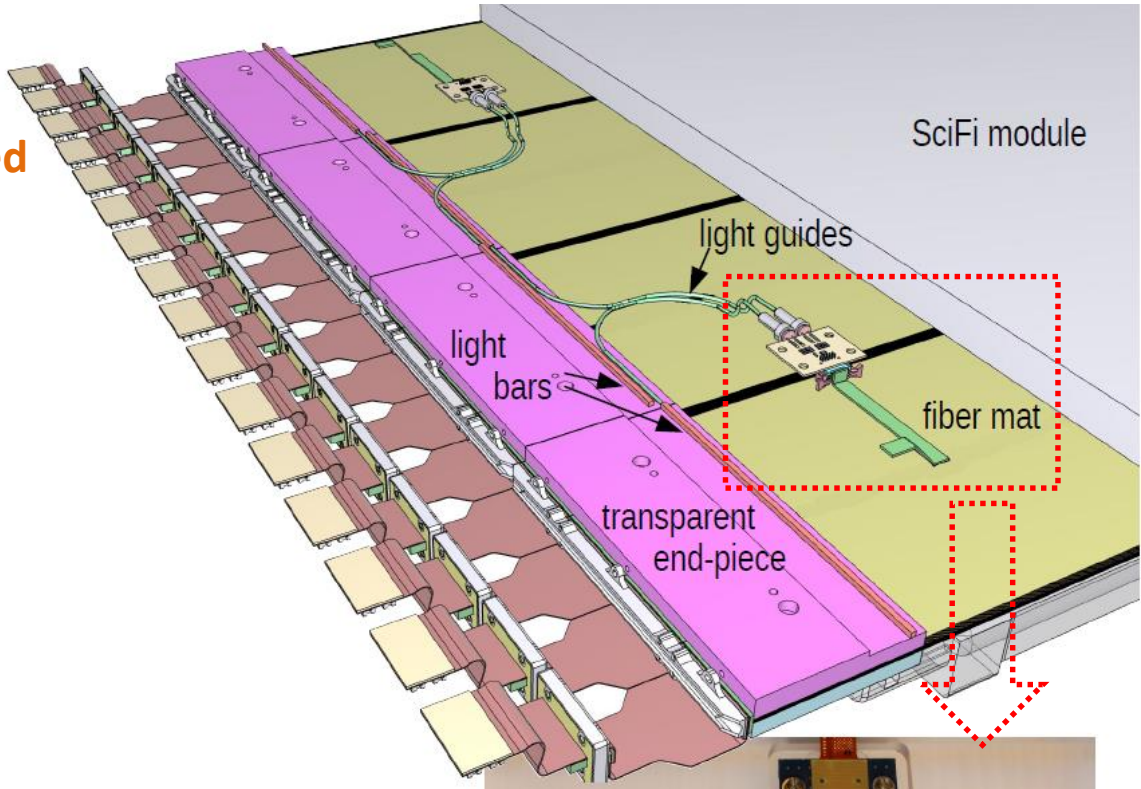
Totally ordered 5500 pcs → reived the first 500 pcs

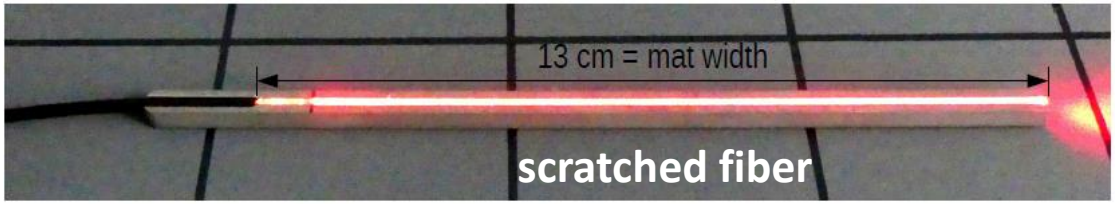


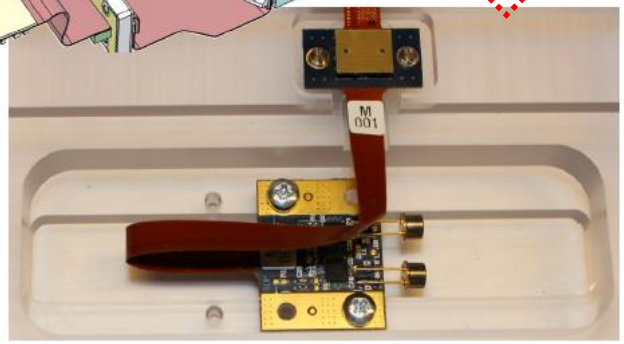
Light Injection System

Remarks;

- **5 ns short light pulses are generated with laser drivers and red laser**
- **light is guided to transparent end-pieces and emitted through a scratched fiber**

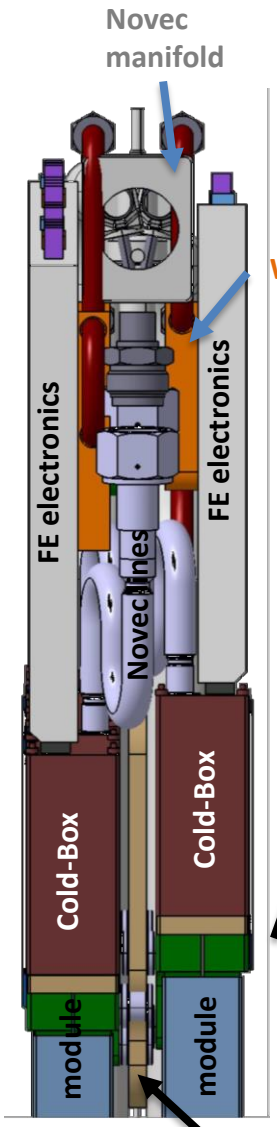


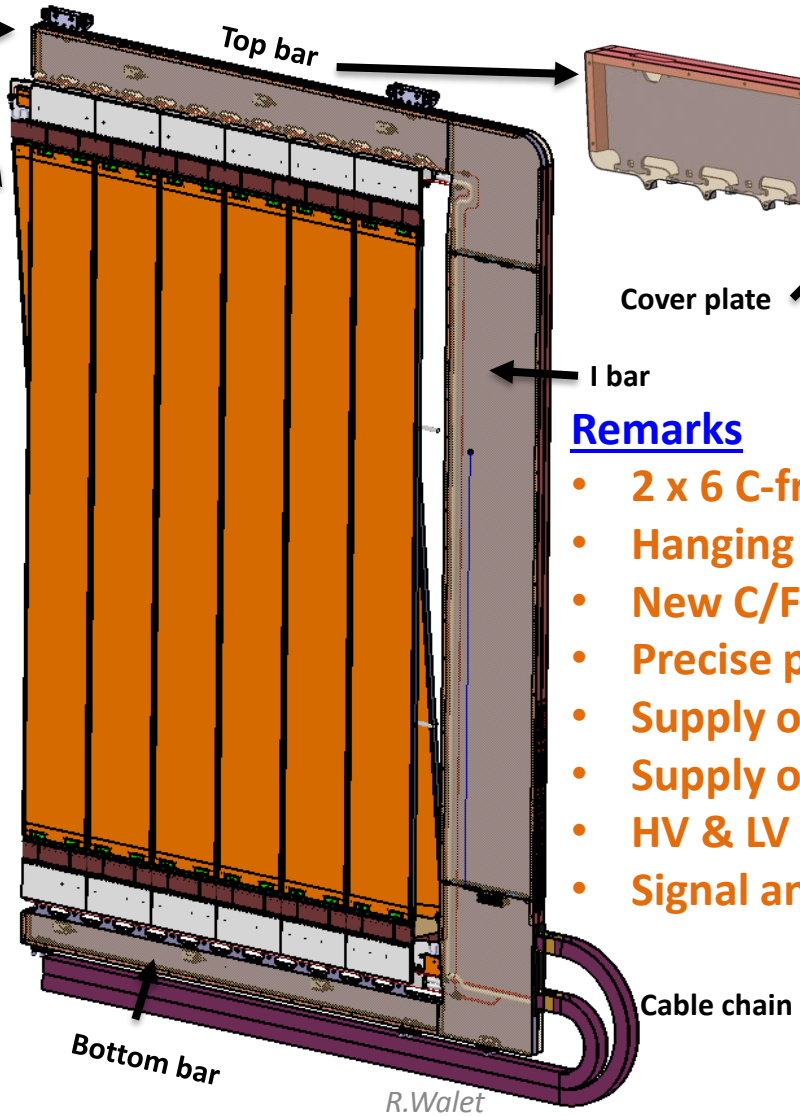


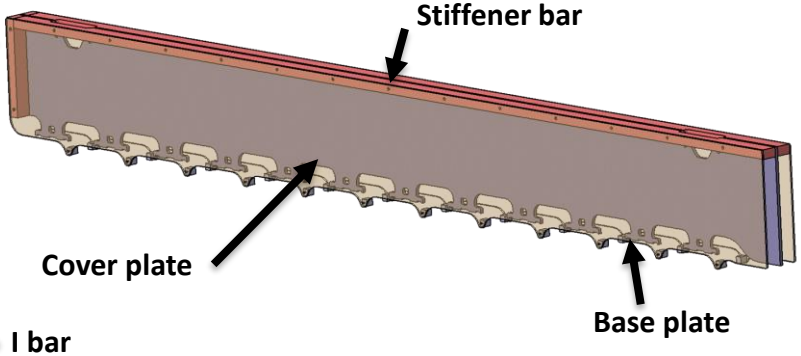


Infrastructure – Mechanics and services

Coordinated engineering efforts (6 institutes) on C-frame design and coherent integration of all services.



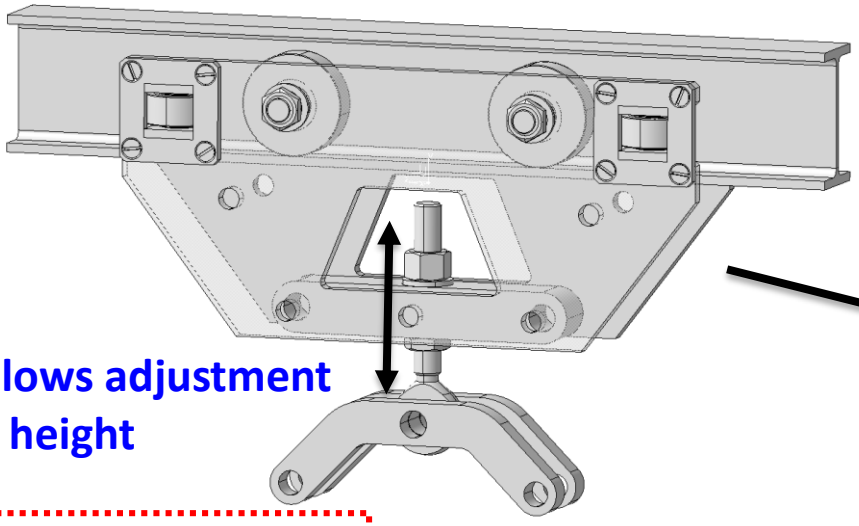




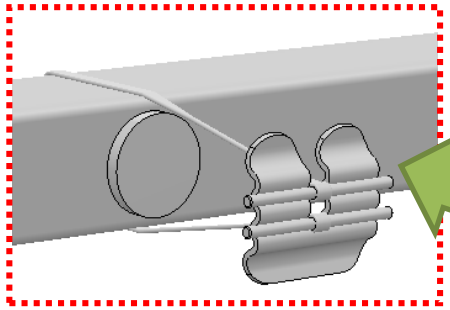
Remarks

- 2 x 6 C-frames
- Hanging under existing bridge,
- New C/Frame rail system
- Precise positioning of 2 x (5)6 modules
- Supply of Novec fluid (@-50C)
- Supply of cooling water
- HV & LV cables
- Signal and control fibres

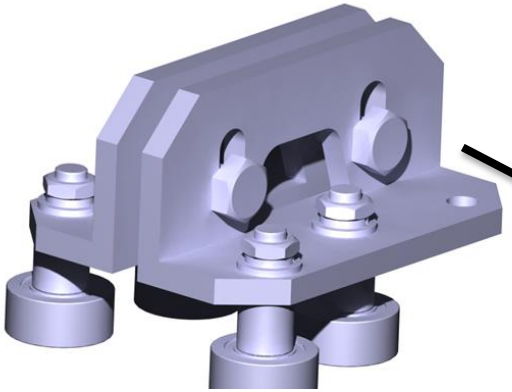
Infrastructure – Mechanics and services

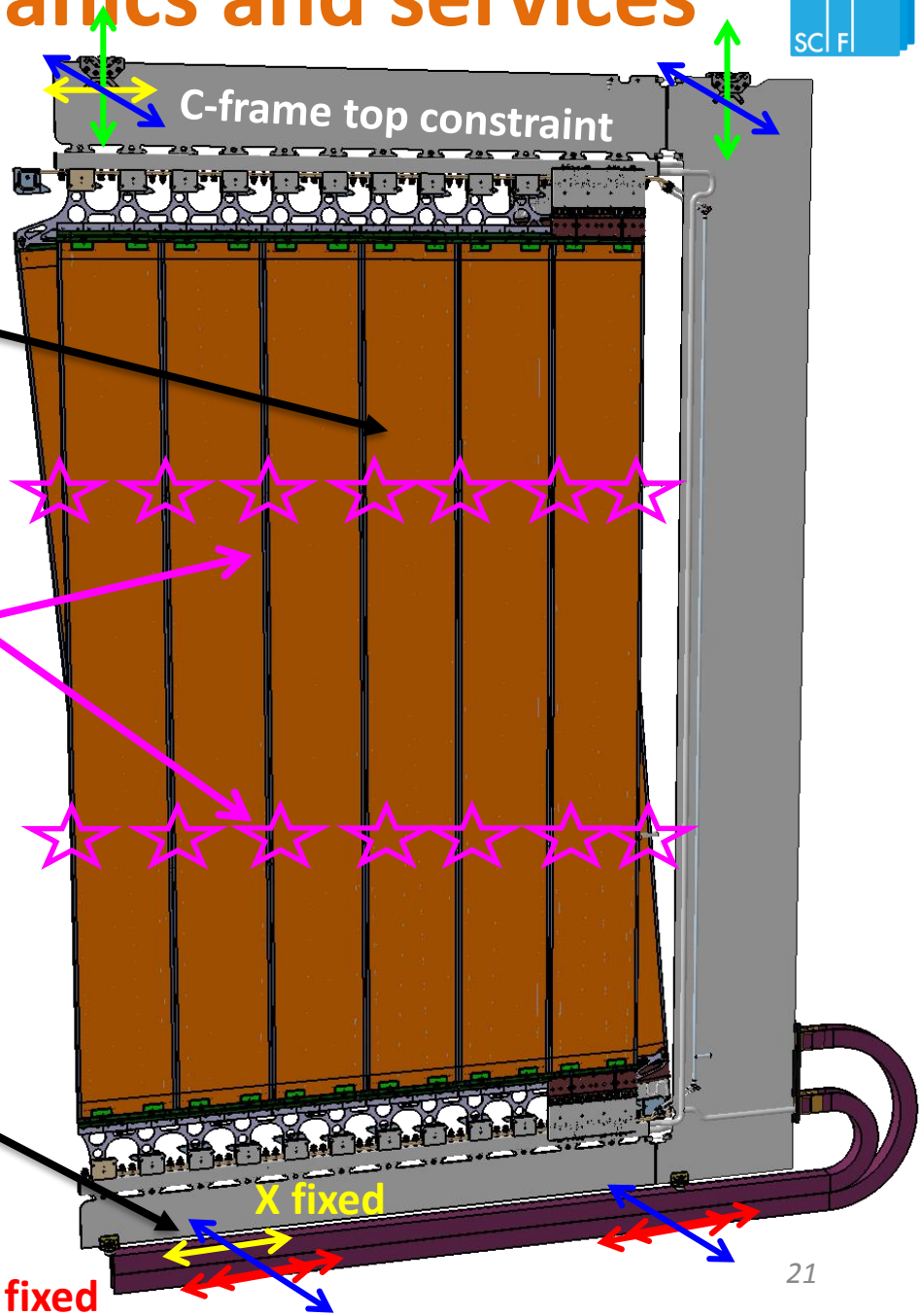


Allows adjustment in height

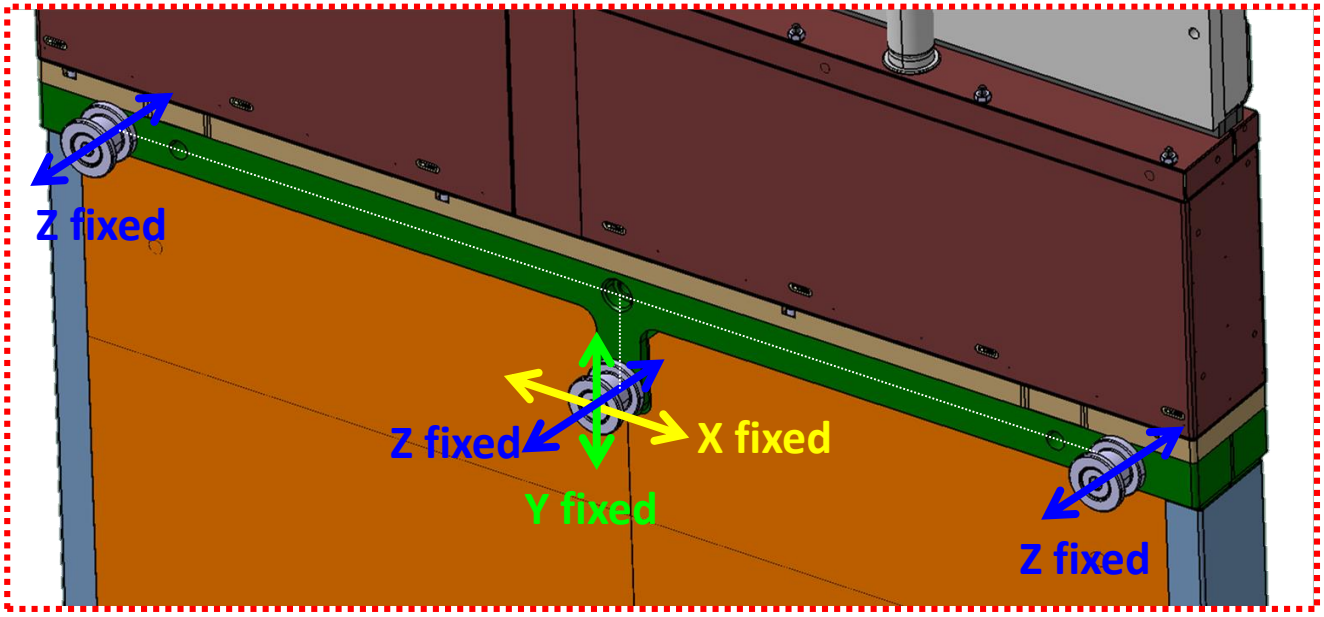


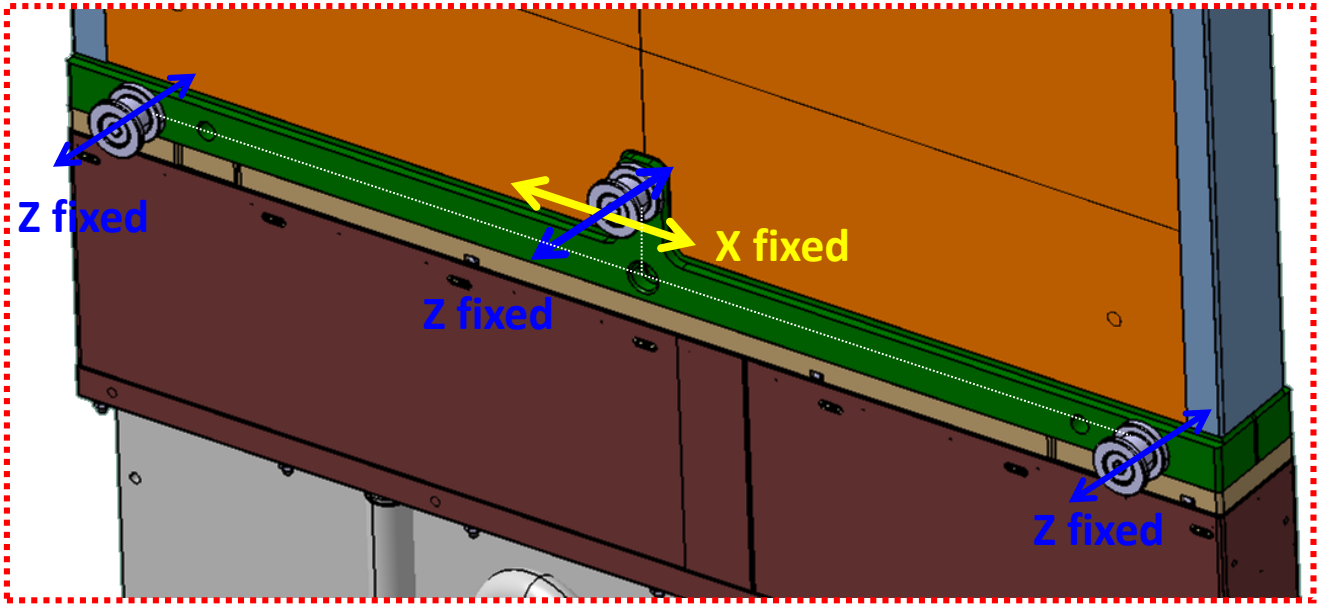
Clamping force in Z between modules

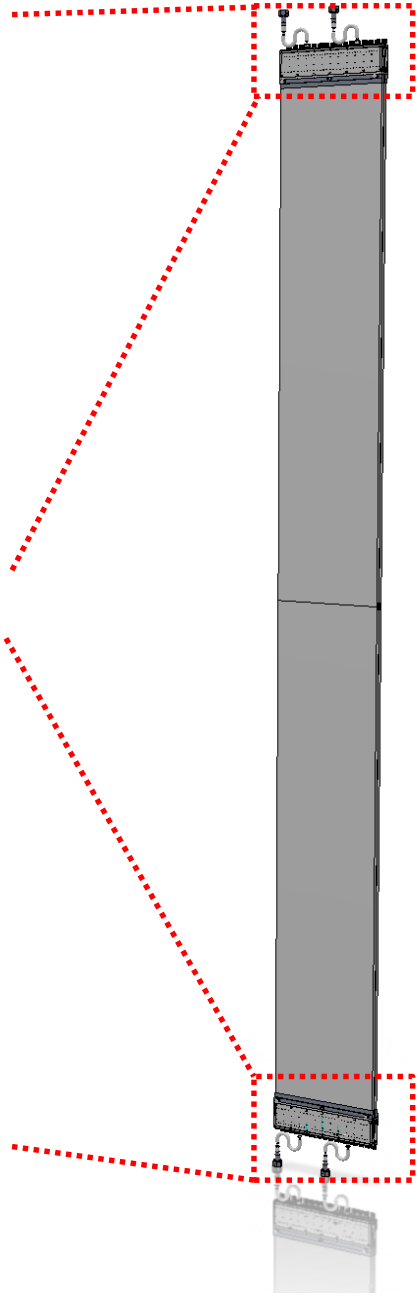




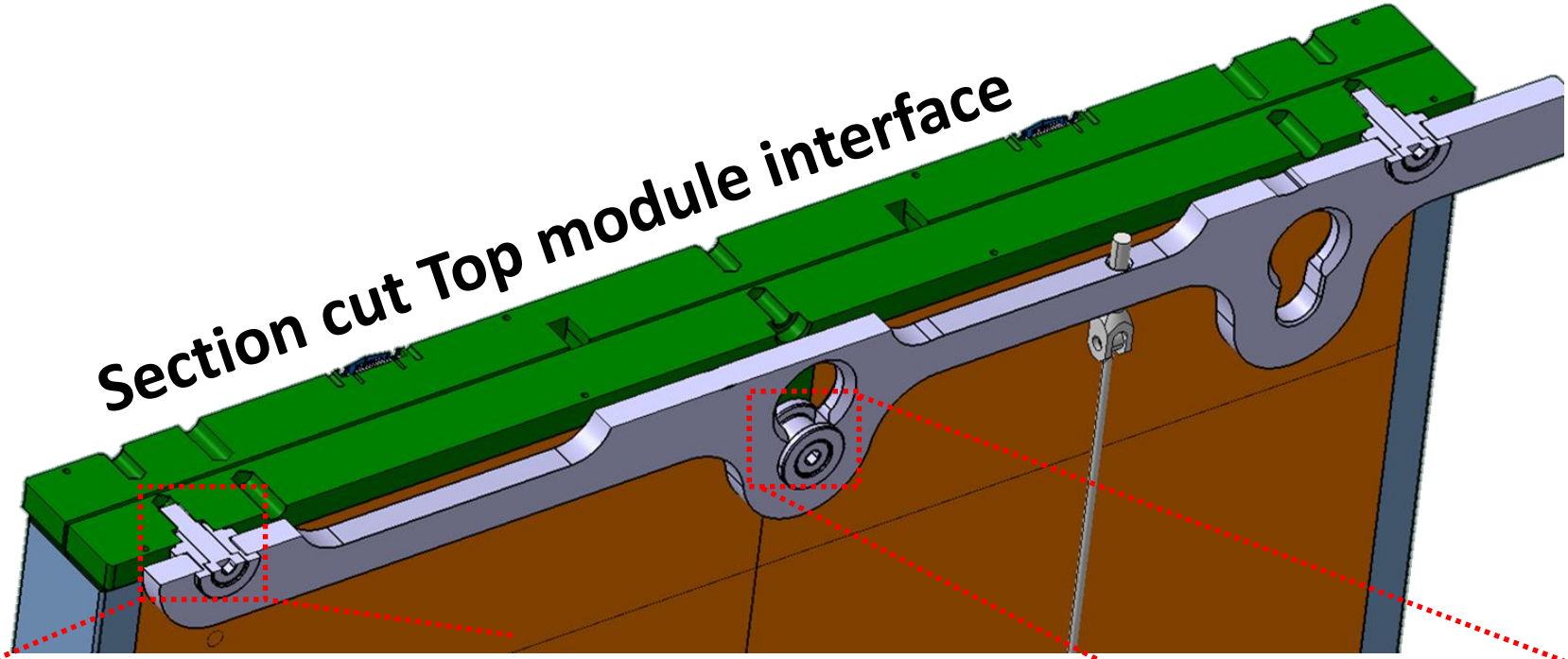
Infrastructure – Module Mount

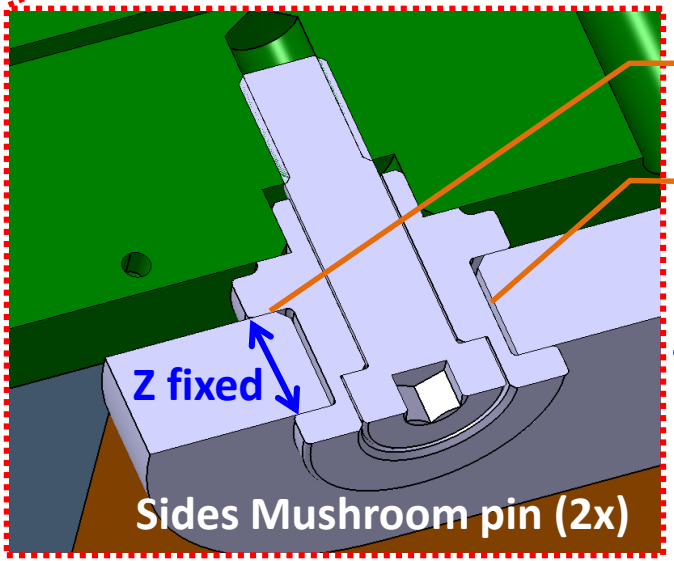






Infrastructure – Module Mount

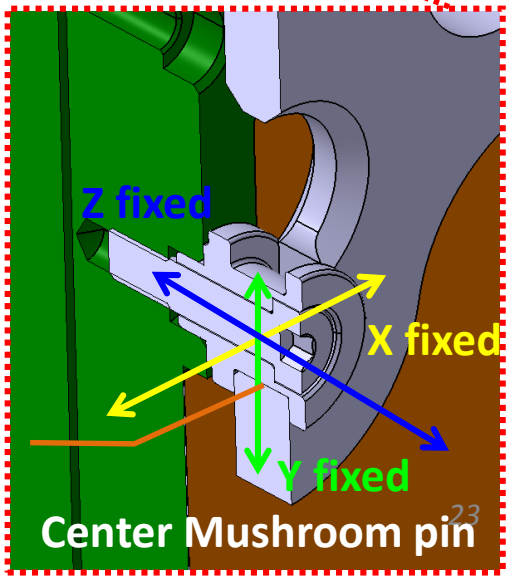




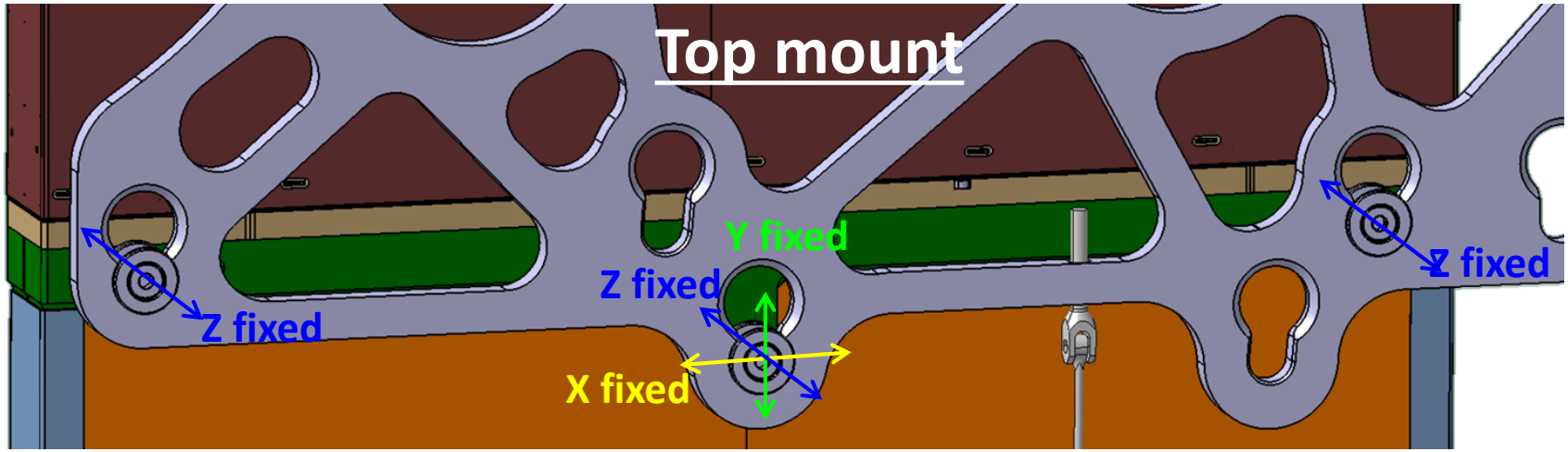
Small clearance in Z, +100/+20 [µm]

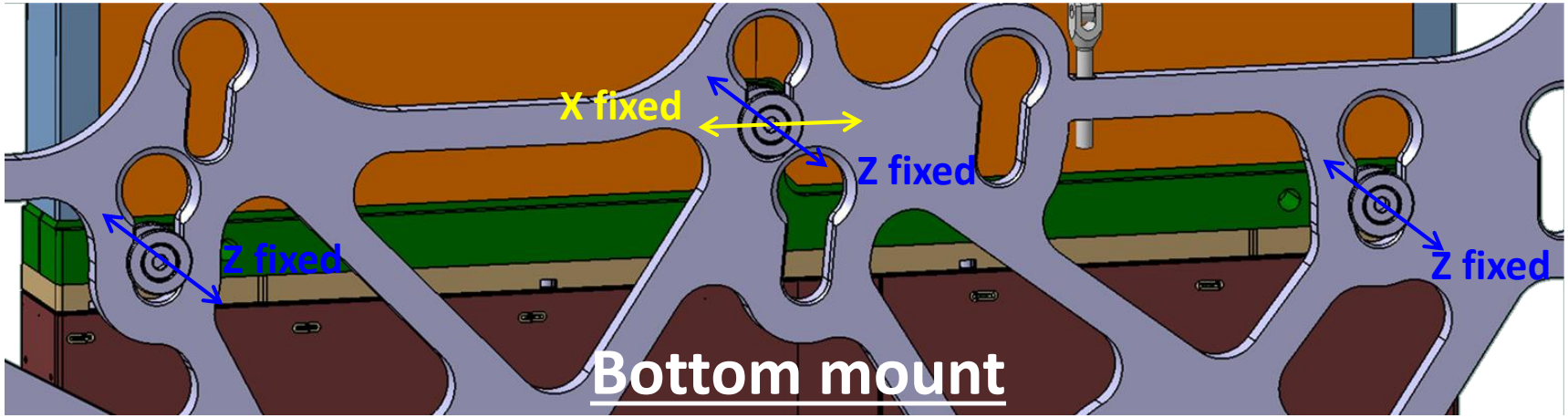
Radial clearance 0,3 [mm]

Tight fit in Z,X and Y by gravity and fixed by mechanical lock

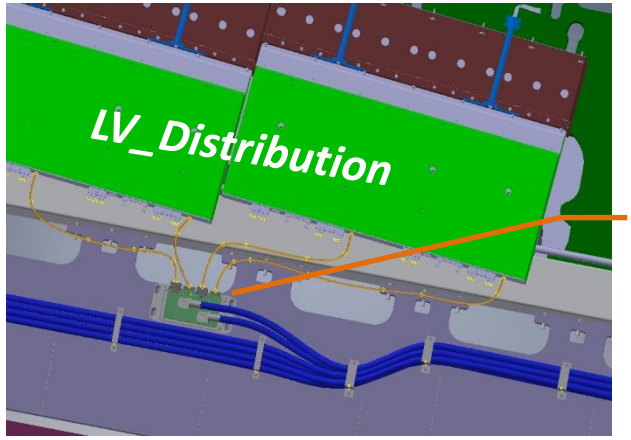


Infrastructure – Module Mount

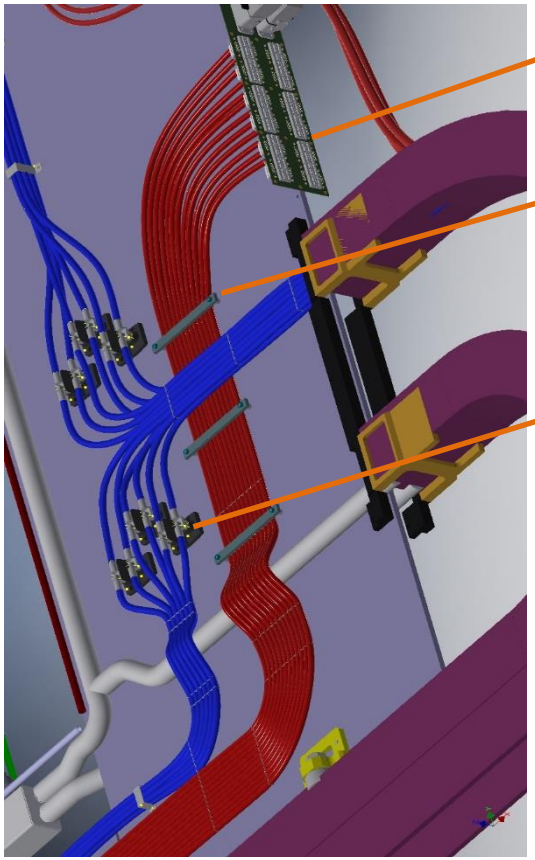




Infrastructure – Cabling



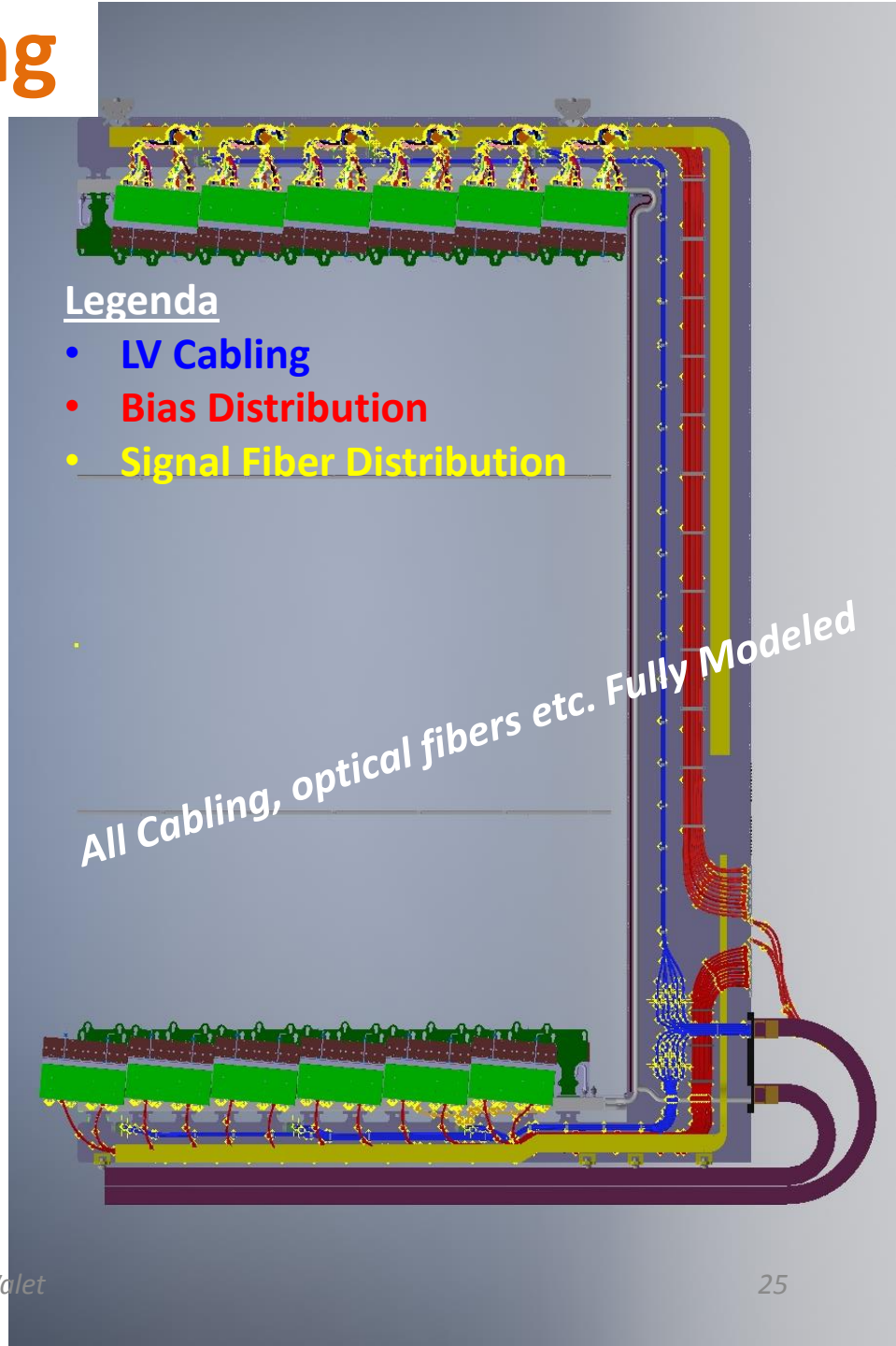
LV-Distribution BOX



Patch-Panel

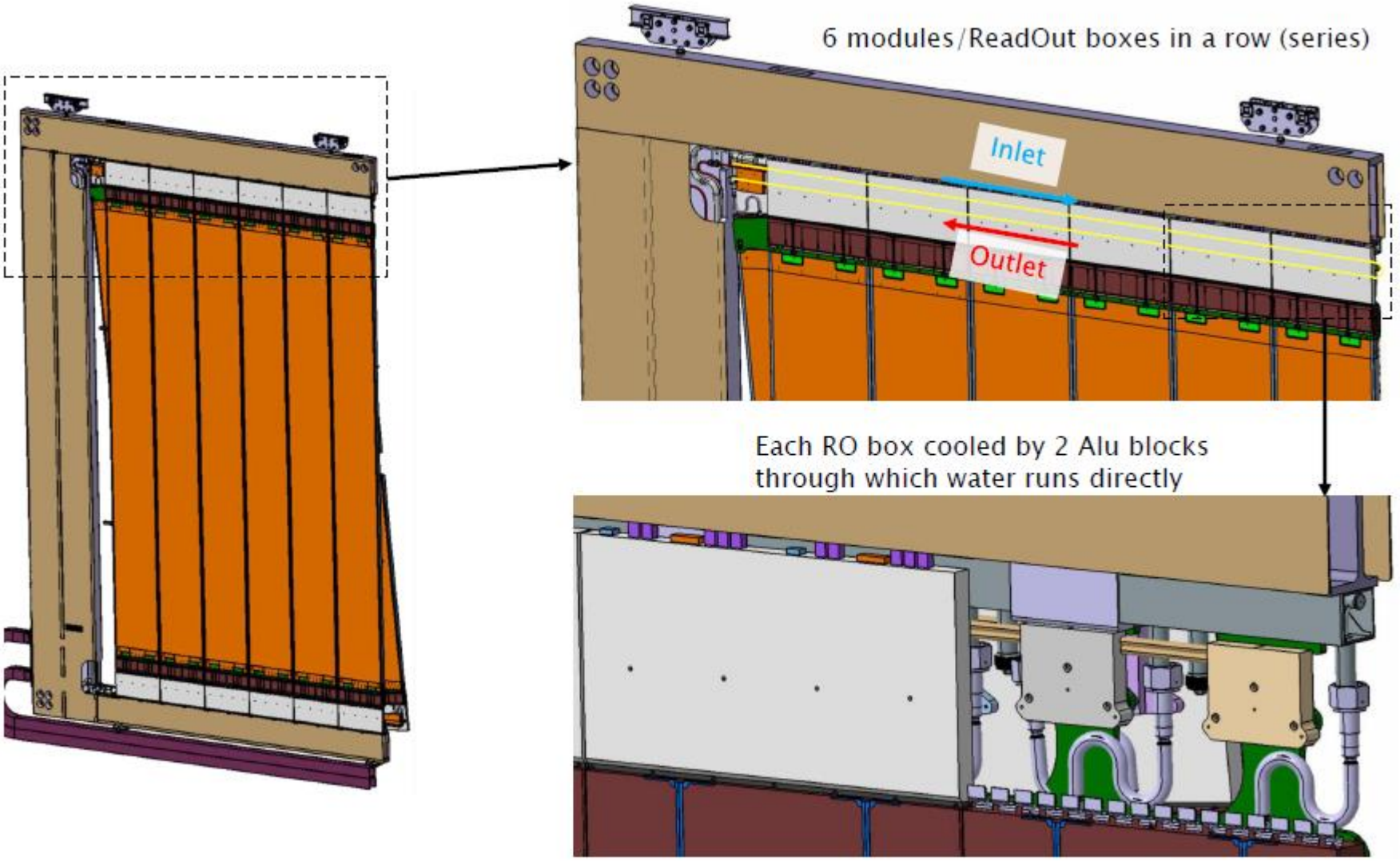
Cable Clamps

Cable Clamps



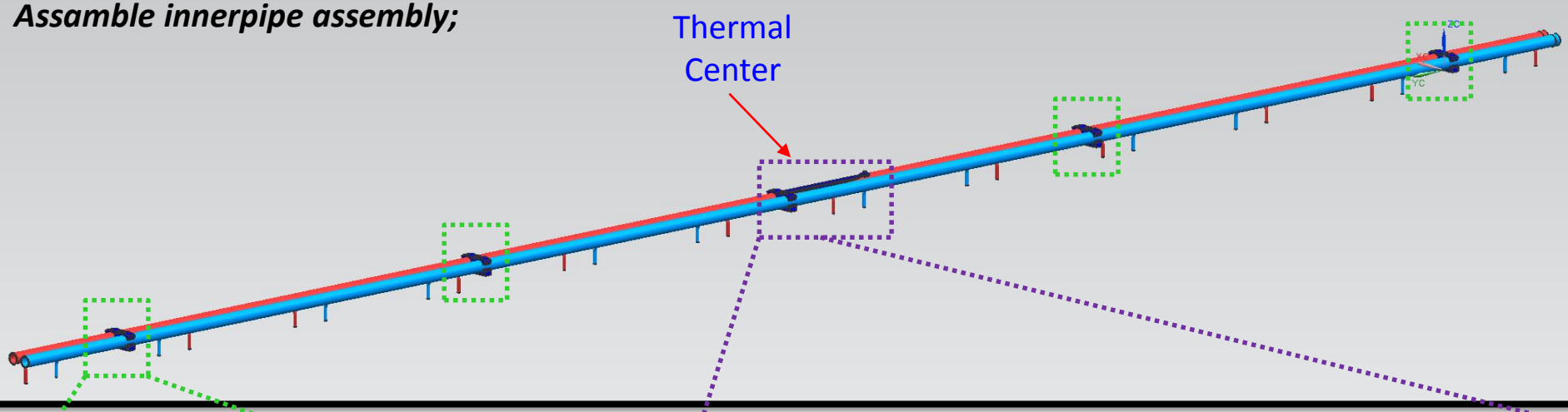
Infrastructure – Water (FEE) Cooling

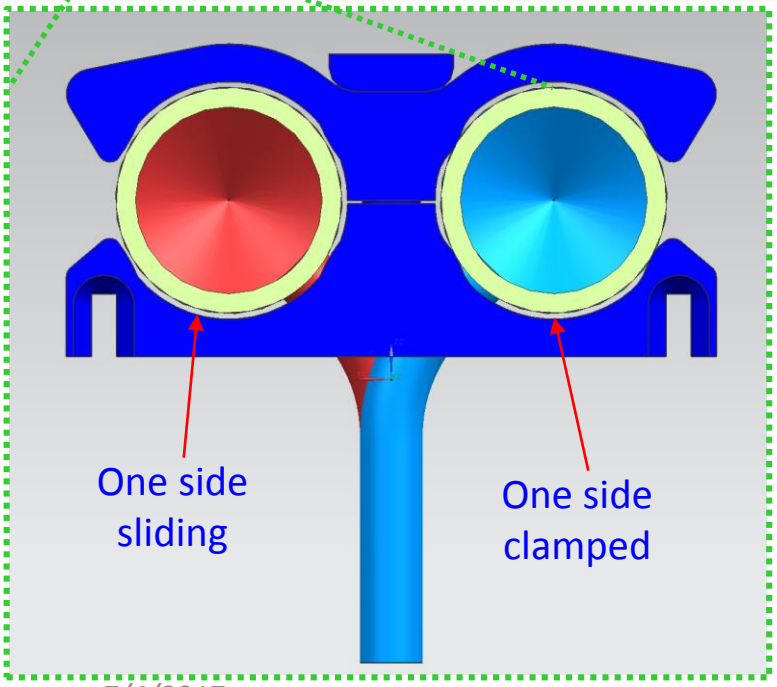
Water Temperature; 19[°C] / Cooling of 6x FEE Boxes in Series / ΔT of 0.5-1 °C

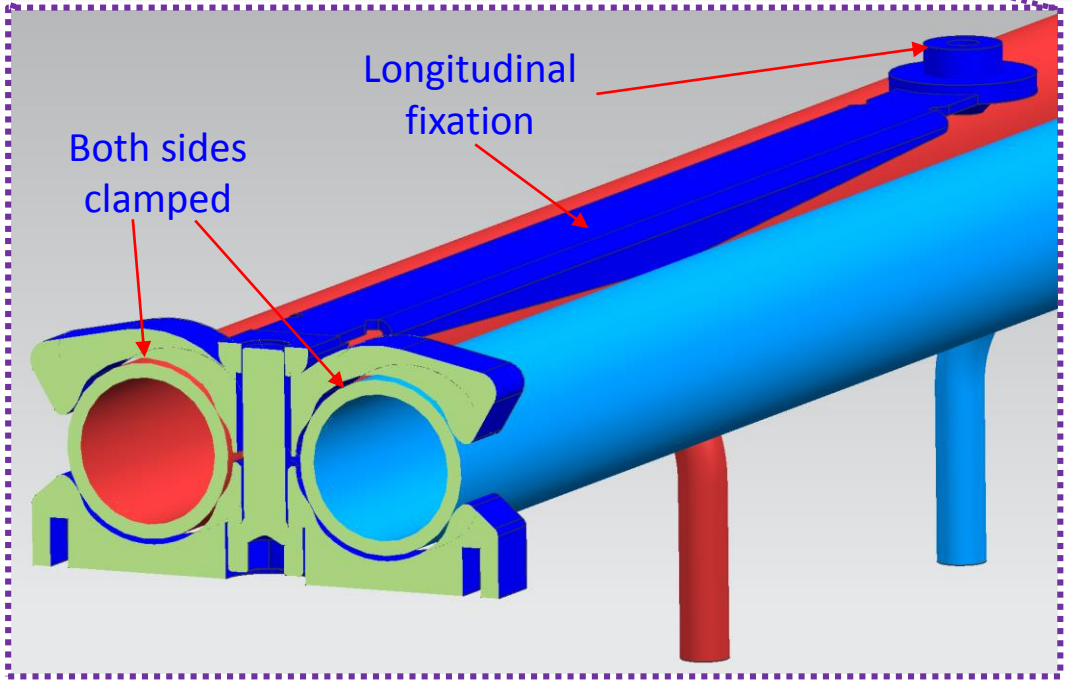


Manifold – Assembly Step 4.

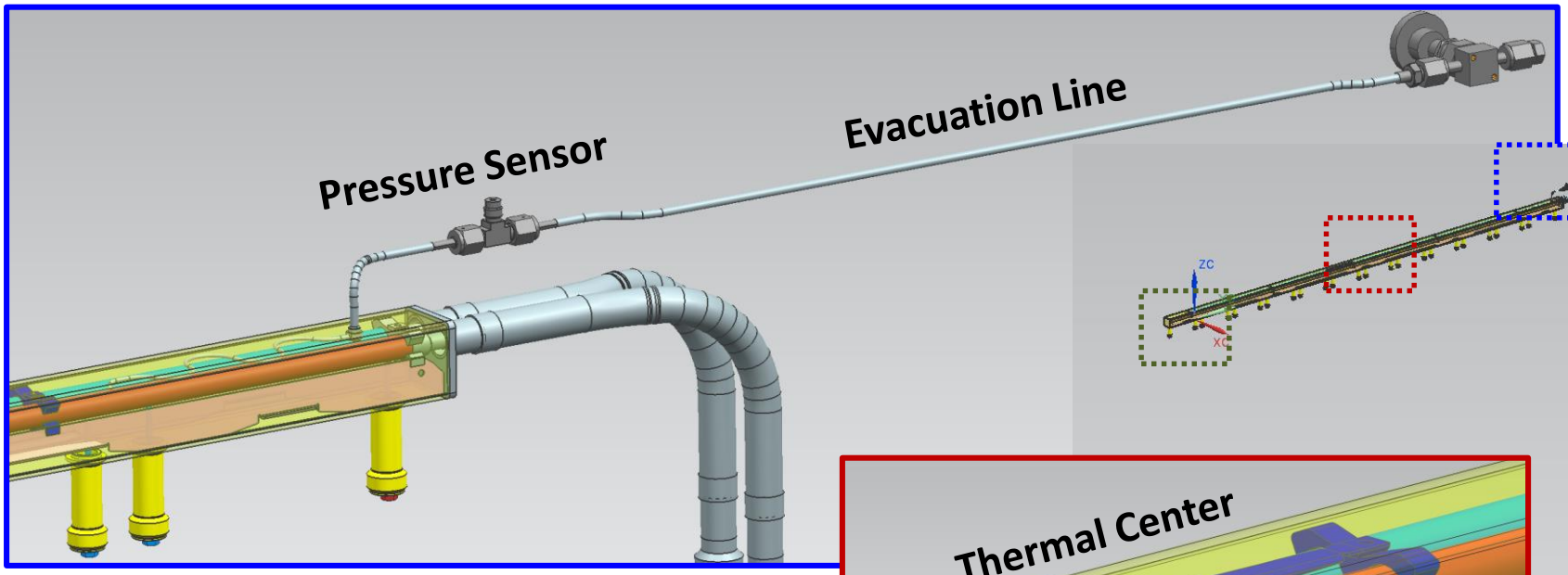
Assamble innerpipe assembly;

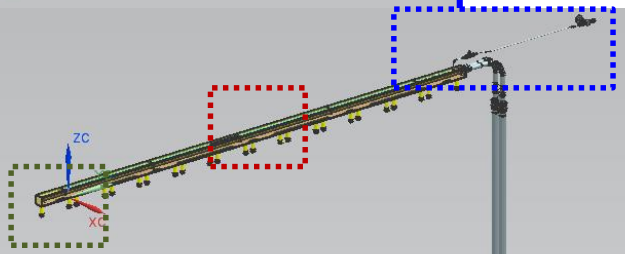


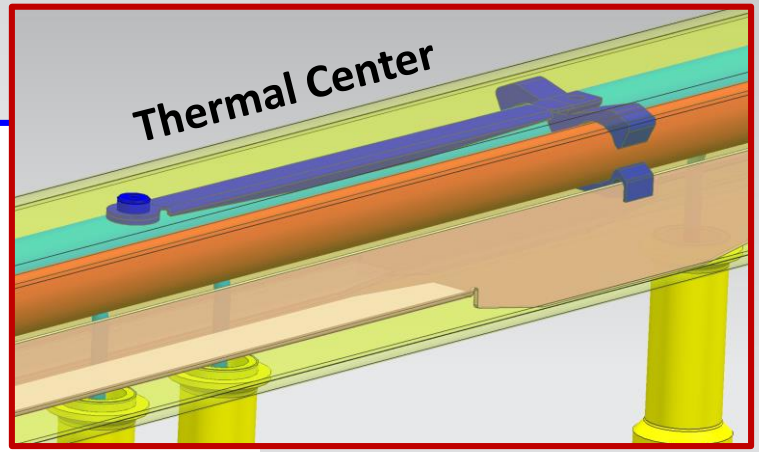


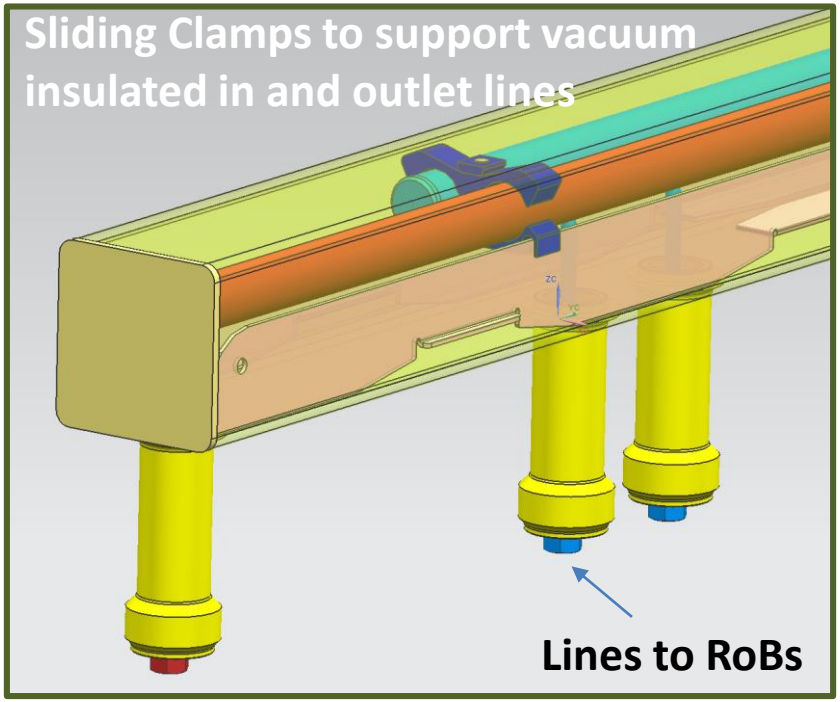


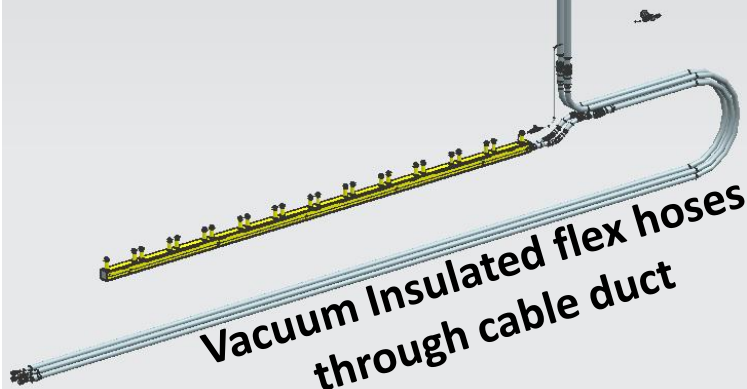
Infrastructure – Novec (SiPM) Cooling











R.Walet

Status:

SciFi project has transited to production phase (fibres, mats, modules)

SiPM arrays: model chosen, tendered and ordered. Pre-series received

Cold box: mature design, preparing for mass production

Intense effort on C-frame design and service integration

Outlook:

we are on track for starting the assembly of the first C-frame in spring 2018 and completion in autumn 2019

A very busy year ahead!

Thanks to a great spirit and cooperative attitude in the SciFi-team

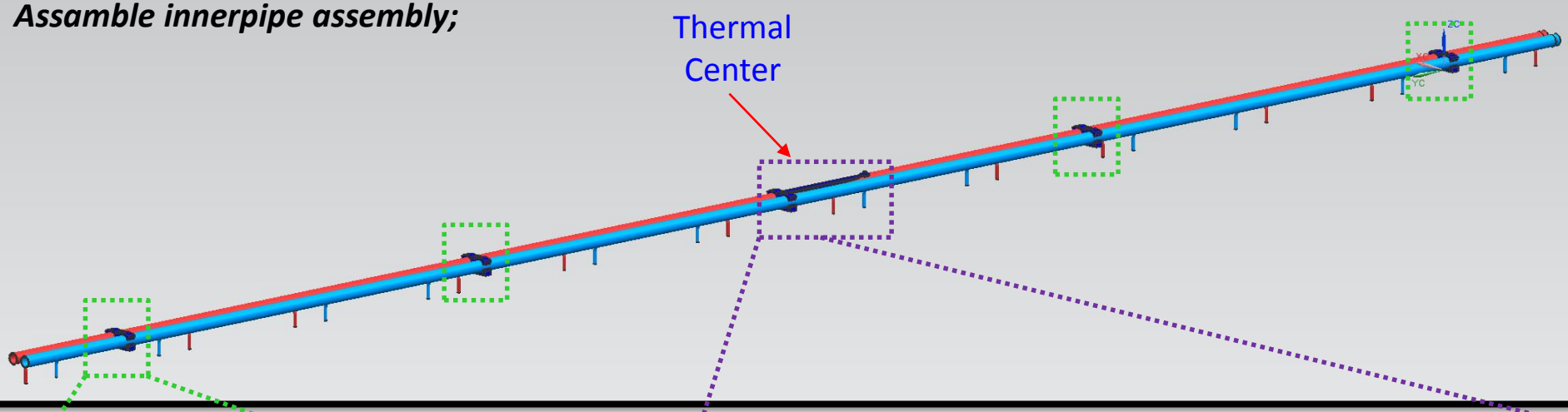
Backup

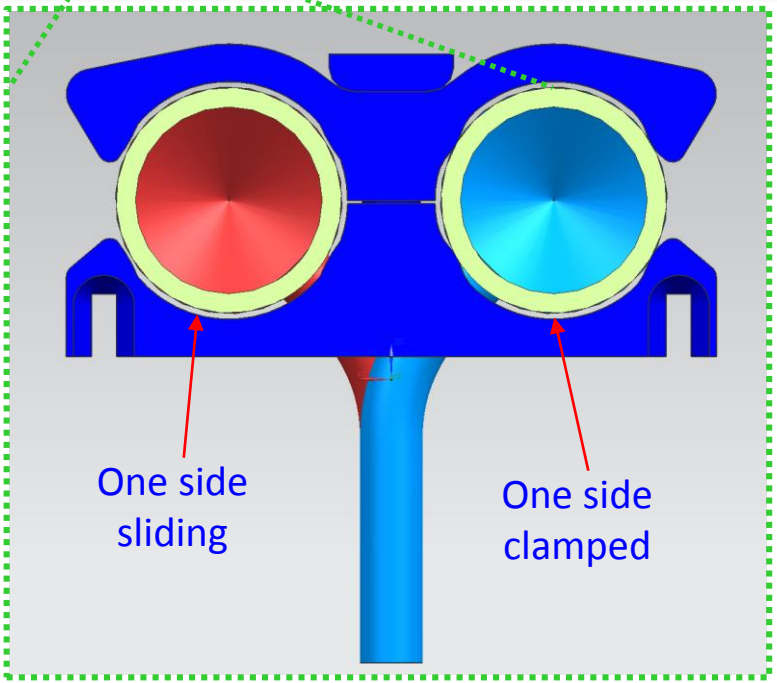
Specifications for water cooling plant

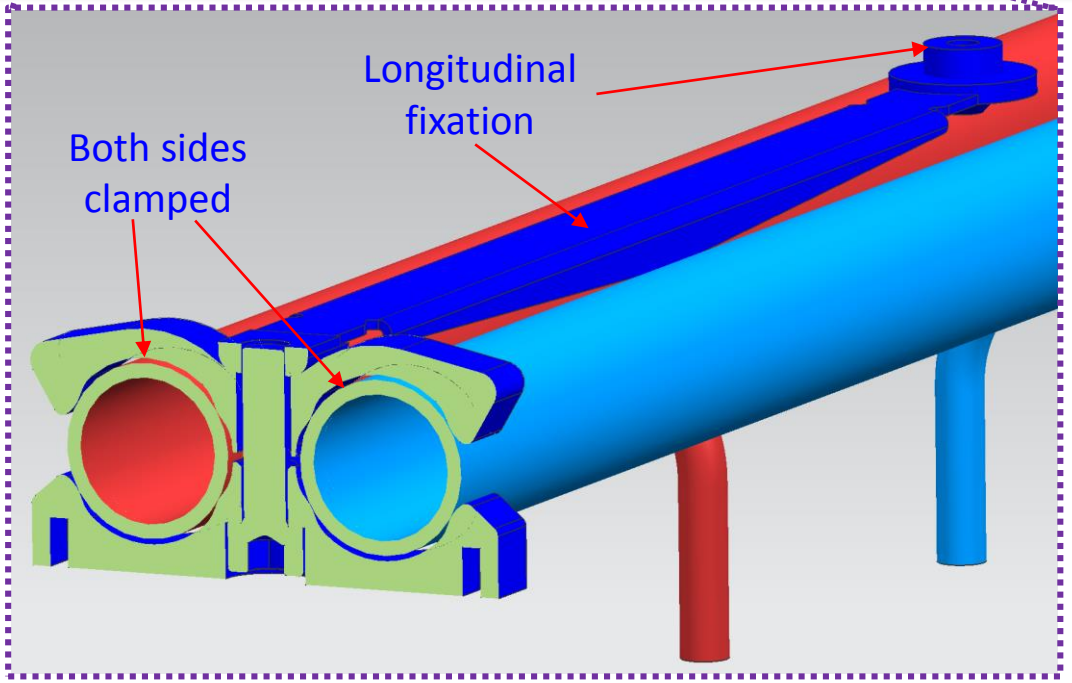
- Power to dissipate :
  - 1 ROB/Electronic box = 120 W (w. 15% margin)
  - 2 ROBs per module, 128 (144) modules
  - 30,7 kW (34,6kW) in total
- Coolant : Demineralized water at 19°C
- Flow rate :
  - Between 1l/min and 4l/min per branch of 6 ROBs in series
  - 4 branches per C-frame, 12 frames
  - Between 2,9m^3/h and 11,5m^3/h
- ΔT inside the detector : between 3 and 6°
- Pressure Drop : to be evaluated precisely (max expected 6 bars)
- Reuse existing manifolds located under the OT
- Aluminium (or Copper) tubing

Manifold – Assembly Step 4.

Assamble innerpipe assembly;

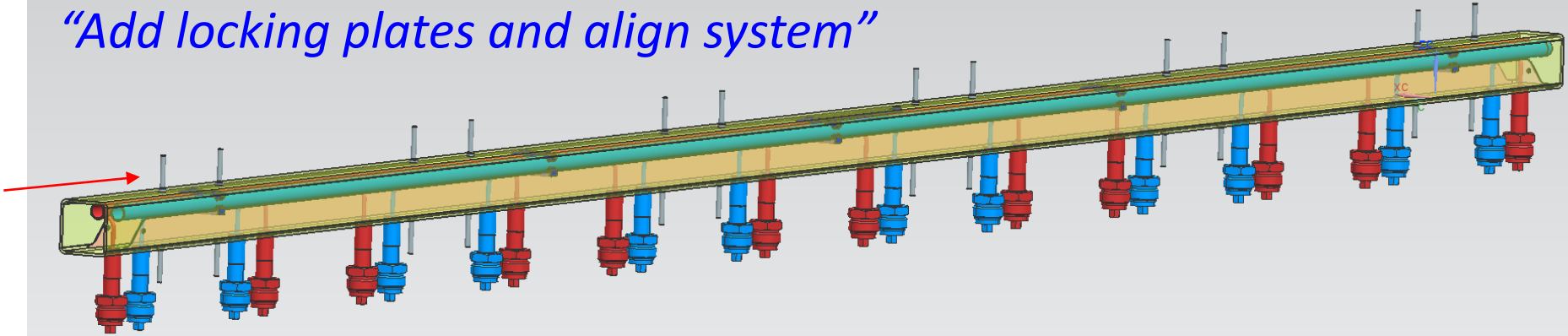


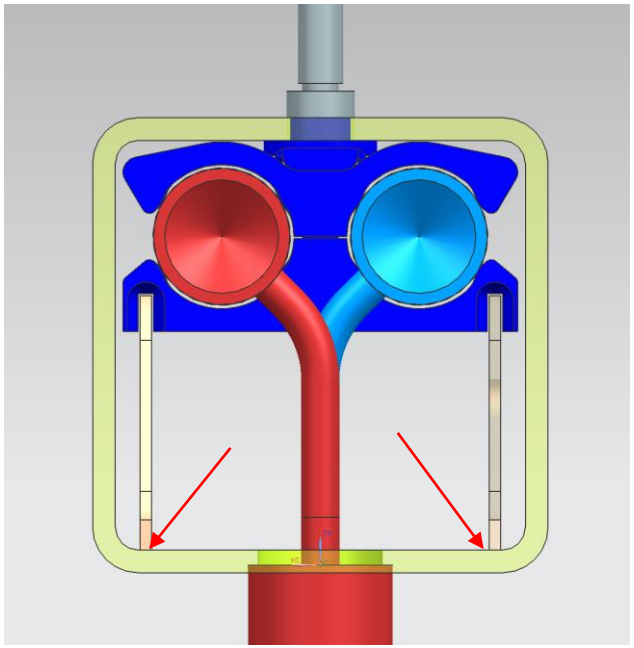




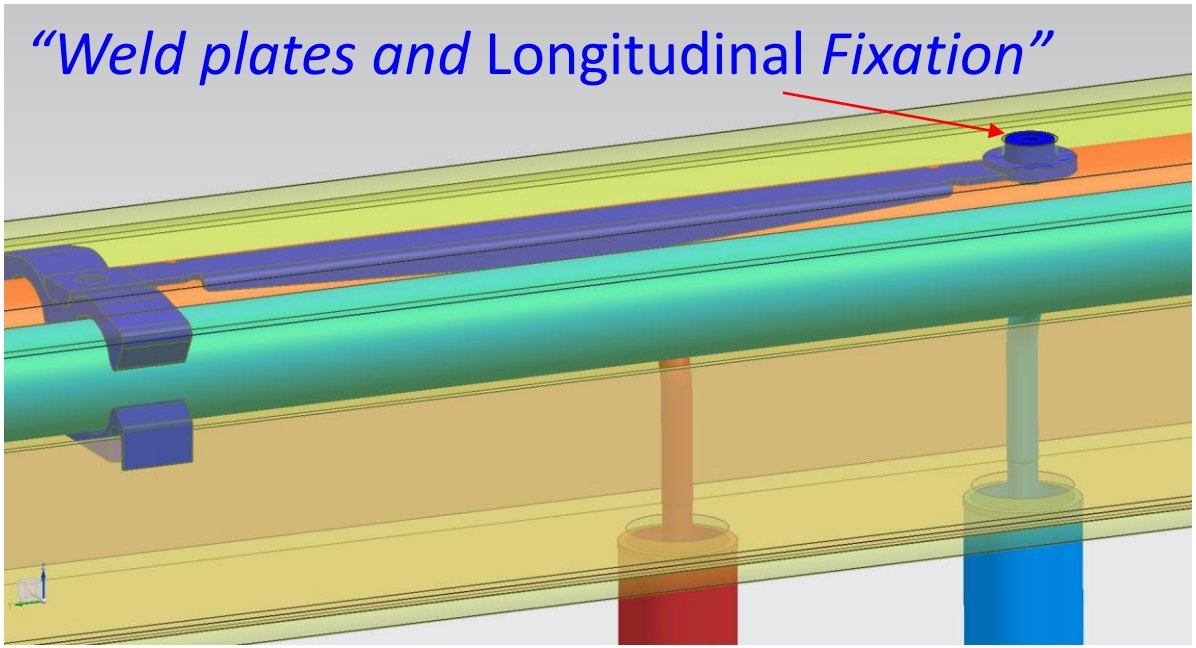
Manifold – Assembly Step 6.

"Add locking plates and align system"

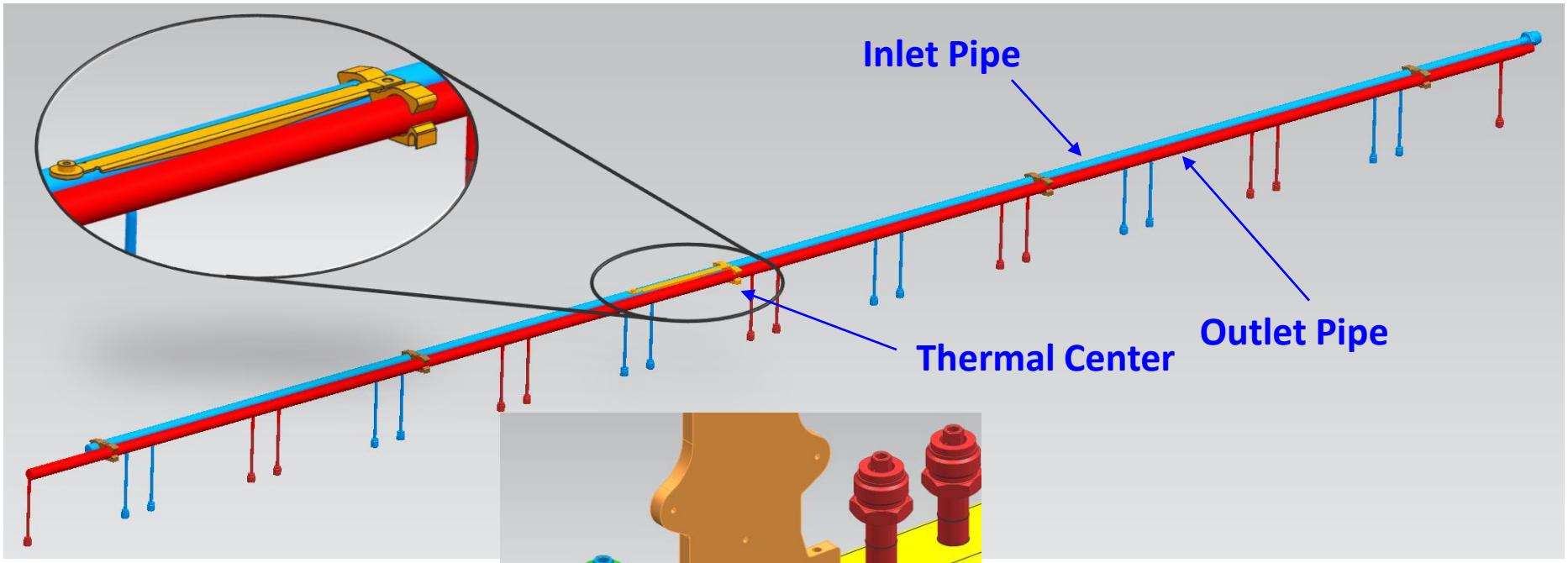


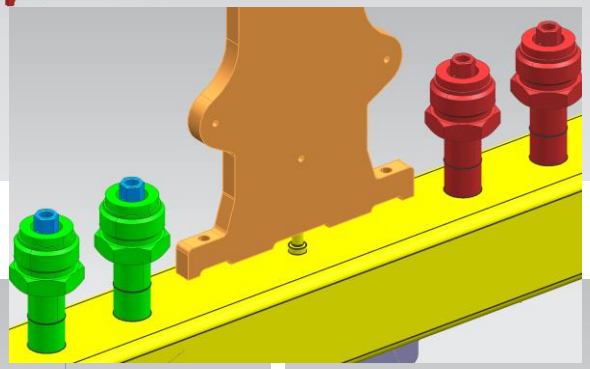


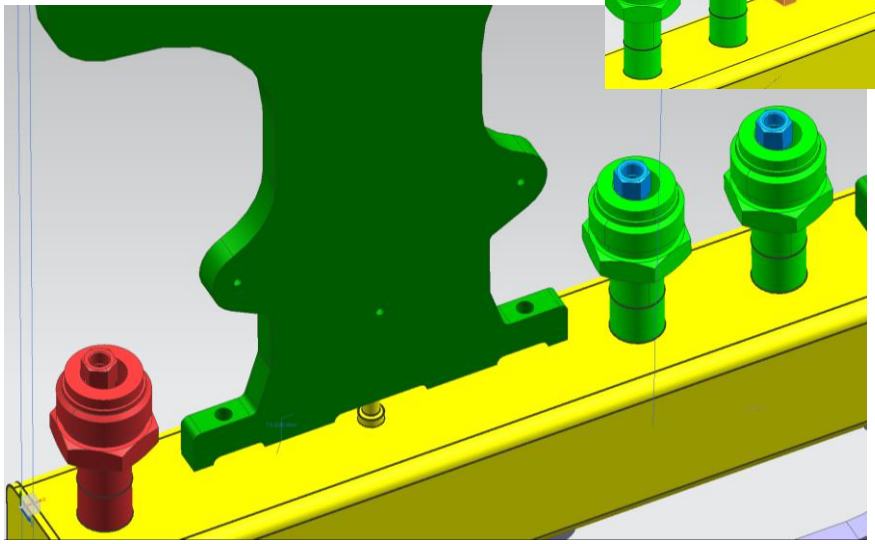
"Weld plates and Longitudinal *Fixation"*

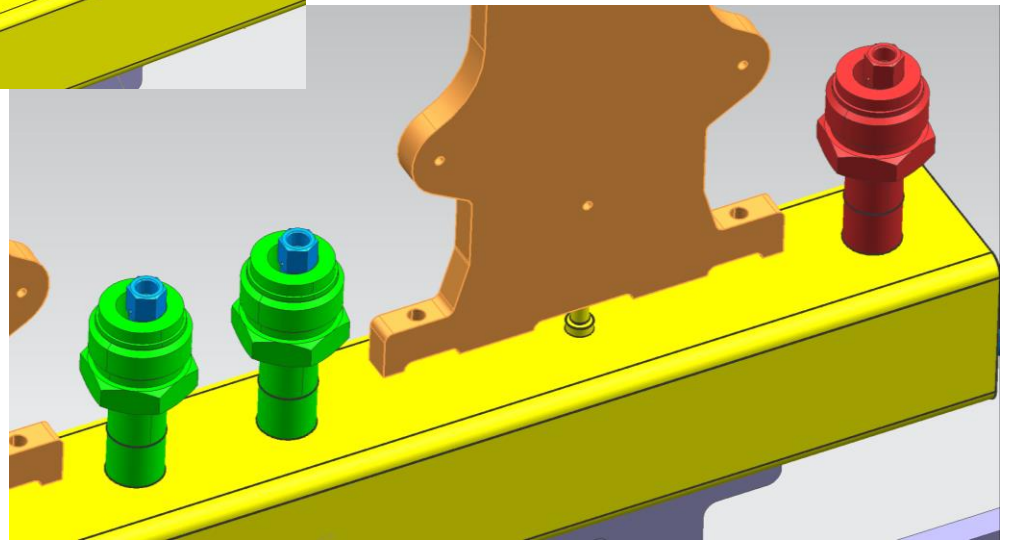


Inner Pipes

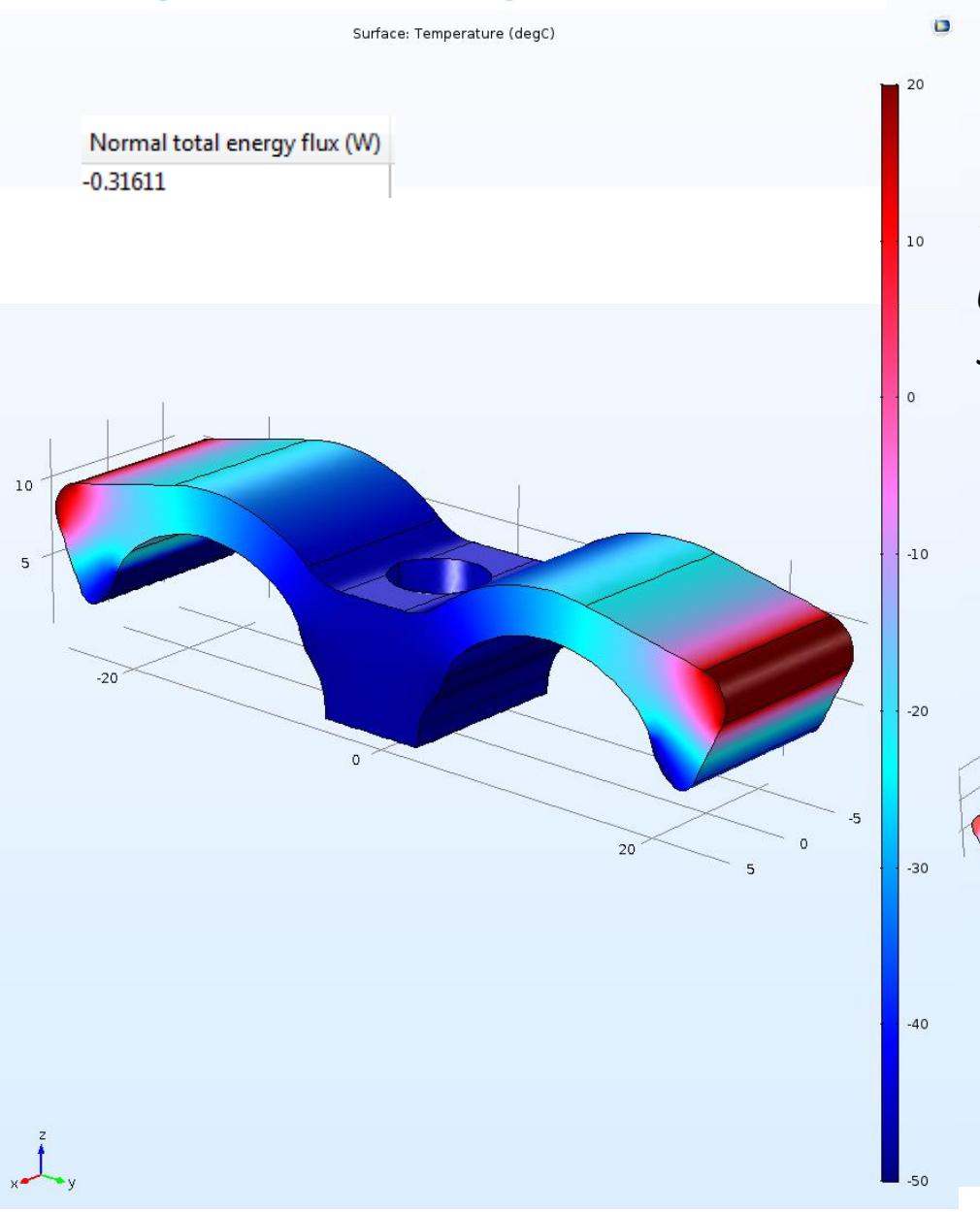


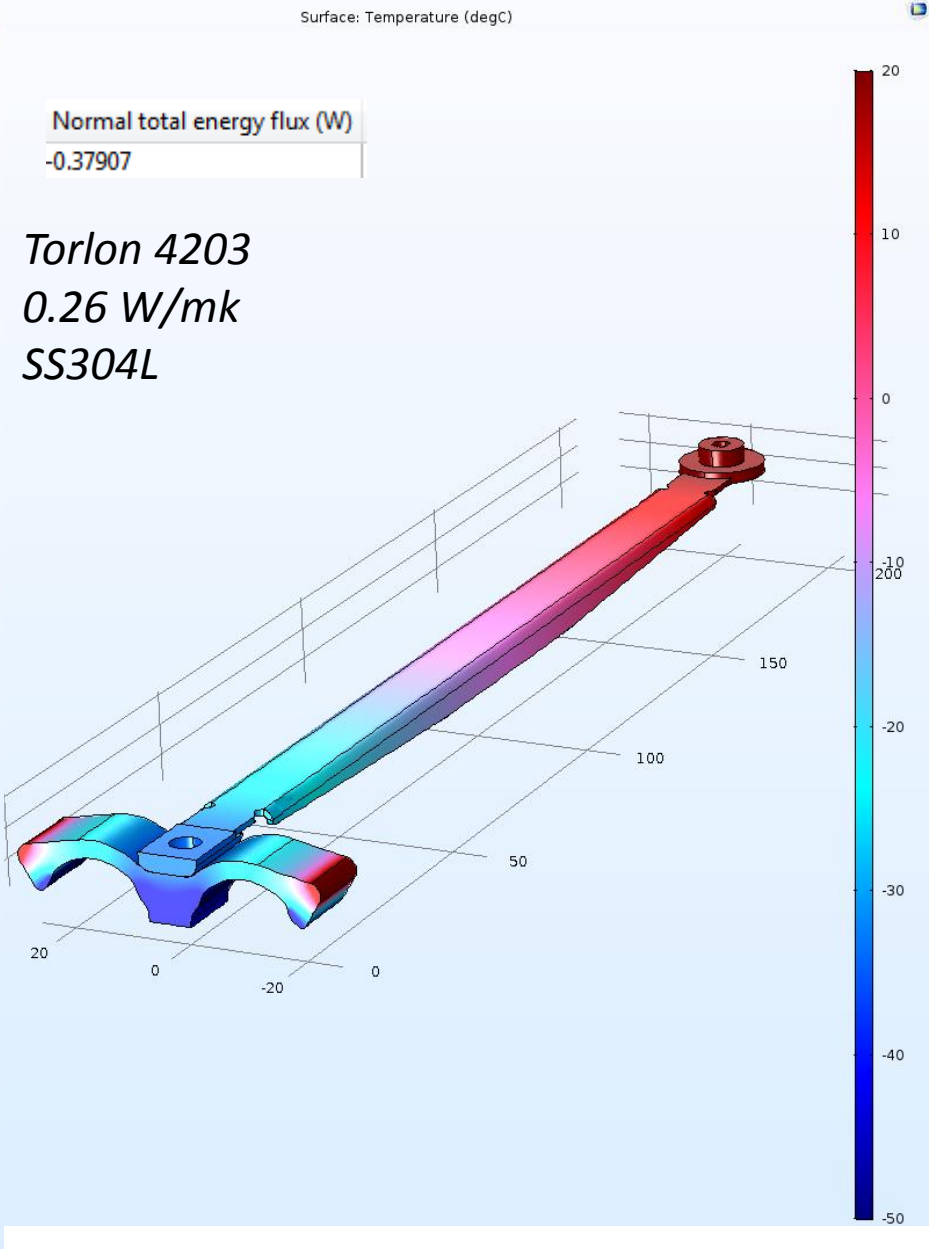




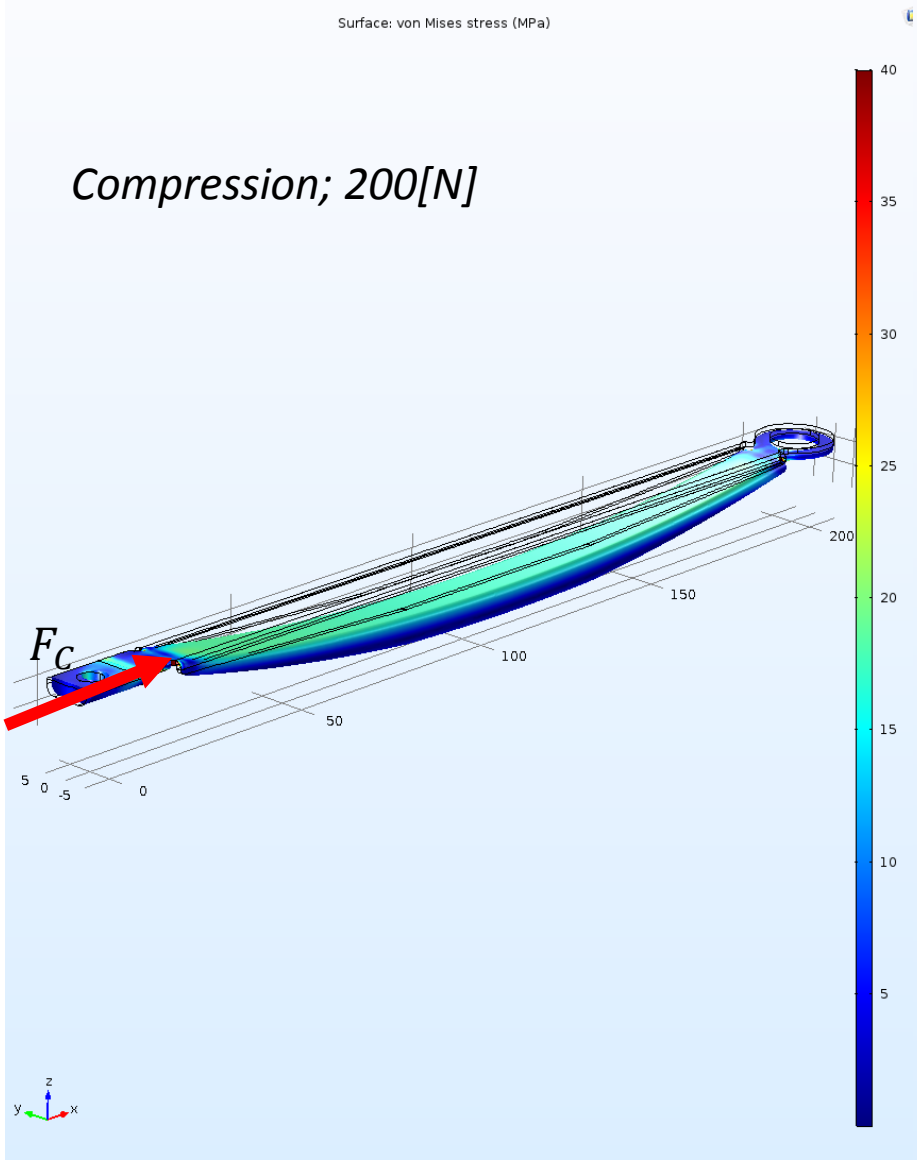


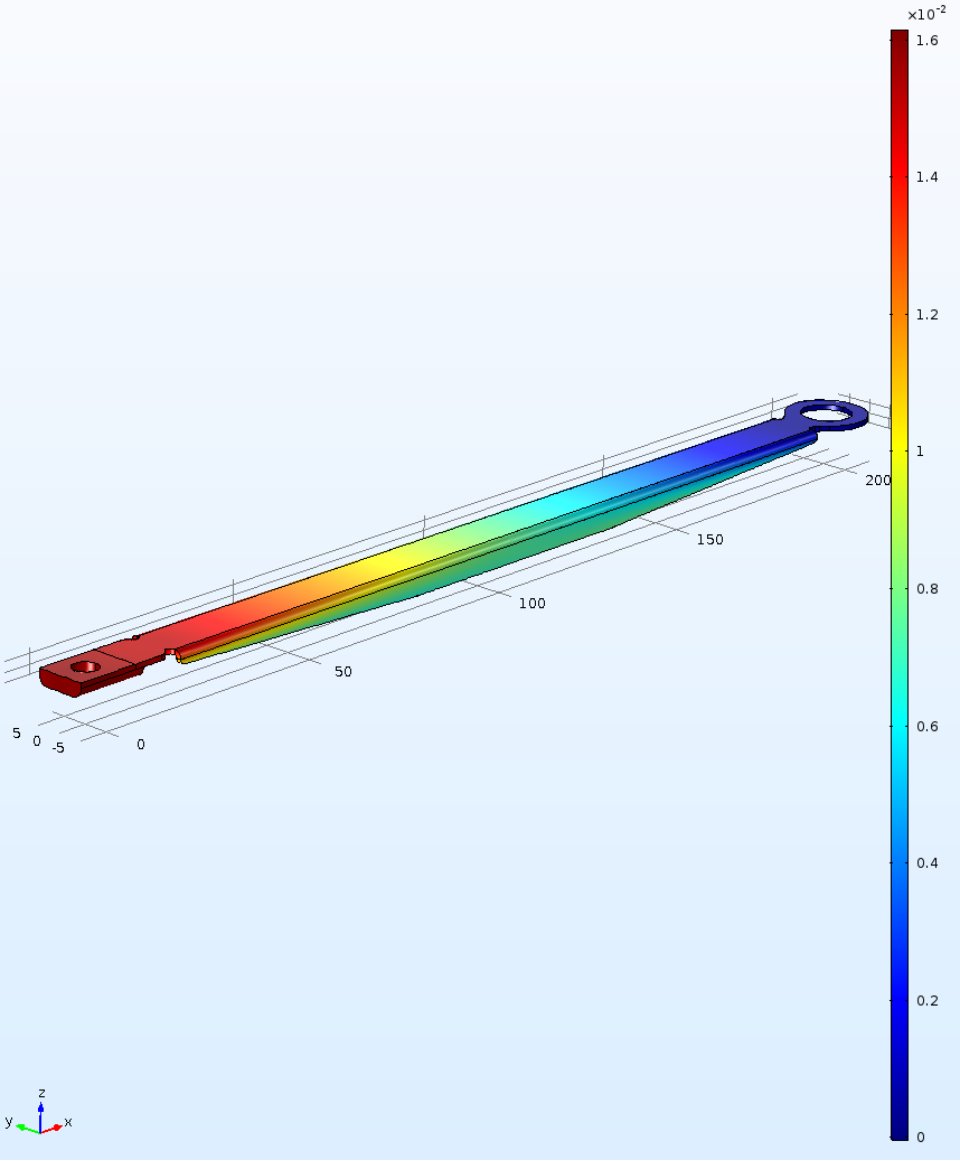
Pipe Clamps; Heat Loss



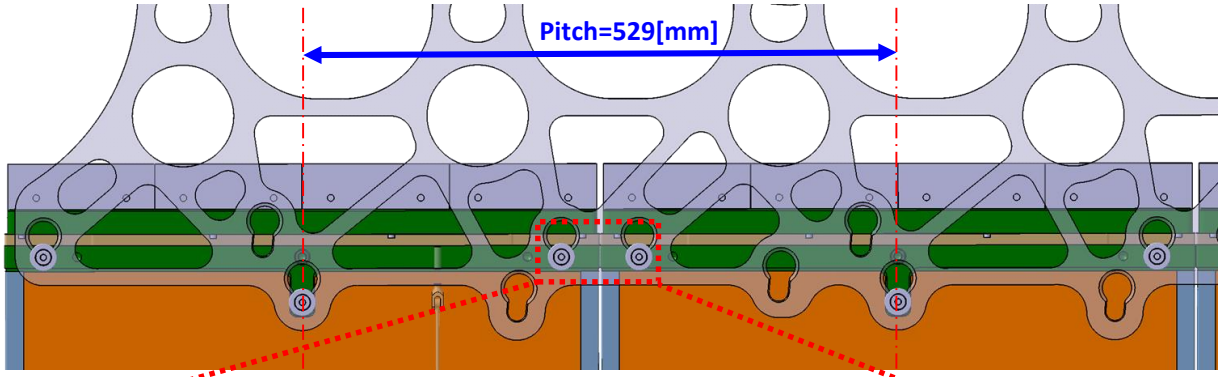


Pipe Clamp; Stress





Infrastructure – Module Mount



Lock Mechanism Not shown