LHCb Scintillating Fibre Tracker

Comparison of kinematic and structural FEA with measurements on a prototype

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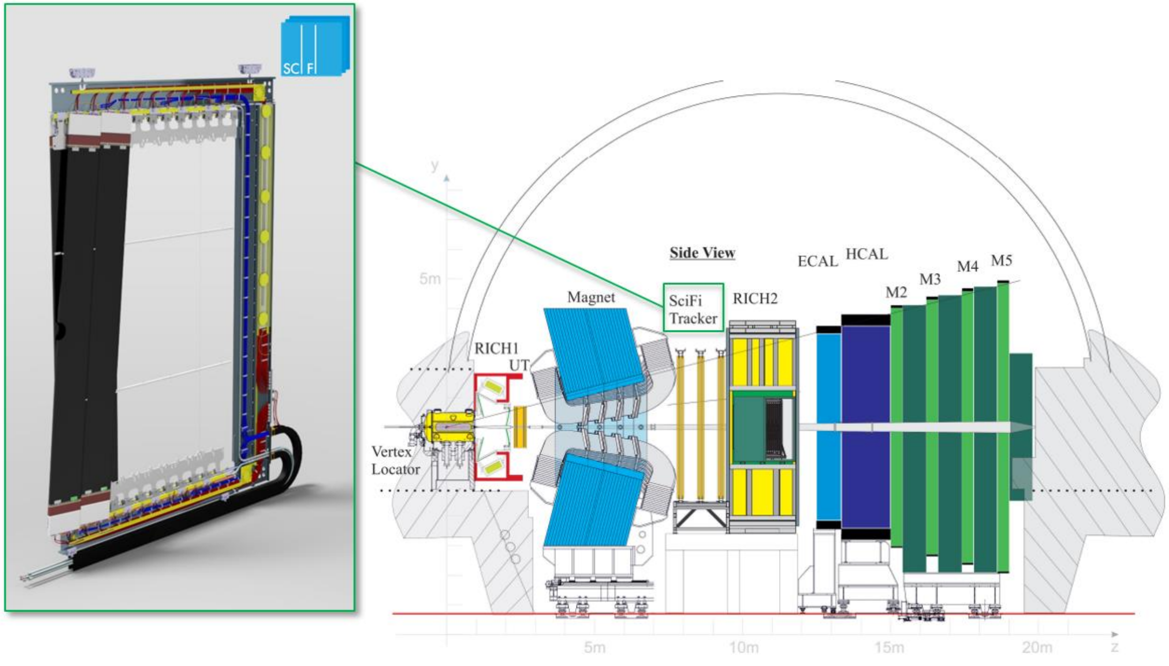
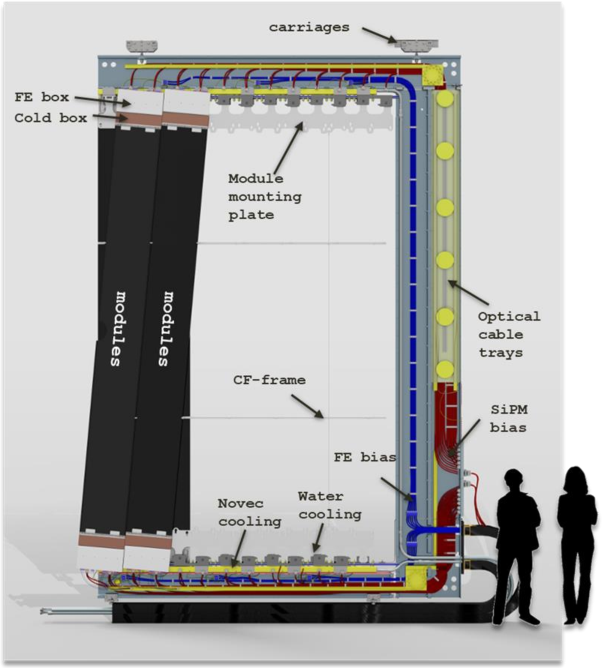
on behalf of the
LHCb SciFi mechanical engineering team

SCIFI PROJECT OVERVIEW

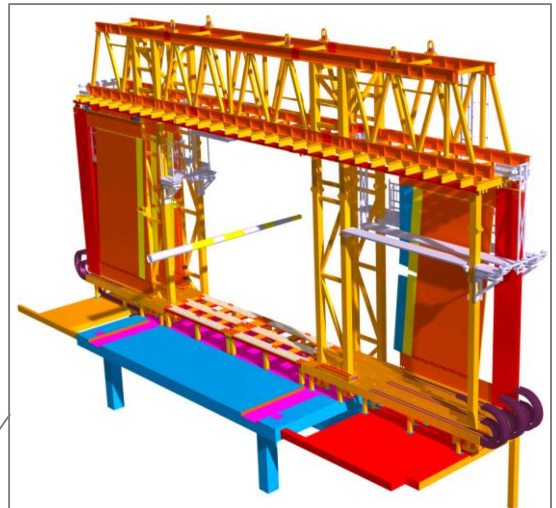
- During the Long Shutdown 2 of the LHC, the LHCb experiment will upgrade several systems
- In particular two of the principal particles tracking sub-detectors, the current Outer Tracker (based on gas drift tubes) and the Inner Tracker (silicon micro strips), will be replaced by a single tracking detector, the SciFi, in order to manage the higher instantaneous luminosities and to read out the data at 40 MHz using a trigger-less read-out system
- The active part is based on 2.42 m long scintillating fibres with a diameter of 250 µm, readout by silicon photo-multipliers (SiPM)
- The new Scintillating Fiber Tracker covers a total detector area of 340 m^2 and provide a spatial resolution of 100 µm in the bending direction of the LHCb spectrometer

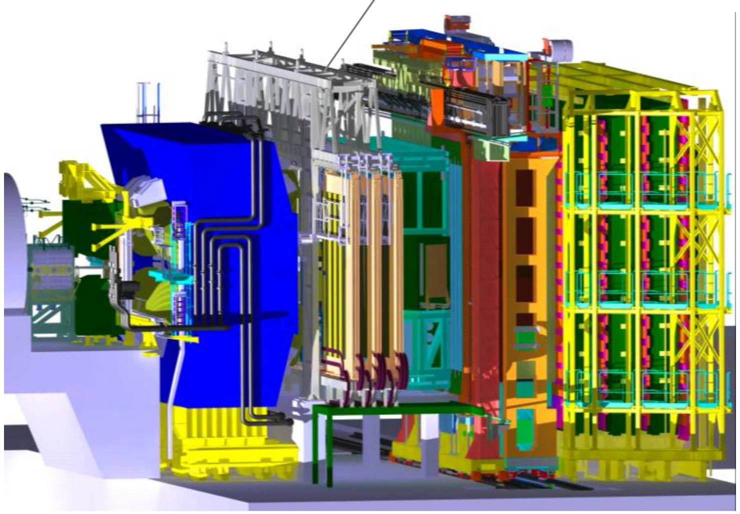


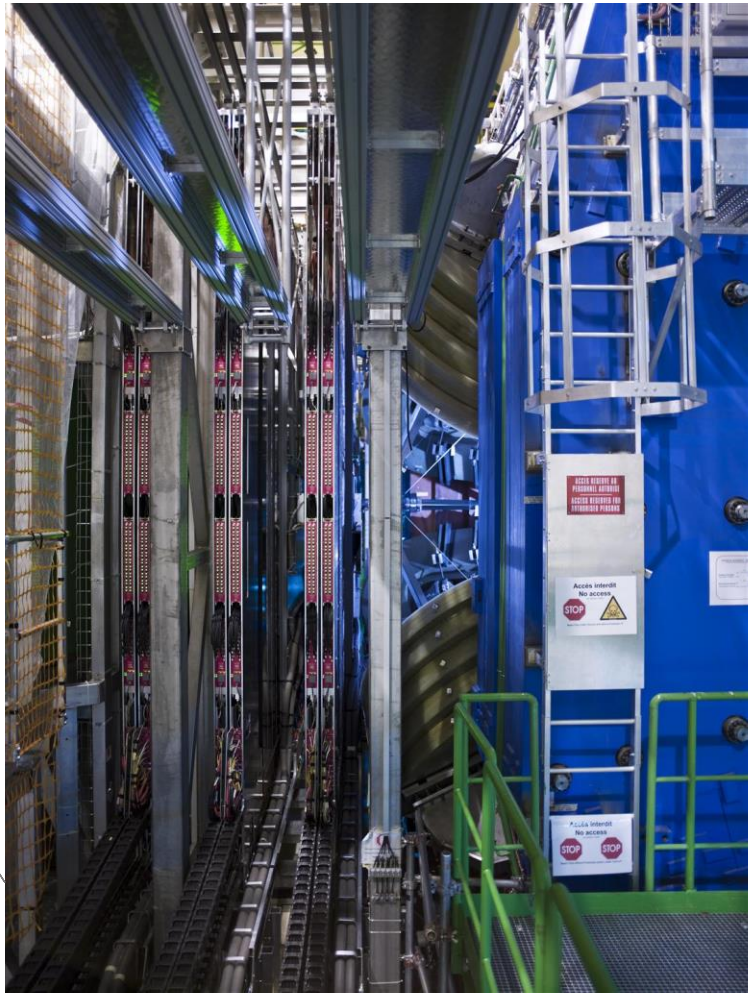
1 OF THE 12 C-FRAMES OF THE SCIFI SUB-DETECTOR



- The SciFi half stations will be inserted in the LHCb bridge
- On the top and on the bottom of the bridge, rails are fixed to support and guide the detector from the open position to the operational position and vice versa



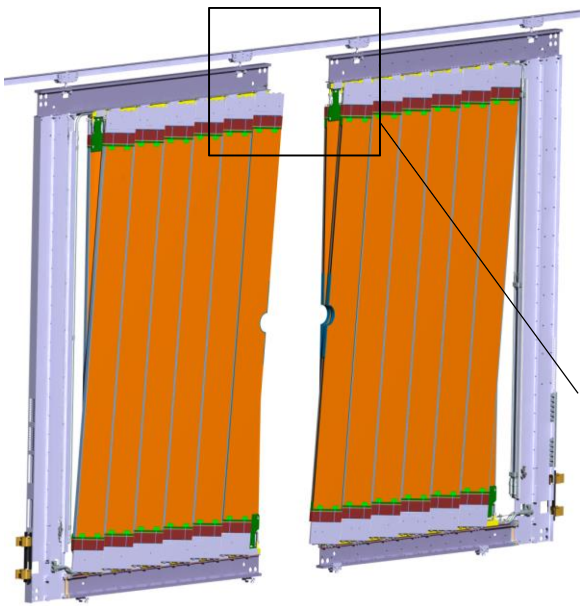


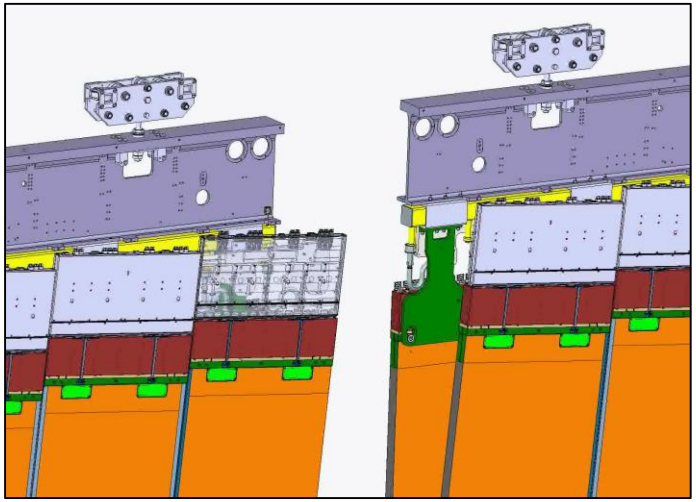


- The rails (top and bottom) could be not perfectly aligned each other in all the points. A lateral difference up to 11 mm could be present. The rails will be re-aligned but it is not expected a better precision (alignment complexities). An adjusting system is needed mainly for two important reasons:
  - The half-stations are relatively close. The smaller gap between half-stations of the same station is around 2 mm. A precise, reliable and functional adjusting system have to be used to properly set the relative position of the half-stations
  - An enough precise positioning of the detectors is need as input for the particles track-based alignment software to improve the software efficiency. A precise, reliable and functional adjusting system have to be used to properly set the absolute position of the stations
- The modules required a planarity better than 300 µm

HOW TO PROPERLY ALIGN THE SYSTEM WITHOUT ADDING ADDITIONAL DEFORMATIONS/STRESSES?

HOW TO IMPROVE THE MECHANICAL BEHAVIOUR OF THE GLOBAL SUPPORTING STRUCTURE AND CONSEQUENTLY THE MODULES?



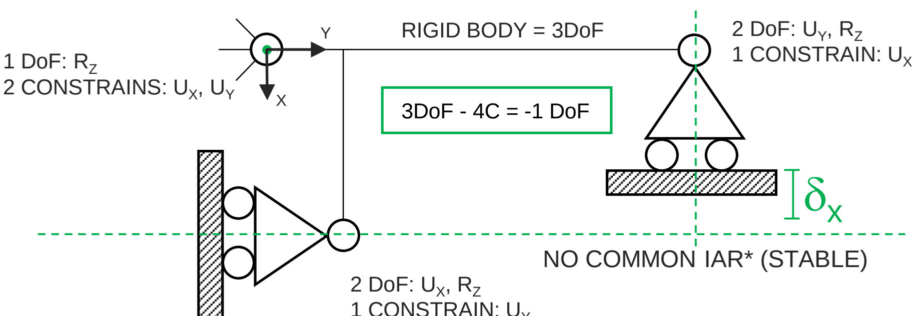


KINEMATIC ANALYSIS – A GENERAL CASE

- A straight forward solution, for the fixing of a rigid body, for which the position have also to be adjusted in the space, usually by an individual movement of the supports, is to arrange an isostatic constraint configuration (with the constraints arranged in a proper configuration)

- A straight forward solution, for the fixing of a rigid body on fixed supports (like rails) along which the rigid body have to be moved, is to arrange an isostatic constraint configuration (with the constraints arranged in a proper configuration)

IN-PLANE 2D KINEMATIC (OVER CONSTRAINED)



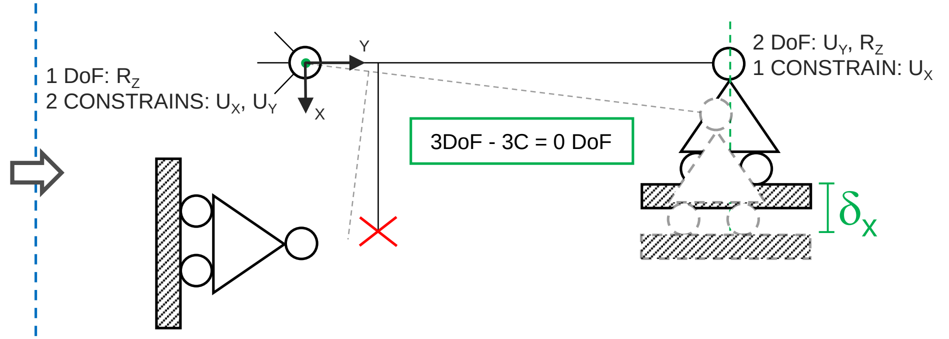
*IAR: Instantaneous Axis of Rotation

A displacement δ of a support (or a thermal expansion/contraction of the supports/structures) might introduces a variation of the reaction forces on the supports and a structure deformation

⇩

The intensity of the reaction forces, the stresses and deformations on the structure, depend mainly on the stiffness of the structure and the magnitude/direction of the displacement

IN-PLANE 2D KINEMATIC (ISOSTATIC)

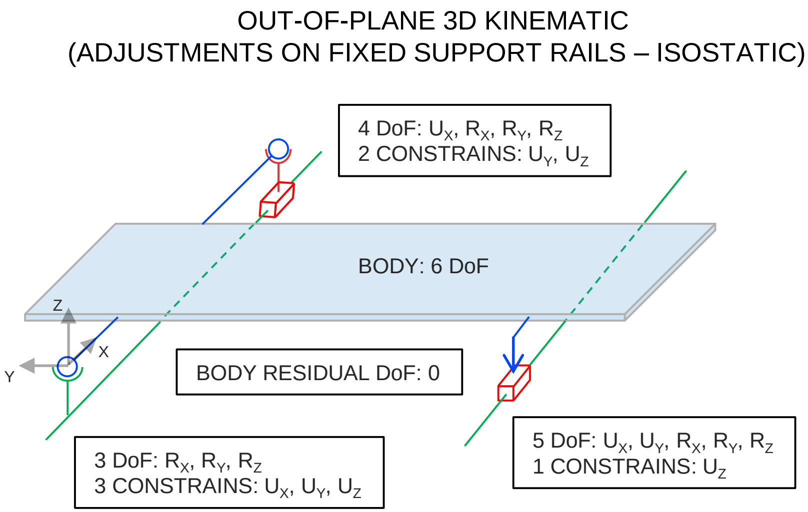


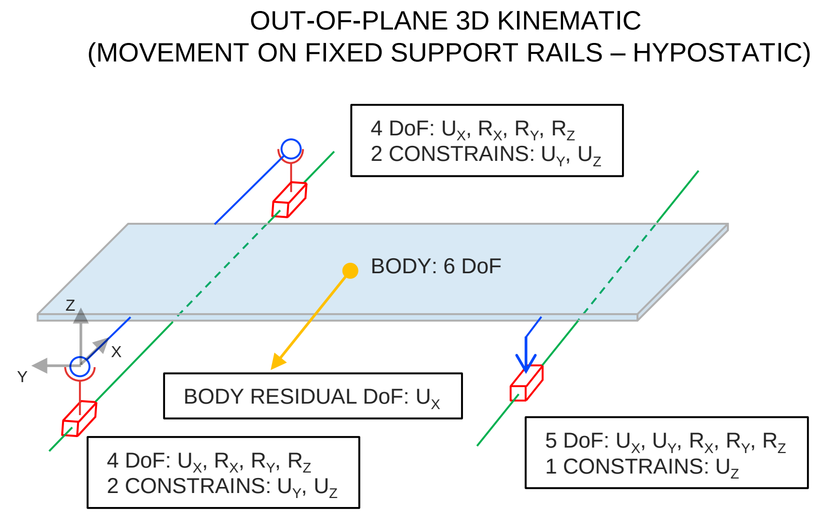
To avoid the creation of additional forces, during the adjustment/displacement of a rigid body, is needed to release a degree of constraint in order to convert the structure kinematic into an isostatic configuration

⇩ IN COMPARISON WITH THE CASE WITH 3 SUPPORTS OVER CONSTRAINED

The body is supported in two points instead of three points (the stability and global stiffness are affected). The reaction forces on the connected supports might be higher (if the support disengaged was contributing)

- Since the body can be usually adjusted and moved in 3D (out of the main structure plane) a simple example for the 3D global kinematic has been proposed
- The same hypotheses and analysis made on the 2D rigid body can be extended for the 3D rigid body
- This configuration is the guideline that has been used to set up the proper kinematic of the SciFi detector global structure

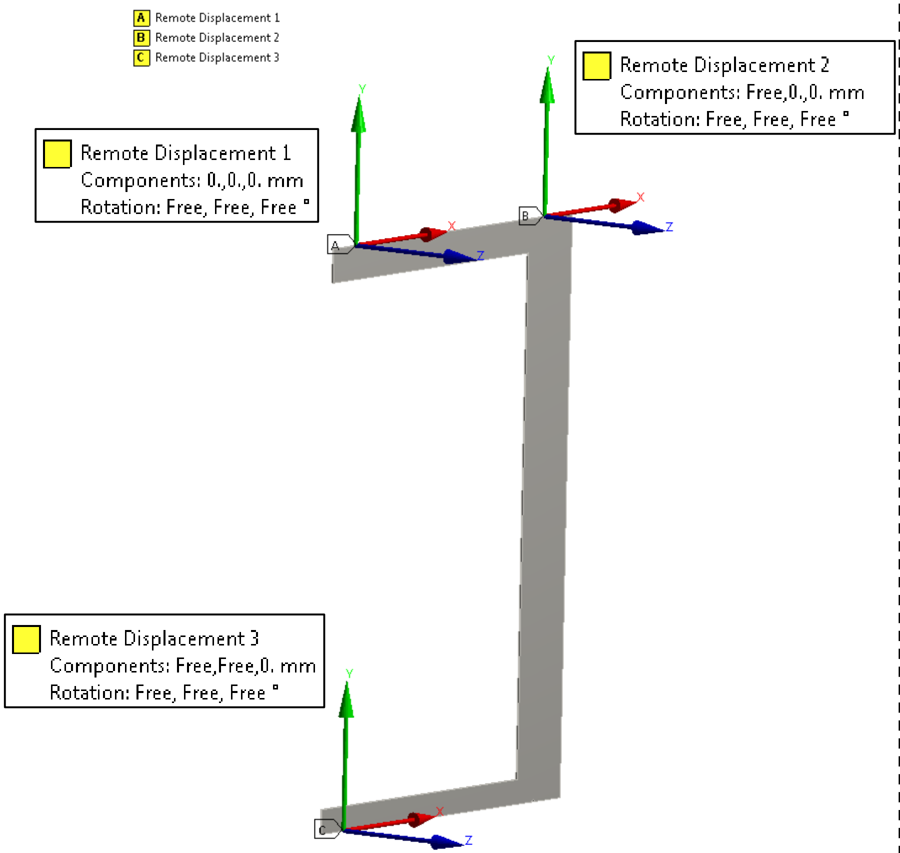




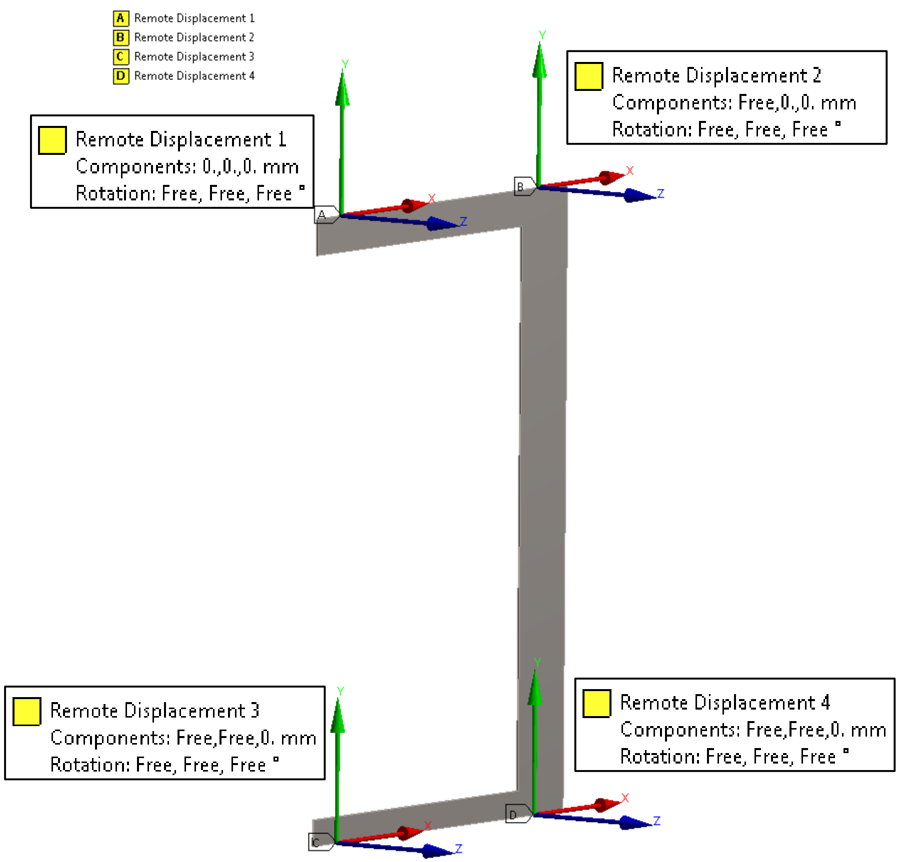
- A simple investigation on an isostatic and hyper static constrained flexible body, similar to the SciFi supporting structure, subjected to relatively small supports movements, has been carried out, by means of a FEA, to investigate the structure global deformation and the additional forces/stresses generated at the level of the supports and in the structure

- The two configurations are reported

ISOSTATIC (CONSTRAINTS)

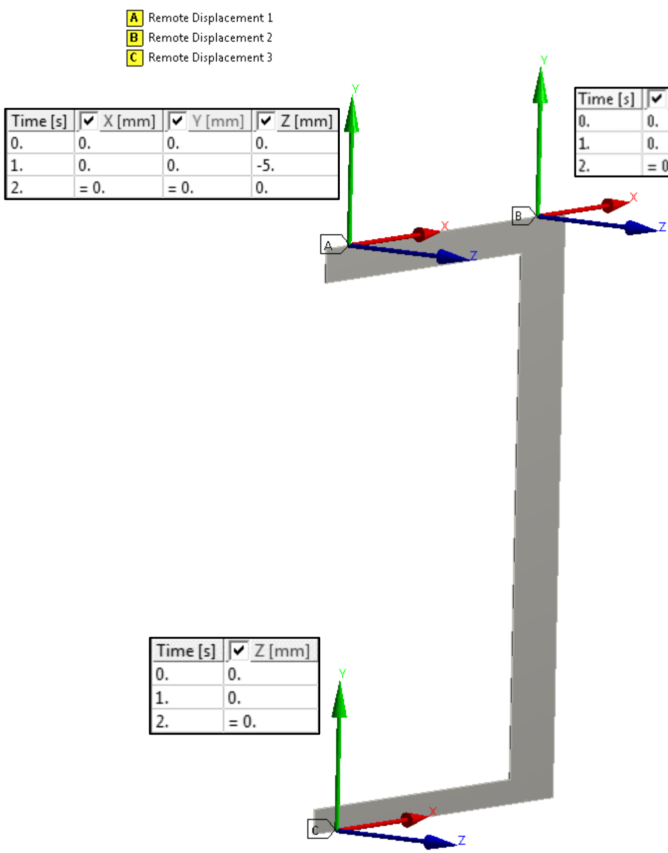


HYPER STATIC (CONSTRAINTS)

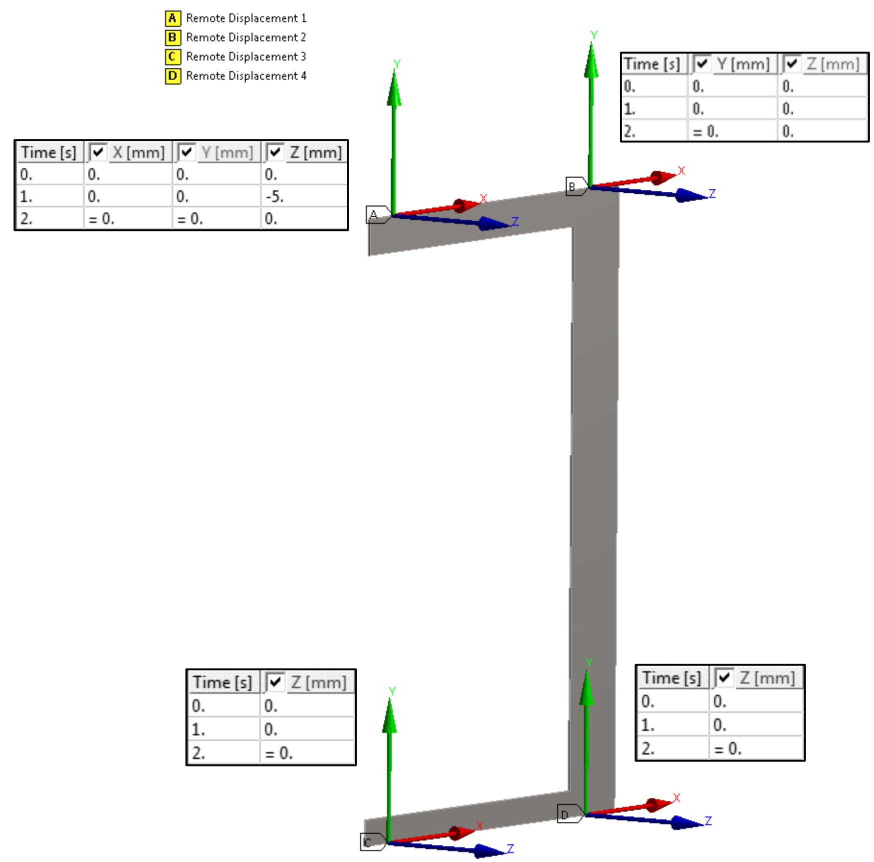


- Displacements have been imposed at the level of some supports
- The magnitude of the displacements are coherent with one (a basic translation along the z axis of one of the support) of the several possible cases during the adjustment phase
- This very simple example provide an idea of the behaviour of the structures by adjusting 1 support

ISOSTATIC (IMPOSED DISPLACEMENTS)



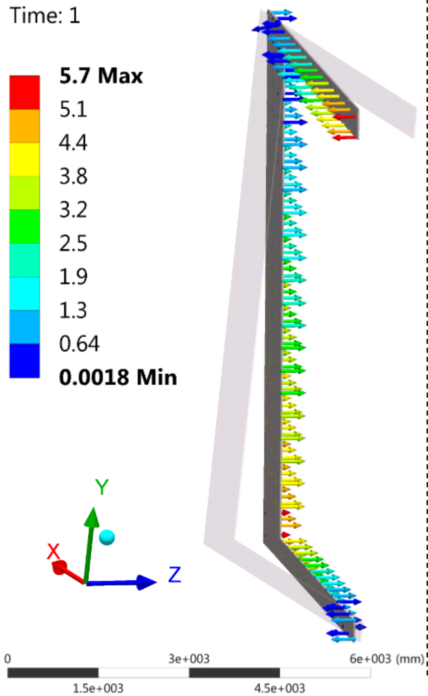
HYPER STATIC (IMPOSED DISPLACEMENTS)



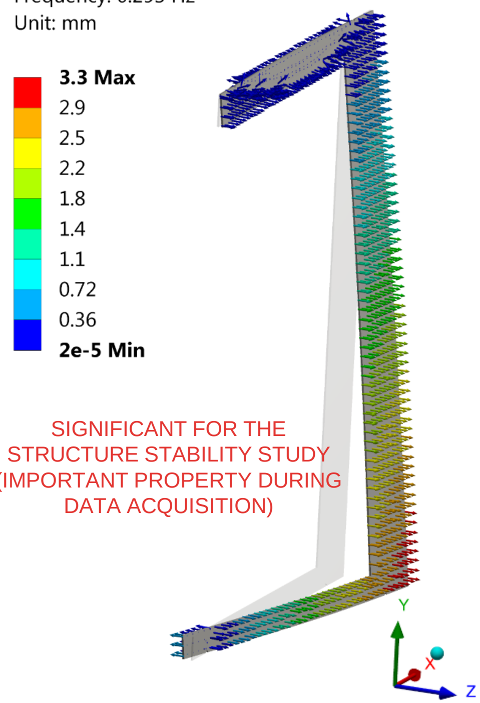
- Following a supports displacement, the isostatic constrained structure, rigidly moves in its proper plane. Additional forces/reactions are not generated on the supports (except the forces due to a different loads/weights arrangement)
- Following a supports displacement, the hyper static constrained structure, deforms out of its proper plane. Additional forces/reactions are generated on the supports

ISOSTATIC (RESULTS)

DEFORMATION
Type: Total Deformation
Unit: mm
Time: 1



MODAL (1ST NATURAL FREQUENCY)
Type: Total Deformation
Frequency: 0.293 Hz
Unit: mm

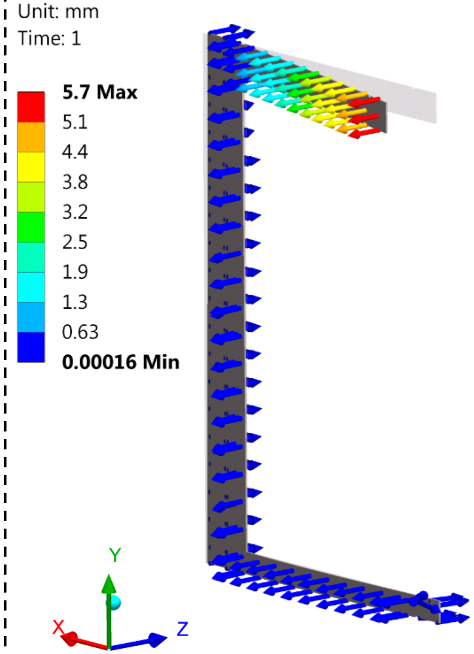


SIGNIFICANT FOR THE STRUCTURE STABILITY STUDY (IMPORTANT PROPERTY DURING DATA ACQUISITION)

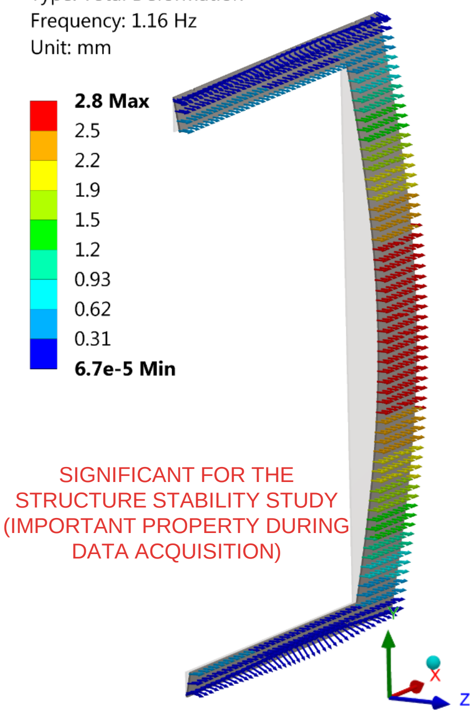
Probe: Reactions	X Magnitude	Y Magnitude	Z Magnitude	Total	Units	Time (s)
All - Force Reaction - Remote Displacement 1 - 1. s	-5.22e-006	-5.98e-006	-1.97e-007	7.94e-006	N	1.
All - Force Reaction - Remote Displacement 2 - 1. s	0.	1.42e-006	4.28e-007	1.48e-006	N	1.
All - Force Reaction - Remote Displacement 3 - 1. s	0.	0.	3.57e-007	3.57e-007	N	1.
All - Force Reaction - Remote Displacement 1 - End Time	-1.07e-005	-1.69e-005	7.19e-008	2.e-005	N	2.
All - Force Reaction - Remote Displacement 2 - End Time	0.	1.18e-005	-4.34e-007	1.18e-005	N	2.
All - Force Reaction - Remote Displacement 3 - End Time	0.	0.	3.24e-007	3.24e-007	N	2.

HYPER STATIC (RESULTS)

DEFORMATION
Type: Total Deformation
Unit: mm
Time: 1



MODAL (1ST NATURAL FREQUENCY)
Type: Total Deformation
Frequency: 1.16 Hz
Unit: mm

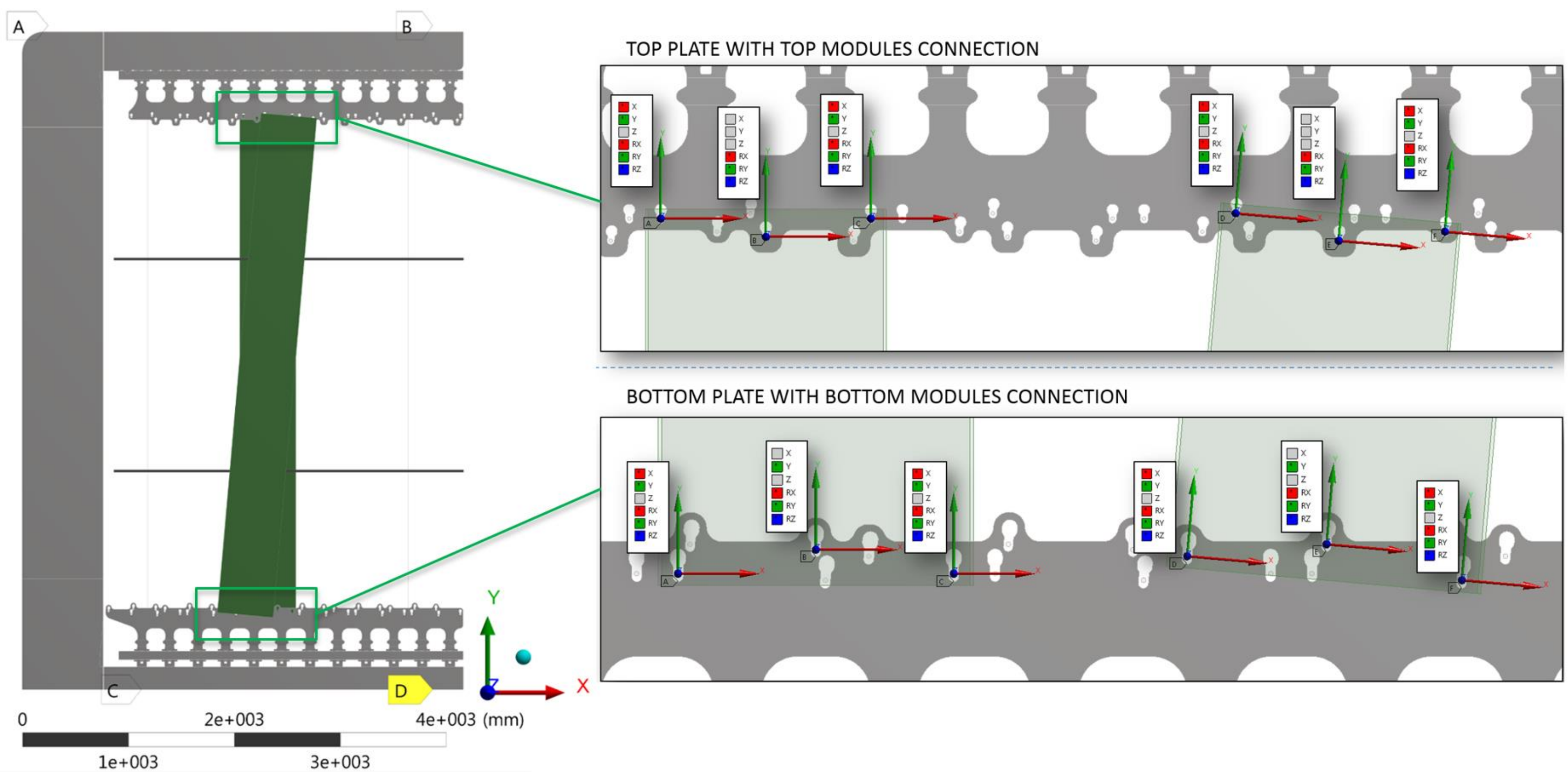


SIGNIFICANT FOR THE STRUCTURE STABILITY STUDY (IMPORTANT PROPERTY DURING DATA ACQUISITION)

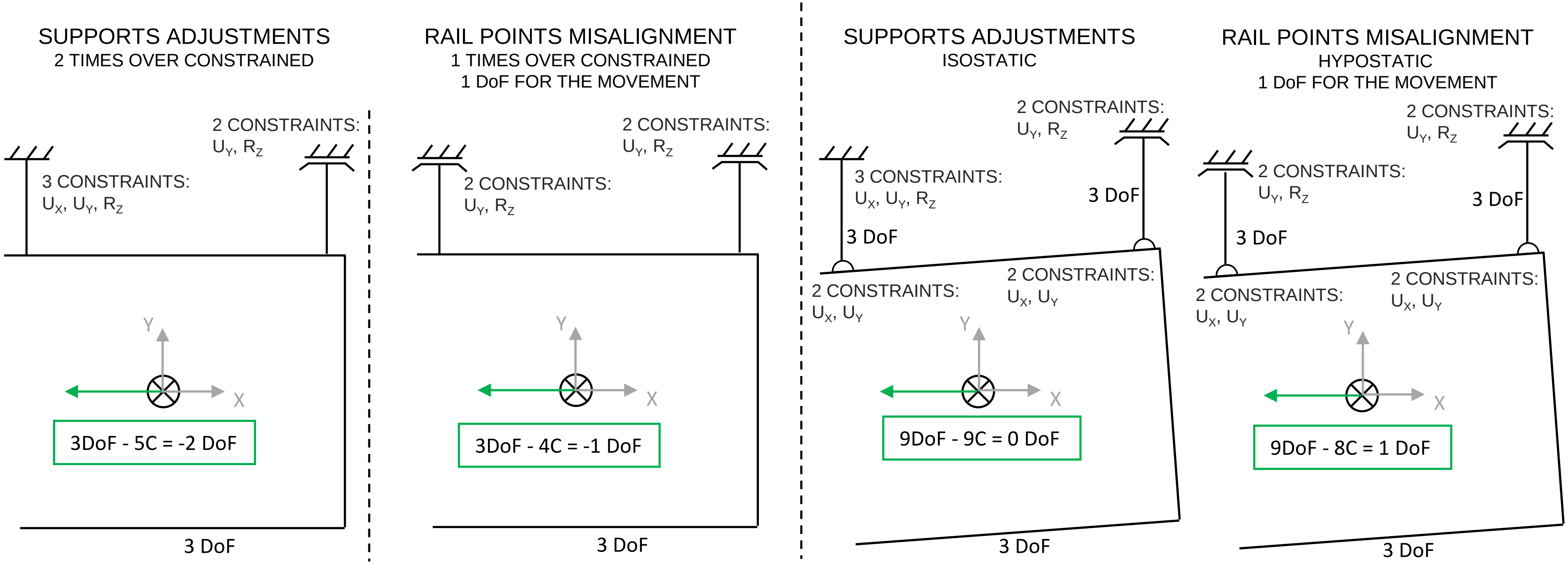
Probe: Reactions	X Magnitude	Y Magnitude	Z Magnitude	Total	Units	Time (s)
All - Force Reaction - Remote Displacement 1 - 1. s	9.46e-004	-3.43e-003	-1.85	1.85	N	1.
All - Force Reaction - Remote Displacement 2 - 1. s	0.	-7.15e-004	1.85	1.85	N	1.
All - Force Reaction - Remote Displacement 3 - 1. s	0.	0.	1.85	1.85	N	1.
All - Force Reaction - Remote Displacement 4 - 1. s	0.	0.	-1.85	1.85	N	1.
All - Force Reaction - Remote Displacement 1 - End Time	-3.09e-007	-1.34e-006	-5.7e-008	1.38e-006	N	2.
All - Force Reaction - Remote Displacement 2 - End Time	0.	-1.44e-007	-3.35e-007	3.64e-007	N	2.
All - Force Reaction - Remote Displacement 3 - End Time	0.	0.	5.84e-008	5.84e-008	N	2.
All - Force Reaction - Remote Displacement 4 - End Time	0.	0.	-1.73e-007	1.73e-007	N	2.

KINEMATIC STUDY ON THE SCIFI DETECTOR GLOBAL SUPPORTING STRUCTURE

- The SciFi modules are linked on the SciFi supporting structures with their own kinematic that guarantee a proper fixation and stability to the active components
- The modules are hyper statically connected to the C-Frame
- The modules could contribute to the global structure stiffness and be deformed following a deformation of the global supporting structure



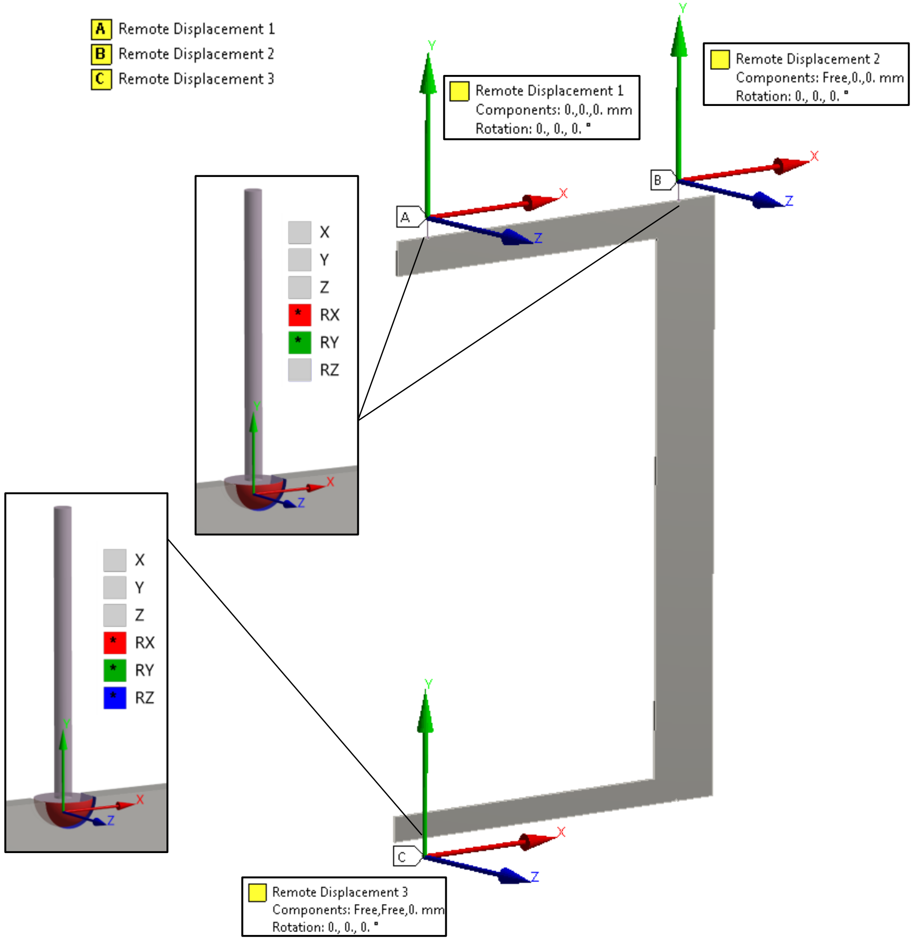
- During the detector adjustment phase, by moving the supports, the kinematic shall be isostatic to avoid additional forces on the supports, structure deformation and stresses
- To minimized the additional forces and structure deformations it is preferable that the movements on the rails is performed in an isostatic configuration (in particular will be hypostatic since the DoF in the rail longitudinal direction will be permitted)
- A 3D kinematic layout for the insertion and the adjusting phase has been studied and proposed. For simplicity, the 2D case with support adjustments (or rail misalignments) is reported. In case of a hyper static structure the insertion could be stuck due to additional forces (and consequently frictions) on the insertion supports



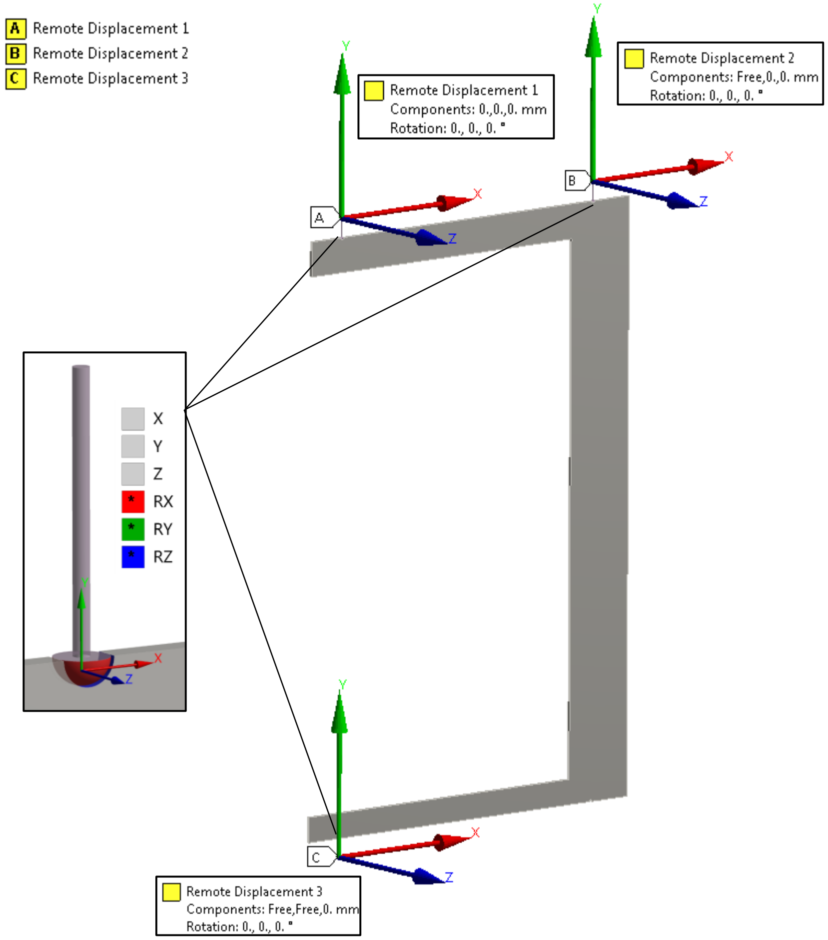
- Several kinematic studies (analytical and with the support of FEM) have been carried out to investigate the global behaviour in case of support relative displacements and misalignments during the insertion phase

- In case of non foreseen additional forces on the supports, the adjustment and insertion could be compromised and the system blocked

SUPPORTS ADJUSTMENTS
2 TIMES OVER CONSTRAINED



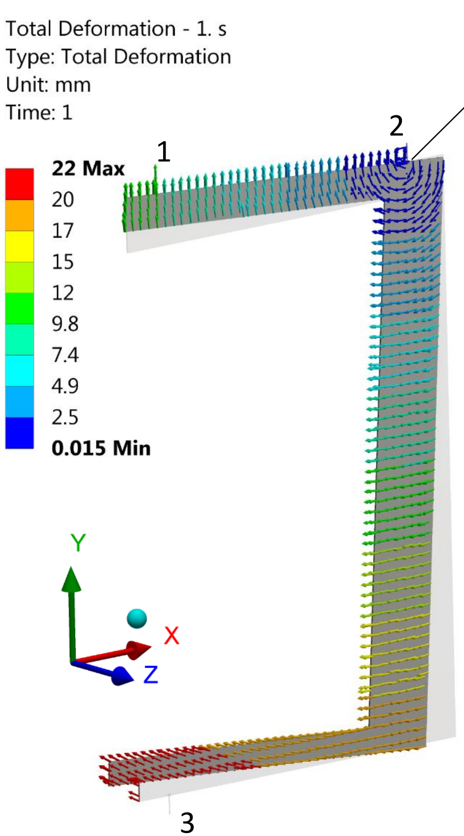
SUPPORTS ADJUSTMENTS
ISOSTATIC

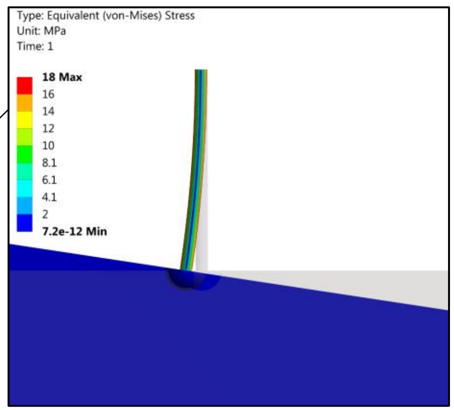


- A simple adjustment study have been reported to show the global movement and the associated deformations and stresses (if existent) for the over constrained and isostatic configuration

- Even if the total global deformation/displacement seem to be similar by comparing the 2 configurations, the stresses on the support of the over constrained system are not negligible, considering the small displacement imposed

SUPPORTS ADJUSTMENTS
2 TIMES OVER CONSTRAINED





1

Time [s]	X [mm]	Y [mm]	Z [mm]	RX [°]	RY [°]	RZ [°]
0.	0.	0.	0.	0.	0.	0.
1.	0.	10.	0.	0.	0.	0.
2.	= 0.	0.	= 0.	= 0.	= 0.	= 0.

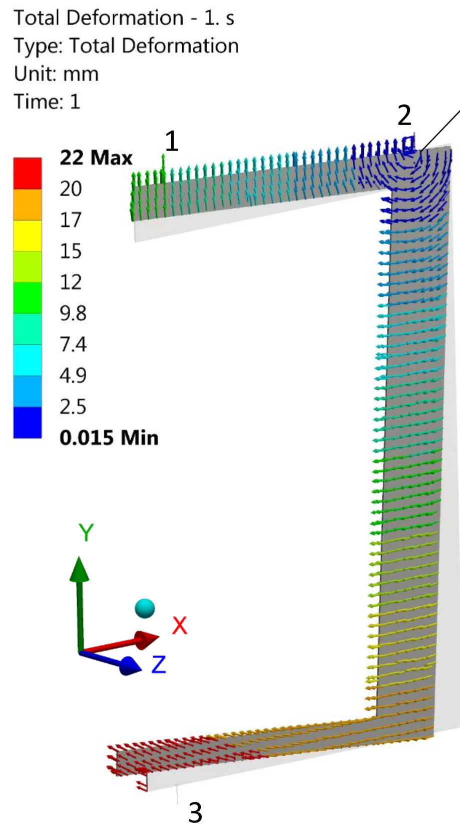
2

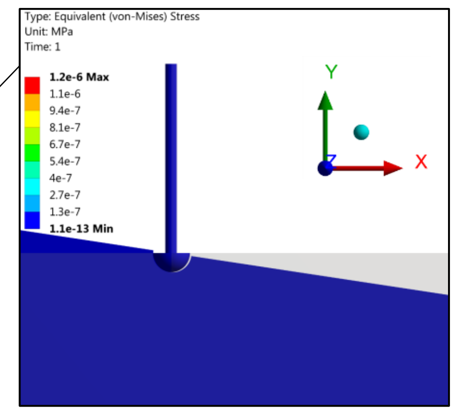
Time [s]	Y [mm]	Z [mm]	RX [°]	RY [°]	RZ [°]
0.	0.	0.	0.	0.	0.
1.	0.	0.	0.	0.	0.
2.	= 0.	= 0.	= 0.	= 0.	= 0.

3

Time [s]	Z [mm]	RX [°]	RY [°]	RZ [°]
0.	0.	0.	0.	0.
1.	0.	0.	0.	0.
2.	= 0.	= 0.	= 0.	= 0.

SUPPORTS ADJUSTMENTS
ISOSTATIC





1

Time [s]	X [mm]	Y [mm]	Z [mm]	RX [°]	RY [°]	RZ [°]
0.	0.	0.	0.	0.	0.	0.
1.	0.	10.	0.	0.	0.	0.
2.	= 0.	0.	= 0.	= 0.	= 0.	= 0.

2

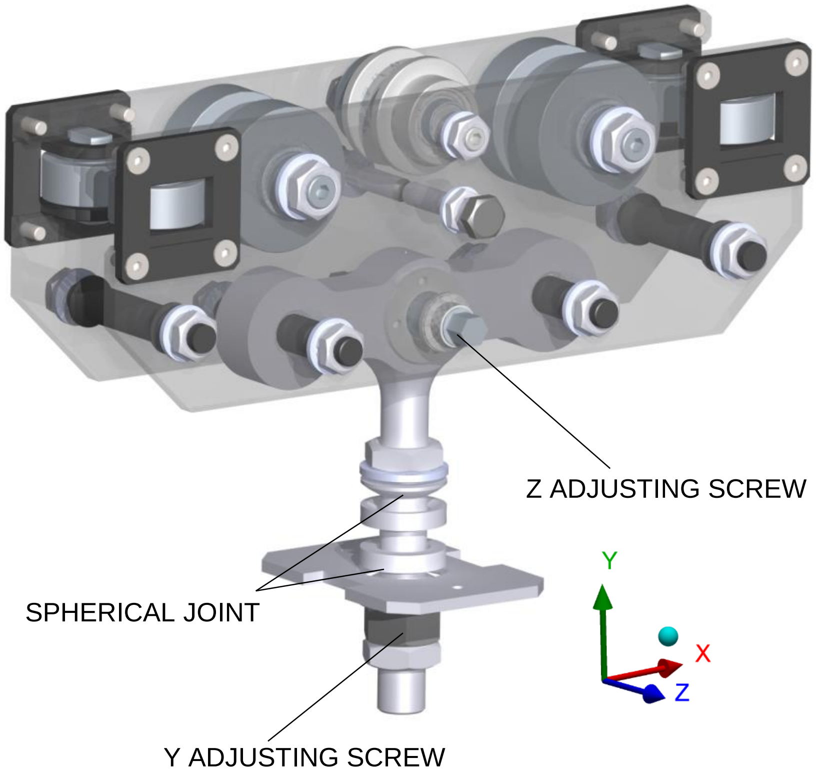
Time [s]	Y [mm]	Z [mm]	RX [°]	RY [°]	RZ [°]
0.	0.	0.	0.	0.	0.
1.	0.	0.	0.	0.	0.
2.	= 0.	= 0.	= 0.	= 0.	= 0.

3

Time [s]	Z [mm]	RX [°]	RY [°]	RZ [°]
0.	0.	0.	0.	0.
1.	0.	0.	0.	0.
2.	= 0.	= 0.	= 0.	= 0.

- The design of the carriages has been done in order to satisfied the preferred kinematic configuration identified, leaving the rotations free around all the axes of a coordinate system located at the center of the spherical joint and adding the devices able to provide the adjustments along Y and Z

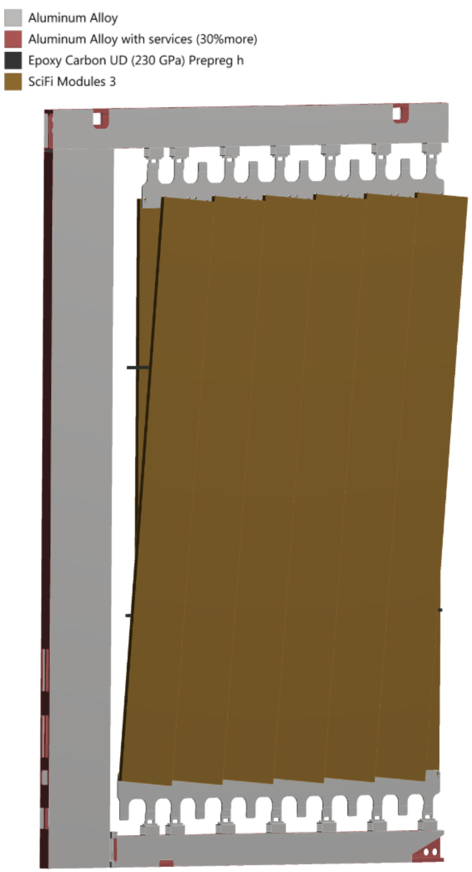
- Adjustment functional tests have been carried out on carriages prototypes attached to a concrete block of 950kg (to verify that the max allowable force does not create friction effects too high to prevent the free movement of the parts) and combined with the over all structure (to verify that the kinematic is correct and does not introduce over constrained conditions)

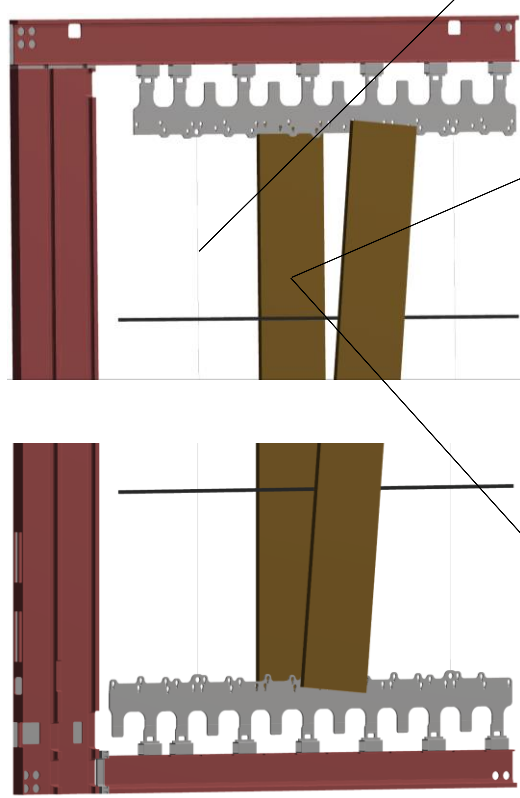


STRUCTURAL STUDIES ON THE SCIFI DETECTOR GLOBAL SUPPORTING STRUCTURE

Finite Element Model: design, materials and simplifications

- A finite element model has been created to verify the global behaviour of the structure
- The modules (active part) are made of a complex sandwich structure*. To avoid to increase the FEA computational time, a simplified structure with similar structural behaviour has been defined and implemented
- The weight of the services has been approximated by increasing the density of the material of the structure were the services are attached





CABLES BEHAVIOUR

Details of "Beam To Cable"

Geometry	
Scoping Method	Geometry Selection
Geometry	1 Body
Definition	
Cross Section Area	Beam Cross Section
Advance Settings	
Cross-Section Scaling	Enforce Incompressibility
Define Initial State	Yes
Initial Strain	0.000432

DEFORMATIONS

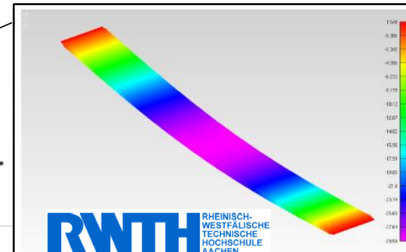
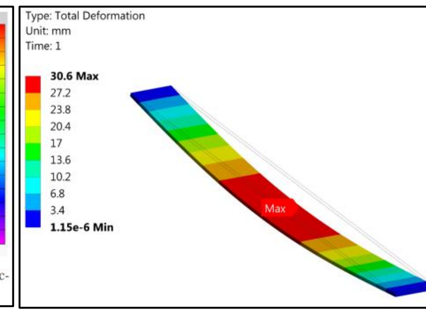
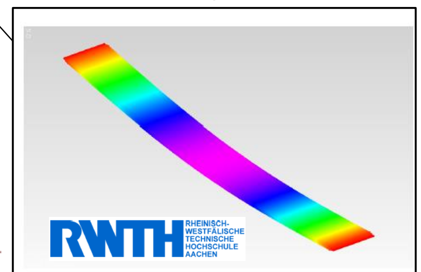


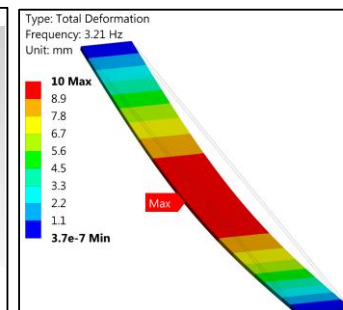
Figure 3: Deformation of the panel through own weight. Max deflection 29.6 mm (21.98 mm)



NATURAL FREQUENCIES



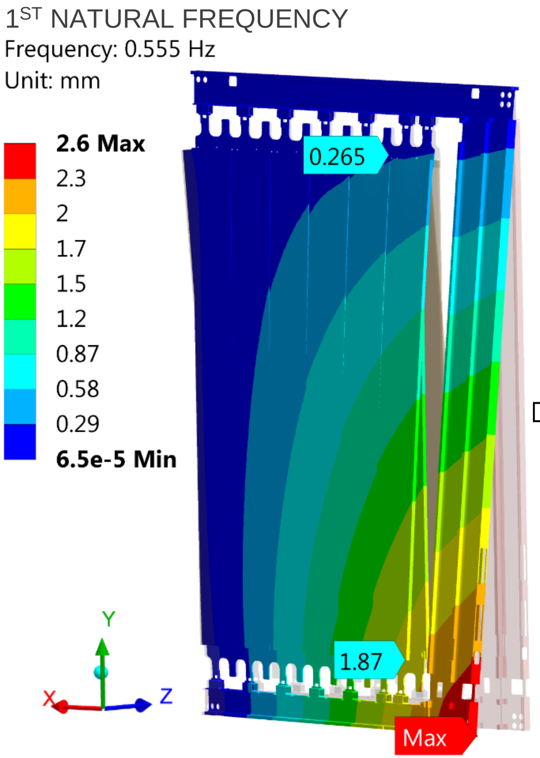
First eigenfrequency 3.3 Hz (3.86 Hz)

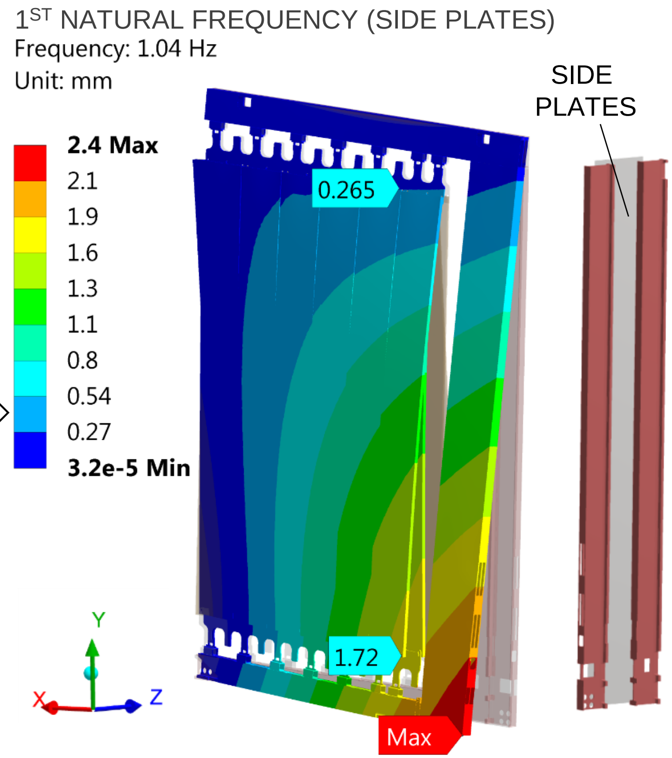


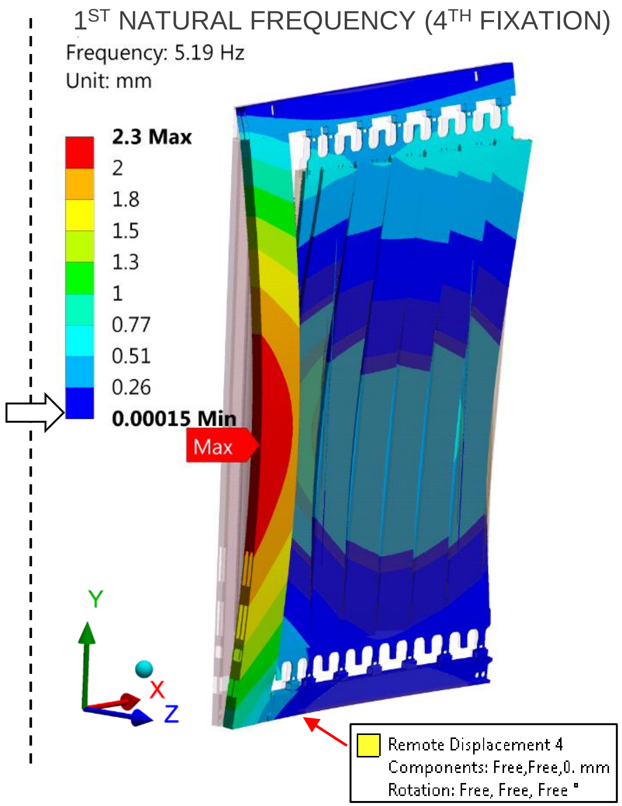
*Finite Element Analysis of the SciFi-Nomex-Sandwich Panels - A. Schultz von Dratzig, RWTH Aachen, March 2015

- The very first investigation carried out has been the modal analysis of the structures with the modules. The modal analysis is important to obtain a preliminary overview of the structure mechanical behaviour and stiffness and to evaluate if these properties are coherent/consistent with the expected/preferable structure behaviour

- The modules (active part) have to maintain a predefined shape in particular during the data acquisition. The precision on the particles tracks reconstruction highly depend on the modules stability and shape, that have to be as flat as possible without significant twists. Structure modifications and additional supports have been arranged to improve the structure stiffness and stability





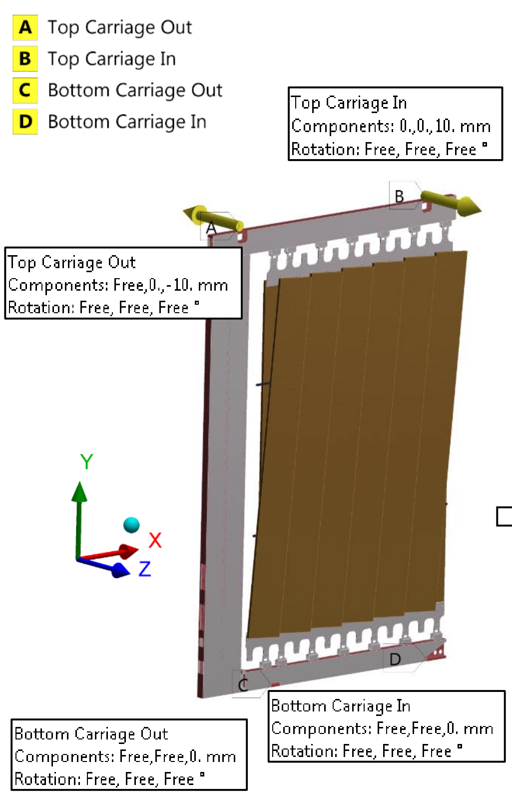


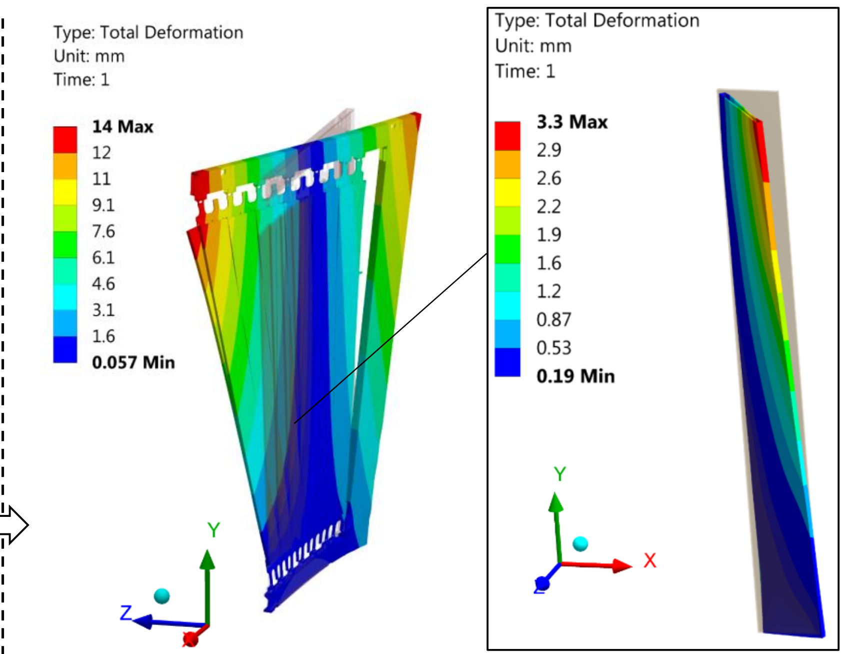
Finite Element Model: results – deformations (additional deformations, forces and stresses on the hyper static structure)

- To improve the structure stiffness and stability, a 4th fixation point (in the z axis direction) has been added on the bottom part of the structure. The structure is hyper-static. In particular the hyper-staticity has effect for a support adjustment/misalignment out of the characteristic plane of the structure (x-y). As reported in the previous slides, additional forces, deformations and stresses can be introduced on the supports and in the structure. The intensity of the forces, deformations and stresses have been studied for different configurations

- During the insertion and the adjustment phase, it is preferable to avoid hyper-staticity in order to avoid uncontrolled modules deformation and additional forces and stresses on the supports and the structure. For this reason, the 4th point of fixation will be engaged only after the final adjustment

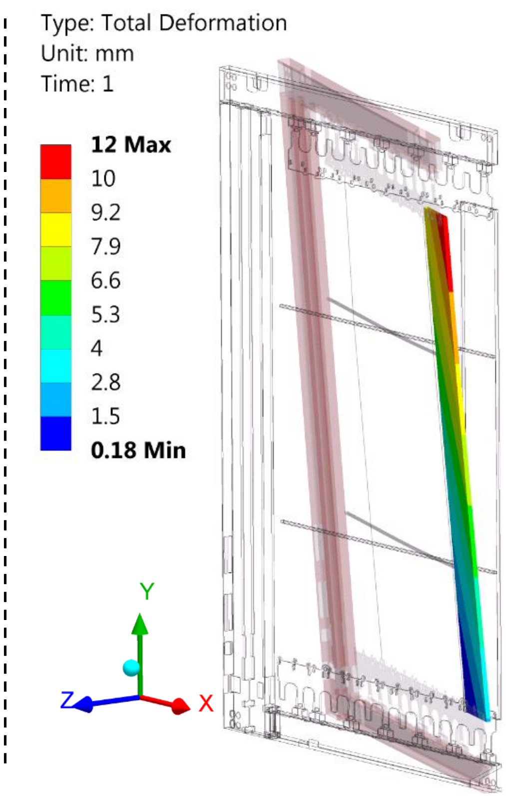
RANDOM SUPPORTS ADJUSTMENT AND EFFECTS ON THE OVER CONSTRAINED STRUCTURE





Probe: Reactions	X Magnitude	Y Magnitude	Z Magnitude	Total	Units
All - Force Reaction - Top Carriage Out - 1. s	0.	6.98e+003	-185	6.98e+003	N
All - Force Reaction - Top Carriage In - 1. s	6.68e-002	5.77e+003	188	5.77e+003	N
All - Force Reaction - Bottom Carriage Out - 1. s	0.	0.	215	215	N
All - Force Reaction - Bottom Carriage In - 1. s	0.	0.	-213	213	N

ISOSTATIC STRUCTURE

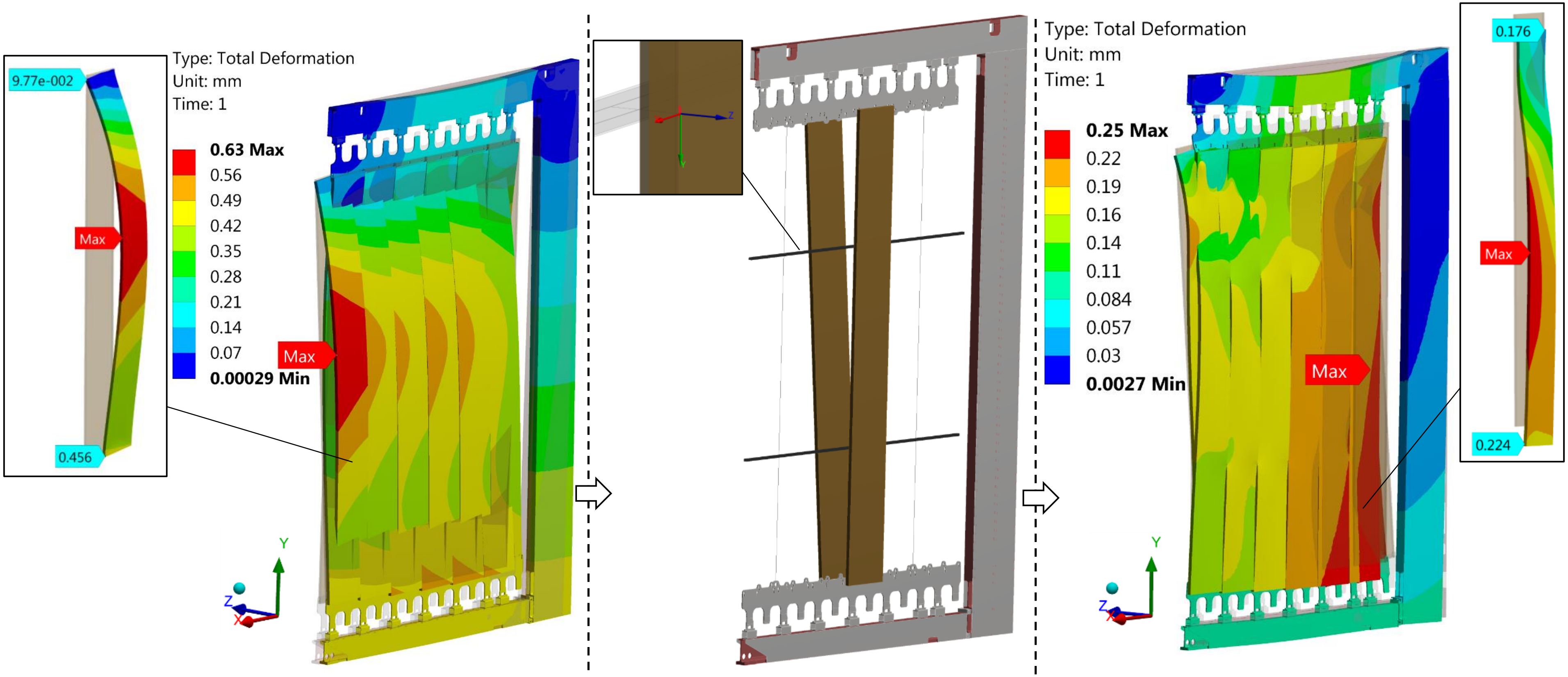


Finite Element Model: results – deformations (structure optimization)

- The finite element model is very important as support and "virtual mock-up" for the optimization of the structure mechanical behaviour to minimize the deformations on the modules

- An important improvement to minimize the modules deformation has been carried out by adding 2 horizontal support beams, longitudinally to the modules length. The modules are fixed on the horizontal beams by means of small but stiff pre-tensioned carbon fibres wires

- In addition, the horizontal beams create a "package of modules" that increase the overall stiffness and decrease the free inflection of the modules (structures relatively long)



MEASUREMENTS ON THE PROTOTYPE

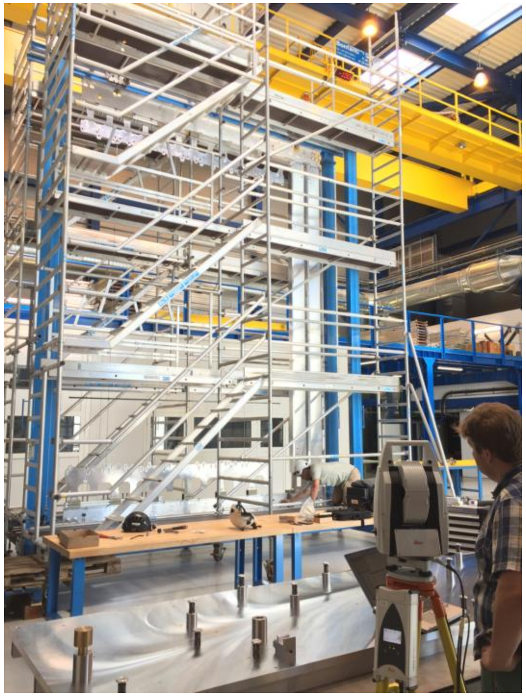
- A prototype of the SciFi detector is going to be assemble. The main components of the global supporting structure are already in place

- A very preliminary metrological investigation has been carried out to control the planarity of the plates where the modules will be installed

- Preliminary adjustment tests have been carried out by moving the supports along the permitted axes

- The prototype is very useful to set up a proper adjusting procedure and to identify design problems (saturation of the permitted degrees of freedom, frictions between components that prevent movements,..)

- A preliminary metrological investigation shown that the structure moves as expected by moving the supports



CONCLUSIONS AND ADDITIONAL CONSIDERATIONS

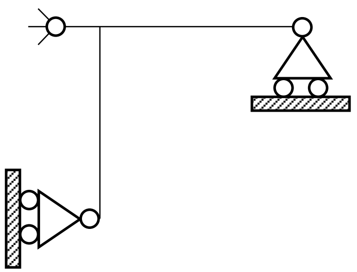
- The SciFi detector will be inserted in the LHCb experiment during the LS2 upgrade
- To improve the stability of the light modules structure (precise active components with delicate optical fibres), they have been over constrained on the global supporting structure that must be properly designed to guarantee the stability and accuracy requirements
- The mechanical behaviour of the global supporting structure has been extensively studied, by means of analytical and finite element kinematic and structural analysis, during the different phases (detector insertion, adjustment and data acquisition)
- An isostatic kinematic configuration has been arranged during the insertion and the adjusting phase to avoid dangerous/uncontrolled deformations/stresses on the structure whereas an hyperstatic kinematic configuration has been arranged for the final position to improve the stability of the structure
- A finite element model has been created to verify and investigate the structure behaviour. The “virtual mock-up” and FEA carried out have been used to optimize the structure stiffness and mechanical behaviour to meet the important requirements on shape and stability of the detector active parts (the modules)
- A real prototype useful to set up a proper adjusting procedure and to identify design problems has been assembled


THANK YOU FOR YOUR ATTENTION

BACK-UP SLIDES

- The configurations to create an appropriate fixation are several and are highly dependent from the structure properties (stiffness, geometry,..), requirements and constraints. Different arrangements of the previous configuration are reported with some advantages and drawbacks

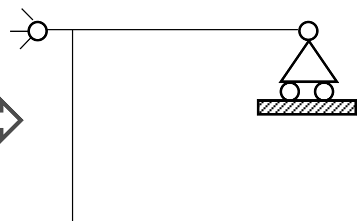
1. Hyper static



Advantages
- Structure proper weight and loads shared (in the better case) on 3 supports
- Deformation can be minimized
- Stability and stiffness can be optimized
- Simple adjustment (if 1 constrain is suppressed)

Drawbacks
- Might introduce additional deformation, forces and stresses due to thermal expansions/contractions and/or constrain displacements
- Complex sharing of supports loads study if adjusted in the over constrained configuration but also in an isostatic configuration (as soon as the last support is engaged, complex control on the sharing of the forces)
- Stresses and deformations might change between the adjustment phase and the final fixation

2. Isostatic with fix point

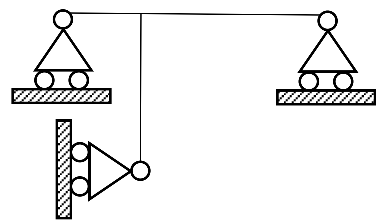


COMPARISON WITH PREVIOUS CONFIGURATION

Advantages
- No possibility to introduce additional forces due to thermal expansions/contractions and/or constrain displacements
- Simple adjustments

Drawbacks
- Structure proper weigh and loads shared (in the better case) on 2 supports instead of 3
- Relatively larger deformation on the structure
- Relatively less stable and less stiff

3. Isostatic without fix point

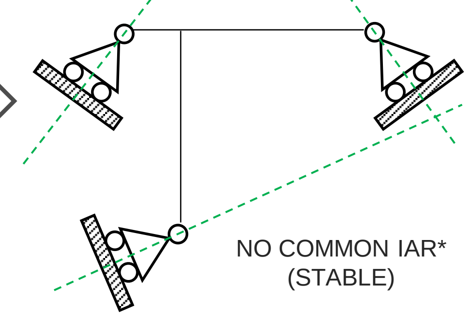


COMPARISON WITH PREVIOUS CONFIGURATION

Advantages
- Structure proper weight and loads shared (in the better case) on 3 supports instead of 2

Drawbacks
- Less simple adjustments (more complex kinematic)

4. Isostatic without fix point (supports inclination optimization)



NO COMMON IAR*
(STABLE)

COMPARISON WITH PREVIOUS CONFIGURATION

Advantages
- 3 supports might be always engaged (load distribution optimized according to their supports arrangement)

Drawbacks
- Even less simple adjustments (alignment system can be integrated)
- The IAR shall be accurately verified to avoid structural instabilities

*IAR: Instantaneous Axis of Rotation

- One of the most simple and clean way to fix a single rigid body in the space is to suppress its own degrees of freedom (3 rotations and 3 translations) with the same number of constraints correctly arranged

- With this fixing philosophy, the structure is isostatically constrained and, if the constraints are well arranged, an imposed displacement, at the level of one of those constraints, and/or a thermal expansion/contraction does not introduce additional loads or relative deformations (change in shape and/or size of the body from an initial or un-deformed configuration) but just a rigid displacement (translation and/or rotation of the body without changing its shape and/or size) of the system (deformation >> stress/strains)

- If additional redundant constraints are arranged, a support displacement could generate additional loads and a relative deformations. The magnitude of the additional forces is also proportional to the structure stiffness

- For these reasons, the adjustment of an isostatically constrained structure to the nominal position is relatively easier and more direct (relative deformations, coming from the movement of the supports, will not be present). The structure behaviour is relatively easier to study (deformations and stresses depend on the applied loads and the structure proper weight and they are not dependent on the support displacement magnitude)

- Anyway, it is not always possible to adopt an isostatic fixation. In some cases the structure stability needs to be improved and additional constraints have to be arranged at least for the final fixation in the service position. In this case the flexibility of the structure is very important since the additional loads on the supports strictly depend on the structure stiffness

- One of the most important properties of a detector supporting structure is to be relatively stable during the data acquisition.

- A precise, coherent, reproducible and reliable positioning of the detector around the operational location is also very important as input for the particles track-based alignment software that otherwise is less efficient

- The alignment of the rails where the SciFi will be inserted and supported is complex and can not be as precise as needed. An adjusting system is required to correct misalignments, to place the detector in the correct position and to improve the reliability and precision of the particles track-based alignment software

- A 3D kinematic layout for the insertion and the adjusting phase has been studied and proposed

- To avoid dangerous deformations and additional stresses on the delicate scintillating fibres and the modules structure, quasi-isostatically (global rotation around Y is constrained) connected to the C-Frame, the fixation and the kinematic of the main supporting structure has to be carefully studied

- The isostatic kinematic also prevent additional forces on the supports and deformation and stresses on the global structure

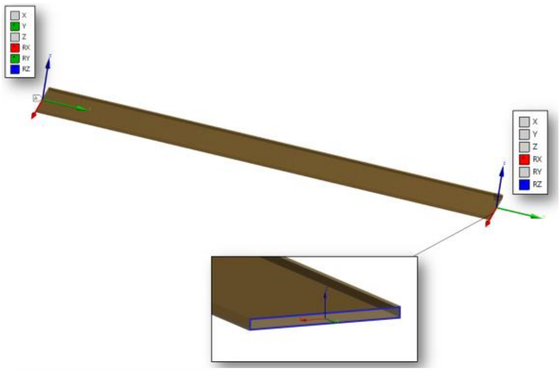
- Several kinematic studies (analytical and with the support of FEM) have been carried out to investigate the global behaviour in case of support relative displacements and misalignments during the insertion phase

- The stresses and additional forces have been reported for a simple case. Considering the small displacement imposed, the stresses on the support of the over constrained system are not negligible

- The carriage prototype created satisfied the preferred kinematic configuration identified

- An simplified structure that approximate the stiffness and the behaviour of the complex module structure has been studied

BOUNDARY CONDITIONS



DEFORMATIONS

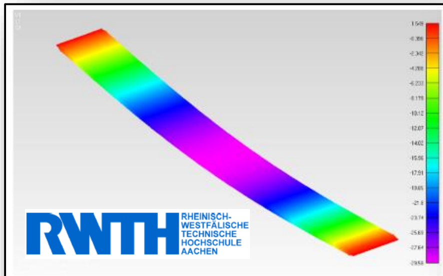
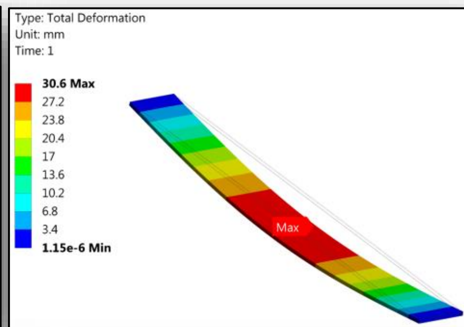


Figure 3: Deformation of the panel through own weight. Max deflection 29.6 mm (21.98 mm)



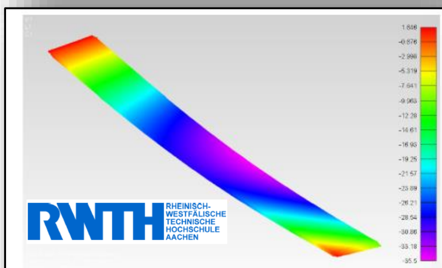
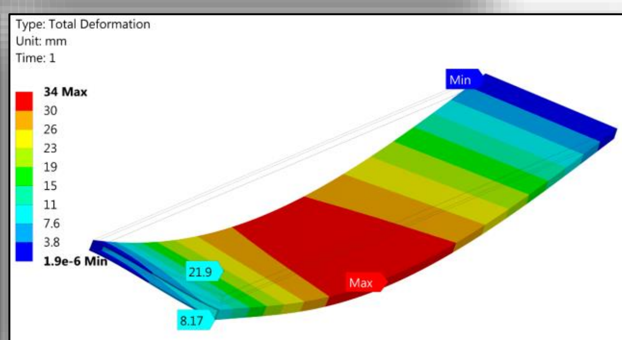
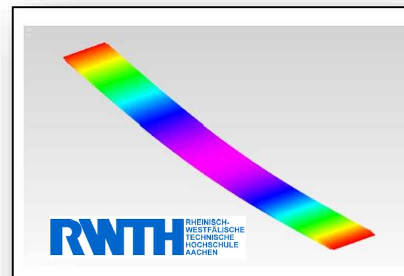


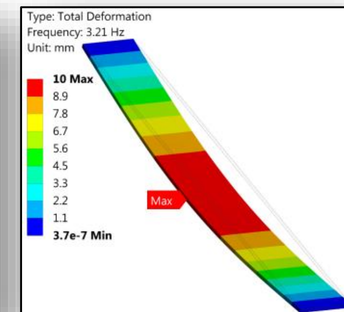
Figure 4: Deformation of the panel through own weight, support in lower right corner removed. Max deflection there 9.9 mm (7.85 mm)

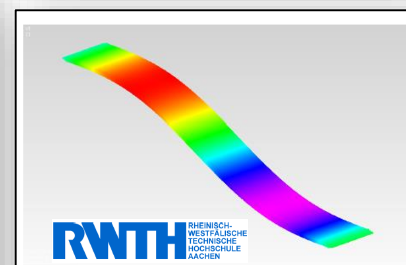


NATURAL FREQUENCIES

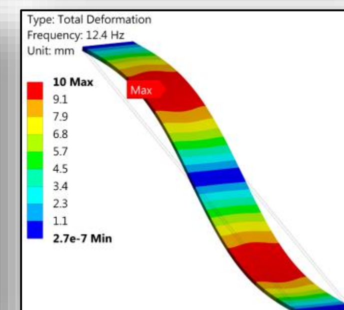


First eigenfrequency 3.3 Hz (3.86 Hz)





Second eigenfrequency 13.2 Hz (15.34 Hz)



- The materials used in the FEM have been reported

ALUMINIUM ALLOY

Density	2.77E+03	kg m^-3
Isotropic Secant Coefficient of Thermal Expansion		
Coefficient of Thermal Expansion	2.3E-05	C^-1
Zero-Thermal-Strain Reference Temperature	22	C
Isotropic Elasticity		
Derive from	Young's Modulus and Poisson's Ratio	
Young's Modulus	7.1E+04	MPa
Poisson's Ratio	0.33	
Bulk Modulus	6.96E+10	Pa
Shear Modulus	2.67E+10	Pa

ALUMINIUM ALLOY WITH SERVICES (30%MORE)

Density	3.6E+03	kg m^-3
Isotropic Secant Coefficient of Thermal Expansion		
Coefficient of Thermal Expansion	2.3E-05	C^-1
Zero-Thermal-Strain Reference Temperature	22	C
Isotropic Elasticity		
Derive from	Young's Modulus and Poiss...	
Young's Modulus	7.1E+04	MPa
Poisson's Ratio	0.33	
Bulk Modulus	6.96E+10	Pa
Shear Modulus	2.67E+10	Pa

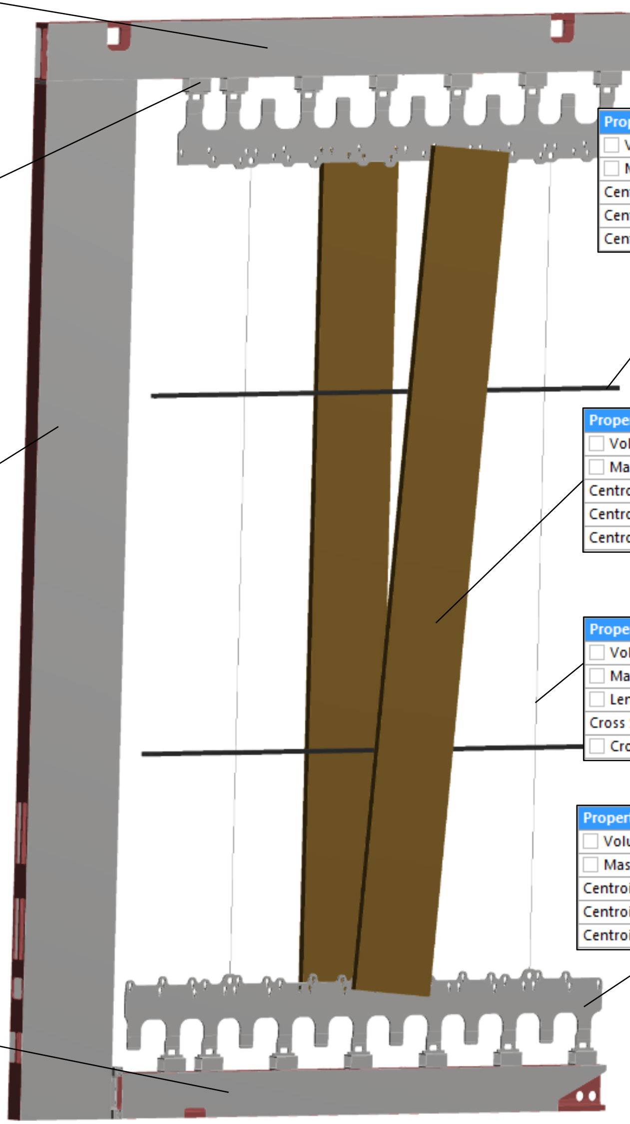
EPOXY CARBON UD (230 GPA) PREPREG H

Density	1.49E+03	kg m^-3
Orthotropic Secant Coefficient of Thermal Expansion		
Coefficient of Thermal Expansion		
Coefficient of Thermal Expansion X direction	-4.7E-07	C^-1
Coefficient of Thermal Expansion Y direction	3E-05	C^-1
Coefficient of Thermal Expansion Z direction	3E-05	C^-1
Zero-Thermal-Strain Reference Temperature	20	C
Orthotropic Elasticity		
Young's Modulus X direction	1.21E+05	MPa
Young's Modulus Y direction	1.21E+05	MPa
Young's Modulus Z direction	1.21E+05	MPa
Poisson's Ratio XY	0.27	
Poisson's Ratio YZ	0.4	
Poisson's Ratio XZ	0.27	
Shear Modulus XY	4.7E+03	MPa
Shear Modulus YZ	3.1E+03	MPa
Shear Modulus XZ	4.7E+03	MPa

SCIFI MODULES 3

Density	635	kg m^-3
Isotropic Secant Coefficient of Thermal Expansion		
Coefficient of Thermal Expansion	2.3E-05	C^-1
Zero-Thermal-Strain Reference Temperature	22	C
Isotropic Elasticity		
Derive from	Young's Modulus and Poisso...	
Young's Modulus	4.8E+03	MPa
Poisson's Ratio	0.33	
Bulk Modulus	4.71E+09	Pa
Shear Modulus	1.8E+09	Pa

- The loads applied on the structure have been reported



Properties	
Volume	2.53e+006 mm³
Mass	7.02 kg
Centroid X	-2.08e+003 mm
Centroid Y	2.93e+003 mm
Centroid Z	56. mm

Properties	
Volume	2.44e+005 mm³
Mass	0.675 kg
Centroid X	-3.05e+003 mm
Centroid Y	2.74e+003 mm
Centroid Z	-5.3e-006 mm

Properties	
Volume	7.43e+006 mm³
Mass	20.6 kg
Centroid X	-3.84e+003 mm
Centroid Y	-127 mm
Centroid Z	56. mm

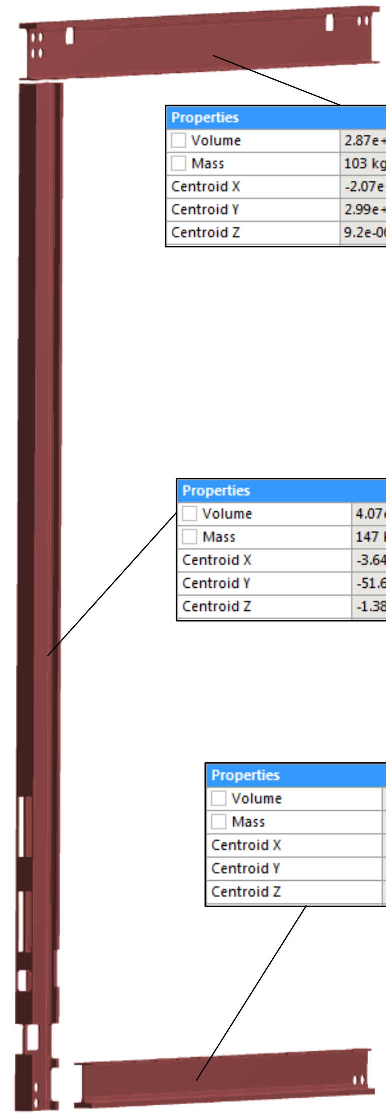
Properties	
Volume	1.62e+006 mm³
Mass	4.48 kg
Centroid X	-1.8e+003 mm
Centroid Y	-2.9e+003 mm
Centroid Z	56. mm

Properties	
Volume	3.23e+005 mm³
Mass	0.482 kg
Centroid X	-1.65e+003 mm
Centroid Y	-998 mm
Centroid Z	1.53e-007 mm

Properties	
Volume	3.15e+007 mm³
Mass	32. kg
Centroid X	-2.38e+003 mm
Centroid Y	0.123 mm
Centroid Z	-34.9 mm

Properties	
Volume	1.7e+005 mm³
Mass	0.253 kg
Length	4.5e+003 mm
Cross Section	CircularTube1
Cross Section Area	37.7 mm²

Properties	
Volume	1.08e+007 mm³
Mass	29.8 kg
Centroid X	-1.71e+003 mm
Centroid Y	-2.43e+003 mm
Centroid Z	4.57e-008 mm



Properties	
Volume	2.87e+007 mm³
Mass	103 kg
Centroid X	-2.07e+003 mm
Centroid Y	2.99e+003 mm
Centroid Z	9.2e-002 mm

Properties	
Volume	4.07e+007 mm³
Mass	147 kg
Centroid X	-3.64e+003 mm
Centroid Y	-51.6 mm
Centroid Z	-1.38e-006 mm

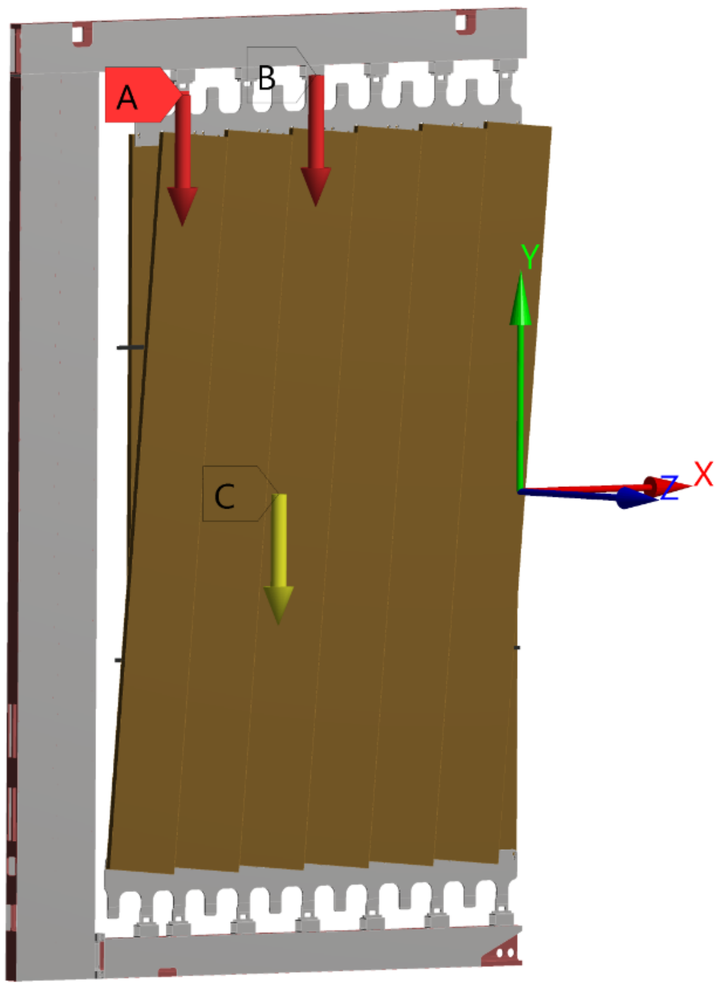
Properties	
Volume	2.17e+007 mm³
Mass	78.1 kg
Centroid X	-1.74e+003 mm
Centroid Y	-2.95e+003 mm
Centroid Z	0.236 mm

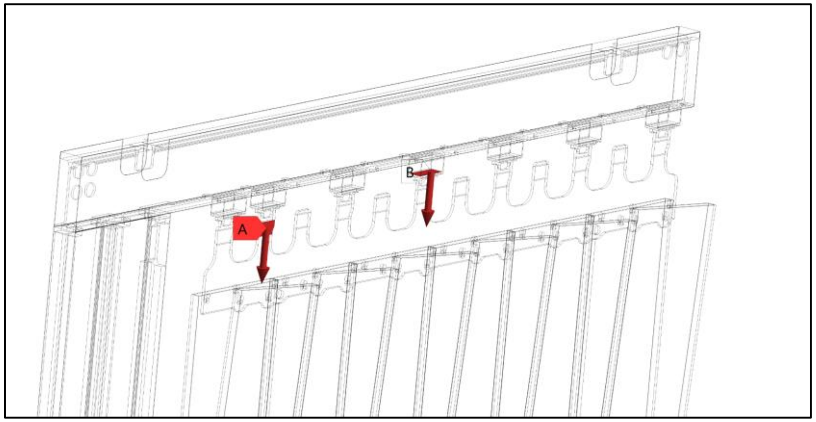
- The loads applied on the structure have been reported

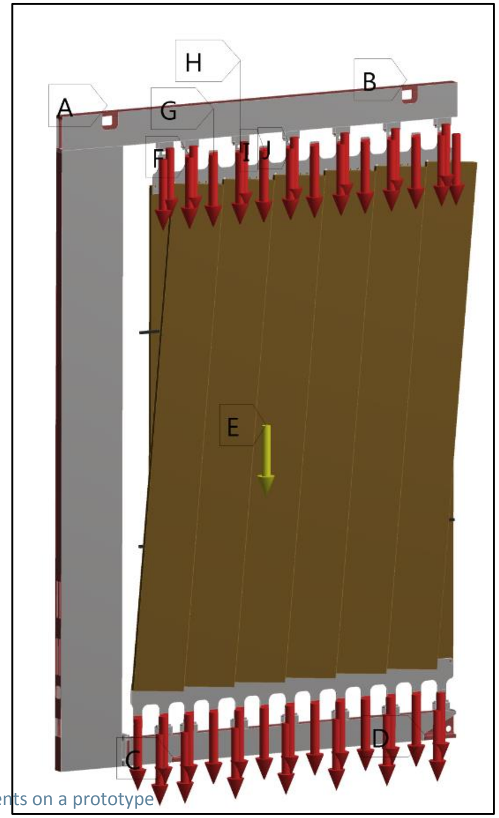
C Standard Earth Gravity: 9.81e+003 mm/s²

A Cooling Blocks + Electroni Board 1: 50. N

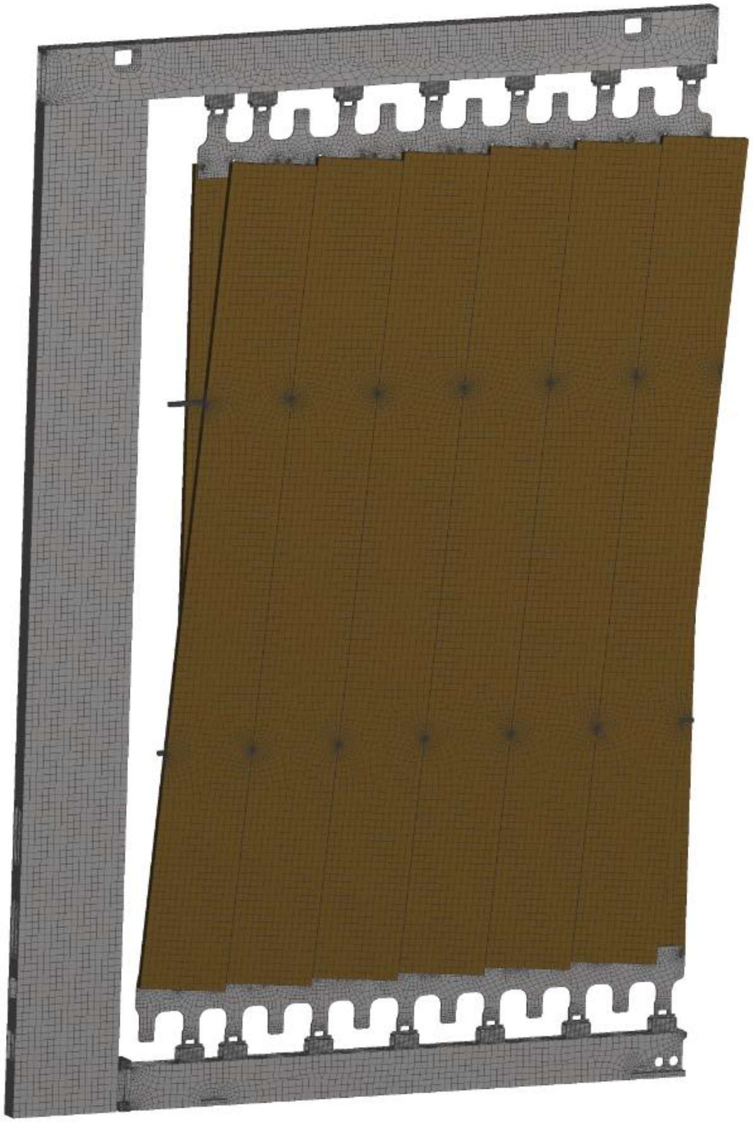
B NOVEC Manifold 4: 42. N



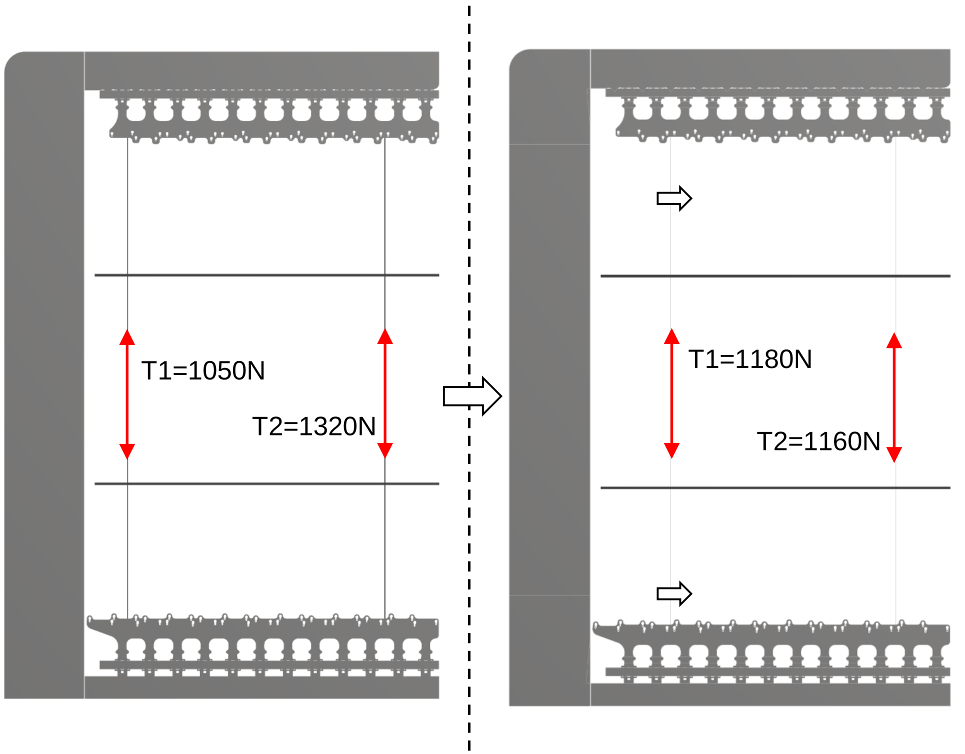


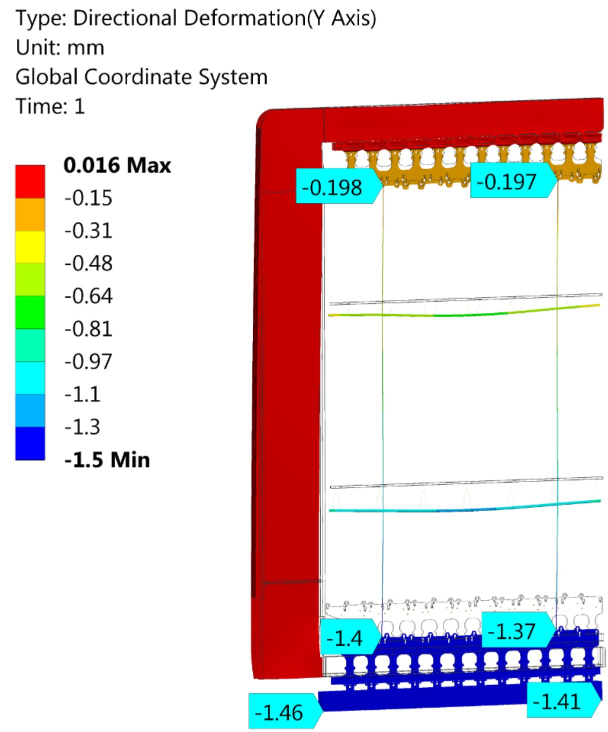


- The mesh is already quite good for a first deformation approximation. A sensitivity analysis has been carried out for the final model



- The finite element model has been used to define the correct position of the carbon fibres cables in order to obtain the same forces and omogeneusly distribute the stresses on the structure close to the fixation points





Data:

$R := 4\ mm$ $\quad E := 121000\ MPa$

$r := 2\ mm$ $\quad T := 1170\ N$

$L := 4607.5\ mm$

Teoretical cable elongation:

$A := \pi \cdot (R^2 - r^2) = 37.699\ mm^2$

$\sigma := \frac{T}{A} = 31.035\ MPa$

$\varepsilon := \frac{\sigma}{E} = 0.000256$

$\Delta L := \varepsilon \cdot L = 1.182\ mm$

Similar to the elongation observerd by FEA:

$\Delta L_{FEA} := 1.4\ mm - 0.198\ mm = 1.202\ mm$

Since the length to recover is 1.44mm, the strain to be imposed on the cable is:

$\Delta L_{recov} := 1.44\ mm$

$\varepsilon_{imp} := \frac{\Delta L_{recov}}{L} = 0.000313$

Details of "Beam To Cable"	
Geometry	
Scoping Method	Geometry Selection
Geometry	1 Body
Definition	
Cross Section Area	Beam Cross Section
Advance Settings	
Cross-Section Scaling	Enforce Incompressibility
Define Initial State	Yes
Initial Strain	0.000313

- It is very important for the correct functioning of the particles track-based alignment software that the modules are as flat as possible and stable during the data acquisition. Two additional horizontal beams have been added to the structure to increase the overall stiffness and decrease the free inflection of the modules. The deformation magnitude and shape of the modules is considerably better.

- To improve the structure stiffness and stability, a 4th fixation point has been added on the structure. The structure became hyper static

- To avoid uncontrolled modules deformation and additional forces and stresses on the supports and the structure, the kinematic has been kept isostatic for the insertion and the adjustment phase. The 4th point of fixation will be engaged only after the final adjustment