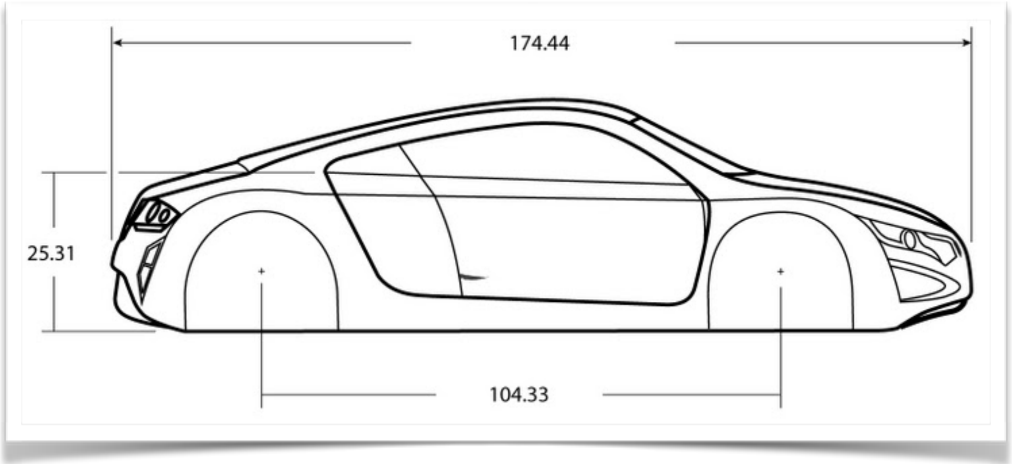
Mechanics for the 5th and 6th pixel layer

Sergio Gonzalez Sevilla, Sebastian Michal (UniGe)

UNIVERSITÉ DE GENÈVE

2nd ATLAS HV-MAPS mini-workshop
July 2nd, 2015



1.- Conceptual design

Introduction

- Much work on-going to (re)-define the ITK layout for Phase-2
  - *ITK Layout Task Force Workshop* (June, 23): https://indico.cern.ch/event/394897/
    - see Andi's summary talk in this workshop

- High-level functional requirements (ATL-COM-UPGRADE-2015-015)

  1.- basic operational parameters

  2.- required tracking performance

  - pile-up robustness, coverage, track reco. efficiency (e, μ, π), track parameter resolutions, occupancies, fake-rates, etc.

  3.- interface to the LHC machine (protection against beam losses)

  4.- interface to the rest of ATLAS

  - ITK conforming to TDAQ requirements, latencies, L1-track trigger, etc.

  5.- access scenarios

  - beam-pipe removal, inner pixel layers removal, whole pixel removal, whole ITK removal

  6.- mechanical constraints

  7.- electrical requirements,

  - power dissipation, noise occupancy, ESD protections, SEU, grounding & shielding, specs for components (cables, capacitors), etc.

  8.- safety requirements (interlocks, etc.)

Mechanical constraints

- 6.1.- *"While meeting all different requirements, the goal is also to minimize the amount of material inside the ITK volume by careful choices of material and routing. The layout if ITK structures should take into account the feasibility of cable routing and the effect of that routing on the material budget and detector performance"*.

  - material budget directly affecting the tracker performance
    - tracking resolution (low p_T tracks)
      - multiple scattering
    - tracking efficiency
      - pions: nuclear hadronic interactions
      - electrons: bremsstrahlung
  - passive material (services, mechanical support structure, interfaces) dominate over active material in the forward region $|\eta|>1.5$
    - though typically everywhere in the detector: more sensors = more services

Positioning requirements

ATU-SYS-ES-0027

- Hermeticity and overlaps
  - ITK must be fully hermetic for 1 GeV p_T tracks originating from a cylinder of length z = ±150 mm along the beam direction.
  - Minimum overlap of 5 sensing elements (pixels or strips)
- Assembly tolerances
  - local assembly placement accuracy (between adjacent modules) of ±100 μm
  - local assembly survey: comparable or better than the intrinsic sensor resolution
- Stability
  - directly to the track-based alignment strategy

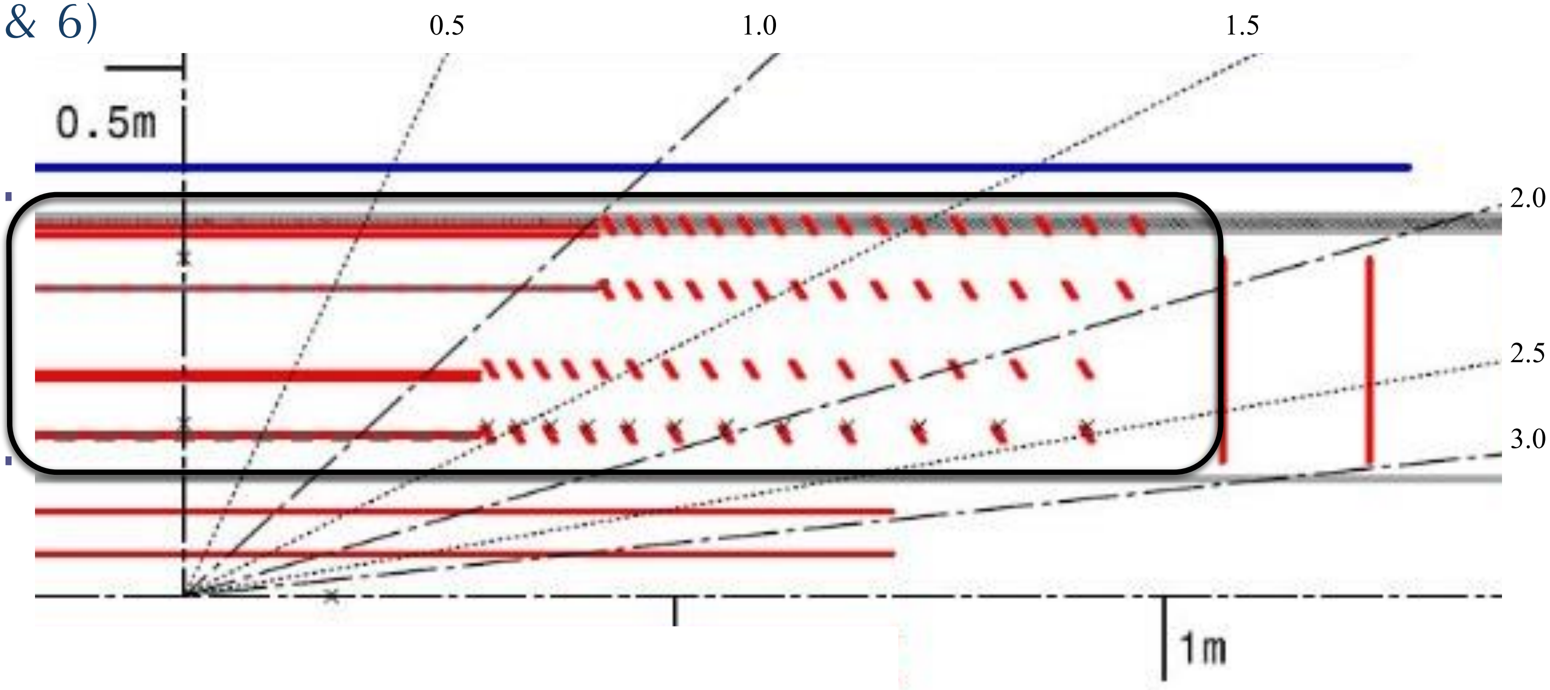
	Timescale	Load	Requirement (RMS, rφ)	Alignment level
Short	1 d	- external vibrations - variations of thermal load (trigger rate variations)	2 μm	L1, L2
Medium	1m	- (infrequent) 'seismic' perturbations: magnet ramps, cooling system cycles, power and HV cycles	5 μm	L3
Long	several months to years	- relaxation (creep)	100 μm	-

SLIM concept (1/3)

- Main motivation: strongly reduce the total amount of material along the track path in pixel layers at large radii
  - fulfilling tracking performance requirements and complying with mechanical constraints and positioning requirements
  - (classical) barrel-modules layout (// z-axis) + **inclined modules** for |η| > ~1.0 (Pixel layers 5 & 6)

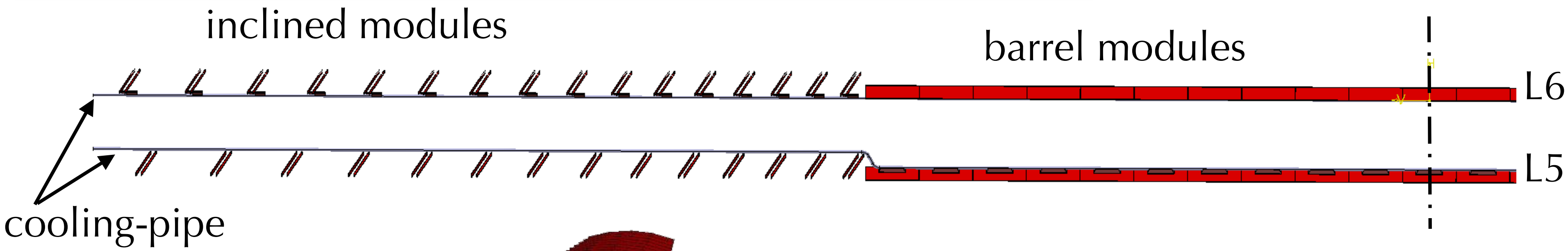
SLIM

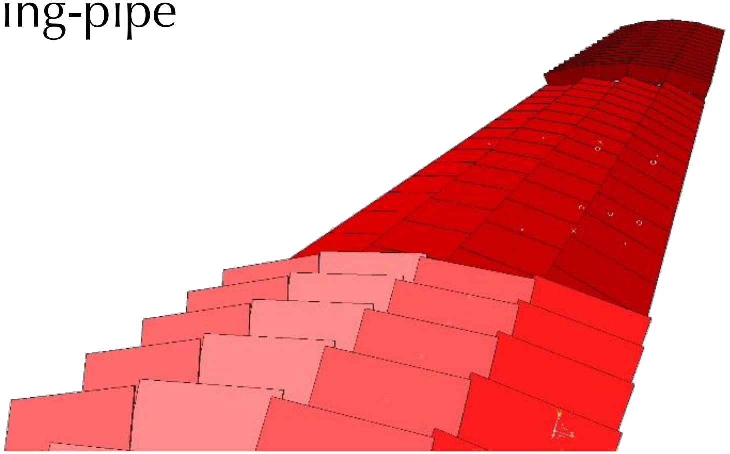
Stiff **L**ongeron for **I**TK **M**odules

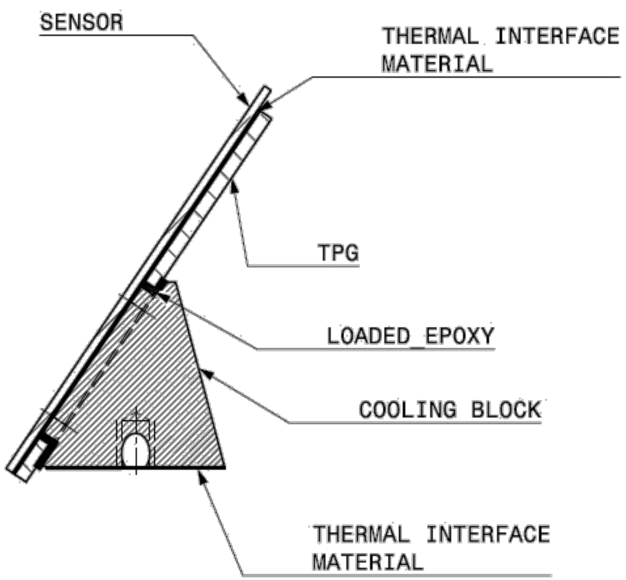


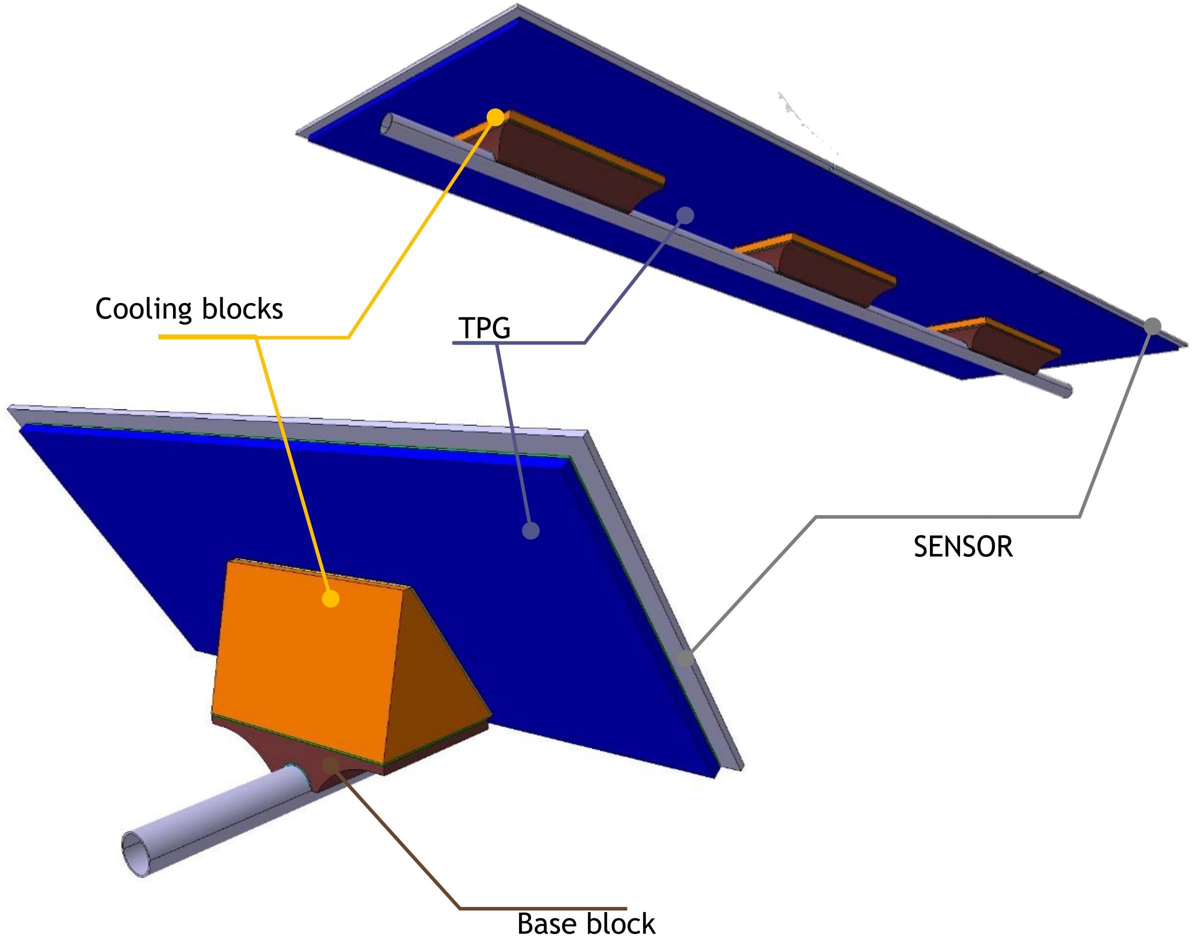
- Benefits:
  - less sensors
  - less services / dead material
  - cost savings
  - similar tracking performances, barrel / endcap transition region can be moved forward

SLIM concept (2/3)



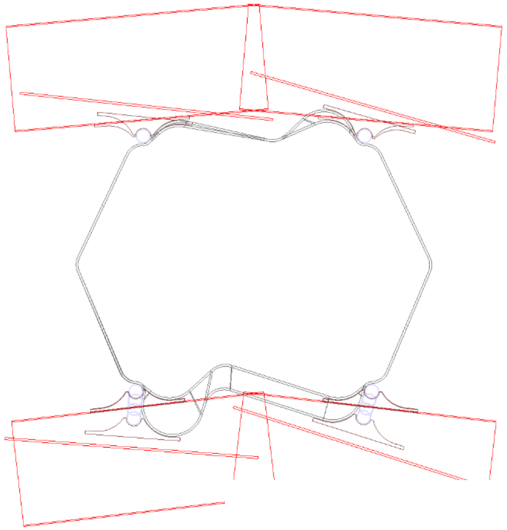


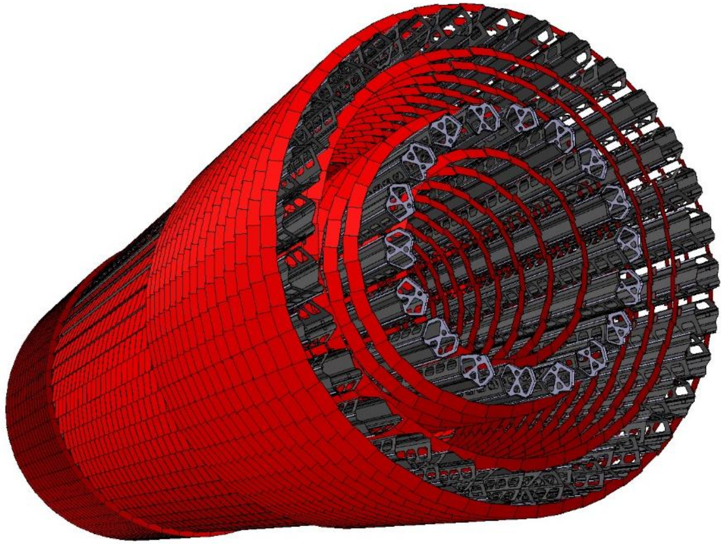


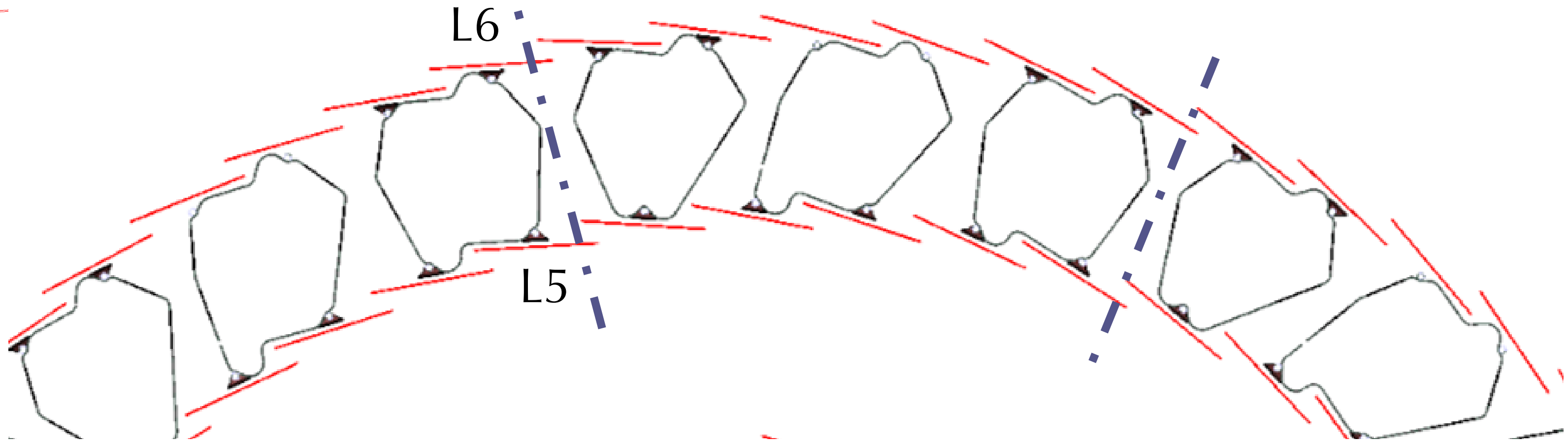


SLIM concept (3/3)

- Modules implemented on both sides of the carbon structure (Longeron)
- Same modules (barrel, tilted) for all layers, but different types of support structures depending on layer pairs
  - Layers 56: 3 types of longeron

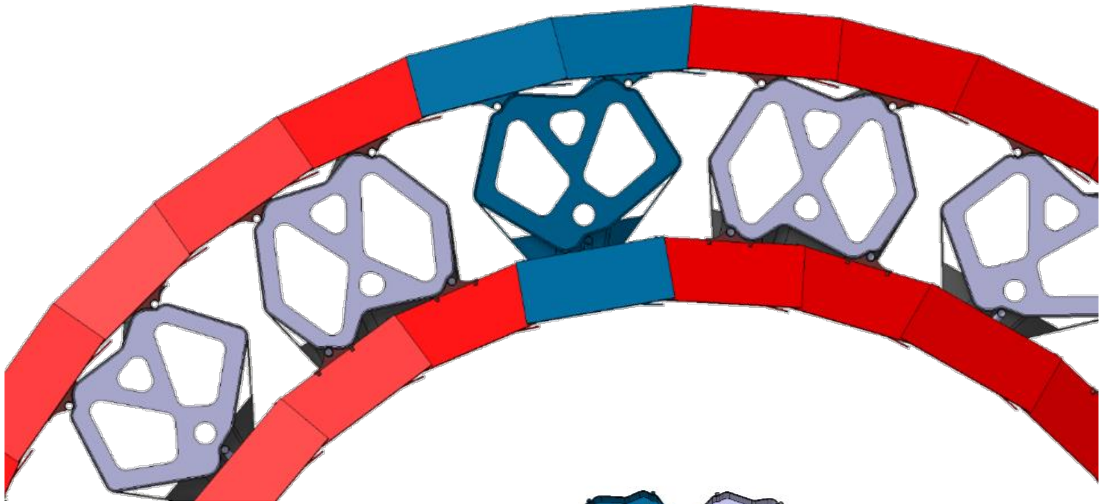


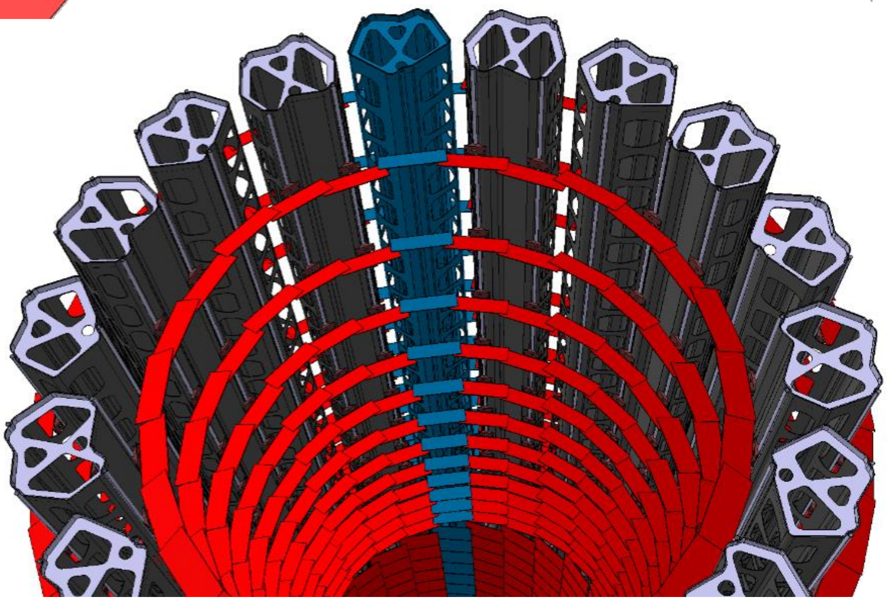




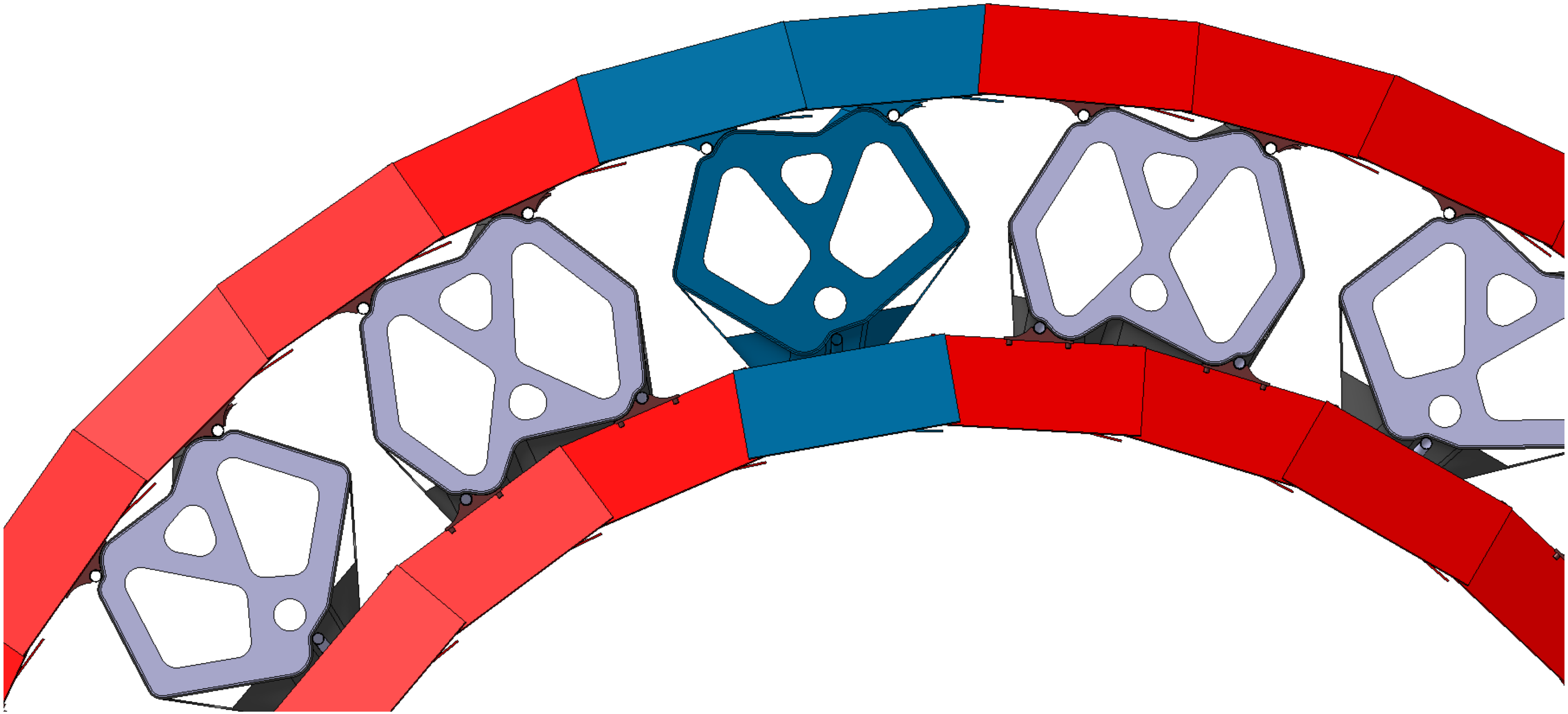
Stave integration

- IBL experience on integration stand
- Stave extracted radially with a combined kinematic

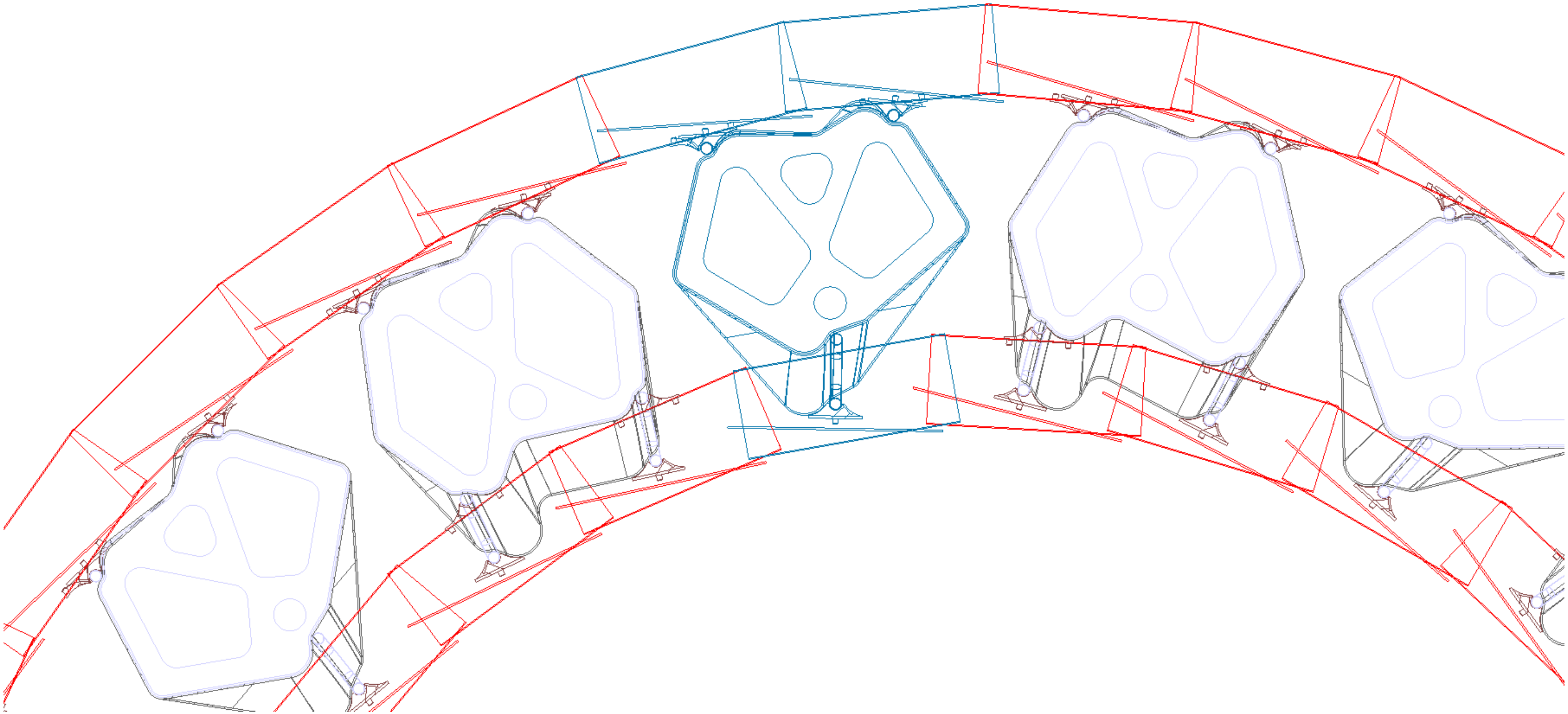




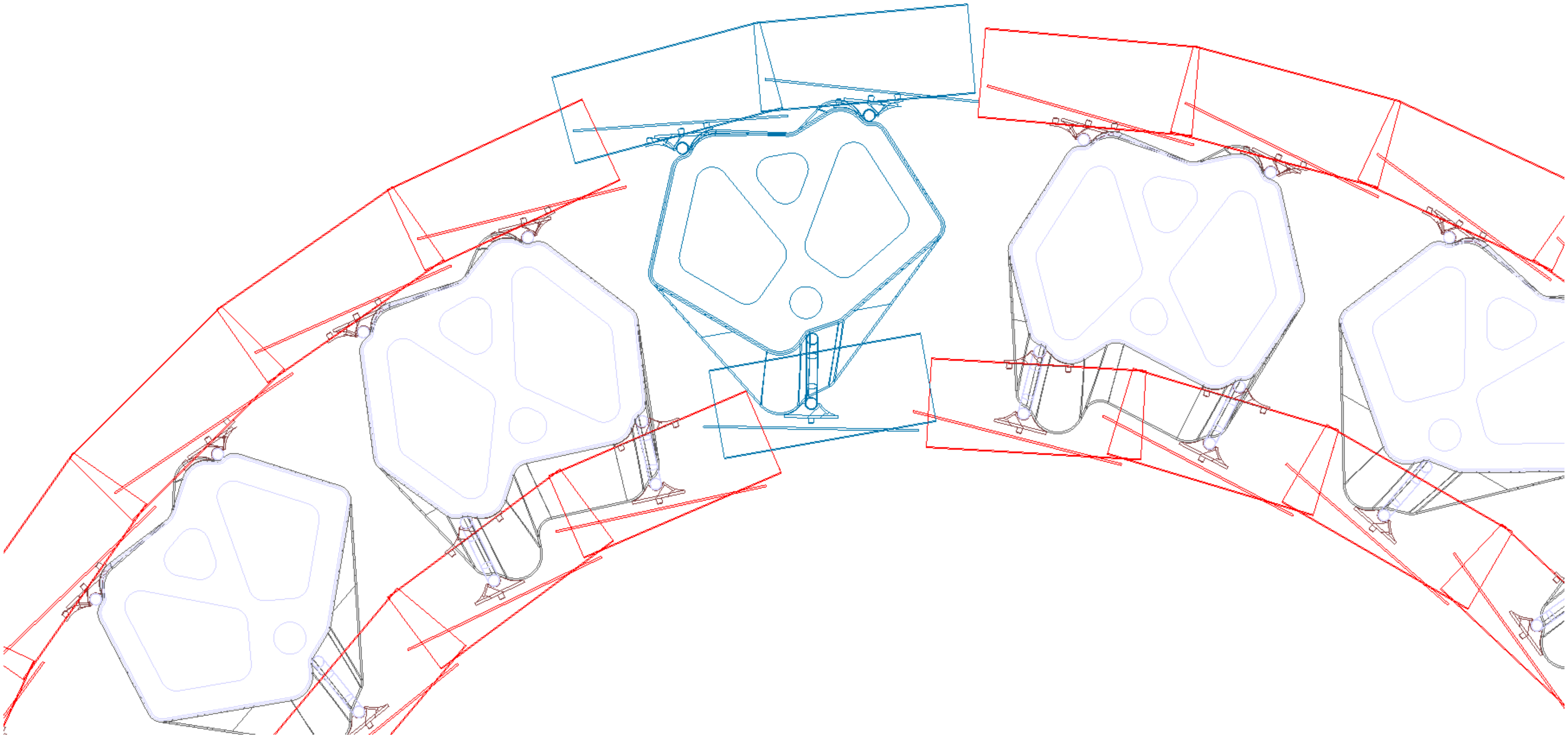
Stave integration



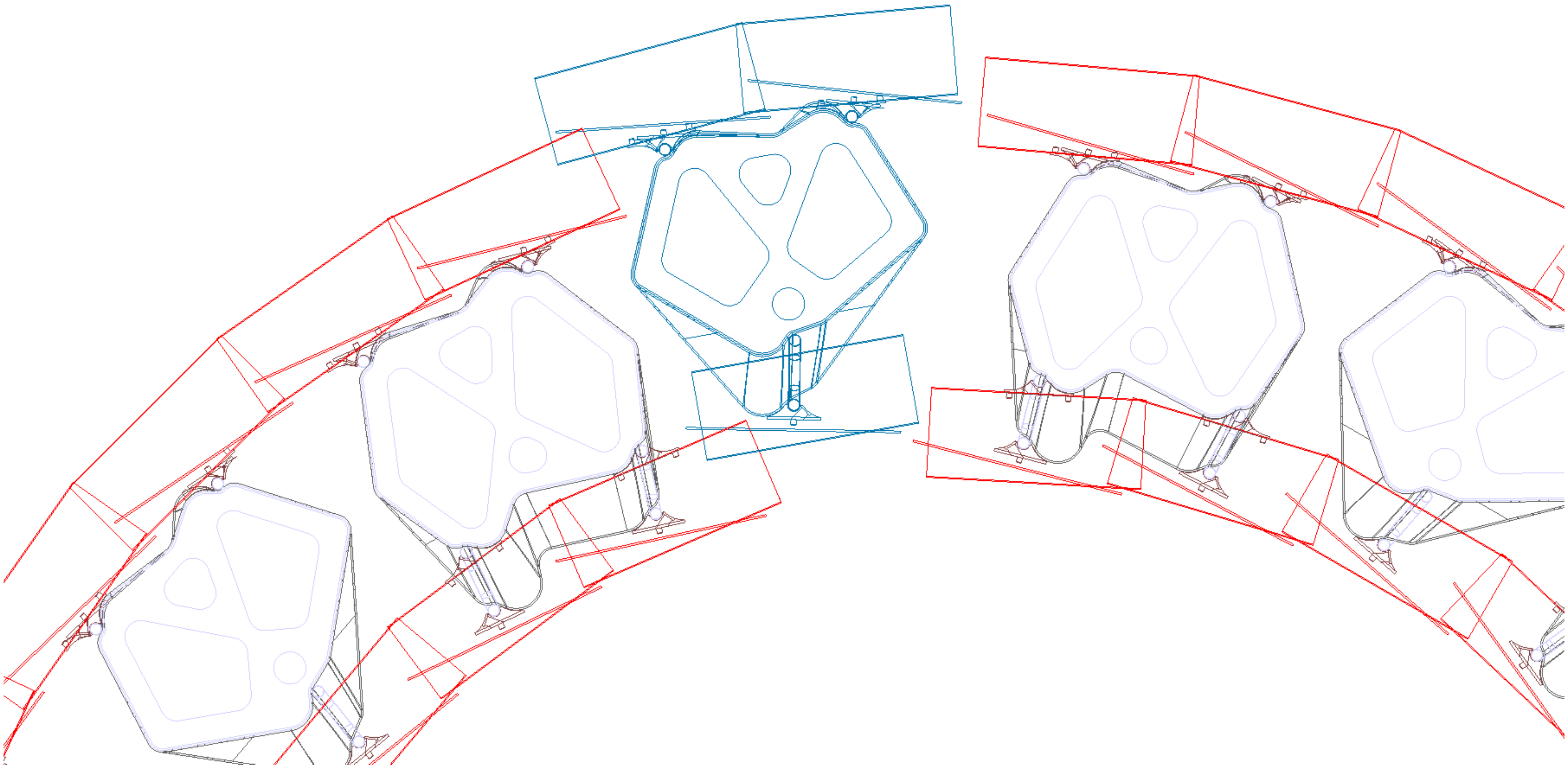
Stave integration



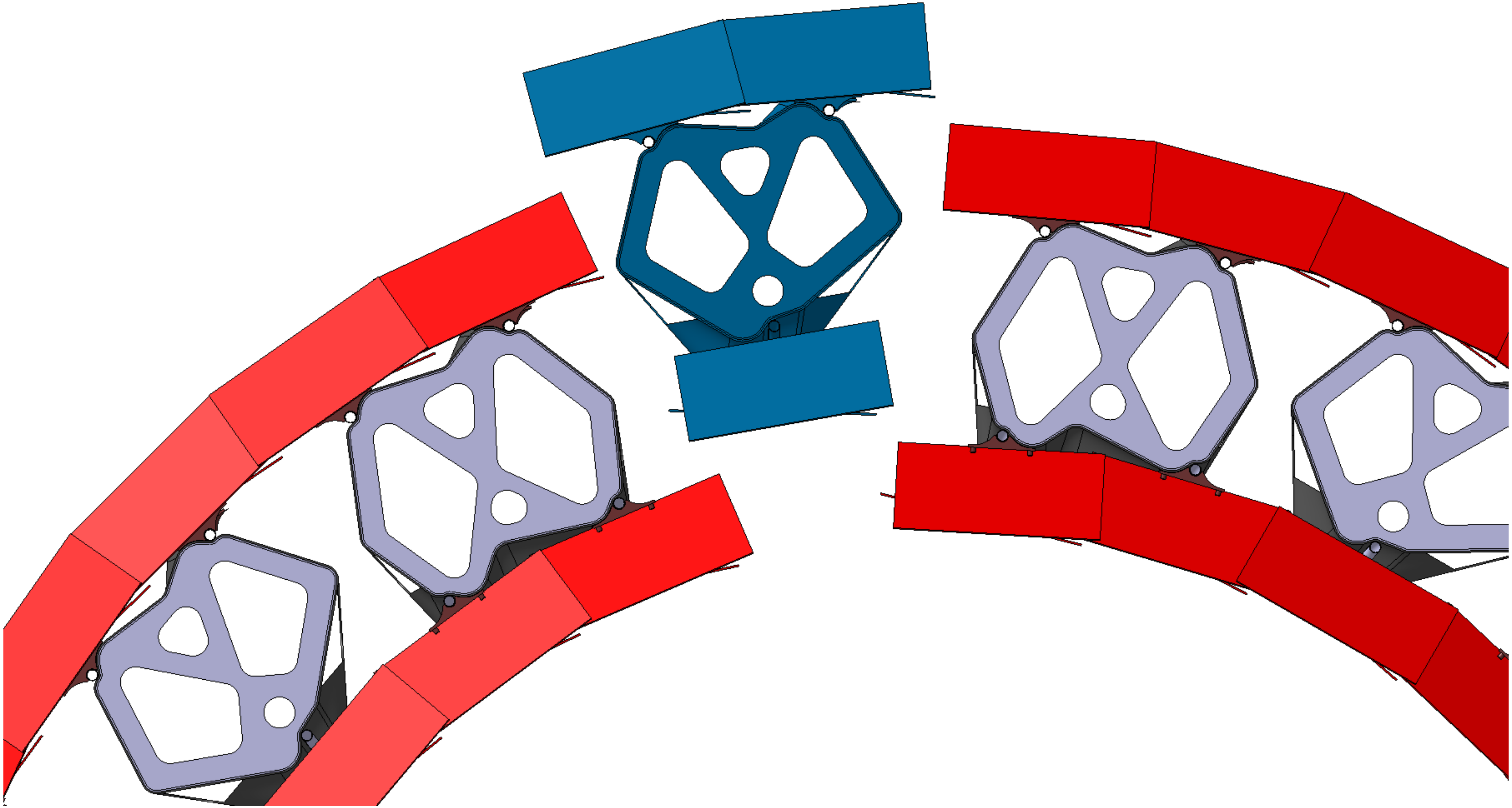
Stave integration



Stave integration



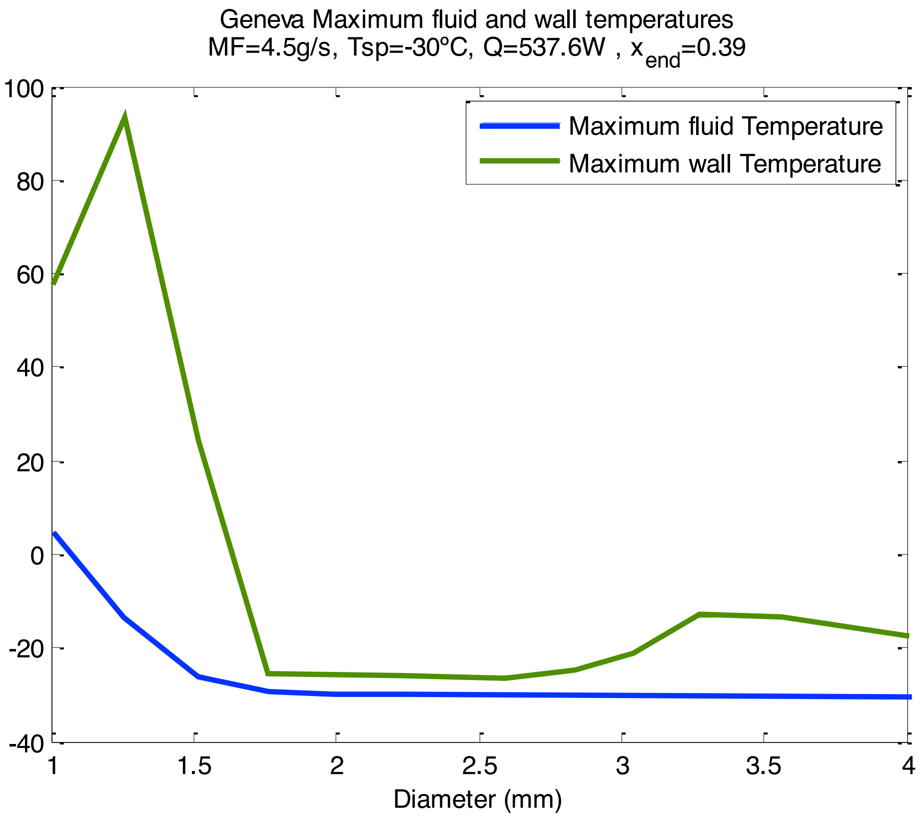
Stave integration

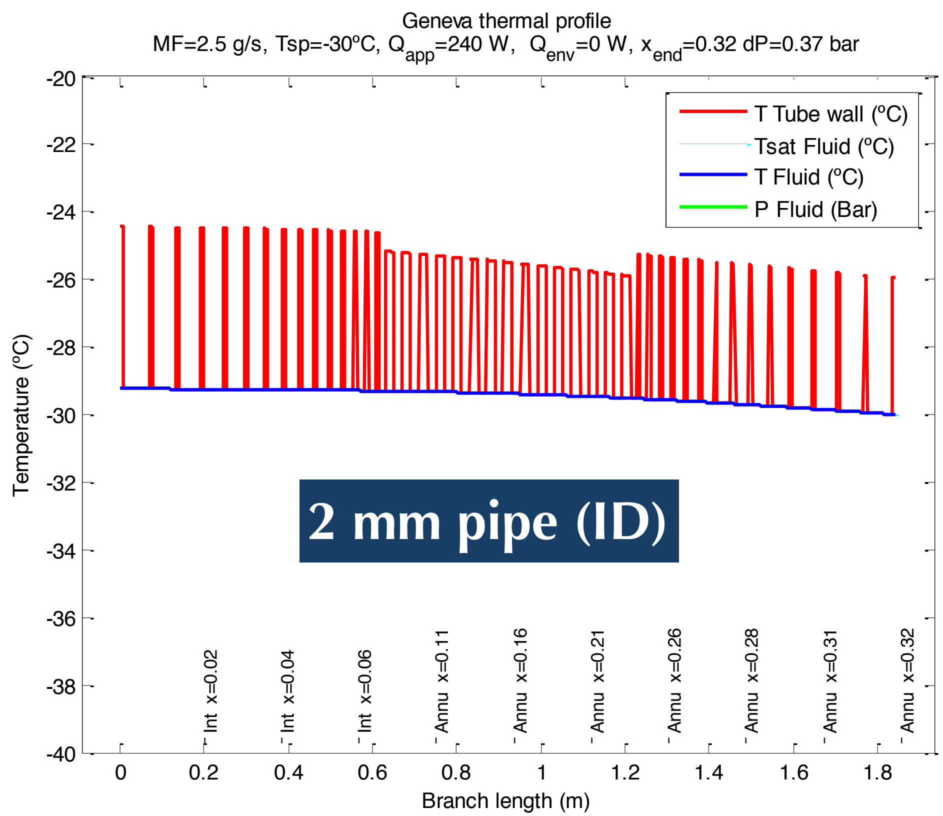


Cooling line

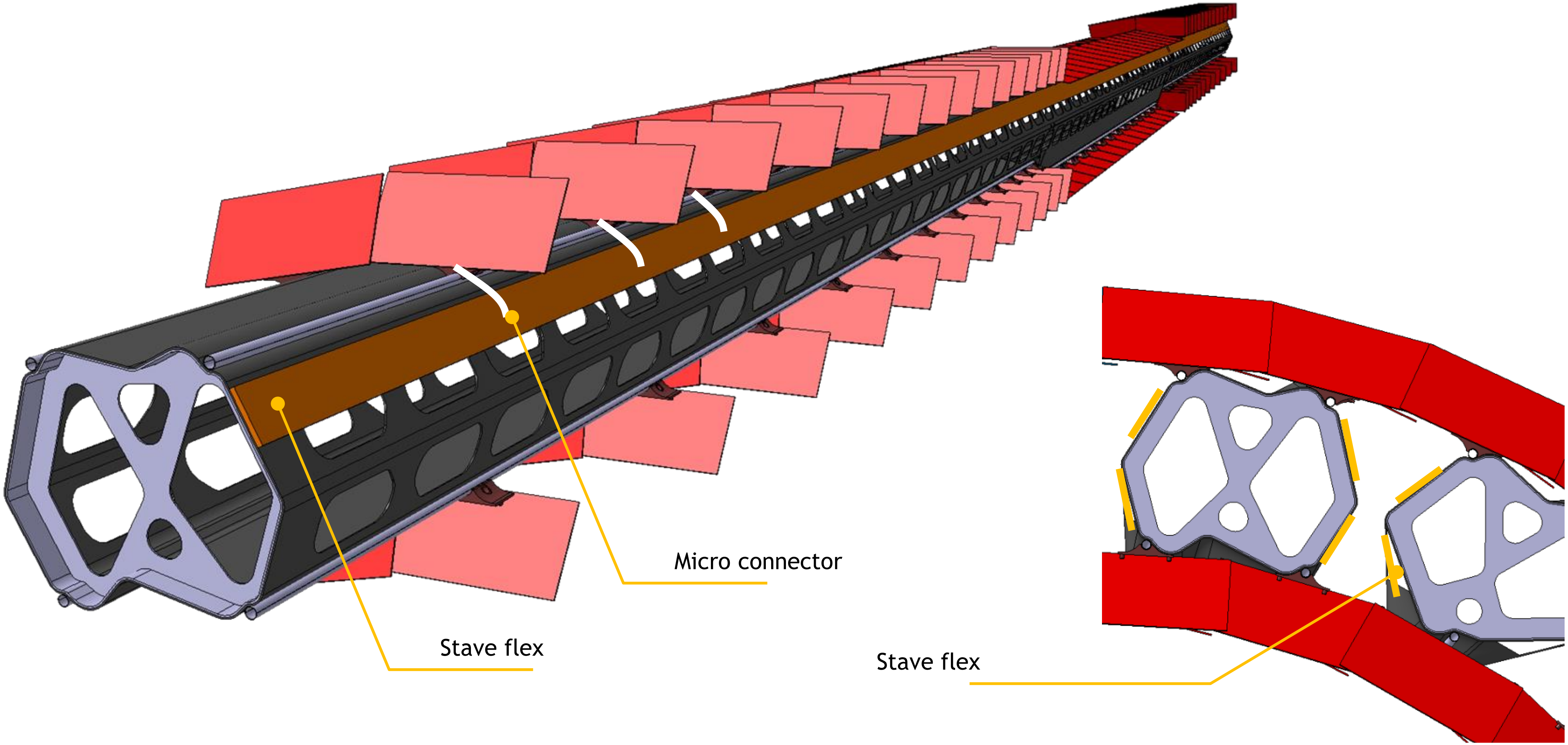
bverlaat@nikhef.nl
Bart VERLAAT

- Simulation of cooling performance using CAD cells
  - pipe with ⌀2 - ⌀2.5 mm inner diameter OK (CO_2 cooling)
  - stability of cooling temperature along longeron ±1°C



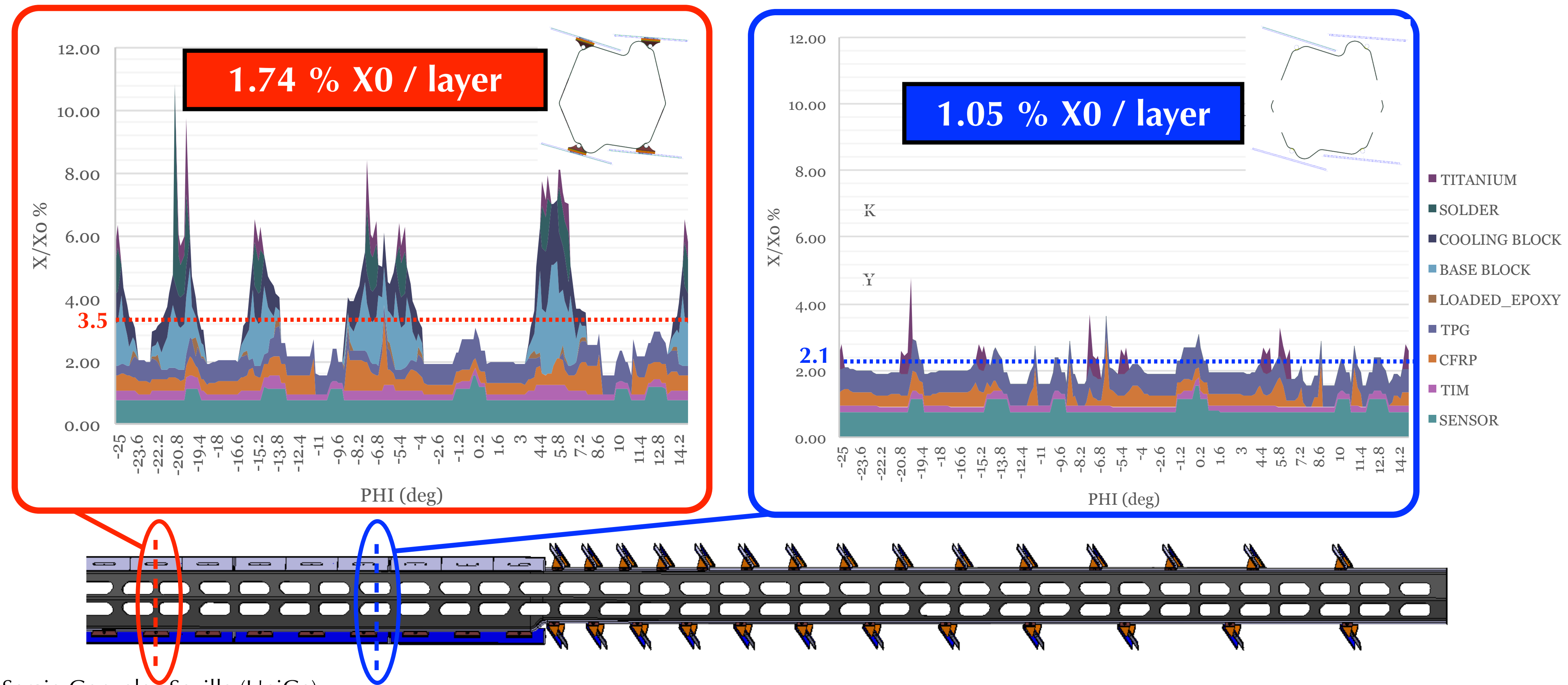


Services routing



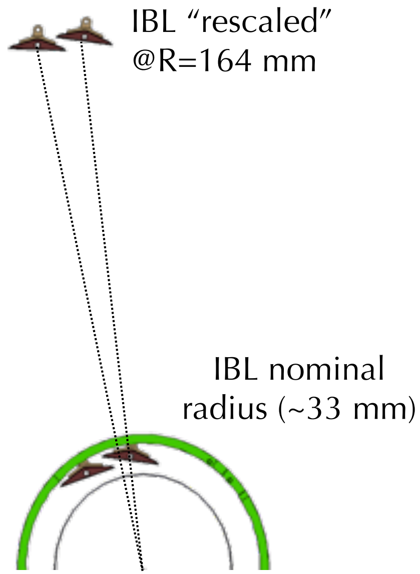
Material budget (1/2)

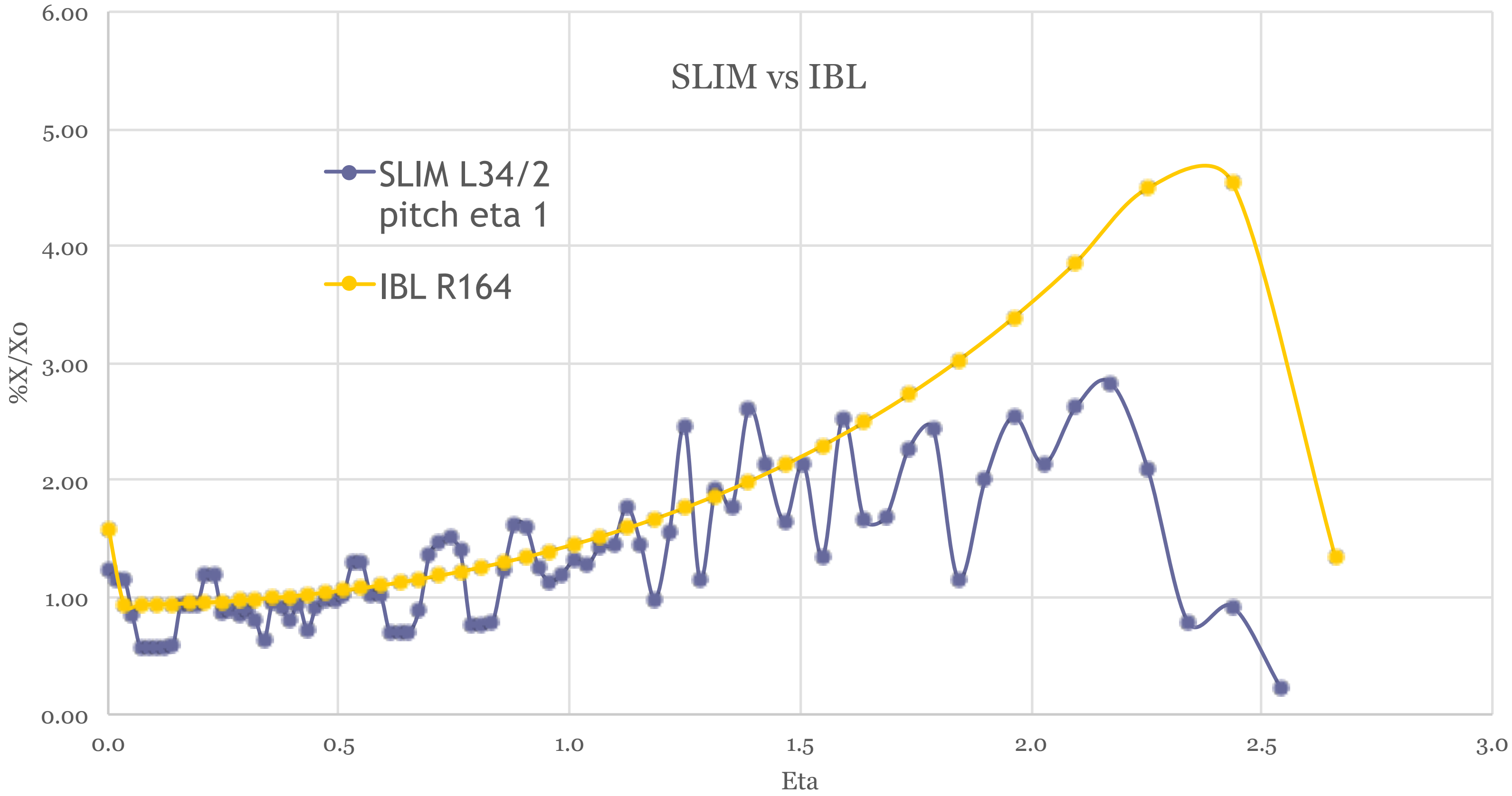
		SLIM				CLASSIC				
Layers	Radius (mm)	Number of Cooling Lines	Number of tilted modules	Number of Barrel modules	Total SLIM surface (m2)	Number of stave	Stave area (mm^2)	Total area (m^2)	Ratio	Saved surface (m²) For a 2 m long stave
3rd	160	27	24	15	1.2	26	80000	2.1	0.56	0.9
4th	200	36	30	15	1.7	34	80000	2.7	0.64	1.0
5th	300	50	28	21	2.8	50	80000	4	0.70	1.2
6th	340	60	32	21	3.6	57	80000	4.6	0.78	1.0

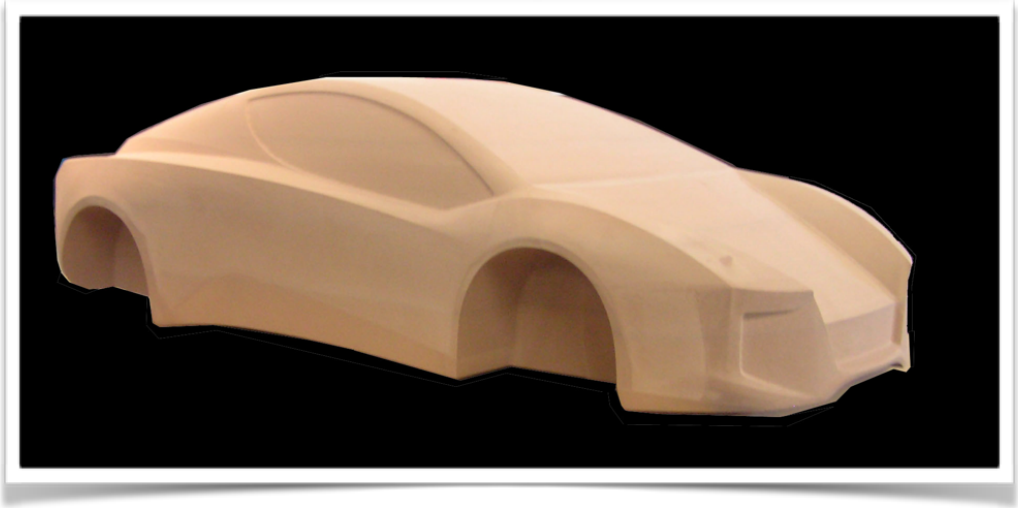


Material budget (2/2)

- Comparison of material budget: SLIM vs IBL
  - R=164 mm, 2 m long stave
  - rescale IBL position up to 164 mm
  - only local supports, no silicon







2.- Prototyping

Prototyping campaign for SLIM concept

1.- **Longeron**

- manufacturing
  - short section: transition region

2.- Cooling lines

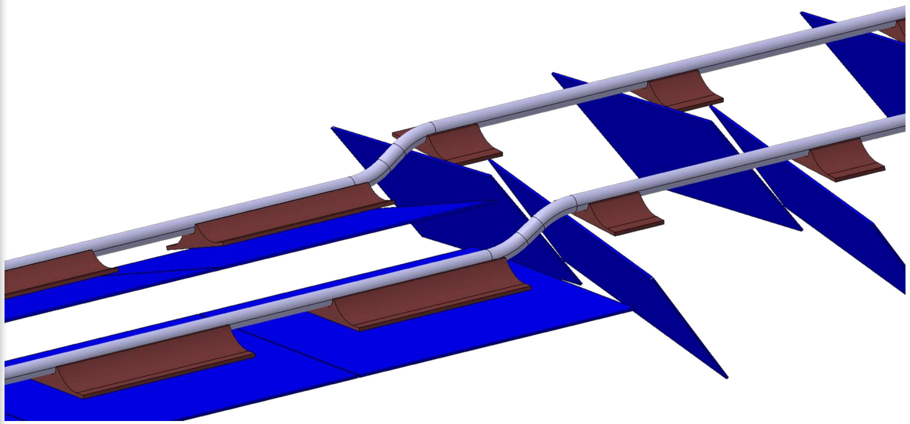
- cooling pipe bending jig
- cooling line-to-longeron bonding jig

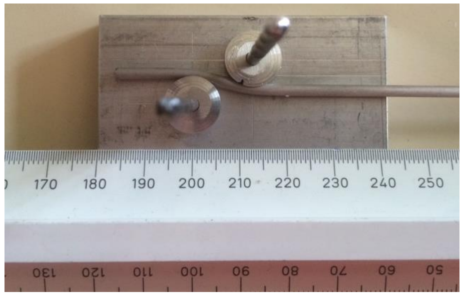
3.- Module cells

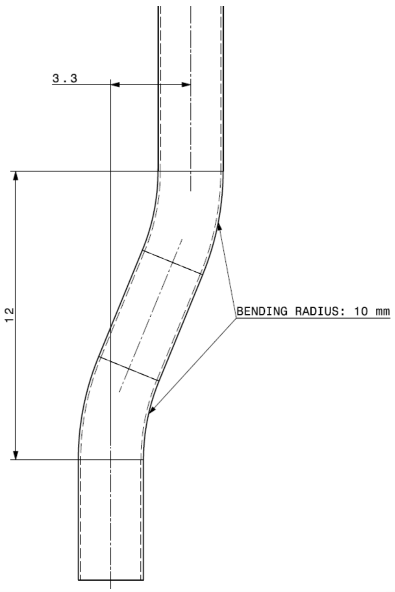
- cooling blocks production
- barrel cell assembly and loading
- tilted cell assembly and loading
  - ➡ measure thermo-mechanical performances of cell assembly

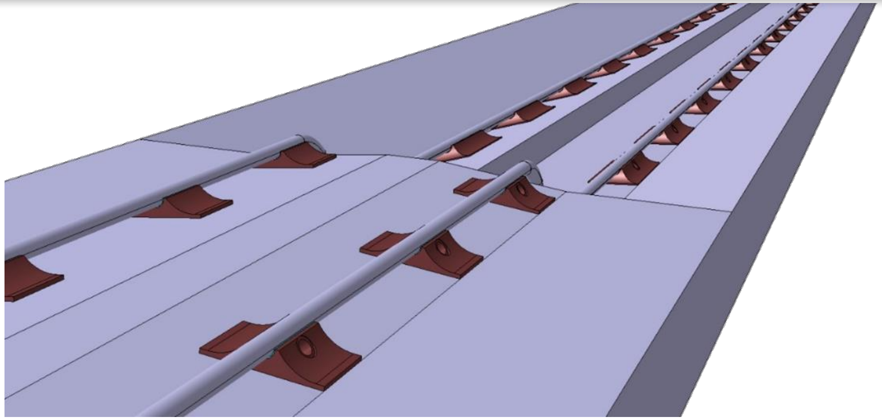
Cooling lines

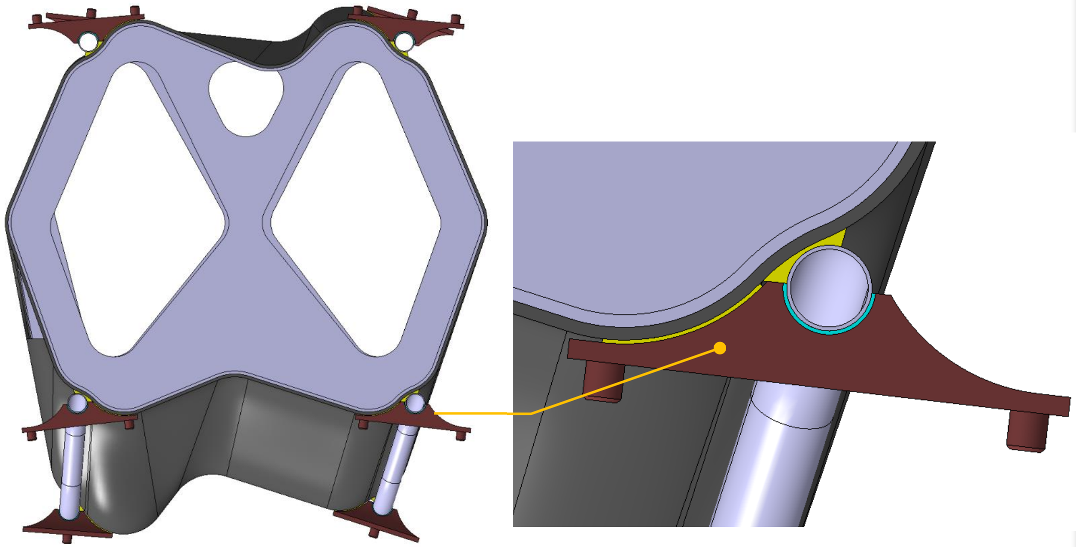
- Cooling pipe bending jig
- Cooling line-to-longeron bonding jig
  - adhesive type (epoxy film / glue) ? thickness ?





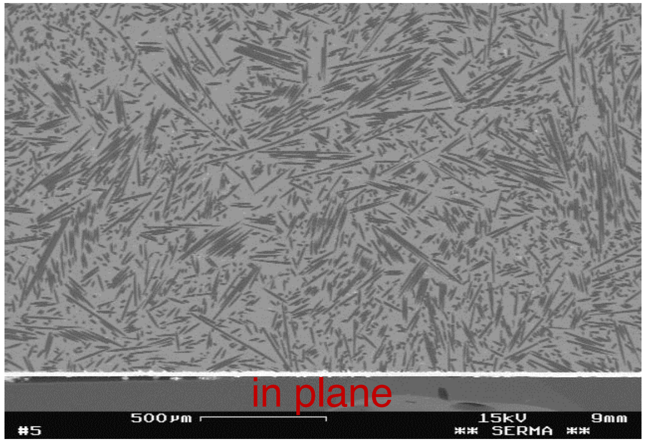


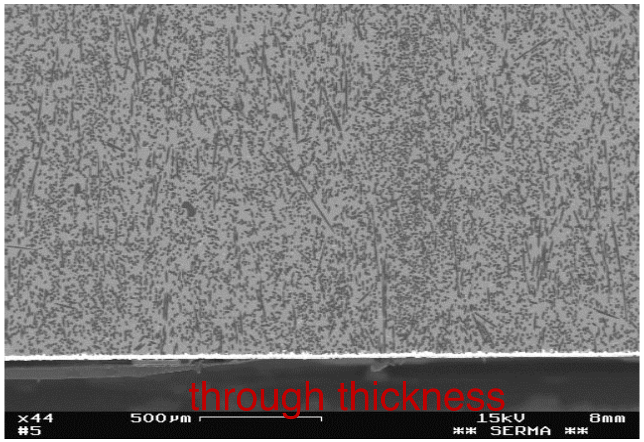




Base- and cooling-block prototypes (1/2)

- Aluminium-Carbon composite (60% Cf) from NovaPack (France)
  - Al alloy poured into a matrix of carbon fibres grown with given fibre orientation
  - in-plane fibres alignment, low CTE (Si CTE: 2.6 ppm/^{o}C)





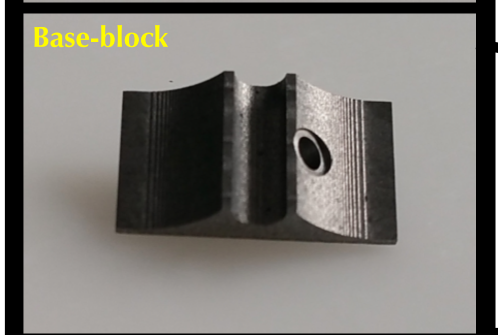
NovaPack

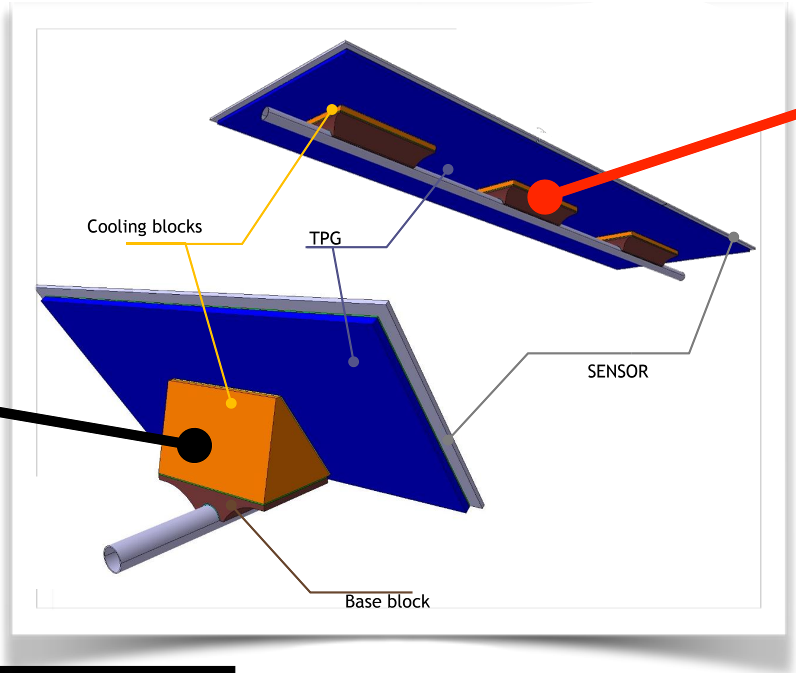
PROPERTIES	- 7	- 4
Thermal properties		
Thermal conductivity (W/m.K) / (X-Y)	200	230
Thermal conductivity (W/m.K) / (Z)	125	120
Specific Heat Capacity (J/kg.K)	880	850
Physical properties		
CTE 25 - 150°C (ppm/°C) / (X-Y)	7	4
CTE 25 - 150°C (ppm/°C) / (Z)	24	24
Density (g/cm^3)	2.46	2.4
Mechanical properties		
Young's modulus (GPa)	90	98
Flexural Strength (MPa)	160	185
Electrical properties		
Electrical resistivity (µohm.cm)	6.9	

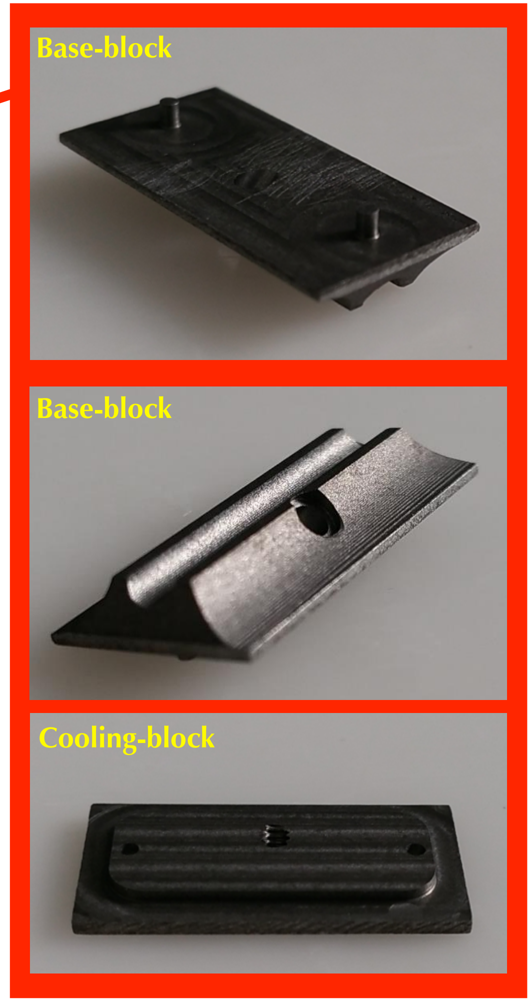
Base- and cooling-block prototypes (2/2)

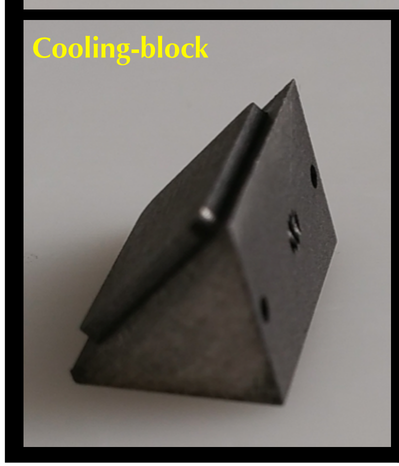
- First prototypes already received, **extremely good quality**
  - e.g: specifications for base-block positioning pin diameter: [0.994-0.980] mm ; metrology survey = 0.984 mm

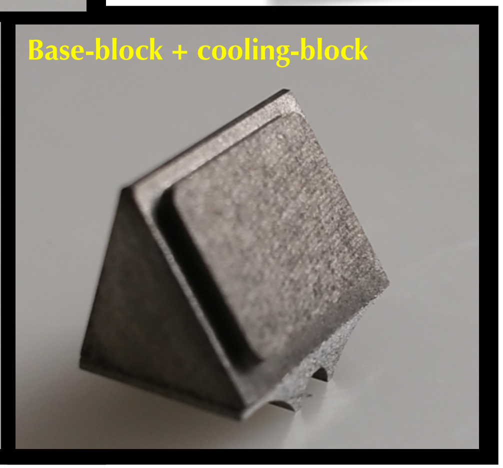
BARREL CELL



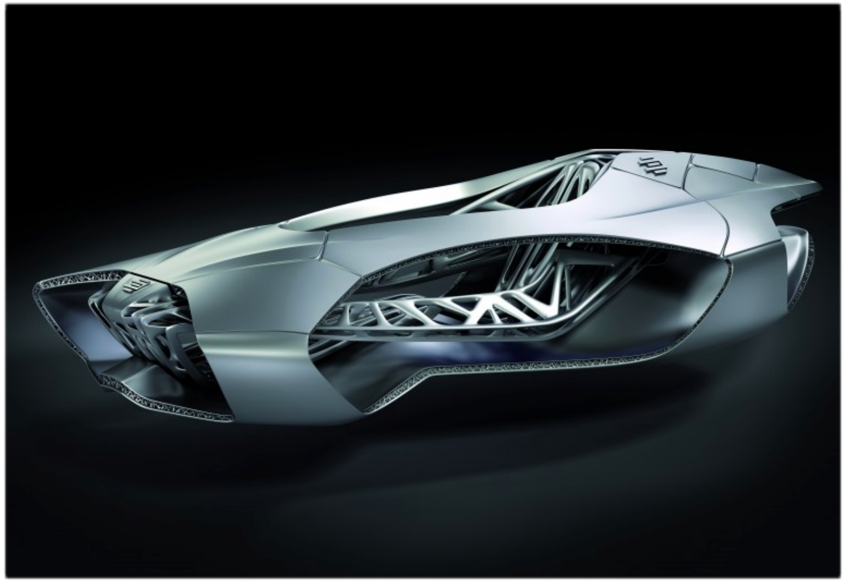






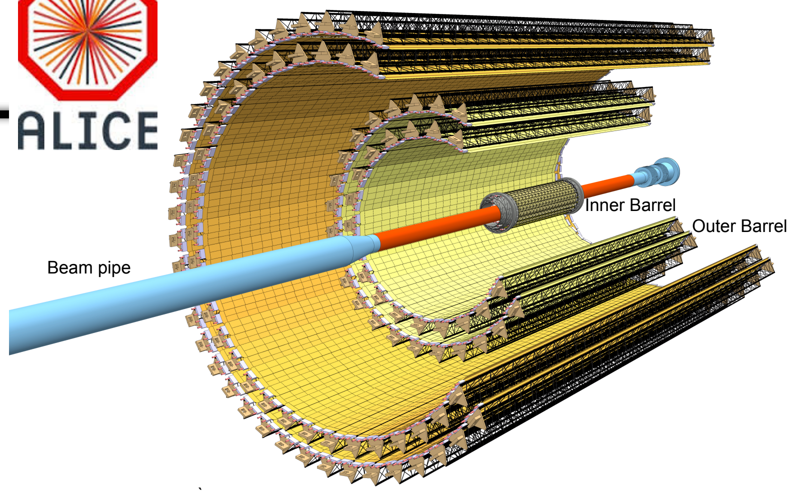


TILTED CELL

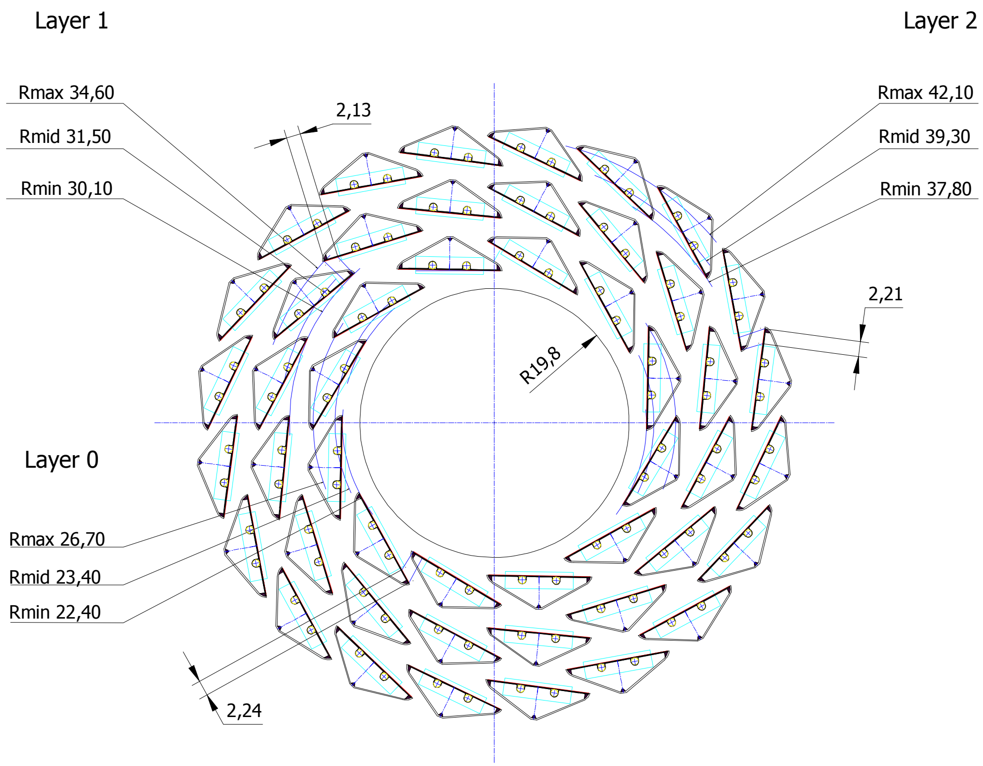


3.- Alternatives

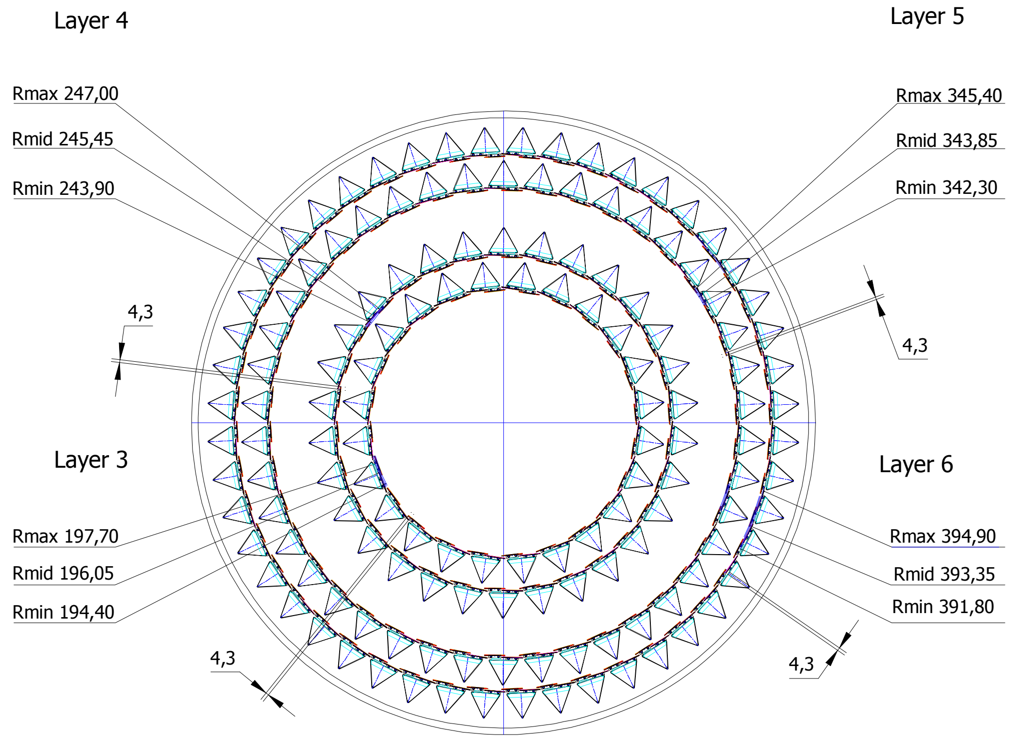
Upgrade of the ALICE ITS (1/2)



- ALICE Inner Tracking System (ITS)
  - 7 layers with MAPS
    - Inner Barrel: 22, 31, 39
    - Outer Barrel: 194, 247, 353, 405
  - 10.3 m^2, ~12.5 x 10^9 pixels with binary readout
- Operated at room temperature (20 - 30 °C), water cooling



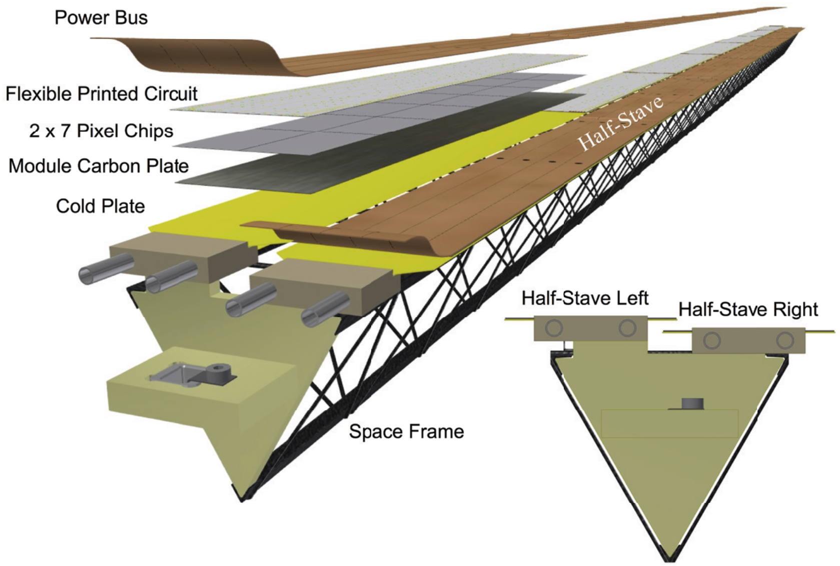
Inner Barrel

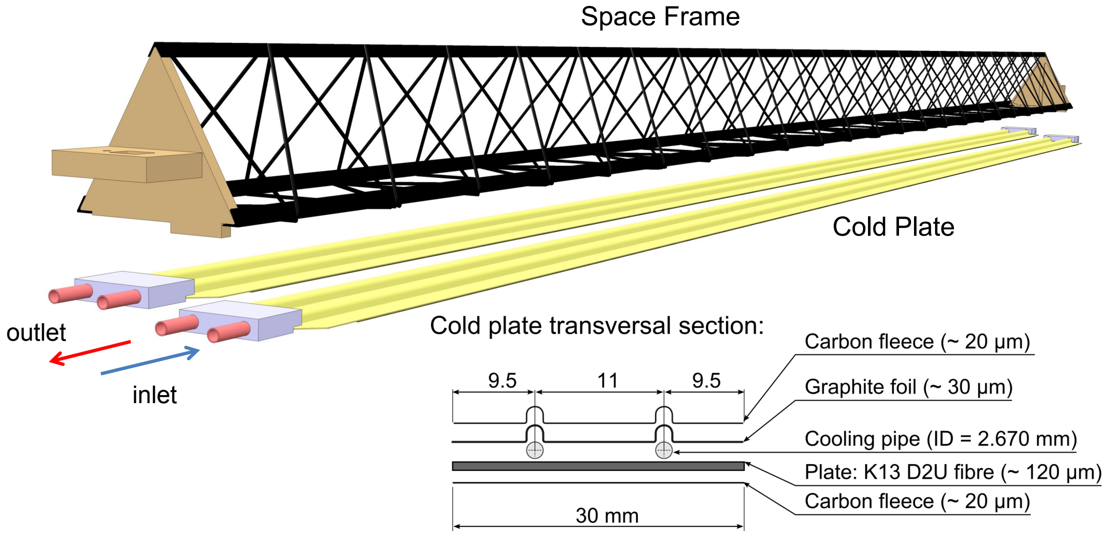


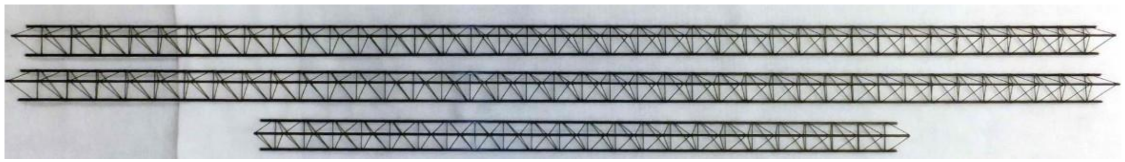
Outer Barrel

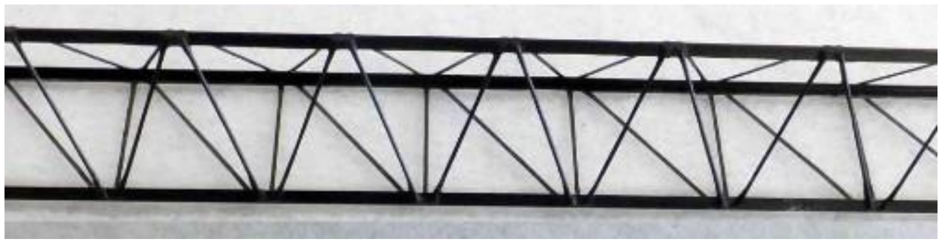
Upgrade of the ALICE ITS (2/2)

- Stave mechanical components:
  - **space-frame:** truss-like lightweight mechanical support structure for the single stave based on composite material (CFRP)
  - **cold-plate:** sheet of high-thermal conductivity CF laminate, with embedded polymide cooling pipes, ⌀1.0(2.7) mm ID for IB(OB) staves







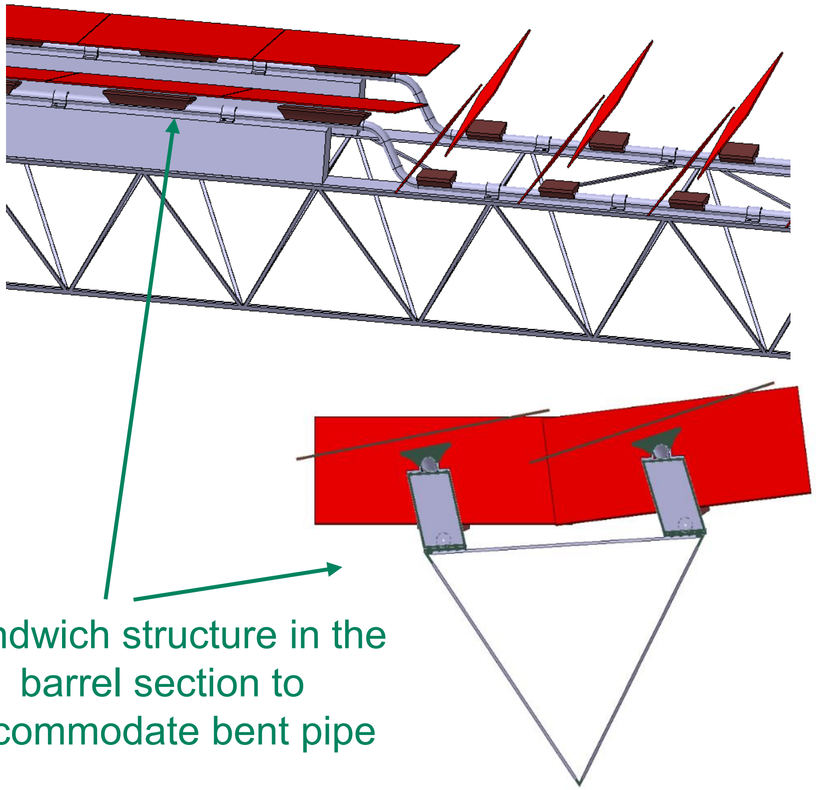


SLIM + Truss structure (1/2)

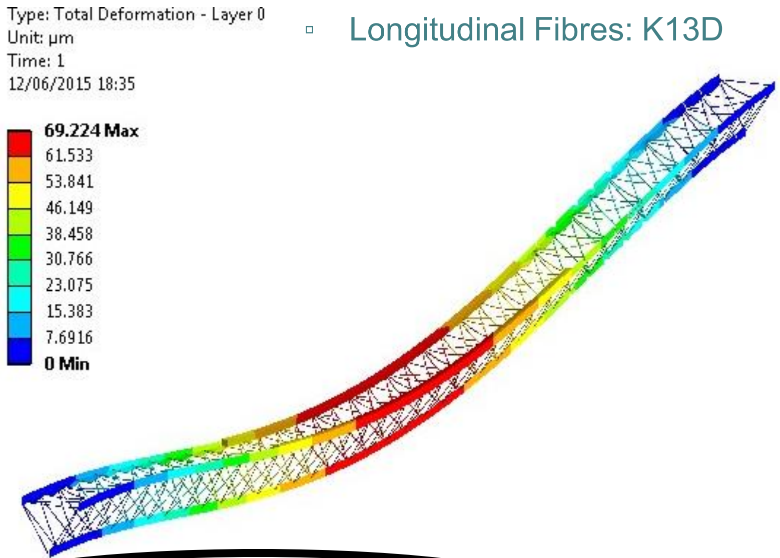
PH-DT Engineering office

1. Cooling lines + cooling pads attached to truss structure
   - adhesive bonding
   - mechanical fixation system

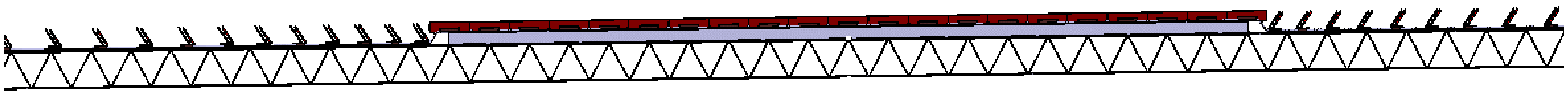
- Preliminary FE Analysis
  - End vertex fully constrained
  - Mass per cooling line: 160g
  - Cross members: M55J
  - Longitudinal Fibres: K13D



Sandwich structure in the barrel section to accommodate bent pipe



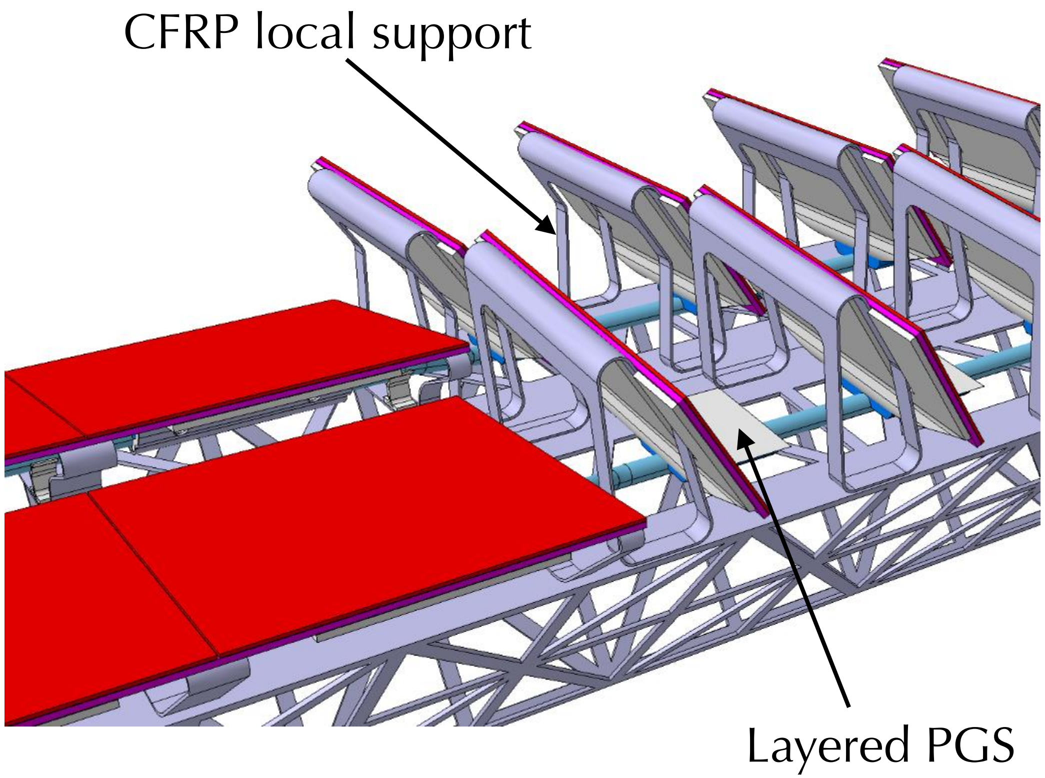
Mass of Truss Structure: ~ 55g

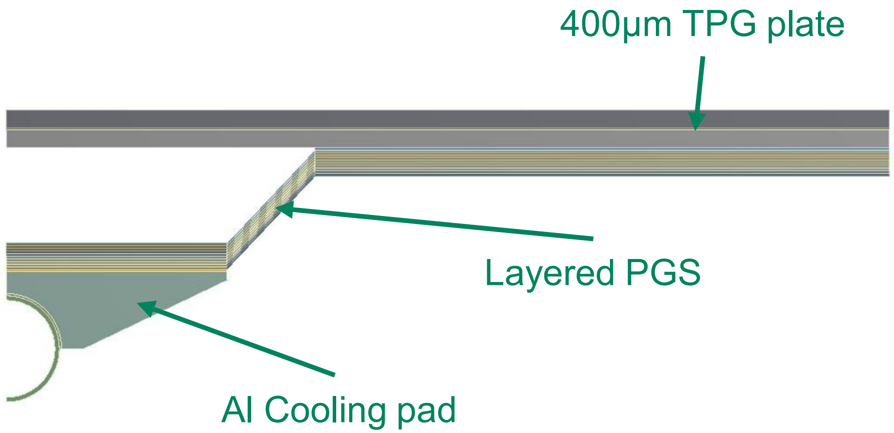


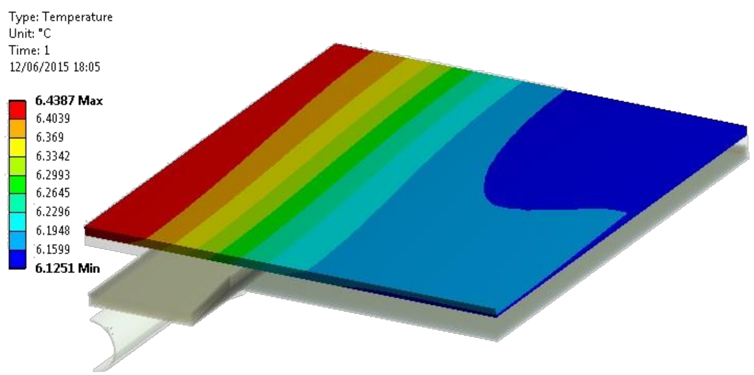
SLIM + Truss structure (2/2)

PH-DT Engineering office

2. Flexible thermal strap for heat management
   - TPG plate behind module to minimise T within sensor
   - Layered PGS (Pyrolytic Graphite Sheet) connecting TPG and cooling pads (floating pipes)
   - modules positioned on truss-structure via CFRP local supports







Summary

- Still a number of uncertainties in the layout of the future ITK
  - hopefully to be solved soon

- SLIM has been presented as a possible engineering solution for the outermost pixel layers of the ITK tracker
  - large benefits from using inclined sensors
    - large reduction in material budget
    - large reduction in cost

- First real prototypes currently being developed
  - evaluation of thermal and thermo-mechanical performances
  - comparison with detailed FEA simulations
  - validation of different component types and assembly techniques (pipe bonding)

- Further optimization of the layout after feedback from physics simulations

Thanks for your attention !

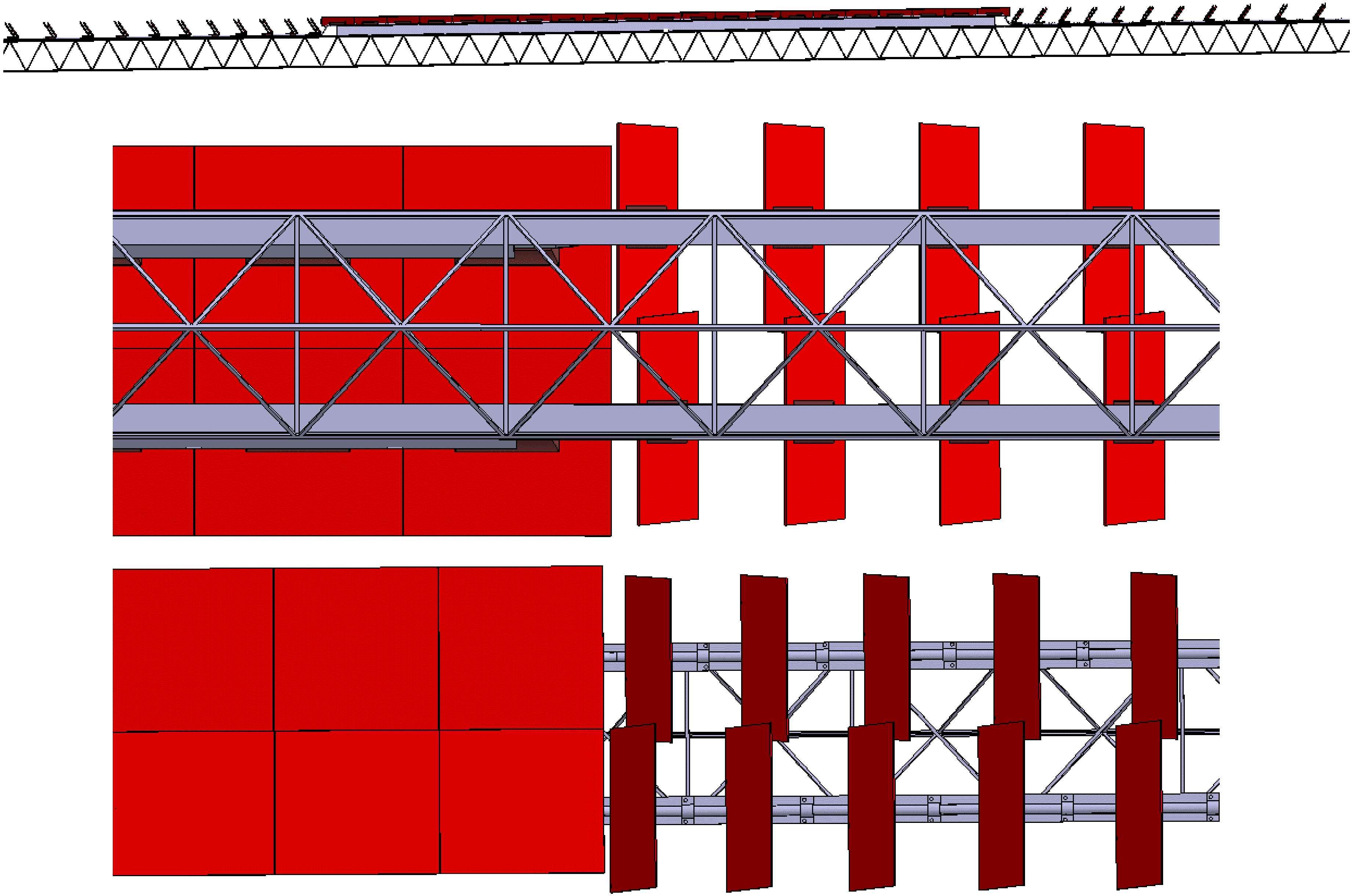
Backup

Electrical requirements

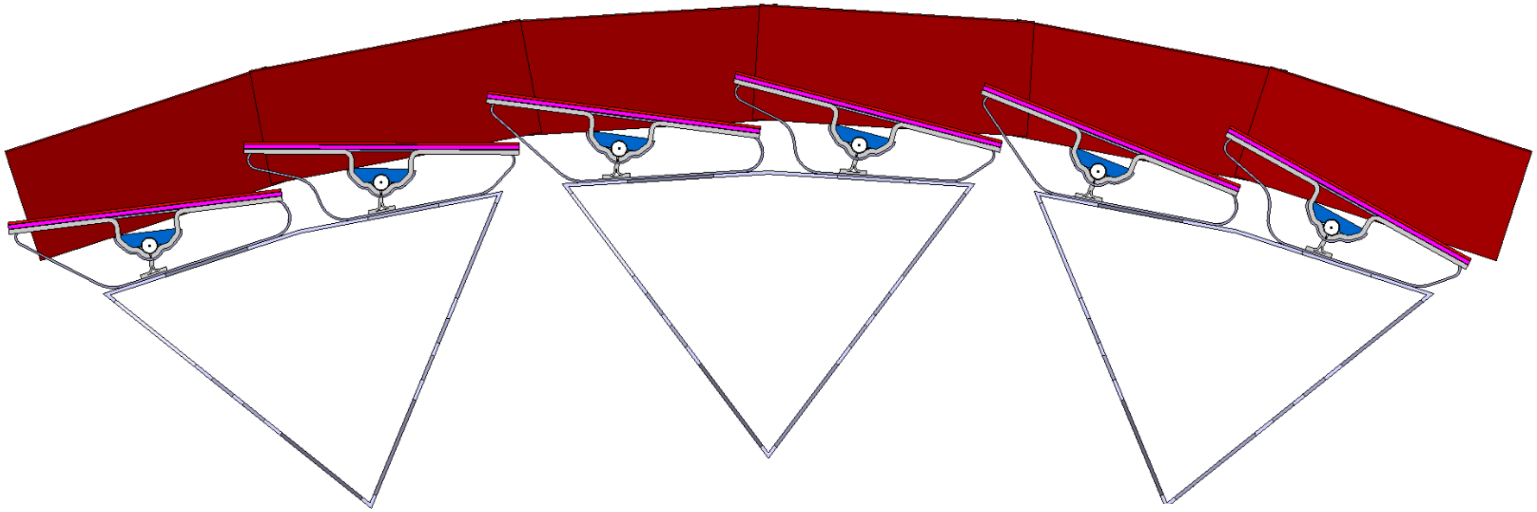
- 7.2.- “**Power dissipation** per detector module must be low enough to prevent thermal runaway of Pixel and Strip sensors defined in conjunction woth the cooling capacity specification. Power dissipation of end of stave or petal circuitry must be low enough to prevent a rise in stave or petal temperature above that required for the attached modules to present their sensor thermal runaway”.

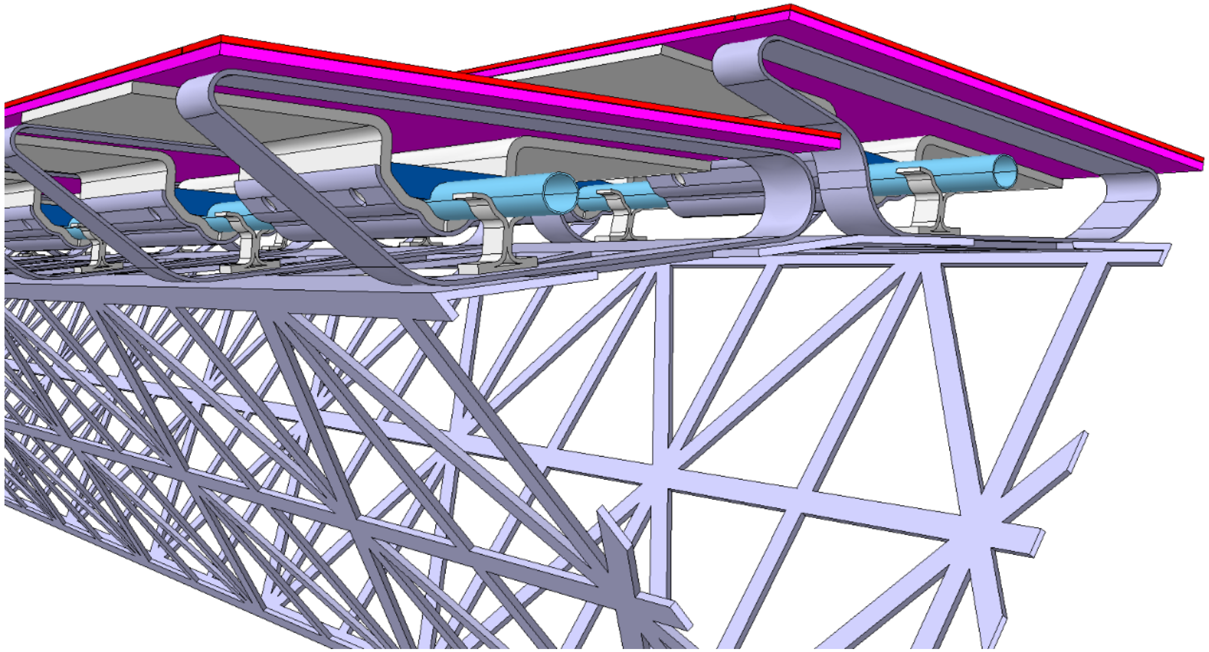
- 7.3.- “**Noise occupancy** of the Pixel and Strip detectors should be at least one and preferably two orders of magnitude less than the occupancy due to hits on tracks after exposure to lifetime irradiation”.

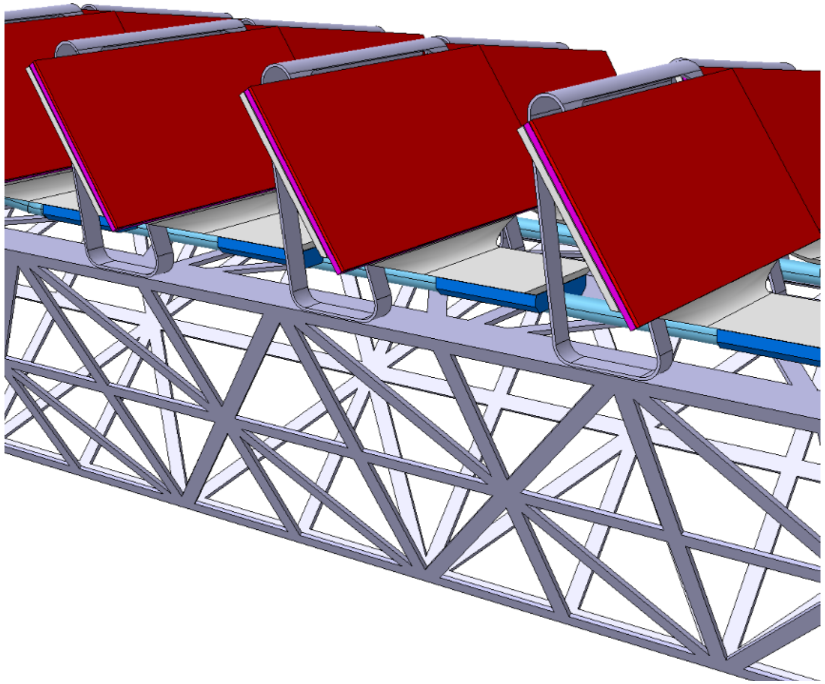
SLIM with CFRP Truss structure: baseline



SLIM with CFRP Truss structure: alternative

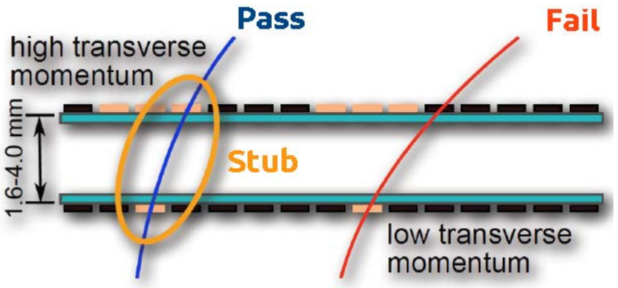


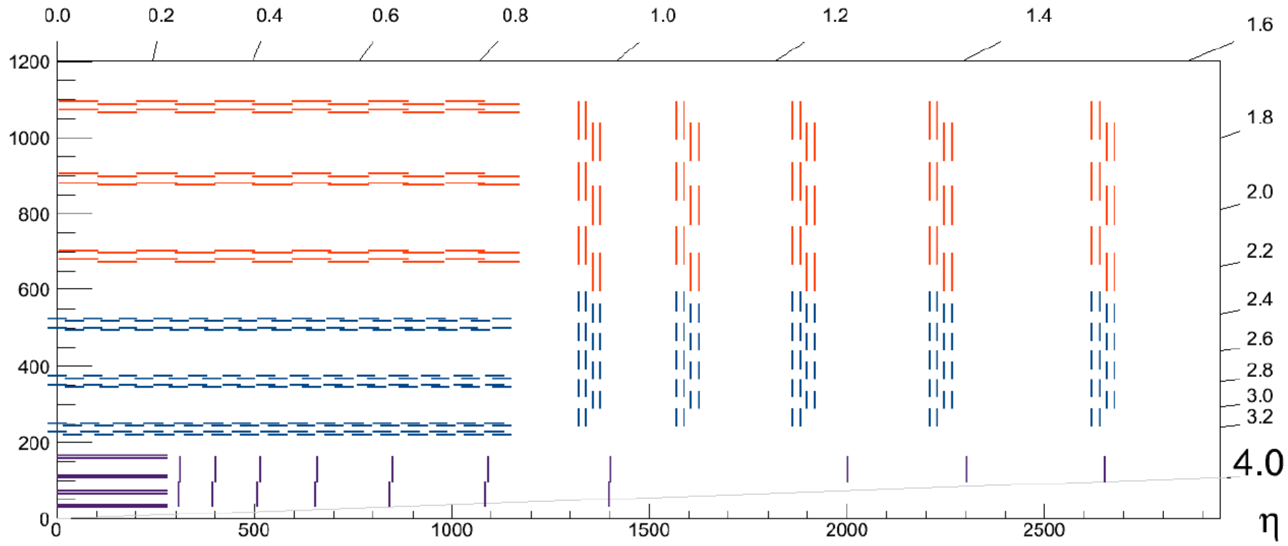




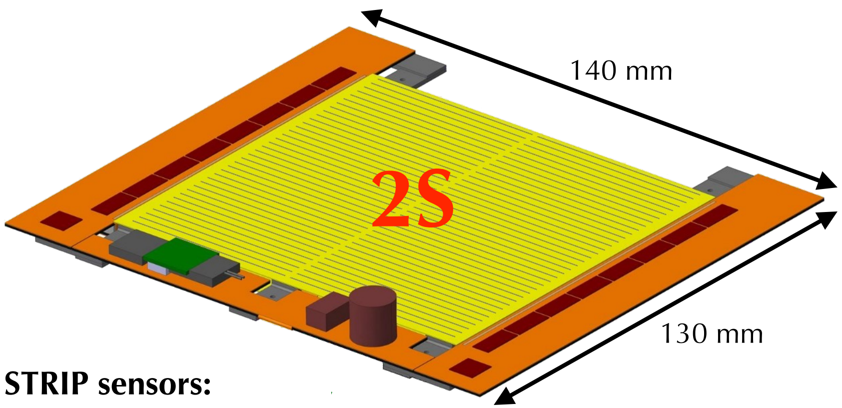
CMS layout options

- <u>**Flat geometry (baseline)**</u>
  - **Pixel modules**
  - **PS modules** (OT)
  - **2S modules** (OT)



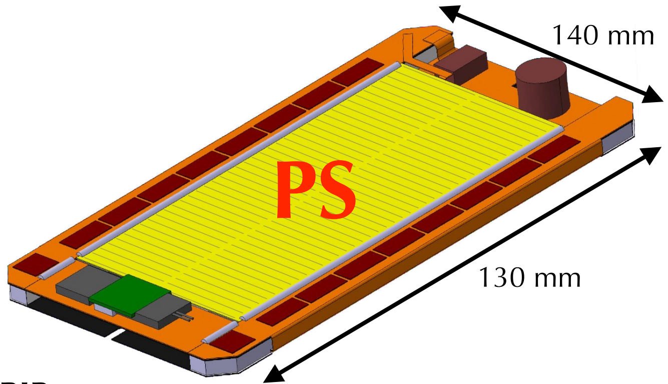


Technical Proposal for the Phase-2 CMS upgrade
[CERN-LHCC-2015-010 / LHCC-P-008]



STRIP sensors:
- AC coupled, 10 x 10 cm^2
- two rows of 5 cm long strips, 90 μm pitch

➡ COARSE z-information



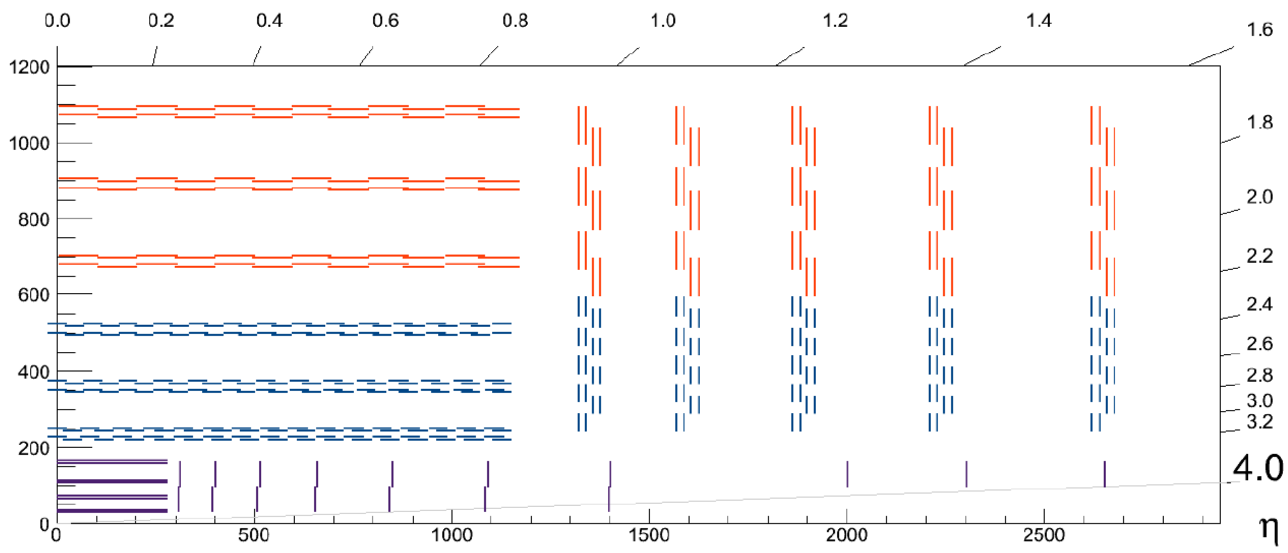
STRIP sensor:
- AC coupled, 5 x 10 cm2
- two rows of 2.5 cm long strips, 100 μm pitch

PIXEL sensor:
- DC coupled, 5 x 10 cm^2
- 32 rows "macro-pixel", 1.5 mm long, 100 μm pitch

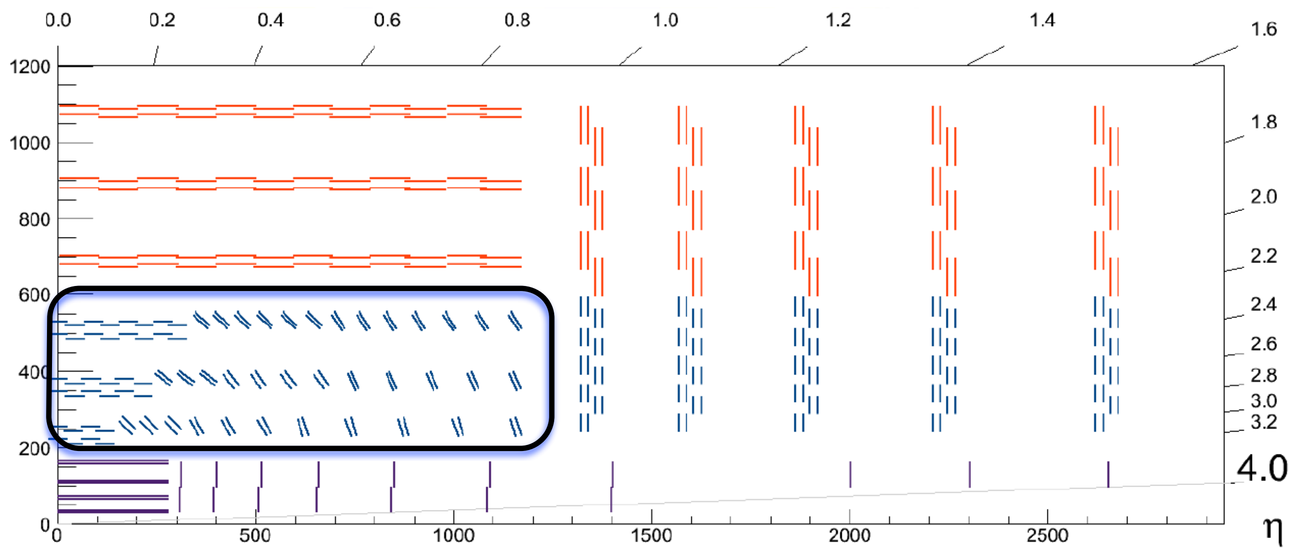
➡ PRECISE z-information: primary vertex discrimination @L1

CMS layout options

- **Flat geometry**
  - Pixel modules
  - PS modules (OT)
  - 2S modules (OT)



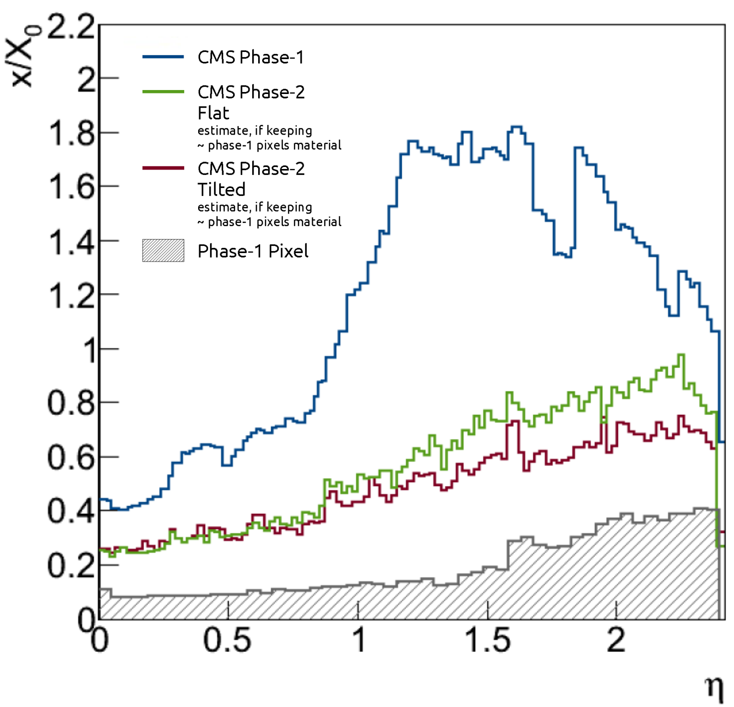
- **Tilted geometry**
  - Pixel modules
  - PS modules (OT)
  - 2S modules (OT)

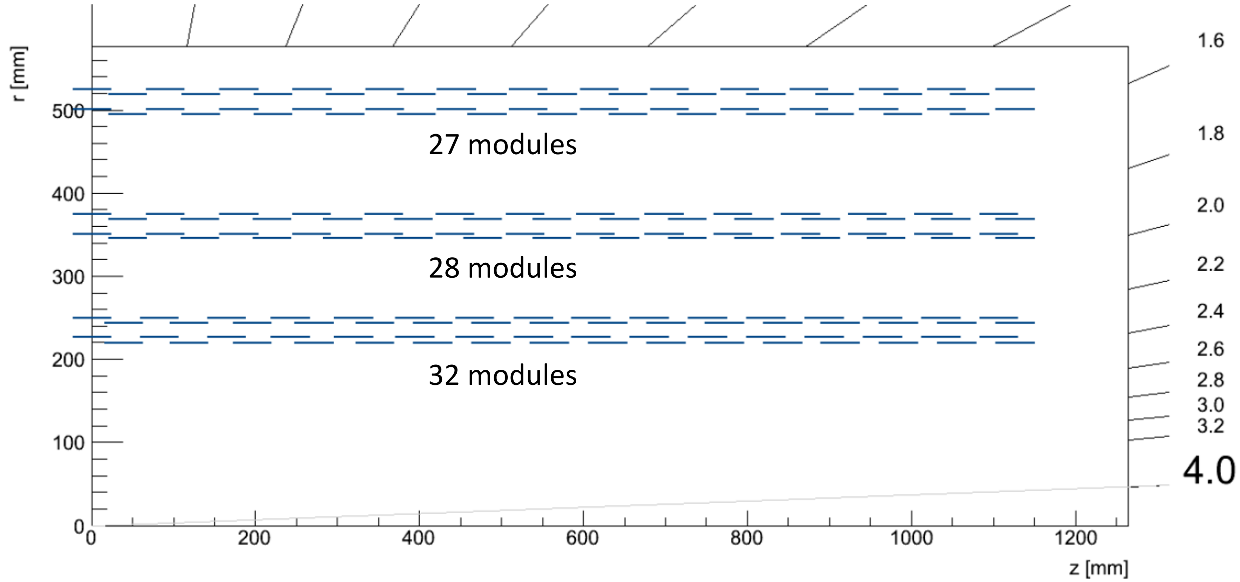


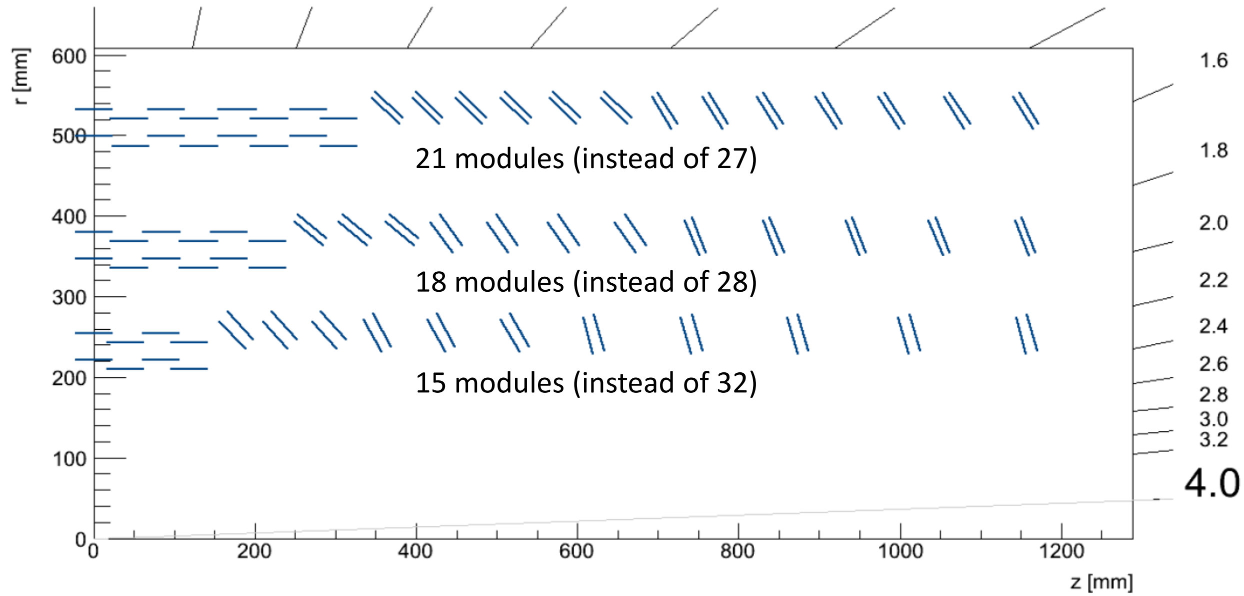
CMS layout options

Layout	PS modules
Flat	~7000
Tilted	~5700

Material Budget in radiation length

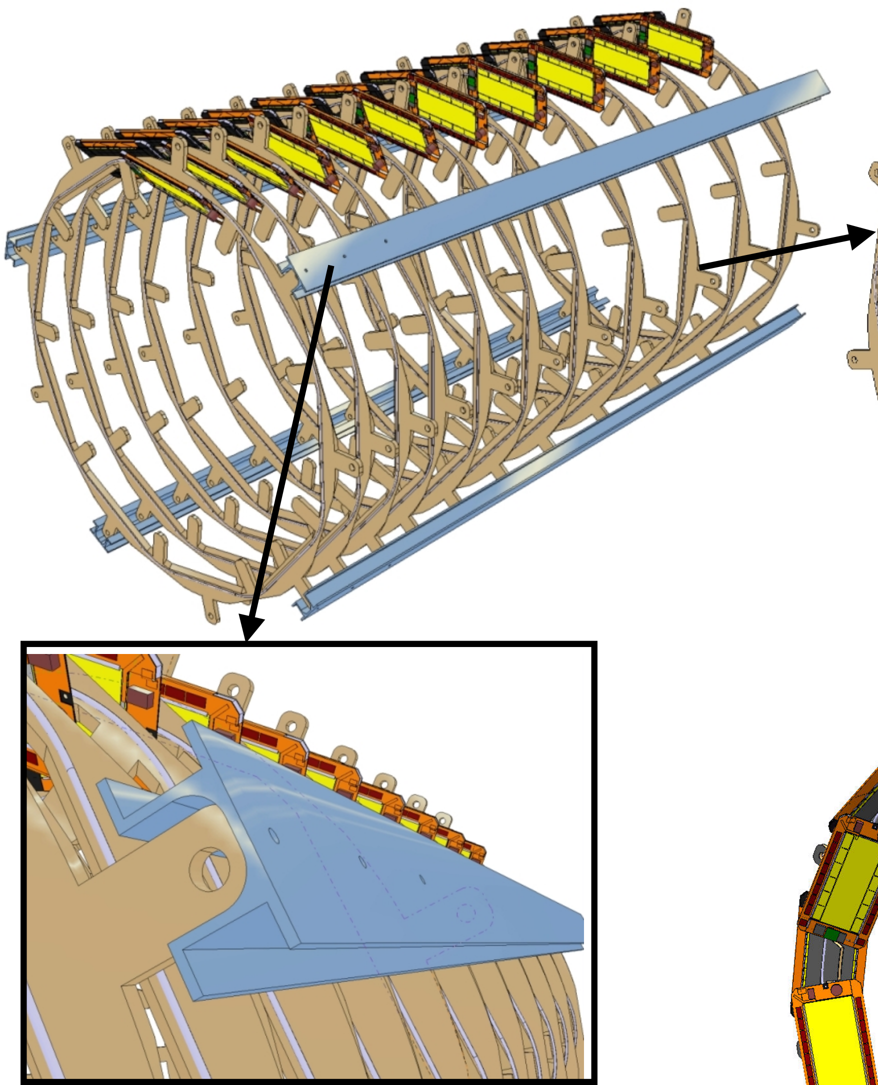


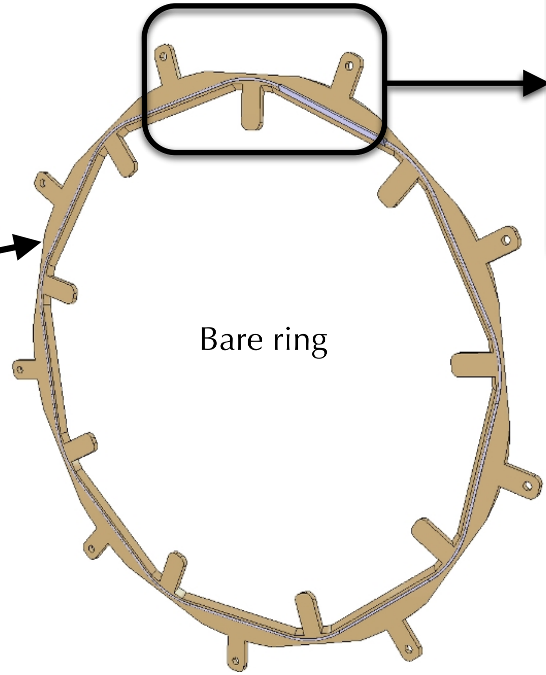


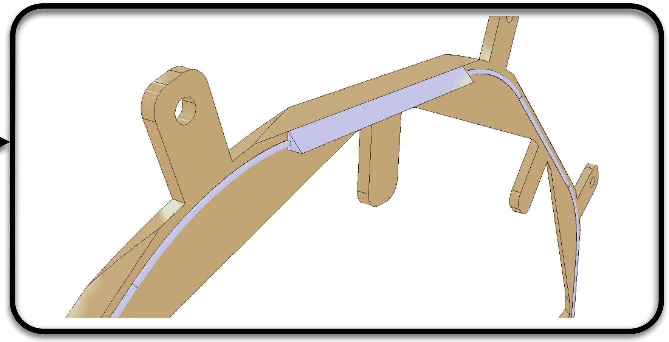


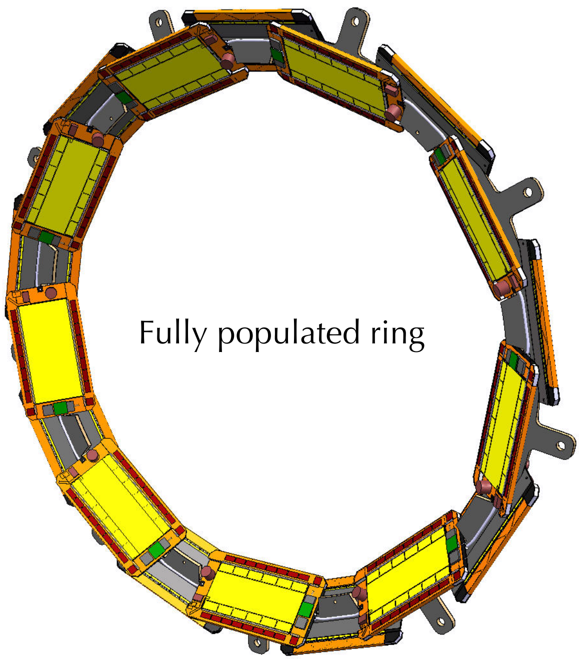
A. Onnela & K. Cichy, "*Concept of a tilted barrel for the CMS Tracker Phase 2 upgrade*", Forum on Tracking Detector Mechanics (2014)
https://indico.cern.ch/event/287285/contribution/22/material/slides/0.pdf

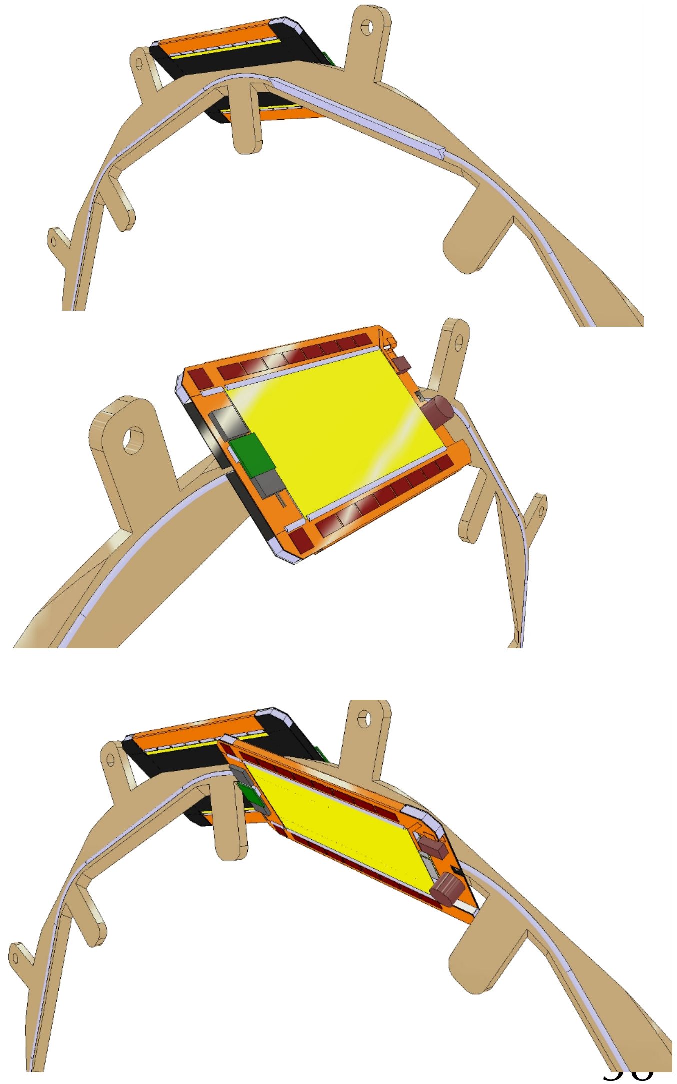
Engineering solutions for tilted modules: CMS











- Tilted modules supported by rings
- rings joined by longitudinal bars
- Cooling pipes and services routed along bars