Forum on Tracking Detector Mechanics
30 June – 2 July 2014 at DESY

Concept of a Tilted Barrel for the CMS Tracker Phase 2 Upgrade

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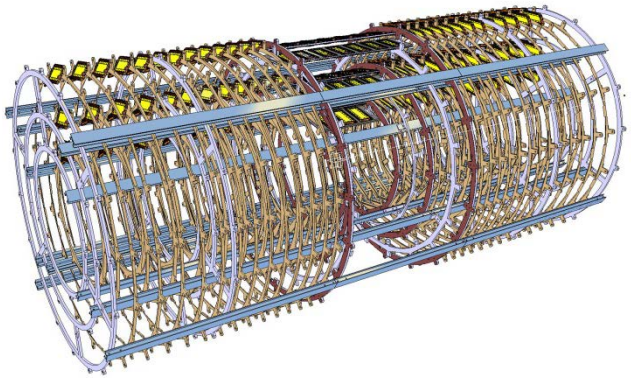
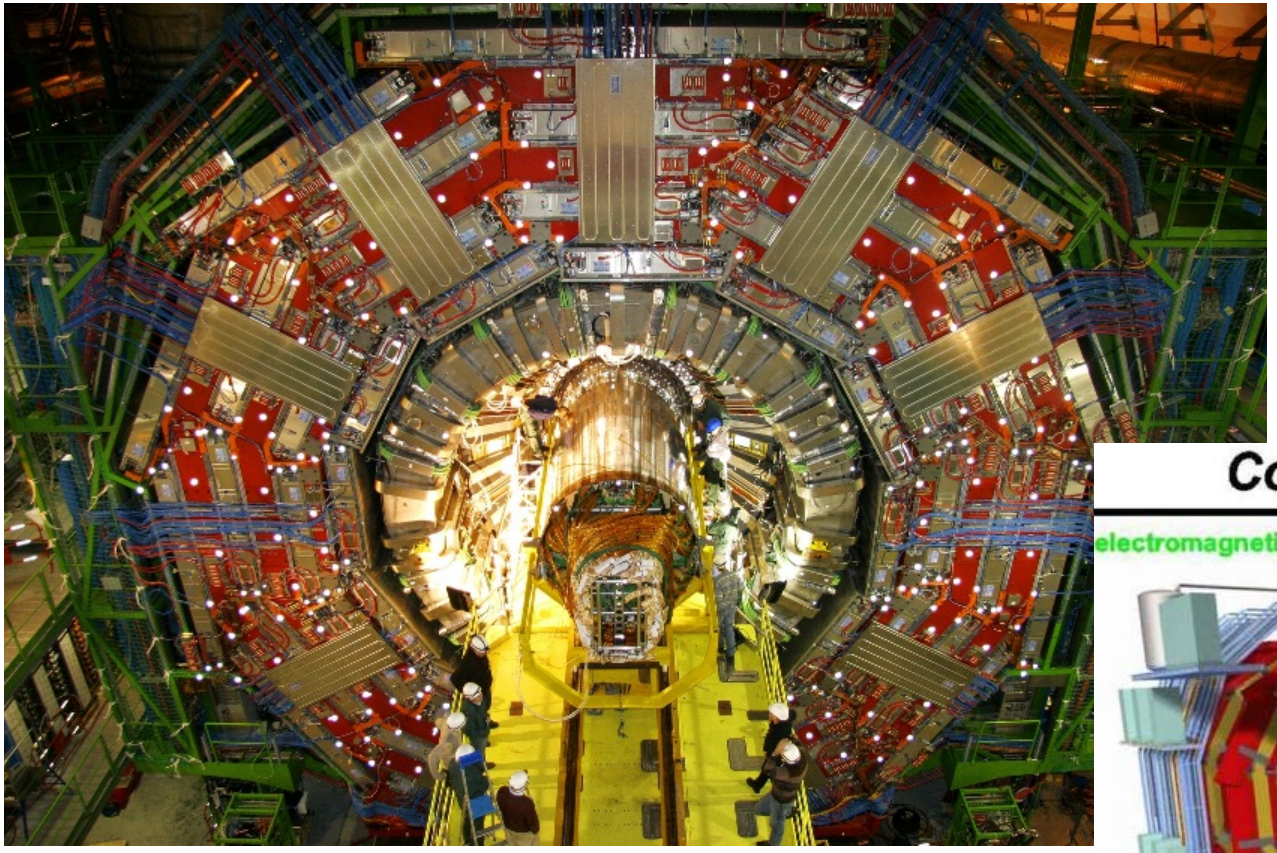
on behalf of the design team Duccio Abbaneo, Giovanni Bianchi, Antonio Conde Garcia, Jaakko Esala, Alan Honma, Mark Kovacs, Stefano Martina, Stefano Mersi, Pierre Rose, Ankit Verma

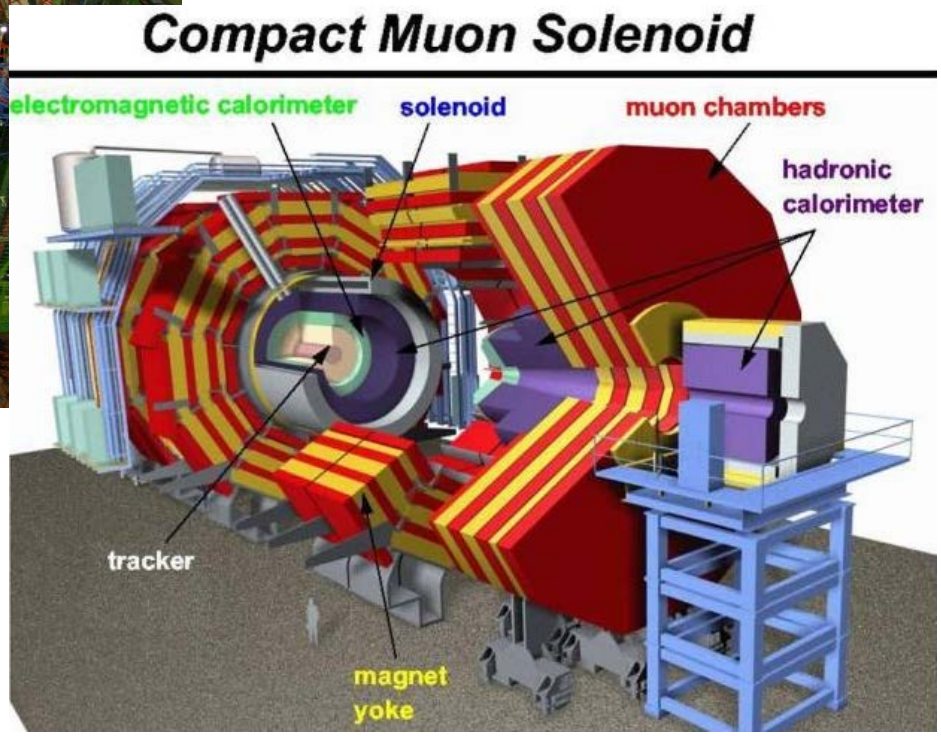


Outline

- Introduction
  - Detector modules and layout of the Upgrade Tracker
- Tilted geometry
  - Central Flat section
  - Tilted Ring sections
  - Assembly steps
- Summary and Outlook

CMS Tracker

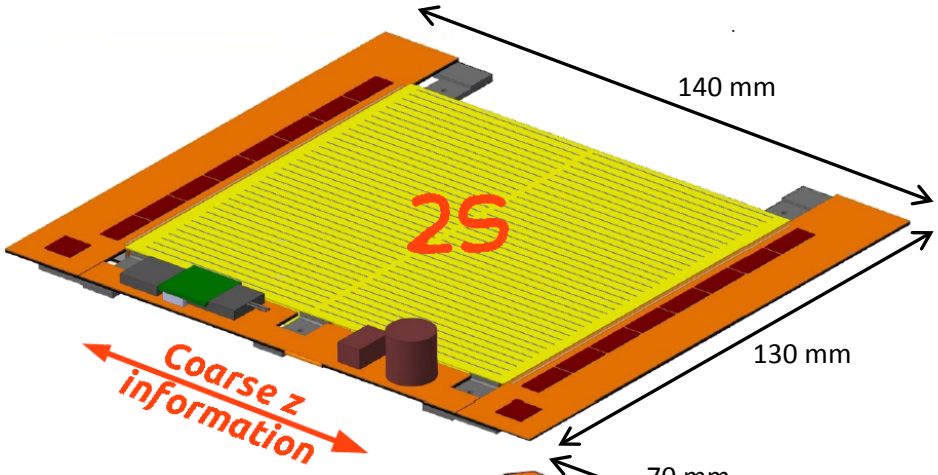




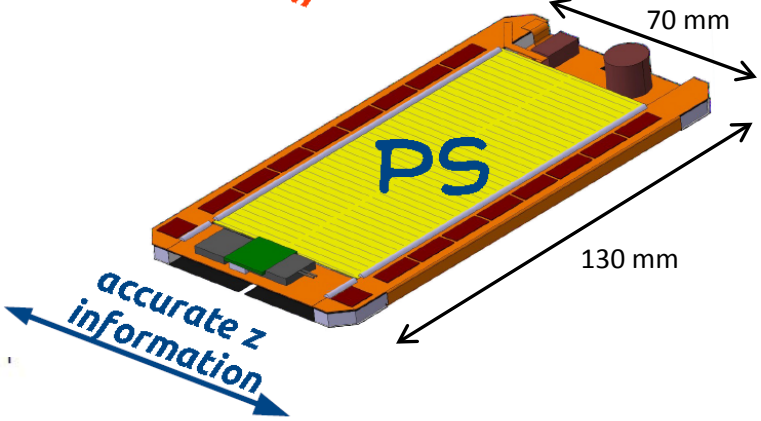
- Operational since 2008
- To be replaced in “Phase 2 Upgrade”. Exchange to happen during LHC Long-shutdown 3 in ~2023-2025
  “Phase 1 Upgrade” = 1st Pixel detector replacement at LHC YETS in 2016-2017
- See Andreas Mussgiller talk on CMS Tracker Module R&D for general requirements set on the Tracker Upgrade

New types of modules for the Upgrade

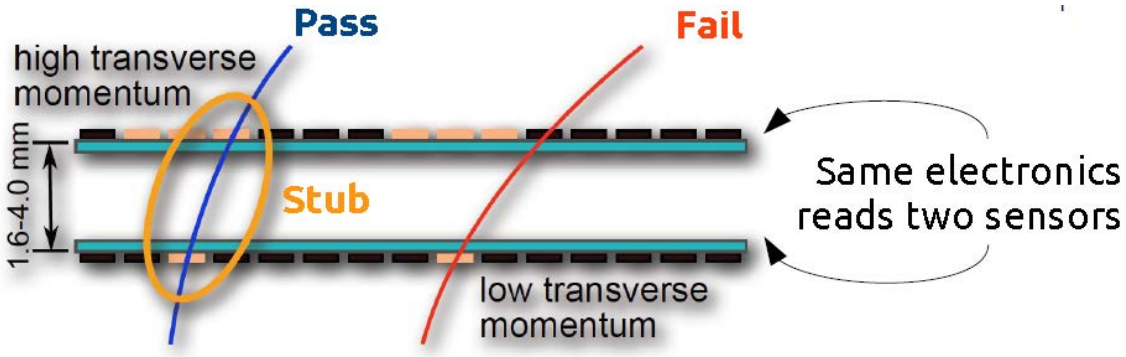
2 Strip sensors
Strips: 5 cm × 90 μm
Strips: 5 cm × 90 μm
P = 2.7 W
~ 92 cm^2 active area
For r > 40 cm



Pixel + Strip sensors
Strips: 2.5 cm × 100 μm
Pixels: 1.5 mm × 100 μm
P = 5.0 W
~ 44 cm^2 active area
For r > 20 cm

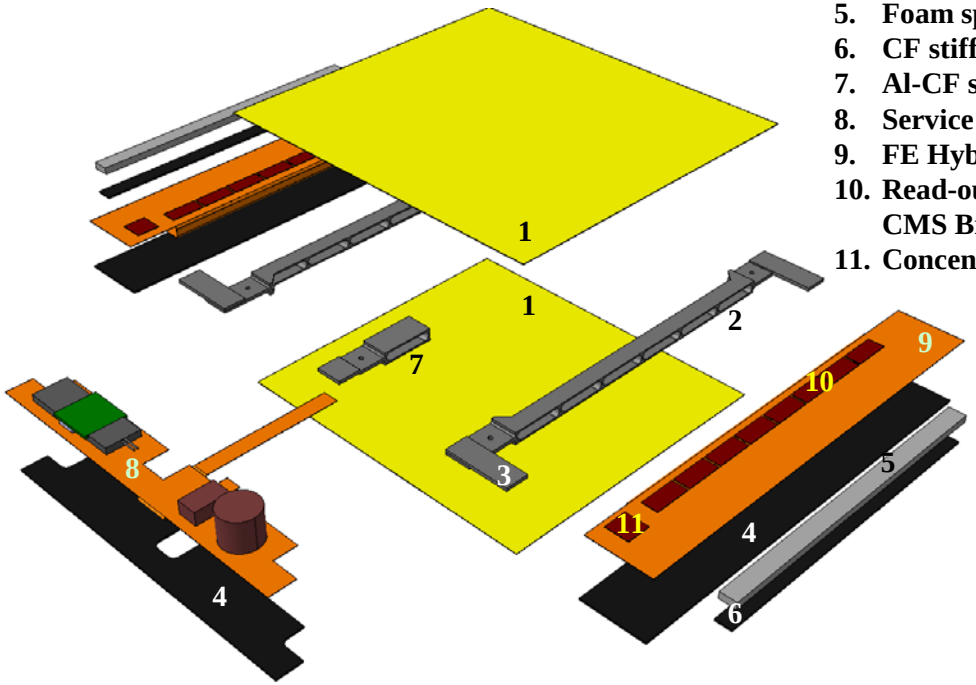


Using two superposed sensors each module is able to filter tracks by momentum

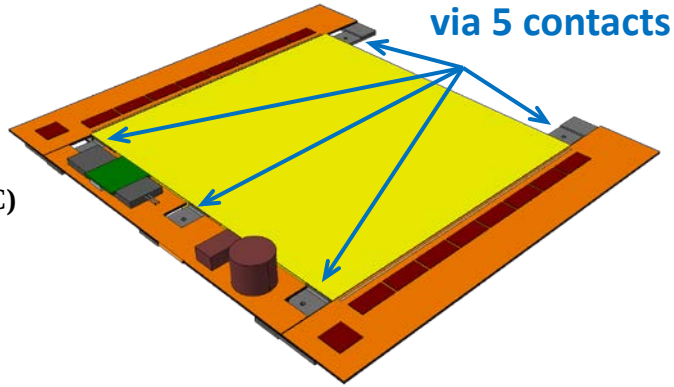


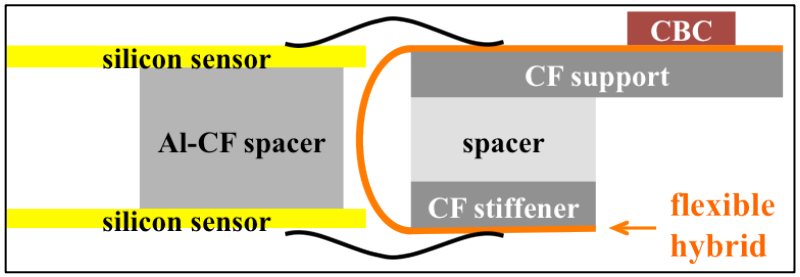
2S module

1. Silicon strip sensors
2. Al-CF spacer
3. Al-CF tab
4. CF support
5. Foam spacer
6. CF stiffener
7. Al-CF short spacer
8. Service Hybrid
9. FE Hybrid
10. Read-out chips
    CMS Binary Chip (CBC)
11. Concentrator IC (CIC)



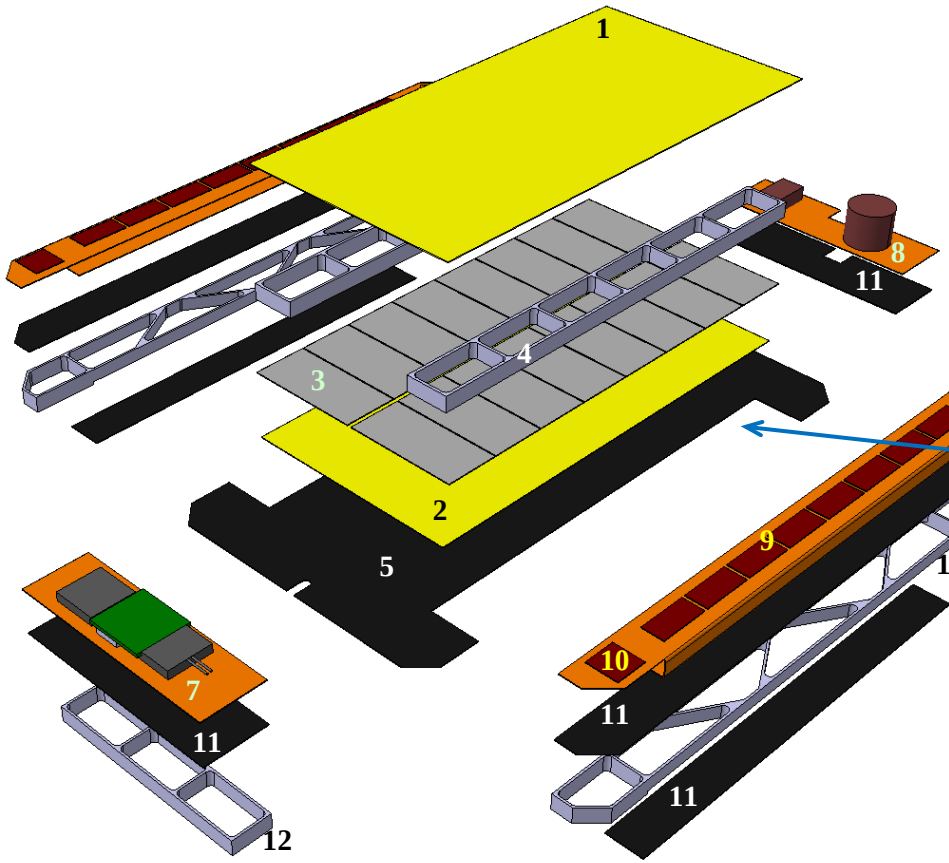
Support and cooling via 5 contacts

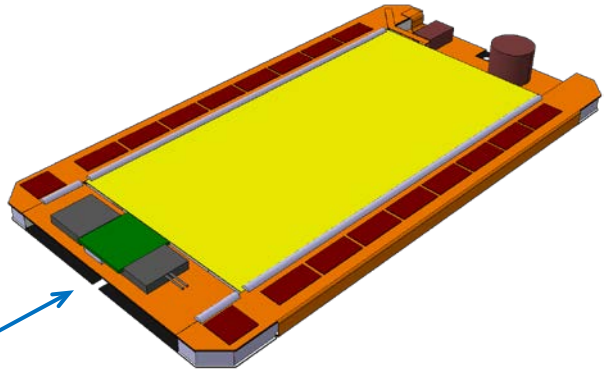




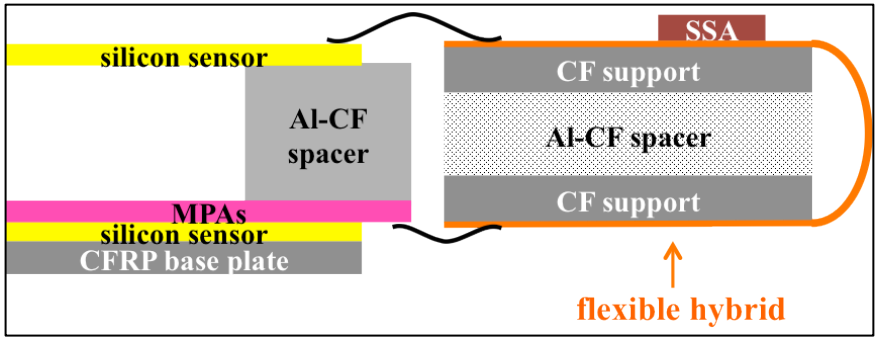
PS module

1. Silicon strip sensor
2. Silicon pixel sensor
3. Macro-Pixel ASIC (MPA)
4. Al-CF sensor spacer
5. CFRP base plate
6. FE Hybrid
7. Opto-Link Hybrid
8. Power Hybrid
9. Short-strip ASIC (SSA)
10. Concentrator IC (CIC)
11. Hybrid CF support
12. Al-CF Hybrid spacer





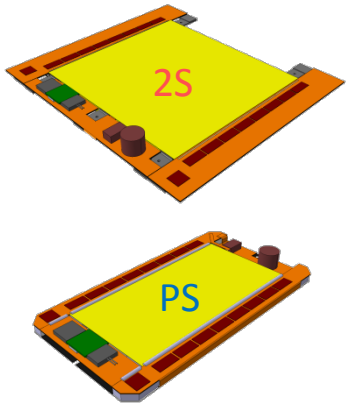
Support and cooling via a large-area base plate



Layout

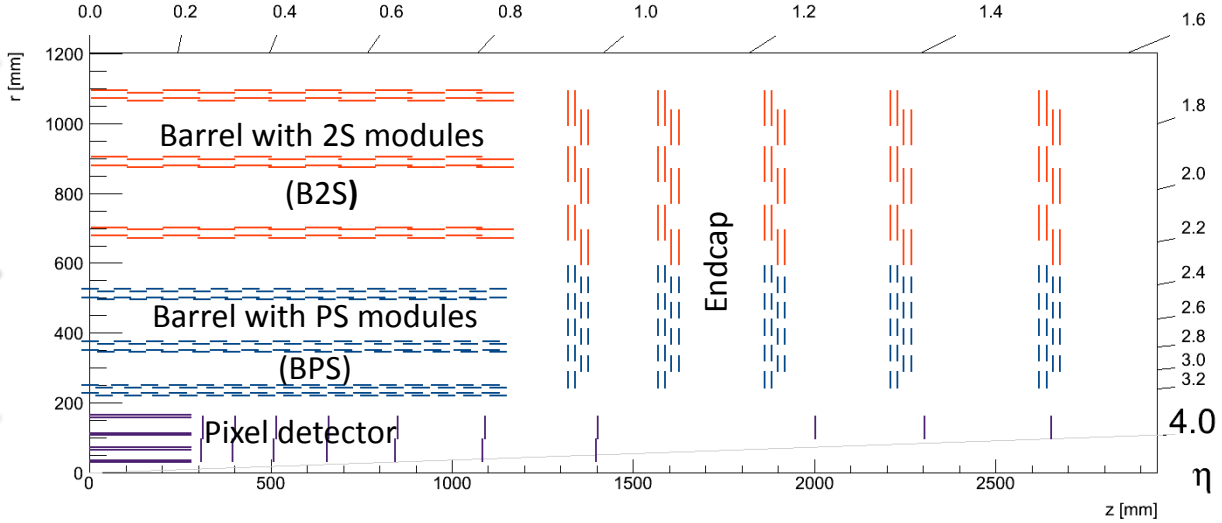
Two alternative layouts considered:

- Flat geometry



2S modules
~ 8400

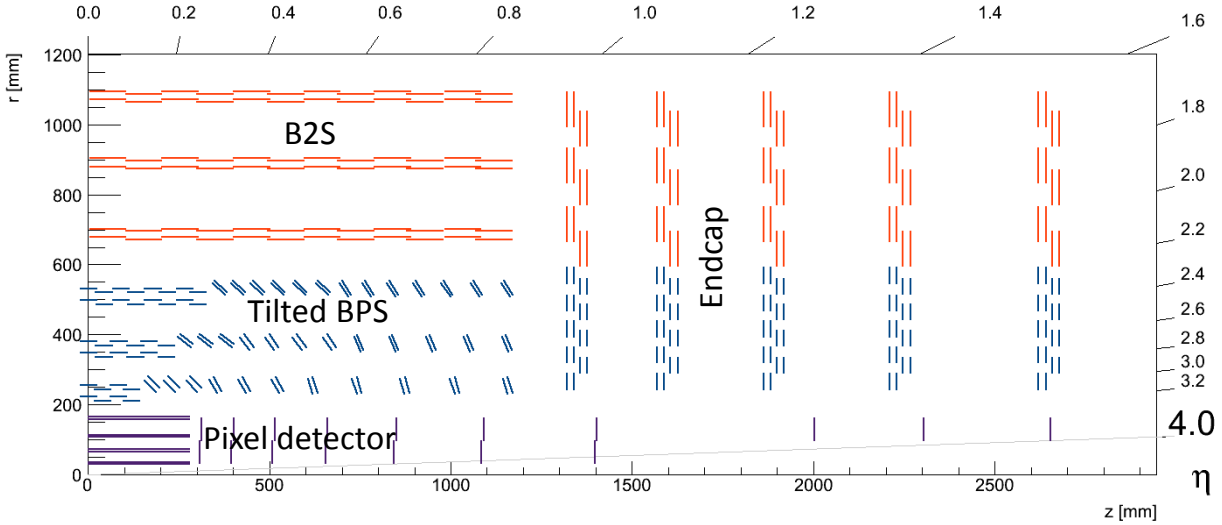
PS modules
~ 7000



- Tilted geometry

2S modules
~ 8400

PS modules
~ 5700

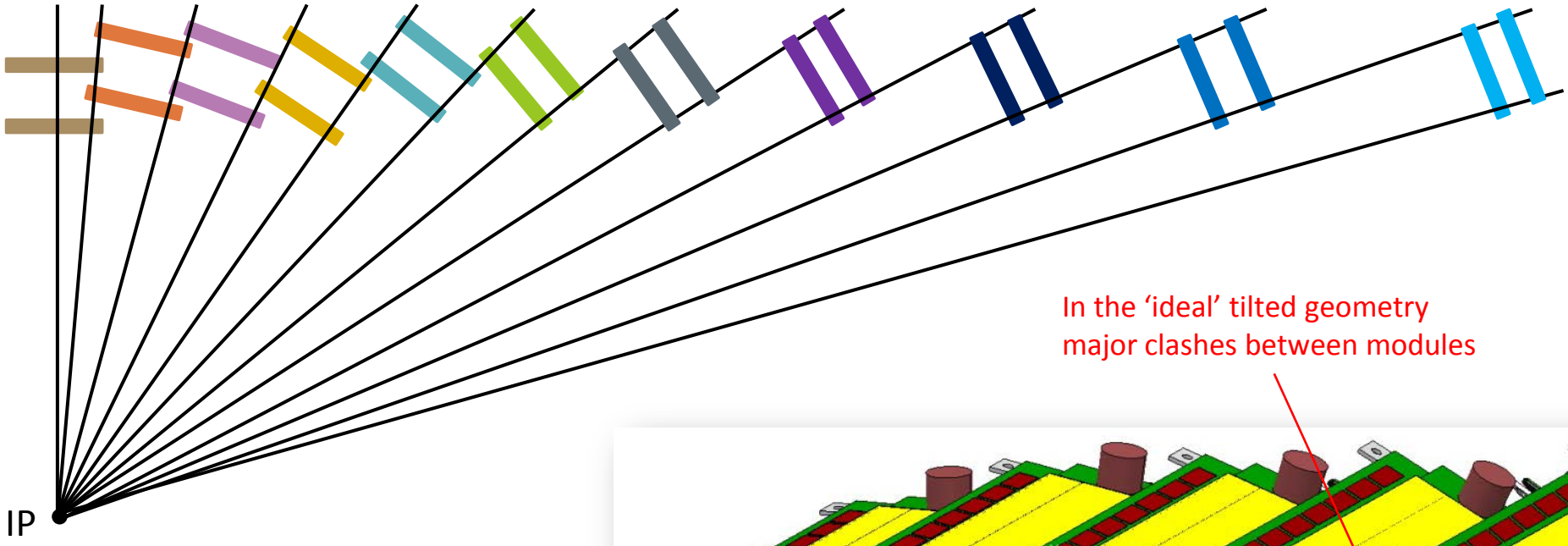


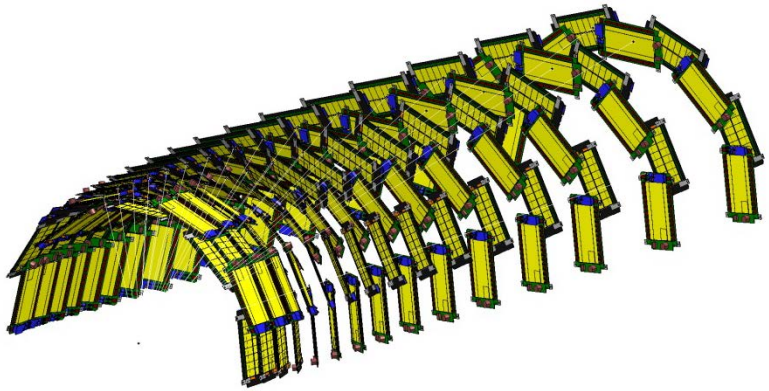
Layout comparison

S. Mersi at al., Performance of Tilted Inner Barrel, CMS Upgrade Workshop 1 April 2014

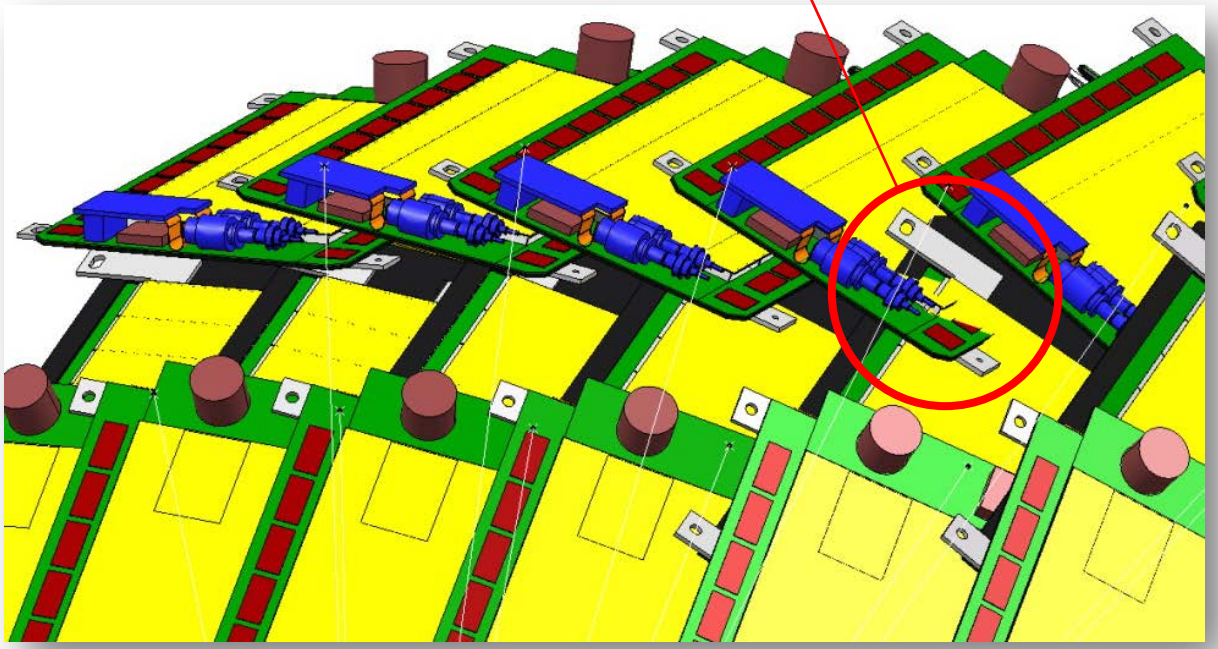
	Current	Upg flat	Upg tilted
Silicon [m^2]	~200	216	206
Strips [M]	9.3	47.6	45.2
MacroPixels [M]	0	212.9	175.3
Modules	15'148	15'354	14'132

‘Ideal’ tilted geometry



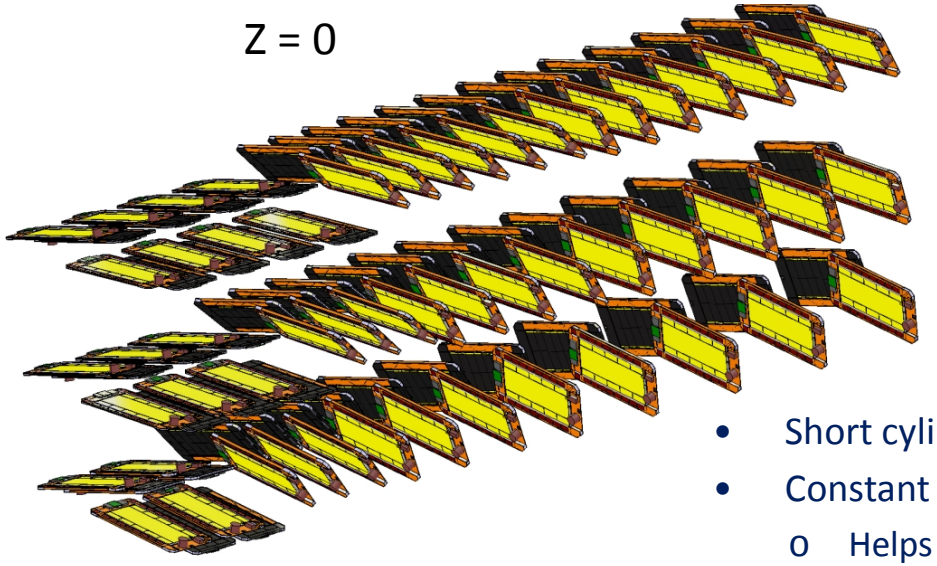


In the ‘ideal’ tilted geometry
major clashes between modules



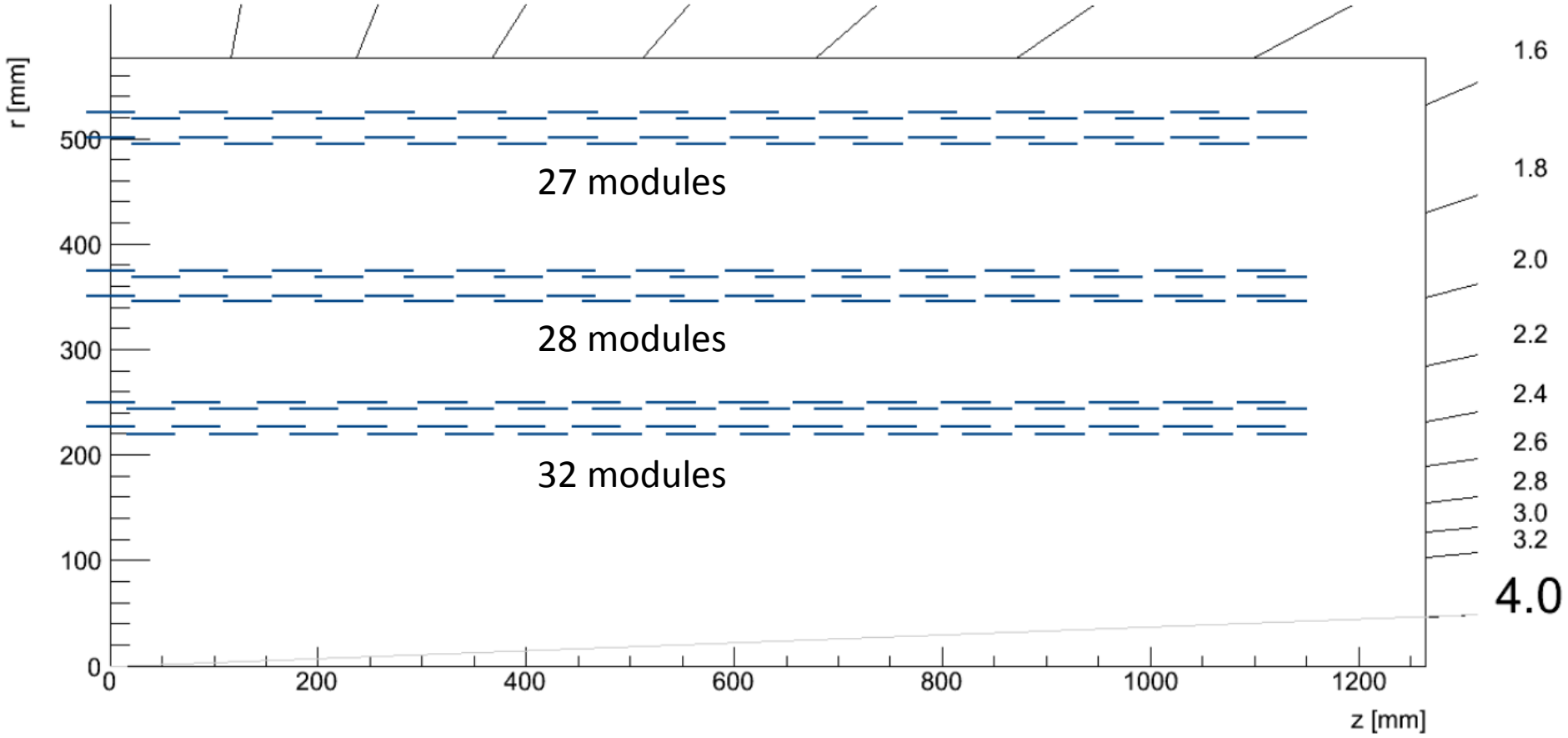
More realistic tilted geometry

Z = 0

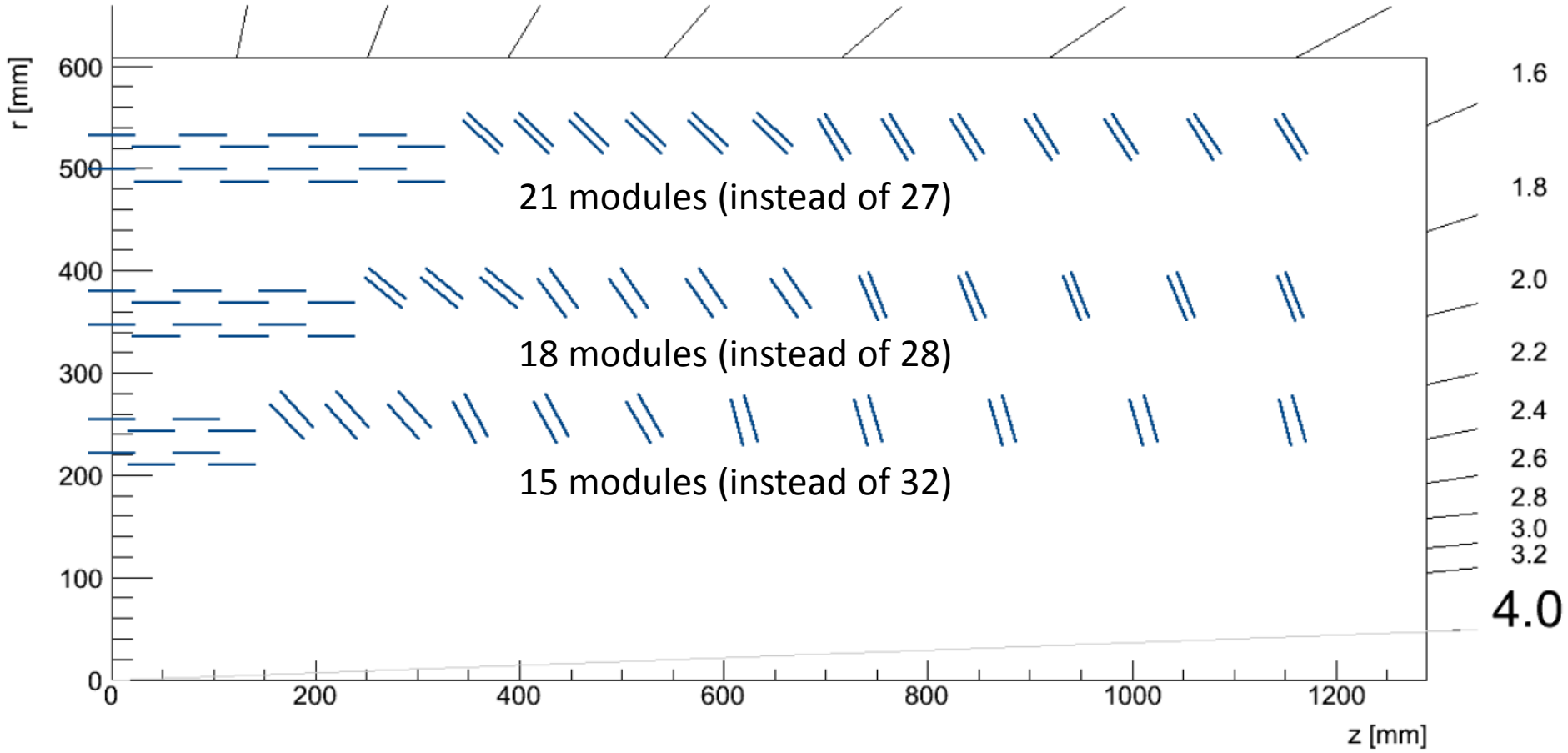


- Short cylindrical section in the center
- Constant tilt angle in several successive rings
  - Helps avoiding clashes
  - Also, reduces support structure variants.

Gain of tilted wrt flat (simpler) geometry



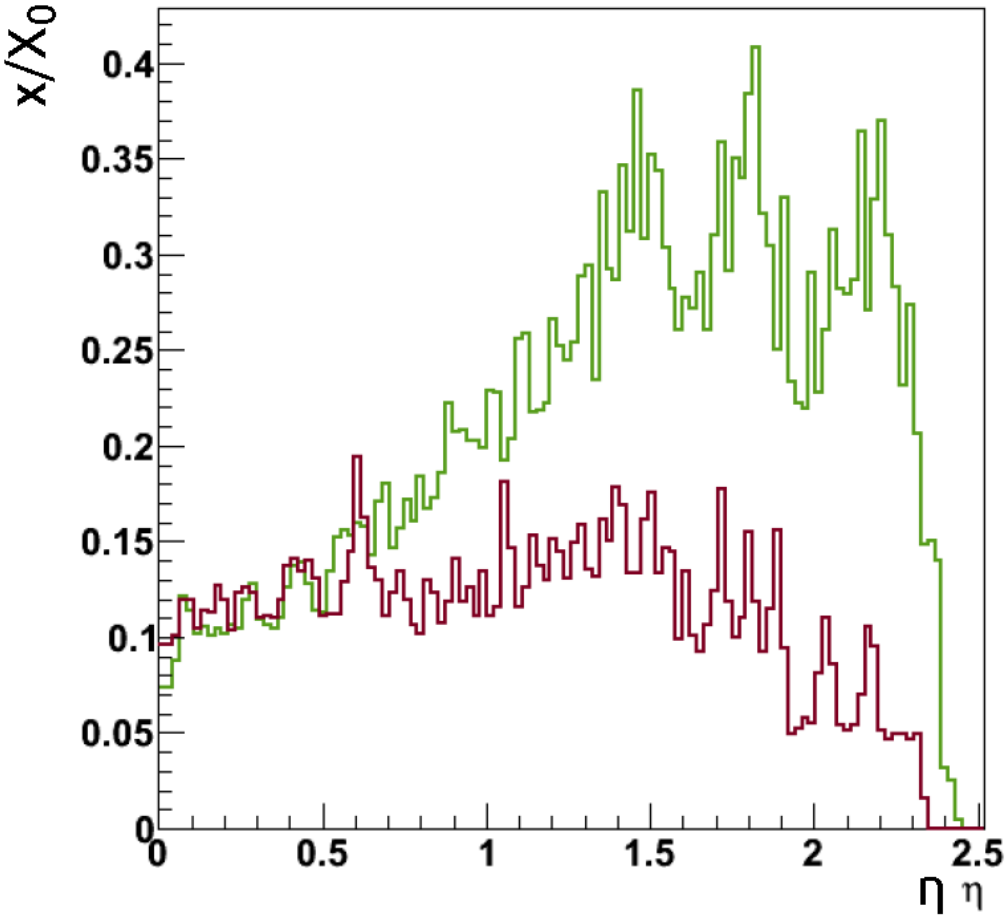
Gain of tilted wrt flat (simpler) geometry



Material budget Flat vs Tilted

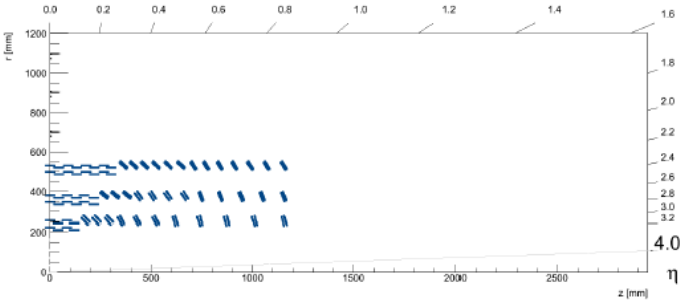
S. Mersi at al., Performance of Tilted Inner Barrel, CMS Upgrade Workshop 1 April 2014

Includes estimated material contributions from services and mechanics.



CMS Phase-2
Flat Inner Barrel

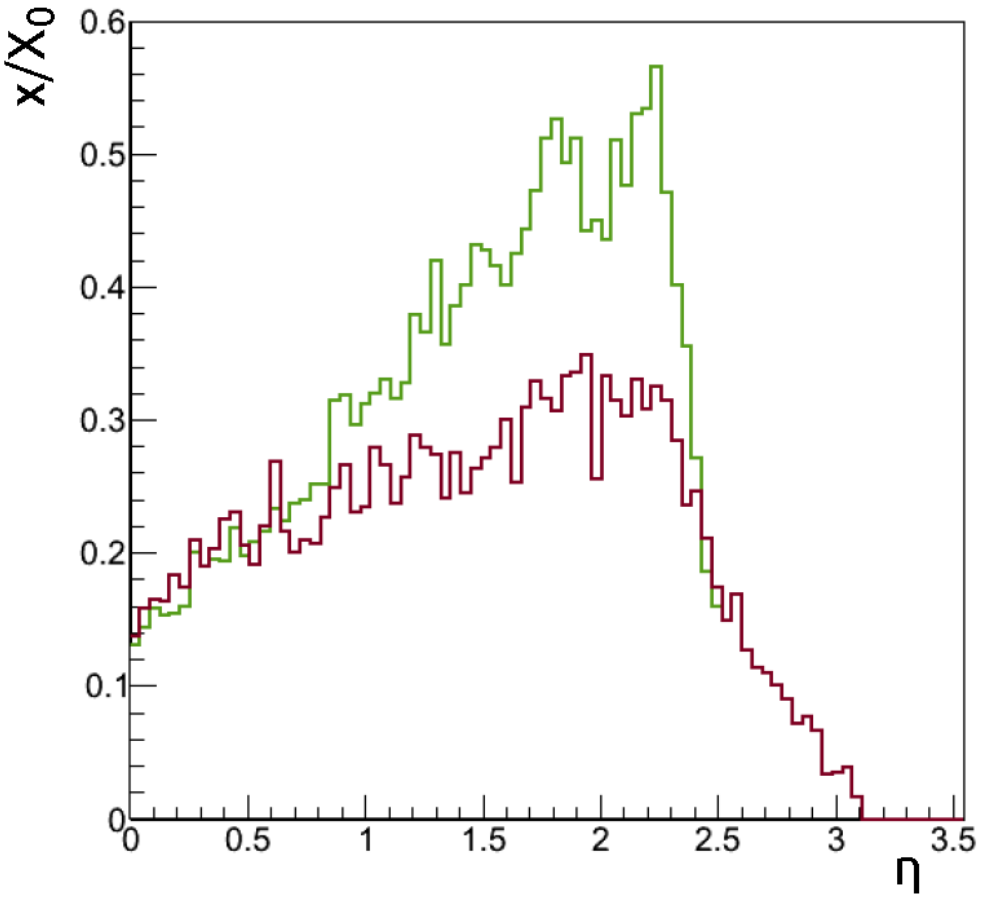
CMS Phase-2
Tilted Inner Barrel



Material budget Outer Tracker (no Pixels)

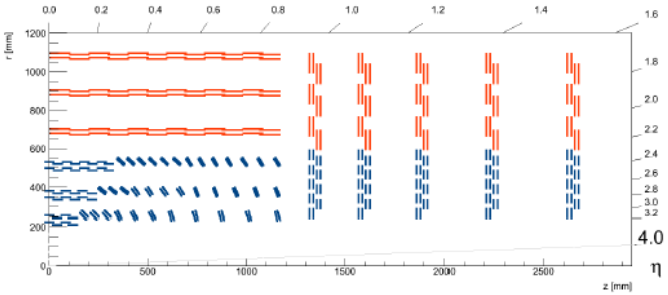
S. Mersi at al., Performance of Tilted Inner Barrel, CMS Upgrade Workshop 1 April 2014

The gain by the Tilted inner section is clearly visible even at the full Tracker level



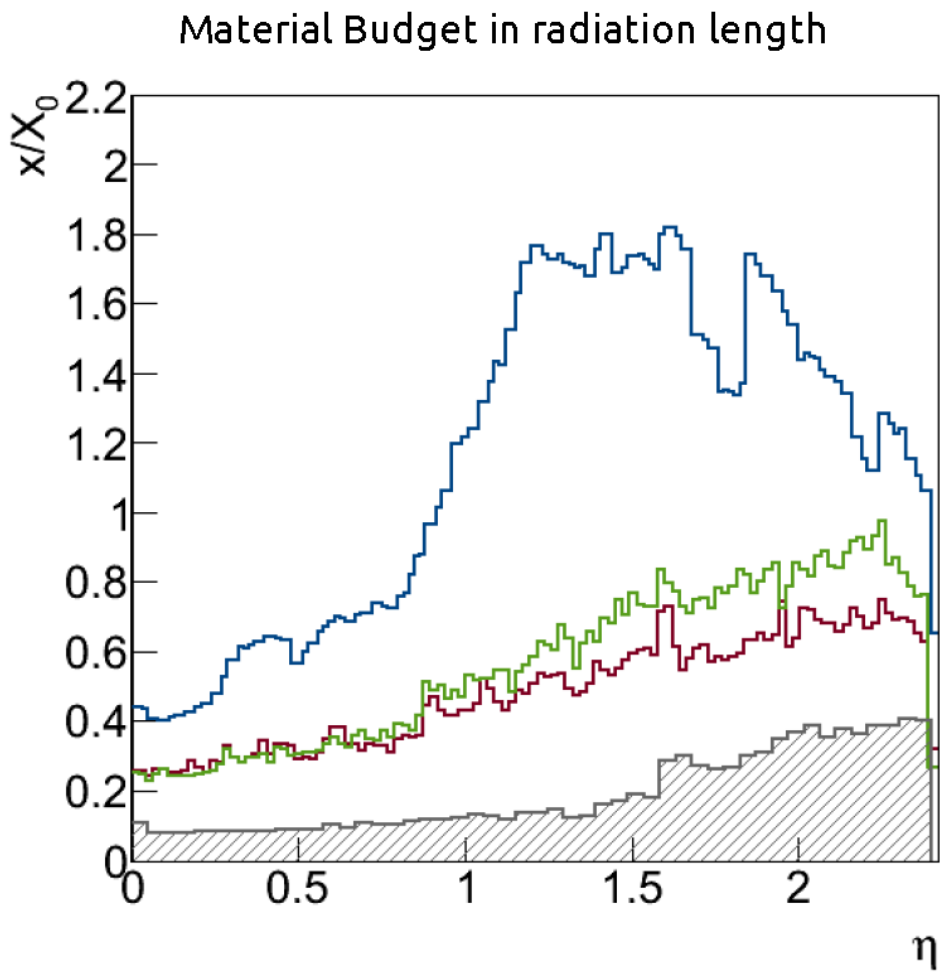
CMS Phase-2 Flat

CMS Phase-2 Tilted



Material budget full tracker

S. Mersi at al., Performance of Tilted Inner Barrel, CMS Upgrade Workshop 1 April 2014

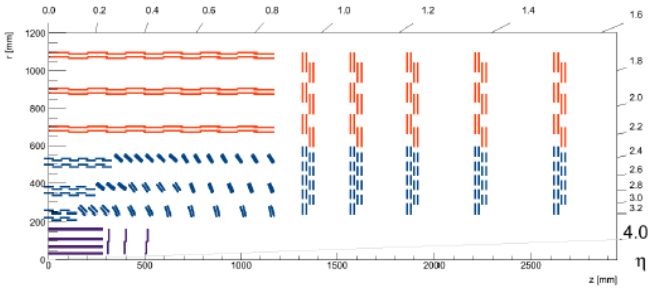


CMS Phase-1

CMS Phase-2 Flat
estimate, if keeping
~ phase-1 pixels material

CMS Phase-2 Tilted
estimate, if keeping
~ phase-1 pixels material

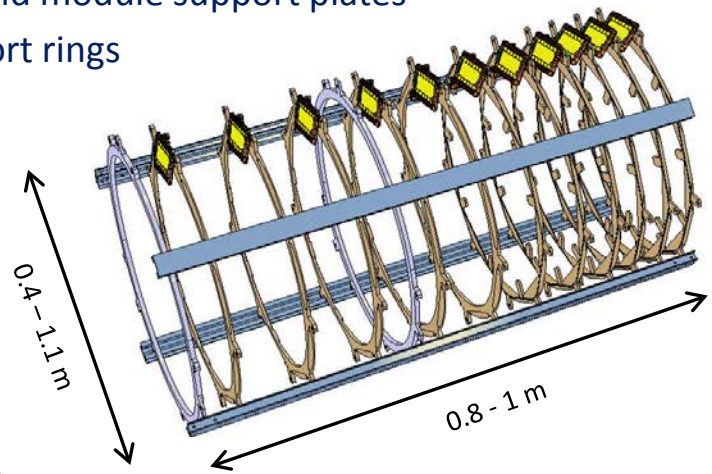
Phase-1 Pixel

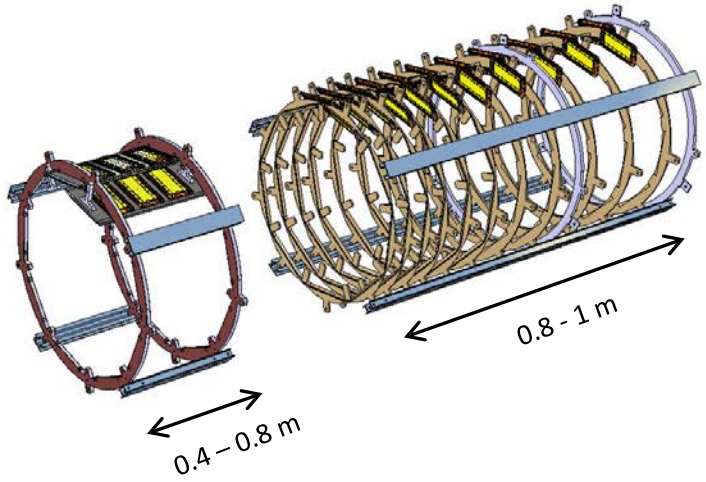


How to construct the tilted geometry?

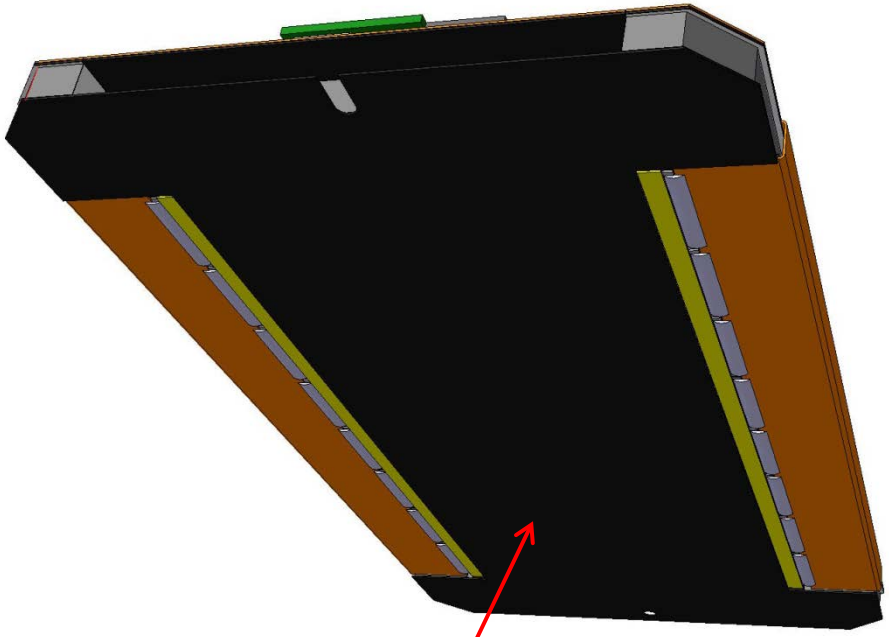
The current idea is to divide the assembly into following sub-structures:

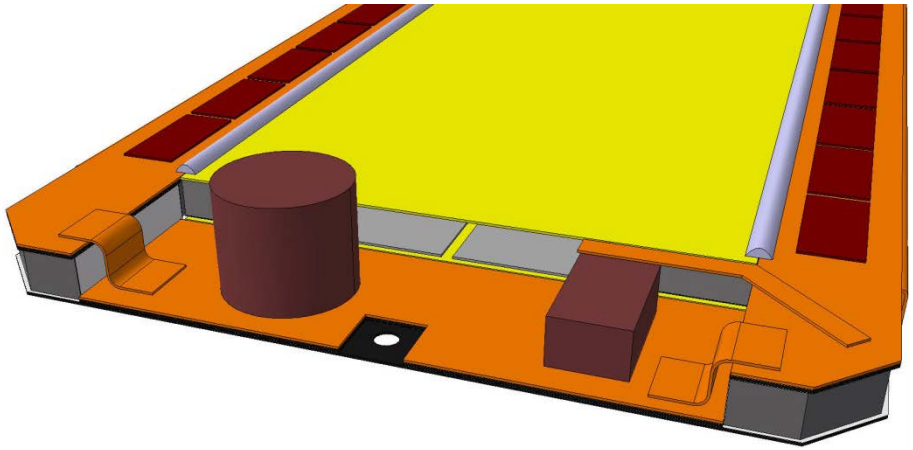
- Three layers as individual units
- Each layer: Central flat section + 2 tilted sections
- Central section: 2 end rings and module support plates
- Tilted sections: module support rings
- Longitudinal profiles join the sections and provide for services routing paths.

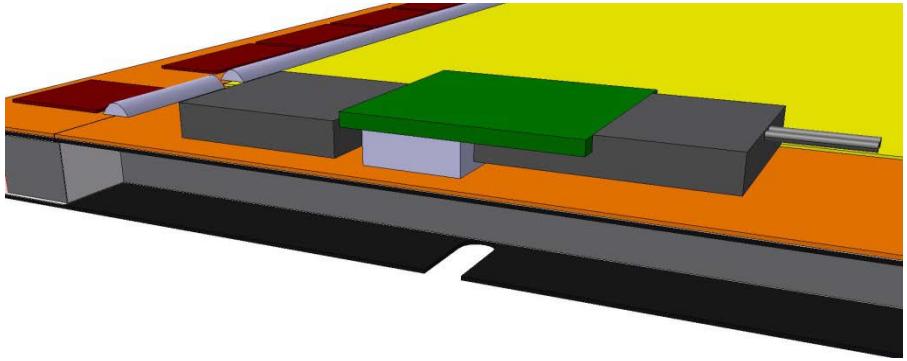




PS Module Base plate and Positioning holes

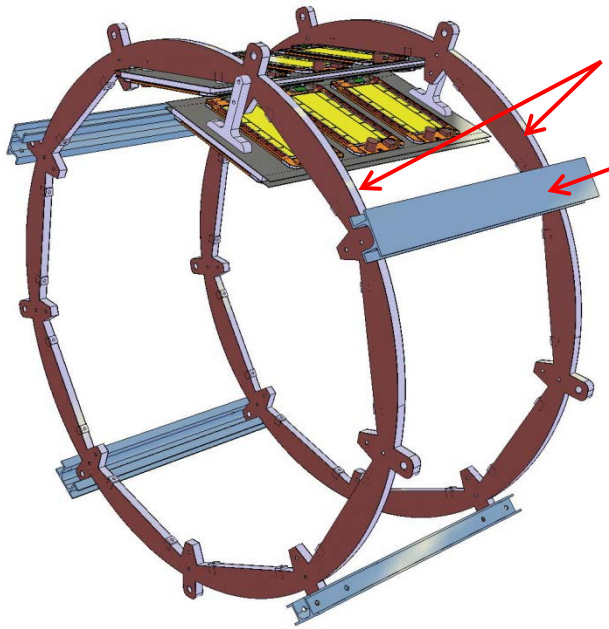






Module base-plate.
Attached to support/cooling structure with phase-change adhesive

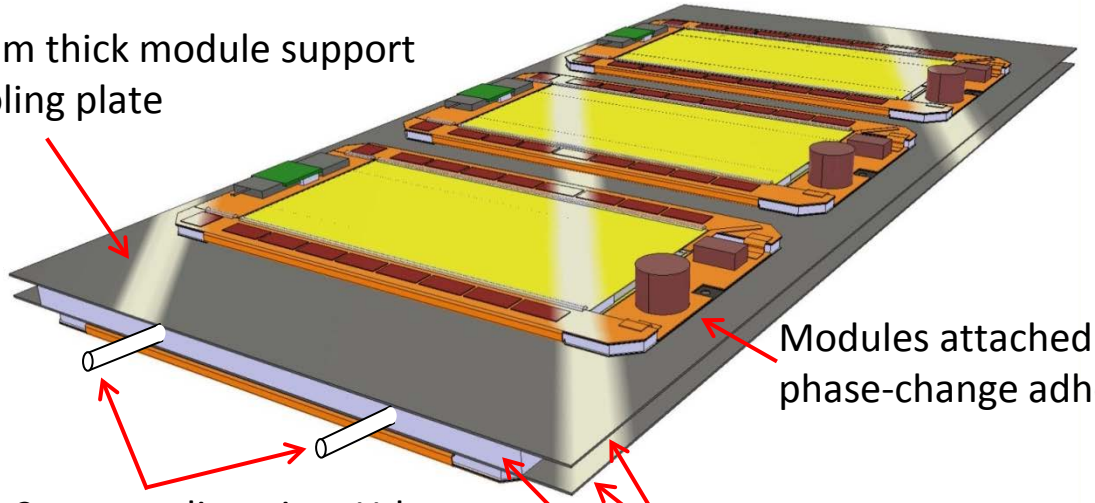
Central flat section



Space frame made of
end rings

and longitudinal profiles

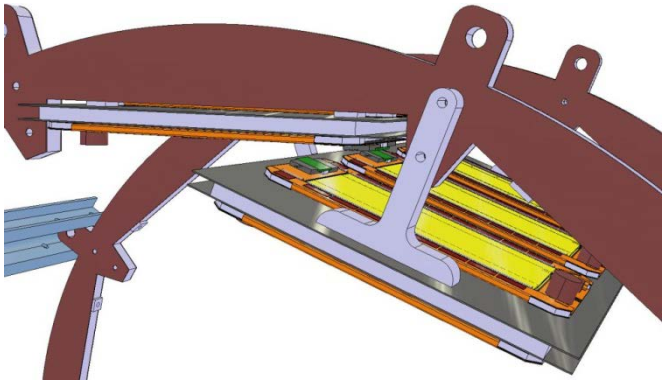
4-6 mm thick module support
& cooling plate



Modules attached with
phase-change adhesive

Diam ~2 mm cooling pipe, U-loop
Carbon foam or aluminium/carbon-fibre block next to cooling pipe

~0.5 mm high-conductivity carbon-fibre composite skins
Foam core

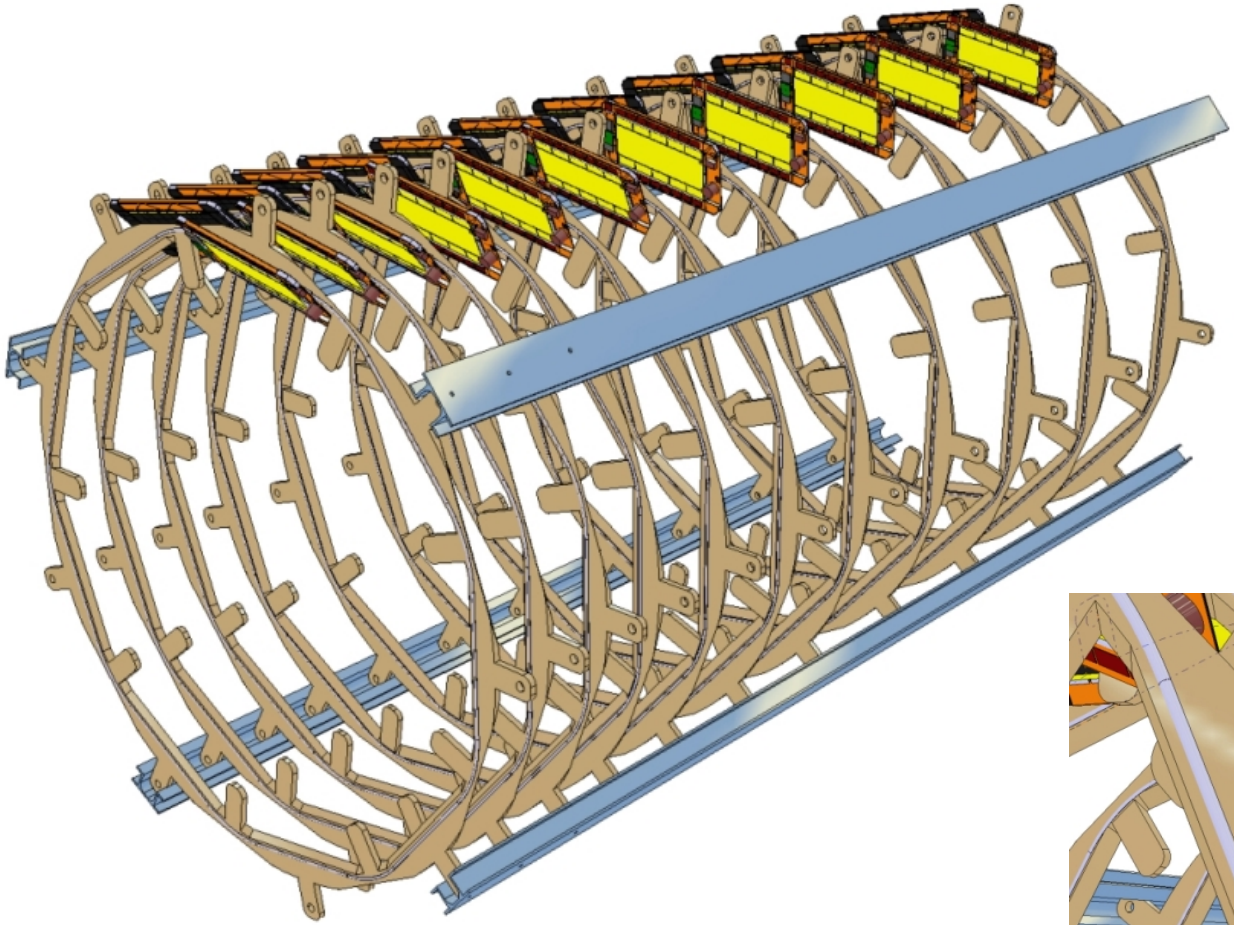


Geometrically simple building blocks

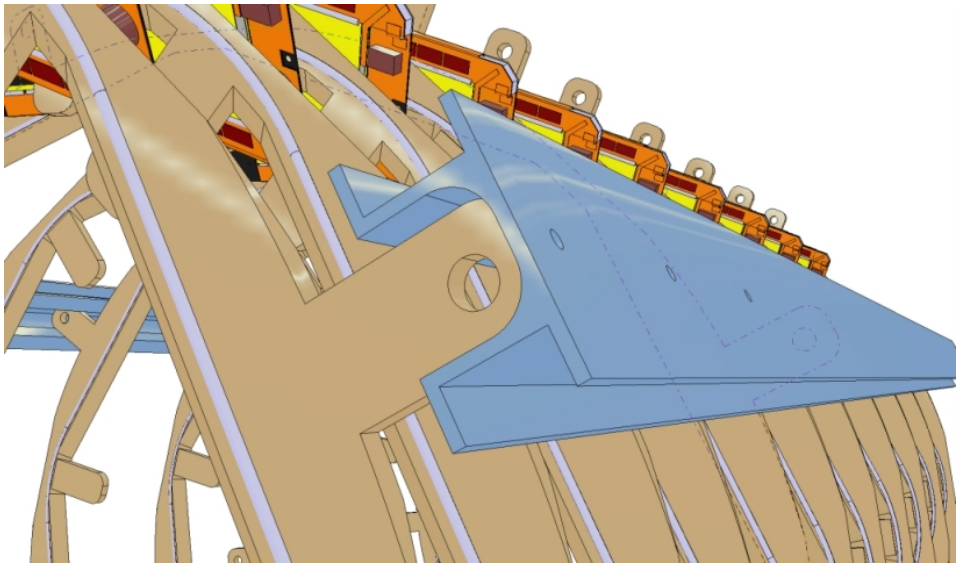
Main challenges:

- Precise and light plates with integrated cooling
- Thermal and mechanical connections

Tilted section

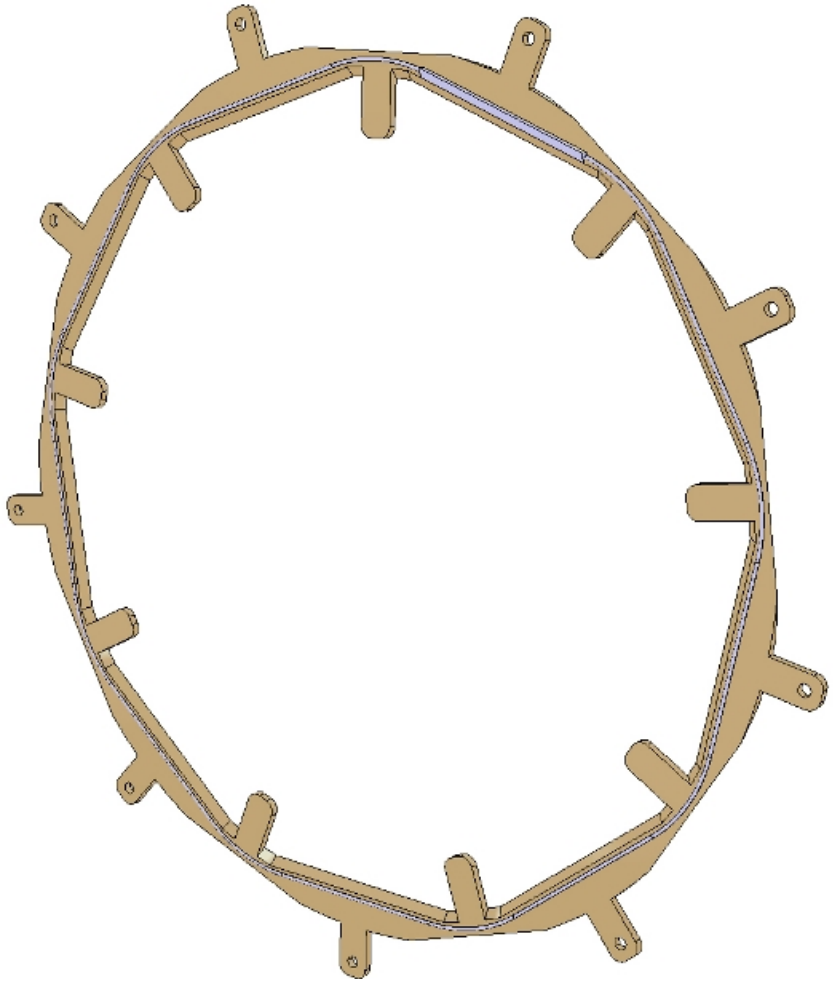


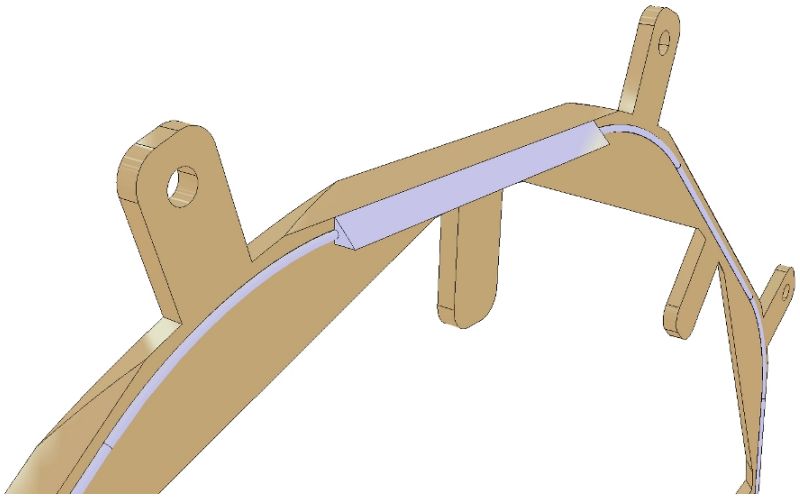
- Modules supported by Rings
- Rings joined by longitudinal bars.
- Cooling supply pipes, wires and fibres routed along the bars.

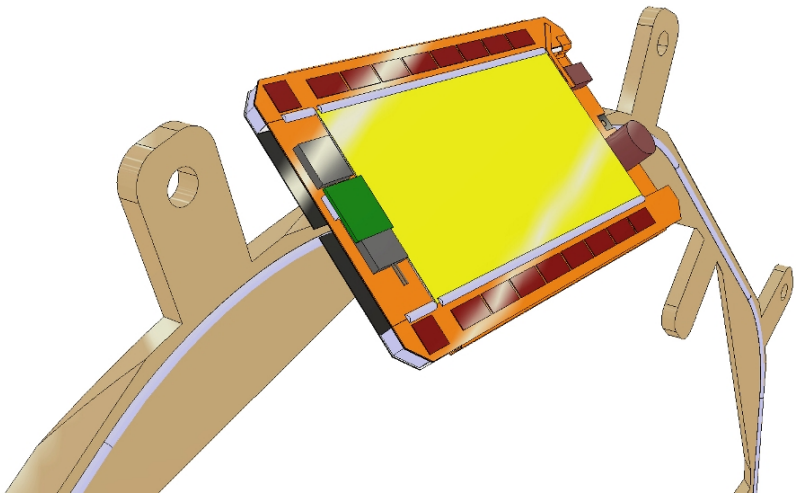


The Ring concept

- Flat disk with cooling pipes and module supports on each side.

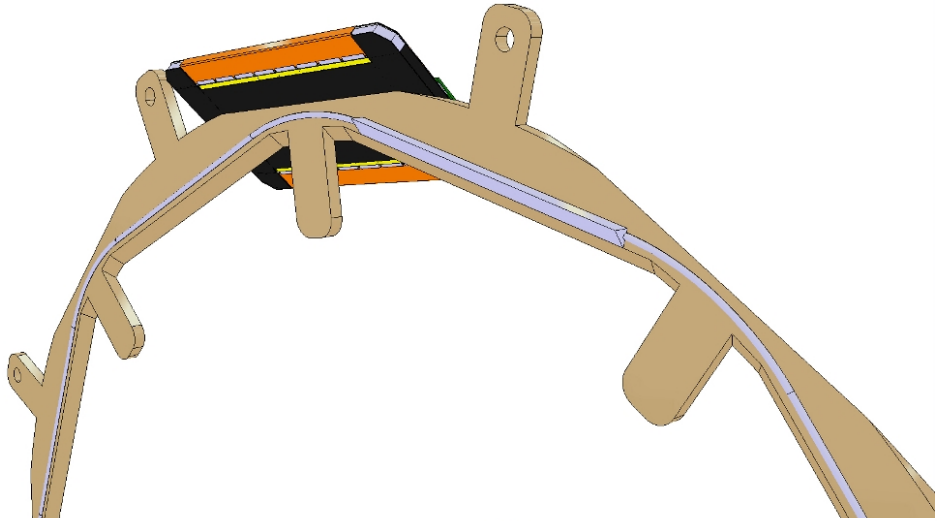


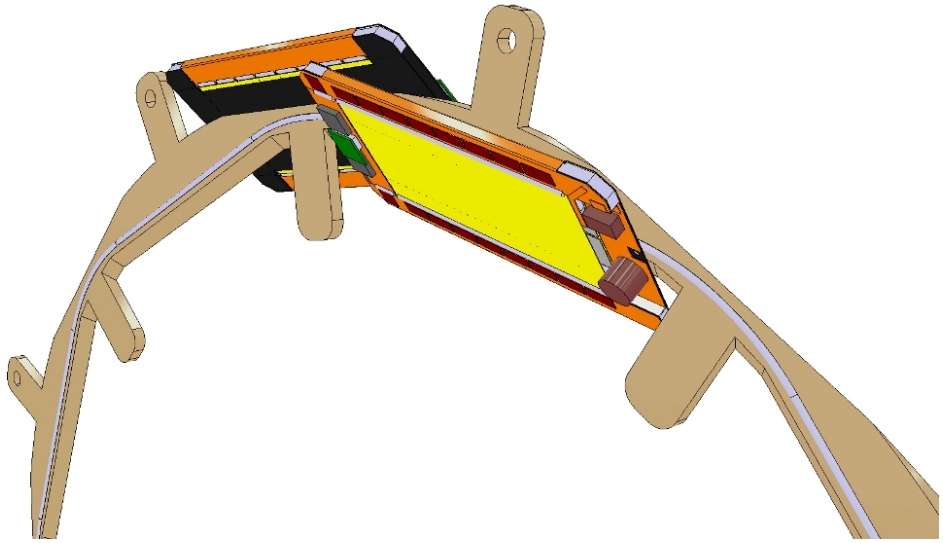


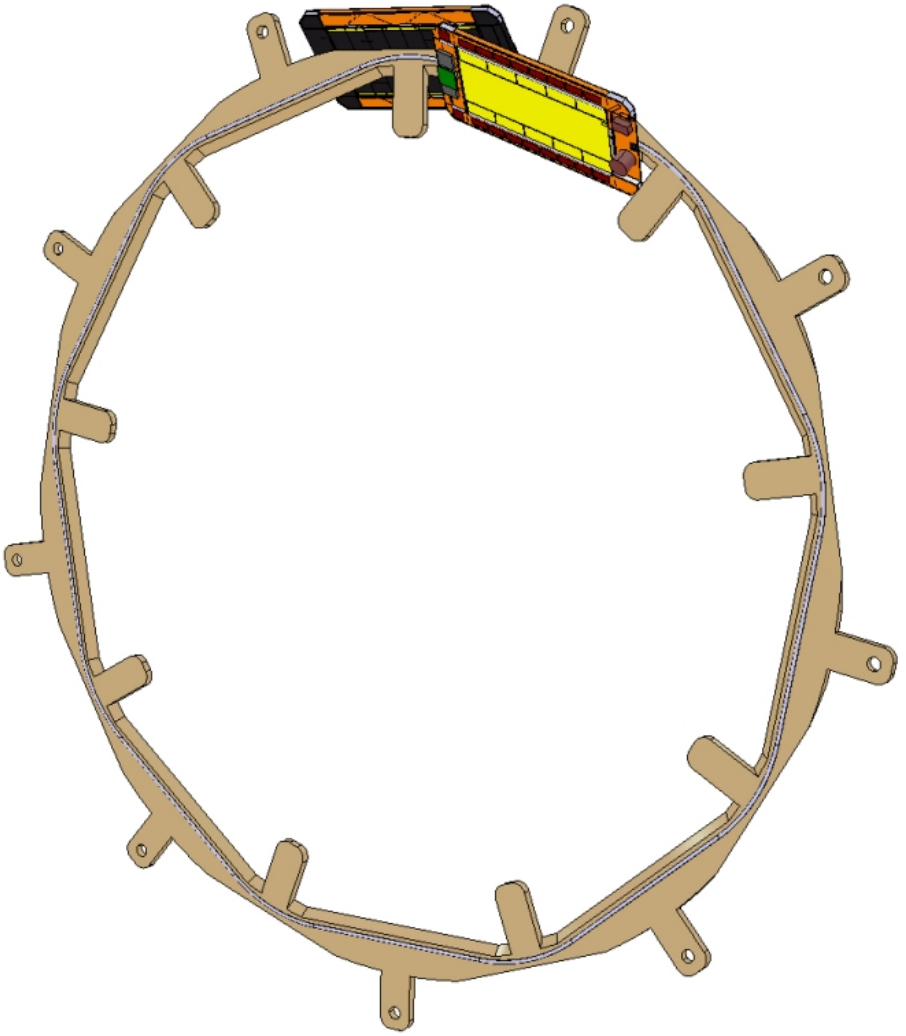


The Ring concept

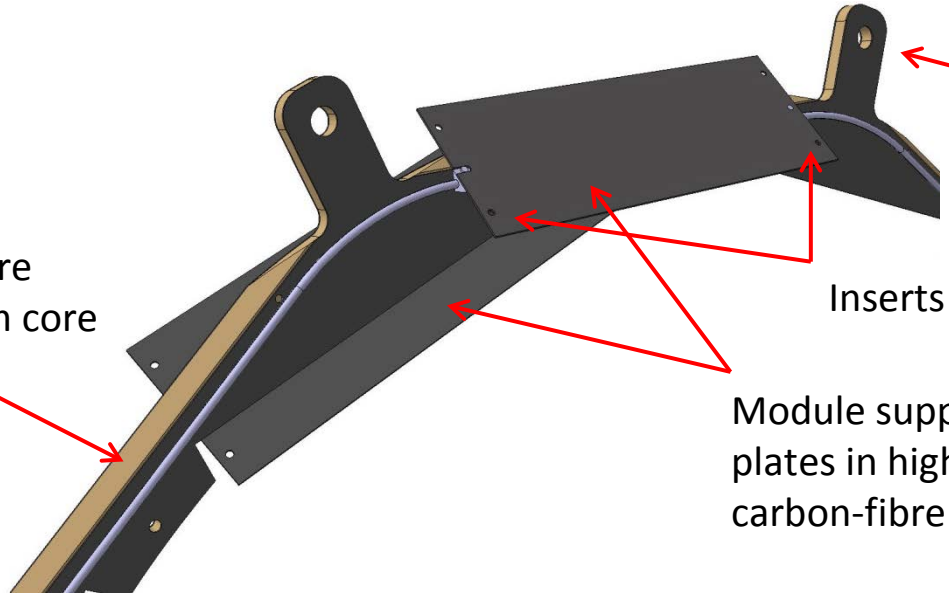
- Here the other side







The Ring

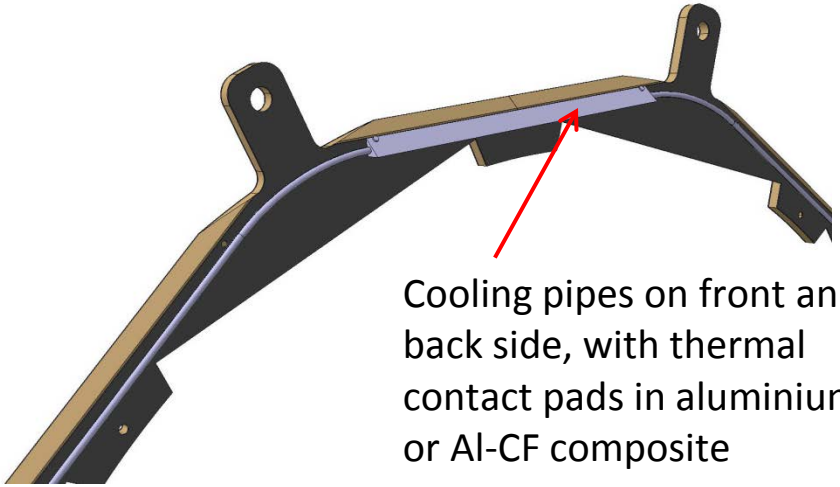


Ears for joining the Ring to the other Rings of the Layer

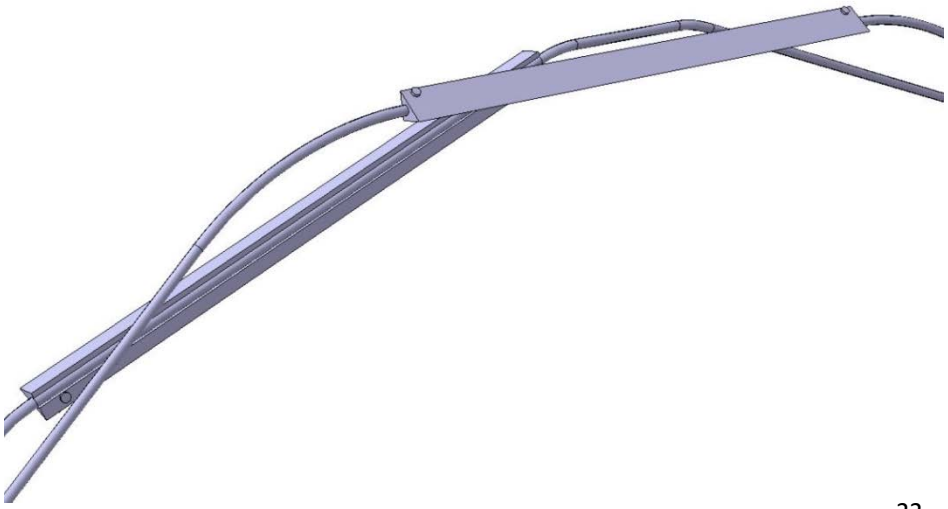
~5 mm thick sandwich structure with carbon-fibre composite skins and foam core

Inserts for module positioning

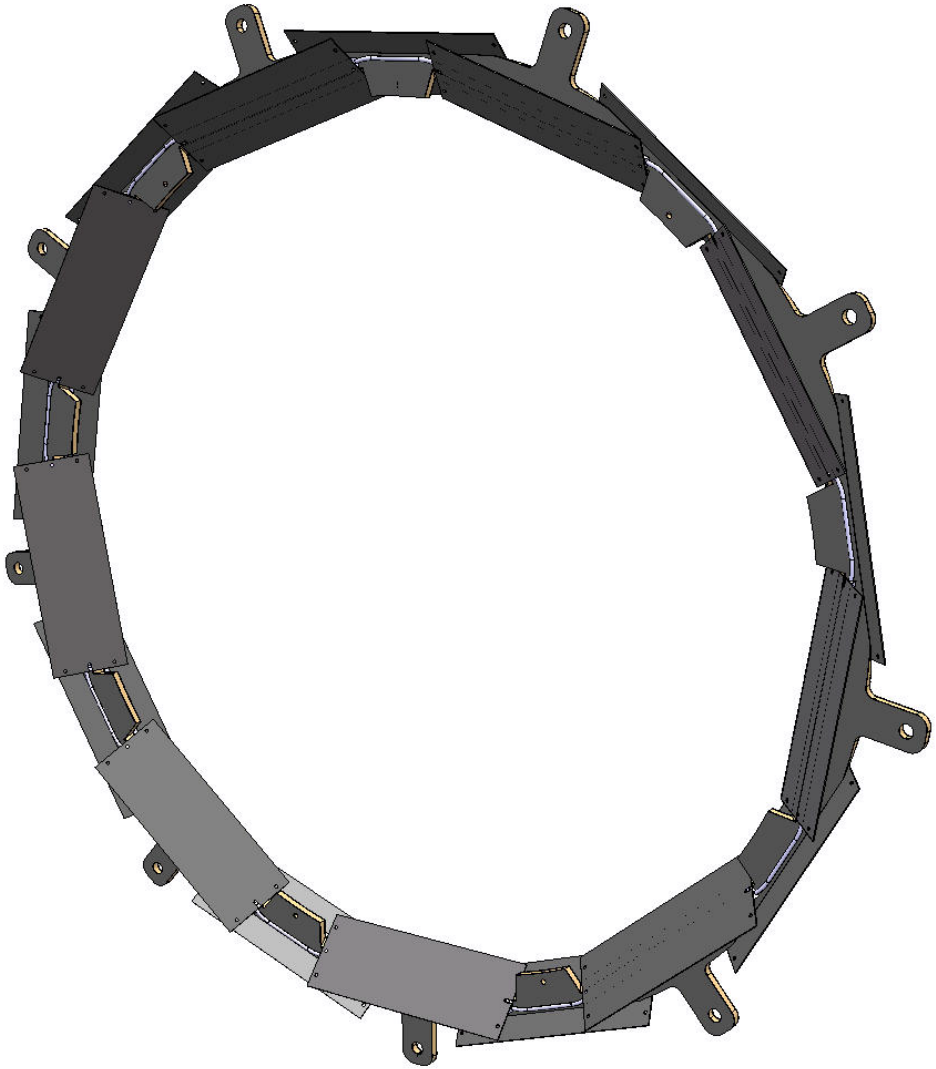
Module support / thermal contact plates in high thermal conductivity carbon-fibre composite

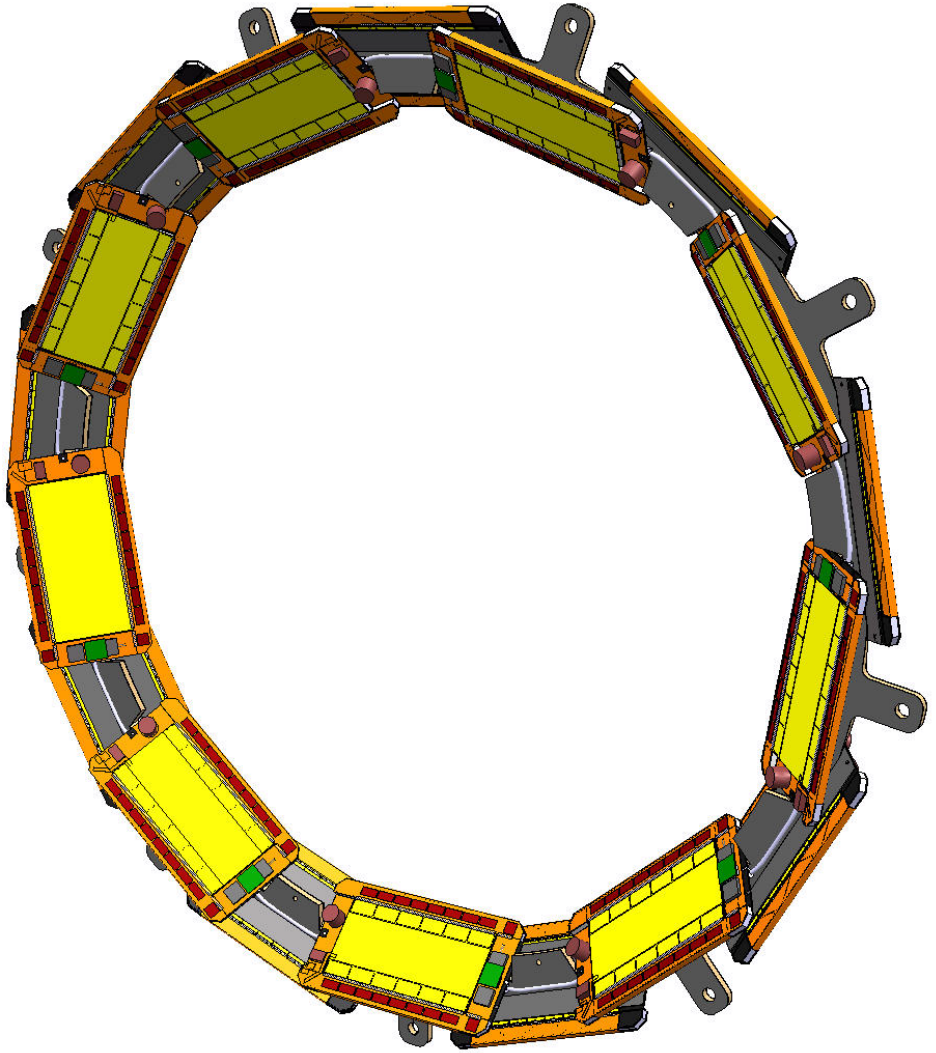


Cooling pipes on front and back side, with thermal contact pads in aluminiun or Al-CF composite

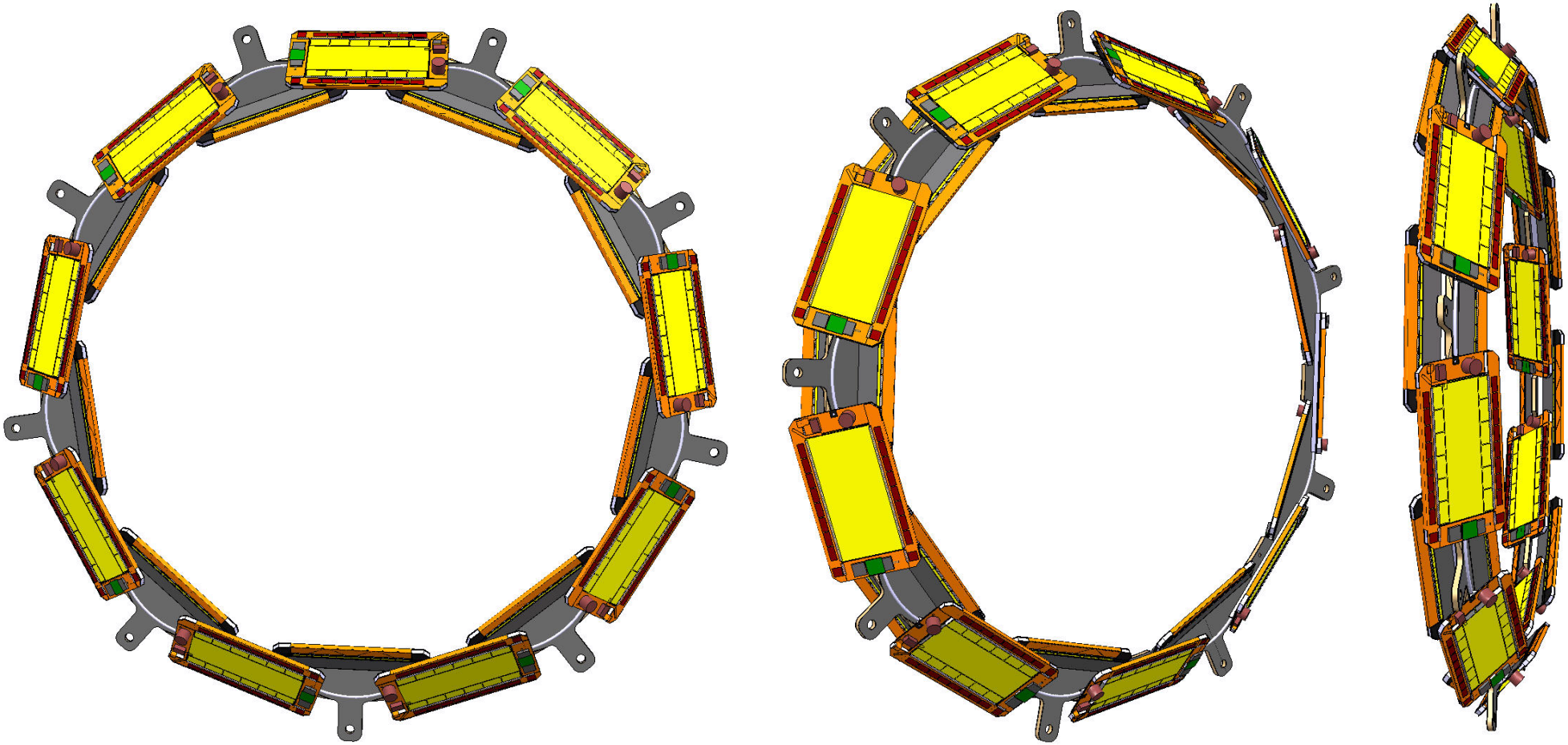


Ring & Modules

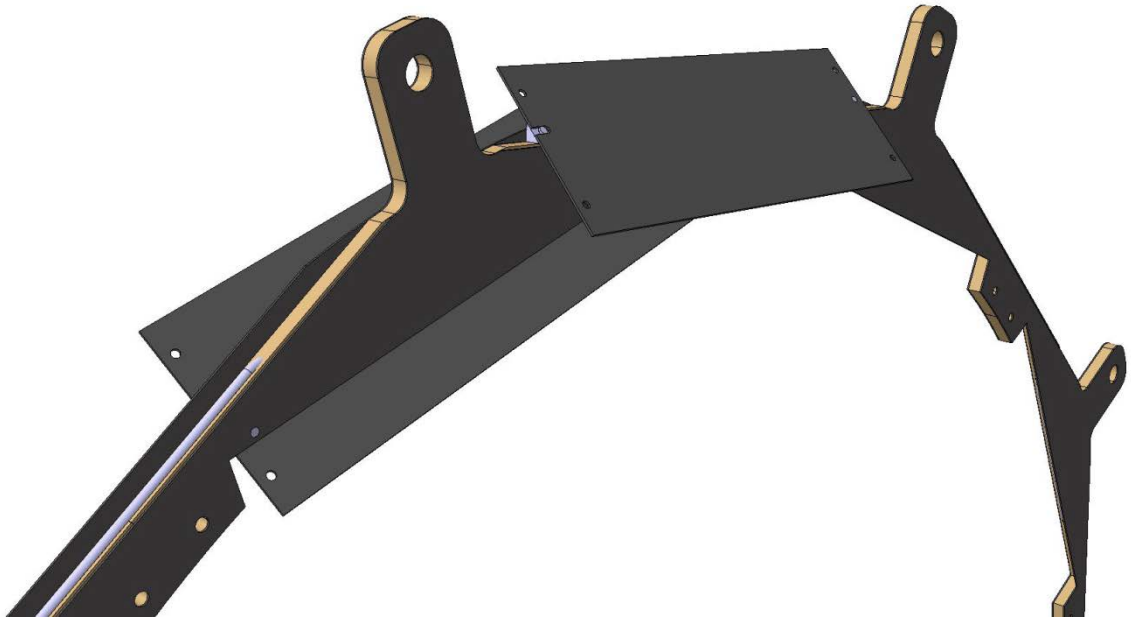


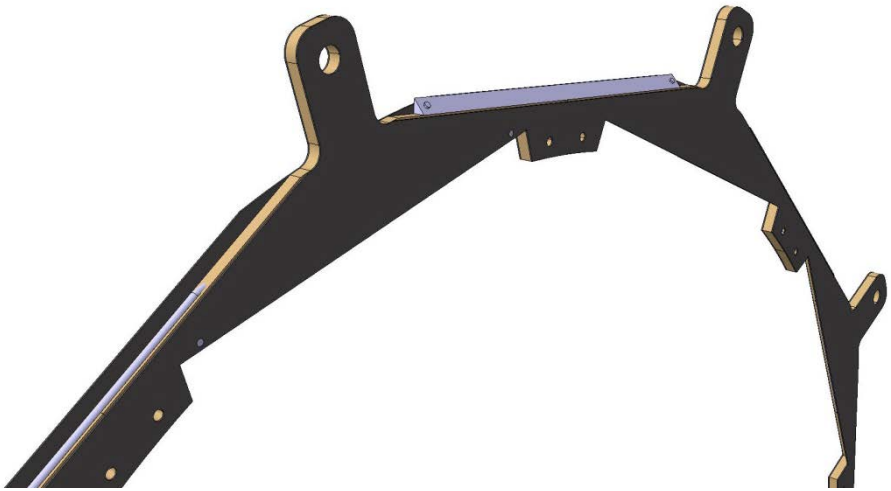


Ring with modules

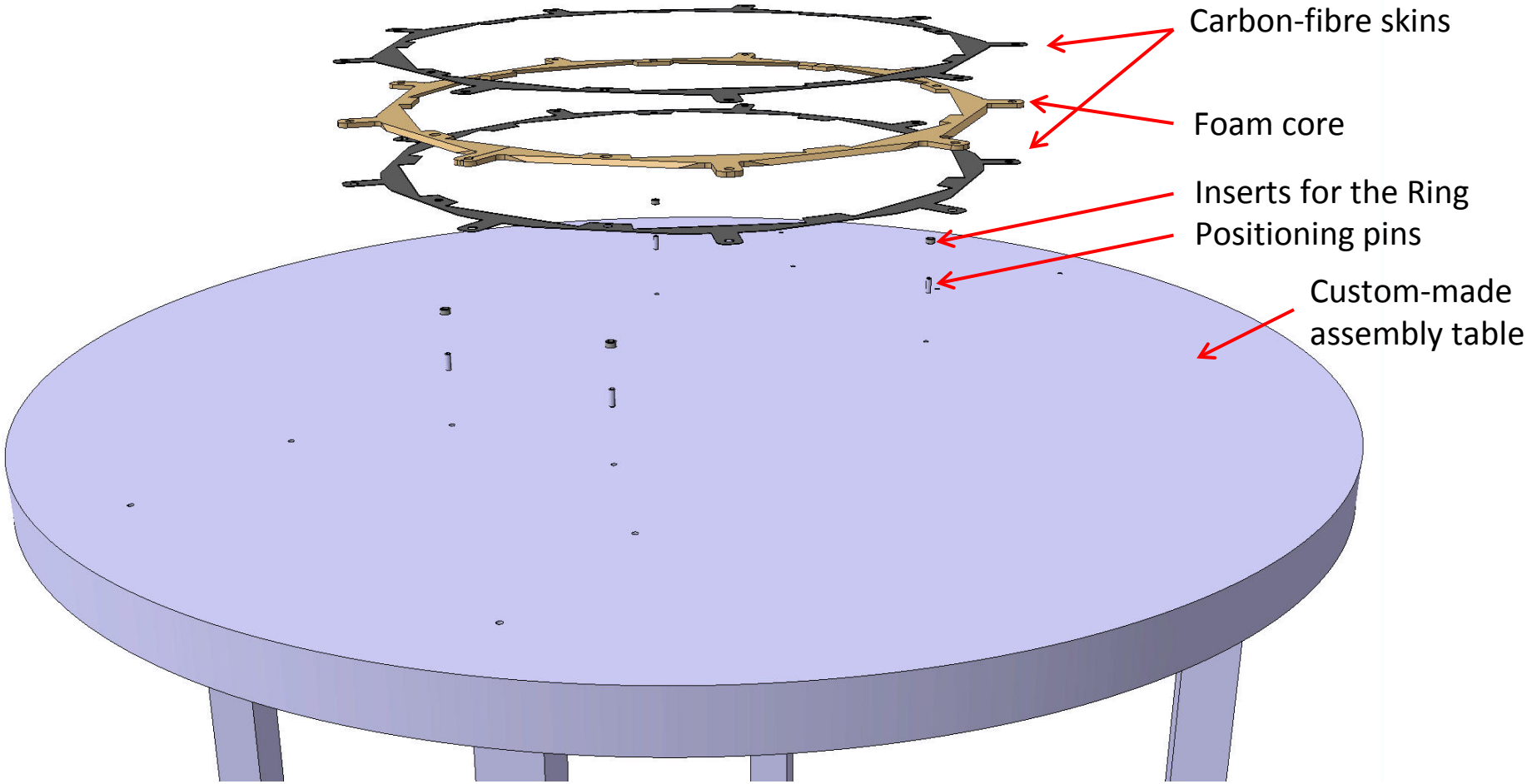


Another option: Ring with 1 cooling pipe

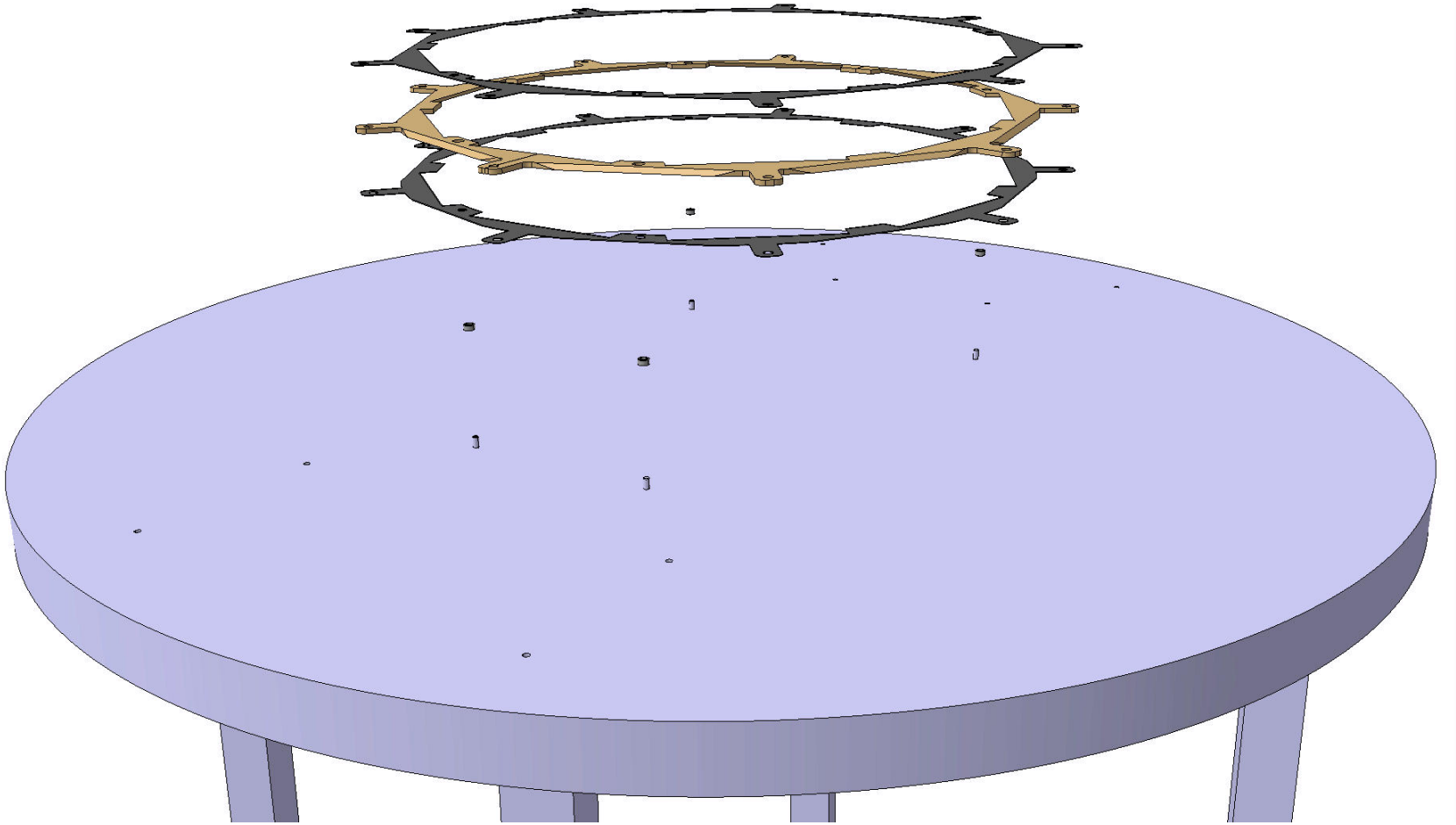




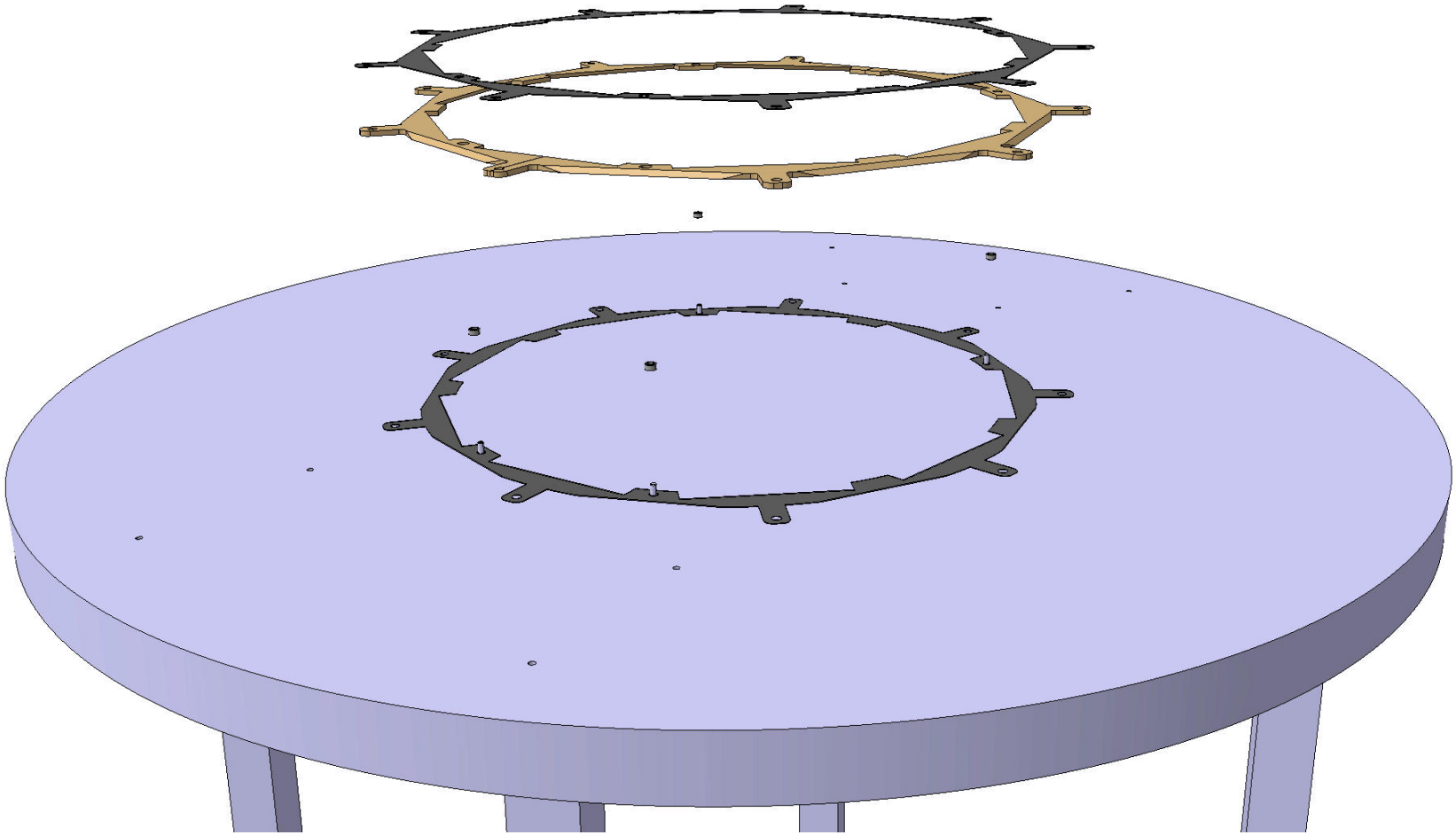
Assembling of a Ring



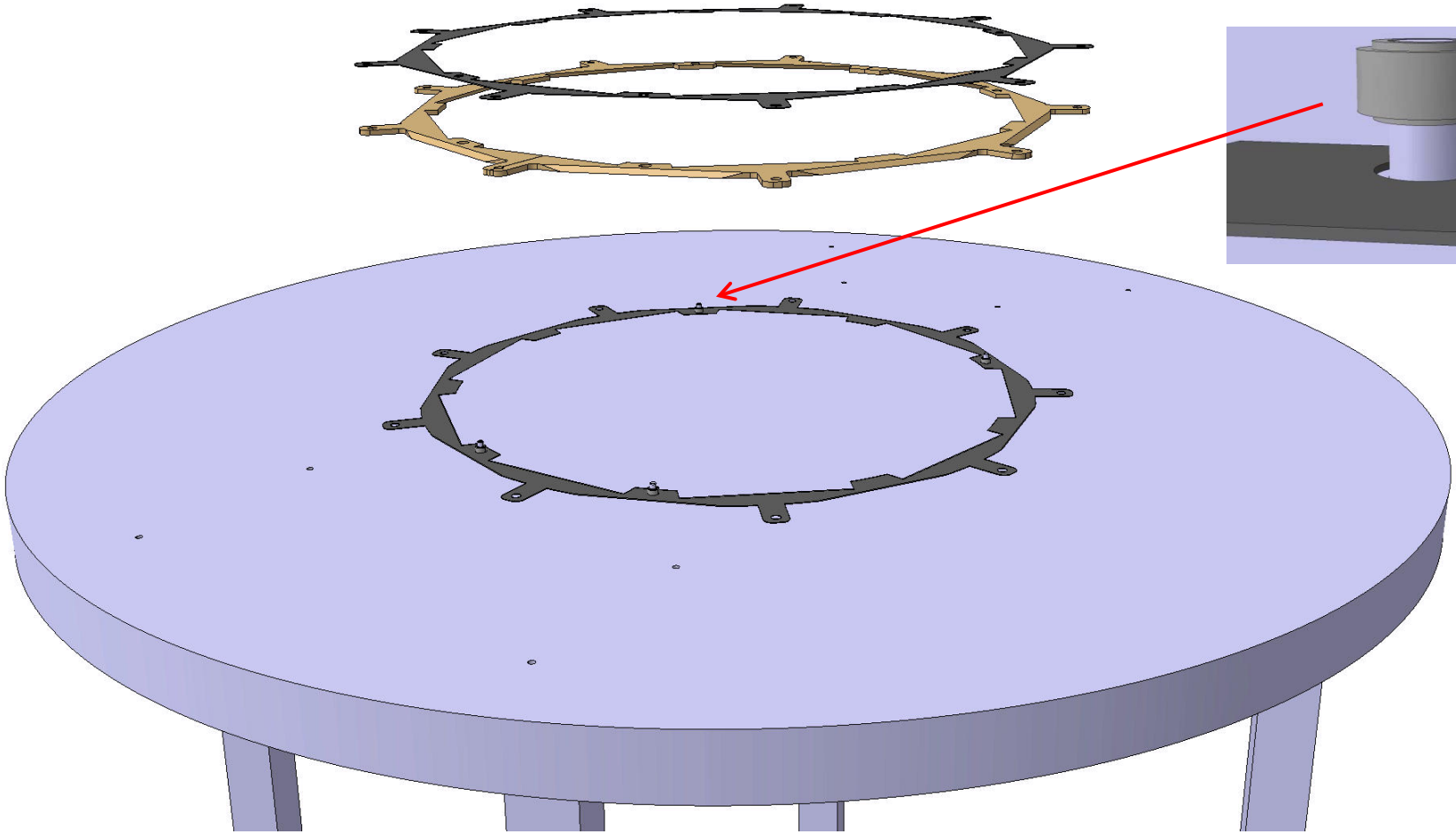
Assembling of a Ring



Assembling of a Ring



Assembling of a Ring



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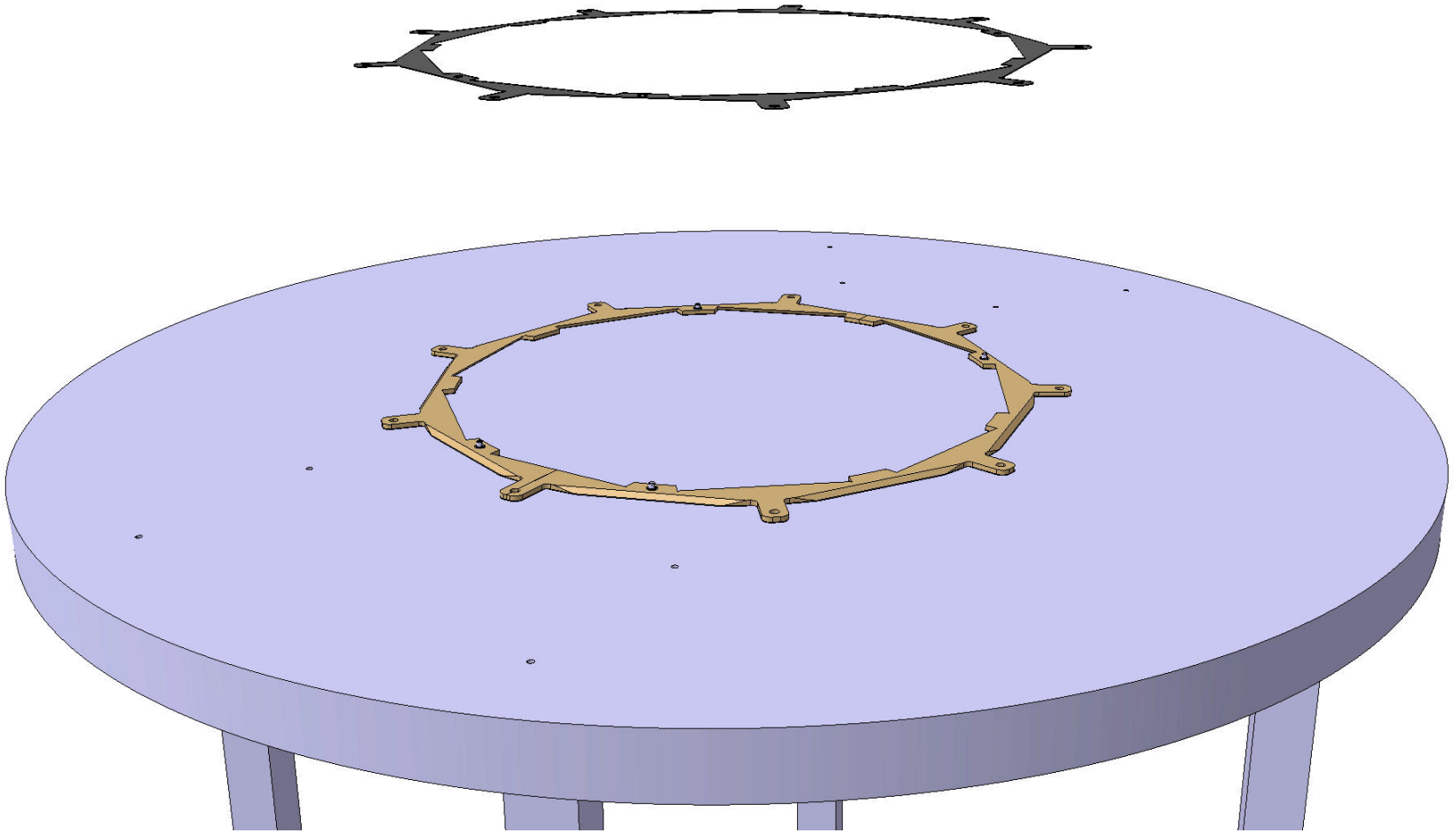
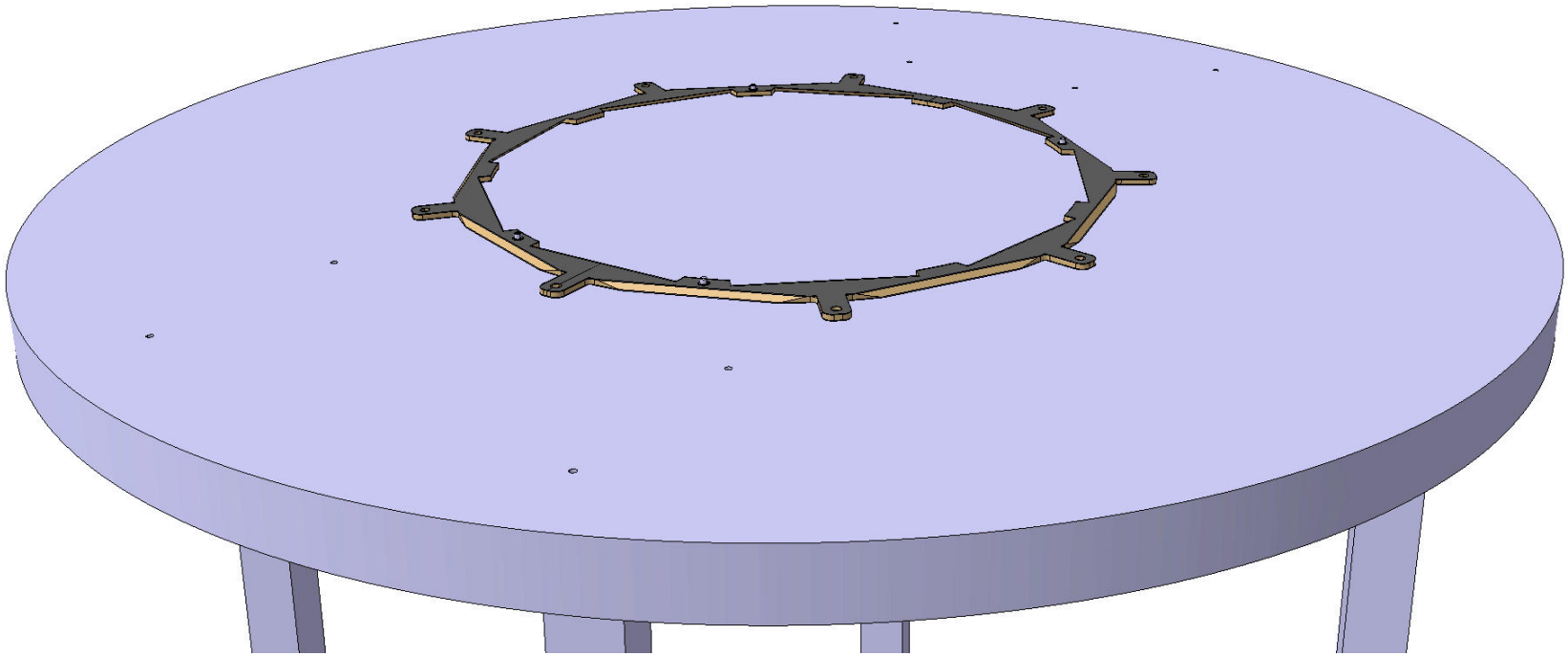
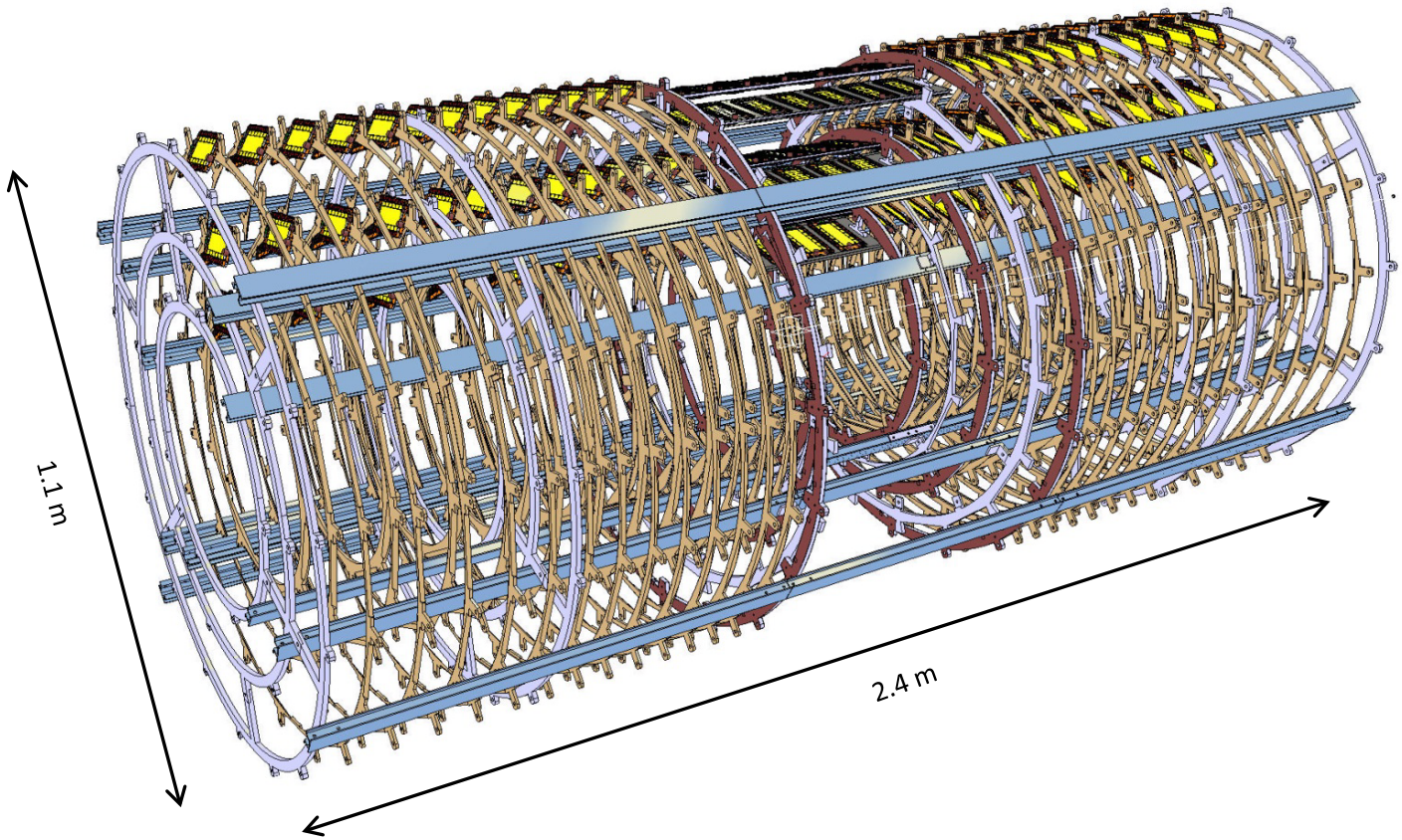


Assembling of a Ring

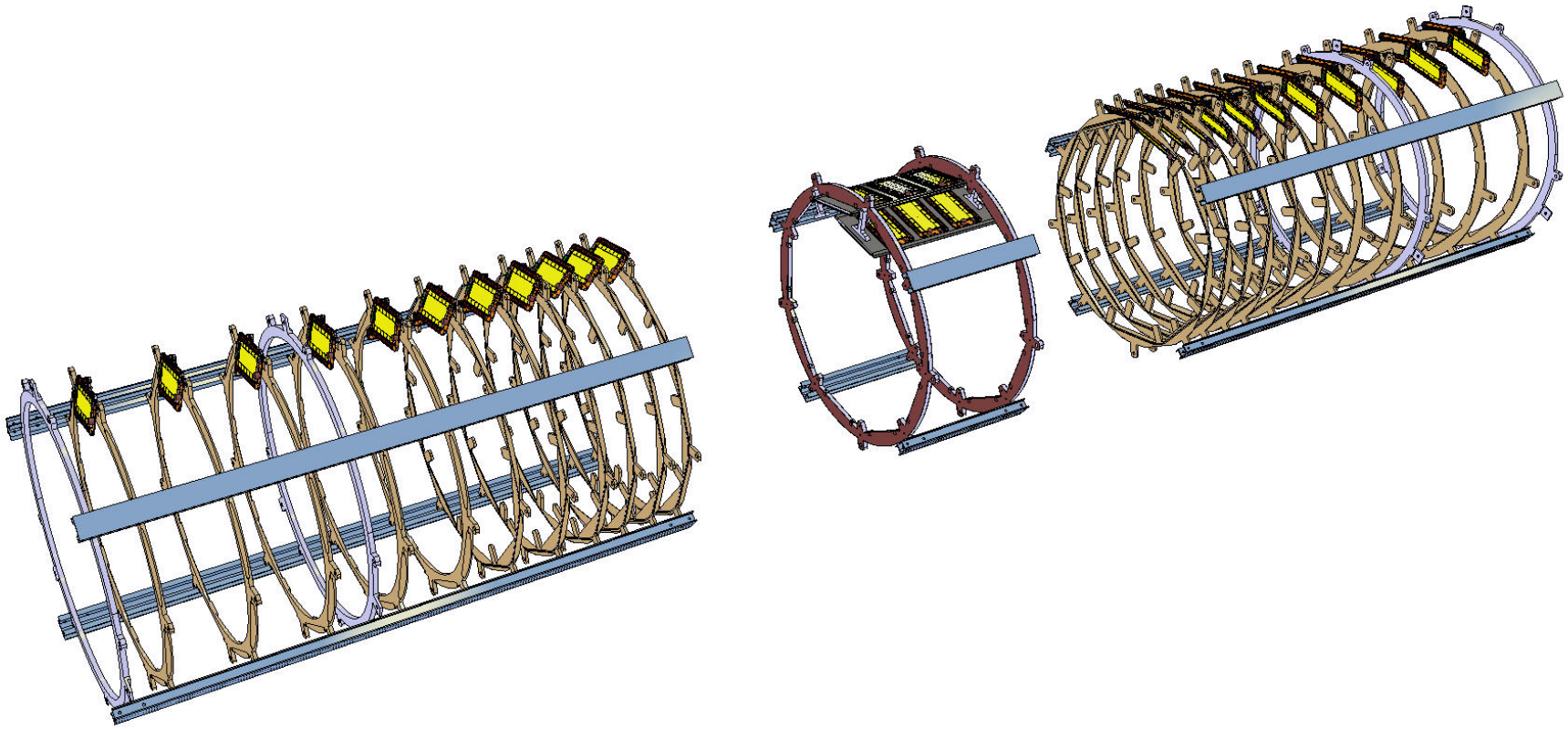


Towards the complete structure

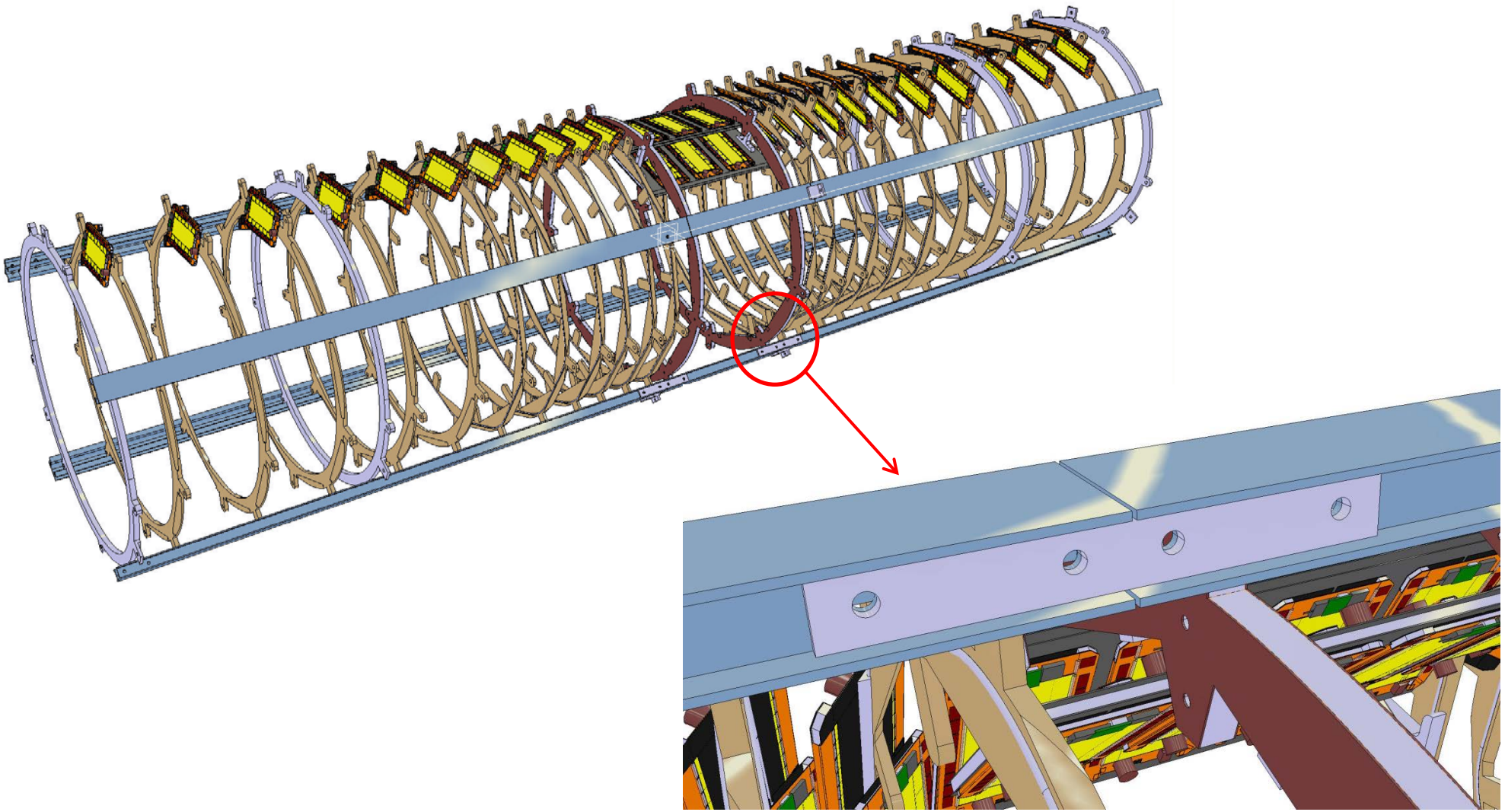
1. Produce sub-structures (Short barrels, Rings)
2. Group the sub-structures to 3 complete layers
3. Join the 3 layers



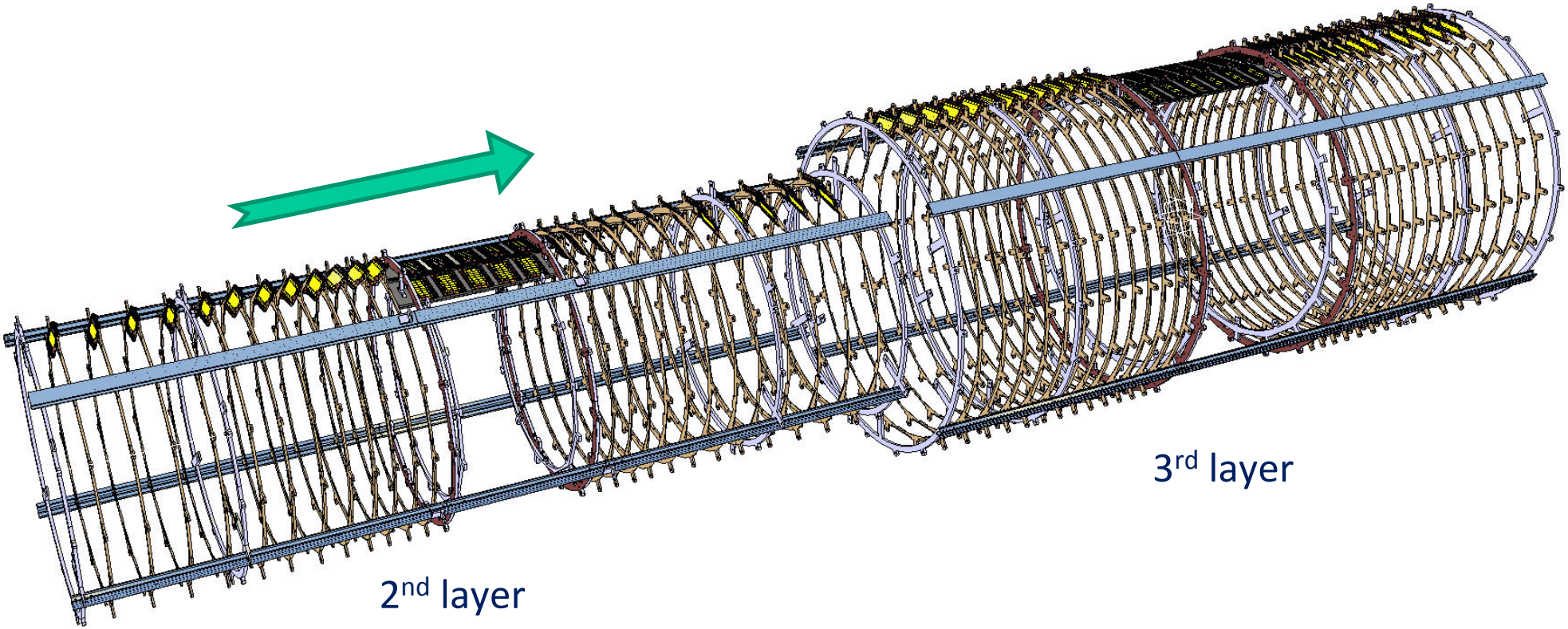
Barrel and Ring sections of a layer



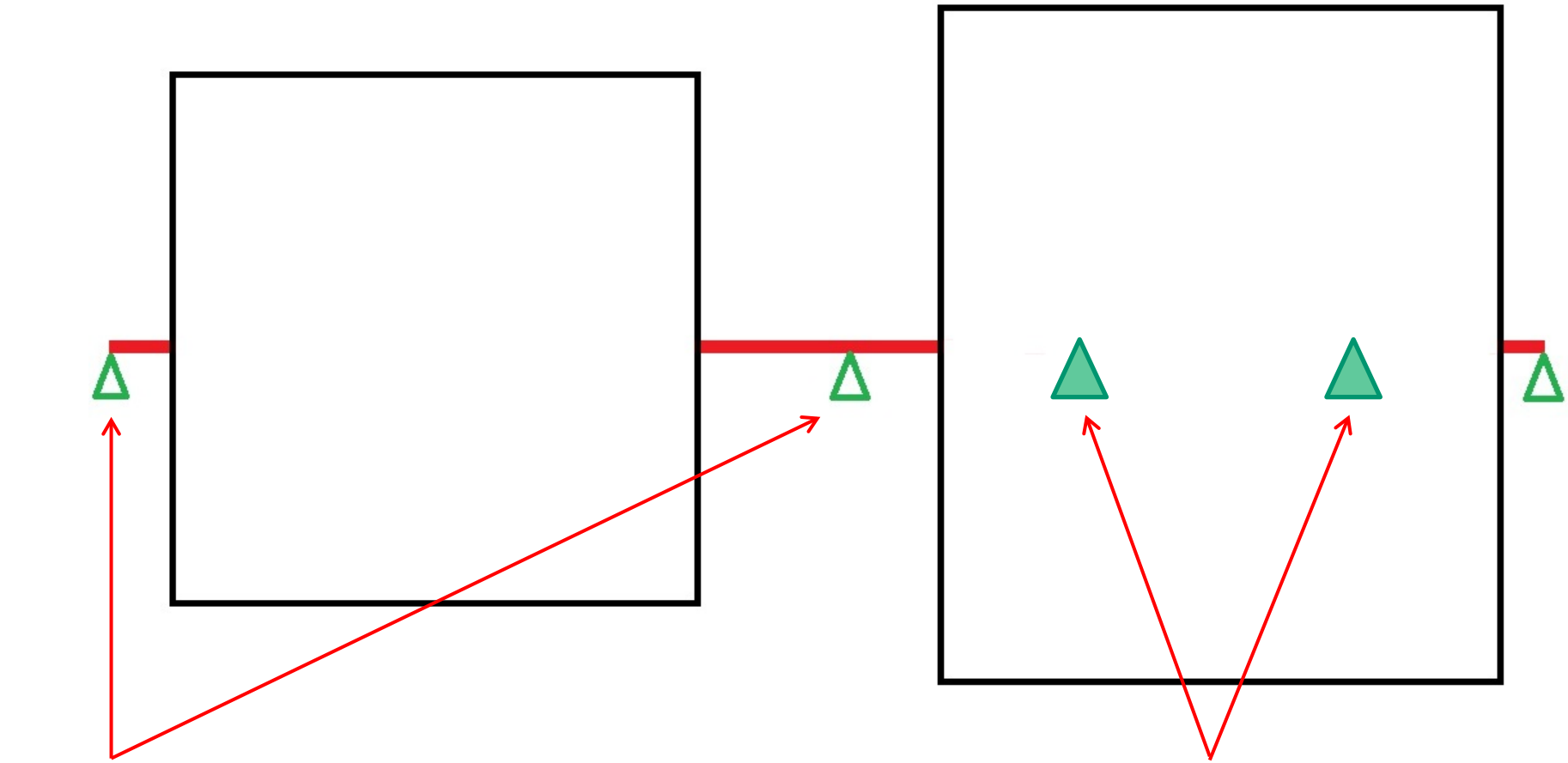
Joining the sections of a layer



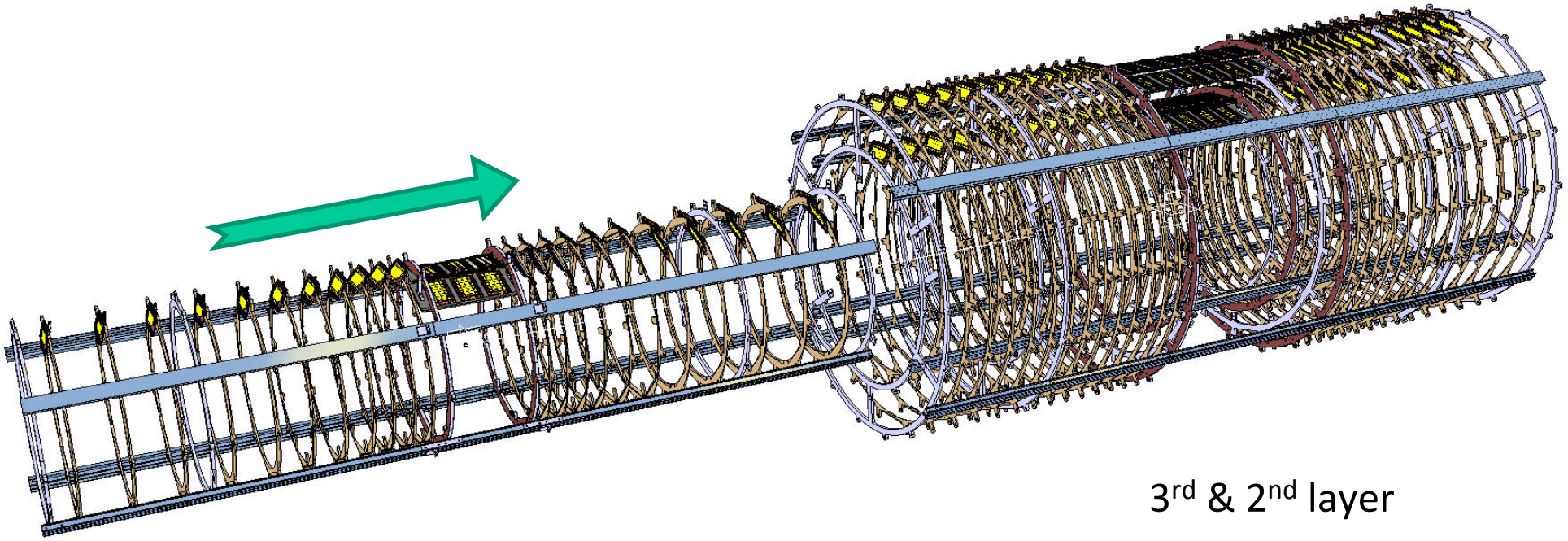
Joining layers



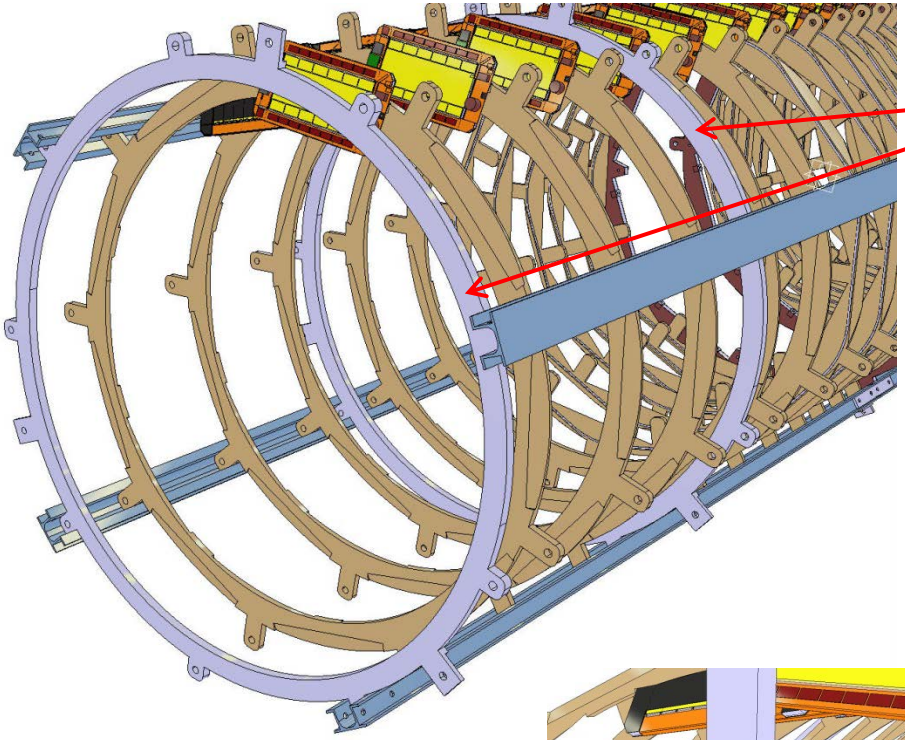
Joining layers



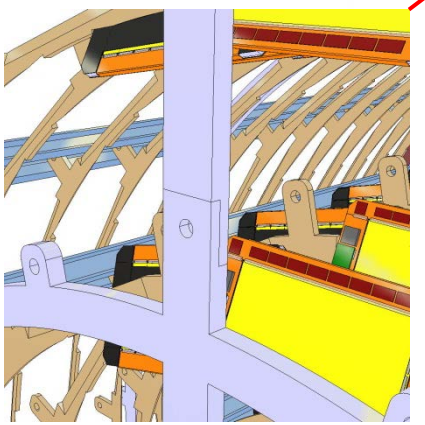
Joining layers

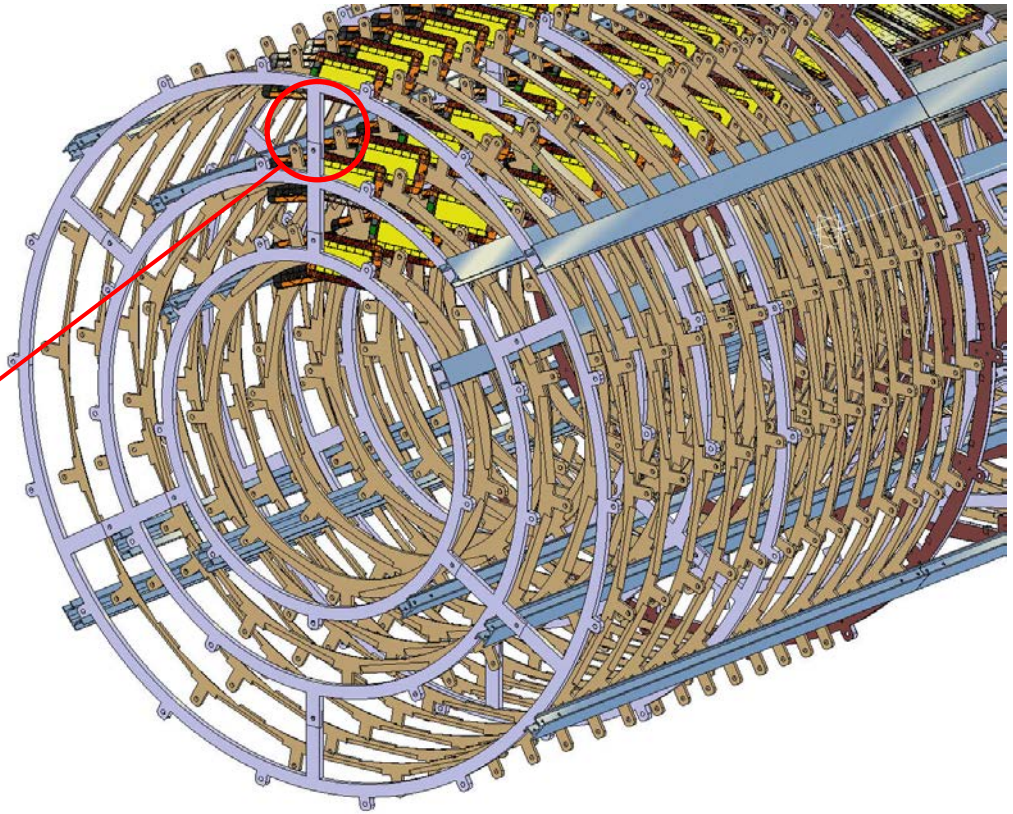


Joining layers

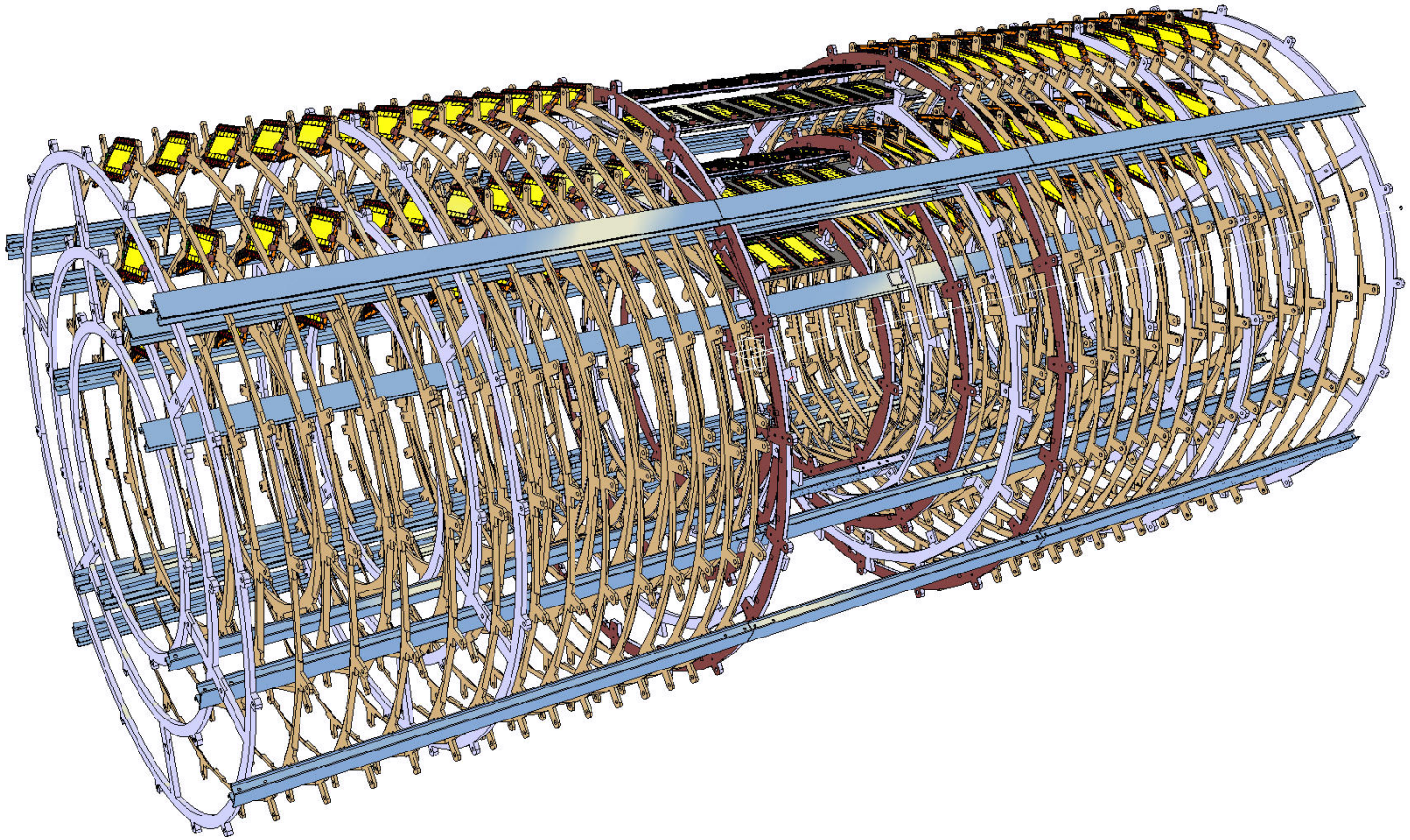


Additional rings for joining layers together





The results



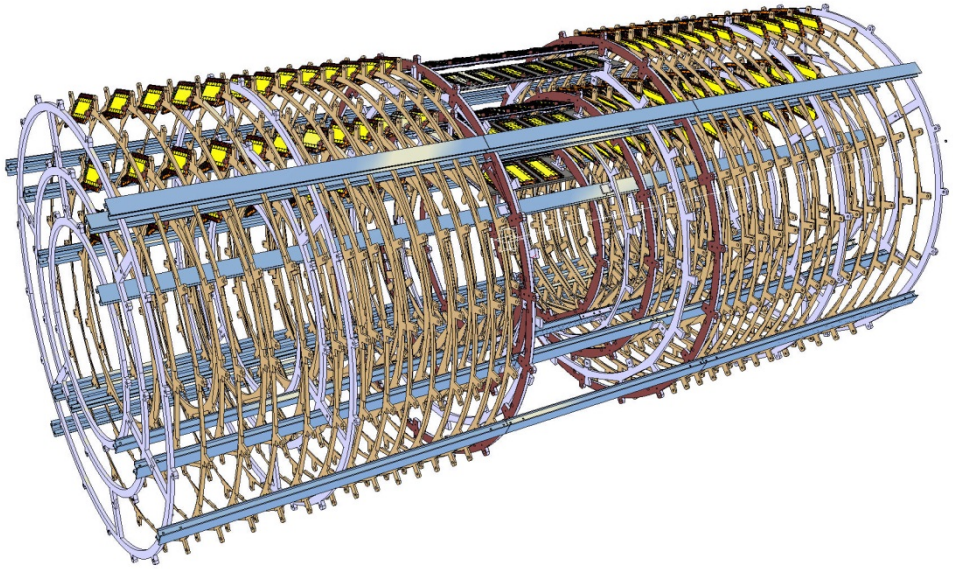
This design still misses a few ‘details’:

- Most of the modules (on purpose to keep CAD model size reasonable).
- Power wire and optofibres and their handling during various assy stages
- Cooling pipe manifolding, supply lines and connections
- Outer supports (4 supports, in the layer 3)

Summary and Outlook

- The Tilted geometry has major advantages compared to the base-line Flat geometry
  - Less modules and therefore lighter and cheaper (order of magnitude -5 MCHF).
- But, the Tilted geometry is a major challenge for the mechanics
  - More complicated and surely less proven than the usual Barrel + Endcap geometries.
  - Expect more expensive mechanics, even if there would be 'less' of it (estimated to be +1 MCHF)
- Nevertheless, the Tilted geometry looks mechanically feasible
  - Module collisions in the 'ideal' all tilted geometry solved by grouping modules to constant tilt angles and using a short flat barrel section.
    - Still fully hermetic layers and close to the ideal tilts.
  - Space available for support structures.
    - Better than in current CMS Tracker thanks to less layers (3 instead of 4).
    - If necessary, further space can be provided by moving neighbouring modules in/outwards.

- Next to do:
  - Add missing components in CAD: Outer supports, cooling supplies and connections, services routing
  - Structural + thermal analysis (started recently) and detail material choices
    - May induce many changes to the design.
  - A lot of prototyping
    - Ring manufacture, module support precision, cooling contacts, module installation, etc.

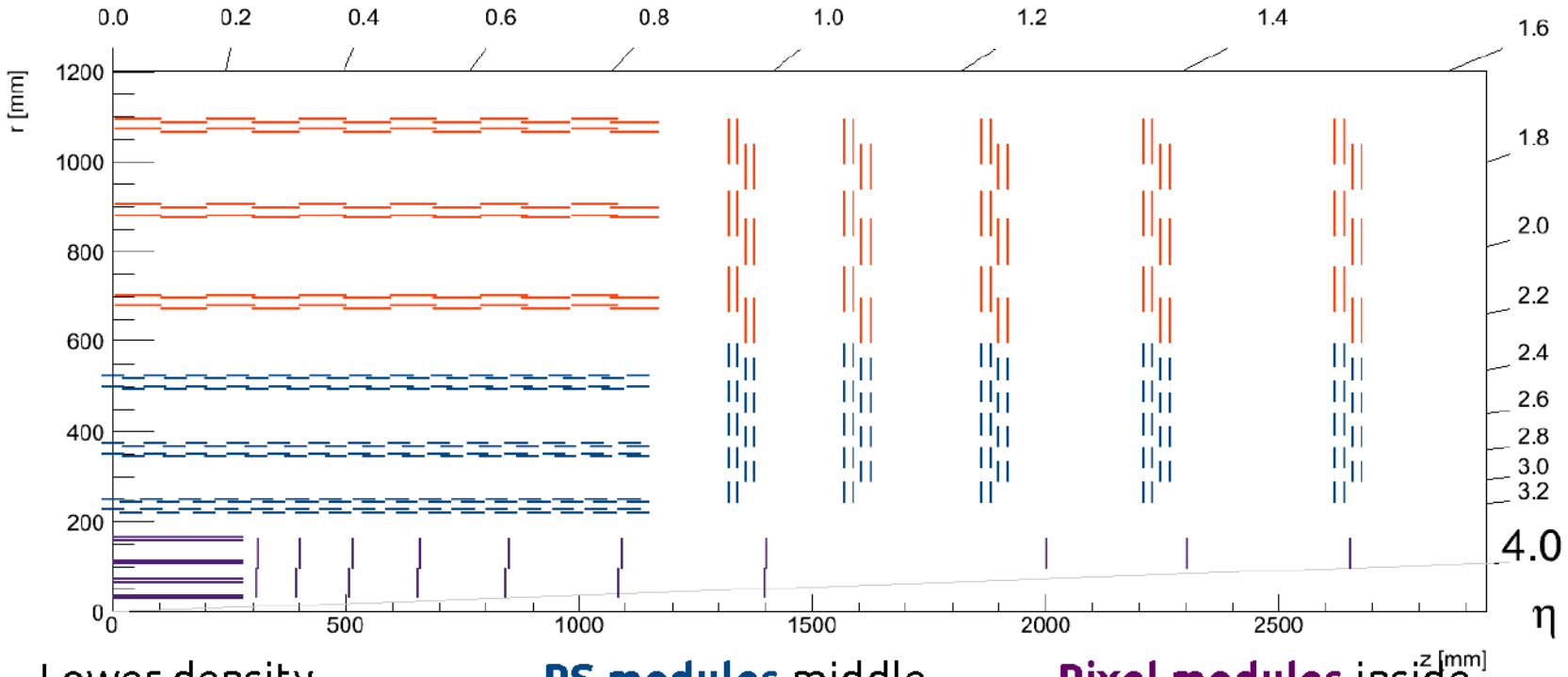


Thank you for your attention!

Back-up slides

CMS Tracker layout options

S. Mersi at al., Performance of Tilted Inner Barrel, CMS Upgrade Workshop 1 April 2014



Lower density
2S modules outside
(~8'424 modules)

PS modules middle
z info in trigger
θ info in trigger
(~6'930 modules)

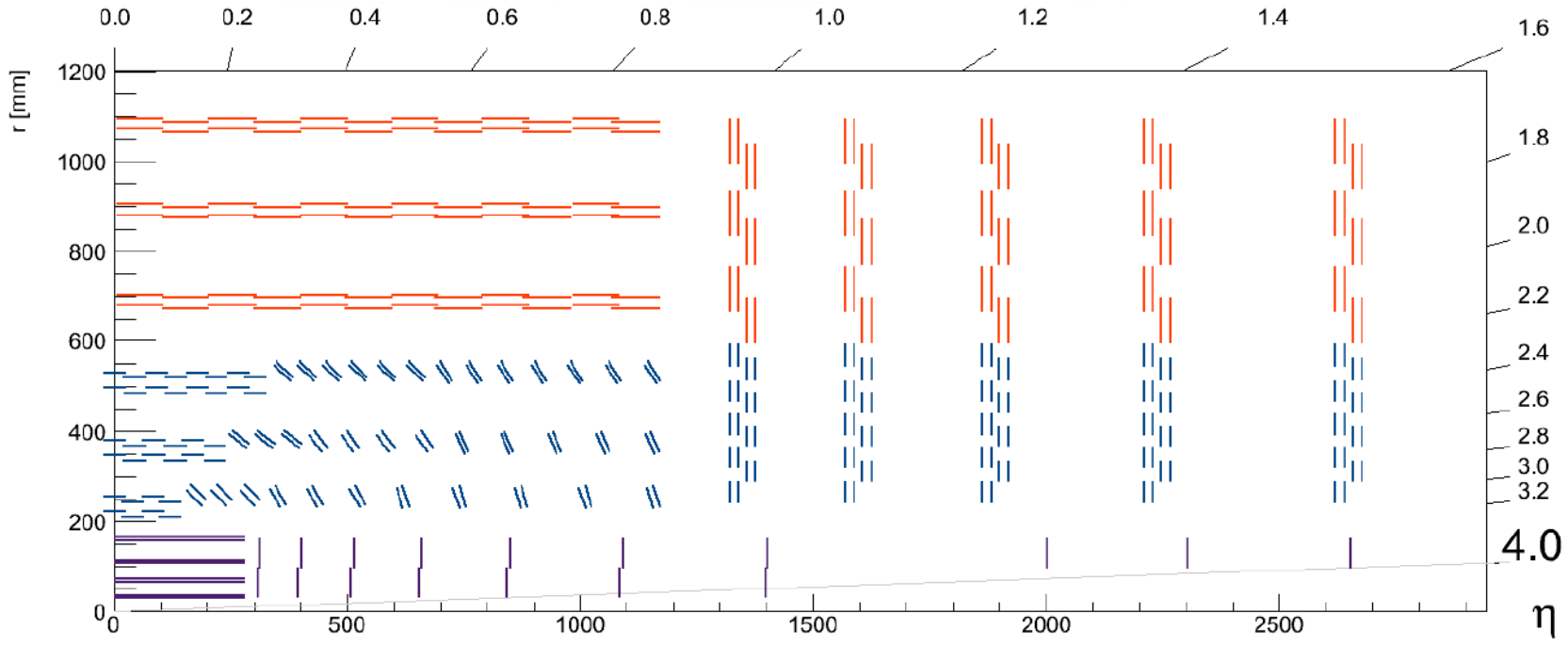
Pixel modules inside
accurate impact parameter resolution & forward coverage

More detailed model
15'354 total modules

No detailed model: using Phase-I detector layout w/ more disks in the forward

CMS Tracker layout options

S. Mersi at al., Performance of Tilted Inner Barrel, CMS Upgrade Workshop 1 April 2014



Lower density
2S modules outside
(~8'424 modules)

PS modules middle
z info in trigger
θ info in trigger
(~5'708 modules)

Pixel modules inside
accurate impact parameter resolution & forward coverage

More detailed model
14'132 total modules

No detailed model: using Phase-I detector layout w/ more disks in the forward

Filtering off low pT hits at the modules

S. Mersi, CMS Tracker Upgrade layout and requirements, ACES 2014

Need to ship hits off detector

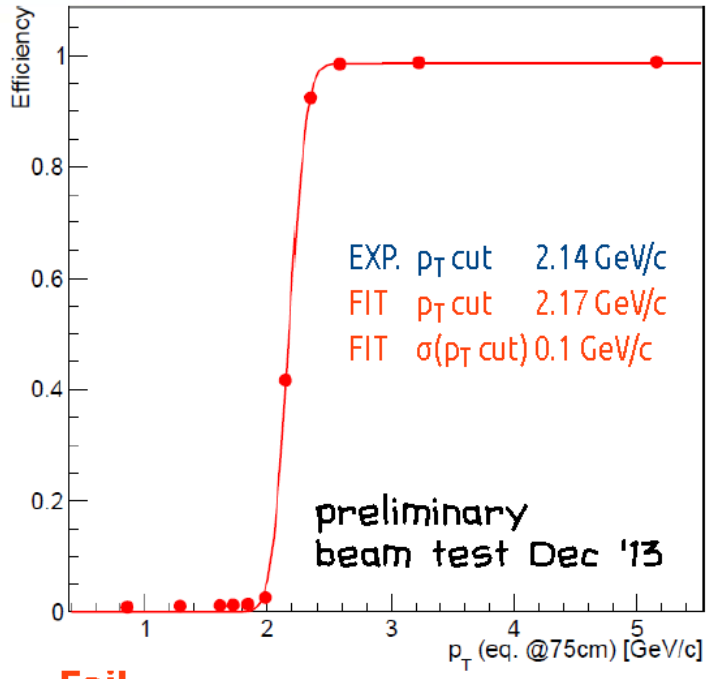
Ship all hits @ 40 MHz? No

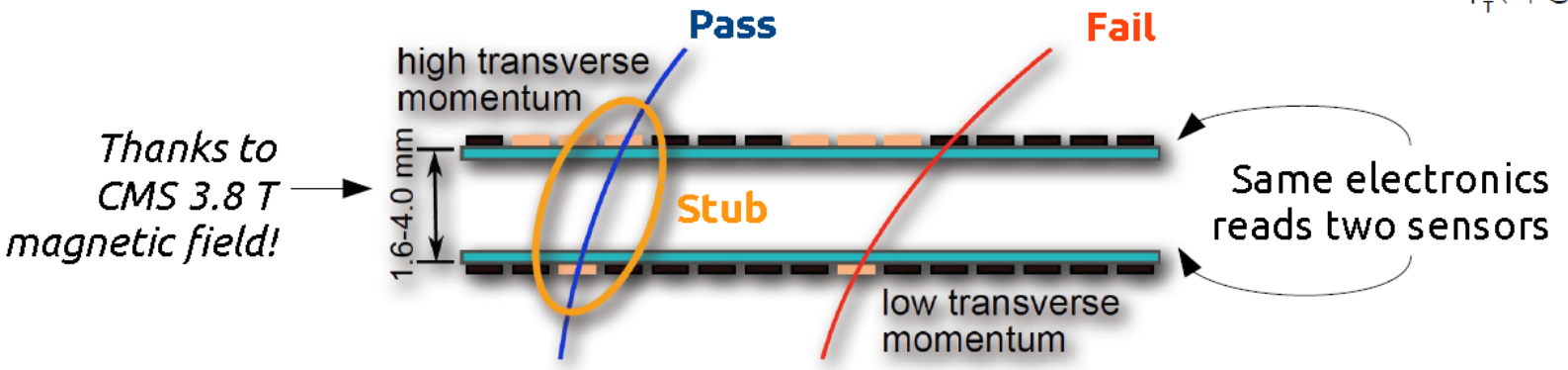
- Bandwidth needed: off by 1 order of magnitude (order of 10 Gbps per module)
- Track reconstruction ~ impossible

Solution: ship only high-pT hits (stubs)

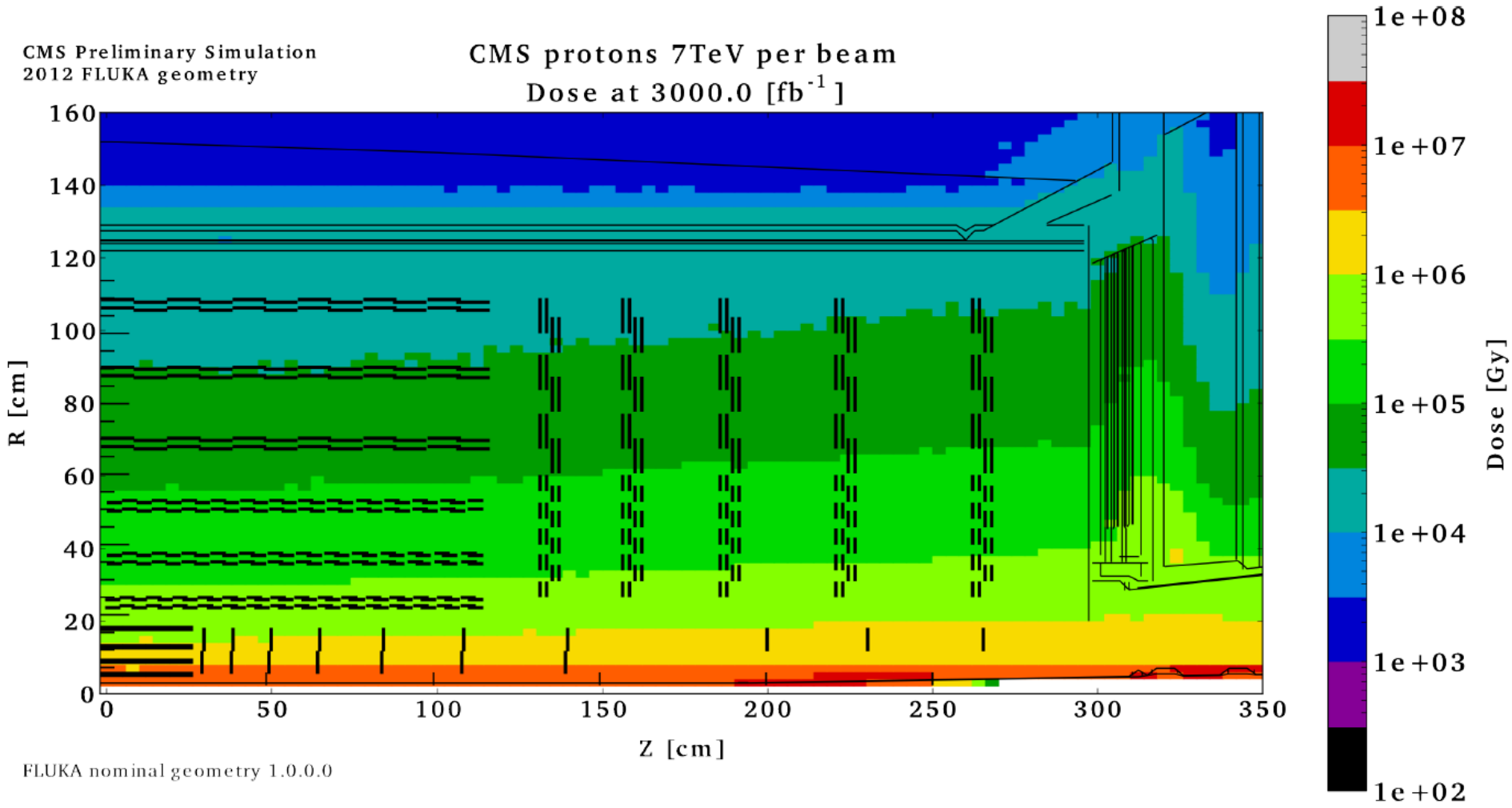
- Threshold of ~ 2 GeV
- Data reduction of one order of magnitude or more

Modules with pT discrimination ("pT modules")



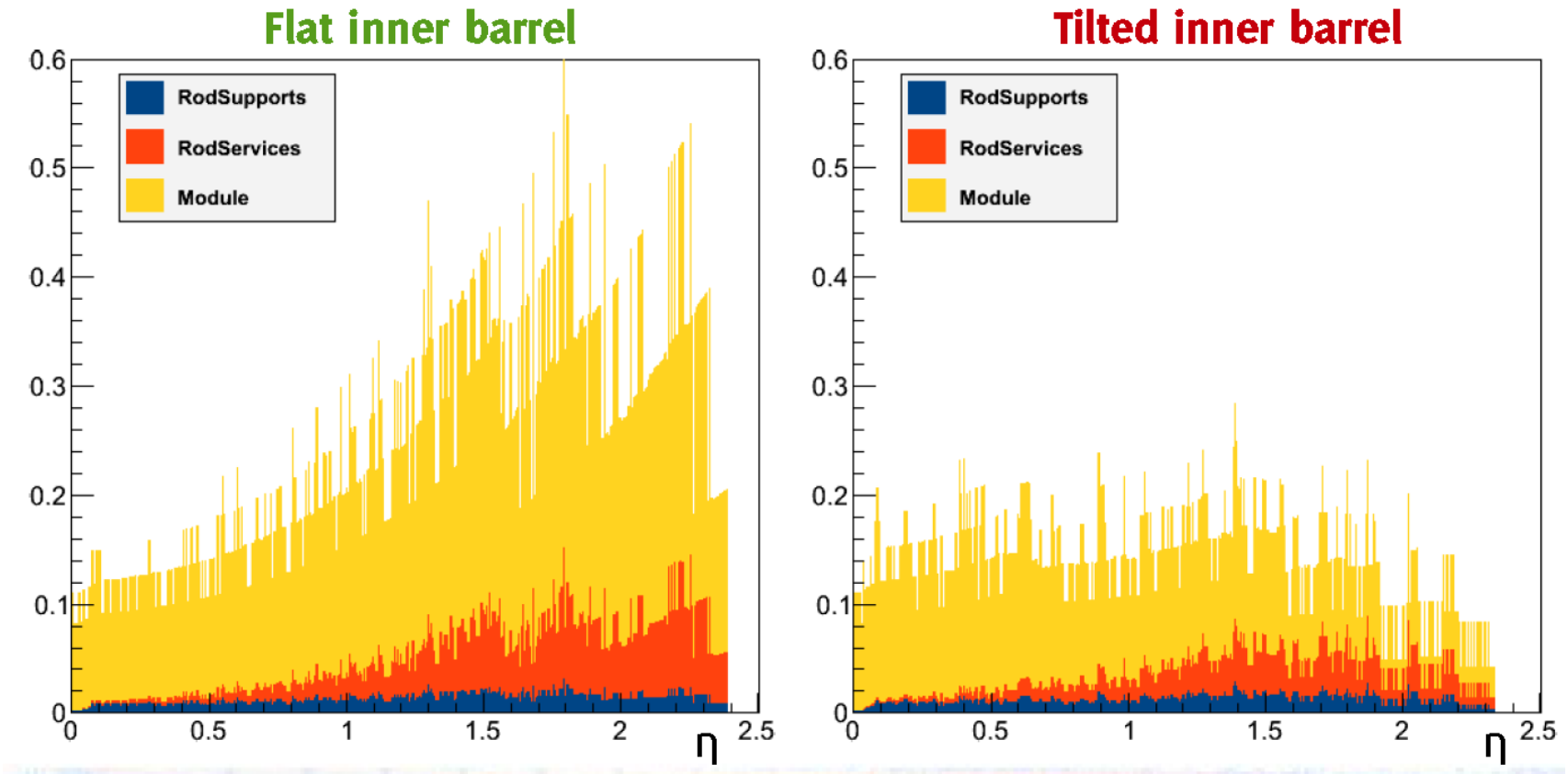


Radiation map for the Phase 2 Tracker



Material budget Flat vs Tilted

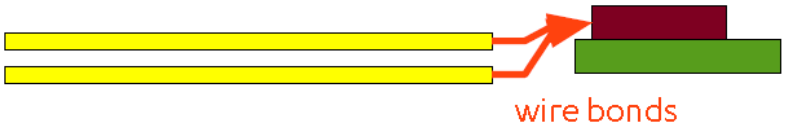
S. Mersi at al., Performance of Tilted Inner Barrel, CMS Upgrade Workshop 1 April 2014

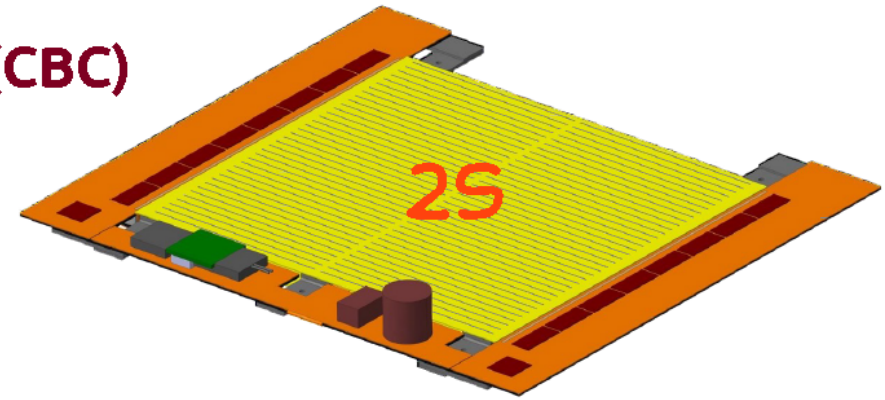


2 upgrade module types

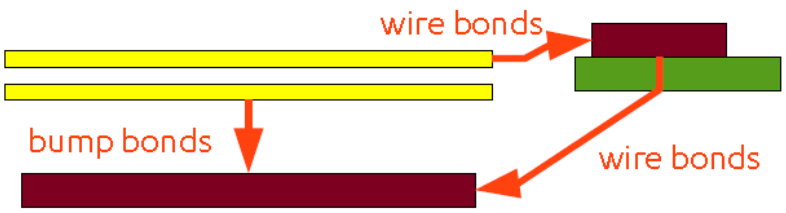
Hit correlation in different chips

Cms Binary Chip (CBC)
strip readout
+ correlation



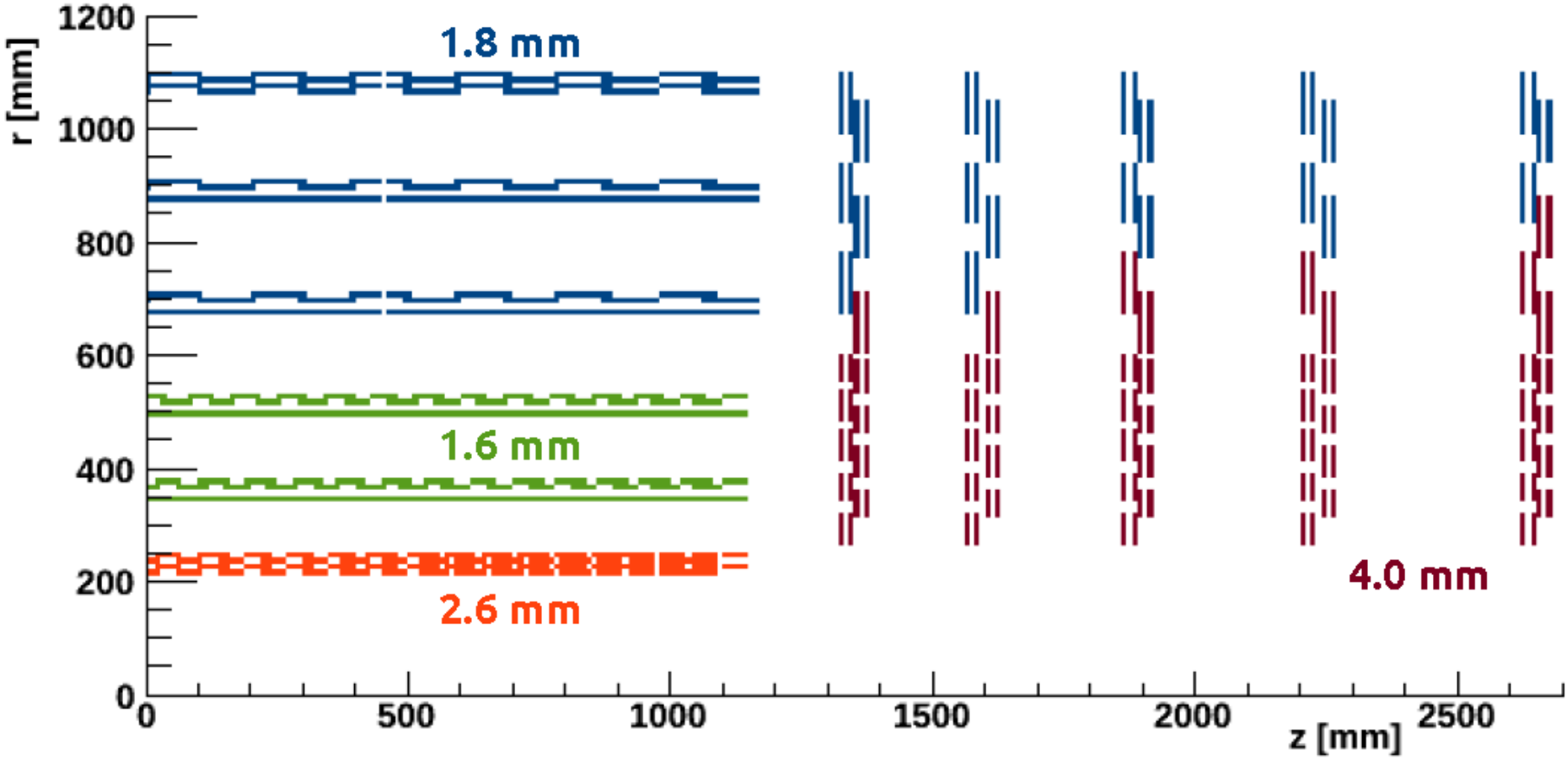


Readout only

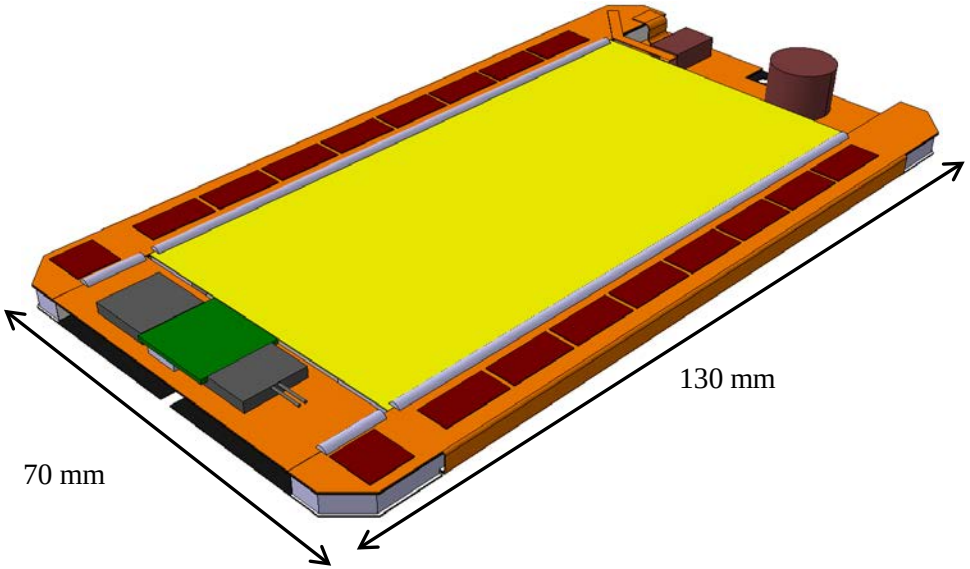


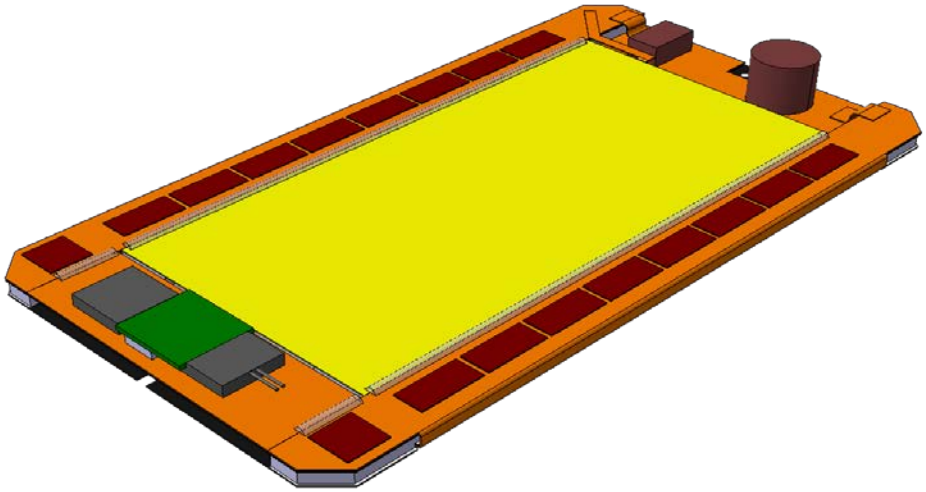
MacroPixel ASIC (MPA):
pixel readout
+ correlation

Sensor spacing



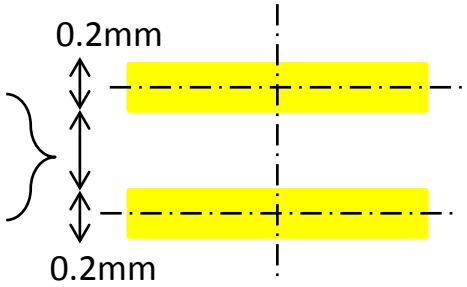
PS module variants

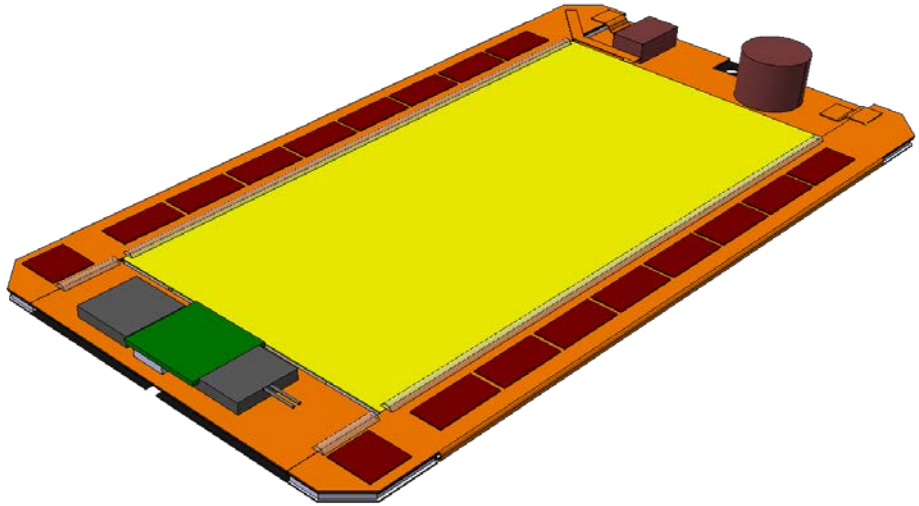




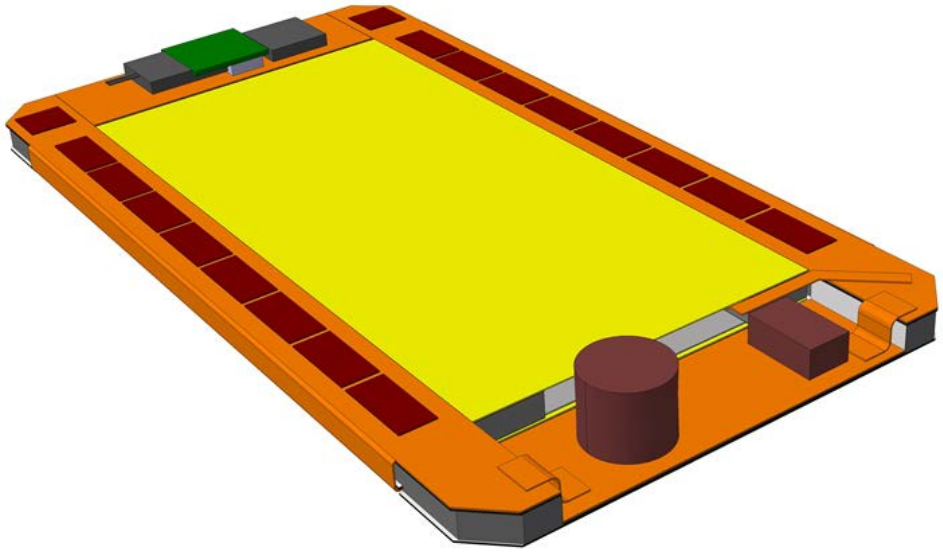
3 Different heights :

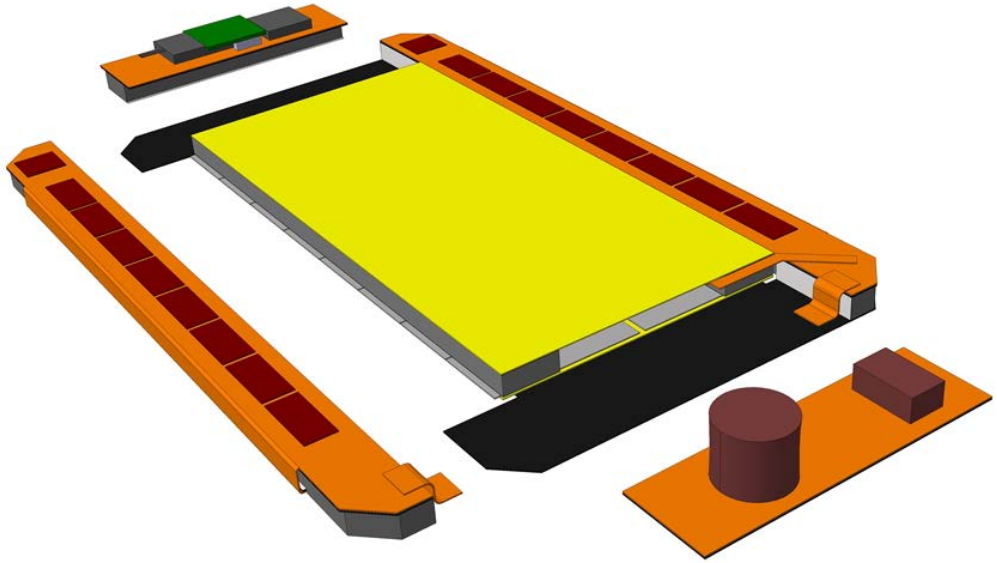
- 4.0mm
- 2.6mm
- 1.6mm



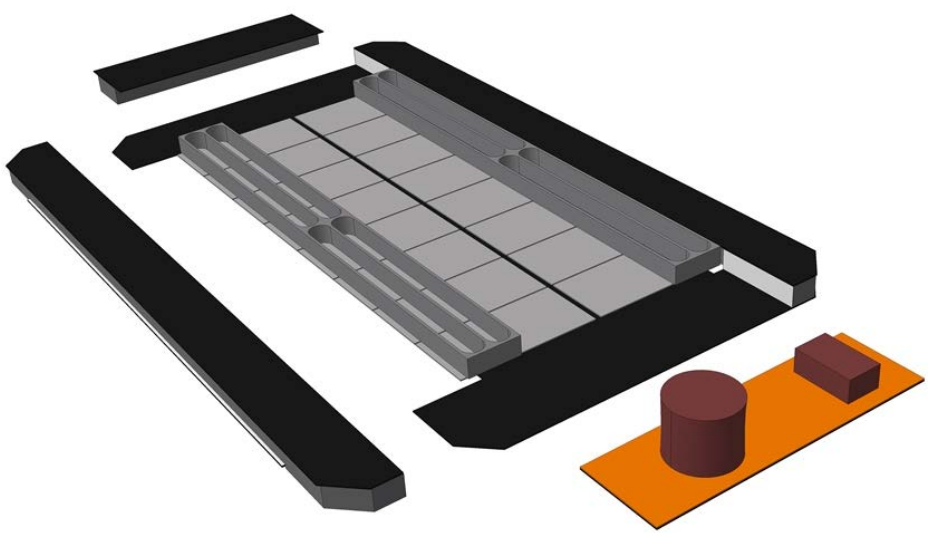


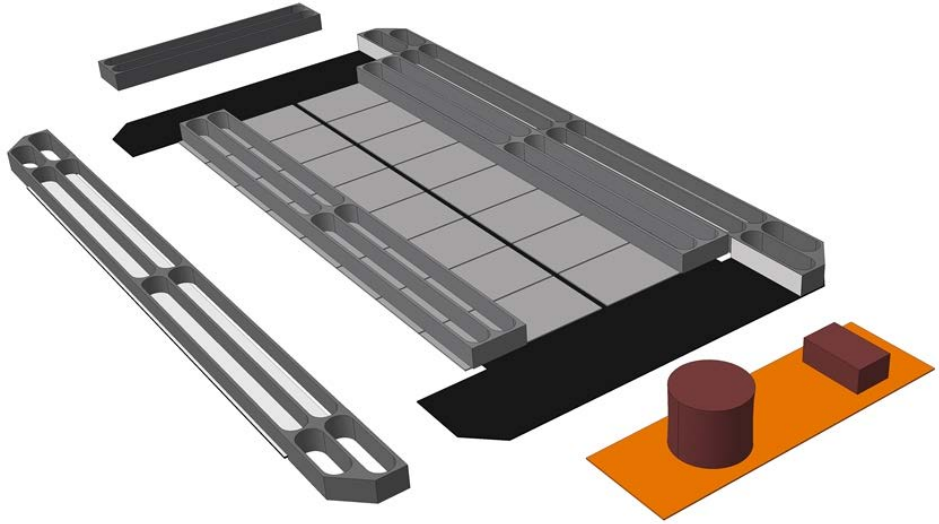
PS module sub-assemblies

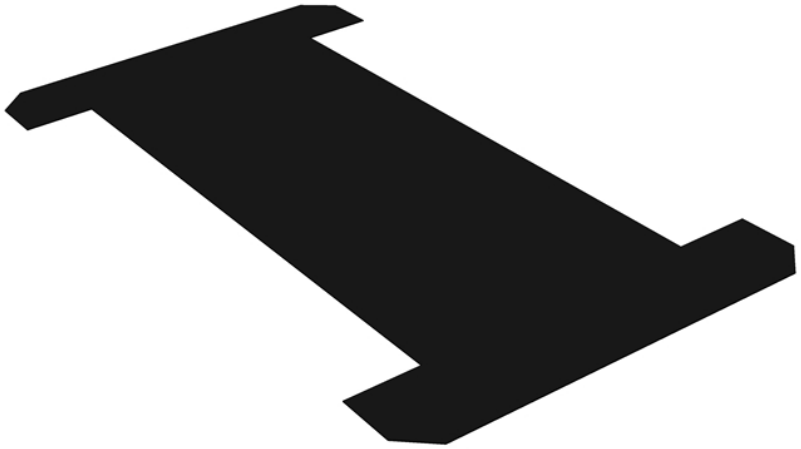




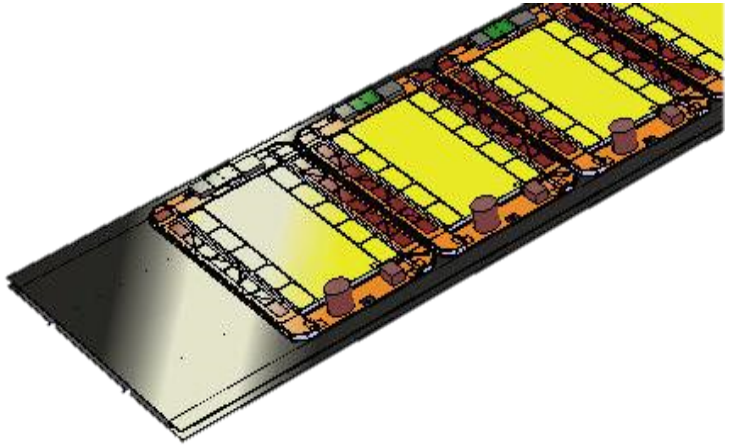
PS module base-plate and spacers

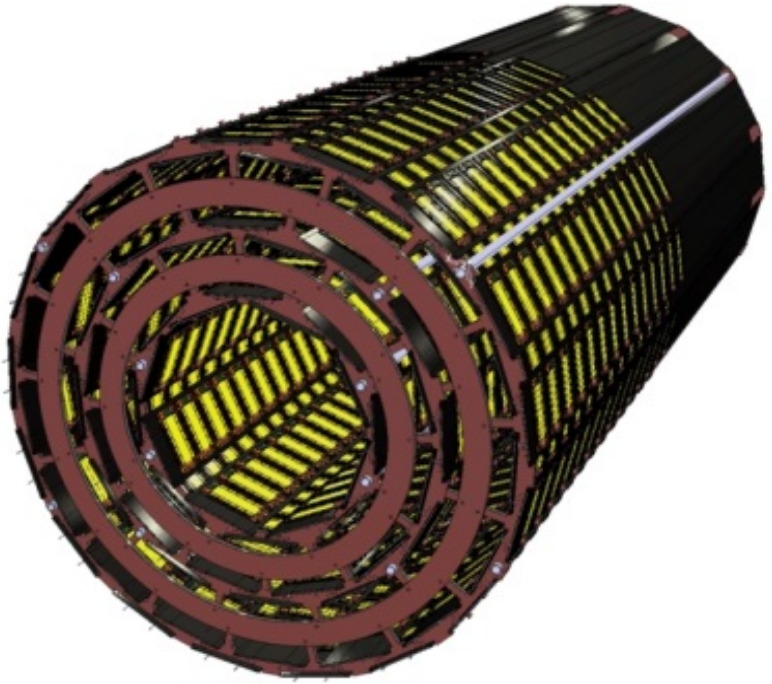




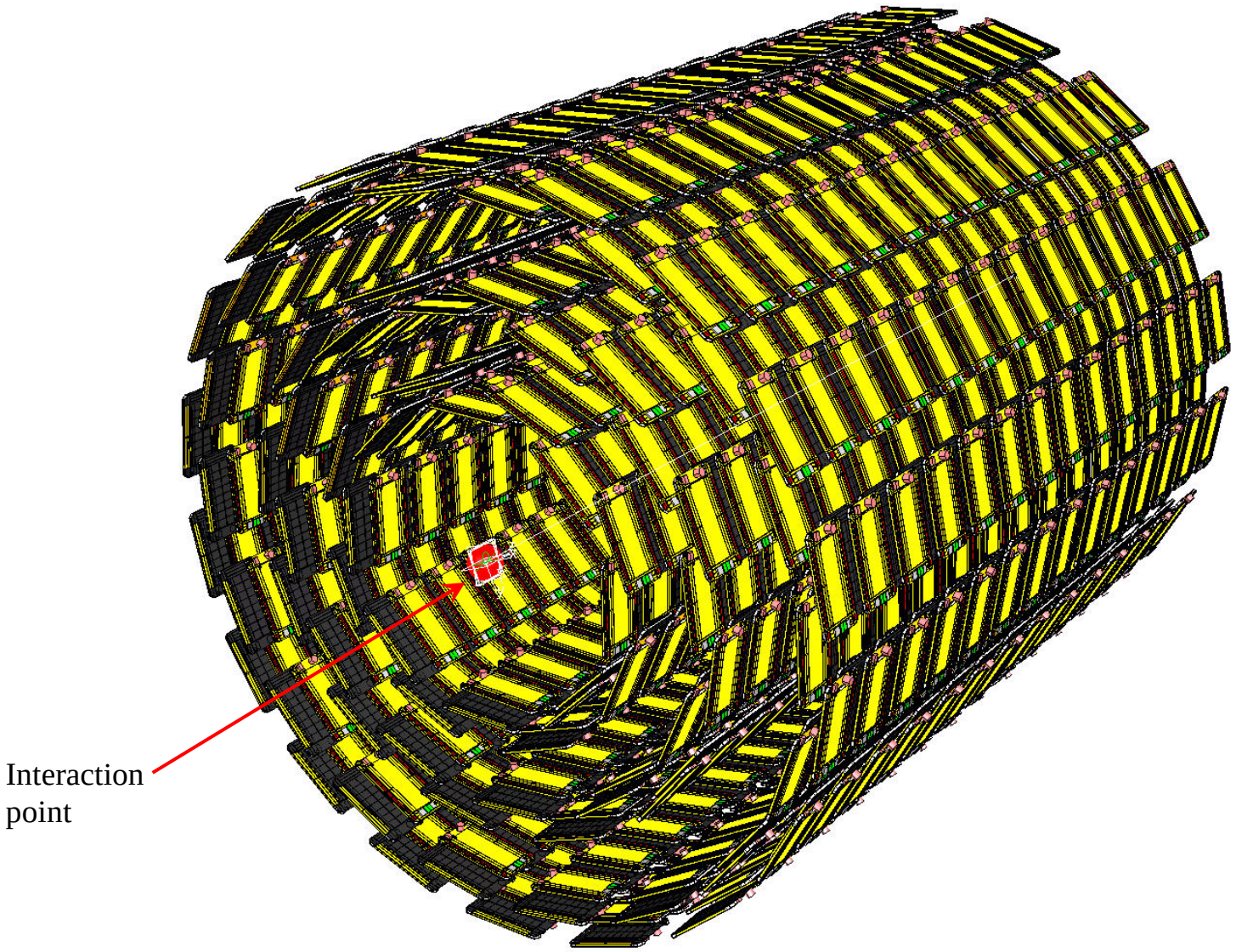


Flat Barrel





Flat Barrel



Old Tilted geometry as in Forum 2013 in Oxford