CMS Tracker Module Design

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Humboldt University Berlin

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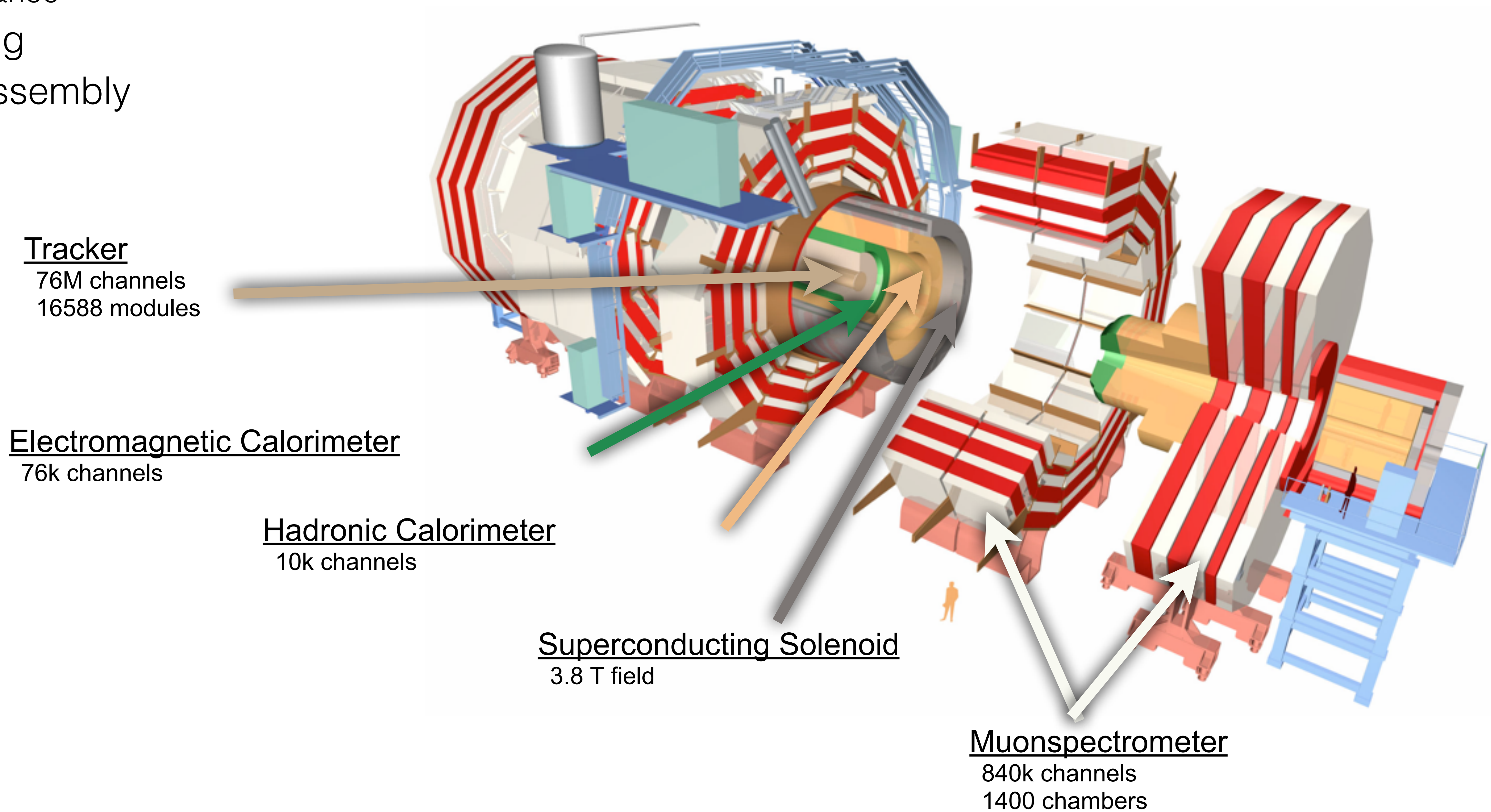
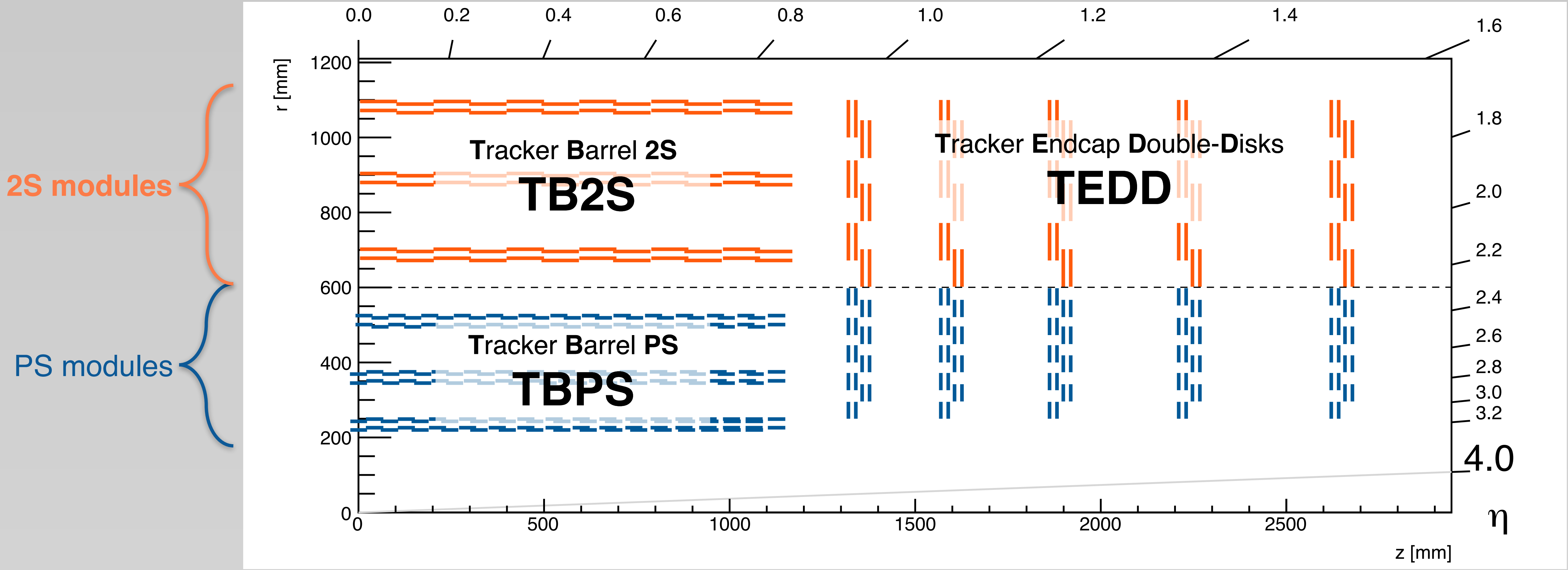
Outline

- introduction
- module designs
    - 2S module
    - PS module
    - performance
- prototyping
- module assembly



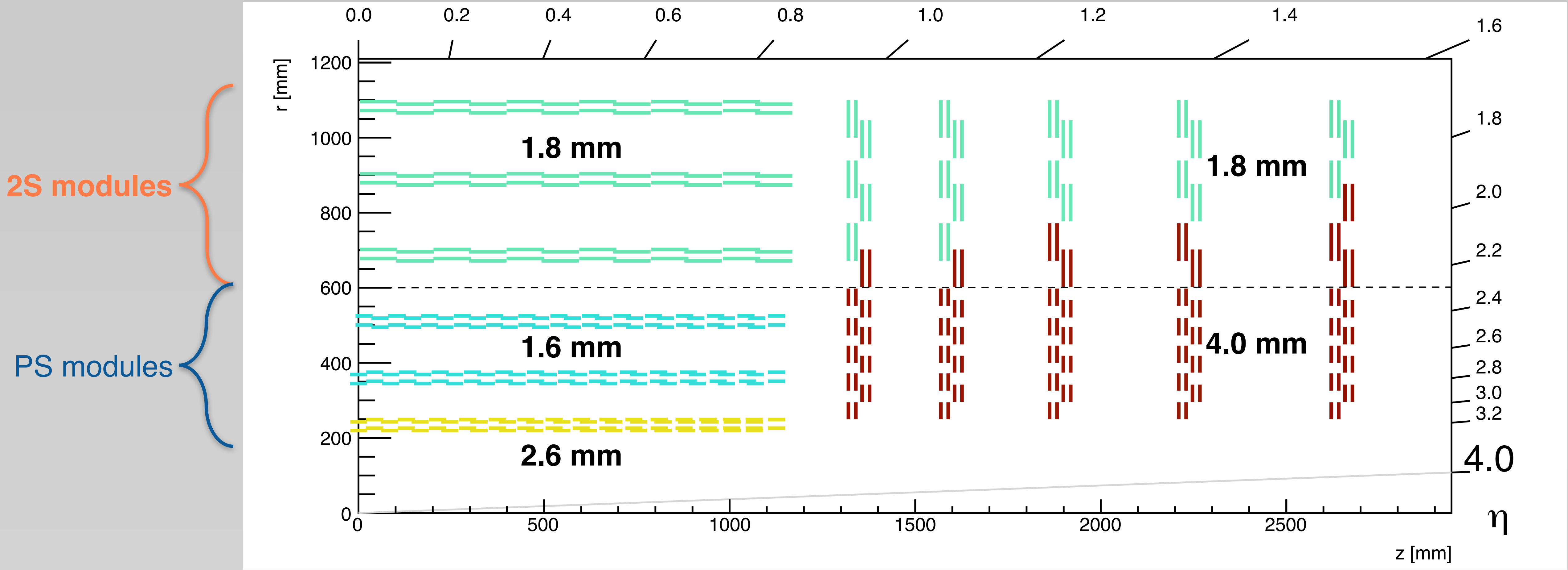
Introduction - Tracker Layout

- layout with 6 barrel layers and 5 end cap double-disks
  - pixelated modules at r < 60 cm - stack of pixel and strip sensor (**PS**)
  - stack of two strip sensors at r > 60 cm (**2S**)



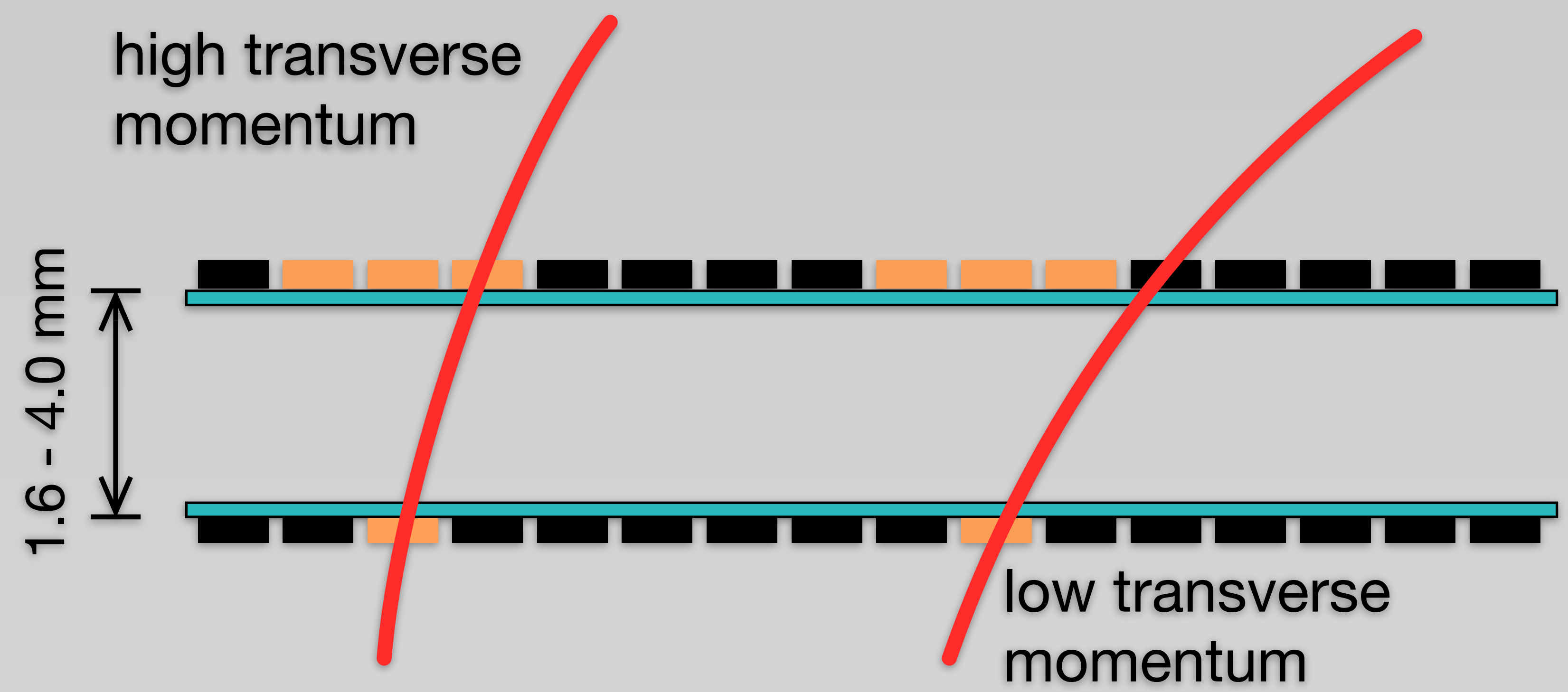
Introduction - Module Configuration

- layout with 6 barrel layers and 5 end cap double-disks
  - pixelated modules at r < 60 cm - stack of pixel and strip sensor (PS)
  - stack of two strip sensors at r > 60 cm (2S)
- PS modules
  - sensor spacings: 1.6 mm, 2.6 mm and 4 mm
- 2S modules
  - sensor spacings: 1.8 mm and 4 mm



Introduction - Module Concept

- modules will have on-board pT discrimination
  - signals from two closely spaced sensors are correlated
  - exploit strong magnetic field for local pT measurement
  - local rejection of low-pT tracks to minimize data volume
- detector modules provide Level-1 and readout data at the same time
  - the whole tracker sends trigger data („stubs“) at each bunch crossing (40 MHz)
  - readout data at 100 kHz
- „stubs“ are used to form Level-1 tracks
- cooling via evaporative CO2
  - sensors at ~ -20 °C
- integrated at module level:
  - low power giga-bit transceiver (LP-GBT) as data link
  - powering via DC-DC conversion
- two different module types
  - different sensor spacings are treated as ‚variants‘
  - requires optimization of only two designs



Introduction - Module Concept

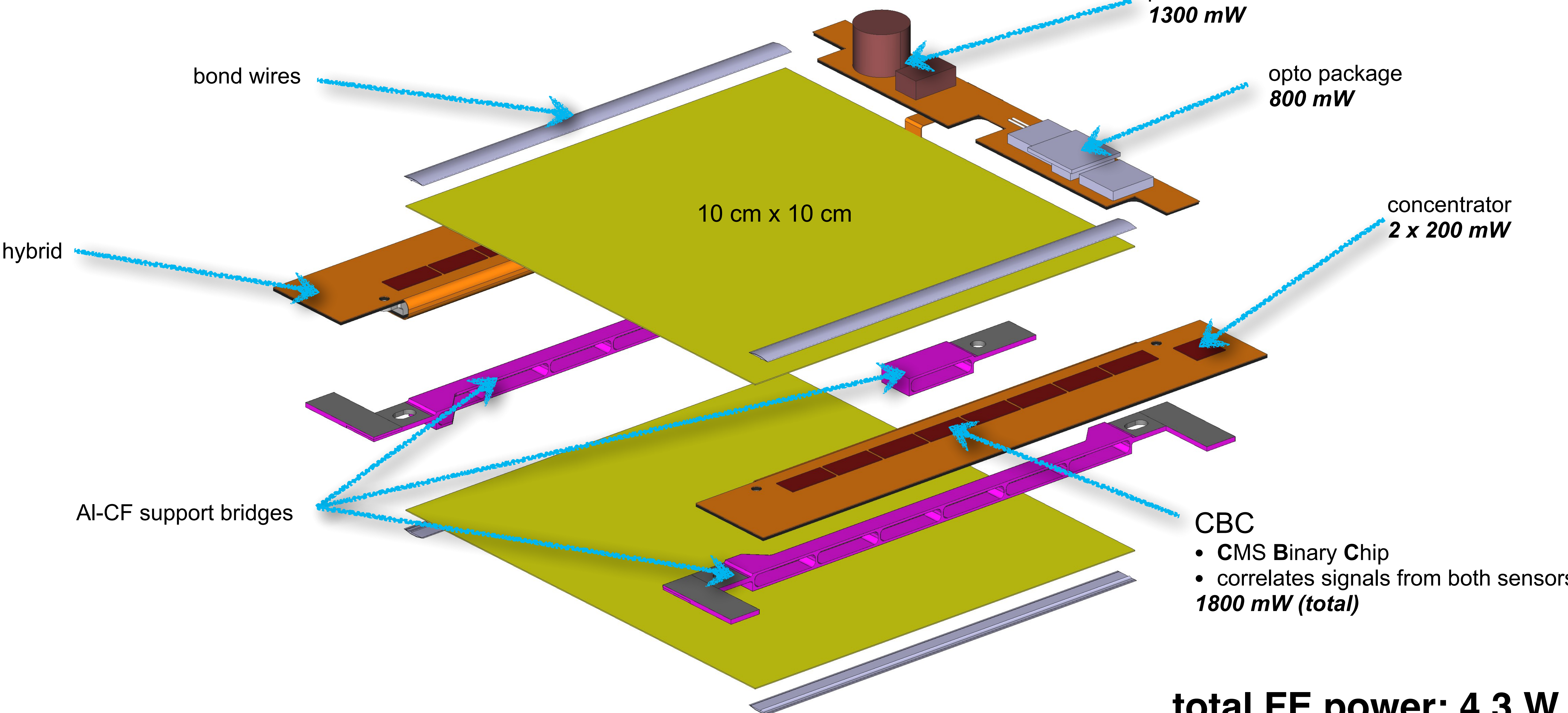
- modules will have on-board pT discrimination
  - signals from two closely spaced sensors are correlated
  - exploit strong magnetic field for local pT measurement
  - local rejection o… volume
- detector modul… data at the sam…
  - the whole track… bunch crossing…
  - readout data at…
- „stubs“ are use…

- cooling via evaporative CO_2
  - sensors at ~ -20 °C
- integrated at module level:
  - low power giga-bit transceiver (LP-GBT) as data link
  - …ated as ‚variants‘
  - … designs

	# of modules
1.8 mm 2S Module	7440
4.0 mm 2S Module	984
1.6 mm PS Module	3156
2.6 mm PS Module	1008
4.0 mm PS Module	2840
	15428

Design of the 2S Module

4.0 mm variant is shown

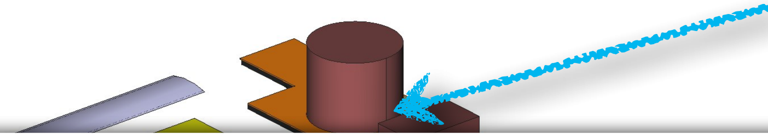


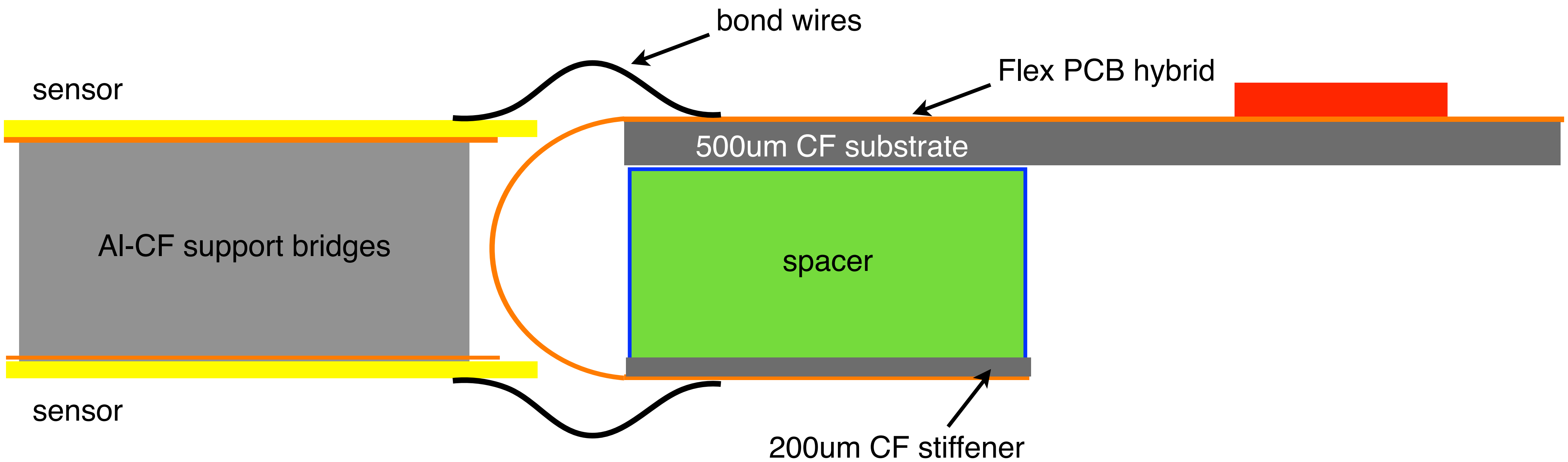
total FE power: 4.3 W

- 2S module comes in two variants: 1.8 mm and 4.0 mm
- different sensor spacings are treated as variants of one design
- only minimum amount of changes needed
  - Al-CF bridges and hybrid spacers

Design of the 2S Module

4.0 mm variant is shown

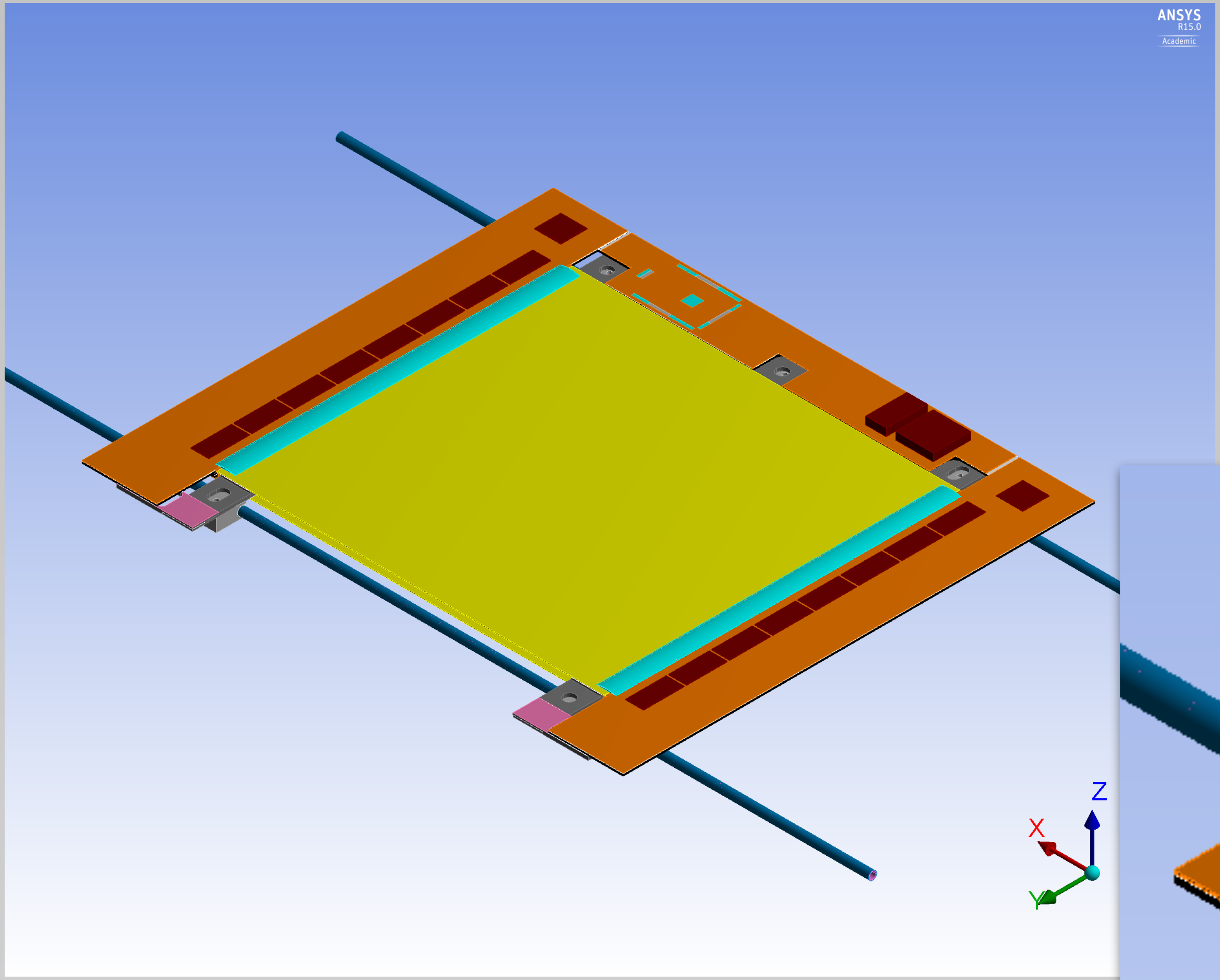


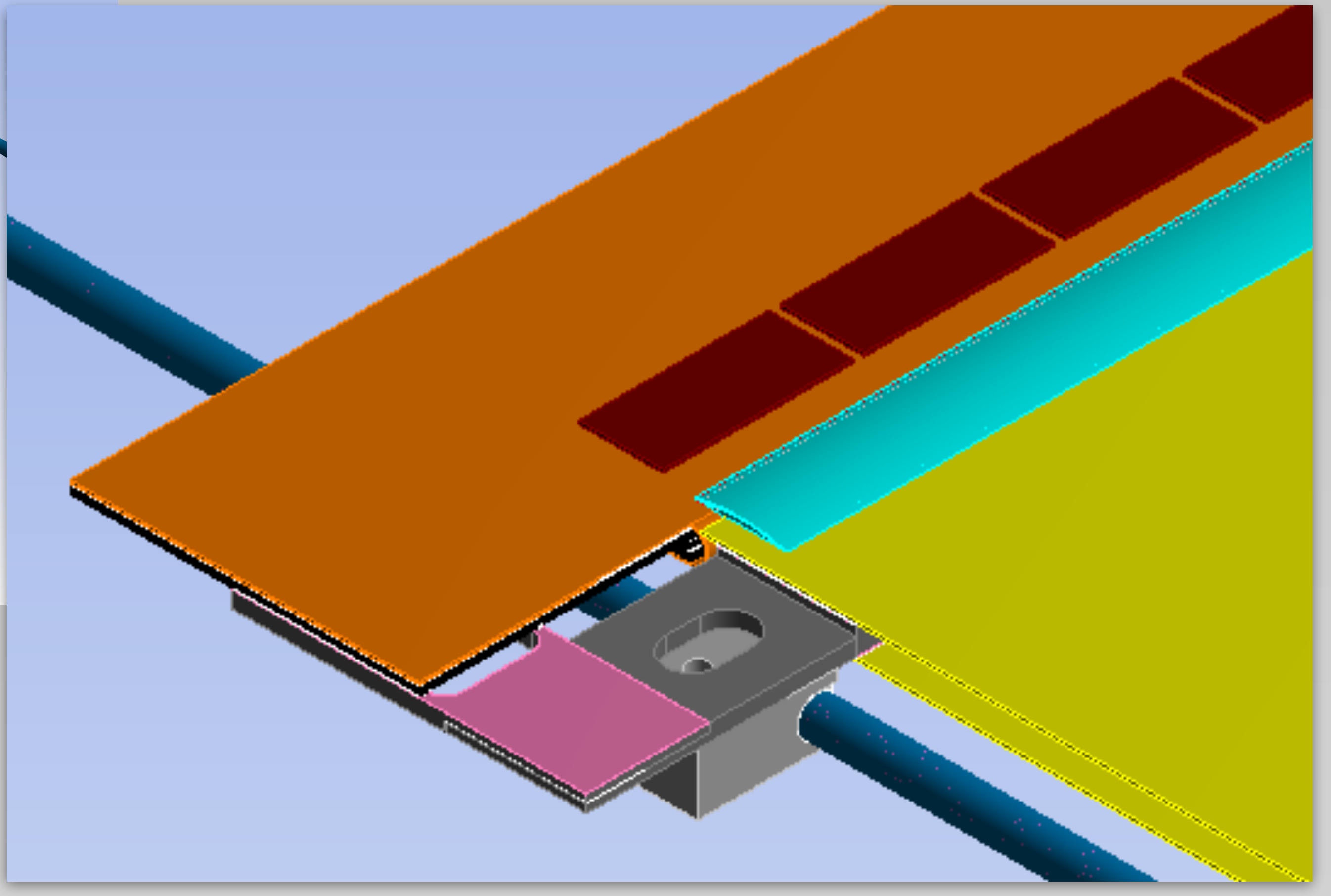


- flexible hybrid is glued on CFRP stiffeners and folded around a spacer
- bond pads on hybrid are on the same level as the bond pads on the sensor
- requires different spacer thicknesses and hybrid variants

- 2S module comes in two variants: 1.8 mm and 4.0 mm
- different sensor spacings are treated as variants of one design
- only minimum amount of changes needed
  - Al-CF bridges and hybrid spacers

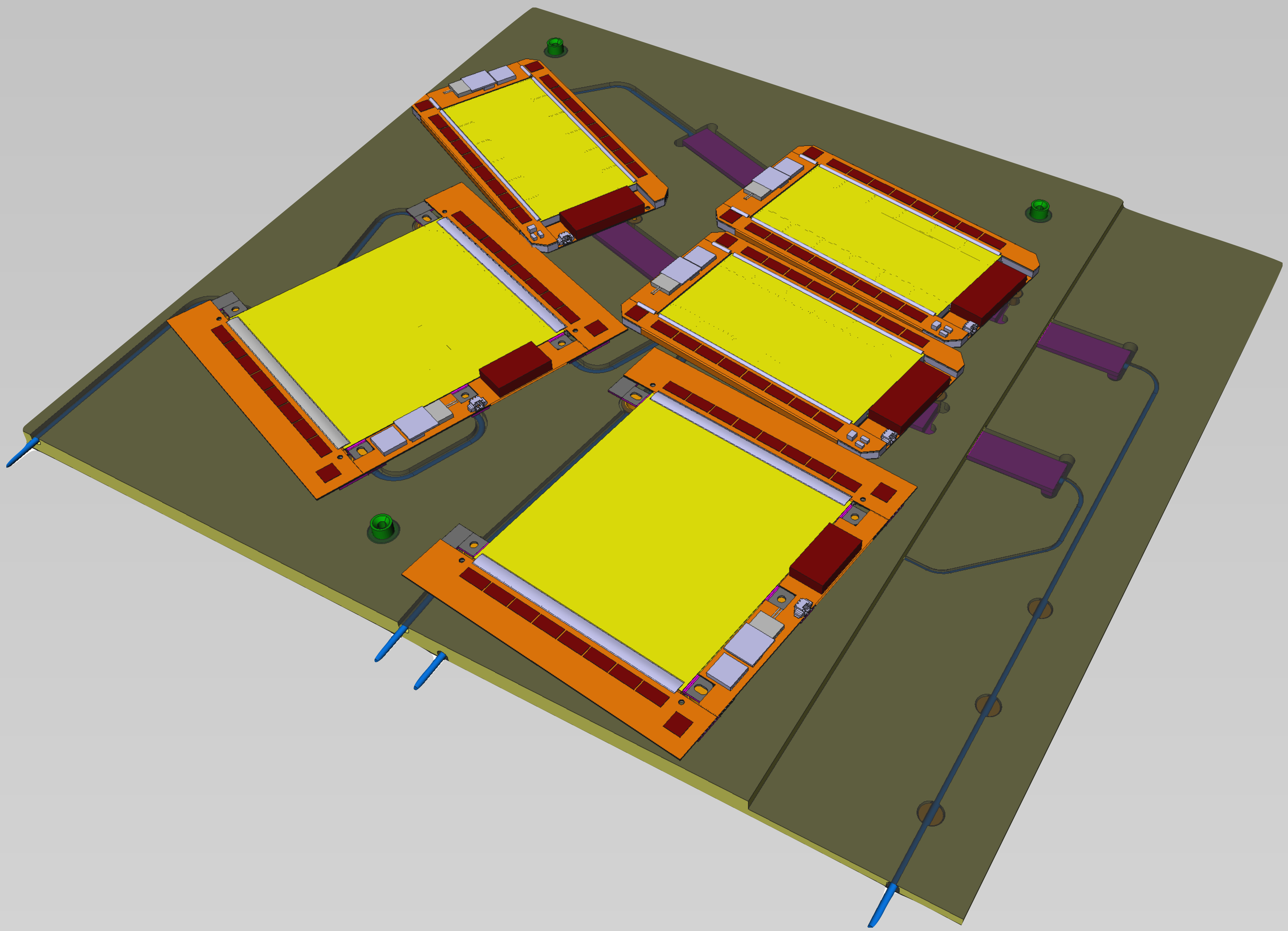
2S Module on Support Structure - Barrel





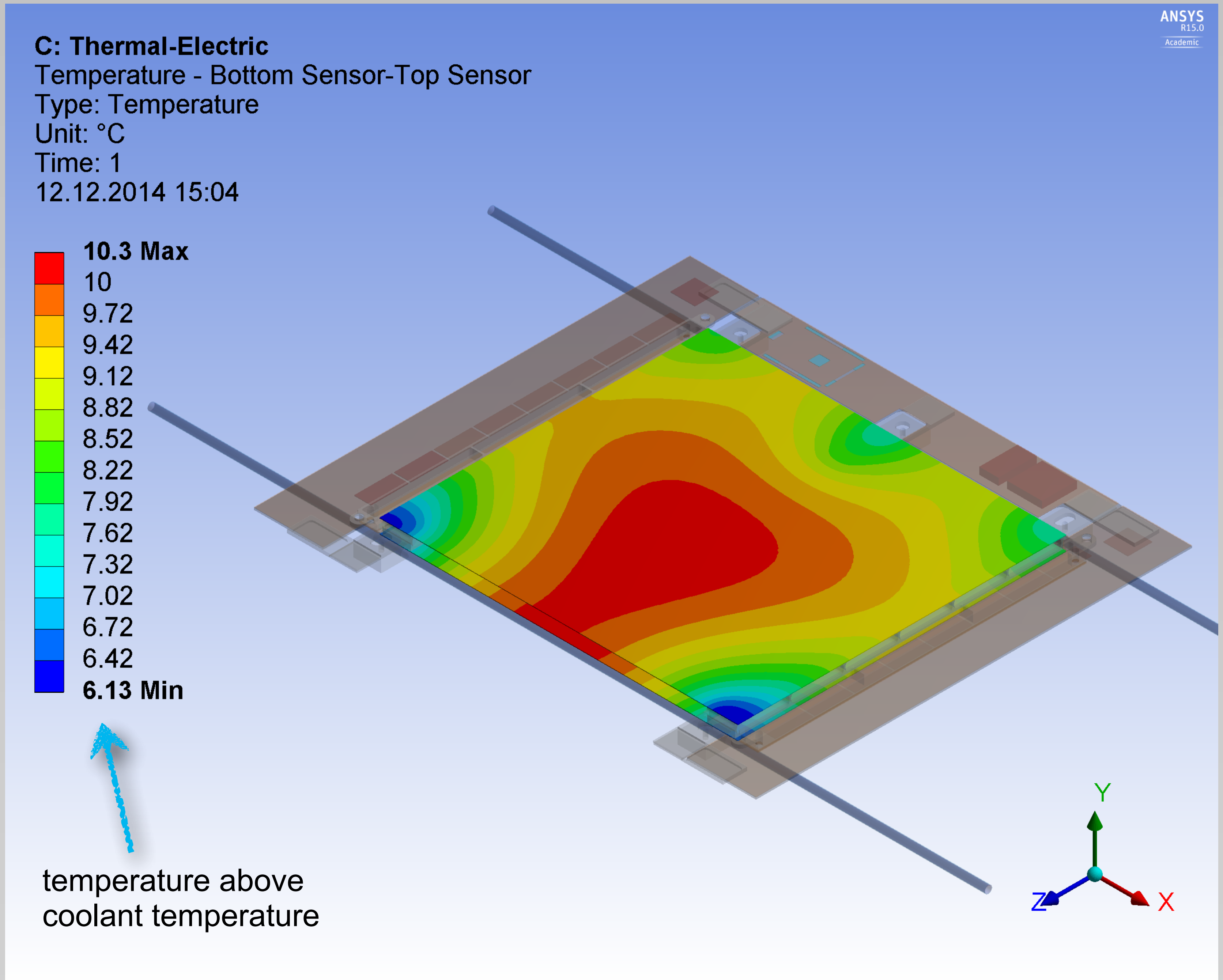
- five cooling contacts per module

2S Module on Support Structure - End Cap



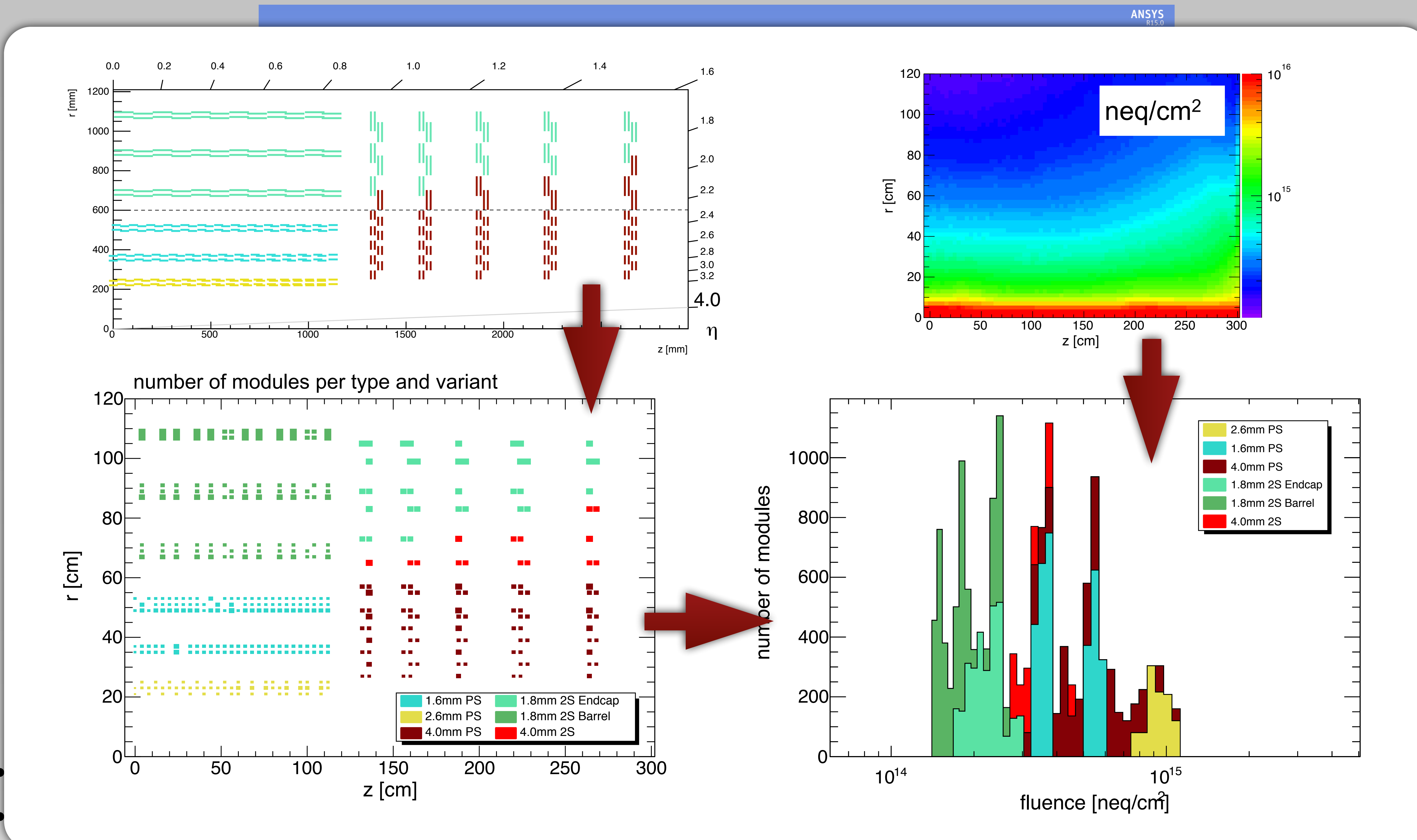
- five cooling contacts per module

Thermal FEA of 2S Module



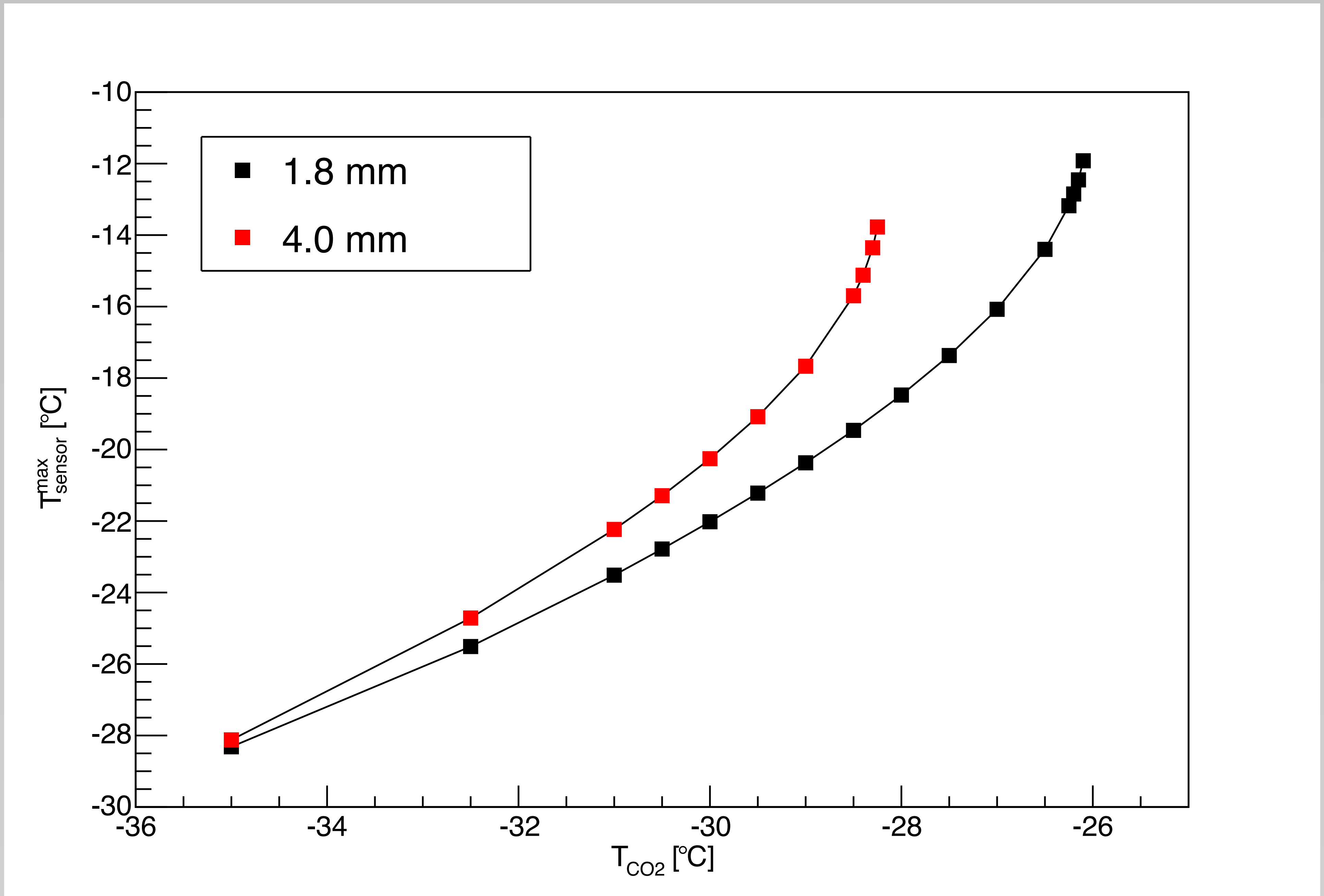
- results for 4.0 mm variant are shown
- sensor power dissipation: 572 mW each
  - calculated from expected worst-case fluency for a module variant
- total power: 5.4 W

Thermal FEA of 2S Module



-
-
  - calculated from expected worst-case fluency for a module variant
- total power: 5.4 W

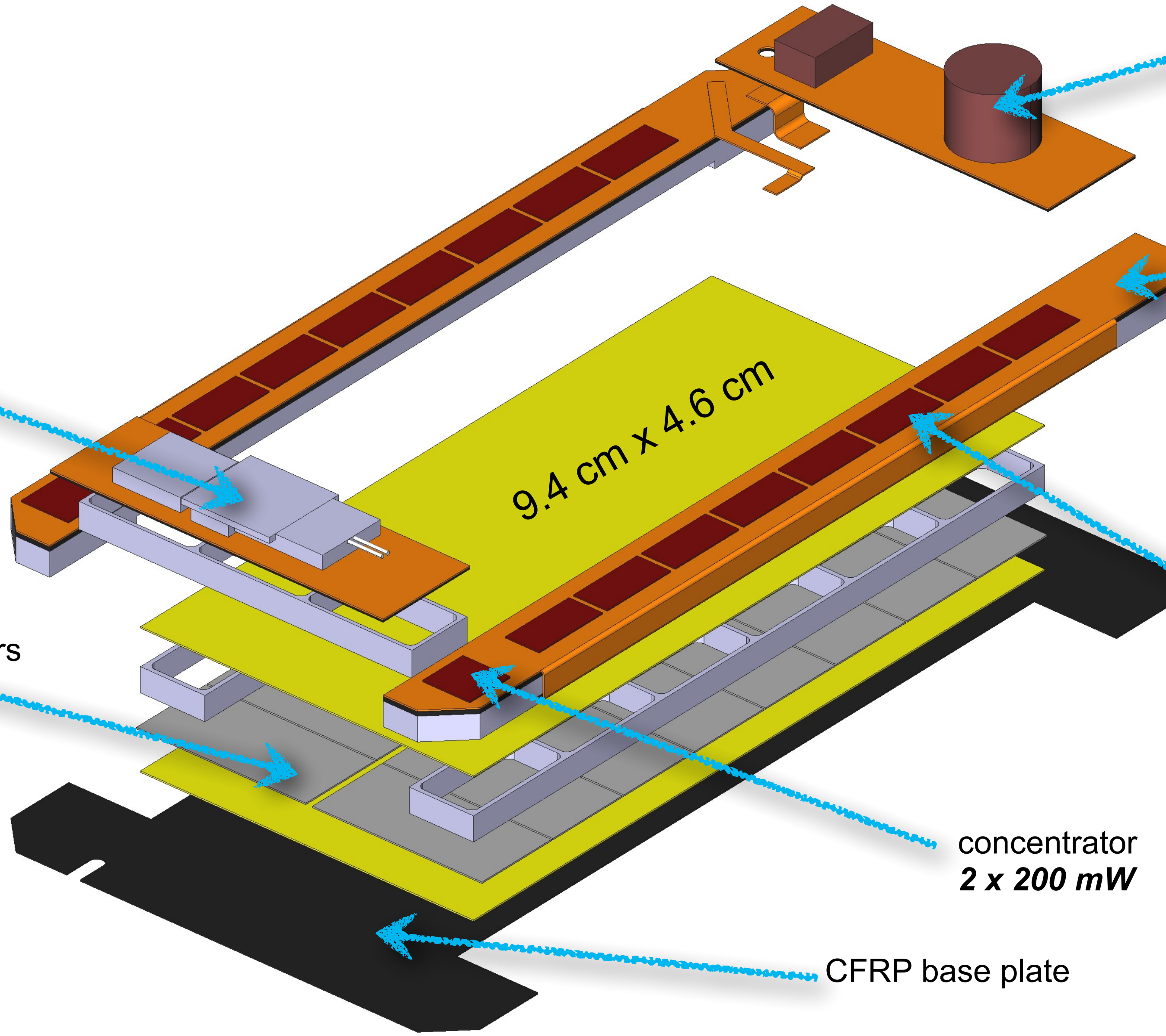
Thermal Runaway of 2S Module



- coolant temperature is varied and sensor power dissipation is dynamically calculated
- thermal runaway starts at > -29°C
    - worst case is the 4.0 mm variant - highest sensor power

Design of the PS Module

4.0 mm variant is shown



MPA

- **Macro Pixel Asic**
- pixel size: 1400 x 100 µm
- correlates signals from both sensors

3000 mW (total)

SSA

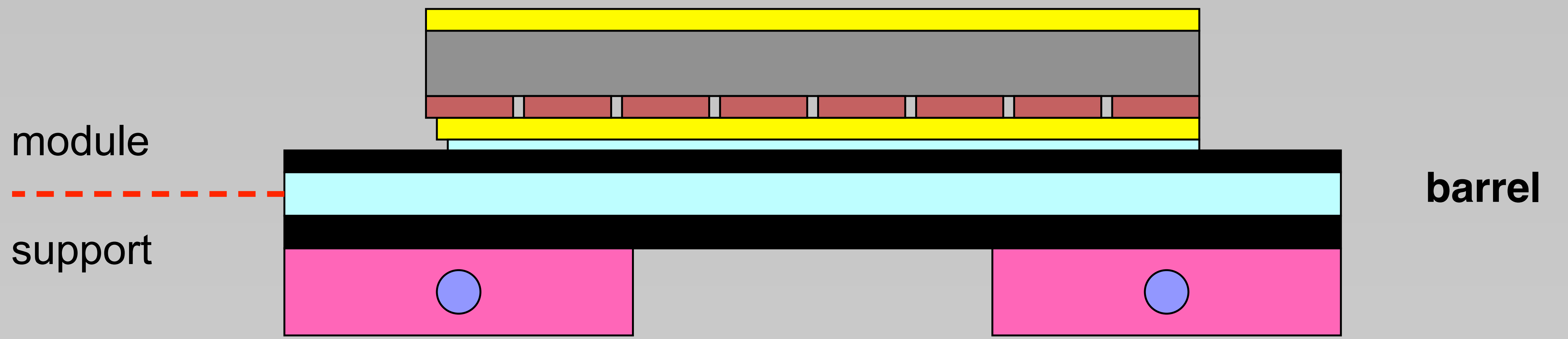
- **Strip Asic**
- handles signals from strip sensor
- transfers data to pixel chip

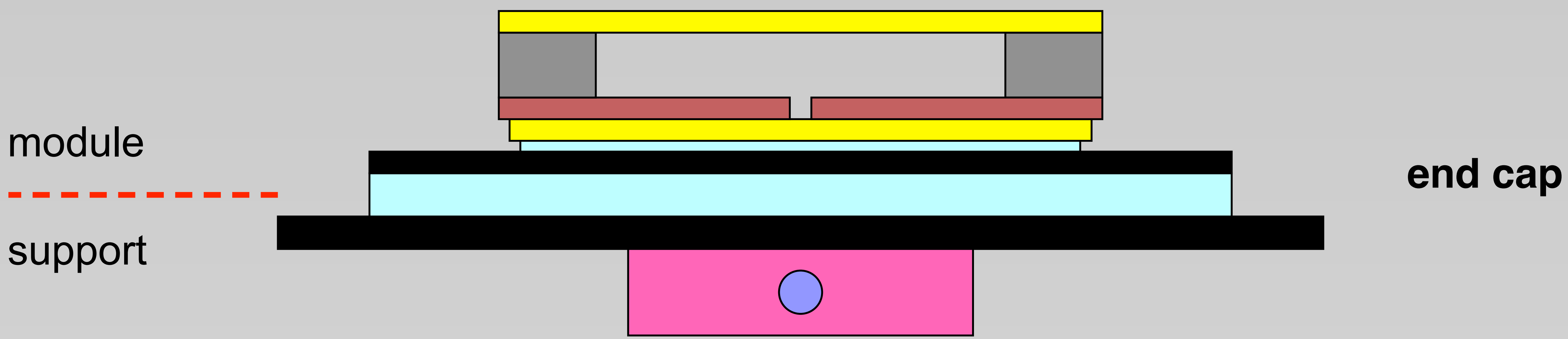
500 mW (total)

total FE power: 6.7 W

- PS module comes in two variants: 1.6 mm, 2.6 mm and 4.0 mm
- different sensor spacings are treated as variants of one design
- only minimum amount of changes needed
  - Al-CF bridges and hybrid spacers

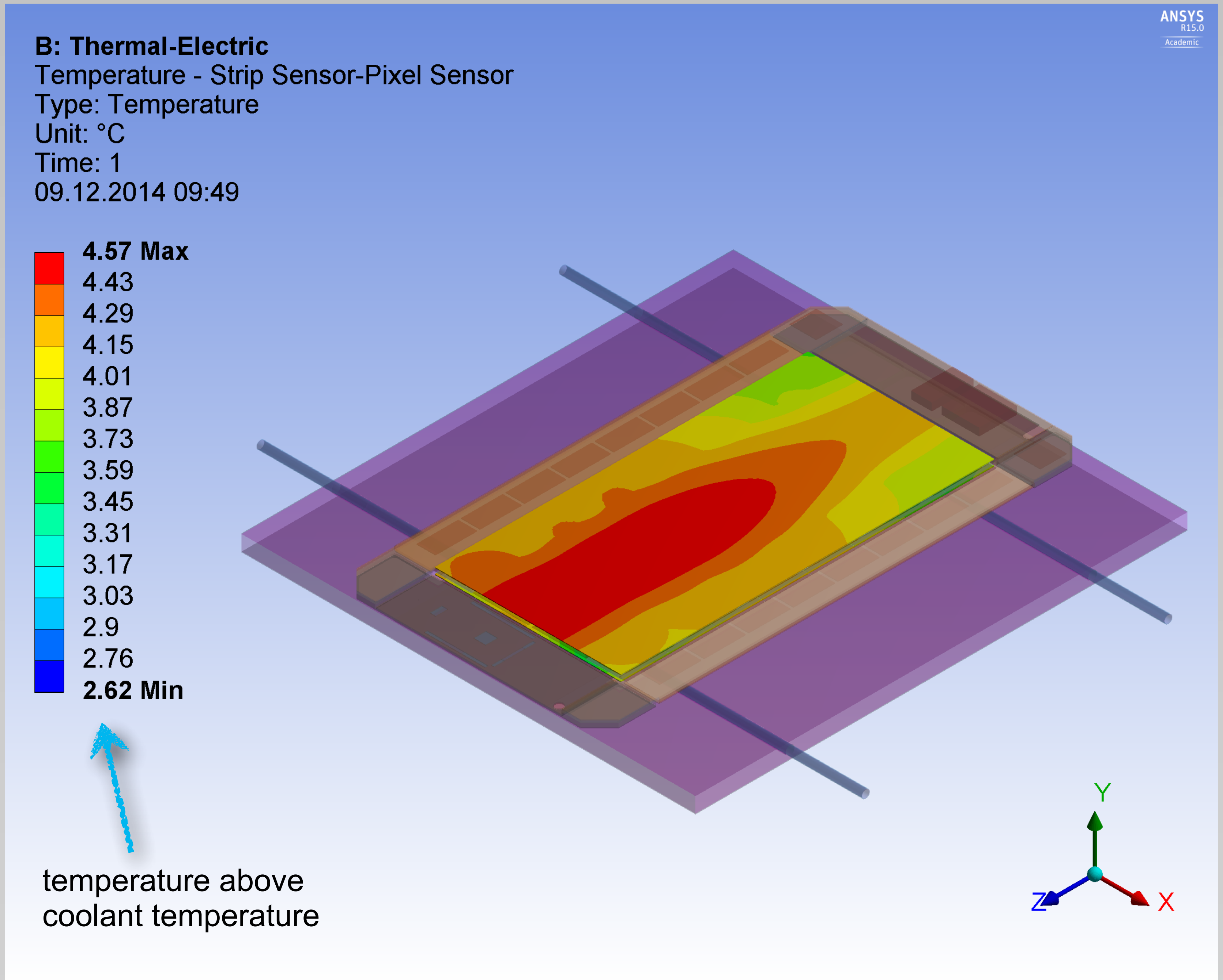
2S Module on Support Structure





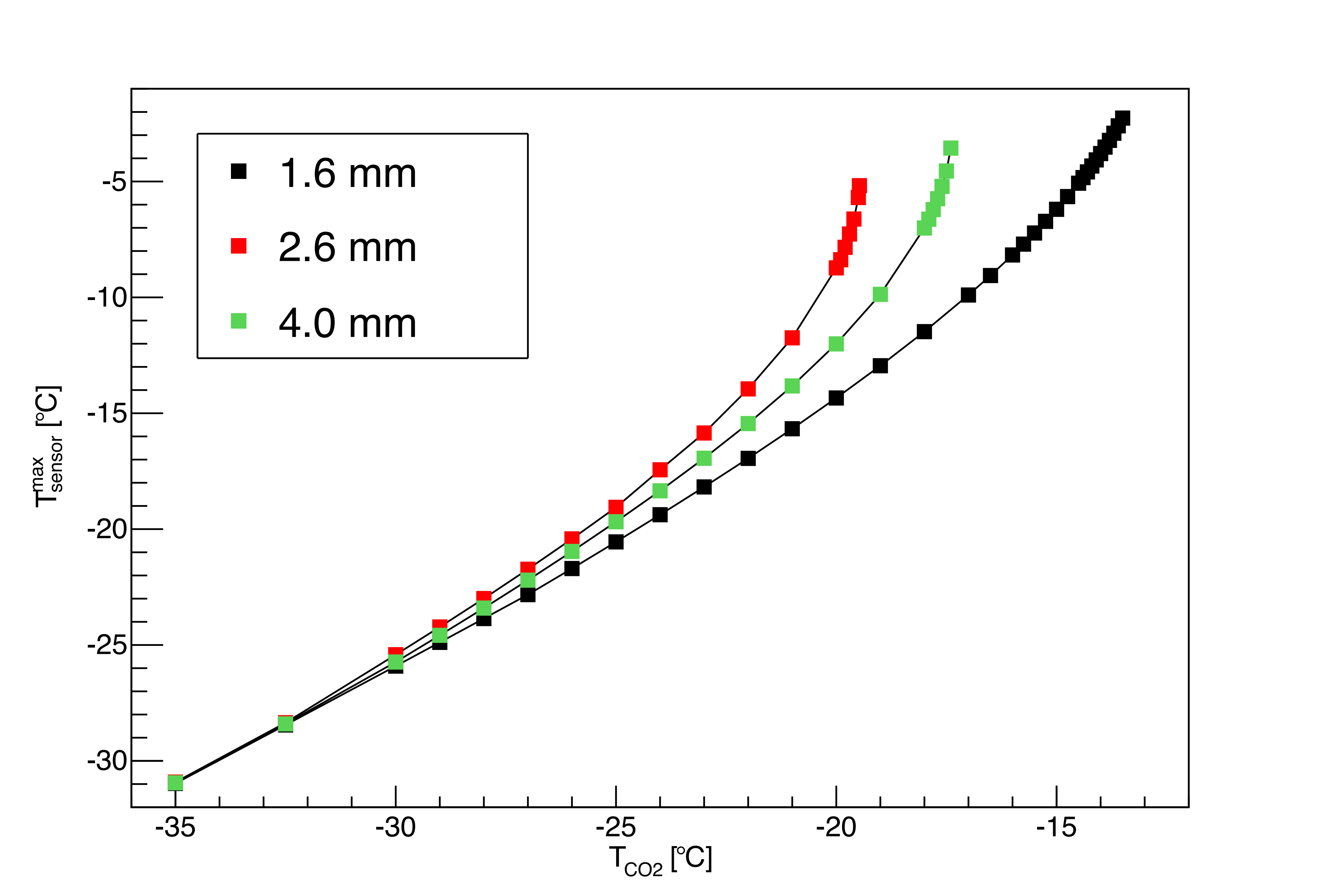
- module is built on top of a CFRP base plate
- base plate serves as a large-area thermal interface between module and support structure

Thermal FEA of PS Module



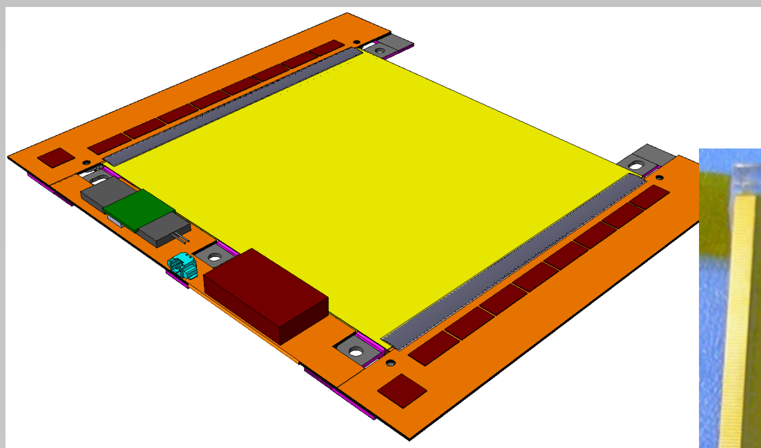
- results for the 1.6 mm variant are shown
- maximum sensor power dissipation: 363 mW each
    - calculated from expected worst-case fluency for a module variant
- total power: 7.4 W

Thermal Runaway of PS Module

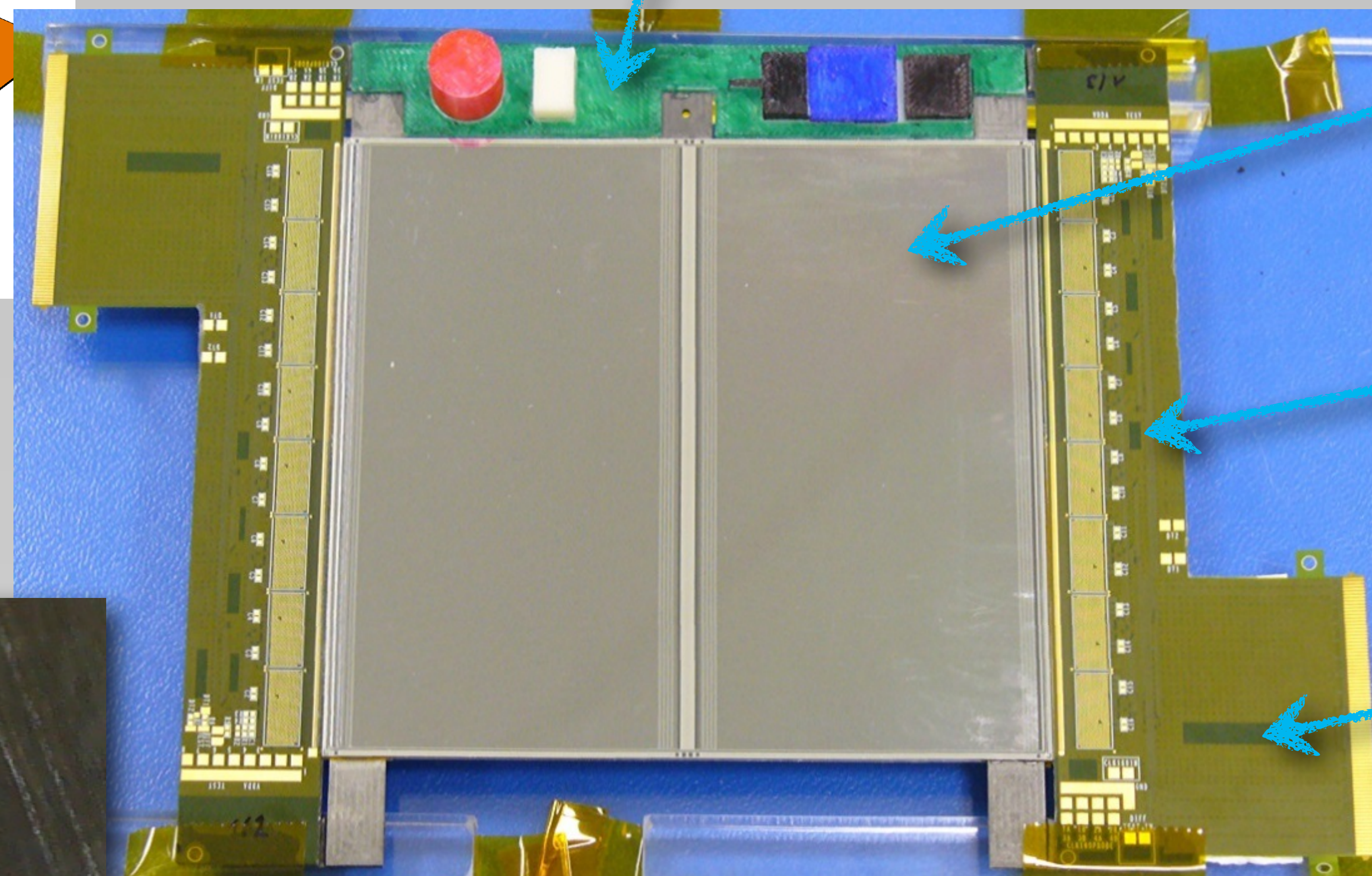


- coolant temperature is varied and sensor power dissipation is dynamically calculated
- thermal runaway starts at > -20°C
  - worst case is the 2.6 mm variant - highest sensor power

Prototyping - 2S Module



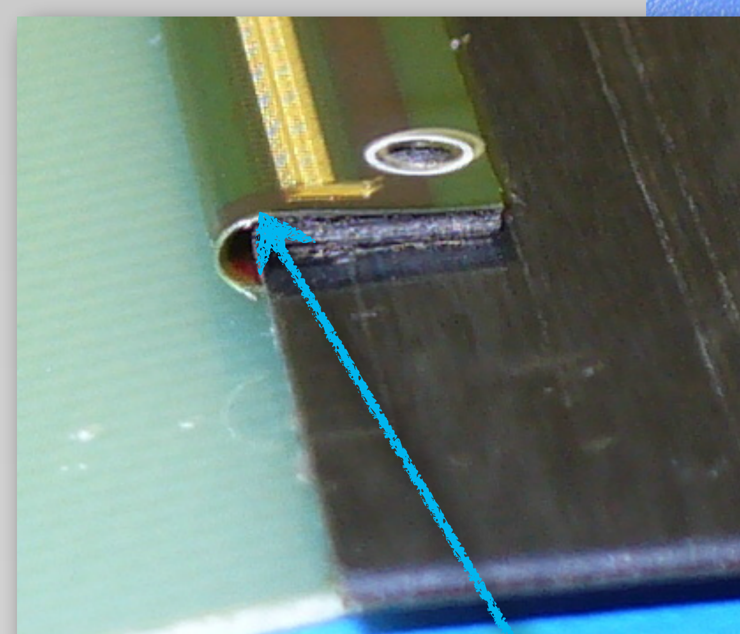
3D Printed Service Board



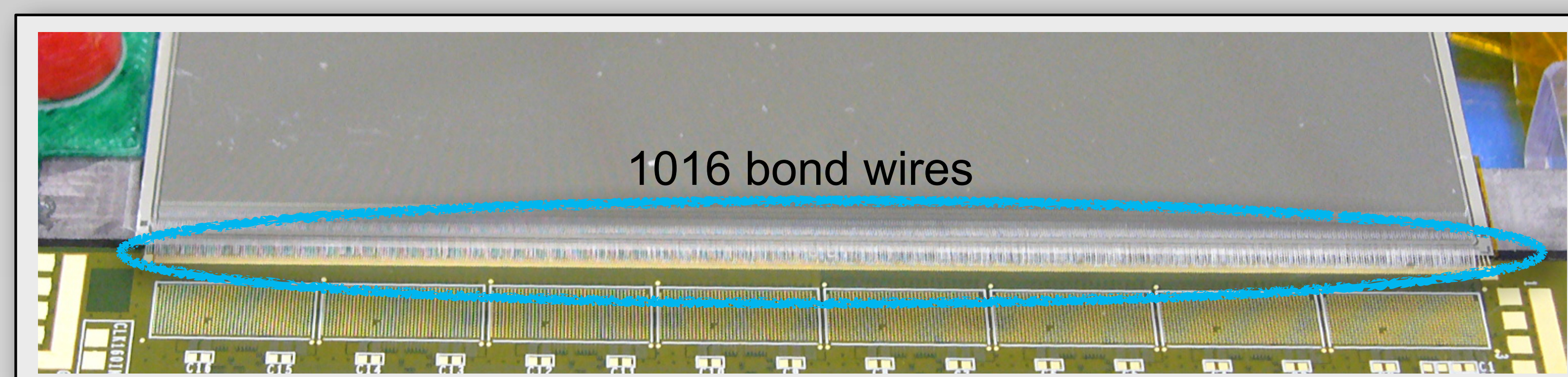
2S module
dummy sensor

eight CBC flex
prototype hybrid

flex tail for testing
and connectivity

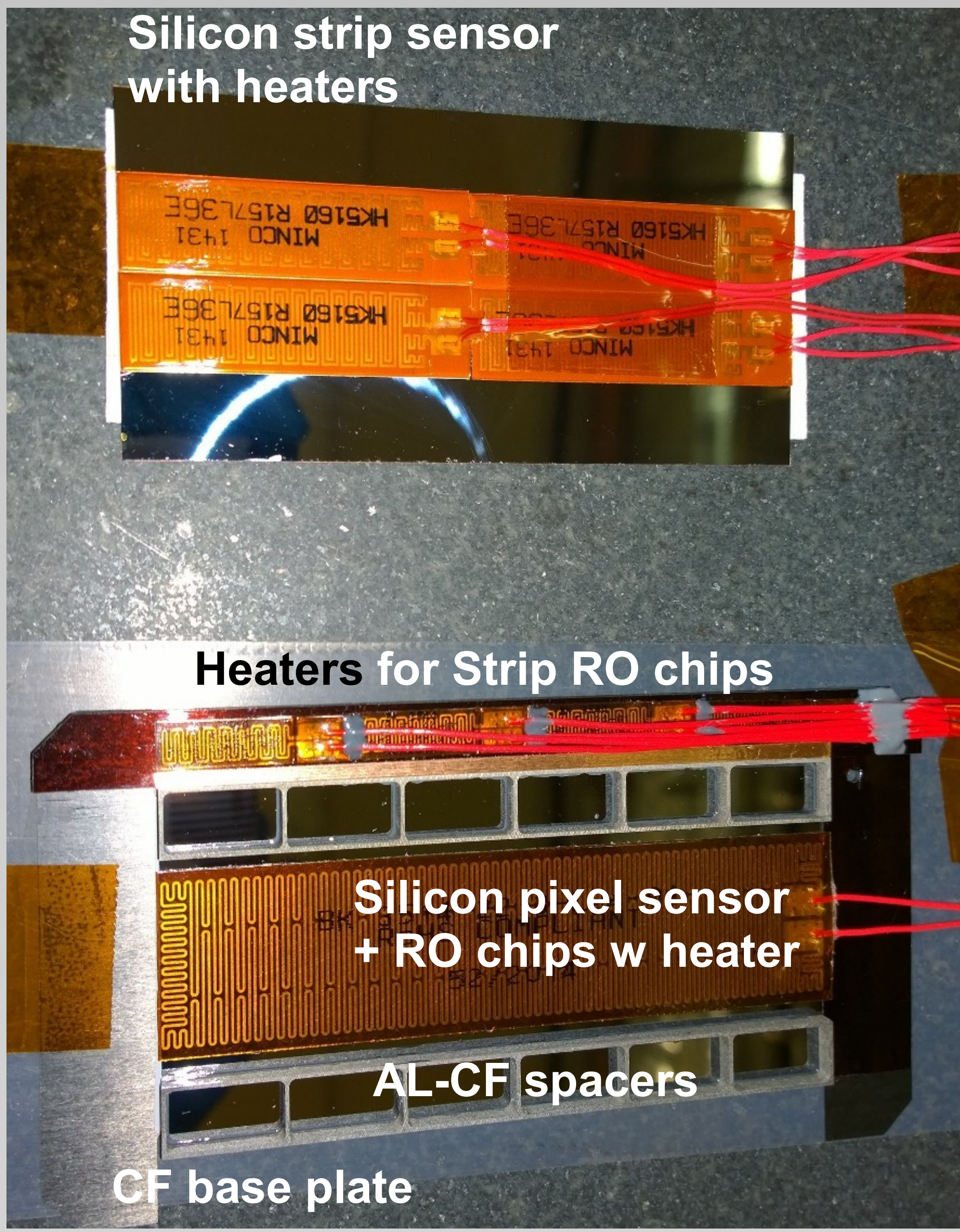


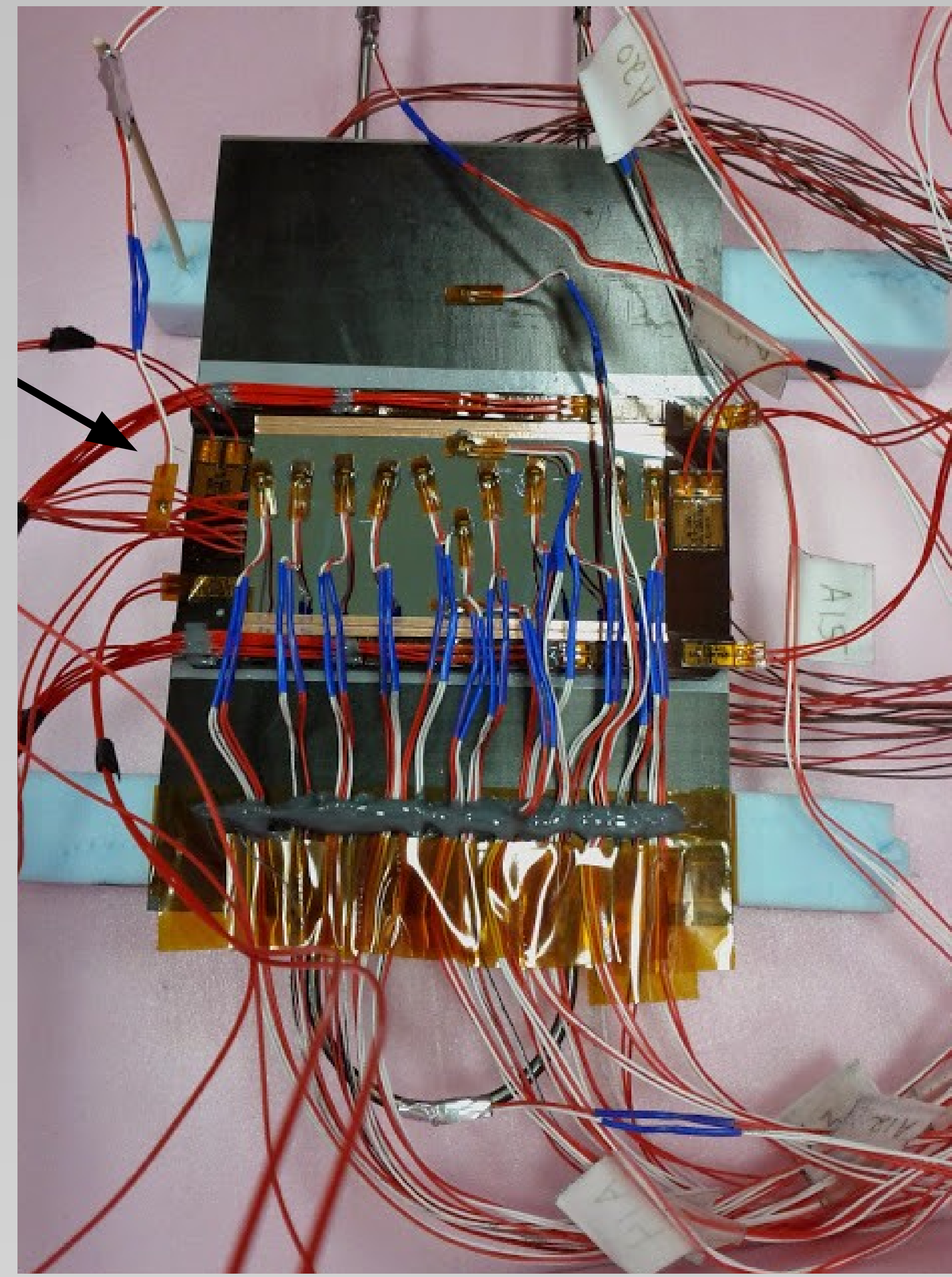
folded flex hybrid



Prototyping - PS Module

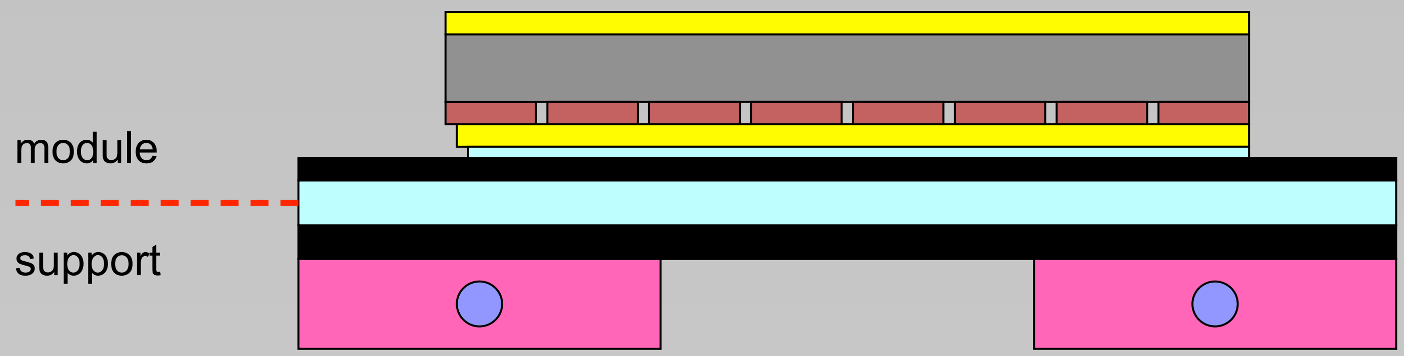
thermal mock-up module built at FNAL

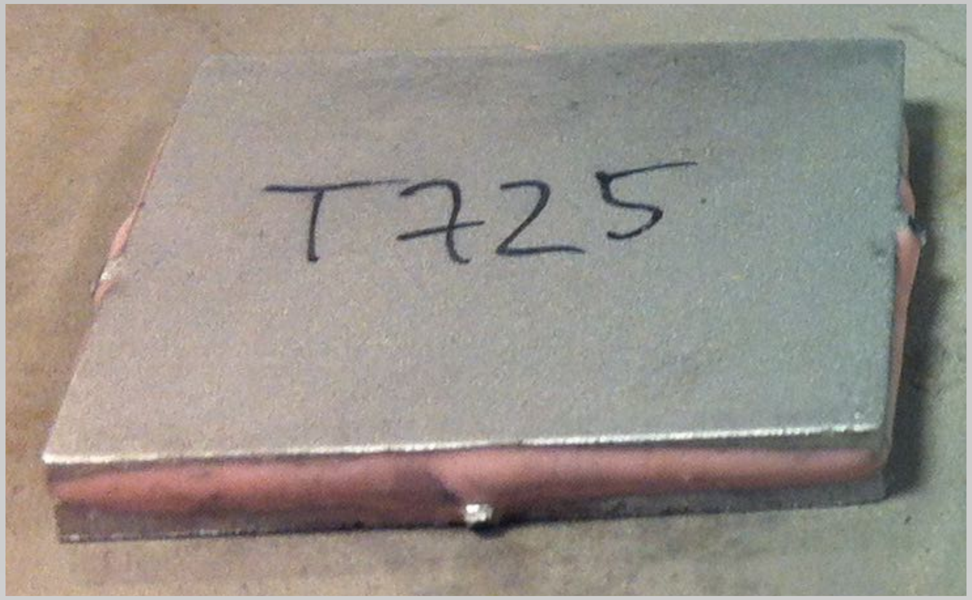


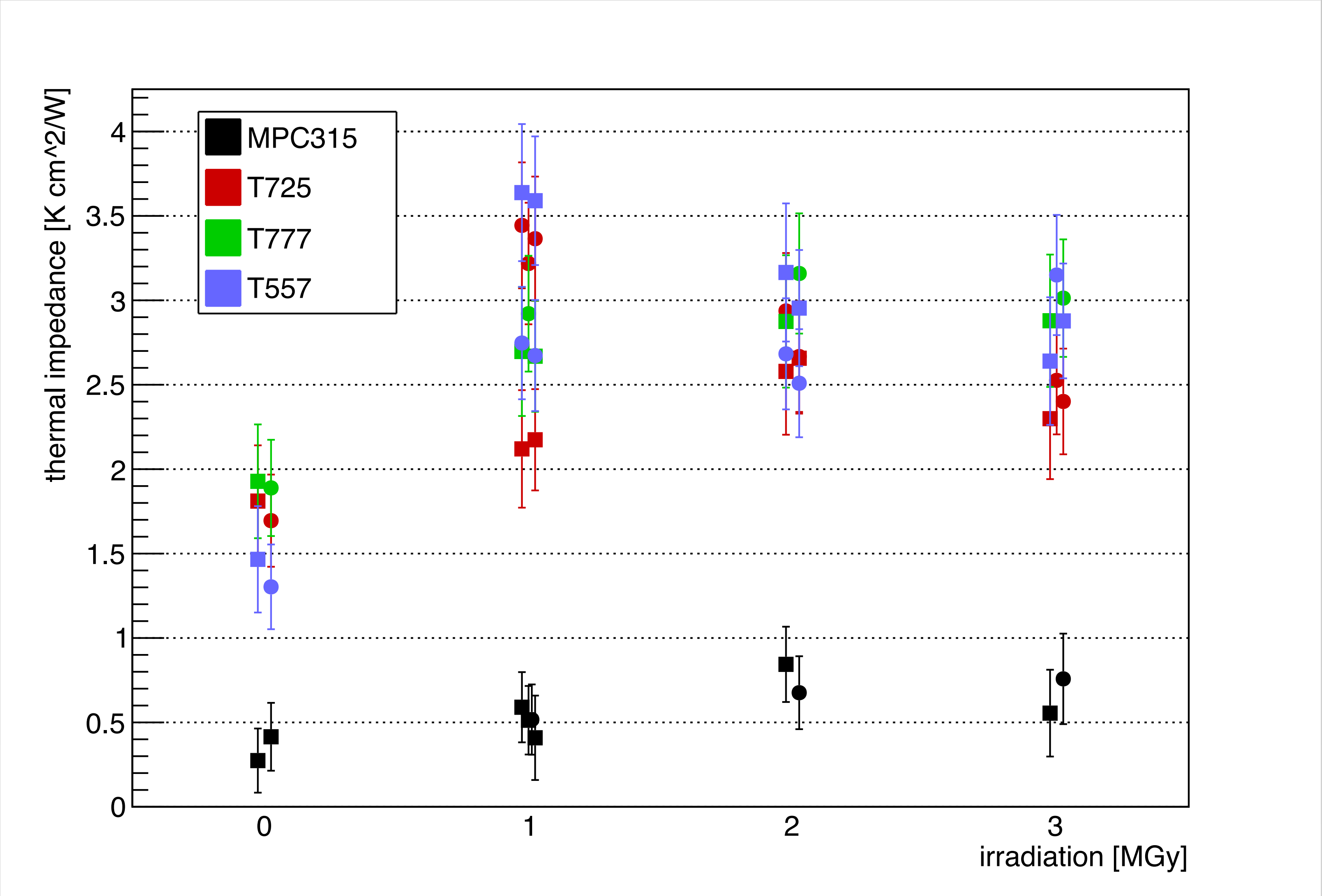


Generic R & D

- material could be used as thermal interface between PS module and support structure
- high thermal conductivity
- reworkable connection via heating

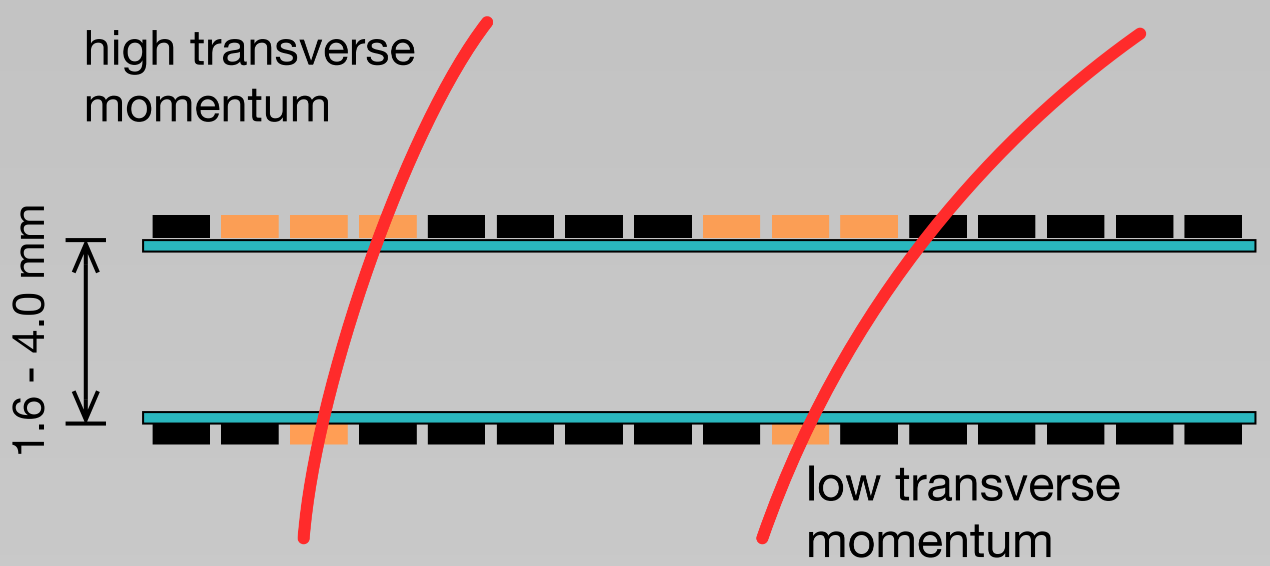




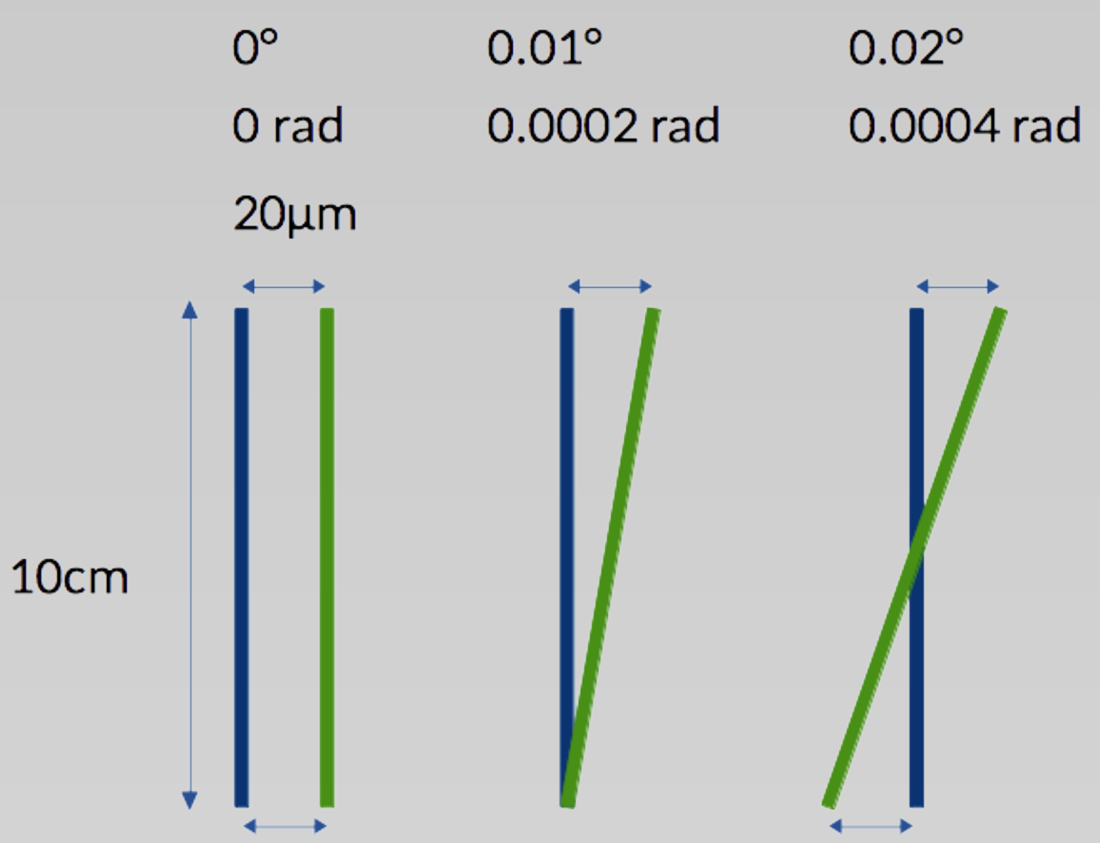


Module Assembly Requirements

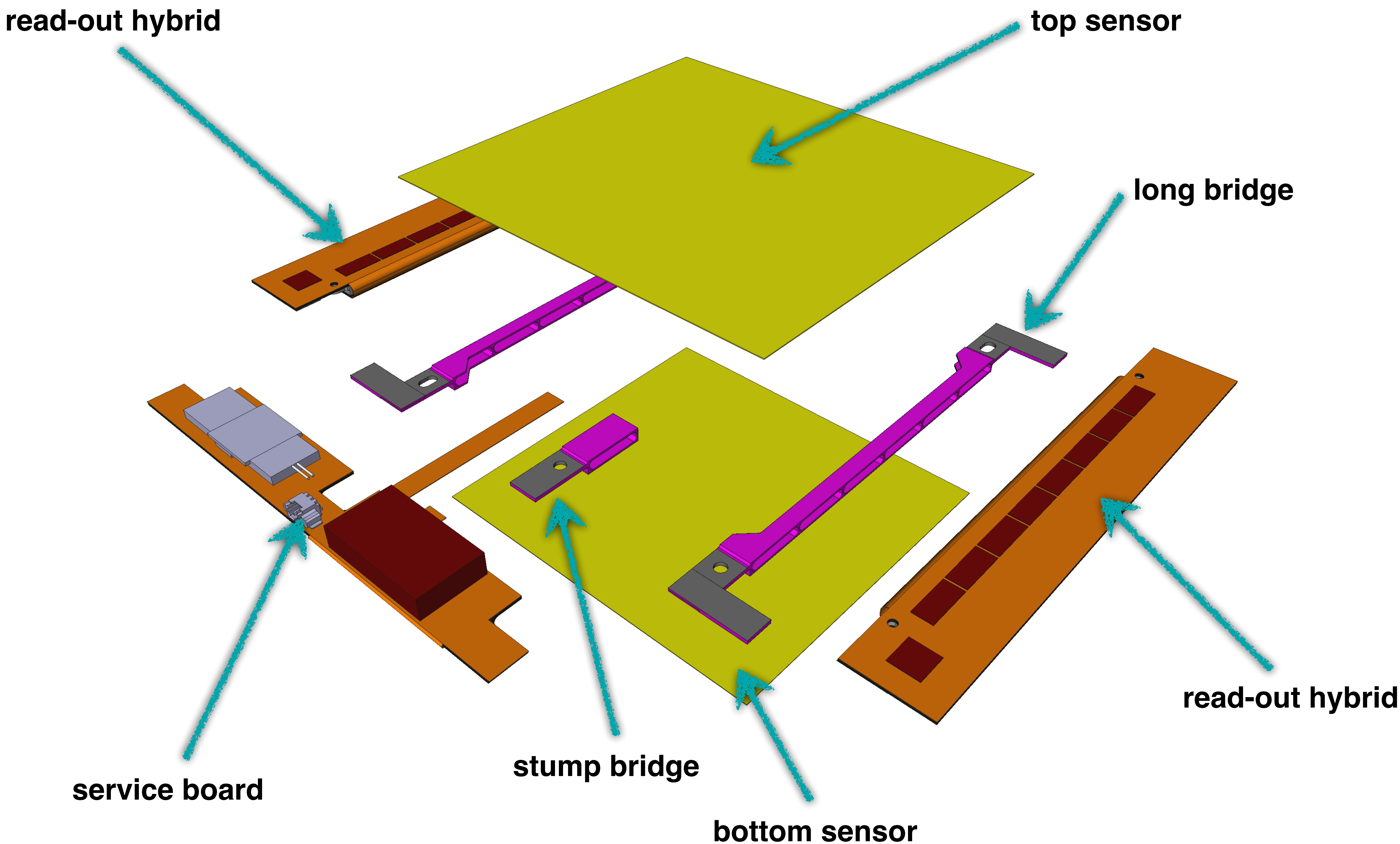
- on-module pT-measurement depends on alignment between both sensors
  - parallel displacement will lead to systematic errors in one direction
  - angular displacement will reduce the systematic errors in certain sections of the strips



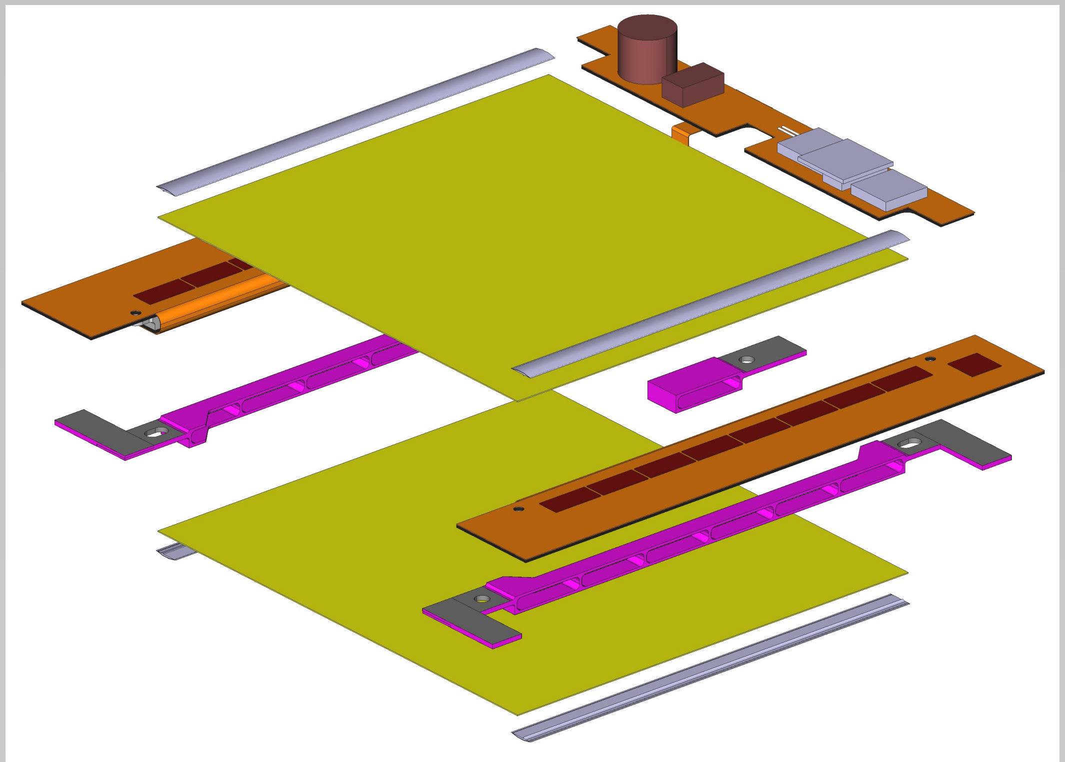
- misalignment can not be corrected in offline processing
- precise positioning needed already during production of the module
  - aim at alignment of "better than 20 µm"
  - < 0.02° for 10 cm long strips (2S module)

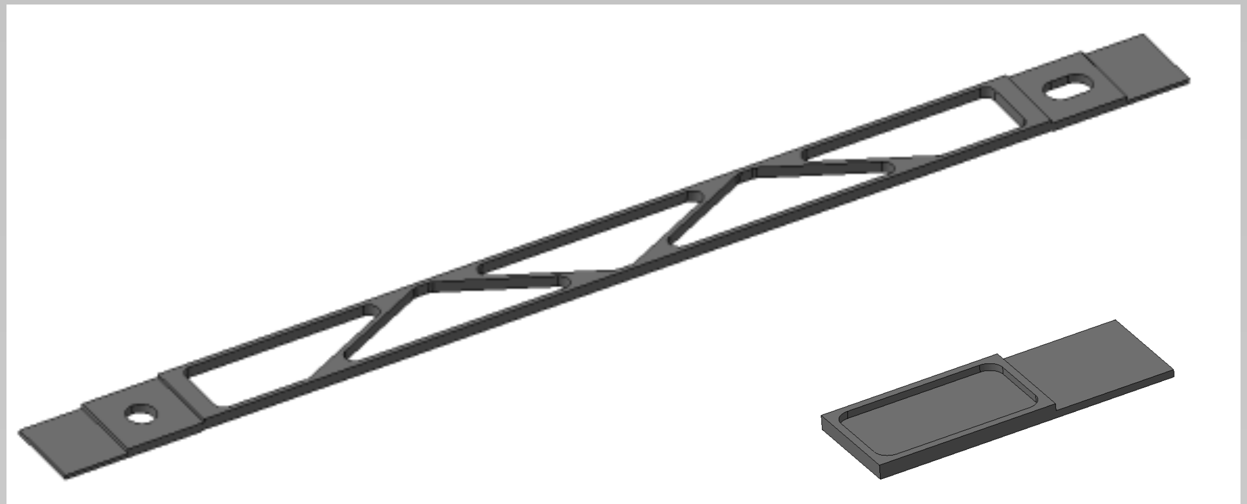


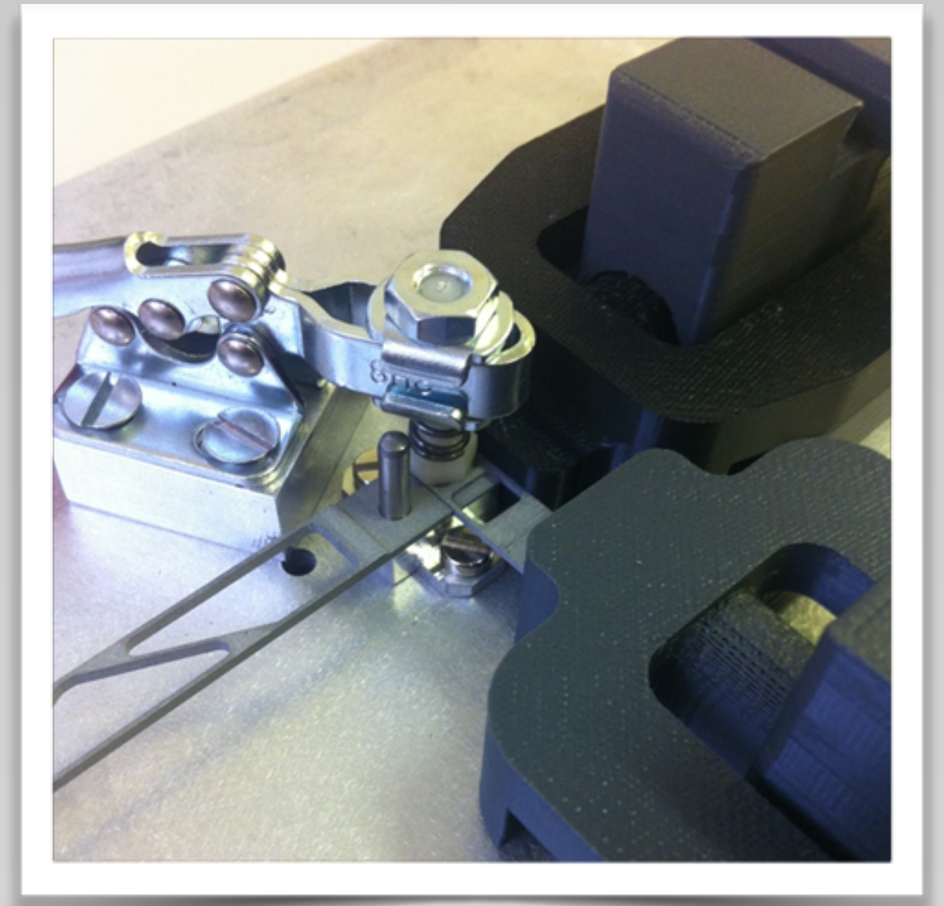
Assembly-Friendly 2S Module



Manual Module Assembly



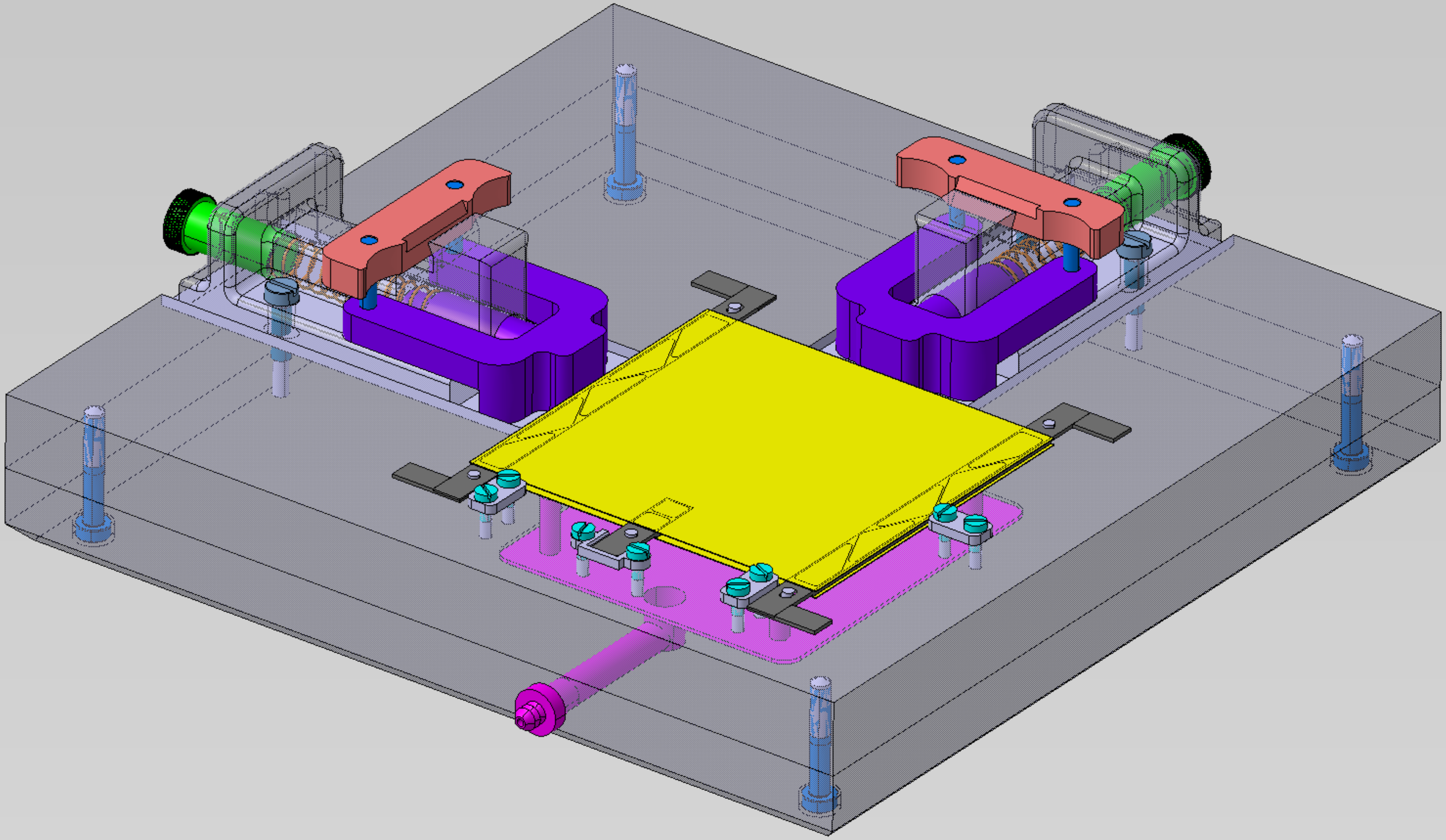




- long bridges of 2S module are produced from three AlCF pieces
    - the actual bridge and two hybrid supports
- hybrid support tabs are glued to the bridge in a dedicated jig
- jig works for both flavors of 2S modules

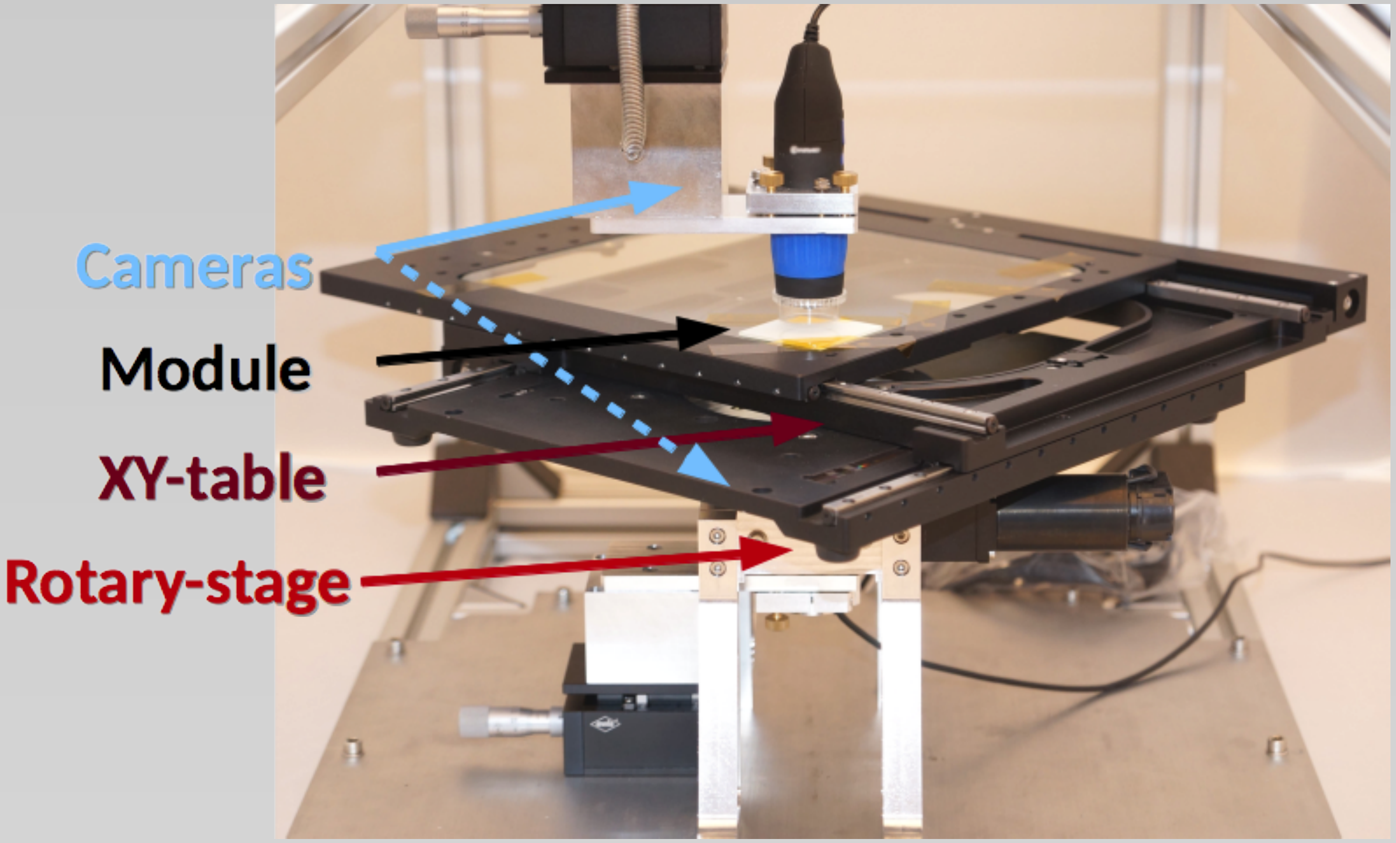
Manual 2S Module Assembly

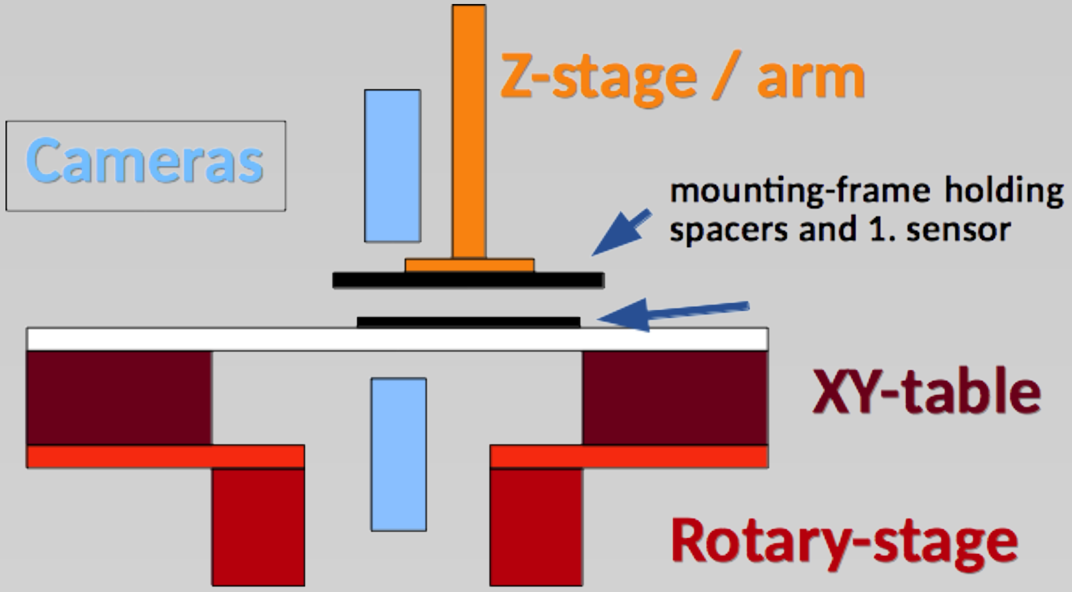
- gluing of bridges onto back of top sensor
- gluing of bridges+top sensor onto back of bottom sensor
  - sensors are positioned by springs/stops and held by vacuum
  - requires sensor edges to be cut to better than 10 μm
  - bridges are positioned by pins or stops onto gluing jig
- same strategy is also possible for the PS module



Automated 2S Module Assembly

- based on double-sided metrology setup developed in Aachen
  - metrology setup can be used to measure sensor-sensor alignment (both module types)
- x-y-stage is mounted on a rotation stage
- cameras look from top and bottom onto x-y-stage (close to rotation axis)
- module is placed on x-y-stage and alignment marks are moved into field of view of cameras
- position of marks in coordinate system of x-y-stage is obtained from images at different rotations
  - minimum is 0° and 180°
- radial measurement accuracy is ~1.5 µm rms
- a z-stage is used for automated module assembly
- a similar concept is developed for the PS module assembly





Summary

- CMS will use two different module types for the LH-LHC tracker
- modules come in different variants of the same design
  - strip-strip module (2S): 1.8 mm and 4.0 mm
  - pixel-strip module (PS): 1.6 mm, 2.6 mm and 4.0 mm
- only two designs need to be optimized
- design team has a pretty good understanding of the behavior and performance of both designs
  - adjustments can be implemented quickly

- prototyping has started
  - a full-sized mechanical 2S module is available
  - a thermal mock-up PS module has been used to test thermal performance

- 2S mini module was successfully tested in beam in November 2013
  - functionality of CBC chip could be shown
- a test beam with irradiated 2S mini module(s) will be carried out in a few weeks

- several groups have started to look into module assembly procedures
  - both manual and automated

- many details still have to be understood
  - e.g. glues, production of parts, etc.