Modules for the HL-LHC CMS Strip System

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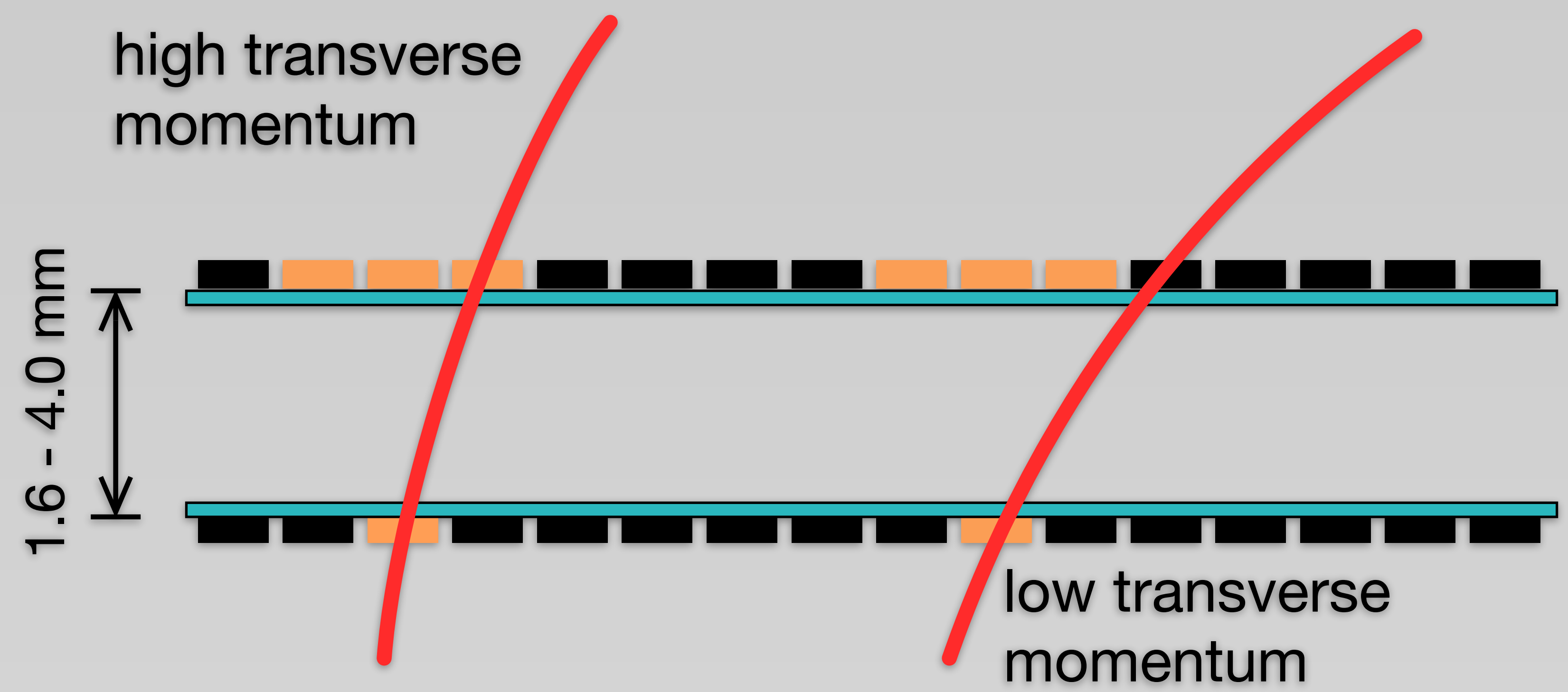
Outline

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

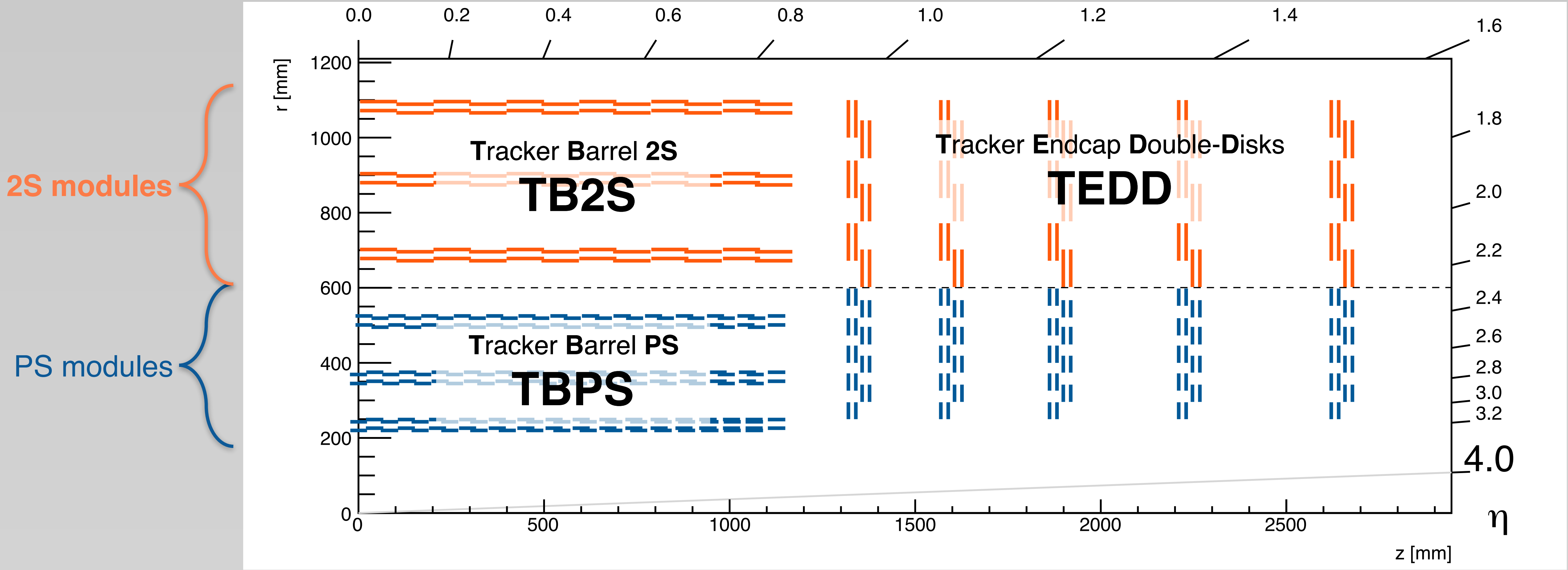
Introduction - Module Concept

- 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 minimise 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 optimisation of only two designs



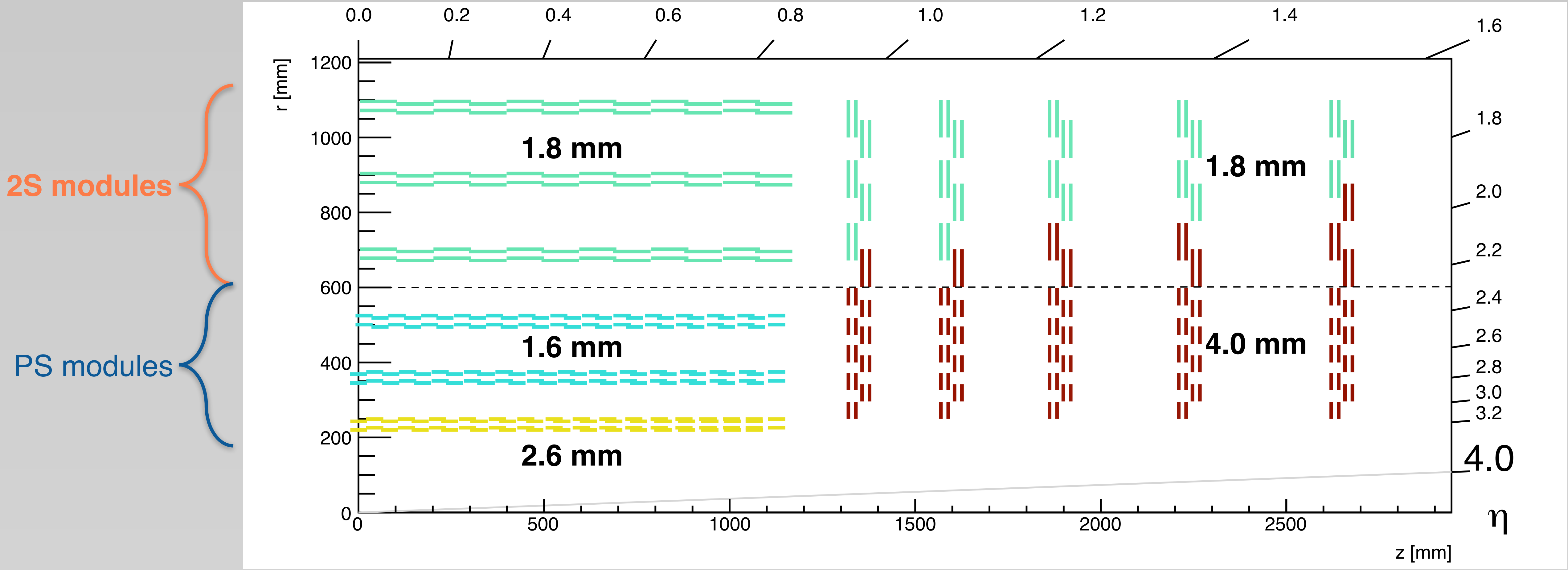
Introduction - Tracker Layout

- 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



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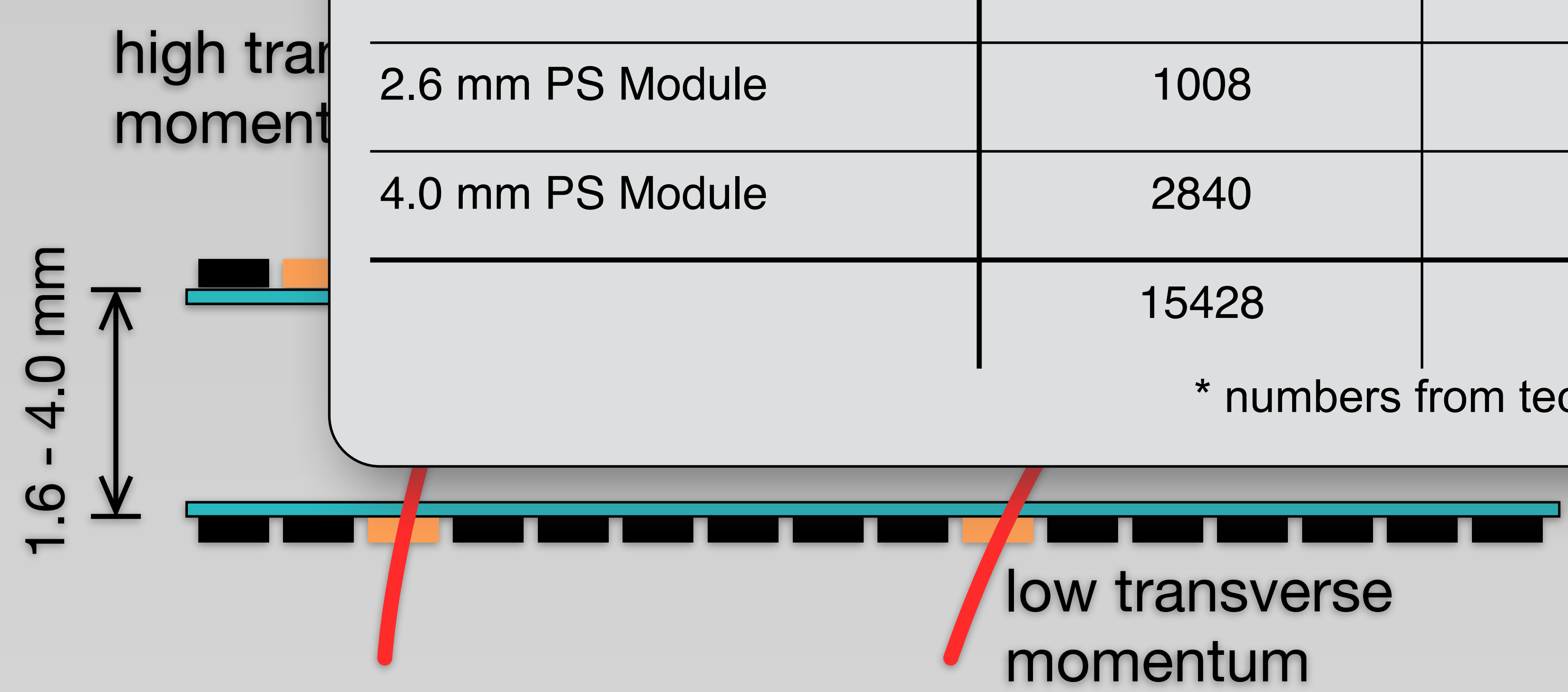
	full tracker	per end cap
1.8 mm 2S Module	7440	1488
4.0 mm 2S Module	984	492
1.6 mm PS Module	3156	
2.6 mm PS Module	1008	
4.0 mm PS Module	2840	1420
	15428	3400

* numbers from technical proposal



Module Design vs. Everything Else

electronics

- front-end powers
- form factors of ASICs
- wire bonded / bump bonded ASICs
- mechanical properties of hybrids
- connectivity
- …

mechanics

- clashes, clashes, clashes

module design

- noise performance
- thermal performance
- ease of (mass) assembly
- storage / transport / testing
- integration on structure

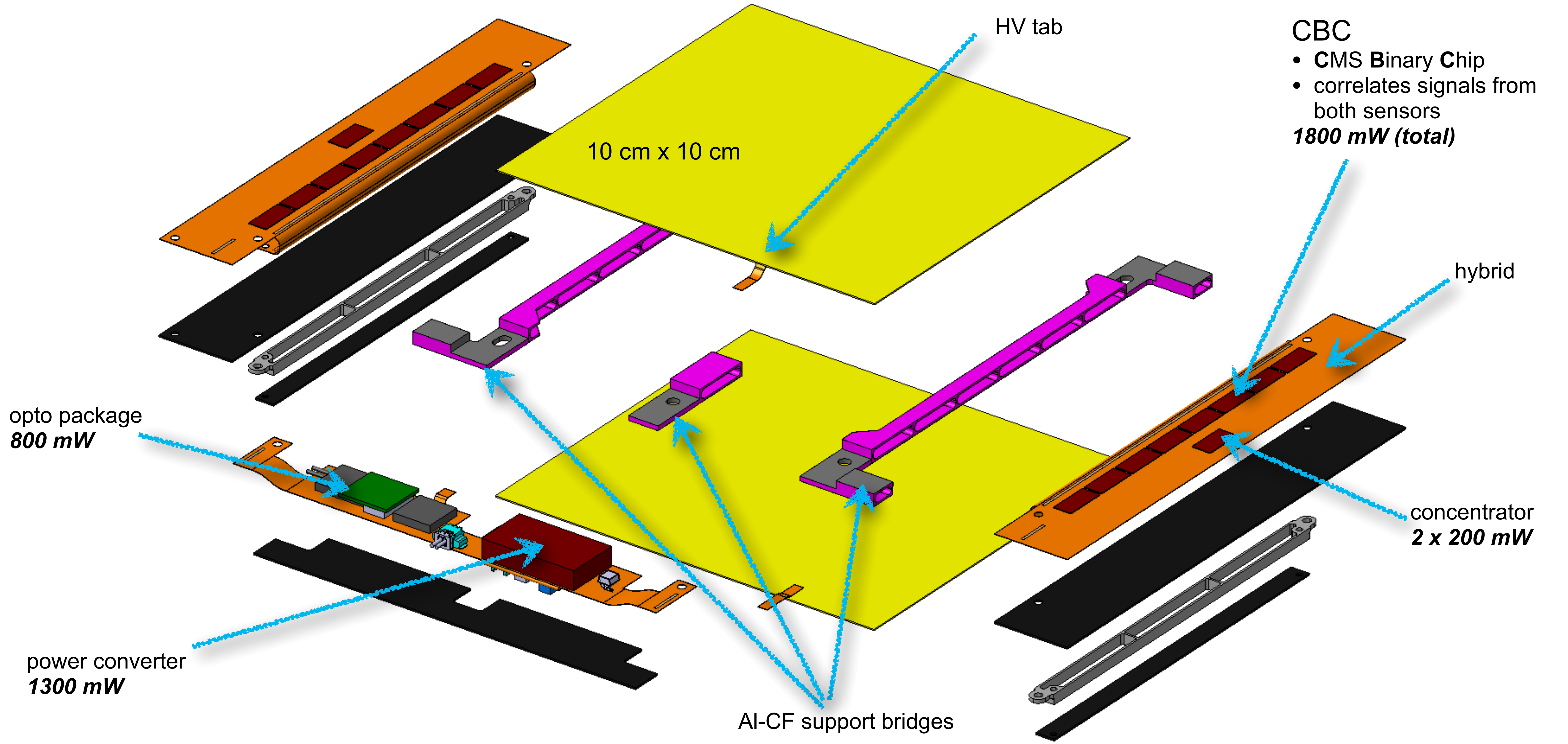
sensors

- physical size and tolerances
- active / physical thickness
- …

layout

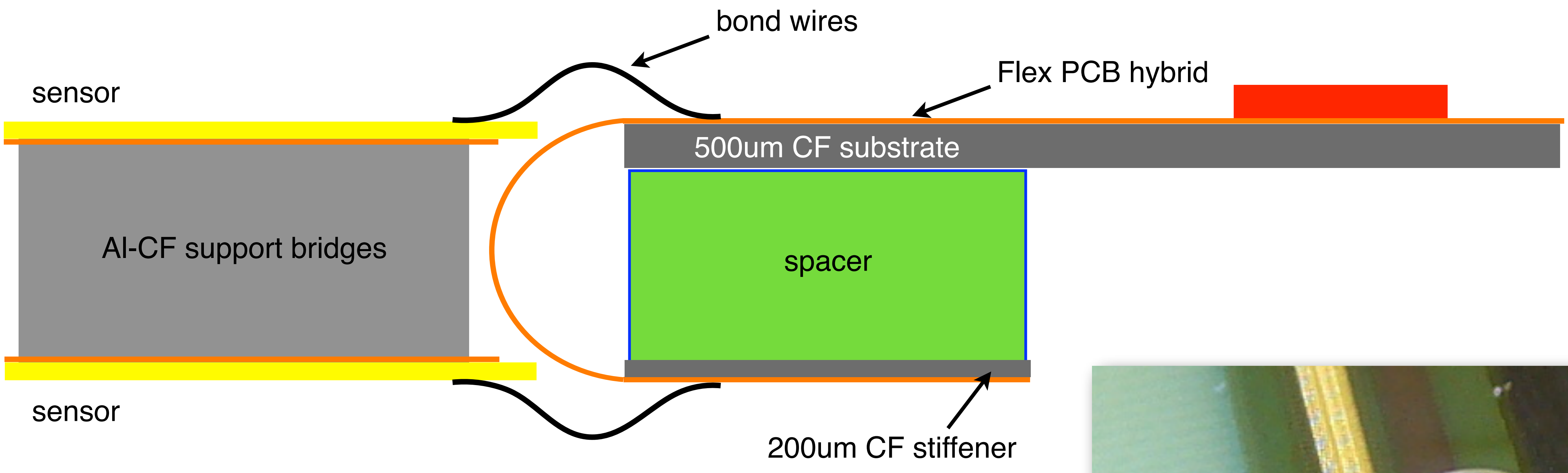
- maximum distance between modules vs. overlaps thickness
- …

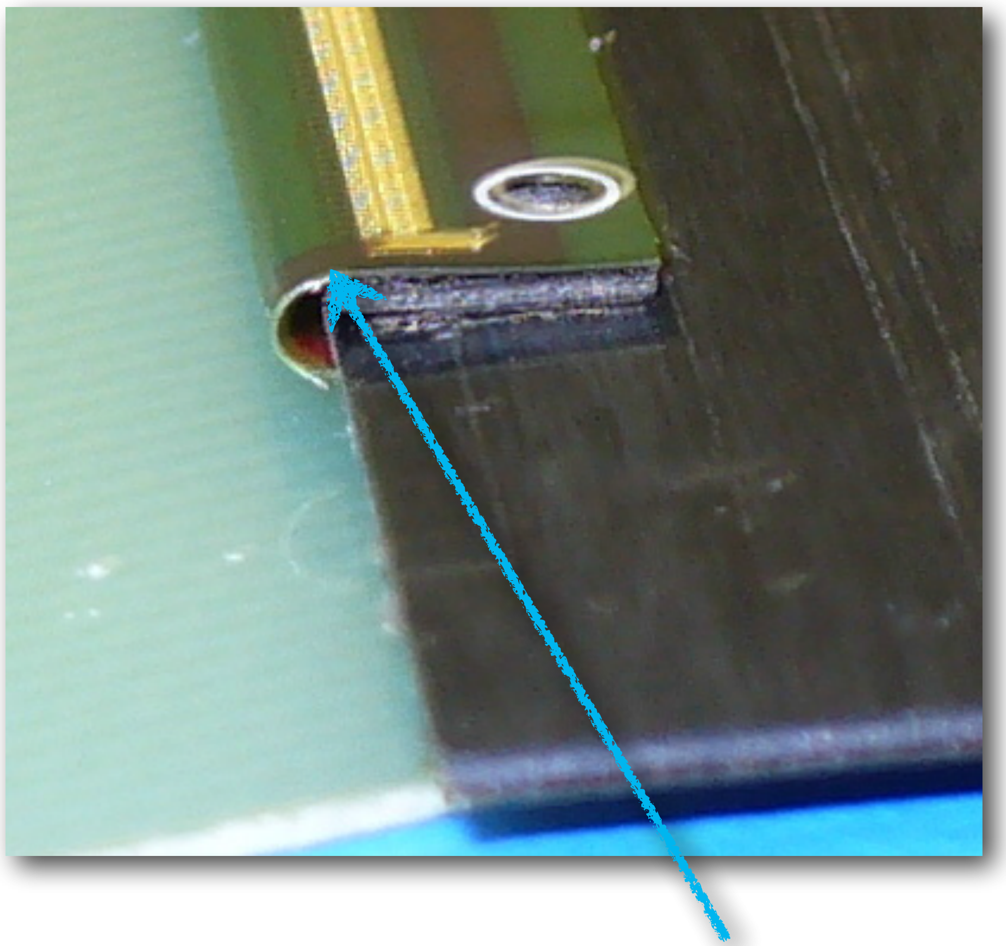
Design of the 4.0 mm 2S Module



- sensors are supported by AlCF bridges
  - AlCF = carbon fibre reenforced aluminum
  - good CTE match to silicon: 3.6 ppm/K vs. 4 ppm/K
  - coated with parylene for HV insulation
- five cooling contacts per module
  - extra AlCF stumped bridge introduced for thermal management
  - heat load from service hybrid (~2W)

Flex Hybrid

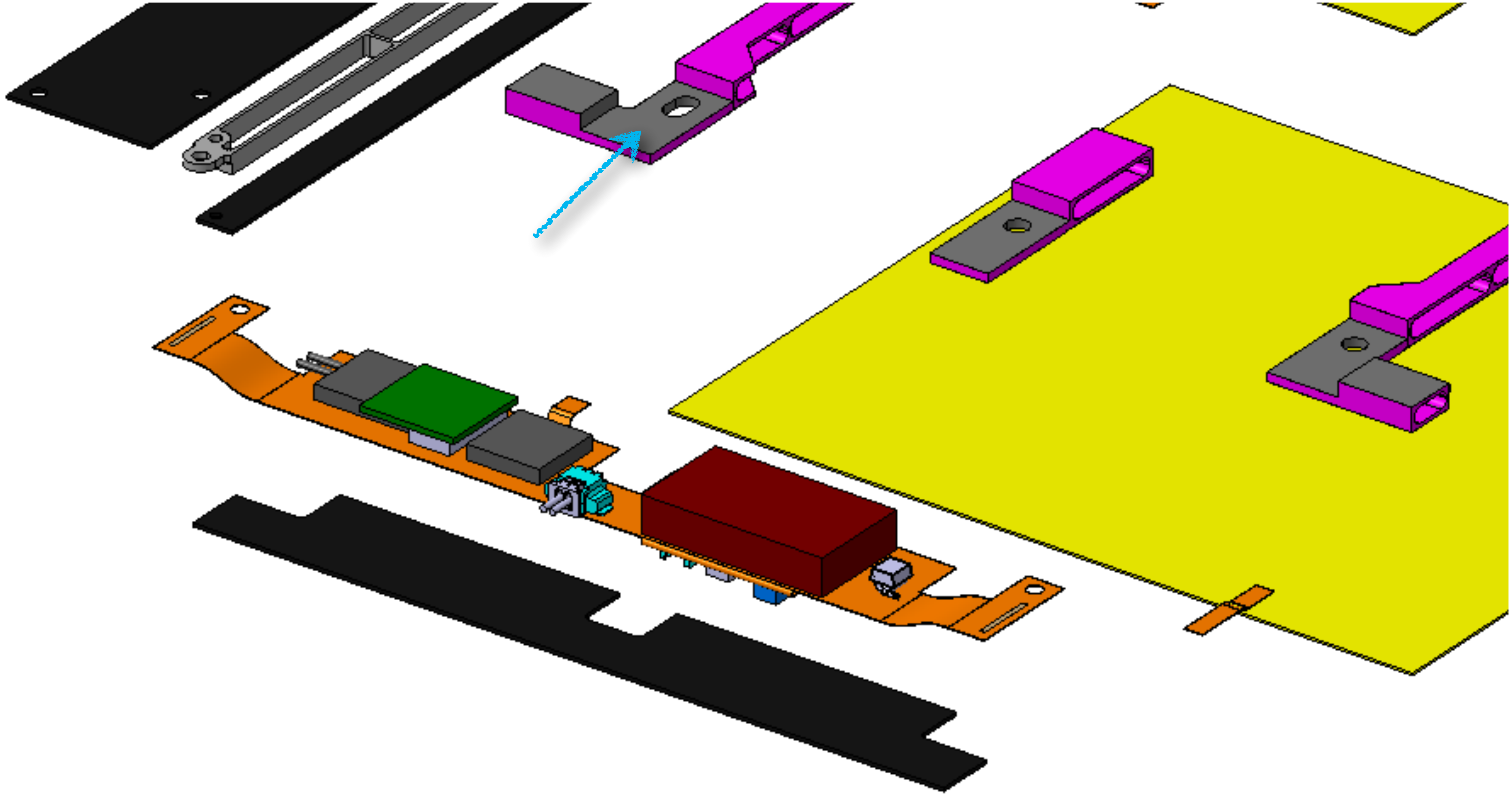




folded flex hybrid

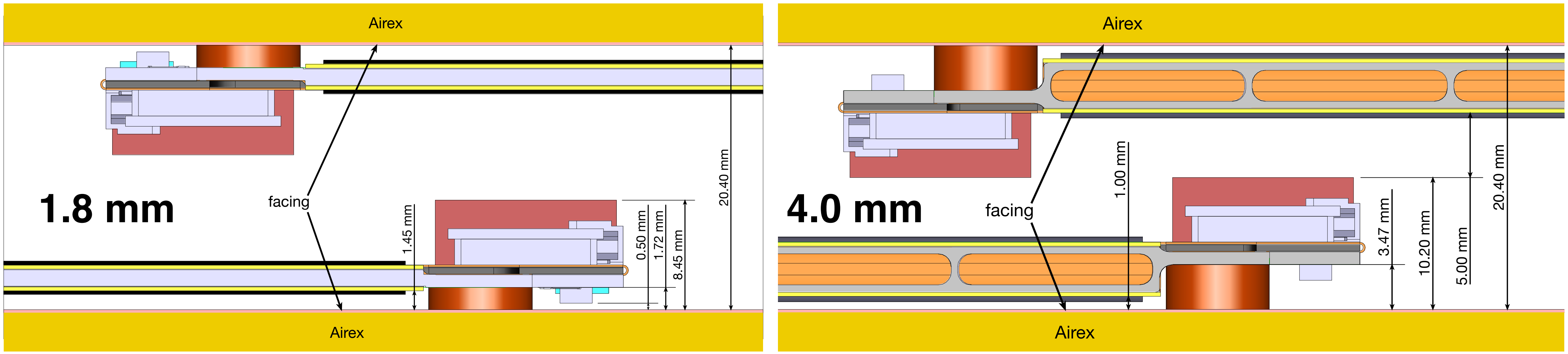
- flexible hybrid is glued on CFRP stiffeners and folded around a spacer
- bond pads on hybrid are on the same level as the bond pads on the sensor
- folding will be done in industry
- first prototypes did show delamination
    - flex tries to get back into original shape
    - glue was to soft
- service provider will pre-bend flex before gluing
    - at increased temperature to make pre-bending ‚permanent'

Al-CF Bridges and Service Hybrid

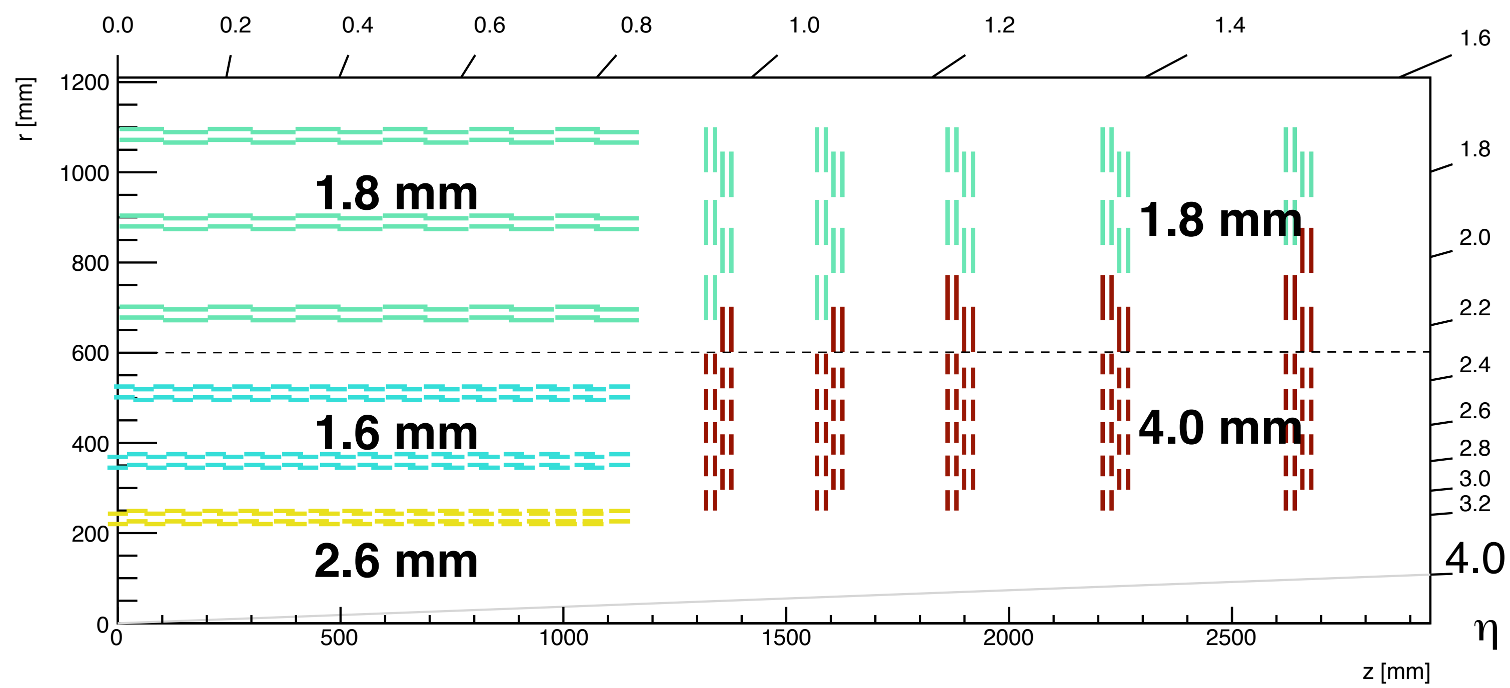


- Al-CF bridge have a very complicated shape due to integration issues
- 4.0 mm module is a rather special case
  - only installed in end cap
- 1.8 mm module will be installed in both barrel and end cap
- goal: keep module designs from integration point of view compatible with barrel and end cap support structures

Al-CF Bridges and Service Hybrid



optimized 4.0 mm module support bridge geometry would result in more complicated end cap support structures
➡ make module a bit more complicated but keep structure simple



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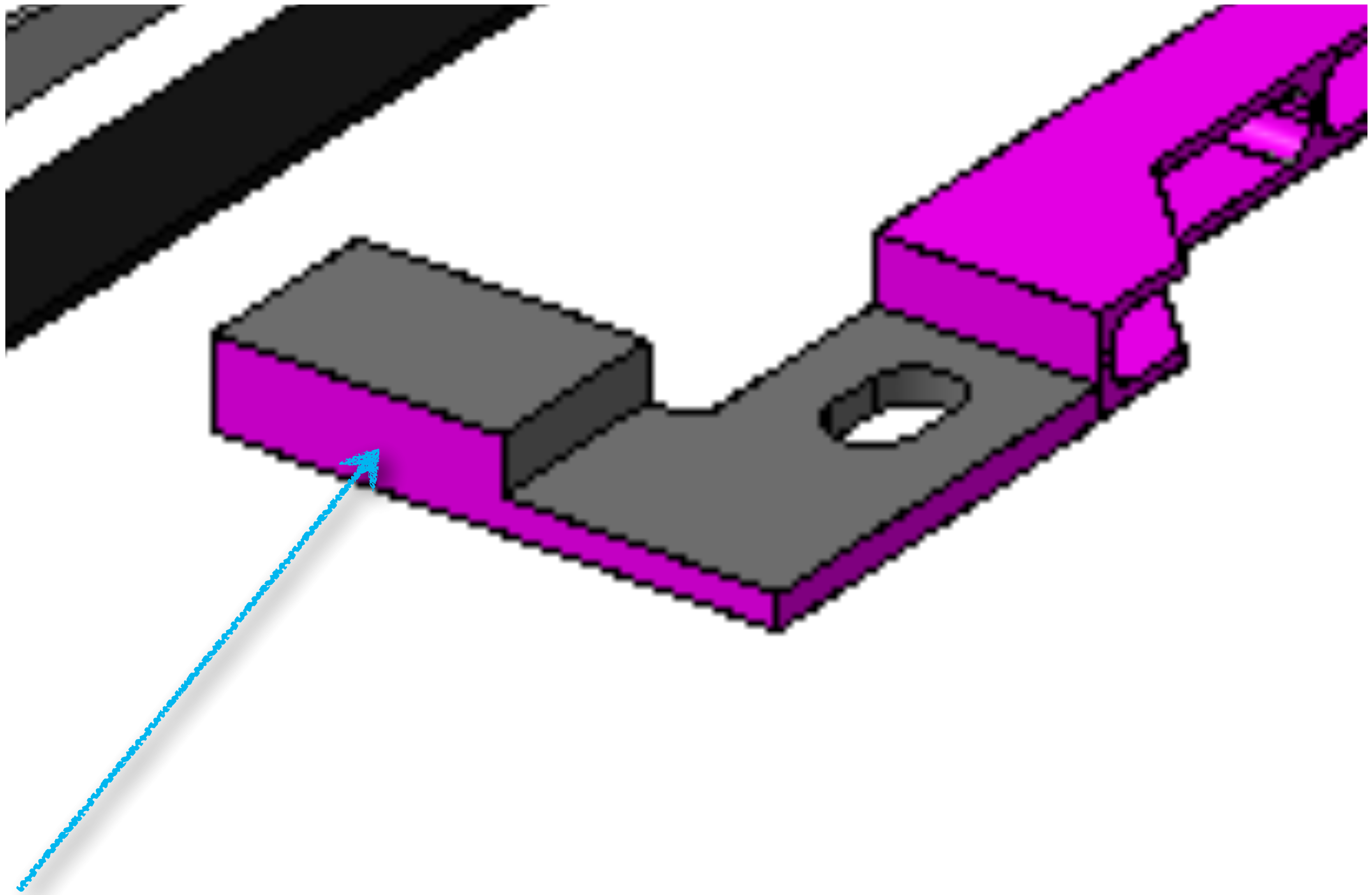
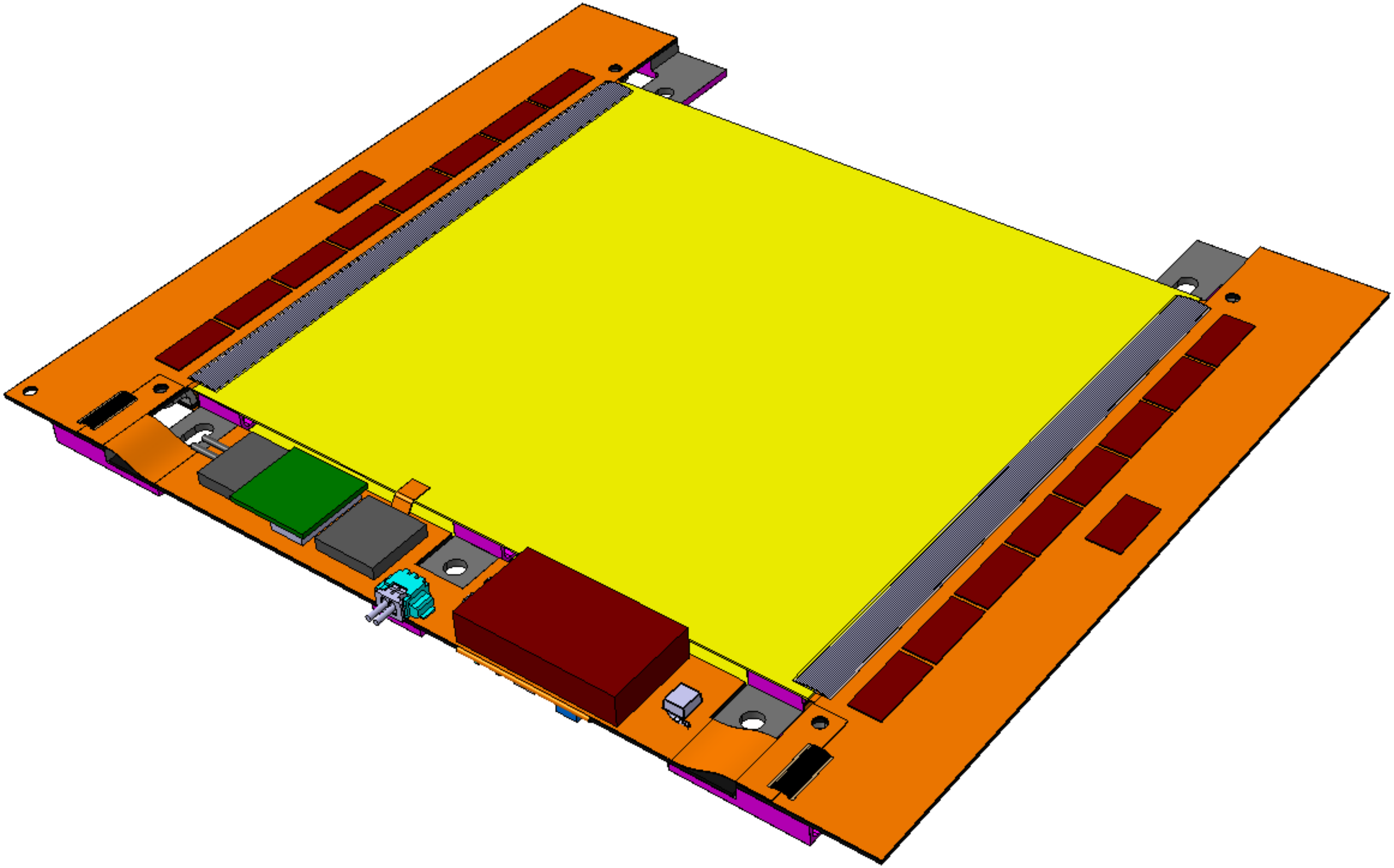
Parylene Coating

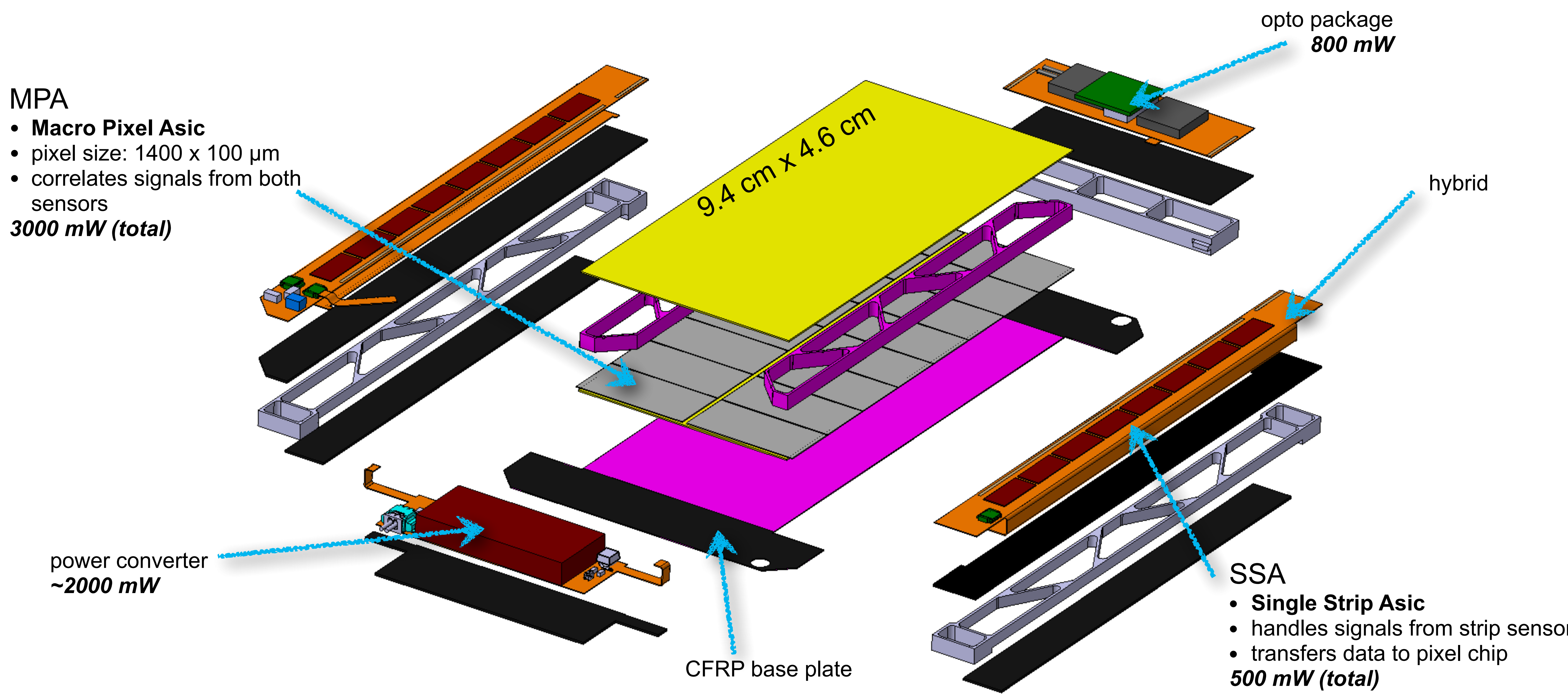


- parylene is used for HV insulation
- parylene is also a pretty good thermal insulator
- need to mask areas where we cannot afford coating
- a very labor extensive / expensive process

The Final Product - 4.0 mm 2S Module

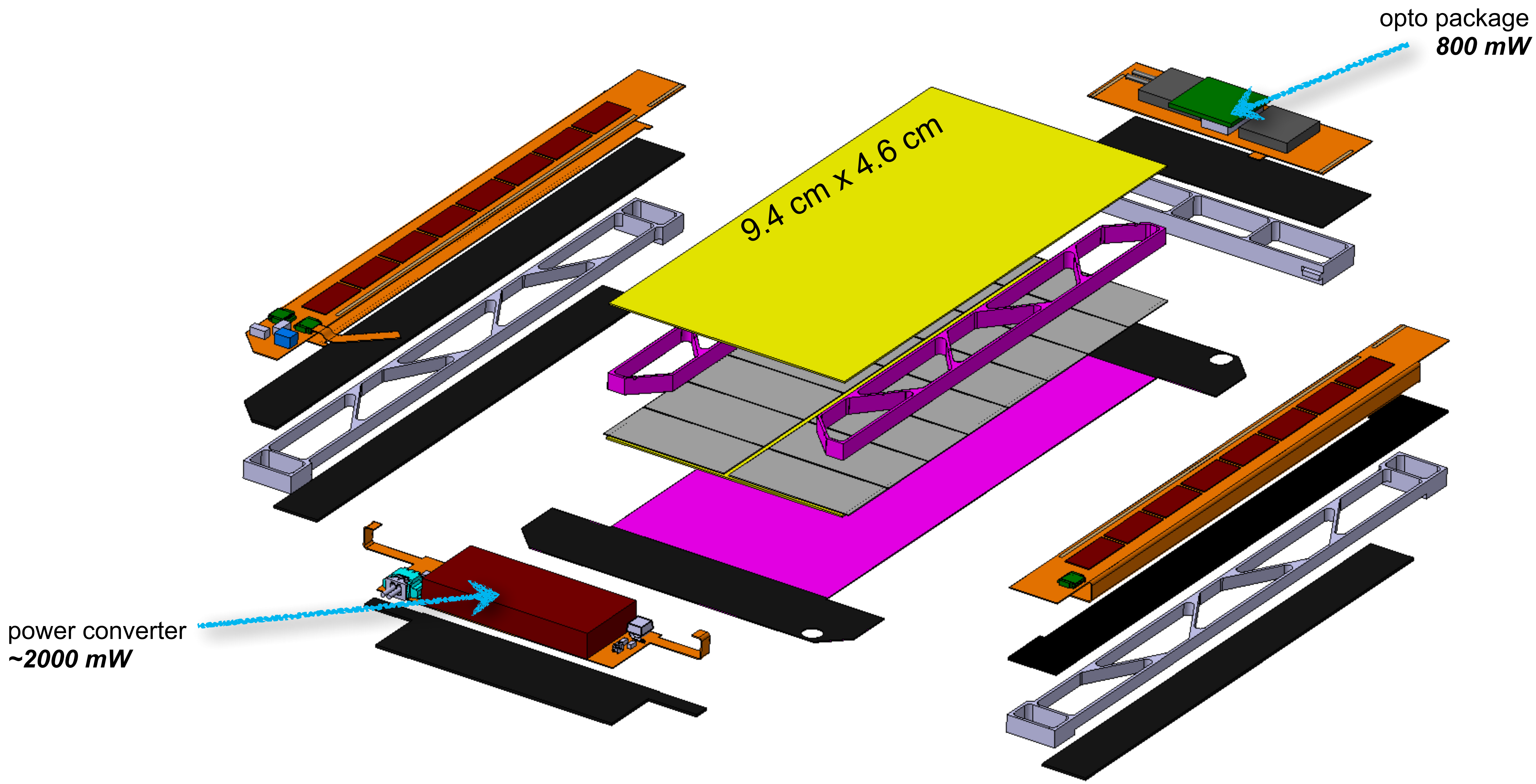


Design of the 4.0 mm PS Module



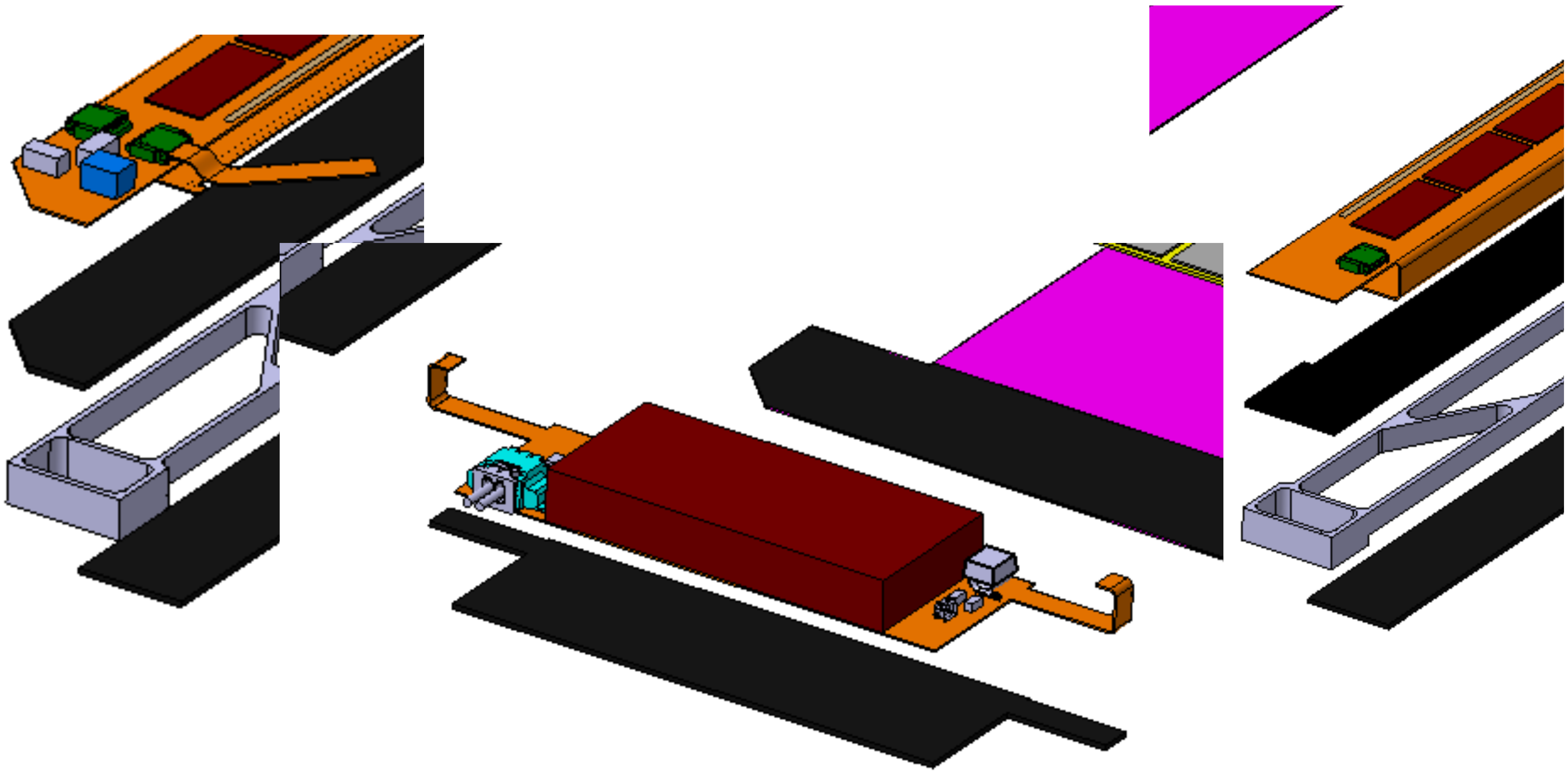
- sensors are supported by AlCF bridges
- initially same cooling concept as in 2S module
  - four cooling contacts at end of bridges
  - power density of PS module is too high
- PS module needs large-area thermal contact
- module is built on top of a CFRP base plate
- MPAs and sensors are cooled through base plate
  - requires a large-area glue joint between pixel sensor and base plate
- Concentrator ASIC is located on bottom side of hybrid

Design of the 4.0 mm PS Module



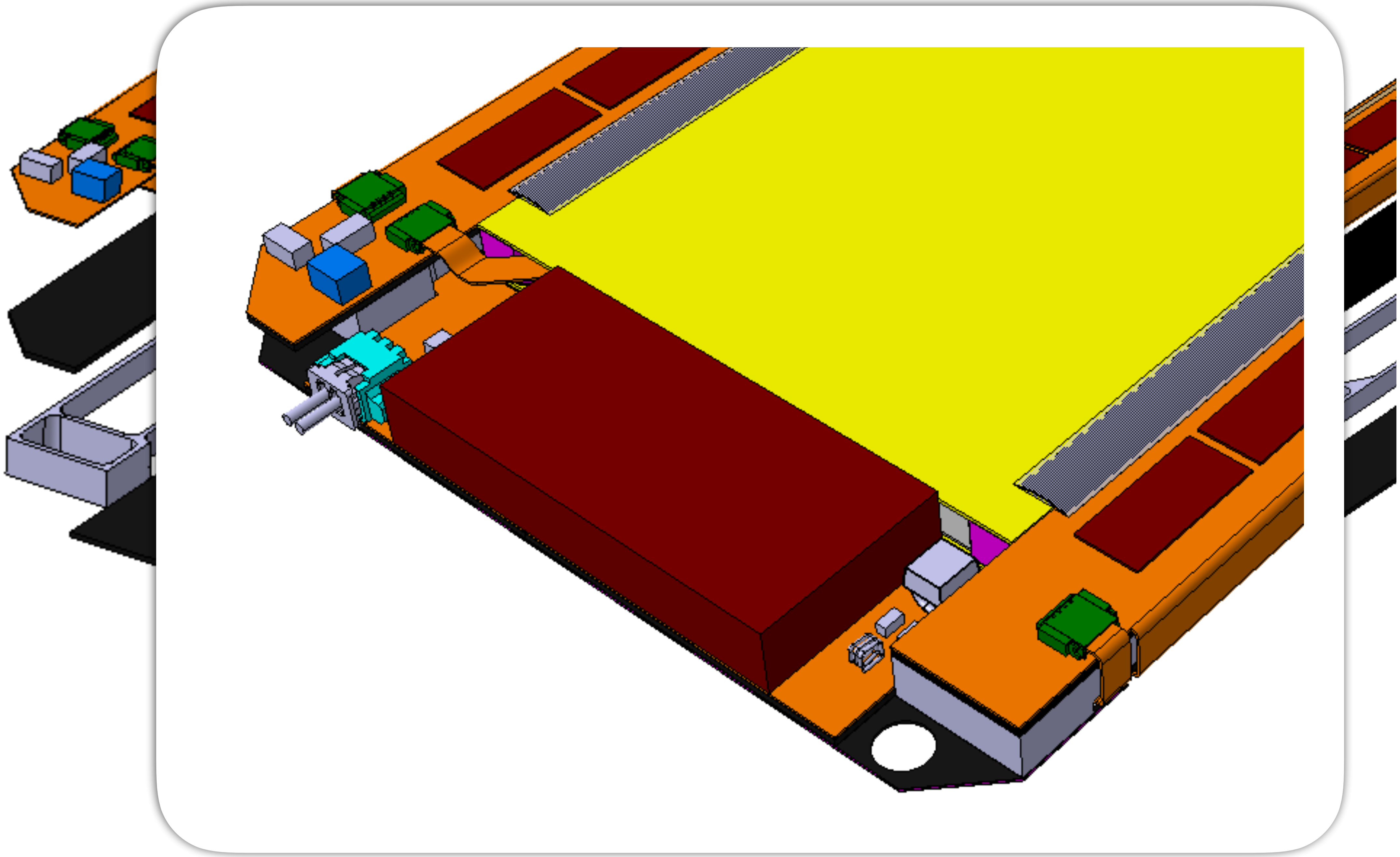
- large number of bond wires between read-out hybrid and opto hybrid requires opto hybrid to be at the same level as read-out hybrid
- heat load from power converter and size of package requires power converter to be at level of base plate

Connectivity



- supplying power to the read-out hybrid requires complicated layout of power service hybrid
  - pig-tails on service hybrid
  - connectors on read-out hybrid

Connectivity



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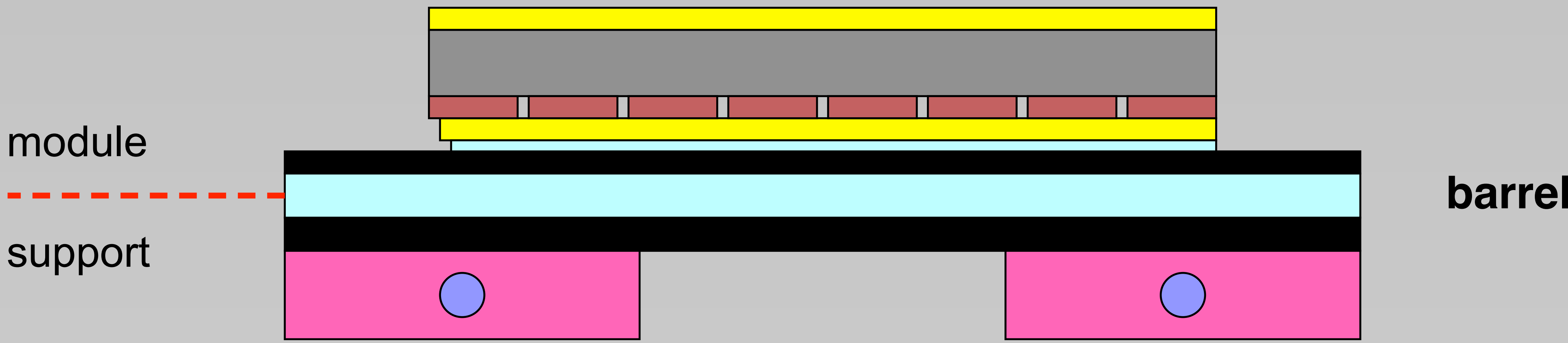
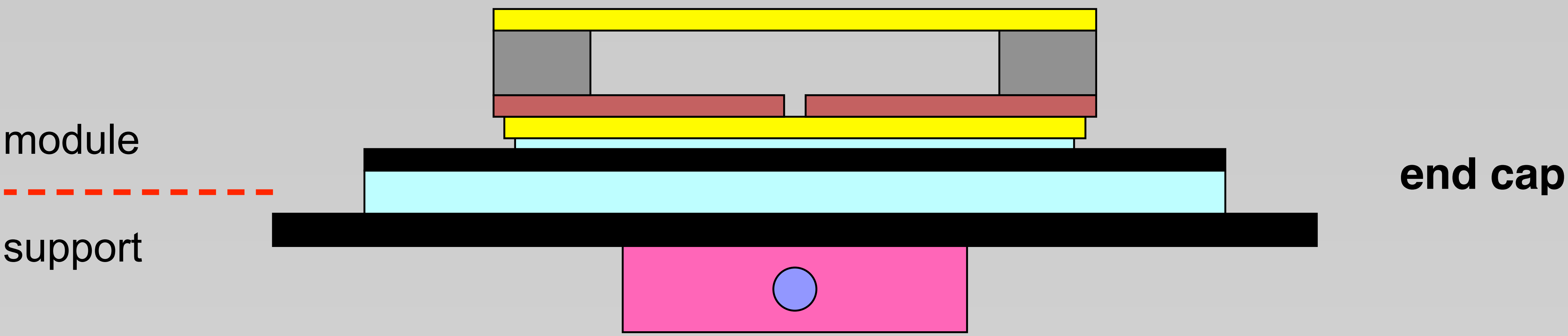
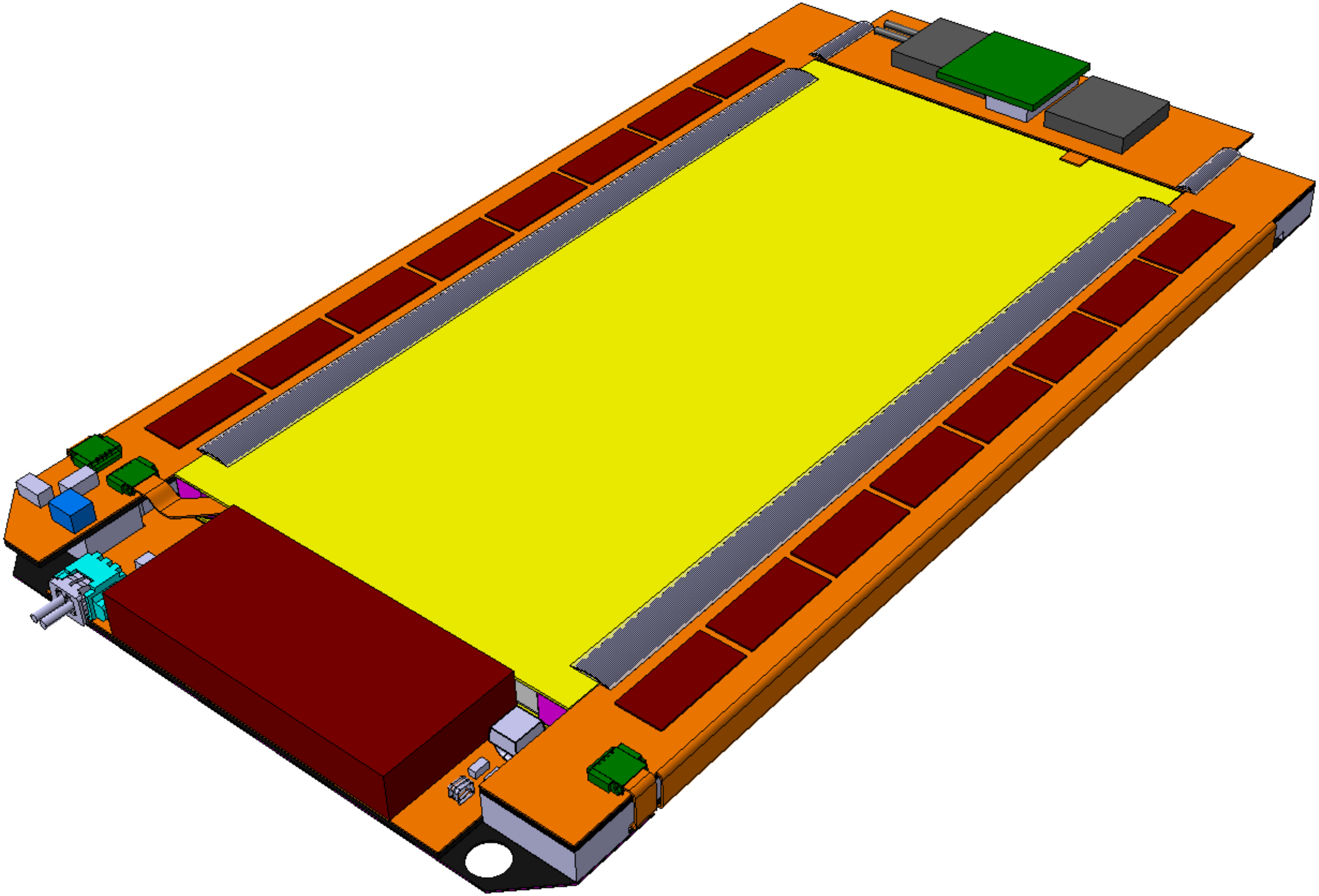
PS Module on Support Structure



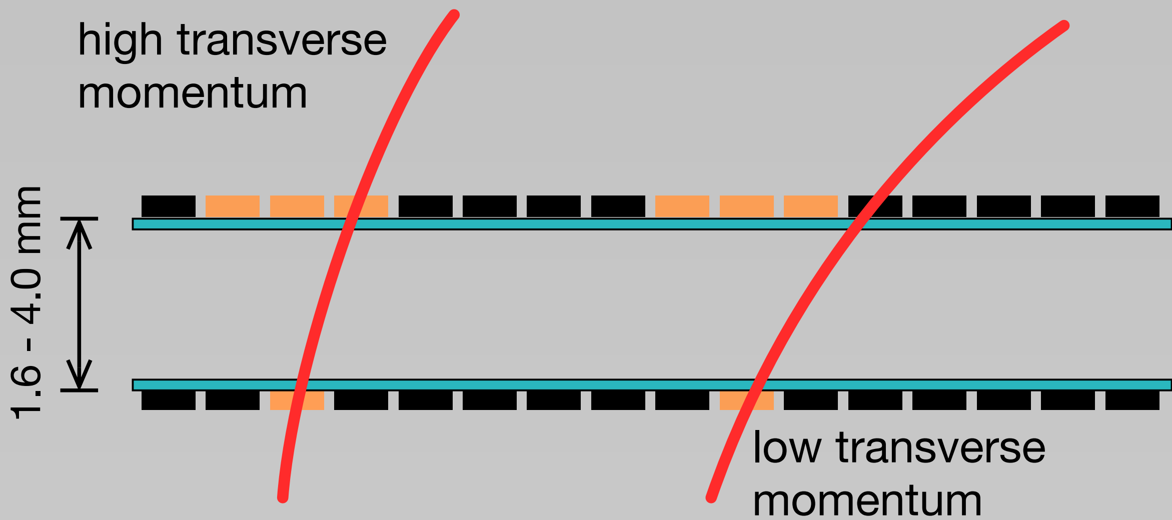


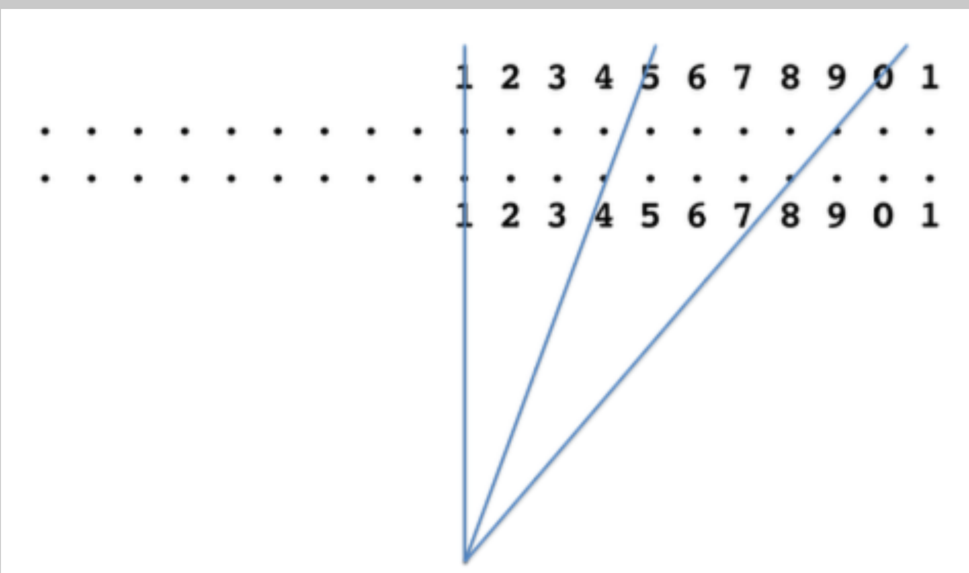
- module is built on top of a CFRP base plate
- base plate serves as a large-area thermal interface between module and support structure
- thermal contact should be reworkable
- how to deal with cooling during module tests

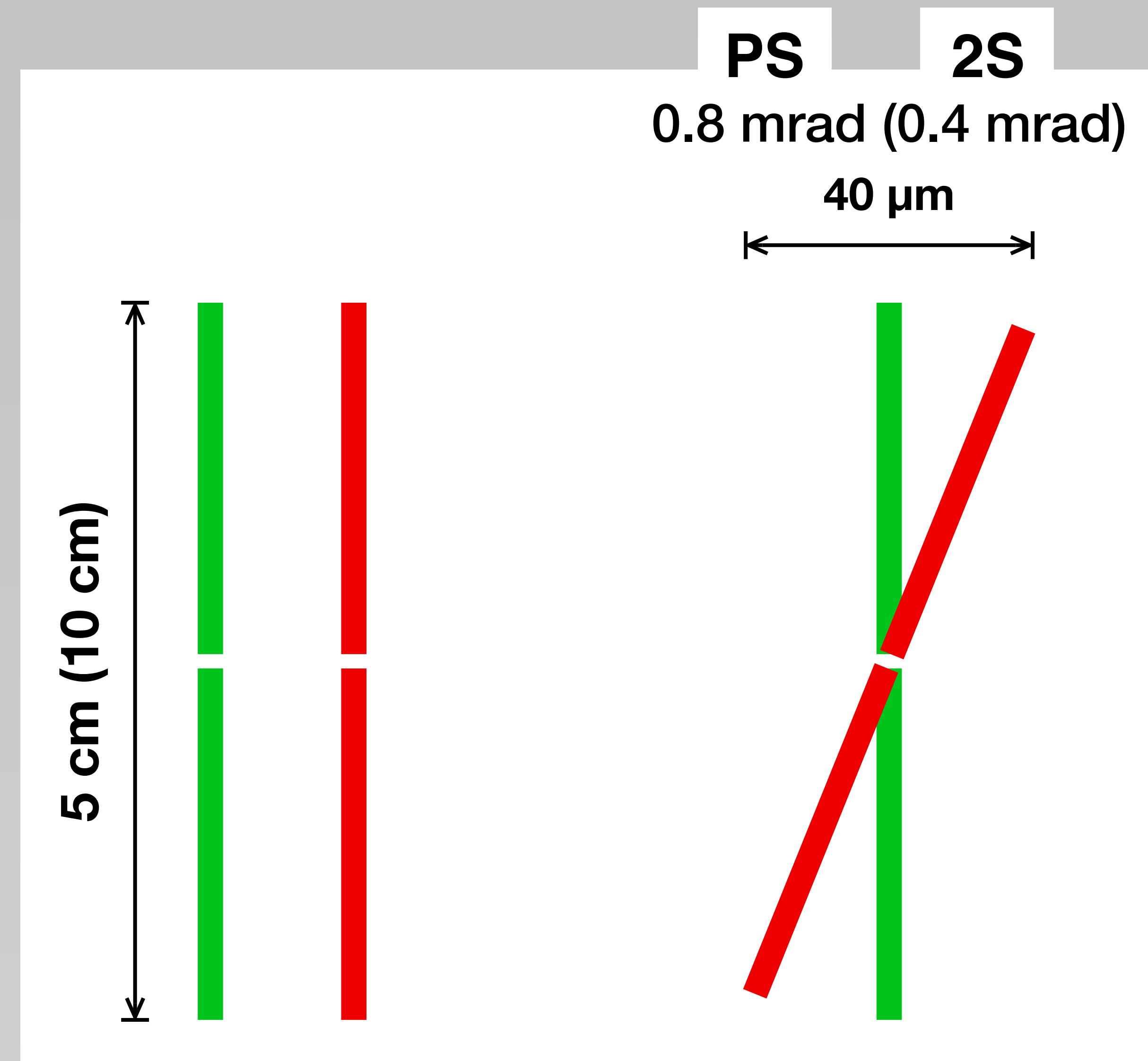
The Final Product - 4.0 mm PS Module



Module Assembly Requirements

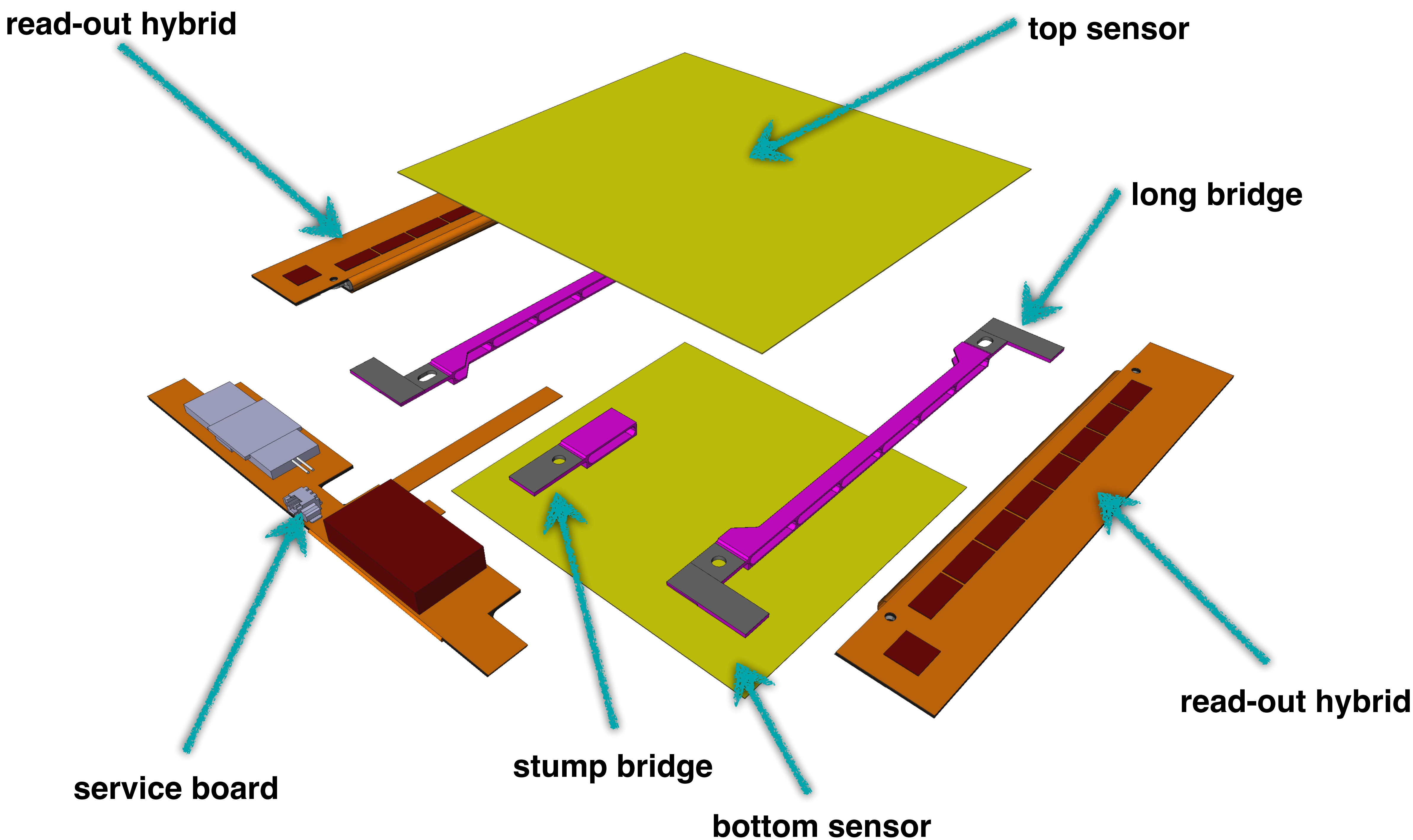






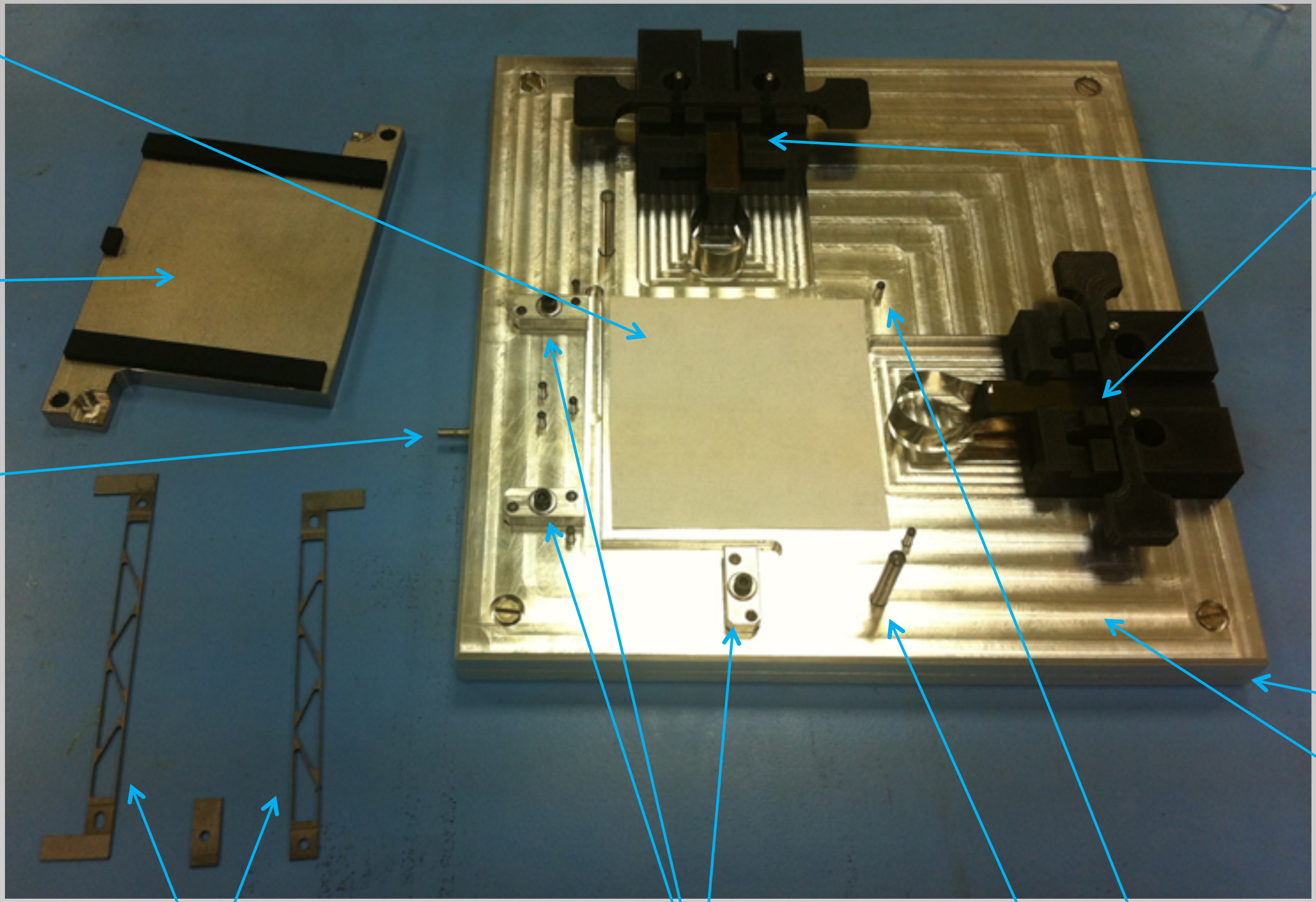
- straight trajectories do not cross the same strip on the sensors of a module
  - offset can be corrected for in the stub finding logic of the chip
  - programmable in steps of 0.5 strips
- a tilt of one sensor with respect to the other introduces a variation of the offset along the strip that cannot be corrected for
- to minimise the effect on the resolution the requirement on the assembly precision is t < 40 µm

2S Module Assembly



- assembly-friendly view
- read-out hybrids are already folded around their spacers
  - done in industry

Manual Module Assembly Jig



Clean room tissue to protect the sensors (250um thick)

Weight plate with foam to push on the bridges

Vacuum hose fitting

2 spring pushing devices, 3D printed, using metal foil bands as springs

Vacuum plate

Base plate

Long bridges with hybrid supports already glued (one support was broken in handling)

3 toes, very precisely machined

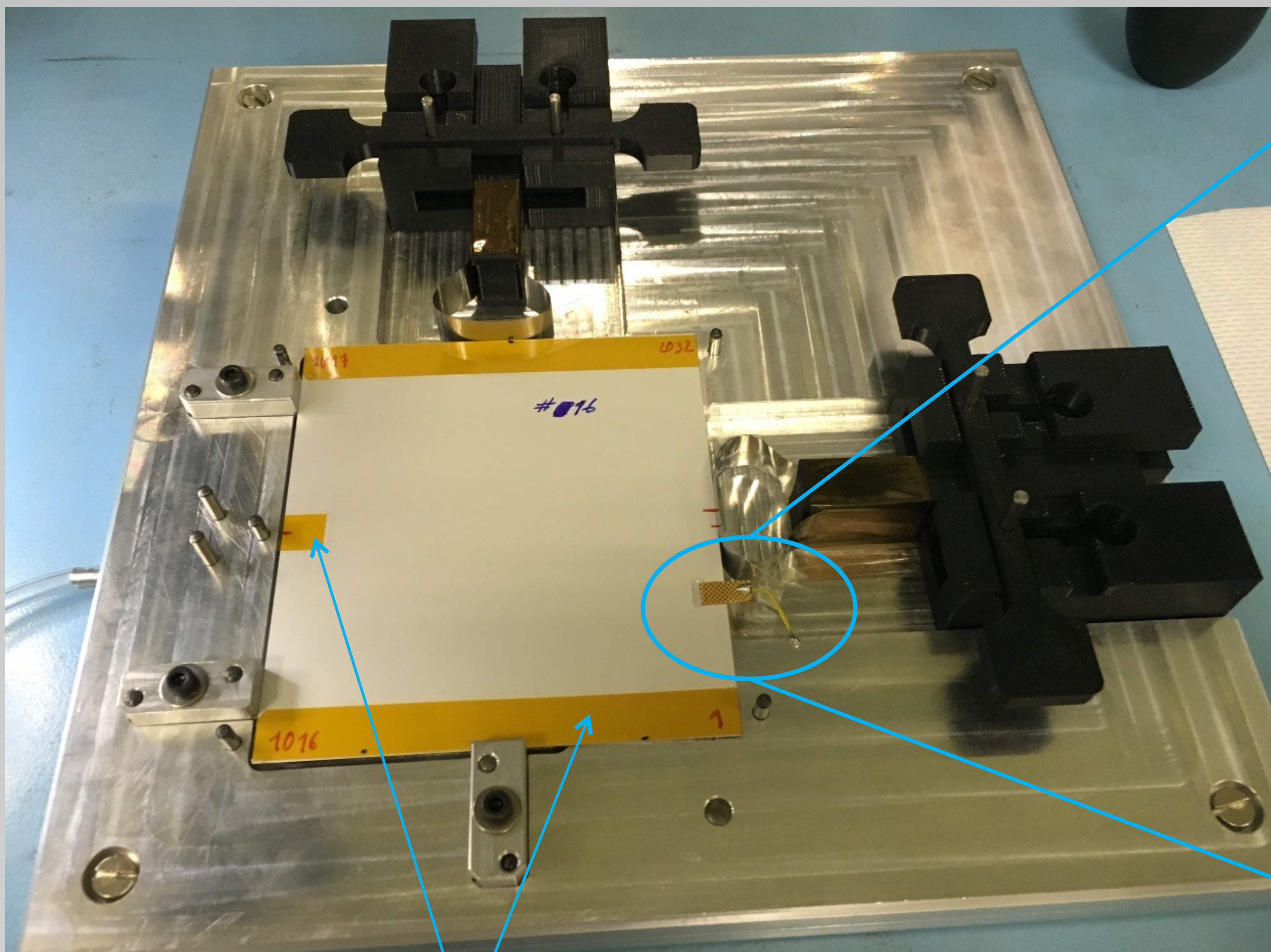
Pins for positioning the bridges

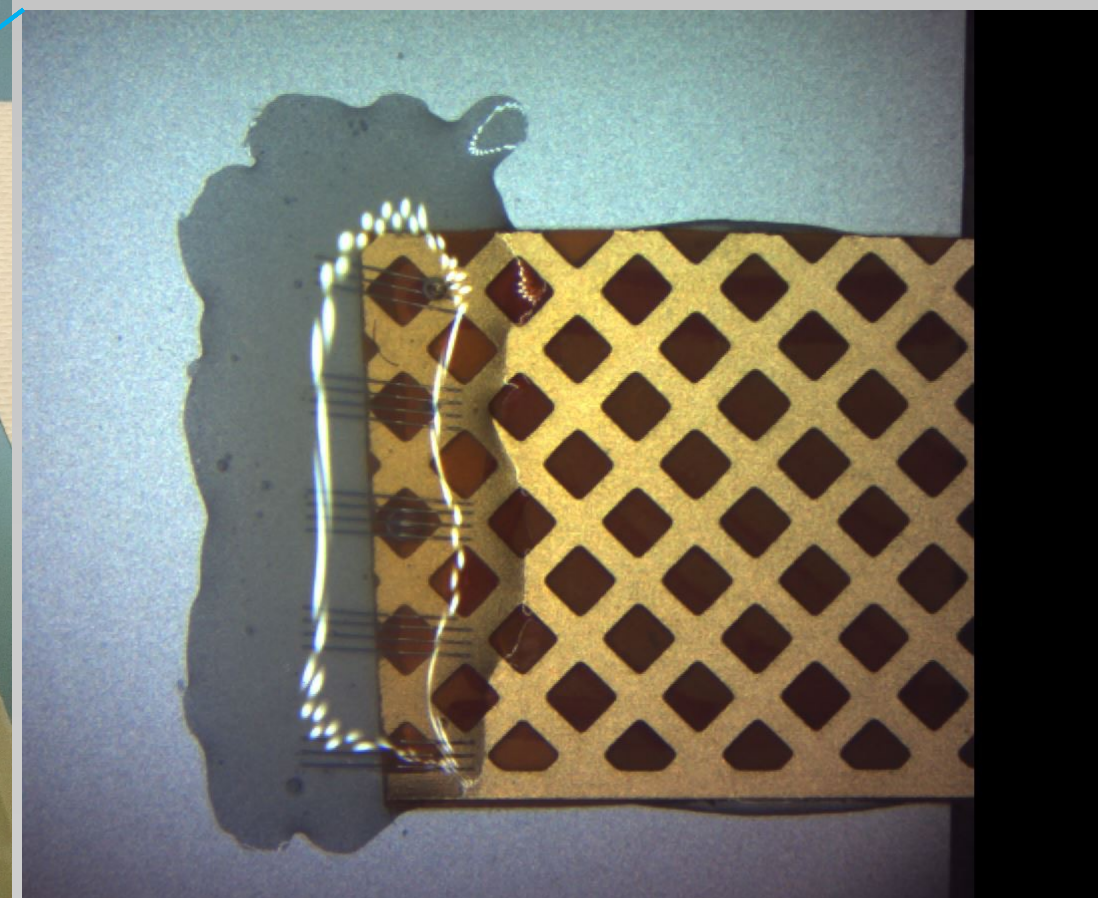
Pins for guiding the weight plate

basic steps:

1. gluing of bridges to top sensor
2. gluing of bottom sensor to top sensor package
3. gluing of hybrids to module
4. wire-bonding of top and bottom sides

Gluing of Bridges to Top Sensor

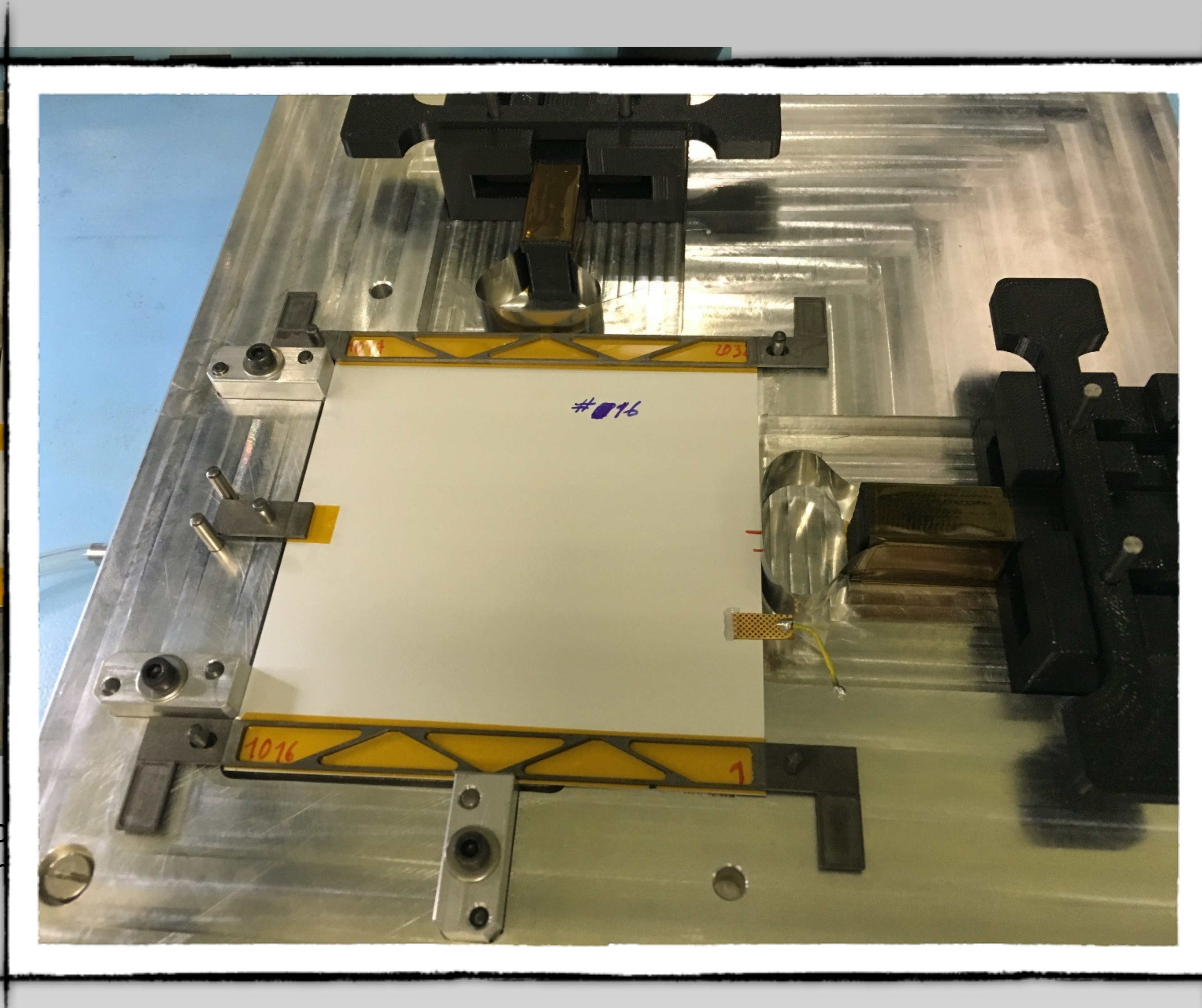




Kapton tape to simulate the Parylene coating (for isolating the Al-CF Bridges)

HV Connection glued to the Backplane of the Sensor Wire Bonding (between the Backplane and the HV connection) encapsulated with Araldite 2020

Gluing of Bridges to Top Sensor



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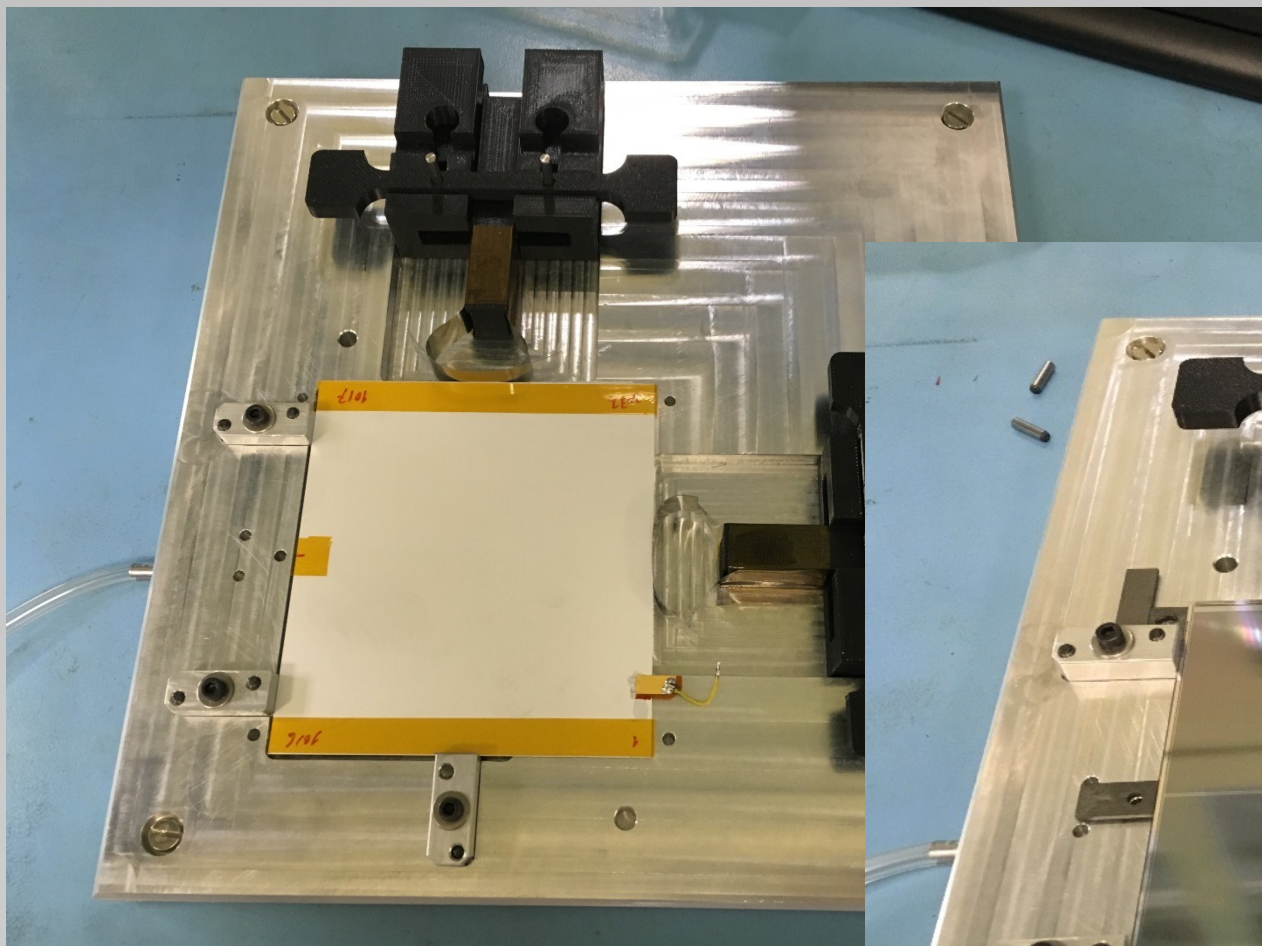
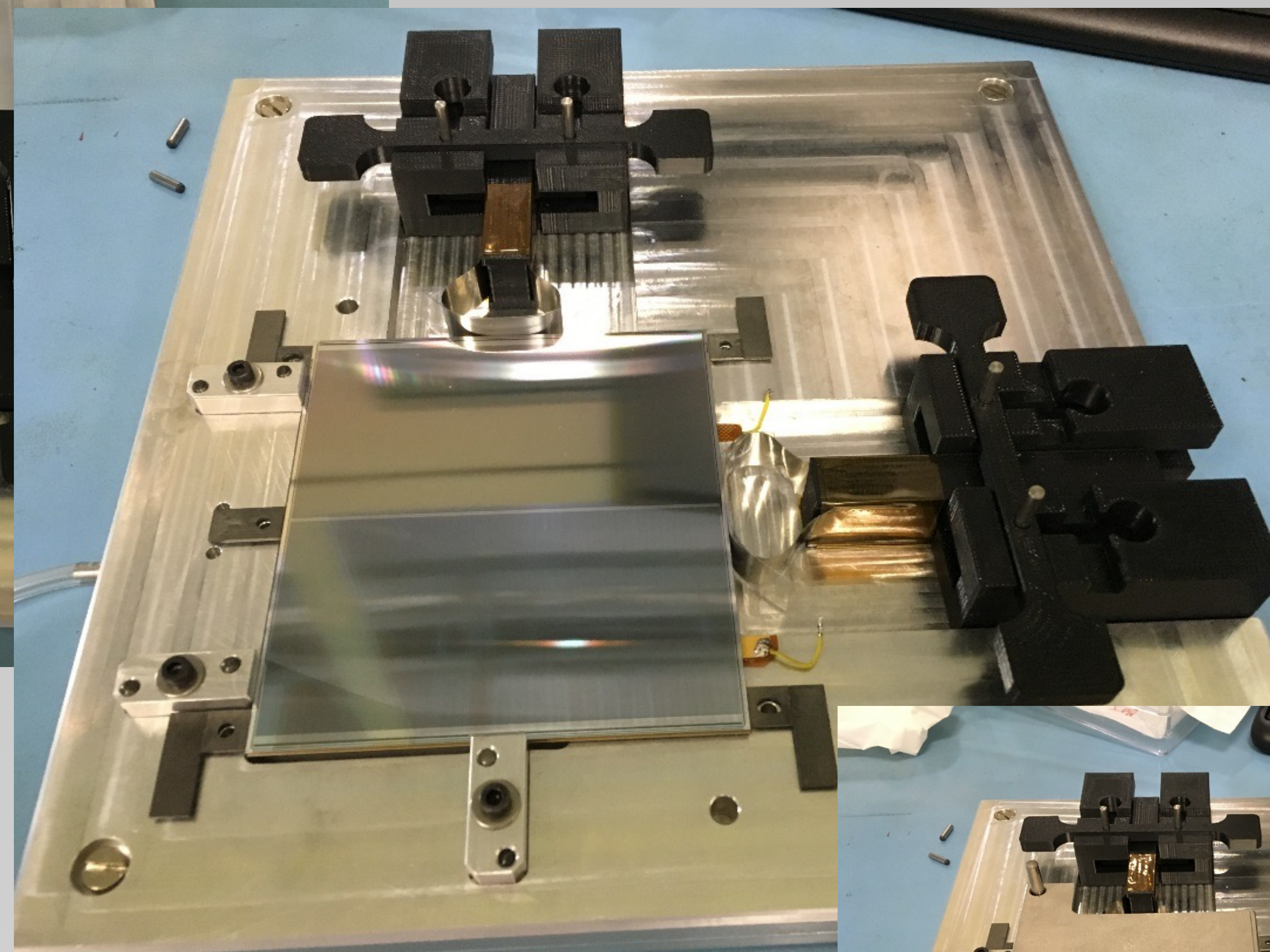
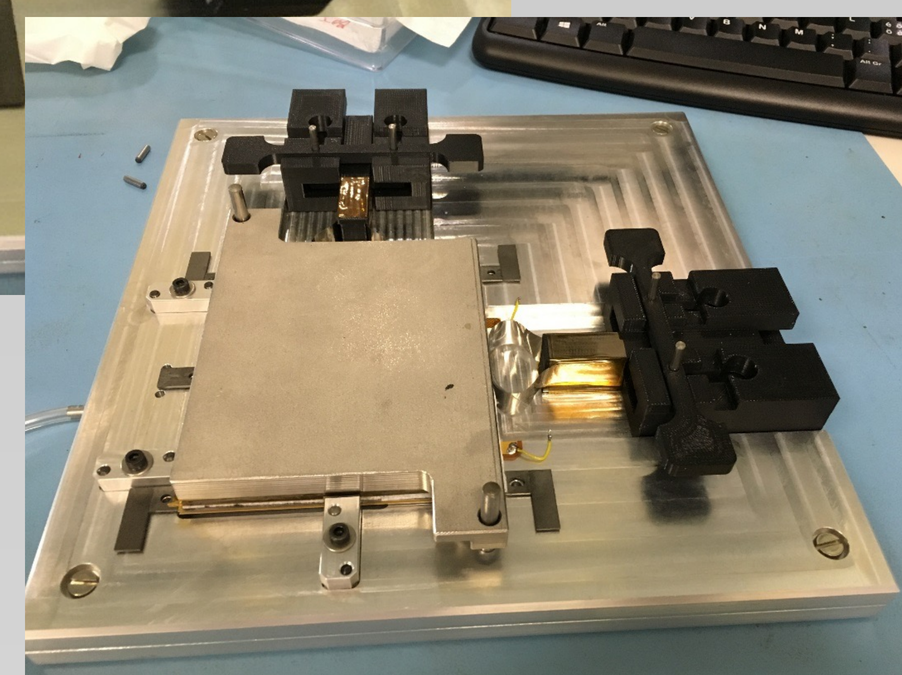
Gluing of Bottom Sensor to Top Sensor Package

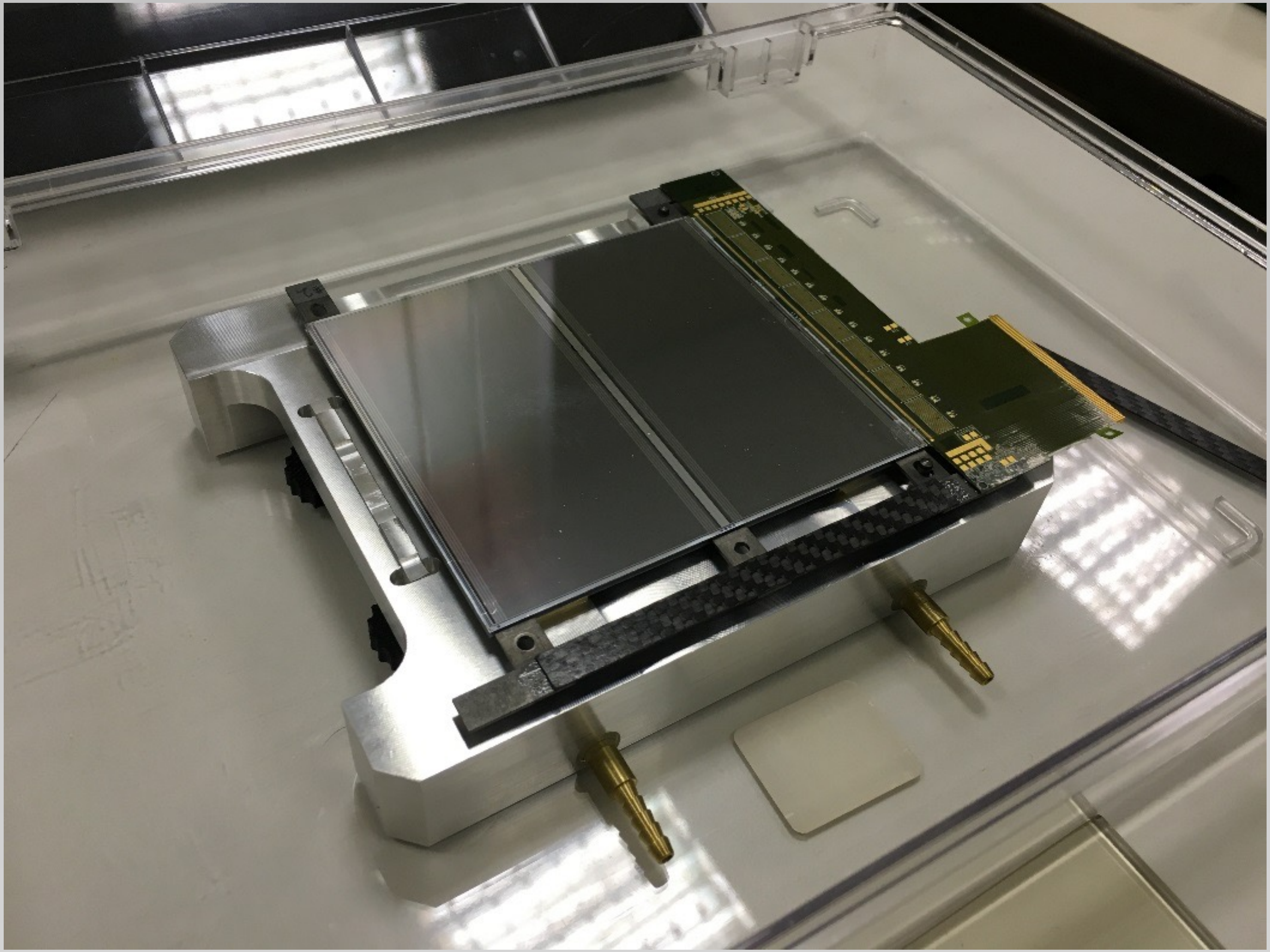




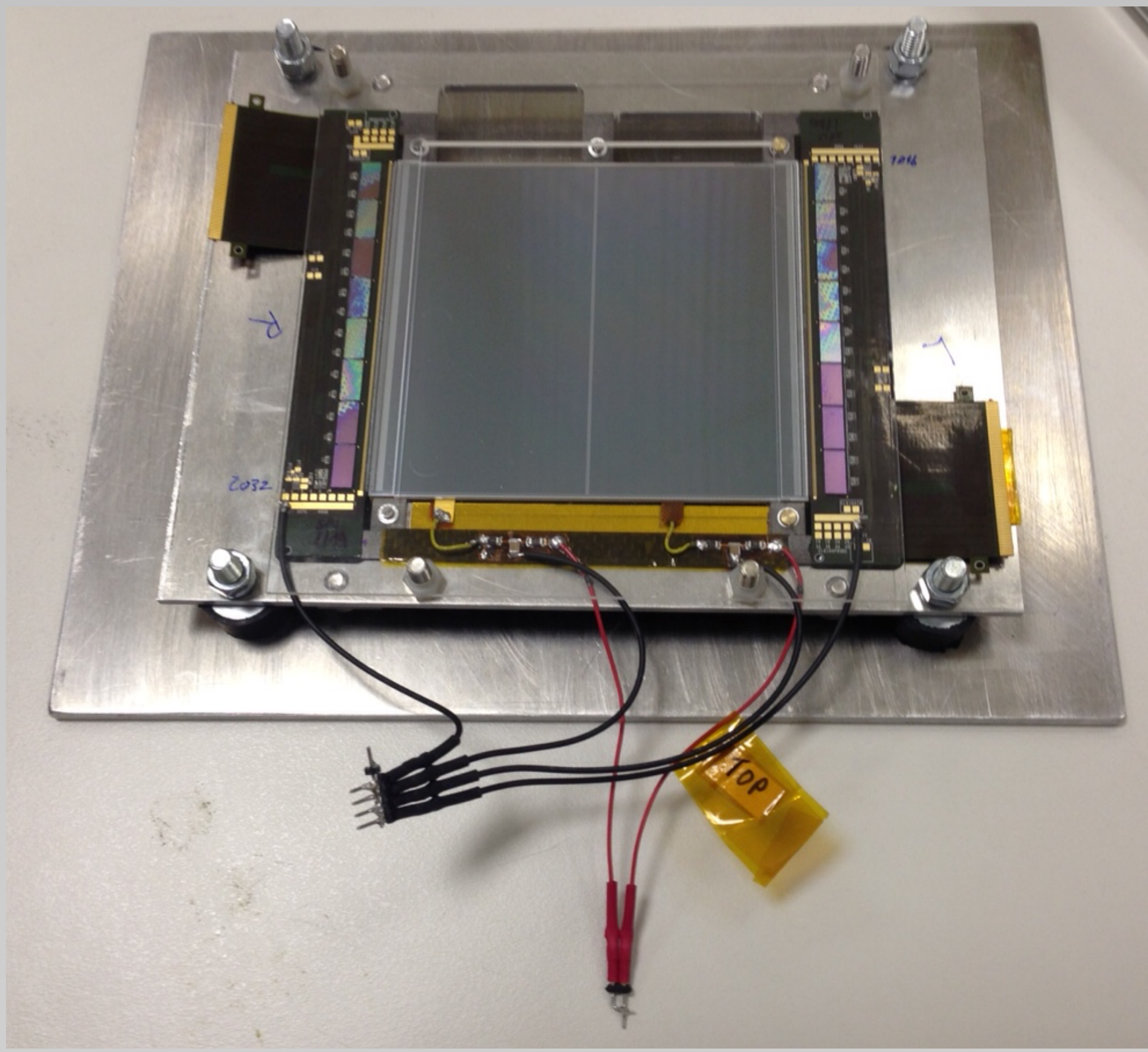


1. place bottom sensor on jig
2. engage springs
3. switch on vacuum
4. place top sensor package
5. engage springs
6. place weight plate

Wire Bonding Jig



1st Working 2S Module



- module successfully tested in test beam
- sensor to sensor alignment measured in Aachen on two dummy modules
    - 14 / 1 µrad (27 / 13 µrad rms)
    - goal is < 400 µrad

Summary

- module design goes beyond an object that spits out signals
- stable operation at <-20 °C for >10 years without repair / exchange
- one has to be able to build the object in large quantities
- parts have to be manufacturable at a reasonable cost
- used materials have to be available
- one has to be able to test the modules with reasonable effort
- …