CMS Outer Tracker Module Production

Doris Eckstein

12th Terascale Detector Workshop

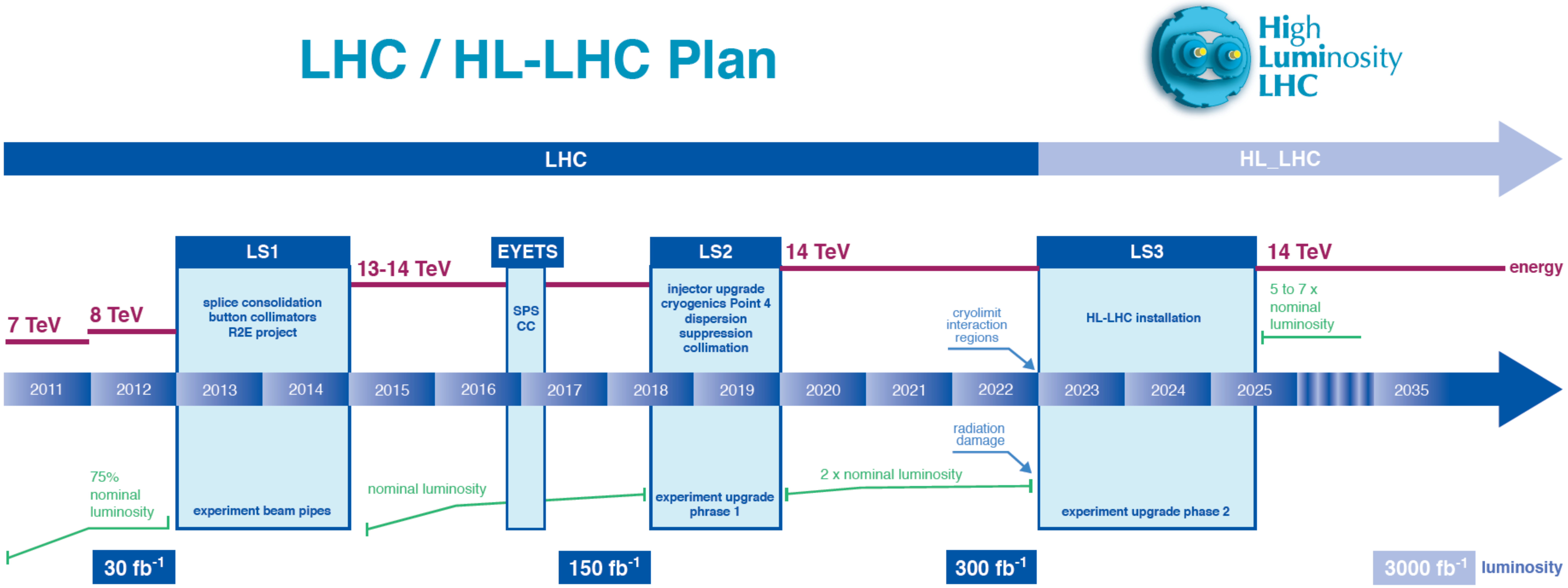
Dresden

14.3.2019

HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

DESY.

LHC Schedule



During LS3: upgrade of accelerator to peak luminosities of 5×10^{34} $cm^{-2}s^{-1}$ (ultimately up to 7.5×10^{34} $cm^{-2}s^{-1}$)

—> collect up to 300 fb^{-1} per year (450 fb^{-1} ultimately)

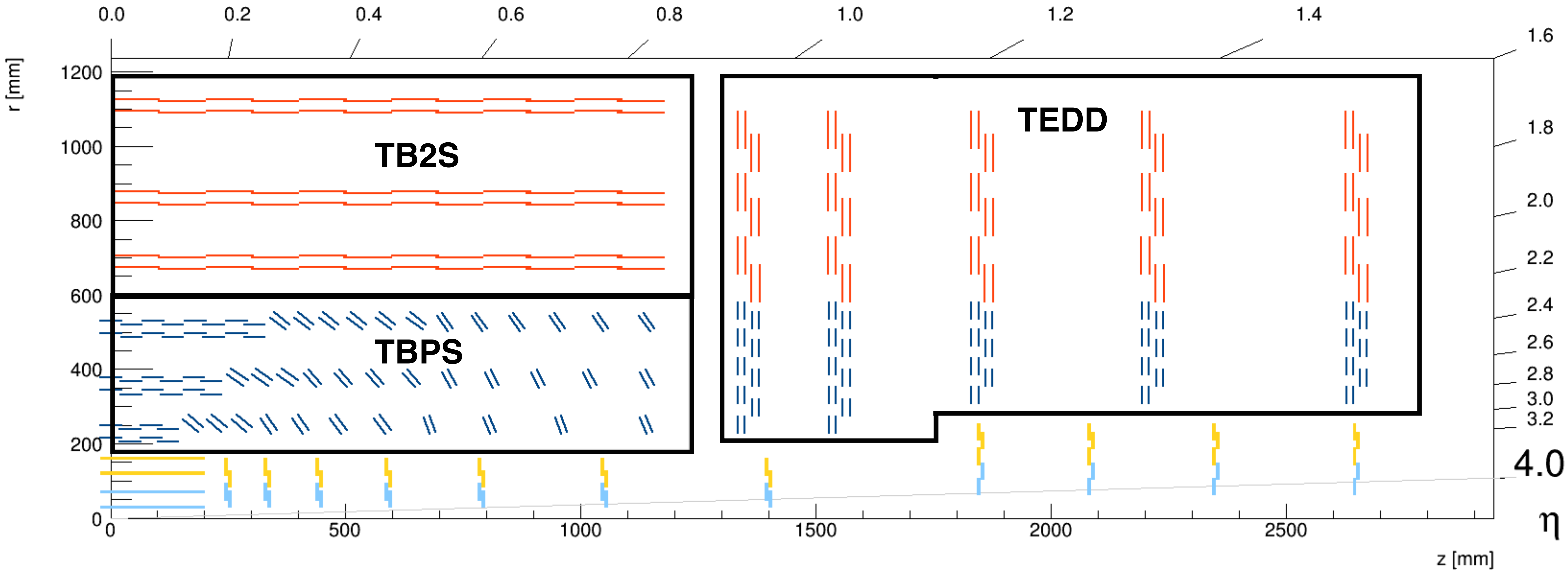
—> irradiation levels 1.1×10^{15} $n_{eq} \times cm^{-2}$

—> requires new trigger concepts

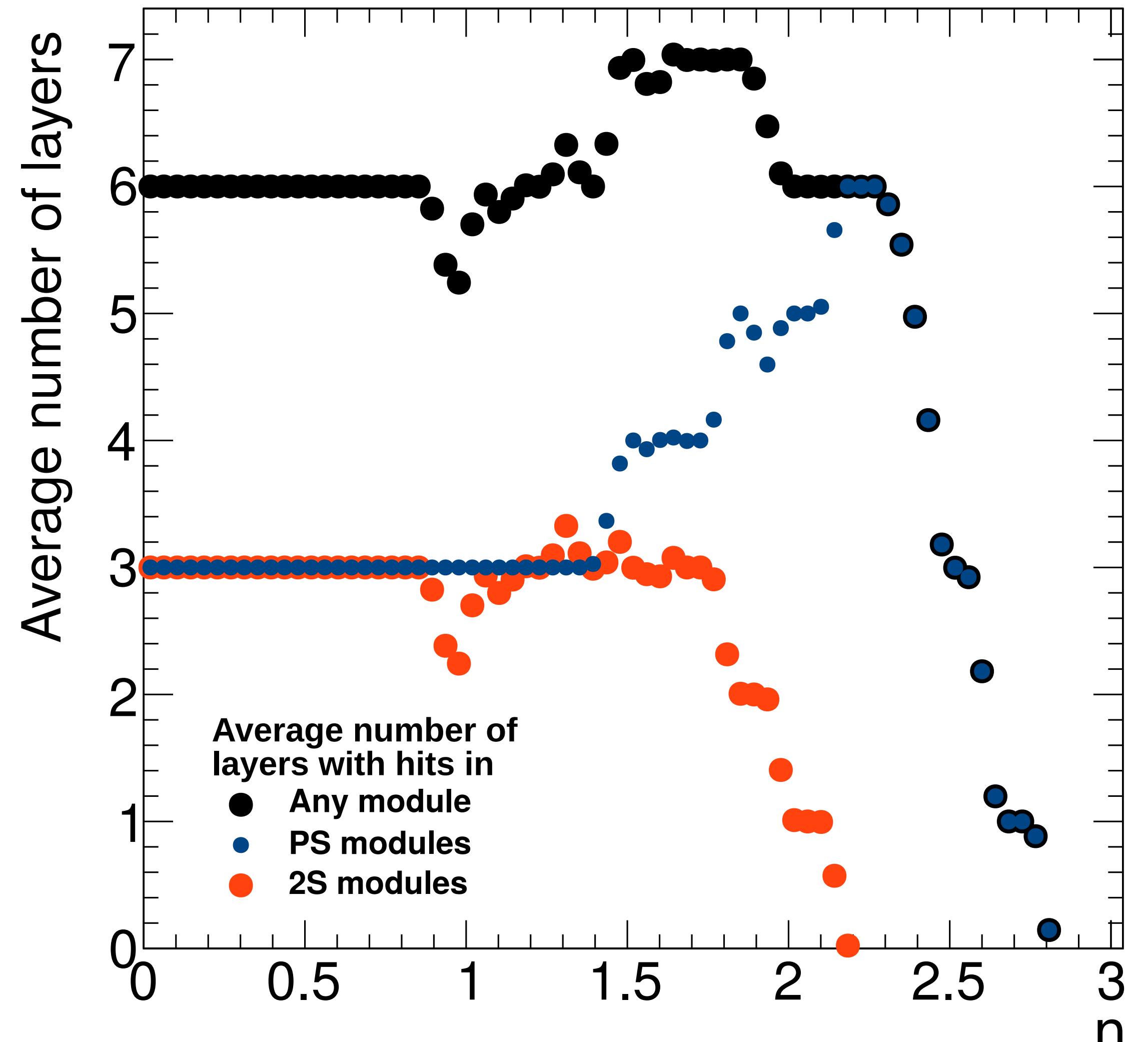
—> requires higher granularity

CMS Tracker will be upgraded

CMS Tracker Concept

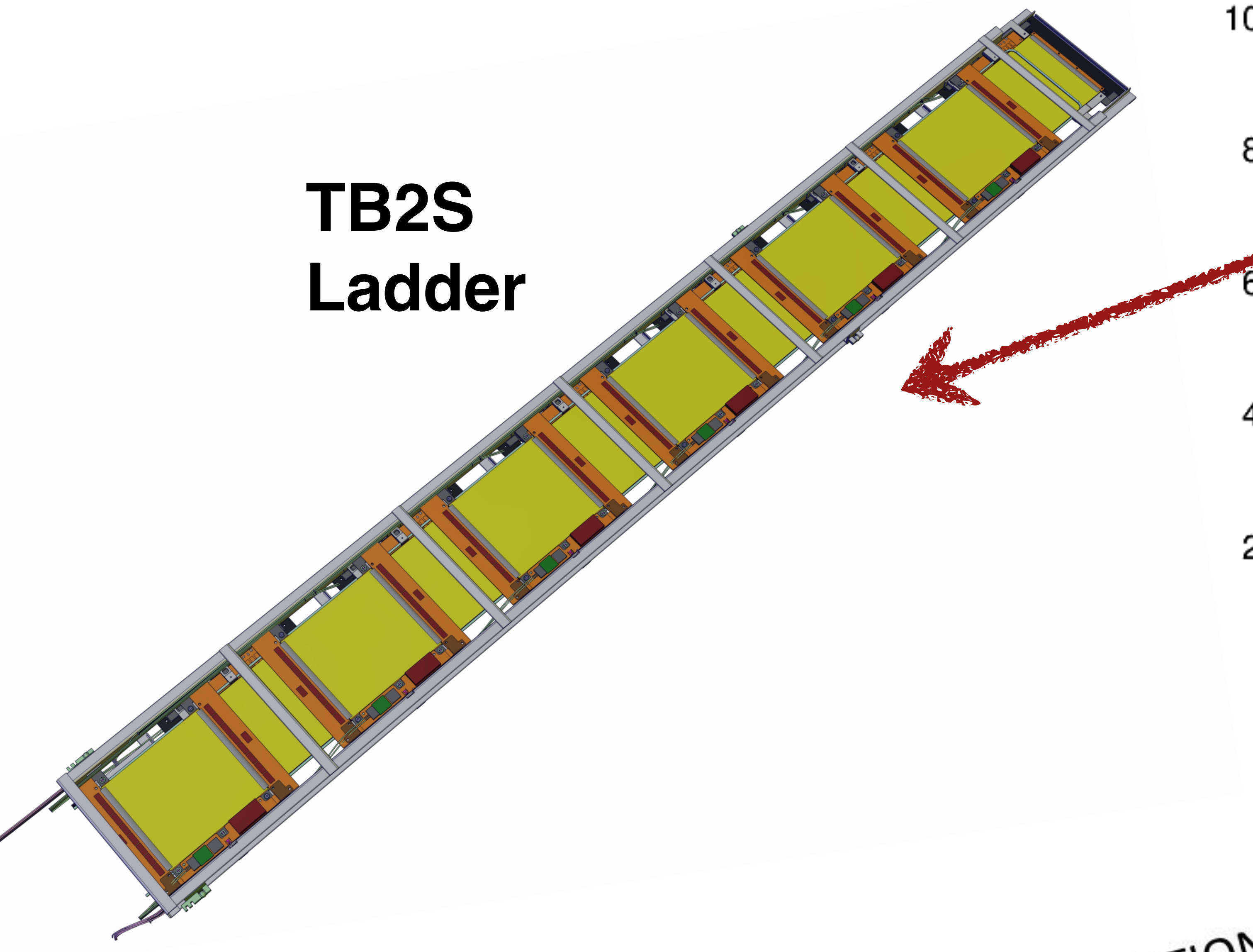


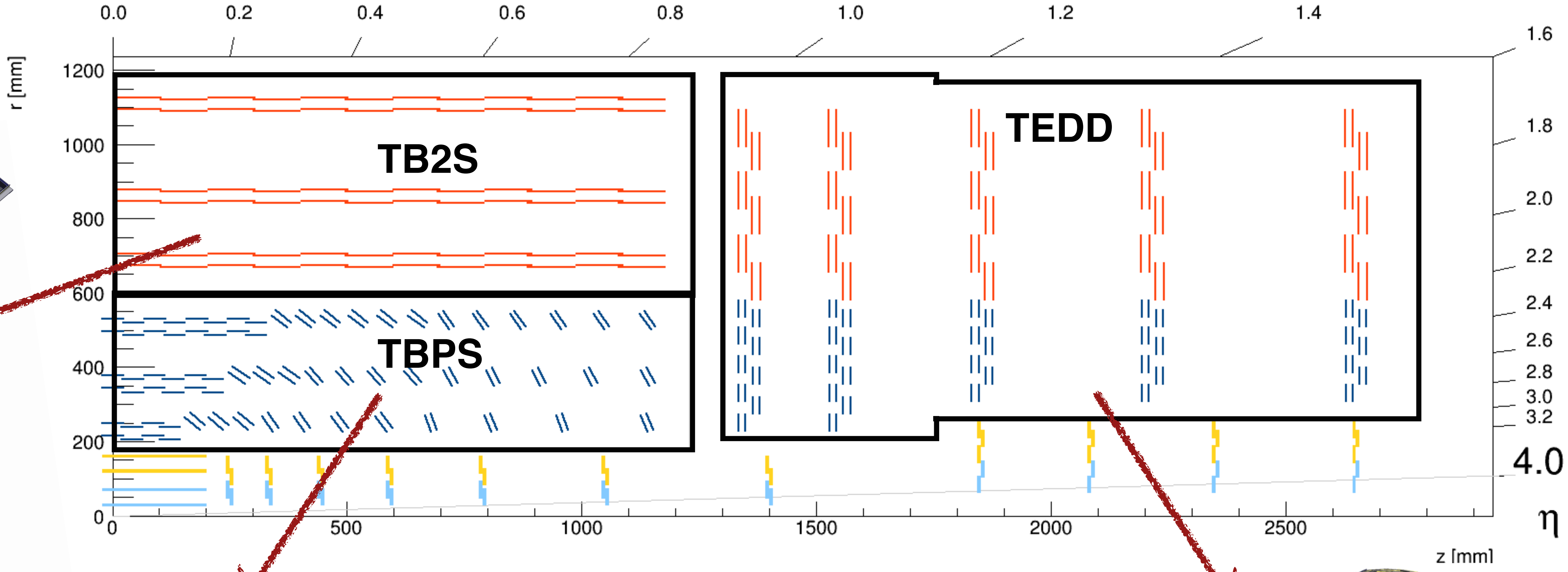
- Layout with barrel (6 layers) and endcaps (5 double discs)
- Only 3 types of rectangular sensors in two types of modules throughout tracker
  - TBPS: barrel with straight and tilted section of PS modules
  - TB2S: barrel with 2S modules
  - TEDD: endcap with PS modules in inner and 2S in outer region
- Modules are cooled via evaporative CO_2 to keep sensors at <-20°C
- German groups will build modules and assemble and integrate one endcap



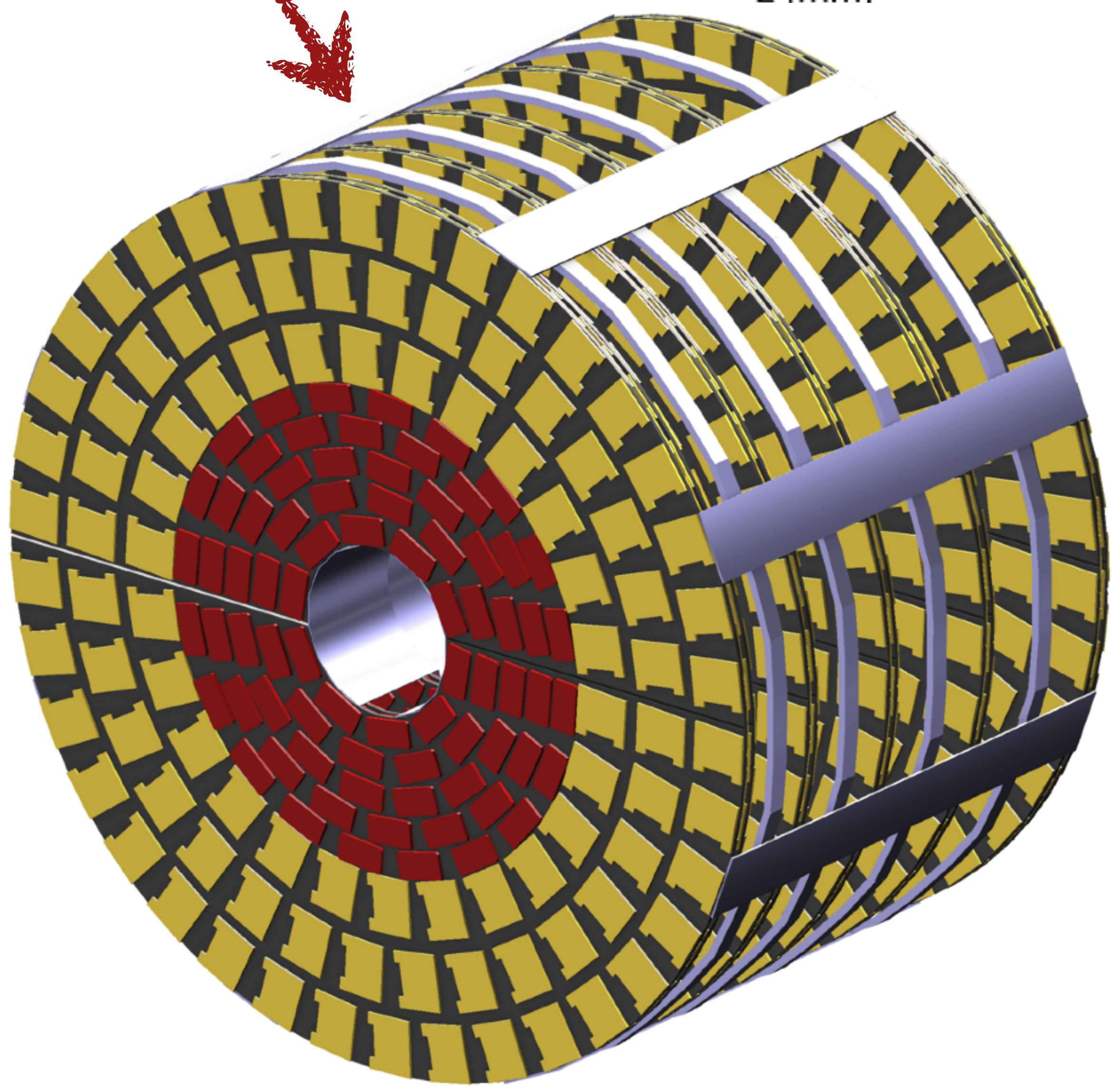
CMS Tracker Concept

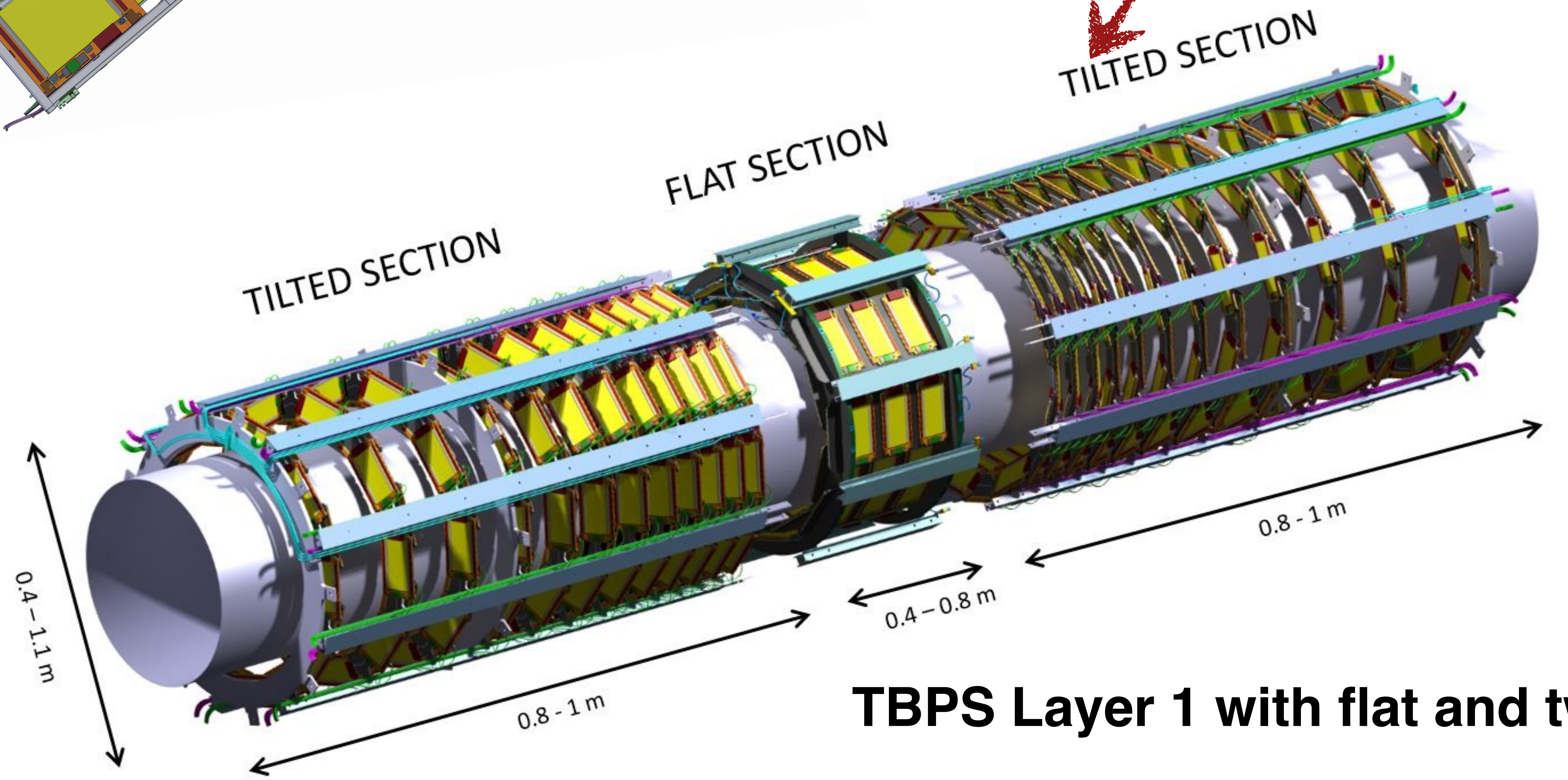
TB2S
Ladder





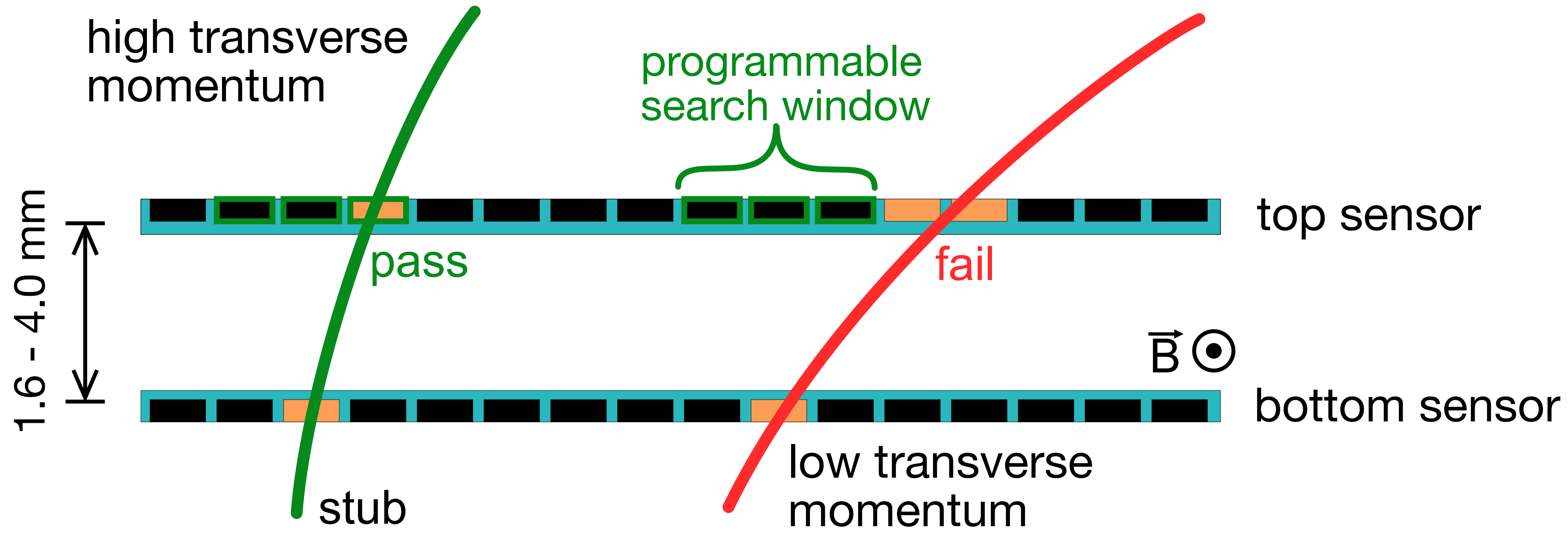
TEDD with
5 layers

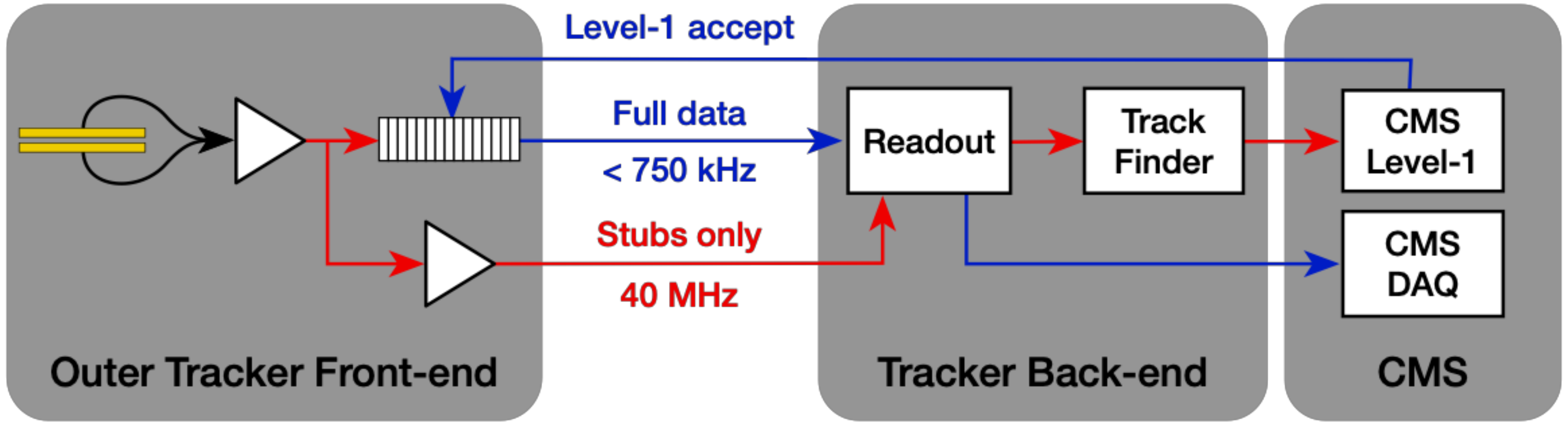




TBPS Layer 1 with flat and two tilted sections

CMS Module Concept

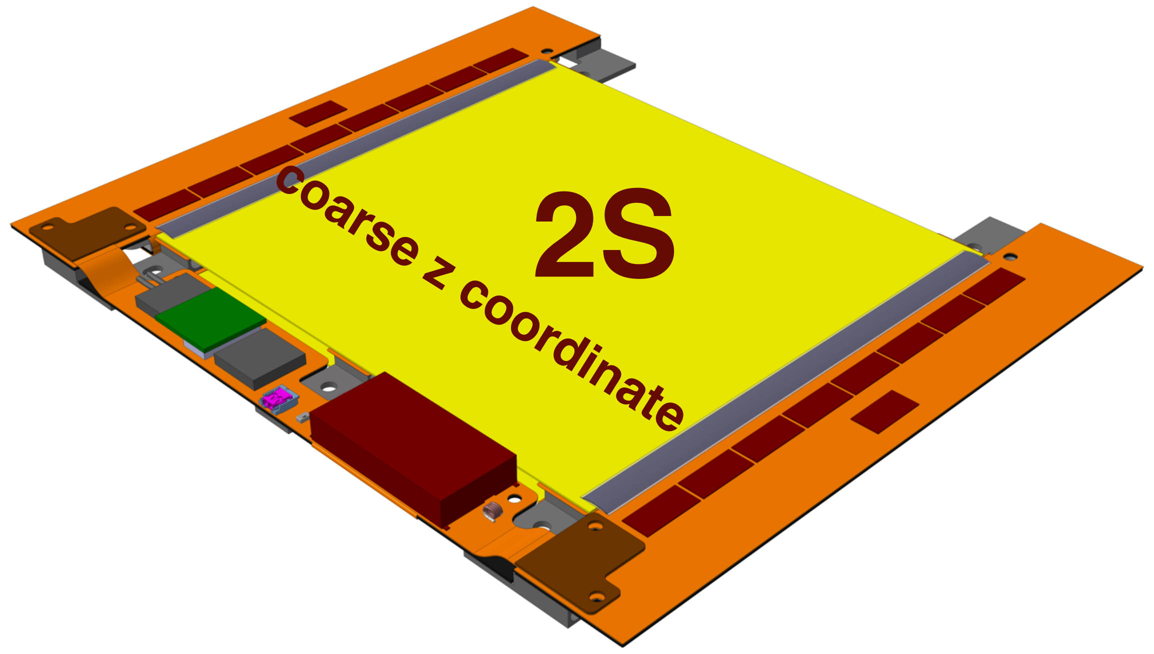


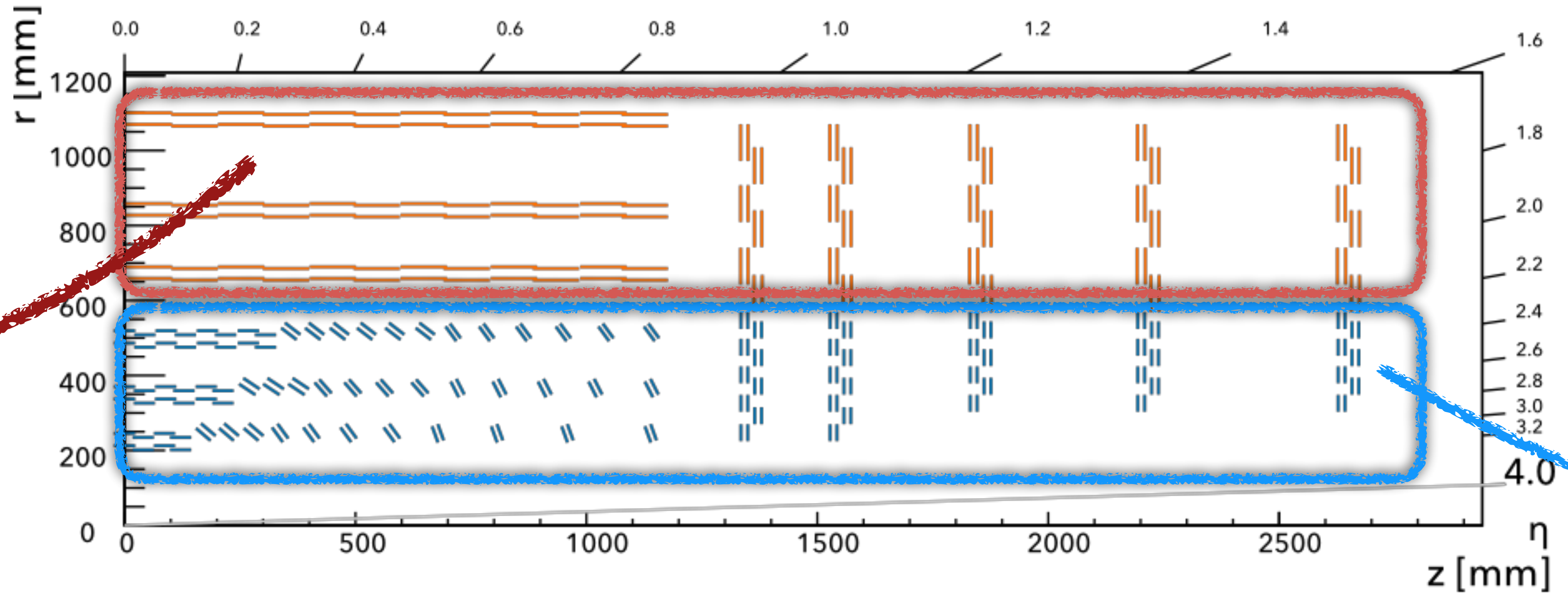


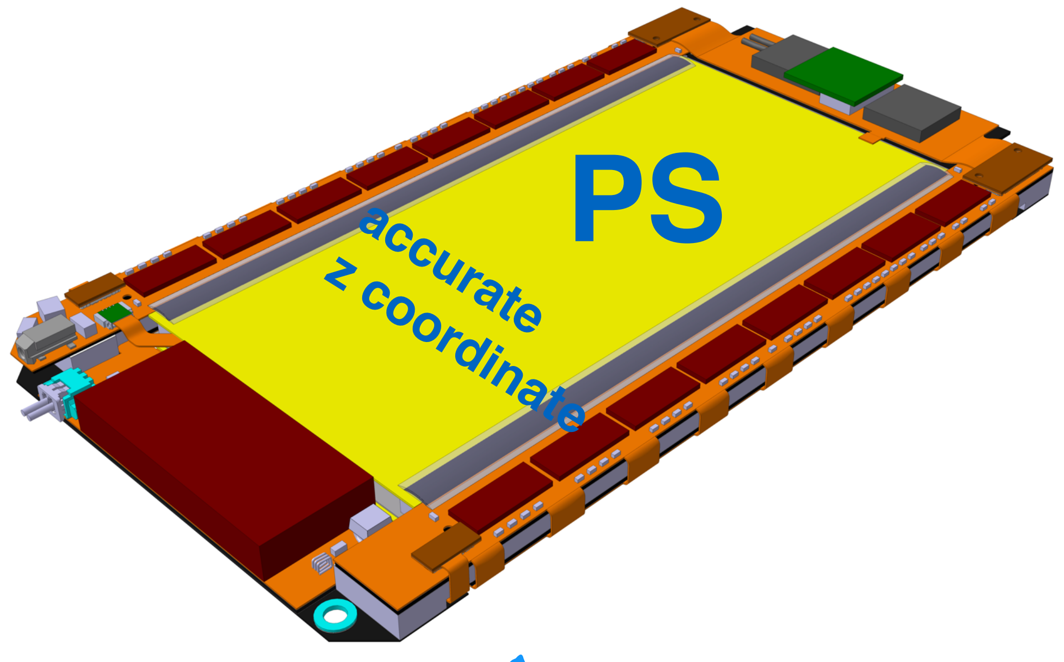
- exploit strong magnetic field of 3.8 T of CMS solenoid
- p_T discrimination on board:
  - two closely spaced sensors
  - correlate signals —> local p_T measurement
  - reject low p_T Tracks —> minimise data volume
- 'stub' is formed of signals found within search window

- Level-1 and readout data provided
  - 'stubs' are sent at each bunch-crossing (40 MHz)
  - Full data are read out on trigger decision (<750 kHz)

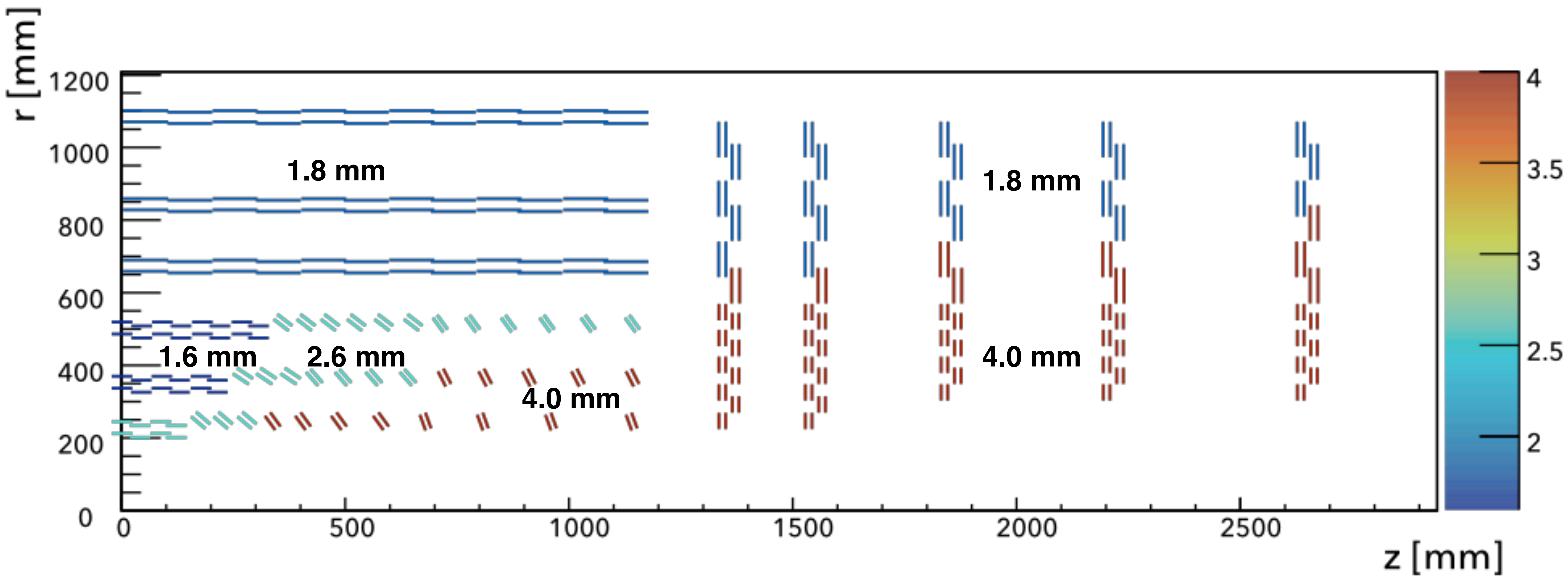
CMS Tracker Concept — Modules



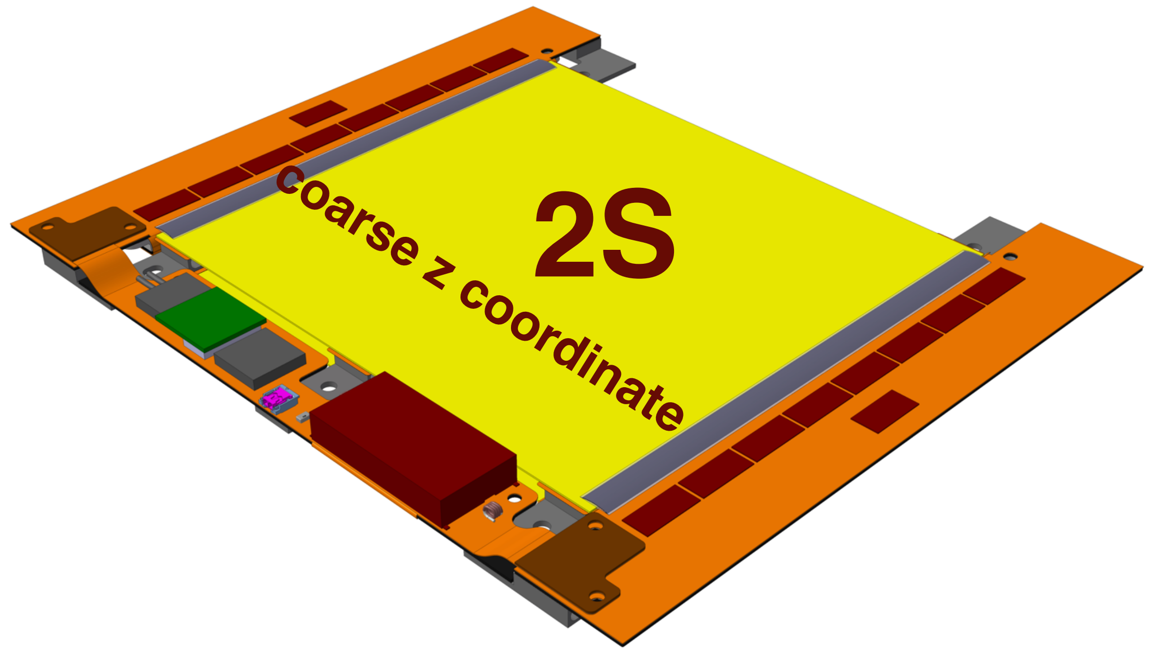


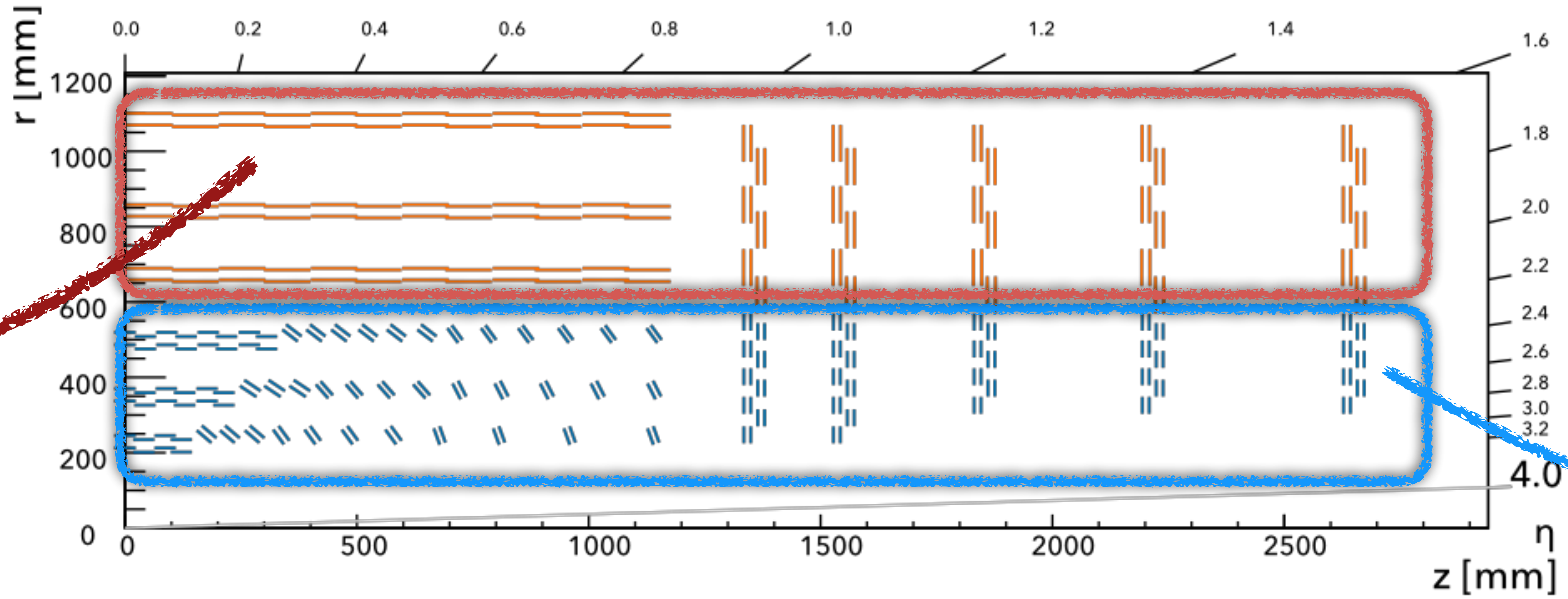


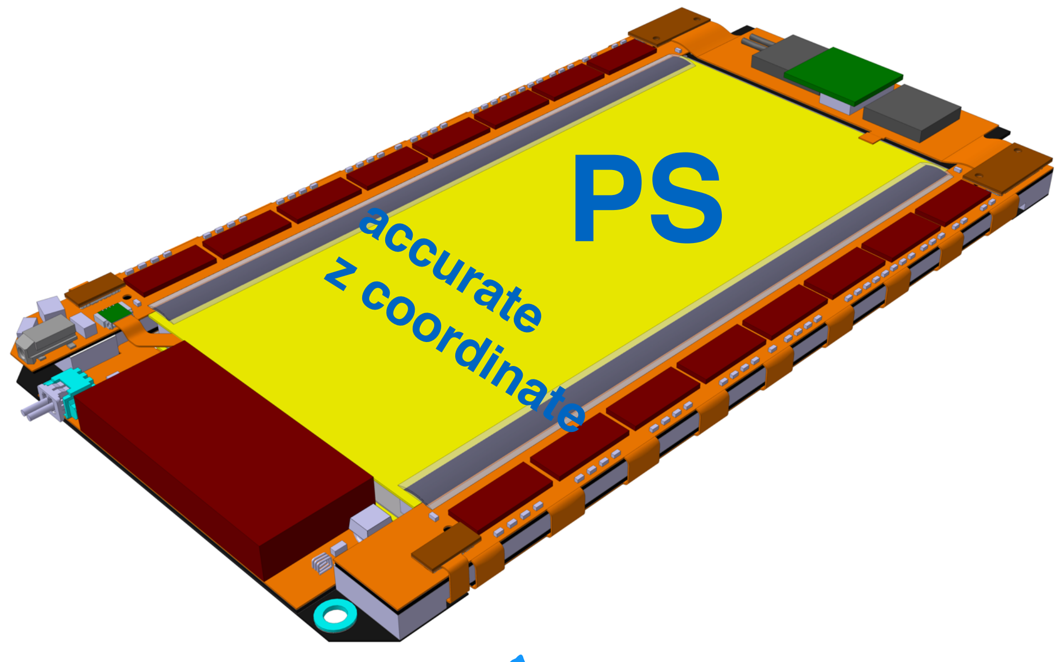
- Two main types of modules:
  - 2S with two strip sensors
  - PS with one strip and one pixelated sensor
- variants differ in sensor spacing
  - arranged to optimise p_T discrimination vs. geometrical position in Tracker



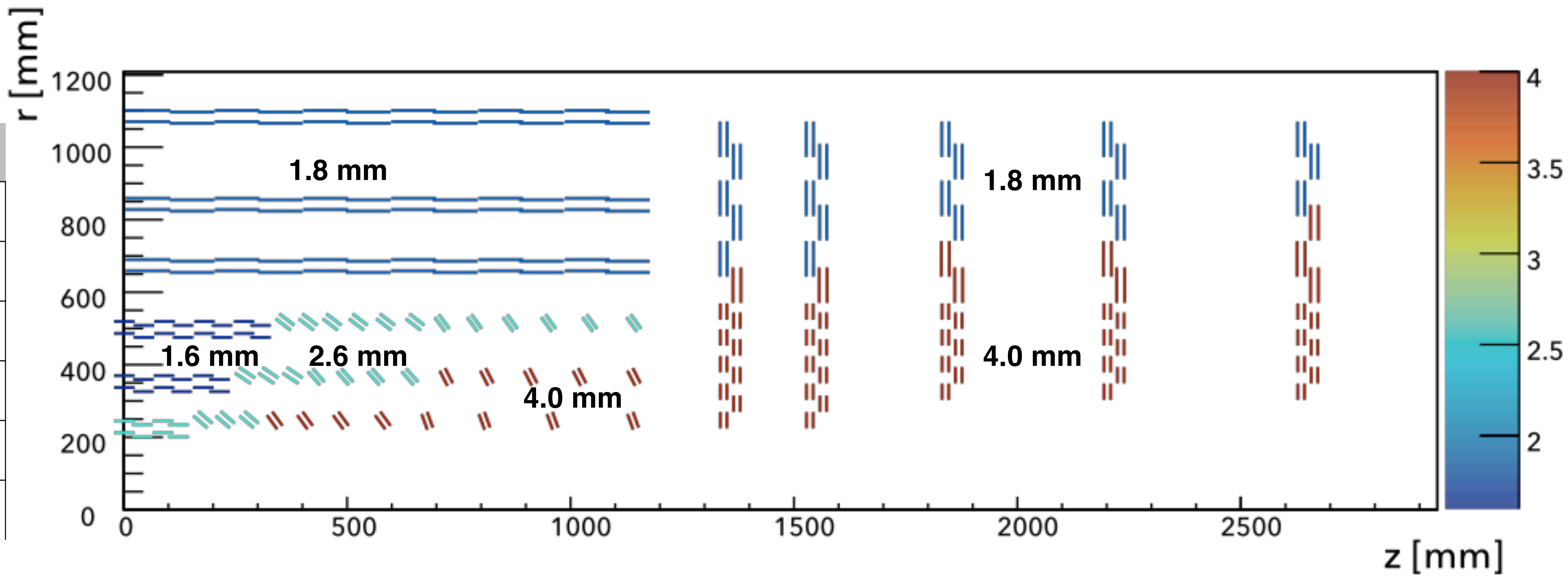
CMS Tracker Concept — Modules



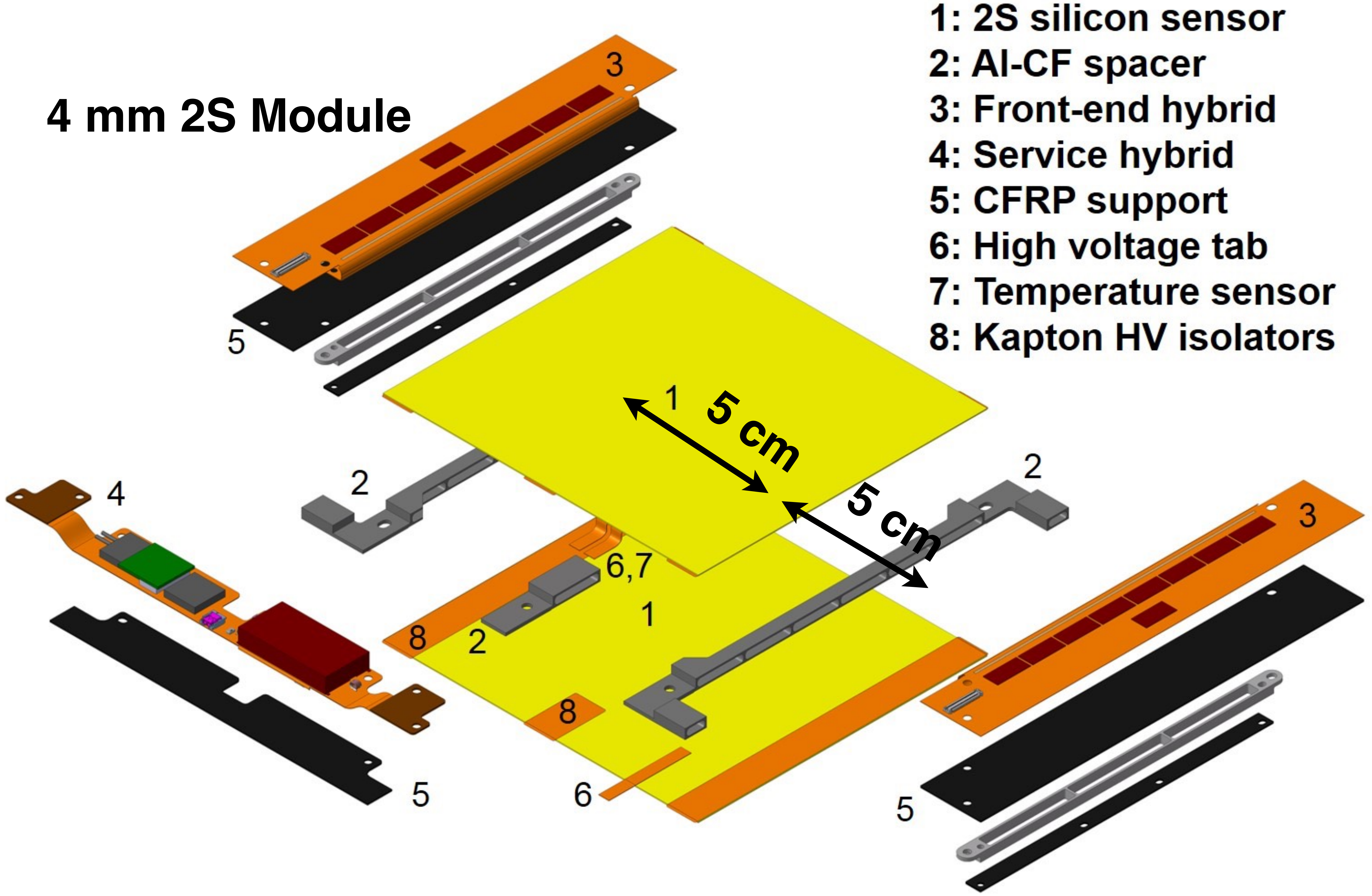




	barrel	one end cap	tracker
1.8 mm 2S Module	4464	1396	7256
4.0 mm 2S Module		212	424
1.6 mm PS Module	826		826
2.6 mm PS Module	1462		1462
4.0 mm PS Module	584	1372	3328
total	7336	2980	13296

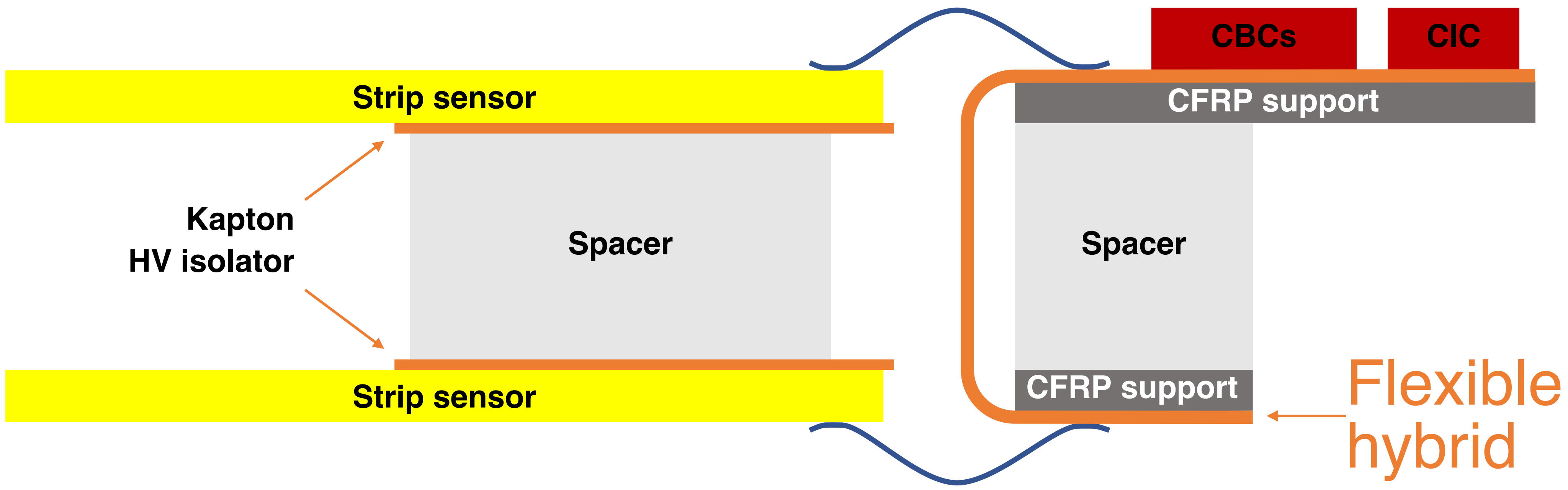


2S Module



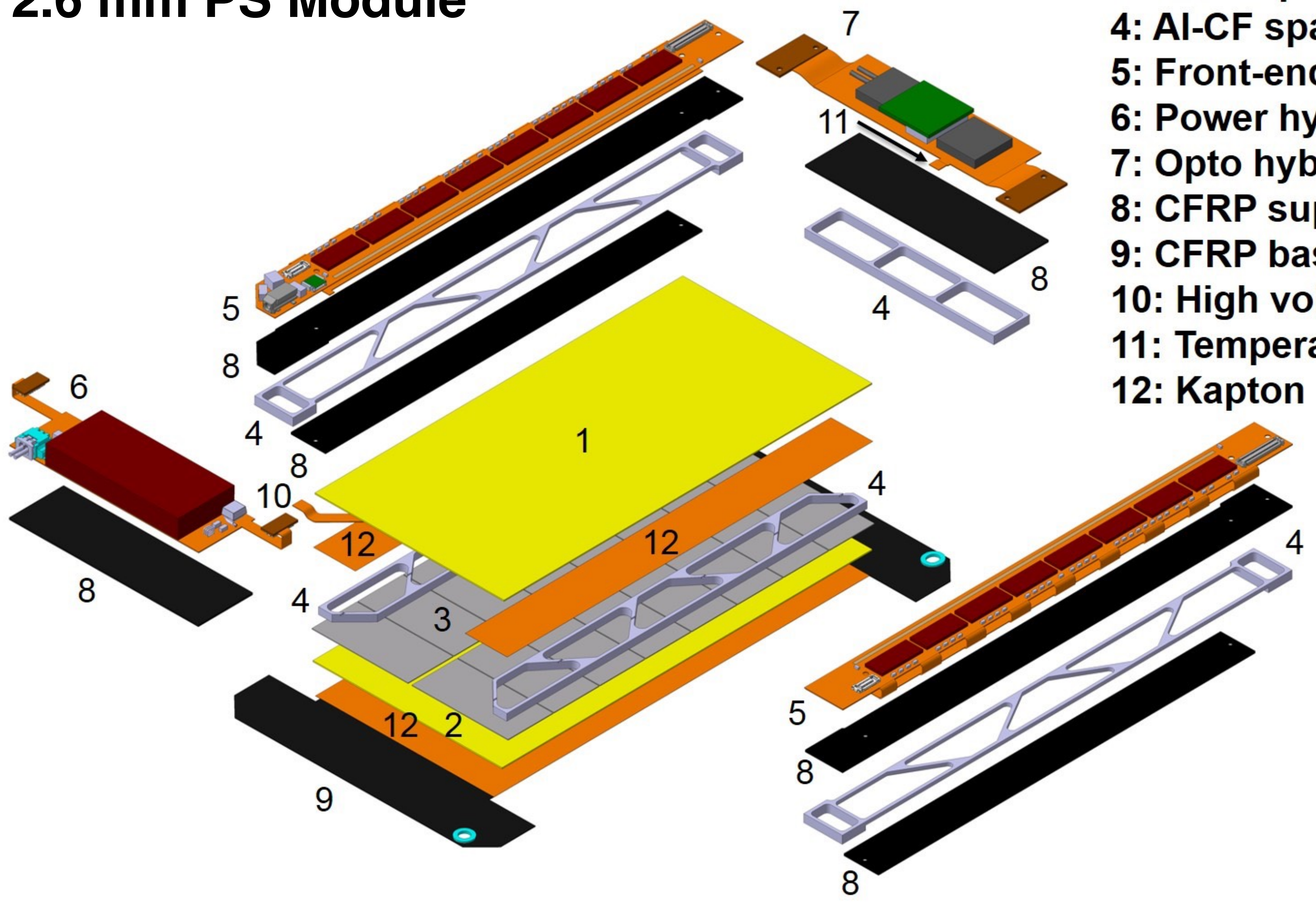
- 2 x 1016 strips of ~5cm x 90 µm per sensor
- Front-end power ~5 W
- Sensor power ~1 W at -20°C
- Flexible hybrid brings signal of top and bottom, sensor to CBC chip
- Sensors are supported and kept at distance by Al-CF bridges
  - Al-CF is carbon-fibre reinforced Aluminium
  - Coefficient of thermal expansion matches Silicon
  - no or minimal thermal stress when module is operated at low temperature
- HV Isolation necessary

- CBC processes data from 2x127 strips and builds stubs
- 8 CBC's per FEH
- exchange data with neighbours
- CIC receives data, performs zero suppression



PS Module

2.6 mm PS Module



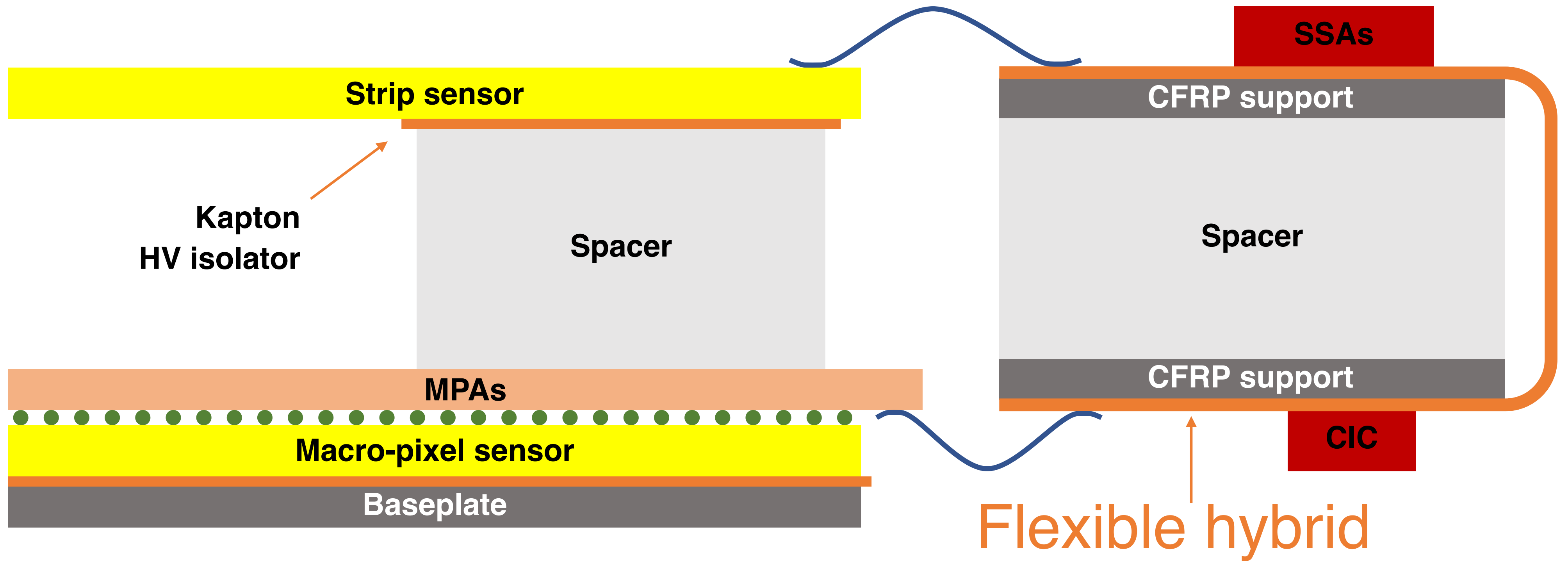
1: PS-s sensor
2: PS-p sensor
3: Macro-pixel ASICs
4: Al-CF spacer
5: Front-end hybrid
6: Power hybrid
7: Opto hybrid
8: CFRP support
9: CFRP baseplate
10: High voltage tab
11: Temperature sensor
12: Kapton HV isolators

- 2 x 960 strips of ~2.4 cm x 100 μm for PSs sensor
- 32 x 960 macro-pixels of ~1.5mm x 100 μm for PSp sensor
- Front-end power ~8 W
- Sensor power ~1.4 W at -20°C
- AlN spacers might replace Al-CF

  —> no Kapton strip gluing would be necessary
- MPAs and sensors are cooled through base plate

  —> requires a large-area glue joint between pixel sensor and base plate

- SSA processes strip sensor data, sends data to MPA
- MPA processes macro-pixel sensor data, receives SSA data, correlates strip and pixel clusters and builds stubs
- CIC as for 2S module

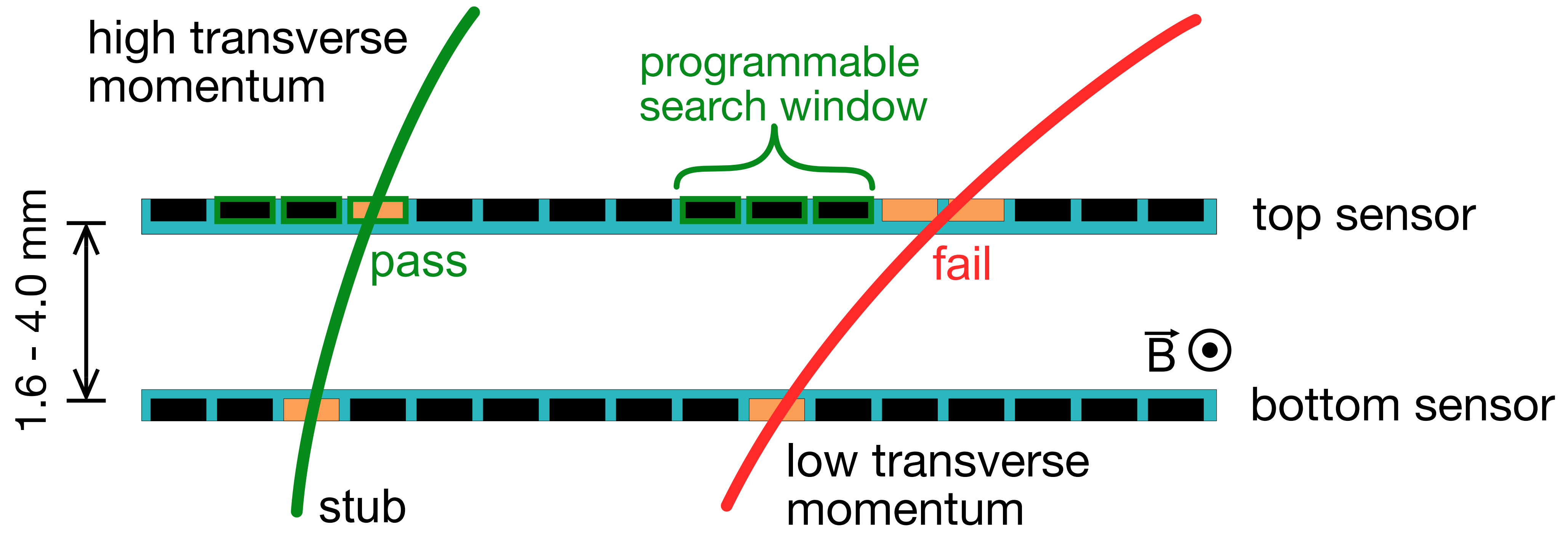


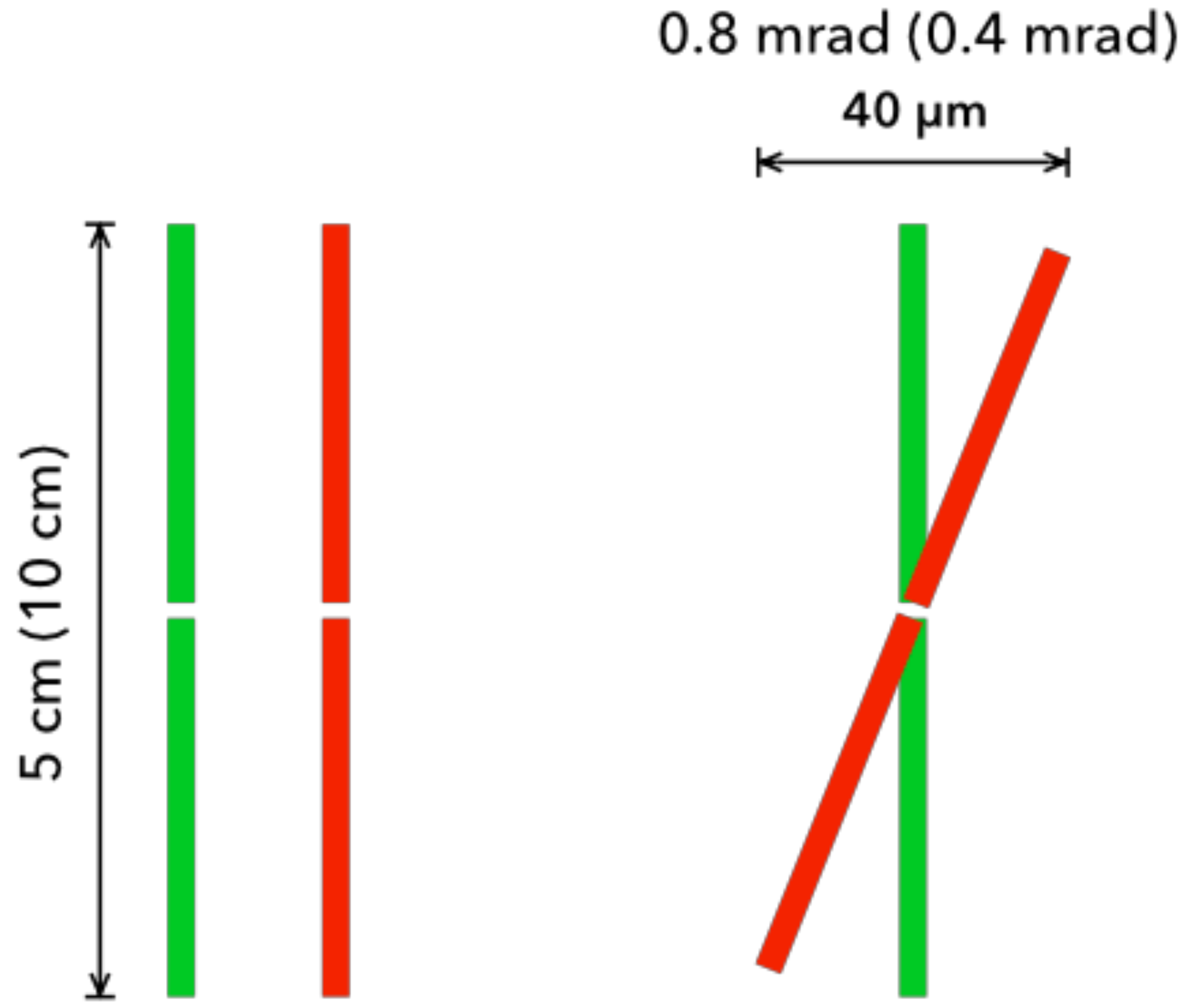
Requirements on p_T Module

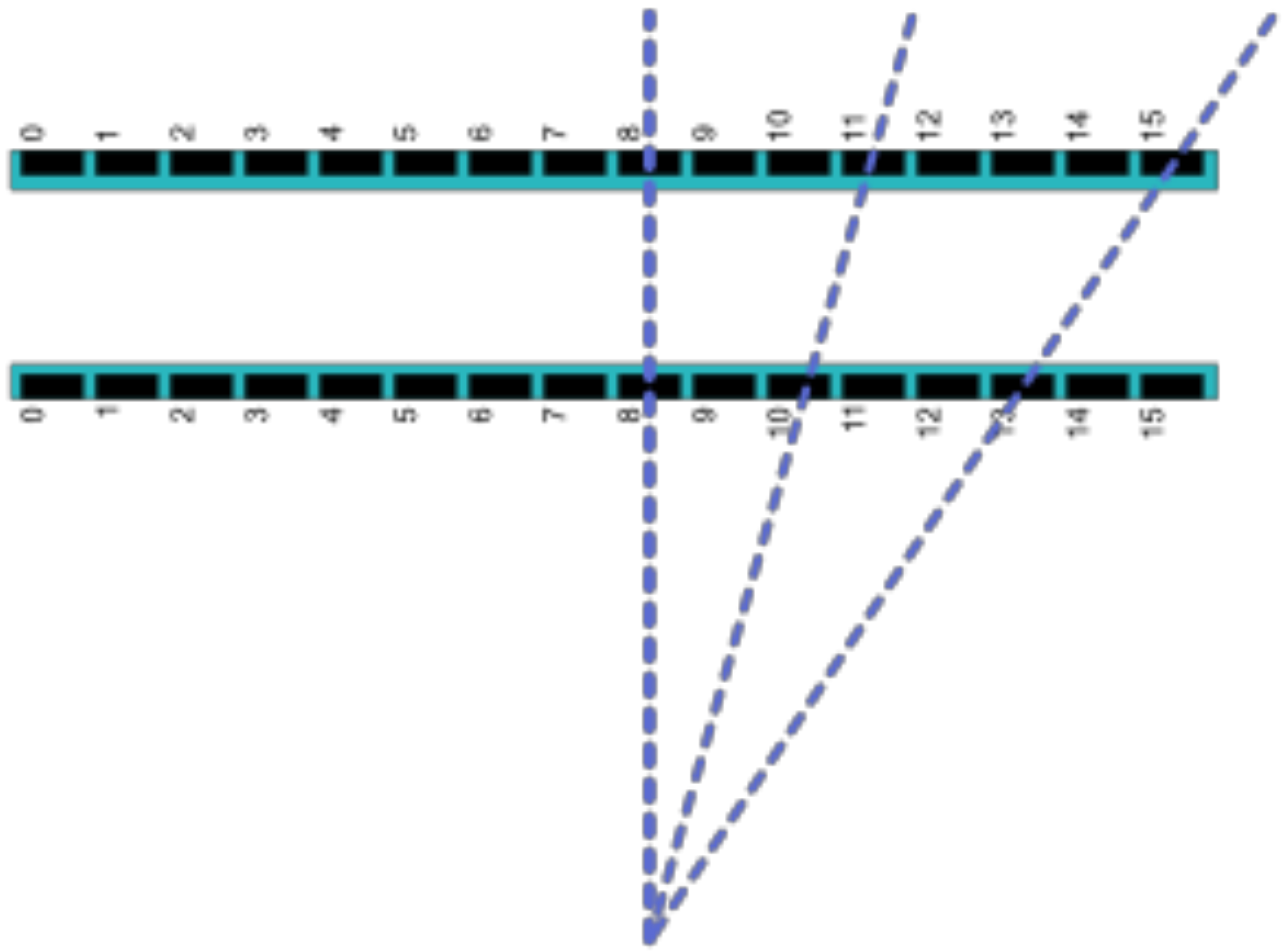
Relative sensor position

- p_T modules use programmable search window to correlate hits
- discrimination requires precise sensor alignment within module
    - parallel shifts can be corrected for in ‘stub’ finding logic
    - rotations result in position-dependency along strip direction

  —> max misalignment for PS sensor 800 µrad







Assembly of 2S modules jig-based
For PS we are working on establishing a partially automated assembly

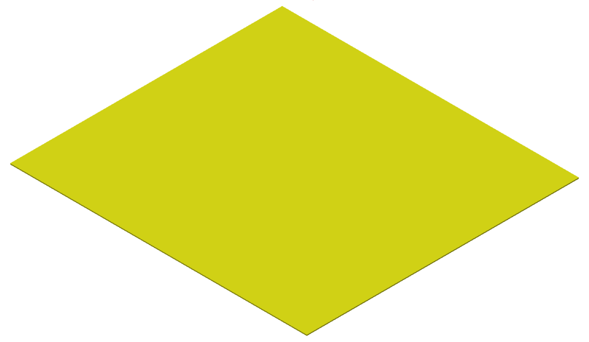
2S Module Assembly Sequence

S. Maier, KIT

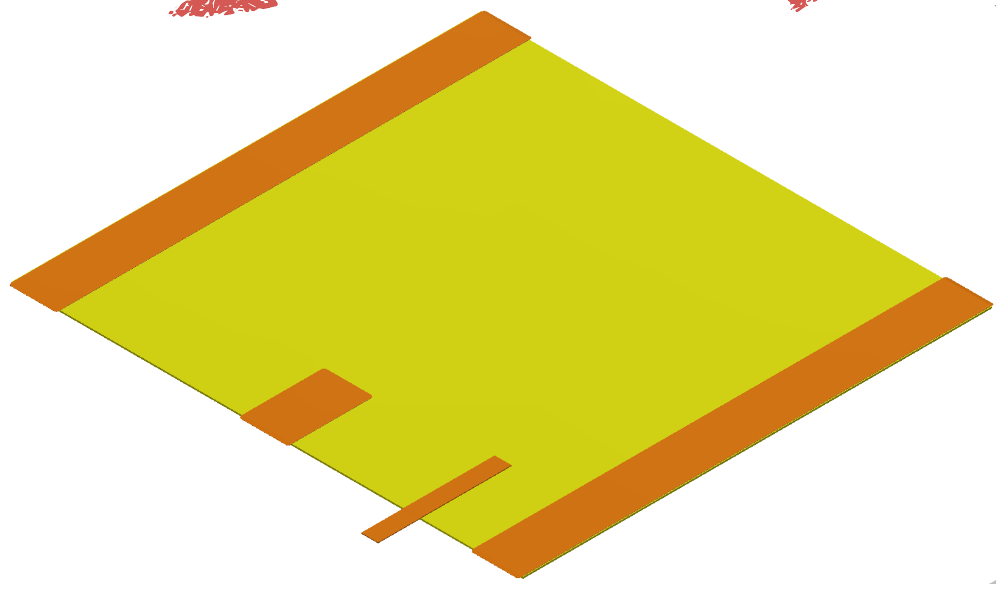
Glue Kapton isolator and attach HV tails on sensor backside

Wire bond and encapsulate HV tails

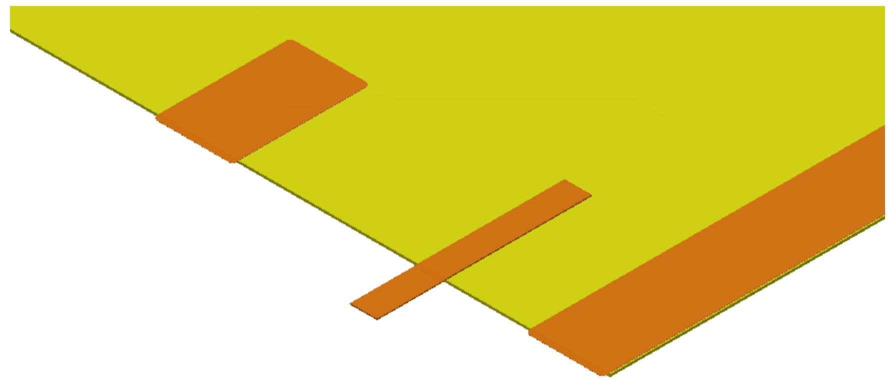
Glue sensors on Al-CF bridges



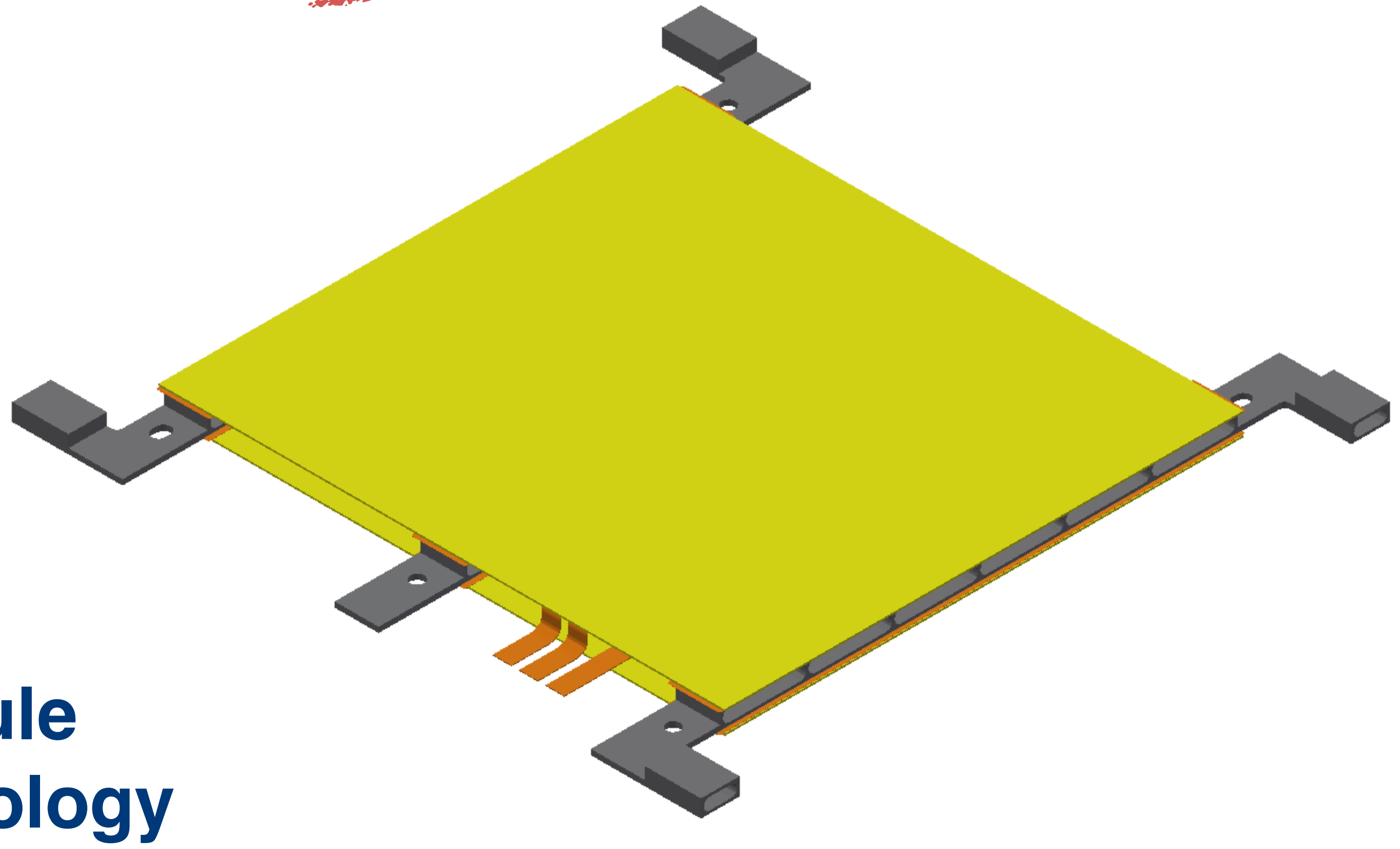
Reception test of all parts



Optical inspection

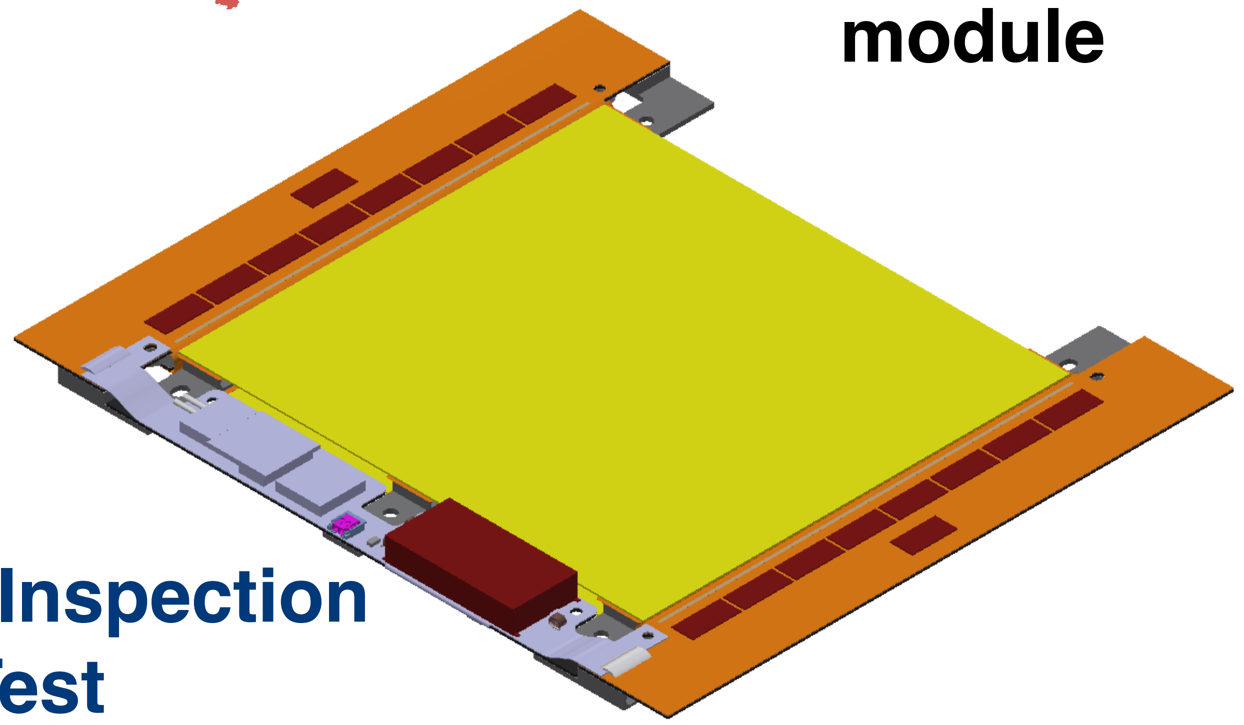


HV Test Sensor IV



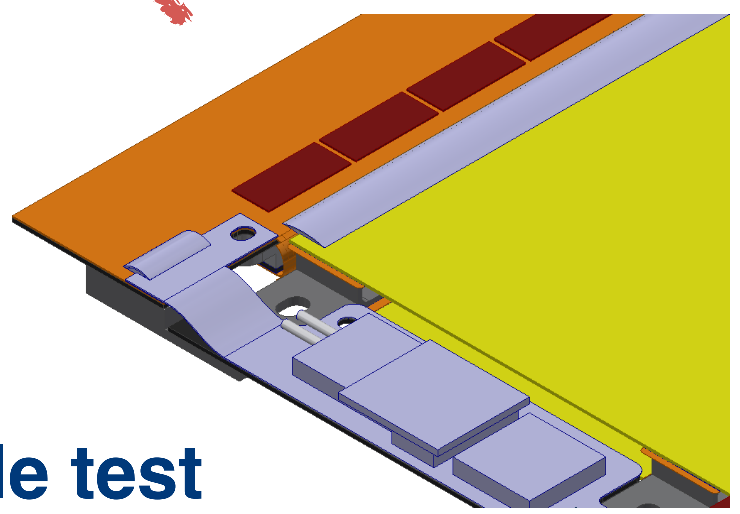
Module metrology

Glue readout and service hybrids on bare module



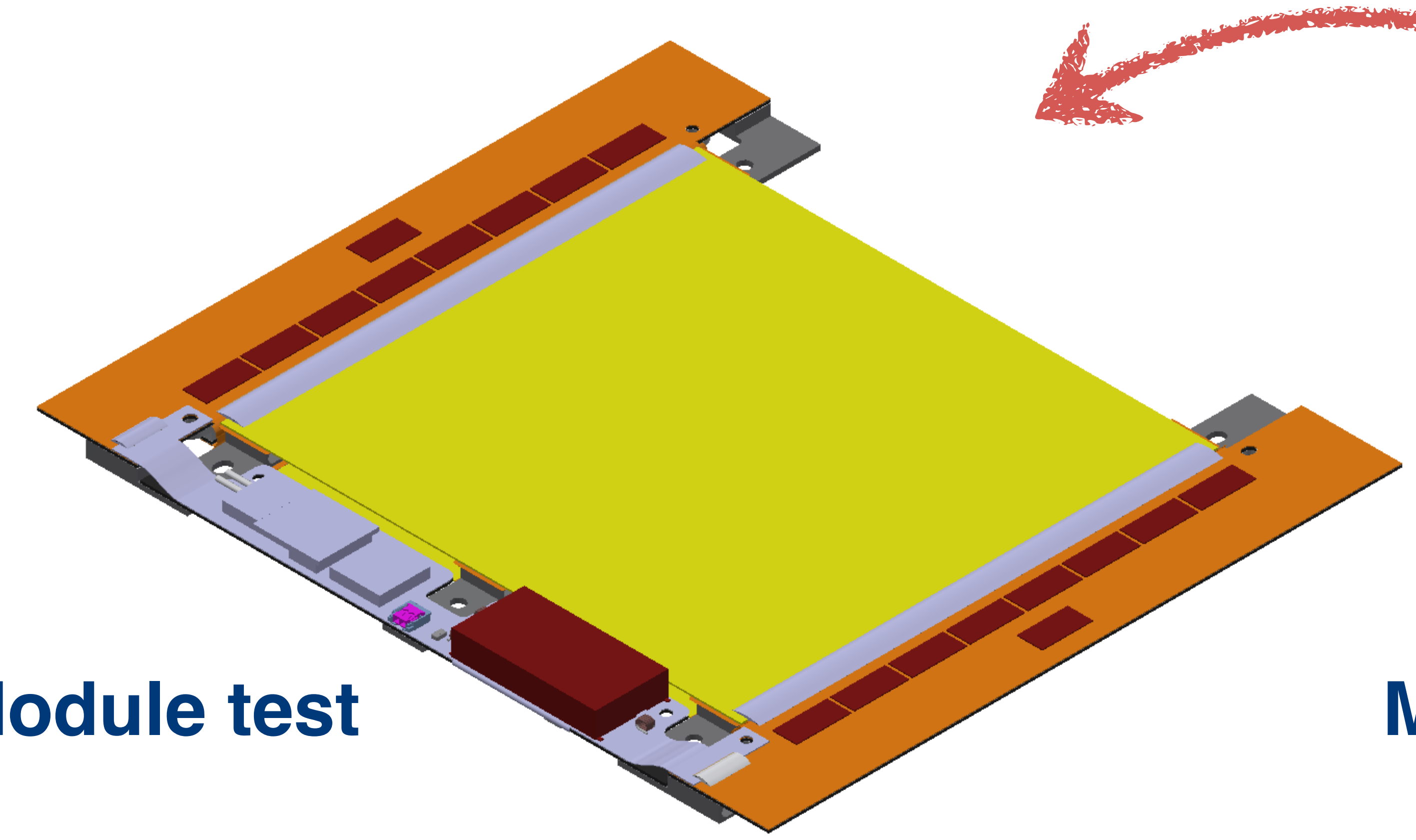
Optical Inspection HV/LV Test

Place 2 x 2 x ~1000 wire bonds



Module test

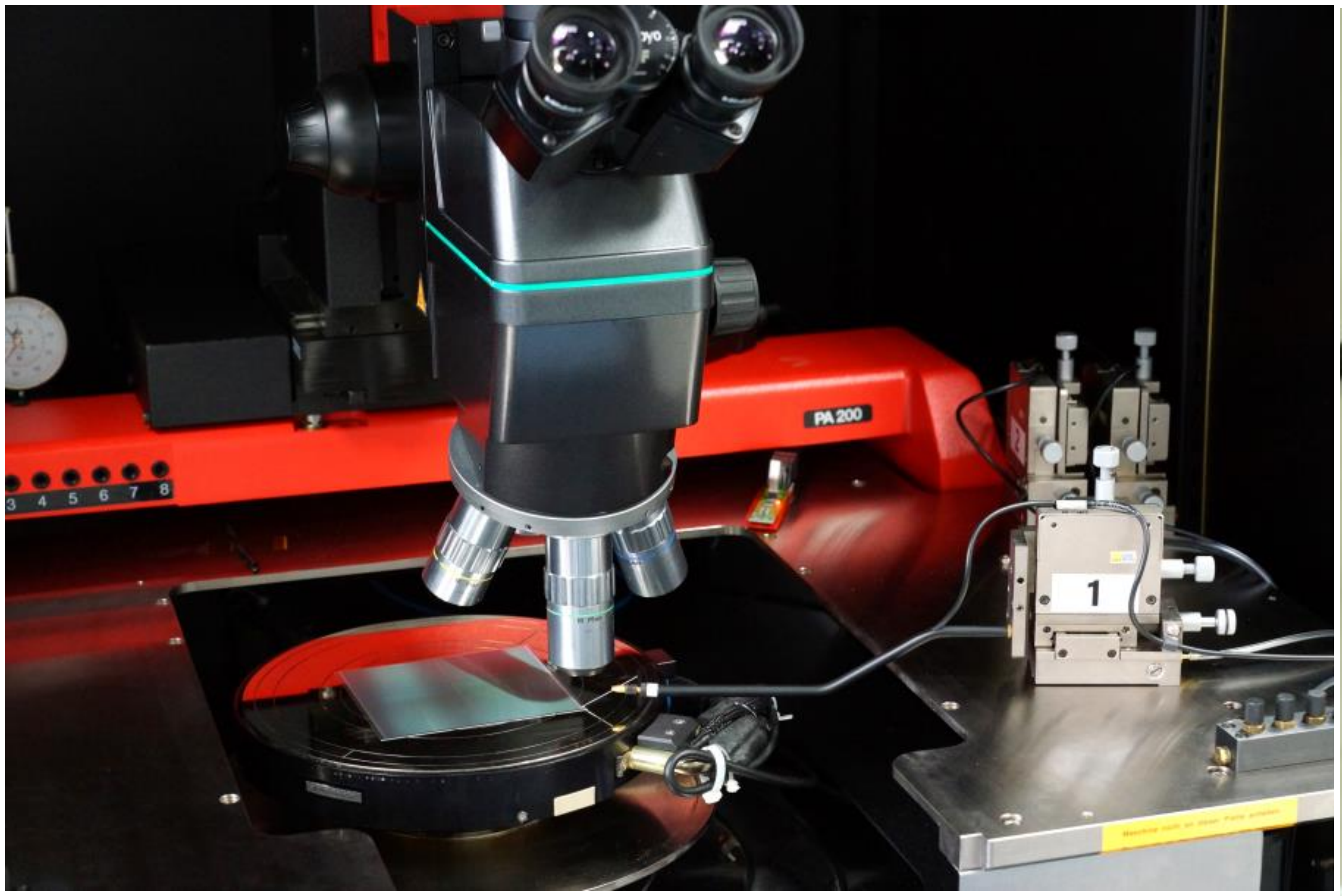
Encapsulate wire bonds

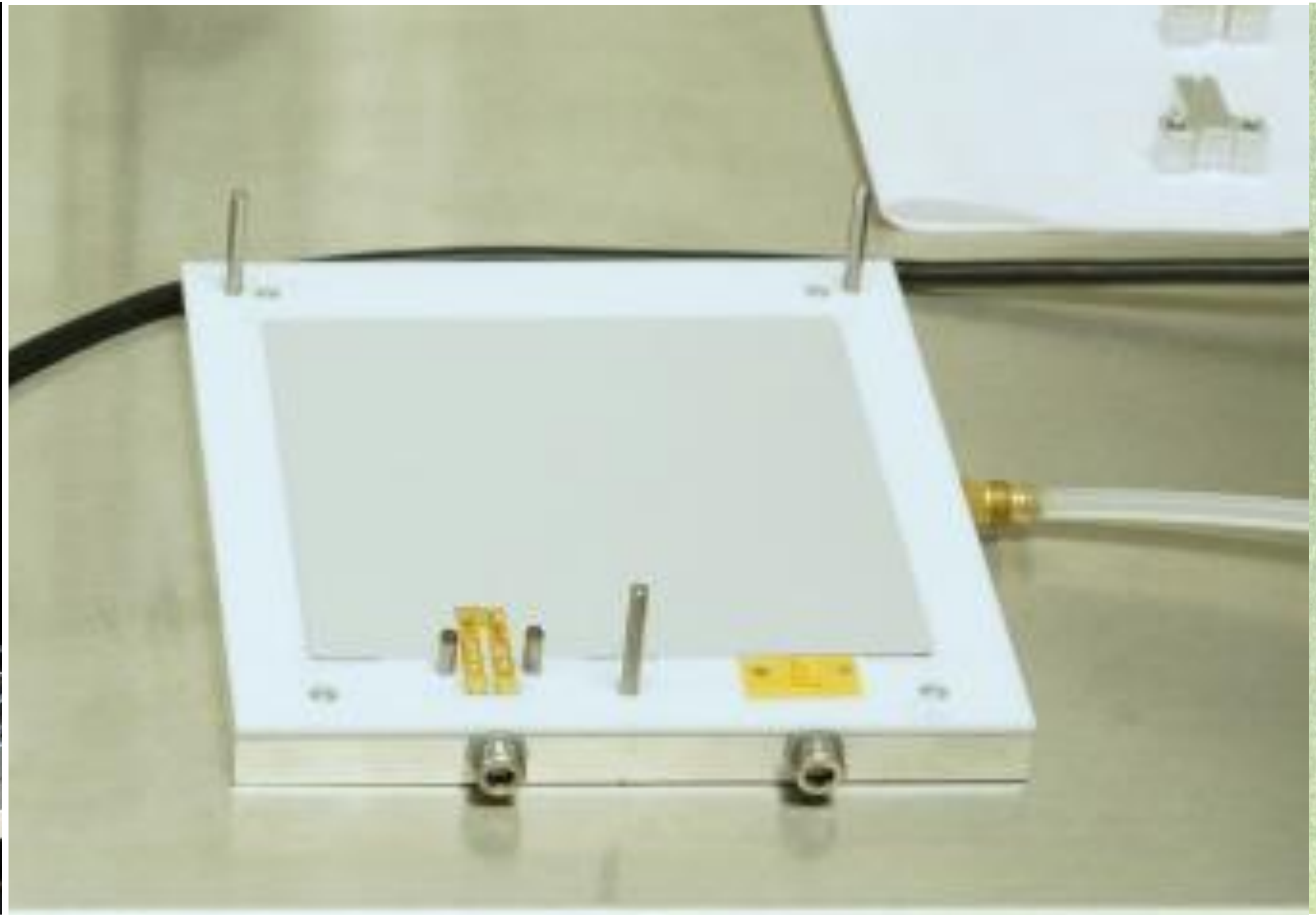


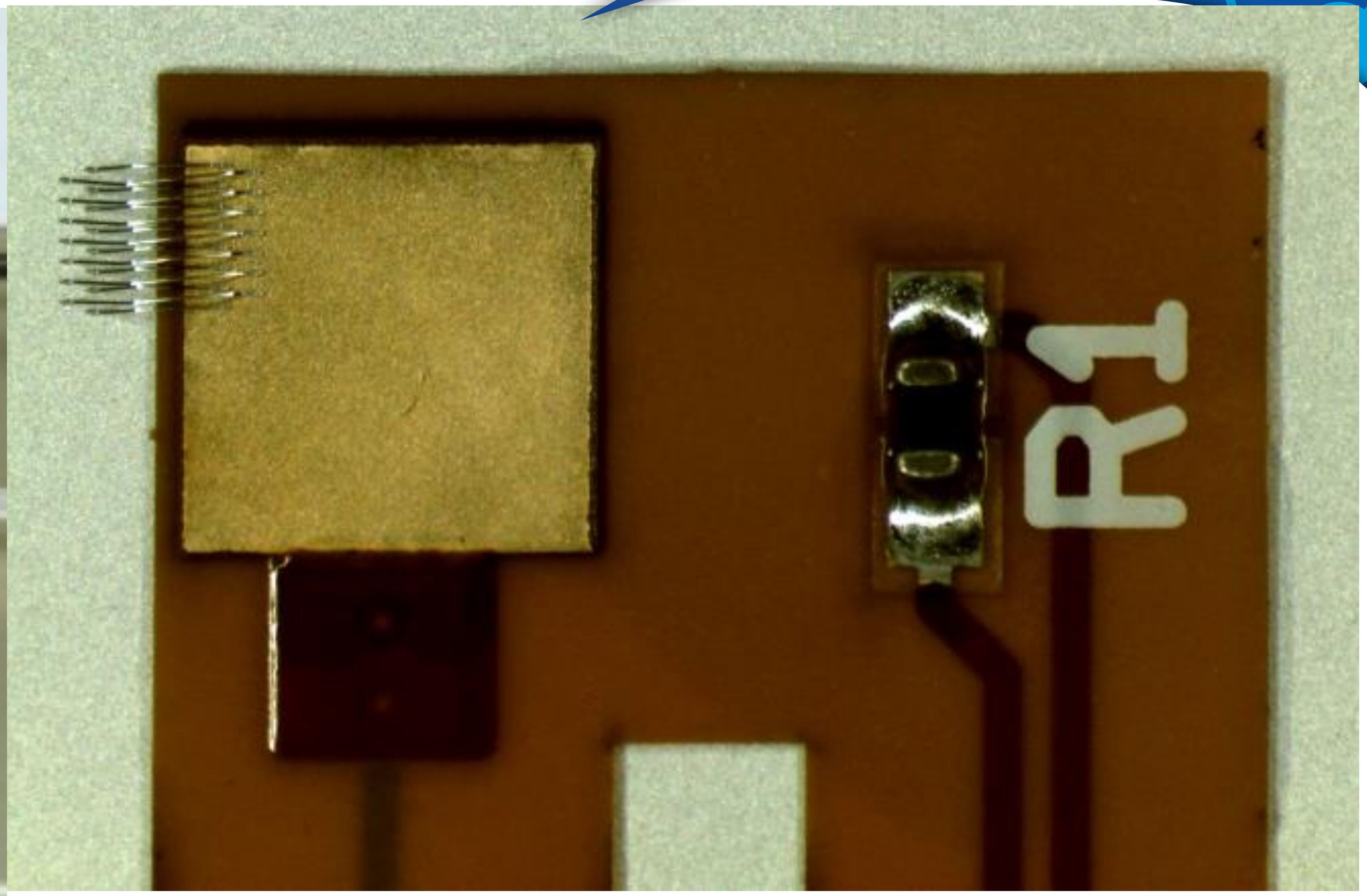
Module test

2S Module Assembly Steps

T. Ziemons, Aachen





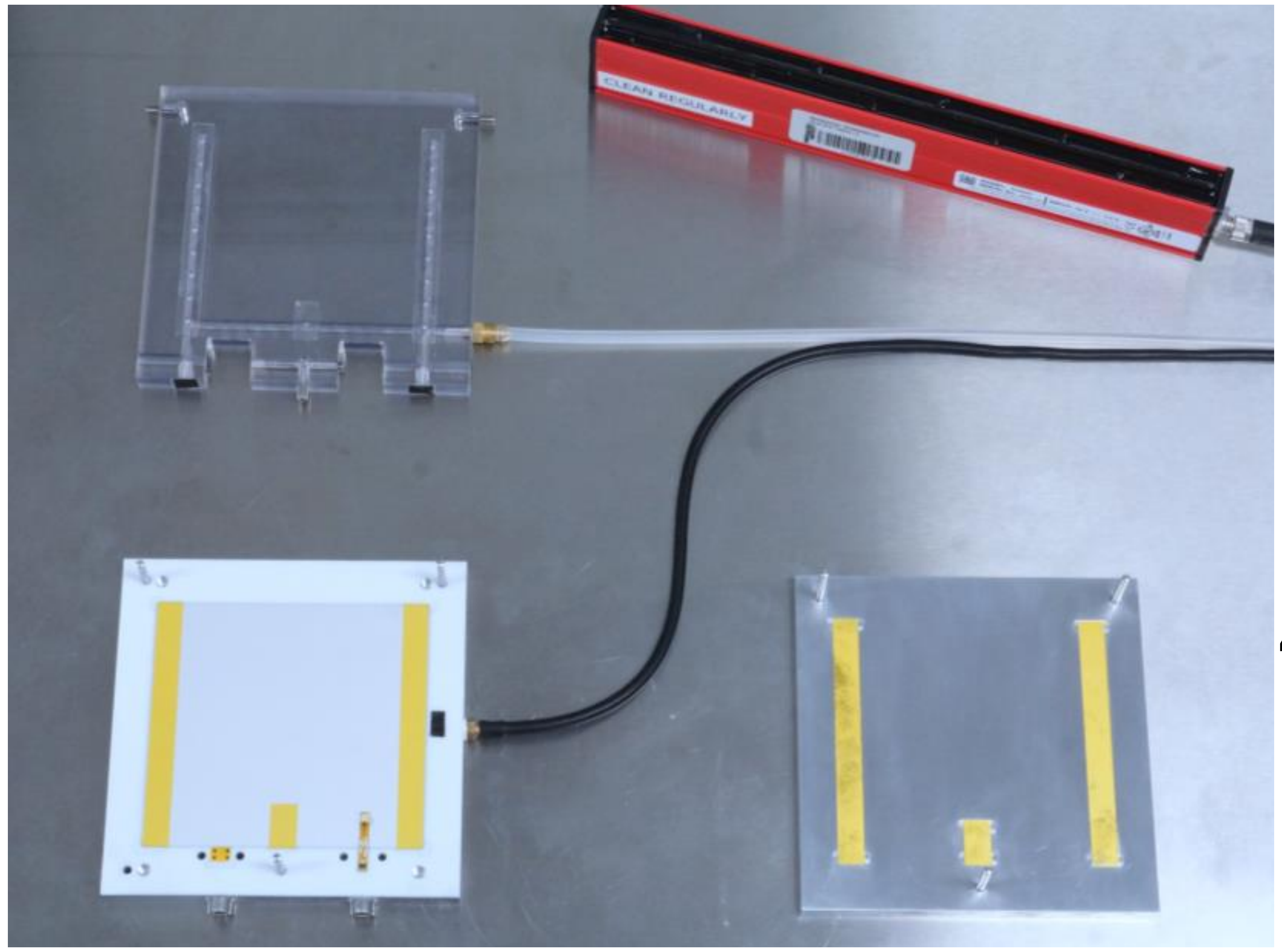


2. Glueing of HV pig tail

3. Wire bonding of HV connection, encapsulation

1. Reception tests:

- visual inspection of all parts
- IV curves of sensors
- hybrid tests
- check sensor edges



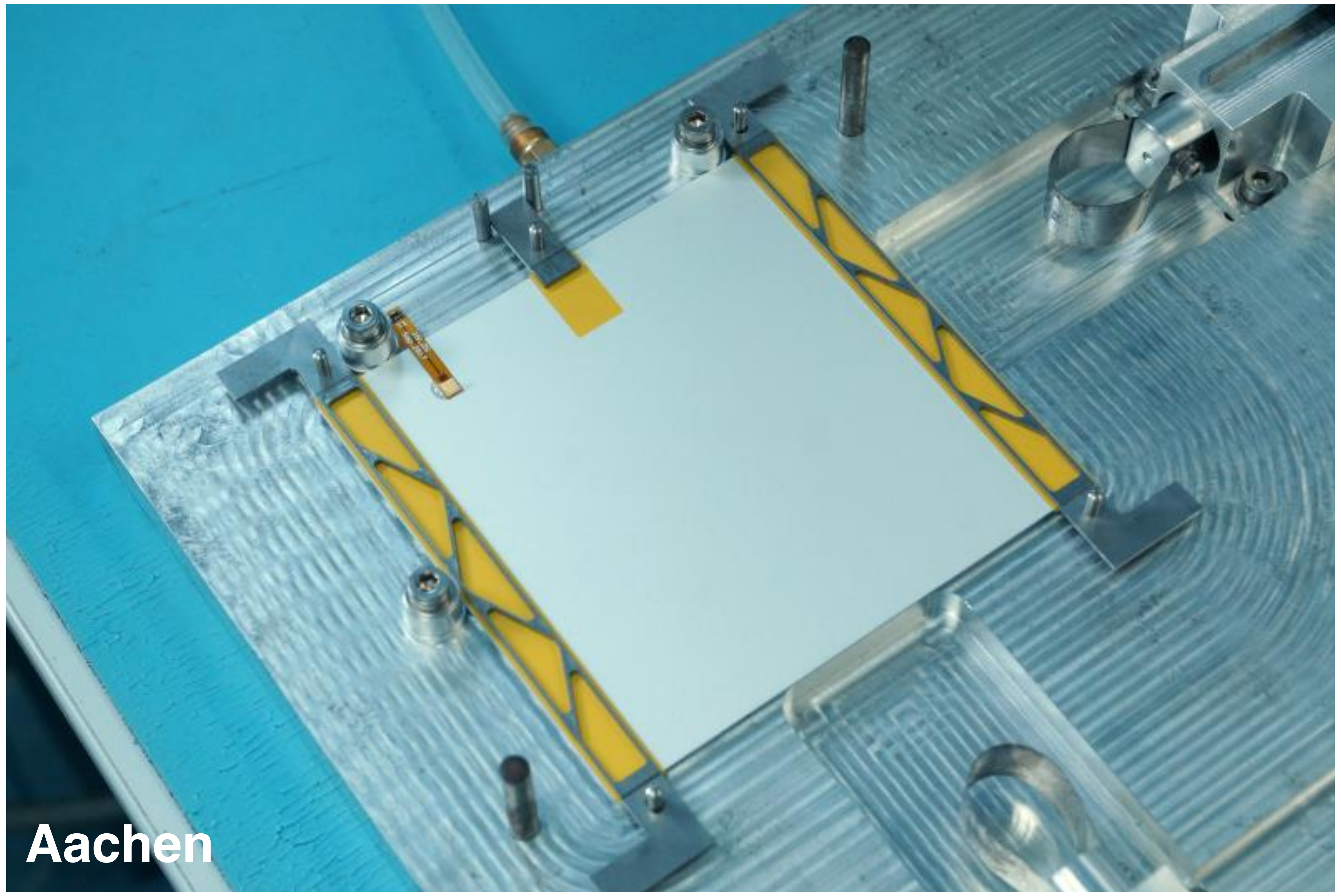
4. Glueing of Kapton strips for HV insulation

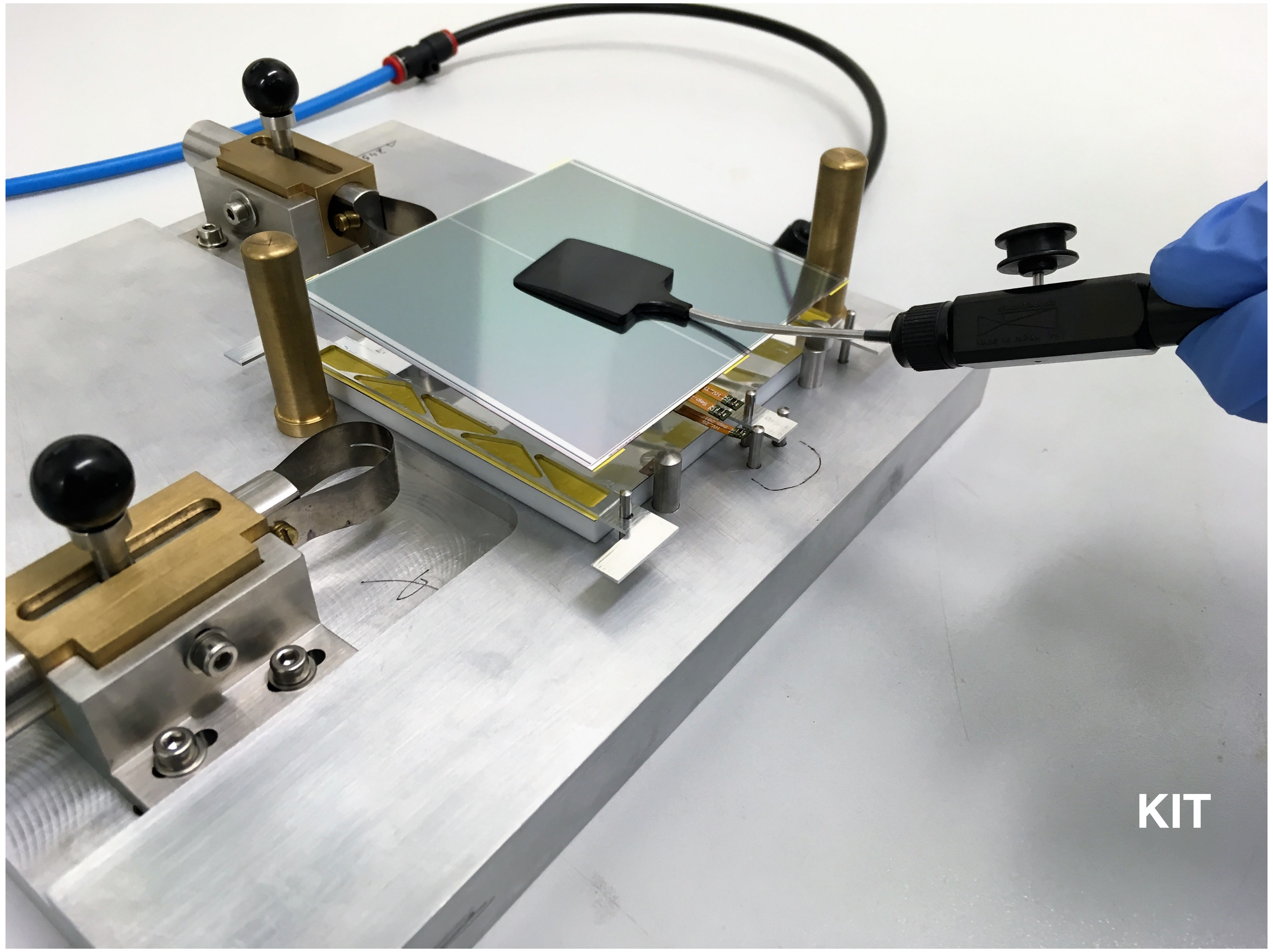
2S Module Assembly Steps

5. Module glueing:

glue sensors to spacers

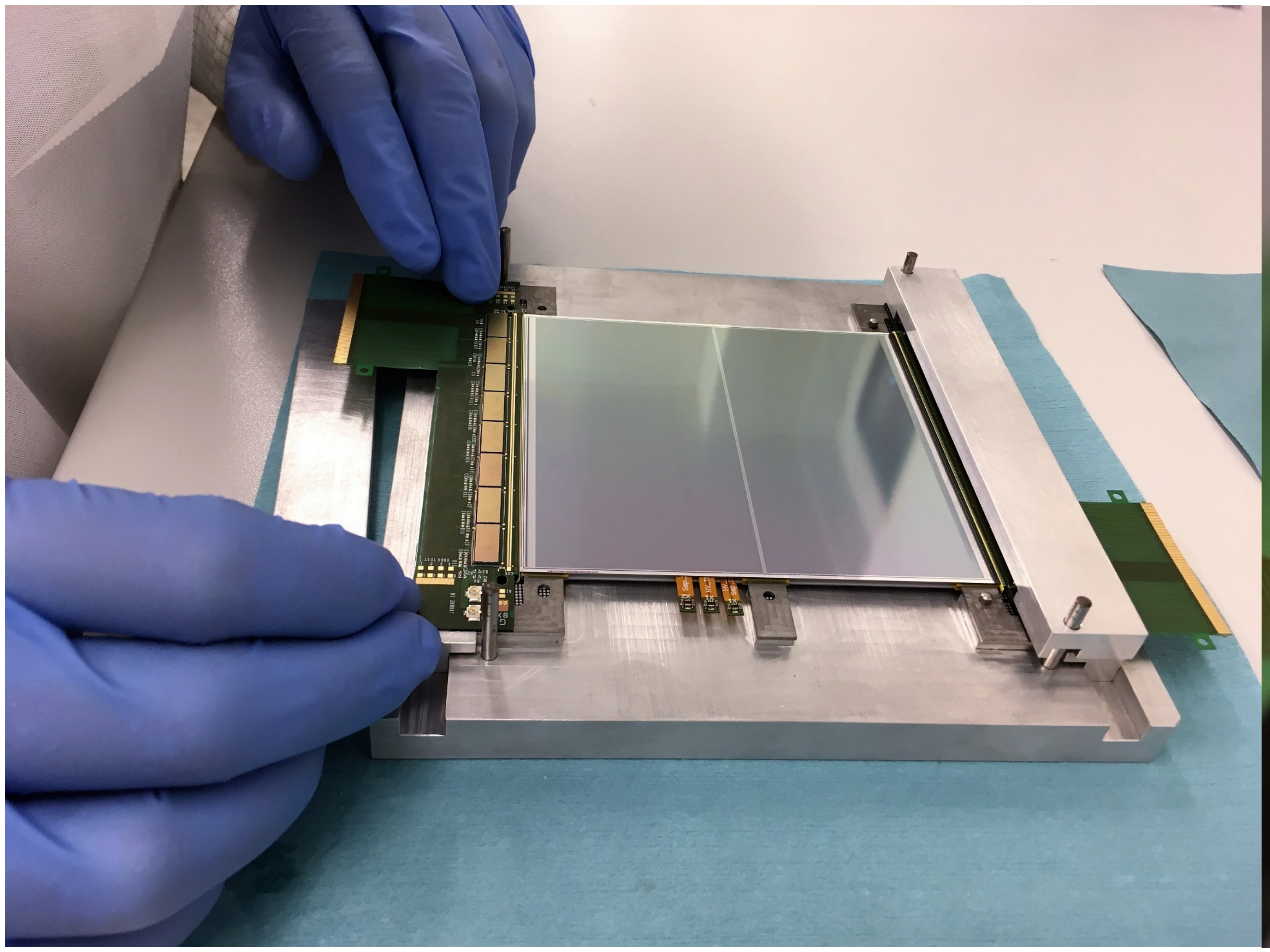
alignment through sensor edges pushed to stoppers



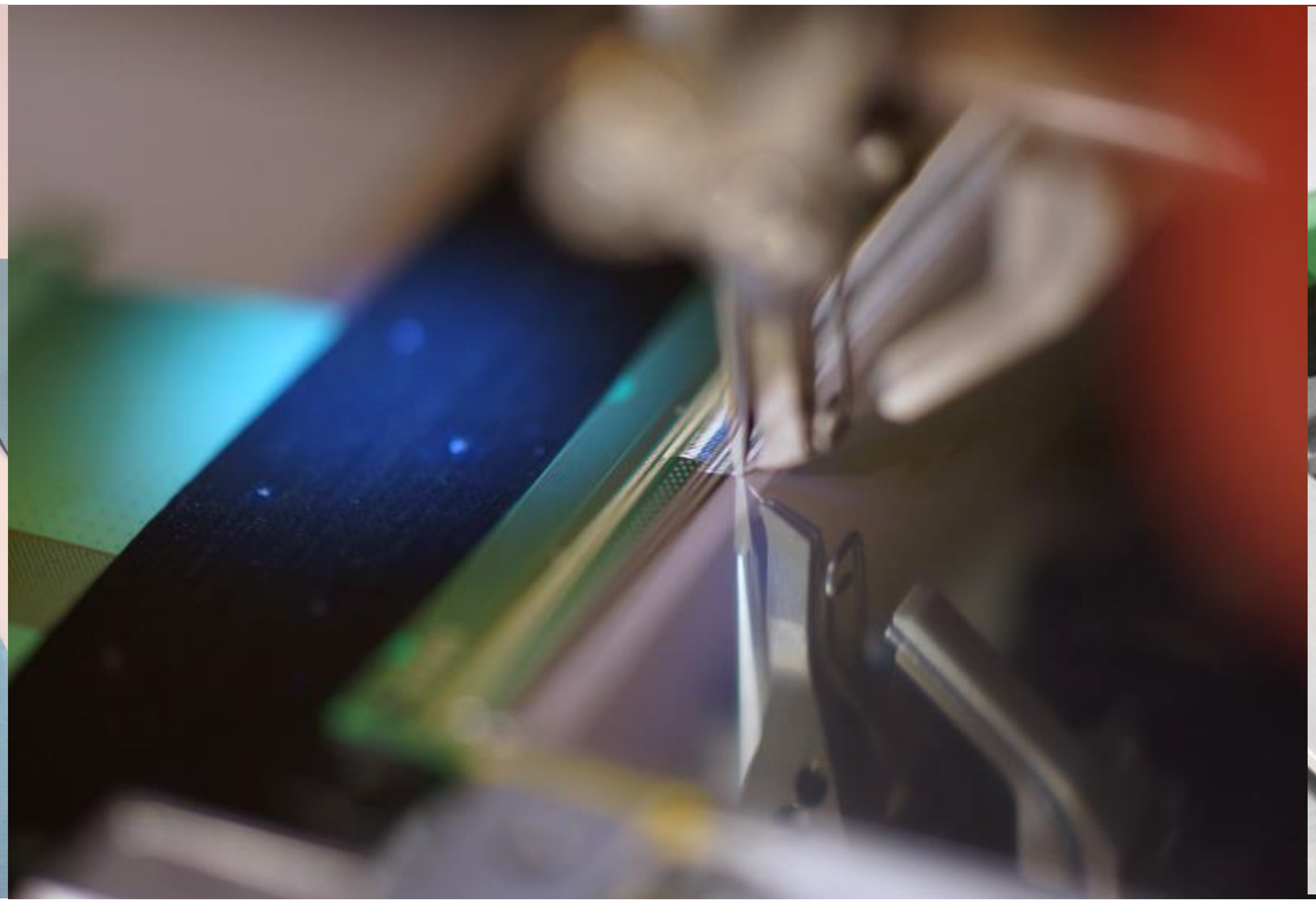


2S Module Assembly Steps

6. Hybrid glueing



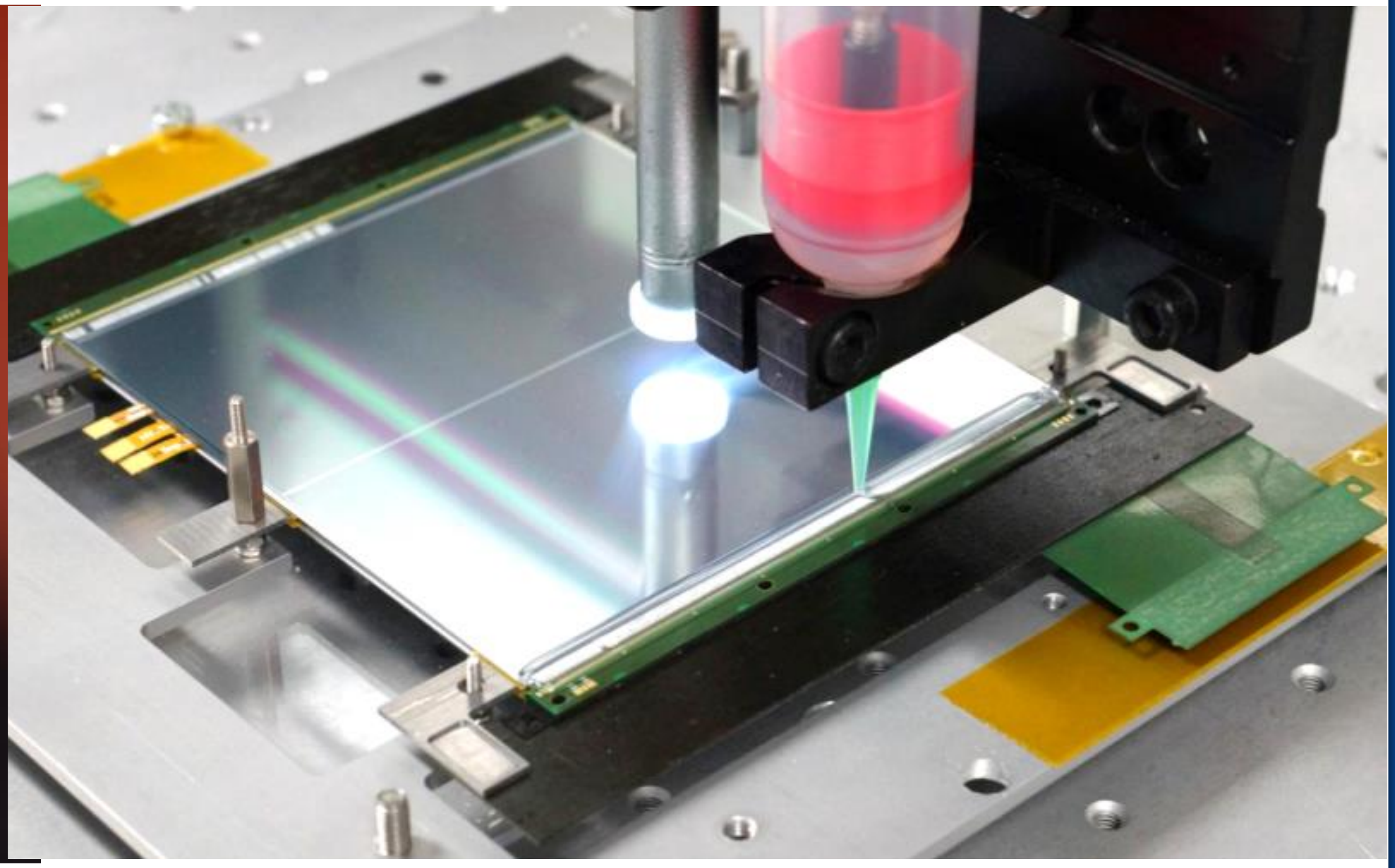
7. Wire bonding



8. Wire bond encapsulation

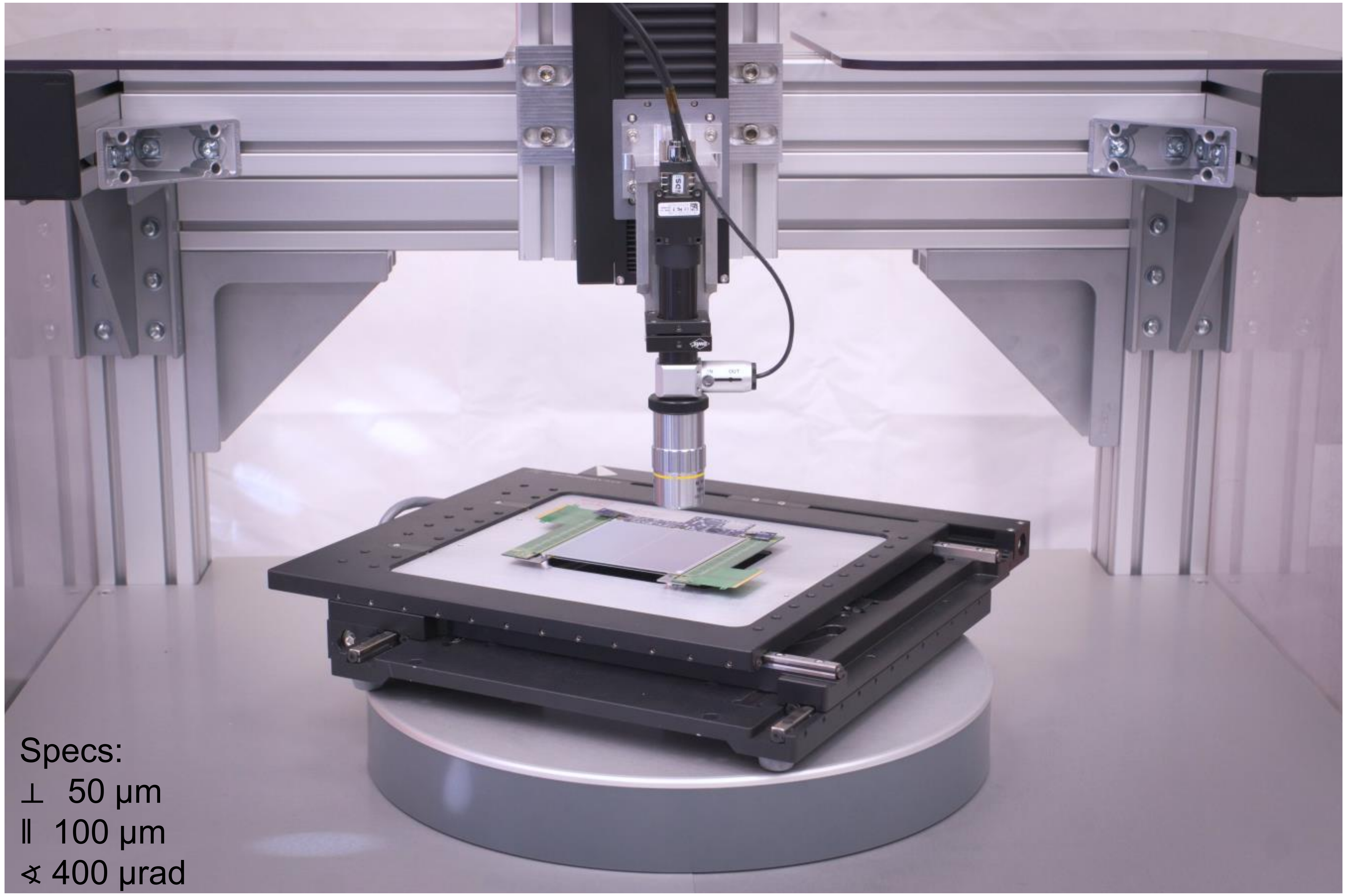
protect from damage

cover with Sylgard 186



Metrology

Aachen



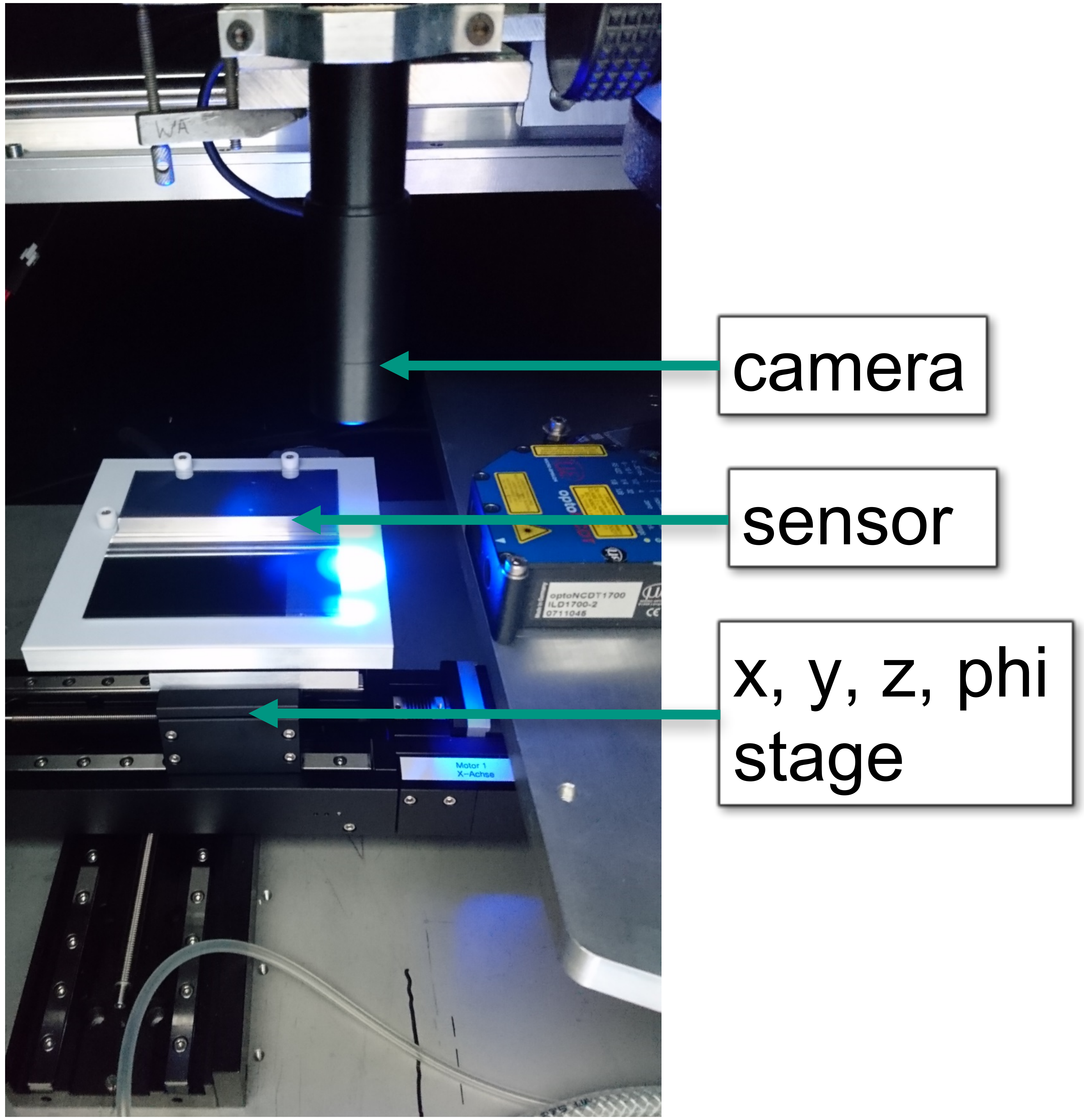
Double sided metrology system

- Measure sensor misalignments (translation and rotation)
- Automated optical inspection
- Measurement of module thickness

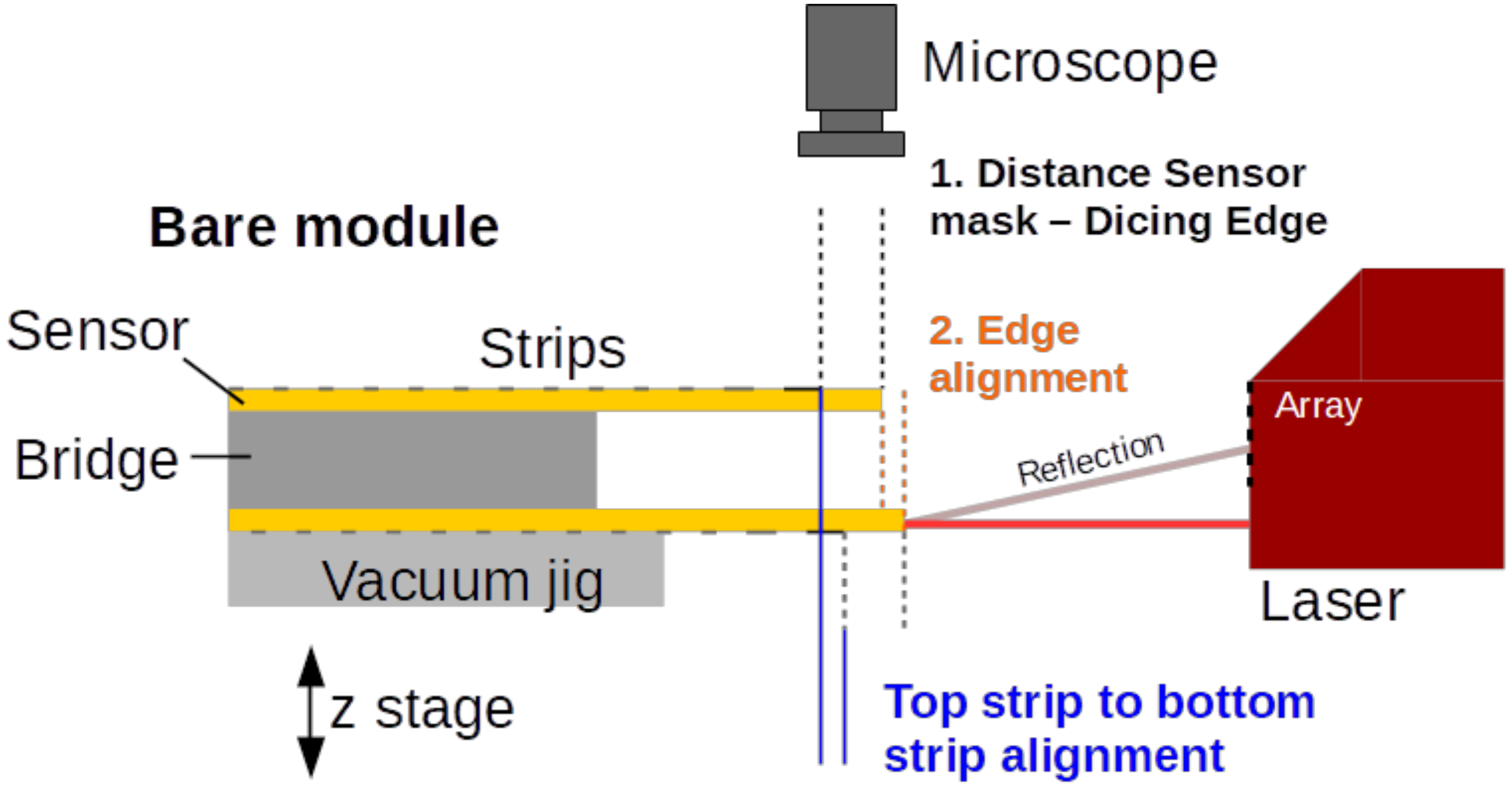
- Camera from top and from bottom
- Calibrate shift of the camera axes by rotation of module

—> all produced modules within specs

KIT



- Measure dicing angle (position of sensor ende to mask) for both sensors
  - used for qualification sensors before they are used for production
- Measure edges alignment with laser system
  - top and bottom sensor distance measured at 300 Hz while sensor edges move along laser (10mm/s)
  - fit of distances vs. position of sensor gives edge orientation rel. to laser

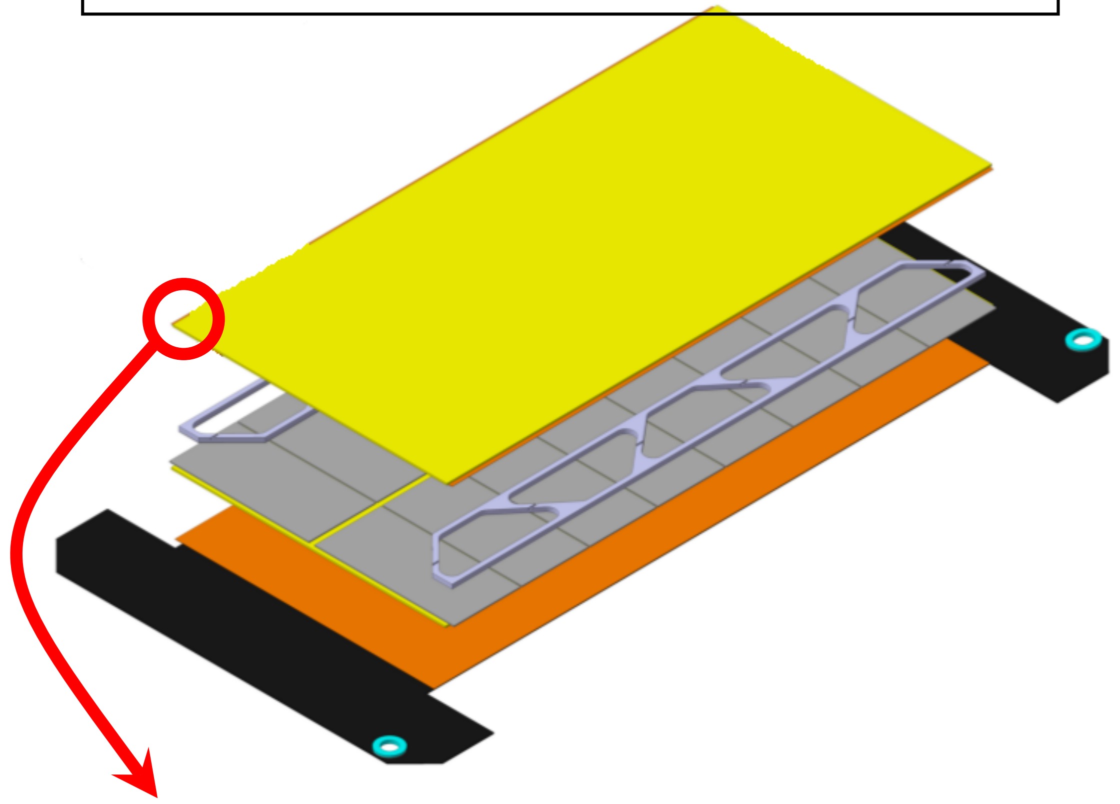


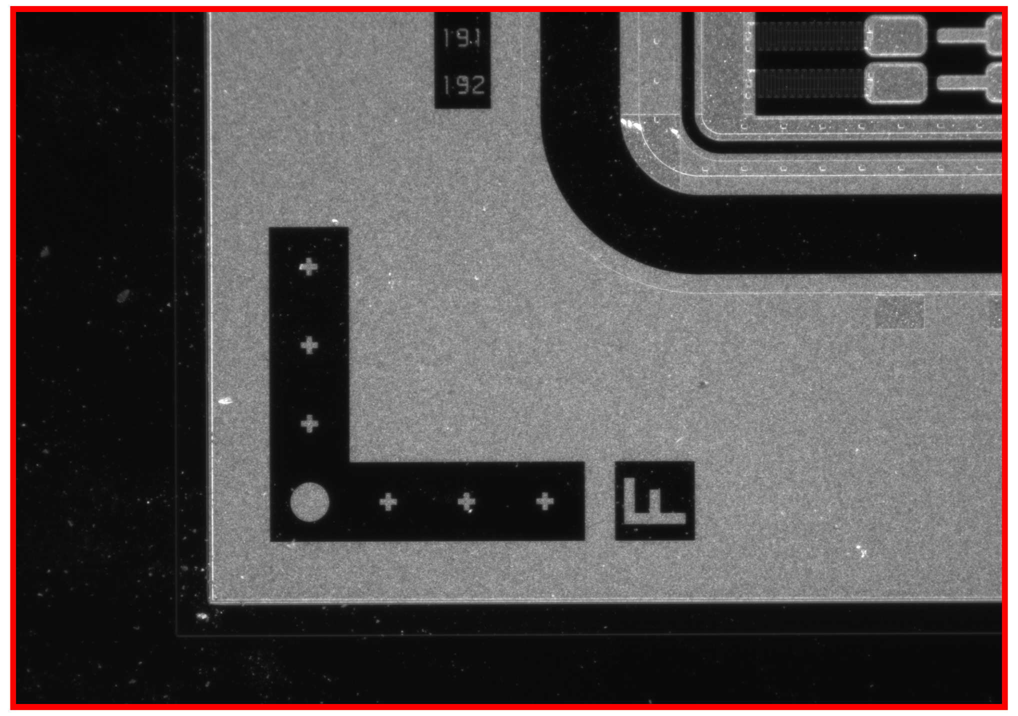
Why automate?

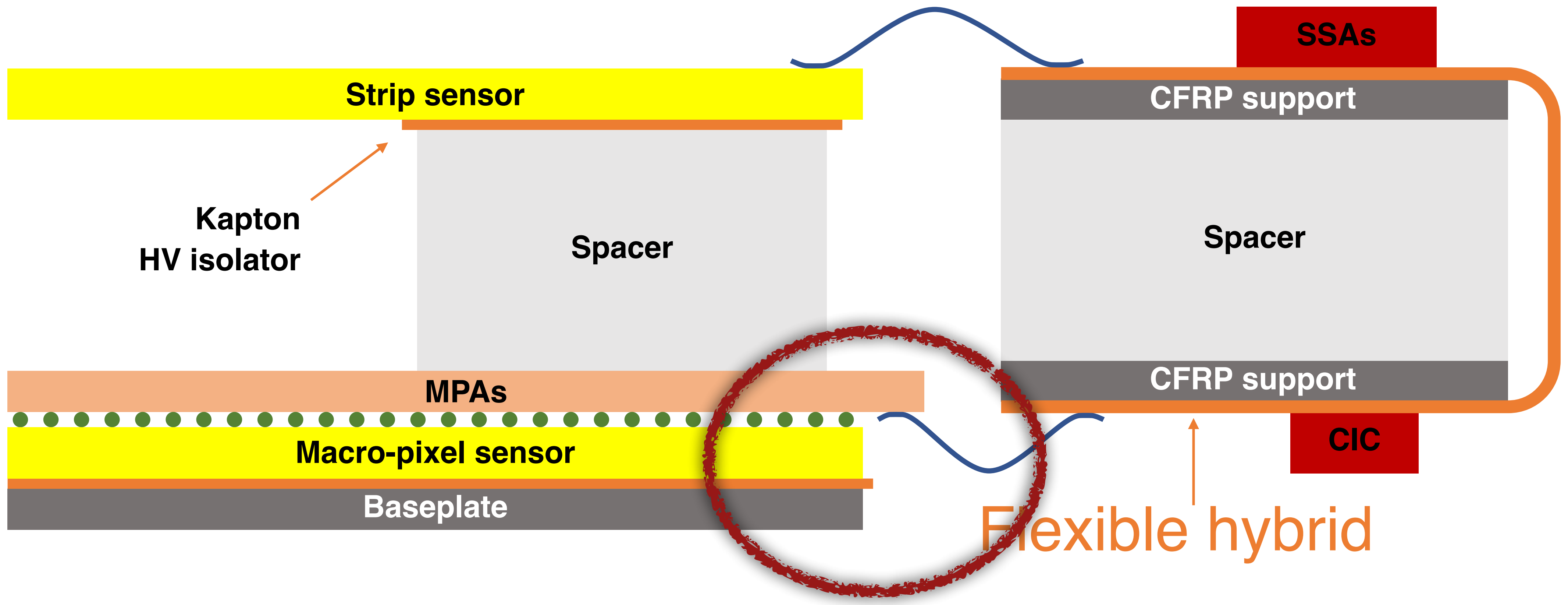
- Requirements on precision
- 300 µm overhang plus undersell are a challenge
- PSp and PSs sensor oriented upwards

  —> can look from top and see markers on both sensors

tolerance on PSp-PSs alignment: 800 μrad







What to automate?

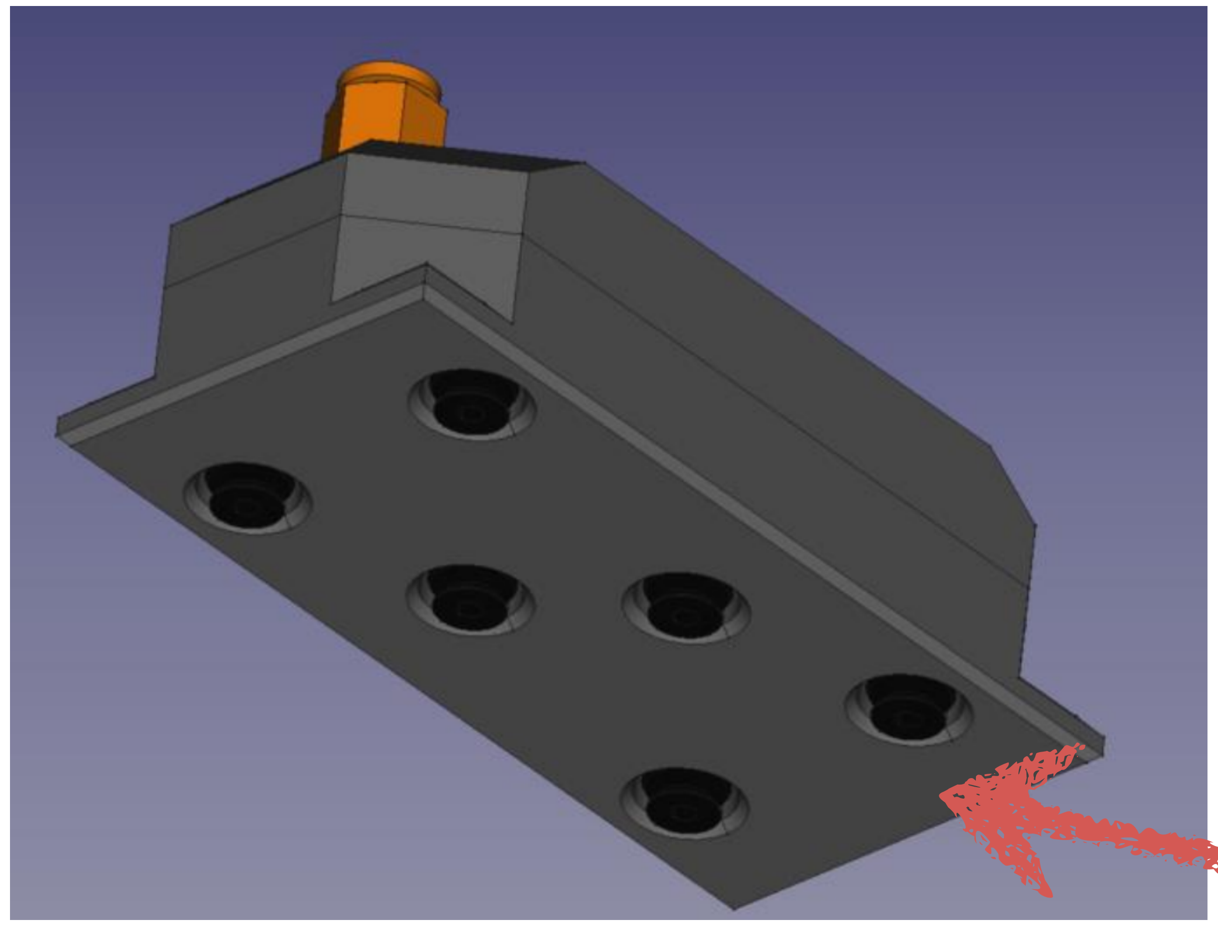
- high-precision steps of assembly:
  - baseplate + MaPSA + spacers + PSs
- use high-precision markers on sensor corners and precise mounting jig with markers
- PSp sensors edges extended by 300 µm wrt. PSs

  —> both corner markers visible from top

  one camera sufficient

  metrology 'built in'

Automated PS Module Assembly

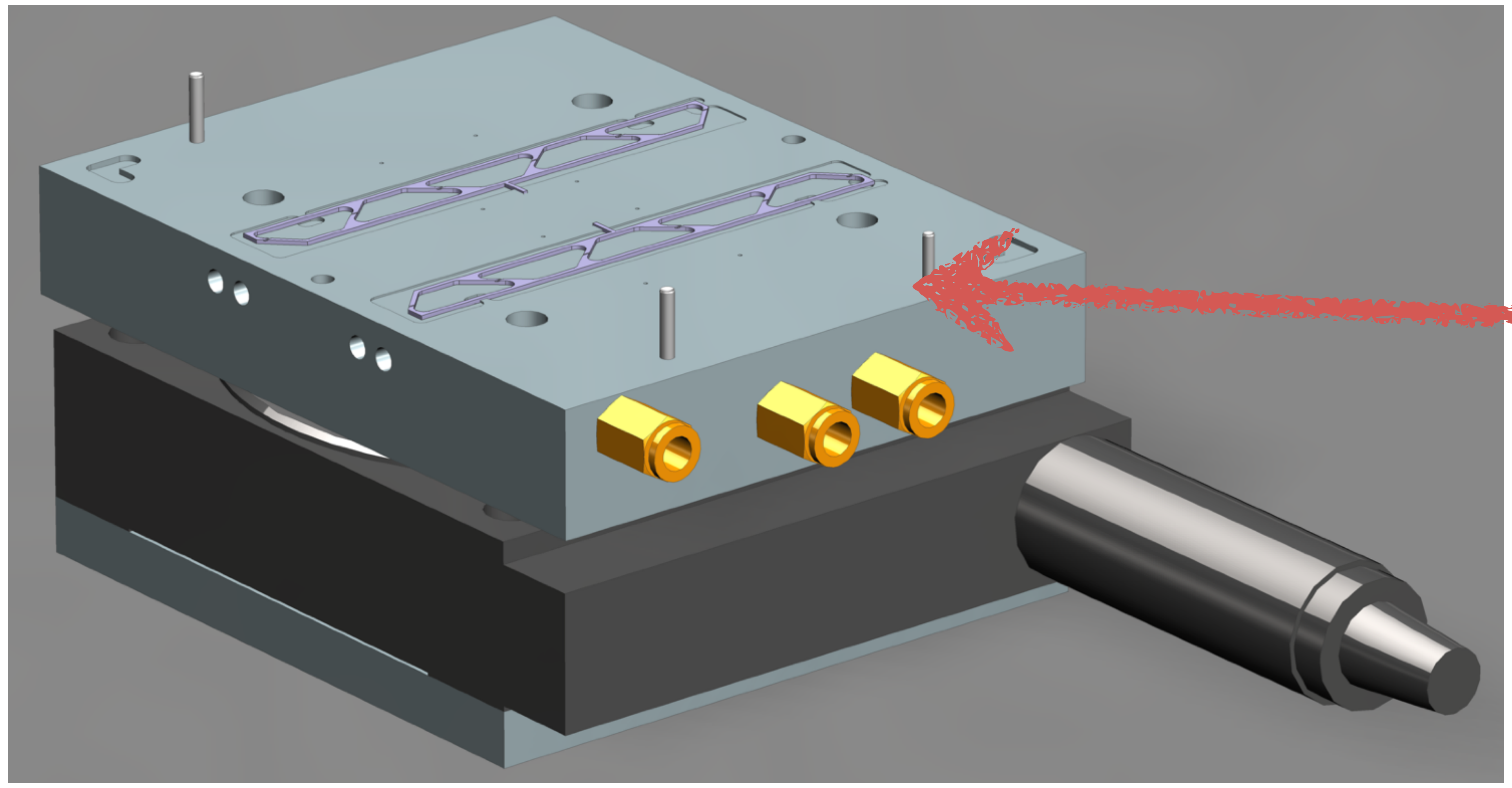


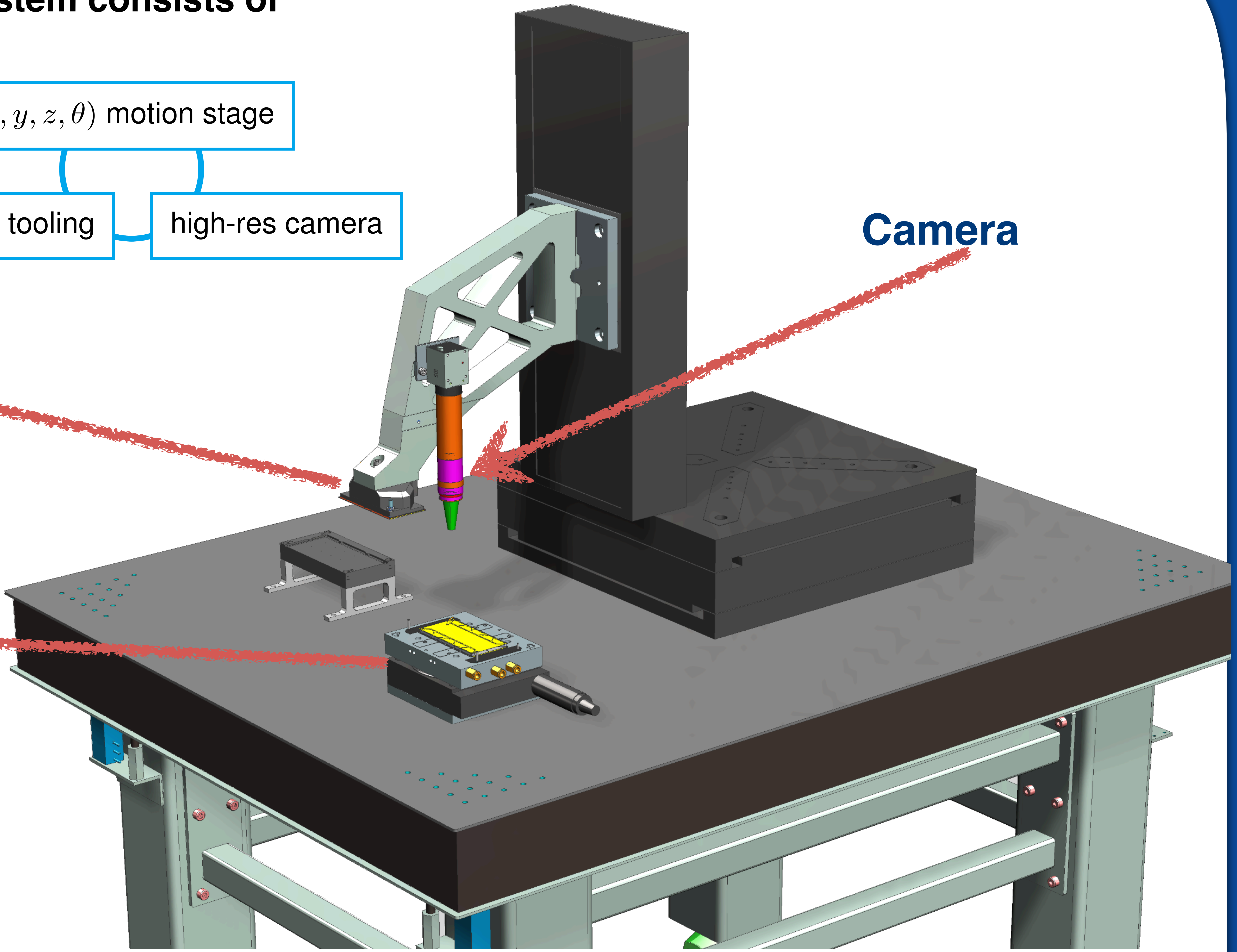
system consists of

(x, y, z, θ) motion stage

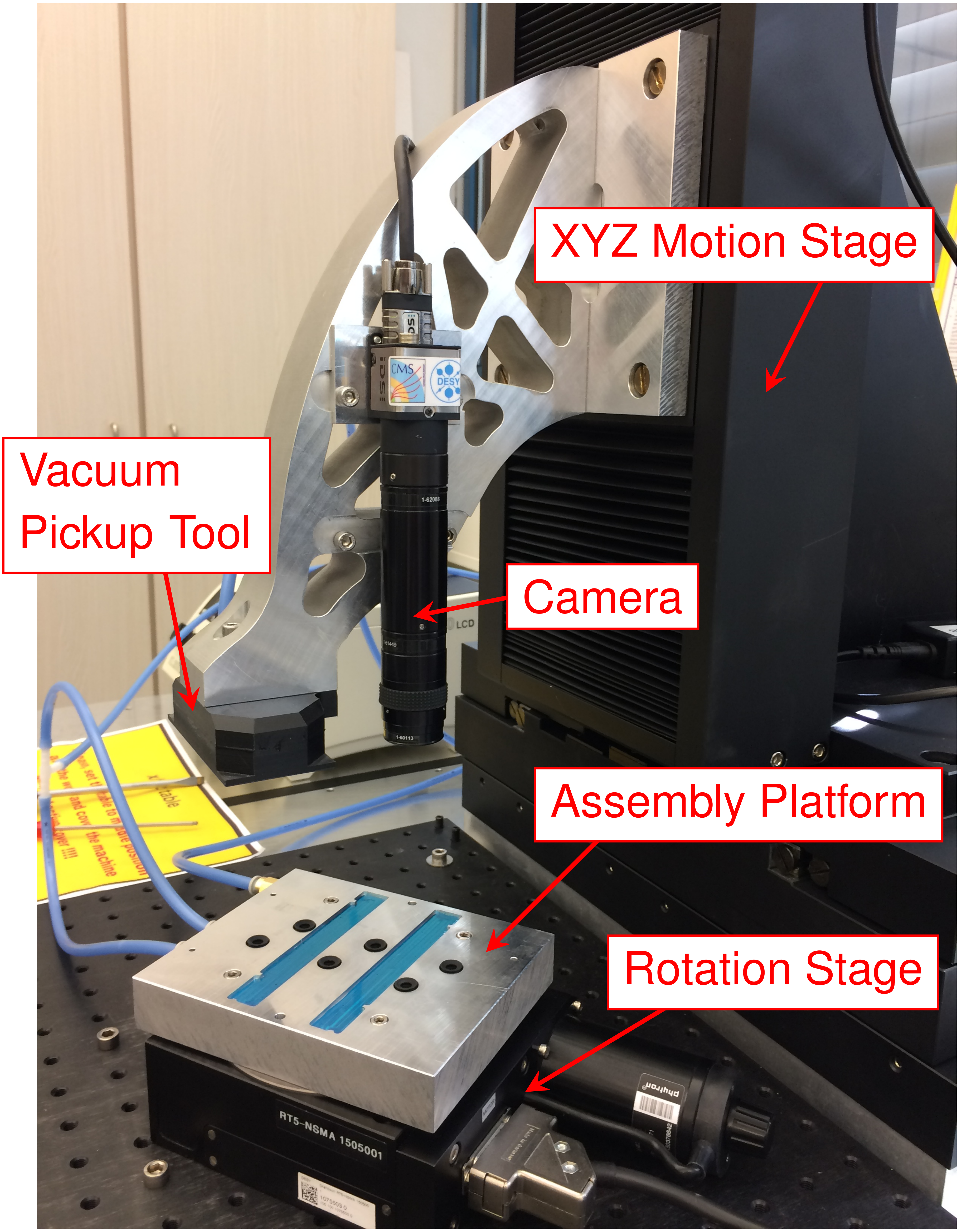
vacuum tooling

high-res camera



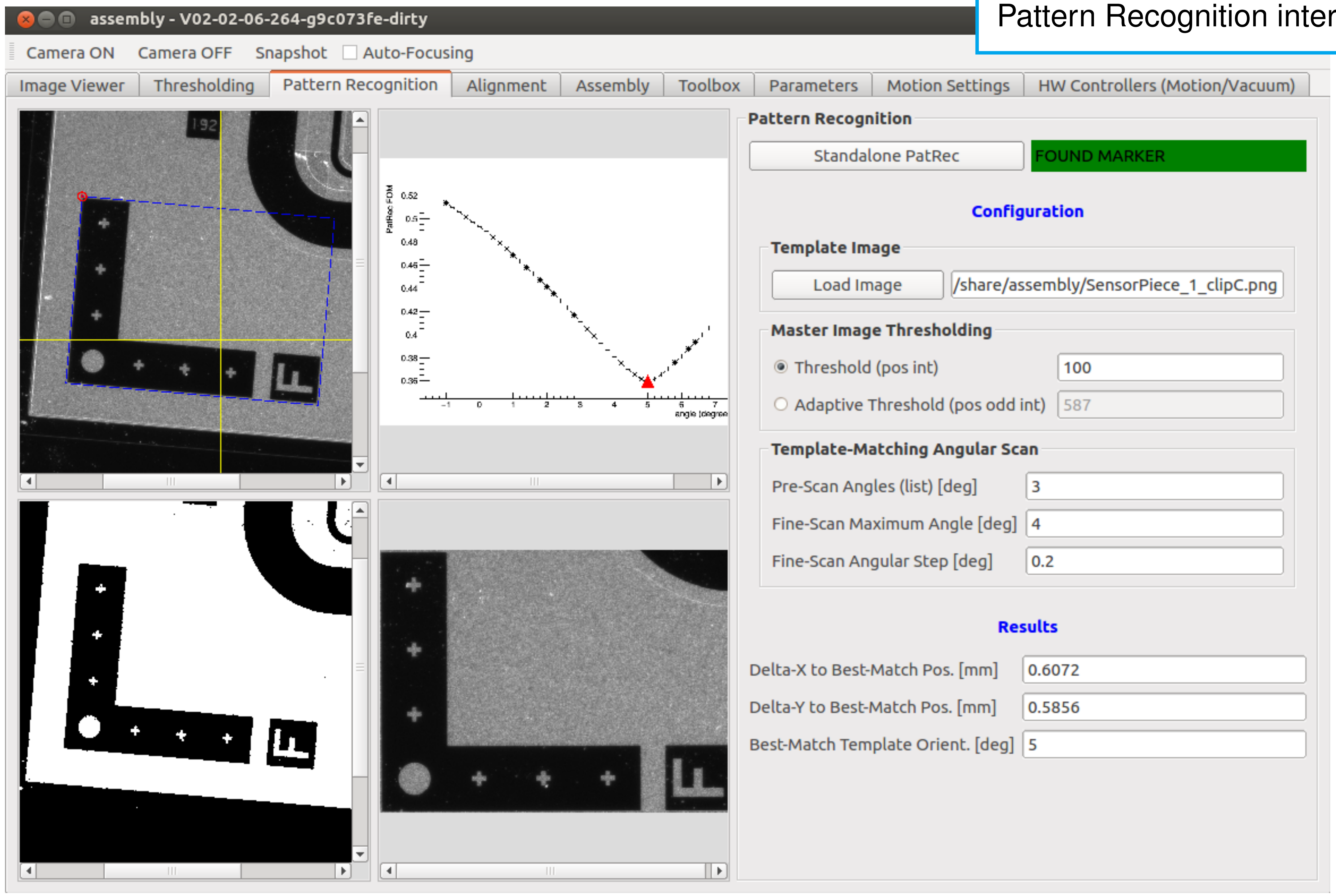


Automated PS Module Assembly

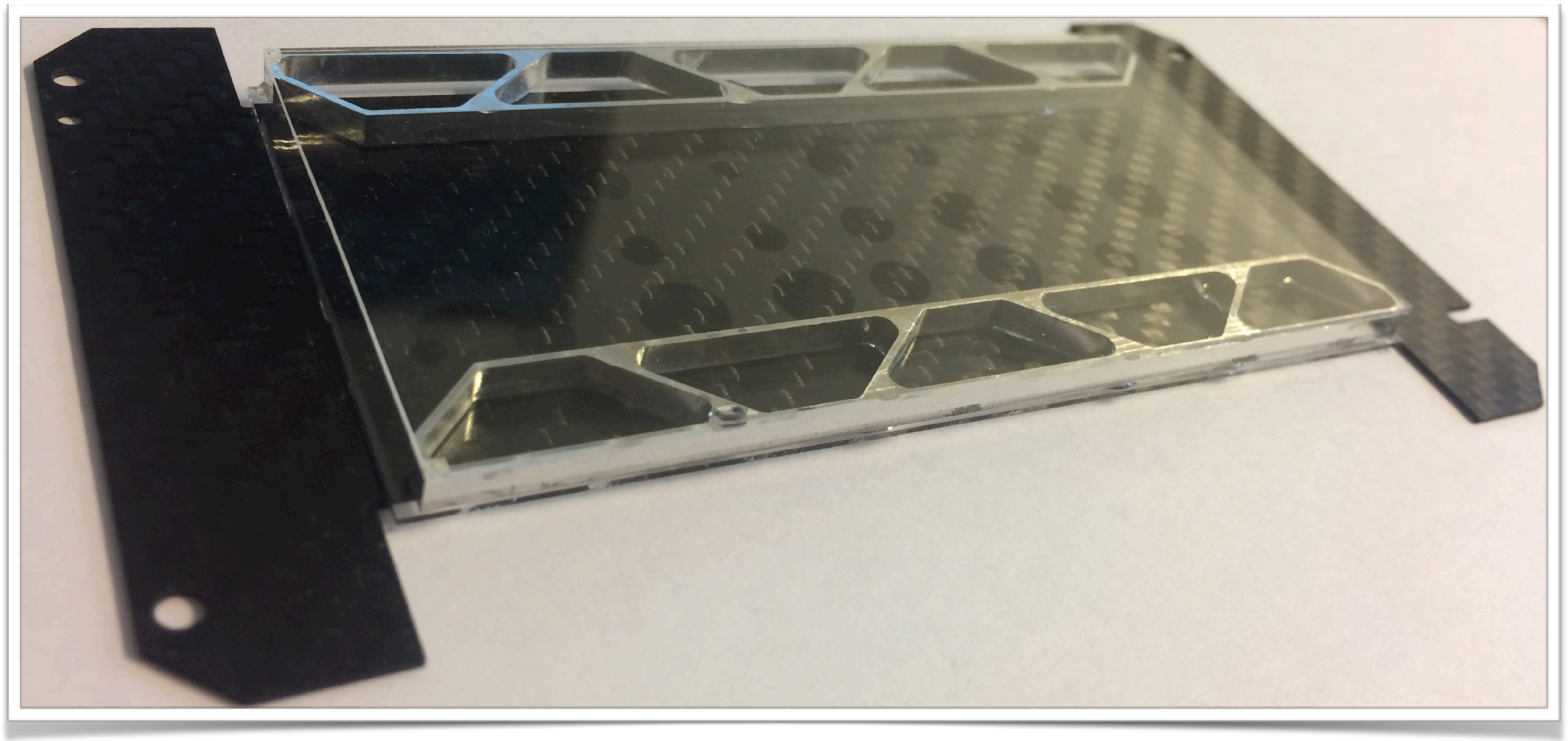


- Dedicated software developed to control motion, vacuum, image acquisition
- need to use small amounts of fast-curing glue (epoxy) to allow for handling (R&D ongoing)

Pattern Recognition interface



Automated PS Module Assembly



- Mechanical prototypes assembled with glass sensor dummies with laser engraved markers
- All within specs
- Next steps: evaluate glues

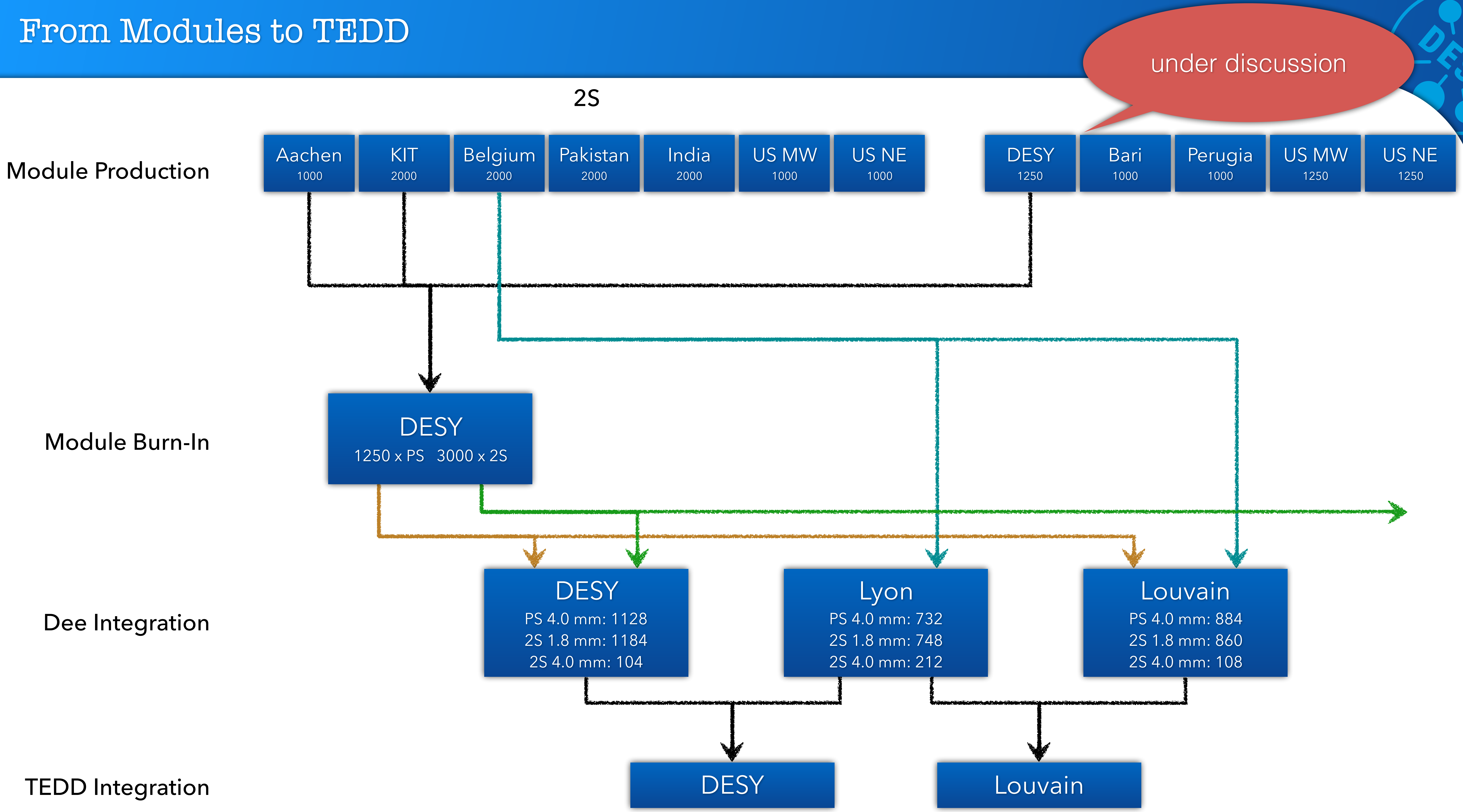
- Other assembly steps will be jig-based

- two types of glue used in the assembly
- Polytec EP 601 LV
  - standard glue used for OT module assembly
  - slow curing: approx 24h
  - fully uniform thin glue layer

- Loxeal or Loctite fast Epoxies
  - fast curing: approx. 10 min
  - very small amounts needed

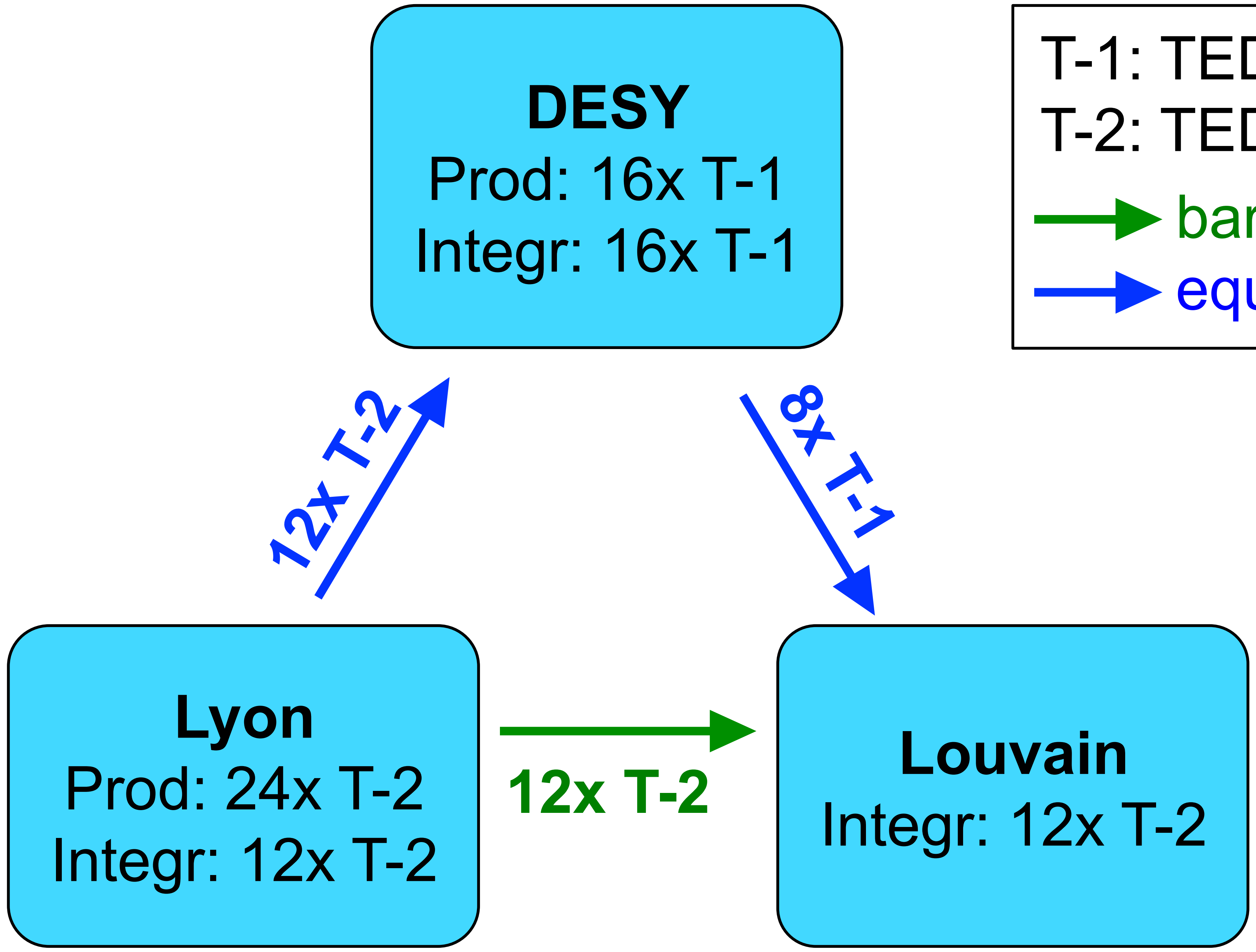
- fast glue necessary to be able to lift assembled parts
- similar dispensing for baseplates and spacers
- qualification ongoing

From Modules to TEDD



Options for

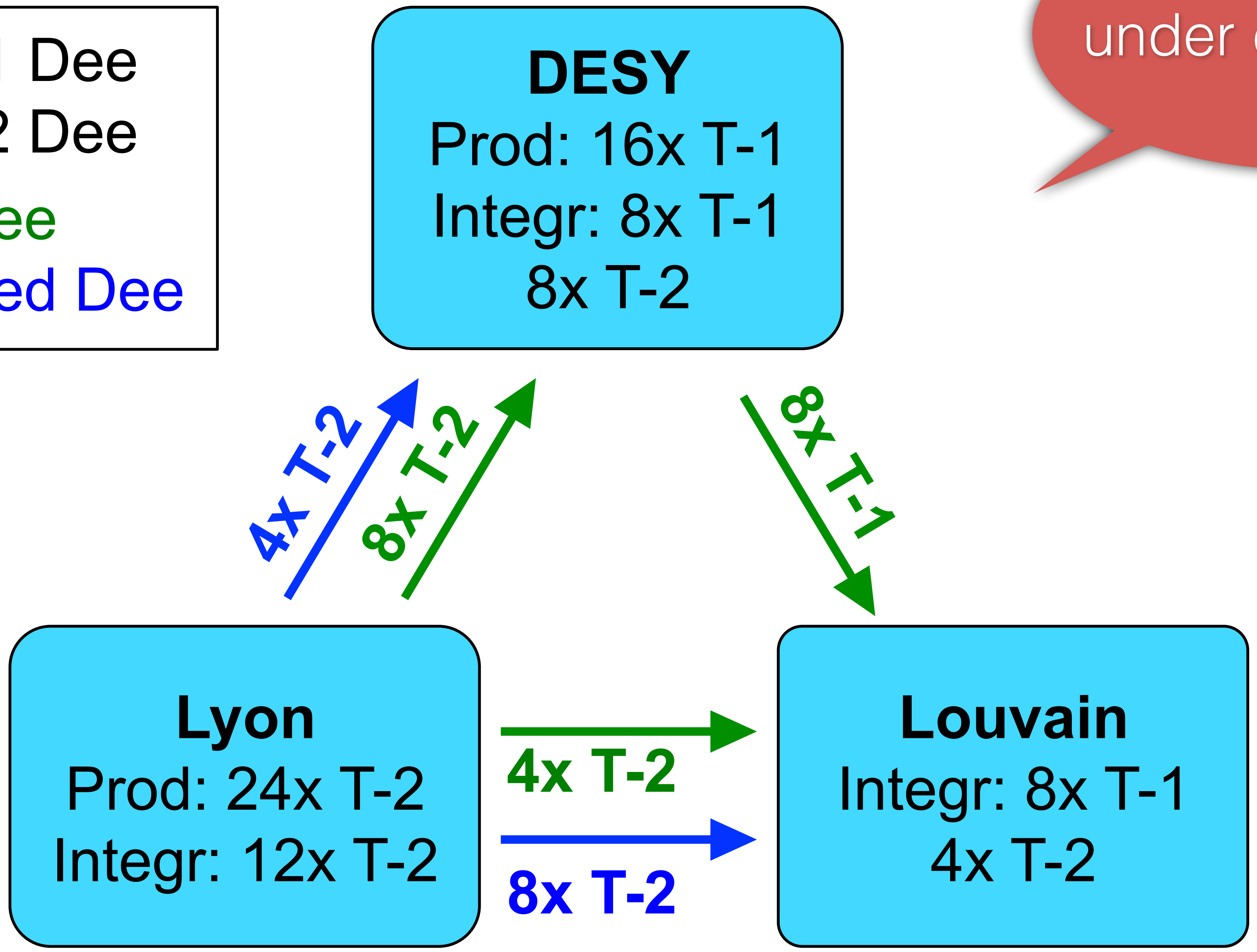
Option 1



T-1: TEDD-1 Dee
T-2: TEDD-2 Dee
bare Dee
equipped Dee

Option 2

under discussion



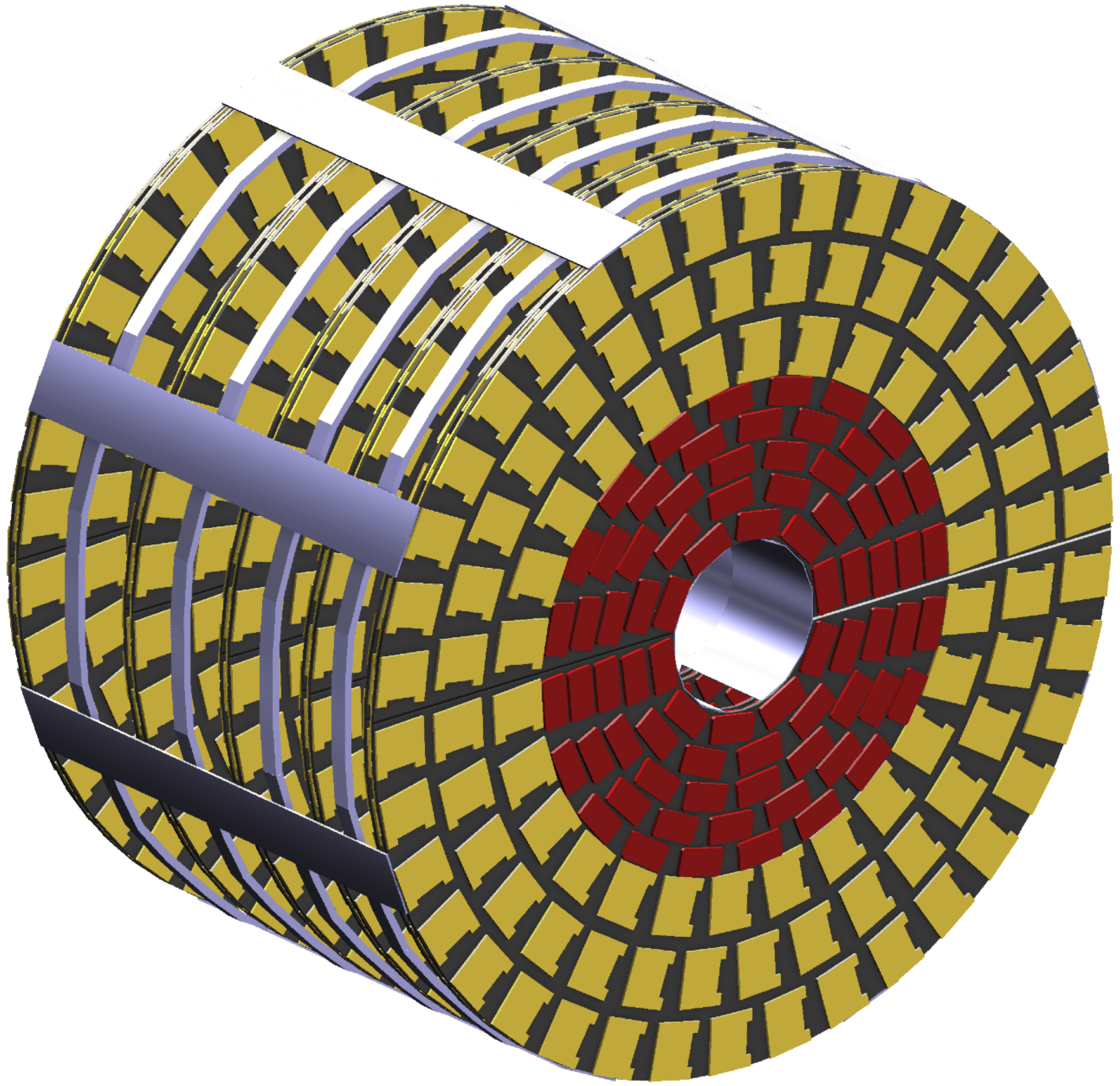
- **Only one type of integration tooling per center.**
- High number of shipments of integrated Dees
  - DESY uses Lyon shipping box

- **Minimized number of shipment of integrated Dees.**
  - Less testing
- DESY and Louvain integrate both types.
  - More flexibility

Current Planning - under development

Title	Start	End
R&D and Prototyping	01.10.16	17.06.21
MaPSA	01.10.16	10.12.20
Modules	01.10.16	04.03.21
Mechanical Prototypes	01.10.16	10.01.20
Early Prototypes	10.01.20	06.08.20
Final Prototypes	07.08.20	04.03.21
Burn-In Test	01.03.19	09.07.20
Dee	01.10.16	17.06.21
TEDD	01.10.16	06.07.20
MaPSA	10.12.20	25.10.23
MaPSA Pre-Production Testing	10.12.20	28.04.21
MaPSA Production Testing	29.04.21	25.10.23
Module	03.09.20	17.11.23
Module Pre-Production	25.06.21	16.12.21
Module Production	17.12.21	16.11.23
Burn-In Test	09.07.20	14.12.23
Pre-Production Module Burn-In Test	23.07.21	26.01.22
Production Module Burn-In Test	27.01.22	14.12.23
Dee	05.08.19	02.04.24
Dee Pre-Production	28.04.20	06.07.21
Dee Production	07.07.21	06.06.23
Dee Integration and Testing	04.05.22	02.04.24
TEDD	22.02.22	17.09.24
Disk & Double-Disk Integration & Testing	03.05.23	16.04.24
TEDD Integration	01.05.24	23.07.24
Packing and Shipping	24.07.24	17.09.24
OT Integration & Commissioning	01.09.23	09.10.25
TEDD Insertion @ CERN	08.11.24	16.01.25
Outer Tracker Commissioning @ CERN	17.01.25	09.10.25

Summary and Outlook



- **One CMS tracker endcap will be produced in Germany Aachen, KIT and DESY contributing**

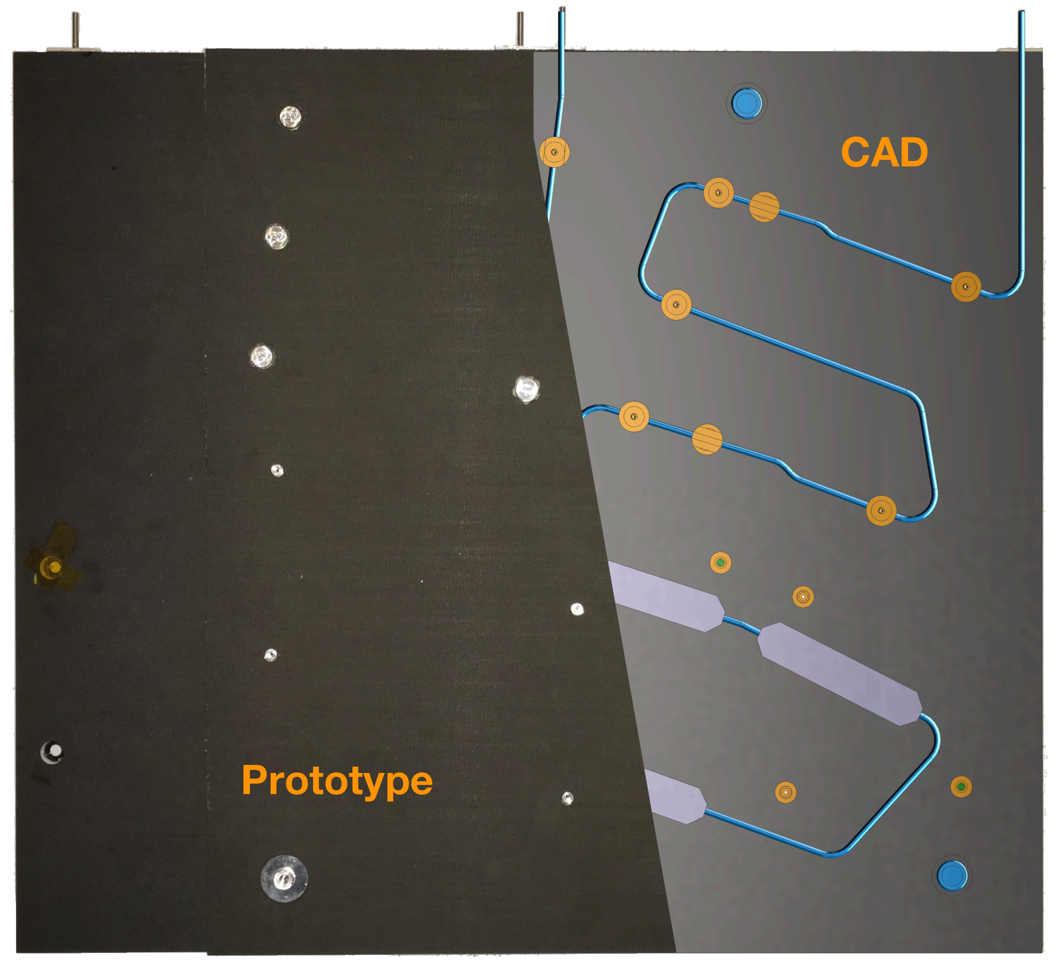
- **Aachen and KIT will assemble 2S modules**
- **DESY will assemble PS modules**
- **Systems under development to test full modules, cooled**
- **All modules will undergo burn-in at DESY and will be integrated onto TEDD**

- **R&D and prototyping towards production are well under way**

Thanks to colleagues from Aachen, KIT and DESY

especially T. Ziemons, S. Maier, M. Missiroli, A. Mussgiller, M. Haranko who provided me with information and plots

BACKUP



Cooling

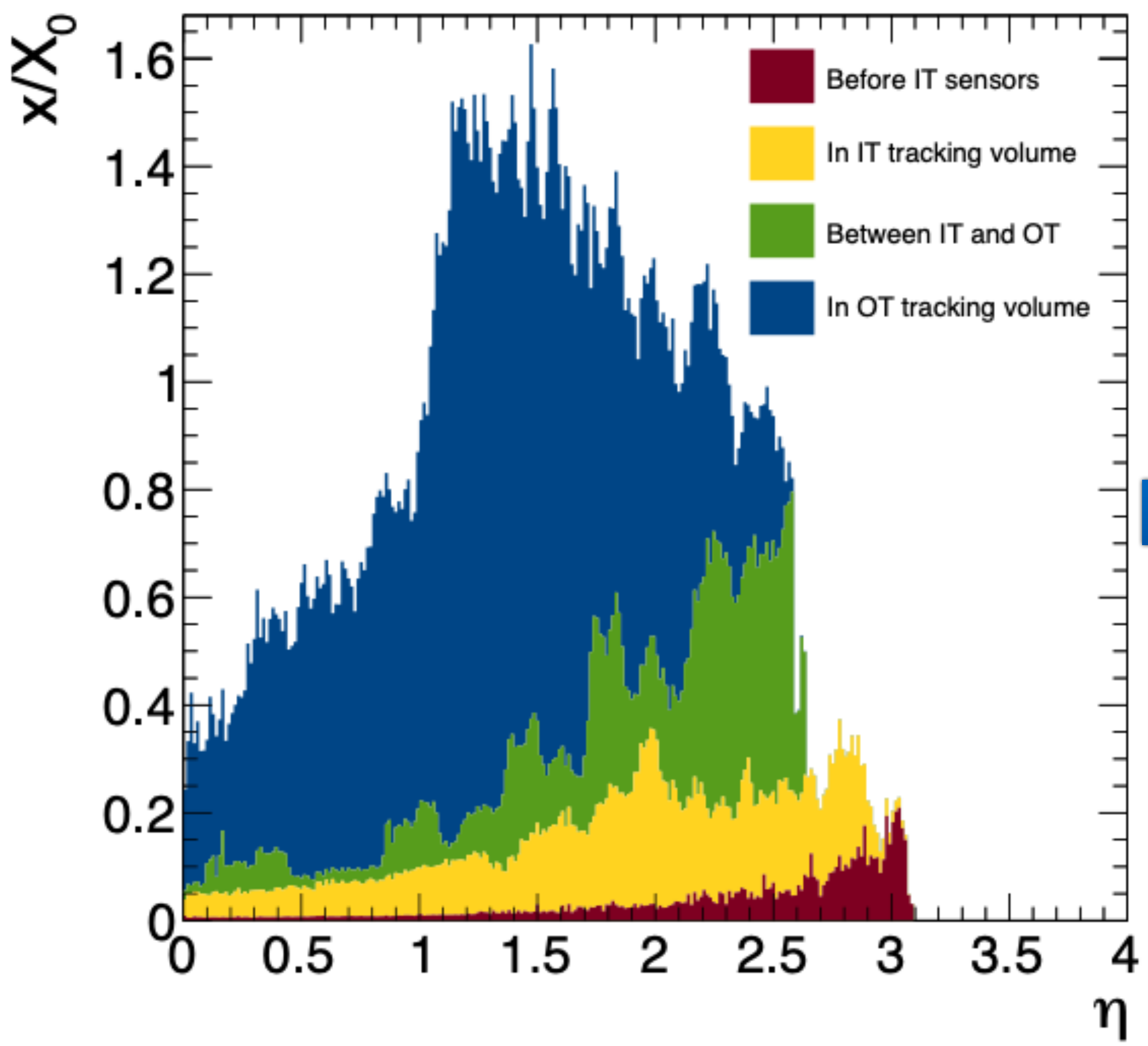
- Modules are cooled via evaporative CO_2 to keep sensors at <-20°C
  - cooling contacts to pipes embedded in e.g. Dee through

  —> carbon foam —> Dee facing —> PS baseplate to sensor

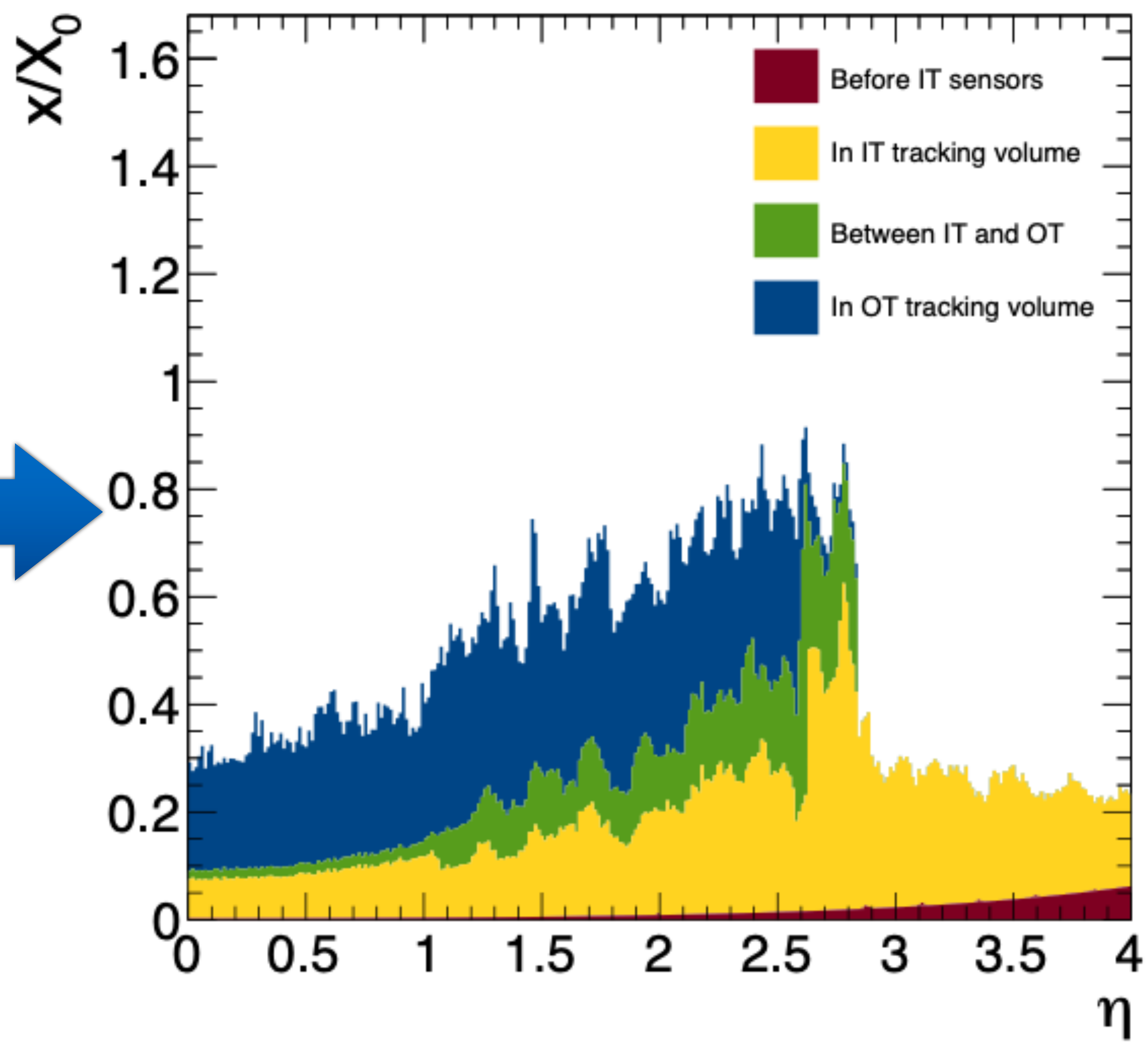
  —> aluminium inserts in Dee with cooling pipe embedded to 2S spacer

  —> good thermal contacts necessary

Phase 1 Tracker



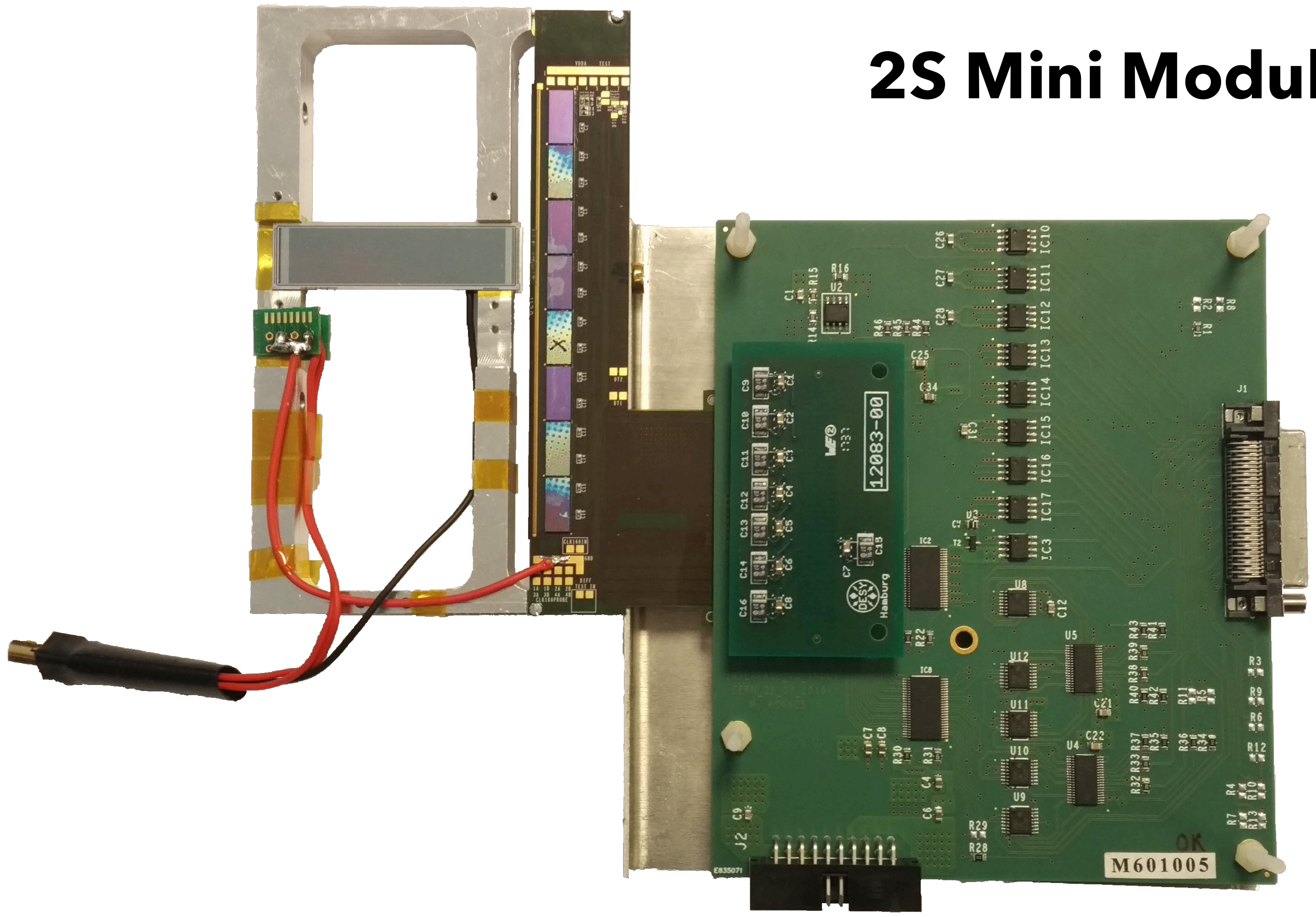
Phase 2 Tracker

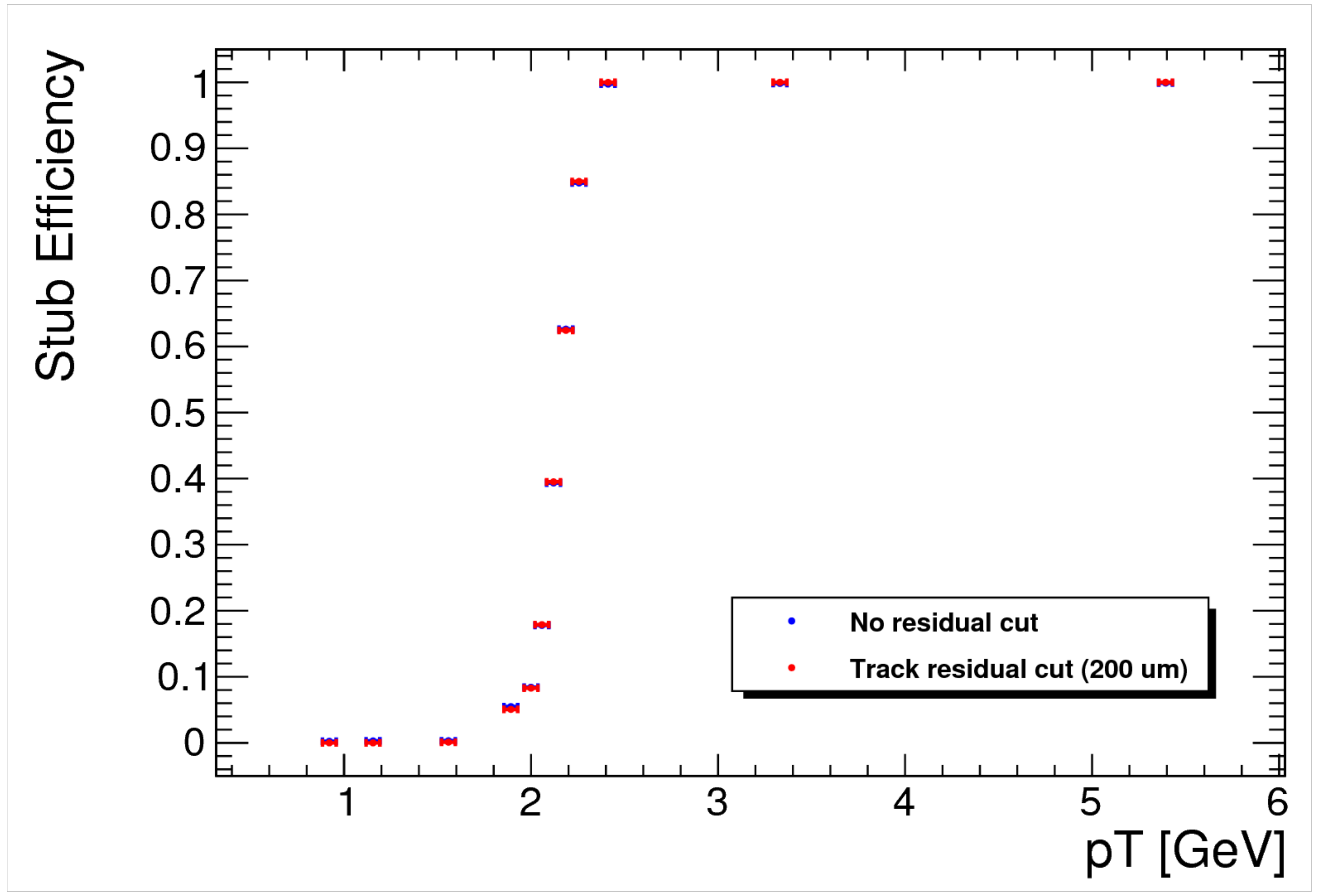


Test of produced Modules - mini Modules in Test Beams

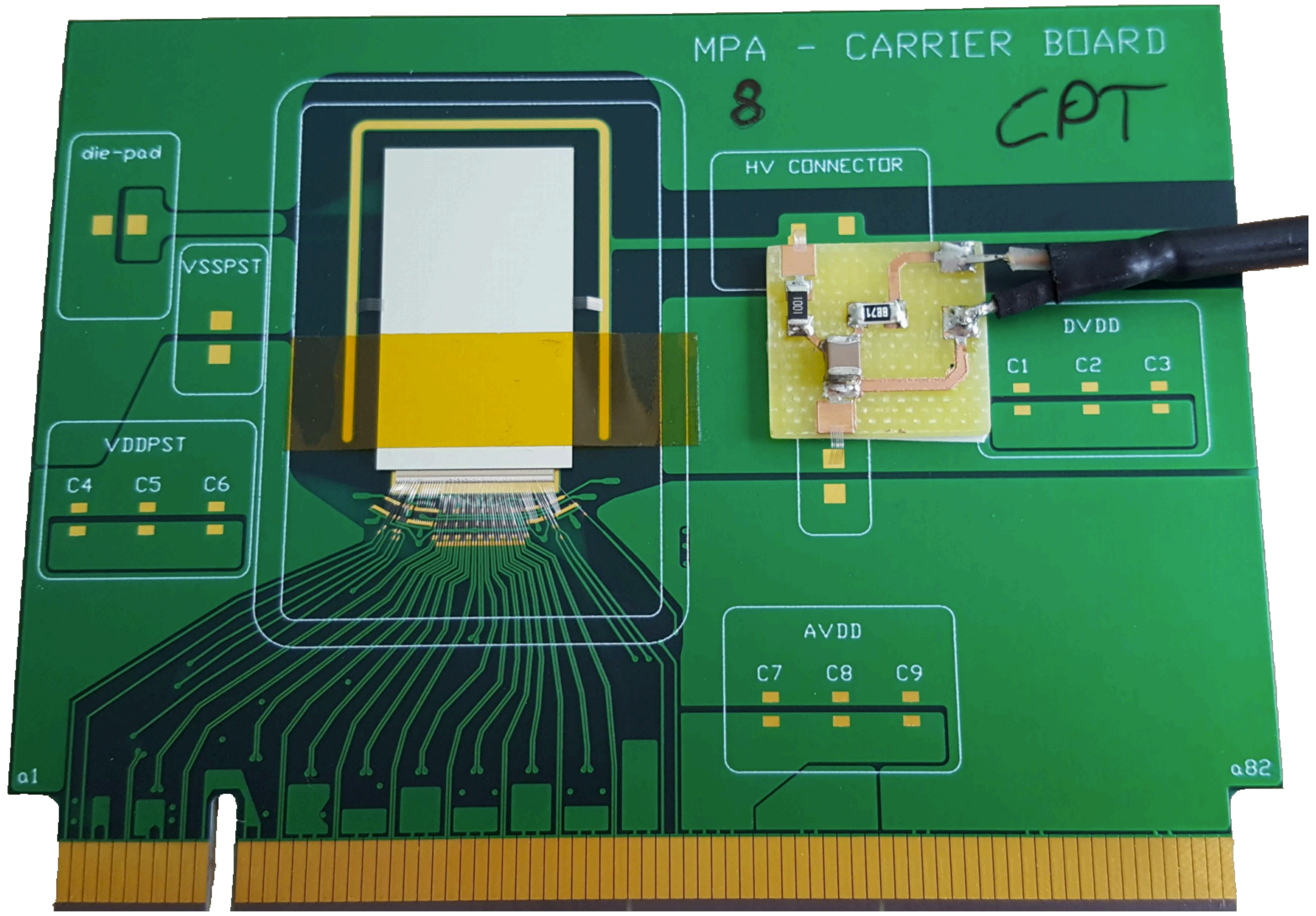
DESY

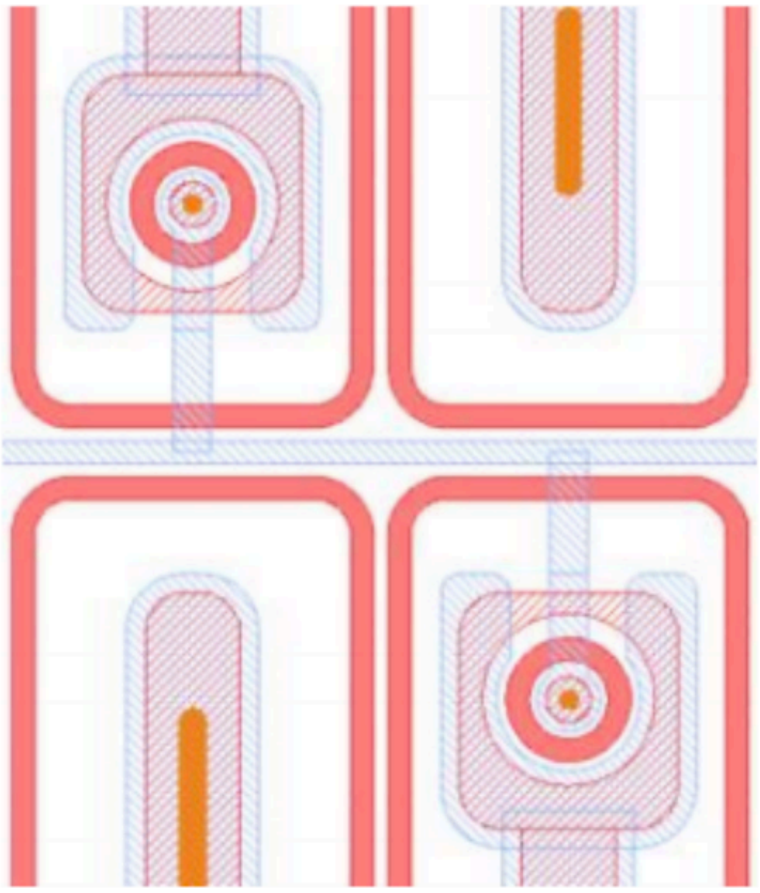
2S Mini Module

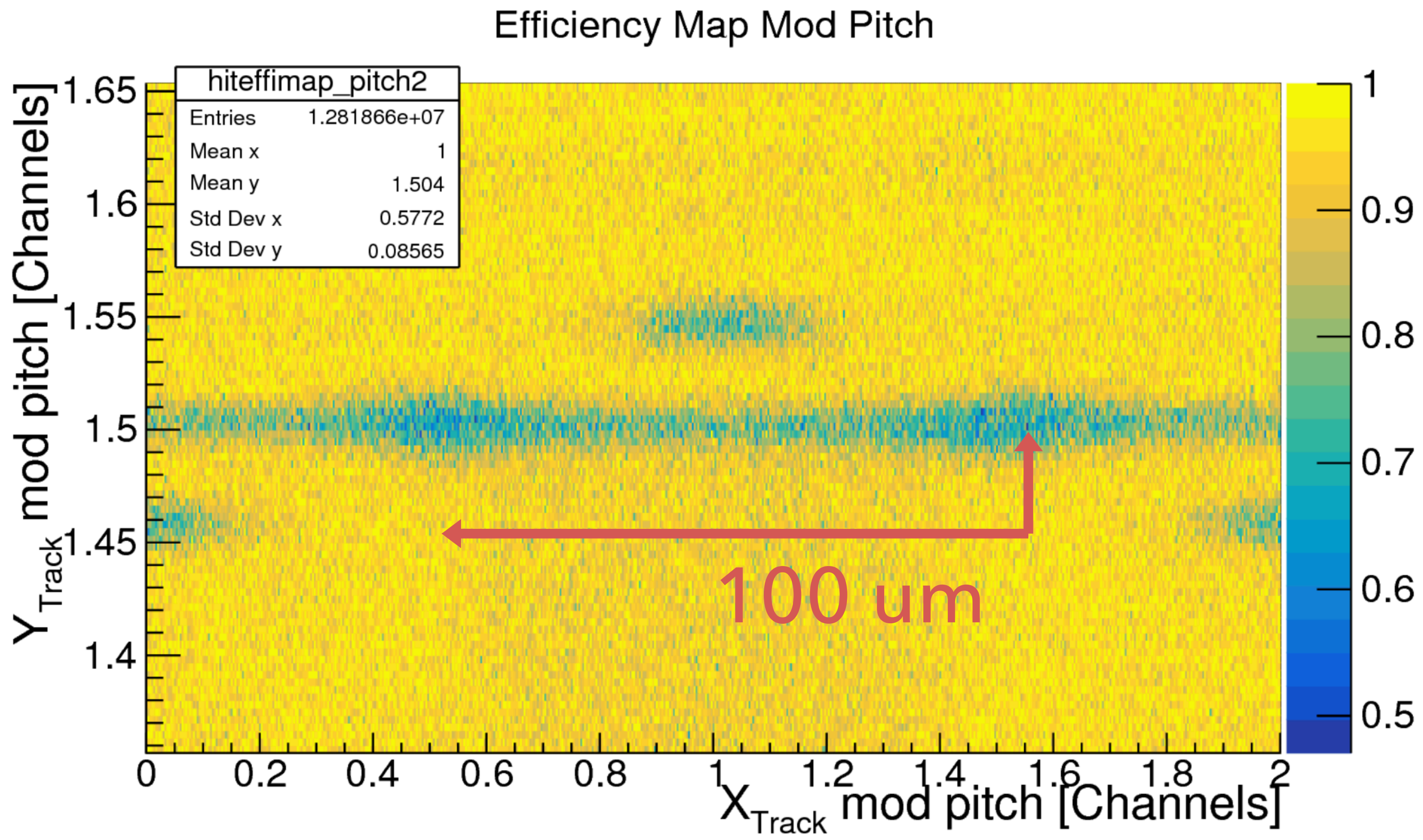




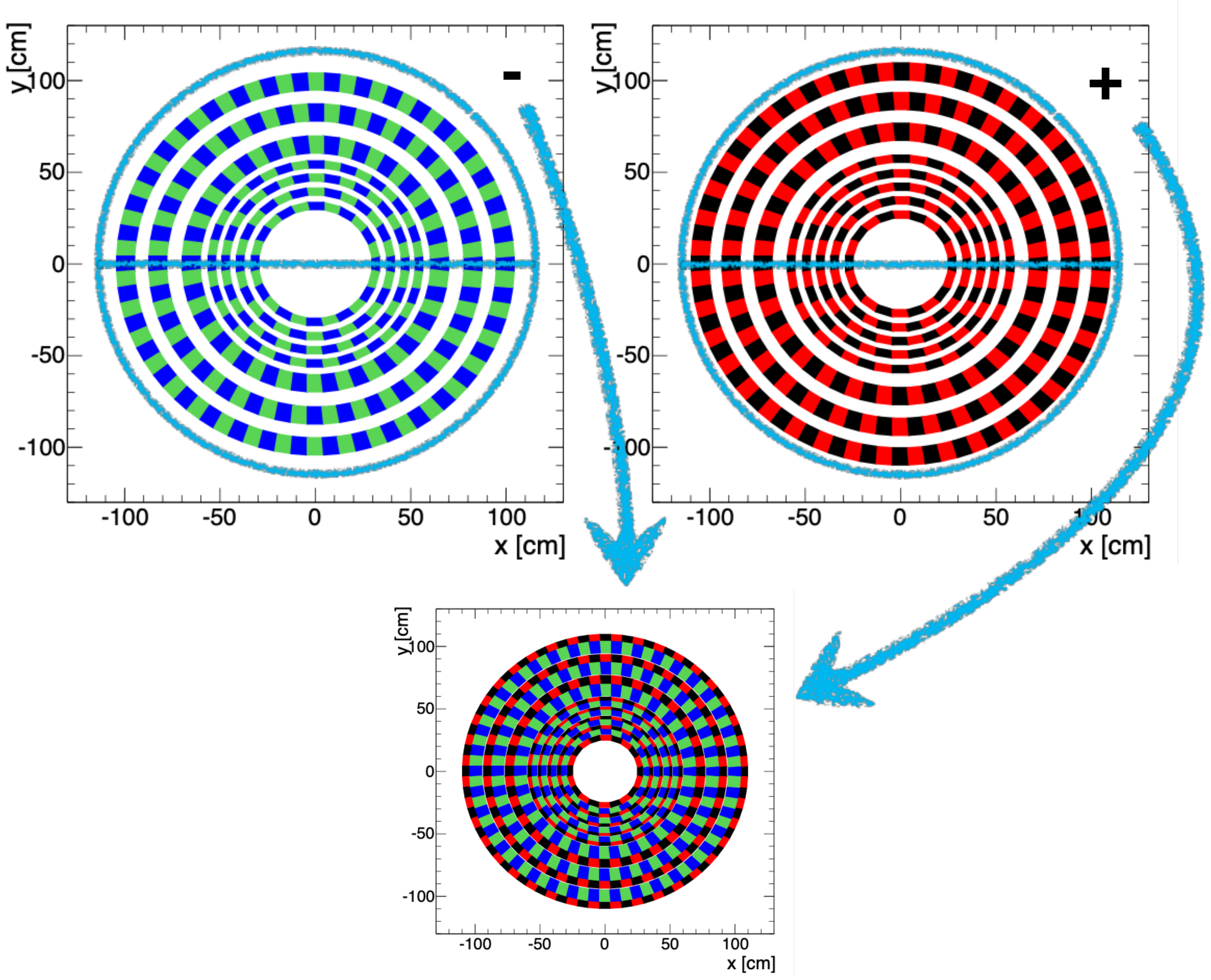
Single-Chip MaPSA

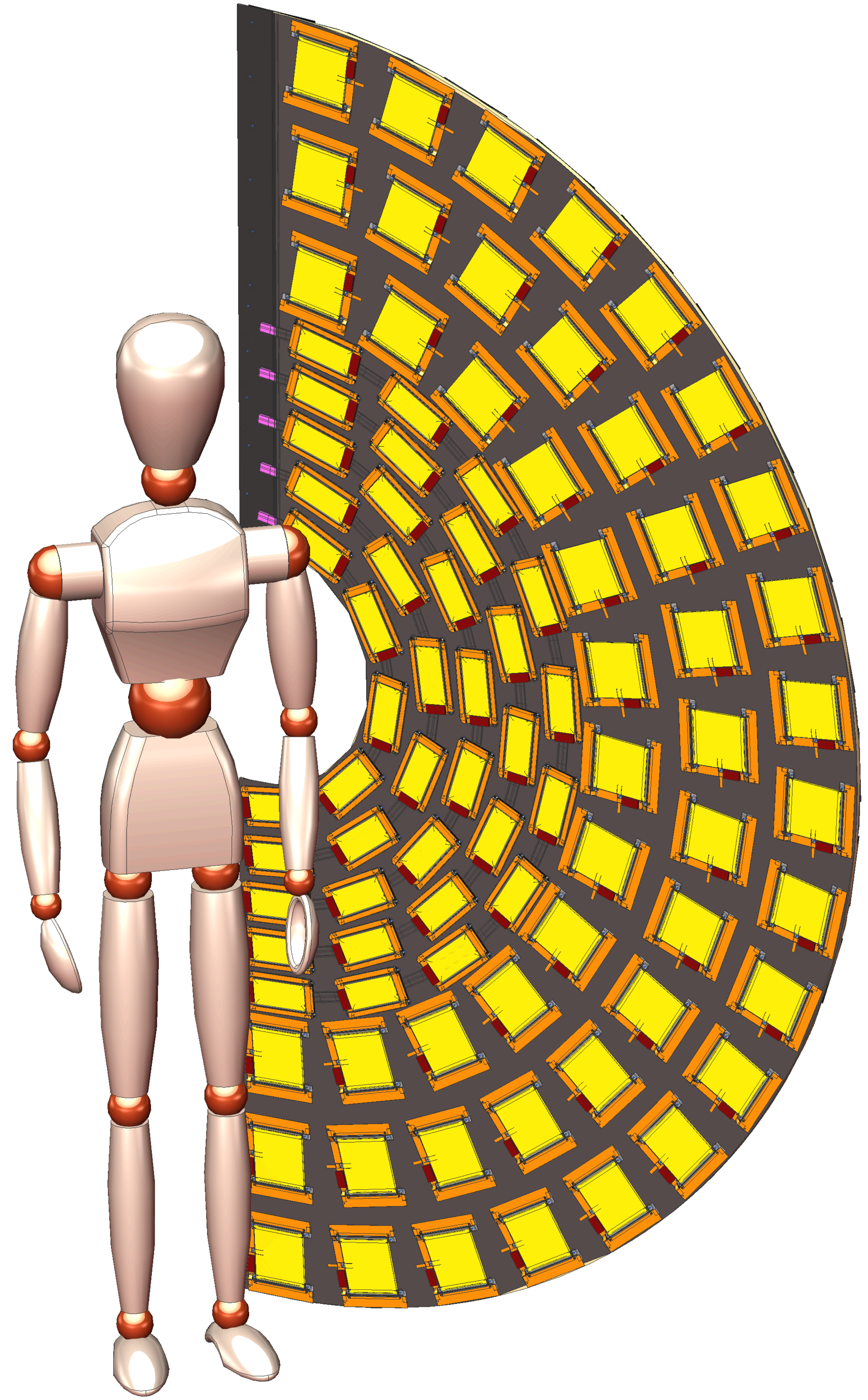






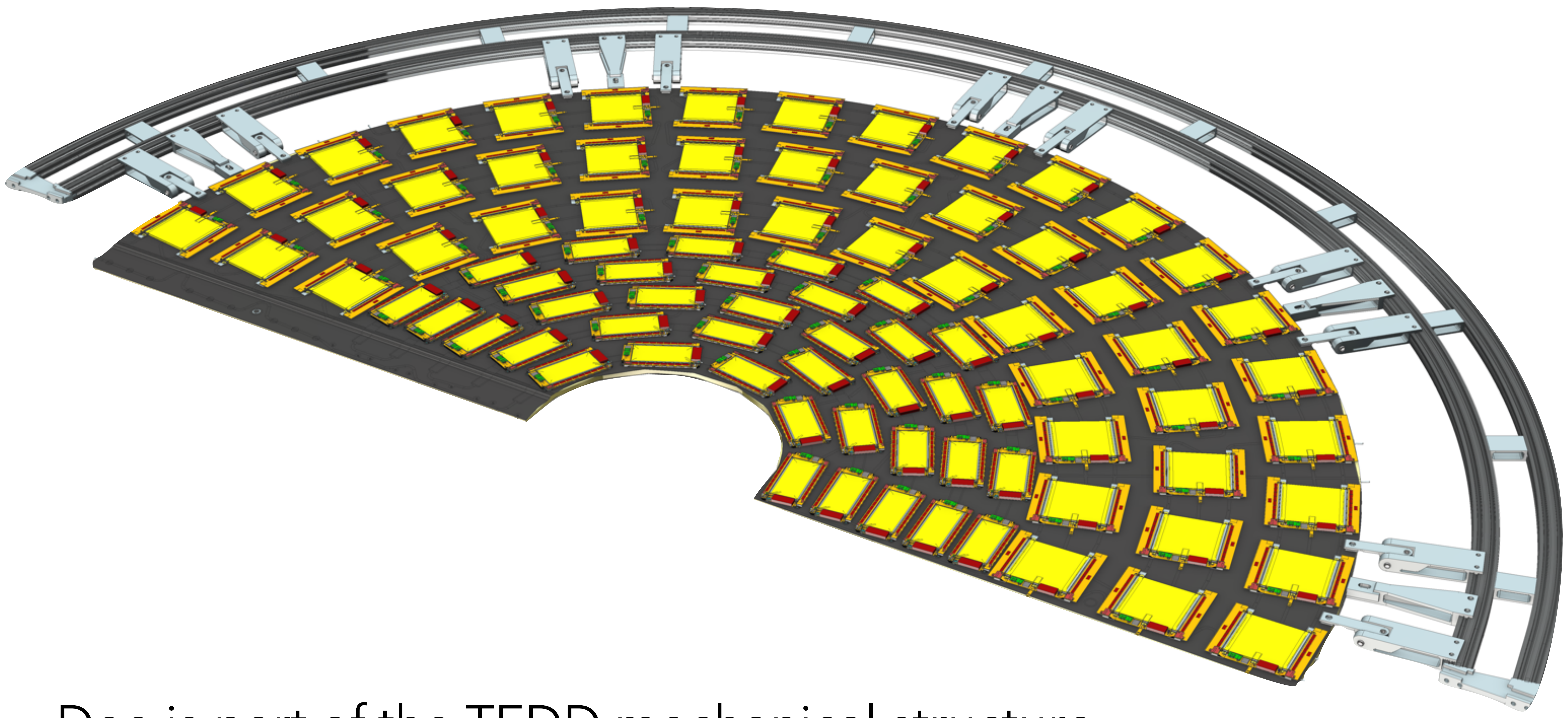
TEDD Support Structure - Dee





- Backbone is a carbon fibre sandwich half-disk structure (Dee)
  - ~225 cm in diameter
  - 10 mm thickness
- Modules are mounted from both sides onto structure
  - O(300 μm) positioning precision
- 20 Dees are combined to build one TEDD
  - 150 cm total length

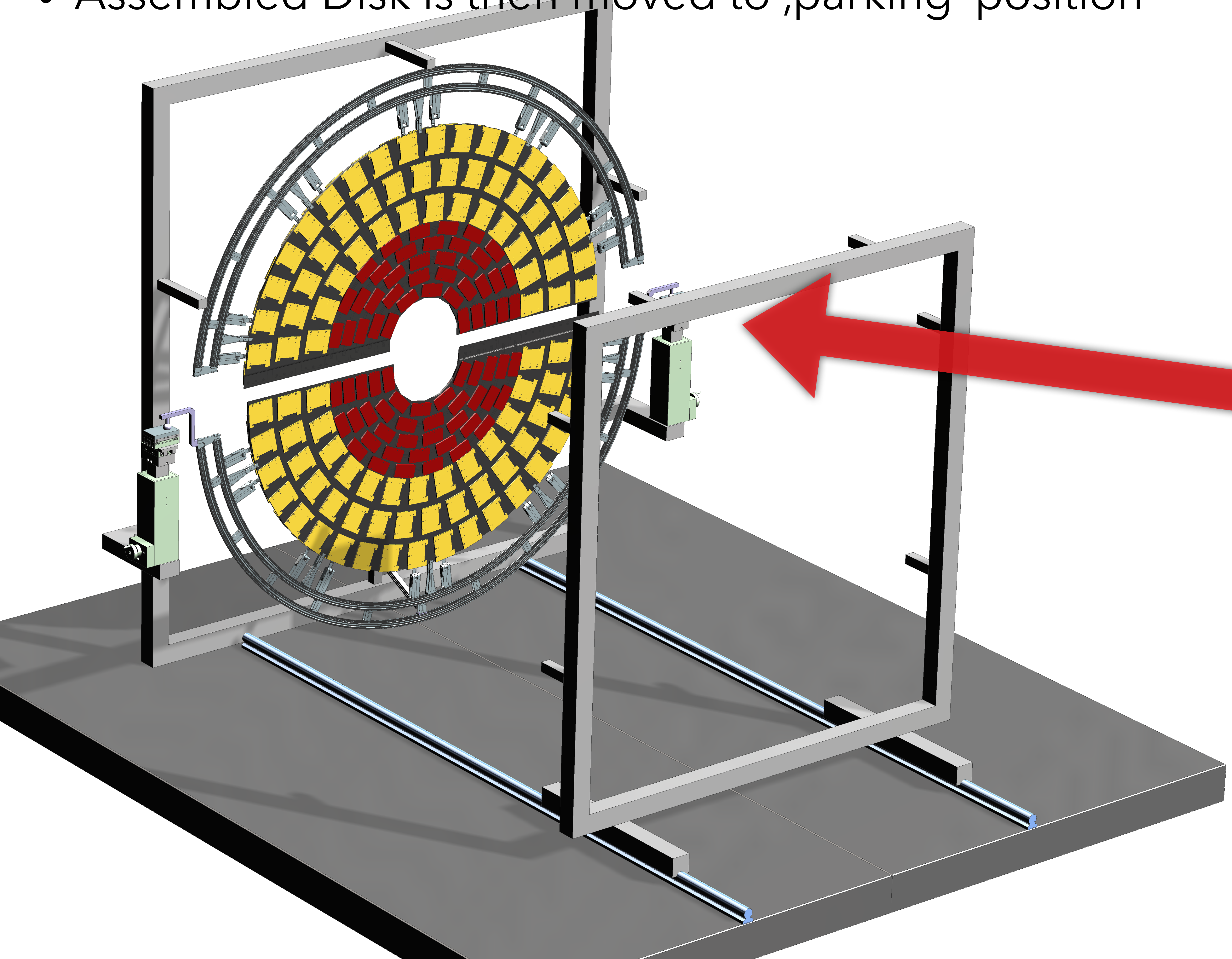
End Cap Integration - Arc-Frame

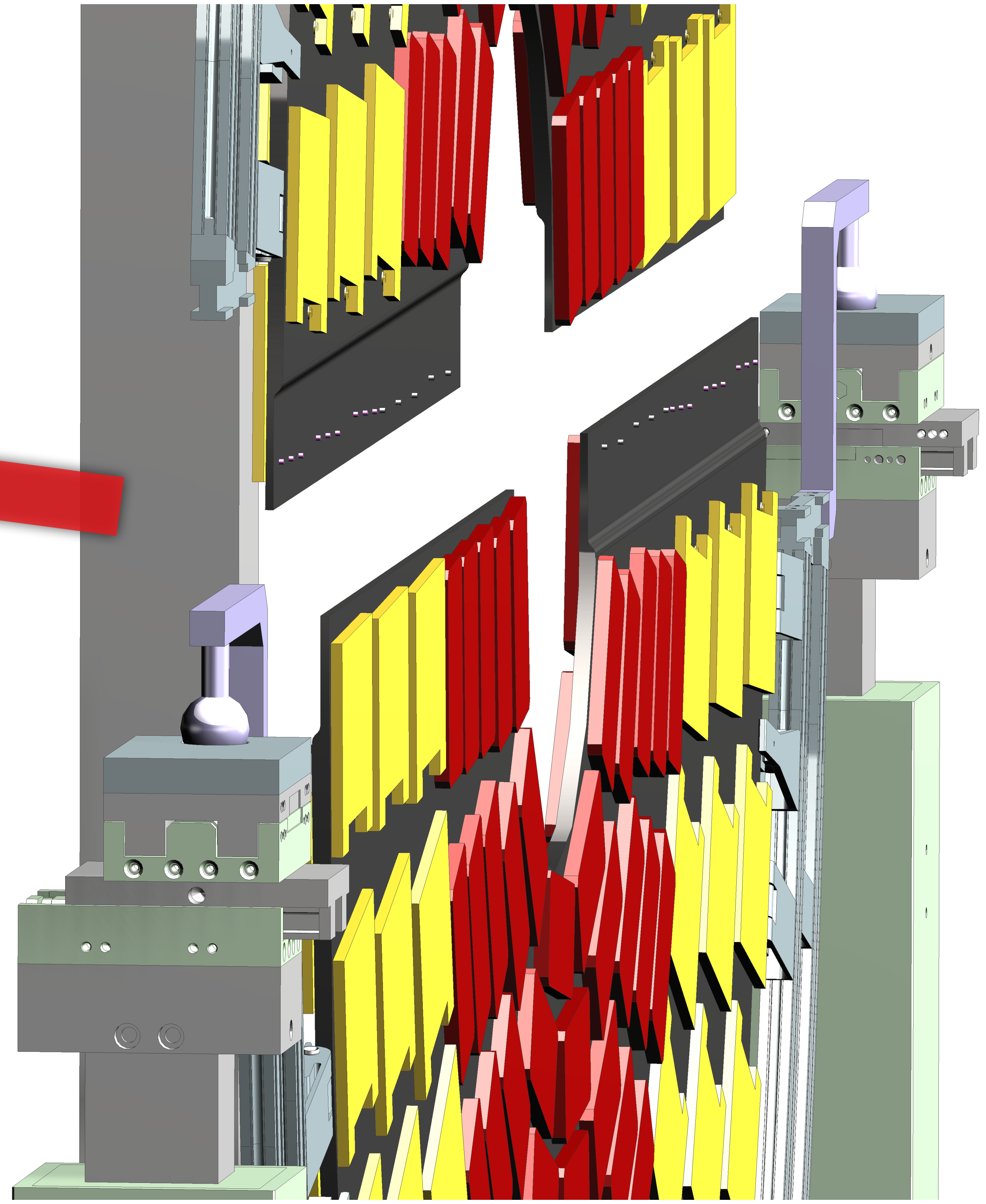


- Dee is part of the TEDD mechanical structure
  - TEDD has no ‚super-structure' into which Dees are inserted
- A single Dee is a rather floppy object
- Dees will stay in dedicated handling frame through-out integration process
  - reception tests ➡ module integration ➡ TEDD assembly
- Only when all 20 Dees are combined they become a stiff object
  - 4 Dees ➡ 2 Disks ➡ Double-Disk
  - 5 Double-Disks ➡ TEDD
- Arc-frame design has to be compatible with all integration steps

End Cap Integration - Disk & Double-Disk Assembly

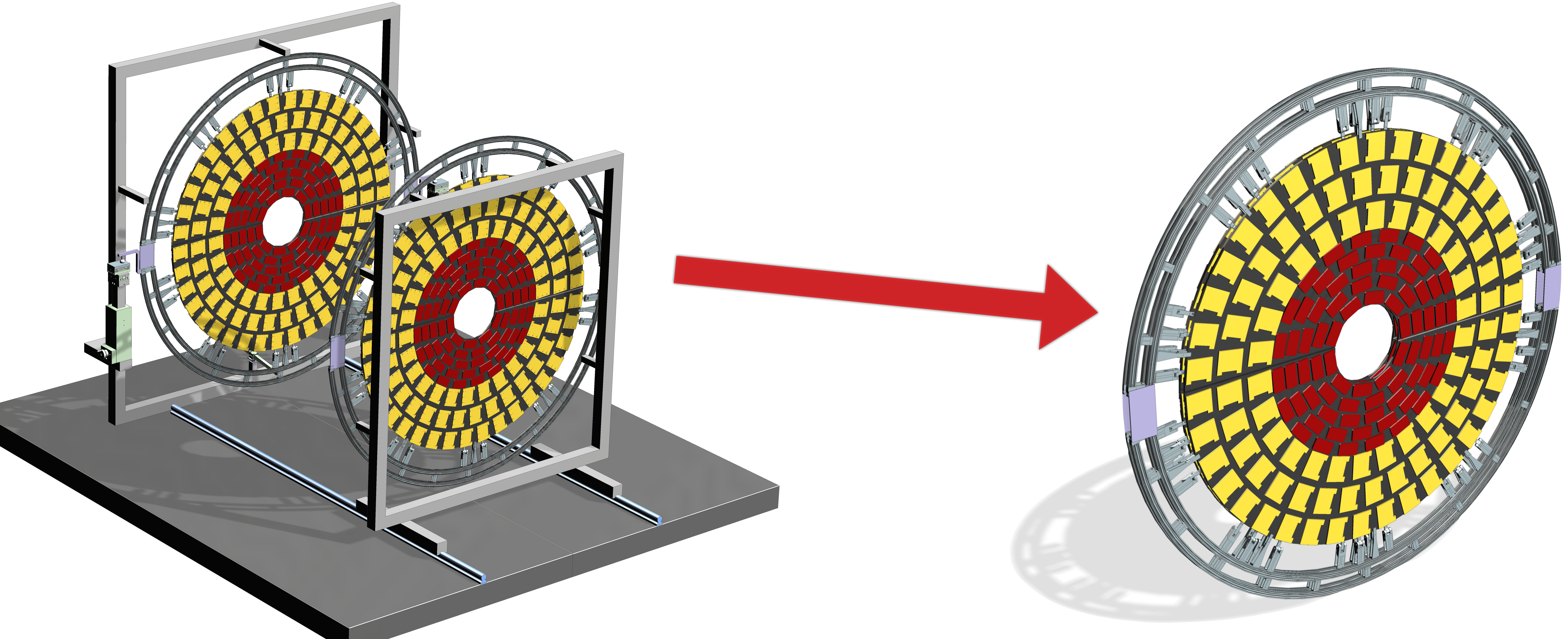
- Upper Dee is mounted in a static holding frame, lower Dee is supported by manual motion stages
- Relative alignment via metrology and motion stages
- Upper and lower Dees are pinned together and both Arc-Frames are mechanically connected when alignment is achieved
- Assembled Disk is then moved to ‚parking' position



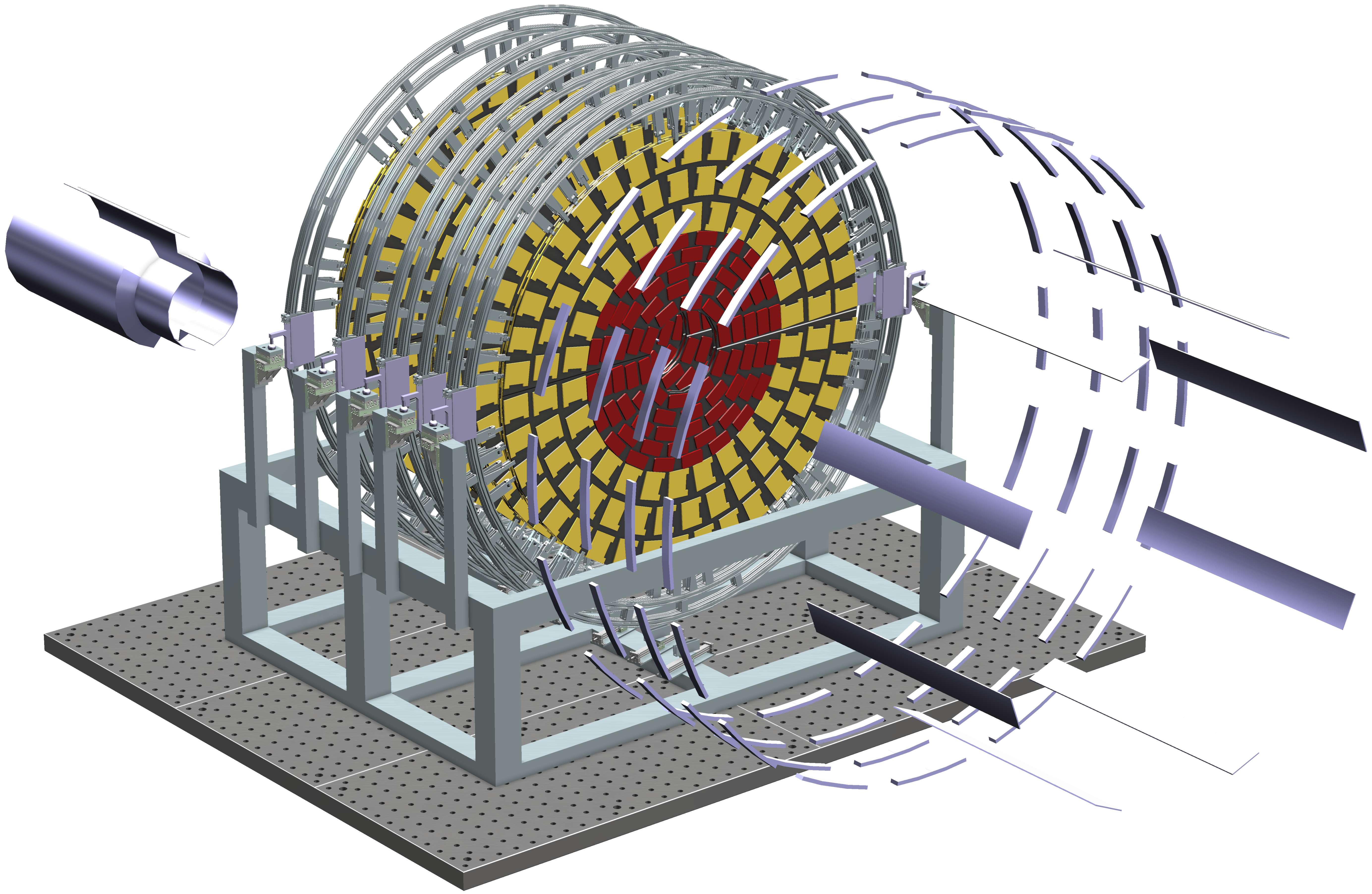


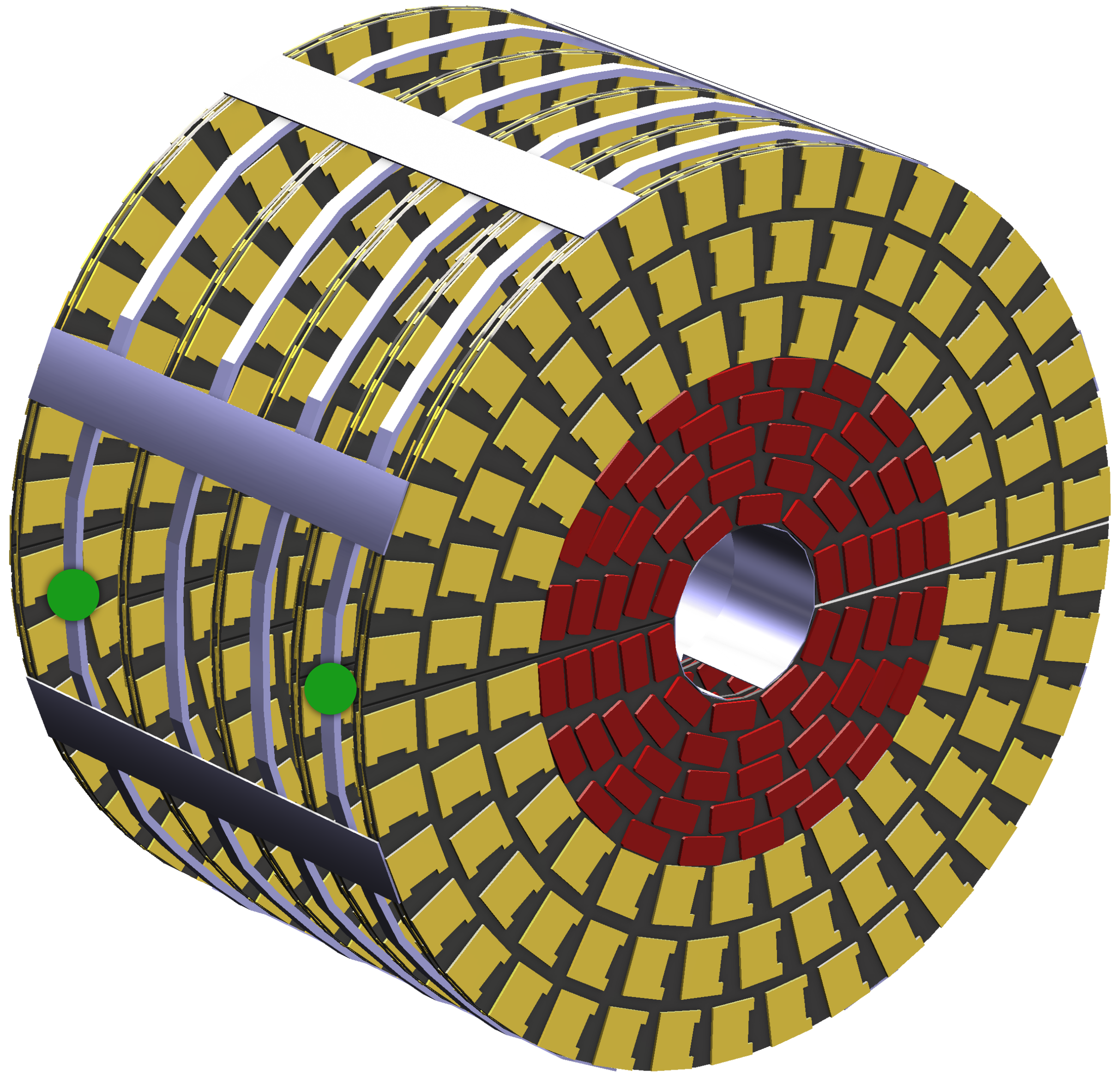
End Cap Integration - Disk & Double-Disk Assembly

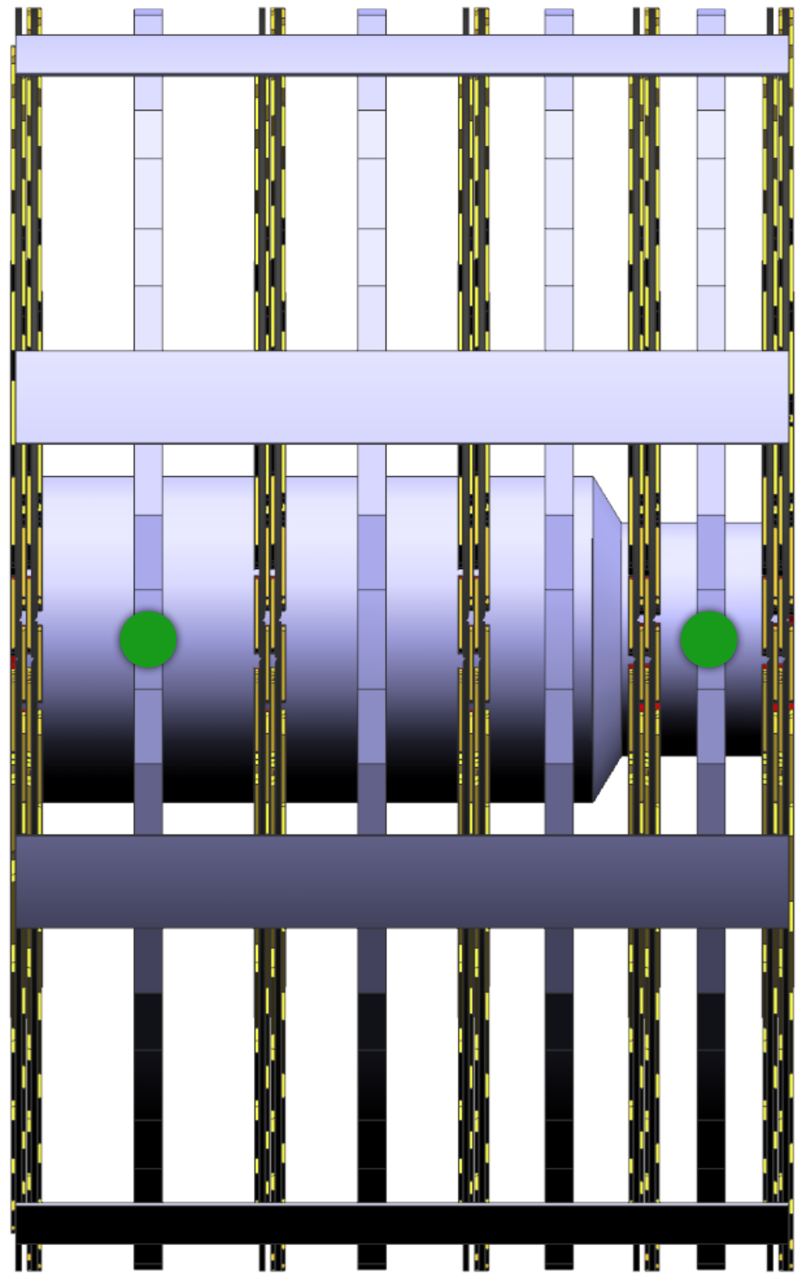
- Second Disk is assembled and remains in static holding frame
- First Disk is moved back from ‚parking‘ position and supported by manual motion stages
- Relative alignment via metrology and motion stages
- Both Disk are bolted together and Arc-Frames are mechanically connected when alignment is achieved



End Cap Integration







- Relative alignment of all five Double-Disks via metrology and manual motion stages
- Insertion of inner tube, longitudinal support bars and support rings when alignment is achieved