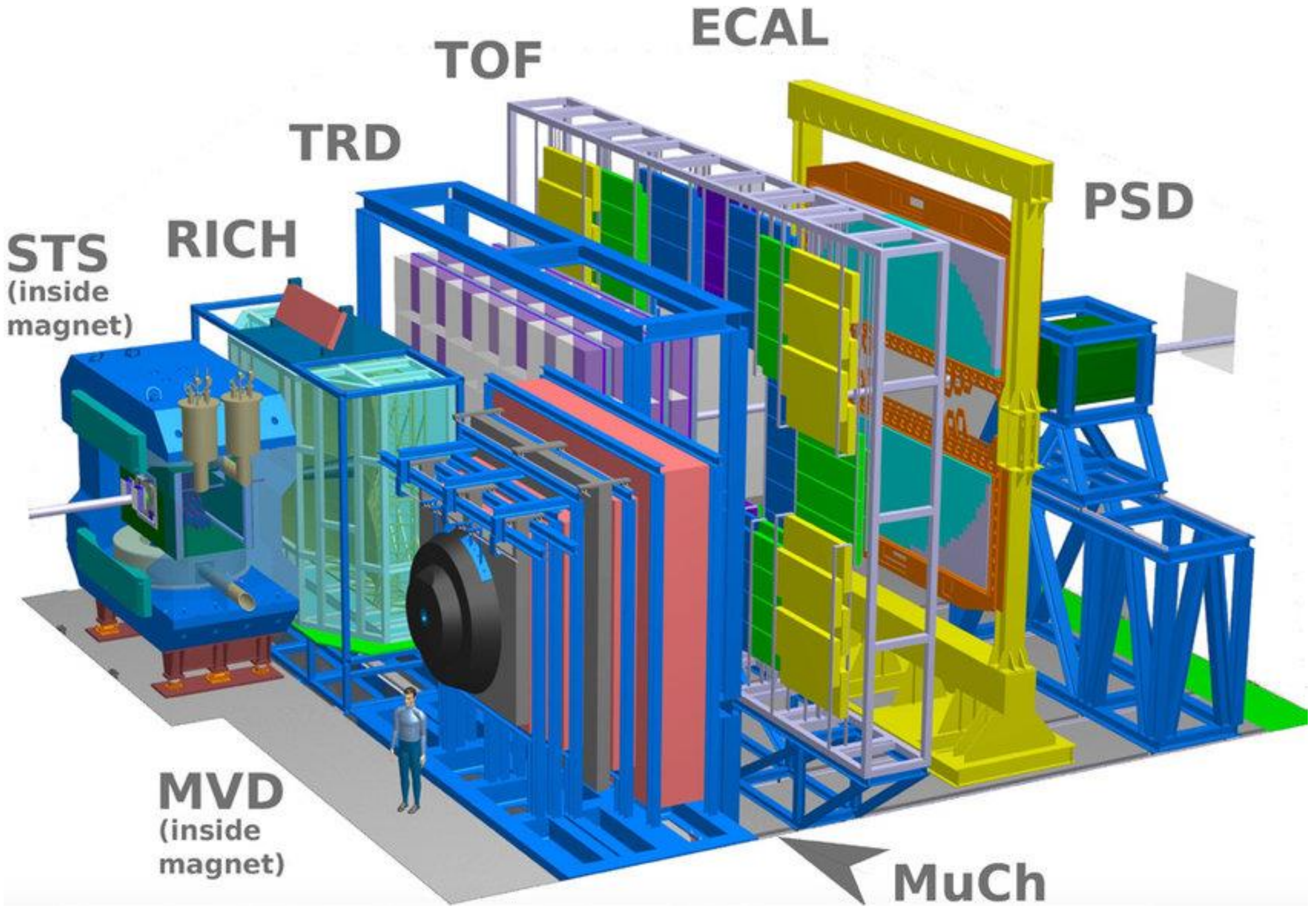
Mechanical Integration of Tracking Devices for Vacuum Operation

The CBM MVD



Franz A. Matejcek for the CBM MVD Team

Forum on Tracking Detector Mechanics 2023, 31.05.2023

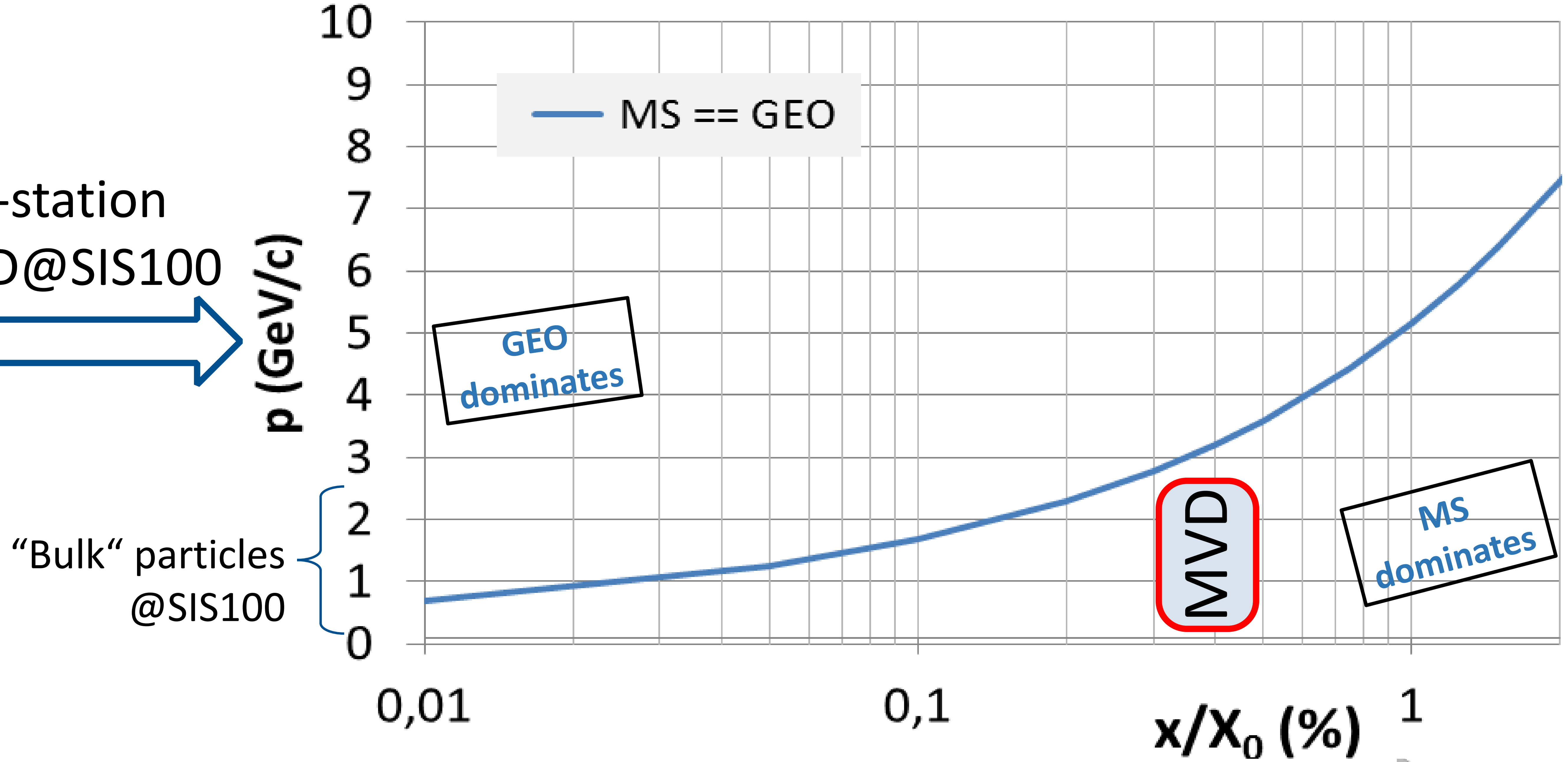
Design Considerations

$$\boxed{\sigma^2 = \frac{\sigma_1^2 r_1^2 + \sigma_2^2 r_2^2}{(r_1 - r_2)^2} + \frac{r_1^2}{sin^2(\theta)}\left(\frac{p_0}{p_{lab}\cdot\beta}\sqrt{\frac{x}{X_0}}\right)^2}$$

Geometry

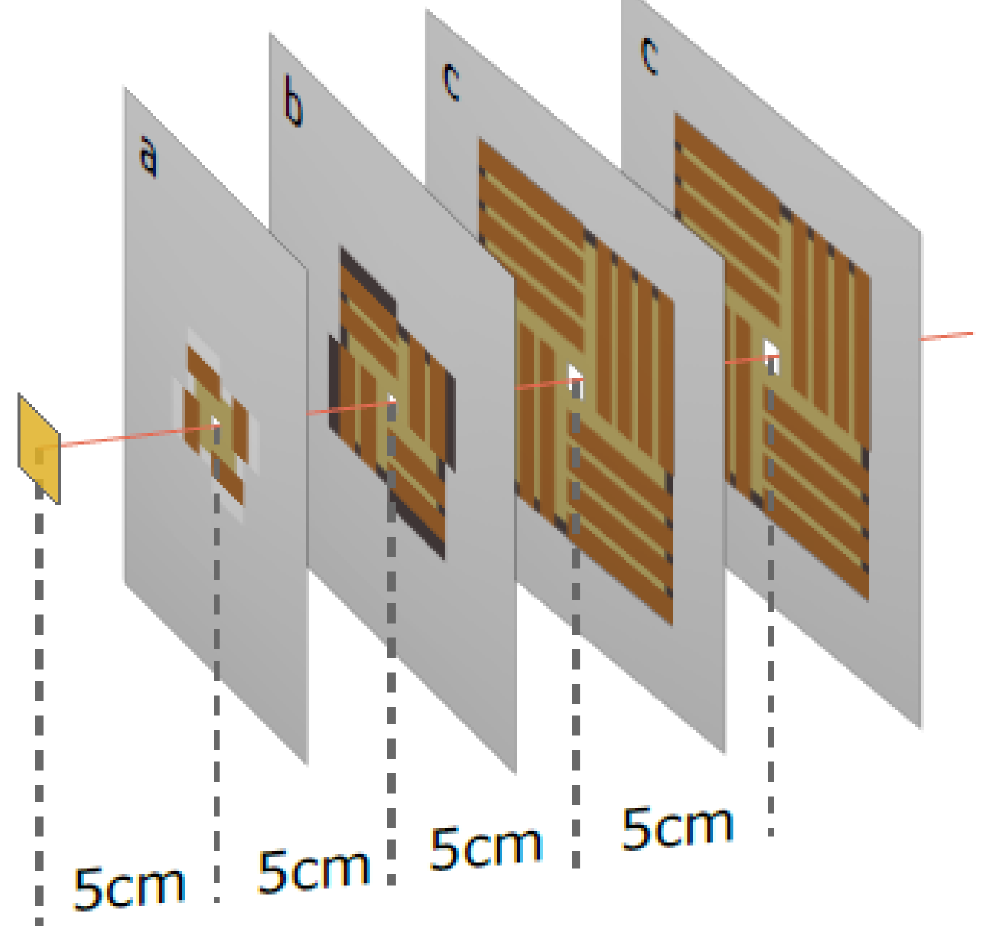
Multiple Scattering

* For a 2-station CBM MVD@SIS100



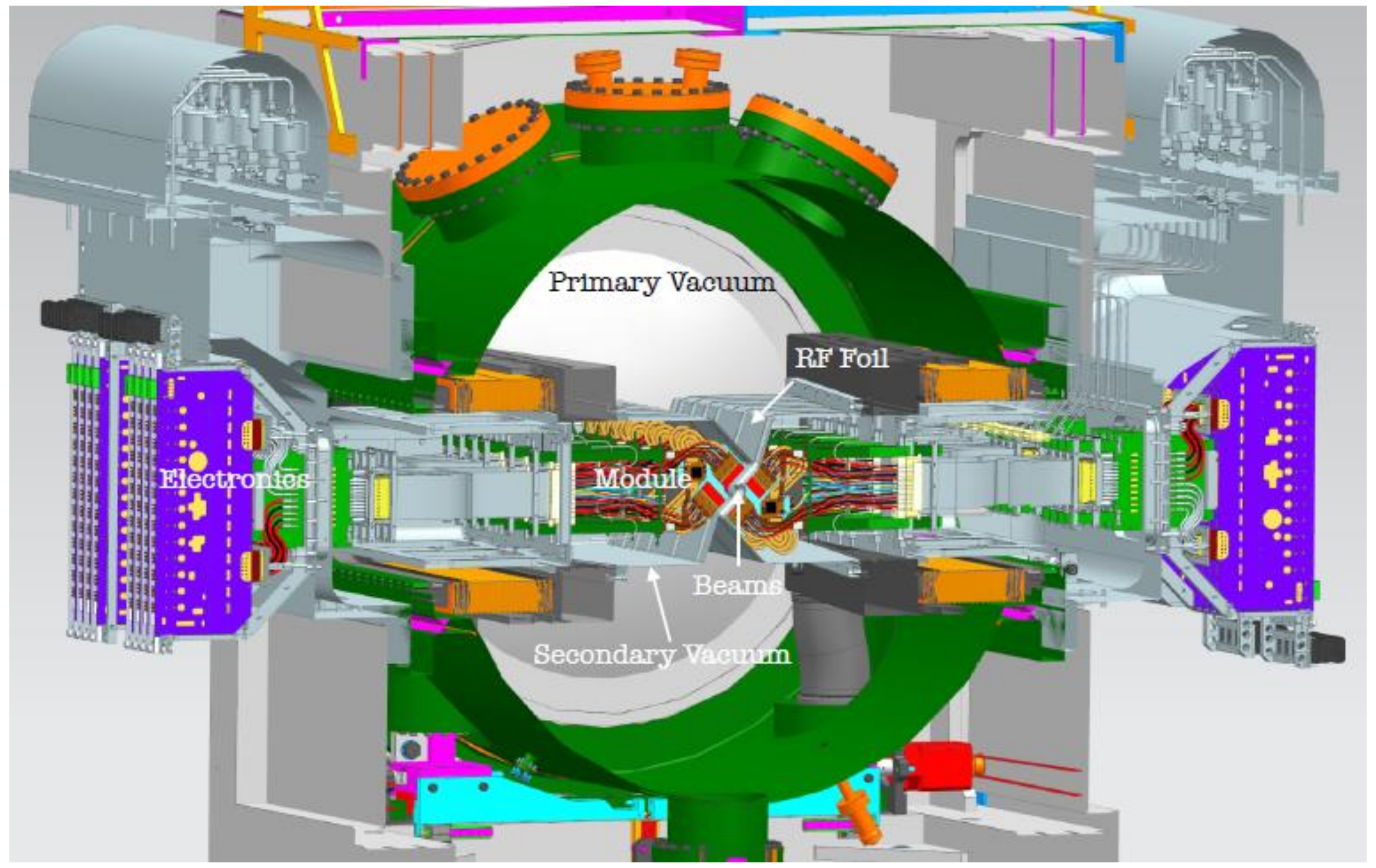
Use-case: CBM Micro Vertex Detector (MVD)

- Planar station for fixed target experiment
  → **Double-sided integration**
- Strong, localized, inhomogeneous radiation field
  → ~5 Mrad (IEL) & ~10^{14} n_{eq}/cm^2 (NIEL)
  → High radiation tolerance of all components
- Tracks with p=0.3,…,~2 GeV/c (MS-dominated regime)
  → **x/X_0 = 0.3,..,0.5 %** per station
  → Placed in **target vacuum**

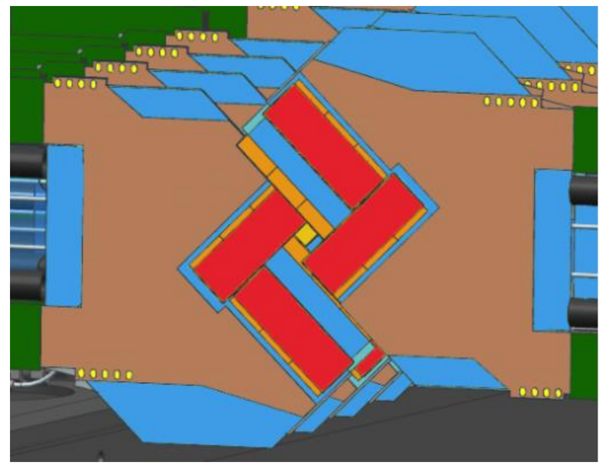


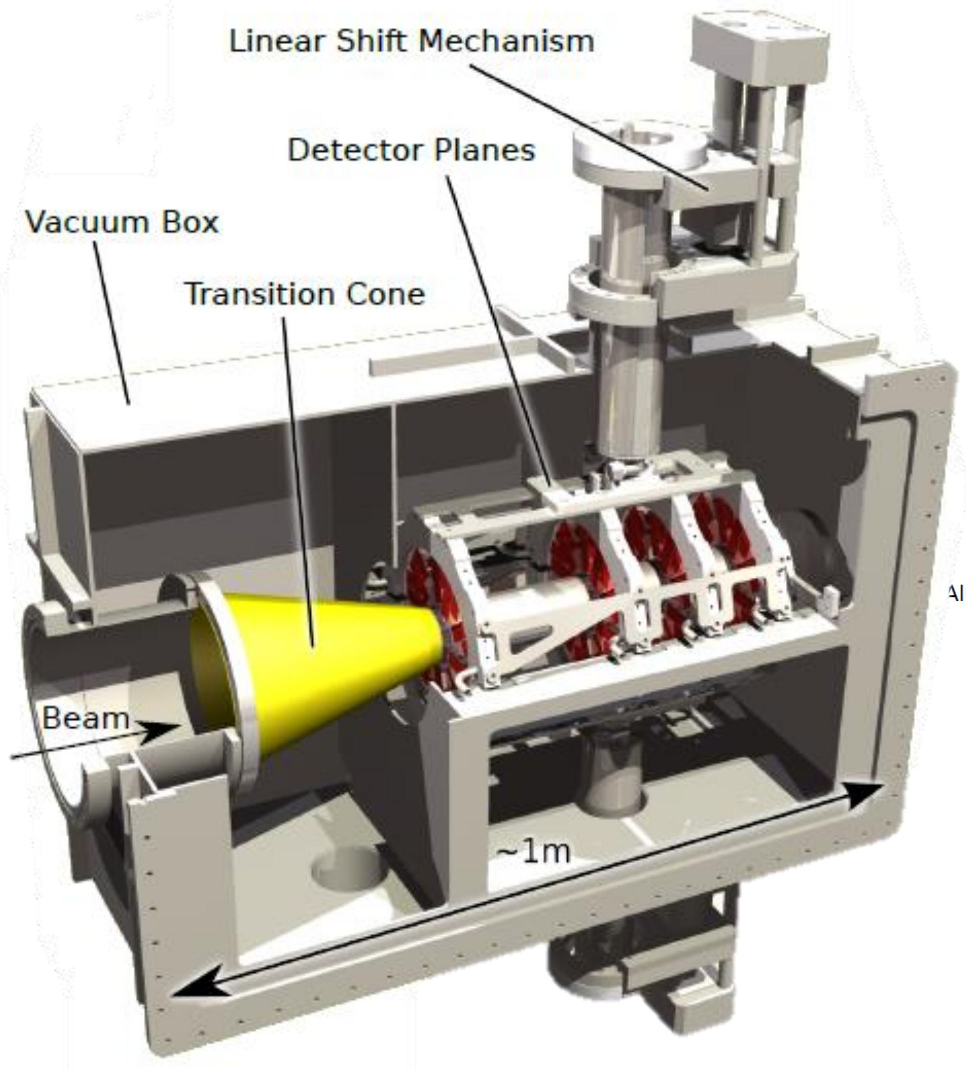
*See: Wermes, N. (2006). Pixel Vertex Detectors. Lectures notes SLAC Summer Institute, arXiv:physics/0611075 [physics.ins-det].

Approaches (Selected)

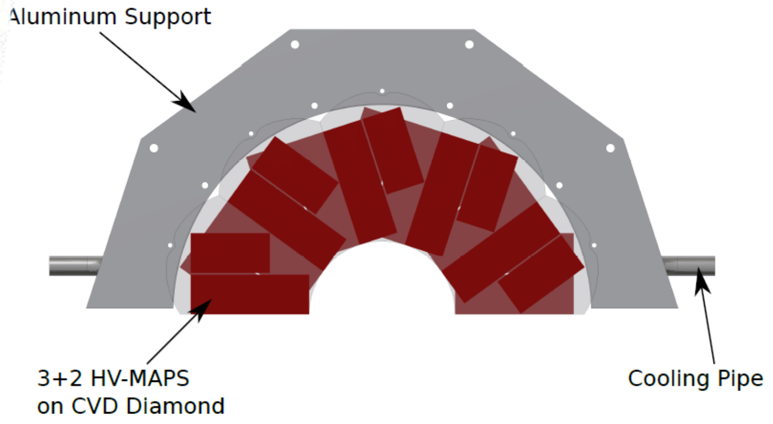


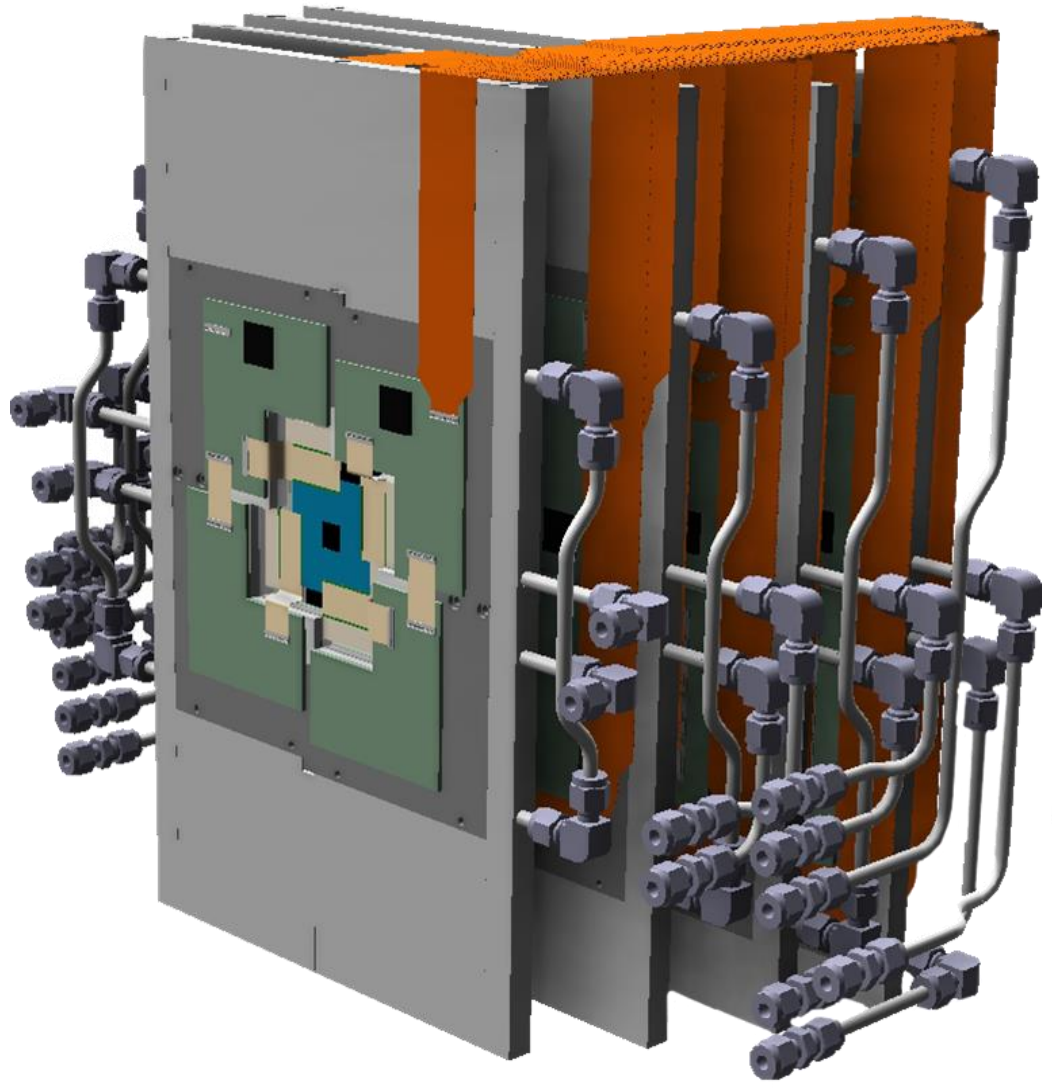
Upgraded LHCb Vertex Locator



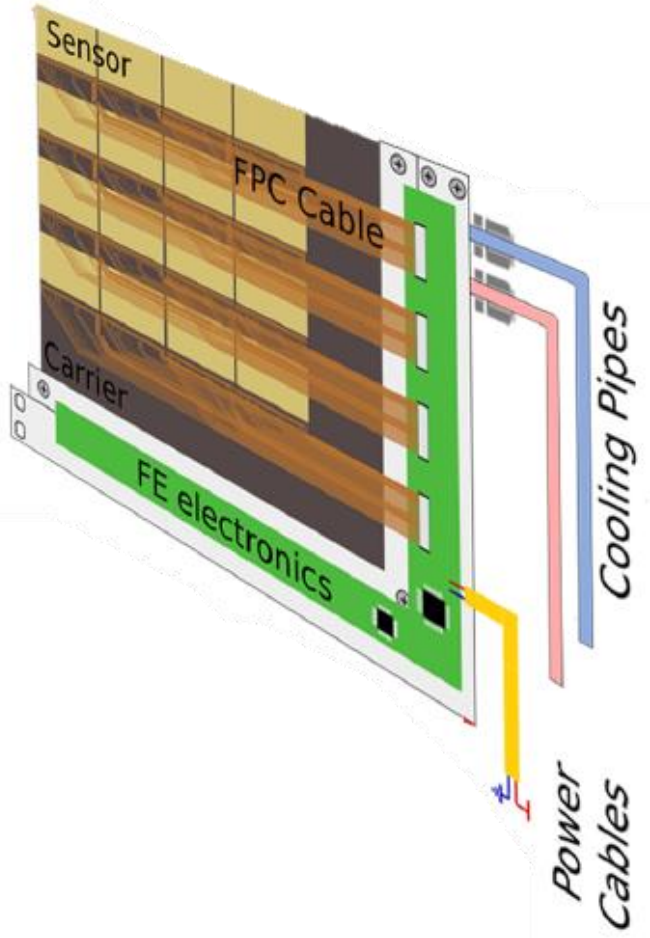


PANDA Luminosity Detector





CBM Micro Vertex Detector



per module	P [W]	T [°C]	$x_{\text{avg.}}$ [% X_0]	$x_{\text{max.}}$ [% X_0]	Cooling solution
LHCb VELO	$\sim$43	< -20	0.94	$\sim$1.2	Active; Si microchannels
PANDA LMD	$\sim$28	< 30	0.32	0.37	Passive, pCVD diamond (conduction)
CBM MVD	$\sim$10	< 0	0.37	0.52	Passive, TPG/pCVD diamond (conduction)

See: LHCb collaboration. LHCb VELO Upgrade Technical Design Report. CERN-LHCC-2013-021. 2013.
PANDA Collaboration. PANDA LMD Technical Design Report. arXiv:1207.6581 [physics.ins-det]. 2012.
CBM Collaboration. CBM MVD Technical Design Report. 2021.

Towards MVD@SIS100

Upgraded LHCb VELO: Geometry ⟷ CBM MVD: Multiple Scattering

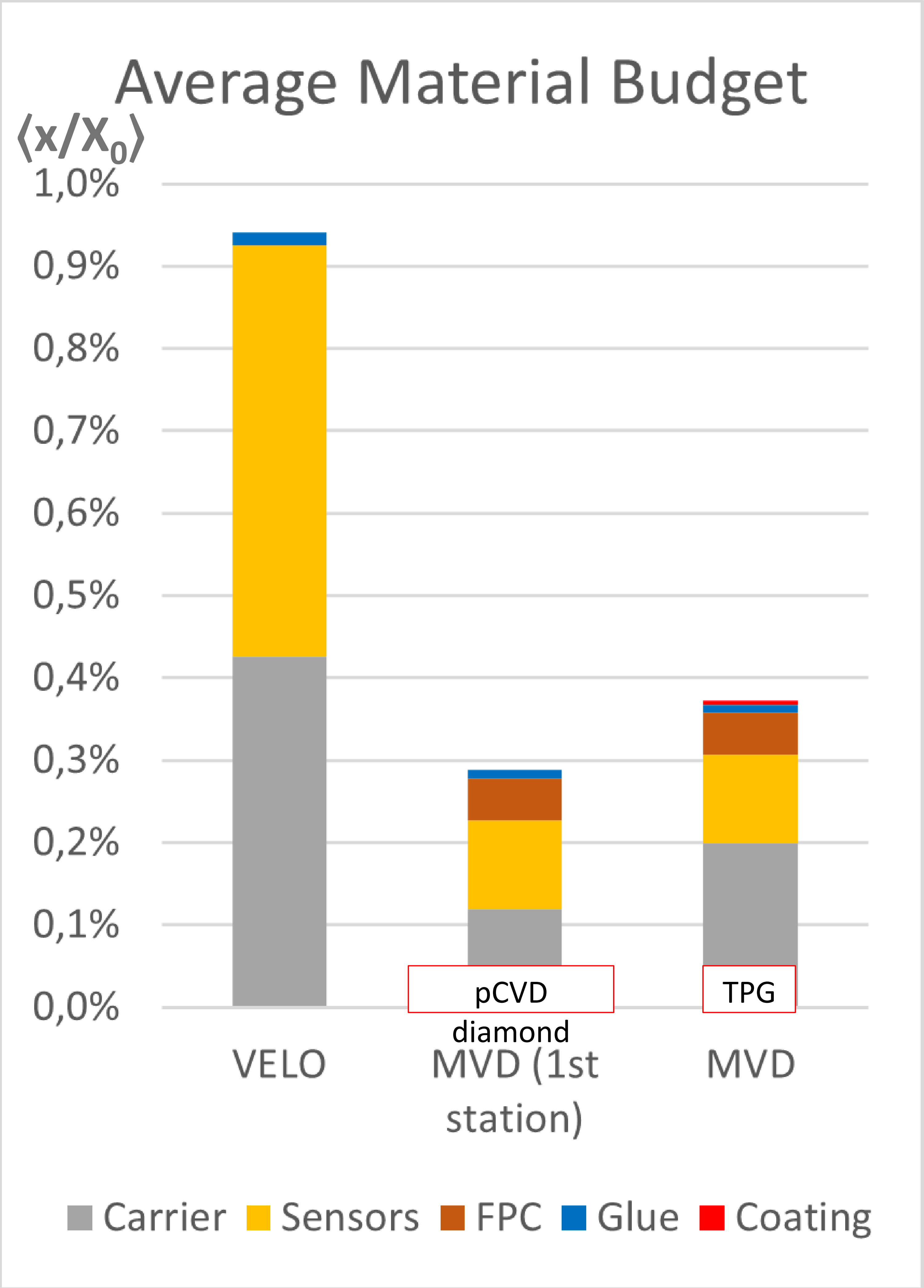
Reference Setup: Upgraded LHCb VELO

- In-vacuum tracking/vertexing detector
- But: higher average momenta (p > 5 GeV/c)
  → Higher constraints for CBM MVD wrt. x/X_0

Where to gain on x/X_0?

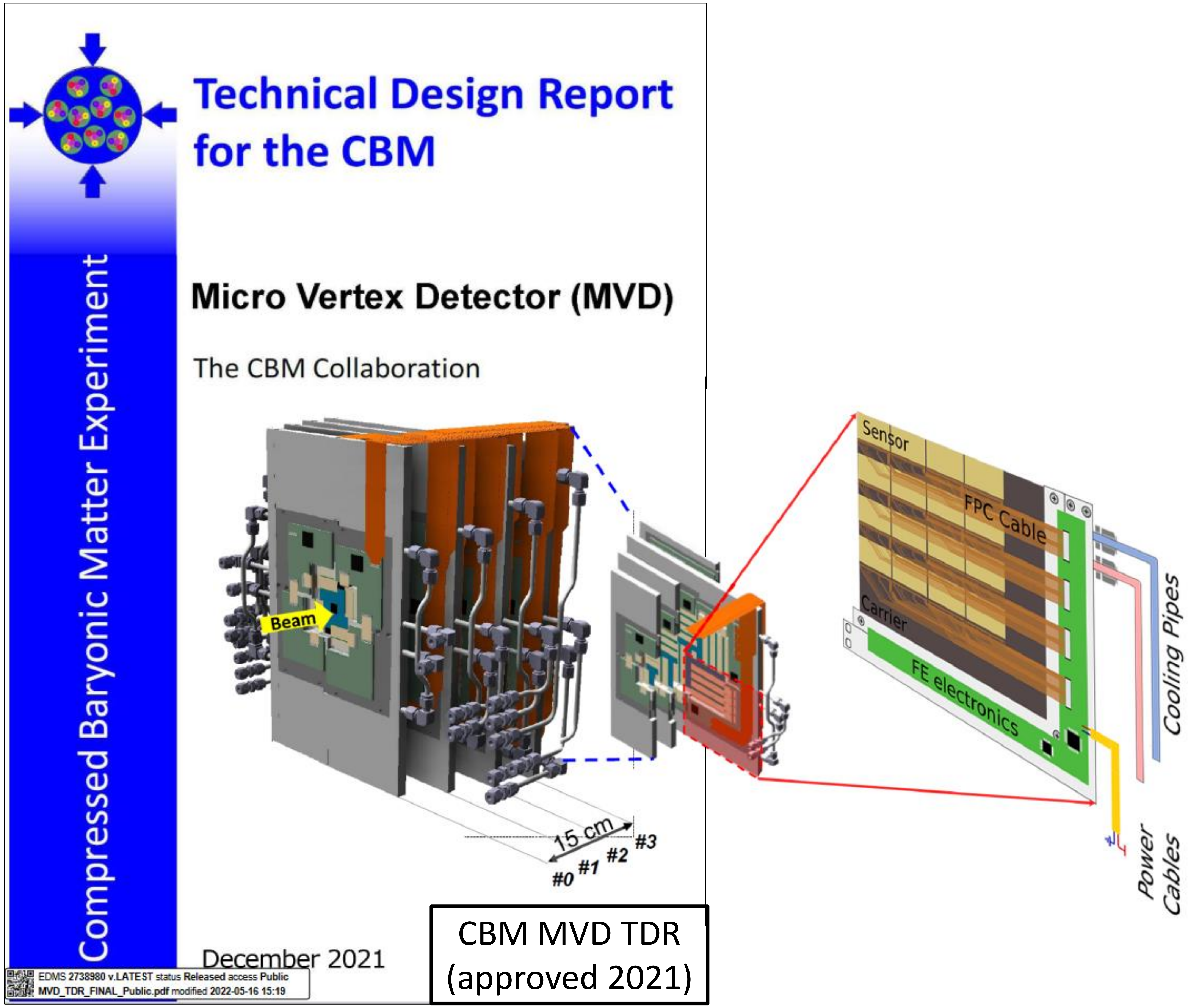
- Sensors: thinned CMOS MAPS instead of hybrids
  → Double-sided integration for 100% fill factor
- Cooling & mechanics: Active cooling **outside** the acceptance
  → Integrate on high-performance carbon materials
  → **No lunch for free**: CTE mismatch, increased thermal FOM,…

⇒ Higher demands on carrier, glue,…



See: LHCb collaboration. LHCb VELO Upgrade Technical Design Report. CERN-LHCC-2013-021. 2013.
CBM Collaboration. CBM MVD Technical Design Report. 2021.

The CBM MVD



Compressed Baryonic Matter Experiment

Technical Design Report
for the CBM

Micro Vertex Detector (MVD)

The CBM Collaboration

December 2021

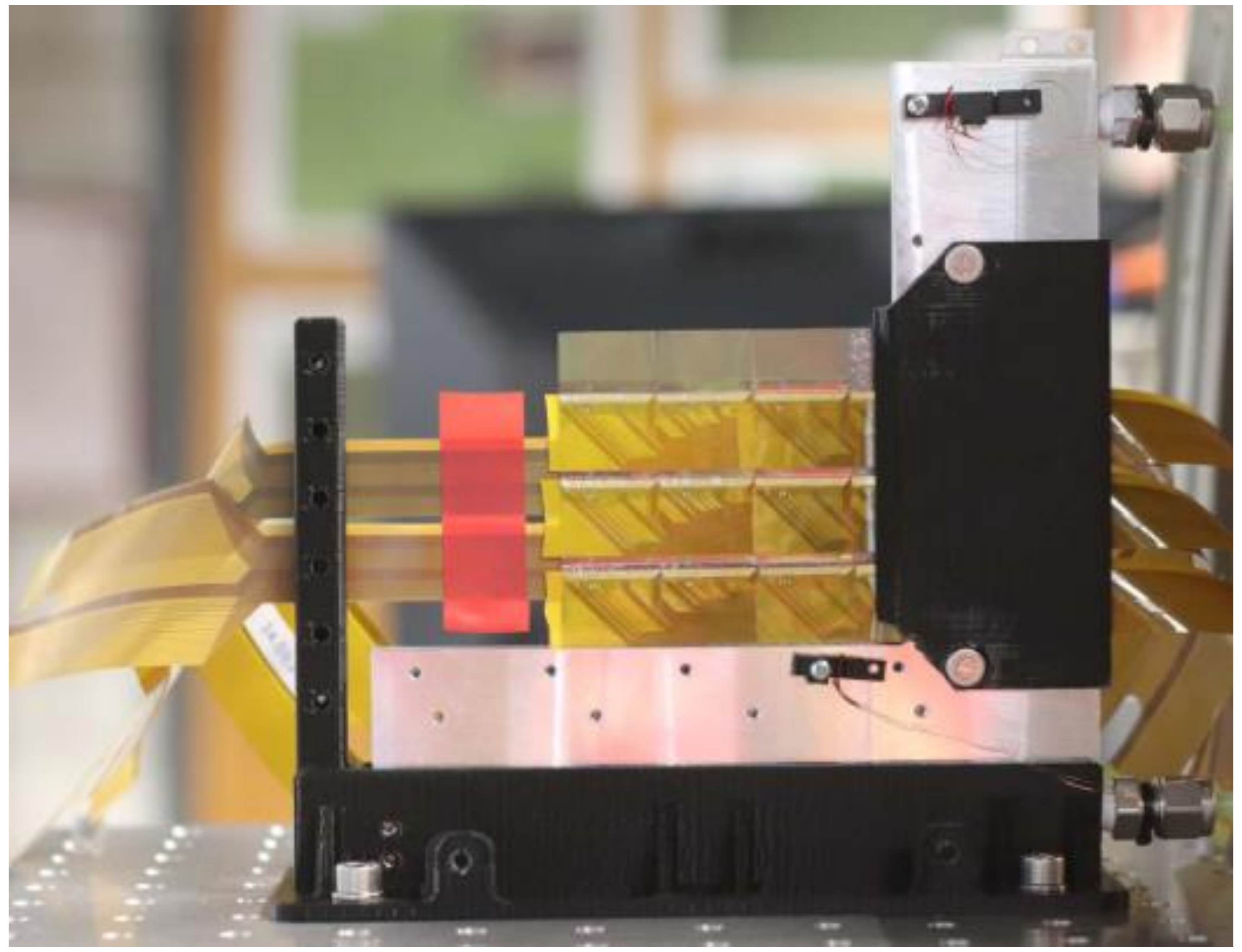
EDMS 2738980 v.LATEST status Released access Public
MVD_TDR_FINAL_Public.pdf modified 2022-05-16 15:19

CBM MVD TDR
(approved 2021)

The CBM MVD Quadrant

Start of **pre-production** phase

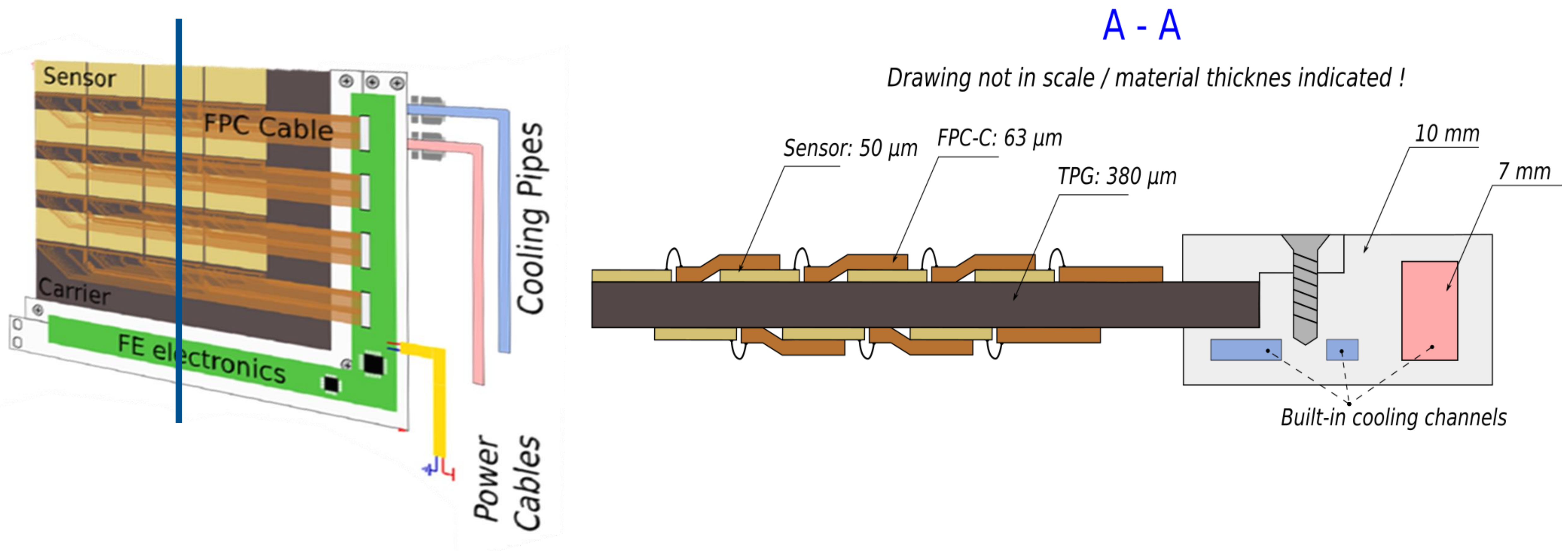
- R&D, prototyping done
- Baseline concept: TDR
- Fine-meshed QA for high yield integration
- High modularity
  → Four planar stations, four **quadrants** each



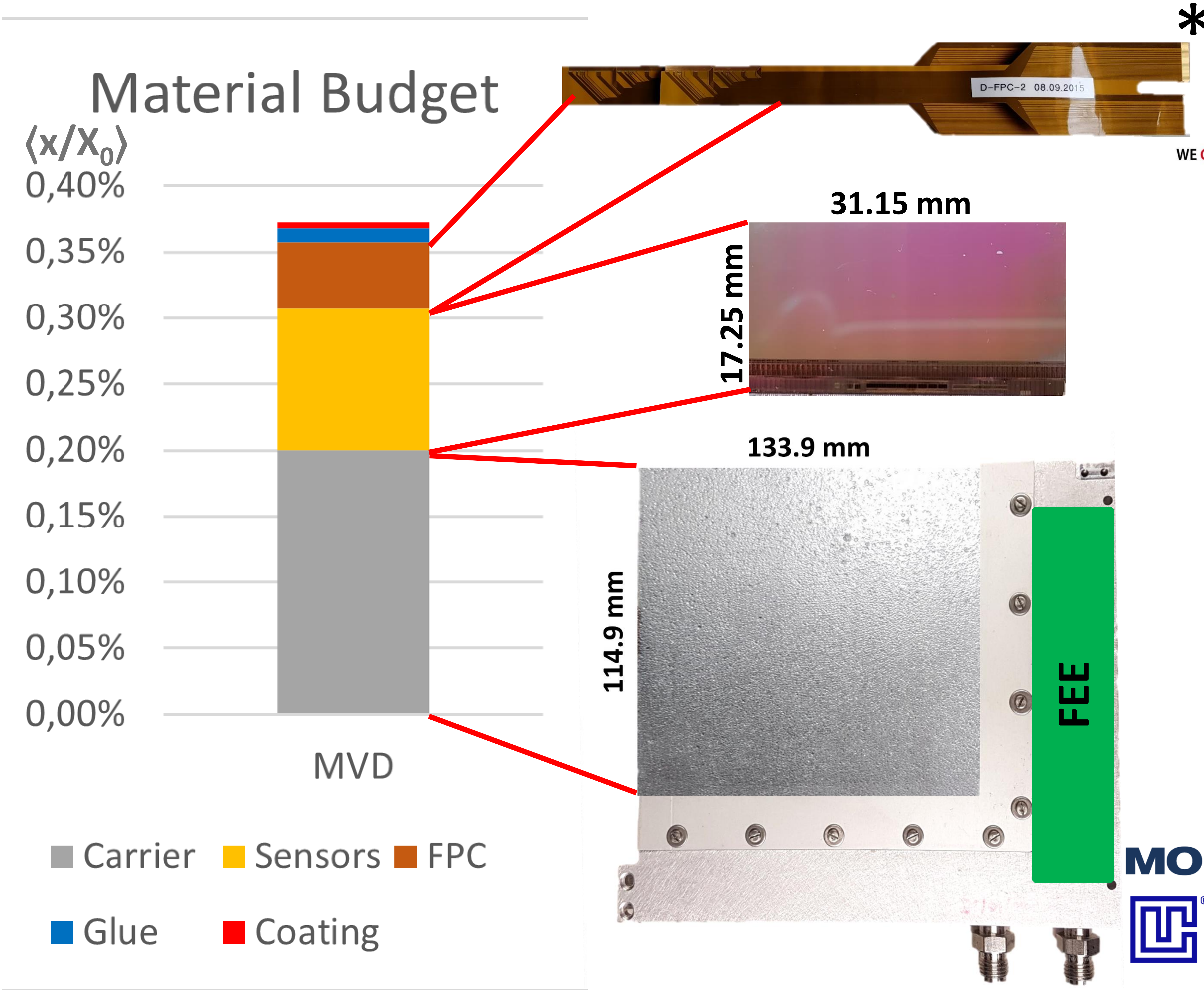
Prototype with smaller form factor

Quadrant: smallest functioning unit

- 16 + 12 **CPS** (front + back), **FPC** for biasing & r/o
- **Carrier**
  → Mechanical support inside acceptance
  → Conducts heat to periphery
- Actively cooled **heat sink**
  → Mechanical support of carrier and FEE
  → Cold plate for sensor, FEE cooling



Components, Material Budget



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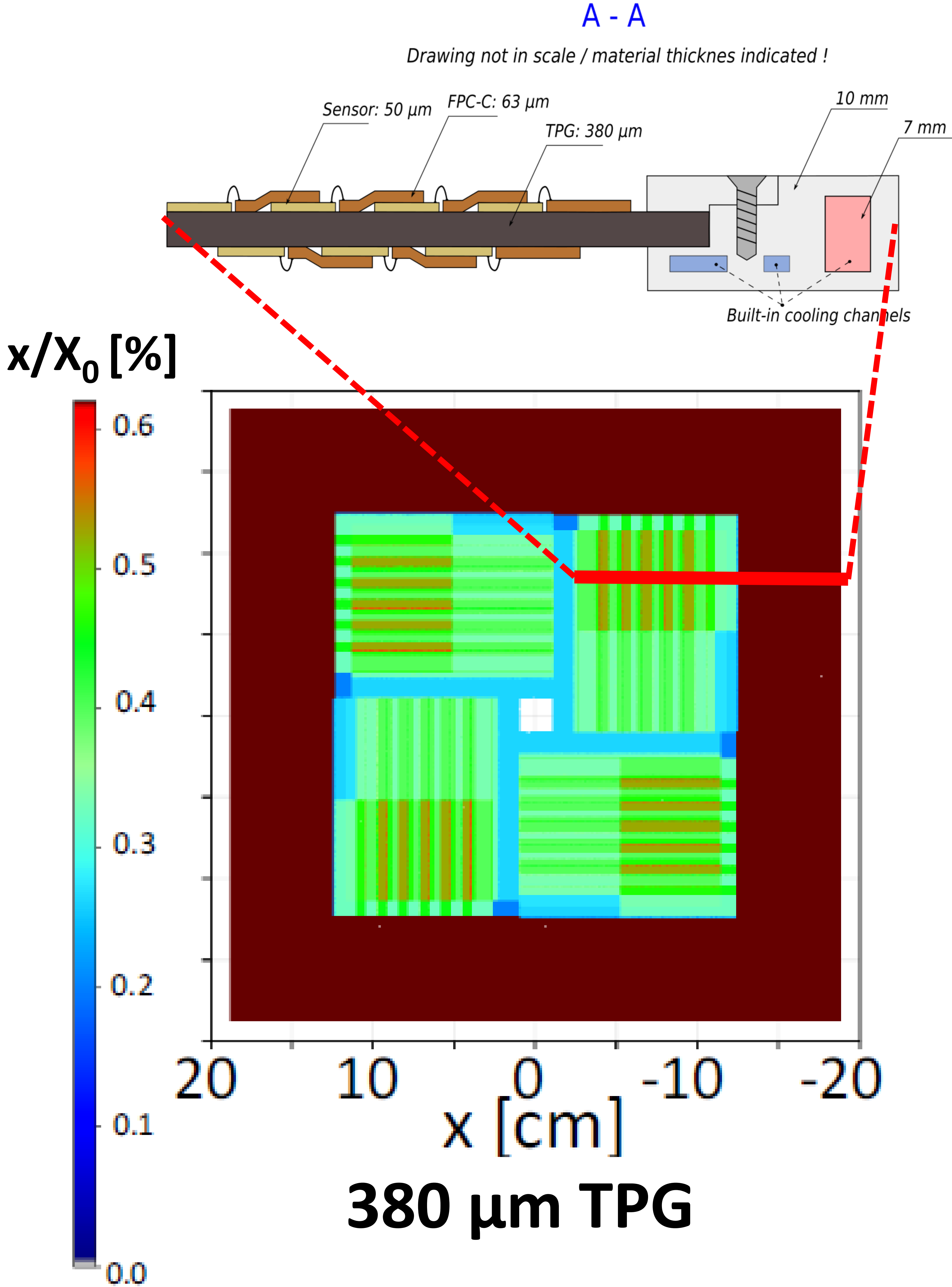
Electronic GmbH



380 µm TPG

* Only, if single layer FPC is used, possibly multi layer FPC needed

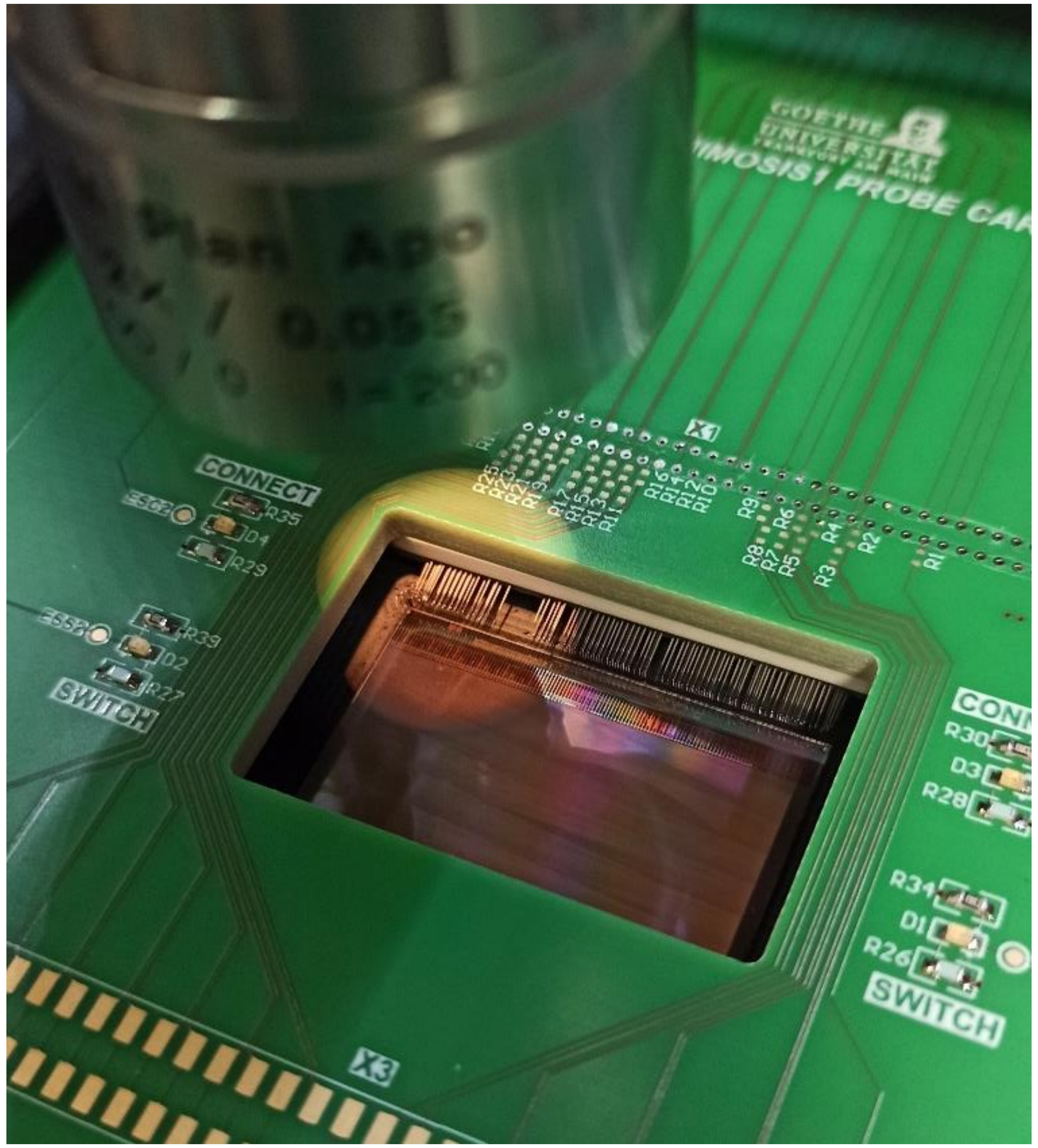
The Sensor

CMOS MAPS (**MIMOSIS**)

- IPHC Strasbourg, Tower Semiconductor
- Expected: ~5 Mrad (IEL) & ~10^{14} n_{eq}/cm^2 (NIEL)
- **Large area**, **thinned** to 50 µm (0.05 % x/X_0)
  → Delicate in handling, placing, connectivity,…
- Power density **~100 mW/cm²**
  → Dedicated cooling
- Active pixel matrix, passive digital part
  → Double-sided integration for 100% fill factor

QA @IKF, CTU Prague

- Visual inspection after thinning and dicing
- Probe testing (**work in progress**)
  → Yield not measured yet
  → I^2C communication, DAC scans established already
  → Also: hot/dead pixels, (+noise and s-curves?)



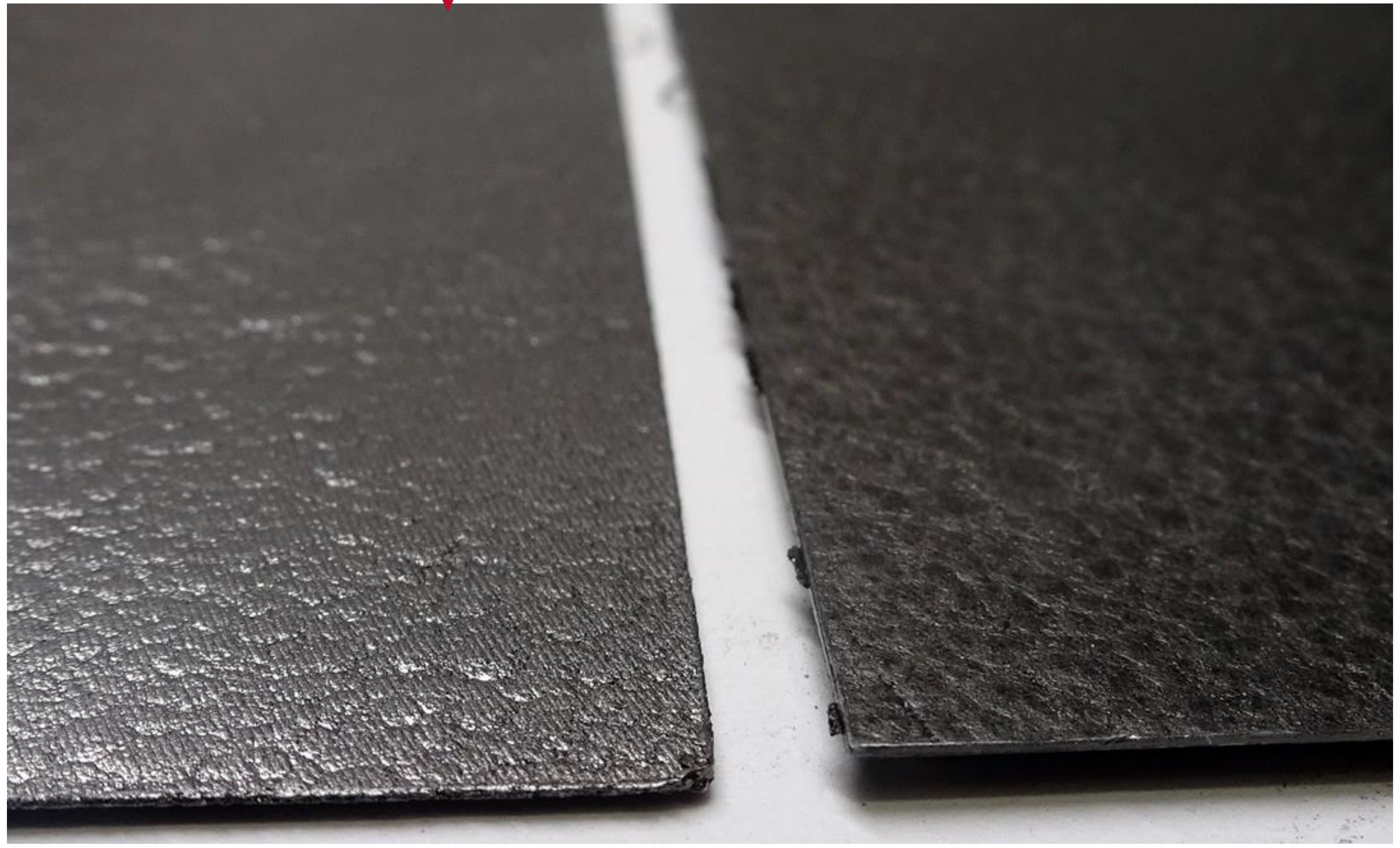
The Carrier

Double integration: Mechanical, heat evacuation

- Baseline: Thermal Pyrolytic Graphite (**TPG**)
- Thickness 380 µm (0.2 % x/X_0)
- Thermal conductivity ~1500 W/mK (in plane)
  → Anisotropic; irrelevant for quasi-2D use case
- Bare TPG needs some post-processing
  → Polishing @Momentive
  → Laser cutting @GSI (EEL)
- Coating necessary
  → Surface stability, electrical insulation
  → Baseline: Parylene (validated) @Fraunhofer IGB

QA: Inspection for damages, planarity

- Metrology w/ microscope
- Thermal inspection w/ IR camera



The Glue

Radiation hard, low outgassing, low viscosity, high elasticity glue

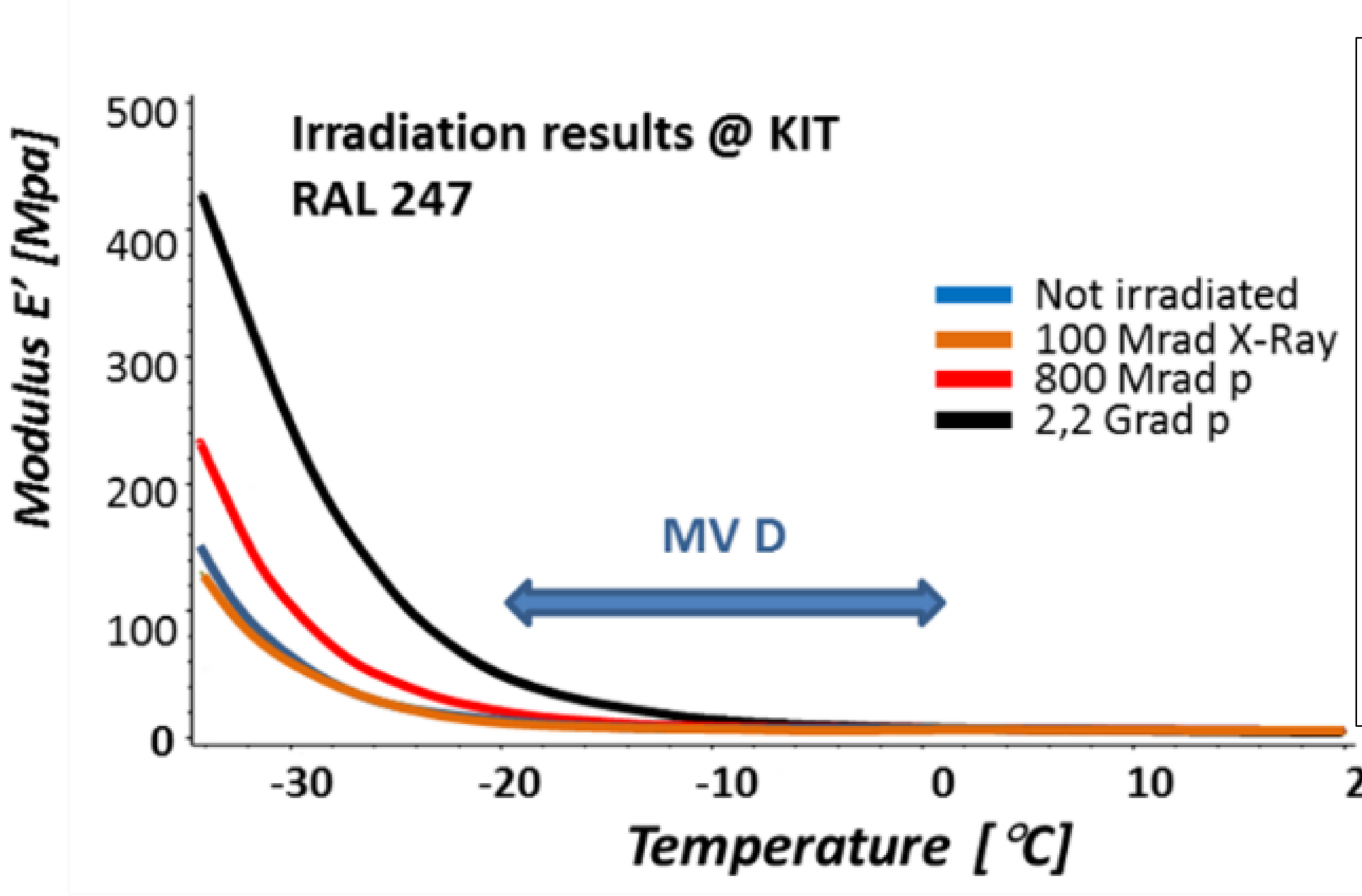
- Baseline: RAL–247 (custom made)
  →Large batch-to-batch fluctuation wrt. curing properties
- Fallback option: Epo–Tec 301–2

Vacuum compatible gluing on Parylene-coated TPG

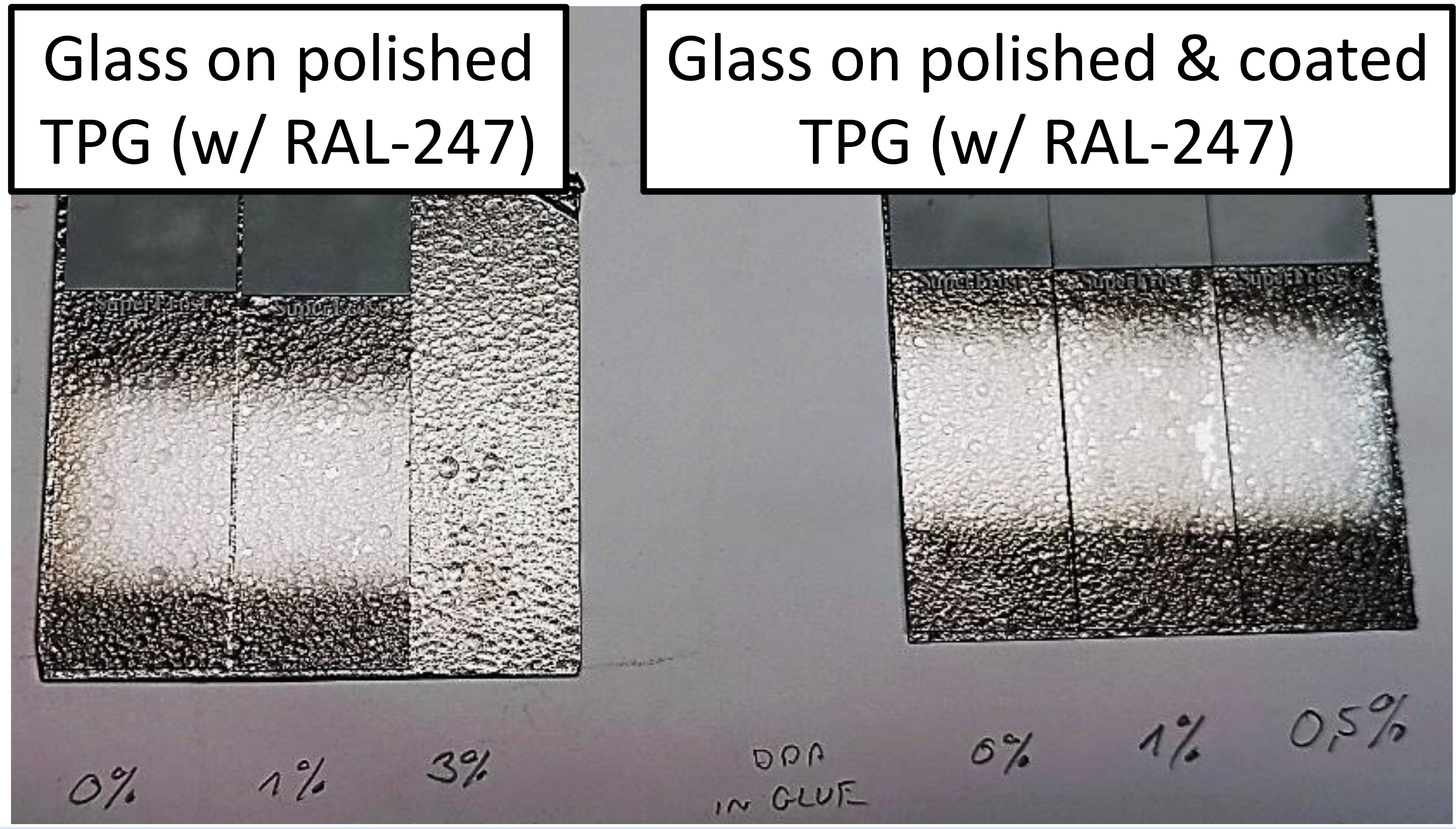
- **Polished TPG** (eases distribution)
  → Glue spreads evenly (capillary flow)
  → Additional cavity-preventing pattern e.g. star?
  → Thin layers ~25 µm (0.01 % x/X_0) possible (x/X_0, thermal interface)
- **Parylene coating**
  → No influence on adhesiveness, but changes glue flow
  → Small amounts of wetting agent (& plasma activation?)
- Pre- & post-curing procedure (@T_{room}?) under evaluation

QA: Test for cavities, thermal interface

- Your experience with IR thermography?



RAL, private communication


Glass on polished TPG (w/ RAL-247)

Glass on polished & coated TPG (w/ RAL-247)

The Flexprint Cable

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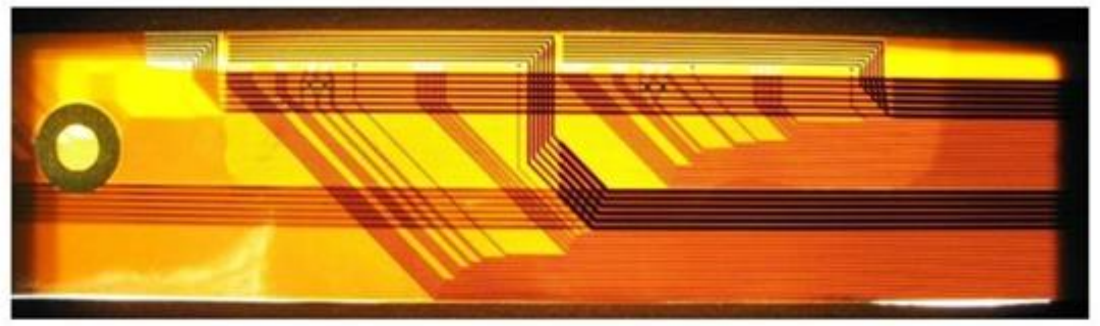
Low-mass FPC @ILFA

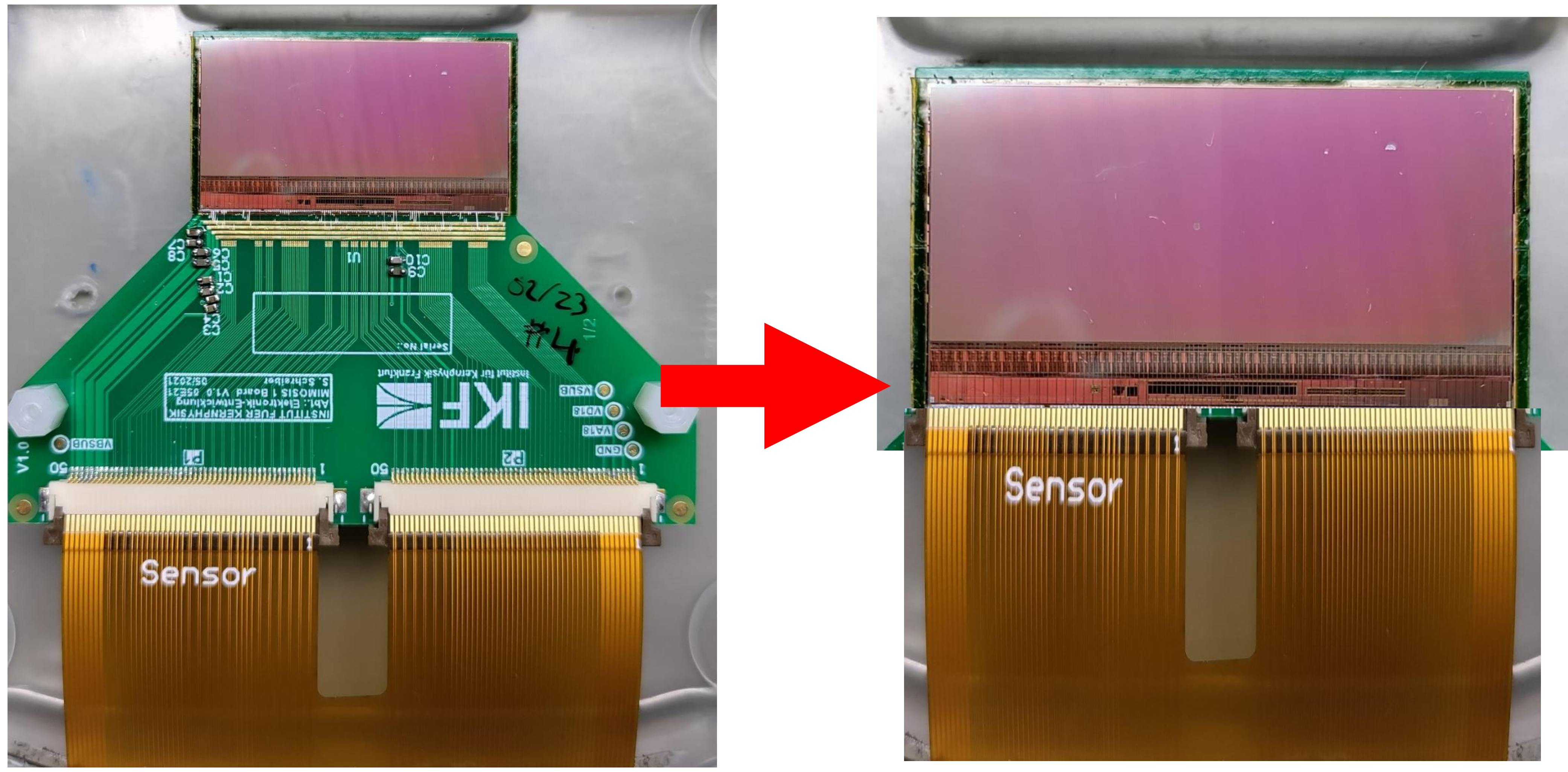
- Baseline: Commercially available, Cu traces
  → **Industry “standard”**, established technology
  → ILFA offers R&D
- Single layer (traces: 12 µm): 63 µm (0.05 % x/X_0)
  → Significant contribution to total material budget
- Improvement after establishing MIMOSIS cable?
  → FPC with Al traces to reduce x/X_0
  → CBM STS: Al microcables (LTU Ltd. Kharkiv, Ukraine)
  → Additional risks during assembly

Design in (three) iterations

- MIMOSIS form factor, number of traces, width: 23 mm
- Partially multi-layer FPC?
- Signal quality under evaluation
  → Pick-up noise, power supply (cable length, DC/DCs,..)

Vacuum-compatible 2–layer FPC (MIMOSA–26)





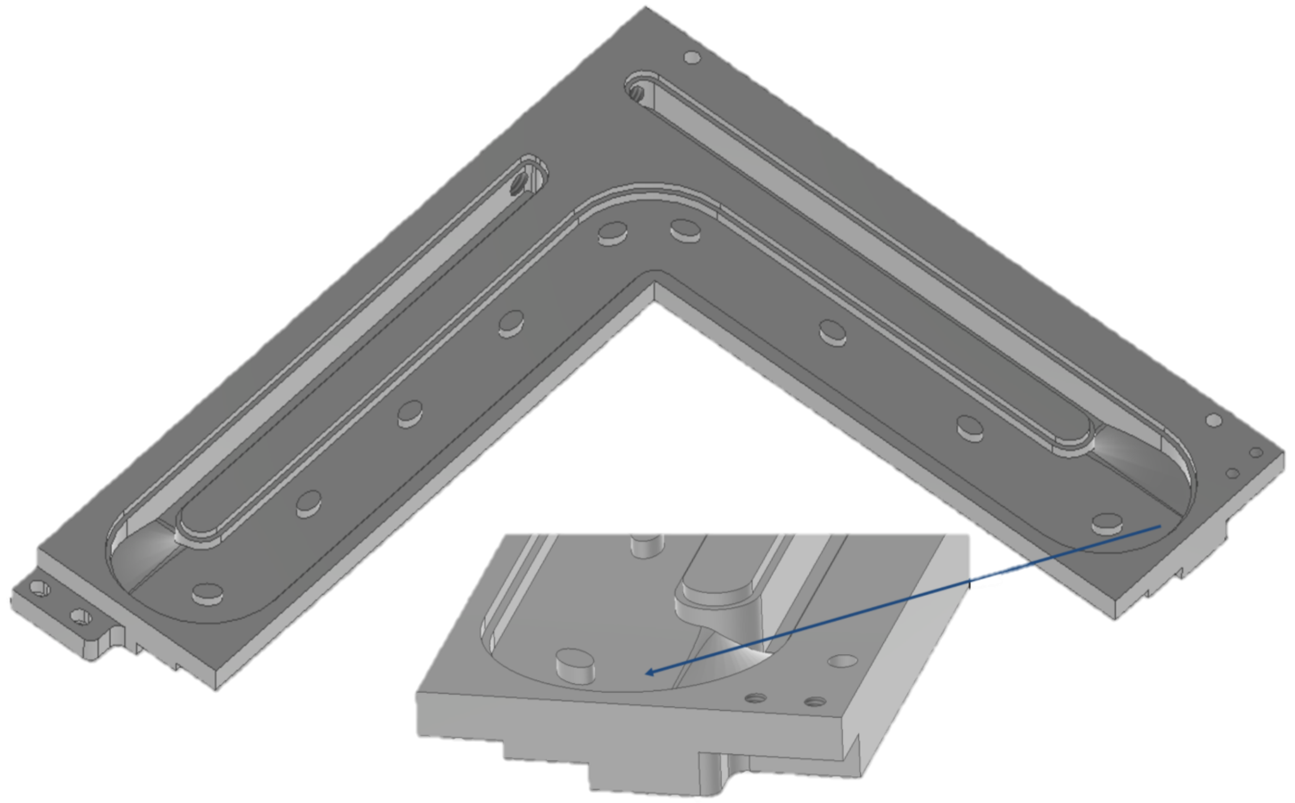
(Cooling of the) Heat Sink

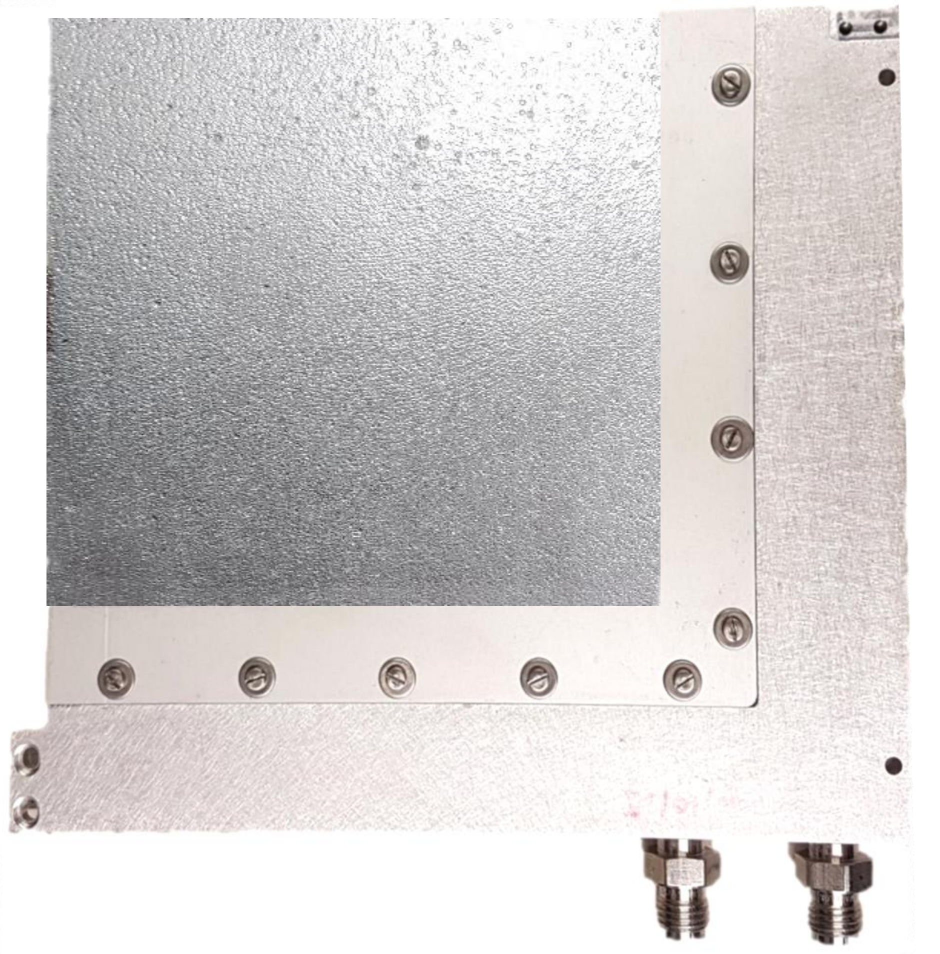
Heat sink v2.5 @CoolTec (matches MVD requirements)
- CNC milled Al, cover plate welded
- Design currently finalized
  → Minor adjustments in form factor
  → Carrier and FEE alignment pins

Low–viscosity, single–phase liquid cooling (**Novec–649**)
- Availability issues (solved?)
- Affects of radiation? Filtering?
- Connection Stainless Steel–Al
  → Loctite 511 (radiation hardness?)
  → Radiation hard glue (Novec compatibility?)*
  → Copper gaskets (torque?)
- Fallback option: water/ethanol

3M Novec™ Brand

Cool Tec Electronic GmbH





*See also: Lee, G. (1985). Radiation resistance of elastomers. IEEE Transactions on Nuclear Science, NS-32(5), 3806-3808.

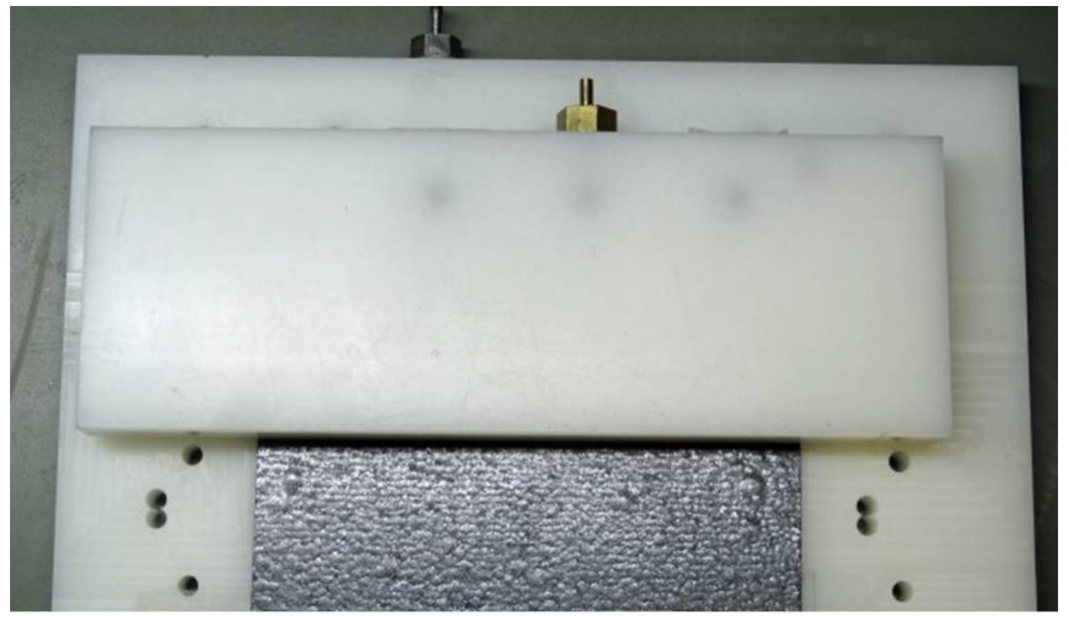
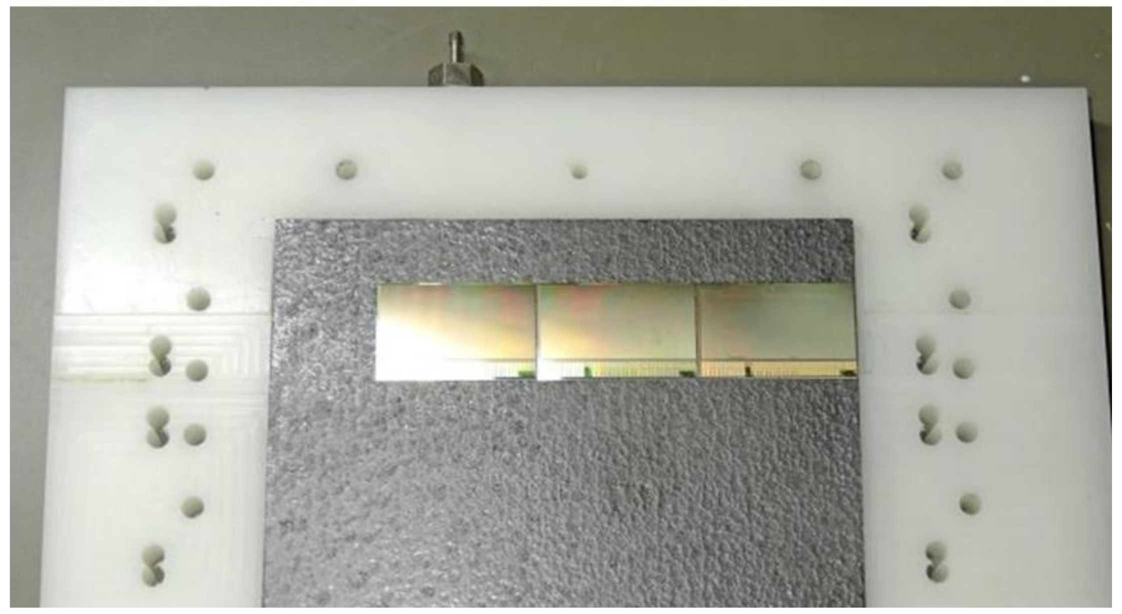
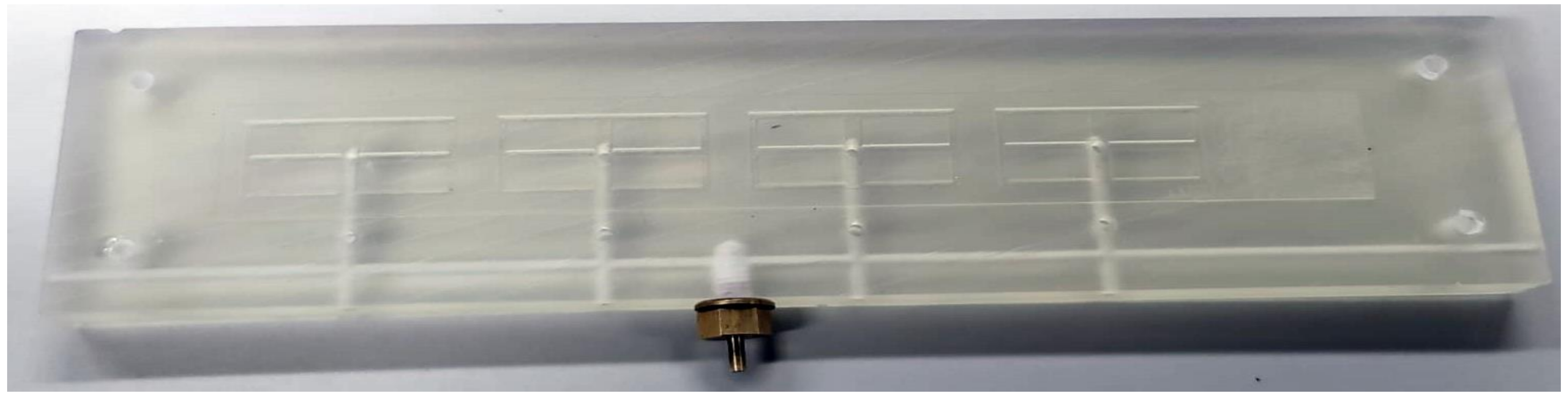
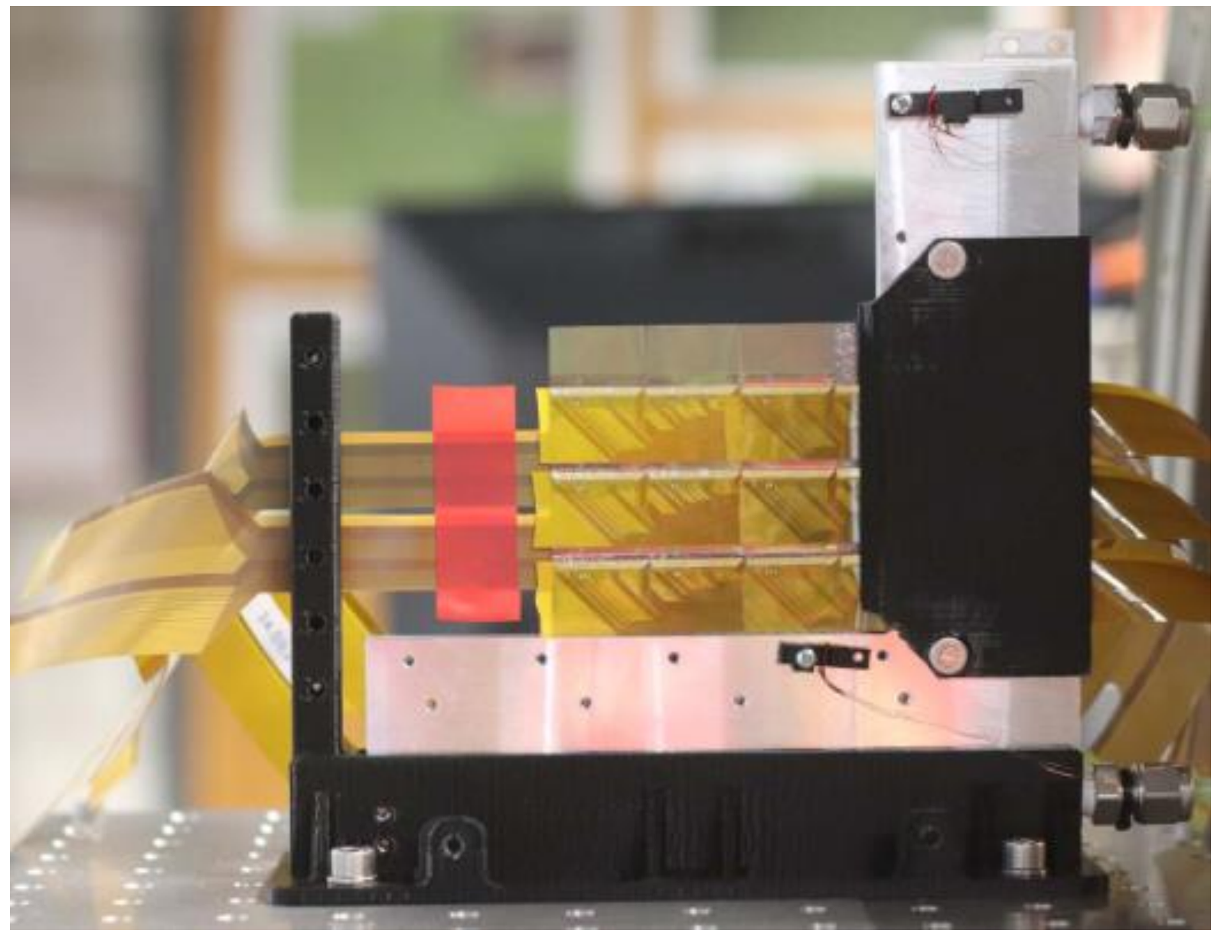
Assembly Tools, Alignment

Challenge: **Double-sided integration on thin carrier**

- 500 µm overlap of active regions front/back
- 100 µm butting distance between sensors in a row
- Prevent glue flow from FPC onto sensor
- Bonding pad support

Baseline verified with **prototype**

- Double-sided integration on thin TPG
- Jigs for sensor alignment, carrier fixation
  → Prototype: POM (problems w/ ESD?)
  → (Pre-)production: CNC machined Al
  → Transfer to heat sink after integration
- Challenge: Alignment and gluing of FPC
- Precision of alignment <100 µm reached
- Vacuum compatibility, long-term stability proofed
- Translate to final form factors (sensor, carrier)

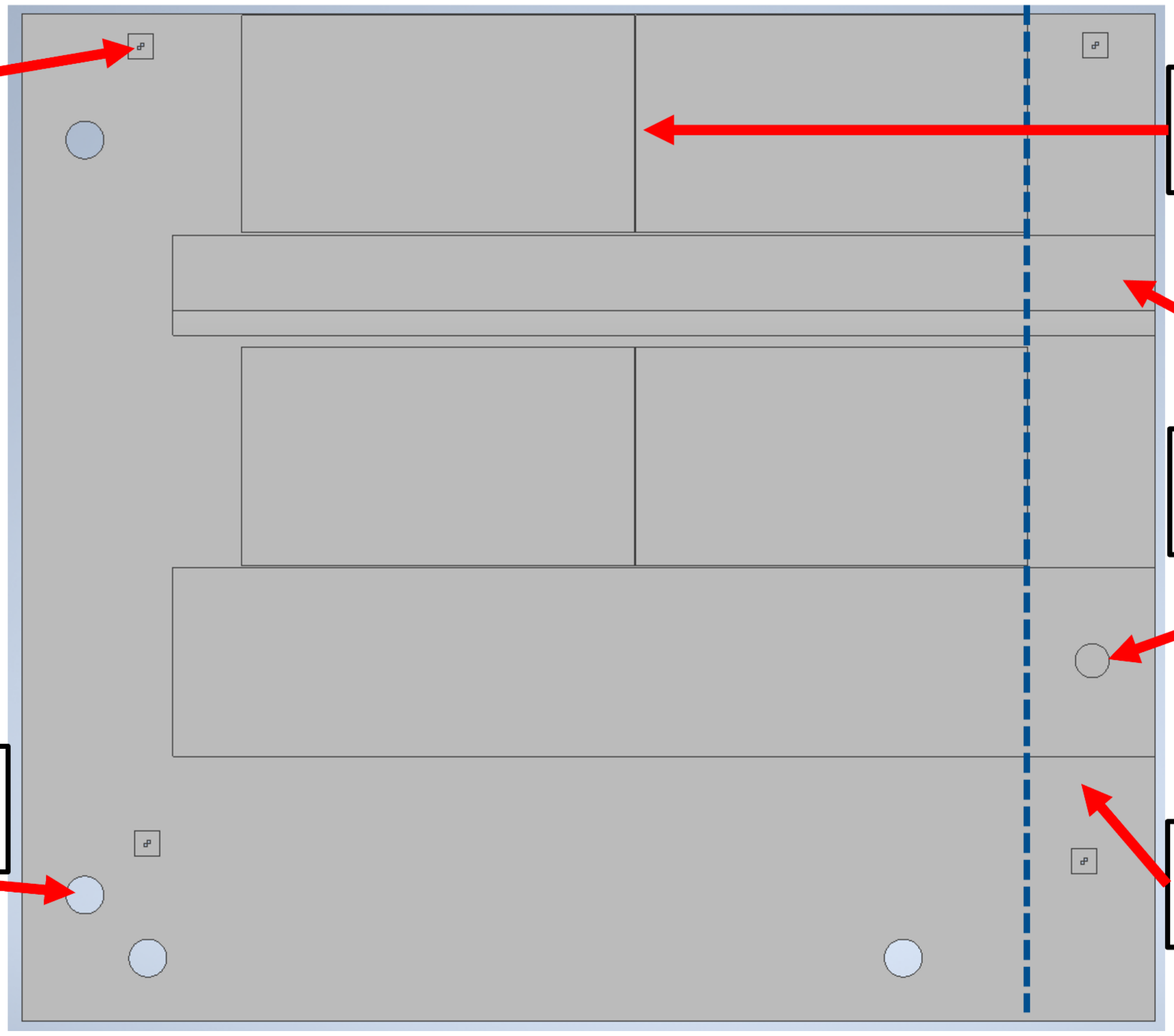





Prototype jigs for MIMOSA-26 (smaller form factor), 3D printed mock–up jig for MIMOSIS, TPG Prototype (PRESTO)

Assembly Tools, Alignment

Upgraded concept: **3D-structured TPG**

- High precision, low assembly risk
- Use carrier as “jig” (self-aligning)
- µ-structuring: fiducials, pins, pockets for sensors and FPCs
  - → Eases placement
  - → Improves front/back alignment
  - → Constraints glue flow
- Integrate carrier in the heat sink
  - → Risky step of transfer after assembly avoided
- Possible due to **laser cutter @GSI EEL**
- Details: Depth of pockets, “safety margins”



Fiducials for front/ back alignment

Bridge for 100 µm butting distance

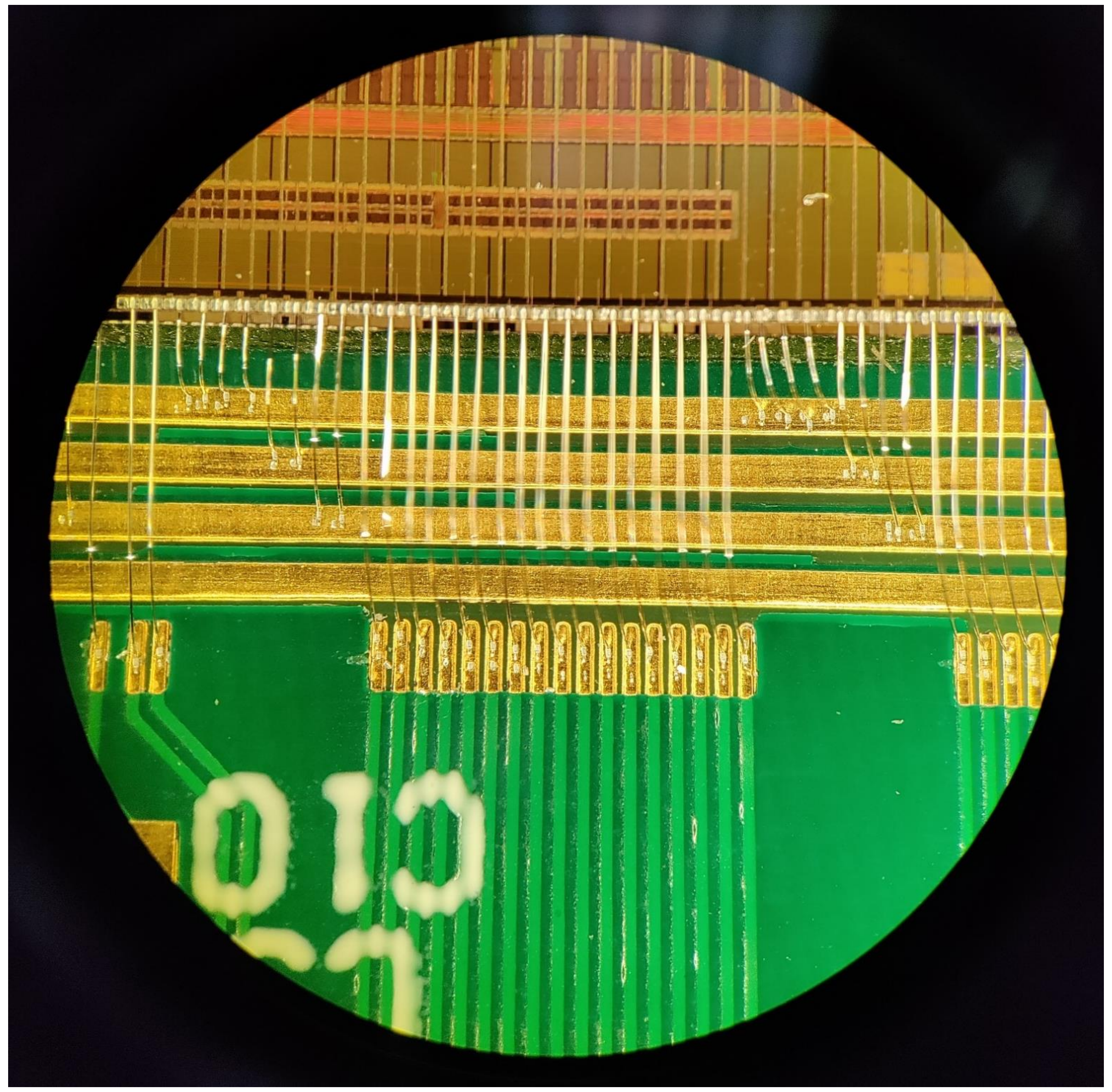
FPC gluing area w/ and w/o alignment pin

Alignment pins (heat sink)

To be removed after assembly

Demonstrator for alternative concept in progress,
Laser cutter @GSI EEL

Bonding and Metrology



Wire bonding

- (Semi-)Automatic, 25 µm Al wire
- Challenge: Bonding of ultra-thin FPC
  → Use hard glue underneath?
- Not planned so far: glob-top
- QA: Pull tests
  → Sacrificial bonds or non-destructive pull tests?

Metrology after placement of sensors

- Check uniformity of integration
- Coordinates of fiducials: alignment seeds
  → Heat sink as reference
- Large working-area digital microscope
  → Mostly lateral dimensions of interest (quasi-2D structure)

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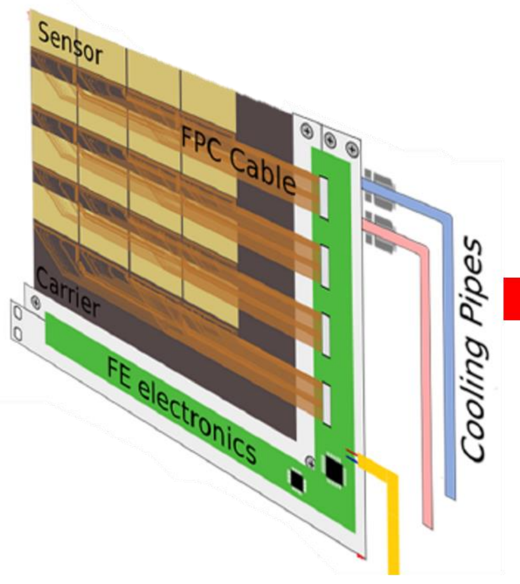
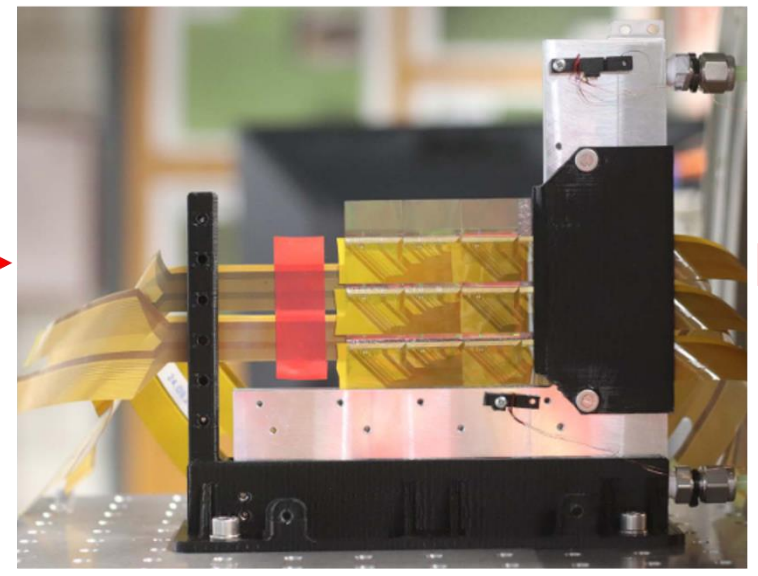
From Quadrants to a Tracking Detector

Final QA of quadrants (MVD: **16 quadrants)**

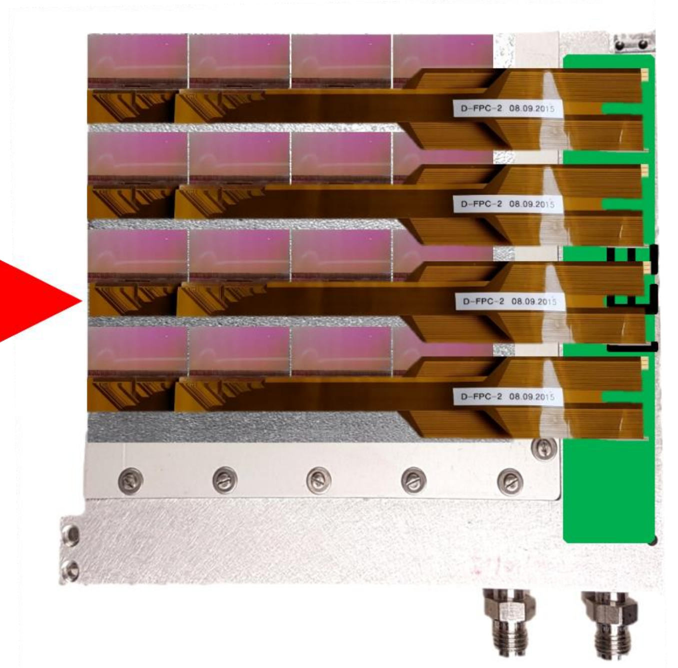
- Electrical tests
  → Powering, I²C communication, DACs (+noise?)
- Thermal tests
- Aging Tests
  → Power, temperature, vacuum cycles



CAD drawing of quadrant (TDR)



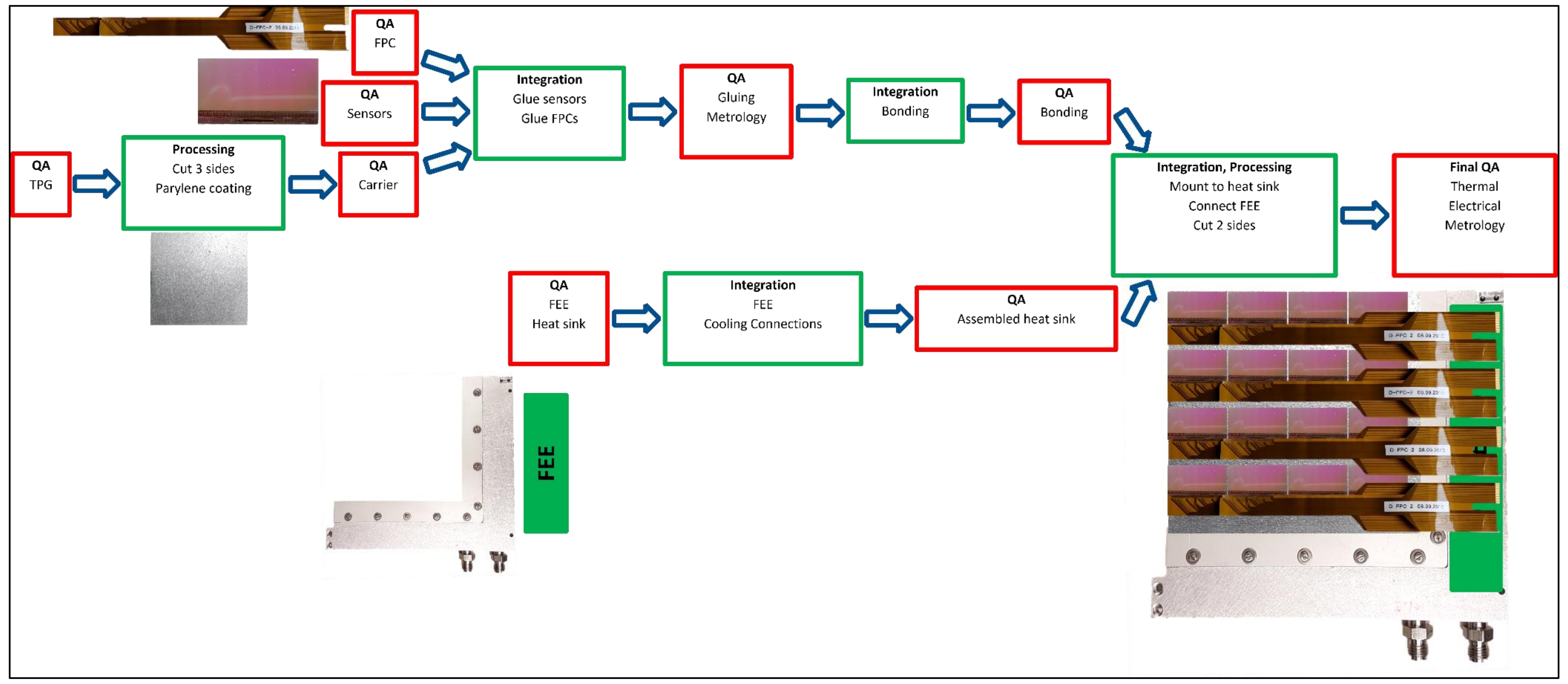
Prototype with smaller form factor



Photomontage, Impression of pre-production quadrant

Baseline concept (stated in TDR) validated

- MVD currently in pre-production phase
  → Finalization of engineering designs
  → Hard parameters for QA
  → Integration of pre-production quadrant
- Towards pre-/ mass-production: “The Devil in the Detail?”
  → Assembly environment, connectivity, grounding, aging,…?



Draft of assembly flow:
Fine-tuning, detailing to be done

Discussion

Glue QA

- Thermography? Alternatives?

Novec-649

- Availability
- Radiation, filtering,…
- Connection Stainless Steel-Aluminum: Loctite, Glues,…

Towards pre-/mass-production: “The Devil in the Detail”

- Assembly environment, connectivity, grounding, aging, bonding,…
  → By your experience: The most problematic?

The CBM MVD team @IKF