# Tracking for LHCb Run3 - VELO detector construction and the Silicon Upstream Tracker

*The 30th International Workshop on Vertex Detectors*


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*on behalf of the LHCb Collaboration*

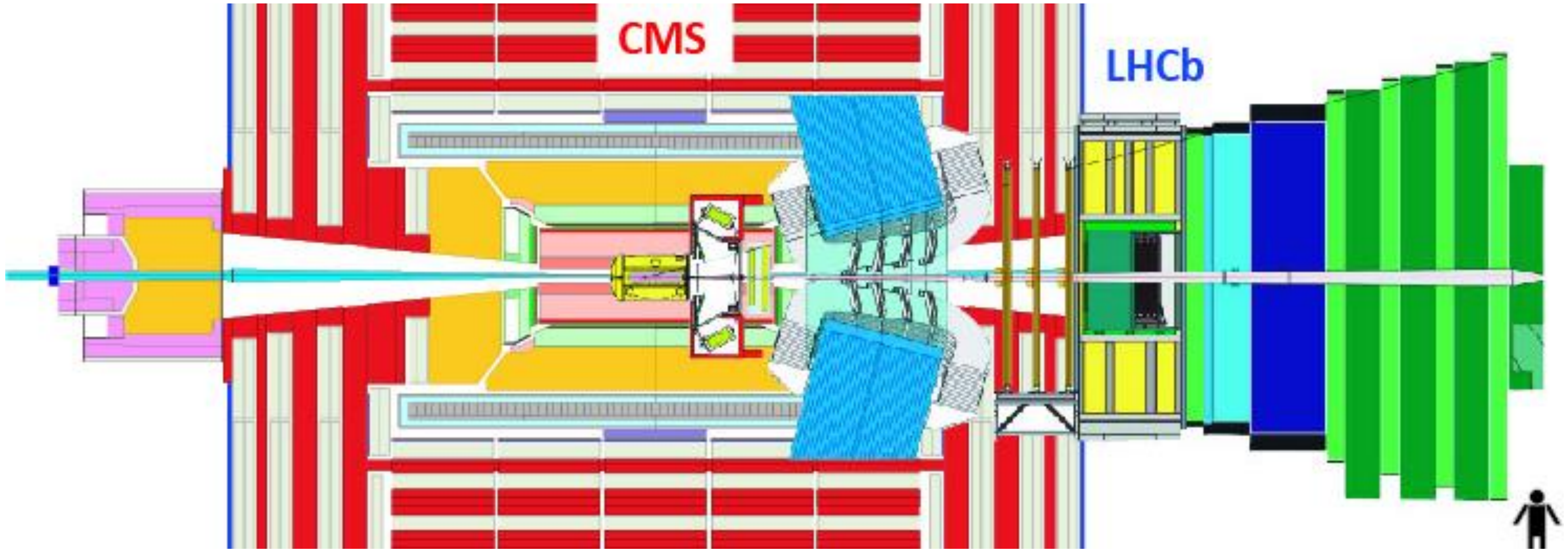

27-09-2021

# The Run1 & Run2 (previous) LHCb detector

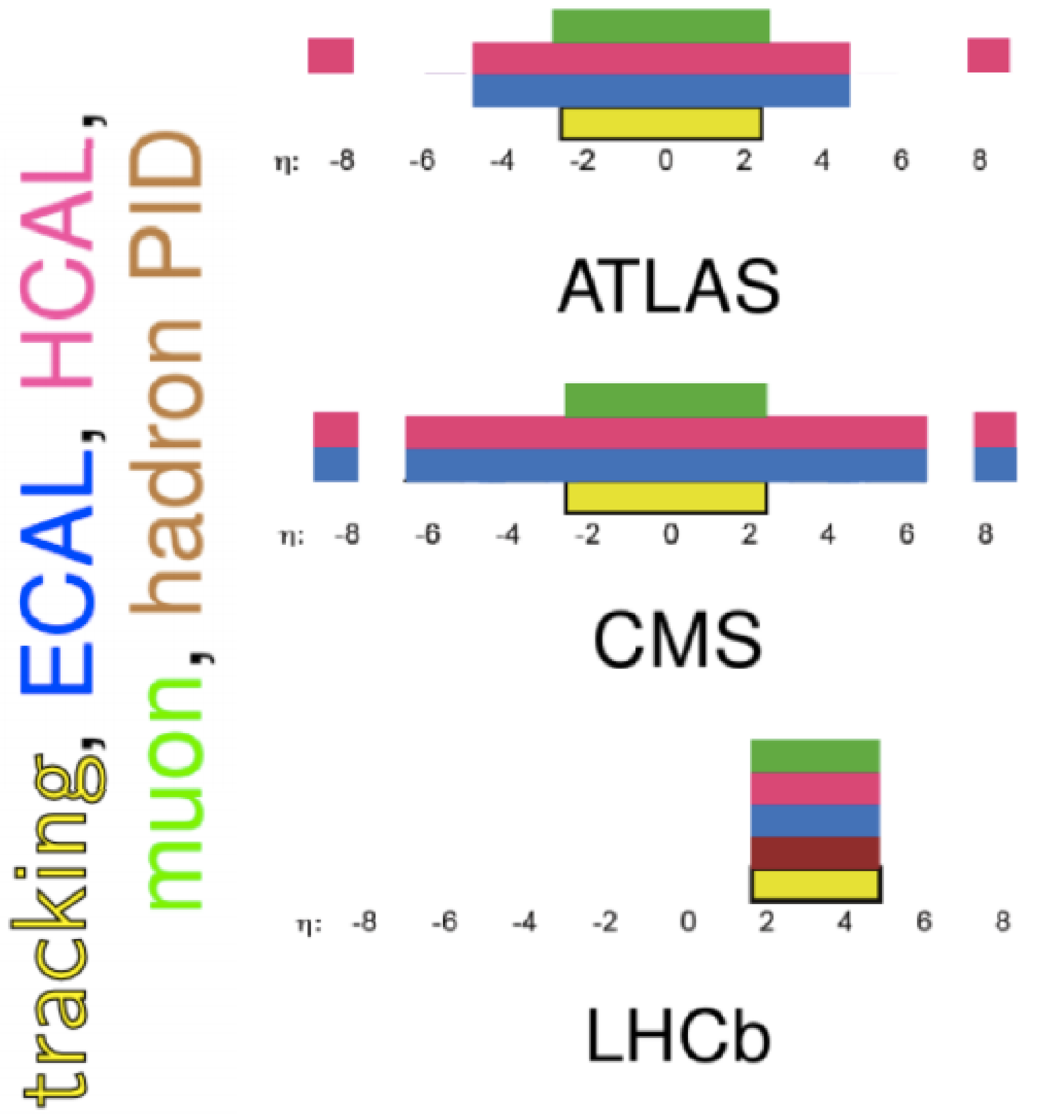
- ❑ Complementary coverage to GPDs
- ❑ Softer triggers than GPDs
- ❑ Unique acceptance ($2<\eta<5$)
- ❑ Vertex resolution ($\sigma_\tau$~45 fs for $B_s^0$)

- ❑ Muon ID efficiency ~97% for 1-3% $\pi\rightarrow\mu$ misid
- ❑ Mass resolution (0.5% in $\mu\mu$ for the $\Upsilon$ region)
- ❑ Jet reconstruction:
  - energy resolution ~10% (jets with $p_T$>10 GeV)
  - $b$(c) tagging efficiency ~65%(25%)

[JINST3 (2008) S08005]



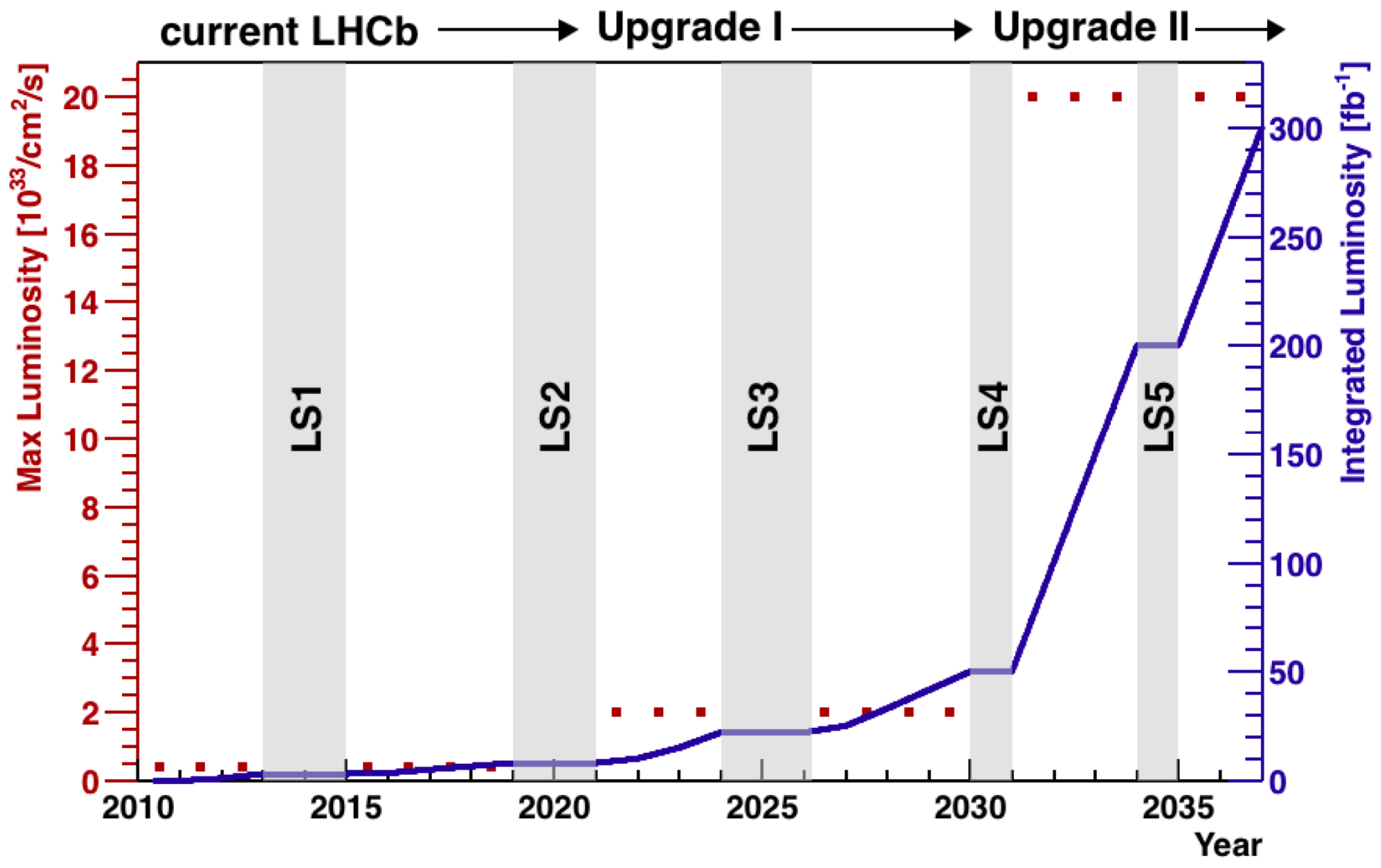

[Int J Mod Phys A30(2015)1530022]



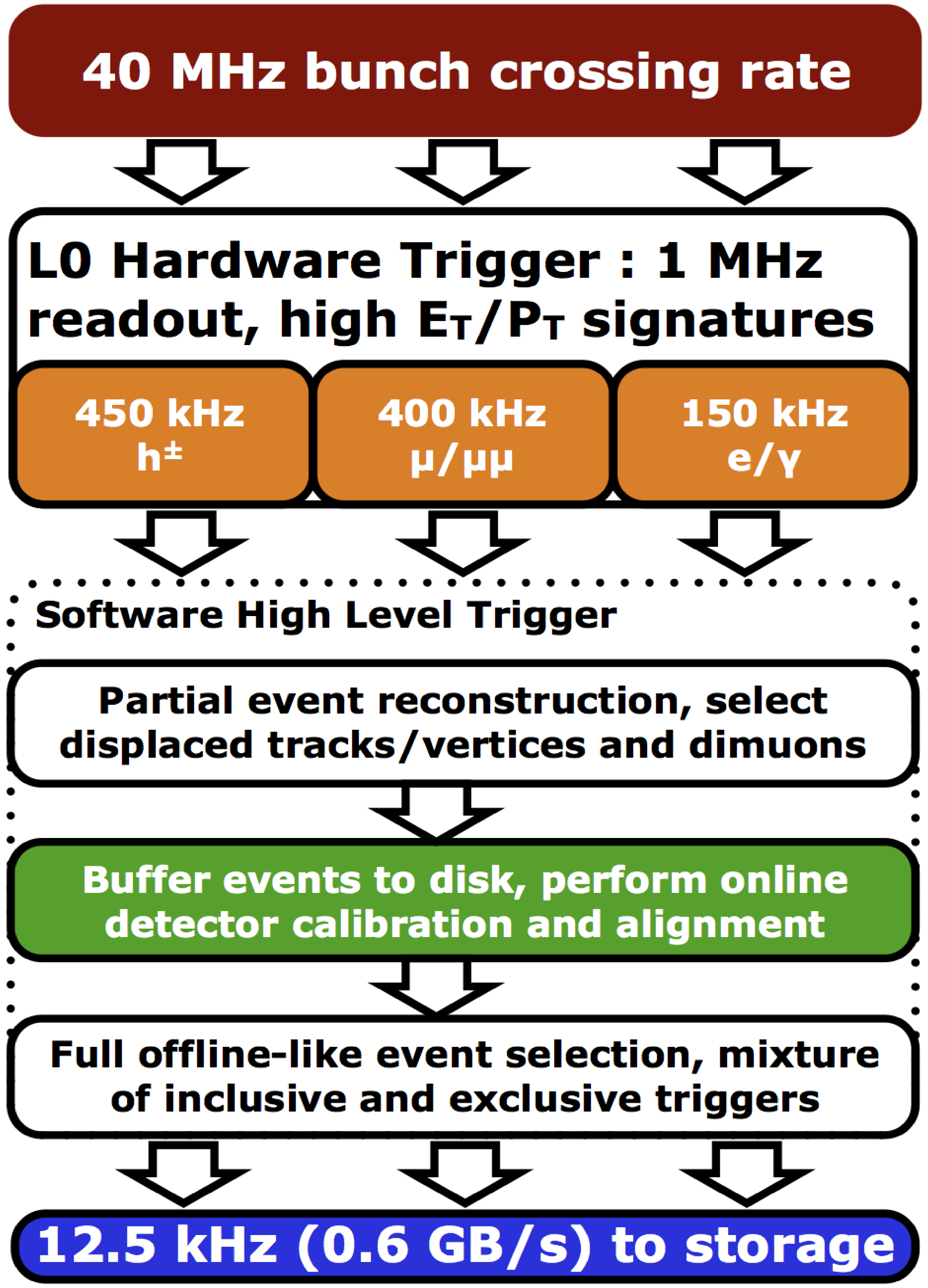
# LHCb Upgrade Run3

- ❑ New subdetectors:
  - Vertex Locator (VELO)
  - Scintillating Fibre Tracker (SciFi)
  - Upstream Tracker (UT)
- ❑ Hardware level L0:
  - Removed for Upgrade Run 3
- ❑ GPU-based HLT1 (Allen):
  - Starting Upgrade Run 3

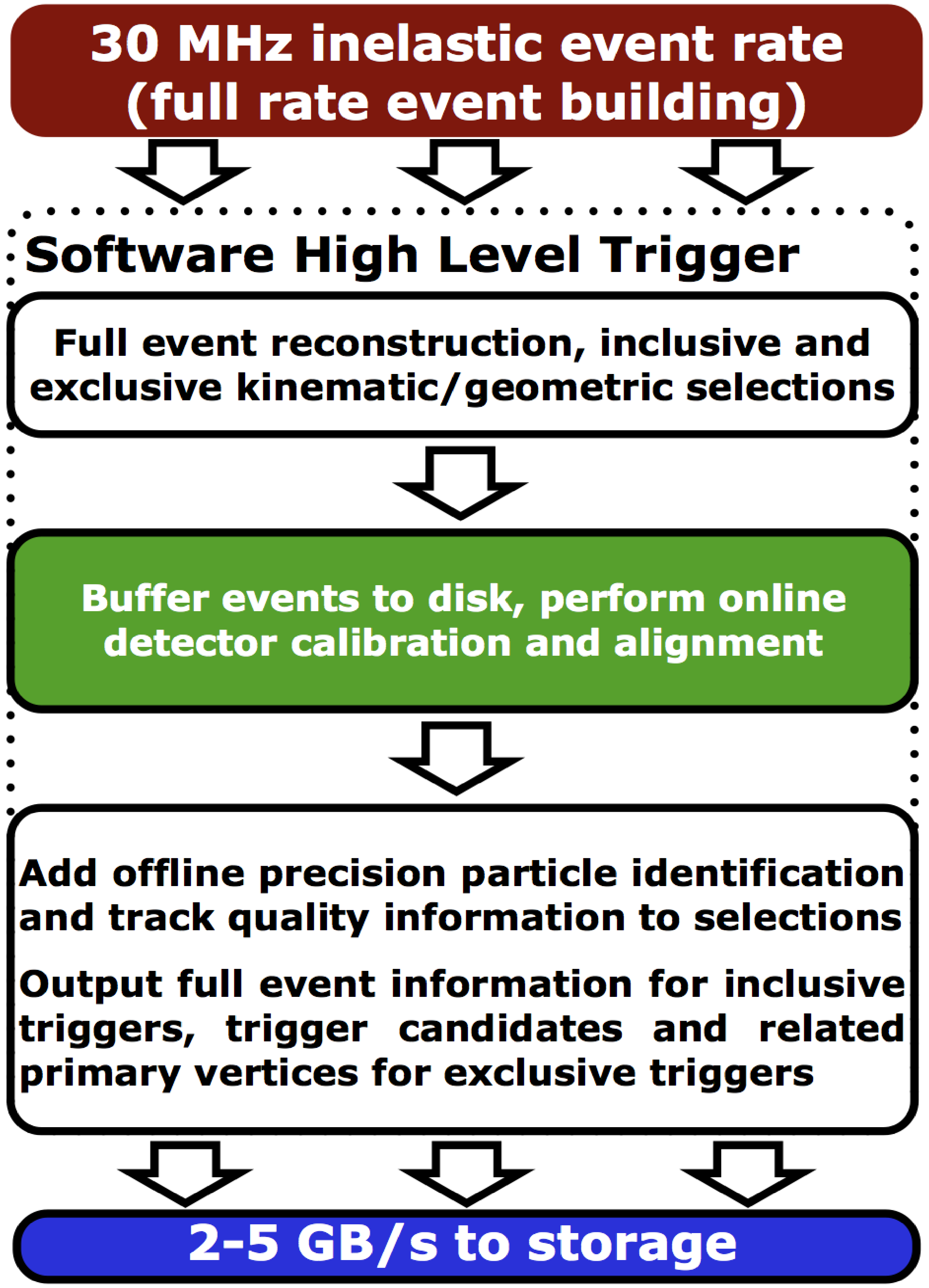
[Comp Soft Big Sci (2020) 4 7]



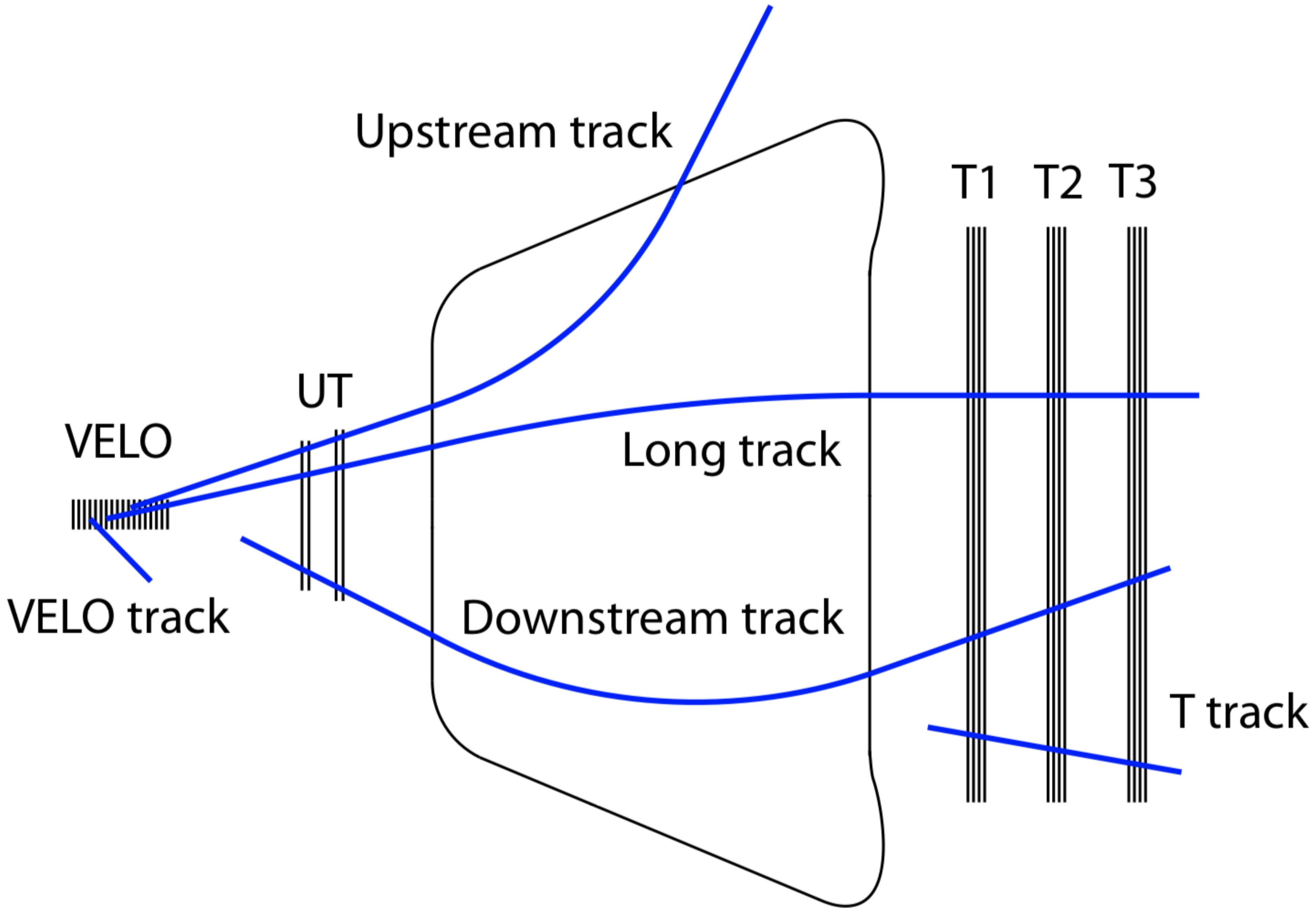

**LHCb 2015 Trigger Diagram**



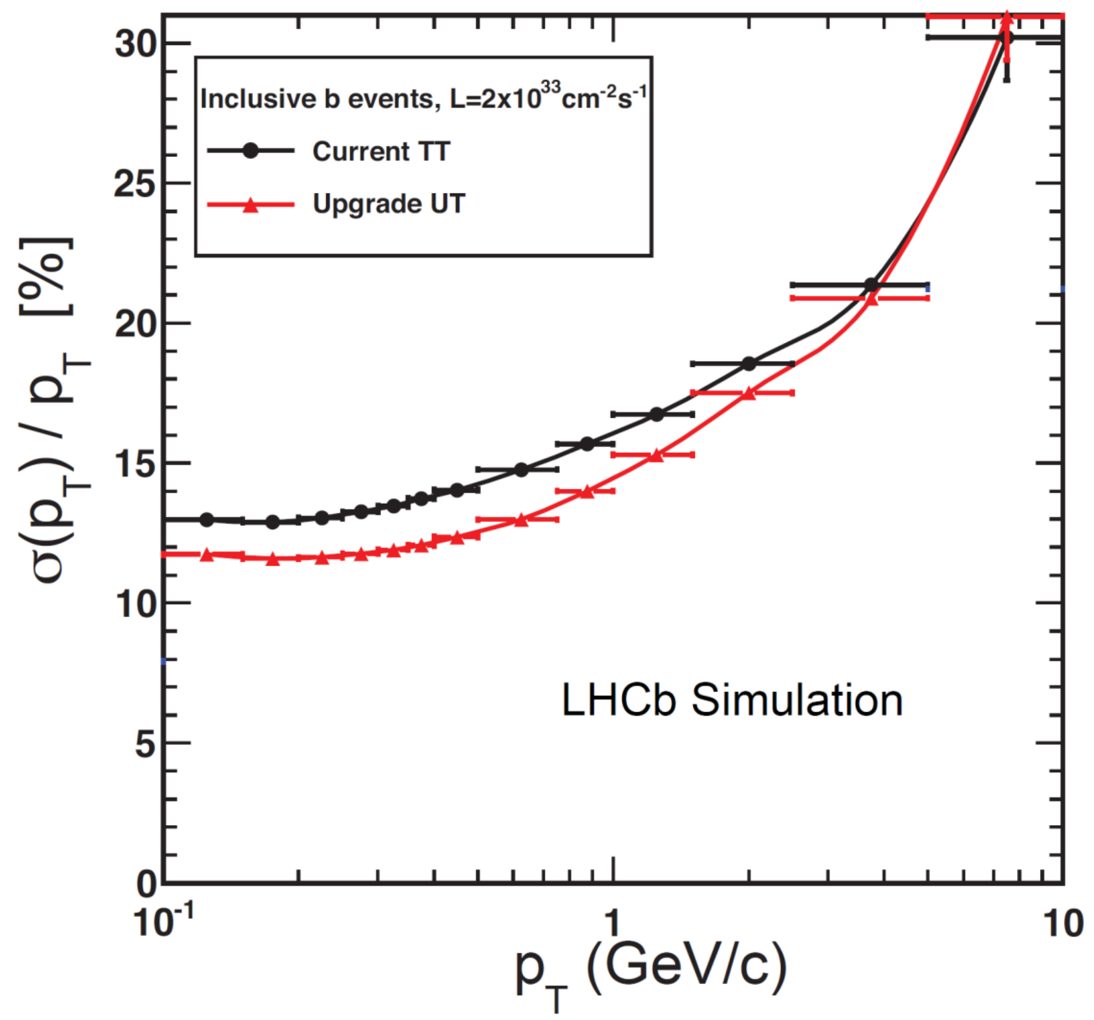

**LHCb Upgrade Trigger Diagram**

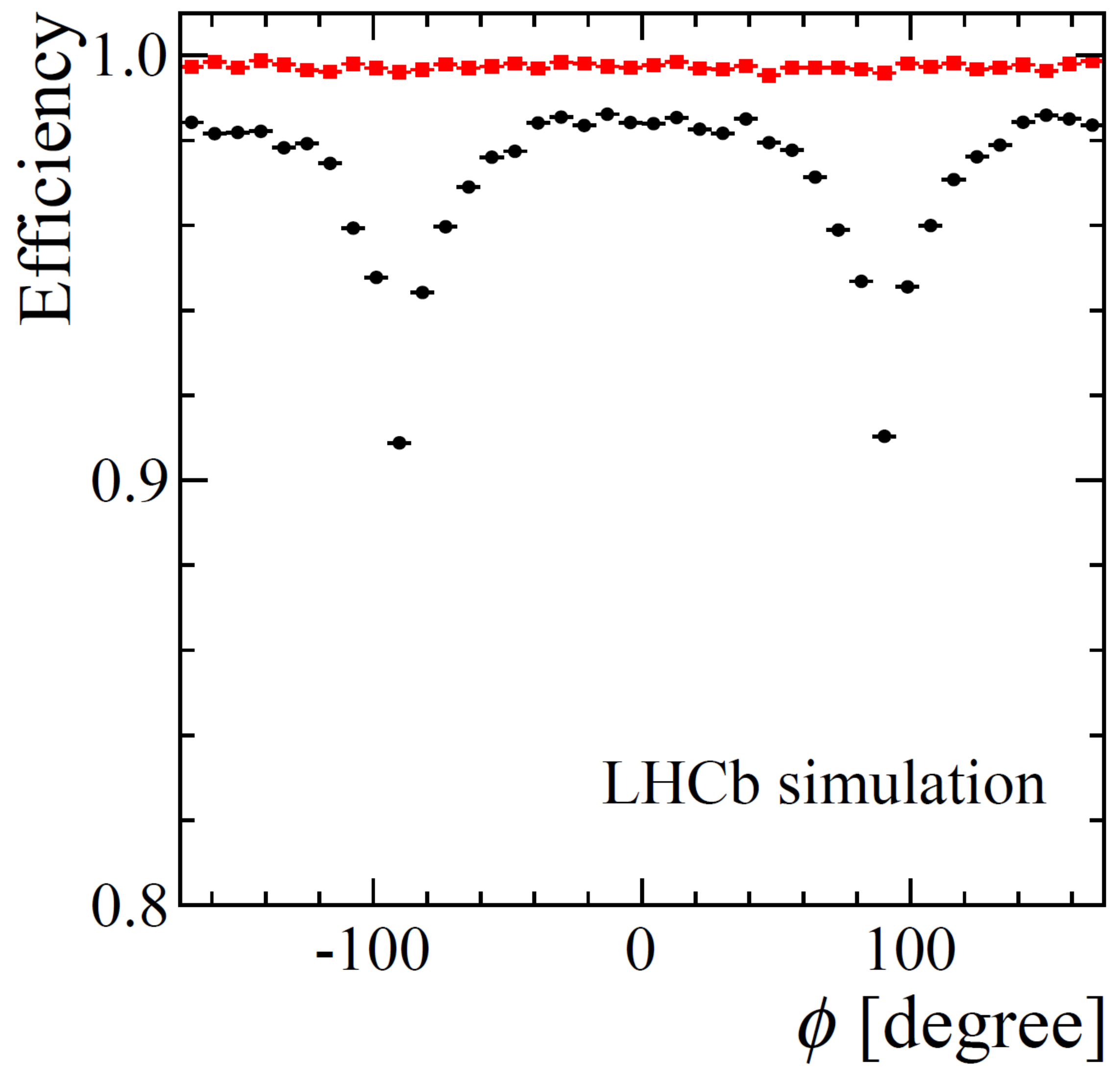


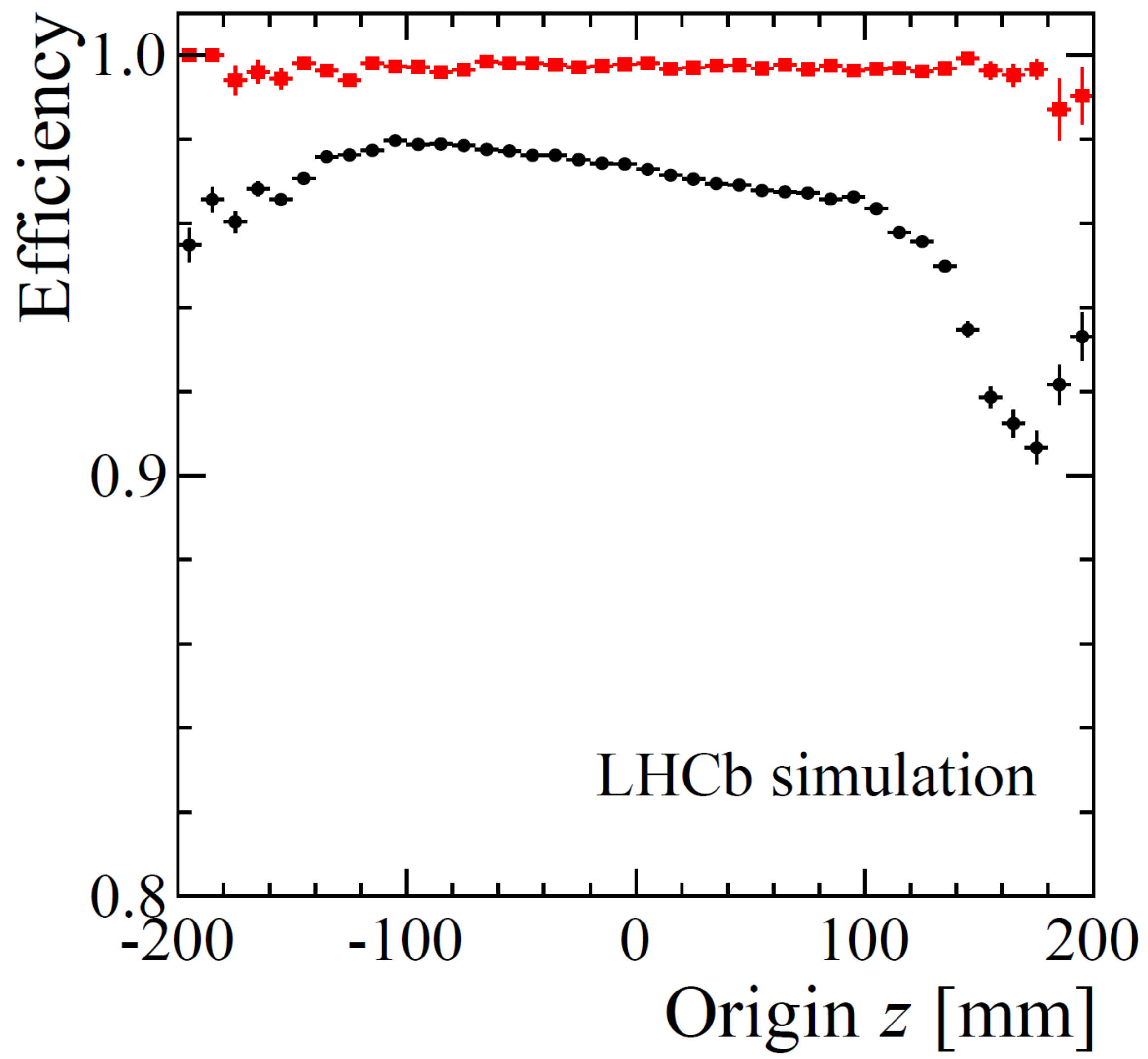
# Tracking Upgrade




- ❑ New pixel VELO
- ❑ UT instead of TT
- ❑ SciFi instead of IT+OT



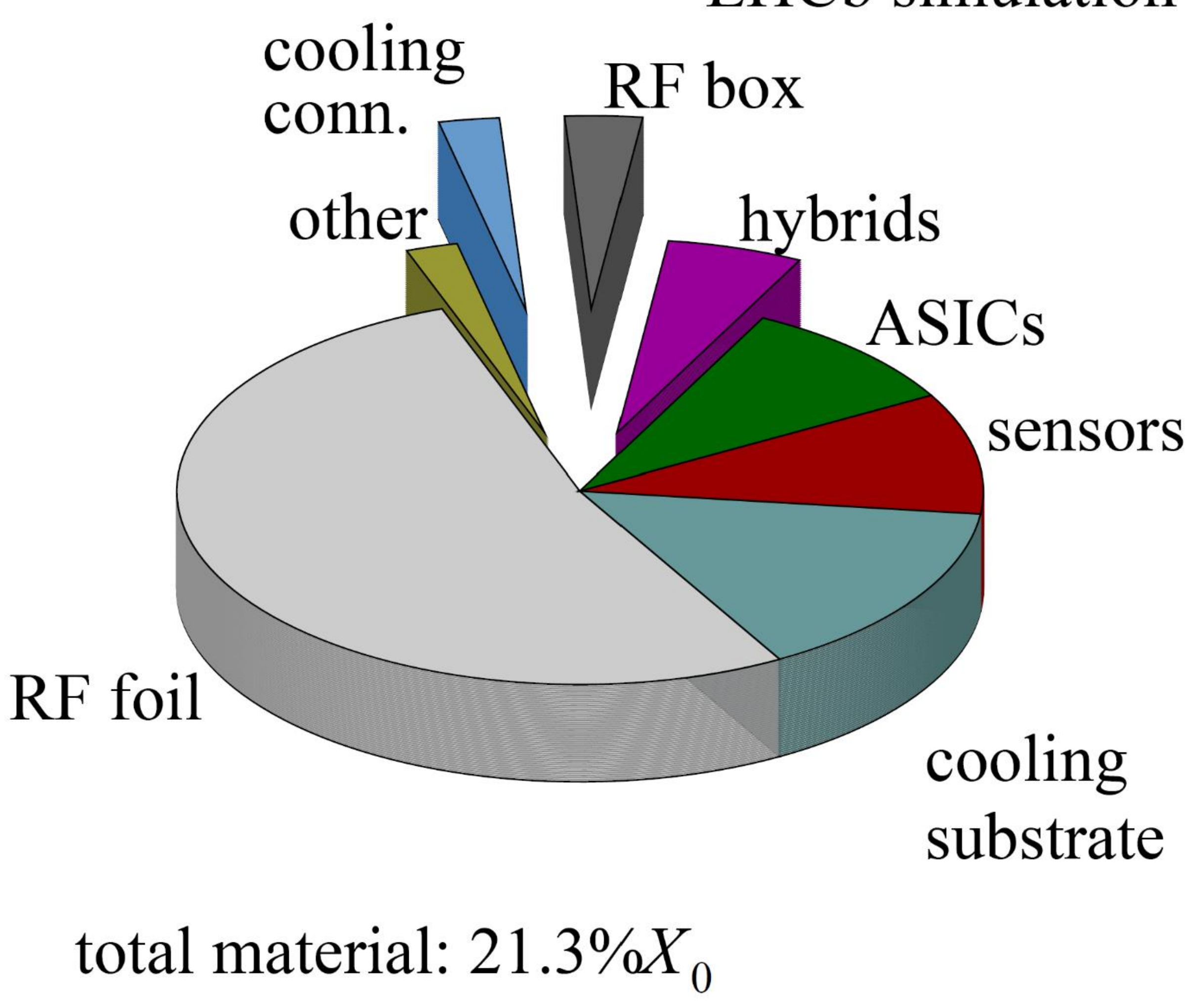



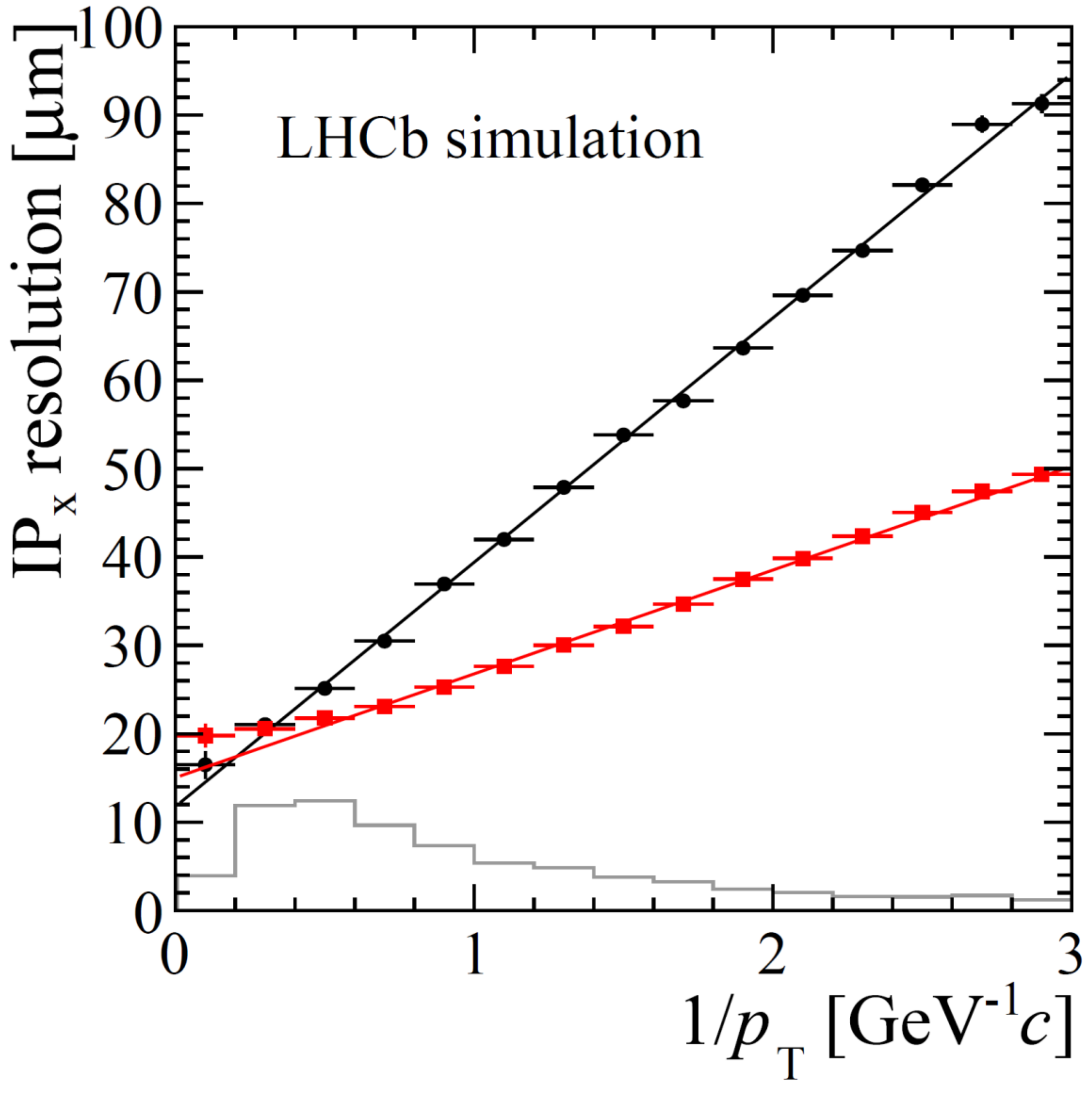

- ❑ Improved reconstruction time which allows for software-only trigger
- ❑ Improved $p_T$ resolution
- ❑ Improved IP resolution

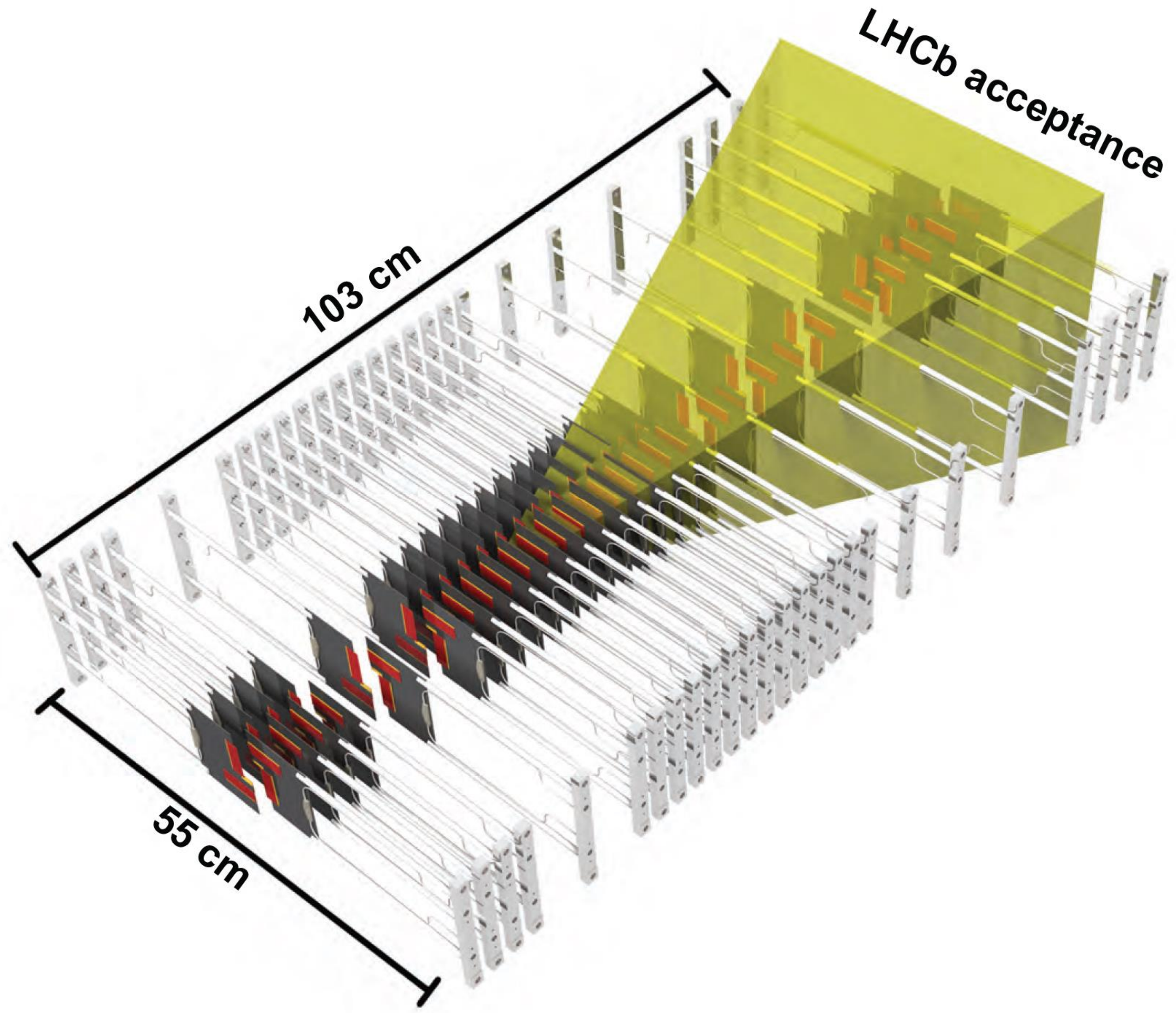
# Overview of LHCb VELO (Vertex Locator) in Run3

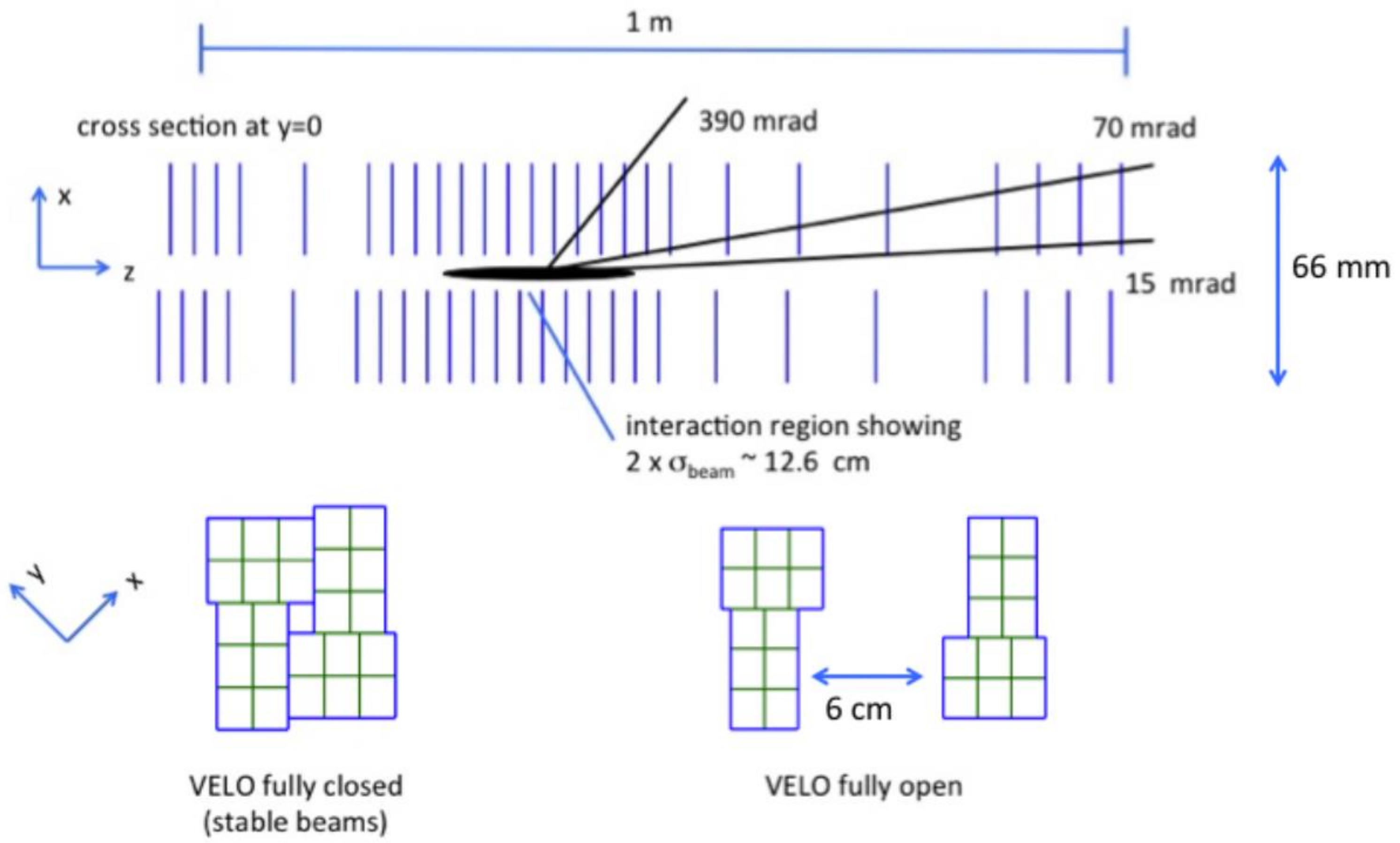
[LHCb-TDR-013]

- ❑ Upgraded VELO with pixels
- Improved IP resolution (two times better at $p_T$~0.5 GeV)
- Reduced material interaction (three times better)
- Reduced fake rate and improved pattern recognition



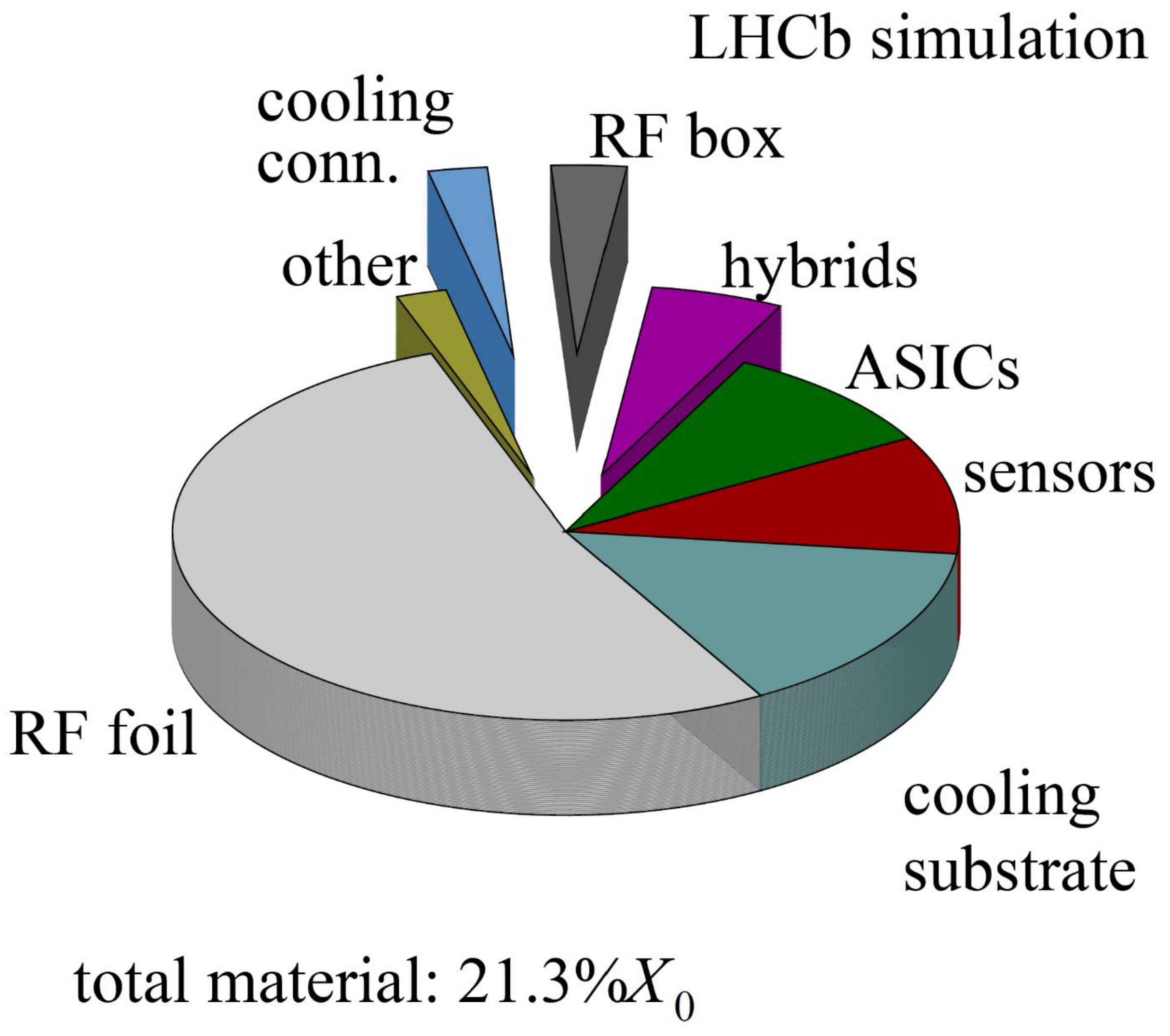



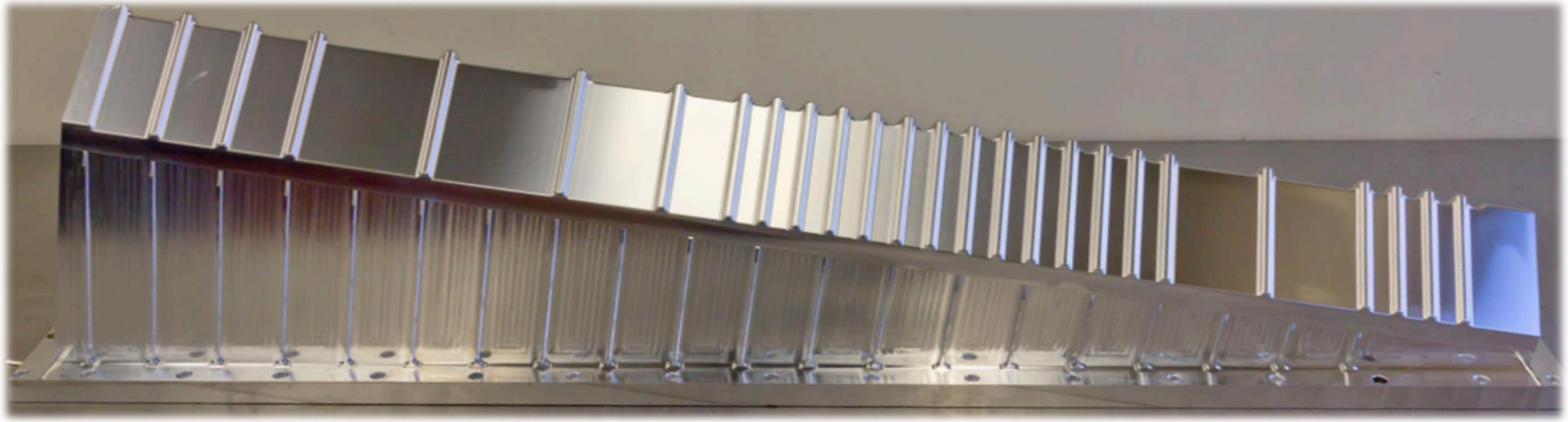



# Overview of LHCb VELO (Vertex Locator) in Run3 (ii)

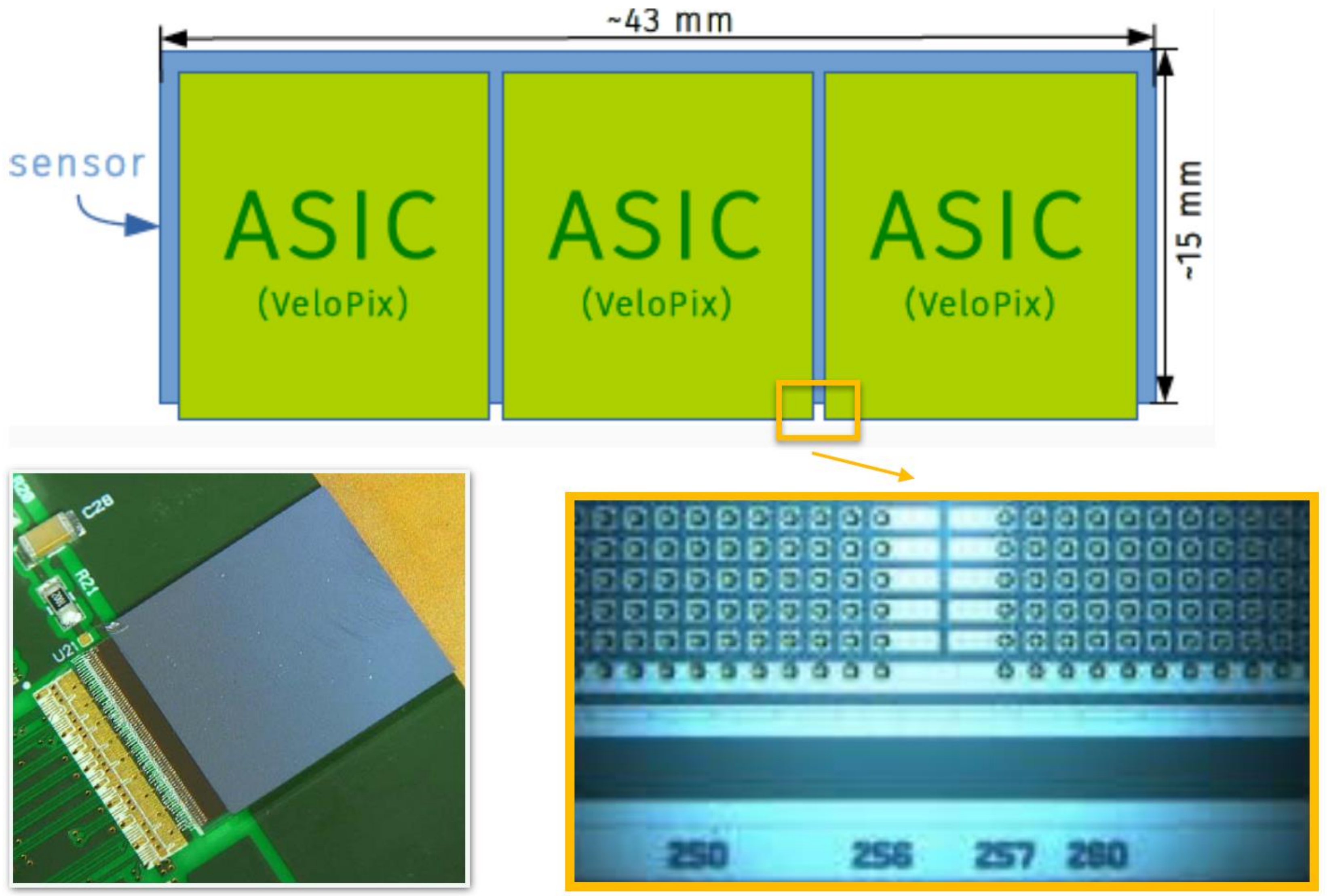
# New RF foil

- ❑ RF foil is used to separate beam vacuum and VELO vacuum
- ❑ Contributes a lot of material
- ❑ Milled and then etched to 150 µm (300 µm planned initially)
- ❑ Etched using NaOH



# Sensors and ASICs

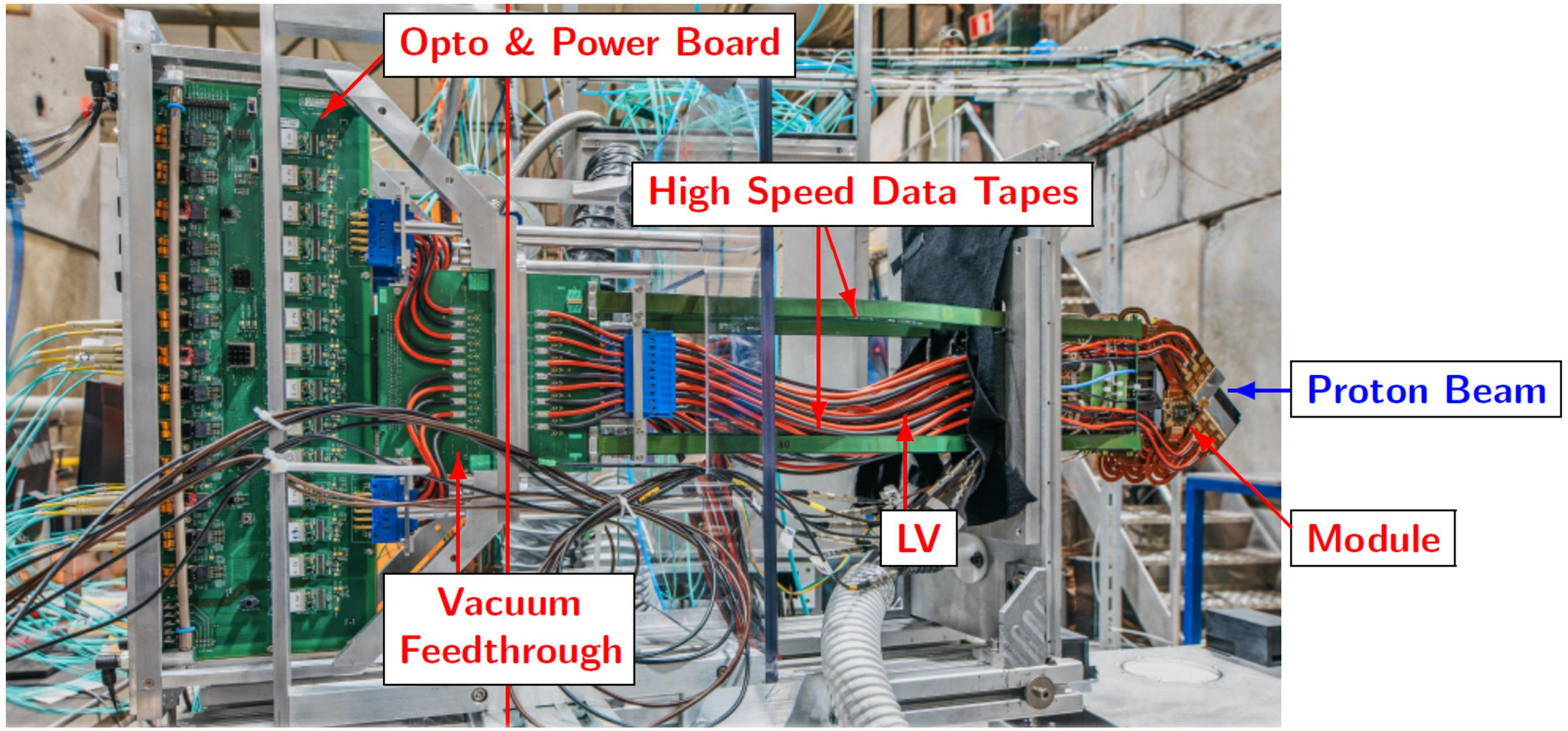


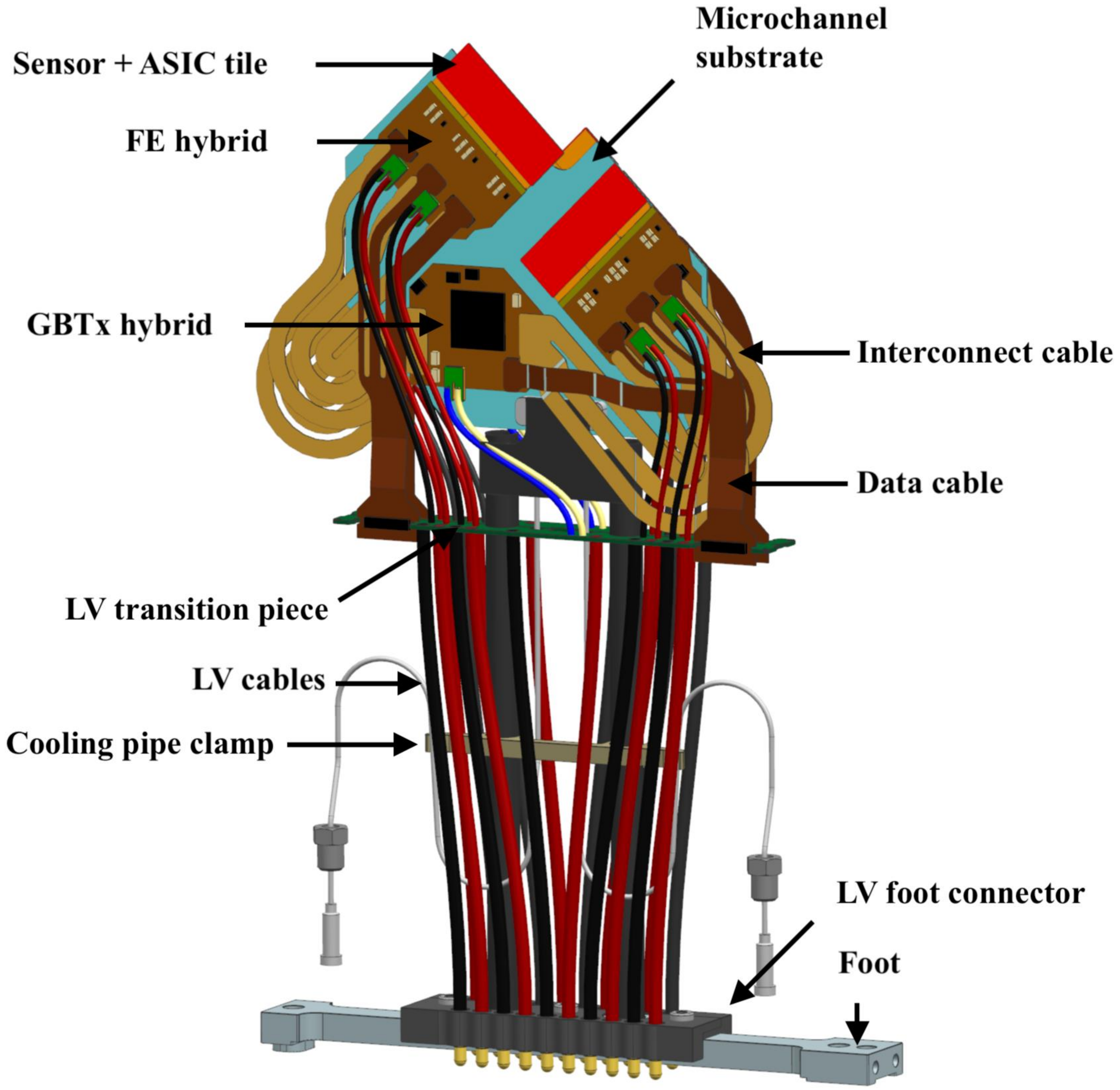

- ❑ Silicon sensor 200 μm thick
- ❑ P-type, $8\times10^{15}$ 1 MeV $n_{eq}/cm^2$ lifetime fluence
- ❑ $768\times256$ pixels, each $55\times55$ $\mu m^2$

- ❑ Each sensor has three ASICs
- ❑ Each bump-bonded to $256\times256$ pixels
- ❑ Readout of every hit: up to 50 khits/s/pixel
- ❑ Power consumption $< 2$ W

# Readout electronics

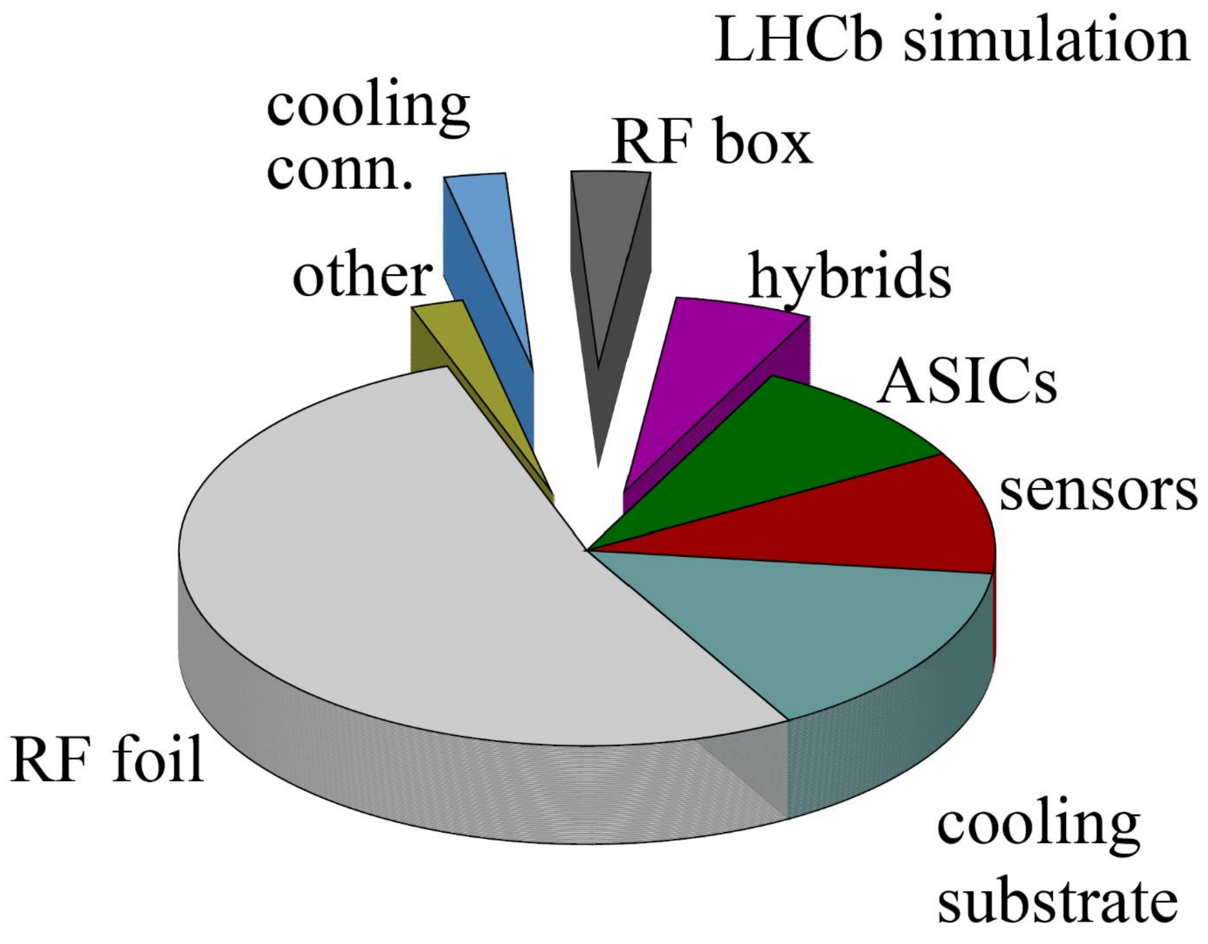
- ASICs wirebonded to FE hybrids
- GBTx hybrids deserialize control signals
- Opto & Power Board outside vacuum and high radiation zone



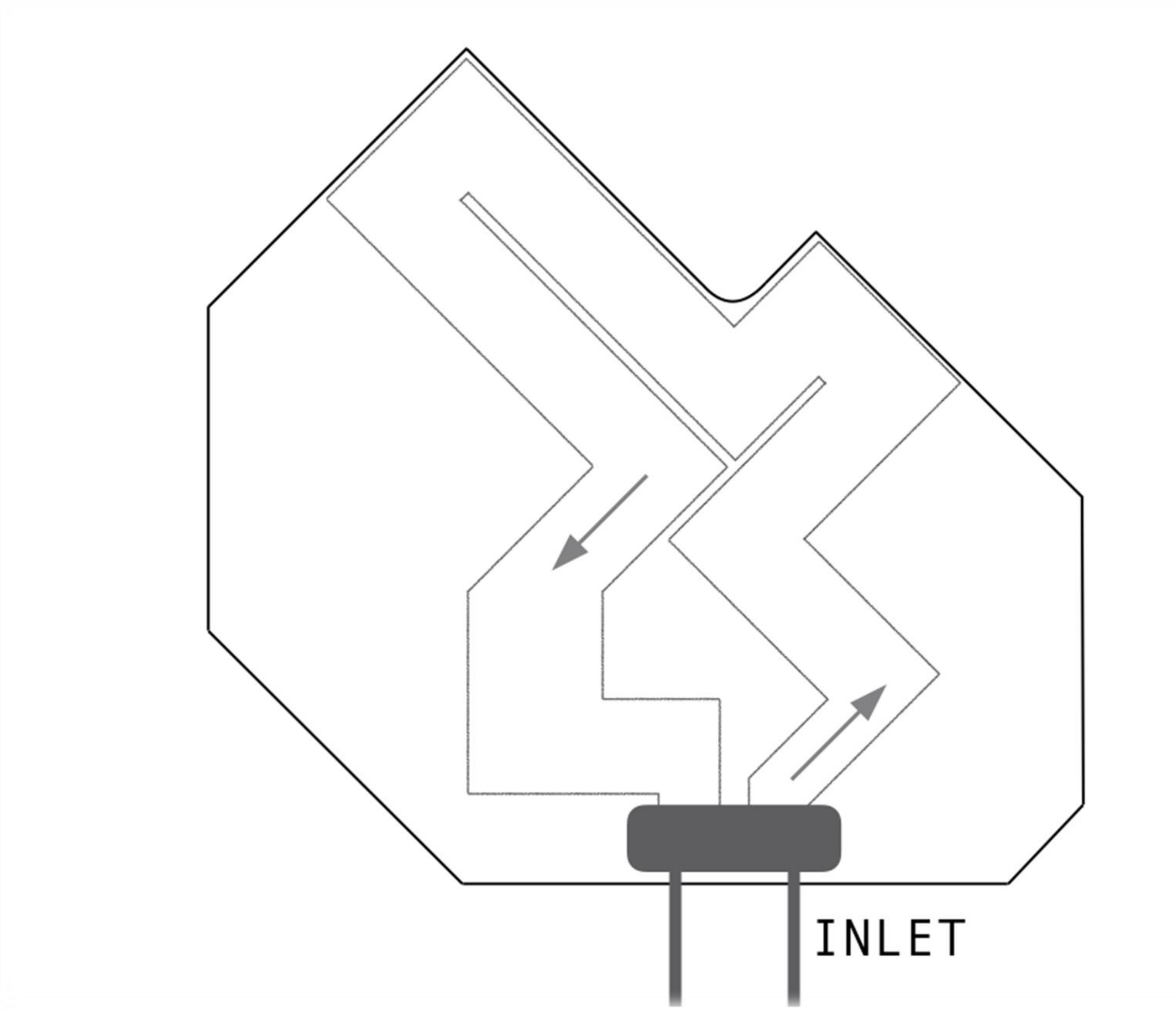



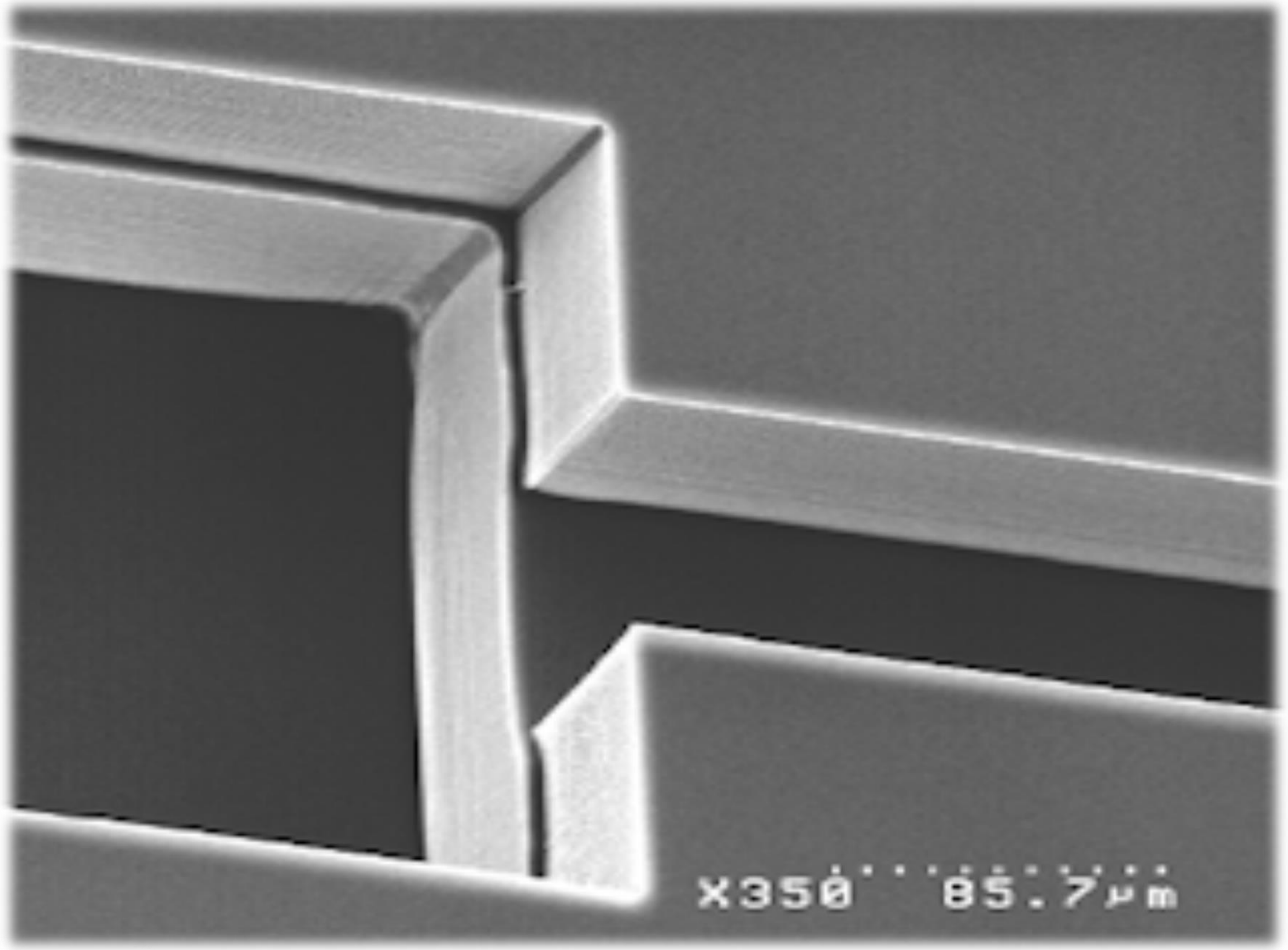
# Microchannels

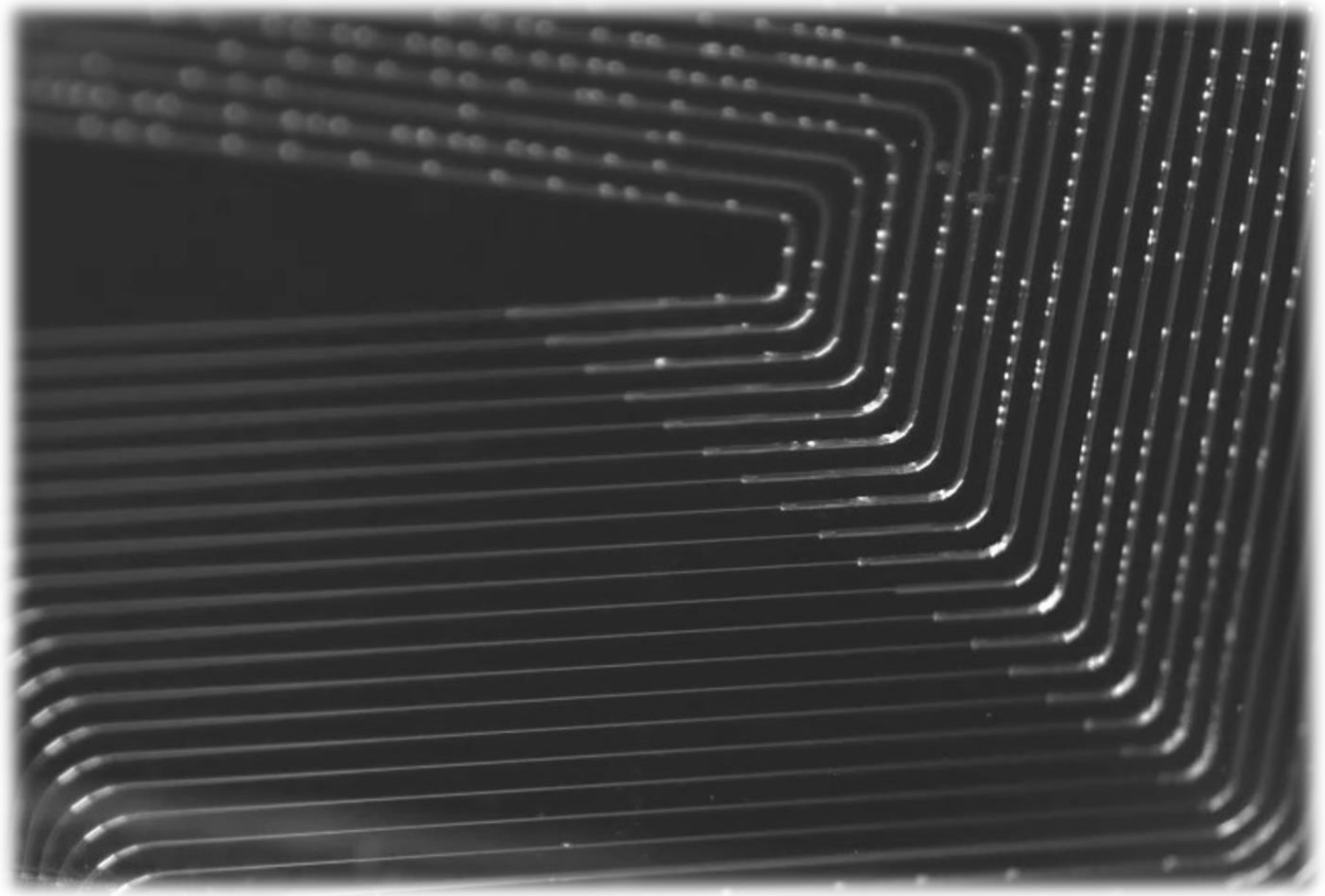
- ❑ Four tiles per module (12 ASICs total)
- ❑ Cooled by two-phase $CO_2$ boiling in microchannels
- ❑ Microchannels are etched in silicon (500 µm thickness)
- ❑ Power consumption < 2 W




total material: 21.3% $X_0$

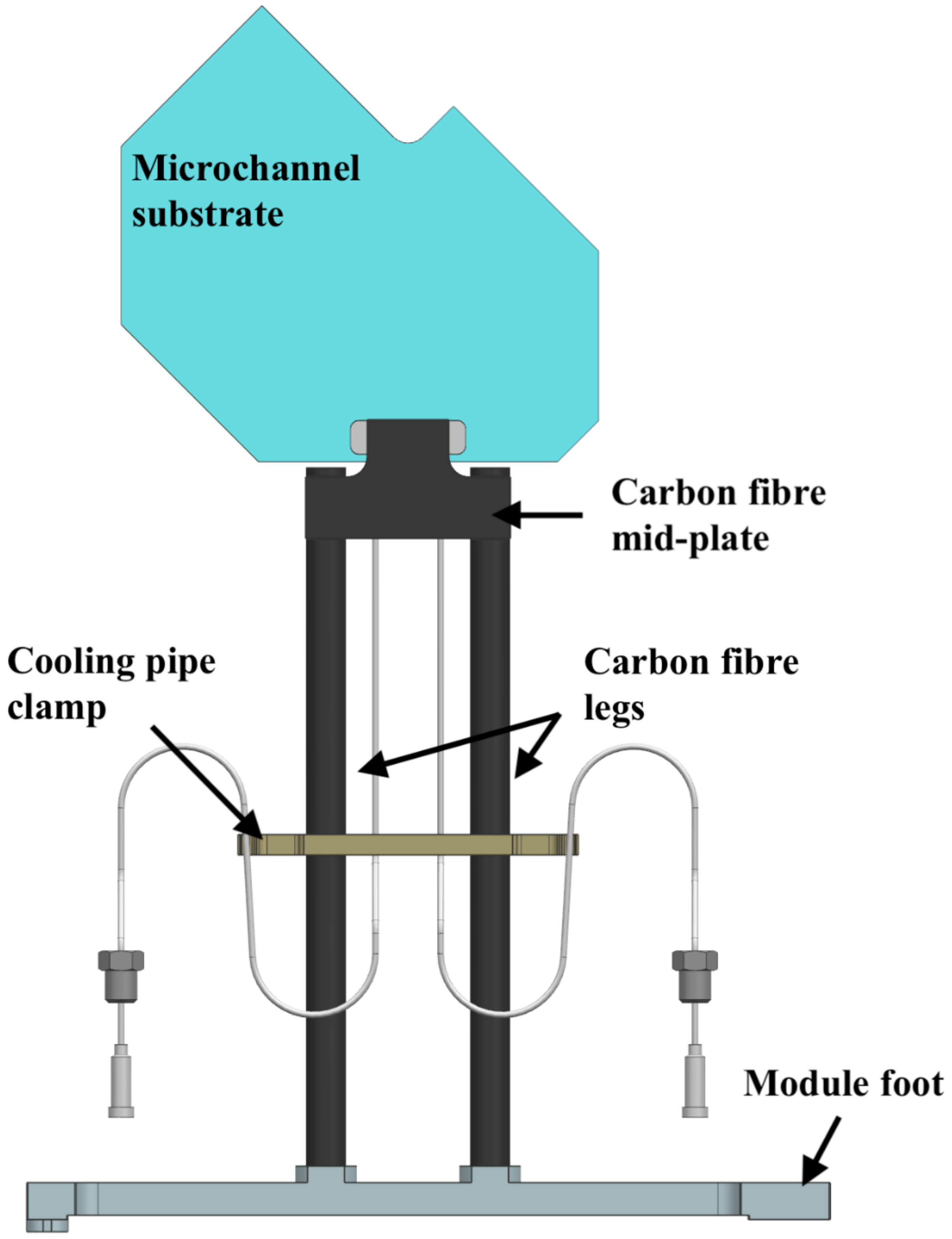


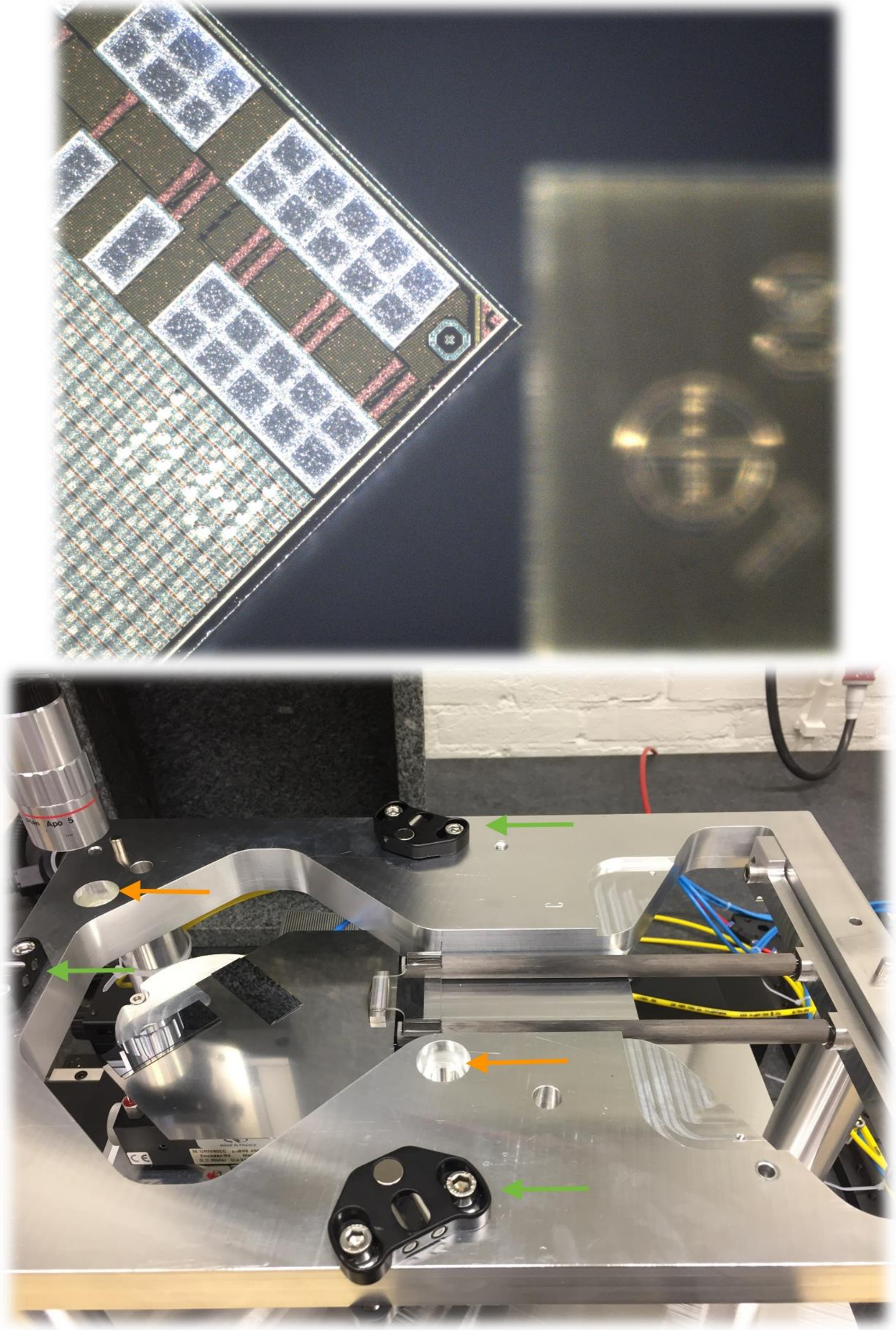



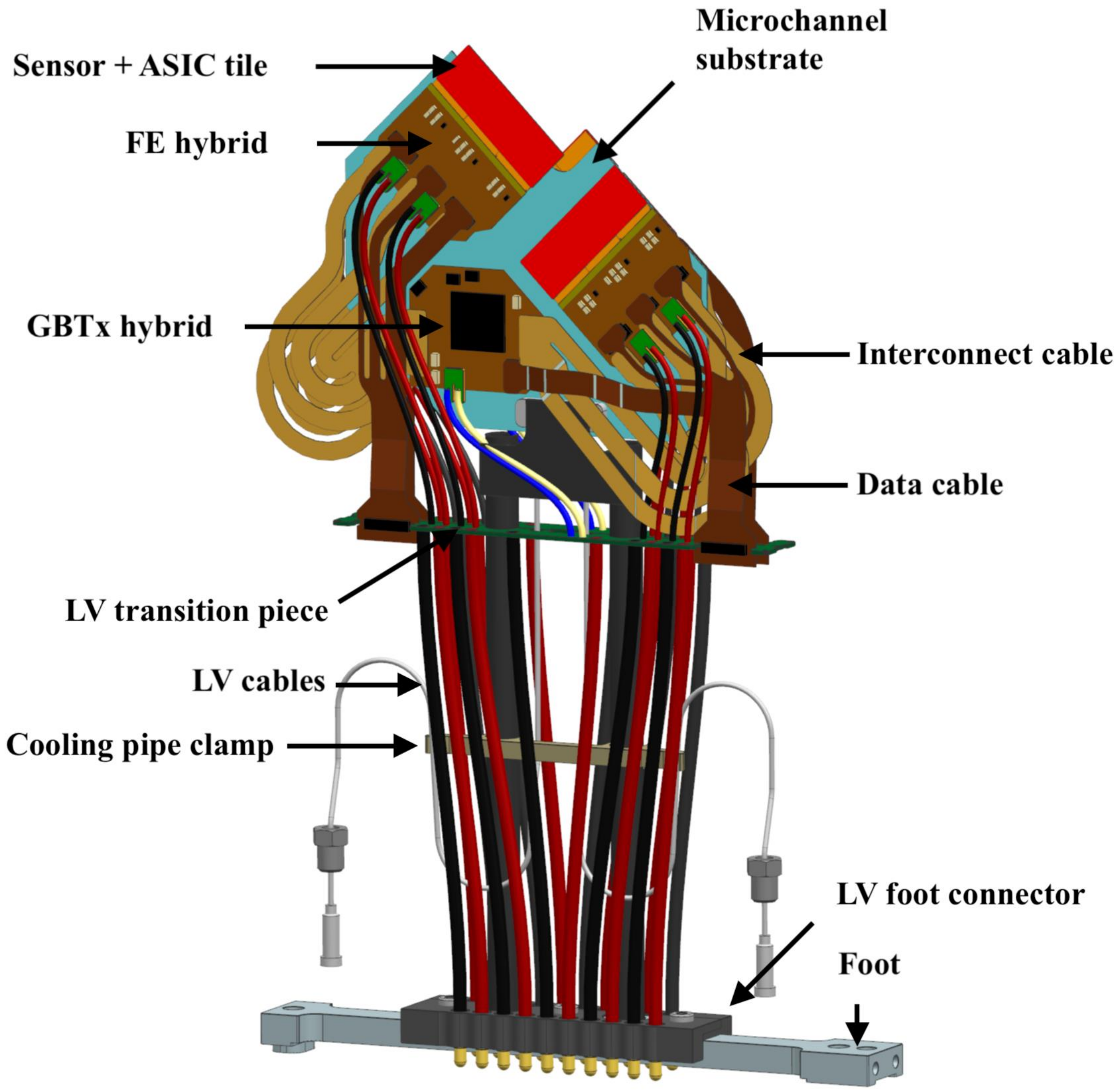



# Assembly

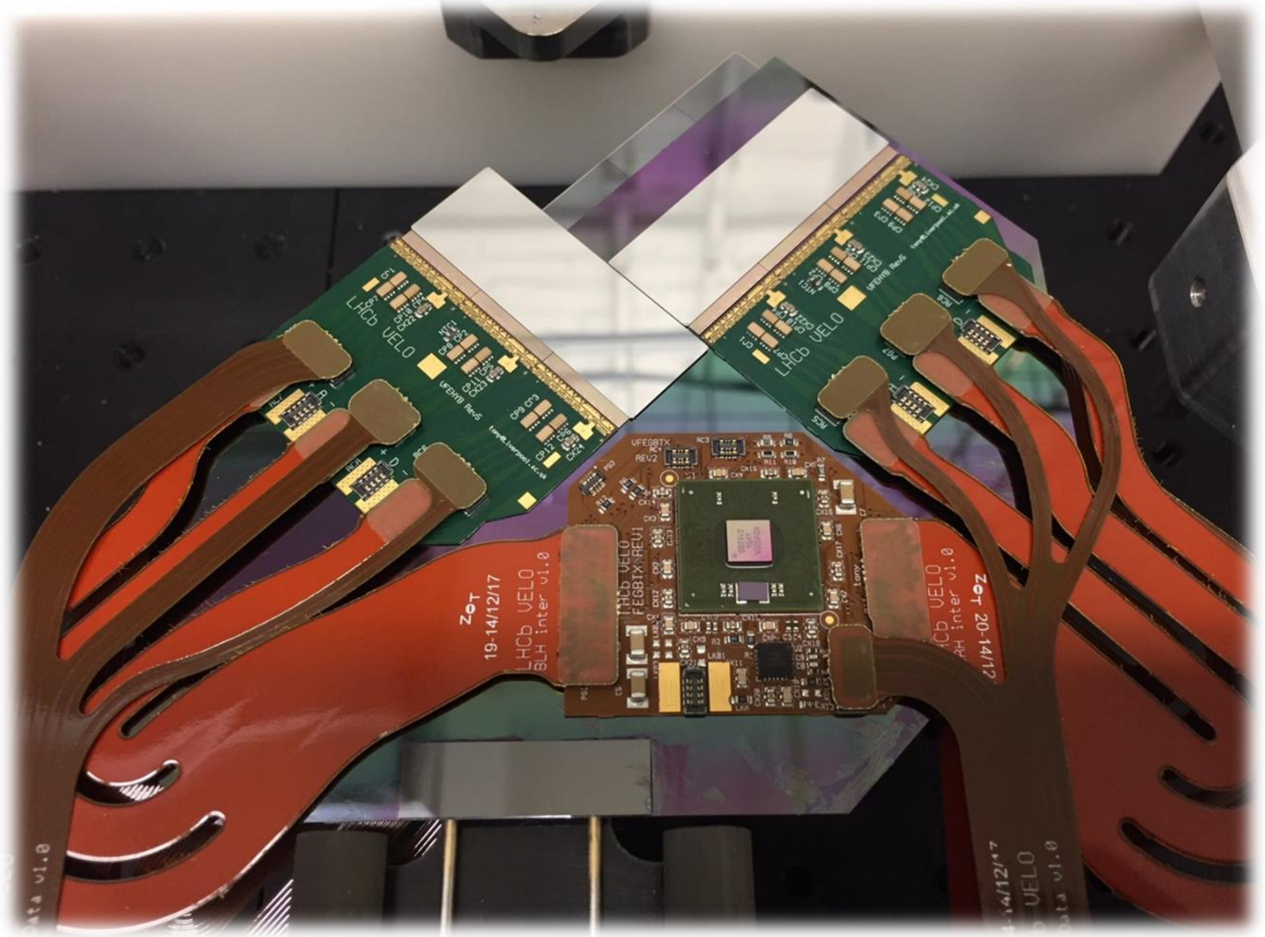
- ❑ Construction of the bare module
- ❑ Precise positioning of sensors
- ❑ Innermost sensors have 5mm overhang

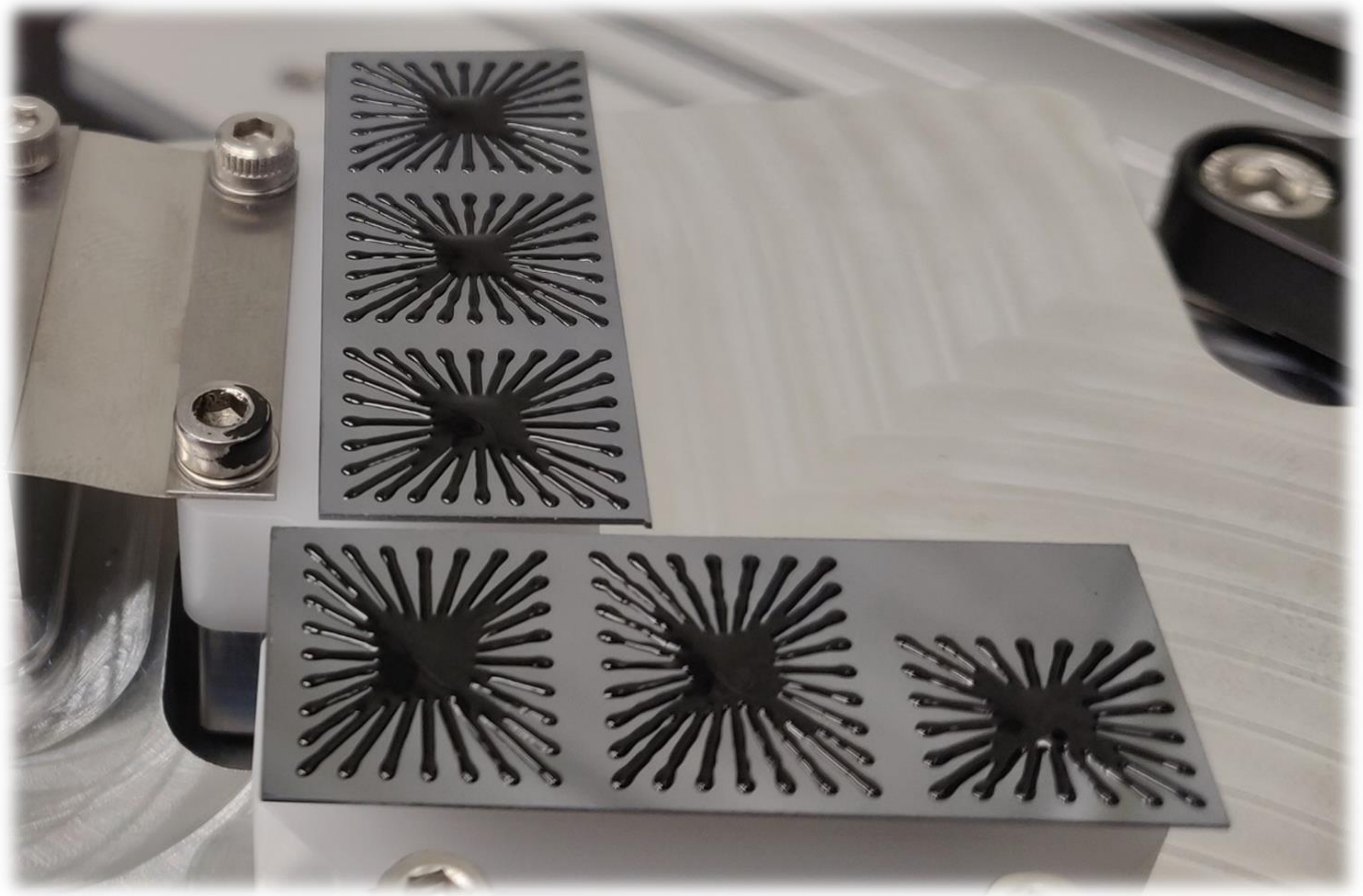


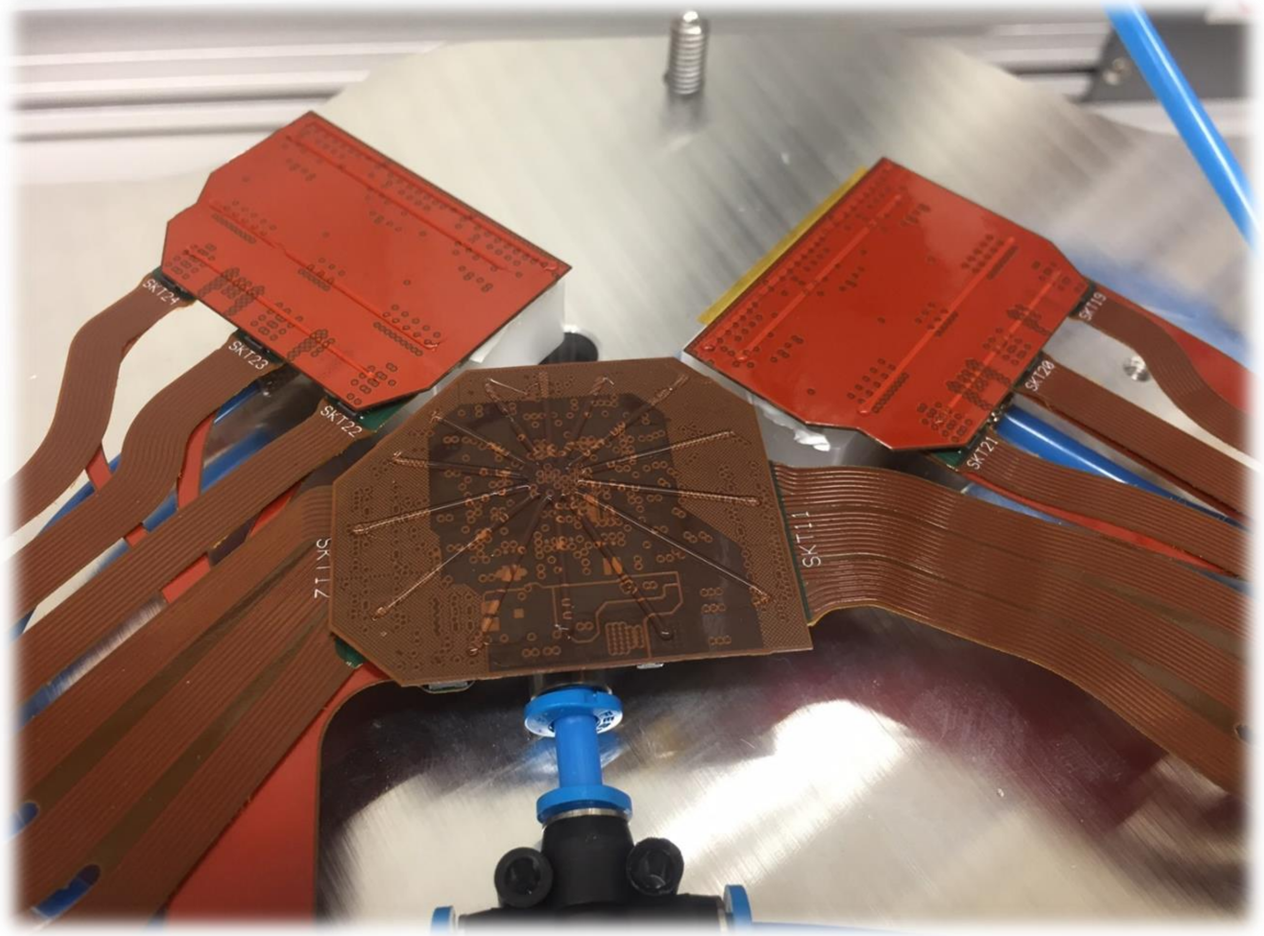



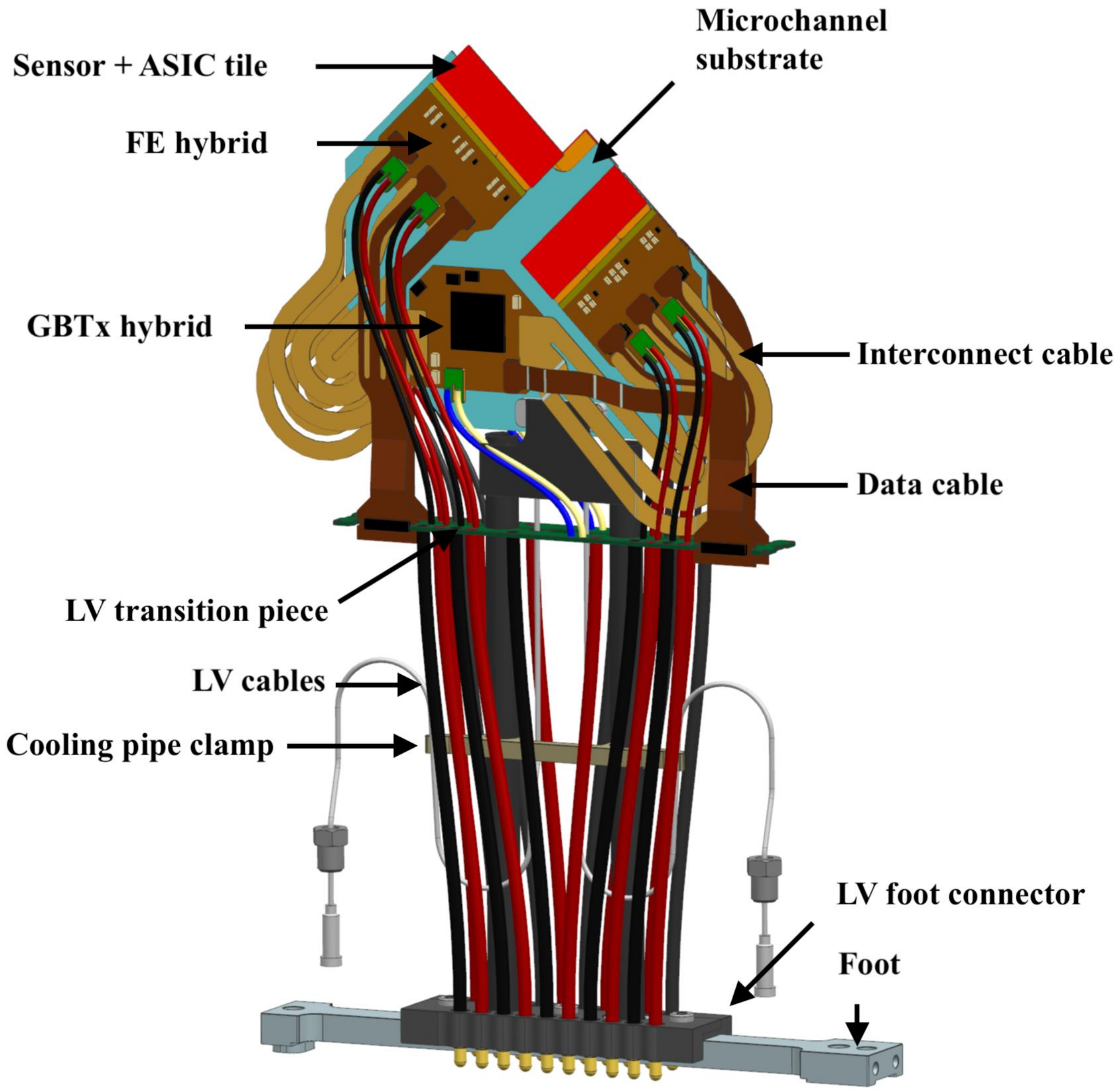


- ❑ Attaching the tiles
- ❑ Attaching the hybrids
- ❑ Wirebonding
- ❑ Attaching power cables



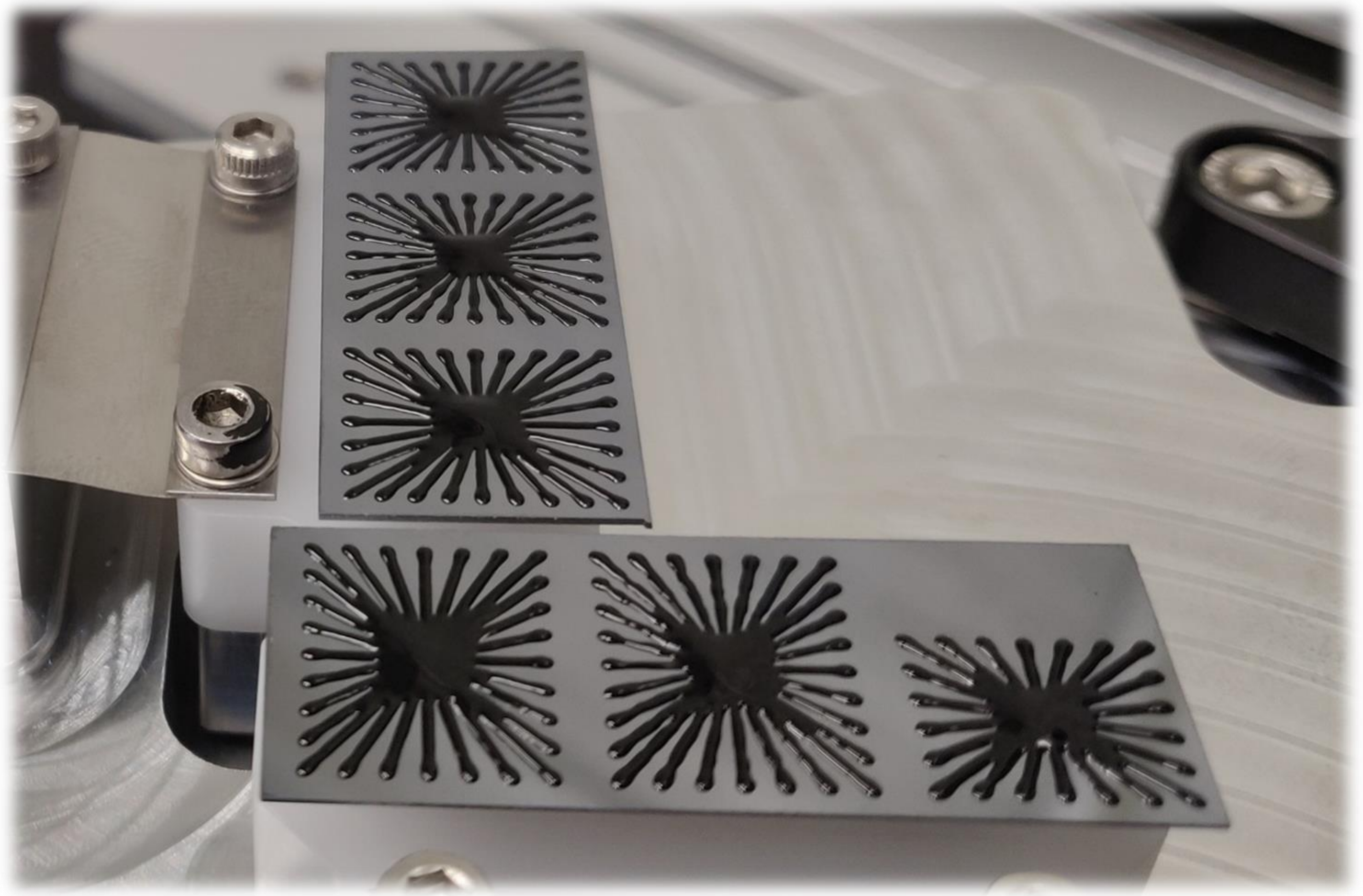


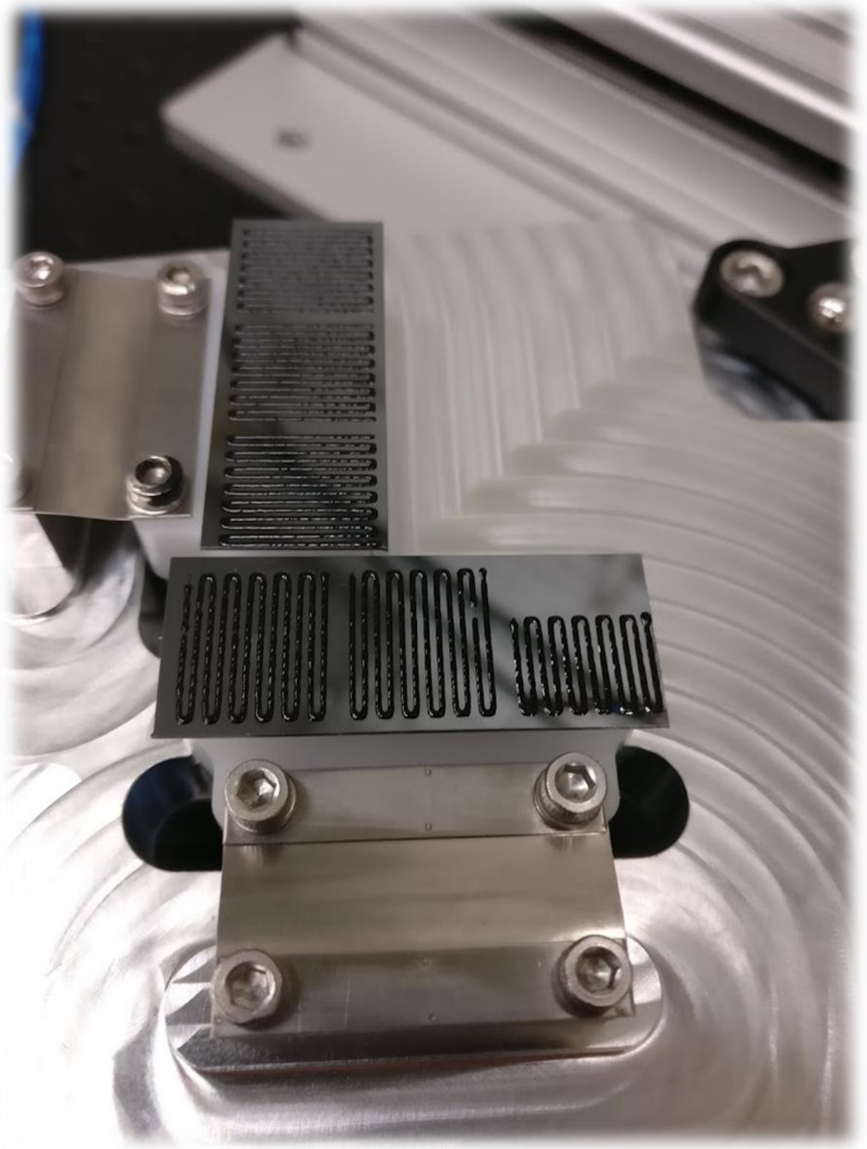


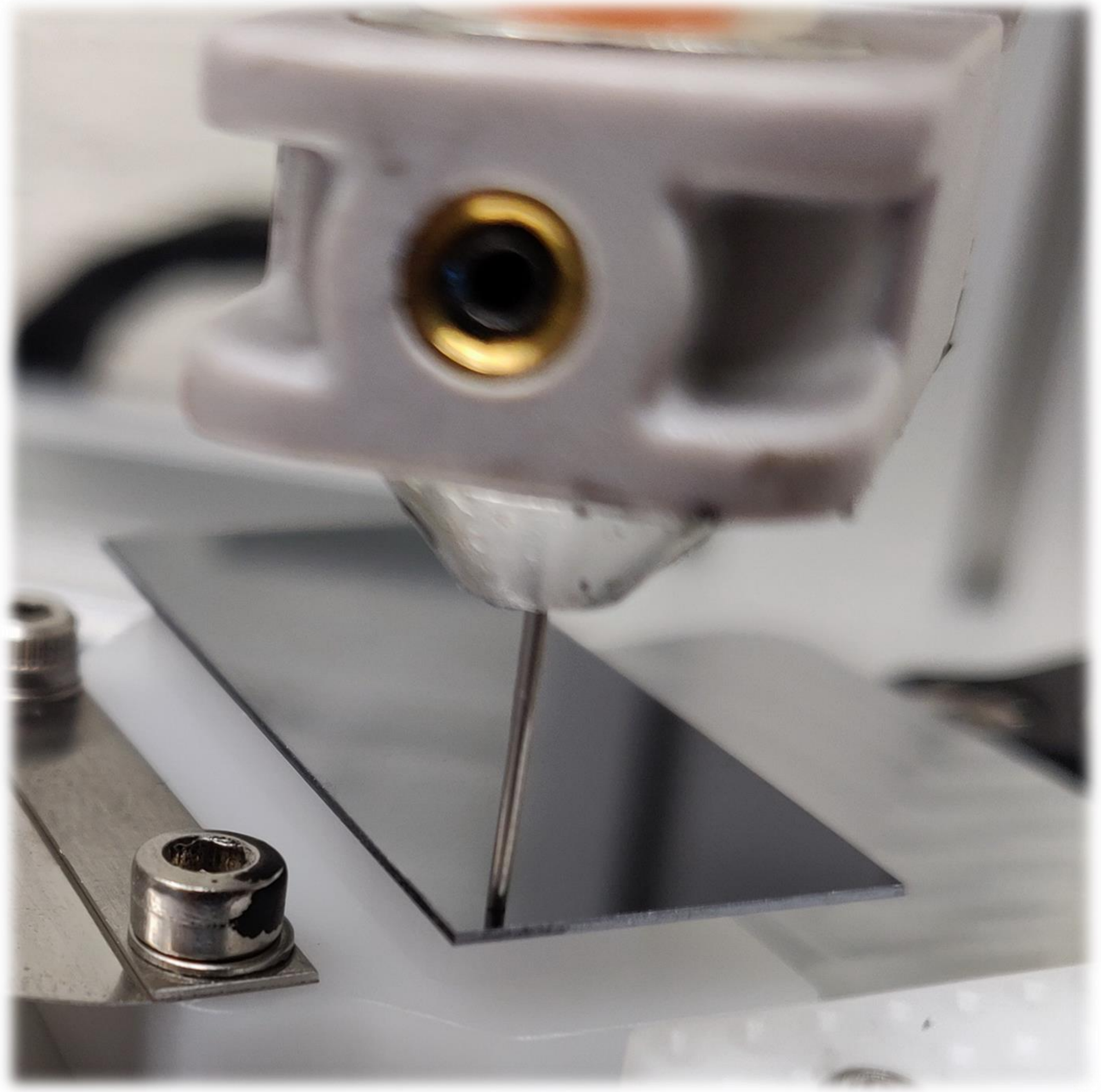


# Interlude: attaching the ASICs

- ❑ Choosing the glue. And the hardener
- ❑ Choosing the pattern
- ❑ Repeatability
- ❑ Avoiding common problems
- ❑ Missing some things!

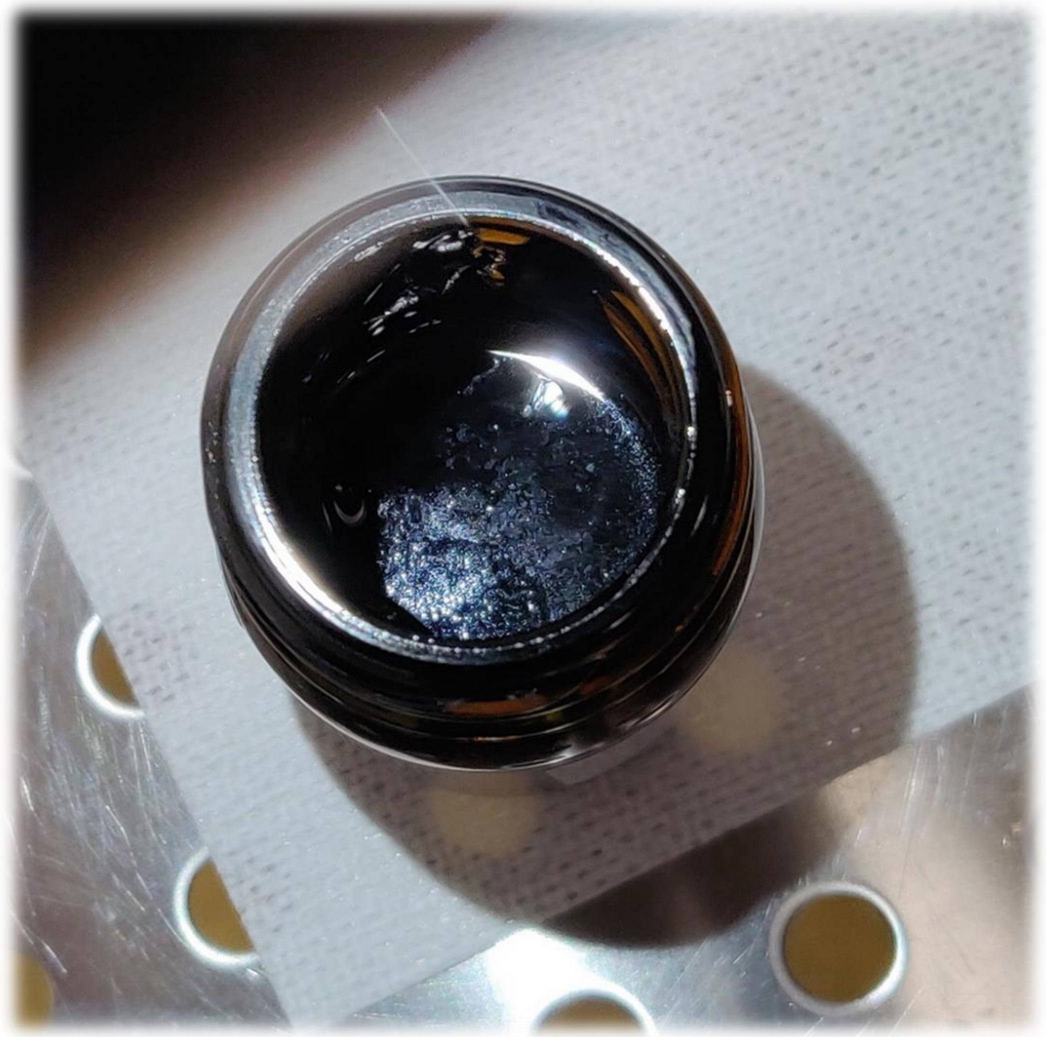


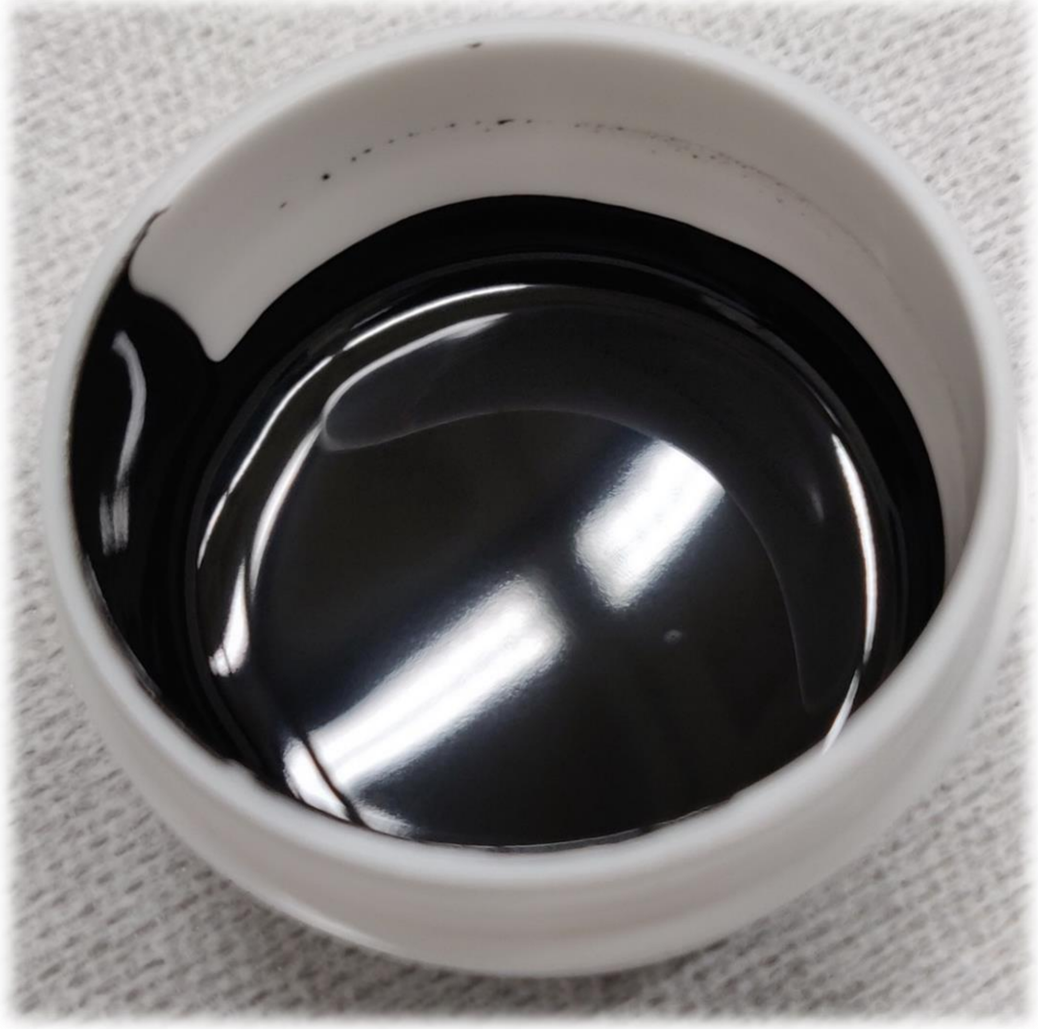




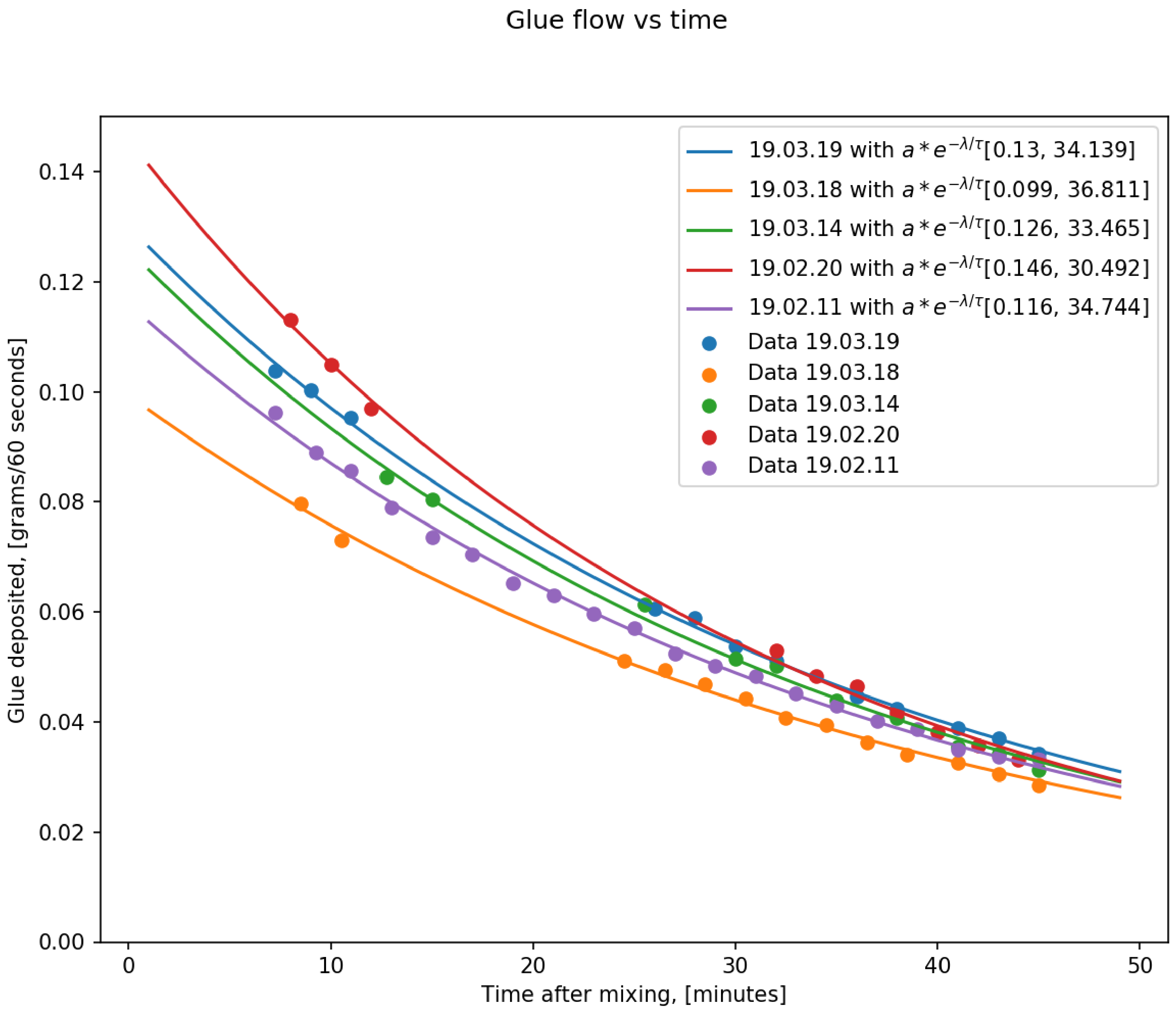
- ❑ Stycast 2850FT. 2 components: epoxy and hardener
- ❑ Multiple hardener options
- ❑ Pattern optimization: coverage, avoiding air bubbles

# Interlude: attaching the ASICs. Repeatability and avoiding issues





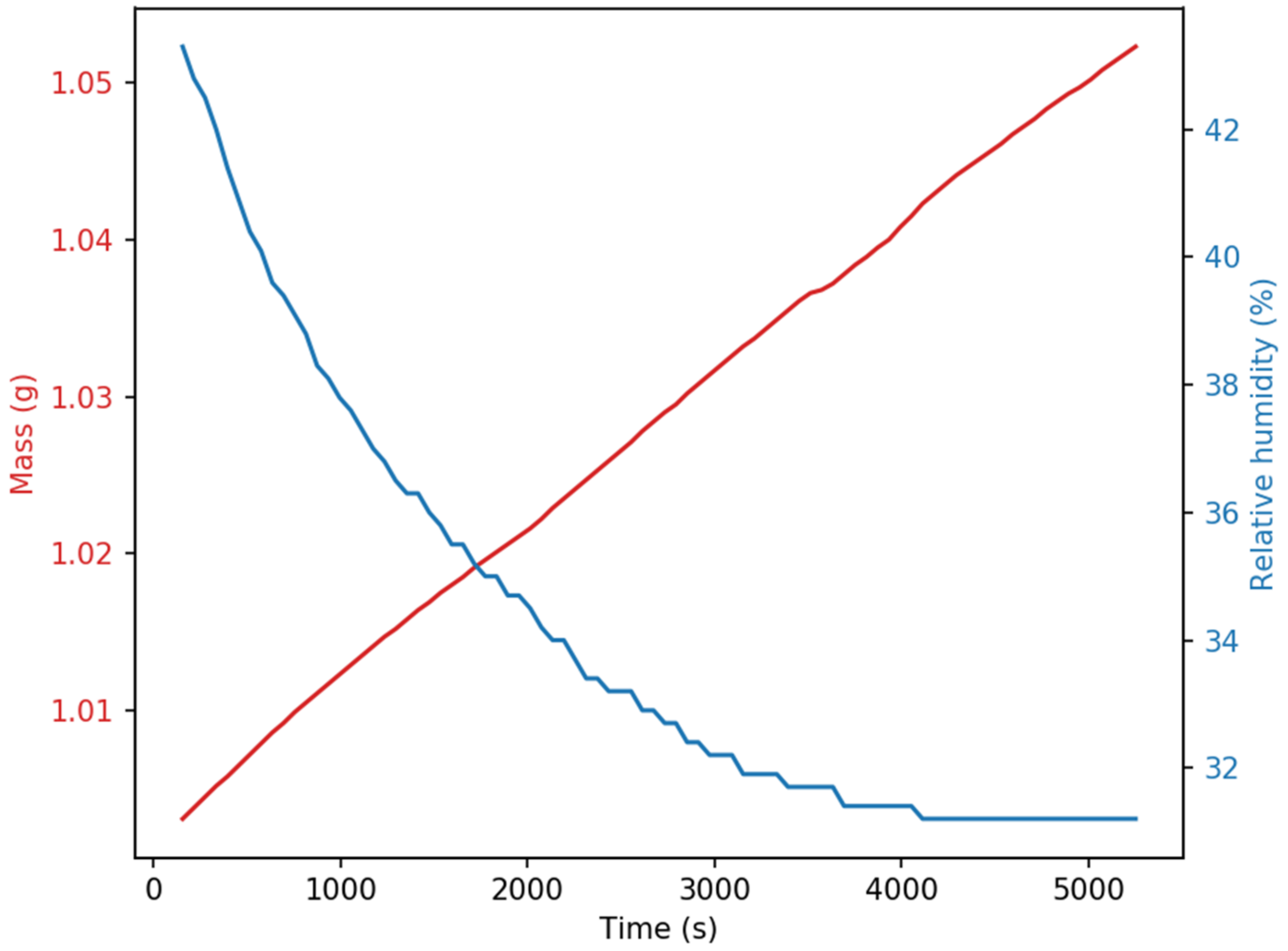

- ❑ Reheating to decrystallize
- ❑ Decanting to limit the number of reheats
- ❑ Centrifuging for deaeration
- ❑ Controlling the temperature to account for hardening

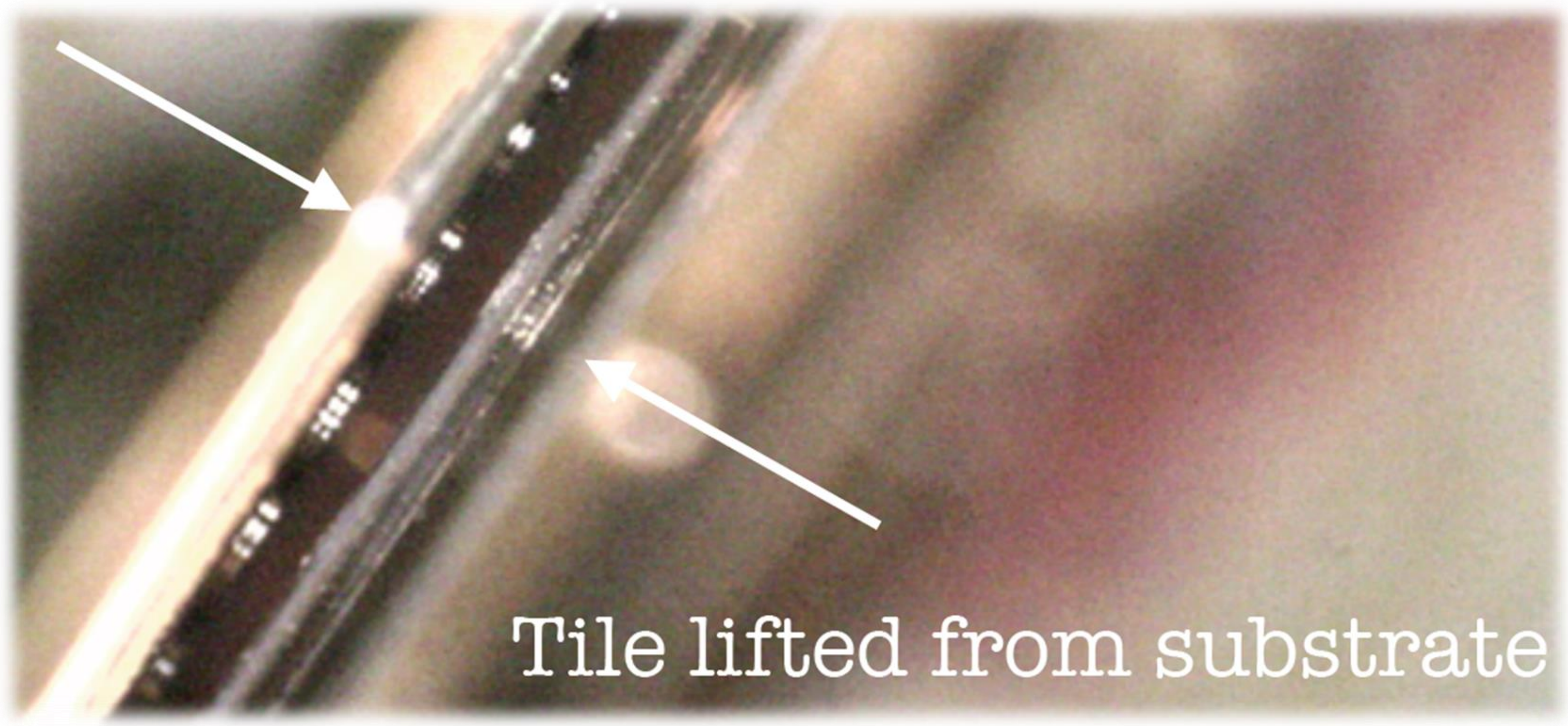


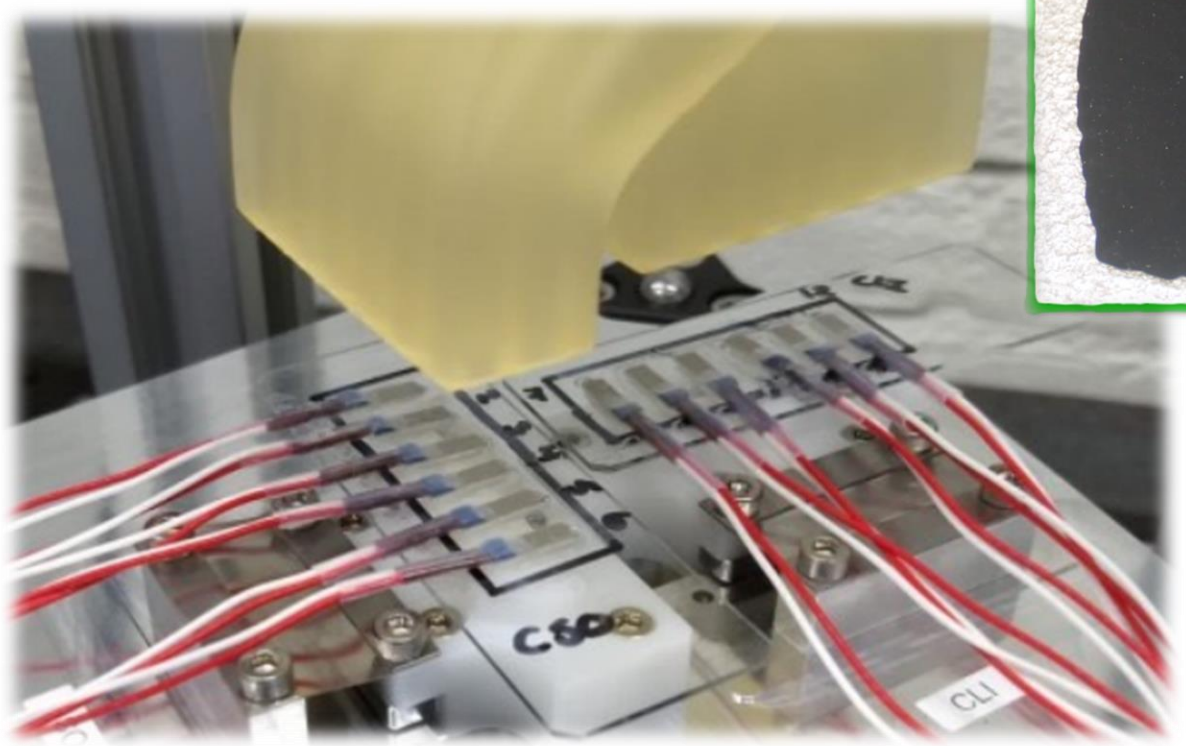
# Interlude: attaching the sensors. Avoiding issues (almost)

- During QA a detached tile, connected only by wirebonds was found
- Hypothesis: water is a problem
- Possible solutions: avoiding the water (drybox), or removing it with heat
- Accounting for all the water: microchannels, epoxy, hardener
- Heating chosen, controlled by thermal camera
- Thermal cycling, peel and shear tests

When you think the sensors have gone berserk…

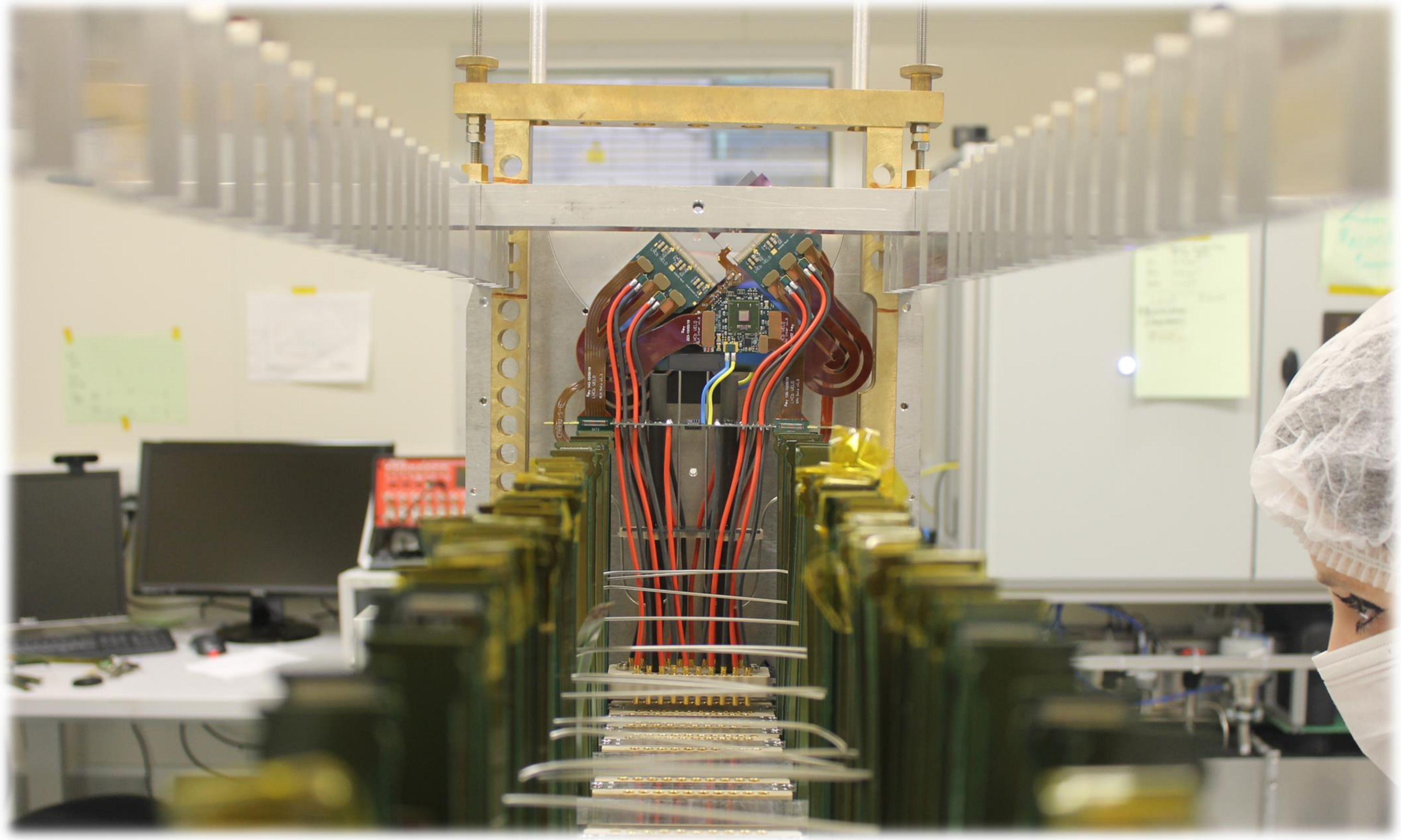



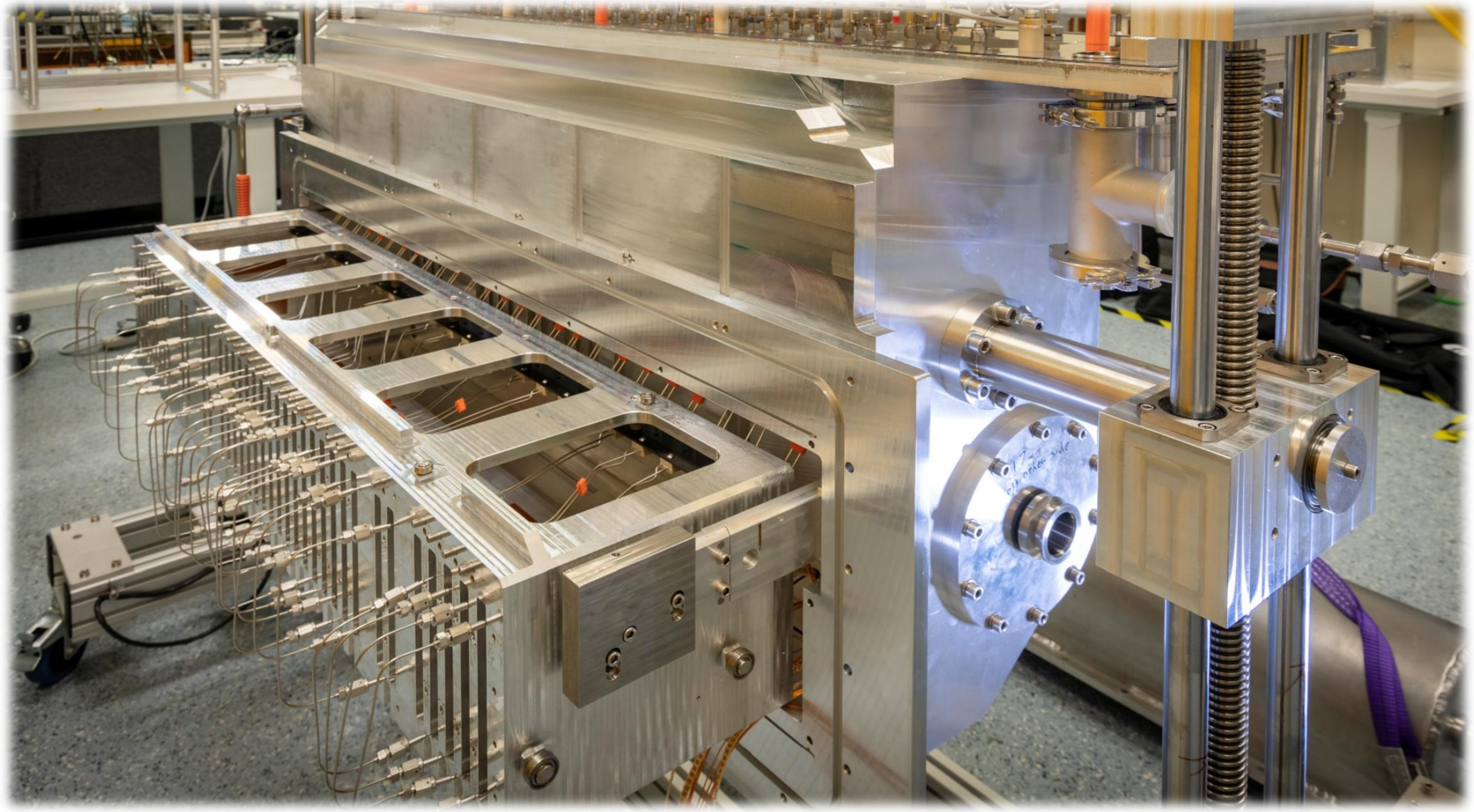



Following the long process of R&D work the sensors are attached. Gluebound.

# Installation and pre-commisioning

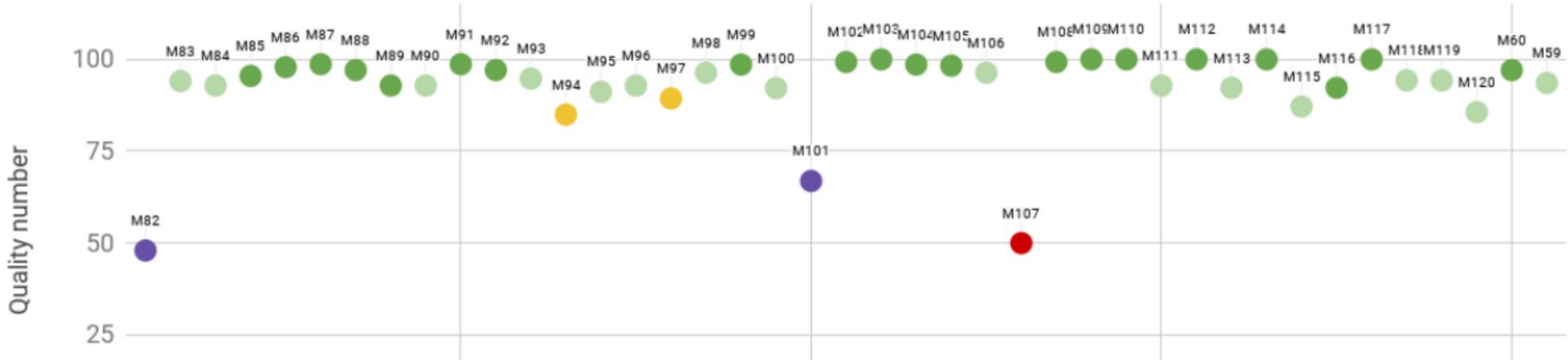
- ❑ RF box is installed
- ❑ Modules are being mounted
- ❑ DAQ and cooling are in progress

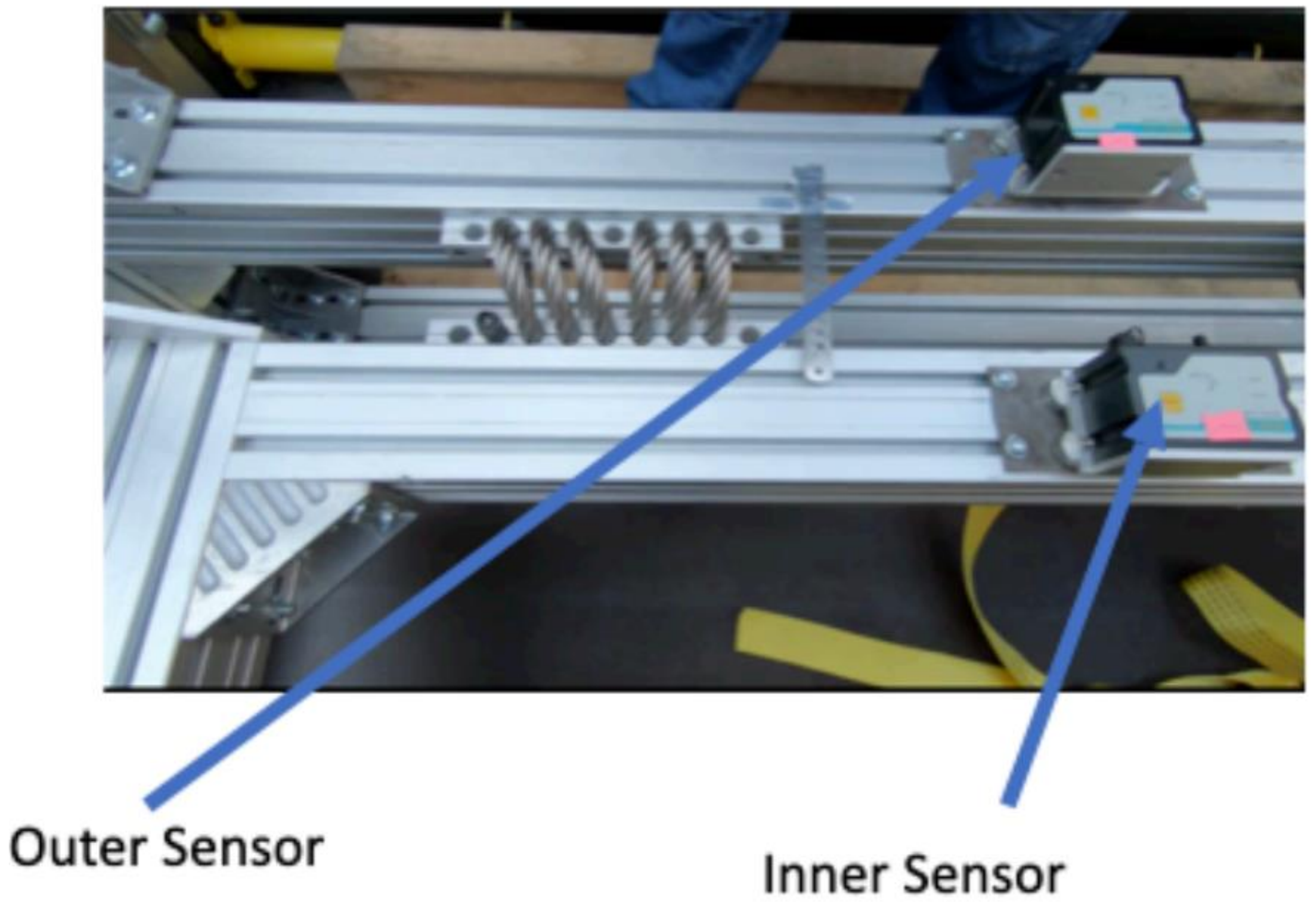




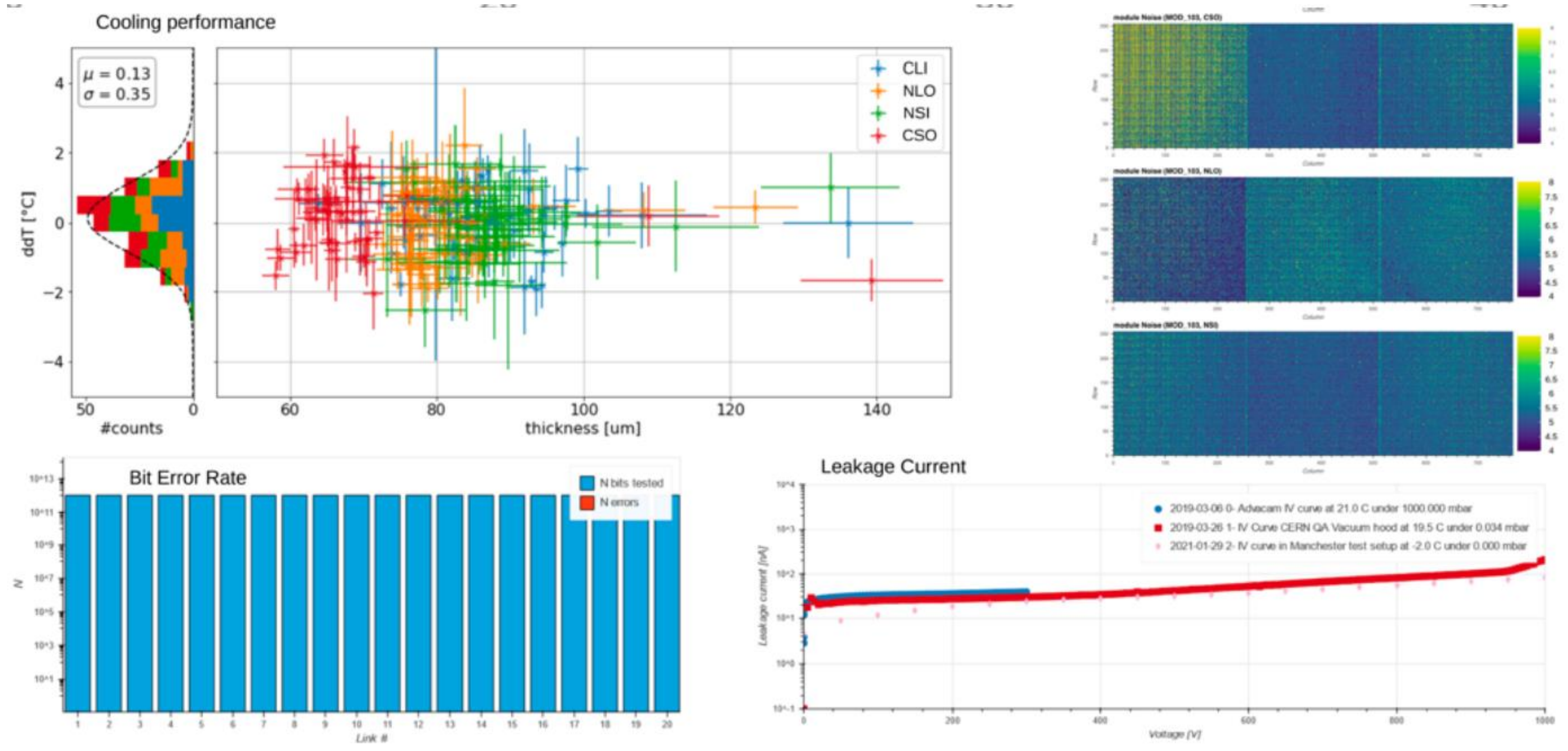
# Current status and testing

- Transport tests are under way
- 43 modules out of 52 are completed and qualified

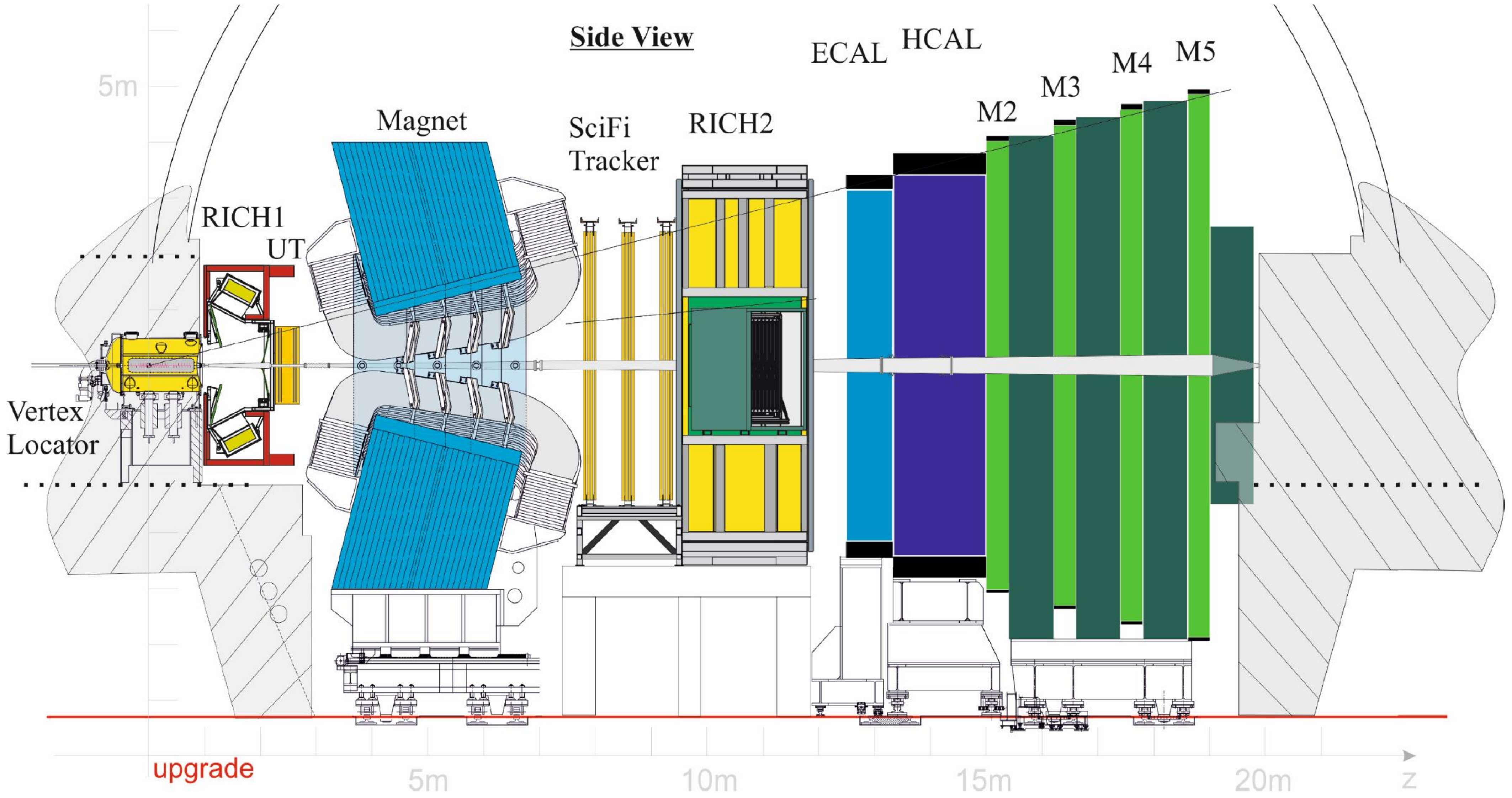


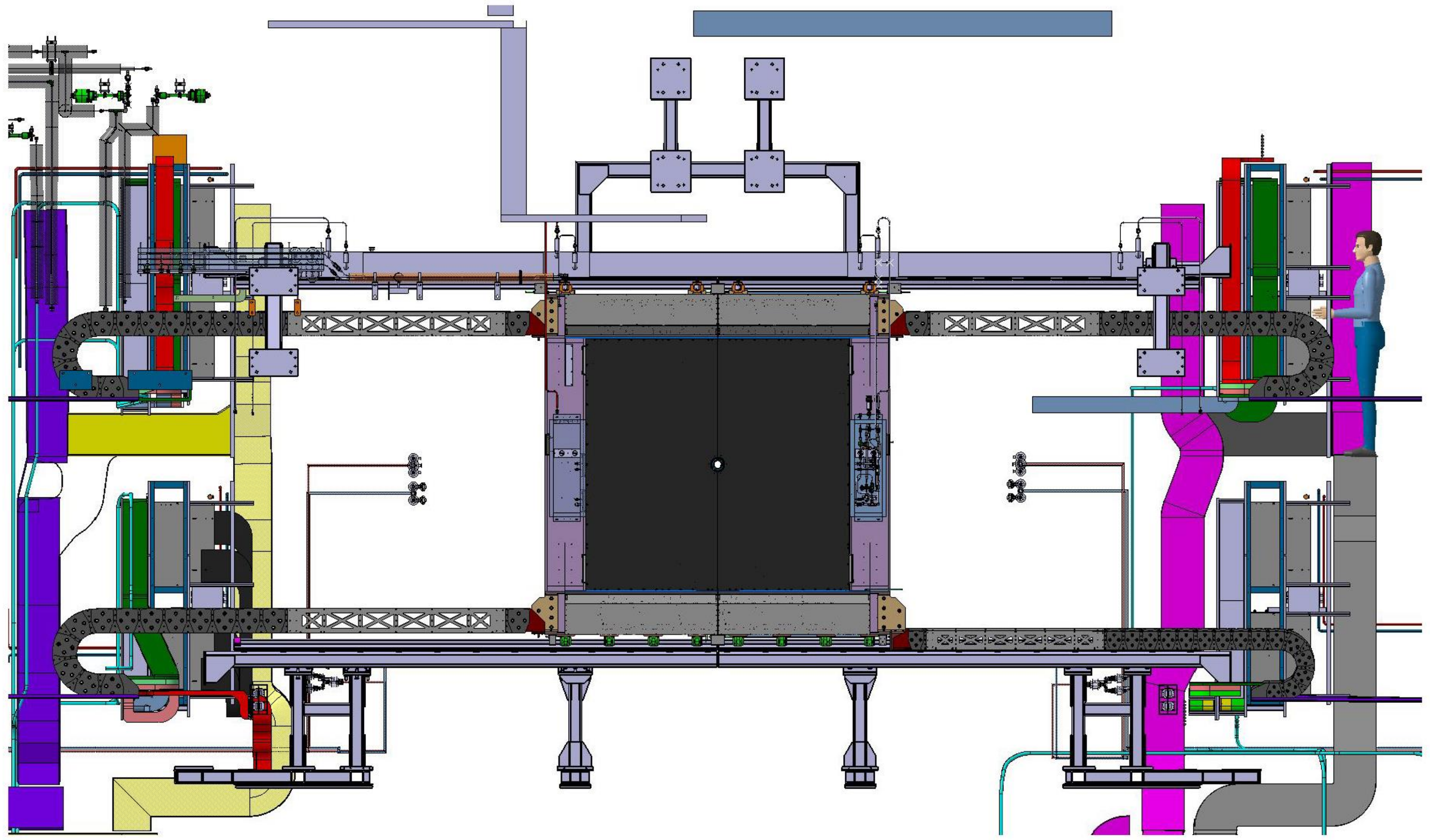



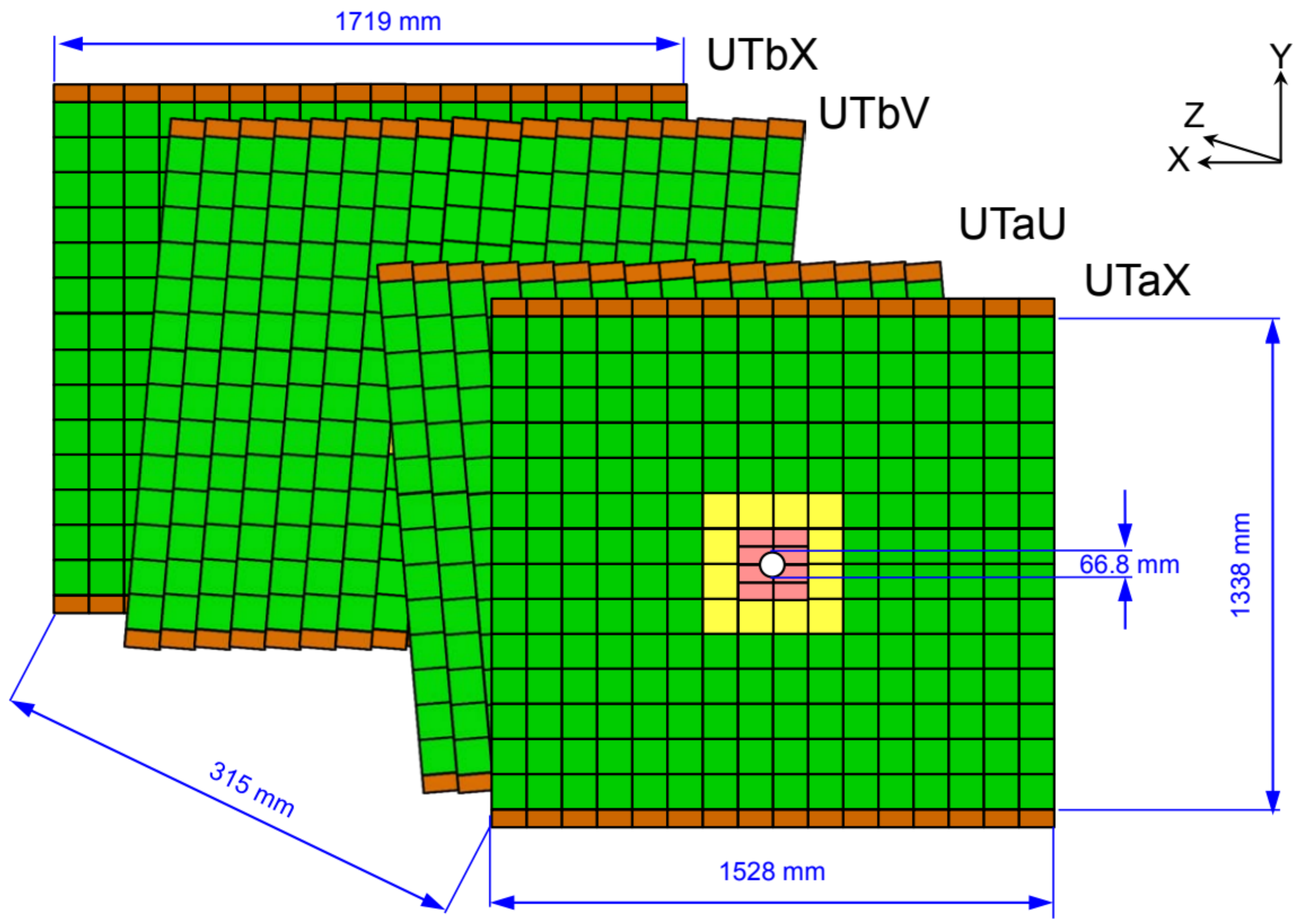

- "Quality" concatenation of 7 assembly processes, 9 metrology steps, 7 electrical tests



# Upstream Tracker: overview



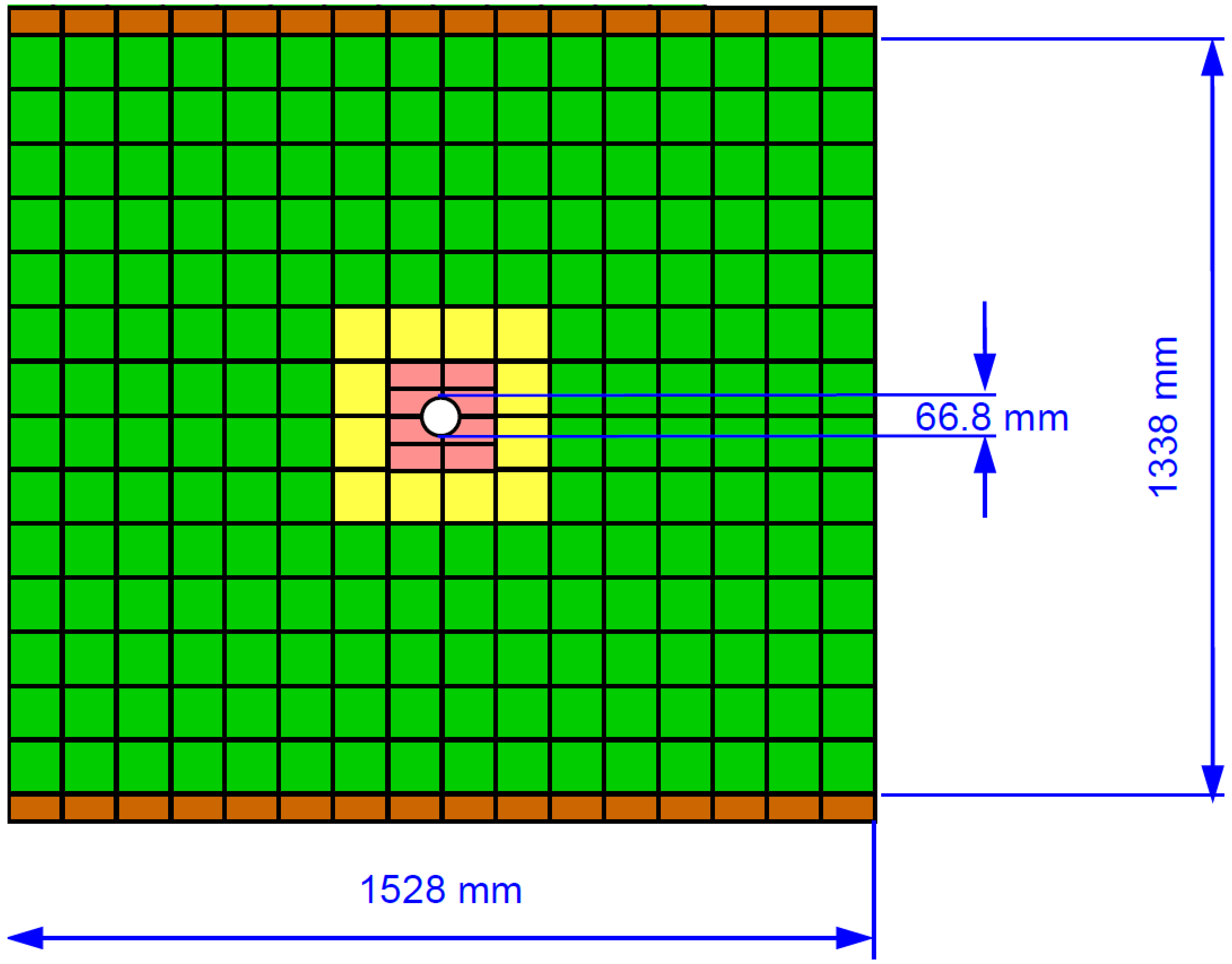


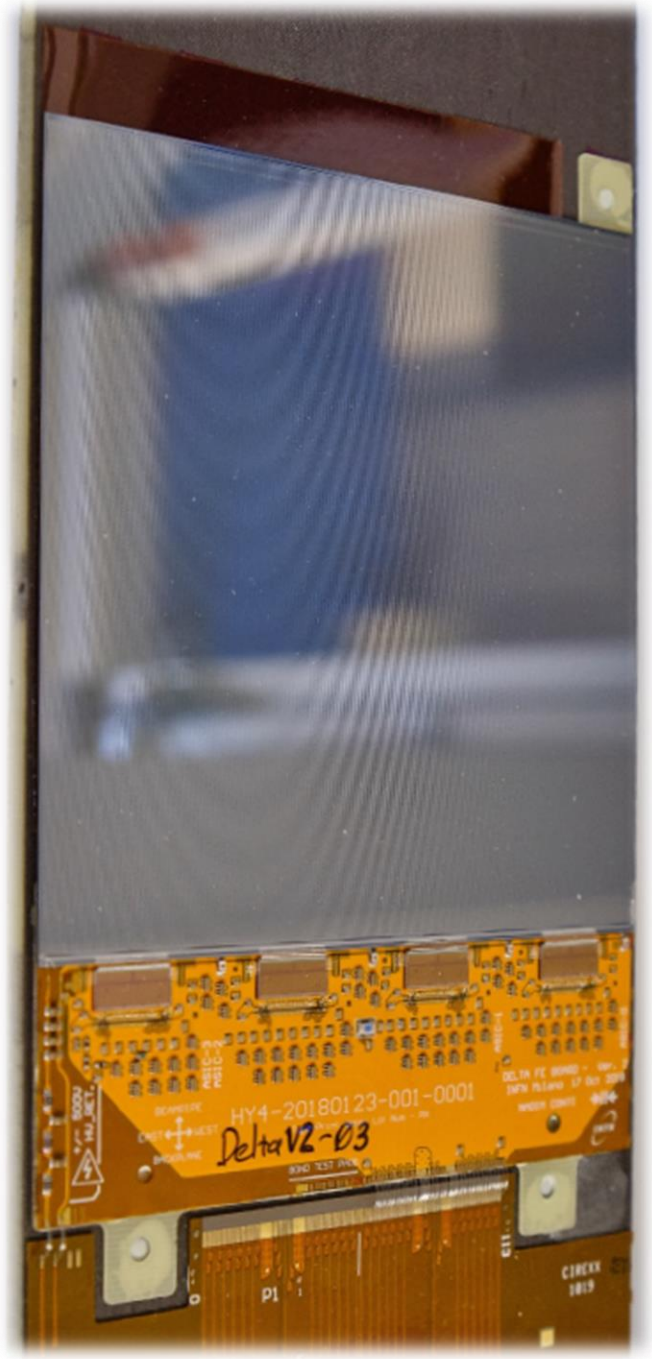

- ❑ Situated between VELO and dipole magnet
- ❑ Comprises four layers of silicon strips (to be compatible with TT)
- ❑ Greater performance: coverage, radiation hardness, 40 MHz readout, improved granularity
- ❑ Less material

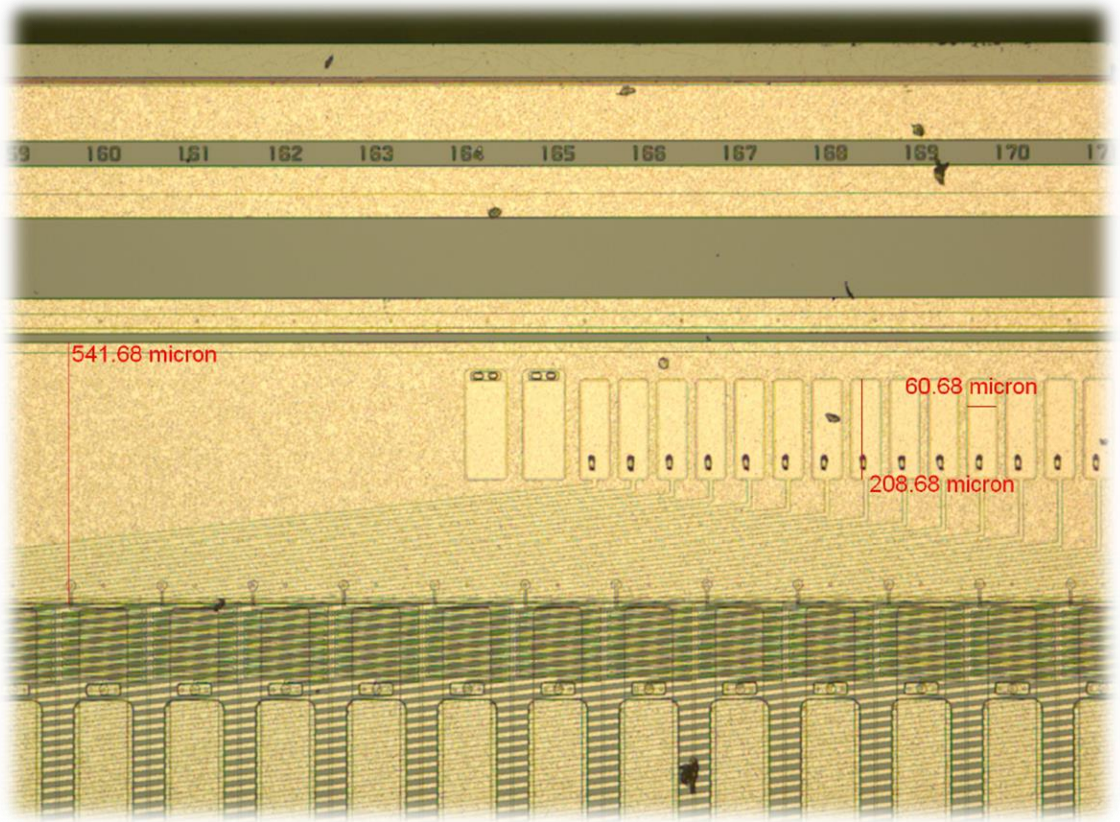
# Upstream Tracker: silicon sensors

| Sensor | Type | Pitch, µm | Length, mm | Strips | Sensor # |
|---|---|---|---|---|---|
| A | p-in-n | 187.5 | 98 | 512 | 888 |
| B | n-in-p | 93.5 | 98 | 1024 | 48 |
| C | n-in-p | 93.5 | 49 | 1024 | 16 |
| D | n-in-p | 93.5 | 49 | 1024 | 16 |

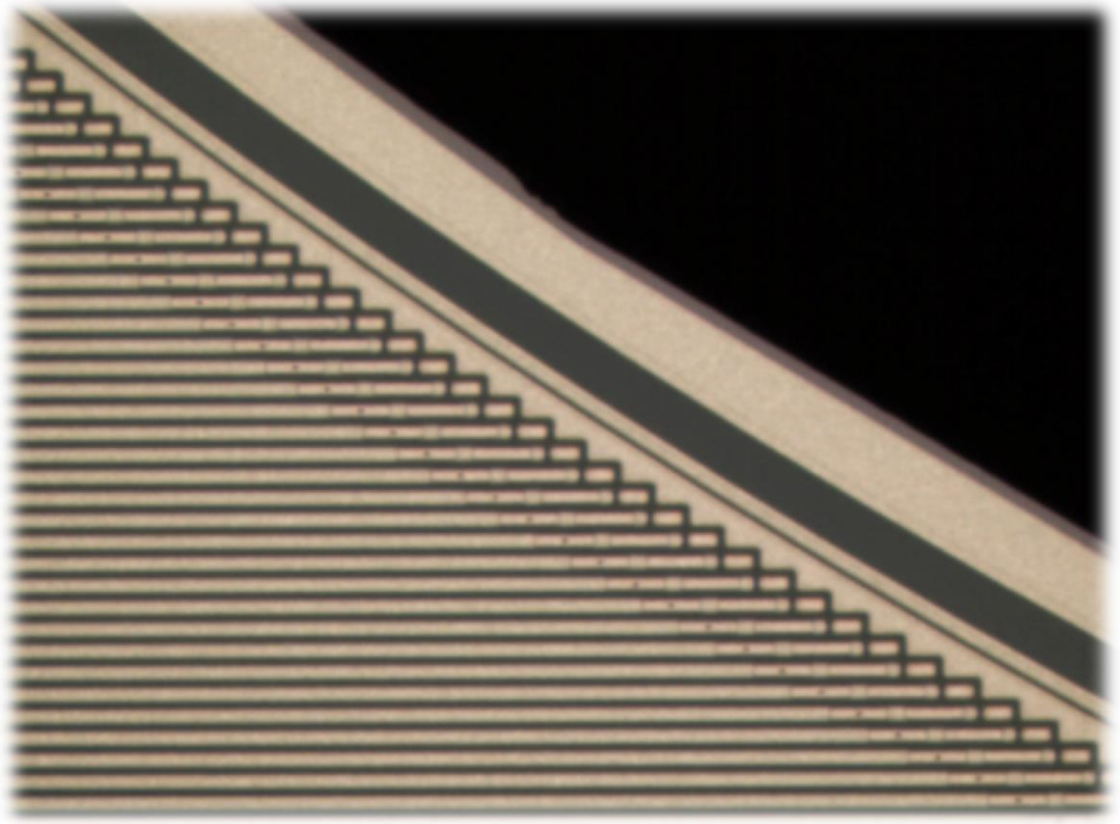
Four designs to optimize for granularity and cost effectiveness!



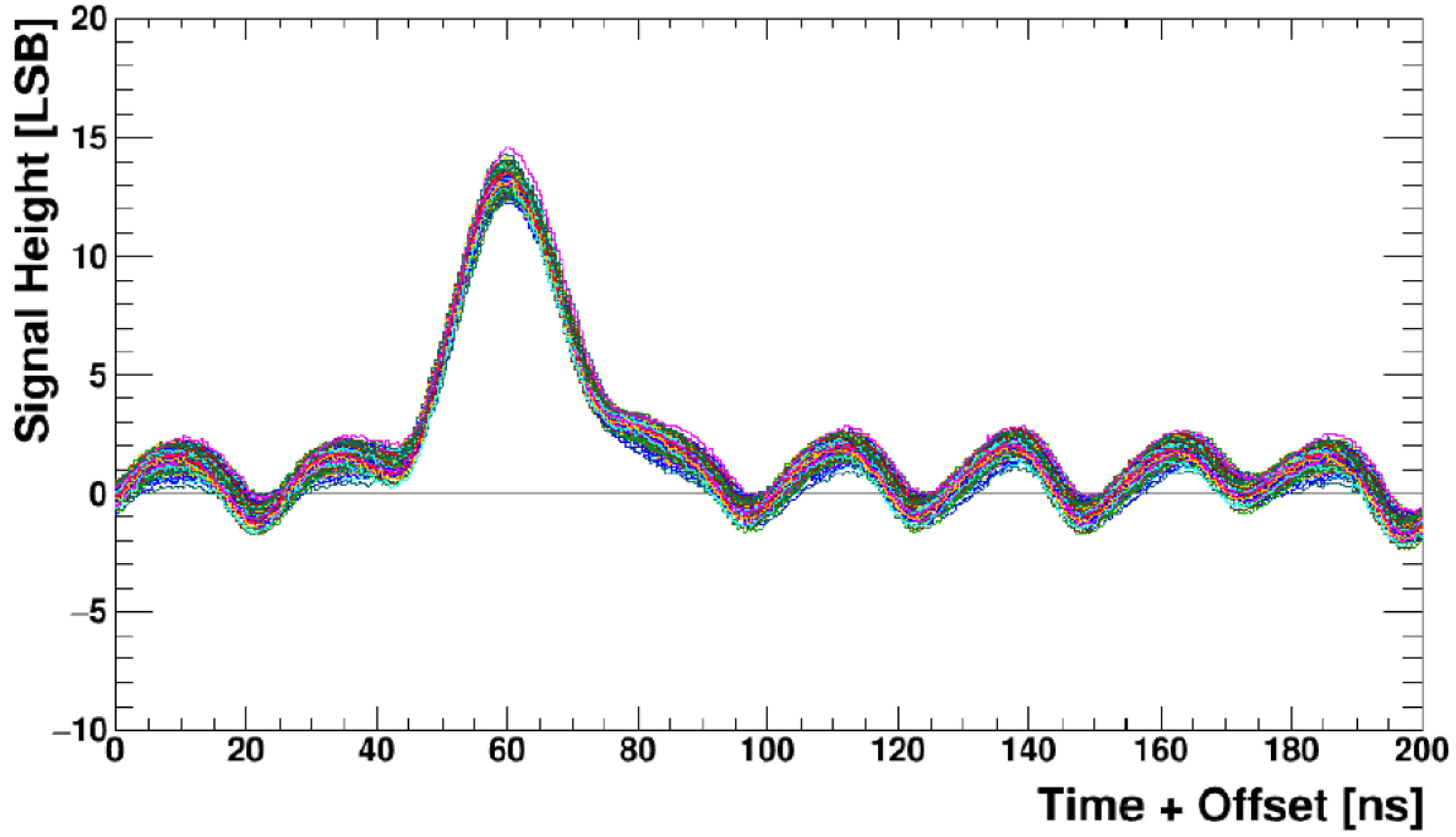

Embedded pitch adapters

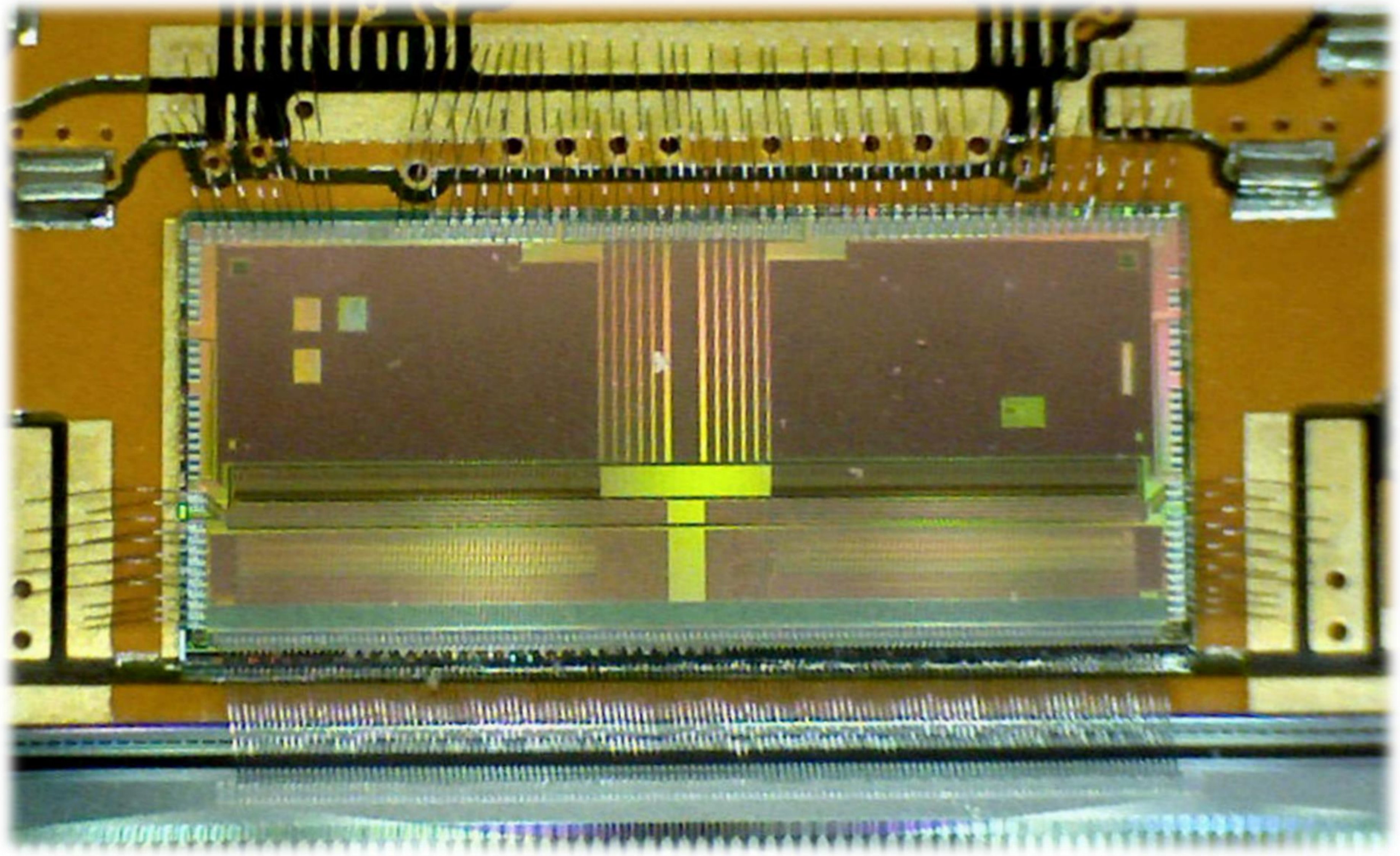


Circular cutout near the beamline

# Upstream Tracker: ASICs

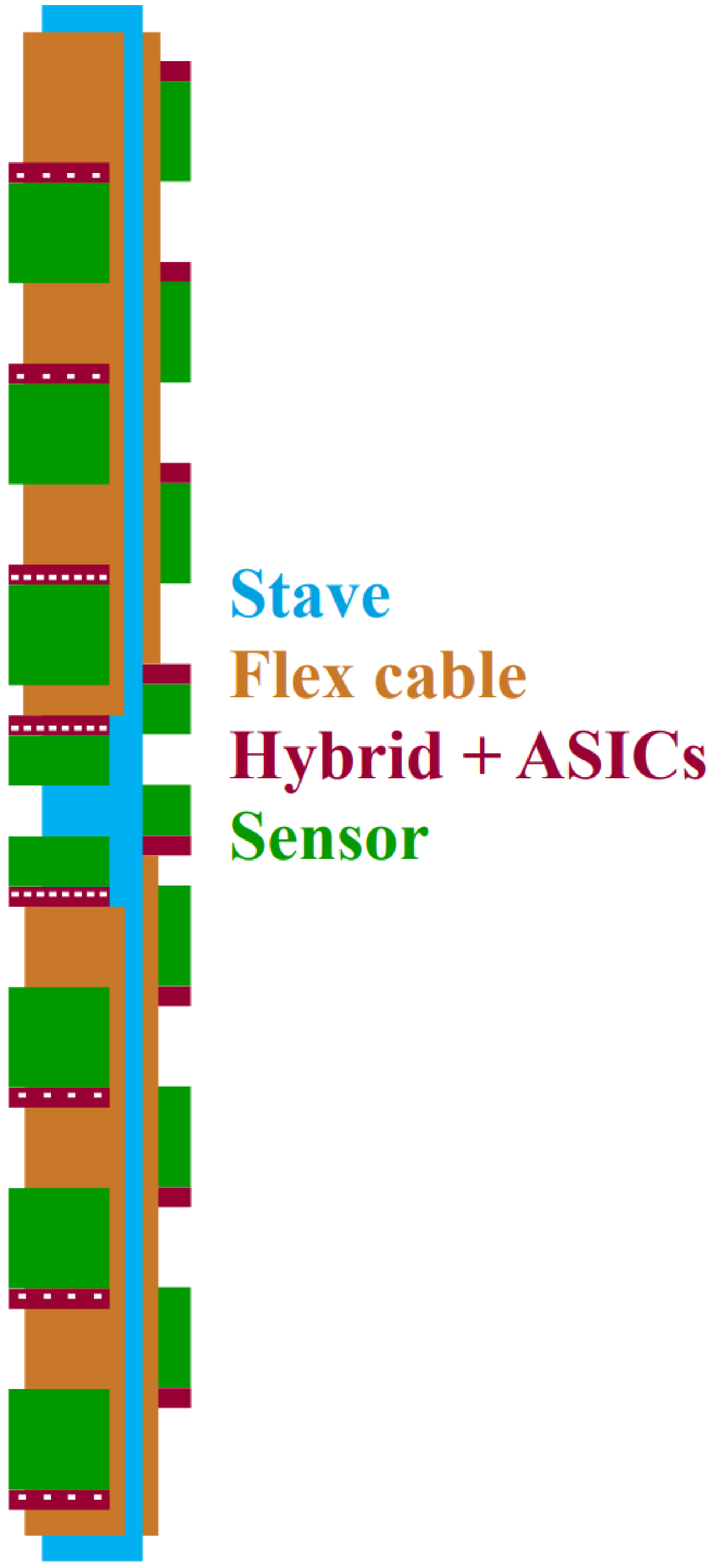
- ❑ 4192 ASICs with 128 channels each
- ❑ 130 nm-TSMC with 30 MRad radiation tolerance
- ❑ Wire-bonded to sensors
- ❑ Input pitch 80µm
- ❑ Allow for 40 MHz readout of UT
- ❑ Up to 5 SLVS e-links @ 320 Mbps



- ❑ Fast shaping
- ❑ 6-bit ADC
- ❑ On-chip memory

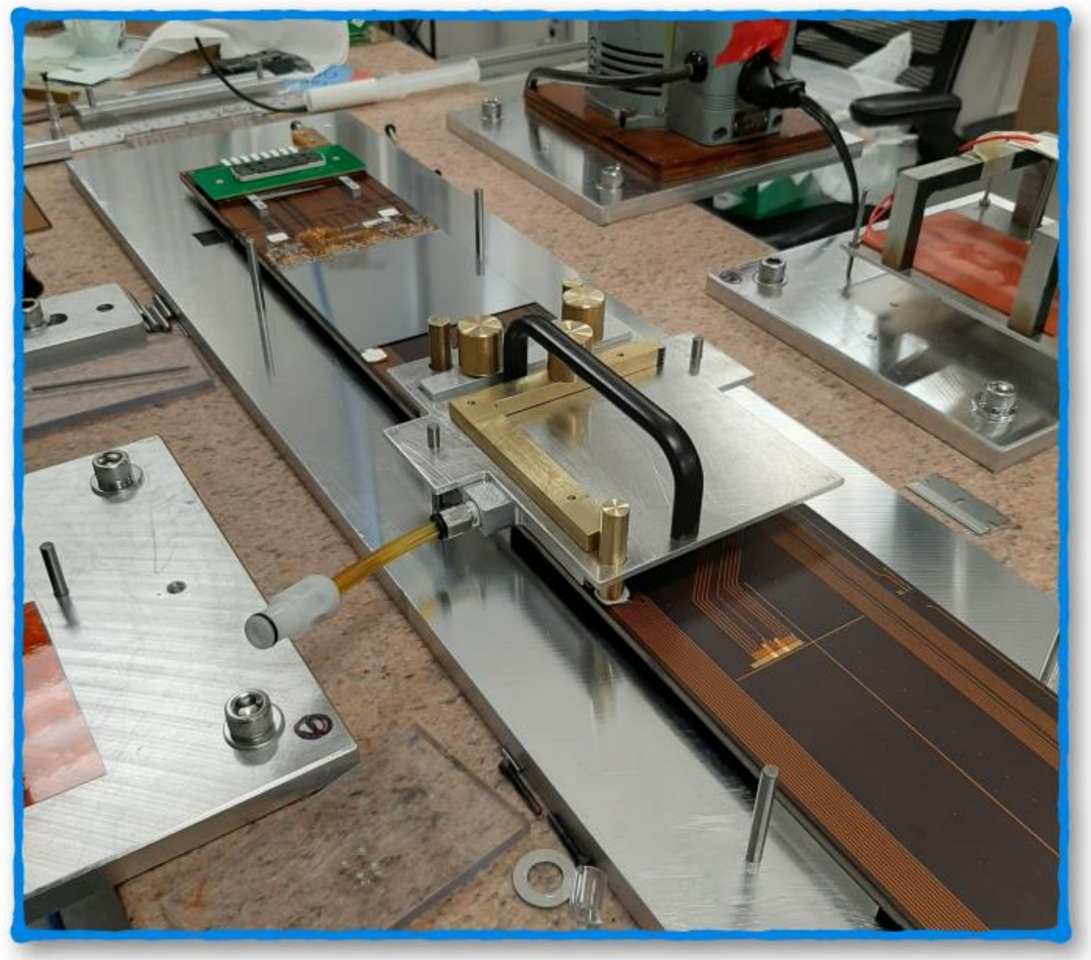
# Upstream Tracker: integration



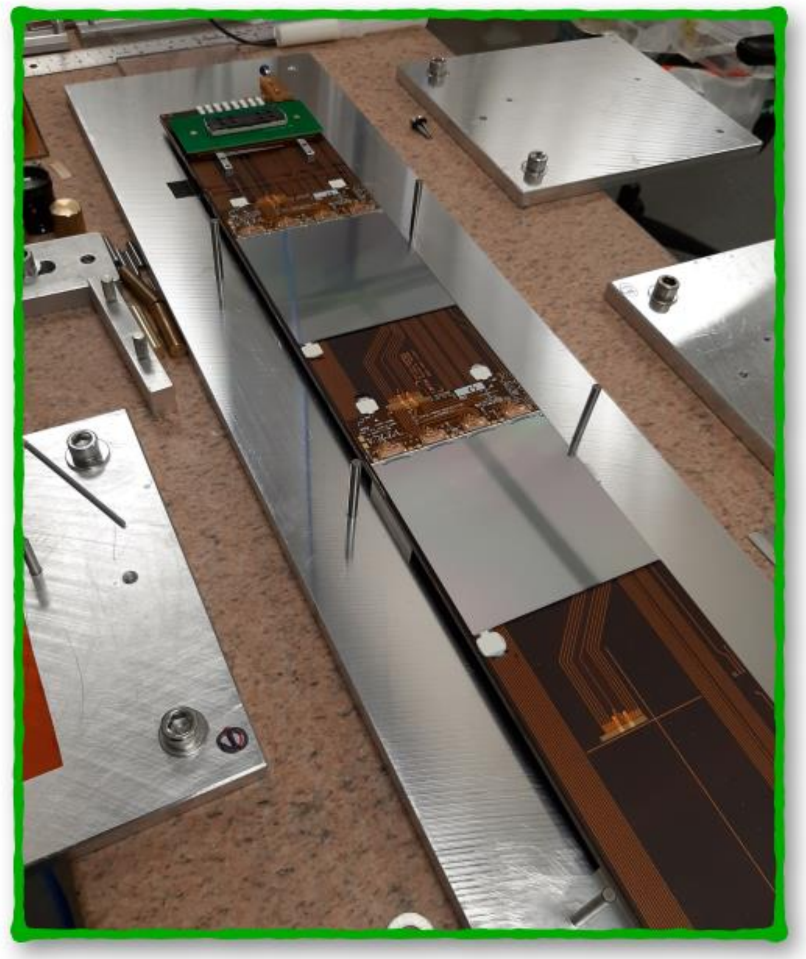

- Modules (hybrids+sensors) and flex cables are mounted onto a stave
- Low-mass support of 1.6 m x 10 cm
- Overlap between sensors on the front and back
- Integrated titanium pipe for $CO_2$ cooling

Stencil application of TIM, epoxy, silicone pedestal

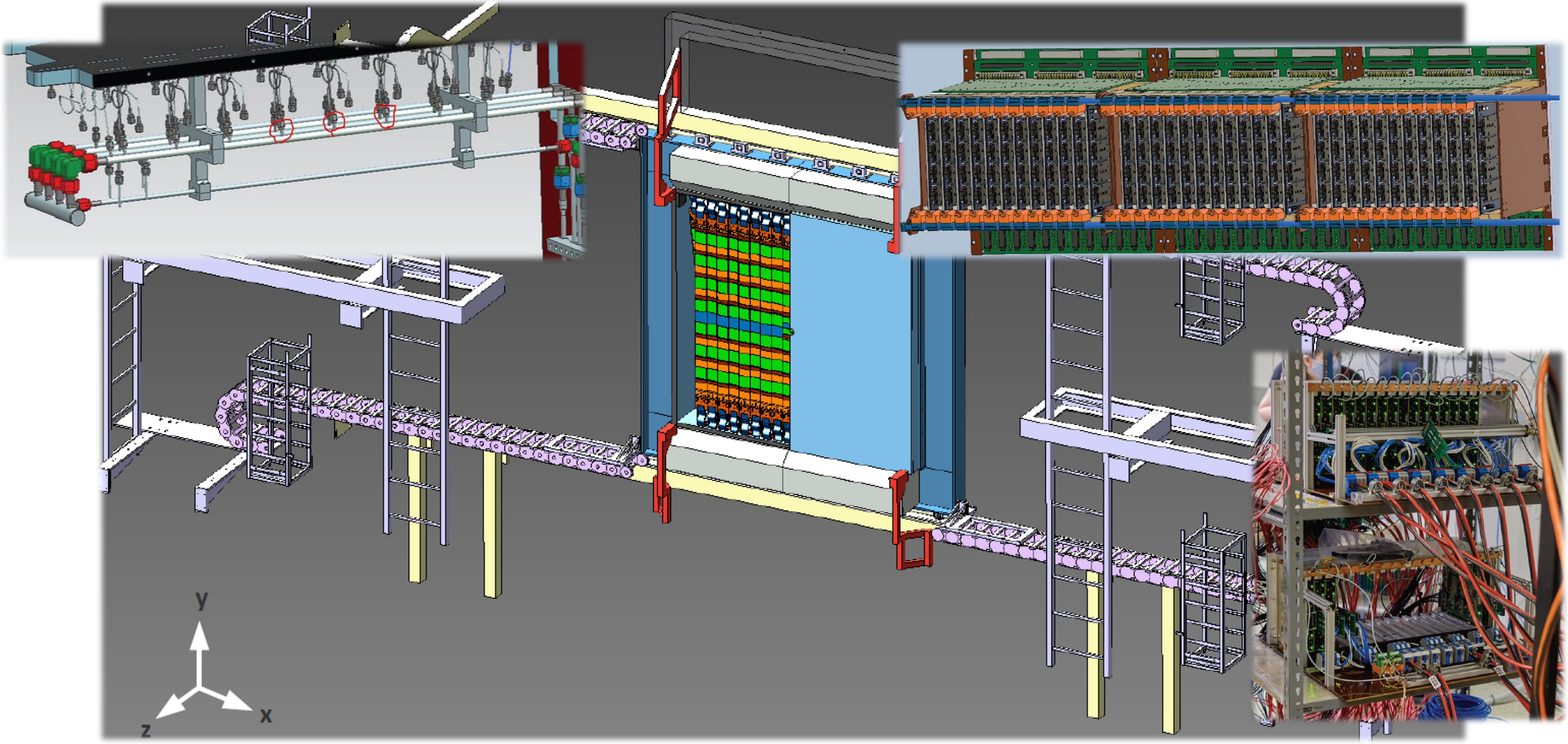
Heat TIM, place module, overnight curing



Another module on the stave!



# Upstream Tracker: integration



# Summary

- ❑ A huge upgrade is about to conclude: no more hardware trigger, better performance and longer expected lifetime
- ❑ VELO and UT persevered through the challenges and are in the final stages of production and installation

# Thank you!