ALICE ITS3: a bent stitched MAPS-based vertex detector

Ola Groettvik*
on behalf of the ALICE collaboration

TWEPP 2023
Topical Workshop on Electronics for Particle Physics
Geremeas, Sardinia, Italy

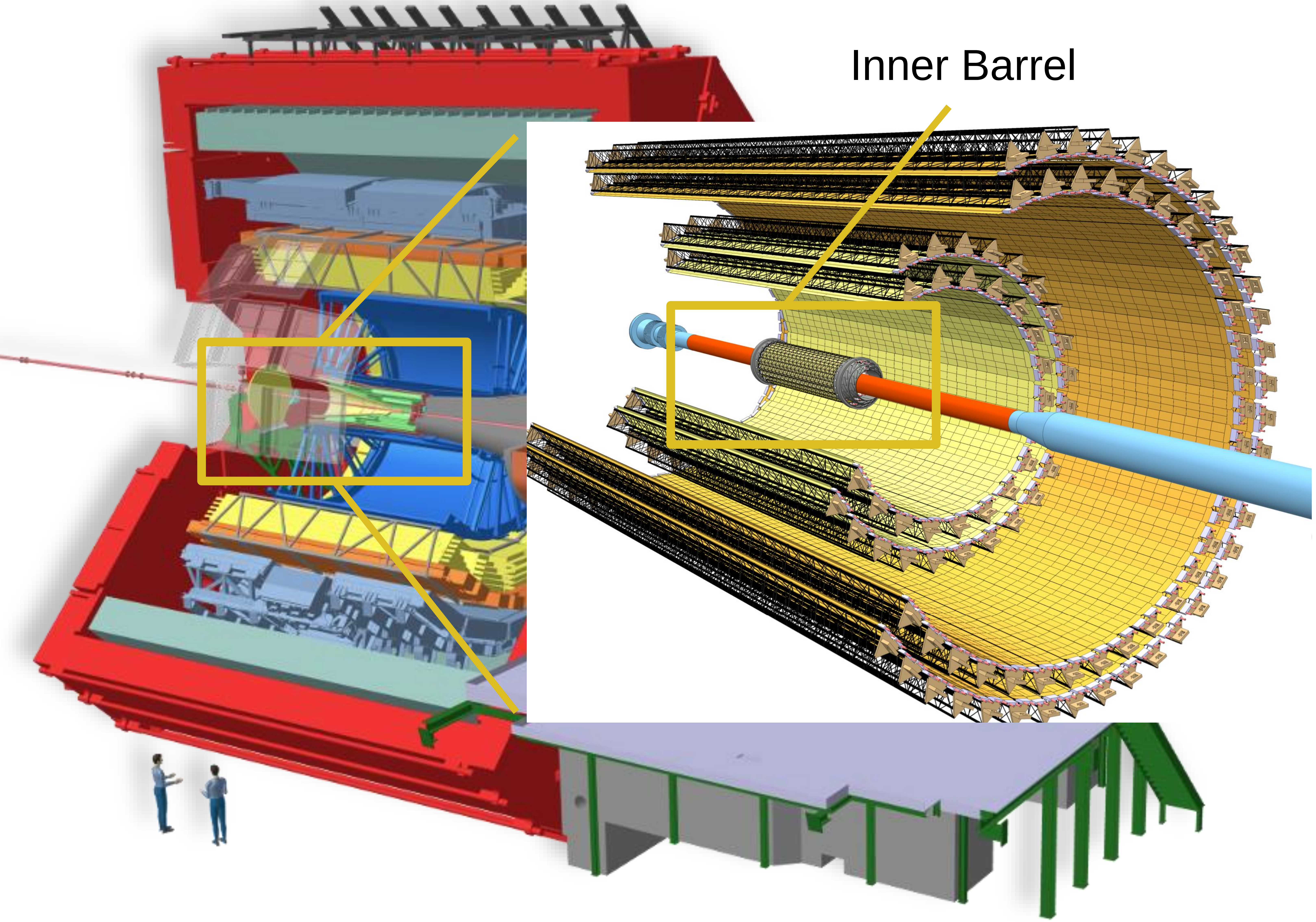
*ola.groettvik@cern.ch

Outline

- ALICE Inner Tracking System Introduction
- ITS3 Detector Overview and Concepts
- Sensor Developments
- Services and Integration

ALICE Inner Tracking System

Introduction



ITS2

- 7 layers
- 24k CMOS MAPS
- 12.5 Gigapixels
- 10 m^2

ITS3

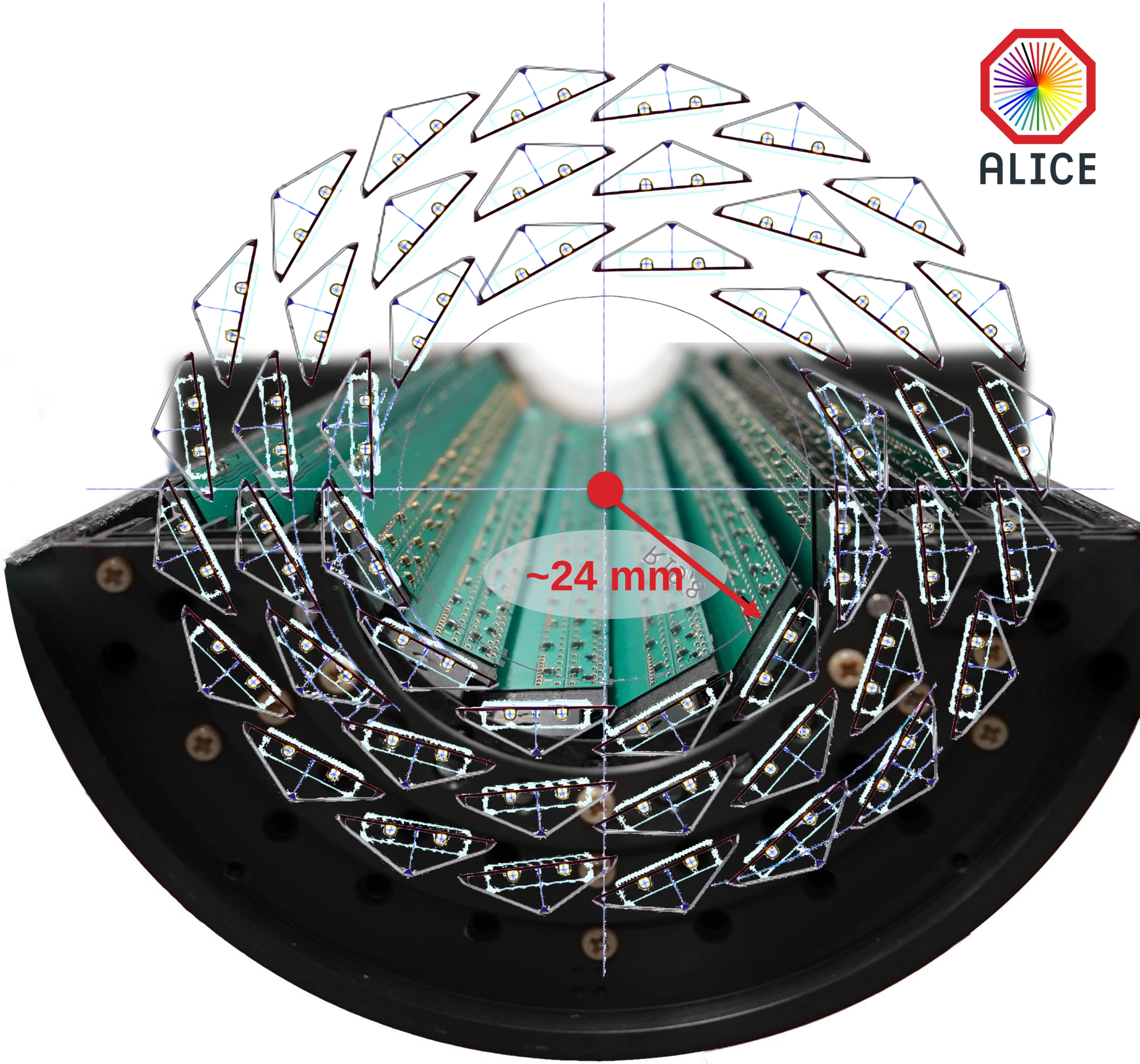
- Replacing the ITS2 Inner Barrel
- To be installed during LS3 (2026-2028)

Inner Tracking System 3

Motivation

What can we improve?

- Can the material be further reduced?
- Can we get closer to the interaction point?

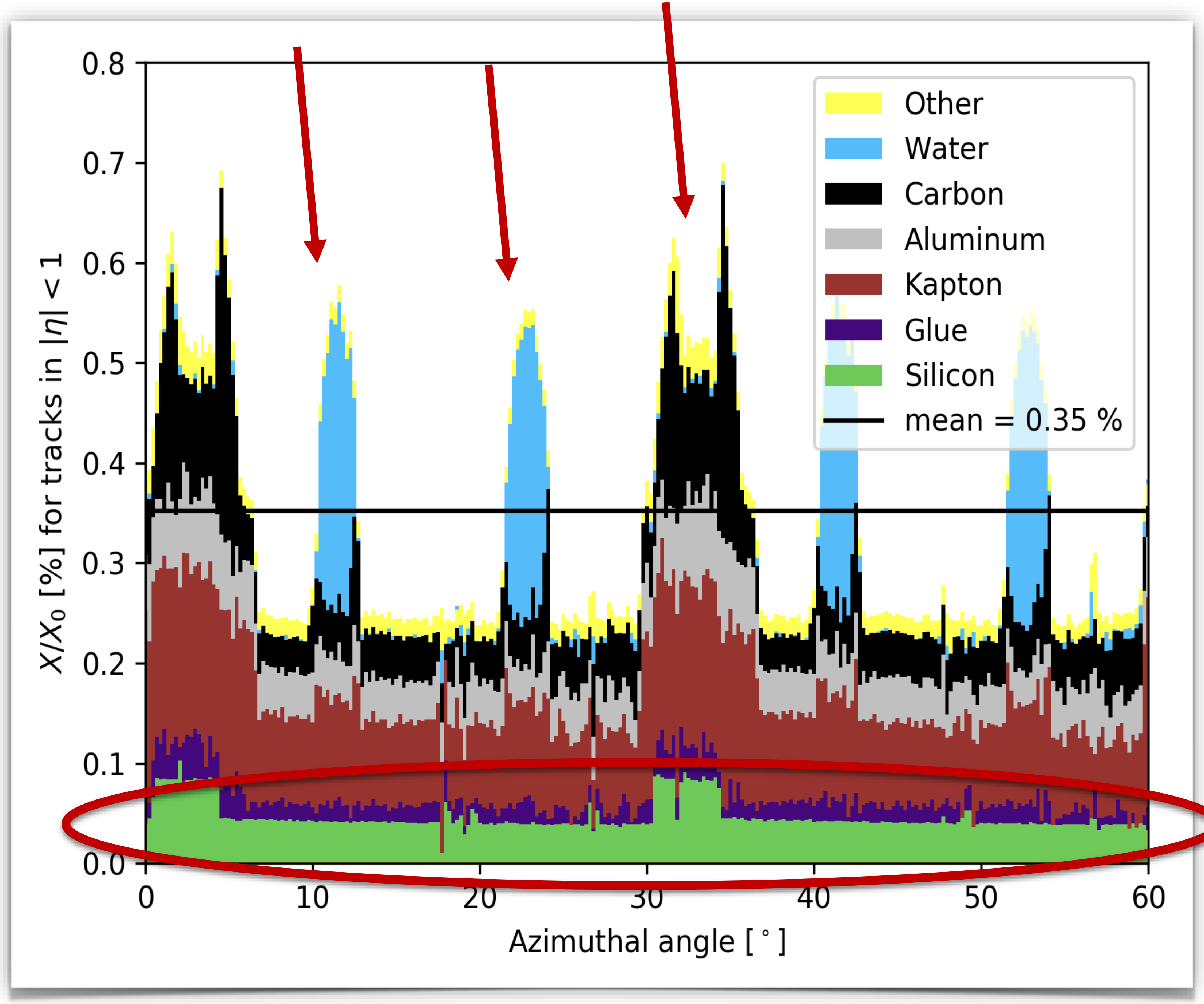


Inner Tracking System 3

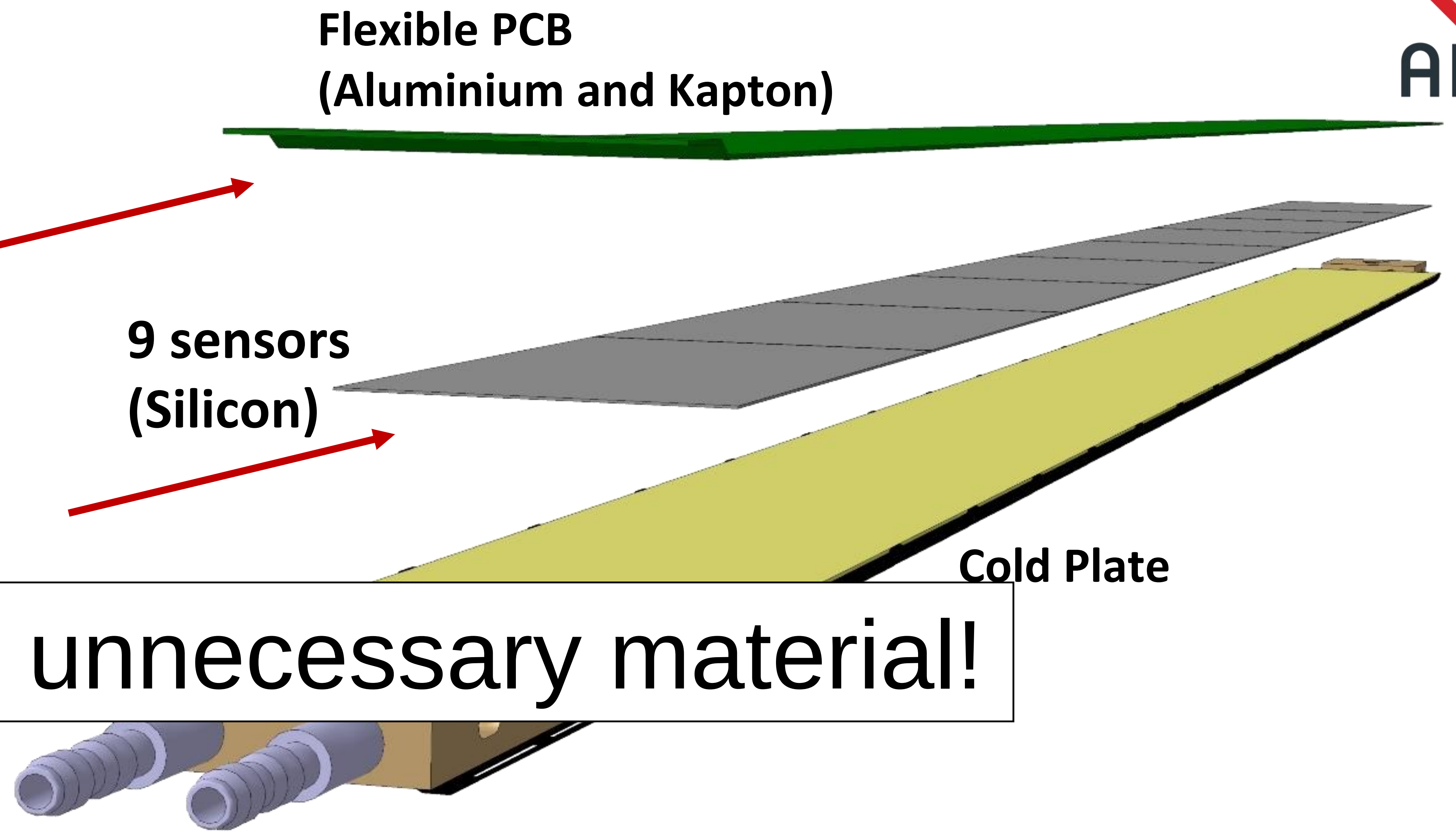
Motivation

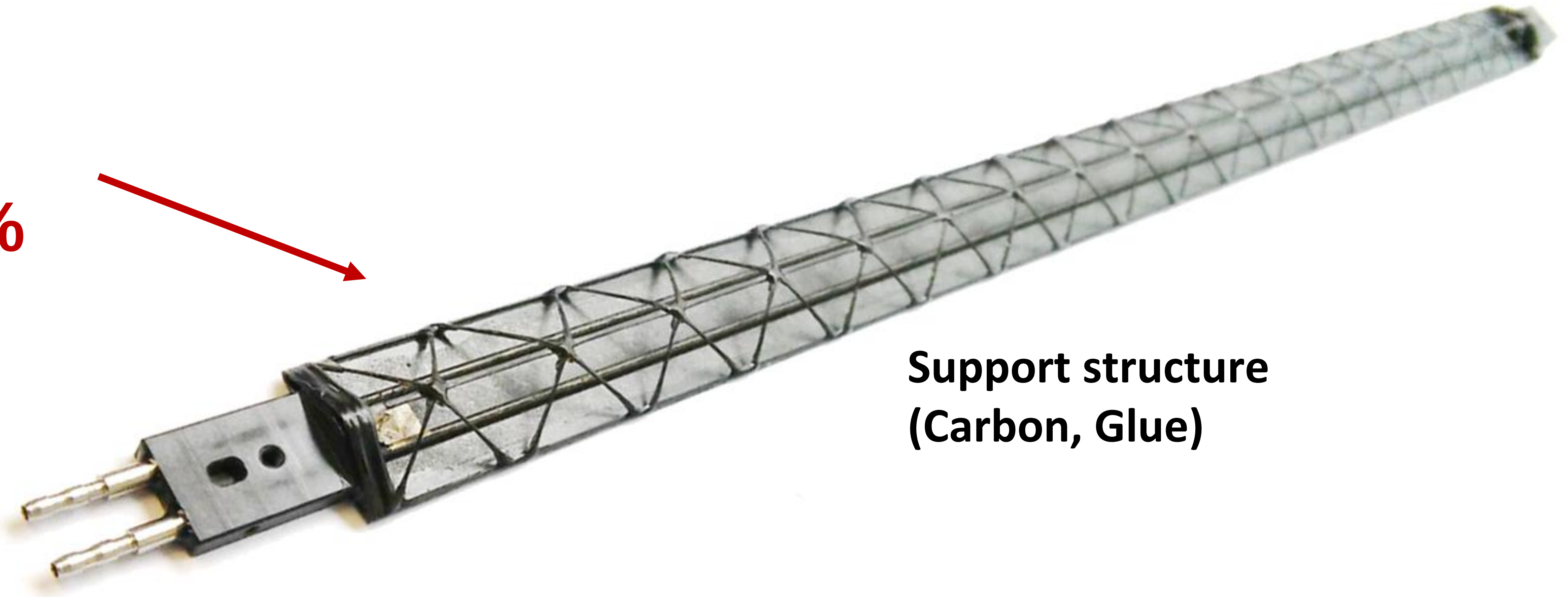
- Only 15% of total material is silicon
- Irregularities due to cooling and support structures
- Material degrades p

ITS3 removes almost all unnecessary material!



15 %



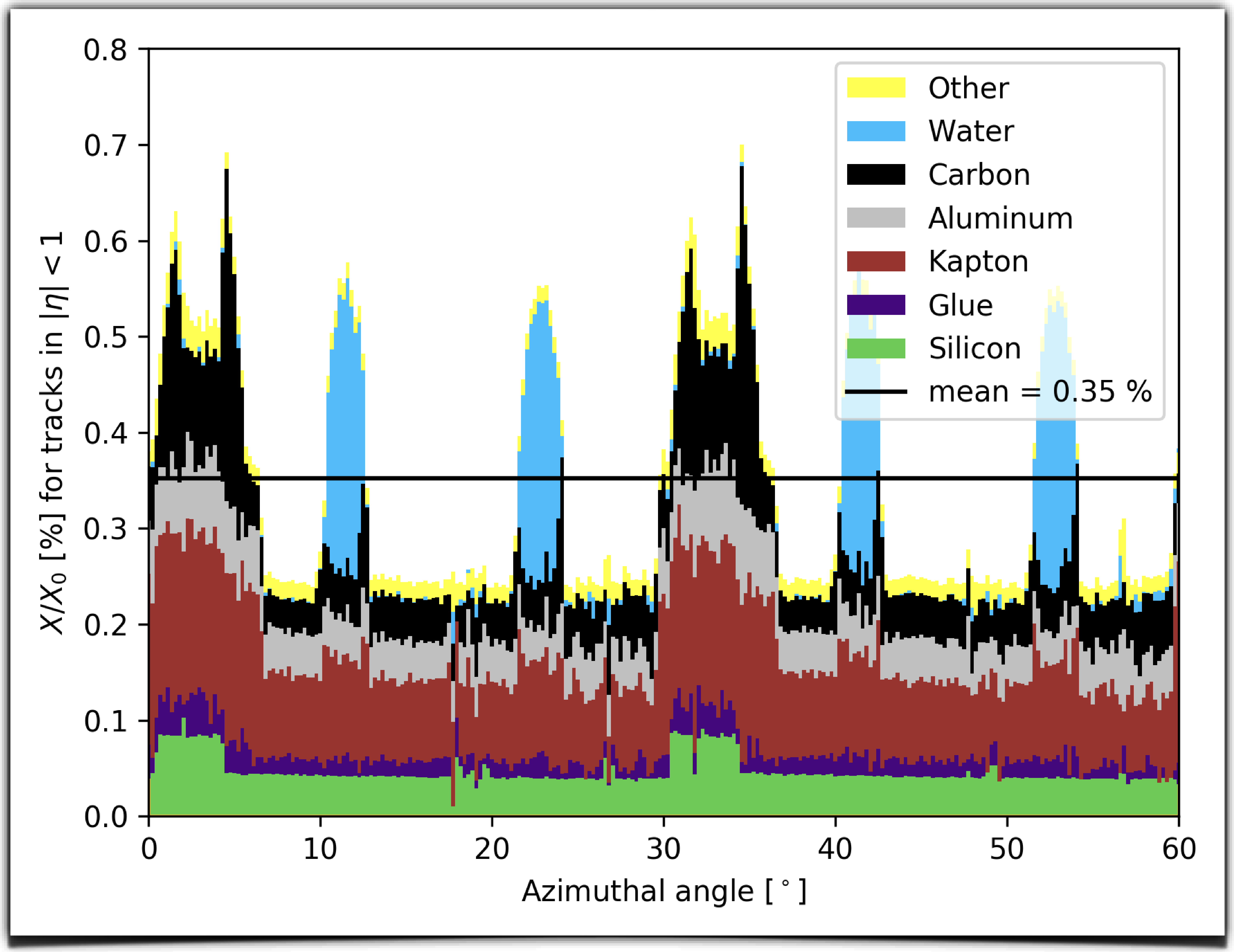


Inner Tracking System 3

Goals

- **How can we achieve it?**

- Remove water cooling
  - Air cooling
- Remove the circuit board
  - Integrate data, control and power distribution on chip
- Removal of mechanical support
  - Self-supported arched structure

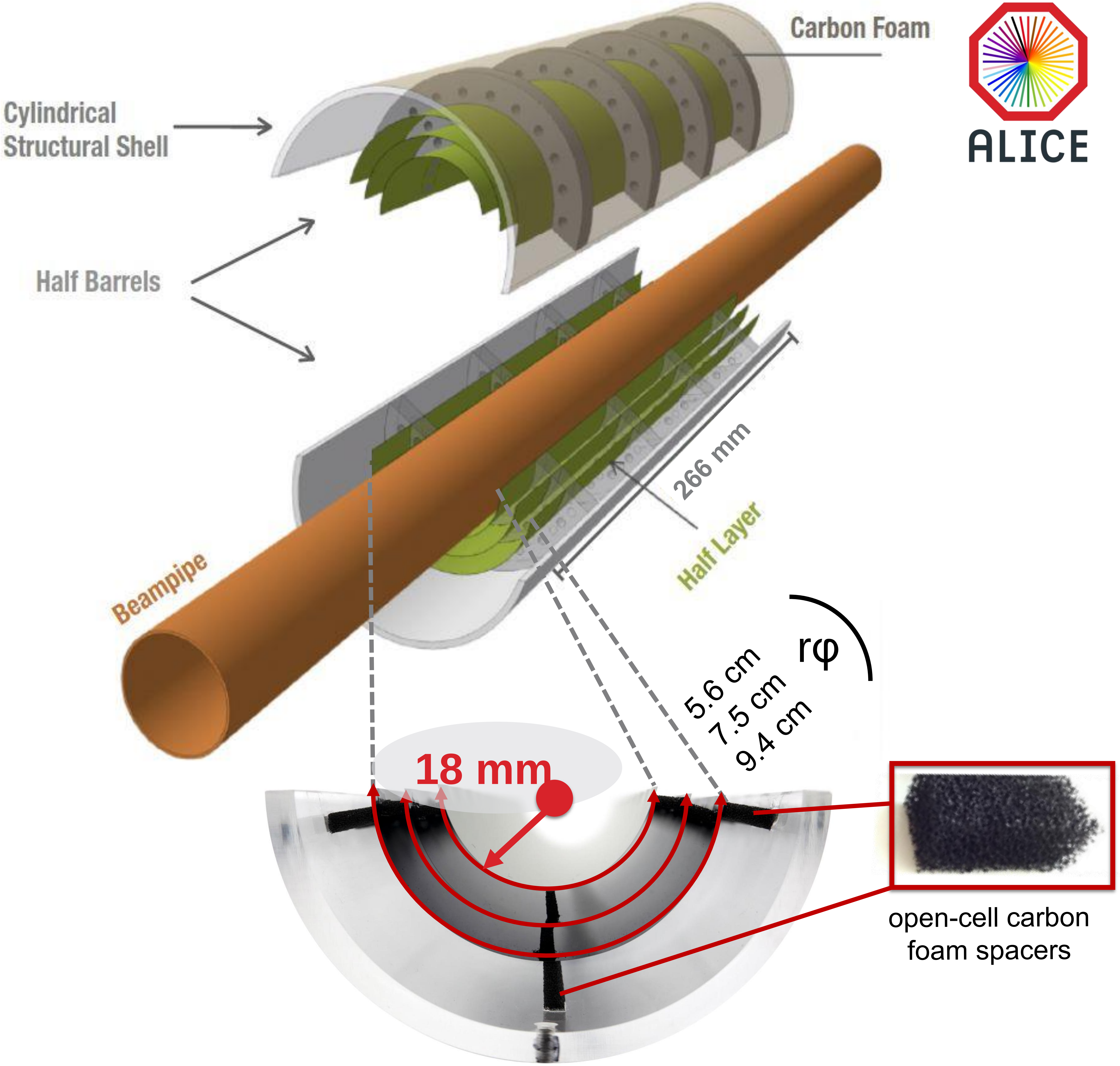


Inner Tracking System 3

Detector Overview

- Wafer-scale sensor ASICs
- Fabricated with stitching
- All electrical signals and power routed on-chip
- Ultra-thin and bendable: 50 µm
- 266 mm (Z) x variable width* (rφ)
- CMOS MAPS
  - 65 nm technology
- Open-cell carbon foam spacers

- Key benefits
  - Extremely lightweight
    - Material budget: 0.35% X_0 => 0.05% X_0
  - Uniformly distributed material
  - Closer to interaction point
    - Beam pipe radius: 18.2 mm => 16 mm
    - Radial position: 24 mm => 18 mm



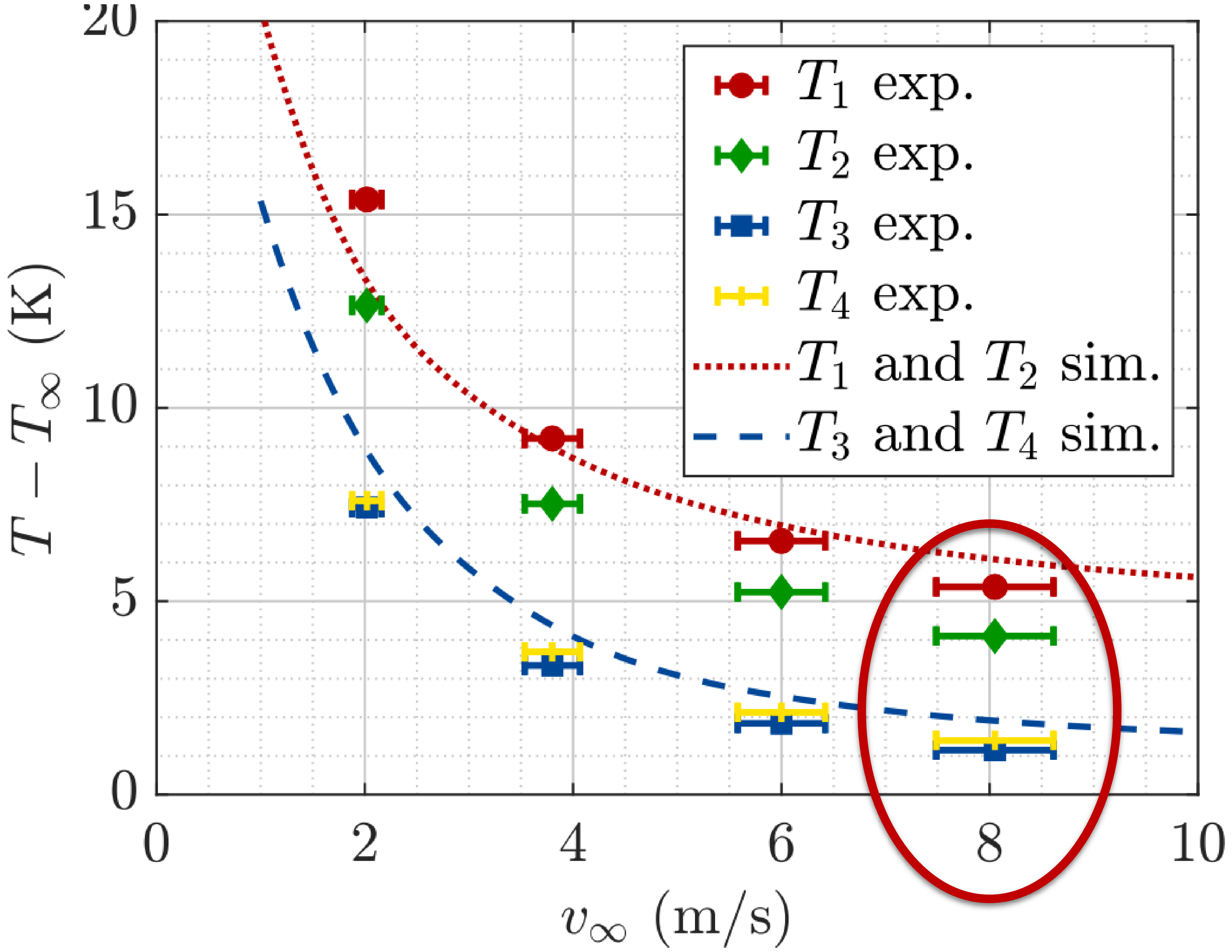
---

* The sensor width (rφ) varies with layer

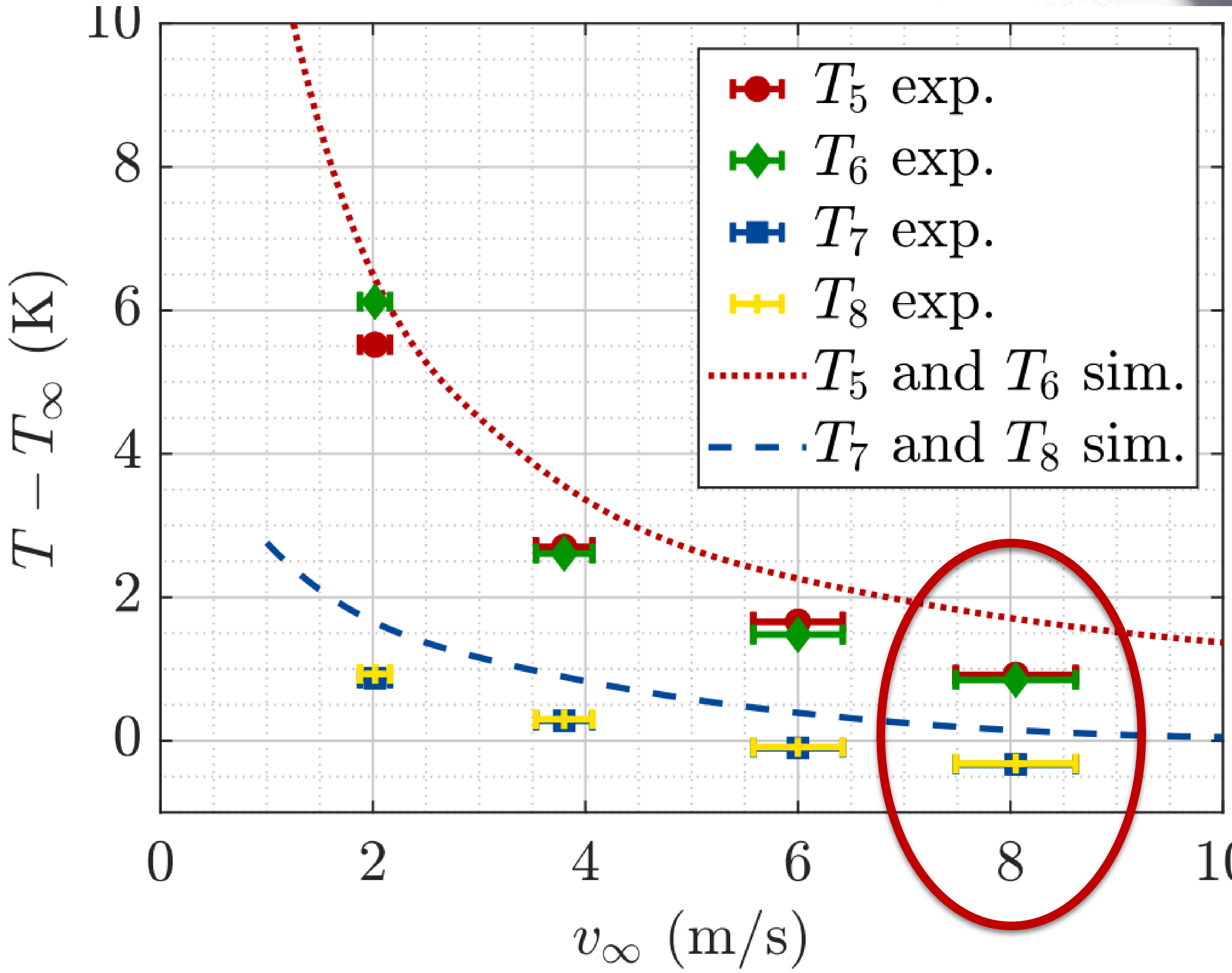
Detector concept

Cooling

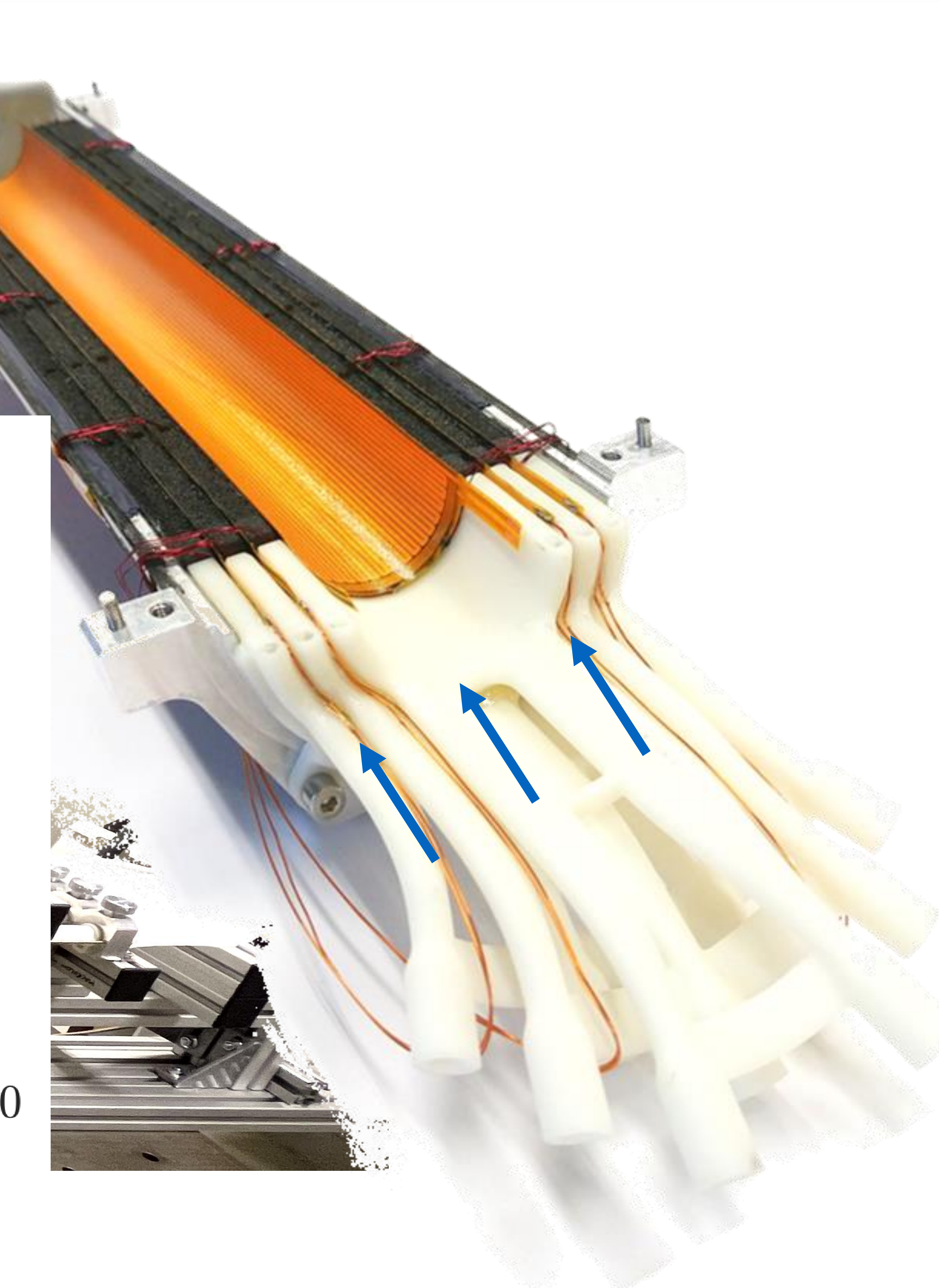
- Effects of air cooling is investigated in detail
  - Breadboard model
  - Wind-tunnel test setup
- Maximum vibrational level measured within +/- 0.5 µm
- Detector can be operated at 5 ºC above inlet air temperature



(b) Layer 0 - Endcap



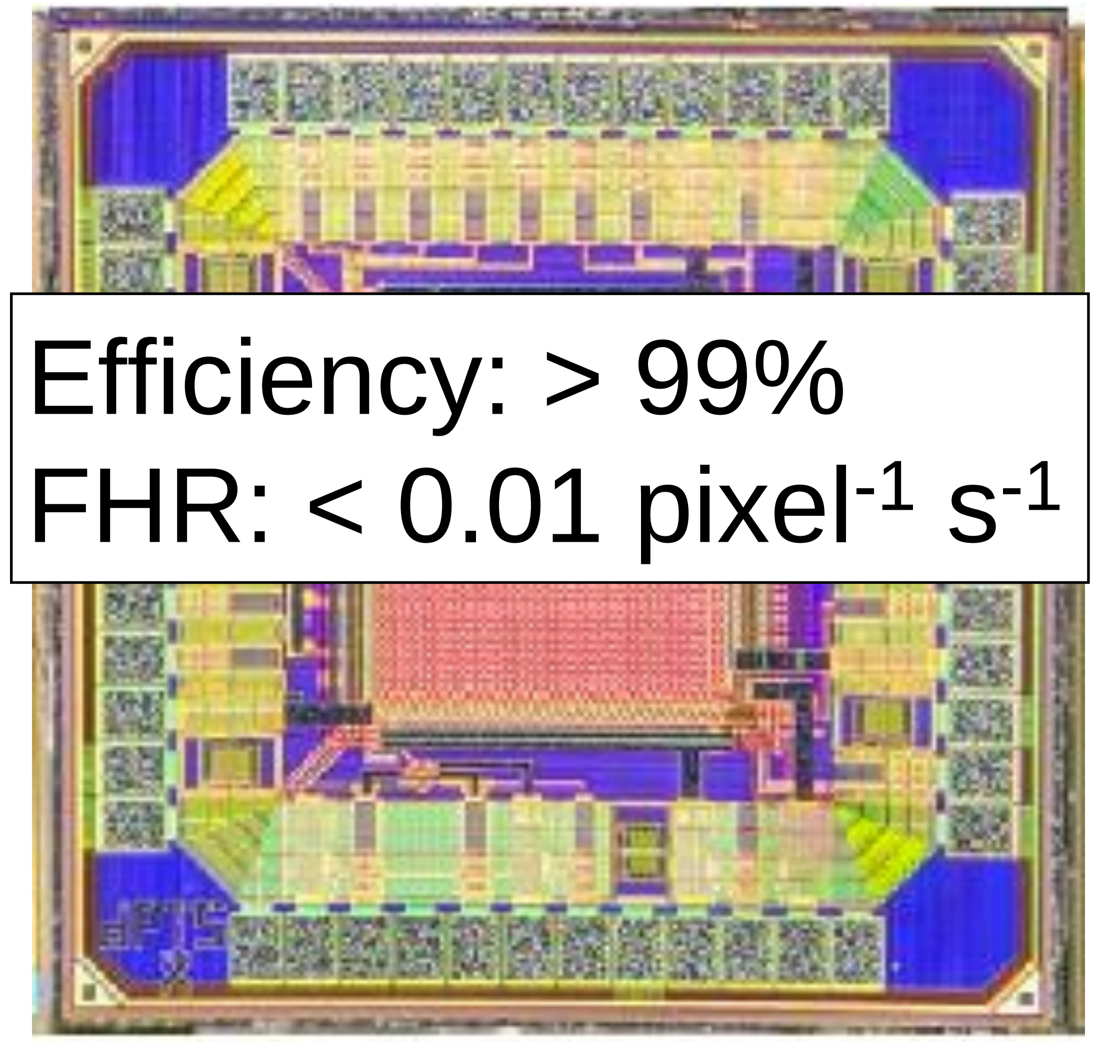
(c) Layer 0 - Matrix



Sensor developments

Early R&D and first stitching prototype (ER1/MOSS)

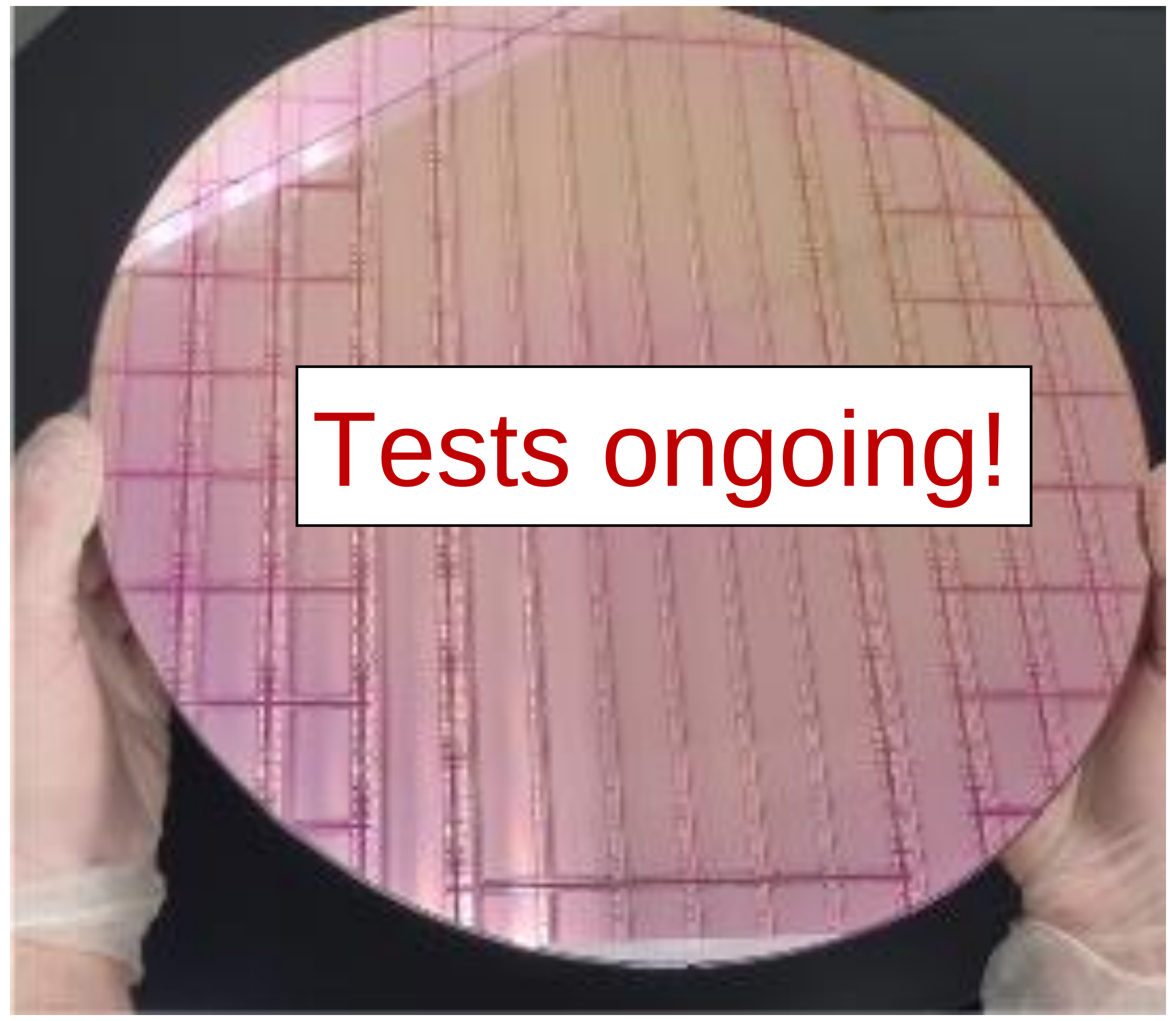
2021	2022	2023	2024	2025	2026	2027	2028	2029
RUN3					LS3			RUN4
MLR1		ER1 **MOSS**	ER2 **MOSAIX**	Final sensor	Installation and commissioning			


Efficiency: > 99%
FHR: < 0.01 pixel^{-1} s^{-1}

65 nm CMOS process
- Digital and analog test structures
- Detection efficiency measurements


Efficiency agnostic to bending radius

Bent MAPS
Demonstrated operation and detector efficiency


Tests ongoing!

Stitching
- **MOSS:** a complete sensor
- Investigate performance
- Assess yield

More @ TWEPP:
- G. Rinella: The Monolithic Stitched Sensor (MOSS) Prototype for the ALICE ITS3 and First Test Results
- C. Lemoine: Prototype measurement results in a 65nm technology and TCAD simulations towards more radiation tolerant monolithic pixel sensors
- C. Ferrero: Validation of the 65 nm TPSCo CMOS imaging technology for the ALICE ITS3

Sensor developments

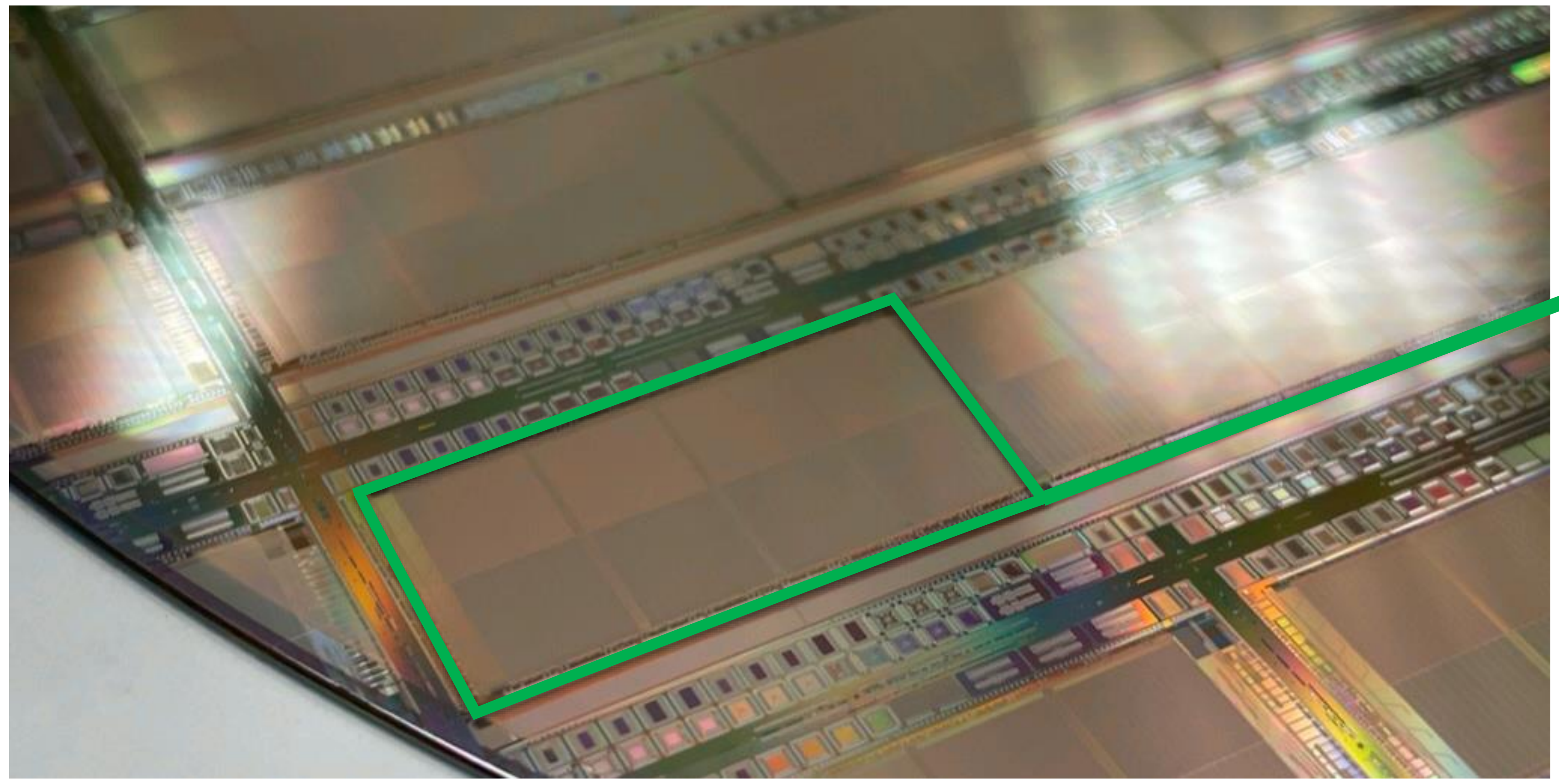
Engineering Run 2: towards a complete sensor (MOSAIX)

Layer 0: 12 x 3 rows

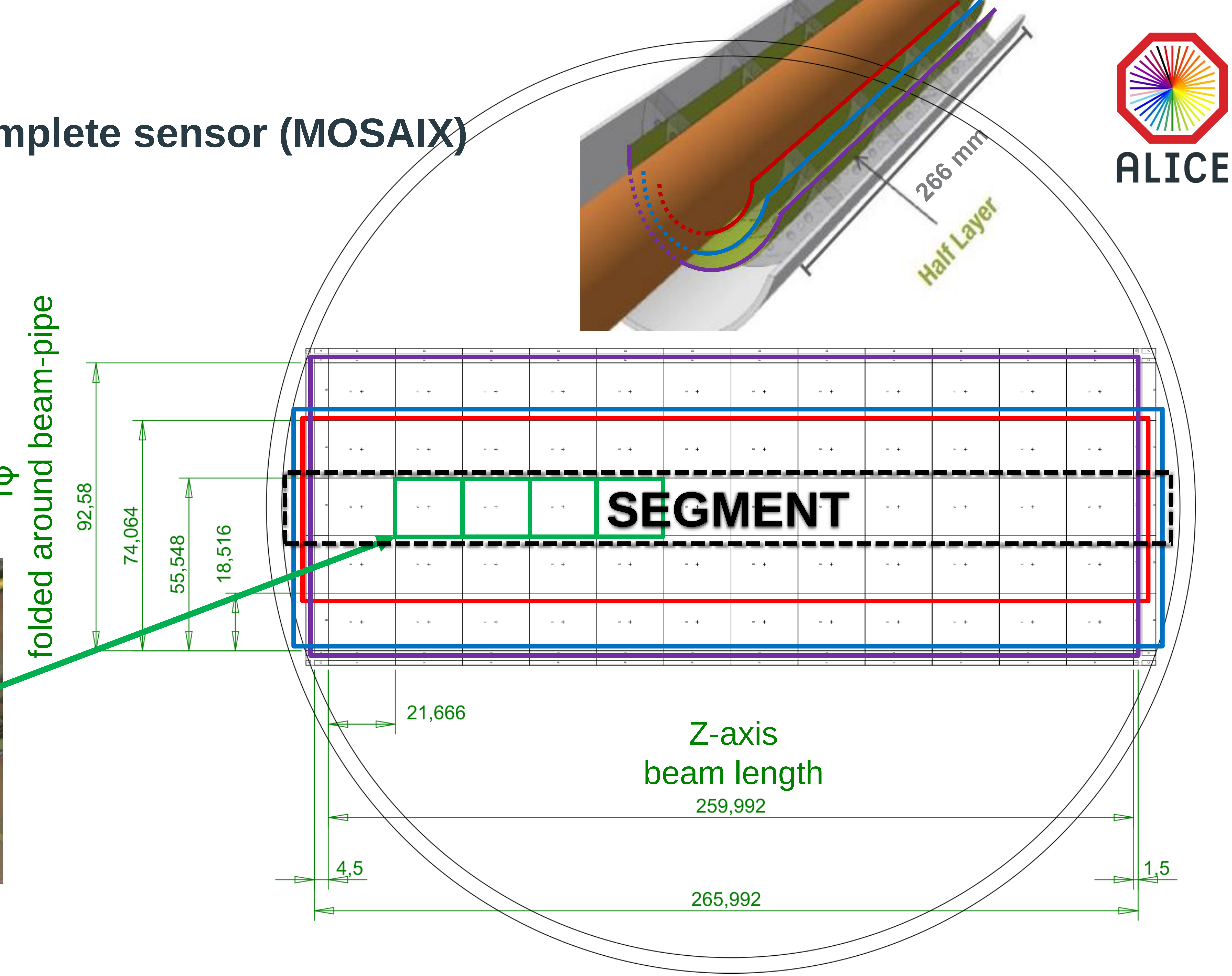
Layer 1: 12 x 4 rows

Layer 2: 12 x 5 rows

🟩 Repeated (Stitched) Sensor Unit



*Illustrates repeatable unit on ER1 (MOSS)



More @ TWEPP:
- M. Rodriguez: Model and analysis of the data readout architecture for the ITS3 ALICE Inner Tracker System
- P. Dorosz: Development of the data transmission architecture of the stitched sensor prototype towards the ALICE ITS3 upgrade
- V. Gromov: Prototype of a 10.24Gbps Data Serializer and Wireline Transmitter for the readout of the ALICE ITS3 detector

Sensor developments

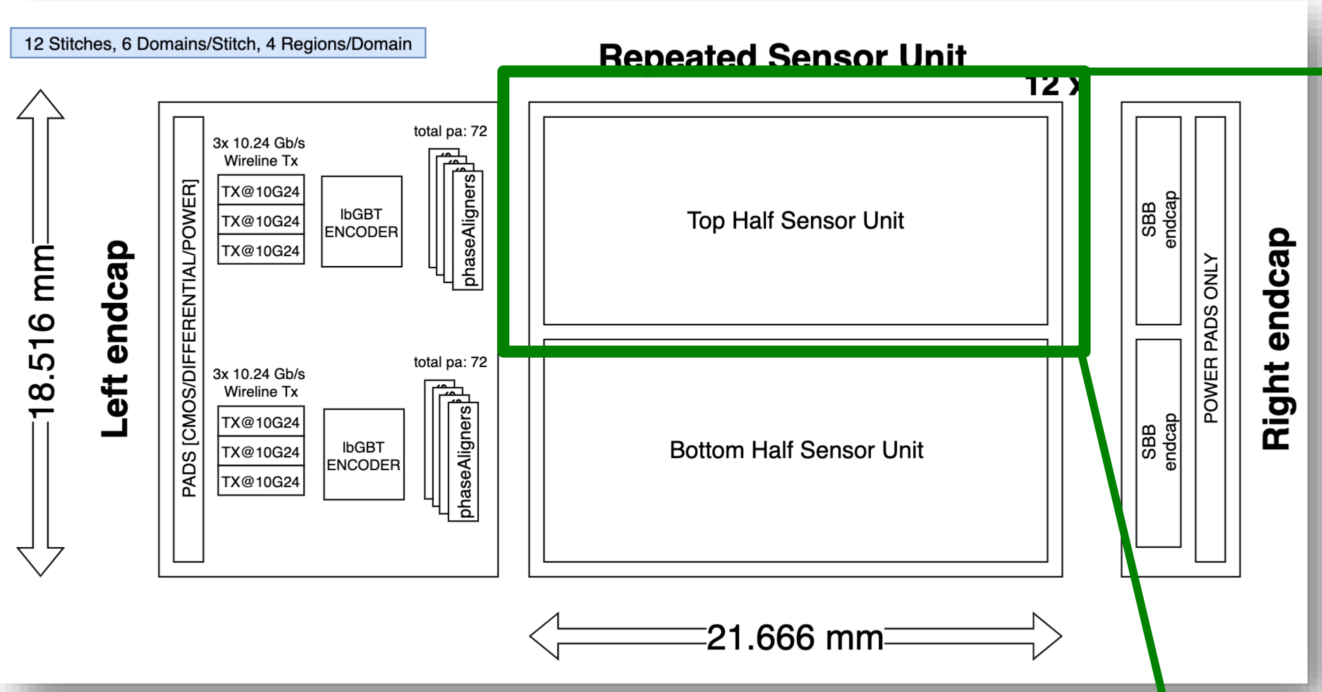
Engineering Run 2: towards a complete sensor (MOSAIX)

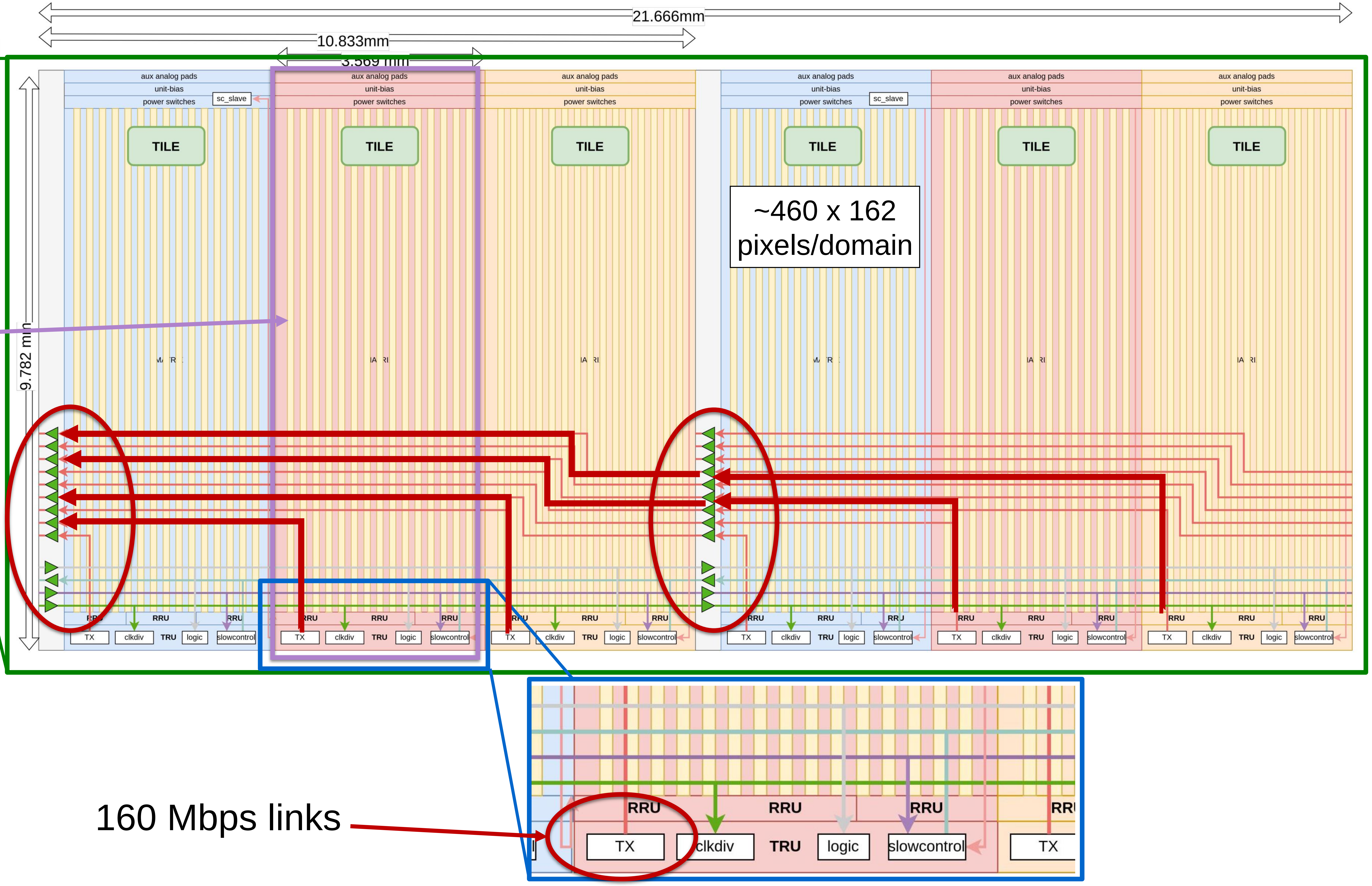
- 3 sub-designs:
  - REC
  - LEC
  - RSU
- Stitched backbone:
  - Power distribution
  - Control and data readout

Power and data carried via stitched backbone (27 cm!)

Sensor developments

Engineering Run 2: towards a complete sensor (MOSAIX)



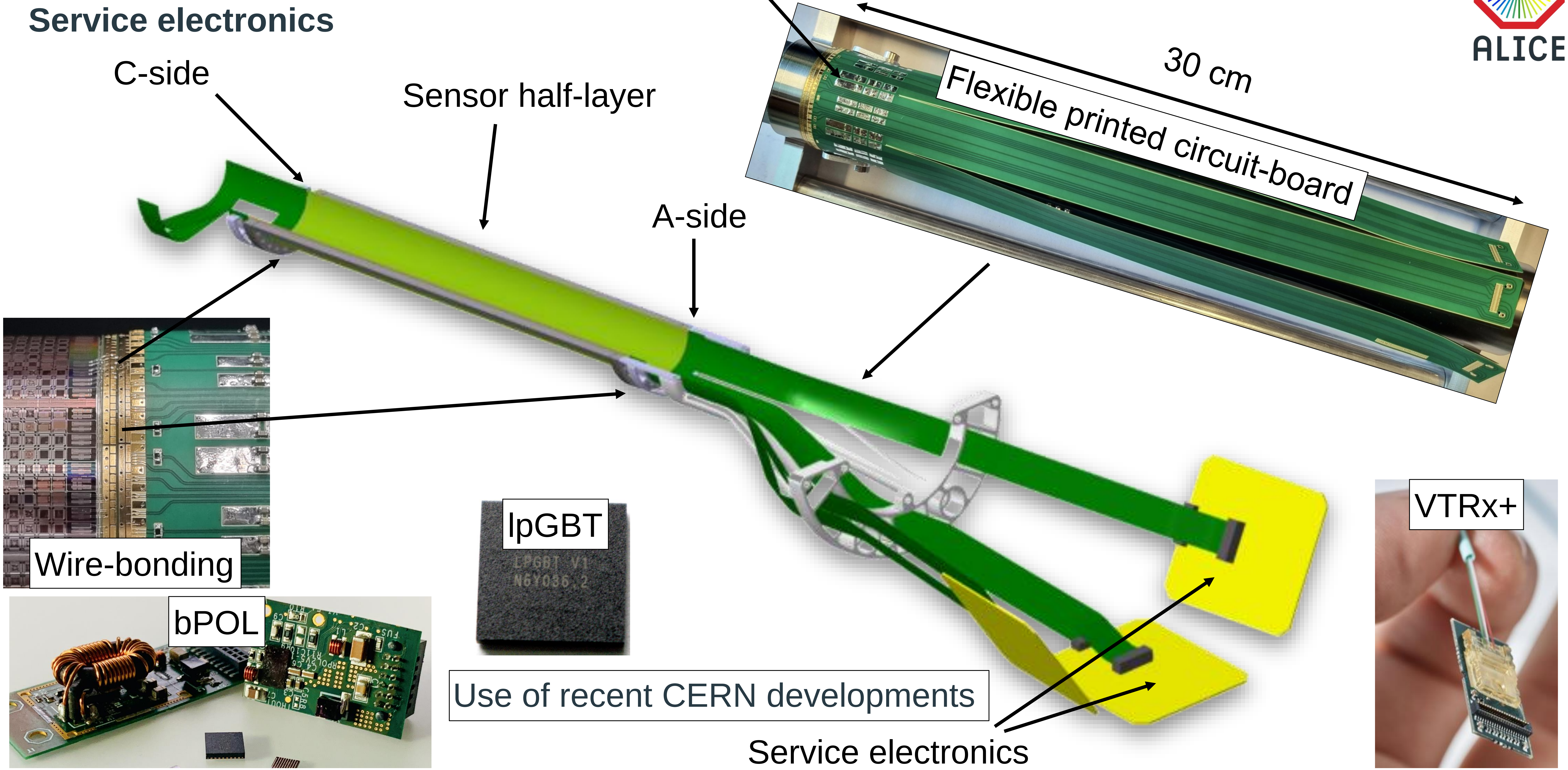


- Each **tile**:
  - Independent controllable power domains
  - 4 readout regions*
  - Stitched backbone data transfer at 160 Mbps link
- Buffers needed to drive signals across backbone
- Designed to maximize pixel matrix fill factor

* Exact number is being optimized

Services and integration

Service electronics

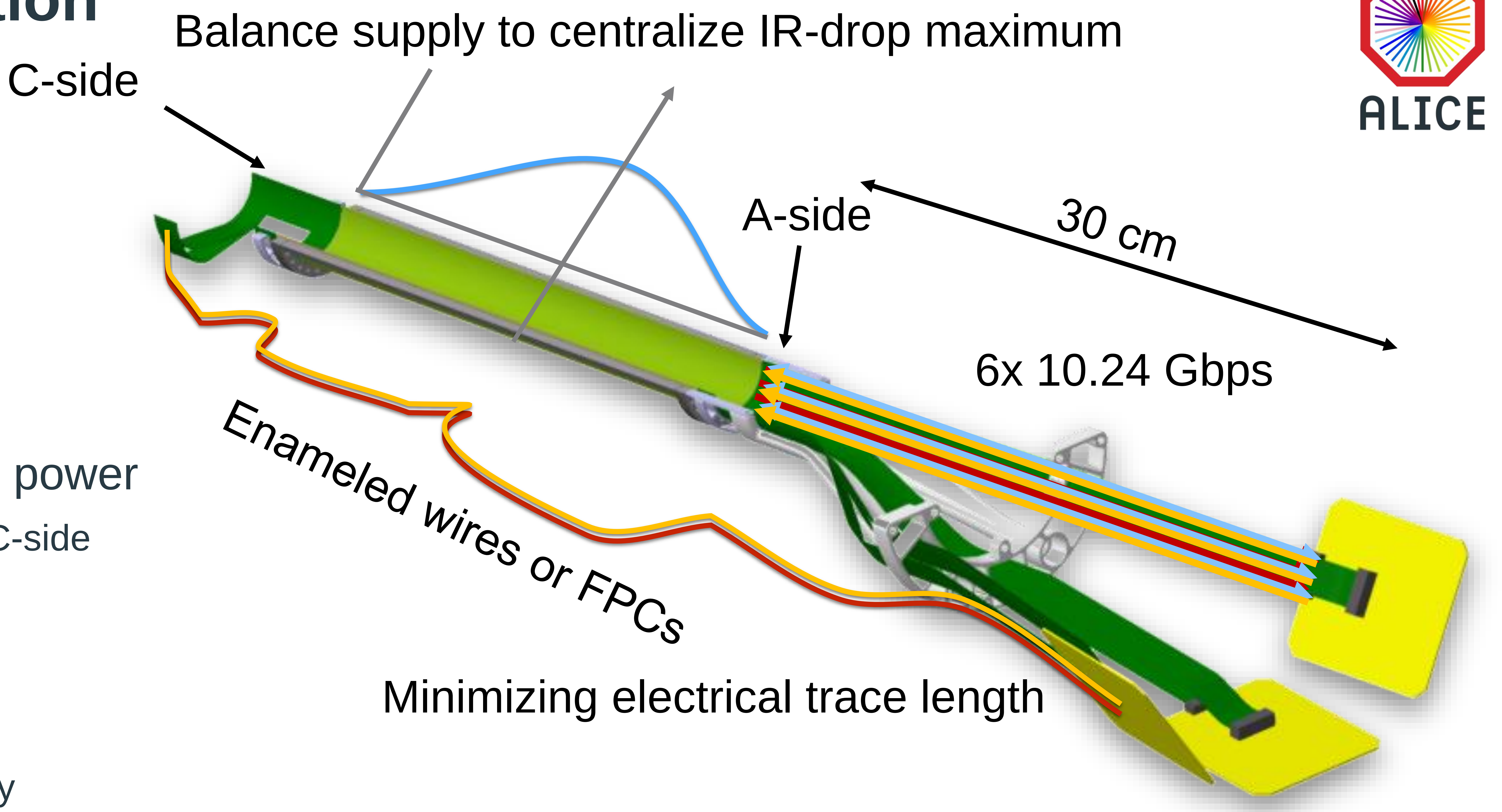


Use of recent CERN developments

Services and integration

System Requirements

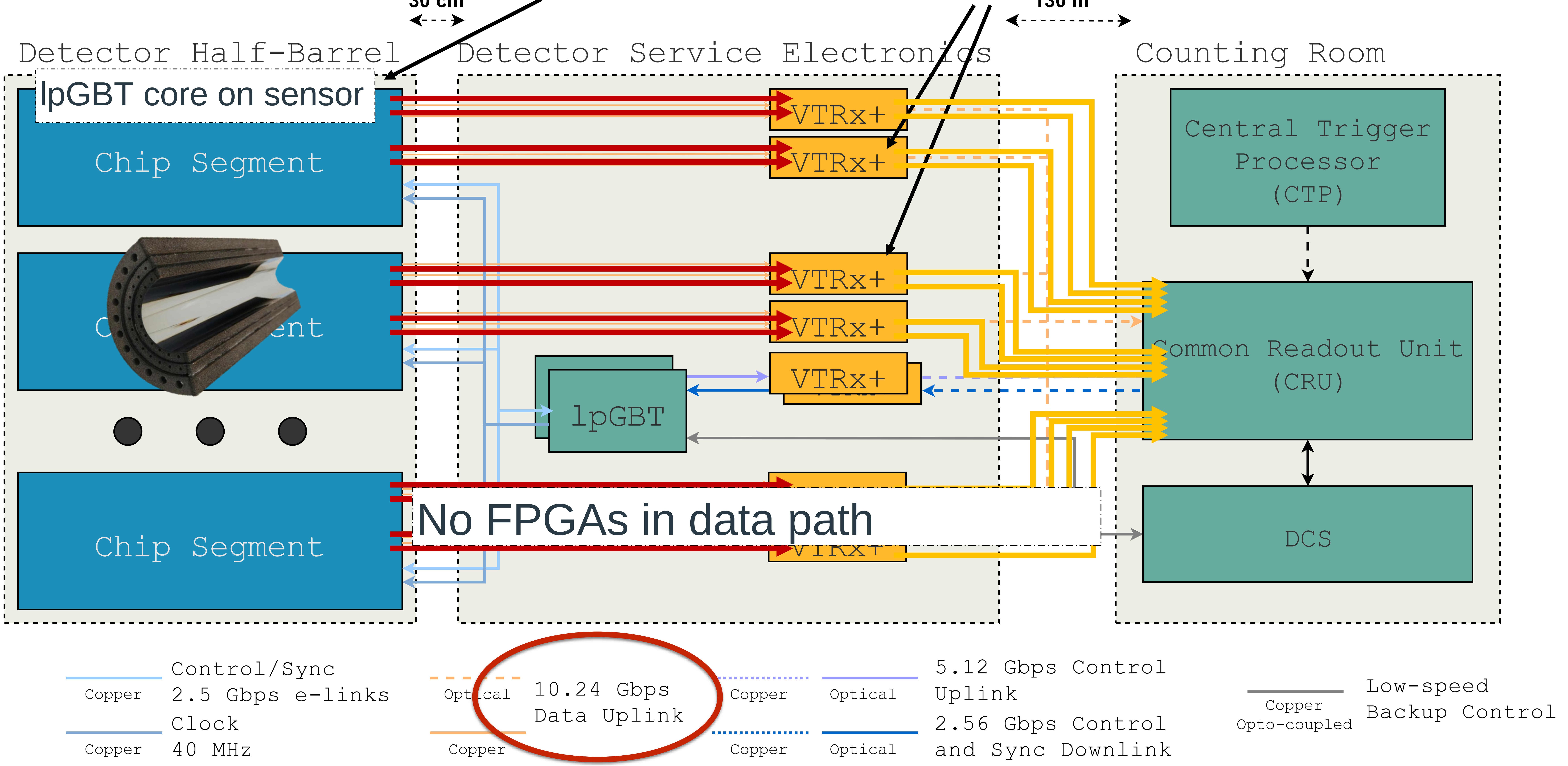
- Close proximity to detector
- Transmit data upstream
  - 6x 10.24 Gbps per segment
- Facilitate detector operation
- Supply and monitor detector power
  - Balanced power on both A- and C-side
  - 4 power domains
- Services environment
  - 0.5 T
  - Total Ionizing Dose (TID) of 1 kGy
  - 1×10^{12} 1 MeV n_{eq}/cm^2
- Services not easily accessible



Qualification and commissioning to prove reliability!

Services and integration

Data and control

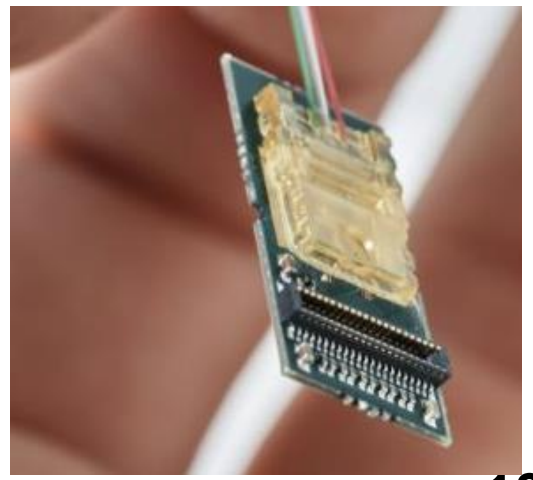


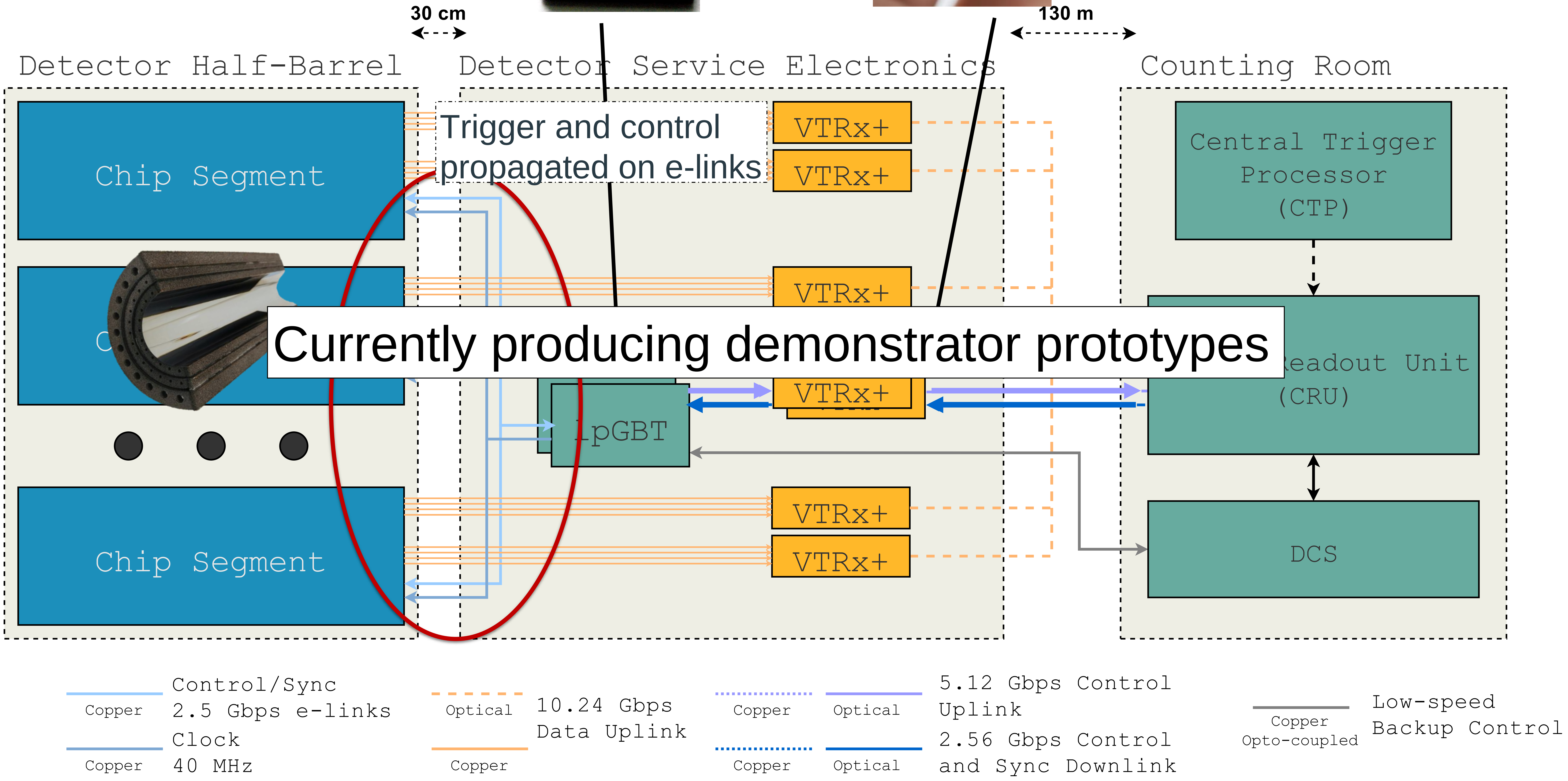
lpGBT core on sensor

No FPGAs in data path

Services and integration

Data and control





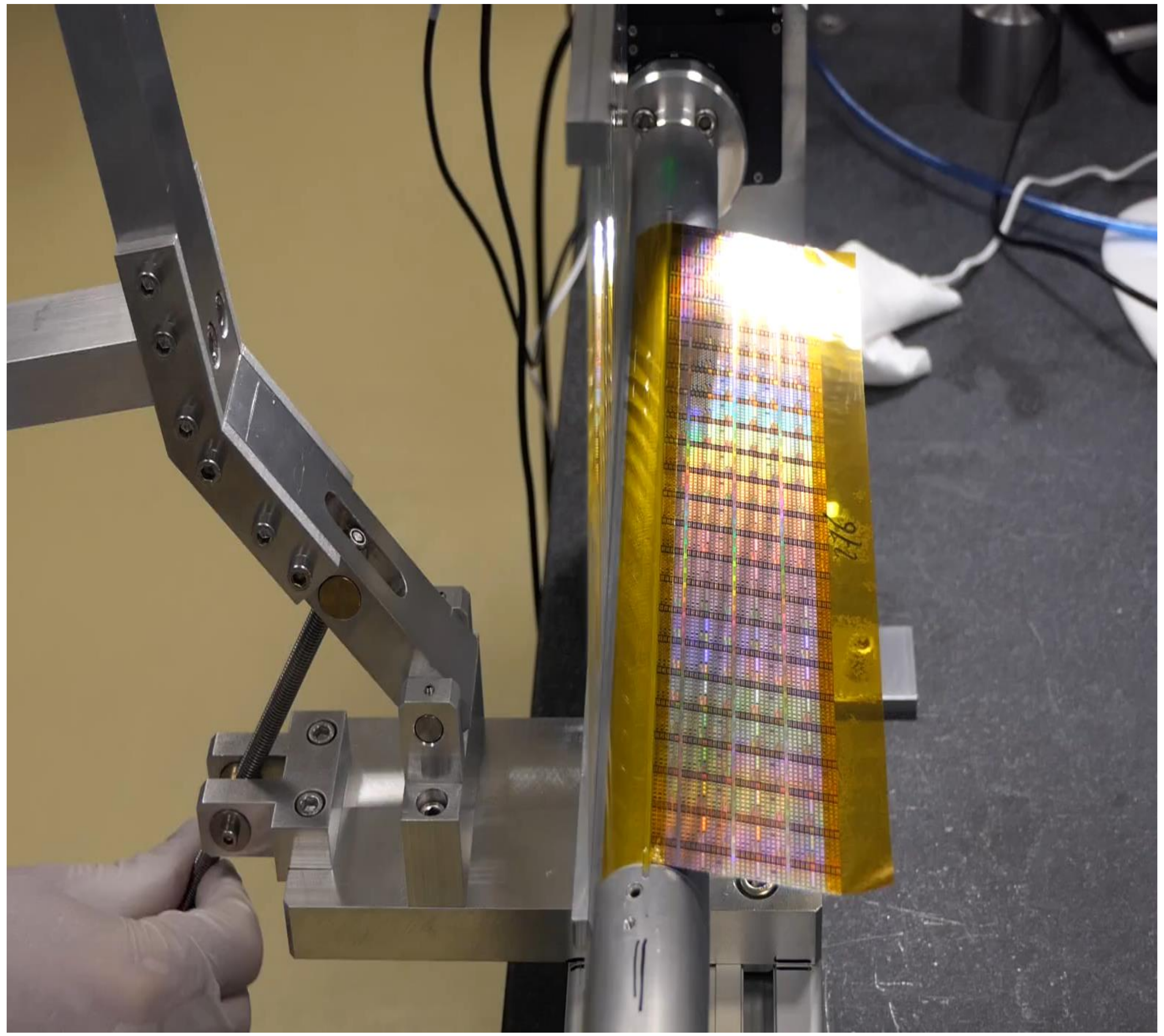
Trigger and control propagated on e-links

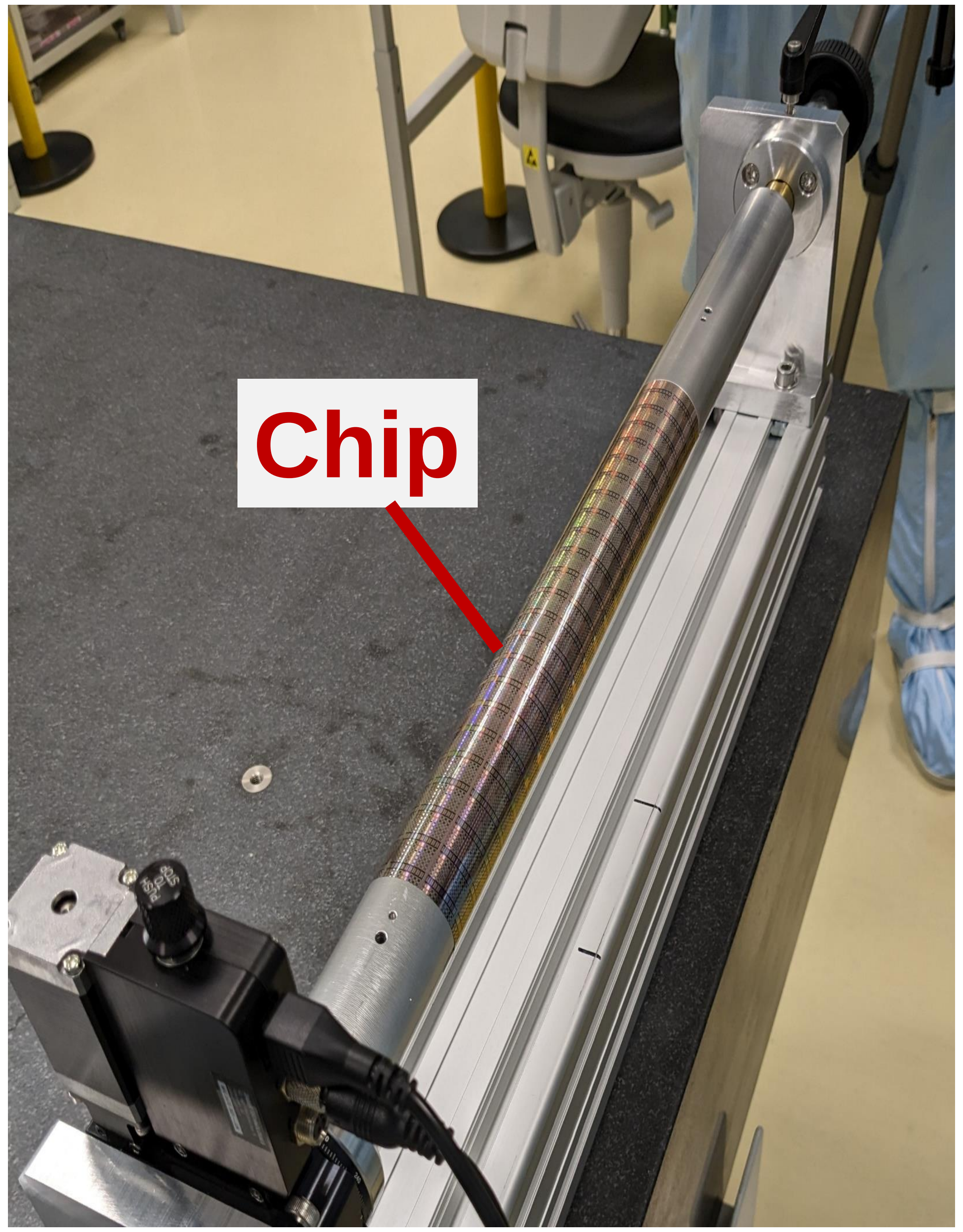
Currently producing demonstrator prototypes

Services and Integration

Detector Assembly

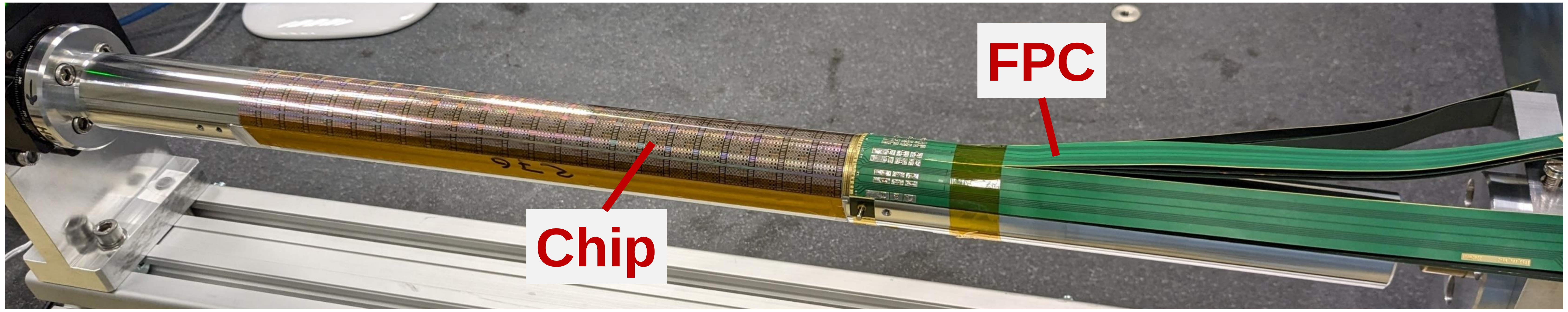
- Thin sensors are difficult to handle
- Bending is an intricate procedure
- Prototyping procedure using early R&D sensors





Chip bending

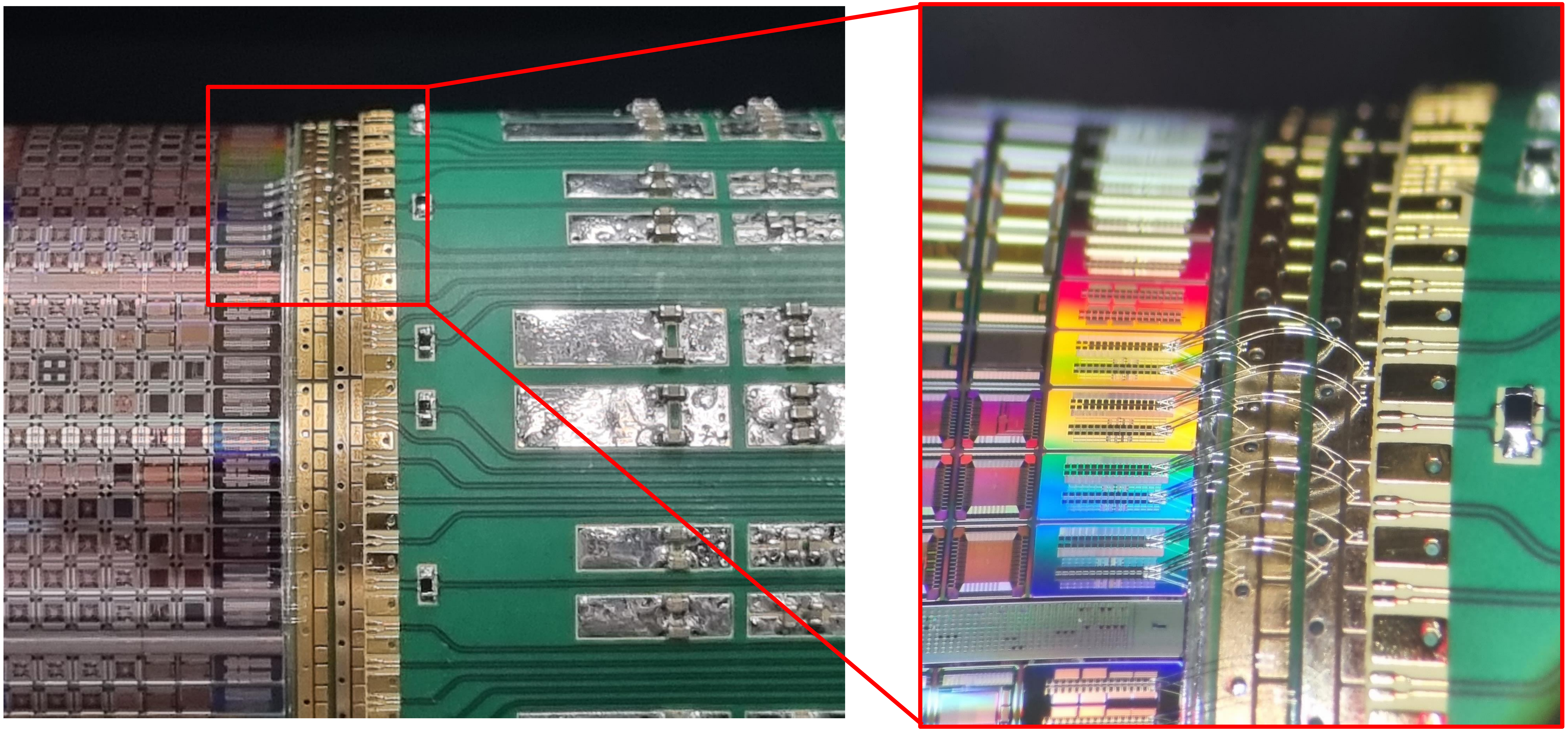
FPC alignment



Services and Integration

Detector Assembly

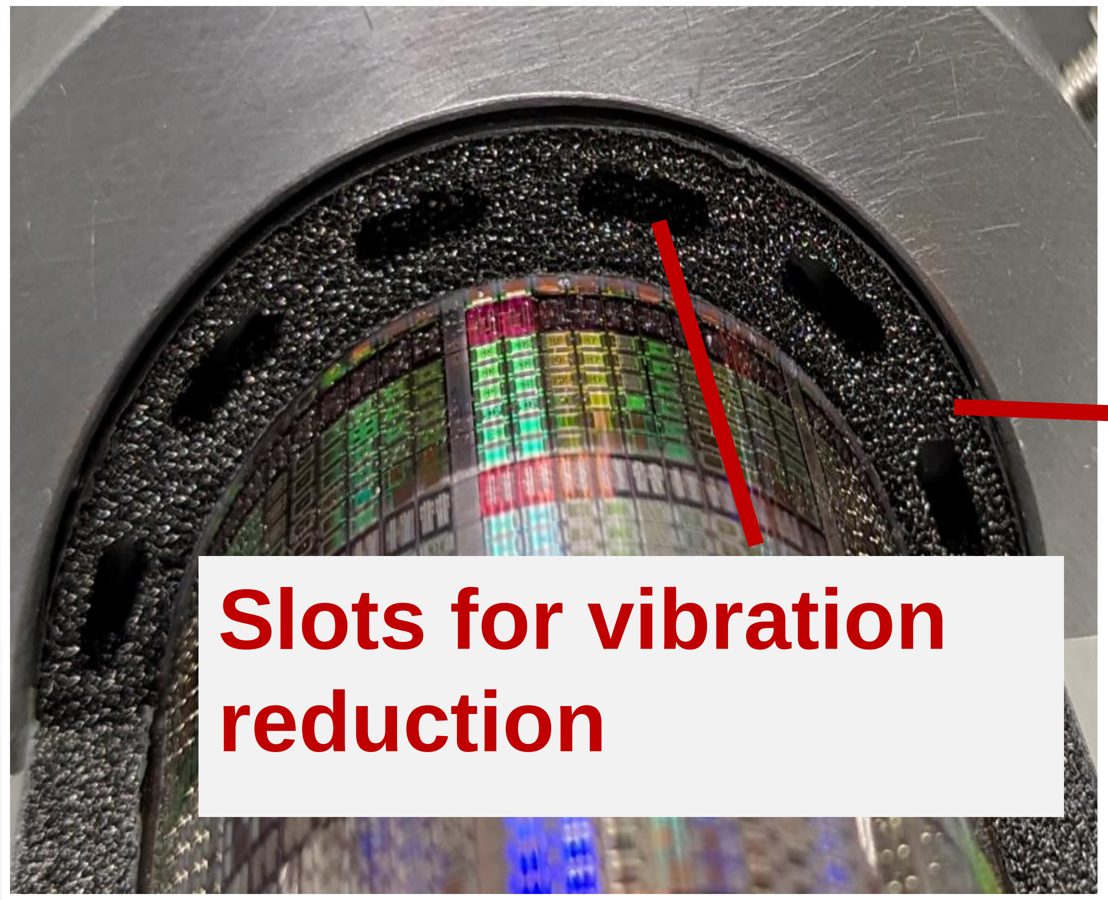
Wire-bonding

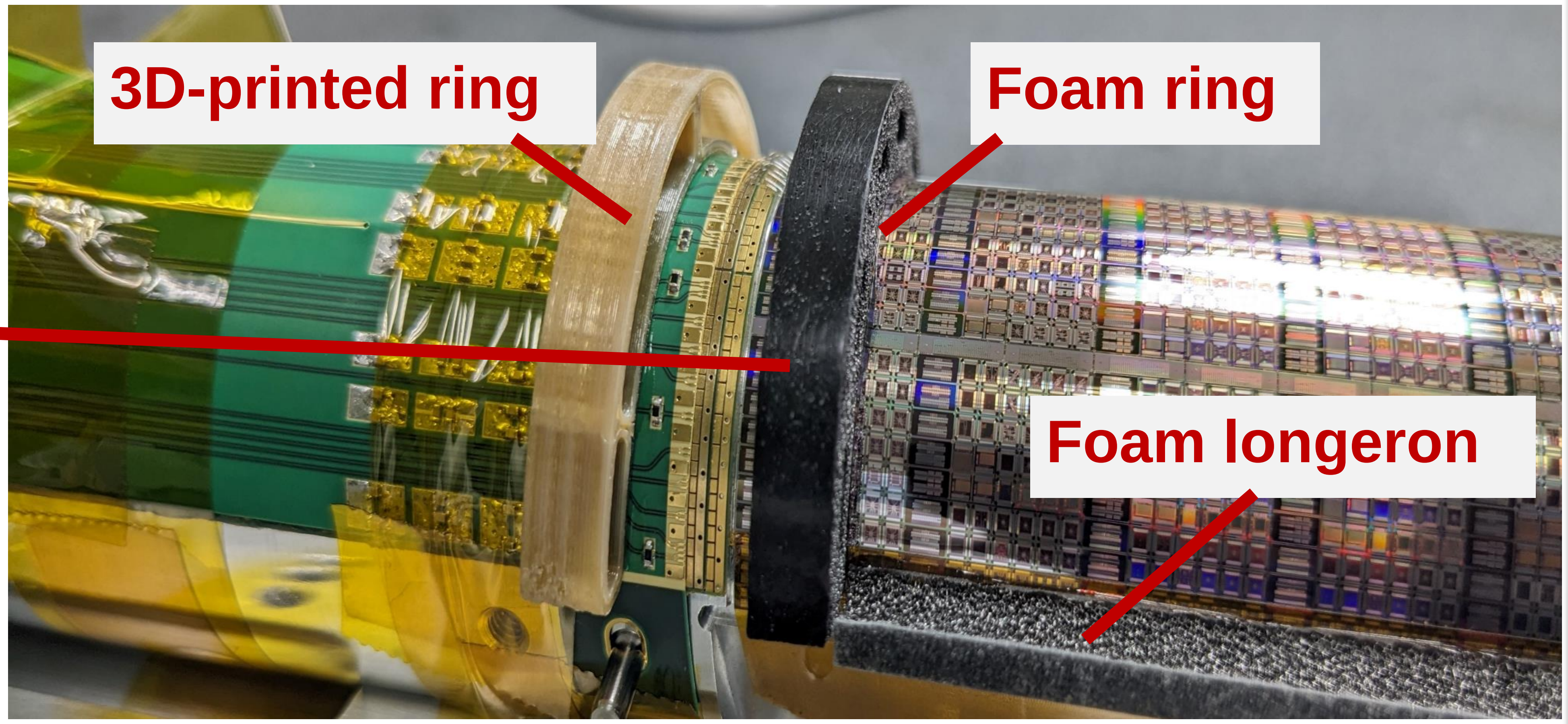


Services and Integration

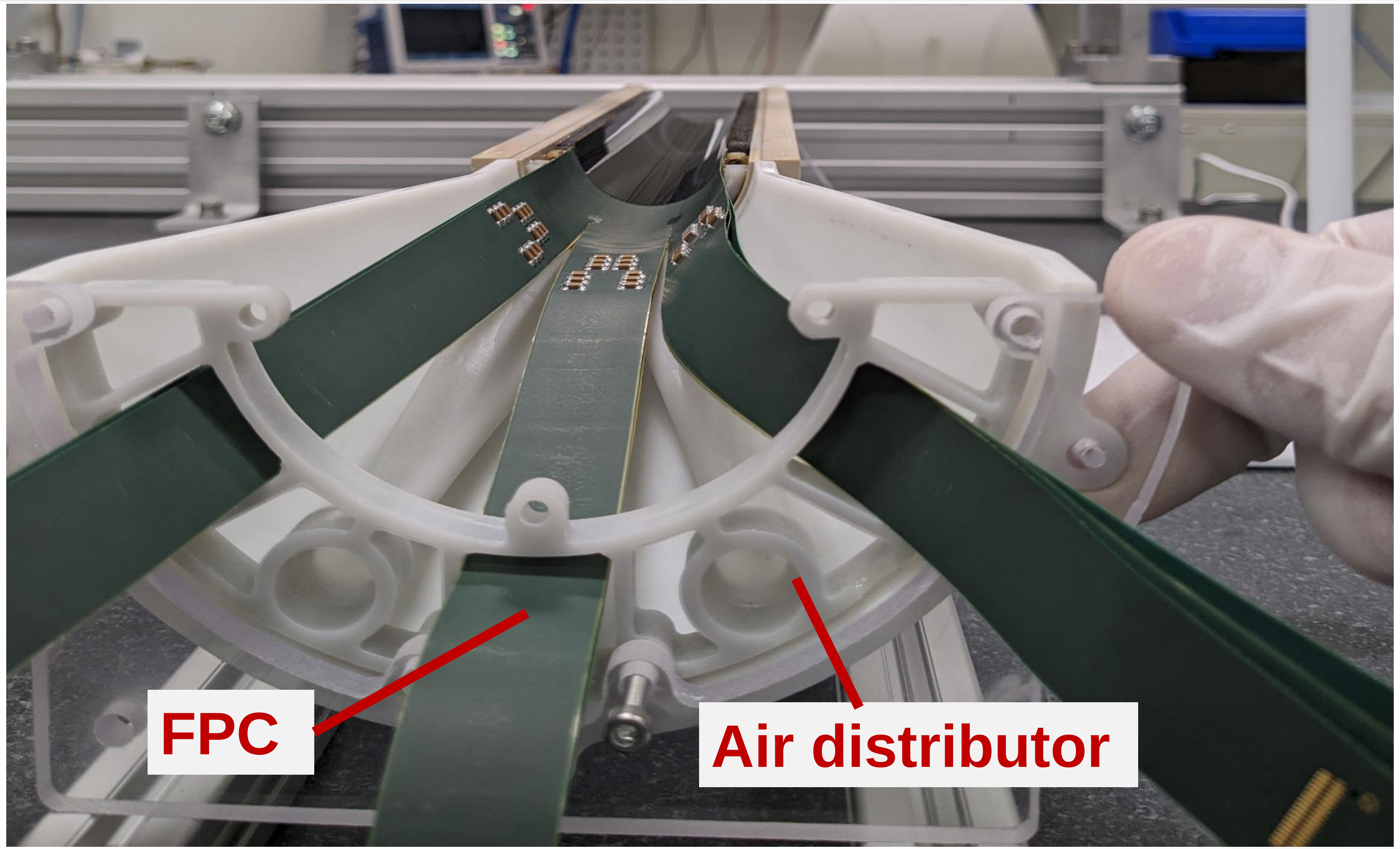
Detector Assembly

Gluing foams and supports





Gluing of the air distributor



Final Result

ALICE

Summary and Outlook

- **ITS3 on track to replace ITS2 IB during LS3 (2026-2028)**

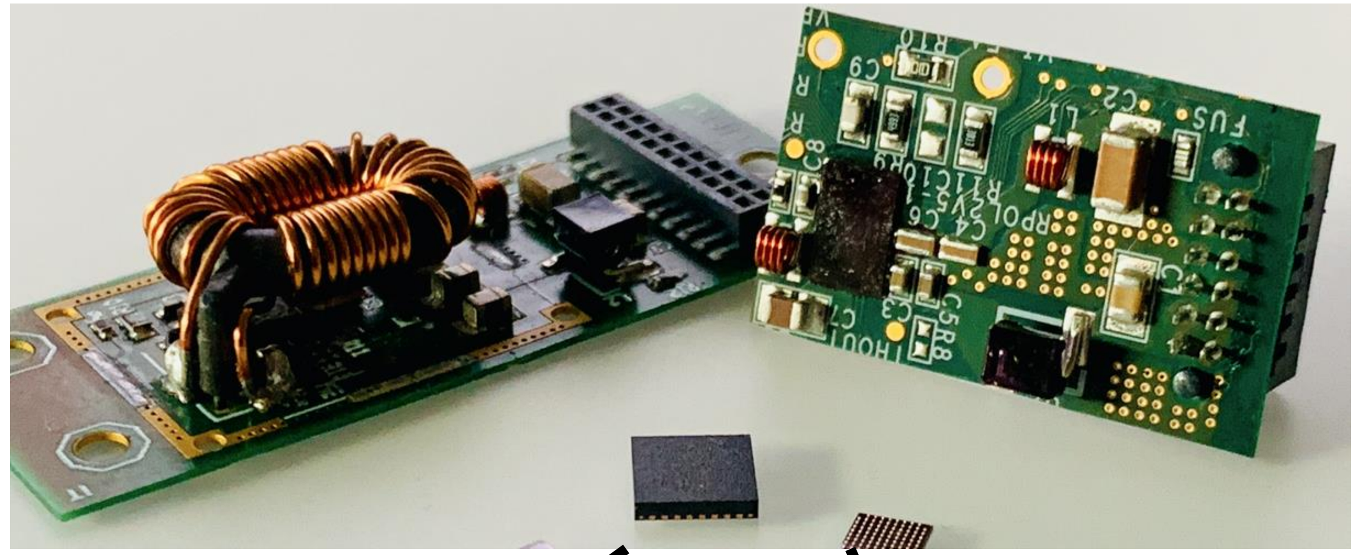
- **R&D milestones completed:**
  - Air cooling concept tested
  - Demonstrated operation of bent MAPS
  - 65 nm technology qualified
  - First stitched sensor designed – under testing
  - Services architecture designed – prototyping underway

- **Next steps:**
  - Design of first full prototype (MOSAIX) in progress
  - Testing and qualification of services prototype
  - Optimize the assembly procedure for complete half-barrel

Backup

Services and integration

Power distribution



30 cm

130 m

Detector Half-Barrel

Chip Segment

Chip Segment

Chip Segment

Detector Service Electronics

LDO

MONITOR

DC-DC

LDO

MONITOR

DC-DC

4x DC-DC per segment

MONITOR

DC-DC

LDO

MONITOR

DC-DC

DETECTOR POWER CONTROLLER

SERVICES COMPONENTS

MONITOR

DC-DC

3x DC-DC for services

Power Infrastructure

Bias Supply

Detector Supply

Services Supply

Low current towards infrastructure

Detector Power
10V
1V8
1V2

Services Power
10V
1V2
2V5

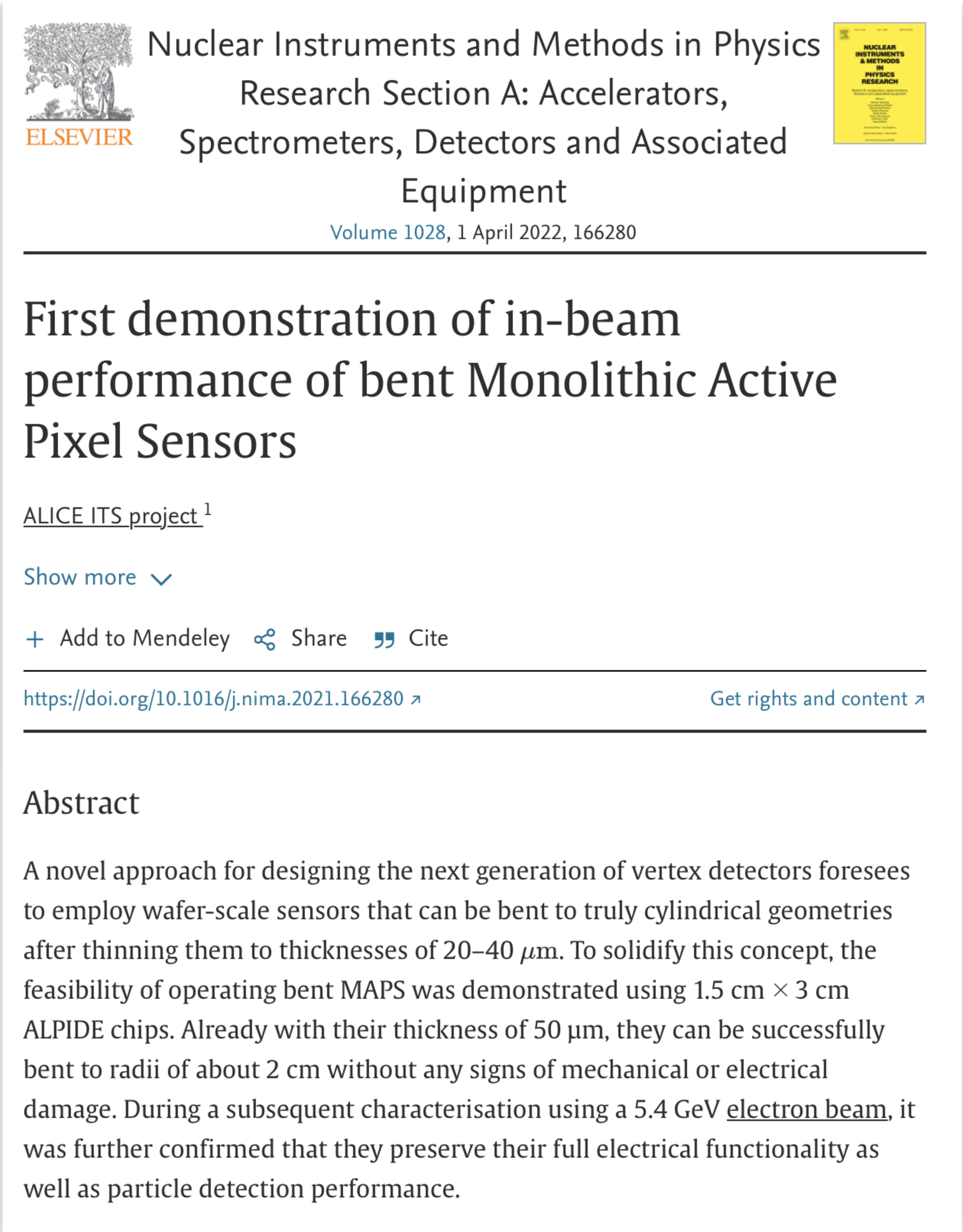
Main supply
45V

Bias supply
-8V - 0V

Enameled wires or FPCs for distributing power to C-side

Detector concept

Bending MAPS sensors



ELSEVIER

Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment

Volume 1028, 1 April 2022, 166280

First demonstration of in-beam performance of bent Monolithic Active Pixel Sensors

ALICE ITS project [1]

Show more

+ Add to Mendeley   Share   Cite

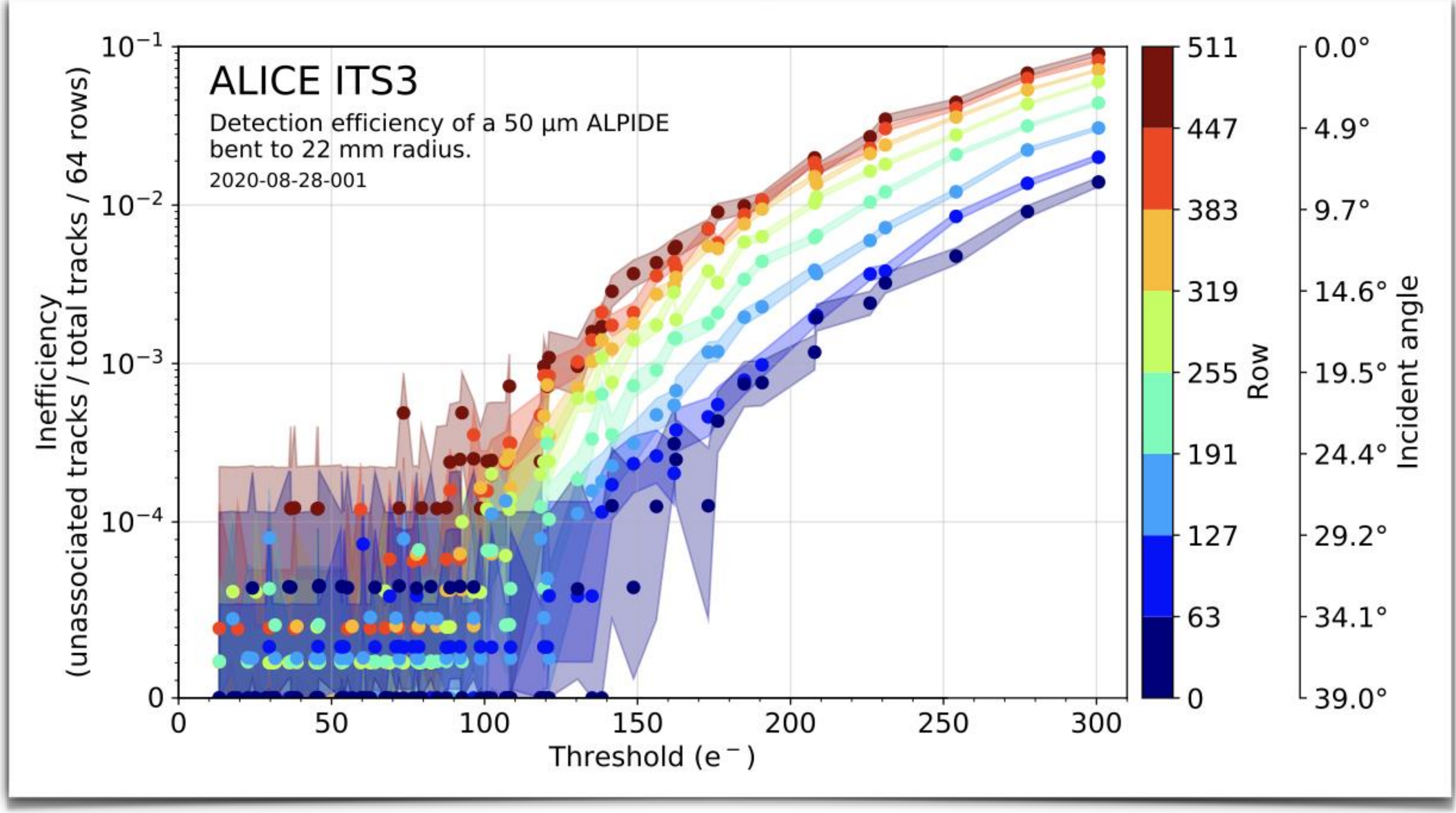
https://doi.org/10.1016/j.nima.2021.166280 ↗

Get rights and content ↗

Abstract

A novel approach for designing the next generation of vertex detectors foresees to employ wafer-scale sensors that can be bent to truly cylindrical geometries after thinning them to thicknesses of 20–40 μm. To solidify this concept, the feasibility of operating bent MAPS was demonstrated using 1.5 cm × 3 cm ALPIDE chips. Already with their thickness of 50 µm, they can be successfully bent to radii of about 2 cm without any signs of mechanical or electrical damage. During a subsequent characterisation using a 5.4 GeV electron beam, it was further confirmed that they preserve their full electrical functionality as well as particle detection performance.

doi.org/10.1016/j.nima.2021.166280



Detector concept

Mechanical models

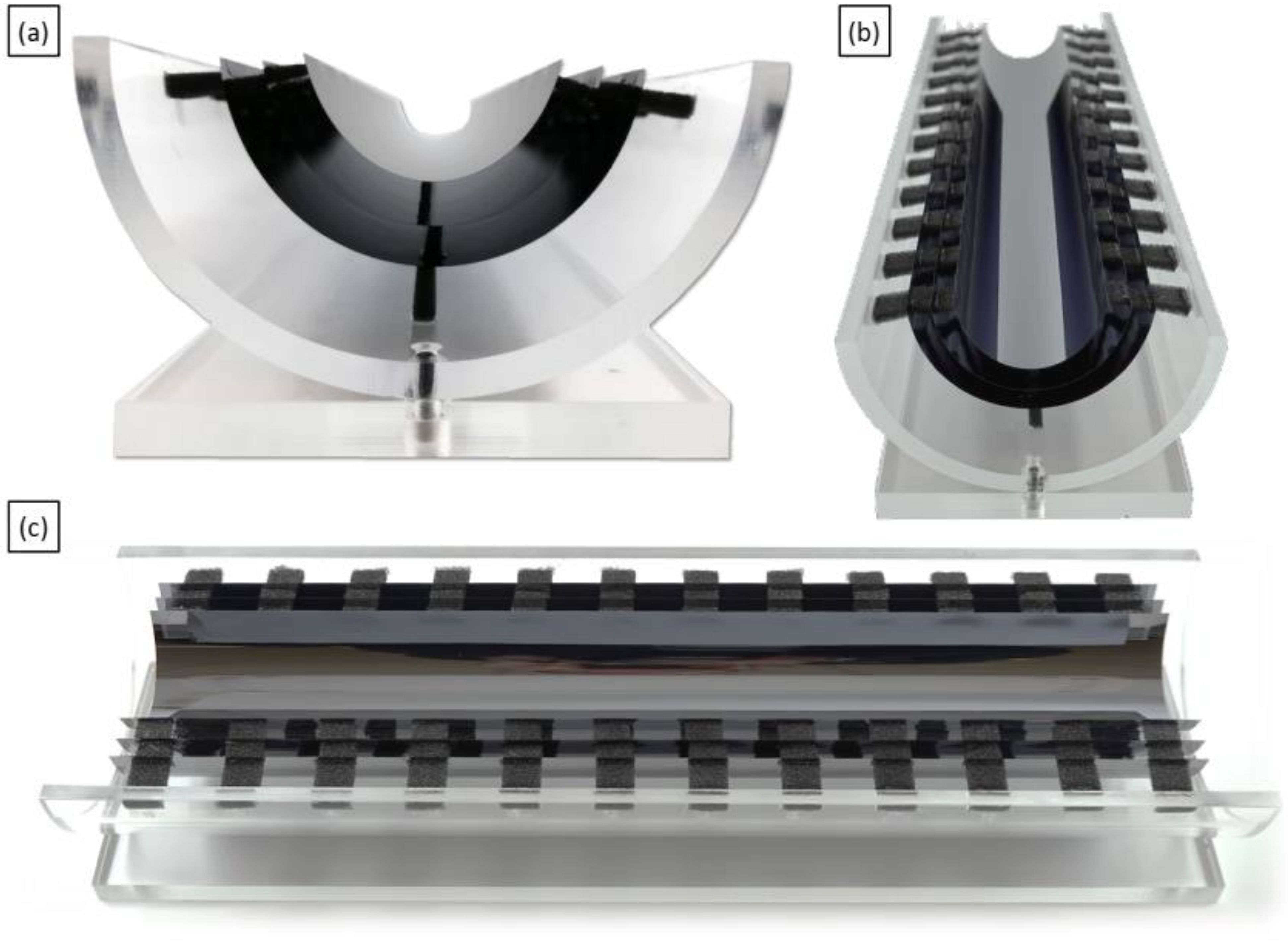


Figure 4.4: Engineering Model 1. (a) Front, (b) perspective and (c) top views of the prototype. Three wafer-size blank silicon pieces (40 µm thin, 280 mm long), simulating the half-layers are kept bent by carbon foam wedges only at the half-layer edges.

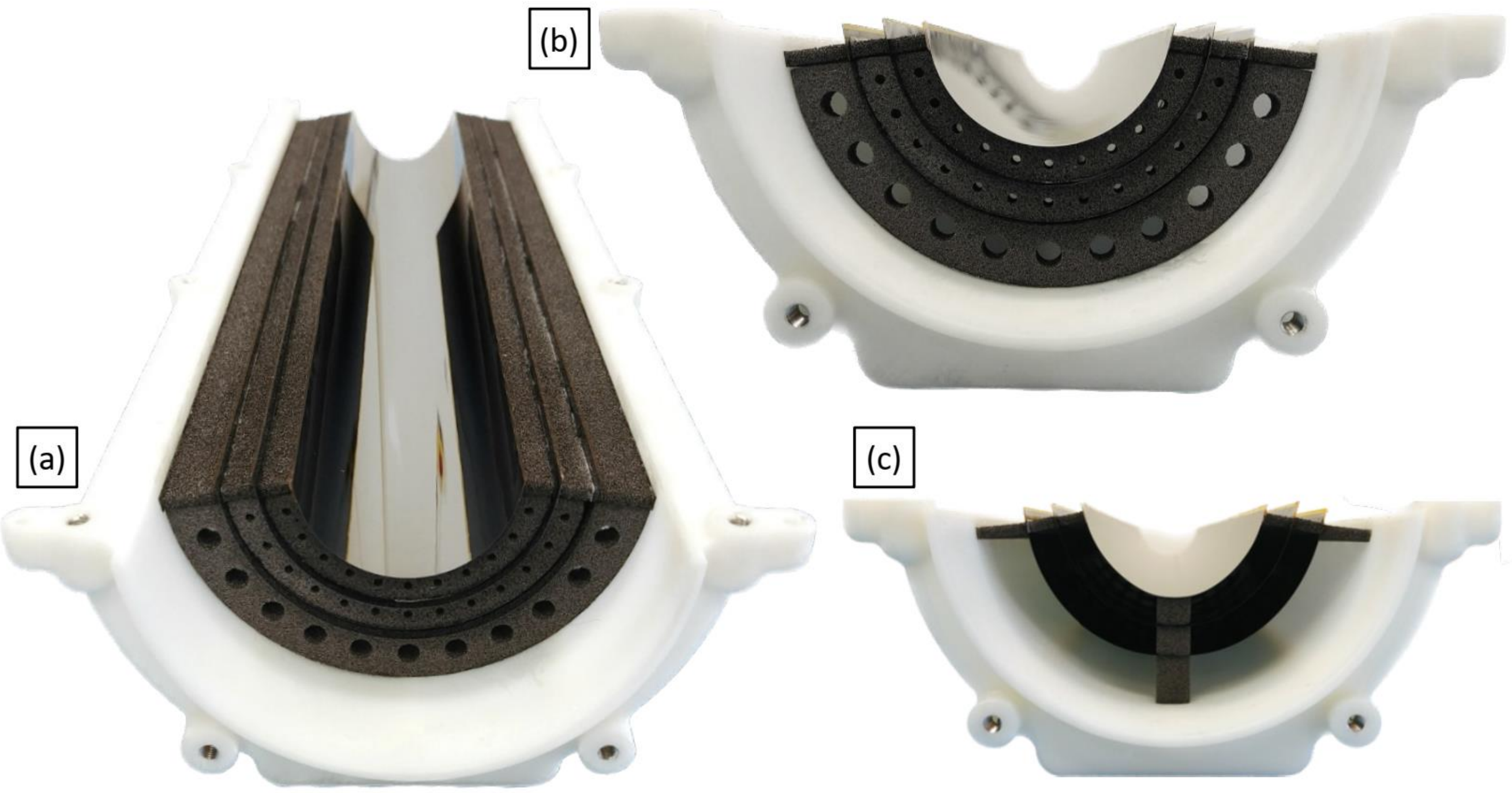
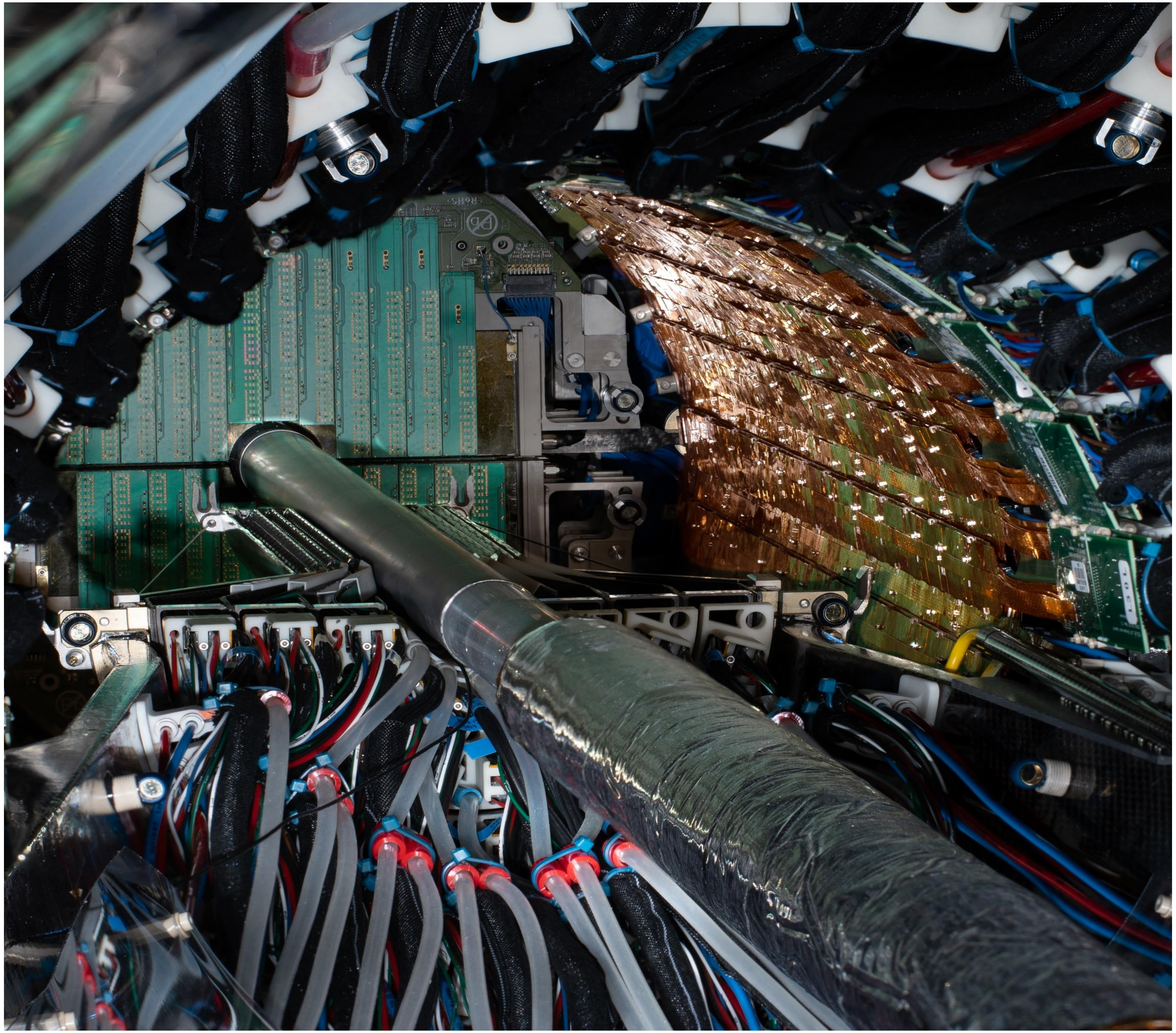
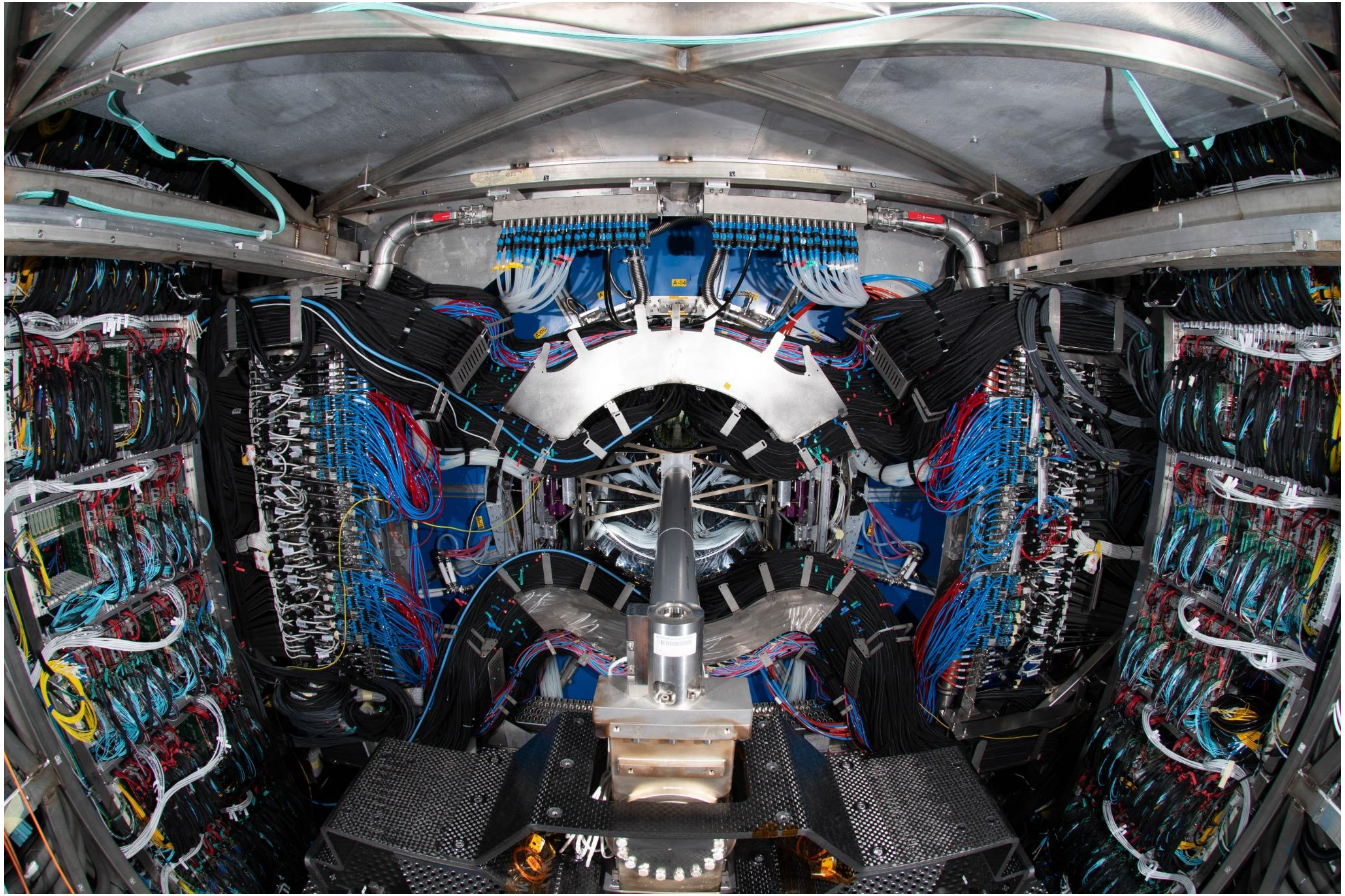


Figure 4.5: Engineering Model 2. (a) Perspective, (b) A-side and (c) C-side views of the prototype. Three wafer-size blank silicon pieces (40 µm thin, 280 mm long), simulating the half-layers are kept bent by half-rings (A-side), longerons and wedges (C-side) made in carbon foam.

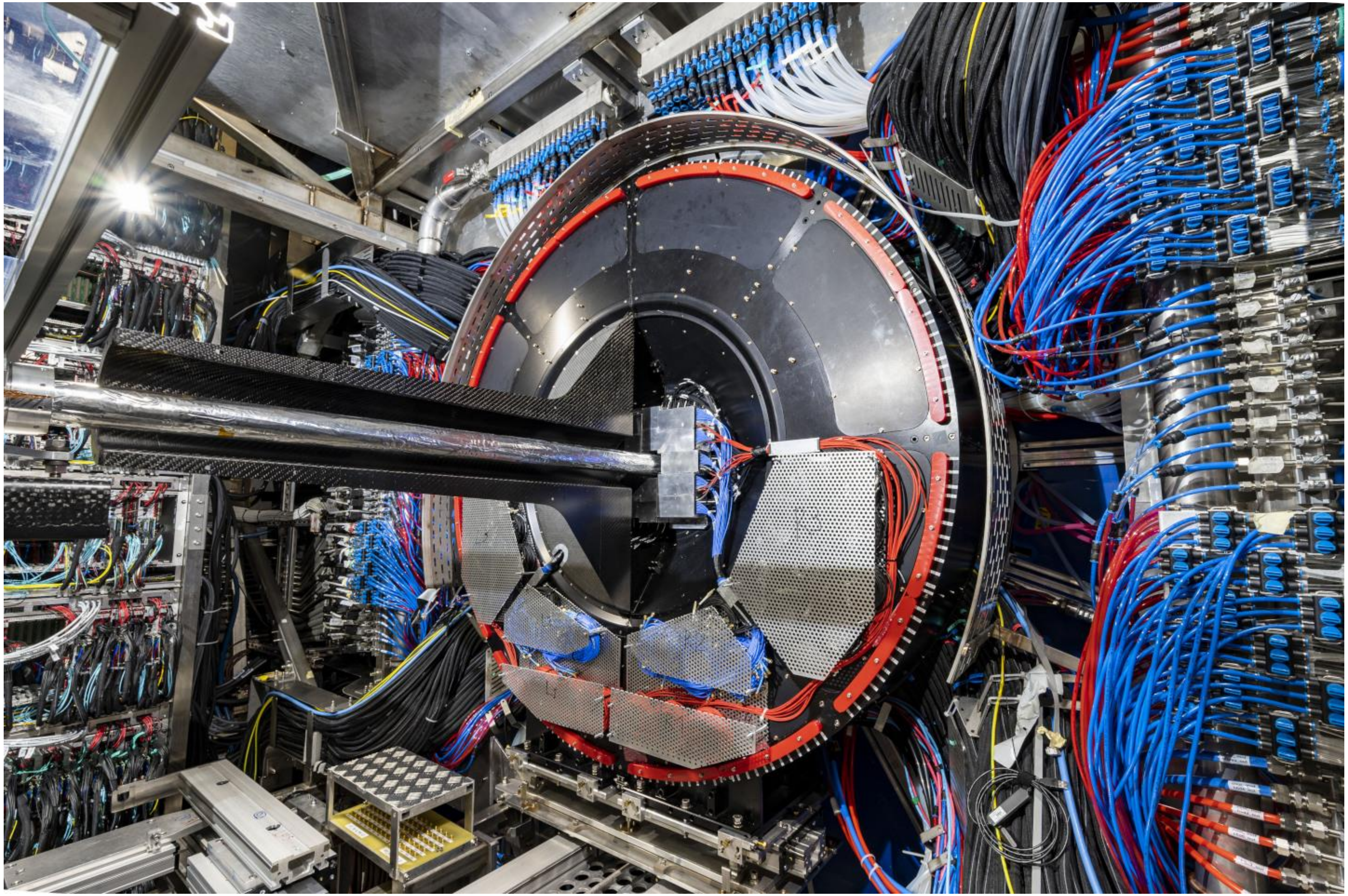
ALICE P2



ALICE P2



ALICE P2

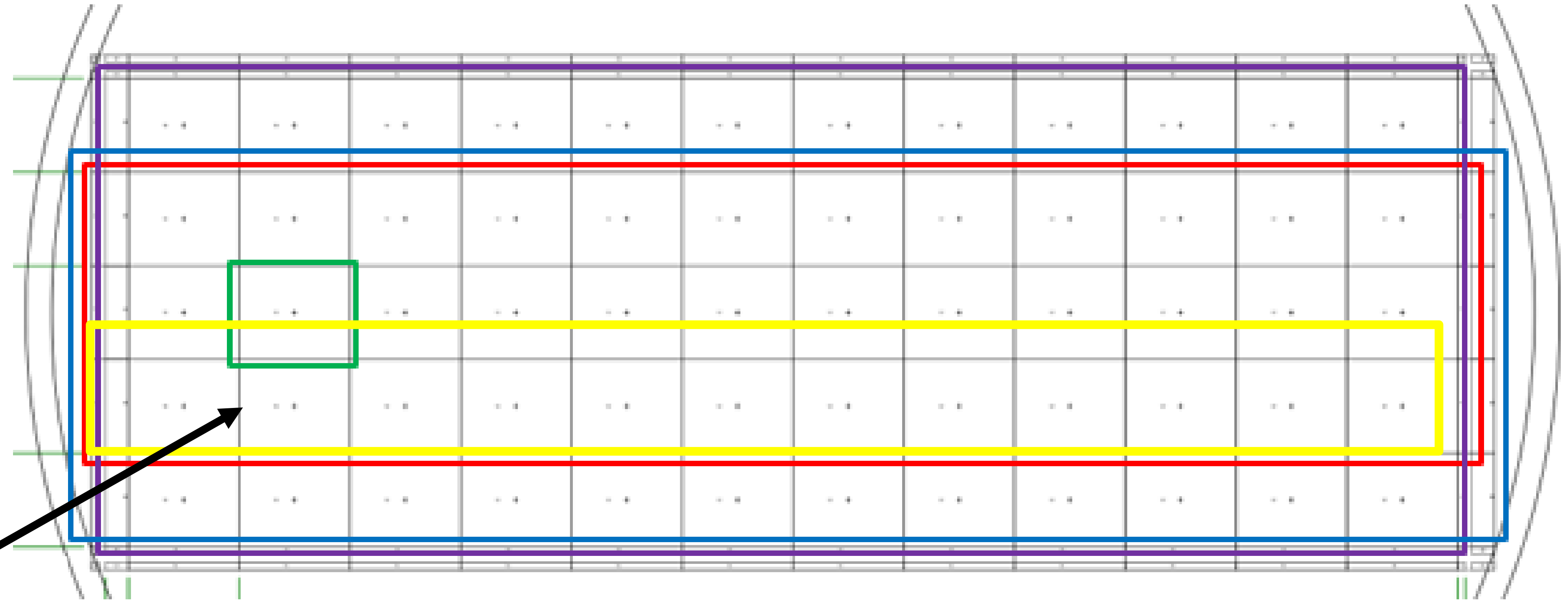


Services

System Requirements

- Transmit data upstream
  - Line rate: 10.24 Gbps
- Facilitate detector operation
  - Clock and synchronization signal (trigger)
  - Power control
  - Detector control
- Supply and monitor detector power
  - Supply balanced power on both A- and C-side
  - 4 domains (AVDD, DVDD SC, DVDD core, DVDD TX)
  - Granularity at chip segment level
- Environment
  - 0.5 T
  - Total Ionizing Dose (TID) of 1 kGy
  - 1×10^{13} 1 MeV n_{eq}/cm^2

Half-Layer	**0**	**1**	**2**	**Half-Barrel**	**Detector**
Chip segments	3	4	5	12	24
Data links	18	24	30	72	144
Control e-links	6	8	10	24	48
Sync e-links	3	4	5	12	24
Detector power consumption (W)	8.5	11.3	14.1	33.9	67.8



Chip segment:
12 x RSU
Left & right endcap