UNIVERSITY OF LIVERPOOL

The ePIC Silicon Vertex Tracker for the Electron-Ion Collider

Jian Liu (University of Liverpool)

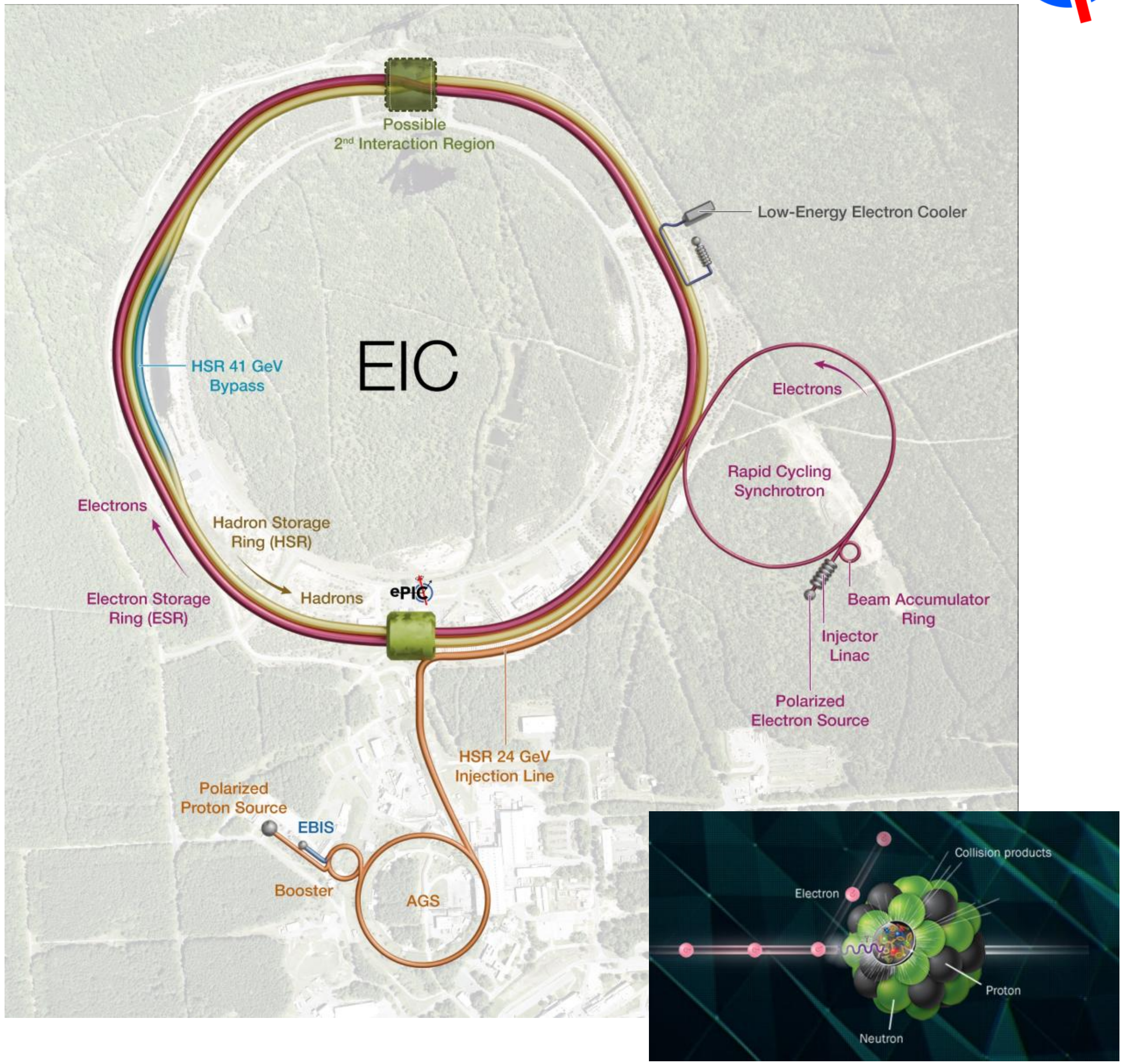
On behalf of the ePIC SVT collaboration

The 14th International Conference on Position Sensitive Detectors

1-4 September 2026, Queen Mary University of London, London, UK

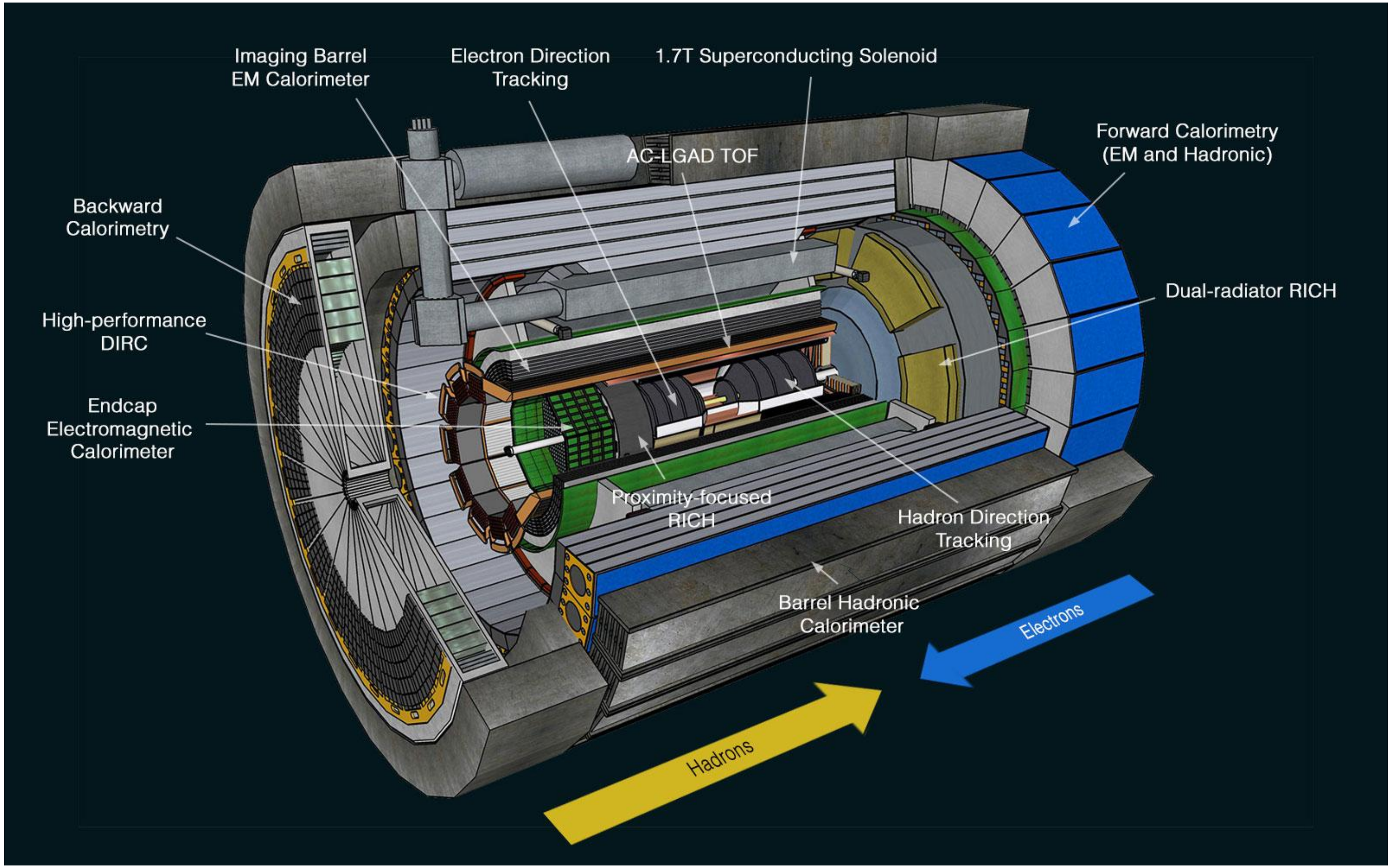
EIC - Electron-Ion Collider

- **Facility**
  - To be built at Brookhaven National Laboratory, on the RHIC site
  - Two intersecting storage rings: one carrying an intense electron beam and the other a high-energy proton or ion beam
  - Luminosity: $10^{33} – 10^{34}$ $cm^{-2}s^{-1}$
  - Beam polarisation up to 70% for electrons, protons and light ions
  - Centre-of-mass energy: $\sqrt{s}$ = 29 – 140 GeV
  - Ion species ranging from protons to uranium
- **Uniqueness**
  - The world's first collider of polarised electrons with polarised protons and light ions
- **Science questions to be answered**
  - How do nucleon mass and spin emerge?
  - What is the three-dimensional structure of nucleons and nuclei?
  - How do quarks and gluons behave inside nuclear matter?
  - What mechanism confines quarks?
  - What are the properties of high-density gluonic matter?
- **Timeline**
  - First beams and initial science: 2034
  - Full science programme: from 2036



ePIC detector

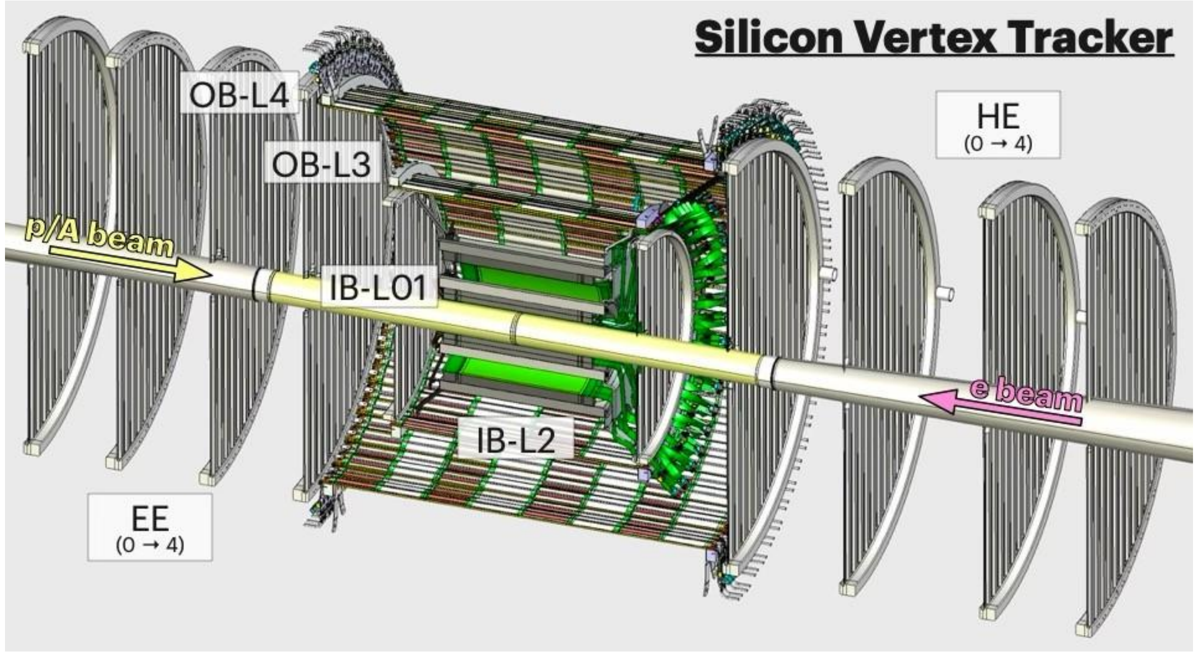
- **The ePIC collaboration**
  - Formed to design, build and operate the first experiment at the EIC
- **Detector concept**
  - High-precision tracking, particle identification and electromagnetic and hadronic calorimetry
  - Comprehensive detector coverage, approximately $-4 < \eta < 4$, depending on the subsystem
  - Dedicated electron- and hadron-going endcaps, optimised for the asymmetric beam energies
  - A 1.7 T superconducting solenoid for charged-particle momentum measurement
  - Continuous streaming readout with AI-assisted online data processing and event selection



Silicon Vertex Tracker (SVT)

Large-acceptance, high-precision tracker based on low-power, large-area MAPS in a 65 nm CMOS imaging process

- Spatial resolution: σ_{pos} ~ 5 µm
- Power density: < 40 mW/cm^2
- Framing time: ≤ 2 µs



Inner Barrel (IB)

- Three layers, L0–L2, at radii of 38, 50 and 126 mm
- Active length: 26 cm
- Material budget: approximately 0.07% X/X_0 per layer
- Bent, wafer-scale ALICE ITS3 sensors

Outer Barrel (OB)

- Two layers, L3 and L4, at radii of 270 and 420 mm
- Material budget: approximately 0.25% X/X_0 for L3 and 0.55% X/X_0 for L4
- EIC-LAS sensors mounted on hollow, air-cooled staves

Electron- and hadron-going endcaps

- Five disks per endcap: EE0–EE4 and HE0–HE4
- Disk outer radii: 240–420 mm
- Material budget: approximately 0.25% X/X_0 per disk
- EIC-LAS sensors mounted on corrugated disk structures

Mechanics, services, and cooling

- Aluminium flexible printed circuits for low-mass services
- Carbon-foam and carbon-fibre composite support structures
- Room-temperature operation using forced-air cooling
- Readout based on lpGBT, VTRx+ and FELIX
- Serial powering for the OB and endcaps

SVT tracking performance

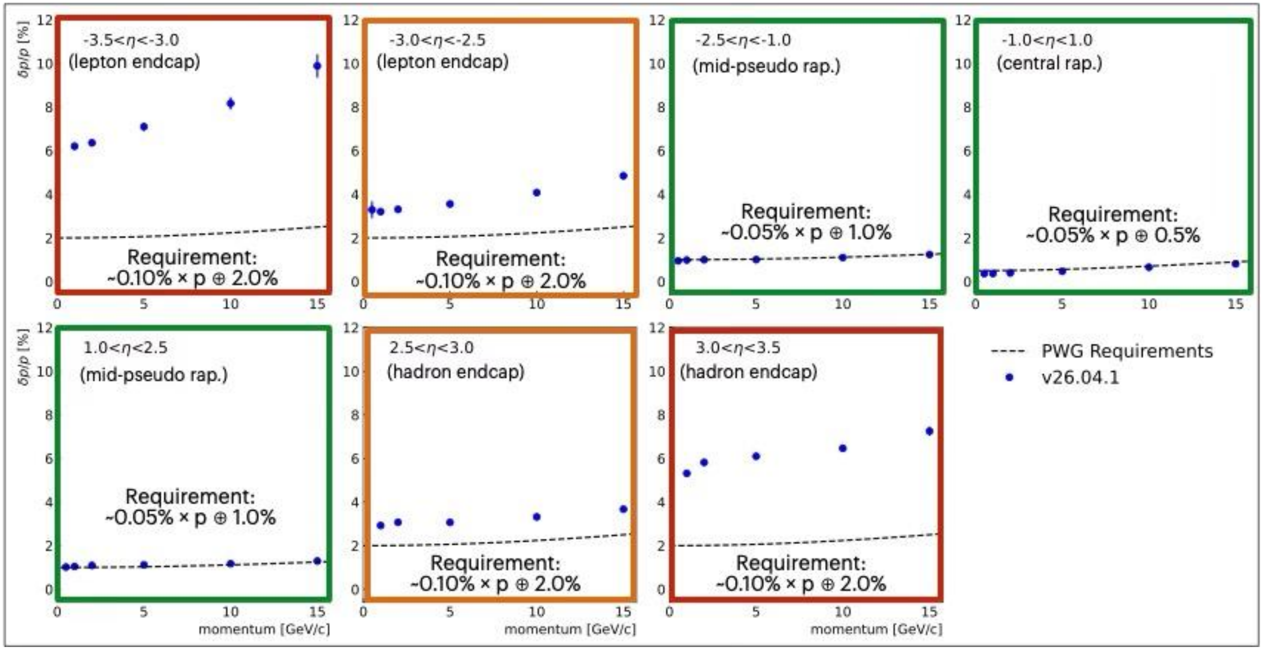
Relative momentum resolution

- Meets the requirement for |η| < 2.5
- Approaches the target for 2.5 < |η| < 3.0
- Below the target for 3.0 < |η| < 3.5, particularly in the electron-going endcap → a recent study shows that combined tracking and ECal reconstruction achieves the required electron momentum resolution in the electron-going endcap

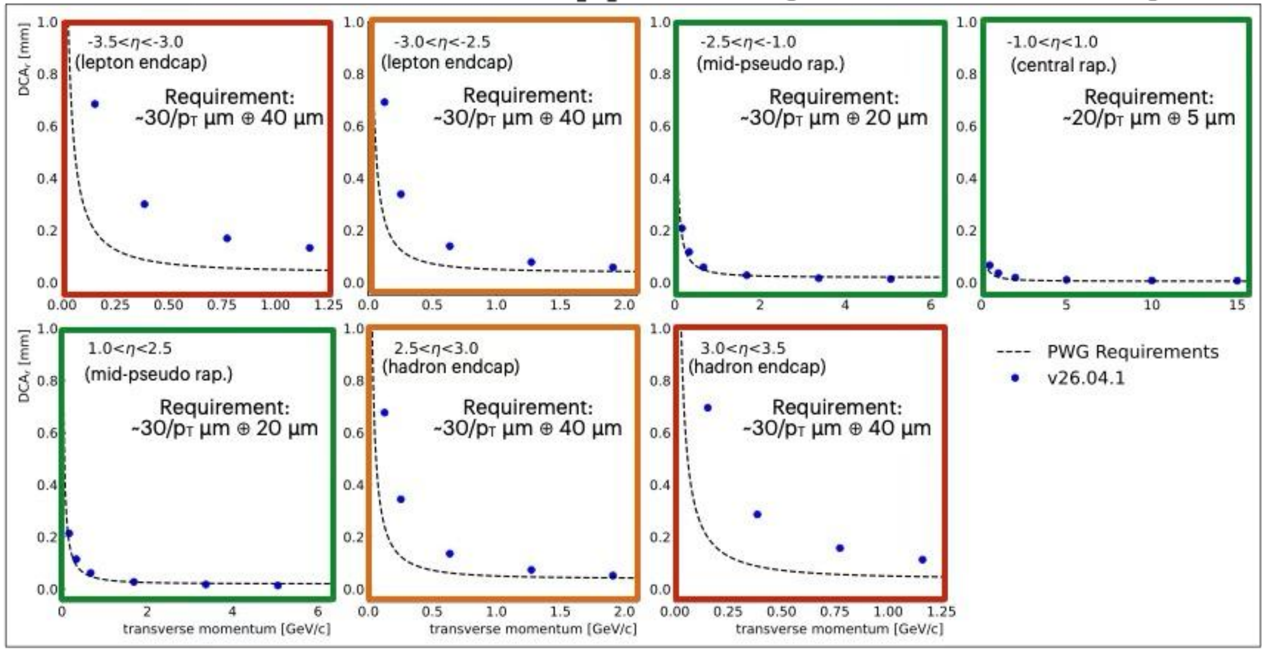
Radial DCA (pointing) resolution

- Meets the requirement for |η| < 2.5
- Good agreement with the target for 2.5 < |η| < 3.0
- Some degradation relative to the target for 3.0 < |η| < 3.5

Relative momentum resolution

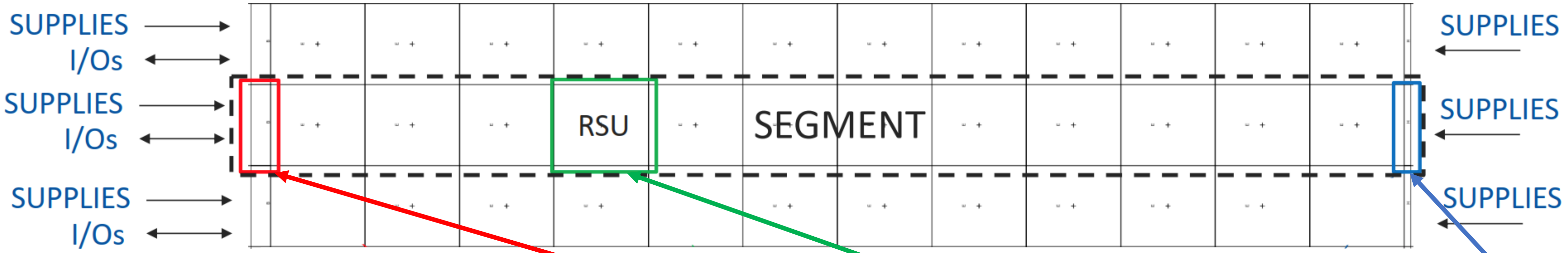


Distance of closest approach (radial direction)



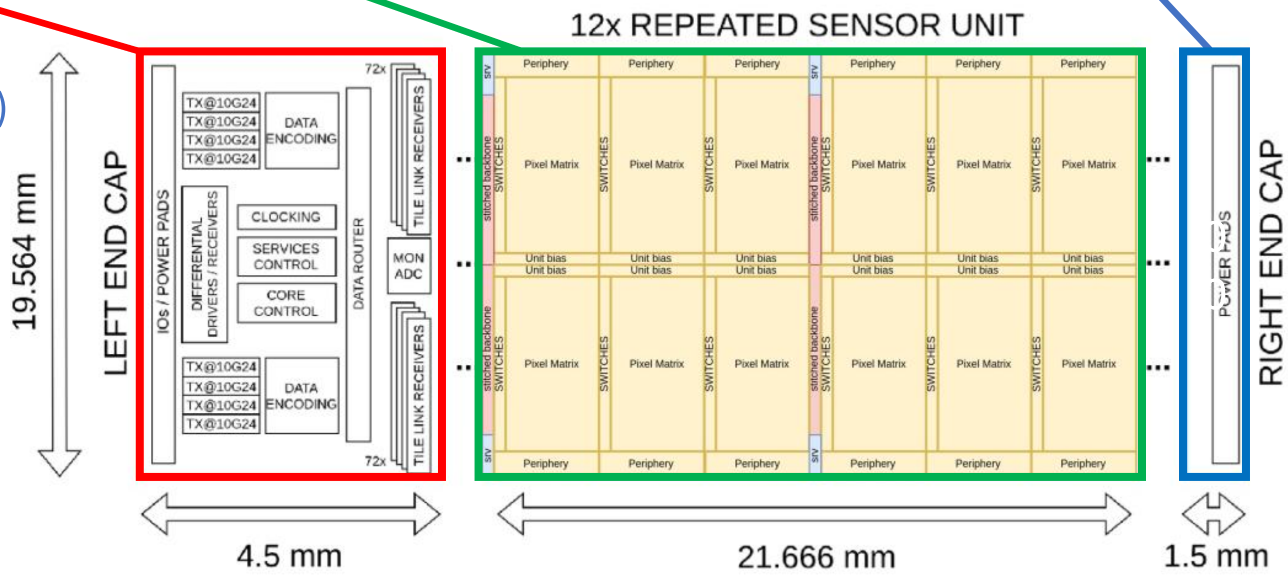
Tracker-only single-pion simulation (0.5–15 GeV/*c*) using a preliminary detector model and ACTS-based combinatorial Kalman-filter track reconstruction

ALICE ITS3 sensor - MOSAIX

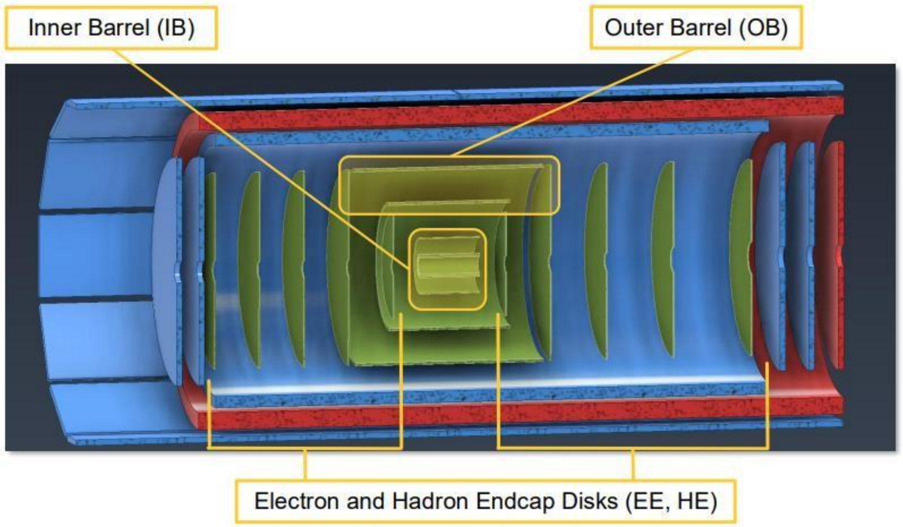


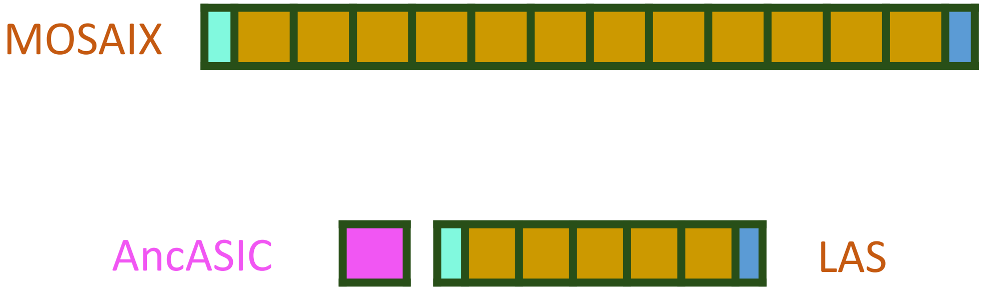
TPSCo 65 nm CIS process

- Interfacing through the Left End Cap (LEC) and Right End Cap (REC)
  - Powering from both sides
  - Control and readout from the LEC only
  - The LEC aggregates eight lpGBT-encoded 10 Gb/s data links
- 12 RSUs per segment, 12 TILEs per RSU
- 144 TILEs can be switched on, biased and read out independently
- Power consumption: 40 mW/cm^2
- Yield target: > 98% of pixels active



SVT sensor variations





One RSU architecture, two sensor implementations

Both designs use the same stitched RSU building block, with sensor size and services optimised for each detector region

Inner barrel — MOSAIX

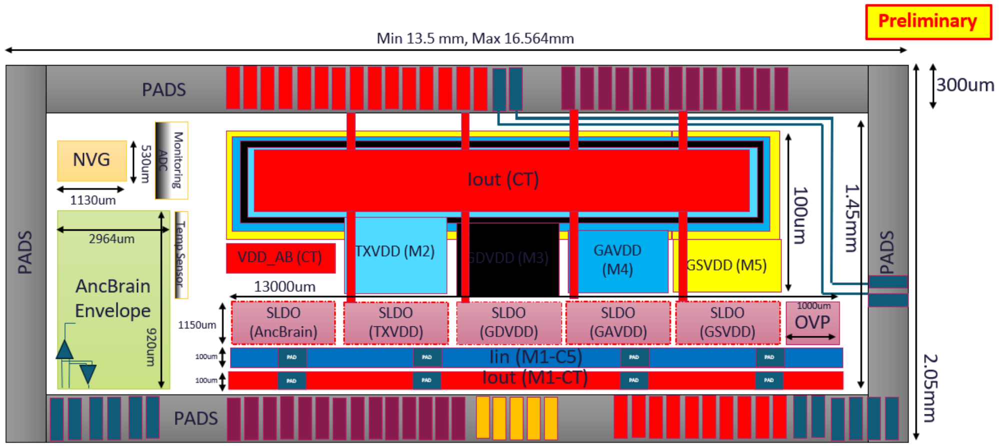
- Wafer-scale sensor developed for ALICE ITS3
- LEC + 12 RSUs + REC
- Direct powering: four power domains plus sensor bias
- 7 slow-control links (5 Mb/s; 160 MHz clock)
- 8 lpGBT-encoded 10 Gb/s data links

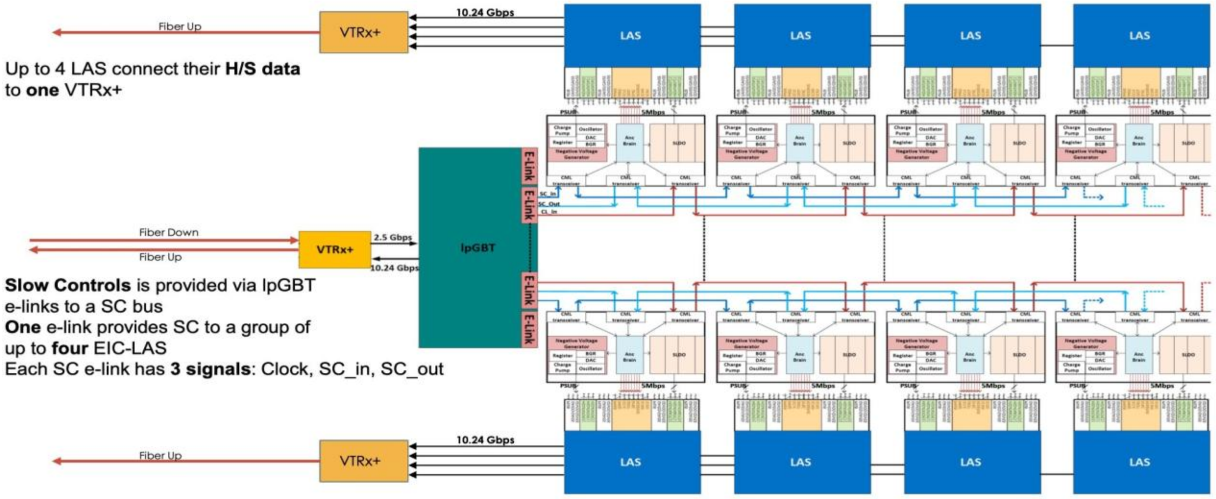
Outer barrel and endcap disks — EIC-LAS

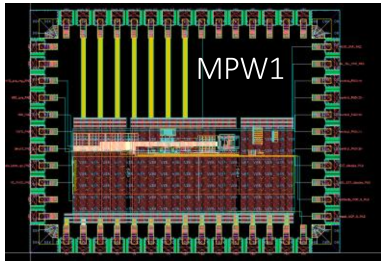
- Shorter sensor, optimised for yield and detector coverage
- LEC + 5 or 6 RSUs + REC
- Single data link, sufficient for the lower bandwidth requirement
- Ancillary ASIC provides serial powering and multiplexed slow control
- Optimised to reduce material and simplify integration

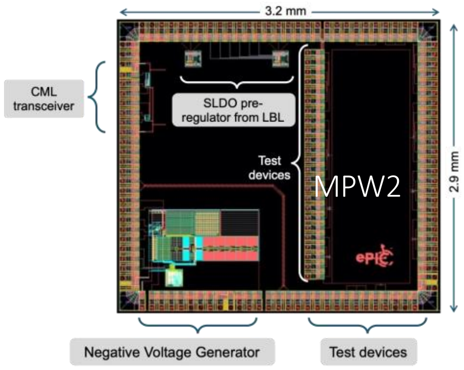
AncASIC

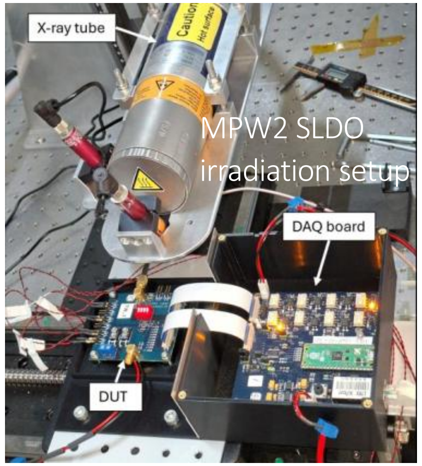
- **Connects each EIC-LAS sensor to counting-room services, providing power conditioning and slow-control distribution**
  - Required for the outer barrel and endcap disks to meet material-budget and integration constraints
  - Provides serial powering and multiplexed slow control
  - XFAB 110 nm PD-SOI process
- **Main functional blocks**
  - SLDOs: local voltage regulation for serial powering
    - Pre-regulator
    - Bandgap reference
    - SLDO core circuit
  - NVG: programmable negative sensor-bias generation
  - AncBrain: configuration and slow-control multiplexing





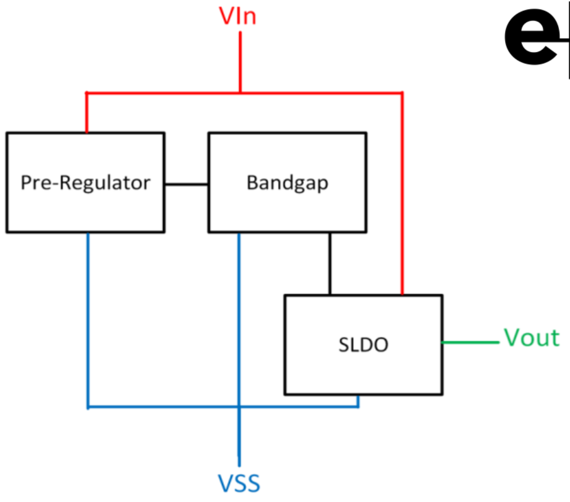


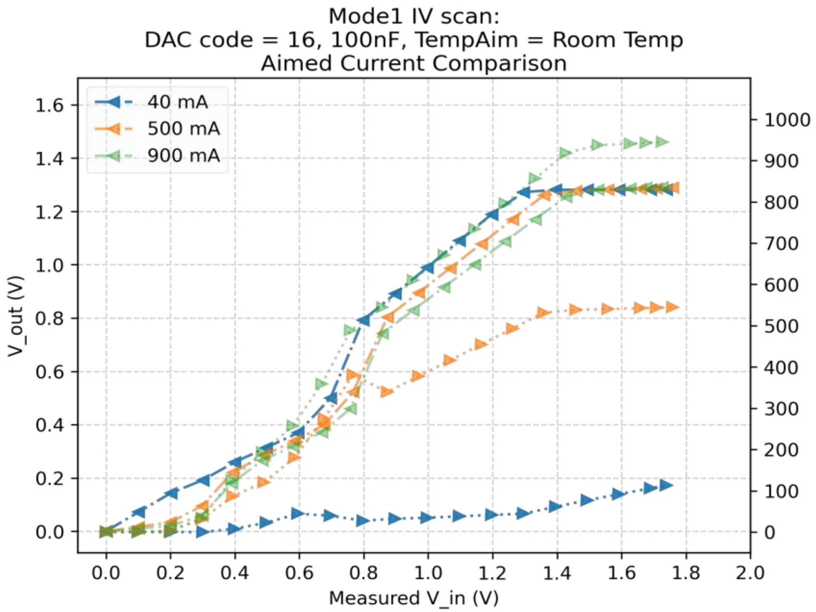


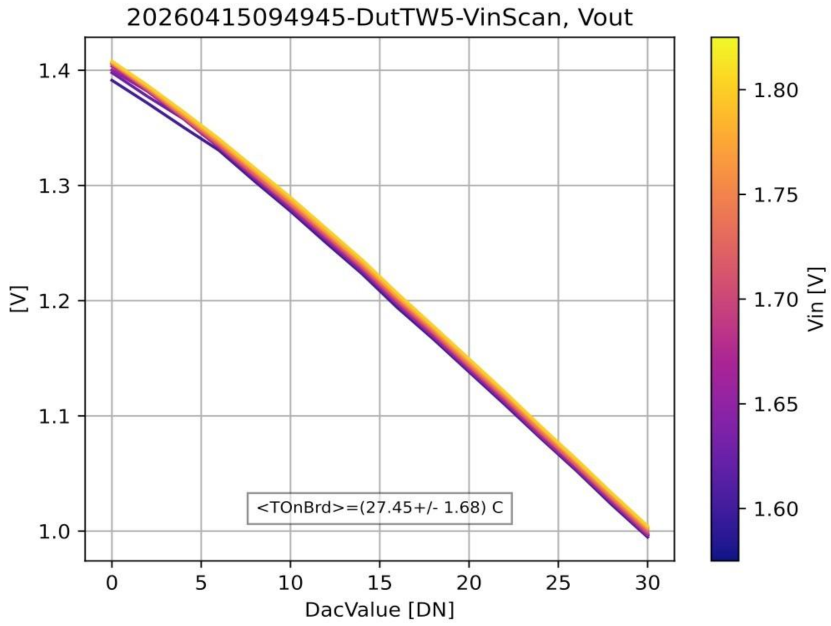


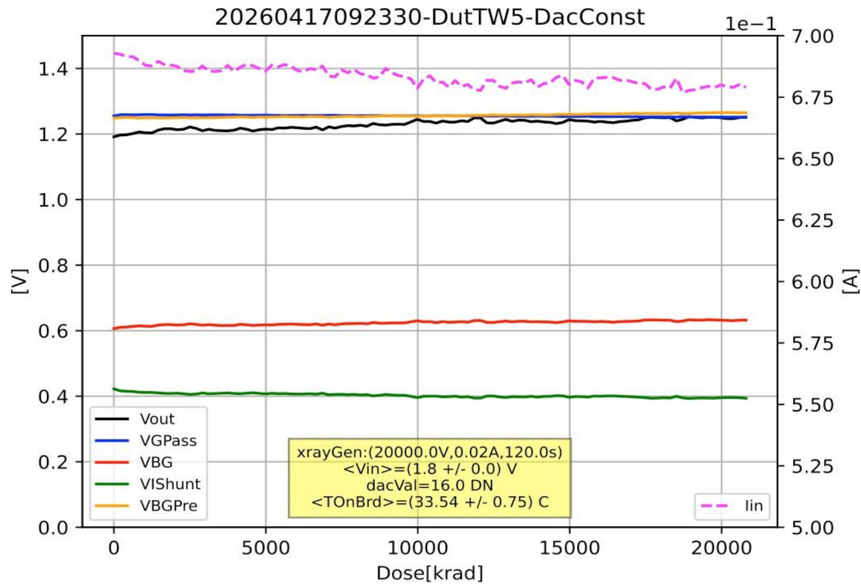
MPW2 SLDO

- Power-up verified across the specified loads at room temperature and at -20 °C
- V_{out} tunable within the designed range of approximately 1.1–1.4 V
- Limited voltage shift up to 20 Mrad—well beyond the expected ePIC TID of less than 500 krad



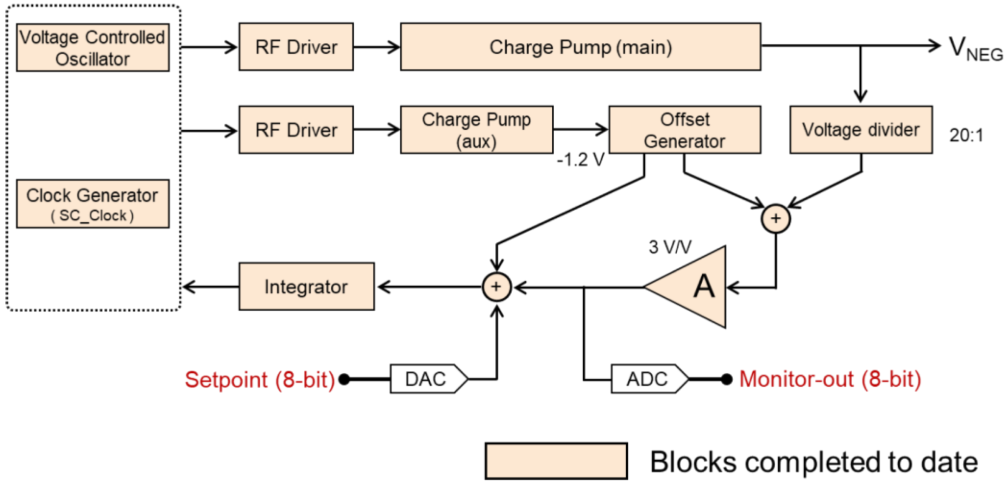


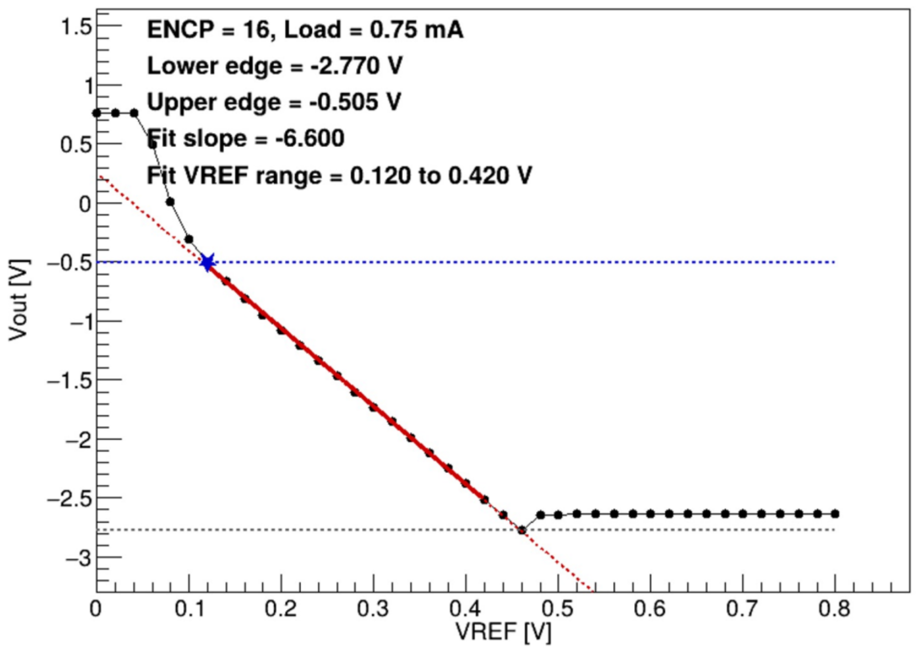


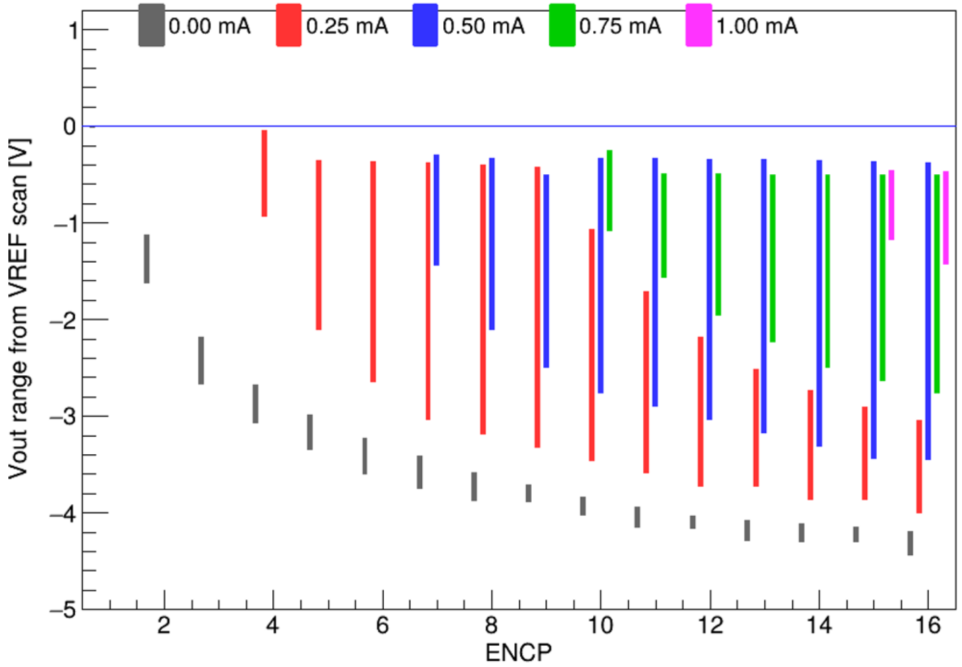


MPW1 NVG

- Validated target linear response: $V_{out} = -(20/3)V_{REF}$
- Confirmed expected V_{out} dependence on load current and the number of enabled charge-pump branches (ENCP)



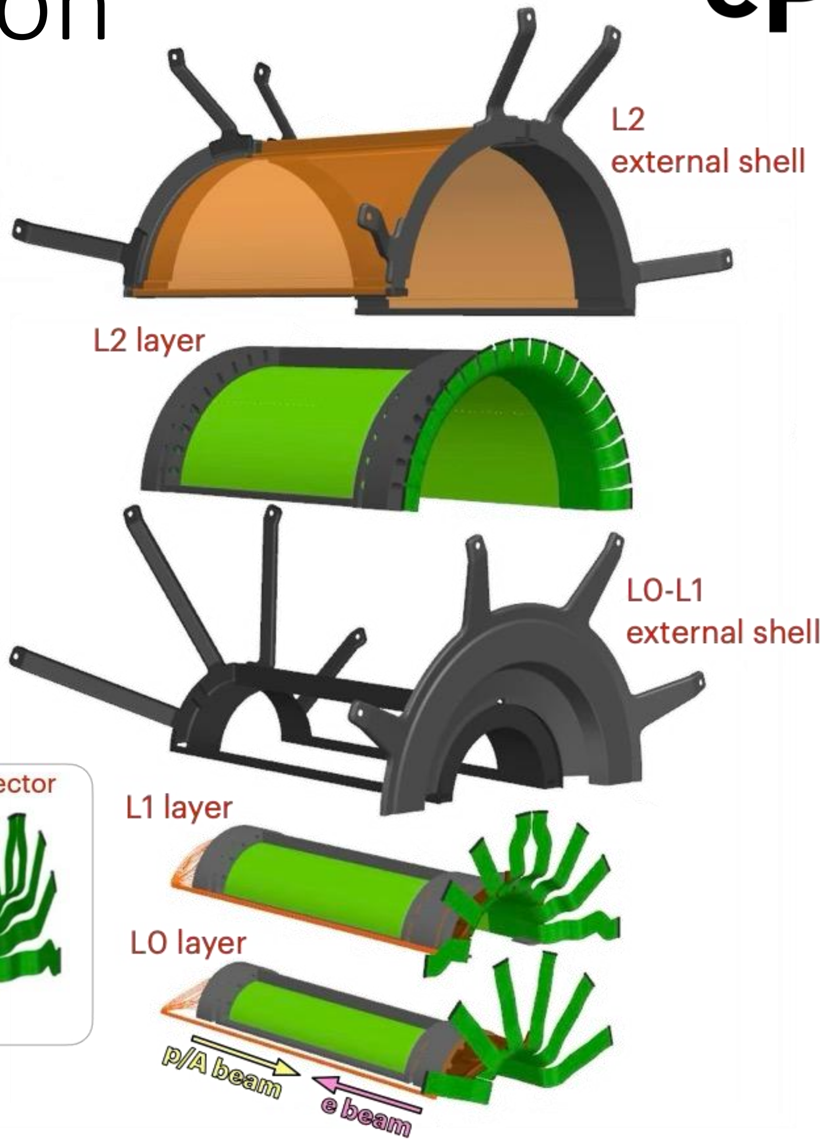


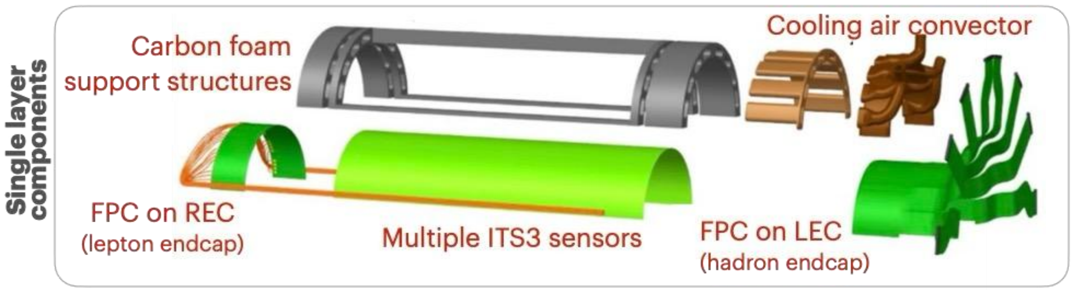


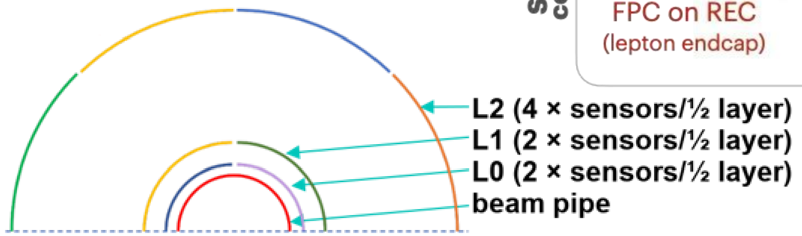
Inner barrel: ultra-thin bent silicon

Ultra-thin bent silicon for precision vertexing, adapting the ALICE ITS3 wafer-scale sensor and ultra-thin detector concept

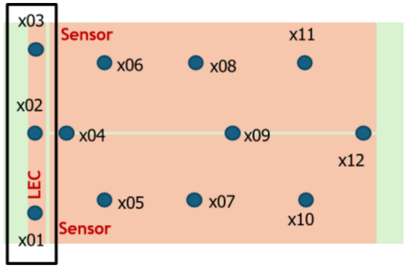
- Three cylindrical layers—L0, L1 and L2—at radii of 38, 50 and 126 mm
- Active length: 26 cm
- Sensor thickness ≤ 50 µm, bent into cylindrical half-layers
    - L0 and L1: two sensors per half-layer
    - L2: four sensors per half-layer
- Ultra-light carbon-foam local supports and carbon-fibre composite global structures
- Air cooling through the gaps between layers
- Layer positions optimised for transverse impact-parameter resolution within beam-pipe, mechanical and service constraints







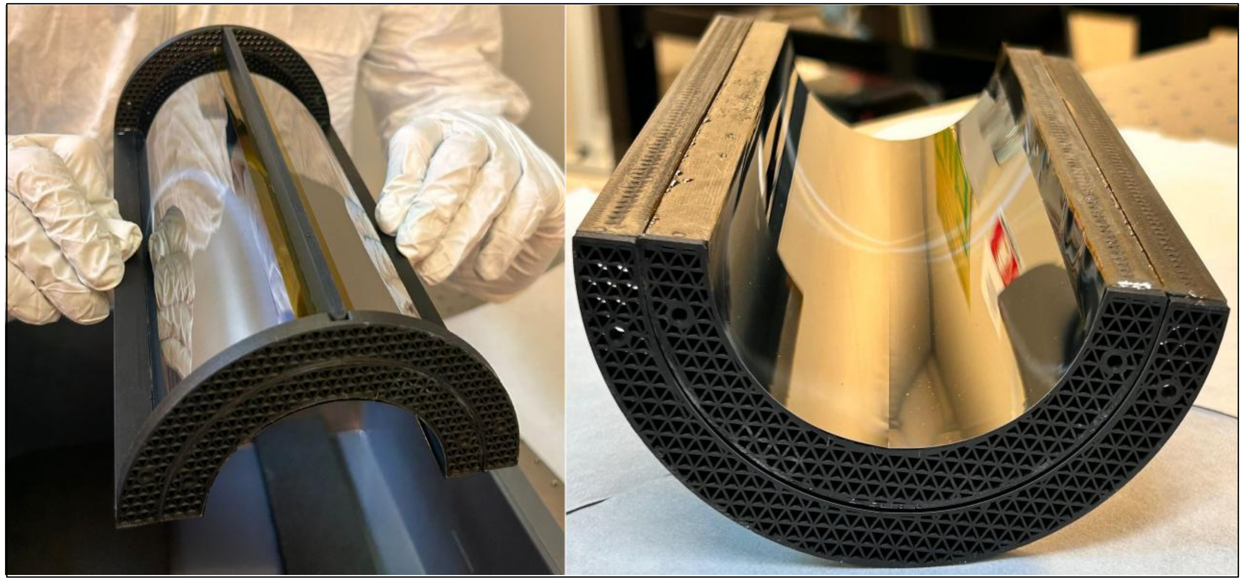
IB: assembly and cooling studies

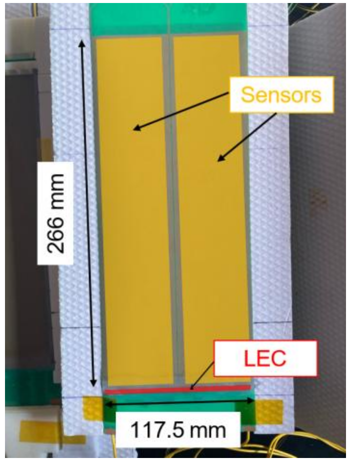


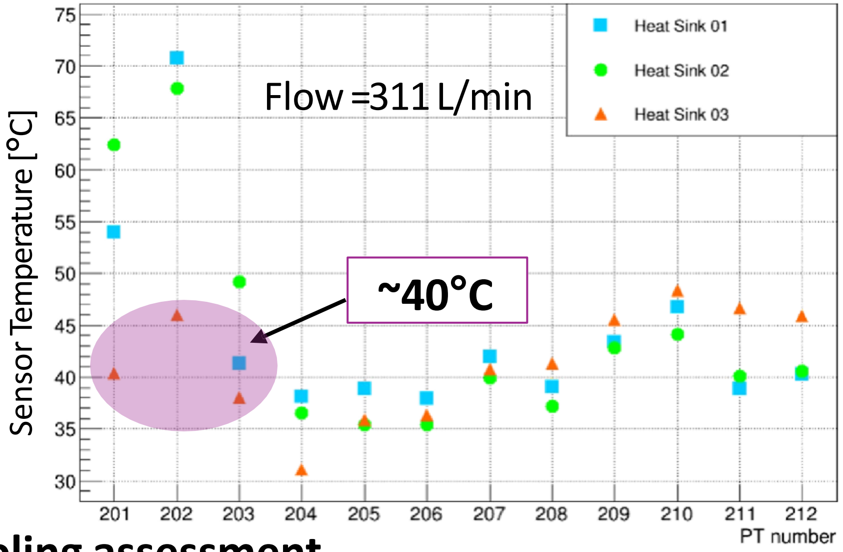
Inner-barrel layer assembly: defined for L0–L1, extending to L2

- Tooling and assembly procedures are well defined for L0–L1
- Core assembly sequence:
  - Bend the silicon sensors to the required radius
  - Wire-bond the sensors to the FPCs
  - Glue the carbon-foam local support structures
  - Bond the layers to one another or to the external support shell

L0-L1 bent-layer prototype





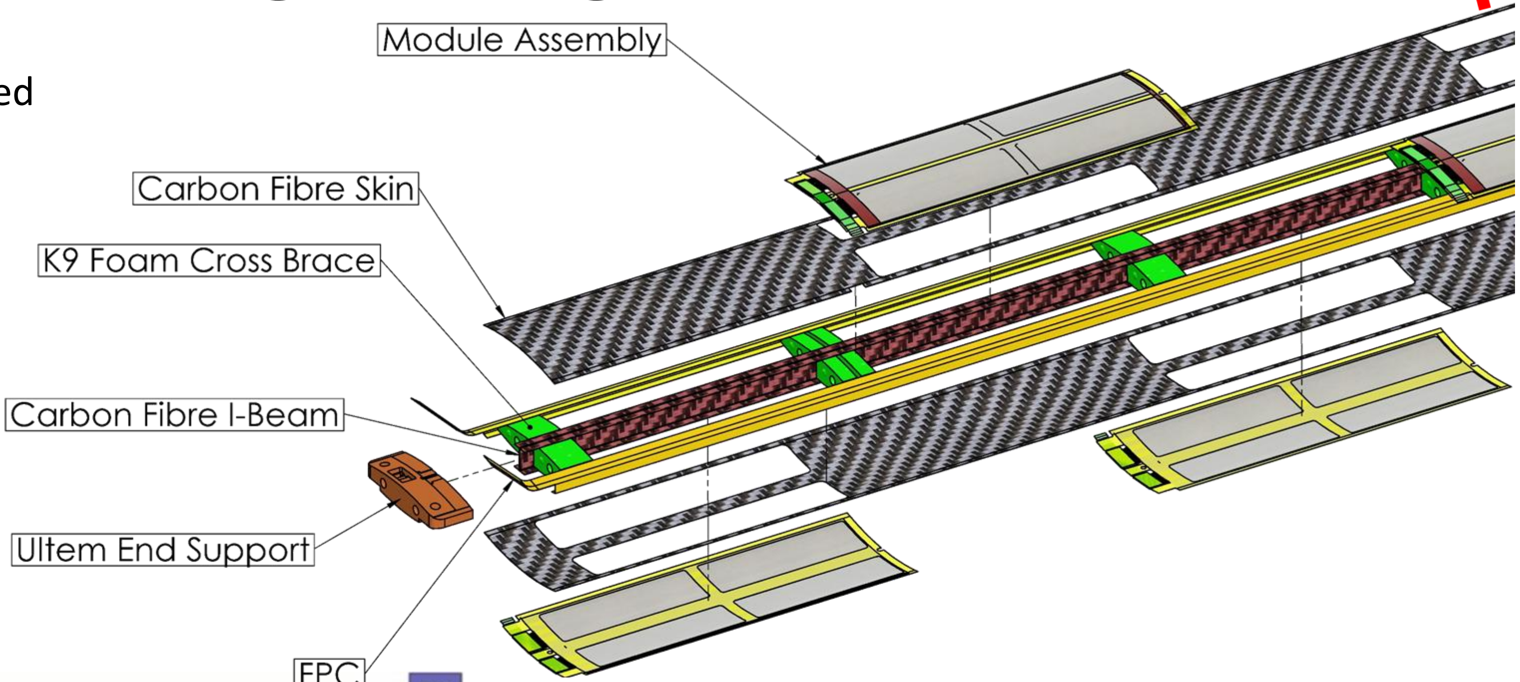


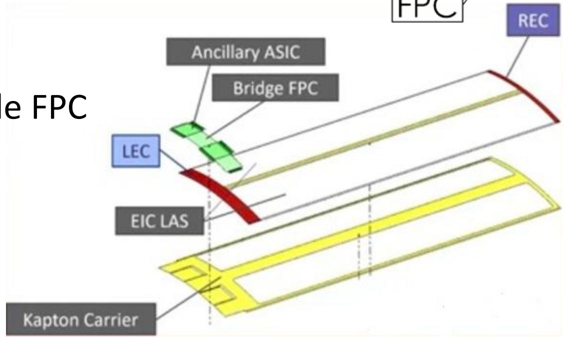
Preliminary air-cooling assessment

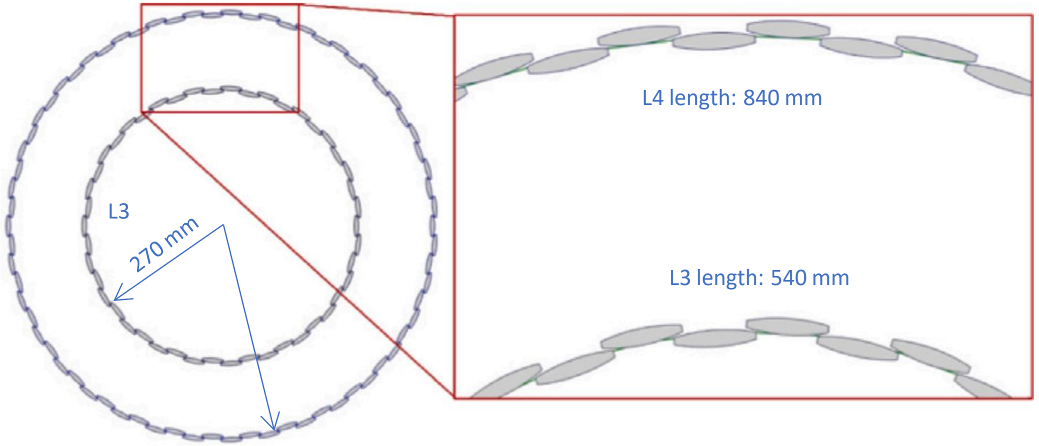
- Simplified L0–L1 thermal mock-up tested with 40 mW/cm² sensor and 1.6 W/cm² LEC power densities
- Sensor temperatures decrease with increasing airflow, supporting the feasibility of air cooling
- Three low-density, 3D-printed aluminium LEC heat sinks were evaluated as an alternative to the carbon-foam baseline
- At the highest tested airflow, the best-performing aluminium heat sink keeps the measured LEC temperatures at approximately 40–45 °C
- Tests with geometry and materials closer to the final design are the next step

Outer barrel: integrated lightweight staves

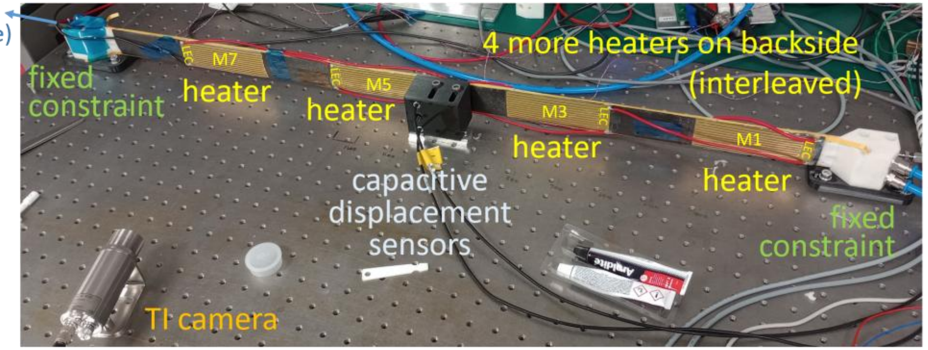
- **Two cylindrical layers** built from staves with integrated cooling and electrical interfaces
- Closed, hollow stave structure comprising
  - Central carbon-fibre I-beam
  - Carbon-foam cross-ribs
  - Carbon-fibre skins with openings for the modules
  - Stave FPC completing the lateral enclosure
- Modules mounted alternately on the two faces, with overlap to maintain continuous active coverage
- Air cooling through the hollow stave structure
- Module
  - 2 EIC-LAS sensors and 2 AncASICs on one module FPC
  - Silicon dies wire-bonded to the module FPC
  - Module FPC spTAB-bonded to the stave FPC
- Sensor population per stave
  - L3: 4 modules along the stave = 8 × 6-RSU EIC-LAS sensors
  - L4: 8 modules along the stave = 16 × 5-RSU EIC-LAS sensors





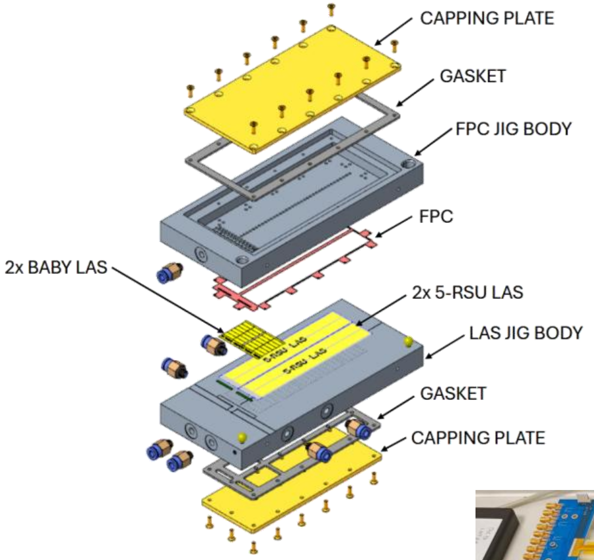


OB: module and stave validation

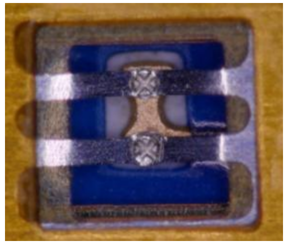


Module assembly

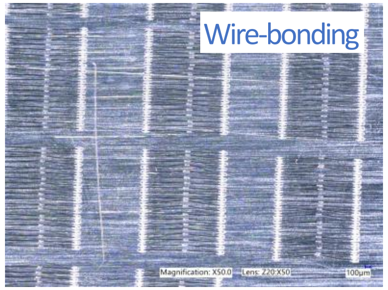
- Satisfactory spTAB and wire-bonding results obtained with candidate FPC foils
- Module-assembly jigs designed
- The spTAB-bonded main-FPC is currently under test
- Dummy silicon LAS and AncASIC dies with bonding pads are available



Assembly jig design



spTAB bonding

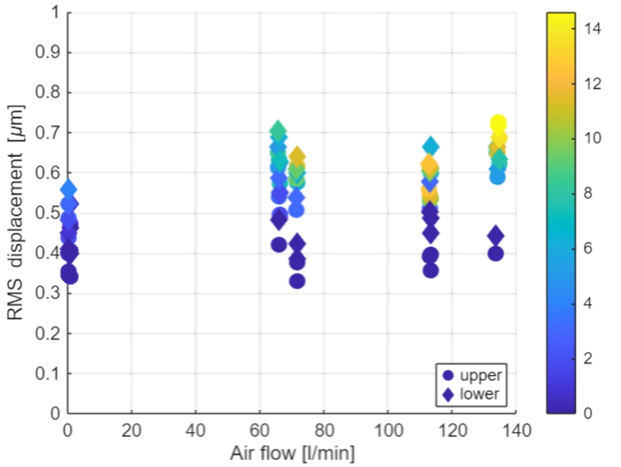


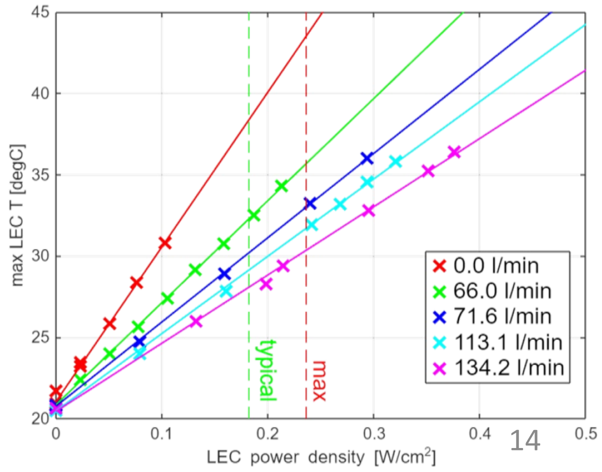
Wire-bonding

spTAB-bonded FPC

Stave thermo-mechanical mock-up

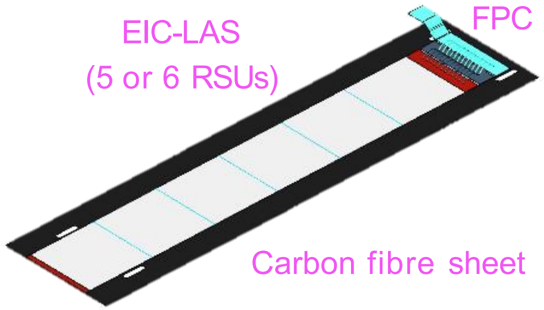
- 50 µm steel shims with Kapton/Cu heaters reproduce the AncASIC, LEC and RSU power loads
- K9 foam cross-ribs with K13C2U/EX1515 carbon-fibre prepreg skins in a 0°/90° lay-up
- Measured AncASIC, LEC and RSU temperatures remain within specification
- Airflow-induced displacement remains below 1 µm RMS (5 kHz sampling in 1 s windows)

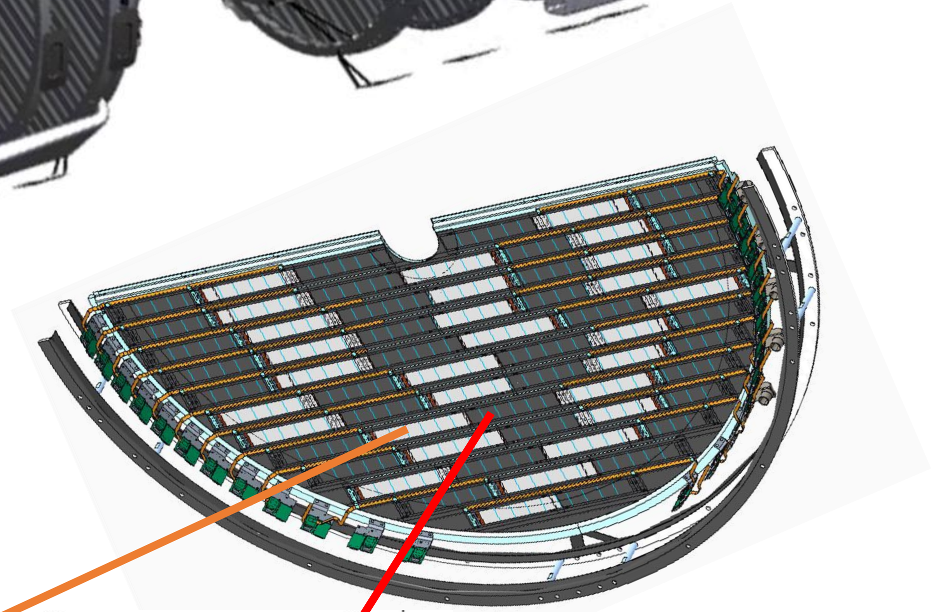


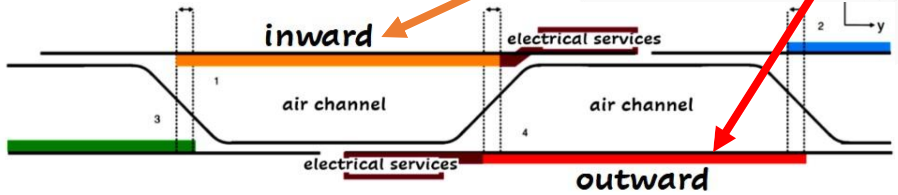


Endcaps: lightweight corrugated disks

- **Two endcaps, each comprising five disks with integrated cooling and electrical interfaces**
- Each disk consists of
  - Carbon-composite corrugated core
  - Tiled face sheets assembled from sensor modules
  - Stave FPCs routed alongside the modules
- Modules mounted on both sides of the disk, alternating between inward- and outward-facing orientations
- Air cooling through channels within the corrugated core
- Each module integrates
  - One 5- or 6-RSU EIC-LAS sensor
  - One AncASIC
  - One module FPC
  - One carbon-fibre support sheet
- Eight module variants accommodate
  - 5- or 6-RSU sensor configurations
  - Inward- or outward-facing orientation
  - FPC routing direction







Endcaps: mechanical and thermal validation

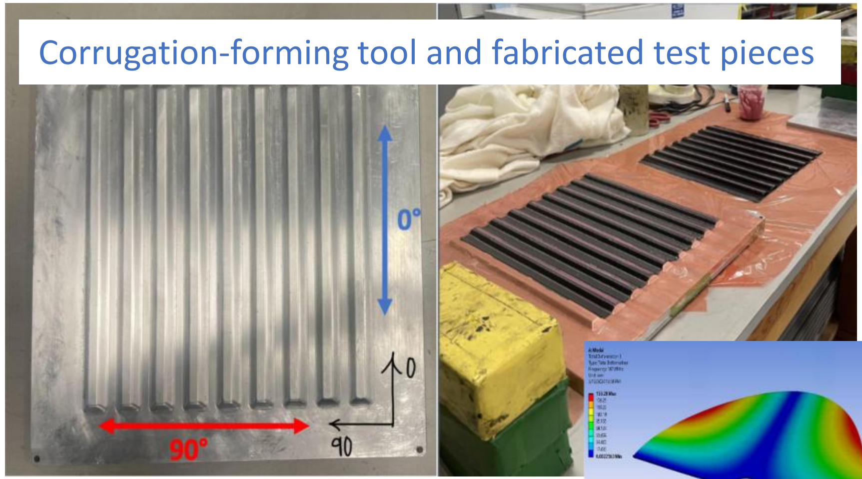
Mechanical validation

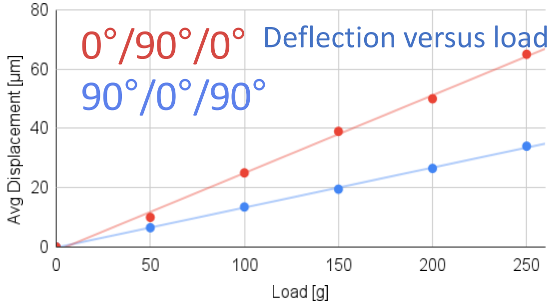
- Three-ply support structures made from unidirectional K13C2U high-thermal-conductivity carbon-fibre prepreg
  - Flat module sheet - [0°/90°/0°]: thermal advantage
  - Corrugated core - [90°/0°/90°]: better stiffness
- Three-point flexural tests show about 50% lower deflection with [90°/0°/90°], supporting its selection for the corrugated core
- Modal FEA predicts the first structural mode at approximately 108 Hz

Preliminary thermal performance

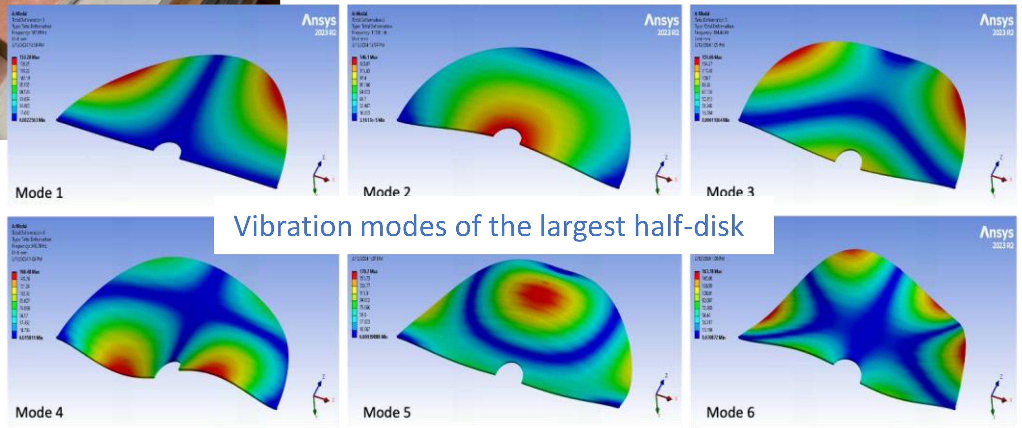
- Heater mock-up reproduces the power-density distribution of the LEC and RSU regions
- Temperature peaks correspond to the high-power LEC regions and decrease with increasing airflow
- With 25 °C inlet air, the peak temperature approaches 40 °C at the highest tested airflow; cooler inlet air would provide additional margin

Corrugation-forming tool and fabricated test pieces



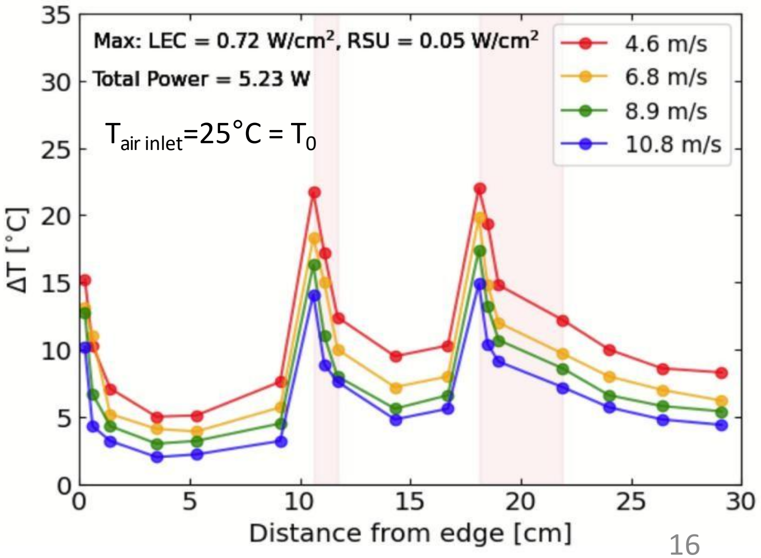


Mode	Frequency [Hz
1.	107.69
2.	117.61
3.	164.44
4.	346.76
5.	392.68
6.	432.55



Vibration modes of the largest half-disk

Single-channel heater mock-up



Summary

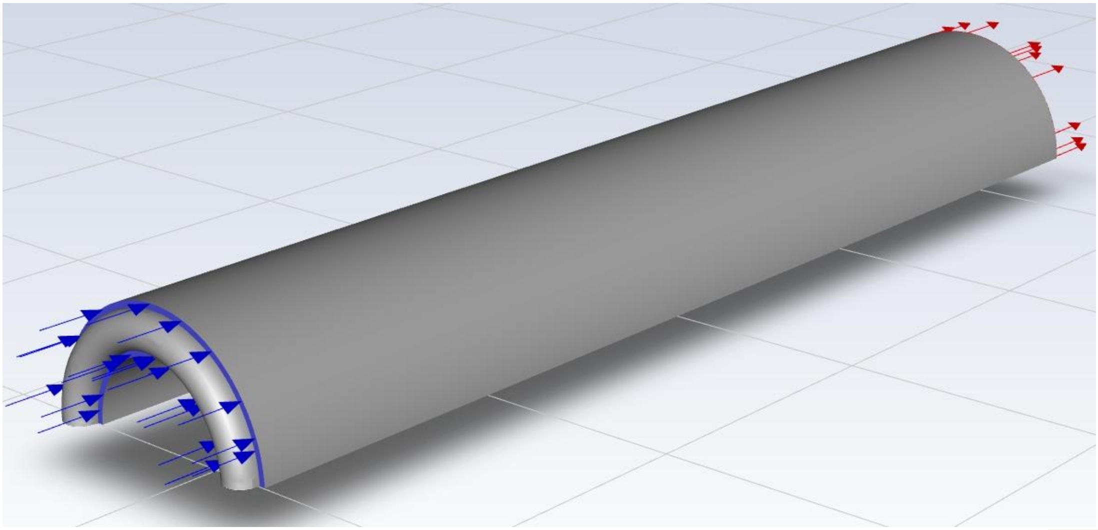
- The ePIC SVT is a **large-acceptance, high-granularity and ultra-low-mass MAPS detector** for precision tracking and vertexing

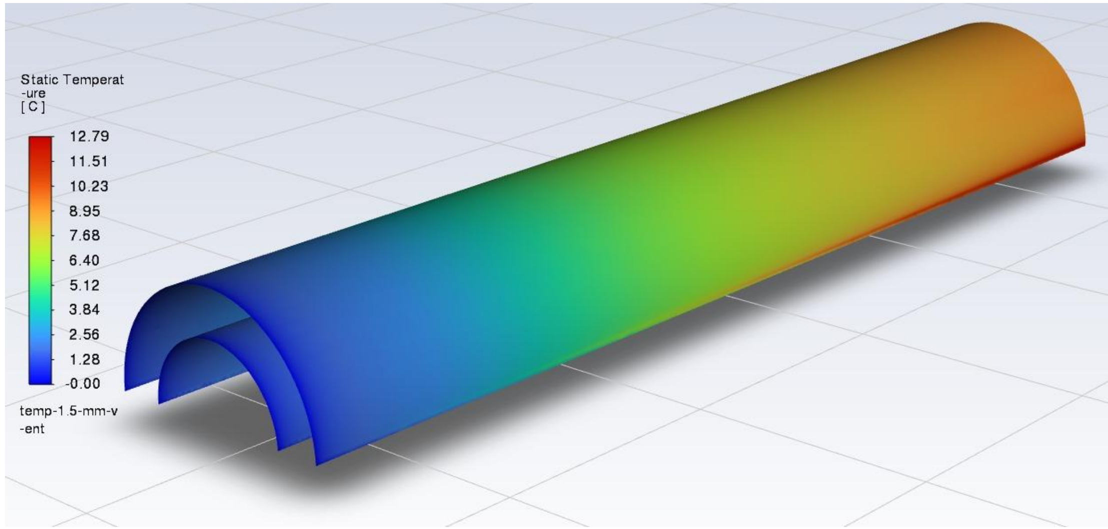
- **Sensors and electronics:** MOSAIX for the Inner Barrel; EIC-LAS and AncASIC for the Outer Barrel and disks. Key AncASIC blocks have demonstrated their intended functionality; development and tests are underway
- **Inner Barrel:** L0–L1 assembly procedures established; L2 tooling and more representative cooling tests are in progress
- **Outer Barrel:** FPC bonding and mechanical stave mock-up tests are encouraging; module assembly and stave development are ongoing
- **Endcap disks:** Corrugated carbon-composite support prototypes show encouraging mechanical and thermal performance; sensor integration, module development and larger-scale disk validation continue

- Development remains aligned with SVT **installation currently foreseen in 2032**

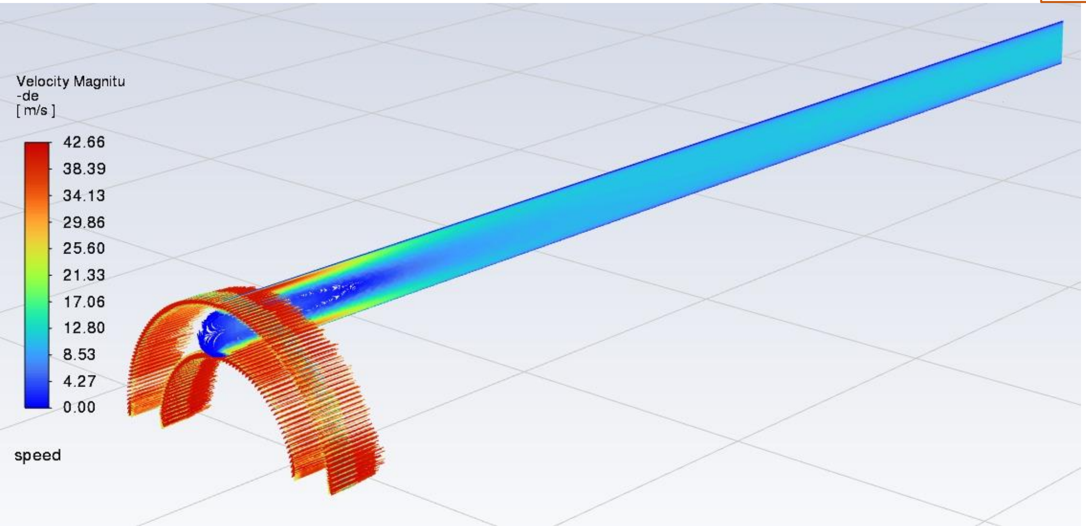
Backup

Preliminary CFD simulations on IB





Preliminary



Sensor temperature simulations

- Air speed average: 10 m/s
- ΔT_{AIR}=8 ℃ measured in preliminary tests, consistent with what seen here