SVT Design Status

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10th EIC DAC Meeting
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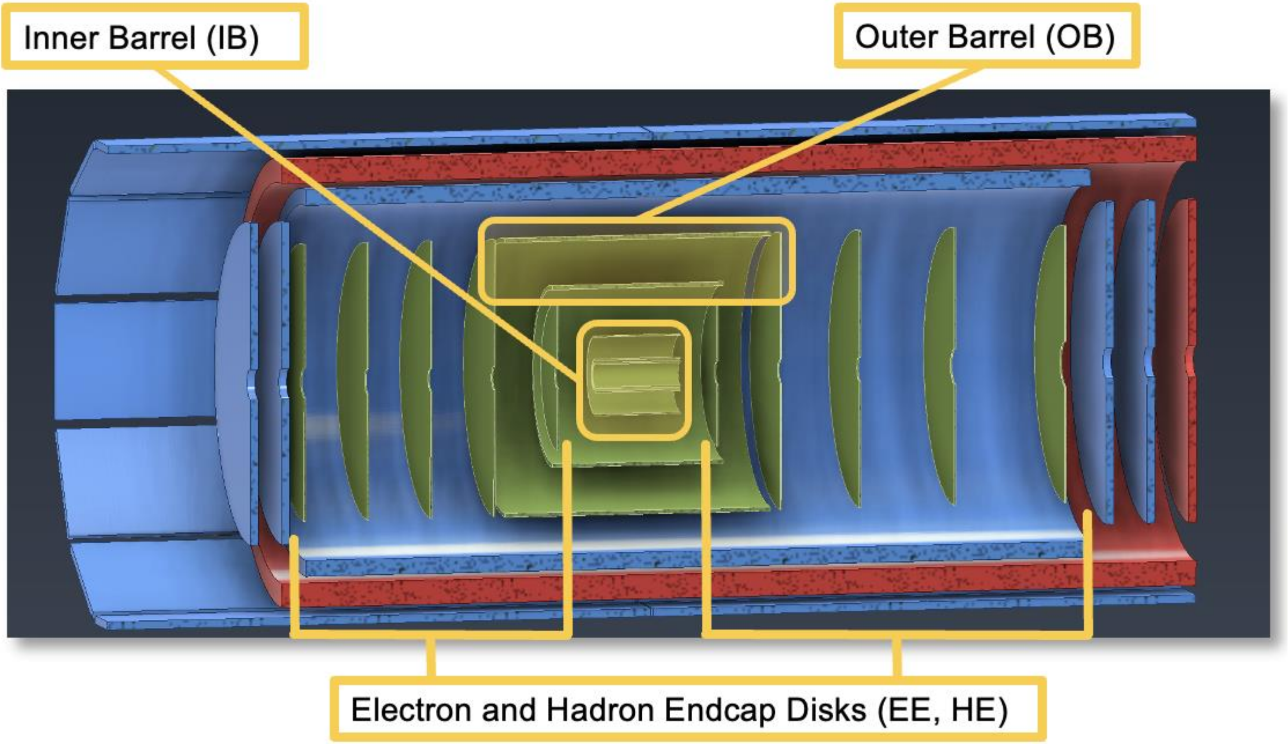
SVT Concept

Inner Barrel (IB)
Three layers, L0, L1, L2,
Radii of ~ 36, 48, 120 mm
Length of approx. 27 cm
x/X_0 ~ 0.05% per layer
Curved, thinned, wafer-scale sensor

Outer Barrel (OB)
Two layers, L3, L4
Radii of ~ 27 and 42 cm
X/X_0 ~0.25% and ~0.55%
More conventional structure w. staves

Electron/Hadron Endcaps (EE, HE)
Two arrays with five disks
x/X_0 ~0.25% per disk
More conventional structure w. halves



Constrained by beampipe + 5mm at the inner barrel and disk radii; r_{SVT} < 43 cm; -105 < z_{SVT} < 135 cm,

Lengths for L2—L4 increase so as to project back to z = 0; disk radii adjust accordingly,

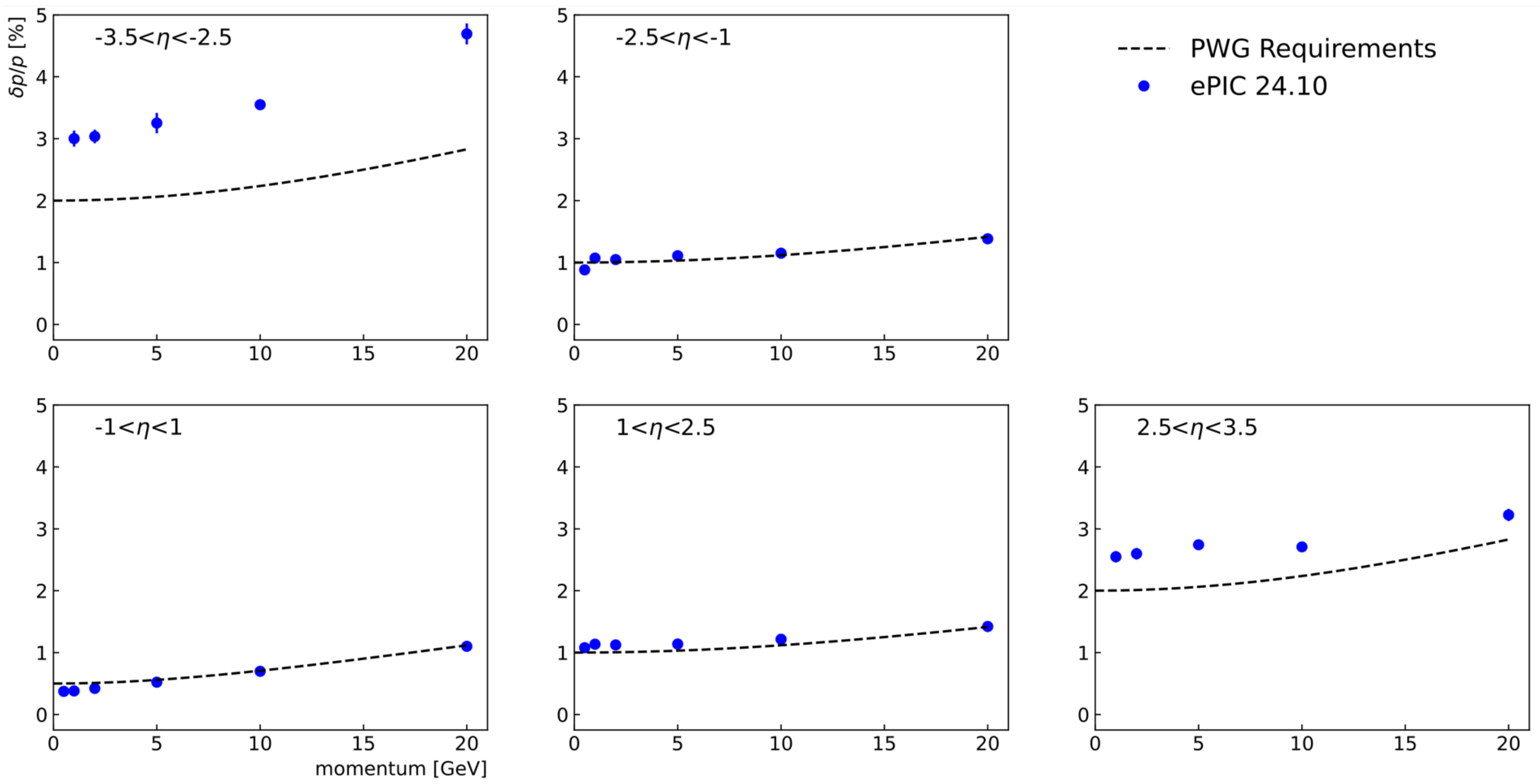
Optimized for acceptance and resolutions within constraints,

Clamshell of detector halves; beam-pipe bake-out with SVT installed,

OB staves, IB halves, and half Disks will be shipped to BNL – installation sequence OB, IB, disks.

ePIC Tracking Simulations

relative momentum resolution



Simulated resolutions shown for single pion tracks,

Based on actual track finding and reconstruction,

Increasingly realistic descriptions of active elements, supports, and services,

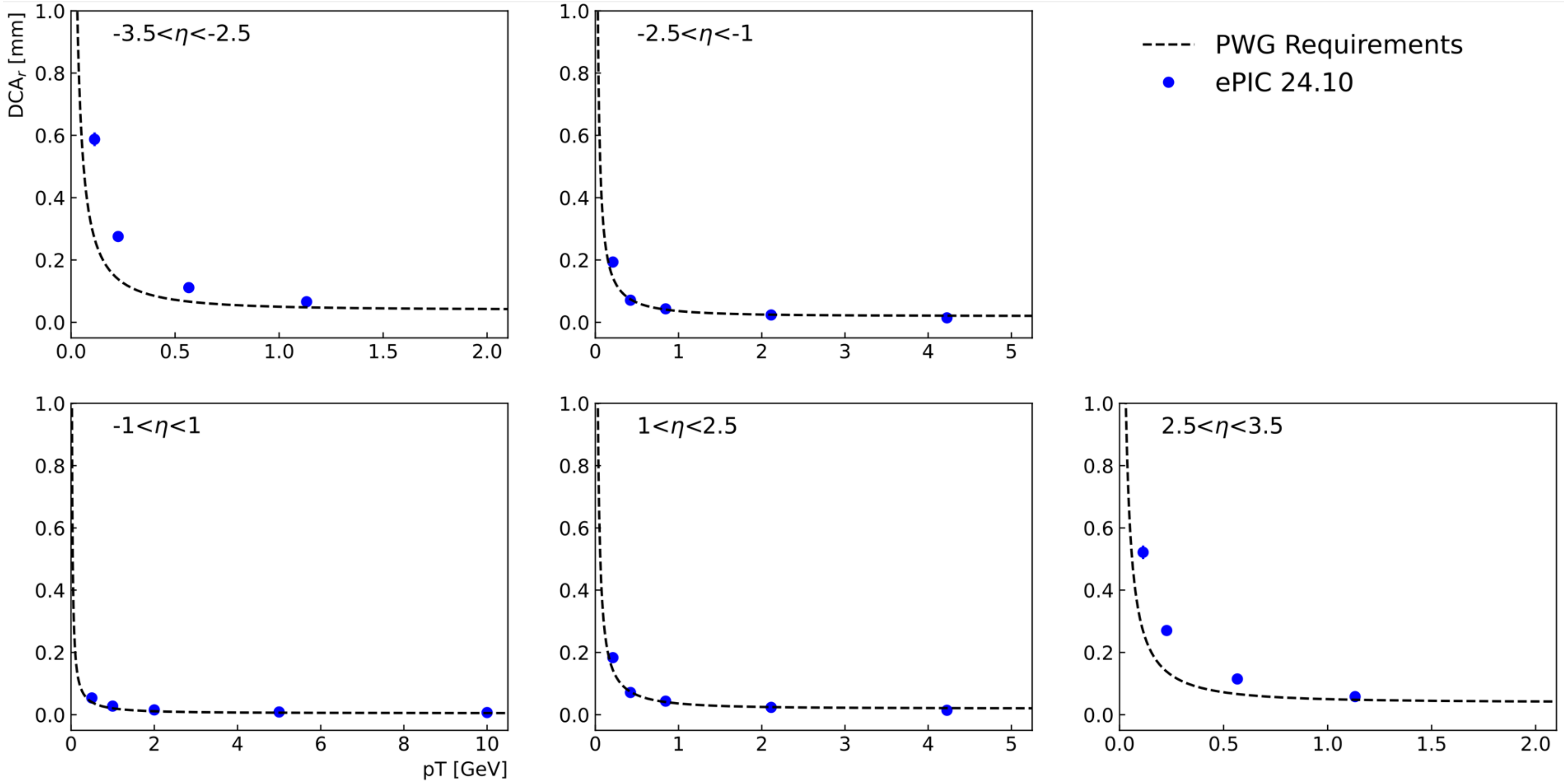
Simulations have been extended to deep-inelastic scattering events; detector noise and backgrounds ongoing.

Difference between most forward/backward resolutions due to asymmetric constraint on spatial extent along the beamline,

Rely on combination with precision EM calorimetry to achieve electron resolutions necessary for EIC science program.

ePIC Tracking Simulations

DCA



Simulated resolutions shown for single pion tracks,

Based on actual track finding and reconstruction,

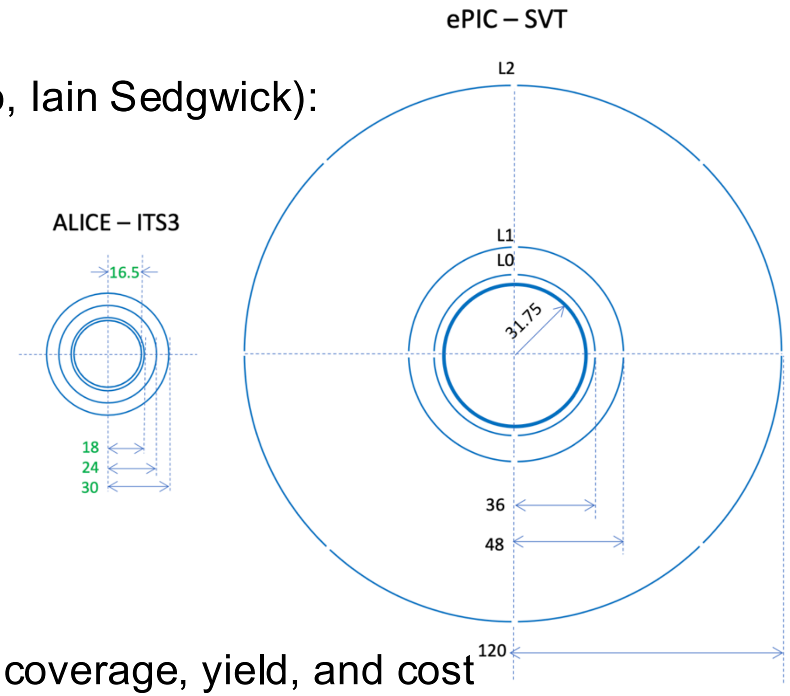
Increasingly realistic descriptions of active elements, supports, and services,

Simulations have been extended to deep-inelastic scattering events; detector noise and backgrounds ongoing.

Fast simulations show least resolution sensitivities to material budgets in outermost barrel layer and outermost disks.

SVT Sensor and Ancillary ASIC

Recall sensor and ancillary ASIC development (preceding talks by Joao de Melo, Iain Sedgwick):



1. ITS3-like Inner-Barrel layers

- Re-use the **ITS3 sensor** as is
- Adapt the ITS3 detector concept to the EIC:
  - Mechanics of bent layers — sensor and support — for the larger EIC radii
  - Services and cooling design and routing for the EIC acceptance requirements
  - Considerations related to in-situ beam-pipe bake-out at the EIC

2. EIC variant for the staves in the Outer Barrel and the Endcap Disks

- **EIC Large Area Sensor (LAS)**, i.e. ITS3 sensor optimized for large-area coverage, yield, and cost
  - EIC LAS will be stitched, but not to wafer scale; functionality and interfaces stay largely unchanged
  - Size(s) of the EIC LAS defined by requirements for full coverage and yields, cost; studies have shown 5 and/or 6 RSUs
  - Approximately 4,000 EIC-LAS sensors will be used in the OB and Disks,
- More conventional carbon composite mechanical support structures with integrated cooling
- Lightweight electrical interfaces with **Ancillary ASIC** and aluminum flexible printed circuit technology

Ongoing characterization – wafer-probing development, irradiation and test beams, thermal and mechanical tests,

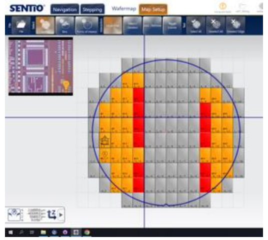
Preparation for production testing – probing of all ER3, EIC-LAS, ancillary ASIC.

MOSAIX wafer probing development

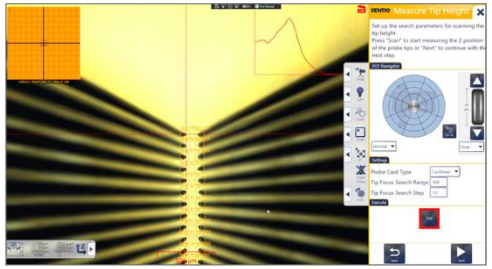
- Wafer probing development for MOSAIX ongoing at CERN with significant SVT contribution
- Goal: automated high speed wafer probing with vertical probe card

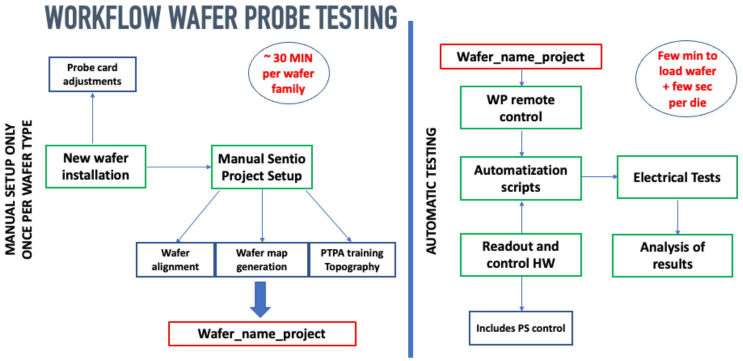
- Commissioning and first tests in **non-automated mode**
- Development of **automatization SW** tools

Wafer map generation



Probe To Pad Alignment training

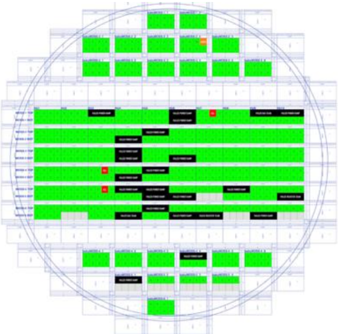




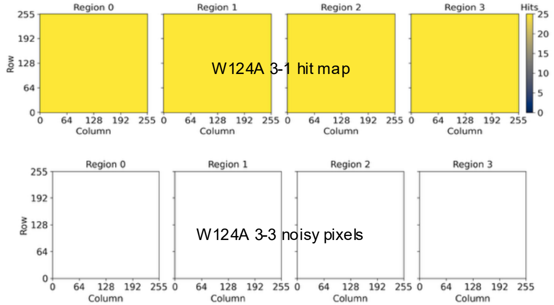
- **Automated probing** of an ER1 wafer with **cantilever probe card**, ER1 DAQ and analysis tools

Tested all 25 babyMOSS top unit in the wafer in 25 minutes with comparable results to ALICE

ITS3 results



SVT results

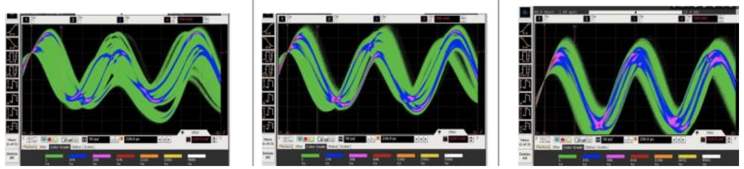


- Tests of NKF7 transmitter chip with **vertical probe card**

10 GBPS FIXED PATTERN WITH DIFFERENT VOLTAGE ACTIVE PROBE

- Fixed pattern set to: 4h'5555

@1.2V | @1.3V | @1.4



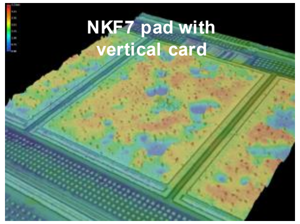
- > 600 mV amplitude
- Eye width of > 50 ps

- > 650 mV amplitude
- Eye width of > 80 ps

- > 700 mV amplitude
- Eye width of > 80 ps

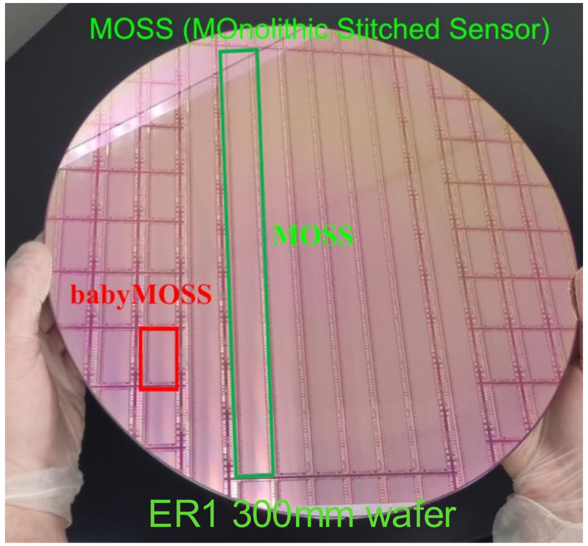
The results obtained are relatively similar to the results of testing by chip designers 5

Ongoing study of the penetration of the needles as function of the applied force to optimise electrical contact between needle and pad (Optical Microscopy)

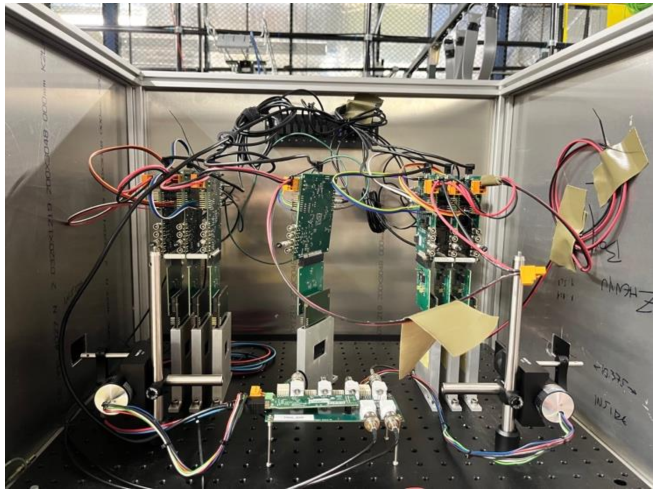


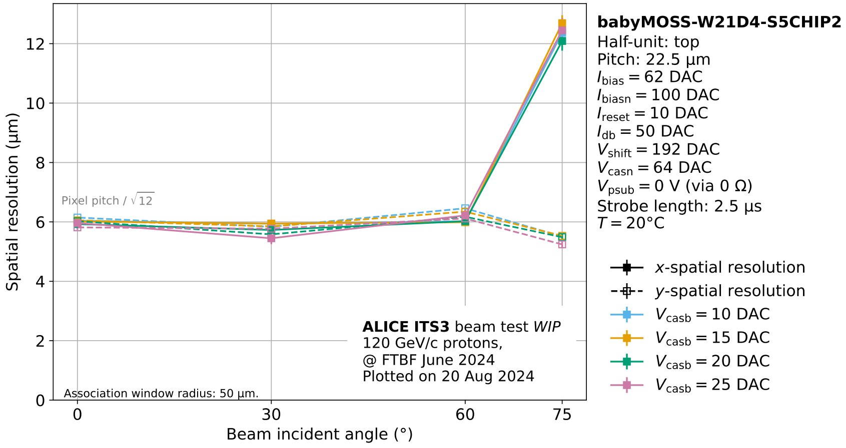
ER1 beam and irradiation tests

- Single RSU ER1 sensor, a.k.a. “babyMOSS”, tests in climate chamber, beams at FNAL and JLab; irradiation campaigns at LBNL and UC Davis
- Goals: quantify point resolution and its angular dependence, fake hit rate and signal efficiency in dependence of temperature and irradiation, handling and assembly tests
- Main effort now shifting to ER2 and ancillary ASIC MPW-1,2

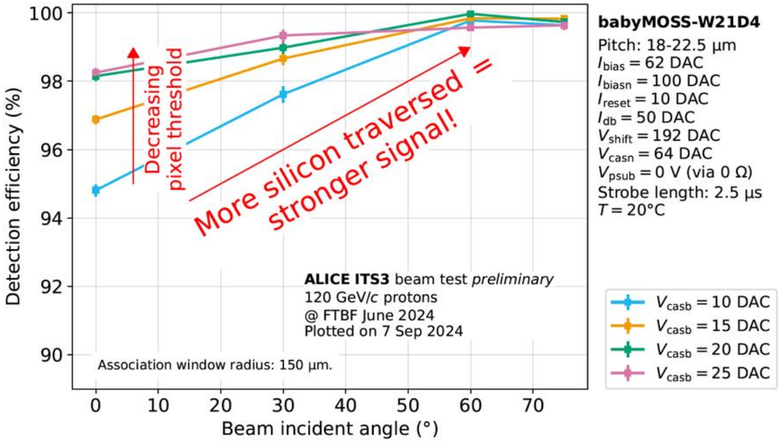


Test beam at FNAL - 120 GeV pions- ER1 telescope



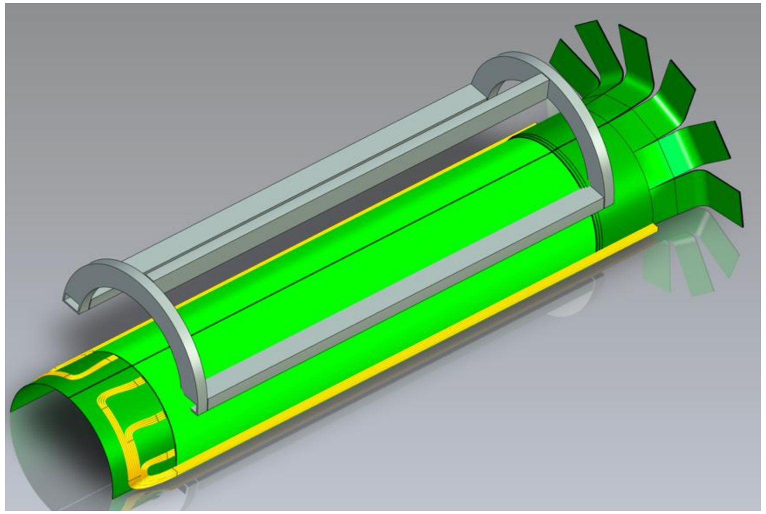


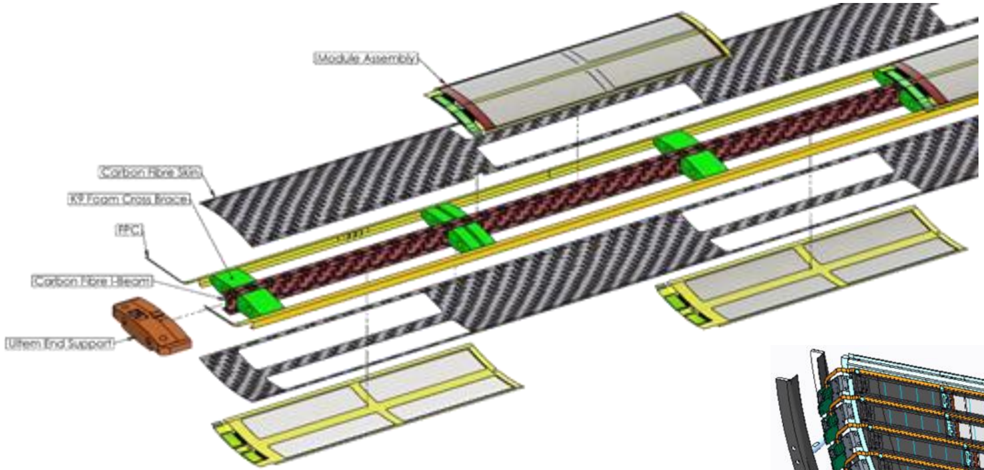
Spatial resolution at largest angle dominated by multiple scattering in the sensor holding frame

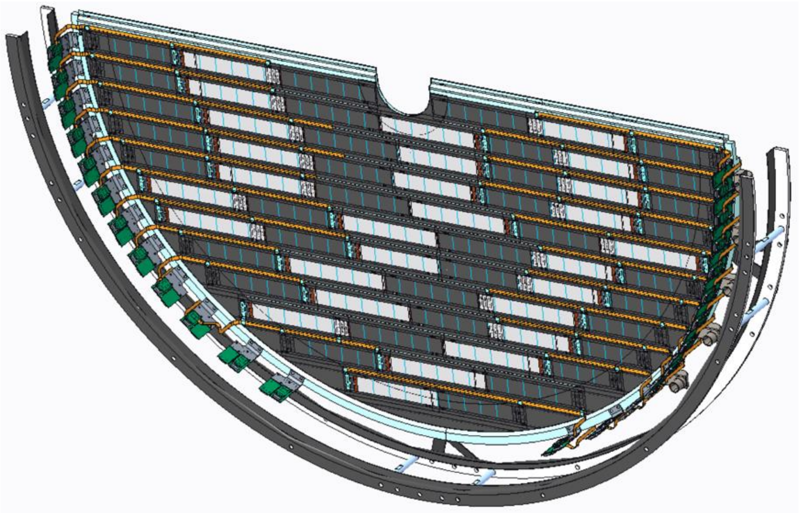


Mechanical design and test articles

- Ongoing effort for engineering test articles for IB layer, OB stave, disk quadrant aimed at demonstrating
  - Assembly, tooling, and procedures
  - Mechanical performance
  - Thermal performance
  - Feedback into design

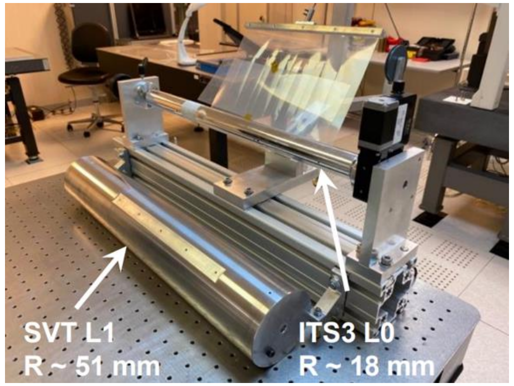


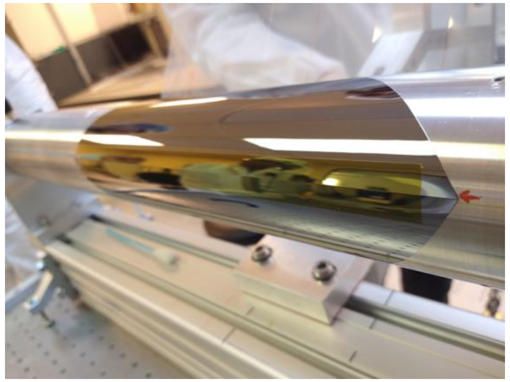




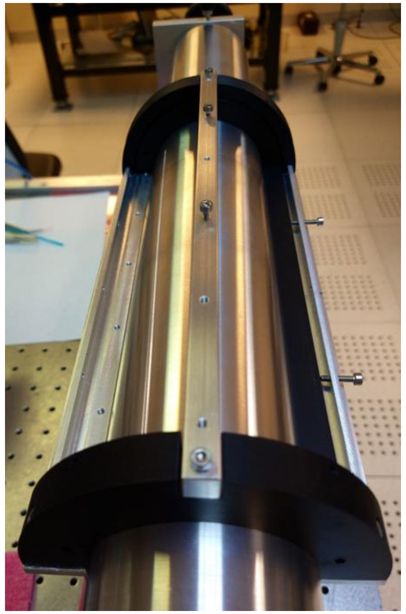
Mechanics – Inner Barrel

- SVT Inner Barrel will be constructed from wafer-scale curved ITS3 sensors
- Larger SVT radii require two or more sensors per half barrel, unlike ITS3 which uses one sensor per half barrel
- Need to precisely align the sensors, join them, handle the joint sensors during the bending, and adhere supports
- Developed and successfully exercised using thinned and diced dummy silicon wafers, 3D printed half-ring, 3D printed/plexiglass longerons
- Thermo-mechanical half-barrel this Summer/Fall; on track towards readiness for ER2 sensor.





Attempts #	Conditions	Dates	Success	Notes
1	2 half-moon shaped L0 3D printed longerons and half-rings mandrel produced on our workshop	25/11/2024 - 26/11/2024	NO	Breakage of the second silicon piece during the bending
2	2 half-moon shaped L0 3D printed half-rings and plexiglass longerons mandrel produced on our workshop	13/01/2025 - 31/01/2025	YES	
3	2 half-moon shaped L0 3D printed half-rings and plexiglass longerons mandrel produced on our workshop	24/03/2025 - 28/03/2025	NO	One silicon piece already broken from the transport box
4	2 half-moon shaped L0 3D printed half-rings and plexiglass longerons mandrel produced on our workshop	03/04/2025 - 10/04/2025	YES	



		Components	Goal
MAR 2025	IBL01_P1 (half-layer)	• 2 naked silicon L1 sensors • L1 local support structure (3-D printed) • outer support shell (machined in PEEK)	• finalize half-layer assembly procedure
MAR 2025	IBL01_P2 (half-barrel)	• IBL01_P1 + • 2 naked silicon L0 sensors • L0 local support structure (3-D printed)	• finalize half-barrel assembly procedure
JUL 2025	IBL01_P3 (half-layer)	• 2 naked silicon L1 sensors • L1 local support structure (carbon foam) • outer support shell (carbon fiber, to be defined)	• thermal chamber test
JUL 2025	IBL01_P4 (half-barrel)	• IBL01_P3 + • 2 naked silicon L0 sensors • L0 local support structure (carbon foam)	• thermal chamber test
OCT 2025	IBL01_P5 (half-barrel)	• 2+2 silicon L0+L1 **sensors with heaters from CERN** • L0+L1 local support structures (carbon foam) • outer support shell (carbon fiber, to be defined) • **air distribution inlet et outlet** (to be designed) • **PT1000 sensors** (to be glued on heater surface)	• wind tunnel test

They require dummy silicon sensors from DISCO;
to validate 2-sensor connection and bending, to design local support structure, external shell etc

In addition to DISCO dummies, they require:
- carbon foam local support (procurement and machining TBD)
- carbon fiber outer support shell TBD

(if yes, needs for design&simulation, procurement and machining)

IBL01_P5 requires:
- dummy silicon sensors with heaters
- air-cooling mechanism verification
- Possible preliminary FPC (mechanical) prototype to check volumes, transport etc)
- transport issues to wind tunnel facility

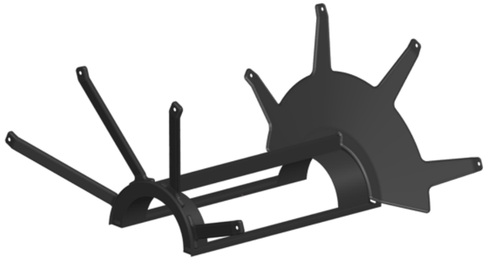
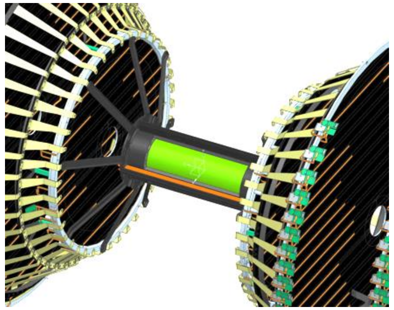
	Components	Goal	Date
IBL012_P6/7	• 2+2+4 ER2 pad wafer L0+L1+L2 sensors (x 2 HB?) • L0+L1+L2 local support structures • gloabal support mechanics (advanced design) • FPCs (advanced design) • air distribution inlet & outlet (advanced design)	• first complete IB HB prototype w/o sensors • including test of wirebonding to FPCs • final test on HB support mechanics • possibly built 2 complete HBs (to allow HB mechanical support matching test)	2026/07
IBL012_P8	• 2+2+4 ER2 wafer L0+L1+L2 sensors • L0+L1+L2 local support structures • mechanics, FPCs, cooling (~final/advanced design)	• complete IB HB prototype w/ sensors • qualification model w/ bent sensors for cooling + powering/DAQ/DCS finalisation	2026/10

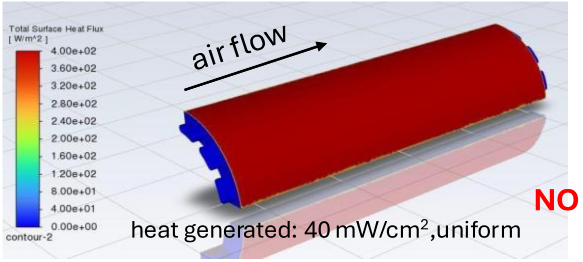
Mechanics – Inner Barrel

- Mechanical support design and engineering test article
  - Updated L0, L1 design with supporting arms with feedback from simulations; update to L2 to follow
  - Planned engineering test article production by October; company identified

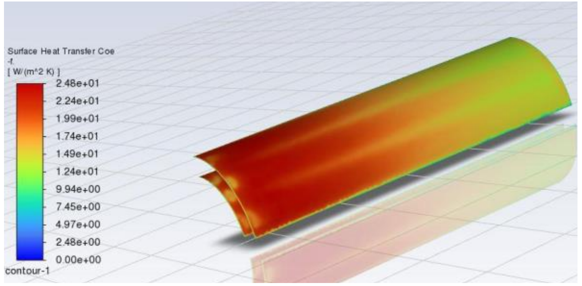
- Mechanical and thermal load simulation
  - Heat transfer simulation of quarter-barrel L0+L1
    - Heavily dependent on mesh definition
    - Turbulence (critical for proper cooling) not easily set
  - Simulation of structure deformation
    - 300 μm close to the sensors, 600 μm on the edge of longerons
    - Good starting point towards effective production strategy and limited material budget

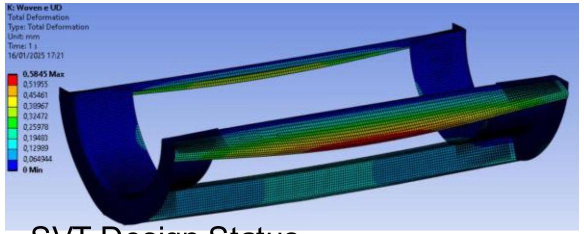
- IB transport boxes design
  - Safe handling/transportation of bent sensors of the SVT inner layers between labs
  - Plexiglass container with polystyrene holder of the sensors; designed for simplicity, robustness and durability

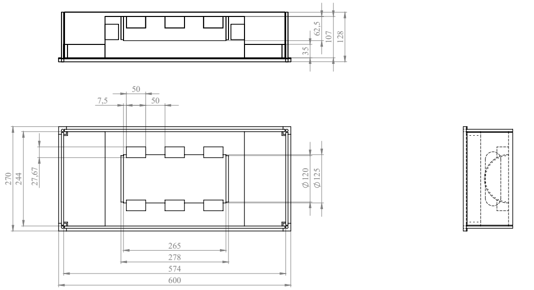
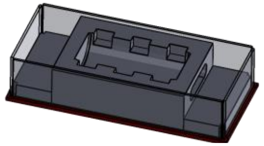






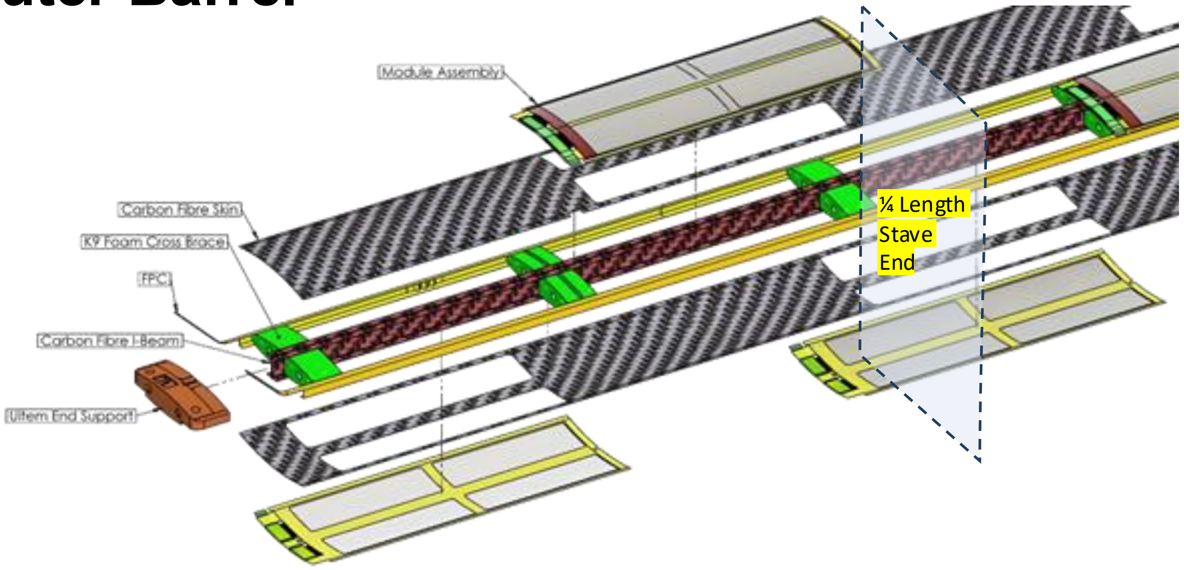
NO LEC!






Mechanics – Outer Barrel



- Tooling developed to construct a first quarter-length L4 stave with curved face-sheets

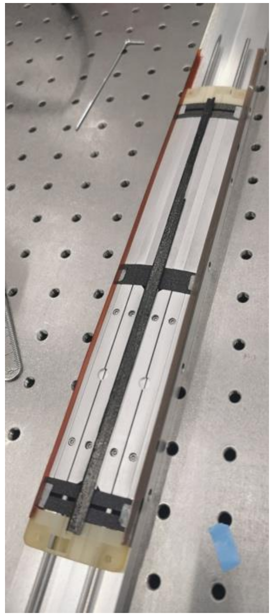

Kapton Former

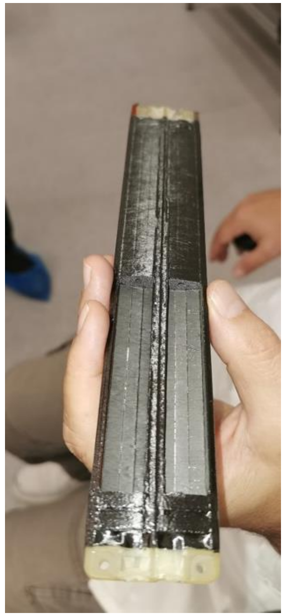

Carbon Fiber I-beam Mould


Internal Formers

- First quarter-length stave article constructed
  - Hand-cut CF top and bottom skins (2 layers 90/0 of K13C2U/EX1515)
  - Pure Kapton FPC mock-ups
  - SLA 3D printed stave ends
  - Production intent I-beam and K9 foam blocks

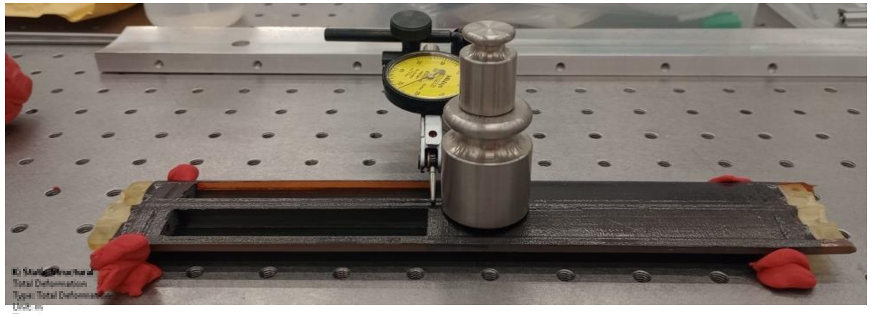
- Take-aways from the first article
  - No noticeable twist in stave
  - Strategically placed threaded holes needed for controlled removal of internal tooling
  - Reinforcement needed for end supports (deformed/failed)

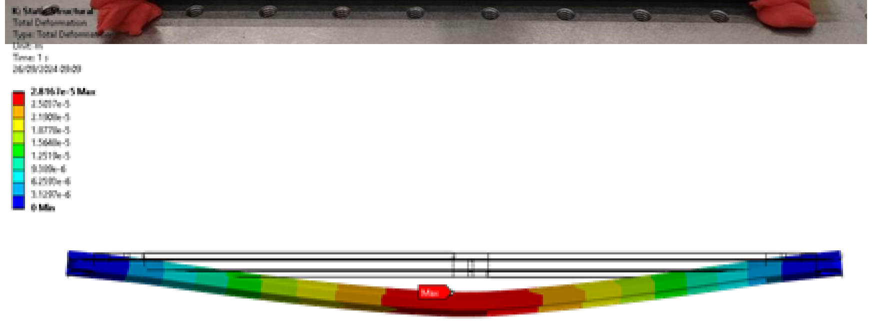




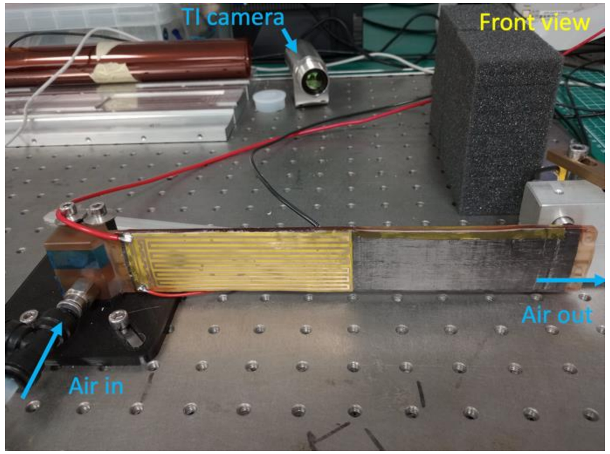
Mechanics – Outer Barrel

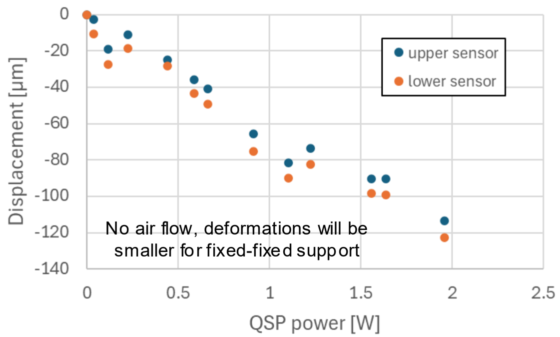
- Good agreement between estimated and measured mass, as well as deflections in 3pt bend tests
- ANSYS Modal model for a quarter-length stave without sensors gives a 1st mode frequency of 97Hz
- Ongoing displacements (vibrations, deformations) studies under dissipative load and airflow using capacitive probes
- Initial tooling for modules exists and thinned dummy silicon have just become available
- Valuable lessons learned in terms of tooling and handling towards full length engineering test article

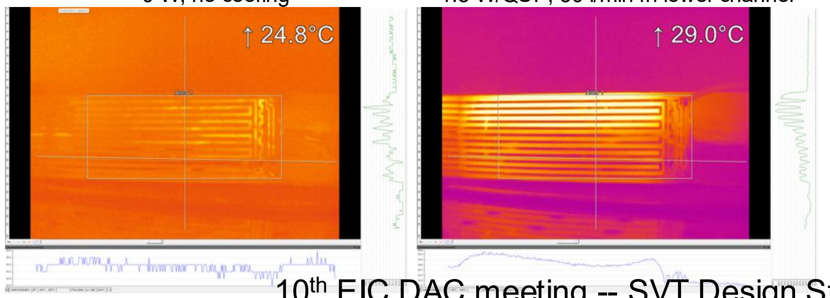


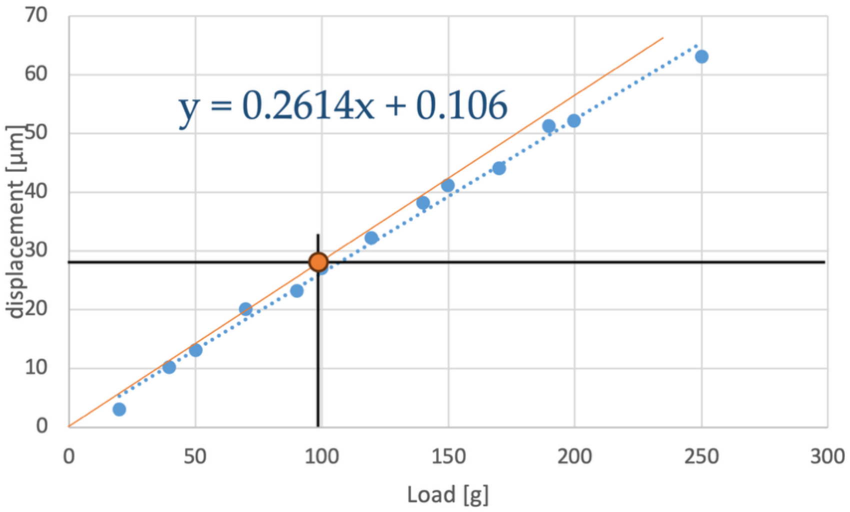


Quarter stave prototype with resistive heaters

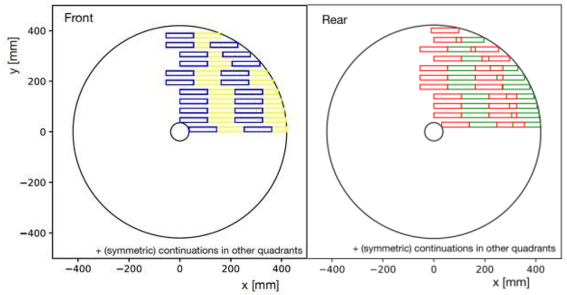


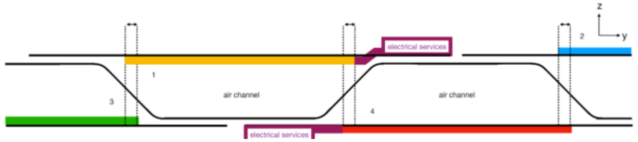






Mechanics – Disks

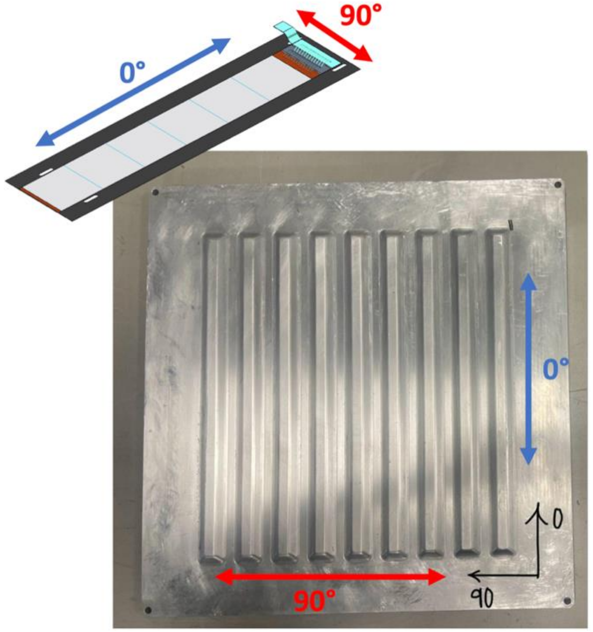


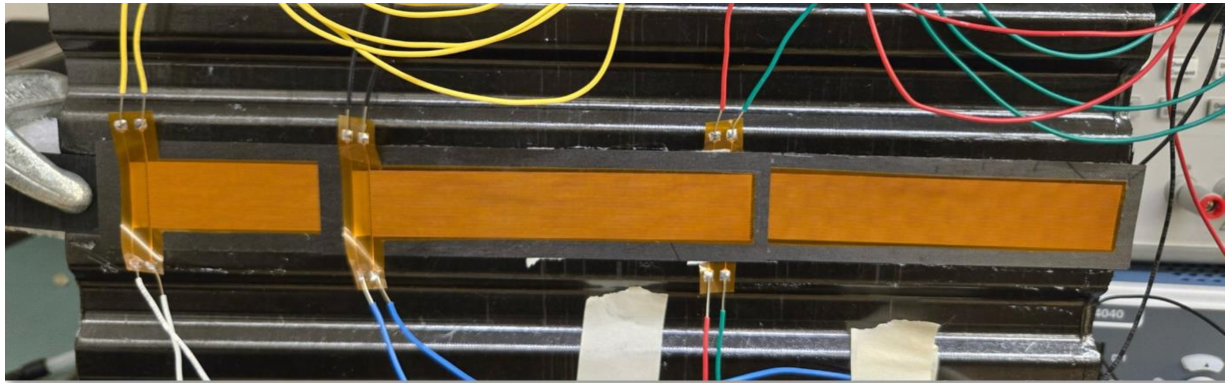


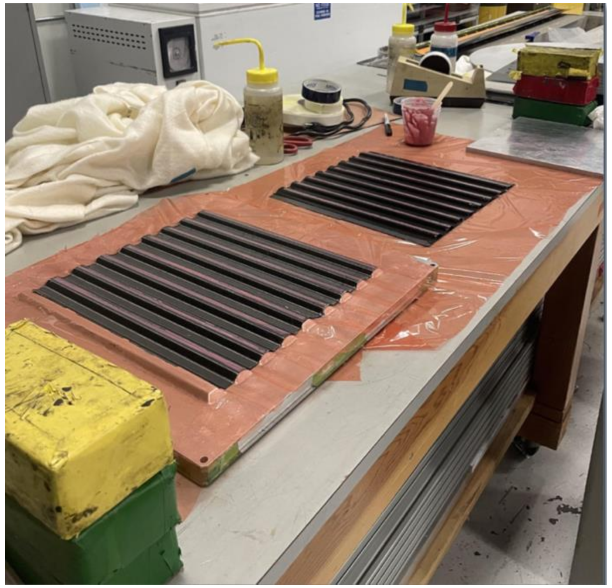
- Test articles created using K13C2U unidirectional high thermal conductivity CF

- Three-layer CF layups, 90/0/90 and 0/90/0, as the corrugated disk core and as the sensor support

- Thermomechanical models constructed thus far using resistive circuits (FPCs) powered separately so as to correspond to the anticipated dissipations from the EIC-LAS LEC and RSUs

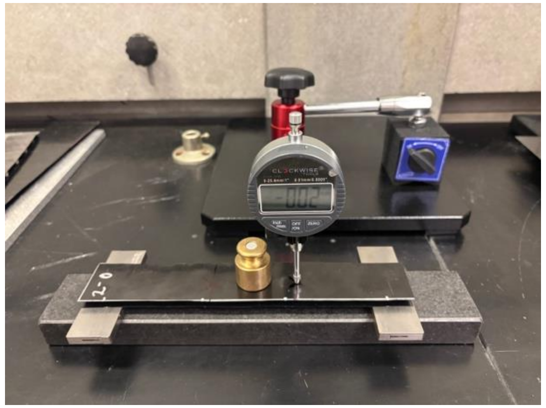


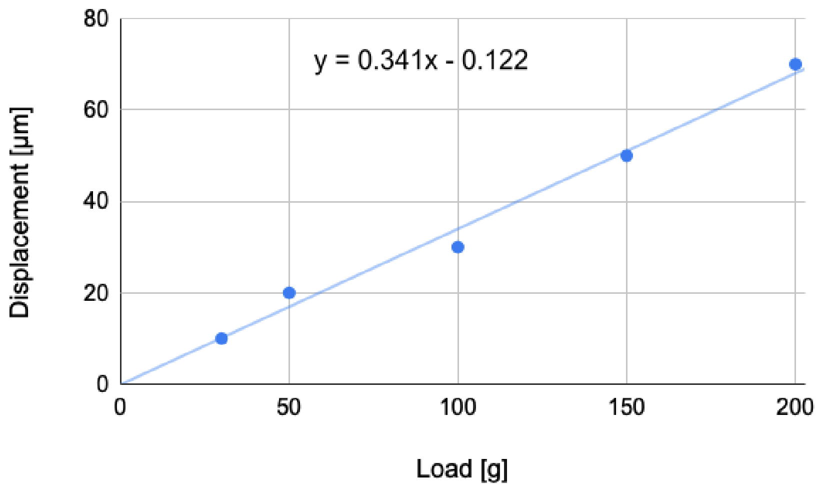


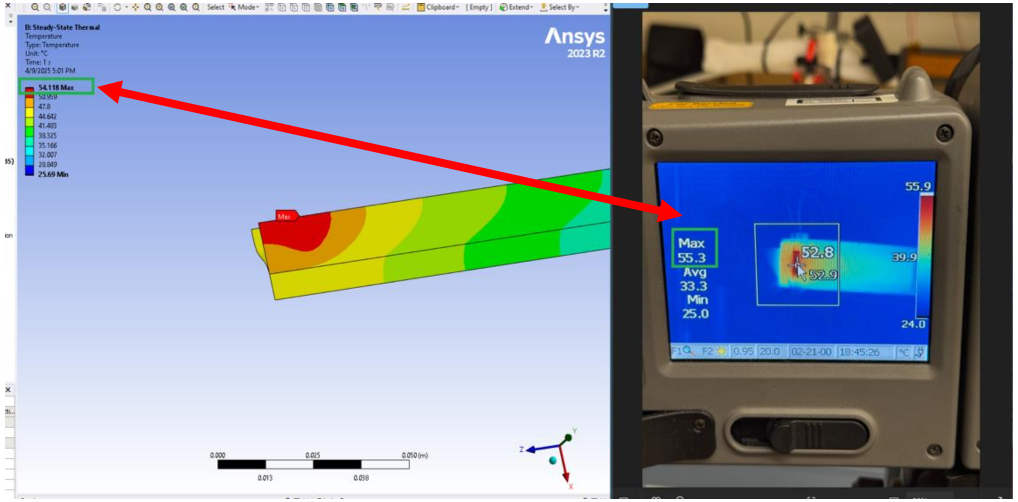


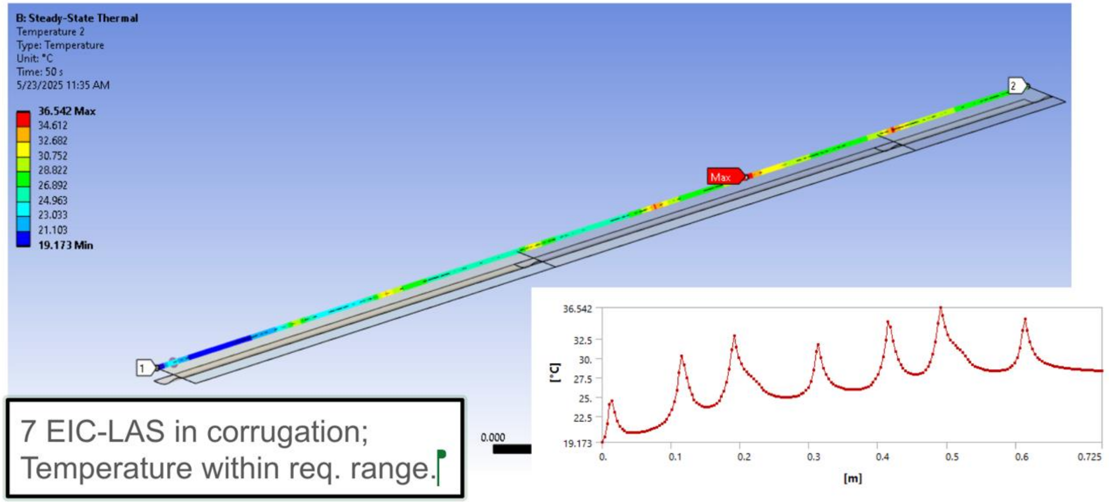
Mechanics – Disks

- 3-point bend tests performed, shown here along the corrugation, simulation to follow
  - One corrugation width, approx. length of small disc radius; load on the hump of corrugation
- Early ANSYS mechanical evaluation gave a 1st mode frequency of 108 Hz for a half-disk,
- Steady state thermal simulations for a single corrugation channel are in good agreement with measurements
- Ongoing studies for a range of sensors and airflows



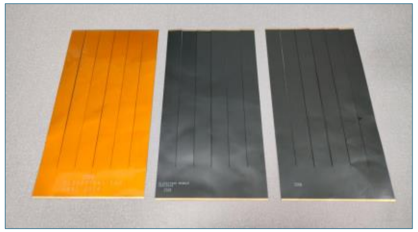




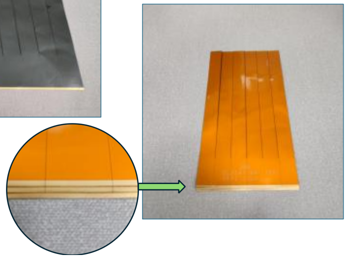


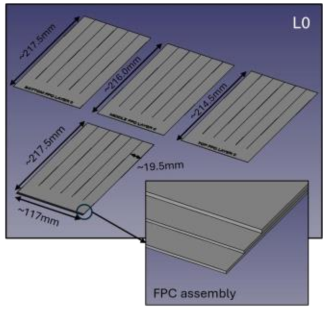
Low-mass electrical interfaces – test articles and vendor selection

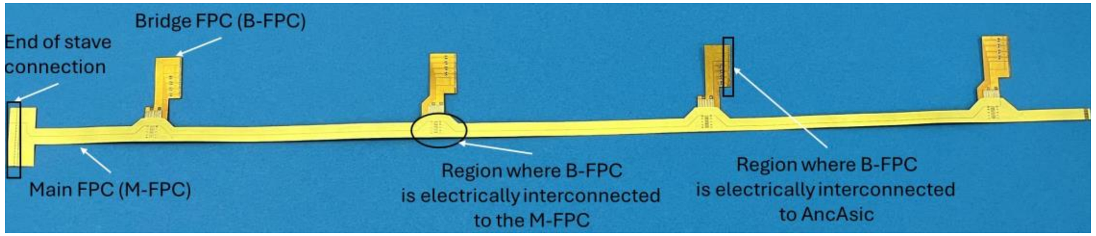
- **Mechanical mock-ups of IB L0 and L1** FPC procured in Cu technology to be used for IB mechanical prototypes
  - Based off ITS3 design
- **OB L4 ½ stave length test article** delivered
  - Aluminium conductor technology by **LTU**
  - Test setup incl. adapter boards and FPGA card ready
  - Visual inspection completed; ongoing trials of tab bonding FPC to adapter boards
- Copy of bridge FPC ordered from alternative vendor, **QFlex**
- **Two iterations completed with Omni Circuit Boards** (CA); third version under development
  - Tests on second iteration designed for high-speed data transmission indicate good signal integrity at 10 Gbps

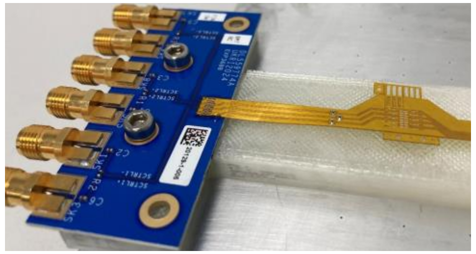


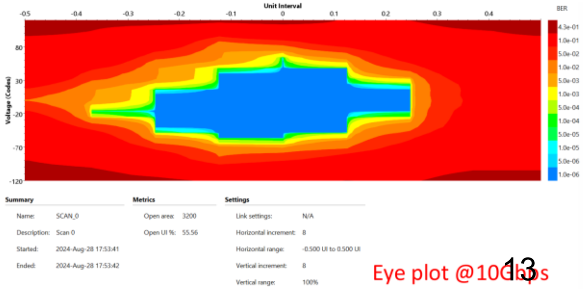
SVT IB L0 FPC
Cu mock-up











Eye plot @10Gbps

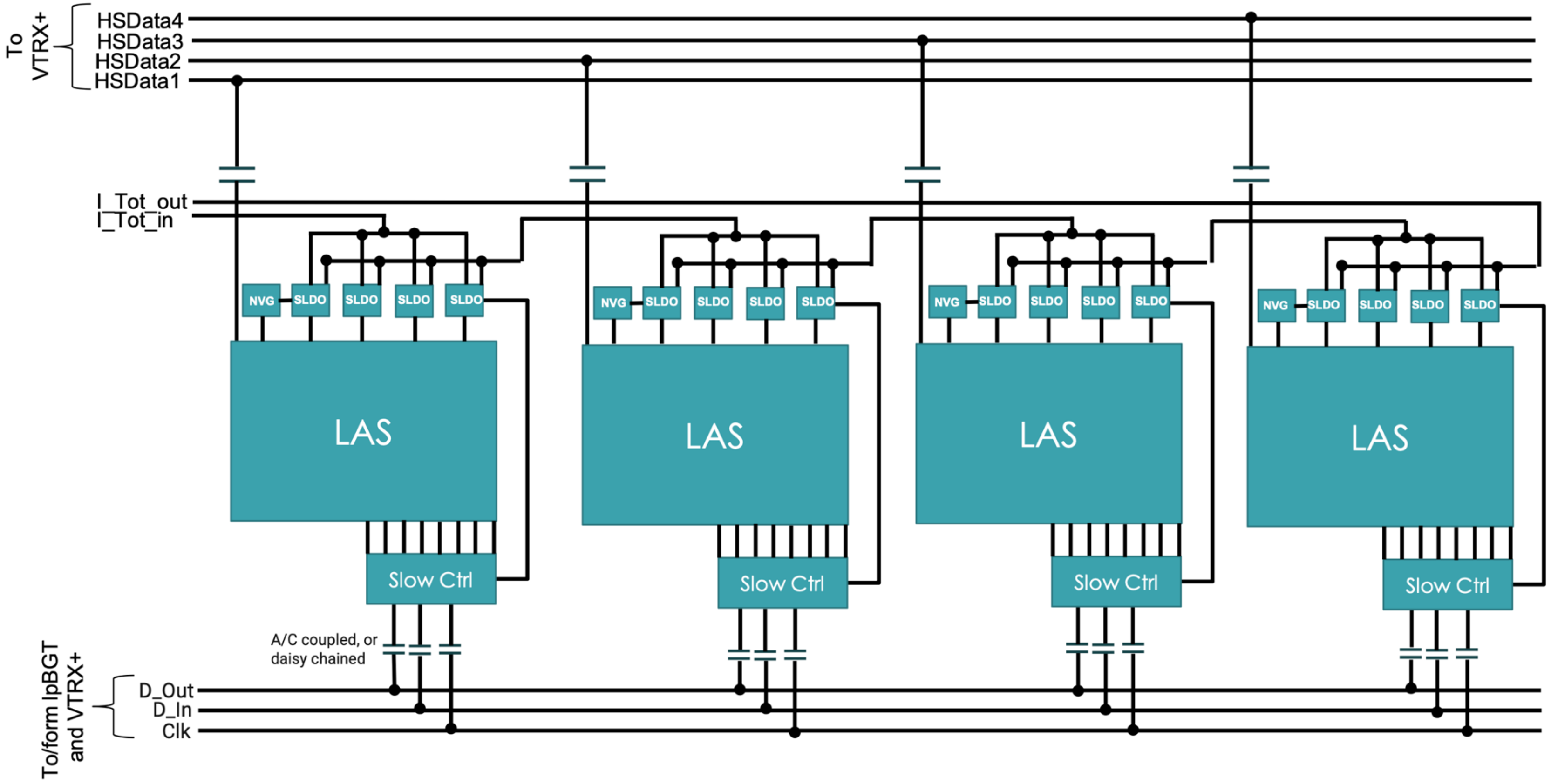
Powering and Readout

Inner Barrel will be directly powered and read out, adopting (and adapting) ITS3 design,

Doing so for the outer barrel and/or disks would incur prohibitive service loads,

Instead, the outer barrel and disk design uses:

- serial powering of up to 4 EIC-LAS sensors,
- Multiplexing of slow control,



Readout chain and boards – OB, disks

Overall approach: transition to fiber as close as possible to the stave ends and disk outer radii; aggregate fibers outside of the detector, before FELIX

FPC Interface Board -- FIB

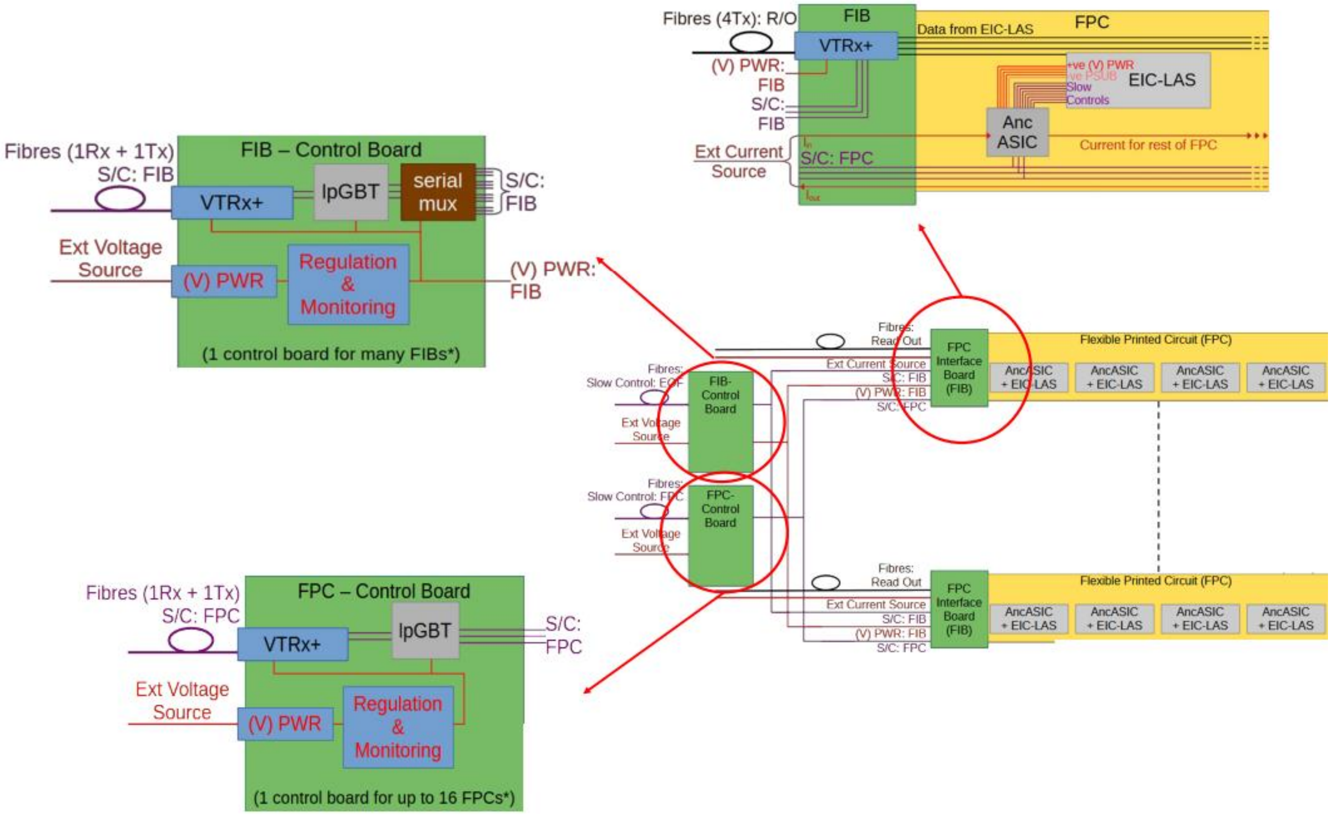
- AC-coupled data links to VTRx+ for up to four EIC-LAS, electro-optical conversion, connection to fibers,
- Routing of serial-powering current and slow control signals to FPC,

FIB Control Board – FIB CB

- Provides control signals and power for the VTRx+ on the FIB

FPC Control Board – FPC CB,

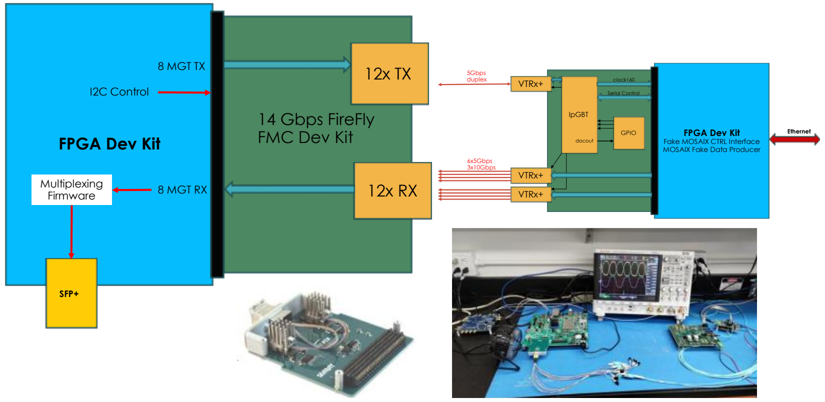
- Provides slow control signals for the ancillary ASIC/EIC-LAS modules on the FPC via the FIB,



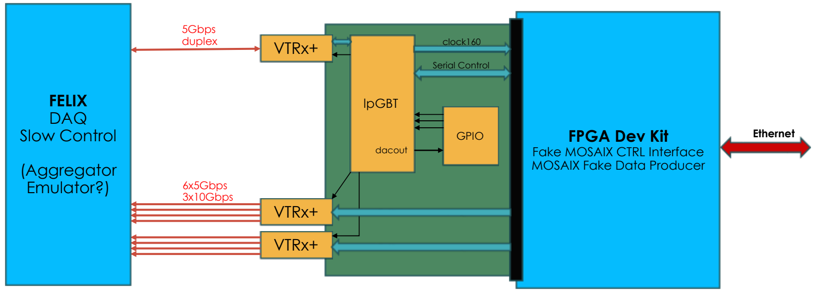
Readout and test articles

- Full setup with **lpGBT, VTRx+**, and FPGA development boards (stand-ins for FELIX) for evaluation of the various readout components established
- Evaluation of **Fiber Aggregator Board** architectures with commercial FPGA development ongoing
- Development version of **MOSAIX hardware mockup** available
- Characterization of the **NKF7 serializer** to be used in MOSAIX and EIC-LAS ongoing

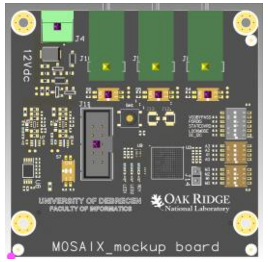
Aggregator Board Prototyping



MOSAIX Hardware Mockup

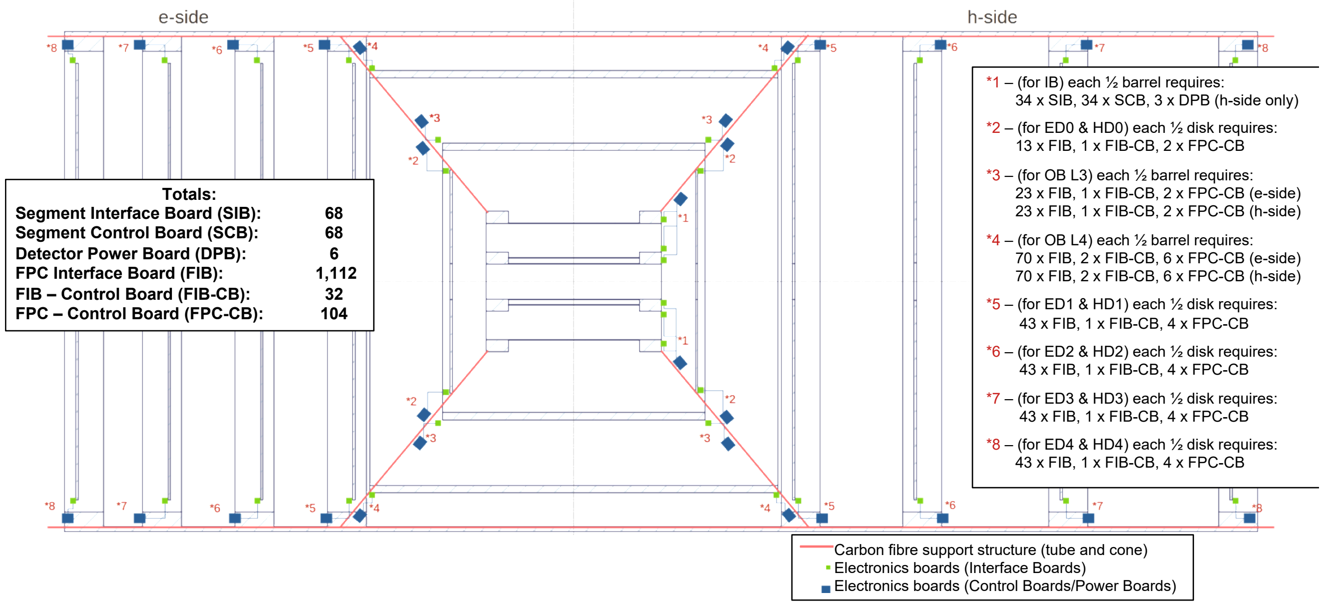


VTRx+ connected to FMC HPC (8 MGT available), emulate typical packets

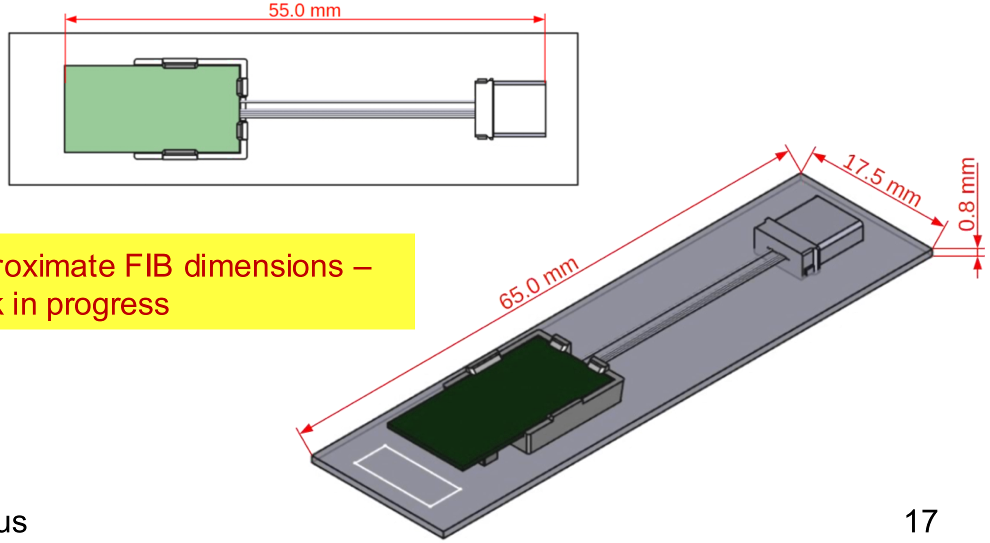


Readout boards – numbers, sizes, integration

- 1 FIB for up to 4 EIC-LAS sensors
- 1 FPC control board for up to 12 FIB
  - 16 elinks per lpGBT, 4 reserved for internal FPC CB use
- 1 FIB CB for up to 48 FIB
  - 12 lpGBT links used, each connected to a 1:4 MUX



- Length of boards roughly the same driven by VTRX+ (pigtail) size
- Control boards also need space for
  - lpGBT, power regulation, monitoring, serial multiplexers
- Space to bond/solder connections on all boards



Approximate FIB dimensions – work in progress

Power to cool

Staves and disks
(incl. sensors, AncASIC, voltage drop on FPC)

	nominal		max	
	Power/stave [W]	Total power/system [W]	Power/stave [W]	Total power/system [W]
L0		30		37
L1		40		50
L2		101		124
L3	15.4	706	22.5	1037
L4	31.4	2199	48.2	3377
Disks		5051		7345
Total power [kW]		8.12		11.97

Readout boards - OB

	Count	Dissipation [W]
Total FIBs	372	75
Total FIB-CBs	8	171
Total FPC-CBs	32	55
Total		**301**

Readout boards - IB

	Count	Dissipation [W]
Total SIBs	68	27
Total SCBs	68	297
Total DPBs	6	88
Total		**385**

Readout boards - Disks

	Count	Dissipation [W]
Total FIBs	740	149
Total FIB-CBs	18	385
Total FPC-CBs	70	121
Total		**655**

Sensors + AncASIC: ~ 8 – 12 kW
Readout boards: ~1.4 kW

MOSAIX, EIC-LAS power estimates

- based on recent MOSAIX figures; not fully final numbers

AncASIC power estimates

- only SLDO regulators power consumption; by far the largest contribution, but will need to include NVG and AncBrain

Readout boards power estimate

- lpGBT and VTRX+ power consumption figures
- MUX power consumption (FIB SC only)

Aim remains air-cooling of IB, OB, and disks,

- liquid cooling for readout boards (as necessary),
- liquid fall-back for L4, outermost disks,
- detailed distribution and pressure regulation remains to be designed,

Closing comments

- SVT design is progressing well,
  - Sensor and ancillary ASIC: ITS3 ER2 submission to foundry is now imminent; first ancillary ASIC MPW submission (NVG and SLDO) done, preparing slow-control MPW this Summer,
  - Characterization: high-speed wafer probing demonstrated, ongoing irradiation and test-beam efforts, preparing for ancillary ASIC MPW testing,
  - Mechanical designs: joining and bending of thinned wafer-scale dummy silicon with local supports demonstrated for the SVT inner barrel; tooling and test articles for outer barrel in agreement with expectations and feed back into design; disk
  - Electrical interfaces: initial low-mass prototype / test articles undergoing tests – there are, however, some remaining challenges / risks with potential suppliers,
  - Powering and readout: initial ancillary ASIC MPW with SLDO (and bias) blocks submitted; failure modes evaluated, startup and control in progress; preparation for upcoming slow-control MPW incorporates hardware simulation of differing ground levels; setups with key components (VTRx+, NKF7 serializer) under test,
  - Global supports and integration: increasingly specified; effort picking up with availability of PED funds,
  - Simulation efforts increasingly realistic algorithms and material/response descriptions; background and noise are a work in progress,
- Not explicitly addressed as part of this presentation: necessary interlocks, control-room side of slow-control, database, startup running needs (e.g. alignment; unlikely to impact main design, but possibly its optimization), …
- SVT stave and disk production (population) are projected to take about 2.5 years in a technically driven schedule with EIC-LAS production sensors; inner barrel about a year with ITS3 production sensors,
- CERN-EIC agreement(s) essential for EIC-LAS development; this is increasingly time-critical for the design and characterization itself, for chain tests, and to be able to meet the current EIC installation timeline (milestone) for SVT of mid-2032; we need access to the design this Fall.