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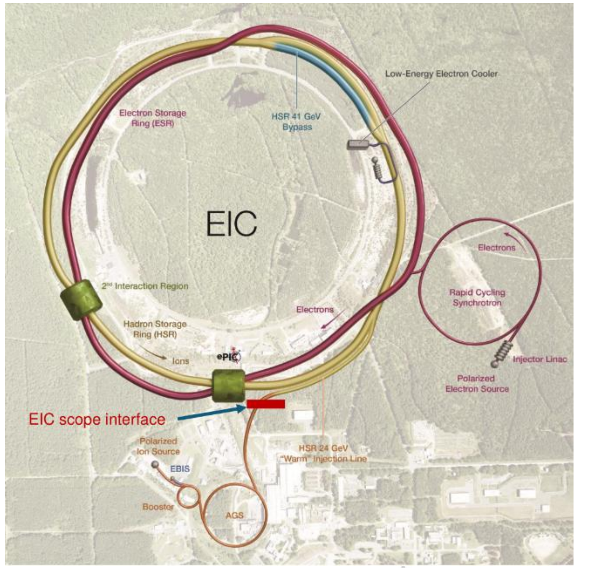
EIC vertex and tracking detector

James Glover
(on behalf of the ePIC SVT subdetector collaboration)

VERTEX 2025: 33rd International Workshop on Vertex Detectors

August 2025

EIC



The facility.

- The EIC is to be built at the Brookhaven National Laboratory (BNL) incorporating the existing Relativistic Heavy Ion Collider.

Overarching science questions.

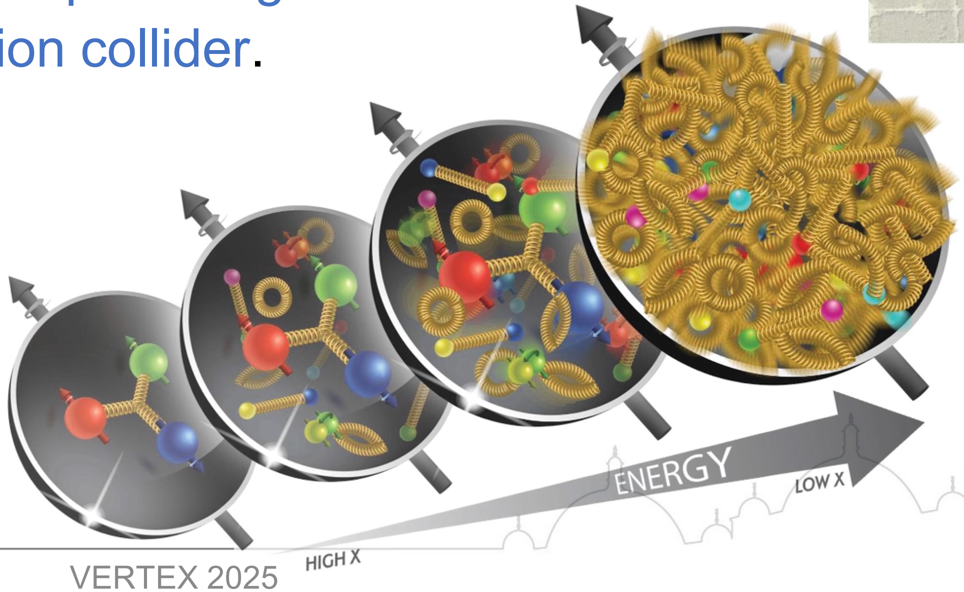
- How does the mass and spin of the nucleon arise from its constituents?
- What are the emergent properties of dense systems of gluons?

Uniqueness

- World's first polarised electron, polarised proton/light-ion collider.
- World's first polarised electron, heavy-ion collider.

Timeline

- Dec 2019: EIC project approved.
- Dec 2025: EIC project detector TDR.
- 2033 –2035: Transition to operations.



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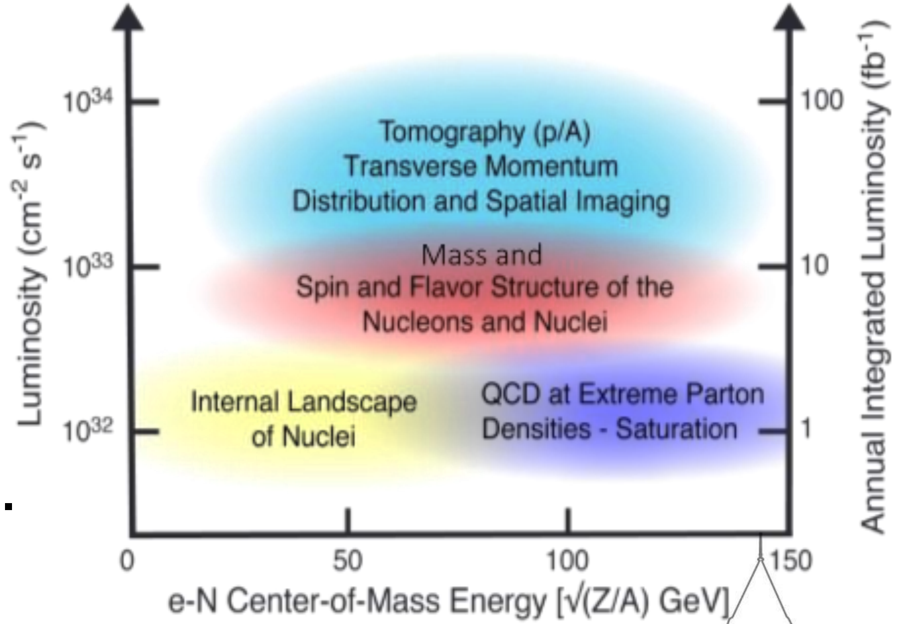
Design goals

- High Luminosity: $L = 10^{33} – 10^{34}$ cm^{-2}sec^{-1}, 10 – 100 fb^{-1}/year.
- Center of mass energy: 20 – 100 GeV, upgradable to 140 GeV.
- Highly Polarized Beams: 70%.
- Large Ion Species Range: protons – Uranium.
- Large detector acceptance and good background conditions.
- Accommodate a Second Interaction Region (IR).
  - The EIC Project covers the accelerator and one detector.



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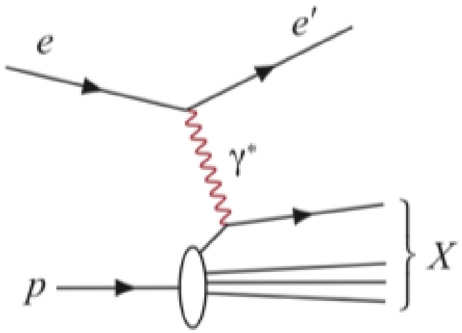
Detector requirements

Internal Landscape of Nuclei

QCD at Extreme Parton Densities Saturation

Inclusive DIS

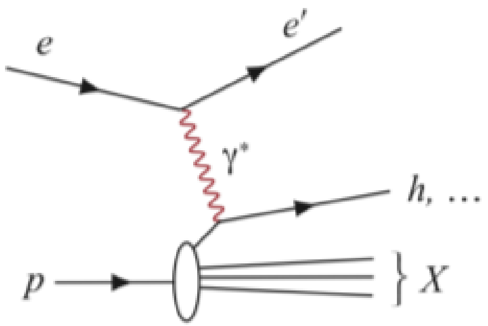


- High performance electron identification and reconstruction.

Mass, Spin, Flavour Structure of the Nucleons and Nuclei

Tomography Transverse Momentum Distribution Spatial Imaging

Semi-inclusive DIS

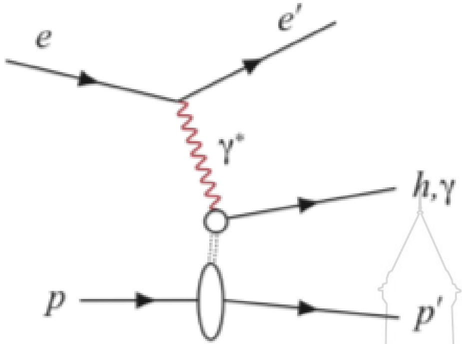


- Tracking and hadronic calorimetry.
- Heavy flavors identification from vertexing.
- Light flavors from dedicated PID detectors.

QCD at Extreme Parton Densities Saturation

Tomography Transverse Momentum Distribution Spatial Imaging

Exclusive DIS



- Efficient proton tagging.
- Cover full acceptance range.

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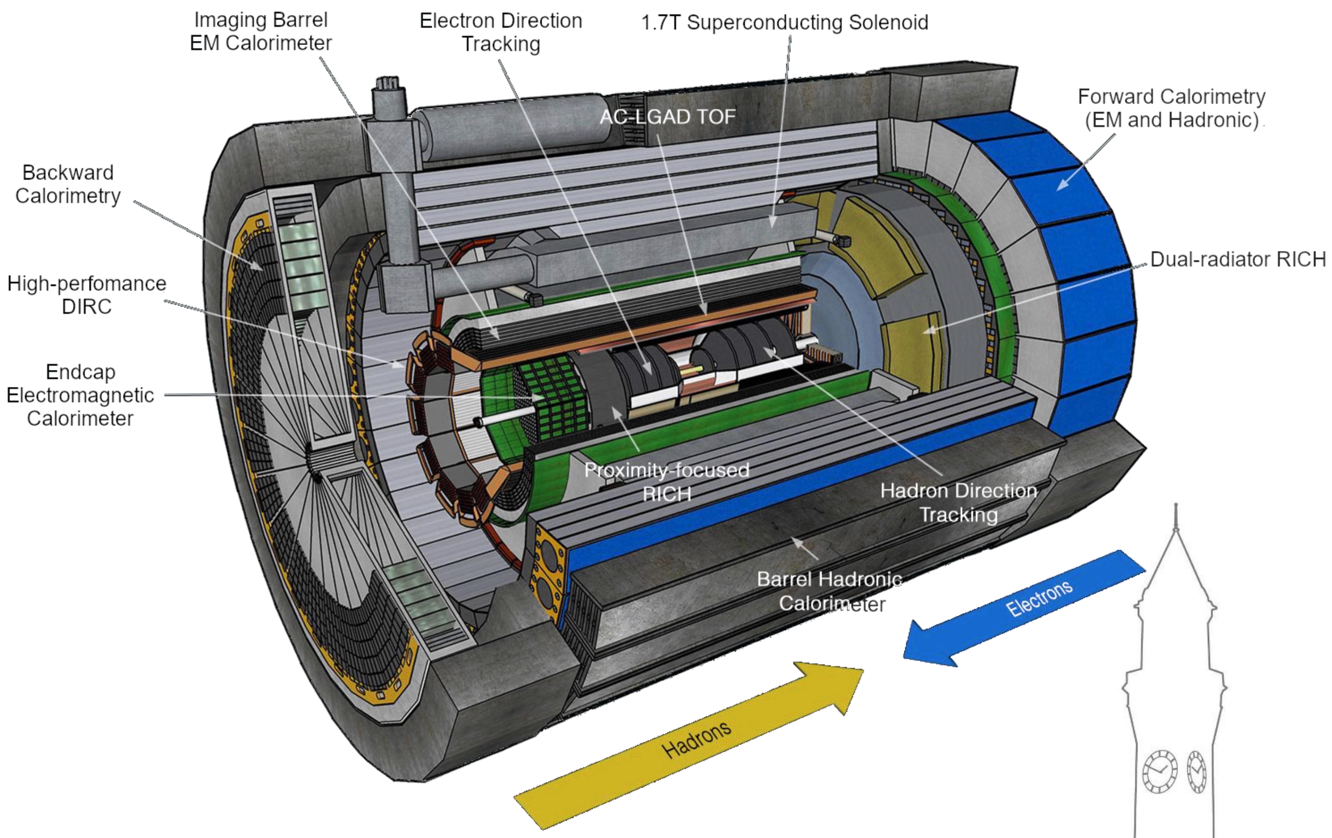
ePIC detector

- Compact central detector.
  - 2.67 m radius and 9.5 m length.
  - Combines tracking and vertexing, PID, and EM and hadronic calorimetry.
  - Asymmetric beam energies, different electron and hadron endcaps.
- 1.7 T solenoidal field.
- Streaming readout approach.
- Extensive beamline instrumentation integral to science programme



Tracking requirements

- Physics derived requirements on precise low momentum particle tracking has driven the need for very high point resolution and ultra-low material budget → most challenging requirements:
  - High granularity, low power active element.
  - Minimal material from mechanics, cooling, power and data distribution.

Tracking requirements from PWGs						
			Momentum res.	Material budget	Minimum pT	Transverse pointing res.
η						
-3.5 to -3.0	Central Detector	Backward Detector	σp/p ~ 0.1%×p ⊕ 0.5%	~5% X0 or less	100-150 MeV/c	
-3.0 to -2.5					100-150 MeV/c	dca(xy) ~ 30/pT µm ⊕ 40 µm
-2.5 to -2.0			σp/p ~ 0.05%×p ⊕ 0.5%		100-150 MeV/c	dca(xy) ~ 30/pT µm ⊕ 20 µm
-2.0 to -1.5					100-150 MeV/c	
-1.5 to -1.0					100-150 MeV/c	
-1.0 to -0.5		Barrel	σp/p ~ 0.05%×p ⊕ 0.5%		100-150 MeV/c (~MAPS + MPGD trackers)	dca(xy) ~ 20/pT µm ⊕ 5 µm
-0.5 to 0						
0 to 0.5						
0.5 to 1.0						
1.0 to 1.5		Forward Detector	σp/p ~ 0.05%×p ⊕ 1%		100-150 MeV/c	dca(xy) ~ 30/pT µm ⊕ 20 µm
1.5 to 2.0					100-150 MeV/c	
2.0 to 2.5					100-150 MeV/c	
2.5 to 3.0			σp/p ~ 0.1%×p ⊕ 2%		100-150 MeV/c	dca(xy) ~ 30/pT µm ⊕ 40 µm
3.0 to 3.5					100-150 MeV/c	dca(xy) ~ 30/pT µm ⊕ 60 µm

YR Report, Table 11.2

Operational environment

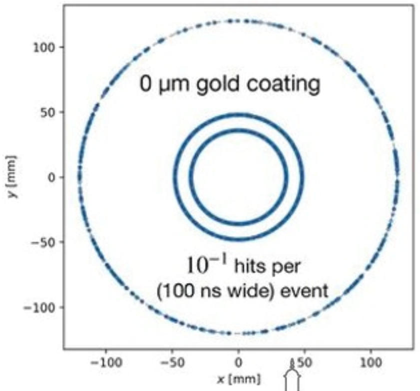
- EIC bunch crossing frequency 98.5 MHz.
  - Interaction frequency orders of magnitude lower.
- Rates for DIS e+p events up to 500 kHz.

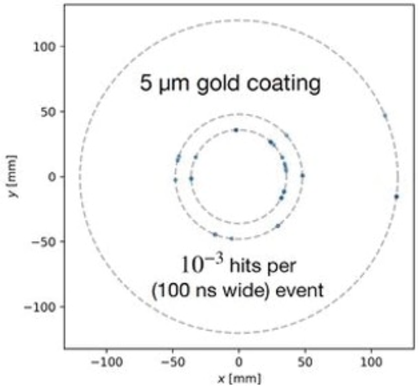
Beam energy [GeV]	5 x 41	5 x 100	10 x 100	10 x 275	18 x 275
L [10^{33}cm^{-2}s^{-1}]	0.44	3.68	4.48	10	1.54
DIS ep rate [kHz]	**12.5**	**129**	**184**	**500**	**83**

EIC Conceptual Design Report, Table 3.3

- Up to $\mathcal{O}$(GHz) rate for background events.
  - Hadron and electron beam gas event rate lowers with improving vacuum condition.
  - Synchrotron radiation reduced of two orders of magnitude with 5 μm gold coating of the beam pipe.
- Manageable readout frame rate.

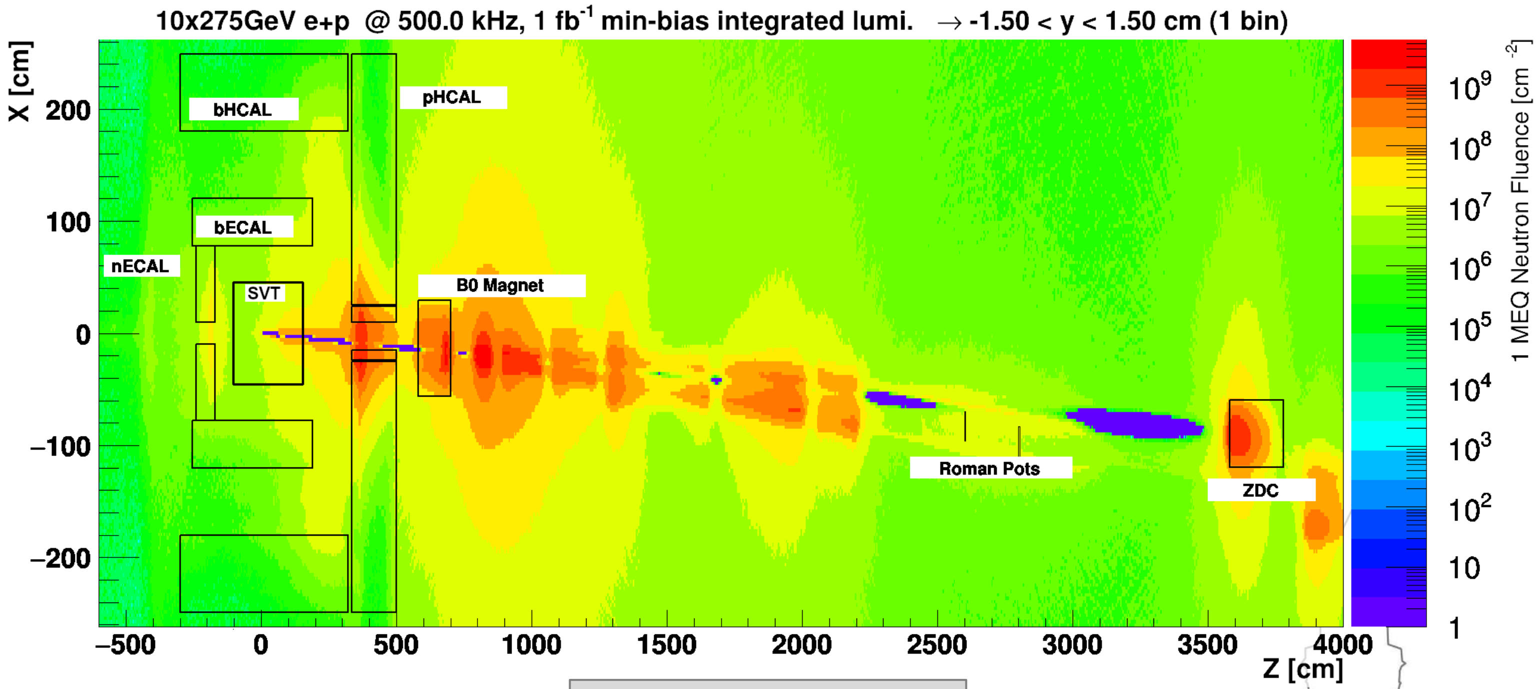
Scatter plots of SR hits in the innermost silicon tracker layers.





Operational environment

- Low-moderate radiation levels.
  - Much lower radiation fluxes than LHC, widens technology options.



ePIC Backgrounds

- 10 × 275 GeV DIS e+p, top luminosity (1×10^{34} cm^{-2}s^{-1}).
  - Total Ionising Dose below 1 Mrad.
  - Neutron fluence below 1×10^{10} n_{eq}/cm^2.

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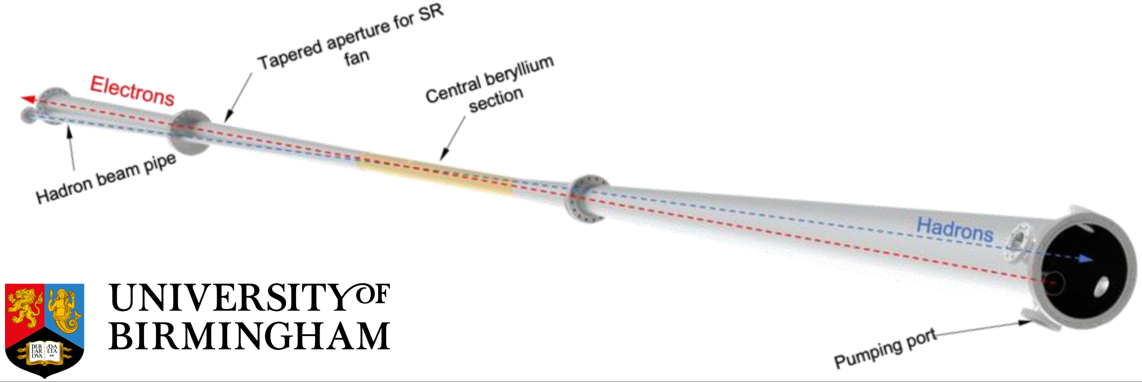
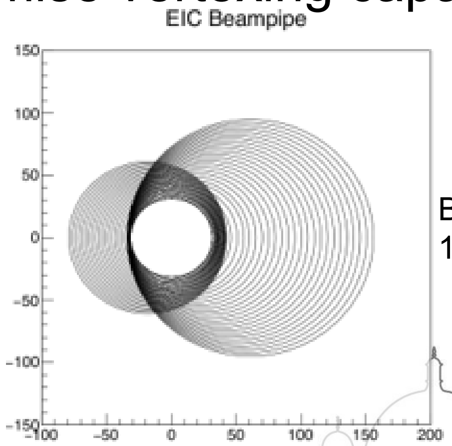
Integration constraints

- Large beam pipe diameter, 33 mm radius; (more) challenging to reach required vertexing precision.
- Beam pipe diameter increases away from the interaction point.
  - Silicon tracker to be built in two halves clamped around the beam pipe
  - Divergence already in silicon tracker envelop.
  - Complex mechanical support design (local and global) and integration procedure.
- Beam pipe bake-out performed with silicon tracker in situ.
  - Demanding cooling requirements to maximise vertexing capability and acceptance at large eta within material budget.





Beampipe profile;
100 mm steps

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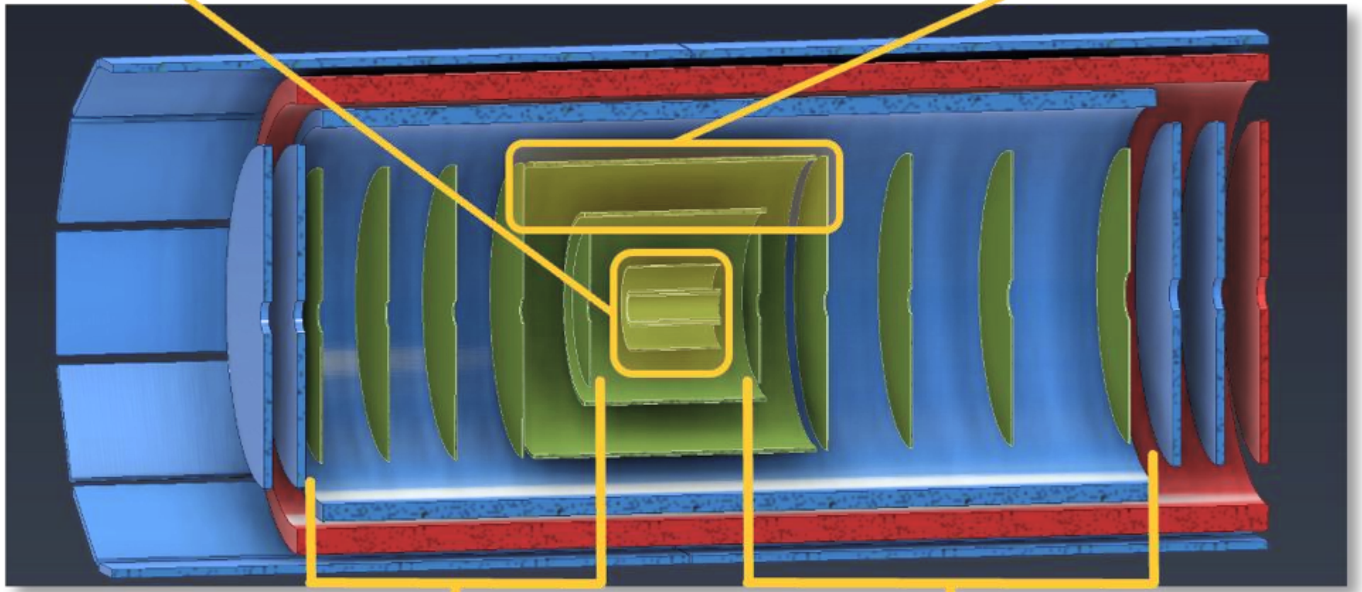
ePIC silicon vertex tracker (SVT)

- Well integrated, large acceptance, high precision Silicon Vertex Tracker based on large area, low power MAPS in 65 nm CMOS imaging technology.



SVT total (active) area: **~ 8.5 m^2**

ePIC SVT target specifications	
Spatial resolution	~ 5 um
Power	~ 40 mW/cm^2
Frame rate	≤ 2 μs
Material budget (per layer)	IB: **0.05%** X/X_0 OB: **0.25**, **0.55%** X/X_0 EE/HE: **0.25%** X/X_0

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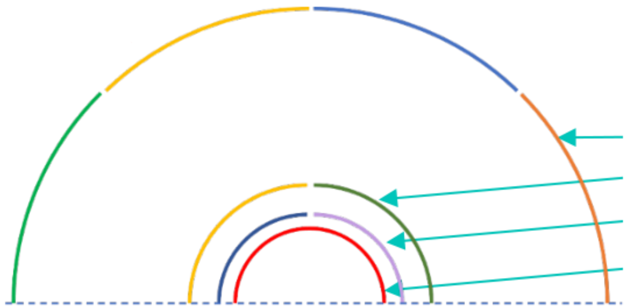
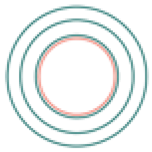
Inner barrel

- Transverse pointing resolution is multiple scattering dominated.
- The IB will adopt the ALICE ITS3 wafer scale sensor and ultra-thin detector concept.
  - Three layers of thin, bent, silicon sensors.
  - Minimal mechanical support, air cooling, no services in active area.
- Layers positioned to optimise transverse pointing resolution within operational constraints.
  - L0, L1: large beam pipe diameter, beam pipe bake-out (5 mm clearance), sensor width.
  - L2: r = 125 mm, dual purpose vertexing & sagitta layer, without increase in material.





IB	MOSAIX /sensor	Diced W (mm)	Diced L (mm)
L0	3	58.7	266
L1	4	78.3	266
L2	5	97.8	266

The sensors

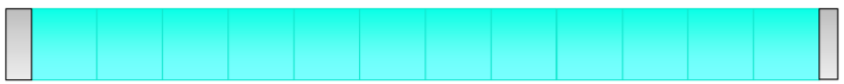
Two variations of the same stitched, repeated sensor unit (RSU).

RSU = 21.67 × 19.56 mm^2, array of 22.8 × 20.8 μm^2 pixels.

MOSAIX

- To be used for the IB layers (L0-2).
- Same sensor as for ALICE ITS3.

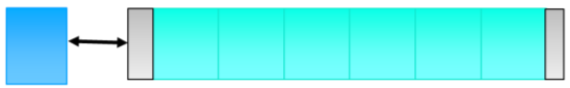
MOSAIX segment



EIC-LAS

- To be used for the OB layers (L3-4) and the endcap disks (ED0-4, HD0-4).
- Modified version of MOASIX, specifically for EIC.

EIC-LAS and ancillary chip



- 12 RSUs. → (Improve yield and coverage) → **5 or 6 RSUs.**
- 8 data links. → (Lower material budget) → **Single data link.**
- 7 slow control links. → (Lower material budget, fit integration requirements) → Multiplexed slow controls.
- Direct powering → (Lower material budget, fit integration requirements) → Serial powering.

EIC-LAS: 5 or 6 RSUs; Single data link.

Ancillary ASIC: Multiplexed slow controls; Serial powering.

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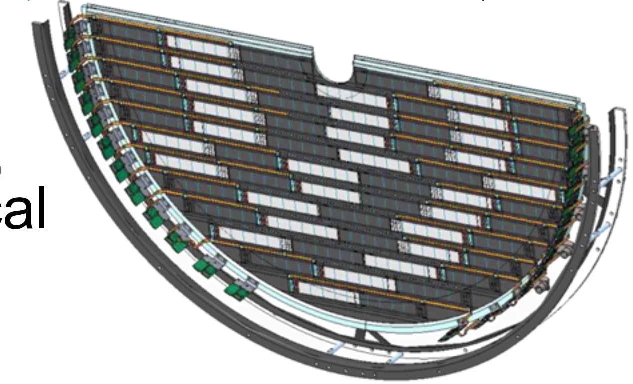
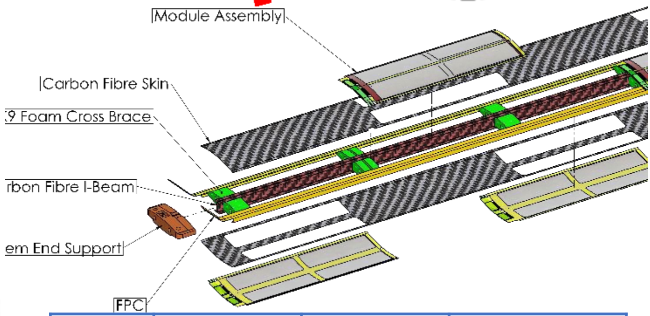
Outer barrel and endcap disks

- EIC Large Area Sensor optimised for high yield, low cost, large area coverage.
  - Modification of the ITS3 sensor; LAS stitched, but not wafer scale; planned modification(s) in the periphery to reduce number of readout links.
- Lightweight mechanical supports (staves, disks) with integrated cooling and electrical interfaces.
- Large lever arm with high precision measurements.
  - Improve momentum resolution.
  - Maximise acceptance at high eta.
- Disk inner opening defined by beam pipe bake-out constraints and off-centred, where beam pipe diverges.





OB	r (mm)	L (mm)	x/X_0 (%)
L3	270	540	**0.25**
L4	**420**	840	0.55

Disks	+z (mm)	-z (mm)	r_out (mm)	x/X_0 (%)
D0	250	-250	240	**0.25**
D1	450	-450	420	**0.25**
D2	700	-650	420	**0.25**
D3	1000	-850	420	**0.25**
D4	**1350**	**-1020**	420	**0.25**

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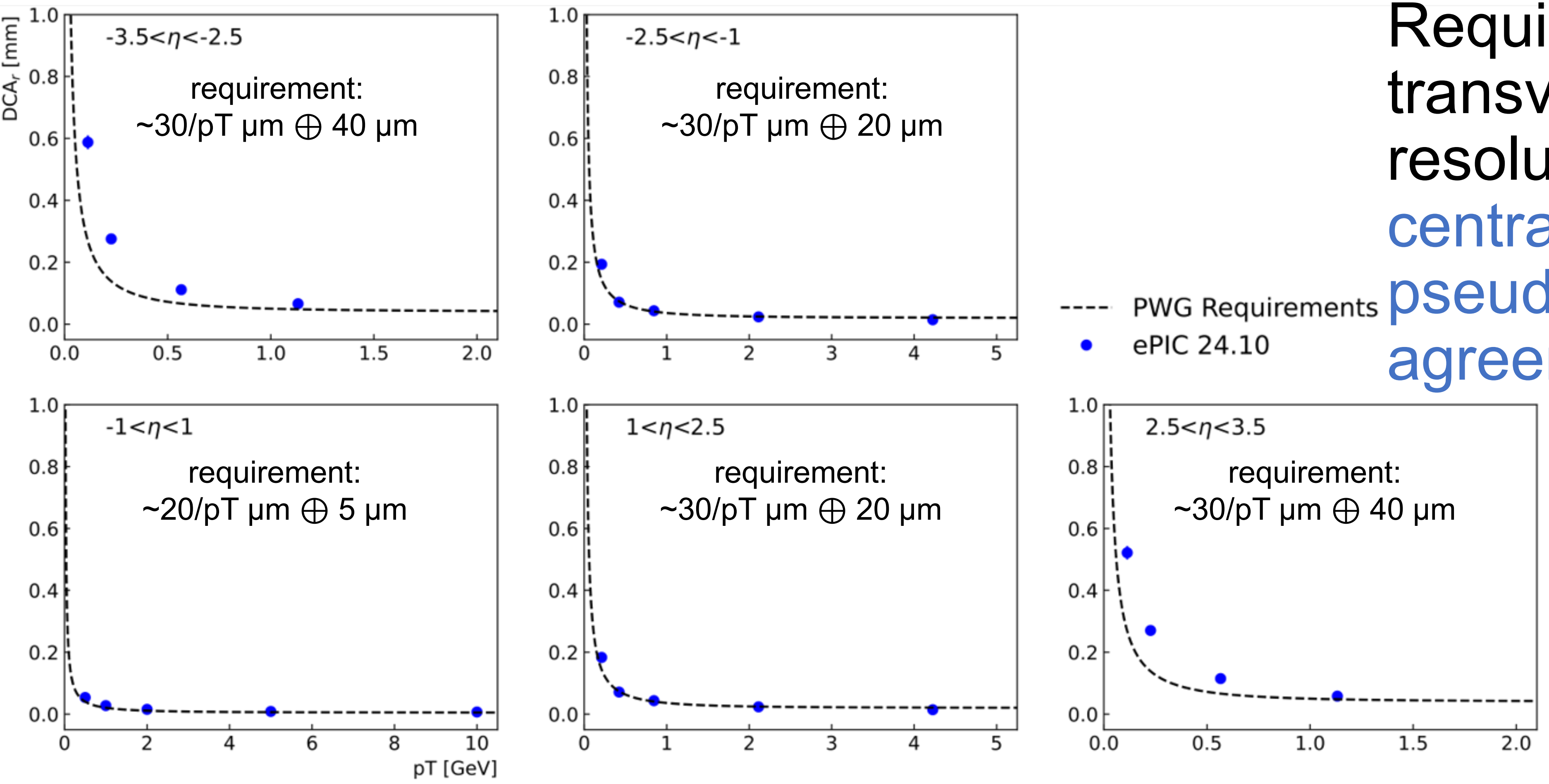
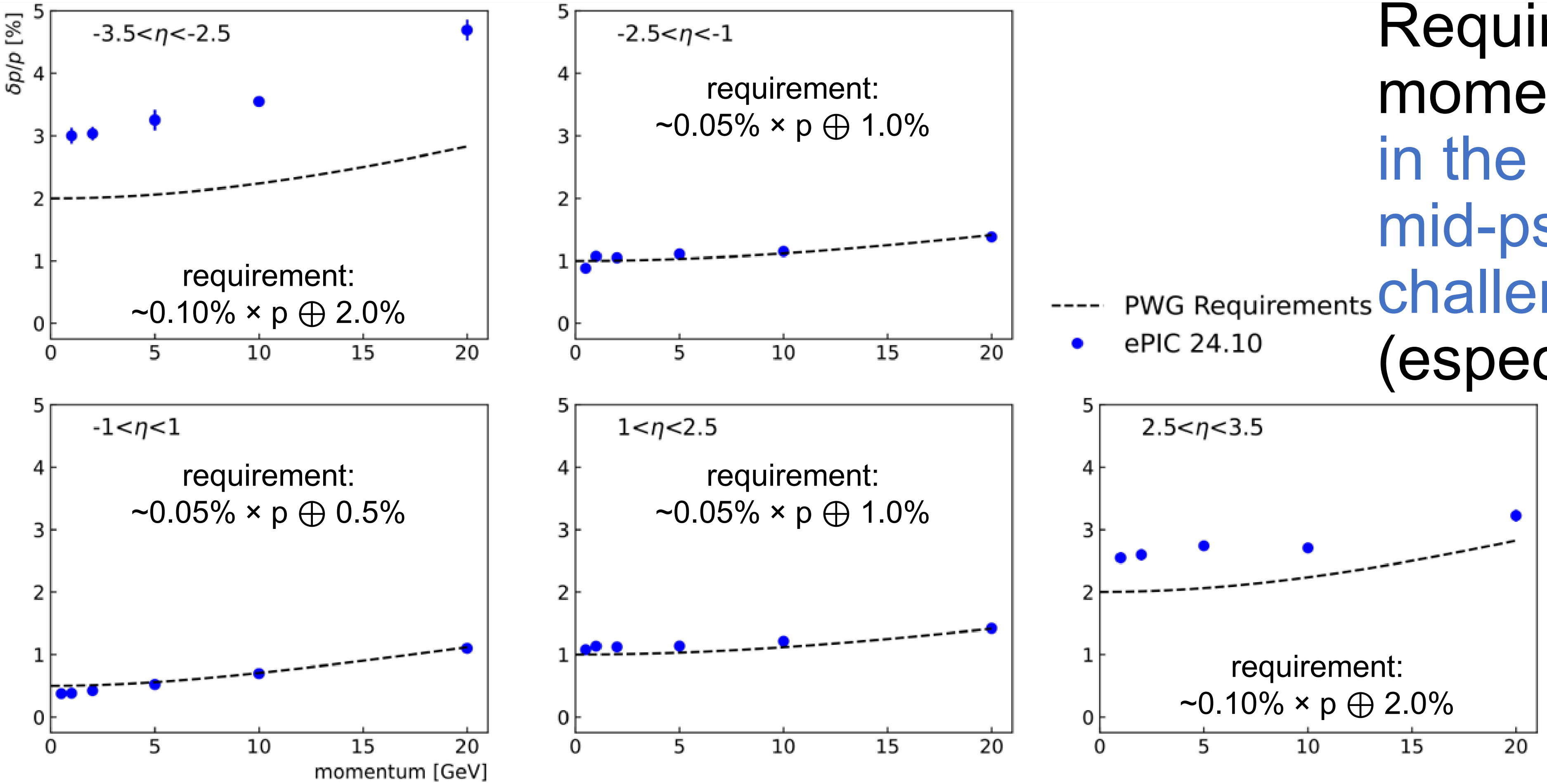
Tracking performance



Requirements on transverse pointing resolution met in the central region and at mid-pseudo rapidity, with good agreement at large eta.

preliminary

Tracking performance



Requirements on relative momentum resolution met in the central region and mid-pseudo rapidity, but challenging at large eta (especially e-going side).

preliminary

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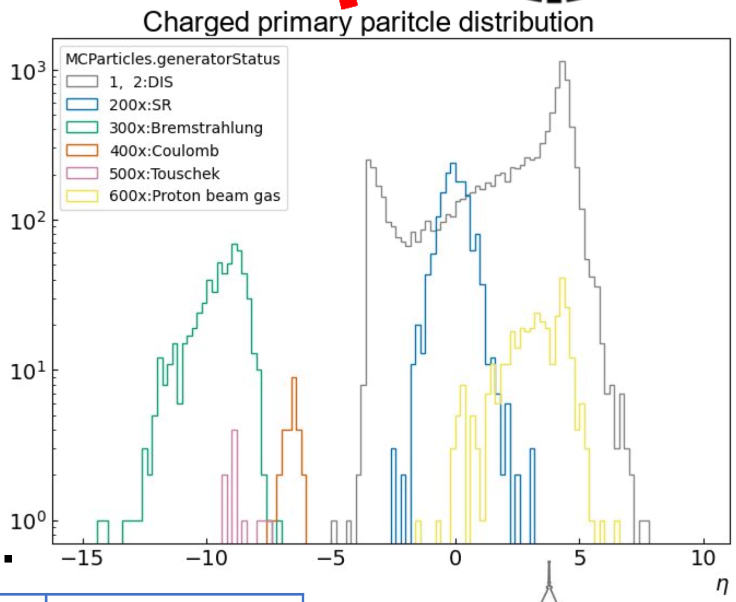
Hit rates in the SVT



- Background event dominate the hit rates in the SVT.
- Example study; 18 × 275 GeV DIS e+p events mixed with proton/electron beam gas and synchrotron radiation.
- Each tracking layer is segmented with a 2 × 2 cm^2 grid to approximate the active pixel array structure.

IB, OB	max hits /(2×2 cm^2 ms)	average hits /(2×2 cm^2 ms)	EE	max hits /(2×2 cm^2 ms)	average hits /(2×2 cm^2 ms)	HE	max hits /(2×2 cm^2 ms)	average hits /(2×2 cm^2 ms)
L0	2365	1105	ED0	729	105	HD0	553	97
L1	958	493	ED1	657	61	HD1	541	41
L2	197	107	ED2	620	59	HD2	110	12
L3	45	16	ED3	176	40	HD3	132	4
L4	9	3	ED4	23	7	HD4	79	3

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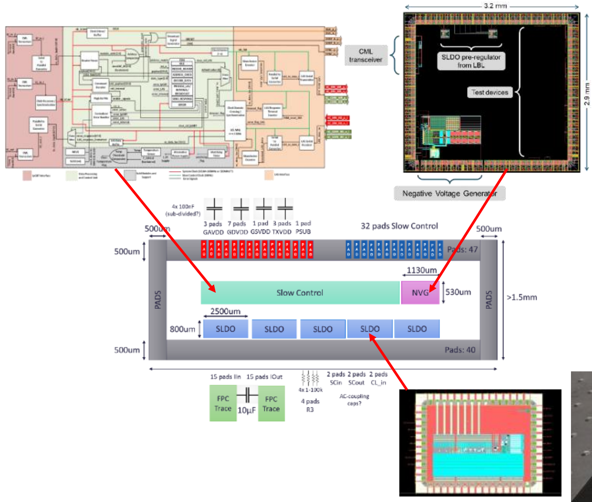
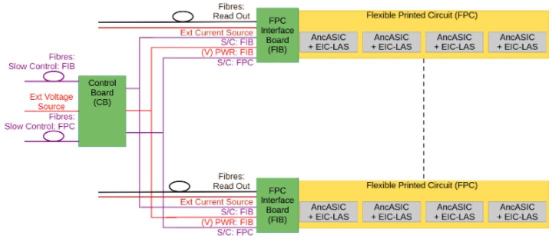
Ongoing activities

- Developments targets low mass technological solutions to satisfy the physics requirements and achieve tight integration of the different SVT regions.

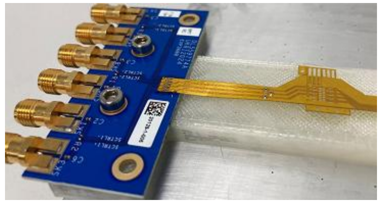
Ancillary ASIC development



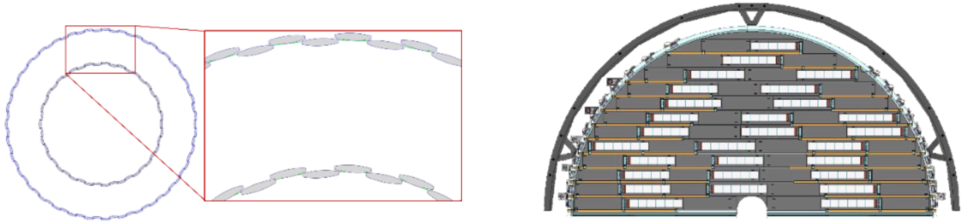
Readout chains



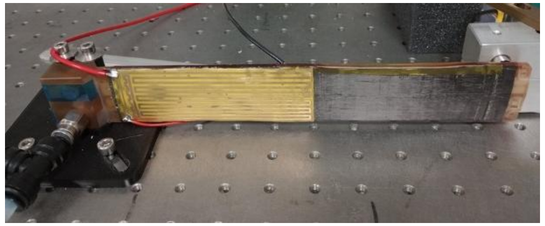
Low-mass electrical interfaces



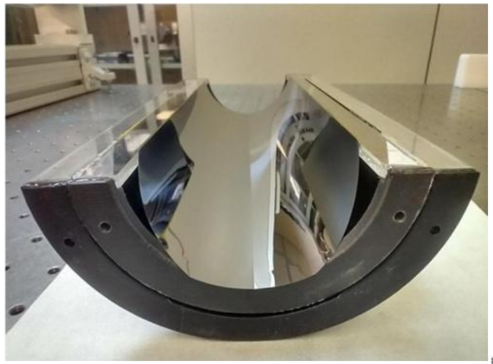
Design of OB and endcap disks



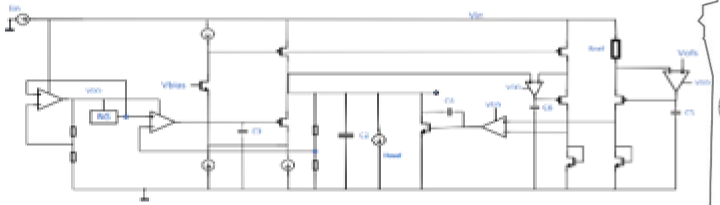
Air cooling through support structures



Bending of large 50 μm silicon structures



Serial powering



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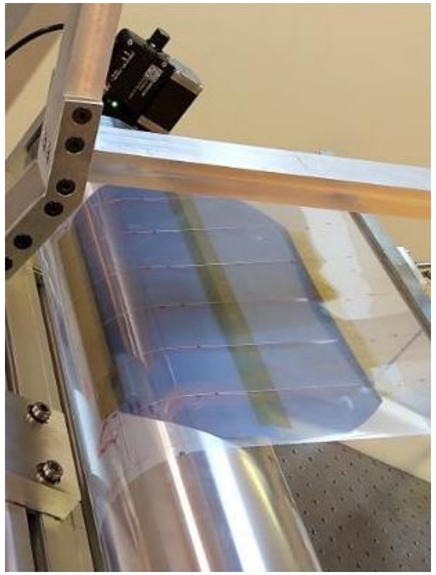
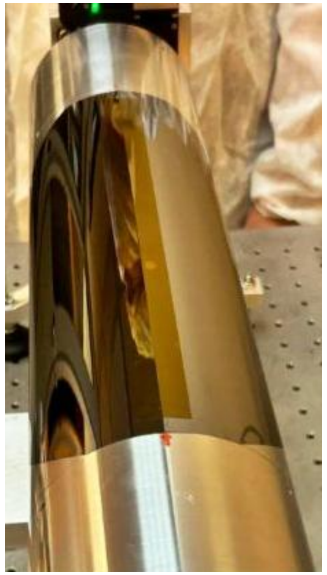
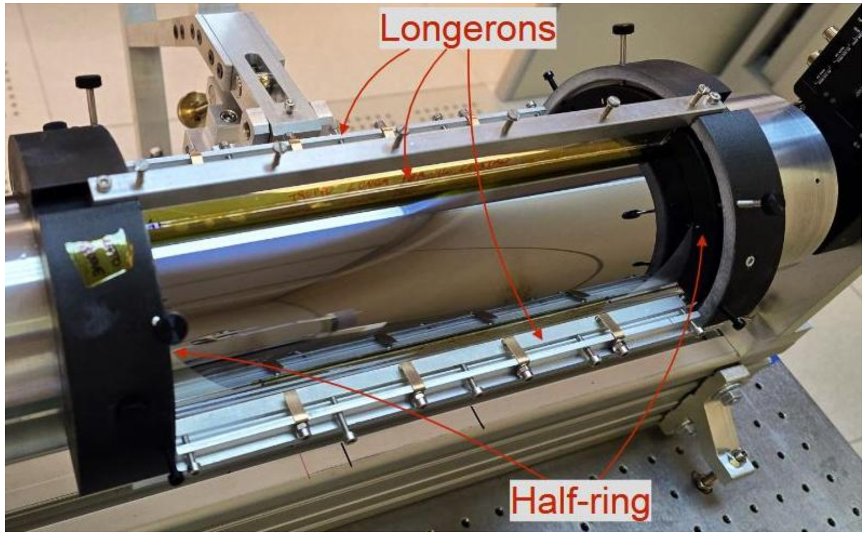
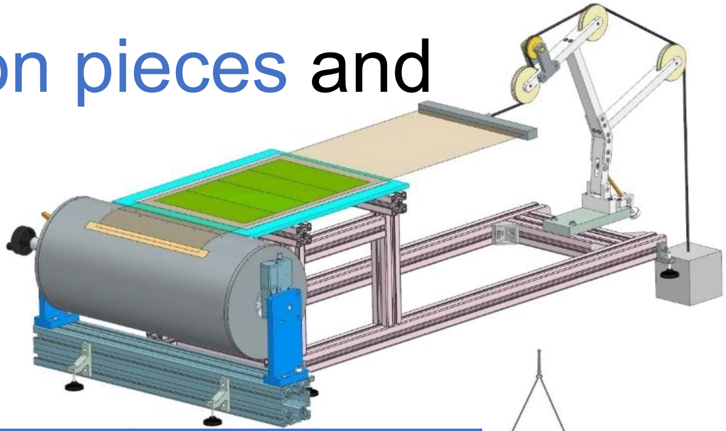
IB: Bending large scale sensors

- Larger radii that ITS3.
- Need to bend multiple sensors together.
- Initial trials performed on joining two dummy silicon pieces and bending to required radii.









IB	MOSAIX /sensor	Diced W (mm)	Diced L (mm)
L0	3	58.7	266
L1	4	78.3	266
L2	5	97.8	266

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Integrated mechanics and cooling

- The SVT will operate at room temperature with an estimated total sensor power consumption of $\mathcal{O}$(10kW) (incl. overhead for powering and data transmission).

- Preferred cooling solution for the SVT is air cooling.
  - Baseline for IB, OB and disks (OB and disks also considering strategic liquid cooling).
  - Ongoing studies of airflow internal to the support structure for OB and disks.

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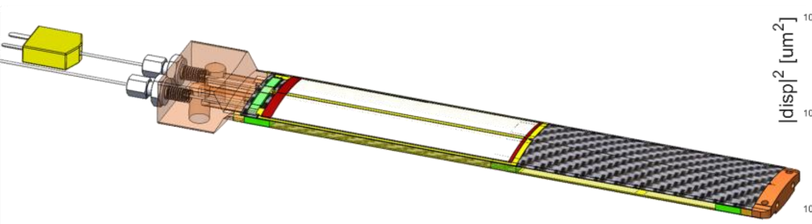
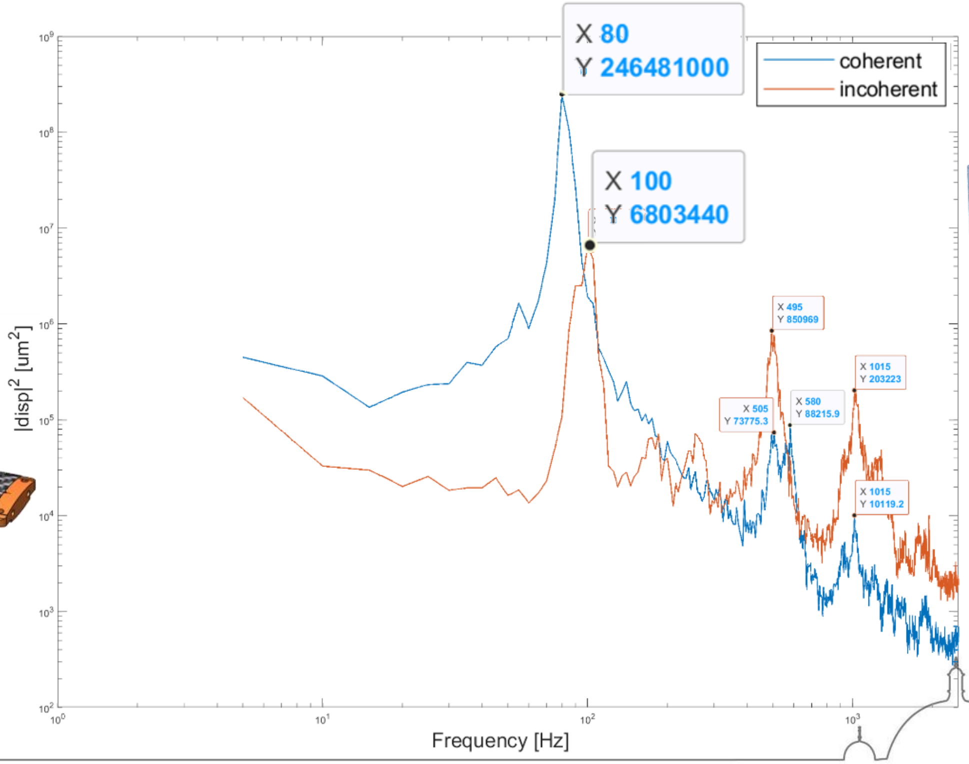
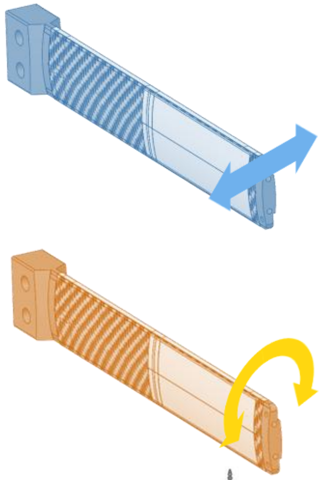
OB: Air flow through stave

- EIC-LAS curved (convex) on both sides of a carbon foam/fibre stave structure.
- Support and electrical services around the sensors; stave core is the air channel.
- Prototyping of test structure ongoing (¼ length stave); utilised for mechanical and thermal tests.







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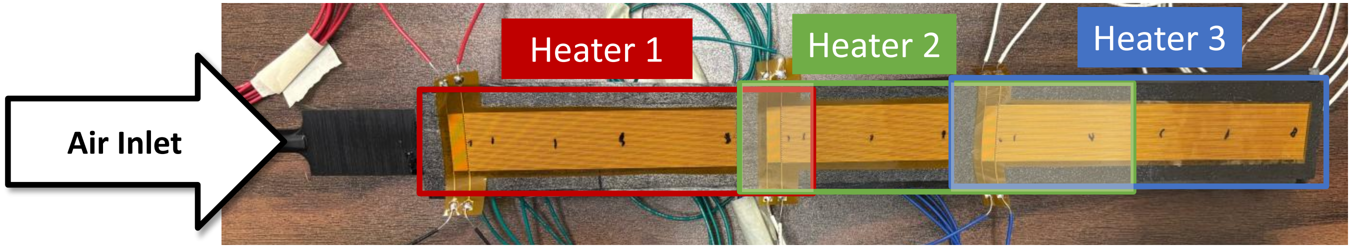
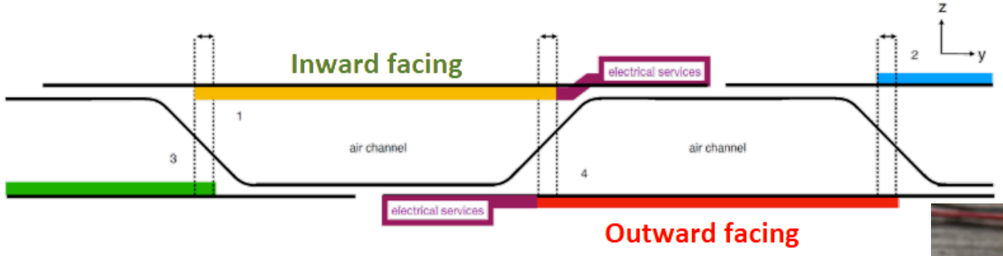
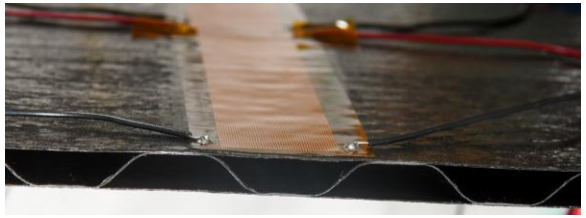
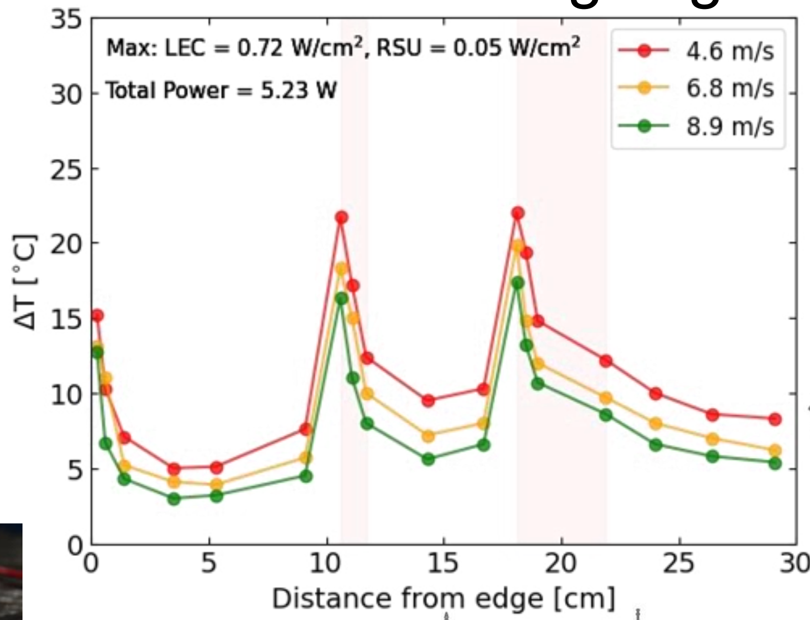
Disks: Air flow through corrugation

- EIC-LAS on both sides of corrugated support structure on carbon fibre sheets.
- Support and space for electrical services between modules; channel for air flow.
- Prototyping of test structures; mechanical and thermal tests are ongoing.



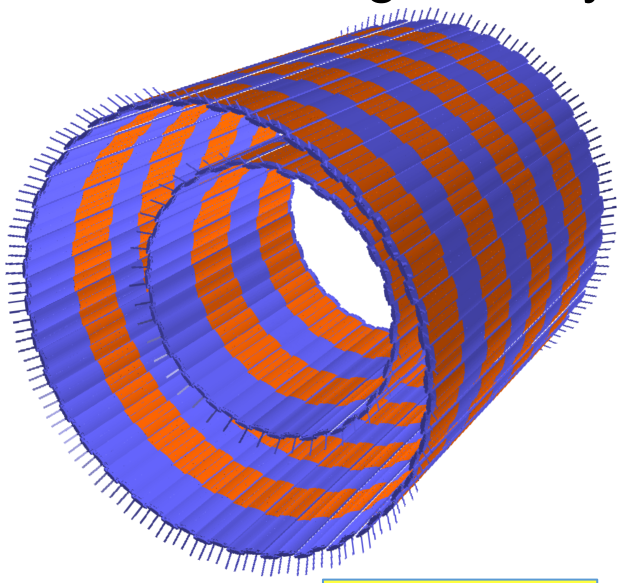


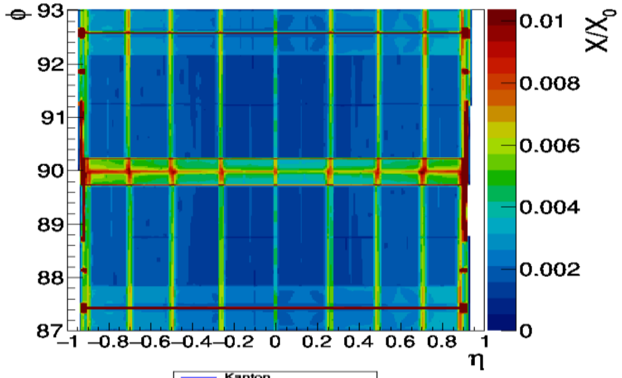


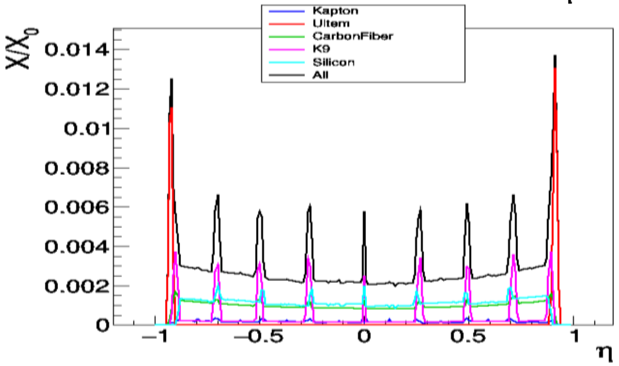


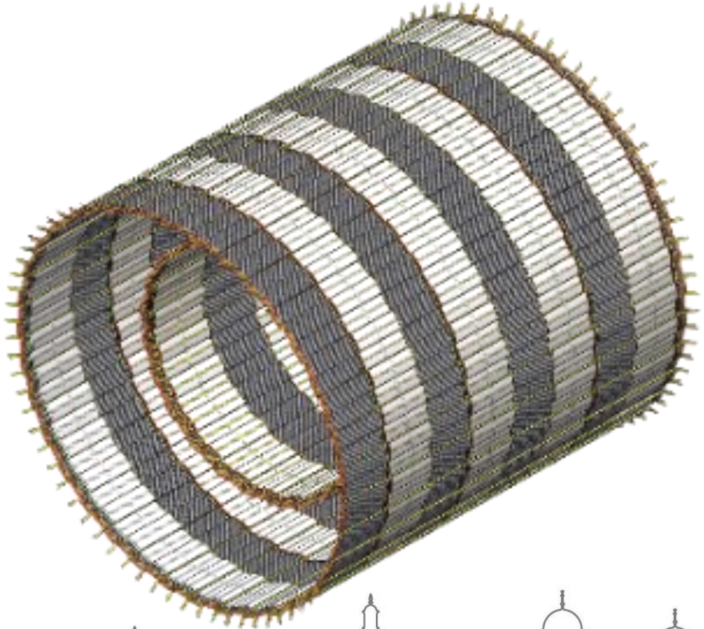
CAD geometry in simulations

- Scripts to convert a CAD model (.step) to a geometry for simulation (.gdml).
- Comparison tool to cross-check standard simulation geometry.
  - Much slower to run (very complex geometry, many vertices).
  - Planned to inform accurate material values and locations for a comparable simulation geometry.









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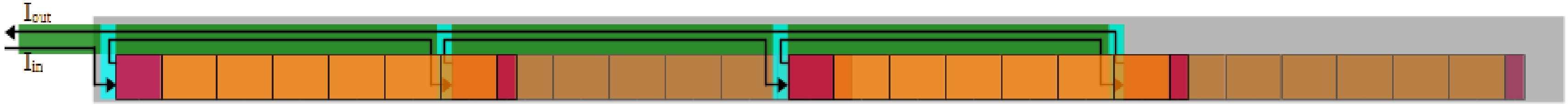
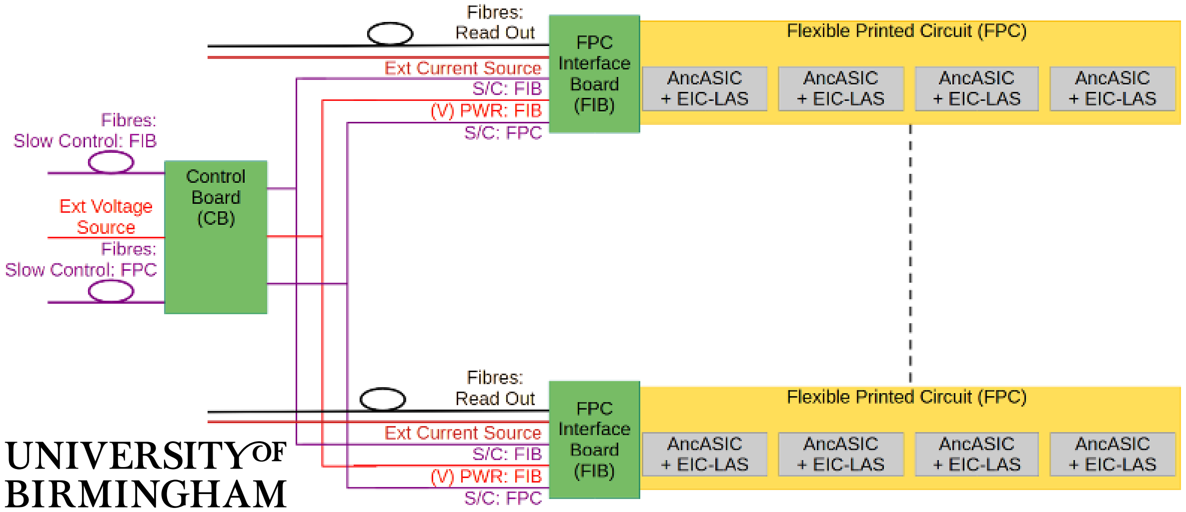
preliminary

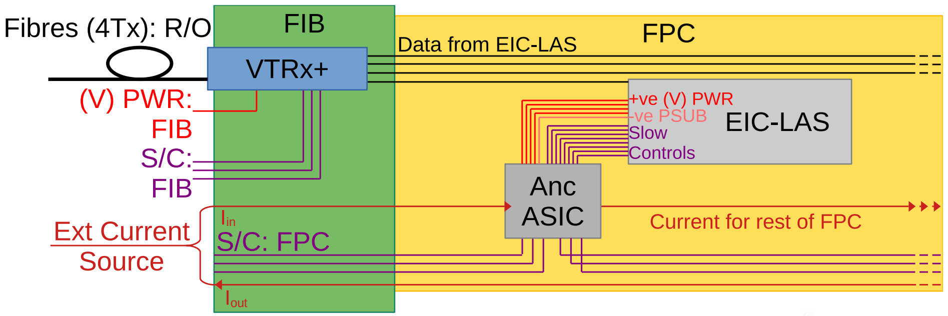
Services: Material reduction

Considerations have been made to keep the service material to a minimum.

- Serial powering of sensors (OB and disks).
- All data transmission (readout and S/Cs) over fibre optics.
- Aggregating EIC-LAS S/C into a single I^2C bus per flexible printed circuit.
- Consolidation of S/C related boards to minimise numbers.







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Conclusions

- The EIC will be a world's unique facility to continue exploration of strongly interacting matter using DIS, commencing operation in the mid 2030s.
- The ePIC Silicon Vertex Tracker is a large, thin, MAPS-based detector, with very demanding requirements for precision measurements and integration.
- Synergies with ALICE ITS3 developments + large programme of dedicated development on a low-mass detector with integrated mechanical and cooling structures, and multifaceted service reductions.

It is not too late to get involved!

ePIC Silicon Vertex Tracker Detector Subsystem Collaboration

Detector Subsystem Leader: Ernst Sichterman (LBNL)
Detector Subsystem Technical Coordinator: Laura Gonella (Trieste)
Detector Subsystem Technical Coordinator: Georg Viehhauser (Oxford)