EIC Detector R&D

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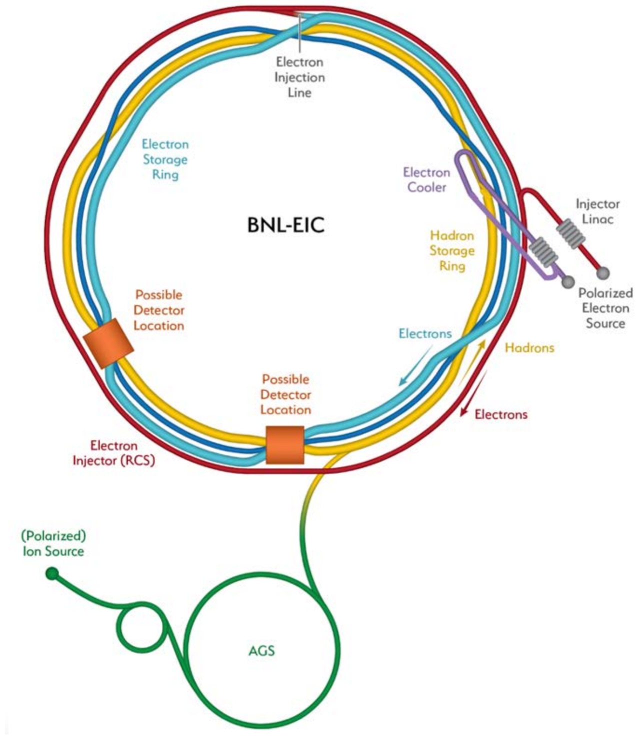
University of Birmingham

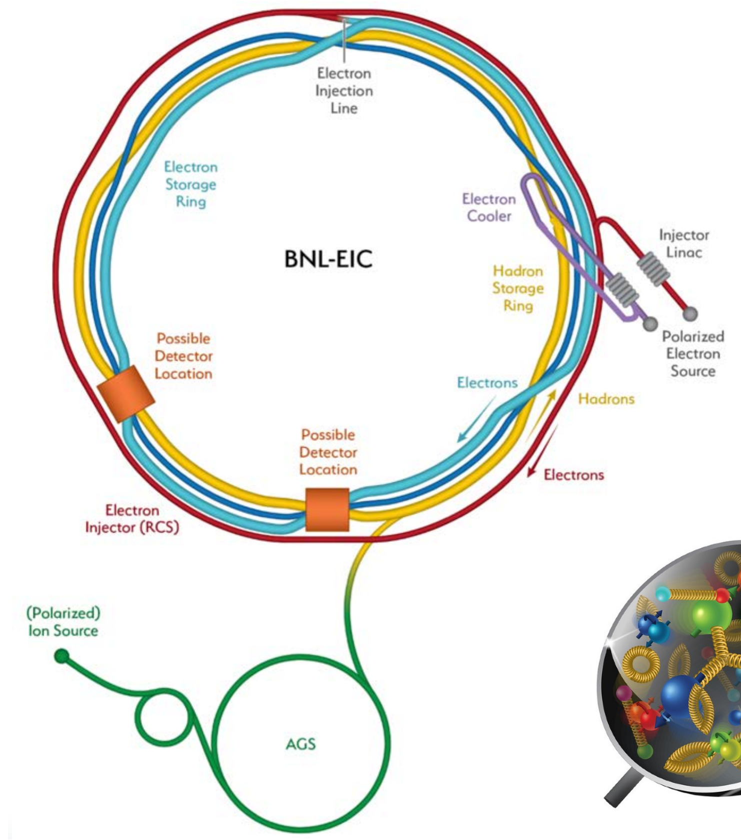


Daresbury Laboratory
Rutherford Appleton Laboratory

Electron-Ion Collider (EIC)

- Overview of the facility

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



- Uniqueness

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

World's first polarised electron, 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?

- US Project Overview

Total Project Cost = $2.4B incl. contingency

Covers approx. 90% of the accelerator and 66% of one detector (the project detector)

Currently in R&D and prelim. design phase

Start of construction expected 2025

Start of operations expected 2032

UK Project Overview

- UKRI Infrastructure Preliminary Activity

EIC Detector R&D awarded £2.97m

Duration 2.5 years (Oct 2021 – Mar 2024)

Detector R&D work packages:
WP1 – MAPS: silicon tracking and vertex reconstruction in the central detector
WP2 – Timepix: high-rate tracking of scattered electrons in the far-backward detector region
WP3 – Polarimetry: developing new technology to measure recoil nucleon polarisation

Funded institutes:
Birmingham, Brunel, Glasgow, Lancaster, Liverpool, York, STFC/DL, STFC/RAL (TD and PPD)

Aims of this phase are/were:
(i) Establish technical and scientific leadership in the EIC project detector collaboration (ePIC)
(ii) Define the size and scope of the UK's contribution to detector construction

- UKRI Full Infrastructure Project

Total request £58.8m, 100% FEC, incl. contingency

Duration 7+1.75 years (Jul 2025 – Mar 2034)

Contains 3 Detector WPs and 1 Accelerator WP

Detector WPs are:
WP1 – Silicon Tracker
WP2 – Electron Tagger
WP3 – Luminosity Monitor (New)

Plan to pursue Polarimetry development via US EIC Generic R&D program

Peer Review and STFC prioritisation

Submitted to UKRI on 24th of July

Decision expected in Q1 2024

Proposal institutes:
Birmingham, Brunel, Glasgow, Lancaster, Liverpool, Oxford, York, STFC/DL, STFC/RAL (TD and PPD)

EIC Project Detector

6.10
EIC
Detector

6.10.01 Detector Management	6.10.08 Electronics
6.10.02 Detect. R&D & Physics Design	6.10.09 DAQ / Computing
6.10.03 Tracking	6.10.10 Detector Infrastructure
6.10.04 Particle Identification	6.10.11 IR Integration & Auxiliary Detectors
6.10.05 Electromagn. Calorimetry	6.10.12 Detector Pre-Ops & Commiss.
6.10.06 Hadronic Calorimetry	6.10.13 Detector #2 Development
6.10.07 Magnets	6.10.14 Polarimetry and Luminosity

Hadronic Calorimeters (HCAL)

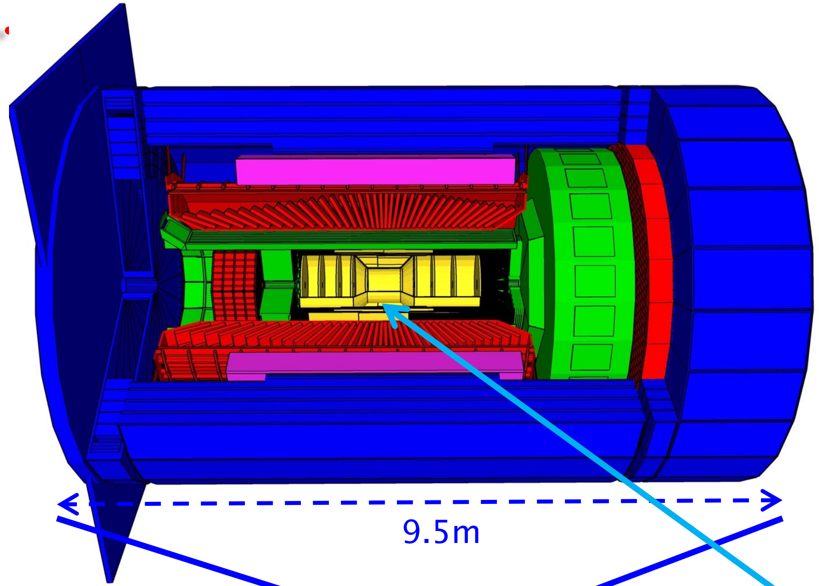
Solenoidal Magnet

E/M Calorimeters (ECal)

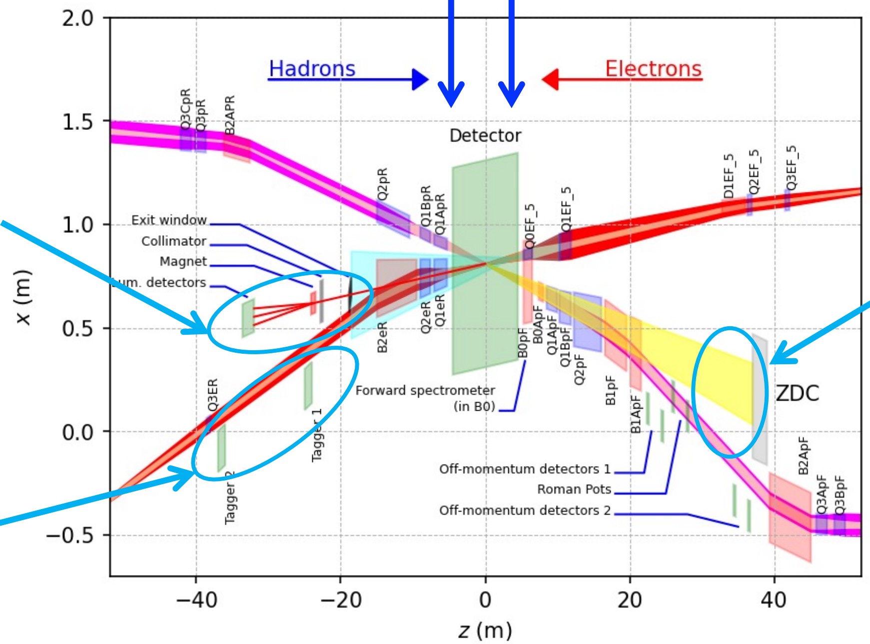
Time.of.Flight (ToF), DIRC, RICH detectors

MPGD trackers

MAPS tracker



WP1: Silicon Tracker



WP3: Luminosity Monitor

WP3: Polarimeter

WP2: Electron Tagger

EIC Full Infrastructure Project – Deliverables

- WP1 – Silicon Tracker: Precision tracking and vertexing in the central detector

  65 nm stitched (wafer-scale) monolithic active pixel sensors; developed in partnership with CERN/ALICE-ITS3

  Deliverable: Build ~33% of central silicon tracker.

  Institutes: Birmingham, Brunel, Lancaster, Liverpool, Oxford, STFC RAL, STFC DL

- WP2 – Electron Tagger: Precision tracking of low-Q^2 scattered electrons

  Low-Q^2 tagger using Timepix pixel sensors.

  Deliverable: Build two tracking stations in the far backward region. Timepix4 is the baseline technology.

  Institutes: Glasgow, STFC DL and Lancaster (beam impedance studies)

- WP3 – Luminosity Monitor: Bunch-by-bunch measurement of collision luminosity

  Design of the luminosity monitor comprising a pair spectrometer (PS) and photon detector (PD)

  Deliverables: Build the two calorimeters needed for the PS and half the modules needed for the PD

  Institutes: York

- WP4 – Accelerator: Cavity design and cryomodule fabrication

  Cavity design and cryomodules for the Energy Recovery Linac that forms part of the hadron beam cooler

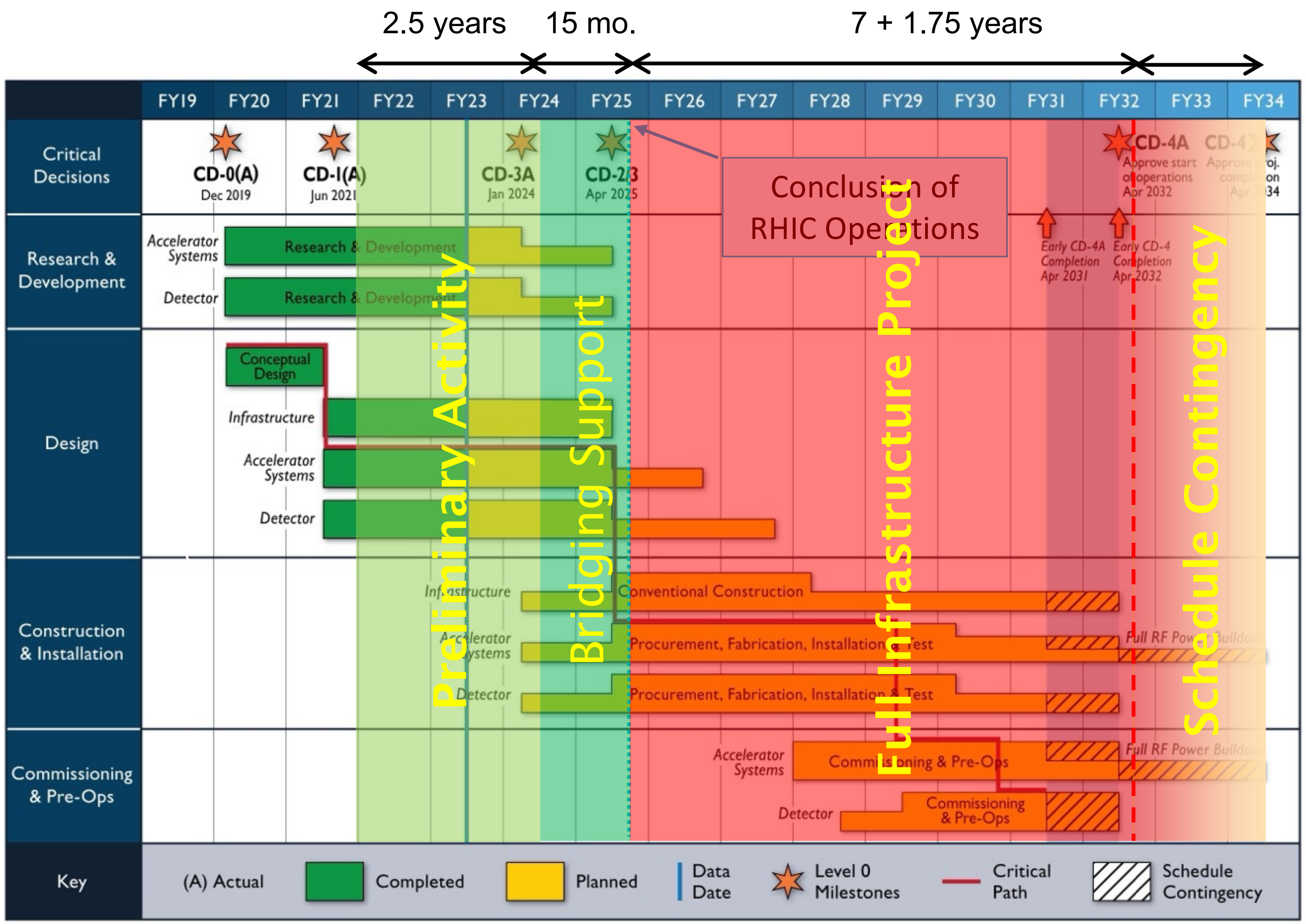
  Deliverables: Build two cryomodules for the ERL cooler

  Institutes: Lancaster and STFC DL

EIC Project – Schedule

Critical Decision (CD) Milestones
CD-0 Approve Mission Need
CD-1 Approve Cost Range
CD-2 Approve Baseline Performance
CD-3 Approve Start Construction
CD-4A Approve Start of Operations
CD–4 Approve Project Completion

Upcoming Project Milestones
TDR – Q4 2024
CD2/3 review – Q1 2025
CD2/3 approval – Q2 2025 (April)



NOTE: US Financial Years (FY) = Oct-Sep

UK-EIC Detector R&D Project
UK-EIC Detector Construction Project

Schedule shown by Project Director, Jim Yeck, at EIC RRB meeting 3-4 April

ePIC Silicon Vertex Tracker

- Precision central tracking and vertexing

  Approximately 8.5 m^2 detector

  65 nm MAPS technology driven by physics requirements and validated with simulations

  Developed in partnership with ALICE-ITS3

  - Proposed ITS3 sensor meets EIC requirements; partnership minimises risk

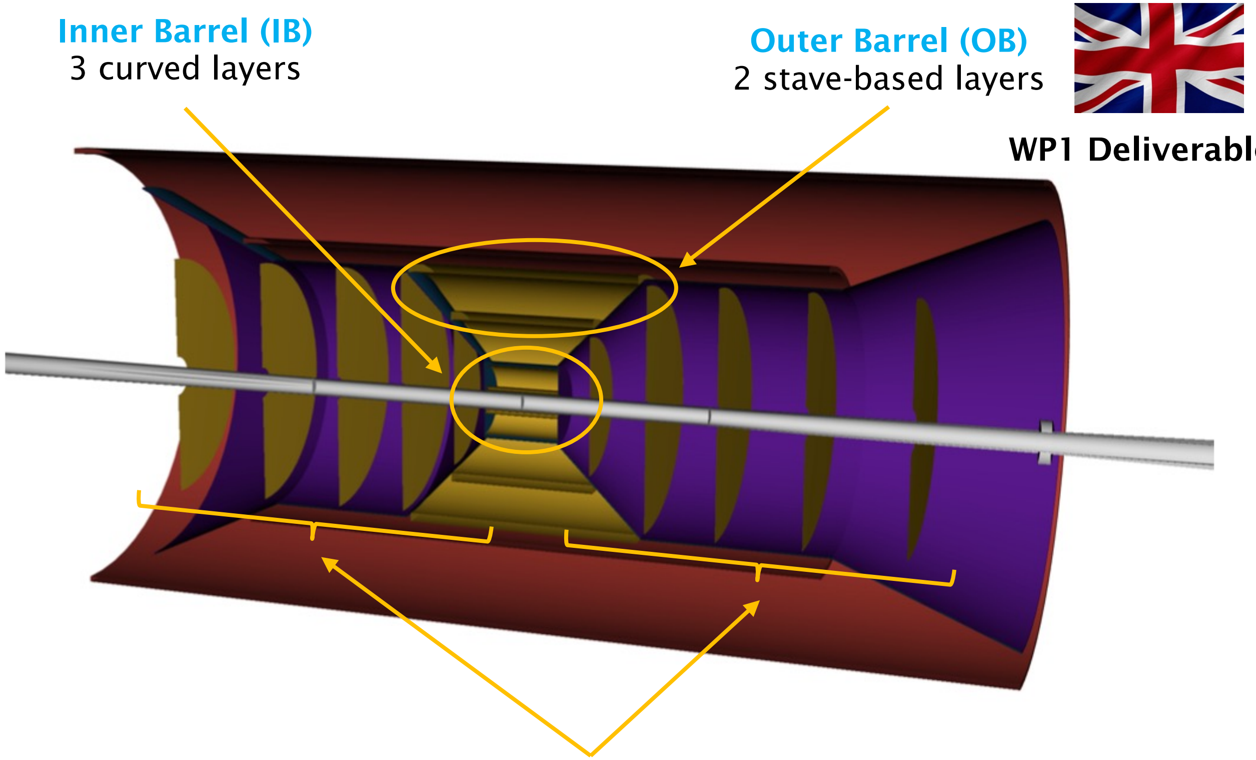
  ePIC will use same concept for vertex layers:

  - ITS3 wafer-scale stitched sensors, thinned and bent around the beam pipe

  Development needed for the barrel layers and disks:

  - large area stitched sensor (not wafer scale), and "conventional" low-mass support structures
  - Requires changes to the ITS3 sensor stitching plan and possibly some changes to the digital periphery; pixel matrix unchanged

ePIC SVT Requirements		
Spatial Resolution		~ 5 µm
Power Consumption		~ 20 mW/cm^2
Frame Rate		≤ 2 µs
Material Budget	IB	0.05% X/X0
	OB L3	0.25% X/X0
	OB L4	0.55% X/X0
	EE/HE	0.24% X/X0



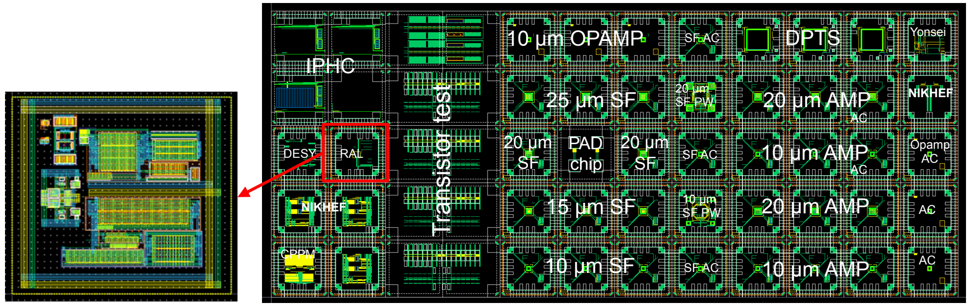
WP1 – MAPS – UK Technology Developments

- Large area MAPS sensor

ALICE ITS3 and ePIC SVT first experiments to develop wafer-scale sensors for charged particle tracking

65 nm CMOS imaging technology: 300 mm wafers, stitching, low power

UK (RAL) involved in 65 nm development from the beginning with ITS3 and CERN EP R&D WP1.2



RAL IP Block – MLR (Q4 2020): LDVS receiver and CML transmitter

ER1 (Q4 2022) RAL contributed additional functional blocks for high-speed on-chip data transmission

Plus, redesigned digital libraries for DFM: Buffers, AND gates, NAND gates, inverters, Filler cells, Flipflops

- Lightweight support structures

Carbon fibre mechanical support with integrated cooling channels for evaporative cooling

ePIC SVT stave layout not yet defined; work not yet started in earnest

Ideas to move away from conventional flat stave geometry to achieve required stiffness with less material

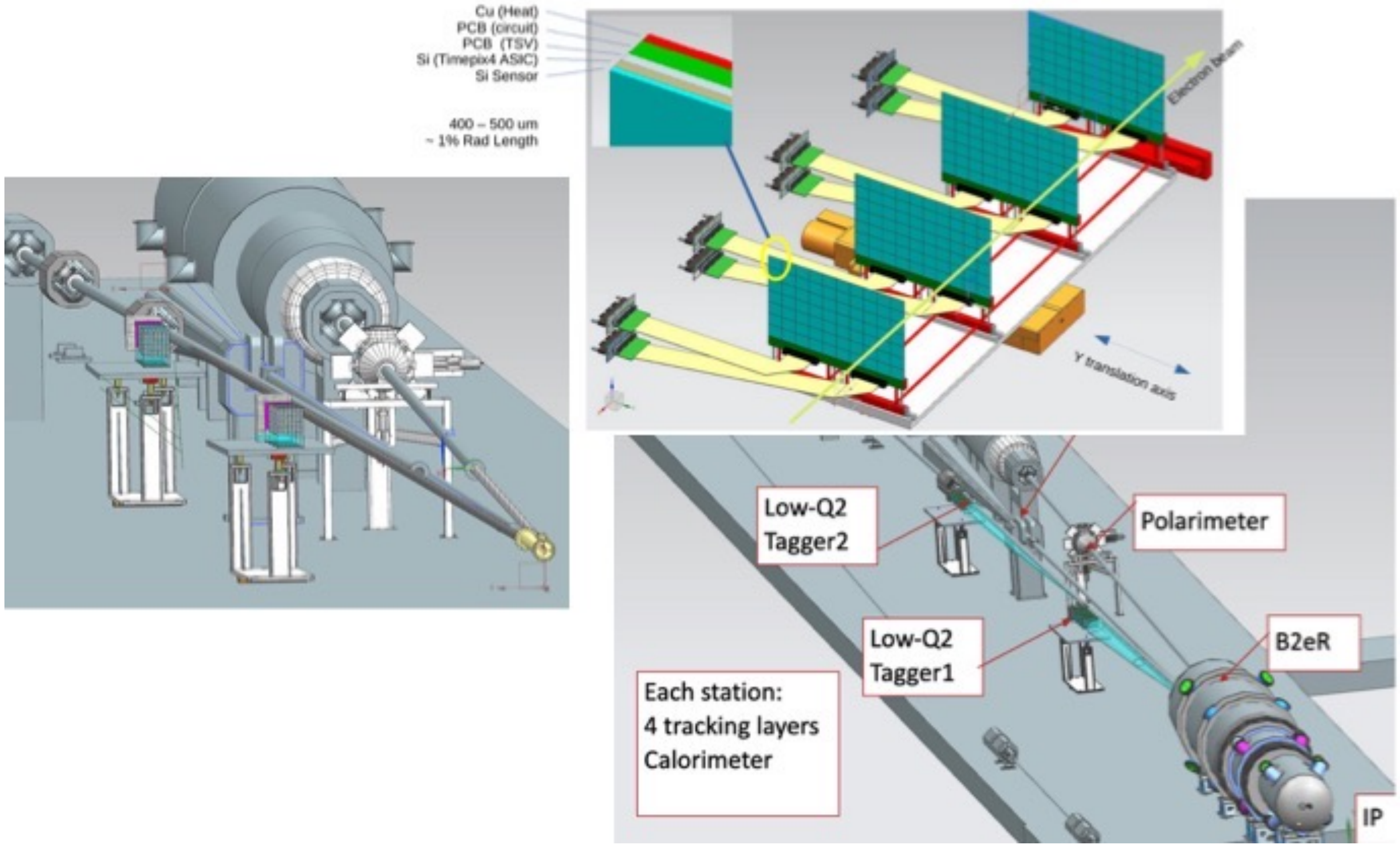
- Serial powering

Development of Shunt-LDO regulator in commercial CMOS imaging technology

Development of full serial powering architecture for MAPS tracker for low mass power distribution

WP2 – Timepix

- ePIC CAD design with Timepix4 tracker



WP2 – Timepix

- Development of Timepix4 high-rate-trackers and readout for EIC applications

  Research involving Glasgow Particle Physics and Nuclear Physics Groups (including Medipix collaboration) and NIHKEF

  S. Gardner, K. Livingston, D Manueski

- Development of TI-LGAD with Timepix

  Research involving Glasgow Particle Physics and Nuclear Physics Groups (including Medipix collaboration)

  Proposal to US EIC Generic R&D Program

  Fabrication and characterisation of the *Trench Isolated Low Gain Avalanche Detectors* for 4D tracking

  S. Gardner, D Manueski

- Machine-Detector Interface (MDI)

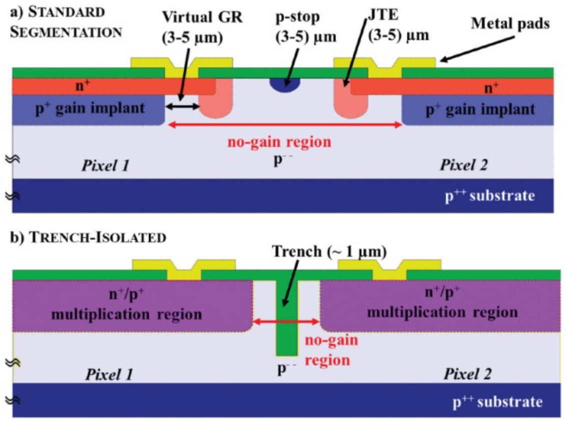
  Research involving Glasgow Nuclear Physics and Lancaster Accelerator group on impedance modelling for EIC far-backward detectors

  S. Gardner, D. Glazier, K. Livingston, R. Apsimon

- Data processing technologies

  Development of fast-tracking solutions with Graph Neural Networks

  S. Gardner, D. Glazier, R Tyson

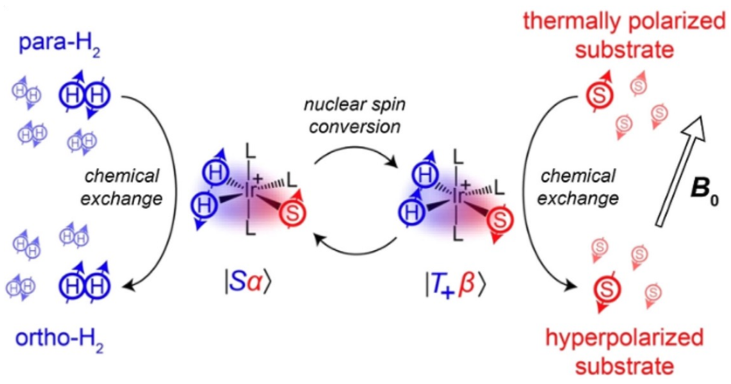


G. Paternoster et al. "Trench-Isolated Low Gain Avalanche Diodes (TI-LGADs)". In: IEEE Electron Device Letters 41.6 (2020), pp. 884–887. doi:10.1109/LED.2020.2991351.

WP3 – Polarimetry / Luminosity Monitor

- **Polarimetry R&D (Preliminary Activity)**

NMR technique: chemical hyperpolarization – transfer nuclear spin order from parahydrogen (pH_2) to substrate molecule via catalyst



Substrate polarisable at room temp with weak field

Maintain polarisation with pH_2 bubbling

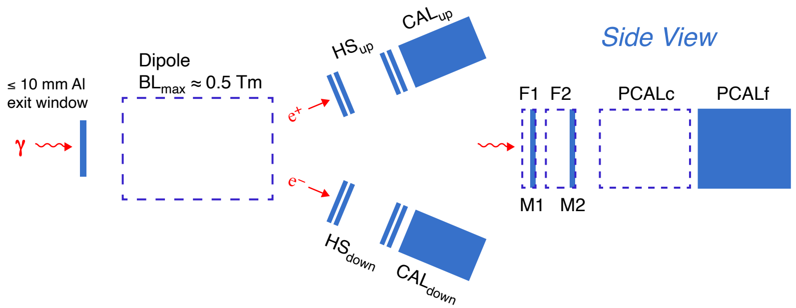
Aiming to develop large volume, active, liquid polarised scattering media with several applications:

1. Detector to measure recoil nucleon polarisation
2. Explore suitability as polarised (frozen) target

Proposal to US EIC Generic R&D Program

- **Luminosity Monitor R&D (Full Project)**

Design and fabrication of calorimeter modules for pair spectrometer and direct photon detector



1. R&D to optimise the W/SciFi ratio
2. Investigating ways to improve position resolution that eliminate the need for tracking planes

   The x-y vs z shower profiles are expected to provide better constraints on the gravity of the shower

   Develops out of AI/ML guided detector design and data analysis for high-rate photon luminosity monitoring and calorimetry

3. Exploration of new methods for linear photon polarisation determination in the GeV energy range

Synergies with UK DRD and ECFA Detector R&D Roadmap

WP1 – MAPS (DRDT 3.1)

Work for the ePIC SVT brings expertise in a new, smaller technology node:

e.g., circuit blocks; stitching methodology for high yield in dense logic design; …

WP1 – Mechanics and Cooling (DRDT 8.3/8.2)

Scope for collaboration and sharing of ideas / technologies:

e.g., low-mass structures, evaporative cooling and integration of cooling channels, additive manufacturing, fluid system connections, gas cooling

WP1 – Serial Powering (DRDT 7)

Development of serial powering scheme could add to the UK involvement in DRDT 7 projects

- WP2 – Sensors for 4D tracking (DRDT 3.2)

Developing tracking systems with high-rate capability with Timepix4 and TI-LGADs

- WP2 – Fast tracking with Graph Neural Networks

DRDT 7.5 – Evaluate and adapt to emerging electronics and data processing technologies

- WP3 – Active polarised scattering media

Polarisation measurement at future colliders?

- WP3 – AI/ML guided detector design & analysis

DRDT 7.2 - Develop technologies for increased intelligence on the detector

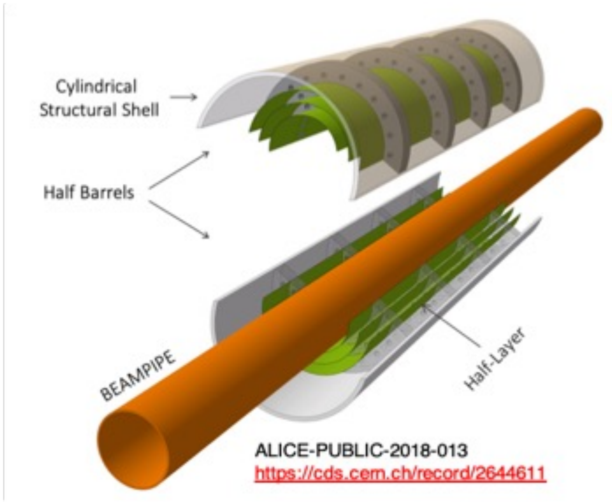
Overarching synergy with UK Strategic R&D towards low-material tracker for e+e−

ePIC SVT OB developed by the UK could be part of the low material tracker demonstrator programme

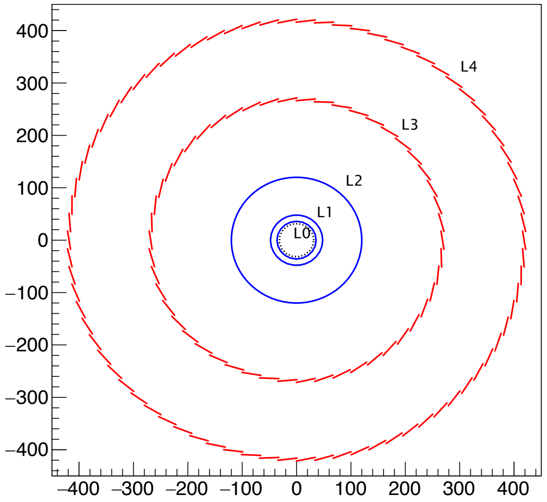
See discussion at https://indico.stfc.ac.uk/event/781/

Backup – WP1 – MAPS

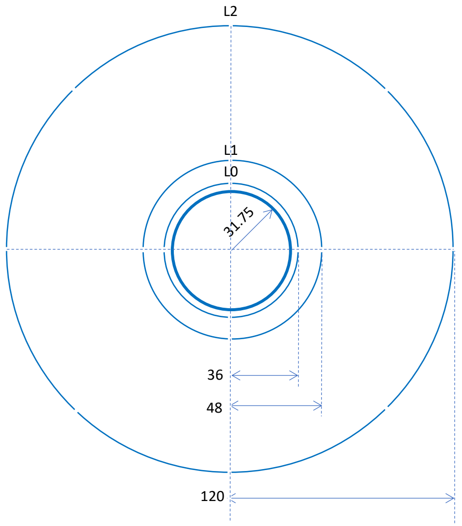
- Vertex and Barrel Layers



ALICE-ITS3 development



ePIC-SVT Vertex and Barrel Layers



ePIC-SVT Vertex Layers

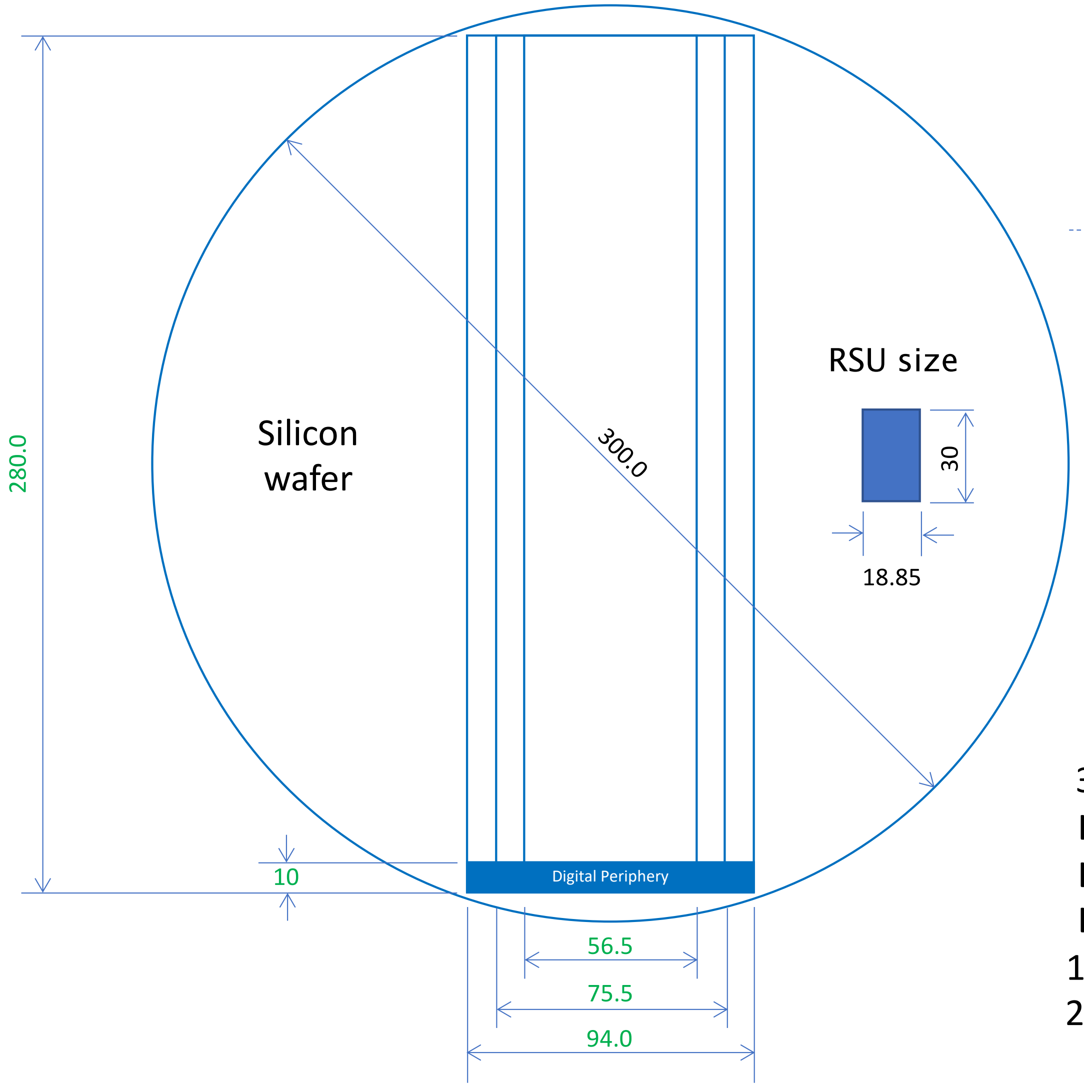
Vertex Layers

Wafer-scale, stitched sensors, thinned and bent around the beam pipe
Use unmodified ITS3 sensors with bespoke support structure
Air cooling

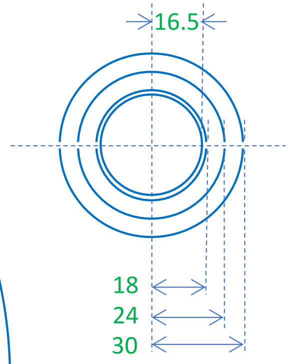
Barrel Layers

Large-area, but not wafer-scale (yield consideration), stitched sensors
Conventional, low-mass support structures
Two-phase cooling

Backup – ALICE ITS3 Sensor Layout



ALICE – ITS3

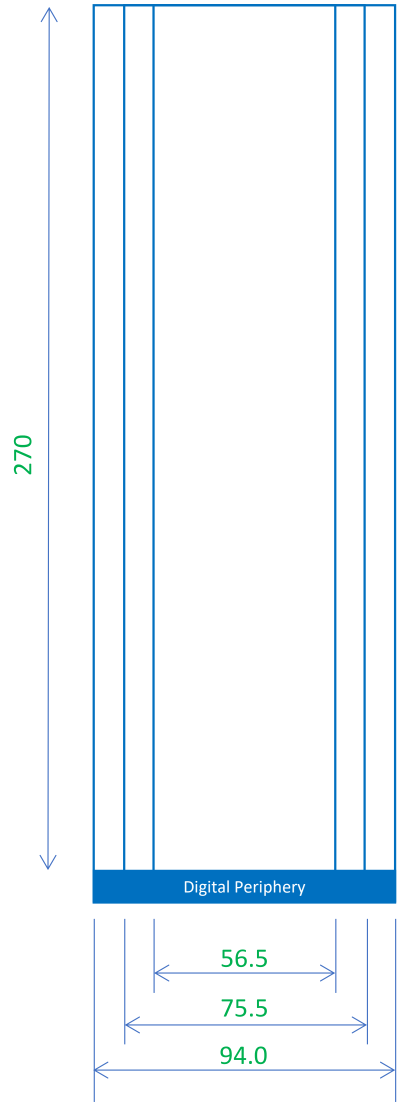


Units = mm

ITS3
3 sensor formats:
L0 = 3 x 9 reticles
L1 = 4 x 9 reticles
L2 = 5 x 9 reticles
1 sensor per wafer
2 sensors per layer

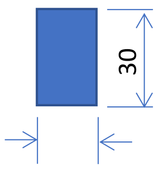
Note: RSU size and dimensions taken from ITS3 LoI – not final

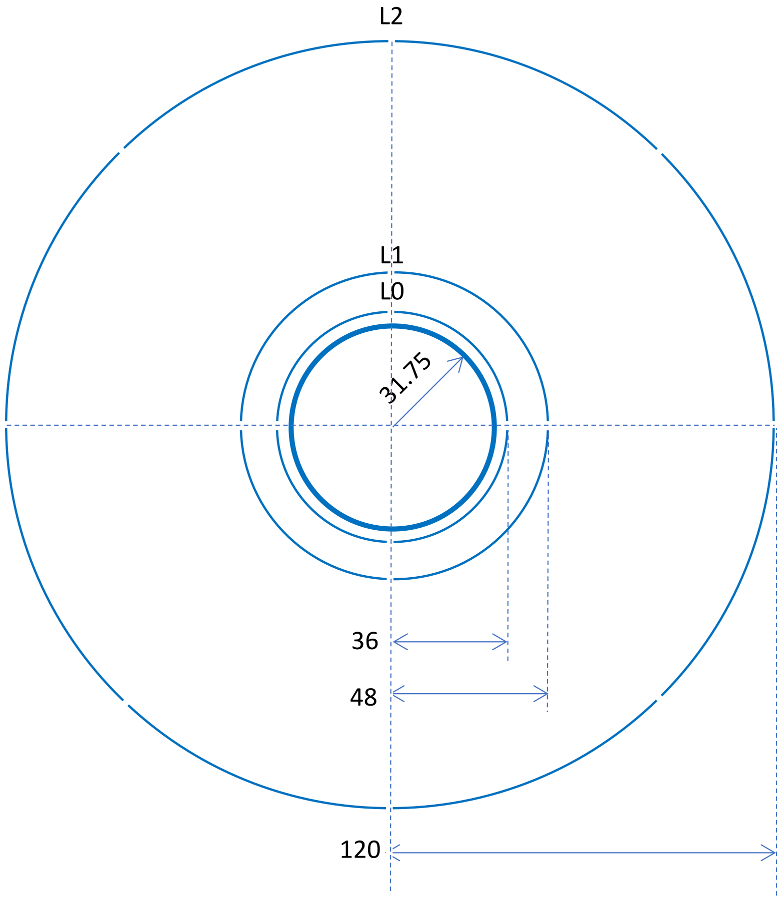
Backup – ePIC Vertex Layers



L0 = 4 x 56.5; R = 36
L1 = 4 x 75.5; R = 48
L2 = 8 X 94.0; R = 120

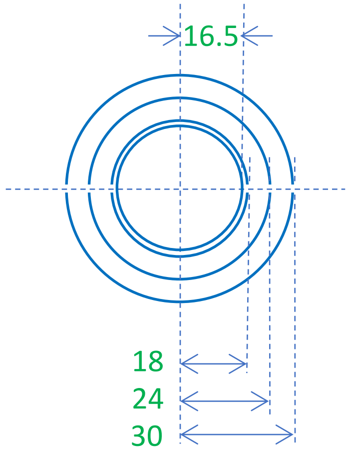
ePIC - SVT
Same 3 sensor formats:
L0 = 3 x 9 reticles
L1 = 4 x 9 reticles
L2 = 5 x 9 reticles
1 sensor per wafer
4 or 8 sensors per layer





Units = mm

ALICE – ITS3



Note: RSU size and dimensions taken from ITS3 LoI – not final

Backup – ITS3 Stitched Sensor

- Updated sensor specifications

ER2 Stitched Sensor

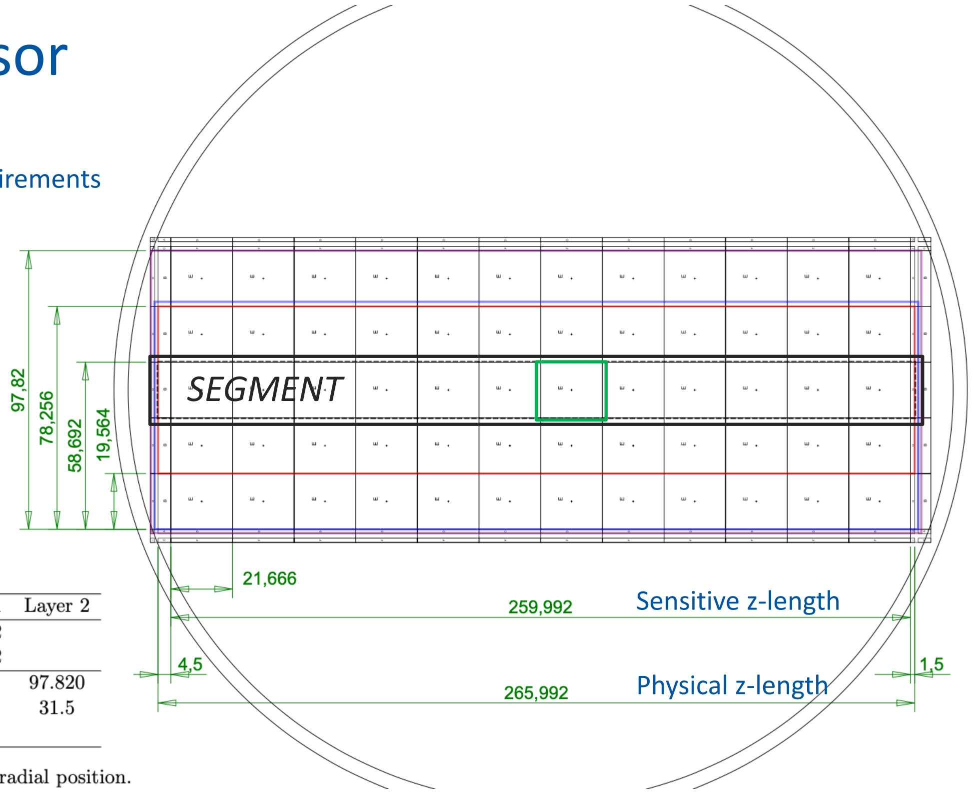
ER2 Sensor aims to meet the ITS3 requirements

Layer 0: 12 x 3 repeated units+endcaps

Layer 1: 12 x 4 repeated units+endcaps

Layer 2: 12 x 5 repeated units+endcaps

Repeated (Stitched) Sensing Unit



AZIMUTHAL WIDTH UPDATED

IB Layer Parameters	Layer 0	Layer 1	Layer 2
Sensor length [mm]		265.992	
Sensitive length [mm]		259.992	
Sensor azimuthal width [mm]	58.692	78.256	97.820
Radial position [mm]	19.0	25.2	31.5
Equatorial gap [mm]		1.0	

Table 3.2: Design dimensions of the sensor dies and radial position.

LoI: RSU = 18.85 x 30 mm^2, 9 RSUs per segment, active length = 270 mm

ER1: RSU = 14 x 25.5 mm^2, 10 RSUs per segment, active length = 255 mm

ER2: RSU = 19.564 x 21.666 mm^2, 12 RSUs per segment, active length = 260 mm