eRD104/111/113
Report and progress

Laura Gonella on behalf of the EIC Silicon Consortium

DAC meeting, 19 - 21 October 2022

Outlook

- Introduction to EIC SC and silicon related eRD projects
- Overview of an EIC SVT concept based on 65 nm MAPS
- Status of targeted R&D for the EPIC SVT
- FY23 proposal and request

EIC Silicon Consortium

- The overarching goal of the EIC Silicon Consortium is the development and construction of a full tracking and vertexing detector subsystem for the EIC detector(s) based on 65 nm MAPS sensors.

- The EIC silicon consortium grew out of the “eRD25: Silicon Tracking and Vertexing Consortium” project, part of the former EIC Generic Detector R&D program (full history in backup slides).
  - Expand scope of the work to include all aspects of detector development for the realisation full SVT detector for the EIC.
  - Increase participation to build the critical mass required to deliver the EIC SVT.

- The EIC SC works on two streams of research:
  - Targeted R&D for the EPIC detector - eRD104, eRD111, eRD113.
  - Generic R&D for EPIC upgrades/further optimisations or for a second detector – proposal submitted to the new Generic EIC-related Detector R&D Program.

Project directed R&D activities

- The EIC targeted R&D for the EPIC detector is carried out in the framework of eRD104, eRD111, eRD113.

- eRD104 Services reduction – Investigate methods to significantly reduce the services load for an EIC MAPS based tracking detector.
  - Powering system.
  - Readout system.
- eRD111 Si tracker – Development of a full tracking detector solution composed of next generation 65 nm MAPS sensors.
  - Forming modules from stitched sensors.
  - Barrel & discs.
  - Mechanics, integration, & cooling.
- eRD113 Sensor – Development of the EIC MAPS sensor
  - Sensor design.
  - Sensor characterisation.

NEW in FY23

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FY23 proposal and request

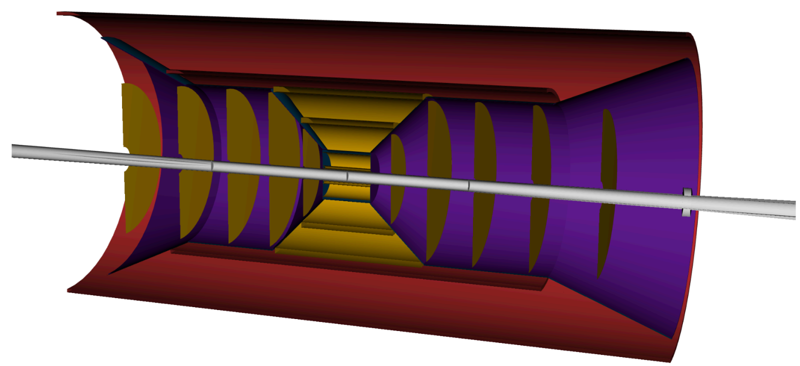
EIC Silicon Vertex and Tracking Detector

- The EIC science program requires a well integrated, large acceptance vertex and tracking detector designed with high granularity and low material budget.

- The core of this detector is a system of pixel layers in the central region and pixel disks in the forward and backward regions.
    - Surrounding tracking layers, e.g. in MPGD or AC-LGAD technology, are outside of the consortium scope.

- The pixel technology identified to satisfy the EIC SVT requirements is Monolithic Active Pixel Sensors, specifically a new MAPS generation in 65 nm CMOS imaging technology.

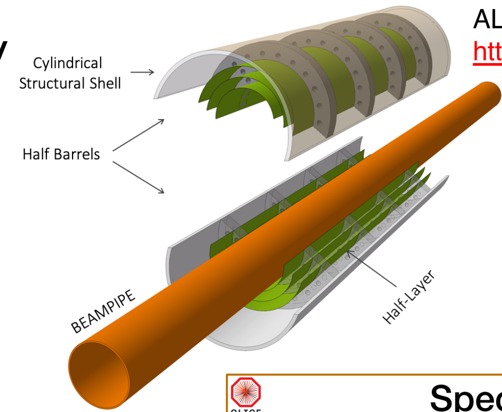
Example: EPIC SVT



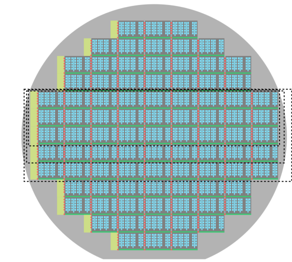
Requirements	
Spatial resolution [um]	~ 5 um
Material budget [% X0]	<0.3 <0.1 (vtx)
Power dissipation [mW/cm^2]	< 20
Integration time [us}	~2 us or better

65 nm MAPS sensor for EIC

- Leading development of this technology is the ALICE ITS3 project.
  - Truly cylindrical vertex detector with 0.05% X0.
  - Stitched, wafer scale sensors, thinned and bent around the beam pipe.
  - Mechanics and services outside active area.
  - Air cooling with low power sensor design in 65 nm.



ALICE-PUBLIC-2018-013
https://cds.cern.ch/record/2644611



Specifications

Parameter	ALPIDE (existing)	Wafer-scale sensor (this proposal)
Technology node	180 nm	65 nm
Silicon thickness	50 μm	20-40 μm
Pixel size	27 x 29 μm	O(10 x 10 μm)
Chip dimensions	1.5 x 3.0 cm	scalable up to 28 x 10 cm
Front-end pulse duration	~ 5 μs	~ 200 ns
Time resolution	~ 1 μs	< 100 ns (option: <10ns)
Max particle fluence	100 MHz/cm^2	100 MHz/cm^2
Max particle readout rate	10 MHz/cm^2	100 MHz/cm^2
Power Consumption	40 mW/cm^2	< 20 mW/cm^2 (pixel matrix)
Detection efficiency	> 99%	> 99%
Fake hit rate	< 10^{-7} event/pixel	< 10^{-7} event/pixel
NIEL radiation tolerance	~3 x 10^{13} 1 MeV n_{eq}/cm^2	10^{14} 1 MeV n_{eq}/cm^2
TID radiation tolerance	3 MRad	10 MRad

M. Mager | ITS3 kickoff | 04.12.2019 |

- The EIC sensor requirements are in line with the ITS3 sensor specifications → The EIC sensor is based off the ITS3 sensor.
- Further considerations
  - The ultra low mass ITS3 vertex layers concept is very attractive for the EIC.
  - The timelines of the two projects are well aligned. ITS3 TDR schedule and EIC CD-2/3A review schedule on the same timescale.

EIC SVT based on 65 nm MAPS

- The path to an EIC detector based on 65 nm MAPS thus requires to develop:

1. ITS3-like vertexing layers
    - Re-use ITS3 sensor as is.
    - Adapt ITS3 detector concept to the EIC radii.
        - Mechanics of bent layers needs specific development for EIC.

2. EIC variant for the staves and disks
    - EIC Large Area Sensor (LAS), i.e. ITS3 sensor size optimised for high yield, low cost, large area coverage.
        - EIC LAS will be stitched, but not wafer scale. Functionality and interfaces stay the same as the ITS3 sensor.
        - Size(s) of the EIC LAS to be defined based on yield of stitching process and requirements for full coverage.
    - Convectional carbon fibre support structures with integrated cooling.

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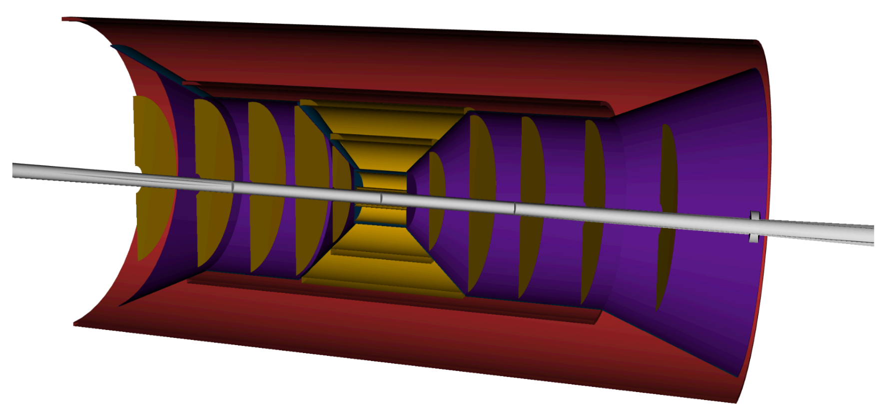
EPIC Vertex and Tracking Detector

- Members of the EIC SC are heavily engaged with the EPIC Tracking WG (and beyond) and are delivering the optimisation of the reference detector design to meet YR requirements.

- Barrel
  - Radii of two innermost vertex layers optimised for beam pipe bake out and ITS3 sensor size.
  - 3rd vertex layer moved at r = 12 cm to improve momentum resolution without increase in material.
  - Sagitta layers moved further out to improve momentum resolution.
    - Conceptual design change of 1st sagitta layer for lower material.
- Disks
  - Increased number of disks in both directions to improve acceptance at high eta/increase number of points on track.
  - Increased lever arm.

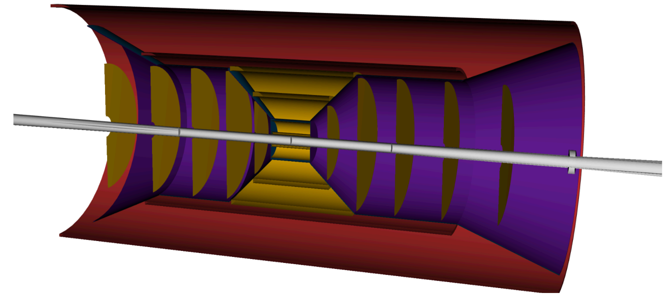
- In addition to layout optimisations, there has been other significant changes with respect to the reference detector happening simultaneously.
  - Magnetic field 1.5T → 1.7T
  - Ongoing transition to a new SW framework for simulations.



EPIC Vertex and Tracking Detector

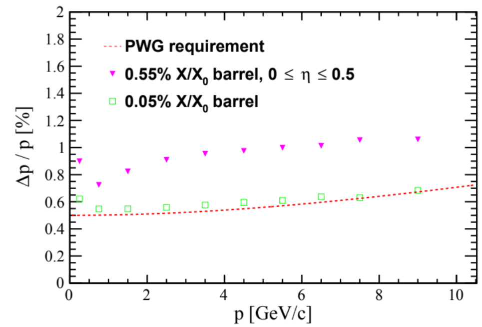
BARREL	r [mm]	l [mm]	X/X0 %
Layer 1	36	270	0.05
Layer 2	48	270	0.05
Layer 3	120	270	0.05
Layer 4	270	540	0.25
Layer 5	420	840	0.55

DISKS	+z [mm]	-z [mm]	X/X0 %
Disk 1	250	-250	0.24
Disk 2	450	-450	0.24
Disk 3	700	-650	0.24
Disk 4	1000	-900	0.24
Disk 5	1350	-1150	0.24

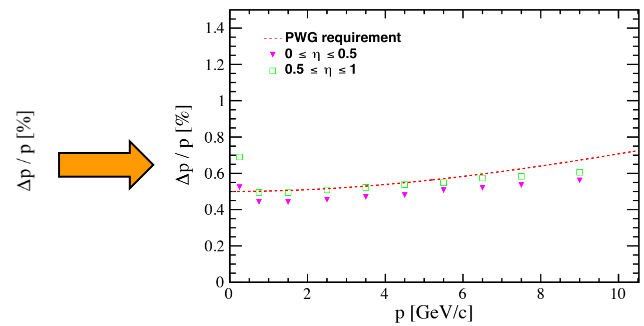


Institutes involved in simulations: INFN, Berkeley, ORNL, UK groups.

EIC SC groups are also working on solving track finding for EIC.

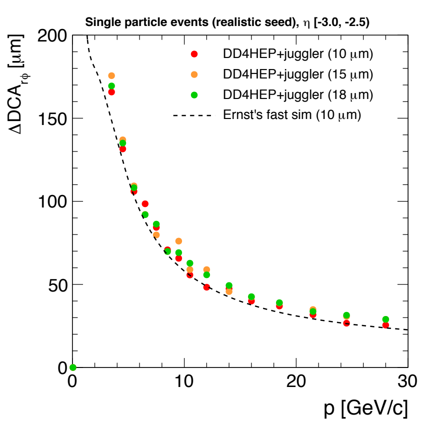


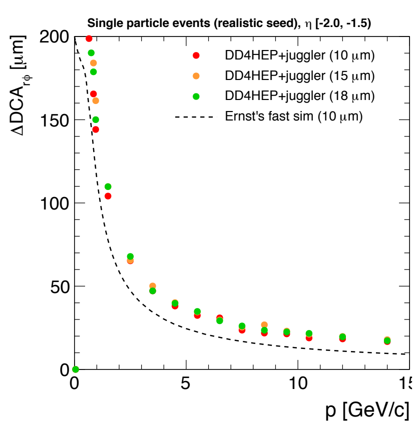
Reference detector with updated, eng/R&D informed parameters

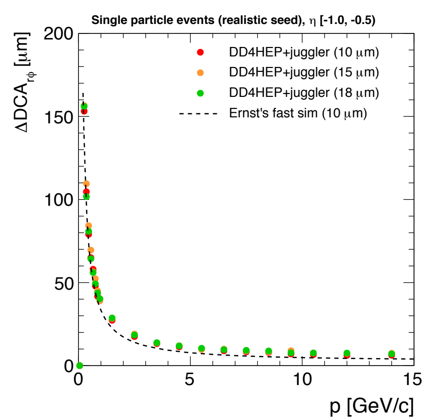


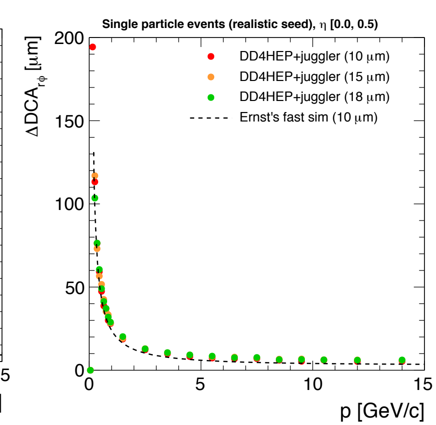
Optimised layout with 1.7T.

Optimised layout with 1.7T, DCA_T with DD4Hep + Juggler







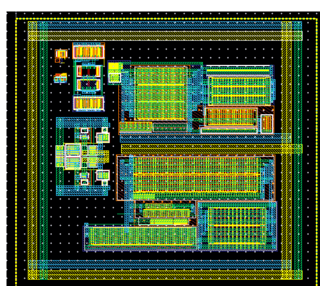


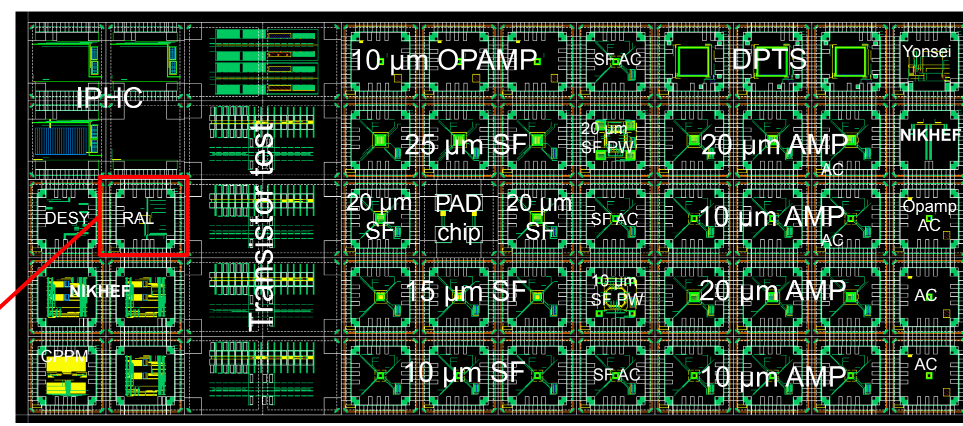
Sensor design

- EIC SC designers groups: BNL, LBNL, RAL.

- MLR1 – Q4-2020:
  - First submission in TowerJazz 65nm; scoped within CERN EP R&D WP1.2, significant drive from ITS3, important contributions from many groups.
  - Scope: Technology exploration and prototype circuit blocks for future sensors.
  - Large number of test structures included.

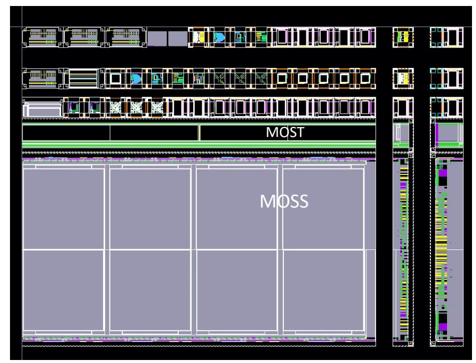
EIC contribution (RAL group):
High-speed data transmission IP blocks (LVDS receiver, CML transmitter).

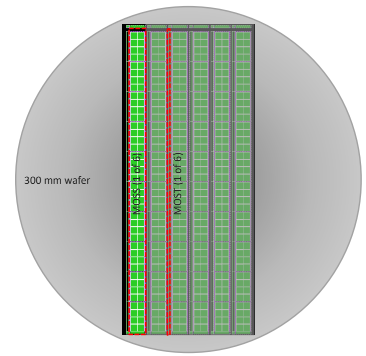




Sensor design

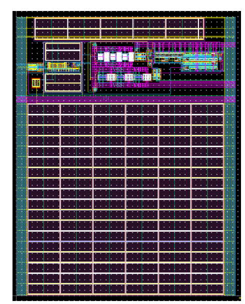
- ER1 – scheduled Q4 – 2022
  - First Engineering Run, driven by ITS3 stitched sensor prototype.
  - Scope: learning about stitching and yield of large area sensor.
  - Two large stitched sensor chips (MOSS, MOST) plus small test and development chips.

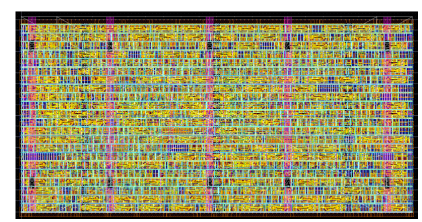




<u>EIC contribution (RAL group):</u>
High-speed data transmission IP blocks (PLL, CML receiver); on-chip signal transmission I2C block; DFM cells improvements.

<u>Preparation work at BNL & LBNL:</u>
Access to and familiarisation with to TPSCo 65 nm design kit.
Discussions with ITS3 management to define contributions.



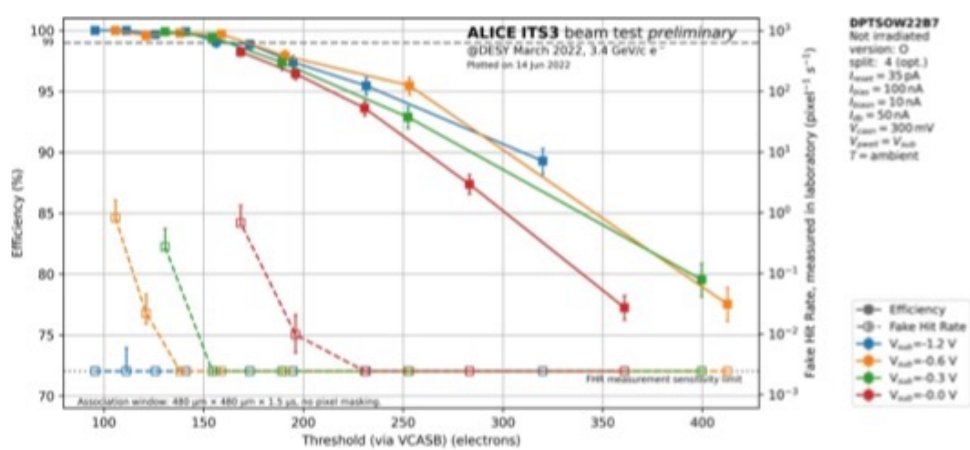


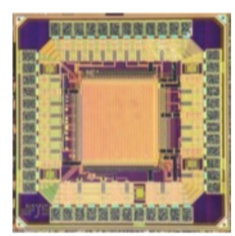
The UK contributed to the MLR1 and ER1 submissions with resources from the former eRD18/25 funding and the recent UKRI-STFC Infrastructure Fund.

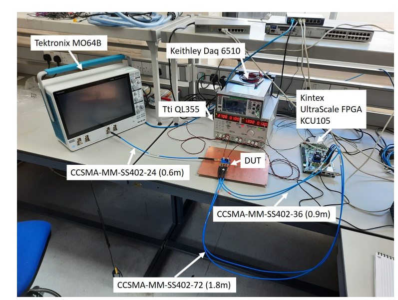
Sensor characterisation

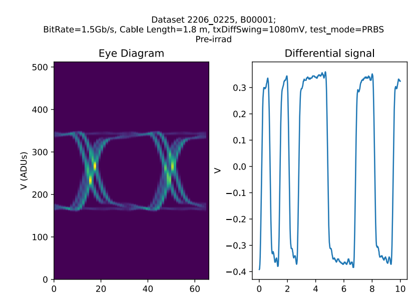
- Increasing participation in MLR1 APTS and DPTS circuits.
  - Test structures developed by ITS3 groups; setups development and distribution organised by ITS3.
  - INFN groups leading testing of DPTS circuit.
  - INFN and LBNL groups participated in test beams.
  - Test setups being received and commissioned by LBNL, ORNL, UK groups.

- Characterisation of the MLR1 RAL IP blocks carried out by UK groups.
  - Setup development, lab tests, x-rays irradiations.
  - Circuit works up ~1.5 Gbps.









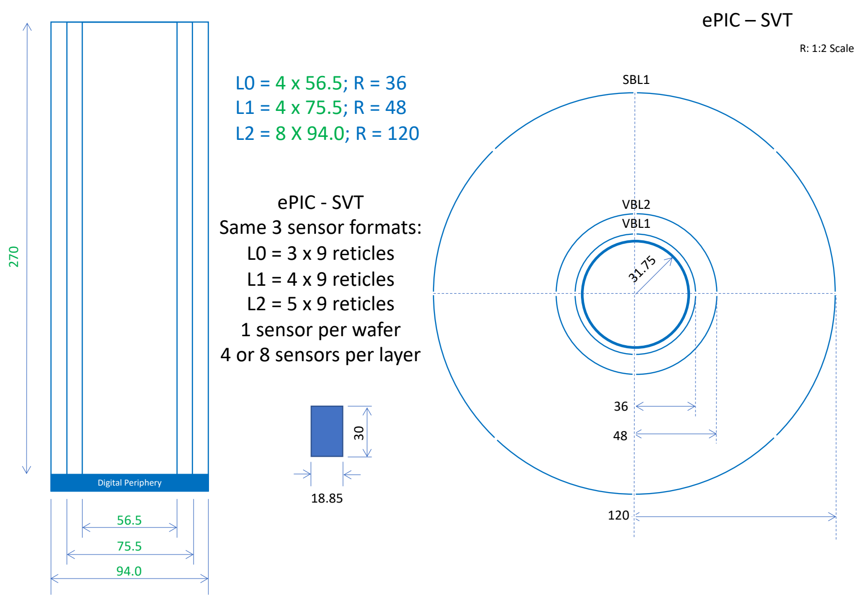
Sensor characterisation

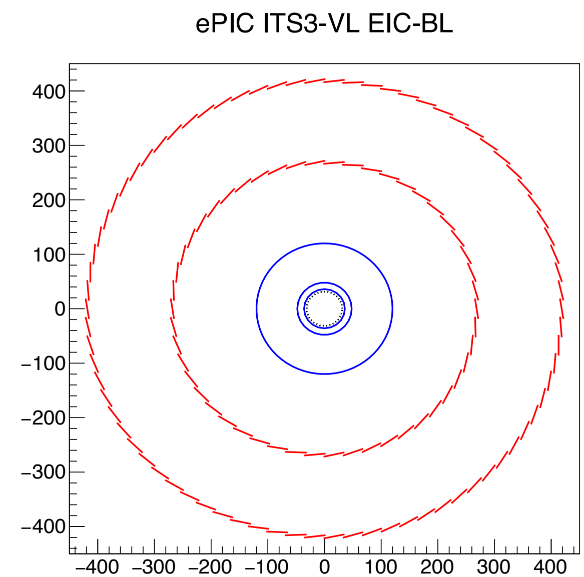
- Contributions to test setups development are being planned.
- LBNL staff are investigating the possibility of producing additional test boards (DAQ) for MLR1 circuits to use within the EIC Silicon Consortium.
- LBNL and ORNL to be involved in the ER1 test setup development.
- Both activities are under discussion with ALICE ITS3 colleagues at CERN.

EIC LAS configuration for staves and disks

- Studies advancing on the required LAS sizes for tiling of staves and disks (UK groups).

- Tiling of vertex and barrel layers considers re-use of ITS3 sensor and maximisations of wafer surface usage.

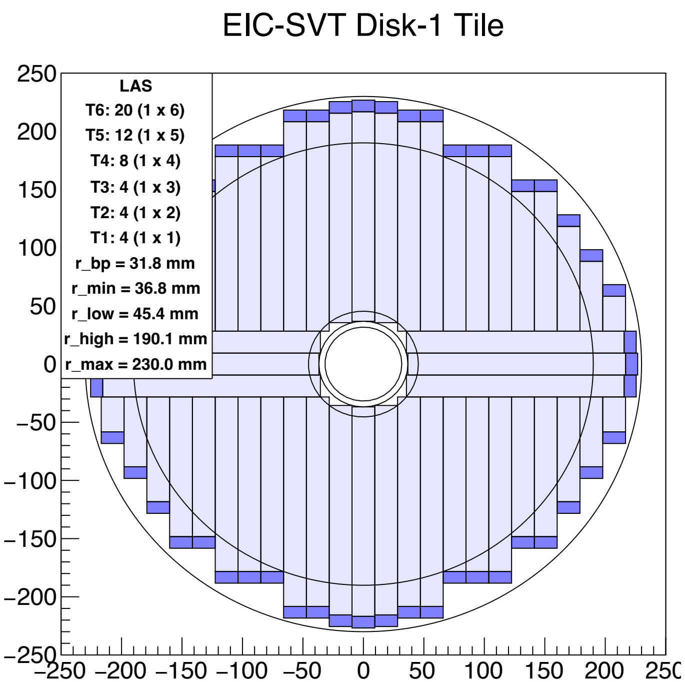


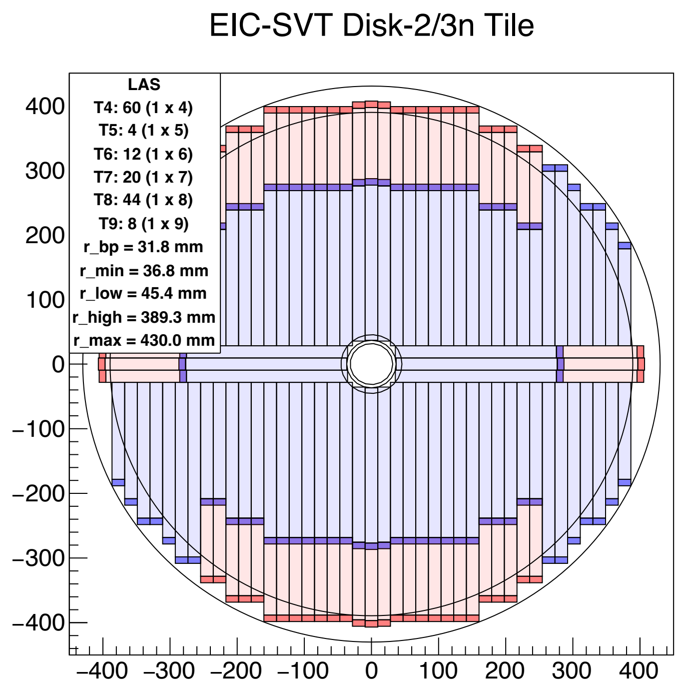


L3 = SBL2; R = 268.4 mm; LAS = 2 x 9; 100 sensors; rϕ olap = 3.5 mm
L4 = OBL2; R = 418.5 mm; LAS = 2 x 7; 312 sensors; rϕ olap = 3.5 mm
Length of L3 is made of two 270 mm sensors.
Length of L4 is made of four 210 mm sensors.

EIC LAS configuration for staves and disks

- Macro developed to study best LAS configuration for disks.
  - Multiple sensor formats needed, requiring changes to stitching plan & organisation of the digital periphery.
  - Attempt to minimise the number of formats by restricting the maximum and/or minimum sensor length.
  - Aim to keep periphery to larger radii.





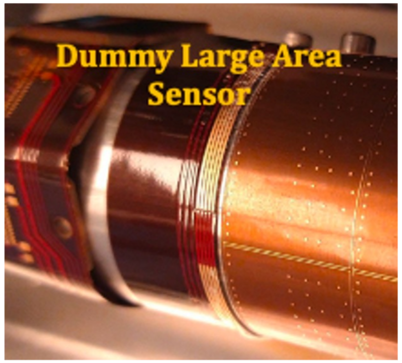
Example of possible configurations

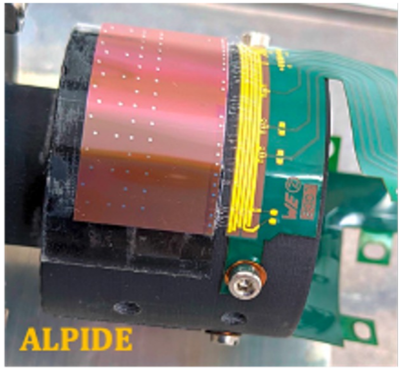
Mechanics & cooling studies

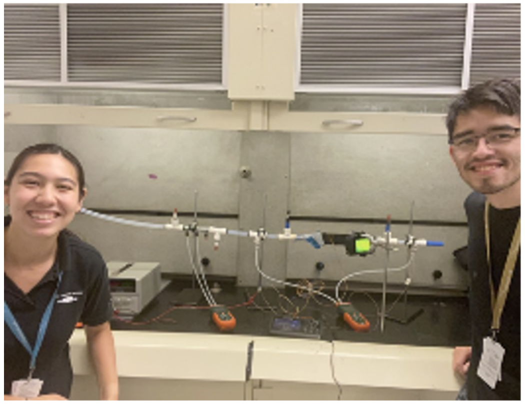
- Mechanical studies on single-reticule sensors & large-size MAPS at INFN.
  - Bending, thinning, & interconnection.
  - Characterization in flat & curved geometries.
  - Bending & wire-bonding have been successfully exercised at EIC vertex radii.

- Initial study of (internal) air cooling as an option for staves & discs at LBNL.
  - Summer student project.
  - Different carbon foam types/thicknesses under evaluation.

- Starting assessment of materials for making discs & supports at LANL.

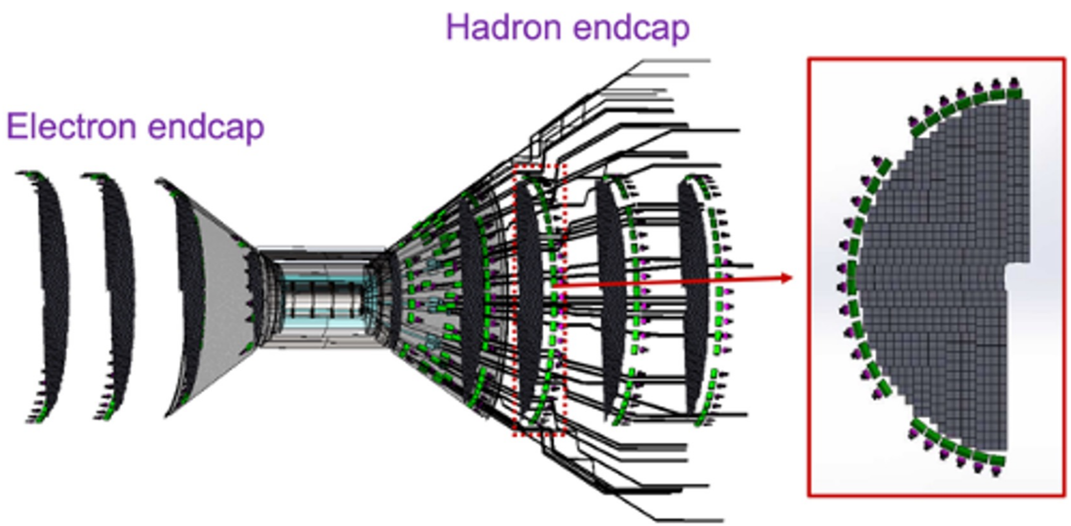


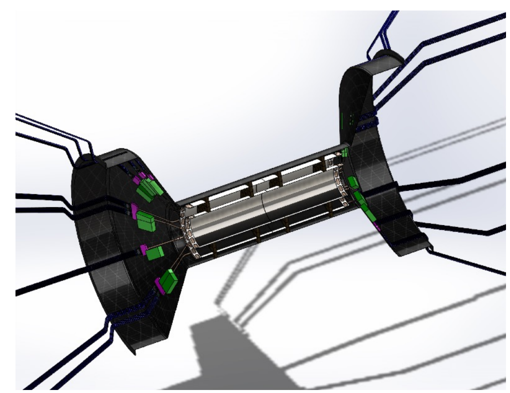




CAD model development

- CAD modelling continues from detector proposals development at LANL and JLAB.
- CAD also used to explore different sensor & stave configurations and to study minimization of material minimization.





Powering and readout

- Powering work by UK groups.
  - Review of existing serial powering and DC-DC converter based powering schemes completed based on large experience within ATLAS.
  - Serial powering and DC-DC conversion with integrated regulator identified as the most promising candidates for the EPIC SVT.

- Readout work at ORNL.
  - Possible candidates for radiation tolerant FPGA and optical interconnect, and electrical/optical interface identified.
    - Microchip PolarFire FPGA, CERN “lpGBT”, Samtec optical “FireFly”.
  - An initial exercise to estimate number of hits and links in the detector has started to be updated in line with the evolving EPIC configuration.

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Overview

- Work in FY22 was affected by delays due to multiple factors (continuing resolution, late submission of SoW, long time for contract setup, …).
  - R&D was limited to what could be done without engineering and technician support.

- FY22 funding only just being received at the institutes now.

- The plan for FY23 includes the rollover of the FY22 activities with expansion to account for the accelerated timeline in preparation for the project TDR.

This talk presents revised requests with respect to the proposals submitted on 1 October, following discussions with the EIC project.

Revised proposals have been made available just before this meeting.

eRD104: Services reduction

- Aims for FY23:
  - Conceptual design of powering and readout schemes for the EPIC tracker.
  - Initial assessment of components to inform selection.

Table 1: Institutions involved and institutional contacts

Topic	**Institute**	**Institutional contact**
Powering System	Birmingham	Laura Gonella
	RAL	Fergus Wilson
Readout System	ORNL	Jo Schambach
	BNL	Grzegorz Deptuch

Milestone	**Date**
Report on powering schemes architectures.	May 23
Report on powering tests with existing regulators.	Sept 23
Report on readout chain test beam results.	Aug 2023
Report on MUX architectures.	Sept 2023

eRD104: FY23 request

Table 2: Known in-kind contributions [FTE]

Institute	**staff**	**eng**	**tech**	**M&S**
UK groups	0.3	0.2		6k
ORNL	0.2			

Table 3: Total funding request and breakdown by institution. All costs in k$.

Institute	**staff**	**eng**	**tech**	**M&S**	**travel**	**total FY23**
ORNL		64.3		16	7	
Total		**64.3**		**16**	**7**	**87.3**

Total request = 87.3k$

eRD111: Si tracker

- Aims for FY23:
  - Define LAS sensor variants and associated module concepts.
  - Detailed conceptual design of vertex layers, staves and disks.
  - Advanced CAD model for the EPIC tracker.
  - Analysis of cooling options.

Topic	**institute involved**	**institute contact**
modules	INFN groups UK institutes (Birmingham, Daresbury, Lancaster, Liverpool)	Giacomo Contin Roy Lemmon, Peter Jones
barrel & discs	LANL LBNL ORNL UK institutes (Birmingham, Daresbury, Lancaster, Liverpool)	Walter Sondheim Nicole Apadula Ken Read Roy Lemmon, Peter Jones
mechanics, infrastructure, & cooling	LANL LBNL ORNL	Walter Sondheim Nicole Apadula Ken Read

eRD111: FY23 Request

Table 3: Known in-kind contributions

institute	eng (FTE)	tech (FTE)	staff (FTE)	m&s ($k)
INFN groups	0.1	0.25		
UK institutes	0.6	1.0	0.2	8.0

US labs will provide staff & postdocs in-kind.

Table 2: Total funding request and breakdown by institution. All costs in k$

institute	eng	tech.	PD	student	m&s	travel	total cost in FY23 k$
INFN groups			20.0		10.0		30.0
LANL	90.0					3.0	93.0
LBNL	300.0	76.7		7.5	23.0		407.2
ORNL	66.8	15.7		3.6	12.0		98.1
Total	**456.8**	**92.4**	**20.0**	**11.1**	**45.0**	**3.0**	**628.3**

Total request = 628.3 k$
(separate PED request)

Table 4: Funding request broken down by task. All costs in k$

task	eng	tech.	PD	student	m&s	travel	total cost in FY23 k$
Modules			20.0		10.0		30.0
Barrel & discs	223.4	46.2		3.7	10.0		283.3
M/I/C	233.4	46.2		7.4	25.0	3.0	315
Total	**456.8**	**92.4**	**20.0**	**11.1**	**45.0**	**3.0**	**628.3**

eRD113: Sensor - New for FY23

- Aim of FY23: Ensure readiness for EIC LAS in FY24.
  - Develop EIC specific circuit blocks and contribute to ITS3 sensor design.
  - Understand implications of change in stitching plan for LAS.
  - Complete characterisation of MLR1 structures.
  - Develop DAQ for ER1 testing and yield evaluation.

Table 4: Institutions involved and institutional contacts

Topic	Institution	Institutional contact
Sensor Development	RAL	Iain Sedgwick
	BNL	Grzegorz Deptuch
	LBNL	Carl Grace
Sensor Characterization	INFN	Domenico Elia
	UK institutes	Laura Gonella
	LBNL	Yuan Mei
	ORNL	Jo Schambach
	LANL	Xuan Li

- The goals of the eRD113 project are fully dependent on the relationship with ITS3.
  - Access to design files and use of the ITS3 sensor need negotiations in terms of legal agreements and monetary contribution(s).
  - Such negations are better carried out at the EIC project level, or even beyond, with inputs and support of the EIC SC.

eRD113: FY23 request

Table 1: Known in-kind FTE contributions by function category and M&S.

Institution	Scientific Staff	PD	Design Eng.	Electrical Eng.	Tech.	M&S [k$]
UK Institutes	0.2	2.0	1.0	1.2	1.0	100 (design) 20 (char.)
INFN	0.3			0.2	0.3	

Institution	effort	travel	M&S	Total
UK Institutes				0
INFN	20		10	30
BNL	962	22		984
LBNL	375	15		390
ORNL			7	7
LANL			5	5
+Total	1,357	37	22	1,416

Total request = 1,416 k$
(separate PED request)

FY24 outlook

- Plans for FY24 will evolve alongside the R&D in FY23.
- The main aims for FY24 will be:
  - Advance design of the EIC LAS sensor, target submission end of FY24/beginning of FY25.
  - Development and testing of vertex layers prototype mechanics, cooling, DAQ, powering with the ITS3 ER1 sensor.
  - Based on the planned LAS variants, for barrel and disks:
    - Conceptual module design.
    - Advance barrel and disks design with iterative prototyping/testing for mechanical structures, and cooling options
    - Further detail and develop readout and powering schemes.
- This plan is based on a successful outcome of the FY23 R&D which requires:
  - Funding available from the start.
  - Finalisation of EIC/CERN agreements asap.
  - Successful outcome of ITS3 ER1 submission (fallback solutions are identified, as described in the EIC SC Strategy Document)

Conclusion

- In preparing these proposals we have carefully considered how to scale up the effort, incorporating milestones and delayed funding from FY22.
- Milestones have been scheduled assuming funding is available in December 2023.
- Updated proposals have been made available ahead of this meeting following discussions with the project.
- The combined aim of eRD104/111/113 for FY23 is to be ready for the LAS sensor submission in FY24 and to reach a mature conceptual design of all items of the EPIC detector.
  - In addition, we will work to increase the membership including (more) EPIC institutes that expressed an interest in tracking.
- In summary our request for FY23 is as follows:
  - eRD104 (contact: Laura Gonella): 87.3k$.
  - eRD111 (contact: Nikki Apadula): 628.3k$.
  - eRD113 (contact: Grzegorz Deptuch): 1,541k$.

Backup

EIC Silicon Consortium origins

- The EIC Silicon Consortium grew out of the eRD16/18/25 part of the former EIC Generic Detector R&D.
- The former eRD16 initially focused mostly on forward/backward charged particle tracking with disks using MAPS.
- The former eRD18 initially focused on central vertexing with MAPS barrels, and sensor development (Depleted MAPS).
- eRD16 and eRD18 increasingly worked together over the years; barrel and disks are closely related, mutual technical interests.
- Both groups studied integrated tracking and vertexing concepts, hybrid as well as the first all-silicon concepts for EIC.

EIC Silicon Consortium origins

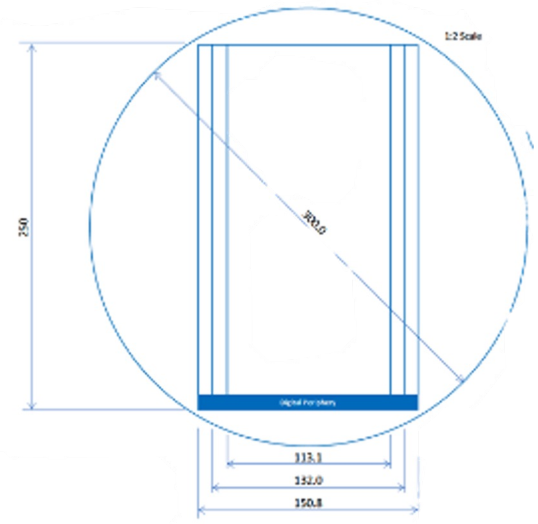
- In the January 2020 EIC generic detector R&D meeting, eRD16 and eRD18 proposed to form a consortium to work toward a 65 nm MAPS based EIC silicon vertex and tracking detector.

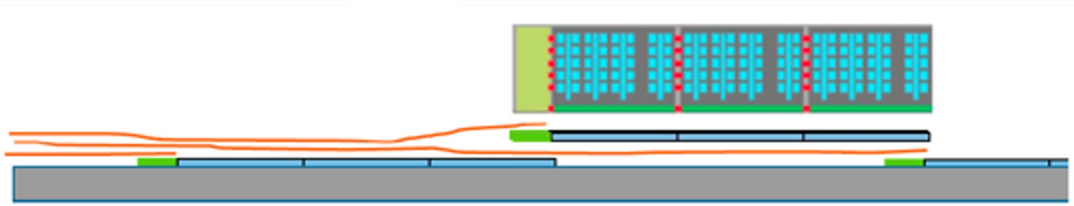
- The committee encouraged the plan to merge into a unified silicon tracking R&D effort, open to new collaborators and take advantage of emerging technological opportunities.

- The "eRD25: Silicon Tracking and Vertexing Consortium" was formed and the eRD25 proponents also started the "EIC Silicon Consortium".

eRD111: Modules

- Optimize 65 nm stitched sensor for EPIC module
  - ITS3 ER1 yield
  - Bending & interconnection studies
- Explore options for the module(s) (staves & discs)
- Written report (September 2023)

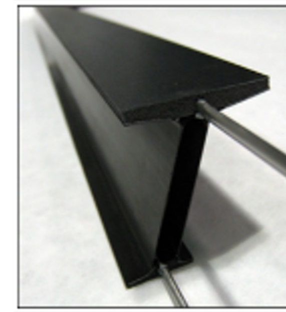
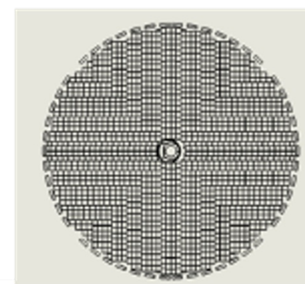
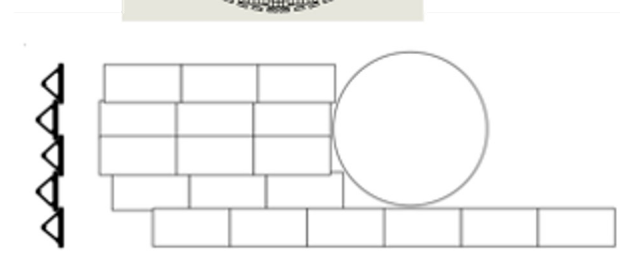




Traditional module: support+FPC+sensor

eRD111: Barrel & discs

- Vertex
  - Study of beam pipe bakeout
  - Layout/mechanics for expanded radii
- Staves
  - Basic concepts (truss, i-beam)
- Discs
  - Plates, staves, etc.
  - Different disc diameters & inner hole openings
- Written report on conceptual designs (May 2023)
- Production of prototype pieces (August 2023)

eRD11: Mechanics, integration, cooling

- Up-to-date CAD model of full tracker (September 2023)
- Analysis of cooling options: Written report (August 2023)
  - Add vertex cooling studies → EPIC vertexing is different enough from ITS3 that it should be a separate R&D
  - Add liquid cooling options
    - Particularly important for periphery
- Conceptual designs for full detector support
  - Written report (June 2023)
  - Prototype pieces (September 2023)