Silicon: Overview

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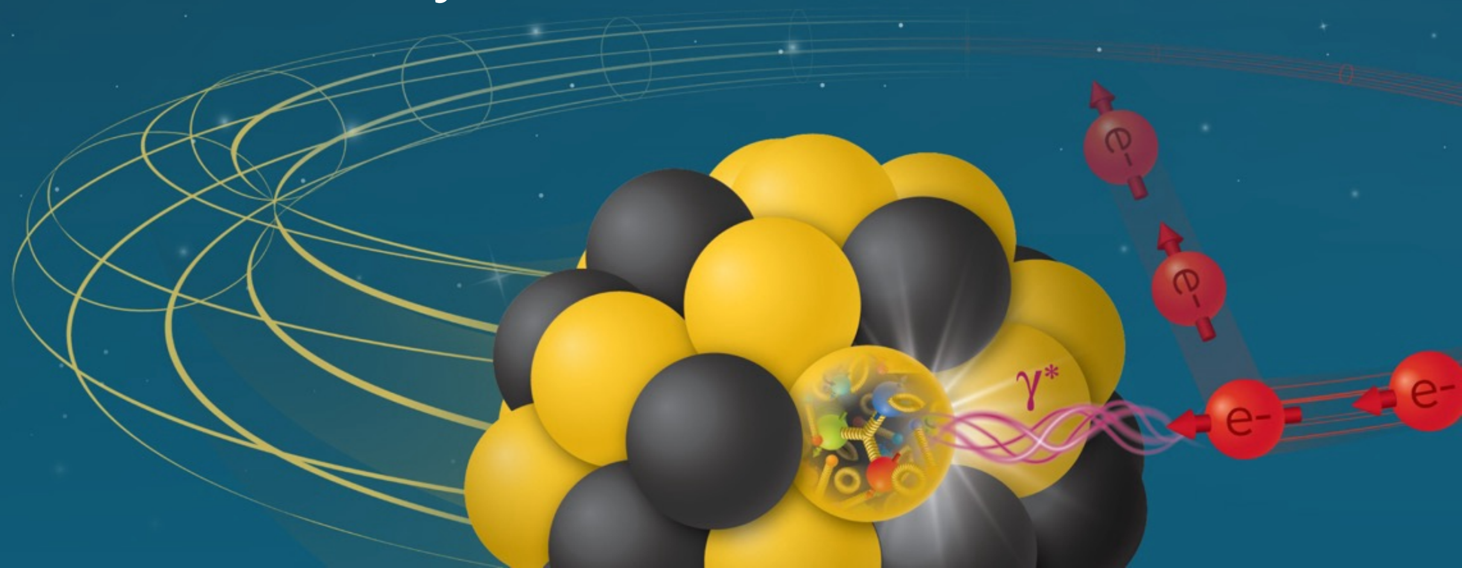
Lawrence Berkeley National Laboratory

Incremental Design and Safety Review
of the EIC Tracking Detectors
March 20-21, 2024

Electron-Ion Collider



Charge Questions Addressed

1. Are the technical performance requirements appropriately defined and complete for this stage of the project?
2. Are the plans for achieving detector performance and construction sufficiently developed and documented for the present phase of the project?
3. Are the current designs and plans for detector, electronics readout, and services sufficiently developed to achieve the performance requirements?
4. Are plans in place to mitigate risk of cost increases, schedule delays, and technical problems?
5. Are the fabrication and assembly plans for the various tracking detector systems consistent with the overall project and detector schedule?
6. Are the plans for detector integration in the EIC detector appropriately developed for the present phase of the project?
7. Have ES&H and QA considerations been adequately incorporated into the designs at their present stage?

Outline

- Requirements
- Sensor
- Sensor Tiling and Grouping
- Local Mechanics
- Detector Subsystem Collaboration
- Timeline
- Risks and Mitigation
- Summary

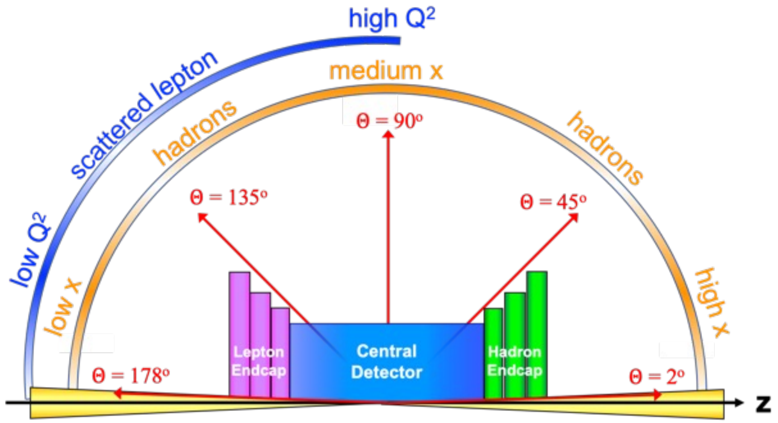
Requirements

Performance Requirements

Charge 1

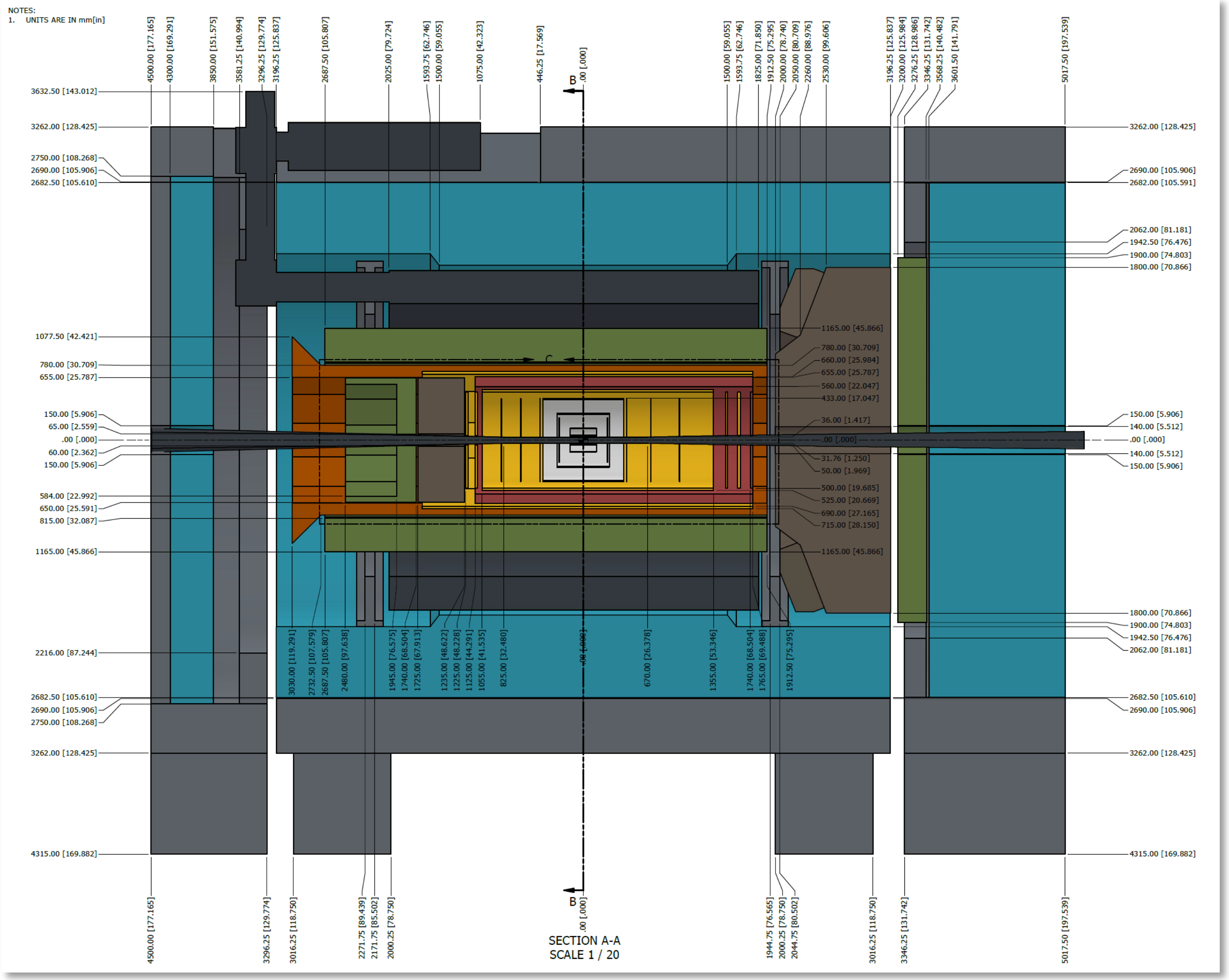
- https://eic.jlab.org/Requirements/index.html
- Based on physics in the Yellow Report

	Momentum Resolution	Spatial Resolution
Backward (-3.5 to -2.5)	~0.10%×p⊕2.0%	~ 30/pT µm ⊕ 40 µm
Backward (-2.5 to -1.0)	~ 0.05%×p⊕1.0%	~ 30/pT µm ⊕ 20 µm
Barrel (-1.0 to 1.0)	~0.05%×p⊕0.5%	~ 20/pT µm ⊕ 5 µm
Forward (1.0 to 2.5)	~0.05%×p⊕1.0%	~ 30/pT µm ⊕ 20 µm
Forward (2.5 to 3.5)	~0.10%×p⊕2.0%	~ 30/pT µm ⊕ 40 µm



Experiment Constraints

Charge 1,6



Spatial extent along the beam axis:

$-106.25 < z_{SVT} < 136.25$ cm

Radially:

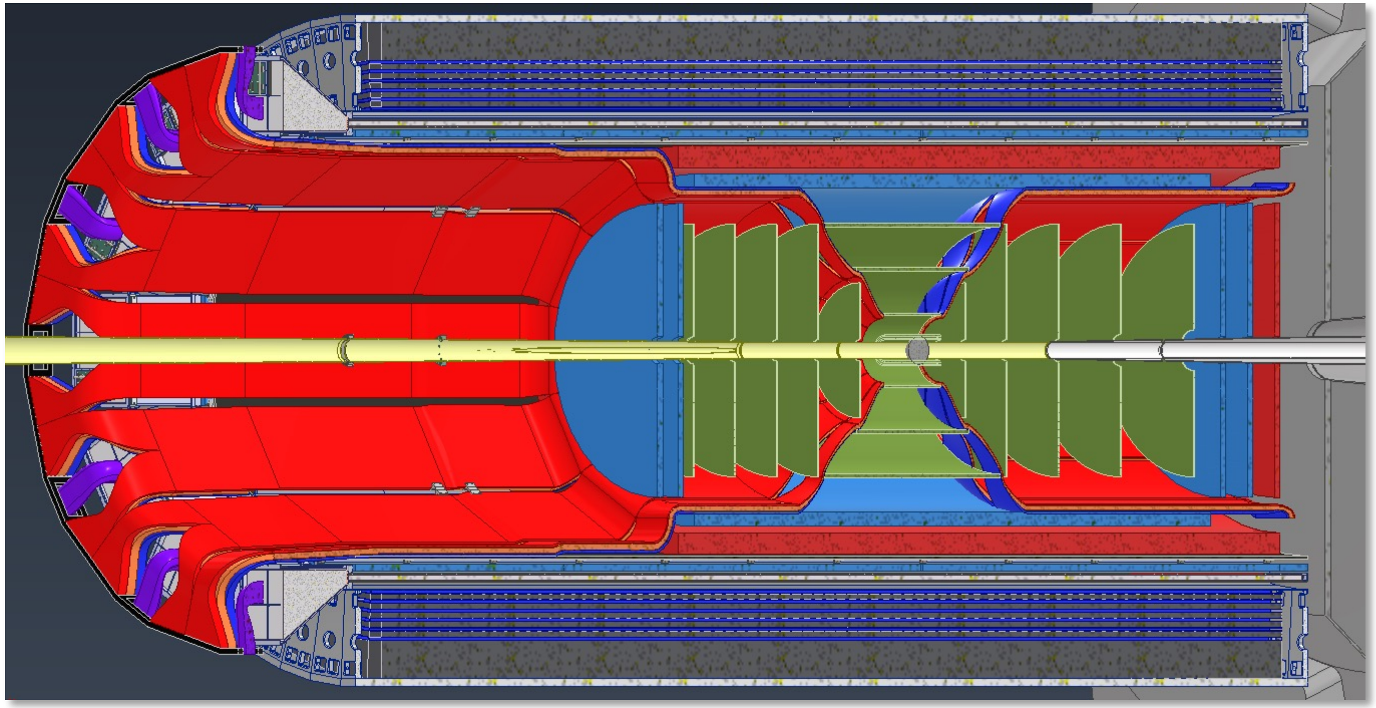
$r_{out} < 43.00$ cm

$r_{in}(z)$ determined by beam-pipe + 5mm

Beam-pipe bake-out with SVT installed; clamshell of detector halves,

Experiment Constraints

Charge 1,3



Spatial extent along the beam axis:

$-106.25 < z_{SVT} < 136.25$ cm

Radially:

$r_{out} < 43.00$ cm

$r_{in}(z)$ determined by beam-pipe + 5mm

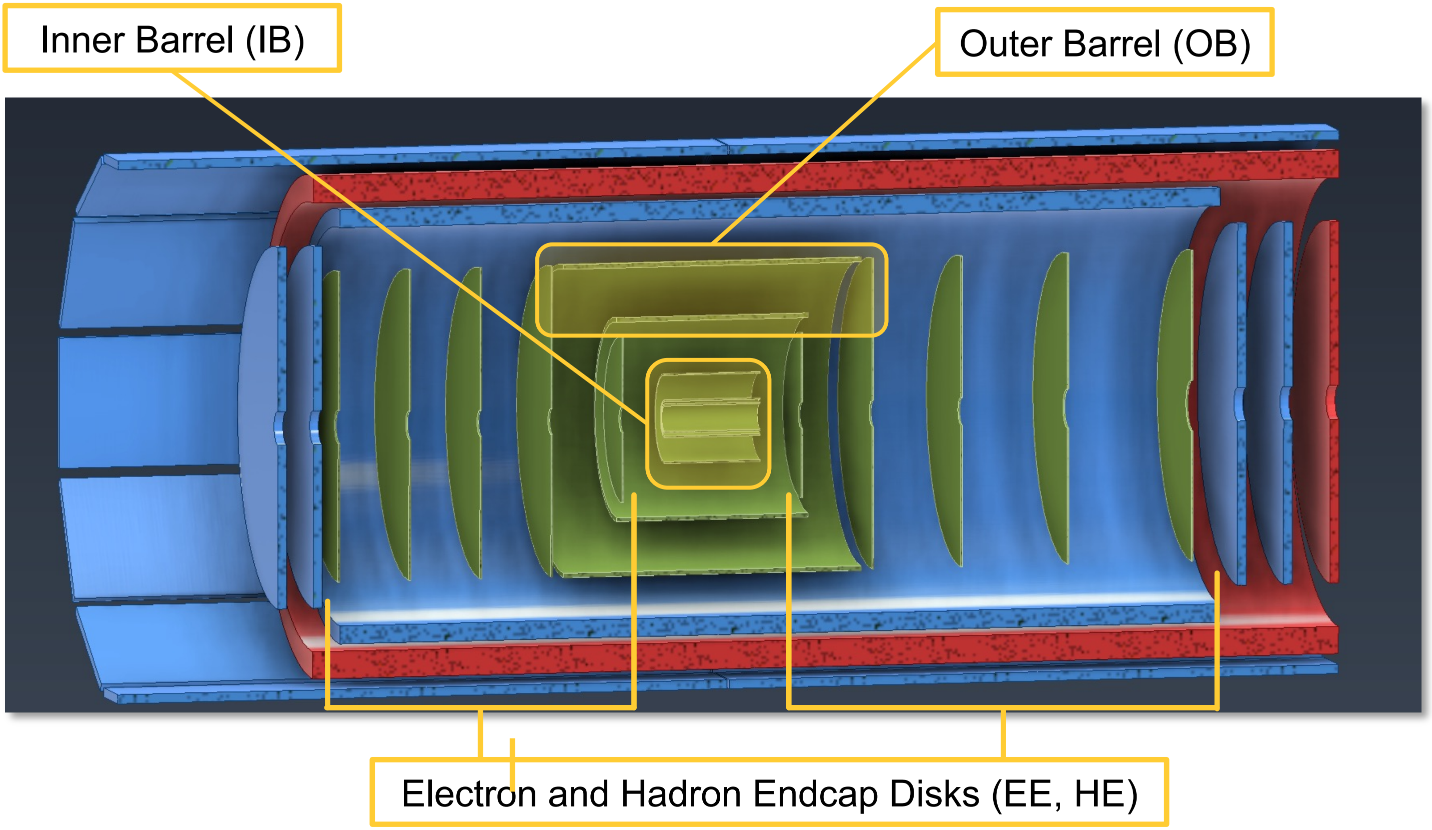
Beam-pipe bake-out with SVT installed; clamshell of detector halves,

Minimized services – space is at a premium.

SVT Concept

Charge 1,2

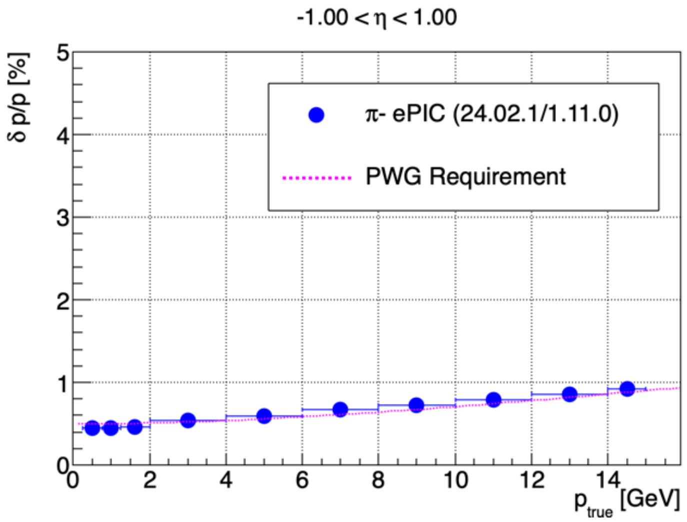
- **Inner Barrel (IB)**
  - Three layers, L0, L1, L2,
  - Radii of 36, 41, 120 mm
  - Length of 27 cm
  - X/X_0 ~ 0.05% per layer
  - Curved, thinned, wafer-scale sensor
- **Outer Barrel (OB)**
  - Two layers, L3, L4
  - Radii of 27 and 42 cm
  - X/X_0 ~0.25% and ~0.55%
  - More conventional structure w. staves
- **Electron/Hadron Endcaps (EE, HE)**
  - Two arrays with five disks
  - X/X_0 ~0.25% per disk
  - More conventional structure

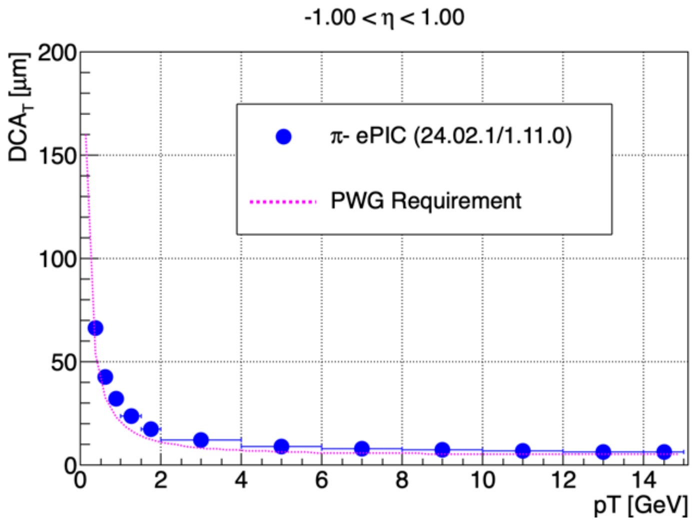


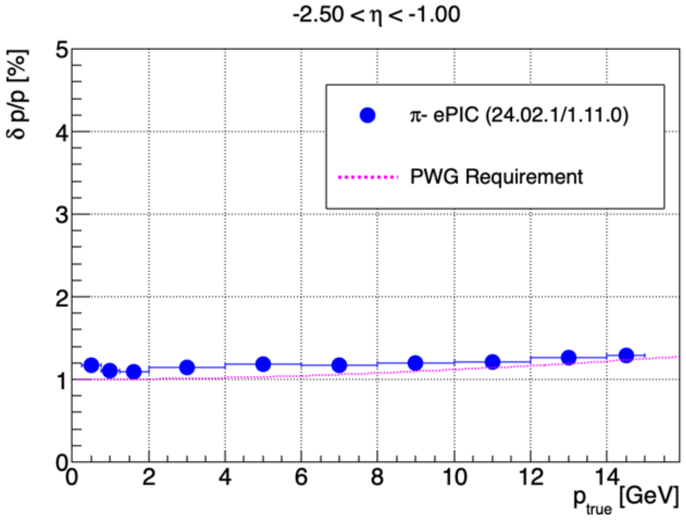
- **Lengths for L2—L4 increase so as to project back to z = 0; disk radii adjust accordingly**

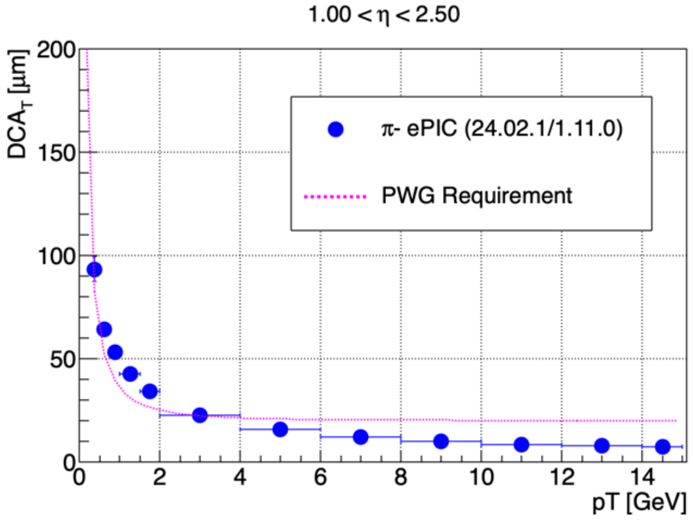
Preliminary Performance

Charge 2,3









Momentum

Distance of Closest Approach

SVT concept is optimized for resolution,

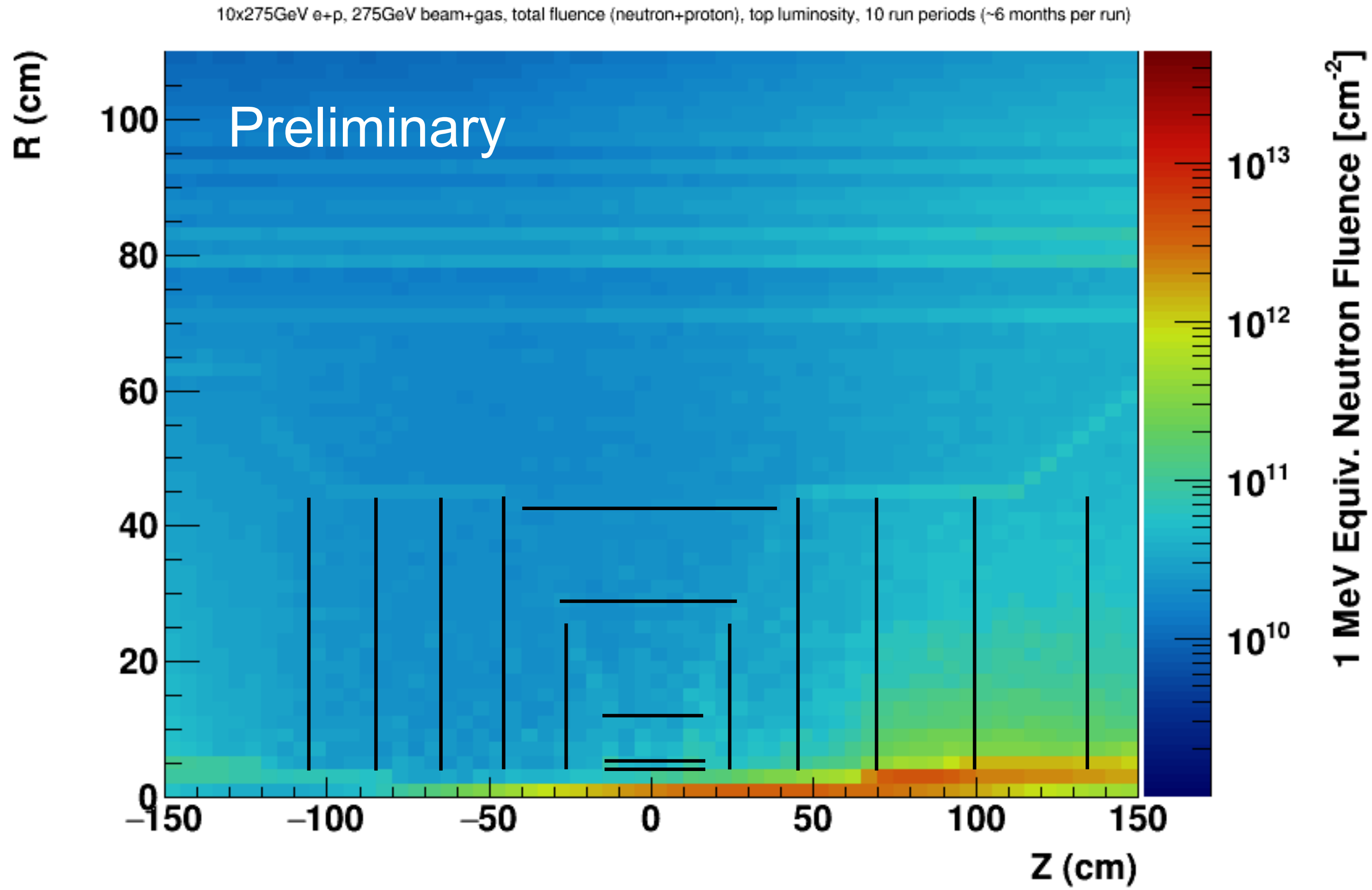
Simulated resolutions meet the requirement in the central region,

Simulated resolutions substantially meet the requirements in the forward/hadron and backward/electron region,

Physics objectives in the far backward/ electron region will need to be met by means of a combination of precision tracking and precision electron calorimetry.

Preliminary Radiation Environment

Charge 1



Evaluation for:

10 GeV electron beam,
275 GeV proton beam,

10^{-34} $cm^{-2}s^{-1}$ luminosity,
DIS interactions (~ 500kHz),

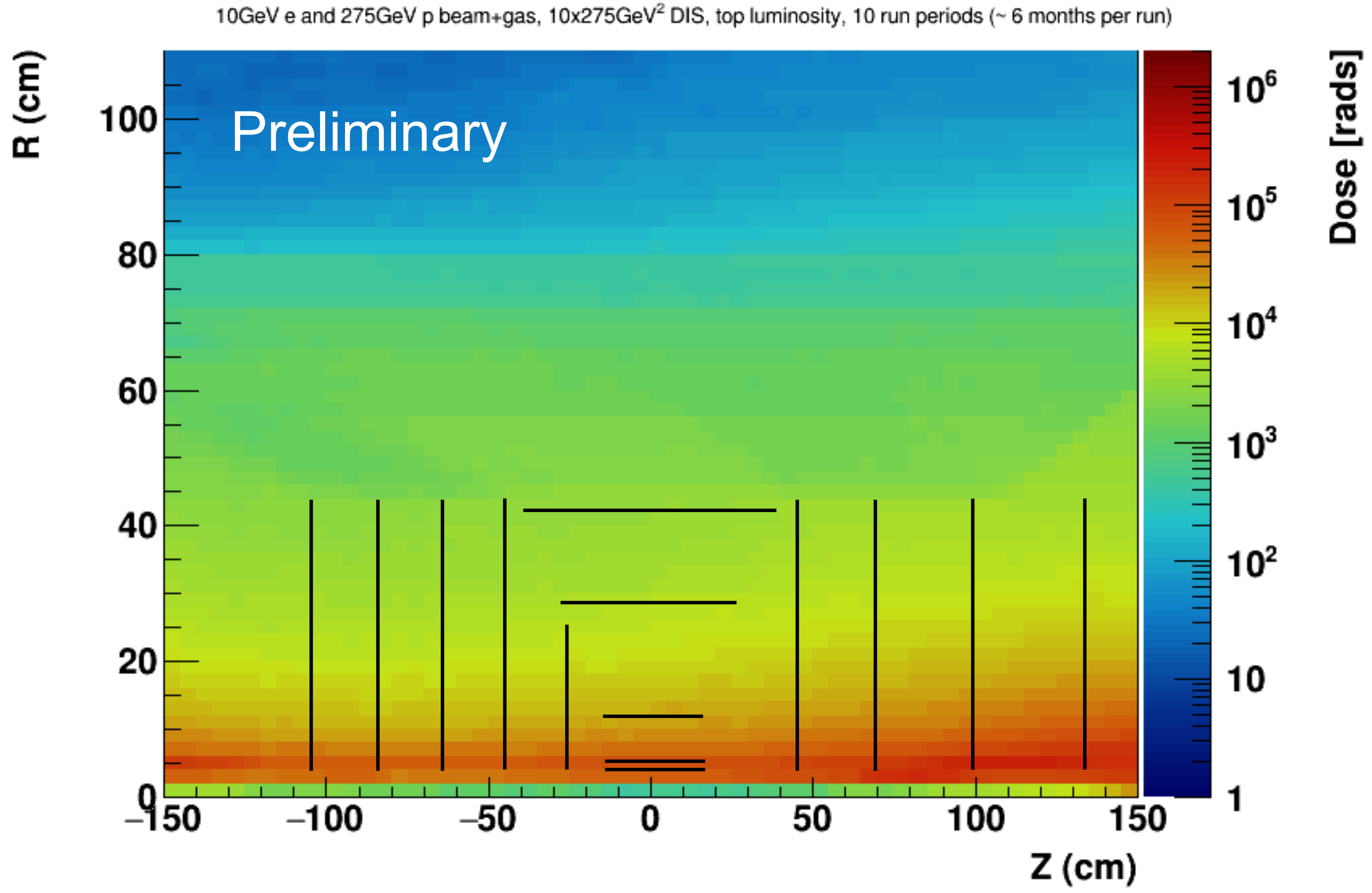
Beam-gas background 10 kAhr,

No synchrotron radiation (yet),

10 half-year running periods,
100% up-time,

Preliminary Radiation Environment

Charge 1



Region close to the beampipe is projected to experience a few hundred kRad,

Most of the SVT projected to be below ten kRad,

Fluence up to few 10^{12} n_{eq}/cm^2 for the inner region of the the hadron endcap, otherwise 10^{11} n_{eq}/cm^2 or less,

Low, $O(10^{-7})$ hit occupancy per pixel in a O(μs) readout frame

Sensor

Sensor Choice

Charge 2,3,4

Technology of choice for the SVT is Monolithic Active Pixel Sensor,

This choice was made following a technology survey, c.f.

Laura Gonella on behalf of eRD16 and eRD18, *“EIC Silicon Vertex and Tracking: Technology Survey”* at the 1st EIC Yellow Report Workshop

Drivers include high granularity, low power consumption, and low material, as well as synergies with large-scale developments in the broader community – in particular the ALICE-ITS3 development,

Pragmatic choice to seek to join the ITS3 development and adapt, where needed, the sensor, called “MOSAIX”, for use in the SVT,

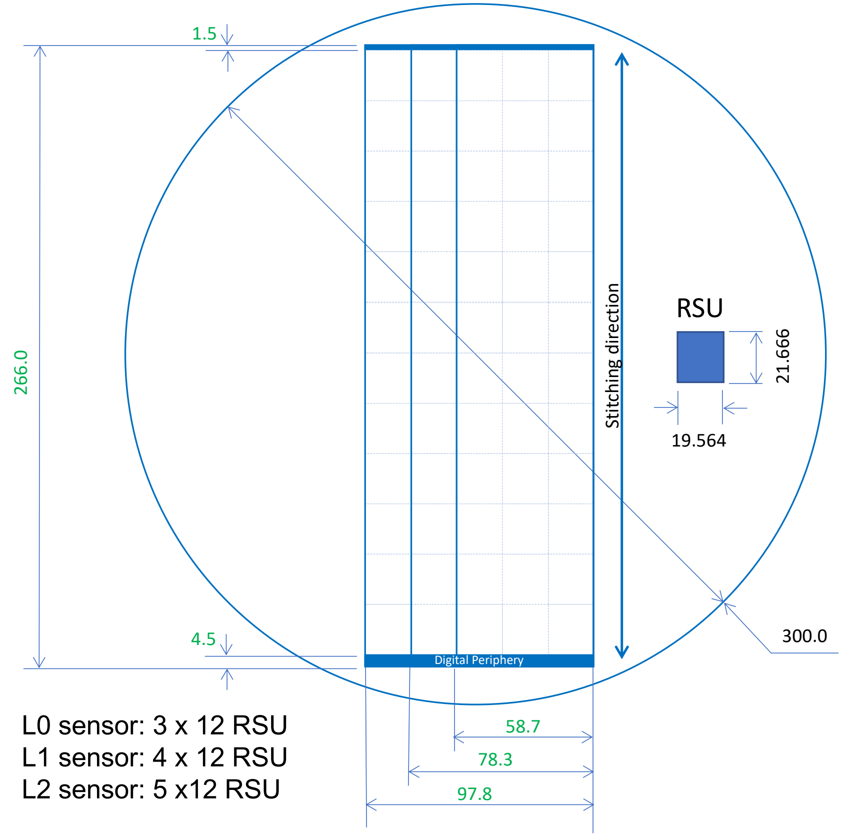
Large SVT area of ~8 m^2 is one of the drivers in the need to adapt ITS3 to become EIC-LAS; same for the choice to use an ancillary IC to provide serial powering, bias voltage, and multiplex slow controls,

Formal partnership with ITS3 now in an advanced stage.

MOSAIX

Charge 1,2,3

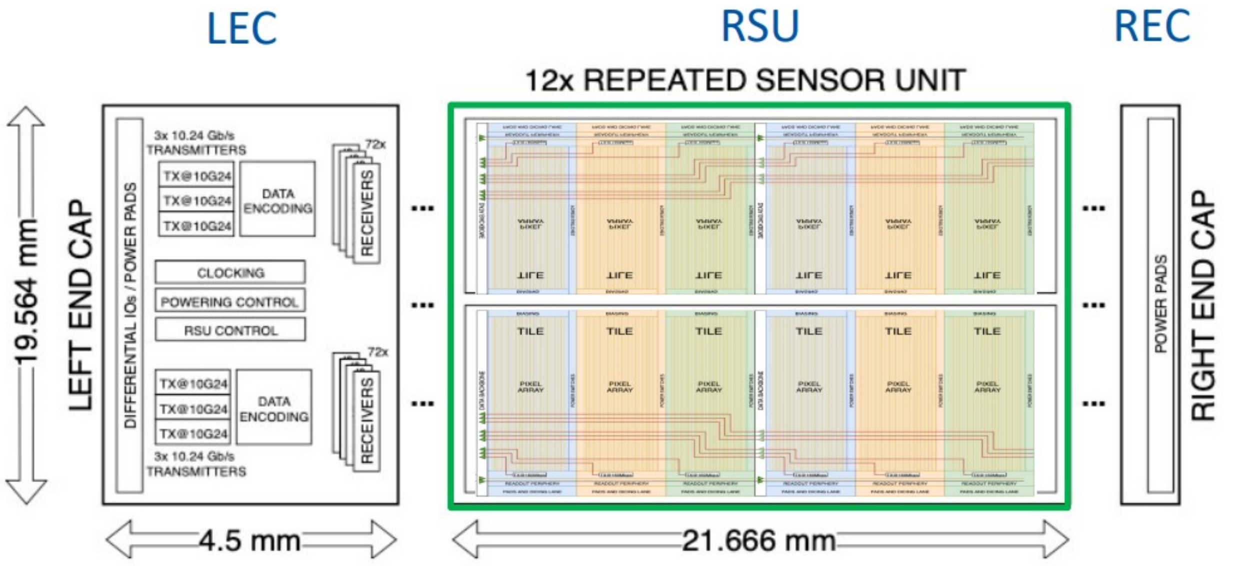
Credit: ALICE ITS3 Collaboration



L0 sensor: 3 x 12 RSU
L1 sensor: 4 x 12 RSU
L2 sensor: 5 x12 RSU

ER2 sensor widths

19.564 x 3 = 58.692
19.564 x 4 = 78.256
19.564 x 5 = 97.820



Pixel size: ~ 20 x 22 μm^2
Frame duration: 2 to 5 μs
Data link: 10.24 Gbps

Sensor Tiling and Grouping

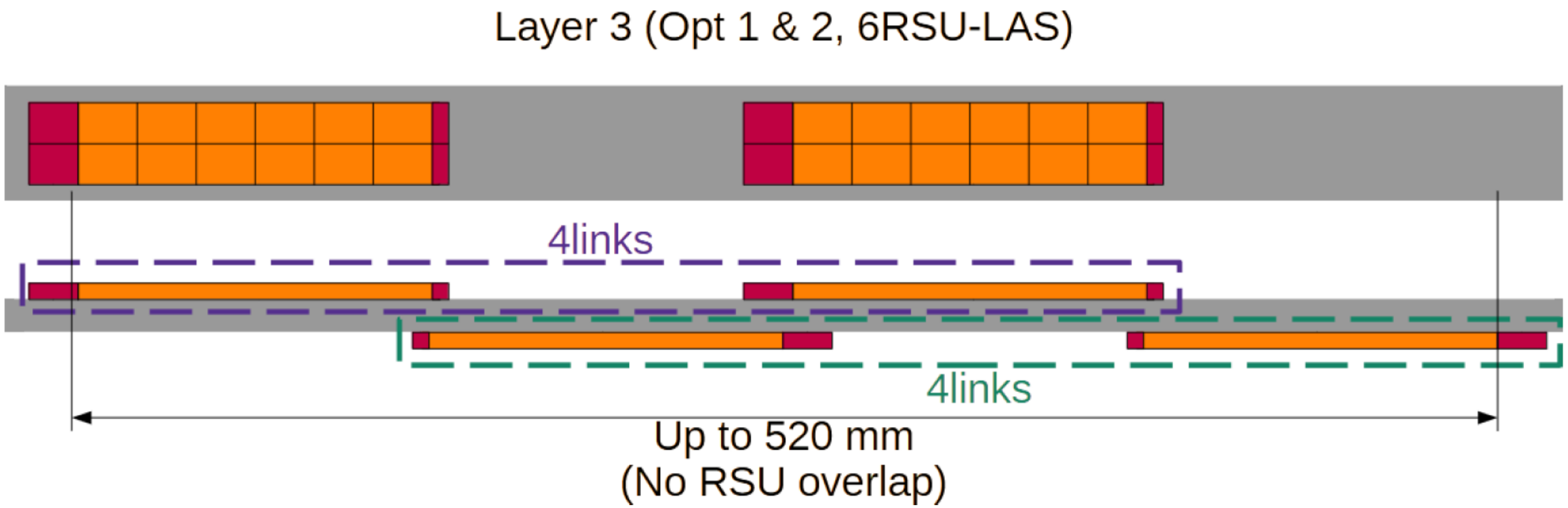
Sensor Tiling and Grouping

Charge 2,3

EIC-LAS with 5 or 6 RSUs is the outcome of extensive tiling studies and foundry constraints as they are currently known; a) only a single variant will be accommodated on any given wafer and b) NRE considerations limit the number of variants to two, at most.

Staves are foreseen as the basic building elements for the Outer Barrel, i.e. L3 and L4.

Tiling of EIC-LAS sensors onto staves is relatively straightforward, provided the structure allows for geometrical overlap:



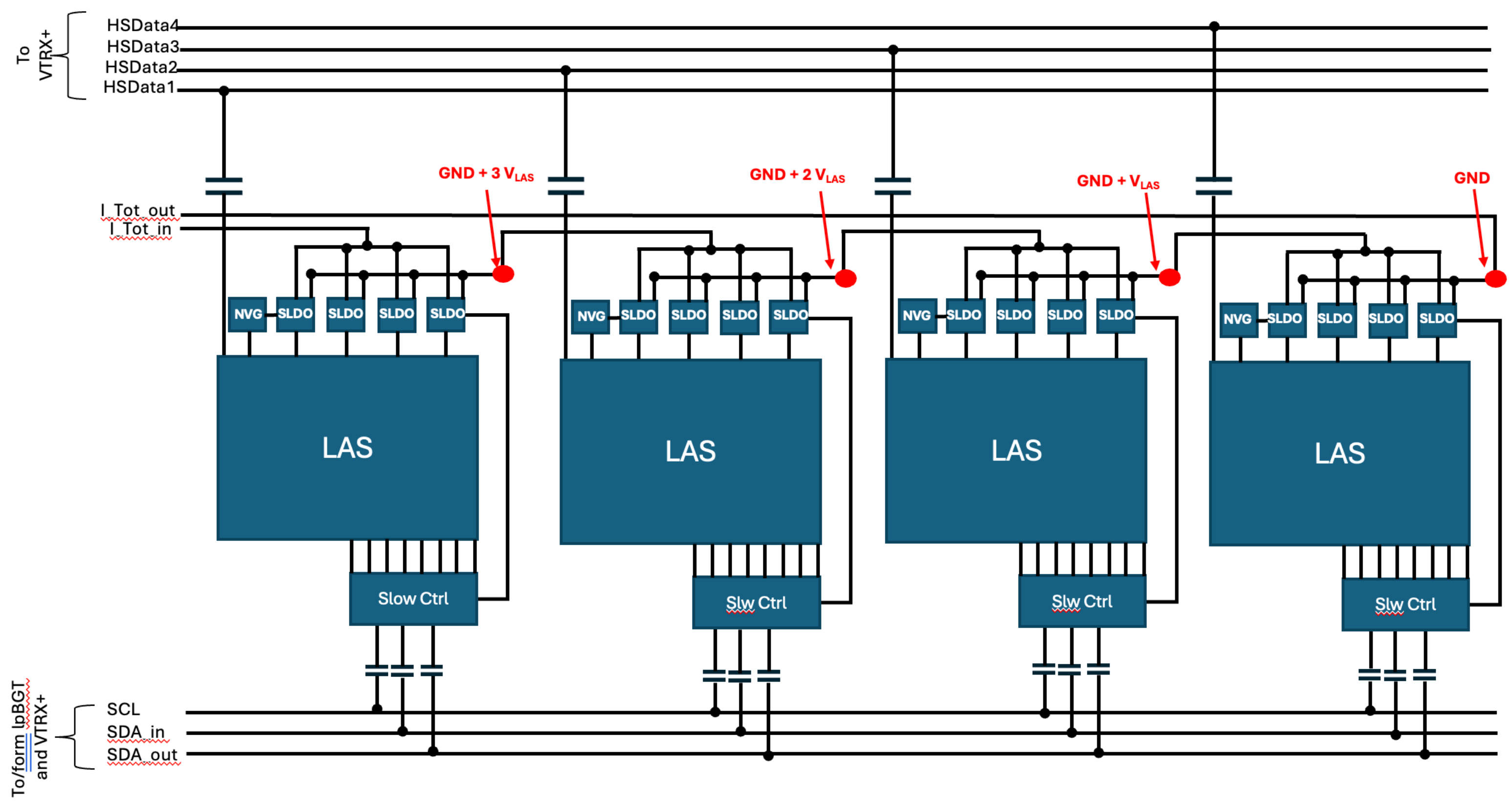
This tiling naturally leads to groupings of (up to) four EIC-LAS in powering, readout and slow-control.

Sensor Tiling and Grouping

Charge 3

Tiling naturally leads to groupings of (up to) four EIC-LAS; this is key to service reduction with serial powering and multiplexed slow control.

At a functional level:



A group of (up to) four EIC-LAS is serially powered via one current loop; controlled with three slow-control lines.

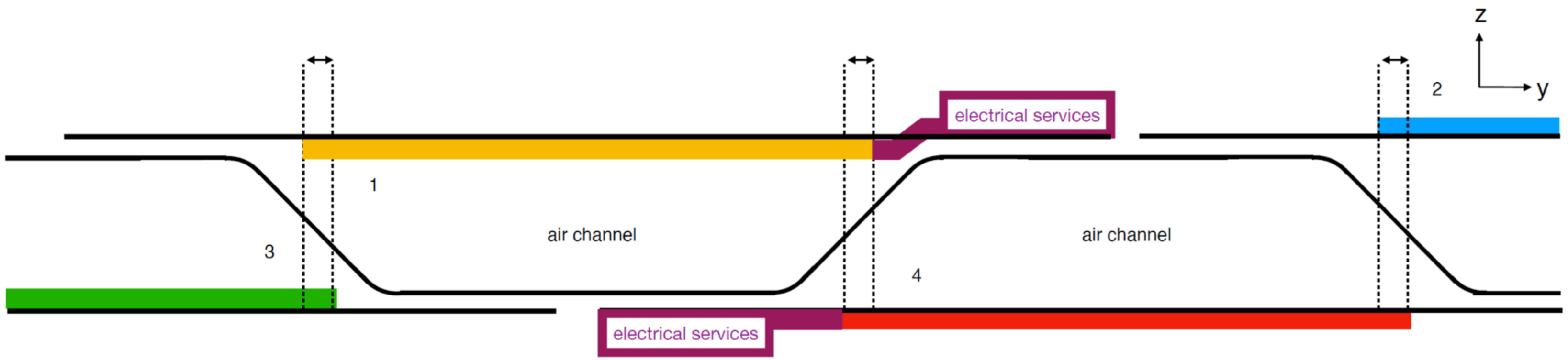
Sensor Tiling and Grouping

Charge 2,3

EIC-LAS with 5 or 6 RSUs is the outcome of extensive tiling studies and foundry constraints as they are currently known; a) only a single variant will be accommodated on any given wafer and b) NRE considerations limit the number of variants to two, at most.

Disks are currently foreseen to have a corrugated core. Tiling can then be done on four surfaces.

In sideview, with the length axis of the sensor going into or coming out of the screen:



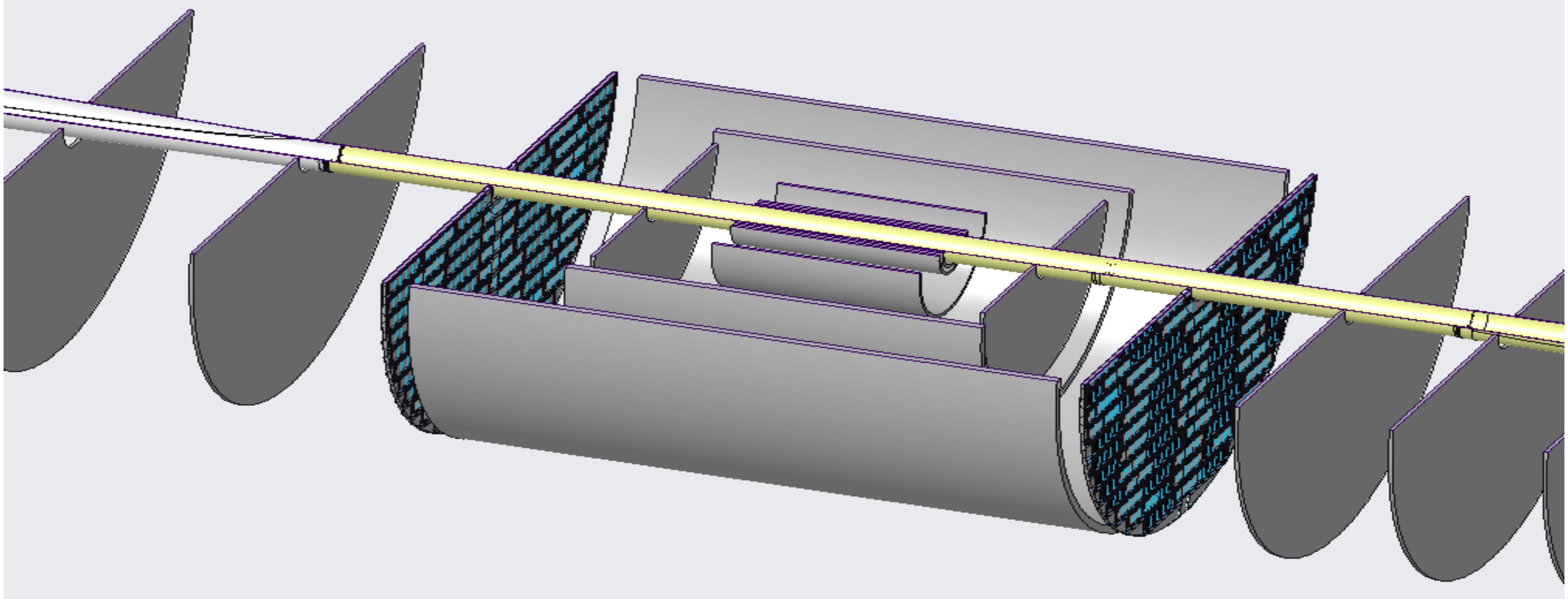
Overlap along the length axis is possible by alternation,

Corrugation pitch and height determine EIC-LAS overlap along the short axis; current values of ~34 mm and 6 mm, respectively, are being further optimized.

Local Mechanics

Disks

Charge 3



Note the crossing angle and acceptance cones of the beampipe. Top-down symmetry favors a horizontal segmentation of the disks.

Outer Barrel

Charge 3

The Outer Barrel will consist of staves,

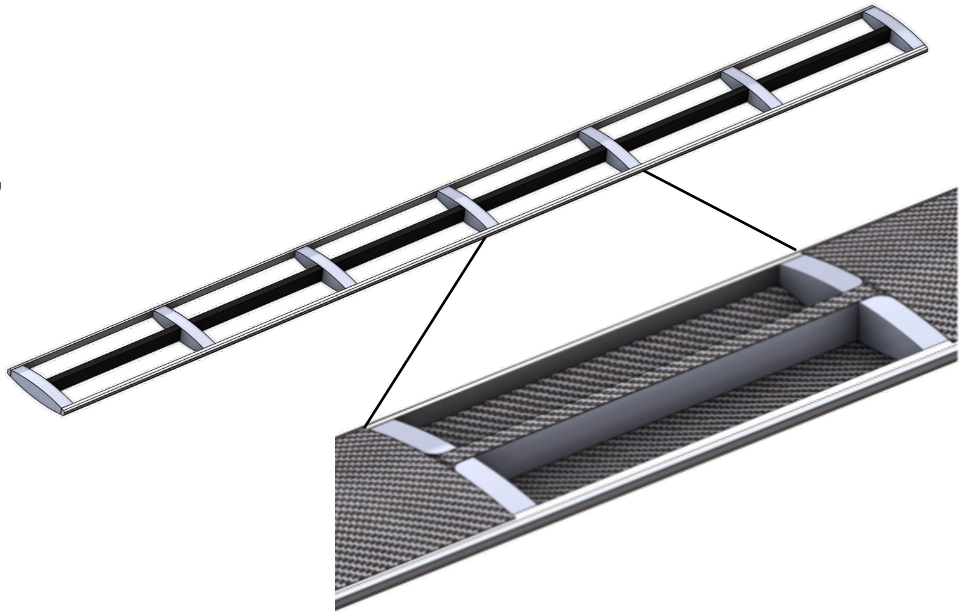
Stave will have twins of sensors on alternating sides (c.f. slide 16),

Core will consist of foam blocks, supporting all sensor edges,

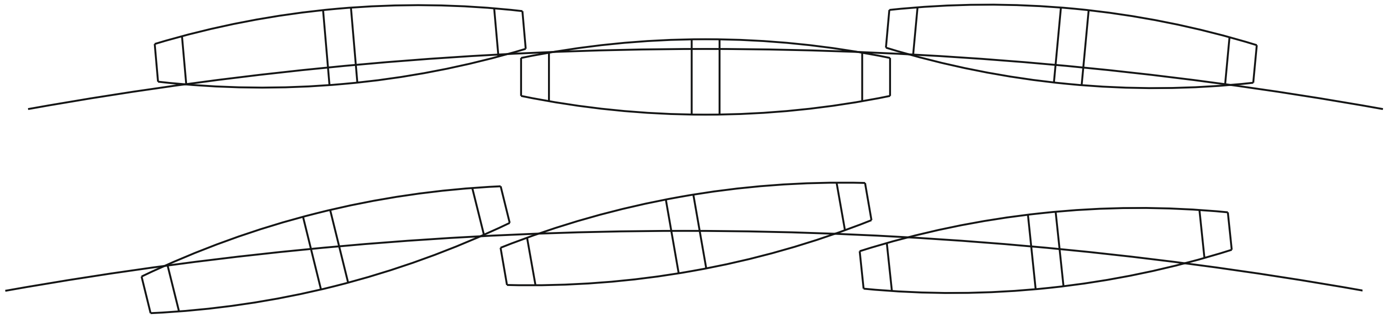
Surface between twins of sensors will be covered with a CF skin,

Thickness and possible curvature, as well as material and lay-up remain to be optimized,

After co-cure or bonding the structure will be self-supporting.

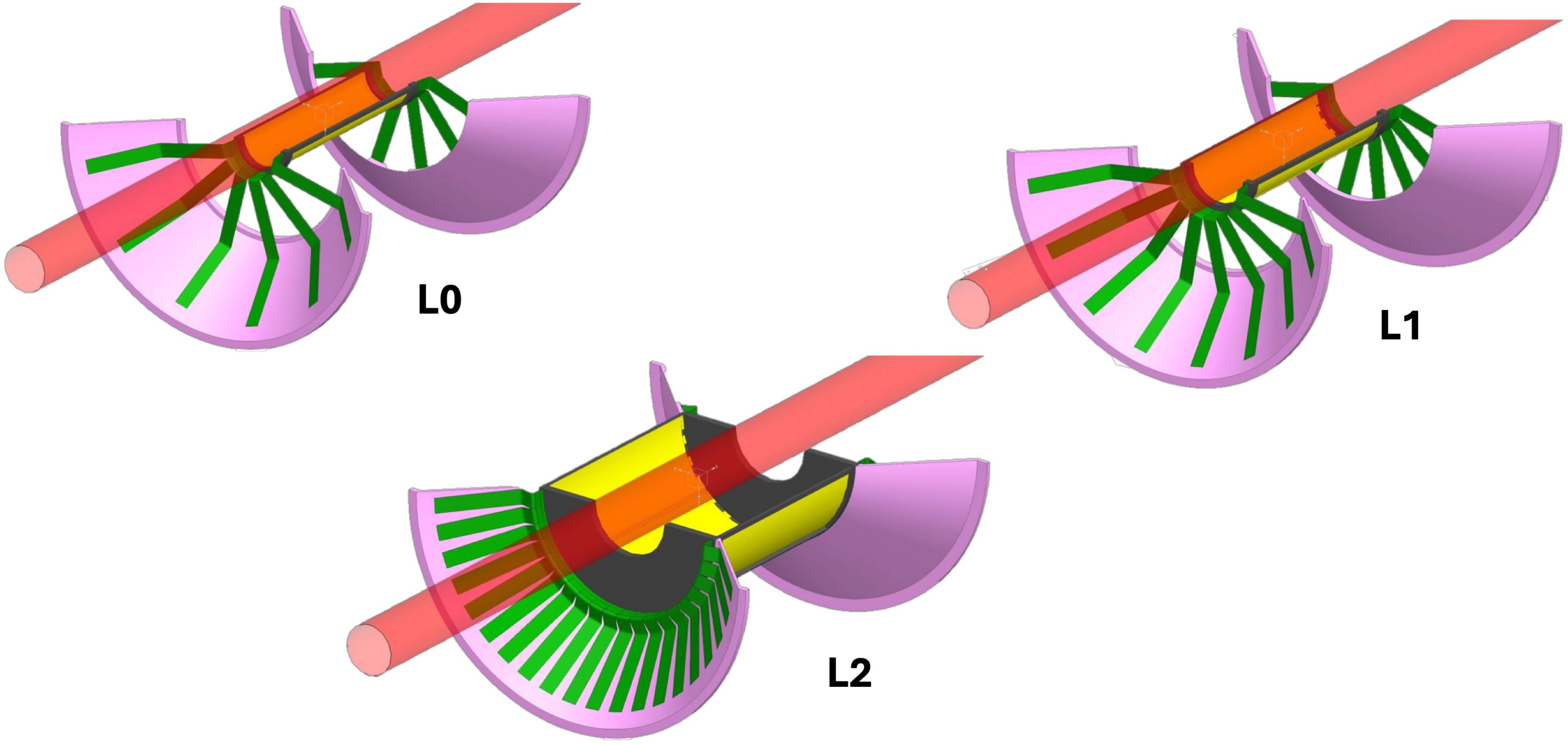


Castellated as well as tilted arrangement of staves being considered for the OB.



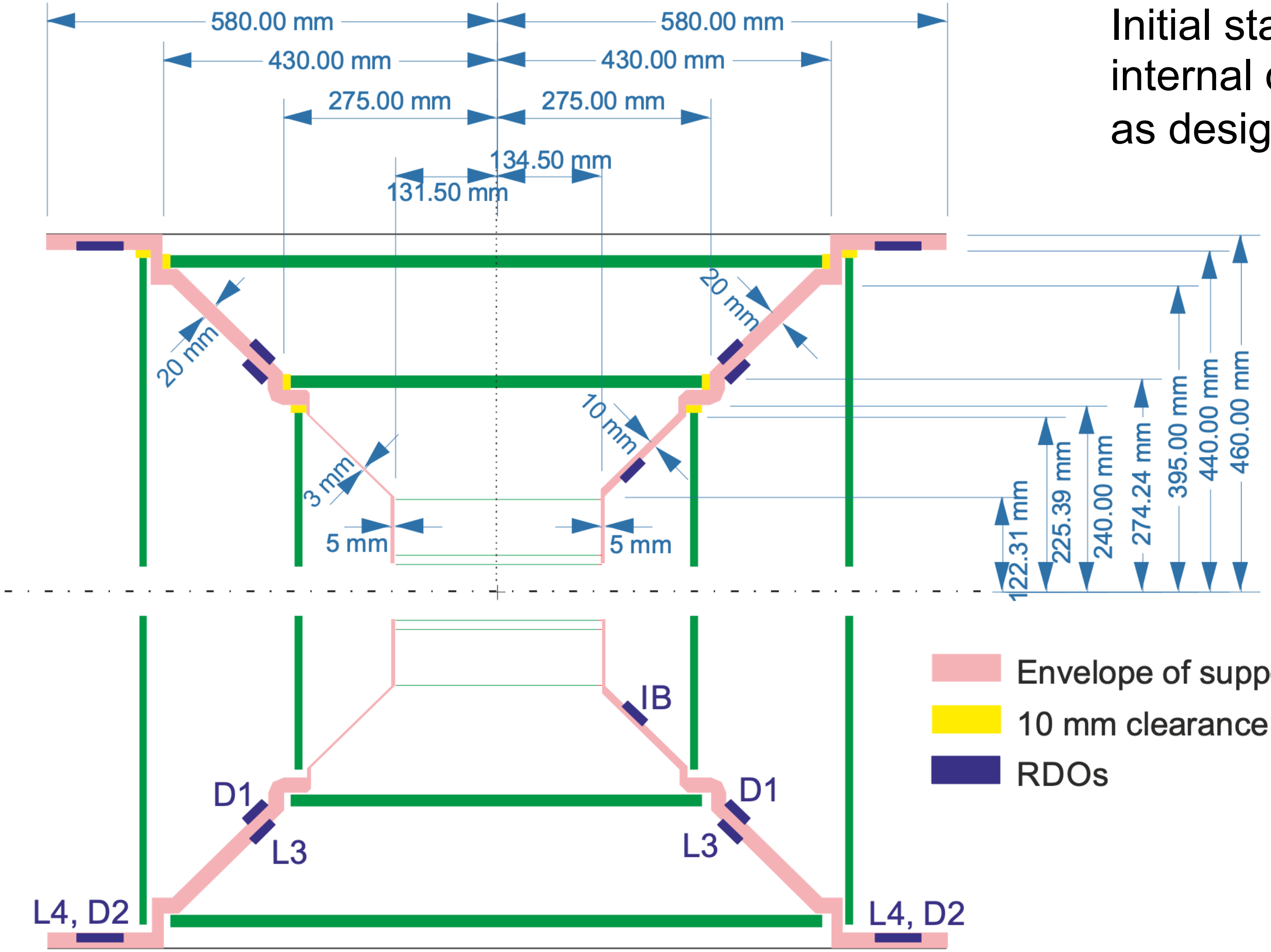
Inner Barrel

Charge 3



Initial stages of suitably adapting the ITS3 concept(s) to the ePIC SVT

Internal Envelopes



Initial stages of developing internal envelopes; internal dimensions are indications and will change as design advances.

- Envelope of support cones and services (electrical, optical and air)
- 10 mm clearance at end of local supports
- RDOs

Detector Subsystem Collaboration

Participating Institutions

Charge 5

UNIVERSITY OF BIRMINGHAM

INFN

BERKELEY LAB

Jefferson Lab

Berkeley UNIVERSITY OF CALIFORNIA

Brookhaven National Laboratory

Brunel University London

UNIVERSITY OF OXFORD

UNIVERSITY OF LIVERPOOL

UKRI Science and Technology Facilities Council

Los Alamos NATIONAL LABORATORY

CTU CZECH TECHNICAL UNIVERSITY IN PRAGUE

UIC

MIT

PURDUE UNIVERSITY

OAK RIDGE National Laboratory

Extensive Si-detector experience in the ALICE, ATLAS, CMS, sPHENIX, STAR collider experiments

Organization

Charge 5

Lead
Ernst Sichtermann (LBNL)

Technical Coordinator
Laura Gonella (Birmingham)

WP1 -- Sensor Design
Iain Sedgwick (RAL)
Joao de Melo (BNL)

WP2 -- Sensor Testing
Gian-Michele Innocenti (MIT)
Lukas Tomasek (CTU)

WP3 – Electrical Interfaces
Marcello Borri (Daresbury)
TBD

WP4 – Layers and Disks
Domenico Elia (INFN)
Georg Viehhauser (Oxford)
Nicole Apadula (LBNL)

WP5 – Readout and Powering
James Glover (Birmingham)
Jo Schambach (ORNL)

WP6 – Global Mechanics and Integration
Andreas Jung (Purdue)
Eric Anderssen (LBNL)

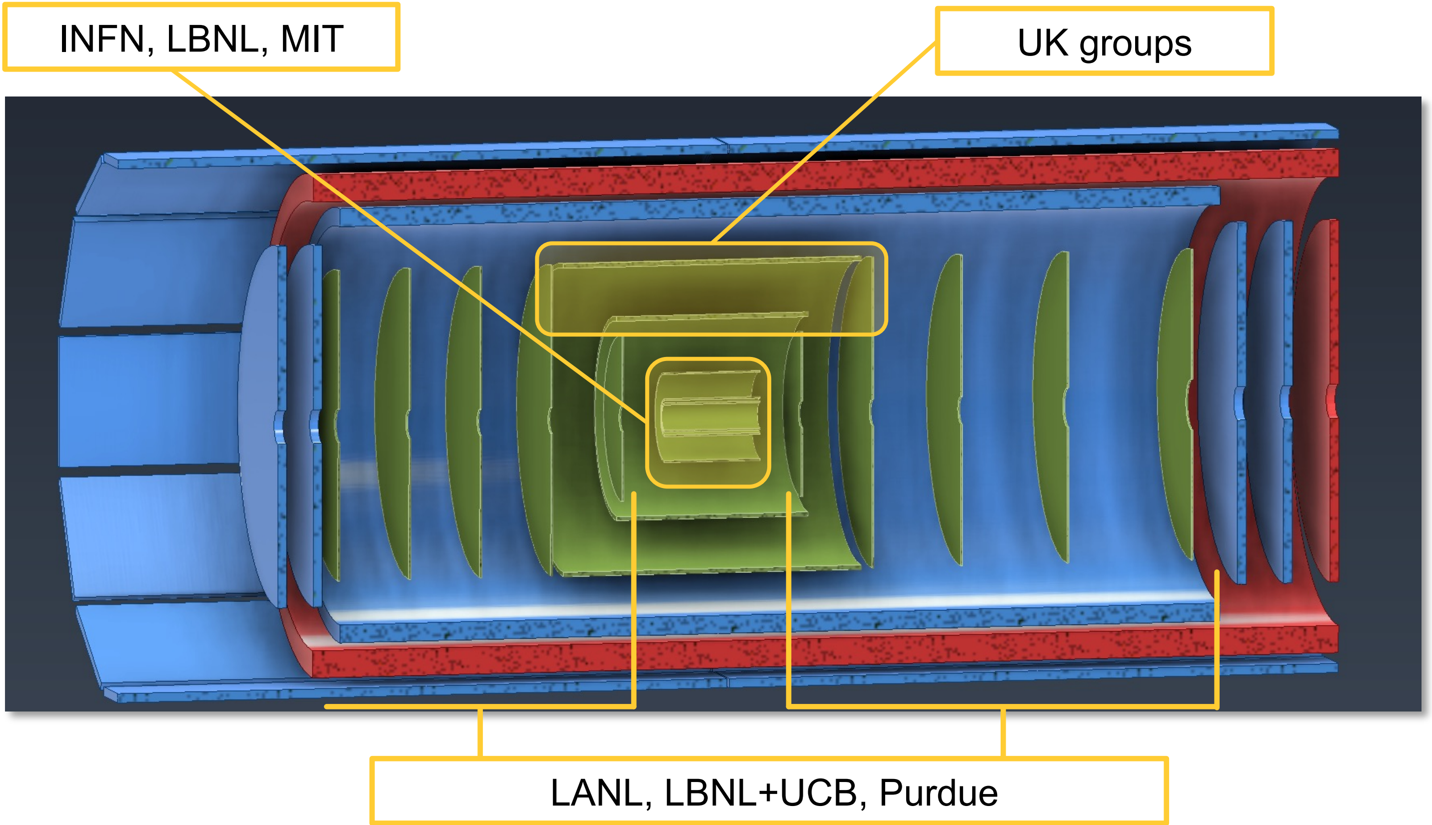
WP7 – Interlocks, Slow Control, and Monitoring
TBD

WP8 -- Database
TBD

WP9 – Software and Simulations
Shujie Li (LBNL)

Institutional Interests

Charge 5



Sensor and IC design: BNL, LBNL, MIT, RAL – further groups in characterization

Readout: ORNL, MIT

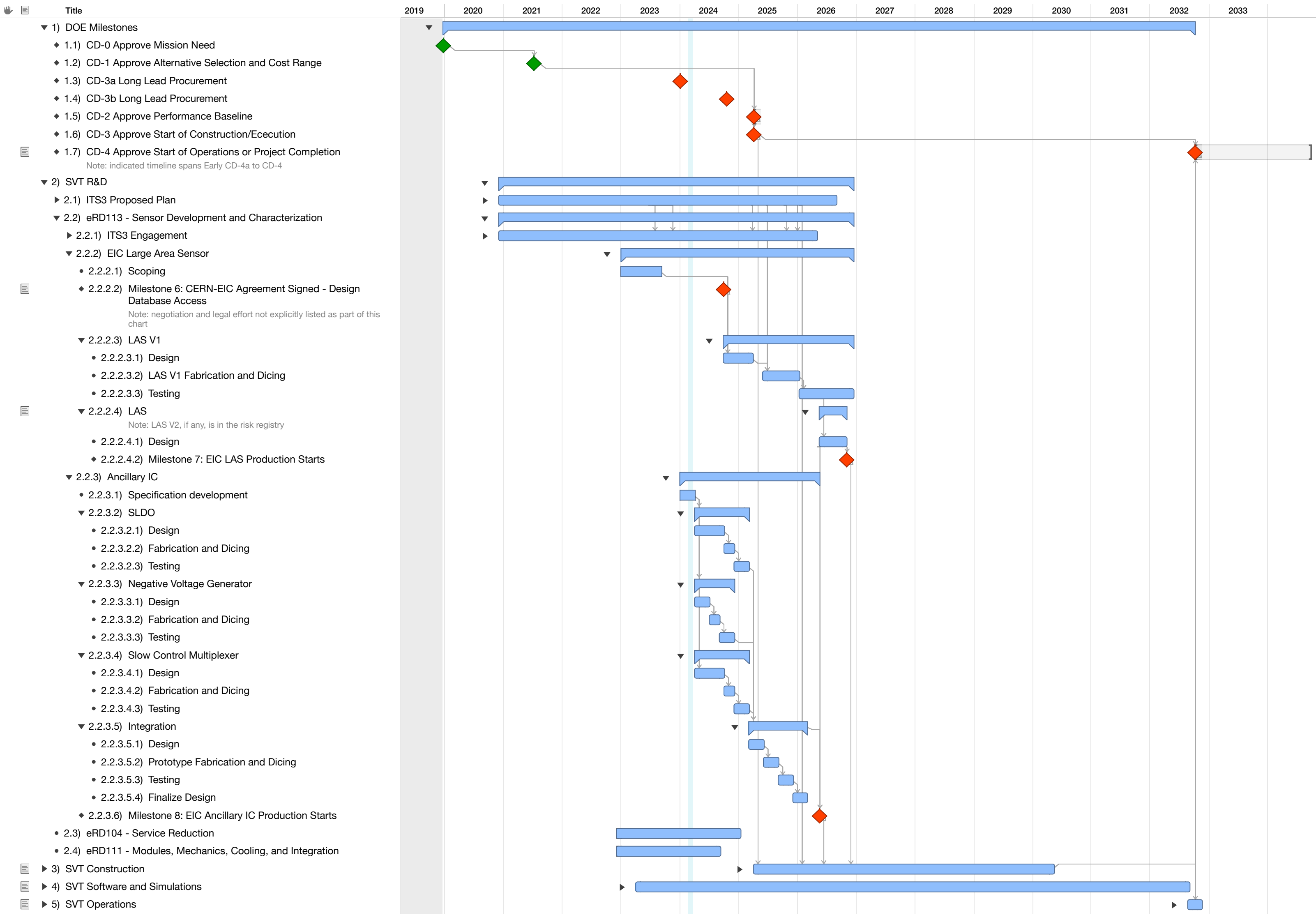
Additional groups expressed interest

Schedule

Timeline

Charge 5,7

- Sensor development:
  - ITS3 wafer scale sensor development (ER2, ER3) for IB 2024 – 2026,
  - EIC-LAS development for OB and Disks complete and ready for production start in calendar Q4 2026,
  - Ancillary IC development for EIC-LAS complete and ready for production start in calendar Q2 2026.

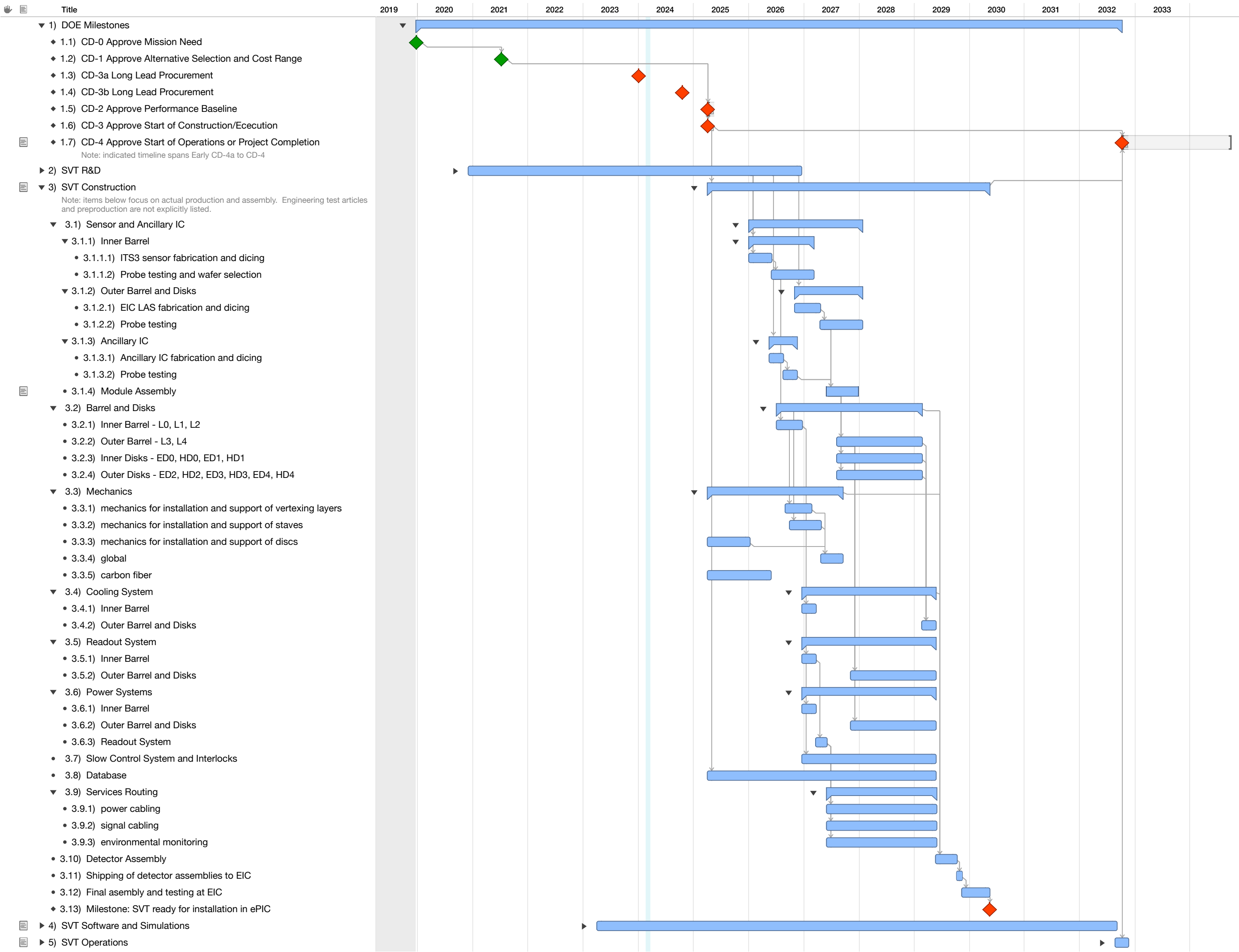


Timeline

Charge 5,7

- Construction:
  - Engineering test articles following R&D in 2025—2026,
  - Pre-production phase of about 1 year for IB; 2 years for OB,
  - Production and QA through calendar Q2 2029 followed by assembly,
  - Current plan is shipment of surveyed and assembled half barrels and disks to BNL in calendar Q4 2029,
  - Final assembly and testing at BNL through calendar Q1 and Q2 2030, prior to installation in ePIC.

- SVT schedule is compatible with Project requirements, being finalized.



Risks and Mitigation

Alternative Tracker

Charge 4

- Goal is always to progress towards using ITS3 based sensors
  - Only way to meet full performance requirements

- Branchpoints – both based on schedule delays:
  1. ITS3 (inner barrel) schedule remains compatible with project schedule but LAS (outer barrel & disks) development is delayed
  2. ITS3 (inner barrel) schedule becomes incompatible with project schedule

Alternative Tracker – Layout

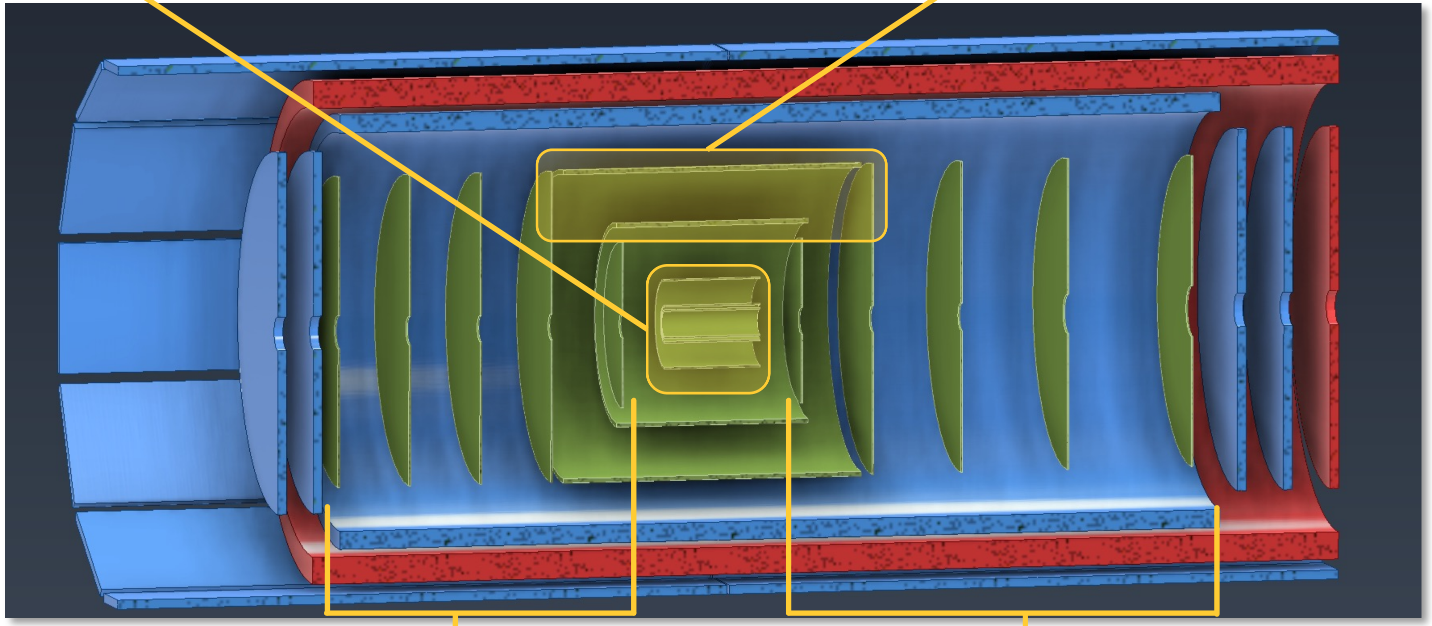
Charge 4

Replaced by two or three layers based on the existing ITS2 sensor, as used in ALICE and sPHENIX without EIC specific modifications
Branchpoint 2 only

Inner Barrel (IB)

Outer Barrel (OB)

Replaced with two MPGD barrel layers derived from the outer MPGD tracker, specifically its innermost (Micromegas) layer
Branchpoint 1 & 2



Electron and Hadron Endcap Disks (EE, HE)

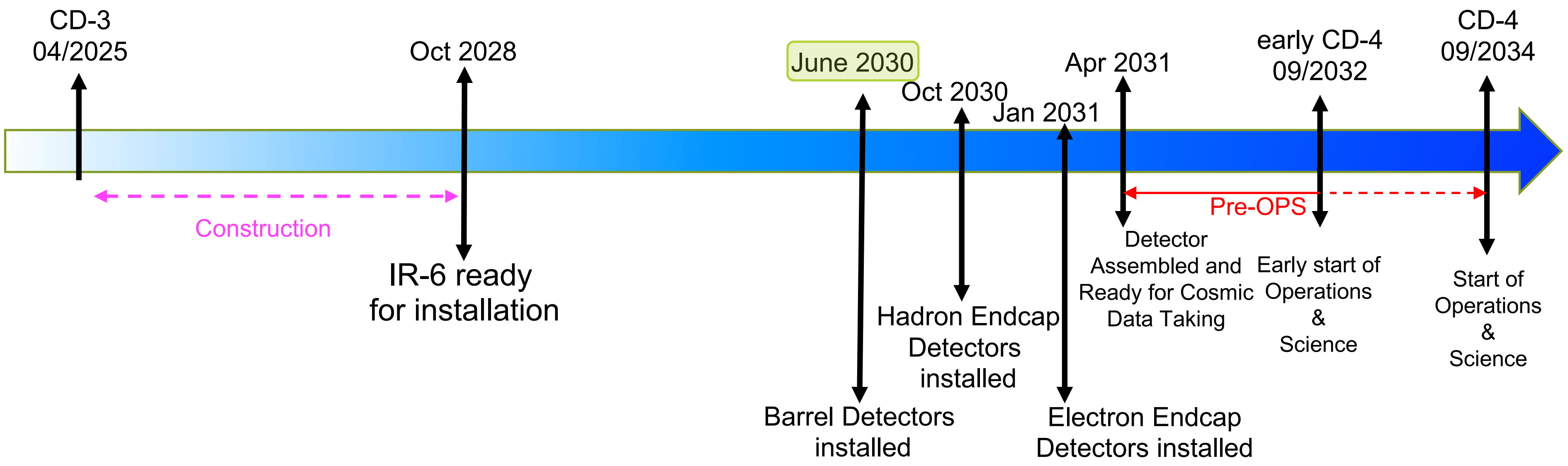
Replaced with (in total up to) seven near-identical MPGD disks on each side, specifically based on existing uRWELL disks
Branchpoint 1 & 2

Alternative Tracker – Schedule

Charge 4

- Will be further refined leading up to CD-2 based on ITS3 development

Branchpoint	Date	Milestones
1 (LAS Delay)	Q2/Q3 2026	1 year for MPGD foils + 3 years construction
2 (ITS3 Delay)	Q3/Q4 2027	Same 3 years construction as current IB



Summary

- Silicon Vertex Tracker acceptance and technical performance requirements are defined,
- SVT layout, consistent with the requirements, has been optimized for resolution,
- SVT will be based on a new Monolithic Active Pixel Sensor in 65 nm technology that is being developed in collaboration with the ongoing ALICE-ITS3 MOSAIX development,
- SVT will use an ancillary IC for serial powering, biasing, and multiplexing of slow controls with minimized material in view of risk, schedule, and resources,
- SVT designs are advancing,
- SVT workforce identified and growing,
- SVT timelines are consistent with the Project timelines and critical decisions.