The Silicon Vertex Tracker of the ePIC Detector at the Electron-Ion Collider

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FCC conference

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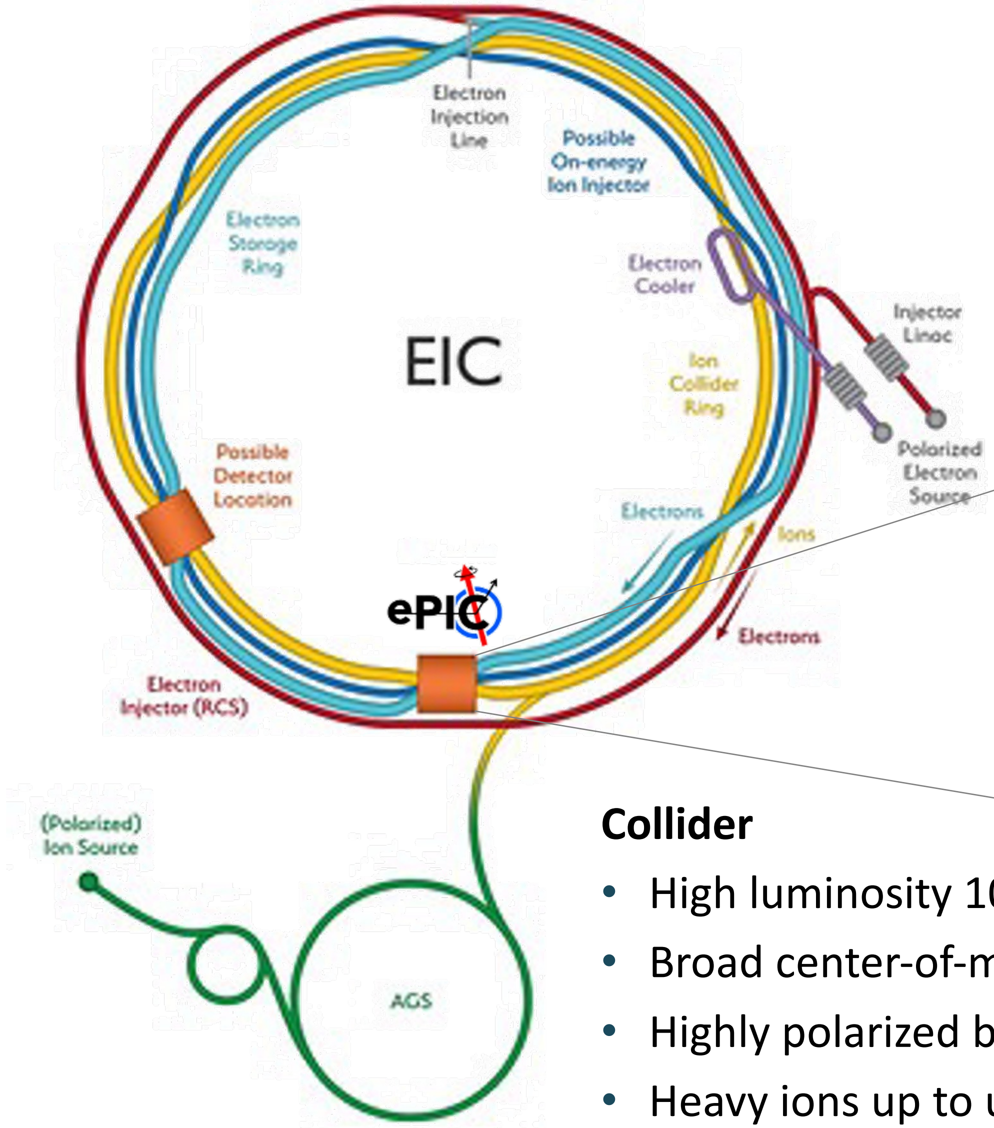
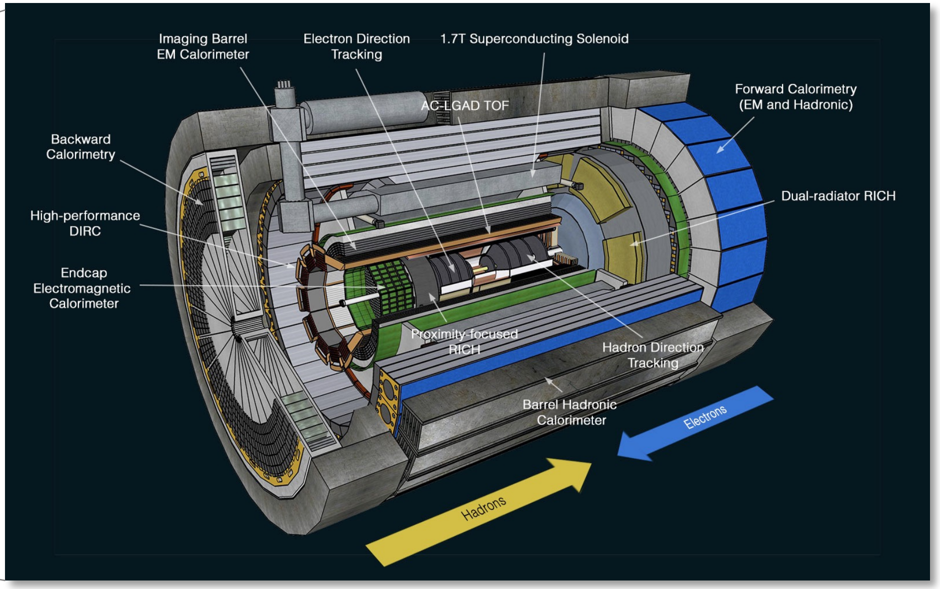
Electron-Ion Collider and Detector



Detector

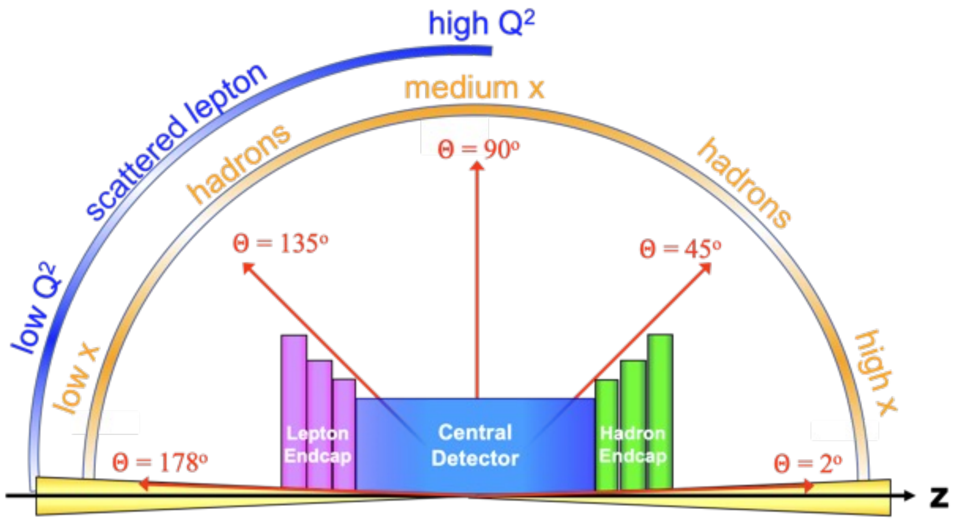
- Compact, only ~9 m in length
- Tracking, PID, Calorimetry
- Silicon Vertex Tracker (SVT) at core, ~8m^2



Collider

- High luminosity $10^{33} – 10^{34}$ cm^{-2}s^{-1}
- Broad center-of-mass energy range, $\sqrt{s}$ = 29 –140 GeV
- Highly polarized beams (e$^-$ & ion), ~70%
- Heavy ions up to uranium

Tracking & Vertexing Requirements



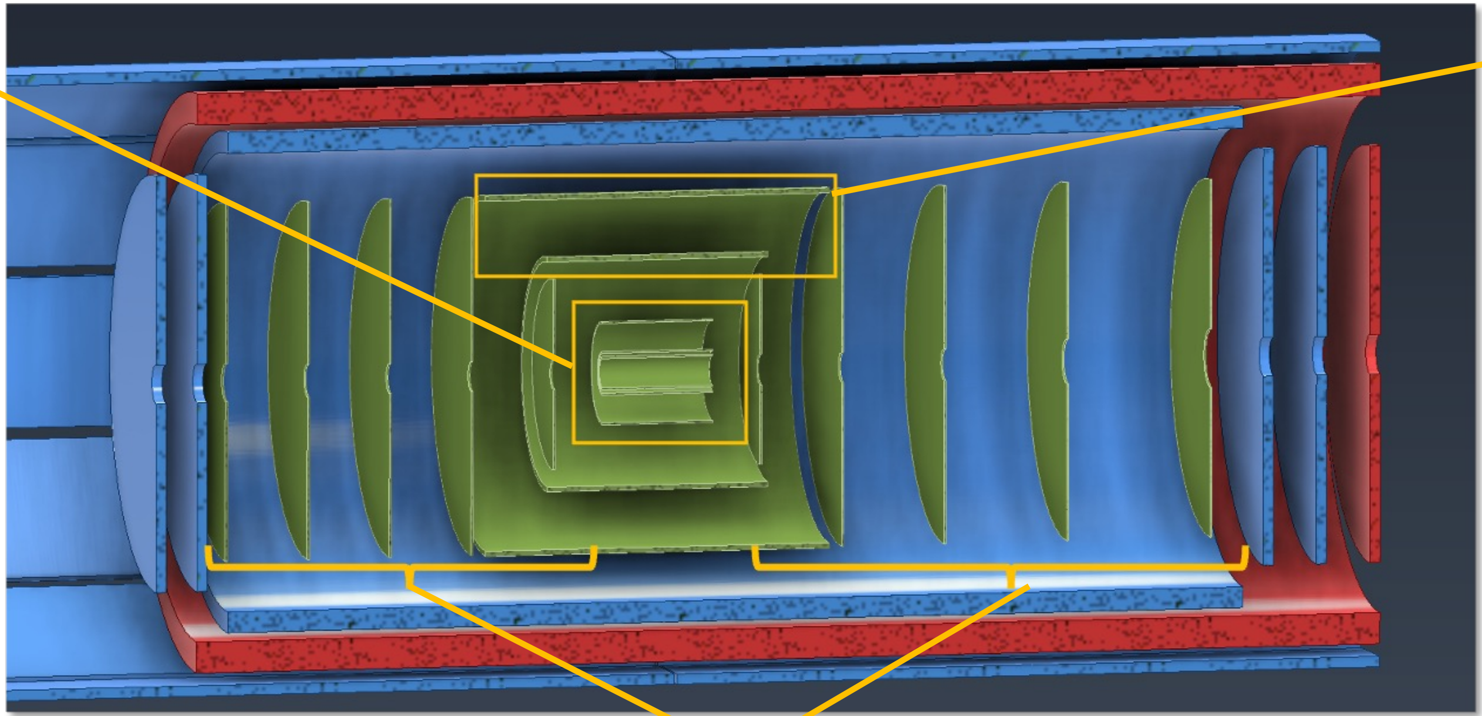
More details in Zhenyu Ye's talk

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

Requires a large acceptance, high-granularity, low-mass, well-integrated Silicon Vertex Tracker subsystem

ePIC SVT Concept

Inner Barrel (IB)
3 curved layers
R = 36, 41, 120 mm
L = 27 cm
X/X_0 ~0.05% per layer
Sensor → MOSAIX

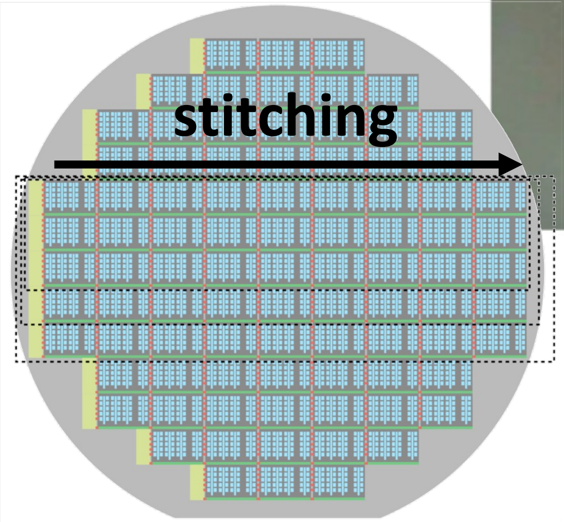


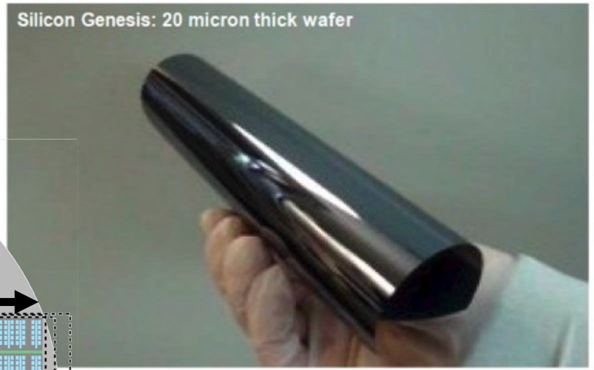
Outer Barrel (OB)
2 stave-based layers
R = 27 & 42 cm
L = 54 & 84 cm
X/X_0 ~ 0.25% and 0.55%
Sensor → EIC-LAS

Electron/Hadron Endcaps (EE, HE)
10 discs, 5 on each side of IP
Min R_{out} ~24 cm, Max R_{out} ~42 cm
X/X_0 ~0.25% per disc
Sensor → EIC-LAS

Silicon Sensor Technology: MAPS

- **Monolithic Active Pixel Sensors (MAPS)**
  - 65 nm technology
- **Stitched** (up to **~28 x 10 cm**)
- **Ultra-thin** (**20 – 40 μm**)
- **Bent**
- **High granularity** and **low power** → High spatial resolution
- **Stitching** on 300 mm wafers for large area sensors → Increased detector active area, reduced material budget
- Collaboration with ALICE ITS3 → Reduced risk and cost of sensor development

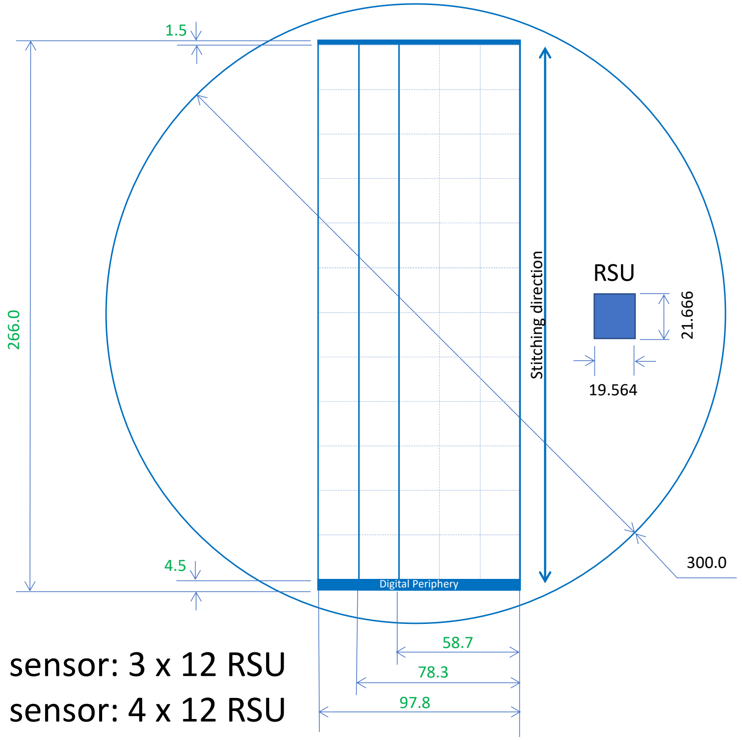




ALICE ITS3 LOI

MOSAIX

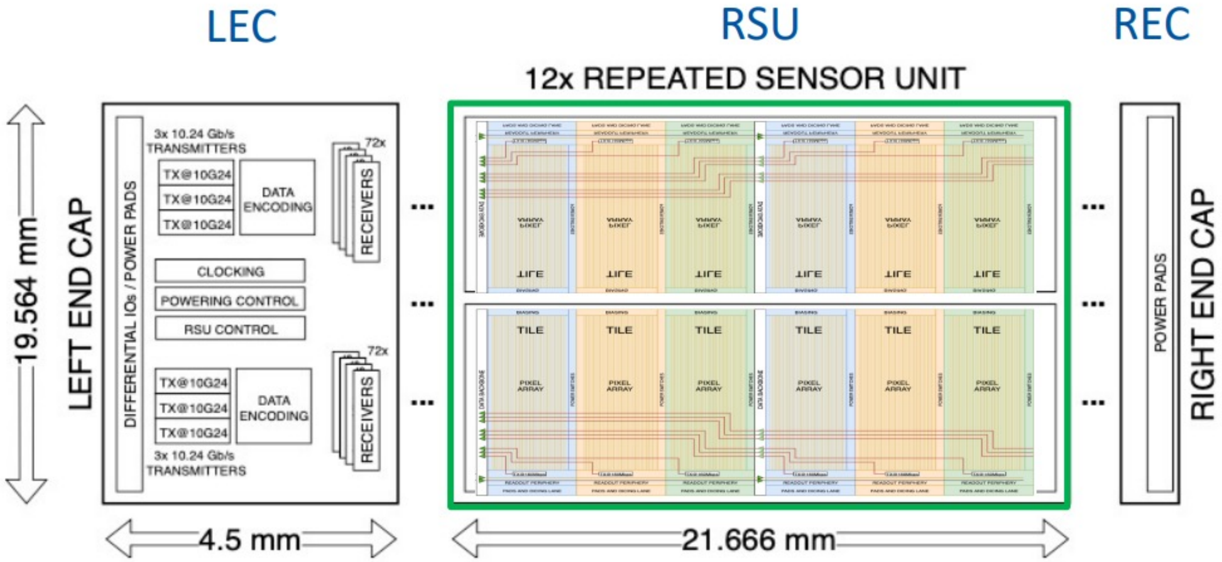
- Complex circuit designed, led by ALICE ITS3 team at CERN
  - Approximately 30 FTE of designers working on the submission, including ePIC SVT designers



ER2 sensor widths

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

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



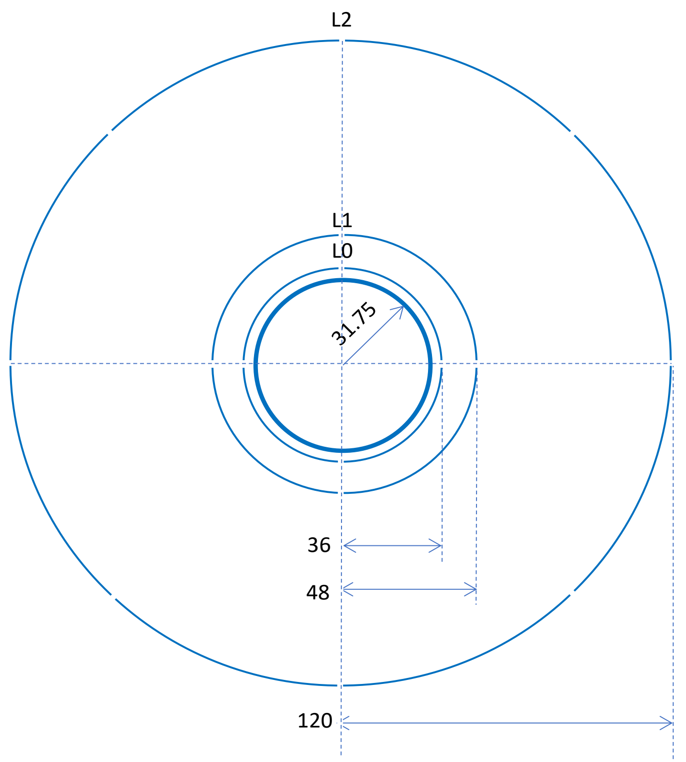
Pixel size: ~ 20 x 22 μm^2
Frame duration: 2 to 5 μs
Data link: 10.24 Gbps

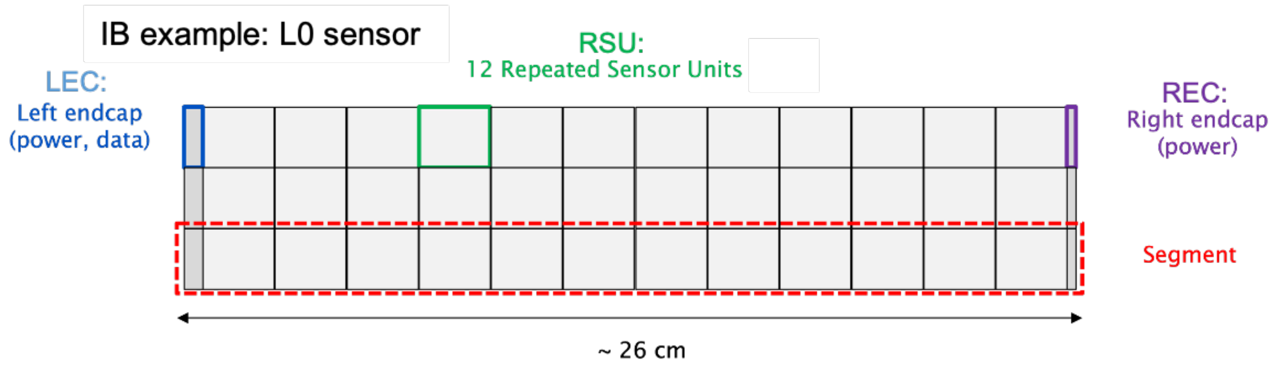
ALICE ITS3 TDR

Ongoing development → 2nd Engineering Run later this year, production in 2026

Inner Barrel Concept

- 3 layers of thin, bent, wafer-scale sensors
- Uses same MOSAIX sensor as ALICE ITS3
  - **L0**: 3 x 12 RSUs (4 each)
  - **L1**: 4 x 12 RSUs (4 each)
  - **L2**: 5 x 12 RSUs (8 each)
- Minimal mechanical support, air cooling, no services in active area





MOSAIX → EIC-LAS

- The ePIC SVT IB will use 16 MOSAIX sensors and cover ~0.3 m^2
- The SVT OB layers and Endcap discs will cover ~8 m^2
- This requires a sensor design optimized for **yield, high acceptance, large area coverage**
- The EIC-LAS sensor will be based off of the MOSAIX design
    - EIC-LAS will be thinned and stitched, but *not* wafer-scale
- MOSAIX modifications kept to a minimum
    - Based on reduced risk and time/resource availability
    - No changes to pixel matrix
- Low-material powering, biasing, & slow control for the EIC-LAS is essential and will be provided with a single **Ancillary ASIC**

MOSAIX → EIC-LAS

Inner Barrel

MOSAIX segment

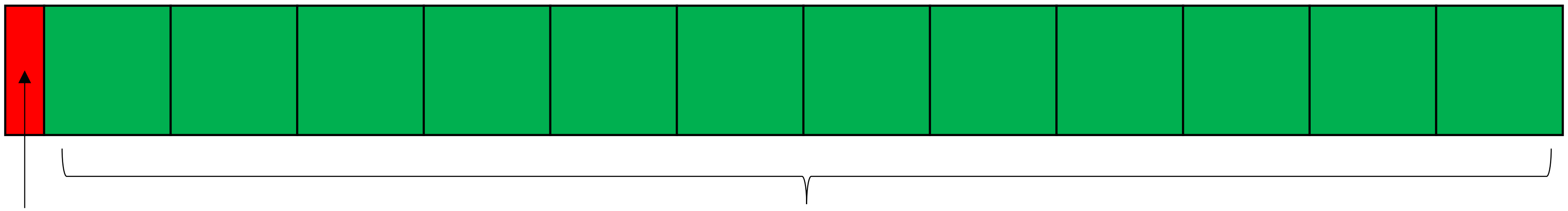
Outer Barrel, E/H Endcaps

EIC-LAS and ancillary chip

Inner Barrel		Outer Barrel, E/H Endcaps	
• 12 RSUs	Improve yield and coverage →	• **5 or 6 RSUs**	EIC-LAS
• 8 data links	Lower material budget →	• **Single data link**	EIC-LAS
• 7 slow control links	Lower material budget, fit integration requirements →	• Multiplex slow control	Ancillary ASIC
• Direct powering	Lower material budget, fit integration requirements →	• Serial powering	Ancillary ASIC

Sensor Power Regions

IB sensor: MOSAIX



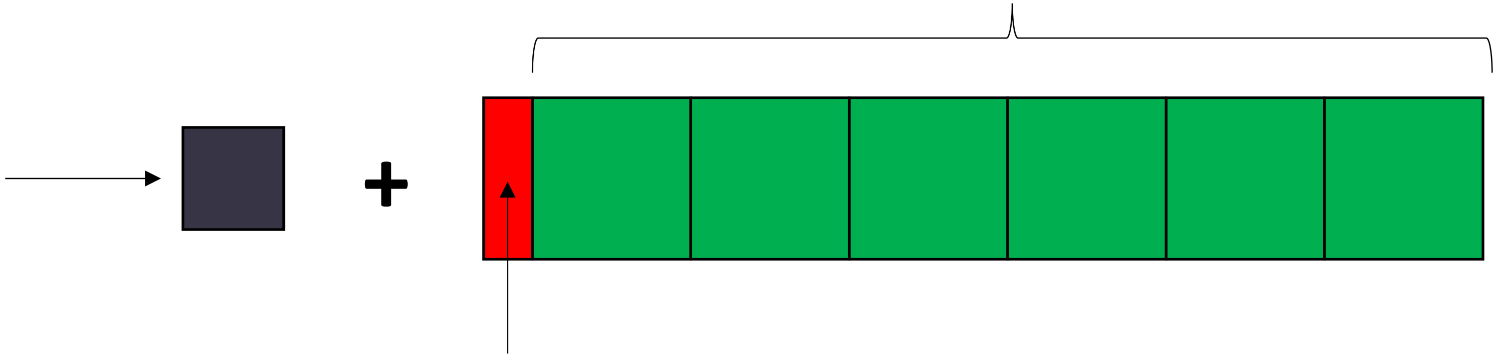
LEC: ~0.8 W/cm^2

12 **RSUs**: up to 40 mW/cm^2

OB/HE/EE sensor: EIC-LAS

5-6 **RSUs**: same power density as MOSAIX

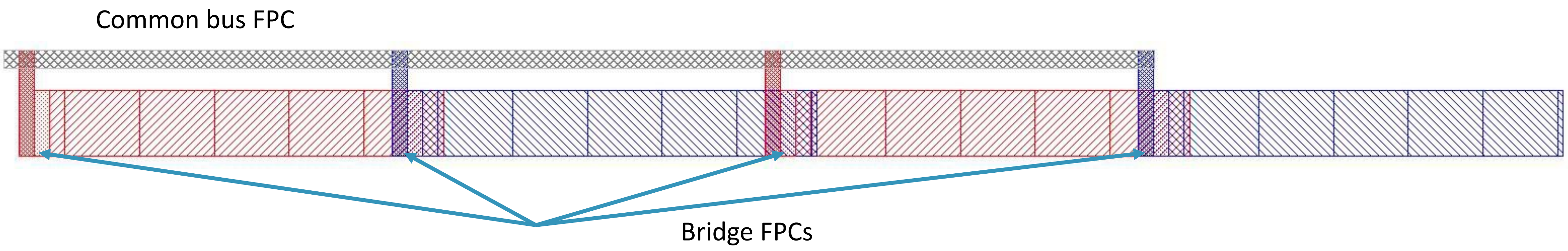
AncASIC:
Size & power TBD



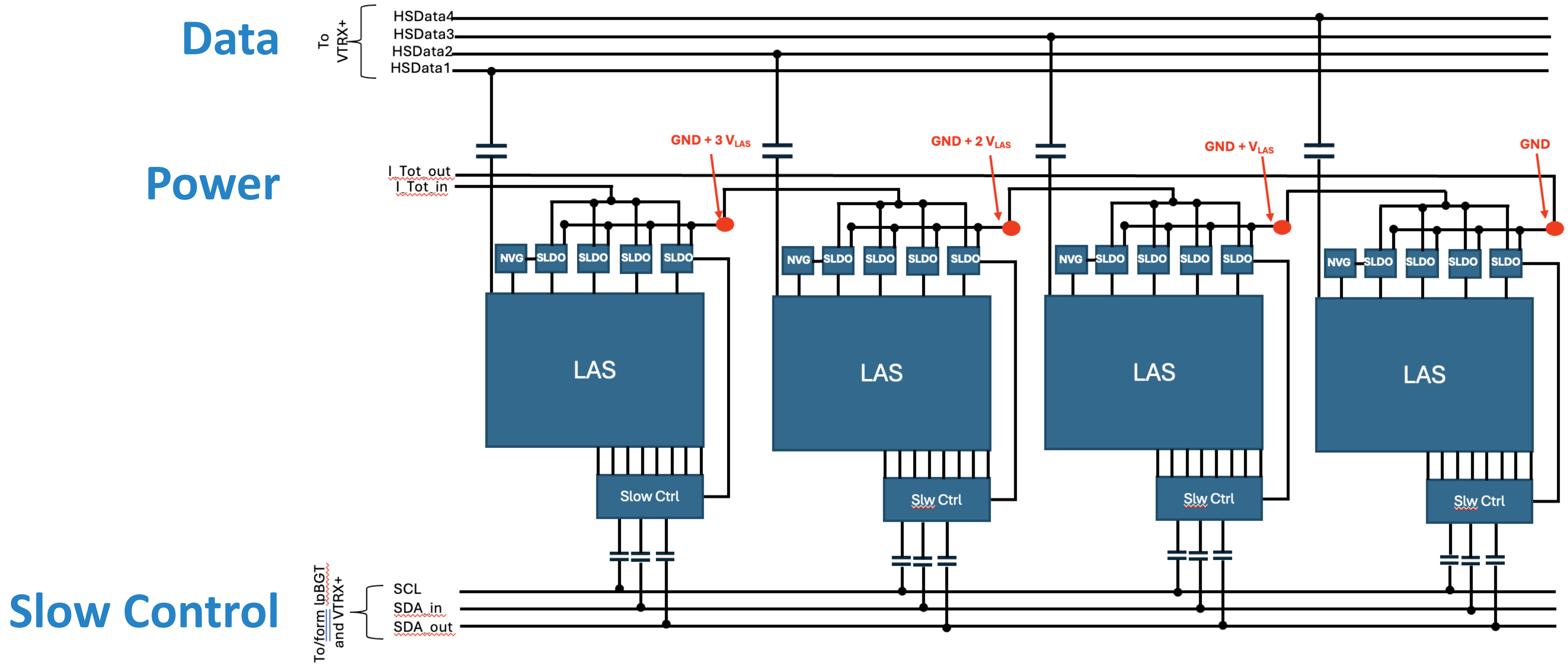
EIC-LAS LEC ≤ MOSAIX LEC

Module grouping

- Up to four EIC-LAS grouped together
- Reduces services with serial powering and multiplexed slow control
- EIC-LAS bonded to AncASIC and FPC bridge
- Up to four FPC bridges connect to common bus FPC
- Common bus FPC connects to Readout Board up to 40 cm away

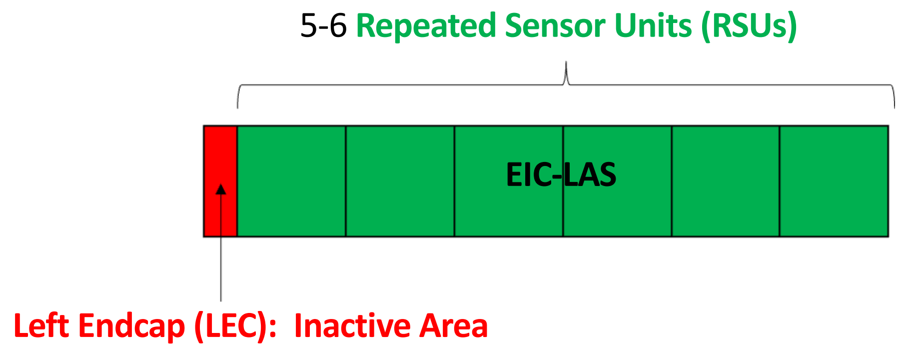


EIC-LAS Services

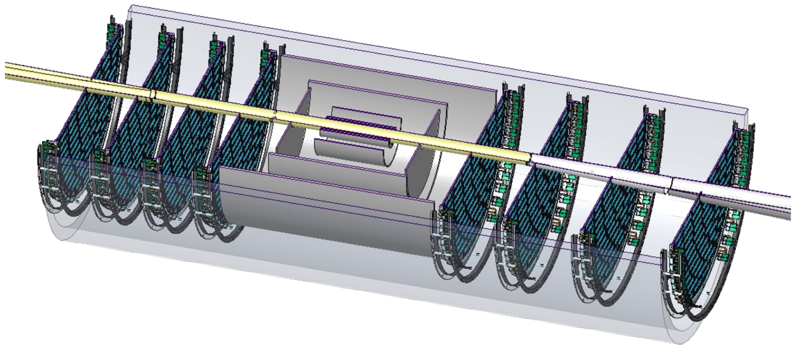


- Data routed onto fiber to the control room
- Groups of (up to) four EIC-LAS serially powered via one current loop
- MOSAIX slow controls grouped/multiplexed onto 3 control lines and routed onto fiber to/from control room
- Air cooling *internal* to the OB staves and Endcap discs

OB & Disc Design

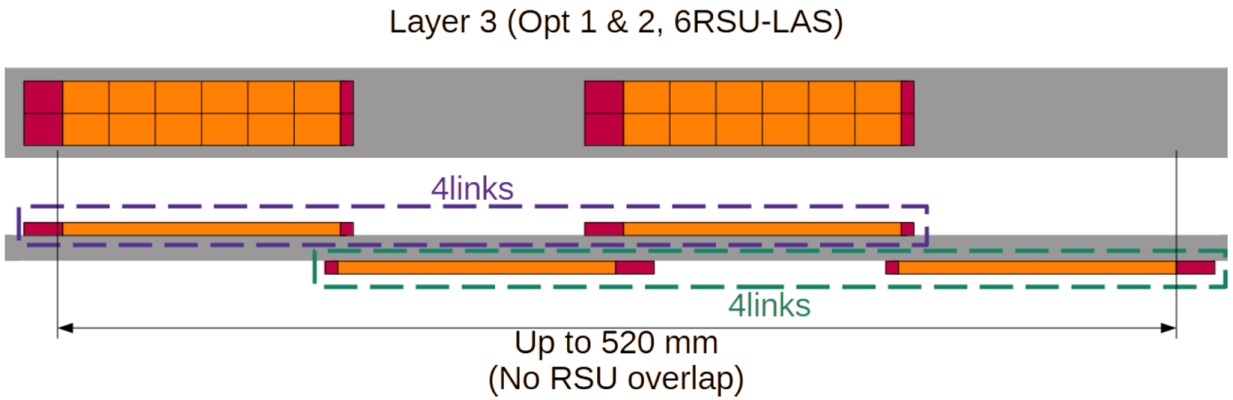


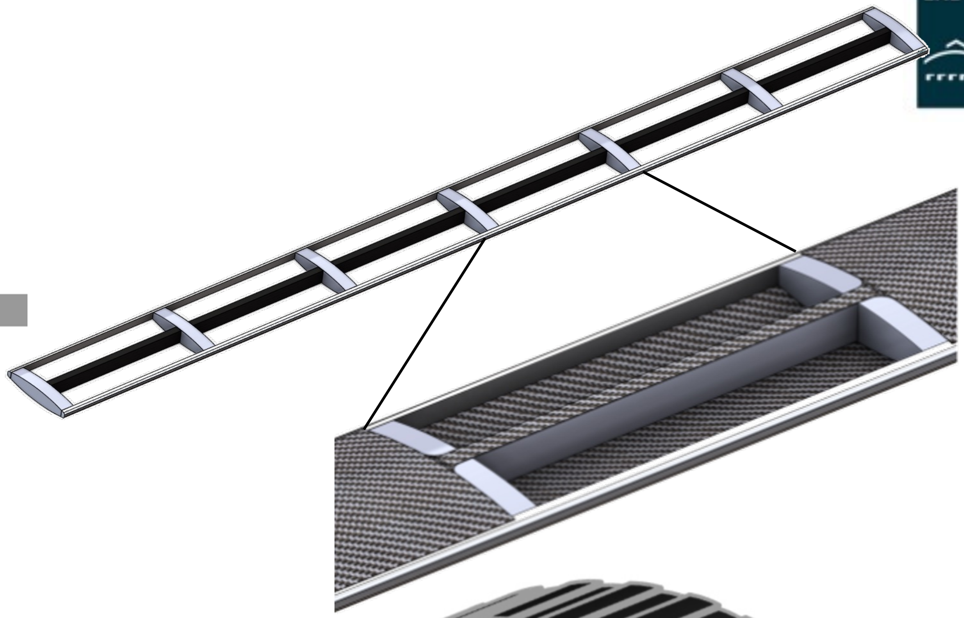
- Double-sided design
  - Overlap to account for inactive areas on sensor (EIC-LAS)
- Need to be assembled in halves for installation
  - Horizontal segmentation preferred

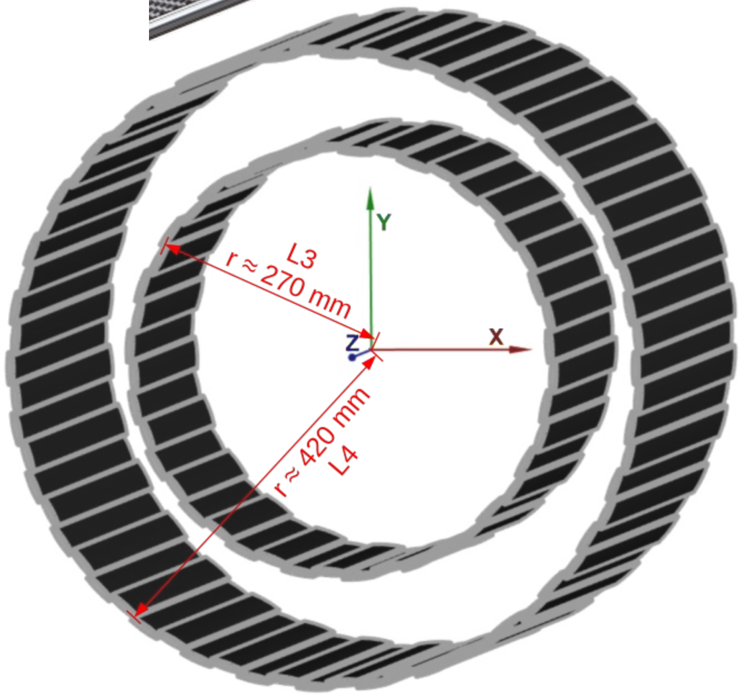


- Material budget is challenging (0.25% X/X_0 for L3 & all discs)
  - Want strength without added mass
- Minimal number of module types to simplify production/construction

Outer Barrel Layout

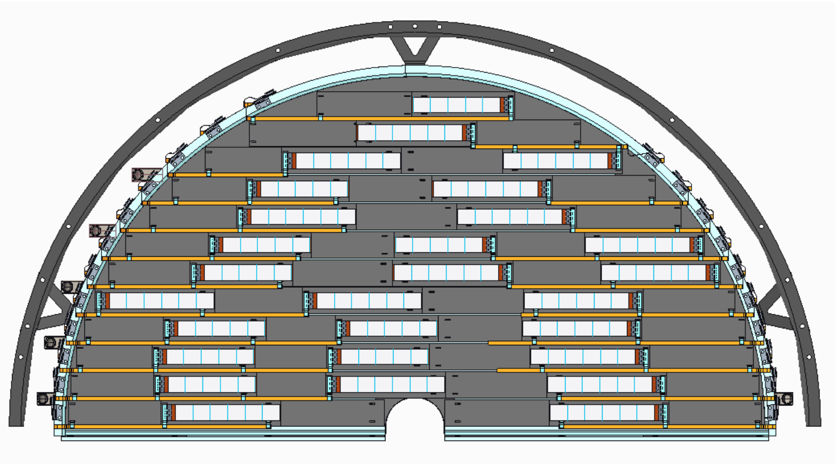




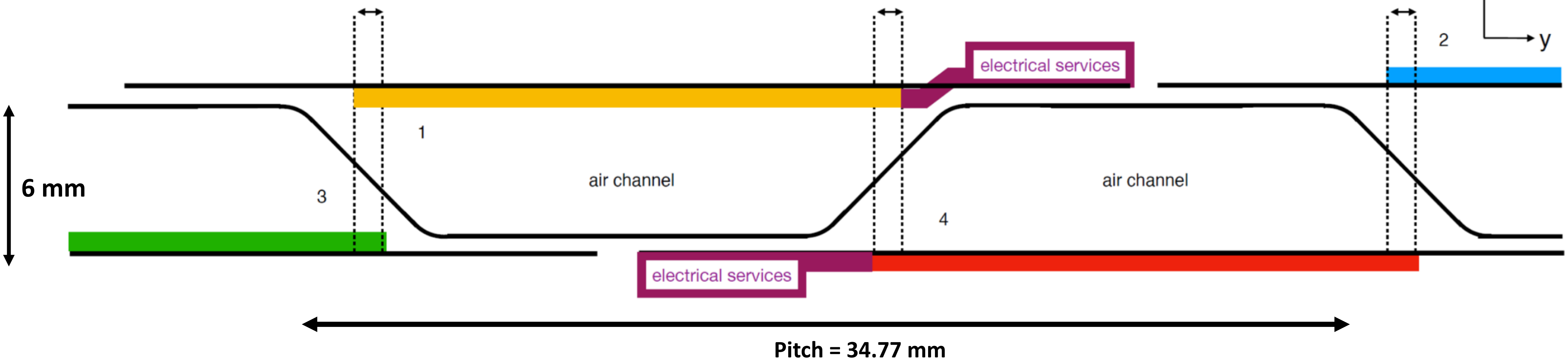


- Modules placed in an alternating top/bottom arrangement
- Barrel layers comprised of castellated staves
  - L4 (8 x 5 RSU long EIC-LAS) at approx. 440 mm radius
  - L3 (4 x 6 RSU long EIC-LAS) @ approx. 270 mm radius

Disc Layout: corrugated core



Length axis of sensor going into or out of the screen



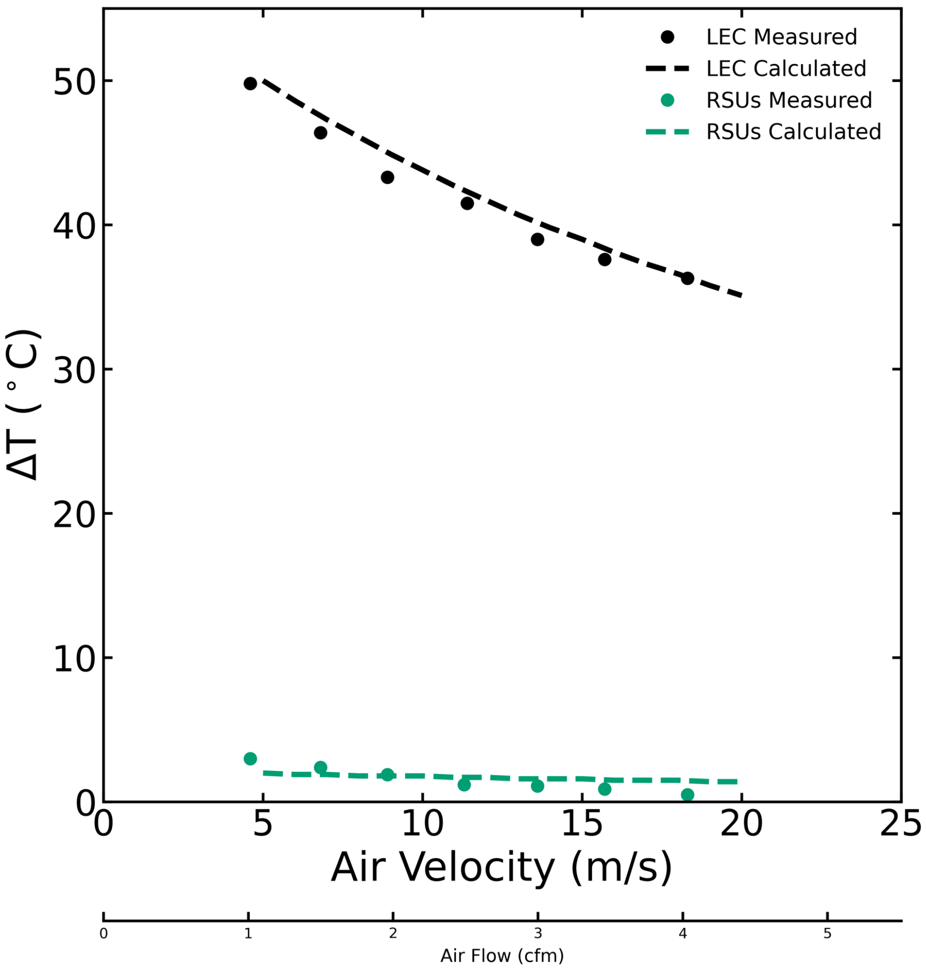
Overlap along the length axis by alternation

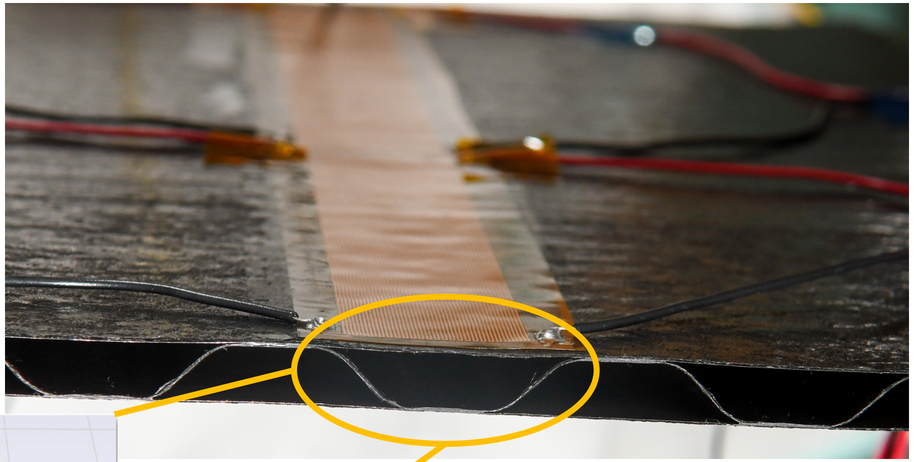
Corrugation pitch and height determine overlap along the short axis → Optimization ongoing

EIC-LAS Cooling

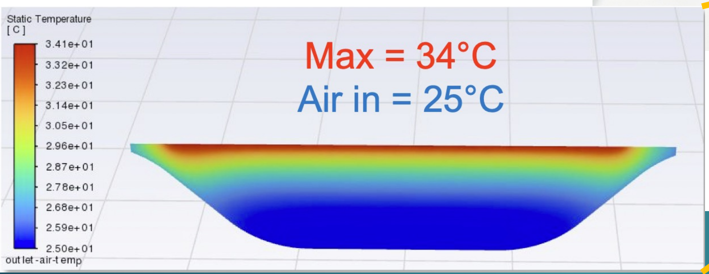
- SVT Baseline
  - Operation at/near room temperature
  - Air cooling (forced convection) internal to mechanical structures
  - Air cooling is an area of ongoing SVT R&D

LEC: 1 W/cm²
RSUs: 40 mW/cm²





Static temperature of corrugated cooling channel outlet for air velocity of 10 m/s

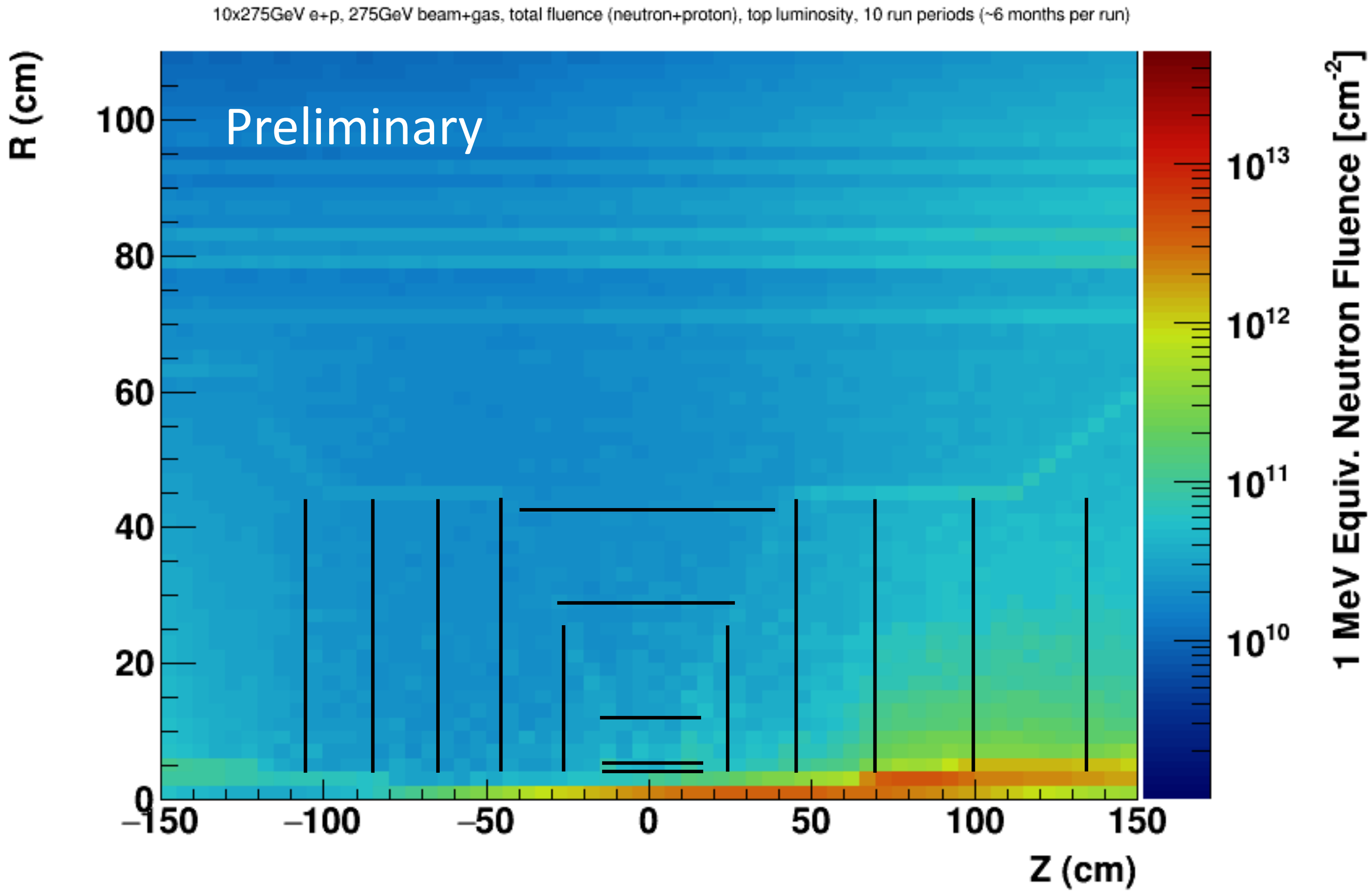


Summary

- ePIC is a compact detector with stringent tracking and vertexing requirements
- The ePIC Silicon Vertex Tracker is a large acceptance, high granularity, thin, MAPS-based detector designed to meet these requirements
- Complex sensor design benefitting from ALICE ITS3 development and collaboration
- Layout and design optimizations are being finalized
- Mechanical and thermal prototyping is ongoing
- EIC aims to come online in early 2030s

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),

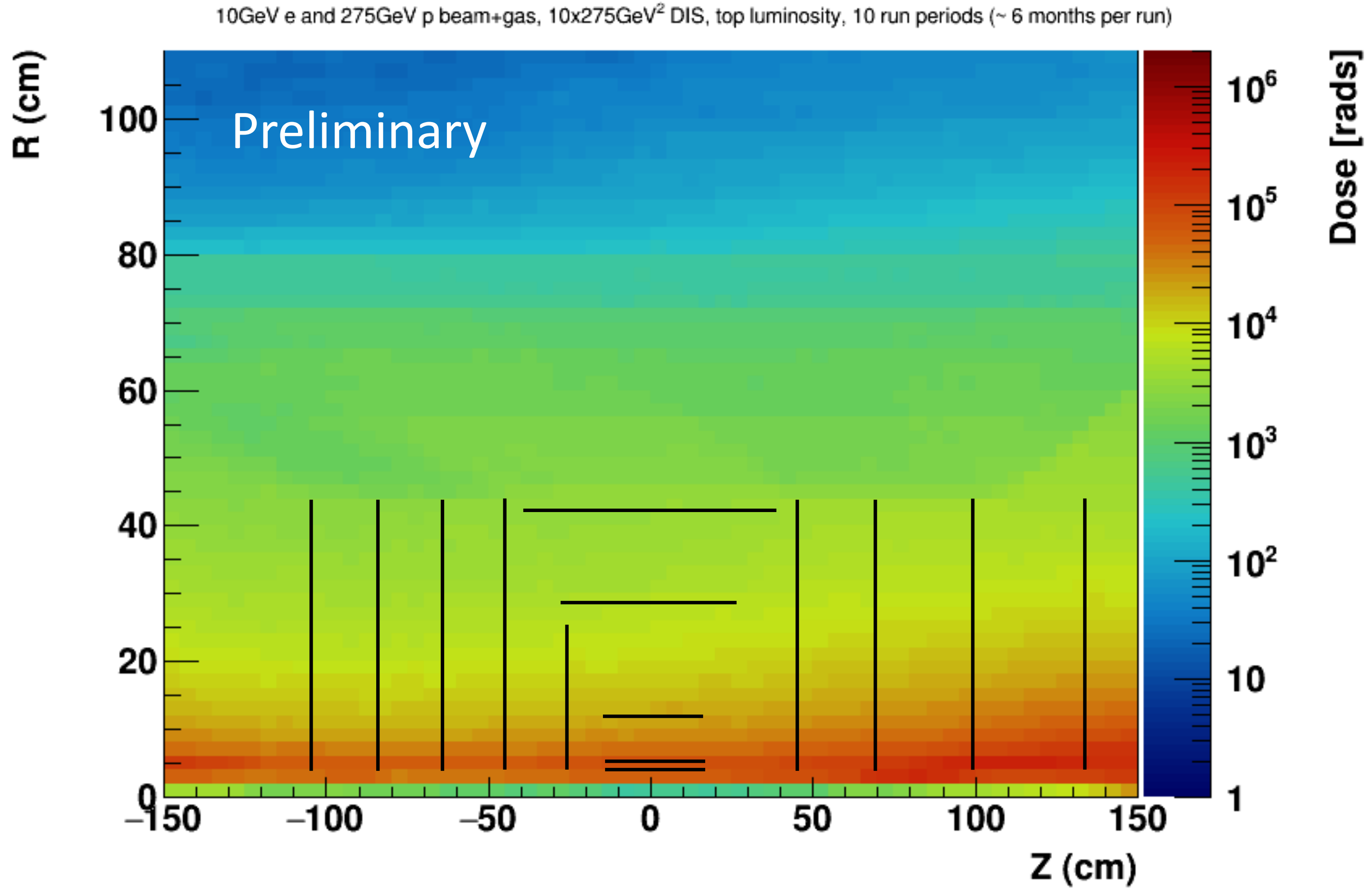
Beam-gas background 10 kAhr,

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

ALICE 3 Vertex Detector and Outer Tracker — in numbers

	Vertex Detector	Outer Tracker	ITS3	ITS2
Pixel size (μm^2)	÷ 9 $O(10 \times 10)$	• 2.8 $O(50 \times 50)$	$O(20 \times 20)$	$O(30 \times 30)$
Position resolution (μm)	÷ 2 2.5	• 2 10	5	5
Time resolution (ns RMS)	÷ 10 100	÷ 10 100	100* / O(1000)	O(1000)
Shaping time (ns RMS)	÷ 25 200	÷ 25 200	200* / O(5000)	O(5000)
Fake-hit rate (/ pixel / event)	≈ $< 10^{-8}$	≈ $< 10^{-8}$	$<10^{-7}$	$<< 10^{-6}$
Power consumption (mW / cm^2)	+ 75% 70	67% 20	20 (pixel matrix)	40 / 30**
Particle hit density (MHz / cm^2)	• 20 94	÷ 100 0.06	8.5	5
Non-Ionising Energy Loss (1 MeV n_{eq} / cm^2)	• 3000 1×10^{16}	• 100 2×10^{14}	3×10^{12}	3×10^{12}
Total Ionising Dose (Mrad)	• 1000 300	• 20 5	0.3	0.3

* goal, not crucial, like not possible due to power budget

** Innermost layers / outer layers

Improving performance concerning all aspects

Vertex Detector and Outer Tracker need different optimisation