Silicon: Cooling

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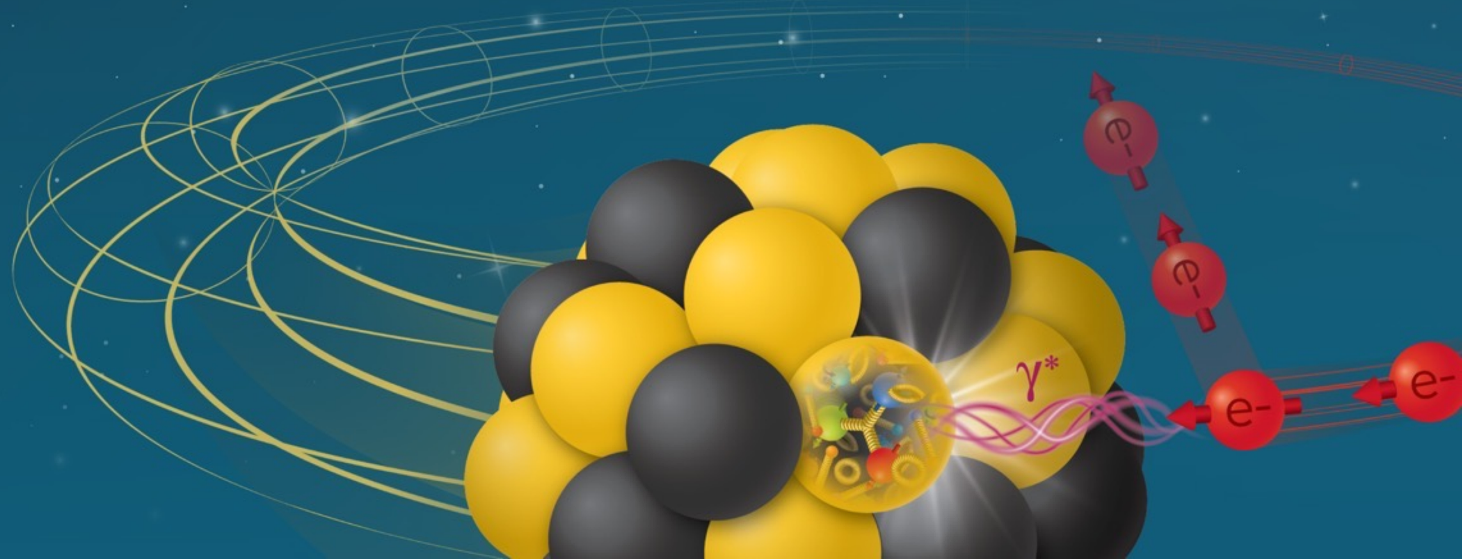
Incremental Design and Safety Review
of the EIC Tracking Detectors
March 20-21, 2024

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

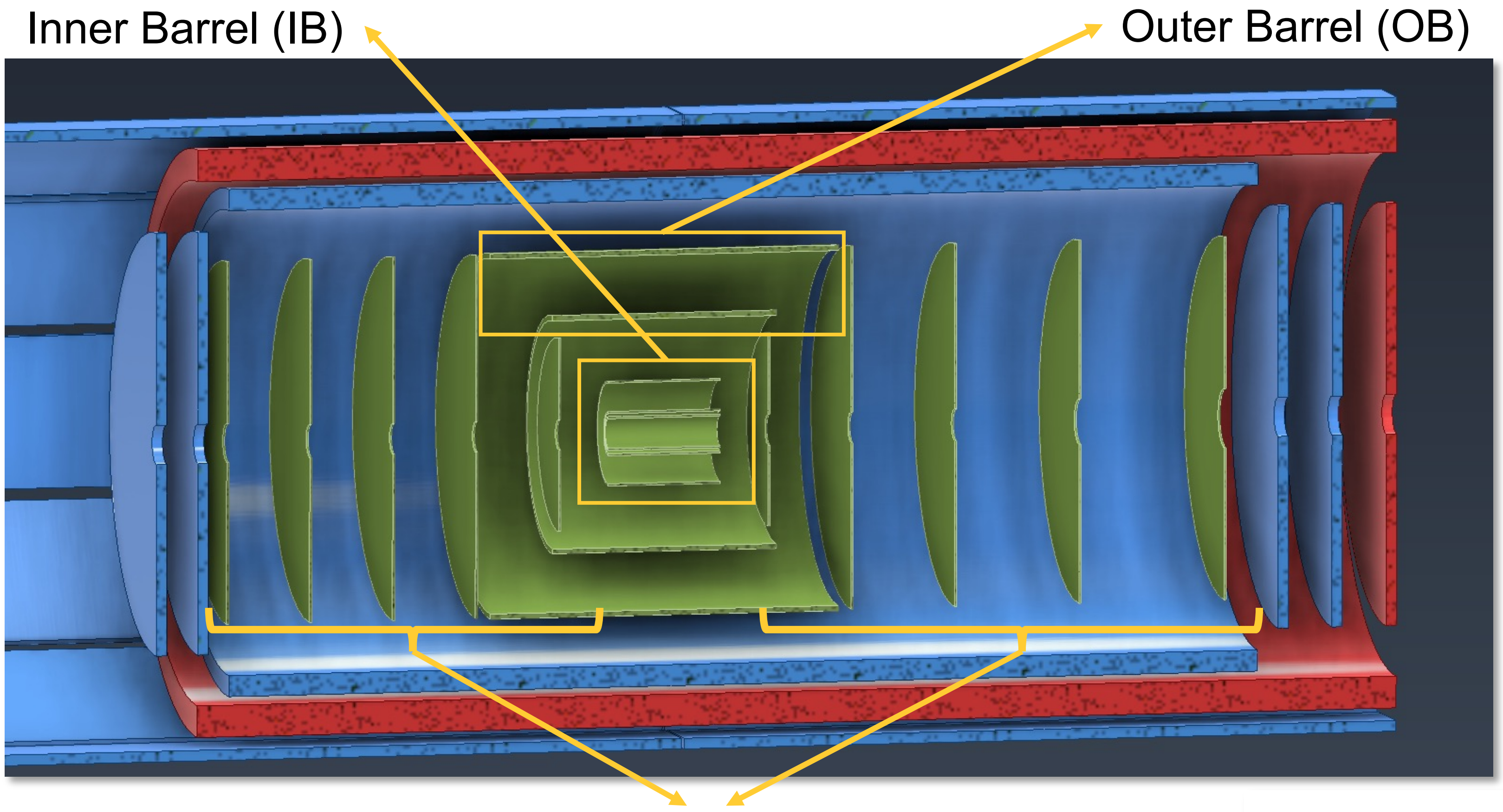
- Overview/Introduction
  - Baseline design
  - Sensor power
- SVT Cooling
  - Inner Barrel
  - EIC-LAS cooling
    - Outer Barrel
    - Endcaps
  - System
- Summary

Overview

SVT Material Overview

Charge 1

- Minimized material → mechanics, cooling, power, readout, etc.



Target Specifications

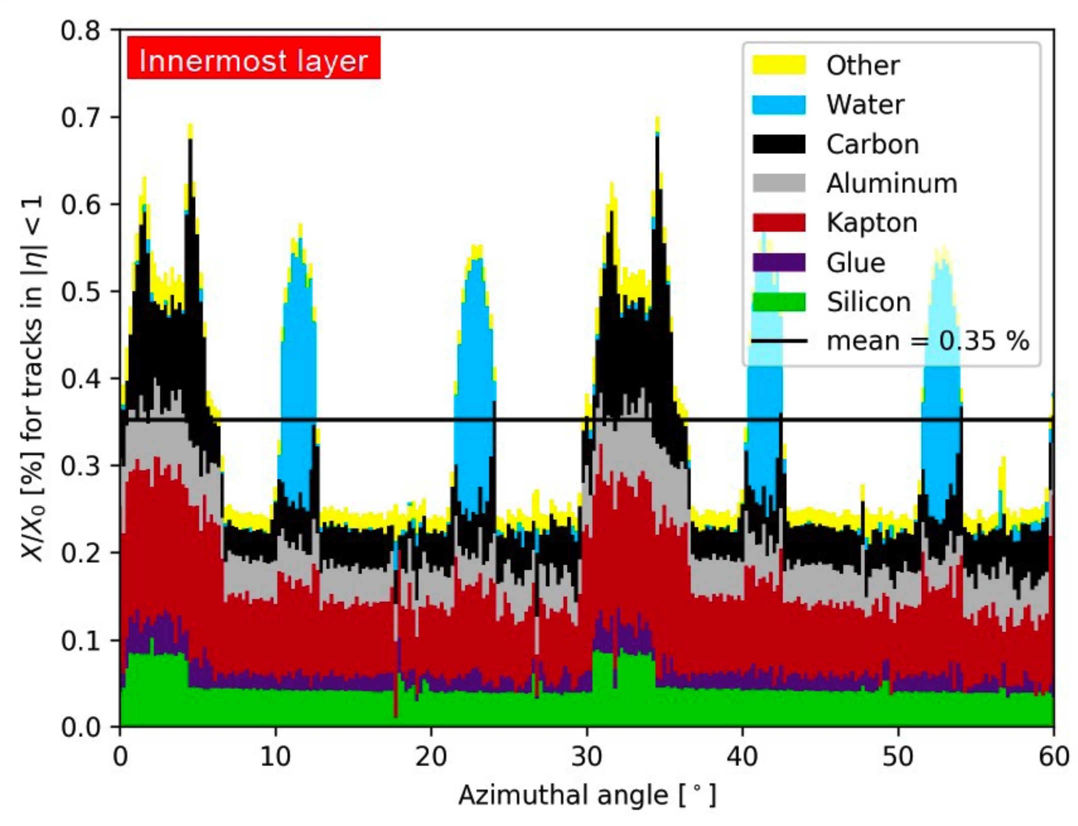
- IB
  - L0 - L2: 0.05% X/X_0
- OB
  - L3: 0.25% X/X_0
  - L4: 0.55% X/X_0
- Endcaps
  - ED0-4: 0.25% X/X_0
  - HD0-4: 0.25% X/X_0

Cooling has a big impact on X/X_0

Material Implications

Charge 1, 2

- Water cooling pipe: 1 mm ID tube made with 25 μm Kapton walls is ~0.3% X/X_0
- ***Average*** X/X_0 of water will be less
  - Dependent on number of pipes & coverage
  - Non-homogenous material distribution
- Difficult to reach target material budget with liquid cooling **alone**
- Air <0.01% X/X_0 for relevant thicknesses



Baseline design

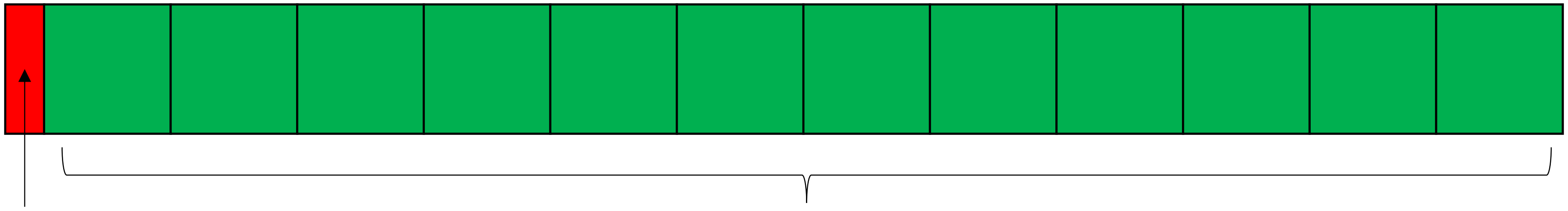
Charge 1, 3

- 4000 EIC-LAS sensors in the SVT
  - Power consumption based on best estimates: up to 1.6 W per EIC-LAS
  - Paired with an Ancillary chip (AncASIC) for slow control, serial powering
- ***Baseline*** cooling design is ***air*** → liquid cooling in strategic places as necessary
- End goal is operation of sensor at/near ***room temperature***
- Measure thermal performance with $\Delta T = T_{sensor} - T_{inlet\ air}$
- "Reasonable" ΔT is one that achieves room temperature operation with sensible air inlet temperature
  - $\Delta T < 10°C$ is used often as a "standard", but is not a requirement

Sensor Power Regions

Charge 1

IB sensor: MOSAIX



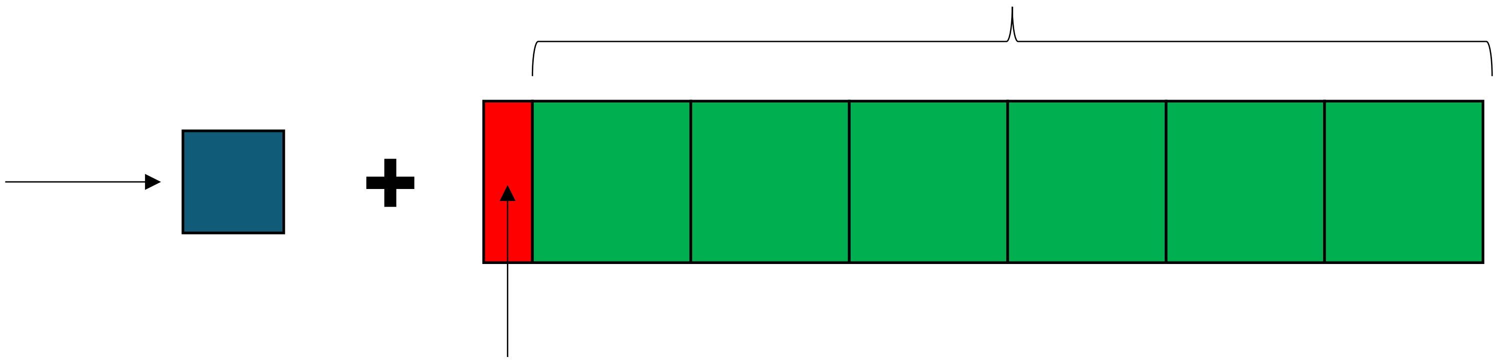
LEC: ~0.8 W/cm^2

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

OB/HE/EE sensor: EIC-LAS

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

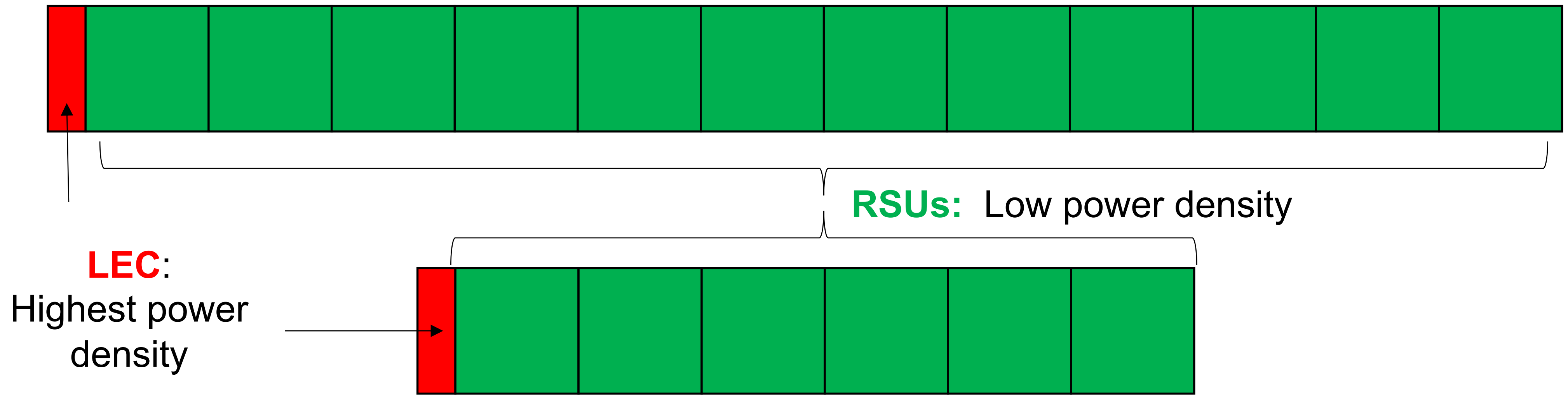
AncASIC:
Size & power TBD



EIC-LAS LEC ≤ MOSAIX LEC

Sensor Power

Charge 1



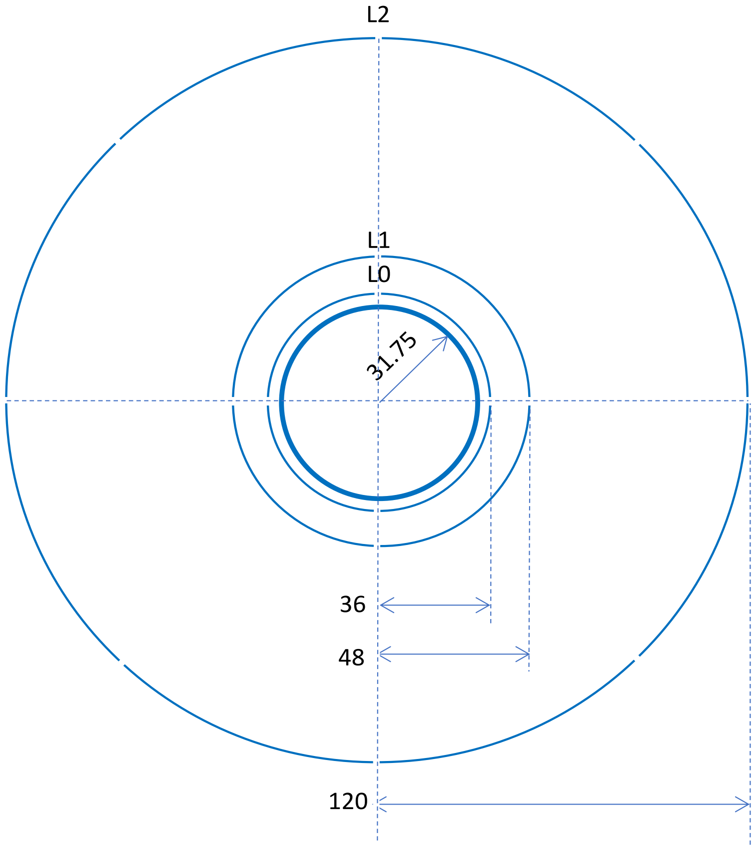
- Power consumption ***estimates*** for **LEC** & **RSUs** based on publicly available information → continuing effort with sensor designers
- Investigated a range of values for cooling tests/calculations
- ER2 crucial for more finite power numbers

SVT Cooling

Inner Barrel

Charge 3

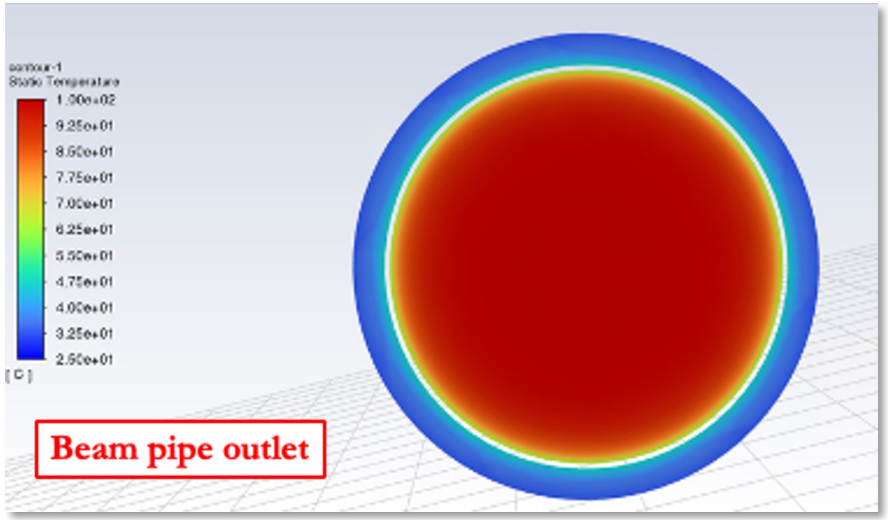
- ***Baseline:*** Air cooling with thermally conductive carbon foam near LEC
  - Measurements from ALICE ITS3 show this is reasonable to cool sensor
- Forced convection between L0 & L1
- L2: Natural convection paired with liquid cooling near LEC (as necessary)
- Air inlet and outlet under design

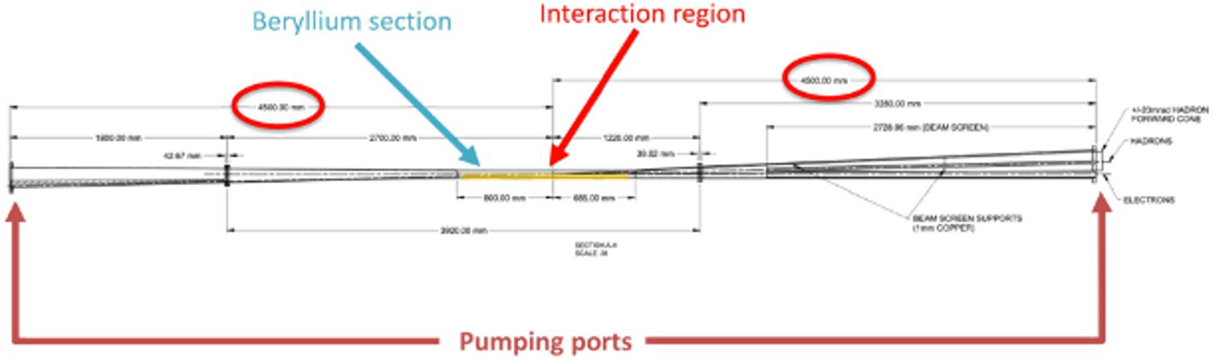


Beam-pipe Bake-out

Charge 1, 3

- Beam-pipe bake-out with SVT installed
- Aiming for no additions to cooling
  - No extra material (e.g. insulators) or changes (i.e. liquid instead of air)
- ANSYS studies at JLab and LBNL
  - Flow N2 in beam-pipe to get inner wall >100°C
  - Room temperature air between beam-pipe and silicon
  - Studies done with both full length of beam pipe and shortened section near SVT IB
- Bench setup at JLab verifies results
  - Covers 1 m of 3 m Be beam pipe section
- Path forward to cool detector





Beam-pipe Bake-out

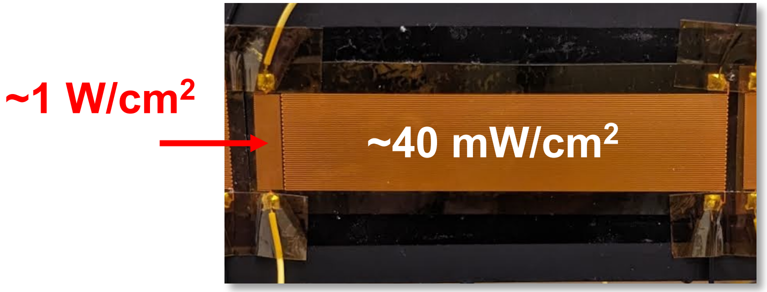
Charge 1, 3

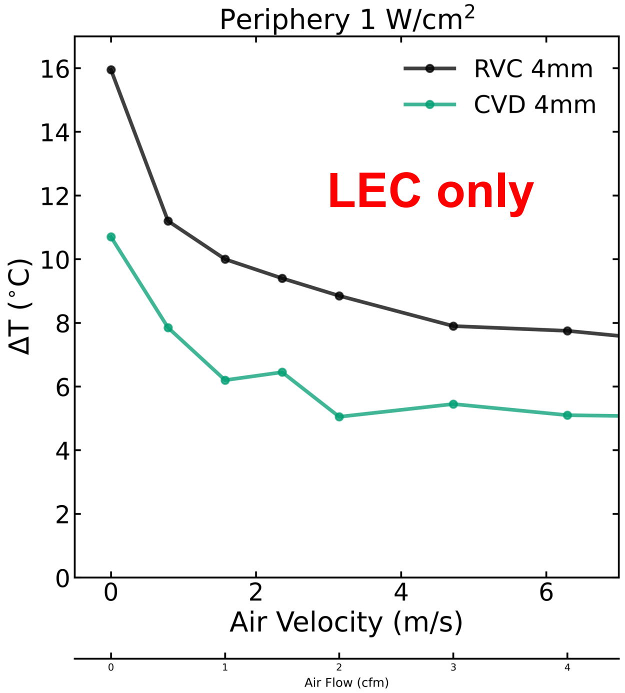
- Refine temperature envelopes for materials
  - ALPIDE (ITS2) can work reliably at 40°C
  - Estimates from climate chamber studies at LBNL up to 50°C show 65 nm DPTS performs reliably
- Initial thermoelastic study done by ALICE ITS3
  - 16 cycles between 10 – 48°C on ITS3 layer 2 (includes glue, foam, silicon) → no failures
- Similar thermoelastic study upcoming for ePIC SVT IB
  - Cycle test, longevity test, bake-it-til-you-break-it test

Air cooling

Charge 2, 3

- Air cooling internal to the mechanical structure offers advantages (air routing, mechanical strength)
- Built on previous LBNL LDRD with carbon composite structures and **RVC** or **CVD (thermally conductive)** carbon foam
- Heaters with two regions to model SVT sensor power dissipation (**LEC** & **RSUs**)
- ΔT reasonable (<10°C) to achieve operating temperature, but structure is material "heavy"
- Can build upon this concept



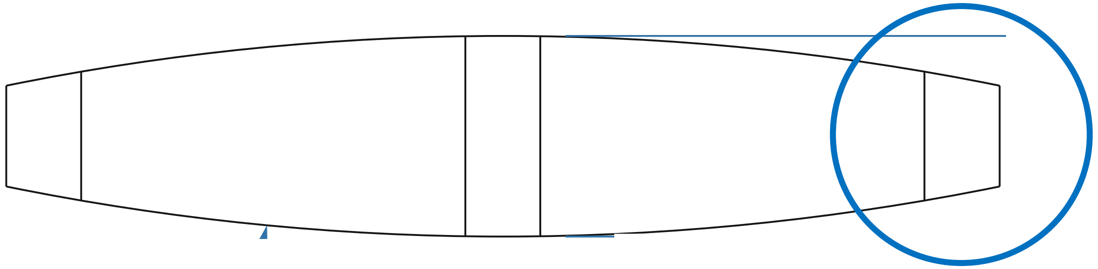


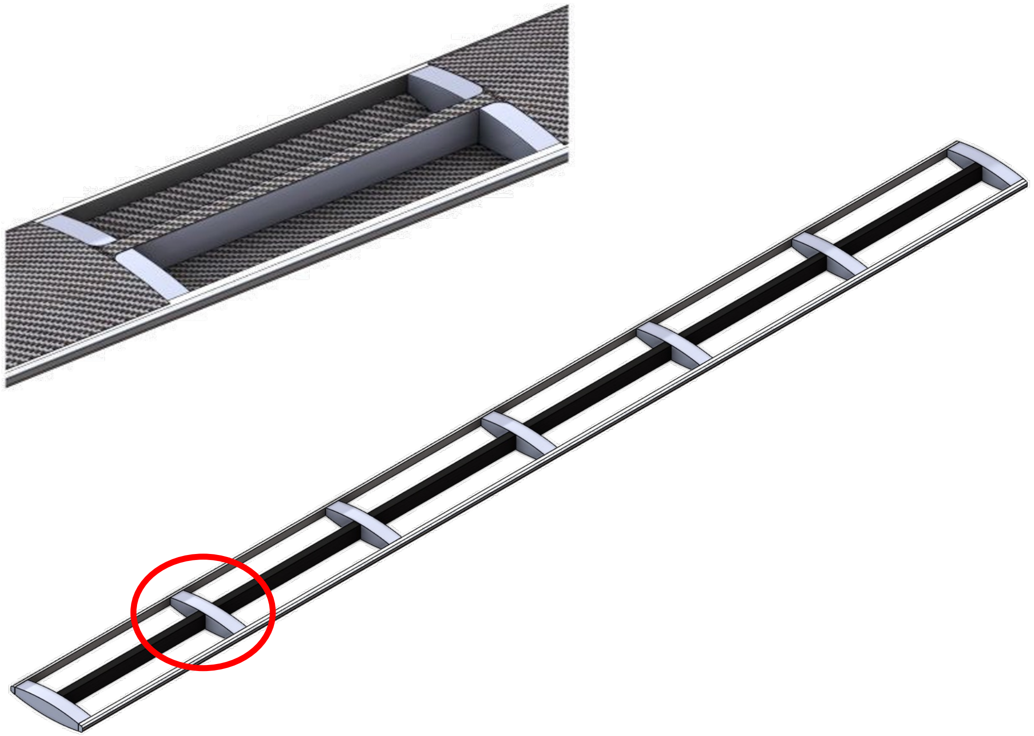
*Air velocity calculated at duct

Outer Barrel

Charge 2, 3

- ***Baseline*** design has options for both air and liquid cooling
- **Crossribs** → thermally conducting carbon foam
- **Edges** → carbon foam, could contain liquid cooling pipe
- ***Assumptions/Estimates***
  - 4 x 0.5 cm^2 cross section
  - 8 m/s air speed
- Max estimate: 400 cfm total
  - Work ongoing that can reduce this (liquid, re-routing air, etc.)

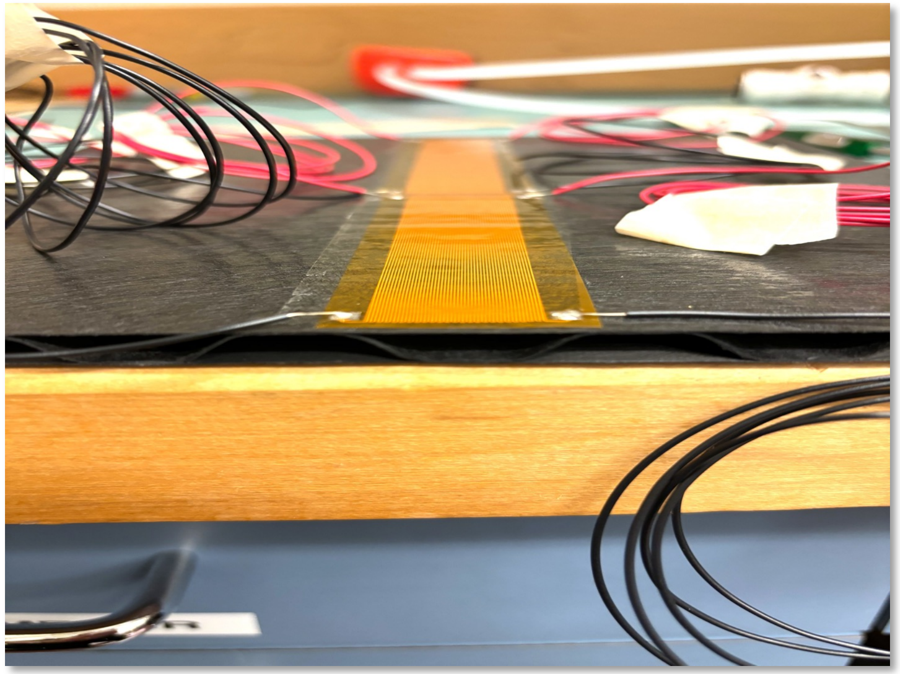




Discs: Corrugated Carbon Fiber

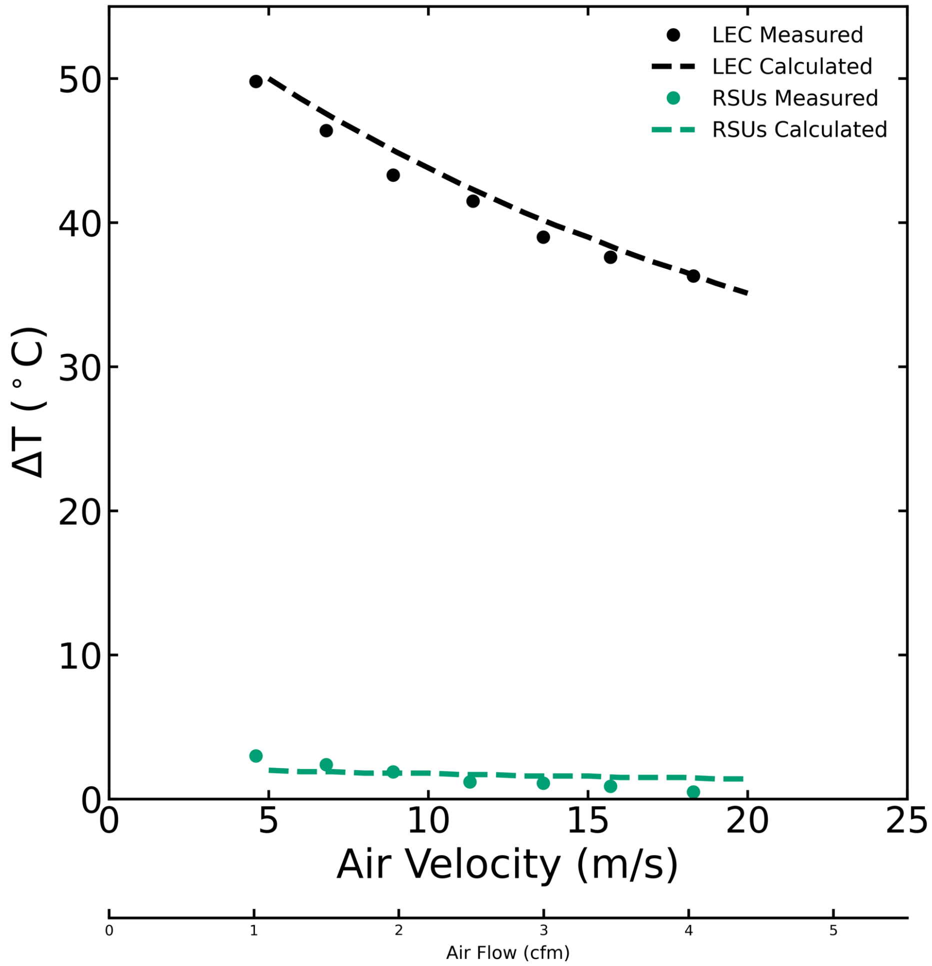
Charge 2, 3

- ***Baseline*** disc design using corrugated carbon fiber
  - Provides a channel for forced air convection
- Air cooling sufficient for **RSUs**
- **LEC** trending in the right direction



LEC: 1 W/cm²

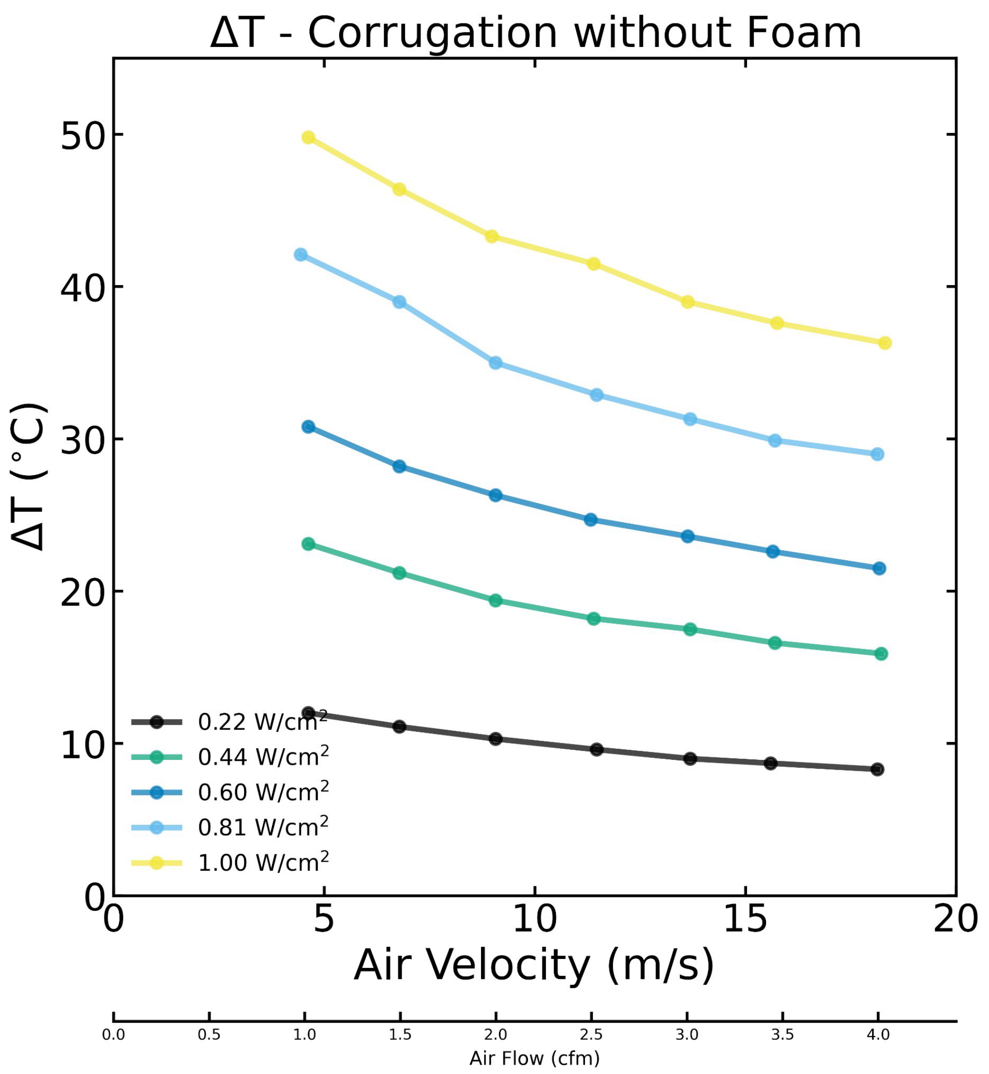
RSUs: 40 mW/cm²



Discs: Corrugated Carbon Fiber

Charge 2, 3

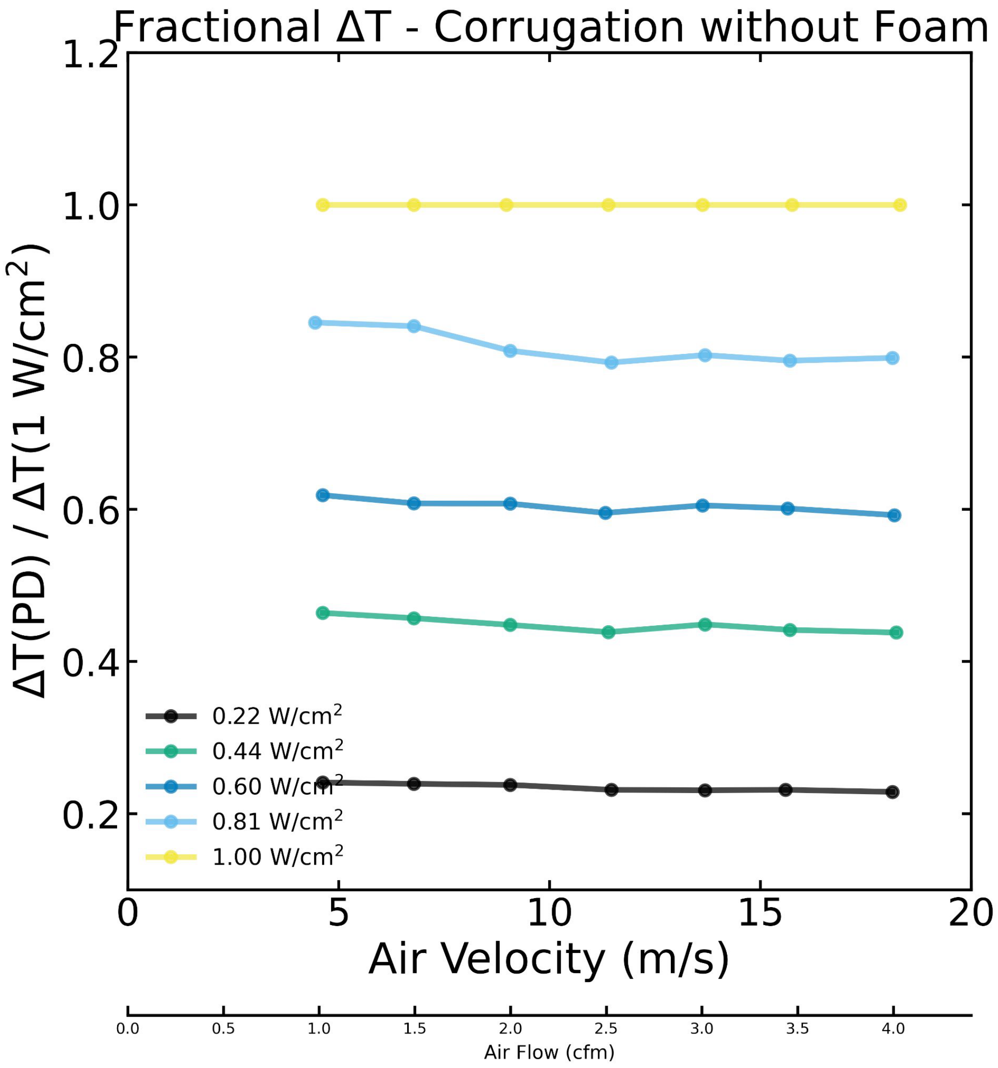
- Studied a range of LEC power densities
- **ΔT reasonable for power < 0.6 W/cm²**



Discs: Corrugated Carbon Fiber

Charge 2, 3

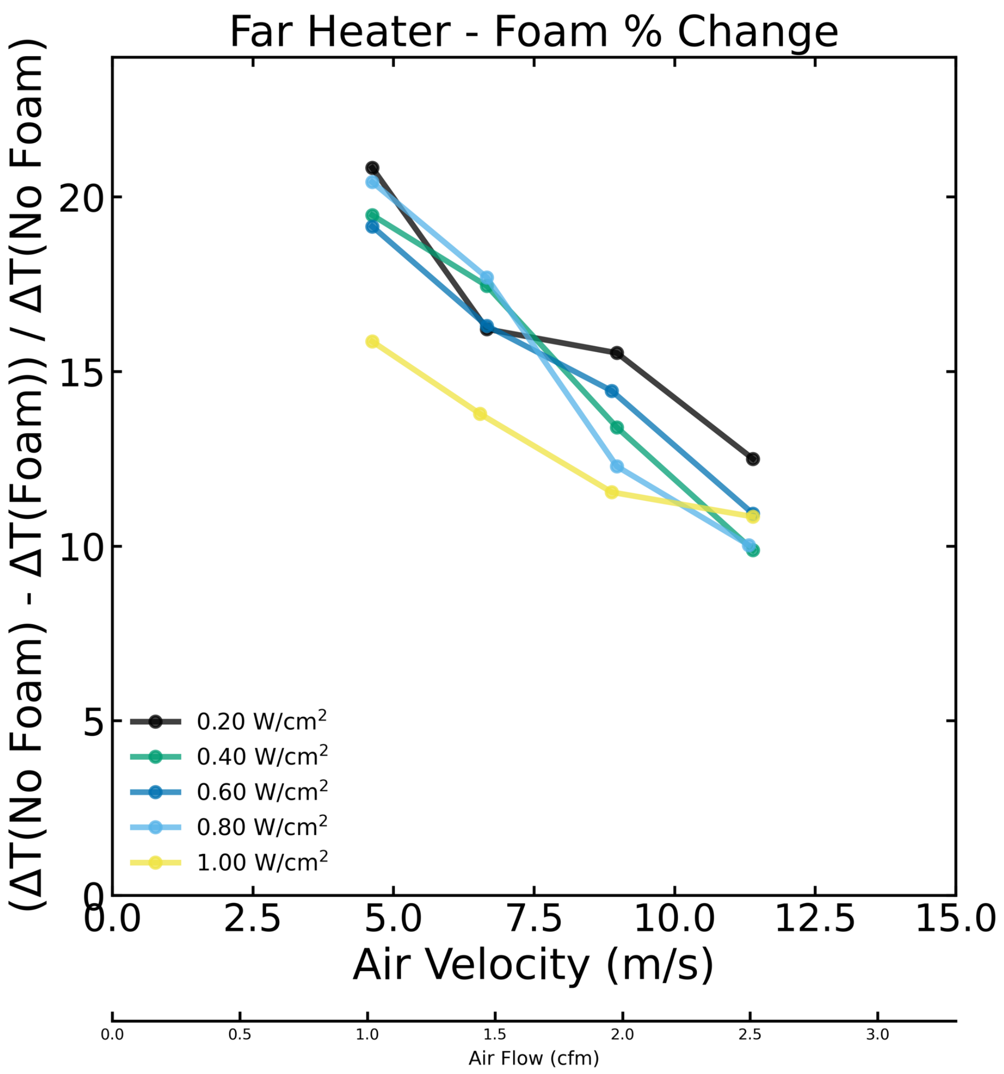
- Studied a range of LEC power densities
- ΔT reasonable for power < 0.6 W/cm^2
- **ΔT scales with power density**



Discs: Corrugated Carbon Fiber

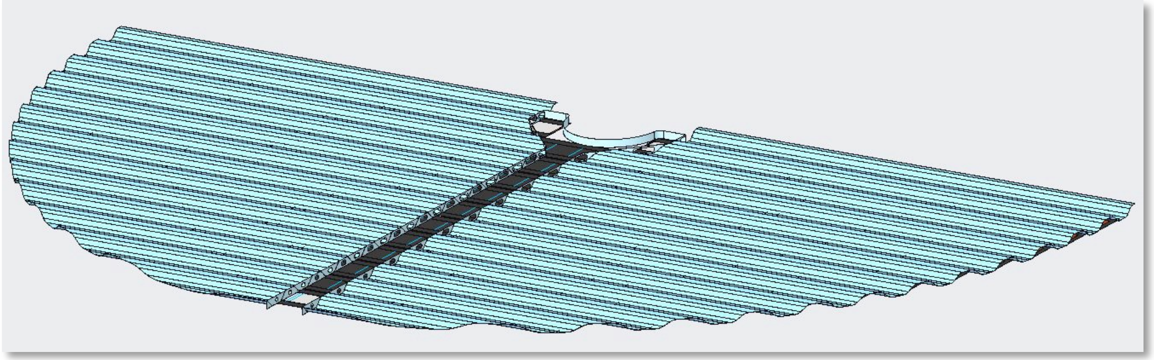
Charge 2, 3

- Studied a range of LEC power densities
- ΔT reasonable for power < 0.6 W/cm^2
- ΔT scales with power density
- **Carbon foam** under LEC provides **10-20% reduction in ΔT**
  - Caveat: this is insulating foam. Will be measured with thermally conductive foam

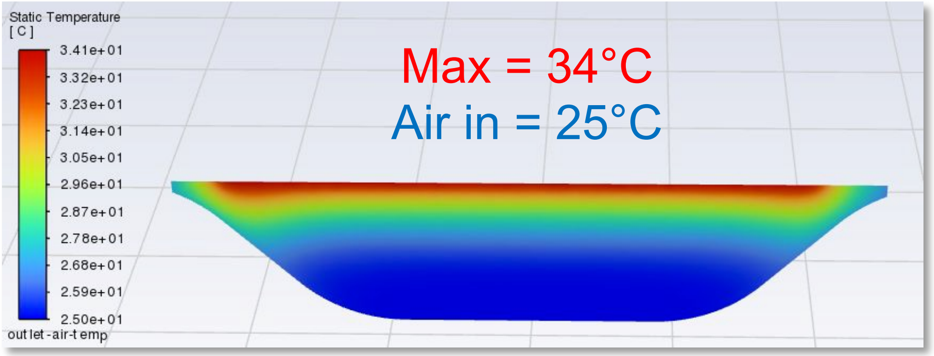


Discs: Corrugated Carbon Fiber

Charge 2, 3



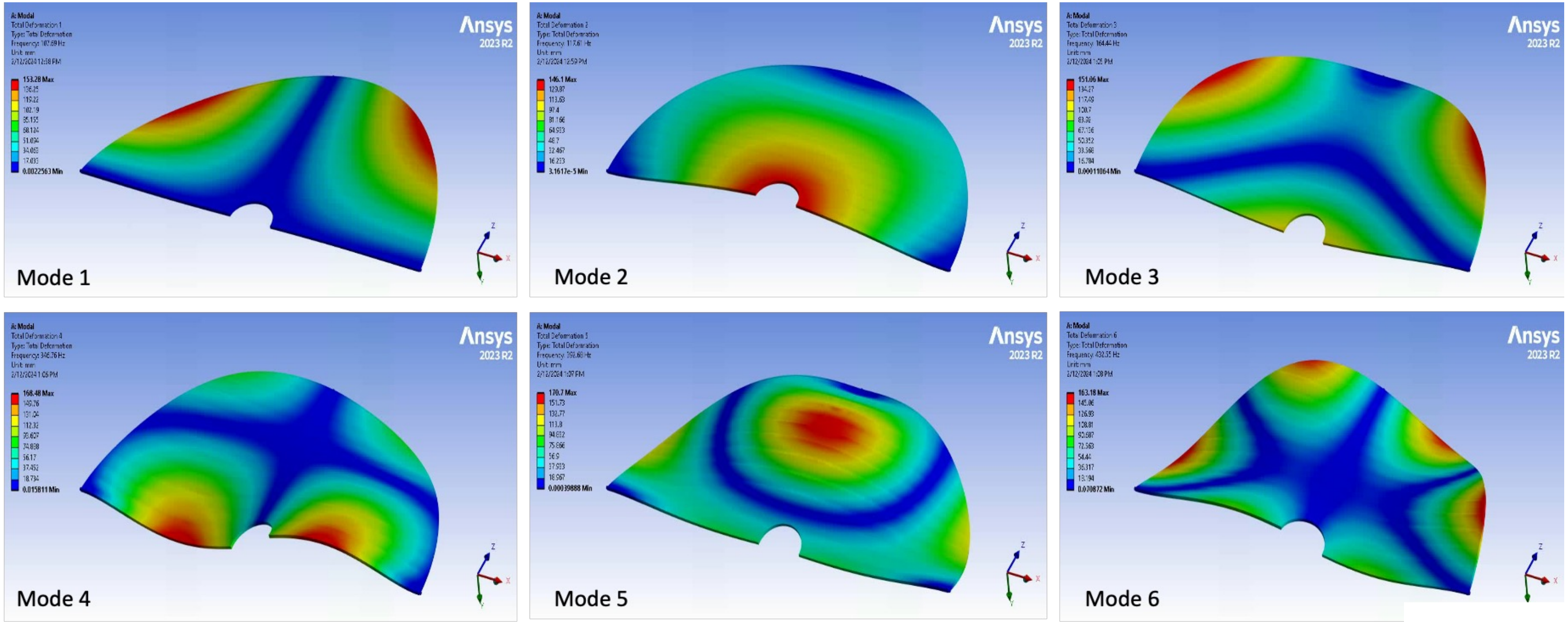
Static Temperature of Cooling Channel Outlet at a Velocity of 10 m/s



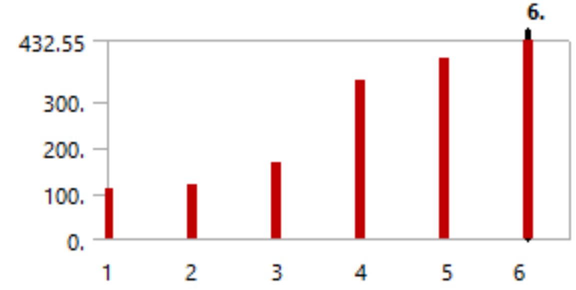
- Center manifold and air metering strip through middle
- Volumetric static temperature of air minimal
  - Air can be used in multiple channels → reduces total air volume
- Under further optimization

Discs: Corrugated Carbon Fiber

Charge 2, 3



Mode	☑ Frequency [Hz
1.	107.69
2.	117.61
3.	164.44
4.	346.76
5.	392.68
6.	432.55



Corrugated Disc of 6 mm Height – Rev 2 (Mesh size = 2 mm)

SVT Air

Charge 6

- ***Current*** baseline estimates
- IB: 50 cfm
- OB: max 400 cfm
- Discs: max 500 cfm

- Total system as we understand it is ~1000 cfm
  - Requires compressed air

- Optimization continues and we expect this number to go down

EH&S

Charge 6, 7

- All work follows local laboratory EH&S requirements & training
  - LBNL: ISM, Work Planning & Control
  - JLab: ISM, Task List and ePAS (JLab-PR-725)
  - NRTL listed electrical equipment

Overall System

- Temperature interlock → work with slow control group to ensure detector safety
  - Automatic turn-off if temperature goes above designated value
- Pressure system → work with engineers for design and safety
  - Also monitored with slow control if air system fails (over-temperature)
- Liquid/water cooling → flow under atmospheric pressure designed to prevent leaks
  - Cooling plant, temperature, flow, etc. monitoring

Summary

- ***Baseline*** cooling design is hybrid with the dominant part done by air for material considerations
- End goal is operation of SVT at/near ***room temperature***
- Thermal performance studied with a range of power dissipation values based on current sensor knowledge
- EH&S
  - Following local laboratory requirements & training
  - Work with system engineers and slow control for monitoring and interlocks
- Next Steps
  - Incorporating additional heat generating components (AncASIC, RDOs)
  - Continuing design of individual components and overall system