Berkeley Lab

Composites Structures for Detectors in Colliding Beam Experiments

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ESIPAP

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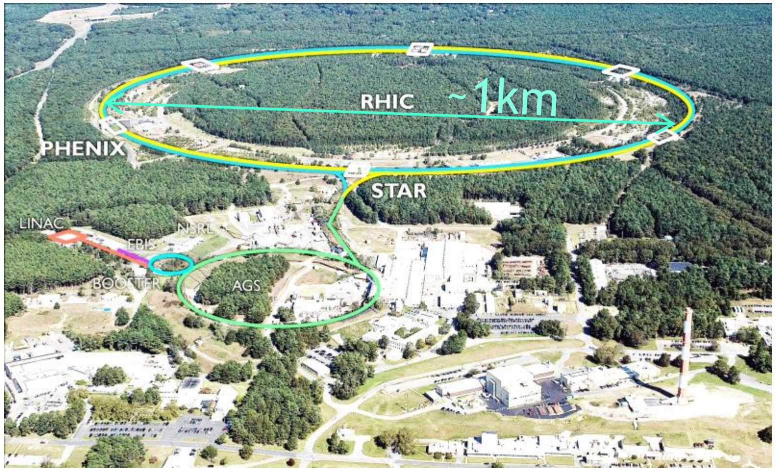
Overview

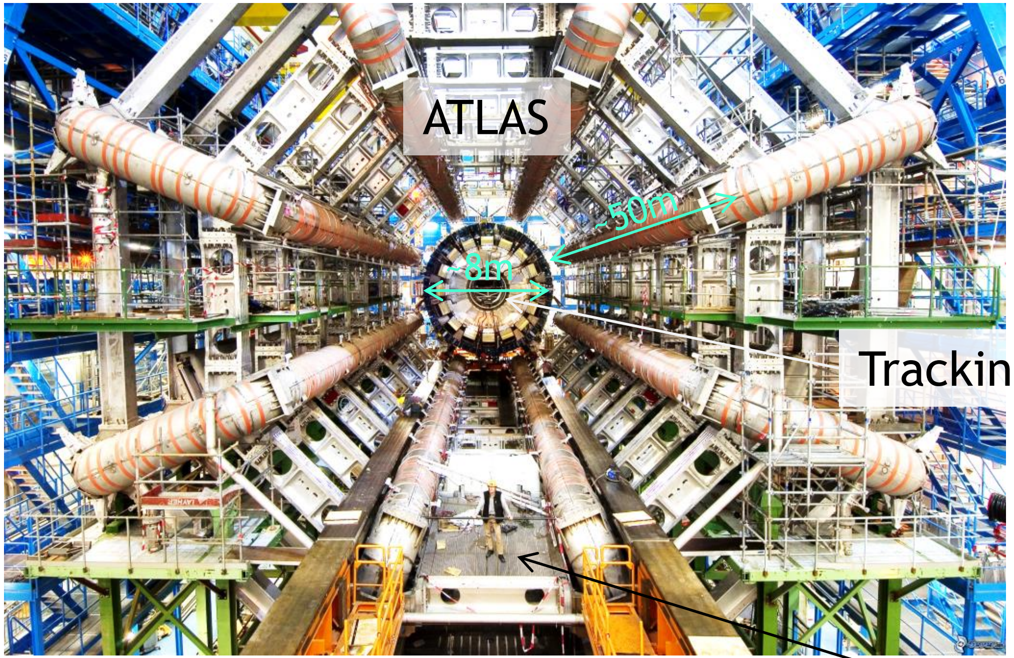
- Detectors in General
  - Where and What are they
- Tracking Detectors Overview
  - Stability and Mass Requirements
  - Detecting Elements
  - Thermal Management
- Global Support Structures

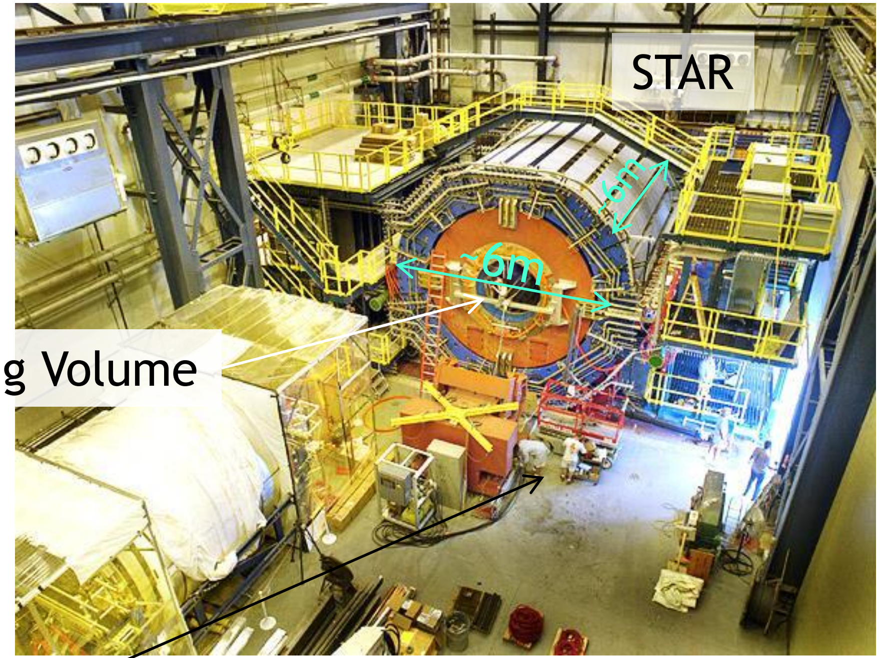
Synchrotron Colliders—two examples

- RHIC (Relativistic Heavy Ion Collider) at Brookhaven National Lab
- LHC (Large Hadron Collider) at CERN
- Counter-rotating beams cross at defined interaction regions
- Experiments placed at these points in underground or buried caverns



Particle Detectors: ATLAS and STAR



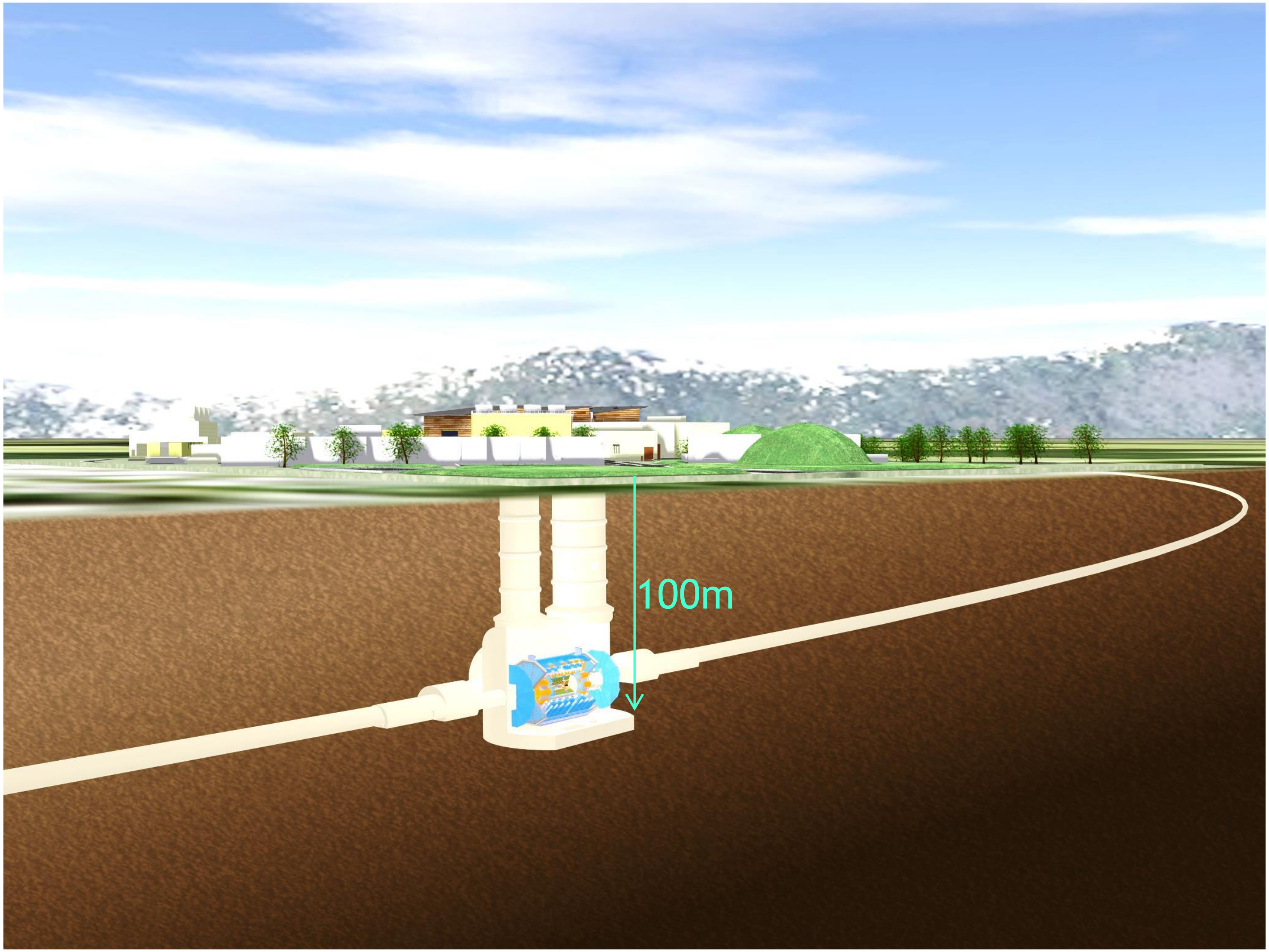


Tracking Volume

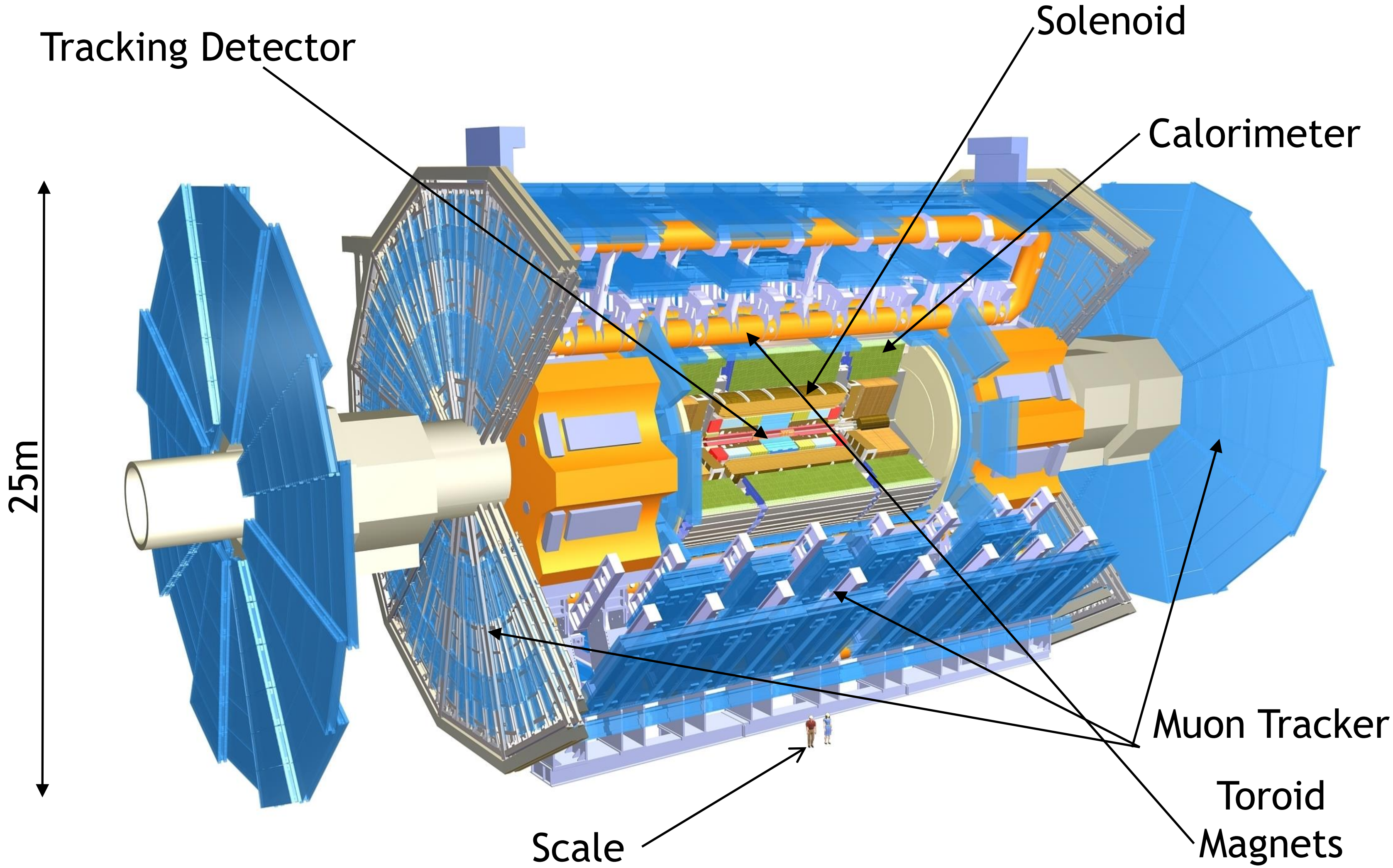
2005 Scale 1995

- Detector size is defined by resolution requirements to peek into new and different physics frontiers—they are size appropriately for their goals
- STAR was aimed at discovering Quark Gluon Plasma, qualifying its properties and enhancing further Nuclear Science understanding
- ATLAS was aimed at discovering the Higgs Boson, then later expanding the frontier of fundamental particle physics—perhaps Dark Matter
- Both achieved their initial goals and will be upgraded in the future

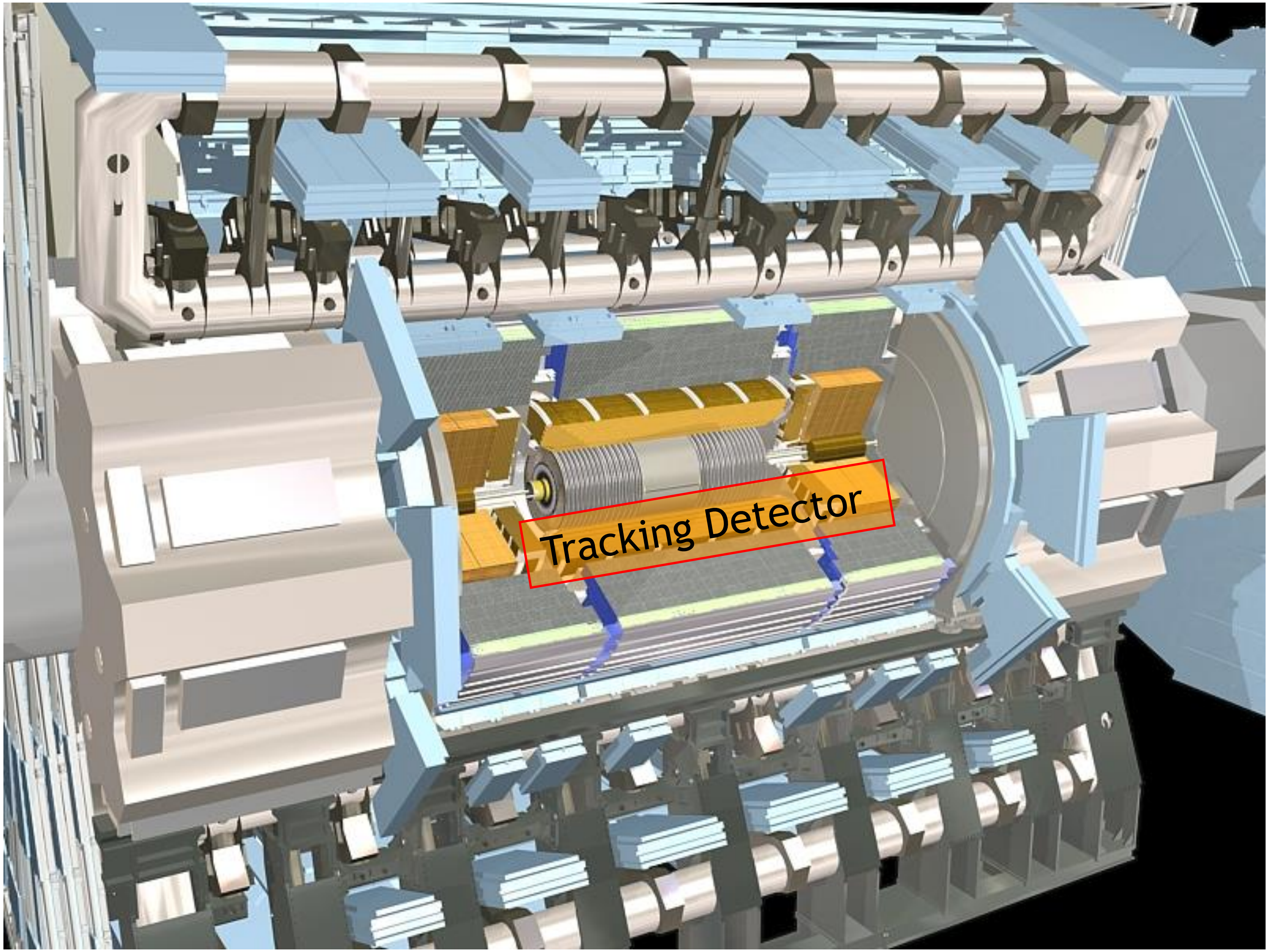
ATLAS Cavern and Surface Buildings at CERN



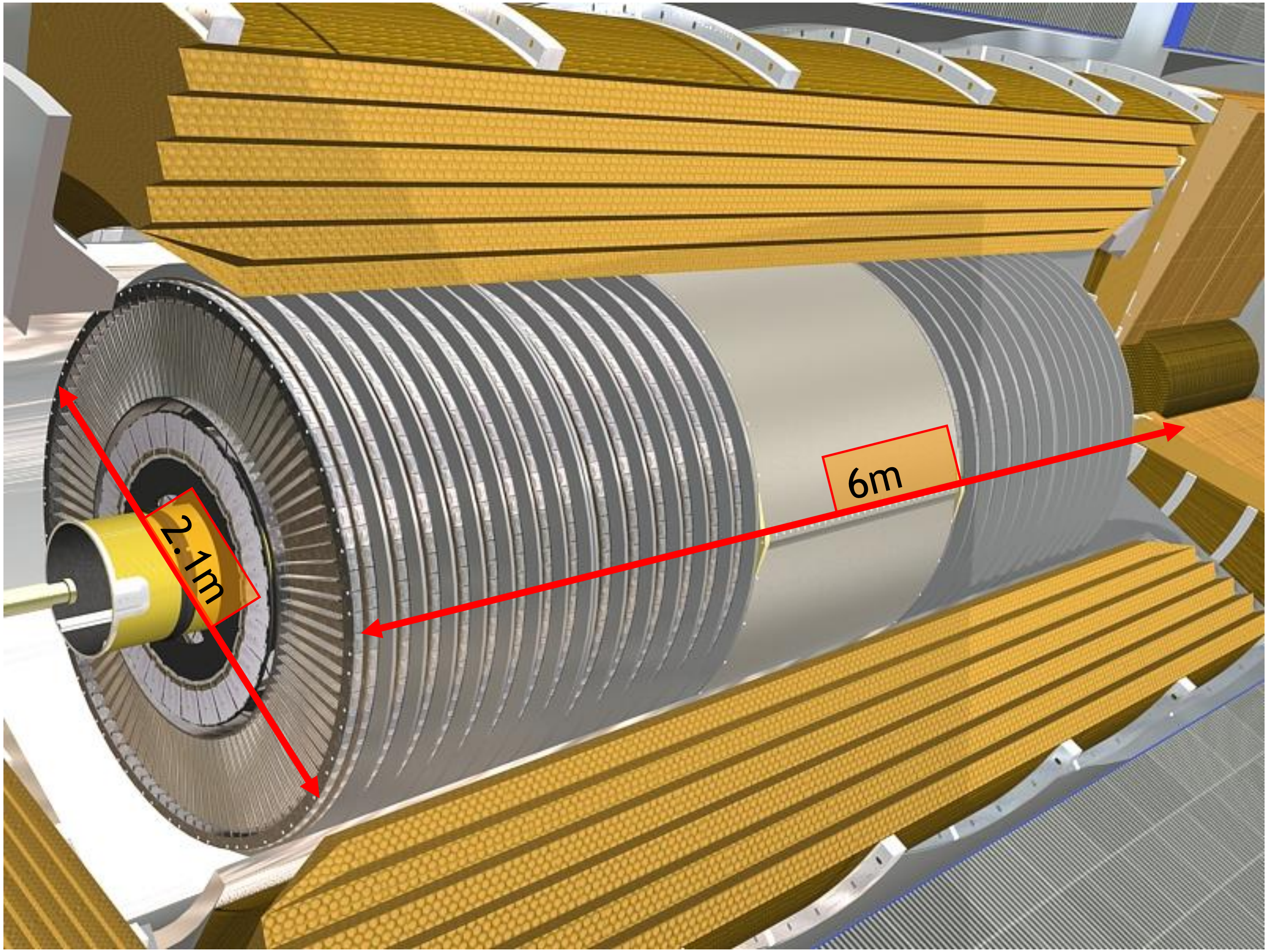
ATLAS Detector



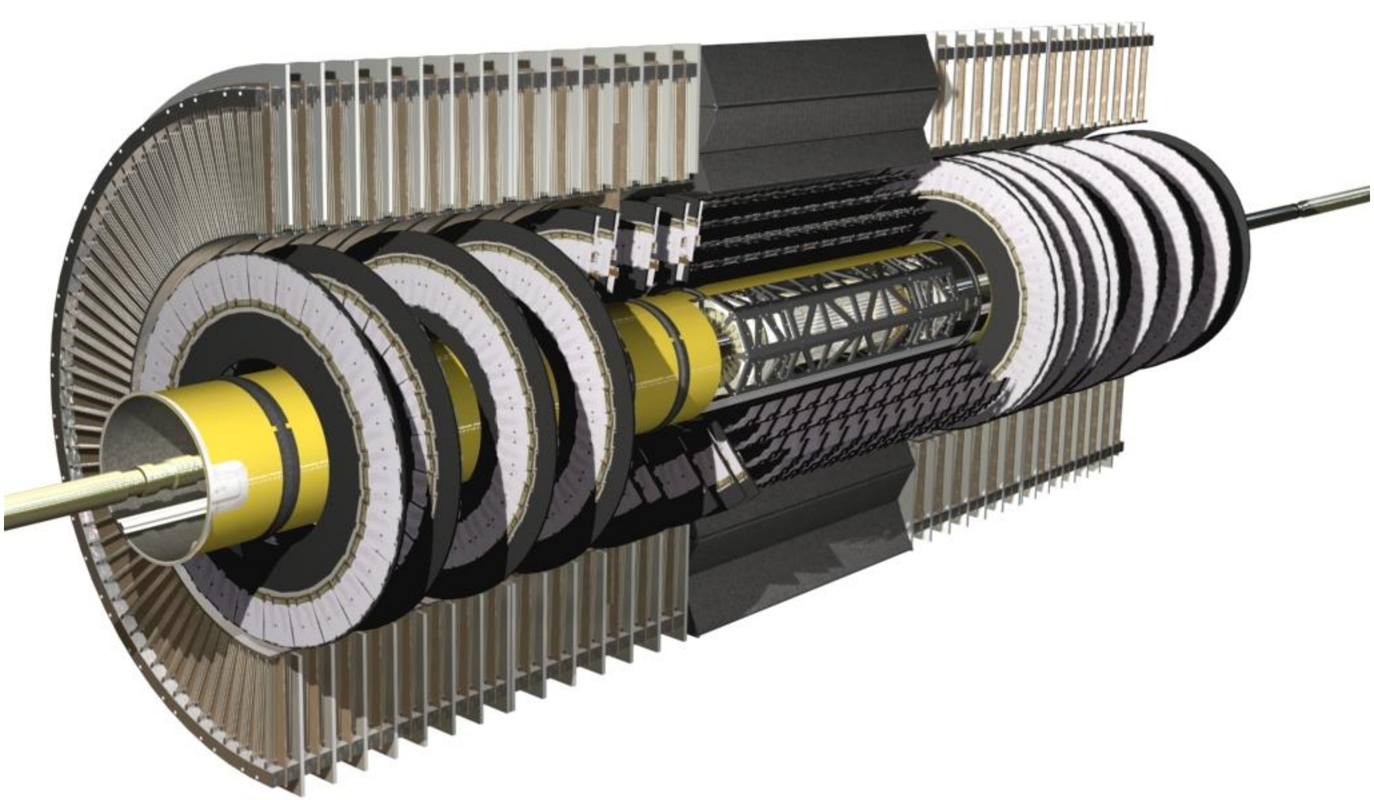
ATLAS Detector



ATLAS Inner Detector



ATLAS Inner Detector

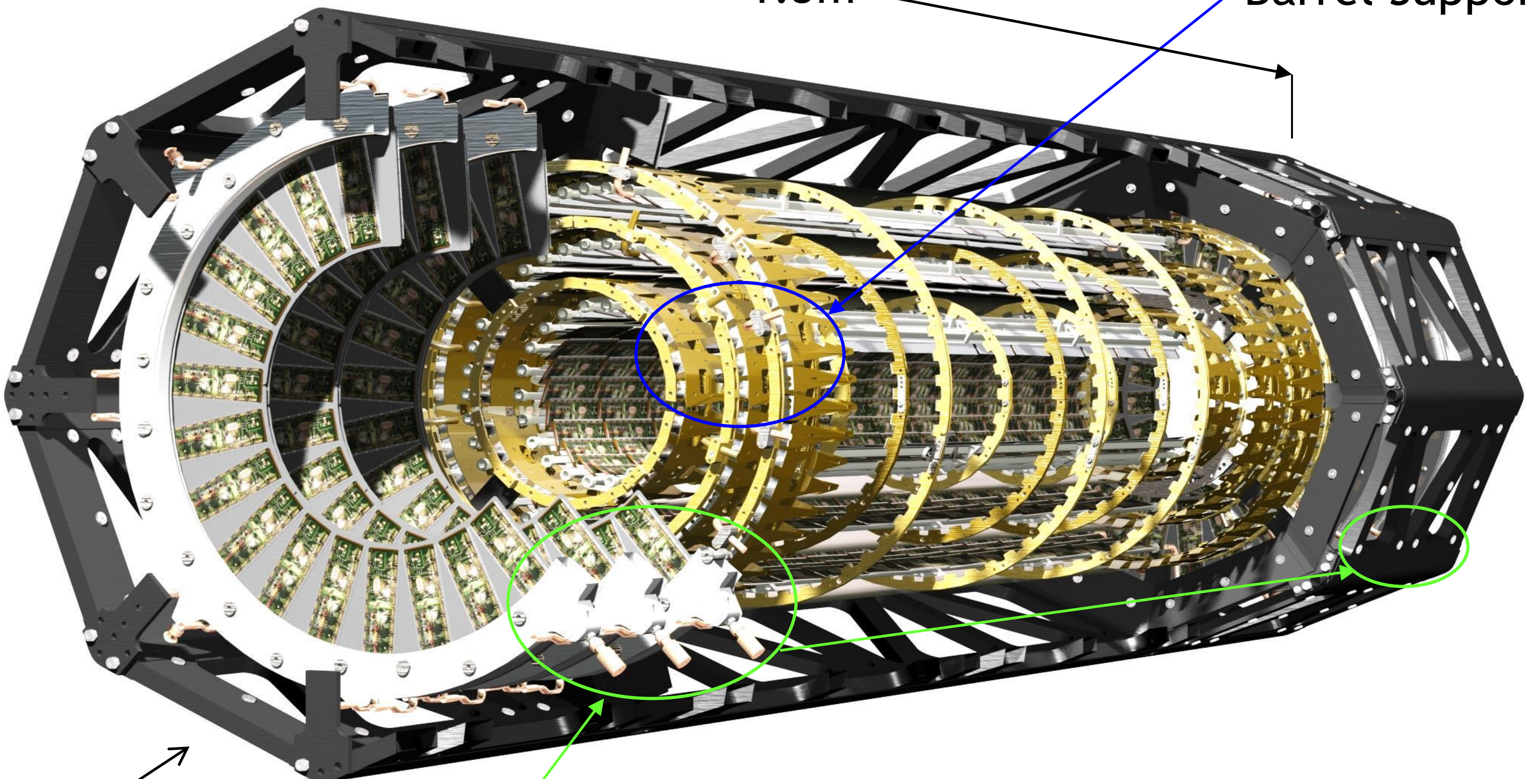


ATLAS Pixel Detector

Pixel Detector is the innermost detector

1.5m

Barrel Supports

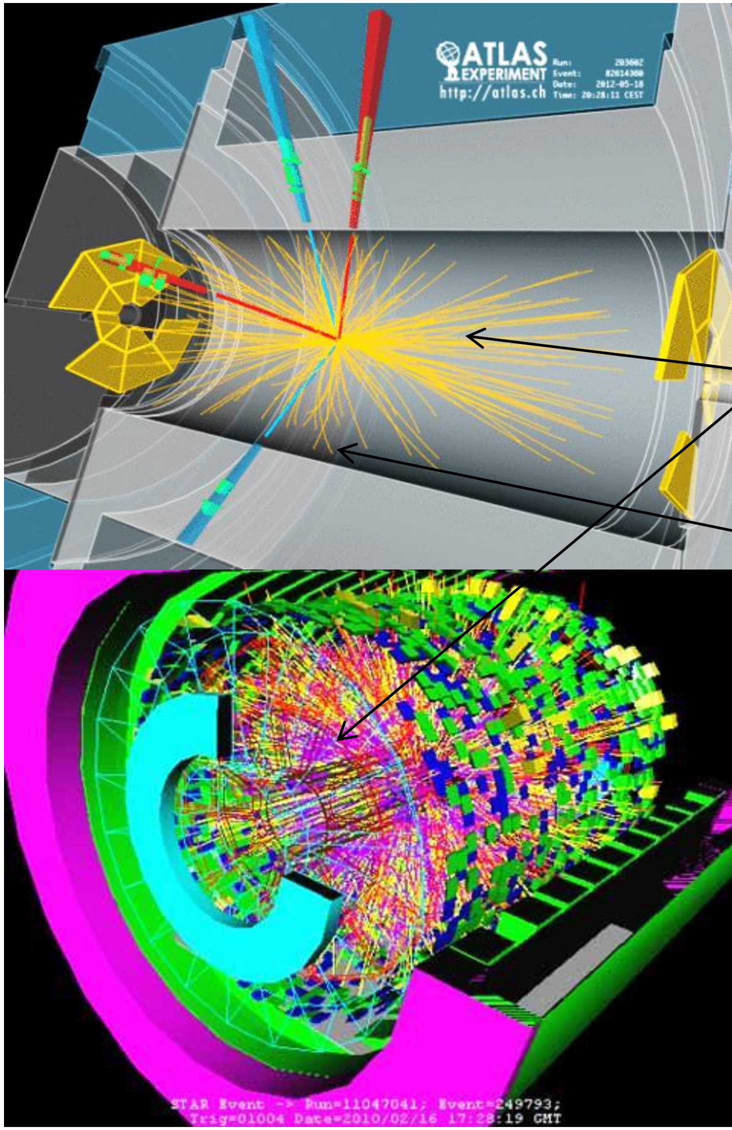


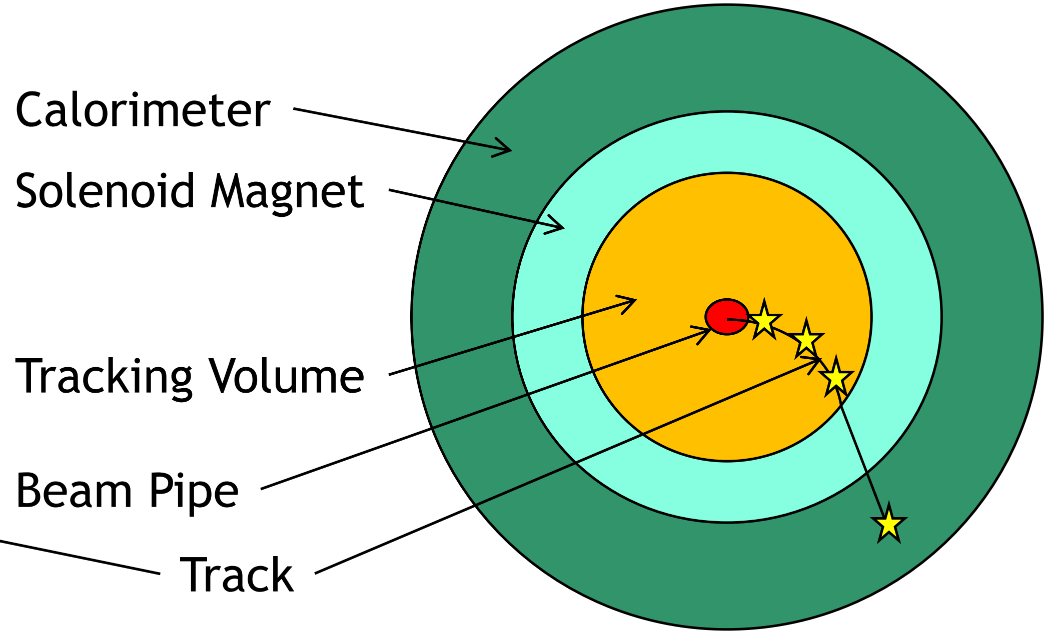
Dissipates 15kW

Global Support

Disk Supports

How do Detectors Work?



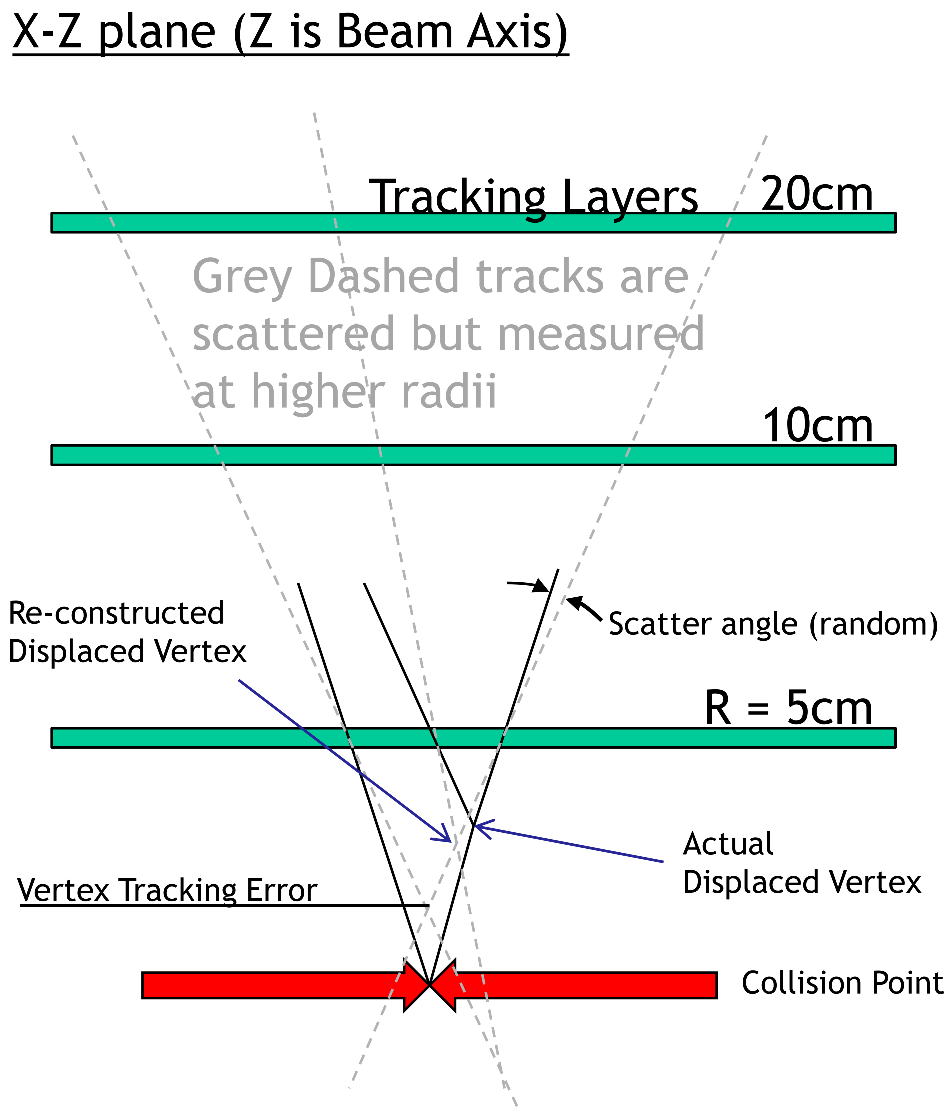


- ***Tracks are debris from collision events***
- ***Magnetic Field bends charged particles***
- ***Tracking detectors measure position at discrete locations determining Charge and Momentum—also displaced vertices***
- ***Stopping distance (position) in Calorimeter measures track Energy***

Detectors are layered like Onions

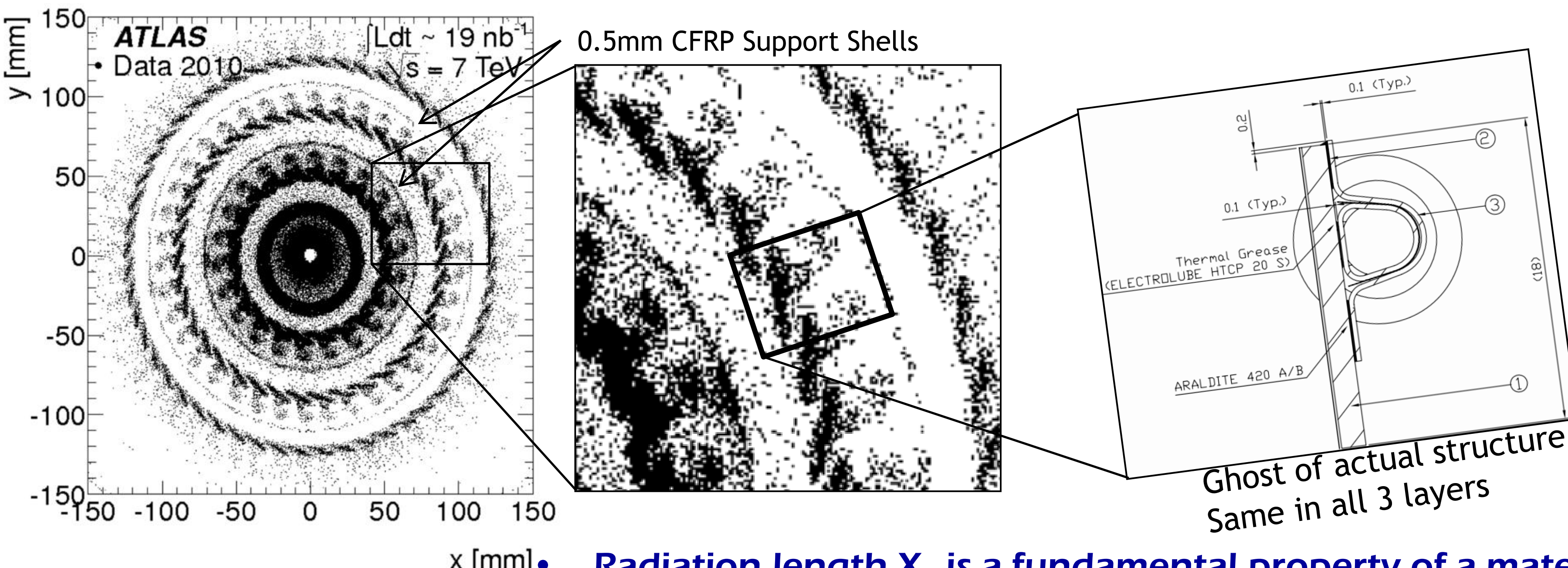
- The Tracking Detector is several layers inside Calorimeter
  - Multiple detection points in the tracking volume are recorded and used to determine trajectory of tracks
  - Resolution is graded as a function of radius (tracks spread from collision)
- The Calorimeter has multiple layers to determine the energy of a track
  - Each layer has some spatial resolution to determine position of a track in 3D
  - Linking tracks from the tracking volume to energy deposition in the Calorimeter is important to quantify the nature of the track particle
- Calorimeters are necessarily High mass (W & Cu)
- Tracking Detector volumes have low mass requirements

Very Simplified Track Reconstruction



- Multiple layers help statistics (ATLAS has 9+ Tracking Layers)
- Finer resolution detectors at lower radius (track separation is small)
- Tracking in XY plane gives track curvature (charge/momentum)
- Material of detecting elements their services and supports cause Coulomb Scattering, detracting from precision of measurement
- Small angle change at low Radius leads to large projected tracking errors at higher radii
- Displaced vertices are short lived particle decays (important to ID)

Mass affects precision of Measurements



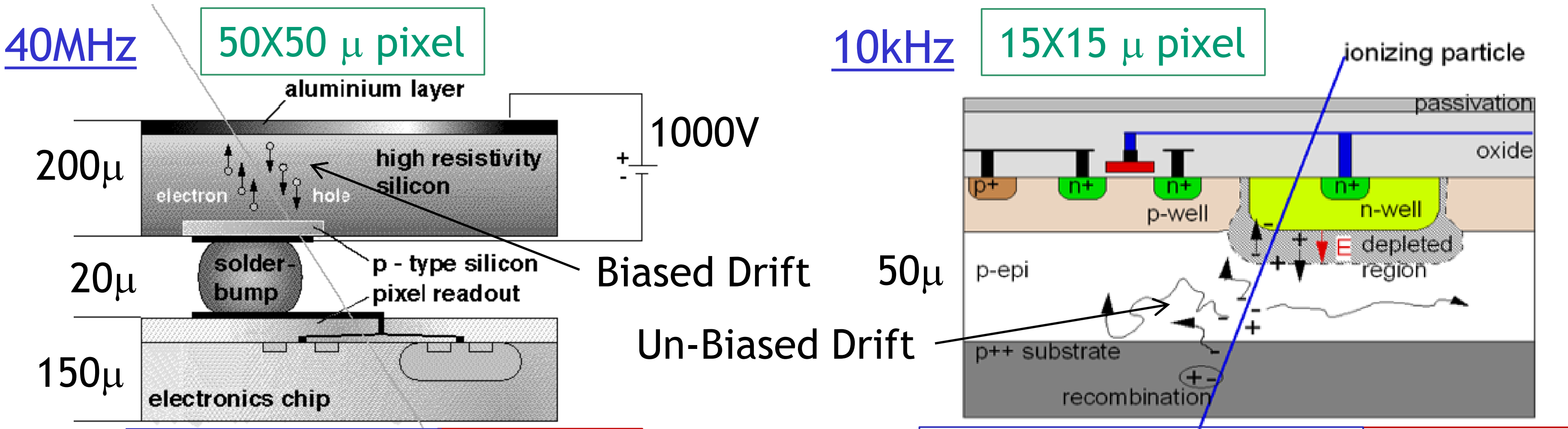
Conversion map showing reconstructed secondary vertices

Structures are clearly visible in the data and corrected for as much as possible

This is not ‘metrology;’ this is an experiment. Statistics dominate, but metrology is the inroad to understand the requirements; mass detracts from resolution in a measurable way.

- **Radiation length X_0 is a fundamental property of a material**
- **In 1 Radiation Length 1/e of the particles will scatter**
- **Requirements are set in “ % X_0 ” to normalize against various materials for example:**
  - **X_0 Si = 9.4cm, X_0 CFRP = 24.7cm; 1% X_0 is equivalent to either 2.5cm CFRP or 0.9cm Si.**
- **Above plot for current ATLAS detector shows 2.5% X_0 per layer; The upgrade is looking for under 1% X_0 per layer to improve resolution…**

Pixel Detector Sensor Technologies



-30C Operation | >6kW/m²

'Hybrid Pixel' 0.4% X_0

Room Temp Operation | <1kW/m²

'Monolithic Active Pixel' 0.05% X_0

- **Hybrid Pixels are fast—used in P-P detectors (ATLAS, CMS) low temp operation due to high radiation dose>500Mrad Speed requires higher mass dual layer sensors to meet requirements**
- **MAPS used in Heavy Ion experiments (STAR, ALICE) low power, lower radiation dose <2Mrad allows RT operation Physics requires very low mass**
- **Boxed Values Drive mechanical requirements on Structures**

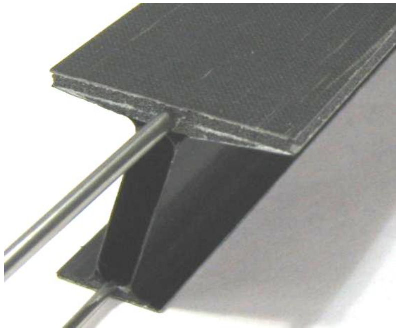
Mechanical Requirements on Structures

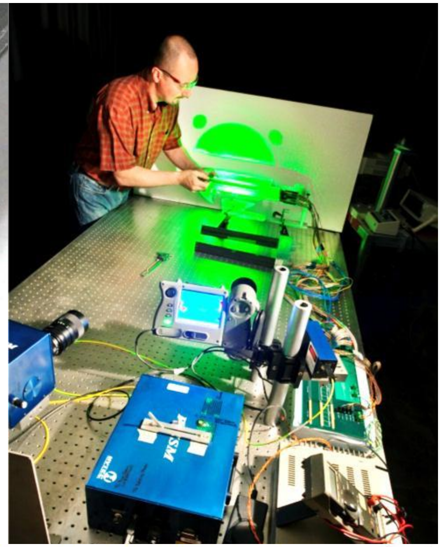
- Stability tied to Pixel Size e.g. 50μ Pixel
  - RMS of Square distribution = (1/root(12))*pixel size
  - Vibration, Varying heat-loads, Cooling System,
  - Ultimately tied to tracking resolution
- Cooling (Heat Load, Operating Temp)
  - Auxiliary requirement is maximum Sensor temp; as radiation accumulates, leakage current increases and is dependent on temperature. If Max temp is exceeded, thermal runaway is possible
- Structures must provide sufficient stability and cooling capacity at the lowest possible mass

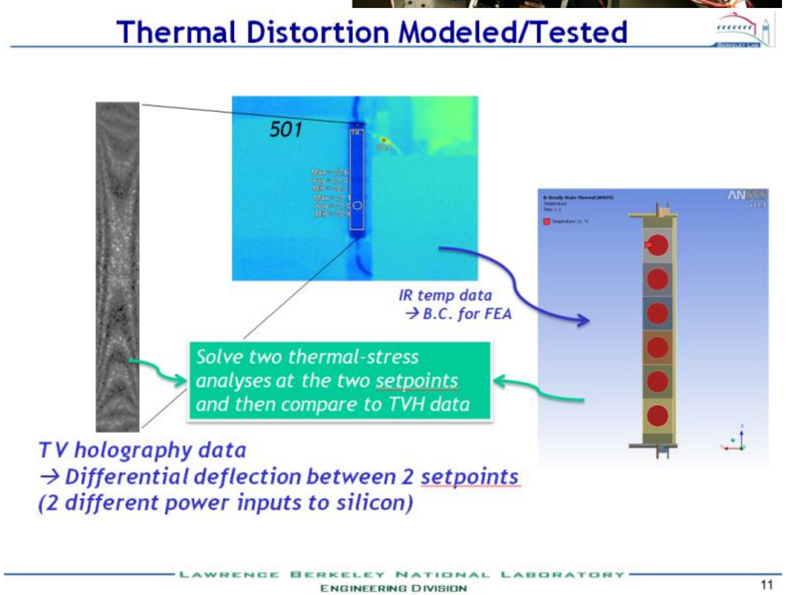
Silicon Detectors

- Detector is an array reverse biased Diodes that are well surveyed/calibrated for location and held stable
- Particles traversing any given diode ionize the semiconductor releasing electrons which are amplified and read out giving ‘hits’ based on location
- Saturated diodes have a leakage current which heats the substrate and is also temperature dependent
- Depletion voltage depends on Radiation dose
- There exists a temperature at which this goes unstable leading to thermal runaway
- Detectors dissipate ~0.6W/cm^2 which must be extracted and the temperature must always stay below the thermal runaway Temp (with goodly margin)

Detector Local Supports





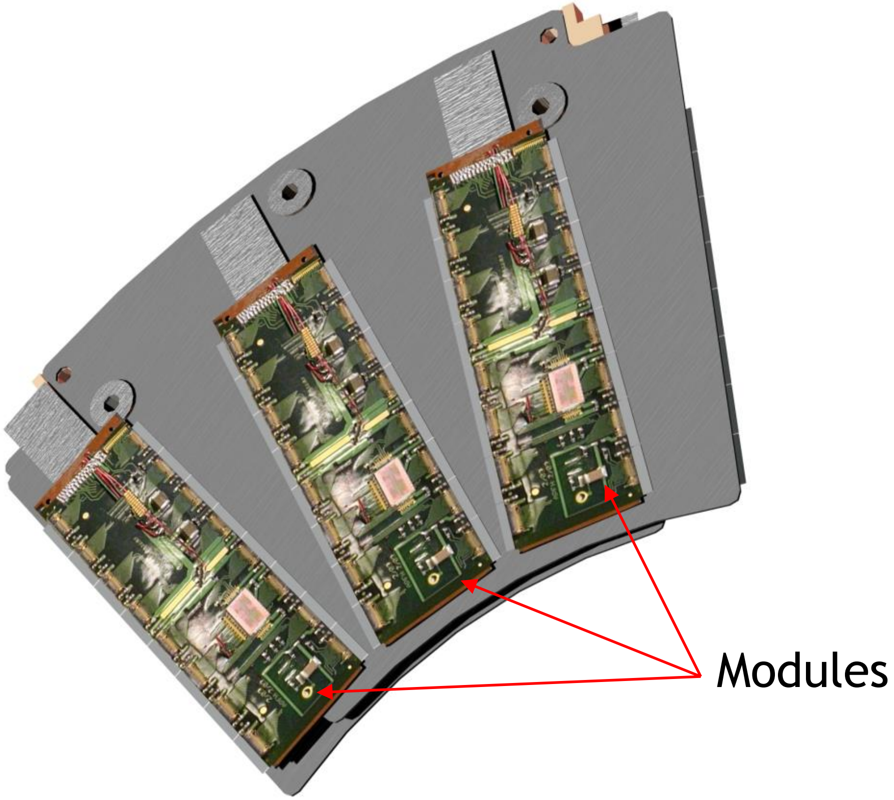


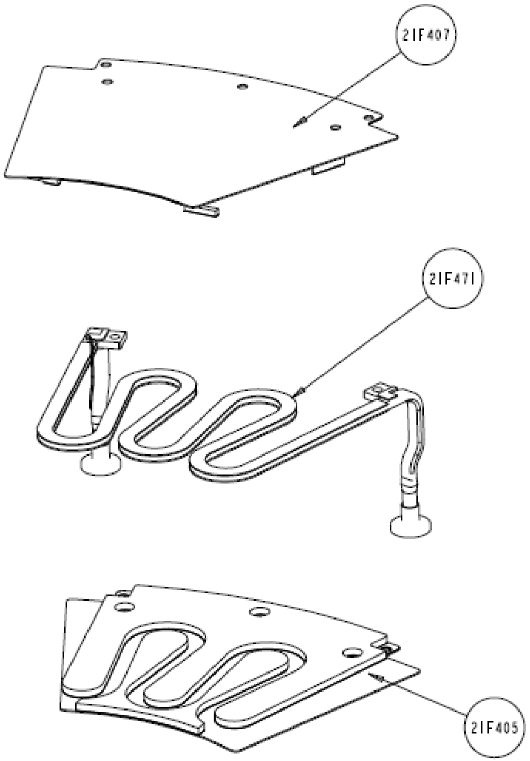
- Silicon Detector Supports with integrated Cooling
- High Stability requirements—under 50μm motion for 50C ΔT for 1m long structures dissipating 250W
- Integrated R&D supporting structured engineering approach
  - Design → Fabricate → Test, Feedback results into new Design
- Integrated IR Thermography and Speckle Holography allow direct comparison with FEA results
- Used in developing materials with industry via SBIR (Conductive Carbon Foam)
- Deliver highly stable Detector local supports to HEP customers with high production quality

Integrated Design Problem

- Nominal Structures are beam-like with foam/other core
- Integrated cooling channel for heat extraction
- Bi-metallic effects from various CTE mis-matches
  - Si is ~4ppm/C (grease interface or very rigid structure)
  - Tubes range from 9-22ppm/C
  - C-Foam ~1ppm/C; CFRP/CC -1.5 to -.25ppm/C
- 1.2-2.5m long structures, ΔT 50-60C—airy stresses resolve at extremities (adhesive joint stresses)
- Detector supports need to be stable on order of resolution
- Thermal performance is as important as structural, both are coupled to reduce material

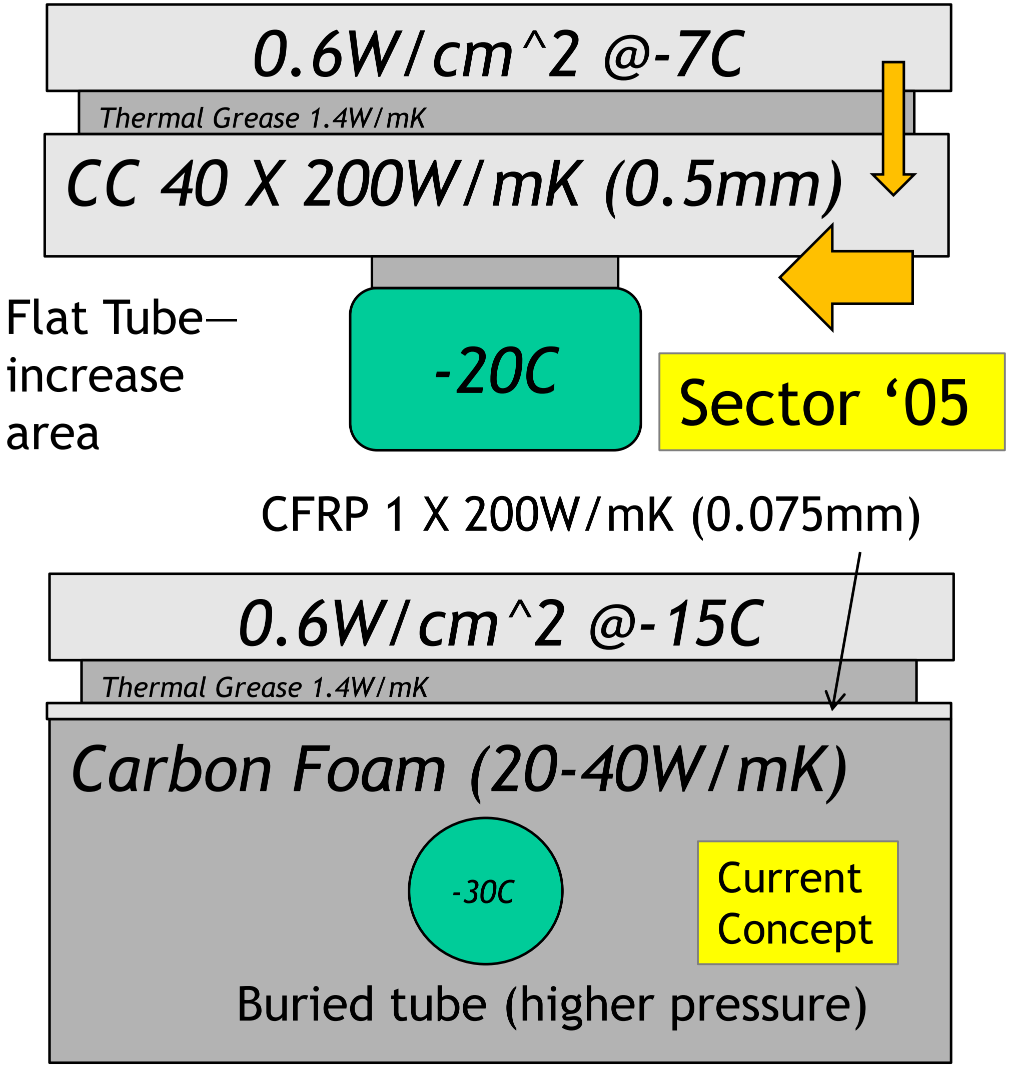
Pixel Disk Sector Circa '02





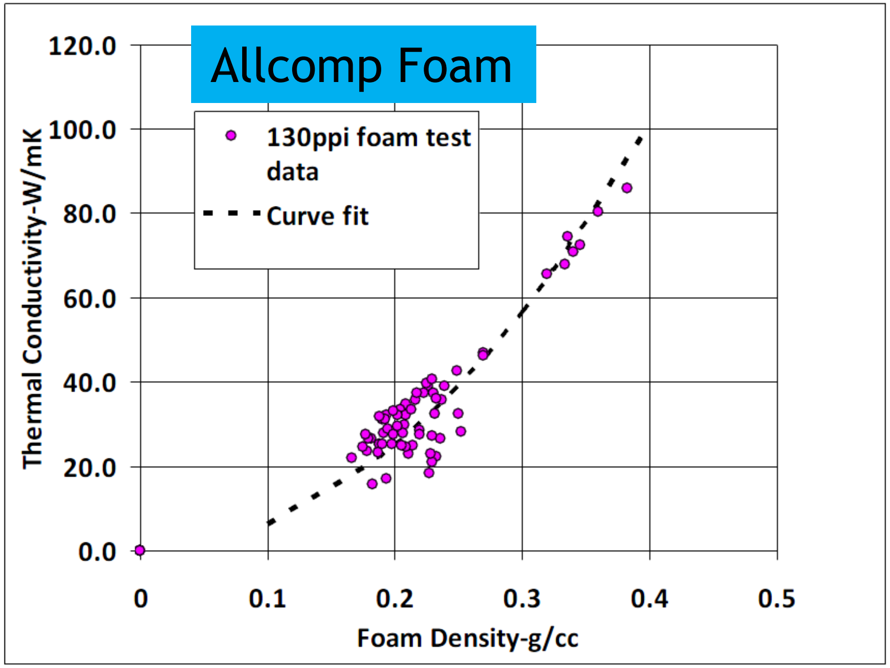
- *Modules mounted on CC face sheets for thermal control*
- *Internal Tubing with evaporative cooling is used to extract heat from Modules*
- *Carbon Foam is used internally as a structural core (not conductive back in '02)*

Heat Flow paradigm change

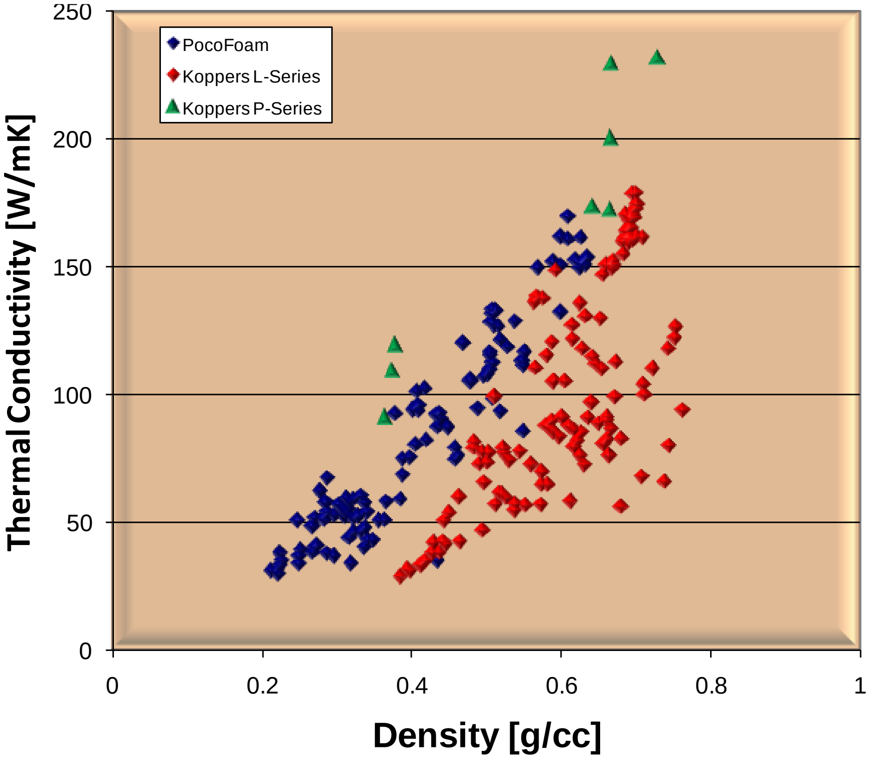


- Dog on Beach Problem
- Sector used 'thick' CC facing to move heat to cooling tube
- Relied on 40W/mK transverse conductivity to 'get' heat into section via 200W/mK in-plane K
- New development uses C-Foam with larger net section, but lower K
- Section*K ~ equivalent
- Lower overall mass

Custom Foam Developed via SBIR



Plot of K9 130ppi foam conductivity, Kz, as function of foam density.

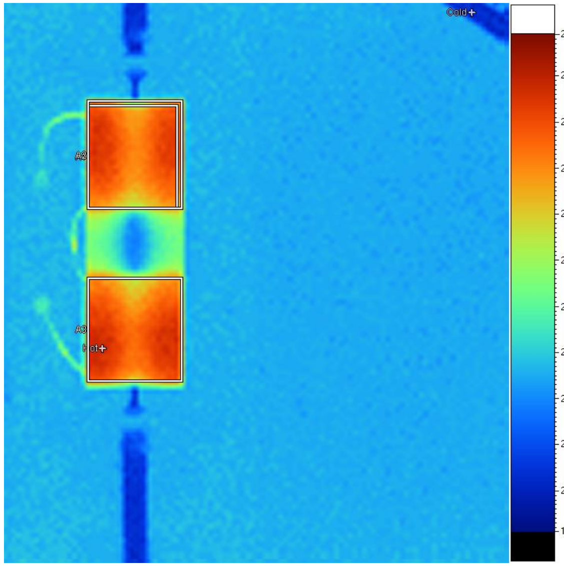


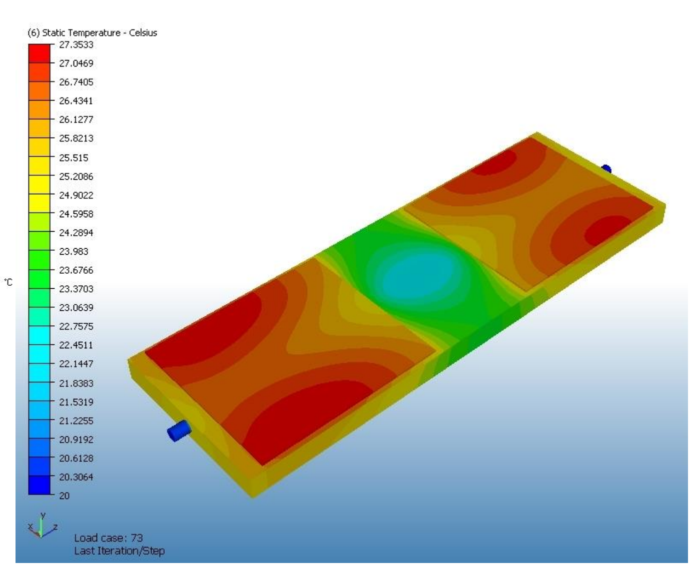
- Allcomp developed a foam (K9) using different method from Klett patents
- Our interest is in lower mass foams where 'foaming' yields poor uniformity
- Compared to Reference 0.5mm Carbon-Carbon heat-spreader, 0.2g/cc @30W/mK can be 5mm thick for equivalent X0, and gives performance near to the CC heat spreader, but more shape optimization is possible (see later)

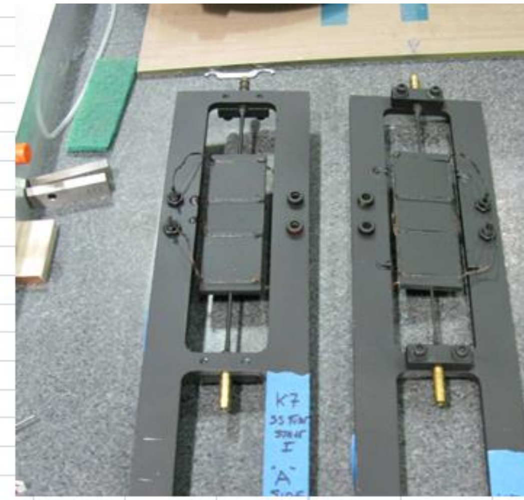
Interfaces are Important

- Many interfaces between heat source and coolant
- Si to face-sheet well understood and tested
- HTC of coolant to Tube studied elsewhere but known
- Face-sheet to Foam and Foam to Tube introduce less well qualified thermal impedances that need study
- Thermal interfaces are also structural
- Joining materials (adhesive) have very low K (<1W/mK) and E (~0.5Msi) compared to Graphite or Metals
- Foam is not isotropic volumetrically at interface scale
  - Von Mises useless at scales under cell size (for example)
  - FEM can be tuned to bulk properties, but sub-models required
- Some of this has been studied via SBIR with Allcomp

Standardized Prototypes and Tests

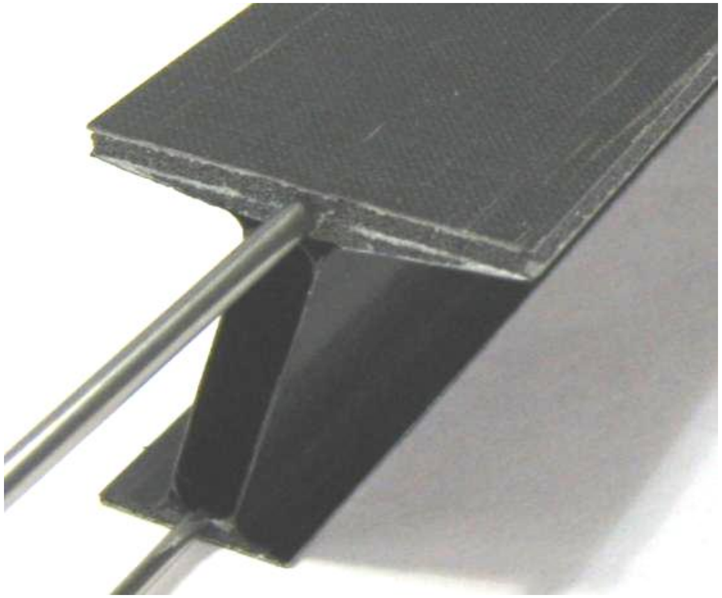


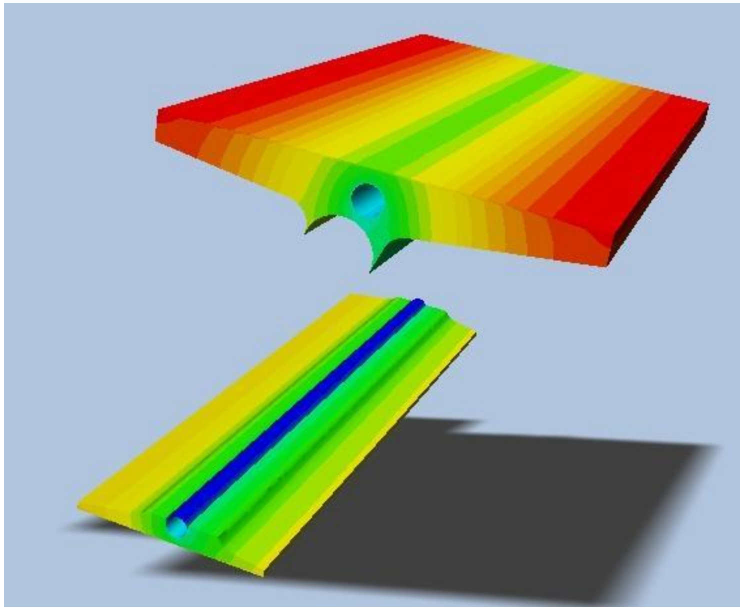




- Development of FEM properties is required
- Standardized samples allow quick turn prototypes and testing (tooling/test stand)
- 'Bulk' properties are well understood, e.g. Laminate, Foam K, E
- Interface Properties can dominate giving offsets in T (ΔT to Silicon)
- Interface modeling is 'frontier' work

Foam Cross Sections versus Material

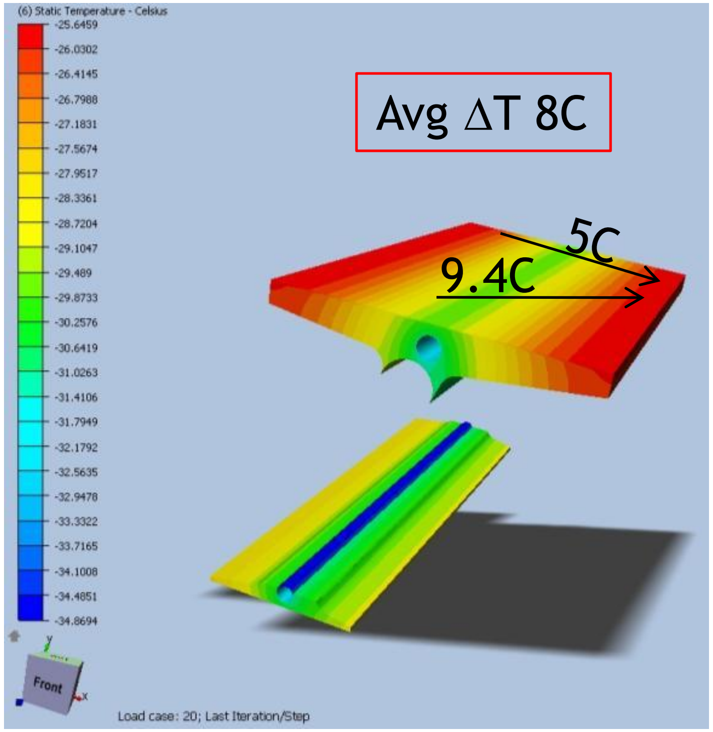


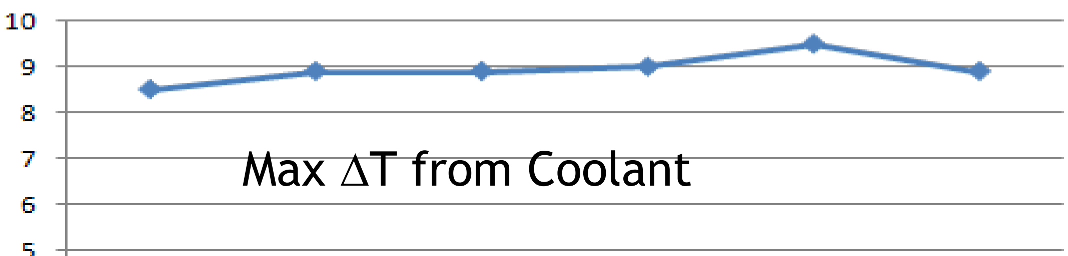


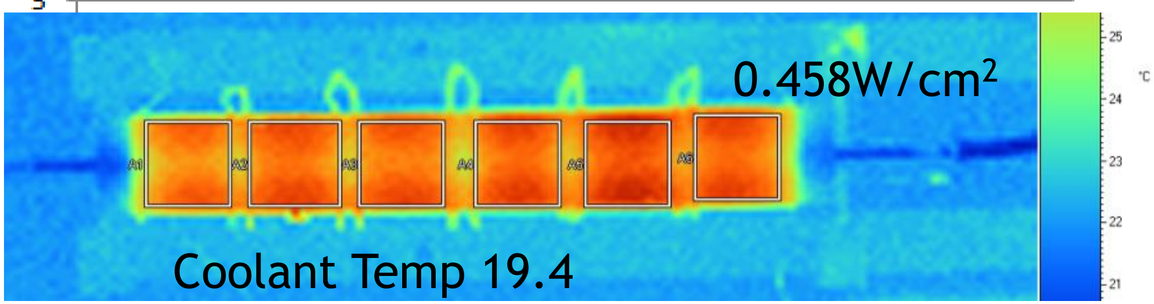
- Thickness of foam can be tailored to heat flux—edges here are thicker than required—note uniform gradient to tube
- Foam for both is K9 130ppi ~30W/mK
- Hard to reduce cross-section of Inner Foam
  - Could go back to K7 100ppi foam ~20W/mK to reduce material, but increase ΔT
- This could not be done with CC facings which are uniform thickness

Thermal Performance Outer Face

- **Increased Edge Thickness of Top Foam to improve thermal performance; plus larger tube**
- **Model calculated temp to silicon w/SE4445 but did not include conductivity from the Si (better width range than 5C)**
- **Results within 10% of expected**







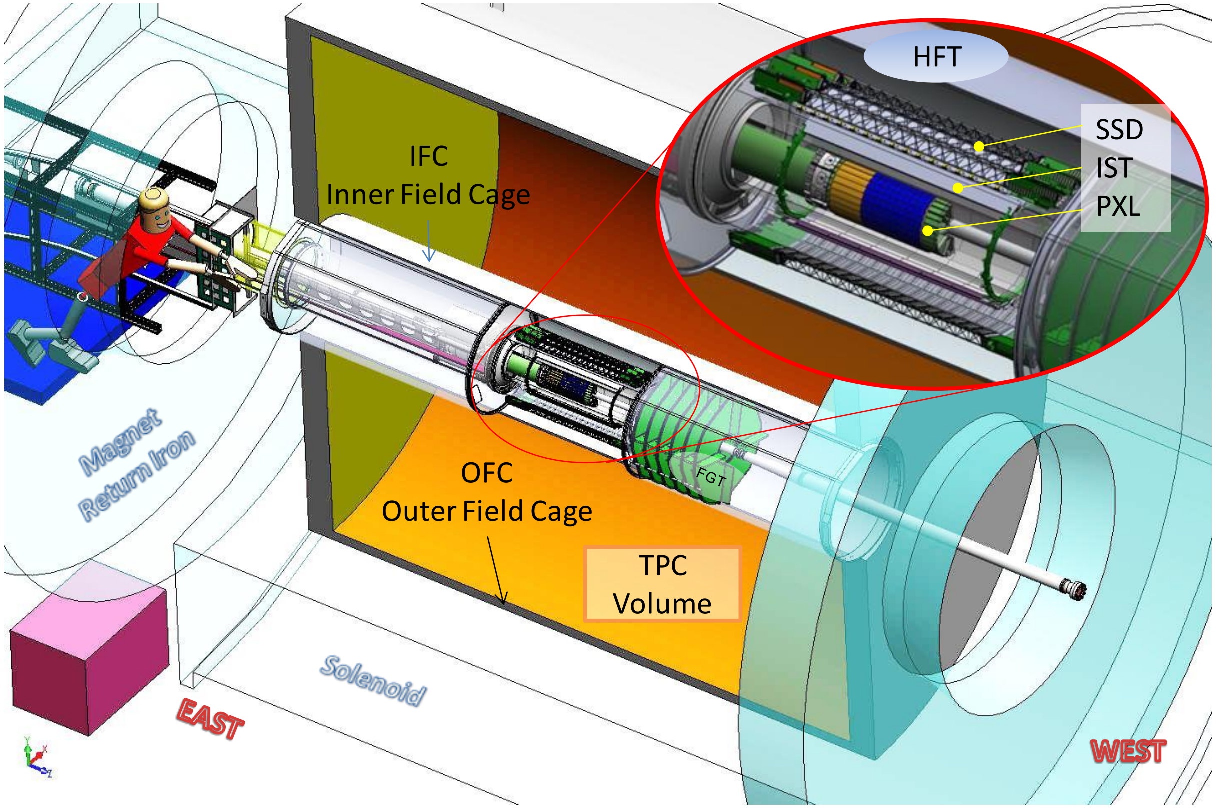
	Average ΔT	Range	Max to Coolant
A1	7.6	2.5	8.5
A2	8	2	8.9
A3	8	2	8.9
A4	8.1	2.4	9
A5	8.6	2.1	9.5
A6	8.1	1.9	8.9
Average	8.1	2.2	8.95

Detector Global Supports

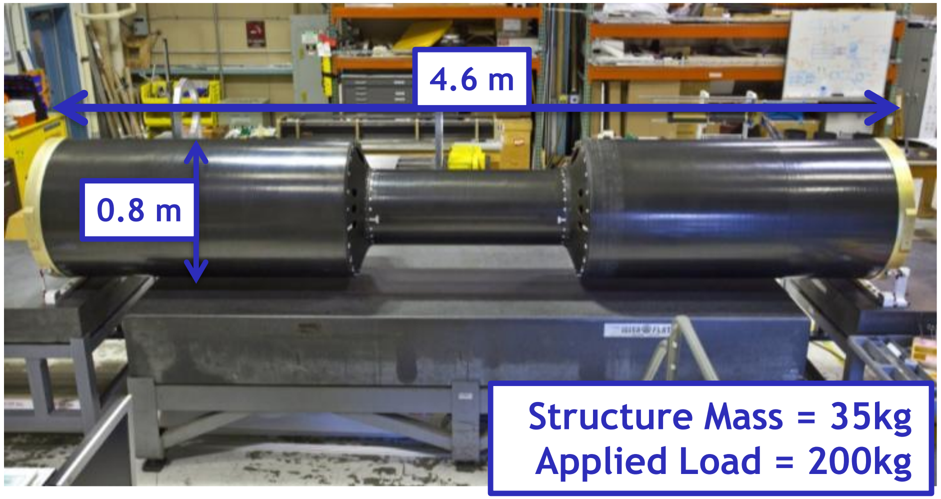
- Hold and locate local supports
- Precision Assembly of large structures (4-8m)
- Position ~ 100μ within detector volume (survey or build tolerance)
- Generally achieved with precise bonding
- Very few components are thick enough to 'machine' for precision

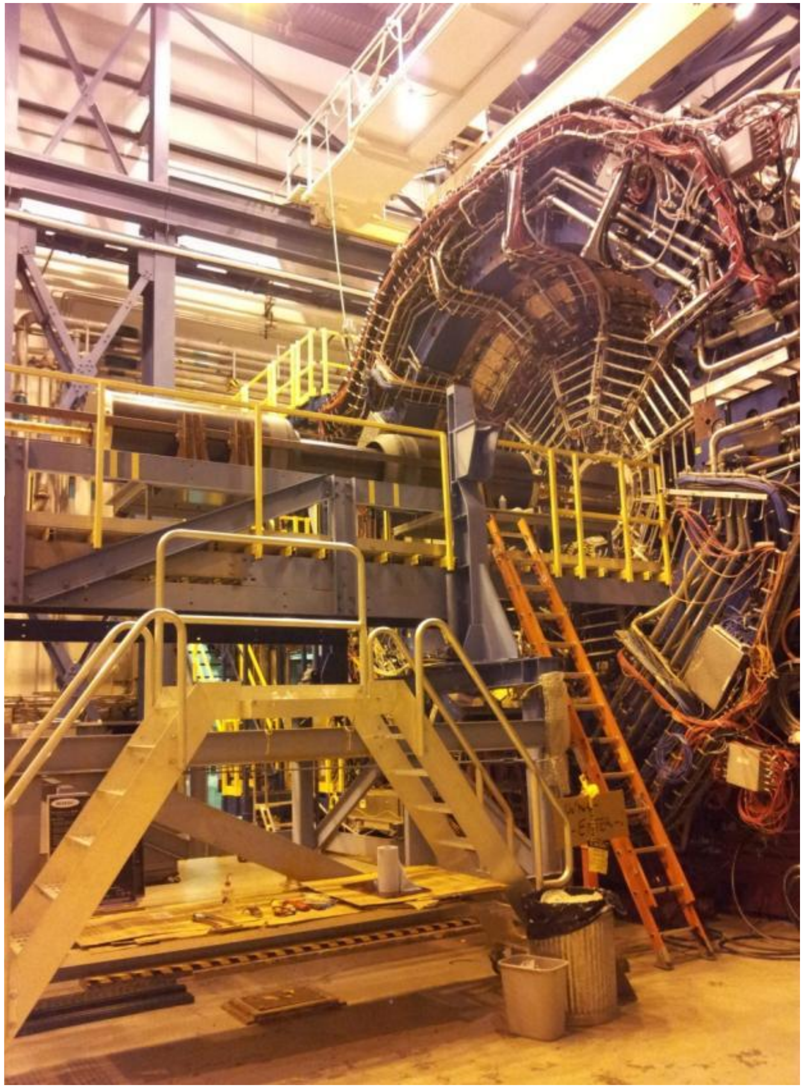
STAR HFT

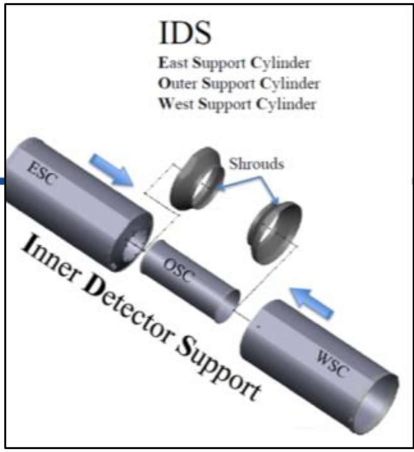
- HFT is a new inner tracking system for STAR, with 4 layers of silicon and 6 gem disks
- Timeline:
  - Nov 2011 main support structures + FGT were installed
  - July-Dec 2012 PXL support and PXL for engineering run
  - Summer 2013 full PXL + IST + SSD
- Key component is PXL:
  - 2 innermost silicon layers
  - Truly rapid insertion/removal
  - Very low mass
  - TPC is great; PXL will much improve pointing
- At LBL we're building / have built:
  - All the support structure (IDS)
  - All of PXL
  - IST local supports



STAR HFT Inner Detector Support (IDS)



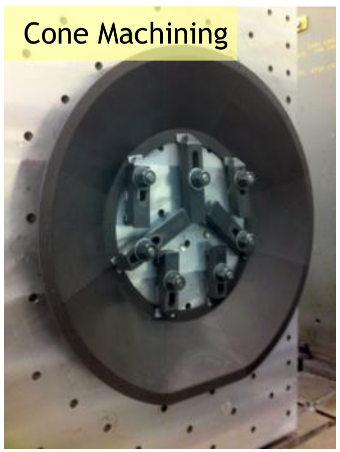


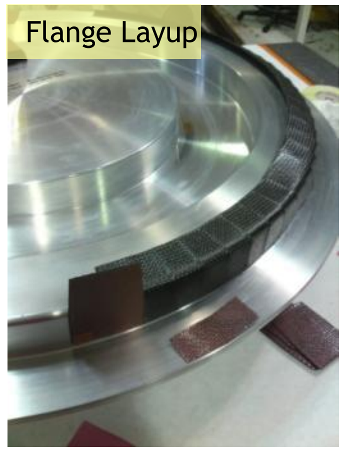


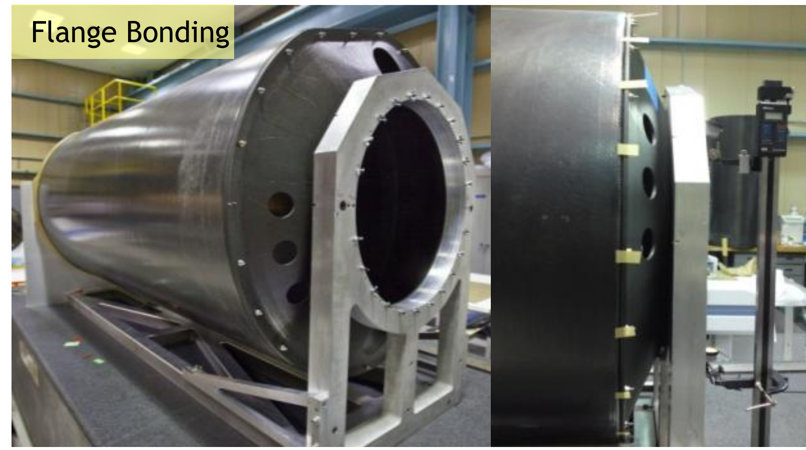

WSC/ESC Mandrel

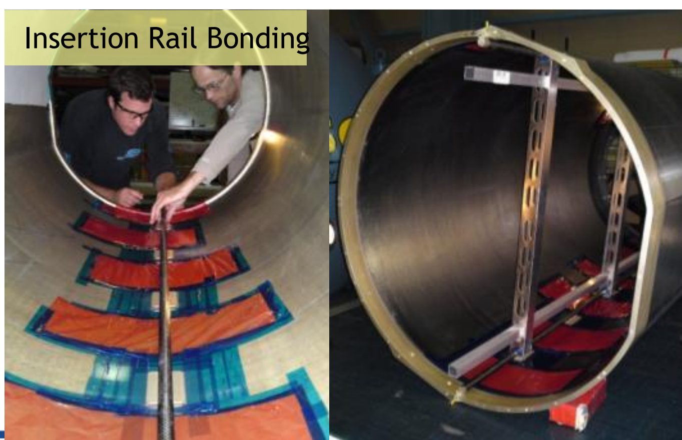

WSC/ESC Layup


Cone Layup

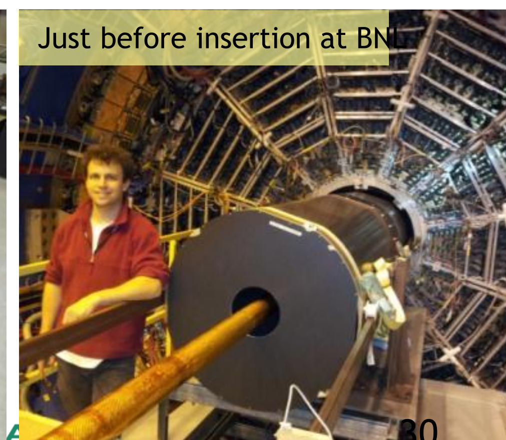

Cone Machining


Flange Layup

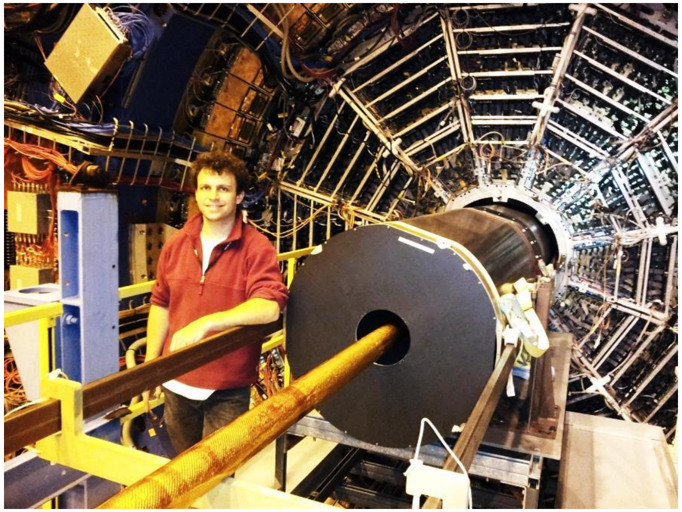

Flange Bonding


Insertion Rail Bonding

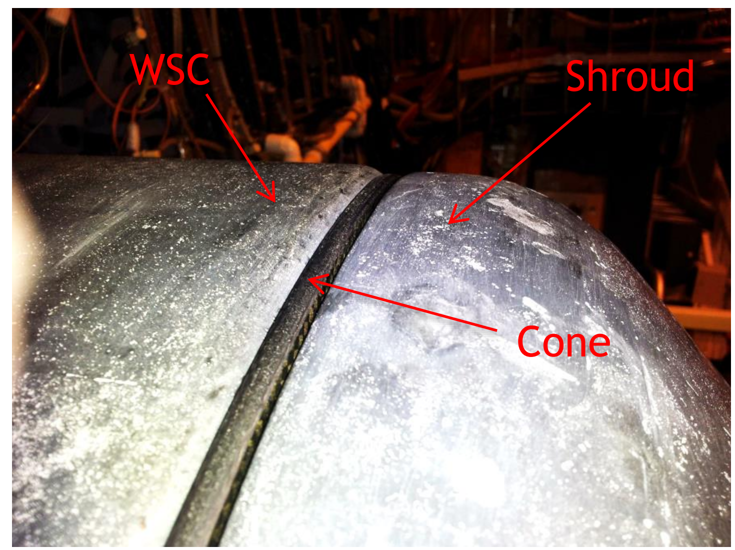

Assembled Structure at LBNL


Just before insertion at BNL

Some Unique Requirements

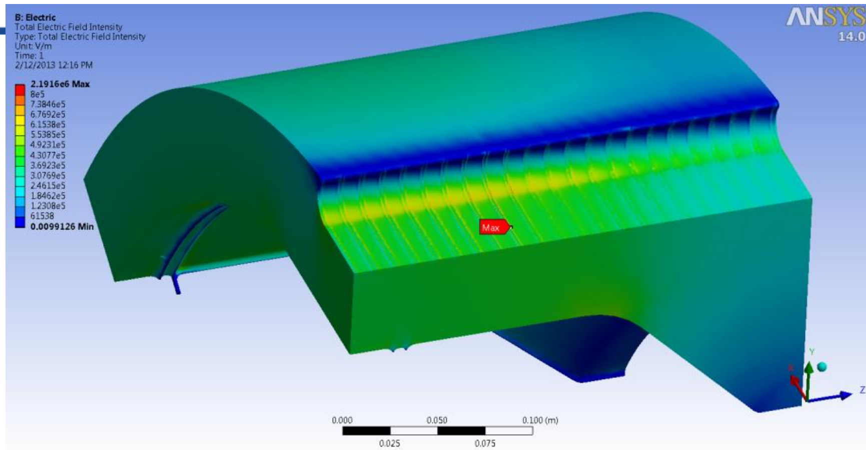


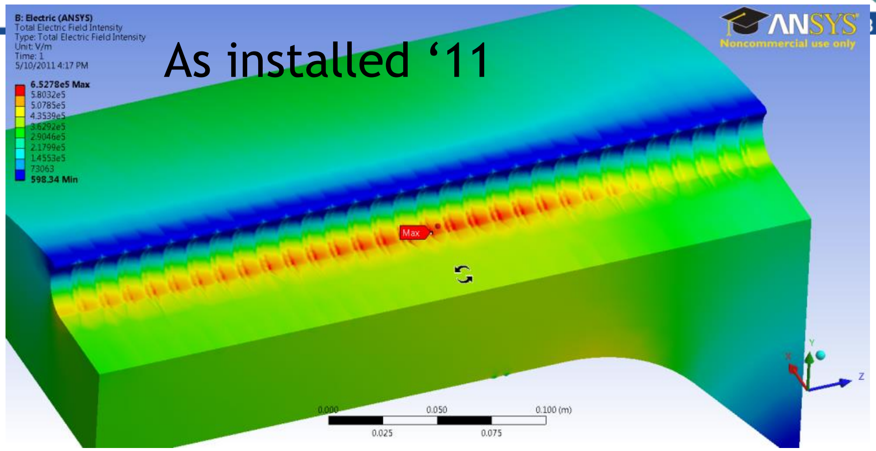
- The IDS was installed into STAR Time Projection Chamber
- TPC is a High Voltage (30kV) field cage—electrostatics of composite structure is important
- Qualified 'anti-static' veil to assure conductive surface

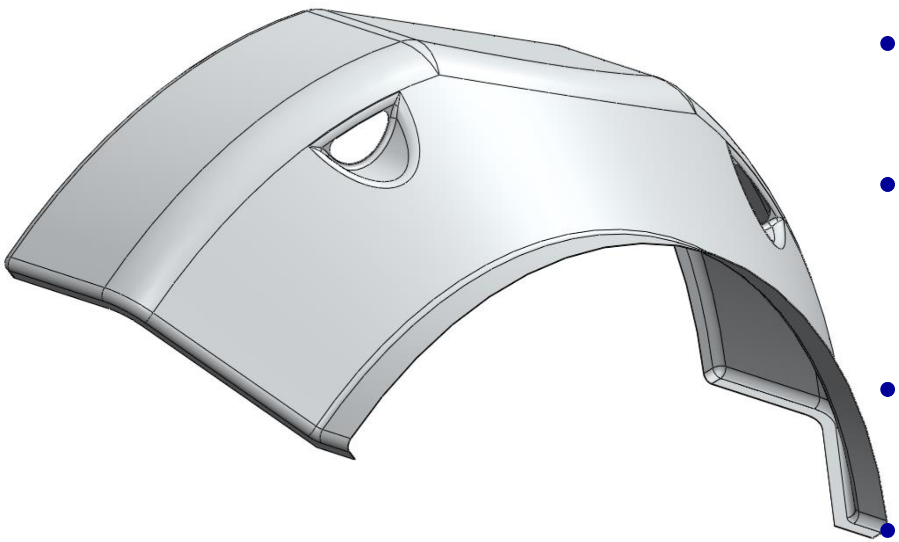


http://www-eng.lbl.gov/~jhsilber/photos/STAR_IDS_Installation_Nov2011/

E-Field Shroud Segmented Design







- Design changed to segmented to allow for assembly order
- Detailed Electro-static analysis required to assure no ‘corona’ or surface breakdown
- Tested key geometry (small radii) in previous installations
- Non-traditional use of of structural composites

Conclusion

Thanks for your attention

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