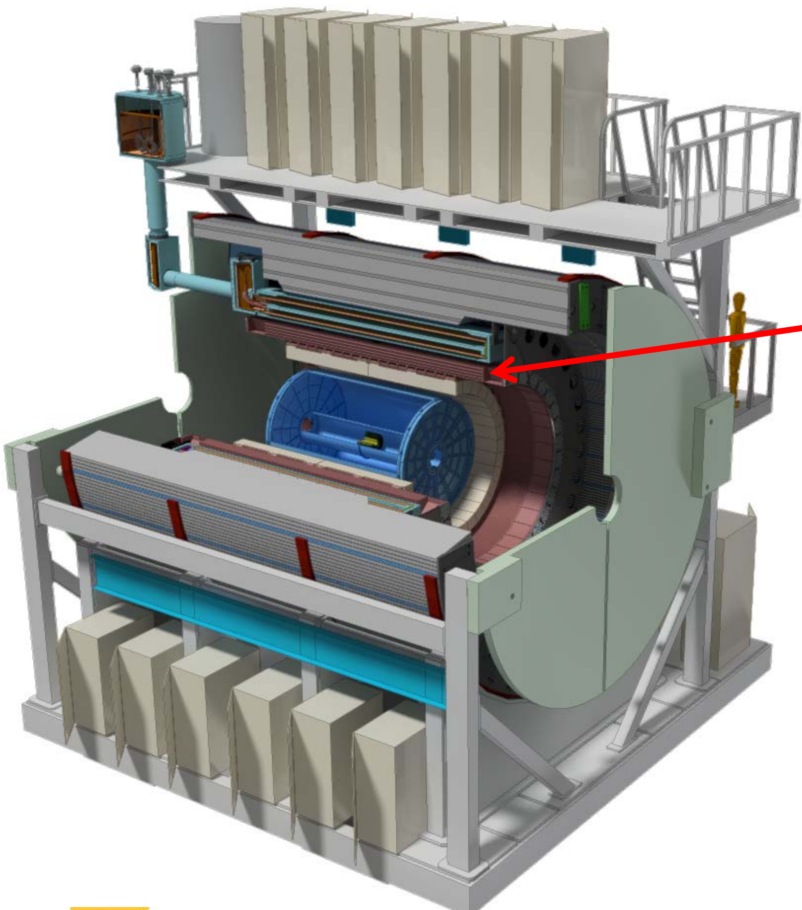
# Inner HCAL WBS 1.4.2



| WBS | sPHENIX MIE Project Elements |
|---|---|
| 1.1 | Project Management |
| 1.2 | Time Projection Chamber |
| 1.3 | Electromagnetic Calorimeter |
| 1.4 | Hadron Calorimeter (inner) |
| 1.5 | Calorimeter Electronics |
| 1.6 | DAQ-Trigger |
| 1.7 | Minimum Bias Trigger Detector |

| WBS | Infrastructure & Facility Upgrade |
|---|---|
| 1.8 | SC-Magnet |
| 1.9 | Infrastructure |
| 1.10 | Installation-Integration |

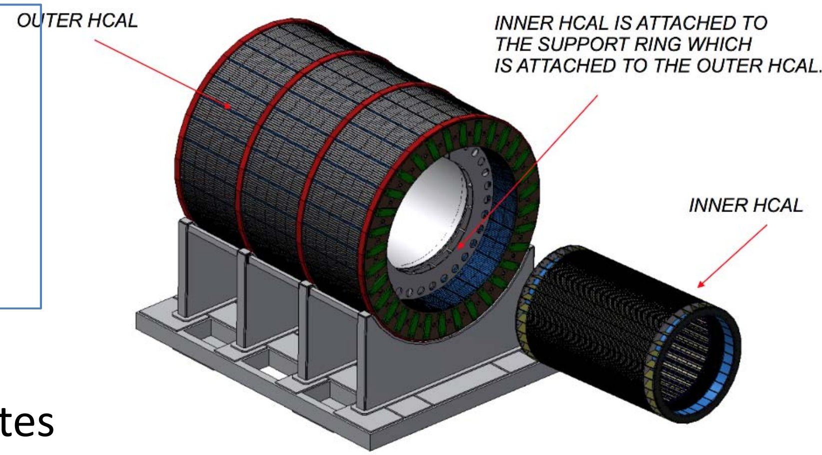
| WBS | Parallel Activities |
|---|---|
| 1.11 | Intermediate Silicon Strip Tracker |
| 1.12 | Monolithic Active Pixel Sensors |

John Lajoie
*Iowa State University*

# Inner HCAL

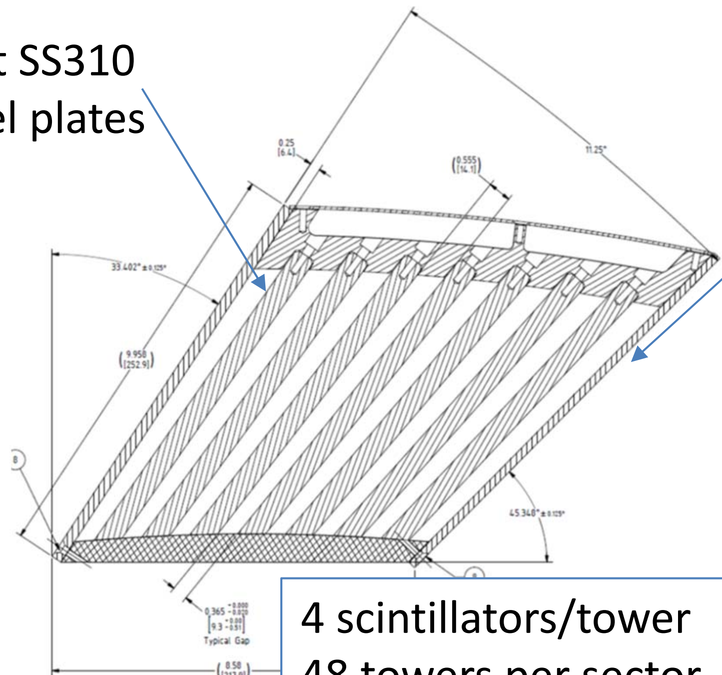
**DELIVERABLE:**
32 sectors - 1.16m inner radius, 1.37m outer radius
8 rows of 7mm scintillator tiles (24 tiles per row)
32$^{o}$ tilt angle, flat stainless steel plates ~10.2mm - ~14.7mm

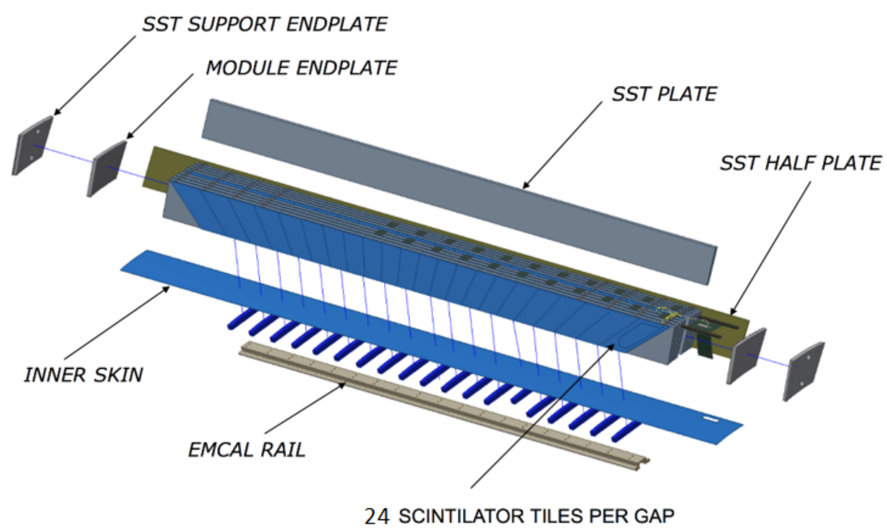
**Completed sector is 4.3m long, weighs ~ 1 ton**




Flat SS310 steel plates

Half plates on sides






4 scintillators/tower
48 towers per sector
32 sector; 1536 channels
(6144 SiPMs)

# HCAL Performance Specifications

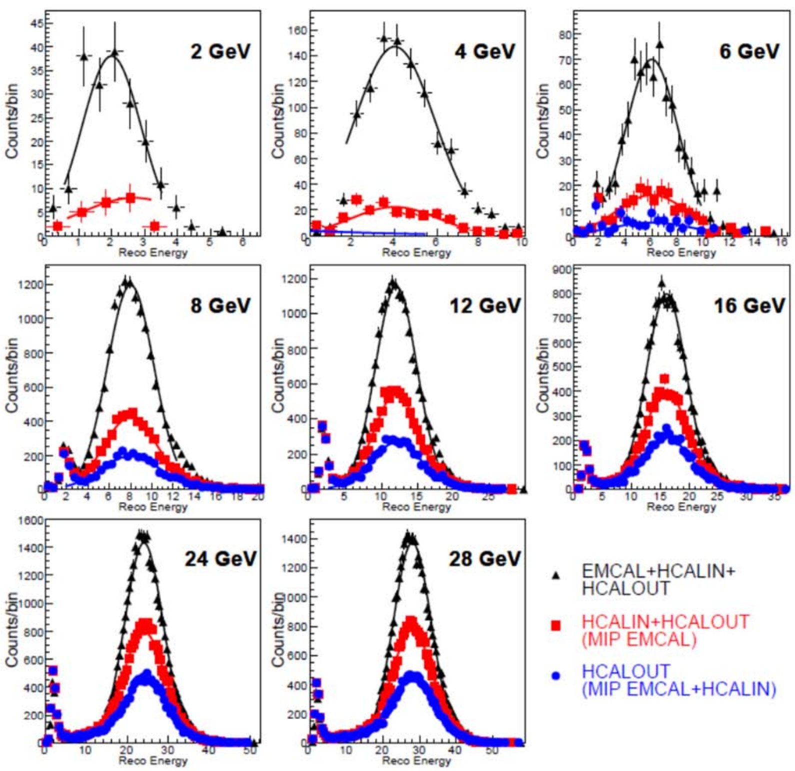
- HCAL performance driven by jet physics in HI collisions
- Uniform fiducial acceptance $-1<\eta<1$ and $0<\phi<2\pi$
  - **Extended coverage $-1.1<\eta<-1.1$ to account for jet cone**
- Absorb >95% of energy from a 70 GeV jet
  - **Requires 5.5 nuclear interaction length depth**
- Hadronic energy resolution of *combined* calorimetry:
  - $\frac{\sigma}{E} < \frac{100\%}{\sqrt{E}}$ **with constant term <15%**
  - **Gaussian response (limited tails)**
  - **Performance optimized/demonstrated in three test beams**
- Inner HCAL is inside superconducting solenoid
  - **Must be made of non-magnetic material**

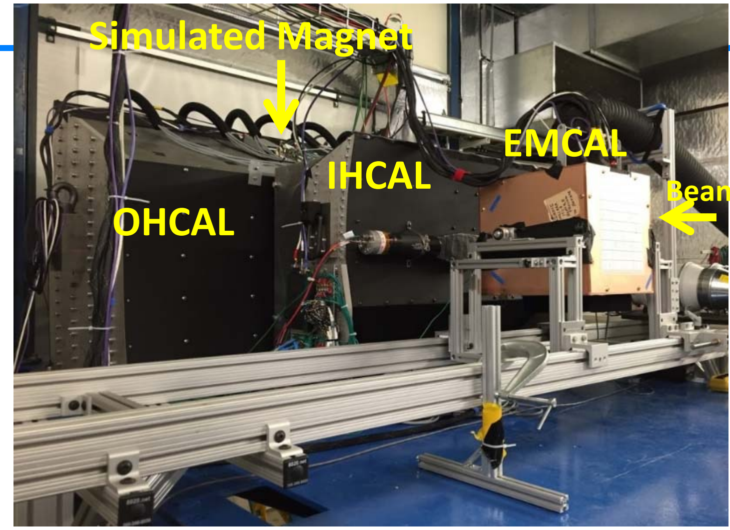
# Design Drivers

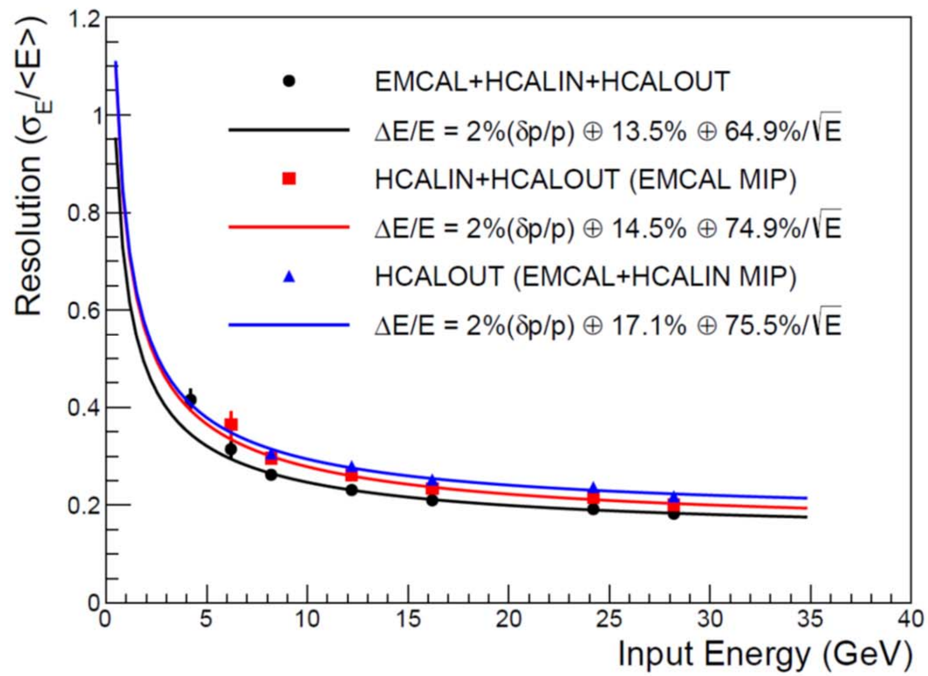
- Why an inner and outer HCAL segment?
  - **Size limitations set by existing interaction hall**
  - **Set by radius of BaBar solenoid, the design of the mechanical support for the detector, and overall cost effectiveness**
- Why a tilted plate design?
  - **A tilted plate design can provide a uniform acceptance, adequate energy resolution and simplified construction**
- How are the tilt angles chosen?
  - **Chosen to avoid channeling (tails in resolution function)**
- Why $\Delta\eta \times \Delta\phi \approx 0.1 \times 0.1$?
  - **Driven by occupancy in Heavy Ion collisions**
  - **Good match to scale of hadronic jets**

# Test Beam Performance

Three test beams (2014/15/16):




In all cases, the combined system meets the sPHENIX spec!

# Personnel

- **BNL**
  - Edward Kistenev (scientist)
  - Don Lynch (engineer)
  - Rich Ruggiero (designer)
  - Anatoli Gordeev (engineer, OHCAL L3)
- **ISU**
  - J. Lajoie (L2 Manager/IHCAL L3)
- **Colorado** (tile testing)
  - J. Nagle (faculty)
- **GSU** (tile testing, outer HCAL)
  - Megan Connors (faculty)
  - Xiaochun He (faculty)
- **WSU**
  - Bill Llope (faculty)
  - Joern Putschke (faculty)
- **ACU**
  - Rusty Towell (faculty)
- **Rutgers**
  - Sevil Salur (faculty)
- In discussions with Russian institutions (MEPHI/IHEP/Kurchatov)

BNL engineering has decades of experience with PHENIX.

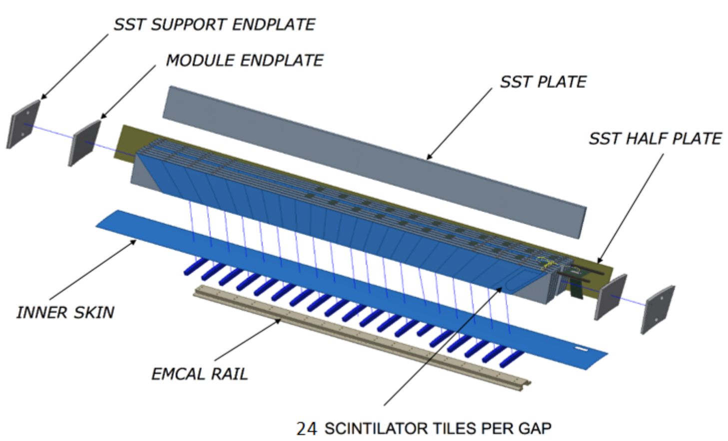
ISU was responsible for the PHENIX LL1 trigger and MPC-EX.

WSU has a wide range of experience in building detectors.

ACU worked on the PHENIX MuTR chambers.

# Schedule Drivers

- **Sector Mechanical Prototypes: 3-9/2017**
- **Prototype v2.1 Test Beam: 2/2018 – 3/2018**
- **Inner HCAL Production: 2/2020 – 7/2021 (CD3b)**
  - **Mechanical sectors produced every 15 working days**
  - **University assembly (scintillator/electronics/testing) keeps pace**
  - **Shipped in groups of four to BNL; sectors retested**




Production schedule integrates availability of electronics/SiPMs (WBS 1.5).

Schedule slip in assembly can be addressed by adding additional University labor.

# Cost/Resource Drivers

- SS310 steel is essentially a commodity material but precision machining is expensive
  - **Cost dominated by production of sector mechanicals**
- Scintillator tile production
  - **Surface flatness over long distances a key specification**
    - **Wrapped tile thickness < 7.5mm, Uniplast can meet this spec.**
  - **Uniplast (T2K, PHENIX)**
    - **FNAL/Elgen also investigated, Uniplast most economical for complete tile assemblies**
- Module Assembly and QA
  - **Assemble inner HCAL at multiple university sites**
    - **Make use of university labor and facilities**
    - **Deliver assembled, cosmics tested sectors to BNL**

# Basis of Estimate

- The Inner HCAL will be assembled at two (or more) University sites.
  - **ISU, WSU and ACU have expressed interest**
    - **Rutgers may provide some machined parts**
  - **Sector assemblies provided by local vendors, populated with scintillator and electronics by University labor**
  - **Shipped to BNL, tested after shipping and stored.**
  - **IHEP Protovino investigating construction alternatives**

- Costs in BoE are based on:
  - **Experience with test beam prototypes**
  - **Experience with sector prototypes**
  - **Quotations**
  - **Engineering estimates (Inner HCAL End Ring)**

# Sector Prototype

Light cover
(reflection)

# Assembled Sector Measurements

In lifting fixture

Assembled sector moved to mill table, supported on ends (4 blocks). Twist and sag in middle measured @ 70ºF.

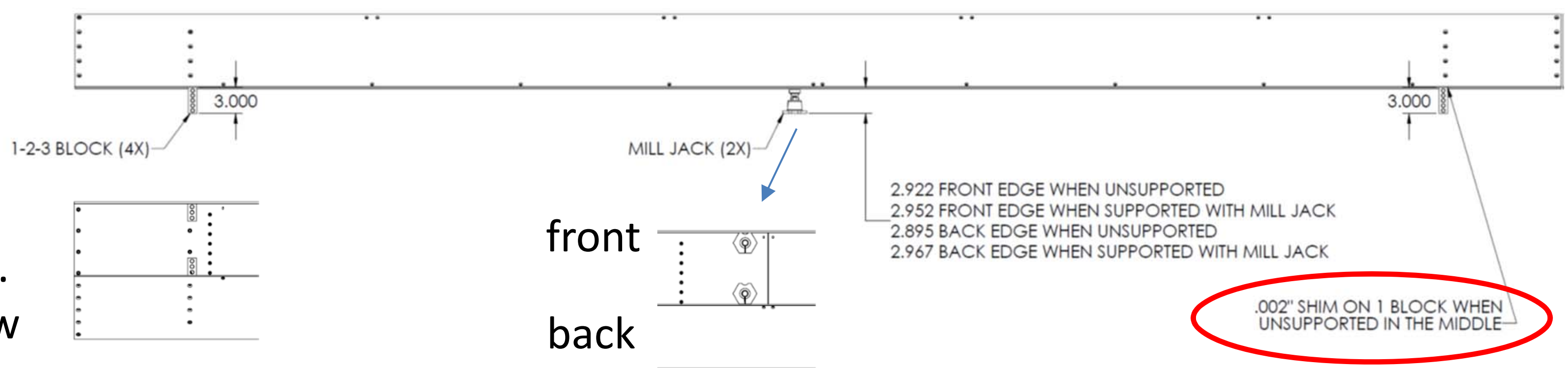
“Back” sags more than front when unsupported (CG shifted towards back). Supported measurements show not all sag is due to weight, some could be taken out by assembling on mill table.

Similar results at 90ºF.

Bot. view

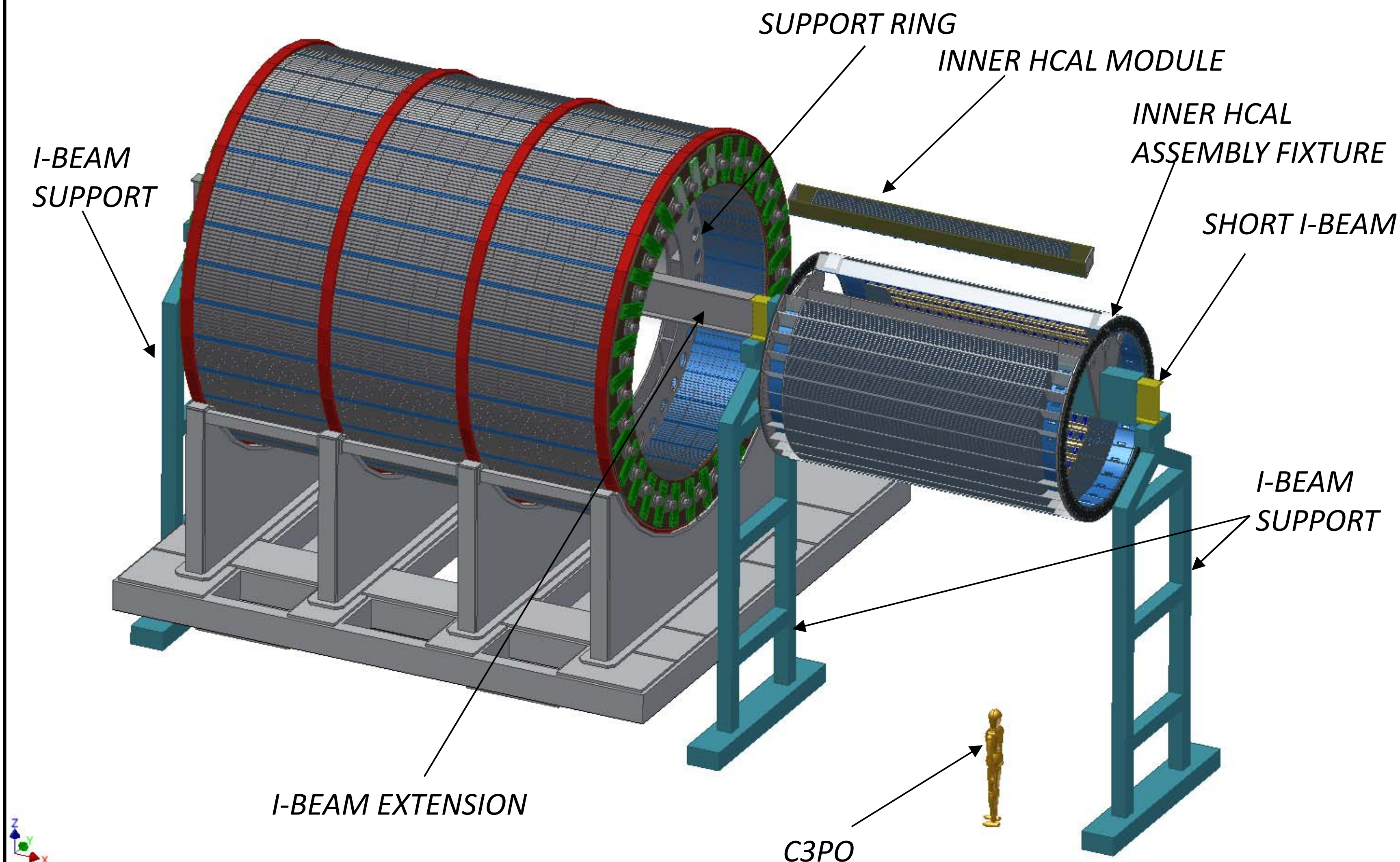
front

back




Very little twist!

# INNER HCAL INSTALLATION



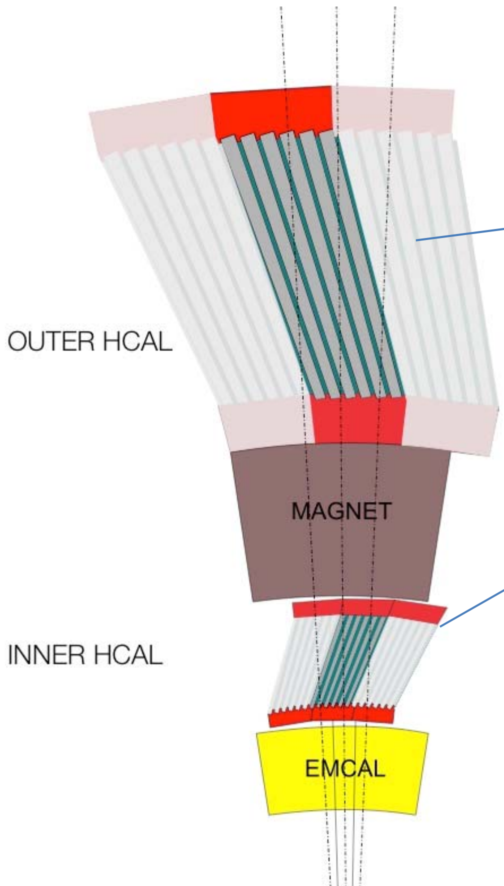
# Risk Registry/Issues and Concerns

| | | | | | |
|---|---|---|---|---|---|
| 1.4 HCal | Loss of scintillating tile provider (Uniplast) | Uniplast is unable to engage in or complere the production contract | Schedule delay in the procurement of rthe scintillating tiles, along with corresponding delays in inner and outer HCAL assembly. | Moderate | Explore alternate scintillator vendors (FNAL, Elgin, IHEP). |
| 1.4 HCal | Unable to produce inner HCAL in SS310 in a cost effective manner | Evaluation of inner HCAL prototype yields higher than anticipated production costs | Schedule delay in finalizing the design of the inner HCAL; re-engineering required. | Moderate | Investigate value-engineering designs and alternate materials (brass); will require re-engineering. |
| 1.4 HCal | Unable to identify suitable site(s) for inner HCAL assembly (scint. and electronics) | No participating University site can idetify the space resources for assembly. | Schedule delay to set up assembly site at BNL | Low | Investigate possibility of assembly (scintillator and electronics) at BNL. |

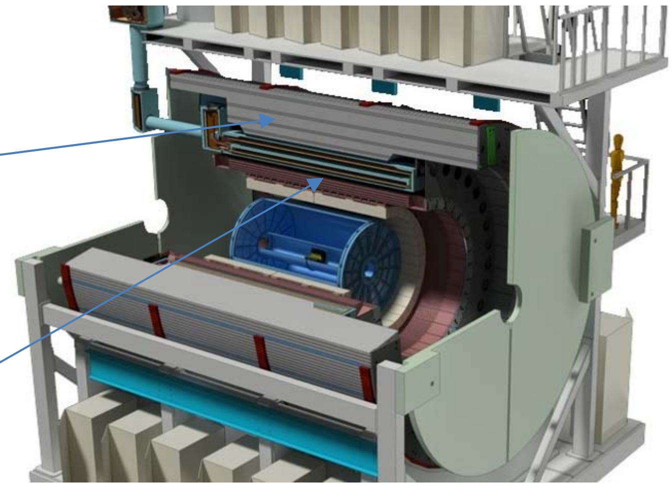
Risk registry currently includes three major items, two of which are rated at moderate risk (all three relevant to inner HCAL).

# Back Up

# sPHENIX HCAL Description




- Outer HCAL $\approx 3.5\lambda_I$
- Magnet $\approx 1.4X_0$
- Inner HCAL $\approx 1\lambda_I$
- EMCAL $\approx 18X_0 \approx 1\lambda_I$

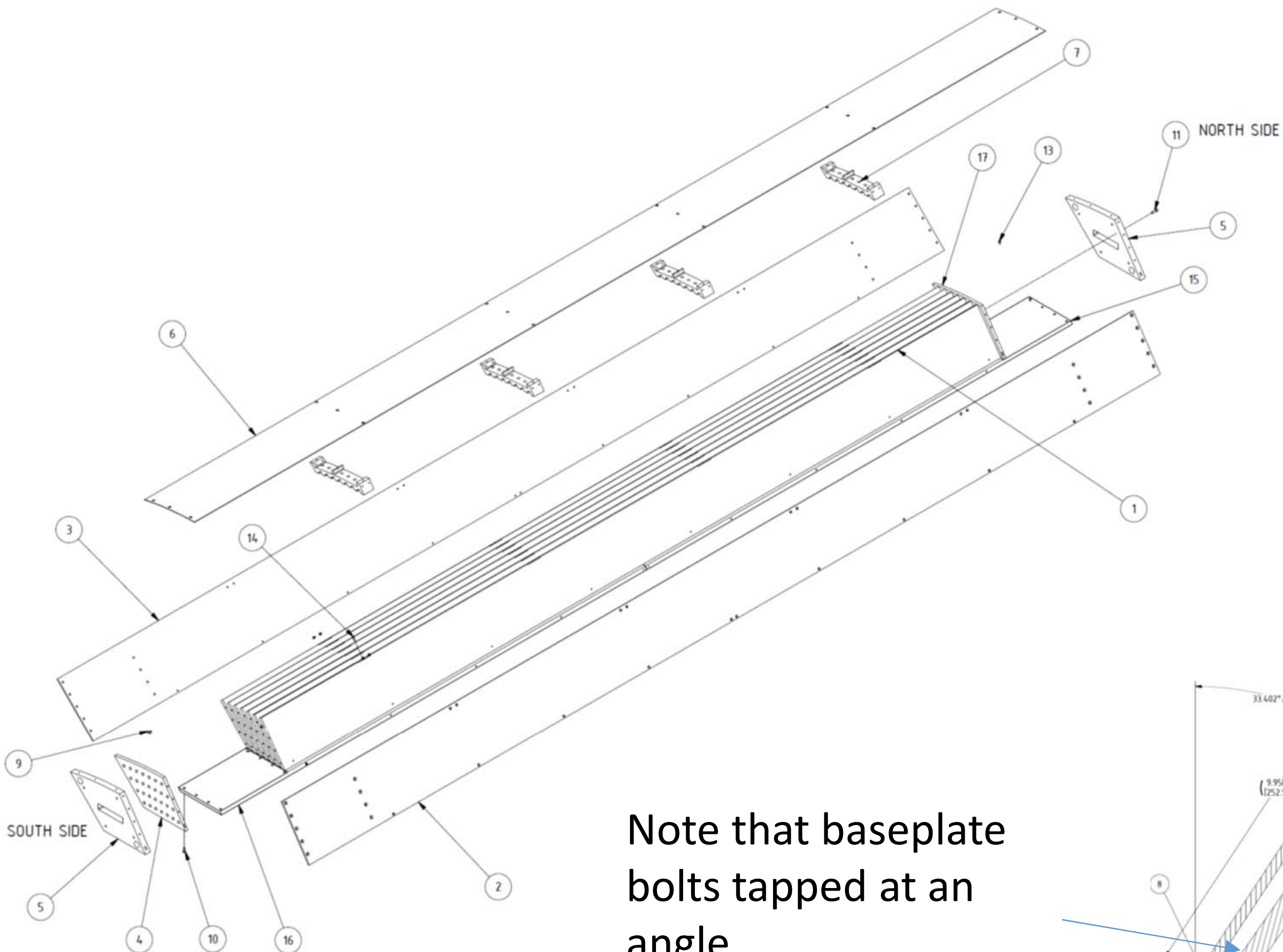


- HCAL steel and scintillating tiles with wavelength shifting fiber
  - **2 longitudinal segments.**
  - **An Inner HCal inside the solenoid.**
  - **An Outer HCal outside the solenoid.**
  - **$\Delta\eta \times \Delta\phi \approx 0.1 \times 0.1$**
  - **3,072 readout channels**
  - **$\sigma_E/E < 100\%/\sqrt{E}$ (single particle)**
- SiPM Readout

# Why a Sector Prototype?

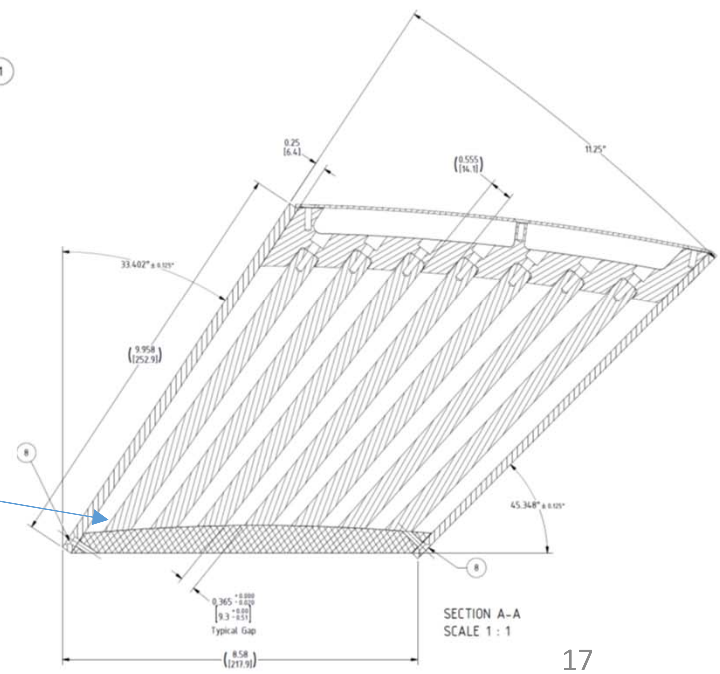
- Need to verify sector cost estimate ($43.6k)
  - Are the estimated machining times/effort reasonable?
  - Are there any unforeseen difficulties?
  - Can the manufacturing process be optimized?
- Sector prototype produced by TSI in Ames, IA (contract from Iowa State)
  - All machining done by TSI (Jeremy Johnston), with exception of combs, which were sent out for wire EDM machining
  - Absorber plates were ordered ground to thickness to reduce bowing/maintain flatness

# Sector Prototype Drawing



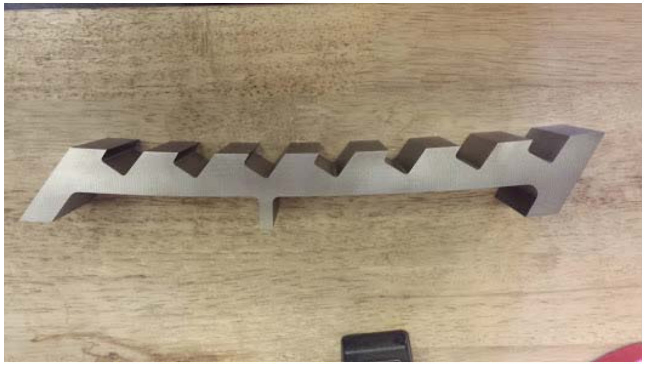

Baseplate and “endcaps” are Al; everything else is S310.

Note that baseplate bolts tapped at an angle



# Some Pictures

Comb (wire EDM)



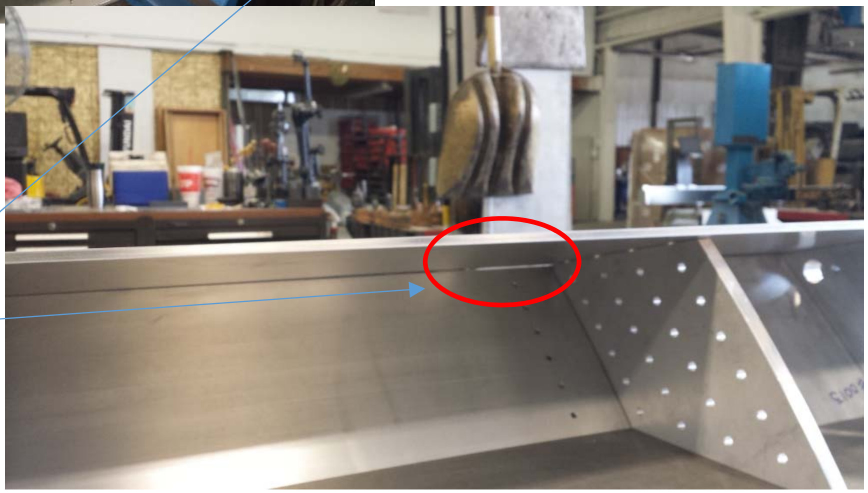
Example of bowing in thin absorber plate (sides), had to be manually straightened.

Al baseplate machining

# More Pictures

Machining baseplate mounting holes in absorber

Test fit of end plates, baseplate and side plates – gap due to bowing in outer plate.



# Finished Product

Light cover
(reflection)

# Assembled Sector Measurements

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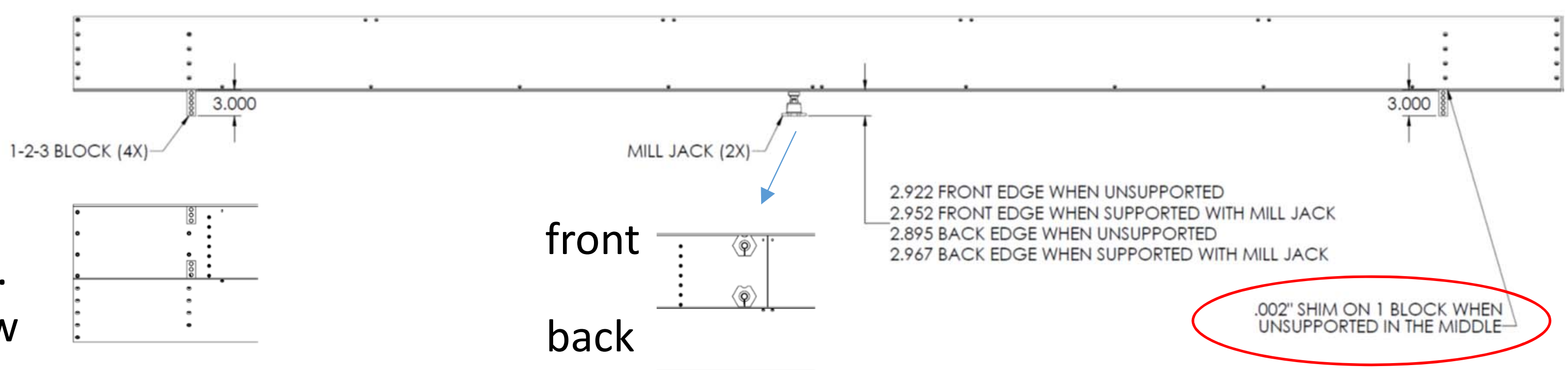
Similar results at 90°F.



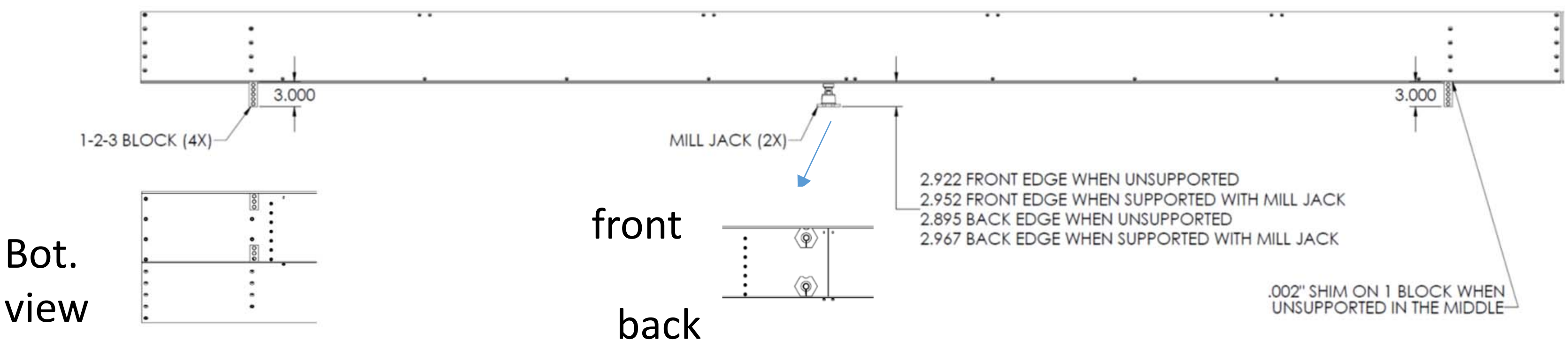

Bot. view

front

back

Very little twist!

# Sector Sag




@ 70°F :

| | Unsupported | Supported |
|---|---|---|
| Front Mill Jack | 78 mils | 48 mils |
| Back Mill Jack | 105 mils | 33 mils |

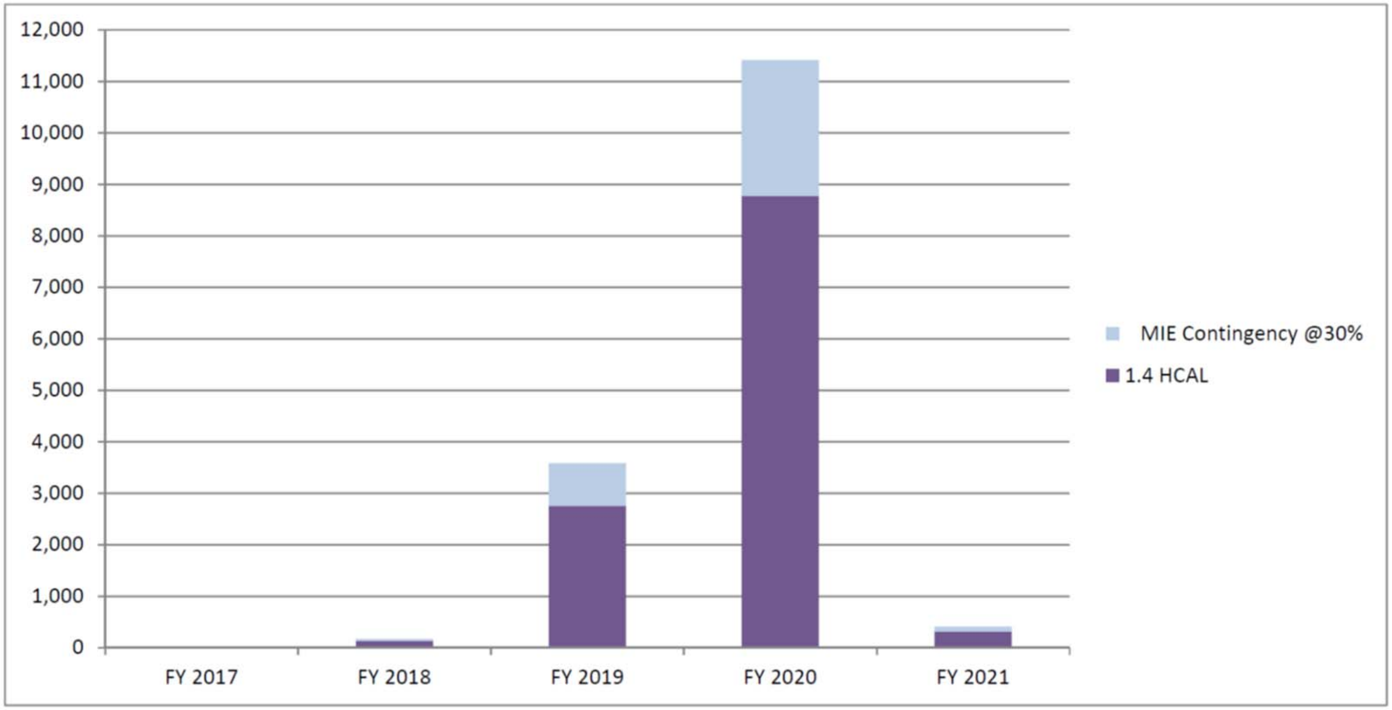
@ 90°F :

| | Unsupported | Supported |
|---|---|---|
| Front Mill Jack | 72 mils | 45 mils |
| Back Mill Jack | 98 mils | 34 mils |

# HCAL Budget Profile

Baseline Scenario

AY k$'s - with Extraordinary Construction Overhead Application (PM Labor in Ops Support)




Baseline Scenario

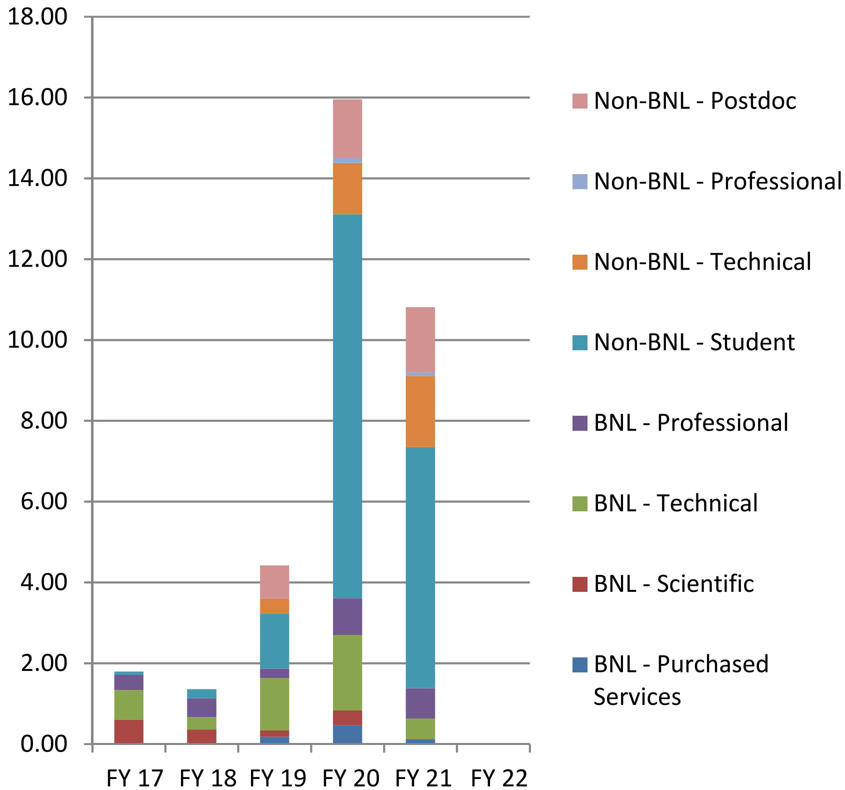
AY k$'s - with Extraordinary Construction Overhead Application (PM Labor in Ops Support)

| WBS | SYSTEM | FY 2017 | FY 2018 | FY 2019 | FY 2020 | FY 2021 | Total |
|---|---|---|---|---|---|---|---|
| 1.4 | **HCAL** | 15 | 129 | 2,752 | 8,777 | 313 | 11,986 |
| | MIE Contingency @30% | 5 | 39 | 826 | 2,633 | 94 | 3,596 |
| | MIE Total | 20 | 168 | 3578 | 11410 | 407 | 15582 |

| WBS | **SYSTEM** | **Baseline** | Contingency(30%) | **Total** |
|---|---|---|---|---|

# HCAL Staffing

## FTE Profile by Category




## FTE Profile by Fiscal Year

| WBS Level | Org Sort | Group | FY 17 | FY 18 | FY 19 | FY 20 | FY 21 | FY 22 |
|---|---|---|---|---|---|---|---|---|
| **1.4** | **BNL** | Purchased Services | 0.00 | 0.00 | 0.18 | 0.46 | 0.12 | 0.00 |
| | | Scientific | 0.60 | 0.36 | 0.16 | 0.37 | 0.00 | 0.00 |
| | | Technical | 0.74 | 0.31 | 1.29 | 1.87 | 0.51 | 0.00 |
| | | Professional | 0.38 | 0.47 | 0.23 | 0.91 | 0.75 | 0.00 |
| | **BNL Sum** | | **1.71** | **1.13** | **1.87** | **3.61** | **1.38** | **0.00** |
| | **Non-BNL** | Student | 0.08 | 0.23 | 1.35 | 9.50 | 5.97 | 0.00 |
| | | Technical | 0.00 | 0.00 | 0.38 | 1.27 | 1.76 | 0.00 |
| | | Professional | 0.00 | 0.00 | 0.00 | 0.12 | 0.10 | 0.00 |
| | | Postdoc | 0.00 | 0.00 | 0.82 | 1.46 | 1.61 | 0.00 |
| | **Non-BNL Sum** | | **0.08** | **0.23** | **2.55** | **12.34** | **9.43** | **0.00** |
| **Grand Total** | | | **1.79** | **1.36** | **4.42** | **15.95** | **10.81** | **0.00** |

# Quality of Estimate

HCal

| SUBSYSTEM | PERCENT OF ESTIMATES | CONTINGENCY |
|---|---|---|
| Engineering estimate | 43 | 0.40 |
| Quotes | 57 | 0.20 |
| Average contingency | | 0.29 |