Sci-Glass Based Barrel Electromagnetic Calorimetry Detector and Integration

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January 2023 ePIC Collaboartion Meeting

January 9-11, 2023

Electron-Ion Collider

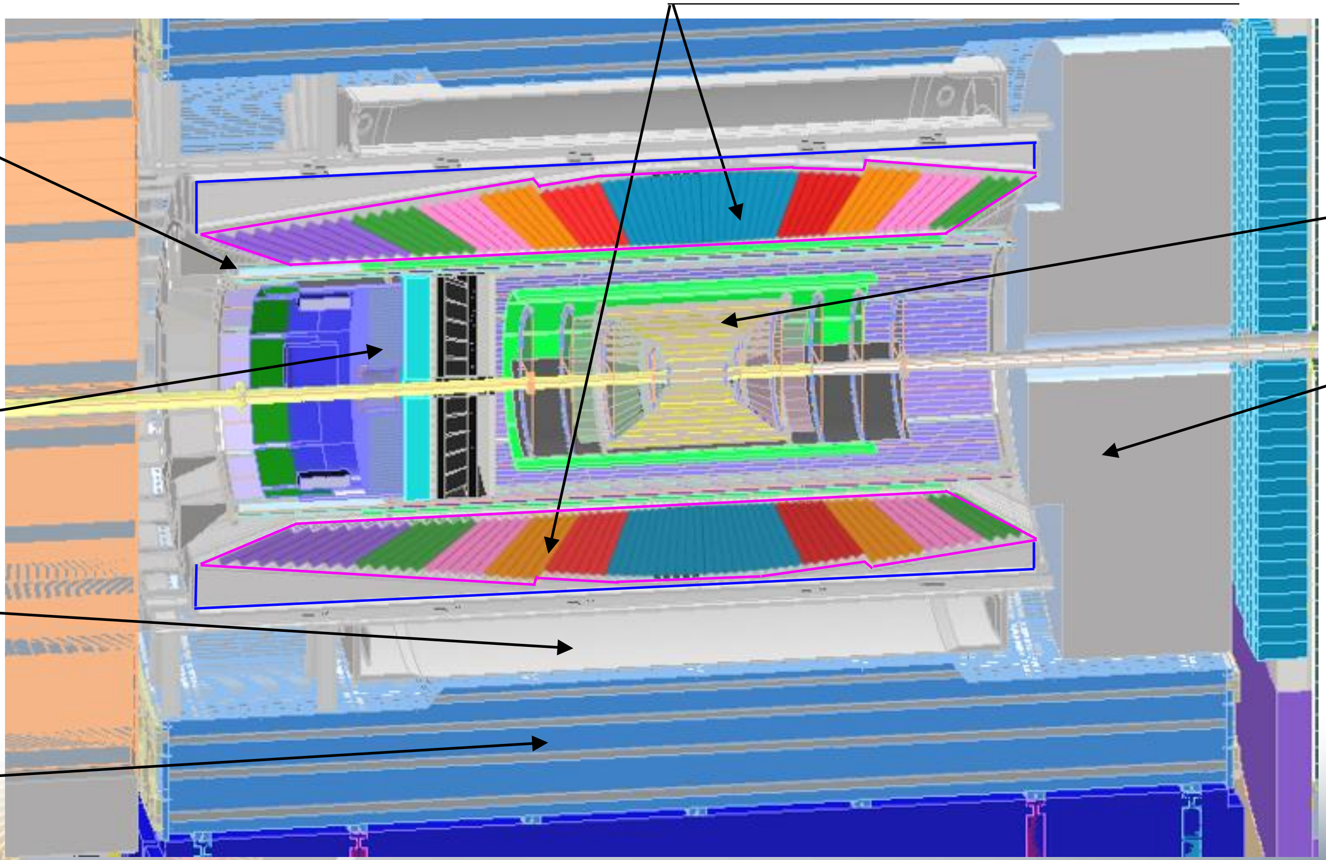
BROOKHAVEN NATIONAL LABORATORY Jefferson Lab U.S. DEPARTMENT OF ENERGY | Office of Science

Introduction

- Development of Glass Scintillator material for use in the EPIC Detector.
  - Recent developments and improvements optical properties and scale-up production.
  - Ongoing beam test campaigns and readout development.
- Design of a Homogeneous Barrel Calorimeter based on the Scintillating Glass.
  - Technical overview
  - Design features.
  - Support structure and integration

Design Considerations

Goal: Provide continuous coverage in EM Calorimetry in particular on the electron going direction.
This talk will focus on the Barrel EMCal.

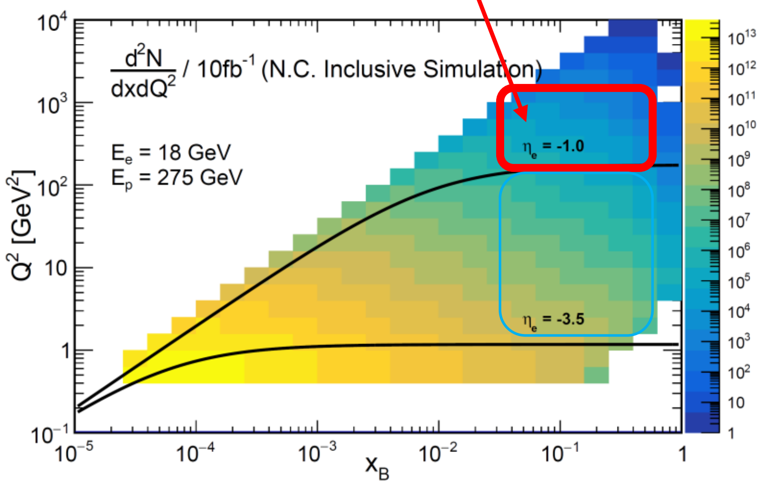


Detector Requirements

- High precision, hermetic detection of the scattered electron is required over a broad range in η and over an energy range from 0.3 to tens of GeV.
  - In the very backward direction high precision is required for electron kinematics measurement.
  - In backward and barrel region it is required for clean electron identification. In the barrel region, driven by high-x and high-Q^2 science drivers.
- Here, we selected Sci-Glass for the barrel as it supports excellent e/h separation due to its good energy resolution, matched to the backward region needs

η	[-4 .. -1.75]	[-1.75 .. 1.3]
Material	$PbWO_4$	SciGlass
X_0 (mm)	8.9	24-28
R_M (mm)	19.6	35
Cell (mm)	20	40
X/X_0	22.5	17.5
Δz (mm)	60	56

Physics kinematic region enabled by the Barrel EMCal



Requirements

- Good energy resolution
  - e.g., region -2 < η < -1 requires ~7%/√E
- e/h separation up to 10^{-4}

Glass Scintillator Production

SCINTILEX

SBIR/STTR DE-SC0020619

- Scintilex in collaboration with the VSL at CUA has made much progress with the development and fabrication of Sci-Glass over the last 3 years
- Scintilex has an SBIR phase-II award to start large-scale production of larger blocks (40+ cm, rectangular and projective shapes) to meet the specific schedule of the EIC
- Sci-Glass of length 20cm can now be produced reliably and 40cm long blocks can now be produced routinely – so far we have received 3 lab size batches (10-20 samples), most recently 10 blocks of 40cm length and 16 more blocks are anticipated early in 2023


SciGlass Scale-up production

Custom fabrication setup for 40cm SciGlass

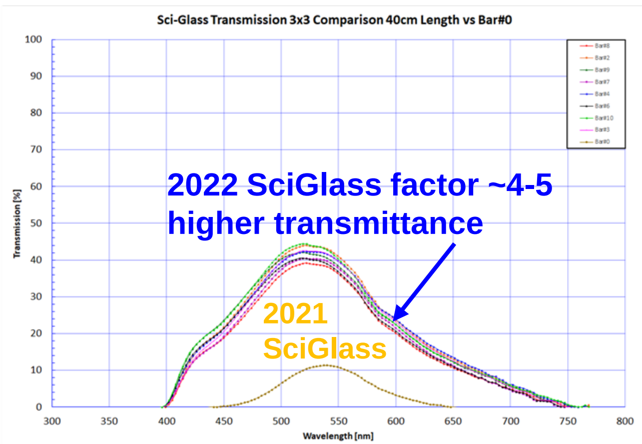

Glass pouring into the mold at Scintilex/VSL

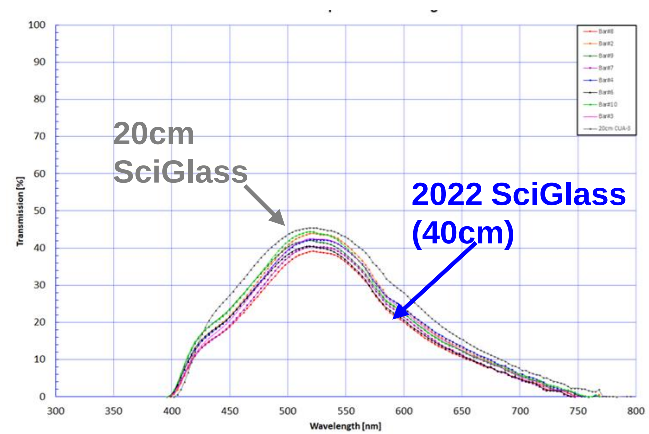

SciGlass 40cm before polishing

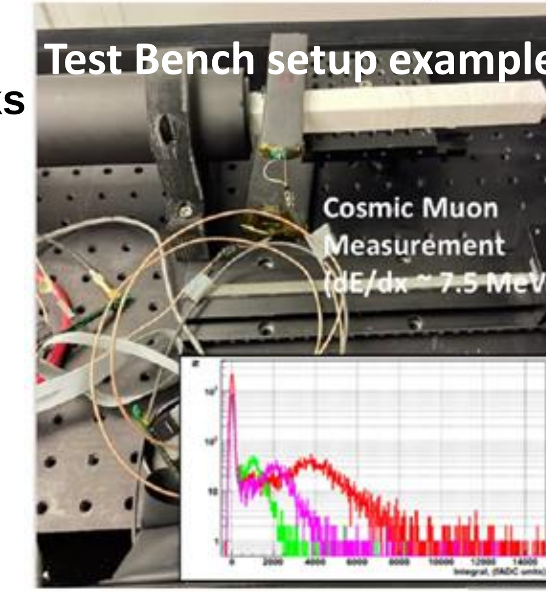

After polishing

Sci-Glass Characterization

Longitudinal Transmittance of 40cm (and 20cm) long glass blocks







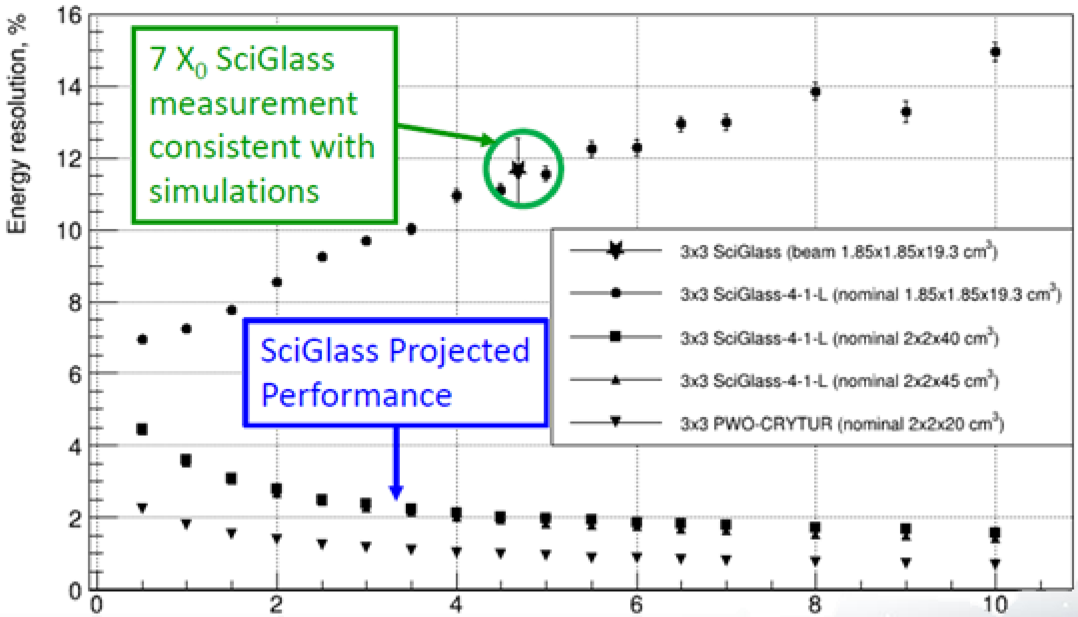
- Significant improvements made in 40cm Sci-Glass performance within one year – now reaching ~45% peak value along the block
  - Maintaining and optimizing optical properties is of the most significant challenges in scaling up scintillating glass for nuclear physics.
  - Test Bench: optical characterization and response to comics and radioactive sources allows for rapid feedback and optimization of glass production
- Further improvements in transmittance anticipated after new glass production method (e.g., an alternative crucible) is implemented

3x3 Prototype tests Completed

SciGlass development is supported by SBIR/STTR DE-SC0020619

Test Stand Prototype Installed in Hall D

- Prototype 3x3 array installed and tested – energy resolution measured for three different beam energies
- **Results for ~7 X_0 blocks – matches with Geant4**
- **Ongoing 2022: Test with ~15X_0 (40cm) Long Blocks**

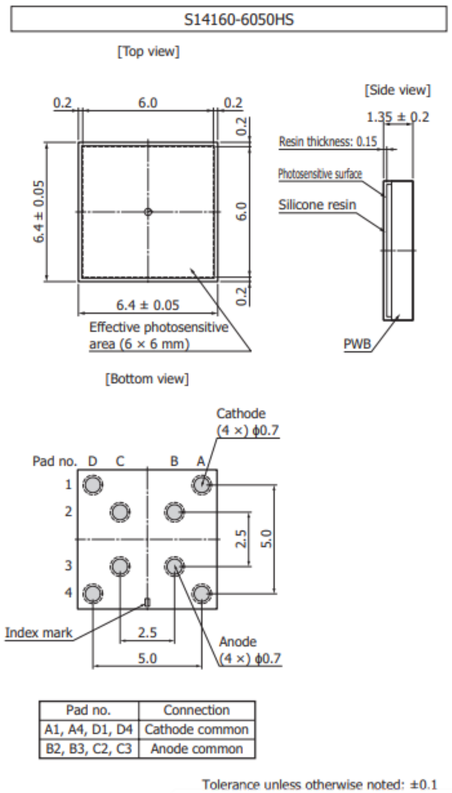


5x5 Prototype 40cm Beam Test Campaign Planned for Spring 2023

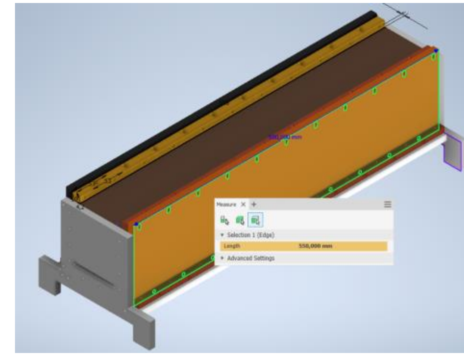
- On schedule for beam test campaign in early 2023 at Jefferson Lab.
- Towers are constructed with SiPM readout modules utilizing S14160-6050HS from Hamamatsu.
- Utilizing 25 of 2x2x40cm blocks.

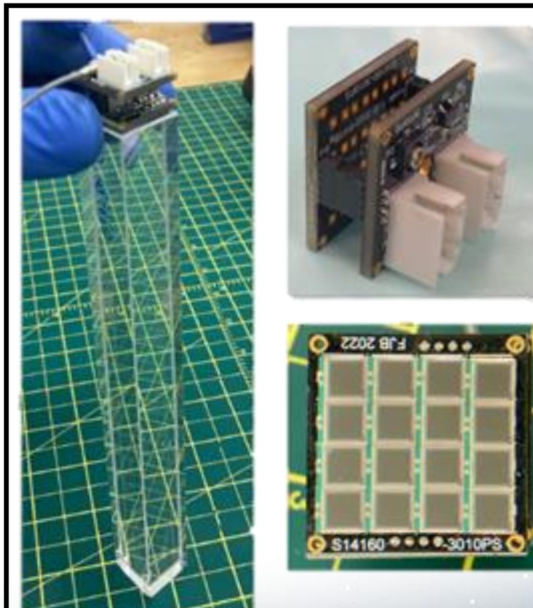
The 5x5 prototype readout test will allow for:

- Characterization of the transverse shower development
- Optimization of the readout (SiPM matrix and services).
- Provide feedback for implementation of the process for production and performance comparison of different glass geometry shapes.



Photosensitive Area	6x6 mm²
Pixel Count	14331
Pixel pitch	50μm
Peak Sensitivity	450nm
Gain (typ)	$2.5x10^6$



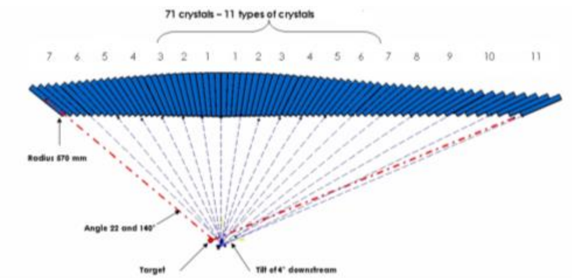


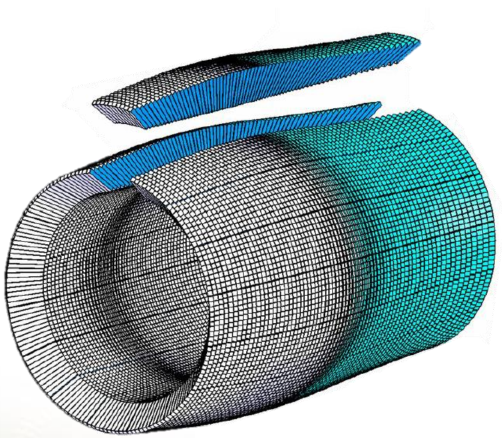
Initial test design using HA 14160-3010PS

EIC Barrel EMCAL Mechanical Design

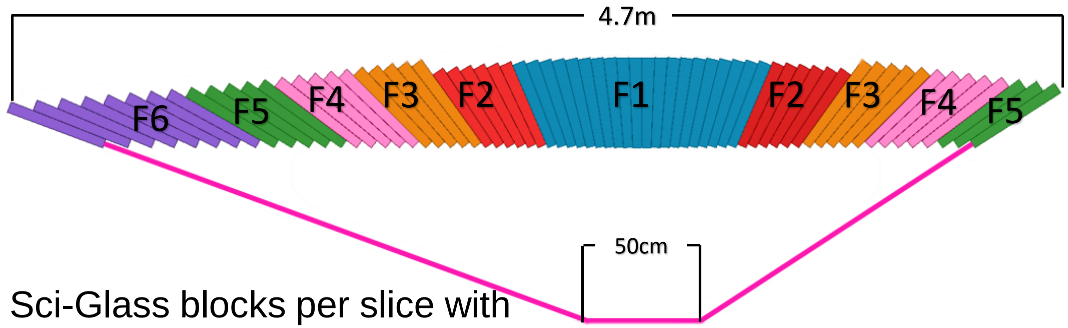
The design is based on that of the PANDA Barrel EMCAL taking into account the different needs of the EIC

- PANDA

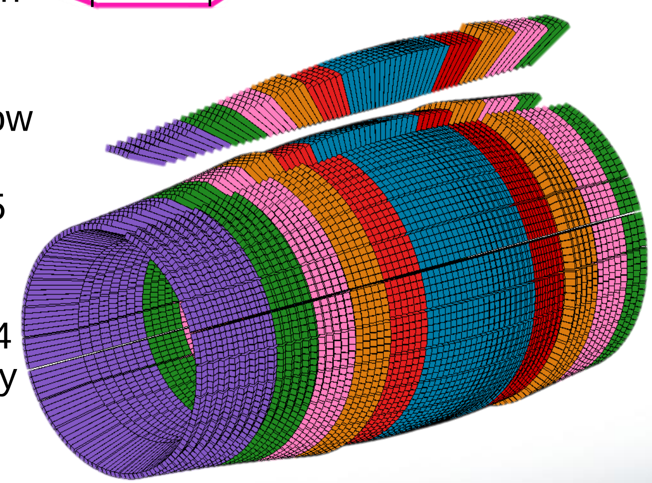




- EIC BEMCal

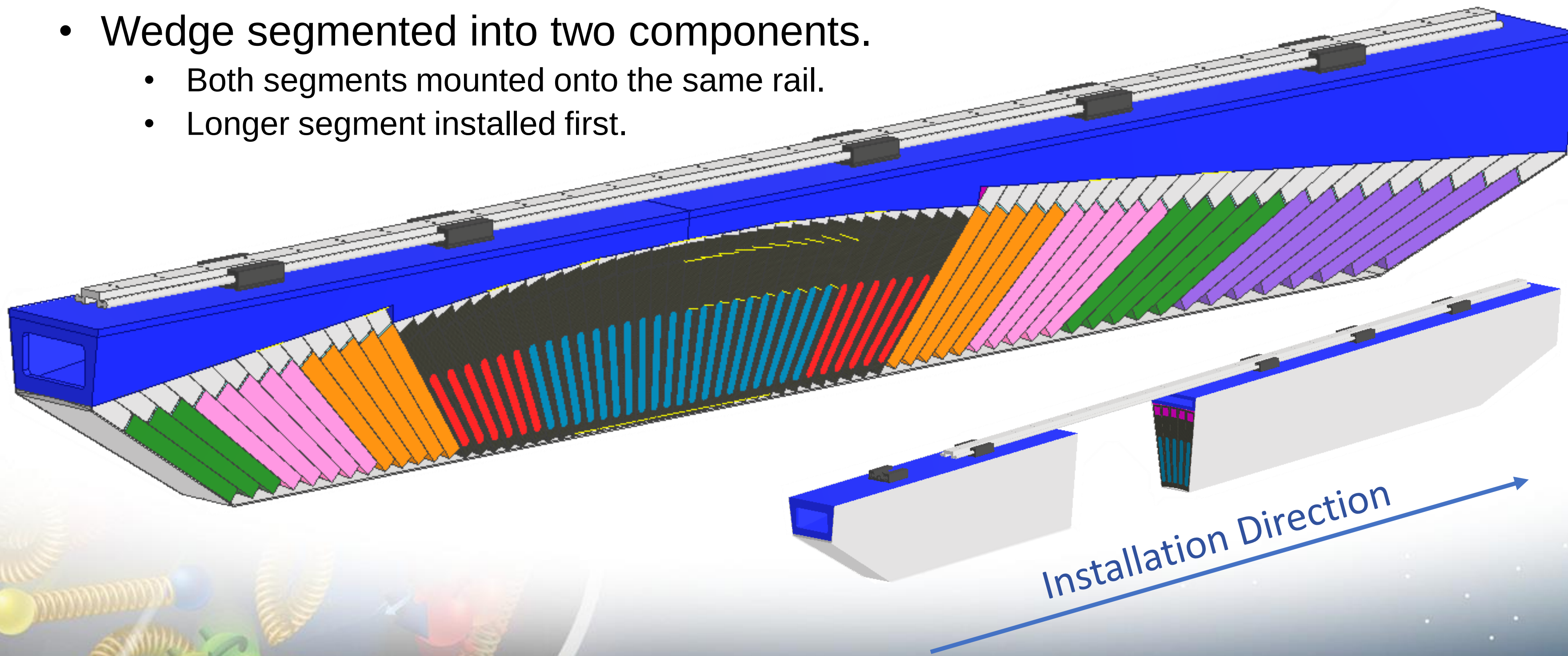


- 68 Sci-Glass blocks per slice with 6 family variations.
- Central section (family 1 & 2) reduced in length to 40cm to allow for clearance others at 45.5cm.
- Slices combined into groups of 5 separated by 2.811° radially to produce a wedge
- 120 slices combined to create 24 wedges separated by 15° radially (see next page)
- Central region of 50 cm considered due to non-fixed target.
- Currently 8,160 towers to complete the barrel



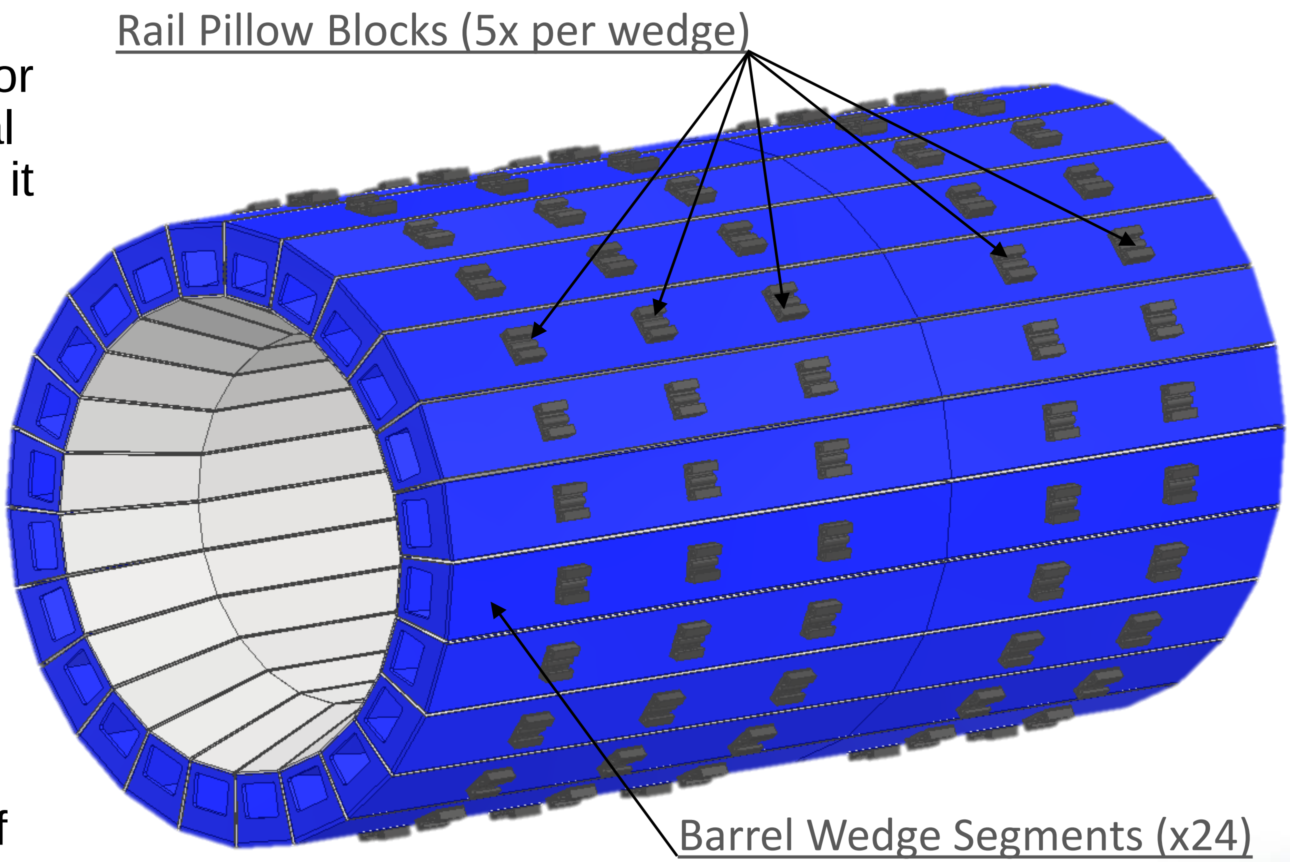
Full Wedge

- Each wedge weighs 1500kg including Sci-Glass and Aluminum.
- The wedges are then covered with a 3mm plate which connects to the sides of the support beam.
- Wedge segmented into two components.
  - Both segments mounted onto the same rail.
  - Longer segment installed first.



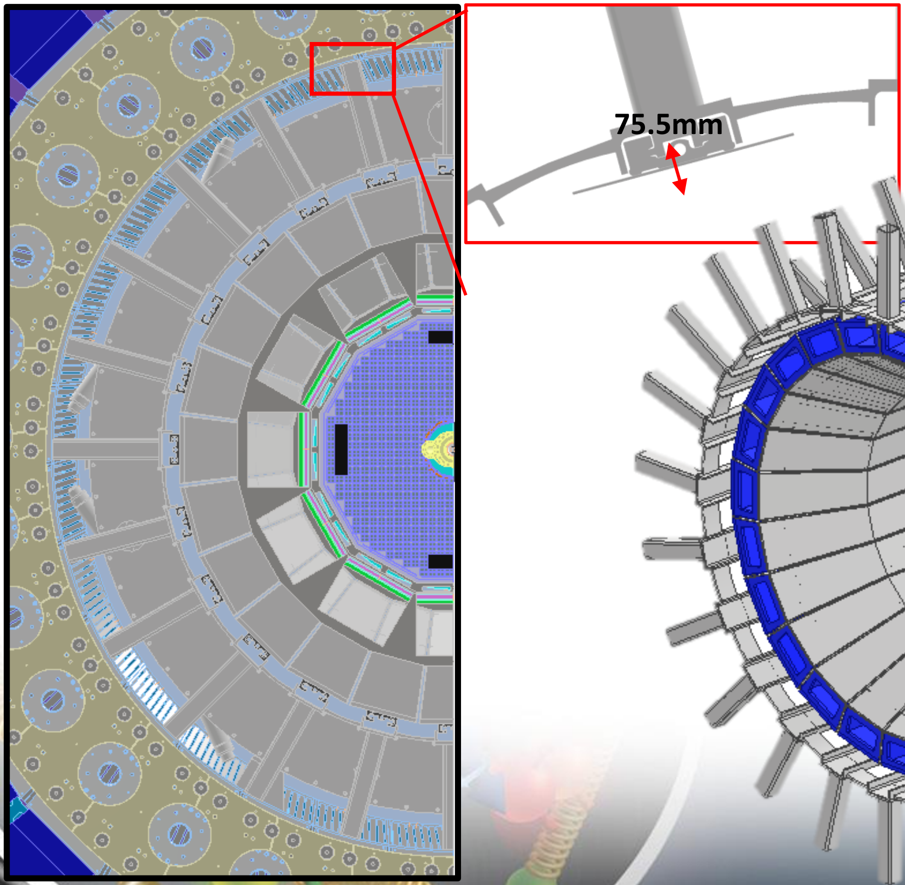
Barrel EMCal Mechanical Design Summary

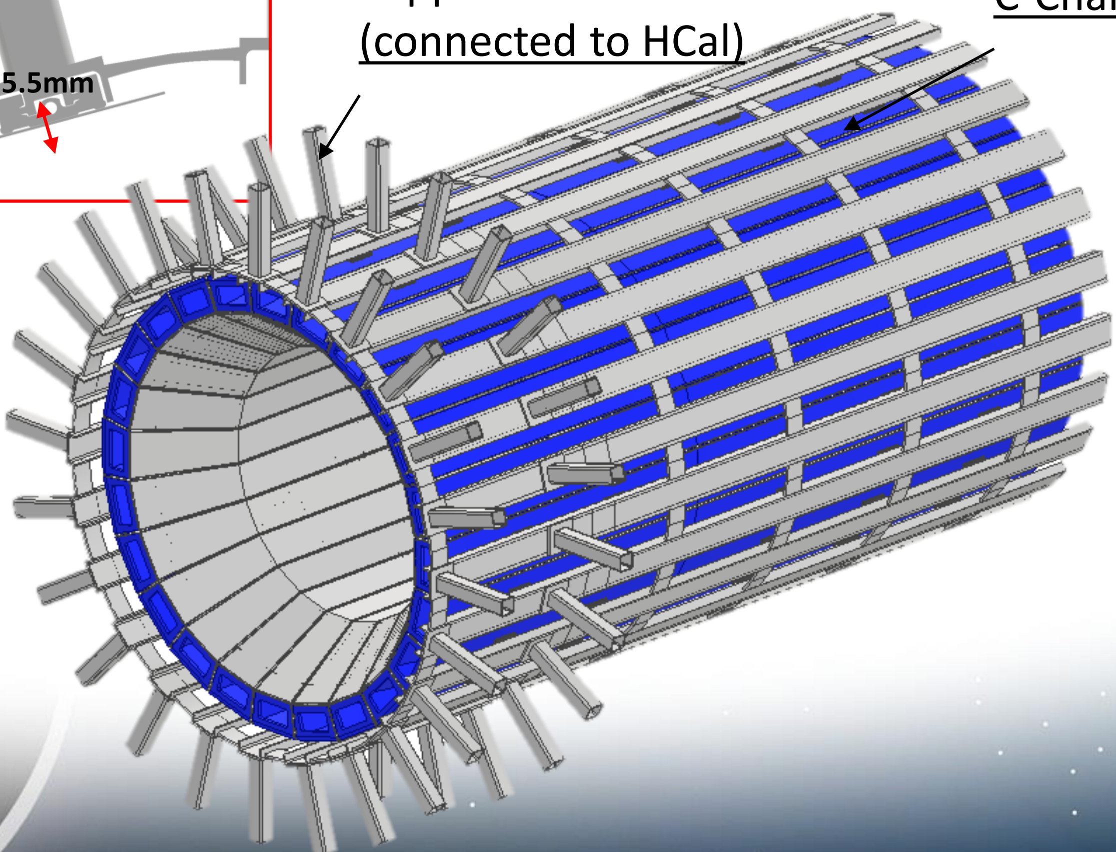
- Overall Barrel detector supported by external frame that surrounds it and attaches to the Barrel HCal inner surface
- In order to allow for maintenance the detector is segmented into 24 wedge segments which can be removed individually by extracting them along the long axis of the detector.



External Support Structure

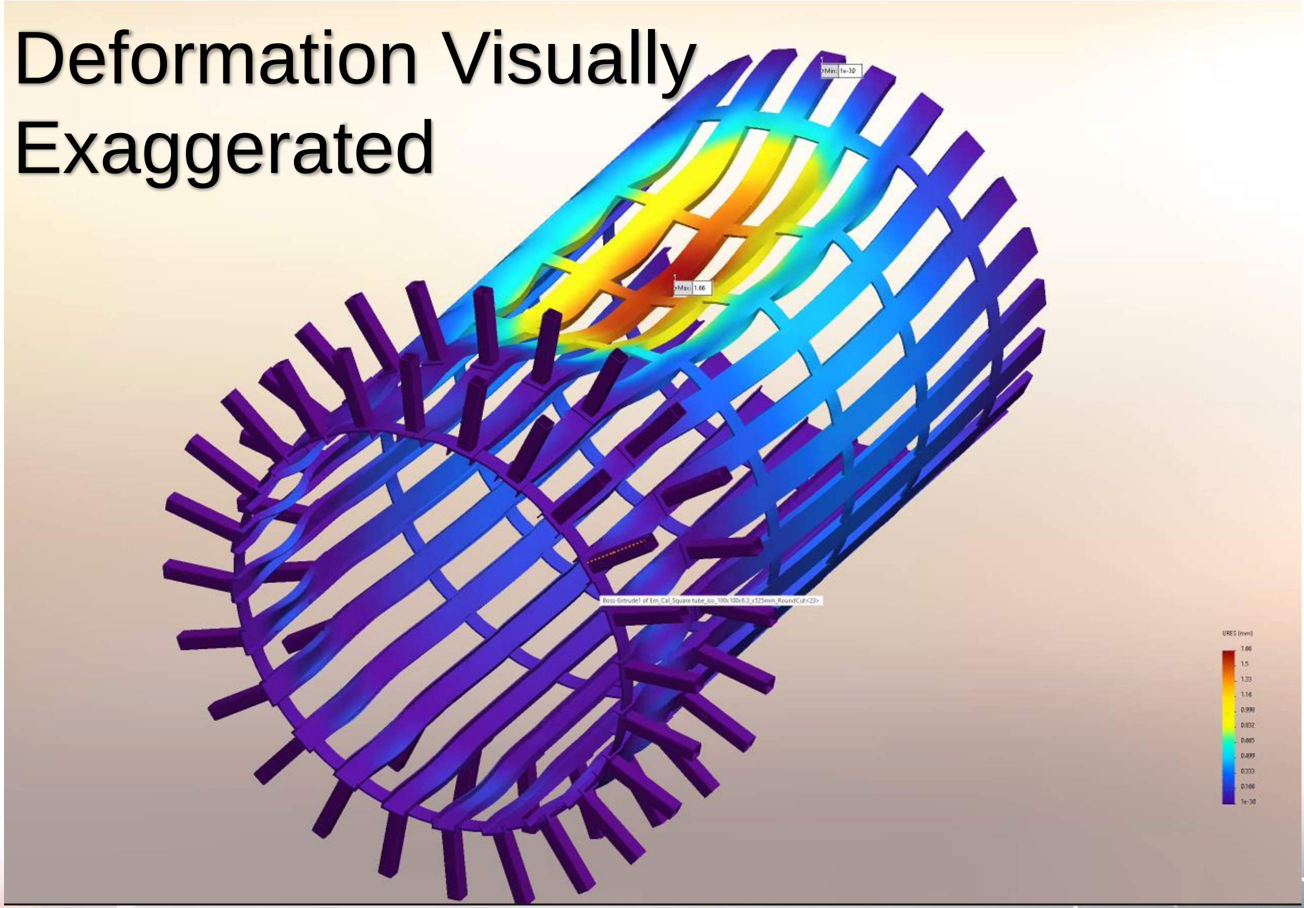
- **Goal: Transfer the load from the wedges to the inner radius of the HCAL via support members at both ends of the detector.**
- In our design, individual wedges segments are loaded along the longitudinal axis into the support frame





Support Structural Simulation

- Latest simulations with the support frame constructed of stainless steel results in a maximum deflection of 1.6mm under full load (all 24 wedges implemented)



Consortium Electromagnetic Precision Calorimetry

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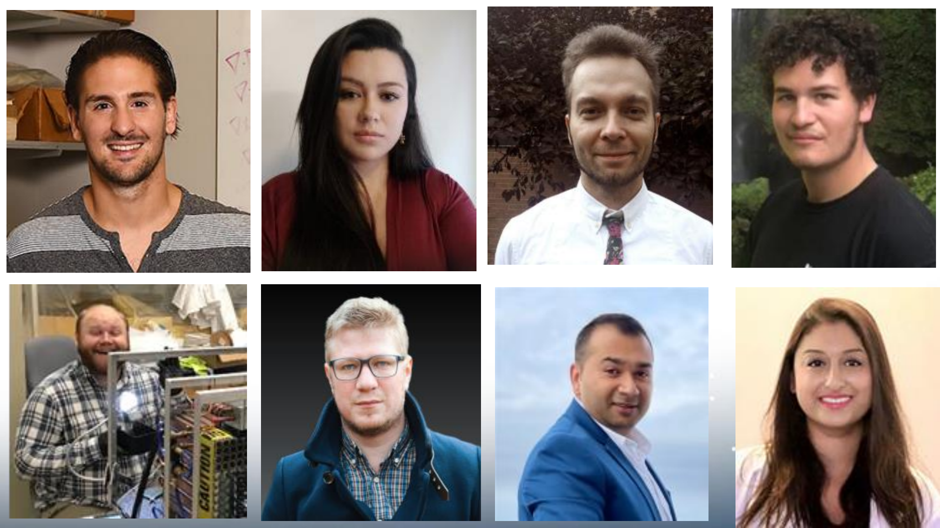
JMU JAMES MADISON UNIVERSITY
Jefferson Lab

EEEMCAL

+ possible additional institutional interest

AUGUSTANA UNIVERSITY
University of Colorado Boulder
UNIVERSITY OF ILLINOIS URBANA-CHAMPAIGN

Experienced team of institutions (AANL, CUA, FIU, JMU, UK, MIT..) including **many early-career researchers** working on design, simulation, and prototypes.



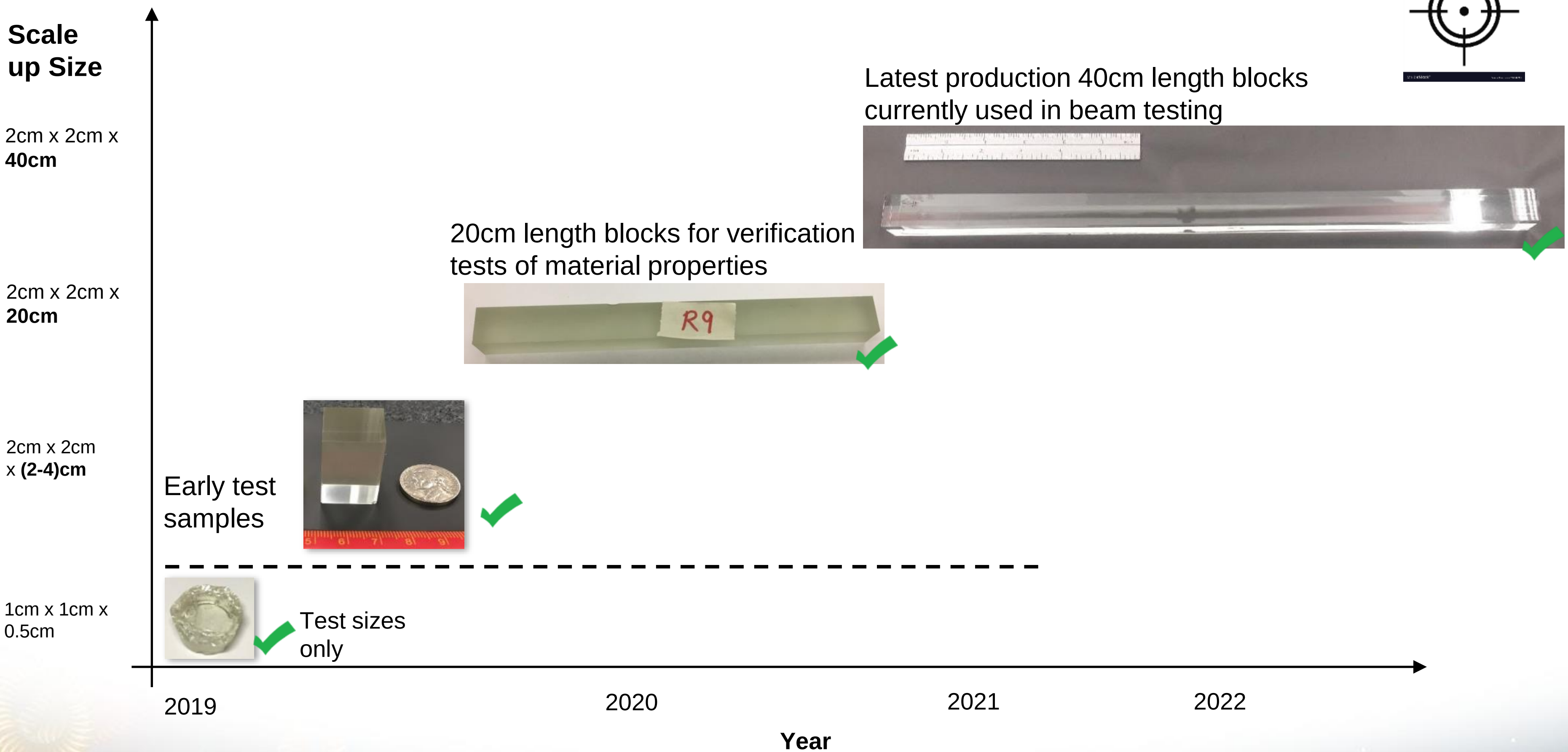
Summary

- **Scintillating Glass R&D is nearing completion –progress in manufacturing process**
  - Characterization of longitudinal light transmission and radiation tolerance.
  - Successful beam test with 3x3 prototype of 20cm blocks.
  - Validation of scaled-up blocks (40cm) with test beam is ongoing. Studies also include characterization of optical properties and block size optimization.
  - Studies are ongoing to understand production times for uniformly shaped blocks and those with projective geometries as well as the impact of using an external foundry for production.
- **Mechanical model for the Barrel is maturing with efforts in integrating the design smoothly into the overall detector.**
  - Good initial pass model setting interaction points and volume constraint requirements.
  - Further mechanical modeling and tests are planned for the upcoming year.
  - More physical details will be added as more information becomes available.

Thank You!

Glass Scintillator Scale-Up

- Significant progress made over the past years.



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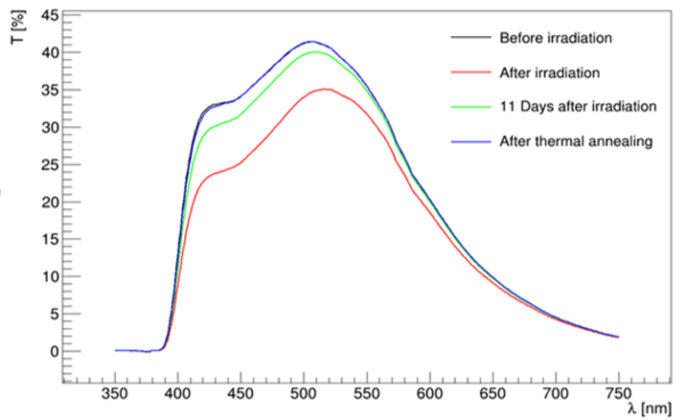
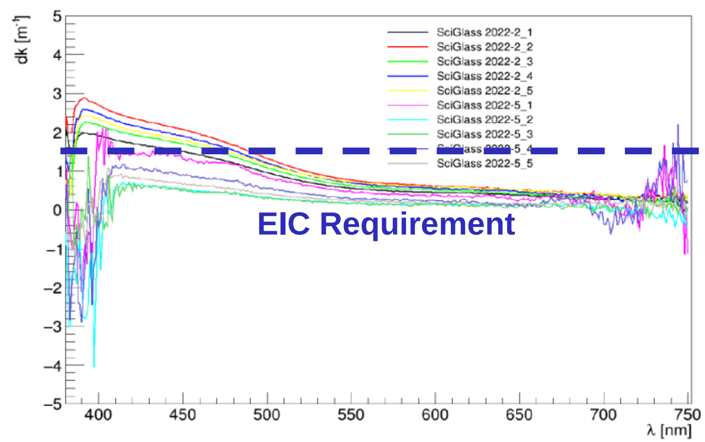
Sci-Glass Radiation Tests

Sci-Glass Bars fulfill the radiation hardness requirements of the EIC

Transmittance before and after irradiation



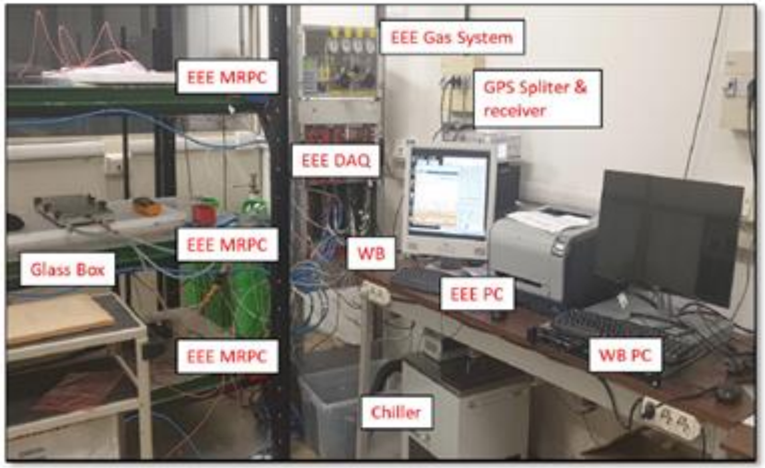
Radiation Induced Absorption Coefficient

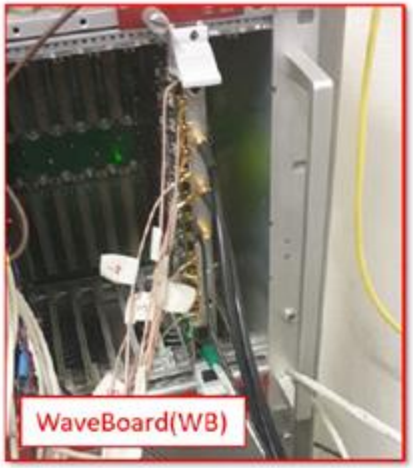


IJCLab Irène Joliot-Curie Laboratoire de Physique des 2 Infinis

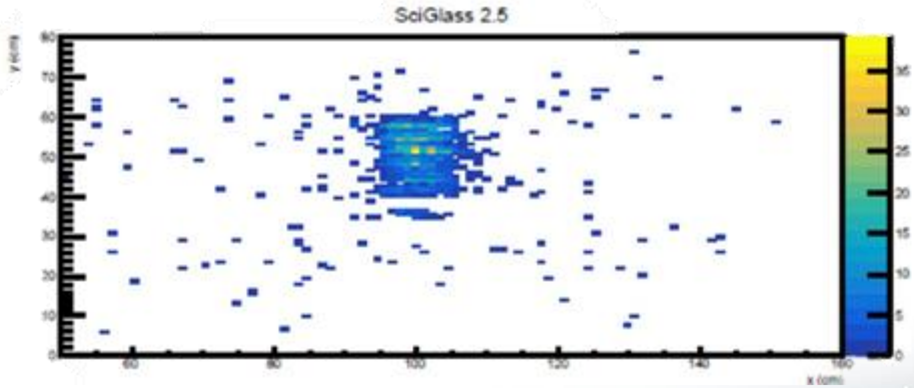
- Sci-Glass has been shown to be radiation hard up to 1000 Gy (highest dose tested to date) EM radiation
  - Also radiation resistant up to 10^{15} n/cm^2 hadronic irradiation (not shown here).
- Shown here are studies with 20cm bars exposed to 30Gy at a rate of 1Gy/min.
- Further tests will be conducted with 40cm samples.

Testbench measurements with SiPM

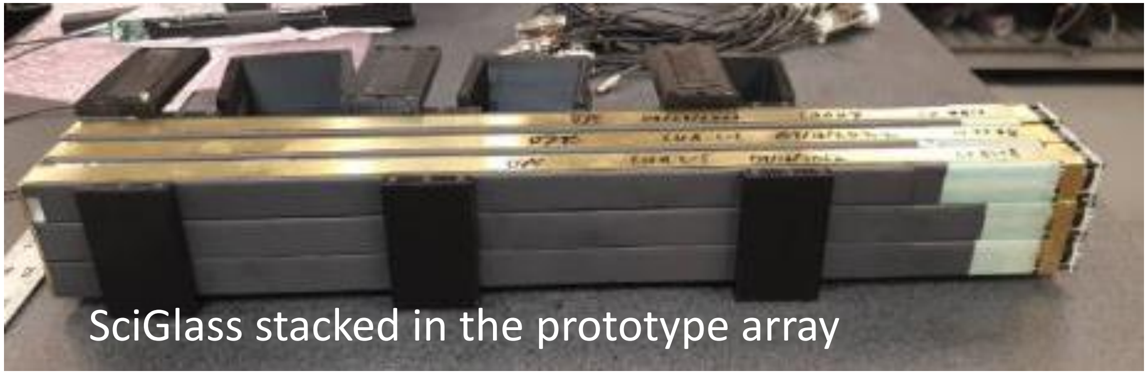


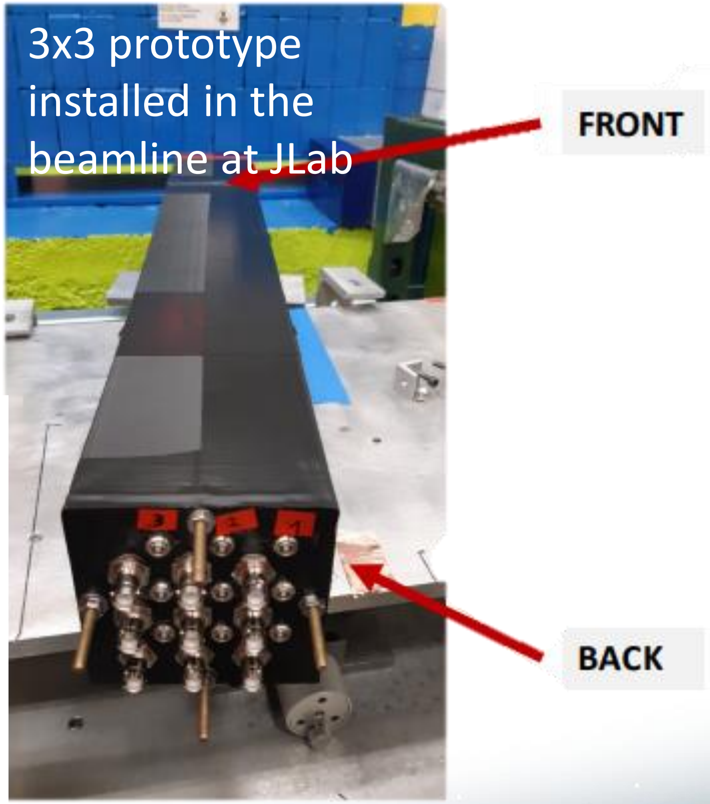


- Cosmic muon trajectories are tracked by three EEE Multi-Gap RPC ALICE-Like.
- Signals are collected by 10 Wave Board (trigerless mode) channels.
- Online event filtering: Waveformes are collected only if a trigger from EEE DAQ branch is present.
- EEE data and WB data have a GPS timestamps for (absolute) synchronization.

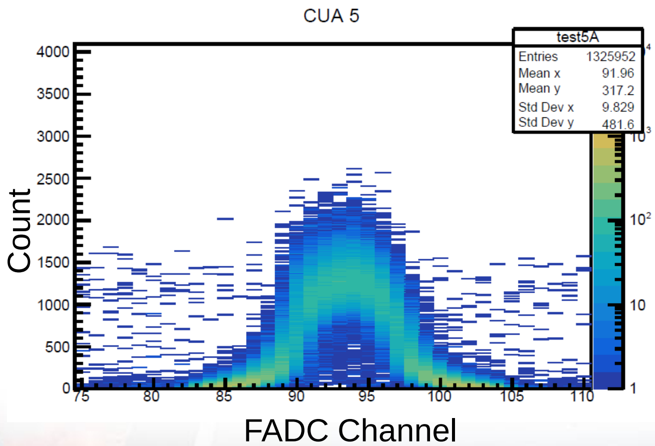


3x3 Prototype 40cm Beam Test Campaign Currently Ongoing





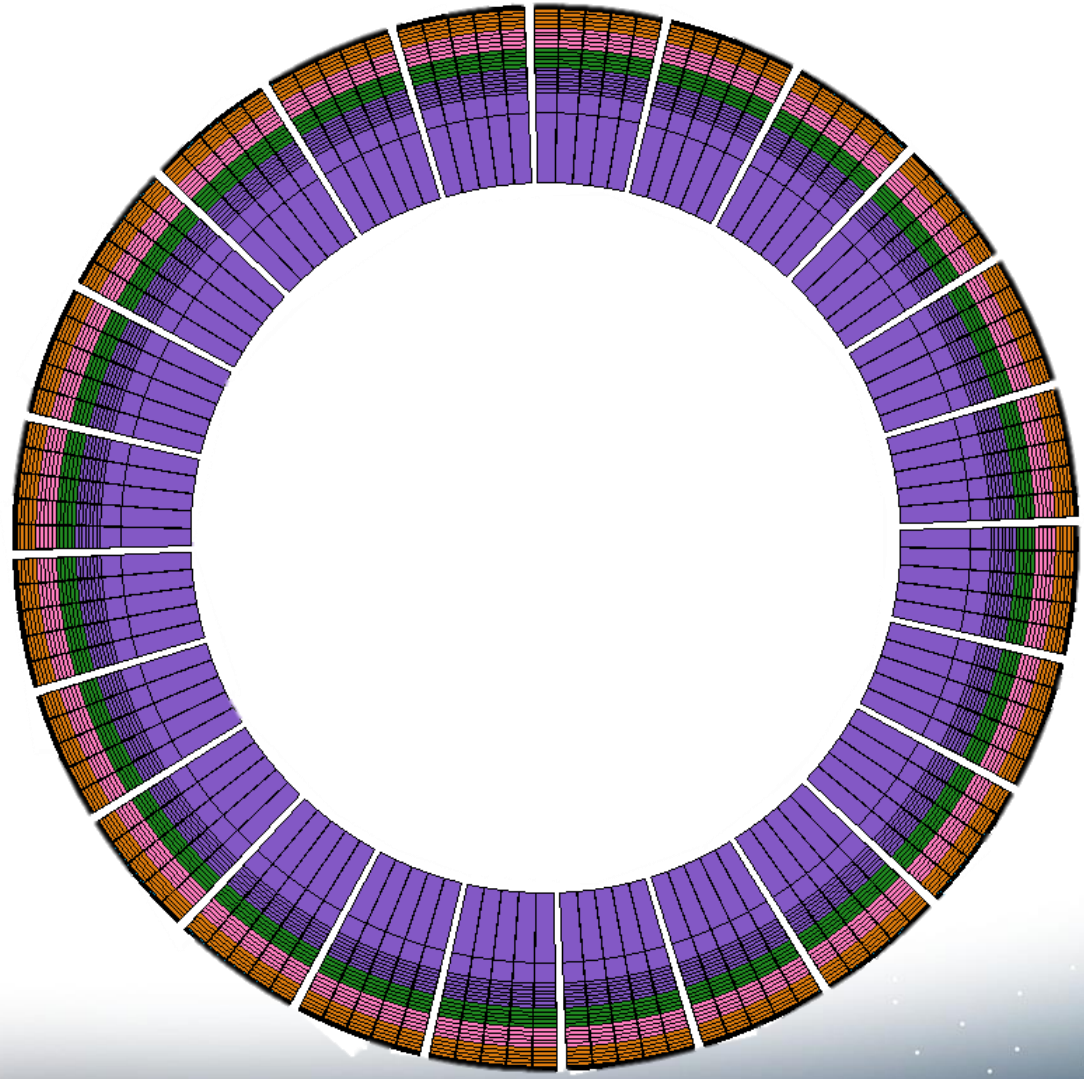
- All 9 channels were operating as expected – here, we show the amplitude spectrum for the central block
- Commissioning completed successfully
- Data acquisition, processing, and analysis ongoing now.



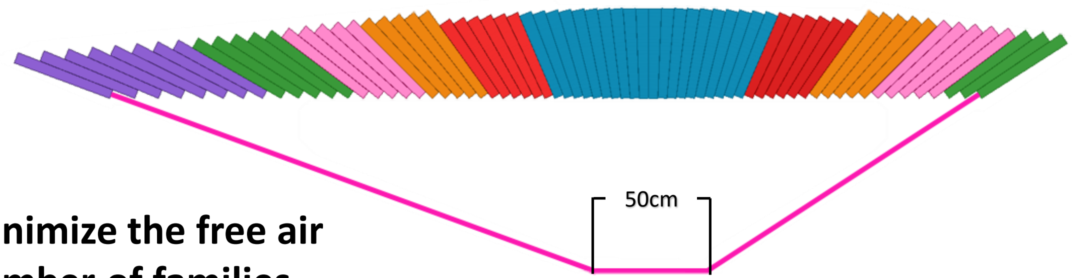
Wedge Azimuthal Profile

Goal: Allow for Maintenance of the Barrel Calorimeter.

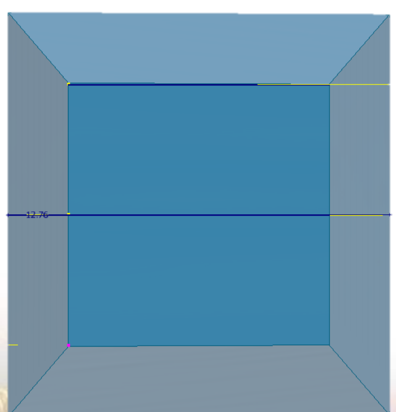
- Wedges separated to allow for clearance when maintenance is required.
- For clearance reasons there should be no more that 5mm of deflection in the wedges near the 3 and 9 o'clock positions.
- This has been validated, with simulations including the external support frame.
- Each wedge covered with a thin (3mm) sheet of aluminum to protect internal structure.

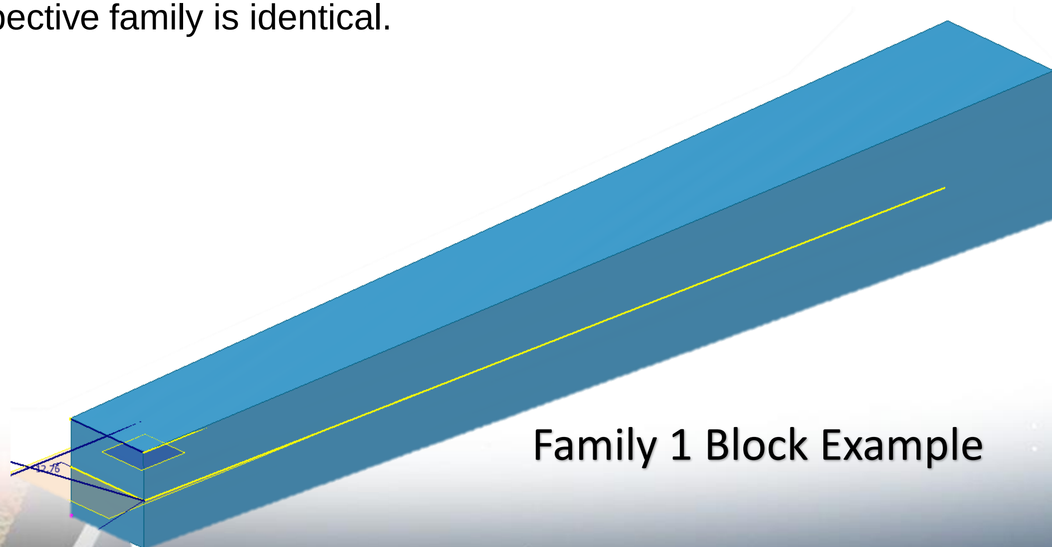


Sci-Glass Families



- **Goal: Design the Sci-Glass Families to minimize the free air gap between the blocks with optimal number of families**
- The Sci-Glass Family Characteristics.
  - Based on a original rectangular prism 4x4x45.5 or 4x4x40 cm.
  - Long axis angular deflections (flare) set to allow the centerline axis of each family starting and ending block to pass through the correct point in the 50cm region.
  - Rotational axis angles determined by family to allow for the trailing end radial surfaces of each family end block to be parallel with their radial neighbors.
  - Both angles combined produce a truncated rectangular pyramid.
  - Each block within the respective family is identical.

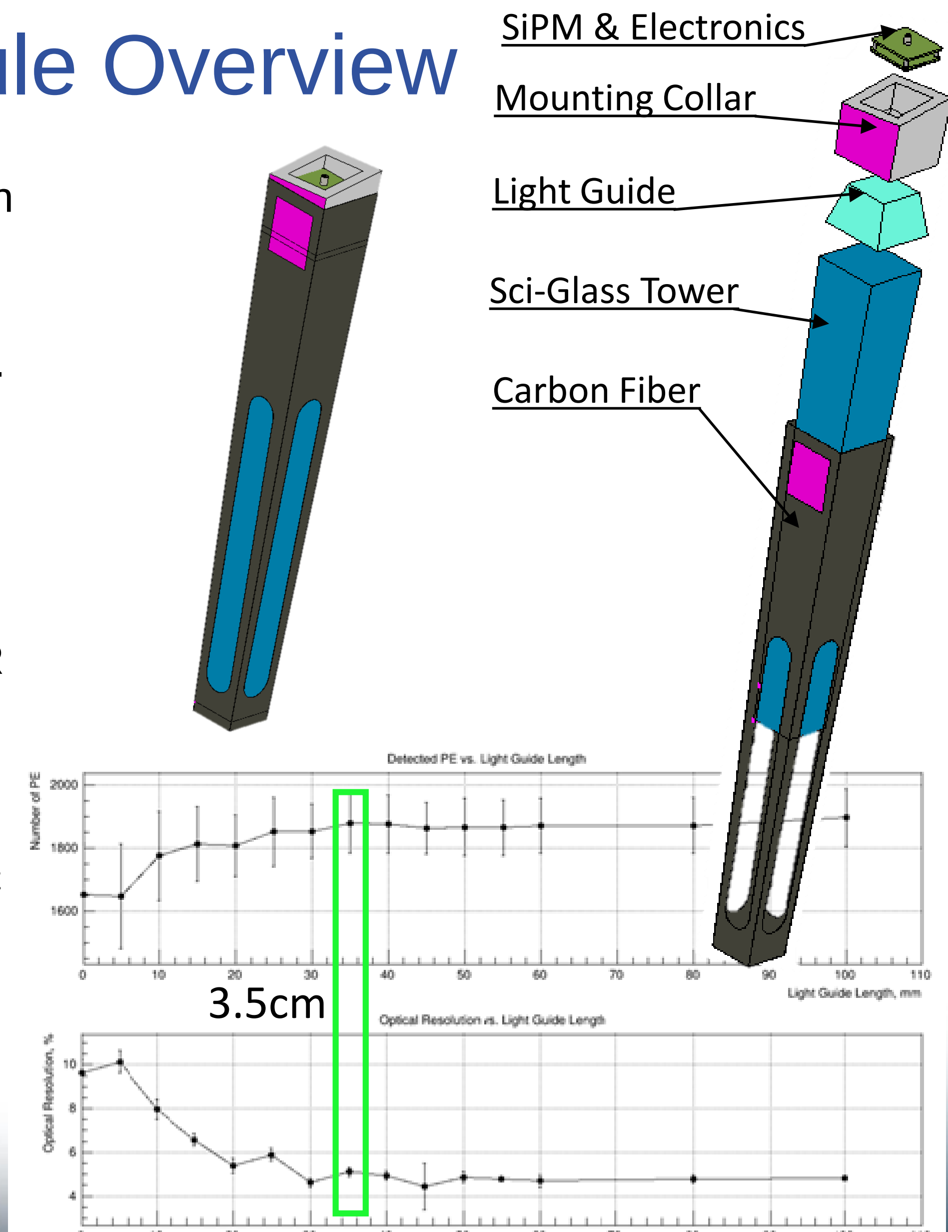




Family 1 Block Example

Sci-Glass Tower Module Overview

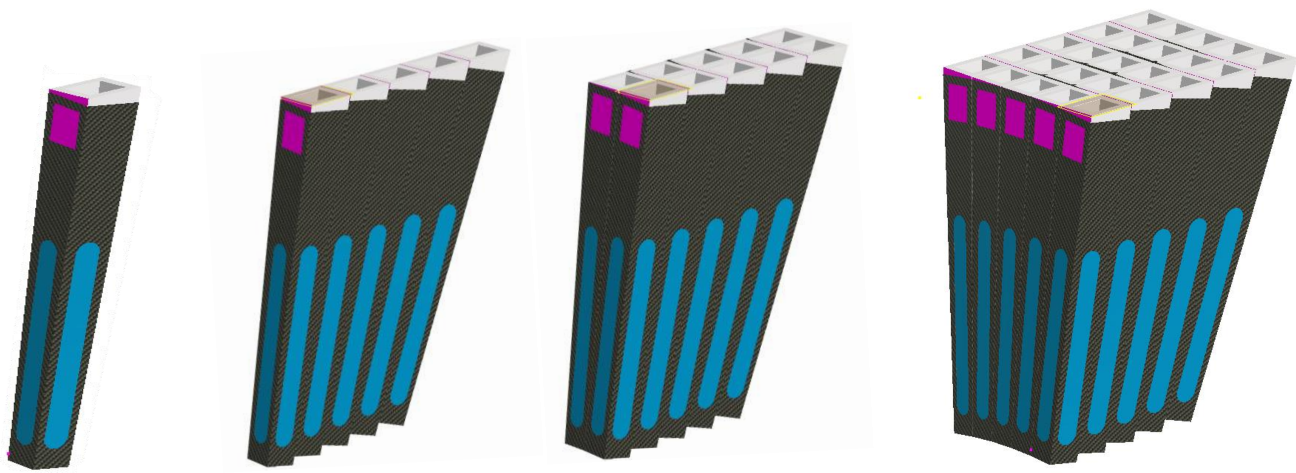
- The blocks are encased in tapering carbon fiber tubes forming a grid structure.
  - Wall thickness 0.25mm.
  - Blocks grouped into “SuperModules”.
- Light Guide of PMMA Acrylic with a length of 3.5cm used to connect the Sci-Glass towers to the SiPM reducing the surface area of tower.
- Sci-Glass wrapped in both Reflective ESR material and light tight Tedlar.
- Aluminum mounting collar is glued to the carbon fiber tube.
  - This transfers the load of the tower to the support structure on the outer radius of the wedge.
- SiPM and electronics inserted into the support Collar.

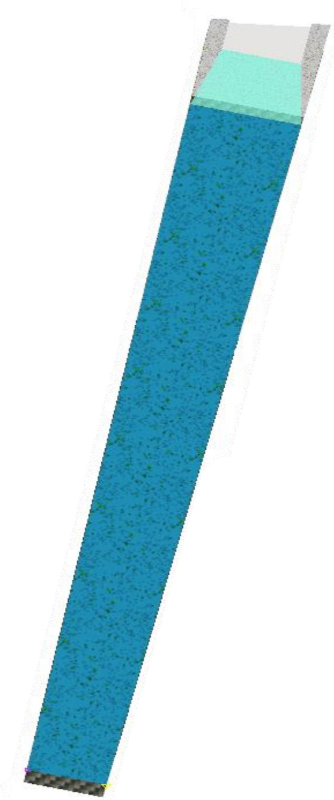


Light guide optimization simulation

SuperModule Assembly Process

- Each Tower is assembled individually, then towers are grouped together into full SuperModules.
- Each SuperModule being sufficiently supported it can then be attached to the support beam.
- Once the SuperModules are loaded they can be fitted with their electronics and cabling.

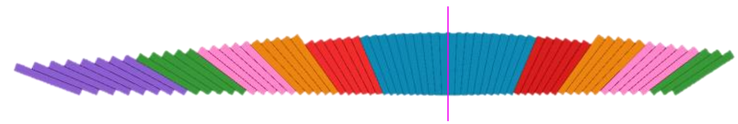


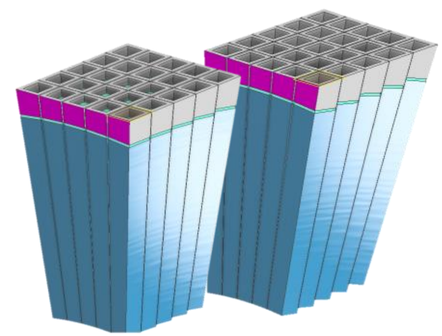


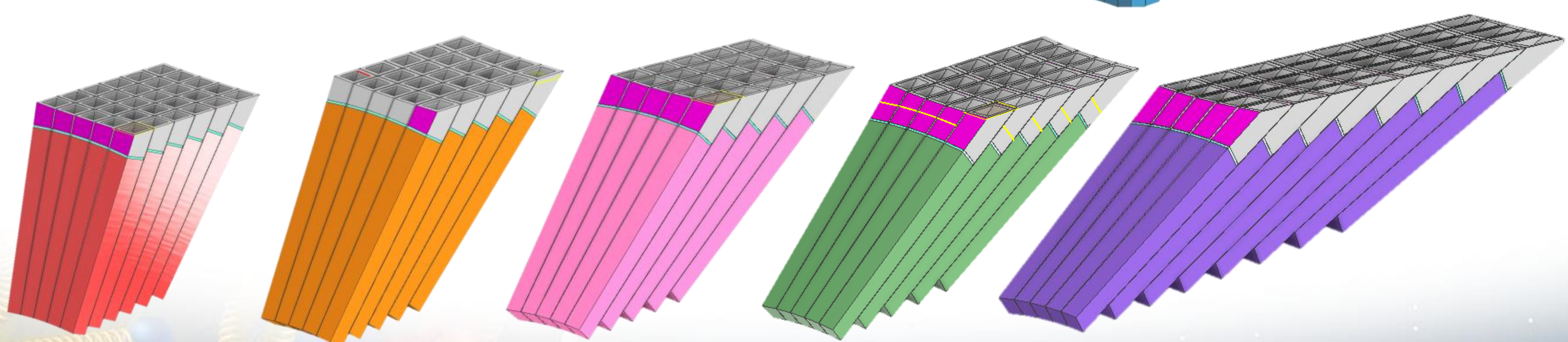
Process →

Family SuperModules

- Design variants of family SuperModules
  - Families are mirrored across the detector midline.
  - Family six only occurs in the electron going direction of the barrel
  - Family 5 is shortened to 3 towers in length on the hadron going end of the barrel.

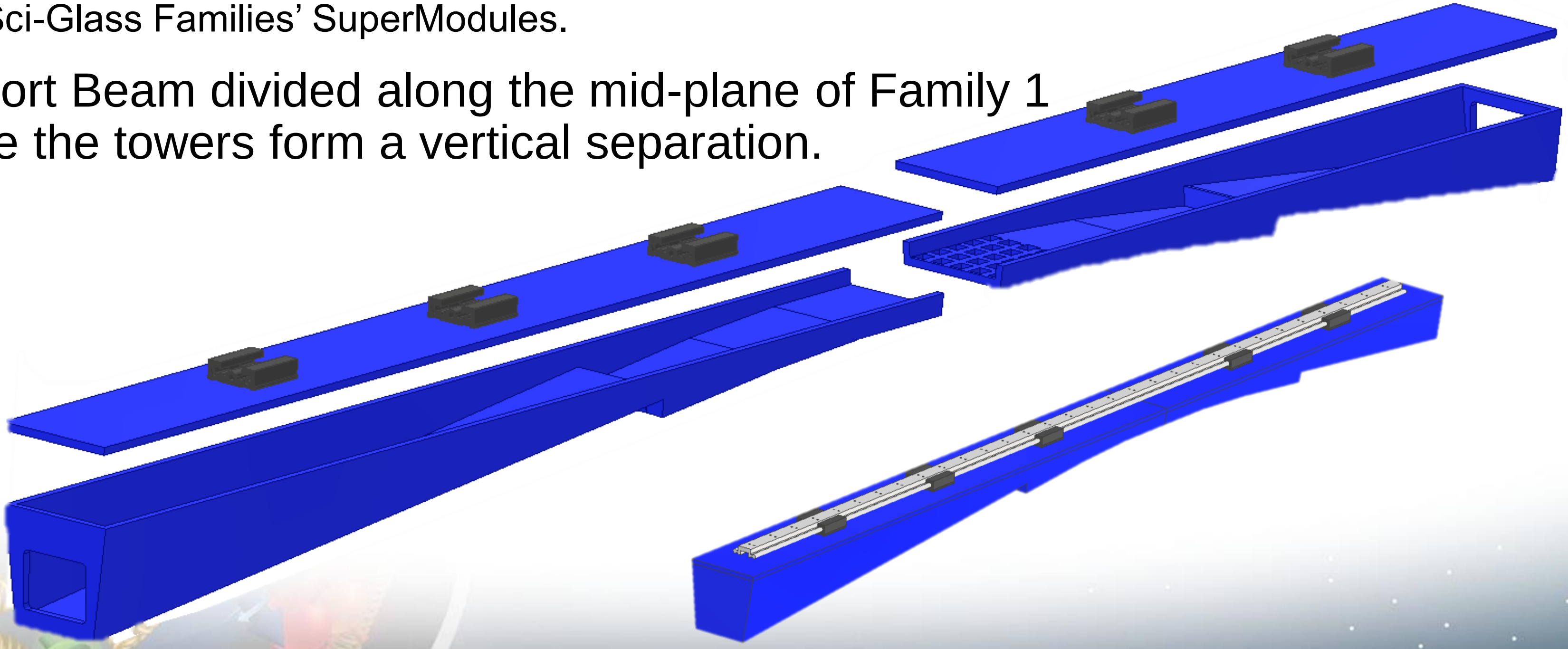






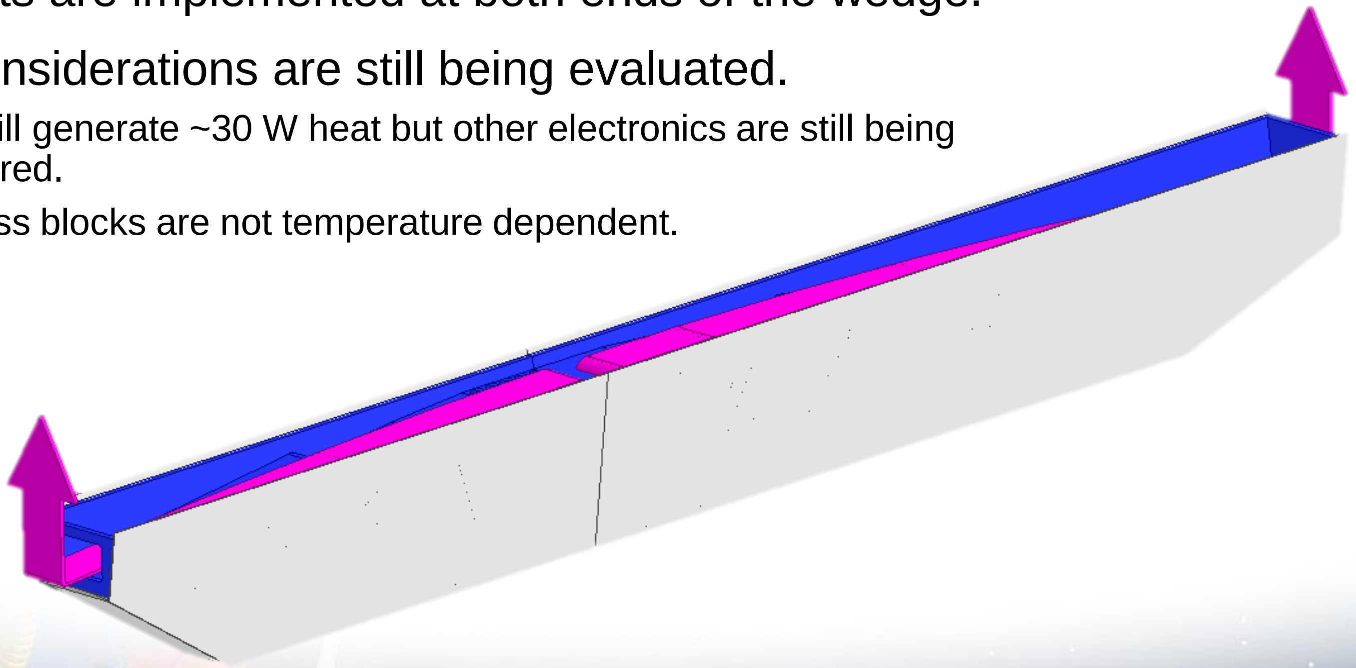
Support Beam Description

- **Goal: Provide rigid structure attaching to the external support frame for the SuperModules and provide space for cable routing.**
- The beam is constructed using 2cm thick aluminum.
  - Outer plate holds the pillow blocks that attach to Thomson rails on the next support structure.
  - Main beam profile is then attached to this plate as well as the Sci-Glass Families' SuperModules.
- Support Beam divided along the mid-plane of Family 1 where the towers form a vertical separation.



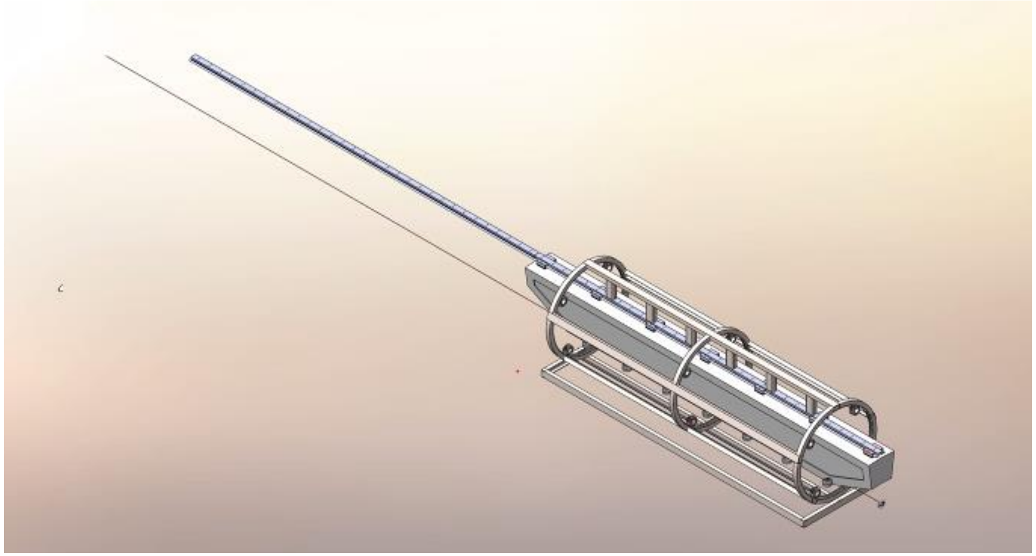
Cabling/feedthrough

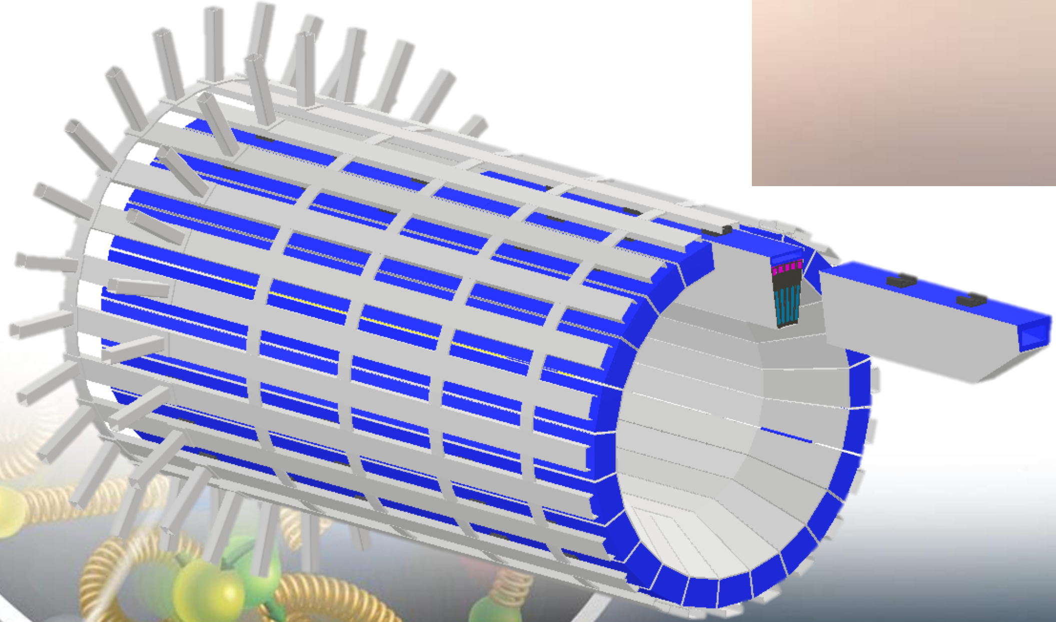
- Cables for low voltage supply and signal will be run through the hollow region inside the support beam and pass through the ends of the beam via feed through plates.
- Disconnects are implemented at both ends of the wedge.
- Cooling considerations are still being evaluated.
  - SiPM will generate ~30 W heat but other electronics are still being considered.
  - Sci-Glass blocks are not temperature dependent.



Assembly & Maintenance

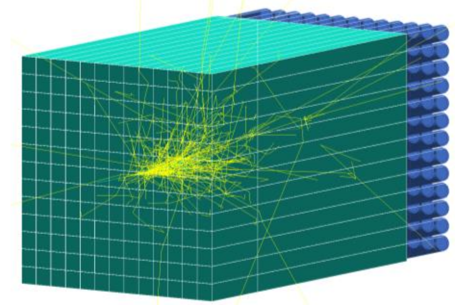
- For maintenance and installation individual wedges will be extracted or inserted along the long axis of the detector.
- A custom support cradle will be required in order to align the wedges onto the support rails.



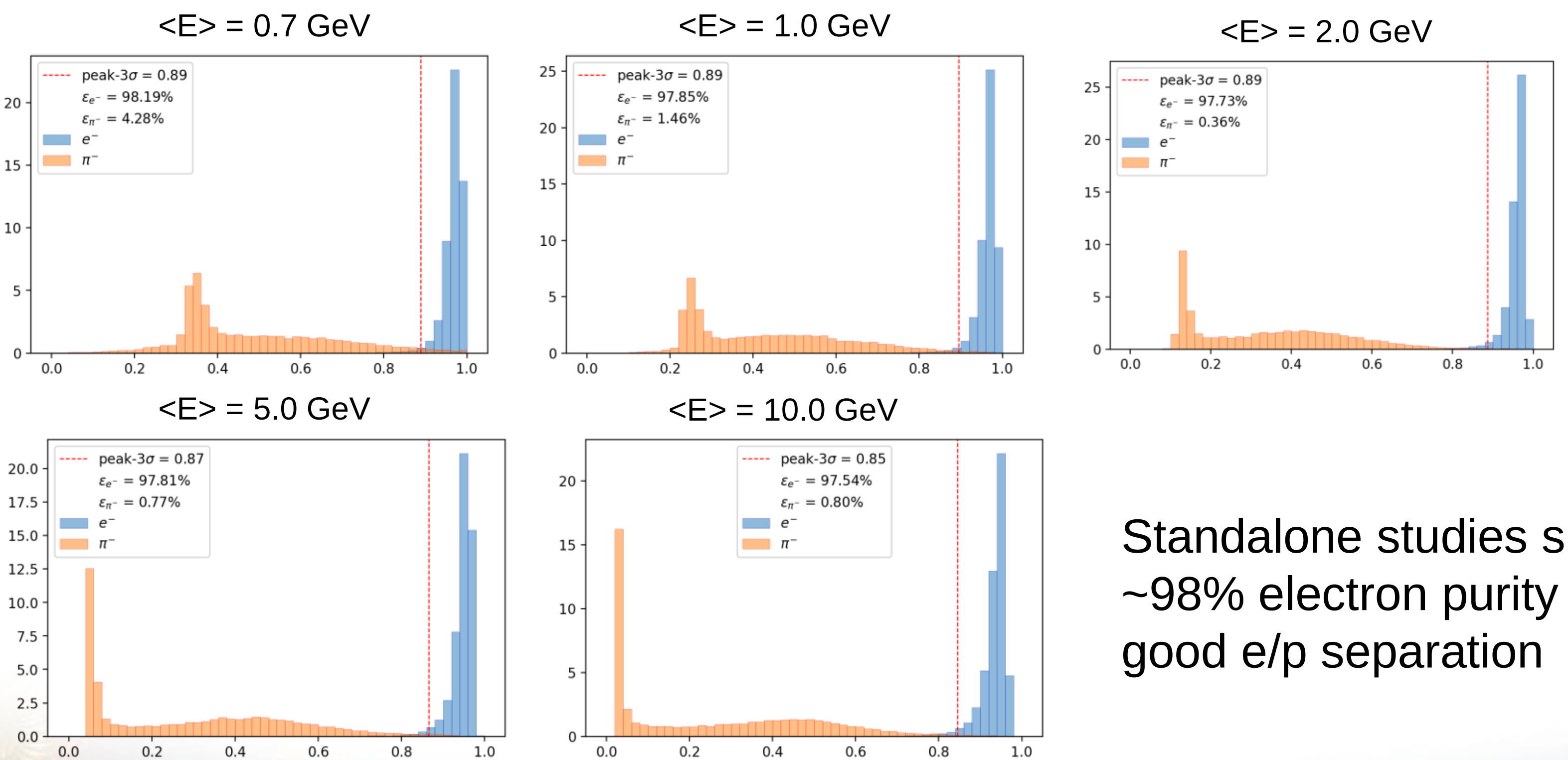


SciGlass Simulations - ongoing

Sci-Glass e$^-$ shower



GEANT4 – prototype e/pi



Standalone studies show ~98% electron purity and good e/p separation

Calorimeter Calibration

- The primary calibration could be done using a light monitoring system. The light (optical photons) will be delivered to each calorimeter tower using optical fibers from the light source (TBD, Laser or LEDs) to the (TBD, back or front) face of the crystal. The light intensity (amount of photons) should be the same as much as possible for all channels.
- The secondary calibration could be done using cosmic muons and will allow to take into account the variations between crystals, wrapping, and optical coupling.
- The final calibration could use neutral pions and an iterative procedure based on detection of these pions.