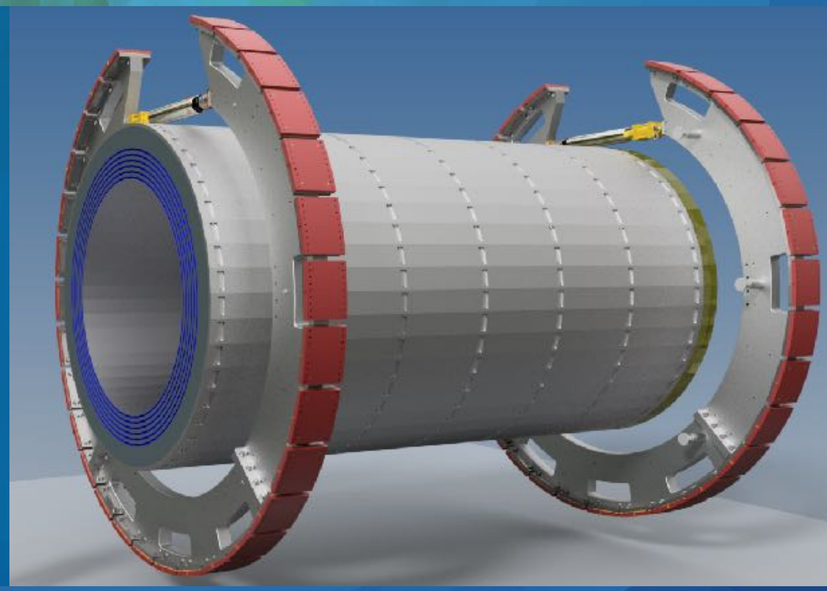
EIC-Asia Workshop on QCD and Hadron Structure, Academia Sinica | May 1, 2026

Status of the Barrel Imaging Calorimeter (BIC) for the ePIC Experiment



Shin Hyung Kim (金信亨)
Kyungpook National University
on behalf of the BIC DSC

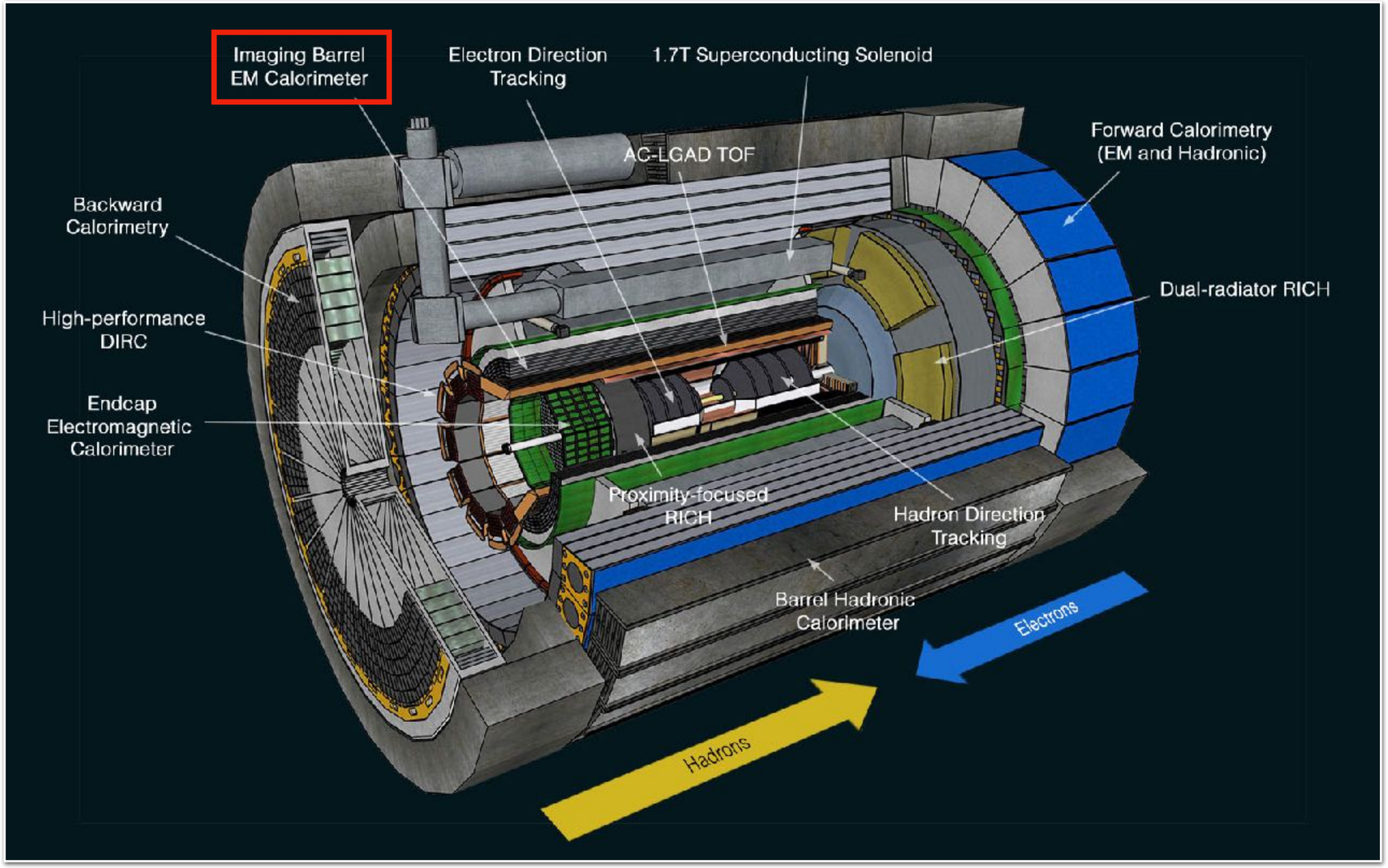
Scope of this talk

- **BIC overview**
  - detector requirements, and hybrid calorimeter concept
- **Korean R&D contributions**
- **Focus on ESB / DAQ & readout R&D**
  - Light guides and optical coupling
  - SiPM calibration, irradiation, and light monitoring
  - SiPM summing-board studies
  - Cooling prototype and thermal validation
- **Summary**

Main references: BIC PDR materials (September 2025) - BIC overview, ESB

Barrel Imaging Calorimeter

in the ePIC detector system



Barrel Imaging Calorimeter

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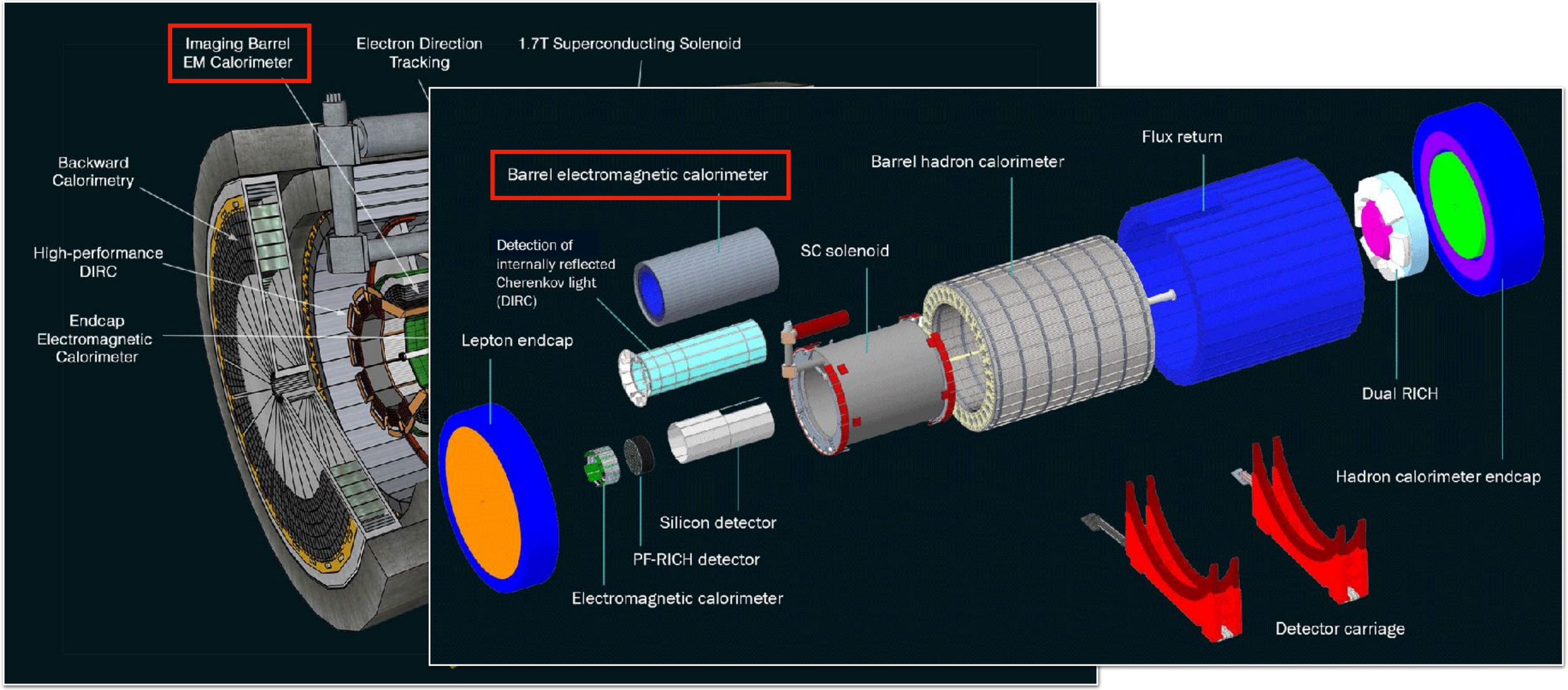


Detector Requirements for BIC

https://eic.jlab.org/Requirements/

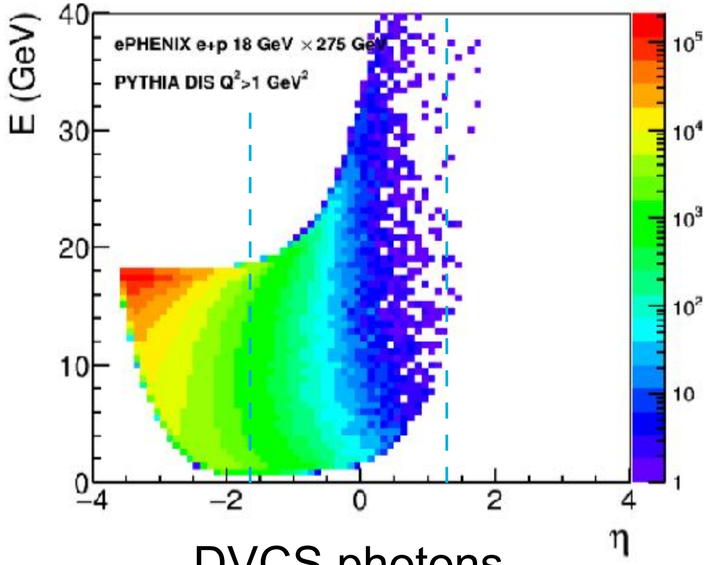
Identify scattered electrons and measure their energy, in high Q^2 events, also decay electrons, e.g. from vector or heavy flavor meson decays, and to measure DVCS photons and decay photons

- **Electron ID up to 50 GeV** and down to 1 GeV and below
  - Energy resolution < **10%/√(E) + (2-3)%**
  - High power for **e/π separation down to 1 GeV/c**
- **Photon measurements up to 10 GeV**
- **γ/π^0 separation up to 10 GeV**
  - Distinguishing two showers with opening angle down to 30 mrad

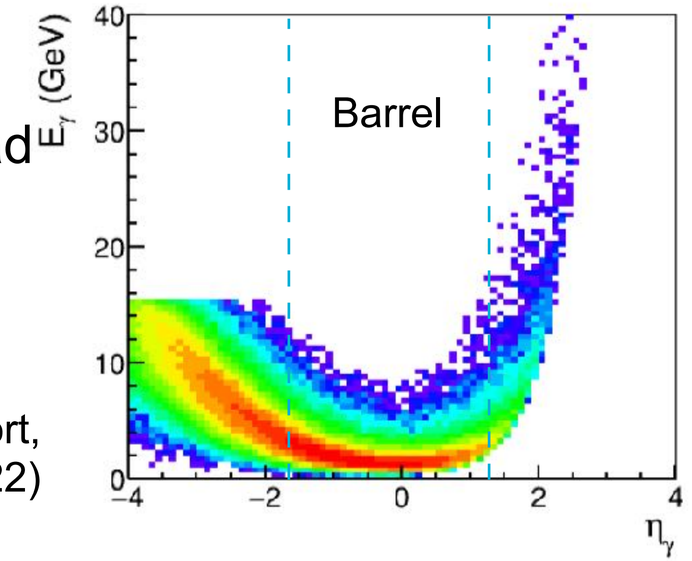
Assist with muon identification

Sufficient dynamic range to **detect MIP** signals in all layers

DIS electrons



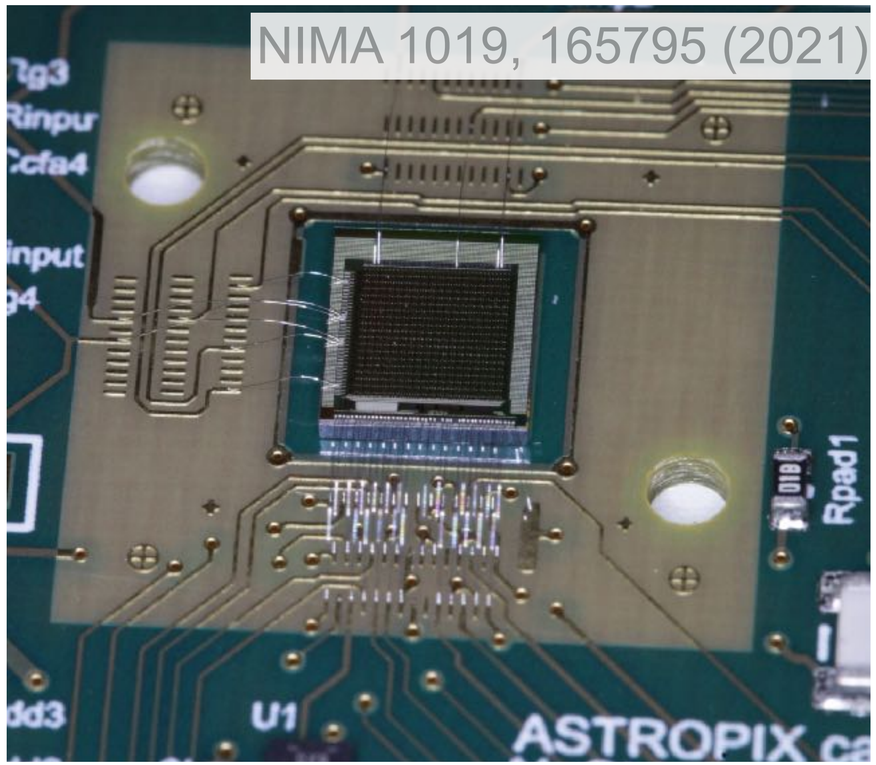
DVCS photons



EIC Yellow Report,
Nucl. Phys. A 1026, 122447 (2022)

Hybrid BIC concept: Pb/SciFi + AstroPix

Combination of a high-performance sampling calorimeter with silicon sensors for shower profiling



Pb/SciFi sampling calorimeter, based on mature technology similar to the **GlueX** barrel calorimeter
➔ **energy** measurement

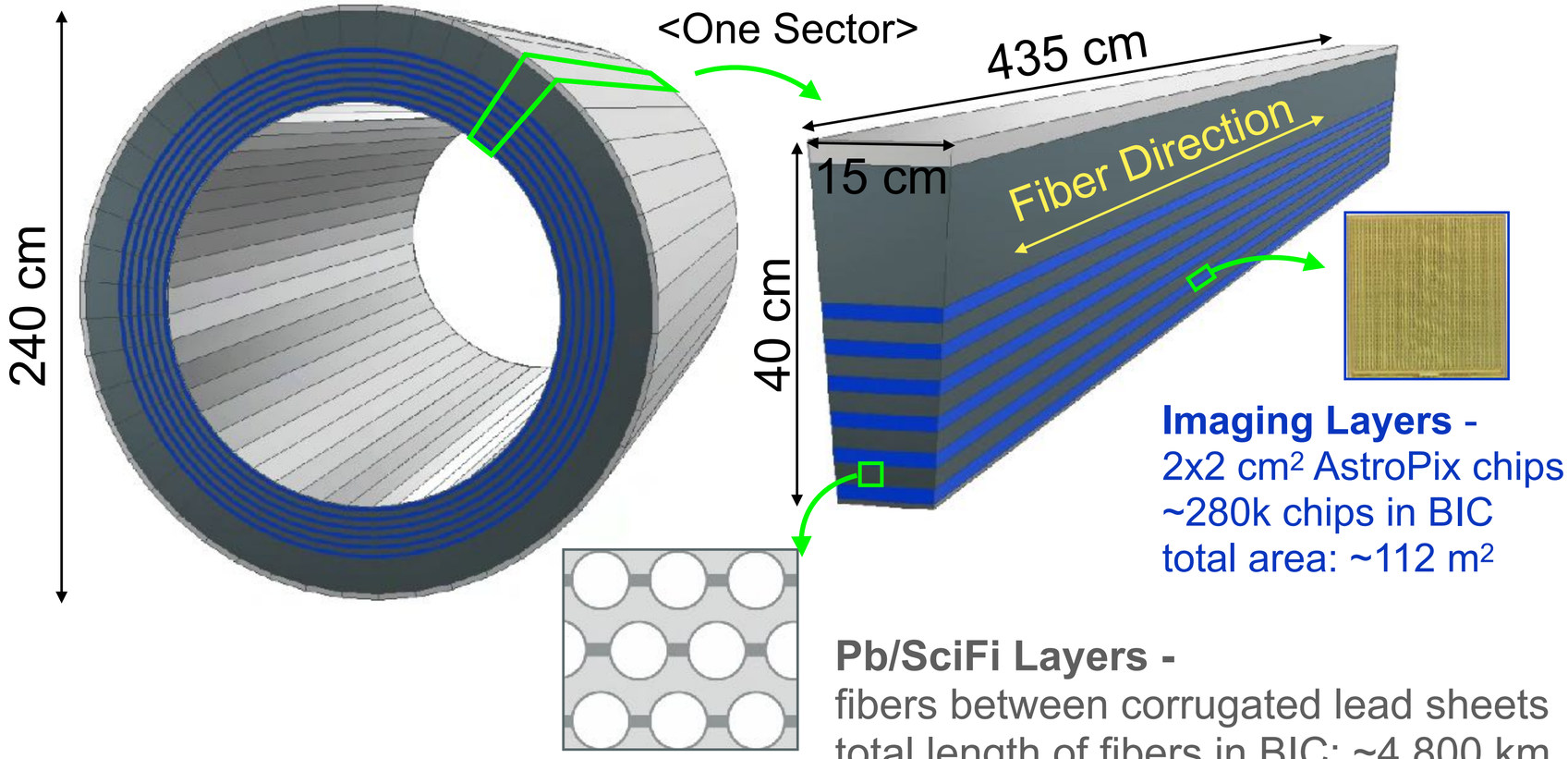
AstroPix silicon pixel sensor, developed by **NASA** for space applications
➔ **3D electromagnetic shower** information

Barrel Imaging Calorimeter

Detector architecture

BIC Geometry

- 48 trapezoidal sectors
- Active Length: 435 cm
- Inner Radius: 82 cm
- Sector thickness:~40 cm, >17.1X_0 *depending on η*
- η Range: -1.71<η<1.31
- Weight: 42.5 US Tons

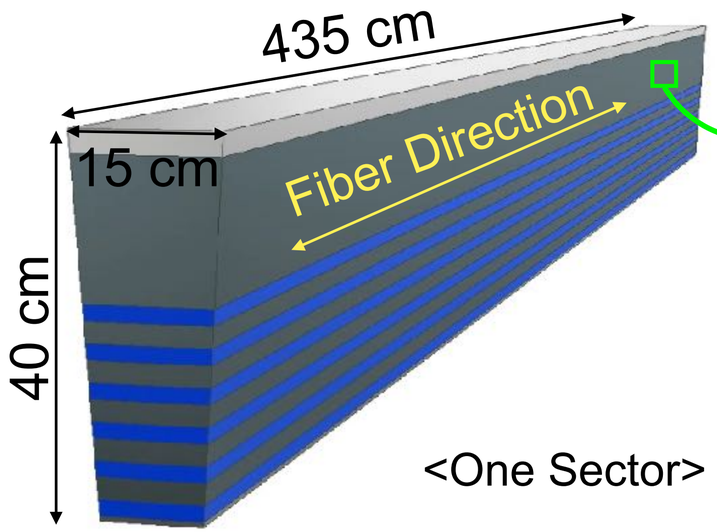


Imaging Layers -
2x2 cm² AstroPix chips
~280k chips in BIC
total area: ~112 m²

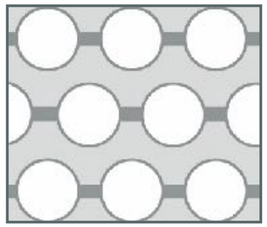
Pb/SciFi Layers -
fibers between corrugated lead sheets
total length of fibers in BIC: ~4,800 km

Energy resolution - Primarily from Pb/ScFi layers (+ Imaging pixels energy information)
Position resolution - Primarily from Imaging Layers (+ 2-sided Pb/ScFi readout)

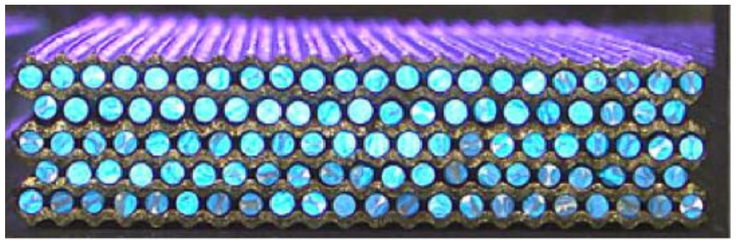
BIC Structure: Pb/SciFi Layer



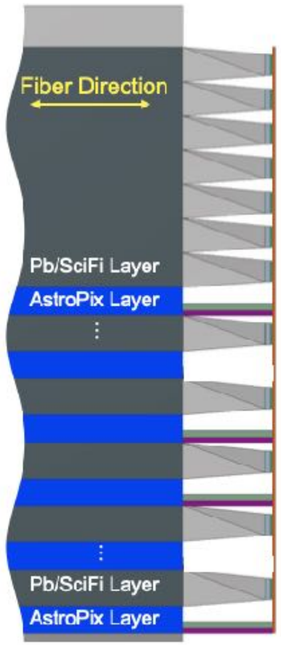
<One Sector>

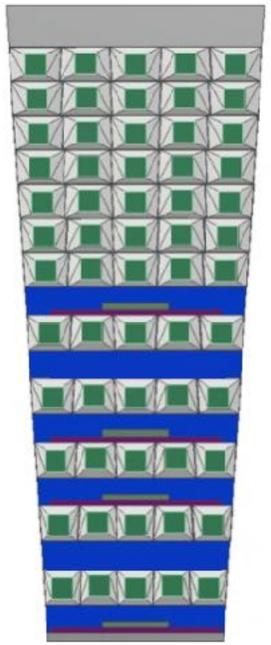


Pb/SciFi Layers



Pb/SciFi test article



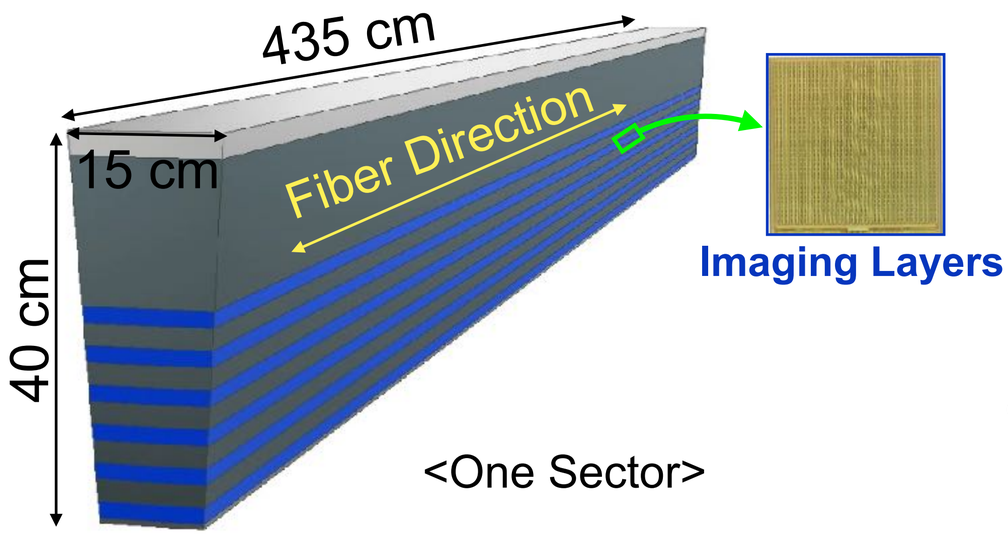


Bulk section of Pb/SciFi

6 slots for AstroPix sensors, 4 instrumented, interleaved with 5 Pb/SciFi layers

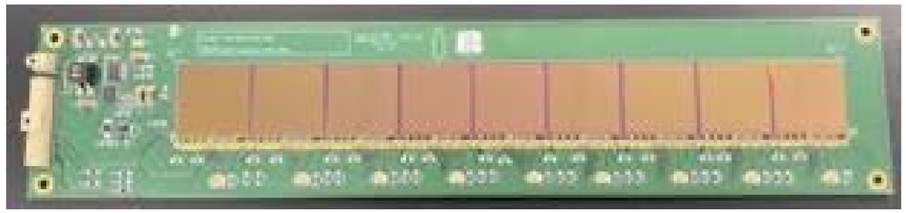
- Each sector has **12 Pb/ScFi layers**.
  - 7 layers for large back section
  - 5 layers interleaved with imaging layers
- Each layer: **stack of fibers + lead sheets:**
  - ~17 rows of ϕ1 mm single clad fibers
  - between 0.5 mm corrugated lead sheets
- At both ends, individual light guides divide each layer in **5 readout cells**.
- SiPM (Hamamatsu S14161-3050, 4x4 array) - 5 per layer x 12 layers = 60 per sector end

BIC Structure: AstroPix Imaging Layer



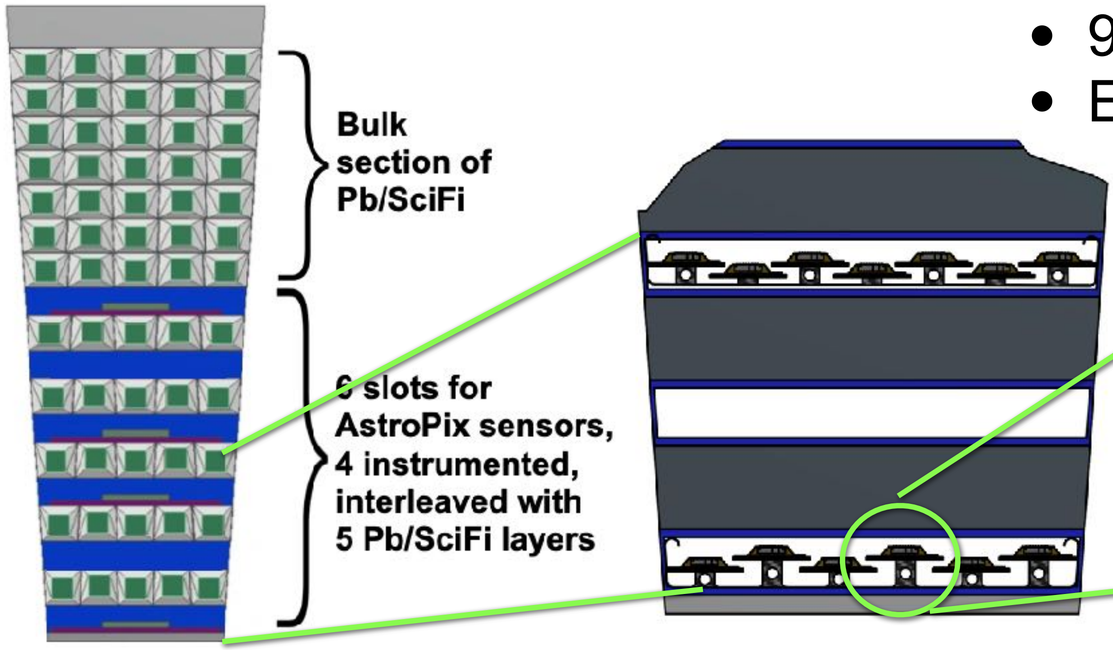
<One Sector>

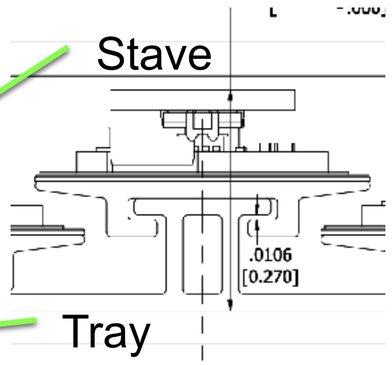
Imaging Layers

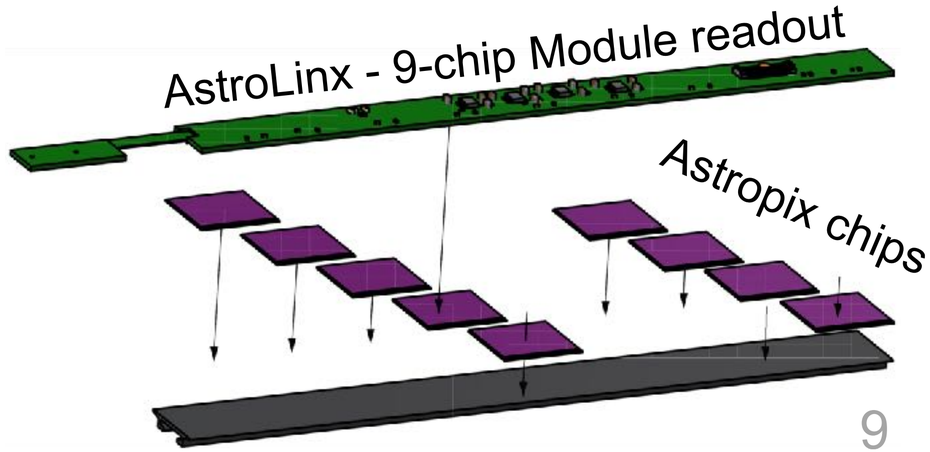


AstroPix module test article

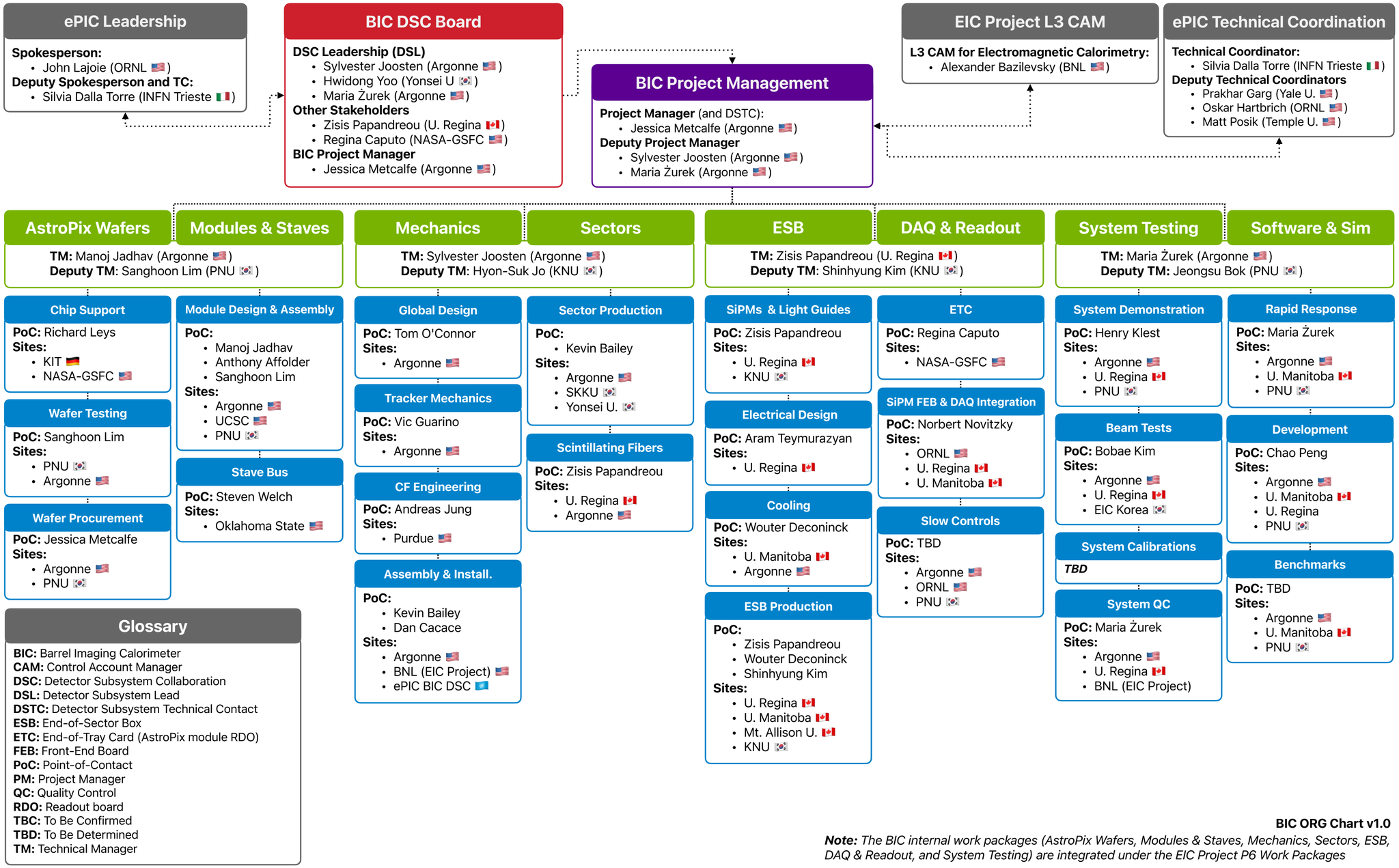
- **4 instrumented imaging layers** in 6 slots per sector
- 6–8 **trays** per layer;
  2 **staves** slide into each tray from opposite ends
- Each **stave** consists of 12 modules;
- 9 daisy-chained AstroPix chips per **module**
- Each **chip**: 2x2 cm^2 with 500x500 μm^2 pixels







BIC Organization Chart

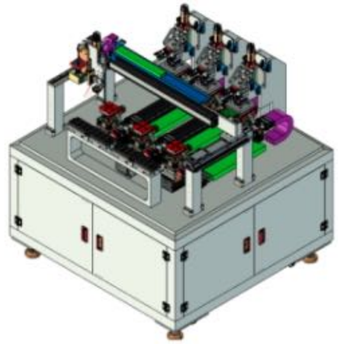


BIC ORG Chart v1.0

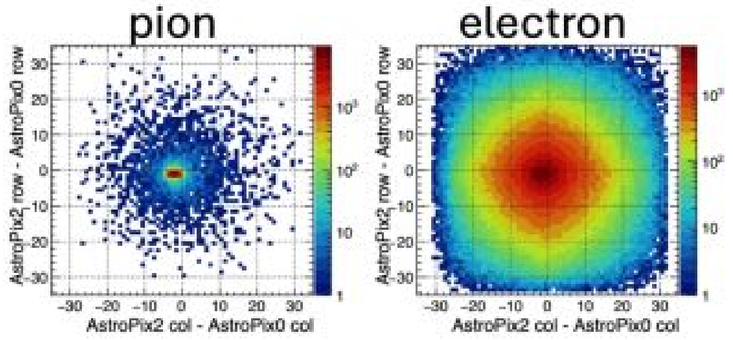
Note: *The BIC internal work packages (AstroPix Wafers, Modules & Staves, Mechanics, Sectors, ESB, DAQ & Readout, and System Testing) are integrated under the EIC Project P6 Work Packages*

Korean R&D contributions to the BIC

Team 1: AstroPix Wafers / Modules & Staves

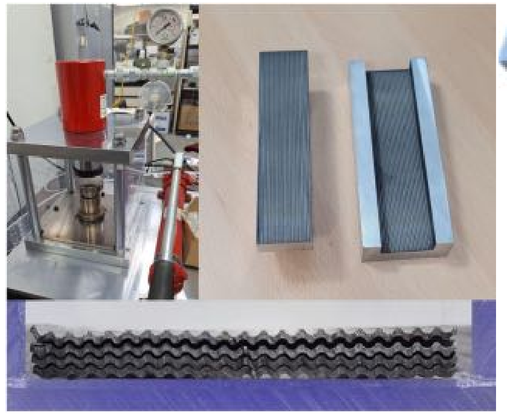


AstroPix chip test



Shower profile measurement

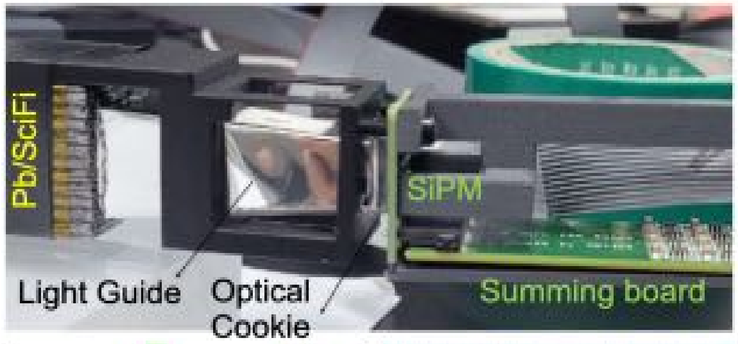
Team 2: Mechanics / Sectors



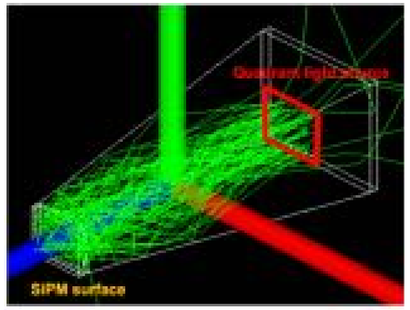
lead-sheet forming

scintillating-fiber stacking
3x3x32 cm^3 prototype module

Team 3: ESB / DAQ & Readout

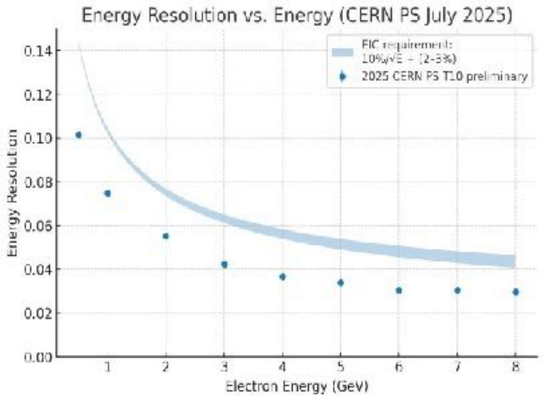


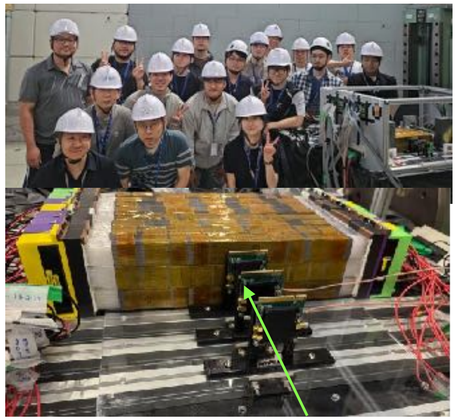
Pb/SciFi readout test



Optical simulation

Team 4: System Testing / Software & Simulation





KEK PF-AR / CERN PS beam test

- To-be-submitted very soon:
  - Beam test of a Pb/SciFi prototype for the Barrel Imaging Calorimeter at the Electron–Ion Collider
  - Test-Beam Performance of the AstroPix Silicon Sensor for Imaging Calorimetry

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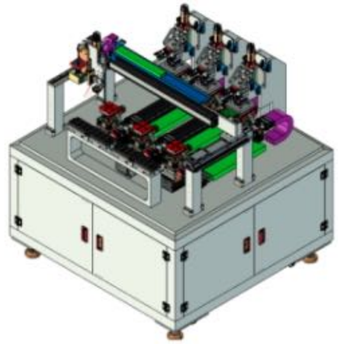
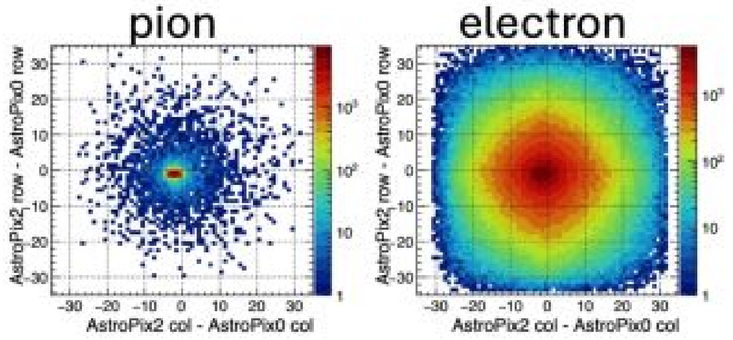


AstroPix chip test



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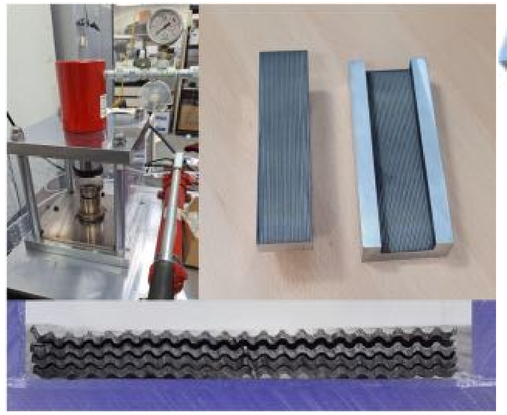

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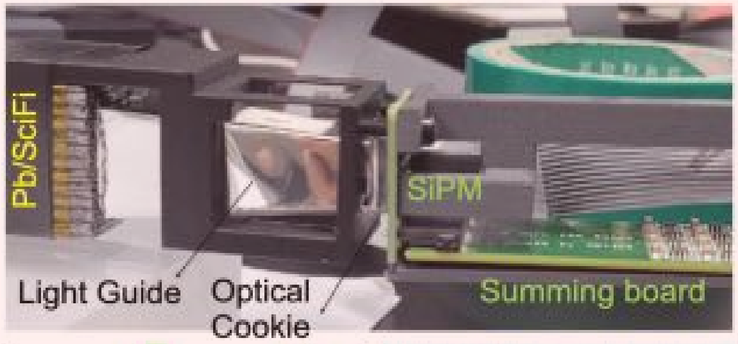
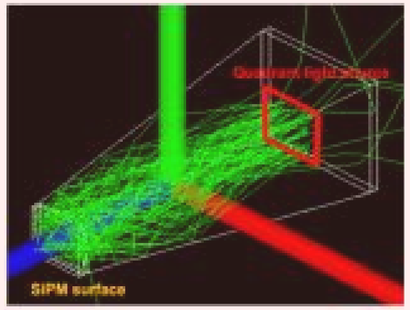


Pb/SciFi readout test



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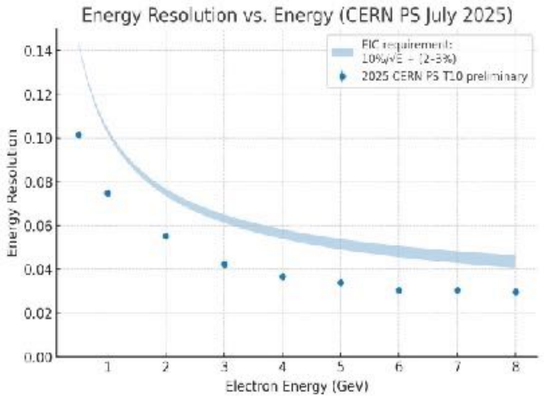

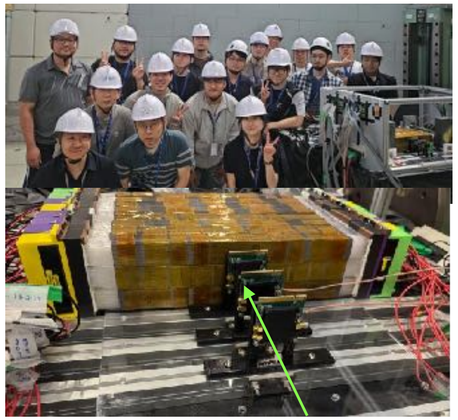

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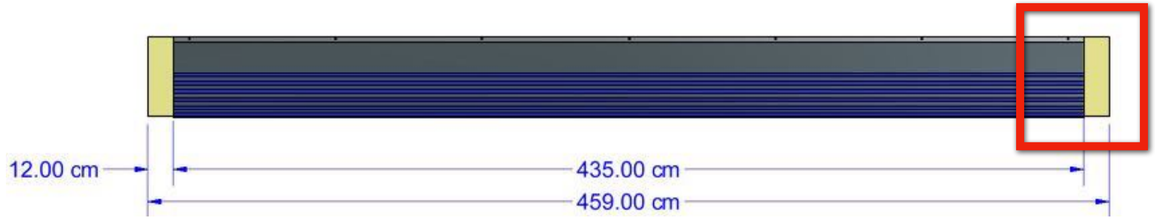
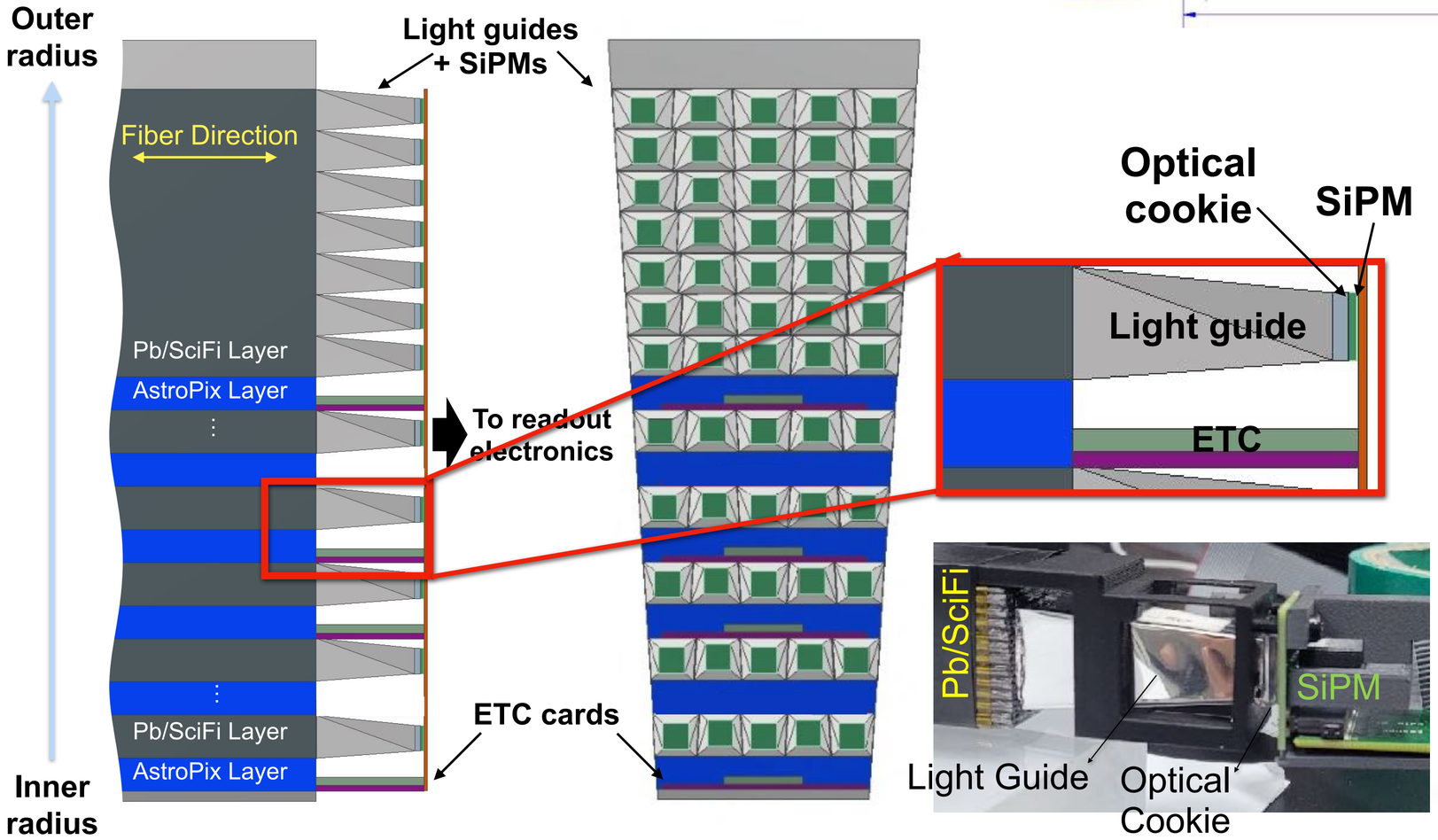
  - Test-Beam Performance of the AstroPix Silicon Sensor for Imaging Calorimetry

BIC Readout: End-of-Sector Box (ESB)



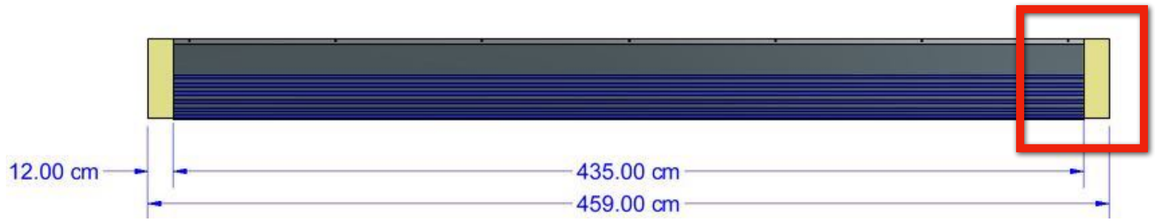


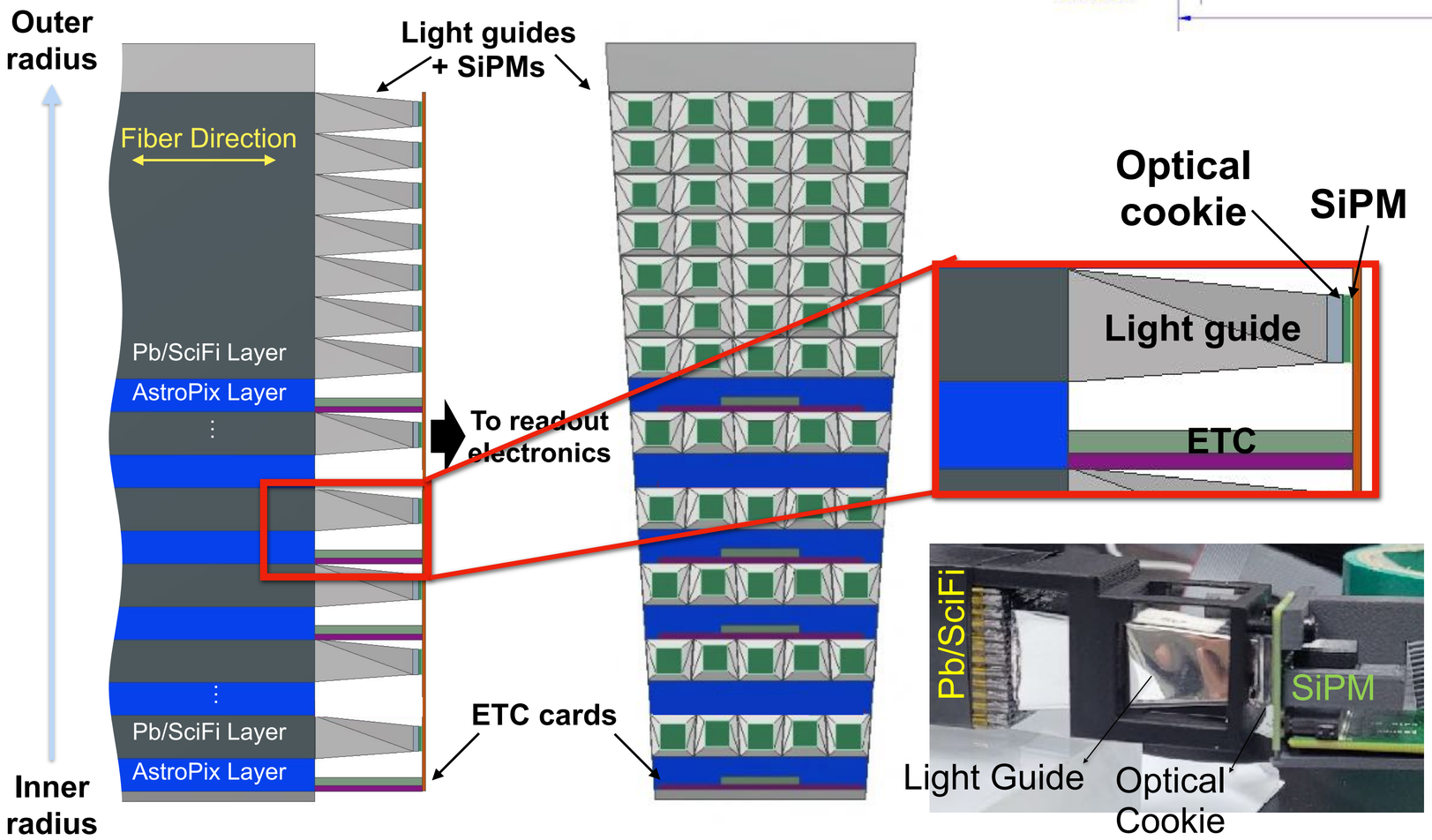
Pb/SciFi Layer:
- Light guides
- Optical cookies
- SiPMs
- H2GCROC (→CALOROC)

Imaging Layer:
- ETC (End-of-Tray) cards for AstroPix readout

Cooling

BIC Readout: End-of-Sector Box (ESB)





Pb/SciFi Layer:

- Light guides
- Optical cookies
- SiPMs
- H2GCROC (→CALOROC)

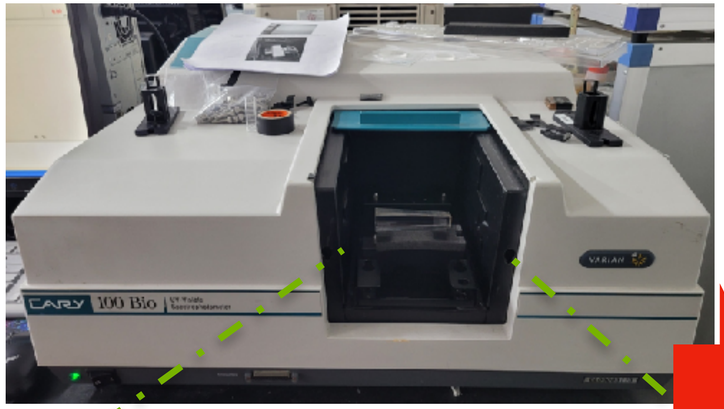
Imaging Layer:

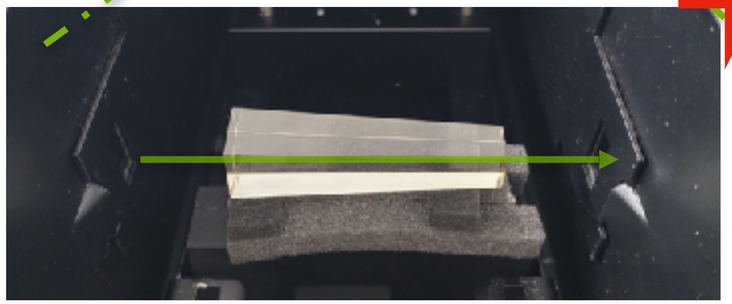
- ETC (End-of-Tray) cards for AstroPix readout

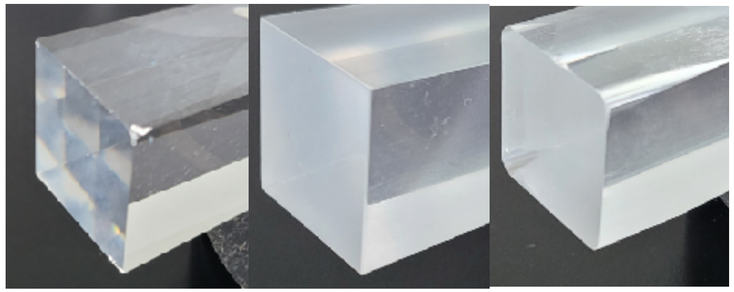
Cooling

Light Guides Material & length

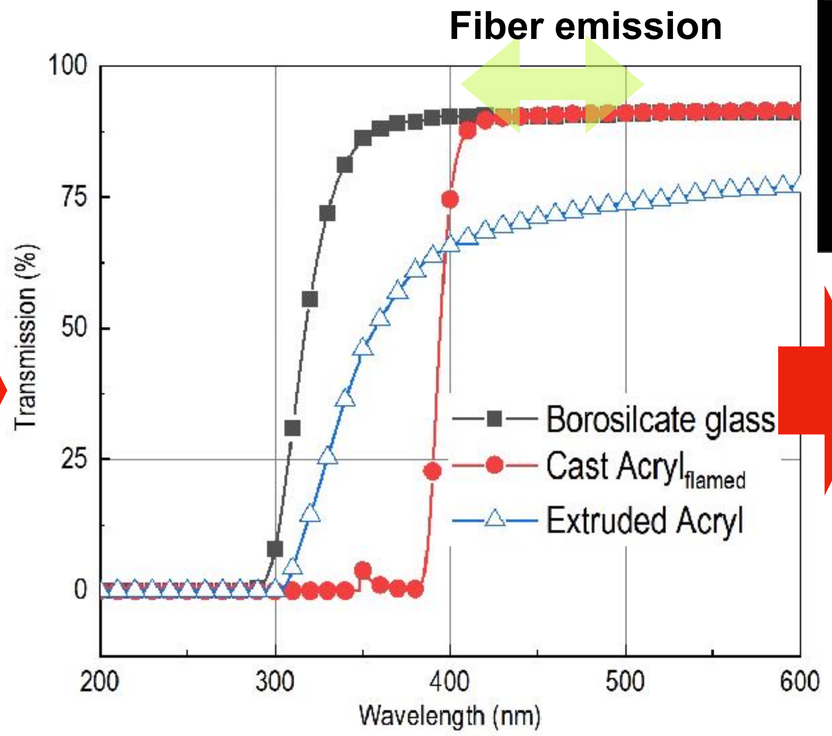
UV-Vis Spectrophotometer (Cary 100)



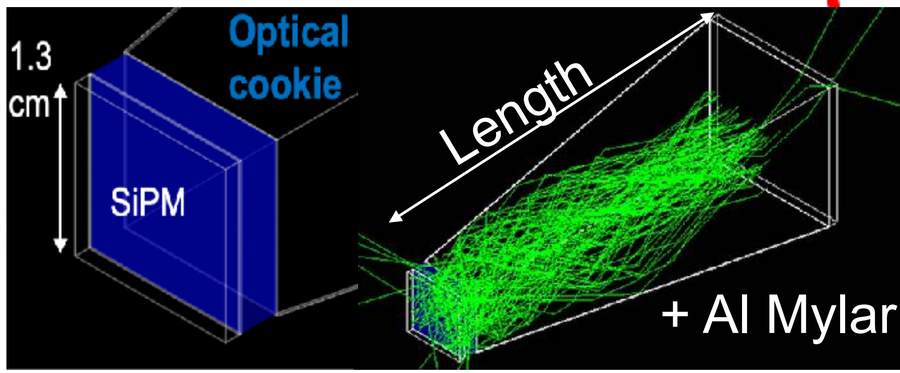


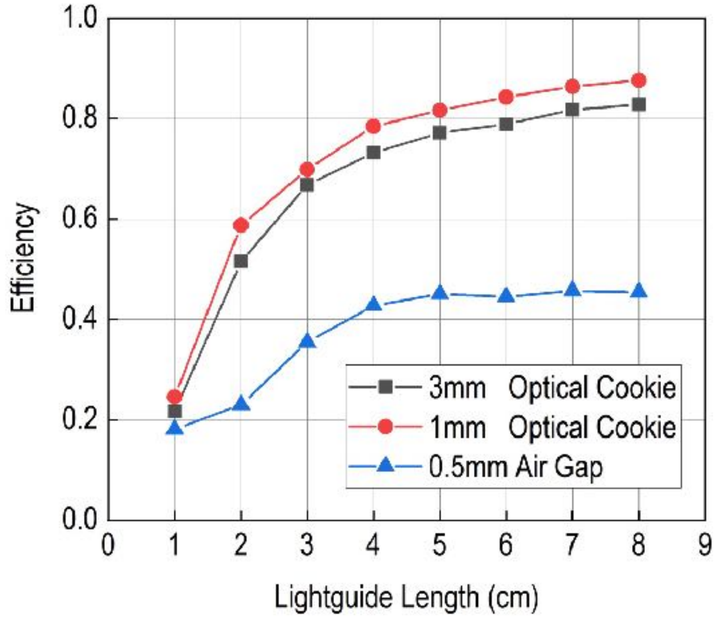


Borosilicate Glass **Cast** Acrylic **Extruded** Acrylic



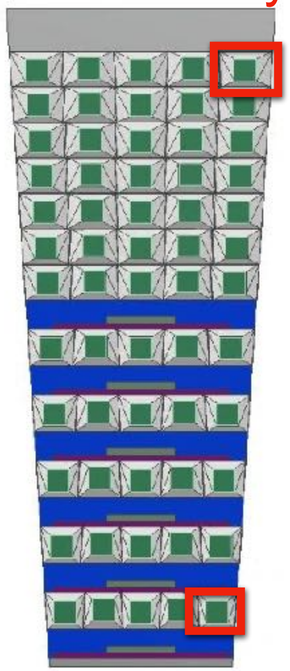
- <400 nm not relevant for fiber emission
- **Cast acrylic** chosen



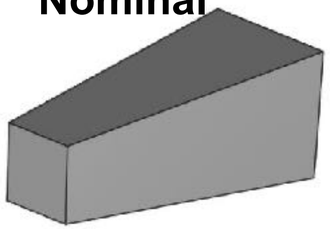


- **>5 cm** length
- Optical cookie needed

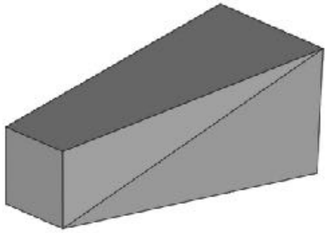
Light Guides Shape



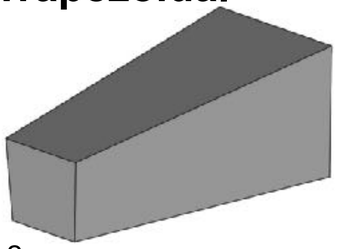
Nominal

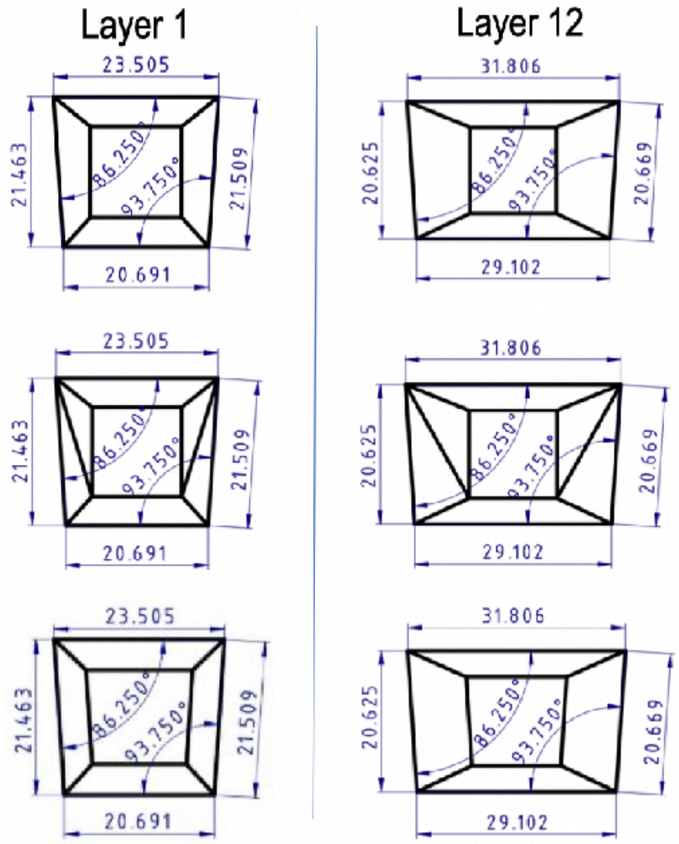


Hexagonal

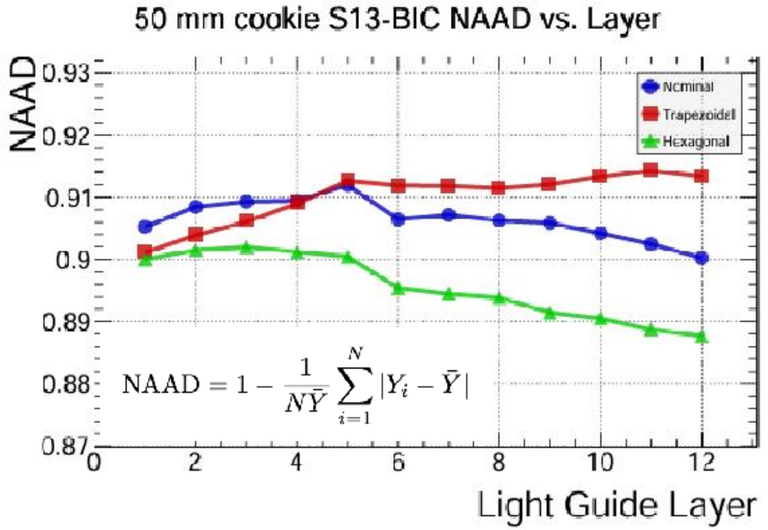


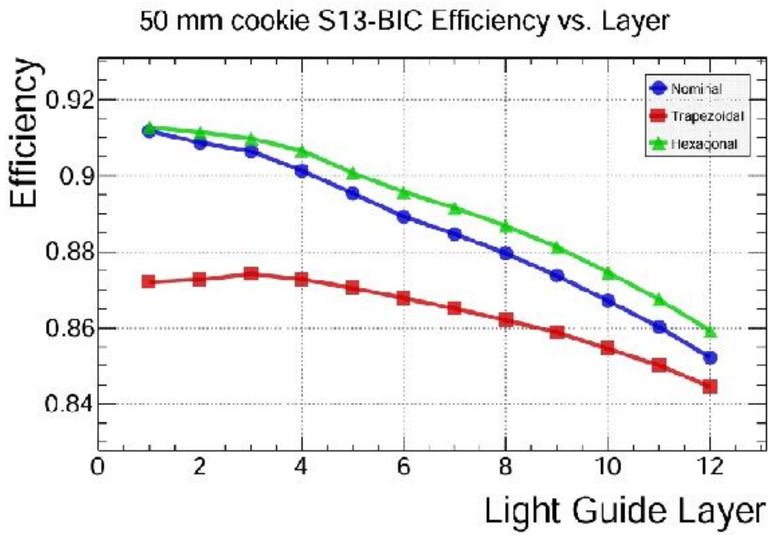
Trapezoidal





*SiPM Array: 13 x 13 mm^2





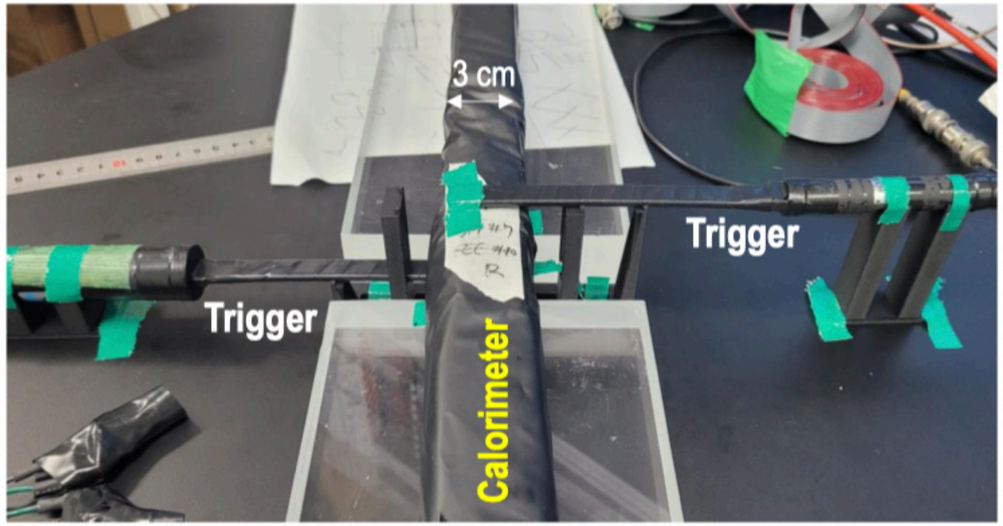
- Candidate light-guide shapes are being compared to optimize both collection efficiency and light-mixing uniformity.

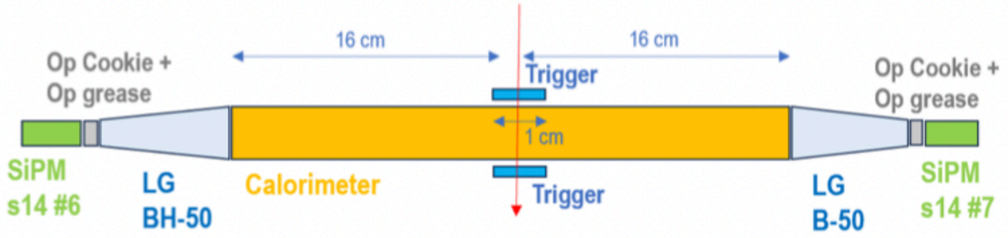
epic-TN-TC-2025-002: Barrel Imaging Calorimeter Light Guide Simulations

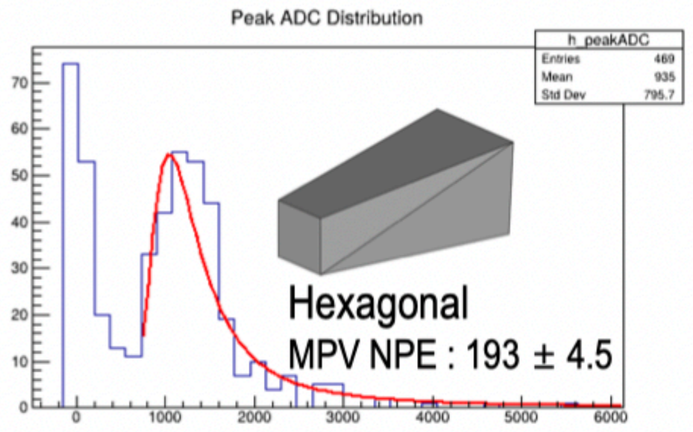
Beattie, Tegan (Contact person)[1]; Papandreou, Zisis (Project leader)[1];
Teymurazyan, Aram (Project member)[1]
Show affiliations

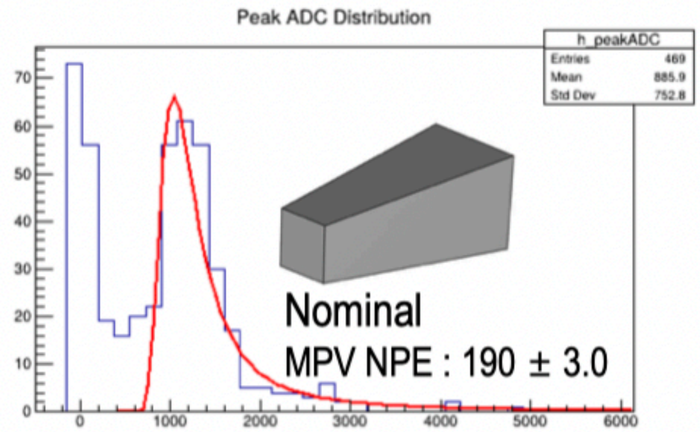
Light Guides

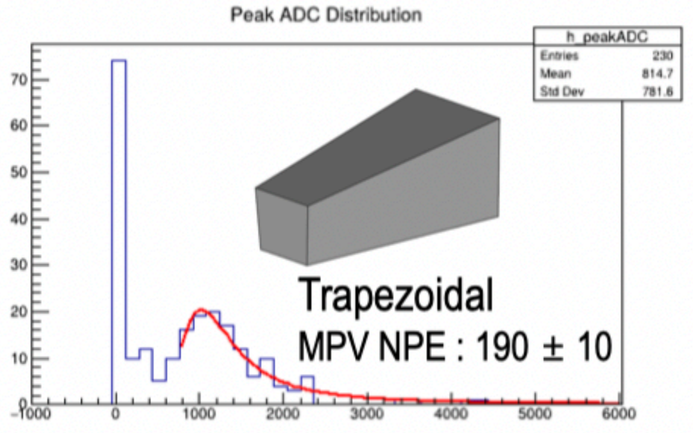
Cosmic-ray test

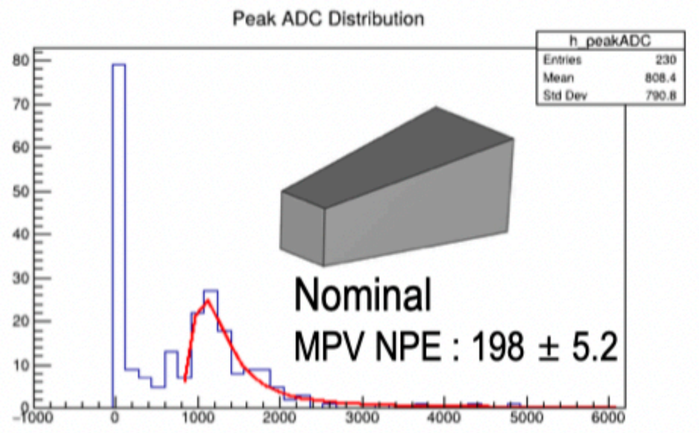








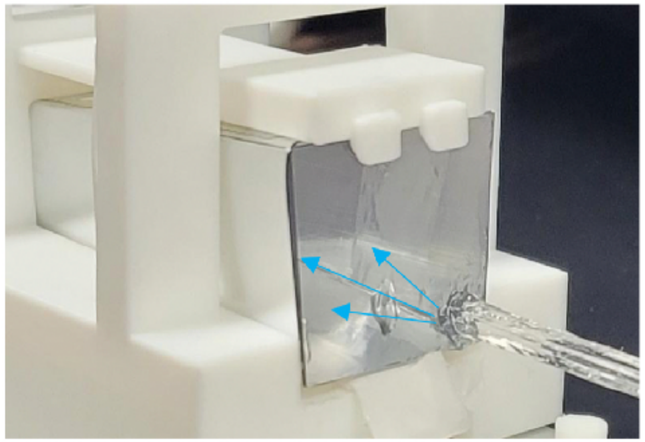


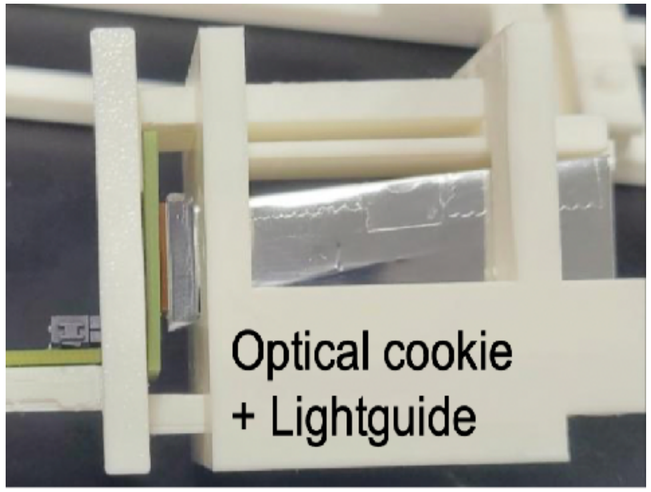


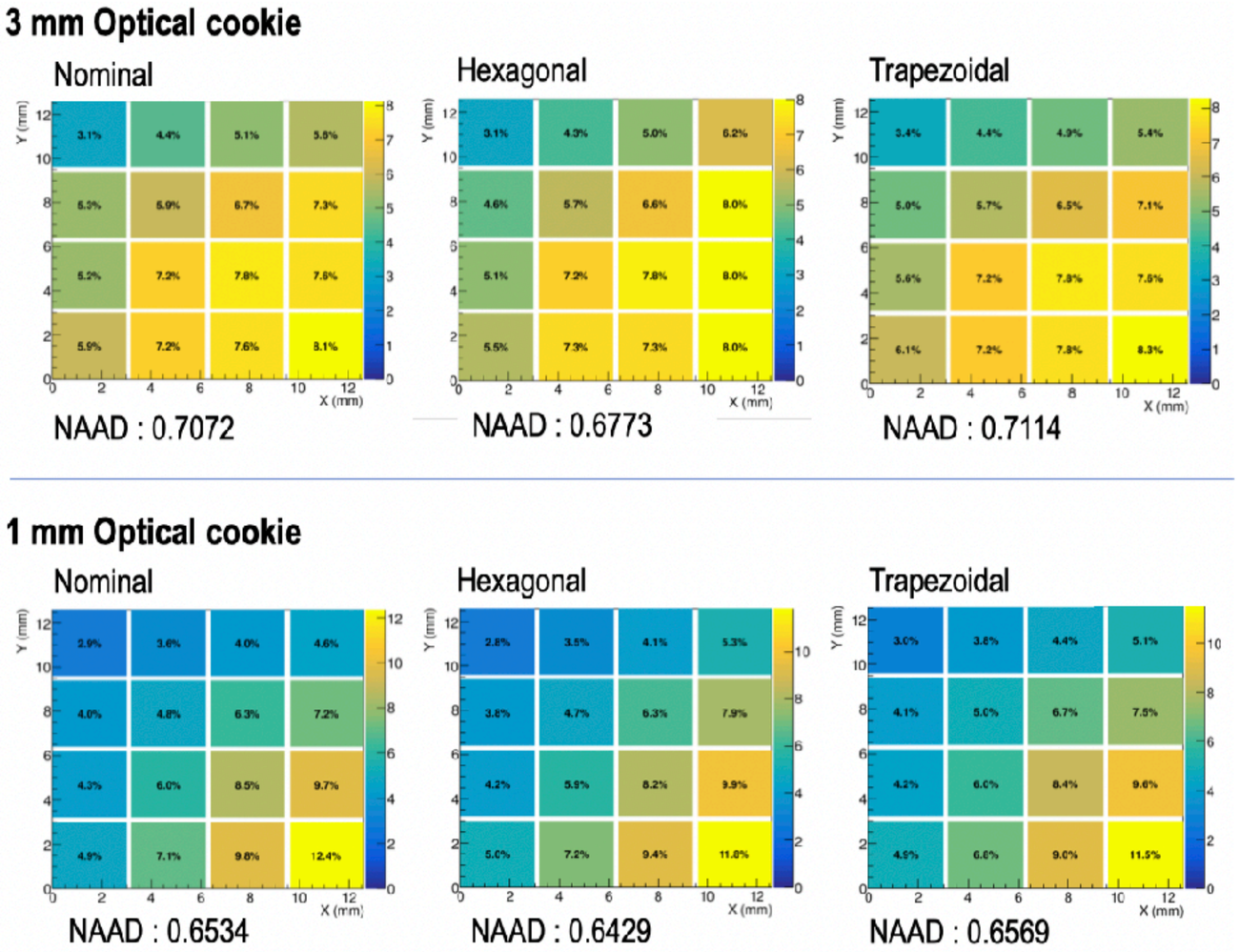
- Cosmic-ray measurements show comparable MIP response among the candidate light-guide geometries.

Light Guides

Light mixing test using LED

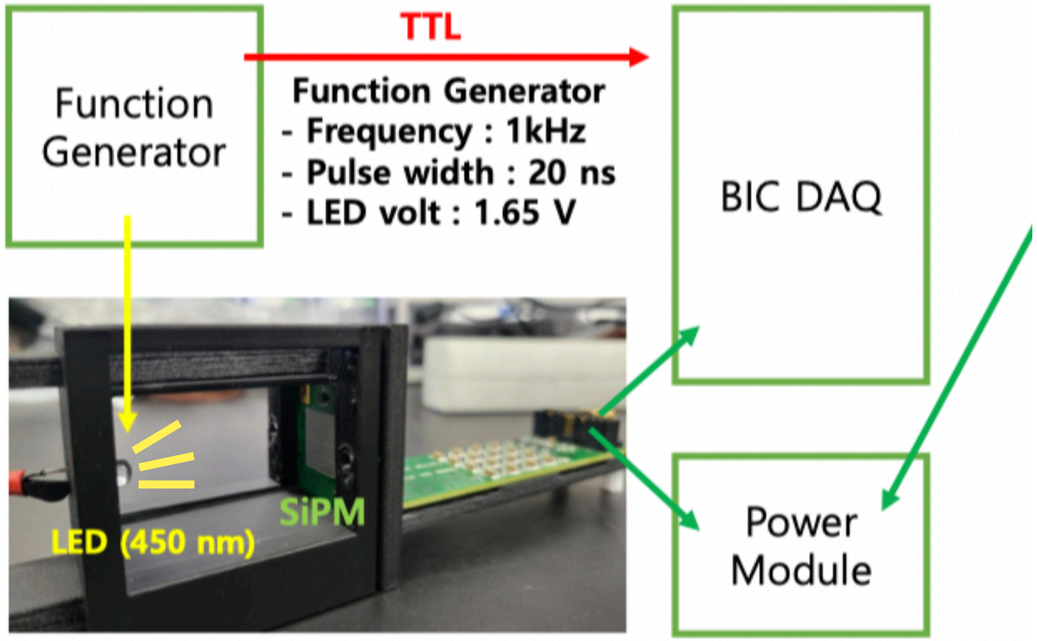


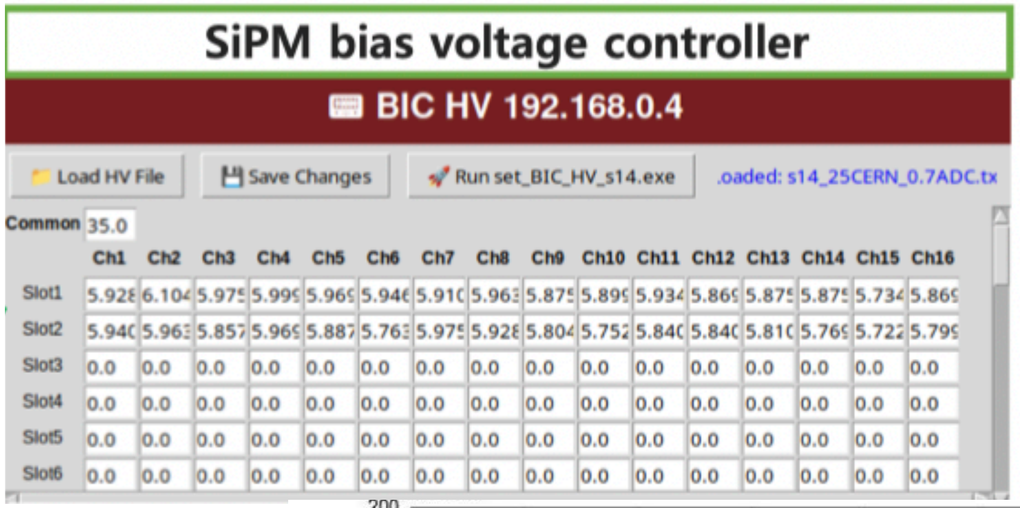


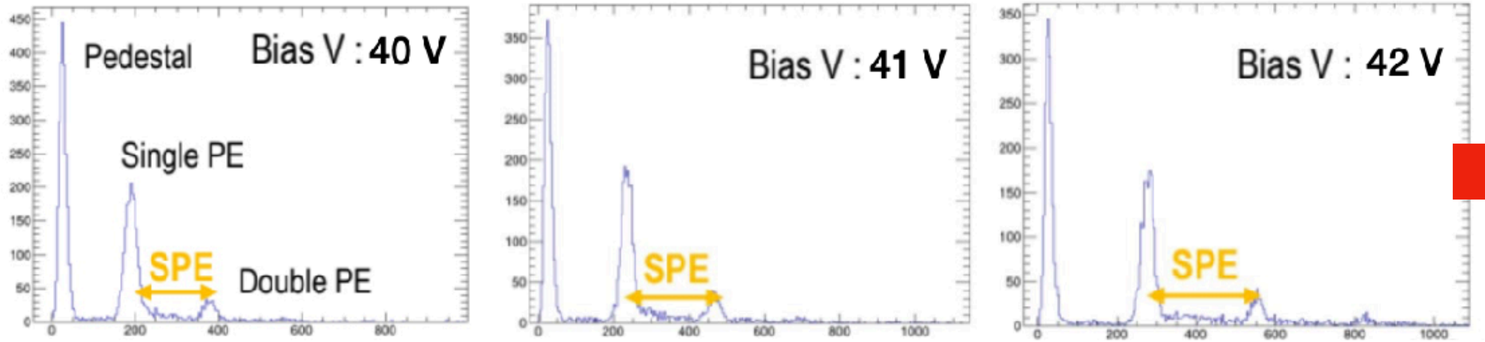


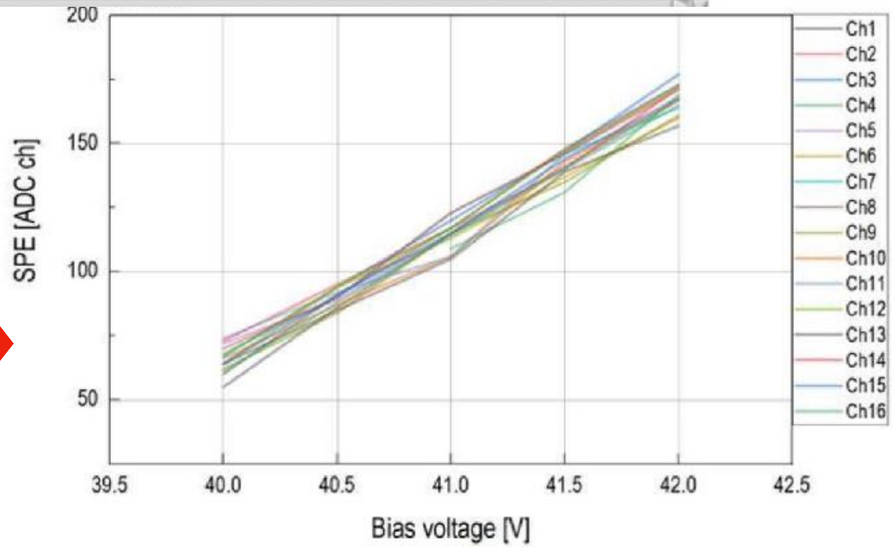
- The corner-injection LED test indicates that the 3-mm optical cookie gives better light-mixing uniformity, while the light-guide geometries show comparable performance.

SiPM Gain Calibration





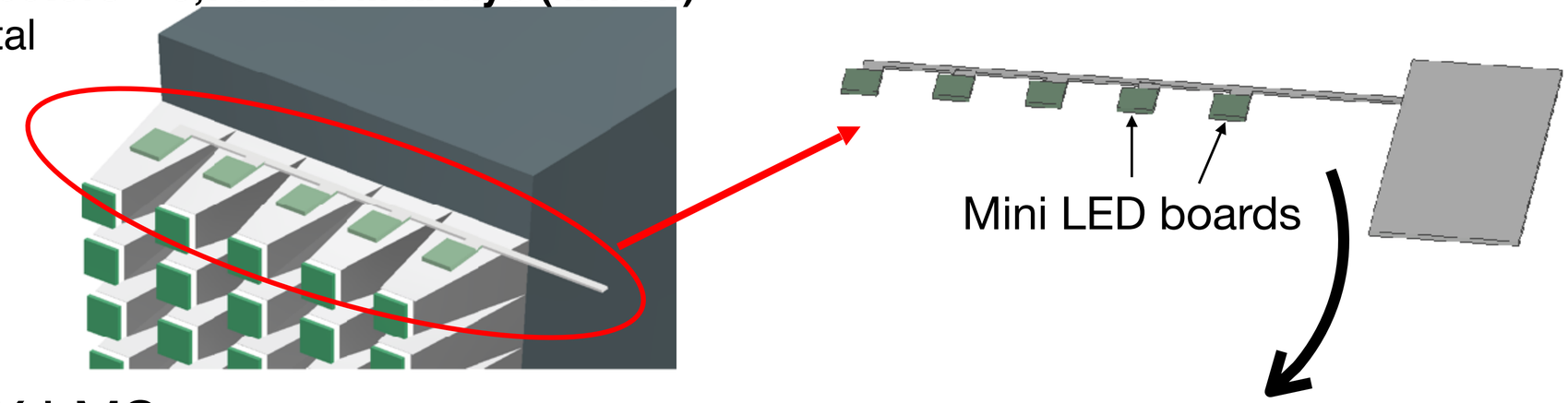




- Channel-by-channel SPE calibration provides the basis for stable SiPM gain control.

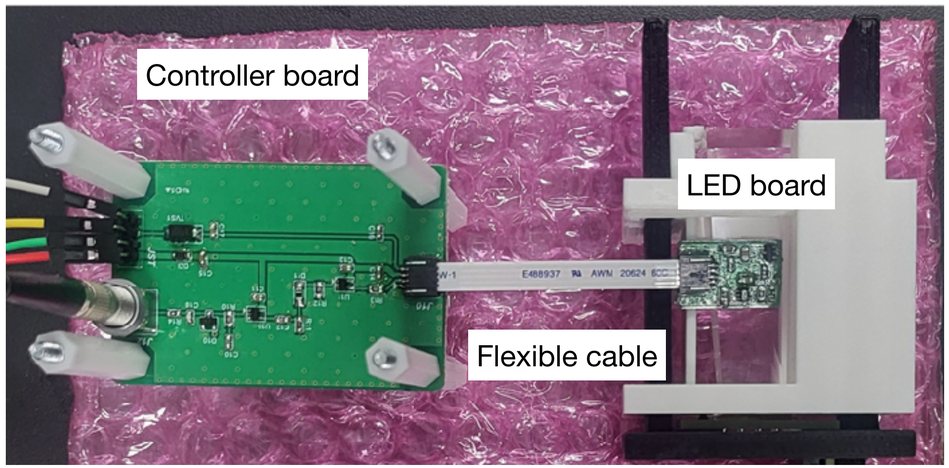
Light Monitoring System (LMS)

60 X both ends **X 48 sectors = 5,760 SiPM arrays (4x4 ch)**
92,160 channels in total



- GlueX LMS system

- 1-ch prototype board at KNU

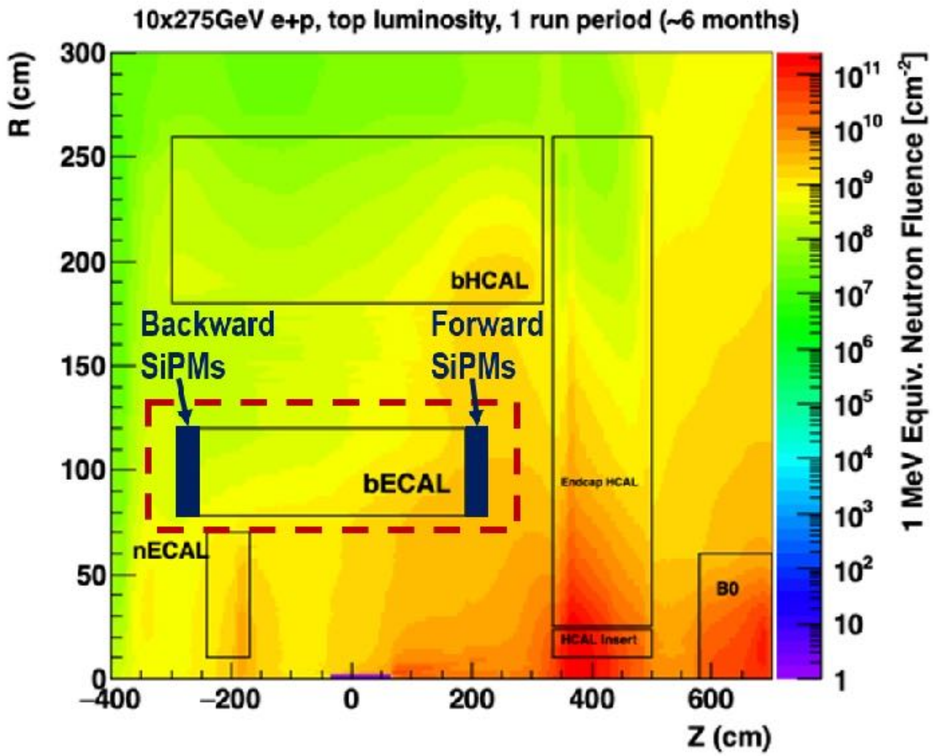


- Test ongoing

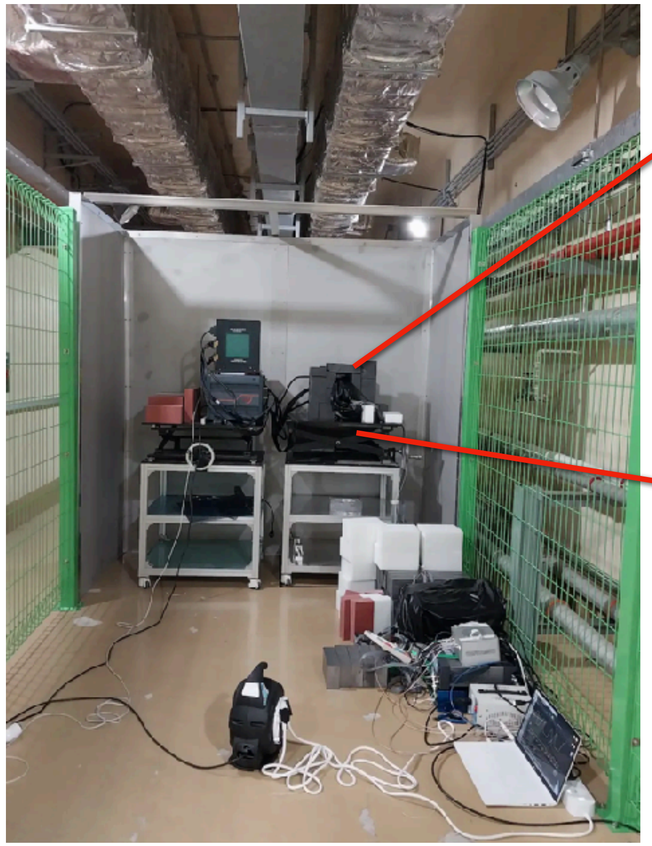
- Light monitoring system is being prototyped to track gain stability across a total of 92,160 SiPM channels in BIC

SiPM neutron irradiation test

- Maximum neutron fluence at the BIC SiPM location for a 6-month run: 10^{10} MeV neq/cm^2

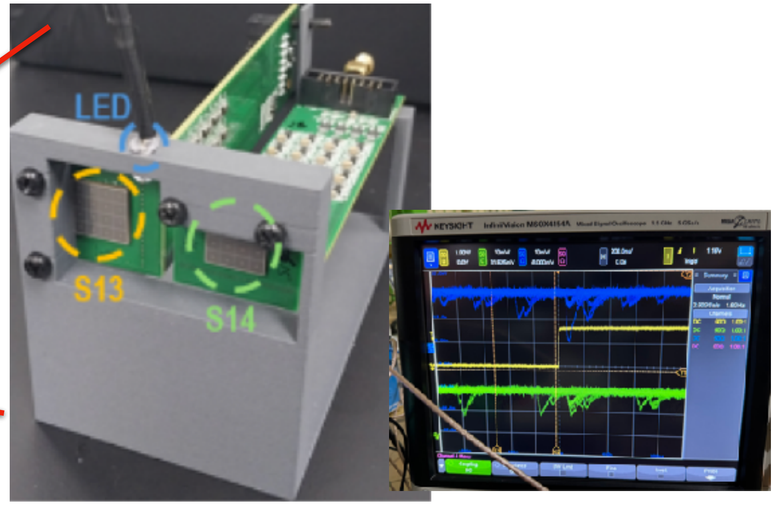


- Neutron Irradiation Test at KOMAC, Korea



100 MeV proton beam dump
Neutron energy: <90 MeV

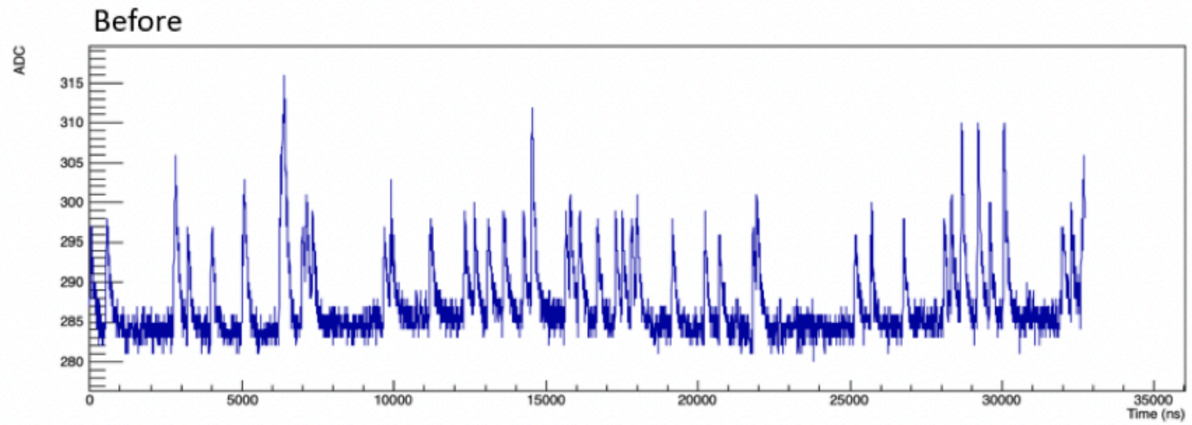
- 10^4 n/cm^2 in a 100-us pulse

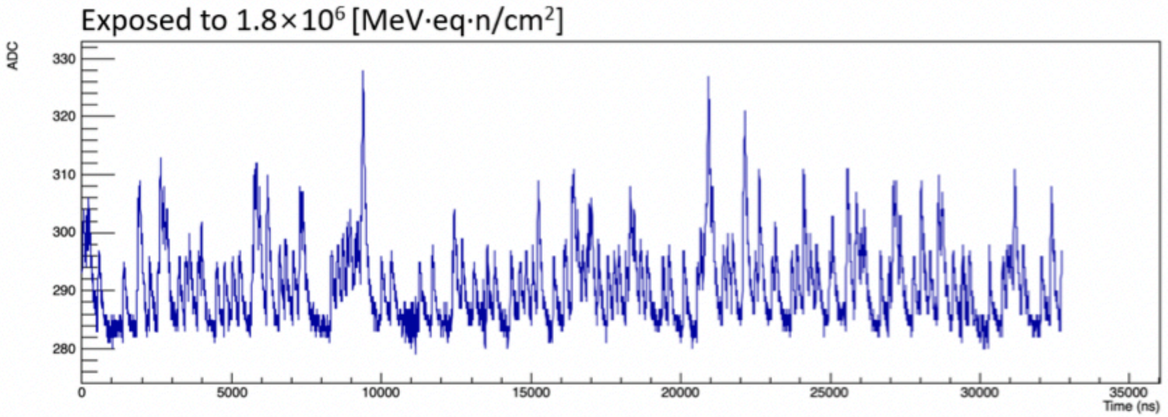


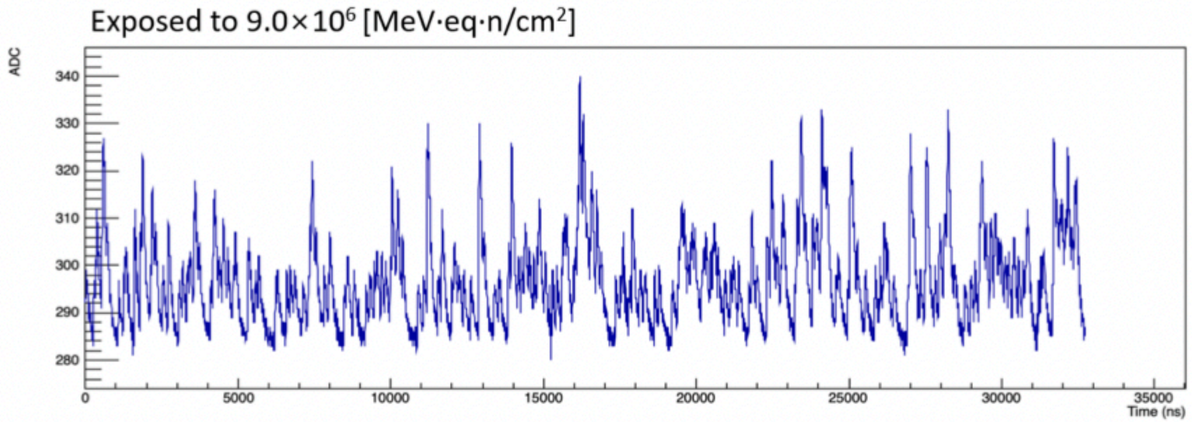
- SiPM: S13361 and S14161
- Monitor gain, DCR, baseline by taking LED data with 500 MHz FADC

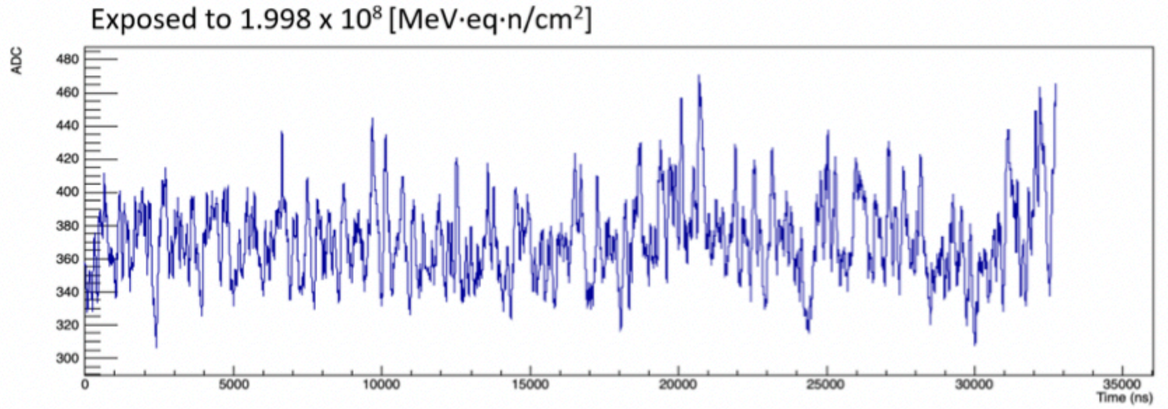
SiPM neutron irradiation test

a 32-μs Single Waveform with Neutron Fluence





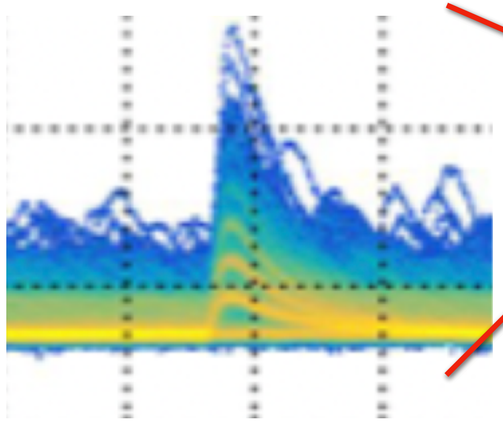


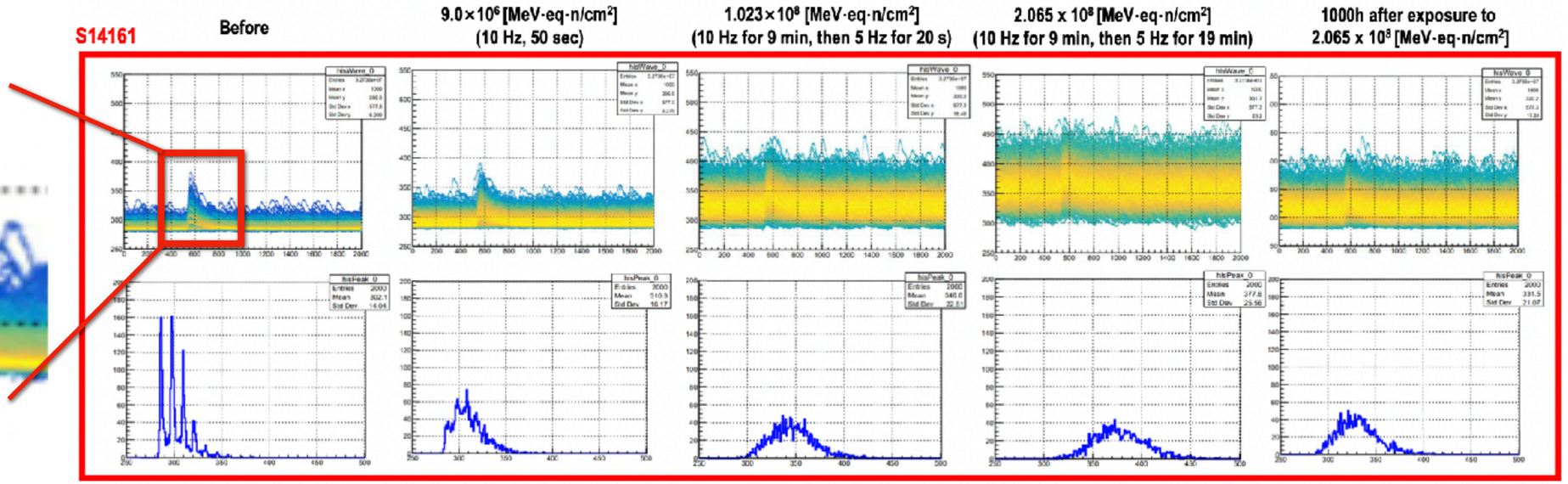


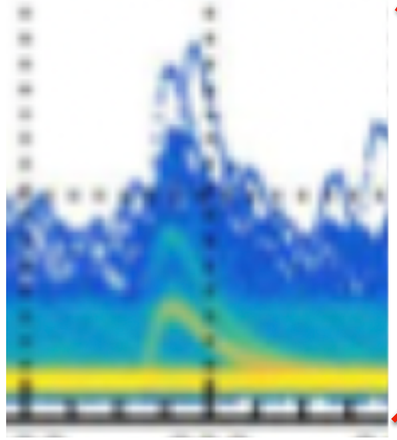
- As neutron fluence increases, the dark current rate keeps rising, making the baseline indistinguishable.

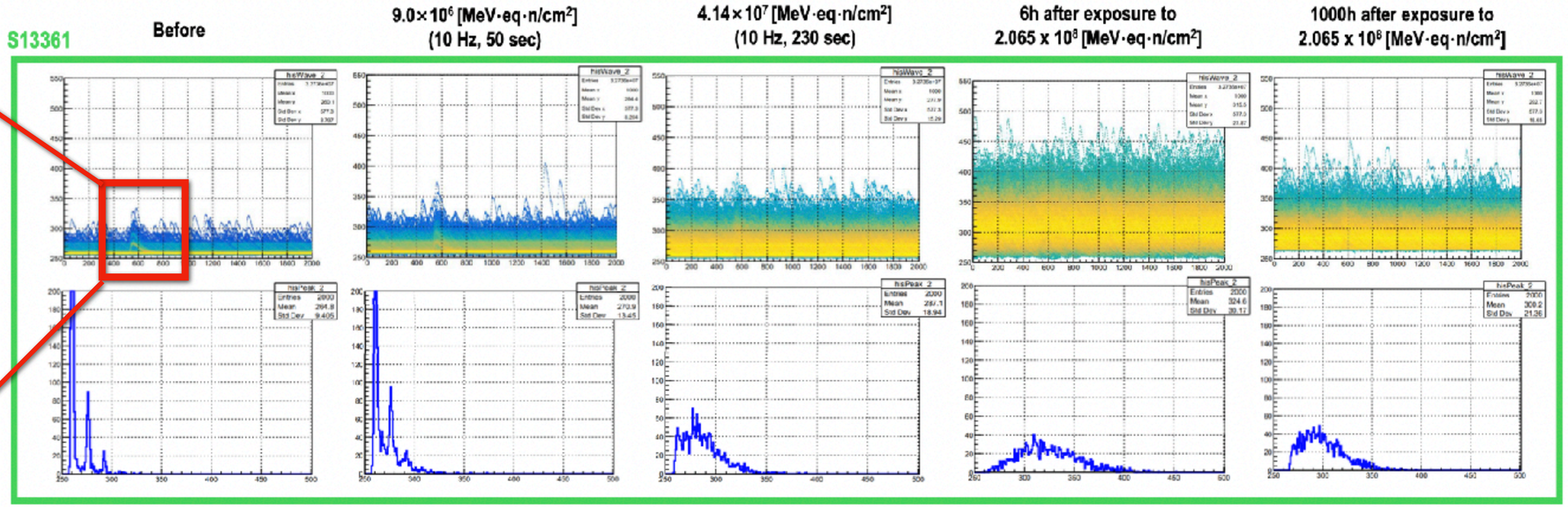
SiPM neutron irradiation test

Overlaid Waveforms and Peak ADC Distributions



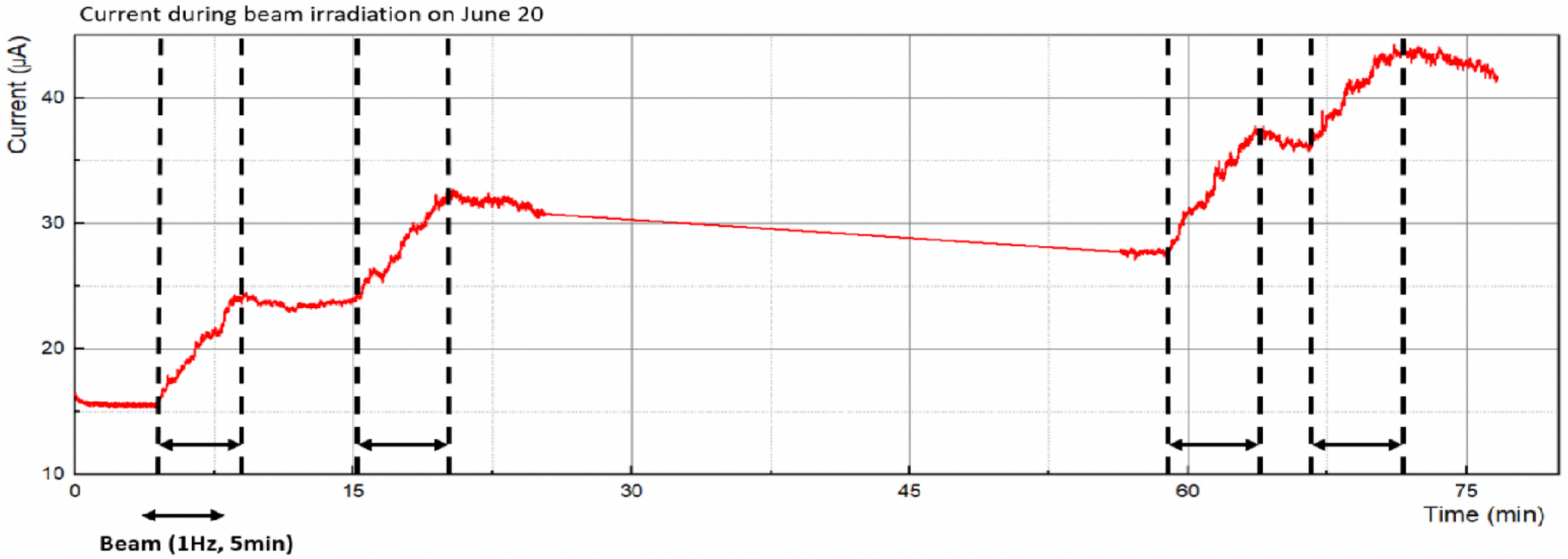






SiPM neutron irradiation test

Current Monitoring of S14 during Irradiation

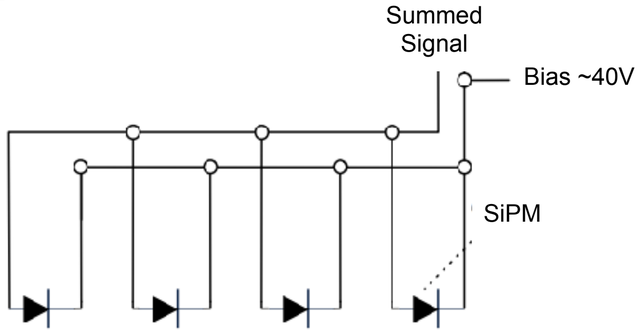


- The current increases when the beam is on, and when the beam stops, it slowly recovers.

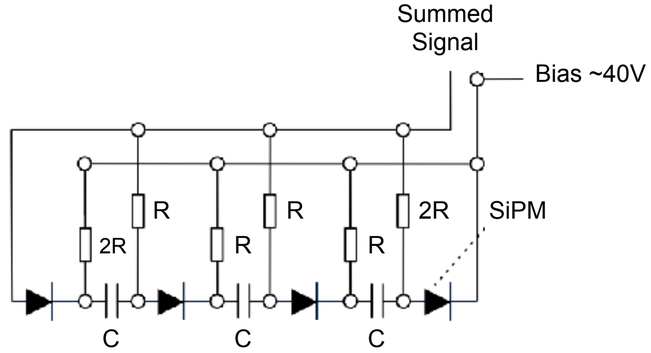
SiPM array summing board

- 1-ch Individual

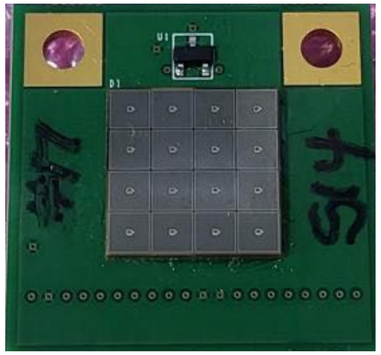
- parallel sum

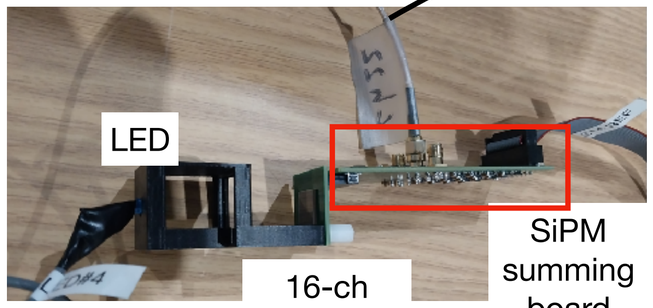


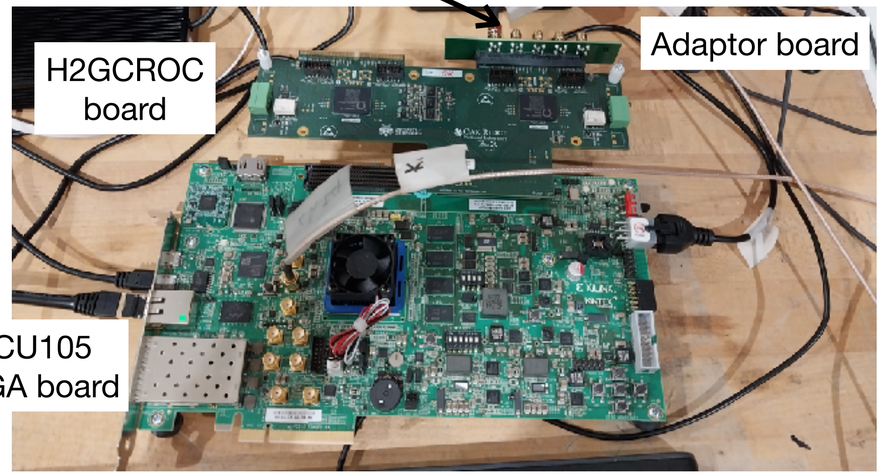
- hybrid sum



- SiPM summing board test setup





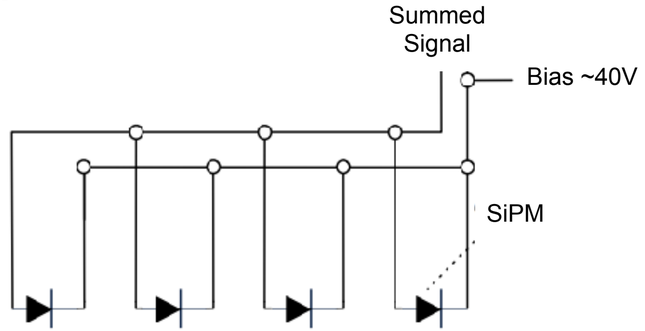


- 1 light guide -> 16-ch SiPM array
- SiPM signal summing can reduce the ASIC channel count by ×16.

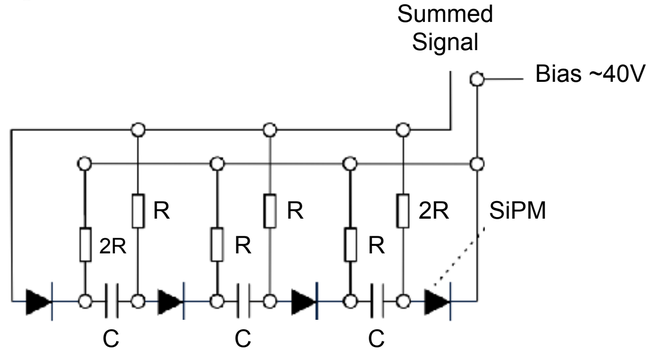
SiPM array summing board

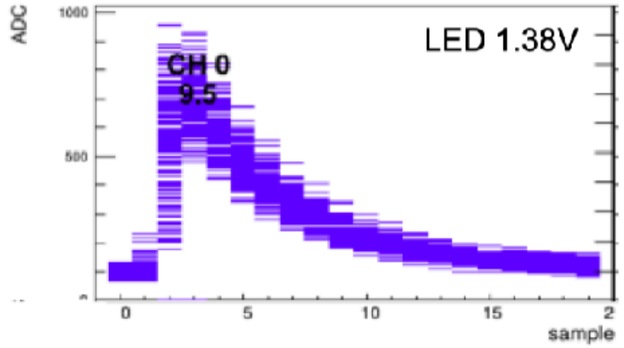
- 1-ch Individual

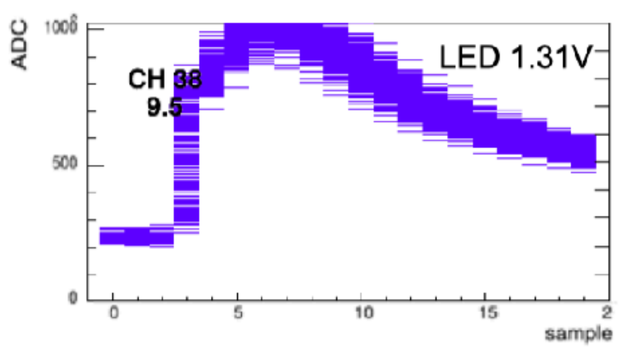
- parallel sum

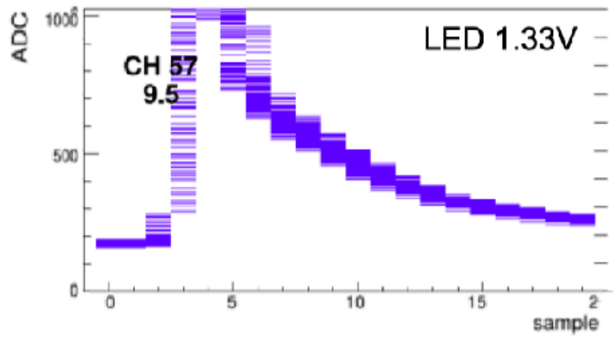


- hybrid sum





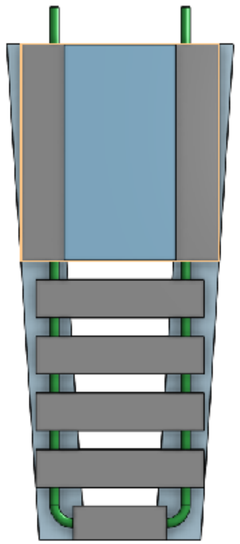




- Parallel sum: larger effective capacitance → broader pulse
- Hybrid sum: parallel bias + series signal sum → pulse width close to individual readout
- KEK PF-AR electron beam test is scheduled on May 14 - 22

Cooling

- Thermal simulation at Manitoba Univ.



Aluminum cold plate,
PCBs on both sides:

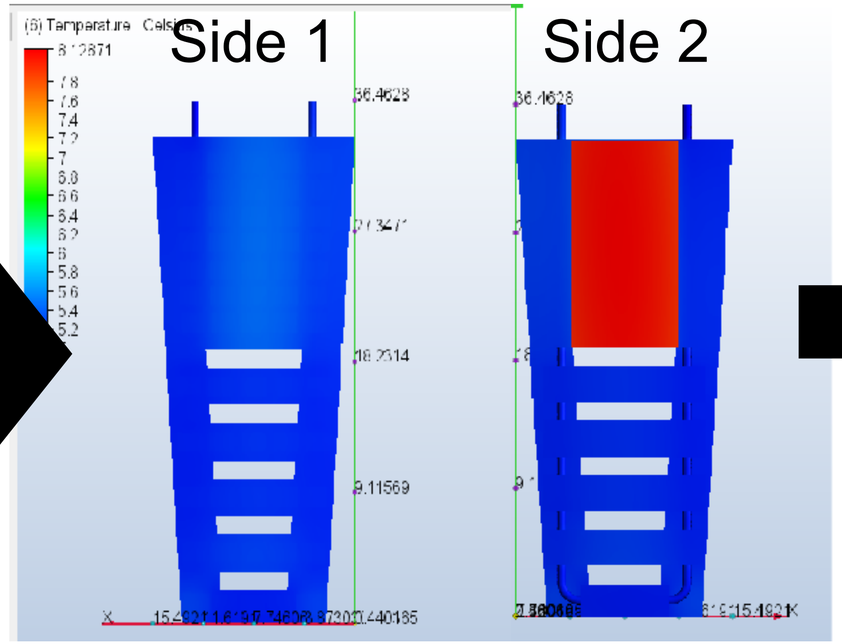
- Side 1: ESB PCB with SiPMs
- Side 2: CALOROC and ETC

Design dimensions:

- Cu cooling lines ¼” OD
- Aluminum plate thickness ½”

Boundary conditions for CFD:

- Water 5°C, flow rate: 0.3 gal/min
- Heat flux per SiPM: 0.046 W/cm²
- Total power from CALOROC: 5 W
- ESB metal core; CALOROC FR4



Simulation shows ΔT ~0.5 °C at the SiPM side and a peak of ~3 °C at the CALOROC side.

- Prototype at KNU

- The KNU cooling prototype translates the CFD-guided cold-plate design into hardware for validation.

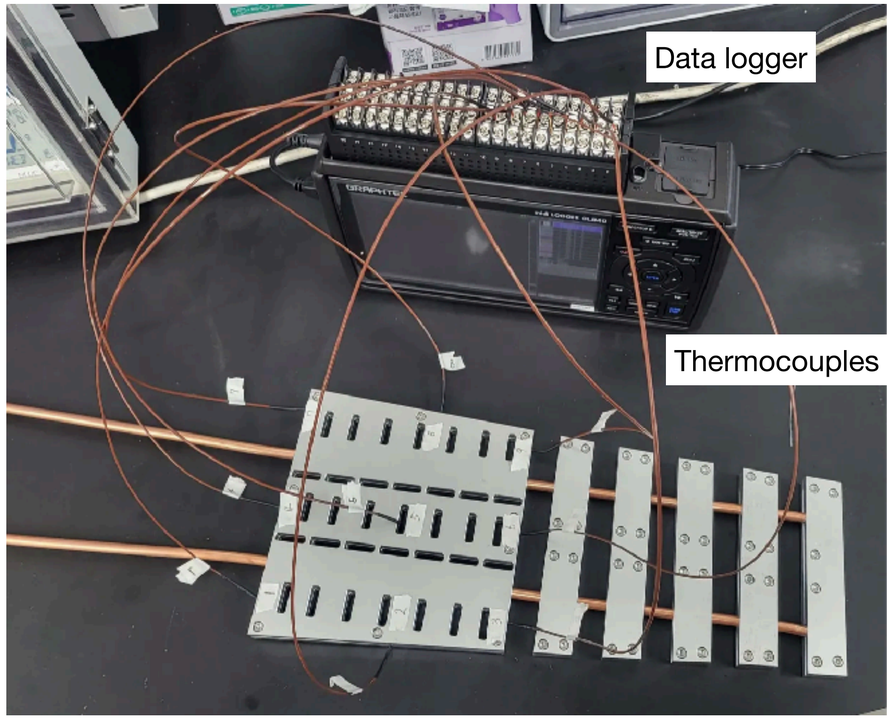
Cooling

- Water chiller

Chiller (7 °C , 1.1 L/min)

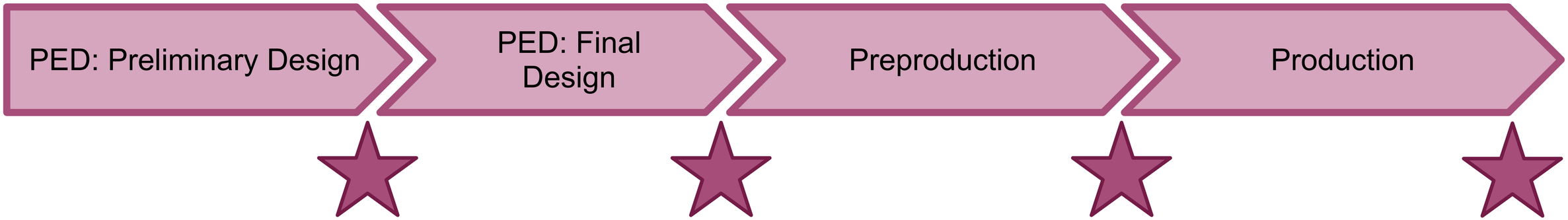
- Water temperature: -25 ~ 150 °C
- flow rate: 0.006 ~ 3400 mL/min

- Temperature monitoring



- Ongoing: development and construction of PCB (thermal) test articles for validation of CFD calculations
  - resistive element array distributed at locations of SiPMs

Overall BIC Project Phases



- Preliminary Design Review, 60% design completion
- AstroPix v3 (and v4)
- BabyBCal & Lanky BCal
- Individual components
- First (second) test articles

- AstroPix v5
- One full sector
- Final designs (90%)
- Production style procedures
- AstroPix v6 validation tests

- AstroPix v6
- 48 sectors

Summary

- **The ePIC BIC is a hybrid Pb/SciFi + AstroPix imaging calorimeter** designed for barrel electromagnetic calorimetry and 3D shower profiling.
- **Korean groups contribute across the main BIC R&D areas**, including AstroPix testing, Pb/SciFi prototypes, ESB/readout, and system testing.
- **KNU-centered ESB R&D is validating key readout-service components**: light guides, optical cookies, SiPM response, LED monitoring, summing boards, and cooling.
- This workshop is a good opportunity to connect BIC experience with ZDC calorimetry, electronics, calibration, and test-beam discussions.

Thank you!

Backup slides