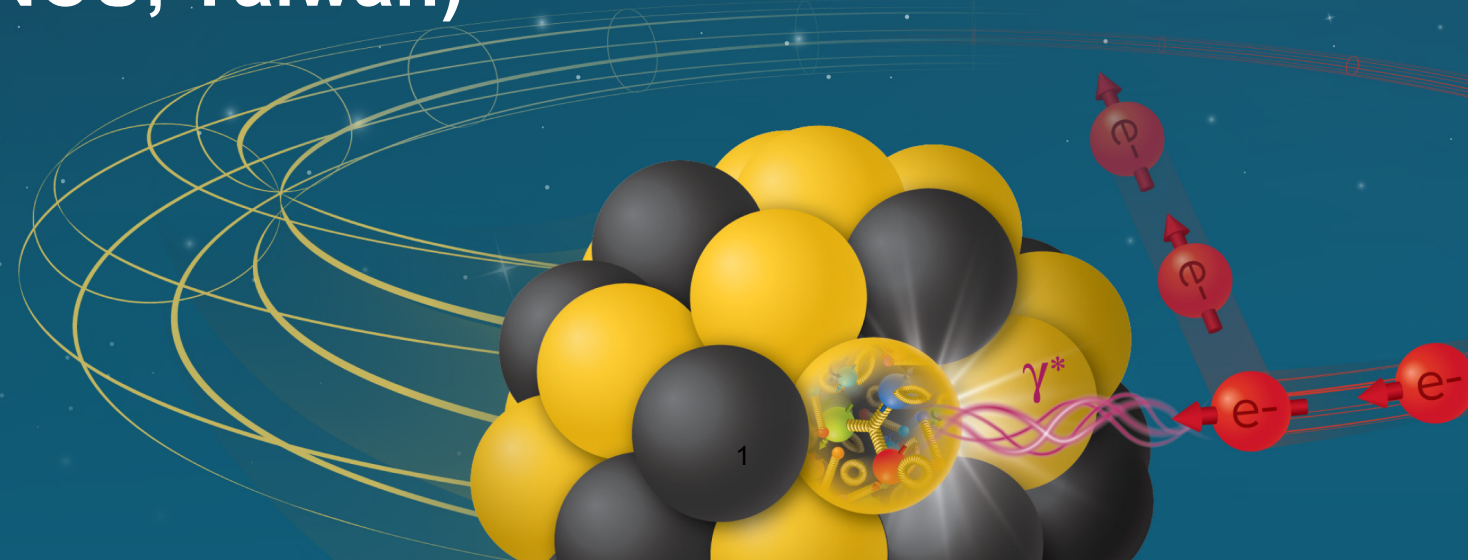


ZDC Electromagnetic Calorimeter

- Summary from the PDR3 auxiliary detector review

Yuji Goto (RIKEN, Japan)

Chia-Ming Kuo, Po-Ju Lin (NCU, Taiwan)

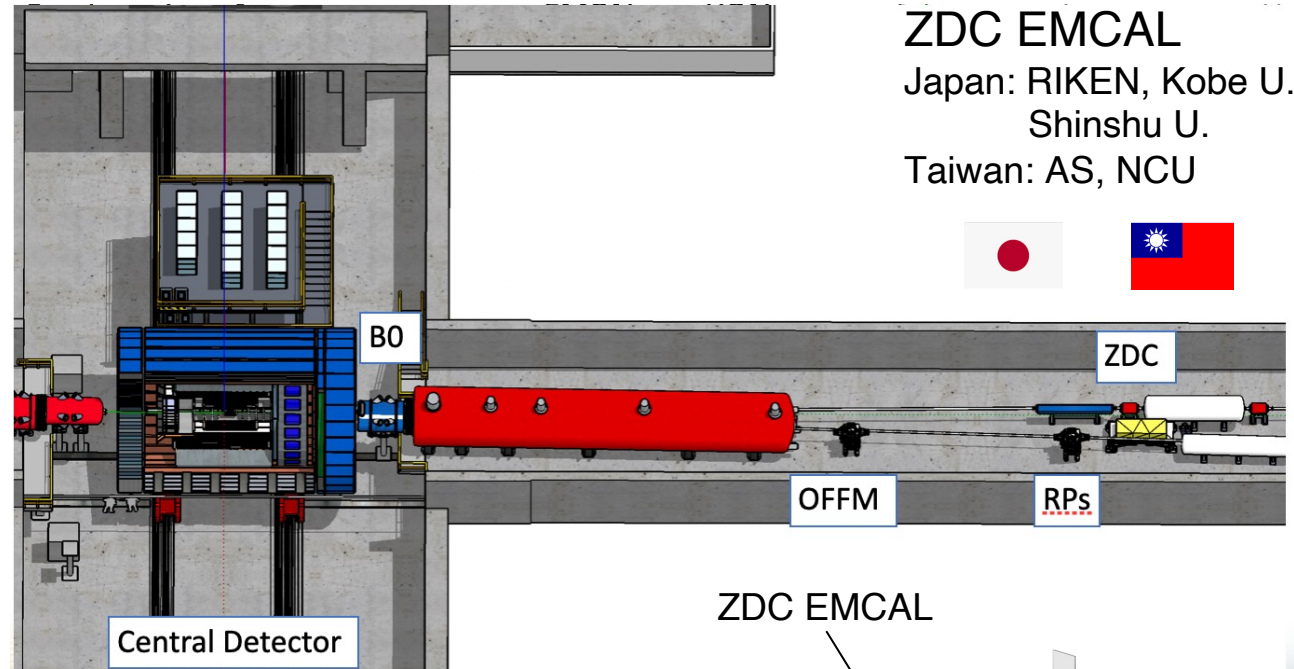


Outline

- Detector Overview
- Requirements, Major Interfaces, Internal Interfaces
- Technical Progress (since last review)
- Production Planning
- QA
- Calibration
- Alignment
- ES&H
- Internal Subsystem Risks and Dependencies
- Technical Path Forward, Schedule and Milestones
- Summary

Detector overview

- The ZDC EMCAL is a key component of the ePIC forward neutral detection system
- Its primary role is to provide electromagnetic shower measurement in the zero-degree region and to support the overall ZDC physics performance
- The detector concept has been developed to satisfy physics-driven performance goals while respecting integration, infrastructure, and operational constraints
- The present design emphasizes:
 - Adequate energy measurement capability
 - Compatibility with the ZDC mechanical envelope
 - Integration with common readout, and detector services
- At this stage, the detector concept is stable and the design direction is well established

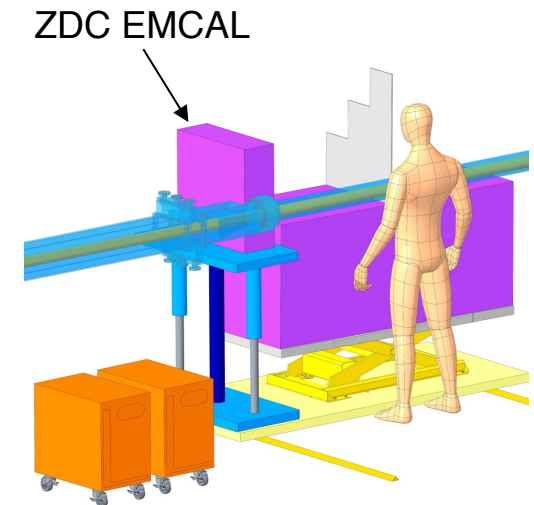


ZDC EMCAL

Japan: RIKEN, Kobe U.,
Shinshu U.
Taiwan: AS, NCU



- Design:
 - A homogeneous scintillating PbWO_4 crystal calorimeter (729 crystals) with SiPM readout
 - Crystal dimensions: 20.5 mm × 20.5 mm × 7 cm ($\sim 8X_0/\sim 0.34\lambda$)



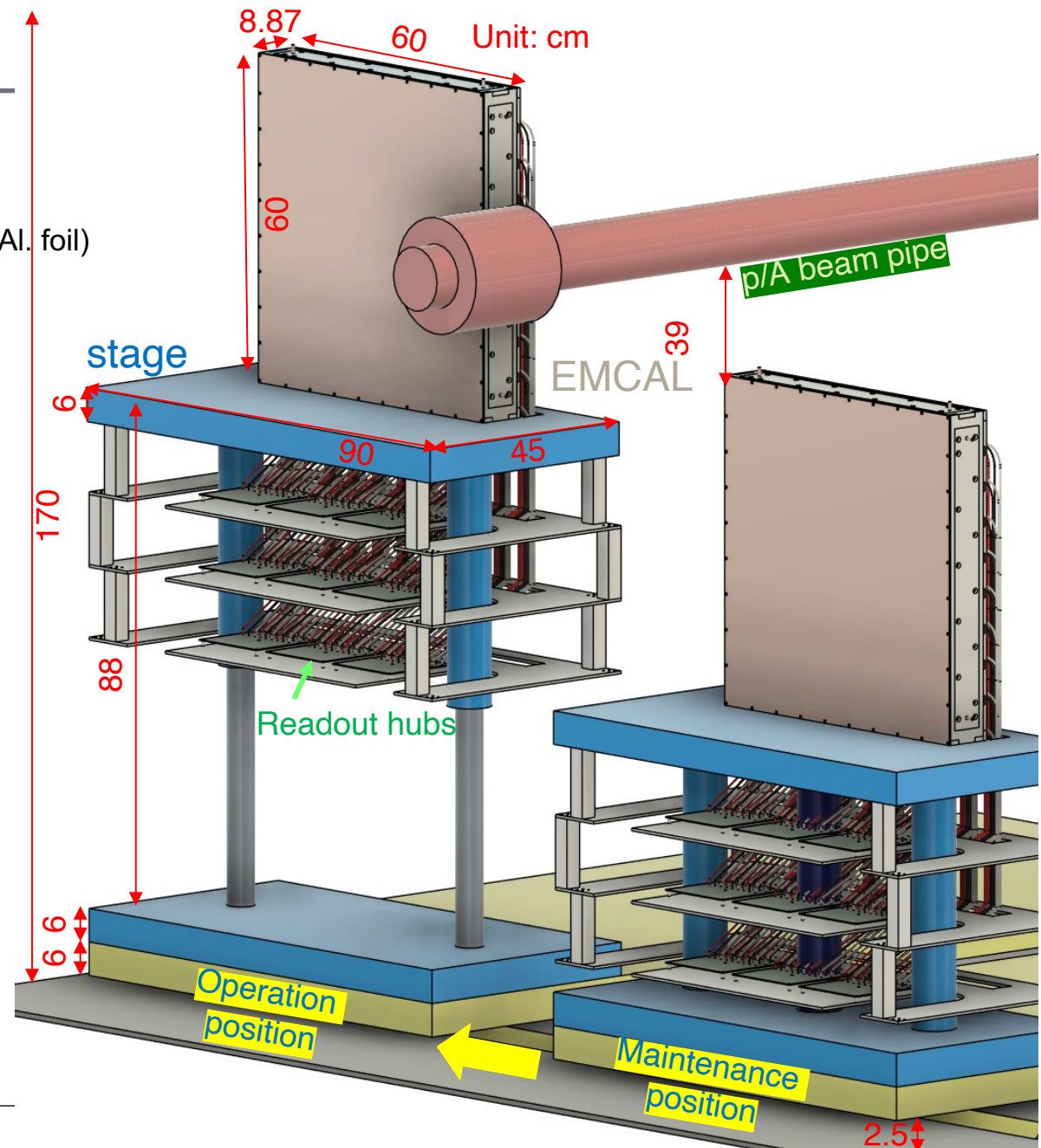
Requirements, Major Interfaces

- Physics performance requirements:
 - The detection of very forward neutral particles requires a clear, beam-element-free path from the interaction point to the detector
 - For **photons**, provide photon measurements down to **100 MeV** in eA collisions and enable π^0 detection with an energy resolution better than **$20\%/\sqrt{E}+5\%$** and angular resolution better than **$3 \text{ mrad}/\sqrt{E}$**
 - For neutrons, together with HCAL, provide good angular resolution and energy measurement better than **$50\%/\sqrt{E}+5\%$**
- Major interfaces have been defined at the system level, including:
 - Mechanical interface to the ZDC support structure and available envelope
 - Electrical interfaces for power, grounding, and cabling
 - Electronics and DAQ interfaces for readout, timing, and controls should be similar to, or the same as, those for the backward EMCAL
 - Thermal and service interfaces
- The remaining work will be focused on refining interface details and maintaining consistency with evolving detector-wide integration assumptions

Work closely with the backward EMCAL in all aspects

Major Components and Interfaces

- **PbWO₄ crystal array:**
 - Crystal size: 20.5 mm × 20.5 mm × 70 mm
 - Allow an additional 0.5 mm for the reflector (3M ESR) and wrapping (Al. foil)
 - One super module (SM): 9×9 crystals, with carbon-fiber spacers
 - Allow 1 mm of stainless steel for the SM wrapping
 - Full array: 3 × 3 SM = (3 × 191)² mm²
 - Total number of crystals: 729
- **SiPM:** Hamamatsu S14160-3015PS
 - Number of SiPM channels for each crystal: 4 × 4 = 16
 - Total number of SiPM channels: 11,664
- **ROC:** We will use the same ROC as for the backward EMCAL
- **Support and cooling design:**
 - Use 8 mm-thick aluminum plates and a 3 mm copper plate
 - The coolant is circulated through the copper tubing
- **Cable routing:**
 - The cables run downward through the table
 - Maximum length: ~95cm

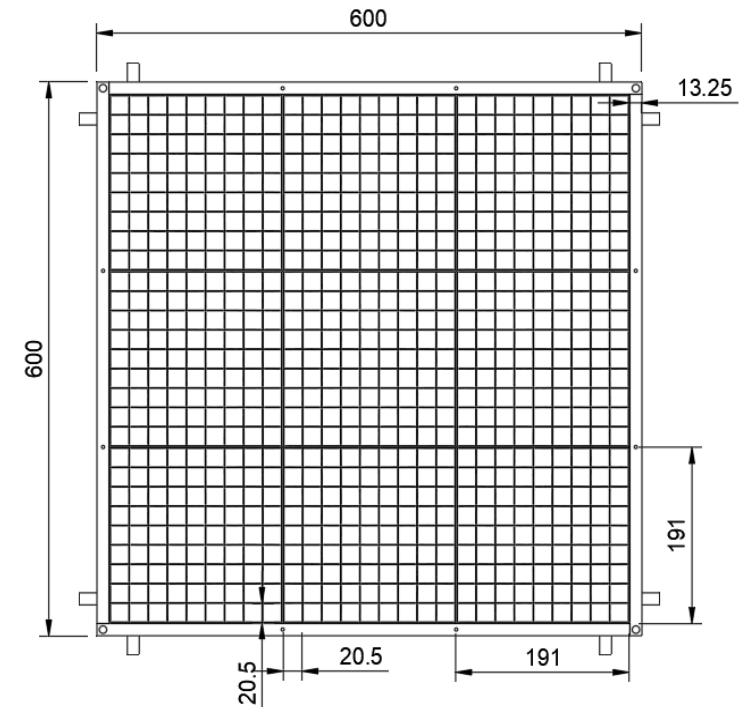
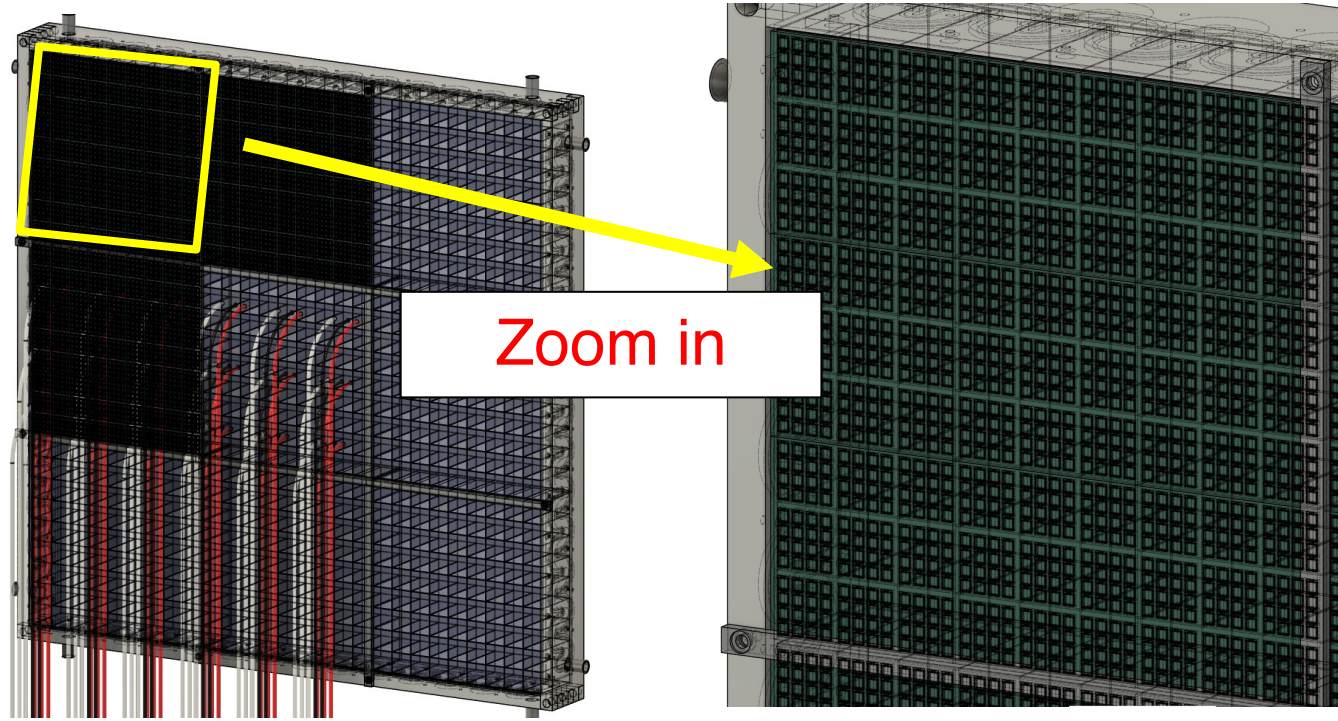


Homework

- Need to discuss with Yulia to fix the finalize the detector size
- If possible, we should build a mock-up detector, both with and without crystals, on the table and check the cable routing is ok
 - IMHO, we do not want any surprises when we start the in-situ assembly

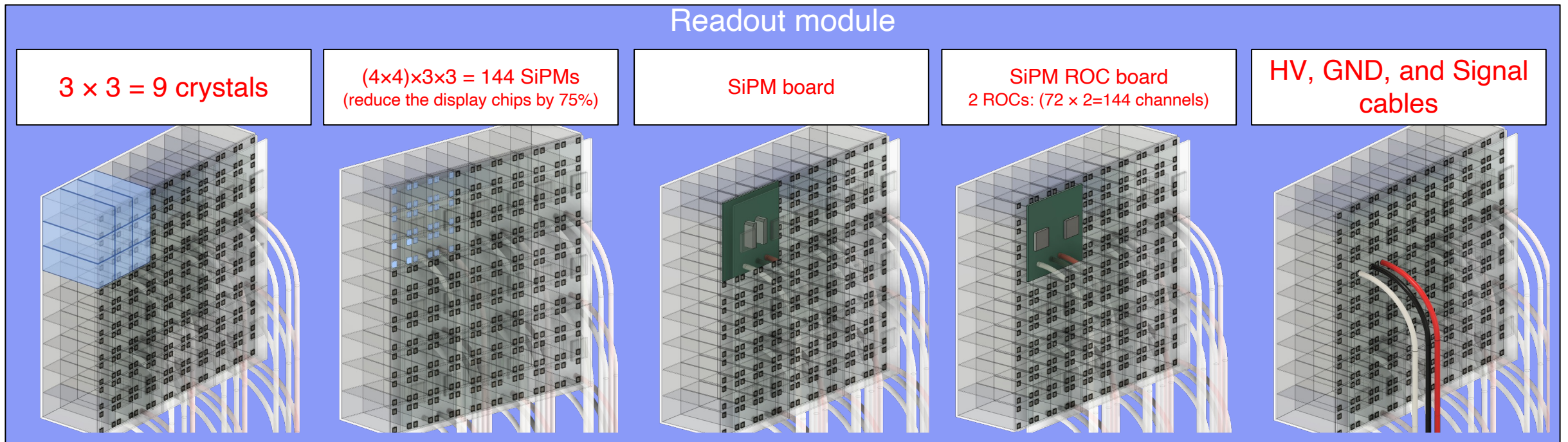
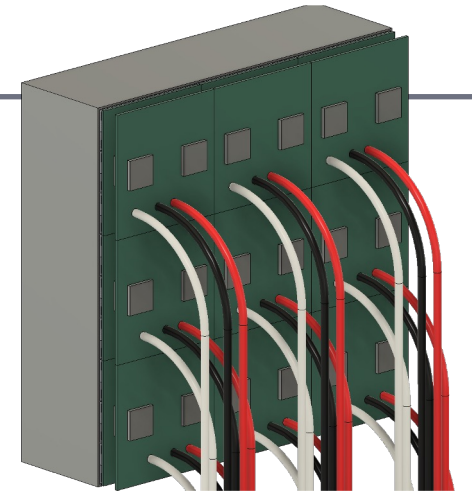
Internal Interfaces (1/3)

- The size of one SM: $(21.0 \times 9 + 2)^2$ mm²
- One SM contains:
 - 9×9 PbWO₄ crystals
 - The total number of SiPM channels is $16 \times 9 \times 9 = 1,296$



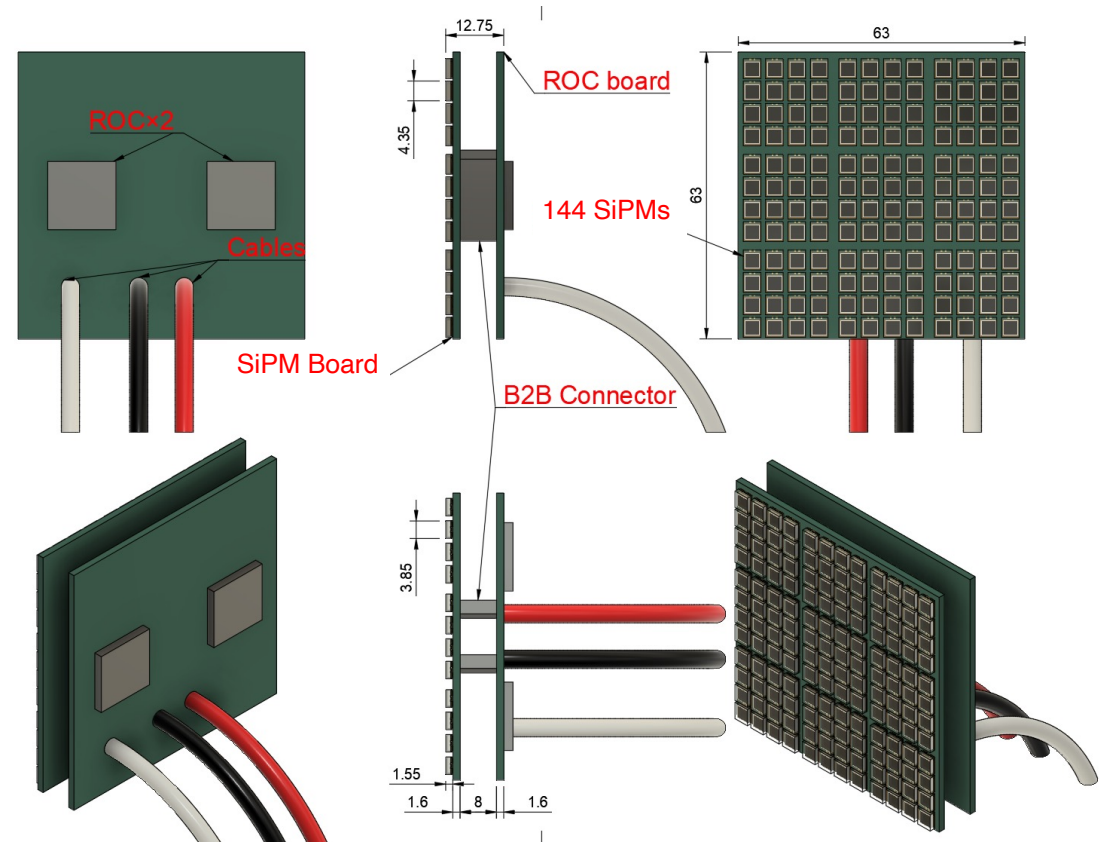
Internal Interfaces (2/3)

- SiPM readout module
 - One readout module contains:
 - 144 SiPM channels, 2 ROCs, and thermal contact



Internal Interfaces (3/3)

- The readout module boards
- Accommodates 144 SiPMs on a 63 mm × 63 mm PCB
- Dual-Layer PCB stack
 - SiPM board (front): Used for photon detection and signal interfacing with the crystal array
 - ROC board (back): Includes two readout chips (ROCs) for signal processing and digitization
- Interconnect & connectivity
 - Board-to-board connector:
 - Uses a 8 mm standoff height to minimize the analog trace length between SiPMs and ROCs, ensuring signal integrity and low noise
 - External cabling:
 - Includes three robust rear-exit cables for HV bias, GND, and high-speed data transmission



Cooling and Mechanical Support

- Need to operate crystals stably at room temperature (1°C variation causes 2% change on light yield and an additional 2% change on SiPM gain) \rightarrow Aim to control at 0.1°C
- 4 cooling tubes (6mm) are used to circulate the coolant and dissipate heat
- The front panel is a 3 mm copper plate
- The main heat source is the ROCs



Thermo Scientific ThermoChill II LR
Recirculating Chiller 1000W Cooling,
115V PD1 Pump PN 197211010000

Condition: New
Part Number: P106050
Warranty: Full Manufacturer's Warranty

Available Now 1

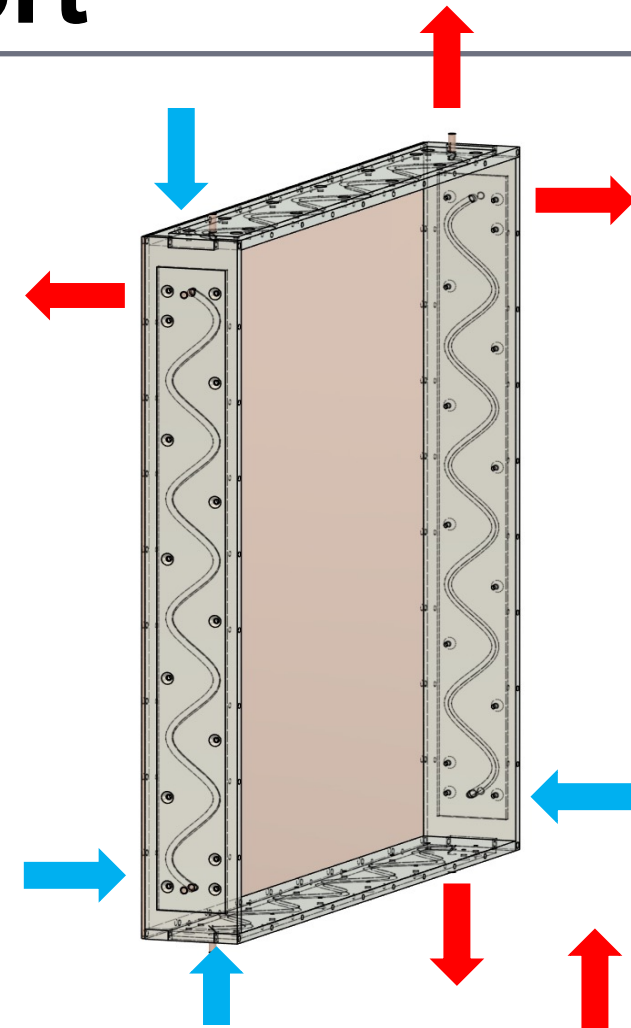
Sale: \$7,809.29

Tariffs: \$477.70

1

Add To Cart

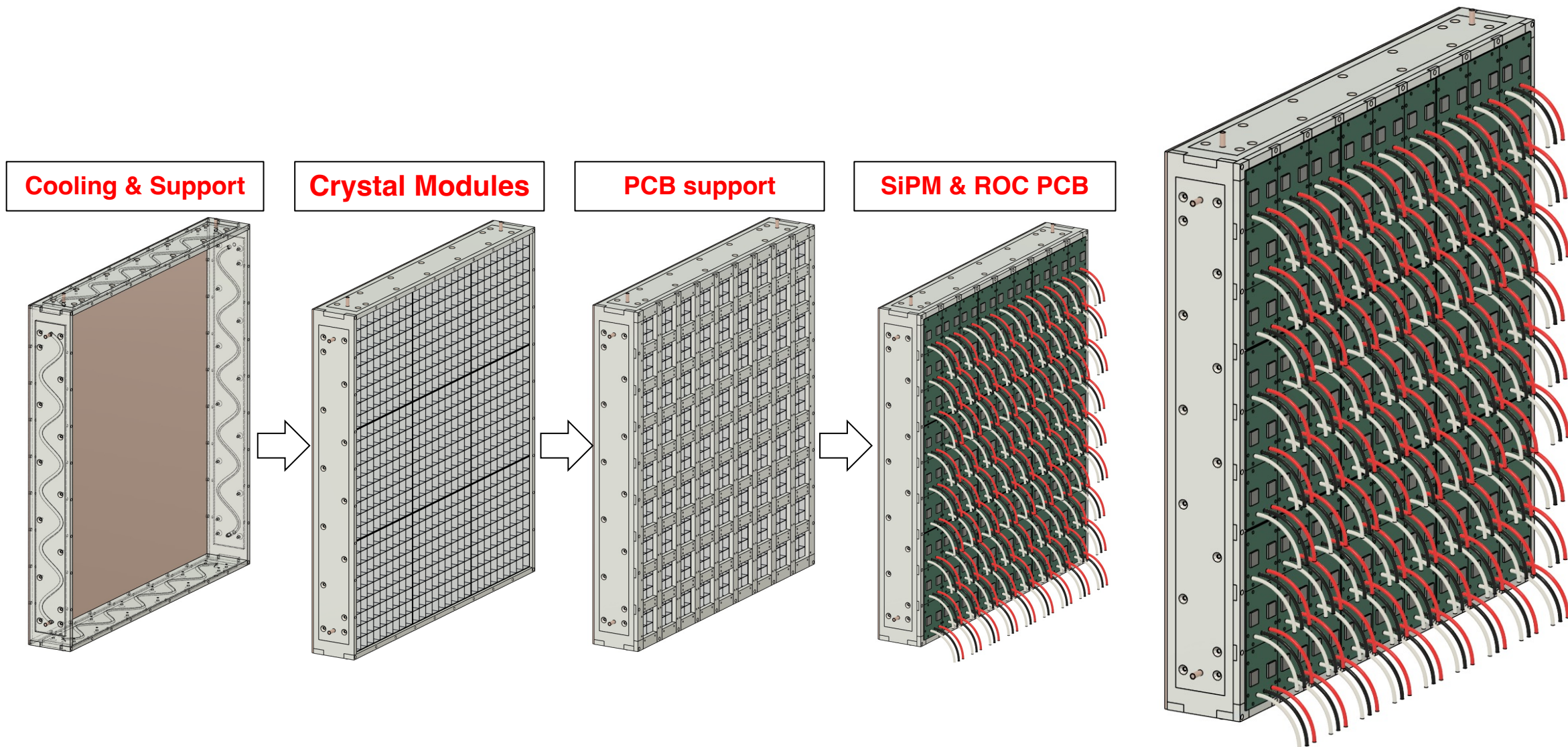
Currency: US Dollar (USD)



Homework

- Need to check cooling design and requirements
- Perform an ANSYS simulation to evaluate the temperature distribution across the entire detector
 - Note that a 0.1°C temperature variation contributes a 0.4% constant term
- Build a cooling system prototype, mimic temperature variations in the RHIC tunnel, and evaluate its performance
 - Then, refine the design accordingly

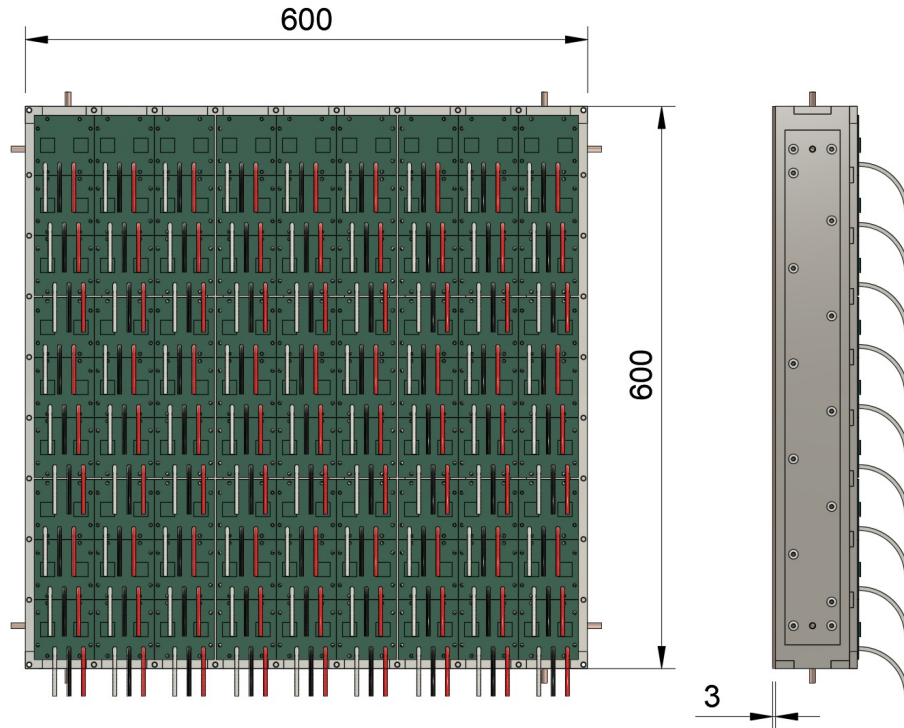
Assembly Procedures



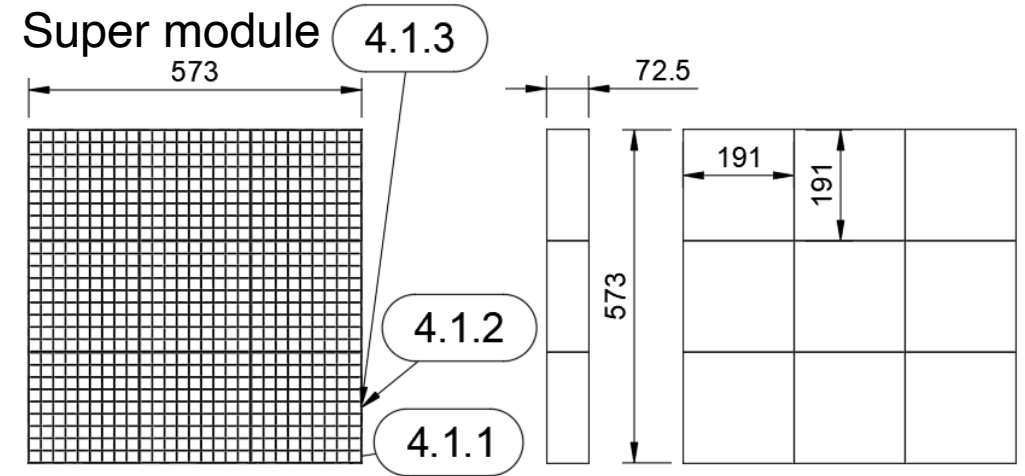
Homework

- Include 3D Movie to see overall assembly and installation sequence

Detector Weight



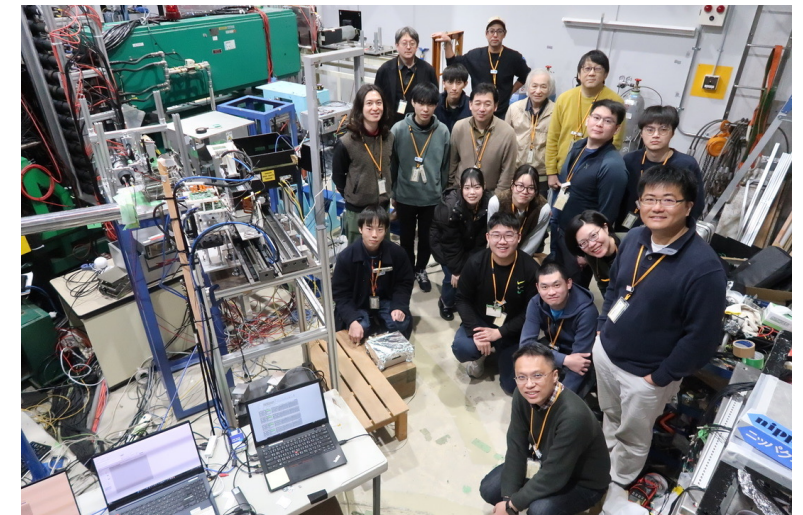
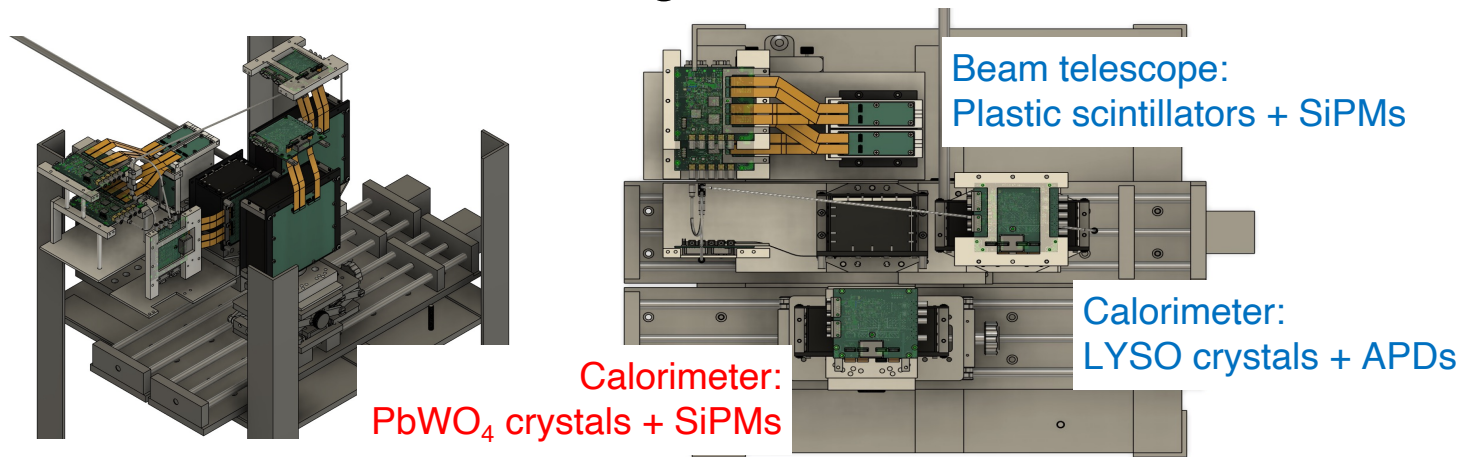
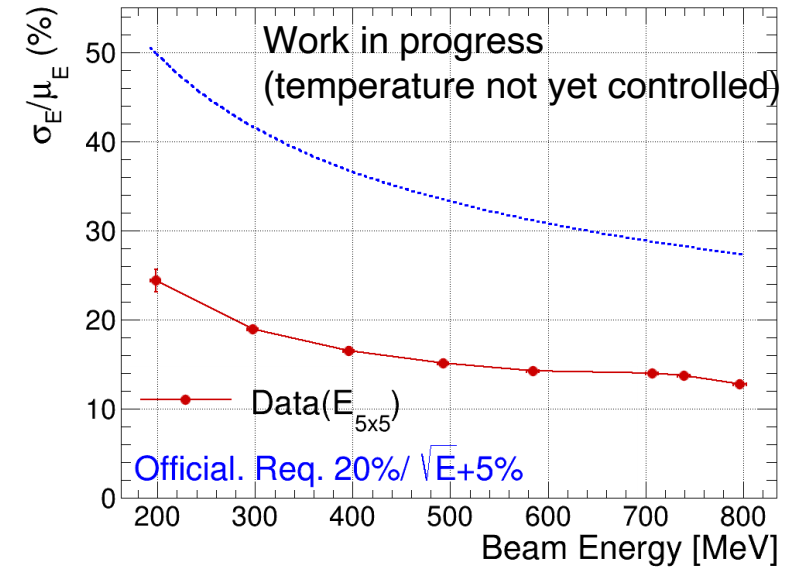
- Super modules: $21.1 \text{ kg} \times 9 = 190.3 \text{ kg}$
- Cooling system: 12.1 kg
- PCB support frame: 3.6 kg
- SiPM and ROC PCBs: 3.5 kg
- Total weight: 290.5 kg



Parts List				
Item	Qty	Part Number	Material	Mass
4	1	CrystalSys	---	190.3 kg
4.1	9	SuperModule_9x9_70 mm	---	21.1 kg
4.1.1	81	PWOModule	PBWO4	0.2 kg
4.1.2	1	SuperModeluShell	Steel	0.7 kg
4.1.3	1	CrystalShells	Aluminum	0.4 kg

Technical Progress (since last review)

- Test beam @ RARiS, Tohoku University
 - 47 - 823 MeV positron beam
- February 2024: LYSO + SiPM
- February 2025: PbWO_4 + SiPM (default design) & LYSO + APD (potential upgrade option)
 - Linear response observed in the initial analysis
- July 2026: PbWO_4 + Hamamatsu SiPMs + CALOROC + Discrete readout + Cooling



Production Planning

- Production and SM assembly sites: Japan and Taiwan
- Final in situ assembly site: BNL
- Major components: PbWO_4 crystals, SiPMs, and related readout/assembly parts
- Budget: funding support may be provided through IKC
- Assembly and QA approach: established procedures, following the backward calorimeter where applicable
- Installation strategy: coordinated with accelerator equipment installation and overall integration schedule
- Facilities readiness: facilities at Japanese and Taiwanese institutes have been or will be fully equipped with all the necessary equipment for the assembly, QA, and testing of PbWO_4 crystals and SiPMs
- Technical basis: the current production concept is supported by existing expertise, available infrastructure, and prior detector experience within the collaborating institutes

Homework (done)

- Crystal delivery schedule
 - Assuming we place the order at the beginning of 2028 and purchase 972 crystals
 - The estimated lead time is around 12-14 months
 - Deliveries will be made in multiple batches, starting about 2-3 months after the order is placed

QA (1/2)

- PbWO_4 crystals:
 - Every crystal: check size, light output, and light-collection uniformity
 - Optical scan: measure transmission to catch defects linked to radiation hardness
 - Barcode each crystal box and store results in the production database
- SiPMs:
 - Breakdown voltage: measure every SiPM and group similar parts
 - I-V curve and leakage: catch early breakdown or odd dark current
 - Noise check: log dark current
 - Gain and light response: use low-light LED or laser tests to verify
 - Temperature scan: map gain and breakdown shifts
- Will work closely with backward EMCAL on QA

QA (2/2)

- Radiation and modules
 - Radiation qualification: irradiate sample SiPM, then re-measure dark current, dark count, and gain
 - Binning and matching: place similar parts on the same board so one bias setting works
 - Module QA: after soldering and optical coupling, test full channels again
 - Traceability: link serial number, batch, QA data, and detector channel
- All SMs will also undergo cosmic ray tests before final installation
- These QA will be performed in Japan and Taiwan
- After shipment to BNL, the SMs will first undergo QA, followed by final in situ assembly and subsequent cosmic-ray testing

Latest Progress

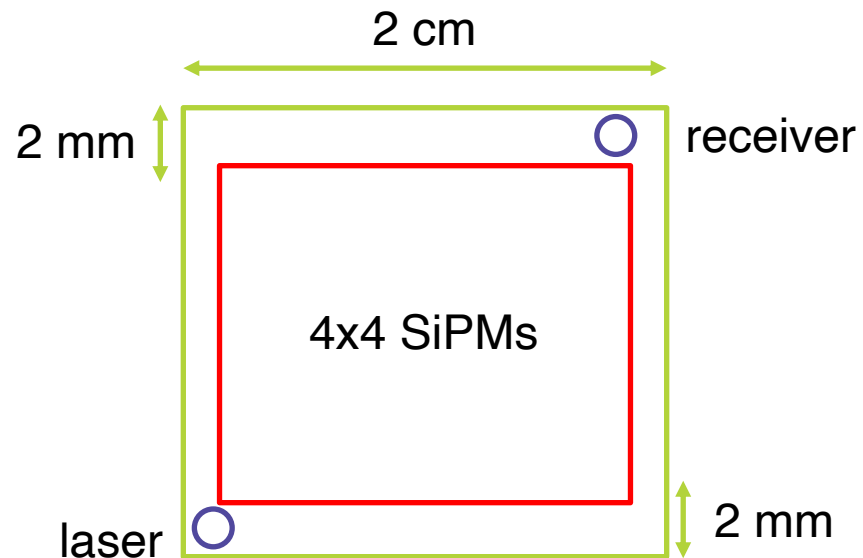
- A condense matter physicist in Taiwan with laser expertise is willing to work with us to perform optical scans of the crystals
- Based on what we learned from Tanja, if we purchase SiPMs together with other sub-detectors, the acceptance of SiPMs will be done centrally

Calibration

- Calibration required hardware
 - Blue laser (447 nm for transparency check) and cross check with other wavelengths of laser
 - LED light sources
 - Light distribution system
 - Long quartz optical fibers to deliver light to reach SM
 - Reference photodiodes (PN silicon photodiodes) to monitor the light intensity
 - Readout and control electronics, plus front-end charge injection for checking the electronic chain
- Calibration procedures
 - Pre-calibration: performed using beam tests at RARiS or cosmic-ray tests
 - Laser/LED light will be injected during the EIC abort gap to monitor time-dependent response and calibrate time-dependent transparency corrections

Latest Progress

- The same condense matter physicist in Taiwan with laser expertise is willing to help us design the laser monitoring system
- Will send him a few crystals so that he can start developing the optical scan and laser monitoring system



Alignment

- Alignment requirements:
 - Relative transverse positioning between neighboring crystals: **0.1 mm**
 - Longitudinal positioning with respect to a common reference surface: **0.1 mm**
 - Mechanical alignment concept:
 - Crystal positions are defined by a precision support structure, dedicated assembly jigs, and a common reference surface
 - The wrapping thickness and the required assembly clearance are explicitly included in the mechanical design
 - Assembly tolerances are controlled through machining precision and the installation procedure
- Alignment, survey and validation procedure
 - Crystal QA before assembly
 - Mechanical assembly using precision fixtures
 - Post-assembly survey to confirm that the relative crystal positions are within 0.1 mm
 - Cosmic-ray data, together with finely segmented scintillating bars or fibers, can be used to validate the relative alignment

Environment, Safety, and Health (ES&H)

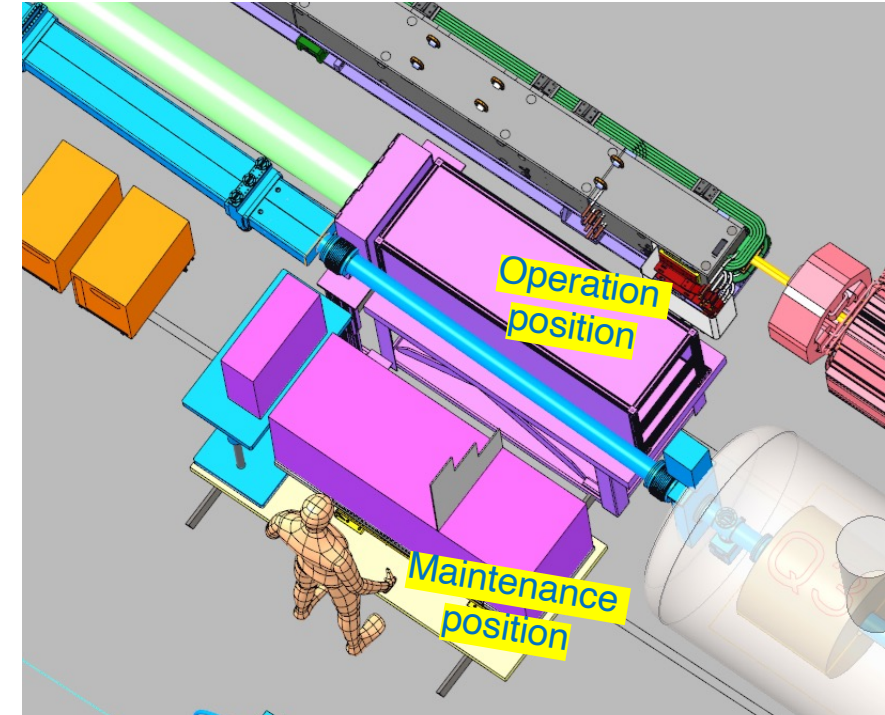
- ES&H has been incorporated into the design and planning process in a manner appropriate for the current phase of the project
- We will implement the appropriate ES&H and Radiation Safety measures as required by the participating institutes, universities, and BNL. All personnel working at the lab must receive the appropriate training to ensure compliance with these safety protocols
- Key ES&H topics considered so far include:
 - safe handling of detector components and materials
 - use of appropriate Radiation Safety measurements and controls
 - electrical safety for low-voltage and high-voltage systems
 - mechanical handling, lifting, and installation safety
 - work planning for assembly, testing, and integration activities
 - access control and procedural controls during commissioning and maintenance
- The project plan assumes that formal procedures, hazard analyses, and training requirements will be completed before production and installation activities begin
- At present, no ES&H issue has been identified that would require a significant change to the detector baseline

Internal Subsystem Risks and Dependencies

- No formal high-risk items have been identified in the risk matrix, and the remaining challenges are expected to be minimal.
- The main uncertainties are related to execution and integration, rather than to the basic feasibility of the detector. The key potential risks are listed below.
- Key risks:
 - Schedule impact from procurements
 - Interface changes driven by system-level integration updates
 - Vendor and component qualification delays
 - Assembly reproducibility and tolerance control
 - Coupling to common electronics, DAQ, or infrastructure schedules
- Key dependencies:
 - Final mechanical envelope and support definition
 - Shared electronics and timing decisions
 - Infrastructure availability for power, cooling, and cabling
 - Integration schedule for assembly, survey, and installation

Technical Path Forward, Schedule and Milestones

- Items to be completed before the FDR:
 - Finalize the mechanical design, including the lifting table, to improve detector maintainability
 - Finalize the design of the laser/LED monitoring system
 - Complete the readout integration
 - Refine the assembly and installation concept
 - Refine the QA and testing plan
 - **Need to check cooling design and requirements**
- Schedule and milestones:
 - Preliminary design finalized: Q3 2026
 - Completion of key design optimization and validation studies: Q4-2026 - Q1 2027
 - Finalize interface and integration: Q1 2027
 - FDR: April 2027
 - Final design finalized: Q3 2027
 - Production and procurement preparation: after final design completion
 - Finish SM assembly and QA in Japan and Taiwan, then ship to BNL for final in situ assembly and cosmic-ray testing : Q1 2031
 - Ready for installation: Q3 2031



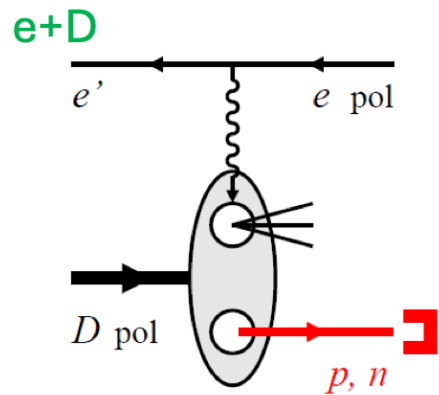
Summary

- The technical performance requirements for the ZDC EMCAL are well defined for the current stage of the project.
- The preliminary design is sound with a clear path to finalize design.
- The main tasks to be completed before the FDR have been identified, including mechanical design refinement, readout integration, and development of the monitoring system.
- Plans for fabrication, assembly, QA, and ES&H have been included at a level that is appropriate for the 60% preliminary design stage.
- The proposed schedule and milestones provide a reasonable path toward final design, production readiness, and installation.
- Overall, the ZDC EMCAL project is moving in the direction toward the next stage of design and implementation, with technical risks that appear manageable.
- ZDC EMCAL review went well with positive feedback

BACKUP

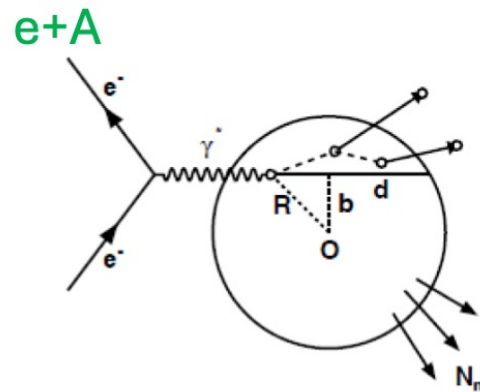
Physics Motivation

- Measure forward neutrons from nuclear breakup in eA collisions
- Tag nuclear dissociation in exclusive and diffractive reactions
- Distinguish coherent and incoherent scattering channels
- Provide input for event characterization in eA
- Study electromagnetic dissociation and other very-forward neutral signatures



High-energy process

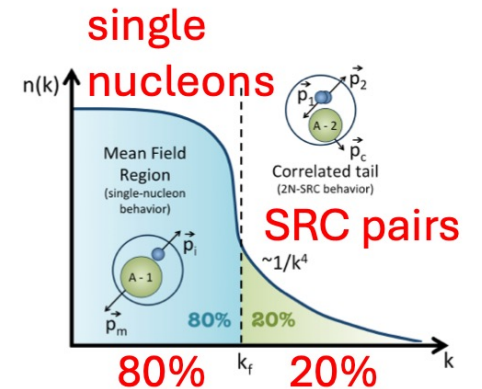
Forward spectator detected **Roman pot ZDC**



Intra-nuclear cascading increases with d (forward particle production)

Leads to evaporation of nucleons from excited nucleus (very forward)

Nucleon Momentum Distribution



Temperature Deviations Inside the RHIC Tunnel

