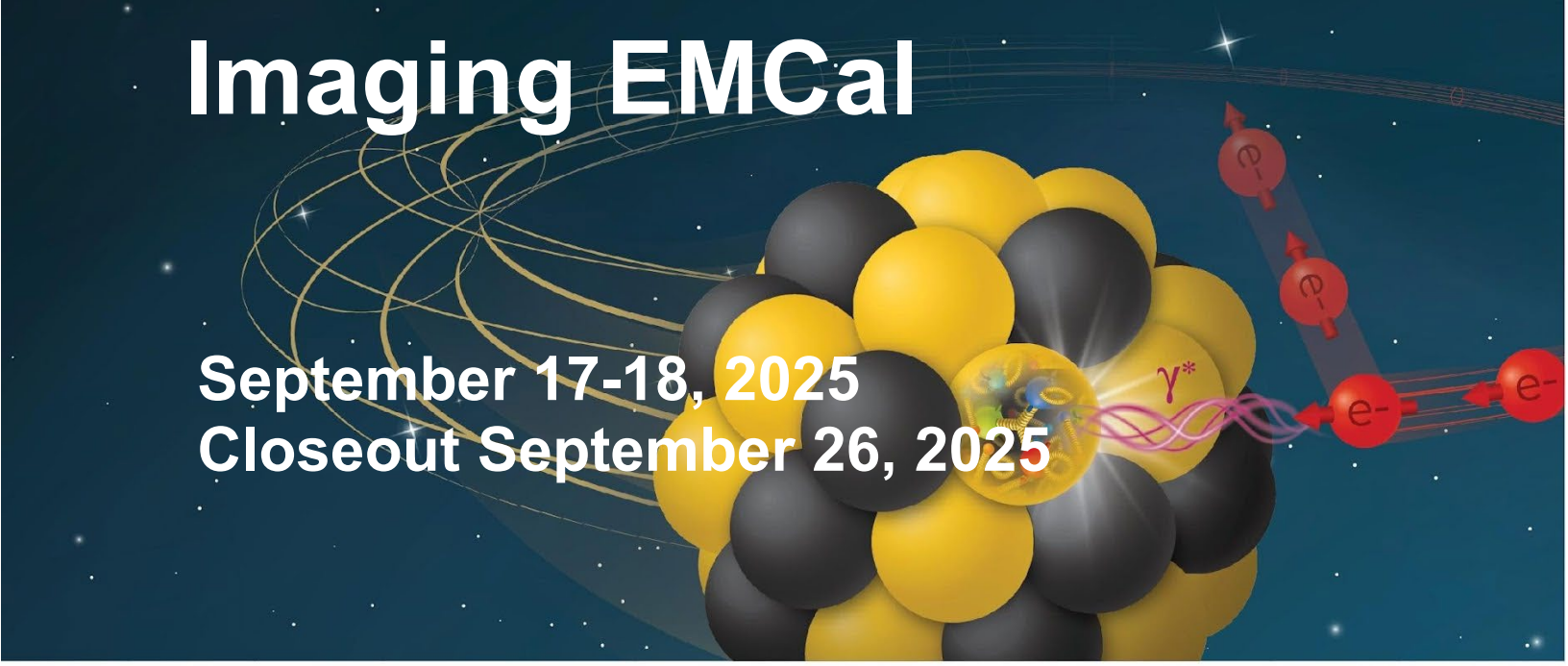
Electron-Ion Collider

Brookhaven National Laboratory | Jefferson Lab | U.S. DEPARTMENT OF ENERGY | Office of Science

Final Report

Incremental Preliminary Design and Safety Review of the ePIC Barrel Imaging EMCal



September 17-18, 2025
Closeout September 26, 2025

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1 Executive Summary

The scope of this review includes all aspects of particle detection using the Barrel Imaging electromagnetic Calorimeter (BIC) of the ePIC detector at EIC, which combines two technologies, light-collecting calorimetry based on SciFi embedded in Pb and imaging calorimetry based on monolithic silicon sensors AstroPix. The review includes design and fabrication scenarios and their cost-effectiveness, optimization of physics performance, construction schedule, early considerations for safety and quality assurance, front-end electronics and interface to the data acquisition system, commissioning and calibration procedures, considerations for materials and labor, operational reliability and longevity, and any other considerations that may influence the construction and operation of the Calorimeter.

The review was conducted via Zoom. Charge questions that were developed were clear and concise and the BIC team presented a series of high-quality presentations directly related to the charges. Throughout the presentations, there were very helpful Q&A periods and overall, the team was well prepared. The team appears to be well positioned to meet the requirements for CD2 next summer.

The main concerns of the review committee regard the following topics:

- SiPM noise increases with radiation damage and needs to be counteracted with sufficient cooling. Therefore, SiPM radiation hardness should be tested and compared to expected radiation loads within the lifetime of the experiment to obtain the requirements for the design and operation of the cooling system.
- AstroPix chip schedules have shifted over the past year and need to be monitored closely, in particular in view of the change of foundry from TSI to AMS. The next version v5 needs to be compared directly with results of v3 test articles to properly adjust the design of modules and the overall integration of the imaging layers.
- The design of End-of-Sector-Boxes (ESB) appears to be very complex as both SiPM readout and the connections to the AstroPix trays happen in the same volume and cooling and supplies get together in the boxes. The accessibility of the ESB should be evaluated in relation to potential failure rates in order to grant sufficient possibilities for maintenance.

2 Reponses to Charge Questions

Charge Question #1: Is the progress and design maturity of the barrel electromagnetic calorimeter systems aligned with being baselined in June 2026 (>60% maturity is required)?

Response: Yes, the BIC EmCal project seems to be well aligned with the expected baseline in June 2026. The Collaboration has shown an impressive progress in the various systems with respect to the previous review.

Charge Question #2: Are the technical performance requirements appropriately defined and complete for this stage of the project?

Response: SciFi has shown, through extensive single fiber and prototype beam tests, to be capable to achieve and even exceed the requested performances in light yield and energy resolution.

Comment: Evaluation of SiPM noise dependence from temperature is currently based on GlueX data. A similar analysis of EIC layout should be conducted, to optimize the choice of T working conditions, also considering the need of avoiding dew effects.

AstroPix system has been tested with v3 chip and showed excellent response to MIP in test beams.

Comments:
- Single layer full efficiency must still be demonstrated with v5 chip which should not suffer from depletion issues of v3 version. Test articles with v3 should be repeated analogously with v5.
- As requirement 2γ separation and e/γ separation should be defined more clearly seconded by π^0 reconstruction in simulation.

Charge Question #3: Are the plans for achieving detector performance and construction sufficiently developed and documented for the present phase of the project?

Response: SciFi: Yes, thanks to GlueX experience, plans show a very good degree of development, together with the needed documentation.

AstroPix: Largely yes, but with the chip being still in the engineering and design stage and transitioning to another foundry, final performance data remain open and could still change plans of the construction.

Assembly/integration: Plans for ESB have been developed, but their complexity entails certain risks on performance and maintainability.

Charge Question #4: Are the current designs and plans for detector and electronics readout likely to achieve the performance requirements with a low risk of cost increases, schedule delays, and technical problems?

Response:

Yes, the current designs cover well the performance requirements.

Comments:
- For SciFi CALOROC is very well suited to readout SiPMs. Validation of engineering test articles should verify their performance.
- For AstroPix specifications are promising, but the evolution of AstroPix versions (v5, v6) is still on a critical path, and an issue in this area of the project may shift the whole schedule

Charge Question #5: Are the calorimeter fabrication and assembly plans consistent with the overall project and detector schedule?

Response: For SciFi, yes, the fabrication and assembly plans seem realistic and consistent with the project schedule, as this is based on the excellent GlueX experience.

Regarding AstroPix, the extremely large number of modules and the uncertainties of the AstroPix chip evolution pose challenges and their schedule needs to be tightly watched.

Charge Question #6: Are the plans for detector integration in the EIC detector appropriately developed for the present phase of the project?

Response: Plans for integration of BIC were presented.

Comment: The interfaces and interferences with neighboring systems in ePIC need to be more sufficiently explained, and key elements like the brackets for the Global Support Tube are not yet designed. Interface control, overall assembly sequence within ePIC, detailed assembly steps, and FEA are required for CD2.

Charge Question #7: Have ES&H and QA considerations been adequately incorporated into the designs at their present stage?

Response: ES&H considerations have been addressed in all relevant places.

Comment: For the FDR the expected content should cover hazard assessment, equipment life cycle, risk mitigation actions and post-mitigation assessment of residual risks. The design phase is the most important phase, to avoid hazards *by design*.
QA considerations likewise have been addressed in the relevant places.

Comment: The processes and the availability of resources need to be carefully checked folding in the sheer volume of QA work.

Charge Question #8: Have the recommendations from previous reviews been adequately addressed?

Response: Yes, each presentation made reference to the previous recommendations, which were addressed.

Findings

AstroPix: AstroPix v3 chips were extensively used to evaluate the technology performance and to build prototype modules, yielding excellent results. The submission and production of AstroPix v5, originally foreseen for 2025, have been delayed and are now expected by early 2026.

SciFi: Kuraray single-cladded fibers have been selected. Hamamatsu S14 SiPMs have a high light yield and can very well read the fibers/light guides. Matrix production procedures and tooling were transferred from U Regina to ANL and are exercised there.

Mechanics: Mechanics of sectors was presented. Several test articles for the individual components were built and tested both for PbSciFi and AstroPix layers.

Integration: An installation and integration concept was presented.

Labor: 80+ team members are involved in the design and R&D phase.

Schedule: A detailed schedule was submitted in the material but not discussed separately. Cf remark on AstroPix schedule above.

Management: A dedicated BIC project management was established at ANL.

Comments

SciFi

- The Kuraray single clad fibers have been tested for performance and chosen to use in the SciFi portion of the calorimeter. The cladding is only 20 μ thick compared with the GlueX 70 μ cladding. Testing with the epoxy matrix should be completed to verify that they are compatible.

- In connection with defining to which T the SiPM system should be cooled, has SiPM irradiation at longer term any effect on this choice? Is there a map of irradiation levels at the SiPM locations?

- Radiation hardness of SiPMs has to be tested. An item in the BIC schedule is there. Their behavior and noise evolution under irradiation will determine parameters of the cooling system to manage an acceptable noise level. Cooling to low temperature (to e.g. +7°C) should be possible.

AstroPix

- There has been very good collaboration with NASA on the requirements for the AstroPix v5. The schedule to receive and test AstroPix v5 seems to be very aggressive. Adding contingency to the module pre-production deadline should be considered.

- Much work has been accomplished on the stave design for the removable sections. The plan to test smaller sections first seems to be a good idea. Tight tolerances are needed for repeatability.

- The move from TSI to AMS needs to be monitored closely. In general, the support by KIT and NASA will be important to achieve the needed functionality and operation. This includes documentation, firmware for controls, setup, readout, etc.

- The AstroPix module QC is a huge enterprise. Eventually all modules need to be tested to insert only functioning modules in the detector system. Automation and industrialization should be considered in the cases of large numbers of components to be controlled for the AstroPix layers

- Given the number of steps still needed on the AstroPix side (v3 -> v6 + various system tests) and globally on electronics integration, it would be useful to identify milestones and their dependence with the rest of the construction steps.

Mechanics

- It appears that there are solid plans in place for the SciFi layup. As is known by the presenters, QA during the fiber, epoxy and lead work is very critical to achieve the proper thickness and prevent delaminations. Very detailed procedures with QA check points should be written.

- There are plans to perform testing of short assemblies of the entire layup with SciFi and AstroPix sectors. The carbon fiber boxes may be subject to hydraulic pressures during curing which may cause deflections in the middle. Plans to design adequate stiffening or providing temporary support should be made.

- ESB objects seem quite complex to handle, in particular if one realizes that to access the AstroPix staves an entire wedge has to be dismounted.

- The brackets of the GST are not yet designed, and the GST design itself is not yet complete; it will give some boundary conditions.

- Sector FEA is a prerequisite of the evaluation of the stability and handling of the 800kg sectors. Then prototypes will show finally the real deformations and feasibility of the mechanical layout.

- Regarding barrel sliding high load ceramics rollers should be compared with steel rollers, that could suffer from magnetic adhesion even for non-magnetic steel.

Integration

- The current plan of the BIC collaboration is to use cooling water of as low as 5°C to cool the ESBs and have a nitrogen purge. This should mitigate condensation issues. The

cooling lines going in will need to be insulated but there may not be available space. There was a comment that the cooling may operate at a higher temperature to avoid condensation. This may affect the SiPM performance. A final requirement should be defined.

- The group has supplied an active area envelope for all the detectors. This needs to be tied into the remaining components outside the detectors.

- Cross sections of services were not presented. Integration of services among neighboring systems needs to be further coordinated to ensure there is no collision. Also, the installation sequences should be checked for collisions. In addition, maintenance and staged installation seem difficult regarding the current design of ESB.

- The Roman arch structure is very nice but also challenging. Some more degree of flexibility should be given to the system. In particular, the top sector must have enough space to move down to complete the arch. How will it be moved? How each module will be maintained at the right angle before “laying” it on the neighboring one? Also considering that the lower part cannot sustain weight.

Labor

- The team seems adequate and experienced (GlueX people), and Korean effort also is there.
- Personnel resources are not given in detail and could become critical in view of large QC campaigns of modules and boards. For the design phase the resources seem adequate.

Schedule

- The schedule submitted as additional material is very detailed. A high-level schedule will be helpful for a better overview.
- Buffer should be made available for a realistic planning of critical external components (AstroPix and CALOROC). If AstroPix is significantly delayed, consider a staged installation, PbSciFi only at first, insertion of AstroPix layers later.
- A very detailed “Merlin” schedule has been developed for the BIC procurements, assembly and testing.

ES&H

- The topic is addressed in several places referring to the procedures in the large labs (ANL, BNL, ORNL, …). In the end a safety risk assessment should be compiled that gives the details of potential hazards in all phases (construction, installation, commissioning, operation, maintenance, dismantling) along with mitigation steps. Reducing hazards at the design phase is the best. Further measures are documentation, training, warning and protective measures.

Recommendations

- AstroPix: closely follow the AstroPix v5/v6 production schedule and design implications of their performance.

- SiPM: SiPM aging and noise evolution should be appropriately addressed in the design. Irradiation tests and radiation dose simulations should tell if a significant increase in noise level is expected during the experiment lifetime. This impacts on the design regarding the cooling infrastructure of SiPM.

- SciFi - Enhance QCs and procedures on module assembly at production sites, both for optimal fiber assembly and for correct structural glue curing.

- Integration and mechanics:

    - Coordinate interfaces, cross sections and assembly procedures with the neighboring systems at an early stage with an interface control drawing and a detailed assembly sequence.

    - Maintenance should be addressed taking accessibility and expected potential failure rates into account.

- Schedule: Monitor the schedule of critical components under development and foresee sufficient schedule buffer for these.

3 Conclusion

- We congratulate the BIC team for the remarkable achievements.

- We thank the team for the excellent quality of the presentations and the constructive discussions in the Q&A.

- We are looking forward to further progress towards CD2 and the realization of the project.

4 Appendices

4.1 Appendix A: Charge to the Review Committee

Date: August 12, 2025

To: Stefania Beole' (University of Torino, INFN Torino), Pierluigi Campana (INFN-LNF), Lars Schmitt (GSI Darmstadt), Timothy Whitlatch (JLab)

From: Elke Aschenauer and Rolf Ent, EIC Co-Associate Directors for the Experimental Program

Subject: Charge - Preliminary Design and Safety Review of the ePIC Barrel Imaging EMCal, September 17-18, 2025

The scope of this review includes all aspects of particle detection using the Barrel Imaging electromagnetic Calorimeter (BIC) of the ePIC detector at EIC, which combines two technologies, light-collecting calorimetry based on SciFi embedded in Pb and imaging calorimetry based on monolithic silicon sensors AstroPix. The review includes design and fabrication scenarios and their cost-effectiveness, optimization of physics performance, construction schedule, early considerations for safety and quality assurance, front-end electronics and interface to the data acquisition system, commissioning and calibration procedures, considerations for materials and labor, operational reliability and longevity, and any other considerations that may influence the construction and operation of the Calorimeter.

Please address the following questions point-by-point:

1. Is the progress and design maturity of the barrel electromagnetic calorimeter systems aligned with being baselined in June 2026 (>60% maturity is required)?
2. Are the technical performance requirements appropriately defined and complete for this stage of the project?
3. Are the plans for achieving detector performance and construction sufficiently developed and documented for the present phase of the project?
4. Are the current designs and plans for detector and electronics readout likely to achieve the performance requirements with a low risk of cost increases, schedule delays, and technical problems?
5. Are the calorimeter fabrication and assembly plans consistent with the overall project and detector schedule?
6. Are the plans for detector integration in the EIC detector appropriately developed for the present phase of the project?
7. Have ES&H and QA considerations been adequately incorporated into the designs at their present stage?
8. Have the recommendations from previous reviews been adequately addressed?

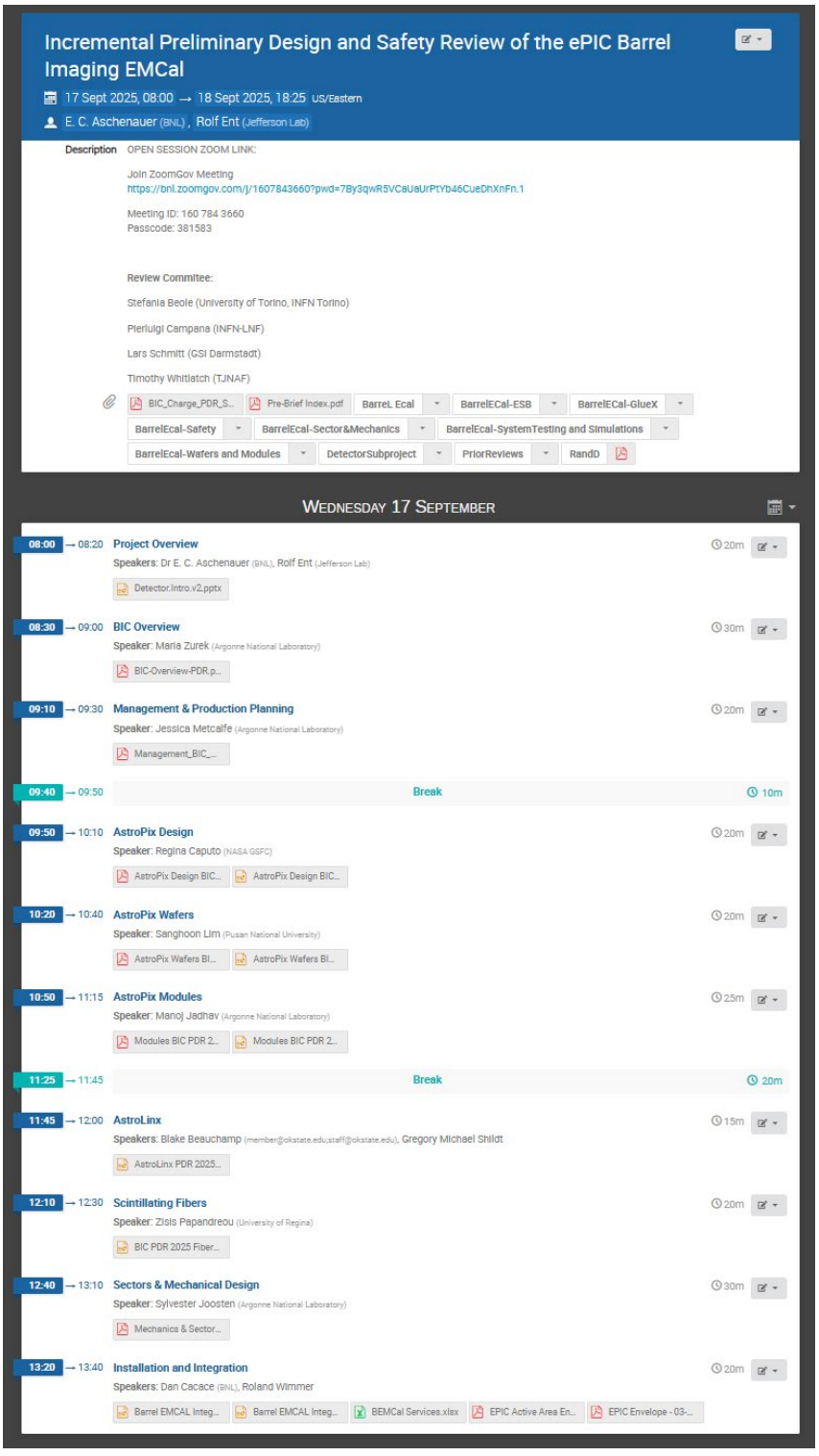
You will be supplied with the detailed schedule and manpower assumptions, drawing packages, copies of presentations relevant to this subject material, and the project milestones extracted from the most current EIC resource loaded P6 schedule as part of the pre-brief material.
Note that several aspects of the EIC detector including electronics and data acquisition systems are reviewed separately. You will be supplied with the reports from recent reviews.

4.2 Appendix B: Review Committee

Review Committee

- Stefania Beole (University of Torino, INFN Torino)
- Pierluigi Campana (INFN-LNF)
- Lars Schmitt (GSI Darmstadt)
- Timothy Whitlatch (TJNAF)

4.3 Appendix E: Agenda



Incremental Preliminary Design and Safety Review of the ePIC Barrel Imaging EMCal

17 Sept 2025, 08:00 → 18 Sept 2025, 18:25 US/Eastern

E. C. Aschenauer (BNL), Rolf Ent (Jefferson Lab)

Description: OPEN SESSION ZOOM LINK:

Join ZoomGov Meeting
https://bnl.zoomgov.com/j/1607843660?pwd=7By3qwR5VCaUaUrPtYb46CueDhXnFn.1

Meeting ID: 160 784 3660
Passcode: 381583

Review Commitee:

Stefania Beole (University of Torino, INFN Torino)

Pierluigi Campana (INFN-LNF)

Lars Schmitt (GSI Darmstadt)

Timothy Whitlatch (TJNAF)

BIC_Charge_PDR_S... | Pre-Brief Index.pdf | BarreL Ecal | BarrelECal-ESB | BarrelECal-GlueX | BarrelEcal-Safety | BarrelEcal-Sector&Mechanics | BarrelEcal-SystemTesting and Simulations | BarrelEcal-Wafers and Modules | DetectorSubproject | PriorReviews | RandD

WEDNESDAY 17 SEPTEMBER

08:00 → 08:20 Project Overview — 20m
Speakers: Dr E. C. Aschenauer (BNL), Rolf Ent (Jefferson Lab)
Detector.Intro.v2.pptx

08:30 → 09:00 BIC Overview — 30m
Speaker: Maria Zurek (Argonne National Laboratory)
BIC-Overview-PDR.p...

09:10 → 09:30 Management & Production Planning — 20m
Speaker: Jessica Metcalfe (Argonne National Laboratory)
Management_BIC_...

09:40 → 09:50 Break — 10m

09:50 → 10:10 AstroPix Design — 20m
Speaker: Regina Caputo (NASA GSFC)
AstroPix Design BIC... | AstroPix Design BIC...

10:20 → 10:40 AstroPix Wafers — 20m
Speaker: Sanghoon Lim (Pusan National University)
AstroPix Wafers BI... | AstroPix Wafers BI...

10:50 → 11:15 AstroPix Modules — 25m
Speaker: Manoj Jadhav (Argonne National Laboratory)
Modules BIC PDR 2... | Modules BIC PDR 2...

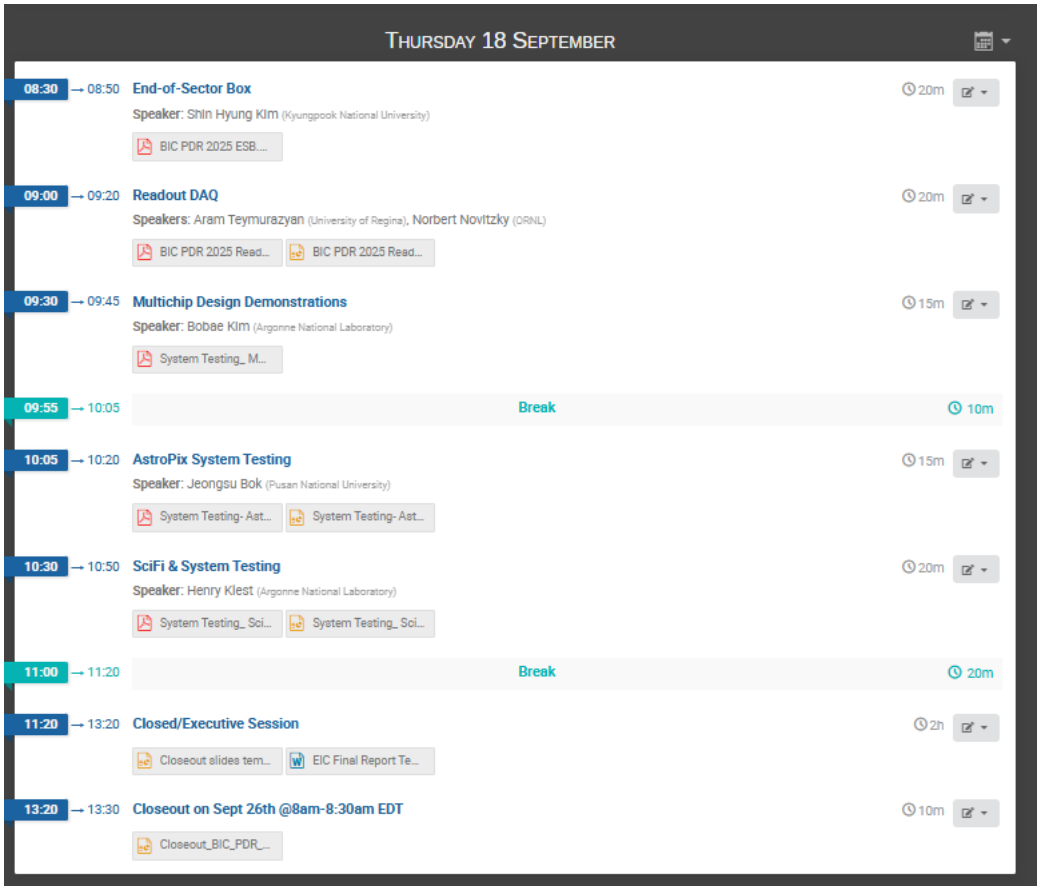
11:25 → 11:45 Break — 20m

11:45 → 12:00 AstroLinx — 15m
Speakers: Blake Beauchamp (member@okstate.edu;staff@okstate.edu), Gregory Michael Shildt
AstroLinx PDR 2025...

12:10 → 12:30 Scintillating Fibers — 20m
Speaker: Zisis Papandreou (University of Regina)
BIC PDR 2025 Fiber...

12:40 → 13:10 Sectors & Mechanical Design — 30m
Speaker: Sylvester Joosten (Argonne National Laboratory)
Mechanics & Sector...

13:20 → 13:40 Installation and Integration — 20m
Speakers: Dan Cacace (BNL), Roland Wimmer
Barrel EMCAL Integ... | Barrel EMCAL Integ... | BEMCal Services.xlsx | EPIC Active Area En... | EPIC Envelope - 03-...


THURSDAY 18 SEPTEMBER
08:30 → 08:50 End-of-Sector Box 20m
Speaker: Shin Hyung Kim (Kyungpook National University)
BIC PDR 2025 ESB....
09:00 → 09:20 Readout DAQ 20m
Speakers: Aram Teymurazyan (University of Regina), Norbert Novitzky (ORNL)
BIC PDR 2025 Read...
BIC PDR 2025 Read...
09:30 → 09:45 Multichip Design Demonstrations 15m
Speaker: Bobae Kim (Argonne National Laboratory)
System Testing_ M...
09:55 → 10:05 Break 10m
10:05 → 10:20 AstroPix System Testing 15m
Speaker: Jeongsu Bok (Pusan National University)
System Testing- Ast...
System Testing- Ast...
10:30 → 10:50 SciFi & System Testing 20m
Speaker: Henry Klest (Argonne National Laboratory)
System Testing_ Sci...
System Testing_ Sci...
11:00 → 11:20 Break 20m
11:20 → 13:20 Closed/Executive Session 2h
Closeout slides tem...
EIC Final Report Te...
13:20 → 13:30 Closeout on Sept 26th @8am-8:30am EDT 10m
Closeout_BIC_PDR_...