Electron-Ion Collider

Incremental Design and Safety Review of the Particle Identification Detectors

July 20, 2023

Performed Remotely at Jefferson Lab

Newport News, Virginia

July 5-6, 2023

Table of Contents

1. Executive Summary

The PID detector proponents provided excellent presentations and discussions during this review.

We are very happy to see the state of the project and the very interesting R&D for the PID community, and encourage a continuation of R&D and beam tests to complete the designs.

The PID detectors are fully on track for the CD2/3 review on the current project timeline.

2. Responses to Charge Questions

Charge Question 1: Are the technical performance requirements appropriately defined and complete for this stage of the project?

Yes. Detailed assessment in the comments.

Charge Question 2: Are the plans for achieving detector performance and construction sufficiently developed and documented for the present phase of the project?

Yes. Detailed assessment in the comments.

Charge Question 3: 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?

Yes. Detailed assessment in the comments. However, regarding the evaluation of the risk of cost increases and schedule delays, we have not received sufficient information.

Charge Question 4: Are the fabrication and assembly plans for the various particle identification detector systems consistent with the overall project and detector schedule?

Yes. Detailed assessment in the comments.

Charge Question 5: Are the plans for detector integration in the EIC detector appropriately developed for the present phase of the project?

Yes. Detailed assessment in the comments.

Charge Question 6: Have ES&H and QA considerations been adequately incorporated into the designs at their present stage?

Yes. All presented projects discussed at a sufficient depth possible ES&H issues and their mitigation.

No. We were missing detailed QA plans, including the fraction of devices to be tested.

3. Comments

Technical performance requirements:

- Initial detector performance requirements were provided by the EIC Yellow Report which were translated to the JLab Requirements webpage. However, the JLab requirements page does not include all the performance requirements (or at least with the same terminology as PID detectors, e.g. tracking position and angular resolution at the radiator). The Yellow Report requirements may also need to be tailored to the ePIC detector and defined for the project.

- Many studies have been carried out with standalone simulation and reconstruction. However, additional support should be provided for integrating the latest designs and realistic PID performance into the full ePIC simulation.

- Recent progress has been made in ePIC's cross-cutting PID WG to understand tracking requirements for PID detectors. Requirements documents should capture the bi-directional interface between tracking and PID detectors: e.g., translation between extrapolated track impact point and angle resolution requirements for PID detectors. It could be evaluated where the PID subdetectors can contribute to improving the tracking performance and how in the reconstruction algorithms this could be integrated.

- A specification on the tolerable clock drift and the robustness to phase irregularities should be defined and will help to ensure that these parameters are measured and controlled in the architecture from the beginning of the design phase. The DAQ design should include a backup solution for a directly distributed clock to the RDO boards to provide the clock precision required by each subsystem.

- It is encouraging to see the effort made to keep uniformity across the ePIC electronic readout boards in order to keep cost and firmware/software development to a minimum. Using a single optical link technology, in this case FPGA and SFP+ at the RDO level, will also reduce the overall R&D effort that must go into the clock filtering and timing distribution from DAM to RDO/FEB.

- The quartz window to separate the photodetector box from the gas radiator was identified as a point of attention. A thermal simulation is required with the SiPM array at the foreseen operating temperature of -30 C and the approach to avoid condensation or convection of the C2F6 gas radiator should be described. The reviewers fully recognize the importance of the foreseen small-scale system tests in the SPS test-beam facility later this year.

Detector performance and construction:

- (AC-LGAD) 35ps Barrel/ 25ps FW timing resolution seems to be almost the best performance without safety margin. Under these circumstances, a bias voltage scheme should be more flexible than only one pair of cables for each board, because the temperature gradient and the position-dependent radiation fluence require different operation voltages.

- The initial requirements for the EICROC were specified mostly for the Roman Pot detector and not for all detectors which use EICROC. We advise summarizing the requirements for all detectors and making a single EICROC specification before submitting further prototype chips.

- Following the discussion, the integrated anode charge for the HRPPD over the experiment lifetime is understood to be only a few C/cm^2 in a worst-case estimate at 10^7 gain. Operating at a lower gain can increase the lifetime but should be balanced with reduced PDE. It would be good to have the integrated charge numbers available from the simulation, also for different quartz HRPPD window thicknesses.

- A charged particle timestamp with a resolution of ~20 ps is required. It was stated that an SPTR of ~50 ps is required to achieve this track resolution, based on the minimum of 6 photons per track and the requirement of ~100% geometric efficiency. However, it was also presented that the mean number of photoelectrons lies around 12 (in the aerogel) and >80 (in the entrance window). It, therefore, appears that for the majority of tracks, the requirement on SPTR could be relaxed. It would be good to see the results from simulation on how the overall pfRICH and ePIC performance behaves as a function of this SPTR.

- It would be good to evaluate the effect of the different photon angles of incidence on the quartz window across the detector plane on the number of detected photons and Cherenkov-angle resolution.

Detector and electronics readout:

- The reviewers also suggest considering the option of replacing the SiPM array once during the experiment lifetime as an alternative to the “oven” annealing process.

- To reduce dark current, heavy annealing is planned. It is required to check that the charge collection efficiency is not reduced due to over-annealing. The reviewers understand that this is part of the ongoing R&D campaign and that encouraging first results have been obtained.

- For online self-annealing, all materials, including glue, PCB, etc., have to be

checked to see if these are tolerant to the high temperature and if the thermal cycling does not affect the components due to CTE mismatch.

- We advise exploring the operation of SiPMs at a lower temperature (for example -40C) to guarantee a low level of DCR.

- The online annealing procedure requires forward biasing of the sensors creating local heat generation and large current flows close to the front-end electronics. Precautions will have to be taken to avoid damage to the ASIC. It was understood that this is a part of the R&D effort, for example, through the use of MOSFETs to protect the readout.

- The reviewers acknowledge that the EICROC will not be available before the design is finalized; thus, evaluation of the HRPPD performance will take place with the existing HGCROC under the assumption that similar performance will be achieved with the EICROC.

Fabrication and assembly plans:

- In the worst-case scenario that unexpectedly the reused BaBar bars do not meet the quality requirements, an alternative production can be started, albeit with a penalty in production time and costs. It is encouraging to see that the first tests of the BaBar bars are planned in the near future, in order to leave sufficient time for this fallback scenario of a new bar production.

- In the worst-case scenario that HRPPDs cannot meet performance specifications or production schedule, a backup solution of MCP-PMTs is being considered and should be evaluated in parallel to the HRPPDs.

- (AC-LGAD) The type of interconnection to the sensors (like wire bonding or bump bonding) must be clearly specified. If a detector uses a bump bonding connection, we would advise to start testing the flip-chipping process since it takes longer to develop a stable procedure.

Detector integration:

- Encouraging track momentum resolution improvement was achieved by including the AC-LGAD in reconstruction. The reviewers suggest extending this study to understand the impact on the extrapolated track impact point and angle at the radius of the DIRC.

- It was mentioned that the 3.375 mm (or potentially smaller) pitch at the HRPPD backplane is dominated by requirements of the hpDIRC using the same photodetector, and the pfRICH could operate at larger pixel areas. It should be investigated whether a small change in layout would allow multiple pixels to be grouped into a single readout channel, in order to reduce the overall channel count and cost.

4. Recommendations

1. Capture the bi-directional interface between tracking and PID detectors: e.g., translation between position and angular resolution requirements for PID detectors.
2. Perform a thermal simulation of the dRICH SiPM array considering different operating temperatures and impact on the quartz window and gas radiator.
3. Create detailed QA plans, including the fraction of devices to be tested.

5. Appendices

5.1 Appendix A: Charge to the Review Committee

Jefferson Lab
Thomas Jefferson National Accelerator Facility

Date: June 23, 2023

To: Peter Krizan (U Ljubljana), Floris Keizer (CERN), Ana Amelia Machado (UniCamp), Koji Nakamura (KEK), Justin Stevens (W&M)

From: Elke Aschenauer and Rolf Ent

Subject: Charge for the Incremental Design and Safety Review of the Electron-Ion Collider (EIC) Particle Identification Detectors

The scope of this review includes all aspects of particle identification detectors (but not those that are calorimetry-based) in the central EIC detector, which includes the barrel, the forward endcap, and the backward endcap regions. This includes five detector systems. In particular, a proximity-focusing RICH in the backward region, a high-performance DIRC and AC-LGAD to augment particle identification with TOF in the barrel region, and a dual RICH and AC-LGAD in the forward region. The review may include design and fabrication choices and their cost-effectiveness, the construction schedule, considerations for safety and quality assurance, levels of redundancy, 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, maintenance and operation of these particle identification detectors.

Please address the following questions point-by-point:

1. Are the technical performance requirements appropriately defined and complete for this stage of the project?
2. Are the plans for achieving detector performance and construction sufficiently developed and documented for the present phase of the project?
3. 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?
4. Are the fabrication and assembly plans for the various particle identification detector systems consistent with the overall project and detector schedule?
5. Are the plans for detector integration in the EIC detector appropriately developed for the present phase of the project?
6. Have ES&H and QA considerations been adequately incorporated into the designs at their present stage?

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.

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Jefferson Lab
Thomas Jefferson National Accelerator Facility

Note that several aspects of the EIC detector including its electronics, and data acquisition systems have been reviewed previously. Along with your briefing materials, you will also be supplied with the reports from earlier reviews (e.g., on the magnet design, electronics and data acquisition, calorimetry).

cc:
James Fast

5.2 Appendix B: Review Committee

Peter Križan - Chair	U. Ljubljana	peter.krizan@ijs.si
Floris Keizer	CERN	floris.keizer@cern.ch
Ana Amelia Machado	UniCamp	aameliabm@gmail.com
Koji Nakamura	KEK	koji.nakamura@cern.ch
Justin Stevens	W&M	jrsteven@jlab.org

5.3 Appendix E: Agenda

Incremental Design and Safety Review of the Electron-Ion Collider (EIC) Particle Identification Detectors

Wednesday, July 5, 2023 – Thursday, July 6, 2023

Wednesday, July 5 (Day 1)

Click here for Plenary (OPEN) Zoom

CET	PST	CST	EST	Topic	Presenter	Duration (Min)
2:00 PM	5:00 AM	7:00 AM	8:00 AM	Executive Session (Closed)	Review Committee	30
2:30 PM	5:30 AM	7:30 AM	8:30 AM	Welcome & Introduction	R. Ent (JLab) / E. Aschenauer (BNL)	30
3:00 PM	6:00 AM	8:00 AM	9:00 AM	Particle Identification Systems Overview & Requirements	Beni Zihlmann (JLab)	30
3:30 PM	6:30 AM	8:30 AM	9:30 AM	Detector Integration Status & CAD Design	Alex Eslinger (BNL) Discussion/Q&A	20 10
4:00 PM	7:00 AM	9:00 AM	10:00 AM	Flow of Requirements, Interfaces & System Engineering	Walt Akers (JLab) Discussion/Q&A	15 5
4:20 PM	7:20 AM	9:20 AM	10:20 AM	BREAK	All	20
4:40 PM	7:40 AM	9:40 AM	10:40 AM	Backward Region: Proximity-focusing RICH	Alexander Kiselev (BNL) Discussion/Q&A	30 20
5:30 PM	8:30 AM	10:30 AM	11:30 AM	Forward Region: Dual RICH	Marco Contalbrigo (INFN Ferrara) Discussion/Q&A	30 20
6:20 PM	9:20 AM	11:20 AM	12:20 PM	Barrel Region: High-performance DIRC	Grzegorz Kalicy (CUA) Discussion/Q&A	30 20
7:10 PM	10:10 AM	12:10 PM	13:10 PM	Executive Session (Closed)	Review Committee	50

Thursday, July 6 (Day 2)

Click here for Plenary (OPEN) Zoom

CET	PST	CST	EST	Topic	Presenter	Duration (Min)
2:00 PM	5:00 AM	7:00 AM	8:00 AM	DAQ Streaming Readout Overview	David Abbott (JLab) Discussion/Q&A	15 5
2:20 PM	5:20 AM	7:20 AM	8:20 AM	Readout and Sensors Status LAPPD/HRPPD	Alexander Kiselev (BNL) Discussion/Q&A	15 5
2:40 PM	5:40 AM	7:40 AM	8:40 AM	Barrel and Forward TOF: AC-LGAD	Zhenyu Ye (University of Illinois at Chicago) Discussion/Q&A	20 10
3:10 PM	6:10 AM	8:10 AM	9:10 AM	AC-LGAD readout systems	Dominique Marchand (IJCLab), Tonko Ljubicic (BNL) Discussion/Q&A	15 5
3:30 PM	6:30 AM	8:30 AM	9:30 AM	Readout and Sensors Status SiPMs	Roberto Preghenella (INFN Bologna) Discussion/Q&A	15 5
3:50 PM	6:50 AM	8:50 AM	9:50 AM	BREAK	All	20
4:10 PM	7:10 AM	9:10 AM	10:10 AM	Discussion	All	60
5:10 PM	8:10 AM	10:10 AM	11:10 AM	Executive Session (Closed)	Review Committee	140
7:30 PM	10:30 AM	12:30 PM	13:30 PM	Closeout	All	20