ePIC backwards RICH review

March 20-21, 2023

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1. Introduction

On March 20-21, 2023, the ePIC collaboration conducted a scientific review of two proposed designs for the backwards Ring Imaging Cherenkov (RICH) detector. The modular RICH (mRICH) design corresponds to a set of modules with an aerogel insert and a focusing lens, while the proximity focusing RICH (pfRICH) consists of a large aerogel wall and a conical set of mirrors.

The agenda and presentations of the review can be found at the indico page: https://indico.bnl.gov/event/18499

The committee appointed by the collaboration was a combination of a subset of the current Global Detector and Integration (GD/I) conveners, four external reviewers, and the EIC project level 3 CAM for RICH particle identification as an ex-officio member. The L3 CAM was included to ensure communication between the collaboration and the project. The complete committee membership was:

Ichiro Adachi (KEK)
Roberta Cardinale (University of Genova)
Carmelo D'Ambrosio (CERN)
Antonello DiMauro (CERN)
Jin Huang (BNL)
Richard Milner (MIT)
Carlos Munoz Camacho (IJCLab Orsay)
Joe Osborn (BNL, chair)
Beni Zihlmann (Jefferson Laboratory, ex-oficio)

The committee received a charge from ePIC leadership, which can be found on the indico page here. In organizing the review, the GD/I conveners requested a set of points to be addressed by the proponents which can be found here. This report summarizes the findings and comments from the committee on the two designs and in response to each of the questions of the charge.

The committee congratulates both design proponents for the excellent presentations and the high level of discussions. We highly appreciate the efforts of both groups and the ePIC collaboration in preparing for this review. We hope this report will help the collaboration in making a decision in the technology choice for the ePIC backwards RICH detector.

2. Responses to the charge questions

2.1 Question 1

Is the anticipated performance, as demonstrated by simulations, test beam, R&D, etc. realistic given existing experience? Is the anticipated performance adequate to address the full EIC science program, as outlined in the National Academy report and the EICUG Yellow Report?

The EIC PID and physics community should evaluate a lower limit of PID performance needed, in addition to the upper limit given by the Yellow Report, to help guide the index of refraction requirements for the backwards RICH design. Nonetheless, both designs meet the Yellow Report requirement for K/pi separation up to 7 GeV/c based on the review. However, neither design showed studies of the performance in realistic DIS events with backgrounds. The comparison between the two designs would be simpler if they had both worked within a common software framework.

2.1.1 mRICH design

The mRICH detector involves a novel design with a focusing+UV filtering element of a Fresnel lens. This modular design leads to

(1) a ring resolution of 3-4 mrad measured in test beam, and implemented in simulation, leading to a K/pi separation beyond the YR requirement was presented. Potential improvement via an optimization of the sensor position with respect to the focal lens was also presented.
(2) shorter longitudinal space usage to ease global backward design
(3) more prominent acceptance gaps at the module or shoebox boundaries

The mRICH simulation was validated by a series of successful test beam programs supported by the generic EIC R&D program. We note that the number of signals and scattered photo-electron count should be further studied in the current data and tested with the proposed HRPPD sensor.

Multi-hit probability should be studied, in particular for the higher-density environment of a backwards-going jet. The performance with at least 2 hits per module should be studied in simulations.

2.1.2 pfRICH design

All presented performance results are based on simulations and test beam studies are necessary to validate the design and quantify the realism of the simulation; however, the design is simpler and understood from established implementations (e.g. Belle). Based on the current simulation study, the proponents showed a ring resolution of 1-2 mrad and that the expected performance exceeds the YR requirement. Further simulation work is required to quantify the impact of event and beam backgrounds on the design.

The wall structure separating aerogel blocks leads to some loss in acceptance, although less than the case for mRICH. A single-volume aerogel was mentioned in the review as a mitigation strategy, but further R&D is needed to demonstrate its mechanical stability. We encourage exploring photo-transparent or reflective ribs that separate/support the aerogel blocks.

The use of a C4F10 radiator as an alternative option is not required to meet the YR requirement. Aerogel could absorb C4F10 and lead to significantly increased weight and mechanical stress.

2.2. Question 2

Does the mechanical integration of the detector present any unique challenges?

The mechanical integration by both designs was clear and well developed for the current stage of the project. Any material to be used should be evaluated for safety prior to engineering development.

2.2.1 mRICH design

The committee points out that the design of RICH detectors using aerogel as the Cherenkov radiator usually foresees the implementation of dry gas (e.g. N2 or Ar) flow inside the vessel in order to control the environmental conditions, specifically the relative humidity inside the detector. Past experience in LHCb with hydrophilic aerogel has shown an important degradation, with complete loss of transmission, due to absorption of CF4 used as a second radiator in the system. The presence of humidity and in general not controlled atmosphere will result in aerogel aging, in particular for the hydrophilic one.

The committee observes that the designed detector boxes will require a dedicated production of HRPPD with a smaller support frame, which might result in delays of availability or increase of cost that are currently unknown.

2.2.2 pfRICH design

The committee commends the pfRICH team for leading the R&D of the photodetector integration.

The committee suggests that a strategy to access the photodetector from the outside be developed. This would allow access from the backside of the photodetector wall after integration of the radiator and the photodetector components. Such a strategy would avoid taking apart the entire pfRICH structure when one needs access to a photodetector element.

2.3 Question 3

Is there an adequate workforce to build, commission and maintain the detector, or are there adequate plans to evolve the workforce towards these goals?

Plans to evolve the workforce for commissioning and maintaining the detector should be developed. The schedules that were provided and discussed were largely focused on the development of prototypes and construction of the actual detector. This is natural given the current stages of the project; however, the workforce needed post construction should also be considered.

2.3.1 mRICH design

Detailed descriptions of the technical and engineering workforce to realize the mRICH design were not provided. What was provided was the scientific workforce that is available to the project now as well as the scientific workforce that has provided contributions to the design in the past. From the presentations and discussion, there were not detailed or clear plans on how this workforce would be grown to successfully realize the construction of the mRICH.

2.3.2 pfRICH design

A description of institutions that were interested in working on the project was provided. This included vendors, universities, and national laboratories. The current effort between project and scientific workforce, as supplemented by the costing, is unbalanced with only 2% of the project cost and labor coming from in-kind contributions.

2.4 Question 4

Is the cost and schedule presented realistic? Are the production capabilities of vendors fully understood and consistent with the schedule?

The committee suggests that both designs explore other companies for the aerogel and photodetectors to help reduce risk associated with the completion of the project. As a concrete example, due to global political circumstances, aerogel purchases from vendors in Russia will be complicated. Milestones for the photodetector selection for both designs should be identified, as the photosensor selection, integration, production, etc. was not clearly defined and is an area of the schedule with large uncertainty.

2.4.1 mRICH design

A realistic cost and schedule estimate was not presented in the review. A rough estimate of the cost per module was provided, but it was unclear how accurate this was. In particular, the committee was concerned that the cost of the LAPPD was underestimated. The only schedule that was provided was the overall EIC project schedule, and it was not clearly stated how the mRICH design would fit into this schedule in terms of beam tests, prototypes, full scale production, and installation and commissioning. The committee assumes that this information exists somewhere given that the mRICH is currently the baseline in the project.

2.4.2 pfRICH design

Detailed descriptions were provided for costing and scheduling the construction of the design, including test beams. These included material and labor for both project and in-kind costs. The cost and schedule appeared realistic for this stage of the project. Contingencies in the cost should also be considered.

2.5 Question 5

Have the proponents adequately identified technical, cost and schedule risks? Are appropriate risk mitigations identified? Please comment on production and performance uncertainties for both the aerogel and the LAPPD's.

The committee finds that the uncertainty associated with the photodetector is the most critical issue in both designs. The baseline photodetector is the HRPPD, a common technology for both, and recent developments in the HRPPD and LAPPD by Incom are presented by each group. The committee understands that significant studies of the HRPPD performance characterizations at the lab bench as well as in test beam should be performed. In addition, more technical information such as on the HRPPD production yield at Incom should be closely tracked. Both teams should consider alternative options such as SiPM or Planacon MCP-PMT, as these alternative options may mitigate risk in the photodetector. However, they require readout electronics different from the baseline, which can impact the cost. Considering these situations, the photodetector strategy should be seriously progressed and both groups should significantly advance the schedule of the photodetectors and their integration, where important milestones in this timeline should be addressed. The schedule should include a decision time to switch to the alternative option.

It would be profitable to explore other companies for the aerogel and the photodetectors although it may not be straightforward. Nevertheless, this could widen a possible choice, resulting in risk and cost reduction in the relatively long-term perspective of the RICH development.

2.5.1 mRICH design

The committee thinks that Fresnel lenses represent a very interesting and elegant solution to improve Cherenkov angle resolution in RICH detectors planned for applications where the particle multiplicity is low. The committee also notes that this design carries higher risk, given that it is the first use of such a design in a large experiment. The information on the optical quality provided by the supplier is sufficient for a first rough assessment and validation of the concept; however, the usage in a large RICH system at a collider experiment requires a more detailed characterization of such a device. In particular, the optical properties should be measured on a large sample (and eventually on all parts that will be installed) to verify the photons transmission, scattering, and focusing. In addition, one should carefully study the performance dependence on lens alignment with respect to the photodetector, and on particle impact position with respect to the lens center. The comparison between simulation and beam test performance should not be limited only to ring images and include quantitative estimates of the number of detected photons, homogeneity of radius along the ring, and Cherenkov angle accuracy. A further validation concerns the performance in a real environment, to be assessed by simulations of collision events including, possibly, beam background.

The committee considers the procurement of aerogel tiles from a supplier in Russia risky considering the global political situation, and other companies should be considered. In addition, the design based on 5 cm thick tiles could be modified to adopt smaller thickness in case of optical quality improvement, which could be achieved by dedicated development or is available at other suppliers.

As already mentioned in 2.2.1, the committee suggests implementing gas purging (with N2 or Ar) of the boxes to control the environmental conditions and prevent aerogel aging due to moisture or other volatile substances included in the assembly.

2.5.2 pfRICH design

The committee finds that technical and cost risks are appropriately identified in the pfRICH system. Several institutions expressed interest in participating in the design stage but not in the construction phase. Responsibilities for these institutions should be clearly defined.

3 Conclusion

We hope this report is useful to the ePIC collaboration in moving forward with the detector design. The ePIC collaboration greatly appreciates the time, effort, and expertise that the external reviewers provided in the review and in the preparation of this report.