ePIC barrel ECAL review

March 13-14, 2023

1. Introduction

On March 13-14 (2023) the ePIC collaboration conducted a scientific review of two proposed designs for its barrel electromagnetic calorimeter. One design consists of a homogeneous calorimeter based on scintillating glass, and the other one presents a hybrid imaging calorimeter based on monolithic silicon sensors interleaved with SciFi/Pb layers, followed by a larger section of SciFi/Pb.

The agenda and presentations of the review can be found at:

https://indico.bnl.gov/event/18517/

The committee appointed by the collaboration was a combination of a subset of the current GD/I conveners and three external reviewers. The EIC project L3 CAM for electromagnetic calorimetry was an ex-officio member of the committee in order to ensure good communication between the ePIC collaboration and the EIC project. The committee was formed by:

Etiennette Auffray (CERN)
Alexander Bazilevsky (BNL, ex-officio)
Silvia Dalla Torre (INFN Trieste)
Jin Huang (BNL)
Tom LeCompte (SLAC)
Carlos Munoz Camacho (IJCLab Orsay, chair)
Rainer Novotny (Giessen)
Joe Osborn (BNL)
Thomas Ullrich (BNL)

The committee received a charge from the ePIC leadership, which can be found here. During their presentations, the proponents were requested to address a set of points outlined 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 proponent groups for the excellent presentations and the high level of the discussions. We highly appreciate the efforts of both teams and the overall ePIC collaboration in preparing this review. We hope this report will help the collaboration in making a decision on the technology choice for the ePIC barrel electromagnetic calorimeter.

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?

2.1.1 SciGlass design

The proponents did not show a detailed characterization of the chosen material. That would have included transmission and emission spectra, light output and the kinetics of the luminescence and contributions of slow components. Also, the uniformity of the transversal transmission and the non-uniformity of the light output all along the length of the glass bar of 40cm were not presented. In particular, the challenging technology of large towers to guarantee the sufficient overall radiation length coping with electron energies up to 50 GeV needs the documentation of the optical transmission. In addition, one needs the transmission loss along the bar length in order to estimate the final light output as well as any impact to the linearity of the energy response. All these values are necessary for the design concept of the photosensors.

The committee feels that without conclusive beam test results of prototypes, which consider the above mentioned parameters, it is difficult to evaluate the level of realism of the simulations shown and it leads to a significant level of risk.

Nonetheless, the committee is excited about the potential of this technology for electromagnetic calorimetry and the already achieved technological level of the manufacturing of nearly full size, 40-cm-long detector blocks. The present size is limited by the existing crucible that the company plans to upgrade if this technology is chosen.

Concerning performance, the SciGlass design, and based on the shown simulations, addresses most of the physics requirements, but falls short of providing the stringent pion rejection factors at forward pseudorapidity as well as the required γ/π^0 discrimination up to 10 GeV, which might be in general limited by the chosen granularity of the segmentation and the Molière radius of the scintillator.

In order to overcome some of the shown limitations one might reconsider the layout of the barrel with respect to granularity, non-projective orientation and different tapering of the elements exploiting the advantage of the manufacturing process of glass as well as the significantly lower production costs compared to inorganic crystals.

2.1.2 Imaging design

The combination of two technologies in the same calorimeter makes this subsystem significantly more complex than a monolithic detector. In particular, its calibration will present major challenges to achieve the projected performance and was not presented in this review beyond the idealized world of simulation.

No test beam results of a realistic and complete prototype were presented in this review. However, we recognize (1) the prototyping efforts on the scintillation fiber calorimeter that benefited from the GlueX experience, (2) the joint effort with NASA/HEP on the prototyping test of the current versions of the Astropix sensors.

An extensive simulation study was performed that demonstrated an excellent performance. Simulation results shown fulfill the physics requirements.

The committee sees a great level of potential in this technology.

2.2. Question 2

Are the plans for the detector front-end electronics realistic and well-matched to the sensor properties? Is the detector readout compatible with a streaming readout DAQ, as planned for ePIC?

2.2.1 SciGlass design

The size, number and pixel granularity of the required SiPMs needs deeper assessment to be adapted to the realistic light yield and the dynamic range over at least 4 orders of magnitude of expected scintillation photons. The reference values are strongly dependent on the optical transmission and light collection influenced by the tower geometry (optical focussing effect), surface reflectivity and optical coupling (see findings under question 1). Detailed tests are still needed to estimate the achievable energy resolution over the whole energy range. That will strongly depend on the energy thresholds of individual detector components and will determine the resolution of the reconstructed shower.

In addition, one could exploit the possibility to provide a precision timing measurement for each detector element, either by the design of the FEE or a dedicated SiPM with separate read-out chain. A timing signal could be very helpful to reduce background events from several sources.

The benefits of light guides were presented with simulation, but the committee could not assess if this was needed, given the lack of information on light yield, optical transmission and light collection. The collaboration should be mindful of the challenges of light guide production.

In general, the readout and FEEs are compatible with a triggerless DAQ.

2.2.2 Imaging design

The readout of the SiPMs equipping the sampling component of the calorimeter is adequate, thanks to the extensive expertise and experience from the work of the team on a similar calorimeter in the GlueX experiment. Given the wide use of SiPM readout in EPIC calorimeters, we consider that its electronics chain will be compatible with the ePIC streaming readout DAQ.

Astropix is still in the stage of prototyping. Prototyping and tests are still yet to be performed for the final-sized ASIC, multi-chip staves, a prototype joining imaging and sci-fi layers, the on-detector data aggregation board, and LV/HV/cooling services. Nonetheless, a large safety factor for an effective lossless readout of the Astropix hits was envisioned.

The committee encourages fully designing the readout chain, along with the stave HV and LV services, and testing with the stave prototypes. The anticipation that the stave's data throughput scales with the number of chips in the daisy chain (for example, the statement that 108 chip staves can support 10Gbps throughput) should be demonstrated with the goal of reliably handling collider data where the local multiplicity could fluctuate dramatically in a short time scale.

2.3 Question 3

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

2.3.1 SciGlass design

Changes in the mechanical design to increase the pion rejection need to be considered. There was some presentation about possible alternative designs which, for example, reduce gaps in the mechanical structure of the blocks and sectors. There were some initial indications that these alternative designs could increase the pion rejection factor. The committee would have liked to see these implemented in simulation in order to determine whether or not they are viable and can improve the pion rejection factor.

To simplify the assembly procedure, the committee suggests avoiding the cut-outs in the carbon fiber alveoli. It was not clear to the committee that the advantages they present are worth the greater complications they may imply in assembling the modules into supermodules. Without cut-outs the optical crosstalk between neighboring modules is prevented and there is no need for adding black tedlar around the ESR reflector, simplifying the insertion into the alveoli. As an alternative, the final assembly could be simplified to produce large alveoli made of carbon fiber with individual cells housing up to 15 elements, for example. The size should be determined by comfortable handling.

Cooling needs to be better studied. It is unclear that air cooling is enough for the gain stability of the SiPMs.

Installation and maintenance procedures should be further developed. Potential difficulties regarding the precise details of the processes and safety factors need to be examined closely to ensure all potential factors are understood.

2.3.2 Imaging design

The integration-engineering details of the imaging calorimeter are less advanced than that of the SciGlass calorimeter since it was not considered a baseline detector by the project. Hence efforts by project engineers focused less on the imaging version. The engineering of the detector itself, however, seems far advanced. This entails studies on the mechanical properties of the staves including stiffness and deflection, the mechanical integration of the Astropix layers, and the detailed design of the imaging layers. Plans for the various assembly steps exist in parts benefiting from experiences gained in GlueX. Cooling techniques for SiPM (water cooled at each end of stave) and Astropix (heat conduction and water cooling at outer radius only) are considered and simulated. The proponents also considered condensation risks due to humidity during the summer operation. A list of required utilities and services was presented.

The approximate weight of the detector is around 53 tons, approximately 17 tons heavier than the SciGlass version. The mass ratio between the two technologies reflects approximately the ratio of interaction lengths provided.

Currently the inner radius of the imaging calorimeter is similar to that of the SciGlass version. Due to the smaller depth of the imaging calorimeter this leaves a ~17 cm gap between its outer radius and the inner radius of the magnet. There is room for further optimization of the inner volume to better accommodate services to inner subsystems. The list of utilities and services, while not on TDR level, is quite detailed and thought-out for a project at this level.

Comparison with and experiences from GlueX should be considered carefully and considered within the context of the full ePIC detector. The ePIC imaging calorimeter differs in size, weight and construction scheme.

The imaging layer utilizes low power HVMAPS sensors. Based on the current expectation of the sensor power consumption, heat transfer calculations show that no fluid cooling on the silicon staves was required, which significantly simplifies the service design. Given the final production-scale sensor is not available and other risk factors (e.g. radiation-induced leak current) could contribute to higher heat loads. Risk mitigation for potentially higher heat loads will be needed.

Should the imaging calorimeter be chosen for the barrel electromagnetic calorimeter of ePIC, the installation and maintenance procedures need to be further studied with high priority. The LV and HV distribution schemes to and within the HVMAPS staves should be developed, as well as the imaging layer's FPGA aggregator board and its services (e.g. LV, cooling, data link). During the final assembly, the GlueX-style inner support wheel as presented during the review does not seem to be compatible with the delicate inner silicon shelf structure. Maintenance procedures for replacing the damaged silicon staves between runs needs to be investigated.

Overall the specifics of the integration of the imaging calorimeter are different to that of the SciGlass and probably similarly complex. More space is available but also more weight has to be accommodated. One advantage is that there are no service requirements for the PbSciFi portion apart from the electronics which can be done with the calorimeter in-situ. On the other hand, the Astropix section is more complex, especially in terms of cooling.

2.4 Question 4

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

Observations related to both concepts:

- The two designs need to grow their workforce to succeed in such challenging projects. They need to both expand their overall size and possibly specialized skill sets, as well.
- Quality control requires dedicated setups, important workforce and dedicated time that needs to be included and spelt out in the subsystem timelines. Plans were not presented.

2.4.1 SciGlass design

A substantial amount of R&D effort is needed to select and characterize the glass. This might direct effort away from the detector construction.

The project relies on contributed workforce, and the committee was not able to discern exactly how much off-project labor was required, nor how secure it was (i.e. is it dependent on research funding, university-supported effort, etc.). This will need to be better understood.

2.4.2 Imaging design

While some silicon expertise is already present in the collaboration, this workforce should increase. A plan for the stave assembly facilities and production scaling up needs to be developed. The stave production QA process needs to be specified and tested with a large-stave prototype. The commissioning and maintenance plan was not detailed in this review.

The non-detailed breaking into different tasks of the workforce data does prevent from understanding if the workforce for an appropriate quality control of the various components of the two technologies is included and if it is adequate. The provided global figures look optimistic. Globally, this results in the above observation that a larger collaboration is needed for this challenging project.

The committee appreciates the rapid increase in the number of institutions interested to cooperate in the realization of this design.

2.5 Question 5

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

2.5.1 SciGlass design

The total project cost, the estimated workforce and schedule were presented. It was divided into workforce needs for (i) preliminary design, (ii) final design and integration, (iii) procurement and (iv) assembly, QA & production. The proponents also detailed the in-kind contributions to the workforce in terms of hours for postdocs, undergrad and grad students, mechanical and electrical techs as well as engineers. In terms of availability of the various workforce packages, the proponents stated that many tasks cannot be labeled *granted*, *expected* or *possible* at this time. There are currently ten groups involved in the SciGlass efforts six of which are universities. Three institutions are non-US based. Additionally, eight universities are considered "potentially interested".

The committee is concerned about the lack of detailed characterization of the SciGlass. The need for this was already emphasized in the Oct '22 Detector Advisory Committee (DAC) meeting and the Dec '22 project calorimetry review. The R&D of the glass and the study of its properties will likely need more time than currently presented to the committee. The committee sees the characterization for the SciGlass as a high priority item. Experiences from E-705 (long lived light components, opacity) and PANDA show that a profound understanding of the glass/crystals is essential and also feeds into a complete understanding of future test beam results.

The committee believes that the technology transfer to industry may take longer than anticipated in the current planning efforts. Recent experiences from other experiments show that the response and iteration times in the glass industry are considerably longer than foreseen by the proponents.

The committee believes that the amount of workforce required is underestimated. For example: for assembly, QA and production the estimated total workforce presented was equivalent to 5.8 FTE, including both project and in-kind, and over the period of Dec '24 to Mar '29. This amounts to 1.4 FTE/year total workforce. In addition, experience shows that especially the characterization/testing of the produced glasses is more person-power intensive than estimated by the proponents. The consortium workforce would soon need to evolve from an R&D project into an assembly line. The skill set to make the first complete prototype work and the skill set to make 8000+ items are naturally different.

2.5.2 Imaging design

The labor for lead scintillating fibers is provided as a global number that prevents us from understanding whether the assembly of the two technologies together is included.

The schedule presented is very aggressive and the committee is concerned about possible delays that may impact the ePIC detector as a whole, as well as the EIC project.

2.4 Question 6

Have the proponents adequately identified technical, cost and schedule risks? Are appropriate risk mitigations identified?

2.6.1 SciGlass design

Only risks associated with SciGlass production were presented. Alternatives are very challenging: PWO is expensive and production capabilities are limited and uncertain; lead glass requires detailed studies due to its lower light yield and non-linearities at lower energies.

2.6.2 Imaging design

Risk analysis was well presented and complete for a project at this stage. Mitigations for these risks look appropriate.