# Report of the in-depth Review of the eRD14 Collaboration: "Integrated Particle Identification for a Future EIC"

***EIC Detector Advisory Committee***

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## Introduction

Given the importance of particle identification for the EIC and the scope of the R&D being carried out within the eRD14 consortium, the advisory committee requested an in-depth review of the R&D being carried out within the consortium. The project leads were requested to present the status of their respective research projects. The meeting was held by video on September 19, 2019. Due to conflicting obligations that arose after the meeting had been scheduled, two members of the Advisory Committee were unable to attend (M. Demarteau and C. Haber). One member, I. Shipsey, joined the meeting late. The agenda for the in-depth review can be found at https://indico.bnl.gov/event/6819/; slides were provided in advance of the meeting.

The committee expresses its appreciation to the consortium for a very well-prepared set of presentations of the excellent work to date. The meeting was very informative and valuable. The next sections provide some detailed feedback on the reports presented.

## eRD14: Integrated Particle Identification for a Future EIC

**High-Performance DIRC for the EIC**
Speaker: Joe Schwiening (GSI)

Great progress was reported on the development of the DIRC detector in large part due to the contributions from the Panda group at GSI. The Panda test beam results from data taken at CERN are very good, reaching the performance limit of their present optical design. The only way to improve on the Panda results seems to be to change the present optical design to the so-called SLAC "ultimate design", which is a combination of plates and bars (NIMA 876 (2017), 141), which was briefly mentioned during the presentation. This would, however, require a change of the Panda optical design and therefore a change in simulation strategy. The EIC design would still keep lenses at the end of the bars, which the SLAC design did not have. It was not clear if the group is really assigning real priority to this possible change. Given the manpower it is assumed that, for now at least, the group will stick to the present Panda design.

The US side of the group made very important measurements of the radiation hardness of several lens materials and proved that the original materials would not work at an EIC. It then performed the important optics verification measurements of the Panda design using a laser. Two lens material candidates still need proof that they can be machined and polished; several vendors are presently doing it.

The present plan is to bring the Panda CERN prototype to Stony Brook in 2020, and then make it ready for a Fermilab beam test in 2021/22. What is expected from this Fermilab beam test was not adequately addressed. The committee believes that it is not enough to just to repeat the Panda results. Examples of a good test plan would include: (a) testing of real EIC detector candidates; (b) testing of EIC electronics candidates; and (c) some possible optics upgrades compared to the Panda design. Given our experience and based on what was presented, it seems that the EIC electronics will need easily 4 to 5 iterations and the same is true for any photon detector choice. In addition, the experience of many groups shows that test beams are not always successful initially and need to repeat several times. For example, to the best of our knowledge Panda had four tests at the CERN test beam; Belle-II had never a successful beam test with the final TOP counter design. The beam tests are not very convenient for small iterative upgrades and can become rather costly. Furthermore, there is always something missing (an example is mRICH, which did not have sufficiently good tracking). The committee believes it is better to invest in a good cosmic ray telescope and test various EIC DIRC upgrades in it. It is true that the cosmic ray telescope (CRT) will have slightly worse Cherenkov angle resolution (for example, in the case of the SLAC CRT, FDIRC had about 1-1.5 mrad worse single photon Cherenkov angle resolution compared to the ultimate limit), but this small effect can be simulated and is known. The advantage of a CRT is that one can keep changing detectors and electronics any time. One can also subject the DIRC to 3D tracking, something not easily accomplished in test beams because the mechanical support of fragile optics is complicated. An added advantage is that one could test several other EIC detectors in parallel, such as mRICH or dRICH, with one common tracking system, which could be provided by eRD6. So, it would be a win-win for both eRD14 and eRD6, as they both would benefit from the CRT. For example, the eRD6 micro-well detectors would provide excellent position resolution for a DIRC. This way of testing the devices would also provide a continuously operating tool for many students and postdocs with minimal travel costs.

DIRC R&D requests $134,000 in support of which $60k is for personnel and $89k for materials for FY 2020. This includes postdocs and a purchase of one 1024-pixel Photonis Planacon XP85112 MCP to start tests using the SiREAD readout electronics from the University of Hawaii, and funding of a Panda prototype shipment to US.

The DIRC research will require a significant increase in budget in 2021 due to the purchase of photon detectors for the test beam. The question of what detectors will be used was not addressed. The committee has reservations that the detectors will be understood before the purchase, especially if a switch is made to LAPPD or SiPMT detectors. The time sequence of the research program was not presented. If the goal is to run at 3T, the consortium might as well switch to SiPMTs and focus solely on this development.

As a comparison, by the time of testing of the final FDIRC in the CRT at SLAC for BaBar, the detectors used were those that would definitely operate at SuperB, and the group had years of experience testing them. The committee would really like to know how the new 1024-pixel MCP, which is planned to be purchased, will be readout. Will small pixels be grouped to larger macro-pixels, or is the plan to read out all 1024 pixels independently?

**dRICH Development - Design and Performance**
Speaker: Evaristo Cisbani (Italian National Institute of Heath and Italian Institute of Nuclear Physics)

**dRICH - Validation through Prototyping**
Speaker: Marco Contalbrigo (INFN Ferrara)

The dRICH group has finished the Monte Carlos studies of its performance, and is proceeding towards their next step, a concept prototype for the test beam. This prototype will certainly be useful, but it is clear that the preparations will require considerable resources, a freon purification scheme, very good Si-tracking detectors, beam PID detectors, complex electronics, understanding of aerogel quality, mirror development, etc. While at the July meeting the committee was not convinced that the consortium is ready and has the resources to carry out this project, it became clear at the September meeting that the dRICH effort has a strong team in Italy with a lot of experience, which can support the building of the proposed prototype.

An important remaining issue is the SiPM noise rate after irradiation which should be clarified. We expect that it will take 2-3 years to fully understand if SiPMs can be used in RICH detectors at EIC

**Photosensors:**
Speaker: Junqi Xie (ANL)

The committee believes that the LAPPD MCP effort has a long road ahead before it can be accepted as a baseline detector choice for inclusion in the TDR in 2023. To be included in the TDR requires that the consortium provides detectors with 3mm pixels, 10µm MCP holes to allow 1.5T operation and have small dead space around the boundary. The only suitable LAPPD devices for RICH application seem to be the Gen-III detectors, scheduled for 2021 delivery.

There is a number of tests required before these detectors can be placed in the DIRC prototype. A possible list includes:

- Provide a prototype to the Hawaii group to allow tests with the SiREAD electronics.
- Determine the S/N ratio and reliable voltage range operation. Measure timing resolution as a function of S/N ratio with an appropriate amplifier.
- Determine cross-talk to neighboring pixels for capacitively coupled pixels. Two amplifiers are needed to do this.
- Determine charge sharing to neighboring pixels for capacitively coupled pixels, with and without magnetic field. Two amplifiers are needed to do this.
- Determine ion feedback as function of voltage for tubes with and without ALD coating.
- Determine photocathode deterioration as a function of total anode charge and general tube operation instability in case of large charges.
- Make a 2D scan of these tubes to determine possible inefficiencies around the edges. The SiREAD electronics is needed to do this.

This test program will take easily one year to accomplish, depending on how many iterations are needed and how many people get involved. When carrying out these tests, care should be taken not to run excessive gain on these tubes. It is also strongly suggested to distribute four LAPPD prototypes to several groups to get a common understanding of this device. This means one tube to JLAB, one tube at ANL, one to Lehmann and one tube to Hawaii. Without an agreement among all these participants, the committee does not see a path towards inclusion in the TDR. It could be mentioned as an option in the TDR. It also looks that LAPPD Gen-III is the only one to satisfy the RICH requirements. This version is scheduled for 2021 delivery. That may be very tight for the RICH detector tests scheduled for 2021-22. The most likely scenario is that it is mentioned as an option in the TDR.

The LAPPD sub-project requests $115,000 of which $95k is for personnel and $20k for materials for FY 2020. The budget request lists a Photonis XP85122-S MCP at a cost of $6.5k. That sounds too small and we wonder if the cost is shared with other institutions. It is not clear what tests are planned for 2020 and what detector will be used for those tests. The budget does not anticipate an increase to take into account a purchase of four LAPPD Gen-III tubes in 2021. On the contrary, the budget seems to be decreasing. How four LAPPD Gen-III tubes will be financed in 2021 is not clear. Incom should provide them at a reduced price, because they get the evaluation for free. This is what other companies, such as Burle, have done in the past (for example, SLAC paid $4k for a 1024-pixel MCP, the same one, more or less, as the DIRC wants to buy now for $20k from Photonis). Burle received the evaluation for free.

SiPMTs are the only detector that work in a 3 Tesla magnetic field at present. If the SiPMT radiation damage can be handled by cooling, as CMS studies indicate, one should start an effort to understand how to cool them and to what temperature and demonstrate that all this works, first in calculation, and then in a test beam. If SiPMTs fail this test, it is recommended that this detector be dropped from consideration. Commercial MCPs made by Photonis are an available solution for fields up to 1.5 Tesla. LAPPD detectors do not make sense unless they provide pixel sizes between 3-5 mm and operate at magnetic fields of at least 1.5 Tesla. If there is a serious proposal for a 3T magnet, the committee would like to hear the magnetic field value and gradient at the photosensor's locations and a realistic plan to address the performance issues for operating above 1.5T. A realistic plan needs to be developed with an endpoint of 2023 when detector proposals need to form.

**Electronics:**

Speaker: Gary Varner (University of Hawaii)

A suite of particle ID detectors (DIRC, mRICH, dRICH) with similar electronics needs was presented. The eRD14 consortium has proposed a more or less common solution for reading out these different detectors which all rely on photon detection with good spatial and temporal precision regardless of the photon sensor technology chosen.

A more or less common set of sensor and electronic requirements was presented:

- Small pixel size: 3x3mm is the baseline for the DIRC, dRICH and mRICH.
- Fast timing: < 100 ps for DIRC, ~500 ps for dRICH and not specified for the mRICH.
- Large channel count: about 100,000 channels for the DIRC, and not specified for the other detectors. Nevertheless, both dRICH and mRICH sketches imply sensitive areas on the order of a square meter or more, which is of the order 100,000 channels for 3mm pixels.

The eRD14 electronics group has shown a well-developed plan to design a suitable front- and back-end electronics suitable for all three types of detectors. The proposed design is based on a new waveform sampling ASIC developed at the University of Hawaii with appropriate back-end DAQ electronics based on commercial devices.

In general, the electronics plan seems reasonable and, in some ways, advanced beyond the state of the photosensors for the different detectors, where there is no clear baseline. However, the electronics is also challenging, and the consortium is far from a detailed plan that could result in a robust EIC particle ID system. This is understandable as there is not yet even a site selection and we are far from being able to engage in a detailed design for a particular detector. Nevertheless, there are at least a few worrying general issues that should be addressed sooner rather than later.

Primary among the worries for the committee, is the power required to achieve the performance, especially in the case of the DIRC and then the mass and radiation length of the cooling system(s) required to deal with the associated heat. In a private conversation, the power per channel for the proposed system was estimated to vary from 5 to 100 mW per channel depending on the performance required for a particular detector. As 100,000 pixels at 10 mW per channel is a total of a kW, which is not entirely trivial, and with 10 kW at the upper end of the estimated power usage, it would seem useful for each detector sub-consortium to develop, in concert with the electronics group, a crude estimate of the total power required for a strawman detector and then work out a plausible cooling scheme for that power. That scheme should not degrade the performance of the sub-detector either by requiring too much space or having too much associated material. Even a crude existence proof for each detector type would be very encouraging. Any clear problems identified at this relatively early stage could be addressed in future R&D efforts. It is probable that other, lower power, solutions exist so a search for such possibilities would be valuable – especially if initial attempts at a plausible design do not seem promising.

As to the budget request, it is suggested to concentrate on the near-term development of the front-end and delay the back-end work by another quarter. We encourage the group to interact face-to-face to make the estimates suggested above. There may be alternatives to a waveform sampler but a more detailed estimate of the power issues is called for.

**mRICH:**
Speaker: Xiaochun He (Georgia State University)

The RICH detector with the Fresnel lens optics is very sensitive to incident beam position and its direction. In the second beam test they were not instrumented to measure this, and that is why the resolution was about two times worse than expected. To reach 10 GeV/c with a decent pi/K separation with aerogel is a tough task, and for that they need to make a) a beam test with proper tracking (or use a cosmic ray telescope), exploring different impact points and angles, b) develop a reconstruction method that would cover all angles and impact points and also ambiguities like mirror reflections. For a) the group has a plan, and for b) the team should try to adapt a likelihood method similar to the one that is used in the Belle II ARICH. The plan presented, a look-up table to correct for the circle distortions, does not look very practical; it would work in the test beam where the beam particles are parallel, but it is hard to understand how it would work in the final experiment where incident angles vary; they should explain it better next time. The budget looks reasonable. In fact, it includes a sizable investment into simulation and reconstruction which should be the main priority early on.

**Summary:**
Speaker: Pawel Nadel-Turonski (Jefferson Lab)

The eRD14 consortium has a broad R&D portfolio for particle identification at an EIC. The ps-TOF effort has for the moment been put on hold, giving higher priority to the other research topics. Although the proponents believe that the largest technical risks have been addressed for various conceptual designs, the committee is of the opinion that a significant amount of research still needs to be carried out before a design can be incorporated in a TDR. The consortium does have strong groups carrying out the research and is on track to make significant progress in the next four years. With the current spectrum of projects, the group operates on a resource limited schedule. The three Cherenkov projects (DIRC, dRICH, mRICH) carry the highest priority since they are the key enablers of a future EIC detector.

The committee considers the DIRC effort to be the strongest effort at the moment, partly due to the synergy with the Panda project. The most efficient path forward seems to be built a cosmic ray telescope, and test several detectors at the same time with one common tracking system and validate the electronics. The committee was equally impressed by the dRICH effort. A very strong team is in place in Italy with a lot of experience, which can support building of the proposed prototype. The work on both the DIRC and dRICH are fully supported by the committee. Regarding the mRICH, it is still not completely clear to us how the key performance parameters will be obtained for this detector in the final experiment where incident angles vary. The consortium should try to resolve the photodetector issue shortly and then carry out the still relatively large research program for the photodetectors. The electronics development is in the hands of a team of experts and full developments is not as pressing at this moment as it is for the Cherenkov counter developments.