Report of the 15th Electron Ion Collider Detector R&D Meeting

EIC Detector Advisory Committee

August 21, 2018

M. Demarteau (Argonne), C. Haber (LBNL), P. Krizan (Ljubljana University/J. Stefan Institute), I. Shipsey (Oxford University), R. Van Berg (U. Pennsylvania), J. Va'vra (SLAC) and G. Young (BNL)

Introduction

BNL, in association with Jefferson Laboratory and the DOE Office of Nuclear Physics, has established a generic detector R&D program to address the scientific requirements for measurements at a future Electron Ion Collider (EIC). The primary goals of this program are to develop detector technologies and detector concepts that are suited to experiments in an EIC environment, which will ensure that the full physics potential of an EIC can be harvested and that the resources for implementing these technologies are well established within the EIC user community.

The EIC Detector Advisory Committee meets twice a year, typically in January and in July. The current Committee members are: M. Demarteau (ANL/Chair), C. Haber (LBNL), P. Križan (Ljubljana University/J. Stefan Institute), I. Shipsey (Oxford University), R. Van Berg (U. Pennsylvania), J. Va'vra (SLAC) and G. Young (BNL). During the January meeting progress reports are reviewed and feedback is provided to the proponents. During the July meeting both progress reports and new proposals are reviewed. Funding recommendations for continuation of existing and for new proposals are provided by the Advisory Committee to the program manager in advance of the fiscal year funding cycle.

This year the committee adopted a new approach to evaluating new proposals. To make the meeting and overall process more efficient, new proposals had to be submitted eight weeks before the EIC advisory meeting and were pre-screened. The deadline for new proposals was May 25, 2018. Three new proposals were received and feedback was provided to the program manager on June 12, 2018, and notification was sent to the proponents on June 13, 2018. One new proposal was invited to proceed to submission of a full proposal. The committee received progress reports and funding requests of all continuing projects and the new proposal on June 27.

The EIC Detector Advisory Committee then met on the campus of the Catholic University of America in Washington DC on July 26 and 27, 2018 to hear status reports of eleven funded projects and evaluate one new proposal. Not able to attend this meeting was Peter Križan due to other commitments. All other committee members were present, though one member arrived after lunch on the first day due to flight cancellations. The committee would like to thank all the collaborations for their excellent presentations and status reports and CUA for their hospitality. The collaborations are to be commended for their progress. It is gratifying to see results being published in peer-reviewed journals and all proponents are strongly encouraged to continue to publish their results.

General Remarks

Shortly before the meeting the National Academy of Sciences (NAS) released its report endorsing the construction of an electron–ion collider (EIC) to investigate the nature of atoms. This recommendation backs the aspirations of the US nuclear science community, which in 2015 ranked the project as its top long-range priority for new facility construction. It's expected to cost in the range of $1 billion. The report was eagerly anticipated by the committee and was received enthusiastically by the whole community. The committee anticipates that with this endorsement of the EIC as the highest priority project for new construction for the nuclear physics community by the NAS there will be a substantial increase in the number of proposals to be considered in the near future. It is also hoped that funding for the detector R&D program will increase.

Currently, however, cognizant of the funding constraints, the committee takes a more focused approach with respect to the funding recommendation. Proponents are requested to provide a research program with a detailed schedule for yearly deliverables. Each proposal was also requested to consider three budget scenarios and articulate deliverables under each scenario: a nominal baseline budget, a nominal budget minus 20%, and a nominal budget minus 40%. A clear set of intermediate milestones had to be presented under each budget scenario. This has helped the committee evaluate all proposals. Only those elements of the proposals that were considered high priority were recommended. The program currently supports 11 projects and the funds are clearly spread quite thin. Reducing the overall number of supported projects, making them more efficient and having them reach their stated deliverables faster is considered to be a more effective approach. This approach has resulted in significant cuts to several existing programs and endorsing fewer new proposals. In this year's evaluation no such drastic measures had to be taken, although the funding remains very tight.

It was noted that the unobligated budget was high, nearly approaching a full year's budget. Some R&D collaborations manage their funding better than others. Although it is understandable that there can be a delay in the initiation of a purchase or the start of a new effort, a carry-over exceeding 70% of the allocated annual budget is symptomatic of deeper issues. The recommendation now includes not only a priority ranking based on the scientific merit of the research, but also a flag indicating the committee's assessment on the level of carry-over for the project. Based on this flag, guidance was provided to the program manager to make the final funding allocation.

This committee is advisory to the research program. We note, however, that many of the recommendations – some of which have been repeated – are not being followed. The decision of the research groups to not follow the recommendations may be well justified. In the previous report of the committee it was requested that clear deviations from the recommendations had to be justified both in the documentation and in the presentations at the next meeting of the advisory committee. This was not done in most cases. We would like to reiterate our request to address the recommendations. If the EIC goes forward, it will need to follow DOE project management rules and responding to recommendations needs to become a habit.

The intent of this R&D program is to support generic and directed R&D as described earlier. When a concept has demonstrated proof-of-principle and has reached a level of maturity where scaling by a factor of a few is involved, this research has reached a level of maturity where it has satisfied the goals of the R&D program, it can be moved out of the program and be easily revived once calls for concept detectors are issued and project R&D funding can be obtained.

Post-docs are an extremely valuable resource to accomplish the research goals. At the same time, post-docs are a long-term commitment and a long-term financial obligation to the program. The committee reiterates its position that extended postdoc terms working solely on instrumentation are (unfortunately) not a good career path for postdocs. We would also like to emphasize that postdoc support does not automatically transfer from one postdoc to a new postdoc. Moving forward, postdocs can be supported at the 100% level for at most two years. Only under exceptional circumstances will a postdoc be funded for an additional year, and then only at the 50% level. Other funding will have to be identified for the third year to facilitate transition to other sources of funding and provide a pathway for the postdoc to move into another position.

The EIC will most likely have CD-1 or CD-2 status within the next five years. This time scale is a near-perfect match for proposals to be submitted to the DOE sponsored Early Career Award Program (https://science.energy.gov/early-career/). We strongly encourage junior U.S. faculty to take advantage of this program. Given the high priority of the EIC within the Office of Nuclear Physics, proposals with an instrumentation element that enables a key goal of the EIC physics program should be very well received. We also note the NSF Faculty Early Career Development (CAREER) Program that is available to the university community (https://www.nsf.gov/career). The next sections provide the committee's assessment on the progress and requests of the eRD collaborations and the report concludes with a table summarizing the committee's overall priorities.

eRD1: EIC Calorimetry

O. Tsai, T. Horn and C. Woody reporting

Tungsten-fiber calorimeter development

The development of the W-powder Sci Fi matrix for use as a spaghetti EM Calorimeter has now reached a certain level of maturity and the proponents are to be congratulated for their diligent pursuit of this over the past eight years. The Committee takes note that the fiber-tungsten EM Calorimeter development has now led to working prototypes with good energy and position resolution plus a choice of readout technology, all coupled with levels of radiation hardness that would result in a capable EM calorimeter for the barrel and hadron-going directions at an EIC. The collaboration is to be congratulated on this achievement. One could remark that the concepts developed to date are ready to be incorporated into the design for an EIC detector, and indeed a version is now in an advanced prototyping stage for sPHENIX. That said, there is still room for improving readout performance, as noted below.

The sPHENIX group reported test beam results of a new prototype, denoted V2.1, that is 2-D projective and addresses the issues noted earlier with light collection from the tower/block edges and the design of the light guides. This large-scale prototype was tested in the FNAL test beam, yields acceptable performance for sPHENIX, and now serves as a final prototype for pre-production fabrication of the sPHENIX EM Calorimeter. It therefore includes designs for the cooling system, light guide coupling, electronics readout, and choice of SiPM and electronics. Results of a simulation study, made by ray-tracing, of light collection by the light guides were presented at the last meeting of the Committee and shown to identify a significant source of non-uniformity in EM Calorimeter position response. The radial space constraints in a collider, in particular with the BaBar magnet that is being re-purposed for sPHENIX, dictate that longer light guides are not feasible. sPHENIX can accept this loss of resolution but a new EIC detector should not. Possible options going forward include tiling a larger area with SiPMs, which may well be feasible given the new development of 6mm x 6mm SiPMs and/or the ongoing decrease in SiPM price. The Committee repeats the remark from the last two reports of the need to improve the light collection uniformity via work on coupling of readout devices such as SiPMs to the fiber-tungsten matrix, and to continue study of light-guide geometry and the trade-off between radial compactness, which favors short guides, and uniformity of response, which favors long ones. Light emission from the fibers favors the addition of a diffuser between fiber and SiPM to utilize the full matrix of micro-pixels of a SiPM; space for this would need to be found also. It would also be of interest to study the timing performance that could be achieved with SiPM readout. Proposals on these subjects would be welcomed by the committee.

The Committee again calls for a full radiation map for a reference detector at the EIC, as also noted below under eRD14. This must include neutron dose. Selection of optical readout technology at the EIC must be informed by this.

The collaboration reported at the last meeting results on their continued measurement of the effects of radiation exposure to the long-term performance of SiPMs. A set of measurements in the STAR interaction region, near the DX dipole, was presented. The Committee again encourages further analysis and dissemination of these results. A note placing these in the context of expected radiation levels at an EIC is of interest. This study also points to the need for a good monitoring system for a W-SciFi calorimeter, more so given the SiPM aging behavior. The design of this could be a subject of future development.

Recommendation
None. The Committee congratulates the group on the completion of this particular line of R&D and looks forward to possible future new proposals addressing the readout, calibration and radiation dose issues noted above.

Alternative Readout of W/SciFi EM Calorimeter Towers

A proposal was made to consider reading out a transversely-segmented array of W/SciFi EMCal towers using axial bars containing a wavelength shifting phosphor, with the bars then coupled to optical sensors at both ends. One bar would span the full axial range of towers for e.g. a central-barrel EM Calorimeter. This was suggested as a way to reduce the number of channels which must be instrumented, taking advantage of the relatively low occupancy of EMCal towers that have transverse size of the order of the Molière radius, with the towers also being placed outside e.g. a TPC or similarly-sized central tracker. Relative timing of signal arrival at each end of the WLS bar would be used to obtain a z-coordinate, whereas the position of the optical sensor firing would give the r.phi coordinate.

The advantages of using WLS bars to readout a series of W/SciFi EMCal towers were not clear to the Committee, more so in comparison to the GlueX approach of using axial SciFi in a lead-SciFi matrix. The GlueX EMCal is structurally sound, allows as much azimuthal segmentation as the Molière radius supports, allows for radial depth segmentation in its readout to compensate for the lack of transverse segmentation to aid in spotting electromagnetic showers, in particular photons, and has been operating the past 5 years.

Recommendation
The Committee does not recommend to pursue this approach.

HCAL Studies

A new proposal was made to examine the timing of the signals from a hadronic calorimeter and compare the time-integral of the early-time component of the signal vs the total time integral and use that as a discriminant between electrons and hadrons. The power of this may well depend on the amount of neutron generation during the hadron shower. The proponents argue to test this concept using a hadron calorimeter in a mixed beam of electrons and hadrons such as is available at the FNAL test beam. The calorimeter would need to be large enough to guarantee transverse and longitudinal containment of the hadronic showers. The proponents correctly note that RD52, the DREAM collaboration at CERN, has suffered significantly from leakage. The Zero Degree Calorimeters built for various fixed-target and collider experiments would be useful devices to test, if they are available. The design and performance of these calorimeters for the mid-rapidity range and zero-degree region are published in NIM A279, 479-502 (1989) and NIM A279, 503-517 (1989), respectively. The proponents suggest making test structures using iron plates and then later lead plates, in order to vary the neutron component of the hadronic showers, and to employ scintillating-tile and (possibly) WLS plate readout.

Recommendation

The Committee finds this suggestion intriguing and encourages its pursuit through a detailed Monte Carlo simulation to study the overall feasibility of the study before starting to build an actual module. The collaboration is requested to report on the simulation study in order to verify adequate shower containment by any proposed device and report to the committee before starting the hardware effort. Some economy in re-using of existing materials and optical readout systems and electronics to accomplish these tests is strongly encouraged.

Shashlik Concept

It was noted at the previous meeting that the shashlik technology has been around for many years and has already shown to be able to achieve good energy resolution and uniformity. The collaboration was encouraged to survey the existing shashlik calorimeters and perform a Monte Carlo simulation on possible improvements. The Committee takes note of an ongoing effort at UTFSM using W-Cu plates to realize a compact shashlik EMCal. The construction of enough of such blocks, which are read out as 2x2 towers, to form a 3x3, 5x5 or similar tower matrix, is encouraged. A goal is to measure performance in a test beam, and then compare to the performance of the old PHENIX shashlik EMCal towers which can be reconfigured to read out the individual WLS fibers, as proposed by the group. Re-use of existing readout sensors and electronics to do this economically is encouraged. Whether these are PMTs or SiPMs or other devices seems less important than understanding the performance of the device as an EM Calorimeter.

Recommendation

The Committee recommends pursuing this idea, including expansion of the current stock of W-Cu plate shashlik devices and performing beam tests, as well as obtaining one or more of the now-surplus PHENIX lead-scintillator-WLS shashlik calorimeters for testing, including in-beam.

Crystal calorimeter development

The committee takes note of the ongoing effort to characterize lead-tungstate crystals from Crytur and SICCAS and recognizes the need to qualify a vendor in order to be able to propose a high-resolution scintillating crystal EMCal for the EIC. The recent acquisition of several hundred crystals from SICCAS and about another hundred from CRYTUR is noted.

Results on light absorption following gamma (^{60}Co) radiation exposure (performed at Orsay) were reported for the SICCAS crystals. A general report on crystal measurements, including light transmission and yield as well as other comments, was provided to SICCAS. Experiments with surface treatment, including controlled surface de-polishing, to address light yield as a function of depth for rectangular vs trapezoidal crystals, were reported for the CRYTUR samples. The collaboration is encouraged to contact the L3 collaboration of LEP, particularly the LAPP Annecy group of Schneegans and Vivargent, concerning their coating of BGO with TiO_2 in a thin layer to address this issue for the tapered BGO crystals used in the EMCal for L3 at LEP.

The group has established required values for light yield, uniformity and radiation resistance for a crystal-based EMCal at the EIC and is actively pursuing measurements to determine if presently-produced crystals meet them. The measured results are now at a level to provide useful feedback to potential vendors. The effort for the EIC benefits from the work being done for the Neutral Photon Spectrometer at JLab by several of the same people.

The Committee remarks that active participation, e.g. by analyzing samples of each batch of raw materials in parallel to the vendor, and eventually even full control by the Collaboration in assaying purity of raw materials, may be needed to obtain good series production of acceptable crystals. This may have to be expanded into on-site presence at the vendors' sites to address crystal growth and surface treatment. Experience with large CsI and BGO calorimeters by other groups is admittedly un-even as to the nature of issues encountered but does suggest a hands-on approach may be needed. Expanded contact with these other groups is encouraged. A detailed understanding of vendor QA/QC procedures is needed at minimum. To quote a specific example, for the BaBar CsI calorimeter SLAC purchased the raw salt and analyzed it chemically before distributing it to various vendors to make crystals. This was the only way to guarantee uniformity in radiation hardness and light yield.

The Committee takes note of the new work reported to model and characterize the constant term in the resolution, in particular the study of material between towers and the gap sizes. The Committee encourages continuation of these studies.

As noted in the last report, "The importance of achieving a small constant term in the normalized resolution was stressed by the collaboration and studied in simulation results reported. It would be of interest to see further analysis of contributions expected to this limiting behavior, including uniformity of response, calibration precision among different towers, rear leakage of showers, dependence on angle of incidence, and the amount of allowable dead zone between towers. For future reference it would be useful to have an understanding of the proposed size of a tower, notably the number of radiation lengths, as well as shape of a tower. The collaboration mentioned a trapezoidal longitudinal shape to improve uniformity of response; the related efforts on the L3 BGO calorimeter for LEP and their coating with TiO_2 to flatten the response as a function of depth could be of interest here."

If an adequate number of crystals can be obtained, for example through leverage with the NPS project, it would be of interest to see a plan for a test beam program that included establishing the limiting energy and position resolution and a determination of the uniformity of response, including both energy and position resolution and energy sum, as a function of transverse position and angle of incidence

Recommendation

We encourage the collaboration to perform a chemical analysis of crystal samples to put some light on observed variability in transmission and radiation hardness. It would be good to understand what the specifications are on the purity of the ingredients to make these crystals. Expanded contact with other groups and a detailed understanding of vendor QA/QC procedures is strongly recommended. The Committee looks forward to the future reports of the collaboration and their plan to address the issues noted above.

Scintillating Glass Proposal

The group put forward a proposal to study various scintillating glasses with an eye to improve the basic characteristics of these glasses as regards impurities, defects, density and average atomic number, and thus Molière radius and radiation length. Such glasses are similar to lead glass in many properties but exhibit up to 100x the light yield per GeV. They thus offer a path to an inexpensive high-resolution EM Calorimeter, which could be of interest to an EIC in the central and forward region, if not necessarily the far-forward region. Such glasses have been made with various compositions but typically have been limited to small samples of 1cm scale due to difficulties with scaling up the production while maintaining the needed purity. The VSL at CUA offers the facilities and expertise to pursue this work and thus offers an interesting opportunity for progress.

Recommendation:

The Committee enthusiastically endorses this new effort and encourages the group to elaborate their research plans and begin the work. The Committee looks forward to reports at future meetings.

eRD3: Fast and Lightweight EIC Integrated Tracking System

M. Posik reporting

The eRD3 effort has concentrated on forward triple-GEM chambers and barrel MicroMegas tracking solutions for an EIC detector. A large, well equipped, laboratory has been created at Temple University partly from this program but with significant help from the University. The laboratory now includes optical ccd-based scanners for large GEM foils, ultrasonic baths, and an X-ray characterization station, that is now a real resource for the MPGD community. Recently the group has evaluated the foils for the BONUS experiment and from the company Mecaro and provided valuable feedback. The group has been very successful in advancing the commercialization of the production of large-area GEM foils with TechEtch. The Temple MPGD instrumentation laboratory has now assembled two 40cm x 40cm triple-GEM detectors using Tech-Etch components. One of the detector was built using Kapton spacer rings. The other detector was built using more traditional G10 spacer grids. The commercial prototypes showed nearly a factor two higher current across HV distribution board than the STAR GEM quadrants and failed during cosmic ray tests due to sparking, the cause of which is still being investigated. A new chamber is being assembled and will also be characterized using the cosmic ray setup and X-rays.

The effort at Saclay has focused on the MicroMegas (MM) technology for the barrel and the design for a 1D MM cylindrical shell has been successfully completed. The data acquisition has also been setup using the DREAM chip, for which a new development is in progress.

The eRD3 collaboration has expressed its desire to fully merge with the eRD6 collaboration and focus on the collaboration with UVa and FIT. This concludes a very successful R&D program. The collaboration is to be congratulated for the execution of a very successful program.

Recommendation:

The committee commends the collaboration for its significant contributions to the development of the MPGD program. Temple has established itself as as a resource for the entire MPGD community and we recommend that the group actively maintain its support to the MPGD community.

eRD6: Tracking Consortium for the EIC

M. Hohlmann reporting

The eRD6 collaboration reported on a broad range of efforts on tracking and particle identification. The TPC zigzag readout work seems to be close to demonstrating fully satisfactory performance for EIC use although some small amount of work may remain in understanding the problems observed in some laser ablated readout boards and whether the optimized chemically etched boards may not also be acceptable. The recent test beam measurements of a small prototype 4-GEM TPC with multi-zigzag readout is waiting for analysis but seems promising. Fabrication of large scale low-mass prototype forward GEMs has proceeded and is encouraging despite a few snags and disappointments encountered in the process. Despite some problems, large scale devices have been assembled and operated in an x-ray test system. The lessons learned in those prototypes are likely to be very useful for the next stages of the project.

The collaboration has also begun to examine μRWell devices as a possible tracking solution. A small size 10 x 10 cm device with 2D x-y readout has been operated in the Fermilab test beam.

On the particle ID front, the collaboration is working on MPGDs for single photon detection for a high-momentum RICH detector – both resistive micromegas with small pads that have shown promising progress and especially THGEMs with an innovative nano-diamond photocathode. The nano-diamond (ND) photocathodes shows systematically higher gain, but the hydrogenated nano-diamond show systematically lower breakdown HV. The non-hydrogenated ND option seems promising and more bench top and beam test results are likely to appear in the near future. Progress has also been made at Stony Brook in bringing on-line a new evaporator for mirror coatings.

For FY19, the collaboration proposes to continue to work on improving and optimizing TPC readout solutions looking at a broad array of options including GEM, GEM plus MM and μRWell with zigzag readout in both small and moderately large test devices and investigate new operating gases for a TPC that would optimize its operation specifically for EIC. Different gain structures and readout modules are being considered. One new initiative is to examine the possibility of building a cylindrical μRWell barrel layer to act as a fast-tracking layer in a non-TPC EIC detector. While the committee supports the general goal of continuing to understand possible tracking solutions in greater detail, the difficulties of actually fabricating a full cylindrical structure from a set of μRWELL planes appear significant and it may make more sense to start by trying to understand the mechanical problems of making a stable half (?) cylinder using just an un-patterned Kapton foil before attempting to deal with a real detector foil. It is also unclear what could be learned from the proposed GEANT simulation program for such a layer that could not be learned from a simple analytic calculation.

The collaboration plans a new initiative to assemble a material test facility at Temple University to validate potential new materials (including various printable plastics) versus outgassing worries. The committee agrees that this could be a useful addition to the community facilities but wonders if a somewhat more sophisticated system including gaseous component measurement tools might not be significantly more valuable at detecting possible problem materials than the proposed simple wire avalanche detector. The committee also notes that the funding remaining at Temple University from the eRD3 R&D is relatively high.

The collaboration also plans to continue work on small pad size micromegas detectors and test it in a beam in the fall. Construction of a second version of the prototype is considered, fixing the gain non-uniformity and enabling its full characterization in the lab. Coupling of innovative photocathodes based on nano-diamond particles to MPGD photon detectors is proposed with the production of a new set of small-size THGEM coated with ND and hydrogenated ND.

In a more speculative direction, the collaboration would like to make a serious effort to see if transformation optical materials could be used to tailor the Cherenkov effect in a way that would greatly improve the particle ID reach. This is a novel (and confusing) opportunity the success of which seems a stretch, but the potential payoff is huge and so a modest effort to involve experts in this emerging field to see if the class of materials that was ideated in the proposal might actually have some possibility of realization within the time horizon of an EIC detector.

Recommendation:

The collaboration has made good progress on many fronts and is encouraged to continue their efforts. The TPC studies are well motivated but relatively broad. Putting the R&D plan more in focus is recommended. The new focus on μRWELL detectors is promising but the detailed simulation effort on a barrel layer may be premature and is not recommended. It is also suggested that a planar geometry be studied in detail first before moving to a cylindrical geometry. The studies of novel photocathodes seem intriguing and promising and support is recommended. The initiative to pursue meta-materials for enhanced Cherenkov detectors is speculative but intriguing and should be pursued. The proposal to assemble a material test facility for outgassing studies could be a useful addition to the community facilities. The committee recommends, though, that a more sophisticated system including gaseous component measurement tools might be more valuable and a reevaluation of the plan is recommended.

eRD14: Integrated Particle Identification for a Future EIC

P. Nadel-Turonski reporting

The eRD14 collaboration is making steady progress towards the realization of particle identification for the EIC. The committee makes the following observations based on the progress report:

1. Photon detectors for RICH detectors: The most important challenge for eRD14 is to provide a reliable highly-pixilated photodetector working at 2-3 Tesla. This problem is not solved yet.
2. SiPMTs: SiPMTs were rejected for RICH detectors ~10 years ago because of a large noise rate after neutron damage. If they are to be considered now, this issue needs a dedicated study to prove that new SiPMT designs are better.
3. MCP-PMTs: The present MCP-PMTs may not be designed correctly for 2-3 Tesla operation. A proper design needs to tune not only the MCP hole diameters, but also MCP-to-MCP gaps, and choice of voltages. As far as the pixel size is concerned, it makes sense to choose 3mm x 3mm (one can always combine them to larger sizes outside the detector). It seems that the effort to develop the 5μm-MCP design should wait until a successful demonstration of the 10μm-MCP design is finished.
4. MCP-PMTs: It is necessary to check each MCP-PMT for its ion feedback rate, which is a measure of a residual gas inside the MCP. The required maximum ion-feedback rate should be less than 1% at full operating voltage. Running a 3% feedback rate or higher is asking for lifetime problems. The feedback rate increases with the voltage and can be reduced by using a higher gain amplifier. For example, FDIRC MCP-PMTs had amplifiers with a gain of 140x. This problem should be properly thought-through for the high B-field operation.
5. Scanning setup: What is really missing in this group is a scanning setup to test various photon detector & electronic choices with single photons to look for detection efficiency & timing distribution across the detector. This will help to develop a timing and pad-sharing strategy.
6. Cosmic Ray Telescope: As was pointed out before, a good cosmic ray telescope facility would help as they can run all the time.
7. Track direction in RICH detectors: One challenge of mRICH, DIRC and dRICH detectors is to provide the input track resolution to better than ~0.5 mrad.
8. dRICH: the Monte Carlo simulation has been finished and the event-based inverted Ray Tracing approach has been initiated. Building a dRICH prototype, funded by INFN, could be useful to tune various components. The committee, however, is of the opinion that SiPMT readout for a dRICH detector is a problem. Tests have been carried out over many years by other groups to use SiPMTs coupled to Aerogel RICH. Although it worked very well in the test beam, tests with neutrons proved that SiPMTs would become very noisy because of expected neutron doses; too noisy for a RICH detector. This problem is currently not being addressed by eRD14.
9. mRICH: The consortium had a very successful test beam run at Fermilab. Analysis of the test beam data is a high priority for the coming year. We hope to see a “proof of principle” from the upcoming Fermilab beam test with 256-channel MaPMTs, using temporary electronics, and results of radiation tests of the Fresnel lens.
10. DIRC: Good results were obtained from the CERN test beam, validating the Panda DIRC design. We also see good results from the MC simulation of the new lens materials, and experimental verification of the focal plane design. There was also an initiation of the radiation damage studies of new lens materials. If a wide plate and wide cylindrical lens is to be chosen, we would like to see if a DIRC could use wider pixel sizes, say 3mm x 12mm, to reduce the number of channels. The committee would like to add a cautionary note with regard to alternative lens materials. Although the new materials may seem to be more cost-effective it is important to evaluate all aspects of

the project, not only the detector performance over its lifetime in harsh radiation conditions, but also the quality control during production ensuring that the highest standards are being met throughout the production cycle.

11. TOF: The consortium has made no request for funding this year. We would need a convincing proof that a resolution at a level of 10ps is possible on such a large scale.
12. Sensors in large magnetic field: Measurements of the timing resolution as a function of magnetic field and MCP orientation would be very useful. However, one should remember that this type of measurement depends on what type of electronics and MCP gain is used. It is essential to have reasonable final electronics in this test, including fast amplifier, matching the BW of the MCP-PMT, with the right gain and a good FADC.
13. LAPPD: The company Incom should be encouraged to spend more time to develop a pixel detector; work on strips should be minimized. To test Incom LAPPDs, one needs the laser-based scanning setup and appropriate pixel-based electronics. The 2D scan should measure single photon response and timing resolution. One needs a strong support of the electronics group.
14. Electronics: Each detector type will need dedicated amplifiers to match the detector's bandwidth and gain. For example, MCP-PMTs operating at 2-3 Tesla, will need a large electronics amplification to reduce the high voltage. It is not clear to us who is taking care of this responsibility. As far as the subsequent electronics stages, the Hawaii group will take the main responsibility for the development of the front-end electronics (ASICs and boards), while INFN together with JLab will take the lead on integration for both the sensors and back-end/DAQ. The development of a common readout for all Cherenkov detectors is proposed, the SiREAD chip, which is a specialized full waveform sampling SiPM/PMT readout System-on-Chip with 32 channels expandable to 64 channels, with timing properties to match all Cherenkov detectors, including the DIRC. A number of electronics schemes were mentioned in the report. There is a certain danger in starting too many schemes, as each one takes a lot of effort to verify its performance in detail. Without proper feedback, it will not be clear how well a given choice works. This verification process could be done easily using the 2D scanning setup to judge both the detector and electronics. Such verification can be done on a scale of a day, once the system is running. So, for example, one could evaluate the effect of radiation damage of SiPMT arrays quickly without need for a test beam.
15. Background: It would be good to estimate the machine-related background in the DIRC, mRICH and dRICH. Neutrons are of primary concern, if one will use SiPMTs. We would like to see a neutron flux profile throughout the EIC detector.

Recommendations:

1. All RICH detectors should propose a scheme how to provide entry track direction with less than ~0.5 mrad resolution. Absence of good tracking will reduce the performance of these detectors at high momentum range.
2. LAPPD: This development should concentrate on the pixel-based readout and reduce efforts on strip-based readouts. The effort should concentrate to verify a single photo-electron response. We would like to see 2D single electron efficiency and TTS timing scans. To design these detectors correctly for 2-3 Tesla operation, one should increase the effort to simulate the MCP design.
3. SiPMT: Based on our information up to this point, we do not consider a SiPMT readout suitable for RICH detectors due to radiation damage concerns. The consortium is strongly encouraged to prove that the new SiPMTs behave better under expected neutron fluences. To deliver a viable solution for a dRICH it is imperative for the new SiPMT array designs to carry out a dedicated study for radiation hardness. The committee request that the collaboration provide quantitative results,

as shown in Figure 1, for the SiPM tests and demonstrate that single photo-electrons can be measured after 10^{11} n_{1MeV}/cm^2 and 10^{12} n_{1MeV}/cm^2

4. mRICH: The radiation damage test should include a measurement of wavelength-dependent transmission of the plastic Fresnel lens. One should evaluate the detector performance with some estimate of total expected mass in front of it.
5. TOF: The group needs to demonstrate a convincing proof that 10ps resolution is obtainable in a very large system.
6. Electronics: One should evaluate carefully the amplifier choice to match MCP BW, and to reduce MCP high voltage at large magnetic field, in order to reduce the ion feedback.
7. Background: We would like to see a neutron flux profile throughout the EIC detector.
8. The effort on the DIRC requests support for one postdoc at the 50% level. Given significant unobligated funds it is recommended that the group support the postdoc from these remaining funds.

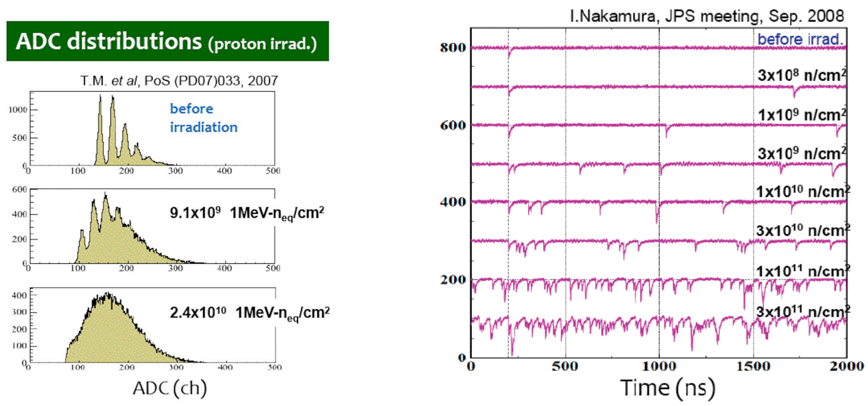

Fig. 1: Neutron damage of SiPMs.

(Left figure shown by Toru Matsumura at IEEE presentation, Dresden, October 2008; see also https://pos.sissa.it/051/033/pdf)

eRD15: Compton Polarimetry

A. Camsonne reporting

The Committee takes note that this effort continues to make good progress on the design of a Compton polarimeter for an EIC, specifically the detector for the Compton-scattered electrons.

Prior reports addressed the general concept and geometry of the polarimeter and gave rate estimates for the detector under conditions, in particular for the JLEIC concept in terms of electron beam current and bunch structure. A model of a possible strip detector for detecting the scattered electrons was put forward and shown to be able to determine the Compton edge and the zero-crossing in the Compton asymmetry.

The group took time since the last report to organize their several existing software packages, and the benefit of this effort is now apparent. The group is congratulated for their good progress.

The requested study of strip width, from 240 microns to 4800 microns, was performed and a conclusion presented that 40 strips, of the largest size studied, would suffice to measure polarization to a systematic uncertainty of better than 1% at all electron energies from 3 to 10 GeV. This is a most encouraging result.

The Compton asymmetry was extracted, systematic errors determined, and agreement with theoretical expectation of the asymmetry demonstrated, including location of the zero-crossing and the end-point. This is quite encouraging regarding the robustness of the models developed. The group plans to improve the systematics and accuracy determinations.

The effect of a 500-micron thick vacuum window was studied and shown to create no obvious effect on the measurement of the Compton asymmetry up to the cutoff energy. The ability to preserve better than 1% systematic uncertainty was demonstrated.

The group is examining beam halo as well as background due to interaction with beam gas. A 10Watt CW laser was shown to suffice, assuming 1 Amp of circulating beam and 10^{-9} torr vacuum. A 1cm aperture was shown to preserve S/B of 10 or better.

The Committee recommends continuing the links that have now been made with the RD-21 group, which works on various beam-background issues in a comprehensive way, and importing the codes and tools they are developing. The synchrotron radiation code has been brought in, for example. A new goal will be to bring in the MolFlow code for further work on beam-gas interactions as well as backgrounds arising from synchrotron radiation.

Contact has been made with TOTEM regarding the design of their Roman Pots. A formal agreement could be established to obtain the actual geometry, which would be of interest to the EIC.

A reference was made to a PEP-II report as a basis for the beam-halo modelling. The Committee would like to understand if the relevant apertures in that case arose from a polarimeter chicane or from the basic machine aperture. The group noted the importance of controlling the size of the aperture around the Fabry-Perot interferometer in the Compton chicane. Advancing the understanding of this will be an important issue going forward. The tool set developed permits now a systematic study of the chicane dipoles, the interferometer cavity and the detector. This study is now well underway. The Committee will be interested to see further results at the next meeting. These could include a phase-space mapping of background in the detector area.

A writeup of the results and documentation of the software package is in progress. No new funding was requested.

Recommendations:
None. Continue the efforts as planned.

eRD16: Forward Silicon Tracking

E. Sichtermann reporting

Report of January 2018 meeting:

Following on the discussions and guidance from the Committee in July 2017 the collaboration has continued a simulation effort aimed at understanding layout and configuration of the forward/backward silicon tracker. Studies were shown optimizing disc placement and configuration, pixel size, material, and beam pipe effects. A study was also presented of timing, rates, and pile-up, apparently based, at least in part, by the performance of the ALICE MAPS. Extending this study further, perhaps to shorter integration times, will benefit significantly from discussions with eRD18 and the BNL Instrumentation Division ASIC and sensors groups, to fully flesh out the performance alternatives of MAPS more generally. For example, MAPS considered for HL-LHC would be much faster. In the end, of course, there needs to be an optimization between power, pile-up, granularity, material etc. and this will only occur with everyone participating.

July 2018 Report:

Findings

- Simulation efforts aimed at pixel size, material, and layout considerations have continued involving project scientists, students, and senior members.
- A continuation, and completion of this work, focusing on a silicon tracker within a larger TPC, is proposed for the upcoming period.
- EIC interaction rates are low (<1 MHz) and pileup small
- The natural readout scheme would be comprised of a tracker with relatively long integration time (microseconds) augmented by a modest fast timing layer at larger distance from the interaction point.
- Such a scheme would optimize mass, power, and speed.
- The development of low mass mechanical support and cooling systems, for prior heavy ion and high energy collider experiments, have resulted in a variety of methods, schemes, and materials which could be applied to a future EIC precision tracker.
- The collaboration proposed to initiate a design study of an optimized and appropriate low mass mechanical support and cooling concept.
- Such an effort would make good use of resources and expertise which are available locally to the collaboration.
- Based, in part, on recommendations for past reviews, the collaboration proposes to also start considerations of an all-silicon tracking system for an EIC detector, and a comparison with the silicon+TPC concept.
- The RD16 collaboration has strengthened its links and cooperation with the eRD18 collaboration with regular meetings and contacts

Comments

- The committee endorses the proposed research plan
- The committee views the proposed plan and the growing relationship with RD18 as a very positive evolution. Local strengths both in physics and in technical/engineering expertise are well matched and complimentary.
- The committee encourages the collaborations to consider carefully, the performance requirements in the transition region between disc and barrel layers.
- The committee notes that the timing requirements were stated as due to “pile-up”, we wonder whether this point could better clarified and also considered more specifically in a JLEIC versus an eRHIC configuration.
- Continue to pursue and exploit other funding and support opportunities which are synergistic to this effort, as described in the report.

Recommendations:

- Please consider adopting a more uniform reporting template (like RD18 and others) consisting of the “What was proposed/achieved, not achieved, was/is planned etc” form.

The case for, and physics use of, a fast timing layer should be better motivated and described in future presentations.

eRD17: EIC Calorimetry: Beagle

M. Baker reporting

BeAGLE is a generator to describe eA collisions for the EIC. The proponents use real data from E665 to validate the physics model. The code is being used for physics-driven refinement of detector requirements, particularly in the forward region at both BNL and JLab and is essential in establishing EIC detector requirements.

The committee notes that BeAGLE is becoming mature and well known: there have been talks on its use in EIC simulations, there was one at POETIC this year, and at DIS, and at EPS in Venice in 2017.

The proponents have been progressing their initial mission statement responding to developments as they go appropriately. One of the aims of the EIC is to measure coherent (no nuclear break-up) diffraction in eA, since it is sensitive to the spatial distribution of gluons in nuclei (depending on gluon density squared). However, this process is swamped by the incoherent (nuclear break up) diffractive process, particularly in the regions where the coherent cross-section takes dips in t. One of the aims of BeAGLE is to understand the detector requirements for the accurate measurement of incoherent diffraction, both as an interesting measurement in its own right- being sensitive to saturation- and as a background to the coherent process.

By confronting their simulations with real data the BeAGLE team have realised that the diffractive process is not optimally modelled and they have been implementing an alternative model RAPGAP instead of PYTHIA, with the cooperation of the RAPGAP author, Hannes Jung. RAPGAP is specific to diffractive processes and is more flexible than PYTHIA in various ways. This illustrates how the team respond to challenges as the project develops.

Recommendations:

The committee recommends this proposal be funded.

Since BeAGLE is essential to establishing the EIC detector requirements, by the next meeting in January 2019 the committee would like to see a plan for accelerating the work, ensuring BeAGLE expertise is held more widely, and addressing continuity.

eRD18: Precision Central Silicon Tracking & Vertexing for the EIC

P. Jones reporting

Report of January 2018 meeting:

This effort focuses on central tracking within two work packages, WP1 being sensors and electronics and WP2 being simulation. For WP2, staffing issues interrupted this effort partially but it is reviving. Some resources will be shifted to an ASIC design study for fast timing.

For WP1 excellent progress was shown in the bench test and evaluation of sensors and pixel variants from the standard and new modified Tower Jazz process. Comparative studies of risetime and charge collection were shown. Upcoming studies will also look at other variants and architectures. The collaboration is encouraged also to make contact with interested colleagues in the BNL Instrumentation Division.

With regard to the proposed study of a faster, lower granularity, outer "timing" layer, the Committee looks forward to hearing results for that study at the next meeting.

eRD18 is strongly encouraged to engage more with eRD16 to inform studies and simulations on both sides.

July 2018:

Findings

- The RD18 project consists of two parts. WP1 focuses on the evaluation of sensor/readout electronics. WP2 focuses on design and simulation of the tracking system.
- In WP1, depleted (D)MAPS alternatives are under study
- A comparison of DMAPS architectures, existing and available was presented.
- Specifications for an EIC DMAPS architecture was presented separately for the tracking and timing layer optimizations
- Standard and modified Tower Jazz circuit implementations are under study with regard to charge collection and radiation effects.
- DECAL and RD50 structures are no longer under consideration due to larger input capacitance.
- Simulations within a barrel and outer TPC configuration were presented
- Addition of an outer timing layer does not degrade performance with the assumed material contributions.
- In earlier discussions the committee agreed that RD18 could divert funds to support an ASIC designer to study readout architectures. This effort has been put off until Fall of 2018 and additional support for an ASIC designer has been requested.
- The collaboration proposes to continue ASIC study towards optimized designs for charge collection, tracking, and timing layers.
- For WP2, the collaboration proposes to continue layout/geometric studies, implement a vertex fit in

EICRoot, and perform further studies of D meson reconstruction.

Comments

- The committee endorses the proposed research plan.
- The committee views the proposed plan and the growing relationship with RD16 as a very positive evolution. Local strengths both in physics and in technical/engineering expertise are well matched and complimentary.
- The committee encourages the collaborations to consider carefully, the performance requirements in the transition region between disc and barrel layers together with RD16.
- The optimization between the specifications and performance of the tracking and the timing front ends should be carefully considered. The best tracker will balance these and the mechanical and cooling aspects in an appropriate way.

Recommendations:

- Considering the general issue of underspending, confirm that past and new funds allocated for ASIC designer are being spent as proposed and report back to the committee in 6 months

The case for, and physics use of, a fast timing layer should be better motivated and described in future presentations.

eRD20: Software Development

Markus Diefenthaler reporting

The goals of the EIC Software Consortium (ESC) for the current year were to reach out to the EIC community and bring existing software to the end users and provide the community with documentation. The ESC has continued to work on common interfaces (geometry, file formats, tracking, etc.) and has explored new avenues of software development. The committee is very pleased that the consortium has followed the recommendation of the committee to take a more active role in working with the detector consortia though, for example, presentations at the EIC Users Group meeting and several major conferences. Progress has been made of developing a common file format using Google protocol buffers. The implementation of the GDML exchange format for the geometry definition has been delayed. The software is distributed to the community through the ESC Container project, which allows the EIC users to run the same software under a standardized environment on Linux, Mac OS or Windows and provides consistency between software generated at different sites. Efforts are also ongoing in the area of Machine Learning and ProIO.

With the recent support of the EIC by the NAS, it is expected that detailed simulation studies will be undertaken by the community very soon. The consortium presented a prioritized budget where outreach activities to the user community had a lower priority. The committee strongly urges the ESC to make outreach its highest priority and attract as many scientists and software developers as possible to use the EIC software framework and its tools.

Recommendation:

Start an active outreach campaign with the EIC user community to make the community aware of the available software infrastructure and broaden the user base.

eRD21: Background Studies

Latifa Elouadrhiri reporting

The progress made by the proponents of ERD21 is substantial. They have created and benchmarked realistic simulation tools and techniques with a validation procedure using the HERA configuration. The proponents have applied this work to the current JLEIC configuration: a realistic machine configuration, vacuum pipe geometry and materials, to produce the first results of background due to synchrotron radiation (SR). The team also developed tools and procedures of general applicability to any EIC design and the proponents are in the process of finalizing the associated documentation.

The committee was pleased to learn the good news that the BNL team have now joined ERD21. This is highly appropriate and strengthens the ERD21 team.

The proponents request funds to perform a *quantitative* evaluation of background radiation due to photons, charged hadrons, and neutrons, at the detectors and front-end electronics, in both the JLEIC and eRHIC configuration. This work is crucial to the machine design and the design of the detectors at both JLEIC and eRHIC.

As we noted in our last report the EIC detector will likely use a large number of SiPMs, it is therefore important to estimate the neutron rate correctly, including thermal neutrons, which are more difficult to simulate. It is now timely to give priority to determining the neutron rate and its energy spectrum and the committee would like to see these results at its next meeting in January, 2019.

The committee notes that the simulations and results presented are from single beam simulations. The committee is also interested in the effect of beam-beam interactions on particle backgrounds. Here we are not suggesting a two-beam simulation but a simple analytic estimate. The committee would like to see this estimate at our next meeting in January, 2019.

Collaboration between the accelerator and detector groups from both laboratories and the users' interaction region (IR) working group is necessary and the committee is pleased to see this is already in place. This collaboration optimizes resources and supports an iterative design process that will maximize the EIC physics program.

Recommendations:
The committee strongly supports the proposal and recommends that it be funded.

eRD22: GEM-based Transition Radiation Detector

Yulia Furletova reporting

It had been recommended that the project in its first phase focuses on MC optimization of the counter parameters, such as radiator thickness, Xe drift length thickness among others. A GEANT4 simulation of a Transition Radiation Detector (TRD) setup with a GEM detector including the gas and radiator volumes was carried out for single layer operation and the e/p rejection estimated. A GEM based TRD prototype was built and its performance was optimized, using a new HV divider, different drift field voltages and such. With regard to the simulation, the committee would like to see more on the MC optimization of a detector design. The background simulation should be part of this effort. For example, it would be good to know at what level of background the neural algorithm fails, how many TRD layers are needed, etc. We note that the ALICE TRD, for example, has 6 layers. With regard to the TRD experimental effort, this effort has started, funded from the external funds. Based on the experimental results so far, it is not clear what pion-rejection factor was achieved, as the JLAB test beam provides only electrons; one needs to go to Fermilab to do this. A gas purity is a nontrivial issue for Xe gases. One may have to circulate the gas to reduce the cost of Xe gas and use a special Xe-getter to clean it. The electronics could be obtained from other EIC collaborators in the community. It seems to us that the work on μRWell detector is still a bit too early and it would be better to first see the results from the eRD6 collaboration. It is noted that a large fraction of the funding has not been allocated.

Recommendations:

1. We would like to see more on MC optimization of the TRD detector design. Background simulation should be part of this effort to find limitations of the neural algorithm.
2. The TRD group should use existing electronics, available within EIC collaboration, for the present experimental tests.
3. Would like to see experimental results next time from the Fermilab test.

New Proposal: Streaming Readout

D. Hassell reporting

The committee was pleased to see a new collaboration forming to examine questions of readout of a full scale EIC detector. As they rightly point out the design of a complete detector and each detector subsystem may depend in various ways on the architecture of the readout electronics and, similarly, the design of the readout depends upon the detector. The committee would like to encourage the collaboration to begin working closely with at least one of the groups working on proposed sub-detector elements with the goal of understanding, in detail, the constraints on and possible optimizations of the detector-readout system. An actual example, worked out in detail and, perhaps even simulated, is likely to be very instructive. Useful examples can be found in the LHCb Trigger TDR [1] and the ALICE O^2 TDR [2].

The LHCb upgrade was given as an example of a trigger-less experiment employing streaming readout. It is noted that one of the main limitations of LHCb is that the collision rate must be reduced to the readout rate of 1.1MHz within a fixed latency. This reduction is achieved using the basic signatures available to the Level-0 hardware trigger. The largest inefficiencies in the entire trigger chain, especially for purely hadronic decays, occur at the Level-0 decision. Given that the experiment triggers on leptons or hadrons with a p_T of about one GeV, there is always significant background. Thresholds have to respect the rate of this background when raising the luminosity. Maintaining the balance between signal yield and background rate would be unfavorable for increased signal rate, hence the move to go to a full software trigger. The same argument holds for ALICE, where certain decays are very difficult to trigger on with a conventional hardware trigger, but where an online event filter with smart reconstruction enables extracting of challenging signals with high efficiency. The proponents have not put forward any examples of similar limitations at an EIC detector or any physics signatures where a standard triggered system could not do the job but a streaming readout would be advantageous.

The committee would also like to point out that the design space for any of these systems is very large and it could be a serious mistake to assume any particular model prior to working through the details and understanding the implications of various schemes in terms of cost, power, services, reliability and effort. The committee does not see any reason to examine hardware at this time.

Recommendation:
The committee recommends limited travel support for the proponents to further develop the proposal. The proponents are asked to compare streaming solutions with a well-designed conventional triggered system and show where a conventional trigger fails but a streaming readout is plausible.

[1] https://cds.cern.ch/record/1701361/files/LHCB-TDR-016.pdf
[2] https://cds.cern.ch/record/2011297/files/ALICE-TDR-019.pdf

Funding Summary

EIC Detector R&D FY2019	PI	Progress Report and/or Proposal	FY 19 Sub-proposals	FY19 Requested Funding	Priority
eRD1	Huan Huang (UCLA), Craig Woody (BNL)	EIC Calorimeter Development	Shashlik Calorimeter	$75,000	High
			W/SciFi + HCAL	$66,180	Medium
			PWO	$30,000	Medium
			Glass Ceramics	$30,000	High
eRD3	Professor Bernd Surrow and Dr. Matt Posik (Temple University) / Dr. Franck Sabatie	Design and assembly of fast and lightweight forward tracking prototype systems for an EIC		$0	N/A
eRD6	Kondo Gnanvo (UVA)	Tracking and PID detector R&D towards an EIC detector	MPGD-RICH	$50,000	High
			μRWell	$123,075	High
			TPC Readouts	$75,000	Medium
			Meta-Materials	$80,000	High
			Outgassing	$51,000	Medium
eRD14	P.Nadel Turonski (Stony Brook), Yordanka Ilieva (S. Carolina)	An integrated program for particle identification (PID) for a future Electron-Ion Collider (EIC) detector	dRICH	$52,000	Low
			mRICH	$77,300	High
			DIRC	$112,000	Medium
			high-B	$39,200	High
			LAPPD	$95,000	High
			Electronics	$86,000	Medium
eRD15	Alexandre Camsonne(JLAB)	R&D for a Compton Electron Detector		$0	
eRD16	Ernst Sichtermann (LBL)	Forward/Backward Tracking at EIC using MAPS Detectors	Simulations	$64,452	High
			Mechanical Design	$27,311	Medium
eRD17	Mark Baker	BeAGLE: A Tool to Refine Detector Requirements for eA Collisions in the Nuclear Shadowing/Saturation		$68,400	High
eRD18	Peter Jones (Birmingham, UK)	Precision Central Silicon Tracking & Vertexing for the EIC	Sensor Development	$80,000	High
			Detector Layout		High
eRD20	Markus Diefenthaler (JLAB), Alexander Kiselev (BNL)	Developing Simulation and Analysis Tools for the EIC		$50,000	High
eRD21	Latifa Elouadrhiri (JLAB)	EIC Background Studies and the Impact on the IR and Detector design		$130,000	High
eRD22	Yulia Furletova (JLAB)	GEM based Transition Radiation Tracker R&D for EIC		$56,240	High
NEW	M. Battaglieri (INFN, Genova), J.C. Bernauer (MIT)	Streaming Readout for EIC Detectors		$50,000	Low

Table 1: Summary of the funding recommendations.