# ELECTRON-ION COLLIDER DETECTOR ADVISORY COMMITTEE

## Report of the 13th Meeting held at Jefferson Laboratory, 13 – 14 July, 2017

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 concepts and technologies that are suited to experiments in an EIC environment, and to help ensure that the techniques and 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 June. The current Committee members are: M. Demarteau (ANL/Chair), 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 (JLab). 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.

The EIC Detector Advisory Committee met this time at Jefferson Laboratory on July 13 and 14, 2017 to hear status reports of nine funded projects and evaluated nine new proposals. All committee members were present for this meeting, though one member arrived after the coffee break on the first day due to flight cancellations. Progress reports and new proposals were submitted before the meeting and evaluated by the committee. The committee thanks all the collaborations for their excellent presentations and status reports. 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

The EIC project is currently being reviewed by a committee of the National Academy of Sciences (NAS). An accelerator scientist has been added to the EIC review committee. The NAS review is expected to affirm the importance of the EIC to U.S. accelerator science. The DOE has already initiated a $7M program for accelerator R&D shared between various national laboratories. It has been recognized in the 2015 NSAC Long Range Plan that U.S. leadership in nuclear physics requires tools and techniques that are state-of-the-art or beyond. Although vigorous targeted accelerator R&D is taking place, support for detector R&D for the Electron Ion Collider has regretfully not yet been realized at a level commensurate with the accelerator R&D.

The committee anticipated that, with the endorsement of the EIC as the highest priority project for new construction for the nuclear physics community by the Long-Range Planning Committee and the support for advanced technology R&D, there would be a substantial increase in the number of proposals to be considered while the funding was not expected to increase. This prediction unfortunately came true at the last meeting, and the trend has persisted with a record number of new proposals and a total funding request exceeding the available funding by a factor of 2.4, exacerbated by the fact that part of the allocated money is not available due to prior hiring commitments. Very cognizant of the funding constraints, interest shown by new international collaborators, and the desire to keep the emphasis of this program on research rather than development, the committee has started taking a more focused approach with respect to the funding recommendation. Proponents were 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.

Given that the funding situation is unlikely to improve in the near future, the committee is of the opinion that a more focused R&D program, with fewer projects, but each with a larger funding base, provides for a more favorable path to quickly increase the overall funding for this R&D program. The program currently supports 11 projects and the funds are clearly spread too 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 has resulted in significant cuts to several existing programs and endorsing fewer new proposals. Despite these actions, the committee is very appreciative of all effort expended to retain the momentum of existing R&D programs under difficult funding conditions.

Anticipating a positive recommendation from the National Academy of Science with regard to the EIC with an associated significant increase in new proposals, we are adopting a new review procedure to make the meeting and overall process more efficient. It is proposed that new proposals will have to be submitted 8 weeks before the EIC advisory meeting and will be pre-screened. Feedback will be provided 30 days before the meeting and the proponents will be notified if they are invited to present their proposal at the meeting. There will be no change to the procedure for on-going projects.

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, but clear deviations from the recommendations with solid justification has to be presented in both the documentation and in the presentations at the next meeting of the advisory committee.

In DOE parlance, mission need is referred to as CD-0. With the National Academy Review ongoing, it will be at least another three years before the EIC project will receive CD-0/1. Until then, the focus of this R&D program is generic R&D or directed R&D. Generic R&D in this context refers to developing a new technology or advancing an existing technology to such a level that it will be very beneficial to the EIC physics program. For example, the study of monolithic active silicon pixel detectors aimed at providing timing information and improving readout speed while retaining high granularity is considered generic R&D. Directed R&D refers to research and development in an area where current state-of-the-art is not able to meet the EIC physics requirements or where a technology is completely missing or unaffordable. The development of photodetectors that operate in magnetic fields up to 3T, for example, falls in this category. The committee has noticed that some of the existing proposals are moving more in the direction of pre-construction engineering design (PED), which some proponents refer to as "targeted R&D". We want to repeat that this falls outside the scope of this program.

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, but at most 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.

As noted in several previous reports, this program should be regarded as initiation funding for research that is able to obtain independent base funding. These are scarce resources and the goal is to maximize the fraction that can be dedicated to the research proper. Requests for travel funds are reaching a level of 10% of the overall request. Although certain travel is an integral part of the research program, for example to carry out a beam test program, it is recommended that institutions try to use their own travel funds where possible. If there exist extenuating circumstances regarding funding, we expect the PIs to contact the program manager, Thomas Ullrich, well in advance to discuss possible transition and mitigation strategies.

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).

## eRD1: EIC Calorimetry

**O. Tsai and T. Horn reporting**

*Tungsten-fiber calorimeter development*

Results were reported on calorimeter uniformity of response for the tungsten powder/SciFi calorimeter from test beam measurements with the sPHENIX prototypes of both EMCal and HCal modules, and in detail with the BEMC prototype. Different shapes of light guides, bending of fibers from the edges to the light guides, coupling media from fibers to light guides and routing of fibers from central regions to the light guides were all explored. The orientation of the SciFi modules with respect to incident electron was also varied. The best constant terms shown were less than 2%, which is encouraging. Definite dependencies on location and orientation of module and light guide boundaries were identified and studied. This aspect of the readout and the source of influences on measured behavior appears now to be understood.

The behavior of SiPMs exposed to a series of ever larger neutron fluences was measured using devices placed around the STAR experiment during a recent run. Exposures to neutron fluences up to nearly $10^{11}$ n/cm$^2$ were made and the resulting SiPM leakage currents measured. The required over-voltages and response were studied. This is important input to the choice of photon readout at an EIC. The results, however, are concerning due to the loss of response with increasing fluence and may point to the need to study other photon readout options for an EIC. The collaboration also measured the response of SiPMs to primary ionization using a triple readout technique and did establish a positive result that SiPMs are insensitive to nuclear counting effects, unlike APDs.

*Crystal calorimeter development*

The crystal calorimeter effort obtained a large number of lead tungstate crystals from SICCAS as part of the Neutral Photon Spectrometer effort at JLab. They have focused on characterizing these as well as a few crystals obtained from CRYTUR for uniformity, transmission and light yield. Acceptance rates from 20-80% were quoted for various vendors under various measurements, indicating that progress is made but significant work remains. Work to understand chemical composition is underway. The proponents note that their highest priority is finding ways to reduce the constant term, which includes nonlinearities in light collection that are in part properties of the crystal itself. More effort to understand doping and impurity levels in both sets of crystals is thus needed and a plan to pursue this was presented.

*Recommendation:*
The SciFi effort is encouraged to complete the current program of light collection and SiPM studies. The crystal effort is encouraged to focus now on measuring properties, including uniformity, light yield and impurity levels and provide feedback to the crystal manufacturers to guide improvements to crystal growth. Prototype construction at this stage is not encouraged. The readout for the forward high-resolution crystal calorimeter would be a future focus.

## eRD3: Fast and lightweight EIC integrated tracking system

**M. Posik reporting**

The eRD3 effort has concentrated on forward GEM 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 very significant help from the University. The laboratory now includes optical scanners for large GEM foils, ultrasonic baths, and hopes to soon commission an X-ray characterization station, once proper radiation shielding has been installed. The Temple MPGD instrumentation laboratory is in the process of assembling prototype 40 x 40 cm triple GEM detectors – a process that should be complete soon and lead to cosmic ray testing of the chambers in the fall of this year. The group has indicated that support for the postdoc is the highest priority.

The effort at Saclay has focused on the MicroMegas (MM) technology for the barrel aiming to complete the 2D curved design using 2D curved metallic and 2D flat resistive layers. The group has been testing both MM and triple-GEM prototypes with a new DREAM chip readout.

Temple has also hosted the very successful 5th International Conference on Micro-Pattern Detectors, MPGD2017, in May of this year.

*Recommendation:*

While the committee supports finishing the shielding for and the commissioning of the X-ray test station as well as thorough cosmic ray testing of the triple GEM chambers, funds are limited and some prioritization is necessary. The committee also acknowledges the use of the Temple laboratory as a resource for the entire EIC GEM community and looks forward to increased co-operation with other members of the EIC community. Temple has established its reputation as a major player in the area of MPGD detectors. As noted before, the proposed R&D program falls more in the area of PED. This program has been supported generously by the EIC R&D program to date. It has also been noted that this support should be seen as seed funding to develop ongoing base funding. Given the success of the group to date, securing base funding should be possible and is encouraged.

## eRD6: Tracking Consortium for the EIC

**K. Gnanvo reporting**

The eRD6 consortium has over the past year worked on testing and optimizing the design of "zig-zag" pad readouts, studied TPC gases, novel materials, aging tests of "chromium" GEM foils and understanding hybrid gain structures, among other efforts. The consortium proposes to continue work on the "zig-zag" pattern readout PCBs, studying the GEM performance under different gas mixtures, continue to work on materials for "Thick GEM" circuit boards, assemble (and learn how to assemble) large low mass GEM prototypes and do more work on "chromium" GEM foils. In addition, the consortium proposes to explore a new photocathode material based on nano-diamond materials, to study ion backflow and to develop a cylindrical micro-RWELL detector intended for fast hit information in the central region.

The eRD3 and eRD6 collaborations held a joint workshop at Temple University from May 20 – 21, 2017 to explore synergies between the two consortia, research priorities and discuss a decision tree process for moving forward. The committee very much appreciates the self-examination of their research programs within the context of highly funding-constrained EIC detector R&D program

Cr GEMs where the Cu layer on a standard GEM foil is removed by Cr constitute an approach to reducing the material budget. At our January meeting the committee noted that no simulations or full material budgets have been presented, so it is difficult to know if the reduction in material is significant; on the other hand, the ablation of the very thin Cr layer in use is a clear problem. The committee reiterates here that the collaboration is requested to show the impact of the switch to Cr layers in global tracking through simulations of one of the existing concept detectors with highest priority. The committee is surprised that the proponents did not perform the SEM inspection and the optical inspection of the damaged Cr-GEM foil from the first prototype. The committee looks forward to learning what that inspection reveals. Other work on Cr GEMs is supported but should be completed during this funding cycle.

The Thick GEM is a 15 to 20-year old detector concept. This type of detector worked in previous experiments, such as COMPASS, which used CsI photocathodes. The question is if a THGEM is a suitable detector for new diamond photocathodes, which would work down to ~140nm. The committee notes that one has to work at very low wavelengths because above ~180nm these photocathodes have quite a low QE. Working at such low wavelengths will increase the chromatic error. Was this estimated by the proponents? It is rather difficult to work in a wavelength region between 140 and 180nm for several reasons: methane gas itself has a UV cutoff at around ~140nm. Any gas contamination will start cutting into the detection acceptance. For example, one has to be careful with oxygen and water contamination. A G-10 material used for THGEM is a potential source of such outgassing, which will continue essentially forever.

The committee notes that another way to do this with more pure materials is a detector, which combines an MCP and a Micromegas. An example of such an idea is illustrated in NIMA 535 (2004) 334 and NIMA 553 (2005) 76–84, where ion backflow suppression was demonstrated.

*Recommendation:*
The committee is supportive of much of the work of the consortium but in light of the very tight funding constraints would observes that:

- The work on the "zig-zag" readout pads is important but seems by now largely a question of identifying the best vendor for some future production run and seems to be PED
- The new photocathode material is very interesting but it is probably important to understand more thoroughly how the operation at very short wavelengths will actually occur – the QE is very low above about 180 nm and Methane has a cut off around 140 nm – more simulation here may be useful.
- Thick GEMs will complicate that picture as the G-10 will outgas water with an even higher wavelength cutoff.
- The committee is not convinced that study of ion backflow is of the greatest urgency at this time.
- The cylindrical micro-RWELL detector is intriguing and could well be a useful device for EIC use.
- The chromium studies are interesting but greater study of the foils already in hand should be pursued.

It is noted that both the study of the "zig-zag" structures and the ion-back flow are the cost drivers of the funding request for FY18.

## eRD14: Integrated particle identification for a future EIC

**P. Nadel-Turonski reporting**

Dual RICH radiator

The proponents have done an excellent simulation study of the optical design for a dual RICH detector. The study calculated various contributions to the final Cherenkov angle resolution from various sources. It seems that the proponents have achieved the goal of the proposed program for the JLab EIC detector concept. They are proposing to continue this study in FY18 to concentrate on the BNL detector design. There is some logic to do this using the same postdoc, as he has a lot of experience.

*Recommendation:*

There does not seem to be enough support to build a small prototype, as it is not clear to us what would be achieved at this stage of development.

Modular Aerogel RICH (mRICH)

The Aerogel RICH detector, with Fresnel lens focusing, enhances the PID capability to higher momenta, and is superior to a multi-layer proximity focusing Aerogel RICH as used by Belle-II. However, a simple Fresnel lens made of plastic material invites a question about its radiation hardness. We expect that the result will be actually poor. The proponents plan to use MaPMTs with 3mm x 3mm pixels in the next test beam. It is not clear to us how this detector is going to be read out? Is the goal to measure a portion of the Cherenkov ring with a single MaPMT? We would like to see this test more clearly defined.

*Recommendation:*

As the committee has asked already before during earlier EIC reviews, we expect the proponents to provide a solution to the radiation hardness of the Fresnel lens.

DIRC

The Panda DIRC has very nice test beam results from the CERN test beam, proving that the 3-layer lens optical concept works. Its resolution is somewhat worse than that of the FDIRC for SuperB, but good enough for Panda. EIC DIRC plans to improve the Panda resolution by using smaller pixels and using better timing. However, as was somewhat suspected by the committee, the radiation hardness of the NLaK33 lens material, used as a middle layer of this 3-lens system, is not radiation hard enough for the EIC DIRC. We were impressed by very nice optical focal plane mapping measurements with a 3-lens system performed in Old Dominion University.

*Recommendation:*

We expect that the proponents will continue radiation hardness studies of the lens materials. The radiation hardness tests should be extended to a glue choice as well. The radiation damage should be done with a $^{60}$Co source as well. We also suggest that the proponents think hard what would happen if there is no working photon detector at 1.5-3T magnetic field. Should one consider an option where bars penetrate the iron as was done for the BaBar DIRC?

TOF

To achieve ~10ps time resolution is very difficult in a small detector setup, and probably impossible in a very large system. For example, C. Williams, years ago, achieved a resolution of ~16 ps in a single 24-layer MRPC in a test beam, i.e., in under ideal conditions. According to him, the MRPC contribution alone was <10ps, and the dominating factor was electronics. In this case, the test beam entered the MRPC perpendicularly. One can consider this result as a proof of principle. However, the question is what one can achieve for (a) an arbitrary direction, (b) multi-track situation, (c) multi-strip readout, etc. Pushing high bandwidth helps the timing resolution at the 10ps level, but invites other problems, such as cross-talk, baseline oscillation effects, etc. More importantly, it is very doubtful that a $t_0$ can be achieved at a comparable timing level with a small number of tracks. For example, ALICE has achieved a $t_0$ resolution of only ~ 85ps for an average number of tracks of 25, and more than ~100ps for less than 5 tracks, expected at an EIC.

*Recommendation:*
The committee recommends that this effort should continue at a very small level to have some option available in case other PID methods do not work out at the end. We would like to remind the collaboration that we had not recommended any funding for FY17, and there is no plan support to do so for FY18.

Photosensors (Sensors in large magnetic field)

The development and understanding of photon sensors at large B is the most important issue for the entire PID group. There is a very impressive test setup at Argonne lab. Testing of various MCP-PMTs is in progress. This includes finding operating points at fields higher than 1.5T, i.e., tuning variables such as gain setting, various MCP voltages, B, $\theta$, and $\phi$. The committee wishes to express some caution: as one increases the MCP operating voltages, one may increase the ion backflow, which will cause after-pulsing. This is especially crucial in older tubes due to increased outgassing level. For example, FDIRC operated MCP-PMTs at a gain of ~$5x10^5$ only to reduce the ion feedback, and the lower gain was offset by higher amplifier gain. It should be investigated if the ion backflow depends on gain or HV.

*Recommendation:*
The committee thinks that the experimental work to investigate MCP at high B-field should be done in parallel with a simulation study. We believe that the work on sensors at large magnetic field should probably be centralized at some point in one location.

Photosensors (LAPPD)

The group has been studying pixelated readout and Innosys, Inc. is still working on overcoming the technical difficulties to provide a more reliable pixelated readout. Meanwhile, proponents have pursued a pixelated readout through capacitive coupling design. The design is to use a resistive anode coated by the ALD method. We would like to see test results if this approach affects rate handling capability and worsen the charge sharing.
The committee also would like to direct the attention of the proponents to the recent TDR for the PANDA DIRC. This collaboration has done a tremendous amount of work on MCP photocathode aging.

*Recommendation:*

The Burle company had MCP-PMT pixilated readout with 1024 pixels worked out ~10 years ago. We suggest that the consortium talk to Paul Hink, now independent consultant, about how Burle made feedthroughs. It should be considered if he could be hired as a consultant? He certainly knows details how the feedthroughs were made. The consortium is encouraged to prepare a setup to evaluate photocathode aging and ion feedback, so this can be easily verified for the photodetectors produced.

Photosensors Electronics

To evaluate multi-pixel readout with MCP-PMTs or SiPMTs or MaPMTs, one needs appropriate electronics even in the early stages of R&D. Although ASICs may be common to different photosensors, each sensor will need a different amplifier, both from the gain and from the bandwidth point of view. This makes the electronics choice rather challenging and it will require, at some point, a substantial effort. It would be nice to define the electronics/detector choice more clearly. One may want to minimize the effort on sensors, which will be not used in the final application. An example of such a sensor is the MaPMTs with 3mm pixels, as they will not work in a magnetic field. That option would be useable only if the DIRC bars penetrate the iron. SiPMTs are also a questionable choice because of their radiation sensitivity to neutrons; they were rejected by Belle-II and SuperB for the RICH and LHCb for its RICH application. It is hard to believe that they could be used for EIC RICH.

*Recommendation:*

Based on the experience with Hawaii electronics for the FDIRC at SuperB and the TOP counter at Belle-II, such electronics will require a substantial and continuous development. Because of that, one should probably limit number of possible choices.

## eRD15: Compton Polarimetry

**A. Camsonne reporting**

An impressive list of results was reported on a large range of topics relevant to the design and operation of the Compton polarimeter. These results are highly encouraging for the operation of such a device at either of the proposed machine solutions. This includes the ability to make measurements of 0.5% accuracy, important for the parity program, and to carry out these measurements periodically for short periods, thus not interrupting production running of the experiments or causing problematic degradation of beam parameters. The analysis included a study of stainless steel windows that would be needed to deploy detectors inside Roman Pots and demonstrated that these windows would not affect measurement accuracy. Detector rates were determined and shown to be acceptable, being less than 1 MHz/strip, for an interesting and feasible range of laser powers and beam currents. A model for beam halo was introduced and behavior of possible collimators studied. This will provide useful feedback to the machine designers, which in turn can provide input to the work on the Compton polarimeter as estimates for beam halo are developed. Beam background was studied, and the calculations set up to incorporate input from other R&D efforts which seek to model machine backgrounds from physics at the IP as well as synchrotron radiation and beam-gas interactions.

Results were reported on wakefield calculations for the proposed Roman Pots used to house the measuring devices. This was studied for beam repetition rates up to 500 MHz, the highest proposed, and the cavity response determined. Power deposition can reach 2 kW but this level can be tolerated with some effort, suggesting the overall idea can be developed and made to work in both EIC machine environments.

*Recommendation:*

The committee recommends to focus first on completing the various simulation results for the behavior of the polarimeter. Once this is done, continue in the future with more definite plans for the Roman Pot and the calculation of its wakefield and resulting power deposited. Feedback to the machine designers on the placement of the Compton Chicane is encouraged.

## eRD16: Forward Silicon Tracking

**E. Sichtermann reporting**

The Committee generally looks with favor upon new or recent proposals which investigate the use of silicon and related new technologies, for the EIC. This is an area which was undersubscribed in the first round of EIC R&D proposals. The Committee would also like to see proactive coordination, and eventually collaboration among proponents with related, overlapping, or complementary efforts in these areas.

At the January 2017 EIC R&D meeting the Committee encouraged the LBNL and Birmingham groups to collaborate more closely. While the groups are still presenting as separate eRD efforts, we note that communication between the groups has increased and a clear dialogue is underway. It is hard for the Committee to imagine that there would not be an integrated barrel/forward/backward tracker design. For these systems to use different approaches to sensors, electronics, mechanical support, and cooling, we would need to see very strong arguments.

The LBNL group is focusing on performance and layout studies, and has largely put the more technical issues off for future consideration. Good progress was shown and we encourage further efforts in this direction and further development of the collaboration with any other groups with similar interest. We recommend continued support recognizing that the limited allocation for the entire EIC R&D program implies tighter funding across the board.

*Recommendation:*
The committee recommends continued support for the simulation efforts.

## eRD17: BeAGLE

**M. Baker reporting**

This project is for the development of an eA DIS event generator, BeAGLE (formerly called DPMJetHybrid), including nuclear shadowing & parton saturation. 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.

In this proposal, the proponents build on previous work, which has been well received by the committee. As last time, the progress was neatly captured in a Table, which identifies thirteen tasks and tracks their status over time and compares it to the status prior to this work. This reporting format is appreciated by the committee. The scope and the manpower seem realistic.

The proponents have previously implemented multi-nucleon shadowing at low-x in about as realistic a manner as one can expect given the current understanding and this achieves the main technical goal of eRD17. As we noted in our previous committee report there can always be unforeseen difficulties. In particular, process specific A-dependence hides potential challenges since it involves the role of diffractive processes as A increases.

The proponents have made significant progress with the BeAGLE simulation program since January. They have a better understanding about diffractive eA processes such that they now worry about the swamping of the coherent cross-section by the incoherent cross-section at larger $t$. They have realized that these events cannot always be efficiently tagged, because they have no evaporation neutrons. Part of the challenge with this work is that it will be the EIC itself which will really extend our knowledge of these processes, so the proponent's task at this time is to keep various choices open within the simulation program. For example, they are implementing ways of describing the possibly different A dependence of diffractive and deep-inelastic events, which will enable them to use E665 data to tune their descriptions.

*Recommendation*

This is important work by proponents with a proven track record, and funding in full is recommended.

We note the co-location of Zheng has been highly valuable for previous work and suggest that given the importance of this work to the refinement of the design of the detector requirements, particularly in the forward region at both BNL and JLab, that management find ways to make travel funds available to bring Zheng back to BNL for part of the next funding period.

## eRD18: Precision Central Silicon Tracking & Vertexing for the EIC

**P. Jones reporting**

At the January 2017 EIC R&D meeting the Committee encouraged the LBNL and Birmingham groups to collaborate more closely. While the groups are still presenting as separate eRD efforts, we note that communication between the groups has increased and a clear dialogue is underway. It is hard for the Committee to imagine that there would not be an integrated barrel / forward / backward tracker design. For these systems to use different approaches to sensors, electronics, mechanical support, and cooling, we would need to see very strong arguments.

The Birmingham group is focusing on two work packages – one towards sensor development and design, the other towards central performance and layout issues. We note that the principals are already strongly coupled into the greater sensor development activities which originate in HEP. The proposed performance and layout studies which address pixel size and layer thickness are of general interest to any inner tracking effort. Good progress has been shown and the Committee generally supports this work. The group has a clear set of deliverables for the second year of this two-year proposal: the characterization of pixel matrices in the CERN TowerJazz demonstrator process and a complete study of single track momentum resolution and impact parameter resolution based on different assumptions on the pixel dimensions and number and thickness of tracking layers, combined with an optimization of the tracker layout.

The Committee notes that a simple analysis was presented of front-end electronics power and speed. We encourage the team to address this in a more general and widely applicable way in hopes that some benchmarks can be established which would be appreciated by any group considering the tradeoffs between resolution, granularity, timing, noise, and power.

*Recommendation*

The proposed costs are somewhat high considering the perceived cost of a post-doc at a university. We recommend continued support recognizing that the limited allocation for the entire EIC R&D program implies tighter funding across the board.

## eRD20: Software Development

**Markus Diefenthaler reporting**

The goals of the software development group for the current year were to explore interfaces and integration of existing frameworks and toolkits; plan for the integration of new computing infrastructure and new computing standards; and build an active user support group that fosters collaboration. The EIC Software Consortium (ESC) has been actively engaged in the workshop on "Future Trends in Nuclear Physics computing" and has reached out to the Geant4-collaboration, the HEP Software Foundation and the HEP Center of Computing Excellence.

A review was held of the EIC software computing environment, in particular the frameworks and interfaces. It was decided that it is too early to decide on an analysis environments for the EIC and the committee completely agrees with this assessment. It is suggested that the focus should at this time be on facilitating the execution of the simulations, the development of common tools and the study of common interfaces. A Gitlab repository was created for EIC software as well as a HEPsim repository for file storage. Good progress has been made on defining a self-descriptive file format (EicMC) and on implementing radiative effects. The main areas of focus for the upcoming year are the development of Monte Carlo event generators for the EIC and the further development of a self-descriptive MC file format. A unified tracking tool with universal geometry and detector interface will be developed. The use of High Performance Computing will be explored.

It was noted that the interaction with the detector collaborations is sporadic and not as strong as desired.

*Recommendation:*
The development of common tools for EIC simulations and analysis is encouraged. It is noted, however, that the computing landscape is changing rapidly. It is recommended that a targeted approach be taken for the software development. The entry into HPC computing should be taken very judiciously with a long-term time horizon. It is not obvious to the committee that the entry into HPC systems is warranted at this time. The committee strongly suggests that the software group take a more active role in working with the detector consortia to help with the simulations and set up a process to easily implement new detector configurations to optimize the detector design.

## New Proposal 1: Shashlik Electromagnetic Calorimeter

**Edward Kistenev reporting**

The construction of a technological prototype Shashlik calorimeter is proposed. The committee notes that the Shashlik technology has been implemented already in the PHENIX HERA-B, LHCb and ALICE experiments. The proposal aims at providing a solution for the response non-uniformity encountered by the W/SciFi project using a fiber density of about $1/cm^2$ with SiPM readout. In addition, it is proposed that through the readout of individual fibers the detector can provide a very effective measurement of the shower shape and thus can provide for good particle identification, in particular electron/pion discrimination. The detector could also furnish accurate timing information.

The committee notes that the Shashlik calorimeter for the ALICE experiment, for example, consists (at $\eta=0$) of $6x6x24.6\ cm^3$ towers, each read out with 36 WLS fibers, for a fiber density close to $1/cm^2$. The uniformity of these modules has been extensively studied and a uniformity of close to 1% has been achieved (see for example arXiv:1008.0413). It seems that a study of the resolutions and uniformity obtained by the various Shashlik calorimeters being used is required to better understand the possible limiting values in these calorimeters. The proponents reference a previous study of a compact readout of a highly segmented shashlik calorimeter with longitudinal segmentation (arXiv:1605.09630v1) that has demonstrated the feasibility of this approach.

A simulation study analyzing the various goals of this proposal and their feasibility may help guide the effort to study the impact on the EIC physics program. We also note that the proposal seems close to an engineering design, which will be interesting in the future but not now unless there is a clear demonstration of the advantages such a calorimeter would provide for the EIC.

*Recommendation:*
The committee recommends that a survey of the running Shashlik calorimeters and their technical limitations be carried out and that a feasibility study of the proposed concept is performed within the eRD1 proposal, corroborated with simulations. Funding of this proposal as a new initiative is not recommended, but it is anticipated that the eRD1 consortium could provide some support.

## New Proposal 2: Small Strip Thin Gap Chamber Detectors

**Lijuan Ruan reporting**

The committee finds that the presented concept on Forward and Backward tracking at the EIC using small strip Thin Gap Chamber (sTGC) detectors has a good physics motivation. On the other hand, STGC detectors have been used in experiments for a long time and have been perfected by the LHC experiments. The main open question of this R&D proposal seems to be the good position resolution required and the low material budget. This can be accomplished by a strongly focused research on a small (~10cm x 10cm) prototype. The committee does not see the need to build a large chamber at this point until the concept has been demonstrated and the value for the EIC physics program demonstrated though simulations. After this is successfully accomplished, methods of scaling the detector to the requested size can be discussed. For testing of the large size chambers, a timely preparation of a cosmic ray test set-up would be highly desirable; such a set up would also benefit other eRD projects as well as the community at large.

*Recommendation:*
The committee recommends that the research be more strongly focused on the open question of the high-resolution and low-mass aspects of such a detector. Once this is achieved, scaling up can be discussed. Due to the tight funding in this program, funding for this project is at the moment not recommended. Given that thin gap chambers might present an opportunity to enhance the EIC physics program, the proponents are encouraged to explore alternative funding for a project with a smaller scope, targeting smaller prototype chambers.

## New Proposal 3: Small GEM based Transition Radiation Tracker R&D for EIC

**Yulia Furletova reporting**

The proponents had submitted a Letter of Intent at the January review meeting to study a GEM-based transition radiation tracker in an EIC detector to aid in electron identification in the energy range of 1 – 100 GeV where most other methods are not providing any e/π separation anymore. The proposal calls for GEANT4 simulations of a TRD setup with GEM detectors to evaluate the e/π rejection factor for different configurations; using the existing facility at JLAB Hall-D to perform a test of various radiators; and to test different Xe-gas mixtures. The proponents were encouraged to strengthen the motivation for a GEM-based transition radiation tracker for an EIC detector through simulations. The added physics reach and pion rejection within a full EIC detector simulation, with other particle identification technologies and tools already included, should be quantified.

The presented concept is considered very interesting, and has a good physics motivation. A research program performing a GEANT4 simulation of TRD setup with GEM detectors is proposed and the construction of two new test GEM based transition radiation detectors to optimize their performance. R&D on various radiators and different Xe-gas mixtures is also proposed. The committee agrees that MC optimization of the counter parameters (radiator thickness, Xe drift length thickness etc) has to be performed. On the other hand, the committee believes that before this is accomplished, it is too early to do any prototyping.

*Recommendation:*

It is recommended that the project be funded at a level below the requested amount, and that its first phase focuses on MC optimization of the counter parameters, such as radiator thickness, Xe drift length thickness among others.

## New Proposal 4: A triggerless data acquisition system for calorimetry

**Andrea Celentano reporting**

The presented concept of a triggerless data acquisition system follows the concepts that are currently being implemented by various experiments, such as LHCb and KM3NET. These developments are timely and could lead to a new trigger paradigm. The proponents note that the use of a triggerless system in the EIC needs to be carefully studied because of its close connection with the detector design. The research program calls for implementing a study on a small PbWO-based calorimeter array.

*Recommendation:*
The committee attributes much value to the study of triggerless data acquisition systems. However, given the tight budget constraints of the R&D program and the very early stage of the research program for the EIC, this project is currently not recommended for funding.

## New Proposal 5: EIC Background Studies and Impact on the IR and Detector design

**Latifa Elouadrhiri reporting**

This is a new proposal about backgrounds that the machine and its design will produce to physics processes of interest, in particular synchrotron radiation (SR) and beam-gas backgrounds. The proposed work will allow evaluation of the background radiation reaching the detectors and front-end electronics which is crucial to developing a viable detector design both with regard to occupancy and radiation damage. Experience at HERA has shown that synchrotron radiation and beam interactions with residual beamline gas are likely the major sources of background that will require mitigation at the EIC.

SR and beam-gas background rates are related through desorption from the beam pipe wall and other surfaces caused by SR (dynamic vacuum). Both SR and the resulting desorption are unlikely to be adequately simulated by GEANT4 alone. Consequently, the proponents use a standalone SR program developed and used at PEP, as well as specialized programs Molflow+ (vacuum simulation from beam pipe geometry and pumping speed) and Synrad+ (desorption due to SR) in conjunction with GEANT4 to simulate the relationship between SR, vacuum, and beam-gas rates.

The basic HERA configuration was simulated: i.e. a 900 GeV proton beam was fired from the center of the beam pipe in front of a higher density gas region and the detector hits were recorded and the rate in the detector found to qualitatively agree with measurements from ZEUS.

The plan for FY2018 is detailed and each step is logical. It starts with completion and documentation of the HERA benchmarking studies. The proposal then moves to modeling the current baseline design of the JLEIC IR beam pipe concept in GEANT4. The simulations will include benchmarking GEANT4 to SR code simulations, interfacing of the SR code to GEANT4 and developing a 3D CAD model needed for physics simulations, background studies, support structure design, and vacuum pressure distribution studies. This is a detailed study using information from HERA as input to simulations with the appropriate benchmarking to calibrate and develop credible estimates. The proponents have the requisite experience.

*Recommendation*

The work described in this proposal will be valuable for both the eRHIC or JLeIC as designs and is an important study worthy of support. As noted by the authors, neutrons with energies around a few hundred keV can be detrimental to detector components. A quantitative estimate of the neutron flux is needed for detector development and placement. To achieve this, modeling the full neutron thermalization from beam-gas events in the experimental hall should be included in the study. Full funding is recommended.

The committee notes that eRD19 is a funded project on the same topic but is currently stalled due to a postdoc leaving. We encourage the proponents of eRD19 to collaborate with the proponents of this work.

## New Proposal 6: Generating Trigger Primitives from an EIC Electromagnetic Calorimeter

**Martin Purschke reporting**

A proposal was made to study EMCal trigger algorithms on a specific set of target hardware developed for ATLAS. The primitives would start from elementary 2x2, 3x3 and similar tower sums and could include energy sums, shower centroids and e.g. invariant mass calculations. These would be included in a pipelined architecture and could be included as part of either a classic triggered architecture or as part of a fully-streaming architecture. In the latter case these primitives would be added to the overall data stream and enable faster trigger decisions based on the full event.

The specific request focused on a specific readout/trigger card available to the group, current expertise, and the need for some digitizers to produce a data stream and a dedicated postdoc to carry out part of the work together with existing staff. The overall concept is a familiar one from current DAQ systems with pipelined architecture. It was not clear to the Committee that the specific proposed target hardware was an optimal path for the long term.

*Recommendation:*
The Committee does not recommend to pursue this as a funded project at this time. Expected progress from ongoing related work for sPHENIX will be of interest.

## New Proposal 7: Study of feasibility of electronics and detectors to determine bunch by bunch beam properties for the EIC ring ring designs

**Nicola Minafra reporting**

A proposal is made to develop and study fast electronics and study fast detectors that could respond and also recover to baseline in time for the electron bunch crossing rate of 500 MHz proposed for JLEIC. The requirement for eRHIC is in the 10-40 MHz range and has already been demonstrated.

It was not clear to the Committee, in particular after hearing the eRD15 report on Compton polarimetry, that the electron detector for this would need to operate at hit rates more than 1 MHz/strip. This is expected to be one of the highest detector rates encountered at EIC. A detector could respond with sufficient timing accuracy to determine which bunch it came from even at 500 MHz, given the more relaxed signal recovery time implied by the overall rate of 1 MHz. The motivation for the proposed requirement was thus not clear to the Committee.

*Recommendation:*
The Committee suggests to put the proposal on more solid footing through simulations, but at this time cannot recommend to pursue this as a funded project.

## New Proposal 8: Investigation of Silicon CMOS

**Jessica Metcalfe reporting**

This proposal addresses two areas of research. Recognizing recent progress in the development of CMOS MAPS devices for application to the HL-LHC, for ATLAS, the proposal seeks to study a subset of these devices, developed within the AMS foundry process. This would complement the proposed work at Birmingham, using the TowerJazz and LFoundry processes. Looking towards an integrated CMOS based detector, the proposal also seeks to study an implementation of ultra-fast readout (10 ps timing resolution) with the CMOS MAPS architecture, aimed at particle identification. The committee notes some disconnect between the written proposal, which clearly puts the ultra-fast readout as the primary goal, and the presentation, which more decouples the two areas.

The aforementioned disconnect implies a certain lack of focus, which also leads to ambiguity in the understanding of the Committee. As we understand it, CMOS MAPS is certainly a viable tracking technology for EIC but the critical issues relate to particular configuration, pixel size, etc. The tracking application, if anything, is less demanding than at the HL-LHC, but the optimization may be different. The application to fast timing, is however, puzzling to the committee. Adding an additional implant, and thereby creating a fast gain structure, is technically of interest, but the proposal fails to address two critical points. One is, what, if any, front-end electronics would be practical here? The other is, what sort of overall system implementation would be appropriate to use the timing information. Where would the timing layers be? What would the pixel size be? How would this integrate into any sort of TOF PID system? The committee believes that these two critical points need to be addressed by the principals before we could consider this work on fast timing. We need to see a clear treatment of practical implementation, a basic layout, and technical constraints, supported by statements from experts in the sensor design and front-end electronics design. If the main role of the fast timing sensors is to be in the EM calorimeter, that should be discussed in more detail as well.

We therefore need this proposal to be better anchored by the known technical limitations, and clearly discussed, within the context of speed, power, granularity, signal, and noise. Furthermore, if the Argonne group is interested in continuing, we strongly encourage them to connect with LBNL and Birmingham, both on the performance and layout side, and in reaching a clear technical consensus on the issues of speed, power, granularity, signal, and noise, and a concrete configuration for TOF application, if sensible at all.

*Recommendation:*

The Committee does not recommend funding for this project at this time.

## New Proposal 9: Novel TPC readout using the TimePix ASIC

**Klaus Dehmelt reporting**

This new proposal confirms the long-known fact that cluster counting, rather than charge measurement, is a promising approach to dE/dx measurement in a TPC, with improved particle type separation power. Nice work was shown further documenting this method. The proposal also points out that a silicon pixel style readout, featuring high density and integrated timing measurement would be well suited to such a TPC pad plane configuration.

While the proposal was very clear about the challenges and concerns for such an approach, the Committee is left skeptical that this can be made to work. Indeed, Figure 11, taken from the TimePix manual v1.0. 2006, already indicates a serious problem. The plot seems to be from a simulation, but it is not clear if it is a full SPICE simulation. The committee asks if measurements been made with such large capacitances. Furthermore, questions regarding stability, crosstalk, and interference are not addressed. We would have liked to see a statement from the analog design engineers here. Also, as correctly noted, the large-scale packaging issues, and interconnections are of serious concern as well.

*Recommendation:*
Rather than spend funds now on boards and students, the Committee recommends going back to the basic system and engineering design and suggests that the proponents come back with a better-informed assessment of the critical issues. Funding at this point is not recommended.

## Funding Summary

Table 1 summarizes the requests for funding and the recommendations by the committee. Regretfully hard choices had to be made to fit within the budget authority and only two new proposal are recommended for funding, with only one proposal recommended for full funding. Of the ongoing R&D projects, only one project has been recommended for full funding, with the average funding for the other projects hovering at the 55% level. The R&D program to be executed within this budget remains highly effective and targeted and ensures that the required R&D is carried out to enable the EIC physics program. It reinforces the notion that transition to base funding should be part of the planning from the inception of the proposals.

| EIC Detector R&D FY2018 | PI | Proposal Name | FY 18 Sub-proposals | Funding Request (Nominal) | Priority |
|---|---|---|---|---|---|
| eRD1 | Huan Huang (UCLA), Craig Woody (BNL) | EIC Calorimeter Development | | **$197,000.00** | |
| | | | Tungsten Powder Calorimeter R&D | $49,000.00 | **High** |
| | | | Crystal Calorimeter Development | $148,000.00 | **Medium** |
| eRD3 | Bernd Surrow (Temple) | Design and assembly of fast and lightweight forward tracking prototype systems for an EIC | | **$104,531.00** | |
| | | | Postdoc GEM Work | $57,025.00 | **High** |
| | | | Travel | $21,606.00 | **Low** |
| | | | Materials | $3,900.00 | **Low** |
| | | | X-ray + 2D MM | $22,000.00 | **Medium** |
| eRD6 | Klaus Dehmelt (Stony Brook), Tom Hemmick (Stony Brook) | Tracking and PID detector R&D towards an EIC detector | | **$200,000.00** | |
| | | | Thick GEM | $50,000.00 | **High** |
| | | | Zig-Zag | $63,000.00 | **Low** |
| | | | Test Beam | $15,000.00 | **High** |
| | | | Ion Back Flow | $42,000.00 | **Low** |
| | | | TPC Gas | $12,000.00 | **Medium** |
| | | | Cr Foils | $4,000.00 | **Medium** |
| | | | Micro-RWELL | $14,000.00 | **Medium** |
| eRD14 | P.NadelTuronski (SBU), Yordanka Ilieva (S. Carolina) | An integrated program for particle identification (PID) for a future Electron-Ion Collider (EIC) detector | | **$420,000.00** | |
| | | | dRICH | $36,500.00 | **Low** |
| | | | mRICH | $99,800.00 | **Medium** |
| | | | DIRC | $94,000.00 | **High** |
| | | | TOF | $43,000.00 | **Low** |
| | | | high-B | $27,700.00 | **High** |
| | | | LAPPD | $75,000.00 | **Medium** |
| | | | Electronics | $44,000.00 | **Medium** |
| eRD15 | Alexandre Camsonne (JLAB) | R&D for a Compton Electron Detector | | **$106,605.00** | |
| | | | Simulation | $54,075.00 | **High** |
| | | | Travel | $23,175.00 | **Medium** |
| | | | Wakefield | $29,355.00 | **Low** |
| eRD16 | Ernst Sichtermann (LBL) | Forward/Backward Tracking at EIC using MAPS Detectors | | **$94,476.00** | |
| | | | Simulation | $91,892.00 | **High** |
| | | | Materials | $2,584.00 | **Medium** |
| eRD17 | Mark Baker | BeAGLE: A Tool to Refine Detector Requirements for eA Collisions in the Nuclear Shadowing/Saturation Regime | | **$60,000.00** | |
| | | | Event Generator | | **High** |
| eRD18 | Peter Jones (Birmingham, UK) | Precision Central Silicon Tracking & Vertexing for the EIC | | **$164,352.00** | |
| | | | Postdoc | $150,351.00 | **Medium-High** |
| | | | Travel | $14,000.00 | **Medium-High** |
| eRD20 | Markus Diefenthaler (JLAB), Alexander Kiselev (BNL) | Developing Simulation and Analysis Tools for the EIC | | **$100,000.00** | |
| | | | Postdocs | $30,000.00 | **High** |
| | | | Travel | $70,000.00 | **Low** |
| New 8 | Jessica Metcalfe (ANL) | Proposal to Investigate Silicon CMOS | | **$155,000.00** | **Low** |
| New 5 | Latifa Elouadrhiri (JLAB) | EIC Background Studies and the Impact on the IR and Detector design | | **$70,000.00** | **High** |
| New 7 | Christophe Royon (Kansas) | Study of feasibility of electronics and detectors to determine bunch by bunch beam | | **$98,100.00** | **Low** |
| New 1 | E.Kistenev (BNL) | Develop the High Density Projective Shashlik EMC with improved energy, position, and timing resolution for EIC | | **$148,000.00** | **Low** |
| New 3 | Yulia Furletova (JLAB) | GEM based Transition Radiation Tracker R&D for EIC | | **$96,380.00** | **Medium-High** |
| New 6 | Martin L. Purschke, (BNL) | Generating Trigger Primitives from an EIC Elec-tromagnetic Calorimeter | | **$66,000.00** | **Low** |
| New 9 | Klaus Dehmelt (Stony Brook) | A novel TPC readout system based on readout chips for Si-pixel detectors | | **$148,500.00** | **Low** |
| New 2 | Lijuan Ruan (BNL) | Forward and backward tracking at the EIC using small strip Thin Gap Chamber detector | | **$64,000.00** | **Low** |
| New 4 | Marco Battaglieri (Genova, Italy) | A triggerless data acquisition system for calorimetry - an R&D activity for the Electron Ion Collider (EIC) | | **$58,000.00** | **Low** |

*Table 1: Summary of the funding recommendations.*