Report of the 19th Electron Ion Collider Detector R&D Meeting

EIC Detector Advisory Committee

July 23 – 27, 2020

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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 (ORNL/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). Due to the Covid-19 pandemic the meeting was held remotely by video conference and spread out over three days rather than two days. All committee members were able to attend. 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.

Prior to the meeting, four new proposals were submitted to the committee by the May 29, 2020 deadline. Feedback on the new proposals was submitted to the proponents on June 12, 2020 with guidance on how to strengthen the proposals. All new proposals were endorsed to proceed to submitting a full proposal. The committee received progress reports and funding requests of all continuing projects and the new proposals on July 2, 2020.

At this meeting status reports were provided by ten funded projects and nine continuing proposals and four new proposals were evaluated. The eRD16 and eRD18 collaborations merged to form eRD25. The efforts of the software consortium eRD20 have now been integrated in the EIC project and no new proposal was submitted. eRD20 is to be congratulated on all their efforts to date, especially the extensive use of the software tools in preparation for the Yellow Report. The committee would like to thank all collaborations for their excellent presentations and status reports and for their understanding for having the review held completely remotely. 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. The funding recommendation is presented in Table 1 at the end of this report.

General Remarks

Brookhaven National Laboratory has been selected as the site for the EIC project and a project office has been established. The project is on an aggressive schedule aiming to receive CD-1 by March 2021. The user community has taken the initiative to write a Yellow Report to advance the physics studies and detector concepts in preparation for the realization of the EIC. This effort aims at providing the basis for further development of concepts for experimental equipment best suited for science needs, including complementarity of two detectors towards future Technical Design Reports. The preparations for the Yellow Report are progressing very well, articulating the key physics goals and the detector requirements to achieve the needed sensitivities. It is satisfying to see that many of the ideas in the detector working group of the Yellow Report are driven by participants in this EIC detector R&D program. Also, a white paper has been submitted to DOE NP related to EIC project-related detector R&D and generic EIC-related detector R&D. It was noted that the management of such a program could be best realized as a continuation of the ongoing generic EIC-related detector R&D program, but in strong coordination with the EIC Project to underscore the strong connection to EIC detectors. An international detector advisory committee is being considered by the EIC project.

As a result of these activities, it is understood that the current EIC detector R&D program will morph into a new structure in the very near future. Consequently, long-term funding requests in this round of proposals are problematic especially requests for postdoc support. If postdoc support is recommended for one of the proposals evaluated, we emphasize that this is only for one year. The proponents need to be acutely aware that long-term commitments, that is beyond fiscal year 2021, cannot be made under the current program at this point.

Given the travel restrictions due to Covid-19, requests for travel have not been considered. The committee recommends that the program manager holds a reserve fund to grant international travel requests on a case-by-case basis.

We note again that with the EIC moving towards CD-1, this is a perfect time 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

Huan Huang, Tanja Horn and Craig Woody reporting

Tungsten-fiber calorimeter development

The eRD1 group noted earlier that there is room for improving the uniformity of response of their W-powder SciFi EM-Calorimeter since results from the FNAL test beam runs indicate that response uniformity across the W/SciFi matrix could be improved by better photo-sensor coverage. A solution that also avoided the radial depth lost to light guides is of interest in an EIC detector barrel region, which needs to be inside the magnet coil. The team presented earlier a concept for a tiling of the readout face of an sPHENIX block (2x2 towers) using newly available 6x6mm^2 SiPMs from HPK and has now obtained the needed sensors in both single and 2x2 matrix form. The current SiPMs on the back of the lightguides of the current sPHENIX towers could be replaced, or the entire light guide array could be removed and the larger SiPMs attached directly to the W/SciFi matrix. A 1-2mm thin 'light mixer' would be needed in that latter case. These SiPMs also exhibit improved noise performance compared to the (now discontinued!) series just procured for sPHENIX. An EIC detector needs an improved uniformity over that accepted for sPHENIX, and deployment of a fully 'tiled' SiPM readout presents a possible path to achieve this. The Committee looks forward to test results.

Recommendation:
Only perform tests with the large area SiPMs.

HCAL Studies

The collaboration has studied the shower containment in combined Electromagnetic and Hadronic calorimeters considered for the hadron endcap. The configurations studied included (W/SciFi and Shashlik) EMCalorimeters and an Fe/Scintillator sandwich design for the hadronic compartment. The Hadronic calorimeter stack includes three designs ranging from 4.3 to 5.3 interaction lengths of steel. The effect of a 10 cm steel thick dead zone radially between the compartments was included. The hadronic shower leakage from the rear face of this device is not inconsiderable, reaching 50% for 60 GeV pions. The option of vetoing on leakage was considered, but this seems to be a problematic approach for a calorimeter system designed for containing jets. The designers should consider an approach with a larger number of interaction lengths to avoid issues of significant shower leakage, since hadron energies up to 50 GeV must be accommodated in any design.

The available longitudinal space for this device needs to be discussed with the machine designers; the current space may be too limited. This would not be a good situation for the jet measurement program. Shifting the accelerator rings radially ±2cm with a crossing angle of 25 mrad in order to shift the IP one meter in the electron going direction would yield perhaps a meter more space (thickness) for the hadronic calorimeter, which should be given consideration, before the machine designs start to be settled for the CDR in 2021.

The proponents should consider an HCal of at least 7 interaction lengths thickness for the jet program. It would be useful to study leakage out to 10 interaction lengths, determine where further thickness exhibits diminishing return, and discuss implications for jet measurements. Later studies might consider the sampling fraction of scintillator vs steel.

Recommendation:
Continued support for student performing simulations if funding permits.

Shashlik Concept

The Committee takes note of the continued development of the shashlik development at UTFSM using W-Cu plates to realize a compact shashlik EMCal. Nine towers are now constructed and prepared for operation in a test beam; they are read out with borrowed sPHENIX electronics. The performance vis-à-vis the existing PHENIX shashlik lead-scintillator devices is predicted to be somewhat improved, yet a compelling improvement needs to be demonstrated.

The comparisons to the performance of the old PHENIX shashlik lead/scintillator EMCal towers, reconfigured to read out the individual or smaller groups of the WLS fibers, as suggested at the last meeting, are still pending, awaiting finding manpower for this effort. The committee notes that full containment of the showers is required to obtain definitive test beam results and that the plans proposed do not meet that criterion. There also is competition for the same resources with other high-priority projects at BNL.

The Committee commends the progress shown, takes note of the concerns expressed about needing manpower to further this work, and looks forward to further reports. The Committee wants to see the results of testing the existing PHENIX designs before committing funds to a modified design. It is not clear what performance relative to the existing PHENIX shashlik is required or justified for EIC.

Scintillating Glasses

The collaboration reported further results on making larger samples of scintillating glasses, with numerous 2x2x20 cm^3 samples of different glass formulation prepared. These have been subjected to intense gamma radiation from 60Co sources and 40 MeV proton bombardment from the U. Birmingham cyclotron to check radiation tolerance. Initial encouraging results were reported from development of grinding and polishing techniques. Efforts have started to develop good coupling to photosensors. It was reported earlier that some glasses perform well under large radiation dose, whilst other formulations were disqualified by these tests. These tests have continued and are being used to identify glasses with good radiation tolerance. Large fluorescence light yields relative to PbWO4 have been noted earlier. Methods to control bubbles and localize them to the surface and tuning of glass composition to control radiation hardness and peak wavelength of light yield were demonstrated earlier. Densities above that of lead glass can be achieved, which makes these glasses of interest.

Near-term plans include measurement of light yield from cosmic-ray events and then for example from tagged photons in Hall D at JLab , which is of great interest to the Committee. Performance of these tests has been hampered by the COVID-19 pandemic, however they remain in the plan for future work.

The Committee congratulates the team for obtaining an SBIR Phase-1 award for Scintilex and strongly encourages continuation of this promising effort and pursuing a Phase-2 SBIR grant.

Recommendation

Fund the Scintillating glass work, including test formulations, lab work measuring glass properties, and the beam tests. The in-beam $PbWO_4$ tests would be done in parallel.

eRD6: Tracking Consortium for the EIC

Kondo Gnanvo, Bob Azmoun and Silvia Dalla Torre reporting

The eRD6 collaboration reported on a broad range of efforts on Micro-Pattern Gas Detectors (MPGDs) for tracking and particle identification. The status of the GEM prototypes for an End Cap Tracker was presented, as well as an update on the cylindrical μRWELL, cylindrical Micromegas and TPC for the barrel tracking. In the area of particle identification, R&D on hybrid MPGDs for a RICH detector, with studies of new photocathodes, development of large mirrors and studies of meta-materials was presented. The team is playing a major role in developing the EIC Yellow Report document and making crucial contributions to the tracking and particle identification discussions.

The problem of persistent shorts between GEM foils has been addressed, but tests have been halted due to the Covid-19 pandemic. It is hoped that the prototype can be tested in the Fermilab test beam in the spring of 2021. The goal is to finish the GEM studies by January 2022.

Cylindrical μRWELL detectors, with the corresponding support structures, were implemented in a Monte Carlo simulation with detectors right before and after the DIRC. The simulations showed an improvement in angular resolution over a TPC-only geometry by a factor of two when a μRWELL tracker is inserted before the DIRC compared to a TPC-only layout, and a significant improvement when the μRWELL tracker is inserted after DIRC. The choice of this type of detector was not clear, since it may not be easy to cover the large area of a DIRC detector with this solution. It is noted that it is crucial that EIC tracking provides a tracking resolution of 0.5-1 mrad to obtain the maximum benefit from the DIRC or other RICH detectors. A full simulation of a μRWELL design is proposed with results available in the fall; a mechanical mock-up has started at the Florida Institute of Technology (FIT). The goal is to find out if the foils can be properly stretched. First attempts indicate that this is somewhat a challenge. We would like to see a detailed QC of this mockup.

Capacitive sharing with large pad readout was studied at the University of Virginia. The transfer of an initial charge from an MPGD by capacitive coupling through a vertical stack of five pad-layers was studied with x-rays. No bias with this readout geometry was observed; good position resolution is expected. An ambitious plan is laid out to design and assemble a fully functional cylindrical μRWELL detector prototype with optimization studies of the geometry to minimize noise and crosstalk and test the prototype in a test beam at Fermilab. The concept of the capacitive readout rate capability depends on the resistivity of the Diamond Like Carbon (DLC) layer and total capacitance of a pad coupled to the amplifier. We would like to know what the rate capability of this design is, the crosstalk from pad to pad, and if there is a long tail in the pad multiplicity distribution, which would affect the double track resolution.

A brief status of the cylindrical micromegas studies at Saclay was presented. Monte Carlo studies of a 6-layer micromegas tracking detector showed better momentum resolution of a TPC under similar conditions. The TPC-based tracker R&D for the barrel is progressing well. Readout is being characterized with a new x-ray source and the results for position resolution are substantially better than the test beam results. Many readout configurations are being studied. The combination of micromegas and GEM readout shows the best performance for ion backflow and energy resolution. The proposed research plan calls for continued x-ray scans to compare the performance of alternate zigzag patterns + avalanche scheme (GEM, MMG, μRWELL) with various working gas combinations. Tracks will be measured using a line laser and compared to tracks from cosmic rays. Readout with both the DREAM and SAMPA frontends will be tested. The studies of a static bi-polar gating grid are intriguing. It is proposed to test the bipolar static gating grid in a 5T magnet. A simulation of various parameters was performed to prepare for the test. In discussions it was made clear that a MMG+2-GEM detector is included in the planned tests. This is strongly supported, since the BNL tests have clearly demonstrated that this solution provides the best pulse height resolution and smallest IFB. Adding the passive gating may create the best combination.

Particle identification at the EIC is critical and an adequate solution to cover the full momentum range in high magnetic fields still needs to be found. Gaseous photon detectors based on MPGD technologies can play a major role in PID using Cherenkov radiation. The MPGD single-photon detectors at INFN Trieste consist of three multiplication stages: two thick GEM layers, the first one with a Nano-Diamond coating, which acts as a photocathode, followed by a resistive MicroMegas multiplication stage. Efforts to address the noise that was observed previously have been ongoing, including the design of a new improved PCB and a new VMM3 readout. A new set of samples has been made and coated. The two-layer THGEM option has been abandoned because of issue caused by too large a gain. Preliminary measurements of the quantum efficiency have been carried out. It was not clear what QE efficiency is required for the successful operation of the detector for the new photocathode materials development at INFN Trieste. It seems that the QE is about 12% at 140nm and close to 1% at 180 nm. One may need an improvement of a factor of three to be competitive with CsI photocathodes. In addition, the 140nm wavelength is the worst wavelength region from the point of view of chromaticity of typical radiators. We would like to see an estimate of the number of photoelectrons and the Cherenkov angle resolution for the proposed radiator length and how that meets the requirements for an EIC detector. We would also like to know what the chromatic error contribution is to the Cherenkov angle resolution. It is noted that this effort has been significantly impacted by the pandemic. Communication with eRD14 is encouraged to explore possible synergies.

The radiator studies being carried out at Stony Brook are interesting and should be pursued. The proposed effort on the high-pressure Argon-based RICH detector addresses the need to move towards eco-friendly gases. This is an important issue, but the effort adds to the already broad R&D program within eRD6.

Recommendations:

The team is strongly encouraged to complete the end-cap GEM studies by January 2022 and publish the results.

The Micromegas research is supported.

The μRWELL detector development is interesting and further R&D is encouraged. The consortium is asked to compare the various choices of technology for different subdetectors in an EIC detector and quantify and validate the choice through simulations and mechanical mockups. For the capacitive readout design, more information at the next meeting on rate capability, crosstalk from pad to pad and results on the pad multiplicity distribution is requested.

At the last meeting a general recommendation was made to carry out a quantitative comparison of the various MPGD technologies, to identify the technological roadblocks of the most promising technologies and prioritize the R&D accordingly. The committee observes that the parameter space still being explored is very large and converging on the timescale of an EIC detector proposal seems challenging. The consortium is encouraged to develop a clear strategy that prioritizes the various research areas, define clear science objectives and give the overall research program more focus.

It is recommended that the PID-MPGD efforts be more quantitative with respect to the requirements for the EIC physics program and compare the current efforts on diamond photocathode development with, for example, CsI. Variables we are interested in are the number of detected photoelectrons per ring, Cherenkov angle resolution and projected PID performance in terms of number of sigmas as a function of momentum.

The efforts to complete studies on Ion Back Flow (IBF) versus resolution with different avalanche schemes and operating gases is strongly encouraged to be completed as quickly as possible. Given the promising results, we strongly support the studies of the MMG+2-GEM detector to the static bi-polar gating grid studies in a strong magnetic field.

Coordination with eRD14 is recommended on the development of MPGD-based particle identification detectors, given the broad research program within eRD6 and the limited resources.

The study of meta-materials is intriguing and could hold a lot of promise, but the required timescale for bringing it to a technological readiness level required for a CDR seems long.

eRD14: Integrated Particle Identification for a Future EIC

Jochen Schwiening, Xiaochun He, Marco Contalbrigo and Gary Varner reporting

The eRD14 collaboration is making progress towards the realization of particle identification for the EIC, but progress is made at a slower pace than expected. The committee makes the following observations based on the progress report:

dRICH:
The dRICH group has finished Monte Carlo studies of its performance. In view of the expected low number of detected photons, it is not clear whether all efficiencies were taken into account, including the gaps in the photon detector plane and UV-filters.

The group has reinforced their efforts to investigate the operation of SiPMs in the radiation harsh environment, and for mitigation methods for the consequences of the radiation damage.

Recommendation:
The group proposes a concept prototype for the test beam. This prototype will certainly be useful. As already noted at our previous review, this will require a fair amount of preparation time and resources. The committee suggests that the proponents explore the option of having two simple vessels for the beam test rather than one with a complicated infrastructure to accommodate two geometries.

mRICH:
The mRICH group hopes to provide hadron PID capability with momentum coverage from 3 GeV/c to 10 GeV/c and e/π separation at lower momenta below 2 GeV/c. The approach of a module RICH detector is novel and initial results are intriguing. An array of mRICH modules was implemented in the sPHENIX software and the analysis was performed. The mRICH team has performed two beam tests observing clear Cherenkov rings. The plan of the group to provide these data from a third beam test campaign had to be postponed because of the pandemics. A beam test is also planned with LAPPD as photosensors.

Recommendation:
The committee would like to see results in terms of the Cherenkov ring resolution, average number of photoelectrons per ring, and projected PID performance. The tests with a LAPPD photodetector are encouraged.

DIRC:
The DIRC group has performed useful radiation hardness tests of various candidate materials for a lens. The Panda DIRC prototype is in the process of being moved to Stony Brook University; because of the pandemics, this operation had to be postponed to the fall of 2020. The committee supports the plan to prepare a permanent cosmic ray test set-up for the studies of the DIRC prototype – this is certainly an excellent long-term investment. This is especially important because the Fermilab beam line schedule in 2021 will be very tight.

MCP tests in magnetic field:
Tests of optimal operation of the Multi-channel plate photodetectors is being continued. In addition to several Planacon samples, a Photek 6 micron tube was tested in the magnet with encouraging results. The work on adapting LAPPDs to EIC requirements proceeds in several directions, including the technology transfer from ANL to Incom for pixelated MCP-PMT read-out, high magnetic field tolerance and fast

timing. A beam test of several devices is planned for spring 2021. We urge the proponents to plot their results on the same plot as Lehmann's results, so that it would be easier to compare with previous studies.

Photodetectors and Electronics:
The committee sees good progress in the area of electronics. This electronics development is essential at this point to evaluate various RICH detector concepts in test beams and on test benches. More details should be presented regarding the analog front-end part of the read-out system. Specifically, we would like to see MCP pulses after the amplification. Alternatives to waveform digitizing electronics employing time-over-threshold pulse height correction to timing should also be explored. The evaluation of an MCP, coupled to a given electronics, will take 3-4 years at a minimum, given the experience with FDIRC at SLAC. Therefore, there is a certain urgency to proceed as fast as possible. This urgency is amplified by the fact that most of MCP-PMT candidates are not yet fully understood or available. The electronics should be distributed among several groups, so that problems can be identified as soon as possible. Some channels in early versions of electronics should be available in raw form, available from scope display, so people can judge the performance better. This was extremely important for the success of the FDIRC. A large part of the budget request is for postdoc support. As noted in the introduction, continued support cannot be guaranteed. It is also suggested that the development of the electronics and the testing be separated.

Recommendation:
The consortium was formed to make the multiple R&D efforts more coherent and amplify the progress, while reducing repetitions. Although there is good progress in most areas, considerable efforts are still needed before a CDR can be proposed in a few years. Some of the subgroups have requested support for a high-end MCP-PMT. We believe that the use of the photodetectors can and should be coordinated between the various groups and that a single, shared tube can meet most of the needs. This effort should be combined with a coordinated effort on the electronics for the readout. It is recommended that the consortium consider a coordinated testing program with a single point of contact who will be the interface with the electronics development group and the multiple testing groups to ensure that all tests are carried out in a uniform way and who can coordinate the development of software tools and mechanical interfaces. That will ease, for example, establishing an agreed-upon operating point for magnet studies and cosmic ray tests.

eRD17: Beagle

M. Baker reporting

BeAGLE is the most fully developed of the generators for physics at the EIC, providing predictions for the hadron/ion final state as well as the lepton/photon induced vertex. As such it is indispensable to the development of informed decisions about the interaction region (IR) and associated EIC detector design. The process of optimizing the IR will continue at least until CD-2 when the project will be baselined, CD-2 is currently expected in September 2022.

The flexibility of the team to the evolving situation is noteworthy and commendable in two respects in particular: i) whereas the team had intended to install RAPGAP in the program, they have recognized higher priorities of the community in identifying benchmark processes to be implemented and they have made substantial progress on this. This effort requires the further development of one of their original goals of tuning BeAGLE to E665 data and so they are already quite advanced in this area; ii) we have all been required to adapt to the COVID-19 crisis. This has understandably slowed their progress since remote working with their Chinese collaborators has not been as efficient as face-to face working. Nevertheless, progress is still being made.

Having the ability to study detector acceptances from e+A events has been crucial to understanding what additional detectors will be needed in the far-forward region to ensure delivery of the full EIC physics program. BeAGLE has been instrumental to the successful Yellow Report studies that are ongoing, and which will be used for design and construction of the EIC detectors. This is evidenced by the talks from the recent EICUG meeting on the Yellow Report status: "Exclusive Reactions Working Group" and the "Diffractive Reactions and Tagging Working Group".

It is reasonable to ask why the benchmark processes are not already addressed adequately by the past five or six years of development of BeAGLE such that any user could now study them using BeAGLE and GEANT? There are two aspects to this answer: (i) For the benchmark processes, it would have been hard to know exactly what these processes would be and tune for them specifically before they were defined, but of course they have tuned for a variety of similar processes. (ii) Serious work can take a long time; tuning still takes place for LHC MC's. The difference to the LHC is that that while BEAGLE is fully integrated and relatively easy to use, and the team are very engaged with helping users which is valuable and would benefit from continuing, significant tuning remains (see next paragraph) such that the interpretation of the results is in some cases is not yet straightforward.

For tuning BeAGLE to E665 data one can always continue to tune but why is the considerable tuning that has already been done not enough and how can that be shown quantitatively? One powerful answer to this is that continued E665 tuning can reveal surprises, slide 12 of the presentation is a prime example. The figure on slide 12 shows the difference in the normalized rapidity distributions of E665 data between μ-Xe and μ-D scattering for positive hadrons and BeAGLE for different τ_0. The amount of intra nuclear cascade "protons" is correct for τ_0 =7fm/c and incorrect for 2 fm/c, and a rapidity shift of 0.6 is seen between the BeAGLE prediction and E665 data. The data confirm the E665 neutron data's preference for a large tau0, indicating a large formation time for produced hadrons and a weak intranuclear cascade. The strength of the rapidity shift implies a large acceptance difference between the BeAGLE prediction and that implied by E665 data, so that tuning to data is the only way to make reliable predictions. It is the committee's understanding that E665 is the only suitable data set available for tuning and this underscores reliance on the E665 data being correct. It is very important to resolve this.

The Committee notes that an effort to model ultra-peripheral p + Pb collision data from LHC, as a means of making contact to photon-nucleus interactions at relevant energies would be merited going forward, at such time as the needed data are released by the collaborations. Explicitly the UPC photon comes from the proton and interacts with the Pb ion; and the BeAGLE e+Pb simulations would be reweighted in Q^2, x to correct for the different UPC photon spectrum. We know the proponents are investigating this possibility.

Recommendation:
Clearly eRD17 has several important milestones (benchmark mark processes and E665 tuning), which need to be achieved expeditiously that following potential modification to the IR design can be integrated before baselining. Therefore, full support for eRD17 during FY21 funding is critical to achieve the best possible IR design. However, given the centrality of BeAGLE development a strong case can be made for BeAGLE funding to be derived from the project rather than from this instrumentation R&D program and this and alternative funding sources should be explored in addition to funding from the instrumentation R&D program.

eRD20: Software Development

Markus Diefenthaler reporting

The committee would like to congratulate the eRD20 EIC Software Consortium (ESC) with their accomplishments to date. The team has done a terrific job in developing the software framework and reconstruction tools to enable detailed studies of the EIC physics. The consortium was formed in July 2016 to develop a robust software environment, compatible with the existing software frameworks, for the development of the physics case for the EIC. When the Yellow Report initiative was conceived there was an explicit desire by the community to use, in as far as possible, the accelerator and detector concepts and simulations using the software tools developed by eRD20. The group has enabled the community to have a rapid entry in the simulation effort and has provided tutorials on the full and fast simulations and the Monte Carlo event generators for the EIC. With the call for Expressions of Interest the consortium is introducing Project Greenfield for the software. The group works on the premise that scientists of all levels, worldwide, should be enabled to actively participate in EIC simulations and analyses. To achieve this goal, they have to develop simulation and analysis software using modern and advanced technologies while hiding the underlying complexities. Project Greenfield intends to define the requirements for EIC software components such as simulation, reconstruction, physics analyses, streaming readout, online monitoring and develop new tools building on existing common software, such as DD4hep, Geant4, ACTS, Gaudi, JANA2, ROOT and Jupyter. The team is very cognizant of the fact that ultimately the EIC scientific collaborations will develop their own software but this will build on the common tools developed and provided by this framework. The EICUG Software Working has now setup a GitHub organization for the EIC (https://github.com/eic) and plans to develop their website (https://eic.github.io) into a portal for EIC Software. The project under this program, the various eRD projects, are encouraged to share their software and simulation setup on this EIC GitHub organization and document it in the EIC Software portal. This will help with communication among the various simulation efforts and build a unified effort. There will also be considerable effort given moving forward to build collaborations with GEANT, event generator teams, io-formats etc. From now on, eRD20 will work solely as EICUG Software Working Group, with a focus on ensuring ensure high-quality simulations for the EIC detector development and developing common software projects for the EIC collaboration(s).

Recommendation:

The eRD20 collaboration has been foundational for the development of the EIC physics program and the detector designs. The importance of adequate, reliable and easy to use software tools will only become more important now that the project is moving towards a Technical Design Reports. The committee strongly encourages the EIC Project to fully support this development and encourages the whole community to contribute to this effort.

eRD21: Background Studies

Charles Hyde reporting

The eRD21 team continues to progress well with simulation studies of both synchrotron radiation and proton beam-gas interaction backgrounds at the EIC interaction region (IR).

A critical milestone for the project was reached with the January 2020 DOE announcement that approves the EIC CD-0, with site selection at BNL and Jefferson Lab as a major partner. The eRD21 team responded rapidly to this announcement, with an immediate shift of focus on background studies for the official EIC IR, in collaboration with BNL. It is a testament to the team's previous efforts on JLEIC, including their development of simulation tools, that an optimized design of the official EIC IR could be rapidly implemented in May 2020, in both GEANT4 and FLUKA. The simulations have resulted in a quantitative evaluation of the photon and neutron flux at the silicon vertex tracker (SVT) and will be vital in finalizing the IR and detector designs, ahead of the Conceptual Design Report.

Synchrotron Radiation and Vacuum studies

CERN's SYNRAD and a code from SLAC have been applied to calculate the homogeneous fan of synchrotron radiation originating from the last upstream dipole, and the SR cone arising from the final focus quadrupoles. The photon flux generated in SYNRAD has been passed to BNL for more detailed studies of detector occupancy. Meanwhile, a high statistics sample of synchrotron radiation (SR) generated with the adapted SLAC code have been simulated through a GEANT4 model of the IR and SVT. For the maximal 0.26 Amp 18 GeV electron beam, the annual dose in the innermost SVT layer is estimated as 50 kGy/year (in the report) however this was revised dramatically downwards at the presentation to 320 Gy/year, which is thought to be the correct dose rate. The eRD21 team identified that this X-ray radiation dose is well below the 10 MGy survival dose for silicon detectors, based on reference [2]. Reference [2] assumes 12 keV X-rays, whereas the tails of an 18 GeV electron beam passing with high amplitude through low beta quadrupoles may generate higher energy X-rays. It is important to evaluate the photon energy spectrum in the transverse plane at the SVT location, for the highest energy 18 GeV electron beam, including the effect of non-linear beam-beam interactions that can further populate the tails to ensure that the energies are still well below the threshold for different damage mechanisms in silicon. If not already considered it will be important to optimize the placement of upstream apertures to restrict the SR fan at the detector and design the electron beam focusing scheme to minimize the magnetic fields seen by the tails. Such a study is already planned in the next period and is encouraged.

Beam-gas backgrounds

An initial FLUKA model of the IR including the detector has been successfully developed and used to evaluate the beam-gas interaction rate and resulting neutron fluence with the detector. The method used for efficient simulation was to create a 3mm diameter pencil target of air with an artificially inflated pressure of 100 mbar along the beam line to increase the interaction rate. An alternative would have been to upscale/re-weight the cross-section for the relevant processes directly in the simulation, while still using a realistic air pressure, which then preserve the physics processes for secondaries. The proponents are aware of this. The results show that the annual neutron equivalent dose in the SVT from beam-gas background alone, is three orders of magnitude below the 10^{14} n/cm^2 relevant silicon radiation damage i.e. 10^{11} n/cm^2, which is encouraging. Overall the studies have progressed well in this period and the future plans look promising with the inclusion of more realistic pressure profiles and studies of the effects of SR induced out-gassing, which will complement and extend the initial MOFLOW simulations.

Given the adoption of the Geant4 model for the SR and detector studies it might be natural to also use Geant4 for the beam-gas background studies. The existing model might be easily ported into the Geant4 based Beam Delivery Simulation (BDSIM) accelerator code, which already offers cross-section upscaling for beam-gas studies, incorporates easily configurable accelerator lattice optics and full particle tracking.

Since most of the efforts are simulation, there was not a direct impact on this work due to Covid-19. However, since there are many subtle aspects of the simulations, such as IR layouts, the lack of face-to-face meetings and cancellation of planned travel to BNL slowed progress somewhat.

Recommendation

The EIC now has three working groups studying backgrounds: the EIC project IR working group; a new working group for a second IR that has different sqrt(s) vs. luminosity dependencies (it has not conducted background studies yet, but will); and a synchrotron radiation task force which includes Machine & Experiment experts from JLab and BNL. It is crucial that eRD21 work closely with these groups going forward which is a requirement for further funding.

eRD22: GEM-based Transition Radiation Detector

Yulia Furletova reporting

The TRD group has presented very nice results from a very challenging GEM-based TRD detection. Identification of secondary electrons is important for EIC physics. It is critical for the project to determine the pion rejection factor at a level of >10 to 100.

To achieve a good TRD performance, the group switched from Argon to Xenon gas, increased the drift distance to ~3 cm and selected a radiator thickness of 5-15cm. A single layer could provide an e/pi rejection at the level of a factor of 10, with a reasonable electron efficiency (85-95%). If a higher rejection factor is needed, multiple layers can be stacked.

The group has performed tests with several radiator types (fleece, aerogel, foam) in electron-only beams and compared the results with MC simulations. The goal was to find a radiator with low material budget, but with a high Transition Radiation (TR) yield. The detector with fleece radiator shows the best results. By comparing electron data with and without radiator, they clearly demonstrated the TR-response. Data are in a good agreement with the MC simulations. The algorithm employed a neural network. No TR-photons were observed from Aerogel, and only a small number from a foam radiator. The group also varied the fleece radiator length in MC simulations and compared it with the electron data for two radiator lengths; the agreement is excellent. The group performed a detector operating point optimization for the fleece radiator of 15 cm thickness for a Xe/CO_2 mixture. Not all tests could be finished due to Covid-19.

A detailed Geant4 detector optimization was performed to study the separation of dE/dx and TR-clusters. In collaboration with the GLUEX collaboration, there is an effort to move part of the reconstruction software to FPGAs. This idea could be applied either to a single TRD detector, or to other PID detectors, or even to global PID.

The group has finished a gas mixing system, allowing to mix Argon, CO_2 and Xenon gases. Gas chromatography indicates good purity down to the level of 50 ppm. The group plans to develop a recirculation system to save money on Xenon; discussions are ongoing with the ATLAS TRD group.

A 3-GEM TRD detector experienced some discharge problems during a beam test in JLAB Hall D, although in bench tests with an ^{55}Fe source it behaved well. The problem was traced to a faulty field cage. We would add that a relatively high operating drift field of 1.5 kV/cm may have helped to trigger these discharges in Xenon gas.

The detector experienced electronics noise problems, both in Hall D and lab tests. The noise was observed when both X and Y-strip readout was connected to the detector at the same time. This indicates that there is coupling on the detector between the X and Y strips. The plan is to add low-pass filters for HV and LV input on the detector. The noise may have come from a bad layout of "carrier" boards. It would probably speed the diagnosis if the group could acquire FFTs of the “noise” under various conditions. A single harmonic peak implies a simple feedback oscillator while a Dirac Comb in the FFT implies coupled oscillators. Even without more evidence, the power supplies for the preamplifiers are likely suspects. It is possible that simply increasing the bypass capacitance on the supply could tame the “noise”. The group is designing a new board, minimizing length, and improving shielding and grounding. These boards will be delivered in September.

A new concept of capacitive readout was presented, similar to that presented by eRD6. The idea is to reduce the number of channels and reduce the capacitance in front of the amplifiers. Since this design has large pixels (1cm x 1cm), we would like to see how this affects the position measurement when hits are close to each other.

The group plans to continue testing various radiators and plans to determine the pion rejection factor in a Fermilab test beam.

Recommendation:

We recommend investigating the breakdown in the field cage. The breakdown may be caused by some imperfection points in the field cage creating high gradients, which are enhanced by a nominal high drift field gradient. One may want to tune the voltage setting for a given gas mixture. The “noise” seen when both X and Y readouts were operated in the test beam needs to be understood, but it is probably, in the end, of fairly simple origin. It would probably speed the diagnosis if the group could acquire FFTs of the “noise” under various conditions. The power supplies for the preamplifiers are likely suspects for the observed oscillation. One needs to investigate the proposed capacitive readout if it will be able to resolve closely spaced hits.

eRD23: Streaming Readout

J. Bernauer reporting

The collaboration organized a successful virtual workshop on streaming readout in May. The workshop covered a number of technical topics and somewhat narrowed the focus of the toolsets that are likely to be useful in an EIC detector. The collaboration has also started to define some general principles to guide the design of any DAQ system. Some progress has been made in operating various test systems that may provide useful information on future EIC DAQ designs. The collaboration plans additional workshops this fall and next year. The collaboration has been using some ERD funding to support travel for undergraduate and graduate student work on DAQ problems.

While the statement of general principles is helpful, it is probably necessary to wait until the detectors are better defined and there are clear physics driven requirements before attempting to define a DAQ design in any detail.

It is clearly useful that some of the problems and opportunities in an EIC DAQ system are being examined in the workshops and meetings that the collaboration has organized, and this should continue.

It is, however, a little unclear exactly what the collaboration means by SRO – in some parts of the proposal explicit triggers are mentioned and zero suppression is certainly discussed. It would probably be good to open up the discussion some to understand what data is and is not important, how one separates the two, what data sources are similar and what sources imply very different methods for determining what to keep and what to discard. This DAQ centric effort should probably also reach back into the "front end" designs to understand what information is actually needed to define a "hit" and what is extraneous. An EIC detector can be a rich source of physics and clearly one should not exclude some class of physics data because of an ill-considered "trigger", but such a detector is also a potential source of TB of data per second and not all of it can be saved forever and much of it can't even be passed on to some next processing stage. The technology may exist for doing almost anything, but the funds certainly do not. Whether the pruning process is via a hardware object or a sophisticated calculation on a general-purpose computing platform is, surely, a matter of sophisticated optimization and where the real challenges lie. The group noted that their budget had a large carry-over, partly due to the pandemic.

Recommendations:

Continue to meet and discuss the challenges and opportunities presented by EIC. Continue to involve graduate and undergraduate students in the effort. Modest support for centrally held travel funds to be used to support students at test beams is suggested.

eRD24: Roman Pots

Alexander Jentsch and Gabriele Giacomini reporting

The collaboration has done extensive simulation work that solidifies the understanding of the temporal and spatial resolution required for covering the physics needs across the energy scale. The conclusion is that timing on the order of 30 ps and pixel sizes of about 0.5x0.5 mm^2 are sufficient for all the physics cases and that really “edgeless” sensors, while advantageous, are not vital to maintain the required physics reach.

The simulations to date provide a broad understanding of the change in physics reach for various performance parameters (pixel size, timing accuracy) and are likely to be very helpful in understanding the optimal tradeoffs required to produce a full system.

The collaboration has recently expanded with the addition of several very strong groups – especially in terms of ASIC development and fast timing knowledge. Some of the groups have extensive knowledge of fast timing ASICs planned for the HL-LHC.

Despite Covid-19 problems, there have been advances in understanding the LGAD sensors especially in terms of AC coupling of the signals which should allow higher area efficiency which might also make it possible to use zig-zag coupling to reduce the number of electronics channels required.

The ALTIROC chip (ATLAS HL-LHC timing layer), which some of the new collaborators are working on, provides a realistic benchmark for what is needed in terms of power and silicon area to meet the EIC requirements. It would seem prudent to quickly estimate the chip area needed for an EIC optimized version of the ALTIROC as this may drive the minimum pixel size for the EIC (the pixel size in ATLAS is 1.3x1.3 mm^2 – about a factor of seven larger than the 500 micron pixel deemed reasonable for EIC use).

While the power required by the ALTIROC chip to achieve the desired timing performance is not huge, it is also not entirely insignificant and it might be wise to understand whether, for the number of pixels desired in an EIC Roman Pot providing and removing that power would present significant engineering challenges. If zig-zag readout or some similar “trick” is shown to be plausible in the coming years then that might greatly relax the power needs, but the collaboration should not count on such an outcome.

The timing performance of both LGAD sensors and the ALTIROC chip seem to meet the collaboration’s goal of about 30 ps, but it could be helpful to understand how easily the other half of the measurement can be made to that precision. The accelerator clock will have some inherent jitter and the transmission of that clock signal from the accelerator control room to the experiment will involve repeaters and long cables which will not improve that jitter and will add errors of their own. To name just a few – the cables will have frequency dispersion which will introduce some time-walk at each repeater; the delay for a 100 m cable will move about 9 ps for each degree of temperature change; mechanical stress can introduce both delay changes and additional dispersion; connectors and kinks will introduce impedance variations and, thus, additional reflections. While a few tens of ps timing resolution is not too difficult in a small test setup, it is not trivial to obtain or maintain in a large, extended, detector embedded in an accelerator complex. It is good that the simulations carried out so far indicate that relaxing the time precision to about 70 ps seems to only moderately affect the physics performance.

Recommendations:

Continue the successful simulation work in order to more fully define the requirements and proceed as planned to further specify and refine a design that should meet those requirements.

eRD25: Silicon Tracking

Laura Gonella reporting

Since the time of the January review there has been considerable re-organization, convergences of activities, and the formation of new alliances and collaborations. All of this is very positive and the Committee acknowledges all these developments with enthusiasm.

Findings

eRD25 has formed out of the union of eRD16 and eRD18. eRD25 is also advocating and organizing the formation of a larger EIC silicon consortium. New collaborations are being integrated.

eRD25 is joining with the ALICE Inner Tracking System 3 (ITS3) group to develop a new sensor based upon the 65 nm Tower-Jazz (TJ) process. While many fundamental specifications for the ITS3 device meet or exceed those of the EIC, ITS3 targets specifically vertex layer and wafer scale devices. This matches with the EIC vertexing needs but there will also have to be an EIC specific development aimed at more traditional stave and disk layers at larger distances from the beamline.

eRD25 proposes to collaborate with ITS3 but also branch, in parallel, after the first test device fabrication run, to address EIC specific needs. The first ITS3 submission with eRD25 participation will be in the fall of 2020. The first EIC specific submission will occur in September 2021.

eRD25 groups, RAL, Birmingham, and LBNL are acquiring licenses and tools. The RAL CMOS group will spearhead activities aimed at the upcoming submission. An important part of the performance studies is now focusing on understanding, parametrizing, and simulating realistic services in the EIC tracker.

Performance studies have compared EICroot and Fun4All, efforts going forward will focus on Fun4All.

Comments

It would be helpful to clarify further the aspects of the 65 nm chip which diverge between ITS3 and EIC requirements. The tables shown in slide 11 uses differing terminology in places, which makes comparisons somewhat confusing. In particular the “time resolution” requirements for EIC appear much tighter than for ITS3 while the comments suggest otherwise.

Recommendations

As activities develop, over the coming year, assess whether the planned EIC specific 65 nm branch remains appropriate. This proposal should be funded at the appropriate level funding permitting and is enthusiastically supported by the Committee.

New Proposal: Compton Polarimetry

Ciprian Gal reporting

The authors propose development of a 10 W pulsed laser system to use as the source of photons that are used to measure electron bunch mean polarization via Compton scattering. Earlier projects presented to the Committee addressed expected analyzing powers for Compton scattering for the expected electron beam energies at an electron-ion collider and the measurement times that would result for various assumed laser powers and beam parameters with a goal of a one percent measurement of electron beam polarization. Discussion among the EIC user community has led to a goal to measure electron beam polarization on a bunch-by-bunch basis. This would need to be done on a timescale shorter than the average bunch lifetime. This also leads to a need to time-resolve the electron bunches, which pass a typical interaction region at 25 or 100 MHz, depending on electron beam energy in the current EIC design.

The authors propose to develop a 10 W pulsed laser, initially of 1064nm wavelength, later to be doubled to 532nm to improve the scattering kinematics. The pulsed character is to concentrate the laser power at the appropriate time when the electron beam transits. This does lead to different requirements on the laser time-structure than e.g. used at JLab for the Compton-scattering polarimeters due to the quasi-CW nature of the JLab electron beam. The proposal addresses needed photon beam parameters, electron-photon luminosity, expected asymmetries, and the measurement time to reach a one percent measurement. In addition, it addresses the novel features of the proposed system, such as degradation of the polarization state through fiber transport and changes in optical properties of the vacuum windows at high power operation. The times quoted are indeed smaller than the projected bunch lifetimes for EIC but not by a large factor. The design appears to aim for at most one scattered electron per bunch crossing to not complicate the measurement.

The need for good electron polarimetry is acknowledged. Development of an adequate laser system would seem to be a good investment in order to allow design and construction of the needed Compton polarimeter on the timescale for initial EIC experiments. The justification for the various expenditures of the laser system was provided, as requested earlier. The system proposed would be of a capability that could be deployed at the EIC as presently foreseen. The labor appears to be fully supplied by the collaborating institutions, which have a good base of experience with the similar if CW systems.

A discussion of the required scale-up of the pulsed laser used for the current CEBAF injector would be welcome; this system provides a proof-of-principle but is in the 100 milli-Watt power range only. A key development of this proposed R&D would be to demonstrate near -100% circular polarization at 10W laser power and then to demonstrate this high power can be transported through a fiber.

The authors discussed the required spatial segmentation of the electron detector that would also need to be deployed. The response speed and count rate capability of this detector needed more elucidation, because overall count rates for electrons reach 100 MHz, which is extremely demanding for detectors and processing electronics. The proponents provided additional information on the detector requirements to successfully execute the project in response to questions from the committee. In particular hit rates for electrons and photons were provided for different detector configurations, which indicate a very challenging environment. Several detector options could be explored and should be integrated in the overall workplan for polarimetry measurements.

The committee thinks that a two-step approach moving forward with this research should be considered. In a first step, a proof-of-principle should be provided using the existing 100 milli-Watt laser and will provide a pathway to a concept of a detector in a more refined way, possibly by doing more tests on various concepts. As a second step, a 10-Watt laser system could be deployed. This can happen on the timescale of a year. We note that a 10-Watt laser is a completely different game from all aspects, notable the safety aspects. Starting the efforts at Stony Brook University is strongly encouraged.

Recommendation:

Although this proposal lies more in the domain of project engineering rather than EIC detector R&D, good polarimetry is essential for the EIC. A key question is the development of the detector that will enable this measurement. Additional information was provided by the proponents addressing the experimental challenges. The proponents are encouraged to reach out to other projects under the current detector R&D program to develop the detectors as well. In particular, it is suggested to reach out to the nanowire, silicon and diamond detector developments. Furthermore, the collaboration is encouraged to consider a phased approach starting with the current laser system and moving towards a full system on the timescale of a year or so.

New Proposal: Precision Timing Silicon Detectors for a Combined PID and Tracking System at the EIC

W. Li reporting

This is a new proposal to develop fast timing layers for PID and tracking. It considerably leverages ongoing work on the CMS endcap timing layers as well as ongoing R&D on LGADs with improved timing resolution and improved spatial resolution

Findings

The application here is PID and tracking in the central and endcap regions of an EIC detector. This is ultimately a large-scale application of fast timing, similar to what is underway for upgraded LHC detectors.

Particular areas of focus include improved timing resolution through thinned sensors, and improved spatial resolution through reduced interpixel dead areas. This is addressed by both trench isolation and AC-LGAD methods.

The proponents acknowledge significant leveraging and commonality with synergistic efforts (CMS) and existing R&D (AC-LGADs). In additional to the technical studies, effort is proposed on simulation to study optimization for PID/TOF, such as pixel size etc.

Comments

Large scale system issues (power density, timing, etc.) are likely to be major challenges going forward.

In principle, fast timing for central/endcap TOF and fast timing for Roman Pots have different technical requirements in a number of areas. However, there are also significant commonalities – readout ASICs, system issues, readout, testing, relationship to vendors, etc.

It would appear natural, and beneficial overall, to see EIC LGAD-based efforts to form a consortium (like silicon tracking with MAPS) sooner rather than later. The Committee would look with approval on such convergences.

Recommendations

Proceed with the contributed effort, the acquisition and test of sample devices, and with the proposed simulation work to the degree that funding will be available from this program or other sources.

New Proposal: High Resolution Zero Degree Calorimetry

Michael Murray reporting

The design of a high-resolution, position-sensitive Zero Degree Calorimeter (ZDC) is proposed to measure neutrons and photons at the EIC. The proponents already made a strong case at the January 2020 EIC detector R&D meeting for the physics value of a zero-degree calorimeter at the EIC to measure the gluon saturation at extreme density through a set of diffractive processes and exclusive vector-meson production in e-A collisions. The requirements to access this physics is a calorimeter at very small angles to accurately measure energies of photons below 300 MeV and fully measure the energy of neutrons up to 100 GeV. A total absorption calorimeter is needed with about 1cm position resolution and 50%/√E hadronic energy resolution. It will require a well-segmented EM compartment with good energy resolution to isolate the soft photons. The proposal seeks to develop a realistic detector configuration that can deliver the performance needed for the EIC physics goal. The study will rely heavily on the tools for design and simulation that have been developed already by Jefferson Lab and BNL. The rate capability of the device was not addressed and the committee is looking forward to receiving more information on this at the next meeting.

Recommendation:

The committee in particular understands the challenge of detecting low-energy photons, and suggests the efforts should be primarily directed to this area but is very supportive overall of this proposal.

New Proposal: Superconducting Nanowire Detectors for the Electron Ion Collider

Whitney Armstrong reporting

The proposal is to qualify Superconducting Nanowire detectors for applications at the Electron Ion Collider. A superconducting nanowire detector utilizes critical phenomena in superconductivity to transform energy or heat into an electric signal. The detector is sensitive to single photons with energy higher than the superconducting energy gap of ~2 meV. Although these devices have been known for about 20 years, they are relatively novel devices in the high energy/nuclear physics field. For example, they were never used to detect relativistic charged particles so far, although a high efficiency response to low energy beta or alpha sources was reported in the literature. The devices were typically used to detect photons in the infrared wavelength range, and for this application, these detectors provided an excellent timing resolution below 20ps, with a current record of 3 ps. In addition, because of the small pixel size they can provide a high spatial precision at the level of ~20-microns, if needed. Furthermore, they are very low noise detectors.

The concept allows for edgeless sensor configuration, since the sensitive element can be positioned to within a few 100 nm of the saturated edge, eliminating dead material between the particle beam and the detector. This allows operation of the detector very close to the beam. The detector is windowless, which means it can operate inside the beampipe vacuum, and all what is needed to reach superconductivity is a cold finger. The capability to operate in a high magnetic field allows placing such detector in the proximity of beam line magnets. Because many magnets will be superconducting, there will be plenty of cooling power available. The proponents also suggest operating with cold FPGAs, which has been successfully demonstrated in the literature (Ref.1), allowing a limited number of feedthroughs through the vacuum vessel. Proponents argue that the challenges for reading out a highly segmented cryogenic detector are similar to many other pixel detector technologies.

For the final application at an EIC, the proponents discuss a detector area of a few cm^2. The detector could be located in four possible areas: (a) A windowless roman pot in the forward region about 35 meters from the IP; (b) Integrating the detector inside the superconducting beam line magnets in the very forward direction, perhaps ~100 meters from the IP, close to spin rotators. In this case, placing the detector inside the magnet and integrating it with the magnet's cooling system, would eliminate a separate cryogenic system. (c) Placing the detector in front of the ZDC detector. (d) Use it as a Compton detector, as it is capable to cope with 100 MHz beam pulse rate and measure polarization by simple pixel hit counting.

The proponents have demonstrated that the device works well in a high magnetic field of 5T, and that it can operate in a high-radiation environment. The proponents have also demonstrated that the detector is capable of detection of 400 nm photons at high rate using LEDs (potentially up to ~100 MHz for 100 $micron^2$ pixel size), with less than 1 dark count per second. The proponents have exposed the detector to a ATLAS neutron background environment for a month with no severe deterioration; this test is continuing.

The proposed test device will initially have the standard meander geometry, with wire thickness of ~15 nm, wire width of 100 nm, and spacing between the wires of 100 nm. The basic pixel element will be 10 x10 $micron^2$. Larger-scale devices will be prepared by parallel connection of these units into larger single-channel super-pixels. As a next step, the proposal asks funding to fabricate a 4x4-pixel array covering an area of ~$1mm^2$, characterizing it with visible light and radioactive sources, and then test it in the Fermilab proton test beam using 120 GeV protons.

The nanowire device consumes essentially zero power (it its superconducting). In its latched state, if the current is shunted through a 50-ohm resistance we expect roughly 20 nW. But keep in mind this latched state only occurs for at most a few nanoseconds. Also, the power requirements for each channel are independent of the pixel size. So, a 10x10 micron^2 pixel and 100x100 micron^2 pixel will have the same power demands. In the case of a kilo pixel array, we estimate it will dissipate in total 20.5 mW for a device that has 100% occupancy (which will effectively be a malfunctioning device).

Initially, for the beam test, they will work with one FPGA and one ASIC. At present, a low power ASIC does not exist, and the proponents plan to work with ASIC designers to develop a custom ASIC for readout of these devices. After some ASIC design work, they plan to do away with the FPGA.

Comments:

The claim that "fabrication of large areas (few cm^2) does not present a technical challenge" (p.2) is potentially misleading. Fabrication is not a technical challenge but getting good performance from that large-area fabricated device could be very hard - it would impossible to guarantee there won't be some defects. Current state of the art for single elements is about 0.1 mm × 0.1 mm, which is a long way away from 1 cm^2.

The claim of 10 ns reset time should be taken with a grain of salt. For detectors fabricated to date it is achievable, but for 1 cm^2 detectors, it is à priori unknown what the performance will be like. It is expected that considerable work will likely be needed to get ns reset times.

To get a 20 ps time resolution, one needs a fast, power-hungry preamp and timing circuitry, which was not yet been considered in detail.

Recommendations:

Superconducting nanowires have never been deployed in a particle or nuclear physics experiment to our knowledge. As such, this proposal represents a true spirit of detector R&D. This project will have to solve many issues before it would have a working detector as indicated above. There are interesting synergistic activities with other projects under this program such as the polarimetry measurement. The idea to test a device in the Fermilab test beam and study the response to protons, electrons and pions is a very worthwhile exercise and would provide new information. We strongly recommend that at the least this aspect of the project is supported, funding permitting.

Funding Summary for FY21

R&D Project	Contact/PI	Topic	FY20 Sub-proposals	FY21 Requested Funding	Priority
eRD1	Huan Huang (UCLA), Craig Woody (BNL)	EIC Calorimeter Development	Shashlik Calorimeter	$90,000	Low
			HCAL and timing	$47,700	Medium
			PWO		--
			Glass Ceramics	$74,613	High
eRD6	Kondo Gnanvo (UVA)	Tracking and PID detector R&D towards an EIC detector	MPGD-RICH	$38,000	Medium
			µRWell	$129,690	Medium
			TPC Readouts	$79,500	Medium
			High Pressure Rich	$24,150	Low
			Micromegas	$8,000	High
			Forward Tracker	$3,490	High
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	$74,000	High
			mRICH	$85,800	High
			DIRC	$130,000	Medium
			high-B	$45,000	Medium
			LAPPD	$110,000	Medium
			Electronics	$133,000	Medium
eRD17	Mark Baker	BeAGLE: A Tool to Refine Detector Requirements for eA Collisions in the Nuclear Shadowing/Saturation Regime		$93,000	High
eRD20	Markus Diefenthaler (JLAB), Alexander Kiselev (BNL)	Developing Simulation and Analysis Tools for the EIC	Postdoc Travel	$0	--
eRD21	Latifa Elouadrhiri (JLAB)	EIC Background Studies and the Impact on the IR and Detector design	0.5 FTE Postdoc 0.5 FTE Postdoc Graduate Student OTR Travel	$145,000	Medium
eRD22	Yulia Furletova (JLAB)	GEM based Transition Radiation Tracker R&D for EIC	Gas System Temple Xe gas system, JLAB Prototyping, UVA	$38,233	High
eRD23	J. Bernauer	Streaming Readout for EIC Detectors		$20,000	Low
eRD24	A. Tricoli	Roman Pots	Labor (20) + MS (10) + Travel	$40,000	Medium
eRD25	L. Gonella, I. Sedgwick, E.P.	Si Consortium		$213,000	High
NEW	C. Gal (SBU)	Proposal for a pulsed laser system for Compton polarimetry at the future EIC facility		$65,000	High
NEW	Y. Goto (RIKEN), M. Murray (UK)	Developing a High Resolution ZDC for the EIC		$62,500	High
NEW	W. Armstrong (ANL)	Superconducting Nanowire Detectors for the Electron Ion Collider		$40,000	Medium
NEW	W. Li (Rice)	Precision Timing Silicon Detectors for a Combined PID and Tracking System at EIC		$63,000	Medium
Total				**$1,852,676**	

Table 1: Summary of the funding recommendations.