

Report

4th Meeting of the Electron-Ion-Collider Advisory Committee (EICAC) February 28/March 1, 2014

EXECUTIVE SUMMARY

At the request of Brookhaven National Laboratory (BNL) and of the Thomas Jefferson National Accelerator Facility (JLab), in coordination with the leadership of the EIC science community, the fourth meeting of the Electron-Ion-Collider Advisory Committee (EICAC) was held on February 28/ March 1, 2014 at Brookhaven. The charge to the Committee has essentially remained as originally defined, i.e., to periodically review progress, and provide feedback and advice on the developments and issues regarding the EIC, along the items 1 to 6 given in the charge (Appendix I).

The context though has evolved substantially in the nearly 3 years since the last EICAC meeting. As indicated in the introductory paragraph to the charge, the 2013 NSAC Subcommittee on Future Facilities identified the physics program for an EIC as absolutely central to the U.S. nuclear science program in the next decade. The bases for this assessment are the broad activities of the two laboratories and the EIC science community in pursuing the science case, the technical concepts for the realization of the EIC facility, and the experimental systems.

This is documented by the EIC Whitepaper from February 2013, commissioned by the managements of BNL and JLab, preceded by the 10-week workshop organized by the two laboratories and the Institute of Nuclear Theory (INT) at Seattle in the fall of 2010, the extensive proceedings of which were published in November 2011. The documents also indicate the significant R&D and facility-design activities at both laboratories, leading to pre-conceptual design reports; and the extensive studies on detector concepts and event simulations to efficiently record the observables identified by the proposed science program.

The key science areas as described in the EIC Whitepaper were presented to the EICAC in an overview talk and in talks on specific sub-areas in the afternoon parallel session (see Appendix II for the agenda): i) Nucleon spin and its 3D structure and tomography; addressing the spin and flavor structure of the nucleon, the confined motion of partons inside the nucleus, and the tomography of the nucleon-spatial imaging of gluons and sea quarks; ii) The nucleus as a QCD laboratory; addressing QCD at extreme parton densities and saturation, the tomography of the nucleus, propagation of a color charge in QCD, and the distribution of quarks and gluons in the nucleus; iii) Physics opportunities at the intensity frontier; including electroweak probes to hadronic systems, and precision electro-weak studies and aspects of Beyond-Standard-Model physics.

The EIC Whitepaper in the Committee's opinion has developed the science case to an impressive stage. The Committee was also particularly pleased to see science vs. machine characteristics tables/matrices, substantiating facility performance requirements. This is done separately for the different sub-areas in the Whitepaper which makes sense. Not in all cases machine parameters are/can be explicitly specified. But it would be useful to extend these considerations to the same parameters for all sub-areas and to provide a combined table to the extent possible. This might help the wider nuclear physics community understand the desired machine characteristic (such as the ones listed in the charge) more directly, and may point to pay-offs between different concepts and draw-backs from compromises in facility scope. Most members of EICAC also felt that an attempt should be made to have the broad and complex physics program captured in a more compact (yet comprehensive) phrase with very few keywords.

The Committee is also very pleased to note the substantial progress made during the past 3 years in all major areas towards the EIC accelerator facility. The two facility concepts, e-RHIC at BNL and MEIC at JLab and their respective underlying technical approaches have continued to evolve and mature. Both concepts involve innovative and novel accelerator aspects. Considerable critical R&D has been

performed; risks and further R&D towards their mitigation have been identified. Pre-conceptual design reports have been prepared by both laboratories. Preliminary cost estimates have been established, or will be available soon. Tentative schedules for Conceptual Design Reports and Technical Design Reports were presented. Both teams have provided approximate timelines for individual key R&D items. How the R&D efforts will lead to a successful initiation of construction was not yet presented.

Collaborations in accelerator R&D exist, particularly through help in areas of the other laboratory's expertise. The Committee expects this to expand. It encourages the two laboratories to identify areas of common interest where accelerator expertise can be shared and used to reach some common objective. The Committee also recommends identifying areas of accelerator R&D which can be postponed for a later stage. Overall the Committee sees the need for increasing investments in accelerator R&D to the level sufficient for timely delivery of the CDR and, later, a TDR.

The Committee was also very pleased to learn about the major and successful simulation efforts for detectors. They allow specifying the requirements for precise measurements and particle identification with precisely controlled systematic uncertainties over the wide and challenging kinematic range necessary to exploit the EIC physics opportunities. Now that simulation tools are available the effort on the study of the systematic uncertainties of the measurements should be intensified.

Both the MEIC and eRHIC detector designs have taken on the need to have full-acceptance detectors. There is good coordination between the detector designers and accelerator physicists on designing the interaction region in such a way as to make this possible. Both accelerator designs allow for the possibility of having two detectors, given that different physics priorities will likely lead to different detector optimizations. The Committee indeed expects that two simultaneously operating detectors optimized with different physics emphasis are essential for fully exploiting the EIC physics potential. EICAC recommends forming teams that evaluate detector options specifically for physics processes. So far the question of background in the detectors has not been attacked in sufficient depth. It may well impact on technological choices. Efforts on the study of beam-gas backgrounds (for both beams) should be intensified.

For a large part of the physics program, accurate and precise measurements of the luminosity and polarization will be required; studying possible realizations for measuring these quantities will be an important issue and should be started now. The Committee understands that the final design of detector, trigger and data acquisition systems will depend on details of the interaction reaction and the time structure of the accelerator design. It encourages enhanced cooperation and discussion amongst the JLAB and BNL based teams which have focused on somewhat different aspects of the detector design.

More specific comments and recommendations on the science program, the detector designs and development, and on the concepts and R&D for the EIC accelerator facility are found in the sub-sections of the detailed report.

In summary, the Committee is very pleased to note the substantial progress made during the past 3 years for all major areas of the EIC initiative. The science case has evolved to a good degree of maturity. The two different principal facility concepts and their respective technical approaches have matured to the stage of pre-conceptual design reports, including innovative and novel aspects; considerable first critical R&D has been performed, risks and further R&D towards their mitigation identified. Extensive physics simulations for detector requirements and evaluation of technical approaches to detector concepts together with specific R&D have been made.

All of this gives testimony to the enthusiasm and the considerable effort made by the two laboratories and the associated science community. Considerable work and challenges lie ahead in all areas. But EICAC wants to congratulate the two laboratories and the EIC science community for the achievements and the status reached so far. It also wants to thank for the hospitality extended to the Committee and, last but not least, for the engaging presentations and discussions of the interesting subject matters.

DETAILED REPORT

The Science Program of the EIC

The science case for the EIC has been sharpened considerably in the last few years and stands very strong. In the area of spin and 3D structure of the nucleon, the goals are the full understanding of the dynamical origin of sea quarks and gluons inside the proton, the origin of the proton spin at the microscopic level, the influence of chiral symmetry and its breaking on hadron structure, and the basic question how confinement manifests itself in the structure of hadrons. The new access at the EIC to nuclei over the full mass range, is providing for studies concerning the role of strong gluon fields, parton saturation, and collective gluon excitations in nuclei, the search for non-linear QCD dynamics in high-energy scattering, the studies of momentum and spatial distributions of gluons and sea quarks, and answers to questions concerning strong color (quark and gluon density) fluctuations and propagation of color charge in nuclei. The EIC also offers new possibilities at the luminosity frontier, including electroweak probes to hadronic systems, and precision electro-weak studies and aspects of Beyond-Standard-Model physics.

Nucleon: Spin and flavor structure, 3D tomography, confined motion of partons

Although the nucleon structure has been studied extensively at various high-energy facilities in the past, none has the capability of imaging the quarks and gluons with the precision and versatility of a dedicated electron-ion collider with the combination of unprecedented luminosity and high energy.

Longitudinal spin of the nucleon: The impact of the EIC measurements on the longitudinal spin structure has been extensively studied and described in the write paper. For example, the 2-dimensional constraints on the truncated moments of gluon and quark polarization demonstrate the power of EIC very well.

Suggestions for further developments towards the EIC studies:

- understanding the implications of observing a central value in the gluon vs. sea-quark polarization diagram that is consistent with the center of the much wider region from the existing data; conversely, how is the picture of the nucleon changed if one obtains a value that is at the border of the presently allowed region.
- emphasizing connections with more general predictions or references would be helpful for outsiders to understand the importance better, such as with Lattice QCD
- exploring possible connection with the confinement problem

3D imaging: EIC will provide a unique facility for precision 3D imaging of quarks and gluons in proton and nuclei. By measuring the semi-inclusive hadron production, one can probe the transverse momentum of the quarks and gluons confined inside the nucleon, hence measuring the 3D momentum space distributions of the partons. With this extra degree of freedom, one can study the correlations between the polarization of partons and the nucleon and the transverse momentum, which gives rise to a range of interesting phenomena such as single spin asymmetry. The study of hard exclusive processes allows probing the parton's transverse coordinate distributions, which provides the critical information on the parton orbital angular momentum.

However, there are a number of issues that one shall resolve before data can be useful for understanding the 3D structure:

- **Scaling:** To learn parton physics, one has to make sure that one is in the scaling region, i.e., the partons dominate the scattering mechanism. For example, single spin asymmetries can arise from non-perturbative scattering mechanisms as well; higher twist contribution might be important in certain kinematic regions.

- In the case of semi-inclusive DIS, it is important to identify the origin of the transverse momentum of fragmentation hadrons, which can arise from parent partons, fragmentation and gluon radiation. One has to demonstrate that the parton's transverse momentum can be isolated and probed.
- It is equally important to learn the physics of fragmentation as are the parton distributions. Without a good knowledge of fragmentation functions, it will be very difficult to extract the TMDs.
- Since there are a large number of distributions derived from the spin dependence of the proton and partons, it is important to focus on quantities that have clear physical interpretation and interests. In particular, one shall have a clear idea how precisely one can learn about the gluon and orbital angular momentum contributions to the proton spin.
- For the GPDs, it is important to leverage the Q^2 dependence so that the full knowledge of GPDs can actually be probed through experiment without much model assumptions. In particular, assessment must be made with regard to learning the actual position space distributions of the partons from the experimental data directly.
- It is important to develop a program of ab initio calculation of the 3D structure of the nucleon from the fundamental theory of strong interactions.

In addition to an overview of what is planned for the future, an update of the status of present measurements and those which can be expected before the EIC start-up should be given.

Confined motion of partons in nucleons: Our understanding of the nucleon structure from inclusive DIS measurements is essentially a 1-dimensional view. For the EIC studies are proposed that are going beyond this simple parton picture, with multidimensional distributions of partons, such as generalized parton distributions and transverse momentum dependent parton distributions (TMDs). The focus of the study has been especially on the TMDs. These measurements should give deeper insight in the following aspects:

- 3D imaging of the nucleons, as also discussed in the previous section. Of particular interest is the impact parameter dependent distribution of gluons inside the proton which connects with confinement dynamics.
- The orbital momentum question: most TMDs would vanish in the absence of orbital momentum.
- Spin-orbit correlations: test of the coupling of the transverse momentum of quarks with the spin of the nucleon.
- Gauge invariance and universality: e.g., the connection with colour gauge invariance.

These measurements will therefore address fundamental properties of QCD. The EIC data will provide a data driven research program, which is expected to guide theory. The potential precision that can be reached, e.g., through semi-inclusive measurements, as worked out in detail in the EIC Whitepaper, is impressive. The EIC offers for example the possibility to study gluon TMDs.

As a next step it would be useful to clarify a few points in more detail. What seems to be missing, and would be useful to have, is a quantitative estimate of the results that can be obtained with the proposed measurements, i.e. what do we expect to learn in a quantitative way. E.g., how well will we be able, for a given experimental scenario, to constrain the total orbital momentum with these measurements, or to what level of precision can we address fundamental properties of QCD, or how accurate is the b-shape of the gluon density and how far out in b can it go? Also one could investigate the connection of b-parameter with confinement.

For the gluon TMDs, the Sivers asymmetries in the DD -bar channel are very important measurements. This is a very challenging measurement and its feasibility and precision should be demonstrated explicitly with full simulation, including acceptance, efficiencies and systematics. It is unclear to the Committee if this was done for that particular result. Further, how important is low-x reach and therefore the requirement of the energy of the machine for this part of the physics program? Finally, we like to see a more critical discussion with other existing and particular planned experiments (such as COMPASS at CERN).

The Nucleus as a QCD laboratory

The EIC, with its large kinematic reach and its capability to probe a variety of nuclei in both inclusive and semi-inclusive DIS measurements will be the first facility to explore the 3D sea quark and gluon structure of a fast-moving nucleus. The nucleus itself promises the study of gluonic matter at unprecedented gluon densities, and of the propagation of fast color charges in the nuclear medium.

High density gluon physics at an EIC: The presentation to the Committee described the highlights of high gluon density physics at an EIC. The study of high gluon densities and gluon saturation at small values of x is one of the key goals of an EIC. Vector meson production, forward di-jet production, and the longitudinal structure function furnish the basic measurements necessary for determining properties of the high density gluon state, the Color Glass Condensate (CGC). Nuclear targets allow saturation effects to show up much earlier than for proton targets because of the $A^{1/3}$ enhancement factor present in nuclear as compared to proton targets. The EIC White Paper gives an excellent and thorough discussion of how the various measurements can be used to gain a good understanding of the properties of the CGC.

Proton-Nucleus collisions at CERN also furnish an interesting window to high density gluon physics and at much smaller x -values than those available at an EIC. Of course electron scattering is a much cleaner probe than hadron collisions. Indeed, recent data on proton-nucleus collisions at CERN suggest thermal effects may be present. If so gamma induced collisions may be necessary to study the CGC and could be very helpful in determining exactly what is being seen in the proton-nucleus data.

The EIC Whitepaper gives a clear and compelling case for small- x physics at an EIC. However, there are a few issues we believe could be more completely addressed.

- Recent CERN data on proton-nucleus collisions have come mostly after the completion of the Whitepaper. An update of the Whitepaper including a discussion of the implications of the new CERN data for the EIC would be useful.
- The ratios of diffractive to total cross section as a function of the diffractive mass are given in the Whitepaper. At HERA, one of the striking observations was that the diffractive to total cross section ratio was constant in W^2 , and saturation provided a simple explanation. Is it possible to make similar measurements, and for various values of A at an EIC?
- The White Paper gives a detailed t -dependence for J/ψ production. Is the t range large enough and the expected data precise enough to give a good transverse spatial profile for a range of A -values?

Quark and gluons, propagation and hadronisation in nuclei: The presentation to the Committee described using hadron production as a function of A and of beam momentum at an EIC to study the properties and time scales of hadron formation from quarks as well as to study the interaction of quarks with cold nuclear matter, in particular to study transverse momentum broadening and energy loss of quarks in nuclear matter.

One of the most striking effects is seen in the ratio of D^0 meson production in nuclei as compared to production on a proton. Because of the close correlation of the charm quark momentum to the D -meson in the fragmentation function there is a strong enhancement in lower momentum D 's in nuclear as compared to proton reactions due to energy loss of the charm quark in nuclear matter. Good data should lead to a determination of the transport coefficient, \hat{q} , for charm quarks in nuclear matter.

For light meson production there is always the suppression in production in nuclear as compared to proton targets, with the amount of suppression depending strongly on the measured hadron's momentum, due to the momentum dependence of the time scale over which the quark fragmentation to the meson occurs. Data using various nuclei and beam energies should lead to a determination of the formation times in quark fragmentation as well as a determination of the transport coefficient, or equivalently, a determination of the size of the fluctuating gluon fields in a nucleus.

The propagation of quarks in cold nuclear matter is a topic which should be well-studied at an EIC without a strong requirement either for the energy or the luminosity of the machine. This topic is well described in the Whitepaper. However, it is a rather complex subject and its importance may not be easily appreciated by the non-expert. It would be useful to try and distill the essence of the physics into a description which can be qualitatively understood, and appreciated, by physicists outside the area of hadron physics.

Connections to p+A, A+A and cosmic ray physics: Both p+A and e+A collisions provide important programs in exploring the saturation regime. In nucleus-nucleus scattering there is a possibility to have a laboratory for studies of the onset of shadowing as well as signals of gluon shadowing.

In the already observed nuclear modification factor as a function of transverse momentum, broadening of the away-side peak in di-hadron correlations for central collisions shows possible signals of gluon shadowing. The EIC kinematics covers very well the region suited for the exploration of saturation and for searches of non-linear effects in its evolution.

For eA collisions the EIC will play the role of a gluon "microscope". With interactions dominated by single photon exchange and precise measurements of x and Q^2 , there is a possibility of precise mapping of gluons and tests of dynamics.

The combination of the results from pA and eA should allow pinning down saturation. For the description of AA collisions where hydro-dynamical as well as CGC models give a good description, input from eA can provide important information to an understanding of the dynamical origin of fluctuations.

Detailed data from eA will also contribute to our understanding of cosmic rays at ultra-high energies. In this field the most important question remains the composition of cosmic rays reaching the Earth's atmosphere. Possible important input from eA will help in the interpretation of air shower development profiles from the Auger experiment as well as of data on muons in showers observed by IceCube.

Questions and comments:

- the new results on ridge observed in pA at LHC require additional discussion in the EIC Whitepaper
- what will be the key measurement(s) at EIC for initial state properties?
- can the single measurement in eA be pointed out which could play a very important role in providing "proof" for the saturation explanation of the pA and AA results?

Intensity frontier and electro-weak physics

While electroweak physics is not one of EIC's primary topics, it is remarkable that the EIC machine parameters and detector capabilities that have emerged to fulfill its major physics motivations provide unique opportunities to measure novel electroweak structure functions, measure the evolution of the weak mixing angle at a range of Q^2 that remains inaccessible by other methods, and search for tau-to-electron flavor violation in a manner complementary to other techniques foreseen for the future. Each of these topics is likely to remain highly relevant a decade from now.

The above-mentioned topics greatly benefit from high luminosity, though the charged current structure function measurements can already provide major new insight at moderate luminosity. The nominal luminosity of MEIC varies from $5\text{-}15 \times 10^{33}$ (5GeV on 60GeV) while eRHIC states 1.5×10^{33} (16GeV on 250GeV). However, eRHIC luminosity is limited by the hadron beam current, which may be increased up to tenfold by proper treatment of the hadron-ring vacuum system (coating).

The Committee also recommends exploring whether—in either facility—foregoing polarization (e.g. by turning off spin rotators and/or snakes) would present opportunities to increase luminosity. For the weak mixing angle measurement, only electron polarization is required, and for the τ -to-e search polarization might not play a significant role.

Accelerator Facilities

In following the charge, the primary focus in this section is on its items 2 and 3, i.e. to review and advice on 'progress in R&D on critical accelerator and detector technology' and 'planning milestones, management proposals, and design reports'.

For items 5 and 6, i.e. 'setting expectations' for 'credible machine (and detector) cost estimates, including possible staging options' and for 'collaboration of BNL and JLab and the future user community on all aspects of the EIC project' the Committee offers some observations and comments. For more detailed considerations the Committee felt that this needed more information and discussion at the future meetings.

The Committee first wants to address the various aspects as they apply more generally to both of the facilities, eRHIC and MEIC. This then is followed by more specific findings and comments and, if applicable, recommendations separately for each facility.

Evaluation of progress in R&D on critical accelerator technology

- Both eRHIC and MEIC designs contain performance risks; namely there is some concern that luminosity and center-of-mass energy objectives may not be met; thus there is also risk of the project cost escalation as these issues are mitigated.
- The eRHIC design is somewhat more mature, mainly because the ion complex exists and because more resources have been available at BNL. Offsetting this is a technically more challenging ERL design and the recent design changes.
- Both teams have creatively pursued R&D funding, and where successful, these activities have made significant advances in EIC technology.
- Both BNL and JLab design teams have taken advantage of R&D being done at other facilities around the world.
- Actual progress on in-house R&D has been slow due to funding limitations; Proof-of-principle (PoP) demonstrations are needed in a number of areas, and are scheduled.
- Areas of R&D that can be delayed until after a CDR should be identified so that critical R&D can proceed with more concentrated resources.

Evaluation of planning milestones, management proposals, and design reports

- Pre-conceptual design reports have been prepared by both laboratories.
- The MEIC design is more stable (over the past few years) and promises $5 - 15 \times 10^{33}$ luminosity depending on detector design.
- Both teams have provided approximate timelines for individual key R&D items. However, the process by which these R&D efforts will lead to a successful initiation of construction was not clearly communicated to the committee.

Expectations for the development of credible machine and detector cost estimates, including possible staging options:

- There is an initial high-level cost estimate for eRHIC, while the MEIC team is actively working on it. Both laboratories understand the importance of developing credible cost estimates and we expect that within the coming two years, cost estimates corresponding to the in-hand designs will be available.

- Both facilities are anticipating upgrade options. eRHIC could increase luminosity by factor of 10 by coating the RHIC vacuum chambers; JLab's design has energy upgrade options.

Expectations for collaboration of BNL and JLab and the future user community on all aspects of the EIC project:

- Collaboration exists, particularly by helping in the areas of the other lab's expertise (e.g., JLab assisting on polarized e-gun for eRHIC). We expect this to expand.
- Both laboratories have developed collaborative relationships with other institutions, e.g., universities, SBIR partners, international collaborations, to get access to accelerator test facilities (e.g., bunched electron cooling PoP experiment in China)
- We see opportunities for the labs to work together on areas of common interest. These should be proactively pursued where it makes sense: Possible examples include:
 - Issues related to high power ERLs
 - Crab cavities
 - Modeling, dynamic aperture studies, chromaticity control
 - High Power guns

The eventual level of collaboration should far exceed the present level.

Facilities Recommendations:

1. Increase the investment into accelerator R&D to the level sufficient for timely delivery of the CDR and, later, a TDR.
2. We encourage the two labs to identify the areas of common interest where the accelerator expertise can be shared and used to reach some common objectives.
3. Identify the areas of the accelerator R&D which can be postponed for a later stage (e.g. after the start of CD process or even to the time of a luminosity upgrade campaign) and concentrate efforts on the remaining items.
4. Generate a timeline of all R&D items (with realistic assumptions of success), providing Proof of Principle (PoP) of high risk items leading to CD0, coordinated between both teams and with identified milestones and projected required manpower and budget resources.
5. Provide an estimate of total wall plug power for each facility.

Findings, comments and recommendations for eRHIC:

Since the last EICAC meeting, BNL has modified their concept for the ERL arcs utilizing a non-scaling fixed field alternating gradient (NS-FFAG) concept that allows all circulations to occur in two rings. This greatly reduces the cost of both the arcs and the linac. The linac cost is reduced due to the fact that it can be lower energy, allowed by more circulations in the two arcs than previously when each pass needed a separate arc. The linac energy is now 1.322 GeV; previously it had been 4.9 GeV in two separate linacs in the RHIC tunnel. RF and cryo-plant costs are accordingly reduced. The arc cost is reduced because there are only two, and because BNL is considering to construct these arcs out of permanent magnets, which might save greatly on utilities and power supply systems. The specific findings then include:

- FFAG concept introduced into electron circulation arcs
- Critical accelerator R&D items for eRHIC include:
 - high current (aiming at 50 mA) polarized electron gun (Gatling gun)
 - demonstration of high energy – high current ERL

- polarized He-3 source R&D and acceleration
- coherent electron cooling
- compact loop magnets for FFAG
- development of eRHIC-type SRF cavities at lower frequency
- crab cavities
- beam-beam simulations for EIC
- The ERL test facility is being considered as a test bed for a number of eRHIC demonstrations including integrating FFAG into the circulation arcs. This is being pursued with program development funds.
- A prototype Gatling gun is under construction
- A potential micro-bunching Coherent Electron Cooling (CeC) concept has been suggested
- There is a first, high level cost estimate for eRHIC
- Considerable progress has been made on chromaticity control and IR design

From these findings the Committee wants to make the following comments and recommendations:

- We commend the eRHIC team for the introduction of the NS-FFAG arcs to the electron beam. This reduces the cost of the electron systems considerably. BNL could make a stronger argument for the cost savings of this change by noting the reduced cost of the linac systems in section 3.1.5. of the CDR.
- The above listed eRHIC R&D efforts address more than 2 orders of magnitude risk in the luminosity.
- We believe that the design of the needed beam spreaders/combiners is in flux and remains challenging, particularly the impacts on synchronization and polarization.
- We encourage the consideration of micro-bunching CeC
- The beam-beam disruption is stronger than in conventional colliders. Detailed study is needed to evaluate if the conventional beam-beam limit is applicable under this operation condition. This is in addition to the kink instability being studied.
- The ERL synchrotron radiation will have a relatively high critical energy, potentially leading to activation issues.
- The flexibility in parameter space to achieve needed performance appears limited, particularly if the ERL parameters fall short.
- Confidence in the ERL design will rely in part on extrapolation from tests at low energy and small energy loss. Scaling up to the full ERL, with 12 MW of synchrotron radiation loss, will require a thorough understanding of all the parameters affecting this scaling. We encourage BNL to articulate the issues and risks in this scaling, and present the needed tests to mitigate this risk.
- We look forward to seeing the results of the 50mA gun test in 2014, the CeC PoP test in RHIC planned for 2015/16, and the prototype system test of ERL planned for 2014-2016

Findings, comments and recommendations for MEIC

The Jefferson Laboratory design has stayed fairly stable since the last EICAC meeting. Tremendous work has been done since the last EICAC meeting for filling the gaps and producing the details of the

accelerator design, though more work is needed to complete some of the critical items. All critical MEIC accelerator R&D topics have been identified, some are under active study; there are research plans for others. The focus of the JLab staff has been to refine critical elements of the design, particularly lattice calculations, chromaticity control and IR design. While actual R&D has been limited, there has been considerable thought about the kinds of experiments that need to be done to verify the design for the high energy bunched beam electron cooling. This includes planning for a demonstration experiment at the Institute for Modern Physics (IMP) in China. The specific findings then include:

- Critical accelerator R&D items for MEIC:
 - cooling by a bunched electron beam
 - high current ERL and circulator ring, utilized by the bunch beam cooling
 - high charge/current magnetized electron source, ultra-fast kicker
 - e-cloud, particularly with the close bunch spacing of 1.3 ns
 - synchronization at various hadron energies
 - special magnets for detector/IR
 - crab cavity development
- JLab has employed LDRD for first time to address some of these issues.

From these findings the Committee wants to make the following comments and recommendations:

- Further design work, including beam-beam simulations, beam dynamics in CCR, CSR and micro-bunching, space charge, e-Cloud (esp. with the close bunch spacing of 1.3 ns) needs to continue.
- These R&D efforts address 1-2 orders of magnitude risk in the luminosity.
- The Jlab team has done a commendable job with a small team, and augmenting these resources is encouraged.
- The MEIC electron beam is 3A. The crossing point of the figure 8 chamber will have 6 A beam crossing the region, and evidently cross at the same elevation. Being a crotch chamber and having 6 A passing beam, HOM generation and heating will need evaluation. We would like to hear a discussion of these issues in the future.
- For synchronization, the MEIC e ring proposed to induce an orbit change of +-20cm. This is a big perturbation for beam operation in a storage ring. It is proposed that its feasibility will be established by a combination of magnet design and by beam dynamics simulations. We encourage experimental verification where possible. This is considered a risk factor.
- MEIC plans for 0.5 A beam current at 1 cm bunch length in the hadron machine, this may present cooling challenges (cf LHC: 0.5 A but at 8 cm bunch length).
- While we have heard some discussion of the shielding for the hadron beam, we would like to see a more thorough analysis of shielding requirements. These may be critical where the hadron beam is pointed upward, which occurs in several places.
- Flexibility in parameter space is important to have confidence that performance objectives can be met. MEIC is encouraged to investigate the range in beam- parameters that allows understanding how to achieve optimal performance.
- The Committee recommends quite strongly exploring ways to expand the R&D effort to levels consistent with the timeline shown at this meeting.

Detectors

In order to exploit the EIC physics opportunities, a wide and very challenging kinematic range in which precise measurements and particle identification with precisely controlled systematic uncertainties is required. Thanks to a major and successful simulation effort these requirements have been specified. In particular the measurements of inclusive and semi-inclusive reactions will be limited by systematic uncertainties. As an example the determination of the DIS kinematics at high and low y is particularly very challenging.

The Committee recommends that now that simulation tools are available the effort on the study of the systematic uncertainties of the measurements should be intensified.

Both the MEIC and eRHIC detector designs have taken on the need to have full-acceptance detectors, and there is good coordination between the detector designers and accelerator physicists on designing the interaction region in such a way as to make this possible. Both accelerator designs allow for the possibility of having two detectors. This is a good idea given that different physics priorities will likely lead to different detector optimizations.

The Committee anticipates that two simultaneously operating detectors optimized with different physics emphasis are essential for fully exploiting the EIC physics potential, and recommend forming teams that evaluate detector options specifically for physics processes (e.g., focusing on F_L vs. focusing on SIDIS or DVCS).

So far the question of background in the detectors has not been attacked in sufficient depth. It may well impact on technological choices.

We recommend that efforts on the study beam-gas backgrounds (for both beams) should be intensified, and their impact on technological choices and systematic uncertainties of the measurements investigated further.

For a large part of the physics program, accurate and precise measurements of the luminosity and polarization will be required. Precision measurements of these quantities are very challenging.

Studying possible realizations for measuring these quantities will be an important issue and should be started now.

The committee understands that the final design of detector, trigger and data acquisition systems will depend on details of the interaction reaction and the time structure of the chosen accelerator design. So far, the JLAB and BNL based teams have focused on somewhat different aspects of the detector design.

We encourage enhanced cooperation and discussion amongst the teams.

MEIC Detector Design

Considerable effort has gone into the design of the interaction region and forward (small-angle scattering) directions for both beams. Evidence was presented that a full-acceptance detector should be realizable at the MEIC. It was also pointed out that two interaction regions will be available. This represents very nice progress. Some points that resulted from the presentation and discussion are:

- Hadron induced background should be further evaluated, as it may not be possible to achieve an LHC-level vacuum (10^{-10} Torr) given the mixing of a (warm) electron beamline with the hadron beamline. The total rate of beam-gas interactions could be high (100 kHz ?). While this would give a small overlap probability with an eA scattering event, this rate will still need to be reduced/controlled.

- Convincing arguments were made that the 1.3ns bunch spacing should not be a problem for reconstructing/separating good eA events. Appropriate timing resolutions have been demonstrated in other settings. The argument in favor of smaller population bunches at higher crossing rate (smaller overlap of events) used an overestimate of the scattering cross section and are not as strong as suggested; however, in general background studies should be pursued.
- Considerable work has been done on the optimization of the interaction region for SIDIS and exclusive processes. Although no technological showstoppers are foreseen, it would be good to focus on detector requirements for other aspects of the physics program, such as structure function measurements. Here, detailed considerations of sources of systematic effects will need to be considered (detector gaps, inactive materials, non-uniform response, etc...).

Detectors for eRHIC

An impressive progress in understanding both generic as well as specific issues of an EIC detector and its interface to the machine has been presented. This progress is based on the development and use of simulation programs for EIC physics and detector performance. For the latter both quick parameterized and detailed GEANT versions are available.

For the central detector, a generic detector, a modified sPHENIX and a modified STAR detector and their performance have been presented. Based on an intensive interaction between machine experts and detector scientists, details of the interaction region, the measurement of small-angle baryons and the tagging of photons, a first order design of the interaction region has been defined. In addition, again in close collaboration with machine experts the requirements and subtleties of the polarization and luminosity measurements have been worked out.

Overall the progress is very impressive and the results achieved are impressive. This progress to a large extent is due the DOE-supported EIC Detector R&D program.

The idea of the present RHIC collaborations to investigate if the detectors can be changed into eRHIC detectors is supported.

Important remaining questions are the evaluation and understanding of

- the systematics of the measurements, in particular of the DIS kinematic variables,
- the beam-induced backgrounds and their impact on the choice of detector technologies,
- how to measure luminosity and beam polarizations to the required accuracy,
- the trigger and data-acquisition concept
- the schedule of decisions for the technologies of the different detector components

Kinematic coverage of detectors

Thanks to intensive simulation efforts the necessary luminosity, polarization values and kinematic range for the different “golden” measurements have been identified, and in these ranges required performance parameters, like accuracy of luminosity and polarizations, resolutions, efficiencies and background determined.

- The wide range in beam parameters and kinematics, which are major challenges for accelerator and detector, are essential for achieving the EIC physics program. For the study of the low x physics, a high center-of-mass energy is essential, and should be possible in later upgrades.

For the central detector the precise measurement and efficient identification of electrons with excellent systematics, in particular at low momenta and the reconstruction of the DIS kinematics at low y values are particularly difficult. This is of particular importance for the FL measurement.

- An excellent understanding over the full DIS kinematic range is required to see if the systematics of the measurement can be controlled. This challenging issue requires significant further efforts.

The measurement and tagging of forward hadrons with good rejection and high precision in a wide kinematic range is essential for a significant part of the EIC physics program.

- Its optimization requires a close collaboration between machine and detector. Major progress has been achieved on this topic and the results are very encouraging.

The clean tagging of low Q^2 photons in a wide y range allows the exploration of the photo-production regime and thus a significant extension of the physics program.

- Its optimization requires a close collaboration between machine and detector. Major progress has been achieved on this topic and the results are very encouraging.

The measurement of photons due to initial state bremsstrahlung allows – possibly only at low luminosities – an experimental determination of radiative corrections.

- A study is encouraged.

APPENDIX I

Charge to Electron-Ion Collider Advisory Committee

(January 2014)

The 2013 NSAC Subcommittee on Future Facilities identified the physics program for an Electron-Ion Collider (EIC), which was described in the 2013 EIC Whitepaper, as *absolutely central* to the U.S. nuclear science program in the next decade.

The Whitepaper has specified the desired characteristics of the EIC:

- Highly polarized ($\sim 70\%$) electron and nucleon beams
- Ion beams from deuterons to the heaviest nuclei (uranium or lead)
- Variable center of mass energies from ~ 20 – ~ 100 GeV, upgradable to ~ 150 GeV
- High collision luminosity $\sim 10^{33-34} \text{cm}^{-2} \text{s}^{-1}$
- Possibilities of having more than one interaction region.

The NSAC subcommittee noted that significant scientific/engineering challenges need to be resolved before construction of an EIC could be initiated.

Both BNL and JLab are developing conceptual designs for how such a facility might be realized, and both depend on a robust program of accelerator R&D. Both labs are pursuing such an R&D program, and a national EIC detector R&D program has been in place since 2010. Establishing construction priority for an EIC will require a very strong recommendation in the next NSAC Long Range Plan, anticipated for the 2014/15 time period. In preparation for the next Plan, the future EIC user community, in concert with BNL and JLab, must further strengthen the science case and generate credible realization plans and cost estimates. Serious discussion of a proposed EIC facility at the next Long Range Plan must be justified by its own compelling science program, and as a natural stepping stone to the technology needed for the full EIC science program.

In the light of these considerations, we request that the EICAC resume its periodical reviews of the progress in the EIC planning process, and provide feedback and advice, on the following issues:

- 1) Development of a compelling science program suited to justify a new facility of EIC's project scope
- 2) Progress in R&D on critical accelerator and detector technology
- 3) Planning milestones, management proposals and design reports
- 4) Establishment of an international EIC user community of sufficient size, skill, and commitment
- 5) Credible machine and detector cost estimates, including possible staging options
- 6) Collaboration of BNL and JLab and the future user community on all aspects of the EIC project

We anticipate convening 1 or 2 meetings of the EICAC per year. The next meeting will focus on presentations and evaluation of items (1)-(4) above. The meeting should also result in the setting of expectations for items (5-6).

APPENDIX II

Agenda EICAC Meeting, 2/28-3/1/2014

Friday, February 28:

8:30 am	Welcome	
8:40 am	Introduction	(B. Mueller / R.McKeown)
9:00 am	Science Overview	(Z. Meziani)
10:00 am	Facility Overview BNL	(T. Roser)
11:00 am	Coffee Break	
11:30 am	Facility Overview JLab	(F. Pilat)
12:30 pm	Lunch	
1:30 pm	Detector overview JLab	(P. Nadel-Turonski)
2:00 pm	Detector overview BNL	(E. Aschenauer)
2:30 pm	Parallel sessions (Facilities; Science & Detectors)	
4:30 pm	Coffee Break	
5:00 pm	Closed Committee session (Report on parallel sessions and HW list)	
6:00 pm	HW list	

Saturday, March 1:

8:30 am	HW Presentations & Discussion	
10:00 am	Coffee Break	
10:30 am	Closed Committee session	
1:00 pm	Lunch	
1:45 pm	Closeout	
2:30 pm	EOB	

Parallel Sessions (Feb 28, 2:30 pm – 4:30 pm)

Facilities:

2:30 pm	e-gun and machine R&D	(I. Ben-Zvi)
2:50 pm	FFAG and Spin Transport	(V. Ptitsyn)
3:10 pm	IR Design and Backgrounds	(D. Trbojevic)
3:30 pm	Cooling and Accelerator R&D	(Y. Zhang)
3:50 pm	Spin Transport	(F. Lin)
4:10 pm	IR Design	(V. Morozov)

Science & Detectors:

2:30 pm	Hadron structure	(H. Gao)
3:00 pm	Low-x physics	(T. Ullrich)
3:30 pm	Nucleus as QCD laboratory	(W. Brooks)
4:00 pm	Generic EIC Detector R&D	(T. Ludlam)

APPENDIX III

2014 EICAC Membership

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