eRHIC: The Electron Ion Collider at BNL and Its Spin Physics Program

Abhay Deshpande

Department of Physics & Astronomy, SUNY at Stony Brook, NY 11794-3800 &
RIKEN BNL Research Center, Brookhaven National Laboratory, Upton NY 11973-5000

Abstract. We motivate the need for a future high luminosity, high energy polarized collider capable of deep inelastic scattering of polarized nucleons and nuclei. We propose that building a state of the art electron beam facility near the Relativistic Heavy Ion Collider (RHIC) complex to use one of its beams for such a facility would be the most cost effective way to achieve the physics goals. After a brief introduction to eRHIC project at BNL we present the spin physics program at eRHIC. The unpolarized e-A physics program and technical status of the collider design and detector ideas are discussed in other talks.

Keywords: eRHIC, nucleon spin, RHIC, heavy ion, low-x, gluon polarization, weak structure functions, Bjorken sum rule, strong coupling constant, confinement, color glass condensate
PACS: 21.10.Hw, 23.20.En, 24.85.+p, 25.30.-c

A (VERY) BRIEF HISTORY & STATUS OF QCD

Understanding the fundamental structure of matter is one of the central goals of scientific research through the ages. Towards the end of the last century scientists developed the theory of strong interactions, Quantum Chromodynamics (QCD), which explains all strongly interacting matter in terms of point-like spin half particles, called quarks, exchanging gauge bosons called gluons. During the last 30 years, experiments have verified QCD quantitatively in collisions involving exchange of large momenta between participants. Quarks and gluons are always confined, yet at the large momentum exchange regime, at distances scales smaller or comparable to the proton size, they seem to behave as if they are free. The discovery of proton's substructure in the late 1960s at SLAC led to a Nobel prize in 1990s to Friedman, Kendall and Taylor. The phenomena that quarks and gluons are quasi-free at short distances, follows from a fundamental property of QCD known as asymptotic freedom. For identifying and understanding this unique characteristic of QCD, Gross, Politzer and Wilczek received the 2004 Nobel prize in physics.

When the interaction distance between quarks and gluons becomes comparable to or larger than the typical hadronic size, the fundamental constituents of the nucleon are no longer free. They are bound by a strong force that does not allow for the observation of colored objects. Most hadronic matter exists in this regime where the symmetries of the quark-gluon interaction are hidden. The QCD calculations of hadrons in terms of dynamic properties of quarks and gluons is as yet impossible. The only hope seems to be to carry out *ab initio* QCD calculations in strong QCD regime using Monte Carlo techniques on large scale computers.

Experimentation in the field of QCD has been the only way to gain insights and new knowledge so far. This has been going on for decades at SLAC, FNAL, CERN, DESY and BNL accelerator facilities. Measurements of structure function including its spin information, verification of many QCD predictions, determination of the strong coupling constant and its scale dependence, all have an experimental foundation.

COMPELLING QUESTIONS IN QCD AND A NEXT GENERATION COLLIDER

QCD has been accepted as the Standard Model of the strong interactions. Despite its great success in describing the strong interactions a detailed understanding of how QCD works at a detailed level is still a mystery. We broadly divide the compelling and un-understood questions in to the following three:

- What is the gluon distribution in an atomic nucleus?
- How does the spin structure of the nucleon understood in terms of its quark and gluon constituents?
- How does the process of hadronization exactly evolve starting from a soup of quarks and gluons?

Since we do not seem to be able to explain these phenomena quantitatively, it is clear that we still do not understand the subtleties of the theory of QCD. It should be the main motivation for detailed, comprehensive precision tests in experimental QCD.

We propose that a next generation lepton-nucleon(-nucleus) collider facility with high luminosity and capable of polarizing both the lepton and the hadron beam be built to study, test and understand QCD [1]. With precision studies in mind we propose a lepton (electron/positron beam), as QED is as yet the best understood interaction in nature and by judiciously choosing the experimental beam parameters, one can maximize sensitivity to different regions of quark and gluon distributions. To fully explore the kinematic regions dominated by quark(high x) *and* gluons(low x) we propose that this facility have a *variable* center-of-mass (CoM) energy (CoM Energy range from ~30-100 GeV). Up to 30 has been explored in fixed target experiments. Since the QED interaction between the lepton probe and the hadron target is weak, we propose a high luminosity ($\sim 10^{33}$ $cm^{-2}sec^{-1}$). To explore the spin properties of the nucleons protons and neutrons, we will need polarized protons and either deuteron or polarized ^{3}He). To understand the QCD in nuclei, where the gluon densities are expected to be extremely high perhaps forming a new phase of matter known as color glass condensate, one would need (heavy) nuclear beams as well. A large variation in A (the atomic number) would be highly desirable. And finally, to supplement such a facility with measurements of the complete event characteristics, a comprehensive detector capable of high rates, large acceptance, good particle identification, hadronic as well as electromagnetic calorimetry, efficient precision-tracking in the inner detector. It would be also highly desirable to have high efficiency and acceptance for the very large rapidity regions.

We believe that all reasonable analyses of the physics goals coupled with the present fiscal reality will lead to a proposal as we are making: the full utilization of existing RHIC in this proposal, i.e. to build an electron beam facility next to RHIC to collide with one of the RHIC rings. We call this facility the eRHIC [2].

The recent excitement in the field of understanding of the parton distributions in the nuclei comes from RHIC (d-A) collisions, and will be described as a motivation for the e-A physics at eRHIC [3]. Ideas of the detector presently under consideration are described in [4]. In this article we briefly describe eRHIC and then we go on to describe highlights of the polarized e-p physics program at eRHIC.

E-RHIC AT BNL

Relativistic Heavy IonCollider (RHIC) was commissioned in 2001. Since then it has not only realized every expectation of its design performance, but in astoundingly many instances, exceeded them. It has reached and exceeded its instantaneous luminosity goals for both heavy ion and proton collisions. It has exceeded its design goals for polarization at this stage of the program. Every year these performance parameters have been achieved in shorter and shorter time since machine turn on. We hence propose that a 10 GeV polarized electron/positron beam facility with high current be added to the RHIC complex. It will allow in addition to the presently possible polarized proton-proton and heavy ion collisions, polarized e-p and e-A collisions. This will make RHIC a unique QCD laboratory in the next decade.

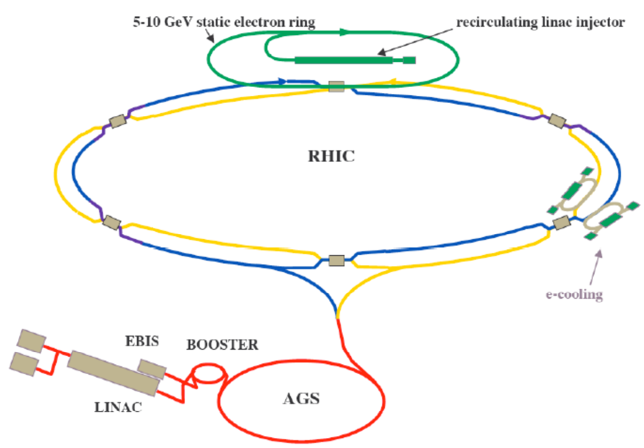

FIGURE 1. The layout of the eRHIC, the ring-ring design as proposed in the Zero-th Design Report (eRHIC-ZDR). A 10 GeV LINAC will inject in to an electron ring to be built next to the RHIC, and will have one interaction region. The linac injection energy range will be from 5 GeV/c to 10 GeV/c, with most optimal polarizaton conditions between 7-10 GeV/c electron/positron beam energy.

Figure 1 shows one of the two design layouts of the eRHIC as proposed in the Zero-th Design Report (ZDR) submitted to the BNL management in April 2004 [5]. Other options including a 10 GeV Energy Recovery Linac (ERL) colliding with one of the RHIC rings. A possible layout of the LINAC design which enable more than one IR has also been described in the appendix of the ZDR [5].

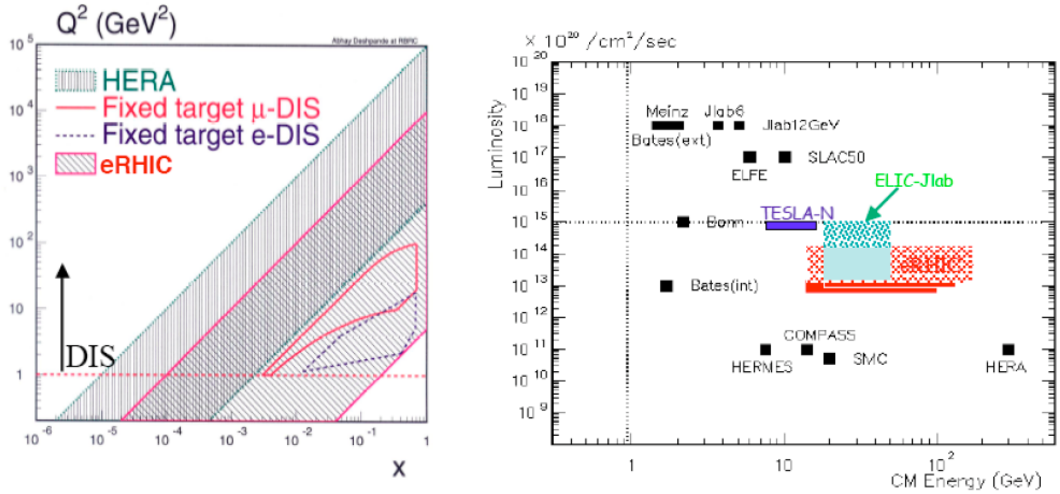

FIGURE 2. (a) The x-Q^2 range in the kinematic region that will be explored by the eRHIC (region between the two magenta lines) with 50-250 GeV/c variable proton beam energy and 5-10 GeV/c electron beam energy. Both beams will be polarized. (b) The center of mass vs. luminosity that eRHIC facility is planning to explore (shown in red). Notice the large range in the CoM possible, uniquely at eRHIC as against other DIS fixed target and collider facilities in the world. The Tesla-N and ELIC at Jlab are other future facilities envisioned.

POLARIZED E-P SCATTERING AT ERHIC

Polarized deep inelastic scattering has only been performed so far in fixed target experiments at SLAC, CERN and DESY [2] and were limited to a CoM energy of ~27 GeV. Figure 2 shows the regions explored by the fixed target facilities. A large x-Q^2 region is being explored by HERA at DESY, but with unpolarized proton beams. eRHIC will enable ~100 GeV in CoM with 250 GeV/c polarized proton beams of RHIC and ~10 GeV/c electron ring facility we propose to build. This will allow low x measurements of the spin structure functions up to 10^{-4} in Bjorken-x in a region of $Q^2 > 1$ GeV^2 (See Figure 2a). In terms of luminosity the design we hope to achieve is 100 times more than the HERA, and the other fixed target facilities (SMC and COMPASS at CERN, and HERMES at DESY). Other possible future facilities being discussed around the world are the TESLA-N (fixed target facility with the TESLA electron beam on a polarized target) and ELIC (Electron Light Ion Collider) being contemplated at Jefferson Laboratory [6].

While it is impossible to give a complete description and significance of the polarized DIS measurements that would be possible at eRHIC, we give a list of highlights and comment on some of them later. It is assumed that a new detector with at least the functionality of one of the HERA Detectors (H1 or ZEUS) will be built [4]. Other detector ideas for a dedicated forward physics measurement are also being discussed [7]. A selection of measurements we could make at eRHIC are [1,2] below:

- Measurement of the spin structure function of the proton and neutron at lower Bj-x than any other present or future facility (low x for $Q^2 > 1$ would be around 10^{-4}.

- The neutron spin structure function will be measured using polarized ^3He beams. Measurement of proton and neutron to low x will allow the test of one of the most fundamental relations of QCD: the Bjorken Spin Sum Rule.
- The extension of measurement of the Bjorken integral to low x will further allow the evaluation of the strong coupling constant α_S

- Measurement of polarized gluon distribution over the largest range of x: using two systematically different methods:
  - The scaling violation of g1 spin structure function
  - Using asymmetry produced in 2-Jet events produced in photon-gluon fusion in e-p scattering
- Measurement of the spin structure of the "resolved" virtual photon in terms of its quark/gluon components
- The parity violating spin structure function g_5 which will allow us to directly access the spin contributions from heavy quarks and anti-quarks through virtual W exchange
- Measurement of exclusive processes such as Deeply Virtual Compton Scattering (DVCS) will allow first look in to the low x behavior of the generalized parton distributions (GPD). GPDs hold a promise for future measurement of the orbital angulr momentum in the nucleon.
- Transversity and other transverse spin effects which have recently been discovered at fixed target ep and pp experiments and their connection to the orbital angular momentum

The list of such measurements is long and exciting. Special mention should be made of the diffractive measurements in the spin DIS which has not been explored to any significant level so far, however, recent surprises in the unpolarized sector begs us to explore this as yet unexplored region.

SUMMARY & OUTLOOK

In summary, we propose that building eRHIC at BNL in not too a distant future is the most cost effective way to study and understand QCD to its fullest extent. In addition the DIS technique, RHIC is a facility in which hadron-hadron scattering between nucleons and nuclei is on going. Adding a possibility to do DIS only enhances this facility. We believe this will allow us to have a very unique QCD facility in the world.

The eRHIC collaboration is forming. Detector simulation projects are starting up [4]. Physics interests are being explored. The basic design of the accelerator complex and the interaction region now exist in form of a ZDR. This work will continue in the next few years and the collaboration is expected to seek the blessing of the Nuclear Science Advisory Committee (NSAC) in their next Long Range Planning (LRP) exercise. This is expected to happen some time around 2007.

ACKNOWLEDGMENTS

The author thanks the organizers of this meeting, on behalf of eRHIC collaboration, for allowing the eRHIC collider presentations in the plenary session in three separate but complementary talks. This work was supported by RBRC.

REFERENCES

1. A White-Paper submitted to long range planning meeting of the NSAC, *The Electron Ion Collider*, BNL-**68933-02/07-REV**
2. A. Deshpande et al., *Study of the Fundamental Structure of Matter with An Electron Ion Collider,* to be published, **Volume 55**, Ann. Rev. of Part. & Nucl. Sci. December 2005, hep-ph/0506148
3. J. Jalilian-Marion, *d-A Physics at RHIC a motivation for the e-A collider at BNL*, these proceedings
4. B. Surrow, *eRHIC Accelerator & Detector Design*, these proceedings
5. L. Ahrens et al, eRHIC Zeroth Design Report, Edited by V. Ptitsyn & M. Farkhondeh; **http://www.bnl.gov/eic**
6. C. Keppel, *The Jlab upgrade plans,* these proceedings
7. I. Abt et al., *A Detector for Forward Physics at eRHIC: Feasibility Study*, hep-ph0407053