RHIC II/eRHIC White Paper

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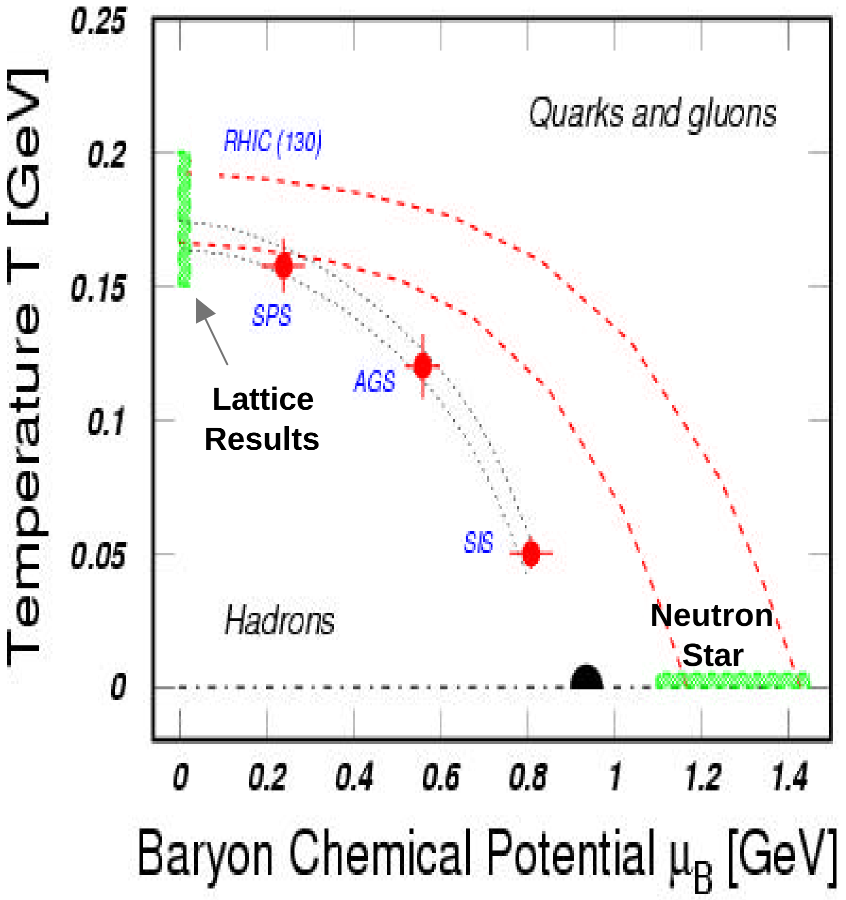
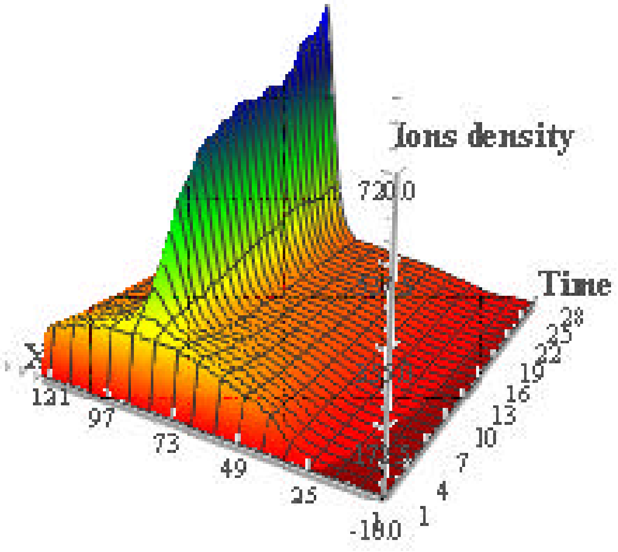


Submitted to the
NSAC Future Facilities
Subcommittee
February 15, 2003



RHIC II/eRHIC White Paper

Submitted to the NSAC Sub-Committee on Future Facilities

By T. Hallman, T. Kirk, T. Roser, BNL and R.G. Milner, MIT

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Executive Summary

We present here, two stages in the evolution of RHIC: 1) provision of a ***10X luminosity upgrade*** to the machine and its two large detectors to exploit the new realm of QCD phenomena revealed by the present high-energy, heavy ion physics investigations (**RHIC II**); 2) construction of a 10 GeV electron ring and a new experimental detector to provide ***electron-heavy ion collisions*** to explore a whole new class of high-energy, heavy ion physics topics (**eRHIC**). In this white paper, we present the ***importance of the science*** provided by these facility improvement steps and note their ***readiness for construction***.

RHIC, built and operated for the U.S. Department of Energy (DOE), now serves as the premier laboratory in the world for the study of Quantum Chromodynamics (QCD) in AA, pA, and polarized pp interactions. Its core scientific mission in the first phase of operation has been to understand the role of quarks and gluons in the bulk structure of nuclear matter and to search for new phenomena predicted by QCD at extremely high energy densities. The next stage, ‘RHIC II’, will continue further heavy ion studies to reveal details of these phenomena, including the study of rare processes that require large amounts of integrated luminosity.

In parallel with the luminosity upgrade, but requiring a longer construction period, we propose to initiate the study of electron-heavy ion and polarized proton e-p collisions at high energies to explore a whole new class of physical phenomena, including the hypothesized new state of matter called the ‘Color Glass Condensate’. This new RHIC mission will require construction of a new 10 GeV electron ring plus a new detector optimized for eRHIC collisions. The associated project is called ‘eRHIC’. The current plan is to combine RHIC II and eRHIC in one project.

The high luminosity RHIC physics program will reap a rich continuing harvest of fundamental science from the nation’s RHIC investment as well as open entirely new horizons for fundamental QCD studies with eRHIC. The program proposed below is fully consistent with the vision of the 2002 Nuclear Science Advisory Committee Long Range Plan, which states, “An upgrade program such as the RHIC II initiative will allow in-depth pursuit of the most promising observables characterizing the deconfined state.”

eRHIC is essential for the study of the fundamental structure of matter. Many of the important scientific questions addressed by eRHIC involve the role and behavior of quarks and gluons in atomic nuclei; *eRHIC is first and foremost a nuclear physics machine.* All future planning for the field of hadron structure worldwide involves serious consideration of electron-ion colliders. Further, eRHIC has sparked considerable synergy among the different sub-fields of nuclear physics – electromagnetic, hadronic and heavy ion communities. ***Both RHIC II and eRHIC are absolutely essential - and absolutely central - to the nation’s future nuclear physics research program***.

Physicists in the RHIC and Electron-Ion Collider Collaborations are pursuing essential R&D for the detector needs of the envisioned program and BNL and MIT physicists are pursuing machine R&D for the required accelerator improvements. This work is noted in the body of the report below. We propose that construction could start for a combined RHIC II/eRHIC line item construction project in FY 2008, with long-lead procurements in FY 2007. These dates have been discussed with DOE but are still preliminary. We also offer a preliminary Total Estimated Cost (TEC) for RHIC II/eRHIC of $664M in FY 2003 dollars. The division between the RHIC II and the eRHIC portions of the combined project are 23% and 77%, respectively. This estimate will require further refinement before it can serve as a project baseline.

Importance of the Science

The science evolution of RHIC encompasses two important missions: 1) the study of ***rare RHIC physics processes*** that are only practical with a factor-10 luminosity upgrade; 2) exploration of ***high-energy electron-ion collision physics*** that will be unique in the world. We discuss these two feasible and compelling science missions in this paper.

The Physics of High Luminosity RHIC

Beyond the first phase of discovery at RHIC, beginning during the second half of this decade, the research program will turn to a broader and deeper exploration of the fundamental properties of matter created by heating the QCD vacuum, the accompanying phase transitions, and the extremely hot, super-dense states that precede the formation of a thermal plasma of quarks and gluons. These studies will address: the nature of chiral symmetry breaking and how is it related to the masses of the hadrons; the relationship between the de-confinement and chiral transitions; the nature of a possible saturated gluon state in strongly interacting particles. The new matter produced at RHIC will provide a unique laboratory for a full, detailed exploration of the fundamental properties of QCD. Exhaustive studies of proton-nucleus and polarized proton collisions will contribute to a growing base of knowledge, providing essential information on the initial conditions, and the role of spin as a fundamental component of QCD. The evolution of a RHIC collision is shown in Fig. 1.

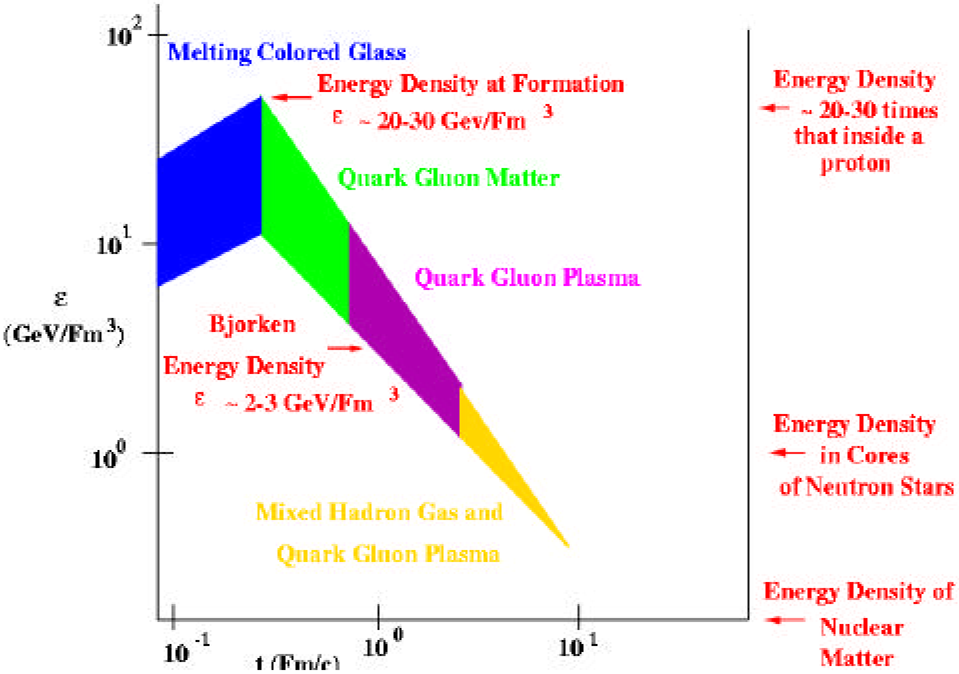


Fig. 1. Estimates of the energy density vs. time during the evolution of a collision. The colored intervals depict a predicted sequence of states, based on the very large initial energy density indicated by the data from RHIC experiments. The energy density of a normal nucleus is 0.14 GeV/fm^3. The horizontal scale is in units equal to the time interval for light to travel a distance of one Fermi: roughly the size of a single proton.

The detector programs during the high luminosity era will center on precision measurement e.g., of the dynamics of heavy flavor (charm and beauty) production as a means of studying the various stages of formation and hadronization of QCD matter, the measurement of observables related to hard-scattering of partons in the kinematic range where perturbative QCD calculations can be reliably carried out, studies of electromagnetic probes (including soft photons and electrons) directly related to the formation and evolution of a de-confined state, and extended capability for the study of new effects related to the spin structure of the nucleon with the RHIC Spin program.

Studies key to fully characterizing the properties of the quark-gluon plasma, and the QCD vacuum will include:

- Measurement of the gluon density of the plasma through high p_t studies of jet quenching using jets tagged in coincidence with high p_t photons (effectively producing "beams" of high energy partons to probe the plasma) and flavor-tagged jets to study the quark mass dependence of energy loss;
- "Complete" mapping of the quarkonium states (J/ψ, Upsilon and excited states) to measure the thermodynamics of de-confinement through varying dissociation temperatures of the quarkonium states;
- Studies of the effects of chiral symmetry restoration in the dense medium via low-mass electron pair spectra;
- Large-statistics measurements of partonic collectivity through correlations among light-, strange-, and charmed-quark states (e.g. participation of heavy quarks in flow as a probe of the thermal evolution of the plasma);
- Direct photon spectra via $\gamma\gamma$ HBT to provide a unique measurement of QGP temperature, size, lifetime; high pt direct photon production to study the saturated gluon phase at very early times.

Additional studies will focus on the search for new phenomena in bulk QCD matter such as strong CP violation associated with the de-confinement phase transition. Such studies require very large samples of unbiased data ($>10^8$ events).

The RHIC polarized proton program will also benefit from the luminosity upgrade, which is expected to result in a luminosity increase of a factor of ~ 4 for polarized proton collisions. This improvement will significantly enhance the measurement at RHIC of the spin dependent gluon distribution of the protons $\Delta G(x)$ using direct photons, and first measurements of sea quark polarization (ubar and dbar) using parity violating W decay. The enhanced PHENIX and STAR detector capability planned for high luminosity running will allow additional measurements for the spin program, such as studies of quark mass effects with b-quark jets, and probes of transversity via A_{TT} in quark-quark di-jets.

The high-luminosity, heavy ion studies discussed above are essential to fully characterize the QCD matter expected to be produced at RHIC. The matter produced at higher energy in an eventual heavy ion program at the LHC will likely be much more sensitive to the low Bjorken-x behavior of the parton distribution functions and may well be fundamentally different than that produced at RHIC. As a practical matter, the type of measurements planned for the high luminosity physics program at RHIC will not begin at the LHC until well after the initial survey phase of that program, some time near the end of this decade. These measurements require large data samples, taken over long running periods with multiple beam conditions. A detailed understanding from the RHIC program may well be required to help guide the LHC experiments to those measurements where the high energy may be exploited to best advantage, given the limited heavy ion running time (~1 month per year) planned to be made available by CERN.

The Physics of eRHIC

Over the last five years, there has been substantial international interest in a high luminosity (approximately, 10^{33} $cm^{-2}s^{-1}$) polarized electron-ion collider covering a CM energy range from about 30 to 100 GeV. Workshops have taken place in Europe in 1997 and in the United States at IUCF (1999), BNL (1999),Yale (2000) and MIT (2000). An Electron-Ion Collider (EIC) collaboration was formed in fall 2000 and in the United States, the 2001 Long Range Plan favorably endorsed the science of EIC and urged R&D support as a high priority. In March 2002, a series of workshops at BNL, involving over 150 physicists from around the world, resulted in a plan to produce a conceptual design of an electron-ion collider within three years. Further, it was agreed to develop this design around the existing Relativistic Heavy Ion Collider (RHIC) at BNL. This design is known as eRHIC.

The primary scientific motivation for eRHIC is to probe the fundamental quark and gluon structure of strongly interacting matter. Essentially all the observable matter in the physical universe is in the form of atomic nuclei. The Standard Model tells us that these nuclei are, to a good approximation, systems of bound nucleons, which themselves are made of nearly massless constituents bound by powerful gluon fields. The advancement of current and planned research into the fundamental structure of matter will require by the end of this decade a new facility, eRHIC.

The scientific opportunities provided by eRHIC are outlined in the February 2002 white paper "The Electron Ion Collider: A high luminosity probe of the partonic substructure of nucleons and nuclei" (BNL-68933). Highlights of that paper include:

- *Quark and gluon distributions in the nucleon*
  eRHIC offers a unique capability for measuring `flavor tagged' structure functions by providing access to a wide range of final states. The collider geometry makes measurement of semi-inclusive reactions very efficient so that quark and gluon distributions in nucleons, nuclei, and possibly even mesons can be mapped in a flavor tagged mode.
- *Spin structure of the nucleon*
  eRHIC, operating at the highest center-of-mass energy, will provide crucial data on the proton's spin-dependent structure functions at lower x than possible in any previous experiment. This is urgently required to verify the dramatic QCD prediction based on existing data. In addition, eRHIC will provide precision measurement of the polarization of the sea quarks, currently a matter of controversy among sophisticated and successful models of the nucleon.
- *Correlations between partons*
  A complete characterization of the partonic substructure of the nucleon requires a description of the correlations among parton densities. Progress in this area can be realized by measuring hard exclusive processes expressed (the result of new QCD factorization theorems) by a new class of 'Generalized Parton Distributions'. The eRHIC kinematics are optimal for measuring these processes.
- *The role of quarks and gluons in nuclei*
  eRHIC opens new horizons fundamental to nuclear physics by determining the quark and gluon momentum distributions in nuclei. In particular, the gluon distribution in nuclei is at present almost undetermined. Further, its determination is vital to understanding the complicated processes underway in relativistic heavy ion collisions.
- *Hadronization in nucleons and nuclei*
  How do the colored quarks and gluons struck by the virtual photon in deep inelastic scattering evolve into the colorless hadrons that eventually appear? This process is one of the clearest manifestations of confinement: the asymptotic physical states must be color neutral. Hadronization is a complex process that involves both the structure of hadronic matter and the long range nonperturbative dynamics of confinement. The eRHIC program will make it possible to observe the complete array of decay products in deeply-inelastic scattering of electrons from the nucleon and nuclei.
- *Partonic matter under extreme conditions*
  Very high-energy, deep inelastic scattering from nuclear targets offers opportunities to study partonic matter under extreme conditions. Measurements of the proton structure function at low x show that the gluon distribution grows rapidly with decreasing x. When the gluon density becomes large, it may saturate and give rise to a new form of matter known as the 'Color Glass Condensate'. The eRHIC will enable a search for this exotic aspect of proton structure in nuclei by using gluon observables.

Detectors

Realization of the high luminosity program of RHIC II and the new physics of eRHIC depend on the provision of experimental detectors of appropriate capability and sophistication. The following material lays out the plans of the physicists who will make these requirements a reality. In the case of high-luminosity RHIC, the two largest existing RHIC detectors, STAR and PHENIX, have developed strong and compelling plans for evolving their detectors to meet the challenges of the 10x luminosity upgrade and the anticipated rare processes that are already seen to be important to investigate. In the case of eRHIC, a new detector is planned to be built at the 12-o'clock collision point of RHIC, where a new 10 GeV electron beam will intersect an existing ion or polarized proton beam to provide electron-heavy ion collisions. The present accelerator plan envisions that *high-luminosity, heavy ion collisions and electron-ion collisions can run simultaneously*, making maximum scientific use of the resources needed to support operations of the RHIC accelerator complex. The detector development plans of the two groups are presented here.

High Luminosity RHIC Detector Upgrades

In the past two years, a series of workshops and town meetings were held in preparation for the 2002 NSAC Long Range Plan, to explore the issue of whether a new major detector would be required for the high luminosity RHIC physics program. These studies showed that the physics goals of the high-luminosity RHIC physics program are most effectively achieved through evolutionary upgrades to the existing PHENIX and STAR detectors, maintaining a strong physics program for each detector through the remainder of this decade; new components will be phased in during the annual shut-downs. This approach will significantly extend the physics reach of PHENIX and STAR during the years up to 2010 and allow them to be fully "run-in" and capable of exploiting the full luminosity upgrade when the machine improvements are completed.

Both PHENIX and STAR have conducted a series of workshops to identify the detector upgrades required for the high luminosity RHIC physics program identified above. These upgrades comprise:

- Precision inner tracking devices capable of directly observing charm and beauty decays;
- Fast, compact, high-resolution Time Projection Chambers;
- "hadron blind" tracking for efficient rejection of Dalitz and conversion electron pairs to enable measurement of low-mass lepton pairs and low-p_t direct photons;
- Micro-electronics for fine-grain, low-mass detectors;
- Improved data acquisition and trigger techniques to handle very large data volumes at high rates.

A "fast-track" program of R&D to develop new technology for STAR and PHENIX for high-luminosity running was recently reviewed by an independent committee appointed by BNL management, the "RHIC Detector Advisory Committee", chaired by P. Braun-Munzinger. This Committee concluded the proposed R&D program was sound, and should begin right away, noting, "…after the beautiful measurements of bulk properties in AuAu collisions, the program will move into a phase where emphasis will shift towards studies with improved sensitivity for rare phenomena as well as studies requiring very large data samples."

The proposed program of detector R&D is focused on development of a suite of upgrades for PHENIX and STAR that will provide the necessary capabilities for high luminosity running. These include: 1) a hadron-blind tracker, silicon-pixel vertex tracker, inner TPC, and DAQ upgrade for PHENIX; 2) a micro-vertex detector, barrel TOF detector, FEE/DAQ upgrade, and compact TPC for STAR. Both experiments require upgrades to reach the 10x luminosity increase for Au beams at RHIC.

To be ready on the time scale suggested by the projected progress of the RHIC scientific program, the RHIC physics R&D plan calls for a robust program of detector and accelerator R&D beginning now. A series of incremental upgrades of the detector's capabilities are to be accomplished between now and 2010, within the base program as much as possible, to allow PHENIX and STAR to take full advantage of ongoing incremental improvements in detector capability and RHIC luminosity while preparing for high luminosity running near the end of the decade. During this period, both the collider and the detectors will evolve. An increase in luminosity to ~4x of the nominal design should be achievable by doubling the number of bunches (from 56 to 112 per ring) and increasing the strength of the focus of the beams at the collision points. This step requires no new accelerator hardware.

The start of construction to implement instrumentation for electron cooling and to finish upgrading the detectors would begin in 2008. This plan is fully consistent with a planned construction start for e-RHIC beginning the same year. This significant upgrade of the RHIC facility would result by 2013, in unparalleled capabilities for fundamental QCD studies in AA, pA, pp, and eA interactions. The plan takes into account the scientific priorities and planned developments for RHIC and eRHIC in a way that has positive benefits for the national program in the near term and provides a path-forward with modest investment to ensure the full scientific mission of RHIC can be carried out.

The eRHIC Detector

The design of an optimized detector for eRHIC is underway. This activity will require iteration between the machine design and the detailed simulation of the physics measurements. In particular, the detailed design of the electron-ion interaction region is closely coupled to the design of the eRHIC detector elements. However, it is certain that at least one central detector element will be required. This will require tracking of the scattered electron and hadronic final state, calorimetry to determined the final state energies, particle identification for both electron and hadrons and jet reconstruction. For example, the ZEUS detector at the electron-proton collider HERA contains many of these characteristics for high center-of-mass energies.

In addition to a central detector, many proposed measurements will require additional instrumentation at small angles in the forward or rear directions. For example, the detection of the complete final state in electron-nucleus collisions (as proposed by M.W.Krasny) will require additional magnetic elements and detector elements at small angles (see the February 2001 white paper). The measurement of hard exclusive processes, e.g. deeply virtual Compton scattering, requires detection of forward hadrons with high momentum.

Accelerator Improvements

RHIC Luminosity Upgrade

The present RHIC luminosity is limited by intra-beam scattering (IBS), which is particularly severe with the high charge of the gold ions. The growth of the beam size due to intra-beam scattering can be overcome by cooling the beams with a high intensity cold electron beam. To cool the 100 GeV/n gold beam with 10^9 ions per bunch in RHIC a 54 MeV electron beam with an average current of about 100 mA is required. In this case the charge of each electron bunch is about equal to the charge of the ion bunch. The high beam power of about 5MW of the electron beam makes it necessary to recover the beam energy by decelerating it in the super-conducting linac as has been successfully demonstrated at JLab with a 50 MeV, 5 mA electron beam.

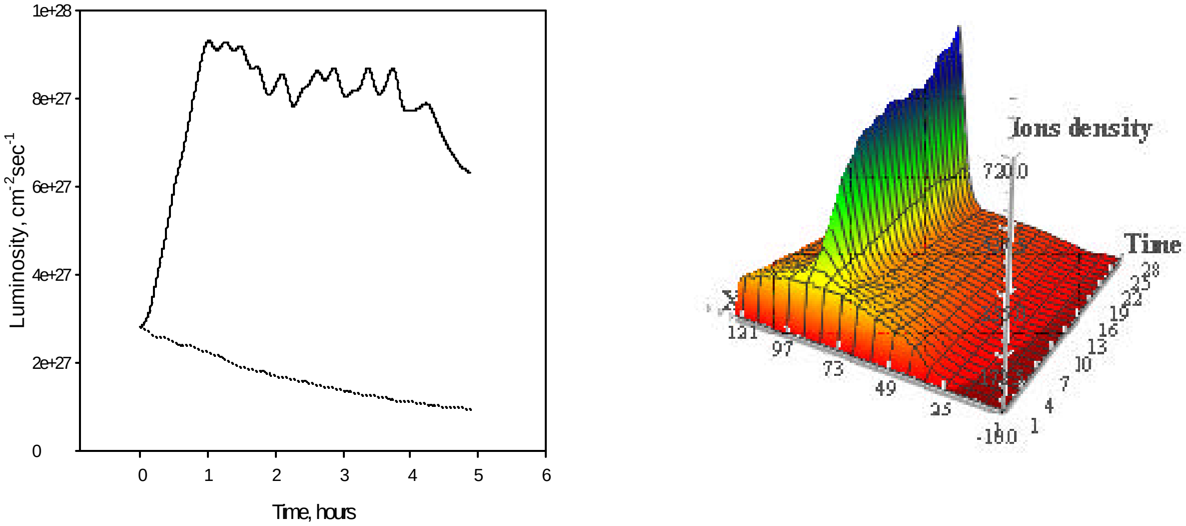


Fig.2 Luminosity behavior with (top curve) and without (bottom curve) electron cooling.

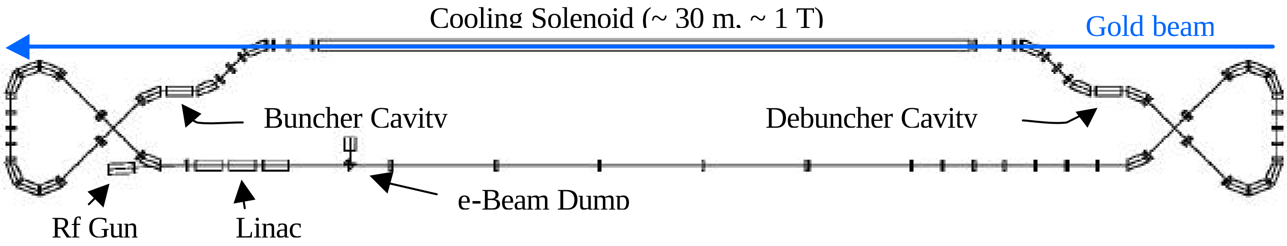
The electron cooling increases the RHIC luminosity in two ways as shown above in simulation results: First, the IBS induced growth of the beam bunch volume is arrested, making the peak luminosity nearly constant over most of the store time. Second, the beam size can be reduced as shown on the right side of Fig. 2, leading to an increase in the peak luminosity.

Electron cooling has the most dramatic effect on the luminosity of gold collisions in RHIC. However, it also improves operation with polarized protons due to the lower beam emittance.

	w/o e-cooling	**with e-cooling**
Gold collisions (100 GeV/n x 100 GeV/n):		
Emittance (95%) [πμm]	15 → 40	15 → 3
Beta function at IR [m]	1.0	1.0 → 0.5
Number of bunches	112	112
Bunch population [10^9]	1	1 → 0.3
Beam-beam parameter per IR	0.0016	0.004
Peak luminosity [10^{26} cm^{-2} s^{-1}]	32	90
Average luminosity [10^{26} cm^{-2} s^{-1}]	8	70
Pol. Proton Collision (250 GeV x 250 GeV):		
Emittance (95%) [πμm]	20	12
Beta function at IR [m]	1.0	0.5
Number of bunches	112	112
Bunch population [10^{11}]	2	2
Beam-beam parameter per IR	0.007	0.012
Luminosity [10^{32} cm^{-2} s^{-1}]	2.4	8.0

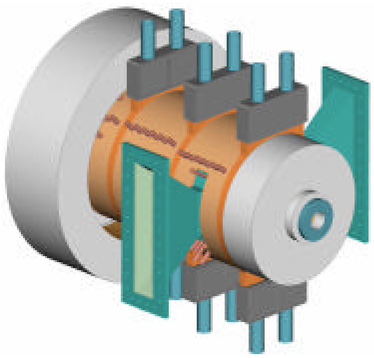
The proposed RHIC luminosity upgrade changes neither the time interval between bunch crossings at the detectors nor the available space for the detectors, making it compatible with the installed RHIC detectors.

Electron cooling is a technique to reduce the emittance of an ion beam circulating in a storage ring. A high quality electron beam is velocity-matched and merged with an ion beam over a fraction of the storage-ring circumference, immersed in a solenoidal magnetic field. The cooling is mediated by scattering of the ions on the electrons, a process in which the ions lose random-motion energy to the electrons. Since the electrons are constantly renewed, the process leads to a continuous improvement in the quality of the ion beam. In the past 35 years of development electron cooling has been applied successfully to various low energy storage rings, which may be found in numerous laboratories across the world.



The proposed RHIC electron cooling system consists of a cooling section solenoid, bunching and debunching optical inserts and cavities, an electron linac structure, an electron gun and a beam dump. Solenoidal transport of the electron beam through an extended cooling section is needed to suppress space-charge divergence of the electron bunch and prevent electron-ion transverse instabilities. The electron gun has to be properly immersed in a solenoidal magnetic field in order to match the beam size and divergence to the magnetic field strength in the cooling section. The debunching optical insert has to increase the electron bunch length to reduce the electron relative momentum spread to a value of about 10^{-4} required for effective cooling. After deceleration and beam energy recovery, the electron beam of about 1 MeV is dumped. The 30 m cooling section is the longest available straight section in RHIC.

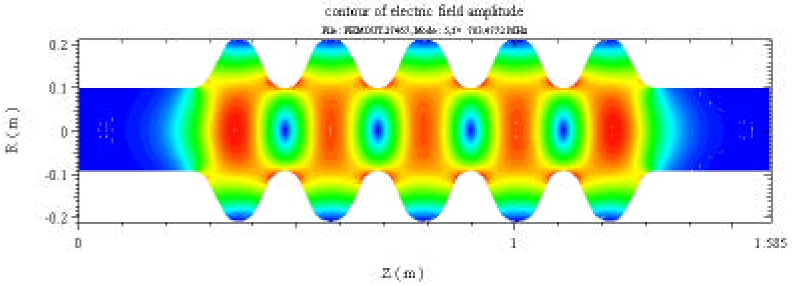
Electron cooling of the high energy, heavy ion beams in RHIC extends beyond presently operating electron cooling facilities in several regards: the use of bunched electron beam accelerated by a linear accelerator, beam cooling during collider operation, and the use of magnetized, angular momentum-dominated electron beam to avoid recombination of e^- and Au^{79+}.

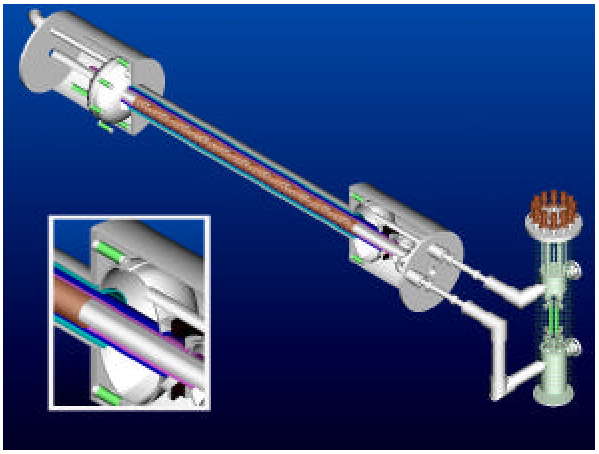


An R&D program has started to develop the critical items of the RHIC electron cooling system.

The high-brightness, high-current electron source consists of a rf photo-cathode gun operating at 700 MHz capable of providing 2.5 MeV and about 100 mA current.

A 700 MHz super-conducting cavity for the energy-recovering linac will be developed that is capable of accelerating the high intensity electron beam without causing beam-breakup.



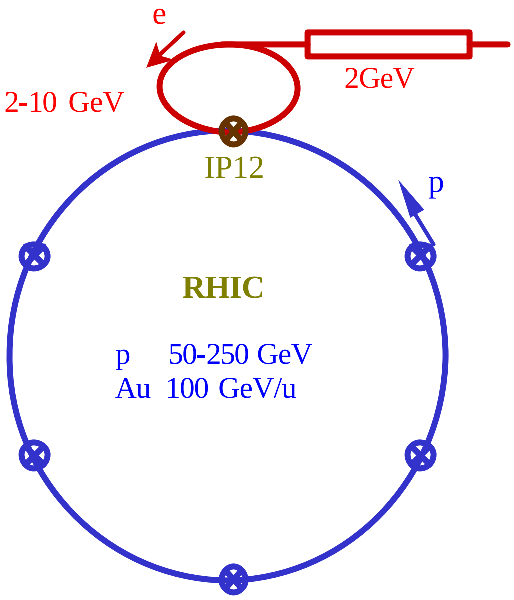


The feasibility of a long, highly uniform super-conducting solenoid for the electron cooling section will be demonstrated with a prototype.

eRHIC

The present design of an electron-ion collider, based on the existing RHIC machine, requires the construction of an electron accelerator ring with 5-10 GeV energy, that will have 1/4 of the RHIC circumference and collides with the ion beam in one of the existing RHIC experimental areas. The injector is either a 2 GeV linac or a 2 GeV Booster ring. The electron beam is then accelerated to collision energies and acquires polarization through the synchrotron radiation process.

The electron ring consists of two arcs with regular FODO structure and two straight sections: one includes the interaction region and the other injection and rf systems. A special design of the electron ring bending magnets, with relatively high field (2 T) in a short central part of the magnet, will decrease the polarization time at the lower energies. These so-called "super-bends" magnets will allow a polarizing time of only 5-16 minutes, depending on the electron beam energy. The polarization setup for the electron beam also includes a pair of solenoidal spin rotators around the interaction region to produce longitudinal polarization.

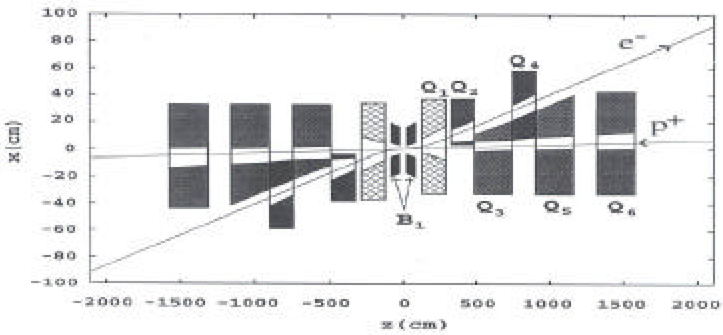


The RHIC ion rings already have dedicated magnet insertions, Siberian Snakes and spin rotators, in order to provide high energy polarized proton beam for the collisions.

Main beam parameters for the present design for e-p and e-Au collisions are shown in the Table below. Improvements in the electron beam emittance are being studied that could bring the luminosity to 10^{33} cm^{-2} s^{-1}.

	p	e	Au
Circumference [m]	3833	958.25	3833
Energy [GeV]	250	5-10	100/u
Number of bunches	360	90	360
Bunch population [10^{11}]	1	1	0.01
Beam current [A]	0.45	0.45	0.36
Rms emittance [10^{-9}m]	9-13	45-63	9-13
Beta function at IP [m]	0.5	0.1	0.5
Beam size at IP [mm]	0.07-0.08	0.07-0.08	0.07-0.08
Beam-beam parameter	0.005-0.0035	0.05-0.014	0.005-0.0035
Luminosity, [10^{33} cm^{-2} s^{-1}]	0.5-0.35		0.005-0.004

The electron and proton beam currents are quite achievable based on the experience of recent high luminosity electron (B-factories) and proton (Tevatron, RHIC) colliders. In order to achieve and maintain the required Au beam emittance during collisions the electron cooling system discussed above is required. The electron cooling is also required for experiments using the proton beam below 200 GeV. The proposed design of the electron-ion collider involves minimal changes in the existing ion RHIC rings. Just one interaction region needs to be reconstructed to provide electron and ion beam separation at the interaction point. One of the suggested separation schemes is shown below, where the beam separation is initiated by the vertical field at the collision point.



Thus the present design of eRHIC with a self-polarizing electron ring seems to be a feasible solution for an electron-ion collider that could be realized using the present level of the accelerator technology.

Readiness for Construction

The proposed full set of improvements to the RHIC Facility discussed above are feasible and practical over a period of about 10 years and are planned to evolve sequentially. The first RHIC luminosity improvements, a factor of 4 over the base RHIC design, are realizable without any new accelerator hardware. The detectors can accommodate this luminosity increase by making incremental upgrades within the presently planned program funding over a period of a few years. These improvements are considered "programmatic" and are not regarded as part of the requested RHIC II/eRHIC construction project addressed in this paper.

The RHIC II luminosity upgrade for the heavy ion and spin program comprises the full-energy electron cooling of the RHIC beams plus substantial upgrades to the PHENIX and STAR detectors. This project component will have completed its necessary R&D and be positioned for a construction project start in FY 2008 if funding can be made available. It should even be ready for long-lead procurements in FY 2007 if the Nuclear Physics Program can provide appropriate resources. The RHIC II luminosity upgrade project for the accelerator and detectors can be completed in 3 years.

The eRHIC project component will also have completed its necessary R&D by FY 2007 and be ready for a construction project start as early as FY 2008. This project is projected to require 5 years for its completion. A set of cost and schedule bullets is provided here:

- R&D and preliminary design (incl. e-cooling): FY03 – FY08
- Construction FY08 – FY13
- Cost:

Electron-heavy ion collisions:	
10 GeV electron accelerator & storage ring	$200M
Detector for e-p/A collisions	$100M
Intersection region	$ 15M
Heavy ion Luminosity Upgrade:	
Electron beam cooling at full RHIC energy	$ 34M
Detector Upgrades for rare processes	$ 60M
Total Estimated Direct Costs	$409M
EDIA @ 15%; Contingency @ 25%; Project G&A @ 13%	$255M
Total Estimated Costs (w/o escalation)	$664M

Summary Comments

In summary, an upgrade of the RHIC machine and detectors to utilize a factor of 10 increase in luminosity for Au beams (a factor of ~4 for polarized protons) is absolutely essential after the initial heavy ion program discovery phase to allow a broader and deeper exploration of the fundamental properties of matter created by heating the QCD vacuum, the accompanying phase transitions, and the extremely hot, super-dense states that precede the formation of a thermal plasma of quarks and gluons. With this upgrade, RHIC will have unique, unparalleled capability for a full, detailed exploration of the fundamental properties of QCD. Exhaustive studies of proton-nucleus and polarized proton collisions will contribute to the base of knowledge needed for a complete understanding, providing essential information on the initial conditions, and the role of spin as a fundamental element of QCD.

Likewise, the creation of an electron-ion collider at RHIC will provide a unique world facility that allows new and compelling investigations of eA processes predicted by theory but experimentally realizable by no other contemplated facility. This too is a very compelling goal for international nuclear physics research.