Mid-Term Strategic Plan: 2006-2011
For the Relativistic Heavy Ion Collider
At
Brookhaven National Laboratory

Prepared by
Brookhaven National Laboratory
With the
RHIC Scientific Community

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Table of Contents

1 Introduction

1.1 BNL's vision for RHIC

The first five years of research at RHIC have produced a wealth of scientific discoveries, and some big surprises. These have provided new insights into QCD as it is realized in nucleons and nuclei and a host of exciting and compelling questions. The RHIC experiments have published solid evidence for the creation of a new state of thermalized matter at unprecedented energy densities (more than 100 times larger than that of cold atomic nuclei), which exhibits almost perfect fluid dynamical collective behavior. There are strong indications that this thermalized matter originated from a high energy density state of gluons with possibly universal properties.

The fundamental questions about QCD that the RHIC program addresses can be summarized as follows:

What are the phases of QCD matter?:

> Soon after QCD was developed, it was conjectured that a phase transformation from distinct ordinary hadrons to a state of deconfined quarks and gluons should be expected at high temperatures and/or densities. The initial experimental results from the RHIC program have demonstrated unequivocal evidence for a new state of partonic matter with novel and unexpected properties, and have identified fruitful avenues for further investigation in the fundamental structure of the dense QCD medium.
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> While it is clear that the matter formed at RHIC has unique properties, fundamental questions remain to be investigated. What is the structure of the partonic matter, and what are the relevant degrees of freedom? Are there bound states even above the transition temperature? Is chiral symmetry restored? What is the equation of state of the matter? What are its transport properties? Of particular interest is the ratio of viscosity to entropy, which has been conjectured to obey a universal lower bound. The prospects to study such quantities in a fundamental theory have excited interest well beyond nuclear physics, with emerging connections to ultra-cold atomic systems in traps and to computations via string theory analogs of strongly coupled gauge theories.

What is the wave-function of the proton?:

> The wave-function of the hydrogen atom was computed almost simultaneously with the introduction of the Schrödinger equation. However, 30 years after the formulation of QCD, a corresponding quantitative computation of the proton's ground state remains elusive. Instead, our knowledge of the motion of quarks and gluons within the proton has been derived from precision measurements of deep-inelastic scattering (DIS) combined with analyses based on the evolution equations of QCD. Strikingly,

this work has demonstrated that only about 20% of the proton's spin results from the spins of the quarks within it. The search for the major contributions to the proton spin has now turned to the role of gluon spin, the polarization of the sea quarks, and orbital angular momentum. A polarized proton collider is uniquely suited for this task, because it enables us to probe the spin distributions of quarks, antiquarks, and gluons with strongly interacting probes in a kinematic regime that permits sound theoretical interpretation based on perturbative methods. RHIC, as the world's first and only polarized proton collider, provides an unparalleled opportunity to pursue these studies essential to our understanding of proton structure. In the future, eRHIC, with the collisions of polarized protons and electrons, will provide the next generation of precision probe for understanding the nucleon spin.

What is the wavefunction of a heavy nucleus?:

General arguments suggest that the growth of gluon number density at small momentum fraction x in the proton cannot continue indefinitely, but must saturate. Heavy nuclei at high energy provide an ideal laboratory to study this phenomenon, since the overlap of gluons from the many nucleons that form the nucleus lower the scale for its onset. For example, one QCD-based theory, the Color Glass Condensate (CGC), postulates a universal wave function for gluonic matter in the saturation limit. Models based on saturation have scored successes in describing certain aspects of the RHIC data, such as the relatively low multiplicities of produced particles and the suppression of particle production in the forward direction. Verification of the saturation picture would represent a fundamental advance in our understanding of QCD in extreme conditions and of the high energy limit of the strong interaction. Just as importantly, precise measurement of the gluon distribution at low momentum fraction is essential for understanding the initial state for heavy ion collisions at both RHIC and LHC energies.

What is the nature of non-equilibrium processes in a fundamental theory?:

Out-of-equilibrium processes have profound impact on the formation of structure and matter in the early universe. A spectacular example of the role of a non-thermal process is baryon number generation in the early universe, which depends in an essential way on deviations from thermal equilibrium. This phenomenon occurs at the electroweak scale, and as such is not accessible to direct experimental investigation. However, a rather precise analogy exists between the baryon generation via the electroweak phase transition, and parity and/or CP violation via the axial anomaly in the case of a second-order QCD phase transition. Unlike the electroweak phase transition, characterized by temperatures of about 100 GeV, the QCD transition temperature of "only" 170 MeV has proven to be experimentally accessible, and in fact will be exceeded more than 10,000 times per second in nuclear collisions at upgraded RHIC luminosities.

The generation of thermal behavior, and more generally the production of entropy, from an initial quantum state remains an open and difficult question. The data from

RHIC clearly establish that thermalization develops in the earliest stages of the collision, yet the precise mechanism is not understood. A variety of approaches is currently being investigated, ranging from description of the initial states as classical gluon fields, to exponential degradation of the non-isotropic initial states via plasma instabilities, to interpretations based on Unruh/Hawking radiation experienced by decelerating observers.

These questions can begin to be addressed now in the ongoing operation of RHIC. To exploit the full potential of this research opportunity, however, we plan a staged series of upgrades to the RHIC facility – both to the accelerator complex and to the detector capabilities.

The scope of the upgraded facility – called "QCDLab at RHIC" – has the following features:

- Heavy ion collisions at $\sqrt{s}$ up to 200A GeV and $L_{\text{store avg.}} \geq 7\times10^{27}/\text{cm}^2/\text{sec}$ (40 times the original design luminosity) for nuclear species up to U, with both symmetric and asymmetric collisions, including p + A
- Polarized p + p collisions at $\sqrt{s}$ up to 500 GeV with 70% polarization and $L_{\text{store avg.}} \geq 6.5\times10^{31}/\text{cm}^2/\text{sec}$
- **eRHIC:** e + heavy ion collisions and polarized e + light ion collisions at $\sqrt{s}$ up to $\sim 50\sqrt{A}$ GeV and $L_{\text{store avg.}} \geq 10^{31}/\text{cm}^2/\text{sec}$; polarized electron-proton collisions at $\sqrt{s}$ in the range 30-100 GeV and $L_{\text{store avg.}} \geq 10^{33}/\text{cm}^2/\text{sec}$
- Upgraded and/or new detectors capable of addressing the compelling questions, including a new detector specific to eRHIC.
- Upgraded RHIC Computing Facility which can keep pace with the recording, archiving and reconstructing of experimental data from the evolving program

More broadly, the QCDLab as an intellectual center for the study of QCD, depends on a number of additional activities at (or centered at) BNL. These include an active R&D program in accelerator and detector technology, a strong and growing nuclear theory effort at BNL and at universities and laboratories across the nuclear physics community, supercomputers designed for lattice QCD simulations (a significant fraction of which are devoted to finite temperature QCD) and an involvement in and/or support of forefront QCD research at other accelerator centers, such as the heavy ion program at LHC.

The staged evolution from RHIC to the QCDLab at RHIC can be seen as progressing through a series of time frames – the present, the mid-term future and the long-term future.

The present: Operation and exploitation of RHIC

RHIC is in its 6th year of annual operations. During this era the initial suite of detectors has been completed to the point of their initial conceptions and the machine performance has steadily improved to (and in some cases beyond) its design performance. The scientific output has had high impact on the science questions that drove the construction and operation of RHIC and have enabled us to see the path of future research.

It is noteworthy that the output from RHIC has also had a high impact on the public consciousness of nuclear physics research, and science in general. The discoveries at RHIC have been widely covered by the national and worldwide press and broadcast media. RHIC results have often appeared in annual lists of top stories compiled by popular scientific magazines, and the "perfect liquid" result was named by the American Institute of Physics as the number one science story of 2005.

The mid-term: Operation and construction for high luminosity at RHIC (2006-2011)

The bulk of the present document is aimed at mapping out the strategic plan for this crucial period. Research will continue to produce physics results, addressing or beginning to address the questions summarized above and described in more detail in section 2. Upgrades of the detectors provide new capabilities – with immediate impact on the physics and also longer-term impact as the machine performance (luminosity, polarization, availability, flexibility, reliability) improves incrementally over the mid term. EBIS is a prime component of this improvement program on the machine side. Targeted R&D will continue to address both detector and accelerator enhancements and new capabilities. RHIC luminosity will be upgraded by an order of magnitude (for heavy ions) beyond the ongoing incremental improvements, via construction and commissioning of continuous electron-cooling of beams at full energy – the RHIC II Project. During this period the LHC heavy ion program will begin to produce data and the interplay of results in the RHIC and LHC energy regimes will further expand the potential for discovery in the realm of hot and dense QCD matter.

The long term: high luminosity operation and construction/operation of eRHIC (2012 and beyond)

Research at RHIC will benefit from significantly higher luminosities with the operation of electron cooling through the realization of the RHIC II Project. The higher luminosity enables both new reach with rare probes and higher mass states and also broad systematic studies. The detailed scientific case for RHIC in the mid-term period and beyond is the subject of a document in preparation for release in the spring of 2006. The scientific program presently envisioned will in all likelihood yield more surprises, as it has in the past, and thus new research directions might present themselves from the RHIC (and LHC) results. These may in turn motivate new detector capabilities not yet anticipated.

In this period BNL plans to construct and operate eRHIC. This involves construction of an electron ring (or linac) and new detectors. The R&D and prototyping/testing programs for eRHIC will have started in the mid-term period. These programs are taken into account in the mid-term planning which is the subject of this document.

1.2 Mid-term strategy: Motivation and overview

The aim of the mid-term strategy is to map out an achievable, aggressive plan to explore QCD matter in the new realm opened up at RHIC, and to maximize the science output in the years 2009 and beyond, when RHIC will start to compete with the LHC heavy ion program. This Mid-Term Plan is being developed in response to two recommendations of the July 2005 DOE Science and Technology Review of RHIC:

- Develop a mid-term strategic plan which includes the implementation of necessary detector upgrades in the context of scientific priorities, expected machine performance, and the expected turn-on of the Large Hadron Collider (LHC). This plan should be cognizant of the DOE needs for formulating federal budgets and requirements for project management. The plan should be submitted to DOE by January 2006.

- Update the RCF five-year plan to consistently reflect the needs of a five-year run plan in the context of projected detector upgrades and accelerator performance. This plan should be complete and submitted to DOE by January 2006. This report may be combined with the mid-term strategic plan provided the RCF plan is a prominent component.

To be specific with regard to the first charge, we take the “mid-term” period to be the years 2006-2011. In addressing this strategy, we have kept in mind the long range planning for RHIC. In this regard, under favorable budget circumstances, the mid-term phase leads directly into operation of the collider at high luminosity with e-cooling. The strategy is based on upgrading the capbilities of STAR and PHENIX, as well as providing computing resources via the RHIC Computing Facility (RCF) to deal with the corresponding increases in data volume and analysis requirements of the experiments.

A central element of this strategy is a plan to provide specific upgrades to the two large detectors, upgrades that are designed to address critical measurements not now possible at RHIC, providing new capabilities that will have immediate scientific impact during the mid-term period and will continue to serve, as the machine performance is enhanced over the coming decade, in a long-term program of high-luminosity measurements. Thus, we plan to enable measurements of open charm (and beauty), charmonium spectroscopy, low-mass dilepton pair spectra, and jet tomography in a high-statistics Au-Au run starting in 3-4 years. Also in the mid-term period, the forward tracking and calorimetry upgrades should enable the measurement of $W^{\pm}$ production in 500 GeV p-p collisions. With the completion of the proposed detector upgrades, both PHENIX and STAR will be capable of exploiting the highest planned RHIC luminosity for such measurements.

Therefore, an important consequence of the mid-term strategy described here is a change in the planned scope of the proposed RHIC II Project, which had previously been envisioned to include significant funding for detector upgrades. With the implementation of this mid-term plan, the RHIC II Project can be more narrowly defined, strictly as a luminosity upgrade for the machine. At correspondingly lower cost, this major upgrade in machine performance could become operational at the end of the mid-term period, with two large detectors well equipped to pursue the compelling scientific program for RHIC with high luminosity.

This document updates the long-term planning presented in the report entitled “Twenty-Year Planning Study for the Relativistic Heavy Ion Collider Facility at Brookhaven National Laboratory” (BNL-71881-2003), submitted to DOE December 31, 2003. A detailed plan for the RHIC Spin program is presented in the “Research Plan for Spin Physics at RHIC”, submitted to DOE on February 11, 2005. The reader is referred to that plan (http://www.bnl.gov/henp/docs/spinplan0205.pdf) for more details.

2 The science case for the future

2.1 Discoveries in the first five years

RHIC began operations in June 2000 and has, up to now, completed five runs. The four RHIC experiments BRAHMS, PHENIX, PHOBOS and STAR have collected data on Au+Au, d+Au, Cu+Cu, and p+p collisions, with Au+Au collisions having been studied at four collision energies ($\sqrt{s}$ = 19.6, 63, 130 and 200 A GeV). The largest data samples were collected at the highest energy of $\sqrt{s}$ = 200 A GeV. In addition, a successful spin physics program with polarized proton beams has been started.

<u>Heavy ion collision experiments:</u>

Results from the first five years of RHIC operations with heavy ions have provided solid evidence for the creation of a new state of thermalized matter. The medium formed in heavy ion collisions at RHIC produces the highest energy density matter accessible in the laboratory. Its density and enormous interaction cross section are not consistent with hadronic degrees of freedom. Yet its behavior is not that of the expected weakly coupled gas of quarks and gluons. Instead, the medium exhibits collective expansion with an extraordinarily small viscosity-to-entropy ratio, giving rise to the term "perfect liquid". This picture emerges from four fundamental new discoveries:

- large anisotropic collective flow in non-central nuclear collisions which agrees with hydrodynamic predictions.
- suppression of particle production at high transverse momenta and quenching of jets in central Au+Au collisions.
- larger production rates for (anti-)baryons than for mesons at intermediate transverse momenta (2 GeV/c < p_T < 6 GeV/c), in conjunction with a scaling of hadron production yields and their anisotropic collective flow with the number of valence quarks.
- unexpectedly low multiplicities of produced hadrons in heavy ion collisions at the RHIC energies, and the discovery that high transverse momentum particles are suppressed in the forward direction in d+Au collisions, leading to a detailed picture of strong gluon saturation, as embodied in the theory of the color glass condensate.

In addition, RHIC experiments confirmed with higher accuracy and better systematics important features of ultra-relativistic heavy-ion collisions that were previously discovered at lower energies. These include

- hadron abundance ratios that are characterized by a chemical equilibrium distribution with "chemical freeze-out" temperature $T_{chem} \approx$ 160-170 MeV, a value that is observed to be independent of collision system and collision centrality and agrees with the value for the quark-hadron phase transition temperature predicted by Lattice QCD.
- a strong transverse momentum dependence of the Hanbury Brown – Twiss (HBT) radius parameters extracted from two-particle momentum correlations between

pairs of identical particles, consistent with predictions from models which incorporate fast collective expansion of the collision fireball at hadronic freeze-out.

First results on charmonium production and direct photon emission have been obtained. An unexpectedly strong suppression of electrons from charmed hadron decays at high transverse momenta has been observed. First studies of elliptic flow of electrons from semileptonic decays of charmed hadrons seem to indicate large flow anisotropies for charm quarks, indicating strong interactions between the charm quarks and the collectively expanding medium.

For all of these measurements, the ability to study proton-proton, nucleus-nucleus, and deuteron-nucleus collisions with identical center-of-mass energies at the same facility has been the key to eliminating many sources of systematic error. Nearly all observables have been studied systematically as a function of collision centrality and of the emission angle relative to the reaction plane, thereby providing complete control over the collision geometry. It is noteworthy that from the very beginning of RHIC operations there has in general been quantitative agreement between the results obtained by the four RHIC experiments wherever their acceptances overlap.

The RHIC spin physics program:

In parallel with the above discoveries in heavy-ion collisions, RHIC has developed the world's first polarized proton collider. This technological coup permits, for the first time, study of spin observables in hard hadronic collisions tractable within the framework of perturbative QCD (pQCD). Such collisions provide critical complements to electromagnetic probes of nucleon spin structure, such as deep inelastic lepton scattering (DIS). The latter studies, fixed target experiments carried out with polarized lepton beams and polarized nucleon targets, have firmly established that, in a partonic description, only a small fraction (~20%) of the proton's spin can be attributed to a preferential alignment of the spins of all quarks and antiquarks in the proton. The remainder must be sought in either the preferential alignment of gluon spins or the orbital motion of quarks or gluons within the nucleon. The RHIC spin program addresses the first of these possible origins directly by probing gluon spin preferences with color forces at collider energy, and illuminates the second in unique ways.

For a detailed discussion of the RHIC spin science program, and it's relation to the world-wide research effort, see the Feb. 2005 report "Research Plan for Spin Physics at RHIC", which can be found at www.bnl.gov/henp/docs/spinplan0205.pdf . The natural evolution of these studies will lead us back to DIS with electromagnetic probes. We will do this at eRHIC (http://www.bnl.gov/eic) with polarized beams at collider energies, complementing both RHIC spin and unpolarized HERA studies.

2.2 Implications for the future program at RHIC

Understanding the “perfect fluid”

The best overall description of the RHIC data is obtained if ideal fluid dynamical evolution of a quark-gluon plasma during the early expansion stage is combined with a realistic hadronic cascade after hadronization, and if an equation of state like that obtained from Lattice QCD is employed. To reproduce the magnitude of the observed radial and elliptic flow it is necessary to assume that the produced matter thermalizes very quickly, on a timescale of less than 1 fm/c, building up thermodynamic pressure whose gradients drive the collective expansion.

The need for fast thermalization, the observation of large elliptic flow even for multi-strange (anti-)baryons and heavy charmed hadrons, and the absence of any visible indication for a non-zero viscosity of the fluid during its early partonic (pre-hadronic) stage indicate that the extremely hot and dense medium created in the collision is a strongly coupled plasma. Its apparently almost perfect fluidity contrasts strongly with intuitive pre-RHIC expectations by most scientists in the field that the quark-gluon plasma would exhibit perturbative, gas-like behavior similar to electrodynamic plasmas known from everyday experience. The clarification of the strong-coupling mechanisms at work, the quantitative determination of the liquid’s viscosity and a theoretical understanding of why it appears to be smaller than that of any other known fluid are key tasks for the future program.

Precision probes of the dense medium

The medium created in RHIC fireballs interacts strongly not only with its constituents, but also with hard colored internal probes, such as fast quarks and gluons created at the very beginning of the collision and propagating outward through the reaction zone. Hadrons with high transverse momenta which arise from the fragmentation of such hard partons are found to be suppressed in central Au+Au collisions by a factor 5-6 relative to the experimental p+p baseline, in contrast to direct photons which escape from the collision without further interaction and whose production rates and spectra agree well with expectations based on perturbative QCD. When triggering on a high-p_T hadron with transverse momentum of up to 10 GeV/c, its partner jet going off in the opposite direction most likely traverses the medium an is quenched in central Au+Au collisions: in that case no high-p_T particles correlated with the trigger particle are found, instead the energy is carried away by enhanced production of soft hadrons in the direction opposite to the fast trigger hadron. The average momentum of these soft hadrons approaches that of the thermalized medium as the collisions become more central and the fireball size increases. In addition, certain detailed structures in their angular distribution point to a possible collective or hydrodynamic response of the dense medium to the energy and momentum deposited by the quenched jet.

While not all of these features are quantitatively understood, theoretical estimates of the initial energy and particle density of the medium which are necessary to explain the observed high-p_T hadron suppression agree with those required by the successful hydrodynamic description of the bulk of the matter. The important observation of an angular dependence of jet quenching relative to the reaction plane has opened the possibility to use this process as a tomographic probe for the properties of the dense medium created at RHIC. A second key component of the future RHIC program will be detailed studies of high-p_T hadron production, including the detection of heavy mesons and multiple identified hadrons associated with jets, which enable us to turn jet emission tomography into a precise quantitative tool.

Novel hadronization phenomena at intermediate momenta

Evidence for an active role of deconfined, thermalized and collectively flowing quarks in hadron production comes from the observed valence quark number scaling of hadron yields and elliptic flow at intermediate p_T. While the ideal fluid description gradually breaks down above $p_T = 1.5$ - 2 GeV/c, the flattening of the baryon spectra by the strong radial flow is still visible at even larger transverse momenta, and this explains at least qualitatively the observed excess of (anti-)baryons over mesons in the intermediate p_T region. A phenomenologically quite successful description is provided by the quark-coalescence model which posits that baryon resp. meson production in this p_T region proceeds via the coalescence of three quarks resp. a quark and an antiquark, each carrying a corresponding fraction of the final hadron's momentum. This process imprints the hydrodynamic flow characteristics of low-momentum quarks onto the intermediate-momentum hadrons. As a result, hydrodynamic bulk particle production at low p_T is separated from perturbative hard particle production at high p_T by a novel and unexpectedly interesting intermediate p_T region where quark coalescence and jet fragmentation compete with each other. This leads to interesting new phenomena whose detailed exploration and clarification will be a third major thrust of the future RHIC physics program.

New physics in gluon saturation effects

At very high energies one is able to study the wee parton (small-x) component of the hadron wave function. Theoretical investigations and experimental results from HERA have shown that the density of small-x gluons becomes very large. This led to the QCD based conjecture that these gluons, when measured at some fixed size scale, form a high energy density, saturated, highly coherent universal type of matter. There is a QCD based description of this matter, called the Color Glass Condensate. The earliest RHIC results on the dependence of particle multiplicity on centrality and energy were understood as arising from this high energy density state of saturated gluonic matter. Such matter can be probed in dA collisions, by concentrating on kinematic regions sensitive to the small x gluon nuclear wave function. RHIC measurements showed a distribution of high transverse momentum particles whose dependence on rapidity, transverse momentum and centrality are consistent with the Color Glass Condensate hypothesis.

These observations are the first strong indication that gluon saturation effects play an important role in our understanding of the very early stages of heavy ion collision dynamics. Further exploration of the nature and manifestations of this novel type of physics in asymmetric collisions at forward rapidity will be a fourth key component of the future RHIC and eRHIC physics program.

Addressing fundamental questions at RHIC

The early results at RHIC have opened a new landscape for scientific research addressing questions of bedrock importance for the understanding of QCD, reaching well beyond nuclear physics in their scope. In Section 1 we listed some fundamental questions to be explored in the coming phases of the RHIC program. In the following paragraphs we present some specific approaches to these questions that follow from the RHIC discoveries to date, and that will be undertaken with the upgraded RHIC facility.

2.3 Exploring the QCD phase diagram

Exploring the properties of the new form of QCD matter and characterizing the hot and dense medium will be at the core of the agenda for the future program at RHIC. What is the equation of state? What are the dissipative effects of the medium? What is the nature of the transition between a hadron gas and a quark gluon plasma? We describe here some of the key measurements for addressing these questions.

Energy density and jet energy loss

For the exploration of many characteristics of the QGP, energy (or entropy) density and temperature are critical measurements, as they determine the equation of state. Evidence from both theory and experiment point to a phase transition (or rapid crossover) from hadronic matter to quark-gluon plasma at a temperature of 170 MeV. Thus, the determination of the equation of state of the dense matter produced at the early stage of heavy ion collisions is through independent measurements of energy density.

A direct probe of the initial energy density is through measurements of high p_T hadrons produced when energetic partons propagate through dense matter and lose energy. This energy loss, or “jet quenching”, is thought to be dominated by radiative energy loss induced by multiple parton scattering in the medium. Recent theoretical studies show that the effective parton energy loss is proportional to the gluon density in the medium. Experimental data from RHIC indeed show strong suppression of high-p_T hadron spectra, implying large parton energy loss and high initial gluon density. Phenomenological models based on parton energy loss and modified jet fragmentation functions are very successful in describing the observed suppression of high-p_T hadrons, yielding estimates of gluon density at an initial time τ_0 = .2 fm/c to be ~ 30/fm^3. This corresponds to an initial energy density of ~15 GeV/fm^3, which is about 100 times the energy density of cold nuclear matter, or 20 times the expected transition energy density.

These studies rely on the assumption of the dominance of gluon radiation, which is one of the uncertainties in the theory. Theoretical uncertainties are large due to the neglect of elastic energy loss and the complication of trigger bias associated with the measurement of single inclusive spectra. Future measurements with direct photon-jet correlation and heavy flavor tagging will achieve much needed improvements.

Direct photons are those originating from an initial hard-scattering. Since the photon will not interact strongly with the medium, in direct photon-jet events one has a clean measurement of the initial jet energy before energy loss. The challenge in selecting these γ-jet events is separating the direct photons from those that come from hadronic decays. Initial studies of direct photons have been carried out by PHENIX. These measurements show that the fraction of direct photons is dramatically increased in central A+A collisions due to the suppression of pions from jet fragmentation. The PHENIX measurements show that at p_T ~8 GeV/c, approximately 60% of all photons are direct photons in central Au-Au events. With increased luminosity and, for STAR, enhanced data acquisition rates, this precise means for studying parton energy loss in the dense medium of heavy ion collisions becomes accessible at RHIC, and is expected to be a principal tool when the full RHIC II luminosity is achieved. The photon-jet measurements will benefit from the proposed additional calorimetery in the forward direction in both PHENIX (Nosecone Calorimeter) and STAR (Forward Meson Sprectrometer).

Another type of interaction between energetic jets and the bulk matter is recombination of leading partons from jets and thermal partons in the medium. Such recombination, which has been attributed to the observed enhancement of baryon to pion ratio at intermediate transverse momentum, modifies the hadronization mechanism for jet fragmentation in the medium. Studies of di-hadron or multiple-hadron correlations in this regime with hadron identification will help to quantify the medium modification and shed light on the effective degrees of freedom of the medium just before hadronization. The enhanced particle identification of the upgraded RHIC detectors, as well as increased luminosity, will extend the range of transverse momentum for such studies, providing clear measurements in the intermediate transverse momentum range of interest.

The measurement of parton energy loss for the case of heavy flavor quarks is a key goal for understanding and testing models for describing the properties of the dense medium. Heavy quarks are expected to lose less energy than light quarks via gluon radiation, due to the predicted “dead-cone” feature in the gluon radiation spectra. The length dependence of the heavy quark energy loss is also different from light quarks because of the mass dependence of the gluon formation time. The open charm spectra in heavy-ion collisions in RHIC have been obtained via the measurements of non-photonic single electron spectra, assuming the dominant contributions come from leptonic decays of D and B mesons. The observed suppression of single electron spectra is surprisingly large, as large as the suppression of pions from the fragmentation of light quarks. The results to date remain a puzzle. Theoretical approaches, taking into account contributions from D and B meson decays, require unexpectedly large values of initial gluon density to describe the data, even when including elastic energy loss for heavy quarks. Understanding these results requires direct measurements of heavy quark spectra, utilizing the proposed precision vertex detectors for PHENIX and STAR, allowing the selection of jets whose leading particle has open or hidden charm.

While experiments at LHC will have a higher rate of jet production, and therefore a wider reach in transverse momentum, studies of jet physics in the range of transverse momentum explored at RHIC (out to ~30 GeV) has the unique advantage that the amount of energy loss is a significant fraction of the total jet energy. The lower rate of jet production (per event) at RHIC also translates into a smaller average number of jet pairs per event, and therefore to smaller background for the study of multiple-hadron correlations. Furthermore, in the kinematic range accessible to RHIC one can study both quark and gluon jets, whereas only gluon jets are expected to be accessible to the LHC experiments. Thus, while the LHC program will explore new extremes of both temperature and transverse momentum, the upgraded RHIC program remains essential to understand and characterize the basic properties of the new state of matter seen in experiments so far.

Heavy quarks and tests of deconfinement

Because of the large charm and bottom quark masses, they are produced almost exclusively in the initial parton-parton interactions in heavy ion collisions at RHIC energies. Thus, the abundance and kinematic properties of heavy flavor states in A-A collisions offer powerful measures of the thermodynamic and transport propterties of the final-state medium. Such measurements are a critical part of the future RHIC program, and hence the construction of precision vertex detectors, capable of directly measuring the displaced decay vertices of open charm and bottom states, are central to the upgrade plans for PHENIX and STAR.

A number of dense matter effects on heavy flavor production have been predicted. Heavy quark energy loss by collisional and radiative processes is mentioned in the discussion above. If the medium surrounding the heavy quarks after production exhibits collective motion, such as transverse flow, the heavy quarks may participate in this flow and provide a direct experimental measure that is not possible with the bulk of final-state particles. For many studies of the high-temperature medium an accurate baseline for the total heavy flavor cross sections is required to interpret other effects. This includes the study of electron-pair spectra, for which leptonic decays of charm states are an important background, as well as the need for quantitative understanding of production of charmonium states through coalescence effects in events where multiple charm-pairs are produced.

Detailed measurement of heavy quarkonium (charmonium and bottomonium) mesons offer a means to demonstrate experimentally that deconfinement has occurred, by making it possible to experimentally verify that states which should not survive the deconfinement transition do, in fact disappear. Because of the large quark masses, charm and bottom pairs are produced only in the initial high energy parton collisions, with a small fraction of pairs forming bound quarkonium states. The time scale for development of these quarkonium states is such that they form while passing through the hot dense medium produced in a heavy ion collision. Thus the yield of the quarkonium states will be affected by any changes in their properties in the final state medium.

At sufficiently high energy density, color screening is expected to cause quarkonium to become unbound. This will occur at different temperatures for states of different binding energy and size.
Lattice Gauge Theory charmonium calculations suggest that the J/Ψ remains a well defined state to ~$2T_c$, while the larger χ_c and Ψ' will melt just above T_c. For bottomonium, the Υ(1S) remains well defined to ~$4T_c$, the Υ(2S) to ~$2T_c$, and the Υ(3S) to just above T_c. Thus the quarkonium yields could act as a thermometer of the matter created in heavy ion collisions. However, models of quarkonium production in heavy ion collisions must include the effects of the initial conditions and of the dynamical evolution of the system. To use quarkonia as a probe of the final state, cold nuclear matter effects must be unfolded from final state medium effects by separate measurements in p+p and p+A (or d+A) collisions at the same collision energy per nucleon.

The RHIC quarkonium results available to date are PHENIX J/Ψ measurements for pp, d+Au, Cu+Cu and Au+Au collisions. The measured nuclear modification factors decrease smoothly with the number of participants to a suppression factor of ~3 for the most central A+Au collisions. So far, the preliminary rapidity distributions and mean p_T data have substantial statistical and systematic errors. Most current models overpredict the observed suppression by a factor of three or more. Adding production of J/Ψ by coalescence to the models increases the calculated yields to approximately the observed values. But since the J/Ψ nuclear modification factor is predicted by these models to be a balance between competing effects, this agreement cannot be decisive on its own.

More powerful and comprehensive tools for studying the effects of coalescence will require larger data samples made possible by the implementation of precision vertex detectors, as well as higher luminosity. An important tool will be measurement of the J/Ψ elliptic flow parameter (v_2), which has been very illuminating for hadrons containing lighter valence quarks. Also, the relative importance of J/Ψ suppression and regeneration will change as a function of collision energy. The luminosity upgrade will make it feasible to measure accurate J/Ψ p_T and rapidity distributions for a range of collision energies.

Observation of excited charmonium - the Ψ' and the χ_c states – will become possible with the upgraded detectors and the full luminosity of the RHIC II upgrade. From the lattice calculations, these excited states should not exist in the QGP at RHIC. Therefore comparison of the Ψ' and χ_c yields with the J/Ψ yield as a function of centrality is considered to be a strong test for deconfinement.

The study of bottomonium states, the Υ family, is also possible with the fully-upgraded luminosities. Bottomonium differs in two important ways from charmonium. First, the bottomonium binding energies, particularly of the Υ(1S), are higher so they should dissociate at higher temperatures. Second, there are only ~0.05 bottom pairs per central

Au+Au collision, making bottomonium production by coalescence much less likely. Thus bottomonium production at RHIC will provide a very different window on color screening effects than charmonium production.

The larger cross sections for heavy flavor production at the LHC are approximately balanced by the increased luminosity and running times with the RHIC II upgrade, so that the heavy flavor yields per year are similar. Thus the types and quality of measurements that can be made at the two facilities will also be similar (quantitative detail can be found in the report of the RHIC II Science Working Group on Heavy Flavor, to be found at www.bnl.gov/physics/rhicIIscience/). However, there will be important differences in the physics environments at the two facilities, making the programs complementary. The bottomonium yields at RHIC should reflect only QGP suppression, whereas at LHC energy the effects of coalescence are expected to appear. Measurements of the bottomonium states at RHIC, with high luminosity, and the LHC at significantly higher temperature, should resolve ambiguities caused by the interplay of melting and coalescence at LHC.

Low-mass di-lepton spectra

Dilepton invariant-mass spectra are a unique observable for measuring in-medium spectral functions of low-mass vector mesons, most notably of the ρ meson, and thus probe changes in the underlying vacuum structure due to the effects of the medium. At higher invariant mass, there exists the possibility to detect predicted resonant quark-antiquark states above the critical temperature, which would give direct evidence of the strongly interacting QGP (sQGP) and reveal the scale for the thermal parton mass. The availability of such measurements has generated a great deal of theoretical work regarding possible experimental studies of the effects of chiral symmetry restoration.

The generation of hadronic masses is a key problem in QCD, intimately related to the underlying structure of the vacuum. At zero temperature and baron density, the presence of quark and gluon condensates is believed to create the “constituent” quark mass of 300-400 MeV/c^2, and therefore to be at the origin of the masses of light hadrons (which, in turn, account for ~99% of the visible mass in the universe). At the same time, the so-called chiral symmetry of QCD (which for massless quarks conserves right- and left-handed “chirality” states) is spontaneously broken. At the hadronic level, chiral symmetry breaking entails the splitting of spectral functions within chiral multiplets, e.g., for π-σ, ρ-a_1 and N-N*(1535), amounting to mass differences of typically ~500MeV/c^2. At the critical temperature, $T_c \approx 170$ MeV, chiral symmetry may become restored, forcing chiral partners (multiplets) to become degenerate.

At the SPS, dilepton measurements from CERES have triggered vigorous theoretical activity. Recent precision data by NA60 have enabled substantial progress in discriminating different in-medium effects on the ρ-meson spectral function, but open questions remain concerning possible scenarios of chiral symmetry restoration. Nuclear collisions at RHIC energies provide the unique opportunity to establish quantitative connections with lattice QCD calculations, since both predominantly operate at (almost) vanishing baryon chemical potential. (At the LHC, increased backgrounds from charm production render precision measurements more challenging.)

Low-mass (axial-) vector meson spectroscopy close to the chiral transition:

> Precision dilepton data will provide detailed information on medium modifications of ρ, ω, and ϕ mesons, and thus illuminate the question of hadronic mass generation. "Quality control" of theoretical models via independent constraints from symmetries, QCD sum rules, and phenomenology is essential to limit the scope of viable axial-/vector spectral functions. An excitation function will allow the discrimination of effects of temperature and baryon density and thus systematically map out in-medium effects across a significant regime of the QCD phase diagram. A convincing deconvolution of the vector spectral functions from the measured spectra will require systematic variations of system sizes via centrality and species scans, coupled with reliable space-time descriptions to emerge from progress in hydrodynamic and transport simulations.

QGP resonances:

> The only way of directly testing the exciting possibility of hadronic bound states or resonances in the sQGP experimentally is to search for a resonant dilepton signal. The largest sensitivity for the discovery of pertinent vector states is in the M=2 GeV mass region, which, in fact, coincides with current expectations from lattice QCD and effective models. RHIC energies provide optimal conditions for this search as the initial temperatures are close to the anticipated dissolution temperatures of the bound states. An accurate determination of background and charm sources is mandatory, restricting total experimental errors to below the ~30% level. If the resonance states exist at masses below ~1.5 GeV, their discrimination from chiral mixing effects will be more involved, increasing the demand for accuracy and systematic centrality and excitation function studies.

To achieve the required background rejection and high precision charm measurements necessary for these studies, PHENIX will require its Hadron Blind Detector and Silicon Vertex Detector, while STAR will require the completed Time-of-Flight detector, Heavy Flavor Tracker, and upgraded Data Acquisition System. Initial measurements of dileptons will be accomplished as these new detectors are implemented. However, an energy scan with high statistics comparable to recent NA60 data will require the full RHIC II luminosity upgrade.

2.4 Gluon Saturation

The gluon density in the nucleon has been measured at HERA over a very broad range in the momentum fraction *x*. At small *x*, parton splitting causes the gluon density to grow rapidly. This growth can not continue indefinitely due to unitarity limits. Thus, it has long been recognized that the gluon density in the nucleon must saturate at some scale, but the momentum fraction where this occurs is not yet experimentally well determined.

Heavy nuclei provide an ideal laboratory to explore gluon saturation. The gluon density per unit transverse area is amplified by a factor of ~$A^{1/3}$ relative to that in the nucleon, so saturation effects should become apparent at larger x in nuclei than in the nucleon. This is best studied with d(p) + A collisions at forward rapidity, where the low-x gluons in the heavy nucleus are probed using the high-x partons in the proton or deuteron. All four RHIC experiments have shown that inclusive particle yields in d + Au collisions are strongly suppressed at forward rapidity relative to those in p + p collisions. A likely explanation for these results is that the onset of gluon saturation in the nucleus occurs in the region x = 0.001~0.01 that is probed at RHIC. However, other mechanisms have been proposed that are also consistent with the measurements to date and more detailed studies are required. Multi-particle correlation measurements will be particularly informative. In conventional perturbative QCD, hard scattering processes are dominated by di-jets from parton elastic scattering. In contrast, gluon saturation models predict that forward particle production will be dominated by multiple scattering of energetic partons off the gluon field of the nucleus, leading to the appearance of mono-jets.

Detector upgrades to PHENIX and STAR will facilitate a search for mono-jets in d - Au collisions and direct measurements of the gluon density in the Au nucleus. The upgrades (described in more detail in Section 5) that will enhance the experiments' capabilities to study the low-x region in this period include the STAR Forward Meson Spectrometer (FMS) and Integrated Tracking, and the PHENIX End cap vertex detector (FVTX) and Nose Cone Calorimeter (NCC).

Depending on what is learned, follow-up studies will include direct photon and di-lepton measurements. These rare probes, which will permit more precise, quantitative comparisons to theory, will require RHIC II luminosities and the upgrades described above.

It is essential for us to determine if gluon saturation is the correct explanation for the existing RHIC data. The saturation scale represents a fundamental property of hadrons and nuclei. Even if gluon saturation does not prove to be the correct explanation, it is nonetheless crucial to determine the gluon density at small x in the Au nucleus if one hopes to understand the initial state in Au + Au collisions at RHIC and its rapid evolution from a highly non-equilibrated system to a thermalized one.

We know that the gluon density ultimately must saturate, but a fundamental question is: *When does it occur?* To observe the onset of saturation, it is essential to be able to turn it on and off. RHIC is uniquely situated to explore this phenomenon because the low-x region is kinematically well-separated from the central region. In contrast, particle production in heavy-ion collisions may occur deep within the saturation regime over most of the kinematic region that will be accessible at the LHC. If that proves to be the case, then it will be very difficult to turn saturation effects off at the LHC.

The understanding of the wave functions of the nucleon and of a heavy nucleus, cited above as fundamental issues for QCD, will remain a research thrust of the RHIC facility, both in low-*x* and spin-dependent phenomena, from the mid-term though the high luminosity era and into eRHIC.

2.5 The spin structure of the Nucleon

A key issue in understanding confinement in QCD is the study of the inner structure of strongly interacting particles in nature that are composed of quarks and gluons. Among these, the proton and neutron are clearly special as they make up all nuclei and hence most of the visible mass in the universe. Their detailed study is therefore of fundamental interest. The proton and neutron also carry spin ½ and this immediately brings the central role of spin in nucleon structure to the fore.

A prime question is how the proton's spin is composed of the average spins and orbital angular momenta of valence quarks, sea quarks/antiquarks and gluons inside the proton. Polarization has become an essential tool in the investigation of the strong interactions through nucleon structure.

RHIC is a unique facility for extending our present understanding of the spin structure of the nucleon. Experiments with polarization at RHIC will probe the proton spin in new and profound ways, complementary to polarized deep inelastic scattering (DIS). RHIC provides direct information about the polarization of gluons in the proton and about details of the flavor structure of the polarized quark and antiquark distributions. RHIC will also probe the structure of transversely polarized protons, and we hope to unravel the origin of large observed single-transverse spin asymmetries.

The spin program as formulated in the "Research Plan for Spin Physics at RHIC" achieves its goals by 2-12. Success will depend on detector upgrades which will be constructed during the mid term period. It also depends on achieving the maximum proton beam polarization; this development is under way at present. The proton beams do not suffer emittance growth through intra-beam scattering to the extent that heavy ion beams do, and therefore the luminosity increases for the spin program from the RHIC II upgrade are expected to be a factor of 2 to 3 (this is discussed in Section 4). The spin program goals of the spin Research Plan require high integrated luminosity, achieved in the plan by 2012. The increased luminosity from RHIC II will offer higher precision for these measurements: the gluon polarization and flavor-identified anti-quark polarizations in the proton. The improved precision is proportional to the square root of the integrated luminosity, and a factor 2 or more improvement in precision is anticipated from RHIC II. But also, the much higher luminosity of RHIC II opens exciting new probes of the proton spin structure. One of these is associated production of W bosons, where a charm tag would identify production of the W from a strange quark in the polarized proton beam. This would provide a direct measurement of the strange quark polarization in the proton, from the degree of parity violation of the observed Ws. The second new RHIC II probe is Drell-Yan production. Transverse spin structure is becoming a very active and important field, with large asymmetries observed in the hard scattering domain. Recent work based on perturbative QCD predicts that the asymmetry observed in DIS (by the

HERMES experiment) for pion production from a transversely polarized target should also be observed in Drell-Yan production at RHIC, with opposite asymmetry sign. RHIC II offers access to the low cross section Drell-Yan production to test this prediction, which tests the universality of our understanding of the nucleon. The Drell-Yan measurement is sensitive to the quark motion in the proton, related to orbital angular momentum, which is a remaining issue in the proton spin structure. This suite of RHIC II spin measurements will significantly enhance our map of the proton's internal wave function in terms of its partonic constituents.

The detector upgrades to PHENIX and STAR planned for the mid term will have immediate impact on the spin program as they come on line and are the same ones needed for the high luminosity era running. These upgrades, discussed in more detail in Section 5 include the PHENIX Muon Trigger, Vertex detectors (VTX) and Nose Cone Calorimeter (NCC) and the STAR Forward Meson Spectrometer (FMS), Heavy Flavor Tracker (HFT), and Integrated Tracker (INT) for forward tracking.

2.6 Physics goals for the mid-term

The mid-term strategy outlined here calls for a balance of beam-on running time with investment in accelerator and detector upgrades necessary for crucial measurements of the new form of QCD matter now being investigated at RHIC, and a full realization of the RHIC spin capability.

In the subsections above we have described the key scientific goals for the future program at RHIC. From this description it is clear that the most important next steps in this program require enhanced detector capability as well as, ultimately, a significant increase in luminosity. Thus, the plan outlined here includes a sequence of detector upgrades for PHENIX and STAR over the next six years. The operations planning and physics goals for this period take advantage of a phased implementation of these upgrades, with the aim of maximizing the science impact during these years.

Some of the most urgent science questions for the RHIC program, several of which can be addressed over this period, have been prominently featured in the long-range planning for Nuclear Science for many years, and have been established by NSAC as performance milestones for DOE. (See Report of the NSAC Subcommittee on Performance Measures, Nov. 2003.)

Here, we list the key measurements to be undertaken during the mid-term period, both for the heavy ion and the spin programs. New detector requirements and the resulting essential detector upgrades proposed by PHENIX and STAR to carry out these measurements are shown in italics. Where applicable, we note those cases where measurements directly address DOE performance milestones.

Heavy Ion measurements:

- Electron-pair mass spectrum (DOE performance milestone for 2010)
  Dalitz pair and photon conversion rejection
  PHENIX: Hadron Blind Detector
- Open charm measurements in AA
  High precision secondary vertex detection
  PHENIX and STAR silicon vertex tracker
- Charmonium spectroscopy (DOE performance milestone for 2010)
  High luminosity and lepton identification
  PHENIX: no upgrades needed
  STAR: high rate DAQ; improved particle ID
- Jet Tomography
  High luminosity; particle ID over large acceptance
  PHENIX: upgrades in place
  STAR: High rate DAQ; improved particle ID
- Monojets in d-Au: Gluon densities at low x in cold nuclei (DOE performance milestone for 2012)
  Particle detection at forward rapidity
  PHENIX: Nosecone calorimeter
  STAR: Forward meson spectrometer

Spin measurements:

- Complete initial ΔG/G measurement (DOE performance milestone for 2008)
  No upgrades needed
- Transverse spin measurement
  Forward particle measurement
  PHENIX: Nose cone calorimeter
  STAR: Forward meson spectrometer
- W measurements at 500 GeV (DOE performance milestone for 2013)
  High rate capability and single lepton identification
  PHENIX: Muon trigger upgrade
  STAR: Intermediate/forward tracking upgrade

The figure below shows how each of the proposed upgrades relates to the future physics program…

Upgrades	High T QCD				Spin		Low x
PHENIX	e+e-	heavy flavor	jet tomography	quarkonia	W	$\Delta G/G$	
hadron blind detector (HBD)	x						
Vertex tracker (VTX and FVTX)	x	x	o	o		x	o
μ trigger				o	x		
forward calorimeter (NCC)			o	o	o		x
STAR							
time of flight (TOF)		o	x	o			
Heavy flavor tracker (HFT)		x		x			
tracking upgrade		o			x	o	
Forward calorimeter (FMS)						o	x
DAQ		o	x	x	o	o	o
RHIC luminosity	o	o	x	x	o	o	o

Fig. 2-1: An x indicates the proposed upgrade is critical for the indicated measurement. An o indicates significantly enhanced capability.

3 The Mid-Term Run Plan : 2006 – 2011

In Table 3-1 we summarize the data samples collected in all of the RHIC runs to date. These first runs were characterized by a wide range of operating modes, varying both the collision species and energies; a rapid development of machine capability, leading to performance at the design luminosity after the first three runs; and a rich harvest of physics discoveries, opening up the fundamentally new realms of research described above for high energy heavy ion and spin physics.

Summary of RHIC Runs 1-5

Year	Run Plan	Sample	Physics
2000	Au-Au at 130 GeV/A	20 μb^{-1} (6 wks)	First look at RHIC collisions
2001 – 2002	Au-Au at 200 GeV/A Commission/run pp at 200 GeV Au-Au at inj. E: 19 GeV/A	260 μb^{-1} (16wks) 1.4 pb^{-1} (5 wks) 0.4 μb^{-1} (1 day)	Global properties; particle spectra; first look at hard scattering. Comparison data and first spin run Global connection to SPS energy range
2003	d-Au at 200 GeV/A pp at 200 GeV	74 nb^{-1} (10wks) 5 pb^{-1} (6 wks)	Comparison data for Au-Au analysis; low-x physics in cold nuclear matter Spin Development & Comparison data
2004	Au-Au at 200 GeV/A Au-Au at 62 GeV/A pp at 200 GeV	3740 μb^{-1} 12wks 67 μb^{-1} (3wks) 7.1 pb^{-1} (7wks)	"Long Run" for high statistics, rare events Energy Scan Spin Development: Commission jet target First measurements with longitudinal spin pol.
2005	Cu-Cu at 200 GeV/A Cu-Cu at 62 GeV/A Cu-Cu at 22 GeV/A pp at 200 GeV pp at 410 GeV	42 nb^{-1} 8wks 1.5 nb^{-1} 12 days 18 μb^{-1} 39 hrs 30 pb^{-1} 10 wks 0.1 pb^{-1} 1 day	Comparison studies: surface/volume & impact parameter effects; Energy Scan First long data run for spin Spin Development: Lum., Polarization

Table 3-1: Summary of RHIC runs 1-5. The column labeled "Sample" shows delivered luminosity, summed over all experiments.

Following the successful series of RHIC runs from 2000 through 2005, the two small experiments, BRAHMS and PHOBOS, have achieved their goals for data collection. The PHOBOS detector is now being decommissioned. The BRAHMS detector is still in place, and the collaboration has requested a short (2-3 week) p-p run in 2006 at 62 GeV to provide reference spectra for the heavy ion program, and to make a measurement of the asymmetry parameter A_N for charged pions in polarized p-p collisions at this energy.

The primary goals for the run plan during the mid-term period are focused on the programs of the two large experiments, PHENIX and STAR, to address the scientific questions described above. The critical goals to be achieved during this period are:

a. To follow up on the watershed results of the first RHIC runs by making definitive measurements of the nature and essential properties of the quark gluon plasma, utilizing upgraded detector capabilities as they become available, along with continuously improving machine luminosity, and setting the stage for the RHIC II luminosity upgrade.
b. To obtain spin-polarized p-p data samples of sufficient sensitivity to address the core physics questions of the RHIC spin program, including direct determination of the spin-dependent gluon structure functions, with data samples at 200 GeV and 500 GeV as outlined in the 2005 "Research Plan for Spin Physics at RHIC".

Both PHENIX and STAR have provided Multi-Year Beam Use proposals to BNL, updated annually for review by the Laboratory's HENP Program Advisory Committee. Although the detailed requests for beam use differ between the two experiments, each proposes annual runs with significant data samples for both heavy ion and spin-polarized p-p collisions, calling for an annual operations cycle of approximately 30 weeks of cryogenic operation ("cryo-weeks"). Such a plan is consistent with the findings of the 2003 Twenty Year Planning Study for RHIC, addressing new physics issues with increased sensitivity to rare processes via much larger data samples than were possible in the early runs.

We note that in the 2003 Twenty Year Planning Study it was found that an annual operations period of 32 cryo-weeks was appropriate for a sustained and efficient program in both heavy ion and spin physics, yielding a total of 19 physics weeks for two beam modes. Since then, because of improvements in the operating efficiency of the RHIC collider and injectors, a run of 30 cryo-weeks is expected to yield 21.5 physics weeks for two beam modes.

The goal of approximately 30 cryo-weeks per year is roughly equivalent to the running time that was supported with the FY 2005 operations budget for RHIC. However, the cost of electric power to carry out this level of operations has increased markedly due to a change in the Laboratory's contractual agreement with the New York State Power Authority, and to the deregulation of electric power rates in New York State. For the FY2005 run, the cost of power was \$55/MWhr, with a total power cost for the run of approximately \$10M. The power cost rate is now variable, and driven by market prices. The present rate is ~\$100/MWhr. Thus, with the current cost of power, the FY2005 operations budget would not support a viable physics run.

While the Laboratory continues its efforts to mitigate this increase in power costs, our planning basis for the Mid-Term Strategy assumes an operations budget for RHIC at a constant level of effort based on FY 2005, with incremental support to cover the additional power costs to allow a 30 week annual run.

A complete summary of the facility operating costs to carry out this plan over the Mid-Term period is given in Section 9 of this document.

3.1 Collider performance projections for the Mid-Term

Key accelerator performance guidance for determining the scientific productivity of a particular RHIC operations scenario is given in the document "RHIC Collider Projections (FY2006 – FY2008)", by T. Roser et al., July 2005. (This document can be found on the web at http://www.rhichome.bnl.gov/RHIC/Runs/RhicProjections.pdf). In broad outline, it provides the following constraints on the utilization of RHIC during a single cryogenic run:

1. Cool-down and warm-up of the RHIC magnet rings require a total of 2 ½ weeks.
2. Each mode of running requires 3 weeks of machine set-up and ramp-up to stable physics operation. (A change in collision energy, after stable operation is achieved with a particular beam species pair, requires only ~2-3 days.)
3. Both minimum and maximum luminosity projections are given. The minimum values assume little improvement over presently-established performance. The maximum values assume steady improvement in performance, requiring long periods of sustained running in a given mode.

For the luminosity and polarization projections we assume a long polarized proton run in FY2006. During that time the AGS cold snake will be further commissioned for both polarization and bunch intensity improvements. We expect to reach the Enhanced Luminosity and polarization goals in FY2008. Until RHIC II is commissioned we expect only small improvements after FY2008. The projected luminosities for Au-Au are presented in Table 3-2 and Figure 3-1. The projected luminosities and polarizations for p-p are given in Table 3-3 and Figure 3-2. Proton luminosity projections are for 100 GeV beam energy, and need to be multiplied by 2.5 for operation at 250 GeV beam energy.

Fiscal year		2001A	2002A	2004A	2007E	2008E
No of bunches	…	55	55	45	90	111
Ions/bunch, initial	10^9	0.3	0.6	1.1	1.1	1.1
Average beam current/ring	mA	16	33	49	98	121
β*	m	2	1.0	1.0	0.9	0.9
Peak luminosity	10^{26} cm^{-2}s^{-1}	0.3	5	15	48	60
Average store luminosity	10^{26} cm^{-2}s^{-1}	0.2	1.5	5.0	12.1	14.9
Time in store	%		25	53	58	60
Maximum luminosity/week	μb^{-1}	3	25	160	424	540
Minimum luminosity/week	μb^{-1}				160	160
Maximum integrated luminosity	μb^{-1}	7	89	1370	4450	5670
Minimum integrated luminosity	μb^{-1}				1680	1680

Table 3-2: Projected RHIC Au-Au luminosities for 100 GeV/n beam energy

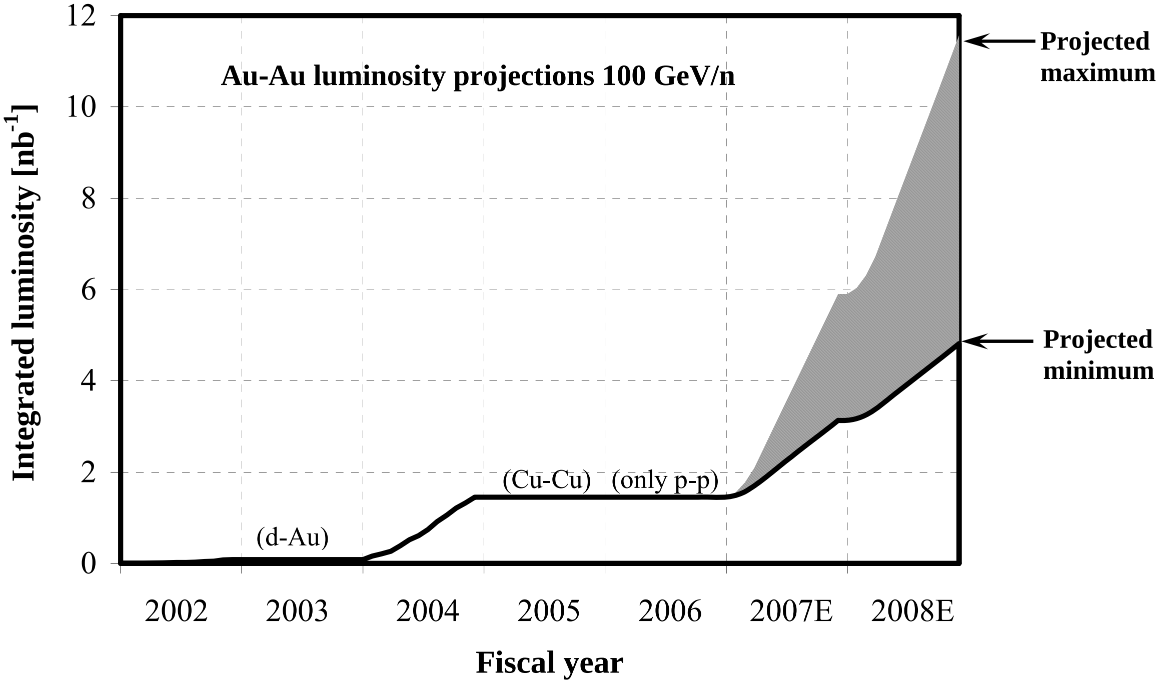

Figure 3-1: Minimum and maximum projected integrated luminosity for Au-Au collisions.

Fiscal year		2002A	2003A	2004A	2005A	2006E	2007E	2008E
No of bunches	…	55	55	56	106	111	111	111
Ions/bunch, initial	10^{11}	0.7	0.7	0.7	0.9	1.3	1.7	2.0
Average beam current/ring	mA	48	48	52	119	180	236	278
$\beta*$	m	3	1	1	1	1	1	1
Peak luminosity	10^{30} cm^{-2}s^{-1}	2	6	6	10	37	64	89
Average store luminosity	10^{30} cm^{-2}s^{-1}	1.5	3	4	6	25	43	60
Time in store	%	30	41	41	56	58	59	60
Maximum luminosity/week	pb^{-1}	0.2	0.6	0.9	1.9	8.8	15.2	21.7
Minimum luminosity/week	pb^{-1}					1.9	1.9	1.9
Maximum integrated luminosity	pb^{-1}	0.5	1.6	3	13	72	131	179
Minimum integrated luminosity	pb^{-1}					16	16	16
AGS polarization at extraction	%	35	45	50	55	65	70	80
RHIC store polarization, average	%	15	35	46	47	60	65	70
Maximum LP^4/week	nb^{-1}	0	9	40	90	1130	2720	5220
Minimum LP^4/week	nb^{-1}					90	90	90

Table 3-3: Projected RHIC p-p luminosities and polarization for 100 GeV/n beam energy

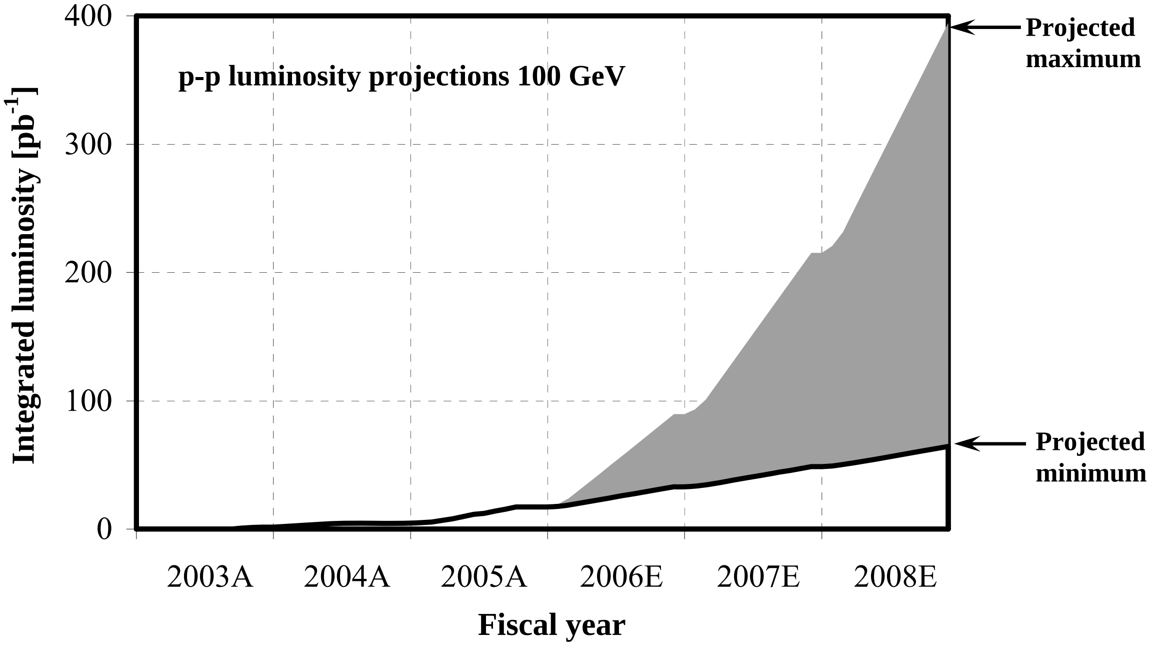

Figure 3-2: Minimum and maximum projected integrated luminosity for p-p collisions.

4 Collider upgrades and development: 2006-2011

In the quest for higher luminosity and polarization, more flexibility, and increased uptime, a number of upgrades are planned for the next few years:

1. The evolution towards the Enhanced Luminosity and polarization goals
2. The construction of the new ion injector EBIS
3. The development and implementation of electron cooling for RHIC II
4. Improvements to the aging infrastructure
5. Design of the electron-ion collider eRHIC

1. The evolution towards the Enhanced Luminosity and polarization goals

In both Au-Au and p-p operation RHIC now exceeds the Design Luminosity. The RHIC Enhanced Luminosity goals consist of

$\mathcal{L}_{\text{store ave}} = 8\times10^{26}\,\text{cm}^{-2}\text{s}^{-1}$ **for Au-Au at 100 GeV/n (4× design)**

$\mathcal{L}_{\text{store ave}} = 6\times10^{31}\,\text{cm}^{-2}\text{s}^{-1}$ **for p-p at 100 GeV,**
$\mathcal{L}_{\text{store ave}} = 1.5\times10^{32}\,\text{cm}^{-2}\text{s}^{-1}$ **for p-p at 250 GeV (16× design)**
both with 70% polarization

To reach the luminosity goals requires the completion of the vacuum upgrades in RHIC, currently undertaken and expected to be finished by the end of 2006. For both the proton luminosity and polarization goals, the AGS cold snake needs to be fully commissioned. For heavy ions, longitudinal stochastic cooling is being pursued, with the expectation of increasing the average store luminosity by up to 50% and reducing the experimental background. We expect to reach the Enhanced Luminosity goals by the end of 2008, provided that the machine runs a sufficiently long time in every year from FY2006 to FY2008. Should one of the modes not be run in any particular year, the performance development will be delayed.

2. The construction of the new ion injector EBIS

The new Electron-Beam Ion Source EBIS replaces the 35-year old Tandem electrostatic accelerators. Without EBIS the Tandems would require a multi-million dollar reliability upgrade. With EBIS the ion injector operation is expected to be simpler and more reliable, at operating costs reduced by $1.5M/year. With EBIS new species can be offered such as uranium and polarized He-3. EBIS has received CD-1. Technically driven, it can proceed to CD-2 at the end of FY2006, and construction can begin at the beginning of FY2007 (CD-3). Commissioning can then start in FY2009. The total DOE cost of the project is $14.8M, with an additional $4.5M from NASA.

3. The development and implementation of electron cooling for RHIC II

The enabling technology for RHIC II is electron cooling. For the first time electron cooling will be attempted at a high-energy collider, aiming at a ten-fold increase of the average heavy ion luminosity. This will make RHIC the first collider in which the dominant total beam loss comes from the physical interactions that the experiments study. For polarized protons a luminosity increase of a factor 2-3 is expected, from cooling the beams at injection down to an emittance that can be sustained under the limiting effects of the beam-beam interaction.

Electron cooling at RHIC is based on a high-intensity, low emittance superconducting electron gun, and an Energy-Recovery Linac (ERL), also superconducting. Both critical components are under development and will be tested in a scaled down ERL in building 912. The test ERL will accelerate an electron beam of the required intensity and emittance to about half the required energy. The test ERL is expected to be completed by the end of 2007. It is partially supported by funds from the U.S. Navy.

During 2006 we expect to establish feasibility of the RHIC II electron cooling upgrade, based on benchmarked simulations, and an assessment of the ability to reach the parameters needed in the critical components. With this milestone, CD-0 could be established in the same year, and technically constrained, CD-1, CD-2, and CD-3 decisions could follow, spaced approximately one year apart. With construction starting in FY2009, electron cooling could be commissioned in RHIC in FY2012.

4. Improvements to the aging infrastructure

The more than 40-year old injector complex, and increasingly parts of RHIC, require the replacement of obsolete components to maintain reliability and performance. These upgrades will be undertaken with operating capital and Accelerator Improvement Project (AIP) funds. The most important immediate upgrade is, at a cost of \$3.6M, the replacement of the AGS Main Magnet Power Supply Transformer, a critical piece of equipment that is at the end of its useful life. Cable and cable tray replacements in the AGS are necessary for five years, from FY07 to FY11, at a cost of approximately \$2M/year. In RHIC, an upgrade of the refrigeration system will lead to a power reduction of up to 1.5MW in steady state operation. To increase RHIC's reliability and to protect the installed equipment from unfavorable environmental conditions that shorten its lifetime, an improvement of the RHIC service buildings is needed. Electronics hardware in all parts of the RHIC complex can become obsolete, and parts unavailable, after a few years to a decade, making replacement necessary.

5. Design of the electron-ion collider eRHIC

The proposed electron ion-collider eRHIC has a center-of-mass energy range of 30-100 GeV with a luminosity of 10^{32}-$10^{34}cm^{-2}s^{-1}$ for e-p and 10^{30}-$10^{32}cm^{-2}s^{-1}$ for e-Au collisions. An essential design requirement is the availability of longitudinally polarized electron, proton, and possibly light ion beams at the interaction point. The eRHIC design work concentrates on the electron beam preparation with either a ring or a linac, the high-intensity polarized electron gun, the interaction region optimization, and the mitigation of limiting beam dynamics effects such as the beam-beam interaction, and electron clouds for the hadron beam. The eRHIC accelerator R&D and design effort has the goal to support a CD0 for eRHIC in 2008 and CD1, CD2 and CD3 approximately one year apart.

The most important of the planned upgrades are shown in Figure 4-1. The budget requirements for these upgrades are included in the operations capital, AIP, and MIE project lines of the RHIC Facility Costs summary shown in Table 6-2.

FY05 FY06 FY07 FY08 FY09 FY10 FY11 FY12

RHIC Enhanced Luminosity
2x AA luminosity, 9x pp luminosity, 1.5x polarization (from FY05 levels)

EBIS ($19m)
CD-1 CD-2 CD-3 CD-4
Increased reliability and performance, new species including U and polarized He-3

E-Cooling R&D, Test ERL (about $2m/year)
Feasibility established
Test of critical components for e-cooling: SC gun, SC ERL, MW e-beam

RHIC II
CD-0 CD-1 CD-2 CD-3 CD-4
Electron cooling: 10x AA luminosity, 2-5x pp luminosity (from Enhanced Luminosity levels)

eRHIC R&D (about $3m/year)
e-beam preparation (linac or ring), polarized e-gun
interaction region design, beam dynamics

eRHIC
CD-0 CD-1 CD-2 CD-3
High-luminosity electron-ion collider, polarized electrons, protons and light ions

RHIC Longitudinal Stochstic Cooling ($1.5m)
1.5x AA luminosity, reduced background

AGS MMPS Transformer ($3.6m)
Single point of failure

AGS Electrical Infrastructure Improvements (about $2m/year)
Replacement of AGS cables and cable trays at end of their useful life

RHIC Cryo Cold Turbine ($1.4m)
Up to 1.5MW power savings

RHIC Service Buildings Environment ($2m)
Increased reliability, lifetime extension of installed equipment

Figure 4-1: Planned upgrades in the RHIC complex through 2012

5 PHENIX and STAR Upgrades

Each of the experiments has a planned suite of upgrades to address the physics topics described in Section 2. We give here an overview of each experiment's plans, followed by a brief listing of specific upgrade projects, noting the status of each. We have divided them into "short term" and "mid-term" upgrades. The short term upgrades are projects that either already underway, or expected to proceed in FY 2006. The mid-term upgrades are projects that are far enough along in the planning/development/proposal stage that they could be implemented as DOE construction projects and completed during the time window of this strategic plan.

It is important to note that a large fraction of each of the PHENIX and STAR collaborations is actively collaborating on the detector upgrades: ~ 30 universities and research labs in PHENIX, and ~28 institutions in STAR. A number of new institutions have joined both collaborations with strong expressions of interest in the physics associated with the upgrade detectors.

5.1 Overview of PHENIX Upgrade Plans

The PHENIX experiment has developed a plan to incrementally upgrade its detector subsystems over the next five to seven years. The upgrades are designed to allow PHENIX to pursue the spectrum of compelling physics topics as RHIC evolves from the relativistic heavy ion discovery phase to the realm of exploration and characterization of strongly-coupled dense partonic matter. In addition, the upgrade program will enable PHENIX to significantly expand the systematic exploration of the sources of nucleon spin and to begin a comprehensive program of p(d)+A physics at RHIC. All detector upgrades are optimized for the increase in RHIC luminosity from electron cooling. The upgrade physics program will reach its full potential once the RHIC luminosity upgrade becomes available.

Key physics measurements of the PHENIX Upgrade Program include:

- Precision study of heavy quark production (charm and beauty) in A+A, p(d)+A and polarized p+p
- Detailed measurement of the electron pair continuum in the low mass (ρ to ϕ) and intermediate mass range (ϕ to J/ψ) in all collision systems.
- Jet tomography for γ+jet, direct photon and π^0 measurements over a pseudo-rapidity and azimuthal range increased by an order of magnitude.
- $\Delta G/G$ with charm, beauty and γ+jet correlations in p+p
- $\Delta q/q$ for sea quarks determined through W-polarization in p+p
- Transversity and transverse spin components of proton spin
- Gluon shadowing and gluon saturation (Color Glass Condensate) in p(d)+A over a large x range (10^{-1} to 10^{-3})

- Measurement of Υ at mid-rapidity. Improved S/B for J/ψ, ψ' and Υ in A+A, p(d)+A and p+p.

Details of the PHENIX upgrade subsystems are given in Table 5-1 and their locations are shown in Figure 5-1. The upgrade detectors include a Hadron Blind Detector composed of CsI-doped triple Gas Electron Multipliers (GEMs) in a proximity-focused Cerenkov counter (HBD), a four-layer silicon vertex barrel at mid-rapidity (VTX), a forward, four-layer, silicon vertex tracker (FVTX), Resistive Plate Chamber (RPC) tracking stations located in the Muon Spectrometer arms (MuTrig), and a compact tungsten-silicon calorimeters in the forward rapidity region (NCC). All the new subsystems complement the PHENIX baseline detector, and in all cases enhance or extend physics capabilities of the existing detector. All upgrade subsystems rely on technologies that were unavailable at the time of the construction of the PHENIX baseline detector.

Upgrade Subsystem	Detector type	Physics program	Collaborating Institutions 12/2005
Hadron Blind Detector	GEM-based Cerenkov	Low mass di-electrons	BNL, Columbia U, U Mass, RBRC, Stony Brook U, U Tokyo, WIS
Muon Trigger	Res Plate Chambers	Quark spin structure W-polarization	ACU, Columbia U, ISU, Kyoto U, Peking U, RBRC, UCR, U Colorado, UIUC
Silicon Vertex Barrel	Silicon pixel + strips	γ+jet, heavy quark spec. jet tomography	BNL, Ecole Polytech., FSU, ISU, KEK, Kyoto U, LANL, Niigata U, ORNL, RIKEN, Rikkyo U, Stony Brook U, UNM
Forward Silicon Vertex	Silicon mini-strips	γ+jet, heavy quark spec. jet tomography, CGC	BNL, Charles U, Columbia U, Czech Tech U, Inst Phys Czech Acad Sci, ISU, LANL, NMSU, UNM
Nose Cone Calorimeter	Tungsten-silicon calorimeter	γ+jet, W-polar., heavy quark spectroscopy, jet tomography, CGC	BNL, Charles Univ, Columbia U, Czech Tech U, EWU-Korea, Inst Phys Czech Acad Sci, ISU, JINR-Dubna, Korea U, Moscow State, RIKEN, Stony Brook U, Tsukuba U, UCR, UIUC, Yonsei U
Data Acquisition	Electronics, computing	High luminosity, high rate	BNL, Columbia U, ISU

Table 5-1: Summary of the PHENIX mid-term Upgrade program

Future PHENIX Beam Use Proposals will be optimized to take advantage of the new physics available as the subdetectors in the Upgrade Program are commissioned and operated in PHENIX. Physics runs with substantial integrated luminosities for collisions of Au+Au, d+Au and p+p (both $\sqrt{s}$ = 200 GeV and $\sqrt{s}$ = 500 GeV) will be requested during the next five to seven years of RHIC operations. Collisions of U+U will be requested once EBIS is completed and the beams become available to RHIC. The goal is to have all PHENIX upgrade subsystems installed and commissioned with initial physics measurements completed by the time RHIC II luminosities become available circa 2012.

The PHENIX upgrade subsystems will join the PHENIX baseline detector, and previously completed High p_T (Aerogel + Time of Flight), TRD and Muon Piston Calorimeter upgrades, to enable the experiment to carry out a comprehensive physics program for the next decade and beyond. An active R&D program is underway for each of these upgrade subsystems and in certain cases, such as the HBD, construction of the final detector has begun. A team of PHENIX engineers, scientists and upgrade subsystem personnel has been working since Fall 2004 on infrastructure and installation planning for the upgrades. Progress on integration and facilities issues is advancing on a timeline consistent with the anticipated construction schedules of the upgrade subsystems.

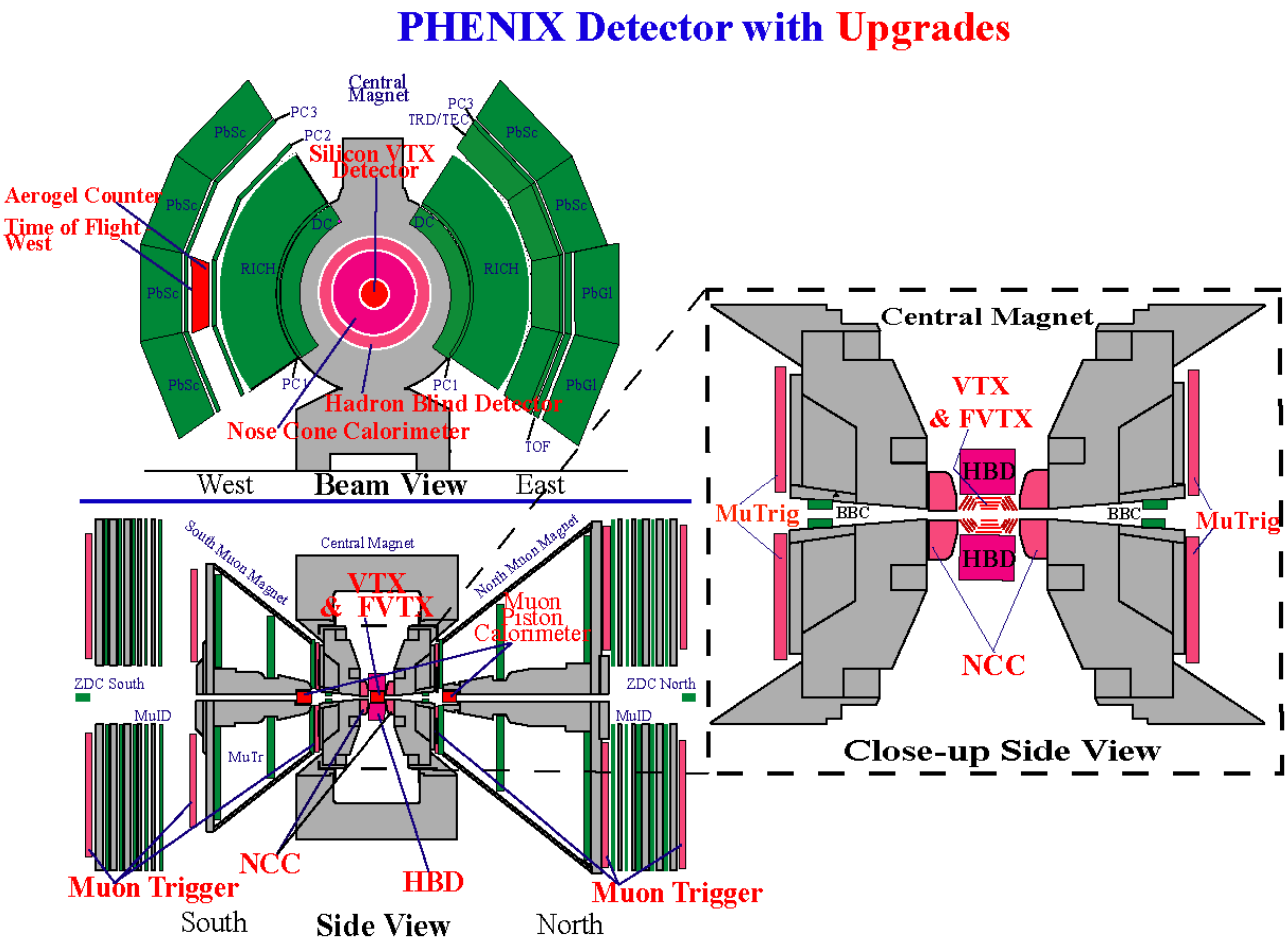

Figure 5-1: Schematic view of PHENIX Detector including upgrade subsystems: Aerogel Counter, Time of Flight-West, Hadron Blind Detector (BD), Silicon barrel (VTX) and Forward VTX (FVTX), Muon Piston Calorimeter, Muon Trigger, and Nose Cone Calorimeter (NCC).

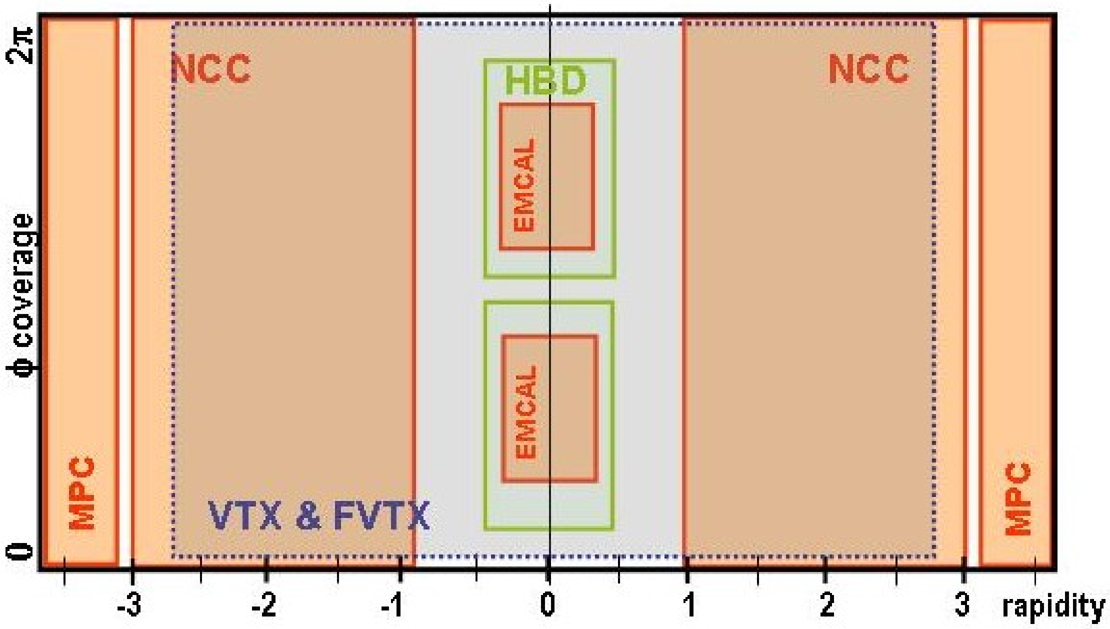

Figure 5-2: Map of upgraded PHENIX acceptance for (i) π^0 and direct photon detection with the existing EMCAL in the central arms and the MPC added in 2006 and the projected NCC; for (ii) precision vertex tracking for charm and bottom decays with the silicon vertex tracker upgrades VTX and FVTX; and (iii) for low mass dilepton measurements with the HBD. The combination of (i) and (ii) indicates the acceptance for jet tomography with γ-jet coincidences. Not shown in the graph are the upgraded PHENIX muon spectrometer covering 2π azimuthally and 1.2 to 2.4 in pseudo-rapidity.

5.2 Overview of STAR Upgrade Plans

In the coming decade, the STAR Collaboration plans a challenging program of measurements to elucidate fundamental properties (speed of sound, transport coefficients, structure) of the new state of strongly interacting matter produced in RHIC collisions. These measurements allow STAR to test and extend QCD theory and its predictions regarding the behavior of bulk color-deconfined matter.

Studies key to this program will include:

- measurement of the energy density of the plasma using direct-photon tagged jets
- direct reconstruction of charm and beauty decays as well as measurement of flavor tagged jets to allow precise measurements of the spectra, yields, hadrochemistry, and flow of open charm and bottom; measurement of the nuclear

modification factor (R_{AA}) for particles containing heavy quarks to test perturbative QCD predictions of heavy quark energy loss

- measurement of spectra and yields for the Upsilon family of states to place significant constraints on the temperature in the initial stage of the collisions and search for evidence of deconfinement
- studying partonic collectivity by measuring bulk physics properties (e.g. spectra, elliptic flow, particle ratios, non-identical particle correlations) for identified particles and resonances containing light, strange, and charmed quarks
- detailed unfolding of large and small scale fluctuations and correlations for identified particles to map the dynamics and evolution of the produced matter
- searching for the effects of chiral symmetry restoration via leptonic decays of hadronic resonances in-medium

Additional studies will focus on the search for new phenomena in bulk QCD matter such as strong CP violation. Proton-nucleus studies to measure gluon densities at low momentum fraction to probe the effect of the nuclear medium on parton densities will be carried out. These measurements as well as a search for forward mono-jets in p(d) + A collisions will be used to determine the saturation scale for gluons in the intial-state wave functions of entrance channel nuclei in AA collisions.

The second core goal of the STAR scientific program is to carry out spin physics measurements to study the spin structure of the proton. The contribution to the proton spin from gluons will be determined as a function of momentum fraction ($\Delta G(x)$) using direct photon + jet, charm and beauty production, inclusive jets and di-jet production at moderately high p_T (<5 GeV/c). The flavor-dependence ($\bar{u}$ vs. $\bar{d}$) of the sea quark polarization, and thereby the mechanism for producing the sea in a proton, will be probed using parity-violating W production and decay. Additional studies of the effects of quark mass terms in the QCD Lagrangian and of quark transverse spin preferences in a transversely polarized proton will be carried out by measuring transverse spin asymmetries for b-quark jets, for π^0 from forward-going jets, and for quark-quark di-jets.

To accomplish this program, the STAR detector will require significant upgrading. The required upgrades include:

- a full acceptance TOF barrel based on multi-gap resistive plate chamber technology to significantly extend the momentum range of STAR's particle identification capabilities
- a precision micro-vertex detector and inner tracking detectors capable of directly observing charm and beauty decays
- a high rate data acquisition system and corresponding TPC front end electronics upgrades to allow maximal utilization of RHIC luminosity to study bulk physics properties of the produced matter

- a forward tracking upgrade to enable reliable charge sign determination for *W* decay.
- A forward meson spectrometer.

These upgrades and their importance in extending the scientific reach of STAR are summarized in Table 5-2. The Collaboration is fully committed to their construction to provide the essential capability required for the above scientific measurements planned for the mid-term period and beyond. The proposed upgrades will add significant new scientific reach to STAR, increasing the sensitivity, rate capability, and acceptance of the detector, thereby enabling STAR to achieve its core scientific goals.

The location of the various upgrades in the STAR detector is shown in Figure 5-2, where the new systems summarized in Table 5-2 have been highlighted. They include:

- An upgrade of the TPC electronics and data acquisition (DAQ1000) to increase the event recording rate from the present level of 50-100 Hz to 1000 Hz

- A 2π acceptance barrel Time of Flight detector ($-1 < \eta < 1$) which, when used in conjunction with ionization energy loss measurements in the Time Projection Chamber, will provide comprehensive particle identification for charged hadrons (π, K, p) out to momenta of 10 GeV/c

- A Forward Meson Spectrometer consisting of ~ 1400 Pb Glass cells covering the pseudorapidity interval $2.5 < \eta < 4$

- A high resolution micro-vertex detector (Heavy Flavor Tracker) based on active pixel sensor (APS) technology to minimize multiple scattering

- An Intermediate Silicon Tracker (IST) consisting of three layers of silicon sensorss surrounding the HFT; a Forward Tracking Upgrade consisting of four disks of silicon strip detectors and a Gas Electron Multiplication (GEM) based tracking detector to provide accurate charge sign determination for $W^{\pm}$ bosons which decay into electrons (positrons) which enter the acceptance of the Endcap Electromagnetic Calorimeter.

The acceptance provided by these upgrades is shown in Fig. 5-3.

Table 5-2

Upgrade System	**Physics**	**Collaborating Institutions**
Forward Meson Spectrometer (FMS)	Gluon density distributions in gold nuclei for $0.001 < x < 0.1$ Proton transversity	Penn State Univ.; BNL; UC Berkeley Space Sciences Inst.; IHEP, Protvino; Texas A&M Univ.
Barrel Time of Flight (TOF)	Identified hadron spectra to allow mapping of freeze out dynamics and hadronization mechanism Identified particle correlations to map the chemical and kinetic properties of in-medium jet-associated particles Single and di-lepton spectra to measure in-medium vector meson properties, heavy flavor production	BNL; HuaZhong Normal U., Wuhan; IHEP, Beijing; IMP, Lanzhou; LBNL; MEPHI, Moscow; NASA-Goddard Space Flight Center; Rice Univ.; SINR, Shanghai; Tsinghua Univ., Beijing; UCLA; USTC, Hefei; U.T. Austin; U. Washington; Yale Univ.
Heavy Flavor Tracker (HFT)	Direct topological reconstruction of large samples of charmed particles to allow precise measurement of charm quark yields, flow, nuclear modification factor (R_{AA}), soft di-lepton spectrum	BNL; U. Ca. Irvine; UCLA; Czech Republic Nuclear Physics Inst.; Strasbourg; MIT; LBNL; Ohio State Univ.
Inner and Forward Tracker (IST), (FST/FGT)	Topological reconstruction of charm decays in p-p and low multiplicity interactions, charm R_{AA}. Contribution of sea quarks to proton spin	Argonne Nat. Lab; BNL; IUCF; LBNL; MIT; Valparaiso Univ.; Yale Univ.; Univ. of Zagreb.
High Speed Data Acquisition (DAQ1000)	Collection of large data samples needed for precision open charm measurements, photon HBT and symmetry violation/restoration studies. Increase live time for rare, triggered processes by a factor of 2.	BNL; U.T. Austin; LBNL

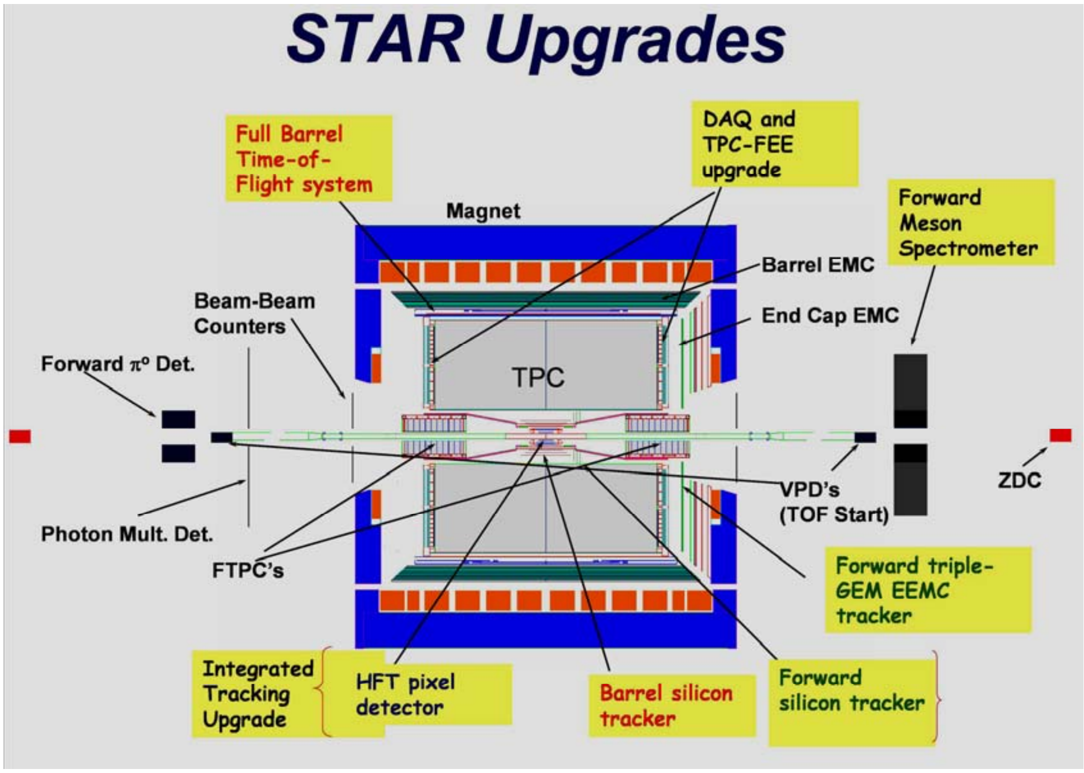

Figure 5-2. Location of planned upgrades (highlighted text) in the STAR detector.

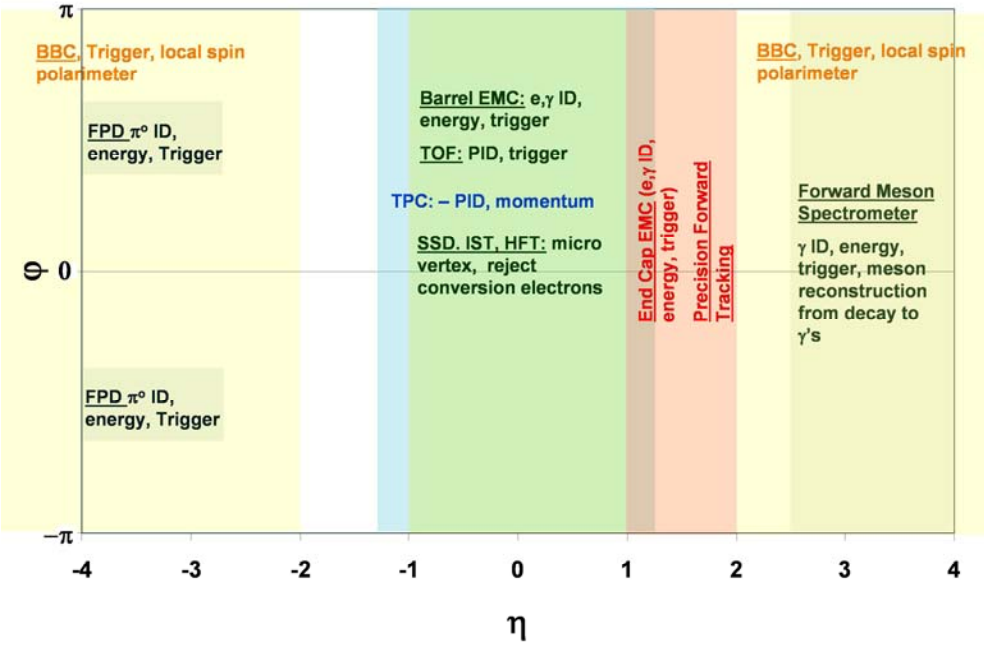

Figure 5-3. Coverage in azimuth and pseudorapidity of major STAR detectors and upgrades. The ZDC (Zero Degree Calorimeter covering full azimuth for η>6.5) is not shown.

Performance of the STAR TPC at high luminosity

The Time Projection Chamber is clearly central to the utility of the STAR detector, providing accurate momentum and dE/dx measurements for charged particles over full azimuth in the rapidity range –1 to +1. Clearly, a crucial consideration for upgrading STAR, in readiness for RHIC II luminosity, is the question of whether the TPC will continue to function effectively in this high-rate environment. The STAR collaboration has developed considerable experience and a large array of tools to correct track distortions in the TPC. The distortion of most concern for future operation at higher luminosity is due to space charge build up in the TPC gas volume. The charge build up in the TPC gas volume, which distorts the nominally purely longitudinal electric field, arises from the slow drift time of positive ions created by the flux of ionizing radiation through the TPC. It takes almost one second for a positive ion to traverse the full 2m drift distance. The charge buildup is proportional to the flux of charged particles through the TPC which will vary with luminosity and background and can vary on a short time scale. The tools used to correct these distortions include accurate modeling of the shape of the charge distribution, adequate scaler information to monitor the flux through the TPC and the ability to adjust the correction locally in time by using individual events. Details of the corrections can be found at: http://xxx.lanl.gov/abs/physics/0512157 . A powerful monitor of the quality of the corrections that is used in the short time scale corrections is the "signed distance of closest approach" (sDCA). This is simply the distance of closest approach of a track to the primary vertex (defined from a fit using all tracks) with a sign given by whether the primary vertex lies inside or outside the track's curvature. The width of the sDCA distribution is a global monitor of tracking resolution. Figure 5-3 shows the mean (markers) and width (black bars) of the sDCA distribution as a function of luminosity after all corrections are applied for 200 GeV Au-Au collisions.

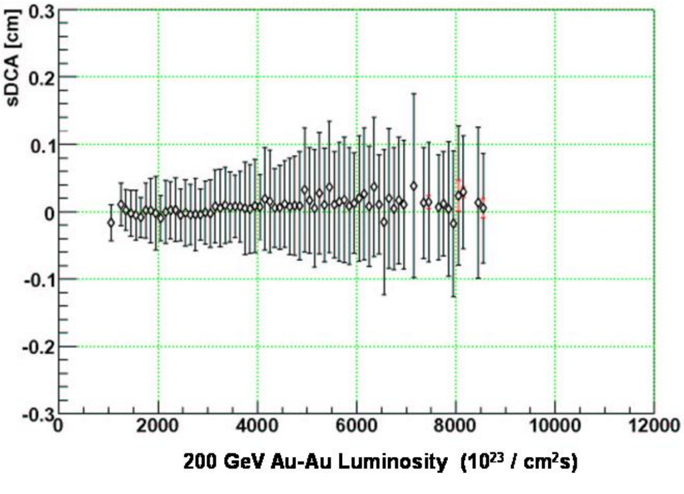

Figure 5-4 Signed DCA (sDCA) as a function of Luminosity for 200 GeV Au-Au collisions. The markers show the mean sDCA, the red bars the statistical error on the mean and the black bars the RMS of the event by event fitted sDCA mean. The latter is a monitor of the quality of the distortion corrections.

There is some increase in the sDCA width from the lowest luminosity to ~5 x 10^{26} /cm^2sec however the width remains constant above this to the highest luminosity sampled (~8.5 x 10^{26} /cm^2sec). This indicates the corrections are understood and there should be no difficulty running at even higher luminosity. We note that the peak luminosity for

RHIC (30 x 10^{26} /cm^{2}sec) after the near term RHIC improvements is expected to be reached in FY09 and is within a factor of 2-3 of the RHIC II luminosity. This will be achieved five years before the full RHIC II luminosity is expected which should allow adequate time for refining the corrections, improving monitoring of the flux in the TPC and developments of improvements to the TPC (different operating gas and or increased drift field) if these are required. A research effort using a spare TPC sector is being initiated now to characterize various operating gases.

5.3 Summary and Status of Detector Upgrades

Short Term Upgrades:

PHENIX Hadron Blind Detector: The HBD will enable PHENIX to measure the low and intermediate mass electron pair continuum for all collision systems. The HBD is a windowless Cerenkov detector operated with pure CF4 in a proximity-focus configuration. The cylindrical detector, located in the central spectrometer magnet, consists of a 50 cm long radiator directly coupled to a triple-GEM which has CsI evaporated onto the top face surface of the GEM foil and a pad readout at the bottom of the GEM stack. The HBD's ability to detect the electrons of Dalitz decays from π^o and γ conversions will increase the S/B of the electron-pair continuum in the low mass region by two orders of magnitude. The DOE cost is \$1.0M, funded from RHIC operations capital. An additional \$0.5M is funded through NSF plus Stony Brook and Weizmann Institute contributions. A full size prototype is installed for an engineering run in Run 6. The complete detector should be operational for Run 7.

PHENIX Muon Trigger: The fast muon trigger system (MuTrig) will be used to select events containing W bosons produced in polarized p+p collisions. The measurement of single longitudinal spin asymmetry A_L in W production makes it possible to determine the spin contributions of sea and valence quarks to the proton spin. The fast muon trigger system consists of three resistive plate chamber (RPC) stations installed in each of the PHENIX forward muon spectrometer arms. The MuTrig will have the same azimuthal and rapidity coverage as the existing PHENIX forward muon arms, and will use two-gap RPC technology developed for the CMS muon trigger at LHC. It is designed for a background rejection of > 10^4 , which is sufficient for efficient operation at the anticipated 9 MHz collision rates at RHIC for polarized p+p running at $s^{½}$ = 500 GeV. This project is funded by the NSF, at a cost of ~\$2M. Construction is scheduled to begin in FY 2007, with completion in 2009.

STAR Time of Flight (TOF): A fast, fine-grained barrel array of multi-gap resistive plate chambers (MRPC) that will surround the STAR TPC. In addition to doubling the momentum range over which π, k, and p can be identified, when the TOF measurement is combined with the TPC dE/dx measurement, electrons can be cleanly identified from the lowest momentum measured (~200MeV/c) up to a few GeV/c. This capability complements the STAR electromagnetic calorimeter, which works well for momenta above ~2GeV/c and provides the capability in STAR to measure the soft lepton and di-lepton spectra. The presence of a high granularity fast detector covering the TPC barrel will also allow pile-up events in the TPC to be filtered out in the analysis. This is especially important for the collision rates that are expected in p-p collisions at the highest luminosity. The TOF detector is a joint US-China project with a collaboration of Chinese institutions providing the MRPC modules and the US providing the readout electronics and mechanical infrastructure. This is a line-item (MIE) project with a DOE cost of $4.7M. It is funded in FY 2006, with completion in 2009.

STAR Forward Meson Spectrometer (FMS): A Pb glass array of ~1400 existing blocks, covering the η range from 1-4, over the full azimuth. Addition of this detector to STAR will allow observation and characterization of the parton model gluon density distributions in gold nuclei for $0.001<x<0.1$. The greatly expanded coverage in the forward direction compared to the existing Forward Pi-zero Detector (FPD) will also allow measurements to resolve longstanding questions about the origin of very large transverse spin asymmetries for forward π^0 production in $p\uparrow + p \rightarrow \pi^0 + X$ reactions initiated by transversely polarized proton beams. The FMS is being funded from RHIC operations capital, at a cost of $600K. It is expected to be fully operational in FY 2007.

STAR DAQ1000: Replaces the front-end electronics of the STAR TPC with a fully pipelined system using the readout chip designed for the ALICE TPC. This will increase the readout rate from its present 100Hz to 1000 HZ, allowing very large data sets for untriggered rare processes, and virtually eliminating front-end dead time, thereby approximately doubling the luminosity seen by rare triggers. The project is funded from RHIC operations capital at a cost of $1.8M, it should be implemented by FY 2008.

Mid-Term Upgrades

PHENIX Si Barrel Vertex Detector: The VTX will allow precision measurements of heavy quark production (charm and beauty) in A+A, p(d)+A and polarized p+p collisions. It will enable γ + jet measurements over 2.4 units in pseudorapidity and almost 2π in azimuth. It will significantly increase the x-range for gluon shadowing and saturation measurements. The VTX is a four-layer silicon detector configured as concentric cylinders located in the PHENIX central spectrometer magnet and positioned immediately around a new 3 cm diameter beam pipe. The silicon sensors in the inner two layers are pixels (r = 2.5, 5.0 cm) and the outer two layers are strips (r = 10, 14 cm). The VTX barrel will cover $|\eta| < 1.2$. This is a joint U.S. and Japanese effort. The U.S. component, the silicon strip layers, is proposed as an MIE project with a DOE cost of $4.7M. It has been reviewed, and a management plan accepted by DOE. It is expected to be funded for a construction start in FY 2007. The two silicon pixel layers are presently under construction, funded by RIKEN at a level of $3M. the project should be completed by 2009.

PHENIX Si Forward Vertex Trackers: The FVTX extends the solid angle coverage of the VTX barrel. The FVTX will allow precision measurements of heavy-quark (charm and beauty) production in the forward and backward rapidity regions in A+A, p(d)+A, and polarized p+p collisions. It provides new coverage in the small Bjorken-x region where gluon saturation is thought to be important and significantly extends the range over which PHENIX can examine the gluon structure functions and their polarization. The FVTX will be composed of four silicon mini-strip planes in each of two endcaps matched to the muon arms. It will provide vertex tracking with a resolution of <200 μm over a large coverage in rapidity ($1.2 < |\eta| < 2.2$) with full azimuthal coverage. The proposed DOE cost will be ~$4.5M. A formal proposal for construction starting in FY2008 will be reviewed by BNL in March 2006.

PHENIX Nose Cone Calorimeter (NCC): The NCC is a compact tungsten-silicon sampling calorimeter (NCC) built to identify and make precision measurements of forward electromagnetic showers, provide jet identification, jet energy, γ/π^0 and γ/hadron discrimination. The NCC has a circular geometrical coverage of a 50 cm radius at a distance of 40 cm from the nominal PHENIX collision point corresponding to a forward rapidity range from 0.9 to 3.5. Two calorimeter modules, one located on each of the pole faces of the PHENIX central spectrometer magnet, are built with an electromagnetic compartment, shallow hadronic compartment, a preshower section and a γ/π^0 identifier. The NCC is designed by a collaboration of U.S., European and Japanese institutions. A formal proposal for one NCC, requesting construction funds of $4M through DOE, will be reviewed by BNL in March 2006. PHENIX expects that the second calorimeter would be supported at a similar level by Japanese and European funding agencies.

STAR Heavy Flavor Tracker (HFT): A silicon pixel inner tracking device with vertex point-back accuracy <50 μm, consisting of two layers of CMOS active pixel sensors, 10^8 pixels, thin, 2 cm radius beampipe, with detector thickness ~ 50μm per layer. The HFT uses new technology. A significant R&D program is underway with collaboration from UC Irvine, Lawrence Berkeley National Laboratory and IRES, Strasbourg. It is expected that this effort could produce a prototype device to be installed in STAR by FY09. This device would allow *in situ* demonstration of the technology, demonstrate that a tracking device can operate only 2 cm from the RHIC beams, demonstrate the mechanical concepts for alignment are sound and allow vetting of the required tracking software with real data. The final devices would be installed in the following 2-3 years. This is an on-going development effort, with expectation that a project to construct a functioning detector for STAR could be undertaken in 2-3 years. The cost would be in the range $5-10M.

STAR Inner/Forward Tracking (integrated tracker): A silicon barrel consisting of 3 layers of Si strip detectors, replacing the present SVT, surrounding the HFT, and utilizing the existing SSD Si strip layer, provides a track pointing device for the HFT, connecting TPC tracks to the high precision inner layers, compatible with DAQ 1000. Forward tracking consists of 4 Si strip discs just forward of the Si barrel, and a GEM layer on the front face of the Forward EM Calorimeter. The forward tracking components provide precision tracking in the range $1 < \eta < 2$, giving charge sign discrimination for leptonic decays of W bosons. The charge sign determination of forward scattered $e^{\pm}$, tagged in the STAR end cap calorimeter in polarized p-p collisions is the main motivation for the forward tracking upgrade. Detailed simulations for the Integrated Tracker are in progress, and are expected to lead to a technical proposal during FY 2006. The estimated cost is ~$10M.

6 Upgrade costs and schedules

In Table 6-1 we summarize the estimated costs and schedules for these upgrades. Only the DOE costs are shown. Here, the estimates for the short-term upgrades are well-established. For the mid-term upgrades we have provided the current best estimates. The schedules shown for the mid-term upgrades include the time required for review of technical designs and management plans by BNL and DOE in advance of the budget preparation cycle for the proposed construction start. (Thus, for example, proposed project starts in FY 2008 must be reviewed by mid-FY 2006).

In discussing these projects in the context of the strategic plan, we have considered the resources required to implement them, including manpower; the costs and expected funding sources; the R&D requirements, including R&D costs; the incremental operations costs and computing resources once the upgrade becomes operational; and the timing of these upgrades with respect to possible physics operations scenarios for the facility. Thus, for example, the planning for the next high-statistics Au-Au run is coupled to the availability of detector upgrades to allow direct observation of open charm. These considerations are the subject of the "integrated plan" for upgrades that we discuss below.

A complete summary of the facility operating and construction costs to carry out this plan over the Mid-Term period is given in Section 9 of this document.

		FY 2006		FY 2007		FY 2008		FY 2009		FY 2010		FY 2011	
		R&D	Constr.	R&D	Constr.	R&D	Constr.	R&D	Constr.	R&D	Constr.	R&D	Constr.
STAR													
	FMS		0.2		0.3								
	DAQ1000		0.9		0.9								
	TOF		2.4		2.4								
	HFT	0.3		1.0		0.8	0.3		2.5		2.5		
	Int. Trk.	0.2		0.2		0.5			3.0		4.5		1.0
	STAR tot.	0.5	3.5	1.2	3.6	1.3	0.3	-	5.5	-	7.0	-	1.0
PHENIX													
	HBD	0.1	0.5		0.1								
	VTX	0.1			2.0		2.0		0.6				
	FVTX	0.1		0.3			1.8		2.0		0.7		
	NCC	0.1		0.2			2.0		1.5		0.5		
	DAQ	0.1		0.2		0.2		0.2		0.2		0.2	
	PHENIX tot	0.5	0.5	0.6	2.1	0.2	5.8	0.2	4.1	0.2	1.2	0.2	-
Generic detector R&D						0.5		1.0		1.0		1.0	
Detectors total		1.0	4.0	1.8	5.7	2.0	6.1	1.2	9.6	1.2	8.2	1.2	1.0
EBIS			2.1		7.5		4.5						
e Cooling R&D		1.9		2.0		2.0							

Table 6-1. Upgrade cost profiles (DOE costs): R&D and Construction

As R&D for the Mid-Term detector projects is completed, it is anticipated that development effort on detector technologies will continue, with an eye to future detector improvements as well as the design and development of detector systems for the eRHIC program. Hence, Table 6-1 includes a line for "generic detector R&D", beginning in FY2008.

The total annual R&D and equipment fabrication costs for detectors in FY 2005 and 2006 is about $6M per year. In Table 6-1 one sees that this annual investment would rise to levels of $7-10M per year for the period 2007 – 2010 in order to implement these upgrades.

6.1 Contributions from non-DOE sources

In the preceding sections we have noted important on-DOE contributions to the upgrades of the facility and detectors. These are contributions in addition to the already substantial support for the on-going program. We summarize here the projected contributions from these sources:

Project	**Source**	**Projected contribution**
EBIS	NASA	$4.5M Approved funding
STAR TOF	China	$3.0M In kind
PHENIX HBD	NSF	$0.3M Approved funding
PHENIX Muon Trigger	NSF	$1.9M Approved funding
PHENIX VTX	Japan (RIKEN)	$3.0M In kind
PHENIX NCC	Europe and Japan	$3.5M In kind

6.2 The effect of upgrades on facility operating costs

The annual cost of operating the RHIC detectors will increase incrementally as major new subsystems come on-line. This results mainly from the need for additional trained personnel on site at BNL to commission, maintain, de-bug, and repair these systems. Estimates from PHENIX and STAR of the added costs of material, travel, and personnel due to these upgrades indicate that the total incremental operating costs for the two experiments, once these upgrades are in place, will be about $1M. This is roughly equivalent to the cost of operating an additional small experiment, on the scale of BRAHMS or PHOBOS. This does not include the incremental cost of computing, which is discussed in Section 7 below.

When EBIS becomes operational, toward the end of the mid-term period, it will replace the 35-year-old Tandem Van de Graaf machines, which are relatively expensive to operate, with a modern, linac-based pre-injector. It is estimated that the implementation of EBIS will reduce the operating costs by about $1.5M per year, beginning in 2010.

7 RHIC Computing Facility

The RHIC Computing Facility (RCF) uses a scalable architecture consisting of three main components – a CPU farm, central and distributed disk, and a hierarchical mass storage system (HPSS) – interconnected with a Gigabit Ethernet network. The CPU farm is based on dual-CPU commodity hardware running the Linux operating system. Each annual CPU purchase brings in an identical set of machines, this minimizes the number of machine configurations and greatly reduces the effort required to maintain the systems.

The disk storage in the facility started as high quality, expensive RAID arrays. As the volume of data collected by the experiments quickly exceeded expectations and the cost of non-RAIDed disk came down, the experiments began shifting to distributed disk on the farm nodes for the bulk of their online data storage, leaving the centralized RAID disk for files requiring high availability or not redundantly stored in HPSS. With this strategy, the experiments are able to afford much more storage than they would if they used only centralized disk. At this point they have over twice as much distributed disk as they have centralized disk.

The HPSS hierarchical mass storage system stores the entire raw data set from the experiments as well as the data derived from the reconstruction and analysis passes through the Linux farm. After some initial problems with HPSS, which were addressed by IBM, HPSS has been quite stable. The rapid increase of the data rates from the experiments, well beyond the initial design profile of the HPSS system, did result in some reconfiguration of the system during the first part of Run-5. It is felt that with continued upgrades to HPSS, RCF will be able to keep up with the data rates from the experiments.

7.1 Computational Resource Planning for the Mid-Term Period

The systems within the RCF and the experiment counting houses are connected via gigabit Ethernet including some trunked gigabit Ethernet paths. All individual machines are directly connected to large central switch chassis that initially were segregated by experiment. As the facility grew it became impossible to connect all of the nodes of one experiment on a separate switch and interswitch traffic has become significant; to the point where RCF will be upgrading these links to 10 gigabit connections in the near future.

The annual replacement of ~1/4 of the installed hardware within the facility by new, more performant, hardware at a cost of about $2M per year has generally been successful in ramping up facility capacity at a rate adequate to meet the increasing demands of successive RHIC runs. Working with the experimental groups, RCF has developed algorithms to estimate the required capacities for CPU, disk, and mass storage for anticipated RHIC running scenarios. During annual meetings, the experiments provide the input used by the algorithmic model. From their beam use plans, the experiments estimate the amount of raw data they will collect for each species in each year. Each experiment then provides factors for the maturity of their codes, the number of reconstruction passes they believe will be required and a "richness" factor for the data, which indicates improvement in the density of interesting events compared to the data set used as the reference of the model. The model then calculates the required resources per Terabyte of raw data by scaling the corresponding parameters used historically by each of the experiments. The current model uses the 2005 Cu-Cu values as the reference data set. Finally, using the historical and Moore's Law projected costs for CPU, disk, etc., the model produces a profile of required and delivered capacity for each year and the associated cost to meet it.

Since the actual species and duration of each future running period is not settled until shortly before the run begins, the model is flexible and a range of possible run conditions can easily be entered into the model. An example of the output of the model is shown in Table 7-1, Table 7-2, and Table 7-3. The total data volumes given by the experiments are shown in the first line of Table 7-1. The increases in expected data volumes over the coming years are based on the projected schedule for detector upgrades (increased read-out data volume per event, and increased data acquisition rate for STAR) and projected increases in the machine luminosity. The following lines in Table 7-1 show the scaled capacities required to process the raw data based on FY '05 Cu-Cu experience. The lower half of the table shows the required installed capacities in the facility consisting of the resources required to process the data for that run plus a fraction of the previous year's requirement.

Total Requirement	2005	2006	2007	2008	2009	2010	2011	2012
Real Data Volume (TB)	2000	1700	2700	3500	4500	7200	8600	8600
Reco CPU (KSI2K)	1200	600	1000	2900	4700	8500	9700	9700
Analys CPU (KSI2K)	730	310	570	1800	2700	4600	5400	5400
Dist. Disk (TB)	520	220	480	1500	1700	3000	3600	3600
Cent. Disk (TB)	70	30	60	190	260	450	560	560
Annual Tape Volume (TB)	2300	2000	3200	4200	5400	8700	10300	10300
Tape bandwidth (MB/sec)	460	690	920	920	1700	2100	2300	2300
WAN bandwidth (Mb/sec)	280	1400	2000	2100	4300	5700	6700	6700
Simulation CPU (KSI2K)	260	110	200	610	1000	1800	2100	2100
Simulation Data Volume (TB)	390	330	530	710	900	1400	1700	1700
Total Installed Requirement								
CPU (KSI2K)	2200	2100	2800	6800	11800	20800	27700	31100
Dist. Disk (TB)	520	480	720	1900	2600	4300	5700	6400
Cent. Disk (TB)	200	200	200	290	400	650	880	1000
Tape Volume (TB)	2300	4300	7500	11800	17200	25900	36200	46500
Tape bandwidth (MB/sec)	460	920	1400	1600	2500	3300	4000	4300
WAN bandwidth (Mb/sec)	280	1500	2700	3500	6100	8700	11000	12200

Table 7-1 Total computing requirement for each running scenario and the total RCF installed requirements

Table 7-2 shows the resulting detailed equipment cost profile for each year and Table 7-3 shows the estimated profile for the delivered capacity.

	2005	2006	2007	2008	2009	2010	2011	2012
CPU	800	230	670	680	790	950	940	1210
Distributed Disk	340	50	110	380	170	250	130	40
Central Disk	360	150	250	400	330	450	310	140
Tape Robotics	300	200	0	0	200	200	0	0
Tape Drives	230	100	180	100	480	160	130	340
HPSS Disk & Servers	300	340	410	150	380	210	120	30
LAN	250	120	190	250	300	320	190	50
Other Infrastructure	70	0	0	0	0	0	0	0
Overhead	260	120	180	190	270	250	180	180
Total	2900	1300	2000	2140	2930	2790	2000	2000

Table 7-2 Detailed RCF equipment cost profile (at year $K)

	2005	2006	2007	2008	2009	2010	2011	2012
CPU (kSI2k)	1800	2100	4000	6800	11800	20800	34100	60900
Distributed Disk (TBytes)	350	410	630	1800	2500	4200	5600	6300
Central Disk (Tbytes)	170	170	200	290	400	650	900	1000
Disk (GBytes/sec)	25	24	34	47	54	65	70	78
Tape (PBytes)	5	4	8	12	17	26	36	46
Tape (MBytes/sec)	1400	1900	2800	3300	5200	6700	8000	8600

Table 7-3 Estimate of delivered capacity profile

The model shows that, given this particular set of Run scenarios, an increase in equipment funding over the nominal $2 M a year would be required between FY'08 and FY'10 in order to meet the expected requirements of the experiments. The estimated rate of increase in expected data volume flattens out in the years beyond FY'09, and, within our model, further impacts on the budget are moderated by Moore's Law. The out years, of course, have the greatest uncertainly and the impact on the experiments' data volume due to the proposed detector upgrades is not well known. Given the significant increases in detector capability and machine luminosity expected over this period, we are planning that the level of annual equipment funding for RCF will rise to $3M by 2012.

CPU has historically been the primary driver of RCF equipment costs, and, to date, the predictability of Moore's Law has been excellent for increasing CPU capacity through annual purchase of new hardware. Moreover, new Dual Core Processor technology promises a significant price/performance enhancement, as well as a reduction in Watts/performance. On the other hand, growth in data volume and data recording rates has outpaced early expectations, hence RCF is moving toward cheaper (more commodity-like) solutions for mass storage. The model for future requirements takes this trend in mass storage into account.

7.2 Resource Utilization

RHIC Computing Facility CPU resources are assigned to particular experiments on the basis of long term anticipated needs. Within an experiment resources are then assigned for production reconstruction or for later stage individual or group level analysis. In the past, this allocation of resources resulted in some inefficiencies in the use of computational resources. This situation has now been corrected so that machines are no longer the exclusive province of particular groups. Assignments to particular experiments now relate to highest priority use of individual machines and are implemented by high priority queues in the Condor batch system. In addition to these high priority queues there are low priority queues on all machines which allow jobs of any experiment to migrate into and use computing resources assigned to another experiment when those resources become idle. If the assigned user of a machines begins submitting jobs, the jobs from the low priority queues are stopped so as not to interfere with this high priority use. In this way it is anticipated that utilization of the RHIC computing resources will be higher and more consistent across the ebbs and flows of use by individual experiments during the upcoming RHIC run. In addition, as a result of the fact that both RHIC and ATLAS are using the same version of the Red Hat operating system, it is now expected that low priority cross utilization of idle computing resource will also be possible between these two projects.

7.3 RCF Staffing

The issue of manpower is not addressed by the model. Presently the facility is at 19.5 FTEs with that effort distributed as shown in Table 7-4. This number fluctuates around 20 FTEs as RCF staff members depart and are replaced. The facility has, in general, been understaffed, but the collocation of the US ATLAS Computing Facility with the RCF has allowed for a sharing of expertise and effort among the manpower of the two facilities. This sharing of effort has benefited both facilities and has enabled both facilities to function at an effort level significantly below what would be required for either facility stand alone. Provided the US ATLAS facility remains collocated with the RHIC facility and the technologies used remain well aligned, it is not expected that an increase in manpower for the RHIC facility will be required over the next five years. However, an increase of two to three FTEs would allow for more aggressive involvement in new technologies resulting in more cost effective use of equipment funds as well as better support to the user community. A scenario that would require an increase in the manpower of the facility would be a dramatic change in the architecture of the facility. If it were decided that a dramatic shift in say storage or computer architecture were appropriate, then additional manpower would be required to allow for the transition to the new architecture while maintaining the current architecture until it could be phased out. Such a major architectural shift is not presently anticipated.

	FTE's
Linux Farms	4.6
Mass Storage	3.2
Central Disk	2.2
User Support	2.2
Fabric Infrastructure	3.1
Wide Area Services	1.7
Local Area Network	0.9
Admin	1.6
TOTAL	19.5

Table 7-4 Current RHIC effort

7.4 RCF Physical Infrastructure

Finally, a very serious issue for RCF relates to physical infrastructure. The scale of computing has grown to the point where the physical hardware will soon outgrow the available floor space. More pressing is the fact that the facility has reached the limit of the power and cooling capacity of the building. Over the next one to two years, power and cooling can be added at the current location, but after that additional floor space as well as the accompanying power, air conditioning, fire detection/suppression, etc. will have to be provided. This problem is being studied at the Laboratory level. While it is not expected that the cost of providing this space and the associated power, cooling and fire detection/suppression equipment will be passed to the RHIC budget, the increasing power costs themselves are paid out of the RCF budget and will significantly impact it.

8 An Integrated Strategic Plan

Based on the details discussed in Sections 4 and 5, we believe that the mid-term accelerator and detector upgrades could proceed over the coming 5-6 years while carrying out a physics operations program of 30 weeks each year. In Figure 1 we show a time-line in which we have assumed a straw-man beam-use program that is consistent with the recent Beam Use Proposals from PHENIX and STAR, and is also consistent with the present C-A Dept. projections for beam performance over this period.

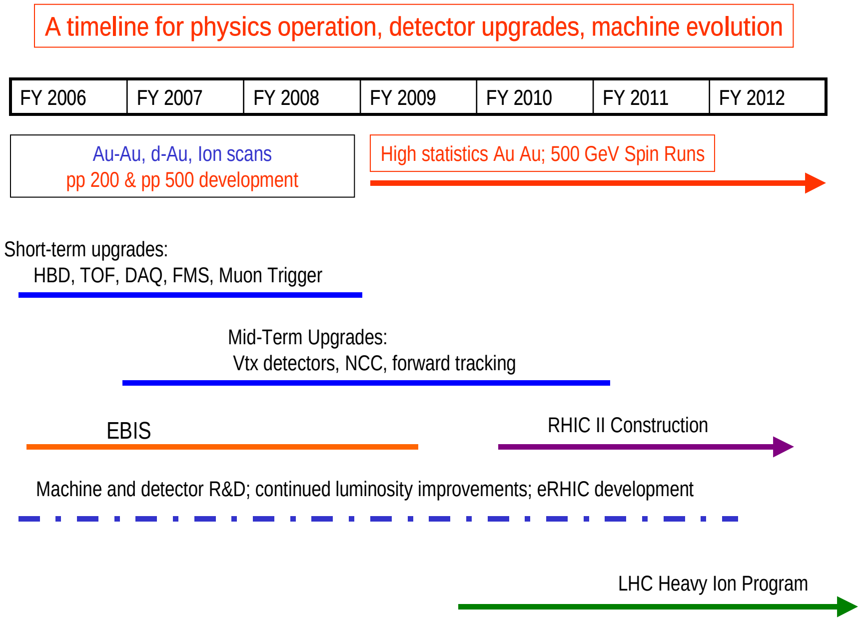

Figure 8-1: A Mid-Term timeline for physics operation and upgrades

A key element of this timeline is the readiness for high-statistics Au-Au runs from 2009 onward. This corresponds to the time when we expect the first results to emerge from the LHC heavy ion program. An important part of the strategy, reflected in the funding plan of Table 6-1, is to complete a complement of detector upgrades to enable measurements of open charm (and beauty), charmonium spectroscopy, low-mass dilepton spectra, and jet tomography in a high-statistics Au-Au run starting no later than 2009. Also in the mid-term time period, the forward calorimetry upgrades should enable us to explore low-x physics. Forward tracking/trigger upgrades will ensure the measurement of $W^{\pm}$ production in 500 GeV p-p collisions.

We have noted that the development of electron cooling is proceeding at a pace that should allow the initiation of a construction project to implement full-energy cooling of the RHIC beams, producing the RHIC II luminosity gains, with a construction start (CD-3) in 2010. With the completion of the proposed detector upgrades, both STAR and

PHENIX will be capable of exploiting the RHIC II luminosity to carry on with the physics program described in Section 2 of this report.

Therefore, an important consequence of the mid-term strategy described here is a change in the planned scope of the RHIC II Project, which had previously been envisioned to include significant funding for detector upgrades. With the implementation of this mid-term plan, a RHIC II Project can be more narrowly defined, strictly as a luminosity upgrade for the machine. At correspondingly lower cost, this major upgrade in machine performance could become operational at the end of the mid-term period, with two large detectors well equipped for RHIC II physics. The graphic in Figure 8-2 illustrates this plan in detail, showing the timeline for machine and detector upgrades along with the evolution of machine capability over the mid-term period, and the corresponding readiness to begin the key physics measurements.

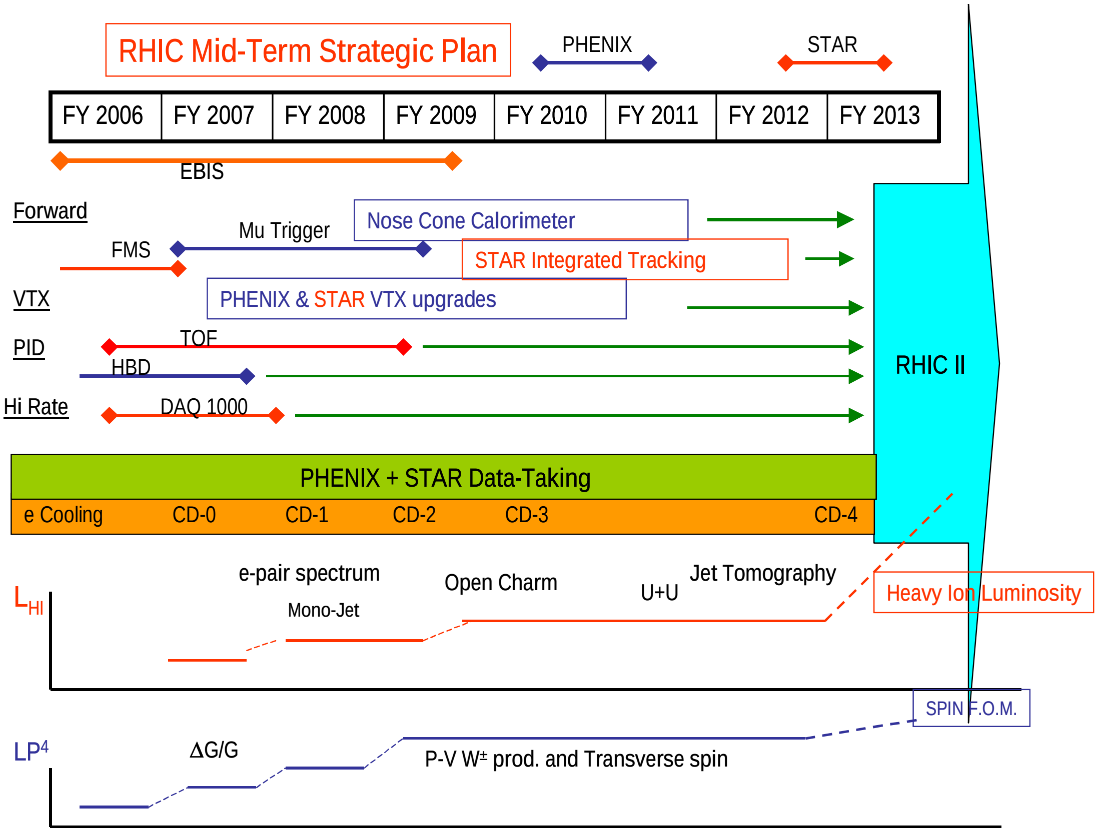

Figure 8-2: Graphic illustration of the Mid-Term Plan. The lower plots show projected luminosity increases for Au-Au collisions, and projected increases in the "figure of merit", luminosity times the fourth power of the polarization, for polarized proton collisions.

9 Summary of Facility Costs

Summary of RHIC Facility Costs

	FY 2005	FY 2006	FY 2007	FY 2008	FY 2009	FY 2010	FY 2011
No. Cryo weeks	32	20	30	30	30	30	30
RHIC Machine (C-AD)							
Base ops.	83.2	85.8	89.5	93.1	96.8	99.2	103.1
Ops equip.	1.5	1.2	1.6	1.7	1.7	1.8	1.8
AIP	3.1	1.0	3.5	3.6	3.7	3.9	4.0
Base Power	3.1	5.3	5.3	5.5	5.7	6.0	6.2
Accel. R&D	2.7	1.9	3.0	3.0	2.0	2.0	2.0
RHIC Computing							
Base ops.	5.3	6.0	6.2	6.3	6.5	6.8	7.0
Ann. Equip.	2.5	1.3	2.0	2.5	2.7	2.9	3.0
Detectors							
Base ops.	12.5	11.6	11.8	12.3	12.8	14.3	14.9
Ops Equip: upgrades	1.5	1.6	0.9	0.5	0.5	0.5	0.5
Ops Equip: other	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Detector R&D	1.5	1.0	1.8	2.0	1.2	1.2	1.2
Total base costs	117.4	117.2	126.1	131.0	134.1	139.1	144.2
Incremental costs							
Incr. Ops.	6.4	4.0	6.0	6.2	6.5	6.8	7.0
Incr. Power	5.5	7.5	10.9	11.3	11.8	12.3	12.8
Total Operations	129.3	128.7	143.0	148.5	152.4	158.2	164.0
Upgrade Constr. MIE							
EBIS	0.0	2.0	7.5	4.5			
PHENIX	0.0	0.0	2.0	5.8	4.1	1.2	
STAR	0.0	2.4	2.4	0.3	5.5	7.0	1.0
eCooling	0.0						
Total Constr.	0.0	4.4	11.9	10.6	9.6	8.2	1.0

Table 9-1: Summary of projected operating and construction costs for the mid-term period

Table 9-1 gives a summary of the operating and construction costs for RHIC through the mid-term period, in at-year dollars. Actual costs for FY 2005 and the budgeted costs for FY 2006 are shown. The FY 2006 operations costs include a $13M contribution from Renaissance Technology Corporation. The base operations costs in FY 2010 and FY

2011 reflect a $1.5M reduction in the RHIC Machine costs due to the implementation of EBIS, and a $1M increase in the cost of operating upgraded detectors, as discussed in Sec. 6.2.

Appendix I
Mid-Term Plan Working Group

The mid-term strategic plan is being developed by a working group established by Sam Aronson early in September. The group is broadly representative of the two major experiments, including both the heavy ion and spin interests. It includes the leadership of RCF and the accelerator team responsible for machine development and upgrades in the C-A department. The planning group includes two members of the BNL theory group, and two leaders of the BRAHMS and PHOBOS collaborations who provide their own perspective on the future program at RHIC and its relation to the LHC heavy ion program. In addition, the working group has included the computing leaders for PHENIX and STAR in its discussions of the RCF planning. The membership of the planning group was as follows:

T. Ludlam, convenor
S. Aronson, *ex officio*

PHENIX: A. Drees, E. O'Brien, W. Zajc, A. Deshpande
STAR: R. Majka, T. Hallman, B. Surrow
C-AD: P. Pile, W. Fischer, T. Roser
RCF: B. Gibbard, T. Throwe
Theory: D. Kharzeev, W. Vogelsang
RHIC Spin: G. Bunce
At Large: M. Baker, F. Videbaek
Consultants on Exp. Computing: J. Lauret, D. Morrison

Material presented at the working group meetings is available on the web at:
http://www.rhic.bnl.gov/midterm/

Formal presentations were heard from the PHENIX and STAR collaborations on their detector upgrade plans. Presentations were also heard from the Collider-Accelerator group on machine development and performance expectations, and from RCF on the current status and mid-term planning for the computing facility. In articulating the scientific questions that drive the mid-term planning, the working group received invaluable input from the RHIC II Science Working Groups and Writing Committee.