Report of the Brookhaven AGS-RHIC Program Advisory Committee

5-6 December 2003

1 Executive Summary

This PAC meeting differed from the typical meeting of the committee in several important ways. The goals of this meeting were two fold, first to evaluate the scientific progress and status of the RHIC program, and, second, to evaluate the appropriateness and promise of the laboratory's decadal plan for the future of the RHIC program. In a typical past meeting the committee evaluated specific proposals for experiments or specific proposals for the disposition of the next RHIC runs - that is to say, the energies and species of the colliding particles.

It is no exaggeration to say that the early RHIC physics program has been successful beyond reasonable expectations. The accelerator has achieved half the design luminosity for Au+Au, d+Au, and less, but still a good start for p+p, a remarkable achievement for a new collider. Even more remarkable when one considers the great range of species and energies required for RHIC research!

All results, some very striking, are compatible with the expectation that a new state of matter is produced in Au-Au collisions at RHIC. Perhaps the most remarkable result of the experiments is the demonstration that it is indeed possible to learn the characteristics of this dense early phase despite the fact that many of its features must be viewed through the "veil of hadronization". We also note that there are many puzzling features of the data which promise very interesting insights when further studied and elucidated. We also note that in the future some signals will be observed which can be directly produced by the early phase, such as direct photons and lepton pairs.

There seems little doubt that with continued and upgraded detection equipment and adequate running time a great deal of the deeper physics nature of this new state of matter can be determined. Further details of the accomplishments of RHIC's first years will be discussed in the body of the report. For brevity, we include, in this summary, only the very brief synopsis above.

It is important, however, to emphasize here that the level of running time currently foreseen, 27 weeks per year, seriously limits and compromises the physics output of RHIC. Although the program was designed for 37 weeks per year of running and can best be exploited at that level, even modest increases in the running time would have significant benefits.

It has been suggested that a more efficient run plan would combine runs from two years so that the start up and cool down penalties would be lessened. This is an attractive possibility but, unfortunately, the Committee did not have time to consider all the positive and negative features of such a plan. It is, however, an interesting possibility to alleviate, although not to remove in any major way, the the problems of the 27 week schedule and it should be studied.

However, the Committee very much hopes that it will be possible to improve the support for RHIC and to more fully realize the scientific advances the RHIC program makes possible.

We turn next to the laboratory plans for the next ten years. We strongly support the scientific targets of the upgrade plans. Each of them adds a capability that allows deeper insight into the nature of the early dense state and its production and evolution. There are important facets of the physics that can only be studied with the increased luminosity which is the goal of RHIC II. Each of the detector upgrades enables measurements that are necessary for a proper, complete elucidation of the physics of the new state and of the collision process which produces it.

It is important to point out here that many of the detector upgrades are of great value at the current level of the luminosity and the program should not delay their implementation until the luminosity upgrades are available.

Turning to the spin program, we note that the scheduled increases in luminosity and polarization of the proton beams are crucial to this program to determine the spin structure of the nucleon and to study new aspects of the fundamental symmetries of the interaction.

However, it should be clear that apart from these general comments, we cannot provide detailed advice on the scheduling and temporal priorities of these upgrades at this time. The same is true of the different proposed running scenarios. In the body of the report we do (briefly) discuss the various upgrades and the particular physics they enable.

There are too many details of technical readiness, financial feasibility, international agreements, and the pace of future progress in the accelerator performance, for us to develop useful detailed advice at this time. This is not to say that the Program Advisory Committee would not do so at a future time. Indeed as the program progresses, the committee members do indeed wish to consider matters of scientific priorities, efficiencies and the inevitable tradeoffs.

2 Status and Accomplishments of RHIC Research in the First Three Years

2.1 Heavy Ion Physics

The Relativistic Heavy Ion Collider (RHIC) was constructed to explore the properties of nuclear matter in a new domain of extremely high energy densities far above 1 GeV/fm^3 and small net baryon density. Lattice studies of QCD predicts that in such circumstances nuclear matter can exists in a novel state: a quark-gluon plasma in which quarks and gluons are not locally confined and the chiral symmetry of QCD is restored, broken only by bare quark masses. These unusual properties are caused by a dramatic change in the structure of the QCD vacuum at high temperatures from a state characterized by strong quark and gluon condensates to a perturbative vacuum.

The machine parameters of RHIC were chosen to reach into this new domain - to "engineer" a new quantum vacuum - and the four RHIC detectors, BRAHMS, PHENIX, PHOBOS, and STAR, were designed to observe a large number of probes signaling the formation of a quark-gluon plasma. In parallel, RHIC was designed to produce intense beams of polarized protons, which can be used to study the internal spin structure of the nucleon in unprecedented detail. After three years of RHIC running, the PAC has been asked to assess the status of the RHIC physics program and to comment on the plans of the detector collaborations over a decadal time frame.

It is no exaggeration to say that the early RHIC physics program has been successful beyond any reasonable expectation. The accelerator has reached half of the design luminosity for Au+Au, d+Au and less, but still a good start for p+p, a remarkable achievement for a new collider. The detectors, which are as complex as any detector previously built, have operated without major problems in configurations which been augmented from run to run. Physics results from the three RHIC runs have been presented and published with unprecedented speed and in remarkably large numbers. In short, the productivity of RHIC as a research facility has been exceptional.

All results are compatible with the expectation that a new state of matter has in fact been produced in Au+Au collisions at RHIC. The energy spectra and relative abundances of a wide variety of particles, from light mesons to baryons containing several strange quarks are well described by the assumption of a source of matter in quasi-thermal equilibrium exhibiting hydrodynamic behavior. The internal pressure of this matter must be higher than any previously observed, causing it to explode with extreme violence, spewing out particles with an average velocity of half the speed of light. Semi-peripheral collisions of Au nuclei, which produce an almond-shaped region of hot, compressed matter, have yielded clear evidence of very rapid thermalization through the azimuthal asymmetry ("elliptic flow") of the expansion.

The most remarkable result so far obtained at RHIC is the strong suppression of the emission of hadrons with high momentum (jet quenching). This phenomenon was predicted on the basis of perturbative QCD as the result of strong radiative energy loss of fast quarks and gluons traversing a quark-gluon plasma. The observed suppression corresponds to an energy loss under these RHIC conditions that is more than an order of magnitude greater than that for cold nuclei. The disappearance of the "back-side" jet in central Au+Au collisions confirms these conclusions. Since the energy loss of a parton is proportional to the gluon density of the matter through which it propagates, the measurement provides evidence of the high gluon density of the matter created in Au+Au collisions at RHIC. The latest RHIC run, colliding d and Au beams, showed the absence of a similar effect in these collisions and have thus clearly established the suppression as a final state effect.

This result is not only a new phenomenon unique to RHIC, but also provides an independent diagnostic tool for probing the density evolution of this early phase . Analyses of those data out to $p_T \sim 10$ GeV indicate that the initial energy density of the early dense phase exceeds a hundred times the (proper) energy density of the individual incident nuclei. This inferred initial energy density is remarkably consistent with the value deduced from the bulk entropy (multiplicity) which drives the bulk hydrodynamic flow patterns described above.

A number of other remarkable results were also obtained by the RHIC Au-Au experiments. The bulk collective flow of thousands of produced hadrons have now been experimentally established. Strong transverse radial and elliptic flow have been discovered for all hadron species: $\pi, K, p, \Lambda, \Xi, \Omega$. The latest data also show clear evidence of directed (side-wards tilted) flow at the highest rapidities, proving that bulk collective flow is correlated over the full rapidity range. While precursor phenomena were observed at lower SPS/CERN energies, the magnitude, transverse momentum, and hadron mass-dependence of the observed tilted, elliptic bulk collective flow was measured for the first time at RHIC. The results agree with predictions of hydrodynamic models for an equilibrated quark-gluon plasma in QCD.

In the intermediate transverse momentum range of $p_T = 2 - 4$ GeV/c baryons are produced as abundantly as mesons, and they exhibit an even higher degree of elliptic flow than mesons. Both phenomena can be naturally explained by the assumption that these baryons are formed out of the quark-gluon plasma by recombination of three quarks. Measurements of the quantum correlations among identical particles (HBT correlations) show that the breakup of the matter occurs extremely abruptly. In fact, the measured parameters indicate an emitting source which is considerably more concentrated than expected from a hydrodynamical model of the expansion.

The critical control d+Au experiment in run III proved unambiguously that the phenomena of jet quenching and mono jet production in Au+Au reactions were absent when the initial conditions where too dilute and the space-time geometry too small to support a quark-gluon plasma. These d+Au data rule out the possibility of strong gluon shadowing or saturation in the incident Au nuclear wavefunctions for Bjorken $x_{Bj} > 0.01$. However, hints of an entirely new phenomena have recently appeared for high rapidity observables which probe the parton distribution of nuclei at x_{Bj} down to 0.001. These may be precursor signatures of the onset of nuclear gluon saturation which need to be followed up by more detailed investigations.

2.2 Key Physics Questions for Future Heavy Ion Research

All of the evidence collected so far is consistent with the assumption that a new form of matter, characterized by a very high gluon density and locally free quarks, has been created. However, many important questions have not yet been answered: We list below some of the pressing key experimental facts which must be obtained in order to obtain a more complete characterization of the properties of the system(s) produced in the early phases of the collisions at RHIC. These questions, studied via systematic and quantitative measurements, will be the focus of the RHIC physics program over the remainder of the decade.

A question which is often asked is whether or not the "quark gluon plasma" has been discovered. The key features of a quark gluon plasma are first that the correct description of the system is via quark and gluon degrees of freedom (not hadron degrees of freedom), and second that the system has reached a sufficient level of equilibrium that it may usefully be described as a state of matter.

New experimental results will both provide information on these issues and provide a measure of interesting properties of the new state of matter once its existence, in the above sense, has been established. The list below is not inclusive but typical of the programs that need to be carried out. They do suffice to demonstrate the importance of the detector upgrades and the need for adequate running time.

1. Responses to Variations in the Initial Conditions: The focus of the heavy ion program up to now has been properly directed to Au+Au and d+Au at 200 AGeV. However, future runs with systematic variation of the energy and species of the colliding nuclei will be essential in answering key physics questions. How different is the matter created at RHIC from that produced at the much lower CERN energies? Is the change as a function of energy gradual or abrupt? How and why local equilibrium was apparently reached in Au+Au at 200 AGeV? How do the critical observables change as a function of nuclear size and energy? Do light hadrons, especially vector mesons, dissolve inside the hot and dense matter?

   At lower CERN/SPS energies we already know that local equilibrium was not reached from the large deviation of the collective flow observables from hydrodynamic predictions. The study of the beam energy dependence is very important in order to provide decisive information about the conditions necessary for the onset of local equilibrium. The very remarkable, and unexpected essentially dissipation-free bulk collectivity is an outstanding puzzle. The beam energy surveys will provide the information on the dissipation mechanisms (viscosities and thermal conductivity) operating in the new dense system.

2. Extended Jet Studies: For example, differential measurements of energy loss through measurements of the away side jet region, not simply observation of the absence of the away side jet. Study of the high p_t v_2 behaviour and jet production. In connection with the initial condition scans discussed above, the search for the away side jet in collisions of smaller nuclei and the energy variation of jet quenching.

3. Heavy Quark Phenomena: Are charm quarks liberated from hadronic binding? Do heavy quarks lose less energy than light quarks, as predicted by QCD? Thus, as emphasized in the last PAC recommendations, a top priority will be to map out the QCD dynamics of heavy quarks in the produced dense system. Run IV has been dedicated to measuring both open charm and hidden charm observables. The high mass of the charm quark is predicted to inhibit energy loss in the medium which should lead to smaller attenuation at energetic charm as well as reduced elliptic collectivity. In addition, the melting of the J/ψ in the deconfined quark gluon plasma and the competitive recombination processes are predicted to lead to specific signatures which must be tested. Both STAR and PHENIX are well instrumented and prepared to make definitive measurements of the heavy quark observables. New discoveries will very

likely result from these investigations. The full characterization of the physics of bottom flavor quarks must await the the luminosity upgrade as well as the detector upgrades.

4. Direct Photon Thermometry: Direct photons originating from the quark gluon plasma have long ago been proposed as a direct probe of the temperature evolution of the quark gluon plasma. Is there an anomalous abundance of direct photons or lepton pairs? Fortunately, the now established jet quenching reduces greatly the background sources of photons, so that the thermal photons should be much more readily observable from the early dense system, perhaps a quasi equilibrated plasma. Both STAR and PHENIX will be able to perform direct photon thermometry for transverse momenta above 1.5 GeV/c during the next few years.

5. Nuclear Parton Distributions: Another critical priority of the heavy ion program is to determine with precision the nature and physical mechanisms of the initial conditions from which an equilibrated plasma may evolve. This requires the exploration of the nuclear parton wavefunction over the broadest possible Bjorken x_{Bj} region. As noted above the first preliminary results from Run III at high rapidities indicated new effects in regions of $x_{Bj} \sim 10^{-3}$ where strong nuclear modifications of the gluon structure of nuclei are anticipated. In addition, such information is essential in order to correctly interpret the heavy ion data on heavy quarks which will emerge next year.

2.3 Spin Physics at RHIC

The program of polarized proton collisions is a key element in the world-wide effort to understand the spin of the proton. The heavy ion program and the spin program are complementary: both are crucial for reaping the maximum scientific benefit from the community's investment in RHIC.

RHIC will play a unique role in probing the spin carried by gluons and also by the up and down quarks. The initial results on the double-spin asymmetry in π^0 production from longitudinal pp collisions at $\sqrt{s} = 200$ GeV have already demonstrated that double-spin asymmetries can be measured in a polarized collider and represent an important "proof of principle".

An essential part of the RHIC pp program is the production of the W and Z bosons. The production of $W^{\pm}$ bosons in polarized pp collisions at RHIC offers unique access to the polarized quark distributions, Δu and Δd, via single spin asymmetries. Intrinsic charm distributions at high x_{Bj} can also play a novel role. Measurements of the spin carried by the quarks will require pp collisions at $\sqrt{s} \sim 500\ GeV$ in order to have a sufficient rate to observe $W^{\pm}$ bosons. The high energy run will also allow measurements of the polarized gluon distribution at very small values of $x_{bj} \sim 10^{-3}$.

High polarizations ($\sim 70\%$) and high luminosities are critical requirements for the measurements of spin asymmetries. These polarization and luminosity goals for spin physics are extremely challenging and demand a program of testing and tuning the beams and polarization hardware. Dedicated time for machine development with polarized protons is vital for the success of this novel accelerator program.

3 Future Utilization of RHIC

As discussed in the previous section, the first three years of RHIC operations have provided evidence that a new form of bulk partonic matter may have been formed in central collisions of Au+Au at 200 AGeV. That evidence includes (1) the striking collective flow patterns of thousands of produced particles, (2) the strong suppression of rare high transverse momentum hadrons as well as back-to-back correlations, a signature of jet quenching, and (3) the absence of such collective phenomena in the control experiment d+Au. These initial milestone achievements provide a baseline for assessing facility and detector needs crucial for verifying the conclusion that a new form of partonic matter has been created and to tease out its key characteristics.

The RHIC facility represents a substantial investment by our nation, both in real and scientific capital. In order to maximize our return on this investment over the next ten years, it is now apparent that three physics directions must be pursued vigorously: First the heavy ion program, the physics which originally drove RHIC construction, requires systematic measurements of a broad array of observables for different nuclear species and energies. So far only Au+Au collisions at two energy settings, 130 and 200 AGeV, have been measured. Second, high luminosity polarized proton+proton experiments will allow RHIC to resolve longstanding puzzles in parton polarization distributions. Third, proton+A (or equivalently deuterium+A) running is essential for isolating final-state interaction effects (as initial RHIC running illustrated) and as a tool for probing the high virtual gluon density domain of initial nuclear wave functions. The importance of this third class of studies was recently brought into focus by the surprising analysis of high rapidity spectra in d+Au. Saturation of gluon fields in nuclei may have been seen, although a much more extensive series of observations will be needed to verify this possibility.

The dilemma for RHIC management is that these three priority physics programs cannot be accommodated in a timely fashion if restricted to the 19 weeks (27-3-5) per year mode of data collection (for 1 beam energy setting). A second setting requires an additional 5 weeks RHIC beam set-up time, leaving only 14 weeks per year for data taking. This mode of operation worked successfully during RHIC start-up (2001-3) because the initial runs were surveys. It will not be satisfactory for future runs which focus on rare and difficult observables and which require large data sets, and thus long running periods. From the presentations we have heard, the PAC has concluded that such restricted running will allow RHIC to pursue, at best, only two of its three priority physics goals. For example, in our previous PAC meeting we recommended a 14-week physics run, after 5 weeks of beam development, to begin an exploration of rare heavy-quark observables in Au+Au. This limited the polarization program to a mere five weeks of machine development. In 2005 an essential low-energy (64 AGeV) Au+Au comparison run may be limited to just nine physics weeks, since 5+5 weeks will be needed to make a modest start on polarized proton physics. In 2006 another compromise will likely limit d+Au running for initial-state heavy quark physics to an inadequate 5+9 weeks, with the new detector upgrades (vertex detectors) planned in the near future. Nine weeks will probably be insufficient to measure the highest p_T yields in d+Au needed to compare with the highest ($\sim$ 20 GeV) yields which will be available from Au+Au. The polarized proton program will likely again be limited to 5+5 weeks in 2006. The five-week set-up time for a beam switch contributes to the inefficiencies inherent in a program with several important goals but very limited beam time. Our projections envision no window for exploring the atomic number dependence of A+B collisions through 2008.

Our summary expectation is that the present 27 weeks per year operations would allow the highest priority heavy ion program to proceed, provided the detector upgrades are implemented in a timely fashion. However, running time limitations would then restrict the polarized p+p program to about 90 pb^{-1}, far below project goals neede for measurement of the gluon spin structure function and for the study of the sea quark spin distribution functions in the proton (via the observation of W bosons) and will leave no room for substantial p+Au or d+Au runs. Thus two of RHIC's three main programs will be compromised.

The prognosis greatly improves if operations are extended by five weeks to 32 weeks/year: there is great physics leverage in such an extension. This would lead to a doubling of the 2008 integrated luminosity for the polarized proton program (160/pb) and allow a 5+9 week run for an additional species (e.g., Fe+Fe) by 2009.

Despite excellent machine performance and important physics results in its inaugural years, RHIC is in danger of being under-utilized. A modest additional investment of operations funding will leverage a great deal more physics. The identified physics directions include the quark-gluon plasma, the spin structure of the proton, and the color glass condensate. These physics programs require three distinct modes of RHIC running which cannot be simultaneously pursued, given 27 weeks/year of running. An increase to 32 weeks/year will greatly accelerate the physics output; an increase to 37 weeks/year, the Long Range Plan goal, would optimized RHIC's physics output over the next decade.

The exploration of novel nuclear physics at small x_{Bj} will eventually be measured in heavy ion collisions at the LHC; however, RHIC could pre-empt discoveries in this new field if further dedicated p+Au or d+Au could be squeezed into its over-committed program for the current decadal plan. As discussed above, the current 27 week per year operation schedule does not allow the full exploitation of this new physics direction before LHC has come online. This would not only be a loss for the US/DOE/Nuclear pre-eminence in this field to the CERN/LHC, but it delays the experimental input necessary for the continue theoretical development of this field.

3.1 The PAC View of Priorities

Tough priorities choices are mandatory. We recommend that in the next five years of the decadal plan the top priority be given to the heavy Au+Au runs as well as the polarized pp runs (unfortunately at the expense of the d+Au) in order to advance, to the extent possible, the two highest priority programs.

The very much needed and important dedicated second d+Au run must be accommodated in the latter half of the decadal plan unless a significant increase in RHIC operations funding occurs. With a very modest increase to 32 weeks of operations, the STAR collaboration has argued that the polarized pp program with 156 pb^{-1} integrated luminosity will be achievable together with a second d+Au run.

This PAC and all external RHIC committees have often noted the serious under-utilization of this world class facility which was originally envisioned to operate in a 37 week/year mode. While the experimental collaborations have made valiant efforts to cope with a less than optimal beam schedule, it is clear that a 27-week schedule severely comprises important RHIC physics goals.

4 Accelerator and Detector Upgrades

The upgrade program at RHIC represents the opening of new doors in spin and heavy ion physics which follow on the very successful current program at RHIC. Significant new detectors have been proposed by the STAR and PHENIX collaborations which are scientifically well-justified and are well focused to leverage the existing investment at RHIC.

The phase transition of deconfinement is expected to be associated with the restoration of chiral symmetry - with the quarks interacting as nearly massless particles. This physics can be addressed via the measurement of low mass vector mesons with the PHENIX proposed hadron blind detector (HBD) and inner silicon tracking and with the STAR proposed time of flight (TOF) system together with the (proposed) improved STAR data acquisition system. Additionally the question of heavy quark thermalization and interactions with the dense medium have been shown to provide key information on the temperature and dynamics of the dense phase. Both STAR and PHENIX have proposed inner silicon tracking devices in order to measure displaced vertices from D and B mesons to answer these questions.

The STAR data acquisition and FEE upgrade will provide a unique set of enormous data samples to search for rare or subtle fluctuations and correlations. These are important because such correlations may reveal radical new physics, such as strong CP-violation. PHENIX has proposed a forward nose-cone calorimeter which allows for the measurement of forward photons, including photons from $\chi_c \to J/\psi + \gamma$. Inclusion of the χ_c which can be produced directly in the color-singlet state from gluon fusion provides a critical handle on quarkonia production and suppression from color screening in the plasma.

When RHIC runs proton-proton collisions at 500 GeV one can access the sea quark spin contribution via the W asymmetry. PHENIX requires a muon spectrometer upgrade to effectively trigger on W's and STAR requires an inner tracker and forward tracking upgrade to cleanly identify the decay electron charge sign. These upgrades are crucial before a significant full energy proton-proton run. Additionally, the inner vertex detectors proposed by both STAR and PHENIX allow for the clean identification of charm and beauty which gives one an excellent handle on the gluon spin structure.

RHIC has proposed electron cooling of the ion beams to increase the Au-Au luminosity by a factor of 10. This is a critical step the RHIC program in the later part of the decade. There are further upgrades of a possible micro-TPC in STAR and data acquisition upgrades for both STAR and PHENIX to utilize this luminosity. Key physics measurements are gamma-jet for precision tomography and high statistics Upsilon measurements to probe the temperature dependence of the plasma screening length.

However, we find that only a limited subset of the proposed upgrades is clearly tied to the increase to 40 times design luminosity. Most of the upgrades, as mentioned above, will generate substantial scientific benefits if implemented with the current machine configuration. We therefore recommend that the RHIC program pursue an aggressive schedule of detector R&D and upgrades to improve these detectors as quickly as possible, prior to the 40 times luminosity upgrade.

It is also important that a careful prioritization of the sequence of upgrades be made, in order to leverage the available resources. Planning for the RHIC running program (choice of beams and energies) must take into account the likely schedule of implementation of new equipment, in order to maximize the physics output of each run. If the different upgrade proposals are reviewed separately and phased in with different schedules, major physics will be lost.

We understand and are pleased that the Lab plans to submit proposals for the STAR TOF and the PHENIX pixel projects this year (2004). However, because many of the others (e.g. the STAR pixel detector, the PHENIX hadron blind detector, the forward tracking system for spin)) are most useful and important at the current luminosity, we are concerned lest they be delayed by virtue of their incorporation into the RHIC II proposal. If they are to be available by 2008-9, a technically reasonable target, funding for the R&D needs to start very soon and construction money would need to become available in 2006. We urge the Lab to work to make this possible, perhaps by structuring the RHIC proposal in phases, or via some other approach.

This upgrade program is crucial for continuing to open new doors in understanding nuclear matter at the highest temperatures and the basic structure of the proton.

4.1 Specific Comments on Upgrade Proposals

We now specifically discuss in turn each of the upgrade items specified in the PHENIX and STAR decadal plans. We shall comment on the scientific impact and, where appropriate, the scheduling issues which should be taken into account.

We will only touch on the major upgrades discussed by the collaborations in their presentations to the PAC. The Decadal Plans themselves contain additional improvements of more limited scope which may also have significant physics impact.

We will avoid technical comments, since in almost all cases no proposal exists yet, and we did not review the two proposals which do exist (PHENIX Vertex Tracker and STAR Time of Flight).

4.1.1 PHENIX

(i) PID upgrade (aerogel and time of flight): significant extension of PHENIX's already world-class PID capabilities, will provide definitive answers to questions central to the understanding of high p_T particle production in nuclear collisions at RHIC. Implementation well under way, upgrade will be completed soon.

(ii) Silicon vertex detector: provides major new physics capability to detect open charm and beauty, addressing partonic energy loss and providing essential measurements to enable low mass dilepton studies. Early implementation based on ALICE technology is appropriate.

(iii) Hadron-blind detector (HBD): provides unique capabilities for critical measurement of low mass dilepton pairs, to study chiral symmetry restoration. Technical approach to RICH detector is radical (GEM detectors in pure CF_4 gas) but appears to work well. Physics impact will be large.

(iv) Micro-Time Projection Chamber: an extension of HBD to provide additional tracking to aid in Dalitz-pair rejection for the low-mass di-electron measurement. R&D currently underway to gauge necessity of this upgrade. Additionally, this will extend significantly the PHENIX acceptance for charmed-particle tracking, although this improvement alone provides only modest physics gain.

(v) Forward detectors: several related upgrades aimed at maintaining muon triggering capabilities at 40 times design luminosity through improved background rejection. Items include end-cap vertex tracker, nose cone EM calorimeter, and modifications to 1st level trigger. The nose cone calorimeter can trigger on forward γ, π^0 and electrons, immediately providing interesting new capabilities, and thus should be considered for early implementation. Remainder of items is only required at time of 40 times luminosity upgrade.

4.1.2 STAR

(vi) TOF: high precision Time of Flight over very broad acceptance. Large physics impact in several areas. Significantly extends STAR's PID capabilities, expanding measurements of stable hadrons, resonances, and open charm, and enabling measurements of low mass dilepton pairs. Technology in hand, prototype has already produced an important publication.

(vii) Microvertex detector: very high precision device based on new technology (Active Pixel Sensors) for world-class charm and beauty measurements. Although technically challenging, the physics impact would be very large.

(viii) Forward tracking upgrade: two related tracking upgrades (inner silicon, outer GEM) in the acceptance of the EMC end-cap ($1 < \eta < 2$), necessary to resolve the charge sign of $W^{\pm}$ for measurement of the flavor dependence of the sea quark polarization in polarized p+p collisions. World-class measurement of fundamental importance for understanding the spin structure of the proton. Upgrade must be completed prior to the 500 GeV p+p run.

(ix) Data acquisition and Front End Electronics: related upgrades to improve STAR's data rate to 1000/sec. Will provide unique set of huge data samples to search for rare or subtle fluctuations and correlations. Extremely important because of its potential to reveal radical new physics, such as strong CP violation. For technical reasons, the FEE upgrade is necessary for implementation of the Forward Tracking Upgrade and thus must be completed prior to the 500 GeV p+p run.

(x) Forward Hadron calorimeter: addition of hadronic calorimeter behind current Forward Pion Detector to allow triggering and reconstruction of jets in forward direction. Crucial to resolve origin of observed large single transverse spin asymmetry for forward pion production in polarized p+p, also important to study low-x phenomena in d+Au collisions. Will be based on existing devices, should be in place prior to next significant p+p or d+Au run.

(x) TPC upgrade: currently under study whether STAR Main TPC will perform well at 40 times design luminosity, because of distortions due to accumulated space charge. Compact tracker based on GEM technology under development as TPC replacement in high luminosity era.