Report of the RBRC Scientific Review Committee to the President of RIKEN

Brookhaven National Laboratory

October 27-29, 2010

I.Introduction

The last time the RBRC Scientific Review Committee met was October 21-22, 2009. This report discusses important developments over the past year and the future prospects for the RBRC, in particular for the period covered by the proposed 6-year extension of the RIKEN BNL Collaboration MOU beyond 2012.

The Scientific Review Committee consists of Professor Wit Busza (chair), Miklos Gyulassy, Kenichi Imai, Alfred Mueller, Charles Prescott, Akira Ukawa from last year's committee, Richard Milner, who has been a member in the past, and new members Teiji Kunihiro, Horst Stocker and Robert Sugar. The committee membership is listed in an appendix to this report, with members' addresses and affiliations.

At the beginning of the meeting, at an executive session, the committee was pleased to hear the opening remarks given by Dr. Hideto En'yo, Director of the RIKEN Nishina Center for Accelerator-Based Science, who traveled to Brookhaven specifically for the purpose of attending this review.

Dr. En'yo reviewed for the committee the organizational structure of the RIKEN Nishina Center, its budget and manpower, the RIKEN Advisory Panels, the RIKEN Review System and Schedule, and the role this review and report play in the flow of decisions at RIKEN. He specifically mentioned the date of May 26-28, 2011, during which the Nishina Center Advisory Council (NCAC) will meet. This is an important meeting that gives input to the RIKEN Advisory Council (RAC), which will meet on October 25-28. 2011.

The chairman of the RBRC Scientific Review Committee is expected to attend the NCAC meeting. Since Wit Busza will not be free at the time of the NCAC meeting, it will be attended by Richard Milner.

Dr. En'yo asked that in addition to reviewing recent activities and achievements the committee evaluate the scientific scope of the 6-year extension and expected outcomes and future opportunities at proposed electron-ion facility, eRHIC.

In the report we start with a review of the current program and recent achievements, and then concentrate on a discussion of the plans for the proposed 6-year extension period.

II. Overview of current program and plans

Dr. Nick Samios, the RBRC Director, presented an overview of recent achievements in the scientific program, the performance of the RHIC accelerator and management issues.

He pointed out that on the experimental side, the physics that emerges from the heavy ion program at RHIC continues to be extraordinary. As is well known, at RHIC a new state of matter has been discovered, a hot dense, strongly coupled plasma of quarks and gluons (sQGP), a perfect liquid. Recently direct photons produced in the plasma have been observed and studied, indicating plasma temperatures substantially above those projected for the transition from ordinary nuclear matter to the quark and gluon phase. Also, during the last year a possible local violation of (P,CP) has been observed in the hot sQGP. If the interpretation of the data is correct this will indeed be a very exciting result.

Dr. Samios also pointed out that in the spin program, progress continues to be made in our understanding of the puzzle as to the origin of the proton spin (i.e. due to the quarks or gluons, or their angular momentum), an issue of fundamental importance. Recently, for the first time, measurements have been made of spin asymmetry in leptonic W decays at 500 GEV. Such measurements are important to determine the anti u and anti d quark polarizations.

Related to the high energy density matter studies, Dr. Samios was particularly proud of the important contributions of RBRC theorists to the development of the Glasma and Color Glass Condensate concepts. He noted that the recent Ridge Structure observed in Long Range Two Particle Correlations in Au+Au collisions at 200 GW at RHIC and in p+p collisions at 7 TeV observed by CMS at LHC as well as the observed disappearance of away side peak in two particle correlations in deuterium gold collisions at 200 GeV at RHIC, all reinforce the Glasma and CGC pictures of the early phase of heavy ion collisions.

Discussing the impressive progress in Lattice QCD calculations he pointed out the important contribution of RBRC physicists to the first calculation of the eta and eta' masses and a determination of the light quark masses that included electromagnetic effects.

Dr. Samios was particularly pleased to be able to report that for the RHIC Accelerator the last year, RUN 10, was a good year. Much data was obtained for Au+Au collisions at a variety of energies, including very low energies (needed in the search for the critical point). Furthermore, the 500 GeV polarized p+p engineering run gave very encouraging results.

At the end of his presentation, Dr. Samios discussed the management of RBRC and the role RBRC plays in the career development of scientists and scientific leadership. He pointed out that Dr. Y. Akiba remains Experimental group leader with Dr. A. Deshpande, his deputy, and Dr. L. McLerran remains Theory group leader with A. Baltz, his deputy.

Dr. Samios showed the successes of RBRC in placing its young scientists in tenure and tenure-track academic positions. RBRC continues to provide a first class path for these young scientists.

Finally, he proudly showed the large number of honors and grants received by RBRC personnel in the last year, the number of workshops organized (6) and the impressive publication record (42 in theory and 29 in experiment).

III. Scientific Progress

A. Experimental Program

The committee heard presentations from Yasuyuki Akiba summarizing the experimental program. PHENIX remains the focus of activity for the experiments at RBRC. The three major activities are RHIC spin physics, heavy ion physics, and PHENIX detector upgrade.

Since the last RBRC review progress in spin physics has been strong. Upgrades to PHENIX are ready to come on line, and they promise to expand substantially our knowledge of the spin components of the proton and how they contribute to the overall proton spin. These upgrades, the silicon vertex tracker and the North and South muon arms, will provide major enhancements to PHENIX's capabilities. The vertex tracker will enable PHENIX to isolate and study events containing the heavy quarks (b and c), while the muon arms will provide identification of events containing the $W^{\pm}$ bosons. Together these new tools will add uniquely new data to the global body of data on nucleon spin structure. The RHIC run plan in the coming years allocates generous running time with polarized protons at $\sqrt{s} = 200$ and $\sqrt{s} = 500$ GeV center-of-mass.

The nucleon spin puzzle continues to baffle the nucleon structure community more than ever. The message that has resulted from global analyses of all relevant data points to a surprising mystery....that the net spin of the nucleon cannot be ascribed directly to the constituents which underly the structure of the nucleon. Run 9 results from polarized pp collisions at RHIC have been analyzed and incorporated into global spin structure models. The resulting fits to quark and gluon spin suggest rather small contributions, less than perhaps 20%, to the spin 1/2 total.

This story began in the 1980's with deep inelastic scattering of e's and mu's on polarized proton targets. The EMC collaboration measured significant spin asymmetries at finite x values, but when summed over all x, the data could account for only 10-20% of the nucleon spin. Hence the "spin crisis" was born. The missing spin was assumed to lie with the gluons, and the search for the gluon contribution ensued. Probing the nucleon with e's or mu's had limited value since neither of these couple directly to the neutrally-charged gluon components of the nucleon. Polarized protons were called for, and pp running at RHIC took on the important role of probing the polarized gluon structure of the proton. Run 9 most recently, along with the earlier runs at RHIC, mostly using data from the PHENIX detector with its gamma and hadron identification capabilities, extended the search for spin of the gluons.

At this meeting, Stefan Bathe, the run coordinator for PHENIX Run 10, summarized the spectacularly successful Run 10, Atsushi Taketani discussed the Pixel detector of the PHENIX Vertex Tracker and Rachid Nouicer gave an overview of the progress in the construction of the

Stripixel Detector for a PHENIX upgrade. Abhay Deshpande introduced the spin physics topic. We heard of the Run 9 results on the longitudinal spin asymmetries (A_{LL}) for π^0 and $\pi^{\pm}$. These measurements address ΔG, the gluon spin contribution, directly. The measured asymmetries are consistent with zero, within quite small errors, and mostly exclude the gluon as a significant source of spin, over a quite large range of x (0.01 to 0.4). Thus the so called "spin crisis" continues to puzzle everyone. For the future experimental measurements, there still remains a need to explore x below .01. PHENIX at RHIC is best suited for this task. The anticipated high luminosity running in the coming Runs 11-13 should extend the data to lower x with quite small errors.

Meanwhile, the search for the origins of the nucleon spin are being extended to orbital motion of the constituents.
This is the only remaining possibility if the quarks , anti-quarks, and gluons are ruled out. Transverse spin measurements and models incorporating transverse orbital motion are being developed.

The issue of anti-quark spin is being addressed directly at RHIC. Kensuke Okada described the observation of W bosons in the PHENIX central arms. PHENIX has now seen $W^{\pm}$ production (Ws decaying to $e^{\pm}$ in the central detector) and has measured cross sections and asymmetries in polarized pp collisions at $\sqrt{s}$ = 500 Gev in the center-of-mass. With the PHENIX upgrade of the forward muon arms, PHENIX will soon have direct measurements of forward and backward W's in the upcoming RUN 11, giving the first indications of the anti-quark spins. This will be a significant input to the models.

To utilize the growing RHIC luminosity and polarization, PHENIX has completed and installed the North and South muon arms. Itaru Nakagawa described the current status of the muon system. Tracking consists of 3 layers of cathode strips, followed by 5 layers of Iarocci tubes in x and y, sandwiched between steel plates (total of 80 cm). Penetrating mu's (for p>2 Gev/c) can trigger the system. Performance has been measured in Run 9 and with cosmic rays. Efficiencies are greater than 99 % for high p_t tracks. Hadron absorbers in the forward and backward directions have been added to help reject penetrating hadrons (largely neutrons) which can trigger the muon system.

Kieran Boyle described the analysis of π^0s and direct γs in Run 9's 200 GeV running. Polarized longitudinal spin asymmetries (A_{LL}) in π^0 and γ production probe the gluon spin in the proton. The $\pi^0 \rightarrow 2\gamma$ signal was seen clearly. A background subtraction of 5-20 %, depending on p_t, was made. The higher luminosity of Run 9 initially caused a rate dependent bias in the detector. Accounting for multiple collisions in a beam crossing was required, and a "probability of zero" estimator of the luminosity corrected for these rate effects. The results for $A_{LL}(\pi^0)$ are consistent with earlier data from Runs 5 and 6, but with substantially improved errors. A global analysis incorporating Run 6 and Run 9 data was shown, with ΔG consistent with 0 and with errors approximately ± 0.2.

David Kawall reported on the longitudinal asymmetries in charged hadron production ($h^{\pm}$ is mostly $\pi^{\pm}$) at 62 GeV. The production of $\pi^{\pm}$ is largely by quark-gluon scattering. Since Δq is reasonably well known from deep inelastic scattering, the Δg(x) component can be extracted from data. If $\Delta g(x) > 0$, then $A_{LL}(\pi^+) > A_{LL}(\pi^0) > A_{LL}(\pi^-)$ in the models. Measuring the asymmetries for $h^\pm$ clearly constrains $\Delta g(x)$. Changing $\sqrt{s}$ changes the range of x probed, with higher x values being probed with lower $\sqrt{s}$ data. The results for one week of running at 62 GeV show charged hadron asymmetries consistent with global fits from other data and consistent with $\Delta G = 0$. With substantially more data from future running, these charged hadron asymmetries would further constrain the models.

John Koster described progress with single spin measurements. Single spin transverse asymmetries (A_N) probe quite different processes from those of the longitudinal double spin asymmetries (A_{LL}). Theoretical predictions from QCD of cross section for simple processes have been successful. Most notably, the process $p + p \rightarrow \pi^0 + X$ has been calculated and agrees very well with cross section data over a wide range of kinematics. The processes involved are thus believed to be understood. Transverse asymmetries are predicted to vanish in the perturbative QCD (pQCD) models, but at high p_t forward production, clear non-zero A_N (π^0) has been seen earlier in Fermilab fixed target experiments, and more recently at STAR and PHENIX. The data agree and are clearly pointing to mechanisms not in the standard pQCD models. Two models have been proposed; the "Sivers effect" introduces transverse momentum of the proton's partons relative to the spin direction, while the "Collins effect" ascribes a transverse momentum to the fragmenting hadron after the collision. A third explanation ascribes additional interactions during the interactions (higher twist).

John Koster also showed the Run 8 data. At mid-rapidity, the asymmetries A_N (π^0) are near 0 well out to p_t = 11 GeV, which is a large extension of the previously existing data. To reach the forward region, two $PbWO_4$ scintillating crystal calorimeters ("Muon Piston Calorimeters") were installed in 2006-2007. This allowed for detection of π^0s in the forward and backward directions. In the ensuing 63 GeV running, clear non-zero asymmetries (A_N) were seen, in agreement with earlier data, while the backward π^0s showed no comparable asymmetries. Future plans to extend the data analysis to include eta mesons and the double spin asymmetries, $A_{LL}(\pi^0)$, were described.

Assessment of the Experimental Program at RBRC

RBRC continues to play a very important role at RHIC, both in its contributions to the PHENIX research program and to the RHIC accelerator. The successful completion of the long awaited VTX vertex detector upgrade, led by RBRC, is a major milestone for the RHIC heavy ion physics at BNL. The committee notes that it was the RBRC/DOE cost sharing and invested RBRC manpower that made the PHENIX detector upgrade, so crucial for identification of charm and beauty mesons, a reality. The physics fruits from this investment of manpower and effort will be harvested in the next 6-year extensive period.

It should also be pointed out that the leadership of the RBRC experimental group has been excellent.

B. Theory Program

The committee heard a presentation from Larry McLerran summarizing theory activities at RBRC. It was followed by presentations given by members of the RBRC University Fellows Program and from current RBRC post-docs describing in detail work on a wide variety of problems focused on QCD theory and a phenomenology of heavy ion and hadronic physics.

Zhongbo Kang undertook to explain the transverse single spin asymmetries seen in various experiments. Examples from HERMES and STAR in π^+ production ($A_N(\pi^+)$) and from FERMILAB's E704 (polarized Λs) were described, showing large non-zero transverse asymmetries. Standard pQCD does not explain these asymmetries, so must be augmented in particular ways to allow for these non-zero values. Spin correlations via asymmetric parton distributions functions ("Sivers functions") or asymmetric fragmentation functions (FF) have been suggested.

Data from spin-independent deep inelastic scattering (SIDIS) can serve to extract the Sivers functions (see HERMES publications for examples). Predictions for the polarized DRELL-YAN (DY) process ($p\uparrow p \rightarrow e^+e^- X$) using the Sivers functions call for a sign change in the asymmetry, ie., a negative A_N. In contrast, analysis of the asymmetric fragmention function (FF) process leads to a positive DY asymmetry prediction. Thus a measurement of the DY asymmetries at RHIC is called for, to help understand the dynamics in these transverse asymmetry processes.

Jianwei Qui, a member of the Physics Department at BNL, discussed the future for spin physics theory at RHIC. The proton's spin remains a central puzzle for QCD. Understanding the role of the intrinsic partons' spin and the role of dynamical parton motion remains open. Theoretical progress in understanding assumes factorization in hard scattering and factorization in transverse momentum-dependent terms. Both need to be proven as valid assumptions. Next-to-leading-order (NLO) perturbative QCD calculations have been quite successful in explaining observed cross sections. Measurements on the ΔG are converging, consistent with being small or zero. Theory needs to extend the calculations (NNLO and to lower x) to match the progress expected in experiments. Presently theory awaits the critical test of transverse asymmetries, the measurement of the DY asymmetries. With the PHENIX VTX system coming online in the upcoming RHIC run, heavy quark asymmetries are anticipated for the upcoming runs. Predictions for J/Psi and open charm and bottom quark asymmetries are being made.

A possible exciting future is with the electron-ion collider. The impact of an electron-ion collider on understanding the nucleon spin structure is large. Theorists are playing an integral part in the planning and a leading role in the motivation for this facility for the future.

Feng Yuan could not present his slides in person but provided summary of his work on kT dependent unintegrated gluon distributions. He contrasted CGC color dipole calculations with his own perturbative QCD work on transverse momentum dependent structure functions. The key advantage of Feng's new approach is that unlike color dipole/CGC models, his approach naturally recovers the collinear factorized results at large momentum transfers where 100%

violations of kt-factorized approximations arise. His current applications focus on forward RHIC data and future applications are directed toward EIC physics. In the extension period his interests address high x pt dependent geometric scaling of inclusive particle production.

Derek Teaney discussed his recent work on the consequences of event by event fluctuations of the initial conditions in A+A collisions at RHIC. In particular recent focus is on triangular flow that is predicted to occur in hydrodynamic evolution of such inhomogeneous geometries. He proposed a cummulant method to quantify the correlations between the well know elliptic flow and the new higher moment flow fluctuation moments. This leads to a series of new predictions that to help further constrain the viscosity over entropy ration of the strongly coupled Quark Gluon Plasma produced at RHIC. His previous work on viscous corrections to freeze-out phase space distributions is now routinely used in the field to reduce theoretical uncertainties in the determination of transport coefficients from heavy ion phenomenology.

Rainer Fries presented new work on the sensitivity of high pt higher Fourier moments to probe the fluctuating geometries in A+A collisions. This work complements the work of D. Teaney above which concentrates on low pT long wavelength bulk observables. This work aims to reduce the present very large uncertainty in the jet quenching transport parameter "qhat" that measures the rate of transverse momentum diffusion of a high energy jet propagating in a sQGP. Eccentricity fluctuations enhance the systematic uncertainties in determining qhat from single particle nuclear modification factors, RAA(pt). The preliminary studies of higher azimuthal moments were shown to provide a new experimental handle to constrain correlations induced by initial state sQGP inhomogeneities. His future work will be to test non QCD proposals for jet energy loss based on AdS/CFT phenomenology.

Adrian Dumitru presented recent work on CGC small x evolution of two particle correlations at RHIC and LHC energies. The long range rapidity "ridge" correlations of two "near side" hadrons has been interpreted evidence for novel longitudinal color electric and magnetic field localized flux tube configurations similar to previously propose Lund color flux tube models but with novel saturation momentum dependent features. For examples the radius of the flux tube scales with the inverse power of Qsat(x,A) that controls the local rapidity density of produced particles. It leads to even more novel parallel color electric magnetic domains in which parity and CP are dynamically violated. The first results from CMS on finding of ridge like correlations fro the first time in p+p collisions at 7 TeV is claimed to be evidence CGC predicted n-point functions. This work will address in the upcoming extension period possible applications to eRHIC as well as near term LHC heavy ion data.

Zhong-Bo Kang discussed progress together with F. Yuan and others on transverse spin asymmetry as a probe of transverse momentum dependence of the spin dependent structure functions. The problem investigated is how to define universality of transverse momentum dependent structure functions.

In general they are not universal. He proposed a new formalism that appears promising to solve this problem. Predictions for ep->polarized lambda were proposed to test the universality of parton fragmentation functions.

Cecilia Lunardini discussed work on neutrino astrophysics and cosmology. She performed model independent scans of big bang nucleosynthesis parameter space and report possible room for extra light degrees of freedom perhaps involving sterile neutrinos that could be tested in the future experimentally. She computed a possible new signal of extra neutrinos from failed supernova collapse events from M>40 Msun collapse that could account up to 20% of all collapses. She showed that these could be observed over standard neutrino sources in the energy range above 30 MeV. Future studies in this direction are planned.

Toru Kojo presented recent work with Y. Hidaka, L. McLerran, and R. Pisarski on trying to understand the nucleon axial charge in terms of coherent versus quantum pion clouds. This is one of a series of studies exploring the large Nc versus topological picture of baryon dynamics. He suggests that at large Nc the skyrmion pion cloud collapses and the axial charge gA~1.25 is more naturally explained in terms of constituent quarks rather than coherent cloud of pions. The model has similar properties as the string theory motivated Sakai-Sugimoto model in which skyrmions are unstable to collapse. They postulate that one unpaired quark sit in a non-overlapping spatial wavefuntion that they propose could be tested in lattice QCD with higher Nc>3 simulations. This could lead in the future to a useful collaboration between large Nc phenomenology work such as this and RBRC lattice theory work.

Denes Molnar reported on detailed parton cascade transport model comparisons of off-equilibrium transport phenomena in sQGP as compared second order Israel-Stewart extended viscous hydrodynamic theory. To quantify corrections to bulk collective flow observables that are used to test the lattice QCD equation of state predictions advanced covariant dissipative theories are under development around the world.

Assessment of the Theory Program at RBRC

The concept of seeding joint University/RBRC junior faculty positions and the rigorous selection process for the fellows has worked very well for a decade. The Department of Energy and the National Science Foundation have in several cases taken over their obligation to fund RBRC fellow's research. Two of the current fellows received recently the highly prestigious and well funded DOE Early Career Award. Three others current fellows received Outstanding Junior Investigator Awards.

An important mechanism for disseminating the new results of the RBRC theory effort in the past decade has been the hosting many RBRC Workshops including 41 in spin physics, 10 on lattice gauge theory advances, 40 on heavy ion phenomenology, and a number of specialized topics. The steady state of 20 theorists (approximately ½ fellows and ½ postdocs) and 10 experimentalists continues to be optimal for critical discussions and stimulation of new ideas.

The management of the RBRC theory effort first through T.D.Lee's initiative and currently through L.McLerran's leadership has produced a world class theory center that has an important impact on the many body theory of strong interaction systems.

The committee acknowledges with satisfaction that RBRC has indeed succeeded in fulfilling its founding director, T.D. Lee,'s vision and expectation to train a new generation of physicists who become world recognized leaders in the physics of strong interactions and spin structure. There is every reason to expect this remarkably productive component to continue to flourish in the next six year extension period.

C. Lattice QCD computing Program

Lattice gauge theorists in the RBRC, together with colleagues at BNL and Columbia, form the RBC Collaboration, which carries out state of the art lattice QCD calculations at both zero and high temperatures. The zero temperature work makes use of the domain wall fermion (DWF) formulation of lattice quarks. Up to now, the research in high temperature QCD has primarily made use of staggered quarks, but a promising exploratory study with DWF quarks has recently been undertaken. DWF quarks have the advantage of nearly exact chiral symmetry at finite lattice spacing, but require at least an order of magnitude more computing resources than most other quark formulations. So, the existence of powerful, dedicated computers at BNL plays an important role in the numerical studies of QCD. Work in zero temperature QCD is carried out in collaboration with the British group UKQCD. The research in high temperature QCD is performed with colleagues at Bielefeld and GSI, and in some cases within the hotQCD Collaboration, which consists of most of the lattice gauge theorists in the US studying high temperature QCD. Thus, RBRC lattice gauge theorists have formed a number of important international collaborations that play an important role in advancing their work.

Zero Temperature QCD

Taku Izubuchi, Thomas Blum and Norman Christ described recent progress and future plans of the RBC/UKQCD Collaboration in its studies of zero temperature QCD. The Collaboration is in the process of generating ensembles of gauge configurations with up, down and strange DWF quarks for use in its broad research program. It had previously produced ensembles with lattice spacings of approximately 0.09 fm and 0.11 fm, and pion masses down to 287 MeV. In the past year, it has made good progress on two new ensembles with pion masses of 180 MeV and 250 MeV at lattice spacing of approximately 0.14 fm. Because of their light pion masses, these ensembles should significantly improve the chiral extrapolations for many of the calculations pursued by RBC/UKQCD. Tom Blum presented evidence that even at the relatively large lattice spacing of 0.14 fm, finite lattice spacing artifacts would only introduce systematic errors of order a few percent. Among the most impressive physics results of the past year were a first calculation of the eta and eta' masses, and their mixing angle; and a determination of the light quark masses that included electromagnetic effects.

The study of kaon physics has been and will continue to be a major emphasis of the RBC/UKQCD group. The near exact chiral symmetry of DWF quarks plays a particularly important role here. The Collaboration has already made an impressive determination of the kaon bag parameter Bk, which plays an important role in tests of the standard model. A study of the decay K--> pi+pi is in progress, and the determination of the ratio epsilon'/epsilon is an ambitious, long term goal.

Norman Christ described the QCDCQ, and set out the program of gauge configuration generation that is planned with it during its first year of operation. He also described the long term physics goals for RBC/UKQCD. Finally, Norman indicated his hope for a one Pflops computer in 2015. Given the length of time before such a machine would be installed, it is natural that no plans for its architecture or funding were presented. The latter would appear to require considerable thought and discussion.

In addition to the overview talks mentioned above, there were several detailed descriptions of RBC/UKQCD projects:

Shigemi Ohta described the current status of work on nucleon structure. This project includes the calculation of nucleon form factors and structure functions from which one can determine the axial charge, and the momentum and helicity fractions carried by partons. The new light quark ensembles should be of considerable help in this work because the expected dependence on quark mass in the chiral regime has not been observed in several cases.

Yasumichi Aoki discussed RBC/UKQCD's work on the decays and mixings of B mesons. The immediate objects are the leptonic decay constants and the mixing parameter xi, which play important roles in tests of the standard model. Calculations to date have used DWF light quarks and static-b quarks. These calculations are in an early stage, and have not yet reached the level of precision of those using other quark formulations. However, given the importance of the results, it is highly worthwhile to perform these calculations with several quark formulations. In the long run chiral quarks may well win the day.

Christof Lehner described the challenges that arise in working with very light and very heavy quarks on the lattice. He discussed the tuning of the Columbia formulation of relativistic heavy quarks which RBC/UKQCD plans to use in its work on B mesons in order to go beyond the static approximation for b-quarks. He also described earlier work he and his collaborators performed with very light quarks in the epsilon regime.

Eigo Shintani described the use of low mode projection to accelerate the inversion of the DWF Dirac operator. The results appeared to be very promising. This work is the latest in a series of algorithm improvements made by RBC/UKQCD, which have gone a long way towards making simulations with DWF quarks practical. Dr. Shintani indicated that early use of this preconditioning would be in calculations of the neutron and proton electric dipole moments, and of the decay of the neutral pion to two photons.

High Temperature QCD

Frithjof Karsch described RBC's research program in high temperature QCD. The primary objectives are to understand the QCD phase diagram and its universality properties in the chiral regime, to calculate the equation of state and the transition temperature, and to determine the curvature of the chiral transition line for small chemical potential. He presented evidence for the expected O(n) scaling behavior at very small quark masses, and showed how scaling laws could be used to determine Tc and the curvature of the critical line. He also showed recent results for the equation of state and the behavior of screening masses in the transition region. Up to now, most of RBC's work on high temperature QCD was made use of three staggered quark actions: P4, asqtad and, most recently, HISQ. The HISQ action appears to have excellent potential because its finite lattice spacing artifacts and taste symmetry violations are smaller than the other two. Dr. Karsch also showed results from a recent exploratory study with the DWF quark action. Although it is considerably more computationally expensive than staggered quarks, the DWF action has nearly exact chiral symmetry at finite lattice spacing, and may therefore be especially useful for studying high temperature QCD in the chiral limit.

Assessment of Lattice QCD at RBRC

The RBC Collaboration is engaged in a broad, high quality research program in lattice QCD. The work on high temperature QCD directly supports the RHIC experimental program in heavy ion collisions, and that on the internal structure of the nucleon supports the RHIC spin program. Other research efforts, while less directly coupled to RHIC experiments, address important problems in high energy and nuclear physics. Large scale lattice QCD calculations require multi-year efforts, so it is natural that in any one year progress will be incremental. Nevertheless, we believe that good progress is being made across the board, and should accelerate later this year with the arrival of the QCDCQ. In short, the RBC research program is very strong with excellent prospects for the future.

IV. Assessment of the Proposal for the six year extension from JFY2012 through 2017

The committee has carefully considered the proposal for a six year extension from JFY2012 through 2017 and enthusiastically supports it.

The Proposed Experimental Program

The study and understanding of QCD is the central topic of Nuclear Physics today. The current centers for experimental Nuclear Physics-QCD studies are Brookhaven National Laboratory and the Jefferson Laboratory with CERN just beginning a major effort in heavy ion physics to complement its ongoing COMPASS experiment. From the beginning, RBRC has played a leading role in the success of the RHIC program.

The upcoming vertex detector and the new muon trigger will provide important new capabilities for PHENIX starting with the FY2011 run. We expect an outstanding period of data taking with heavy ions (heavy quark flavor) and with polarized protons (A_{LL} to determine ΔG , A_L with W-boson detection to determine the antiquark polarization, and A_N to study transverse spin structure). The years 2012 through 2017 should yield a great harvest of important data which has the potential to significantly enhance the understanding of QCD. This is the fruit of the investment made by the RBRC over many years. Further, it is noted that the RBRC group is playing a leading role in considering the future of the PHENIX detector beyond 2015.

The forward physics program, particularly in d+Au collisions at RHIC has replaced HERA as the main experimental program studying high energy QCD. Over the next decade BNL will share this leadership with CERN which will have much higher energy but less flexibility in the variety of collisions. RBRC physicists and alumni along with BNL theorists have led the way in studying these high density, pure (unequilibrated) states of QCD matter, parton saturation and the color Glass Condensate, probed in such collisions. This is the matter which, when produced in a high energy ion-ion collision, forms the initial state which then later evolves into the quark-gluon plasma. The electron-ion collider, eRHIC, would give definitive precise studies of such matter.

Looking further into the future, eRHIC is foreseen as the major upgrade to RHIC and will be the focus of a major proposal by BNL at the next U.S. Nuclear Physics Long Range Planning Exercise, expected to take place in 2013. eRHIC is motivated by the need for a dedicated, optimized machine to study the virtual particles of QCD, namely the sea quarks and gluons, and to understand their central role in the structure and properties of hadronic matter. BNL over the last two years has developed an impressive linac-ring accelerator design and a strong group of physicists working on developing the physics case for this machine. eRHIC will be based in part on the polarized beam capability in RHIC and has outstanding opportunities for RBRC in the areas of developing the science case, of developing new detectors and of building the accelerator. Further, it complements well the capabilities of the new J-PARC machine in Japan. We encourage the increased participation of RBRC in eRHIC, particularly aiming to attract Japanese physicists to the different aspects of this exciting, new project in the critical planning phase ahead.

The committee very strongly supports the statement in the RBRC extension proposal that

"RBRC is heavily involved in the discussion and planning process of PHENIX upgrades, and will have a major role in the upgrade. This involves R&D of superPHENIX detector upgrades, and possibly staging implementation of it. We also explore physics opportunity in future eRHIC."

It took over five years to plan and complete RBRC VTX detector upgrade of PHENIX. Planning for the next sPHENIX detector is critical throughout the extension period. The importance of

RBRC participation in this sPHENIX long range planning cannot be overstated. It was through close cooperation of RBRC and DOE that made it possible to complete the VTX upgrade. The very ambitious proposal like superPHENIX will certainly require strong international support and cooperation. The stakes in this direction are very high. As a "spin off" of this planning will be that both the RBRC spin and the heavy ion experimental programs at RHIC will be greatly benefited from the sPHENIX planning.

The Proposed Theory Program

The leading center for QCD theory in the U.S. is in the RBRC and BNL nuclear theory groups which have played a crucial role in training a large number of the outstanding young theorists recently entering the field. In particular the RBRC fellows program has been quite successful in identifying young leaders in nuclear theory. The recent measurements of the polarized gluon distribution in the proton show that is quite small. This result has two important consequences. On the one hand it shows definitively that the constituent quark model does not work well for the flavor singlet partonic spin content of the proton and, on the other hand, it indicates the likelihood that there is a considerable partonic orbital angular momentum contribution to the spin of the proton. Measurements to be performed at Brookhaven in the next 5-10 years should somewhat improve the gluon spin measurement and greatly improve the determination of sea quark contributions. Orbital angular momentum contributions to the proton spin will start after the 12 GeV upgrade at JLab, for valence quarks, but good determinations will require an electron ion collider like that being planned at Brookhaven, eRHIC.

The next decade should be a very fruitful period for spin physics. The Brookhaven theory group is very strong in spin physics and, in collaboration with young theorists at RBRC, should lead the world effort to interpret and more deeply understand the implications of the data. eRHIC would be especially exciting for the longer term future of spin physics where a determination of the spatial distribution and partonic content of angular momentum, spin and orbital, should be definitively determined.

The heavy ion experimental program has been extraordinary successful at Brookhaven over the past decade. The task over the next decade is to better understand the properties of the quark gluon plasma that has been produced. There is intense theory effort in this direction with ideas coming from perturbative QCD, hydrodynamics and string theory, and BNL-RBRC theorists and alumni are playing a leading role in this work. The upcoming experimental program, focusing on heavy quark probes, should add important new information on the formation and properties of the plasma. That, together with high energy data soon to be coming from CERN, should give theorists the information necessary to characterize and better understand the plasma, and to determine at what level strong coupling effects are important and to what extent string theory is useful in understanding such effects.

The Proposed Lattice QCD Computation Program

RBRC has been playing a world-leading role in lattice QCD computation ever since it entered the field in 1997. The RBRC activities have been supported initially by the 0.6 Tflops QCDSP machine completed in 1998, and more recently by the 10 Tflops QCDOC machine commissioned in 2005. An international group of physicists, from RBRC and Columbia University, from England and Germany, and from Japan, whose size continued to grow over the years, produced remarkable progress in the field of lattice QCD.

For the near future, an important event will be the installation of the 400 Tflops QCDCQ expected in 2011. Supported by RBRC, physicists at Columbia University and Edinburgh University have been working on its development in collaboration with IBM. Recent tests on the prototype hardware are showing very good performance for domain-wall QCD. The installation will replace the aging QCDOC, and place RBRC in a strong position to continue its admirable track record over the next several years. The expected outcomes are domain-wall QCD simulations with the physical pion mass on a large volume, also including isospin breaking effects and even QED depending on the target quantity. Those advances will bring lattice QCD computing to a new level as a physics tool for quarks and gluons.

Looking further ahead, RBRC should continue to function as a hub of international collaboration in lattice QCD computing as it has marvelously done so far. There seems to be a need to think again about how RBRC computing should be set up, however. High performance computing is developing fast. By 2012 at the latest there will be several 10 Pflops-class machines in the USA and in Japan. 100 Pflops-class machines will soon follow possibly around 2015, and there have already been activities to explore the possibility of Exa-scale machines in ten years time. Whether RBRC should continue to pursue machine building, whether that should be in collaboration with major vendors or pursued with a more commodity approach, and how that activity should be funded need to be discussed.

V. Summary

It is the committee's overall assessment that the physics issues addressed by RBRC are among the most important in particle and nuclear physics. The quality and quantity of RBRC science continues to be excellent and the environment of RBRC fosters excellent international collaboration and the development of young leaders in the field. In our judgment, to date, RBRC has been good both for RIKEN and BNL, for Japan and the US. The proposed 6 year extension is well thought out, matches superbly the strengths of RBRC and addresses important and timely scientific questions. It has the potential for major scientific discoveries.

eRHIC is in the proposal stage. If it becomes a reality it will be an opportunity for RBRC equal to that of RHIC at the time when RBRC was founded. As in the case of the spin program at RHIC, for the good of both sides, it is essential that RBRC play a major role in the planning of and preparation for the eRHIC research program.

Appendix

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