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January 15, 2008

Dr. Yasushige Yano, Director
RIKEN Nishina Center for Accelerator-
Based Science
2-1 Hirosawa, Wako
Saitama 351-0198, Japan

Dear Dr. Yano;

Enclosed is the RBRC Scientific Review Committee's Report on the SRC Review held at Brookhaven Lab on November 5-6, 2007. I have included a copy of my cover letter to Dr. Noyori which has a few comments to add in general.

Best wishes to you and your endeavours at the RIKEN Nishina Center.

Sincerely yours,

Charles Y. Prescott
Chair, RBRC Scientific Review Committee

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January 15, 2008

Dr. Ryoji Noyori, President
RIKEN
2-1 Hirosawa, Wako
Saitama, 351-01, Japan

Dear Dr. Noyori;

I am pleased to enclose the Report of the RBRC Scientific Review Committee. The Committee held its review on November 5-6, 2007 at Brookhaven. The Committee membership consists of 4 members from the previous Review plus two new members. The membership list of the Committee with addresses and affiliations and the Agenda for the Review are included with the Report.

The Committee was pleased to have Dr. Yasushige Yano in attendance for the Review. His comments and his presentation on the structure of the RIKEN Advisory Panels were valuable to this Committee.

The accelerator performance in RHIC has been excellent. The major goals that were discussed at the previous Review in October 2005 have been accomplished in all essential aspects. Luminosity and polarization at RHIC have increased steadily throughout the runs, achieving the more optimistic projections made two years ago. Credit for the successful runs goes to the Brookhaven management and the Collider-Accelerator Department.

The scientific progress at RHIC in the spin program has been equally satisfactory. The majority of this work occurs within the RBRC where the spin physics program is a priority. Measurement of the gluon contribution, ΔG, has shown increasing statistical significance, and the results have been somewhat surprising, indicating that the preferred theoretical/phenomenological models may be inadequate. The "spin crisis" for the proton was expected to be resolved by the ΔG, but the measurements so far indicate only a small contribution from ΔG exists. Further measurements of ΔG will extend the kinematical range, but now we must consider looking into the angular momentum measurements (both experimentally and theoretically) to fully understand the proton. The story on the proton spin structure is not yet finished.

I should also mention the exceptional progress in lattice QCD computing. This is a technically complicated subject requiring one be an expert to follow, but the contributions to theoretical underpinnings in support of recent experiments have begun to make an impact. Lattice QCD computing is now addressing important issues such as CP violation in the B-meson and K-meson systems. With the coming peta-flop systems, the RBRC can be expected play a central role in these important calculations in the future.

The Committee held discussions with the RBRC staff during the second day of the Review. The morale is quite high and productivity is high, as discussed in the report. I should note that the Director, Nick Samios, continues to provide excellent leadership.

So, for the near future, the situation with RBRC seems quite healthy. BNL treats the RHIC program with highest priority. Support from the Department of Energy's Office of Science is strong. The Committee foresees continued excellence in RBRC's scientific output.

Sincerely yours,

Charles Y. Prescott

Charles Y. Prescott
Chair, RBRC Scientific Review Committee

cc: Dr. Yasushige Yano

Report of the RBRC Scientific Review Committee

Brookhaven National Laboratory

November 5-6, 2007

I. Overview

Two years have elapsed since the last RBRC Scientific Review Committee meeting. Since that time, significant developments affecting the RBRC have come to pass. This Report discusses the important developments and future prospects for the RBRC.

The Scientific Review Committee consists of four members from past reviews, plus two new members. The continuing members are Dr. Jean-Paul Blaizot, Profs. Akira Masaike, Akira Ukawa, and Charles Prescott (Chair). The two new members are Profs. Wit Busza and Alfred Mueller. The Committee membership is listed in an appendix to this report, with members' addresses and affiliations.

The meeting began with an hour-long executive session. The Committee was pleased to hear the opening remarks by Dr. Yasushige Yano, Director of the RIKEN Nishina Center for Accelerator-Based Science, who travelled to Brookhaven for the purpose of attending this Review. Dr. Yano presented to the Committee the structure of RIKEN Advisory Panels and the role this Review and Report plays in the flow of decisions at RIKEN. Important dates were highlighted for the Committee. He specifically mentioned the date of January 2009 when the RIKEN Nishina Center Advisory Council will prepare recommendations on future programs (including RBRC) to forward to the RIKEN Advisory Council in the April 2009 time frame. This Committee's Report next year ($\sim$ November 2008) will constitute an important step in the decision on the future program of RBRC.

Dr. Nick Samios, the RBRC Director, presented an overview of progress since the October 2005 RBRC Review. The most significant step for RBRC was the signing of the third MOU extending the RIKEN-BNL Collaboration for five years. The signing ceremony was held in Tokyo on January 16, 2007 with

Dr. Noyori representing RIKEN and Dr. Aronson representing Brookhaven National Laboratory. Prof. T. D. Lee, a founding father of RBRC, was honored on the previous day by receiving the Order of the Rising Sun.

Dr. Samios discussed major physics activities in 2006 and 2007. Several conferences during this period showcased the RHIC results and the RBRC personnel involved in the physics analyses. The Quark Matter conference (QM2006), held in Shanghai in November 2006, was dominated by RHIC results. Spin 2006 held in Kyoto, Japan had significant RBRC participation, and Lattice Gauge 2007 in Regensburg, Germany was organized by a RBRC graduate and attended by a number of RBRC collaborators.

Progress on the physics front has been significant. The past two years have developed according to projections. At the top of the list of scientific accomplishments would be the gluon spin (ΔG) results from PHENIX and STAR. The measurement of the A_{LL} asymmetry in pi-zero and jet production leads to a ΔG value for the contribution that gluons make to proton spin. The best value appears close to zero, for the kinematic range covered. Extending the kinematic coverage is necessary to confirm this value, but the current results were not expected in the preferred models of proton spin. The proton "spin crisis" may still be with us, and plans to investigate orbital angular momentum with new techniques are underway.

Lattice gauge computing at RBRC has progressed rapidly with three QCDOC machines (10 Tflops each) in production and a NY Blue machine (100 Tflops) coming online. The results from these machines are becoming accurate and relevant to other areas of particle physics. These results are discussed later in this report.

The RHIC accelerator complex has performed exceptionally well in the past two years. The delivered luminosity in the Run 7 200 GeV/Amu center-of-mass running achieved close to the maximum that was projected earlier, and well above the minimum luminosity promised. The two detectors PHENIX and STAR, performed well during this run as well. Polarization of protons in the 100-100 GeV running during Run 6 achieved a value of 60%. The accelerator staff are optimistic that a 70% goal can be achieved in future polarized proton collisions, when energies up to 250 on 250 GeV are planned.

Dr. Samios proudly showed the successes RBRC is having in placing its

young scientists in tenured and tenure-track academic positions. The quality of the upcoming scientists in RBRC has been high in the past and remains excellent today. RBRC continues to provide an excellent career path for these young scientists.

Dr. Hideto En'yo presented the experimental program overview. The RBRC program for the duration of the third MOU is in superb shape, building on the successes of the past ten years. For the next several years, the goals of the experimental program are to investigate the contribution of anti-quarks to the proton spin, to investigate the contribution of orbital angular momentum, and to complete precise measurements of gluon contribution to the proton spin. These entail the completion of the upgrades to PHENIX and the successful operation of RHIC at 500 GeV cms at 70% polarization.

The RBRC has received strong support in Japan through accelerator and the PHENIX detector upgrades and through physics analysis. The computing facility at Wako Japan supports the analysis with the CCJ Center. Data transfer between RIKEN CCJ in Wako and Brookhaven has achieved an astonishing 60 MB/sec.

The RBRC staff has matured and stabilized presently at $\sim$50 persons consisting of students ($\sim$15), Fellows and postdocs ($\sim$14), tenured professors and University Fellows($\sim$12) and visitors ($\sim$9).

II. Scientific Progress

a. The Experimental Program

The experimental program of RBRC has two goals, to understand the spin structure of the proton and related polarization phenomena, and to explore matter at extremes of temperature and energy density. In the former the essential question is to quantify what fraction of the total spin of the proton can be attributed to the spin of the various quarks, to the spin of the gluon and to the angular momentum of quarks and gluons. In the latter it is to characterize the various states of QCD matter that exist and what are their properties, in particular states in which the quarks and gluons are deconfined.

These questions are currently of great interest in the nuclear and particle communities. They are directly related to our understanding of the solutions of the equations of QCD.

The initial focus of the experimental program of RBRC was a.) to prepare the tools to probe the spin structure of the proton using spin polarized protons at RHIC, b.) to use the tools to make the first sensitive measurements of the gluon polarization in the proton and c.) to participate in the exploratory phase of the study of heavy ion collisions at RHIC energies using the PHENIX detector with the hope of finding evidence for the creation of new states of high density QCD matter. All these objectives have now been realized with RBRC - RIKEN physicists playing key roles.

The luminosity and polarization of RHIC as a spin polarized proton collider has steadily increased. In 2006 in Run 6 it achieved a polarization of each beam of 60%, close to the design value, and an integrated luminosity of 45 pb^{-1}. These allowed important measurements of double spin asymmetry in inclusive pion production that narrowed to low values the possible value of the contribution of the gluons to the spin of the proton, and ruled out the theoretically favored maximum gluon polarization scenario.

In the heavy ion program a new state of matter, the so-called strongly interacting Quark Gluon Plasma (sQGP) has been identified and the study of its properties begun.

Under the able guidance of Associate Director and Experimental Group Leader Hideto En'yo and the Deputy Group Leader Gerry Bunce, the RBRC contribution to both these programs has been profound and unique, both in hardware and analysis of data, as well as in leadership and management of the research.

Both Nick Samios and Hideto En'yo, in their overview talks in which they discussed recent progress, emphasized the important contribution of RBRC and RIKEN physicists to the operation of RHIC as a polarized pp collider and to the PHENIX research program. They pointed out that Prof. Perdekamp and Dr. Akiba are currently PHENIX deputy spokespersons and that since the last review, RBRC and RIKEN experimentalists have published more than 50 articles in refereed journals. At the important Quark Matter Conference in Shanghai in 2006, Perdekamp gave one of the plenary talks, and at SPIN06

in Kyoto, Deshpande gave a plenary talk, while Bunce and Liebing gave invited parallel session talks. They further pointed out that in addition to the leadership role in the spin physics program and in the determination of the gluon polarization in the proton, the RBRC/RIKEN physicists contributed in a major way in the recent heavy ion/unpolarized pp program, in particular in J/Ψ measurements, heavy flavor measurements via single electrons, direct photons at high P_t, and low P_t direct photons via internal conversion, all of which significantly increased our understanding of the matter created in RHIC heavy ion collisions.

Another recent achievement has been the electronic transfer at a rate of 60 MB/s, of data from Run 6 from RHIC to the CCJ at RIKEN-WAKO. CCJ is the center for PHENIX RHIC spin physics analysis.

There is no doubt that to date the RBRC experimental program has been remarkably successful and all indications are that this will continue to the foreseeable future, for which RBRC/RIKEN physicists have well thought out plans.

In the spin program they plan to study anti-quark polarization in the proton through the study of W boson production at 500 GeV. They also plan to determine with high precision the gluon polarization in the proton through the study of $\gamma+$ jet production, and to obtain some handle of the role of angular momentum in the proton through the study of the collision of transversely polarized protons.

In the heavy ion program they plan to study the colored glass condensate using d-A data, and using A-A data, to study heavy flavors and direct photons, as well as search for the critical point.

Extensive discussions of these achievements and plans were presented in talks given by individual RBRC researchers. These talks were very informative and well presented. Here we briefly summarize each talk.

Abhay Deshpande gave an overview of the RHIC spin physics program and the recent results from PHENIX on the measurement of the gluon polarization in the proton. The polarized gluon distribution can be extracted from measurements of double spin asymmetry A_{LL} in inclusive pion production, open heavy quark production and direct photon production, while anti-quark polarization can be extracted from parity violating production of $W^{\pm}$ in sin-

gle spin A_L measurements, and a possible connection to orbital angular momentum can be made through the study of transversity and transverse spin effects. He emphasized how the flexibility and spin manipulation capability at RHIC gives access to different physics. So far measurements have been limited to ΔG using $pp \rightarrow \pi + X$ and $pp \rightarrow jet + X$ probes. With higher luminosity and upgrades to PHENIX (Si vertex detector, new high η detectors, and various triggering capabilities) measurements will be extended to include $pp \rightarrow \gamma X, \gamma\gamma X, DX, BX, \mu^-\mu^+ X$ and $Z^\circ W^\pm X$ which will give more precise information on ΔG as well as information on Δq and $\Delta\bar{q}$. He showed and discussed the beautiful new (Runs 5 and 6) result on $A_{LL}(\pi^\circ)$ which, together with the excellent agreement in the production yield of π°s with next to leading order (NLO) QCD calculations, can be used with confidence to extract ΔG, the gluon contribution to the spin of the proton. The results favor the GRSV scenario with ΔG =0 and exclude $\Delta G(Q^2 = 1\ \mathrm{GeV}^2) = 0.4$ by more than 3 σ.

Kensuke Okada discussed direct photon measurements in Run 5 and 6. Direct photons radiate from quarks which couple to the gluons. This process is the cleanest and best understood, so is considered to be the "golden test" of gluon spin in the proton. In 2007 the PHENIX direct photon spectra, using combined data from Runs 5 and 6, were published in a PRL article. They agree well with pQCD calculations. They have also analyzed Run 5 data to obtain the first measurement of double spin asymmetry A_{LL} for direct photon production. The errors are still too big for the measurement to be useful. Low signal to noise is the main issue and background estimates need to be improved. They are currently analyzing Run 6 data.

Patricia Liebing described heavy flavor (open charm and bottom) asymmetry extracted from single electron asymmetry of Run 5. The current statistics do not reveal systematically different asymmetries of background and signal, and Run 6 data will not change the picture. With the current detector setup, A_{LL}(heavy flavor) in the central arm has no sensitivity to $\Delta G/G$. It will be a difficult measurement even with the silicon vertex upgrade because of the small predicted asymmetries (few parts in 10^{-4}).

David Kawall presented the development of a trigger for high P_t charged pions for PHENIX. Currently, because of the lack of a high P_t trigger for charged pions, the yield of charged hadrons, in contrast to neutral pions, is

too small for useful asymmetry measurements. Studies show that coincidence between the RICH and the Hadron Blind Detector (HBD) can be used to trigger on $\pi^{\pm}$s with momenta > 5 GeV/c with a rejection factor of 1 in 500. This should be sufficient at design luminosity to obtain the desired rate of $\pi > 5$ GeV/c below 20 Hz in a 500 kHz background. Work on this trigger is underway and the goal is to have it in place for Run 9 in the fall of 2008. It should result in π^+ and π^- yields roughly 80% of the π° yields. Since the π^+ asymmetry has greater analyzing power for ΔG than the π° asymmetry, with such yield, the charged pion measurements should give important results on the gluon polarization in the proton.

Itaru Nakagawa described the muon trigger that will be necessary for W detection. This is important since double spin W boson production leads to an asymmetry that can be used to measure the specific type of quark and anti-quark contribution to the proton spin. At 200 GeV the current total μ-trigger rate is acceptable (< 2 kHz). However at 500 GeV and design luminosity it would be $\sim$12 MHz! Thus a rejection factor $\sim$10,000 will be necessary. Since at 500 GeV the yield of μs from W-decay is not a strong function of transverse momentum, while those from the background charm and bottom decays steeply fall with transverse momentum, one can reject most of the background muons without a significant loss of muons from Ws by triggering on high P_t muons (>25 GeV). A high P_t muon trigger is under development in the PHENIX detector. It consists of a nosecone absorber followed by three layers of resistive plate chambers (RPC) inserted in the muon arms with which high momentum muons can be detected on line. A prototype of the system was completed in 2007 and the final system should be ready by 2009.

Atsushi Taketani described the new silicon detector being developed for PHENIX. It will greatly increase the detection of heavy quarks and jet identification, the former by measurement of the displaced vertex and the latter because of the increased acceptance. These improvements will significantly enhance both the heavy ion and the spin physics program of PHENIX. RBRC has a major role in this PHENIX detector upgrade project, with Taketani as Pixel subsystem manager and Akiba the overall manager of the vertex detector project. The vertex detector will occupy the innermost region of the PHENIX detector. It will consist of a barrel section consisting of pixels followed by strips, and a forward region consisting of four layers of mini-

strips. State-of-the-art radiation hard electronics, under development at CERN, would live on board the detector. Work on both the pixel and strip sensors is proceeding well and a partial system may be installed in 2009. The final system is scheduled for installation in the summer of 2010.

Matthias Perdekamp described the group activities of the University of Illinois group and the future of transverse spin studies. In recent years the UIUC group has focused on fragmentation function analysis of BELLE and LEP data, and analysis of PHENIX data on asymmetries in neutral pion and di-hadron production, and on forward neutral pion production in d + A. Their next focus will be on parity violation and single transverse spin asymmetries at RHIC. On the experimental front they are focusing on the RPC muon level-1 trigger for W-physics and muon piston calorimeter for forward physics. During the discussion of transverse spin studies he pointed out that in recent years the interest in transverse spin has increased exponentially, with more than 100 publications in 2007. He discussed how the gauge link formalism makes it possible to describe k_T-dependent phenomena in a rigorous QCD framework, how a fundamental test of this framework is possible measuring single transverse spin asymmetries in Drell-Yan at RHIC, and how the extraction of quark transversity distributions will come from a global QCD analysis of single transverse spin asymmetries from semi-inclusive deep inelastic scattering (SIDIS), pp and e^+e^-.

Yuji Goto discussed how, in 2001-2002 a large neutron single spin asymmetry ($A_N \sim 10\%$) was discovered at the very forward production of neutrons in pp collisions, and as a result how the forward neutron spin asymmetry can be used to monitor the longitudinal polarization of the proton beams. At RHIC it has now been successfully used to monitor the longitudinal polarization of the proton beams at the collision point. In order to understand the mechanism of the production of the forward neutrons, measurements have been made on the x_F dependence of the cross section and asymmetries. Comparing the cross section with ISR data indicate no violation of x_F scaling at higher energies.

Wei Xie discussed the importance of measuring with good resolution the orientation of the reaction plane for determination of the elliptic flow parameter ν_2. To augment the beam-beam counter (BBC), the current reaction plane detector in PHENIX, a new scintillation counter hodoscope with much larger

phase space coverage was added to PHENIX and commissioned during Run 7 in 2007. This Reaction Plane Detector not only improved the resolution of determining the reaction plane but also will help in triggering during low energy Au+Au runs.

Yasuyuki Akiba summarized the Heavy Ion Physics at PHENIX. To date the main achievement at RHIC is the production of high density partonic matter, deduced from the strong suppression of high P_t hadrons in Au+Au (jet quenching), absence of suppression in d+Au, and strong elliptic flow. The next step is a detailed study of the newly discovered matter. Is the matter de-confined? What is the viscosity of the matter? How hot and dense is the matter? Measurement of "penetrating probes" such as J/Ψ, heavy quarks and direct photons should help answer these questions. He went on to discuss PHENIX heavy ion/unpolarized pp results on these topics and emphasized the important contribution RBRC/RIKEN physicists have made to these measurements. In particular he mentioned Wei Xie's role in J/Ψ suppression studies, Kajihara's role in heavy flavor studies in pp collisions, and in heavy quark energy loss and flow studies, Yamaguchi's role in searches for direct photons via virtual photon analysis, and his own contribution to all these studies. He pointed out that since 2001 PHENIX has published 63 papers in Physical Review Letters, Physical Review, Physics Letters and Nuclear Physics. These had > 5000 citations in total. Since January 2006 25 papers have been submitted for publication of which 8 had significant RIKEN/RBRC contributions. Overall these are impressive achievements.

b. The Theoretical Program

The Committee heard a presentation from Larry McLerran concerning the theory activities at RBRC, which concern several aspects of strong interactions and QCD. These are explored with a variety of techniques including lattice gauge theory (the latter is discussed in the following section of this report). Major accomplishments have taken place in the study of the spin of the nucleon and in that of matter with high energy density. The RBRC University Fellow Program continues to be very successful with three new Fellows being recently appointed and two having obtained a tenure track position. The committee also interviewed the RBRC Fellows and postdocs.

They all manifested their strong appreciation of the stimulating scientific environment that they find at BNL, the many opportunities they have to meet other researchers in their field and the excellent contact with the experimentalists. They all underlined the extremely positive role played by Larry McLerran towards the young researchers. Some postdocs suggested the need of activities that could favor the integration of newcomers, in particular that of the young Japanese postdocs. A seminar reserved to the young researchers could play a positive role in this regard. The Committee was very impressed with the quality of the RBRC theory postdocs and Fellows. It is in large part because of them that Brookhaven Laboratory has become the worlds leading center for QCD and hadronic physics.

Derek Teaney made a presentation of his work on transport in heavy ion collisions. His main focus is to understand the role of viscosity in relativistic hydrodynamic flow and more precisely how viscosity affects the elliptic flow observed in nucleus-nucleus collisions. He used the strong coupling techniques provided by the AdS/CFT correspondence to calculate the energy loss. He emphasized the relation between jet quenching and elliptic flow and tried to draw conclusions about the value of the viscosity that can be extracted from the measurements of these quantities.

Kirill Tuchin reported on his recent investigation of the scale anomaly in QCD at finite temperature. He recalled that a measure of the breaking of conformal symmetry at finite temperature is related to the trace of the energy momentum tensor, a quantity which is well determined by lattice calculations. He also showed how to extract the bulk viscosity of the quark gluon plasma from the trace of the energy momentum tensor calculated on the lattice. The result is that the bulk viscosity increases very rapidly near the transition temperature.

Cecilia Lunardini is a new RBRC fellow, with a joint position at the Arizona State University. Her work concerns neutrino astrophysics. She studies in particular the effect of neutrinos masses on the spectrum of neutrinos produced during the explosion of supernovae. She is also engaged in research on geochemical traces of supernova neutrinos and in investigations of non-standard neutrino matter interactions.

Agnes Mocsy reported on the work that she has been doing together with P. Petreczky on heavy quark bound states at finite temperature. She showed

that it is possible to reproduce the Euclidean correlators of mesonic currents calculated on the lattice using potential models. A particularly remarkable result of her investigation is the fact that lattice data are consistent with charmonium dissolution just above the deconfinement temperature in contrast to many recent claims based on a study of spectral functions that are reconstructed from the lattice correlators using the maximum entropy method.

Yoshimasa Hidaka reported on his work done in collaboration with R. Pisarski on real time properties of hot QCD. He presented a calculation of the effect of a strong classical background gauge potential on Debye screening mass using the hard thermal loop approximation. He intends to apply his technique to the calculation of the shear viscosity.

Denes Molnar described a program of research aimed at extracting the viscosity to entropy ratio in the quark gluon plasma produced at RHIC. This is a topical and ambitious program using viscous hydrodynamics to describe the evolution of the plasma. First results indicate a very small value of the viscosity to entropy ratio, compatible with the conjectured lower bound.

Cyrille Marquet described forward particle production in deuterium-gold collisions. The use of angular correlations between two forward particles as a test of the color glass condensate was advocated, and numerical results for correlations, but without final state fragmentation, were given.

Feng Yuan reported on an extended program of work that he and his collaborators have been doing with the emphasis on recent work on quark polarization at large values of the Feynman-x variable. The large x region for which predictions are now available could be tested at the Jefferson Lab and at the proposed electron-ion collider at Brookhaven.

Rainer Fries described his work on developing a detailed formalism to treat multiple scattering of quarks and gluons in hot and cold matter with the object of having a sound basis to analyze such topics as transverse momentum broadening and the Cronin effect in hard scattering processes.

c. Lattice QCD Computing

Since 2005, lattice QCD computing at RBRC has been carried out by the two QCDOC machines installed at BNL, plus one more at Edinburgh through the RBRC-UKQCD collaboration. Since 2006, the resource has been augmented by access to BlueGene/L at LLNL and NYCS(New York Center for Computational Sciences). In total RBRC scientists have had access to about 20 Tflops (sustained throughput for lattice QCD) of computing power, which has placed them as one of the most competitive in lattice QCD computing worldwide.

The RBRC lattice QCD program was reviewed by Norman Christ on the second day of the review. RBC(RIKEN-BNL-Columbia) Collaboration with 34 members forms the core of the program, but it also worked with UKQCD (Great Britain) and Bielefeld (Germany) Collaborations in Europe, and with HotQCD and USQCD Collaborations within USA. The RBRC computing efforts over the past two years have focused on two directions; (i) the domain-wall lattice QCD simulations, pioneered since ten years at RBRC, and (ii) lattice QCD thermodynamics using the p4 staggered quark formalism.

In domain wall QCD, simulations with inclusion of the full effect of up, down and strange sea quarks (2+1 DWQCD) have been pushed forward. Gluon configurations with a pion mass down to 300 MeV have been successfully generated on a 24^3 spatial lattice, and an effort on a larger lattice size of 32^3 is well underway. Calculations in kaon physics with direct impact on the CP violation issue have made a steady progress. New quantities (nucleon structure, charm and bottom quark related spectral quantities, etc.) relevant to particle and nuclear community have been explored.

A brief description of the next computer project was also given. A design collaboration between Columbia, Edinburgh and IBM is underway. The target is a system sustaining 300 Tflops, achieving a ten-fold increase of the computing power.

Robert Mawhinney followed up with a review of the status of kaon physics calculations in 2+1 DWQCD. The main outcome so far is the first calculation of the mixing parameter B_K in 2+1 DWQCD. The result, albeit only at one lattice spacing so far, indicates a value 10% smaller and an error band reduced

by about a factor two compared to those adopted by the CKM Fitter (2007). Preliminary results on the matrix elements needed for the direct CP violation parameter ϵ'/ϵ were also shown.

Peter Petreczky discussed the status of the p4 staggered thermodynamics with 2+1 light flavors. Notable among the results are: detailed calculations on N_τ=4 and 6 lattices which confirm a weakly interacting plasma picture at $T/T_c \geq 2$ but indicates a higher critical temperature compared with previous estimates, and study of magnetic and electric screening lengths which show perturbative behavior up to overall constants. N_τ=8 calculations are underway in a collaboration with HotQCD and USQCD to control finite lattice spacing errors.

Presentations by the individual RBRC members were made in the Theory Group Presentations on the first day. Sinya Aoki discussed a recent work with N. Ishii (KEK) and T. Hatsuda (U. Tokyo). In a quenched calculation done on a BlueGene/L at KEK, they succeeded in deriving the nuclear potential, including the short-distance repulsive core, using the Bethe-Salpeter amplitude for the two nucleon state. A preliminary result for the nucleon-Ξ potential was also presented.

Shigemi Ohta presented a progress report of nucleon form factors and moments of structure functions from 2+1 DWQCD on 16^3 and 24^3 spatial lattice sizes. Results are broadly in agreement with experiment, but there are hints that finite-size effects are important already at the used lattice sizes.

Yasumichi Aoki discussed $B\bar{B}$ mixing and proton decay matrix elements, relevant for the Standard Model and beyond, calculated on 2+1 DWQCD configurations. For proton decay, the chirally reduced amplitude was obtained for the first time in the realistic 2+1 flavor setting. Further analyses without relying on the chiral reduction are planned to directly evaluate the matrix elements.

Taku Izubuchi discussed a new simulation method to investigate the strong CP problem by analytically continuing the vacuum angle to the imaginary axis and rotating it into the quark determinant. The initial 2-flavor results show it to be competitive with standard methods. An extension to U(1) problem and the eta spectrum is under investigation.

Tomomi Ishikawa presented a phase diagram analysis of the twisted Eguch-

Kawai model. This model can describe Yang-Mills theory in ordinary space or that in a non-commutative space depending on the large N limiting procedure if Z_N symmetry in not broken in the weak-coupling limit. His results show that this condition is violated in the Eguchi-Kawai model with the plaquette gauge action.

Adam Lichtl discussed an investigation of the excited baryon spectrum. His method combines a systematic group-theoretical construction of non-local operator basis plus a variational determination of mixing coefficients. Initial results in quenched and 2-flavor QCD show an encouraging qualitative agreement of the mass spectrum pattern with experiment.

The Review Committee considers that the progress reported at the review broadly fulfills the expectation anticipated at the time of the last review in October 2005. The successful execution of 2+1 DWQCD simulation with light pions, and calculations of a host of physical quantities relevant for particle and nuclear physics, including a first report of B_K, is an impressive achievement. The calculations with the p4 staggered action have deepened our understanding of QCD thermodynamics directly relevant for RHIC heavy ion experiments.

The wide variety of results reflects the initiatives and high level of activity of the group members, and has added breadth and wealth to the RBRC lattice program. On the other hand, since the Collaboration is well positioned to take lead in the issue of CP violation in kaon physics critical to the Standard Model, a strategic concentration of computing and human resources may be considered to accelerate progress and a timely output on this important issue. The p4 staggered formalism is computationally less demanding than the domain wall formalism, but theoretically less satisfactory due to lack of full chiral symmetry and the correct flavor content. Thus, while the p4 approach is viable and important for interface with current experiments, over long term, shifting thermodynamic studies from staggered-based to domain wall-based will be desirable. The Committee understands that this point has been and is being discussed seriously within the Collaboration.

At the last review, the need to provide senior leadership to the lattice program within RBRC was pointed out. This was to ensure, on the one hand, an active role by RBRC in a research program which includes senior scientists and a number of collaborations outside of RBRC. Another important factor was to

provide a steady and coherent on-site guidance to junior members so that they can work effectively and feel integrated to the program. The Committee felt that the need had increased over the two years with the growth of the RBRC Collaboration. The Committee was therefore happy to learn that establishing a joint senior position between RBRC and BNL is being sought for. The Committee strongly endorses this move.

III. Career Development

The RBRC continues to attract an excellent community of scientists. Success in its scientific program depends on creating the finest young scientific talent available and providing for them access to the scientific tools and academic environment where they can pursue their ideas. The RBRC staff has been successful through its close attention to the career development and career opportunities of its young scientists.

The overall staff level of RBRC has grown from a headcount of around 20 in 2001 to a level of 45 - 50 since 2004. Today the headcount remains at about 50 persons. Of this 50, approximately 15 are students, 15 are Fellows and/or postdocs, 12 are university Fellows and tenured staff, and 8 are visitors.

Since the previous RBRC Scientific Review in October 2005, 4 university Fellows have been promoted to tenured positions, 9 individuals have received appointments at universities as RBRC University Fellows, and 4 graduates of the RBRC program have been promoted to tenure-track positions. Of the 17 universities involved in these promotions, 5 are non-US (3 are Japanese, one Canadian, and one European). Within the RBRC, there are 5 new postdocs. This record of successful academic appointments is an excellent testimonial to the strength of the program as viewed by a broad set of universities and institutions.

The Department of Energy sponsors a program of Outstanding Junior Investigator Awards to support the development of individual research programs of early career scientists in theory and experiment. Annual awards to typically 5 scientists are given. The RBRC has been successful with 8 such awards to its young scientists and Fellows in the past 8 years.

The RBRC sponsors workshops regularly, covering topics closely related to the RHIC physics. These workshops not only further the scientific research, but also provide the venues for exchanges of ideas and opportunities for reporting progress from the young scientists. The Table below lists the recent workshops.

Workshop Topic	Date	Conveners
Heavy Flavor Production and Hot Dense Quark Matter	Dec 12-14, 2005	Akiba, Huang, Rapp, Tuchin, Xie
Parton Orbital Momentum	Feb 24-26, 2006	Bunce, Fields, Vogelsang
Can We Discover the QCD Critical Point at RHIC?	Mar 9-10, 2006	Ludlam, McLerran
RHIC Physics in the Context of the SM?	June 18-23, 2006	Desphande, Kharzeev, Venugopalan, Vogelsang
QCD in Extreme Conditions	Jul 31- Aug 2, 2006	Datta, Pisarski, Petreczky
Domain Wall Fermions at 10 Yrs	Mar 15-17, 2006	Blum, Soni
Parity Violating Spin Asymmetry at RHIC-BNL	Aug 26-27, 2007	Grosse, Perdekamp, Surrow, Vogelsang
Global Analysis of Polarized Parton Distributions in the RHIC Era	Oct 8, 2007	Deshpande, Vogelsang
Joint Doctoral Training Prgm QCD Spin Physics	Oct-Dec, 2007	ECT and RBRC, Trento, Italy

The RBRC has been exceptionally successful at promoting its young scientists into academic positions widely distributed in the US and abroad. This remains a major strength of the RBRC program.

IV. Future Plans

No one ever said that understanding the proton's spin would be easy. The proton is known to be a complex object which we already learned through studying it's unpolarized structure. Adding the spin degree of freedom creates additional challenges to understand. Nevertheless, the pursuit of the

proton structure (including it's spin structure) remains one of the most important issues for the understanding of matter at its roots.

The experimental goals for the upcoming several years are clearly defined. The RBRC will concentrate on the $\Delta G(x)$ measurements through more precise $A_{LL}(\pi^0)$ measurements and direct γ measurements. The direct γ measurements, $A_{LL}(\gamma)$, are particularly important. The $A_{LL}(\pi^0)$ measurements have already been measured with rather good statistics, but the $A_{LL}(\gamma)$ have a simpler interpretation for the contribution of ΔG to the proton spin, so the direct γ measurements remain a significant goal.

When the Vertex Detector is ready, the channels coming from heavy quarks will contribute to this program. At the highest RHIC energies (500 GeV cms), W bosons are produced and the asymmetries associated with the different W charges allow for the anti-quark production to be flavor-separated and the spin contributions measured. Further in the future, but starting earlier perhaps, will be the studies of angular momentum contributions to spin from the constituents of the proton. Measurement of transversity through left-right asymmetries in single beam transverse polarization (A_N) will become possible. Considerable experimental and theoretical work is still needed to understand the transversity processes and make these measurements.

To achieve these goals, the luminosity and polarization must continue to improve. Frequent attention to the measurement of the polarization is necessary to assure accuracy in this important parameter.

Upgrades to the PHENIX detector are an essential part of the RBRC activities. These upgrades are focussed on providing the specific tools needed to carry out the spin program to its completion. The Nose Cone Calorimeter, described by Itaru Nakagawa in his experimental talk, will contribute to the high P_t muon trigger, important to the ΔG and W physics. The trigger for high P_t charged hadrons, based on the Hadron Blind Detector, was described by David Kawall. This trigger greatly increases statistics for the ΔG measurements. The Vertex Detector, described by Atsushi Taketani in his talk, will enable detection of heavy quarks and jet identification, and should participate in the ΔG measurements and heavy ion physics. The Vertex Detector should be completed in 2010. Matthias Perdekamp described the work of his University of Illinois group on the muon trigger and the muon piston calorimeter. That work should be ready by 2010, and will better enable

the identification of W's. With these systems coming online, the PHENIX program should continue to advance rapidly in the coming years.

The run plans for 2008-2013 exist in preliminary form. Ten weeks in 2008 and 2009 and 5 weeks in 2010 are planned for 200 GeV cms running. These runs should complete the ΔG program. Five weeks in 2010, followed by 10 weeks each in 2011-2013 at 500 GeV would allow the W physics program to be finished in that time frame.

RBRC has achieved an excellent record in lattice QCD computing by combining the development of QCD-dedicated computers, timely physics programs, and the formation of an excellent research group. Looking toward future, while QCDOC is losing competitiveness in a rapidly developing high performance computing environment, the access to BlueGene/L machines at LLNL and NYCCS shall provide guarantee, at least over the next few years, that the RBRC program stays in the leadership position in lattice QCD. Going beyond requires a significant leap in the computing resources, to 1 Pflops range in a few years and to 10 Pflops range in 5 years or so. The Committee is happy to learn that a next computer project to meet this need has been started as a Columbia-Edinburgh-IBM collaboration.

Theoretical support for heavy ion and spin physics, two of the major areas of nuclear physics, has to a large extent been led by physicists trained through the RBRC program. What characterizes RBRC theorists in general is their strong interactions with RHIC experimentalists. There is no doubt that in the future they will continue, as they have so successfully done in the past, to play an active role in the interpretation of RHIC data and provide support to the ongoing experiments on spin physics and ultra-relativistic heavy ion collisions. One can make the case that the Brookhaven heavy ion physics program has been the most exciting research program in all of nuclear physics, and with the LHC program to begin in a few years heavy ion physics can be expected to dominate nuclear physics for some time to come. We expect RBRC to continue playing a leading theoretical role in nuclear physics, and to lead the way in training young theorists during what should be an exciting decade to come.

V. Outlook

The RBRC has made outstanding progress in its scientific goals since the last Review. The performance of the RHIC accelerator complex has been strong, and advances in the luminosity and polarization have been excellent, achieving the goals they set out to meet. RHIC is blessed with the excellent Collider-Accelerator Department. RHIC has consistently focussed on luminosity and polarization upgrades, so we should expect to see improvements continue into the foreseeable future.

With the PHENIX upgrades currently underway, the next several years should see the detector capabilities improving and the data resulting from the upgrades significantly more selective on the physics signatures of interest. The results coming from the physics analyses should continue to provide greater insights into the fundamental issues.

Beyond the 2013 period, the running plans are not specified. The current RIKEN-BNL MOU will end before that time, so reaching the goals the RBRC program will depend on a 4th MOU. The study of transversity and the contribution of angular momentum by the proton constituents will likely be continuing in this later period. Today one can only speculate on the outcome of the ΔG measurements and the need to understand more about the proton spin. Preliminary indications from the existing ΔG data, however, point to the need to extend the program into the angular momentum sector.

Appendices:

Committee Members

Review Agenda

RBRC Scientific Review Committee Membership 2007

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RIKEN BNL Research Center

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Agenda

Brookhaven National Laboratory, Upton, NY
Physics Department, Building 510
Large Seminar Room
November 5 and 6, 2007
Open Sessions

Committee Members

Jean-Paul Blaizot	C.E.A. - Saclay
Wit Busza	MIT
Akira Masaike	JSPS, Washington, D.C.
Alfred Mueller	Columbia U
Charles Prescott, Chair	SLAC
Akira Ukawa	U. of Tsukuba

Monday, November 5, 2007

8:00 AM - 9:00 AM *Open Executive Session & Working Breakfast (Room 2-160)*
(Presentations by RIKEN/RBRC Administration)

THEORY GROUP PRESENTATIONS
LARRY MC LERRAN, CHAIR
LARGE SEMINAR ROOM, BLDG 510

Talks by Fellows

9:00 AM - 9:15 AM Sinya Aoki: *Nuclear force from lattice QCD*

9:15 AM - 9:30 AM Shigemi Ohta: *Nucleon structure from lattice QCD with 2+1 dynamical domain wall fermions*

9:30 AM - 9:45 AM Yasumichi Aoki: *Hadronic matrix elements with 2+1 flavor domain fermions*

9:45 AM - 10:00 AM Taku Izubuchi: *Lattice QCD with Theta Terms*

10:00 AM - 10:15 AM Derek Teaney: *Quark Energy Loss*

10:15 AM - 10:30 AM Kirill Tuchin: *Scale anomaly in QCD at zero and finite temperature*

10:30 AM	10:45 AM	Denes Molnar: Determining the shear viscosity of dense QCD matter at RHIC
10:45 AM	11:00 AM	Break
11:00 AM	11:15 AM	Rainer Fries: *Probing Hot and Cold Nuclear Mater*
11:15 AM	11:30 AM	Feng Yuan: *Spin structure functions*
11:30 AM	11:45 AM	Cecilia Lunardini: *Neutrino Astrophysics*

THEORY GROUP PRESENTATIONS
ANTHONY BALTZ, CHAIR
LARGE SEMINAR ROOM, BLDG 510

Talks by Postdocs

11:45 AM	12:00 PM	Tomomi Ishikawa: *Phase structure of twisted large N reduced model*
12:00 PM	12:15 PM	Agnes Mocsy: Heavy quark bound states at finite temperature
12:15 PM	12:30 PM	Adam Lichtl: *Excited resonance physics from the lattice*
12:30 PM	12:45 PM	Yoshimasa Hidaka: *Real time behavior of the Quark Gluon Plasma*
12:45 PM	1:00 PM	Cyrille Marquet: *Particle production in dA collisions*
1:00 PM	2:00 PM	SRC Executive Session - Working Lunch (Room 2-160)

EXPERIMENTAL GROUP PRESENTATIONS
HIDETO EN'YO, CHAIR
LARGE SEMINAR ROOM, BLDG 510

2:00 PM	2:15 PM	Abhay Deshpande - *Gluon's spin in the proton: recent results from PHENIX and the path forward*
2:15 PM	2:30 PM	Kensuke Okada: *Direct photon measurements*
2:30 PM	2:45 PM	Patricia Liebing: *Delta G from open charm production*

2:45 PM	- 3:00 PM	David Kawall: *Development of a trigger for high p_T charged pions for PHENIX*
3:00 PM	- 3:15 PM	Itaru Nakagawa: *Muon trigger upgrade for W boson detection*
3:15 PM	- 3:30 PM	Atsushi Taketani: *Vertex detector for PHENIX*
3:30 PM	- 4:00 PM	Break
		EXPERIMENTAL GROUP PRESENTATIONS **GERRY BUNCE, CHAIR** **LARGE SEMINAR ROOM, BLDG 510**
4:00 PM	- 4:15 PM	Matthias Grosse Perdekamp: *QCD and Transverse Spin - Future Studies*
4:15 PM	- 4:30 PM	Yuji Goto: *Very Forward Neutron Asymmetry at RHIC*
4:30 PM	- 4:45 PM	Wei Xie: *PHENIX Reaction Plane Detector and its Physics Input*
4:45 PM	- 5:00 PM	Yasuyuki Akiba: *Heavy Ion Physics at PHENIX*
7:00 PM		**Dinner - Three Village Inn, Stony Brook**

Tuesday, November 6, 2007

8:00 AM	- 9:00 AM	*Executive Session & Working Breakfast (Room 2-160)*
		COMPUTING PRESENTATIONS **N.P. Samios, CHAIR** **SMALL SEMINAR ROOM, BLDG 510**
9:00 AM	- 9:30 AM	Norman Christ: *RBRC lattice QCD program and the Next Computer Project*
9:30 AM	- 10:00 AM	Robert Mawhinney: *K meson physics with domain wall fermions in the chiral limit*
10:00 AM	- 10:30 AM	Peter Petreczky: *The QCD phase transition and equation of state: toward physical quark masses and vanishing lattice spacing*
10:30 AM	- 12:00 PM	INTERVIEWS (Experimental) - Meetings with Individual RBRC Staff (Room 2-78) INTERVIEWS (Theory) - Meetings with Individual RBRC Staff (Room 2-160)
12:00 PM	- 1:00 PM	Executive Session - Working Lunch (Room 2-160)
1:00 PM	- 3:00 PM	INTERVIEWS (Experimental) - Meeting with Individual RBRC Staff (Room 2-78) INTERVIEWS (Theory) - Meetings with Individual RBRC Staff (Room 2-160)
3:00 PM	- 4:15 PM	Executive Session
4:15 PM	- 5:00 PM	Closeout