Report of the RBRC Scientific Review Committee November 21-22, 2002

1 Overview

The Scientific Review Committee met at Brookhaven on November 21-22, 2002. The membership of the Committee and the agenda are attached.

The committee was again impressed with the success of RBRC which continues to operate as a superb institute, at the forefront of modern nuclear science. This field, essentially the study of the so-called strong interaction, is fundamental to an extremely broad array of physical, astrophysical, and technological applications. These range from the new states of hadronic matter now being created at the BNL Relativistic Heavy Ion Collider (RHIC), the early universe, neutron stars, and the study of the violation of CP symmetry in the electroweak interaction.

With its basic focus, namely to provide a venue and environment for the scientific interaction and research of young scientists, RBRC is one of the most efficient and productive means of developing both the physics and the physicists in this important area. Because of the youth and international character of the scientific Fellows and the spirit and direction of its leadership, RBRC is also a most successful mechanism for promoting international collaboration.

Clearly that success depends on the proper selection of the scientific fellows and the leadership which directs the center. This leadership, provided by Director T.D. Lee and Deputy Director N.P. Samios is to be commended for its judgement, wisdom, and for the fine spirit which is clearly evident in RBRC. RBRC had reached its desired size even by last year (as noted in the Scientific Review Committee report of 2001). For more than two years now, RBRC has operated most successfully in a stable style as regards its size.

The quality of the scientific fellows is also demonstrated by the fact that a number of them have already moved on to established research positions in Universities

and Laboratories. We noted in the previous report that Kharzeev, Rischke, and Bodecker had received tenure positions. In the last year two new tenure positions have been offered, to R. Vanugopalan, and T. Schaefer. The "Outstanding Junior Investigator Award" was initiated by the Department of Energy (DOE) in 2000. We note that four RBRC members (D. Son (00), M. Stephanov and U. van Kolch (01), T. Shaefer (02)) have received the award.

The strength of the research is also demonstrated by the publication record with 75 papers published since the last Scientific Review Committee meeting. The practice of sponsoring workshops focused on active topics has continued with 11 being held since the last meeting of the Committee. These workshops are a particularly effective way of advancing the research and fostering collaboration between scientists. They are run in a most efficient manner, with copies of the transparencies presented put in a workshop report but without official "proceedings".

The details of our reviews of the theoretical and experimental activities are given in the following sections of this report. In the interest of brevity we comment here on only a selected few of the topics covered.

The experimental program is in a most dynamic and interesting state. The first runs with polarized protons in RHIC occurred shortly after the 2001 meeting of the Review Committee. The runs were successful in that polarized protons were injected into RHIC and accelerated to 100 GeV. The polarization produced by the AGS was less than it could be because of the need to use the older (Westinghouse) magnet power supply system while the newer (Siemens) system was undergoing repair. The analysis of the data is ongoing and focused on spin asymmetries. This run was to a large extent an "engineering" run for the future program.

RBRC and RIKEN were active in the completion of the SOUTH muon arm before the run and the subsequent completion of the NORTH muon arm which will be ready for the upcoming run. RBRC with BNL led the development, construction, installation, and operation of the proton-carbon (Coulomb nuclear interference) polarimeters, one in each RHIC beam. These allowed a relative accuracy of 2% and were, and are, essential for the operation of polarized proton runs. The measurement of absolute polarization is limited to about 20% because of unknown calibration factors. However, a polarized atomic beam jet target is being prepared for next year which will allow absolute measurements to 10% accuracy initially, improving to 5% - 6% in subsequent years.

We await the results of the upcoming run with enhanced polarization and enhanced equipment with great interest.

In addition to the polarized proton, running Au-Au data were also taken. Most inter-

esting results on π^0 production were obtained with the electromagnetic calorimeter (in which there was a large RBRC contribution). The muon arm also allowed the measurement of the production of charmonium, J/Ψ, via its $\mu^+ - \mu^-$ decay.

Important longer term R&D is also underway. We note, for example, the effort to develop a precise vertex detector for PHENIX.

The theoretical activities are many and highly varied. The investigations are at the forefront of the world efforts in many areas of particle physics. Brief summaries of the fascinating topics covered are given in the theoretical section of this report.

The committee was impressed with the results obtained with QCDSP, the 600 Gigaflop supercomputer, with an architecture specially designed to support lattice calculations, which has now been in operation for several years. A wide variety of important problems were addressed using this computer and were reviewed by Norman Christ and Robert Mawhinney. These problems are of the type that cannot be attacked by any other known means.

We also learned of the current state of the QCDOC project, a supercomputer under development in collaboration with IBM, which is confidently expected to provide RBRC scientists with 5 Teraflop capability for lattice calculations. The Committee noted last year that we were very pleased with the approval of the QCDOC computer. We are impressed with the excellent progress on the computer which will soon provide RBRC researchers with truly a world class facility.

2 Theoretical Physics at the RIKEN-BNL Center

Professor Lee gave a brief summary of the activities of the RBRC theory group since the last visit of the committee. The size of the group has reached, since last year, a steady state, with 10 research associates, 3 fellows and 8 RHIC fellow. The tenure-track/RHIC fellow program has been remarkably successful, with two new tenure positions being offered this year (R. Vanugoplan and T. Schaefer).

The committee was pleased to note that the overall quality of the scientific work of the theory group continues to be excellent. This is in particular attested by the "Outstanding Junior Investigation Award in Nuclear Theory" : This award was established in 2000 by DOE and, as Professor Lee reminded us, four RBRC members have received it since (D. Son (00), M. Stephanov and U. van Kolch (01), T. Schaefer (02)).

RBRC members are well integrated in the laboratory and interact well with BNL physicists in the nuclear theory and high energy groups. In fact the fellows unani-

mously acknowledge the truly exceptional atmosphere of the laboratory and appreciate the unique opportunities offered by RBRC.

The committee noticed a slight unbalance in the geographical origins of the various categories of fellows. Thus, the Research Associates are almost exclusively Japanese, while the fellows, and the tenure-track/RHIC fellows have mixed origins, but there are no Japanese among them. The committee feels that ways to obtain tenure-track positions in Japanese Universities should be explored. This would give Japanese physicists more chances to take full advantage of the opportunities offered by RBRC.

The committee heard presentations by almost all the RBRC theorists and enjoyed discussions with most of them. The scientific activities are very diverse and of high quality.

Alexander Kusenko gave an account of his work on non-topological solitons and how these could constitute a viable candidate for dark matter.

Steffen Bass reported on his work of modeling nucleus-nucleus collisions within a parton cascade model, elaborating on the pioneering work of K. Kinder Geiger.

Raju Vanugoplan presented an update of his numerical calculations of particle production in the Color Glass Condensate model. He pointed out that the model cannot fully account for the experimentally measured elliptic flow.

Thomas Schaefer made the very interesting observation that instantons, contrary to naive expectations, may contribute at large N_c because their density can be of order N_c. He discussed applications of his instanton calculations to the topological susceptibility, the meson masses, etc.

Werner Vogelsang presented applications of perturbative QCD to the calculation of the cross-section of hadronic collisions. He focused in particular on asymmetry observables which can be measured in polarized pp collision. Such calculations are of primary importance for the RHIC spin program.

Sangyons Jeon reported on several topics, related to the physics of heavy ion collisions (charge fluctuations and balance functions, energy loss) or of pp and pA collisions with an interesting discussion on the role of the h' meson.

Bira van Kolck has been pursuing for several years a systematic program aiming at describing nuclei and nuclear matter in terms of effective theories. He presented an update of his work with in particular an interesting application to halo nuclei.

Mikhail Stephanov presented a general discussion of fluctuations in thermal QCD, focusing in particular on contributions which become important near a critical point such as that believed to exist in the QCD phase diagram.

Tom Blum presented an investigation aimed at calculating the hadronic contribution

to the anomalous magnetic moment of the muon. This is a crucial quantity for deciding whether the recently obtained, highly precise experimental results for this quantity are in agreement with the standard model or require an extension of the model, incorporating new fundamental interactions.

Yasumichi Aoki illustrated an interesting application of domain wall fermions to the lattice calculation of matrix elements which determine the lifetime of the proton in models which predict proton decay. Domain wall fermions constitute a lattice regularization of the Dirac equation which entails many theoretical advantages, such as preservation of chiral symmetry for sufficiently large separation between the walls, and which is currently considered one of the most promising, albeit computationally very demanding, ways to include fermions in lattice calculations. The scientists at RBRC have pioneered the application of this technique and, beyond Aoki's contribution, several other presentations highlighted such efforts.

Kostas Orginos showed how domain wall fermions can be used in lattice QCD to calculate moments of nucleon structure functions and other matrix elements, including matrix element directly relevant to the spin properties of nucleons. Jun-Ichi Noaki presented a calculation of hadronic matrix elements, always with domain wall fermions, that determine the rate of kaon decays, while Chris Dawson used this regularization technique to evaluate the fundamental masses of light quarks.

Yukio Nemoto has studied an effective theory for Polyakov loops in lattice QCD and used a recently introduced multi-level algorithm for the calculation of two and three loop correlation functions.

Tilo Wettig presented a very interesting reformulation of the path integral for coupled gauge-fermion systems, based on a color-flavor transformation, and its potential applications to lattice QCD.

T. Ikeda and K. Itakura could not be present at the meeting. They provided the committee with a summary of their accomplished work as well as their research plan. Takashi Ikeda is studying the QCD critical-end point and the quark-number susceptibility. Kazunori Itakura is developing the Color Glass Condensate model in order to explain the phenomenon of geometric scaling observed in Deep Inelastic Scattering.

The committee also held a discussion with Y. Hatta, a RBRC young researcher, who just arrived at BNL and started working with R. Pisarski and his collaborators. Y. Hatta is a very promising young physicist, already well integrated in the theory group.

Finally Norman Christ and Robert Mawhinney reviewed results obtained with the QCDSP supercomputer and illustrated the current state of development of the QC-

DOC project. QCDSP and QCDOC are powerful supercomputers, with an architecture specially designed to support lattice calculations. QCDSP has been in operation for several years and the machine installed at RBRC, with its peak capacity of 600 Gigaflops, is the main computational resource for RBRC lattice theorists. Mawhinney gave a concise, yet very informative presentation of results recently obtained with QCDSP. QCDOC, developed in partnership with IBM, is a successor to QCDSP, which will be more versatile and much more powerful. Christ and Mawhinney informed the committee about progress in the development of both hardware and software for QCDOC. The project appears to be substantially on track and there is a well-grounded expectation that it will provide RBRC scientists with a supercomputer capable of sustaining 5 Teraflops on lattice QCD calculations by early 2004.

In summary, the committee was most highly impressed by the outstanding research and dedication of the RBRC theorists. Their investigations are at the forefront of the world efforts in many areas of particle theory. The committee found it particularly gratifying to see that some of the technical research issues raised during last year's visit have been properly addressed by the RBRC scientists, leading to impressive advances in their investigations. The committee was also extremely pleased with the progress in the development of the QCDOC supercomputer, which will soon provide RBRC researchers with computational resources that will rank among the most powerful worldwide.

3 Experimental Program at the Riken-BNL Center

The RBRC experimental group, headed by Group Leader Hideto Enyo and Deputy Group Leader Gerry Bunce, has enjoyed a very busy and successful year of progress. The year 2002 operations of RHIC resulted in its first polarized p-p collisions at 100 GeV on 100 GeV. The successful acceleration and storage of polarized protons is a major step in the spin physics program at RHIC. The polarized proton source achieved the design goals for polarized protons with polarizations in excess of 70%. The acceleration in the AGS caused this polarization to drop to $\approx 30\%$, but the subsequent injection into RHIC and acceleration to 100 GeV preserved most of the remaining polarization. The loss of polarization in the AGS was due primarily to the failure of the principal power supply for the magnets. Substitution with a backup supply allowed the 2002 run to proceed, but resulted in slower ramping of the magnets and the corresponding loss of some polarization in the passage

through depolarizing resonances of the AGS. The AGS performance for polarization is expected to improve significantly in the next run when the repaired generator is brought back into operation, and a stronger Siberian snake in the AGS is installed.

The experimental program at the RHIC made significant progress with the first polarized proton running, which occurred during the period December 2001- January 2002, and with the Au-Au data in 2002. The RBRC Workshops led the RHIC spin physics planning for this run. PHENIX recorded $\approx 150\ nb^{-1}$ of p-p data during the three weeks in this period. PHENIX recorded 24 mb^{-1} of the Au-Au collisions in addition to the polarized p-p data.

The RBRC and RIKEN were active in the PHENIX Collaboration. The SOUTH muon arm operations and the NORTH muon arm installation proceeded effectively under the leadership of Atsushi Taketani, RIKEN/RBRC and Doug Fields, an RBRC/UNM Fellow. The di-muon invariant mass in the SOUTH arm shows a clear J/Ψ signal in the p-p data, while the Au-Au analysis is underway but not ready yet. The NORTH arm installation was completed; it is ready for the 2003 running. In 2003, the J/Ψ data are expected to contribute to the ΔG measurements, along with other channels. The single muon data are important to the anticipated longitudinal polarization runs.

Beam tests of the PHENIX EM calorimeter were carried out, and analysis of the π^0 and γ signals in the Au-Au and p-p collisions commenced. Development of the tracking software and planning for future upgrades occurred. A silicon upgrade for the tracking for high luminosity operations in the period 2004-2005 and beyond is under study.

Studies of spin asymmetries for the p-p running were the principal focus of the physics analysis during 2002. The RBRC also contributed to the BELLE physics analysis studies, primarily in the investigation of quark fragmentation functions. The fragmentation functions are studied most easily in $e^+ - e^-$ processes such as obtained at BELLE. These data will be of important value in the interpretation of p-p collisions at RHIC. Important results of π^0 production resulted from the high p_t photon trigger for the EM calorimeter. Next-to-leading order (NLO) QCD calculations resulted in a very good agreement at $\sqrt{s} = 200$ GeV between theory and data. Development of a reliable luminosity monitoring at PHENIX permitted the observation of cross sections ranging over 8 orders of magnitude for p_t from 1 to 13 GeV/c. Comparison between p-p and Au- Au collisions were also made in the π^0 signal.

The RBRC with BNL led the development, construction, installation, and operations of the proton-carbon CNI (coulomb nuclear interference) polarimeters, one on each RHIC beam. Measurements of beam polarization to a relative accuracy of

$\pm 2\%$ in short one- minute snapshots were obtained. Absolute accuracy was limited to $\approx \pm 20\%$ because of unknown calibration factors. The RBRC is participating in the effort to install a 3rd polarimeter based on an atomic beam polarized jet target. With the jet target polarimeter, measurements next year will calibrate the pC-CNI systems initially to $\pm 10\%$ absolute, and in future years to $\pm 5\%$ absolute. A fourth pC-CNI polarimeter is also planned, this one for the AGS to be used for optimizing the AGS operation for polarized protons. The asymmetry measurement of proton-carbon scattering in the coulomb nuclear interference region may be an interesting topic, since it gives some information on the interference between the hadronic non-spin-flip amplitude and the electromagnetic spin-flip amplitude. The experimenters should be encouraged to make an interpretation of the experimental results.

The RBRC built, tested, and installed a forward photon detector for π^0 and γ detection to serve as a "local" polarimeter for PHENIX. Tests during the p-p running showed no π^0 asymmetry in the forward direction, but a large neutron asymmetry was discovered, and work on using this signal for future runs has begun. The large neutron asymmetry is interesting from the viewpoint of spin physics as well as beam monitoring, even though the origin of the asymmetry is not so clear yet. This local polarimeter will be used for fast monitoring and for tuning of the spin components at the PHENIX interaction region.

The RBRC is involved in a number of other detector related projects. Triggering for high rates for spin physics will increase rates for asymmetries by a factor of 100 over minimum bias triggering. Electronics for luminosity monitors, useful for luminosity of individual beam crossings, were tested. Triggering for the muon arms was an important activity, and asymmetries for muons and pions in the forward directions will become available from this activity. Overall, the RBRC has been very active in PHENIX preparations, in the spin physics planning, in polarimetry for RHIC, and in the PHENIX detector hardware and analysis. It has been a very productive year for all.

Planning for the upcoming p-p run in 2003 is underway. The polarization is expected to be significantly larger than before, and the polarimetry will continue to mature. Single beam asymmetries (A_n) and beam-beam asymmetries (A_{ll}) will be key objectives for the upcoming run. PHENIX, STAR, BRAHMS and PP2PP all expect to be involved. Expectations for the first measurements of the gluon polarization are high. Work on the polarized jet target will receive high priority, leading to precise measurements of asymmetries in the subsequent 2004 run. The Committee also heard short presentations on the status of computing (CC-J at RIKEN, the primary center for PHENIX simulation and data analysis) and data analysis at BELLE.

Scientific reporting at conferences and publishing of results on spin physics were also active. Analysis of the data from 2002 has stretched the manpower that is preparing the hardware for the next run. Continuing work on the PHENIX detector must not slip, since deadlines for closing the detectors and turning on the machine are fixed. Manpower devoted to analysis was lost from efforts to close up the detector subsystems. The Committee heard the concerns of the experimenters regarding the workload being placed on those responsible for the detector hardware. Although concerns were expressed, it is clear that the demands on the RBRC and RIKEN researchers are a strong indication of the richness of the physics and the growing success of the RHIC research program.

The International Spin Physics Symposium (SPIN2002) was held at Brookhaven in September. Many reports ($\sim$ 10) on the progress and plans for the spin physics were presented by members of RBRC and PHENIX. The RHIC polarized beam operations and the upcoming measurements of polarized proton structure, large asymmetries in inclusive processes at high pt, and theoretical interest in transversity were important themes at the Symposium. The papers presented by RBRC physicists largely related to spin physics in PHENIX and the polarimeters at RHIC. RIKEN and the RBRC will stand out in the spin physics story for years to come.

The RBRC has seen a number of promotions, additions, and other changes in personnel. Five researchers have advanced to tenure appointments in Japan. K. Kurita and N. Saito were promoted to Associate Professor positions at Rikkyo University and Kyoto University, respectively. J. Murata was promoted to RIKEN tenure at another lab. Y. Goto was promoted to a RIKEN tenured researcher position, and T. Kawabata has moved to a CNS-U Tokyo tenure post. In addition, M. Perdekamp was promoted to a RHIC Physics Fellow position (joint tenure-track with Illinois). A. Baxilevsky and F. Messer have become RBRC Fellows.

A number of younger researchers associated with the PHENIX project at RHIC have received research appointments at RIKEN. The spin physics program and the PHENIX Collaborations have attracted many aspiring young scientists to the study of nuclear physics and the demand among young physicists for these attractive research positions is high.

Last year this Committee recommended that support be considered for students to allow them to stay longer than 1 month. BNL has responded with support through its Technical Collaborator program, and three additional students have been added to RBRC. The success that RBRC has had in placing its young researchers into outstanding academic positions and attracting new young researchers to its program is a strong indicator of the vitality and momentum of its research program.

The RBRC Scientific review committee spent its first day listening to public pre-

sentations from the Fellows and students, about equally split between experiment and theory. On the second day, a number of the experimental RBRC physicists and students were interviewed by the Committee. The presentations covered their scientific and technical progress of the past year, while the (private) interviews were concerned more about career development, quality of life issues, and listening for suggestions in the ways in which RBRC could improve its support of these individuals. Overall, the young scientists seemed quite pleased and happy with their work environment with the RBRC. Suggestions and comments of value were noted and subsequently brought to the attention of the RBRC management by the Committee members.

In summary, the past year has seen excellent progress. The SOUTH muon arm was commissioned, and the NORTH muon arm was completed and prepared for running. Two polarimeters were used effectively for the first run with polarized protons. Work on the PHENIX triggers, both hardware and software, was a major effort with significant progress. Analysis of the data was underway, and a number of presentations at SPIN2002 were chosen from the RBRC and RIKEN work. The RBRC also participated in activities at RIKEN (CC-J and Si Upgrades) and BELLE.

Final Comments:

(1) The RBRC continued to grow in strength and effectiveness in PHENIX and in the contributions to RHIC, primarily in leadership in PHENIX detector hardware and with the polarized beam preparations.

(2) The young scientists have been successful in career moves. Several have moved to tenured positions at other institutions and universities. RBRC continues to attract excellent young researchers into positions that have opened up. The RBRC is an excellent place for training and career growth opportunities.

(3) As noted in earlier reports, it would be desirable for an increase in participation in RBRC by universities in the US, Japan, and other countries. The RBRC-University Fellowships have been important in establishing contacts and exchange between RBRC and universities and as a conduit for students to become involved in world class research. A healthy cadre of students is essential to the physics analysis and output of physics results, so these contacts with university groups should be encouraged.

(4) Spin physics has been strongly supported by RBRC, RIKEN and RHIC. This program is at its beginning. It will provide unique and exciting new physics results in the years ahead. The initial results have come out from the 2002 run. Upcoming runs in 2003 and 2004 promise to provide precision data in a variety of spin topics.