Report of the RBRC Scientific Review Committee
September 28-29, 2000

1. Overview

The Scientific Review Committee met at RBRC at BNL on September 28-29, 2000. The membership of the committee and the agenda are attached.

The committee continues to be impressed with the successful development of RBRC under the leadership of Director T.D. Lee and Deputy Director N.P. Samios. The evolution of the center's program and the excellence, productivity, and intellectual atmosphere of the young physicists are all superb.

The center has now just about reached its planned size and is not scheduled to grow appreciably in numbers in the future. This seems a wise plan to the committee and is consistent with the objectives of the center. The committee was also pleased to learn of the successful carreer paths of the young scholars who were amomg the first Fellows. This both demonstrates the excellent choices made by the center in its appointments and enhances the attractiveness of center Fellowships to the best of the generations which will follow.

The addition of Fellows active in the spin program in the past year (theorist Vogelsang and experimentalist Deshpande) has brought the program to an excellent level. The RIKEN spin group, together with the new BNL spin group has now reached a critical mass.

One important additional new development is the establishment RIKEN-University Fellowships for experimental physicists. This will add to the graduate student involvement in the spin program and further encourage young experimentalists to work in the field of spin experiments.

A substantial number of important theoretical studies were carried out. Among these are the new ideas about hitherto unexpected states of hadronic matter which would exhibit color superconductivity; exploration of the possibility that when a quark gluon to hadronic phase transition occurs, unusual states of the physical vacuum can be produced leading to violations of parity and time reversal invariance by the strong interaction; higher order corrections to the analysis of polarization experiments. These and other most interesting studies are described in somewhat more detail in a subsequent section.

One very important component of the theoretical research carried out at the

RBRC has been the QCDSP supercomputer which together with the similar machine at Columbia University has set records in the price/performance ratio and continues to be very effectively used. This computer has allowed studies of QCD in the lattice gauge theory framework which could not otherwise be possible. The approach of lattice gauge theory offers the only known possibility to perform certain QCD calculations with very well controlled approximations.

The committee was pleased to learn about the proposal for a new computer, the QCDOC which is being developed by Professor Christ's group at Columbia and the IBM company. This machine would provide a power in excess of 10 Tflops and would have the potential of producing invaluable results for QCD. The committee strongly supports the development and utilization of this new advance in the RBRC.

Finally, the commissioning and first successful run of the Relativistic Heavy Ion Collider at BNL must be noted. This success has inspired all the scientists working in this program, broadly defined. The successful operation of the polarized proton beam in RHIC with a Siberian snake has been a milestone in the spin program, such as important part of RBRC efforts, and the first data on Au-Au collisions is beginning to provide essential input to the theoretical activities of the center.

2. Theoretical Physics at the RIKEN-BNL Center

2.1 General Impressions about Theory Group Activities at RBRC

At the beginning of the committee meeting an overview of the RBRC theory group was presented by Professor Lee. We heard that during the period of Sept. 1999 ~ Sept. 2000 the RBRC theory group has grown to support 17 young theorists (8 postdocs, 3 Fellow, 6 tenure track University/RHIC Fellows) and this resulted in a dramatic boost of theory activities as indicated in more than doubled increase in the number of publications (from 31 to 78 including experiment) over the year. We also heard that 5 more appointments have been made for tenure track University/RHIC Fellows in theory starting from October 2000. There are 3 weekly seminars organized by members of RBRC and 3 more weekly seminars are organized jointly with BNL staff. IN addition many topical workshops are organized on site: RBRC published 14 workshop proceedings since the last 1999 scientific review committee.

We were all deeply impressed by this very rapid growth of the theory group activities nurtured by Professor Lee. We welcome in particular the successful implementation of the tenure track university/RHIC Fellow program, a very innovative method for attracting the very best young people and preparing them for the challenges of research in strong interaction physics.

The committee heard 16 presentations by young staff members of the theory group. They were all of excellent quality. The research program in the theory group is very well focused and is also quite in phase with experimental programs (for RHIC). We were impressed not only by the breadth of topics covered by these presentations but also by the depth of the research of each presentation. These young people are all of the top quality and most productive in the field.

Theory members of the committee met 14 individual RBRC theorists in three groups after the presentations. We all felt great enthusiasm, very high working spirits and morals in all these young people working at RBRC under the superb intellectual leadership of Professor Lee. They all appreciate the highly intellectual, stimulating environment at RBRC which encourages interactions among various members within the group and with others in the BNL particle and theory groups, including their senior visitors, as well. Some theorists are working very closely with experimentalists at the laboratory who engage in RHIC experiments.

We would also like to note that some of these young people expressed great appreciation of unusual opportunities to propose and organize their own workshops at RBRC. These workshops in turn create opportunities for young theorists at RBRC to be exposed to larger community and to interact and initiate collaborations with participants from various other institutions all over the world.

2.2 Review of Theoretical Activities at RBRC

The research by individual members of the theory group may be summarized into the following specific areas:

・Lattice gauge theory and non-perturbative QCD
・Matter under extreme conditions
・Dynamics of relativistic heavy-ion collisions and phenomenology
・Spin physics at RHIC
・Other topics

We now review each area of theoretical works.

Lattice gauge theory is a unique theoretical method to study the non-perturbative regime of the quantum chromodynamics (QCD), the fundamental theory of strong interaction. The work done at RBRC in this area is of very high quality and addresses challenging problems which are at the leading edge of current developments.

Chiral matrix theory, chrial perturbation theory and symmetry considerations have been used to derive information on the distribution of eigenvalues of the Dirac operator, which has been compared with numerical results from lattice calculations, finding excellent agreement. (Wetting)

A major effort has been mounted to perform simulations of lattice QCD using the domain wall discretization of the lattice Dirac operator. Domain wall fermions offer one of the most promising ways out of the impasse of chiral symmetry breaking versus mode doubling in lattice fermions. However, one pays the price of increased computational complexity. Scientists at RBRC have been pioneering work in the exploration of this regularization technique and in its application to QCD phenomenology. In particular the formalism has been applied to the study of excited nucleon states, to the calculations of the nucleon axial vector coupling (Sasaki) and to the calculation of matrix elements governing the weak decays of kaons into pions. (Blum) Some of the results have turned out in good agreement with experimental data, some indicate discrepancies whose origin needs to be understood, other calculations are still in progress. Substantial attention has been paid to the computational aspects of the domain wall method, in particular to maintaining under control the residual chiral symmetry breaking induced by the fact that in an actual numerical calculation one cannot implement the theoretical limit of infinite separation between the walls. (Aoki)

The study of matter under extreme physical conditions is a basic motivation for the experimental programs of ultrarelativistic heavy-ion collisions at RHIC. Although much progress has been made for computation of the equation of state at high temperatures but at zero net baryon density by the first principle calculation with lattice gauge theory, a similar study at finite baryon densities has been hampered by formidable technical difficulties. Important developments in this area have been made using analytical weak coupling techniques and a variational approach for investigating symmetry breaking aspects in quark-gluon many body systems. Particularly interesting are the conjectures on color superconducting phases of high density quark matter and how they may be related continuously to some specific forms of hadronic matter. (Schaefer) In quark matter the attraction responsible for the instability leading to color superconductivity is the one gluon exchange in the antitriplet channel; the possible feedback on the gap equation of medium effects on the gluon propagator is being studied (Rischke), The possibility of existence of a critical point in the phase diagram has been studied by various methods together with its implications for possible observations in heavy-ion collisions. (Stephanov)

Efforts have been made also in constructing effective field theories of QCD applicable to study finite nuclei and infinite nuclear matter. In particular cases, well known expansions are recovered, but in an approach which is both more systematic and has a clear connection to QCD. (van Kolck) Mechanism of spontaneous breakdown of chral symmetry in vacuum has been studied in the framework of light front quantization method. Difficulties associated with the triviality of the vacuum and the existence of zero modes are solved by recognizing proper constraints. In a simple application to the Nambu Jona Lasinio model, these constraints result in a gap equation describing chiral symmetry breaking. (Itakura)

Theoretical description of the space-time evolution of ultrarelativistic nucleus-nucleus collisions from basic quark-gluon degrees of freedom all the way to hadronic final state poses a major challenge for theorists. The initial conditions for gluon distribution at small longitudinal momenta have been studied by solving a classical Yang-Mills equation with random color source created by valence quarks. (Venugopalan) The subsequent evolution of an expanding gluon partonic system toward local thermodynamic equilibrium system in the early stages of nuclear collisions at high energies has been studied systematically by adopting the method of perturbative QCD. (Son) Modeling of parton cascade dynamics into a Monte-Carlo code for computer simulations of high energy nuclear collisions has been investigated together with hadronization algorithm and final state hadron-hadron interactions. (Nara)

Signals of new physics are of utmost importance in studying physics for RHIC. Theoretical interpretation of J/Ψsuppression observed at SPS experiments has been intensively studied together with its implication for RHIC experiments. A new conjecture has been put forward for an implication of axial anomaly in QCD for a possible existence of a strong parity violating phase and its observable consequences in particle production. Scale anomaly has been used to describe charmonium-charmonium interaction at large distances. (Kharzeev) Strangeness production in heavy ion collision is also an important observable to characterize the primordial form of matter produced in the collision. Double hyperon production in heavy ion collision has been studied with aim to extract information about hyperon-hyperon interaction which seems to be inaccessible in any other processes. (Schaffner-Beilich)

Theoretical efforts have been devoted also to support the experimental program at RBRC for spin physics with polarized proton beams at RHIC. One of the important observables to be measured by the RHIC spin program is a prompt photon production via a gluon-quark "Compton" scattering process which carries information of the gluon polarization in the initial state. It is however known that the next-to-leading order QCD corrections to unpolarized processes are not sufficient to account for the existing data with unpolarized beams. Higher order QCD corrections due to soft gluon emissions have been studied systematically within the framework of collinear factorization using resummation technique. (Vogelsang) Lambda polarization in production process from unpolarized initial states is another interesting problem involving spin degrees of freedom. A new method of analysis in terms of polarized fragmentation function of (unpolarized) quark has been adopted in order to make prediction for lambda polarization at RHIC. (Boer)

Other topics studied at RBRC theory group include the origin of ultra high energy cosmic ray exceeding the Greisen-Zatsepin-Kuzmin limit at 5 X 1019eV due to interaction with cosmic microwave background radiation. A new mechanism postulating decay of superheavy relic particle emitting a neutrino which triggers "Z-bursts" of high energy photons was studied together with its signatures in high energy neutrino flux.(Kusenko)

2.3 Comments

The numerically based research done at RBRC has been supported by its QCDSP supercomputer, which, together with the similar machine at Columbia University, has set records in the price/performance ratio and continues to be very effectively used. The committee heard a presentation by Norman Christ, of Columbia University, about QCDOC, a new, very powerful supercomputer specialized for QCD calculations, which is being developed by Christ's group in collaboration with IBM and with support from the U.S. Department of Energy and RIKEN. A proposal has been made to RIKEN for the deployment at RBRC of a 11264 node QCDOC supercomputer, with a peak performance in excess of 10 Tflops and expected sustained performance of 5 Tflops on lattice QCD calculations. The architecture of QCDOC is based on the integration of a powerful CPU, 4 MBytes of embedded DRAM and communication units on a single chip. This appears quite well adapted not only to lattice QCD calculations, but also to a wide range of computational applications dealing with large volumes of distributed data with local interrelations (e.g.~the solution of transport equations). The active participation of IBM, a company with very large resources and expertise for processor development, gives additional confidence in the successful outcome of the project.

Both the existing QCDSP supercomputer and, even more so, the envisaged QCDOC supercomputer have the potential of producing invaluable results for QCD. It would be desirable to provide further support to the lattice QCD program at RBRC by hiring a few additional young researchers working in this field. This would allow one to reap the full potential of the above mentioned supercomputers and expand the investigations in areas such as high-temperature QCD and hadron structure which closely relate to the experimental program carried out under the auspices of RIKEN.

As already mentioned, collaborations with local (BNL) theory groups and nearby theory groups, such as those at Columbia University, SUNY at Stony Brook, and MIT, are of crucial importance for the research at RBRC. Some of senior members of these groups have played essential roles in shaping up the research programs of young physicists at RBRC, either directly as a senior collaborator or indirectly as a mentor. With the appointments of tenure track University/RHIC Physics Fellows, we hope much more stimuli will be brought in to the activities at RBRC from wider university based intellectual communities in the U.S.

RBRC has been playing very special role in training young Japanese nuclear/particle theorists. Two of them who had been appointed as Research Associates at RBRC returned Japan for permanent positions at University of Tokyo. A new appointment has been made in the area of lattice gauge theory where there is a very strong research activity in Japan centered at Tsukuba. It is hoped that more Japanese physicists trained in this area will participate in the research at RBRC and that this will lead to a much closer collaboration of the RBRC lattice group with Japanese lattice groups.

Future career paths are among the major concerns of young physicists all over the world, and we learned from our interviews with young physicists at RBRC that they are no exception in the sharing of such concerns. It is hoped that the tenure track University/RHIC Fellow program will ensure a systematic consolidation of the career paths for young physicists trained at RBRC. We are pleased to hear that one of the former RBRC Fellows and then tenure track University/RHIC Fellow (Kharzeev) has just been promoted to tenured member of the nuclear theory group at Brookhaven. We also heard that another RBRC Fellow (Rischke) has been recently offered a full professor position at one of the major universities in Germany. These success stories of some individual members of RBRC tell not only of the high recognition achieved by these individuals in their research but also of the significance and impact of the basic program of RBRC carefully laid down by Professor Lee.

3. Experimental Program at the RIKEN-BNL Center

The RBRC scientific review committee heard presentations of the experimental program of the RBRC and enjoyed individual conversations with a number of the scientists and graduate students carrying out research in the program.

The experimental program is focused on the study of spin phenomena in the interactions of polarized colliding protons. This represents a new and exciting opportunity in high energy physics as RHIC will be the first high energy hadron collider with the capability of polarized beams, a feature made possible by the RIKEN collaboration.

The program is making excellent progress and appears almost certain to achieve its physics goals. These have been described in earlier reports and we just briefly, recapitulate the major items. The basic study is that of the spin structure of the nucleon, especially the gluon spin structure function. A number of other studies are made possible by the availability of the polarized beams such as the study of "transversity" a new polarization parameter describing aspects of the spin structure previously unstudied, studies of Standard Model parity violations in W boson production and searches for new sources of parity and time reversal violations beyond the Standard Model.

We particularly note two accomplishments in the past year:

First the spin commissioning program at RHIC succeeded in accelerating a polarized proton beam in RHIC from 24.3 GeV/c to 30 GeV/c using one Siberian snake. This is especially significant since there is a strong depolarizing resonance in this energy region. It confirmed that the snake worked well, as expected. This bodes well for the program, although, of course, much further effort is needed (and planned) for acceleration to higher energy.

Secondly, the polarization of the proton beam in RHIC was measured with a polarimeter based on the Coulomb nuclear interference, both at the injection energy and after acceleration. Before the spin commissioning in September we had been concerned about the polarization measurement in the ring. We were pleased to hear the clear experimental result on the polarization measurement from Dr. Kurita. Precise measurements of the absolute beam polarization are challenges in the future.

Below we make a number of specific comments about the state of the program, other major accomplishments since last year, and some issues to be faced in the coming years.

1. The collaboration between RIKEN and the RBRC efforts is excellent. It is one of the true strengths of the program. The collaborative efforts between RIKEN physicists, Japanese physicists from university, the dedicated efforts of their graduate students, and BNL and U.S. physicists are key elements in the project. We note that it would be desirable, if possible, to increase the participation of Japanese universities in the program. At present this participation is concentrated mainly at Kyoto University and a little at Tokyo Institute of Technology.

2. The committee was pleased to learn about the establishment of a BNL spin physics group. This group will work very closely with the RBRC and RIKEN spin groups and will substantially add to the overall success of the spin program.

3. The addition of Werner Vogelsang, a theorist interested in spin phenomena, Mathias Grosse Perdekamp and Abe Deshpande, experimental physicists have substantially strengthened the RBRC effort. The RBRC group together with the BNL spin group now form a "critical mass" with positive reinforcement. We note for example the excellent series of regular meetings devoted to the relevant physics issues and the regular planning meetings.

4. The expansion of the RIKEN faculty fellowship program to include faculty with experimental interests is an excellent move. In particular, this will add to the graduate student involvement in the program. General experience plus the recent experience with the students from Japanese universities shows how important this involvement is for the vitality, success, and future evolution of the program. This will further encourage young experimenmtalists to work in the field of spin experiments.

5. The RBRC effort and the RIKEN collaboration are strongly centered on the PHENIX experiment. The contributions of RIKEN to the PHENIX apparatus and to the spin program in general have been crucial to its success. The successful test of the Siberian Snake in the first run of RHIC was a major milestone in the program.

6. The committee was pleased to learn of the excellent performance of the PHENIX electromagnetic calorimeter during the recent run. Clear signals of neutral pion decay with resolutions close to the expected value were observed. As is well known, the performance of the electromagnetic calorimeter is a major ingredient to spin measurements which allow maximum extraction of relevant physics information. A classic example of this is the determination of the gluon spin structure from the direct photon measurements.

7. The committee was also impressed with the advantages offered by the new trigger for spin at PHENIX presented by Dr. Perdekamp. This clearly is going to improve the success and productivity of the program.

8. One concern which was expressed by a number of the spin physicists and which is shared by the review committee is that sufficient running time be allocated to the spin program. The polarization experiments are subtle and complex. The

beam needs to be carefully tuned, evaluated, and monitored, and adequate time must be devoted for the collection of data, once the paramenters are set. If there is a shortage of running time, overall, the time for spin studies must have sufficient priority to insure a successful set of studies.