Report of the RBRC Scientific Review Committee November 29-30, 2001

1 Overview

The Scientific Review Committee met at RBRC at BNL on November 29-30, 2001. The membership of the committee and the agenda are attached.

The committee was very pleased to see that the RBRC has now developed into a superb institute which is one of the most productive and important scientific institutions in the field of modern nuclear science. This broad field covers the physics of the strong interaction, from its most fundamental aspects to its application to a myriad of scientific topics from astrophysics, to the new states of matter which are now being produced in the BNL Relativistic Heavy Ion Collider (RHIC), and to the study of the violation of the CP symmettry in the weak interaction.

The leadership of Director T.D. Lee and Deputy Director N.P. Samios is to be commended for this successful development. Their vision of a center, basically focussed on young scientists, providing a venue for creative scientific interaction and research has been realized. As noted in our previous report, the center had, by last year, reached its desired size. This past year has been the first year of full operation of the center in the mode envisioned by its creators.

The success of the center is illustrated, for example, by the publication of 92 scientific papers in the last year, and the sponsorship of 7 workshops focussed on specific topics of research. In addition, two of the RIKEN-University Fellows (Stephanov and van Kolck) were awarded Department of Energy Outstanding Junior Investigator awards. Six of the plenary reports at the recent International Quark Matter conference were given by RBRC Fellows. We also note that a number of RBRC Fellows have moved on to established research positions. Kharzeev, Rischke, and Bodecker have received tenured positions at Laboratories and/or universities. Several other similar actions are expected. It is clear that the RBRC Fellows have been most carefully chosen.

The committee was pleased to learn that Professor Douglas Field of the University of New Mexico is the new experimental RIKEN-University Fellow. The addition of an experimental RIKEN-University Fellow was anticipated in our last year's report and as noted will add to the graduate student involvement in the spin program and further encourage young experimentalists to work in the field of spin experiments.

The experimental program is in the midst of major developments. At the time of our meeting, the first runs with polarized protons in RHIC were about to begin and we look forward with great interest to the first results. The Coulomb-Nuclear Interference polarimeters, which are RBRC responsibilities are operational in both the AGS and RHIC. Their successful design, testing, and installation are a tribute to the RBRC experimental group. Plans for a polarized hydrogen jet target, which will provide the important absolute measurement of the beam polarization are well underway.

Important work on the trigger system for the PHENIX experiment with polarized protons is well underway with RBRC experimentalists. Additionaly, research and development is underway for a Silicon vertex detector for PHENIX. This would be a major upgrade to the capabilities of the detector, which would facilitate many fundamental experiments involving the production of the the W and Z bosons which "carry" the electroweak interaction. With the polarized beams, fundamental studies of the symmettry properties of the electroweak interaction can be carried out which would be sensitive to physics beyond the standard model. These and related topics will be discussed more fully in the following sections of the report.

A large number of theoretical researches were carried out and will be discussed in greater detail in the following. We note the increased understanding of the usefulness of the classical equations of QCD, which apply when the number of partons (gluons) is large, and its application to a number of areas of RHIC experimentation. The new subject of the fascinating structures of quark matter at low temperature and high density has been developed further. These new phases of quark matter might well be realized in the cores of neutron stars which would then be super conductors of the color electric charge!

Finally, we note the successful calculation of the ratio ϵ'/ϵ in the standard model framework by the RBRC group using the RBRC super computer at BNL together with the "sister" machine at Columbia University, providing a combined power of one Teraflop. This calculation still makes several approximations (so-called quenched approximation and the use of chiral perturbation theory) but is, within that paradigm a complete calculation - something never before possible. The fact that this ratio is different from zero establishes that direct violation of CP symmettry occurs in nature. In principle, this ratio is predictable from the physics of the standard model but it involves strong interaction matrix elements which have, heretofore, been impossible to calculate in any fundamental way.

The calculated ratio disagrees with the experimental measurement of this ratio and this could represent the first evidence that the CP violation in nature has its origin in physics beyond the standard model. Future improvements in the calculation will allow this issue to be finally settled.

In this regard, the committee was most pleased with the approval of the QCDOC computer and impressed with the progress and plans for its production. This device will provide unprecedented power for lattice gauge theory calculations, including the one discussed above as well as a myriad of studies in the basic properties of the underlying theory of the strong interaction, Quantum Chromodynamics (QCD). It will open a new era in the study of QCD.

2 Theoretical Physics at the RIKEN-BNL Center

The theory group activity during the period of Oct. 2000 - Nov. 2001 was summarized by Professor Lee at the beginning of the committee meeting. As of the day of the committee visit, the size of the RBRC theory group consists of 10 tenure track University/RHIC Fellows, 3 Fellows and 7 postdocs, with a total of 20 personnel on its payroll. This number is not considerably larger than the 17 of last year. Since last year's committee visit, one tenure track University/RHIC fellow left for a permanent position and 5 new appointments were made for tenure track University/RHIC Fellows. The theory group has reached a steady state in terms of its total manpower. The overall theory group activity has also reached a very high level steady state as indicated by other measures such as total annual publications (92 including experimental papers) and the number of workshop organized (half a dozen workshops per year).

At the end of his overview talk, Professor Lee briefly discussed his very interesting work on a new method of solving the Schrödinger equation in arbitrary N dimension by reducing it to a series of first order liner differential equations which can be solved by integration along one definite path, in contrast to the sum over the paths in usual path-integral approach. Professor Lee showed that this method works remarkably well to solve the Stark effect. This discussion was a wonderful treat for the review committee. It is very interesting to see how it can be applied to solve problems in quantum field theories.

The committee heard 13 oral presentations by young scientists of the theory group; other members of the theory group provided us with written abstracts of their research at RBRC. One presentation (Vogelsang) was cancelled due to unexpected change of the travel itinerary of the scheduled speaker by accident. We were all very happy to find that the high creativity and the quality of the works which we had seen last year have been maintained and, indeed, even brought to a higher level at the RBRC. We were impressed to see that the older members of the group, whose works we had reviewed last year, have striven to produce more high quality works with many new ideas in this short period, and the newer members of the group have been integrated very well coherently into the program.

The theory members of the committee interviewed 13 individual RBRC theorists in four groups after the presentation; 6 of them have joined RBRC since the last review. Again, we witnessed a very good working spirit, with enthusiam and appreciation for the opportunities offered by the RBRC.

The RBRC theory group addresses a very diverse range of problems all related to the basis of strong interaction physics with many different approaches. We now review individual works in four major areas of research: lattice gauge theory, theory of dense matter, theory of high energy nuclear collisions, and signals of new physics, in this order.

1. Theorists at RBRC have made major progress in the application of computational techniques based on the lattice regularization to the study of Quantum Chromodynamics. In these investigations they have embraced a new regularization technique for fermionic fields, i.e. the "domain wall regularization", which offers crucial theoretical advantages, such as exact chiral symmetry even at finite lattice spacing, but at the cost of a highly increased computational complexity. By combining analytical insight with a clever use of RBRC's powerful computational resources (the QCDSP supercomputer) the scientists in the lattice gauge theory group have been able to produce pioneering research on domain wall fermions and have brought RBRC to a position of world leadership in this area of investigations.

   The committee heard five outstanding presentations. Costas Originos illustrated problems which occur in the domain wall regularization because of the frequent occurrence with the Wilson gauge action of low eigenvalues in the transfer matrix, which, in turn, reduces the accuracy of some necessary numerical approximations. He showed then how one can remedy to the problem with the use of a modified gauge action, the so-called DBW2 action. Yasumichi Aoki presented a calculation of the spectrum with the DBW2 action, confirming that the improved action leads to better results. Chris Dawson presented a very interesting study showing chirality localization with domain wall fermions. This topic has been controversial, with different groups finding evidence in favor and against the fact that the lowest eigenmodes of the Dirac operator exhibit localization of chirality, and this study will help resolve the issue.

Thomas Blum gave a superb account of the RIKEN-BNL-Columbia lattice calculations for the study of CP violation in kaon decays. This has been a monumental effort. It entails the numerical evaluation on the lattice of several amplitudes and renormalization constants which are then combined to calculate the matrix elements which determine decay rates. One must achieve a degree of accuracy which has been elusive prior to the introduction of domain wall fermions. The most coveted prize, a precise determination of the ϵ'/ϵ ratio still eludes the theoretical analysis, because its precise value is the result of a cancellation between large numbers of opposite sign. But the investigation has shown that the magnitude of the theoretical result is within range of experimental observations and has set the premise for its future accurate calculation. Moreover, other important theoretical results have been established, like the first principles derivation of the $\Delta I = 1/2$ rule.

Finally, Junichi Noaki, who recently joined RBRC from the CP-PACS collaboration (another group which has done leading edge research in lattice gauge theory) presented results obtained by CP-PACS for non-leptonic kaon decays, which nicely confirm the results obtained at RBRC.

Tilo Wettig, who could not be present at the meeting, provided the visiting committee with a summary of his past research and future plans. He has studied the properties of the Dirac operator in Quantum Chromodynamics by means of effective theories and by lattice techniques. He is also playing an important role in the design of the new QCDOC supercomputer (see below).

2. The quest for properties of matter under extreme physical conditions continue to be a main theme of the theory group as well as the main motivation of the RHIC experiments.

   The fascinating theoretical conjecture that cold dense quark matter, which may be realized at the hearts of neutron stars, may exist in the form of a color superconductor, has been studied extensively by RBRC theorists, together with other possibilities. Dam Son presented his work with Misha Stephanov and Dirk Rischke on the interplay between color superconductivity and confinement. For the two flavor case, they predict that the confining length scale becomes considerably larger, exceeding that of the size of Cooper pairs. The role of strange quark mass and the electron chemical potential on the structure of three flavor "color-flavor-locked" condensate was studied by Thomas Schaefer as reported in his written resume.

Dynamical properties of matter in the phase transition region were discussed by Stephanov, based on his work with Son, in which they showed how to determine the dispersion relation of soft Goldstone modes from static properties. Schaefer also analyzed the excitation spectrum on kaon condensed states. Jurgen Schaffner Bielich reported in his resume his work to apply recent results of the equation of state of dense matter have for studying the structure of neutron stars and quark stars.

3. The theoretical description of the evolution of matter produced by high energy nuclear collisions at RHIC requires studied of many facets of theoretical problems, including the initial states of colliding nucleus and non-equilibrium dynamics of produced matter.

   The initial states of dense gluonic system produced by the nuclear collision have been described by Raju Venugopalan and Yasushi Nara in terms of the McLerran-Venugopalan model which views the colliding nuclear pancakes as classical Weizsäcker-Williams gluon fields created by random color charge distribution, the picture which has been coined as "Color Glass Condensate"(CGC). In particular, Venugopalan analyzed the first RHIC results of the transverse momentum distribution and showed that the data is consistent with the scaling laws as predicted by their CGC picture. Nara implemented the picture into a cascade code on computer and studied in detail the thermalization process and resultant flow effects. The non-linear evolution of gluon structure function at small x region has been studied by Kazunori Itakura in detail by the mean field approximation and the random phase approximation and the results were compared with the previous ones by others.

   Non-equilibrium dynamics of coupled long wavelength modes in QCD plasma has been studied by Dierich Bodecker who presented his work on an effective theory to describe this non-perturbative regime in terms of classical fields and stochastic dynamics. Yukio Nemoto discussed his attempt of using renormalization group method to improve the time-dependent Ginzburg-Landau equation for similar infrared problems.

4. The theoretical study of signals of new physics is indispensable for the success of the RHIC experiments. Several new ideas were proposed and studied by RBRC theorists beside the works already mentioned above.

   Sangyong Jeon discussed, among other things, the time evolution of fluctuations of rarely produced particles, such as kaons at SIS and charmed mesons at RHIC energies, in terms of the rate equations which respect the exact conservation laws and found that the fluctuations around the mean values of such observables are sensitive probe of the chemical equilibrium achieved in the collision. In his resume Steffen Bass reported his work on a hybrid model of matter evolution, combining hydrodynamical description of the earlier stages of quark-gluon plasma evolution into hadron gas and microscopic transport description of the subsequent freezeout stage, to study the Hanbury-Brown–Twiss intensity interferometry of pions and kaons.

The experimental program of polarized proton-proton collisions at RHIC will provide a unique opportunity to get informations about proton wave function, especially its spin structure, which are not available from other experiments. Werner Vogelsang developed a new method to analyze the experimental data to extract information about spin structure function by applying the Mellin transformation technique and studied its utility in the planned experiments by RBRC experimentalists. (Unfortunately, this talk was cancelled due to unexpected change of his travel plan in Europe.)

Novel phenomena which occur in ultrahigh energy cosmic ray interactions and in the very early universe has also been among the interests of the RBRC theory group. Alexander Kusenko reported in his resume his new work on the possibility that the dark matter exists in the form of non-topological solitons since they are not excluded by the unitarity constraint on the ratio of cross section to its mass at high energies unlike the heavy particle candidates of dark matter.

Many of these works of the RBRC theorists have been done in collaboration with scientists from other institutions. Especially close collaborations with local (BNL) theory groups and theorists from nearby institutions, such as Columbia University, SUNY at Stony Brook, Yale University, MIT continue to play important roles. We like to comment, in particular, on the very fruitful collaboration with the Columbia group in the area of computational lattice gauge theories and its future.

As emphasized above, the successes of the RBRC theory group in the area of lattice gauge theory stem from the combined use of analytical insight and powerful computational resources. This committee has been very pleased to learn that in the near future even more powerful resources will be made available to RBRC in the form of the QCDOC supercomputer, currently under development by Columbia University in partnership with IBM Corporation. This committee heard very interesting presentations from Norman Christ and Robert Mawhinney summarizing the physics which has been done on the current QCDSP supercomputer and the status of the QCDOC project. This latter project appears to proceed according to schedule and it is expected that a QCDOC machine with peak power of 10 Tflops will be delivered to RBRC before the end of 2003. Substantial attention is being paid not only to the development of the hardware, but also of the software which will be needed to take full advantage of the supercomputer. From this point of view, great benefit is being derived from the experience with QCDSP, a machine which shares many architectural features with QCDOC, although QCDOC will be more flexible and easier to program. The scientists at RBRC are fortunate to have in their future such an impressive supercomputer, which will certainly help them maintain a position of leadership in lattice gauge theory investigations.

The committee was pleased to see the collaboration with Japanese lattice groups at Tsukuba and other institutions have been enhanced by the addition of one more new postdoc from the Tsukuba group. RBRC continues to provide an invaluable opportunity for many young Japanese physicists to be exposed to a very stimulating intellectual environment and trained well through very productive international collaborations.

We welcome the implementation of the University/RHIC Fellow positions also from the point of view of enlarging the range of the collaboration to much wider scientific communities in the U. S. As mentioned already, we were pleased to learn that some of these University/RHIC Fellows have been offered tenured appointments and have left RBRC. As the time elapses and more young scientists trained at RBRC "graduate" from the RBRC taking permanent positions at other institutions, we anticipate that the nature of the collaborations with external communities would experience another methamorphosis.

It is the opinion of this committee that the success of the RBRC would be further enhanced if one could establish some way to allow its graduates to maintain some formal relation with the Center and the Brookhaven National Laboratory and to backup the research at RBRC. In particular, many of the former RBRC scientists will continue their career in the academia, and the existence of such a relation would make it easier for them to involve their students in the scientific life of BNL and RBRC. Even a short exposure to the intellectually very stimulating environment at RBRC would be a life-shaping great experience for such graduate students.

3 Experimental Program at the RIKEN-BNL Center

The RBRC Scientific review committee heard presentations from essentially all of the RBRC experimental Fellows and advanced students, and enjoyed the opportunity to have individual conversations with most of them.

This has been a very active year on the experimental side for the RBRC group. We note several of the major accomplishments in the past year. A number of interesting topics which were presented and discussed are not mentioned simply to keep to a reasonable length of report.

The major focus of the experimental program is the study of spin phenomena in the interactions of colliding beams of polarized protons. As has been noted, the RHIC accelerator, with the essential collaboration of RIKEN, makes such studies possible for the first time. At the time of the meeting the first run with polarized protons was about to begin. The scientific community (and the committee) await the first results with keen interest.

Activity in the spin program has concentrated on preparations for these experiments. One key activity has been the development and testing of the p-carbon Coulomb-nuclear interference (CNI) polarimeter. Experiment E-950 at the AGS provided a convincing test of the design. Preliminary results were available last year and the data have now been fully analyzed, confirming the usefulness of this polarimeter. Three such polarimeters are now poised to operate in the polarized proton run. One in the AGS to determine the polarization of the final AGS beam prior to injection into RHIC, and two in RHIC (one in each ring) to measure the polarization after injection and acceleration.

These polarimeters will be very useful for monitoring the polarization and for tuning. However, because of the relatively large systematic uncertainty in their absolute analysing power, a better method of determining the absolute polarization of the beams is needed. This is the reason for the polarized hydrogen jet which is under study by the RBRC group and collaborators. It will be important for the RBRC group to make close collaboration with the BRAHMS collaboration to facilitate the use of the polarized jet target for absolute determination of the beam polarization, and of course, to provide calibrations for the other polarimeters.

Design work has also been carried out on another type of calorimeter using the assymmettry of π^0 production in collisions of transversely polarized protons. This polarimeter, if successful could be faster and more convenient to use than the CNI polarimeter.

We point out that a polarimeter based on π^0 production would be important because the faster operation would allow the accelerator to fine tune its performance for the maximum polarization. Similarly, research on other fast polarimeters would be useful for the same reason. As the research progresses, small improvements in the beam polarization will be very valuable as the data taking time scales inversely as the square of the beam polarization.

Analysis procedures for the determination of the gluon spin structure functions have been developed and first attempts to study these will be made with the forthcoming data.

The committee also notes with pleasure the progress of the CC-J computer system at RIKEN. This important facility will be the home of much of the data analysis to be done on the spin data.

Another important activity has centered on the development for triggering the PHENIX detector on interesting events for various spin physics topics. This is necessary because the luminosity of the p-p collisions is too high to allow each interaction event to be recorded.

We note also that the PHENIX calorimeter, which has been the responsibility of RBRC in large part, has succeeded in a very interesting measurement in the recent heavy ion run. This calorimeter, which will be essential for the spin physics, was completed last year and was used in the Au-Au runs both in 2000 and 2001. The production of π^0 mesons has been observed to be suppressed at large transverse momenta relative to those produced in p-p interactions. This effect was predicted to occur if a quark gluon plasma (QGP) were produced in the collision. At this time it is still too early to be sure that this is the correct explanation of the effect as the baseline measurement of π^0 production in p-A (proton - nucleus) collisions remains to be done. Nevertheless, this is an exciting possible clue to the existence of the QGP. It was made possible by the excellent performance of the calorimeter.

Another system with major RBRC responsibility is the muon detection system. This comprises the south and the north "muon arms". The south muon system is now completed and ready for data taking. The north arm will be completed for the 2002 run. These are major detector subsystems and the excellent progress is another demonstration of abilities of the RBRC experimenters.

We conclude by listing a few comments on the program and its future.

1. We note, as we did last year, that the collaboration between RIKEN and RBRC efforts is excellent. RIKEN physicists, RBRC physicists, Japanese physicists from University and their graduate students, and BNL and U.S. physicists all collaborate in a most effective manner. The excellent cooperation between the physicists at STAR, PHENIX, and RHIC with the program has been central to the successful production and measurement of the polarization. As we noted above close collaboration with BRAHMS will be necessary to facilitate the use of the polarized jet target to determine the absolute beam polarization.

2. We note, again as we did last year, that it would be desirable to increase

the participation of Japanese Universities in the program. At present this participation is concentrated mainly at Kyoto University and partly at Tokyo Institute of Technology.

3. We look forward to the addition of graduate students from the University of New Mexico, working with RBRC - University Fellow Doug Field, to the RHIC spin program.

4. If possible, it would be good to extend the experimental RBRC-University Fellowships to other universities. In a similar vein, we note that as experimental RBRC Fellows move on to University positions, they might well initiate new experimental work in spin physics.

5. The Junior Research Associate (JRA) of RIKEN is a valuable addition to the program. The committee notes that if, possible, the program would be usefully extended to other countries than Japan. It could, for example, provide a good opportunity for students from developing countries to participate in the experimental program.

6. We are pleased to note that the establishment of the BNL spin physics group, which was set up already last year, has substantially added to the overall spin program. The BNL and RBRC and RIKEN groups work very closely together and the BNL spin physics group helps to make the total a "scientifically" critical mass.

7. In our last year's report we expressed concern that an adequate amount of running time be alloted to the spin physics program. We are pleased to note that in the distribution of running time in this year, a high priority was placed on commisioning and running the spin program.

8. We would like to express a word of caution in the expectations for the results of the present spin run. RHIC is a new and quite unique high energy accelerator. As such, many features of its operation must be studied and developed to produce consistent, high performance. The best performance of the accelerator, which has been achieved, show that the basic design is excellent. The tests with the polarized protons which have been carried out also show that the performance for spin physics can be achieved.

   At the same time, it has become clear that a fair amount of work, albeit not of a fundamental nature, must be done to achieve consistently high performance. This is to be expected for a new instrument as innovative and complex as RHIC. Thus the present run may not produce the physics goals which, in the most, optimistic scenario, had been anticipated. The success of the present run should not be underestimated even if this is the case. Crucial information is being gathered which will permit future runs to reach the highest goals.