Report of the RBRC Scientific Review Committee
Brookhaven National Laboratory
November 6-8, 2012

I. Introduction

The last time the RBRC Scientific Review Committee met was October 27-29, 2010. This report discusses the important developments over the past two years.

The Scientific Review Committee consists of Wit Busza, Miklos Gyulassy, Kenichi Imai, Richard Milner (Chair), Alfred Mueller, Charles Prescott, and Akira Ukawa. The committee membership is listed in an appendix to this report, with members' addresses and affiliations.

At the beginning of the meeting, in executive session, the committee was pleased to hear the opening remarks given by Dr. Hideto En'yo, Director of the RIKEN Nishina Center for Accelerator-Based Science, who traveled to Brookhaven specifically for the purpose of attending this review. Dr. En'yo reported on the renewal of the agreement between BNL and RIKEN to continue RBRC for the six years 2012-17, with the possibility of further extension. The committee congratulates BNL and RIKEN for this important achievement.

In this report we review the current program and recent achievements.

II. Overview of the current program

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

At the beginning of his presentation, Dr. Samios discussed the management of RBRC and the role RBRC plays in the career development of scientists and scientific leadership. He pointed out that Dr. Y. Akiba remains Experimental group leader with Dr. A. Deshpande, his deputy, and Dr. L. McLerran remains Theory group leader with R. Pisarski, his deputy. Dr. T. Izubuchi has assumed the position of Computing Group Leader.

He pointed out that on the experimental side, the physics that emerges from the heavy ion program at RHIC continues to be outstanding. PHENIX has recently brought online muon and silicon vertex trackers. As is well known, LHC has confirmed the discovery at RHIC of a new state of matter: a hot, dense, strongly coupled plasma of quarks and gluons (sQGP), a perfect liquid. LHC measurements of the nuclear modification factors at high p_t are in good agreement with those from RHIC at lower p_t. He reported on the determination of the higher harmonics in the flow analysis. These further constrain the determination of the ratio of viscosity-to-entropy.

Discussing the impressive progress in Lattice QCD calculations he pointed out that QCD Chiral Quarks was brought into operations at 600 TFlops in 2012. This will be increased by another 100 TFlops early in 2013.

Dr. Samios was particularly pleased to be able to report that for the RHIC Accelerator the last year, Run 12, was an exceptional year. Stochastic cooling was fully implemented; increased proton beam polarization was obtained; and Uranium beams were delivered using the new EBIS source. A Au-Au energy scan was carried out as a function of beam energy from 5 GeV/nucleon to 100 GeV/nucleon.

Finally, Dr. Samios pointed out that RBRC has had a perfect safety record over its 15-year lifetime.

III. Scientific Progress

A. Experimental Program

Yasuyuki Akiba described an overview of the activities of the experimental group at RBRC and presented highlights of their recent results on heavy ion physics and detector upgrade at PHENIX. Spin physics, heavy ion physics and detector upgrade at RHIC-PHENIX are three major thrusts of the RBRC experimental group. Study of the spin structure of proton with RHIC polarized proton collider has been a main activity of RBRC/RIKEN. RBRC/RIKEN has focused on penetrating probes such as leptons and the photon to study the properties of the quark gluon plasma formed in heavy ion collisions at RHIC. The silicon vertex tracker (VTX) and muon trigger upgrade which have been important activities of RBRC for many years were both recently completed, and it is now the time to reap the “harvest”.

The group consists of a group leader (Y.Akiba), a deputy group leader (A.Desphande), 4 Fellows, 3 PostDocs and 6 RIKEN/RBRC members. In addition, the group supports 10 students and visitors and collaborators.

Among 115 papers of the PHENIX Collaboration published since 2001, RBRC members are involved in paper writing committees for 46. This clearly demonstrates the significant contributions of RBRC to PHENIX. Since the last RBRC Scientific Review (Oct. 2010), 22 papers have been published and RBRC members have made significant contributions to 9.

A highlight of heavy ion physics at RBRC is the successful measurement of thermal photons from the QGP. It is the first measurement of the initial temperature of the QGP formed by heavy ion collisions. The result showed that the initial temperature is in the range 300~600 MeV which is well above the transition temperature to QGP. The Nishina Memorial Prize 2011 was awarded to Yasuyuki Akiba for this achievement.

The PHENIX muon trigger upgrade has been primarily motivated by the measurement of the parity violating W boson production, which allows the study of the polarization of $\bar{u}$ and $\bar{d}$ quarks. The first data (Run 11) were successfully taken with the upgraded trigger. The vertex tracker can identify charm and bottom decays and is a major PHENIX upgrade led by RIKEN/RBRC. It was completed in Nov. 2011 and the first data (Run 11) were presented at the 2012 Quark Matter Conference.

Rachid Nouicer described charm and bottom measurements with the VTX tracker. It is known that electrons from the decay of heavy quarks are suppressed in Au-Au collisions and show elliptic flow. Separating charm and bottom is the next step to understand the energy loss mechanism. The VTX tracker was commissioned in p+p at 510 GeV and the first data on Au+Au was obtained in Run-11. The data were also taken with some VTX improvement in Run-12. The obtained vertex resolutions were 54 μm in x, 37 μm in y and 68 μm in z-direction. With help of Monte Carlo simulation, from the distance of closest approach (DCA) of single electrons, bottom production in p+p and Au+Au collisions was directly measured for the first time. The obtained ratio b/(b+c) in p+p collision is consistent with previous PHENIX and STAR results. The preliminary data show that bottom quark production is very much suppressed compared to charm production in Au+Au.

Maki Kurosawa described the flow measurements of charged hadrons and heavy quarks with the VTX tracker. The VTX enabled the measurement of charged hadrons at high transverse momentum with less background. The elliptic flow parameter v2 *vs*. p_t for charged hadrons was consistent with that for π^0 and its rapidity dependence was also measured. By the DCA measurement of single electrons, the v2 parameter for charm has been measured for the first time and has been observed to be non-zero.

John Chin-Hao Chen discussed the performance of the VTX tracker, especially pixel detectors and obtained spectra of charged hadrons and heavy flavor electrons with VTX. The pixel detector consists of two layers. The first layer has 10 ladders and the second layer has 20 ladders. One ladder has about 128 pixels. The map of dead/hot pixel layers was made using real data throughout the run period, and it showed the pretty stable operation of the pixel detectors was achieved in Run 12. The spectra of charged hadrons and heavy flavor electron in Au+Au collisions were obtained using the VTX tracker. They are quite consistent with previously obtained spectra without the VTX tracker, which proves the good performance of the VTX and its data analysis procedure.

Stefan Bathe discussed the measurement of high p_t hadrons with the VTX tracker. High p_t hadrons are the important probe to study energy loss mechanism in the QGP. The measurement of charged hadrons was previously limited to p_t< 8 GeV at PHENIX due to off vertex background, which can be much improved by using the VTX tracker. The possibility to extend the p_t range of charged hadrons up to 20 GeV/c was shown.

RBRC continues to play a major role in PHENIX not only spin physics but also heavy ion physics. The committee highlights the Nishina Memorial Prize awarded to Yasuyuki Akiba for the measurement of the initial temperature of the QGP as recognition of the strong contribution of RBRC to heavy ion physics. The VTX tracker has been a major project of the RBRC experimental group. The successful commissioning of the VTX tracker and data taking in Run 11 and Run 12 is a big milestone for RBRC, PHENIX and RHIC. Already very interesting results have been obtained such as much larger suppression of bottom at low p_t compared to charm. Systematic uncertainties are, however, sizable at present and more analysis effort is needed to reduce systematic uncertainties to finalize the result. More fruitful physics is surely expected to be harvested in the coming few years.

Prof. Abhay Deshpande described the recent progress in polarized proton running and applications to the spin physics program. During 2012, RHIC ran with polarized p-p collisions at 100 GeV and 250 GeV for periods of approximately 5 weeks at each energy. The Collider Accelerator Department (CAD) performed magnificently, achieving a record high polarization for RHIC of 59% at 100 GeV and 52% at 250 GeV, while delivering record high integrated luminosity at 250 GeV. These records were achieved in spite of the relatively short run periods.

The RHIC spin program continues to mature with these data runs. The primary studies involve the double spin asymmetries, A_{LL}, for various final states (π^0s, $\pi^{\pm}$s, γs, c-cbar..) These are used to determine the polarized gluon distribution $\Delta g(x)$ over a range of x allowed by the kinematics, and the net gluon spin, ΔG, for this x range.

Antiquark polarizations (ΔQ-bar) can be determined by studying $W^{\pm}$ decays at the highest energies. These studies currently are limited by statistics and await the longer exposures planned for the future RHIC running. The central arm results from 2009 running, based on high p_t electrons (> 30 GeV/c), showed large A_L but with rather large errors. Analysis of the Run 12 data is underway. The forward arm detector upgrade is just now coming online and PHENIX anticipates a good Run 13 next year.

Dr. Deshpande showed recent global fits to A_{LL} data from PHENIX and STAR by Sassot and Stratmann ("DSSV++"), which are updates of earlier fits. The data fit by DSSV++ include $A_{LL}(\pi^0)$ from PHENIX and A_{LL} (jets) from STAR. Both of these data sets are now showing significant non-zero values for A_{LL} as p_t increases. The fits from DSSV++ suggest non-zero values for the net gluon polarization, ΔG, a new result and conclusion. Previous fits to the more limited data sets had showed no net gluon polarization, but with rather large errors.

The picture that seems to be emerging from these data and fits is of a proton spin consisting of ~20-40% quark spin, ~20% gluon spin, and unknown contributions from anti-quarks and orbital motion. Errors on these fits remain rather large, and further work is required. In particular, the range of x for which the A_{LL} data exist is limited from .05 to 0.2, and the contributions from constituents lying outside these limits remains to be measured.

Transverse spin asymmetries (A_N) remain a subject of considerable interest, with large non-zero values present and growing as x_F increases. The source of these asymmetries is likely connected to initial and/or final-state interactions.

Dr. Deshpande went on to discuss PHENIX upgrade activities. sPHENIX and a companion forward arm, sPHENIX-forward, were described. The forward arm addresses low-x physics, while the central detector, sPHENIX, addresses more comprehensively jet physics in the central region. These activities are discussed in follow-on talks by the RBRC experimenters. Dr. Deshpande then discussed studies for a future electron-proton or electron-ion collider facility ("eRHIC"). sPHENIX and sPHENIX-forward are designed to meet the performance requirements of eRHIC physics. The detectors can be readily and appropriately upgraded for physics at an electron-ion collider. At eRHIC the gluon and sea quark polarizations can be extended down to $x \sim .001$. Uncertainties in ΔG and ΔQ would be reduced to the 5% level. Dr. Deshpande and colleagues have a White Paper in preparation, which discusses extensively the physics program of an electron ion collider. Current R&D activities are underway, with a technical review completed (Aug 2011) and a cost review in the near future being planned.

Following Dr. Deshpande's summary, he introduced several RBRC speakers who then presented more information on their activities.

Dr. Kieran Boyle discussed a study of systematic effects in asymmetries (A_{LL}) due to beam dynamical effects. False asymmetries arise from sources including inconsistent results from run to run, blue beam versus yellow beam differences, spin pattern dependencies, and luminosity uncertainties. Part of the non-zero false asymmetries observed in A_{LL} data were caused by residual transverse spin (i.e., non-zero transverse spin components) coupled with beam angles and beam position offsets. Some accelerator beam time in 2012 running was devoted to studying these beam dynamical effects. The studies clearly showed false asymmetries arising from these effects. Plans are underway to implement new detector readouts that can be used to monitor and control these beam parameters.

Joe Seele, in the capacity as a working group convener, described physics studies related to the sPHENIX detector proposal. SPHENIX is conceived as a compact state of the art central detector with uniform azimuthal coverage and precision tracking, optimized for jets studies in heavy ion collisions. It consists of a superconducting coil, silicon tracking inside the coil, electromagnetic and hadronic calorimeters outside. Monte Carlo studies of spin asymmetries measured in sPHENIX were presented. Studies of heavy ion collisions with PHENIX were also described.

Much of the physics emphasis depends on the forward direction. Dr. Seele went on to describe the forward arm under consideration (rapidity coverage from 1.2 to ~ 4) that would greatly augment the sPHENIX central detector capabilities. As conceived, it would reuse parts of the current PHENIX (i.e., electromagnetic calorimetry), and would add several new elements (a RICH-based particle identifier, a hadron calorimetry section, and enhanced muon tracking). Dr. Seele also emphasized that the sPHENIX

and sPHENIX-forward detectors are designed to be suitable for a future eRHIC facility.
Xiaorong Wang described the forward silicon vertex detector (FVTX) status. Two silicon strip arrays exist (North and South) each consisting of 4 discs of 48 "wedges" of strips. The detectors cover 2π in φ at a range of 1.2 to 2.4 in rapidity. The detectors were operational for the recent p-p, U-U, and Cu-Au running. Reconstruction software is running. Alignment studies were underway during the 2012 runs. Combining the FVTX and muon trackers has significantly improved the distance-of-closest approach measurements for muon tracks. Dr. Wang described heavy quark physics anticipated from $W^{\pm}$ data in the next p-p runs. They anticipate much cleaner $W^{\pm}$ reconstruction due to the suppression of mis-constructed tracks using the FTVX.

John Koster discussed the operations at PHENIX during Run12. Polarimetry remains a central issue for the spin physics program. For longitudinal spin runs, setting of the magnets depends on the PHENIX polarimeter readout that allows for nulling out the transverse components. The residual transverse asymmetries contribute to the systematic errors. The polarization is monitored by scalers, a new tool available for Run 12, speeding up tuning and enhancing precision. The blue and yellow beams are monitored separately.

New elements in PHENIX were also discussed. The muon trigger was improved for Run 12. The FVTX, a resistive plate chamber ("RPC1, RPC3") and additional absorbers were new. Commissioning of these components was completed and used during Run 12 for the 250 on 250 p-p running.

Itara Nakagawa, representing the Forward Upgrade Group, discussed sea quark polarization studies in the forward rapidity region via W-production. Single spin asymmetries in $W^{\pm}$ can be related to the u-bar and d-bar quark spins in the proton by these processes. PHENIX has reported the first measurements of the single longitudinal spin asymmetry, $A_L(W^{\pm})$, from Run 11 and Run 12. Polarizations ~50% were achieved. Errors on the asymmetries are still substantial, but projections for Run 13 are promising.

B. Theory Program

The collection of theorists at the RBRC along with neighboring theorists in the BNL Nuclear and High Energy theory groups constitute the strongest theory effort in the world focused on QCD and related topics. The different groups fit together very well with the BNL groups furnishing mainly a set of outstanding senior theorists and the RBRC group first rate post docs and Theory Fellows. Larry Mc Lerran has been very successful in insuring good mentoring of the RBRC postdocs. They are very active, produce excellent and timely work often in collaboration with senior theorists, and go on to get good positions after their post doctoral time at RBRC. The Theory Fellows program is one of the most successful efforts in RBRC. Fellows, mostly at universities with a few at BNL, account for much of flow of QCD theorists into permanent positions in American universities and laboratories. During their time as RBRC Fellows they often collaborate with each other and with post docs and senior theorists at RBRC, as well as with members of the BNL theory groups. All in all the theory effort has been very successful and we see no signs of tiredness or slowing down.

Larry Mc Lerran summarized the theory activities currently under way at RBRC. While most of the effort is directed toward finite temperature QCD and heavy ion physics there is also impressive work being done on hadron-nucleus collisions, spin physics, and even some particle physics. Larry described his own work with University Fellow Jianfeng Liao (who was unable to attend the review) and other collaborators on progress in describing the very early stages of evolution after a heavy ion collision, but before equilibrium sets in. This is an exceedingly important topic and the progress being made by Liao, Mc Lerran and collaborators is quite exciting.

Anna Stasto described work focused on using correlations in dA and pA collisions at RHIC and the LHC as a measure of parton densities, and the saturation momentum, for cold nuclear matter at small values of Bjorken x. Dihadron correlations have already become a topic of intense study at RHIC and, along with hadron-Drell-Yan pair correlations, are expected to become a major focus of research for the pA program at the LHC.

Fedor Bezrukov described a picture where the top quark mass at 173 GeV and the Higgs mass at 126 GeV arise “naturally” as a condition that the Higgs self coupling evolve to reach a minimum of zero at the Planck mass. Although quite speculative the research is solid and interesting.

Koji Kashiwa described using lattice gauge theory calculations of the gluon and ghost propagators to evaluate the effective potential and find the critical temperature for SU(2) and SU(3) pure gluon Yang-Mills theories. The results are in good agreement with direct lattice gauge theory calculations of pressure, entropy and energy densities.

Adrian Dumitru, associated with Baruch CUNY, described progress in the past year extending the CGC model to describe recent measurements at the LHC on p+Pb. By deforming the MV model of initial conditions via an additional anomalous dimension to fit e+p data, LO k_t factorization is now able to account for the observed p+p high p_t data at LHC. Using the running coupling BK equation to evolve to small *x* and taking realistic global geometric fluctuation effects into account with Monte Carlo, the current MC-rcBK-MVg model was shown to reproduce the observed multiplicity fluctuations in p+p as well as global features of p+Pb. An open source code of the current model has been developed and is maintained at Baruch CUNY.

Derek Teaney, associated with SUNY, was unable to attend but sent a report on his recent work on NLO corrections to photon emission rate in hot quark gluon plasmas. He found that corrections to LO rates were surprisingly small over the whole kinematic range. This work establishes important NLO baseline predictions for the thermal photons within the weakly-coupled paradigm. While not reported, Teaney has also continued his productive research in the strongly coupled AdS/CFT gravity dual paradigm. His recent work on Hawking radiation with MIT collaborator Paul Chesler shows how thermal photon spectra could serve to differentiate strongly-coupled QGP dynamics from NLO weakly coupled dynamics.

Ho-Ung Yee reported on recent work on the chiral magnetic effect proposed by D. Kharzeev *et al*. based on the triangle anomaly in the presence of parallel electric and magnetic fields. In A+A collisions the transient large B fields produced can lead to induced charge waves along the B field direction. The new proposal was that a possible experimental signature of this effect is that the bulk elliptic flow moment of negative charged pions could exceed (slightly) the bulk elliptic flow of positive charged pions. Recent preliminary STAR data on this asymmetry can be fit well by suitable adjustment of the parameters. Recent work on chiral magnetic induced elliptic flow and induced polarization asymmetry of thermal photons was also reported. This work is carried out in collaboration with senior colleague Dmitri Kharzeev and continues to be a major focus of experiments at both RHIC and LHC.

Adam Bzdak reported recent work in collaboration with senior Volker Koch at LBNL on the energy dependence of baryon and charge cumulants. He discussed a major limitation of these class of baryon observables which arises because of the experimental inability to measure neutrons. Hence, the focus of these studies is shifting to charged particles. This type of research would benefit from using more realistic Monte Carlo transport models.

Shu Lin discussed his recent progress on glueball correlators in a model of strongly coupled AdS gravitationally collapsing massive shell backgrounds initiated with Edward Shuryak in 2008 and continued in collaboration with J. Erdmenger (Max Planck, Munich) in 2012. He reported the expected time scale for thermalization of order 1/(Pi T) characteristic of infinite coupled gravity dual black hole holographic models. The technical progress reported is the demonstration that real time correlators have divergences at only a finite number reflection times between the AdS boundary and the collapsing shell.

C. Lattice QCD computing program

Taku Izubuchi, as the newly appointed group leader of the computing group, reviewed the organization of the group as well as the physics highlights over the past two years. In addition to himself, the RBRC computing group now consists of two fellows, two postdocs, 6 visiting scientists and 2 students. The group has been engaged in a close collaboration with physicists at Columbia University, University of Connecticut, and BNL (high energy theory and lattice gauge groups) since 1998, and with the UKQCD Collaboration in Great Britain since 2005. It has also started a somewhat looser collaboration with the JLQCD Collaboration in Japan on measurement methods since 2012. These collaborations have worked well in fostering young talents, producing 22 PhD theses since 2005. The computing resources of the group consist of the new QCDCQ at RBRC, BlueGene/Qs operated at US laboratories (LLNL and ANL) and at Edinburgh and KEK, the latter two through the collaborations. The scientific activity of the group continued to attract world attention as evidenced by a large number of plenary talks presented by the group members over the last two years. They have also played active roles in the lattice QCD community, serving on various committees and organizing workshops and meetings.

Physics highlights were briefly introduced by Izubuchi, and were followed up in detail by individual presentations. It was emphasized that a new generation of lattice QCD simulations had started; (i) QCD ensembles are now generated aiming for a large volume of $(5fm)^3$ and the physical pion mass of 135MeV, (ii) unprecedented precision of less than 1% is beginning to be achieved for a number of important physical quantities, the light quark masses, light meson decay constants etc, (iii) unprecedented physics computations are under way, which include the two pion decay of kaon, light by light contributions to the muon anomalous magnetic moment, neutron electric dipole moment etc, and (iv) those developments are made possible through the new computing resources as well as the new computational algorithms developed at RBRC and elsewhere.

Norman Christ, after briefly mentioning the ongoing work on finite temperature QCD, presented the status of kaon physics calculations. Calculating the two-pion decay amplitude of kaon, thereby verifying the Standard Model understanding of CP violation, has been a long-term goal of lattice QCD. For the I=2 final state, a successful calculation was carried out on a 32^3x64 lattice at a lattice spacing of 1/a=1.36 GeV with almost physical kinematics. The final result is ReA_2= $(1.436\pm0.063_{stat}\pm0.258_{sys})$ $\times10^{-8}$GeV and $ImA_2=(-6.29\pm0.46_{stat}\pm1.20_{sys})\times10^{-13}$GeV. The real part is in good agreement with the experimental value of $(1.479\pm0.004) \times 10^{-8}$GeV. This is the first ever calculation of the I=2 decay amplitude treating the two pion final state directly and with physical kinematics. The PRL paper reporting this result rightly received the 2012 Ken Wilson Lattice Award. For the I=0 amplitude, exploratory studies on a 16^3x32 and 24^3x64 lattice with a heavy pion mass of 300-400MeV, albeit producing encouraging results, demonstrated the difficulty presented by the disconnected diagrams. It was stated that the goal is the calculation of the CP violation parameter ε'/ ε with a 20% total error with all errors controlled. It was argued that the technique of all to all propagators plus a factor 20 speed up of the calculation by the new QCDCQ/BluGene/Q computer should enable to overcome the difficulty. First results are anticipated in 2 years. An attempt was also reported of calculating the K_L-K_S mass difference using the K^0-K^0 mixing amplitude perturbed to second order in the weak Hamiltonian.

Robert Mawhinney presented the status of machines. After 6 years of service, RBRC and USQCD 10 TFlops QCDOC were shutdown on 19 September 2011. The first rack of the new QCDCQ/BlueGene/Q machine arrived on 20 December 2011, and 3 racks, 2 funded by RBRC and 1 by BNL, have been in operation since 18 May 2012. An additional half a rack funded by USQCD is to be installed in January 2013. The 2 RBRC racks are in production mode although there still remains some work to improve the mean time between failures. Each rack of BlueGene/Q has a peak speed of 200 TFlops. On 26 December 2012, using 96 racks of Sequoia at LLNL, the domain wall conjugate gradient inverter achieved 6.16 PFlops. Currently the 3 racks are being used for various physics calculations and code development. Ensemble generations are being done using the Moebius formalism with an improved residual mass on a 48^3x96 and 64^3x128 lattice, starting on the RBRC machine and moving the configurations to Edinburgh or ANL for further evolution. It was also reported that discussions with IBM about the next generation of computers had been started.

Brian Tiburzi described his work to apply lattice methods to further explore the nuclear properties and confront them with modern experiments. One such quantity is the electromagnetic polarizability of hadrons. The experimental value for the charged pion disagrees with the chiral perturbation theory prediction, providing one of the motivations for application of lattice QCD. An exploratory study using external fields to obtain the electric polarizability was reported, and future plans for removing systematics to make a physical prediction were mentioned. Another quantity is parity violation in the nuclear force for which experimental progress is expected from the new round of neutron experiments. Theoretical considerations to set up lattice calculations were discussed.

Tomomi Ishikawa discussed efforts to include dynamical QED effects in the calculation of hadron properties. As lattice QCD calculations become increasingly precise, isospin-breaking effects from quark masses and electromagnetic charges are no longer negligible. Some years ago, the RBC Collaboration carried out a calculation treating QED in the quenched approximation. In the new work, dynamical QED effects were incorporated by the reweighting method; the ratio of quark determinant with and without the coupling to U(1) electromagnetic field is stochastically evaluated and inserted into the observable averaging procedure. A test calculation on a small lattice of 16^3x32 shows that there is a reasonable overlap between the original and reweighted ensemble. As a physical product the low energy constants of chiral perturbation theory governing the electromagnetic mass difference of pseudoscalar mesons are determined.

Eigo Shintani reported work on the electric dipole moment of nucleon. Experiments have steadily pushed down the upper bound on the neutron electric dipole moment, whereas a reliable theoretical bound is still non-existent. Lattice QCD allows a calculation of the linear term of the dipole moment proportional to the QCD vacuum angle θ. This, however, requires a calculation of the electromagnetic form factor weighted with the topological charge, which suffers from large statistical errors. Results of a calculation on a 24^3x64 lattice with 300 MeV pion mass employing the new AMA (all-mode-averaging) method for error reduction was reported. More realistic calculation on a 32^3x64 lattice with smaller pion mass of about 200MeV is in progress.

Christoph Lehner reported on renormalization needed to match lattice computations to continuum results. One important instance is the recent computation of the I=2 two pion decay amplitude of kaon. For the relevant four-quark operators, matching factors to the MS scheme were calculated to one-loop perturbative order for four RI schemes, and the spread of results were used to estimate the systematic uncertainties in the matching procedure. Another line of work is development of a new computer algebra system for carrying out lattice perturbation theory, similar to FORM but built from scratch to extend the capability to lattice field theory for which complicated trigonometric functions appear in propagators and vertices. It was applied to one-loop determination of the improvement coefficients of relativistic heavy quark action used for B meson calculations.

Assessment of lattice QCD computing at RBRC

Lattice QCD with domain wall fermion action has been pursued at RBRC since 1997. It has matured to the stage where calculations with light quarks with physical masses and on large volumes are possible. While this is a trend taking place worldwide, the added strength of the activity at RBRC is the richness of the physics program. The RBRC computing group keeps exploring new physics possibilities, and at the same time consistently addresses the long-standing issues in the Standard Model. QED effects and CP violation in the kaon decays, for which impressive results were presented, are two exemplary cases in point. With the arrival of QCDCQ at RBRC and BlueGene/Qs elsewhere, the computing at RBRC in collaboration with Columbia and other institutions is sure to produce world-leading results in QCD over the next couple of years.

D. RHIC and Accelerator developments

To provide the committee with a good grasp of the status of RHIC and accelerator developments at BNL, Dr. Thomas Roser gave a special presentation "*RHIC, the next decade, and eRHIC*". It covered:

-- Recent performance of RHIC
-- Future plans for RHIC
-- Accelerator R&D towards eRHIC
-- The next machine: eRHIC

With great satisfaction, Dr. Roser summarized the variety of nuclei that RHIC has accelerated and the extensive range of energies at which it has collided the beams.
It is an impressive list indeed:

-- Au-Au at 3.8, 4.6, 5.8, 10, 14, 32, 65 and 100 GeV/n
-- U-U at 96.4 GeV/n
-- Cu-Cu at 11, 31 and 100 GeV/n
-- Polarized protons on polarized protons at 11, 31, 100, 205, 250 and 255 GeV
-- d-Au at 100 GeV/n
-- Cu-Au at 100 GeV/n

Planned or possible future modes of operation of RHIC include:

-- Au-Au at 2.5 GeV/n
-- Polarized protons on Au at 100 GeV/n
-- Polarized protons on polarized He^3 at 166 GeV/n.

Dr. Roser was particularly proud of the fact that RHIC has achieved peak luminosities comparable to that of the other large hadron colliders, the Tevatron and LHC (scaled to 255 GeV), and that in every run, since the first in 2000, both the integrated luminosity and (in the case of polarized proton runs) the polarization of the beams has significantly increased.

These successes are a consequence of a systematic program of upgrades to the facility.

Recent upgrades include: The construction of EBIS, a low maintenance linac-based pre-injector for all species, including uranium and polarized ^{3}He; the "RHIC II" luminosity upgrade program which involved the introduction of a 0.5 m beta star for Au-Au and polarized p-p operation and stochastic cooling of Au beams; and development of the ability to collide Au-Au at extremely low energies (down to 5 GeV/n).

Future planned RHIC upgrades include: addition of electron lenses to double the p-p luminosity, electron cooling of heavy ion beams to increase the luminosity at low energies, improvement of the stochastic cooling and installation of the 56 MHz storage SRF system to further increase the heavy ion luminosity.

Dr. Roser went on to discuss the progress in the work related to the proposed Electron Ion Collider at BNL, the so-called "eRHIC" facility in which an electron accelerator is added to the existing RHIC to create a unique and powerful collider that will have the capability to study the collision of 5-30 GeV polarized and unpolarized electrons with 50-250 GeV polarized protons, with 50-167 GeV/n polarized ^{3}He, and with 50-100 GeV unpolarized heavy ions, ranging from deuterium to uranium. It will bring to BNL a facility which will enable us to study lepton-hadron scattering, for center-of-mass energies in the range 30-175 GeV for all possible polarizations of the lepton and hadron.

Dr. Roser emphasized that design studies and R&D of various aspects of eRHIC are proceeding extremely well. For example, significant progress has been made in the development of the polarized electron gun, the energy recovery linac and coherent electron cooling.

Assessment of the performance of RHIC and of the accelerator R&D

The construction of RHIC and continues improvements to its capability have been an incredible success story. A good illustration is the performance of Run 12, during which record luminosities and polarizations were established and new species collided, at a cost well below projections. Furthermore the flawless operation and very short set-up times exceeded all expectations.

The indications are there that Dr. Roser and his colleagues have the expertise to do the necessary R&D and construct eRHIC, if it is funded and BNL chosen for its siting.

IV. Findings

- In general, the committee is very positively impressed. The RBRC enterprise is healthy and strong.
- We congratulate BNL and RIKEN on the renewal of the agreement for the six years 2012-17, with the possibility of further extension.
- RBRC remains a unique, highly successful model for international scientific collaboration. The growing, world-wide network of RBRC faculty at research universities and laboratories is very impressive.
- The young people in RBRC are a dynamic, enthusiastic, and effective group.
- RBRC workshops continue to play a major role in the evolution of the RHIC scientific community.
- It is important that the PHENIX collaboration produce spin results competitive with those from STAR in a timely way. RBRC can play a key role in this effort.
- RHIC has had an exceptionally successful recent period of operation with
    - increased luminosity
    - increased proton beam polarization
    - EBIS coming online with Uranium beams
- The committee congratulates the BNL CAD for achieving RHIC II luminosities a factor of 10 below cost and ahead of schedule. The committee notes that it is the stated top-level priority of the 2007 Long Range Plan to seize the scientific opportunities made possible by RHIC II.
- The RHIC heavy-ion and spin programs are in a very productive period with substantial detector and accelerator upgrades largely completed and a very productive phase of "reaping the harvest " starting. LHC has confirmed the RHIC discovery of a perfect liquid and both facilities can make unique and complementary contributions for at least the next 3-5 years.
- While there are significant uncertainties about the future due to constrained funding in the U.S., there is a clear, well-motivated, strong scientific case for continuing the RHIC program to study the hot, dense matter and to constrain the contribution of gluons and antiquarks to the proton's spin.

Appendix

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