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Preface to the Series

The RIKEN BNL Research Center (RBRC) was established in April 1997 at Brookhaven National Laboratory. It is funded by the "Rikagaku Kenkyusho" (RIKEN, The Institute of Physical and Chemical Research of Japan. The Memorandum of Understanding between RIKEN and BNL, initiated in 1997, has been renewed in 2002 and again in 2007. The Center is dedicated to the study of strong interactions, including spin physics, lattice QCD, and RHIC physics through the nurturing of new generations of young physicists.

The RBRC has both a theory and experimental component. The RBRC Theory Group and the RBRC Experimental Group consists of a total of 25-30 researchers. Positions include the following: full time RBRC Fellow, half-time RHIC Physics Fellow, and full-time, post –doctoral Research Associate. The RHIC Physics Fellows hold joint appointments with RBRC and other institutions and have tenure track positions at their respective universities or BNL. To date, RBRC has ~100 graduates of which 27 theorists and 14 experimenters have attained tenure positions at major institutions world wide.

Beginning in 2001 a new RIKEN Spin Program (RSP) category was implemented at RBRC. These appointments are joint positions of RBRC and RIKEN and include the following positions in theory and experiment: RSP Researchers, RSP Research Associates, and Young Researchers, who are mentored by senior RRC Scientists. A number of RIKEN Jr. Research Associates and Visiting Scientists also contribute to the physics program at the Center.

RBRC has an active workshop program on strong interaction physics with each workshop focused on a specific physics problem. In most cases all the talks are made available on the RBRC website. In addition, highlights to each speaker's presentation are collected to form proceedings which can therefore be made available within a short time after the workshop. To date there are one hundred and two proceedings volumes available.

A 10 teraflops RBRC QCDOC computer funded by RIKEN, Japan, was unveiled at a dedication ceremony at BNL on May 26, 2005. This supercomputer was designed and built by individuals from Columbia University, IBM, BNL, RBRC, and the University of Edinburgh, with the U.S.D.O.E. Office of Science providing infrastructure support at BNL. Physics results were reported at the RBRC QCDOC Symposium following the dedication. QCDSP, a 0.6 teraflops parallel processor, dedicated to lattice QCD, was begun at the Center on February 19, 1998, was completed on August 28, 1998, and was decommissioned in 2006. It was awarded the Gordon Bell Prize for price performance in 1998. The next generation computer in this sequence, QCDCQ (400 Teraflops), will become operational in the summer of 2012.

N. P. Samios, Director
February 2012

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Presentations

Heavy ion physics at RHIC: experimental status and outlook

Stefan Bathe, Baruch College, CUNY, and RBRC

A few microseconds after the Big Bang the Universe was too hot for quarks and gluons to be bound in baryons and mesons. Instead, Quantum-Chromodynamics (QCD), the theory of the strong interaction, predicts the existence of a deconfined state of quarks and gluons, the Quark-Gluon Plasma (QGP), for temperatures larger than ca. 170 MeV. The QGP is experimentally accessible through the collision of heavy nuclei at ultra-relativistic energies. The original mission of the Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory (BNL) was to find the QGP. This has been established. Now, we are trying to understand the properties of the QGP quantitatively.

Evidence for QGP formation at RHIC is based on several key findings: (i) the energy density is found to be several times that required for QGP formation as predicted by QCD; this is a prerequisite; (ii) high transverse momentum particles are suppressed, suggesting significant energy loss of fast partons traversing the QGP, which implies that the produced matter is very dense; this is one of two major discoveries at RHIC; (iii) spatial anisotropies in non-central collisions are translated into large azimuthal anisotropies in particle production (elliptic flow), the strength of which is consistent with (almost) ideal hydrodynamical behavior, suggesting a low viscosity-to-entropy ratio of the produced matter; this is the second major discovery.

The nearly-perfect fluid behavior implies that the matter is strongly coupled. This finding has led to a paradigm shift as the QGP had naively been expected to be weakly coupled before the RHIC program. The success of hydrodynamics allows to employ a single physics scenario to reconcile the various theoretical and experimental inputs with the predicted and observed outputs in describing heavy ion collisions; as such it constitutes a major advancement in the field.

Recent progress has been made by determining the temperature of the QGP to 300 to 600 MeV through a measurement of the radiation of direct photons. Also, it was realized that triangular flow arising from fluctuations in the initial state provide a handle on further constraining the viscosity. One of the current puzzles is the unexpectedly large energy loss of heavy quarks.

The properties of the QGP will be further studied through detailed heavy quark measurements with new silicon microvertexing detectors. Then, a transformational upgrade has been proposed enabling full jet reconstruction at RHIC, which will allow to study the details of parton interactions with the QGP.

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Electron Ion Collider
(an overview)

Abhay Deshpande
Stony Brook University & RBRC

While there is no doubt that QCD is the correct theory of Strong Interactions, our understanding of QCD remains very incomplete. For example, we can't explain the basic properties of hadrons such as their mass and spin from the QCD degrees of freedom at low energy. We don't really know what the ingredients (degrees of freedom) of QCD are at high energy and what are their interactions like amongst themselves & with experimental probes? What can be learnt about the confinement and such universal and fundamental aspects of QCD if we were really to do such experiments? It is safe to say, that unless we experiment we won't know. We are only just beginning to scratch the surface of understanding QCD.

To this end we propose a future high energy, high luminosity polarized e-p and electron nucleus collider. The electron beam energy would nominally be 10 GeV, but variable from 5-30 GeV, the proton & nucleus beam energies 50-250 GeV & 20-100 GeV/A , respectively. The electron beam and the light nuclei (proton, deuterons, and possibly ^{3}He) would be polarized to about 70%. The luminosity of the collider is planned to be $10^{33\text{-}34}$ cm^{-2}sec^{-1}. This is about 100-1000 times larger than the HERA collider at DESY which operated in the 1992-2007. HERA had neither polarized hadrons nor did it have any nuclei.

The physics program of the EIC is focused on the following goals: To study and understand in detail, the role of gluons and sea quarks in QCD through their detailed study in [1] polarized and un-polarized hadrons, and [2] also in nuclei of different sizes. In terms of understanding the nucleon (spin) structure, the EIC would enable not only to resolve completely the gluon's contribution to the nucleon spin, but also, for the first time systematically decipher the transverse momentum distribution (TMDs) of the partons in the nucleons, and through measurements of generalized parton distributions (GPDs) would be able to reconstruct a full three dimensional momentum correlated position picture of the partons, thus enabling a tomography of the proton. This may in future lead to measurement of the orbital angular momenta of the quarks and gluons. With nuclei, the EIC would be able to study and understand the highest possible gluonic density regions in nuclei and systematically test some of the recent effective field theories of QCD, which seem to indicate existence of novel features of gluonic matter, known as the Color Glass Condensate (CGC), currently only hinted at, based on results at RHIC and LHC. It will also allow us to study, the structure and dynamics of partons inside the nucleus, even before the CGC phase may be reached.

The EIC collaboration and the BNL+Jefferson Lab Managements seek the support for the EIC from the NSAC long range planning group in 2013.

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Detector Design and Physics at an Electron-Ion Collider

Rolf Ent
Jefferson Lab

EIC is the generic name for the nuclear science-driven Electron-Ion Collider presently considered in the US. Such an EIC would be the world's first polarized electron-proton collider, and the world's first $e-A$ collider. Very little remains known about the dynamical basis of the structure of hadrons and nuclei in terms of the fundamental quarks and gluons of Quantum Chromodynamics (QCD). A large community effort to sharpen a compelling nuclear science case for an EIC occurred during a ten-week program taking place at the Institute for Nuclear Theory (INT) in Seattle from September 13 to November 19, 2010. The EIC science case and the initial detector design ideas are well documented in a report on this joint BNL/INT/JLab program [1].

The critical capabilities of a stage-I EIC are a range in center-of-mass energies from 20 to 70 GeV and variable, full polarization of electrons and light ions (the latter both longitudinal and transverse), ion species up to A=200 or so, multiple interaction regions, and a high luminosity of about 10^{34} electron-nucleons per cm^2 and per second. The physics program of an EIC imposes several challenges on the design of a detector, and more globally the extended interaction region, as it spans a wide range in center-of-mass energy, different combinations of both beam energy and particle species, and several different physics processes. These encompass inclusive measurements ($ep/A \rightarrow e' + X$), which require detection of the scattered lepon and/or the full scattered hadronic debris with high precision, semi-inclusive processes ($ep/A \rightarrow e' + h + X$), which require detection in coincidence with the scattered lepton of at least one (current or target region) hadron; and exclusive processes ($ep/A \rightarrow e' + N'/A' + \gamma/m$), which require detection of all particles in the reaction. For the latter two processes, an extended range in kinematics can *only* be accessed by varying the beam energies, due to resolution issues in both the scattering kinematics and the relation of the momentum transfer vector and final hadron(s). In addition, variability in and a range of energies is needed to optimize resolution and particle identification capabilities.

The main science themes of an EIC are to i) map the spin and spatial structure of quarks and gluons in nucleons, ii) discover the collective effects of gluons in atomic nuclei, and (iii) understand the emergence of hadronic matter from color charge. In addition, there are opportunities at an EIC for fundamental symmetry and nucleon structure measurements using the electroweak probe. To truly make headway to image the sea quarks and gluons in nucleons and nuclei, the EIC needs high luminosity over a range of energies as more exclusive scattering probabilities are small, and any integrated detector/interaction region design needs to provide uniform coverage to detect spectator and diffractive products. This is because $e-p$ and even more $e-A$ colliders have a large fraction of their science related to what happens to the nucleon or ion beams. This poses challenging constraints on the fully integrated EIC detector and interaction region design.

As a result, the philosophy of integration of complex detectors into an extended interaction region is similar in both JLab and BNL designs. Both designs feature crossing angles between the protons or heavy ions during collisions with electrons. This removes potential problems for the detector induced by synchrotron radiation. Both designs allocate quite some detector space (7 and 4.5 meters, respectively) before the final-focus ion quads. This goes at the cost of luminosity, but a uniform detection coverage is a must for deep exclusive and diffractive processes. The integrated EIC detector/interaction region design at JLab focused on maximizing the acceptance for such processes over a wide range of proton energies (20-100 GeV), and has established full acceptance for reaction products with well achievable interaction region magnets. The detector design at BNL uses the higher ion beam energies to achieve good detection efficiency for instance for protons following a DVCS reaction, for proton beam energies starting from 100 GeV. BNL, in association with JLab and the DOE Office of Nuclear Physics, has also established a generic detector R&D program to address the scientific requirements for measurements at a future EIC.

[1] D. Boer, M. Diehl, R. Milner, R. Venugopalan, W. Vogelsang *et al.*, "Gluons and the quark sea at high energies: Distributions, polarization, tomography," Institute for Nuclear Theory Report on EIC Science (2011), arXiv:1108.1713 [nucl-th].

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sPHENIX upgrade at mid-rapidity

ShinIchi Esumi, Univ. of Tsukuba

During the first decade of running the PHENIX experiments, several major discoveries in Quark Gluon Plasma (QGP) properties have been reported in the ultra-relativistic heavy ion collisions at RHIC-BNL. The main results from RHIC experiments are the partonic energy loss (jet quenching) in the QGP and partonic collectivity (elliptic flow) during the pre-hadronic phase as well as the thermal photon temperature and J/psi measurements, where the PHENIX experiment including other RHIC experiments have given the significant contributions for all of these measurements. Several upgrade projects in the PHENIX experiment are currently on going in order to study the heavy quark mass dependence of these observables and to investigate more detailed properties of the QGP at RHIC energies. The beam energy scan program and colliding system size and shape dependence studies are also in progress at RHIC in order to look for an onset of 1st order phase transition, which is expected close to the critical point in the qurak-hadron phase diagram at higher baryon density that would be achieved at relatively lower energy than the top RHIC beam energy.

In order to continue the detailed investigation of QGP properties, the upgrade proposal sPHENIX experiment is now being prepared for the next decade of experimental studies at RHIC-BNL. The sPHENIX experiment mainly consists of a large acceptance (electromagnetic and hadronic) calorimeter with inner silicon tracking layers, where the primary focus of the current plan of sPHENIX experiment is the high-energy partonic jet energy loss as well as the heavy quarkonia measurements. The hadron particle identification and low pT electron, photon identification capabilities will greatly enhance the analyzing power of such critical point and phase transition signatures. Therefore these possibilities are also being investigated and discussed.

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A Holographic Thermalization

Koji Hashimoto (RIKEN)

String theory has provided a useful and new interesting tool to analyze strongly coupled gauge theories. It enabled to calculate analytically various physical observables concerning hadron physics. The problem which we are going to address in this talk is a possible derivation of the rapid thermalization at heavy ion collisions. It is expected that the thermalization time scale is $t_{\rm th} < 2$[fm/c] which means a quite rapid process. This constraint comes from hydrodynamic simulation of the quark-gluon plasma expansion.

Why is it difficult to derive this thermalization time-scale? There are two reasons: first, our QCD is strongly coupled and it goes through a phase transition from the confined phase to a deconfined phase, in the heavy ion collisions. Second, any thermalization is a non-equilibrium and time-dependent process which is quite difficult to analyze, and it is indeed difficult to even define the concept of the thermalization. These are obviously two hard causes which make the analysis difficult.

Now, a way to solve is in the AdS/CFT correspondence. For both the causes, indeed the AdS/CFT can provide a strategy. In AdS/CFT, a deconfined phase of gluons at a finite temperature is provided by a black hole geometry in the bulk. Therefore, formation of a black hole horizon is equivalent, in the AdS/CFT dictionary, to a thermalization and a deconfinement. Once one is able to describe the formation process of the black hole horizon in the bulk, it can be interpreted as a thermalization.

In our paper [1], we noted that there is a similarity to condensed matter systems where typically one can consider a process of sudden change of external parameters, such as charge density. In the heavy ion collisions, we may think of the collision process as a sudden change of the baryon number density. Idealizing the system by approximating the collision by a QCD with varying density, we can cast the question into a more tractable situation.

We performed the calculation of this system and looked at the thermalization timescale due to the sudden change of the baryon number density. The result we found is, interestingly, consistent with the above constraint for the rapid thermalization.

Although string theory techniques are not good at precision evaluation (because of the large N_c expansion) and also treating asymptptic freedom (because of the strong coupling expansion), they are on the other hand good at analytic calculations, at finite densities or with time dependence. So superstring is better applied to analyze robust features of strongly coupled QCD with time-dependence, and with density. Heavy ion collisions are the best place to be applied.

I am grateful to the organizers of the workshop for a pleasant environment for discussions.

[1] K. Hashimoto, N. Iizuka, T. Oka, "Rapid Thermalization by Baryon Injection in Gauge/Gravity Duality" Phys. Rev. **D 84**, 066005 (2011).

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Recent Results in Particle and Nuclear Physics from Lattice QCD

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Abstract

After a brief introduction to lattice QCD, its application to the structure of hadrons, interactions among hadrons and the physics of quark-gluon plasma are reviewed. Special emphasis is place on the physical point simulations which became possible recently. Future perspective of the lattice QCD simulations is also discussed.

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Theoretical status and outlook of heavy ion collisions

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Physics of the quark gluon plasma (QGP) is getting matured thanks to the successful operation of Relativistic Heavy Ion Collider (RHIC) in Brookhaven National Laboratory. Last year Large Hadron Collider (LHC) in CERN has also started its operation and already provided a lot of intriguing data in relativistic heavy ion collisions.

One of the major discoveries which has attracted much theoretical and experimental interest is that one of the anisotropic flows, elliptic flow, is as large as prediction from relativistic hydrodynamics. Since local thermalization is a key assumption in hydrodynamics, the agreement allows one to investigate the thermalized quark and gluon matter under extreme conditions by means of relativistic heavy ion collision experiments and further calls for more sophisticated framework to describe space-time evolution of created matter in terms of relativistic hydrodynamics towards precision studies of the QGP.

Later PHOBOS Collaboration at RHIC discovered an effect of initial state fluctuation originated from random configuration of nucleons inside colliding nuclei on final elliptic flow parameter. Consequently, deformation beyond ellipticity in initial states is also equally important as coefficients of higher order harmonics (v_n, $n < 7$) turn out to become finite. This challenges theoretical calculations since initial fluctuation effects require event-by-event hydrodynamic simulations.

Elliptic flow is a phenomenon which, by definition, correlates with reaction plane. Experimental flow analysis is, however, much involved in comparison with theoretical calculations since the reaction plane is known in the latter case but not *a priori* in the former case. Thus, several definitions of flow coefficients, v_n, appear in experimental papers such as $v_n\{\mathrm{EP}\}$, $v_n\{2\}$, $v_n\{4\}$, $v_n\{\mathrm{LYZ}\}$ and so on. Unfortunately, results are not the same among these definitions: Some include positive contribution of flow fluctuation, but others negative contribution. Therefore, it is of great importance to calculate flow parameters, v_n, theoretically in the same way as they are obtained experimentally. Lots of event-by-event hydrodynamic simulations have been performed so far to investigate the initial fluctuation effects. Most of them are, however, not adequate since final particle distribution calculated from the Cooper-Frye formula is smooth and continuous function even in an event and does not contain fluctuation from finite number of final particles. So either sampling of particles from smooth final distribution or further evolution using a hadronic cascade is necessary to do an event-by-event flow analysis.

We employ a hybrid model (a Monte Carlo calculation of initial conditions, full 3-dimensional ideal hydrodynamics for the QGP and a microscopic approach for the hadronic gas), perform these simulations on an event-by-event basis and demonstrate flow analysis in the same way as ATLAS Collaboration did in their flow analysis. If one wants to compare theoretical results with data within a few percent accuracy, a direct comparison using the same flow analysis method is mandatory. Towards precision studies of bulk and transport properties of the QGP, development of an event generator based on hydrodynamics in the intermediate stage in relativistic heavy ion collisions is particularly important. This would also bring more sophisticated framework to analyses of hard and/or rare probes such as jets, J/ψ, heavy quarks and thermal radiation.

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“QCD at KEKB and SuperKEKB”

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With the world highest luminosity e^+e^- collider KEKB, the Belle experiment offers opportunities for studying not only CP violation phenomena in weak interaction, but also QCD phenomenology such as the nucleon structure function and hadron spectroscopy physics.

Belle has studied spin-dependent fragmentation functions, which are necessary ingredients to deduce the transverse quark spin in the nucleon. We obtained the first evidence of the azimuthal asymmetry in the inclusive production of pion pairs, known as “Collins effect”, with $29 fb^{-1}$ data[1], and updated the results with $547 fb^{-1}$ data[2]. The measured asymmetry has been used in a global analysis to deduce the transversity PDF [3]. More recently, with $672\ fb^{-1}$ data, we have observed transverse asymmetries of charged pion pairs in opposite hemispheres, which can be used to extract the interference fragmentation function (IFF) [4]. The extracted IFF has been used in a global fit to the SIDIS data to obtain the transversity distribution function.

As for the hadron spectroscopy physics, Belle has brought discoveries of many new hadronic states, especially the charmonium-like states, known as “XYZ” mesons [5]. Recently, in $121.4\ fb^{-1}$ data taken in the vicinity of Υ(5S) resonance we observed two charged bottomonium-like states, referred to as Z_b (10610) and Z_b (10650) [6]. They are observed in the mass spectra of the π^+ - Υ(nS) (n=1,2,3) and π^+ - h_b(mP) (m=1,2) pairs that are produced in association with a single charged pion in Υ(5S) decays. They could be counterparts of the Z (4430) in the charmonium region. They are very interesting since at least 4 quarks are required to make such a charged state. We are also studying detailed properties of observed new states, such as radiative decays of X(3872) [7].

In future, the SuperKEKB/Belle II experiment will start in 2015, and will provide us opportunities to study such QCD related phenomena with much more variety and much better precision.

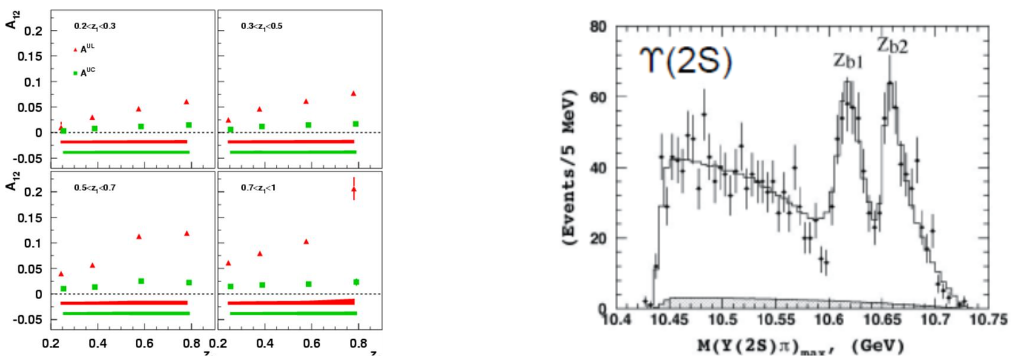

Figure: left: observed asymmetry of pions pairs [2], right: mass distribution of π^+ - Υ(2S) pairs.

References

[1] R. Seidl et al. (Belle Collaboration), Phys. Rev. Lett. 96, 232002 (2006).
[2] R. Seidl et al. (Belle Collaboration), Phys. Rev. D 78, 032011 (2008).
[3] M. Anselmino, M. Boglione, U. D’alseio, A. Kotzinian, M. Murgia, A. Prokudin, C. Turk, Phys. Rev. D 75, 054032 (2007).
[4] A. Vossen et al. (Belle Collaboration), Phys. Rev. Lett. 107, 072004 (2011).
[5] Recent review can be found in, for example, Stephan Godfrey and Stephan L. Olsen, Ann. Rev. Nucl. Part. Sci. 58, 51 (2008).
[6] A. Bondar, et al. (Belle Collaboration), submitted to Phys. Rev. Lett., arXiv:1110.2251.
[7] V. Bhardwaj et al. (Belle Collaboration), Phys. Rev. Lett. 107, 091803 (2011).

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Small-*x* phenomenology

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I gave a brief review on the recent progress towards precise understanding of the hadron cross sections at forward rapidities which effectively correspond to high-energy scattering. The recent highlight includes the use of numerical solutions to the *running-coupling Balitsky-Kovchegov (rcBK) equation*, which governs the evolution of the scattering amplitudes at high energies under the change of scattering energy. The simplest example is the deep inelastic scattering of an electron off a nucleon. One can use the numerical solutions to the rcBK equation which are evolved from certain initial conditions having several parameters to be determined. A parametrization ``AAMQS" was quite successful in describing small-*x* data at HERA. In hadron-hadron scattering at forward rapidities, one has to include the effects of gluon saturation in the target. There is a nice formula called Dumitru-Hayashigaki-Jalilian-Marian (DHJ) formula, which captured the scattering of large-*x* partons in a projectile and small-*x* partons in the target. One can again use the numerical solutions to the rcBK equation to describe the target.

Most recently, we have proposed a Monte-Carlo implementation of the DHJ formula with the forward scattering amplitude from the rcBK equation to describe forward hadron productions in high-energy nuclear collisions. We describe the target nucleus as a collection of nucleons that are randomly distributed consistently with the Woods-Saxon potential. We test initial conditions adopted in the AAMQS parametrization as well as the newly proposed one from the ``running coupling MV model". We found the theoretical calculations shows good agreement with the experimental results of deuteron-Au collision at forward rapidities.

Ref:

H. Fujii, K. Itakura, Y. Kitadono and Y. Nara, ``*Forward particle productions at RHIC and the LHC from CGC within local rcBK evolution*," J. Phys. G 38 (2011) 124125 [arXiv:1107.1333 [hep-ph]], and references therein.

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The LHCf experiment and future high energy QCD

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Recent progress in air shower observations of the highest energy cosmic rays with $\sim 10^{20}$ eV gives us an enigmatic problem about their origins and propagations. One difficulty is implication of air shower observations due to uncertainty of hadron interactions in such high energy. There are a few key quantities at the primary interaction vertices which determine the development of air showers. Among them the particle production at the very forward region plays an important role in air shower development, since it carries most of collision energy. So far there are several phenomenological interaction models such as SYBILL, QGSJET2, DPMJET3, EPOS, etc. available for air shower simulations at such high energy.

The LHCf experiment is dedicated to measure spectra of neutral particles at very forward region of the LHC collision point in order to verify cosmic ray interaction models. Proton-proton collisions at 14 TeV can provide us information for interactions of 10^{17} eV cosmic rays with air. Two pairs of electro-magnetic calorimeter, Arm1 and Arm2, with small aperture were installed at both side of 140m apart from the IP1 collision point.

Total radiation length and interaction lengths of the detector are 44 X_0 and 1.6λ, respectively. Position sensitive layers made of SciFi for Arm1 and Si strip detectors for Arm2 allow us to reconstruct incident position of particles. Those information is useful to correct shower leakage or invariant mass reconstructions of π^0 or η.

The data taking had been carried out during 2009-2010 commission phase of LHC machine with low luminosity in order to prevent radiation damage and pile-up events. The first phase of data taking at $\sqrt{s}$=0.9TeV and 7TeV has been successfully completed. The results of "inclusive" energy spectra for single gamma incident in the two rapidity ranges $8.81 < \eta < 8.99$ and $\eta > 10.94$ have been obtained from the 3.5+3.5TeV collision data. The result shows that the obtained spectra lied among the range of various models, however hardly explained by none of them.

These regions observed by LHCf is in the small P_T region less than a few 100 MeV, where non-perturbative aspects of QCD such as multi-pomeron interactions plays an important role. Possible connection to low-x physics such as colour-glass condensation is interesting. Nuclear modification effects in this region is also indispensable to understand air shower development. Future plan for very forward measurement at p-A or A-A collisions is also now being discussed.

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QCD with LHC pp collisions

Osamu Jinnouchi (Tokyo Institute of Technology)

With the superb success of the LHC runs at $\sqrt{s} = 7$ TeV for the last two years, the QCD measurements in the LHC energy regime became of a fundamental importance not only for the pure principle test of the QCD properties in high energy domain, but also for the basis in understanding the Standard Model physics precisely as a background against the new physics beyond the Standard Model before proclaiming any discovery of them. In the talk, the latest status of the LHC runs and brief overview of the ATLAS and CMS experiments, both are general purpose detectors optimized for the collider physics at LHC, were introduced. A good number of measurements from both ATLAS and CMS during the year 2010/2011 were shown. The topics covered the measurements based on the objects described by the perturbative framework. This included the signatures, those from jets, high-energy photons, and the gauge bosons, etc, which are categorized in hard scattering physics. The physics related to the soft QCD, which shows a non-perturbative nature, are also presented, where phenomenological approach and measurements play a crucial role. The category includes the measurements of event properties of minimum bias process, the multiple particle interactions in the proton-proton collisions. Finally the measurements in searching for new particle resonances in the di-jet invariant mass distribution was shown as a good example of the importance of QCD measurements at high energy.

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STAR UPGRADE OVERVIEW

J.H. LEE
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FOR THE STAR COLLABORATION

The STAR Collaboration has identified key physics questions that will drive RHIC science over the coming decade. With future detector upgrades in STAR and accelerator improvements in RHIC, a wide range of the unanswered questions will be explored and answered. Near-term upgrades in STAR, including the Heavy Flavor Tracker and the Muon Telescope Detector, will open a new door to precisely explore heavy flavor dynamics. Upgrades to the forward region will enable detailed studies of the partonic structure of nuclei and characterizations of the onset of gluon saturation. Additional upgrades planned for the latter part of the decade including backward electron reconstruction capabilities will enable STAR to make the first and significant measurements in e+p and e+A collisions in the early phase of the eRHIC.

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QCD at JLab 12 GeV

Zein-Eddine Meziani

Temple University

With the advent of the 12 GeV energy upgrade of Jefferson Lab exciting physics opportunities are presenting themselves as the project is well underway. In this presentation I sketch the physics goals of the energy upgrade and show mature examples where Jefferson Lab will have a clear impact for a deeper understanding of hadron structure and QCD. A combination of novel experimental and theoretical tools offer a compelling case of how to confront the problem of hadron structure intertwined with learning about the inner working of Quantum Chromodynamics. With the 12 GeV upgrade at least four clear scientific opportunities have been identified and are undertaken by the experimental programs of four separate Halls. Hall D, a new experimental Hall is built with the mission of exploring the origin of quark confinement by studying exotic mesons with the GlueX experiment. Hall B, is upgraded with a newly built large solid angle detector, known as CLAS12, emphasizes unraveling the three-dimensional structure of the nucleon (two dimensions in transverse position-space and one dimension in longitudinal momentum-space) using the framework of Generalized Parton Distributions (GPDs) or (three dimensional in momentum-space) using the framework of transverse momentum distributions (TMDs). In both cases the novel and sought-after structure and dynamics information is contained in the transverse position or transverse momentum of quarks in the hadron at a common longitudinal momentum for which information has been derived from a history of 30 years of investigation of hadron structure. Hall C benefits from a newly constructed Super High Momentum Spectrometer (SHMS) complementing the existing High momentum spectrometer (HMS) with the goal of a precision determination of the valence quark properties in nucleons and nuclei. Last but not least a fourth Hall, Hall A, a large installation Hall with the advantage and flexibility to accommodate a range of experiments with a variety of physics goals among them, the measurement of elastic scattering form factors at large momentum transfers, high precision parity violation experiments to test the standard model and the search for the possible dark matter force carrier (A' particle search).
In all cases whether it is exploring of the physical origins of quark confinement, newly accessing more of the spin and flavor structure of nucleons in the valence quarks region or revealing the quark/gluon structure of nuclei there are opportunities for new collaborations to participate with new proposals to contribute. While the construction is well underway the following experiments offer prospects for collaborations to join and have a strong impact in detector construction and the physics program. They are the Moller and the SoLID projects in Hall A, the A' searches experiments in Hall A and B and the RICH detectors for CLAS12 in Hall B as well as GlueX in Hall D. New proposals and collaborations are most welcome.

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Status and outlook of COMPASS experiment

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for the COMPASS experiment

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The COMPASS experiment has studied the nucleon spin structure using the 160 GeV polarized muon beam with the polarized NH_3 or ^{6}LiD target at CERN SPS. Inclusive measurements of deep inelastic scattering (DIS) determined the quark spin contribution to the proton spin as $\Delta\Sigma = 0.35 \pm 0.03 \pm 0.05$ and semi-inclusive measurements decomposed it into each quark flavor. The polarization of gluon was also determined by the measurements of high-pt hadrons or open charm production.

Measurement with the transversely polarized targets provided a unique tool to access transverse momentum dependent PDF (TMD). Azimuthal amplitudes of the single spin asymmetry, which arise from TMDs in conjunction with fragmentation functions, were determined for the proton and deuteron. The consistent results of Sivers and Collins amplitudes to the preceding measurements by the HERMES experiment were obtained.

COMPASS II proposal accepted by CERN SPS includes two new programs for the proton spin puzzle. Measurement of pion induced Drell-Yan process with the transversely polarized NH_3 target will be carried out for the first time in 2013. The azimuthal amplitudes of cross section asymmetry allow to access TMD without the hadron fragmentation. Measurements of TMD in Drell-Yan and DIS with the same experimental apparatus at COMPASS will verify the sign difference of naive T-odd TMDs, such as Boer-Mulders and Sivers, in the different processes predicted in QCD.

In GPD program in 2014 and 2015, hard exclusive production of real photon or meson will be measured using a polarized muon beam and an unpolarized liquid hydrogen target with Recoil Proton Detector. The beam charge and spin sum or difference of the cross sections allows to access Generalized Parton Distribution (GPD) which provides information on the transverse localization of a parton as a function of the longitudinal momentum fraction. COMPASS covers kinematic region between the electron proton collider experiments at HERA and the lower energy fixed target experiments at DESY and JLab.

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Future Challenges of Relativistic Heavy Ion Physics

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After a decade of experiments in relativistic heavy ion collisions at RHIC, the investigation of the quark-gluon plasma is in a transition from the discovery phase to to the precision measurement phase. The main discoveries of the past decade are the nearly inviscid character of hot QCD matter, its high opacity to energetic colored probes, and the valence quark scaling of the elliptic flow, indicating collective flow at the parton level prior to hadronization. The "big" questions now facing the field include:

- What makes the quark-gluon plasma behave as a "perfect" liquid with shear viscosity near the quantum bound? It is clear that this property requires strong coupling, but can we be more quantitative?
- What is the (color) structure of the quark-gluon plasma near T_c? Are there any well defined quasi-particles?
- We know that QCD becomes weakly coupled at short distance scales, but at which scale does the transition between weak and strong coupling occur in the quark-gluon plasma?
- How does the parton structure of colliding nuclei manifest itself in the quark-gluon plasma? How does it influence the initial energy density, the transverse profile of the fireball, and the magnitude and number and size of initial state density fluctuations?

Important quantities that can be used to quantitatively characterize the quark-gluon plasma include: its equation of state $P(\varepsilon)$ or the speed of sound c_s^2, the chromo-electric screening mass $m_{\rm D}$, the shear viscosity η, and the two "jet quenching" parameters $\hat{q}$ and $\hat{e}$ characterizing radiative and elastic energy loss of a fast parton. At the moment, lattice QCD is able to provide precise results for the equation of state and the screening mass, but not for the shear viscosity and the jet quenching parameters, because these characterize non-equilibrium processes. At present, these must be obtained from comparison with experimental data.

Comparison model calculations of elliptic flow (v_2) using event-by-event fluctuating viscous hydrodynamics and hadronic Boltzmann transport with RHIC data from Au+Au collisions have set a tight limit $1 \leq 4\pi\eta/s \leq 2.5$ on the shear viscosity of the quark-gluon plasma, depending on the initial transverse density profile. This is nicely confirmed by triangular flow (v_3) data. Measurements of v_2 and v_3 in Pb+Pb collisions at LHC have confirmed that the quark-gluon plasma created at these higher energy densities has almost identical fluidity. The most pressing challenges are now the constraint of the transverse profile and the check of system independence of the value of η/s. The measurement of angular correlations due to event-by-event fluctuations may also provide independent ways to determine η/s and c_s experimentally.

The study of the opaqueness of the quark-gluon plasma has recently gained access to many new observables through the reconstruction of full jets. This will make it possible to explore the mechanism of parton energy loss and the transport of the energy-momentum carried by radiated gluons in much more detail. The LHC data on R_{AA} and the di-jet asymmetry appear to be describable in the frameworks of jet quenching developed to describe the RHIC data. However, a major difference between jet quenching at RHIC and LHC is that in the p_T range of the LHC the primary parton's virtuality is mostly vacuum dominated, while it is dominated by rescattering in the medium in the p_T range accessible at RHIC. This may explain why the jet fragmentation looks like vacuum fragmentation even when the jet has lost more than half its energy in Pb+Pb events at LHC.

Important challenges are: What are the density and length dependence of parton energy loss, and its color and flavor dependence? What happens to the lost energy, is it scattered to larger cone angles, or is it thermalized? At what scale Q^2 does a jet in the quark-gluon plasma becomes strongly coupled? Can the event-by-event fluctuations of the flow anisotropy be used to perform true jet tomography on locally inhomogeneous density profiles?

The study of color screening by its effect on heavy quarkonia is another important challenge. While charmonium suppression has been observed in all collision systems, its dependence on kinematic parameters currently does not fit into a consistent scheme. Recombination may contribute significantly at the LHC, but this has not yet been clearly demonstrated. Precision data in different systems and energies below the top RHIC energy, as well as in d+Au collisions will be essential to resolve the open questions. Recent theoretical progress on the theory of charmonium suppression shows that inelastic interactions of heavy quarks with the medium are an integral component of the suppression mechanism. Quarkonium suppression and heavy quark energy loss must therefore be understood together.

In order to address these challenges, RHIC will need detectors with large acceptance, excellent particle ID, and the capability to perform high quality jet measurements. The high integrated luminosity and collision system flexibility of RHIC will be strong assets in this physics program.

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sPHENIX Upgrade for Forward Rapidity

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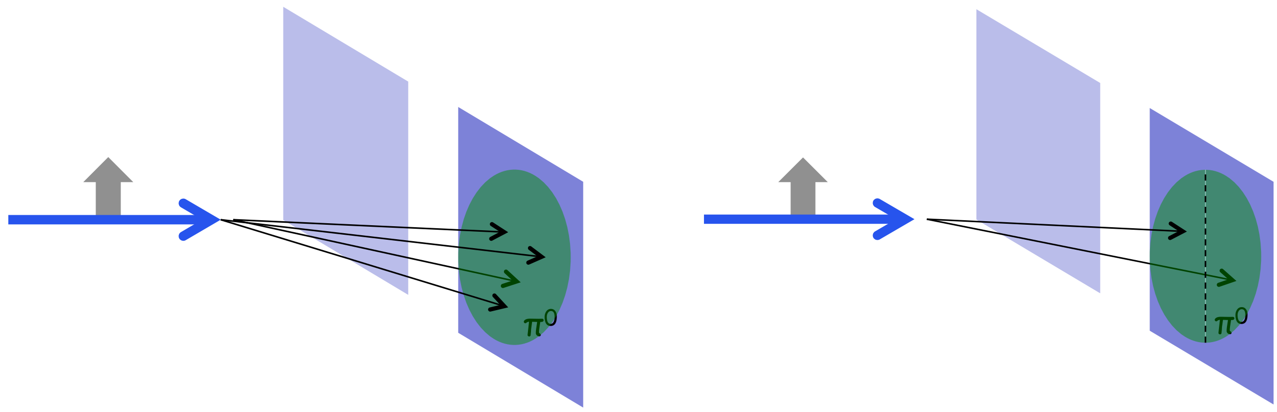
Based on the present sPHENIX design concept, i.e. compact and hermetic coverage, the basic idea of the sPHENIX forward detector is designed to cover as large rapidity as $1 < y < 4$ with EM and hadron calorimetries in addition to tracking capability and a RICH detector with momentum threshold of electrons around 10 GeV. One of the major questions of nucleon spin structure is the dynamical origin of spin dependent interactions. The large transverse single-spin asymmetries (SSAs) have been observed in the existing forward experiments. However many of these observables appear in the combination between initial (Sivers) and final (Collins) state effects. The new forward design with the detection capability of jets will address the question. These effects can be separately observed by measuring not only left-right asymmetries of a jet axis with identified particles (left panel below) but also the their asymmetries inside the jet (right panel below), respectively.



Another interesting topic to be addressed by the forward sPHENIX is the theoretical prediction of SSAs that the attractive final-state interaction in SIDIS becomes repulsive initial-state interaction in the DY production of the virtual photon. This fact is independent of pQCD approach. This opposite force appear as the observable sign flip between the analyzing powers of DY and SIDIS providing unique opportunity for the forward sPHENIX to stringent test of pQCD. The DY process is to be detected by the EM calorimeters and its heavy flavor background processes to be suppressed using the forward vertex detectors (FVTX) for DY invariant masses $4 < M < 10$ GeV.

Taking advantage of hermetic coverage of the acceptance, the gluon spin measurement is to be attacked via correlation measurements. Such measurements provide a much better handle on the parton kinematics and are therefore a very useful tool for constraining the shape of the polarized parton distributions. Extension to lower-x region is also important.

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Hadron physics at J-PARC

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First hadron beam for experiment has been delivered from Japan Proton Accelerator Research Complex(J-PARC) to the hadron experimental facility (Hadron hall) since February 2009[1]. The main feature of the J-PARC facility is that the world highest beam intensity will be available once the accelerator reaches its design intensity. Thus the new facility opened new era for the hadron physics which cannot be accessible due to limited beam intensity available at old facility.

The main goal we are focusing on the hadron physics which planning to perform at J-PARC can be expressed as explored rich phenomena induced by QCD at low energy region where perturbative QCD cannot be applied. Three main topics are in front of us. First one is to understand the mechanism of "confinement" *i.e.* how the colored object, quarks and gluons, are sticking together and forming color singlet object. We believed that we will be able to extract those information or hints from spectroscopy of exotic hadrons. Especially, the detail investigation for the penta-quark state, Θ^+, is urgent and very important topics at J-PARC[2, 3].

Another topics is to understand origin of hadron mass. As we know that the mass of the contribution of the constituent quarks to the mass of the hadron is only a few % at most. The question need to be answered is the mechanism to generate more than 90% of the hadron mass from vacuum. This mechanism is now known as spontaneous breaking of chiral symmetry, which create non zero $\langle \bar{q}q \rangle$ expectation value in vacuum. In the theoretical framework, the $\langle \bar{q}q \rangle$ expectation value (chiral order parameter) is a function of temperature and chemical potential (density). Various experimental studies have been performed to detect the restoration of the chiral symmetry. However, no conclusive evidence have not been observed yet. At J-PARC, new experiments has been proposed to search for the signal form partial restoration of chiral symmetry in high density matter. Here, normal nucleus is used for the laboratory for high density matter, and mesons[4], *i.e.* ω[5], ϕ[6], and η' are embedded in to nucleus as a probe of partial restoration of chiral symmetry, which lead to the mass reduction of the embedded meson. Those experimental programs have already been approved and the preparation to perform the experiments are under the way.

Final topics which can be achieved at J-PARC is to investigate property of nuclear matter using charmed baryons and charmed mesons. Because mass of the charm quark is too heavy compared with contents of normal nuclear matter, namely u and d quarks, interaction between heavy quark and light quark will be negligible, which is known as heavy quark symmetry. Thus, if we success to embed charmed meson, D meson $(Q - \bar{q})$ for example, we will have a chance to investigate interaction of $\bar{q}$ with nuclear matter. Physics ideas for the measurement have been discussed deeply, however, beam line to perform the experiments are not available in the current facility. To realize those experiments, extension of the hadron hall is mandatory and the project is now under the discussion.

References

[1] J-PARC press release; http://www.kek.jp/intra-e/press/2009/J-PARC50GeV2.html
http://www.kek.jp/intra-e/topics/2009/J-PARChadronK18BL.html

[2] E19 proposal; http://j-parc.jp/researcher/Hadron/en/pac_0606/pdf/p19-Naruki.pdf

[3] LoI; http://j-parc.jp/researcher/Hadron/en/pac_0606/pdf/p09-Nakano.pdf

[4] E16 proposal; http://j-parc.jp/researcher/Hadron/en/pac_0606/pdf/p16-Yokkaichi_2.pdf

[5] E26 proposal; http://j-parc.jp/researcher/Hadron/en/pac_0903/pdf/Ozawa.pdf

[6] E29 proposal; http://j-parc.jp/researcher/Hadron/en/pac_0907/pdf/Ohnishi.pdf

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Theoretical status and outlook of spin physics

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Study of the hadronic structure is one of the main goals of modern nuclear physics. A lot of information has been gained by studies of conventional parton distribution function (PDFs) and fragmentation functions (FFs). These distributions depend on the fraction x of proton's momentum carried by the parton or parton momentum fraction z carried by the produced hadron. Apparently these distributions do not give us information on spatial or transverse momentum distributions of partons in a hadron which is an extended object in space, partons are confined inside of the hadron and thus must have transverse motion.

Collinear theory gives a description of spin structure of the hadron in term of helicity distributions and a well known "spin crisis" is still actual today. In particular there is no definite answer to the total gluon contribution ΔG to the spin.

Spin sum rule can be formulated in terms of so called Generalized Parton Distributions (GPDs) and connect total angular momentum carried by quarks and gluons to particular moments of GPDs.

GPDs describe spatial distributions of partons and can be accesses in hard exclusive reactions such as Deeply Virtual Compton Scattering or exclusive meson production. GPDs are related to the following bilocal matrix element

$$\int \frac{d\xi^-}{(2\pi)} e^{ip\cdot\xi} \langle P', S_{P'}|\bar{\psi}_j(0)\,\mathcal{U}^{n_-}_{(0,\xi)}\,\psi_i(\xi)|P,S_P\rangle\Big|_{\xi^+=0,\xi_T=0} \tag{1}$$

Eight GPDs parametrize the leading twist part of the matrix element of Eq. (1). By Fourier transform they can be related to distributions in impact parameter space b_T.

Transverse Momentum Dependent Distributions (TMDs) describe the spin structure of the proton in momentum space. TMDs depend on two independent variables: fraction of hadron momentum carried by parton, x, and intrinsic transverse momentum of the parton, $\mathbf{p}_T$. At leading twist spin structure of spin-1/2 hadron can be described by 8 TMDs. TMDs reveal three-dimensional distribution of partons inside polarised nucleon. Experimentally these functions can be studied in polarised experiments using Spin Asymmetries in particular Single Spin Asymmetries (SSAs).

TMDs originate from the following bilocal matrix element:

$$\int \frac{d\xi^- d^2\xi_T}{(2\pi)^3} e^{ip\cdot\xi} \langle P, S_P|\bar{\psi}_j(0)\,\mathcal{U}^{n_-}_{(0,+\infty)}\,\mathcal{U}^{n_-}_{(+\infty,\xi)}\,\psi_i(\xi)|P,S_P\rangle\Big|_{\xi^+=0} \tag{2}$$

One realizes that generalization of GPDs and TMDs can be done via so called Wigner distribution and one can define an object

$$\int \frac{d\xi^- d^2\xi_T}{(2\pi)^3} e^{ip\cdot\xi} \langle P', S'_P|\bar{\psi}_j(0)\,\mathcal{U}^{n_-}_{(0,+\infty)}\,\mathcal{U}^{n_-}_{(+\infty,\xi)}\,\psi_i(\xi)|P,S_P\rangle\Big|_{\xi^+=0} \tag{3}$$

which corresponds to such distribution. It is not known at present if Wigner distribution can be studied directly by some process, however having such a common origin for GPDs and TMDs is a very promising fact for search of relations betweend those.

A lot of progress has been done recently both for GPD and TMD theory and henomenology. NLO evolution is very well known for GPDs and knowledge emerges for TMDs. Experimental data allow for extraction of these distributions and we alreay gained a lot of information.

New experimental data coming from RHIC, JLAB, CERN and EIC will boost our understanding of the hadron structure. New theoretical developments in understanding relation of distributions to fundamental quantities such as Orbital Angular Momentum and development of new Spin Sum rules will certainly be done in future.

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eA physics at an electron-ion collider

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Almost all the mass of visible matter in our universe is carried by nuclei, which are made of protons and neutrons - known as nucleons, while the nucleons themselves are not elementary and are believed to be made of quarks and gluons. Quantum Chromodynamics (QCD) is the theory that describes the dynamics of quarks and gluons, so as the properties of nucleons and nuclei.

After almost 40 years since QCD was introduced, although it has been very successful in interpreting the data in high energy collisions, we still do not know exactly how quarks and gluons are bounded together to form the nucleons and then the nuclei. Unlike the atom, which is made of electrons and a tiny (about five orders of magnitude smaller in size) but very heavy nucleus that carries almost all mass of the atom, the nucleon is unlikely to have any heavy mass centers and localized charges since the gluon is massless and the current quark mass is about three orders of magnitude smaller than the nucleon mass. The quarks and gluons are likely zooming around each other at the speed of light, and yet, confined to form the nucleon. Unlike the molecule, which are made of atoms and have almost stable and localized masses centering at the nuclei with electrons occupying the vast space between the mass centers, the nucleus does not have the localized charge and heavy mass centers. Nucleons seem to be packed close together with short-range effective forces to form the nucleus. We understand the electromagnetic charge carriers: the nuclei and the electrons make up the atoms and molecules, the building blocks of all known visible matter in our universe. But, it has been a real challenge to understand the structure of nucleons and nuclei in terms of quarks and gluons!

It would be a great help to have a femtoscope, or even better to have an attoscope to "see" the quark-gluon structure of nucleons and nuclei, to explore the dynamics that confines the quarks and gluons, and ultimately, to understand the origin of the visible matter in our universe one-step beyond the molecules and atoms.

It is great to have a workshop on "Future directions in high energy QCD", organized by RIKEN, to explore the future opportunities in our quest for understanding QCD and the origin of the visible matter in our universe. I am delighted to be a part of the effort. In my talk, assigned to concentrate on "eA physics at an Electron-Ion Collider (EIC)", I will argue that the proposed EIC, the first electron-ion collider in the world, could be the much needed "scope" to "see" the quarks and gluons inside a nucleon or a nucleus at a distance scale from 1/10th of a femtometer to the tens of attometers, and could open a new era of nuclear physics: the quark-gluon nuclear physics.

The importance and the physics reach of the proposed EIC was recently summarized in a report (D. Boer *et al.*, arXiv:1108.1713 [nucl-th]) following the INT workshop on "Gluons and the quark sea at high energies: distributions, polarization, tomography". In my talk, I will explore the opportunities of an eA program at the proposed EIC. The EIC will give us the first real opportunity to cleanly "see" gluons via the better measurement of the longitudinal structure function, F_L. I will argue why the gluon recombination and the saturation phenomena are the consequences of the non-linear QCD dynamics and ought be existed, and the EIC with a heavy ion beam gives the best opportunities to reach and to explore this new domain of non-linear dynamics. I will demonstrate that as a collider, the semi-inclusive deeply inelastic scattering (SIDIS) at the EIC provides the natural and ideal two-scale observables to explore the 3D motion of quarks and gluons inside a nucleon and a nucleus, from which we have the opportunities to explore the color correlation, density fluctuation, and other quantum phenomena inside a nucleus. With the capability of measuring diffractive scattering, the EIC could provide the first picture of 2+1D spatial image of quarks and gluons inside a nucleus, as a "scope" that we have been dreaming of!

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eRHIC Design and R&D

Thomas Roser, BNL

eRHIC is a future Electron-Ion Collider (EIC) based on the existing Relativistic Heavy Ion Collider (RHIC) hadron facility with its two intersecting superconducting rings, each 3.8 km in circumference. RHIC itself is in the middle of a luminosity upgrade that will result in luminosities that are more than ten times the original design luminosity.

We plan to add a polarized 5-30 GeV electron beam to collide with a number of ion species in the existing RHIC accelerator complex, from polarized protons with a top energy of 250 GeV to fully-stripped heavy ions with energies up to 100 GeV /u. Using the present significant margin of the RHIC superconducting magnets one could increase the maximum beam energy by 10 or more percent.

The eRHIC design is based on using one of RHICs hadron rings and a multi-pass Energy Recovery Linac (ERL). Using an ERL as the electron accelerator assures high luminosity in the 10^{33} - 10^{34} cm^{-2} s^{-1} range. Locating the ERL inside the RHIC tunnel allows for a natural staging: the energy can be increased from the initial 5 GeV of the first stage to the final 30 GeV by incrementally adding additional accelerating cavities to the two linacs. eRHIC will be able to provide electron-hadron collisions in up to three interaction regions.

To reach the required performance, eRHIC will employ several novel technologies such as a polarized electron gun delivering a current of 50 mA, strong hadron beam cooling using coherent electron cooling (CeC), a high current multi-pass energy-recovery linac, and acceleration of polarized He-3 to high energy. BNL, in collaboration with JLab and MIT, is pursuing a vigorously R&D program to address these technical challenges.

The production of polarized He-3 beams can be accomplished with the new Electron Beam Ion Source (EBIS) and first tests of production and acceleration of polarized He-3 is planned for the near future. In addition to its application for eRHIC polarized He-3 beams could also be used in high energy polarize p-He3 collisions in RHIC.

The concept of coherent electron cooling will be tested in 2014 with 40 GeV/n gold beams. If successful coherent electron cooling could be implemented in both RHIC rings. Strongly cooled RHIC beams could allow for very high, polarized proton luminosities of up to 5 x 10^{33} cm^{-2} s^{-1}.

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Heavy ion physics with PHENIX upgrades

Takao Sakaguchi

The PHENIX detector system has continuously been upgraded since its start of running. There are major upgrades for the next five years (and last two years), which include hadron blind detector (HBD), resistive plate chamber (RPC), muon trigger electronics, silicon vertex detector (VTX), forward vertex detector (FVTX) and muon piston calorimeter extension (MPC-EX). HBD was installed in RHIC Year-9 and 10 runs in order to reduce the electron background from photon conversions and Dalitz decays, for the $\rho/\varpi/\phi$ measurement. The initial results from Run-9 p+p show the signal to background in the $\rho/\varpi/\phi$ region is improved as expected. The analysis for Run-10 Au+Au is on-going and making a good progress. VTX was installed in Year-11 run, successfully commissioned in 500GeV p+p running, and took good physics data in two weeks period out of 200 and 27GeV Au+Au running. The VTX detector is now de-installed for repair and integrating with FVTX. The large suppression of electron yields and strong elliptic flow of electrons in Au+Au collisions are long standing puzzles yet to be understood, and both VTX and FVTX detectors are mainly for disentangling the puzzles by identifying electrons from b and c-quarks from their decay vertices. RHIC has a large flexibility in its operation, and can run p+A, A+A, and asymmetric system such like Cu+Au at various energies. We could explore critical end point in the QCD phase diagram with RHIC. One should not forget that photons are very important in the sense that they escape the system unscathed once produced, and thus they can carry out the dynamical information of the state. RHIC is a suitable place to measure soft (low pT) direct photons primarily coming from QGP phase, because the yield of photons produced by the interaction of medium partons and hard partons may still be low. PHENIX has measured low pT direct photons and their elliptic flow both by real photons and their internal conversions. It was confirmed from the data that in Au+Au collisions, there is significant enhancement of photon yield at low pT compared to the ones produced in hard scattering process and cold nuclear matter effect. The statistics is yet to be accumulated to make a firm conclusion, especially on the elliptic flow of the photons. One may want to explore another degree of the freedom in photon measurement. One another degree is rapidity. The particles, including photons, measured in forward rapidities may shed light on the early times of the collisions (e.g. pre-equilibrium state), and therefore would give a new information on time evolution scenario. Another aspect on the higher rapidity measurement is a new method of critical point search. From the BRAHMS measurement, it was found that the higher rapidity region would have higher baryon chemical potential. Utilizing this fact, one could explore QCD phase diagram by keeping the same beam energy. PHENIX is planning to build MPC-EX detector in forward region to measure π^0/photons. It would be interesting to see if one can measure photons in forward region by adjusting the position of MPC-EX in A+A collisions.

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Spin physics with PHENIX upgrades

Ralf Seidl

The PHENIX experiment at the relativistic heavy Ion Collider RHIC has been successfully contributing to the quest of understanding the spin structure of the nucleon. It has also a history of continually improving the detector capabilities with new upgrades. In particularly in the last few years, three upgrades have been installed or are currently being installed. Mostly dominated by the requirements to separate charm and bottom quark related processes in heavy ion collisions two silicon vertex detectors have been created. The first is covering the central rapidities at almost 2 Pi in azimuth using two layers of Silicon Pixel detectors and two layers of Silicon Strip detectors read out two-dimensionally. The second silicon vertex detector covers the acceptance of the PHENIX muon arms (1.2<eta<2.4). Apart from the general improvements in the actual primary vertex reconstruction these two detectors can also help the PHENIX measurements dedicated to understand the gluon spin contribution to the nucleon via improved acceptance for gamma-hadron correlation measurements as well as heavy flavor detection. In addition the forward detector will help to reduce the hadron background in the forward W to muon measurements.

The other large PHENIX upgrade is generally geared towards spin physics. One goal of the RHIC spin physics program is to measure the polarization of sea quarks in the nucleon via W production. Thanks to the parity violating nature one is directly sensitive to the quark and antiquark helicities and the charge of the produced W separates the quark flavors. As PHENIX is not a hermetic detector one relies on the leptonic W decays to measure the resulting single spin asymmetries. At forward/backward rapidities PHENIX can detect the decay muons. However, as the bulk of background muons gets created at smaller transverse momenta but are much more abundant a new, momentum sensitive trigger needed to be developed.   This trigger upgrade consists of fast readout of the muon tracking system for a trigger decision as well as the addition of two planes of resistive plate counters. Both systems were installed before the 2011 500 GeV Proton-proton run and were commissioned at the beginning of the run. Using this new trigger it was possible to sample essentially the full luminosity for which PHENIX was taking data in both muon arms which amounts to about 17 pb-1 in a 30cm vertex region. The analysis of the data is ongoing with a good description of the signal and background processes contribution to the single muon spectrum reached. Once the signal to background ratio is finalized the corresponding single spin asymmetries will

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be extracted. This first run will give a first indication of the quark and antiquark helicities, but as stated in the RHIC spin plan a total of at least 300 pb^{-1} is expected which is will be collected over the next several years.

In addition to these upgrades also a new detector at very forward rapidities is being considered to allow to study the transverse spin structure and disentangle the difference effects causing the observed large transverse single spin asymmetries.

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QCD at energy frontier: from HERA to the LH*e*C

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In the last one hundred years after Rutherford's discovery of the nucleus, a lot of knowledge has been accumulated on the structure of the matter. The discovery of partons inside the nucleon and their identifications to the quarks and gluons were breakthroughs in the middle of the 20th century. In 1992, HERA, the first *ep* collider, began to be operational with the centre-of-mass energy about 300 GeV; more than one order of magnitude larger than the previous experiments. HERA has been exploring the structure of the proton and QCD dynamics at the highest precisions. The rapid rise of the gluon density at low-x was discovered at early running period. The perturbative QCD amazingly explains the evolution of the structure functions for the wide range of Q^2. The structure functions of the proton were measured very precisely, which are also precious inputs on searches of the new physics at the LHC. Yet, still many un-answered questions are left including where the saturation at low-x starts, what are the flavour compositions of the proton, etc.

The LH*e*C is the successor of HERA toward the energy frontier and luminosity frontier in *ep* (and *eA*) collisions. The design study has been done extensively during three 'Divonne Workshops' held in 2008-2010. The draft CDR is ready and accessible from http://cern.ch/lhec. Currently it is being circulated among the referees. Simultaneous running of LHC and LH*e*C appears feasible and is important to complement the LHC physics.

The LH*e*C delivers a 2-pronged approach on the study of the parton saturation; its lower x reach and the higher parton density. Having the higher centre-of-mass energy than HERA, x_{min} reachable at the LH*e*C is ten times lower. The density of the parton is roughly proportional to $A^{1/3}$ so that, in electron-lead collisions, the parton density is about 6 times more than the case in the *ep* collisions. Having these two parameters, the mechanism of the saturation (if it happens) can be better investigated.

It is very demanding for experimentalists to measures the low-x region where both the scattered electron and hadronic system are highly boosted toward the electron beam direction. The high energy electron beam at the LH*e*C is the very intense source of photons, which generate many background particles. In detector design, one needs to handle four beams; i.e. the colliding beams, photon beam from the synchrotron radiation, and non-colliding proton (or heavy ion) beam used by the LHC experiments. The basic design of the detector to cope with the difficulties is described in the CDR.

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e+A Experiments at an Electron Ion Collider

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The probing of nuclei and nucleons via deep-inelastic and diffractive processes in the high-energy (low-x) regime will open a new precision window for the investigation of the gluonic structure of matter. Studies of *ep* collisions at HERA and especially *d*Au collisions at RHIC have found tantalizing hints of saturated gluon densities, a phenomenon with substantial impact on the physics of heavy-ion collisions. Unveiling the collective behavior of densely packed gluons under conditions where their self-interactions dominate will require an Electron-Ion Collider, a new facility with capabilities well beyond those of any existing accelerator.

A remarkable property of strongly interacting particles is that the small x part of their wave function is dominated by gluons. The rapid growth in gluon densities with decreasing x is understood to follow from a self-similar Bremsstrahlung cascade where harder, large x, gluons successively shed softer daughter gluons. It is this gluon-rich part of the hadron wave function that controls the high energy limit of QCD. At large x and/or large Q^2, the properties of quarks and gluons are described by the linear evolution equations DGLAP (along Q2) and BFKL (along x). However, they fail to describe the low-x region at moderate Q^2, violating unitarity in the high-energy limit; they are not applicable in the non-perturbative very low-Q^2 domain. The non-linear, small-x renormalization group equations, JIMWLK and its mean field realization BK, solve these issues by propagating non-linear effects (e.g. recombination into harder gluons) to higher energies leading to saturation. The onset of saturation and the properties of the saturated phase are characterized by a dynamical scale Q^2_S which grows with increasing energy (smaller x). The nature of gluon saturation at high energies is *terra incognita* in QCD.

A naive argument of the A-dependence of the saturation scale for nuclei gives $(Q^A_S)^2$ $A^{1/3}$. This dependence, including a realistic impact parameter dependence, is supported by more detailed studies. They show that collisions with nuclei probe the same universal physics as with protons at values of x at least two orders of magnitude lower (*i.e.* an order of magnitude larger $\sqrt{s}$). Thus the nucleus is an efficient *amplifier* of the universal physics of high gluon densities allowing us to study the saturation regime in *e*A at significantly lower energies than would be possible in *ep*.

In Fall of 2010, a ten week workshop on “Gluons and the quark sea at high energies” was held at the INT in Seattle. It’s goal was to articulate the theoretical motivation for an EIC and to compare those goals with reality by examining the sensitivities of simulated experiments. One of the outcomes was the identification of a small number of key measurements whose ability to extract novel physics is beyond question. In my talk I will discuss these “golden” measurements in *e*A and present some of the related ongoing feasibility studies and how they affect the requirements on machine and detectors.

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Future Challenges of Spin Physics

Feng Yuan
Lawrence Berkeley National Laboratory

1. Ultimate goal is to fulfill the proton spin sum rule $\frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + L$
   1. Quark spin has been well determined from inclusive DIS measurements. However, we don't know yet how large the sea quark spin contribution. Currently, the global fit found about 6% with large uncertainties. It will be crucial to constrain this contribution in future experiments, such as RHIC and EIC.
   2. Gluon spin was not so well constrained so far. There have been recent hint that it is sizable. An important consequence would be the strong Q-dependence for this part of spin contribution, which can be tested in future EIC experiments.
   3. Bothe quark and gluon orbital angular momenta can be, in principle, extracted from the relevant generalized parton distribution functions. However, current experiments are not sufficient to determine either of them. A dedicated program at Jlab upgrade and EIC would be very much needed to finalize these contributions
2. Study QCD dynamics is very important to understand the nucleon structure associated with the spin
   1. Scale dependence of the spin contributions. In particular, the gluon helicity and orbital angular momentum contribution parts
   2. Recent years, it has been realized that the transverse spin phenomena are closely related to the important QCD dynamics in hadron physics: such as the factorization, and the universality of the parton distribution and fragmentation functions. Future experiments in DIS and Drell-Yan lepton pair production shall provide important information on these physics.
3. Nucleon tomography
   1. Important message we can unveil from spin physics study is to map out the internal structure of partons in nucleon through various parton distributions: TMDs, GPDs, …
   2. Wigner distributions of quarks and gluons help us to map the 3-dimension imaging of partons in nucleon
   3. These distributions have close relation to what have been explored in the small-x physics with saturation phenomena.

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Thursday 20 October 2011

Overview (I) (20 October 09:00-10:30)

- Conveners: Goto, Yuji

time	title	presenter
09:00	Opening address (00h20')	EN'YO, Hideto
09:20	Experimental status and outlook of heavy-ion physics at RHIC (00h30')	BATHE, Stefan
09:50	Future challenges of heavy-ion physics (00h40')	MUELLER, Barndt

coffee break (10:30-10:50)

Overview (II) (20 October 10:50-12:40)

- Conveners: Seidl, Ralf

time	title	presenter
10:50	Experimental status and outlook of spin physics at RHIC (00h30')	BOYLE, Kieran
11:20	Theoretical status and outlook of spin physics (00h40')	PROKUDIN, Alexei
12:00	Future challenges of spin physics (00h40')	YUAN, Feng

lunch (12:40-13:40)

RHIC upgrade (I) (20 October 13:40-15:30)

- Conveners: Deshpande, Abhay

time	title	presenter
13:40	PHENIX upgrade overview (00h40')	JACAK, Barbara
14:20	STAR upgrade overview (00h40')	LEE, J.H.
15:00	Heavy-ion physics with PHENIX upgrades (00h30')	SAKAGUCHI, Takao

coffee break (15:30-15:50)

RHIC upgrade (II) (20 October 15:50-17:40)

- Conveners: Shibata, Toshi-Aki

time	title	presenter
15:50	Spin physics with PHENIX upgrades (00h30')	SEIDL, Ralf
16:20	sPHENIX upgrade at midrapidity (00h40')	ESUMI, Shinichi
17:00	sPHENIX upgrade at forward rapidity (00h40')	NAKAGAWA, Itaru

Friday 21 October 2011

Theory (I) (21 October 09:00-10:20)

- Conveners: Hatsuda, Tetsuo

time	title	presenter
09:00	Theoretical status and outlook of heavy-ion (00h40')	HIRANO, Tetsufumi
09:40	Theoretical status and outlook of small-x (00h40')	ITAKURA, Kazunori

coffee break (10:20-10:40)

Experiment (I) (21 October 10:40-12:20)

- Conveners: Nakagawa, Itaru

time	title	presenter
10:40	QCD at JLab-12GeV (00h40')	MEZIANI, Zein-Eddine
11:20	Status and outlook of COMPASS experiment (00h30')	MIYACHI, Yoshiyuki
11:50	QCD at J-PARC (00h30')	OHNISHI, Hiroaki

lunch (12:20-13:20)

Experiment (II) and EIC Overview (21 October 13:20-15:20)

- Conveners: Torii, Hisayuki

time	title	presenter
13:20	QCD with LHC pp collision (00h40')	JINNOUCHI, Osamu
14:00	Heavy-ion experiments at LHC (00h40')	COLE, Brian
14:40	EIC project overview (00h40')	DESHPANDE, Abhay

coffee break (15:20-15:40)

Electron Ion Collider (I) (21 October 15:40-17:40)

- Conveners: Saito, Naohito

time	title	presenter
15:40	detector design and physics at EIC (00h40')	ENT, Rolf
16:20	Spin physics at EIC (00h40')	BURKARDT, Matthias
17:00	eA physics at EIC (00h40')	QIU, Jianwei

Dinner at RIKEN cafeteria (18:00-20:00)

Saturday 22 October 2011

Theory (II) and Experiment (III) (22 October 09:00-10:20)

- Conveners: Koike, Yuji

time	title	presenter
09:00	Approach to non-perturbative QCD with AdS/CFT (00h40')	HASHIMOTO, Koji
09:40	LHCf experiment (00h40')	ITOW, Yoshitaka

coffee break (10:20-10:40)

Experiment (IV) (22 October 10:40-12:00)

- Conveners: Miyachi, Yoshiyuki

time	title	presenter
10:40	QCD at KEKB and Super KEKB (00h40')	IIJIMA, Toru
11:20	QCD at HERA and LHeC (00h40')	TOKUSHUKU, Katsuo

lunch (12:00-13:00)

Electron Ion Collider (II) (22 October 13:00-15:00)

- Conveners: Akiba, Yasuyuki

time	title	presenter
13:00	eA experiment at EIC (00h40')	ULLRICH, Thomas
13:40	eRHIC design and R&D (00h40')	ROSER, Thomas
14:20	MEIC design and R&C (00h40')	HUTTON, Andrew

List of participants

Last name	First name	Affiliation
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Li Keran

Nuclei as heavy as bulls
Through collision
Generate new states of matter.
T.D. Lee

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