Recommendations
Brookhaven National Laboratory
Nuclear and Particle Physics
Program Advisory Committee
March 29-30, 2007

1. Responses to Presentations

On Mar. 29, 2007, the PAC heard updates of the monopole search and deuteron EDM experiments first addressed at the Sept. 2006 PAC meeting, as well as the beam use proposals for PHENIX and STAR.

1.1 R20: Monopole Search

In Sept. 2006, the PAC reviewed the proposal R20 for a magnetic monopole search at the RHIC complex. At the time the PAC appreciated the advantages of the proposed detection technique - which relies solely on the intrinsic character of the monopole. However, it did not find the documentation and studies at the time to be of sufficient detail to be evaluated as a proposal. The PAC stated that, to be evaluated at this level, considerably more detail on the motivation, experimental sensitivity, and evaluation of operating a SQUID in a high radiation and noise environment would be necessary.

At this Mar. 2007 meeting of the PAC, the update included new calculations of possible Drell-Yan and coherent photoproduction mechanisms, and a brief presentation of results of a test involving a SQUID placed inside an insulated dewar located near the beam pipe during RHIC collisions. The PAC re-iterates its finding that a detector that makes no assumptions about absorption cross sections and energy deposition is highly desirable.

The current estimates from AuAu collisions using the Drell-Yan mechanism appear reasonable, though any such Drell-Yan calculation must be taken with a grain of salt. Similarly, the assumption of coherent photoproduction seems to overestimate the relevant mass range for production of monopoles. It seems that such an experimental effort in AuAu collisions at RHIC is unlikely to set limits significant relative to earlier searches, though with a very important advantage in the detection method. Overall, we believe the cost and laboratory impact of the project is quite high relative to the potential for scientific discovery. It appears from these calculations that the discovery potential would be enhanced at the LHC. We note that at RHIC, if the experiment were run with the pp program (giving the best sensitivity), it would have a significant impact on the luminosity available for the RHIC experiments. This factor would very substantially increase the effective cost of the program.

For these reasons, the PAC believes that the specific physics case for the R20 proposal of running the full experiment at RHIC with AuAu collisions is legitimate, but does not rise to the level of compelling. Thus the PAC does not recommend approval of the R20 proposal.

As the collaboration has indicated, the physics case for running at the LHC may be compelling. If the proponents are strongly interested in pursuing this effort, further tests of SQUID sensitivity and performance near the RHIC intersection regions may be enlightening. These performance tests should be done without coupling to the vacuum, which would still allow for a full assessment of radiation issues. The electromagnetic background arising from directly coupling to the vacuum could be tested in other ways. In order to more fully explore an LHC experiment, the group should consider actively engaging a few experimentalists with expertise in high energy collider physics.

1.2 LoI: Search for a Deuteron Electric Dipole Moment Using a Charged Particle Storage Ring

The PAC remains enthusiastic about the novel storage ring approach to measuring the deuteron electric dipole moment (EDM), in which the velocity is modulated at the in-plane g-2 precession frequency to permit buildup of vertical polarization proportional to the EDM. The sensitivity goal of 10^{-29} e-cm is superior to that of all other hadronic EDM techniques currently under discussion, giving it the greatest potential reach for non-standard-model physics. Brookhaven is a natural host for such an experiment, given its expertise in polarized storage rings.

We are favorably impressed by the aggressive approach the collaboration has taken since Sept. 2006, planning polarimetry tests for KVI and COSY, and beginning investigation of spin dynamics systematic errors using analytic calculations and simulations. It is important that the run at COSY also provide calibration for the spin tracking simulations. New ideas are under discussion for correcting parasitic spin resonances which mimic the EDM signal.

This is a very challenging experiment. It will require a staged approach to reducing the systematic errors, as false EDM sources are identified and overcome. We realize that some basic concepts of the design are still being worked out, but it is essential that the collaboration now take a more structured approach to the project so BNL management can evaluate it in a timely fashion. The collaboration should immediately define the essential quantitative milestones that need to be met in order to prove the principle of the technique at a modest sensitivity, say 10^{-26} e-cm, and establish a work plan to accomplish this and future goals. This will require sustained, dedicated effort by several people. BNL support for the project should be tied to this work plan.

A Technical Review should take place in about a year to assess progress. The collaboration should aim within two years from now to establish whether the technique is viable and what the approximate cost of the experiment is, at a level that could pass a CD-0 review. Precise control over the spin dynamics is clearly essential for the success of the experiment. Several collaborators should be actively involved in this area, to allow cross-checks using different tools and to ensure timely development of the project.

The collaboration asks the PAC to endorse its request to BNL management for $570K over the next two years, to support manpower and hardware. We recommend R&D support for this effort (perhaps LDRD), but also recommend BNL management determine whether this request is at the level needed to ensure development consistent with the criteria discussed above.

1.3 STAR and PHENIX FY08 - FY10 Beam Use Proposals

The PAC recommendation regarding the STAR and PHENIX beam use proposals for Runs 8 through 10 is:

Run 8: 10 weeks (physics) dAu at $\sqrt{s_{NN}}$ = 200 GeV, plus 12-13 weeks (physics) polarized pp at $\sqrt{s}$ = 200 GeV;

Run 9: 10 weeks (physics) of AuAu at $\sqrt{s_{NN}}$ = 200 GeV, plus 12 weeks (physics) polarized pp at $\sqrt{s}$ = 200 GeV and/or 500 GeV; and

Run 10: 14 weeks (including time for changes of beam energy) of AuAu at a variety of lower collision energies dedicated to a search for the QCD critical point, followed by 8 weeks (physics) of polarized pp at $\sqrt{s}$ = 500 GeV.

The specific splits and collision energies suggested for Runs 9 and 10 are contingent on the performance and achievements of Runs 7 and 8 and should be revisited at the appropriate time.

In its recommendation the PAC has been guided by the following considerations:

Prompted by delays in passage of the FY07 budget by Congress and the resulting abbreviation of Run 7, BNL has decided to commit this run to AuAu collisions at the top RHIC energy, with the goal of eventually increasing the integrated AuAu luminosity by more than an order of magnitude. Progress in beam luminosity and recent detector upgrades will significantly extend the physics reach of this high-statistics AuAu run, by dramatically improving the statistics of bulk observables and extending the range of transverse momentum for hard and rare probes.

STAR and PHENIX both request 10 weeks of dAu collisions during Run 8, in order to again take advantage of significant advances in beam luminosity and detector capabilities. The data collected on this essential baseline system will be increased by more than an order of magnitude. In this run, decisive measurements will be made at forward rapidity, targeting the role of gluon saturation in the initial state wave function of the incoming gold nuclei at RHIC. Both collaborations express a strong desire to accumulate sufficient integrated dAu luminosity during Run 8 to complete this program in 'one shot' (reflected in our recommendation of 10 physics weeks of dAu collisions in Run 8). However, they give even higher priority for this period to a polarized pp run (postponed from Run 7) of sufficient length to make meaningful advances in the measurement of the *x*-dependence of the gluon spin and quark transversity distributions in the proton. The PAC endorses this view, recognizing that another year without new polarized pp data would seriously affect the momentum and threaten the continued health of the important RHIC spin program. We understand that modification of β^* at the STAR intersection point does not affect pp running at PHENIX, so running pp2pp as requested by STAR is left at the discretion of the STAR collaboration.

For Run 9 both STAR and PHENIX request AuAu and polarized pp running, but the requests do not fully agree on the lengths and energies of these measurements. In view of the inherent difficulties in projecting two or three runs into the future, the presently unknown outcome of Run 7, and the potential for FY08 budget difficulties, the PAC does not view this as problematic. We note that PHENIX's desires are driven by the fact that they are presently planning to remove the Hadron Blind Detector (HBD) aimed at a high-quality measurement of low-mass dileptons after Run 9 in order to make room for the Vertex Barrel in Run 10, and that they would like to get all essential physics out of this detector during Runs 7 through 9. Because HBD measurements require significant integrated luminosity at each collision energy, it not obvious how much the HBD can contribute during an energy scan with AuAu collisions at a variety of lower collision energies. This is especially true below RHIC injection energy, unless the luminosity is significantly increased by beam cooling in the AGS. Such cooling could become available in Run 10, and the collaborations, Lab management and C-AD should discuss whether this should be made a priority, in order to facilitate and improve the physics reach of the low-energy scan for the QCD critical endpoint anticipated for Run 10. STAR's pp plans for Run 9 are driven by the desire to bring their initial 200 GeV polarized pp collision program to conclusion, and to have the Forward GEM Detector available for the
W-physics program at 500 GeV in Run 10. They therefore request polarized pp and AuAu running, both at $\sqrt{s_{NN}}$ = 200 GeV. The low energy QCD critical endpoint scan requires the full STAR TOF upgrade and is therefore requested in Run 10.

For Run 10, the PAC recommends the QCD critical endpoint search with low-energy AuAu collisions as well as 500 GeV polarized proton-proton measurements. The STAR and PHENIX BUPs for Run 9 contain short or not sharply defined run periods with polarized protons at 500 GeV for commissioning or initial physics purposes. The PAC feels, in view of delays in polarized proton beam development in Run 7, and specific detector improvements needed for this program, this request may be premature. Short development runs for 500 GeV polarized pp should be at the discretion of C-AD, with the goal of physics production in Run 10.

2. Recommendations for Future Planning

The PAC was asked to provide advice on the development and articulation of the science cases for the RHIC II luminosity upgrade and the Electron-Ion Collider based on presentations at the afternoon session on Mar. 29. Below we offer some observations, reactions to the presentations, and suggestions for strengthening future presentations of the science cases.

The PAC was also asked informally for its comments on utilization of the presently unused interaction regions in the RHIC ring. The PAC recommends that BNL management encourage discussions about small (order $10M) experiments that could utilize these collision regions. Such experiments might target particular physics topics arising from the RHIC discoveries that cannot be addressed by PHENIX or STAR. The RHIC Users Meeting would be a good vehicle to announce these intentions which might include plans for a future workshop. A possible timescale for a "call for proposals" is spring 2008.

2.1 RHIC II

Since the last PAC meeting, a significant amount of work has been done in preparing presentations of the RHIC II Spin and Heavy Ion physics programs for audiences outside our immediate community (specifically for the broader nuclear physics community at the imminent Long Range Planning meeting). The case for this science was improved as compared to the last PAC meeting, yet the presentations could be further polished in several ways. Both presentations established the basis for future measurements using present measurements as a starting point. Although the case for the physics was clear, the necessity, benefit, and urgency of the RHIC II luminosity increase did not come through clearly. The clarity and impact of the message can be improved significantly by simple cosmetic changes and by formulating a set of 'flagship' observables for each program.

One particular example/opportunity for improvement is the transition from existing energy loss measurements on [slide 6 of the heavy ion presentation] to the rates of gamma-jet correlation measurements on [slide 7]. On the former slide, the transverse momentum scale is divided into "hydrodynamic", "medium response", and "vacuum fragmentation" (or pQCD) regions. Meaningful gamma-jet correlation measurements require the trigger photon to be cleanly inside the pQCD regime, however this regime is not highlighted on the gamma-jet correlation slide. To a non-expert, a plot of "Annual Yield" as a function transverse momentum does not make a lasting impact unless the plot gives guidance on both the relevant regime of transverse momentum and the threshold in annual yield necessary to make a significant measurement. The latter is not trivial since this measurement requires a significant background subtraction. The existing slide 7 is additionally confusing to a general audience by having the "without RHIC II" label inside the frame of the plot and the "with RHIC II" label outside the frame. Plots can be much more compelling if the vertical axis shows a physics quantity (*e.g.* integrated away-side partner production) instead of a yield, and projects the measurement's precision to a potential RHIC II dataset. Further clarity can be achieved by comparing these anticipated uncertainties to competing theories. All slides that emphasize the physics gain of the luminosity upgrade should be made "standalone" in the sense that they do not require reference to a previous slide in order to deliver the take-home message.

In general, presentations of projected error bars should not simply be a projection for RHIC II, but should also always show (on the same plot or at least on the same slide) how these uncertainties compare to those from RHIC I. The projected J/Ψ R_{AA} and v_2 [slide 12 from the heavy ion presentation], for example, presents RHIC II without either a RHIC I or theory overlay.

The relation between RHIC and LHC running should be presented clearly. New forms of matter must be characterized as a function of temperature and energy density. In this sense, LHC running is complementary to RHIC rather than competitive; we recommend that presentations of corresponding LHC measurements be made with this emphasis. Relative to LHC, we note RHIC's great flexibility in terms energy and species. In addition, RHIC is able to produce high mass reaction products at high transverse momentum with integrated luminosity two orders of magnitude above that of LHC.

The spin presentation began with a very nice introduction for people outside our field, however, later in the presentation, particularly when data were shown, the take-home message from a plot was frequently available only from the speaker's voice and was not printed on the slide itself. This was particularly true for the last few slides concerning the spin program and RHIC II. The $\Delta G(Q^2=1\ GeV^2)$ extrapolation [slide 24 from the spin presentation] presents the progress on error bars with time but doesn't even mention RHIC II. The physics impact of these measurements was clear only to experts and would be missed by a general audience .

The RHIC II heavy ion and spin programs are each challenged to construct 3-4 slides with 'flagship' observables. Each flagship slide should show how the RHIC II luminosity upgrade improves or enables a particular measurement, and what, in a few word summary, the impact of this knowledge would be on nuclear physics. The emphasis should be on the new understanding we reach over and above the precision of the measurement, i.e. on answering the question: What are the qualitative improvements in our understanding of the new phase of matter or spin structure of the nucleon?

2.2 EIC

The electron-ion collider (EIC) is a recognized priority of the QCD community. The report on the EIC presentations at the fall 2006 PAC meeting stressed the importance of establishing laboratory-based working groups on the spin and eA components of the EIC project, and of contacts between parallel efforts at Brookhaven and the Jefferson Laboratory. We were pleased to see that these steps have been taken. In addition, the fall 2006 report made several strong recommendations concerning the presentation of the physics cases for the EIC.

At this meeting, the committee heard two new presentations on the EIC. Overall, the committee was impressed with the improved clarity and accessibility of these presentations, constituting a major advance from the previous meeting. The endorsement of the EIC at the Rutgers Town Meeting testifies independently to a strong case for the physics goals of this collider project. Looking toward the NSAC meeting in Galveston, however, the PAC committee feels that the presentation of this proposal to a wider community in nuclear physics can be improved further. Referring to the fall 2006 PAC report, we emphasize again the necessity of stressing the "landmark results that could be generated by this project, and their implications for contemporary ideas in nuclear physics and quantum chromodynamics."

<u>Spin:</u>

In part, the motivation for polarized collisions at the EIC is found in its increased reach in the scaling variable x and in momentum transfer Q, due to increased energy and luminosity. This would allow much more precise measurements of the polarized distributions and tests of QCD evolution in polarized scattering. Such studies would provide information complementary to the current RHIC spin program. It is likely, however, that even after Run 6 and future polarized runs at RHIC, the puzzle of where the proton spin resides will remain, with the only candidate being orbital angular momentum, not accessible to the inclusive cross sections of polarized deep-inelastic scattering.

Recent years, however, have seen major developments in the study of nucleon structure with high-energy leptonic probes. Alternative observables can provide information on orbital angular momentum, and more. Indeed, one of the first slides of the spin at EIC presentation shows a report on the "3D quark and gluon structure of the proton". This title reflects such developments, and the abstract reproduced on that slide refers to the generalized parton distributions that can provide multi-dimensional insight into nucleon structure, going far beyond conventional parton distributions in a single momentum fraction. Clearly, much of the excitement generated by the EIC is connected with this potential breakthrough in the study of nucleon structure. This is a primary driver for the one of the new aspects of EIC, namely the large increase in luminosity needed for measurements of exclusive channels.

The EIC spin presentation suggested that generalized parton distributions and related functional portraits of the nucleon can be accessed, at least in part, by a combination of the 12 GeV upgrade of JLab and the EIC. *The potential of this synergy should be illustrated even more forcefully.* This could be accomplished, for example, by presenting sample predictions, even if model-dependent, which would bring these concepts to life.

An analogy may be drawn here to the familiar presentation of the "GRV" models for the polarized gluon distribution, which are customarily included in plots of projected experimental errors, and data as it becomes available. Clearly, such as-yet unmeasured observables, and models for generalized parton distributions that might be derived from them, would have to be presented as tentative, and not oversold. In any talk, one or two such examples would suffice. In the end, however, these aspects of the EIC program will have to be more fully stressed to communicate to a wider community the full range of excitement that motivated the Rutgers Town Meeting endorsement of the EIC.

Nuclear:

The physics motivation for the ion program is in large part to explore quantum chromodynamics in a regime of large, effectively classical fields. This regime is thought to be universal, in the sense that it can, in principle, be explored by probing any hadron, although at accessible energies only using nuclear targets and collisions. (The committee found the introduction of the 'oomph factor' $(A/x)^{1/3}$ instructive, although some members found the term itself less than attractive - 'enhancement factor' might be better.)

The intellectual underpinnings of this viewpoint are strong, and lie deep in the history of nuclear and particle physics. Indications of a universal substructure in hadronic matter have long been found in the high-energy behaviors of total cross sections, which appear to be dominated by a mechanism that has come to be known as "pomeron exchange". Contemporary views of the mechanism point to the role of the fundamental gluon degrees of freedom of QCD in this process.

The application of quantum-mechanical reasoning to the pomeron picture suggests the importance and persistence of diffractive processes at high energy. This topic also has a long and suggestive experimental history, culminating in the observation of large diffractive cross sections at HERA, even for photons at large virtuality. Although the existing suite of experimental results is wide-ranging, it has not yet allowed a definitive study of the transition between independent partonic degrees of freedom, as observed in large momentum transfer experiments, and the multi-gluon excitations of the so-called 'saturation region', which has been analyzed as a 'colored glass condensate'. It is here that the EIC may make an indispensable contribution.

Many of the modern theoretical developments that led to this picture were formulated at Brookhaven. They are a response to opportunities presented by RHIC, where certain experimental results, associated particularly with particle production at large rapidity, may signal the onset of this dynamical region. At the same time, based on the developments to date, it is clear that a full exploration of the strong field, multi-gluon aspects of QCD will require a comparison of electron-ion and ion-ion collisions, the latter at both RHIC and LHC. The theoretical and experimental tasks here are even more challenging than those that led to the picture of hadrons as collections of co-moving partons in hard scattering at larger values of momentum fraction, x. The arguments for an electron-ion collider as a key part of this program are strong, and were generally well presented at the meeting (and in the accompanying document). Again, the committee notes great progress in communicating the underlying ideas and motivations.

Regarding the electron-ion program, it will be clear even to non-experts that the parameters of the EIC can bring it to the threshold of the saturation region and somewhat beyond, but not far within. As noted above, in many ways it is this transition region that is most interesting, and is an important part of the motivation for this new project. It is important to continue emphasizing as well that measurements in this region are crucial for reliable interpretation of higher-energy measurements at RHIC II and LHC.

The details of the EIC design are still evolving. In order to present the project successfully outside the high-energy nuclear community, it will be necessary to demonstrate even more clearly that the project is moving forward on the three fronts of accelerator development, detector conceptual design and theoretical motivation. Perhaps unavoidably, the presentation emphasized these topics in precisely the opposite order, at least in part because the physics requires certain baseline parameters. Nevertheless, there are vigorous developments along each of these fronts, and the overall case will be the stronger for including significant mention of all three, even while continuing to emphasize the underlying physics motivation.