Recommendations
Brookhaven National Laboratory
Nuclear and Particle Physics
Program Advisory Committee
May 8-9, 2008

1. Introduction

On May 8, 2008, the PAC heard PHENIX and STAR Beam Use Proposals as well as background information regarding machine and instrumentation upgrades. In addition, an update on the plan for RHIC Spin measurements was presented. Lastly, we heard both a proposal for a deuteron electric dipole moment (EDM) search and a more general discussion of laboratory planning for the ~2015 time frame.

The second section of this report includes recommendations for the Run 9-10 and 11-13 periods in addition to comments on machine and instrumentation development priorities, and the spin plan; the third section addresses the deuteron EDM proposal.

2. RHIC run plans

2.1 Runs 9-10

The PAC was asked to prioritize the physics goals listed in the Beam Use Proposals submitted by the STAR and PHENIX collaborations, on both short and intermediate time scales. In view of uncertain short-term budget prospects, the PAC decided to consider Runs 9 and 10 together (notated below as Run 9-10). We recommend the following "must do" measurements in the order of their priority:

1. Longitudinally polarized proton-proton collisions at $\sqrt{s}$ = 200 GeV with 60% average polarization for 10-12 weeks, sufficient to record an integrated luminosity of about 25 pb^{-1} in PHENIX and about 50 pb^{-1} in STAR.

2. High luminosity Au+Au collisions at $\sqrt{s}$ = 200 GeV for 8-10 weeks, corresponding to an integrated luminosity of 1.2-1.4 nb^{-1} in PHENIX, to exploit the capabilities of its Hadron Blind Detector (HBD). This will allow both a high precision measurement of the low mass di-lepton spectrum in PHENIX and STAR, and development of transverse

stochastic cooling of the Au beams. In addition, it will enable STAR to exploit its new DAQ capability in a high statistics run.

3. Longitudinally polarized proton-proton collisions at $\sqrt{s}$ = 500 GeV for 5 weeks to allow beam development and commissioning by C-AD, a first measurement of W boson production in PHENIX, and background studies in STAR.

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

Both STAR and PHENIX list as their highest priority the completion of programs to provide a definitive measurement of the polarized gluon distribution function, $\Delta G(x)$, in the region $x > 0.03$ using longitudinally polarized proton-proton collisions. The PAC concurs, noting that, due to budget constraints, polarized proton running in the last two years (Runs 7 and 8) has not had a high enough integrated-luminosity-polarization product to make significant progress toward this goal. The requested integrated luminosity over the Run 9-10 period will yield results for the gluon contribution to the proton spin, ΔG, whose statistical accuracy will, for the first time, be fully dominated by RHIC measurements.

The requested high luminosity 200 GeV Au+Au run will enable PHENIX to exploit its HBD detector to make a decisive measurement of the low mass di-lepton spectrum, with a precision and statistical accuracy similar to the very successful NA60 experiment at CERN which studied In-In collisions at $\sqrt{s}$ = 17 GeV. These measurements will shed light on medium effects of the hot collision fireball on the spectral functions of vector mesons created in the late hadronic stage of the collision. Such modifications of the spectral functions are associated with the spontaneous breaking of chiral symmetry and the change of the QCD vacuum in the quark-hadron phase transition. The HBD commissioning began in Run 7, but high voltage problems were discovered. These problems have been resolved in bench tests and the HBD is expected to be ready to take data in Run 9. Run 9-10 provides a singular window for exploiting the unique physics capabilities of this detector since it must be removed prior to vertex detector upgrades (VTX and FVTX) enabling charm/bottom flavor separation. The PAC considers it crucial that PHENIX be provided with full-energy Au+Au collisions with sufficient integrated luminosity to make full use of this detector in the Run 9-10 timeframe. Furthermore, because installation of the STAR TOF system is expected to be completed in 2QFY09, STAR will be able to participate fully in the exploration of the low mass di-lepton spectrum given the likely schedule for starting Run 9. With the TOF detector, STAR will be able to make electron-positron pair measurements (including the measurement of ϕ mesons) of competitive precision and statistical significance. It will also greatly enrich STAR's program to reconstruct a large number of unstable resonances in the hadronic final state.

During this high luminosity 200 GeV Au+Au run, C-AD will be able to implement and test transverse stochastic cooling of the RHIC Au beam. This run is expected answer the question of whether cooling in one transverse plane is sufficient (due to dynamical coupling between the transverse planes), or whether each transverse plane requires separate cooling. It is, therefore, a critical step in the exciting process of implementing the RHIC-II luminosity upgrade. If successful, stochastic cooling will enable the upgrade on a much shorter time scale than anticipated in the 2007 Nuclear Physics Long Range Plan, and at dramatically reduced cost. Commissioning of transverse stochastic cooling during Run 9-10 is well matched to the STAR and PHENIX detector upgrades (see Section 2.4 below) and would allow initiation of the RHIC-II precision research program in Run 11.

Collisions of longitudinally polarized protons at $\sqrt{s}$ = 500 GeV for 5 weeks in Run 9-10 will enable PHENIX to meet an important RIKEN milestone (March 2011). With this run, they will be able to demonstrate their ability to reconstruct W's and to make a first measurement of the W production cross section. Such a run is also required to allow C-AD to commission full-energy polarized proton beams in preparation for physics production runs by the RHIC Spin Collaboration in the period of Runs 11-13. STAR will use the run to commission its detector for physics at the higher collision energy. This run is of crucial importance to keep the RHIC Spin program on track for producing new physics in the out years.

2.2 Runs 11-13

There are four, clearly identified, "must do" physics measurement areas for RHIC during Runs 11-13 and beyond. They are listed below (<u>not</u> in rank order of physics priority or running order). We note that they are not all at the same level of readiness as indicated in the detailed comments.

The LHC heavy ion program will be adding complementary physics information to the overall picture of high temperature QCD matter during this time frame. Given the detector upgrades and luminosity enhancement projected at BNL, we expect the RHIC program to remain vital and at the scientific forefront as it pursues precision characterization of the quark-gluon fluid. It is critical during this time that RHIC have sufficient running time to exploit these advances.

2.2.1. High luminosity Au+Au collisions

The upgraded capabilities in this time frame will allow a number of observables to be accessed for the first time at a level that will provide significant quantitative support for the emerging picture of the QCD matter produced at RHIC. The PHENIX VTX will qualitatively enhance the experimental capabilities of charm/bottom separation on a timeline which is competitive and timely with respect to LHC measurements. It is one of the measurements accessible in future high luminosity Au-Au running particularly suited to further advance our fundamental understanding of hard probes in hot and dense QCD matter. Progress has been made on theoretical frameworks for making direct physics interpretations from energy-loss measurements. This progress is expected to continue in an interplay of experiment and theory to which PHENIX VTX measurements can contribute substantially.

Significant additional physics capabilities for the Au+Au physics program will come from the STAR HFT and the PHENIX NCC. However, the PAC notes that these upgrades will become available for physics somewhat later and the running to utilize their capabilities should be considered separately.

In this time period, C-AD will be completing the stochastic cooling upgrade, as well as undertaking other luminosity enhancements. A large fraction of the expected increase in luminosity is projected to be available for Run 11. We note that, depending on the time schedule, a long Au+Au run at 200 GeV need not coincide with the full luminosity enhancement, though a significant luminosity enhancement over previous full energy heavy ion running is critical.

We are concerned about the critical heavy flavor physics measurements during this period, because stochastic cooling for luminosity enhancement is not as effective as reduction of the z-vertex interaction distribution. The PHENIX VTX and STAR HFT have smaller z-vertex acceptances than those of the full detectors. In addition, for interactions outside of this limited z-vertex range, detector support structures for these new elements may degrade other measurements not requiring the silicon detectors. These effects should be further quantified by the experiments, and C-AD should continue to pursue additional methods for reducing the z-vertex distributions.

2.2.2. U+U collisions

With the expected completion of EBIS in 2010, the possibility of colliding heavier ions such as U opens opportunities to study a novel, qualitatively different collision system, in which both substantially higher initial energy densities in the most central collisions and anisotropic initial spatial configurations are possible. These opportunities must be weighed against the complication of increasing the variability of the initial geometry, and the correspondingly smaller cross sections for some of the measurements of greatest interest. Detailed simulations of the trigger conditions required for selecting interesting collision geometries and of the rates for specific measurements must be performed. An important example of such a measurement is jet tomography as a function of the angle relative to the axis of deformation,. These results will help the community to ascertain the viability of these measurements (setting, for example, the required integrated luminosity for an effective U+U run), and to establish their compatibility with the general goals of the RHIC program.

2.2.3. Heavy ion collisions at lower energies

There are multiple compelling motivations for running RHIC at lower energies. The search for the QCD critical point is a “must do” experiment. Beyond this specific search, the collision energy dependence of various signature characteristics such as quasi-ideal hydrodynamic flow and jet-quenching should be determined. To date, however, the PAC has not seen a compelling presentation of the key observables and their potential physics impact for this measurement program.

Both STAR and PHENIX have expressed interest in low-energy running and have started to evaluate their physics capabilities. However, the experimental capabilities, in particular at sub-injection energies (i.e. below the normal AGS injection energy), are quite different for the two experiments, due to overall acceptance and triggering issues. In addition, luminosities at sub-injection energy are limited. This makes it natural to consider running in two separate energy ranges: above injection and sub-injection energies.

Concerning above injection energies, both experiments have interesting programs. There has been previous running at energies ranging from 22-200 GeV. Further input is needed on the critical measurements and projected uncertainties from both experiments. For example, ideal hydrodynamics does not describe heavy ion data at the CERN-SPS, but does so at an approximate level at RHIC full energy. Experimentally exploring the dynamics between these two cases is exciting and will provide important comparisons with the developing viscous hydrodynamics calculations.

Sub-injection energy running can substantially extend the critical point search to much larger baryon chemical potentials. Significant measurements exist already in the sub-injection energy range from fixed target experiments at the CERN-SPS. In the view of the PAC, a modest improvement or confirmation of these CERN-SPS results does not present a compelling physics case for running. However, the PAC believes that many additional observables which have not previously been measured or have different systematic uncertainties may be measurable at RHIC, particularly by the STAR experiment. These additional observables need to be identified, their measurements simulated and luminosity requirements established. Although the PHENIX capabilities may be more limited, it is important to quantify them for this energy regime as well.

In the view of the PAC, the experiments must define a strategic approach to the energy scan program, with a first exploratory run of order 8-10 weeks that will indicate whether and how to further explore this region with additional running in later years. For both experiments, the essential set of energies and the details of the physics implications (beyond projected statistical uncertainties) from different data sets need to be developed. This will require input from the theory community. The upcoming INT workshop provides a timely opportunity for the experimental and theoretical communities to work together toward this goal. This input is required to determine the future run duration, energy range, and number of energy points as correlated with physics potential (both for discovery and for further quantification).

Test runs at sub-injection energies have shown promise, although the expected luminosities are small and some energies restrict running to one experiment at a time. C-AD presented two specific luminosity enhancement concepts for sub-injection energies. The first is referred to as "top-off" and has an estimated cost of $1M with a one year development timescale. The second is electron cooling and has an estimated cost of $5M with 3 year time scale (and potential availability by 2013). At this time, the PAC believes it is premature to initiate a large investment for the cooling option. We recommend pursuing technical feasibility studies of increasing the luminosity via top-off, and re-visit the long term sub-injection luminosity issue when the additional physics input requested above is available.

2.2.4. Polarized p+p collisions at 500 GeV

Determining the flavor dependence of the (anti-) quark spin contribution to the nucleon spin, measured via the spin asymmetry in $W^{\pm}$ production, is a "must do" physics program (see also more detailed comments in the Section 2.5 below). The PAC was presented with updated measurement capabilities for the STAR and PHENIX experiments. These measurements, involving detection of high p_T leptons (muons or electrons), depend crucially on good charge discrimination of the leptons (thus tagging W^+ versus W^- decays), rejection of hadronic background, and good momentum or energy resolution. The projected sensitivities are being updated; the PAC believes it is important to then relate these projections to the existing measurements from, e.g. the HERMES experiment, taking account of the advantage of the much higher momentum scale at RHIC.

To achieve these physics goals, the STAR experiment requires the Forward GEM Tracker (FGT) upgrade. This detector addition is necessary to separate the electron charge sign at forward rapidities. We note that whereas charge separation of W decays can already be effected at mid-rapidity, much of the anti-quark spin sensitivity is from forward rapidity measurements. The PHENIX experiment is also upgrading their detector in order to trigger effectively on the relatively rare muon decays from W's at the highest RHIC luminosities. This upgrade includes multiple components and is staged over a period of years. The PAC believes it is important to quantify the available trigger rejection as a function of year within the staged upgrade as a necessary input to the Run planning process.

As noted above, there is a high priority for at least a 5 week proton-proton run at 500 GeV in the Run 9-10 period. This earlier run is important for accelerator development and for the experiments to look at backgrounds and make a first W production cross section measurement. However, for the longer running period discussed here, in order to make substantial measurements it is critical that the above detector upgrades be fully operational. We would also like more quantitative input on the future constraints on ΔG from 500 GeV longitudinal running, and in particular on its x-dependence, in order to better balance potential future 200 GeV and 500 GeV running.

2.3 Accelerator development

Increasing the luminosity of the RHIC collider is of overwhelming importance to the future physics program at the laboratory. The PAC is very impressed with the new plan for luminosity increase, both in terms of the cost-effectiveness and the schedule for the expected rapid implementation. The PAC is especially impressed with the successful development of longitudinal stochastic cooling using bunched beams, the first such development in the world. We commend the principal players in this activity and the ability of the C-AD management to recognize important innovation and foster it. Consistent with our recommendations for Run 9-10, we strongly endorse the planned transverse cooling test during the Au+Au running in this time period.

The C-AD activities and efforts are focused on increasing the beam luminosity in heavy ion (HI) and proton runs, and well-tuned and responsive to the needs of the experimental program. As such, the improvement program from the C-AD needs to follow the physics priorities, as outlined in the previous sections. In addition to providing the highest luminosities (and polarizations) for the Run 9-10 program, C-AD is encouraged to further study and improve the performance of the machine for a low energy scan in support of measurements of the collision energy dependence of the signature signals of the quark-gluon fluid and the search for the QCD critical point. The versatile RHIC machine has the capability for such an energy scan, although currently with low luminosity. The C-AD presented two plans for low energy luminosity increases: 1) the top-off mode, where the expectation is a factor 2-3 in luminosity increases, and 2) low energy e-cooling, where the expectation is a factor of 3-6 luminosity increase. The top-off implementation period is estimated to be about one year and its cost about $1M, while the corresponding values for e-cooling are three years and about $5M. We recognize the importance of an early exploratory search for critical point as landmark of the QCD phase diagram and recommend that C-AD go ahead initially with the top-off implementation with necessary test time as outlined in Section 2.2.3 above.

Since the physics effectiveness of the polarized proton runs is proportional to P^4L, special attention should be given to increasing the polarization at the source and preserving it through acceleration. We would also like to encourage the ongoing work on solving the 10 Hz vibration problem to allow near integer working-point operation, as well as the R&D efforts on, e.g., the electron lens.

2.4 Instrumentation development

The upgrade plans of the RHIC experiments have been formulated to expand the physics opportunities and take advantage of anticipated increases in machine luminosity. The upgrades are staged in time, and this timing, in several cases, has a strong influence on formulating the priorities in near and long term beam use.

2.4.1. Upgrades that influence Run 9-10

The high priority of a full energy Au+Au measurement in the Run 9-10 recommendations is based on the compelling physics of the low mass di-lepton spectrum. In addition, the incompatibility of the PHENIX HBD and VTX upgrades requires the HBD physics measurements be completed soon so the device can be removed to allow for timely use of the VTX. Progress has been made in demonstrating the effectiveness of a functional HBD based on the partial coverage of the device from the Run 7 data, as well as in solving, at least on the bench, the high voltage problems encountered at that time.

The PAC congratulates STAR for the anticipated completion of the DAQ1000 project prior to Run 9. This system greatly enhances STAR's bandwidth in time to take full advantage of future luminosity increases. Further, STAR reports that 75% of the TOF upgrade will be in place for an on-time start of Run 9. The remaining TOF trays can be available for full implementation after second quarter of FY09. The next STAR run will demonstrate significantly enhanced capability for all colliding systems.

2.4.2. Upgrades that influence Run 11-13

Among the "must do" priorities for RHIC is the full characterization of the interactions of heavy quarks (charm/bottom) with the medium. The PHENIX VTX will be the first upgrade device to enable direct and independent measurements of charm and bottom dynamics. Optimistic run plans enabling a long Run 9 would allow a partial implementation of the VTX in Run 10, followed by full implementation for Run 11. The PAC agrees with PHENIX that the HBD should remain in place for Run 10 if the Au+Au running is not realized in Run 9.

The STAR HFT detector system also addresses heavy flavor physics, but with larger acceptance than the PHENIX VTX. In optimistic upgrade funding scenarios, this detector system could be available for Run 12. Funding realities may postpone its implementation until or beyond Run 13. As in the case of the luminosity upgrade (as discussed in the Run 11-13 recommendations above), the PAC recommends that the HFT schedule should not delay full energy Au+Au running targeting heavy flavor measurements, but instead provide motivation for further full energy running once it is installed.

Two upgrades provide specific capabilities necessary for 500 GeV running of the polarized proton program. The STAR FGT system is necessary to provide charge sign tagging of leptons from W decays. The earliest 500 GeV running is likely to precede the installation of the FGT, however, this running period can be used fruitfully to determine machine backgrounds and compare these to existing detector performance studies. STAR should clarify the value of such background studies and make appropriate plans. The PHENIX muon trigger upgrades will provide trigger capability to match increases in machine luminosity. As they will be implemented in a staged fashion over several years, the PAC asks PHENIX to clarify how this timeline matches the anticipated luminosity upgrades.

The PHENIX FVTX detector system will greatly improve momentum and mass resolution for all muon measurements. As such it is valuable for all running conditions and not a driving force in our recommendations.

The PHENIX NCC detector awaits its cost and schedule review. The NCC provides a vastly enlarged acceptance for calorimetry and influences measurements in all colliding systems, particularly those involving direct photons and photon-jet measurements. Funding realities may push its implementation past Run 13, therefore its schedule does not yet influence our recommendations.

2.5 Spin program

PHENIX and STAR are in a good position to meet major milestones for the spin program by following the general outlines of their proposals for longitudinal polarization in Run 9-10. There is a broad agreement between the experiments on the outline of the polarization program. The PAC agrees that p+p running with longitudinal spin at 200 GeV for a substantial period during Run 9-10, augmented by a significant commissioning run at 500 GeV are the natural and necessary next steps in the RHIC Spin program. The PAC strongly endorses the collaborations' focus on two subjects of key importance: the measurement of the gluon polarization, and the measurement of quark and anti-quark polarizations via W production. RHIC has a unique capability to perform these vital measurements. Their value is underscored by two DOE milestones; it is important to both the RHIC program and to the hadron physics community that these milestones be achieved on schedule (by 2013 in both cases).

In addition, there are opportunities for further exploration of the large transverse polarization asymmetries already observed in the forward direction, and a strong proposal to run the pp2pp experiment at STAR for a short period during the 200 GeV run. The PAC finds these directions of compelling physics interest, but emphasizes that the allocation of beam time to these pursuits should not hinder completion of the ΔG and Δq milestones.

2.5.1. Gluon polarization

The PAC supports the allocation of the largest fraction of available beam time in Run 9-10 to 200 GeV running with longitudinal beam polarization for the purpose of determining the gluon polarization. The reduced beam time in recent years caused by unfavorable funding conditions has negatively impacted the spin program in particular, with no high-statistics polarized data taking since Run 6. It is vital to the health of the RHIC Spin program that this be redressed with a large new data set in Run 9-10. A data-taking time of 10-12 weeks seems practical under the most likely scenarios. These data will increase the statistics of the experiments' A_{LL} measurements for inclusive neutral pions and jets by more than a factor of five, and the impact of this enhanced precision on our knowledge of the sign and magnitude of ΔG (partial moment of the gluon polarization) will be considerable. This impact is evidenced by the latest global fits to world data, which have been pioneered by the theory group at BNL. In addition, the PAC is enthusiastic about the new di-jet and photon-jet channels to be explored at STAR thanks to its large acceptance and the increase in recorded luminosity enabled by the DAQ1000 upgrade. As these measurements are essentially exclusive, they allow the determination of the hard scattering kinematics on an event-by-event level, and will provide key constraints on the *x*-dependence of the gluon polarization.

The PAC recognizes that 200 GeV running is important to these ΔG measurements, as it enhances gluon scattering from polarized quarks rather than from other weakly-polarized gluons. However, as noted above, we encourage the collaborations to explore the potential of 500 GeV running at high luminosity for constraining ΔG, as this may influence the beam energy choice in later years.

2.5.2. Anti-quark polarization from W production

The proposals of both collaborations request commissioning at 500 GeV within the next two years. The PAC gives high priority to commissioning the future 500 GeV spin program as soon as possible. Achieving the RIKEN milestone of a clear start to the W production program by 2011 is important both to ensure the renewal of vital funding and to prepare for the next phase of RHIC Spin in a timely fashion. The commissioning run of duration 5 weeks, the minimum required by C-AD, would allow demonstration of the fundamental elements of the 500 GeV program, tests of detector components and observation of W signals. Specifically, the 25 pb^{-1} requested by PHENIX will enable a preliminary but important physics measurement: that of a non-zero value for the parity-violating A_L. This measurement will be performed with the PHENIX central detector rather than with the muon arms as mentioned in the RIKEN milestone, because the upgrades for forward W production (muon trigger at PHENIX and FGT at STAR) will not be complete by Run 10. Nevertheless, the PAC finds it essential to complete a commissioning run as soon as possible. It is particularly urgent to quantify rates and backgrounds at 500 GeV so solutions can be devised in time for 500 GeV production by Run 11. A Run 9-10 commissioning period will provide other useful physics results including cross-sections, and a limited precision, forward measurement of A_L at PHENIX using the partially-installed muon trigger system.

Both the STAR and PHENIX request a long p+p run at 500 GeV with longitudinal polarization in Run 11, to provide the first significant measurement of the quark and anti-quark polarizations from W production. The PAC encourages that this next step in the spin program be pursued expeditiously, once the essential muon trigger and FGT forward upgrades are completed. Full installation may be completed for Run 11, but funding realities may induce a delay of a year or more. As to an appropriate length for the first 500 GeV p+p production run, the PAC finds it difficult to evaluate at present, given the rapidly changing projections for the Δq measurements. The PAC welcomes the more realistic simulations of W signals and their implications for quark and anti-quark distributions shown in the PAC presentation (the expected results shown in the proposals derive from earlier simulations). The apparently significant impact of backgrounds and detector effects on these projections is particularly noteworthy; we look forward to a more detailed explanation at the next PAC meeting. Further, we ask that the significance of the anticipated Δq measurements relative to theoretical models be more clearly presented in future projections. The current plots display the expected data on A_L overlaid with numerous model curves whose relevance is unclear. For example, are all the displayed fits compatible with existing semi-inclusive DIS data, and do they contain model-dependent assumptions? It is important that the experiments respond by addressing directly the question in the RHIC Spin program review charge letter as to how Δq will be extracted ultimately from the W production asymmetries including identification of any model-dependent assumptions that may be involved.

2.5.3. Transverse-spin physics

Transverse-spin running at RHIC has already produced exciting results and the PAC encourages the collaborations to pursue this physics in the future. In particular, the STAR proposal contains an intriguing new idea to look for the predicted sign change in the Sivers asymmetry, as compared with semi-inclusive DIS, using photon-jet measurements. The photon-jet channel can be explored in the near future, before the full luminosity upgrade opens up the possibility of Drell-Yan measurements (where the sign change was originally predicted), and would provide further confirmation of the transverse momentum picture of high-energy single-spin asymmetries and the consequent access to quark orbital motion.

The STAR Beam Use Proposal requests an exploratory 2 week (6 pb^{-1}), 200 GeV run in transverse mode in order to establish the necessary figure-of-merit for this sign change measurement. The PAC is in favor of this use of time, but only if it does not significantly impact higher priority items in the heavy ion or spin programs. The PAC also requests that both collaborations investigate what physics can be explored with transverse running at 500 GeV.

2.5.4. pp2pp program at STAR

The STAR collaboration has proposed two, half week, runs during 200 GeV running for the pp2pp experiment. Incorporating pp2pp into the STAR detector has added to pp2pp's elastic-diffractive program the possibility of observing so-called "double Pomeron" events, with central particle production bracketed by large rapidity gaps. There are reasons to characterize such a central system as "glueball rich", and observations could be correlated with spin observables. The basic elastic/diffractive measurements that will be possible with pp2pp would add archival observations to the historic series of energy and momentum transfer measurements of elastic and diffractive cross sections. The added control over spin makes the observations of pp2pp unique for collider energies.

At the same time, because C-AD estimates a reduction by a factor of 5 in the instantaneous luminosity at PHENIX during a pp2pp run, the measurement should only be carried out in a context of excellent machine operation, with an assured delivery of sufficient luminosity for both PHENIX and STAR to reach the goals necessary for the determination polarized gluon distribution.

3. AGS Proposal: Search for a permanent electric dipole moment of the deuteron nucleus at the 10^{-29} e-cm level

3.1 Previous recommendation

The PAC has previously reviewed Letters of Intent by this collaboration for a new, storage ring-based experiment to search for a permanent Electric Dipole Moment (EDM) of the deuteron. The most recent review was in March 2007. At that time, the PAC was enthusiastic both about the physics reach of such a measurement, which, in principle, has superior sensitivity to all other techniques currently under consideration, and about the concept of a storage ring approach. The PAC stated that "Brookhaven is a natural host for such an experiment, given its expertise in polarized storage rings." Our observations and long-term recommendations last year were as follows:

> 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.
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> 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.
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> We recommended funding the Collaboration's request for LDRD funds to continue R&D.

3.2 Current findings

We find that the scientific case for a large, long term effort to measure the permanent EDM of the deuteron remains compelling. Observation of a T-violating permanent EDM in any system would be revolutionary. Understanding the physics underlying it would require EDM measurements in several systems, so a deuteron EDM measurement will be of the highest importance even if it is not first.

On a theoretical level, we find that the proposal understates the uncertainties in the present estimates of the deuteron EDM. The calculations of both the deuteron and neutron EDMs at the hadronic level (in terms of CP-violating meson-nucleon interactions) are difficult, and, presently, are essentially at the level of naive dimensional analysis. The electric dipole moments of the nucleons resulting from strong CP-violation (encapsulated in the parameter $\bar{\theta}$), and beyond the leading $\log(m_\pi)$ term, are highly uncertain, as are the contributions from the dimension-5 P- and T-violating operators (the quark electric- and chromo-dipole moments). Calculation of the deuteron EDM from the quark level CP-violating and T-violating interactions must include both these uncertainties and others related to the nuclear binding. In the situation where $\bar{\theta}$ vanishes, which can occur in some beyond the standard model scenarios (e.g. SUSY and a Peccei-Quinn symmetry), the neutron and deuteron EDM's should be dominated by the quark-level dimension-5 operators. The present significant uncertainties in the hadronic matrix elements of these operators would translate into corresponding uncertainties in the scale of the new physics, given any hadronic measurement. We do, however, expect significant advances in the coming decade in lattice calculations of the hadronic contributions, and we re-iterate that, on general grounds, discovery of a non-zero EDM in any system would be an extraordinary achievement, which we expect would spur major new theoretical developments.

Turning now to the experimental proposal, we find that the present design is fundamentally different than that presented last year. The current concept is simpler, with more clearly defined issues, and we support the change. However, it still presents an array of formidable problems to be addressed. The collaboration has begun to address these problems, with particular emphasis on field imperfections and polarimetry.

We find, however, that the collaboration has not yet established the structured approach to the project we recommended last year. The overall design remains more or less at the level of a sketch, with development of various components appearing to be parallel, but relatively isolated, efforts. It is difficult for the PAC to provide meaningful comments on the overall viability of this design, since, again this year, essential components are still only very broadly specified.

Last year we recommended the immediate establishment of quantitative milestones and identification of a staged approach to achieving the target sensitivity. Such a plan was not presented to us, and does not appear to have been established. We recommended last year that a detailed Technical Review be held around now, to assess the progress of the collaboration toward a technically viable design whose cost is at least approximately known. We find that insufficient progress has been made over the past year to warrant such a review at this time.

3.2 Recommendations

The deuteron EDM measurement remains a compelling scientific opportunity, but carrying it out successfully will require a carefully managed, long term investment of resources. This is the third presentation of the concept to the PAC since 2004, with only modest progress over that period towards fixing a design and establishing a practical plan for a robust project. In our view, the current collaboration has failed to demonstrate the capability to carry out the process that will be necessary for a successful experiment. BNL Management should determine immediately whether this initiative fits within its long term vision for the lab. If so, they should take appropriate steps to put in place a strong scientific and management team to establish a well structured project, with clear plans for R&D and a design strategy. The aims of this group should be a detailed Technical Review within one year and a CD-0 review within two years. Absent the immediate establishment of such a team, we recommend that BNL Management terminate this effort.