Recommendations
Brookhaven National Laboratory
Nuclear and Particle Physics
Program Advisory Committee
June 7-8, 2012

1. Introduction

On June 7, 2012, the PAC heard background information on progress in Run 12, accelerator performance and plans, and the PHENIX and STAR Beam Use Requests (BURs) for Runs 13 and 14. In the afternoon we heard a summary of planning for the facility for approximately the next ten years, including specific reports from STAR and PHENIX. Based on this input, we begin with our assessment of the progress in Run 12 (Section 2) and report our recommendations for Runs 13 and 14, with discussion of heavy ion and polarized proton running (Section 3). We also discuss our reactions to the plans for the laboratory's future activities (Section 4).

2. Discussion of Run 12

2.1 Measurements

Polarized proton beams were collided at $\sqrt{s}$ = 200 GeV (with transverse polarization) and at 510 GeV (with longitudinal polarization) in Run 12. The PAC is delighted to see that the accelerator performed extremely well, delivering integrated luminosities near the maximum of the range projected by C-AD, and meeting polarization goals of 60% (55%) at 200 (510) GeV. The PAC commends C-AD for these achievements, which bode well for the forthcoming p+p runs. Data taken with transverse polarization at 200 GeV from Run 12 will significantly improve the precision and kinematic coverage of the present RHIC measurements of single transverse spin asymmetries. In particular we note the exciting first results from STAR on interference fragmentation functions and the Collins effect that were recently presented. At 510 GeV, the total figure of merit was a factor 4 or so higher than that achieved in Run 11. These data will provide incremental improvements on double-helicity asymmetries A_{LL} used for extraction of ΔG and on the single-longitudinal asymmetries A_L in W-boson production that are sensitive to the flavor dependence of the nucleon's helicity structure.

The U+U period of Run 12 involved the first operation of RHIC with full three-dimensional stochastic cooling of both heavy ion beams. The cooling provided a dramatic increase in the delivered luminosity, with the average luminosity during many fills exceeding that at the beginning. Furthermore, for the first time, the beam lifetime was consistent with the calculated rate based solely on losses due to beam burn-off. The PAC applauds these extraordinary technical accomplishments. These accomplishments also enabled both collaborations to achieve their U+U goals, even though the U stripping probability was lower than expected.

In Run 12 RHIC also provided the first asymmetric collisions of large nuclei at collider energies, which, together with the first U+U collisions, open a new chapter in the study of the role of collision geometry on collective expansion of, and jet quenching in, the strongly coupled quark gluon plasma. During the first half of the Cu+Au running period (prior to the PAC meeting) RHIC performance exceeded expectations with the integrated luminosity 10% above the maximum projected luminosity curve. The successful Cu+Au run following on the heels of the first U+U run further emphasizes the unique capabilities of the RHIC facility in carrying out research at the forefront of nuclear physics.

2.2 Upgrades

In the last year, PHENIX completed muon trigger and FVTX upgrades, and commenced an upgrade to its muon piston calorimeters with the addition of a pre-shower detector (MPC-ex). The muon trigger is critical to the success of the PHENIX W polarization physics program. The FVTX will improve the precision of di-muon mass measurements and allow detection of muons from heavy flavor decays—a key component of the 2014 Au+Au program. PHENIX is also working on refurbishing non-functional ladders in the VTX detector and will have these in place for the 2014 run.

For the 2012 run, STAR had a partial installation of the Forward Gem Tracker (FGT, 60%) and the Muon Telescope Detector (MTD, 10%). For the 2013 run, the FGT will be complete, the MTD will be outfitted to 43% coverage, and a prototype of the Heavy Flavor Tracker (HFT), consisting of up to 33% coverage with the innermost PXL layers only, will be installed for commissioning purposes. For the 2014 run, the MTD will be complete. The HFT will also be fully installed, with full coverage for the intermediate SSD and IST layers and the innermost PXL layers. The FGT extends the mid-rapidity W program into the forward direction. The MTD extends quarkonium studies into the di-muon sector, increasing the resolution for separating the upsilon states beyond the bremsstrahlung-limited di-electron channel. In addition, via electron-muon correlations, it allows for a clean measurement of the heavy flavor contribution to the intermediate-mass di-lepton signal, providing a determination of the thermal radiation component. The HFT is essential for measurements of open heavy flavor production and modification in the QGP, enabling direct reconstruction of charm hadrons with low background. This is made possible by its extremely low mass (radiation length), which enables unparalleled resolution, especially at low momentum.

3. RHIC run plans

3.1 Executive summary

For Run 13 the PAC recommends the following (*in order of priority*):

1. Running with polarized proton collisions at 500 GeV to provide an integrated luminosity of 750 pb^{-1} at an average polarization of 55%.
2. Depending on the amount of running time remaining after priority #1
    a. If less than 3 weeks remain, a week of 200 GeV Au+Au collisions.
    b. If at least 3 weeks of running time remain, 3 weeks of 15 GeV Au+Au collisions.
3. 8 days of 62 GeV p+p collisions.
4. At the discretion of the ALD, 4 days of low-luminosity running to accomplish the pp2pp goals.

For Run 14 the PAC recommends the following (*in order of priority*)

1. 8-10 weeks of 200 GeV Au+Au collisions.
2. 4-5 weeks of 200 GeV polarized proton collisions.
3. For any remaining time, 200 GeV d+Au collisions.

3.2 Discussion of 2013 and 2014 priorities

The STAR and PHENIX experiments have both chosen as top priorities for 2013 an extended polarized proton run at 500 GeV to complete the first phase of the W single spin asymmetry measurements. For 2014, the two experiments proposed an extended Au+Au run at 200 GeV to make high-statistics measurements of heavy flavor production. As these measurements address key goals of the RHIC science program and take advantage of recent detector upgrades, they are strongly supported by the PAC.

STAR and PHENIX requested 200 GeV polarized p+p running, PHENIX in 2013, STAR in 2014. This running will provide essential comparison data for the 200 GeV Au+Au measurements and additional spin measurements. Due to the scheduling of the STAR HFT upgrade, the PAC recommends that 200 GeV p+p running take place in 2014 to allow the HFT to be used for both the Au+Au and the comparison p+p measurements.

STAR proposed a short 200 GeV Au+Au run in 2013 with a primary goal of commissioning a portion of the HFT using high-multiplicity collisions. Given the importance of the success of the HFT upgrade to the Au+Au program in 2014, the PAC recommends that at least one week in 2013 be dedicated to such running if sufficient time remains after the completion of the 500 GeV p+p program. The PAC also concluded that if at least three weeks of running were available after the completion of the 500 GeV p+p program, that time could be used most advantageously to complete the first phase of the low-energy scan by taking data at 15 GeV.

3.3 Discussion of p+p running in Run 13

The PAC's highest recommendation for Run 13 is longitudinally polarized p+p running at $\sqrt{s}$ = 500 GeV, in order to reach (or nearly reach) 750 pb^{-1} of delivered luminosity at high polarization of about 55%, commensurate with both collaborations' requests. To reach this goal may require running in this mode for the entire Run 13. The prime scientific focus is clearly on W physics. According to the collaborations' projections, a run at 500 GeV with $L = 250\ pb^{-1}$ (PHENIX) or $P^2 L = 50\ pb^{-1}$ (STAR) collected would result in exciting measurements of A_L in W-boson production for various bins in pseudo-rapidity of the charged decay lepton, which would allow discrimination among various models of the flavor dependence of the proton's helicity structure. The PAC views this science case as compelling. It also observes the complementarity between PHENIX and STAR measurements, with the former having best sensitivity at large rapidity ($1.2 < |y| < 2.2$) and the latter at mid-rapidity ($|y|<1$). In combination, very significant constraints on the quark and anti-quark polarizations on the proton will emerge, and feature prominently in global analyses of nucleon spin structure. The measurements would complete (or nearly complete) the presently envisaged W physics program at RHIC, fulfilling the DOE performance milestone (HP8).

At the same time, double-longitudinal spin asymmetries in pion and jet production at 500 GeV would push toward smaller momentum fractions x of the colliding partons and hence extend our knowledge of the spin-dependent gluon distribution and its contribution to the proton spin, another DOE performance milestone (HP12). Additional constraints on ΔG would also be obtained from di-jets and di-hadrons. As double-spin asymmetries A_{LL} tend to become quite small toward higher energy and lower transverse momenta, an important issue in such low-x ΔG studies in 500 GeV running is good control of systematic uncertainties and relative luminosity. This also makes high polarization particularly important for A_{LL} measurements.

On pp2pp:
Given the likely short duration of the forthcoming run, the PAC does not give a high priority to the proposed pp2pp experiment. We leave it to the discretion of the ALD to determine whether the 4 days of low luminosity running required for this measurement can be fit in in a way that does not adversely affect higher priority goals.

On A_NDY:
As per last year's PAC report, a proposal for the experiment was produced by the collaboration, and the Laboratory conducted a review of the proposal. As a result of this review and upon subsequent discussion between the proponents and the management it became clear that the present Laboratory priorities do not allow for this experiment to go

forward. The science case for Drell-Yan transverse-spin asymmetry measurements continues to be very strong, and the PAC hopes that such measurements will become possible at PHENIX and/or STAR in the future, possibly as part of a future extended W physics program. In this context, initial studies of Drell-Yan sensitivities in the PHENIX BUR are encouraging.

3.4 Discussion of heavy ion running in Run 13

The PAC recommends devoting time to Au+Au running if beam time remains during Run 13 after the W asymmetry measurement has been completed. If only a short time remains, we recommend devoting time to Au+Au at $\sqrt{s_{NN}} = 200$ GeV. If three weeks remain, we recommend devoting the time to Au+Au at 15 GeV to bridge the current gap of more than 100 MeV in μ_B.

3.4.1 Au+Au at 200 GeV in Run 13

If only a short time remains in Run 13 after the W asymmetry measurement has been completed, the PAC recommends devoting that time to Au+Au collsions at 200 GeV. As noted below, the PAC believes it is essential that both PHENIX and STAR perform crucial measurements of heavy flavor production in Au+Au collisions during Run 14. The STAR HFT is based on a new technology with (state-of-the-art) very low mass. Such a detector inevitably requires commissioning time with realistic in-beam conditions before it is fully functional. In order to ensure the success of the HFT during Run 14, STAR will install two to three sectors of the HFT pixel detector for engineering studies during Run 13. This will permit STAR to address many final issues involving the integration of the HFT with the rest of the STAR detector and data acquisition system, slow controls, etc. However, with only the pixel layers installed and without the IST and SSD, it will be difficult to verify that the detector achieves the required pointing resolution using only p+p data. A week of 200 GeV Au+Au collisions during Run 13 will provide the data to evaluate the pixel detector position resolution and increase the probability that the HFT will produce physics-quality data early in Run 14.

3.4.2 Au+Au at 15 GeV in Run 13

The RHIC Beam Energy Scan (BES I) has produced a wealth of new data on the evolution of QCD matter as the baryon chemical potential changes. One particularly suggestive result involves the higher moments of the net-proton distributions. As one approaches the critical point from higher energies, the kurtosis is expected to first decrease from a value near 1, then increase above one. STAR has shown that the skewness (normalized to the Poisson expectation) and kurtosis are essentially constant from 200 to 39 GeV, then decrease as the energy is decreased from 39 to 19.6 GeV. Below 19.6 GeV, the skewness then increases. The kurtosis may also increase, but the limited statistics of the existing data at 11.5 and 7.7 GeV preclude a definitive conclusion.

Current calculations have not yet been able to determine how rapidly the expected changes in the higher moments will occur as the baryon chemical potential changes. The gap in the current beam energy scan between 11.5 and 19.6 GeV involves a change in the baryon chemical potential of more than 100 MeV. If the higher moments change rapidly with chemical potential, the critical point might lie between the regions of the QCD phase diagram that are being sampled by the 19.6 and 11.5 GeV data. Thus, it is important to add another measurement at a collision energy of 15 GeV, with precision comparable to the existing measurement at 19.6 GeV. Such a run would require 20 days. The PAC notes that, at this energy, RHIC cannot provide collisions to both PHENIX and STAR concurrently.

3.5 Discussion of heavy ion running in Run 14

The PAC considers a long Au+Au run at 200 GeV to be the highest priority for Run 14. This run will enable both PHENIX and STAR to perform high precision measurements of heavy flavor production, including detailed studies of R_{AA} and v_2 for electrons and muons from separated charm and bottom decays as well as R_{AA} and v_2 for fully reconstructed D mesons. These measurements have been a major goal of the RHIC program for many years. Several major upgrades that will be completed prior to Run 14 make this run particularly timely, including the STAR HFT and MTD and the RHIC 56 MHz RF cavity. In addition, the PHENIX FVTX was completed in Run 12, but the proposed Au+Au operation in Run 14 will provide the first PHENIX Au+Au measurements using the FVTX. PHENIX also expects to refurbish and re-install some malfunctioning ladders in the VTX detector prior to Run 14.

Previous measurements by PHENIX and STAR of single electrons from semi-leptonic heavy flavor decays indicate strong suppression of both charm and bottom meson production in Au+Au collisions at RHIC. The strong suppression of heavy flavor production has presented a challenge for theoretical models of quark energy loss, and a unique understanding of the currently available results is not yet available. During Run 14 new measurements will be made by PHENIX of charm and bottom decay electrons at mid-rapidity and muons at forward rapidity. STAR will directly measure D meson v_2 and R_{CP}, and will make first measurements of B meson and Λ_c production that will likely need to be followed up in future years with higher statistics. The separate measurements of bottom and charm suppression as a function of p_T and corresponding measurements of charm and bottom meson flow are expected to significantly improve constraints on theoretical descriptions of heavy quark quenching.

The completion of the MTD will enable measurements of Y suppression at mid-rapidity through measurements in the muon decay channel. These measurements will have much better mass resolution than previous Y studies at RHIC, allowing separation of the 1s, 2s, and 3s states which are expected to melt at different temperatures in the QGP. The MTD will also enable measurements of e-μ correlations that are essential to isolate the thermal contribution to the intermediate mass di-electron spectrum.

3.6 Discussion of p+p running in Run 14

In Run 14, $\sqrt{s}$ = 200 GeV p+p measurements will provide an essential baseline for the Au+Au heavy flavor measurements that will be made by both STAR and PHENIX. The heavy hadron spectra measured in p+p collisions will be used to quantify the suppression in Au+Au collisions through the nuclear modification factor, R_{AA}. The p+p data will also be valuable for providing the first direct tests of perturbative QCD calculations of open bottom production at 200 GeV.

PHENIX proposes to study p+p with transversely polarized beams during Run 14, notably to achieve a precision measurement of A_N for clusters in the MPC and to reduce the errors on the mid-rapidity measurement of interference fragmentation functions. STAR proposes to study p+p with longitudinally polarized beams during Run 14, notably to reduce the uncertainty on A_{LL} for inclusive jets and di-jets.

These measurements are very well motivated. The origin of the large A_N that is seen for forward hadron production remains an important open question. Additional data with enhanced precision and extended p_T coverage are clearly needed. The unpolarized parton distributions, together with the helicity and transversity distributions, are the three leading-twist, collinear distribution functions of the nucleon. Much less is known about transversity than is known about the other two. Recently, STAR has presented preliminary measurements of interference fragmentation function (IFF) and Collins asymmetries in jets that provide the first clear indication of transversity in mid-rapidity p+p collisions. IFF measurements by PHENIX have the potential to both confirm and extend the STAR observations.

PHENIX measurements of π^0 A_{LL} and STAR measurements of inclusive jet A_{LL} provide the most stringent current constraints on gluon polarization in the proton. Recently, the DSSV group performed an initial fit including preliminary PHENIX π^0 and STAR jet results from the 200 GeV period of Run 9. It finds that the integral of ΔG over the range $0.05 < x < 0.2$ is approximately 0.13. Additional studies using the DSSV code demonstrate that the RHIC data are now sufficiently precise that they are also beginning to provide meaningful constraints on the gluon polarization in the region $x > 0.2$. Additional measurements of A_{LL} for inclusive jets and di-jets at 200 GeV will provide increased precision on the gluon polarization at intermediate to large x, complementing the low-x sensitivity that will be obtained from Runs 12 and 13.

4. Physics opportunities at RHIC over the next decade

4.1 Introduction

Over the last decade, RHIC has discovered a partonic phase at high energy density and temperature with unique and largely unanticipated properties, the sQGP (the 'strongly interacting perfect liquid'). Current results indicate that this partonic phase is qualitatively similar at LHC but also shows some quantitative differences. The energy densities between top RHIC energy and LHC differ by at least a factor of three (even with the conservative assumption of constant equilibration time), and by a comparable factor within the energy range of RHIC itself. The initial states probed at low RHIC energy ($\sqrt{s_{NN}} \approx 10$ GeV) and top LHC energy therefore differ by an order of magnitude in energy density, spanning a large range of initial temperatures and baryon chemical potentials (μ_B) in the QCD phase diagram. Within this range, a number of significant and possibly non-trivial T- and μ_B-dependent changes in the nature (e.g., constituents/quasi-particles) and properties (e.g., coupling strength) of the partonic matter are expected. In addition, as the world's only polarized collider, RHIC will continue to play a vital role in determining how the spin of the proton emerges from the spins and orbital angular momenta of the proton's constituents. For example, preliminary analysis of recent RHIC data suggests a significant, non-zero gluon polarization.

The next decade will see progress toward *precision measurements* of the sQGP at both RHIC and LHC. Similarly, a more *complete picture* of partonic angular momentum and transverse momentum in the nucleon will be obtained. We also expect the *continuation of discovery* by following up on intriguing hints seen in the current RHIC data.

4.2 Precision measurements of the sQGP

RHIC has clearly established the existence of a surprisingly strongly interacting partonic phase, with properties like strong absorption of fast partons and almost ideal hydrodynamic flow—which are far from the ones of the anticipated gas of free, weakly interacting partons. The important question over the next decade is to understand the reason for this set of characteristics. It must be addressed with precision measurements of the sQGP properties, e.g., viscosity η/s, opacity/transport coefficient $\hat{q}$, the Debye screening length, and their temperature dependences. This will help to both identify the constituents (effective degrees-of-freedom) of the sQGP, and clarify the nature and strength of their interactions.

Precision measurements are well under way at both RHIC and LHC to extract a better upper bound (or make an actual measurement) of η/s, which is directly related to the interaction strength. Constraining the initial conditions (pressure gradients) is one of the main obstacles currently being addressed in a variety of ways by both experiments and theory. Using RHIC's flexibility in controlled changes to the nuclear geometry (Cu+Au, U+U) will provide one of the crucial inputs, and will be combined with higher harmonic flow measurements at both LHC and RHIC. For η/s, the data already taken at the two colliders stand a good chance of being sufficient and decisive. They may be also precise enough to answer the question of whether there is a change of viscosity, equation-of-state, and/or sound velocity with temperature.

Precision measurements have just started for the other two high priority observables needed, as a minimum, to characterize the sQGP: opacity (parton energy loss) and Debye screening length (quarkonium suppression). Decisive measurements will either greatly benefit (energy loss) or even require (quarkonium suppression) data from both colliders.

Parton energy loss ('jet quenching'):
The observable to be investigated is the amount of energy loss (to extract $\hat{q}$); but more particularly its dependence on color charge, parton mass, parton energy, path length, and energy density/temperature. For each of these characteristics, a range of testable predictions exist, and each dependence is sensitive to one or more aspects of the underlying mechanism (e.g., collisional, radiative energy loss) and the underlying theory (e.g., pQCD, AdS/CFT, etc.) used to make the predictions. Current indications from both RHIC and LHC show that the 'lost energy' appears in very soft particles (< 2-4 GeV) which are scattered out to very large angles with respect to the jet axis. A detailed study of the phase-space distribution of the lost energy and its coupling (or not) to the bulk matter is still at a very early stage, but will be crucial to learn about the dynamical features and processes of the energy loss (e.g., few hard versus multiple soft scatterings, timescales of energy loss and fragmentation, re-interaction of radiated gluons, etc.). Measuring energy loss at two sufficiently different points in the phase diagram (different energy densities) will be important to test models and gain confidence in them, and *may even be crucial* to unravel the nature of the sQGP constituents and their interactions, both of which are likely to change with energy density and temperature.

The completed (PHENIX) or on-going (STAR) heavy flavor detector upgrades have made RHIC very competitive both in terms of precision and timescale for heavy flavor energy loss at low and intermediate p_T (< 10 GeV/c), which is the crucial region to measure color charge and parton mass dependences. Energy loss measurements with low energy jets (< 30-40 GeV), where the effect is strongest in relative terms, should be easier at RHIC because of the reduced soft background and smaller background fluctuations. Studying the soft particles which constitute the 'lost energy' will likewise benefit from the lower particle density and can be done well with the jet energies accessible at RHIC because the energy loss depends only weakly (~ logarithmically) on parton momentum. A long anticipated 'golden' channel for energy loss study is gamma-jet coincidence, where the photon serves to tag the energy of the scattered parton. This channel is easier to measure at RHIC, including down to substantially lower parton energy, as the gamma/π^0 ratio is much higher than at LHC. Comparing jets of the same energy interacting with the different medium at the two colliders would be a particularly powerful way to extract the temperature dependence of the interaction strength, with the coupling expected to be potentially much stronger at RHIC. These studies are beginning with the existing detectors but would become high statistics precision measurements only with the proposed sPHENIX. The path-length dependence can be investigated very well at RHIC because of its flexibility in changing the nuclear geometry (A+B collisions). At higher

$\sqrt{s_{NN}}$, the LHC is better suited to study energy loss over a large dynamic range in jet energy to extract the dependence on parton energy.

Quarkonium suppression:
Deconfinement is a defining property of the QGP, but the interpretation of its most prominent observable, J/Ψ suppression, is still an open issue more than 25 years after the first experimental observation, largely because of the unexpected similarity found in the J/Ψ suppression pattern between RHIC and SPS. The initial J/Ψ measurements at the LHC and the first measurements of the Y family at both LHC and RHIC finally hint at a resolution of this long standing puzzle, in terms of recombination of charm quarks into J/Ψ's at hadronization. These new results show a clear way forward, to go beyond a single meson and measure the suppression pattern of all 5 states which are experimentally accessible (Ψ, Ψ', Y, Y', Y") at different temperatures (points in the phase diagram). The J/Ψ and Ψ' pattern as function of beam energy should reflect the combination of deconfinement ('melting') and regeneration, with the first effect depending on temperature and the latter on charm density. The Y-family suppression pattern should reflect primarily deconfinement because bottom production even at LHC is too small to have the signal masked by recombination. Observation of a threshold in one of the states (with the Y' being a prime candidate) within the RHIC energy range or between RHIC and LHC would be a clear and potentially unambiguous sign for deconfinement. Further precision measurements of the J/Ψ family between SPS and top RHIC energies would help to quantitatively extract the different roles of melting and regeneration. Only the SPS and RHIC results together could have 'established' the J/Ψ puzzle; likewise RHIC and LHC measurements of quarkonium suppression do not compete with each other as they are not expected to be equal—melting and recombination depend strongly on both energy density and heavy flavor production. Therefore, only the combination of measurements from the colliders can show definitive patterns and provide the ultimate answer (the long awaited 'smoking gun') about the deconfining properties of the QGP. Precision measurements at RHIC of the three members of the Y-family, made possible by the recent detector and luminosity upgrades, will require at least 10 nb^{-1} of Au+Au running at 200 GeV to measure the suppression in central collisions. To measure the centrality dependence with similar accuracy would require at least a five times more statistics, which could only be achieved in a reasonable time frame with lighter ions and/or detector upgrades along the lines proposed by PHENIX. In addition, comparable statistics with p+p and d+Au will be needed to establish a baseline and quantify cold nuclear matter effects.

4.3 Precision measurements of the proton spin

The RHIC spin program has led to major advances in our understanding of the proton's spin structure. Highlights of the achievements so far are

- constraints on the proton's gluon spin distribution that feature prominently in global analyses of nucleon spin structure—preliminary results from Run 9 indicate for the first time that the fraction of the proton's spin carried by gluons may in fact be nonzero,

- detailed studies of tantalizingly large single transverse spin asymmetries in particle production at forward angles that show a puzzling p_T dependence, and
- observation of parity-violating spin asymmetries sensitive to sea polarization, by which RHIC has demonstrated the feasibility of measuring the flavor separation of the quark polarization by use of charged weak-current interactions.

It is essential to perform these measurements with increased statistical accuracy and over broader ranges of Momentum fraction *x*. Additional insights are expected from the runs currently planned. Measurements of double-helicity asymmetries for jets and identified hadrons at $\sqrt{s}$ = 500 GeV will provide access to the gluon helicity distribution at lower *x*, while additional data from 200 GeV will tighten the present constraints at medium to moderately large *x*. The measurement of prompt photons as a clean and independent 'golden probe' of ΔG would require p+p running in addition to that proposed for Runs 13 and 14. As mentioned elsewhere in this document, a successful RHIC Run 13 with p+p at 500 GeV would complete the first phase of the W program. Judging from the experiments' projections, it is clear that, even then, the emerging constraints on sea quark and anti-quark polarizations will remain approximately on par with those from semi-inclusive lepton scattering. Future runs at higher luminosity (with electron lenses, etc.), will be important to fully exploit this powerful method. Finally, the field has recognized over the past few years that transverse momentum distributions of partons provide a new window into the structure of the proton. They are tied to parton orbital angular momenta and also provide access to a three-dimensional imaging of the nucleon. While a future electron ion collider would ultimately offer the cleanest opportunities for accessing these distributions, the RHIC transverse spin physics program can provide crucial new measurements. The transverse-spin asymmetry in the Drell-Yan process would be a particularly promising avenue for a high-impact measurement from future runs at RHIC. From this asymmetry one can extract the quark and anti-quark Drell-Yan Sivers functions. Theoretical work predicts that these have opposite signs compared to their counterparts extracted from lepton scattering, a prediction that tests our combined concepts of hard-scattering reactions in QCD. We encourage continued consideration of such a program at RHIC.

4.4 Continuing discovery

The beam energy range of RHIC covers a factor of 25, from 7.7 to 200 GeV—— larger than the difference between top RHIC and LHC energies. In the RHIC energy regime, the properties of the hot and dense fireball change drastically from baryon rich matter, dominated by the hadronic phase, to the nearly net-baryon free sQGP, where partonic degrees of freedom dominate a large part of the system evolution. This energy range provides RHIC with unique and unchallenged opportunities to search for a number of phenomena which are either predicted and/or have been hinted at in current beam energy scan data; each of them very much comparable in terms of relevance and scientific potential to the precision measurements listed above.

Transition from hadronic to partonic degees of freedom:
The recently completed beam energy scan (BES-I) has revealed in several soft, large cross section observables (e.g. flow measurements) a mostly smooth but pronounced change in matter properties below $\sqrt{s_{NN}}$ = 40 GeV, while these variables change little from 40 GeV all the way to 2.76 TeV. They seem in general consistent with, and indicative of, a progressive disappearance of the manifestations of partonic degrees-of-freedom. The lower energy data are severely statistics limited below 20 GeV and progressing from intriguing indications to significant and precise results, if justified by the final BES-I results, will require a modest machine upgrade with low energy electron cooling and revisiting the energies below 20 GeV with an additional energy scan (BES-II).

Search for the QCD critical point:
No unambiguous signal ('smoking gun') has been identified so far, but some hints for a non-monotonic behaviour have emerged in the higher moments of net proton distributions. The BES-I analysis has to be finalized and compared to models to substantiate these first indications. If the evidence becomes more convincing, more and higher statistics data will be required in the vicinity of the interesting region. If no clear indications emerge, one additional energy point around $\sqrt{s_{NN}}$ = 15 GeV may be required to firmly exclude the, albeit unlikely, possibility of having missed the critical point because BES-I leaves a fairly large gap in μ_B between $\sqrt{s_{NN}}$ = 11 and 20 GeV. The QCD critical point may also be at lower energy, below ~5-10 GeV. In this case, some exploratory studies at the lowest RHIC energies may be feasible, but an in-depth study would have to be left to the upcoming dedicated low energy facilities FAIR and NICA.

Chiral Magnetic Effect (CME, strong CP violation):
A very clear correlation signal has been measured at RHIC which is compatible with local, strong interaction CP violation in the presence of a magnetic field. The new BES-I data indicates that the signal disappears at low energy as would be expected below the critical phase transition temperature. However, background correlations related to collective flow cannot, for the time being, be excluded as the source, and are at least equally consistent with some of the features found in the data (p_T and rapidity dependence, size of the effect at LHC). One of the prime reasons for the just completed U+U run was the prediction that the magnetic field and hence the CME signal would disappear in central collisions, whereas any flow related background would still be present in central body-body collisions (central tip-tip collisions should exhibit neither effect). If the U+U results confirm that the correlation signal is not caused by flow-related backgrounds, there is clear motivation for follow-up studies at lower beam energies. The observed signal, if indeed caused by the CME, would be of fundamental importance to QCD (as well as other non-Abelian gauge theories) and therefore determining its origin (one way or another) is very important; this task almost certainly requires the beam time and machine flexibility available only at RHIC.

Cold high density matter (Color Glass Condensate):
Particles at forward rapidity (corresponding to low Momentum fraction x) show significant, non-trivial properties and correlation patterns of the kind and size predicted

by models which describe the high parton density in the initial nuclear wave function with a novel phase of 'dense and cold nuclear matter', the Color Glass Condensate (CGC). Similar effects, of comparable magnitude, should be present at mid-rapidity at LHC in proton-nucleus collisions and the 2012 LHC p+A run could give crucial support, or put into question, the relevance of the CGC as compared to more mundane 'shadowing' modifications of the nuclear parton distribution functions. However, the LHC currently foresees only a very limited p+A program, about two 4-week periods within the next decade, and the three LHC detectors involved in the nuclear program have only very limited capabilities at forward rapidity ($|y| > 2.5$). Assuming supportive results from LHC, there is a window of opportunity at RHIC for a focused and dedicated study of the dense initial state matter, as proposed in the upgrade program of the STAR detector. It would, in principle, also provide a natural stepping stone toward a more precise and detailed investigation at a future EIC machine.

4.5 Continuing and future upgrades of PHENIX and STAR

4.5.1 Introduction

Data from the RHIC and LHC heavy ion programs provide clarification and focus for future RHIC efforts, leading not only to the vital physics program outlined above, but also to requirements for detector development. The recent completion of the 6-plane stochastic cooling system at RHIC dramatically increased its luminosity as dramatically demonstrated in the figure below. Updated detector capabilities are required to take full advantage of the physics opportunities afforded by this upgraded machine performance. PHENIX and STAR presented the status and plans of their ongoing detector upgrades and also their long-range vision preparing for a future EIC facility. From the detector viewpoint, the era of low rate and/or limited acceptance devices is ending. Below, the PAC reviews the plans of both PHENIX and STAR in the new era of high luminosity RHIC operations.

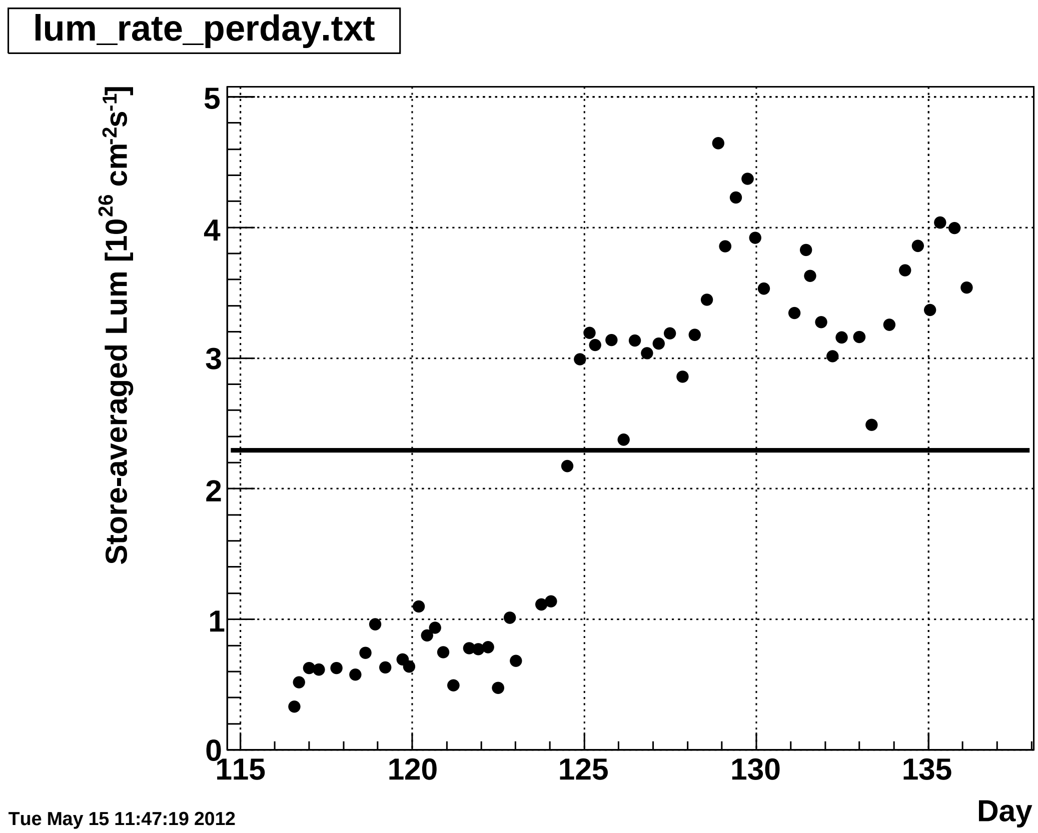

Figure 1. The effect of stochastic cooling on the integrated luminosity indicates the new opportunities and the new challenges of the RHIC-II era.

4.5.2 PHENIX

The PHENIX decadal plan was presented to the PAC in 2011 and described ambitious plans for upgrading PHENIX into a compact large aperture device that would principally leverage prior investments in detector support infrastructure (cabling, high voltage, high speed DAQ, etc…), retaining only the central vertex detector system from the existing PHENIX. The PAC recognizes the necessity of pursuing large aperture and high rate for PHENIX to remain competitive on a world scale in the coming years.

PHENIX's DAQ systems, including upgrades during the past decade remain sufficient to provide a strong basis upon which to build a next generation heavy ion experiment. The clear challenge is to build a capable, staged experiment within realistic financial constraints. PHENIX's approach is to utilize those detector hardware advances that allow each component to be most compact, such as all-silicon tracking and W-based electromagnetic calorimetry. As a comparison point, the outer radius of the proposed tracking system for sPHENIX would fit inside the inner radius of STAR's TPC, and the outer radius of the hadronic calorimeter would nearly fit inside the existing PHENIX drift chamber system. This complete emphasis on compact detector technologies results in a capable detector covering +/- 1 unit in pseudo-rapidity for an estimated cost of $24M plus $6M in redirected labor with 40% contingency.

The 2011 PAC report listed numerous aspects of the PHENIX decadal plan that required further work to clarify the efficacy of the design. These included

- detailed pattern recognition studies to determine the level of false tracks at high momentum resulting from a 6-layer-only tracker,
- the performance of the EMC in the face of higher occupancy that baseline PHENIX,
- detailed analysis of the relative benefits of hadronic calorimetry vs. improved tracking, and
- development of detailed plans in the endcap region.

The PAC was pleased to see significant progress in answering all questions regarding performance of the central barrel. Simulation work presented to the PAC and also shared with the PAC via a preliminary draft of the sPHENIX MIE demonstrate sufficient tracking, good EMC performance (only excellent with the addition of a pre-shower detector), and robust jet triggering and identification for lower momentum jets than currently analyzed at LHC. Currently the specifications for the endcap detectors are only loosely defined, however, PHENIX has relegated these parts of the project to be "staged" after the initial MIE-funded barrel device. Despite its relatively compact size, sPHENIX is a major effort requiring a significantly sized, capable, and enthusiastic group of scientists.

sPHENIX's design brings hadronic calorimetry to RHIC and thereby an opportunity for simple triggering and unbiased selection of the highest energy jets RHIC can produce. Most emphasis was placed upon the relationship between $\hat{q}$ and η/s and how this could be explored with jet loss studies. While jet physics can also be done at LHC, we believe that only by the combination of precision measurements of jets at the widely different $\sqrt{s_{NN}}$ of LHC and RHIC could the temperature dependence of $\hat{q}$ be explored in the region where strongly-coupled behavior may cause a non-trivial dependence of $\hat{q}$ on temperature. The PAC feels that this case would be strengthened by presenting a quantitative plot, showing the variety of predictions for $\hat{q}$ as a function of temperature, along with anticipated error bars from this combination of measurements from sPHENIX and the LHC. Along these lines, in general, we believe there will be gains from further tightening of the critical elements of the physics case.

4.5.3 STAR

STAR presented its upgrade plans, with a focus this year on a request for a start of low-energy electron cooling, and on the evolution of its upgrade plans in for forward direction detection, in response to the recommendations from the PAC last year. Many results from the first phase of the Beam Energy Scan (BES-I) are nearly final, and show clear changes in behavior as the center-of-mass energy drops below about 20 GeV. These changes include indications of the breakdown of constituent quark scaling, a deviation from Poisson expectations in kurtosis and skewness of net-proton distributions, the sign reversal of proton v_1 at $\sqrt{s_{NN}}$ ~ 10 GeV, and the disappearance by $\sqrt{s_{NN}}$ = 7.7 GeV of the azimuthal correlation measure potentially sensitive to the Chiral Magnetic Effect. The PAC recognizes that significant progress has been made in the completion of these measurements, and that, in combination, they provide a significant hint of non-trivial structure in the QCD phase diagram at these energies. The PAC recognizes that preliminary BES-I results point to the potential importance of this project on a several-year timescale. We look forward to the finalization of these results over the coming year, and to considering the question again once these results have been discussed fully in the community. We leave it to the ALD's discretion as to whether it would be optimal to make initial steps towards this project, given the availability of key components and within the context of the overall future plan of RHIC.

STAR presented a new idea, of introducing a fixed target inside its beam pipe, in order to make measurements at lower $\sqrt{s_{NN}}$ in a parasitic mode. This is missing many of the advantages of running in collider mode, but enables partial investigation of the physics at higher net baryon density. The PAC recommends that this idea be fully investigated, in terms of its implications for the machine and the experiments.

The near-term STAR upgrades, the Forward Gem Tracker (FGT), Muon Telescope Detector (MTD), and Heavy Flavor Tracker (HFT), are on a clear path for success. When combined with completed upgrades, this positions STAR well for making full use of the RHIC II luminosity, with a combination of calorimetry and particle identification capabilities that is unique in the world. The PAC notes that the STAR detector as it will be in 2014 retains only the bare minimum of infrastructure from the original STAR detector that took data in 1999; from that experiment, only the TPC sector structures and wires, TPC field cage, and STAR magnet remains. Besides providing capabilities well matched to measurements at the lower energies of BES-I, the upgraded STAR detector provides an excellent device for utilizing heavy ion collisions at the top energy, and, as shown in Run 12, with a wide variety of symmetric and asymmetric colliding systems. STAR did not lay out plans for using these capabilities for heavy ion physics beyond the few-year programs laid out in the HFT and MTD upgrade proposals. The PAC repeats its recommendation from the previous year to detail its plans to use the existing detector on a time scale beyond those programs, in the context of the rapidly evolving knowledge from ongoing RHIC and LHC measurements.

STAR has made progress in its thinking about its longer-term upgrade for forward physics in p+A and polarized p+p collisions. The idea of replacing the TPC inner sectors with a more fully instrumented device is new since the presentation at the previous PAC meeting and appears to be advantageous. This upgrade would essentially double the path length of gas available for dE/dx measurements, providing π/K/p separation at high p_T in Au+Au collisions, and enable higher efficiency tracking in the pseudo-rapidity range from 1-2. In combination with EIC R&D, a prototype tungsten-powder calorimeter has been built and tested, leading to resolutions in agreement with simulations. The concept of using this calorimeter technology has evolved from a monolithic EM and hadronic calorimeter into a more conventional concept of a tungsten EM calorimeter followed by a standard hadronic calorimeter. First simulations of extended disks based on the same technology of the FGT, but covering a more forward pseudo-rapidity region, have also been completed. While significant progress has been made on this front, the PAC recognizes that STAR's upgrade plans are not as fully developed as those of PHENIX, and recommends further effort towards bringing these ideas into a form suitable for a proposal. As with the case for the future of PHENIX, we believe there will be gains from further tightening of the critical elements of the STAR physics case.