Recommendations
Brookhaven National Laboratory
Nuclear and Particle Physics
Program Advisory Committee
June 6-8, 2011

1. Introduction

On June 6, 2011, the PAC heard background information on progress in Run 11, accelerator performance and plans, the PHENIX and STAR Beam Use Requests (BURs) for Runs 12 and 13, and a Beam Use Request for a Drell-Yan measurement at IP2.
We also heard reports on the Drell-Yan workshop held at BNL May 11-13 as well as the proposed proton EDM measurement. The discussion on June 7 was focused on the decadal plan documents prepared by STAR and PHENIX. Based on this input, we report our recommendations for Runs 12 and 13 with discussion of heavy ion, polarized proton (Section 2) and Drell-Yan physics (Section 3). We also make recommendations regarding future development of the decadal plans (Section 4). The recommendations of Section 2 are based on a total of 26 cryo-weeks for Run 12 and 30 weeks for Run 13; we assume there will be 1 week of Au+Au running at 27 GeV at the end of Run 11 to complete that part of the energy scan program.

2. STAR and PHENIX run plans

2.1 Executive summary

For Run 12 the PAC recommends the following (*in order of priority*):
1. 5 weeks of running with polarized proton collisions at 200 GeV.
2. 7 weeks of running with polarized proton collisions at 500 GeV.
3. 5 weeks of running with Cu+Au collisions at 200 GeV.
3. 3 weeks of running with U+U collisions at 193 GeV.

For Run13 the PAC recommends the following (*not* in order of priority):
1. 12 weeks of running with polarized proton collisions at 500 GeV.
2. 5 week of running with polarized proton collisions at 200 GeV.
3. 7 weeks of running with Au+Au collisions at full energy.

2.2 Discussion of heavy ion running

The discussion below is ordered by physics priority and is not to be taken as an optimal scenario for the order of colliding species. As discussed above, this plan is predicated on the assumption that the 27 GeV Au+Au running is completed in Run 11.

2.2.1 Run 11: 1 week of Au+Au at $\sqrt{s_{NN}}$ = 27 GeV

The primary goal of taking data at 27 GeV is to complete the beam energy scan program. At the last meeting, the PAC supported making these measurements but ranked this lower in priority for Run 11. The PAC stated that results from the 39 GeV data could change this prioritization in future. We note, however, that STAR upgrade plans make it timely to complete the energy scan, including both 19.6 and 27 GeV, during Run 11. STAR will install the Forward GEM Tracker (FGT) prior to Run 12 and remove the Forward TPC.

Run 11 is still in progress with Au+Au collisions at 200 GeV and has already collected 19.6 GeV Au+Au data. This leaves two open regions in the scan of μ_B. The~~is~~ first of these would be filled by the running at 27 GeV. The second would be more complicated as it would require running between 11.5 and 19.6 GeV, which would likely require a machine mode during which only one experiment could collect data. Because the run plan for Run 12 already contains a significant number of species changes, it would be prudent to complete the 27 GeV running during Run 11, and the PAC strongly encourages this strategy. Running at an energy in the range 11.5-19.6 GeV should be considered in the out years. However, if further analysis of the results on fluctuations at the lowest energies of the beam scan continue the trend of the preliminary data (that fluctuation signals are not turning on as hinted by prior SPS results), the PAC does not find a compelling reason to measure at yet lower collision energies.

2.2.2 Run 12: 5 weeks of Cu+Au(Pb) at $\sqrt{s_{NN}}$ = 200 GeV

Among the recent lessons learned in heavy ion physics is that initial geometry and fluctuations thereof have profound consequences that influence the final state momenta and produce contributions to both even and odd harmonics in the final state. Such effects are now measured in Au+Au at RHIC and Pb+Pb at LHC and are found to be of quite similar magnitude despite the large difference in beam energy. RHIC is uniquely capable of supplying collisions among asymmetric species that will provide new opportunities to vary the collision geometry and thereby the density profile of the produced matter.

In the last year, two long-standing puzzles associated with unexpected features in di-hadron correlation measurements in A+A collisions have been resolved with data from RHIC and the LHC. These features were the long-range pseudorapidity correlations of particles at small azimuthal angle separation often referred to as the "ridge" and extra "peaks" in the distribution of intermediate p_T di-hadron azimuthal angle separation, $\Delta\varphi$, that were considered a possible signature of "Mach" shocks generated by high-p_T quarks or gluons propagating in the quark gluon plasma. Progress in understanding those features was stimulated by a paper which suggested that the ridge and Mach peaks could be understood if the particle azimuthal angle distribution had a "v_3" component that varied as $\cos[3(\phi-\psi_3)]$ with ψ_3 an angle that varies from event to event. Such an odd harmonic, originally thought to be forbidden by the left-right symmetry of A+A collisions in the transverse plane, could arise from fluctuations in the transverse positions of nucleons undergoing hadronic scattering. To produce the observed features in the angular distributions of hadrons, those initial-state spatial fluctuations must be imprinted on final-state particle momenta through collective (i.e. hydrodynamic) evolution of the system. Measurements presented at the 2011 Quark Matter conference demonstrate that such odd harmonics are present in the data and that they completely account for the ridge and the supposed Mach peaks. In fact, using a Fourier expansion of the azimuthal angle distribution of produced particles,

$$\frac{dN}{d\phi dp_T d\eta} = \frac{dN}{2\pi dp_T d\eta}\left(1 + \sum_m 2v_m \cos\left[m(\phi - \psi_m)\right]\right)$$

statistically (and systematically) significant measurements were obtained for Fourier coefficients, v_n, up to n = 6. The experimental results are now being used to test viscous hydrodynamic calculations that include initial-state spatial fluctuations. Because dissipative effects in the collective motion of the system are expected to more effectively damp higher harmonics of the angular distribution, comparisons of the variation of v_n with n between data and hydrodynamic calculations are expected to substantially improve constraints on transport properties of the quark gluon plasma.

Cu+Au collisions exhibit density profiles that are inaccessible to symmetric colliding systems, and thereby will provide uniquely insightful measurements of parton energy loss. Mid-centrality collisions, for which the Cu nucleus is mostly occluded by the Au, break left-right symmetry and have non-zero ε_1 and ε_3 even without the contribution of initial state fluctuations. Hydrodynamic evolution effectively transfers non-uniformities from position to momentum space and is highly sensitive to early time dynamics.

Cu+Au collisions provide a unique opportunity to disentangle the path length and energy density dependence of medium-induced parton energy loss. In symmetric systems, both the initial energy density and the transverse size of the medium increase with collision centrality. However, in an asymmetric system such as Cu+Au, there is a range of impact parameters for which the Cu nucleus is completely occluded by the larger Au target. Thus, it is possible to select a range of centralities for which the transverse dimensions of the medium are fixed but for which the energy density varies. The zero degree calorimeter in the Cu-going direction will provide measurement of the number of spectator neutrons from the Cu nucleus, and thus allow selection of the fully occluded events, while the multiplicity of produced particles measured in the experiment minimum-bias trigger detectors will allow selection of events with different initial energy density. Measurements of the full suite of high p_T observables as a function of centrality for these fully occluded events, will provide a hitherto unavailable measurement of the dependence of those jet quenching observables on the energy density in the medium for fixed medium size.

The initial-state density profile of the medium created in fully occluded Cu+Au collisions is decidedly more uniform than that from symmetric collisions. This lessens the contribution of so-called "edge-biased jets" for which one imagines a di-jet pair produced tangentially in the "halo" of low density matter surrounding the more interesting dense medium. The increased uniformity of the density similarly simplifies the interpretation of gamma-triggered jet studies.

Although Cu+Au collisions are not a specific request from the STAR collaboration, the program of varying the geometry and fluctuations is explicitly mentioned in STAR's Beam Use Request in the form of U+U collisions. The PAC feels that the geometry of Cu+Au is simpler to control experimentally.

5 weeks at the anticipated luminosity will deliver 2.4 nb^{-1} within the +/-10 cm vertex for PHENIX resulting in ~10 billion recorded collisions, statistics described by PHENIX as a "good" Au+Au run. Among these recorded collisions, only the top 8-10% have the Cu nucleus fully occluded by the Au. Because of this, the PAC recommends that *if* the full 5 weeks of data cannot be delivered, shorter studies U+U collisions should take priority over Cu+Au.

2.2.3 Run 12: 3 weeks of U+U at $\sqrt{\mathbf{s_{NN}}}$ = 193 GeV

The new EBIS ion source is being commissioned during Run 11 and will become available in Run 12, opening the possibility of U+U collisions. The PAC recommends that all U+U collisions be run at the same magnetic rigidity as full energy Au+Au so that switchover time of species can be kept to a minimum. The recommendation from the PAC for Run 11 placed this program at low priority and it has not been carried out due to budget constraints.

U+U collisions potentially provide new physics opportunities because of the large ground state deformation of the U nucleus. So-called tip-tip collisions provide access to higher energy density than that available in central Au+Au collisions. Central "body-body" collisions provide a deformed initial state with little spectator material. If such collisions can be isolated with sufficient purity, the initial state has a well-defined eccentricity over a much larger volume than mid-central Au+Au collisions, providing added dynamic range to jet suppression vs. medium-length studies. The absence of the spectator generated magnetic field would create an excellent control measurement for the evidence of the so-called local parity violating fluctuations observed in non-central Au+Au collisions. The PAC noted that control of the collision geometry relies on the tight interplay between, on the one hand, experimental observables and cuts, and, on the other, detailed modeling. In the case of a nucleus with a deformed ground state, simple and familiar tools like Glauber model calculations become highly sensitive to input assumptions including nuclear skin depth and the precise admixture of participant and collisional scaling terms. Furthermore, measurements made at the sub-percent level are experimentally demanding and the impact of fluctuations on their interpretation remains to be investigated.

Theoretical developments will likely be required in order to reduce systematic uncertainties associated with these measurements. Studies from a Glauber simulation indicate that with 2% most central collisions (selected by ZDC), a significant difference between final state v2 in Au+Au vs Pb+Pb can be obtained from the event-by-event q-vector quantity. However, the simulated magnetic field from U+U collisions would be significantly smaller than that from Au+Au collisions. The RHIC community has a proven track record of ingenious solutions to seemingly intractable issues. Since the last PAC meeting, further data driven studies on geometry and sub-percent level selection has been carried out in STAR in comparison between Au+Au data and simulation. The PAC recommends that sufficient data (3 weeks) be collected to provide a charge-separation study and to determine the feasibility of selecting tip-tip and body-body collisions, and, particular, determining the purity thereof. The analysis of these data should be used to quantify the accuracy with which specific event geometries can be selected experimentally, including uncertainties arising from the a priori unknown role of fluctuations and of multiplicity scaling with number of participants or collisions. This information should be used as input to future beam use requests.

2.2.4 Run 13: 7 weeks of Au+Au at $\sqrt{s_{NN}}$ = 200 GeV

Run 13 will include the full complement of upgrade detectors in both STAR and PHENIX including production runs for the PHENIX FVTX and engineering running for the STAR HFT. A return to full energy collisions is thereby warranted. Whether these collisions should be Au+Au or U+U will depend, on the one hand, the desire to extend previous Au+Au measurements using newly available detectors, and, on the other, to the analysis of Run 12 measurements showing how effectively the geometry in U+U collisions can be constrained.

The PHENIX VTX and FVTX detectors permit the separation of non-photonic electron yields into the separate contributions from charm and bottom. Separating the charm and bottom contributions to non-photonic electron R_{AA} and elliptic flow has been a very high priority for the field ever since the initial measurements showed that high-p_T non-photonic electrons are strongly suppressed in central Au+Au collisions. The data that PHENIX is recording with the VTX during Run 11 are expected to provide the first such separation. But the statistics, and hence p_T reach, of the Run 11 data will be limited. The additional statistics that can be recorded during Run 13 will extend the c-b separation to substantially larger p_T. At the same time, the FVTX will be able to extend separated measurements of charm and bottom R_{AA} and v_2 to the forward direction. In addition, the FVTX will improve the mass resolution of the PHENIX muon measurements. This will provide important measurements of the ψ' in Au+Au collisions that should shed light on the surprising result that R_{AA} for J/ψ appears to be the same at 62 GeV and 200 GeV.

Au+Au collisions during Run 13 will permit STAR to enhance the statistical precision of its Upsilon, gamma+jet, and high-p_T J/ψ measurements. STAR also expects to have a substantial fraction (~1/2) of the MTD installed. This will permit first measurements of mid-rapidity Upsilons and high-p_T J/ψ in the di-muon channel. Au+Au collisions will also provide STAR with an opportunity for an engineering run utilizing a small subset of the HFT detectors. This will significantly increase the likelihood that the HFT will produce significant results during its first year of full operation in Run 14.

2.3 Discussion of p+p running

The PAC is pleased to see that an extended 500 GeV p+p run took place in Run 11. Unfortunately, p+p running in Run 11 suffered from several hardware failures that were, for the most part, not specific to p+p operation. These failures both reduced accelerator up-time and impeded the expected growth of luminosity during the run. As a result, the integrated luminosities delivered to STAR and PHENIX did not reach the envisaged goals of about 170/pb each. However, during Run 11, RHIC was able to achieve an average store luminosity of 9×10^{31} $cm^{-2}s^{-1}$ which falls near the upper end of the expected average store luminosity range, 5.5-10×10^{31} $cm^{-2}s^{-1}$. The polarization achieved during Run 11 was near 50%, a significant improvement over that achieved in Run 9. However, an observed 10-15% loss of polarization during in the ramp from 100 GeV to 250 GeV remains to be understood. During Run 11, PHENIX measured forward rapidity W production in the muon spectrometers with the goal of producing an unpolarized cross-section. PHENIX also hoped for a first measurement of A_L at forward rapidity, but the limited integrated luminosity obtained during Run 11 will make achieving that goal very challenging. During longitudinal running, STAR focused on W production at mid-rapidity. Their final integrated figure-of-merit was similar to that in Run 9, so only a factor ~√2 improvement on longitudinal spin physics results over past results are expected from Run 11. STAR did, on the other hand, reach and exceed its stated luminosity goal of 20/pb with 50% polarization for transverse-spin physics for Run 11.

Guidance given to PAC for Run 12 planning was for a 26 cryo-week run, and for a 30 week run for Run 13. Both experiments have ambitious upgrade plans for Run 12 whose realization would also greatly benefit the spin program, and the W physics program in particular. STAR is planning to install the Forward Gem Tracker (FGT), which will significantly enhance the charge-sign separation capabilities for Ws at forward rapidities. After making successful first use of the silicon microvertex barrel detector (VTX) for heavy-flavor physics in Run 11~~0~~, PHENIX is currently completing the Forward Vertex Tracker (FVTX) and the muon trigger. The completion of the muon trigger upgrade will provide PHENIX with sufficient event selectivity to trigger on the W events in the muon arms, without need for prescaling, up to the highest instantaneous luminosities that RHIC is expected to provide. The upgrade schedules are tight for both experiments, but seem on track. Starting Run 12 as late as January 1, 2012 should help in completing the upgrades prior to the run.

PHENIX views 200 GeV p+p running in Run 12 as important for obtaining a baseline for heavy-flavor studies in heavy-ion running with their new VTX. The 200 GeV running should occur before 500 GeV running in order to allow commissioning of the RPC-1 component of the muon trigger prior to taking W data. STAR also views 200 GeV p+p running as important for heavy-ion comparison, especially for Upsilon and gamma-jet measurements. Their beam use request foresees 200 GeV p+p running only for Run 13, when a long (10 week) 200 GeV p+p period is proposed. It seems to the PAC that there would be no adverse effects to STAR if the 200 GeV p+p running were split, so that 5 weeks took place in Run 12. The period in Run 12 could then also serve for commissioning of the STAR FGT, prior to the switch to 500 GeV.

The beam use requests for both STAR and PHENIX feature extended 500 GeV running in Runs 12 and 13 (a total of 18-20 weeks). Here the prime focus is on W physics. It is clearly vital for the RHIC spin program to obtain precision asymmetry measurements from the W physics program as best and as quickly as possible, in order to realize RHIC's promise of providing independent, clean and precise insights into the light flavor quark and anti-quark polarizations in the nucleon, which is the DOE performance milestone HP8 targeted for 2013. The experiments hope to accumulate 300/pb integrated luminosity with polarization P=0.55 (PHENIX) and P=0.7 (STAR) over the two runs. This would provide very significant sensitivity to quark and anti-quark polarizations, to feature prominently in global analyses of nucleon spin structure. 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 dijets and dihadrons. 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.

Based on these observations, the *PAC recommends for Run 12 with highest priority a ~5 week polarized p+p run at 200 GeV, followed by a ~7 week longitudinally polarized p+p run at 500 GeV*. Our initial guidance for p+p running in Run 13 is for ~12 weeks at 500

GeV and ~5 weeks at 200 GeV. The combined 500 GeV running in Runs 12 and 13 would be expected to lead to results that would fulfill the W program milestone. As for the 200 GeV running, the PAC notes that there is good motivation both for running with longitudinally polarized and with transversely polarized beams. In the latter case, further transverse-spin studies by both PHENIX and STAR would become possible. STAR also makes a convincing case that longitudinal 200 GeV p+p running is important for constraining Δg in jet production, especially toward higher $x \sim 0.2$. The split of 200 GeV running time into longitudinal or transverse polarization is best left to each experiment to choose.

Given that RHIC has not yet achieved its main p+p physics goals, the PAC does not think that a week of RHIC operations should at present be dedicated to the pp2pp experiment. The PAC's viewpoint on this would likely change if the experiment could run with normal beam tunes, that is, parasitically without impacting the other goals at RHIC. We encourage the proponents of the experiment to work toward finding a viable way for achieving this and to present their case again subsequently, including a presentation of the main scientific goals of the experiment.

3. Drell-Yan Measurements at IP-2: A_NDY

This experiment was presented as an LOI at last year's PAC. It is a highly focused experiment whose aim is to obtain the first measurement of the Sivers single-spin asymmetry in the Drell-Yan (DY) process, and thereby provide a much-needed test of the predicted sign change between the Sivers asymmetry in DY and in semi-inclusive deep-inelastic scattering (SIDIS). The importance of testing this sign change cannot be overstated: it is a firm prediction of the TMD framework / factorization theorems that constitute one of the two most promising routes to measuring the orbital angular momentum of quarks within the proton. This measurement is also related to DOE milestone HP13 (2015).

The beam use request for this experiment — now named A_NDY — was a reiteration of last year's LOI with some additional paragraphs describing the results of the tests performed in Run 11. Much more detail was provided in the public session talk, showing the full extent of the work done over the past year. On an impressive timescale, a functioning detector was installed at IP2 and significant data analysis has already been accomplished. At the heart of this test experiment was a recycled hadronic calorimeter (HCAL). With this equipment, the experimenters met their two goals for Run 11: to demonstrate a viable calibration strategy for HCAL, and to determine the impact of collisions at IP2 on PHENIX and STAR operation. The latter was shown to be minimal, and a clever calibration technique using photons in HCAL was convincingly presented in the public-session talk. The PAC congratulates the collaboration on achieving these two goals. The talk also described new developments in the ongoing design of the spectrometer, including expansion of the azimuthal acceptance and concrete plans for the addition of the electromagnetic calorimeter.

Response to key points from last year's PAC report

Last year's PAC suggested the physics case be sharpened to focus exclusively on the high-impact Sivers sign-change test at a single kinematic point. The physics case is now very well focused, and the more ambitious "Model 1" detector has been effectively abandoned (though not removed from the proposal). The PAC also appreciates the experimenters' focus on the narrow region of kinematic overlap with the Sivers measurements in SIDIS from HERMES and COMPASS ($0.1 < x_F < 0.3$ and $p_T < 2$ GeV). The PAC understands that the $x_F > 0.3$ data that will also be collected may produce exciting results, but strongly endorses optimizing the experiment to produce the best possible result in the SIDIS overlap region.

A second point raised by the 2010 PAC was the need for more manpower, particularly given the very tight timescale of the experiment. (It must be out of the IP2 area by 2014.) The PAC was impressed with the experimeters' success in recruiting JLab groups who will contribute the well-tested BigCal electromagnetic calorimeter to A_NDY. Some of the new collaboration members participated already in Run 11, contributing a segment of BigCal to the test experiment. However, it is clear the manpower plan presented in the

BUR is not yet in a form suitable for a final proposal, as only a handful of people are assigned to the many tasks.

Third, PAC 2010 requested a clear demonstration that neither STAR nor PHENIX is capable of performing the measurement. Last year's discussions made it clear that the geometry of those detectors would prevent a far-forward measurement at 500 GeV, leaving 200 GeV as the only possibility left to be studied. The arguments presented during the talk were convincing: in this rate-limited experiment, 200 GeV running would incur losses in cross-section and in beam focusing that would ruin the measurement.

The final request from PAC 2010 was not met in the BUR. The 2010 PAC specifically asked for a plot showing the impact of the projected result, by comparing it with theoretical expectations (with associated error bars) and showing the relevant kinematic range over which the single A_NDY point would be accumulated. However, discussions with the experimenters and a new fit generated during PAC 2011 provided sufficient information for the PAC to generate the requested comparison plot. The result was impressive, and persuaded the committee members that A_NDY *will* be able to make a decisive test of the sign-change prediction. The committee urges the experimenters to display their projected results in this readily interpretable fashion in future presentations. A particular suggestion is to show not only on the comparison with theoretical fits, but to simply overlay the predicted A_NDY point (with negative sign) with the HERMES data for π^+ and K^+ production (with positive sign) as all of these measurements are *u*-quark dominated. This data-to-data comparison is direct and dramatic. We note, however, that the HERMES and A_NDY data are at quite different Q^2 and M^2_γ scales, and involve convolutions over different p_T / k_T distributions; TMD theory is not yet in a position to confidently address these differences.

Recommendation

We endorse running A_NDY in Run 12 to make the first of the two measurements needed to obtain the results discussed above. We encourage lab management to try to find the funds ($\lesssim$ \$350k) to add the full BigCal to the setup for this measurement.

The committee's principal concern is the full \$1.3M apparently needed to complete the present detector design — a figure which is not mentioned in the BUR. The PAC urges the collaboration to write a full proposal to secure this sizable amount of funding. As any reduction in cost will clearly be of great value to this time-constrained experiment, it is vital that the proposal delineate how much money is needed for the split-dipole plus tracking phase planned for Run 13. From our discussions with the experimenters, it seems highly likely that this second phase is not vital for the Sivers sign-change test, which is the physics case that the PAC rates most highly. The full A_NDY proposal must clarify how much of the Run 13 phase is purely outlook for the future, as the case for such a future program – though unquestionably exciting – has yet to be made.

4. Decadal Plans

The PHENIX and STAR collaborations presented their first efforts at preparing a decadal plan, as initiated by a request from Steve Vigdor. Both collaborations acknowledged that preparing for the next decade of RHIC operations is an ongoing process, and that the documents presented to the PAC represent just a first step toward a comprehensive plan for the next decade of RHIC operations.

The PAC recognizes that both collaborations have executed very successful experimental efforts during the last decade that have revolutionized the understanding of the nature of matter under extreme conditions, and also have greatly clarified the structure of the nucleon. The decadal plans must identify physics objectives that build on this success; ones that can have substantial impact and the potential to change the way we think. These objectives must ensure a leadership role of the RHIC program in exploring fundamental aspects of nature, building upon the successes of the existing program. In this context, the start of LHC heavy-ion program during 2010 has emphasized the importance of the main RHIC discoveries as generic features of high energy density nuclear matter. It is important to recognize that these new explorations of high density matter with beams of nuclei with TeV energies must be taken into consideration in the decadal planning process. Lastly, these physics objectives must be consistent with both the operational cost of RHIC and significant potential detector upgrade costs, particularly for the last half of the decade considered in the plans.

Both collaborations have identified physics questions they consider to be key in motivating the next decade of RHIC operations. These questions imply a focus on precision measurements of observables that are central to understanding the phase-structure of QCD and the structure of the nucleon. The PAC interprets their physics agenda as a gradual evolution of the RHIC program from an era of ***Discovery*** towards an era of ***Precision*** in which detailed and quantitative exploration of hot and dense matter will be performed. The recent success in experimentally constraining the ratio of shear viscosity to entropy density represents a first example of this transition toward precision measurements. It provides a clear illustration that detailed analyses of dynamical features of heavy ion collisions place tight constraints on fundamental properties of QCD matter.

The PAC recognizes that a compelling case for RHIC operations and upgrades through the next decade requires a clear articulation of the precision with which key physics observables can be measured and, at the very least equally important, how these measurements impact our understanding of the fundamental properties of QCD matter. At this stage, neither Decadal Plan contained an as yet satisfactory presentation of either aspect. The PAC believes that further progress will greatly profit from a two-pronged approach:

1) The capability of the RHIC program to move towards an era of ***Precision*** must be manifest in the way the decadal planning process evolves. This necessitates the plans becoming quantitative, including full-scale simulations of detectors and

estimates of the expected uncertainties in key observables. However, documenting the capability of experiments to make precise measurements of observables does not in and of itself constitute a compelling case.

2) It is crucial to make strong and quantitative links between the precision with which observables can be determined by experiments and the consequent accuracy and reliability with which these observables can be used to constrain fundamental properties of QCD matter, and then link these properties of matter to the key physics questions with which each decadal plan begins. The best example of a success along these lines is the currently emerging link between precise determinations of a suite of flow-related observables and quantitative constraints on the ratio of the shear viscosity to entropy density. In turn, this ratio informs current understanding of some fundamental questions about strongly coupled quark-gluon plasma, while at the same time posing new ones. The decadal plans should strengthen these kinds of links between fundamental questions, properties of QCD matter, and experimental observables, describe how they will be made more quantitative and precise, and provide examples other than the ratio of shear viscosity to entropy density. Furthermore, with most of the observables underpinning the RHIC program being accessible also to the LHC, it is crucial that the decadal plans document how the measurements at RHIC can uniquely advance the field. This implies, in particular, that the decadal plans should build more prominently on the fact that RHIC operates in a particularly interesting energy regime, closer than the LHC to the phase boundary, where precision measurements will constrain key quantities in what is arguably the more interesting regime. Further, the plans should emphasis the capability of RHIC to collide beams of different nuclei allowing for the exploration of QCD-matter produced with a range of geometries and profiles. Arguments regarding the uniqueness of the future RHIC program must be clearly quantified beyond the valuable observation of complementarity to the LHC.

The PAC firmly believes that addressing the second prong necessitates a coherent effort including modern theoretical techniques and understanding with the aim of documenting how the RHIC program uniquely enhances the predictive capabilities of the field in the coming decade. To this end, theoretical physicists, including in particular existing coordinated phenomenological efforts like the JET topical collaboration, should be more actively engaged in the decadal planning process.

The PAC wishes to stress that the present decadal planning process is somewhat linked to the upcoming nuclear physics long range planning process. As such, a critical time-line exists for the decadal planning process. We anticipate that the final decadal plan will be completed before the nuclear physics long-range planning process begins, which is anticipated for 2012. The PAC expects to see a near-complete decadal plan from each collaboration prior to a potential meeting in early 2012.

Comments specific to the p+p program

The PAC recognizes that the RHIC spin program has made important contributions to our understanding of nucleon spin structure. RHIC has produced the best and most comprehensive results on the spin-dependent gluon distribution $\Delta g(x)$ available so far, which start to constrain the gluon spin contribution to the proton spin. The W program now underway at RHIC offers new and exciting probes of the nucleon's flavor spin structure. An equally exciting highlight of RHIC science has been the observation of large single transverse spin asymmetries in inclusive particle production at forward rapidities, which opens a window on the physics of color flow in high-energy scattering and ultimately, we hope, will address the question of orbital angular momenta of partons inside a proton.

The PAC views the mid-term scientific case for polarized p+p scattering at RHIC as compelling and well developed. It rests on extending and improving the measurements of observables sensitive to Δg, of W production, and of transverse-spin asymmetries, through continued running time, with the planned detector upgrades, and using runs at both $\sqrt{s}$ = 200 GeV and 500 GeV . There is a clear path for the years 2012 to about 2017 to meet the stated goals. The PAC expects that within this time frame RHIC will complete its Δg and W programs. The PAC emphasizes that this does *not* mean the *scientific* cases for the gluon spin contribution to the proton spin and on quark and anti-quark polarization will be closed by 2017. While RHIC is expected to provide very precise information on $\Delta g(x)$ in the region $0.01 < x < 0.3$ or so, information from much lower x will not, just on kinematic grounds, be available at RHIC. Such information may however turn out to be crucial for obtaining a reliable answer for the integral of $\Delta g(x)$, the gluon spin contribution to the proton spin. Likewise, small-x information on the quark and anti-quark polarizations will not be available from W production. The PAC recognizes that to provide definitive answers in these areas would be among the key motivations for an EIC, where precision studies of inclusive and semi-inclusive deep-inelastic scattering would constrain the spin-dependent parton distributions over a wide range in x.

This raises the question regarding the scientific case for polarized p+p running in the far-term time frame from about 2017 to the start of a possible EIC. The PAC views it as unlikely that p+p running in that time frame could still be justified by the Δg or W programs. There would potentially be incremental progress from new (rare) observables, but not at the same level of significance as the planned measurements in the mid-term time frame. STAR and PHENIX consequently primarily focus on transverse-spin physics for the long-term period, which has become a very active and promising area in recent years. While there is unquestionably exciting physics to be done, neither of the two decadal plans makes a very strong case as detailed projections and expected sensitivities are not yet shown in detail. PHENIX and STAR discuss Drell-Yan measurements, with particular focus on observing the sign difference of the Sivers functions between DIS and Drell-Yan. One concern in this area is that the sign of the Drell-Yan spin asymmetry will have already been examined by COMPASS or perhaps A_NDY by the time measurements become possible for STAR or for PHENIX. As was noted in several of the public presentations, a future program of *broader scope* on spin-dependent Drell-Yan scattering would be of great value to the field. Identifying the best location and design for such a future program is one of the open and urgent questions confronting the spin community. However, the documents presented to the PAC do not yet make the case that RHIC is the best choice for such a program. Other proposed measurements will utilize transverse spin phenomena to explore factorization and universality in hadronic interactions, but sensitivities are not provided for these measurements either. The PAC thus encourages the collaborations to work out and document in better detail what they see as the scientific case for p+p running at RHIC in the period after 2017.

Detector Hardware Proposals

As discussed above, the decadal plans aim at timely updates to the vision for RHIC experiments. First, the recent start of heavy ion physics at the LHC delivers not only competition, but also clarification of the physics of the sQGP. The qualitative and quantitative similarity in a number of measures of the matter produced at LHC and at top RHIC beam energies along with the recent results of RHIC's Phase I Beam Energy Scan sharpen the argument that RHIC covers the "sweet spot" in beam energy. RHIC has the unique ability to scan above and below the phase transition region. Second, US nuclear physics is likely to begin the process of forming the next long range plan within the next year. The evolving decadal plans must serve as a crisp statement of the continued relevance and necessity of the RHIC program in quantifying the characteristics of the new phase of matter in this most interesting regime.

STAR and PHENIX have defined outstanding physics questions that will require continued RHIC running and significant detector upgrades to answer. This emphasis will lead to technology choices that are both matched to the envisioned physics program and can be staged in an effective way both from the practical and scientific standpoint. The PAC is optimistic that the continued planning will result in upgrade proposals that:

- deliver the desired physics at the necessary precision;
- present realistic and competitive staging plans that maintain RHIC's status at the forefront of heavy ion physics;
- establish robust cost estimates; and
- continue developing a detailed strategy for delivering physics from electron-ion collisions.

The PAC believes that the decadal plans of both STAR and PHENIX for the mid-term involving RHIC II luminosity and detector upgrades that are underway are detailed, well formulated, and highly likely to succeed. But, it remains crucial that in the coming Long Range Plan process, a compelling case for these plans is put forward---a case built around the promise of quantitative determinations of fundamental properties of QCD matter.

In the remainder of this report, we choose to focus primarily on the longer-term plans. The sections that follow discuss the long-term plans and technology choices from the STAR and PHENIX decadal plans and how these relate to the key physics questions they have presently identified.

STAR

The STAR decadal plan identifies eight key physics questions and the necessary detector upgrades to accomplish its goals:

1. What are the properties of the strongly-coupled system produced at RHIC, and how does it thermalize?
2. Are the interactions of energetic partons with QCD matter characterized by weak or strong coupling? What is the detailed mechanism for partonic energy loss?
3. Where is the QCD critical point and the associated first-order phase transition line?
4. Can we strengthen current evidence for novel symmetries in QCD matter and open new avenues?
5. What other exotic particles are created at RHIC?
6. What is the partonic spin structure of the proton?
7. How do we go beyond leading twist and collinear factorization in perturbative QCD?
8. What is the nature of the initial state in nuclear collisions?

The timeline as outlined is driven by detector upgrades to accomplish the specific physics goals. The baseline STAR plan is to complete its heavy-ion and polarized pp physics programs at mid-rapidity by 2017. However, STAR is well equipped to extend its heavy ion program, taking advantage of its large acceptance and the flexibility of RHIC (energy range, beam species and two separate beams). The case for such an extension may be compelling if evidence for a critical point in the region of the QCD phase diagram that is accessible to RHIC is found in data taken in the first phase of the beam energy scan, or if analysis of this data were to indicate that the onset of deconfinement is at lower energies than have been studied to date. The pattern of many observables changes quite significantly between beam energies of 39 and 11.5 GeV; data taken recently at 27 and 19.6 GeV should make it easier to evaluate the strength of this case by the time of the next PAC meeting. In this same beyond-2017 epoch, STAR intends to significantly extend its capabilities at forward rapidity, targeting an improved understanding of the initial conditions for heavy ion collisions as well as cold nuclear matter effects in heavy-ion collisions and Drell-Yan measurements in pA and polarized pp programs. The rapid developments from results at LHC and RHIC in other frontiers may also result in new programs well suited for STAR to pursue six years from now. The current STAR plan does not have heavy-ion components other than a possible second phase of the beam energy scan beyond ~2017 and assumes eSTAR in 2020. Given the uncertainty of the eRHIC schedule, the PAC believes that experimental planning throughout the next decade should account for the possibility that only hadronic beams are available until 2022. The PAC asks STAR to detail its experimental plans for this case.

While some of the measurements that are proposed for 2017 and 2018 can be conducted with the STAR apparatus provided the ongoing upgrades are in place, many studies, especially those at large rapidities, will require further upgrading of the STAR detector. Improvements in the forward directions will also be necessary for STAR to participate in the *e*+*p*/*e*+A program should an Electron-Ion Collider at RHIC (eRHIC) become a reality. Future upgrades circa 2017 need to be designed with both physics programs in mind, although they must be justified by the science that can be done with them in the 2017-2022 epoch.

Although STAR has specifically stated that “to stay within the scope of this document we limit ourselves to the types of detectors (acceptance, resolution) that are needed without going into much detail on their conceptual design”, the PAC recommends that STAR put priority into detailed studies of detector capabilities and physics observables, with realistic simulations and deliverables. This is necessary for RHIC and a future eRHIC to be successful at presenting its case to the larger nuclear physics communities during the upcoming NSAC long range planning process.

STAR has instrumented a Forward Meson Spectrometer (FMS) and is installing a Forward GEM Tracker (FGT) in the coming runs. However, these two detectors cover different pseudorapidity with little overlap between them. Two options in calorimetry at forward rapidity are presented: FMS+hadronic calorimeter (HCAL) or Forward Spaghetti Calorimeter (FSC). The latter is an R&D project for eRHIC as approved by the EIC R&D program committee last May. In front of FMS (FSC), additional instrumentation for tracking, RICH and preshowers are presented but detailed simulations of these schemes are needed in order to match their performance to the requirements of the planned *p*+*p* and *p*+A measurements.

PHENIX

PHENIX has identified five key questions to be addressed by the heavy ion program in the latter five years of the coming decade:

1. Are quarks strongly coupled to the quark-gluon plasma at all interaction distance scales?
2. What are the detailed mechanisms for parton-QGP interactions and responses? Are the interactions coherent over the entire medium length scale, what are the dominant energy loss mechanisms?
3. Are there quasi-particles in the medium? What are their masses and widths?
4. Is there a relevant color screening length in the quark-gluon plasma?
5. How is rapid equilibration and entropy production achieved?
6. What is the nature of color charge in large nuclei? What role does gluon saturation and the EMC effect play in nucleus-nucleus collisions? How do these modifications evolve?

PHENIX correctly recognizes that despite its superb track record of delivering timely and interesting physics with a small aperture device, all their physics goals will require large aperture measurements with highly selective triggers which are fully efficient for the top RHIC-II luminosity. The PHENIX decadal upgrade plan is thus appropriately ambitious: PHENIX proposes to replace the existing central arms and south muon arm with new, compact spectrometers. We note that although the scale of the upgrade is an appropriate fraction of the cost of running the RHIC facility for the ~5 year period required to realize the benefits of such a detector, in absolute terms, this scale is large in the context of instrumentation projects in the rest of the nuclear physics program. Therefore, in further developing sPHENIX, among other considerations, careful attention must be paid to the best utilization of unique RHIC capabilities (including polarized p+p), as well as coupling to a future eRHIC program.

This design paradigm addresses the central physics issues in a straightforward manner. Coupling of quarks to the medium, energy loss mechanisms, and the existence of quasi-particles are all probed through triggering on, and reconstruction of, full jets. A broad range in Q^2 should allow for an investigation of the interactions of the plasma at various length scales. PHENIX states that the broad dynamic range of accessible interaction length scales combined with RHIC's ability to vary the length and density profile of the produced medium via the appropriate choice of light and asymmetric colliding species, make these measurements ideal for examining the questions of parton coupling to the medium, energy loss mechanics, and quasi-particles.

PHENIX proposes to study the physics of screening and deconfinement by enhancing quarkonia measurements to include the bottom sector. Specifically, by electron tagging with a fine grained EM-calorimeter and high precision tracking the Υ(1s) will be separated from its physically larger cousins Υ(2s) and Υ(3s). Thermalization issues, investigated via direct virtual photon radiation from the early stages of the collision, and gluon saturation phenomena will be addressed by a high quality spectrometer in the forward direction.

Although the connections between the questions that motivate the PHENIX program and their proposed upgraded detector are evident, it is imperative that they be made more quantitative along the lines we have described above. The PAC also notes that the decadal plan was prepared before any heavy ion collisions were done at the LHC and long before the recent Quark Matter conference at which much data from these collisions was reported. In light of what we now know, the PHENIX collaboration needs to tighten the case that they have presented for what aspects of the questions they lay out will not be accessible to the RHIC and LHC experiments in the mid-term (pre-2017), as well as how their upgraded detector will allow quantitative attacks on these questions beyond 2017.

The PAC notes that the design of the spectrometer has evolved since the initial submission of the decadal plan so that its calorimetric coverage is free of gaps in eta. This change is viewed as positive.

The specifications for the central arm spectrometer (a barrel covering $-1<\eta<1$) are significantly more advanced than those of the forward arm. The device relies upon all-silicon tracking to provide excellent momentum resolution for a tracker confined to a radius of ~60 cm. This resolution is sufficient to separate the Y(1s) state from the Y(2s)+Y(3s) states. Although the material for the tracker does generate significant Bremsstrahlung tails, they are at a manageable level. A detailed understanding of the p_T threshold below which tracking results can be trusted is a necessary component in evaluating the performance of the spectrometer as a jet identifier. PHENIX conservatively evaluates the p_T threshold to be 10 GeV/c. In this limit, the design cannot function effectively without a hadronic calorimeter. Simulations show marked, but insufficient, improvement for tracking to be reliable at 20 GeV/c. Further work will sharpen the understanding of this design.

Compact calorimetry is made possible by the use of materials with a small Moliere radius. By replacing the existing Pb-Scintillator and Pb-glass electromagnetic calorimeters with W-based devices, the calorimeter can be made significantly smaller while maintaining the same channel count and occupancy. The sPHENIX design moves the calorimeter closer to the origin than would result from a simple Moliere radius scaling argument. As a result, the occupancy at any calorimeter threshold would be higher in sPHENIX than in PHENIX. The addition of a pre-shower detector (separating close photon pairs) and longitudinal shower profiling improve the performance, as does a "high tower threshold" criterion. Further studies will clarify the level to which the compactness of the EMCAL has changed its performance as compared to the existing PHENIX.

The addition of hadronic calorimetry at RHIC will qualitatively change the jet program, since using calorimeter clusters as a jet rather than individual particles yields a different measurement. There are gains and tradeoffs in this choice, since triggering on hadronic energy is robust to the highest energies whereas tracking allows a detailed investigation of the jet fragmentation function. PHENIX presently assumes modest performance of its tracker and thereby relies heavily upon a hadronic calorimeter of modest granularity to achieve its performance goals. The HCAL will also provide the source of high rejection jet triggers necessary to take full advantage of RHIC II luminosity.

The endcap spectrometer studies need to be advanced beyond the present designs. PHENIX lists these as "not optimized". This is indeed true and the PAC cannot evaluate the efficacy of the plans without results from the additional work that PHENIX has planned. That said, the present vision for sPHENIX is notably asymmetric with a high resolution spectrometer only in the electron direction for eRHIC. The strength of electron scattering measurements rests in a precise determination of the x and Q^2 of each collision. While this information is in principle carried completely by the scattered electron, HERA experience shows that certain kinematic regimes are accessible principally by reconstructing the hadronic final state when the electron scattering angle is too small to be measured practically. The current PHENIX upgrade plans seem to exclude these measurements by having only a forward spectrometer and no backward spectrometer.

In summary, the PAC believes that the ideas in the current decadal plans will allow the collaborations, working in concert with theorists, to build a compelling case for RHIC operations and upgrades throughout the next decade. The PAC requests now a timely further exploration of these ideas, including a clear articulation of the precision with which key physics measurements can be made and how they impact our understanding of fundamental properties of QCD matter.