Recommendations
Brookhaven National Laboratory
Nuclear and Particle Physics
Program Advisory Committee
June 11-12, 2013

1. Introduction

On June 11, 2013, the PAC heard background information on accelerator performance and plans, separate presentations on the status of beam energy scan, d+Au, U+U and Cu+Au analyses, updates on plans for STAR and PHENIX detector upgrades, the PHENIX and STAR Beam Use Requests (BURs) for Runs 14 and 15 and a letter of intent regarding possible very forward angle measurements to help improve cosmic ray shower modeling. Based on this input, we begin with our assessment of the progress on the d+Au, Cu+Au and U+U analyses (Section 2), report our recommendations for Runs 14 and 15 (Section 3, including embedded comments on the beam energy scan), assess the LHCf@RHIC letter of intent (Section 4) and conclude with a brief discussion of the reports on detector upgrade plans (Section 5).

The PAC commends the collaborations and the Lab for the enormous effort in substantially completing the goals of the very demanding W-production measurements during Run 13 and we (as well as the rest of the world) are eager to see the results.

2. Ongoing Analyses

2.1 d+Au

The analysis of d+Au collisions at RHIC has recently revealed several interesting and unexpected phenomena. One surprise is that PHENIX finds $R_{dAu} > 1$ for "peripheral" collisions, whereas R_{dAu} is consistent with one for central collisions. This phenomenon, first reported by PHENIX at the last Quark Matter conference for neutral pions up to moderate transverse momenta, persists also for jets with transverse momenta up to 40 GeV. In addition, R_{dAu} seems to increase with transverse momentum, albeit with larger experimental uncertainties at higher transverse momenta. A potential issue, which may bias this measurement and thus needs to be addressed, is the centrality determination for high p_T events. The LHC collaborations report that event selection cuts in p+A collisions in general, and in particular for events with hard particles/jets, can significantly bias the centrality determination. One way to circumvent this problem is to vary the size of the nucleus as PHENIX is proposes in their Run 15 beam request. In view of the interest expressed by both collaborations in p+A running for Run 15, the PAC feels that it may be worthwhile to organize a dedicated workshop where the issues of centrality selection in p+A and d+A reactions are discussed. The PAC notes that STAR has not presented a similar analysis, and in view of the rather unexpected nature of the PHENIX results, a STAR result would be very welcome, especially in view of future planning for p+A running.

Concerning two particle correlations, PHENIX sees a "double-ridge" like structure in d+Au collisions which is similar to what is seen at LHC, at least for pairs around mid-rapidity. Correlations between particles at mid- and forward- or backward-rapidity, on the other hand, exhibit a clear difference between the Au-going and the d-going direction. The Au-going direction exhibits a considerably stronger nearside "ridge" correlation. Such a difference is not seen at LHC energies. While the PHENIX result is potentially very interesting, the PAC notes that in the preliminary STAR analysis, the nearside structure is sensitive to the background subtraction. Thus, at this time STAR is not able to confirm the PHENIX observations. This potential tension between STAR and PHENIX needs to be clarified in the next several months to make an informed decision about future p+A running.

Published PHENIX results R_{dAu} for J/Psi are consistent with expectations from (anti)-shadowing: more production is observed in Au-going direction. The same trend is also seen in preliminary data on non-photonic electrons. The centrality dependence for the J/Psi R_{dAu}, however, is not yet fully understood. In order to make progress, PHENIX proposes to eliminate final state interactions by measuring direct photon production in these reactions. This may help in the task of constraining the impact parameter dependence of structure functions.

Finally, the PAC notes that the STAR measurement on forward azimuthal correlation, though first reported at conferences several years ago, is not yet published.

2.2 U+U

Both collaborations presented first results from their analysis of U+U collisions. Unfortunately, so far it has not been possible to develop a method that allows for the selection of "tip-on-tip" and "body-on-body" collisions. No attempt has yet been made to extract event by event v_2 probability distributions, similar to those that have been measured at the LHC by, e.g., the ATLAS collaboration. Such a distribution may provide an additional means to control the geometry. Although the smaller particle multiplicity in RHIC collisions may wash out any signal, the PAC believes that it would be worthwhile to attempt such an analysis.

Interestingly, and surprisingly, the most central U+U collisions do not seem to follow the well-established behavior (for spherical systems) of v_2/ε_2 as a function of the transverse density, 1/S dN/dy. This is a potentially interesting result and should be published as soon as possible so theorists can try to analyze it. Having a better understanding of this puzzling behavior is of particular urgency if one is to utilize central U+U collisions as a means to constrain predictions for the Chiral Magnetic Effect (CME). In this context, it is noteworthy that there appears to be no qualitative difference between central Au+Au and U+U collisions in the behavior of the charge dependent correlation function proposed by STAR as a measure of the CME (both are apparently zero within errors while v_2 is nonzero). Using the U+U collisions as an estimator of background contributions due to elliptic flow will require understanding v_2/ε_2 in these collisions.

In summary, while for very central (<1%) collisions a difference of the multiplicity dependence of v_2 between Au+Au and U+U collisions is observed, it remains an open question as to whether the U+U collisions retain promise as a tool to manipulate the geometry of the reaction.

2.3 Cu+Au

The situation is different for Cu+Au collisions. The PHENIX analysis shows a finite value of v_1 for semi-central collisions, confirming initial expectations. Therefore, v_1 may be used to characterize the asymmetric density distribution in the fireball, and thus enables important tests of event by event fluid-dynamics calculations. In addition, these reactions may help to further constrain energy loss models. The PHENIX results on J/Psi production, while qualitatively consistent with shadowing/anti-shadowing, are not yet understood quantitatively and may provide a further test for charmonium suppression models. In conclusion, it appears that asymmetric collisions, such as Cu+Au, provide additional experimental controls for the geometry and stringent tests of “core-corona” type models for a number of observables. It is therefore unfortunate, that the Cu+Au data have not yet been analyzed by the STAR collaboration.

3. RHIC run plans

3.1 Executive summary

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

1. 14 weeks of 200 GeV Au+Au collisions to exploit new capabilities to investigate the heavy quark sector, and
2. 3 weeks of 15 GeV Au+Au collisions to complete the BES I program.

For Run 15 the PAC recommends the following (*in order of priority*)

1. 200 GeV $\vec{p}+\vec{p}$ collisions,
2. 200 GeV $\vec{p}+$Au running, and
3. Additional full energy mixed species running ($\vec{p}+$Si, $\vec{p}+$Cu, d+Au, ^{3}He+Au).

During Run 14, the PAC recommends that running begin with the second priority, 15 GeV Au+Au. This running period completes the BES-Phase I program, and also will serve as a commissioning period for the newly installed STAR HFT and re-commissioned PHENIX VTX.

For Run 15, the PAC anticipates that analysis of recently recorded data could impact the order of priorities among items 1 and 2.

3.2 Discussion of 2014 and 2015 priorities

3.2.1 Run 14

<u>Introduction</u>

The STAR and PHENIX collaborations have both chosen as top priority for 2014 an extended Au+Au run at $\sqrt{s_{NN}}$ = 200 GeV, focused on heavy flavor production and using their new detector capabilities. For this period, PHENIX will install a refurbished VTX detector and run the FVTX detector with Au+Au collisions for the first time, while STAR will install the new HFT detector and complete the MTD. The PAC endorses this priority.

As stated in last year's recommendation, the PAC believes it is essential that both STAR and PHENIX perform crucial measurements of heavy flavor production in Au+Au collisions in Run 14. These measurements are, however, dependent on either completely new or extensively refurbished detector systems, which will need to be fully operational to reach the physics goals stated by the collaborations. Progress on the detector systems must be closely monitored as the run approaches.

Since these are new or extensively refurbished detector systems, it is to be expected that significant commissioning time will be needed before they are fully operational for physics. This commissioning can also be done in Au+Au collisions at $\sqrt{s_{NN}}$ =15 GeV, for which these detectors are not necessary to achieve the physics goals. For this reason the PAC recommends that, should there be sufficient running time expected to complete the 200 GeV Au+Au program, Run 14 begin with Au+Au at $\sqrt{s_{NN}}$ =15 GeV for the three weeks requested by the STAR collaboration. As in last year's recommendation, this program is at second priority.

Both collaborations have bandwidth-limited, rather than luminosity-limited, goals. In the case of PHENIX, the integrated luminosity requested takes account of the 5 kHz recording rate. In the case of STAR, the measurements of D^0 spectra and flow are limited by bandwidth; STAR states a second goal limited by the luminosity delivered by the machine. For this reason, we state the recommendation in terms of the number of weeks, but note that for the STAR and PHENIX goals to be reached there will need to be both high uptime and luminosity, and that optimization needs to take both into account. We also recommend that STAR investigate methods to improve the resolution of their vertex trigger, in order to improve the fraction of data recorded that is usable in the full analysis.

Au+Au at 200 GeV in Run 14

In terms of the importance of the Au+Au running at 200 GeV, the conclusions are unchanged from last year, at which point we stated:

> "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 a significant portion of 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."

Au+Au at 15 GeV in Run 14

The considerations of the physics of the Au+Au run at 15 GeV in Run 14 is unchanged from last year, at which point we wrote:

"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 3 weeks. The PAC notes that the understanding of the collider has developed in the past year, and that at this energy RHIC can provide collisions to both PHENIX and STAR concurrently."

STAR has proposed installation of a gold target into the vacuum pipe, for a test to demonstrate this fixed target capability for future measurements. In principle, this allows for measurements at higher μ_B than can occur in collider mode, but with a strongly limited capability. We conditionally endorse the test, but recommend that

1. the collaboration present to lab management a more fully developed set of

proposed measurements in comparison to existing fixed target measurements at the AGS and SPS, and

2. this test be done in a way that precludes risk of damage to the HFT.

3.2.2 Run 15

p+p at 200 GeV in Run 15

The PAC's highest recommendation for Run 15 is the program of both longitudinally and transversely polarized p+p running at $\sqrt{s}$ = 200 GeV to reach a reasonable integrated luminosity with the electron lenses and a high polarization of about 60%, commensurate with both collaborations' requests. The PAC recommends that p-p running take place in Run 15 after the electron lenses are commissioned during Run 14. The electron lenses should yield an improvement in luminosity by a factor of two and with high polarization for the p-p experiments.

The prime scientific focus is on improvement in the ΔG measurements and transverse momentum distributions. According to the collaborations' projections, a run at 200 GeV with longitudinally polarized beam and L = 30 pb^{-1} (PHENIX) or L = 50 pb^{-1} (STAR) collected, together with the data from Run 13, would result in a factor of two reduction in the present error for the contribution of the spin-dependent gluon distribution of the proton. In addition, the systematic error would be substantially reduced. 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 the low p_T by observing π^0 production and the latter at high p_T by observing dijet production. In combination, a significant constraint on the gluon contribution to the proton spin will emerge (DOE performance milestone HP12). To date, 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. An analysis of PHENIX π^0 and STAR jet results from the 200 GeV period of Run 9 determined that the integral of ΔG over the range $0.05 < x < 0.2$ is approximately 0.10+0.06-0.07.

The measurements with transversely polarized beams put special emphasis on the measurement of the transverse single spin asymmetry (SSA) for photons which will substantially affect the ongoing discussion of the Sivers and Collins effects. These are of great interest for several reasons. For example, the Sivers asymmetry is an observable sensitive to the gauge link structure of nonlocal QCD correlators and thus to a fundamental property of QCD as a *local* gauge theory. It was identified in semi-inclusive lepton-hadron reactions and clear theoretical predictions exist for the Drell-Yan process in polarized p+p. However, its role for single spin asymmetries A_N is highly disputed, in particular with respect to the relative importance of contributions from the Collins fragmentation function (in combination with the transversity distribution function) and the Sivers distribution function. The proposed measurement of the prompt *photon* SSA is highly relevant in this context because initial state interactions and thus the Sivers mechanism should be far more relevant for photons than any Collins effect. (The complication due to the fact that photons can also be produced from fragmentation seems to be under control from the point-of-view of theory.) Therefore, the discriminating power of the planned photon measurement is not affected by the ongoing theoretical controversies.

In parallel to measuring the SSA for prompt photons a substantial number of other spin observables will be analyzed in parallel: interference fragmentation functions, SSAs for π^0 and η mesons at 5-6 GeV/c transverse momentum, SSAs for heavy mesons, constraints on Collins fragmentation functions etc. These measurements will provide a better understanding of a large, rich, and very interesting range of phenomena for which a better theoretical understanding desperately needs more experimental input.

In Run 15, $\sqrt{s}$ = 200 GeV p+p measurements will also 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

$\vec{\mathrm{p}}$+Au , etc. in Run 15

There are two considerations associated with running p+A: the role of providing comparative data for A+A, and the possible sensitivity of $\vec{\mathrm{p}}$+A to initial state physics. As discussed below, the PAC endorses $\vec{\mathrm{p}}$+Au running as second priority for Run 15.

Until now, the RHIC program has used d+Au collisions as a set of control measurements for cold nuclear matter effects. This choice was driven at least in part by the desire to avoid the physical movement of the so-called “dx” magnets surrounding each collision point. Now that results on p+A collisions have become available from the LHC, it is vital for clean comparison data to be collected at RHIC. A clear issue is whether d+Au introduces an initial state v_2 that could be removed with p+Au measurements and augmented with ^{3}He+Au measurements (see below).

It should be noted that STAR measurements at high η are not symmetric and would benefit from the ability to switch from p+Au to Au+p collisions. PHENIX expressed a similar desire as a means to minimize systematics in these measurements. It will be important to next year’s discussion that the PAC receives clear guidance regarding the impact of these swaps on both the machine and the detectors.

The initial state structure of nucleons and nuclei in the low x or high partonic density regime is a topic of continuing and, indeed, intensifying interest, and may reveal novel underlying features such as saturation. Measurements at RHIC and LHC have already revealed phenomena that demand explanation. An interesting new signature of saturation has been suggested to be revealed in measurements of spin asymmetries in collisions of polarized protons with nuclei. This signature is only accessible at RHIC and must be studied with sufficient experimental precision to unequivocally address current predictions.

Because of the new and novel nature of these predictions, the uniqueness of their interpretation following a precise measurement cannot be guaranteed. The nuclear size dependence of any observed asymmetry has been suggested as a method to differentiate between saturation-induced asymmetries and competing processes that might interfere with the interpretation. Although this differentiation capability can only be speculative at this point, it nonetheless offers the possibility of a relatively complete investigation of the phenomenon. The PAC also endorses, as third priority for Run 15 (see also below), the extension of $\vec{p}$ + small nucleus (*e.g.* Si, Cu) as a complement the $\vec{p}$+Au measurement.

d+Au and ^{3}He+ Au Running

Existing data from both LHC and RHIC have revealed interesting correlation structures spanning wide rapidity gaps, spurring speculation about collected phenomena in proton + nucleus collisions. During the course of the next year, it is expected that analysis of already recorded data as well as theoretical insights will be critical in guiding which measurement(s) would have the highest priority in refuting, confirming or extending these conclusions. PHENIX proposes to seed the initial state with v_2 (d+Au) or v_3 (^{3}He+Au) terms as a method of distinguishing flow-like phenomena. With the currently available insight, the PAC endorses these measurements at equal (third) priority to the polarized $\vec{p}$ + small nucleus program.

4. Letter of Intent: LHCf@RHIC

The letter of intent on ``Precise measurements of very forward particle production at RHIC'' proposes to install an LHCf-like calorimeter (RHICf) in the ZDC position at one of the interaction points of RHIC. The proposed high-resolution electromagnetic calorimeter aims to measure forward spectra of neutral particles (photons, neutrons and neutral pions). The physics motivation has three components:

1. Measurements with 500 GeV p+p collisions to improve the existing hadronic interaction models used in simulations of cosmic-ray air showers;
2. With the improved p_T resolution using the combination of RHICf and the ZDC to carry out an improved measurement of the single neutron asymmetry at forward angles which was discovered at RHIC;
3. Measurements with 200 GeV proton-nitrogen collisions and 200-GeV p+p collisions to investigate the nuclear effect in forward particle production.

The proponents propose to use the 500 GeV p+p data from RHIC in combination with the LHCf data from 7 to 14 TeV to test Feynman scaling versus center-of-mass energy in order to provide a better extrapolation in the model for simulations to the much higher energy region (10^{20} eV) of interest for cosmic-ray air showers. It would be helpful to see quantitative information that shows how measurements at 500 GeV will accomplish this goal. Single spin asymmetries in hadron-hadron collisions remain interesting (see discussion in Section 3) and need to be understood. Improved measurements of the forward neutron spin asymmetry will shed light on this important topic. Light ion collision data will also be relevant for cosmic-ray physics, though no quantitative information is given in the LOI.

The proposed RHICf with a front (scintillator) detector would be installed on a vertical support structure that could be moved into or out of the beam line position remotely to minimize potential conflict with the ZDC. Based on the proposed configuration and plan, the request for carrying out these measurements is one week of beam time, which is not insignificant.

To reach an informed decision, the PAC would require additional information:

1. A quantitative study showing the improvement of hadronic interaction models for cosmic-ray air showers of much higher energy with the proposed p-p collision data at 500 GeV.
2. Convincing arguments that the proposed detector design is the best for such measurements. In this context the PAC strongly encourages the proponents to form a collaboration by seeking out collaborators from the PHENIX and/or STAR collaborations and optimize the design for the detector. The PAC also strongly encourages the proponents to come up with a design that allows data for the proposed measurements to be taken parasitically during regular PHENIX and STAR running.

The PAC believes that the proposed 500 GeV p+p collision data at forward angles will be valuable to understand how showers develop at this energy; the PAC encourages the proponents to consider this physics motivation as well.

In summary, the PAC encourages the proponents to address these issues and consider the development of a full proposal in consultation with the lab management.

5. STAR and PHENIX upgrade reports

The PHENIX collaboration has made commendable progress in preparing their plans for the sPHENIX detector to perform definitive jet physics measurements in nucleus-nucleus collisions at RHIC energies. A potentially significant recent development is the possible availability of the BaBar superconducting solenoid, which would considerably reduce the risk associated with the timely procurement of the magnet for sPHENIX. The physics case for sPHENIX is based on the characterization of sQGP dynamics and constituents using high p_T probes such as jets, photons and possibly dileptons. Although a wide spectrum of measurements using reconstructed jets, isolated photons, vector bosons, etc. is available from the LHC, a complementary set of measurements from RHIC could provide unique insight into the evolution of sQGP properties as a function of temperature (i.e. in the vicinity of the phase transition/cross-over). The success of this program will not only rely on sPHENIX's ability to perform these measurements in the challenging RHIC environment, but also on the availability of theoretical tools to extract, e.g., the temperature dependence of $\hat{q}$ from the comparison of RHIC and LHC data where, at each of the collision energies, the system undergoes an evolution over a largely overlapping temperature regime. The PAC recognizes the need for continued support of coordinated efforts to develop these theoretical tools, and for a close collaboration of the theoretical community with both the RHIC and LHC experimental communities. The planned sPHENIX program is also experimentally challenging due to the steeply falling cross-sections for jet production at transverse momenta that are large compared to typical underlying event energy fluctuations. It may be useful at this stage to organize a dedicated workshop to assess the impact and possibly implement some of the lessons learned from the most recent LHC data and their understanding in current theoretical approaches.

The 2010 Decadal Plans of both STAR and (s)PHENIX include conceptual ideas for using the detectors for e+p and e+A collsions in an early stage of the eRHIC program. The Collaborations were asked some six weeks ago by BNL management to provide more specific plans, in the form of Letters of Intent, to upgrade the respective detectors from their present form to first-generation eRHIC experiments. The LOI should be ready by the end September and include a description of the physics reach of the upgraded detectors for a number of the key benchmark measurements identified by the EIC Task Force. In this context the PAC congratulates all contributors to the EIC White Paper for their achievement in further sharpening and extending the physics case for an EIC. Their work constitutes a firm physics basis for all ePHENIX- and eSTAR-related work. The current status of both eSTAR and e/sPHENIX were presented to the PAC. eSTAR plans to use the existing mid-rapidity detectors and augment them with eRHIC-specific elements in the forward/backward regions. In the current design, the hadron side detectors would be used for both RHIC (pA) and eRHIC physics. PHENIX has presented a conceptual design that combines some elements of the central sPHENIX detector (essentially calorimeters and magnet) with eRHIC optimized devices both around mid-rapidity (tracking) and the forward/backward acceptance regions. Design, detector performance, and physics evaluations are clearly in a very early phase and do not allow, at this stage, any conclusion about the physics reach or a comparison with a performance-optimized, dedicated eRHIC detector. The PAC recognizes that both collaborations have taken up the challenging task energetically and encourages them to proceed toward meeting the very tight deadline.