Recommendations
Brookhaven National Laboratory
Nuclear and Particle Physics
Program Advisory Committee
June 21-22, 2010

1. Introduction

On June 21, 2010, the PAC heard background information on Run 10 and 11 planning and performance, accelerator performance and plans, the PHENIX and STAR Beam Use Requests (BURs), two letters-of-intent (LOIs) for Drell-Yan experiments and status reports on the PHENX and STAR decadal plans. Based on this input, we report our recommendations for Runs 11 and 12 with discussion of both heavy ion and polarized proton physics, as well as our recommendations for Drell-Yan (DY) physics at RHIC. We also comment on the decadal plan presentations, as well as on the status and prospects for machine and experimental upgrades. The recommendations of Section 2 are based on a total of 30 physics weeks.

2. RHIC run plans

2.1 Executive summary

For Run 11 the PAC recommends the following (*in order of priority*):

1. 8 weeks Au+Au heavy ion running at 200 GeV
2. 10 weeks p+p polarized proton running at 500 GeV
3. 1.5 weeks Au+Au heavy ion running at 18 GeV
4. 1.5 weeks U+U heavy ion running at 192 GeV (Au rigidity)
5. 1 week Au+Au heavy ion running at 27 GeV

For Run12 the PAC recommends the following (*not* in order of priority):

1. 8 weeks p+p polarized proton running at 500 GeV
2. 7 weeks Au+Au (and U+U) heavy ion running at 200 GeV
3. 2.5 weeks p+p proton running at 62.4, 22.4 GeV

2.2 Discussion of heavy ion running

The discussion below is ordered by physics priority and is not necessarily an optimal nor a practical order for running the experimental program.

2.2.1 Run 11: 8 weeks of Au+Au at $\sqrt{s_{NN}}$ = 200 GeV

An 8 week run of Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV will allow PHENIX to arrive at a first experimental separation of the bottom and charm decay contributions to non-photonic electrons. This measurement is of central importance to make further progress on understanding jet quenching: One of the main discoveries of the RHIC heavy ion program is that all hadronic high-p_T spectra are suppressed strongly by medium effects. This strong and generic physics phenomenon of ultra-relativistic heavy ion collisions is currently understood to result from the highly energetic partons produced within the collision being degraded significantly in energy due to strong interactions with the surrounding medium. This jet quenching provides information about the properties of the medium only to the extent to which the microscopic dynamics of the quenching can be constrained.

The observed strong suppression of non-photonic electrons resulting primarily from semi-leptonic decays of heavy quarks presents a significant challenge to perturbative descriptions of partonic interactions with the medium. However, the interpretation of the current data is hindered by the poorly known charm and bottom contributions to the non-photonic electron yields. The PHENIX silicon vertex detector (VTX) upgrade will provide separation of charm and bottom decays. This will allow the separate measurement of charm and bottom quenching in the strongly-coupled quark gluon plasma (sQGP) and determine whether the quenching is compatible with the results of perturbative energy loss calculations. These measurements will constitute qualitatively important progress in our understanding of the jet quenching mechanism, and thus have the potential to improve our ability to characterize the medium with this probe.

In addition to the measurements of heavy flavor quenching, the PHENIX VTX detector will allow separate measurements of the elliptic flow of charm and bottom quarks (v_2). These measurements will provide critical insight on the extent to which the heavy quarks couple to the collective flow of the medium and/or the degree of thermalization of heavy quarks in the sQGP.

The ability of RHIC to deliver flavor-separated quenching and flow measurements for heavy quarks is contingent upon the expected availability of the PHENIX VTX detector that will be used to identify the displaced vertices of semi-leptonic decays. With 8 weeks of physics running, v_2 is expected to be measured at a transverse momentum greater than 4 GeV/c. Results for hadron suppression (R_{AA}) from Run 11 will require special treatment of the reference measurements. Direct measurements of the central-peripheral ratio, R_{CP}, will be possible out to a transverse momentum of roughly 4 GeV/c. Fixed Order plus Next-to-Leading-Logs (FONLL)-inspired extrapolations could be used to extend this reference to match the range of the central collision results. The PAC deems this technique viable and anticipates that these data will be of high impact and significance. Actual proton collision reference data would be expected in the 2013 run.

Achieving the separated heavy flavor measurement is contingent upon the successful completion and operation of the VTX detector. The PAC notes that although roughly half the detector's "ladders" are in hand (sufficient to azimuthally cover the PHENIX central arms), realizing a fully functional detector system is still a daunting task.

STAR did not request full energy Au+Au running in Run 11, with the aim of deferring the next such by a year to take advantage of the full (6 planes) stochastic cooling. Nonetheless, Run 11 Au+Au data are matched to STAR's long term physics goals.

Given the above considerations, the PAC recommends the following strategy for the full-energy Au+Au running

1. Run 10 should start with proton-proton collisions to allow low-multiplicity commissioning of the PHENIX VTX.
2. PHENIX must demonstrate during this commissioning period that successful operation of the VTX during full-energy Au+Au operation is likely.
3. **If the likelihood of successful VTX operation in full energy Au+Au running is not demonstrated, the PAC recommends full energy Au+Au running be postponed until Run 12.**

2.2.2 Run 11: 1.5 weeks of Au+Au at $\sqrt{s_{NN}}$ = 18 GeV

Completion of the first phase of the beam energy scan program was requested by both the STAR and PHENIX collaborations. This follows a successful start in Run 10, measuring Au+Au collisions at $\sqrt{s_{NN}}$ = 62.4, 39, 11.5 and 7.7 GeV. We applaud C-AD for their strong contribution in bringing this challenging program to fruition. The PAC would like to see the completion of this program, with 1.5 weeks of Au+Au collisions at $\sqrt{s_{NN}}$ = 18 GeV and 1 week of Au+Au collisions at $\sqrt{s_{NN}}$ = 27 GeV. Within the context of the search for a possible critical point in the QCD phase diagram, the 18 GeV data is of higher priority. Collisions with this energy freeze out at $\mu_B \sim 220$ MeV. Data taken in Run 10 at 39 GeV ($\mu_B \sim 110$ MeV) and 11.5 GeV ($\mu_B \sim 320$ MeV) leave a wide gap in the scan of the QCD phase diagram which the Run 11 data at 18 GeV will fill. STAR has demonstrated it can make the measurements of the event-by-event fluctuations expected to characterize collisions that freeze out near a critical point, making the case for completing this phase of the energy scan compelling.

PHENIX would collect 12.4—37 million events (depending on the vertex cut) and STAR would collect 150 million events in a 1.5-week run at 18 GeV. These datasets will enable PHENIX to measure the participant scaling of elliptic flow for pions, kaons and protons for KE/n > 0.5 GeV; and STAR to measure among many observables: proton and pion kurtosis and skewness, ϕ/ω di-electron channels and strangeness fluctuations/correlations (K/π ratio and fluctuations, hypertriton/^{3}He ratio).

Collisions at 27 GeV ($\mu_B \sim 160$ MeV) would make the scan ``dense" for $\mu_B < 220$ MeV and are discussed in more detail in section 2.2.4. In searching for the critical point, this collision energy is not as important as filling in the current big gap in the scan. (Present lattice calculations are under better control for $\mu_B < T$, and none of them find signs of a critical point in this small μ_B regime.)

With the completion of this phase of the beam energy scan, if there is a critical point in the QCD phase diagram with $\mu_B \lesssim 450$ MeV there is an expectation that signs of its presence will be manifest in the data. The PAC looks forward to future data-driven discussions of the case for further exploration in this regime and/or of pushing upwards in μ_B by another ~100 MeV. A machine test at 5 GeV was performed at the end of run 10 for a couple of days, but no collisions were provided to the experiments due to the anticipated short lifetime of the beam in the ring (~second). There have been discussions about further development from C-AD to provide collisions below 7.7 GeV; we recommend a short (one-day) test at an energy near 6 GeV at which collisions could be provided to both experiments in the future.

2.2.3 Run 11: 1.5 weeks of U+U collisions at $\sqrt{s_{NN}}$ = 193.2 GeV

The new EBIS ion source will become available in Run 11 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.

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. Nonetheless, the RHIC community has a proven track record of ingenious solutions to seemingly intractable issues.

The PAC recommends that sufficient data (~1.5 weeks) be collected 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 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 program, begun in Run 10 with measurements at 62.4 and 39 GeV, of investigating where, and how, jet quenching phenomena and participant scaling of v_2 "turn on" as a function of increasing collision energy. The PAC supports making these measurements but ranks this lower in priority at present. 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 18 and 27 GeV, during Run 11. STAR will install the Forward GEM Tracker (FGT) prior to Run 12 and remove the Forward TPC. The FTPC is vital for several of their proposed measurements. Although in our prioritization of the science we rank the one week 27 GeV run last among the heavy ion components of the Run 11 program, there is, nevertheless, a case for completing it.

2.2.5 Run 12: Au+Au or U+U collisions

Ideally, results from the Run 11 U-beam experiments will provide evidence for the feasibility of cleanly identifying the collision geometry for collisions of deformed nuclei as well as the systematic errors resulting from the limits of experimental precision and from model-dependence. Also, Run 11 should allow for an informed estimate of whether the luminosity attainable in future U+U runs will be comparable to that of Au+Au. These results will be key in identifying the relative priority of Au+Au and U+U collisions at full energy. Presently, the PAC estimates that roughly ½ of the Run 12 data time should be allotted to full energy nuclear collisions.

2.3 Discussion of p+p running

The RHIC spin program entered an exciting new phase in Run 9, with operation of the machine at $\sqrt{s}$ = 500 GeV. Collisions at this energy probe the quark and anti-quark spin structure of the proton in a unique and clean way through parity-violating W boson production. This is a cornerstone of the RHIC Spin program, and a DOE milestone for 2013. At the same time, going to higher energy pushes toward smaller momentum fractions, x, of the colliding partons and hence is expected to significantly extend our knowledge of the spin-dependent gluon distribution and its contribution to the proton spin.

Both STAR and PHENIX have reported first results for the parity-violating single-spin asymmetry A_L in W boson production from analysis of the Run 9 data. The PAC applauds the C-AD for achieving acceleration of polarized protons to 250 GeV and the collaborations for their impressive W results. It is clear that with higher polarization and improved luminosity the RHIC spin program is poised to make major new contributions to our knowledge of the spin structure of the nucleon.

During Run 9, machine studies were performed to study the polarization at 500 GeV as a function of vertical beam tune. These studies indicate that running close to the 2/3 machine resonance would result in much higher polarization. During Run 10, the effect of improvements in power supply stability were tested with Au beams; they should enable the stable conditions essential for running p+p collisions close to this depolarizing resonance. It is expected that, for Run 11, polarization at 500 GeV will be significantly higher than previously, at about 50%. Luminosity is also expected to increase.

Both collaborations propose long runs with polarized protons at $\sqrt{s}$ = 500 GeV for Runs 11 and 12. STAR proposes to run for a total of 11 weeks at 500 GeV in Run 11, of which 5 weeks are with transverse polarization and 6 weeks with longitudinal. The transverse spin program aims at measuring single-spin asymmetries with STAR's Forward Meson Spectrometer. In summer 2011, STAR plans to install the Forward GEM Tracker. This would significantly enhance the charge-sign separation capabilities starting from Run 12. PHENIX will have muon triggering capability both arms in 2011 when the new trigger system has been installed, with further enhancement of background rejection in 2012 through RPCs. These developments motivate running at 500 GeV in both Runs 11 and 12.

The PAC's highest priority recommendation for the spin program for Run 11 is a long (about 10 week) run with polarized protons at 500 GeV. It is vital for the RHIC spin program to continue the W physics program as early as possible. The PAC therefore, from today's perspective, also recommends a similarly long 500 GeV run for 2012. The expected combined figure-of-merit of about $P^2L = 70\ pb^{-1}$ for each experiment over the two runs would lead to very significant results for the W spin asymmetries. They would feature prominently in global analyses of nucleon spin structure and hence produce a clear impact on our knowledge of the quark and anti-quark helicity distributions.

Comment on 200 GeV running:

STAR has indicated a desire for further running at $\sqrt{s}$ = 200 GeV. The PAC believes that the best course for the spin program is to concentrate on collecting $\sqrt{s}$ = 500 GeV data. Running at 200 GeV should not be viewed as a fall-back option in case desired polarization and/or luminosity at 500 GeV are not attained, but should rather be based on a demonstrated and developed science case. We would like to repeat and emphasize our recommendation from last year's report:
Assuming the anticipated polarization and luminosity goals for $\sqrt{s}$ = 500 GeV are met in time for Run 11, what, if any, are the pressing observables that would require a return to 200 GeV? BURs submitted to the 2010 PAC should quantitatively address the need for any further spin data at 200 GeV center-of-mass energy.

Although there may be some reasons to return to 200 GeV, they will need to be clearly supported and articulated.

Comment on pp2pp running:

The PAC recommends that further pp2pp running (high β^*) be considered only in the case where the higher priority physics discussed above has been completed. Given the present analysis and presentation of the Run 9 data, it is not clear what significant impact further running will have on our understanding of diffractive physics.

3. Drell-Yan LOIs

The PAC reviewed two Letters of Intent describing future RHIC experiments for measuring spin-dependent Drell-Yan (DY) scattering. Both LOIs are focused on the same physics goal: the first Drell-Yan measurement of the Sivers distribution function in the proton. Interest in this TMD (transverse-momentum dependent PDF) is high as it is sensitive to the unknown orbital angular momentum of the quarks. Measurements of the Sivers function and other TMDs have been performed by HERMES, COMPASS and JLab using semi-inclusive deep-inelastic scattering (SIDIS). The primary goal of the proposed Drell-Yan measurements is to test the TMD factorization theorems on which the interpretation of these SIDIS data rests. This theoretical framework makes a clear prediction: that the Sivers function measured in Drell-Yan scattering is of opposite sign to that measured in SIDIS. This prediction arises from the gauge link that appears in the theoretical definition of the TMDs and its different spacetime topologies in DY and DIS scattering.

Despite their common physics goal, the LOIs describe very different experiments. The first letter proposes a collider experiment and is tightly focused on measuring the Sivers sign change as quickly as possible. In contrast, the second letter describes a fixed target experiment that would take place on a longer time scale and make a more complete measurement of the Sivers function, including its dependence on momentum fraction *x*. Both experiments would take place in the IP2 hall formerly occupied by BRAHMS, and both make maximal use of existing equipment to reduce cost and effort. The proposed schedules have the collider experiment taking data from 2012–2013 and the fixed target experiment from 2014–2018, each preceded by a construction period requiring work in the IP2 hall.

3.1 LOI for a Collider Drell-Yan Experiment at IP2

The DY collider experiment would proceed in three stages. The decision whether or not to proceed with each stage will depend on the results of the preceding stage:

- 2011: machine test of impact on STAR and PHENIX of collisions at a 3rd IP; calibrate HCAL (recycled from AGS) $\rightarrow$ proceed to stage 2 if impact on STAR/PHENIX is minimal
- 2012: install EM calorimeter (possibly recycled from JLab) and preshower (new); collect as much luminosity as possible from planned long pp run
- 2013: (if EM calorimeter + HCAL + preshower insufficient for viable measurement construct new fiber trackers and install PHOBOS split-dipole magnet) measure Sivers sign change with Drell-Yan with 12 weeks pp transverse

Overall, this plan was found to be timely and cost-effective with a good, focused physics case. The PAC encourages the collaboration to prepare a full proposal for the next PAC. As the first stage is less than a year away, we also endorse the commitment of 2-3 machine shifts in 2011 for testing the impact on PHENIX and STAR of collisions at IP2. (Though the LOI did not specify the machine tests in detail, our impression was that 2-3 shifts should be sufficient. If further time is required, it must be explained in the full proposal and reviewed at the next PAC.)

The PAC asks the proponents to consider the following points when preparing their final proposal. First, the LOI did not sufficiently clarify the *scope* of the experiment. The letter gives the impression that this new experiment at IP2 would provide the basis for a long-term facility at IP2 with the physics scope of Drell-Yan measurements at low x. (This impression arises from, e.g., the larger “Model 1” detector shown in the projection plots.) The PAC finds that the case for a low-x DY program has not yet been convincingly made. However, discussions with the spokespersons indicated that this is not the LOI’s intent. The PAC asks that the experimenters also clarify the technical scope of their experiment, and provide a clear schedule for vacating the hall under the various scenarios outlined in the phased approach (i.e., depending on the results that are obtained at each phase). This “exit schedule” impacts other possible activities at IP2, including machine upgrades and the second DY LOI. The experimenters should also provide detailed estimates of the impact of phase 2 and 3 data taking on STAR and PHENIX to those experiments in advance of the next PAC, so that next year’s STAR and PHENIX BURs can show the impact of the Drell-Yan collider experiment on their respective programs.

Second, the LOI does not prove conclusively that phases 1 and 2 of this experiment could not be performed at STAR, using the existing FMS and planned HCAL. This question was largely answered during discussions with the experimenters, the central point being that physical obstructions preclude any future STAR HCAL from reaching the pseudo-rapidity of 3 needed for the Sivers sign change measurement. (This point should, of course, be clarified in the final proposal.) However, it is still not completely clear that the measurement could not be made at STAR *at 200 GeV*. At the lower beam energy (which was favored by a previous DY feasibility study) the need for far-forward angle acceptance would be less severe. Also, though the DY cross-section is lower at 200 GeV, the background is likely to be lower as well. The final proposal should demonstrate explicitly that a convincing Sivers sign change measurement is not possible on a similar time-scale at the existing detectors (including their near-term upgrades) at either beam energy.

Third, to show that the estimated error of 0.01 on the final Sivers asymmetry will provide a convincing test of the sign change, the available *range* of theory predictions must be shown, along with the *uncertainties* on those predictions. Plots of the experiment’s coverage in (x_1, x_2) would also be very helpful in assessing its reach. Finally, the PAC encourages the experimenters in their efforts to recruit new collaborators. The timeline of the experiment is ambitious; the final proposal should delineate the responsibilities of collaboration members so the next PAC may assess its feasibility.

3.2 LOI for a Fixed Target Drell-Yan Experiment at IP2

The fixed-target LOI essentially constitutes an extension of the Fermilab SeaQuest/E906 experiment to polarized beams. After the conclusion of the approved SeaQuest running period in 2013, a significant portion of the experiment would be relocated to the IP2 hall at RHIC. Data taking at the new experiment would proceed in three phases:

- 2014: installation and commissioning
- 2015-2017: 3 years × 10 weeks running in parasitic mode (with two options)
- 2018: 8 weeks running in dedicated mode

The strength of this experiment lies in its statistical precision and kinematic range: it would measure the x-dependence of the Sivers function over the range $0.1 < x < 0.6$. By measuring the dimuons' angular distribution, the experiment will also obtain results on the Boer-Mulders and transversity functions. The LOI briefly discusses an intriguing extension/enhancement of the experiment to include a polarized target.

Spin-dependent measurements of DIS and e+e– annihilation have provided a wealth of information about partonic spin in the proton and in fragmentation. The Drell-Yan process has not yet received this attention, and is likely the "next frontier" in hadron spin structure physics. The PAC recognizes the importance of a dedicated facility for spin-dependent DY and encourages the authors of this LOI to pursue their design. However, as described in the section on "Decadal Planning", STAR and PHENIX are actively considering this very direction for the 2015+ period. Though the kinematics of DY at an upgraded STAR or PHENIX detector would be quite different from those of the LOI, the timescale is the same, and the PAC feels that all three future DY concepts should be considered in concert. We encourage the experimenters to communicate with the directorate and participate in the BNL decadal plan that is being prepared over the next few months.

We offer a few suggestions to the experimenters for their preparation of a full proposal. First, the LOI is unclear on how much impact the experiment would have on other activities in IP2 *before* 2014. Particular attention should be paid to any civil construction needed (e.g. to accommodate new magnets), and to the degree of conflict between this effort, the collider DY LOI described in the previous section and possible machine upgrades involving the area of IP2. Second, more detail is required to support the ambitious timescale of the LOI, which leaves little room between the end of approved SeaQuest/E906 running and data-taking at RHIC. Third, the PAC wonders how much support exists for this project within the SeaQuest collaboration, as extensions to the Fermilab program are also under consideration. Finally, the experimenters might consider exploring the experiment's access to *negative* x_F. With a polarized beam, this region is sensitive to the Sivers and Boer-Mulders functions for *sea quarks*. The TMDs are now rather well constrained by SIDIS data for up and down quarks, but not for antiquarks. While the sea quarks are known to be largely unpolarized, their orbital angular momentum may not be small; a number of models predict significant orbital angular momentum in the sea. The DY process is almost certainly the only route to a precise, model-independent measurement of these PDFs for sea quarks.

The PAC recommends that a workshop be organized that addresses the various plans and possibilities for Drell-Yan physics at RHIC, both in the context of PHENIX and STAR and their anticipated upgrades, and of the LOIs discussed above.

4. Decadal Plans

The PHENIX and STAR collaborations presented an overview of the status of their decadal planning process that was initiated by a request from Associate Laboratory Director Steve Vigdor. 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 purpose of the current planning is to define the physics agenda for the next decade to comprehensively explore the new state of matter formed at RHIC, characterizing its properties with precision, to explore the possibility of presently unknown phase transitions or new states of matter (i.e. to fully explore the phase-structure of QCD), and to further determine the structure of the nucleon.

The PAC believes that planning for the next decade is very important to the long-term health of the experimental nuclear physics program at BNL. Such planning must include the identification of the overarching physics questions that will motivate and drive the next decade of operation of RHIC, and to identify experimental deliverables that will directly or indirectly provide answers to these questions. The clear expression of these questions is crucial, as is an experimental trajectory that will provide the answers. Where theoretical advances are needed, this should also be pointed out. In the process of developing the plan, it is important to put the proposed physics program into the context of other efforts, both national and international, and their associated time-lines. The most obvious comparison that must be made is with the expected physics output from the LHC. It is also important to put the proposed physics program in the context of the next decade of research in the broader field of nuclear physics, and to make connections with other areas of physics where apropriate.

The PAC would like to see the STAR and PHENIX decadal plans begin by articulating "big picture" questions that motivate a decade-long program. The plans should give examples of answers to the question: "What accomplishment does PHENIX/STAR want to be known for in 2020?" Some should be medium-term questions where there is already a clear strategy for experimental measurements that will advance our current understanding. Others should be longer term. In sum, they should make the case that the best young scientists will continue to be attracted to this field and that major discoveries are to come. The collaborations should make the connections as tight as possible between what they see as the big questions and the measurements they envision making to address them. From this, a perspective on detector upgrades beyond those currently in progress, or being planned, should emerge.

In the presentations we heard at the PAC meeting, several big picture questions resonated. We give these as examples to indicate what we mean above, not necessarily to advocate that they be those highlighted by the collaborations:

- Is there a critical point in the experimentally accessible region of the QCD phase diagram?

- When (a medium term question) and how (a long term question) does equilibration occur in heavy ion collisions?

- Is a quasi-particle picture of the quark-gluon plasma produced at RHIC valid?

- Are high energy partons weakly coupled to the quark-gluon plasma? If so, above what energy scale?

- At what momentum scale, x_{sat}, does a transition to saturated gluon matter occur in nuclei, and what are the unique, quantitative and experimentally testable consequences of this transition?

As has always been the situation with the physics program at RHIC, a close connection with theorists will be important to optimize progress in answering the big questions. The PAC would encourage the collaborations to indicate how such connections are expected to develop and evolve during the decade and what advances on the theory front are needed.

One goal of framing these big questions should be to develop a crisp case for how measurements at RHIC will complement those at the LHC, depending on the ways in which the matter created in these two energy regimes is different or similar. The LHC is the "new machine in town", making it crucial to distinguish the physics that RHIC will accomplish in the coming decade and to emphasize its complementarity in as quantitative a fashion as possible. Given its focus on heavy ion collisions, RHIC has a versatility advantage over the LHC – it can much more easily run with varied species, varied collision energies, and varied detector configurations. The PAC would like to see the decadal planning articulate how this versatility can best be utilized to answer the big physics questions and, in particular, which of these physics questions *require* this versatility.

Where possible, the collaborations should also highlight connections between big questions in RHIC physics and those in other areas of physics.

The PHENIX collaboration clearly articulated their proposed physics agenda, and also the detector upgrades that will enable the program to succeed. The PAC positively viewed this presentation and believes the collaboration is currently on-track for arriving at a compelling decadal plan. The longer term physics goals that were identified include several of those highlighted above, as well as that of characterizing the strongly-coupled medium produced in RHIC collisions. The latter goal includes exploring the similarities and differences in the behavior of charm and bottom quarks in the medium (i.e. their flow), the color-screening by the medium (with very good upsilon resolution), the energy-loss of color charges moving in the medium and an identification of the quasi-particles (if they exist). The structure of the nucleon will be explored by extending the range and precision of presently measured parton distribution functions, including those for anti-quarks and gluons, as well as, potentially, opening up qualitatively new directions. An upgraded PHENIX detector is being designed to address these central questions; it would have a substantial cost. The upgrade would replace much of the current detector – including removal of outer tracking, a new 2T solenoid, new layers of silicon tracking, hadronic calorimetry outside the solenoid and high DAQ bandwidth and triggers. The physics output from such detector must be shown to fully justify the large cost. While we endorse the current stage of planning for their decadal plan, it is far too early to judge the proposed PHENIX upgrade. The PAC believes it is critical for the collaboration to tighten the connection between the physics questions and measurements, and the necessity of specific aspects of the upgrade they envision. The presentation emphasized the expected differences between the proposed LHC running and their program, largely due to the different matter that will be produced due to the different kinematic at LHC and RHIC. One aspect of the program that was somewhat de-emphasized was how the proposed program ``fits'' with the current planning for an electron-ion collider (EIC). The PAC would like to see the decadal plan contain a discussion of the PHENIX program in the EIC era.

The STAR collaboration planning appeared to the PAC to be at an earlier stage of development. The presentation was a discussion of the current state of the field; their planned program appeared to be incremental in nature. This can be interpreted as the collaboration being fully prepared for the next decade of physics, with the medium term upgrades in the pipeline yielding a detector that can address their longer-term "big questions". However, this case was not made explicitly to the PAC. The PAC recommends a complete discussion of this proposed plan in terms of the big questions that STAR sees driving the field. STAR's plan highlights the full flexibility of RHIC, for example in the search for the critical point but also in the combination of pA, eA and ep collisions. The experimental upgrades they envision will allow for clean heavy flavor tagging (such as Λ_c's) and further advance STAR's ability to do jet physics. STAR will add muon capability at mid-rapidity, allowing triggered measurements of rare high-p_T probes. They also plan a significant upgrade in the forward direction, largely motivated by the goal of further quantifying the spin structure of the nucleon. STAR is also positioning itself as the best place in the world to detect anti-hypernuclei. The STAR presentation highlighted their intentions for future eA collisions. The PAC came away with the impression that STAR's thinking about the longer term is focused on eA collisions.

As discussed above, the PAC meeting saw presentations of LOIs from two collaborations with desires to refine understanding of the structure of the nucleon through Drell-Yan measurements. It appeared to the PAC that Drell-Yan measurements were the focus of the future of the RHIC-spin program (as evidenced in all presentations), and the future of this line of exploration should be refined sooner rather than later. One the LOIs was specified as a developmental experiment for the upgrade of STAR's future spin-physics program (within the decade). The PAC believes that a coherent discussion among the Lab, PHENIX, STAR and the two collaborations submitting LOIs to develop an optimal spin-program for the next decade is highly desirable and should begin with a workshop in the near-term. It is clear that there has been somewhat limited communications between the collaborations on this subject, and we encourage the start of this discussion.

In summary, the PAC concludes that decadal planning is in its early stages, and that serious thought must be given to identifying and clearly articulating the big questions for the field that can be addressed by RHIC during the next decade. Further, these questions should guide the detector upgrades and resource allocations. Having said this, it is clear that both STAR and PHENIX can provide crucial and complementary information about the nature of matter under extreme conditions and the structure of the nucleon during the next decade. Further, we believe the density and temperature regimes are likely to be sufficiently different from those at the LHC that the RHIC program will have a unique role to play in this area of exploration.

5. Detector Upgrade Plans

Ten years into the RHIC program, the experiments are proceeding with a long-planned set of detector upgrades. PHENIX has completed a physics program with its hadron blind detector (HBD) detector, will complete construction within the next two years of two silicon vertex detectors and will install new detectors and electronics required for a muon trigger upgrade. STAR has recently completed a large-acceptance time-of-flight (TOF) detector and is currently constructing a forward GEM tracker for W measurements. STAR is also planning two new upgrade projects: A Heavy Flavor Tracker (HFT) and a Muon Telescope Detector (MDT).

The PHENIX HBD operated stably in both Runs 9 and 10. Preliminary studies of HBD performance with Au+Au collisions in Run 10 demonstrated the ability of the detector to cleanly separate single electrons and electron pairs from hadrons. Using the HBD to reduce hadron, π^0 Dalitz decay and photon conversion backgrounds, PHENIX should produce unique measurements of virtual thermal photons, intermediate mass di-electrons, vector meson decays to di-electrons, and single non-photonic electrons in 200, 62.4 and 39 GeV Au+Au collisions – all with backgrounds that are significantly reduced compared to earlier PHENIX results. The PAC commends PHENIX for successfully completing HBD physics program.

Before Run 9, STAR had installed ~75% of the MRPC TOF upgrade. The rest of the TOF system was installed prior to Run 10. The TOF system provides STAR with π/K separation up to ~2 GeV and K/p separation to ~4 GeV over the full region $|\eta| < 1$ and 2π in azimuth. The TOF system is expected to enable a broad spectrum of important new measurements, ranging from fluctuations in particle yields as a signature of the QCD critical point to di-electron spectra and the particle composition of jets and of the "ridge". STAR showed preliminary analyses from Runs 9 and 10 that demonstrate the TOF system is performing very well. The PAC congratulates STAR on the completion of this important upgrade, and looks forward to seeing physics results from it in the near future.

PHENIX is proceeding with the construction and installation of a set upgrades to the muon trigger system that are critical for the PHENIX Spin W program and other muon spectrometer measurements. Prior to the start of Run 10, PHENIX installed the first of the muon trigger Resistive Plate Chambers (RPCs) behind station 3 in the PHENIX north muon spectrometer; that chamber is currently being tested using cosmic rays. The station 3 RPC chamber for the south muon spectrometer will be installed during the summer 2010 shutdown. Upgrades of the muon tracker front-end electronics required for the trigger were installed prior to Run 9 and have been tested during Runs 9 and 10. The Level 1 muon trigger processor boards have been installed and tested. With the completion and electronics integration of the station 3 RPC chambers, PHENIX will have a functional Level-1 W trigger ready for Run 11 spin running. To reduce backgrounds in the W measurement resulting from hadrons that "punch through" the steel of the central magnets and subsequently decay to muons, PHENIX is planning to equip both muon spectrometers with additional absorbers behind the PHENIX central magnets. This installation will also be completed during the summer 2010 shutdown.

PHENIX is nearing the completion of construction of the "VTX" -- the first of the two PHENIX silicon vertex detectors. That detector consists of two planes of silicon pixel detector and two planes of two-layer "strip-pixel" detectors. This detector is intended to provide tagging of displaced vertices resulting from heavy flavor decays and has the ability, for example, to separate electrons resulting from charm and bottom decay. The VTX detector significantly extends the acceptance of the PHENIX central arm spectrometers with a pseudo-rapidity coverage $|\eta| < 1$ and an azimuthal coverage that is 80% of 2π. PHENIX is planning on completion of the VTX detector prior to the start of Run 11, and its Run 11 physics heavy ion physics program is focused on taking advantage of the heavy flavor measurements afforded by the detector. However, the detector assembly is still underway and integration of the detector into PHENIX has not yet started. While the PHENIX schedule provides for the VTX detector being ready for commissioning at the start of Run 11, there is significant schedule risk inherent in the mechanical, electrical, and electronics integration of such a complex detector.

STAR is constructing a Forward GEM Tracker (FGT) that is essential for the STAR program of W asymmetry measurements. The FGT will provide charge-sign separation for electrons from W^+/W^- decay that are emitted in the region $1 < \eta < 2$. The forward region provides the greatest ability to separate the contributions of *u* and *d* quarks and antiquarks to the polarization of the nucleon in these measurements. At present, the FGT is on track for installation in STAR before Run 12. To provide space for the FGT, the Forward Time Projection Chambers will be removed from STAR at that time.

PHENIX is proceeding with the construction of forward vertex silicon (FVTX) detectors that will extend heavy flavor decay tagging capabilities to the muon spectrometers. Each muon arm will be equipped with 4 planes of silicon strip detectors. In addition to providing the ability to tag muons produced in charm and bottom decays, the FVTX will also reduce backgrounds in the muon measurements resulting from pion and kaon decays. Assembly of the FVTX silicon detector "wedges" has started at the SciDet facility at FNAL. Completion of FVTX construction is expected in the spring of 2011, allowing for installation of the detector during the summer 2011 shutdown.

STAR is developing a Heavy Flavor Tracker (HFT) to provide direct reconstruction of the displaced vertices from the decays of charmed hadrons, including D^0 and Λ_c, over a broad range of transverse momenta. The initial measurements anticipated with the HFT include flow for fully reconstructed D^0 mesons in the hydrodynamic region to explore thermalization, and the ratio of Λ_c/D^0 yields to determine whether or not the baryon enhancement that has been seen at RHIC extends to the heavy flavor sector. The lifetime of Λ_c is substantially shorter than that of the *D* mesons, and its semi-leptonic branching ratio is smaller. Thus, the latter could imply the need for some reinterpretation of lepton-based heavy flavor yield measurements. The inner two layers of the HFT will be constructed with active pixel sensors of state-of-the-art thinness. STAR expects to receive CD-1 approval for the HFT shortly. The current time line has the HFT ready for physics in heavy ion collisions in Run 14, and ready for physics in proton-proton collisions in Run 15, but there are concerns that the eventual funding profile may push availability of the HFT later.

STAR is also planning to construct a Muon Telescope Detector (MTD) to provide muon/hadron discrimination at the level of 10^2-10^3 and the ability to trigger on high-p_T muons at mid-rapidity. The MTD will consist of MRPC chambers located outside the return yoke of the STAR magnet. It will provide essential capabilities for triggering on and reconstructing dimuons from upsilon decay. The dimuon channel is particularly attractive because it doesn't suffer from bremsstrahlung tails, in contrast to the di-electron channel. This will allow a clean separation of Υ(1s,2s,3s) yields to investigate color screening in the dense medium. This measurement has been identified as particularly important because interpretation of the analogous measurement in the J/ψ system is complicated by contributions from recombination of charm quarks. The MTD will be built by a China-India-US collaboration that involves several institutions that were involved in the construction of the STAR TOF. STAR has submitted the proposal for the MTD to BNL management and DOE. The current schedule has the MTD available for physics beginning in Run 14.