Recommendations of the Brookhaven High Energy and Nuclear Physics Program Advisory Committee: RHIC Out Years, Runs 5-8

September 2003

The first three runs at RHIC have established that Au-Au collisions at center-of-mass energies in excess of 130 AGeV create a state of hot, dense, strongly interacting matter. Comparisons of d-Au and Au-Au collision products indicate that this matter differs qualitatively from ordinary nuclear matter, with hydrodynamic properties consistent with the constituents having short mean free paths. Run 4, Au-Au at 200 AGeV, will extend these studies to final-state projectiles of higher mass and higher momentum, potentially characterizing the properties of the matter far more clearly.

A second major RHIC focus, the program of polarized proton collisions, is a key element in the world-wide effort to dissect the spin of the proton. RHIC will play a unique role in probing the spin carried by gluons and separately by the up and down quarks. High polarizations (70%), high luminosities, and high energies (up to 500 GeV CM) are critical requirements for the envisioned spin program. The development of the necessary beams is far from trivial: time and resources will be required to build, test, and tune beams and polarization hardware.

The dominant factor governing the success of the RHIC program beyond Run 4 is the speed with which RHIC reaches its proton polarization and proton and heavy-ion luminosity and delivered luminosity milestones. This will determine both the quality of the data taken and beam choices available to experimenters. The difference between the projected maximum and minimum five-year (2008) luminosity is currently a factor of seven for Au+Au, and nearly 20 for p+p. This underscores how central strong support for operations improvements will be in allowing the collaborations to progress through their envisioned physics programs.

To date commissioning has gone very well. Among the many milestones reached in Run 3 were the first d+Au collisions with equal-energy injection and acceleration; the commissioning of a new AGS polarimeter as well as eight new spin rotators to produce longitudinal polarization; and the achievement of 50% polarization (40% on average) at AGS extraction and 35% at 100 GeV. Developments will continue in 2004 with the installation of helical snakes in January, eliminating AGS depolarization resonances and avoiding polarization mismatches at AGS injection and extraction.

A second important factor in RHIC's five-year (and beyond) productivity is the success of proposed detector upgrades. For example, STAR's list of urgent upgrades will extend capabilities in data acquisition, forward tracking, final-state hadron four-vector determinations, and high-Q^2 tracking. As it takes time to develop new equipment, it is crucial for the collaborations to receive significant FY04 R&D funding to avoid falling behind their upgrade schedules. It would be tragic if beam commissioning goes well, but the physics is diminished because vital equipment is not yet on the floor.

The PAC's recommendations for Run 4 placed the strongest priorities on Au+Au at 200 GeV and on beam development for p+p at 200 GeV. The collaborations were in reasonable accord on these priorities. Beyond Run 4 there is not such unanimity, and the facility uncertainties discussed above (the pace of improvements in integrated luminosity and polarization) begin to compound. The issues apparent to the PAC at this time include:

- The comparative priority of a lower-energy Au+Au run versus one with a lighter ion.
- The criteria for choosing among suggested lighter ions (Si, Fe, Cu,…)
- The importance of exploiting RHIC's capabilities in heavy ions while at the same time developing the polarized proton program in a timely way.
- The physics focus of BRAHMS and PHOBOS.
- Additional Au+Au running.
- Additional d+Au running.
- The horizon for p+p running at 500 GeV.

With the exception of the first point, the PAC feels that it cannot offer reliable advice on these matters at this time, despite their central relevance to collaboration plans for Runs 5-8. The PAC feels that two uncertainties – commissioning progress and the nature of the new discoveries RHIC will makes – define a "radius of convergence" for our advice of about a year. Beyond this, suggestions we make now are likely to require yearly midcourse corrections. In fact, we feel that the best possible RHIC program is one that will respond quickly as discoveries are made and our understanding improves. *In this spirit we urge the Laboratory and the RHIC community to retain balance between the need for future planning and the ability to respond to exciting unanticipated discoveries. In this regard we suggest that the Laboratory and the community hold workshops at regular intervals (but not more than once a year) to evaluate recent progress and suggest the most fruitful paths forward.*

With this caveat we offer the following:

Varying energy vs. investigating a lighter ion reaction: In our view there is a greater likelihood of finding interesting physics in the energy variation. The proposed Au+Au run at 63 GeV, near the geometric mean of the RHIC and SPS results, is a nicely chosen interpolation point. By placing a data point within the existing energy gap, the experimenters may be able to assess whether the energy evolution is unexpected. *Thus we recommend a 63 GeV measurement in Run 5, followed by a lighter ion experiment at 200 GeV in Run 6.* However, beam availability could prompt us to alter this recommendation. For example, if the Laboratory finds a short run available for one of these measurements, it might then be preferable to do the light ion experiment at 200 GeV: the competing low-energy measurement might suffer statistically if the beam time is too limited.

Choice of the light ion: There is some divergence in the opinions of PAC members in assessing whether the ion choice is a critical issue. One view is that the purpose of the measurement is to explore gross features of ion size and geometry, with the specific nucleus being incidental to the experiment's main goals. A second view – based in part on the fact that the collaborations had made rather specific suggestions of Si, Fe, or Cu – is that the experimenters then have an obligation to explain their choices. The PAC suggests that the collaborations consult with each other and with members of the theory community, with the responses presented to us at the next opportunity.

RHIC's heavy ion and polarized proton programs: Although one could argue there is competition between these areas, commissioning improvements focused on one program often result in enhancing overall machine performance. Thus the PAC views these two areas as complementary pillars that justify the community's investment in RHIC. There is an expectation, over some long but unspecified time period, that beam time between heavy ions and spin will divide roughly in the ratio of two to one (though physics never is predictable for a machine probing qualitatively new regimes). There is clearly a lot of year-to-year flexibility in meeting this rough goal. The heavy ion program's central goal of probing the nature of hot dense nuclear matter was the primary driver behind RHIC. The spin program could well be crucial to the facility's long-term future. The spin program's three-year polarization and luminosity goals are extremely challenging. There is a preference, on the operations and development side, for annual runs so that problems can be identified quickly and adjustments made with a minimum turnaround time. Yet this mode requires frequent beam switching, which is not efficient: time is lost with changeovers, more operations manpower is consumed, and luminosity tends to be lower early in runs. The PAC urges a vigorous program of developing high polarization and luminosity. *We think a plan, contingent on good progress in spin commissioning, that provides for a long (19 week), high-intensity run makes good sense, and could envision that occurring as early as 2007. We support an approach to scheduling that seeks to balance beams on the long term, not the short.* If schemes can be constructed to make the division of beam time more efficient – scheduling two long runs over three years was raised as one possibility – the PAC would be interested in hearing of their merits.

BRAHMS and PHOBOS: The roles of the two smaller detectors in the out years was discussed. There was a strong consensus that these collaborations will maximize their physics by focusing on measurements where they have unique capabilities (as opposed to those where they might compete directly with STAR or PHENIX). This focusing should be part of the plans for completing the envisioned experimental programs.

Additional Au+Au running: Clearly, in addition to new physics, further Au-Au running would depend on the integrated luminosity obtained in the coming run and, as well as for future runs, on the progress and character of the accelerator and detector upgrades. While an additional run has been proposed, the PAC feels it should respond only after the current heavy ion program has had a chance to develop further.

Additional d+Au measurements: Similarly, it is difficult to anticipate at this time, with much of the existing data not yet public, whether additional runs will be a high priority.

This reaction is potentially an important probe of low-x physics, and new runs at low energy could be necessary to better understand Au+Au at 63 GeV, should those data hold surprises. The PAC will need to consider the new physics addressed by these studies and its priority with respect to other aspects of the program. This would include the role of low-x phenomena in the analysis of the collisions and their possible effects on the goal of understanding the partonic systems produced in the collisions.

Running p+p at 500 GeV: This program is probably near or beyond the 5-year horizon we are addressing. Its scheduling depends on the general rate of progress in the spin program and with adequate luminosity for gamma-jet and W studies. The timing could also be influenced by progress on proposed detector upgrades.