Recommendations
Brookhaven National Laboratory
Nuclear and Particle Physics
Program Advisory Committee
June 17-19, 2015

1. Introduction

On June 17, 2015, the PAC heard both the PHENIX and STAR plans for release of recently acquired data as well as their Beam Use Requests (BURs) for Runs 16 and 17 (STAR only), as well as an update on the proposal for *Precise Measurements of Very Forward Particle Production at RHIC* (RHICf). On June 18, the PAC heard about STAR plans for the iTPC upgrade as well as a general discussion about the status of the measurements and interpretations related to the chiral magnetic effect and related physics (CME). Based on this input, we report our recommendations for Runs 16 and 17 and assess the RHICf proposal in Section 2, and provide our assessments of the data release plans, the iTPC and CME in Sections 3, 4 and 5, respectively.

The PAC commends the collaborations and C-AD for successful execution of the Run 15 200 GeV polarized p+p program. We are concerned about the damage to the PHENIX MPC and VTX detectors during the polarized p+Au running as a result of abort kicker pre-fire beam losses. We encourage the laboratory and the collaborations to complete as soon as possible the task-force assessment of these accidental beam losses and the prospects for detector repair in order to better understand the options for operation in Run 16. Asymmetric running continues to be important to address critical questions in heavy ion physics. We comment further on the specific plans for Run 16 below.

2. RHIC run plans

2.1 Executive summary

For Run 16 the PAC recommends the following (*in order of priority*):

1. 10 weeks Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV
2. 5 weeks for a small system beam energy scan. This program can be realized with
    a. Au+polarized proton collisions for a set of energies chosen among 200, 62, 39 and 20 GeV to optimize the physics output, or
    b. d+Au collisions at 200, 62, 39, and 20 GeV
3. 2 weeks of polarized p+p collisions at $\sqrt{s} = 62$ GeV
4. Up to 4 weeks of Au+Au collisions at $\sqrt{s_{NN}}$= 62 GeV

The Au+Au run at $\sqrt{s_{NN}}$ = 200 GeV is recommended as the top priority. In a 22 cryo-week scenario and in the case that asymmetric running conditions can be achieved with acceptable risks to the experiments, the PAC recommends that the small-system energy scan program be performed using Au+polarized proton collisions (switching beam species in the yellow and blue rings compared to Run 15). In the case that the risk of damaging the detectors in a pre-fire event remains significant, d+Au running is recommended as a substitute, although part of the physics program would be lost. We leave to the discretion of the management whether the remaining 2 weeks of running should be used for additional 200 GeV Au+Au or for additional Au+p/d+Au running. The polarized p+p running at $\sqrt{s} = 62$ GeV has lower priority, but is recommended in the case that measurement of collective phenomena at the lowest beam energy, $\sqrt{s_{NN}}$ = 20 GeV, is judged to be not feasible, and/or that the $\sqrt{s_{NN}}$=200 GeV p+Au data are judged sufficient after preliminary analyses of Run 14 p+Au data are in hand. The Au+Au running at $\sqrt{s_{NN}}$ = 62 GeV is recommended in the case that neither Au+p nor d+Au collisions could be provided safely.

For Run 17:

1. The PAC endorses at least 11 weeks of transversely polarized p+p running at $\sqrt{s}$ =510 GeV
2. The PAC encourages the STAR collaboration to continue developing the physics case for isobar running (Ru+Ru and Zr+Zr collisions) and to consider the physics case for p+p running at beam energies matching those of the Au+p or d+Au running in Run 16. The scientific impact of each of these options should be evaluated in comparison to that of the option of running transversely polarized p+p at $\sqrt{s}$ =510 GeV for the entire period of Run 17.

The polarized p+p running at $\sqrt{s} = 510$ GeV will allow the first significant RHIC test of the predicted sign change in the Sivers function in comparison to its value in SIDIS. The large Q^2 range offered by the combination of single spin asymmetry measurements of $W^{\pm}$, Z, direct photon and Drell-Yan production also provides a unique opportunity to investigate the evolution effects in transverse-momentum dependent distributions experimentally. The predicted sign change is a fundamental prediction of QCD, and the 2017 p+p run at RHIC presents a unique opportunity for an experimental test of this prediction to be performed over a large range of Q^2 during this decade. Even if the magnitude of the asymmetries turns out to be too small to be measured with the precision necessary to allow the sign to be determined decisively, the experimental result will nevertheless constrain non-collinear QCD evolution dynamics, the subject of active theoretical development at present. Such a measurement would also inform the planning of future experiments for the next decade.

The proposed Ru+Ru and Zr+Zr isobar running is intended to measure possible magnetic field dependence of the charged particle correlations across the reaction plane. Such a dependence, if established experimentally, could be a major step toward demonstrating observable consequences of the magnetic field generated by spectator protons in heavy ion collisions. As we discuss further in Section 5, the PAC encourages concerted efforts between experimentalists and theorists to attack the fundamental physics/background issues related to the Chiral Magnetic Effect (CME), Chiral Magnetic Wave (CMW) and Chiral Vortical Effect (CVE).

Given the PAC recommendation of a beam energy scan with Au+p or d+Au collisions in Run 16, the STAR collaboration may also wish to consider the case for taking p+p reference data in Run 17, running at beam energies matching those used in the Run 16 energy scan.

2.2 Discussion of Run 16 priorities

2.2.1. Ten to twelve weeks of Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV

A long Au+Au run at full energy is essential to complete the heavy flavor program of the STAR experiment. This program comprises differential studies of D meson flow and nuclear modifications, first measurement of the Λ_c baryon in heavy ion collisions, measurements of quarkonia (J/Ψ, ϒ(1S),ϒ(2S),ϒ(3S)) and their nuclear modifications, and open beauty measurements through the B→J/Ψ decay. Along with the large p+p reference data sample collected in 2015, this new Au+Au data set will allow for full utilization of the STAR HFT and MTD detectors. In Run 16, the STAR HFT will have a new set of PXL layers (inner layers of the HFT) with Al cables that will replace the current PXL layers with Cu cables, significantly reducing multiple scattering for low transverse momentum particles. An effective online vertex selection will also be used in Run 16 to improve the HFT fiducial coverage for acquired events. For low p_T D^0 mesons, an effective figure-of-merit improvement of about a factor of six is expected in comparison to the Au+Au data from Run 14. The combined measurements of charmed mesons and baryons would provide access to the quark evolution dynamics and properties of the QGP created in these collisions. In the beauty sector, the first RHIC measurement of non-prompt J/Ψ mesons from B decays would be possible using combined information from displaced vertex reconstruction in the HFT and J/Ψ reconstruction in the MTD.

The Au+Au running at full energy is less attractive for the PHENIX collaboration for two reasons: 1) During Run 14 the collaboration already collected a substantial data set of over 14 billion events within $|z_{vtx}|<10$ cm, corresponding to an integrated luminosity of 2.3 nb^{-1}. This data set exceeded the Run 14 goals set by the requirements of the PHENIX heavy flavor program by 55%. Additional running at this energy in Run 16 would only provide an incremental improvement to these measurements. 2) During Run 15, the PHENIX VTX detector was partially damaged during an abort kicker pre-fire event. If complete repair is not possible, this damage would adversely impact its performance in the high-multiplicity environment of Au+Au collisions.

After due consideration of the STAR and PHENIX capabilities in 200 GeV Au+Au running in 2016, the PAC recommends a 10 week run to achieve the HFT physics goals. This compromise would allow for at least a 5 week small system beam energy scan, which is a top priority for the PHENIX collaboration. The allocation of the remaining 2 weeks of the run is left to the discretion of laboratory management. If the small system scan is run in Au+p mode and, based on evaluation of the Run 15 p+Au data at 200 GeV, no significant collective effects are expected in Au+p collisions at $\sqrt{s_{NN}}$ =20 GeV (meaning that this energy would not be run), increasing the full energy Au+Au running time from 10 to 12 weeks may be considered in case STAR falls short of their goal in the 10-week running period.

In the case of a shorter 15-week running time, the Au+Au run at $\sqrt{s_{NN}} = 200$ GeV remains the highest priority, in order to fulfill the mission of the STAR HFT upgrade, which is a DOE MIE project. However, this running scenario will severely limit the physics output from the PHENIX collaboration in the *last year* of the experiment.

2.2.2. Five to seven weeks of running to perform a small system beam energy scan

A key discovery of the RHIC experimental program is the near-perfect fluid behavior of the quark gluon plasma produced in A+A collisions. Turning off this signature by varying the beam energy or the system size is essential for understanding the properties of the QGP and how the strongly coupled liquid emerges. One of the hottest topics in heavy ion physics in the past few years is the observed similarity between the behavior of many observables for p+p, p+A, d+A, ^{3}He+A, and A+A, which poses the fundamental question of how small a system can exhibit thermalized QCD behavior. What is the smallest possible droplet of QGP, and how does the answer to this question depend on the collision energy and event multiplicity, which is to say on the temperature of the QGP in question? Addressing this newly opened, and challenging, question promises to deepen our understanding of, for example, which requirements have to be fulfilled for hydrodynamics to be applicable. These considerations were crucial at the time of the last-year's PAC meeting, when a recommendation was made for ^{3}He+Au running at the end of Run 14 and for p+Au and p+Si (Al) running in Run 15. The ^{3}He+Au system allowed for engineering of the shape of the initial energy density deposition in the collisions, and the p+Au and p+Al collisions are expected to provide further insights into both the proton structure and the origin of collective effects in small systems. In addition, a substantial sample of p+p collisions at 200 GeV was collected during Run 15, which may allow for a search for collective phenomena in this system at RHIC energies. These measurements capitalize on the unique and impressive versatility of the RHIC accelerator in providing a variety of collisions systems and energies.

The PHENIX collaboration has already reported preliminary results from measurements of elliptic and triangular anisotropies in the azimuthal distributions of the particles produced in high-multiplicity ^{3}He+Au collisions. These anisotropies are substantial and similar to those expected in the case of QGP formation. Unfortunately, during the p+Au run key components of the PHENIX detector were damaged (the MPC and the VTX detectors), which will limit the PHENIX physics output from Run 15. The STAR collaboration was not impacted by the abort kicker pre-fire events. In view of these events, and the fact that several observables in Au+Au collisions change behavior around 39 GeV, a beam energy scan for small systems is proposed for Run 16. This can be performed either with Au+polarized proton collisions, or with d+Au collisions. Assuming that the MPC detector is repaired as anticipated, PHENIX detector capabilities will be well-suited to achieve its physics goals for either run condition. The Au+p option provides an added benefit of enabling exploration of saturation effects in the Au target as a function of beam energy via measurement of ratios of single spin asymmetries for identified π^0 mesons. This makes Au+polarized proton preferable, if it is judged to be a safe running condition for the experimental equipment. Otherwise, d+Au running would be preferred. The saturation physics can also be addressed by the STAR experiment using the p+Au and p+Al data from Run 15. Presently, a task force is being formed to evaluate the risks of p+Au running in Run 16, including the degree to which they would be mitigated by switching beam directions and running Au+p. The PAC recommends that if at all possible the small system beam energy scan be performed for 7 weeks at a set of energies optimized to fulfill the goals of the program. A possible scenario, as requested by the PHENIX experiment, would include 2 week runs at 20 GeV and 39 GeV, and 1.5 week runs at 62 GeV and 200 GeV. The case for Au+p running at 20 GeV and 200 GeV should be re-evaluated once preliminary measurements of collective effects in 200 GeV p+Au collisions from Run 15 are available, and in light of the PHENIX detector damage incurred during this period of Run 15.

The STAR collaboration has also expressed interest in d+Au beam energy scan to explore the evolution of the Cronin effect and jet quenching, although the requested set of energies is slightly different from the PHENIX proposal. The above scenario would allow these physics topics to be addressed in both experiments.

2.2.3. Two weeks of polarized p+p collisions at $\sqrt{s} = 62$ GeV

The RHIC program still lacks a high-statistics p+p reference measurement to match the high-luminosity sample of Au+Au collisions at 62 GeV collected in Run 10. Such reference measurement is essential for understanding nuclear modifications in the heavy flavor sector, where enhancement rather than suppression of the number of non-photonic electrons from charmed meson decay is observed, along with significant flow signals. The systematic uncertainties in the R_{AA} measurement are dominated by the normalization uncertainty in p+p data from the ISR, which are used as a reference in present analyses. A two week run at RHIC would provide enough statistics to set the normalization reliably. The PAC recommends that p+p running should be considered if the collective effects in the small system energy scan turn out to be at a level where they cannot be measured reliably at $\sqrt{s_{NN}}$ =20 GeV.

2.2.4. Up to four weeks of Au+Au collisions at $\sqrt{s_{NN}}$ = 62 GeV

Au+Au running at $\sqrt{s_{NN}}$ = 62 GeV was proposed by both STAR and PHENIX to further elucidate the production of heavy quarks and their interactions with the QGP at a temperature closer to that of the transition. STAR also proposes inclusive jet measurements at this energy. In view of the current status of the PHENIX VTX detector, the damage to which has still to be fully evaluated, the PHENIX detector performance may not be optimal for heavy flavor measurements. The PAC recommends up to 4 weeks of Au+Au running at 62 GeV, but gives it a lower priority than the small system beam energy scan and the p+p run at this energy.

2.3 Discussion of plans for Run 17

2.3.1. Transversely polarized p+p Collisions at $\sqrt{s}$ =510 GeV

The Transverse Momentum Dependent (TMD) parton distribution functions are part of a newly developed framework that provides an image of the parton structure of the nucleon in both transverse and longitudinal momentum space. QCD predicts a sign change of the Sivers asymmetry depending on whether the process involves initial state QCD interactions, as in Drell-Yan, direct photon production and $W^{\pm}$ production in p+p, or whether there are final state QCD interactions as in SIDIS with final state mesons. (The situation where both initial and final state interactions are present is theoretically unsettled.) Experimental test of this sign change is considered a fundamental test of QCD factorization and is the DOE HP13 performance milestone in hadronic physics.

STAR will measure the single spin asymmetries (A_N) of $W^{\pm}$, direct photon and Drell-Yan pairs from transversely polarized p+p collisions at 510 GeV to investigate the QCD prediction of the sign change in the Sivers function of quarks. The PAC recognizes that this extended p+p running will provide a unique opportunity for RHIC to make a significant measurement of this hadronic physics milestone. Recent theoretical calculations indicate that the magnitude of the A_N for $W^{\pm}$, for example, depends critically on non-collinear evolution dynamics: the value of A_N for $W^{\pm}$ may be reduced only by a factor of a few or by an order of magnitude depending on which evolution model is used.

The A_N of $W^{\pm}$ production is nevertheless among the theoretically cleanest observables. If STAR measures the sign of A_N for $W^{\pm}$ definitively, RHIC will have affirmatively addressed the DOE HP13 milestone and the result will be a major achievement in QCD physics. If the A_N is too small in magnitude for its sign to be precisely determined by the RHIC measurement, the measurement will still be significant because the data will provide the first experimental constraints on non-collinear QCD evolution, a new regime of QCD dynamics whose theoretical exploration has recently begun. The PAC requests STAR to quantitatively address the experimental sensitivity to various evolution models by plotting the A_N as a function of Q^2 for a few selected models together with the projected experimental sensitivity; the same should also be done for the other proposed STAR probes.

Our comments on the Ru+Ru and Zr+Zr isobar running continue in Section 5; we have no comments about additional polarized p+p running beyond those in the Executive Summary, Section 2.1.

2.4 RHICf Proposal: *Precise Measurements of Very Forward Particle Production at RHIC*

This experiment, first presented to the PAC in June 2013, now proposes the installation of one of the existing LHCf calorimeters (Arm2) in front of one of the STAR ZDCs at RHIC ("RHICf") following the 2015 LHC 13-TeV run and before RHIC p+p running at $\sqrt{s}$ =510 GeV. The proposed addition of this high-resolution electromagnetic calorimeter would allow measurements of the forward spectra of neutral particles: photons, neutrons and neutral pions. The physics motivations of the proposed measurements are twofold: (1) the measurement of the cross sections in 510 GeV p+p collisions will improve the existing hadronic interaction models used in simulations of cosmic-ray air showers; (2) using the improved p_T resolution from the combination of RHICf and the STAR ZDC will allow an improved measurement of the single neutron asymmetry at forward angles, which was previously discovered at RHIC. This second measurement requires a radially polarized proton beam. To carry out both proposed measurements, dedicated beam time of 5 days is requested. The cross section measurement, which does not require a special beam configuration, can probably be done more quickly.

The $\sqrt{s}$ =510 GeV p+p data from RHICf in combination with the LHCf data from 0.9 to 13 TeV will allow investigation of Feynman scaling and of scaling violations with the goal of a better extrapolation of interaction models to the much higher energy region (10^{20} eV lab frame ~ 500 TeV cm frame) of interest in cosmic-ray air showers. The single spin asymmetries in hadron-hadron collisions are also of considerable interest. Improved measurements of the forward neutron spin asymmetry might shed light on its poorly understood origin.

The PAC believes the proposed measurements add value to the existing RHIC program particularly because they have broader impact for the high-energy cosmic ray community. The PAC recommends support for carrying out the proposed measurement given the availability of the calorimeter from LHCf, the modest local investment required, and the strong Japanese collaboration behind the RHICf experiment.

While the PAC is in general supportive of the proposed measurements, we have the following comments:

- The proponents are encouraged to carry out more detailed studies of expected systematic uncertainties for the proposed measurements, particularly the 510 p+p collision cross section measurement, which will be important to increase the impact of the RHICf result in high-energy cosmic ray physics.
- While the proposed measurement of the forward neutron single spin asymmetry is interesting, priority should be given to the 510 GeV p+p collision measurement to minimize impact on the STAR experiment, given the significant beam time required to set up the radial polarization.
- The installation of the RHICf detector should not adversely impact the STAR experiment, therefore the compatibility between the two needs to be investigated thoroughly and as soon as possible. A potential issue is the shielding configuration and the location of the STAR ZDC relative to the proposed location of the RHICf detector.

The PAC recommends the approval of the cross section measurements with $\sqrt{s}$ =510 GeV p+p collisions in Run 17 under the assumption that the installation of the RHICf detector would not impact the STAR experiment in any significant way. The PAC conditionally approves the polarization measurement contingent on whether, after review by the accelerator experts, the transition to radial polarization is deemed to have minimal impact on the Run 17 program.

3. STAR and PHENIX data release plans

3.1. Key information presented to the PAC on data release projections

STAR has estimated the following timelines for full production of data from the 2014, 2015 and 2016 data-taking runs at RHIC:

- 2014 data to be fully processed by Spring 2016.
- 2015 data to be processed by the end of 2018.
- 2017 data to be processed by end of 2020.

PHENIX has stated that all data taken through 2013 have been processed with the exception of the data from some new detector components that have required recalibration. Final results from several major (signature) analyses and preliminary results of recent runs are expected later in 2015. PHENIX has stated that its data processing is keeping pace with its data-taking.

3.2. Discussion

The PAC is not concerned with the PHENIX computing resources. A number of long-awaited PHENIX papers and analyses are now scheduled for release in the next six months and the PAC looks forward to those results.

The PAC is concerned that insufficient computing resources may limit the timely production and release of STAR data. This presents untenable delays for extracting the new science from STAR data-taking runs at RHIC. A hallmark of the RHIC scientific program is the versatility of the collider, giving it the flexibility to pose, and answer, important new questions. Realizing this unique advantage, using the world's most versatile collider to best achieve scientific impact, requires the timely production and analysis of data sets taken with varied running conditions. To give one example, the recent ^{3}He+Au and p+Au runs at RHIC give the STAR and PHENIX collaborations unique opportunities to address questions that are presently of great interest in the field world-wide concerning what is the smallest possible droplet of liquid QGP and how the answer to this question depends on the collision energy and hence the QGP temperature. As opportunities to address new questions arise, their answers require matching the timescale for running the collider in new ways to take incisive data and that for producing and analyzing these data.

The shortage of computer resources for STAR will be accompanied by an increased time between data-taking and availability of data for analysis, which presents a major risk to expeditious dissemination and publication of the important science anticipated from the program and may result in missed or delayed opportunities for scientific impact. It may also lead to preliminary results that contain only partial statistics with lower credibility and less frequent release of results due to the longer lead times. Furthermore, younger members of the collaboration will have less opportunity to present results at workshops and conferences. It will lead also to protracted times for completion of PhD theses from STAR data and to negative impacts on the promotion of young physicists working in STAR.

3.3. PAC Recommendations

- BNL management is encouraged to commission a panel to evaluate the STAR needs for computing resources and possible optimization of production software.

- BNL Management must investigate the availability and use of additional computing resources within the laboratory and commercially outside the laboratory, or seek additional computing resources, to enable timely reconstruction of STAR data.

- STAR management is strongly urged to consider the major physics goals that will advance the overall understanding of RHIC physics in the allocation of STAR resources and in the data production priorities.

4. Plans for the STAR iTPC

The STAR collaboration proposes to upgrade the 24 inner sectors of the STAR TPC with new readout modules. This upgrade would enhance charged particle tracking by increasing the effective acceptance of the TPC and improving momentum resolution and particle identification. Tracking performance is a critical element for the planned beam energy scan program (BES-II) in 2019 and 2020. The iTPC upgrade design and timeline are driven by the BES-II physics goals, namely to explore the QCD phase diagram by studying the collision energy evolution of observables related to QGP formation and the QCD critical point. The PAC believes there is potential for the iTPC to have a strong impact on BES-II physics.

Progress in readout electronics design allows the iTPC upgrade to employ a higher density of readout pads compared to the present readout chambers. Within the same geometrical area, this increases the number of pad rows in the inner TPC from 13 to 40, allowing continuous sampling of dE/dx along the particle trajectory in the inner TPC (as is presently the case in the outer TPC). STAR typically requires 20 measured hits for a valid reconstructed track. The larger number of hits produced by the upgraded iTPC would therefore allow reconstruction of a larger fraction of tracks at low transverse momentum (below 100 MeV for pions) or at high pseudorapidity ($|\eta| > 1$) than possible with the current configuration.

The proposed mechanical construction of the upgraded sectors follows well-established practice and given the experience within the collaboration, the PAC did not identify a significant technical risk in this area. The readout electronics is based on the SAMPA preamplifier/digitizer ASIC. This 32-channel chip is currently under development, for installation in the ALICE TPC upgrade during CERN Long Shutdown 2 (LS2). While there was originally significant contingency for the delivery of the production SAMPA chips (scheduled for early-mid 2017), recent delays in the LS2 schedule make it essential that the collaboration identify a fallback solution should the development or production of this complex chip suffer setbacks/delays on the timescale necessary for deployment in the iTPC upgrade.

STAR has performed studies of the projected iTPC upgrade performance in terms of momentum resolution, dE/dx resolution, electron ID and efficiency/acceptance in p_T and rapidity. These improvements are incremental for most performance characteristics, except for the rapidity coverage. Analyses with the current configuration are mostly limited to $| \eta | < 1$, beyond which the tracking efficiency drops steeply. With the iTPC upgrade, the efficiency drop is pushed out to $|\eta| \sim 1.5$, providing a large improvement in coverage. From the studies presented it was not obvious if part of the extended coverage could be achieved by relaxing track selection cuts for the current TPC configuration and how the resulting decrease in resolution and track purity would affect various physics measurements.

The most dramatic potential improvement in sensitivity for key BES-II physics was shown for measurements of net-proton multiplicity fluctuations. A characteristic collision energy dependence of these fluctuations has been predicted as a signature of the QCD critical point. Discovery of the critical point would provide a landmark in the QCD phase diagram and a breakthrough in our experimental and theoretical understanding of QCD matter at finite density. The sensitivity to these fluctuations is sharply enhanced with the increased number of net protons per event provided by the increased rapidity coverage of the iTPC upgrade. To further strengthen the physics case for the iTPC upgrade, the PAC recommends that the collaboration perform additional quantitative studies of the expected uncertainties in the net proton fluctuations measurements at the most relevant energies, comparing projected uncertainties that could be achieved with the current TPC configuration and with the iTPC upgrade, in both cases with BES-II statistics.

The impact of the improved iTPC performance was also discussed for a number of other key physics observables seen as critical for BES-II. Among these are measurements of flow coefficients (v_1, v_2, …) for various particle species (p, ϕ,…). Although the iTPC upgrade shows clear performance improvements for these observables, at this stage and as presented, the PAC would characterize the improvements as incremental, rather than allowing qualitatively stronger physics conclusions.

The enhanced dE/dx resolution achieved with the iTPC upgrade improves electron ID purity to close to 100% over a part of the electron momentum range. In combination with the other tracking performance enhancements, this leads to a significant reduction in the projected uncertainties by a factor of close to two for measurements of dilepton mass distributions (although the studies shown were for 200 GeV collision energy). Simulation studies for Au+Au collisions at BES-II energies would be beneficial to establish whether similar improvements are to be expected in the lower-multiplicity environment of these collisions.

Additionally, STAR is considering a fixed target program using an internal gold foil target. The lack of performance studies based on pilot run data taken in 2014 or on full simulations, in comparison to published data from fixed target experiments or the capabilities of ongoing experiments such as NA61/SHINE, does not allow the PAC to comment on the potential impact of such a program at this time.

The iTPC appears to be technically feasible, modulo possible delays associated with the preamplifier/digitizer ASIC, and has the potential to realize substantial improvements in the sensitivity to signatures for the QCD critical point that would significantly expand the scientific impact of the BES-II program. However, a clear quantitative case remains to be made.

5. Chiral magnetic and related effects

In chirally restored quark-gluon plasma, the handedness of quarks is conserved, but at the quantum level these conservation laws are modified by triangle anomalies. In the presence of an external magnetic field, such as the one generated by the current of the colliding charged ions, these anomalies—which are fundamental microscopic features of QCD—lead to novel macroscopic magnetohydrodynamic effects, in particular the chiral magnetic effect (CME) and the chiral magnetic wave (CMW). These anomalous hydrodynamic effects can introduce charge-dependent correlations with observable consequences. The PAC heard a status report on the search for signatures of the CME, CMW and related phenomena in measurements made by the STAR collaboration, and on the STAR collaboration's outlook for future measurements it has proposed for Run 17 and that are anticipated during BES II.

The PAC commends STAR for its recent and continuing progress in making these challenging measurements. They have shown that the three-particle correlations related to charge separation across the reaction plane, possibly induced by the CME, are present in collisions at top RHIC energies and over most of the BES range, but seem to turn off at $\sqrt{s}$ =7.7 GeV. While some aspects of the data are consistent with CME expectations, STAR reported that significant background effects driven by bulk flow have also been identified. If the CME interpretation is correct, it would imply that the onset of chiral symmetry restoration occurs at energies above $\sqrt{s}$ =7.7 GeV. The CMW, on the other hand, gives rise to a charge-dependent elliptic flow that STAR has also observed for a range of beam energies and centralities. The CMW measurements at BES energies, as well as the indications that the CME-related observables turn off at low BES energies are, at present, statistics-limited. Both measurements demand the higher statistics anticipated from BES-II in order to confirm their interpretation, but this alone will not be sufficient. The present STAR data also demand a strong and concerted theoretical response, pulling together varied expertise and different calculational techniques to construct a theoretical framework which enables a quantitative assessment of the BES II data. Such an effort must be in place in order to either claim discovery or rule out the onset of chiral symmetry restoration in the region of the phase diagram accessible to the RHIC beam energy scan.

In the near term, STAR has proposed running Ru-Ru and Zr-Zr collisions in Run 17, choosing isobars with the same mass but different charge with the goal of changing the magnetic field, and hence changing the magnitude of the CME and CMW effects, while keeping flow-related backgrounds constant. Given the overall plans for future RHIC running, an isobaric collision program like this is unlikely after Run 17. This makes it imperative that the case for this program be made as sharply as it can be at the next PAC meeting.

Given the importance and wide visibility of a potential claim for a CME-related observation, the PAC recommends that BNL convene a working group that includes experimentalists from STAR as well as theorists with expertise relevant to understanding CME and related phenomena and who are familiar with the challenges related to separating its observable consequences from possible backgrounds. This working group should both provide an agreed upon, critical, assessment of the present state of understanding and map out a strategy for how best to use the present suite of measurements (perhaps supplemented by other information that can be drawn from present data) to address open questions of interpretation. It should also help to sharpen the case for the isobar collisions that STAR has proposed for Run 17.