Recommendations of the Nuclear and Particle Physics Program Advisory Committee, Brookhaven National Laboratory

June 7 – 8, 2018

1. Executive Summary

The Program Advisory Committee (PAC) convened on June 7 – 8, 2018, to evaluate the STAR Beam Use Request for Runs 19 and 20 and comment on the overall RHIC program. The PAC was presented with the status of ongoing analysis efforts and publications from the STAR, PHENIX and RHICf research programs. The PAC heard a status report on the STAR upgrades for the Beam Energy Scan II and STAR Plans for physics beyond the beam energy scans. In addition, presentations were made on the performance of RHIC during Run-18, a status report on the science program and progress in sPHENIX, an update of the proposed science program for an EIC detector based on sPHENIX, the Coherent electron Cooling Proof of Principle Experiment, and a report on the status and the prospects for the Low Energy RHIC electron Cooling (LEReC).

The PAC thanks the collaborations for their work and presentations, and the collaborations and CA-D for their input and cooperation in responding to questions. We commend CA-D and STAR for the success of Run 18. The performance of RHIC was outstanding during the isobar run. STAR is congratulated for the successful installation of the EPD, fixed-target program, and the iTPC sector test, which positions STAR to be able to pursue the BES-II goals. The PAC places highest priority on accomplishing the BES-II program. Within this program highest priority running should be placed on the 7.7 GeV collider run. We commend the CA-D for bringing LEReC to the state of the art that it is today and the highest priority for CAD and RHIC for the coming year is the commissioning and successful operation of LEReC. We look forward with anticipation to the results of the BES-II with the 2019, 2020, and 2021 runs.

The PAC commends both the PHENIX and the STAR collaboration for maintaining outstanding scientific productivity in terms of the number of papers published, the number of Ph.D. graduates, and the high impact of papers in the nuclear physics community. The PAC is pleased to see the continued success in utilizing CORI resources to manage the computing operations, and the implementation of the compact data format (picoDST) in STAR. We are pleased to see STAR's progress on understanding the corrections for the detector response in the net-proton cumulant measurement. We strongly encourage the STAR collaboration to pursue the completion of these studies with the highest priority to enable the timely publication of these important BES-I results.

STAR presented a rich program for future operation after BES II that addresses many important and innovative topics in p+p, p+A and A+A physics. The most interesting of these is focused on forward physics that would be made possible by a forward upgrade covering rapidities up to 4.2 with $5.3 M further investment, and would enable studies of novel reaction channels including several specific diffractive reactions and ultra-peripheral collisions of interest to hadron structure and QGP physics alike. Hadron structure measurements, such as diffractive dijet production, are highly relevant for the physics to be investigated at EIC, both for their e+p and e+A components, and may help to further sharpen the EIC physics case. From the heavy-ion perspective, QGP vorticity and Lambda polarization measurements in peripheral collisions would address vorticity generation at the microscopic level. Several international groups have submitted or are ready to submit proposals to finance most of the needed cost-efficient forward hardware upgrades. We commend STAR for developing and sharpening this option, which enriches the range of future opportunities for BNL. However, to realize a significant fraction of this program, multi-year running will be necessary. We urge the directorate to decide within this year whether the realization of these plans is realistic. A timely analysis of the 2017 data with transverse polarization could set the pace for the data analysis of possible STAR running after BES II and should be given high priority.

The PAC congratulates the sPHENIX collaboration for their successful CD1/3A review and their recruitment of new institutions that are pursuing funding opportunities to restore the full configuration of the EMCal. We encourage the collaboration to aggressively find resources that enable the inclusion of the MVTX vertex detector, which is essential for the open heavy-flavor program. We are also encouraged by the progress in the detector development and simulations in sPHENIX. The PAC was pleased to see that the sPHENIX detector may also serve, after suitable upgrades, as a very capable EIC detector.

The PAC congratulates the Low Energy RHIC electron Cooling (LEReC) group and the CA-D for recent progress in commissioning of the electron beam for the LEReC cooler and for bringing LEReC to its current state with use of state of the art methods and technologies. It will be the first RF-based electron cooler with bunched beams for collider operation. The PAC considers the commissioning and successful operation of LEReC as the highest priority in 2019 and 2020 for CA-D and RHIC. This is critical for operation of RHIC in the 7.7 GeV collider mode and essential for accomplishing the BES-II program. The PAC was presented a beam use request for a proof-of-principle experiment for Advanced Coherent electron Cooling (ACeC) in Run 20. If successful, the proposed ACeC could provide strong hadron cooling for a future EIC. The goals for the current tests, which were to conclude shortly after our meeting, are to reliably imprint a RHIC ion-beam signature into the electron beam by establishing a transverse overlap of the two beams and to observe CeC cooling of the ion beam. The ACeC team is to be congratulated for its progress and encouraged to continue development of ACeC techniques to the extent CeC becomes a viable candidate for use in an EIC. We look forward to hearing the results of the Run 18 tests and will consider a proposal for ACeC tests during Run 20 at our meeting next year.

2. Beam Use Recommendations

The PAC recommends for Run 19:

- Commissioning of LEReC for beams that yield Au+Au collisions with center-of-mass energy $\sqrt{s_{NN}}$ = 7.7 GeV and, if possible, also for beams that yield Au+Au collisions with $\sqrt{s_{NN}}$ = 9.1 GeV.

- The highest priority for data acquisition in Run 19 is Au+Au collider runs at $\sqrt{s_{NN}}$ = 19.6 and 14.5 GeV accumulating at least 400M and 300M minimum bias events, respectively. This will begin the BES II program by acquiring the full data sets needed for all analyses proposed at these two highest BES energies, where LEReC is not needed.

- The next priority for Run 19 is acquiring at least 100M events in fixed-target Au+Au collisions with $\sqrt{s_{NN}}$ = 3.9, 4.5 and 7.7 GeV, beginning the fixed-target component of the BES II program, thus extending its reach to lower energies and higher baryon density. The 7.7 GeV data set will later be particularly important, as it will allow direct comparison of measurements made in fixed-target runs and collider runs at the same $\sqrt{s_{NN}}$.

The PAC recommends for Run 20 and (part of) Run 21:

- LEReC commissioning.
- The first priority for data acquisition in Run 20 and Run 21 is Au+Au collider runs with $\sqrt{s_{NN}}$ = 7.7, 9.1 and 11.5 GeV with a goal of accumulating at least 100M, 160M and 230M minimum bias events at these three energies, respectively. This program requires LEReC. Together with the data sets from Run 19, these data will enable analyses that will address the principal scientific goals of the BES II program.
- The second priority for Run 20 and 21 is acquiring at least 100M events in fixed-target Au+Au collisions at $\sqrt{s_{NN}}$ = 3.0, 3.2, 3.5, 5.2 and 6.2 GeV, completing the fixed-target component of the BES II program and extending its reach to lower collision energies and higher baryon densities.

3. The Beam Use Request

The plan for the Beam Energy Scan (BES) II program, as proposed to the PAC by STAR, constitutes a major scientific opportunity. It proposes the use of heavy-ion collisions at RHIC to provide a definitive survey of the phase diagram of QCD, building upon the exploratory phase of the Beam Energy Scan program (BES I) conducted in 2010-2014. Experimental data indicate that a near baryon-free quark gluon plasma with low baryon doping (low excess of quarks over antiquarks, i.e. low baryon chemical potential (μ_B)) is produced in heavy-ion collisions at the top RHIC and LHC energies. Lattice QCD calculations, together with the experimental data, indicate that as this QGP cools and forms hadrons, and that it does so via a continuous crossover. Much less is known about the phase diagram of strongly-interacting matter with larger baryon doping. With QCD the only strongly-interacting theory in our fundamental description of Nature (the Standard Model), mapping the transition region of its phase diagram is a scientific goal of the highest order. In the long term, successfully connecting a quantitative, empirical understanding of its phases and the transitions between phases to theoretical predictions obtained from the QCD Lagrangian could have ramifications in how we understand phases of strongly-coupled matter in many other contexts.

Lattice calculations of the properties of QCD matter with substantial baryon chemical potential μ_B are either indirect, or very challenging, or both. It is thought that the crossover may become a first-order phase transition above some critical point, but there is at present no calculation that can tell us reliably whether such a critical point exists and, if so, at what μ_B it is located. Experimental discovery of a first-order phase transition or a critical point on the QCD phase diagram would be a landmark achievement. The first step in this program should be a quantitative study of the crossover region of the phase diagram as a function of increasing baryon doping, with quantitative comparison between theory and experiment in a regime where both are more tractable. Success in this, in and of itself, would constitute a major and lasting impact of the RHIC program. Questions that can be addressed include quantitative study of the onset of various signatures of the presence of the QGP and the onset of chiral symmetry restoration, as one traverses the crossover region.

A major effort is now underway to use heavy-ion collisions at RHIC to survey the phase diagram of QCD. Doped QGP is produced by colliding large nuclei at lower energies, where the excess of quarks over antiquarks in the incoming nuclei dominates. The flexibility of the RHIC collider has allowed it to dial its collision energy downward from $\sqrt{s_{NN}}$ = 200 to 7.7 GeV, meaning that RHIC can study collisions that freeze out at points on the phase diagram with μ_B ranging from 20 to 400 MeV. Quoting from the 2015 NSAC Long Range Plan: “RHIC is uniquely positioned in the world to discover a critical point in the QCD phase diagram if nature has put this landmark in the” region of the phase diagram with μ_B up to 400 MeV. With its newly demonstrated capability of taking data in fixed-target collisions, it can also explore regimes with even higher baryon doping, albeit at lower temperatures. “Data from BES I provided qualitative evidence for a reduction in the QGP pressure … in collisions that form QGP not far above the crossover region.” “The experimental search for the QCD critical point hinges on the fact that matter near such a point exhibits well understood critical fluctuations.” The data from BES-I collisions with $\sqrt{s_{NN}}$ between 19.6 and 7.7 GeV on the “collision energy dependence of a fluctuation observable that is particularly sensitive to the critical point” namely the kurtosis of the net-proton multiplicity fluctuations, “are tantalizing … and may be indicative of the presence of a critical point in the phase diagram of QCD, although the uncertainties at present are too large to draw conclusions.” Overall, “the trends and features in BES-I data provide compelling motivation for experimental measurements with higher statistical precision from BES-II.” This is the program that STAR has proposed to begin in Run 19. The PAC looks forward to this program with great anticipation, and finds the proposal for Runs 19 and 20 exciting and compelling.

The PAC looks forward with considerable anticipation to the first year of the BES II program in Run 19. BES II was identified as a high priority in the 2015 NSAC Long Range Plan. The plan for Run 19, as proposed to the PAC by STAR, will begin the exploration of the phase diagram of QCD that is the purpose of the BES II program by making definitive measurements at $\sqrt{s_{NN}}$ = 19.6 GeV and 14.5 GeV. Beginning the BES II program with these higher BES energies is well-motivated: it will allow the simultaneous commissioning of the low energy cooling that is critical to completing the program. In the following two Runs, with the low energy cooling commissioned and operating, RHIC will be positioned to make flagship measurements that will complete the exploration promised in the Long Range Plan, and that will give RHIC the opportunity to find a critical point in the QCD phase diagram, if there is one in the region with baryon chemical potential up to 400 MeV.

The PAC commends STAR for its pilot fixed-target measurements in Run 18. This fixed-target program can extend the Beam Energy Scan to lower collision energies, thus extending the exploration of the QCD phase diagram to even higher baryon doping, albeit at lower temperatures. With the first physics run in fixed-target mode completed successfully in Run 18, the PAC is fully supportive of the proposed plans for fixed-target runs (interleaved in Runs 19, 20 and 21 as described below) yielding at least 100 million events at eight center-of-mass energies ranging from $\sqrt{s_{NN}}$ = 3.0 to 7.7 GeV as a strongly motivated second priority. Including the highest of these energies is important as it will allow cross-checking the new and challenging fixed-target measurements with the now well-developed collider analyses at the same $\sqrt{s_{NN}}$.

3.1 RHIC Run 19

The PAC recommends for Run 19:

- Commissioning of LEReC for beams that yield Au+Au collisions with $\sqrt{s_{NN}}$ = 7.7 GeV and, if possible, also for beams that yield Au+Au collisions with $\sqrt{s_{NN}}$ = 9.1 GeV.
- The highest priority for data acquisition in Run 19 is Au+Au collider runs at $\sqrt{s_{NN}}$ = 19.6 and 14.5 GeV accumulating at least 400M and 300M minimum bias events respectively. This will begin the BES II program by acquiring the full data sets needed for all analyses proposed at these two highest BES energies, where LEReC is not needed.
- The next priority for Run 19 is acquiring at least 100M events in fixed-target Au+Au collisions with $\sqrt{s_{NN}}$ = 3.9, 4.5 and 7.7 GeV, beginning the fixed-target component of the BES II program, thus extending its reach to lower energies and higher baryon density. The 7.7 GeV data set will later be particularly important, as it will allow direct comparison of measurements made in fixed-target runs and collider runs at the same $\sqrt{s_{NN}}$.

DISCUSSION OF RHIC RUN 19

Keeping in mind that the highest scientific priority within the BES II program is a collider run that collects at least 100M minimum bias Au+Au collisions at $\sqrt{s_{NN}}$ =7.7 GeV and that this requires LEReC to be working well. Therefore, a high priority for Run 19 is the successful commissioning of LEReC for beams at this energy. If possible, it should also be commissioned at the energy corresponding to $\sqrt{s_{NN}}$ =9.1 GeV during Run 19.

The first priority for data acquisition in Run 19 is collider runs at $\sqrt{s_{NN}}$ =19.6 and 14.5 GeV with a goal of accumulating at least 400M and 300M minimum bias events at these two energies, respectively. These are the highest collision energies in the BES II program, and as such are the energies where the luminosity enhancement provided by LEReC is not necessary. These are thus the energies at which definitive measurements with strong potential for scientific impact can be made in Run 19. For example, measurements made at $\sqrt{s_{NN}}$ =19.6 GeV with much lower statistics during BES I indicate that the net-proton kurtosis is below its Poisson value at this collision energy, and the BES II data set will turn this into a definitive measurement. If data taken later at $\sqrt{s_{NN}}$ =7.7 GeV shows that this observable is well above its Poisson value at that energy, as suggested but not demonstrated by BES I data, the 19.6 GeV measurements made definitively during Run 19 could turn out to be harbingers of a critical point.

This sequence of operations allows the simultaneous (same Run year) acquisition of data at the two highest BES energies and commissioning of the low energy electron cooling, critical to the lower energy measurements at $\sqrt{s_{NN}}$ = 7.7 and 9.1 GeV and also important at 11.5 GeV. The PAC concurs that collider measurements at $\sqrt{s_{NN}}$ =19.6 and 14.5 GeV are the *top priority* for Run 19. In subsequent years, with the low energy cooling commissioned and operating, RHIC will be positioned to make the flagship measurements that will complete the BES II program.

The highly successful data taking during Run 18 in fixed-target collisions with $\sqrt{s_{NN}}$ =3.85 GeV provides strong motivation for beginning the “Fixed Target” component of the BES II program during Run 19. This should include acquiring at least 100M events in fixed-target collisions at $\sqrt{s_{NN}}$ =4.5 and 3.9 GeV, where the beam energy corresponds to those used in the collider running above. It is also a priority for Run 19 to collect at least 100M events in fixed-target collisions at $\sqrt{s_{NN}}$ =7.7 GeV. The comparison between measurements made with this fixed-target data and with collider data taken at the same $\sqrt{s_{NN}}$ will be very important. Making the same measurements with very different systematics offers the opportunity to gain confidence in these results, and in measurements made at lower fixed-target energies, and hence the opportunity to enhance the lasting scientific impact of the BES II program. STAR and BNL should assess the potential value of a few extra days of fixed-target running at $\sqrt{s_{NN}}$ =7.7 GeV, in particular to acquire a larger data set allowing for more differential comparisons with data from the future collider run and measurement of the full rapidity dependence of various observables using data from the fixed-target and collider runs in concert.

3.2 RHIC Runs 20 and 21

The PAC recommends for Run 20 and (part of) Run 21:

- LEReC commissioning.
- The first priority for data acquisition in Run 20 and 21 is Au+Au collider runs with $\sqrt{s_{NN}}$ = 7.7, 9.1 and 11.5 GeV with a goal of accumulating at least 100M, 160M and 230M minimum bias events at these three energies, respectively. This program requires LEReC. Together with the data sets from Run 19, these data will enable analyses that will address the principal scientific goals of the BES II program.
- The second priority for Run 20 and 21 is acquiring at least 100M events in fixed-target Au+Au collisions at $\sqrt{s_{NN}}$ = 3.0, 3.2, 3.5, 5.2 and 6.2 GeV, completing the fixed-target component of the BES II program and extending its reach to lower collision energies and higher baryon densities.

DISCUSSION OF RHIC RUNS 20 and 21

The first priority for data acquisition in Run 20 and beyond is Au+Au collider runs with $\sqrt{s_{NN}}$ =7.7, 9.1 and 11.5 GeV with a goal of accumulating at least 100M, 160M and 230M minimum bias events at these three energies, respectively. Achieving these goals is the highest priority for Run 20 and for a portion of Run 21. Optimizing the sequence of these energies during Run 20 should wait until we know the outcomes of LEReC commissioning in Run 19. First of all, this will determine how much time for LEReC commissioning is required during Run 20. Second of all, this will determine during which run or runs the 7.7 GeV data should be taken. Acquiring data at 7.7 GeV should be the top priority as soon as LEReC is working well enough to make it possible to acquire these collisions at the desired rate. [In fact, if LEReC commissioning in Run 19 is so successful that 7.7 GeV running with the desired rate is possible during Run 19, a fraction of this run could be performed in Run 19 instead of the 14.5 GeV run recommended above, postponing the 14.5 GeV run to Run 20.]

The second priority for data acquisition during the BES program is acquiring 100M events in fixed-target collisions at a sequence of energies: $\sqrt{s_{NN}}$ =3.0, 3.2, 3.5, 3.9, 4.5, 5.2, 6.2 and 7.7 GeV. Anticipating that three of these data sets will have been collected in Run 19, as many of the remaining data sets as possible should be taken in Run 20. The only energy or energies that should be left for Run 21 are those corresponding to collider energies that will be run in Run 21.

We end our discussion of the beam use request with two further remarks:

Our discussions with STAR suggest that 100M events at $\sqrt{s_{NN}}$ = 7.7 GeV might be just barely enough to permit measurements of the net-proton kurtosis in two rapidity bins, something that the iTPC upgrade makes possible. Doing so has the potential to add to the scientific impact of these measurements. This provides a strong motivation for expanding the size of this data set, say by 50%, if it turns out that LEReC works so well that this becomes feasible.

Recent discussions have led to the suggestion of introducing a light nucleus target (such as Beryllium) within the beam pipe so that STAR could study Au+Light-Nucleus collisions at $\sqrt{s_{NN}}$ =7.7GeV, allowing for experimental measurement of the event-by-event fluctuations in proton stopping in collisions at this energy. We recommend a serious assessment of the feasibility of this proposal and in particular confirmation that it can be done without adverse impacts on the higher priority program elements. If it is possible to do this, the consequence would be a definitive experimental measurement of what would otherwise be a source of systematic uncertainty.

4. RHIC Data and Physics Analysis

The PAC commends both the PHENIX and the STAR collaborations for their outstanding scientific productivity in terms of the numbers of published papers and their high and lasting impact in the nuclear physics community. We also congratulate them for their continued production of PhDs and the notable recognition that various members of the collaborations have received. The heavy-ion highlights from last year include STAR's discovery of global Lambda polarization, which provides evidence for the formation of the most vortical fluid (Nature 548 (2017) 62), and the PHENIX evidence for collectivity in d+Au collisions down to the lowest energy measured in small systems at RHIC (Phys. Rev. Lett. 120, 062302 (2018)). In the spin and cold QCD program, STAR reported the first measurements of transverse single-spin asymmetries for inclusive jets and charged pions and the observation of nonzero Collins asymmetries in polarized-proton collisions (Phys. Rev. D 97 (2018) 032004, Phys. Lett. B 780 (2017) 332); the PHENIX collaboration reported the discovery of a surprisingly strong nuclear dependence of the transverse single-spin asymmetry of very forward neutrons produced in p+Al and p+Au collisions (Phys. Rev. Lett. 120, 022001 (2018)). In addition to the published papers, both collaborations released a large number of new results in connection with the Quark Matter conference in Venice, Italy in May 2018. These include measurements of the nuclear modifications and flow of heavy-flavor particles, bottomonia suppression, further studies of dijet imbalance, a new non-zero measurement of global Λ polarization at top RHIC energy and a discovery of a quadrupole structure of the polarization along the beam direction, the first measurement of the Drell-Yan cross section in p+p collisions at RHIC, observation of scaling in the low-p_T direct-photon yield in various collision systems and indication of a thermal source in small systems (p/d+Au), and a complete set of triangular and elliptic flow measurements in p/d/^{3}He+Au collisions that provide evidence of the smallest QGP droplets.

Data analysis relies on efficient data production as well as data formats that allow for efficient access to the data. The PAC is pleased to see that the STAR collaboration successfully utilized the NERSC/Cori resources for their embedding and real data production, and has implemented the compact picoDST format for all new analyses. This has allowed STAR to catch up with the production of the recent high-volume data. PHENIX maintains a highly efficient data access and analysis scheme that continues to pay off with high publication output, despite the fact that the collaboration stopped taking data two years ago. There has been a delay in the production of the recent large-volume Au+Au data sets in PHENIX that could benefit from dedicated resources from the collaboration and the laboratory.

4.1 PHENIX

The PAC congratulates PHENIX on their analysis and reporting of several high-profile results. The continuing high publication rate, despite the decommissioning of the detector, is impressive. The first measurement of the nuclear dependence in the left-right asymmetry, A_N, from polarized p+A collisions challenges the field to explain the strong dependence on target mass. This work has been highlighted on the DOE Office of Science web site. Drell-Yan cross-sections, which provide a critical test of perturbative QCD have been measured for the first time at RHIC and the results were submitted for publication. In heavy-ion collisions, PHENIX has significantly improved our understanding of the limits of perfect fluid behavior by the measurements of the transverse momentum, rapidity, and multiplicity dependence of collective flow in d+Au collisions down to $\sqrt{s_{NN}}$ = 19.6 GeV. At the top RHIC energy, PHENIX has now analyzed a suite of observables characterizing collective flow in small systems, and has submitted a capstone paper to Nature Physics summarizing these remarkable observation of strong flow. By analyzing and comparing collisions of p, d, and ^{3}He beams, PHENIX has been able to demonstrate that the large flow observed in small systems can indeed be associated with the initial spatial anisotropy. PHENIX has also completed and submitted for publication a comprehensive set of thermal photon measurements covering multiple collision systems, which significantly improves our understanding of the thermal properties of the medium produced in the collisions.

The PAC looks forward to PHENIX completing a number of tantalizing analyses in the next one or two years. These include the measurements of the flow coefficients of electrons from open-charm and open-bottom, the correlations of direct photons with hadrons, R_{pA} of forward particles, A_N of neutral pions, and the measurement of $dN_{ch}/d\eta$ and flow coefficients as a function of pseudorapidity in several small systems. The PAC was pleased to see that PHENIX plans to continue their efforts to attract students and postdocs to analyze recent data, and to host a second PHENIX School. Part of the PHENIX detector was damaged prior to the 2016 run, due to a beam incident, which requires a revision of the alignment procedure for the VTX detector. The PAC was concerned that the calibration has not yet taken place.

The PAC has the following recommendations regarding the analysis of existing PHENIX data:

- The PAC strongly encourages PHENIX to implement its stated plan to host a Second PHENIX School, and to recruit students and postdocs in order to exploit fully the wealth of PHENIX data taken in the last few years.

- The PAC is concerned with the delay in the calibration and processing of the Run-16 data from PHENIX. Collaboration and Laboratory management need to procure the resources and effort to accomplish this as soon as possible.

4.2 STAR

The STAR collaboration has maintained high productivity, publishing 11 papers since the last PAC meeting and submitting 10 other papers for publication. In addition, many new preliminary results were released. The PAC looks forward to seeing those finalized. From BES I, we are pleased to see progress on understanding the corrections for the detector response in the net-proton cumulant measurement. We strongly encourage the STAR collaboration to pursue the completion of these studies with the highest priority to enable the timely publication of the important BES-I results.

The data taking in Run 18 is going well, with STAR exceeding its goal in accumulated data in the isobar run, but collecting a somewhat smaller sample in the 27 GeV run than anticipated. The blind analyses of the isobar data has commenced. The PAC encourages the collaboration to continue placing a high priority on this data analysis, as it is expected to provide a definitive measurement of the CME effect. With regard to the 27 GeV run, the PAC suggests that the collaboration reviews the data collection in this run with a view to possible further optimization of run planning during the upcoming BES II.

The STAR TPC upgrades, including the iTPC project, are critical for the BES II program. The tight upgrade schedule must be followed closely without delays. The first iTPC sector was installed and successfully tested during the 2018 run, with full installation planned for completion by the end of February 2019. The PAC congratulates the iTPC team for its outstanding success.

The STAR event-plane detector was installed and successfully commissioned during Run18. The PAC congratulates the EPD team for delivering this detector on schedule and for its excellent performance.

The STAR eTOF detector was partially installed during Run 18 and excellent timing resolution performance (σ_t = 59 ps) has been demonstrated. The completed detector will provide a critical expansion of the identified particle capabilities of STAR in the forward rapidity region. The PAC congratulates the eTOF team for their achievement.

Recommendations:

- The PAC strongly encourages the STAR collaboration to complete with the highest priority its detector response corrections in the net-proton cumulant measurement to enable the timely publication of these important BES-I results.

- The STAR TPC upgrades, including the iTPC project, are critical for the BES II program. The tight upgrade schedule must be followed closely without delays.

- The PAC encourages the collaboration to continue placing a high priority on the blind analysis of the isobar data, as it is expected to provide a definitive measurement of the CME effect.

- The analysis of the 2017 STAR data for transverse polarization should be given high priority, a statement that reiterates the PAC recommendation from last year.

The PAC suggests that the collaboration review the data collection in the 27 GeV run with a view to possible further optimization of run planning in the upcoming BES II.

4.3 RHICf with STAR: 510 GeV p+p with Radial Polarization

The PAC heard the presentation on the Run17 data-taking and data-analysis status of RHICf. Using two compact calorimeters placed at very forward angles 18 meters from the STAR IP, 110M events were collected during three days with 510 GeV p+p collisions with radial polarization. By moving the calorimeter vertically, the measurement had gapless coverage of neutral particles (γ, π^0, neutron) produced at very forward angles. Roughly 80% of the data were collected in coincidence with the STAR detector.

The primary physics goals are (i) to test the $\sqrt{s}$-scaling of hadronic cross sections for cosmic-ray air showers; (ii) to measure single spin asymmetry (A_N) for neutrons and π^0 at forward angles, which was first discovered in the RHIC IP12 experiment, later by PHENIX and a p_T scaling of A_N was suggested by the data. The data analysis of RHICf is progressing well and a clear π^0 peak was observed in the two γ invariant mass distribution. First release of the π^0 A_N result is expected in a few months.

The PAC congratulates the RHICf Collaboration for its successful data-taking and progress in data-analysis. In addition to the π^0 A_N result, the PAC looks forward to the results on neutron A_N and the shower cross sections. Analysis of the STAR data collected in coincidence with RHICf would also be of considerable interest.

5. Forward Physics at STAR

STAR presented prospects for future STAR running, i.e. after BES II, for which the most interesting option is a focus on forward physics made possible by a forward upgrade covering rapidities up to 4.2 and which requires $5.3 M worth of investments. This upgrade would significantly enlarge the kinematic range accessible by STAR and would thus allow to study novel reaction channels, in particular diffractive reactions and Ultra Peripheral Collisions (UPCs). These reaction classes are equally interesting for hadron structure and QGP physics. An example for the latter is QGP vorticity and Lambda polarization. In a peripheral heavy-ion collision many Lambdas will be produced in the forward direction and to understand the process of vorticity generation at a microscopic level it is also important to determine their degree of polarization. One interesting new reaction channel for hadron structure physics is diffractive dijet production, which should allow one to constrain quantum phase space distributions (Wigner distributions). Similar reactions can also be studied in e+p and e+A collisions and will certainly figure prominently in any future EIC program. Early results from forward physics by STAR in p+p, p+A and A+A would therefore help to sharpen the EIC physics case. The PAC commends the STAR collaboration for developing and formulating this attractive option.

To proceed along these lines, the PAC would need to see at next year's PAC meeting a concrete proposal for p+p running with a forward upgrade in place as a part of Run 21, linking numbers of weeks of running to attainable precision for some key observables and including funding and workforce planning, so that the PAC can assess the feasibility and merits of the proposed program. We understand that another necessary condition for this program to proceed is that, much sooner than this time next year, members of the STAR collaboration need to make proposals to their funding agencies for various components of the proposed forward upgrade. At present we expect that if a p+p run takes place during a part of Run 21 it would pioneer various measurements. The long term impact of such measurements depends on the precision that can be attained. The PAC expects that realizing a new, comprehensive, high-precision forward physics program by STAR will require several years of operation, beginning with a part of Run 21 and continuing with running in 2023 and beyond, in coordination with sPHENIX operation and EIC development. Integrating all these pieces, the PAC concludes that for such a program to proceed as a component of Run 21 it is imperative that BNL management make a clear and timely decision concerning a roadmap for possible STAR operation in 2023 and beyond.

On a related issue, the PAC stresses again the importance of a timely analysis of the 2017 data with transverse polarization, which should be given high priority. These results will be very important for the planning of the EIC physics program. Also, this analysis could set the pace for the data analysis of any possible future STAR running after BES II and thus would allow one to judge the extent to which the projected measurements influence EIC planning.

Recommendations:

- A decision by the BNL management should be reached as soon as possible (by the end of the year) on whether continued STAR running is possible in 2023 and beyond and, if so, under which conditions. If the answer were negative it would be good to know how much of the proposed forward program could be realized by sPHENIX or an upgraded sPHENIX.

6. Accessing EIC Physics with a Detector Based on sPHENIX

In response to a charge from the BNL ALD in April 2018, an "EIC Detector Study Group" was recently formed to perform an up-to-date study of the physics capability for an EIC detector based on sPHENIX. The previous study resulted in a Letter of Intent (LoI) in 2014. (arXiv:1402.1209). It is timely to update this LoI, given the recent developments on the plan for a US-based EIC as well as the recent progress in sPHENIX. The goal of the Study Group is to produce a revised LoI by September 30, 2018. The PAC heard the presentation on the current status and future plan from this EIC Detector Study Group. Despite the short duration since the formation of this Group, good progress has been made. Several results shown in the 2014 LoI have now been updated using the latest information on EIC beam energies and the sPHENIX detector configurations. In particular, results of the GEANT simulations for the Q^2 and x resolution in inclusive DIS and the track momentum resolution at mid- and forward- rapidity regions have been obtained. The PAC is pleased to see that the sPHENIX detector may also serve, after suitable upgrades, as a very capable EIC detector.

The PAC commends the Study Group for their effort and the good progress in this important task. With the completion of the recent DOE CD-1/3a review on sPHENIX, it is anticipated that more collaborators will join this effort. The Study Group should take this opportunity not only to update the results presented in the previous LoI, but also to include new results or ideas to effectively illustrate the physics impact of the sPHENIX-based detector. For example, in addition to presenting the detector kinematic acceptance and various performances, it would be extremely useful to pick several EIC flagship measurements, such as TMDs, sea-quark and gluon distributions in nucleon and nuclei, and work out the expected sensitivities using the sPHENIX based detector.

The PAC recognizes that the sPHENIX based EIC detector, with the exception of the additional detectors covering the negative rapidity region for electron detection, is quite similar to the sPHENIX detector with a forward upgrade presented to the PAC in 2017. A detailed study of the performance and physics capability of the sPHENIX based EIC detector might further sharpen the physics case for future RHIC running with forward upgrades.

7. sPHENIX

The sPHENIX Collaboration plans to perform precision measurements of jets, jet correlations and quarkonia. Measurements of open heavy-flavor hadrons are still being considered. This, together with results from the LHC and LHC-Fixed-Target experiments at CERN, should uncover the quasi-particle nature of the degrees of freedom in the QGP as well as help to determine the temperature dependence of transport coefficients.

The sPHENIX detector makes use of the superconducting BaBar magnet and in its present design includes a TPC and silicon strip detectors for tracking, as well as a hadronic and electromagnetic calorimeter (EMCal). The first sPHENIX run is planned for 2023. The sPHENIX Collaboration plans for installation to take place in 2022, with commissioning and the first sPHENIX physics data taking in 2023.

The PAC congratulates the sPHENIX Collaboration for their successful CD1/3A review, which is an important milestone towards the timely completion of the project. The committee is encouraged by the progress of the detector development and simulations, which indicate excellent tracking efficiency and momentum resolution. This performance will enable the spectroscopy of Upsilon states with a quality comparable to the CMS measurements.

Due to budget constraints the EMCal has been descoped from an initial acceptance of $|\eta|<1.1$ to $|\eta|<0.85$, a loss of 25%. This will severely impact the detection capability for photon-jet correlations, which are considered to be the golden channel for the determination of the transport properties of the QGP. We note that given the five-year run plan presented by sPHENIX the 25% loss in acceptance corresponds in statistics to one full year of running at RHIC. We also note that the acceptance of the EMCal cannot be extended as a future upgrade. Therefore, possible funds to restore the full EMCal need to be located or allocated in a timely fashion.

A possible upgrade to include a MAPS-based inner tracking detector (MVTX) based on the ALICE inner tracker technology is presently under discussion. This upgrade would enable the detection of open heavy-flavor hadrons and enhance the capabilities for quarkonium detection as well as jet measurements, especially at high transverse momenta. Given that sPHENIX is destined to be one of the premier detectors in heavy-ion physics in the next decade, this upgrade will very significantly enrich physics results of sPHENIX.

The committee was pleased to see that the sPHENIX detector may serve, after suitable upgrades, as a very capable EIC detector and we encourage the collaboration to continue the exploration and refinement of these studies.

- We strongly encourage the Laboratory management and the sPHENIX Collaboration to explore all possible means to construct the originally proposed EMCal with the acceptance $|\eta|<1.1$, rather than the descoped/reduced version.
- We strongly encourage the Laboratory management and the sPHENIX Collaboration to aggressively pursue all options to construct the MVTX detector upgrade so that it is available at the start of the sPHENIX operation.

8. LEReC

The PAC congratulates the Low Energy RHIC electron Cooling (LEReC) group and the CA-D for recent progress in commissioning of the electron beam for the LEReC cooler and for bringing LEReC to its current state with use of state of the art methods and technologies. It will be the first RF-based electron cooler with bunched beams for collider operation. The electron accelerator has been installed and the PAC heard that the accelerator commissioning was going well. The next goal (September 2018) is to achieve high-current operation of the electron beam with parameters that will accomplish cooling. The transition to operations and cooling will commence in Run 19 and will require stable electron and Au beams in the cooler. Eight weeks of RHIC beam time is requested for LEReC commissioning in Run 19 and seven additional weeks after that.

The PAC considers the commissioning and successful operation of LEReC as the highest priority in 2019 and 2020 for CA-D and RHIC. This is critical for operation of RHIC in the 7.7 GeV collider mode and essential for accomplishing the BES-II program. Therefore, highest priority for the 2019

RHIC run will be given to the commissioning of LEReC for beams that yield Au+Au collisions at $\sqrt{s_{NN}}$ = 7.7 GeV and, once successful, those corresponding to $\sqrt{s_{NN}}$ =9.1 GeV at the proposed BES II luminosities. We hope that this can be completed in six weeks, as envisioned in the STAR Beam Use Request. Successful completion and operation of LEReC is required to be able to complete the proposed BES II program in Runs 20 and 21 at $\sqrt{s_{NN}}$ = 7.7, 9.1 and 11.5 GeV. To fulfill the commissioning requirements of LEReC and the integral luminosity requirements of the BES II physics program, the CA-D has determined that RHIC operation in 2021 will be necessary.

- The LEReC group and CA-D are urged to pursue the commissioning and operation of LEReC with the highest priority, as it is essential for the proposed BES II physics program.

9. ACeC Proof of Principle

The PAC was presented a beam use request for a proof-of-principle experiment for Advanced Coherent electron Cooling (ACeC) in Run 20. If successful, the proposed ACeC could provide strong hadron cooling for a future EIC. This or some yet-undetermined type of beam cooling must be developed to provide for EIC luminosities possibly as high as 10^{34} $cm^{-2}s^{-1}$ for the EIC. The goal is to show that a CeC experiment can exhibit stochastic cooling in the THz (and PHz) frequency range. A superconducting 1.2MV 112MHz quarter-wave photoelectron gun has been commissioned in the setup. The experiment at this time plans to use half or more of the remaining 10 ½ days of RHIC Run 18 beam time for tests. The Run 18 goals are to be able to reliably imprint the ion-beam signature into the electron beam by establishing a transverse overlap of the two beams and to observe CeC cooling of the ion beam. The ACeC request for future RHIC running is for one week of beam time in Run 20. The PAC would like to request a status report of progress on the ACeC project sometime this year after conclusions can be drawn from use of the Run 18 beam time, and will consider a proposal for ACeC tests during Run 20 at our meeting next year. The ACeC team is to be congratulated for its progress and encouraged to continue their development of ACeC techniques to the extent CeC becomes a viable candidate for use in an EIC.

- The PAC would like to request a status report of progress on the ACeC project sometime this year after conclusions can be drawn from use of the Run 18 beam time.

10. PAC Recommendations

- **STAR Analysis**:
  The PAC considers three analysis tasks to be of crucial importance to maximize the physics output of STAR and should therefore be given highest priority.

→ Completion of STAR's detector response corrections in the net-proton cumulant measurement to enable the timely publication of these important BES-I results.

→ Analysis of the 2017 STAR data for transverse polarization. This reiterates the PAC recommendation from last year.

→ Completion of the blind analysis of the STAR isobar data, which is expected to provide a definitive measurement of the CME effect.

- **PHENIX Analysis:**

→ The PAC is concerned with the delay in the calibration and processing of the Run-16 data from PHENIX. Collaboration and Laboratory management are encouraged to procure the resources and effort to accomplish this as soon as possible.

→ The PAC strongly encourages PHENIX to implement its stated plan to host a Second PHENIX School, and to recruit students and postdocs in order to exploit fully the wealth of PHENIX data taken prior to shutdown

- **STAR Preparations for BES II:**

→ The STAR TPC upgrades, including the iTPC project, are critical for the BES II program. The tight upgrade schedule must be followed closely without delays.

→ The PAC suggests that STAR review the data collection in the 27 GeV run with a view to possible further optimization of run planning in the upcoming BES II.

- **LEReC group and CA-D:**

→ The PAC urges the LEReC group and CA-D to pursue the commissioning and operation of LEReC with the highest priority, as it is essential for the proposed BES II physics program.

- **ACeC Proof of Principle and Developments:**

→ The PAC would like to request a status report of progress on the ACeC project sometime this year after conclusions can be drawn from use of the Run 18 beam time.

- **sPHENIX and BNL Laboratory Management:**

→ We strongly encourage the sPHENIX Collaboration and the Laboratory management to explore all possible means to construct the originally proposed EMCal with the acceptance $|\eta|<1.1$, rather than the descoped/reduced version.

→ We strongly encourage the sPHENIX Collaboration and the Laboratory management to aggressively pursue all options to construct the MVTX detector upgrade so that it is available at the start of the sPHENIX operation.

- **BNL Laboratory Management:**

→ A decision by the Associate Laboratory Director should be reached as soon as possible (by the end of the year) on whether continued STAR running is possible and if so, under which conditions. If the answer were negative it would be good to know how much of the proposed forward program could be realized by sPHENIX or an upgraded sPHENIX.

2018 BNL Nuclear and Particle Physics Program Advisory Committee:

Marek Gazdzicki, CERN, marek.gazdzicki@cern.ch

John Harris, Yale, john.harris@yale.edu (chair)

Huan Huang, UCLA, huang@physics.ucla.edu

Volker Koch, LBNL, vkoch@lbl.gov

Jen-Chieh Peng, UIUC, jcpeng@illinois.edu

Scott Pratt, MSU, prattsc@msu.edu

Krishna Rajagopal, MIT, krishna@mit.edu

Andreas Schafer, Regensburg, andreas.schaefer@physik.uni-r-de

Mikhail Stephanov, UIC, misha@uic.edu

Julia Velkovska, Vanderbilt, julia.velkovska@vanderbilt.edu