

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

June 22 - 23, 2021

1. Executive Summary

The Program Advisory Committee (PAC) convened remotely on June 22 – 23, 2021, to evaluate the STAR Beam Use Request for Runs 22 – 25, sPHENIX Beam Use Request for Runs 23 – 25, and the CeC Beam Use Request for Run 22. The PAC also heard presentations by STAR on the status of the ongoing analyses in its research program, by PHENIX on the status of its data analysis and its ongoing efforts for data preservation, by sPHENIX on its progress in construction, installation and schedule, and from the Task Force on small systems flow reported by PHENIX and STAR.

The PAC thanks the collaborations for their hard work, presentations, and input as well as cooperation in responding to questions. Input from the C-AD and BNL NP-HEP managements are acknowledged and were helpful in the PAC's considerations. We commend highly the C-AD and STAR for the extremely successful operation and data-taking in the BES-II program, which is nearing completion. The results for this running period have far exceeded any expectations of the PAC from the previous review in September 2020. We recognize the extra effort and hardship associated with restrictions due to COVID. The performance of RHIC has been stellar.

STAR is congratulated for its successful operation and the excellent performance of the iTPC, EPD and eTOF, which extends the STAR acceptance in the BES-II Run Program. The PAC recognizes and commends STAR on its impressive progress in the construction, installation and commissioning of the STAR Forward Upgrade. The Forward Calorimeter System has been installed and initial commissioning completed and is ready for data taking. The PAC commends both the PHENIX and the STAR collaborations for their outstanding scientific productivity, for delivering stimulating discoveries and high-impact publications, and for their continued production of PhDs.

As stated in the 2015 NSAC LRP the construction and operation of sPHENIX and completion of the STAR BES II are the highest priorities. STAR is currently on the verge of accomplishing its BES II goals for data-taking, which is an enormous accomplishment that must be acknowledged throughout the nuclear physics community. sPHENIX construction, installation and operation to accomplish its science goals is now the overarching priority for RHIC for the next 4 – 5 years. This is of utmost importance and must be kept in mind for any decisions regarding RHIC operations. sPHENIX is on track to accomplish its science priorities assuming the run times they have proposed. sPHENIX is to be congratulated for its progress on the sPHENIX detector project, installation and commissioning plan and proposal for commissioning, data-taking and physics in 2023 - 2025. This places sPHENIX in a good position to accomplish its physics goals.

The PAC thanks the Small Systems Task Force for their comprehensive and informative report. The report recommends that additional measurements with the upgraded STAR detector and sPHENIX are needed, not only to address the present discrepancy in the measurements but also to gain important insights into flow phenomena in heavy ion collisions. The PAC therefore enthusiastically supports the STAR proposal to include d+Au running this year if at all possible.

The CeC experiment appears on the verge of demonstrating longitudinal cooling within a few more shifts of running. This would be a significant achievement, realizing a long-anticipated goal of this experiment and its importance for the design of the EIC. We encourage BNL to find ways to fit in such running, as well as to allow for a d+Au run in the remainder of Run 21.

Guidance from the BNL-ALD for Runs 22 through 25 was presented to the collaborations for the Beam Use Requests and consisted of the following numbers of expected cryo-weeks for each run. The first number is the minimal run duration in weeks expected for RHIC in each year and the second is an optimal run scenario:

2022: 18 (20)

2023: 20 (28)

2024: 20 (28)

2025: 20 (28)

The PAC finds that a reduction in Run 22 from 20 to 18 weeks would result in at least a 15% reduction of the luminosity and have a very detrimental effect on the prospects of achieving the physics goals of STAR and the CeC.

If Run 23 were only 20 weeks long sPHENIX physics data taking will be reduced by more than a factor of two, due to the need for time to commission the detector. This cost is incommensurate with the budget savings and has a substantial adverse impact to the overall program. Likewise, the STAR program and scientific goals would be substantially compromised if Run 23 were shortened to 20 weeks.

The PAC recognizes that completion of the p+p and Au+Au runs in Runs 24 and 25, respectively, as proposed by sPHENIX are essential to accomplish the overall scientific goals of RHIC in the 2015 NSAC LRP, and will also allow STAR to successfully complete its scientific program. The PAC also recognizes the significant opportunities that can be realized by both sPHENIX and STAR from a p+Au run during Run 24.

The PAC recommends that BNL Management do everything possible to ensure sufficient beam time for sPHENIX to accomplish its physics goals in Runs 23, 24 and 25.

2. The Beam Use Request

2.1 Discussion and Recommendations for RHIC Run 21

We repeat here our highest praise for BNL, C-AD, and STAR for an extraordinarily successful Run 21; it is a remarkable achievement that RHIC and STAR are a day or two away from having completed all the runs that the PAC recommended last year, giving us the opportunity to make a further recommendation for the final period of Run 21, between the conclusion of the current fixed target data taking and the date when BNL plans to begin magnet power system tests, likely July 8. *For this final period of Run 21, the PAC sees the highest scientific priority as being a d+Au run.* With the newly extended rapidity coverage provided by its new detector elements, we anticipate that STAR will be able to use the data from such a d+Au run to yield significant new understanding, and hopefully clarity, on the currently incompletely understood differences between data on v_3 in d+Au collisions taken previously by STAR and PHENIX in non-overlapping regions of rapidity. Questions about the possibility of small droplets of quark-gluon plasma are

of high current scientific interest; with data taken from a d+Au run at the conclusion of Run 21, STAR can shed significant light on questions being debated. STAR will have the best chance of settling some of those questions if it is able to take 200M Min Bias events and 200M 0-10% central events. A data set half this size will still allow STAR to make an impact.

We also understand that the CeC experiment has a chance of demonstrating longitudinal cooling with a few more shifts of running during this final period; this would be a significant achievement, realizing a long-anticipated goal of this experiment. We encourage BNL to find ways to slot such running in, so as to allow for optimizing the d+Au run.

2.2 Discussion and Recommendations for RHIC Run 22

The Run 22 BUR of a transversely polarized pp run at 510 GeV with the STAR Forward Upgrade represents a unique opportunity to address important issues in spin physics and will allow exploration of the regimes of low and high- x physics with unprecedented precision. New results anticipated for Run 22 with the Forward Upgrade can have important impacts on the planning for EIC, as well as on the interpretation of EIC data. *The PAC strongly endorses the STAR Run 22 BUR.*

One of the physics goals for Run 22 is to collect additional data on the transverse single-spin asymmetry of W and Z boson production. STAR presented the eagerly awaited preliminary results on these asymmetries from Run 17. The much-improved statistical accuracy over Run 11 indicates a small asymmetry consistent with zero. These interesting results could place stringent constraints on theoretical models for the QCD evolution of Sivers function. Unfortunately, these results also suggest the difficulty in obtaining a conclusive test for the predicted sign-change of the Sivers function based on the W/Z measurement. Additional W/Z production data from Run 22 certainly would help, but might not be sufficient for resolving the sign-change issue.

Some very recent theoretical predictions on the W/Z asymmetries were presented, although some non-intuitive features for W^+ versus W^- asymmetry of these theoretical predictions were noted by the PAC. It is also unclear how the theoretical prediction for the Z boson asymmetry is significantly larger than the predicted asymmetry for the W bosons. Further interactions between the STAR collaboration and the theorists are encouraged to clarify these issues.

Given the preliminary results on the small asymmetry for W/Z production, the PAC emphasizes the importance for analyzing the Drell-Yan data collected in Run 17, as well as the anticipated new Drell-Yan data to be collected with the STAR Forward Upgrade. A successful extraction of the Drell-Yan events from the potentially large hadronic background could test the sign-change of the Sivers function at a lower Q^2 -scale, it would also have an impact on the future plan to use Drell-Yan in p+A collisions to measure the sea-quark content in nuclei.

Another important goal of Run 22 is to extract new information on proton transversity distributions in the valence quark region, taking advantage of the STAR Forward Upgrade. By extending the coverage to the large- x region, Run 22 can significantly improve the determination of the proton's "tensor charge", corresponding to the first moment of the transversity distributions. To fully realize the potential of this interesting physics goal, it remains to be demonstrated that the hadron-in-jet method advocated by STAR can lead to a reliable extraction of the transversity distributions. Based on the results presented during the PAC meeting, a factor of ~ 2 discrepancy between the theory and data is observed for the data collected for the Runs 12+15 200 GeV data. STAR is encouraged to have further interaction with the theorists to understand the origins and implications of this apparent discrepancy.

The PAC commends STAR for its impressive progress in the construction, installation and commissioning of the STAR Forward Upgrade. The Forward Calorimeter System has been installed, and initial commissioning completed and ready for data taking. The Silicon Tracker installation is well underway. The sTGC module production has been completed and performance tests are continuing. The sTGC Gas system is fully ready to be connected. The DAQ slow control is complete and data monitoring is close to being finalized.

The successful operation of the trackers is essential for achieving the physics goals for Run 22. STAR noted the very tight schedule for installing the sTGC tracker. Since the sTGC is required for determining the charges of hadrons associated with a forward jet, the proposed hadron-in-jet physics for Run 22 depends critically on a timely installation of the sTGC tracker. The PAC encourages continuing strong support from BNL management for the STAR Forward Upgrade to meet the tight schedule.

If Run 22 were to be reduced from 20 to 18 weeks that would result in at least a 15% reduction of the integrated luminosity and have a very detrimental effect on the prospects of achieving all the physics goals. Given that the CeC beam time would additionally reduce the STAR run by 2.6 weeks, this would have further negative effects on the physics programme. C-AD is strongly encouraged to optimize RHIC operations to fulfill the goals of both CeC and STAR.

2.3 Discussion and Recommendations for RHIC Runs 23-25

RHIC is poised to deliver, in Runs 23-25, the culmination of the RHIC scientific program on hard probes. It is unusual to build an entirely new detector for the concluding three years of a 25 year program, but the scientific case for doing so that was made in the 2015 Long Range Plan is sufficiently compelling. The PAC looks forward with great anticipation to the insights into the microscopic structure of the quark-gluon plasma that the sPHENIX detector has been designed to deliver. *The top overall priority in planning for these three runs is to commission the sPHENIX detector and to achieve its scientific program.* The investment that the DOE, BNL, and the collaboration have made in sPHENIX means that these three years should be seen and managed as the first three years of a major, brand new, high impact, experimental effort, even though at the same time they are anticipated to be the last three years of the overall RHIC program. BNL and DOE should do everything possible to provide the running time needed in order for sPHENIX to fulfill the goals of its scientific program, as recommended by the 2015 LRP.

At the same time, we commend the STAR collaboration for having developed a complementary science program that takes advantage of new STAR detector capabilities (detector elements developed for the BES program; the forward upgrades developed for Run 22) that will add further scientific impact during these run years.

2.3.1 Discussion and Recommendations for RHIC Run 23

The PAC strongly supports focusing in Run 23 on sPHENIX commissioning using 200 GeV Au+Au collisions. This is the highest priority and must come first. This should be followed by continued running of 200 GeV Au+Au collisions to begin the sPHENIX scientific program. With a 28-week run, we anticipate that sPHENIX will be able to make enough of a start on its data taking that it will then be able to optimize plans for Runs 24 and 25 so as to deliver the major scientific rewards anticipated since the 2015 LRP, and befitting the investment that so many are making in the sPHENIX program.

Because of the necessity to begin by commissioning the sPHENIX detector, if the run were only 20 weeks long sPHENIX physics data taking would be reduced by more than a factor of two, a substantial adverse impact to the overall program. This cost would be incommensurate with the budget savings.

We anticipate that STAR should be able to achieve many scientific goals with the Au+Au data that it will collect during Run 23, assuming a 28 week run with a focus on sPHENIX commissioning during the first part of the run and physics running subsequently. This will provide the first opportunity for STAR to exploit the EPD, eTOF, iTPC and forward upgrade for 200 GeV Au+Au collisions. The scientific impact of STAR would be substantially compromised if the run were shortened to 20 weeks.

2.3.2 Discussion and Recommendations for RHIC Runs 24-25

We will not offer precise recommendations for run times in Run 24 at this time. However, *we note that in order to achieve the sPHENIX scientific program the element of the Run 24 plan that is of highest priority is a pp run of sufficient duration to provide the reference data needed to achieve the science goals, including the precision goals, that motivate the sPHENIX program.* That is, the Au+Au data taken in Runs 23 and 25 will only deliver the insights that motivate this effort if it can be compared to reference data with corresponding precision. We note with great regret that if Run 24 were to be reduced from 28 to 20 weeks this would mean doing no p+Au run at all. There are certainly significant scientific opportunities that can be realized by both sPHENIX and STAR from a p+Au run during Run 24. Losing this opportunity would be a very significant loss to the RHIC program, and would also have an adverse effect on the future scientific impact of the EIC since the motivations for many p+Au measurements include future comparison between insights from p+Au and e+Au.

The PAC anticipates that Run 25 will yield the marquee Au+Au data set that is the *raison d'être* for sPHENIX. *Completion of the proposed 200 GeV Au+Au data set is the highest priority for Run 25.* It will also allow STAR to complete its scientific program.

3. RHIC Data and Physics Analysis

3.1 STAR

We congratulate STAR and C-AD for a very successful Run 21. All of the proposed data were accumulated, even those listed as priority 3 in the 2020 PAC report, despite continued pandemic restrictions. The recent detector upgrades, iTPC, EPD, eTOF, continue their excellent performance, which is essential for successfully delivering the physics program. We look forward to the timely analysis of the BESII data, which will complete the RHIC program mission to explore the phase diagram of nuclear matter with unprecedented precision and breadth. Given that STAR is the only experiment taking this important data, the PAC recommends that the STAR collaboration does everything possible to ensure that the analysis of critical observables in the BESII, such as proton number cumulants, are carried out by at least two independent groups within STAR.

The efficient C-AD and STAR operations allow time for additional physics running in Run 21. In accordance with the Small Systems Task Force report, STAR has proposed to include d+Au running at 200 GeV this year. The PAC enthusiastically supports this proposal and places the highest scientific priority on taking the data and conducting analyses with various kinematic ranges and event selections in order to match the regime of previous PHENIX measurements and extend into new domains.

STAR is commended for its continued high productivity, with high-quality journal publications, Ph. D. production, and its vigorous scientific program that continues to attract new collaborating institutions. The

PAC is pleased to see the first publication from the FXT program, the first measurement of global polarization of Ξ and Ω , the first measurement of the jet mass in pp collisions at RHIC, and the continued output from the heavy flavor program enabled by the HFT detector. The isobar analysis is progressing, and the PAC looks forward to the release of the results later this year.

In the cold QCD program, recent publications include the W^+/W^- cross section ratios which are sensitive to the sea-quark flavor asymmetry at the W -mass scale, double-spin asymmetry A_{LL} for single and double jets production that further constrains the gluon helicity distributions, and the nuclear dependence of A_N which suggests a possible suppression of TMDs in p+A collisions. These results continue to demonstrate the unique role of RHIC for spin physics. The PAC commends the significant effort of STAR to analyze and publish these interesting results. The PAC is also pleased to see the preliminary results on di-hadron correlations in pp and p+A collisions, which provide unique sensitivity to test the effects of the gluon saturation. The forward upgrade is on track for taking data in 2022. The PAC commends the collaboration for the impressive progress in the construction, installation and commissioning of the forward detectors under difficult pandemic conditions, and for the training of a new generation of nuclear scientists with expertise in state-of-the-art technology.

3.2 PHENIX

PHENIX is commended for maintaining productivity despite challenges of the pandemic and some shortage of available effort. In the past year, eight papers including two highlights (J/ψ in small systems and medium effects on hadron-photon correlations) were published, two others are in review, and 12 are in preparation.

The PAC is very pleased to hear that the data production for the remaining part of the 2016 run is almost complete despite earlier challenges of overcoming an accident, which required significant recalibration. This sets the stage for PHENIX to finish its scientific mission.

The PAC highly commends PHENIX on developing and implementing a strategy built on best practices and international expertise for data and analysis preservation through several existing systems such as REANA, Zenodo and HEPData, as well as their own dedicated website.

The ongoing PHENIX School for students and postdocs is crucially important for PHENIX efforts aimed at completing the analysis of their data. It greatly assists students with learning how to analyze and interpret PHENIX data and also how to document and preserve the knowledge base of PHENIX methods and results.

3.3 Small Systems Task Force Report

Following the advice of last year's PAC, the ALD formed a task force to investigate the apparent difference in the flow measurements in p+Au, and d+Au collisions by the PHENIX and STAR collaborations. The report of the task force was presented at this year's PAC meeting.

The PAC thanks the Small Systems Task Force for its comprehensive and informative report. The task force did not find any evidence that any of the measurements were technically flawed. It rather suggests that the difference may be attributed to the different treatment of non-flow effects and to the fact that the

flow measurements by STAR and PHENIX were based on correlations in different rapidity windows. The task force recommends further studies of the rapidity structure of the correlations. It also stresses that the present controversy brings up interesting physics questions and a resolution will require additional measurements, which in turn may provide new and important insights for our understanding of flow phenomena in heavy ion collisions. Therefore, the task force recommended additional data taking with sPHENIX and the upgraded STAR detector and emphasizes that the same centrality selection and rapidity cuts be used. The PAC fully endorses this approach, which could start with d+Au data taking at the end of the current run.

4. sPHENIX

The PAC is extraordinarily impressed with how sPHENIX has managed to maintain its schedule during the pandemic. The sPHENIX Project and the Collaboration appears to be both well organized and to have a remarkably coherent vision, both scientifically and operationally. Both the Laboratory and the Collaboration should be proud of their accomplishments and their progress toward fulfilling what are central RHIC goals of the U.S. Long Range Plan.

sPHENIX has met its goals for the past year, both for hardware and software. The base carriage and cradle are assembled and many of the main detector elements are on schedule for construction and installation. sPHENIX is on track to meet all its scheduled construction milestones, with many of the elements being installed during the coming shutdown. The collaboration has passed all critical reviews and has received their PD-3 approval. Software development is well underway and simulation software is already producing results from mock analyses.

sPHENIX construction is approaching a critical phase when collaboration members and BNL staff need to work closely and install the various elements of the detector. The Laboratory should ensure that no unnecessary COVID protocols hinder this time-sensitive effort.

The PAC concurs with the sPHENIX collaboration that a run plan scenario of only 20 cryo-weeks in 2023, 2024 and 2025 will seriously compromise the sPHENIX physics program. This run scenario would lead to a 40-50% loss in the Au+Au collected statistics and the cancellation of the p+Au run. sPHENIX's principal science goals include understanding jets, rare quarkonium such as the Upsilon, and cold QCD matter dynamics. The first two topics depend critically on statistics and the third requires the p+Au run. If sPHENIX is to fully realize its scientific promise, it is imperative that the BNL Management do everything possible to ensure RHIC full 28 cryo-week operations as previously planned for the sPHENIX running.

The PAC also heard a proposal for construction of a TPC Outer Tracker (TPOT) from a sPHENIX team led by the CEA Saclay group. The TPOT is based on the micromegas detector technology and will provide an accurate track hit outside the main sPHENIX TPC. It represents a unique opportunity to improve on the efficiency and precision of sPHENIX data analyses by providing nearly real-time calibration of tracking within the sPHENIX TPC. This would greatly assist overcoming issues related to space-charge effects, and significantly accelerate nearly all analyses and publication of sPHENIX results. The PAC encourages the TPOT team to develop a funding and construction plan so that sPHENIX and BNL can evaluate the impact of the proposed TPOT project on BNL budget constraints and the installation and commissioning schedule of the sPHENIX detector system. The PAC recommends that sPHENIX review the TPOT proposal for installation into sPHENIX and that BNL Management also monitor plans for its possible installation. A timely decision on the TPOT proposal is expected.

5. CeC

The CeC project represents a pioneering frontier for coherent electron cooling of hadron beams. It is time critical if this technology is to make an impact on the EIC facility enhancing the achievable luminosity. The PAC is pleased to learn that the CeC project has demonstrated the presence of ion imprint and high gain Plasma Cascade Amplifier in Run 20. The project achieved key beam parameters for Run 21 and appears to be on the verge of demonstrating longitudinal cooling of the 26.5 GeV/u ion beam. The PAC remains concerned about the effective management of the project and the timely definitive demonstration of 3D electron cooling of a hadron beam. The PAC recommends accommodating the CeC beam use request in Run 22 in a way that will minimize the impact on the STAR data-taking. For example, if the CeC beam use were to take place early in Run 22, this could optimize overall use of the RHIC beam. Given the short time between now and Run 22, the CeC project should develop a detailed plan including possible contingency if technical issues arise. Any CeC beam use beyond Run 22 would present a major challenge and seriously impact sPHENIX commissioning and the RHIC scientific program.

The PAC was informed by the CeC project director on June 28 that they have observed clear indication of cooling of ion bunches interacting with electrons in the CeC system. This milestone was achieved with still over a week of RHIC run time remaining. The CeC team has continued its effort to improve the cooling of ion bunches and to establish the magnitude of the cooling effect. The PAC congratulates the C-AD and the CeC team for this remarkable breakthrough and looks forward to the final results from Run 21.

At the 2020 PAC meeting, the PAC was concerned about the technical progress from and management of the CeC project. The PAC recommended that the BNL Management convene a review of the project by a committee of experts specializing in the relevant technical research areas. The BNL Management organized a review of the CeC project on Jan 13-15, 2021. The PAC commends BNL Management for the excellent review and concurs with the review committee on the findings. In particular, the review committee raised issues with what is necessary to unambiguously establish hadron cooling using the CeC technology and which key technical goals need to be met in order for the CeC cooling technology to be used for the EIC project. The PAC recognizes the critical importance of these issues among many others identified by the review committee and endorses the recommendations from the review committee. The PAC recommends the BNL Management and the CeC project to follow through with the recommendations from the review committee and requests that the CeC team report progress addressing issues raised by the review committee at the next PAC meeting.

6. PAC Recommendations

STAR Analysis:

- The PAC recommends that the STAR collaboration does everything possible to ensure that the analysis of critical observables in the Beam Energy Scan, such as proton number cumulants, are carried out by at least two independent groups within STAR.

sPHENIX:

- The PAC recommends that sPHENIX undertake a timely review of the TPOT and its installation into sPHENIX, and report to BNL Management.

CeC:

- The PAC recommends that BNL Management and CeC work together to ensure that the CeC beam use request can be accommodated as early as possible in Run 22 in order to allow for optimized STAR data taking.
- The PAC recommends that the BNL Management and the CeC project follow through in a timely fashion with the recommendations of the CeC review committee to establish the CeC technology for possible EIC application.

BNL Lab Management:

- The PAC recommends that BNL Management do everything possible to ensure a run sufficient for sPHENIX to accomplish its physics goals in Runs 23, 24 and 25.
- sPHENIX construction is in a critical phase when collaboration members and BNL staff must work closely to install the various elements of the detector. The PAC recommends that BNL Management do everything possible to ensure that no unnecessary COVID protocols hinder this time-sensitive effort.
- BNL Management should make a timely decision on the TPOT proposal, and monitor the progress of the TPOT project and sPHENIX plans for its installation if the TPOT is approved.

7. 2021 BNL Nuclear and Particle Physics Program Advisory Committee

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