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

October 16 – 17, 2025

1. Executive Summary

The Program Advisory Committee (PAC) convened on October 16 – 17, 2025, to evaluate the sPHENIX and STAR Beam Use Requests (BURs) for Runs 25 – 26. The Associate Laboratory Director (ALD) charged the collaborations to answer specific questions as part of their beam use requests. These are listed at the end of this report. C-AD, sPHENIX, and STAR gave presentations on the performance and challenges in data-taking thus far in Run 25. C-AD also presented a report on RHIC operations and considerations for collisions in Runs 25 – 26 with p+p, p+Au, fixed-target, and A+A (O+O, He+He, and isobar species). sPHENIX and STAR presented their BURs, including their responses to the charge questions from the ALD. The PAC also heard a summary presentation on RHIC Data Preservation and an update from CeC. The PAC thanks the sPHENIX and STAR collaborations and the C-AD for their preparation and presentations for this PAC Meeting. We congratulate sPHENIX and STAR for their detector preparations and successful data taking thus far in RHIC Run 25.

The C-AD has overcome considerable challenges during Run 25 with multiple incidents requiring repair and downtime. It started with a delayed start of the run due to an electrical short in the blue ring main dipole, with RHIC operations commencing on May 31. After successful operation and data-taking throughout most of the summer, a power line failure caused an interruption in late August, requiring a two-week repair and cryo-recovery. This was followed a couple of weeks later by an 11-day abort kicker failure repair in late September. When RHIC has been operational, Au+Au collisions have been available 79% of the time, and RHIC injection and ramp efficiency are the highest ever. At the time of this PAC Meeting, sPHENIX has been able to collect 4.0 nb^{-1} of Au+Au collisions and projects to complete their Au+Au goal of 7.0 nb^{-1} between December 15 – 28. Similarly, STAR has reached 50% of its Au+Au data-taking goal and projects to complete its part of the program by December 31.

This begins the culmination of what has been a very successful RHIC Physics Program that has run over the last 26 years. sPHENIX was conceived 10 years ago to complete the final phase of the RHIC program with decisive hard probe measurements, and is in its second year of operation and final year of data-taking. STAR has been in operation since the beginning of RHIC and has been continually upgraded to increase its physics scope, including recent forward detector systems that were installed in the last three years to address new physics from polarized p+p and p+A collisions. The PAC was pleased to see a broad range of results from STAR, and the first results from sPHENIX at the Quark Matter 2025 Conference. In addition, sPHENIX has begun to publish

its first physics papers. To complete the RHIC physics mission, it is imperative that the program outlined below be implemented and completed.

- There are three ***must-do*** priorities for the successful completion of the RHIC Science Mission in Runs 25 – 26. These follow in priority order.
    - The highest must-do priority for Run 25 is for sPHENIX to collect 7 nb^{-1} of Au+Au data.
    - The next highest must-do priority after the Au+Au run is for sPHENIX to accumulate 13 pb^{-1} of all-subsystem triggered data in at most a 7 cryoweek polarized pp run.
    - The next highest must-do priority after the polarized pp run is a polarized p+Au run for STAR of 5 weeks of physics running.
- There are four additional scientific opportunities to be run at RHIC if time allows. These are listed in priority order: Fixed target Au+Au in STAR, lighter systems (O+O or He+He) requested by sPHENIX, low-energy isobar running (Zr+Zr and Ru+Ru) requested by STAR, and coherent electron cooling R&D requested by the CeC group.

2. Discussion of RHIC Run 25 - 26

We begin with the top priorities, priorities that we see as ***must-do*** for the successful completion of the RHIC Science Mission. We list these three in priority order, but to repeat, all three are central to the successful completion of the RHIC Science Mission.

1. **Au+Au:**
   As stated in the 2024 PAC report: "***The top priority for Run 25 is collecting the marquee Au+Au data set that has been identified by the PAC for at least the past four [now five] years and by the Nuclear Science community since the 2015 Long Range Plan as the raison d'être for sPHENIX. The same run will also allow STAR to complete an impressive suite of impactful measurements. There is no question that this run is essential for the successful completion of the RHIC Science Mission."***

   sPHENIX has made a persuasive case that 7 nb^{-1} of Au+Au data in Run 25 will enable the landmark hard probes measurements that have been stated as goals for Nuclear Science in and since the 2015 Long Range Plan. This is the highest priority among the must-do priorities as it will give sPHENIX access to an unprecedented kinematic range of hard probes, including quarkonia, open heavy flavor, jet physics, and jet-substructure, as well as electromagnetic probes. Even upon noting the multiple outstanding opportunities that remain open as RHIC seeks to complete its scientific mission in its last run, the PAC considers this top priority as so high that the target of 7 nb^{-1} of Au+Au data *must* be matched to within at least 90%.

2. **Polarized p+p:**
   The sPHENIX detector was approved and built to make decisive hard probe measurements with the highest precision at RHIC. A 12 cryoweek pp run would be needed to ensure that the statistical errors in flagship hard probes measurements coming from the pp reference data are comparable to those coming from the Au+Au measurements. That said, sPHENIX has described a 7-cryoweek polarized pp run (specifically, a run in which an additional 13 pb^{-1} of all-subsystem triggered data is taken) as the "minimum request". We concur that matching this 13 pb^{-1} target luminosity to within at least 90% is the next highest must-do priority after the Au+Au run. ***We emphasize that this pp run is essential to realizing the scientific impact of the marquee 2025 Au+Au run and completing the RHIC Science Mission successfully.*** Such a polarized pp run would also allow sPHENIX to collect unique data to improve our knowledge of the spin structure of nucleons and add new measurements of spin asymmetries, such as the single spin asymmetry in open charm production that is expected to provide information on the presence of tri-gluon correlations in the proton.

3. **Polarized-p+Au:**
   A polarized-p+Au run, with STAR including its forward upgrades, will produce unique, landmark measurements that will never again be possible. This has long been seen as an important element of the RHIC Science Mission. With the recent forward upgrade of STAR, ***many yet unexplored kinematic regions and reaction channels in p+Au collisions will be accessible for the first time, offering considerable discovery potential. A polarized p+Au run that prioritizes 5 weeks of physics running for STAR is a must-do for the successful completion of the RHIC Science Mission.*** sPHENIX plans to take data during these collisions also, and will make a scientific impact with its measurements. We encourage efforts by sPHENIX and C-AD toward finding a viable operating point for the sPHENIX streaming mode p+Au data-taking in a timely fashion. That said, the priority during this run should be 5 weeks of physics running with this system for STAR.

RHIC is approaching the conclusion of an amazing 26-year voyage of discovery, 26 years at the center of nuclear and high-energy physics in the United States. Completing the Au+Au and polarized pp data taking that is needed to realize the marquee sPHENIX hard probes and spin physics programs and the p+Au data taking needed to realize the unique STAR cold QCD program will represent a Grand Finale, a triumphant conclusion to a quarter century of world-leading advances in QCD physics realized by Brookhaven National Laboratory, the DOE, and the world-wide community of RHIC scientists.

Next, we list four further scientific opportunities, priority ordered:

4. **Low Energy Au+Au Fixed Target:**
   Mapping the QCD phase diagram and searching for the QCD critical point via the Beam Energy Scan is one of the most scientifically impactful elements of the RHIC Science Mission. The Fixed Target (FXT) component of the Beam Energy Scan extends the search into the region of higher baryon densities, the region which a number of current theoretical estimates point toward as the most likely location of the QCD critical point. It is intriguing that the FXT data collected by STAR so far suggest deviations from the non-critical baseline around the collision energy of 4.5 GeV. The PAC agrees with the STAR collaboration that additional data at this energy, and possibly at 4.2 GeV, is essential to confirm such a deviation from the baseline, which may signal the existence of the QCD critical point in this region of the QCD phase diagram. *The potential high impact of such a measurement justifies putting this STAR BUR component high on the RHIC priority list. The PAC notes that with the increase in the STAR DAQ rate and the repair of the eTOF detector even a few days of Au+Au fixed target running at 4.5 GeV would make an impact. We encourage seizing such an opportunity if at all possible.*

5. **Oxygen+Oxygen, He+He:**
   The BUR of sPHENIX makes a compelling case for a brief O+O run. A two-week O+O run at RHIC would realize the only possibility to make comparisons of hard probe measurements in identical nucleus-nucleus collision systems at RHIC and the LHC, i.e. keeping the geometry fixed but greatly varying the collision energy and thus the QGP properties. First data from the short LHC O+O run in May 2025 have now established that not only collective flow but also jet quenching signatures can be detected in these smaller collision systems. This indicates that O+O collisions are well-suited to study the onset of all QGP-related phenomena as a function of system size, and it strengthens the case for understanding how these QGP phenomena depend on collision energy. *A brief O+O run, with the detectors and luminosity needed to make the requisite measurement, would allow RHIC to contribute to a current central question posed by its two biggest discoveries (jet quenching and flow) and could hence make a lasting contribution within the main focus of the RHIC Science Mission.*

   The BUR of sPHENIX also discussed the case for He+He collisions. A successful determination of jet quenching and flow in He+He collisions would provide a qualitatively novel input to the question of whether the two biggest phenomena discovered at RHIC are also present in the smallest hadronic collision systems. This qualitative opportunity would need to be weighed against the risk that the signals (in particular for jet quenching) are too small to be measurable. The PAC believes that further studies (theoretical extrapolations of the expected signal size in He+He collisions, as well as physics performance studies) would be needed and could be done on a short time scale to inform any arbitration between

O+O and He+He running scenarios if the C-AD schedule permits seizing these unique opportunities.

6. **Zr+Zr and Ru+Ru:**
   STAR presented a request for low-energy isobar running (Zr+Zr and Ru+Ru) to explore charge transport in heavy-ion collisions, and to compare charge transport to baryon number transport. There is a sound scientific argument for this proposal but based upon the assessment of its likely scientific impact, the PAC places a higher priority on each of the opportunities above. The PAC would support RHIC beam time for low-energy isobar running only in a scenario in which the higher priority runs above have been accomplished.

7. **Coherent Electron Cooling (CeC):**
   The CeC team presented a brief report on the status of the CeC effort and requested 9 shifts, each of 12 hours of RHIC-dedicated beam time for R&D. The PAC is pleased to see the team continuing their efforts but notes that there has not been any recent review of their progress by an expert committee. Based upon the assessment of its likely scientific impact, the PAC gives higher priority to each of the six opportunities above than to this one. The PAC would support RHIC beam time for the CeC project only in a scenario in which the higher priority runs above have been accomplished. To be clear, the PAC supports ongoing and future C-AD efforts, which can potentially enhance the luminosity of the EIC in the future.

3. RHIC Collaboration Reports

3.1 sPHENIX

The PAC congratulates the sPHENIX Collaboration for the remarkable efforts in making this second and last year of data taking a success. sPHENIX has so far collected $4nb^{-1}$ of Au+Au data out of the targeted $7nb^{-1}$, representing the ultimate luminosity goal. The PAC highly appreciates the efficient utilization of beam time during Run 25 and the swift recovery following the downtime periods.

Furthermore, the Collaboration is commended for the significant performance improvements implemented since Run 24, allowing sPHENIX to reach its full capability. Thanks to the data buffer server upgrade, enabling a significant increase in data rate, the streaming fraction in pp collisions can now exceed 60%, well above the initial 10% target. This improvement will allow an increase in the available statistics for open heavy-flavor analysis, one of the flagship measurements for sPHENIX. Additional significant improvements on the TPC have enabled a high-quality calibration, enhancing data quality and detector performance in Run 25. The PAC also acknowledges the efforts made by the

Collaboration, together with C-AD, in mitigating the ion-beam background in the MVTX, now allowing for successful Au+Au operations in triggered mode. The PAC strongly supports the continuation of these studies, aiming to identify an operational working point for the MVTX, also for p+Au collisions.

The PAC is pleased to note that the offline data quality assurance provided by sPHENIX, made possible by the substantial computing resources and excellent operation of SCDF, has ensured high-quality data taking, providing readiness towards data analysis.

The PAC congratulates sPHENIX for the release of the first numerous preliminary results, such as that on dijet asymmetry, recently presented at the Initial Stages conference in September. The PAC further commends sPHENIX for the timely publication of its first physics results on charged hadron multiplicity and transverse energy density. These results, based on Au+Au data, were published only a few months after the completion of Run 24, demonstrating the Collaboration's outstanding readiness and capability to deliver physics results. The PAC eagerly looks forward to the upcoming physics results from both Runs 24 and 25 data analyses.

3.2 STAR

We congratulate STAR on their 25 years of continued successful operations, impactful physics program, the high rate of publications, and numerous PhD and MS degrees awarded. We commend the collaboration for bringing to publication in Physical Review Letters (PRL) the highly impactful analysis of the collider-mode data on net-proton cumulants and proton factorial cumulants from the Beam Energy Scan program. The measurements indicate intriguing deviations from non-critical-point model calculations and data from peripheral collisions (70-80% centrality). The results were highlighted as the Editor's suggestion in PRL and featured in Physics. They represent a breakthrough in our understanding of the QCD phase diagram and lay the groundwork for further theoretical investigations and experimental searches. The PAC is pleased to see the recent preliminary results from the Fixed Target component of the Beam Energy Scan presented at Quark Matter. The PAC recognizes the importance of the ongoing analysis of this data that is being undertaken by STAR.

During Run 25 STAR has sustained highly efficient operations and is on track to complete its Au+Au data-taking goal in December. The PAC was impressed with the timely and efficient repairs of the eTOF and TPC RDOs. Taking the opportunity to conduct these repairs during RHIC downtime ensures readiness for the successful completion of the STAR physics program with minimal additional interruptions. Continued efficient operation is key to completing the *must-do* program detailed above, and possibly some of the additional high-impact physics measurements.

4. BNL and C-AD

The PAC recognizes the importance of a successful completion of the sPHENIX program and commends C-AD for making the efforts to provide the integrated luminosity necessary for sPHENIX to accomplish its scientific goals.

The PAC was presented with reports on the "Machine performance and challenges" and "RHIC Ops: Considerations for p-p, p-Au, fixed-target and A-A (O-O, He-He and isobars)". We commend the C-AD and the entire RHIC operations team for their heroic efforts in overcoming challenges to minimize delays in the RHIC start-up and failures during the run in the external powerline and the abort kicker in the machine. The RHIC accelerator has been operating with good efficiency and delivering high-quality beams to both STAR and sPHENIX. RHIC operation is well on its way to another successful year of running.

The PAC was impressed with the thorough and thoughtful report on the machine constraints for the possible beams under consideration for running after completion of the current Au+Au data-taking. We appreciate the input from the C-AD and have considered these constraints.

5. Data Preservation

RHIC's scientific mission would be incomplete without comprehensive data and analysis preservation (DAP). The PAC commends BNL Management for developing and piloting a comprehensive DAP plan. The plan integrates with DOE data policy, implements FAIR principles, and uses AI technology for accessing the data and analysis.

The PAC is pleased to hear that the development of the DAP plan is coordinated with the RHIC experiments via regular round-table discussions and that a prototype for the AI search is being worked on for STAR's documentation. We encourage BNL to apply for funding to support the components of the DAP plan, especially AI integration.

The analysis of RHIC data will continue over the next decade. The PAC recommends that BNL management plan to allocate adequate resources to support this work and to ensure that RHIC data and associated analysis are preserved for future research.

6. PAC Recommendations

General:

- ***The highest must-do priority for Run 25 is for sPHENIX to collect 7 nb^{-1} of Au+Au data.***
- The ***next highest must-do priority after the Au+Au run is a 7 cryoweek polarized pp run*** for sPHENIX to accumulate 13 pb^{-1} of all-subsystem triggered data.
- The ***next highest must-do priority after the polarized pp run is a polarized p+Au run*** for STAR of 5 weeks of physics running.
- The PAC recommends, in priority order, for the remainder of Run 25 - 26 that RHIC run low-energy fixed target Au+Au, Oxygen+Oxygen (or He+He), low-energy isobar collisions (Zr+Zr, Ru+Ru), and coherent electron cooling R&D as time allows.

BNL Lab Management:

- The PAC recommends that BNL management develop a plan to allocate adequate resources to support comprehensive data and analysis preservation (DAP) and to ensure that RHIC data and associated analyses are preserved for future research.
- We encourage BNL to apply for funding to support the components of the DAP plan, especially AI integration.

sPHENIX:

- The PAC strongly encourages the sPHENIX Collaboration, together with C-AD, to continue their studies to mitigate the ion-beam background in the MVTX and to identify an operational working point for the MVTX in p+Au collisions.

7. COMPLETING THE RHIC SCIENCE MISSION

RHIC is within reach of achieving remarkable scientific goals as it approaches the conclusion of its 26-year voyage of discovery, 26 years at the center of nuclear and high-energy physics in the United States, 26 years pushing the boundaries of possibility and knowledge. Completing the RHIC Science Mission requires completing the Au+Au, and polarized pp and p+Au data-taking that we have identified above as must-do. Realizing scientific impacts from the marquee sPHENIX hard probes program and the unique STAR cold QCD program will represent a Grand Finale, a triumphant conclusion to a quarter century of world-leadership in QCD physics realized by Brookhaven National Laboratory, the DOE, and the worldwide community of RHIC scientists. The proposed Au+Au fixed target and oxygen-oxygen runs each present a unique opportunity to add an exclamation point in the record of RHIC discoveries.

The PAC wishes to emphasize that completing the RHIC Science Mission will require a major effort for the coming decade. Continued support from Brookhaven National Laboratory and the DOE for the personnel and computing needed for the sPHENIX and STAR collaborations to reconstruct and analyze the data that has now been taken is absolutely necessary. Without sustained

support, including continued funding from the DOE for necessary experimental and theoretical research efforts around the country, the scientific impacts of these data will be compromised. Without sustained support, there can be no successful completion of the RHIC Science Mission. In addition to successful analysis of the data and publication of results, preservation of the data for future analyses is also critical to the completion of the RHIC Science Mission; we have remarked upon this above.

This PAC remains available to be convened by the ALD during the final RHIC run period if its further advice would be helpful as decisions are being made.

Furthermore, the PAC sees considerable value in forming a RHIC Scientific Advisory Committee, a successor to the PAC, that would meet annually in the years going forward, as the RHIC Science Mission is completed. Both sPHENIX and STAR have recommended this, and we concur. Such a committee would provide a relevant forum to review progress toward completing the RHIC Science Mission and would report to, and make recommendations to, Brookhaven National Laboratory about priorities and resources for ongoing analyses and for data preservation efforts. Its composition should be such that its advice benefits from current developments from the theory community and from the LHC program, as well as from the EIC physics community and from those with expertise in data science.

Charge to STAR and sPHENIX from the BNL ALD

1. What is your current best guess (extrapolation) to achieve your Au+Au luminosity goal of 7.0 nb^{-1}? – a plot with uncertainties would be ideal.

2. What would be your choice of species to run after Au-Au operation? Why?

3. What is the minimum & optimum luminosity / fig-of-merit need for that 2nd species combination?

4. Would your choice of species change (and to what) if only half of the minimum/optimum running time is available?

5. Please update your desired subsequent running (update from the last year's PAC report presentations).

6. What role do you think RHIC-PAC should play (if any) after the end of Run-25?

2025 BNL Nuclear and Particle Physics Program Advisory Committee

Roberta Arnaldi, INFN, arnaldi@to.infn.it

Leticia Cunqueiro Mendez, Rome Sapienza U, leticia.cunqueiro.mendez@cern.ch

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

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

Anna Martin, Trieste Univ. and INFN, anna.martin@ts.infn.it

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

Krishna Rajagopal, MIT, krishna@mit.edu

Claudia Ratti, University of Houston, cratti@central.uh.edu

Anna Stasto, Penn State, ams52@psu.edu

Mikhail Stephanov, UIC, misha@uic.edu

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

Urs Wiedemann, CERN, urs.wiedemann@cern.ch