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

June 2 - 3, 2022

1. Executive Summary

The Program Advisory Committee (PAC) convened on June 2 – 23, 2022, to evaluate the sPHENIX and STAR Beam Use Requests for Runs 23 – 25. In addition to the Beam Use Requests, the PAC 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 data preservation, and by sPHENIX on the status and schedule of installation, readiness for data acquisition, and its computing and commissioning plan. The PAC also heard a report on data-taking in Run 22 from CeC.

The PAC thanks the collaborations for their presentations and cooperation in responding to our questions. Input from the C-AD and BNL NP-HEP managements are acknowledged and were helpful in the PAC's considerations. We highly commend the C-AD and STAR for successful operation and data-taking using collisions of polarized protons for the RHIC Cold QCD Program. We congratulate C-AD for the successful recovery from a number of unanticipated machine issues that appeared in the RHIC run this year. Being able to eventually provide the polarization squared times luminosity for STAR in the polarized pp run after the Siberian Snake failure was an accomplishment and made the run a success.

STAR is to be congratulated for successful installation of the Forward Silicon Tracker, the sTGC tracker, and commissioning and operation of the full Forward Detector Upgrade. This along with C-AD's Siberian Snake recovery allowed STAR to achieve their proton-proton data-taking goals in Run 22, and provides a strong case for a broad, diverse, and complementary science program using the forward upgrade in STAR.

The CeC experimental program failed to demonstrate cooling in Run 2022. The PAC recognizes the potential of the innovative PCA-based CeC for future applications, and supports BNL management's continued pursuit of future opportunities for experimental demonstration of CeC within the constraints of the RHIC program, as well as its re-organization of the CeC project.

STAR and PHENIX are commended for the number of high-quality publications, PhDs awarded and overall high scientific productivity. The PAC is impressed by the overall quantity of different analyses and quality of data presented by the STAR collaboration. PHENIX is commended for achieving the goals set by the collaboration and recommended by the PAC last year. PHENIX has also made significant progress in data and analysis preservation using international expert systems. The PAC supports these efforts in data preservation and the request to BNL management by PHENIX for resources necessary to complete critical analyses such as $b,c \rightarrow \mu$ decays.

The STAR Cold QCD Program is highly visible and proceeding well. The PAC strongly endorses a plan for timely analysis of the Run 22 data. Analysis of the Drell-Yan data collected in Run 22 will test the sign-change of the Sivers functions at lower Q^2 scales, greatly reducing the uncertainties associated with the QCD evolution. Successful extraction of the Drell-Yan

signals from Run 22 would also contribute to the proposed measurement of nuclear antiquark distributions for Run 24 using the Drell-Yan process.

STAR recently published the double-spin asymmetry, A_{LL}, of single-jets and di-jets produced in longitudinally polarized pp collisions. This result, together with the di-jet data taken at the larger rapidity region, will further constrain the gluon polarization in the proton over a wide range of x. The PAC congratulates STAR for achieving this important physics goal.

STAR has released the transverse single-spin azimuthal asymmetries of hadrons produced within a jet in 200 GeV pp collisions. This represents a novel approach to probe the Collins fragmentation functions and the quark transversity distributions, as well as new tests on the universality and Q^2-evolution of TMDs. The PAC looks forward to the timely publications of the final results on the transverse single-spin asymmetry of W and Z boson production from Run 17. The success of Run 22 would further double the statistics and could lead to a conclusive test of the predicted sign-change of the Sivers function.

STAR is to be commended for completing the blind analysis of Chiral Magnetic Effect (CME), achieving unprecedented precision in the data. Progress continues in the analysis of BES II data. The PAC is especially impressed by the successful completion and publication of the 3 GeV FXT data analysis. The PAC looks forward to results on collective flow and vorticity at 19.6 and 14.6 GeV, and eagerly awaits the publication of the net-proton kurtosis results at these energies. Likewise, the analysis and publication of the FXT data at other energies, in particular at 7.7 GeV, and comparison to collider data at the same energy will cross-check the results in a regime where the most intriguing beam energy dependence is observed. The PAC eagerly awaits publication of the STAR Run 15 and 16 small system flow results and the analysis of the new d+Au data taken in Run 21 with extended detector capabilities.

The PAC endorses STAR's emphasis on the importance of maintaining sufficient expert person-power for software, computing and operations at BNL, which is critical for high-quality data collection, and timely calibration and production of data.

The PAC commends the sPHENIX project team for excellent progress in all fronts of the sPHENIX detectors, infrastructure and facilities. Assembly and installation of the sPHENIX calorimeters is progressing well. The TPC is on a very tight schedule, with all GEM readout modules having been completed and pre-assembly offsite tests ongoing. All INTT silicon strip staves have been completed and tested. Half barrel assembly begins at BNL in June with the detector on schedule for installation in January 2023. All the MVTX (MAPS) staves have been completed and tested, and assembly of half-barrel detectors is ongoing at LBNL with expected delivery to BNL in late July. The Event Plane Detector (sEPD) will be completed by the end of August with installation scheduled in January 2023. The TPOT project is moving forward with 8 micromegas chambers planned for installation, which will aid in reducing the impact of beam-induced space-charge distortions in the TPC.

sPHENIX is utilizing technicians and engineers from BNL and from the collaboration to maintain the schedule for the start of commissioning in Feb. 2023. The PAC endorses continued, strongest-possible support of the sPHENIX detector assembly, installation and commissioning as this brand-new, high-impact experimental program is the highest priority of the current RHIC program. . The PAC urges the BHSO to maintain the high priority for the sPHENIX USI and

ASE/SAD approval in order to minimize any impact of these safety approvals on the sPHENIX installation schedule.

The PAC noted the challenges presented by sPHENIX. The sPHENIX installation schedule has no float up to the start-up date of Run 2023. The TPC project is on the critical path, with long lead-time electronics chips (Straitix III FPGA) missing that could significantly impact readiness for commissioning and operation.

The PAC recommends that the sPHENIX project team continue their vetting of the schedule beyond the summer of 2022 with participation of C-AD and other possible contributors matching sPHENIX needs with available resources. It is important for the sPHENIX project to maintain the labor force and other resources for the coming ten months in order to meet the schedule.

sPHENIX has met and surpassed its goals for designing, building and testing its software framework for compression, storage and analysis. It has also improved the memory footprint of the reconstruction software to optimize implementation at the SDCC. Software appears to be on schedule for simulation, reconstruction, calibration, compression and storage, for the inaugural run in February. The PAC is pleased to hear that the software is in place and has passed two Mock Data Challenges.

Detailed hardware requirements for off-line computing for sPHENIX have been provided to BNL management, including the use of off-site computing resources. The 15 kHz event-rate of sPHENIX requires an increase in CPU and storage usage of an order of magnitude. Concerns regarding computing resources were expressed in the 2021 S&C reports but have yet to be addressed adequately. sPHENIX estimates an increase by about a factor of two in resources is needed for initial processing of off-line data. It is imperative that sPHENIX and BNL management address these concerns in time for successful data-taking and analysis for Run 23.

The PAC urges BNL management to assign highest priority to the procurement of the computational resources needed to analyze RHIC data in a timely manner.

The PAC strongly emphasizes that in order for BNL and the sPHENIX collaboration to have the opportunity to realize the compelling experimental program that the sPHENIX detector makes possible within the limitations of a three-year program, 28 cryo-weeks per year is a necessity.

Guidance from the BNL-ALD for Runs 23 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 for RHIC in each year that we were asked to consider and the second corresponds to what the PAC considers a minimal run scenario that gives RHIC and sPHENIX the opportunity to achieve the insights into the microscopic structure of the quark-gluon plasma that the sPHENIX detector has been designed to deliver.

2023: 24 (28)

2024: 24 (28)

2025: 24 (28)

The PAC urges BNL Management and the DOE to do everything possible to ensure sufficient beamtime to accomplish the physics goals in Runs 23, 24, 25 set out for sPHENIX in the 2015 NSAC Long Range Plan.

2. The Beam Use Request

2.1 Discussion of RHIC Runs 23 - 25

RHIC is 9 months away from the beginning of the culmination of the RHIC scientific program. 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. Last year the PAC looked forward with great anticipation to the insights into the microscopic structure of quark-gluon plasma that the sPHENIX detector has been designed to deliver. This year our anticipation is even more palpable – we were delighted to have the unusual opportunity to visit the sPHENIX hall and see the detector as it is today.

The top overall priority in planning for the coming three years 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 (and at the same time final) three years of a major, brand-new, high-impact, experimental effort. Many of the updates that we heard at this meeting confirm that this is indeed how BNL and DOE are proceeding; we commend them and restate the importance of maintaining this management perspective. We also note that the tightness of the schedule is dictated by the June 2025 end-date for the sPHENIX program, which in turn is dictated by the goals of the EIC program, a very high priority for BNL and for the field in the years beyond. Given this, BNL and the DOE must continue to support the efficient installation, commissioning and operation of sPHENIX so as to make it possible to realize the scientific impact that its program promises within this tight schedule.

Given the compelling experimental program that the sPHENIX detector makes possible, and given the limited number of data-taking years, the PAC strongly emphasizes the importance of having the largest possible number of cryo-weeks, so as to allow the Collaboration to reach the foreseen physics goals. Within the limitations of a three-year program, 28 cryo-weeks per year is a necessity.

Similarly, the PAC supports the sPHENIX request for having the highest possible pp luminosity, and sufficient pp running so as to provide a reference data set for the flagship hard probe measurements that are central to the scientific impact and goals of sPHENIX. A reduction in the luminosity or run weeks would have a significant negative impact, increasing the size of the statistical and systematic uncertainties on the reference measurements.

2.2 Discussion and Recommendations for RHIC Run 23

The PAC continues to strongly support focusing in Run 23 on sPHENIX commissioning using 200 GeV Au+Au collisions. This is the highest priority and must come first. We encourage the sPHENIX collaboration to define detector commissioning goals along the lines of those that they shared with us at this meeting, metrics for what constitutes successful detector commissioning. Successful detector commissioning should be followed by continued running of 200 GeV

Au+Au collisions to begin the sPHENIX scientific program. A central goal of this part of Run 23 can be referred to as "physics commissioning". By this we mean collecting, and reconstructing and analyzing, the data needed to establish that the sPHENIX detector has met its previously defined Ultimate Performance Parameters (UPPs). (These were defined previously in such a way that achieving the UPPs will allow the analysis requirements to be met for the data to be taken in Runs 24 and 25, so as to achieve the sPHENIX physics goals first articulated in the 2015 Long Range Plan.) The allocation and deployment of beam time and computing resources during Run 23 should be guided by the perspective that successful sPHENIX installation, detector commissioning and "physics commissioning" is the prerequisite to successful operation of sPHENIX in Runs 24 and 25 so as to accomplish its science goals, which are the overarching priority for RHIC in 2023-25.

STAR has made a strong case for a broad, diverse, and complementary science program that it will be able to carry out using Au+Au data, beginning in Run 23. We commend STAR for its plans and look forward to seeing their measurements to come.

2.3 Discussion and Recommendations for RHIC Run 24

We begin by noting that the PAC anticipates revisiting the questions of how to optimize Runs 24 and 25 next year, based upon whatever has been learned from sPHENIX commissioning and operations up to that point. Although at present we support running pp and p+Au in Run 24, and Au+Au in Run 25, this order could be reversed if Run 23 experience and early data motivates doing so.

As already noted above, the PAC supports the sPHENIX request for a pp run that provides the reference data sets to enable its flagship jet, heavy flavor and Upsilon measurements. The PAC will wait until next year before finalizing this recommendation in terms of a number of weeks, so as to do so with the then-most-up-to-date pp luminosity projections. We also suggest that C-AD, sPHENIX and STAR consider whether a small reduction in the proton polarization goal for the pp run could yield an increase in proton luminosity that would allow for better optimizing the plan for Run 24.

There are many compelling scientific goals that motivate a p+Au run. This includes the cold QCD goals articulated by STAR, goals that complete the realization of the scientific potential of its forward upgrade and that will play a role in framing and enhancing the understanding of important physics that will subsequently be explored by the EIC. For example, this will provide coverage of important spin physics observables at intermediate x and using forward di-hadron, gamma-jet and dijet observables to investigate non-linear QCD effects, seeking signs of saturation. There are also strong motivations from the perspective of the heavy ion program, including addressing the origin of collectivity in small collision systems and extending measurements of nuclear PDF modification where sPHENIX anticipates making considerable impact. We regret that present pp luminosity projections suggest that a p+Au run may have to be as short as five weeks, which would leave some of this potential unrealized.

2.4 Discussion and Recommendations for RHIC Run 25

The PAC anticipates that Run 25 will yield the marquee Au+Au data set that is the raison d'être for sPHENIX and that also will allow STAR to complete its scientific program.

2.5 Other Opportunities

Should the opportunity arise for running RHIC beyond 2025, sPHENIX proposes to double the Au+Au data set and increase by more than a factor of 10 the pp data set enabled by upgrade of the data acquisition system to full streaming mode. In addition, data-taking with other small-ion species such as O+O and Ar+Ar is proposed. These data sets will have no trigger biases or selections that would preclude any analysis within the acceptance and performance parameters of sPHENIX. They will represent the largest data sets at these energies that could be preserved for future exploration when RHIC is no longer running. PAC will consider these proposals in detail in the future, if indeed an opportunity for extending RHIC operations arises.

STAR proposed two possible brief runs for consideration at lower priority than achieving the Run 23-25 goals for Au+Au, pp and p+Au running, for example if the primary goals of Run 24 were to be completed in less than 28 cryo-weeks. The PAC finds this an unlikely hypothetical, given that: (i) if one employs the pp luminosity estimate used in the sPHENIX beam use request there are only five weeks available for p+Au running in Run 24, while STAR has requested 11 weeks of p+Au running; and (ii) the PAC heard during its meeting that the Run 24 pp luminosity estimate may need to be reduced slightly. As noted above the PAC supports achieving the sPHENIX goals for a pp run that yields the reference datasets that make its flagship program possible as the highest priority for Run 24, and supports achieving the compelling scientific goals that a p+Au run makes possible as a very strong second priority. Consideration of the other opportunities that STAR has proposed would only become relevant if there is available beam time beyond that required to achieve these high priority goals.

2.5.1 Space Radiation Protection

STAR observes that it could carry out a program of fixed target measurements using light beam and target combinations (with beams of C, Al and Fe and fixed targets of C, Al and Fe and two day runs for each combination) and that measurements made in such collisions would be of interest to NASA and the Space Radiation Protection community. It seems unlikely to the PAC that NASA's support for such a program would be sufficiently strong and tangible to translate into an extension of RHIC operations beyond the currently planned three 28-cryo-week runs.

The PAC was informed that an NSAC subcommittee has been set up to assess challenges, opportunities, and priorities for effective stewardship of nuclear data following a charge by the DOE Office of Science and the Directorate for Mathematical and Physical Sciences of NSF. Reliable nuclear data plays an essential role in the success of Federal missions including space exploration. The PAC encourages discussions between DOE-NP and NASA to effectuate changes that may allow future investigations of the type proposed by STAR. For such to occur at RHIC, tangible additional support beyond the RHIC program would be required

2.5.2 Nuclear Shapes via Collective Flow Measurements

As another future opportunity, STAR presented the possibility of extracting information about nuclear shapes and radial profiles via measurements of collective flow in heavy ion collisions. Motivated by what has already been learned from Au+Au, U+U, Ru+Ru and Zr+Zr collisions at RHIC and Pb+Pb and Xe+Xe collisions at the LHC, STAR proposes consideration of two three-

day runs of Pb+Pb and Hg+Hg (^{196}Hg or possibly ^{198}Hg) collisions at RHIC as well as three further three-day runs that would allow studies along an isotopic chain of Samarium (^{144}Sm and ^{154}Sm collisions) and by comparing collisions of two isobars of the same mass, ^{154}Sm and ^{154}Gd. STAR reports that these possible future opportunities will be discussed during a month-long program at the Institute for Nuclear Theory in early 2023. Given the present lack of theoretical and experimental studies, the PAC could not assess the added impact on the understanding of nuclear shapes that the various three-day runs that STAR is considering could yield. However, the PAC encourages STAR to investigate the promise of such collisions, especially if such collisions might provide firm quantitative insight into the extent and shape of the neutron skins of nuclei.

3.1 STAR

The PAC is impressed by the overall quantity of analyses and quality of data presented by the STAR collaboration. STAR should also be commended for the number of high-quality publications, PhDs awarded and overall very high scientific productivity.

3.1.1 STAR Run 2022 Report and Cold QCD Update

The PAC commends STAR and C-AD for overcoming multiple challenges and accomplishing the Run 22 goals. The STAR collaboration should be commended for completing the forward detector upgrade on schedule despite many extraneous circumstances. Four major new subsystems, an electromagnetic calorimeter, a hadronic calorimeter, and a tracking system comprised of a Forward Silicon Tracker (FST) and a small- strip Thin Gap Chambers (sTGC), were all built, installed, and commissioned during the pandemic period. In addition to the installation of the FST and sTCG, the online monitoring software was deployed, the detectors operated smoothly during Run 22 and collected physics data achieving the desired figure of merit in the polarization squared times integrated luminosity. The PAC is pleased to see the progress in the software developments for detector calibrations, alignment, offline data reconstruction, and the initial fast simulations. We look forward to seeing the completion of the full detector response simulation software, the optimization of the tracking software, and eventually – the data analysis and physics results.

A major physics goal of the RHIC-spin program is to determine the contribution of gluons to the proton's spin. STAR presented the recently published double-spin asymmetry, A_{LL}, of single-jets and di-jets produced in longitudinally polarized pp collisions. These new results, together with the near-final results of the analysis of additional di-jet data taken in the larger rapidity region, will further constrain the gluon polarization in the proton over a wide range of x. The PAC congratulates STAR for achieving this important physics goal.

STAR has released the transverse single-spin azimuthal asymmetries of hadrons produced within a jet in 200 GeV pp collisions. This represents a novel approach to probe the Collins fragmentation functions and the quark transversity distributions, as well as new tests on the universality and Q^2 evolution of TMDs.

The PAC looks forward to the timely publications of the final results on the transverse single-spin asymmetry of W and Z boson production from Run 17. The success of Run 22 would further double the statistics and could lead to a conclusive test of the predicted sign change of the

Sivers function. Close interaction with theorists is encouraged to understand the QCD evolution of the Sivers function.

The PAC strongly endorses the plan for a timely analysis of the Drell-Yan data collected in Run 22 with the forward upgrade. These Drell-Yan data would test the sign-change of the Sivers functions at lower Q^2 scales, greatly reducing the uncertainties associated with the QCD evolution. A successful extraction of the Drell-Yan signals from Run 22 would also bode well for the proposed measurement of nuclear antiquark distributions for Run 24 using the Drell-Yan process.

3.1.2 STAR - Heavy Ion Update on BES-II, Isobars and Small Systems

STAR should be commended and congratulated for finishing the blind analysis of Chiral Magnetic Effect (CME) observables and achieving unprecedented precision in the data. The PAC is also impressed by the diligence with which STAR is treating the scaling related to the surprising difference in multiplicities and flow between the two isobaric systems.

Progress is being made in the analysis of BES II data. The PAC is especially impressed by the successful completion and publication of the 3 GeV FXT data analysis. These results supply crucial experimental input and anchor our expectations for the search for a possible critical point by providing multiple lines of evidence that collisions at 3 GeV explore hadronic matter. The PAC recognizes the challenges STAR has faced, given the need to incorporate the iTPC and EPD detectors into the BES II data analysis.

The PAC is excited to see results on collective flow and vorticity at 19.6 and 14.6 GeV, and eagerly looks forward to the publication of the net-proton kurtosis results at these energies. The PAC is also looking forward to the analysis and publication of the FXT data at other energies, in particular at 7.7 GeV, with comparison to collider data at the same energy to cross-check the results in the regime where the most intriguing beam energy dependence is observed.

We are eagerly awaiting the publication of the Run 15 and 16 small system flow results and the analysis of flow results from the new d+Au data taken in Run 21 with the extended detector capabilities.

The PAC endorses STAR's emphasis on the importance of maintaining sufficient expert person-power for software, computing and operations at BNL, as is critical for high-quality data collection, and timely calibration and production of data.

3.2 PHENIX - Status of Data Analysis and Data Preservation

PHENIX is commended for achieving the goals set by the collaboration and recommended by the PAC last year. The collaboration maintained a high level of productivity with 12 submitted papers. PHENIX made significant progress in data and analysis preservation using international expert systems such as REANA, Zenodo and HEPdata. The PAC supports these efforts in data preservation.

The PAC supports PHENIX's request to BNL management for resources necessary to complete critical analyses such as $b,c \rightarrow \mu$ decays.

3.3 Theory

The unprecedented detail of the RHIC data sets, combined with the unprecedented detail required to model BES data, represents a commensurately unprecedented challenge in interpreting data with theoretical models. Simulating collisions at BES energies involves three-dimensional models, with complicated thermalization physics, over a wide range of baryon densities. With the expanded experimental coverage and the incorporation of fixed-target data, applying and integrating such models in a way that addresses the key scientific issues requires tight coordination between STAR and the theory/modeling communities. The PAC recommends that BNL pursue a strategy to better facilitate the progress of RHIC physics through strategic involvement of the theoretical community, whether it be through workshops, visitor programs, or sabbatical support.

4. sPHENIX

sPHENIX is designed to investigate the microscopic nature of the Quark-Gluon Plasma with hard probes of unprecedented precisions at RHIC, fulfilling a critical high priority scientific mission of the nuclear physics community as identified in the DOE/NSF NSAC 2015 Nuclear Science Long Range Plan. The PAC has endorsed sPHENIX as the highest priority construction project and scientific program in 2023-2025 for RHIC since the start of the project. The PAC heard three reports from sPHENIX on the installation status and schedule, readiness for data-taking and commissioning plan, and beam use request for runs 23-25. The PAC congratulates the sPHENIX project team and the collaboration for excellent achievements in the past few years in spite of the major challenges due to the pandemic. In this section, we comment on the installation status and schedule, and the readiness for data taking and commissioning plan.

4.1 Installation Status and Schedule

The PAC commends the sPHENIX project team for excellent progress in all fronts of the sPHENIX detectors, infrastructure and facilities. The Outer HCal detector has been installed and tested; the Inner HCal has been assembled and ready to be installed into the magnet (the installation was completed a few days after the PAC meeting); and the EMCal sectors have been assembled and the sector installation fixture is being tested. Most of the TPC mechanical components are ready; all 72 quad GEM readout modules are completed and pre-assembly tests are ongoing. The TPC detector is coming together nicely at Stony Brook, albeit on a tight schedule.

All INTT silicon strip staves have been completed and tested. Half barrel assembly begins at BNL in June and the detector is on schedule for installation in January 2023. All the MVTX (MAPS) staves have been completed and tested, and assembly of half-barrel detectors is ongoing at LBNL with expected delivery to BNL in late July.

The sPHENIX Event Plane Detector (sEPD) consists of two disks of scintillating tiles, a new addition funded by NSF and led by the Lehigh group. The construction will be completed by the end of August and is on schedule for installation in January 2023.

In 2021 the PAC encouraged the TPOT (Time Projection Outer Tracker) team to develop a funding and construction plan to evaluate the impact of this new project in the sPHENIX

experiment. The PAC congratulates the sPHENIX Collaboration since the TPOT project is now moving forward and 8 micromegas chambers are planned to be installed in the gap between EMCal and TPC, helping to reduce the impact of beam-induced space-charge distortions in the TPC.

sPHENIX has been able to secure technicians and engineers from the Laboratory and resources from the collaboration to maintain the schedule towards the planned start-up of the commissioning run in Feb. 2023. The PAC endorses the continued support of the sPHENIX detector assembly, installation and commissioning, consistent with sPHENIX as the highest priority of the RHIC program.

The PAC noted the challenges presented by sPHENIX. The sPHENIX installation schedule has no float to the planned start-up date of the RHIC Run 2023. The TPC project is on a critical path. Some missing long lead-time electronics chips (Straitix III FPGA) could significantly impact DAQ/Trigger readiness for commissioning and operation. It is important for the sPHENIX project to maintain the labor force and other resources for the coming ten months in order to meet the schedule.

The PAC recommends the sPHENIX project team to continue their vetting of the schedule beyond the summer of 2022 with participation of C-AD and other possible contributors matching sPHENIX needs with available resources.

4.2 Readiness for Data Taking including Computing & Commissioning Plan

The PAC was pleased to learn that sPHENIX has met and surpassed its goals for designing, building and testing its software framework for compression, storage and analysis. Using the current snapshot, sPHENIX can analyze a Au+Au event in 21 seconds, where the 2019 goal was set at 24 seconds. Further, sPHENIX has improved the memory footprint of their reconstruction software to optimize implementation at the SDCC. Software is on schedule for simulation, reconstruction, calibration, compression and storage, for the inaugural run in February.

Since 2019 sPHENIX has undergone annual S&C reviews. The PAC is pleased to hear that the software is in place and has passed two Mock Data Challenges. Reports from the 2021 S&C reviews were positive with respect to the software, but serious problems in procuring the resources were discussed. An S&C review was undertaken in May of 2022, but the report from that review was not yet available to the PAC.

Detailed hardware requirements for off-line computing have been provided to BNL management. This includes studies of using off-site computing resources, e.g. the OSG. Not surprisingly, the 15 kHz event-rate of sPHENIX (which was the principal motivation in building sPHENIX) requires an increase in CPU and storage usage of an order of magnitude.

The serious concerns about resources for off-line computing expressed in the 2021 S&C report are not yet addressed. As these concerns affect both STAR and PHENIX, they are addressed below.

5. Off-Line Computing for Runs 23-25

The PAC expresses its most profound concern regarding the computing needs for both sPHENIX and STAR for runs 23-25. Despite the significant progress sPHENIX has made in optimizing their computational software, the sPHENIX computing needs remain an order of magnitude greater than previous experiments, and STAR is managing to double their event throughput while implementing several new detector subsystems. The current SDCC planned computing resources are more than 50% short of what is needed to meet the sPHENIX and STAR needs in 2023, and the shortfall is expected to increase in outer years. Without additional computing resources, the ability of sPHENIX to calibrate their analyses and plan for future runs will be severely compromised, and scientific results from both collaborations will be severely delayed. This shortfall needs to be addressed in the coming months to avoid a tragic underuse of the scientific effort being invested to collect this data.

The PAC urges BNL management to assign highest priority to the procurement of the computational resources needed to analyze this data in a timely manner. The PAC requests that BNL, STAR and sPHENIX provide an update on their plans for procuring the needed resources in October of this year.

6. CeC X

The CeC experimental program failed to demonstrate cooling in Run 2022. Two major failures, lack of awareness of a large calibration offset in the electron bunch charge measurement arising from a firmware upgrade and improper handling of the cathode exchange system resulting in damage to the SRF gun, caused the CeC project to be unable to take advantage of 70% of the beam time they had hoped to use. The PAC urges the CeC project to take steps to improve its communications and to enhance oversight of its operations to avoid similar issues in the future.

The PAC supports the efforts of BNL to improve operation of the CeC experiment by embedding the CeC project within a combined Beam Cooling group. The PAC recognizes the potential of the innovative PCA-based CeC for future applications, and supports BNL management to continue seeking future opportunities for experimental demonstration of CeC within the constraints of the RHIC program.

7. PAC Recommendations

STAR Analysis:

- A conclusive test of the predicted sign change of the Sivers function is the major physics goal of Run 17 and Run 22. With the successful completion of the Forward Upgrade, STAR is strongly encouraged to finalize and publish the analysis of the W and Z transverse single spin asymmetry from Run 17 in the near future. The timely analysis of the Run 22 W and Z data should also be a high priority.

- To fully evaluate the physics potentials for the STAR pp and p+Au program in Run 24, it is essential to validate the expected performance of the STAR forward detectors based on the data collected in Run 22. In particular, the ability for the forward detectors to observe Drell-Yan signals and the direct photons, which are crucial for the success of the proposed p+Au program to measure gluon and antiquark contents in nuclei at small-x, should be demonstrated, preferably by the PAC meeting in 2023.

sPHENIX:

- The PAC endorses the continued support of the sPHENIX detector assembly, installation and commissioning, consistent with sPHENIX as the highest priority of the RHIC program.

- The PAC recommends that sPHENIX work with C-AD to develop a detailed detector installation and testing "end-game integration" plan, starting from the completion of magnet mapping until the time the detector is ready for collisions. This should include a timeline for readiness of slow controls for testing, including pre-calibration as units are installed.

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, 25.

- The PAC recommends that BNL management continue providing necessary resources and administrative assistance to sPHENIX to meet its challenging schedule, and facilitate with BHSO for timely reviews and regulatory approvals needed for the sPHENIX installation, commissioning and operation.

- The PAC urges BNL management to assign highest priority to the procurement of the computational resources needed to analyze RHIC data in a timely manner.

- The PAC recommends that BNL pursue a strategy to better facilitate the progress of RHIC physics through strategic involvement of the theoretical community, whether it be through workshops, visitor programs, or sabbatical support.

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