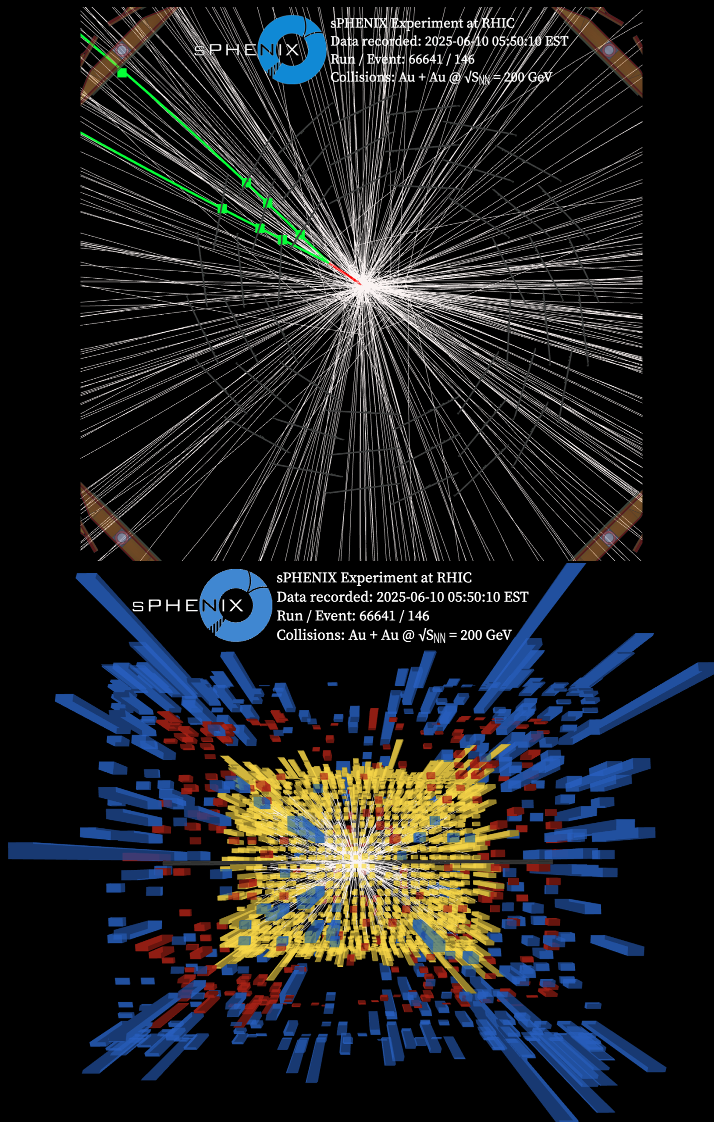
sPH-TRG-2025-01



Central Au+Au collision event recorded by sPHENIX in Run-25, showing a reconstructed $K_s^0 \to \pi\pi$ decay in the tracking system (top) and energy deposits in the calorimeter system (bottom)

sPHENIX Beam Use Proposal

October 3, 2025

Executive Summary

In this document, the sPHENIX collaboration requests that the PAC give its strongest **"must do"** endorsement for p+p $\sqrt{s} = 200$ GeV running to sample 26 pb^{-1} within $|z| < 10$ cm after completion of the current Au+Au data taking goal of 7.0 nb^{-1}. This large p+p dataset, together with the initial statistics recorded in Run-24, will enable the complete Upsilon, open beauty, and jet substructure physics program as previously endorsed by the PAC in 2023. After these goals are achieved, sPHENIX and RHIC have enormous physics leverage with 2–3 additional weeks of a smaller, symmetric light-ion running such as O+O and α+α collisions to uniquely study the onset of jet quenching in small systems. Due to significant risk to the sPHENIX data-taking capability from beam backgrounds, there is no request for p+Au running.

Answers to ALD Charge

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.

Summary answer: Figure 1 shows the total integrated luminosity and the equivalent number of minimum-bias Au+Au events within $|z| < 10$ cm recorded by sPHENIX as a function of the date in Run-25. As of the time of this writing, sPHENIX has collected 3.63 nb^{-1} of Au+Au data out of the target 7 nb^{-1}, and RHIC is not currently running due to the ongoing repair of a vacuum breach. The average data collection rate over the two most recent weeks of active data-taking is 0.049 nb^{-1}/day. Thus, whenever RHIC resumes operation, it will take an expected 69 days, or approximately 10 weeks, to reach the target of 7 nb^{-1}. If RHIC resumes data-taking on October 6th as projected, and assuming no significant further disruptions to the accelerator and experiment operations, the date for achieving the Au+Au luminosity target will be **December 14th, 2025**.

Additional information: sPHENIX Au+Au physics data taking began on June 14, 2025 and continued with improved C-AD delivered luminosity and high sPHENIX efficiency until August 26, 2025 when a damaged utility pole supporting high voltage power lines required repair. Accelerator operations and sPHENIX data collection resumed on September 10, 2025, but were again paused due to a vacuum breach near the Yellow Ring beam dump on September 25, 2025 which is being repaired at the time of this writing. Figure 1 shows the average integrated luminosity per day over the entire data-taking period, excluding these gaps, but including the slower luminosity production at the beginning of Run-24 (yellow) and the same quantity averaged over the most recent two weeks of data-taking (green). This quantity includes all factors relevant for the physics program such as the narrow vertex selection.

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

Summary answer: After the successful achievement of Au+Au data-taking goal, the sPHENIX request is to sample an integrated luminosity within $|z| < 10$ cm of 26 pb^{-1} for transversely-

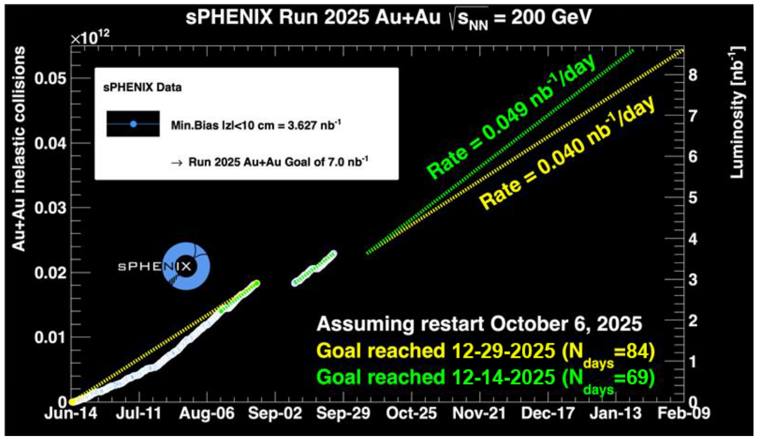


Figure 1: Integrated luminosity over the course of Run-25 Au+Au data-taking, to date as of the submission of this document. The rates and goal reached dates are detailed in the text.

polarized p+p collisions at $\sqrt{s} = 200$ GeV, of which a large fraction would also be read out in streaming mode. This goal is achievable in approximately 12 cryo-weeks of time, which includes switchover and setup time, as shown in Figure 2. This p+p dataset will enable the complete Upsilon and beauty-tagged physics program, as well as provide crucial additional statistics for jet substructure and (in the streaming dataset) open heavy flavor measurements comparing p+p and Au+Au results.

This dataset will provide significant qualitative and statistical improvements over the data collected with the entire sPHENIX detector in Run-24, and would have major benefits for the p+p reference for Au+Au measurements, unique physics with the p+p data itself, and enabling a more comprehensive comparison of p+p and Au+Au data from the same running year. Note that in Run-24, only 13 pb^{-1} was sampled by the full sPHENIX detector within the acceptance $|z| < 10$ cm (approximately 1/3 of the Run-24 goal) and only 2.9 pb^{-1} was collected in tracker-only streaming mode (approximately 2/3 of the Run-24 goal).

Additional motivation for p+p running: In Run-24 p+p, sPHENIX sampled 107 pb^{-1} of calorimeter-only data with rare jet and photon triggers, but only sampled 13 pb^{-1} of all-subsystem data with triggers within the optimal tracking detector acceptance $|z|$ <10 cm and only 2.9 pb^{-1} in the tracker-only streaming dataset. sPHENIX has been producing first-physics measurements of jets, direct photons, and neutral mesons in the former (calorimeter-only) dataset. However, the latter datasets are the relevant ones for a variety of sPHENIX flagship measurements, including Upsilon, beauty jet, open heavy flavor, and jet sub-structure physics. In particular, the triggered all-subsystem dataset corresponds to only 30% of the 45 pb^{-1} previously requested in the sPHENIX 2023 Beam Use Proposal and endorsed by the PAC for the p+p reference dataset. The small size of this sample significantly limits important Au+Au to p+p physics comparisons in these channels.

In addition to the increased statistics in Run-25 p+p running, we note several improvements to the tracking subsystems that would result in a substantially higher quality p+p baseline. For the Time Projection Chamber (TPC), these include the significantly improved gain balancing and stability from the upgraded high voltage system, the deployment of the line laser, and the implementation of digital current monitoring. Other subsystems also benefit from more optimized operating configurations, such as the improved dynamic range of the EMCal gain settings. We stress that

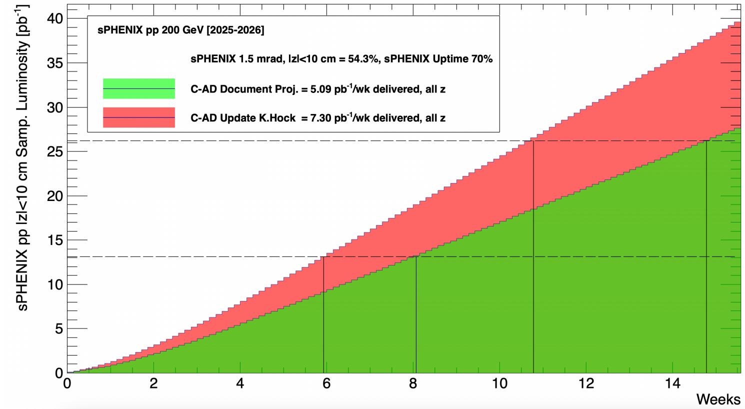


Figure 2: Projection for sPHENIX sampled luminosity within $|z| < 10$ cm in the proposed Run-25 polarized $p+p$ data-taking, as a function of number of weeks, after the initial one-week switchover and setup time. The green scenario is based on the C-AD Projection Document dated October 28, 2024. The red scenario is based on updated information from Kiel Hock and confirmed with C-AD for usage here.

these are expected to provide significant improvements to the data quality in terms of stability and calibration.

Finally, a $p+p$ run would enable data-driven calibrations of the detector state at the end of Run-25, including with the significant upgrades to the TPC listed above and other issues such as the accumulated radiation dose to the EMCal Silicon Photomultiplers, etc. This dedicated $p+p$ running would result in two calibration points which bracket either end of the Run-25 Au+Au data. The experience of sPHENIX collaborators, including from work on the LHC experiments, is that this strategy can help to significantly reduce systematic uncertainties.

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

Summary answer: sPHENIX has the optimum "must do" goal of sampling 26 pb^{-1} of $p+p$ collisions within $|z| < 10$ cm, which is achievable within 12 cryo-weeks, with a minimal goal of sampling 13 pb^{-1} in 7 cryo-weeks. These cryo-week estimate are based on the latest C-AD projections (see Figure 2) and include the estimated time needed for collision species switchover and setup for polarized proton running. We highlight that a very substantial integrated luminosity can be achieved in a shorter period of time, with even a few weeks of $p+p$ running providing significant benefits for detector calibration purposes and for the streaming dataset.

Additional information: Figure 2 shows the most up-to-date projections from C-AD and sPHENIX on the luminosity production in Run-25 $p+p$ running with 1.5 mrad crossing angle, after a one-week switchover and setup time. The luminosity on the vertical axis is the sampled luminosity via jet, photon and Upsilon triggers, and already accounts for the fraction of events within $|z| < 10$ cm, the development of the RHIC luminosity over the first few weeks, and the RHIC and sPHENIX operational efficiency (uptime). We highlight that in these projections, we choose to use a conservative 70% sPHENIX uptime, as the experiment has demonstrated 75-80% uptime during

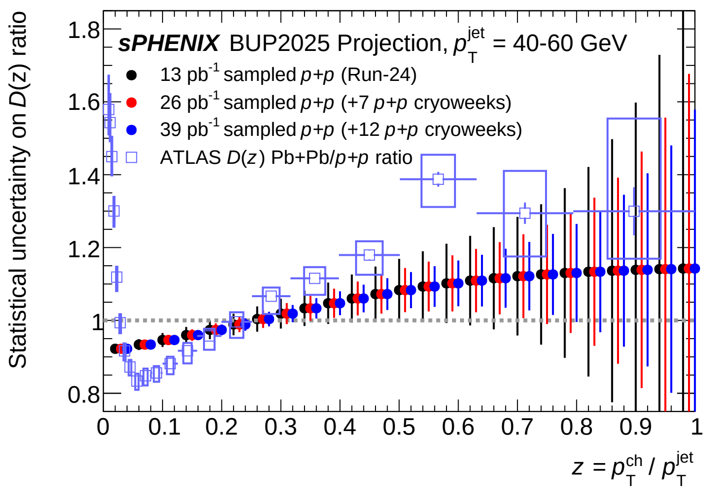


Figure 3: Statistical uncertainty projections on the ratio of the jet to charged hadron fragmentation function $D(z)$ for $p_T = 40$–60 GeV jets, between Au+Au and p+p data. The uncertainties correspond to those from the p+p reference, which is the limiting dataset in the comparison. The points represent the statistics in the triggered full-subsystem dataset recorded in Run-24 (black) and the impact of additional p+p running (red, blue). The uncertainties are compared to the magnitude of the fragmentation function modification found at the LHC by the ATLAS experiment.

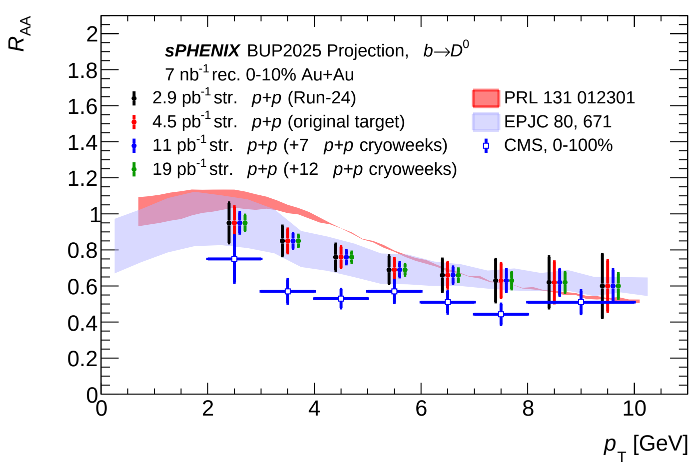


Figure 4: Statistical uncertainty projections on the R_{AA} of non-prompt $b \to D^0$'s as a function of p_T in central Au+Au events, under different p+p luminosity scenarios for the streaming dataset. The CMS measurement of $b \to D^0$ is shown for comparison. While there are $b \to e$ measurements at RHIC in Au+Au events, the sPHENIX measurement in this channel would be unique.

the current Au+Au data taking in 2025.

Running p+p collisions for 12 (7) cryo-weeks results in a projected additional 26 pb^{-1} (13 pb^{-1}) of all-subsystem, triggered integrated luminosity. Figure 3 shows a projection for an example observable, the jet fragmentation function $D(z)$, for which the Run-24 p+p reference is currently the statistically limiting dataset in comparisons to Au+Au data. For the jet p_T range shown here, the uncertainties at mid-z would make the measurement compatible with both no modification and also the magnitude of $D(z)$ modification observed at the LHC. A larger $p+p$ dataset from an additional 12 or even 7 cryo-weeks would significantly improve the sPHENIX capability to map out this aspect of parton shower modification in detail. Similar quantitative benefits would be expected for all jet (sub-) structure, jet–hadron correlation, and b-jet production measurements which use the tracking and calorimeter systems together in the triggered mode.

In addition, a fraction of the total luminosity could be read out in tracker-only streaming mode. The sPHENIX data acquisition data throughput in Run-25 has been more than doubled compared to Run-24, and thus the streaming fraction is estimated to increase to 60% (up from a projected 10% before data-taking and a 30% fraction achieved in Run-24). Thus, 12 (7) cryo-weeks of $p+p$ running could provide at least 16 pb^{-1} (8 pb^{-1}) of additional, fully unbiased $p+p$ collision data for the low-p_T heavy-flavor physics and collectivity programs, compared to the existing 2.9 pb^{-1} streaming dataset in Run-24 and original target of 4.5 pb^{-1}. Figure 4 shows the impact of additional $p+p$ streaming data for the statistical precision of the open heavy-flavor nuclear modification factor. For nuclear modification factors of charm and bottom, the $p+p$ reference is the statistically limiting one. Reducing these uncertainties is crucial for distinguishing between models, constraining specific model parameters, and for complementarity with such measurements at the LHC.

Furthermore, the larger dataset would result in excellent prospects for sPHENIX-unique measurements just within the $p+p$ system itself, which have been previously unexplored at RHIC. These include the D^0 single-spin asymmetry (shown in Fig. 5), the ratios of identified heavy-flavor hadrons for testing hadronization universality, and qualitatively new measurements enabled by the exceptional luminosity. We also highlight that precision measurements in polarized $p+p$ collisions have a natural connection to the physics of the Electron Ion Collider.

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

Summary answer: In the scenario where the Au+Au luminosity target had been met and there are a few weeks remaining, sPHENIX would propose to take some $p+p$ data. Even if the minimum target of 7 cryo-weeks in Question 3 could not be met, the much improved streaming fraction means that a short few-week $p+p$ run could still provide 2–3 pb^{-1} of tracker-only streaming data, thus successfully bringing the total streaming dataset above its original 4.5 pb^{-1} goal, as can be seen in Figure 5. Furthermore, as discussed in Question 2, measurements in the Au+Au dataset would potentially benefit in reduced systematic uncertainties from having an adjacent-in-time $p+p$ data sample with the identical detector configuration.

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

Summary answer: If the Au+Au and $p+p$ luminosity targets have been met, and there is additional beam time remaining, the sPHENIX request is for a few weeks of novel light-ion running, e.g., O+O and potentially a smaller system such as $\alpha + \alpha$. There is no sPHENIX request for p+Au running due to the current lack of a solution for MVTX operation in streaming mode with Au-beam backgrounds.

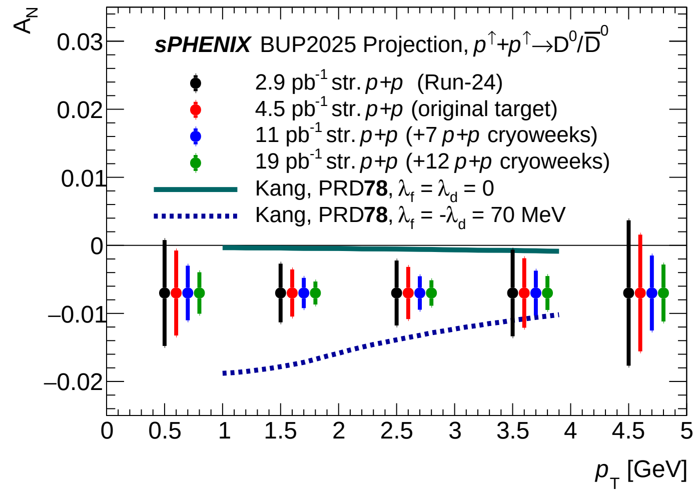


Figure 5: Statistical projections for the D^0 single spin asymmetry A_{N} as a function of p_{T} in polarized $p^{\uparrow} + p^{\uparrow}$ collisions, under different luminosity scenarios. Theoretical calculations for two different physics scenarios are shown for comparison.

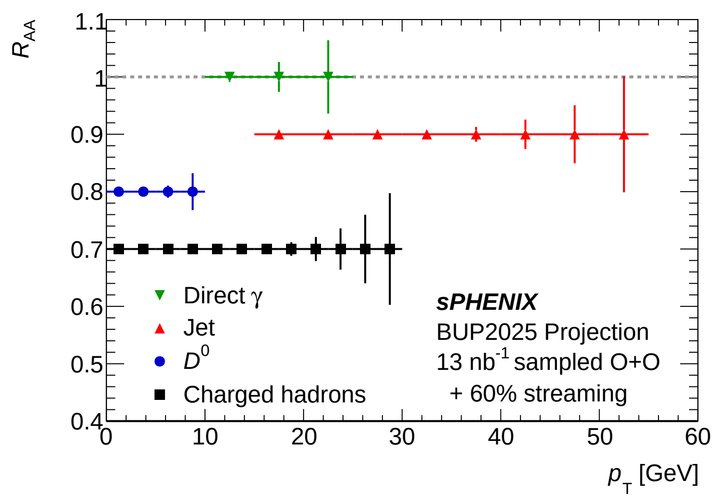


Figure 6: Statistical projections of the R_{AA} for key sPHENIX measurements in two weeks of O+O running, assuming a streaming fraction similar to that in p+p. The R_{AA} values are chosen arbitrarily to illustrate the possible magnitude of quenching effects.

Additional information on O+O operation: sPHENIX has maintained a strong interest in exploring light-ion collision systems such as O+O, dating back to the Beam Use Proposal 2020 and even the original sPHENIX design document. These systems offer a way to understand the relationship between high-p_{T} parton-QGP interactions and strong hydrodynamic behavior, two pillars of the standard model of heavy-ion physics, which appears to be broken in p+A-type collisions. Brand new results from the recent O+O running at the LHC, presented last month at the Initial Stages conference, have confirmed that these systems obey the heavy-ion paradigms of flow and jet quenching, and allow for the exploration of the onset of jet quenching in a much cleaner and

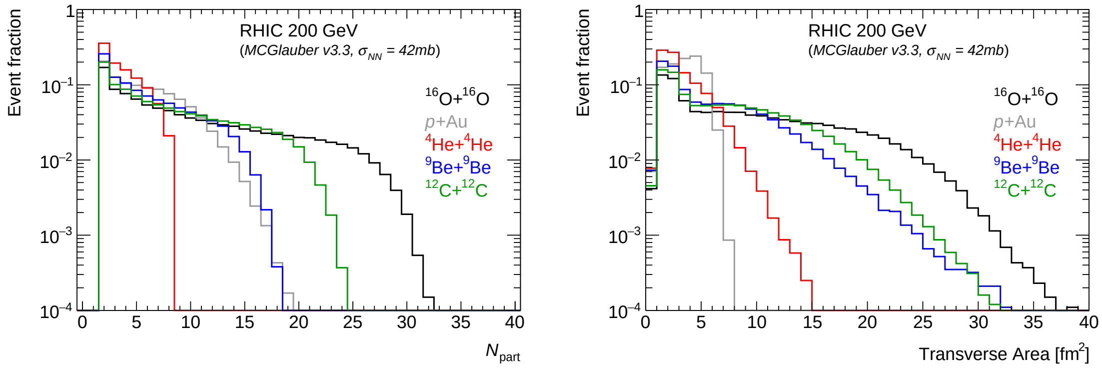


Figure 7: Geometric properties of light-ion collisions at RHIC energies, including O+O (black), p+Au (silver), and three potential systems $\alpha+\alpha$ (red), ^{9}Be+^{9}Be (blue), and ^{12}C+^{12}C (green) available for running at RHIC. Shown are the distribution of the number of participants (left) and the transverse area (right), the latter estimated using smeared nucleon profiles and a 4π prefactor normalization.

high-statistics environment compared to, e.g., peripheral Pb+Pb collisions.

RHIC has run this specific collision species just a few years ago in Run 21, and based on this experience sPHENIX might sample 10–15 nb^{-1} with rare jet and photon triggers in a few-week run. We expect that beam background issues, if any, will not preclude collecting a large streaming heavy-flavor physics and collectivity dataset. This is because the O nucleus is less than one-tenth the mass of Au and thus is much less likely to cause the extremely high density of hits in the MVTX that upsets the streaming mode (as is also suggested by the observed nature of the background in $p+p$ collisions). Although there is an existing STAR O+O dataset, it was not collected with a high-p_{T} trigger and thus corresponds to a significantly smaller integrated luminosity. Figure 6 shows projections for high-p_{T} and collective probes from a two-week O+O run in sPHENIX which, since it is based on the Run-21 experience, also includes the needed few-day setup time.

Additional information on lighter ions: The clear indications of jet quenching in O+O combined with the strong constraints in p+A-type collisions have led to speculation that there is a minimum medium length necessary to induce significant interactions. Figure 7 shows the distributions of the number of participating nucleons, N_{part}, and the transverse area of the collision zone, A_{T}, for O+O and p+Au collisions, as well as a selection of symmetric ions lighter than oxygen. Thus, following the emerging scientific direction of the field, sPHENIX notes that an $\alpha+\alpha$ run (for example) would produce a unique dataset which has a similar transverse size as p+Au but does not have the extreme asymmetry of that system.

C-AD has confirmed that the EBIS source can produce light elements from helium (α) on up, with the particular intensities and injection efficiencies varying by species, and that the setup time is likely to be similar to O+O. Any lighter ion running, which would only be preferred after the successful collection of the higher-priority $p+p$ and O+O data, would capitalize on the unique flexibility and scientific advantage of the RHIC facility one final time. Receiving scientific input from the PAC on the optimal choice of species would be valuable.

Additional information on p+Au operation: At the beginning of sPHENIX commissioning with Au+Au in Run-23, it became apparent that running with Au beams at RHIC includes a beam background to which the sPHENIX MVTX is highly sensitive. In a background event, a displaced

Au nucleus strikes the MVTX structure, causing a very large number of hits in a "streak" along an MVTX sensor, which locks up the readout pipeline for the affected MVTX stave for a significant dead-time until it can perform an auto-recovery (AR). A joint sPHENIX/C-AD beam background task force performed a large number of dedicated studies, including during the conclusion of Au+Au commissioning at the end of Run-24, aimed at understanding and mitigating the nature of the background. These studies included the addition of background scatter ("collar") and monitoring detectors ("donuts") to sPHENIX, and different configurations of the RHIC machine and specific beam orbits by C-AD. While some interventions did affect the observed background, none were demonstrated to successfully reduce it to acceptable levels. Thus, it was decided to run the MVTX in triggered mode during Run-25 Au+Au operation, which reduces the AR rate by a factor of 15 and allows for data-taking with minimal impact to the heavy-flavor physics program. This is possible because Au+Au collision rates are sufficiently low that all $|z| < 10$ cm collisions can be taken with minimum-bias triggers within the DAQ bandwidth.

In p+Au running, the collision rates are much larger than the DAQ trigger rate limit and thus a triggered plus streaming data-collection strategy is most appropriate. If the MVTX were run in triggered mode, then sPHENIX could collect full-subsystem data with rare jet and photon triggers sampling the full luminosity, but record a minimum-bias dataset which is only a small subset of the total p+Au luminosity. This means that sPHENIX would not have a heavy-flavor physics program in p+Au running (except for particularly high-p_{T} heavy-flavor hadrons in jets) or a large minimum-bias sample for studies of multi-particle correlations and collective phenomena.

We further note that RHIC has not run p+Au collisions in ten years, and that C-AD estimates two weeks will be needed for the switchover and setup to this new collision system. After that time, sPHENIX and C-AD could make an additional attempt to identify a beam background and MVTX working point to run in streaming or hybrid triggered + extended readout mode. This would be a period of time in which sPHENIX needs full control of the machine for single-beam and beam-orbit tests, with different configurations of the MVTX and collar absorber. We stress that even after this significant time investment (two weeks for switchover and setup and one week for sPHENIX development), there is no assurance of an operating point that would enable the heavy flavor and collectivity program in p+Au data-taking.

Thus, there is no request for p+Au running from sPHENIX at the end of Run-25. If the decision is made to run p+Au collisions, sPHENIX will attempt to take high-quality data but there is no specific projected physics output, due to the risks described above.

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

Summary answer: The NPP-PAC has played an instrumental role in the sPHENIX physics program over the last decade from the initial planning, through reviews and approval, construction, and now data taking. After the conclusion of RHIC data-taking, there will be many critical years of producing, reconstructing, calibrating, analyzing, and eventually preserving the unprecedentedly large datasets recorded by sPHENIX. These tasks will require strong, continued support by Brookhaven National Laboratory and the Department of Energy, in terms of computing resources, computing person power, and user support. We highly recommend that the PAC continue to meet annually for at least the first few years after the end of Run-25 to discuss these issues and advise the ALD.