sPH-TRG-000: sPHENIX five-year running scenario and luminosity projections

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1 Overview

This sPHENIX note documents one scenario for an sPHENIX five-year run plan, including (1) details on C-AD luminosity inputs, (2) experimental commissioning time and ramp up, and (3) implications for trigger requirements, radiation doses, and charge track densities in the detectors. A summary of this scenario is given in Tables 1 and 2. We note that the C-AD projections cover a range of calendar years from 2022-2027 relevant to sPHENIX running. Since the start of sPHENIX running may move due to external constraints, we refer to the five-years as Year-1 through Year-5.

In the Au+Au at 200 GeV case, the physics will predominately come from recording minimum bias collisions. Some additional physics may be "sampled" with rare event triggers, for example high p_T direct photons. To be explicit, in the Au+Au case, the potential gain in statistics for events within the tight z-vertex cut with selective triggering is 550/239 = 2.3 (just over a factor of two gain). If one can make useful (still to be demonstrated) physics measurements outside that z-vertex range (e.g. with only calorimeters or with just partial TPC tracking and accounting for additional inner detector support material), and effectively trigger, one can gain an even larger factor of 1500/239 = 6.27 (just over a factor of six). Of course if these triggers do not have very good rejection, one will use up bandwidth otherwise allocated for minimum bias Au+Au events.

In the p+p and p+Au case, the physics will predominantly come from Level-1 triggered events utilizing photon, electron (e.g. from Upsilon decays), hadron, and jet triggers. Thus, the key value is the sampled luminosity. Note that some observables such as lower p_T hadrons (from D, B decays) will likely not sample the full luminosity. Calorimeter only measurements

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Table 1: Five-year run plan scenario for sPHENIX. The recorded luminosity (Rec. Lum.) and first sampled luminosity (Samp. Lum.) values are for collisions with z-vertex $|z| < 10$ cm. The final column shows the sampled luminosity for all z-vertex values, relevant for calorimeter only measurements.

Year	Species	Energy [GeV]	Phys. Wks	Rec. Lum.	Samp. Lum.	Samp. Lum. All-Z
Year-1	Au+Au	200	16.0	7 nb^{-1}	8.7 nb^{-1}	34 nb^{-1}
Year-2	p+p	200	11.5	—	48 pb^{-1}	267 pb^{-1}
Year-2	p+Au	200	11.5	—	0.33 pb^{-1}	1.46 pb^{-1}
Year-3	Au+Au	200	23.5	14 nb^{-1}	26 nb^{-1}	88 nb^{-1}
Year-4	p+p	200	23.5	—	149 pb^{-1}	783 pb^{-1}
Year-5	Au+Au	200	23.5	14 nb^{-1}	48 nb^{-1}	92 nb^{-1}

Table 2: Summary of integrated samples summed for the entire five-year scenario.

Species	Energy [GeV]	Rec. Lum.	Samp. Lum.	Samp. Lum. All-Z
Au+Au	200	35 nb^{-1} (239 billion)	80 nb^{-1} (550 billion)	214 nb^{-1} (1.5 trillion)
p+p	200	—	197 pb^{-1} (8.3 trillion)	1.0 fb^{-1} (44 trillion)
p+Au	200	—	0.33 pb^{-1} (0.6 trillion)	1.46 pb^{-1} (2.6 trillion)

may utilize most of the z-vertex range for rare probes such as high p_T direct photons and jets.

For Au+Au minimum bias events, the average number of binary collisions is $\langle N_{coll} \rangle \approx 250$. Thus, for hard processes the 239 billion Au+Au events recorded within $|z| < 10$ cm have a rough equivalence in statistics to 59 trillion p+p events. Similarly, for p+Au the $\langle N_{coll} \rangle = 4.7$, and thus for hard processes the 0.6 trillion p+Au events have a rough equivalence in statistics to 2.8 trillion p+p events. Note of course that for the Au+Au sample, analyses will divide the data into centrality selections.

2 RHIC Luminosity Projections

For planning purposes in this document, we use luminosity projection numbers provided by the Collider-Accelerator Division (C-AD). The version of the document titled "RHIC Collider Projections (FY 2017 - FY 2027)" utilized for this study is dated 12 May 2017 and utilizes knowledge gained from the Run-15 p+p and p+Au at 200 GeV running and the Run-16 Au+Au at 200 GeV running. The document is available at:

http://www.rhichome.bnl.gov/RHIC/Runs/RhicProjections.pdf

Note that the document linked above is periodically updated, so note the date tag. In general, C-AD provides a minimum and maximum luminosity per week for each running period, as well as the fraction of collisions within a given z-vertex range. For calculating the integrated luminosity, we assume a ramp-up curve and then a steady-state physics running at the mean of the minimum and maximum in both luminosity and z-vertex fraction f_z (where a minimum and maximum are given).

2.1 Vertex Range

For this sPHENIX set of calculations, we consider the z-vertex range -10 cm $< z <$ + 10 cm, referred to as f_{z10}, i.e. the narrow vertex range. The f_{z10} values decrease during the course of a store due to broadening of the bunches. This modest effect is not taken into account in these calculations.

With the MAPS inner tracker as detailed in the MVTX pre-proposal, the active ladder length is 271.2 mm or ±135.6 mm. The layers are at R_1 = [22.4-26.7] mm, R_2 = [30.1-34.6] mm, and R_3 = [37.8-42.1] mm [see Table 2 of the MVTX pre-proposal]. Therefore, collisions taking place with ±10 cm will have acceptance of $|\eta| \leq 1.0$ if one requires all tracks in this η range to pass through at least two layers of MAPS. We may also quote values for all z-vertices $f_{zall} = 1$, and these events are potentially useful for calorimeter only measurements (for example inclusive direct photons and photon-jet correlations).

At this point, we do not include effects from the z-vertex resolution of the sPHENIX minimum bias (MB) trigger detector in being able to select specifically events within the ±10 cm range. We expect an approximate resolution of $\sigma \approx 0.5 - 1.0$ cm in Au+Au collisions at 200 GeV. We also highlight that the tracking has a somewhat larger z-vertex collision coverage that can be utilized, just without the same $|\eta| \leq 1.0$ coverage.

2.2 Ramp-Up Assumptions

For mapping out a run plan, we state both cryo-weeks for a running period and also physics data taking weeks, i.e. when Physics Running is declared by C-AD. The guidance from C-AD is that there is a 0.5 week "cool down from 50 K to 4 K", then a 2.0 week "set-up mode" for the specific collision species, and then a 0.5 week "ramp-up". If switching species, there is again a 2.0 week "set-up" and 0.5 week "ramp-up". Lastly, at the end of the running period, there is a 0.5 "warm-up from 4 K to 50 K".

In addition, we assume that in the first, second and third weeks of declared Physics Running, one achieves 25%, 50%, and then 75% of the luminosity target, with subsequent weeks at 100% (again of the mean of the minimum and maximum).

2.3 Summary of C-AD Numbers

Here are the basic inputs for the three collisions systems considered in this sPHENIX run plan (p+p, p+Au, Au+Au all at 200 GeV).

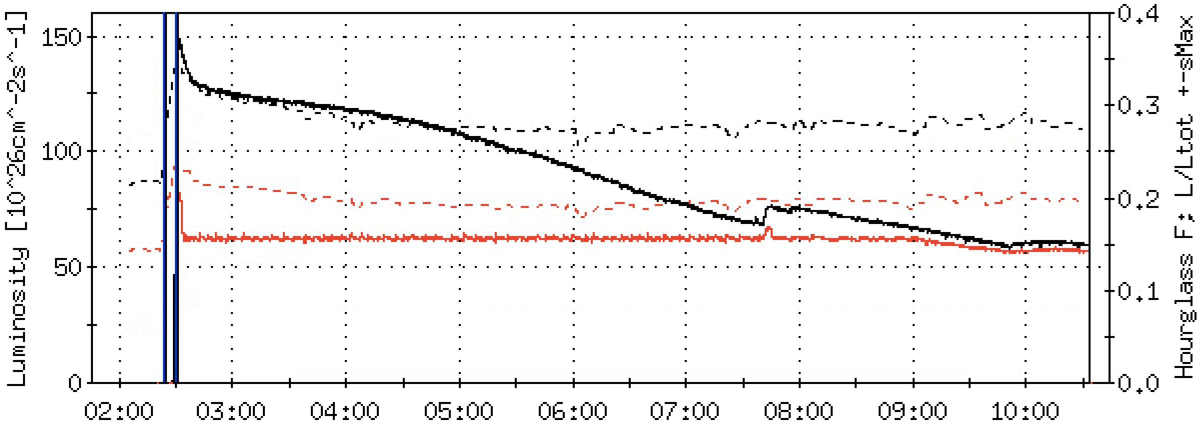

Figure 1: Run-16 Au+Au at 200 GeV store. The black line shows the luminosity (left y-axis units) as a function of time in store in hours. The red dashed line shows the fraction of collisions within ± 10 cm.

2.3.1 Au+Au at 200 GeV

The C-AD projections are summarized in their document, Table 4. We reproduce some of those key values here in Table 3.

Table 3: Summary of C-AD key values for Au+Au at 200 GeV running with the year labels as given in the C-AD document.

Mode	nb^{-1}/wk [min]	nb^{-1}/wk [max]	f_{z10} [min]	f_{z10} [max]	ave/peak	peak rate [max]	peak rate $\times f_{z10}$ [max]
Au+Au (2022E)	3	4.75	0.19	0.3	0.6	1.5E5	4.5E4
Au+Au (2024E)	3	7.02	0.3	0.3	0.6	2.2E5	6.6E4
Au+Au (2026E)	3	7.51	0.3	0.3	0.6	2.4E5	7.1E4

We consider running Au+Au in three calendar years (Year-1, Year-3, Year-5). For the Year-1 run, we utilize the C-AD values they label as **2022E**, where the minimum values correspond to those achieved in the 2016 run and the maximum are 58% higher. Wolfram Fischer has provided us with Figure 1 showing an example "best store" from Run-16 Au+Au at 200 GeV, where "best" is actually one of many stores that were reproduced with the same settings. The $f_{z10} = 0.19$ from Run-16 Au+Au is used as the minimum value, and $f_{z10} = 0.30$ is the projected maximum value.

2.3.2 p+p at 200 GeV

The C-AD projections are summarized in their document, Table 6. We reproduce some of those key values here in Table 4. Wolfram Fischer has provided us with Figure 1 showing an

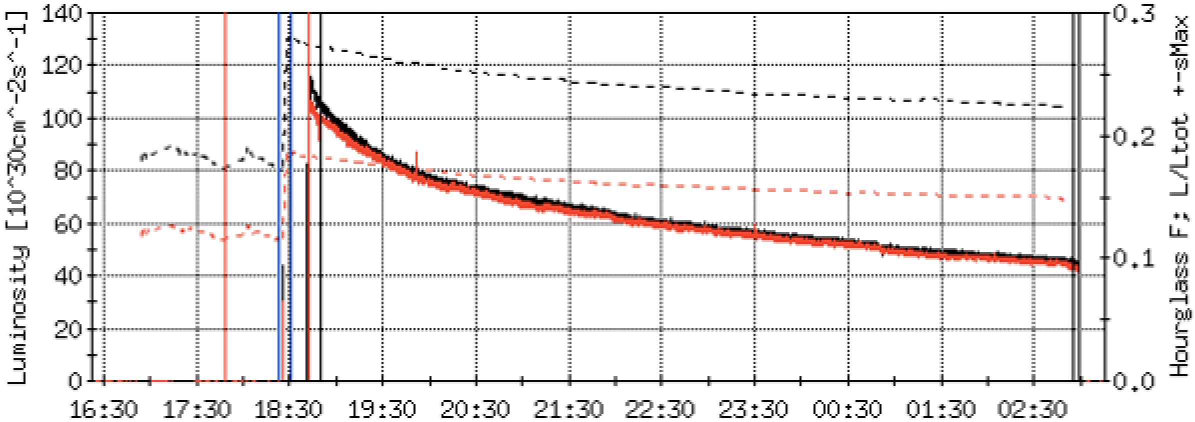

Figure 2: Run-15 p+p at 200 GeV store. The black line shows the luminosity (left y-axis units) as a function of time in store in hours. The red dashed line shows the fraction of collisions within ± 10 cm.

example "best store" from Run-15 p+p at 200 GeV, where "best" is actually one of many stores that were reproduced with the same settings.

Table 4: Summary of C-AD key values for p+p at 200 GeV running.

Mode	pb^{-1}/wk [min]	pb^{-1}/wk [max]	f_{z10} [min]	f_{z10} [max]	ave/peak	peak rate [max]	peak rate $\times f_{z10}$ [max]
p+p (2023E)	25	64	0.16	0.19	0.6	1.2E7	2.4E6
p+p (2025E)	25	64	0.19	0.19	0.6	1.2E7	2.4E6

2.3.3 p+Au at 200 GeV

The C-AD projections are summarized in their document, Table 8. We reproduce some of those key values here in Table 5.

Table 5: Summary of C-AD key values for p+Au at 200 GeV running.

Mode	pb^{-1}/wk [min]	pb^{-1}/wk [max]	f_{z10} [min]	f_{z10} [max]	ave/peak	peak rate [max]	peak rate $\times f_{z10}$ [max]
p+Au (2023E)	0.14	0.35	0.17	0.25	0.6	2.8E6	6.9E5

Weeks	Designation
0.5	Cool Down from 50 K to 4 K
2.0	Set-up mode 1 (Au+Au at 200 GeV)
0.5	Ramp-up mode 1 (8 h/night for experiments)
10.5	sPHENIX Initial Commission Time
16.0	Data taking mode 1 (Physics)
0.5	Controlled refrigeration turn-off
30.0	Total cryo-weeks

Table 6: Example cryo-week run plan for the first sPHENIX run in Year-1 with Au+Au at 200 GeV collisions.

3 5-Year sPHENIX Run Plan

For this plan, we assume an sPHENIX uptime (i.e. the fraction of time when collisions are available that sPHENIX is taking data with high livetime) of 0.60 for the first two years of running (Year-1 and Year-2) since the detector is being commissioned and new Level-1 triggers are being brought online, and 0.80 for the subsequent runs Years-3,4,5. These uptime value fold in the expected deadtime of the data acquisition system - of order 90-95%. Note that the first year of running also includes substantial additional commissioning time, not included in the physics data taking segment.

RHIC C-AD projections for time in store (i.e. RHIC uptime) vary slightly with most of the projected values around 0.60. Thus, we will use this single value for all cases. It is notable that C-AD projections are for a nominal 8 hour store; however, a more optimal store length may be found in future running at closer to 5 hours.

3.1 Au+Au at 200 GeV

For the first sPHENIX run in Year-1 with Au+Au at 200 GeV collisions, we plan on 30 cryo-weeks as detailed in Table 6. Significant commissioning time is included in the run plan. Again note that in addition to the specifically called out ”Initial Commission Time” and assumed sPHENIX uptime is 60% for the first two runs.

Subsequent Au+Au at 200 GeV runs (Year-3 and Year-5) have 23.5 weeks of Physics Data Taking are no additional commissioning time - thus adding up to a total of 27 cryo-weeks each.

A useful number for Au+Au at 200 GeV collisions assuming a 6.8 barn inelastic cross section is that $1nb^{-1} = 6.8 \times 10^9$ events. Thus, the recorded event sets of 7, 14, and 14 $1nb^{-1}$ for the runs in 2022, 2024, and 2026 respectively, correspond to 47, 96, and 96 billion events. The key requirements to achieve these recorded event sets are (1) the sPHENIX Data Acquisition Level-1 accept rate of 15 kHz with livetime from 90-95%, (2) the luminosity corresponds to a rate of collisions within $|z| <$10 cm during the store above 15 kHz, and (3) maintaining the sPHENIX and RHIC uptime projections. Figure 3 shows the Au+Au

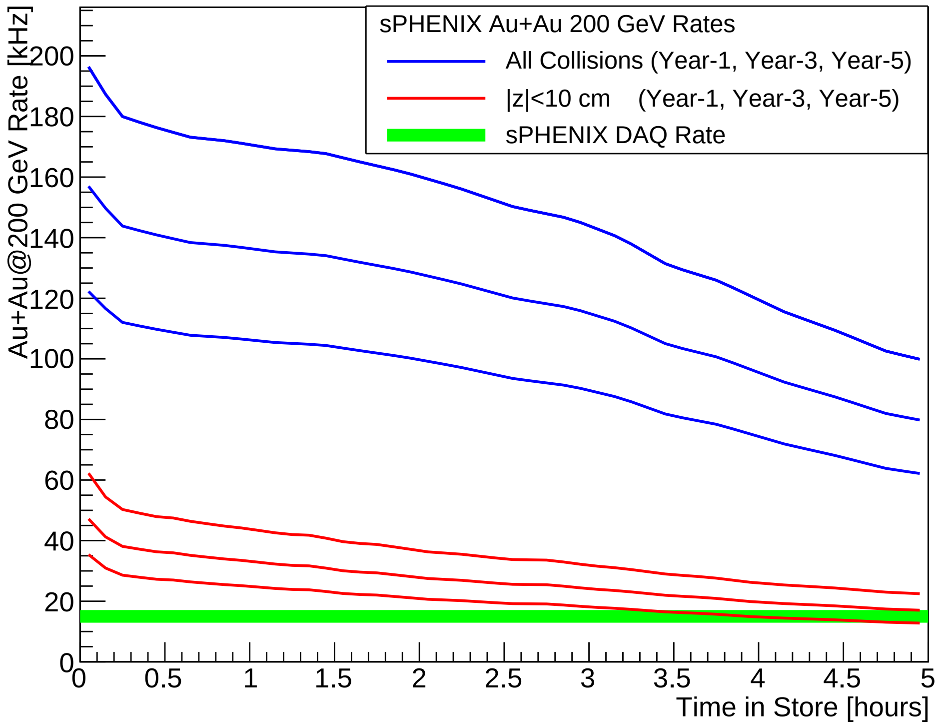

Figure 3: Estimated Au+Au at 200 GeV collision rate as a function of time in store for all collisions (blue) and collisions within ± 10 cm (red). The bottom to top set of curves in each color are for the mean luminosity and f_{z10} for the C-AD projections labeled in their document as 2022E, 2024E, 2026E and corresponding to sPHENIX running in Year-1, Year-3, and Year-5. Also shown as a green band is the sPHENIX DAQ Rate of 15 kHz for reference.

collision rate as a function of time in store in hours for the three years of projected running both with and without the z-vertex cut. This indicates that condition (2) above is satisfied.

3.2 p+p and p+Au at 200 GeV

The run in Year-2 is projected to be split between p+p and p+Au at 200 GeV with the cryo-week plan shown in Table 7.

Note that for all the luminosity projections and conversions to collision rates we utilize as total inelastic cross sections: 6.8 barns, 1.7 barns, 42 millibarns for Au+Au, p+Au, and p+p respectively.

Weeks	Designation
0.5	Cool Down from 50 K to 4 K
2.0	Set-up mode 1 (p+p at 200 GeV)
0.5	Ramp-up mode 1 (8 h/night for experiments)
11.5	Data taking mode 1 (p+p Physics)
2.0	Set-up mode 2 (p+Au at 200 GeV)
0.5	Ramp-up mode 2 (8 h/night for experiments)
11.5	Data taking mode 2 (p+Au Physics)
0.5	Controlled refrigeration turn-off
29.0	Total cryo-weeks

Table 7: Example cryo-week run plan for Year-2.

4 Charge Particle Flux

The inner tracking detectors have performance issues related to the total charge particle flux - i.e. the number of charged particle tracks per unit pseudorapidity per unit time. The Time Projection Chamber in particular will have space charge distortions that are related to exactly this quantity - i.e. $dN_{ch}/d\eta$/second. In Table 8, we show the estimated midrapidity $dN_{ch}/d\eta$, the maximum projected peak collision rate (over all vertices since they all contribute charge in the detector), and the figure of merit $dN_{ch}/d\eta$/second.

Table 8: Charged particle instantaneous rate (max). These values are the maximum projected values during the five-year run plan and are from collisions over all z-vertex values.

System	Energy	$dN_{ch}/d\eta$	Highest Rate	$dN_{ch}/d\eta$/second
p+p	200 GeV	2.29	12.9 MHz	28×10^6
p+Au	200 GeV	9.16	2.8 MHz	29×10^6
Au+Au	200 GeV	190	219 kHz	45×10^6

5 Radiation Dose

There are other detectors that are sensitive to the total integrated charged particle production over all running periods. These are related to things like radiation damage or degredation - for example the SiPMs. Note that radiation exposure can be related to beam-scrape, beam-loss events, which are not accounted for here. The results below give a quantity that should be proportional to the collision related radiation exposure.

Table 9 gives values for the estimated total charged particle exposure per unit pseudorapidity.

Table 9: Scaling with radiation dose (collision related only). The Integrated Charge Particles represents the total number of charged particles per unit pseudo-rapidity in all collisions during the running period. These are maximum values. The values listed for Run-15 p+p and Run-14 Au+Au are very rough estimates given the length of the runs and the high value luminosities.

System	Energy	$dN_{ch}/d\eta$	Run	Integrated Charged Particles
p+p	200 GeV	2.29	Run-15	2.5E13
p+p	200 GeV	2.29	2023	3.7E13
p+p	200 GeV	2.29	2025	11.0E13
p+Au	200 GeV	9.16	2023	3.2E13
Au+Au	200 GeV	190	Run-16	2.7E13
Au+Au	200 GeV	190	2022	5.3E13
Au+Au	200 GeV	190	2024	16.0E13
Au+Au	200 GeV	190	2026	17.0E13

6 Trigger Requirements

In particular for the physics program in p+p and p+Au selective Level-1 triggers are required to sample the full luminosity. Triggering using the EMCal for single photons (typically with p_T greater than 10 Gev/c) and for electrons (from Upsilon decays typically with p_T greater than 3-4 GeV/c) are in development. In addition, triggering using the combined EMCal and HCal are needed for selected jets and single hadrons. At the highest p+p interaction rates, rejection factors of order 5000-10,000 are needed to result in a 1-2 kHz bandwidth allocation. A separate note will detail the Level-1 trigger projected performance.

More challenging will be extracting additional physics in Au+Au collisions beyond the recorded minimum bias sample. It might be reasonable to reduce the 15 kHz minimum bias archiving rate by 1-2 kHz in order to free up bandwidth to sample the full luminosity for a few rare triggers. For example, sampling the full Au+Au luminosity for single photons with p_T greater than 15 GeV/c should require very modest bandwidth. Sampling additional luminosity for the highest p_T jets or Upsilons decays (perhaps in peripheral events only) will be more challenging.