

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

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7 **1 Overview**

8 This sPHENIX note documents one scenario for an sPHENIX five-year run plan, including
9 (1) details on C-AD luminosity inputs, (2) experimental commissioning time and ramp up,
10 and (3) implications for trigger requirements, radiation doses, and charge track densities
11 in the detectors. A summary of this scenario is given in Tables 1 and 2. We note that
12 the C-AD projections cover a range of calendar years from 2022-2027 relevant to sPHENIX
13 running. Since the start of sPHENIX running is not set, we refer to the five-years as Year-1
14 through Year-5.

15 In the Au+Au at 200 GeV case, the physics will predominately come from recording min-
16 imum bias collisions. Some additional physics may be "sampled" with rare event triggers, for
17 example high p_T direct photons. In the p+p and p+Au case, the physics will predominantly
18 come from Level-1 triggered events utilizing photon, electron (e.g. from Upsilon decays),
19 hadron, and jet triggers. Thus, the key value is the sampled luminosity. Note that some
20 observables such as lower p_T hadrons (from D, B decays) will likely not sample the full
21 luminosity. Calorimeter only measurements may utilize most of the z-vertex range for rare
22 probes such as high p_T direct photons and jets.

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

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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)

29 **2 RHIC Luminosity Projections**

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

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

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

42 **2.1 Vertex Range**

43 For this sPHENIX set of calculations, we consider the z-vertex range $-10 \text{ cm} < z < +10 \text{ cm}$,
 44 referred to as f_{z10} , i.e. the narrow vertex range. The f_{z10} values decrease during the course

45 of a store due to broadening of the bunches. This modest effect is not taken into account in
46 these calculations.

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

54 At this point, we do not include effects from the z-vertex resolution of the sPHENIX
55 minimum bias (MB) trigger detector in being able to select specifically events within the
56 ± 10 cm range. We expect an approximate resolution of $\sigma \approx 0.5 - 1.0$ cm in Au+Au
57 collisions at 200 GeV. We also highlight that the tracking has a somewhat larger z-vertex
58 collision coverage that can be utilized, just without the same $|\eta| \leq 1.0$ coverage.

59 **2.2 Ramp-Up Assumptions**

60 For mapping out a run plan, we state both cryo-weeks for a running period and also physics
61 data taking weeks, i.e. when Physics Running is declared by C-AD. The guidance from
62 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
63 mode" for the specific collision species, and then a 0.5 week "ramp-up". If switching species,
64 there is again a 2.0 week "set-up" and 0.5 week "ramp-up". Lastly, at the end of the running
65 period, there is a 0.5 "warm-up from 4 K to 50 K".

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

69 **2.3 Summary of C-AD Numbers**

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

72 **2.3.1 Au+Au at 200 GeV**

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

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

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

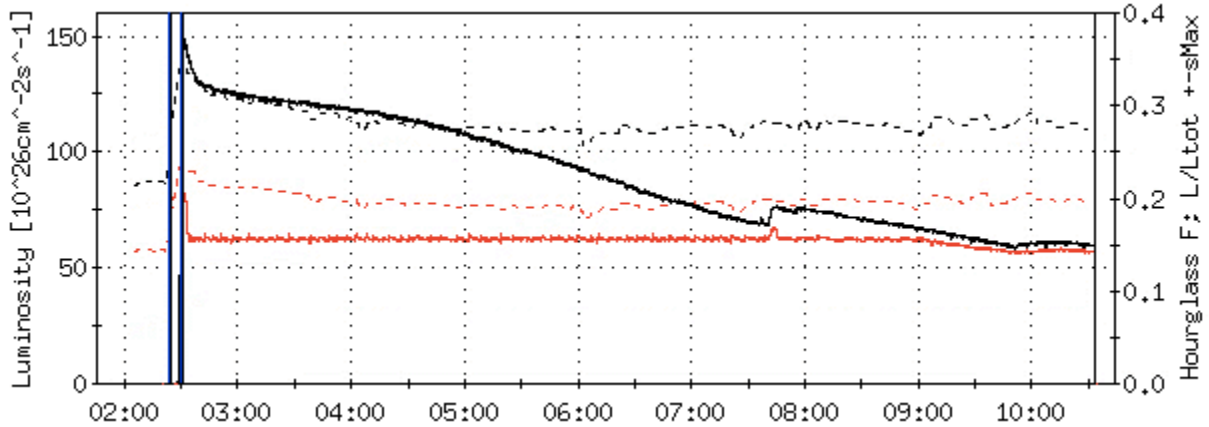


Figure 1: Run-16 Au+Au at 200 GeV store. The black line shows the luminosity (left y-axis units) as a function of time in store in hours. The red dashed line shows the fraction of collisions within ± 10 cm.

82 2.3.2 p+p at 200 GeV

83 The C-AD projections are summarized in their document, Table 6. We reproduce some of
 84 those key values here in Table 4. Wolfram Fischer has provided us with Figure 1 showing an
 85 example "best store" from Run-15 p+p at 200 GeV, where "best" is actually one of many
 86 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

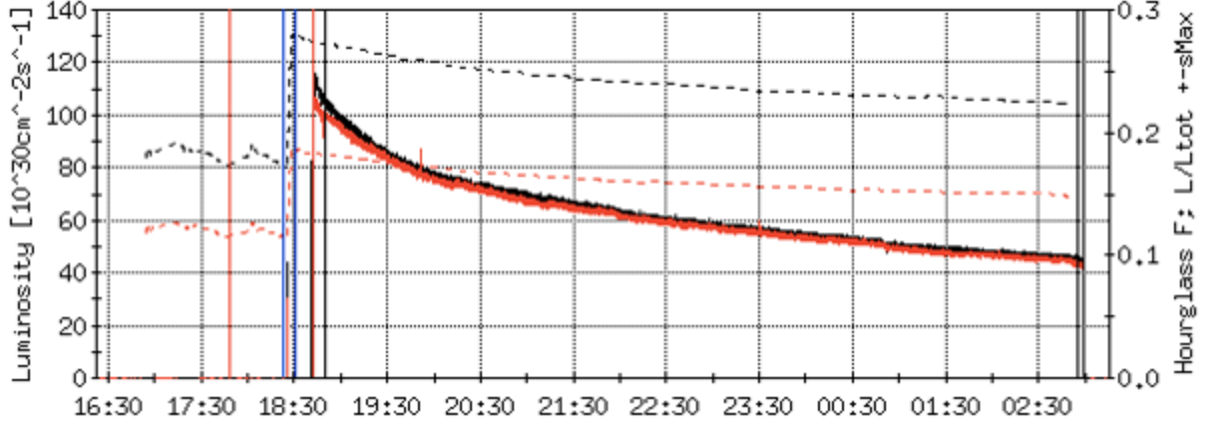


Figure 2: Run-15 p+p at 200 GeV store. The black line shows the luminosity (left y-axis units) as a function of time in store in hours. The red dashed line shows the fraction of collisions within ± 10 cm.

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

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.

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.

3.1 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 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.

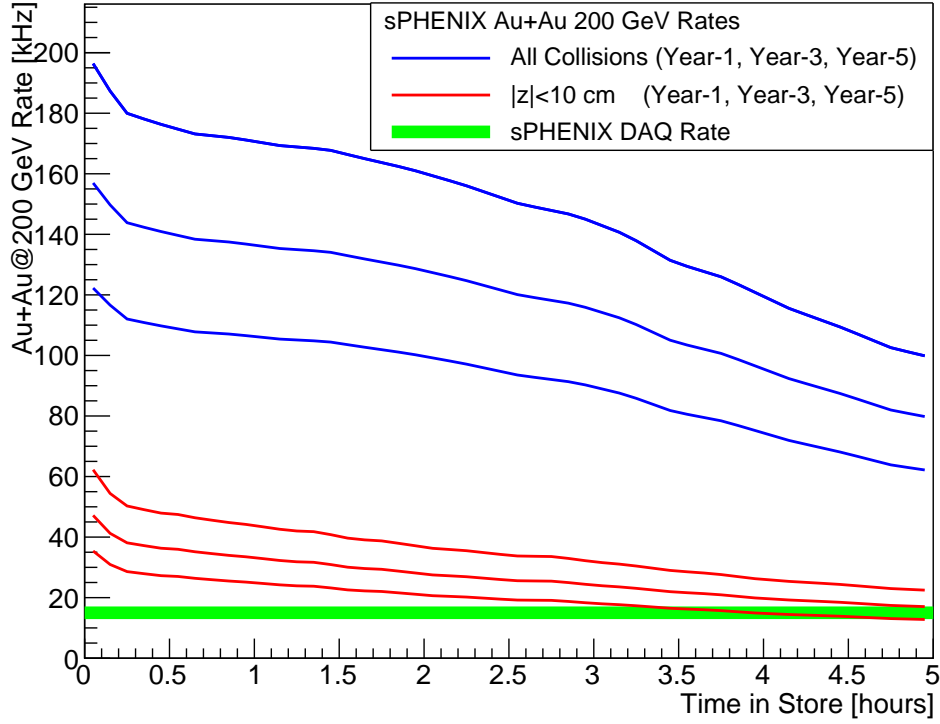


Figure 3: Estimated Au+Au at 200 GeV collision rate as a function of time in store for all collisions (blue) and collisions within ± 10 cm (red). The bottom to top set of curves in each color are for the mean luminosity and f_{z10} for the C-AD projections labeled in their document as 2022E, 2024E, 2026E 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.

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.

125 4 Charge Particle Flux

126 The inner tracking detectors have performance issues related to the total charge particle
127 flux - i.e. the number of charged particle tracks per unit pseudorapidity per unit time.
128 The Time Projection Chamber in particular will have space charge distortions that are
129 related to exactly this quantity - i.e. $dN_{ch}/d\eta$ /second. In Table 8, we show the estimated
130 midrapidity $dN_{ch}/d\eta$, the maximum projected peak collision rate (over all vertices since they
131 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

132 5 Radiation Dose

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

138 Table 9 gives values for the estimated total charged particle exposure per unit pseudora-
139 pidity.

140 6 Trigger Requirements

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

148 More challenging will be extracting additional physics in Au+Au collisions beyond the
149 recorded minimum bias sample. It might be reasonable to reduce the 15 kHz minimum bias
150 archiving rate by 1-2 kHz in order to free up bandwidth to sample the full luminosity for
151 a few rare triggers. For example, sampling the full Au+Au luminosity for single photons

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

¹⁵² with p_T greater than 15 GeV/c should require very modest bandwidth. Sampling additional
¹⁵³ luminosity for the highest p_T jets or Upsilon decays (perhaps in peripheral events only) will
¹⁵⁴ be more challenging.