RHIC Collider Projections (FY 2025)

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This note discusses in Part I general constraints and past performance and in Part II running modes in Run-25. **In the following all quoted luminosities are delivered luminosities. Recorded luminosities are smaller due to crossing angles, vertex cuts, detector uptime, and other considerations. Quoted beam polarization numbers are intensity- and time-averaged as measured by the hydrogen jet. The luminosity-weighted polarization functions and figures of merit can be calculated from the center polarization and polarization profile parameters.**

Part I – General Constraints

After the shutdown the RHIC rings are at room temperature. After scrubbing with room-temperature helium for about 1 month, and bringing the rings to 45 K over about another 1 month, 0.5 weeks will be required to cool them down from 50 K to 4 K. At the end of the run 0.5 weeks are required for a controlled turn-off.
When starting the run, we plan for about 1 week of machine set-up (no dedicated time for experiments) to establish collisions, and about 0.5 weeks machine ramp-up (8 h/night for experiments) after which stable operation can be provided with luminosities that are a fraction of the maximum luminosity goals. The set-up and ramp-up period for polarized protons would be up to 1 week longer to allow for the set-up of polarimetry, snakes, and rotators. During the ramp-up period detector set-up can occur. Higher weekly luminosities and polarization are achievable with a continuous development effort in the following weeks. We propose to use the day shifts from Monday to Friday for this effort as needed and coordinated with sPHENIX and STAR.

Run-25 will have Au+Au collisions at 100 GeV/nucleon. Other modes, with a possible run extension into FY 2026, include p↑+Au (5 weeks), p↑+p↑, O+O and a fixed target program in the STAR detector (3 weeks). In addition, dedicated APEX for EIC was requested (2 weeks). For FY 2025 two financial scenarios are under consideration with 20 and 28 cryo-weeks. Two cryo-weeks were already spent to extend Run-24.

For Au+Au at 100 GeV/nucleon, 18 weeks of RHIC refrigerator operation in FY 2025 could be scheduled in the following way:

Cool-down from 50 K to 4 K	0.5 weeks	
Set-up mode 1 (Au+Au at 100 GeV/nucleon)	2.0 weeks	(no dedicated time for experiments, MVTX background)
Ramp-up mode 1	0.5 weeks	(8 h/night for experiments)
Data taking mode 1	14.5 weeks	
Controlled turn-off	0.5 week	

If the Run is longer and possibly extended into the next Fiscal Year, additional modes can be added.

Luminous region and store length – For bunches of rms length σ_s and zero crossing angle the luminous region is of rms length $\sigma_s/\sqrt{2}$. The expected initial luminous region for ions is 20 cm (σ_s = 30 cm) with the 197 MHz storage cavities. For protons at 100 GeV the initial luminous region is 50 cm (σ_s = 70 cm). The length of luminous region can be reduced with a crossing angle, which also reduces the delivered luminosity. sPHENIX has operated in Run-23 and Run-24 with a full crossing angle between θ = 0 and θ = 2 mrad, and STAR with a full crossing angle between θ = 0 and θ = 1 mrad.
Stores of pre-determined length allow for a synchronized check of the injector chain before the store ends. The optimum store length is determined each run from the luminosity lifetime, the average time between stores, and the detector turn-on times. For polarized proton operation the polarization lifetime is also considered.

Asymmetric collisions – For p↑+A operation all DX magnets need to be shifted transversely by 2.5 cm to allow for maximum aperture. Depending on their location and physical constraints, the DX moves at IR4 was limited to 17.5 cm (due to common 9 MHz RF cavity), and 20 cm at IR10 (electron lenses). The common 9 MHz cavity has been removed to allow for a maximum DX magnet shift for Run24. While DX magnets in IR2 and IR4 can be moved before Run-25, the magnets in the other IRs must be moved during the run. This requires about a day during the run.

Part II – Projections for Run-25

Running modes – For Run-25 and a possible extension into FY 2026 the following modes are under consideration:

Au+Au	at $\sqrt{s_{NN}}$ = 200 GeV
p↑+Au, p↑+ p↑, O+O	at $\sqrt{s_{NN}}$ = 200 GeV
C, Al, Fe targets inside STAR	at E_{kin} = 5, 20, 50 GeV/nucleon for C, Si, Fe beams

with both sPHENIX and STAR. For sPHENIX the luminosity is to be delivered only within a longitudinal range of ±10 cm by applying a full crossing angle of up to 2 mrad. Figure 1 shows the measured reduction due to the crossing angle with O+O, p↑+p↑ and Au+Au collisions. For heavy ions a significant part of the reduction is due to the longitudinal beam profiles with ions migrating to neighboring buckets even with longitudinal stochastic cooling. This effect is reduced with the 56 MHz cavity.

Au+Au collisions – The beam intensity in Run-23 was limited by the injectors and a fast transverse instability at transition, driven by the machine impedance and electron clouds, and possibly the reinstalled 56 MHz SRF. The beam intensity in Run-24 was also limited by the AGS extraction and RHIC injection elements. If the Run-23 intensity limit at transition was caused by SEY deconditioning, bunch intensities achieved in Run-16 are unlikely to be reached again since not enough time is available for reconditioning.

The achievable average luminosity is also limited by intrabeam scattering (IBS). IBS leads to debunching and transverse emittance growth and is counteracted by 3D stochastic cooling. Even with longitudinal stochastic cooling, ions migrate to neighboring buckets. This effect can be reduced with more longitudinal focusing provided by a 56 MHz superconducting RF system (h = 720). After refurbishment the cavity was tested in Run-24 and exceeded 0.5 MV. A full test would have required more Au bunch intensity than was available in the last week of Run-24.

In Run-23 and Run-24 the sPHENIX MVTX auto reset rate exceeded the 3 Hz limit with Au+Au collisions (no issues with p↑+p↑ collisions) primarily in the horizontal plane. Extensive studies in Run-24 suggest that fragments from lost off-momentum Au ions in the Yellow beam reach the MVTX detector. The effect was not fully mitigated in Run-24 and will be studied in simulations in preparation for Run-25. Without momentum collimation in RHIC a solution must be found for distributed losses of off-momentum Au ions in locations from which the created fragments do not reach the sPHENIX MVTX. The demonstrated and projected Au+Au performance is shown in Table 1.

p↑+p↑, O+O and p↑+Au collisions – Experience in Run-23 and Run-24 shows that re-establishing peak performance again after almost a decade is challenging. For p↑+p↑ operation performance as in Run-24 should be assumed, and for O+O operation performance as in in Run-21. For p↑+Au the combination of proton and Au beam expectations give the projected luminosity. The demonstrated and projected p↑+p↑ and p↑+Au performance is shown in Table 2.

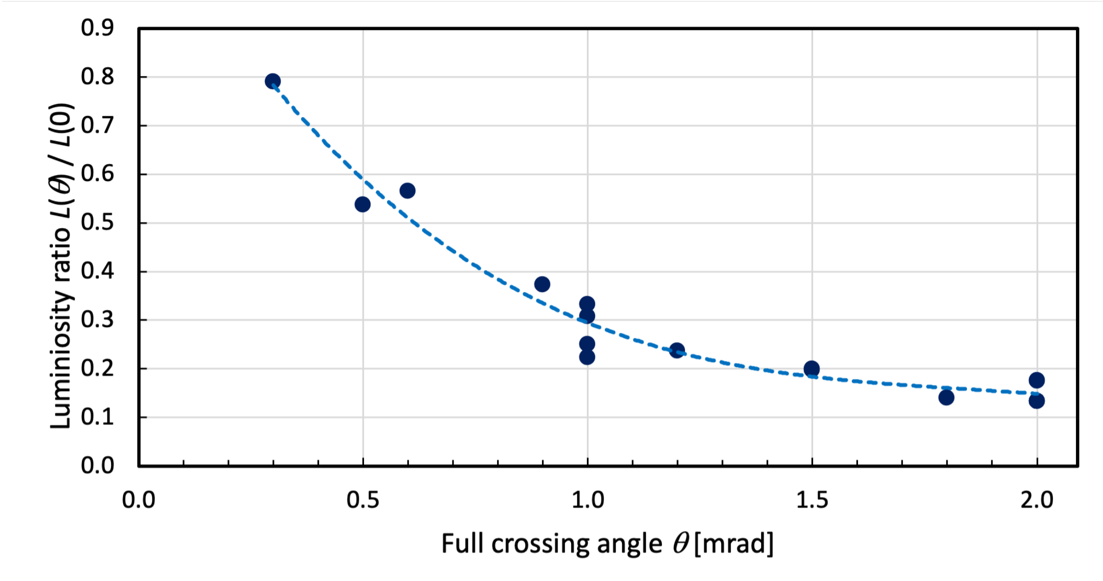

Figure 1: Measured luminosity ratio $L(\theta)$ / $L(0)$ as a function of the full crossing angle θ with data from O+O collisions in Run-21, p↑+p↑ collisions in Run-22, and Au+Au collisions in Run-23. The luminosity L was not necessarily optimized before and after the crossing angle change in every case, and measurement were taken at various times in a store.

Table 1: Demonstrated and projected luminosities for 100 GeV/nucleon Au+Au runs.

Parameter	Unit	FY2007	2010	2011	2014	2016	2023	2025E
No of bunches k_b	…	103	111	111	111	111	111	111
Ions/bunch, initial N_b	10^9	1.1	1.1	1.3	1.6	2.0	1.65	1.75
Envelope function at IP β^*	m	0.85	0.75	0.75	0.70	0.70	0.70	0.70
Beam-beam parameter ξ/IP	10^{-3}	-1.7	-1.5	-2.1	-2.5	-3.9	-3.2	-3.4
Initial luminosity L_{init}	**10^{26} cm^{-2}s^{-1}**	**30**	**40**	**50**	**80**	**155**	**101**	**115**
Average/initial luminosity	%	40	50	60	62	56	56	60
Average store luminosity L_{avg}	**10^{26} cm^{-2}s^{-1}**	**12**	**20**	**30**	**50**	**87**	**44**	**68**
Time in store	%	48	53	59	68	65	44	50
Max. luminosity/week (θ = 0)	μb^{-1}	380	650	1000	2200	3000	1300	2300
Min. luminosity/week (θ = 0)	μb^{-1}							1300

Table 2: Demonstrated and projected luminosities and polarization for p↑+p↑ and p↑+Au runs at 100 GeV.

		p↑+p↑						p↑+Au	
Parameter	Unit	FY2008	2009	2012	2015	2024	2025E	FY2015	2025E
No of colliding bunches k_b	…	109	109	109	111	111	111	111	111
Protons/bunch, initial N_b	10^{11}	1.5	1.3	1.6	2.25	1.95	1.95	2.25/0.0016	1.7/0.0016
Envelope function at IP β^*	m	1.00	0.70	0.85	0.85	0.85	0.85	0.85/0.70	0.85/0.70
Beam-beam parameter ξ/IP	10^{-3}	-5.3	-6.3	-5.8	-9.7	-8.4	-8.4	-5.3/-4.1	-5.3/-3.1
Initial luminosity L_{init}	**10^{30} cm^{-2}s^{-1}**	**35**	**50**	**46**	**115**	**74**	**74**	**0.88**	**0.66**
Average/initial luminosity	%	65	56	71	55	58	58	51	51
Average store luminosity L_{avg}	**10^{30} cm^{-2}s^{-1}**	**23**	**28**	**33**	**63**	**43**	**43**	**0.45**	**0.34**
Time in store	%	60	53	59	64	~60	60	65	50
Max. luminosity L/week	pb^{-1}	7.5	8.3	9.3	25	17	17	0.140	0.115
AGS extraction, P_{max}	%	55	65	72	68	~65	65	68	65
RHIC store average, P_{max}	**%**	**45**	**56**	**59**	**57**	**54**	**54**	**60**	**54**