RHIC Collider Projections (FY 2024 and FY 2025)

W. Fischer, A. Drees, K. Hock, H. Huang, C. Liu, M. Minty, D. Raparia, V. Schoefer, and T. Shrey

Last update: 7 August 2023

This note discusses in Part I general constraints and past performance. Constraints arise from the times needed for cryogenic cool-down, machine set-up and beam commissioning. In Part II an outlook is given for running modes in Run-24 and Run-25.

In the following all quoted luminosities are delivered luminosities. Recorded luminosities are smaller due to vertex cuts, detector uptime, and other considerations. Quoted beam polarization numbers are intensity-averaged 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 a shutdown the RHIC rings are usually at room temperature. After bringing the rings to 50 K over about 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 of refrigerator operation.
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 than for ions 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.

Possible modes for Run-24 are p↑+p↑ at 100 GeV beam energy and p↑+Au at 100 GeV/nucleon. 26 weeks of RHIC refrigerator operation in FY 2024 could be scheduled in the following way:

Cool-down from 50 K to 4 K	0.5 weeks	
Set-up mode 1 (p↑+p↑ at 100 GeV)	2.0 weeks	(no dedicated time for experiments)
Ramp-up mode 1	0.5 weeks	(8 h/night for experiments)
Data taking mode 1	14 weeks	
Set-up mode 2 (p↑+Au at 100 GeV/nucleon)	1.5 weeks	(no dedicated time for experiments)
Data taking mode 2 with further ramp-up	7 weeks	
Controlled turn-off	0.5 week	

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 with a full crossing angle of θ = 2 mrad, and STAR with θ = 1 mrad.
Stores of pre-determined length are desirable. They 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 1.75 to 2.5 cm depending on their location. While DX magnets in IR2 and IR4 can be moved before Run-24, 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-24 and Run-25

Running modes – For Run-24 and Run-25 the following modes are planned:

Run-24	p↑+p↑ and p↑+Au	at $\sqrt{s_{NN}}$ = 200 GeV
Run-25	Au+Au	at $\sqrt{s_{NN}}$ = 200 GeV

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 2 mrad. This was studied and can be accommodated for all species combinations, including p↑+Au. For polarized protons only vertical spin polarization is requested at the detectors. 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 will be reduced with the 56 MHz cavity. The tables below also show the delivered luminosity fraction for full crossing angles of 1 and 2 mrad. The crossing angles were chosen by STAR and sPHENIX to limit vertex region.

Au+Au collisions – Full implementation of 3D stochastic cooling was completed in 2014, and the average store luminosity reached 44× the design value in 2016. The beam intensity was limited by the injectors and a fast transverse instability at transition, driven by the machine impedance and electron clouds. In Run-23 SEY deconditioning was observed with electron cloud effects visible at a lower bunch intensities than in Run-16. This makes it unlikely that the Run-16 performance can be exceeded by Run-25.
The achievable average luminosity is also limited by intrabeam scattering (IBS), and the bunch intensity. 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 under commissioning in Run-23 and was expected to reach a voltage of 1 MV. The demonstrated and projected Au+Au performance is shown in Table 1.

p↑+p↑ and p↑+Au collisions – Experience in Run-23 shows that re-establishing peak performance again after a long time is difficult and Run-24 will likely not exceed the Run-15 performance.
The head-on beam-beam interaction, in conjunction with other nonlinear and modulation effects, is the main luminosity limitation for p↑+p↑ collisions. To partially compensate for the head-on beam-beam effect a compensation scheme with a specific lattice and electron lenses was implemented for 100 GeV in Run-15. Beam-beam compensation is only needed with 2 experiments as the beam-beam parameter for 2 collisions is approximately double the value for 1 collision. Operation with crossing angles also reduced the beam-beam tune spread and electron lenses may not be needed. The demonstrated and projected p↑+p↑ and p↑+Au performance is shown in Table 2.

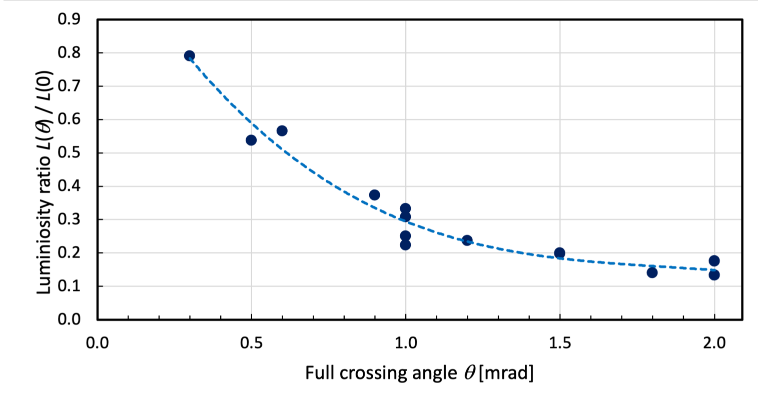

Figure 1: Measured luminosity ratio $L(\theta)$ / $L(0)$ as a function of the full crossing angle θ with data from O+O collisions in Run-21, p↑+p↑ collisions in Run-22, and Au+Au collisions in Run-23. The luminosity L was not necessarily optimized before and after the crossing angle change in every case, 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**	**2023E**	**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	1.8
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	-3.5
Initial luminosity L_{init}	**10^{26} cm^{-2}s^{-1}**	**30**	**40**	**50**	**80**	**155**	**101**	**120**
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**	**57**	**72**
Time in store	%	48	53	59	68	65	50	60
Max. luminosity/week	μb^{-1}	380	650	1000	2200	3000	1700	2600
Min. luminosity/week	μb^{-1}							1820
$L_{avg}(\theta)/L_{avg}(0)$, full crossing angle θ= 1 mrad	%						30	30
Max. luminosity/week, θ= 1 mrad							510	780
$L_{avg}(\theta)/L_{avg}(0)$ for full crossing angle θ= 2 mrad	%						15	15
Max. luminosity/week, θ= 2 mrad							255	390

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

		p↑+p↑					**p↑+Au**	
Parameter	Unit	FY2008	2009	2012	2015	2024E	FY2015	2024E
No of colliding bunches k_b	…	109	109	109	111	111	111	111
Protons/bunch, initial N_b	10^{11}	1.5	1.3	1.6	2.25	2.5	225/1.6	225/1.6
Envelope function at IP β^*	m	1.00	0.70	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	-9.7	-5.3/-4.1	-5.3/-4.1
Initial luminosity L_{init}	**10^{30} cm^{-2}s^{-1}**	**35**	**50**	**46**	**115**	**115**	**0.88**	**0.88**
Average/initial luminosity	%	65	56	71	55	55	51	51
Average store luminosity L_{avg}	**10^{30} cm^{-2}s^{-1}**	**23**	**28**	**33**	**63**	**63**	**0.45**	**0.45**
Time in store	%	60	53	59	64	64	65	65
Max. luminosity/week	pb^{-1}	7.5	8.3	9.3	25	25	140	140
Min. luminosity/week	pb^{-1}					17		100
$L_{avg}(\theta)/L_{avg}(0)$, full crossing angle θ= 1 mrad	%					0.45		0.37
Max. luminosity/week, θ= 1 mrad						11		51
$L_{avg}(\theta)/L_{avg}(0)$ for full crossing angle θ= 2 mrad	%					0.25		0.19
Max. luminosity/week, θ= 2 mrad						6		27
AGS extraction, P_{max}	%	55	65	72	68	68	68	68
RHIC store average, P_{max}	**%**	**45**	**56**	**59**	**57**	**57**	**60**	**60**