RHIC Collider Projections (FY 2021 – FY 2027)

W. Fischer, A. Drees, A. Fedotov, H. Huang, C. Liu, M. Minty, D. Raparia

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This note discusses in Part I general constraints, past performance and possible running modes in Run-21 and Run-22. Constraints arise from the times needed for cryogenic cool-down, machine set-up and beam commissioning. Part II reviews the Beam Energy Scan II (BES-II) in RHIC with a projection for Run-21. In Part III an outlook is given until FY 2027.

In the following all quoted luminosities are delivered luminosities. Recorded luminosities are smaller due to vertex cuts, detector uptime, and other considerations. An estimate of how much of the delivered luminosity can be recorded must be made by every experiment individually. 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 and Past Performance

Time of cryogenic operation – After a shutdown the two RHIC rings are at room temperature. Normally, after bringing the rings to 50 K over approximately 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.

Typically, when starting the run, we plan for about 1 week of machine set-up (no dedicated time for experiments) with the goal of establishing collisions, and about 0.5 weeks machine ramp-up (8 h/night for experiments) after which stable operation can be provided with integrated 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. Estimates for set-up and ramp-up times are based on past performance and expected commissioning efforts and vary with the operating mode.

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 STAR and sPHENIX. The luminosity or polarization development efforts should stop when insurmountable limits, posed by either the current machine or detector configuration, are reached.

After a running mode has been established, the collision energy in the same mode can be changed in about a day depending on the availability of a tested lattice and assuming no unusual machine downtime. A change of the polarization orientation at any or all of the experiments requires 1-2 shifts.

24 weeks of RHIC refrigerator operation in FY 2021 could be scheduled in the following way:

Cool-down from 50 K to 4 K	0.5 weeks	
Set-up (Au+Au incl. LEReC with 1.4 GHz)	1.0 weeks	(no dedicated time for experiments)
Ramp-up and experimenter set-up (Au+Au)	0.5 weeks	
Mode 1A (3.85 GeV/nucleon colliding)	20.5 weeks	
Mode 1B (CeC PoP)	1.0 week	
Controlled refrigerator turn-off	0.5 weeks	

Past performance – Table 1 shows the achieved luminosities for all ion combinations at the highest energy, and for polarized protons at 100 and 255 GeV. The time in store was 65% of the total time for Au+Au (Run-16) and 62% for p↑+p↑ (255 GeV, Run-17). Note that the total time includes all interruptions such as ramping, set-up, maintenance, machine development, accelerator physics experiments, and failures. A comprehensive overview of the past performance can be found at http://www.rhichome.bnl.gov/RHIC/Runs. Performance estimates were requested for a number of new species, which are listed in Table 2.

Table 1: Achieved beam parameters and luminosities at close to full energy for heavy ions, and 100 and 255 GeV for polarized protons.

mode	beam energy [GeV/nucleon]	no of colliding bunches	ions/bunch [10^9]	β^* [m]	rms emittance [μm]	L_{peak} [$cm^{-2}s^{-1}$]	$L_{store\ avg}$ [$cm^{-2}s^{-1}$]	L_{week}
U+U	96.4	111	0.3	0.7	2.2→0.4	8.8×10^{26}	5.6×10^{26}	0.2 nb^{-1}
Au+Au	100	111	2.0	0.7	2.0→0.7	155×10^{26}	87×10^{26}	3.0 nb^{-1}
Ru+Ru§	100	111	1.0	0.7	1.2→0.9	38×10^{26}	21×10^{26}	0.5 nb^{-1}
Zr+Zr§	100	111	1.0	0.7	1.15→0.9	48×10^{26}	22×10^{26}	0.5 nb^{-1}
Cu+Au	100	111	4.0/1.3	0.7	4.1→1.2	120×10^{26}	100×10^{26}	3.5 nb^{-1}
Cu+Cu	100	37	4.5	0.9	2.5→5.0	2×10^{28}	0.8×10^{28}	2.4 nb^{-1}
h+Au	104/100	111	45/1.3	1.0	2.0→3.0/1.5	17×10^{28}	10×10^{28}	33 nb^{-1}
d+Au	101/99	111	130/1.9	0.7	2.4→2.2	85×10^{28}	50×10^{28}	125 nb^{-1}
p↑+Au	103/97	111	225/1.6	0.85/0.7	2.7→3.2/3.0→1.3	88×10^{28}	45×10^{28}	140 nb^{-1}
p↑+Al	103/98	111	240/11	0.85/0.7	2.4→3.7/2.2→1.7	760×10^{28}	380×10^{28}	1.2 pb^{-1}
p↑+p↑*	100	111	225	0.85	2.8→4.0	115×10^{30}	63×10^{30}	25 pb^{-1}
p↑+p↑*	255	111	185	0.65	3.1→3.9	245×10^{30}	160×10^{30}	60 pb^{-1}

§At the request of STAR luminosities for Ru+Ru and Zr+Zr were leveled at 21.5×10^{26} $cm^{-2}s^{-1}$ using a variable vertical separation. The potential peak luminosity with centered beams exceeds the leveled luminosity by a factor of 4.
*Blue and Yellow ring intensity- and time-averaged polarization of P = 55% in stores at 100 GeV in Run-15 and P = 55% at 255 GeV in Run-17 as measured by the H-jet.

Table 2: Maximum luminosities at full energy for selected species combination that can be reached after a sufficiently long running period. The Au+Au, p↑+p↑ and p↑+Au performance projections are listed in Table 4 through Table 6.

mode	beam energy [GeV/nucleon]	no of colliding bunches	ions/bunch [10^9]	β^* [m]	rms emittance [μm]	L_{peak} [$cm^{-2}s^{-1}$]	$L_{store\ avg}$ [$cm^{-2}s^{-1}$]	L_{week}
O+O	100	111	12	0.7	2.5	55×10^{28}	33×10^{28}	120 nb^{-1}
Al+Al	100	111	11	0.7	2.5	48×10^{28}	26×10^{28}	95 nb^{-1}
Ar+Ar	100	111	8.5	0.7	2.5	28×10^{28}	16×10^{28}	57 nb^{-1}
Cu+Cu	100	111	5.0	0.7	2.5	9.8×10^{26}	7.4×10^{26}	27 nb^{-1}
Ag+Ag	100	111	3.5	0.7	2.5	4.8×10^{26}	2.6×10^{26}	10 nb^{-1}

Luminous region and store length – For bunches of rms length σ_s, 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. At the three lowest BES-II energies a 9 MHz RF system is used, resulting in longer bunches. For protons at 100 and 255 GeV respectively the initial luminous region is 50 cm (σ_s = 70 cm) and 40 cm (σ_s = 60 cm). 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.

Operation at energies other than 100 GeV/nucleon – For Au+Au operation at 100 GeV/nucleon the limiting aperture is in the triplets. For energies less than 100 GeV/nucleon the beam size in the triplets is maintained with a smaller β-function, which results in a larger β^*. This together with the increase of the geometric emittance at lower energies leads to luminosity scaling with the energy E as $L(E) \propto E^2$. Figure 1 shows the observed peak and average luminosities and the scaling according to the formula. Note that operation near the transition energy (γ_{tr} = 23 for ions) is not possible. At the nominal injection energy (9.8 GeV/nucleon) and below refilling is very efficient since no acceleration is required. At the lowest energies significant deviations from the quadratic scaling occur. With the use of the storage RF system the initial bunch length is independent of the energy. The storage RF system cannot be used below an energy of 19.5 GeV/nucleon for Au.

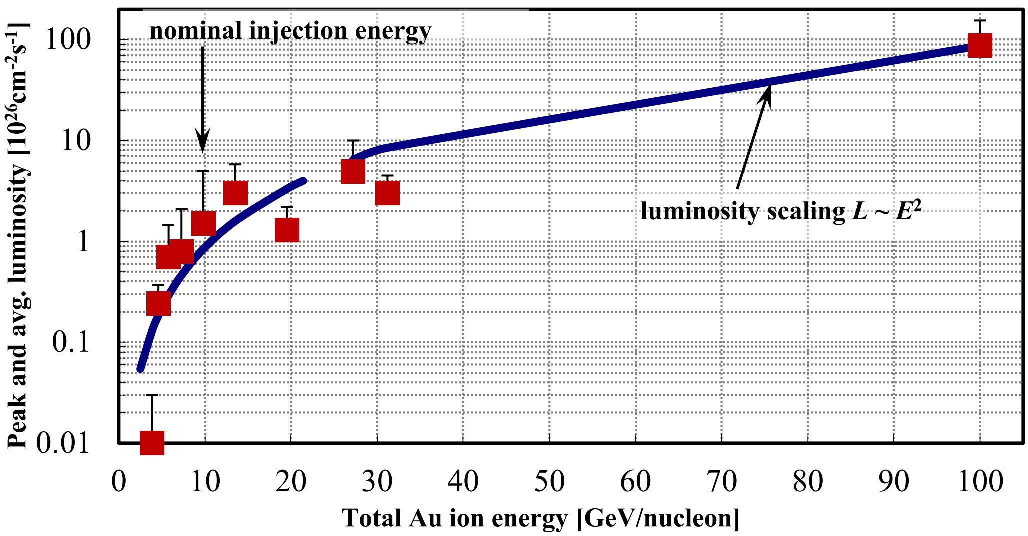

Figure 1: Observed average (red squares) and peak (top bar) Au+Au luminosity for different energies. The blue line shows the luminosity scaling quadratically with the energy. Near the transition energy operation is not possible.

Stochastic cooling has been operated with Au beams at energies from as low as 19.4 GeV/nucleon and up to 100 GeV/nucleon. A few days of parasitic optimization are required to change filters in the stochastic cooling systems after an energy change and re-commission the system. Stochastic cooling at very low energies, e.g. the nominal injection energy and below, is not possible because the beam size in the pick-ups and kickers becomes too large, or the slip factor $\eta = \gamma_{tr}^{-2} - \gamma^{-2}$ becomes too small.

Asymmetric collisions – To date d+Au collisions were provided in Run-3, Run-8 and Run-16, h+Au collisions in Run-14, Cu+Au collisions in Run-12, and p↑+Au and p↑+Al collisions in Run-15. For p↑+A operation all DX magnets need to be shifted transversely by 1.75 to 2.5 cm depending on their location.

Running modes in Run-21 and Run-22 – Run-21 and Run-22 are with the STAR detector only. For Run-21 the following modes are under consideration: (i) colliding Au+Au beams at 3.85 GeV/nucleon, (ii) colliding Au+Au beams at 8.55 GeV/nucleon (iii) O+O at 100 GeV/nucleon, (iv) Au beams at 100, 70, 44.5, 3.85, 3.15 and 2.5 GeV/nucleon on a fixed Au target inside the STAR detector. The primary operating mode will be colliding Au+Au beams at 3.85 GeV/nucleon. In preparation for the run, LEReC was tested at this energy. A new 1.4 GHz cavity will be added to LEReC to double the effective electron bunch length.

Commissioning LEReC with this new cavity will take up to 1 week. For O+O an average store luminosity of $L_{\text{store avg}} = 2\times10^{28}$ cm^{-2}s^{-1} is sufficient and 1 week of data taking in planned.
For Run-22 polarized proton collisions at 255 GeV is the likely main operating mode, and possibly some of the operating modes under consideration for Run-21. For p↑+p↑ at 255 GeV and the Run-17 experience with luminosity levelling, required to avoid pile-up effects in the STAR detector, the Run-22 and Run-17 performances will be close. STAR may be able to raise the target luminosity by up to 25%. This can be accommodated by increasing the bunch intensity.
The Coherent electron Cooling Proof of Principle (CeC PoP) experiment planned to request 2 weeks of dedicated beam time in each of Run-21 and Run-22.

Part II – Beam Energy Scan II (BES-II) Performance and Projections

To reach the event goals for the Beam Energy Scan II (BES-II) an increase in the average luminosity by a factor 3-4 is needed for the 5 collision energies in search of a critical point in the nuclear matter phase diagram. To facilitate this luminosity increase, bunched beam electron cooling was being implemented for the 2 lowest of the 5 beam energies – Low-Energy RHIC electron Cooling (LEReC). The luminosity is further enhanced at the 3 lowest energies with a new 9 MHz RF system that increases the bucket area and produces longer bunches. The 9 MHz RF system also allows for the injection higher bunch intensities by relaxing space-charge limitation.

Table 3: Beam parameters demonstrated in BES-I and the 4 highest BES-II energies, and estimated beam parameters for 3.85 GeV/nucleon in. Parameters for 4.59 GeV/nucleon in BES-II are preliminary since this mode was still in operation and the luminosity not yet calibrated when this document was completed.

Parameter	**Unit**	**BES I** 2010	**BES II** with LEReC **projected** 2021	**BES I** 2008	**BES II** with LEReC 2020	**BES I** 2010	**BES II** 2020	**BES I** 2014	**BES II** 2019	**BES I** 2011	**BES II** 2019
Total particle energy	GeV/nucleon	3.85		4.55	4.59	5.75		7.30		9.80	
No of bunches k_b	…	111	111	56	111	111	111	111	111	111	111
Ions/bunch, initial N_b	10^9	0.5	0.8	0.4	1.2	1.1	1.8	1.1	1.75	0.9	1.8
Transverse rms emittance ε_{xy}	μm	1.7	1.5	6.7	2.4	2.5	2.2	1.7	2.2	2.5	1.8
Envelope function at IP β^*	m	6.0	4.5	10.0	4.5	6.0	4.0	3.5	3.0	2.5	2.3
Direct space charge tune shift ΔQ_{sc}	10^{-3}	-66	-56	-10	-54	-46	-85	-42	-36	-13	-38
beam-beam parameter ξ/IP	10^{-3}	-1	-2	-0.2	-2	-2	-3	-3	-3	-1	-4
Initial luminosity L_{init}	**10^{24} cm^{-2}s^{-1}**	**6.5**	**22**	**0.35**	**40**	**33**	**146**	**100**	**209**	**80**	**502**
Average/initial luminosity	%	40	65	34	65	45	48	20	38	50	30
Average store luminosity L_{avg}	**10^{24} cm^{-2}s^{-1}**	**2.6**	**14.3**	**0.12**	**26**	**15**	**70**	**20**	**79**	**40**	**150**
Luminosity improvement factor	...		5.5x		4.2x		4.7x		4.0x		3.8x
Time in store	%	55	65	--	65	66	64	57	51	71	54
Total event number goal	M		**100**		**160**		**230**		**300**		**400**
Total event number recorded	M	4.3		--	162	11.7	235	24	324	36	581
Running time for physics	weeks	4.6	15	--	TBD	1.4	8.9	3.4	8.6	1.4	5.1

Table 3 and Figure 2 show the main beam parameters and luminosities in BES-I and BES-II for colliding beam operation. All numbers are for demonstrated performance except for BES-II 3.85 GeV/nucleon, which is a projection. The BES-II luminosity at 4.59 GeV/nucleon still needs to be calibrated. In addition, fixed target operation over about 2 days each was completed for beam energies of 3.85, 4.55, 5.75, 7.3, 9.8, 13.5, 19.5, 31.2 GeV/nucleon in Run-19 and Run-20. For each of these energies the goal of 100M events was

met or exceeded. The fixed target program is not constrained by luminosity, i.e. it is always possible to fill the STAR bandwidth.
For Run-21 colliding Au+Au beams at a beam energy of 8.55 GeV/nucleon are under consideration. The performance for this energy can be interpolated from the performance at 7.30 and 9.80 GeV/nucleon. For 250M events about 2 weeks of running time are estimated.

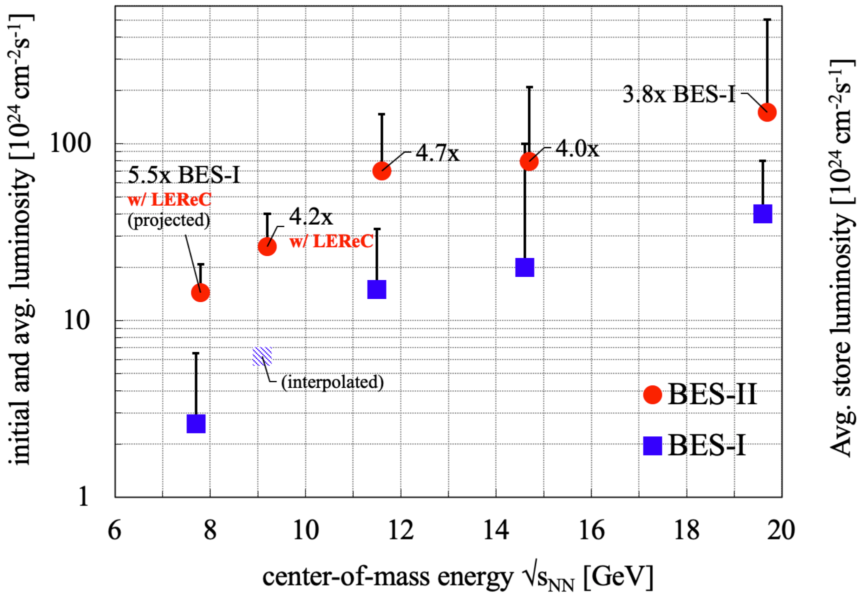

Figure 2: Demonstrated luminosities during BES-I and BES-II and expected luminosity with electron cooling for the lowest energy in BES-II.

Part III – Projections until 2027

sPHENIX requested luminosity and polarization estimates for Au+Au, p↑+p↑ and p↑+Au at 100 GeV/nucleon beam energy, and luminosity to be delivered only within a longitudinal range of ±10 cm by applying a full crossing angle of up to 2 mrad. This was studied and can be accommodated for all species combinations, including p↑+Au. For the asymmetric p↑+Au mode, DX magnets need to be moved. This takes about 1 week if done during a Run. For polarized protons only vertical spin polarization is requested at the detector. The RHIC Machine Protection System (MPS) is being upgraded in order to drastically reduce the number of abort kicker pre-fires, and the MPS upgrade is tested during the current low energy runs. This is particularly important to protect the sPHENIX vertex detector. If this detector is significantly damaged, about 2 months are required for a replacement. Below the fraction of the full luminosity delivered into ±10 cm is noted for full crossing angles of 0, 1 and 2 mrad, and shown in Figure 3 (Au+Au 2023E), Figure 4 (p+p 2024E), and Figure 5 (p+Au 2024E).

Heavy ions – Full implementation of 3D stochastic cooling was completed in 2014, and the average store luminosity reached 44× the design value in 2016. A further luminosity increase is possible, primarily through an increase in the bunch intensity.
The achievable luminosity is 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). This cavity operated in Run-16 without a Higher Order Mode (HOM) damper at 1 MV, below the design voltage of 2 MV. An upgrade is under way and the cavity was removed from the RHIC tunnel for tests in Bldg. 912. In the past 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-16 the beam intensity was limited by the RF amplifiers for the RHIC Landau cavities. These were upgraded in 2017, and this limit has been removed.
The demonstrated and projected Au+Au performance is shown in Table 4. The performance of ions other than Au+Au can be estimated, and some ions are listed in Table 2.

Table 4: Demonstrated and projected luminosities for 100 GeV/nucleon Au+Au runs.

Parameter	Unit	FY2016	2022E	2023E	2024E	2025E	2026E	2027E
No of bunches k_b	…	111	111	111	111	111	111	111
Ions/bunch, initial N_b	10^9	2.0	2.15	2.2	2.40	2.75	2.75	2.75
Average beam current/ring I_{avg}	mA	224	236	242	264	302	302	302
Stored beam energy	MJ	0.71	0.75	0.77	0.84	0.96	0.96	0.96
Envelope function at IP β^*	m	0.70	0.70	0.65	0.63	0.60	0.60	0.60
Beam-beam parameter ξ/IP	10^{-3}	-3.9	-4.1	-4.2	-4.6	-5.3	-5.3	-5.3
Initial luminosity L_{init}	**10^{26} cm^{-2}s^{-1}**	**155**	**171**	**193**	**237**	**313**	**313**	**313**
Events per bunch-bunch crossing μ	…	0.40	0.44	0.50	0.61	0.80	0.80	0.80
Average/initial luminosity	%	56	60	65	64	64	64	64
Average store luminosity L_{avg}	**10^{26} cm^{-2}s^{-1}**	**87**	**103**	**126**	**152**	**200**	**200**	**200**
Time in store	%	65	62	62	62	62	62	62
Max. luminosity/week	μb^{-1}	3000	3860	4710	5700	7520	7520	7520
Min. luminosity/week	μb^{-1}		3000	3000	3000	3000	3000	3000
L within $\|z\|<70$ cm, $\theta = 0$ mrad, $r_0{}^*$	%	72	72	90	90	90	90	90
L within $\|z\|<30$ cm, $\theta = 0$ mrad, $r_0{}^*$	%	59	59	74	74	74	74	74
L within $\|z\|<10$ cm, $\theta = 0$ mrad, $r_0/r_\theta{}^*$	%	19/19	19/19	33/33	33/33	33/33	33/33	33/33
L within $\|z\|<10$ cm, $\theta = 1$ mrad, $r_0/r_\theta{}^*$	%			31/57	31/57	31/57	31/57	31/57
L within $\|z\|<10$ cm, $\theta = 2$ mrad, $r_0/r_\theta{}^*$	%			26/82	26/82	26/82	26/82	26/82

* Luminosity $L(z,\theta)$ within vertex cut $|z|$ for full crossing angle θ. The values r_0/r_θ are $r_0 = L(z,\theta)/L(10\text{ m},0)$ and $r_\theta = L(z,\theta)/L(10\text{ m},\theta)$.

Polarized protons – Based on the experience to date and planned improvements further luminosity and polarization increases for polarized proton operation are possible.
The head-on beam-beam interaction, in conjunction with other nonlinear and modulation effects, is the main luminosity limitation for polarized protons. 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. Head-on beam-beam compensation at full energy has not been tested yet. 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.
Proton beams accelerated to 255 GeV showed about 85% polarization transmission from injection to the beginning of the physics store, and a polarization loss of 0.5-1.0%/h (absolute) in store. During Run-12 extensive tests were made to determine the cause of the polarization losses during the ramp and during store. No single parameter was found that had a large impact on the polarization, and further polarization increases are only expected if the emittance can be reduced. In Run-13 (255 GeV) the event rate reached a limit for the STAR detector and STAR requested a luminosity not exceeding 1.6×10^{32} cm^{-2}s^{-1}, which was implemented in Run-17.
A polarized ^{3}He source is under development in collaboration with MIT. With Extended EBIS as an ionizer we expect that polarized ^{3}He can be made available in RHIC in 2023. To have high ^{3}He polarization in RHIC an upgrade of one of the RHIC rings with 4 more Siberian snakes is necessary. Polarimeters for the injectors and RHIC, and an AC dipole for the Booster also need to be developed and installed.
The demonstrated and projected p↑+ p↑ performance is shown in Table 5.

Asymmetric operation with p↑+Au – In Run-15 the first asymmetric operation with polarized proton beam was demonstrated with p↑+Au and p↑+Al. The expected performance, based on the experience and planned further improvements for gold and polarized proton beam is shown in Table 6.

Table 5: Demonstrated and max projected luminosities and polarization for p↑+p↑ runs at 100 GeV.

Parameter	Unit	FY2015	2022E	2023E	2024E	2025E	2026E	2027E
No of colliding bunches k_b	…	111	111	111	111	111	111	111
Protons/bunch, initial N_b	10^{11}	2.25	2.3	2.8	3.0	3.0	3.0	3.0
Average beam current/ring I_{avg}	mA	312	319	389	418	418	418	418
Stored beam energy	MJ	0.40	0.41	0.50	0.54	0.54	0.54	0.54
Envelope function at IP β^*	m	0.85	0.85	0.85	0.85	0.85	0.85	0.85
Hourglass factor H	…	0.75	0.84	0.84	0.84	0.84	0.84	0.84
Beam-beam parameter ξ/IP	10^{-3}	-9.7	-9.9	-13.8	-14.9	-14.9	-14.9	-14.9
Initial luminosity L_{init}	**10^{30} cm^{-2}s^{-1}**	**115**	**137**	**232**	**268**	**268**	**268**	**268**
Events per bunch-bunch crossing μ	…	0.7	0.8	1.3	1.5	1.5	1.5	1.5
Average/initial luminosity	%	55	60	65	65	65	65	65
Average store luminosity L_{avg}	**10^{30} cm^{-2}s^{-1}**	**63**	**82**	**152**	**175**	**175**	**175**	**175**
Time in store	%	64	60	60	60	60	60	60
Max. luminosity/week	pb^{-1}	25	30	55	64	64	64	64
Min. luminosity/week	pb^{-1}		25	25	25	25	25	25
L within $\lvert z\rvert$<70 cm, θ = 0 mrad, r_0*	%	84	90	90	90	90	90	90
L within $\lvert z\rvert$<30 cm, θ = 0 mrad, r_0*	%	46	52	52	52	52	52	52
L within $\lvert z\rvert$<10 cm, θ = 0 mrad, r_0/r_θ*	%	16	19	19/19	19/19	19/19	19/19	19/19
L within $\lvert z\rvert$<10 cm, θ = 1 mrad, r_0/r_θ*	%			18/41	18/41	18/41	18/41	18/41
L within $\lvert z\rvert$<10 cm, θ = 2 mrad, r_0/r_θ*	%			16/69	16/69	16/69	16/69	16/69
AGS extraction, P_{max}	%	68	70	70	70	70	70	70
RHIC store average, P_{max}	**%**	**57**	**60**	**60**	**60**	**60**	**60**	**60**
RHIC store average, P_{min}	%		57	57	57	57	57	57

* Luminosity $L(z,\theta)$ within vertex cut $|z|$ for full crossing angle θ. The values r_0/r_θ are $r_0 = L(z,\theta)/L(10\text{ m},0)$ and $r_\theta = L(z,\theta)/L(10\text{ m},\theta)$.

Table 6: Demonstrated and max projected luminosities and polarization for p↑+Au runs at 100 GeV/nucleon.

Parameter	Unit	2015	2022E	2023E	2024E	2025E	2026E	2027E
No of colliding bunches k_b	…	111	111	111	111	111	111	111
Protons/bunch, initial N_b	10^9	225/1.6	207/1.9	252/2.0	271/2.2	271/2.4	271/2.5	271/2.6
Average beam current/ring I_{avg}	mA	313/176	288/213	350/218	376/237	376/267	376/277	376/287
Stored beam energy	MJ	0.40/0.56	0.37/0.68	0.45/0.69	0.49/0.76	0.49/0.85	0.49/0.85	0.49/0.85
Envelope function at IP β^*	m	0.85/0.70	0.85	0.85	0.85	0.85	0.85	0.85
Hourglass factor H	…	0.72	0.77	0.77	0.77	0.77	0.77	0.77
Beam-beam parameter ξ/IP	10^{-3}	-5.3/-4.1	-7.9/-3.4	-8.0/-4.6	-8.8/-4.9	-9.8/-4.9	-9.8/-4.8	-9.8/-4.8
Initial luminosity L_{init}	**10^{28} cm^{-2}s^{-1}**	**88**	**97**	**131**	**153**	**172**	**172**	**172**
Average/initial luminosity	%	51	55	60	65	65	65	65
Avg. store luminosity L_{avg}	**10^{28} cm^{-2}s^{-1}**	**45**	**54**	**78**	**153**	**112**	**112**	**112**
Time in store	%	65	60	60	60	60	60	60
Max. luminosity/week	nb^{-1}	140	194	285	361	405	405	405
Min. luminosity/week	nb^{-1}		140	140	140	140	140	140
L within $\lvert z\rvert$<70 cm, θ = 0 mrad, r_0*	%	71	81	90	90	90	90	90
L within $\lvert z\rvert$<30 cm, θ = 0 mrad, r_0*	%	47	62	62	62	62	62	62
L within $\lvert z\rvert$<10 cm, θ = 0 mrad, r_0/r_θ*	%	17/17	17/17	25/25	25/25	25/25	25/25	25/25
L within $\lvert z\rvert$<10 cm, θ = 1 mrad, r_0/r_θ*	%			23/37	23/37	23/37	23/37	23/37
L within $\lvert z\rvert$<10 cm, θ = 2 mrad, r_0/r_θ*	%			20/62	20/62	20/62	20/62	20/62
AGS extraction, P_{max}	%	68	70	70	70	70	70	70
RHIC store average, P_{max}	**%**	**60**	**60**	**60**	**60**	**60**	**60**	**60**
RHIC store average, P_{min}	%		60	60	60	60	60	60

* Luminosity $L(z,\theta)$ within vertex cut $|z|$ for full crossing angle θ. The values r_0/r_θ are $r_0 = L(z,\theta)/L(10\text{ m},0)$ and $r_\theta = L(z,\theta)/L(10\text{ m},\theta)$.

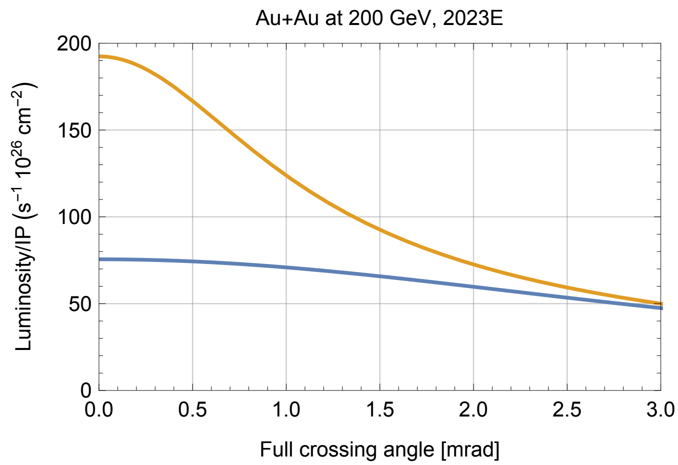

Figure 3: Total luminosity and within ±10 cm for Au+Au at $\sqrt{s_{NN}}$ = 200 GeV with the 2023E parameters.

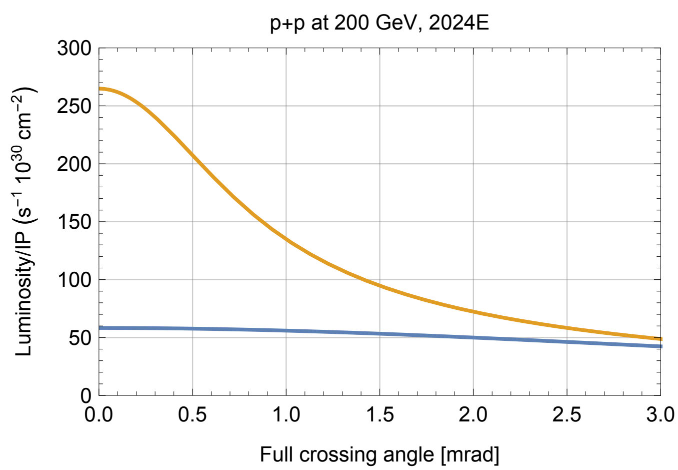

Figure 4: Total luminosity and within ±10 cm for p+p at $\sqrt{s_{NN}}$ = 200 GeV with the 2024E parameters.

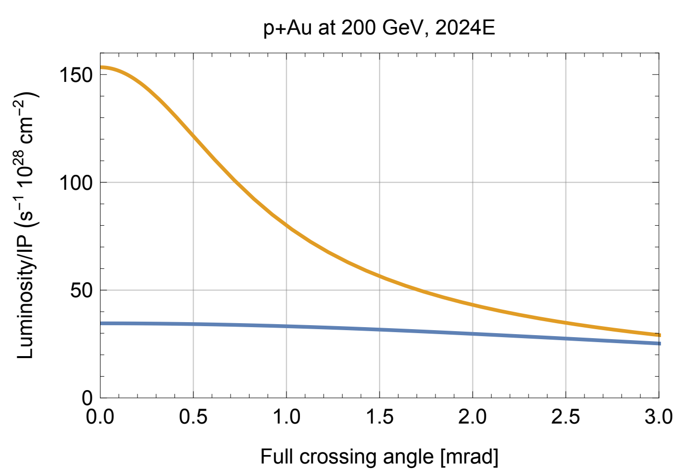

Figure 5: Total luminosity and within ±10 cm for p+Au at $\sqrt{s_{NN}}$ = 200 GeV with the 2024E parameters.