RHIC Collider Projections (FY 2019 – FY 2027)

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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, and in Part II the Beam Energy Scan II (BES-II) in RHIC Run-19 through Run-21. In Part III an outlook is given until 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. In 2019 one half of the RHIC Blue ring will be cooled down to 4 K 1.5 months before the RHIC Run starts, in order to supply liquid helium to IR2 so that the LEReC superconducting booster cavity can be operated in preparation for the LEReC cooling commissioning.

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.

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. 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 1-2 days 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.

28 weeks of RHIC refrigerator operation in FY 2019 could be scheduled in the following way:

Cool-down from 50 K to 4 K	0.5 weeks	
Set-up (Au+Au)	1.0 weeks	(no dedicated time for experiments)
Ramp-up and experimenter set-up(Au+Au)	0.5 weeks	

Modes 1A (LEReC commissioning, dedicated and interleaved)	7.0 weeks
Mode 1B and 1C (9.8 GeV/nucleon colliding and fixed target)	6.0 weeks
Mode 1D and 1F (7.3 GeV/nucleon colliding and fixed target)	8.0 weeks
Mode 1E (31.2 GeV/nucleon fixed target)	0.5 weeks
Start on next energy or continue mode 1A	3.5 weeks
QP diode tests	0.5 weeks
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.

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.

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 system will be 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 50 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.

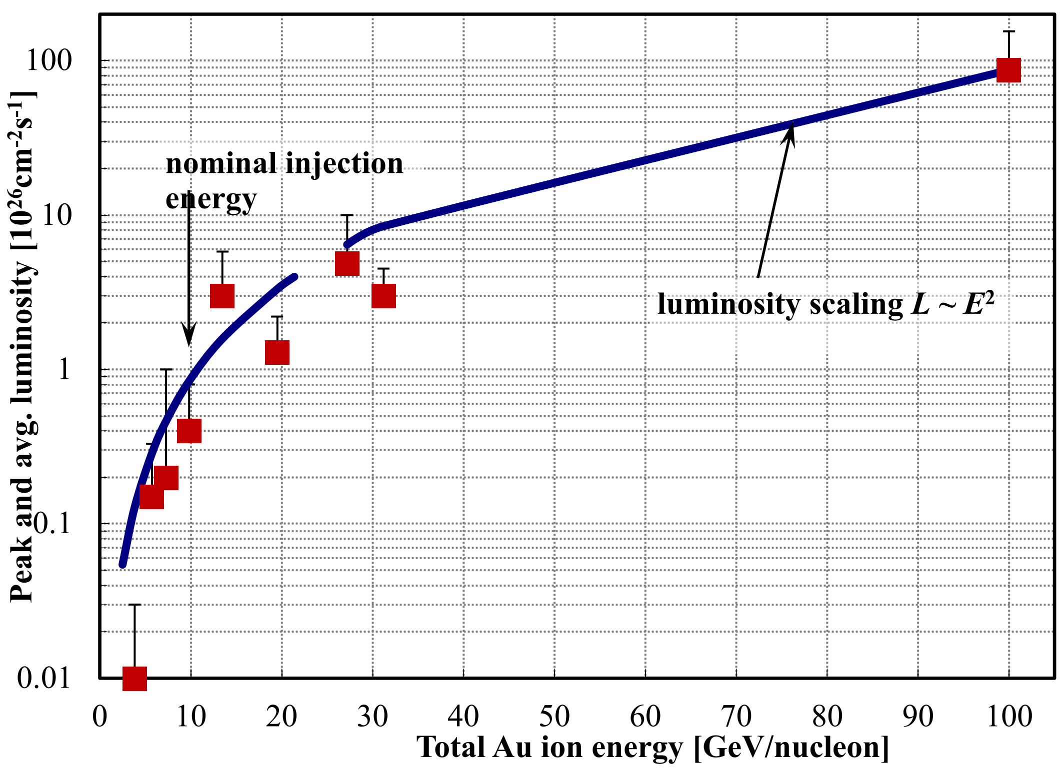

Figure 1: Observed average (red squares) and peak (top bar) Au+Au luminosity for 8 different energies. The blue line shows the luminosity scaling quadratically with the energy. Near the transition energy operation is not possible.

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.

Part II – Beam Energy Scan II (BES-II) 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 is being implemented for the 2 or 3 lowest of the 5 beam energies. 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. Table 2 and Figure 2 show the main beam parameters and luminosities in BES-I and BES-II for colliding beam operation. In addition, fixed target operation over about 2 days is planned at all beam energies of the BES-II with a goal of 100M events at each energy. 36 h were needed to accumulate 100M events in Run-18. The fixed target program is not constrained by luminosity, i.e. it is always possible to fill the STAR bandwidth.

Table 2: Beam parameters demonstrated in BES-I and projected beam parameters for BES-II.

Parameter	Unit	BES-I / II		BES-I / II		BES-I / II		BES-I / II		BES-I / II	
Total particle energy	GeV/nucleon	3.85		4.55		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	0.6	0.4	0.80	1.1	1.30	1.1	2.10	0.9	2.30
Transverse rms emittance ε_{xy}	μm	3.3	2.5	6.7	2.5	2.5	2.5	1.7	1.7	2.5	3.5
Envelope function at IP β^*	m	6.0	6.0	10.0	5.0	6.0	4.0	3.5	3.5	2.5	3.0
Direct space charge tune shift ΔQ_{sc}	10^{-3}	-36	-27	-10	-27	-46	-29	-42	-80	-13	-24
beam-beam parameter ξ/IP	10^{-3}	-1	-1	-0.2	-1	-2	-2	-3	-5	-1	-3
Initial luminosity L_{init}	**10^{24} cm^{-2}s^{-1}**	**3.1**	**6.0**	**0.35**	**15**	**33**	**60**	**100**	**369**	**80**	**330**
Average/initial luminosity	%	40	84	34	117	45	100	20	16	50	40
Average store luminosity L_{avg}	**10^{24} cm^{-2}s^{-1}**	**1.25**	**5.0**	**0.12**	**17.3**	**15**	**60.0**	**20**	**59**	**40**	**132**
Luminosity improvement factor	...		4.0x				4.0x		2.9x		3.3x
Time in store	%	55	65	--	65	66	65	57	65	71	65
Max. luminosity/week	μb^{-1}	0.5	2.0		6.8	5.0	24	8.1	23	15	52
Min. luminosity/week	μb^{-1}		0.5				5.0		8.1		15
total events, min goal	M	4.3	**80**	--	**100**	11.7	**150**	24	**200**	36	**300**
total events, full goal	M		**100**		**160**		**230**		**300**		**400**
total *Ldt* delivered, min goal	μb^{-1}	2.48	19.0	--	41	7.8	75	21.2	82	17.5	164
total *Ldt* delivered, full goal	μb^{-1}		23.8		65		116		123		218
running time for physics, min goal	weeks	4.6	9.7	--	6.0	1.4	3.2	3.4	3.5	1.4	3.2
running time for physics, full goal	weeks		12.1		9.5		4.9		5.3		4.2

Running modes in Run-19 – Run-19 has 6 modes scheduled: (i) bunched beam electron cooling commissioning with Au beam at 3.85 GeV/nucleon, (ii) colliding Au+Au beams at 9.8 GeV/nucleon (Figure 3), (iii) Au beam at 9.8 GeV/nucleon on a fixed Au target, (iv) colliding Au+Au beams at 7.3

GeV/nucleon (Figure 4), (v) Au beam at 7.3 GeV/nucleon on a fixed Au target, and (vi) Au beam at 31.2 GeV on a fixed Au target.
In preparation for the run, the Siemens motor-generator of the AGS underwent maintenance; the 56 MHz SRF cavity was removed; the RHIC orbit corrector PS resolution was upgraded from 12 to 16 bits; and a new vertical orbit corrector in the common section of IR2 was installed to allow for vertical separation of beams while having flat orbit in the cooling sections. 3 new 9 MHz cavities are now installed in both rings (60 kV each) for operation at the 3 lowest of the 5 BES-II energies. At the 2 highest energies the 28 MHz RF system will be used to maximize the average luminosity by providing stronger longitudinal focusing against IBS and a smaller vertex distribution.

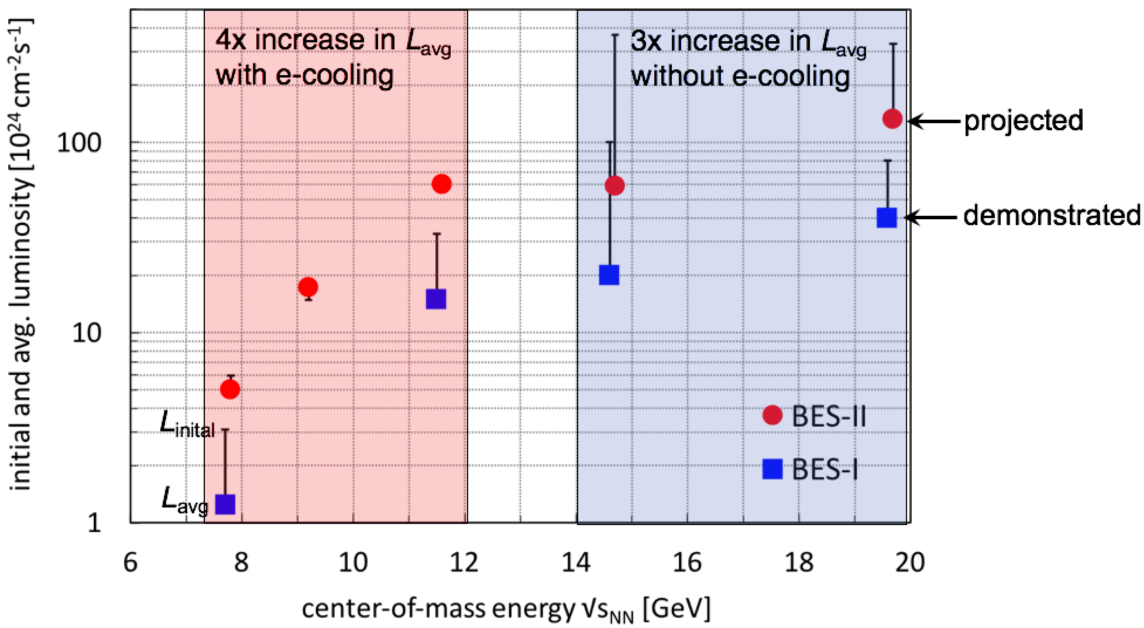

Figure 2: Demonstrated luminosities during BES-I and expected luminosities with electron cooling for the 3 lowest energies in BES-II, and without electron cooling at the 2 highest energies.

In Run-19 Tuesdays will be dedicated to operation so that STAR can reliably train new shift crews. Every other Wednesday will be dedicated to maintenance as in previous years. For all other days scheduling between LEReC cooling commissioning and physics operation will remain flexible in order to allow for maximum progress in the cooling commissioning effort. APEX times, while nominally every other Wednesday as in previous years, may also shift to support the cooling commissioning.

Running modes in Run-20/21 – Assuming successful demonstration of bunched beam cooling in Run-19, cooling still needs to be commissioned for collider operation at the 2 or 3 lowest BES-II energies. A detailed run plan in which order the remaining 3 beam energies will be operated in collider and fixed target mode will be developed after Run-19.

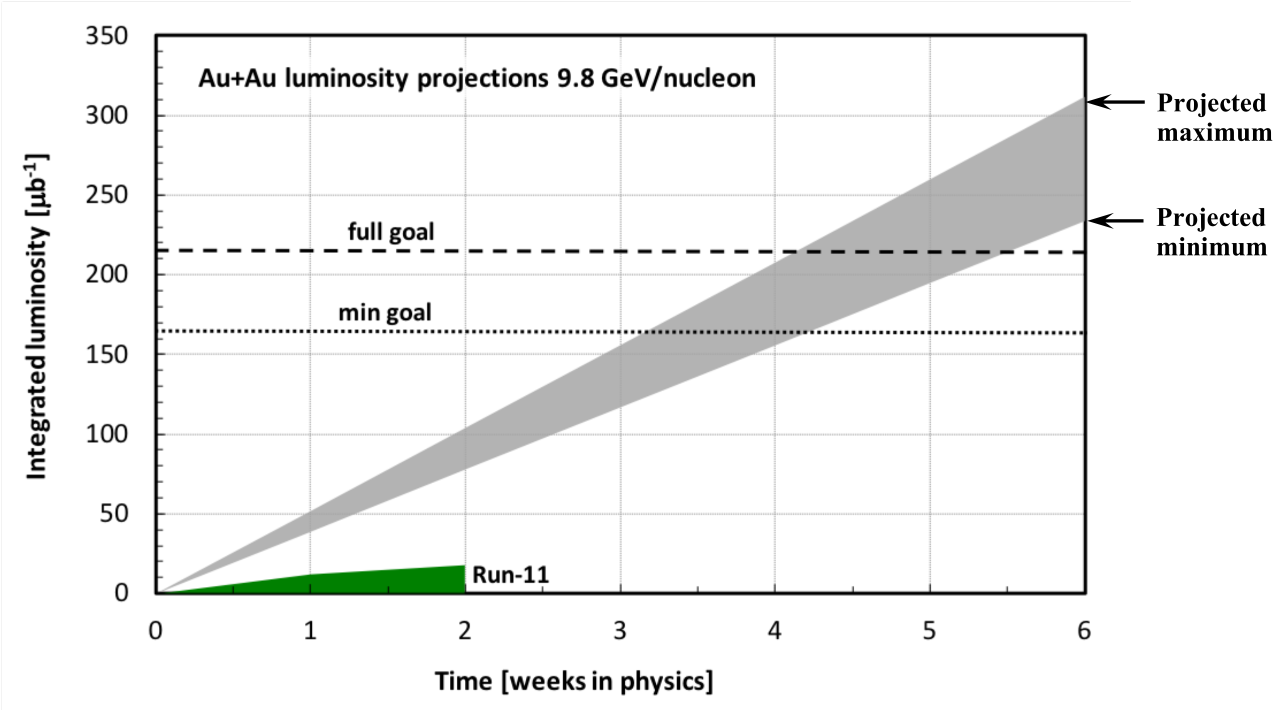

Figure 3: Projected minimum and maximum integrated luminosities for Run-19 Au+Au collisions at 9.8 GeV/nucleon beam energy (no cooling planned for this energy), comparison to Run-11, and the minimum and full luminosity goals for the BES-II physics program at this energy.

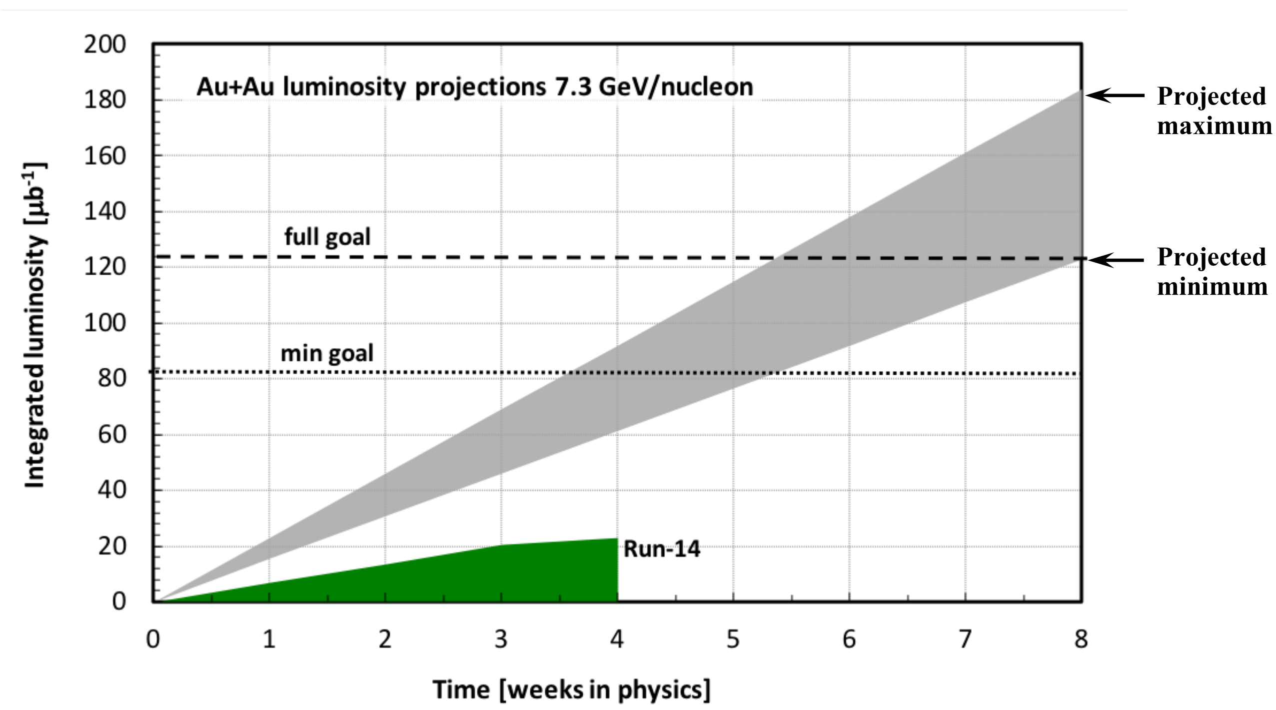

Figure 4: Projected minimum and maximum integrated luminosities for Run-19 Au+Au collisions at 7.3 GeV/nucleon beam energy (no cooling planned for this energy), comparison to Run-14, and the minimum and full luminosity goals for the BES-II physics program at this energy.

Part III – Projections until 2027

sPHENIX requested that luminosity be delivered only within a longitudinal range of ±10 cm, by applying e.g. a full crossing angle of 3 mrad. This is presently being studied, and likely such a large crossing angle cannot be accommodated. In addition, the RHIC Machine Protection System (MPS) is being upgraded in order to drastically reduce the number of abort kicker pre-fires. Below the luminosity delivered into ±10 cm is noted in addition to the full luminosity, albeit assuming no crossing angle.

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, with an ultimate goal of

$\mathcal{L}_{\text{store avg}}$ = 200×10^{26} cm^{-2}s^{-1} for Au+Au at 100 GeV/nucleon (100× design).

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 an Higher Order Mode (HOM) damper at 1 MV, below the design voltage of 2 MV. An upgrade is planned with a new HOM damper. 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 eliminated.

Table 3: 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	2.3	2.5	2.6	2.7	2.7	2.7
Average beam current/ring I_{avg}	mA	224	253	275	286	296	296	296
Stored beam energy	MJ	0.71	0.81	0.88	0.91	0.94	0.94	0.94
Envelope function at IP β^*	m	0.70	0.65	0.60	0.60	0.60	0.60	0.60
Beam-beam parameter ξ/IP	10^{-3}	-3.9	-4.4	-4.8	-5.0	-5.2	-5.2	-5.2
Initial luminosity $\mathcal{L}_{\text{init}}$	**10^{26} cm^{-2}s^{-1}**	**155**	**211**	**270**	**293**	**313**	**313**	**313**
Events per bunch-bunch crossing μ	…	0.40	0.54	0.69	0.75	0.80	0.80	0.80
Average/initial luminosity	%	56	60	65	64	64	64	64
Average store luminosity $\mathcal{L}_{\text{avg}}$	**10^{26} cm^{-2}s^{-1}**	**87**	**127**	**176**	**187**	**200**	**200**	**200**
Time in store	%	65	62	62	62	62	62	62
Max. luminosity/week	μb^{-1}	3000	4750	6590	7020	7510	7510	7510
Min. luminosity/week	μb^{-1}		3000	3000	3000	3000	3000	3000
Luminosity within $\|z\|$<10 cm	%	19	30	30	30	30	30	30

Polarized protons – Based on the experience to date and planned further improvements the ultimate luminosity and polarization goals for polarized proton operation are

$\mathcal{L}_{\text{store avg}}$ = 175×10^{30} cm^{-2}s^{-1} at 100 GeV with 60% average polarization
$\mathcal{L}_{\text{store avg}}$ = 600×10^{30} cm^{-2}s^{-1} at 255 GeV (60× design) with 55% average polarization

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.
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 fundamental 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 ^3He source is under development in collaboration with MIT. With Extended EBIS as an ionizer we expect that polarized ^3He can be made available in RHIC in 2021. To have high ^3He 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.

Table 4: 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	2.8	3.0	3.0	3.0	3.0	3.0
Average beam current/ring I_{avg}	mA	312	389	418	418	418	418	418
Stored beam energy	MJ	0.40	0.50	0.54	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
Hour glass 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	-12.1	-14.9	-14.9	-14.9	-14.9	-14.9
Initial luminosity L_{init}	**10^{30} $cm^{-2}s^{-1}$**	**115**	**203**	**268**	**268**	**268**	**268**	**268**
Events per bunch-bunch crossing μ	…	0.7	1.2	1.5	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**	**122**	**175**	**175**	**175**	**175**	**175**
Time in store	%	64	60	60	60	60	60	60
Max. luminosity/week	pb^{-1}	25	44	64	64	64	64	64
Min. luminosity/week	pb^{-1}		25	25	25	25	25	25
Luminosity within $\|z\|<10$ cm	%	16	19	19	19	19	19	19
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

Table 5: Demonstrated and max projected luminosities and polarization for p↑+p↑ runs at 255 GeV.

Parameter	Unit	FY2013	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}	1.85	2.8	3.0	3.0	3.0	3.0	3.0
Average beam current/ring I_{avg}	mA	257	389	412	412	412	412	412
Stored beam energy	MJ	0.84	1.27	1.34	1.34	1.34	1.34	1.34
Envelope function at IP β^*	m	0.65	0.55	0.50	0.50	0.50	0.50	0.50
Hour glass factor H	…	0.78	0.73	0.76	0.76	0.76	0.76	0.76
Beam-beam parameter ξ/IP	10^{-3}	-7.3	-12.2	-14.5	-14.5	-14.5	-14.5	-14.5
Initial luminosity L_{init}	**10^{30} cm^{-2}s^{-1}**	**248**	**701**	**1000**	**1000**	**1000**	**1000**	**1000**
Events per bunch-bunch crossing μ	…	1.7	4.8	6.9	6.9	6.9	6.9	6.9
Average/initial luminosity	%	64	60	60	60	60	60	60
Avg. store luminosity L_{avg}	**10^{30} cm^{-2}s^{-1}**	**160**	**417**	**600**	**600**	**600**	**600**	**600**
Time in store	%	56	55	55	55	55	55	55
Max. luminosity/week	pb^{-1}	60	139	200	200	200	200	200
Min. luminosity/week	pb^{-1}		60	60	60	60	60	60
Luminosity within $\|z\|$<10 cm	%	19	19	22	22	22	22	22
AGS extraction, P_{max}	%	72	70	70	70	70	70	70
RHIC store average, P_{max}	**%**	**52**	**55**	**55**	**55**	**55**	**55**	**55**
RHIC store average, P_{min}	%		52	52	52	52	52	52

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 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	252/2.1	271/2.3	271/2.3	271/2.4	271/2.5	271/2.6
Average beam current/ring I_{avg}	mA	313/176	350/227	376/247	376/257	376/267	376/277	376/287
Stored beam energy	MJ	0.40/0.56	0.40/0.73	0.49/0.79	0.49/0.82	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
Hour glass 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	-8.4/-4.0	-9.1/-4.9	-9.5/-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**	**127**	**160**	**166**	**172**	**172**	**172**
Average/initial luminosity	%	51	55	60	65	65	65	65
Avg. store luminosity L_{avg}	**10^{30} cm^{-2}s^{-1}**	**45**	**70**	**96**	**108**	**112**	**112**	**112**
Time in store	%	65	60	60	60	60	60	60
Max. luminosity/week	nb^{-1}	140	253	347	392	405	405	405
Min. luminosity/week	nb^{-1}		140	140	140	140	140	140
Luminosity within $\|z\|$<10 cm	%	17	20	25	25	25	25	25
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