RHIC Collider Projections (FY 2013 – FY 2017)

W. Fischer, M. Bai, M. Blaskiewicz, H. Huang, C. Montag, V. Ranjbar, G. Robert-Demolaize

Last update: 27 September 2012

This note discusses in Part I the running modes for the RHIC Run-12 (FY 2012) operating period including constraints from cryogenic cool-down, machine set-up and beam commissioning. In Part II a 5-year outlook is given. This latest update is based on the experience gained during the Run-11 operation, the shutdown work in 2012, and the physics plans for Run-12, the planned luminosity upgrades in RHIC.

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 – Run-12 Projections

Cryogenic operation – After the shutdown the two RHIC rings will be at room temperature. After bringing the rings to 50 K, 1 week will be required to cool them down from 50 K to 4 K. At the end of the run, ½ a week of refrigerator operation is required for the controlled warm-up to liquid nitrogen or room temperature.

Running modes – Running modes under consideration for Run-12 include pp2pp at 255 GeV, polarized protons at 255 GeV, and Au-Au at 7.5 GeV/nucleon. The Run length is not yet determined, and may be between 15 and 20 cryo weeks.

When starting the high energy polarized proton run we plan for about 2 week of machine set-up (no dedicated time for experiments) with the goal of establishing collisions, and about 1 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 goals shown below. The set-up and ramp-up period for polarized protons is about 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, however with priority for machine development. Estimates for set-up and ramp-up times are based on past performance and expected commissioning efforts for a new lattice. We plan for about 4 days of pp2pp before or after the regular 255 GeV polarized proton operation begins.

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

After a running mode has been established, the collision energy in the same mode can be changed in 1-3 days assuming no unusual machine downtime is encountered. The exact time needed for a change depends on the availability of a tested lattice, and on the direction of the energy change. A change of the polarization orientation at any or all of the experiments requires about 1 day.

For example, 20 weeks of RHIC refrigerator operation in FY 2012 could be scheduled in the following way:

Cool-down from 50 K to 4 K	1 week	
Set-up mode 1 (pp2pp)	1 ½ week (no dedicated time for experiments)	
Data taking mode 1	½ week	
Set-up mode 2 (p↑-p↑ at 255 GeV)	½ week (no dedicated time for experiments)	
Ramp-up mode 2	1 weeks (8 h/night for experiments)	
Data taking mode 2 with further ramp-up	12 weeks	
Set-up mode 3 (Au-Au at 7.5 GeV/nucleon)	½ week	(no dedicated time for experiments)
Data taking mode 3 with further ramp-up	2 ½ weeks	
Warm-up	½ week	

Past performance – Table 1 shows the luminosities achieved for U-U (Run-12), Au-Au (Run-11), Cu-Cu (Run-5), d-Au (Run-8), and polarized protons (Run-12). The time in store was 59% of the total time for Au-Au (Run-11) and 54% p-p (255 GeV, Run-12). Note that the total time includes all interruptions such as ramping, set-up, maintenance, machine development, and accelerator physics experiments. 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 for U-U (Run-12), Au-Au (Run-11), Cu-Au (Run-12), Cu-Cu (Run-5), d-Au (Run-8), and p-p (Run-12). The beam energy is stated.

Mode	Beam energy [GeV/n]	No of colliding bunches	Ions/bunch [10^9]	β^* [m]	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	13.5→2.5	8.8×10^{26}	5.6×10^{26}	0.2 nb^{-1}
Au-Au	100	111	1.3	0.75	15→10	50×10^{26}	30×10^{26}	1.0 nb^{-1}
Cu-Au	100	111	4.0 / 1.3	0.7	24.5→7	120×10^{26}	100×10^{26}	3.5 nb^{-1}
Cu-Cu	100	37	4.5	0.9	15→30	2×10^{28}	0.8×10^{28}	2.4 nb^{-1}
d-Au	100	95	100 / 1.0	0.85	15→20	27×10^{28}	13.5×10^{28}	40 nb^{-1}
p↑-p↑*	100	107	160	0.85	20→25	46×10^{30}	33×10^{30}	9.3 pb^{-1}
p↑-p↑*	255	107	170	0.65	21→25	165×10^{30}	105×10^{30}	32 pb^{-1}

*Blue and Yellow ring intensity- and time-averaged polarization of P = 59% stores at 100 GeV, P = 52% at 255 GeV in Run-12 as measured by the H-jet. To have a few non-colliding bunches in both STAR and PHENIX only 109 out of 111 bunches were filled, with 107 collisions at PHENIX and 102 collisions at STAR. If either experiment had elected to have all 111 bunches colliding, the luminosity would have been larger.

Luminosity projections – Table 2 lists the expected maximum peak and average luminosities for possible modes in Run-12 that are likely achievable after a sufficiently long running period, typically a few weeks, unless thus far unknown machine limitations are encountered. With experience from past runs we expect luminosities at the end of the initial ramp-up period to be 25-50% of the value at the end of the running period. The weekly integrated luminosity is derived from the predicted beam parameters and the calendar time in store. The expected rms diamond length for ions is 20 cm with the 197 MHz storage cavities and due to longitudinal stochastic cooling. For protons a new 9 MHz cavity has been operated since Run-11 that allowed for higher intensities, and has the potential to reduce the longitudinal emittance. Commissioning of longitudinal dampers in Run-13 is expected to reduce the longitudinal emittance resulting in an rms diamond length of 40 cm or better at 100 GeV (h = 360, V_{gap} = 300 kV, A_s = 1 eVs), and 30 cm or better at 255 GeV. The minimum luminosity projections are based on previous run performances.

Due to the required abort gaps in both beams, the maximum number of collisions can only be provided for either STAR or PHENIX. In Run-13 we request to align the abort gaps in IP10 to allow for commissioning of the electron lens instrumentation. With this both experiments will have an approximately 9% reduction in the number of collisions. During previous polarized proton runs both STAR and PHENIX required to have a few non-colliding bunches. Only 109 out of 111 bunches were filled, with 107 collisions at PHENIX and 102 collisions at STAR.

To minimize the time from store to store, 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 at store can also be used to maximize the average store polarization or figure of merit.

Table 2: Maximum luminosities that can be reached after a sufficiently long running period. The beam energy is stated. Other ion combinations can be estimated on demand.

Mode	Beam energy [GeV/n]	No of colliding bunches	Ions/bunch [10^9]	β^* [m]	Emittance [mm]	L_{peak} [$cm^{-2}s^{-1}$]	$L_{store\ avg}$ [$cm^{-2}s^{-1}$]	L_{week}
Au-Au	100	111	1.4	0.7	23→8	40×10^{26}	35×10^{26}	1.2 nb^{-1}
d-Au	100	111	110 / 1.4	0.8	17→25	47×10^{28}	28×10^{28}	95 nb^{-1}
p↑-Au	100	111	180 / 1.4	0.8	17→25	76×10^{28}	53×10^{28}	175 nb^{-1}
p↑-p↑*	100	100	160	0.85	17→25	60×10^{30}	35×10^{30}	13 pb^{-1}
p↑-p↑*	255	100	200	0.65	19→25	270×10^{30}	160×10^{30}	54 pb^{-1}

* We expect that an intensity- and time-averaged store polarization P of up to 65%, as measured by the H jet, can be reached at 100 GeV. At 255 GeV we expect the polarization P to reach up to 57%. In Run-11 PHENIX had 107 and STAR 102 colliding bunches.

Operation at energies other than 100 GeV/nucleon – It is generally preferable although not imperative to lower the energy when the collision energy is changed in any given mode. This can be done in 1-3 days. For Au-Au operation at 100 GeV/nucleon the limiting aperture is in the triplets. For energies less than 100 GeV/nucleon the un-normalized beam emittance is larger and, to maintain the beam size within the triplet, the β-function in the triplet has to be reduced, which results in a larger β^*. The combined effect is that the luminosity scales 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} = 26 for ions) is not possible. At the nominal injection energy (9.8 GeV/nucleon) refilling is very efficient, and β^* can be reduced to 2.5 m. 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.

Below energies of 100 GeV/nucleon stochastic cooling is not possible when the beam size in the pick-ups and kickers becomes too large, or $\eta = 1/\gamma_{tr}^2 - 1/\gamma^2$ becomes too large. In practice, this prevents the use of stochastic cooling below about 40 GeV/nucleon, and a few days are required to change filters in the stochastic cooling systems after an energy change. So far stochastic cooling has not been used below 100 GeV/nucleon.

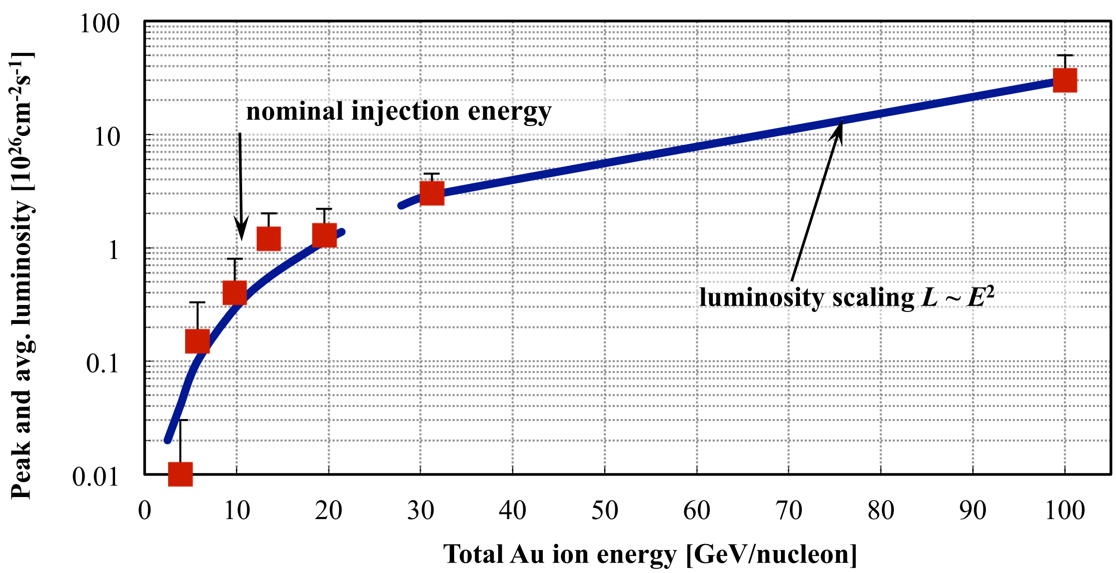

Figure 1: Observed average (red squares) and peak (top bar) Au-Au luminosity for 7 different energies. The blue line shows the luminosity scaling quadratically with the energy. The gap is around the transition energy at which operation is not possible.

Below 10 GeV/nucleon beam energy, due to limitations in the rf system, it is not possible to provide collisions at all energies simultaneously to both. Table 3 lists the energies at which two experiments or only one experiment can run.

For polarized protons the luminosity below 100 GeV scales with the square of the energy, where 100% of the luminosity is reached at 100 GeV. For energies between 100 and 255 GeV, the luminosity increases less than quadratically with the energy. This is shown in Figure 2. The polarized proton bunch length is only weakly dependent on the energy (for constant longitudinal emittance and gap voltage), also shown in Figure 2.

Asymmetric collisions – To date d-Au collisions were provided in Run-3 and Run-8, and Cu-Au collisions in Run-12. The machine was designed for p-Au collisions, and with stochastic cooling only the initial Au beam size needs to be accommodated in the DX magnets. It is then sufficient to move the IR6 and IR8 DX dipoles horizontally by 1 cm (without stochastic cooling all DX magnets need to be moved). This can be done during a long maintenance day. The existing vacuum stands allow DX movements such that operation with Au beam in the Blue ring and proton beam in the Yellow ring is possible. The vacuum stands and shielding arrangement in the IRs need to be modified if proton beam is requested in the Blue ring, and Au beam in the Yellow ring.

A recent study also concluded that it should be possible to collide two Au beams with different energies, namely 7.28 GeV/nucleon and 100 GeV/nucleon respectively. In this case a bunch in the Blue ring will collide with different bunches in the Yellow ring after each turn, and also encounter the abort gap. The abort gap encounters in particular lead to a periodic change of the beam-beam induced tune spread, and will have an adverse effect on the beam lifetime. Matched beam sized can be achieved with $\beta^* = 2$ m in the low-energy ring, and $\beta^* = 11$ m in the high-energy ring. The relatively small β^* value for the low energy ring requires beam scraping. Luminosities of about $5\text{x}10^{26}$ $\text{cm}^{-2}\text{s}^{-1}$ may be possible. Only one experiment can run at a time.

Following are specific comments on pp2pp, polarized proton running at 255 GeV, and Au-Au at 7.5 GeV/nucleon.

Table 3: Au-Au energy ranges in which two or only one experiment can run.

E_{tot} [GeV/nucleon]	$\sqrt{s_{NN}}$ [GeV]	Harmonic number	No of simultaneous experiments
2.42 – 2.55	4.84 – 5.10	387	2
2.55 – 2.67	5.10 – 5.34	384	1
2.67 – 2.84	5.34 – 5.68	381	1
2.84 – 3.08	5.68 – 6.16	378	2
3.08 – 3.32	6.16 – 6.64	375	1
3.32 – 3.69	6.64 – 7.38	372	1
3.69 – 4.33	7.38 – 8.66	369	2
4.33 – 5.17	8.66 – 10.34	366	1
5.17 – 7.30	10.34 – 14.60	363	1
7.30 – 100.0	14.60 – 200.0	360	2

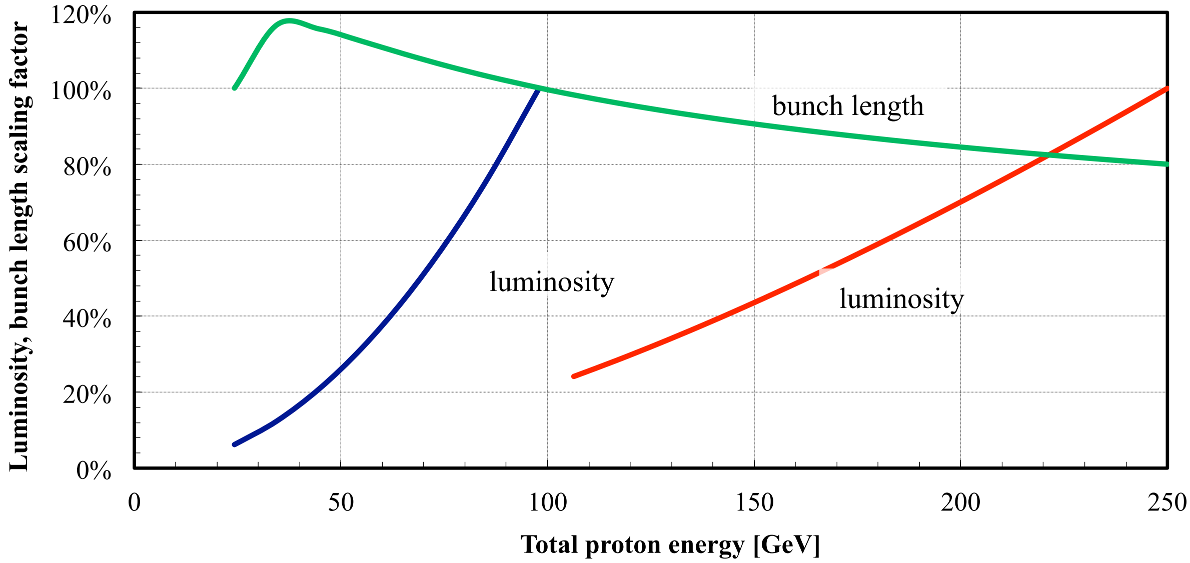

Figure 2: Luminosity scaling for polarized proton operation in the energy range 24 to 100 GeV, and the energy range 100 GeV to 255 GeV as well as bunch length scaling assuming constant longitudinal emittance and gap voltage.

pp2pp at 255 GeV – The pp2pp lattice with β^* = 7.5 m at IP6 requires the reversal of some power supplies in IR6. For this reason it is most time efficient to commission the pp2pp lattice, and then switch to the regular polarized proton lattice. With a bunch intensity of about 10^{10} protons transverse stochastic cooling with cooling times of order one hour is possible. Setup for stochastic cooling is challenging due to the short run time. Collisions can also be provided at IP8 but due to the small bunch intensity, the luminosity is about two orders of magnitude lower than during regular polarized proton running.

Polarized protons at 255 GeV – In Run-13 a new polarized proton source will be used. When fully commissioned the new source is expected to deliver an order of magnitude more intensity at 5% increased polarization. The high intensity can also be used to make bunches that have a small emittance in both transverse and the longitudinal dimensions. The new source will be the main performance upgrade for Run-13. We expect a polarization value of 52% at a minimum, demonstrated during Run-12, and 57% at a maximum.
Also new in Run-13 are one or two electron lenses in the common beam pipe section of IR10. These devices will eventually reduce the beam-beam induced tune spread and allow for higher bunch intensities. The lenses require significant commissioning time and we do not expect luminosity increases from the lenses in Run-13. To minimize resonance driving terms in the beam-beam compensation the electron lenses require a certain phase advance to IP8, and new lattices will be commissioned for both the Blue and Yellow ring.
We will again accelerate with the 9 MHz rf cavity, and use the 28 MHz system at store. It is planned to commission a longitudinal damper at injection to reduce the longitudinal emittance.

Figure 3 shows the projected minimum and maximum luminosity for 255 GeV beam energy, where it is assumed that the peak performance is reached after 4 weeks of linear ramp-up, starting with 25% of the final value.

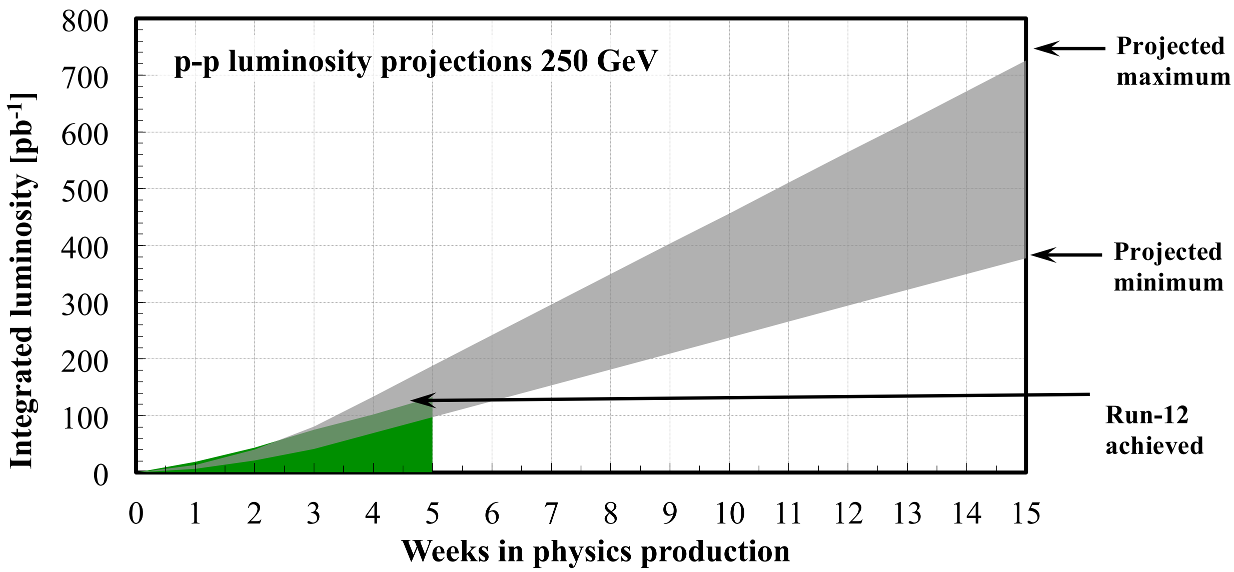

Figure 3: Projected minimum and maximum integrated luminosities for polarized proton collisions at 255 GeV beam energy, assuming linear weekly luminosity ramp-up in 4 weeks. An average store polarization between up to 57% is expected.

Au-Au 7.5 GeV/nucleon – We have previously operated at 9.8 GeV/nucleon and 5.75 GeV/nucleon and expect the performance can be interpolated from the performance at these two energies. We assume $\beta^* = 3.5$ m and anticipate an optimum store length of 25 min with frequent refills. Collisions are possible at both STAR and PHENIX simultaneously. Figure 4 shows the projected minimum and maximum luminosity for 3 weeks operation.

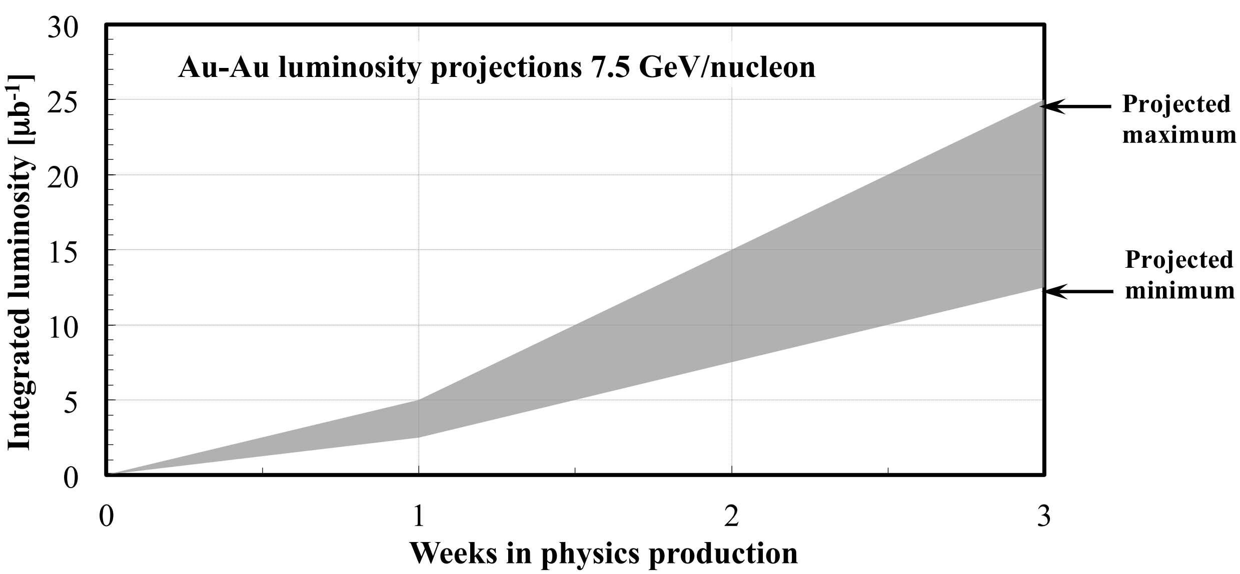

Figure 4: Projected minimum and maximum integrated luminosities for Au-Au at 7.5 GeV/nucleon.

Part II – 5-Year Projections

A number of improvements are planned over the next five years to increase the RHIC luminosity and polarization. For heavy ions most of the luminosity increases are expected to come from a 56 MHz superconducting radio frequency (SRF) system, for polarized protons from a new source and electron lenses to mitigate the head-on beam-beam effect. The performance goals, to be reached in or after 2014, are

$L_{\text{store avg}}$ = 40×10^{26} cm^{-2}s^{-1} for Au-Au at 100 GeV/nucleon (20× design)

$L_{\text{store avg}}$ = 60×10^{30} cm^{-2}s^{-1} for p-p at 100 GeV,
$L_{\text{store avg}}$ = 300×10^{30} cm^{-2}s^{-1} for p-p at 255 GeV (32× design)
both with 70% polarization

55% of calendar time in store (92h/week)

Heavy ion luminosity limitations – A number of effects limit the achievable luminosity. The main hardware upgrades to address these limits over the next five years are shown in Table 4. For heavy ions intrabeam scattering is the most fundamental luminosity limitation, leading to debunching and transverse emittance growth. Debunching can be prevented by longitudinal stochastic cooling, which has been used in both rings. Even with longitudinal stochastic cooling ions migrate to neighboring buckets. This effect can be reduced with more longitudinal focusing provided by a superconducting rf system of 56 MHz frequency (harmonic number 720). The normal conducting acceleration system has a frequency of 28 MHz (harmonic number 360), and the normal conducting storage system has a frequency of 197 MHz (harmonic number 2520). Transverse emittance growth is addressed with transverse stochastic cooling. Vertical and horizontal systems were operational in both rings in Run-12.
The beam intensity is limited by a fast transverse instability at transition, driven by the machine impedance and electron clouds. Further increases of the intensity threshold for these instabilities could be achieved with a transverse damper, and with in-situ coating of the arc beam pipe. Emittance growth due to instabilities at transition can be tolerated with stochastic cooling.
The Electron Beam Ion Source (EBIS) has provided U, Au and Cu ions for RHIC in Run-12. With EBIS all ion species, including noble gases and uranium can be provided.
Table 5 and Figure 5 show the previously delivered and the projected minimum and maximum Au-Au luminosity until FY 2017.

Proton luminosity and polarization limitations – The beam-beam interaction, in conjunction with other nonlinear and modulation effects, is the main luminosity limitation for polarized protons. The head-on beam-beam interaction in proton-proton colliders leads to a tune shift for small amplitude particles (called the beam-beam parameter), and a tune spread of the particles in the transverse distribution. This tune spread is in addition to the tune spread from other sources, including linear and nonlinear chromaticity and magnetic field errors in the interaction region magnets. Only a limited amount of tune spread can be tolerated. In addition to tune spread, nonlinear elements also create, enhance, or modify resonance driving terms that affect the long-term stability of particle motion.
To accommodate the largest possible beam-beam induced tune spread all other sources of tune spread should be minimized. A correction of the magnetic field errors in the interaction regions

has been developed. A beam-based nonlinear chromaticity correction has been implemented. To further increase the beam-beam parameter, it is planned to install at least one electron lens for commissioning Run-13. These are low-energy electron beams that collide head-on with the proton beam and partially reduce the effect of the two head-on beam-beam collisions. A new lattice with a specific phase advance between IP8 and the electron lenses in IR10 is needed to also reduce the resonance driving terms. Together with the polarized source upgrade, the electron lenses are expected to approximately double the luminosity, both at 100 GeV and at 255 GeV. We expect that β^* for protons can be reduced down to 0.5 m at 255 GeV beam energy. In Run-12 a 9 MHz rf system was used that will allow for a reduction in the longitudinal emittance after commissioning of the damping system at injection. This will lead to a reduced bunch length at store, which in turn reduces the hourglass effect.

The polarization in RHIC stores up to 100 GeV beam energy is limited by the source polarization, and the AGS polarization transmission. A horizontal tune jump system in the AGS is used to overcome the depolarizing effect of 82 resonances. Acceleration of proton beams to 100 GeV has not led to a loss in polarization. Proton beams accelerated to 255 GeV showed only about 85% polarization transmission from injection to the beginning of the physics store. At both energies a polarization loss of 0.5-1.0%/h (absolute) are observed in store. During Run-12 extensive test 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, which makes it unlikely that further large polarization gains can be made through parameter changes. Since the primary reason for a reduction in the average polarization is the development of polarization profiles, a reduction in beam emittance will increase the polarization. Such an emittance reduction becomes possible with the new polarized source in Run-13.

A polarized ^{3}He source is under development at MIT. With EBIS an ionizer we expect that polarized ^{3}He can be made available in RHIC in about 3 years. To have high ^{3}He polarization in RHIC an upgrade of one of the RHIC rings with 4 more Siberian snakes may be necessary.

Table 7 and Figure 6 show the previously delivered and the projected minimum and maximum p-p luminosity for both 100 GeV and 255 GeV beam energy until FY 2017.

Time in store – The fraction of the time in stores divided by the total time, reached 59% for Au-Au collisions in Run-11 and 54% for polarized protons in Run-12. All systems are periodically analyzed to maintain or increase the time in store further. We expect that a time in store of about 92 hours per week, or 55% of calendar time, is achievable in future years.

Table 4: Main upgrades for RHIC A-A and p-p operation planned for FY 2013 to FY 2017.

	A-A	p-p
For FY 2013	Longitudinal sc pickup upgrade	Polarized source upgrade 1st electron lens commissioning
For FY 2014	IR power supply upgrades 56 MHz superconducting rf system Longitudinal sc kicker upgrade	2nd electron lens commissioning IR power supply upgrades 56 MHz superconducting rf system
For FY 2015	IR power supply upgrades	IR power supply upgrades
For FY 2016	In-situ beam pipe coating	In-situ beam pipe coating
For FY 2017	Low energy cooling commissioning	

Table 5: Delivered RHIC luminosities of the last two Au-Au runs and projected Au-Au luminosities for 100 GeV/nucleon beam energy.

Parameter	Unit	FY2010	2011	2013E	2014E	2015E	2016E	2017E
No of bunches	…	111	111	111	111	111	111	111
Ions/bunch, initial	10^9	1.1	1.3	1.4	1.5	1.6	1.6	1.6
Avg. beam current/ring	mA	121	147	154	165	176	176	176
Stored beam energy	MJ	0.39	0.47	0.49	0.53	0.56	0.56	0.56
β*	M	0.75	0.75	0.7	0.7	0.7	0.7	0.7
Hour glass factor	…	0.93	0.70	0.75	0.80	0.85	0.93	0.93
Beam-beam param./IP	10^{-3}	1.5	2.1	1.4	1.4	1.5	1.5	1.5
Initial luminosity	**10^{26} cm^{-2}s^{-1}**	**40**	**50**	**41**	**46**	**55**	**60**	**60**
Avg./initial luminosity	%	50	60	85	90	100	100	100
Avg. store luminosity	**10^{26} cm^{-2}s^{-1}**	**20**	**30**	**35**	**41**	**55**	**60**	**60**
Time in store	%	53	59	60	60	60	60	60
Max. luminosity/week	μb^{-1}	650	1000	1250	1500	2010	2190	2190
Min. luminosity/week	μb^{-1}			900	1000	1000	1000	1000

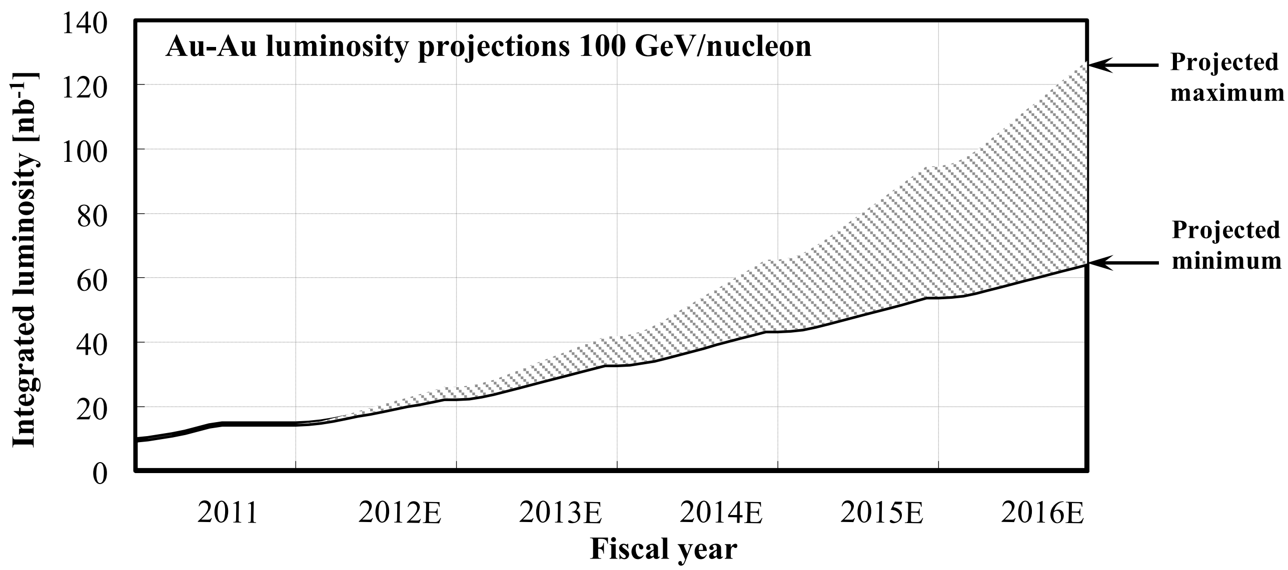

Figure 5: Previously delivered and minimum and maximum projected integrated luminosity for Au-Au collisions at 100 GeV/nucleon beam energy. Future physics runs are assumed to be 12 weeks long with linear weekly luminosity ramp-up in 4 weeks.

Table 6: Delivered RHIC luminosities and polarization of the last two 100 GeV p-p runs and projected p-p luminosities and polarization.

Parameter	Unit	FY2009	2012	2013E	2014E	2015E	2016E	2017E
No of colliding bunches	…	107	107	100	100	100	100	100
Ions/bunch, initial	10^{11}	1.4	1.6	1.6	1.8	1.9	1.9	2.0
Avg. beam current/ring	mA	181	214	200	225	238	238	250
Stored beam energy	MJ	0.23	0.27	0.26	0.29	0.30	0.30	0.32
$\beta*$	m	0.70	0.85	0.85	0.85	0.85	0.85	0.85
Hour glass factor	…	0.72	0.74	0.84	0.88	0.95	0.95	0.95
Beam-beam param./IP	10^{-3}	6.5	5.9	7.0	8.9	9.4	9.4	9.9
Initial luminosity	**10^{30} cm^{-2}s^{-1}**	**50**	**46**	**60**	**89**	**107**	**107**	**118**
Avg./initial luminosity	%	0.72	0.74	0.84	0.88	0.95	0.95	0.95
Avg. store luminosity	**10^{30} cm^{-2}s^{-1}**	**28**	**33**	**36**	**53**	**64**	**64**	**71**
Time in store	%	53	59	60	60	60	60	60
Max. luminosity/week	pb^{-1}	8.3	9.3	13	19	23	23	26
Min. luminosity/week	pb^{-1}			9.3	9.3	9.3	9.3	9.3
AGS extraction, P_{max}	%	65	70	70	70	70	70	70
AGS extraction, P_{min}	%		65	65	65	65	65	65
RHIC store avg., P_{max}	**%**	**56**	**59**	**65**	**65**	**70**	**70**	**70**
RHIC store avg., P_{min}	%			59	59	59	59	59

Table 7: Delivered RHIC luminosities and polarization of the last two <u>250/255 GeV</u> p-p runs and projected p-p luminosities and polarization.

Parameter	Unit	FY2011	2012	2013E	2014E	2015E	2016E	2017E
No of colliding bunches	…	107	107	100	100	100	100	100
Ions/bunch, initial	10^{11}	1.7	1.7	2.0	2.2	2.5	2.8	3.0
Avg. beam current/ring	mA	221	230	250	275	307	350	377
Stored beam energy	MJ	0.71	0.74	0.80	0.88	0.98	1.12	1.21
$\beta*$	m	0.60	0.65	0.65	0.60	0.60	0.50	0.50
Hour glass factor	…	0.71	0.80	0.82	0.85	0.85	0.93	0.93
Beam-beam param./IP	10^{-3}	5.1	6.1	7.7	9.0	10.1	11.5	13.1
Initial luminosity	**10^{30} cm^{-2}s^{-1}**	**145**	**165**	**269**	**389**	**482**	**825**	**1010**
Avg./initial luminosity	%	0.71	0.80	0.82	0.85	0.85	0.93	0.93
Avg. store luminosity	**10^{30} cm^{-2}s^{-1}**	**90**	**105**	**162**	**233**	**287**	**495**	**606**
Time in store	%	37	54	55	55	55	55	55
Max. luminosity/week	pb^{-1}	25	32	54	78	95	165	202
Min. luminosity/week	pb^{-1}			32	32	32	32	32
AGS extraction, P_{max}	%	67	70	70	70	70	70	70
AGS extraction, P_{min}	%		65	65	65	65	65	65
RHIC store avg., P_{max}	**%**	**48**	**52**	**57**	**65**	**65**	**70**	**70**
RHIC store avg., P_{min}	%			52	52	52	52	52

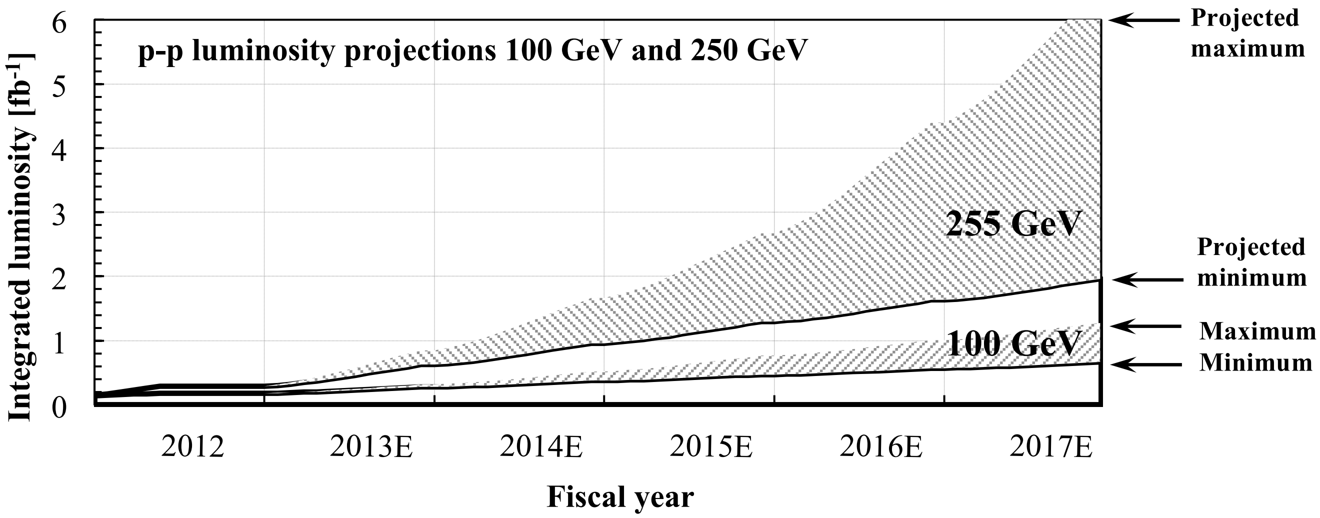

Figure 6: Previously delivered and minimum and maximum projected integrated luminosity for p-p collisions at 100 GeV and 250/255 GeV beam energy. Future physics runs are assumed to be 12 weeks long with linear weekly luminosity ramp-up in 6 weeks.