

# RHIC Collider Projections (FY 2012 – FY 2016)

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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 planned luminosity upgrades in RHIC, the shutdown work in 2011, and the physics plans for Run-12.

**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 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 polarized protons at 100 GeV and 250 GeV, uranium-uranium operation at 96.4 GeV/nucleon, and copper-gold operation at 100 GeV/nucleon.

When starting the high energy ion run we plan for about 1 week of machine set-up (no dedicated time for experiments) with the goal of establishing collisions, and about 1 week 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.

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, 22 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 (p↑-p↑ at 100 GeV)	1 week	(no dedicated time for experiments)
Ramp-up mode 1	2 week	(8 h/night for experiments)
Data taking mode 1 with further ramp-up	5 weeks	
Set-up mode 2 (p↑-p↑ at 250 GeV)	½ week	(no dedicated time for experiments)
Ramp-up mode 2	1 week	(8 h/night for experiments)
Data taking mode 2 with further ramp-up	7 weeks	
Set-up mode 3 (U-U at 100 GeV/nucleon)	1 week	(no dedicated time for experiments)
Data taking mode 3 with further ramp-up	3 weeks	
Warm-up	½ week	

**Past performance** – Table 1 shows the luminosities achieved for Au-Au (Run-11), Cu-Cu (Run-5), d-Au (Run-8), and polarized protons (Run-9, Run-11). The time in store was 59% of the total time for Au-Au (Run-11) and 54% p-p (Run-9). We consider the time-in-store of 37% for the 250 GeV p-p Run-11 an aberration. 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 Au-Au (Run-11), Cu-Cu (Run-5), d-Au (Run-8), and p-p (Run-9, Run-11). For ion operation numbers are given for a beam energy of 100 GeV/nucleon. For polarized proton operation the beam energy is stated.**

Mode	No of colliding bunches	Ions/bunch [10 <sup>9</sup> ]	β* [m]	Emittance [μm]	$L_{\text{peak}}$ [cm <sup>-2</sup> s <sup>-1</sup> ]	$L_{\text{store avg}}$ [cm <sup>-2</sup> s <sup>-1</sup> ]	$L_{\text{week}}$
Au-Au	111	1.3	0.75	15-10	50×10 <sup>26</sup>	30×10 <sup>26</sup>	1.0 nb <sup>-1</sup>
Cu-Cu	37	4.5	0.9	15-30	2×10 <sup>28</sup>	0.8×10 <sup>28</sup>	2.4 nb <sup>-1</sup>
d-Au	95	100d/1.0Au	0.85	15-20	27×10 <sup>28</sup>	13.5×10 <sup>28</sup>	40 nb <sup>-1</sup>
p↑-p↑* 100 GeV	107	135	0.7	15-20	50×10 <sup>30</sup>	28×10 <sup>30</sup>	8 pb <sup>-1</sup>
p↑-p↑* 250 GeV	107	165	0.6	24-24	145×10 <sup>30</sup>	90×10 <sup>30</sup>	25 pb <sup>-1</sup>

\*Blue and Yellow ring intensity-averaged polarization of  $P = 56\%$  stores at 100 GeV,  $P = 48\%$  at 250 GeV in Run-11 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. Unless stated otherwise for all modes it was assumed that the beam energy is 100 GeV/nucleon. The weekly integrated luminosity is derived from the predicted beam parameters and the calendar time in store. The expected diamond rms 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 in Run-11 that allowed for higher intensities, and has the potential to reduce the longitudinal emittance. Commissioning of longitudinal dampers in Run-12 is expected to reduce the longitudinal emittance resulting in an rms diamond length of 40 cm or better at 100 GeV ( $h = 360$ ,  $V_{\text{gap}} = 300$  kV,  $A_s = 1$  eVs), and 30 cm or better at 250 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. The other experiment 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.

**Table 2: Maximum luminosities that can be reached after a sufficiently long running period. For ion operation numbers are given for a beam energy of 100 GeV/nucleon. For polarized proton operation the beam energy is stated.**

Mode	No of colliding bunches	Ions/bunch [10 <sup>9</sup> ]	$\beta^*$ [m]	Emittance [ $\mu\text{m}$ ]	$L_{\text{peak}}$ [ $\text{cm}^{-2}\text{s}^{-1}$ ]	$L_{\text{store avg}}$ [ $\text{cm}^{-2}\text{s}^{-1}$ ]	$L_{\text{week}}$
U-U	111	0.85	0.75	15-10	$20 \times 10^{26}$	$14 \times 10^{26}$	$0.5 \text{ nb}^{-1}$
Au-Au	111	1.3	0.75	15-10	$50 \times 10^{26}$	$35 \times 10^{26}$	$1.1 \text{ nb}^{-1}$
Cu-Cu	68	6.0	0.75	15-20	$8 \times 10^{28}$	$5 \times 10^{28}$	$16 \text{ nb}^{-1}$
Cu-Au	111	4.0Cu/1.3Au	0.85	15-20	$1.7 \times 10^{28}$	$1.0 \times 10^{28}$	$3.1 \text{ nb}^{-1}$
d-Au	111	110d/1.1Au	0.85	18-30	$30 \times 10^{28}$	$18 \times 10^{28}$	$60 \text{ nb}^{-1}$
$p\uparrow-p\uparrow^*$ 100 GeV	107	135	0.85	15-20	$50 \times 10^{30}$	$30 \times 10^{30}$	$10 \text{ pb}^{-1}$
$p\uparrow-p\uparrow^*$ 250 GeV	107	165	0.6	20-25	$200 \times 10^{30}$	$120 \times 10^{30}$	$40 \text{ pb}^{-1}$

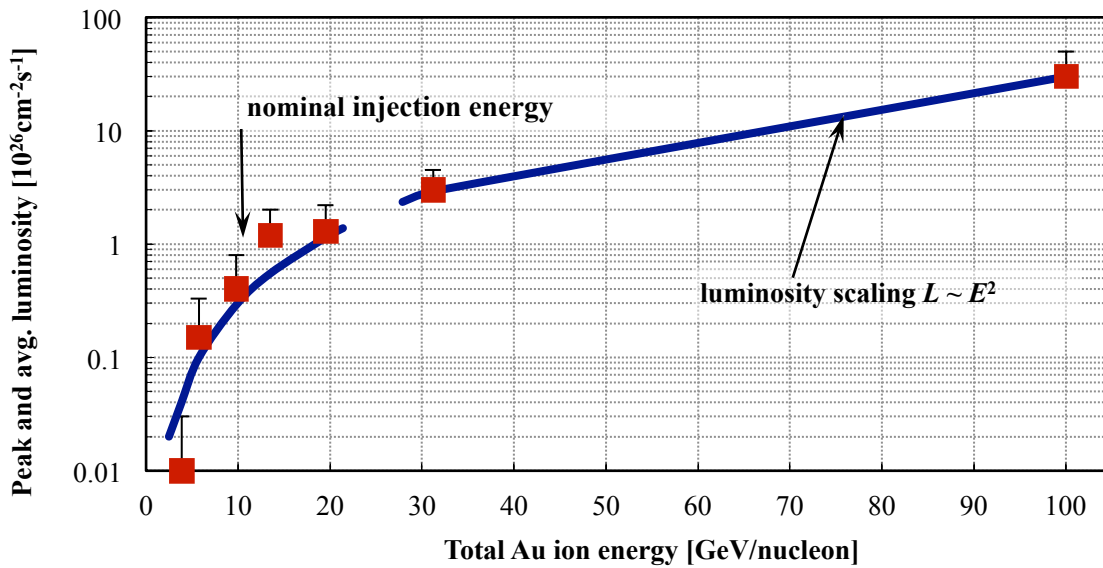
\* We expect that an intensity-averaged store polarization  $P$  of up to about 60%, as measured by the H jet, can be reached at 100 GeV. At 250 GeV we expect the polarization  $P$  to reach about 55%. In Run-11 PHENIX had 107 and STAR 102 colliding bunches.

**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  $\beta$ -function in the triplet has to be reduced, which

results in a larger  $\beta^*$ . 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 ( $\gamma_{tr} = 26$  for ions) is not possible. At the nominal injection energy (9.8 GeV/nucleon) refilling is very efficient, and  $\beta^*$  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.**

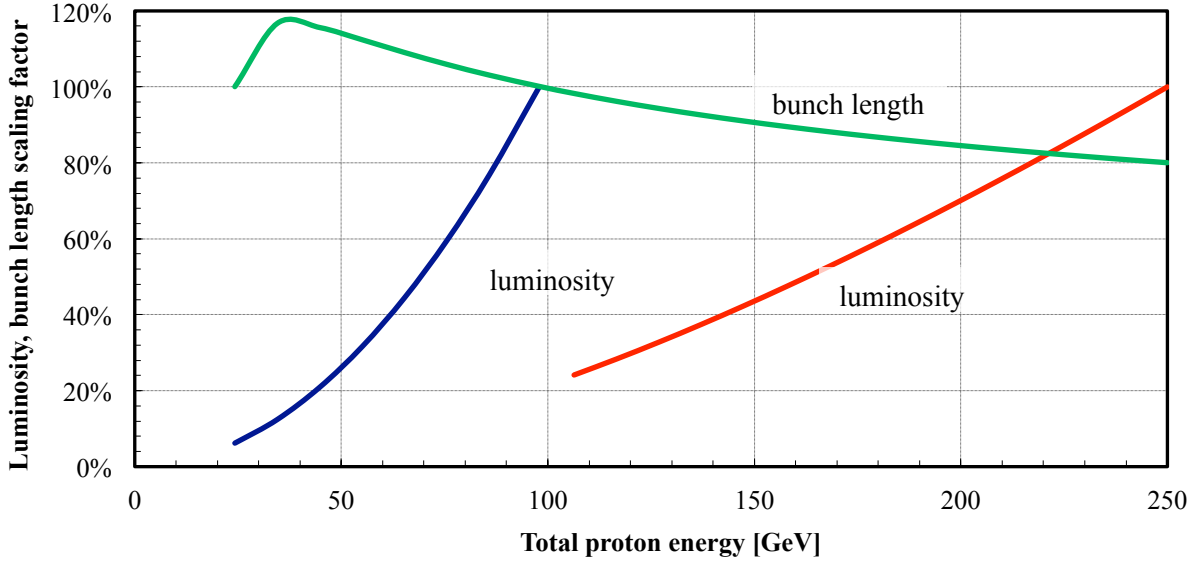
Below 10 GeV/nucleon beam energy, due to limitations in the rf system, it is not possible to provide collisions at all energies simultaneously to both experiments or even only one experiment. Table 3 lists the energies at which two experiments or only one experiment can run.

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 250 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.

Following are specific comments on polarized proton running at 100 GeV and 250 GeV, uranium-uranium, and copper-gold running.

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

$E_{\text{tot}}$ [GeV/nucleon]	$\sqrt{s_{\text{NN}}}$ [GeV]	No of simultaneous experiments
2.46 – 2.55	4.91 – 5.10	2
2.58 – 2.69	5.15 – 5.38	1
2.73 – 2.86	5.45 – 5.72	1
2.90 – 3.08	5.80 – 6.15	2
3.14 – 3.36	6.27 – 6.71	1
3.44 – 3.74	6.87 – 7.47	1
3.86 – 4.30	7.71 – 8.60	2
4.50 – 5.28	9.00 – 10.55	1
5.67 – 7.58	11.34 – 15.15	1
9.00 – 100.0	18.0 – 200.0	2



**Figure 2: Luminosity scaling for polarized proton operation in the energy range 24 to 100 GeV, and the energy range 100 GeV to 250 GeV as well as bunch length scaling assuming constant longitudinal emittance and gap voltage.**

**Polarized protons at 100 GeV** – With the experience from Run-9 we expect that the luminosity can be raised only modestly, and plan to operate with  $\beta^* = 0.85$  m. The polarization should be at least as high as in Run-9, and may be slightly higher due to the fully commissioned AGS tune jump system, and the generally better beam control through feedbacks in RHIC. We expect an intensity-averaged store polarization between 55% and 60%. We plan to use the new 9 MHz rf acceleration system, and need to commission the longitudinal dampers to reduce the longitudinal emittance. At store the 28 MHz system will be used. Figure 3 shows the projected minimum and maximum luminosity for 100 GeV beam energy, where it is assumed that the peak performance is reached after 3 weeks of linear ramp-up, starting with 25% of the final value.

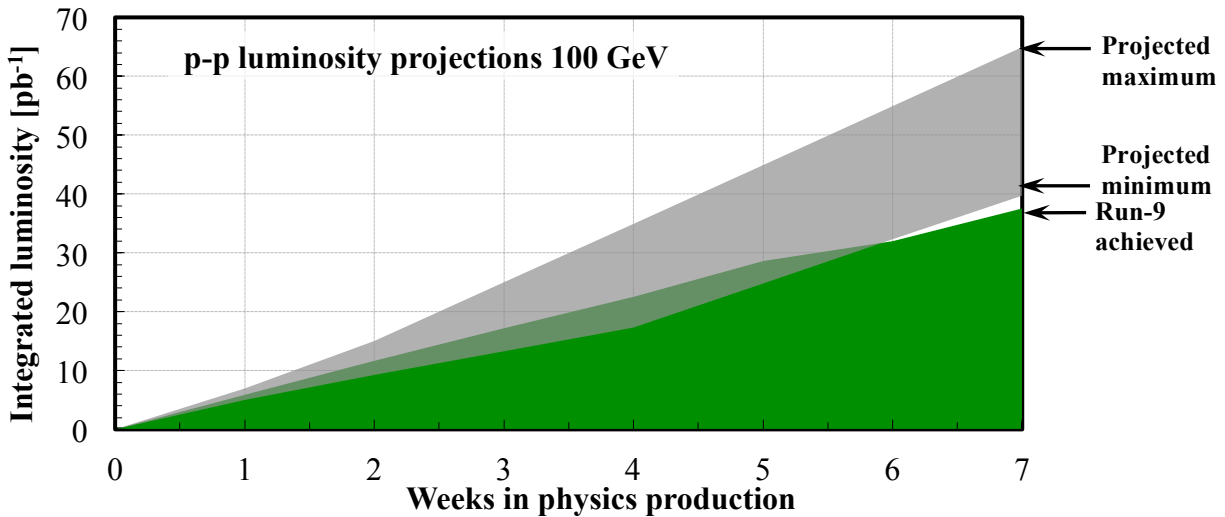


Figure 3: Projected minimum and maximum integrated luminosities for polarized proton collisions at 100 GeV beam energy, assuming a linear weekly luminosity ramp-up in 4 weeks. An average store polarization between 50 and 60% is expected.

**Polarized protons at 250 GeV** – We expect a polarization value of 48% at a minimum, demonstrated during Run-11, and 55% at a maximum. The latter requires changes at the source, a smaller emittance than in Run-10, and a small ( $\sim 1$  GeV) adjustment of the store energy to increase the polarization lifetime observed in Run-11. We plan to operate with the same lattice as in Run-11, which had a  $\beta^*$  as low as 0.60 m at PHENIX. The lattice  $\beta$ -beat can be corrected further. We will accelerate with the 9 MHz rf cavity. At store the 28 MHz system will be used. In Run-11 a new experiment at IP2,  $A_{NDY}$ , was tested. Collisions in IP2 started about 3 h into a store, and IP2 had  $\beta^* = 3.0$  m and no crossing angle. If  $A_{NDY}$  runs also in Run-12, the same operating mode can be used, and  $\beta^*$  may be reduced further down to 1.5 m. Figure 4 shows the projected minimum and maximum luminosity for 250 GeV beam energy, where it is assumed that the peak performance is reached after 8 weeks of linear ramp-up, starting with 25% of the final value.

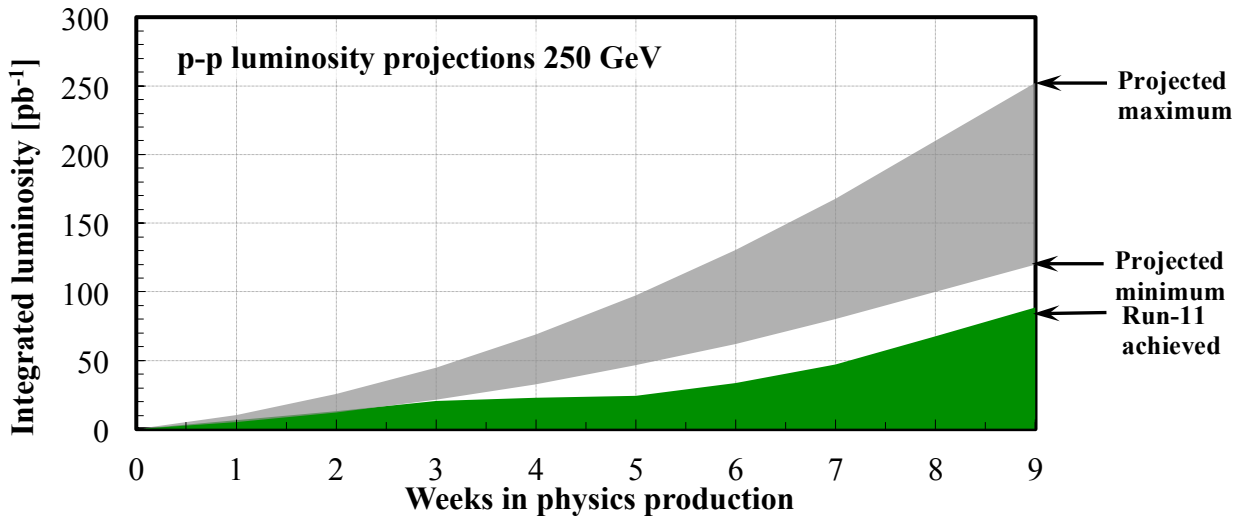


Figure 4: Projected minimum and maximum integrated luminosities for polarized proton collisions at 250 GeV beam energy, assuming linear weekly luminosity ramp-up in 8 weeks. An average store polarization between 45 and 50% is expected.

**Uranium-Uranium at 96.4 GeV/nucleon** – Uranium operation requires EBIS, now under commissioning with gold ions. A uranium cathode is at hand. In the first year of operation EBIS may not yet deliver nominal uranium beam parameters, and the intensity of the uranium beam is lower than the gold beam intensity. The result is a luminosity lower than the luminosity that can be achieved for gold beams.

A fast switchover (about ½ week) from Au-Au 100 GeV/nucleon to U-U can be achieved when the rigidity of the stored beam is retained, resulting in a uranium energy of 96.4 GeV/nucleon. For an uranium energy of 100 GeV/nucleon, all magnet currents need to be raised by 3.7% compared to 100 GeV/nucleon gold operation. This was tested at the end of Run-11 with the exception of the DX magnets.

Stochastic cooling for uranium beams is possible although a new setup is required. In a short run stochastic cooling may not reach full performance. For Run-12 new horizontal stochastic cooling systems will be installed in both rings.

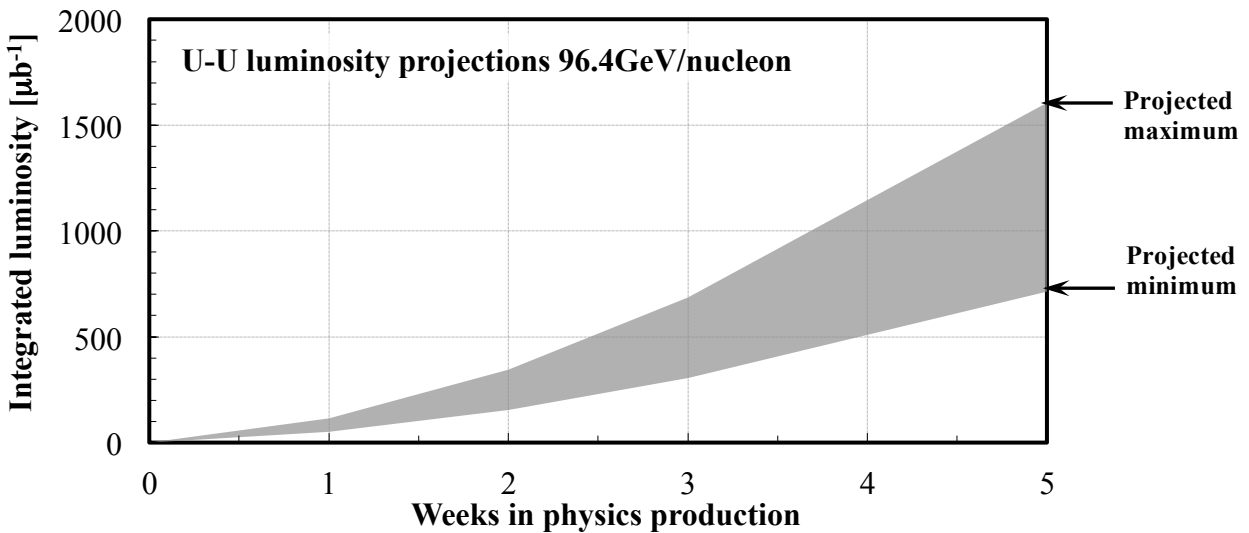


Figure 5: Projected minimum and maximum integrated luminosities for uranium-uranium at 96.4 GeV/nucleon, assuming linear weekly luminosity ramp-up in 4 weeks.

**Copper-Gold at 100 GeV/nucleon** – After full commissioning EBIS can deliver both copper and gold beams for RHIC operation. Operation is similar to d-Au. We assume that the copper beam will be in the Blue ring, and the gold beam in the Yellow ring. The d-Au lattice is usable for Cu-Au, and stochastic cooling in the longitudinal and both transverse planes will be available for both beams. Due to the higher bunch intensity cooling of the Cu beam is not as strong as for Au beam, but intrabeam scattering is smaller.

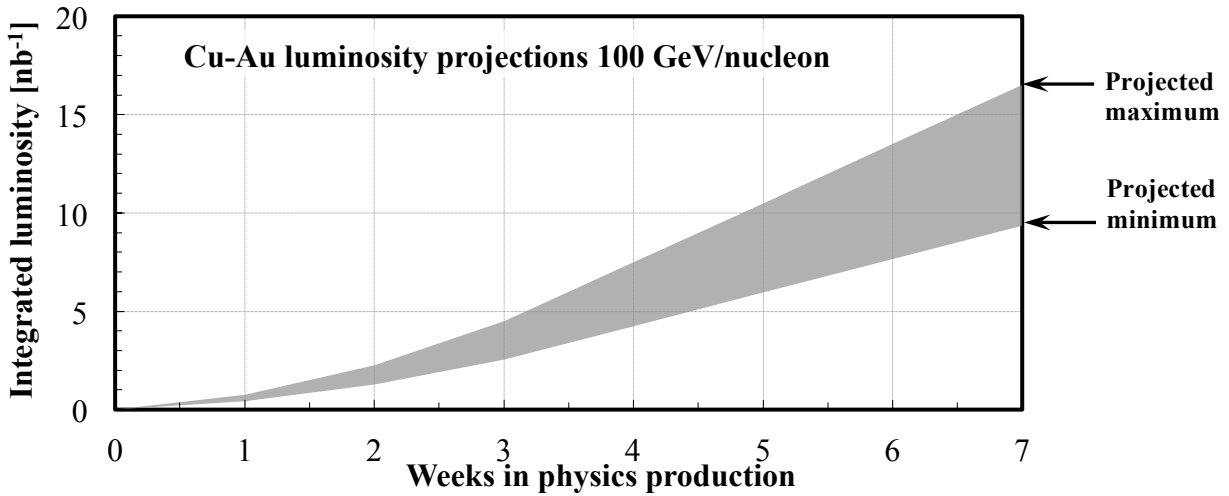


Figure 6: Projected minimum and maximum integrated luminosities for copper-gold collisions at 100 GeV/nucleon beam energy, assuming linear weekly luminosity ramp-up in 4 weeks.

## 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 transverse stochastic cooling and 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

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

$$\begin{aligned} L_{\text{store avg}} &= 60 \times 10^{30} \text{ cm}^{-2}\text{s}^{-1} \text{ for p-p at 100 GeV,} \\ L_{\text{store avg}} &= 300 \times 10^{30} \text{ cm}^{-2}\text{s}^{-1} \text{ for p-p at 250 GeV} \quad (32\times \text{ design}) \\ &\text{both with 70\% polarization} \end{aligned}$$

**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. For this, vertical systems were operated for the first time in Run-10. Additional horizontal systems are being installed for Run-12.

A significant luminosity increase is expected from a further reduction in  $\beta^*$  from 0.75 m in Run-11 down to 0.5 m. A number of tools were developed to measure and correct lattice errors, which become more pronounced with lower  $\beta^*$  values. The beam intensity is limited by a fast transverse instability at transition, driven by the machine impedance and electron clouds. Further improvements of the threshold for these instabilities could be addressed with a transverse damper, and with in-situ coating of the arc beam pipe.

The new Electron Beam Ion Source (EBIS) is under commissioning and has provided ions for the NASA Space Radiation Laboratory in FY 2010 and 2011. It is planned to use EBIS for heavy ions for RHIC beginning in FY 2012. With EBIS all ion species, including noble gases and uranium can be provided.

Table 5 and Figure 7 show the previously delivered and the projected minimum and maximum Au-Au luminosity until FY 2016. For these projections we assume 12 weeks of Au-Au physics operation in each year.

**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 for sextupoles and octupoles as well as 10- and 12-poles. A beam-based nonlinear chromaticity correction has been implemented. To further increase the beam-beam parameter, it is planned to install electron lenses for 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. Together with the polarized source upgrade, the electron lenses are expected to approximately double the luminosity, both at 100 GeV and at 250 GeV. As for heavy ions, we expect that  $\beta^*$  for protons can be reduced down to 0.5 m at 250 GeV beam energy. In Run-11 a new 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 and storage at 100 GeV has not led to a loss in polarization. Proton beams accelerated to 250 GeV showed only about 70% polarization transmission. This can be increased with a reduction in beam emittance. The polarization lifetime at store may be increased with a small change in the store energy. An upgrade of the polarized proton source will lead to higher beam polarization. Development of a polarized  $^3\text{He}$  source has started. EBIS can be used as an ionizer, and we expect that polarized  $^3\text{He}$  can be made available in RHIC in 3-4 years. To have high  $^3\text{He}$  polarization in RHIC an upgrade of one of the RHIC rings with 4 more Siberian snakes may be necessary.

Table 7 and Figure 8 show the previously delivered and the projected minimum and maximum p-p luminosity for both 100 GeV and 250 GeV beam energy until FY 2016. For these projections we assume 12 weeks of p-p physics operation in each year.

**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 53% for polarized protons in Run-9. All systems are periodically analyzed to maintain or increase the time in store further. We consider the time-in-store of only 37% for the 250 GeV p-p Run-11 an aberration. 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 2012 to FY 2016.**

	A-A	p-p
<b>For FY 2012</b>	EBIS commissioning Full 3D stochastic cooling	
<b>For FY 2013</b>		Polarized source upgrade Electron lenses
<b>For FY 2014</b>	IR power supply upgrades 56 MHz superconducting rf system	IR power supply upgrades 56 MHz superconducting rf system
<b>For FY 2015</b>	IR power supply upgrades	IR power supply upgrades
<b>For FY 2016</b>	In-situ beam pipe coating Collimation upgrade	In-situ beam pipe coating Collimation upgrade

**Table 5: Delivered RHIC luminosities of the last two Au-Au runs and projected Au-Au luminosities for 100 GeV/nucleon beam energy. Future physics runs are assumed to be 12 weeks long.**

Parameter	Unit	FY2010	2011	2012E	2013E	2014E	2015E	2016E
No of bunches	...	111	111	111	111	111	111	111
Ions/bunch, initial	$10^9$	1.1	1.3	1.3	1.3	1.3	1.3	1.35
Avg. beam current/ring	mA	121	143	147	140	143	143	148
Stored beam energy	MJ	0.39	0.46	0.47	0.45	0.46	0.46	0.47
$\beta^*$	M	0.75	0.75	0.75	0.70	0.50	0.50	0.50
Hour glass factor	...	0.70	0.70	0.70	0.75	0.80	0.88	0.88
Beam-beam param./IP	$10^{-3}$	1.7	2.0	2.1	2.0	2.0	2.0	2.1
Peak luminosity	$10^{26} \text{ cm}^{-2} \text{ s}^{-1}$	40	50	50	52	80	88	94
Avg./peak luminosity	%	60	60	70	80	85	95	100
Avg. store luminosity	$10^{26} \text{ cm}^{-2} \text{ s}^{-1}$	20	30	35	42	68	83	94
Time in store	%	53	59	55	55	55	55	55
Max. luminosity/week	$\mu\text{b}^{-1}$	650	1,000	1,160	1,390	2,270	2,770	3,130
Min. luminosity/week	$\mu\text{b}^{-1}$			800	1,000	1,000	1,000	1,000
Max. luminosity/run	$\text{nb}^{-1}$	5.2	5.0	12	15	24	29	33
Min. luminosity/run	$\text{nb}^{-1}$	3.3	5.2	8	15	11	11	11

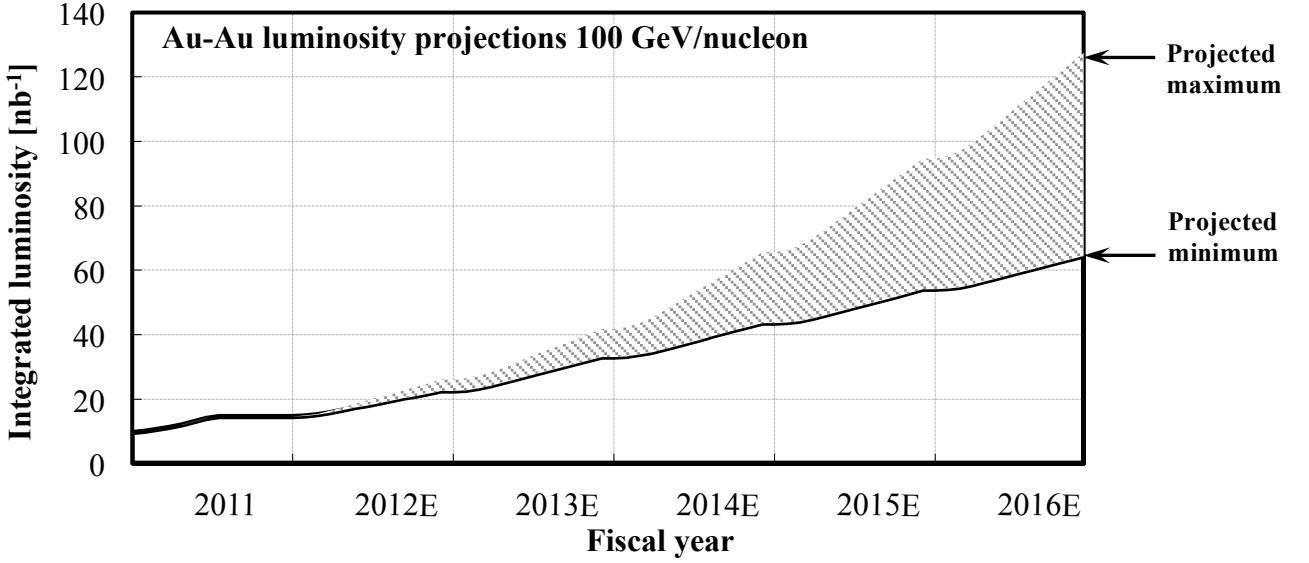


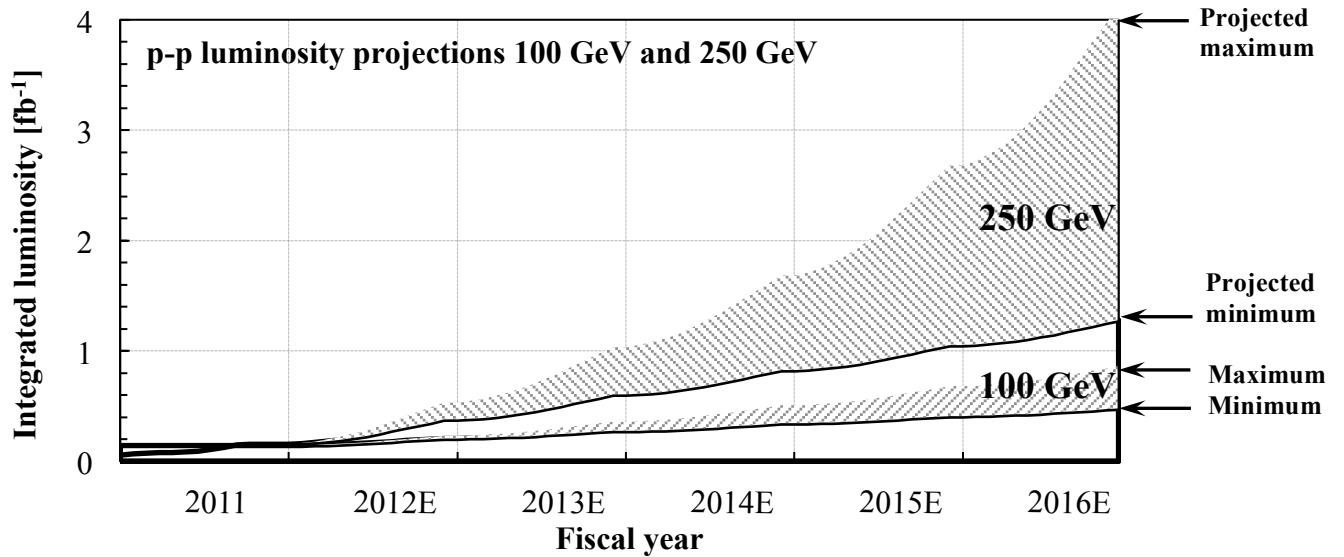
Figure 7: Previously delivered and minimum and maximum projected integrated luminosity for Au-Au collisions at 100 GeV/nucleon beam energy. Future physics runs are assumed to be 12 weeks long with linear weekly luminosity ramp-up in 4 weeks.

Table 6: Delivered RHIC luminosities and polarization of the last two 100 GeV p-p runs and projected p-p luminosities and polarization. Future physics runs are assumed to be 12 weeks long.

Parameter	Unit	FY2008	2009	2012E	2013E	2014E	2015E	2016E
No of colliding bunches	...	107	107	107	107	107	107	107
Ions/bunch, initial	$10^{11}$	1.5	1.35	1.35	1.5	1.6	1.7	1.7
Avg. beam current/ring	mA	201	181	181	201	214	227	231
Stored beam energy	MJ	0.26	0.23	0.23	0.26	0.27	0.29	0.30
$\beta^*$	m	1.0	0.70	0.85	0.85	0.85	0.80	0.80
Hour glass factor	...	0.81	0.72	0.86	0.95	0.95	0.94	0.94
Beam-beam param./IP	$10^{-3}$	5.6	6.5	6.6	7.4	7.9	8.4	8.5
Peak luminosity	$10^{30} \text{ cm}^{-2} \text{ s}^{-1}$	35	50	52	71	81	97	100
Avg./peak luminosity	%	66	56	58	60	60	60	60
Avg. store luminosity	$10^{30} \text{ cm}^{-2} \text{ s}^{-1}$	23	28	30	43	49	58	60
Time in store	%	60	53	55	55	55	55	55
Max. luminosity/week	$\text{pb}^{-1}$	7.5	8.3	10	14	16	19	20
Min. luminosity/week	$\text{pb}^{-1}$			7.5	7.5	7.5	7.5	7.5
Max. luminosity/run	$\text{pb}^{-1}$	19	61	90	128	146	174	180
Min. luminosity/run	$\text{pb}^{-1}$			68	68	68	68	68
AGS extraction, $P_{\text{max}}$	%	55	65	70	70	70	70	70
AGS extraction, $P_{\text{min}}$	%			65	65	65	65	65
RHIC store avg., $P_{\text{max}}$	%	45	56	60	65	65	70	70
RHIC store avg., $P_{\text{min}}$	%			56	56	56	56	56

**Table 7: Delivered RHIC luminosities and polarization of the last two 250 GeV p-p runs and projected p-p luminosities and polarization. Future physics runs are assumed to be 12 weeks long.**

Parameter	Unit	FY2009	2011	2012E	2013E	2014E	2015E	2016E
No of colliding bunches	...	107	107	107	107	107	107	107
Ions/bunch, initial	$10^{11}$	1.1	1.65	1.65	1.85	2.0	2.5	3.0
Avg. beam current/ring	mA	152	221	221	247	269	334	401
Stored beam energy	MJ	0.49	0.71	0.71	0.79	0.86	1.07	1.29
$\beta^*$	m	0.70	0.60	0.60	0.60	0.60	0.60	0.50
Hour glass factor	...	0.78	0.71	0.83	0.88	0.91	0.91	0.88
Beam-beam param./IP	$10^{-3}$	4.7	5.1	6.1	7.2	8.3	10.3	12.3
Peak luminosity	$10^{30} \text{ cm}^{-2} \text{ s}^{-1}$	85	145	200	281	360	556	929
Avg./peak luminosity	%	65	62	60	60	60	60	60
Avg. store luminosity	$10^{30} \text{ cm}^{-2} \text{ s}^{-1}$	55	90	120	168	216	334	558
Time in store	%	53	37	55	55	55	55	55
Max. luminosity/week	$\text{pb}^{-1}$	18	25	40	56	72	111	185
Min. luminosity/week	$\text{pb}^{-1}$			25	25	25	25	25
Max. luminosity/run	$\text{pb}^{-1}$	58	96	359	504	646	999	1669
Min. luminosity/run	$\text{pb}^{-1}$			225	225	225	225	225
AGS extraction, $P_{\text{max}}$	%	65	67	70	70	70	70	70
AGS extraction, $P_{\text{min}}$	%			65	65	65	65	65
RHIC store avg., $P_{\text{max}}$	%	35	48	55	60	65	70	70
RHIC store avg., $P_{\text{min}}$	%			48	48	48	48	48



**Figure 8: Previously delivered and minimum and maximum projected integrated luminosity for p-p collisions at 100 GeV and 250 GeV beam energy. Future physics runs are assumed to be 12 weeks long with linear weekly luminosity ramp-up in 8 weeks.**