RHIC Collider Projections (FY 2011 – FY 2015)

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This note discusses in Part I the running modes for the RHIC Run-11 (FY 2011) 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-10 operation, the planned luminosity upgrades in RHIC, the shut-down work in 2010, and the physics plans for Run-11.

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.

Part I – Run-11 Projections

Cryogenic operation – After the shutdown the two RHIC rings will be at room temperature. After bringing the rings to 50 K using gaseous helium, 1 week will be required to cool them down 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-11 include polarized protons at 250 GeV, gold-gold operation at 100 GeV/nucleon or lower energies, and a short period of uranium-uranium 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. Set-up for 250 GeV polarized protons requires an additional ½ to 1 week since a ramp has to be commissioned with a vertical tune close to a low order resonance. 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 improvements are still possible.

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 about 2 days assuming that the energy is lowered, and no unusual machine downtime is encountered. If the β^* at the lower energy is different from the β^* at this energy during the ramp to the higher energy, more time is required. A change of the polarization orientation at any or all of the experiments requires 1-2 days.

For example, 28 weeks of RHIC refrigerator operation in FY 2011 could be scheduled in the following way:

Cool-down from 50 K to 4 K	1 week	
Set-up mode 1 (Au-Au at 100 GeV)	1 week	(no dedicated time for experiments)
Ramp-up mode 1	1 week	(8 h/night for experiments)
Data taking mode 1 with further ramp-up	8 weeks	
Set-up mode 2 (U-U at 100 GeV)	1 week	(no dedicated time for experiments)
Data taking mode 2 with further ramp-up	2 weeks	
Set-up mode 3 (p↑-p↑ at 250 GeV)	2 ½ weeks	(no dedicated time for experiments)
Ramp-up mode 3	1 week	(8 h/night for experiments)
Data taking mode 3 with further ramp-up	10 weeks	
Warm-up	½ week	

Past performance – Table 1 shows the luminosities achieved for Au-Au (Run-10), Cu-Cu (Run-5), d-Au (Run-8), and polarized protons (Run-9). The time in store was 53% of the total time for both Au-Au (Run-10) and p-p (Run-9). 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-10), Cu-Cu (Run-5), d-Au (Run-8), and p-p (Run-9). 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 [10^9]	β^* [m]	Emittance [μm]	L_{peak} [$cm^{-2}s^{-1}$]	$L_{store\ avg}$ [$cm^{-2}s^{-1}$]	L_{week}
Au-Au	111	1.1	0.75	17-20	40×10^{26}	20×10^{26}	650 μb^{-1}
Cu-Cu	37	4.5	0.9	16-28	2×10^{28}	0.8×10^{28}	2.4 nb^{-1}
d-Au	95	100d/1.0Au	0.85	17-30	25×10^{28}	12.5×10^{28}	40 nb^{-1}
p↑-p↑* 100 GeV	107	135	0.7	15-20	50×10^{30}	28×10^{30}	8 pb^{-1}
p↑-p↑* 250 GeV	107	110	0.7	18-23	85×10^{30}	55×10^{30}	18 pb^{-1}

*Blue and Yellow ring average polarization of P = 55% stores at 100 GeV, P = 34% at 250 GeV in Run-9 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-10 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 lower than at the end of the running period by a factor 2-4. Unless stated otherwise for all modes it was assumed that the beam energy is 100 GeV/nucleon. The average store 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 tested and will be re-commissioned in Run-11 to reduce the longitudinal emittance. After successful commissioning of this cavity we expect for protons 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 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 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 [10^9]	β^* [m]	Emittance [μm]	L_{peak} [$cm^{-2}s^{-1}$]	$L_{store\ avg}$ [$cm^{-2}s^{-1}$]	L_{week}
U-U	111	0.6	0.65	17-20	13×10^{26}	8×10^{26}	270 μb^{-1}
Au-Au	111	1.1	0.65	17-20	45×10^{26}	25×10^{26}	900 μb^{-1}
Cu-Cu	68	6	0.7	15-30	9×10^{28}	4×10^{28}	14 nb^{-1}
Si-Si	68	12.5	0.7	15-30	40×10^{28}	20×10^{28}	65 nb^{-1}
d-Au	95	110d / 1.1Au	0.85	18-30	27×10^{28}	14×10^{28}	50 nb^{-1}
p↑-p↑* 100 GeV	107	140	0.85	15-20	50×10^{30}	30×10^{30}	10 pb^{-1}
p↑-p↑* 250 GeV	107	140	0.6	17-23	170×10^{30}	100×10^{30}	35 pb^{-1}

* We expect that an average store polarization P of up to about 65%, as measured by the H jet, can be reached at 100 GeV. At 250 GeV we expect the polarization P to reach about 50%. In Run-8 PHENIX had 107 and STAR 102 colliding bunches. This reduces the luminosity compared to the 111 bunches assumed in the table.

Operation at energies other than 100 GeV/nucleon – It is preferable to lower the energy when the collision energy is changed in any given mode. This can be done in about 2 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 square of the energy,

$$L(E) \propto L(100\ \text{GeV/nucleon}) \times \left(\frac{E}{100\ \text{GeV/nucelon}}\right)^2$$

This is shown in Figure 1. 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 3 m. 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.
Also note that at energies below 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 use of stochastic 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.

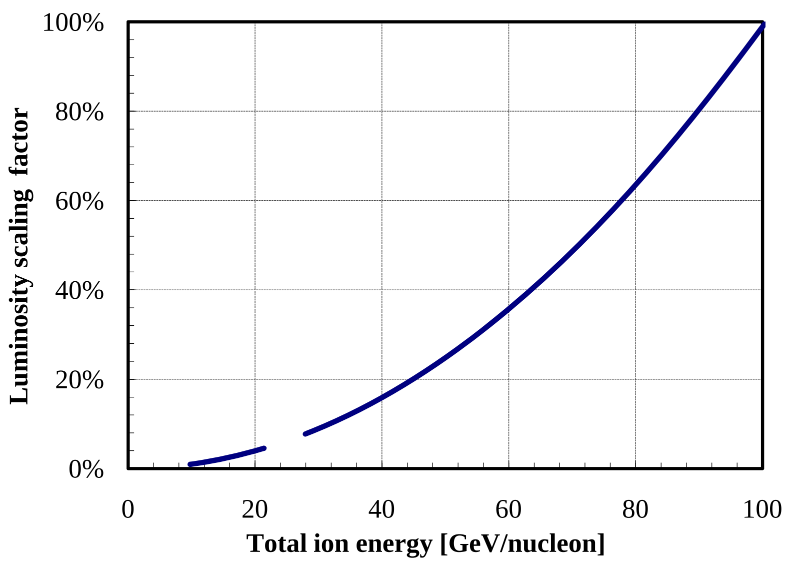

Figure 1: Luminosity scaling for Au-Au operation at energies below 100 GeV/nucleon. The gap is around the transition energy at which operation is not possible.

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 drops 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.

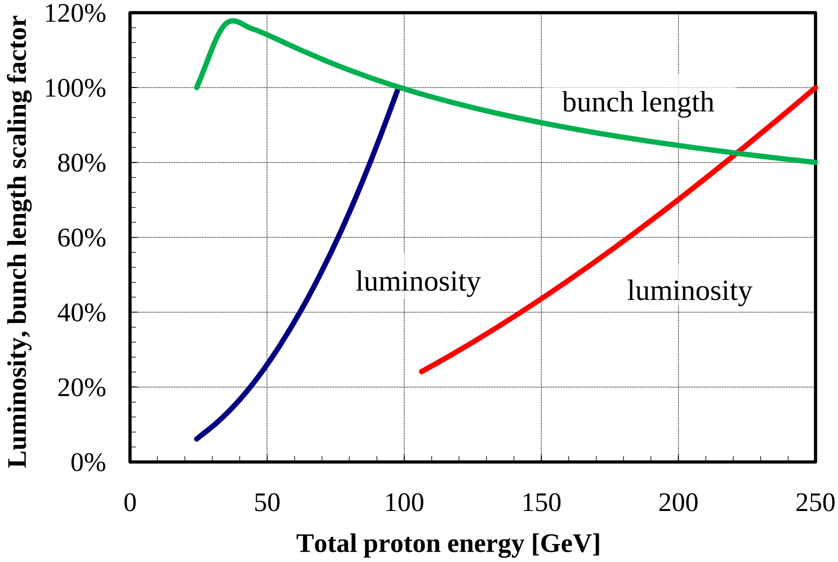

Figure 2: Luminosity scaling for polarized proton operation in the energy range 24 to 100 GeV, and the energy range 100 GeV to 250 GeV as well as bunch length scaling assuming constant longitudinal emittance and gap voltage.

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

Gold-Gold at 100 GeV/nucleon – A number of improvements can be implemented compared to Run-10. With experience from previous Au-Au runs, we assume that β^* can be reduced to 0.65 m. This requires the correction of chromatic aberrations in the lattice design stage. Up to six stochastic cooling systems need to be commissioned or re-commissioned after modification during the summer shut-down. Both longitudinal and both vertical systems were used during Run-10 but not yet in an optimum configuration. The beam intensity was limited by beam loading effects in the common storage cavities during rebucketing. The common cavities will be removed and placed in the Blue and Yellow rings separately, in addition to newly installed storage cavities. The beam intensity is then expected to be limited by fast transverse instabilities at transition, driven by the machine impedance and electron clouds. The projected minimum and maximum luminosities are shown in Figure 3, where it is assumed that the minimum and maximum peak performance is reached after 8 weeks of linear ramp-up, starting with 25% of the final value. The minimum performance is close the performance achieved in Run-10.
During Run-11 the new Electron Beam Ion Source (EBIS) will be in initial operation while the Tandem pre-accelerators will still be available.

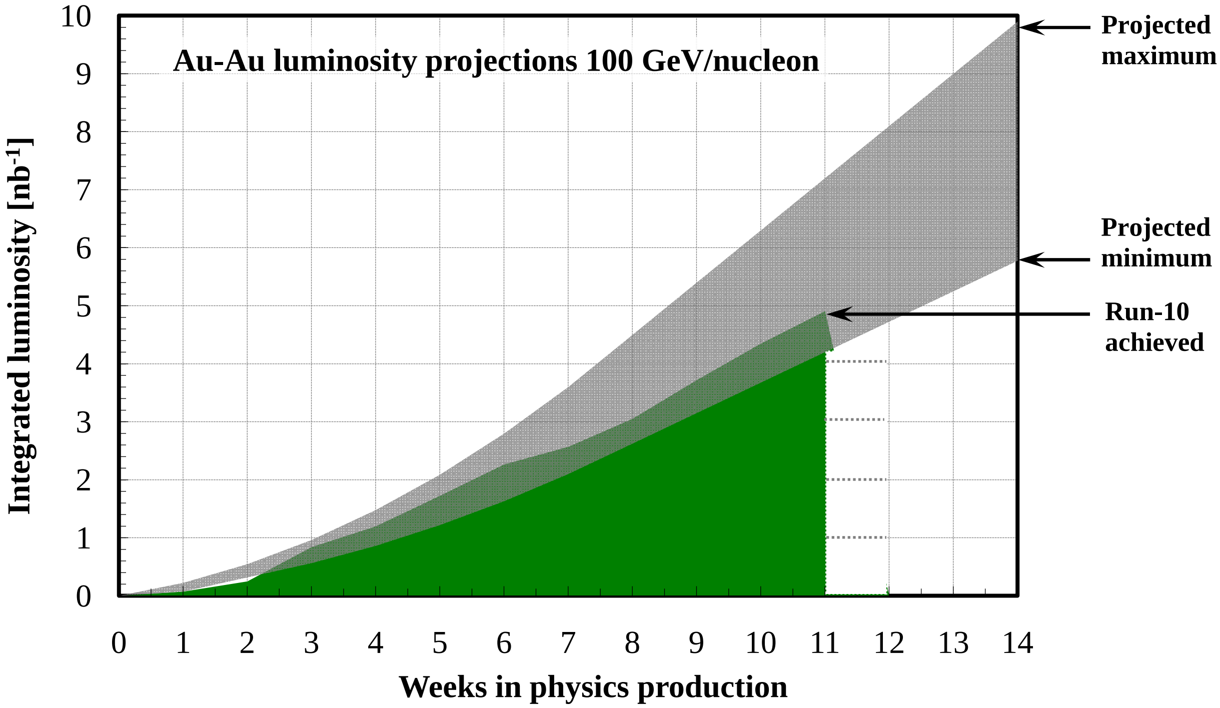

Figure 3: Projected minimum and maximum integrated luminosities for gold-gold collisions at 100 GeV beam energy, assuming linear weekly luminosity ramp-up in 6 weeks for the minimum and 8 weeks for the maximum.

Uranium-Uranium at 100 GeV/nucleon – Uranium operation requires EBIS, now under commissioning. In the first year of operation EBIS may not yet deliver nominal beam parameters, and the intensity of the uranium beam is likely lower than the intensity of gold beam. The result is a luminosity lower than the luminosity that can be achieved for gold beams (Table 2).

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. The implications of such are current increase are still under study.

Stochastic cooling for uranium beams is possible although a new setup is required. In a short run stochastic cooling may not reach full performance.

Gold-Gold at energies lower than 10 GeV/nucleon *[Since the low energy part of Run-10 is still under way, this section has not yet been updated. We note that for* $\sqrt{s_{NN}}$ *= 7.7 GeV the demonstrated average event rate in STAR has reached 3 Hz.]* – The required running time for 5M events in STAR at various energies below the normal RHIC injection energy is shown in Table 3.

Table 3: Required running time for 5M events in STAR at various energies below the normal RHIC injection energy, assuming 70% of calendar time in store.

$\sqrt{s_{NN}}$ [GeV]	μ_B [MeV]	$L_{store\ avg}$ [$cm^{-2}s^{-1}$]	<Event Rate> [Hz]	Days/ million events	No of events	No of beam days [setup+physics]
5.0	535	1.3×10^{23}	0.7	21	5M	5+105
6.1	470	2.4×10^{23}	1.4	11.3	5M	4+57
7.7	405	4.8×10^{23}	2.7	5.7	5M	3+29
8.6	370	6.9×10^{23}	4	3.9	5M	2+19
12	295	1.8×10^{24}	—	—	—	—
18	210	6.2×10^{24}	>30	0.5	5M	1+3
28	145	2.5×10^{25}	>60	<<1	5M	2+1

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 4 lists the energies at which two experiments or only one experiment can run.

Table 4: Energy ranges in which two or only one experiment can run.

$\sqrt{s_{NN}}$ [GeV]	No of simultaneous experiments	$\sqrt{s_{NN}}$ [GeV]	No of simultaneous experiments
4.91 – 5.10	2	6.87 – 7.47	1
5.15 – 5.38	1	7.71 – 8.60	2
5.45 – 5.72	1	9.0 – 10.55	1
5.8 – 6.15	2	11.34 – 15.15	1
6.27 – 6.71	1	18.0 – 107	2

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 β^*= 0.85 m. With the horizontal tune jump system in the AGS, the polarization could be increased by up to 5%, after some commissioning time. Figure 4 shows the projected minimum and maximum luminosity for 100 GeV beam energy, where it is assumed that the minimum peak performance is reached almost instantaneously, and the maximum peak performance after 6 weeks of linear ramp-up.

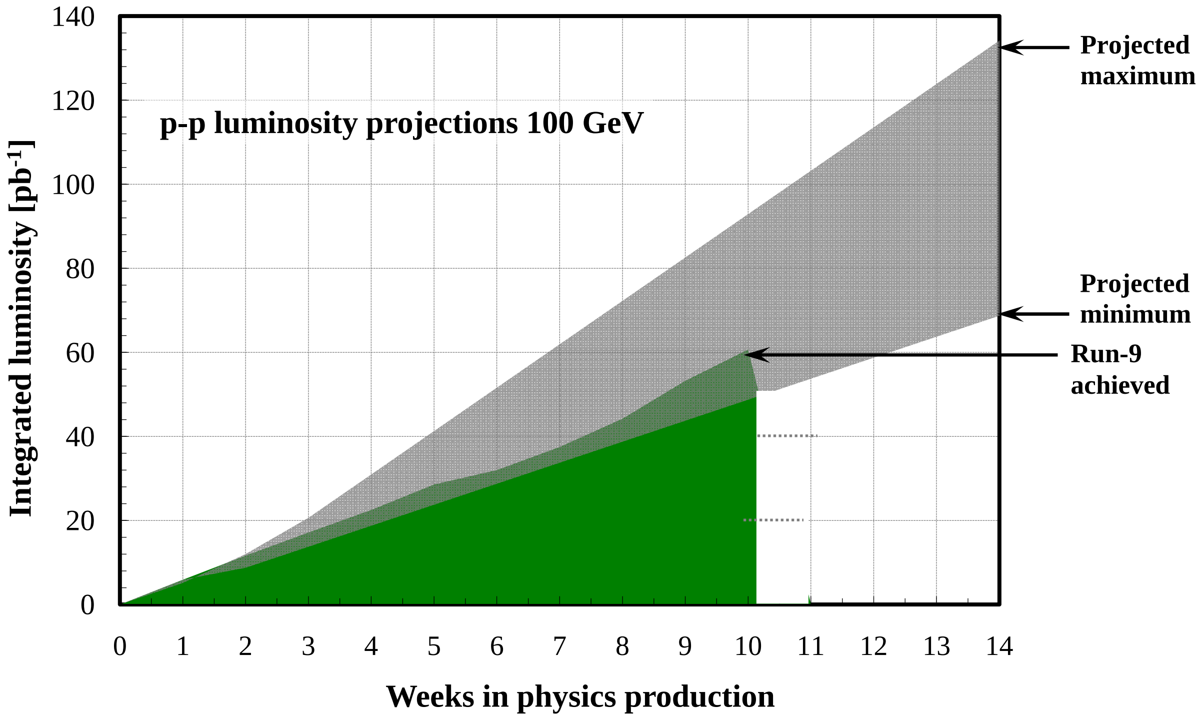

Figure 4: Projected minimum and maximum integrated luminosities for polarized proton collisions at 100 GeV beam energy, assuming almost instantaneous minimum and linear weekly maximum luminosity ramp-up in 4 weeks. An average store polarization between 50 and 65% is expected.

Polarized protons at 250 GeV – We expect a polarization value of 35% at a minimum, demonstrated during Run-9, and 50% at a maximum. The latter requires the commissioning of a ramp with a working point close to the 2/3 resonance. This has been tested with gold beam during Run-10. We plan to operate with β^* as low as 0.65 m. Corrections for chromatic aberrations and nonlinear magnetic field errors in the interaction region are needed. The 9 MHz cavity will be commissioned again after changes to the RHIC main power supplies and the installation a longitudinal dampers in both rings. At store the 28 MHz system will be used, and tests with the 197 MHz system are planned. Beam losses have to be controlled better since it will be easier to quench magnets at the top energy. The beam dump system will be upgraded with a thicker beam pipe at the dump to avoid quenches of the downstream superconducting quadrupole when high intensity proton beams are dumped.

Commissioning of the horizontal AGS tune jump system continued in 2010 but has not been completed. The anticipated gain for this new system, up to 5% more luminosity, will therefore be available only after further commissioning time.

Figure 5 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.

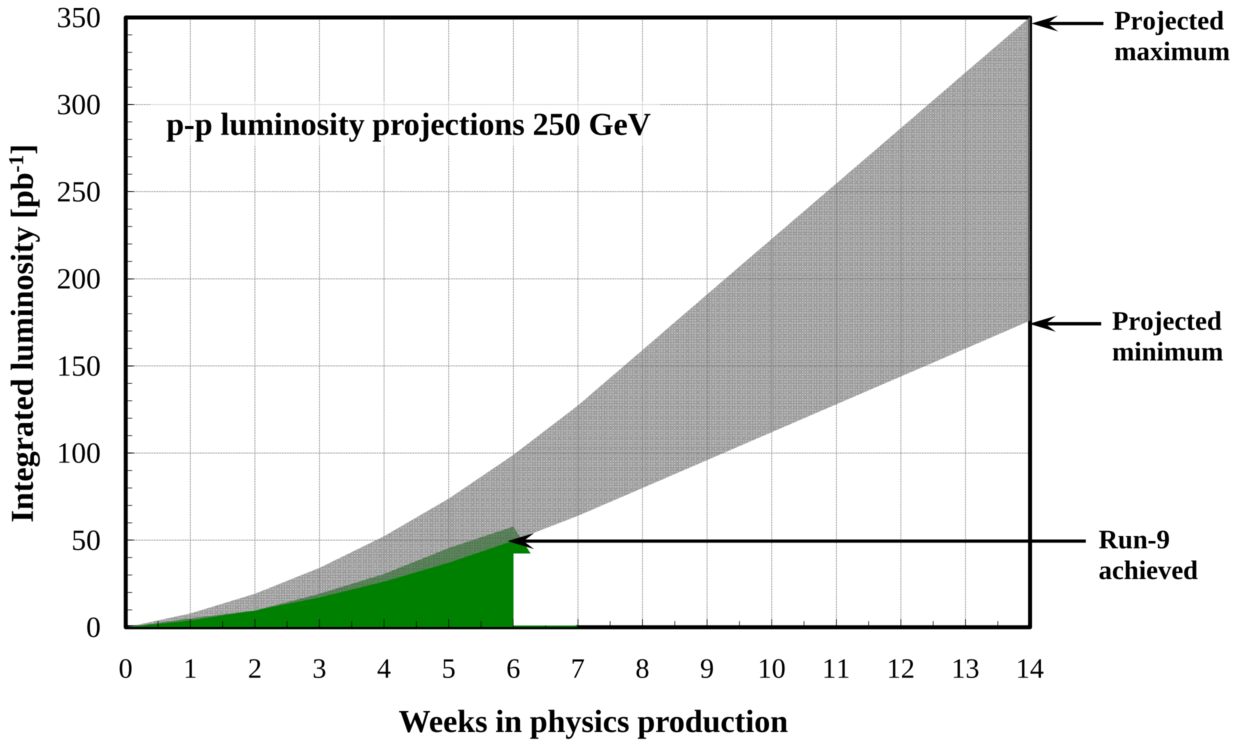

Figure 5: Projected minimum and maximum integrated luminosities for polarized proton collisions at 250 GeV beam energy, assuming linear weekly luminosity ramp-up in 8 weeks. An average store polarization between 35 and 50% is expected.

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 system. The RHIC Enhanced Design goals consisted of

$L_{\text{store avg}}$ = 8×10^{26} cm^{-2}s^{-1} for Au-Au at 100 GeV/nucleon (4× design)

$L_{\text{store avg}}$ = 6×10^{31} cm^{-2}s^{-1} for p-p at 100 GeV,
$L_{\text{store avg}}$ = 1.5×10^{32} cm^{-2}s^{-1} for p-p at 250 GeV (16× design)
both with 70% polarization

60% of calendar time in store (100h/week)

We have exceeded the Au-Au luminosity goal with routine stores of $L_{\text{store avg}}$ = 20×10^{26} cm^{-2}s^{-1}. Performance progress for proton luminosity and polarization is slower than anticipated. With the experience from Run-9 the polarized proton luminosity goal for 100 GeV cannot be maintained, and is now reduced to **3×10^{31} cm^{-2}s^{-1}**. With experience from the runs to date, we now expect to be at **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 5. 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 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 will be addressed with transverse stochastic cooling. For this, vertical systems were installed and used in both the Blue and Yellow ring during Run-10. It is planned to install additional horizontal systems for Run-11.
A significant luminosity increase is expected from a further reduction in β^* from 0.75 m in Run-10 down to 0.5 m. A number of tools were developed to measure and correct lattice errors, which become more pronounced with lower β^* values.
The beam intensity is limited by beam loading effects in the common storage cavities during rebucketing. These cavities will be removed from the common area and installed in the Blue and Yellow ring respectively. The beam intensity is also 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.
It is planned to begin commissioning of the new Electron Beam Ion Source (EBIS) in FY 2010. EBIS will become ready for operation and may be used for lower intensity uranium beams in Run-11, and with full intensity in Run-12. Table 6 and Figure 6 show the previously delivered and the projected minimum and maximum Au-Au luminosity until FY 2015. For these

projections we assume 12 weeks of Au-Au physics operation in each year. Should there be years without heavy ion operation, the luminosity development will be delayed.

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. A new near-integer working point was studied in Run-8 that was expected to accommodate a larger tune spread. This working point can currently not be made operational because of 10 Hz orbit oscillations stemming from mechanical triplet vibrations (see below), and has not shown better ramp polarization transmission to 250 GeV thus far.

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 β^* for protons can be reduced down to 0.5 m at 250 GeV beam energy.

In Run-9 a new 9 MHz rf system was tested to allow longitudinal matching at injection with long bunches. Matched longitudinal injection reduces the bunch length at store, which in turn reduces the hour glass effect. Long bunches at injection experience reduced electron cloud effects, suspected to increase the transverse emittance. To make the 9 MHz system operational for the next run, a smoother transition between the RHIC main flattop and ramp supplies is needed as well as a longitudinal damper at least in the Yellow ring.

The triplet magnets oscillate with eigen-frequencies of around 10 Hz, leading to horizontal beam oscillations at the same frequency. With the previous working points these oscillations have amplitudes as large as 1 mm in the triplet, and about 10% of an rms beam size at the interaction point. With the near-integer working point oscillation amplitudes are amplified by about a factor 5. A 10 Hz orbit feedback system is now under development to stabilize the beam motion in the triplets.

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 now under test 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 60% polarization transmission. This can be increased with acceleration close to the 2/3 resonance for energies between 100 GeV and 250 GeV. Further work in the AGS is expected to lead to better polarization transmission for full intensity bunches.

An upgrade of the polarized proton source, expected to be complete in 2012, will also lead to higher beam polarization.

Table 7 and Figure 7 show the previously delivered and the projected minimum and maximum p-p luminosity for both 100 GeV and 250 GeV beam energy until FY 2014. For these projections we assume 12 weeks of p-p physics operation in each year. Should there be years without polarized proton operation, the luminosity and polarization development will be delayed.

Time in store – The fraction of the time in stores divided by the total time, reached 53% for Au-Au collisions in Run-10 and 53% for polarized protons in Run-9. 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. Our previous goal was 60%.

Table 5: Main upgrades for RHIC Au-Au and p-p operation planned for FY 2011 to FY 2015.

	Au-Au	p-p
FY 2011	EBIS Beam dump upgrade Longitudinal stochastic cooling upgrade Vertical stochastic cooling upgrade Horizontal stochastic cooling installation	AGS tune jump system Beam dump upgrade 9 MHz rf system RHIC polarimetry upgrade RHIC 1 Hz global orbit feedback RHIC 10 Hz orbit feedback
FY 2012	Full 3D stochastic cooling	Polarized source upgrade
FY 2013	56 MHz superconducting rf system Transverse damper for transition	56 MHz superconducting rf system Electron lenses
FY 2014	Collimation upgrade Low energy electron cooling	Collimation upgrade
FY 2015	BPM system upgrade In-situ beam pipe coating Transverse feedback	BPM system upgrade In-situ beam pipe coating

Table 6: Delivered RHIC luminosities of the last three 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	FY2007	2010	2011E	2012E	2013E	2014E	2015E
No of bunches	…	103	111	111	111	111	111	111
Ions/bunch, initial	10^9	1.1	1.1	1.1	1.1	1.1	1.2	1.3
Avg. beam current/ring	mA	112	121	121	121	121	133	137
β^*	m	0.85	0.75	0.65	0.5	0.5	0.5	0.5
Hour glass factor	…	0.95	0.93	0.92	0.88	0.88	0.88	0.88
Beam-beam param./IP	10^{-3}	1.5	1.5	1.5	1.5	1.5	1.6	1.7
Peak luminosity	10^{26} cm^{-2}s^{-1}	30	40	45	55	55	67	72
Avg./peak luminosity	%	40	50	60	72	90	90	100
Avg. store luminosity	10^{26} cm^{-2}s^{-1}	12	20	27	40	50	60	72
Time in store	%	48	53	55	55	55	55	55
Max. luminosity/week	μb^{-1}	380	650	900	1,330	1,660	2,010	2,380
Min. luminosity/week	μb^{-1}			650	650	650	650	650
Max. luminosity/run	nb^{-1}	3.3	0.0	0.0	14	17	21	21
Min. luminosity/run	nb^{-1}		3.3	0.0	3.3	3.3	3.3	3.3

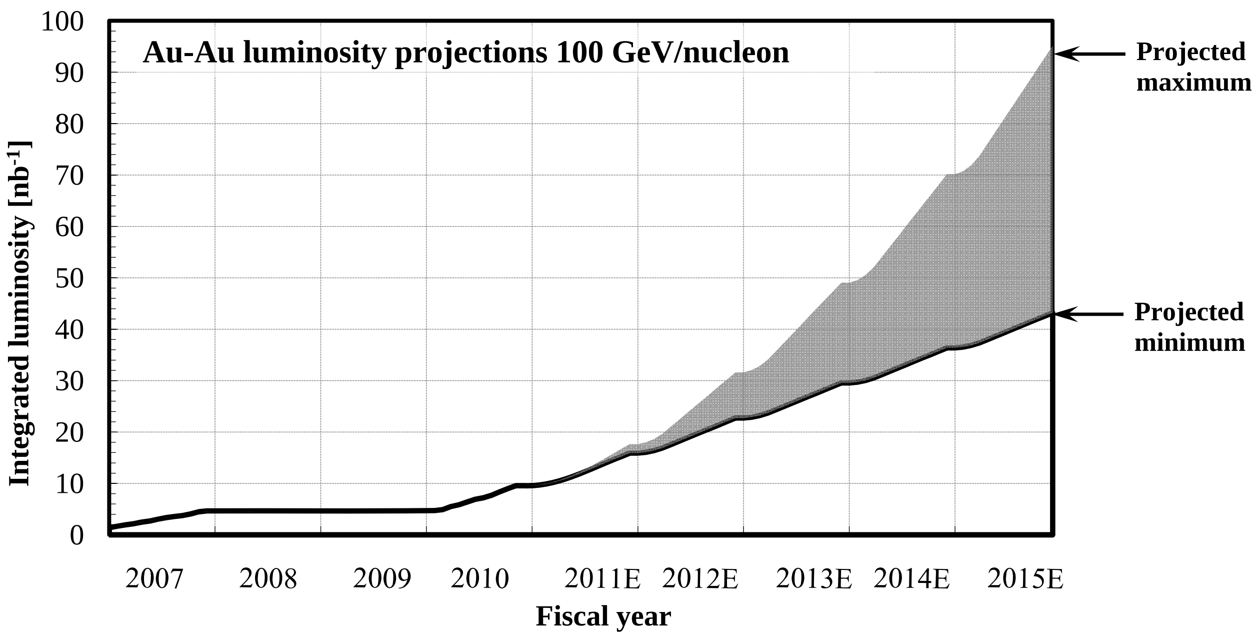

Figure 6: Previously delivered and minimum and maximum projected integrated luminosity for Au-Au collisions at 100 GeV/nucleon beam energy. Future physics runs are assumed to be 12 weeks long with linear weekly luminosity ramp-up in 6 weeks in FY 2011 and 4 weeks thereafter.

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

Parameter	Unit	FY08	2009	2011E	2009	2011E	2012E	2013E	2014E
Beam energy	GeV	100	100	100	250	250	250	250	250
No of bunches	…	107	107	107	107	107	107	107	107
Ions/bunch, initial	10^{11}	1.5	1.35	1.35	1.1	1.4	1.5	1.8	2.0
Avg. beam current/ring	mA	201	181	181	152	187	207	241	269
$\beta*$	m	1.0	0.70	0.85	0.70	0.65	0.50	0.50	0.50
Hour glass factor	…	0.81	0.72	0.86	0.80	0.85	0.88	0.88	0.88
Beam-beam param./IP	10^{-3}	5.6	6.5	6.6	4.7	6.1	7.2	8.3	10.2
Peak luminosity	10^{30} cm^{-2}s^{-1}	35	50	52	87	160	278	376	514
Avg./peak luminosity	%	66	56	60	63	60	60	60	60
Avg. store luminosity	10^{30} cm^{-2}s^{-1}	23	28	31	55	96	167	226	309
Time in store	%	60	53	55	53	55	55	55	55
Max. luminosity/week	pb^{-1}	7.5	8.3	10	18	32	56	75	103
Min. luminosity/week	pb^{-1}			8.3		18	18	18	18
Max. luminosity/run	pb^{-1}	19	60	100	60	290	500	680	920
Min. luminosity/run	pb^{-1}			80		170	170	170	170
AGS extraction, P_{max}	%	55	65	70	65	70	70	70	70
AGS extraction, P_{min}	%			55		55	55	55	55
RHIC store avg., P_{max}	%	45	55	65	35	50	55	60	65
RHIC store avg., P_{min}	%			55		35	35	35	35
Max. LP^4/week	pb^{-1}	0.31	0.8	1.8	0.3	2.0	5.1	9.7	18.3
Min. LP^4/week	pb^{-1}			0.76		0.3	0.3	0.3	0.3

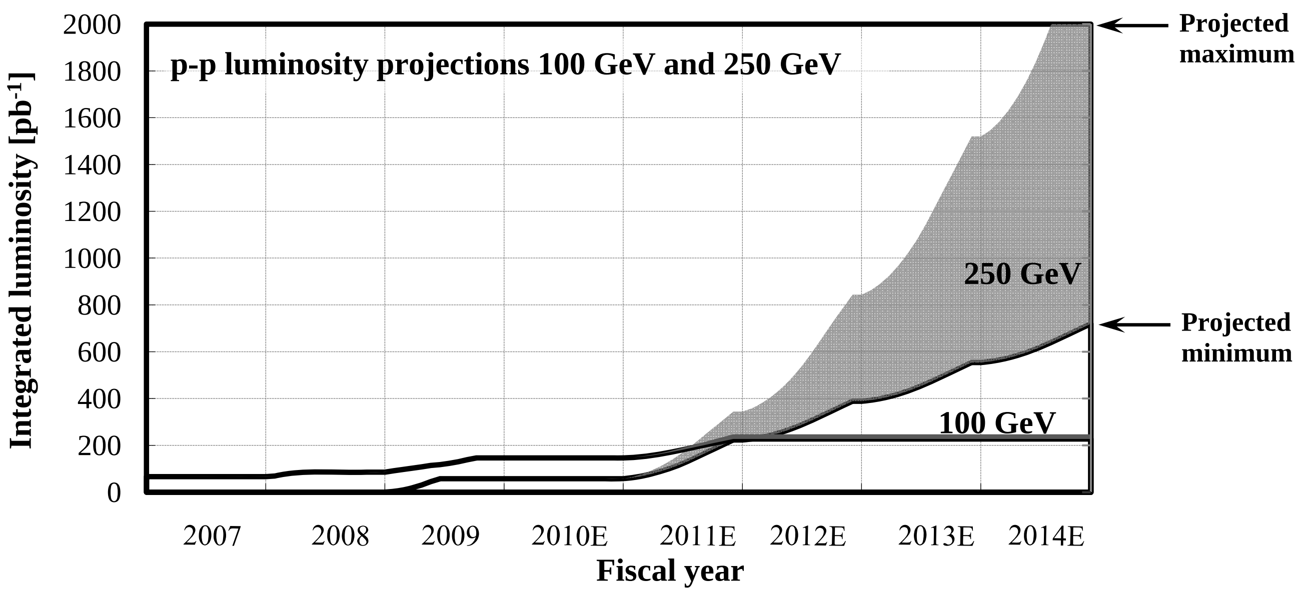

Figure 7: Previously delivered and minimum and maximum projected integrated luminosity for p-p collisions at 100 GeV and 250 GeV beam energy. Future physics runs are assumed to be 12 weeks long with linear weekly luminosity ramp-up in 8 weeks.