RHIC Collider Projections (FY2008 – FY2009)

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This note discusses in Part I the running modes for the RHIC Run-8 (FY2008) operating period including constraints from cryogenic cool-down, machine set-up and beam commissioning. In Part II a 2-year outlook is given. This latest update is based on the experience gained during the Run-7 gold-gold operation.

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-8 Projections

Cryogenic operation – After the shutdown the two RHIC rings will be at liquid nitrogen temperature. 1 ½ 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 – The likely running modes for Run-8 are d-Au followed by polarized proton operation at 100 GeV. We propose to run with ions first to allow more time to prepare for improvements in the proton polarization and luminosity.

When starting the run we plan for 1 ½ week of machine set-up with the goal of establishing collisions, and a 1-week machine development period ("ramp-up") after which stable operation can be provided with integrated luminosities that are a fraction of the maximum goals shown below. In addition, 2 days may be needed for scrubbing to reduce electron cloud effects at transition. About 2 days are needed when switching from d-Au to polarized protons to install a new 9 MHz cavity. The set-up period for polarized protons can be 1 week longer to allow for the implementation of new lattice. 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, can be achieved 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. A change of the polarization orientation at any or all of the experiments requires 1-2 days.

For example, 30 weeks of RHIC refrigerator operation in FY2008 could be scheduled in the following way:

Cool-down from 80 K to 4 K	1 ½ week
Set-up mode 1 (d-Au)	1 ½ weeks
Ramp-up mode 1	1 week
Data taking mode 1 with further ramp-up	11 weeks
Set-up mode 2 (p↑-p↑)	2 ½ weeks
Ramp-up mode 2	1 week
Data taking mode 2 with further ramp-up	11 weeks
Warm-up	½ week

Past performance – Table 1 shows the luminosities achieved for Au-Au (Run-7), Cu-Cu (Run-5), d-Au (Run-3), and polarized protons (Run-6). The time in store was 48% and 56% of the total time for Au-Au (Run-7) and p-p (Run-6) respectively. 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-7), Cu-Cu (Run-5), d-Au (Run-3), and p-p (Run-6). All numbers are given for operation at a beam energy of 100 GeV/nucleon.

Mode	No of bunches	Ions/bunch [10^9]	β* [m]	Emittance [μm]	$\mathcal{L}_{peak}$ [$cm^{-2}s^{-1}$]	$\mathcal{L}_{store\ avg}$ [$cm^{-2}s^{-1}$]	L_{week}
Au-Au	103	1.1	0.85	17-35	30×10^{26}	12×10^{26}	350 μb^{-1}
Cu-Cu	37	4.5	0.9	15-30	2×10^{28}	0.8×10^{28}	2.4 nb^{-1}
d-Au	55	110d / 0.7Au	2	15-25	7×10^{28}	3×10^{28}	4.5 nb^{-1}
p↑-p↑ *	111	135	1	18-25	35×10^{30}	20×10^{30}	7.0 pb^{-1}

* Blue and Yellow ring average polarization of 60%, in RHIC stores at 100GeV. Both STAR and PHENIX elected to have 9 non-colliding bunches. If either experiment elects to have all 111 bunches colliding in the experiment, the luminosity will be increased by 9%.

Luminosity projections – Table 2 lists the expected maximum peak and average luminosities for possible modes in Run-8 that could likely be achieved 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 about a factor 4. 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 calendar time in store. The expected diamond rms length for ions is 20 cm due to the availability of the full voltage from the 200 MHz storage cavities and due to longitudinal stochastic cooling. The actual configuration of the storage rf system for d-Au and p-p is still to be determined. 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 a 9% reduction in the number of collisions.

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. All numbers are given for operation at an energy of 100 GeV/nucleon.

Mode	No of bunches	Ions/bunch $[10^9]$	β^* [m]	Emittance [μm]	$\mathcal{L}_{peak}$ $[cm^{-2}s^{-1}]$	$\mathcal{L}_{store\ avg}$ $[cm^{-2}s^{-1}]$	L_{week}
Au-Au	103	1.1	0.85	17-35	30×10^{26}	12×10^{26}	350 μb^{-1}
Cu-Cu	111	6	0.9	15-30	12×10^{28}	4×10^{28}	14 nb^{-1}
Si-Si	111	12.5	0.9	15-30	50×10^{28}	17×10^{28}	60 nb^{-1}
d-Au	83	120d/1.1Au	1.0	15-30	30×10^{28}	14×10^{28}	40 nb^{-1}
p↑-p↑ *	111	175	0.9	20-25	70×10^{30}	40×10^{30}	14 pb^{-1}

*We expect that an average store polarization of 65% can be reached. If both STAR and PHENIX elect again to have 9 non-colliding bunches, the luminosity is reduced by 9% compared to the numbers stated 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 with $\beta^* = 0.85$ m the limiting aperture is in the triplet. For energies less than 100 GeV/nucleon the unnormalized 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. This is shown in Figure 1. Note that operation near the transition energy is not possible, and that the storage rf system cannot be used below the transition energy. With operation at the injection energy refilling is very efficient, and β^* can be reduced to 3 m.
Since both Tandem accelerators are needed for d-Au operation, a repair of one of the Tandems will make d-Au operation very inefficient or impossible. For an access to a tank about 5 days are needed, during which Au-Au operation at very low energies can be considered.
For p-p operation the luminosity is expected to increase linearly with energies above 100 GeV, and decrease quadratically with energies below 100 GeV. Initial operation at 250 GeV requires about 5 weeks of commissioning time for both luminosity and polarization development.

Following are specific comments on deuteron-gold, and polarized proton running at the energies considered for Run-8.

Deuteron-Gold at 100 GeV/nucleon – The experiments requested to set up d –Au collisions with the deuteron beam in the Blue ring. This also allows using the longitudinal stochastic cooling system in the Yellow ring, which was operational already in Run-8. With asymmetric species it may not be possible to make β^* as small as with symmetric species. We expect that $\beta^* = 1.0$ m is possible. A bunch merging technique in the Booster has been used for deuterons.

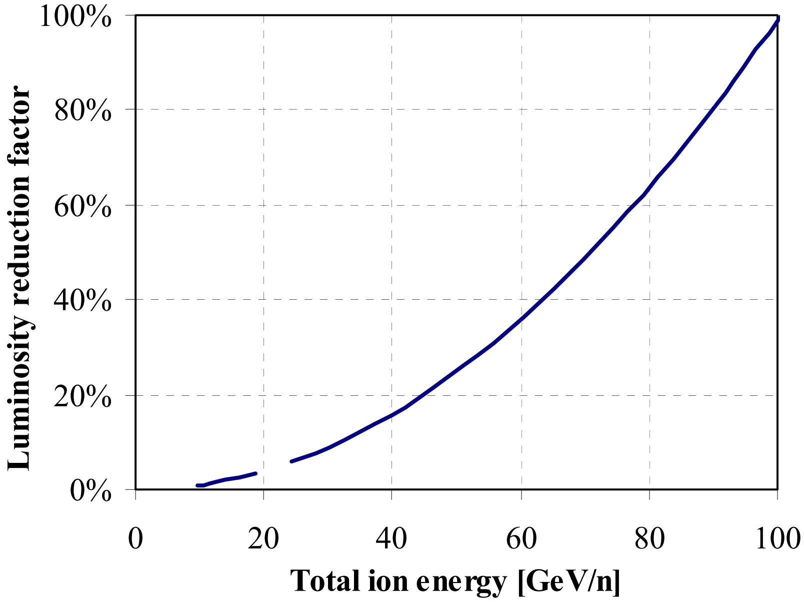

Figure 1: Luminosity scaling for Au-Au operation at energies below 100 GeV/nucleon.

Both electrostatic Tandem accelerators are needed for continuous operation, which could increase downtime in case of a failure since no backup is available. The switching time between species in the injector chain was approximately 5 min in Run-3, while it is only seconds for symmetric species. Due to the need to have both Tandems available for all injections, and the longer switching time, we expect that the calendar time in store is approximately 5% (or 8h/week) less than for symmetric species. We expect that the number of bunches will be smaller than during the Run-7 Au-Au operation since the beam intensity is limited by a fast instability at transition, and the charge per bunch is larger for deuterons. A lattice version with a reduced transverse IBS emittance growth rate is still under investigation. The projected minimum and maximum luminosities are shown in Figure 2, where it is assumed that the peak performance is reached after 6 weeks of linear ramp-up, starting with 25% of the final value.

Polarized protons at 100 GeV – We expect that the peak polarization values in Run-6 (65% store average) can be reliably demonstrated in Run-8. We expect at least 40% average polarization in store after 2 ½ weeks of set-up and ramp-up. This should be improved to the values demonstrated in Run-6 (see Table 1) within a week. Based on the experience gained with polarized proton operation in the AGS during Run-7, the optimum settings for the AGS snakes will be determined.

We aim at doubling the luminosity through an increase in the bunch intensity. This requires a better understanding of the nonlinearities in the machine. We plan to implement a new working point for one of the beams, and will correct the nonlinear chromaticity. A new 9 MHz cavity will allow for shorter bunches at store, thereby reducing the hourglass effect. 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 8 weeks of linear ramp-up, starting with 25% of the final value.

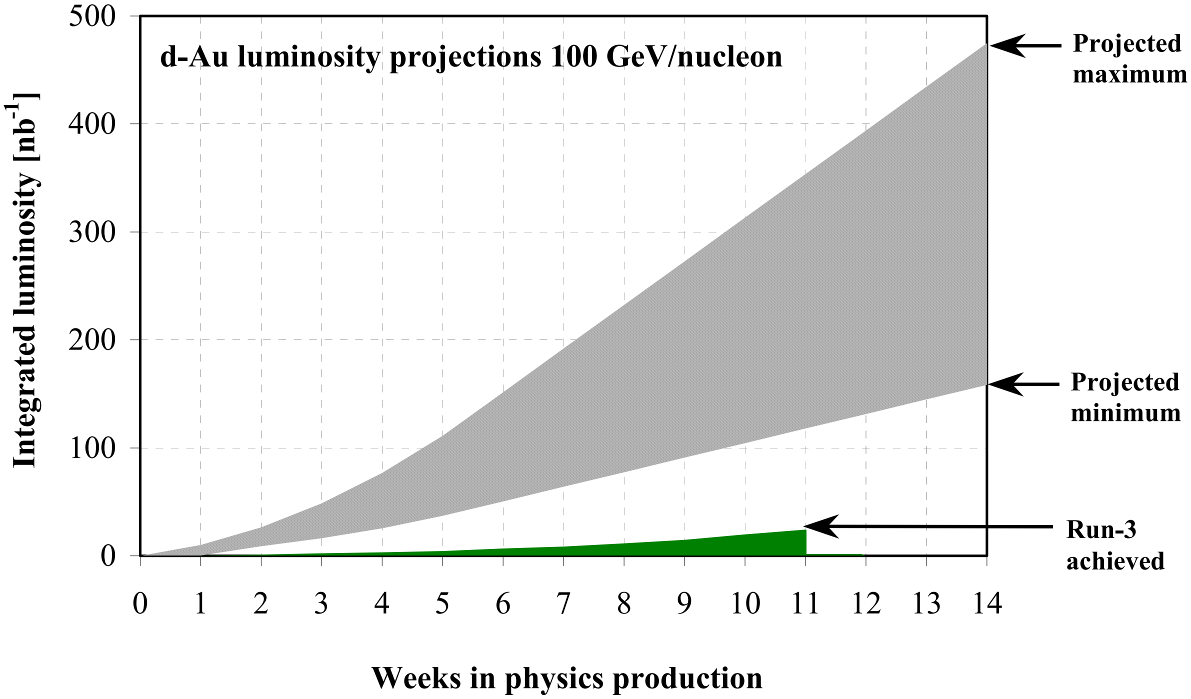

Figure 2: Projected minimum and maximum integrated luminosities for deuteron-gold collisions at 100 GeV/nucleon beam energy, assuming linear weekly luminosity ramp-up in 6 weeks.

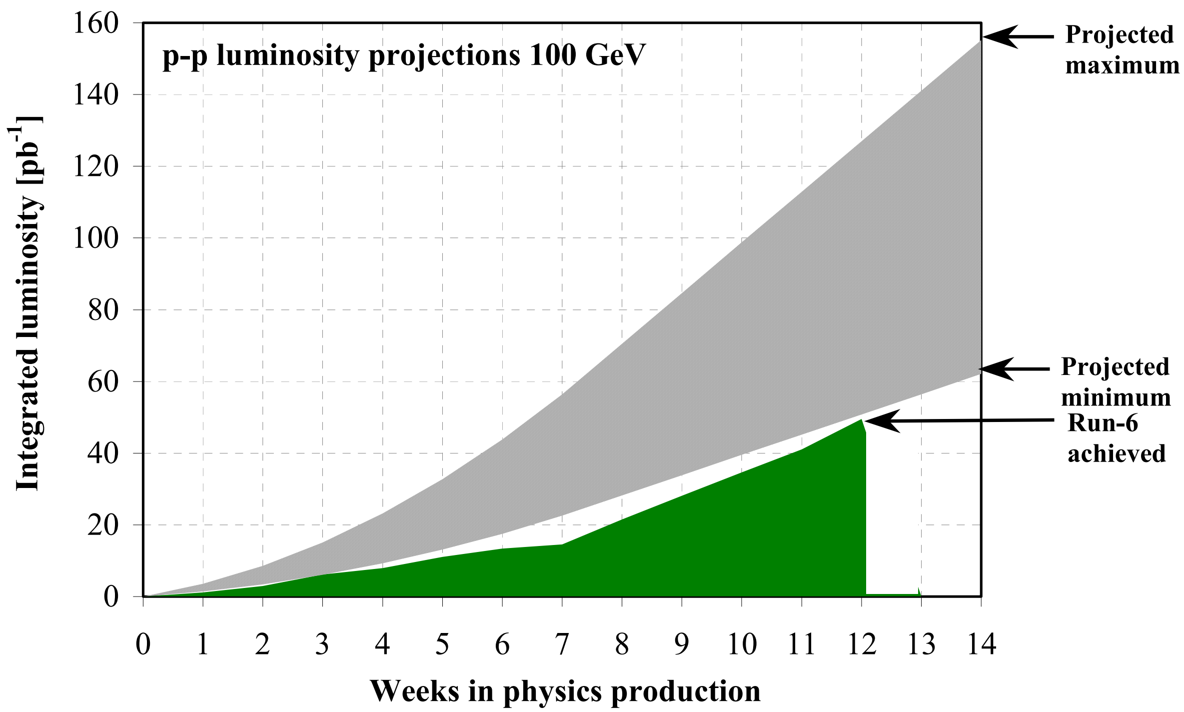

Figure 3: Projected minimum and maximum integrated luminosities for polarized proton collisions at 100 GeV beam energy, assuming linear weekly luminosity ramp-up in 8 weeks. An average store polarization of 65% is expected.

Part II – 2-Year Outlook

The RHIC Enhanced Design goals consist of

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

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

We have exceeded the Au-Au luminosity goal with routine stores of $\mathcal{L}_{store\ avg} = 12\times10^{26}$ $cm^{-2}s^{-1}$. There are still some improvements possible for the Au-Au luminosity. These include longitudinal stochastic cooling in the Blue ring, improved transition crossing resulting in higher beam intensities, a lattice with lower transverse IBS emittance growth rate, and a further reduction in β^*. If all are implemented, these could lead to an increase in the average store luminosity of another 30-50%. However, with no Au-Au operation in Run-8 probably only some of these improvements will be realized in the next 2 years.

We plan to achieve the proton luminosity and polarization goals at 100 GeV within the next 2 years, assuming a long polarized proton run in each of these years. To reach the proton luminosity and polarization goals at 250 GeV requires a long run at this energy.

Luminosity limitations – A number of effects limit the achievable luminosity. High intensity beams lead to electrons clouds, which can cause dynamic pressure rises in a few locations, and lower the stability threshold for bunches that cross the transition energy. To reduce electron cloud effects, the warm beam pipe sections were largely replaced with NEG coated ones, and in the cold sections additional pumps were installed that lower the pressure to 10^{-6} to 10^{-7} Torr before the cool-down to 4 K starts. If electron cloud problems remain, only scrubbing is anticipated to improve the situation.
For heavy ions intrabeam scattering increases the transverse emittance during stores and causes debunching. A longitudinal stochastic cooling system is operational in the Yellow ring, and stops debunching completely. A longitudinal system for the Blue ring is under construction, and transverse cooling stochastic cooling is under development. A new lattice with a reduced transverse IBS growth rate is under investigation.
The beam-beam interaction, in conjunction with other nonlinear and modulation effects, limits the beam and luminosity lifetime for protons. While exploring new working points, efforts are under way to reduce all sources of tune spread that are not beam-beam, and to reduce all known sources of parameter modulations.

Time in store – The fraction of the time in stores divided by the total time, reached 48% for Au-Au collisions in Run-7 (after 53% in Run-4) and 46% for polarized protons in Run-6 (after 56% in Run-5). All systems are currently analyzed in detail to bring the time in store back up. We still expect that the time in store can be increased to about 100 hours per week, or 60% of calendar time.