Accelerator performance

As of 2008 polarized proton beams have been accelerated, stored, and collided in RHIC at a center of mass energy of 200 GeV. A single proton beam was accelerated to 250 GeV beam energy, with 45% of polarization at that energy. At 200 GeV center of mass energy, the average store luminosity reached $23\times10^{30}cm^{-2}s^{-1}$, and the average store polarization 60% (see Table 1). Over the next 2 long polarized protons runs we aim to reach the Enhanced Luminosity goals for polarized protons, consisting of an average store luminosity of

- **$60\times10^{30}cm^{-2}s^{-1}$ for 200 GeV center of mass energy, and**
- **$150\times10^{30}cm^{-2}s^{-1}$ for 500 GeV center of mass energy,**

both with an **average store polarization of 70%**. Further improvements are possible thereafter. Table 1 gives a projection of the luminosity and polarization evolution through FY2013. Luminosity numbers are given for 200 GeV center of mass energy and one of two interaction points. We assume 15 weeks of physics running in FY2009 and 10 weeks in the following years to allow for commissioning of the improvements and developments of the machine performance. To maximize the proton polarization in RHIC about one month of AGS tuning is needed before RHIC operation begins.

Table 1: Achieved and projected polarized proton beam parameters through FY2013. Delivered luminosities are given for 200 GeV center of mass energy and one of two interaction points. 15 weeks of physics operation are assumed for FY2009, and 10 weeks in the following years.

Parameter	Unit	2006	2008	2009E	2010E	2011E	2012E	2013E
No of bunches	…	111	111	111	111	111	111	111
Ions/bunch, initial	10^{11}	1.4	1.5	1.8	1.9	2.0	2.0	2.0
Avg. beam current/ring	mA	187	205	250	264	280	280	280
$\beta*$	m	1.0	1.0	0.8	0.7	0.6	0.6	0.5
Hour glass factor	…	0.76	0.81	0.78	0.80	0.81	0.78	0.76
Beam-beam param./IP	10^{-3}	5.6	4.9	6.1	7.4	7.5	7.5	7.5
Peak luminosity	$10^{30}cm^{-2}s^{-1}$	28	35	63	96	121	129	137
Avg./peak luminosity	%	64	65	63	62	60	60	60
Avg. store luminosity	$10^{30}cm^{-2}s^{-1}$	18	23	40	60	73	77	82
Time in store	%	46	60	60	60	60	60	60
Max. luminosity/week	pb^{-1}	6.5	7.5	14.5	21.6	26.4	28.0	29.8
Min. luminosity/week	pb^{-1}			7.5	7.5	7.5	7.5	7.5
Max. luminosity/run	pb^{-1}	46	19	130	150	180	200	210
Min. luminosity/run	pb^{-1}			64	64	64	64	64
AGS polarization, extraction, min/max	%	65	55	55/65	55/70	55/75	55/75	55/75
RHIC avg. store polarization, min/max	%	60	45	50/60	50/65	50/70	50/70	50/70

In Figure 1 the integrated luminosity delivered to one experiment is shown through FY2013 for 15 weeks of physics operation in FY2009, and 10 weeks in the following years. For every projected period shown in Figure 1 the weekly luminosity starts at 25% of the final value, and increases linearly in time to the final value in 8 weeks. During the remaining weeks the weekly luminosity is assumed to be constant. For the maximum projection the values in Table 1 are used as final values. The minimum projection is what had been demonstrated in the past. For operation at 500 GeV center of mass energy, the luminosity projections in Table 1.need to be multiplied by 2.5. We expect no significant reduction in the average store polarization at this energy.

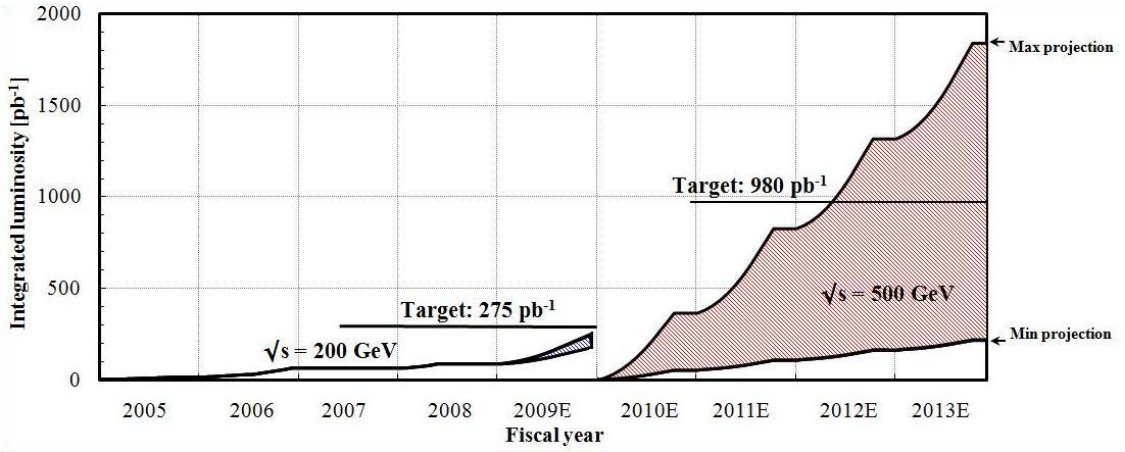

Figure 1: Minimum and maximum projected integrated luminosity through FY2013. Delivered luminosity numbers are given for one of two interaction points, and a physics running time of 15 weeks in FY2009, and 10 weeks of physics operation per year thereafter. The assumed center of mass energy is 200 GeV until the end of FY2009, and 500 GeV thereafter.

The RHIC beam polarization is limited by the source, and the polarization transmission in the AGS. After proper adjustment of tune, orbit, and snake settings no significant polarization loss is observed in RHIC up to a beam energy of 100 GeV, and no significant loss is anticipated at 250 GeV after full commissioning of ramps to that energy. Improvements in the source and the AGS are expected to increase the polarization at the AGS extraction energy from currently 60-65% to 75%. The AGS now operates routinely with both the warm and cold snakes.

The luminosity can still be increased by lowering β^*, especially at 500 GeV center of mass energy. Then the main luminosity limit for the polarized proton operation is the beam-beam effect, leading to a spread in the transverse tunes. To accommodated larger beam-beam parameters other sources of transverse tune spread are minimized and different working points are evaluated. The use of electron lenses for head-on beam-beam compensation is currently studied in simulations. Dynamic pressure rises have been largely eliminated through modifications in the vacuum system. However, operation with short bunches can still lead to emittance growth from electron clouds.

APPENDIX – Accelerator performance improvements

We give here a more detailed account of the plan to increase the average store polarization and luminosity in RHIC.

The maximum polarization is limited by the source, the AGS polarization transmission, and by the tune and orbit control in RHIC. There is a continuous effort to increase the source polarization. However, after modifications for Run-8 the source polarization was only 80-82%, about 5% lower than in Run-7. The goal for Run-9 is a source polarization of again 85%. An R&D effort is under way for a high-intensity proton source with a high-uniformity superconducting solenoid with which a higher brightness beam can be produced.
For the next polarized proton run the Low Energy Beam Transport (LEBT), Medium Energy Beam Transport (MEBT), and Booster injection are modified. The LEBT and MEBT sections are optimized for high-intensity proton operation and are causing emittance increases for polarized protons. With these modifications and for comparable intensities an emittance reduction of 20% or more is anticipated, which is also expected to improve the polarization performance.
In the AGS, a stronger snake and a horizontal tune near an integer number were tested in Run-7. In Run-8 injection on the fly (without a constant dwell field) was tested. Both were attempts to reduce the intensity dependence of the polarization, but in neither test a better polarization performance could be demonstrated, and for the final Run-8 operation the Run-6 setup was used again. Under investigation is now a scheme to jump all horizontal spin resonances in the AGS with fast quadrupoles. Such a scheme could increase the polarization out of the AGS by as much as 5% (absolute).
During Run-8 it became clear that the control of the orbit angles through the RHIC snakes is critical to maintain the polarization, and that some of the polarization problems in RHIC during Run-9 can be attributed to insufficient orbit control through the snakes. This will be addressed for future runs.
A spin flipper in RHIC is under construction for Run-9.

The main limitation for the RHIC luminosity is the beam-beam effect in conjunction with other nonlinear effects and parameter modulations. With the limited time available in Run-8 only a modest (15%) improvement in the average store luminosity could be demonstrated. However, 2 important tests were made. In the first test a near integer working point was studied that is expected to accommodate a larger beam-beam parameter. This working point is currently not operationally usable because 10 Hz mechanical triplet vibration, enhanced at near integer working points, lead to an enhancement and large modulations in the experimental background. A reduction of the 10 Hz mechanical oscillation through passive or active damping of the cold mass movement, or an orbit feedback is under study. In a second test a lattice with a design value of β^* = 65cm was commissioned but could not be made operational in the limited time available. For such a lattice, a nonlinear chromaticity correction, developed over the last 2 years, is essential. We expect that β^* can be ultimately reduced to 50cm at 250 GeV beam energy.

For Run-9 a new 9 MHz radio frequency system will be commissioned. This allows preserving the longitudinal emittance upon beam injection into RHIC which is currently not possible. With the resulting shorter bunches at store the hour glass effect is reduced, leading to about 25% higher luminosity. The longer bunches at injection are also expected to reduce the incoherent emittance growth that was observed in previous runs, possibly caused by electron clouds.
Electron lenses are currently studied in simulations. These could mitigate the head-on beam-beam effect. Also studied is coherent electron cooling which could reduce the beam emittance at store.