Research Plan for Spin Physics at RHIC

Abstract

In this report we present the research plan for the RHIC spin program. The report covers 1) the science of the RHIC spin program in a world-wide context; 2) the collider performance requirements for the RHIC spin program; 3) the detector upgrades required, including timelines; 4) time evolution of the spin program.

Authors:

Christine Aidala, Mei Bai, Leslie Bland, Alessandro Bravar, Gerry Bunce, Mickey Chiu, Abhay Deshpande, Douglas Fields, Wolfram Fischer, Yoshinori Fukao, Yuji Goto, Matthias Grosse Perdekamp, Wlodek Guryn, Masanori Hirai, David Kawall, Edward Kistenev, Stefan Kretzer, Akio Ogawa, Kensuke Okada, Jianwei Qiu, Greg Rakness, Vladimir Rykov, Naohito Saito, Hal Spinka, Marco Stratmann, Bernd Surrow, Atsushi Taketani, Michael Tannenbaum, Manabu Togawa, Larry Trueman, Fleming Videbaek, Steve Vigdor, Werner Vogelsang, Yasushi Watanabe

1 Accelerator performance

As of 2004, polarized proton beams have been accelerated, stored and collided in RHIC at a proton energy of 100 GeV. The average store luminosity reached 4×10^{30}cm^{-2}s^{-1}, and the average store polarization 40% (see Tab. 1). Over the next 4 years we aim to reach the Enhanced Luminosity goal for polarized protons, consisting of an average store luminosity of

- **60$\times$10^{30}cm^{-2}s^{-1} for 100 GeV** proton energy, and
- **150$\times$10^{30}cm^{-2}s^{-1} for 250 GeV** proton energy,

both with an **average store polarization of 70%**. Tab. 1 gives a projection of the luminosity and polarization evolution through FY2008. Luminosity numbers are given for 100 GeV proton energy and one of two interaction point. For operation with more than two experiments, the luminosity per interaction point is reduced due to an increased beam-beam interaction. For each year the maximum achievable luminosity and polarization is projected. Projections over several years are not very reliable and should only be seen as guidance for the average annual machine improvements needed to reach the goal. We assume that 10 weeks of physics running are scheduled every year to allow for commissioning of the improvements and development of the machine performance.

Table 1: Maximum projected RHIC polarized proton luminosities through FY2008. Delivered luminosity numbers are given for 100 GeV proton energy and one of two interaction points. 10 weeks of physics operation per year are assumed. The designation 2002A refers to achieved, and 2005E refers to expected.

Fiscal year		2002A	2003A	2004A	2005E	2006E	2007E	2008E
No of bunches	...	55	55	56	79	79	100	112
Protons/bunch, initial	10^{11}	0.7	0.7	0.7	1.0	1.4	2.0	2.0
β^*	m	3	1	1	1	1	1	1
Peak luminosity	10^{30}cm^{-2}s^{-1}	2	6	6	16	31	80	89
Average luminosity	10^{30}cm^{-2}s^{-1}	1.5	3	4	9	21	53	60
Time in store	%	30	41	41	50	53	56	60
Max luminosity/week	pb^{-1}	0.2	0.6	0.9	2.8	6.6	18.0	21.6
Max integrated luminosity	pb^{-1}	0.5	1.6	3	20	46	126	151
Average store polarization	%	15	30	40	45	65	70	70
Max LP^4/week	nb^{-1}	0.1	5	23	120	1180	4330	5190

In Fig. 1 the integrated luminosity delivered to one experiment is shown through FY2012 for two scenarios: 10 weeks of physics operation per year, and 10 weeks of physics operation every other year. For every projected year shown in Fig. 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 Tab. 1 are used as final values until FY2008. For later years the FY2008 values are assumed with no further improvement. The minimum projection is one third of the maxium projection, based on past experience in projecting heavy ion luminosities [**?**].

For the scenario with 10 weeks of physics operation per year, the assumed proton energy is 100 GeV until FY2009, and 250 GeV thereafter. For the scenario with 10 weeks every other year, the assumed proton energy is 100 GeV throughout the entire period to reach the physics goal.

For the scenario with 10 weeks of physics operation every other year, the final values are not increased in years without proton operation, since no time is available to develop the machine performance. Thus in our projections we reach the Enhanced Luminosity goal in FY2008 with 10 week physics operation per year, but need until FY2011 with 10 weeks of physics operation every other year. For operation at 250 GeV proton energy, the luminosity projections in Tab. 1 need to be multiplied by 2.5. We expect no significant reduction in the averages store polarization after full commissioning of polarized proton ramps to 250 GeV.

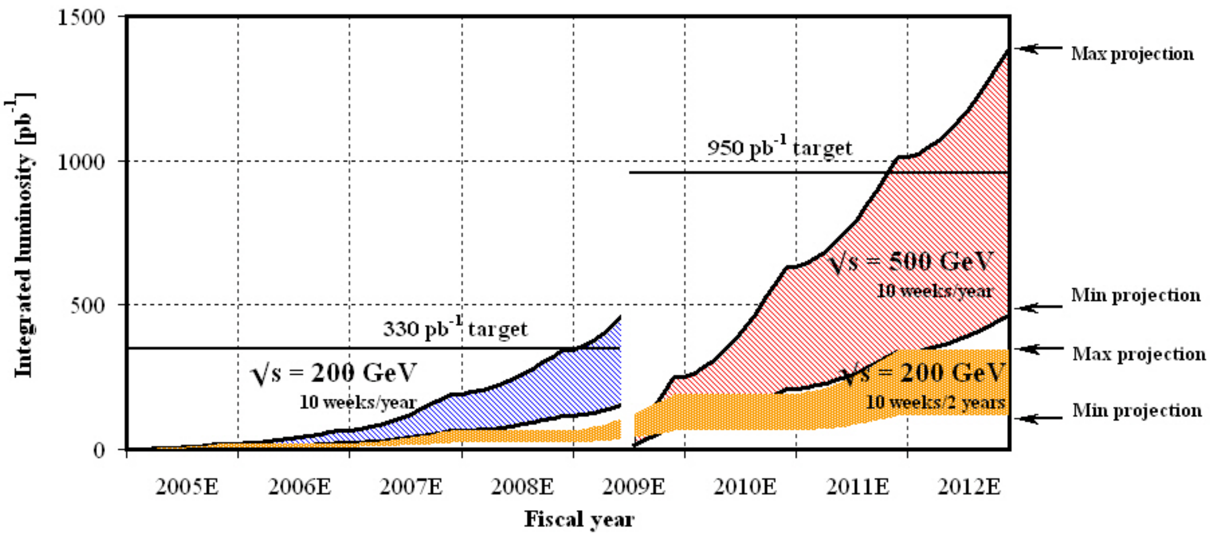

Figure 1: Minimum and Maximum projected integrated luminosity through FY2012. Delivered luminosity numbers are given for one of two interaction points. For the scenario with 10 weeks of physics operation per year, the assumed proton energy is 100 GeV until FY2009, and 250 GeV thereafter. For the scenario with 10 weeks every other year, the assumed proton energy is 100 GeV throughout the entire period.

1.1 Polarization limitations

The RHIC beam polarization at 100 GeV is currently limited by the AGS beam polarization transmission efficiency of about 70%, and the source polarization. With the installation of a new solenoid in FY2005, the source polarization is expected to increase from 80% to 85%. The existing AGS polarized proton setup includes a 5% warm helical snake for overcoming imperfection spin depolarizing resonances and an RF dipole for overcoming 4 strong intrinsic spin resonances. This setup has two drawbacks:

1. All the weak intrinsic spin resonances are crossed with no correction and result in a total depolarization of about 16%.
2. Operation with the RF dipole still leads to about 15% depolarization.

In addition, the AGS has shown a dependence of the beam polarization on the bunch intensity. These shortcomings can be overcome with the installation of a new AGS cold snake, to be initially commissioned in 2005. With a scheme that combines the AGS cold snake of 15%, and the AGS warm snake of 5%, depolarizations at all imperfection and all intrinsic spin resonances should be eliminated, making the AGS spin transparent with the exception of some mismatch at injection and extraction [**?**].

Obtaining 70% beam polarization in RHIC at 250 GeV is challenging because of strong intrinsic and imperfection resonances beyond 100 GeV. Betatron tunes and orbit distortions have to be controlled precisely to avoid depolarization due to snake resonances. Simulations show that orbit distortions have to be corrected to less than 0.3 mm rms. Orbit errors are introduced due to misalignments and remain if the orbit cannot be corrected completely. A realignment of the entire ring is scheduled for the 2005 summer shutdown. Efforts continue to improve the existing beam position monitor system, and the orbit correction techniques. A beam-based alignment technique is under development. With the existing hardware and software, orbit distortions of 1 mm rms were achieved, as measured by the beam position monitors. Acceleration of polarized proton beams beyond 100 GeV is planned in 2005. The result of this machine development effort will provide guidance for the tolerable levels of machine misalignments and orbit errors.

1.2 Luminosity limitations

A number of effects limit the achievable luminosity. Currently the bunch intensity is limited to about 1×10^{11} to maintain maximum polarization in the AGS. This restriction should be removed with the AGS cold snake. With intense bunches the beam-beam interaction will limit the luminosity lifetime. With bunches of 2×10^{11} protons and 2 interaction points, the total beam-beam induced tune spread will reach 0.015. Operation with more than two collision will significantly reduce the luminosity lifetime. RHIC is also the first hadron collider to operate in a strong-strong beam-beam regime. High intensity beams also lead to a vacuum breakdown, caused by electron clouds. In the warm sections, NEG coated beam pipes are installed, that have a lower secondary electron yield, and provide linear pumping. In the cold regions, additional pumps are installed to improve the vacuum to an average value of 10^{-5} Torr before the cool-down starts. With the PHENIX and STAR detector upgrades, the vacuum system in the experimental regions will also be improved.

Time in store can be gained through faster machine set-up, a reduction in system failures, and the injection of multiple bunches in each AGS cycle. We project that the time in store can be increased to about 100 hours per week, or 60% of calendar time.

1.3 Polarimetry

Beam polarization measurements in RHIC provide immediate information for performance monitoring, and absolute polarization to normalize the experimental asymmetry results. Two types of polarimeters are used. Both are based on small angle elastic scattering, where the sensitivity to the proton beam polarization comes from the interference between the electromagnetic spin-flip amplitude that generates the proton anomalous magnetic moment and the hadronic spin non-flip amplitude, and possibly a hadronic spin-flip term.

One type of polarimeter uses a micro-ribbon carbon target, and provides fast relative polarization measurements. The other type uses a polarized atomic hydrogen gas target, and provides slow absolute polarization measurements. In addition, both PHENIX and STAR have developed local polarimeters that measure the residual transverse polarization at their interaction points. These polarimeters are used to tune and monitor the spin rotators that provide longitudinal polarization for the experiments. They polarimeters are discussed in the Experiments section.

The fast proton-carbon polarimeter was first developed at the AGS [**?**]. It measures the polarization in RHIC to $\Delta P = \pm 0.02$ in 30 seconds. Measurements taken during a typical store in 2004 are shown in Fig. 2. A carbon ribbon target is introduced into the beam, and the left-right scattering asymmetry of recoil carbon ions is observed with silicon detectors inside the vacuum. The silicon detectors observe the energy and time of flight of the recoil particles near 90° [**?**]. The detector selects carbon ions with a momentum transfer in the coulomb-nuclear interference (CNI) region, $-t = 0.005 - 0.02$ (GeV/c)^2. In this region, the interference of the electromagnetic spin flip amplitude and the hadronic non-flip amplitude produces a calculable t-dependent asymmetry of 0.03 to 0.02. The cross section is large, so that the sensitivity to polarization is large. A term from a hadronic spin flip amplitude is also possible and is reported in Ref. [**?**]. This contribution is not calculable, so that this polarimeter must be calibrated using a beam of a known polarization.

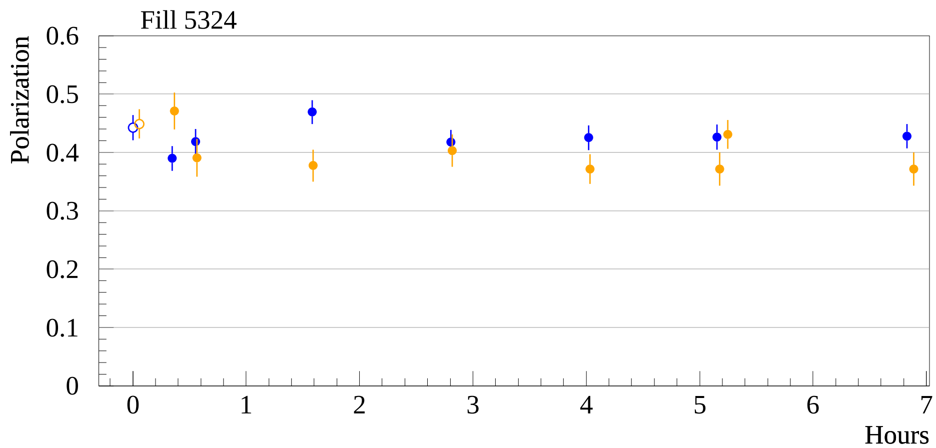

Figure 2: Measured polarization during one store of RHIC in 2004.

A polarized atomic hydrogen gas jet target was used for the first time in RHIC in 2004 [**?**]. The atoms are polarized with the Stern-Gehrlach process to select one electron polarization state, with rf transition to select proton polarization. The atoms are focused in the RHIC beam region to 6 mm FWHM using the atomic hydrogen magnetic moment. A Breit-Rabi polarimeter after the RHIC beam measures the polarization by cycling through rf transition states. The polarization was determined to be 0.92±0.02, including correction for the measured 2% molecular fraction (4% nuclear fraction) that is unpolarized. The online target polarization measurements are shown in Fig. **??**. The target polarization was reversed roughly every 8 minutes by changing rf transitions. Silicon detectors measure a left-right asymmetry for proton-proton elastic scattering in the CNI region, similar to the p-carbon polarimeters. By measuring the asymmetry with respect to the target polarization sign, we measure the analyzing power for proton-proton elastic scattering, as shown in the elastic scattering subsection. By then measuring the left-right asymmetry with respect to the beam polarization sign, flipping each bunch (every 200 ns), we obtain the absolute beam polarization. The absolute beam polarization was measured to better than $\Delta P/P = 7\%$ in 2004 (preliminary).

A remaining issue is whether the carbon polarimeter calibration can be used for different

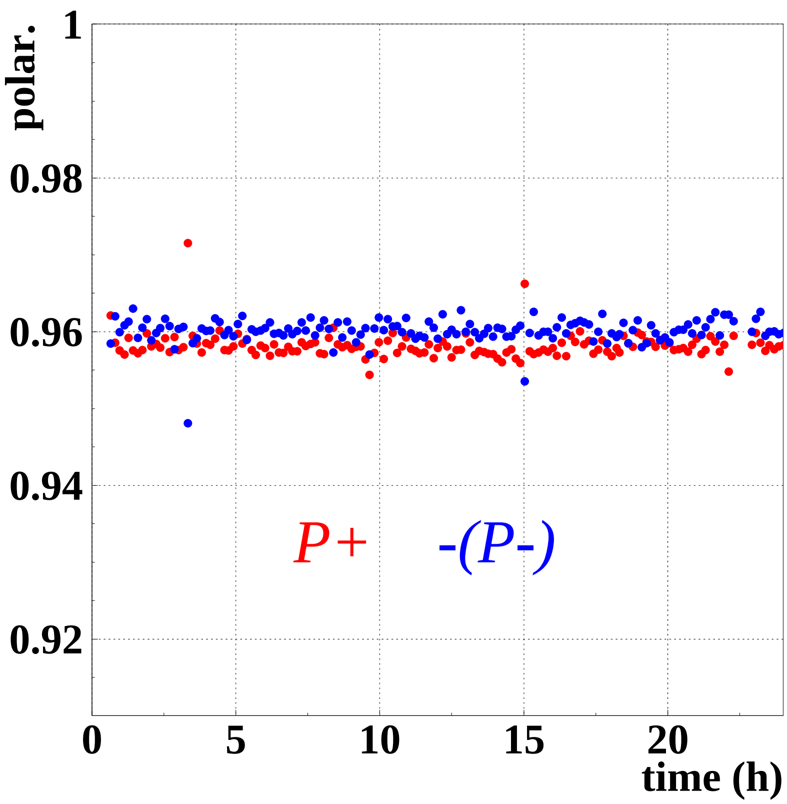

Figure 3: Online polarization measurements for the polarized atomic hydrogen jet target in RHIC during the 2004 run. No correction is included for molecular hydrogen contamination (about 3%).

detectors, from year to year, or whether it will be necessary to recalibrate each year using the jet target. We can also choose to use the jet target as the RHIC polarimeter, with the carbon polarimeter used for corrections, for example for different polarization of the bunches and for a polarization profile of the beams. It will also be necessary to improve the lifetime of the silicon detectors from radiation to avoid changing detectors mid-run, which worsens the RHIC vacuum and is not expected to be compatible with high luminosity running. A related issue is development to be able to bake out the polarimeter region.

1.4 Long-term perspective

A number of ideas are pursued for long-term improvements of the machine performance. RHIC II aims at increasing the heavy ion luminosity by an order of magnitude through electron cooling. For protons, cooling at store is not practical but pre-cooling at injection might be beneficial. A further reduction of β^*, especially at 250 GeV proton energy appears possible. Some benefits may also come from stochastic cooling, currently developed for heavy ions. We expect a luminosity improvement of a factor 2-5 for polarized protons for RHIC II.

With a new interaction region design, the final focusing quadrupoles can be moved closer to the interaction point, thus allowing to squeeze β^* further. This, however, makes some space unavailable for the detectors. Additional increases in the luminosity may come from a further increase in the number of bunches, to close to 360, as is planned for eRHIC, or operation with very long bunches. The latter requires a substantial R&D effort, as well as a new timing system for the detectors.