POLARIMETRY AT RHIC. RHIC POLARIZED BEAM IN RUN 2011

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Abstract

In 2011 Run polarized proton beam collisions of a total energy $\sqrt{s} = 500$ GeV and peak luminosity up to 1.6×10^{32} cm^{-2}sec^{-1} was delivered to experiments for intermediate boson W production studies with the longitudinally polarized beams. The average beam polarization of a 48% was measured with the H-jet polarimeter. Apparently, there are no visible polarization losses during acceleration up to 100 GeV energy, where a 55-60% polarization was measured in Run 2009. Polarization losses at further acceleration to 250 GeV are caused by the presence of depolarizing resonances. As a result, significant polarization profiles of the beams are also generated. Polarization profiles were measured by the p-Carbon CNI polarimeters in the scanning mode of operation. Polarized beam luminosity is weighted by the polarization profiles and "effective" polarization, as seen in collisions was about 53% in Run 2011.

1 Introduction

The RHIC, heavy ion collider, is the first high-energy machine, where polarized proton acceleration was included in the primary design. RHIC is the first collider where the "Siberian snake" technique was successfully implemented to avoid the resonance depolarization during beam acceleration in AGS and RHIC [1] (see Fig. 1). It is also for the first time the intensity of the polarized beams produced in an Optically Pumped Polarized H^- Ion Source (OPPIS) was sufficient to charge RHIC to the maximum intensity limited by the beam-beam interaction. Every source pulse is eventually converted to the RHIC bunch. The source routinely produces about 10^{12} polarized H^- ions per pulse, about half of this intensity (5×10^{11} H^-/pulse) is accelerated in Linac to 200 MeV beam energy for the strip injection to the Booster. The maximum beam intensity in RHIC was limited to about 2×10^{11} protons/bunch, therefore excessive beam intensity was scraped at extraction from Booster. This allowed beam emittance reduction at injection to AGS, which reduces depolarization and increases RHIC luminosity.

There are two “Siberian snakes” in the each ring to meet the conditions that the “snake” rotation is much larger than the total rotation from all other resonances up to highest 250 GeV beam energy. The RHIC “full Siberian snake”, which rotates spin direction for 180° is super-conducting helical magnet system of about 10 m long. Up to 120 beam bunches can be accelerated and were stored in each ring.

The polarization direction of every RHIC bunch is determined by the spin-flip control system in the polarized ion source. Every single source pulse is accelerated and becomes the RHIC bunch of the requested polarity. By loading selected patters of spin direction sequences in the rings the experiments have all possible spin directions combinations for colliding bunches which greatly enhance the systematic error control. Two 90° helical spin rotators in each ring produce the longitudinal polarization for experiments in STAR and PHENIX detectors. The rotators are tuned using “local polarimeters” based on asymmetry in neutron production for pp collisions. The STAR and PHENIX detectors provide complimentary coverage of the different polarization processes [2].

2 Polarimetry at RHIC

Precision, absolute polarization measurements in the wide energy range from a few keV (in the source) to 250 GeV (top RHIC energy) are required for accelerator tuning to minimize depolarization and finally for experimental data normalization. Therefore, the polarimetry is an essential component of the polarized collider facility. A complete set of polarimeters includes: Faraday rotation polarimeter for optical pumpng tuning and monitoring in the OPPIS, Lamb-shift polarimeter at the source energy of a 3–35 keV, a 200 MeV proton-Carbon polarimeter after the linac [3], and polarimeters in AGS and RHIC based on proton-Carbon scattering in Coulomb-Nuclear Interference (CNI) region [4]. A polarized hydrogen-jet polarimeter was used for the absolute polarization measurements in RHIC [5].

Recently a new polarimeter for absolute proton beam polarization measurements at 200 MeV to accuracy better than ±0.5% has been developed as a part of the RHIC

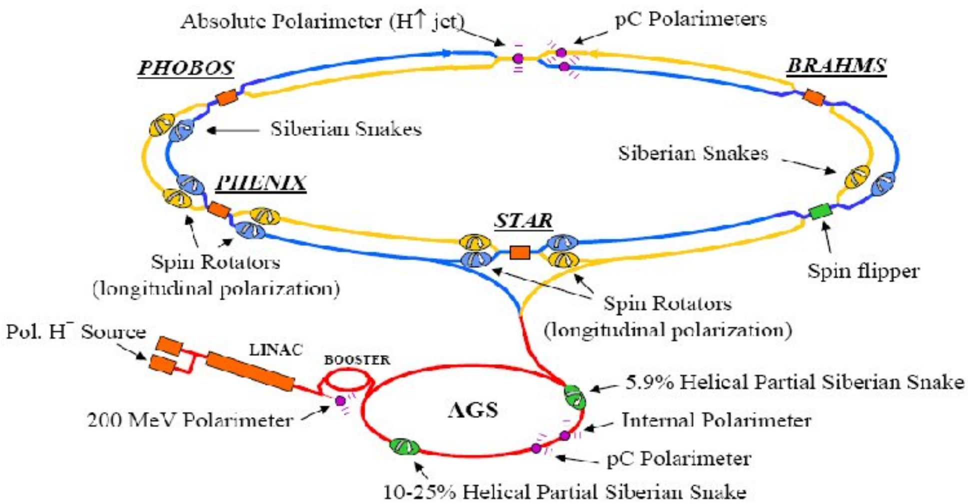

Figure 1: Accelerator-Collider complex RHIC polarization hardware layout.

polarized source upgrade. The polarimeter is based on the elastic proton-carbon scattering at 16.2° angle, where the analyzing power is close to 100% and was measured with high accuracy. The elastically and in-elastically scattered protons are clearly identified by the difference in the propagation through variable copper absorber and energy deposition of the protons in the detectors. This polarimeter Tawas used for calibration of a high rate inclusive 12T-polarimeter for the on-line polarization tuning and monitoring. This technique can be used for accurate polarization measurements in energy range of 160–250 MeV.

The proton-Carbon CNI polarimeters in AGS and RHIC are based on elastic proton scattering with low momentum transfer (Coulomb Nuclear Interference region) and measurement of asymmetry in recoil carbon nuclei production as described in detail elsewhere [6]. A very thin and narrow (30 nm thick 5 μm wide) carbon strip target placed in the high intensity circulating beam produces very high collision rate and an efficient DAQ system acquires up to 10^7 carbon events/sec. The polarization measurement during the beam energy ramp was implemented in AGS and RHIC, which provides an insight of polarization losses pattern. The carbon target width is much smaller than the beam size and polarization profile can be also measured.

The AGS proton-Carbon CNI polarimeter was upgraded for the 2011 Run with the new silicon detectors, amplifiers and new carbon-strip target drives. This upgrade improved the accuracy and reproducibility of polarization measurements and polarization profiles measurements in both vertical and horizontal planes. The polarization profile measurements with the "Jump-Quads" operation confirmed the expected reduction of horizontal polarization profile, which contributed to beam average polarization increase from AGS for about 5% [7]. The polarimeter can be also operated in a fast continuous sweep mode, while beam is stored in the AGS at 23.7 GeV. This measurement produces horizontal and vertical beam intensity profile measurements for the single AGS bunch. These measurements are used for cross-checking of the AGS IPMs measurements and machine set-up to minimize beam emittances.

The RHIC proton-Carbon CNI polarimeters is operated in scanning mode, giving polarization profiles and transverse beam intensity profile (beam emittance) measurements. The polarimeters function as wire scanners, providing a very good signal/noise ratio and high counting rate. This allows accurate bunch-by-bunch emittance measurements during fast target sweeps (< 1 s) through the beam. Very thin carbon strip targets make these measurements practically non-destructive. Bunch by bunch emittance measurements are a powerful tool for machine set-up; in RHIC, individual proton beam transverse emittances can only be measured by CNI polarimeter scans.

The use of thin targets in a polarimeter is essential to reduce multiple scattering for recoil carbon ions and keep the event rate within detector and DAQ capabilities. Carbon strips used in polarimeter are 5–15 μm wide (~ 5 μg/cm^2 thickness), and contain about 10^{13} carbon atoms per mm of target length. The target length is 25 mm. High intensity circulating beam knocks out about $10^7 \div 10^8$ carbon nuclei/s, which cause the eventual target destruction. It was experimentally demonstrated that targets survive in the RHIC beam for at least 100–200 measurements at the full beam intensity, which corresponds to the one target lifetime of about one-to-two weeks. Multiple targets (six vertical and six horizontal) are attached to a target ladder to extend the time between maintenances. The precision procedure was developed to provide about ± 0.1 mm target alignment accuracy on the ladder, therefore the target positioning accuracy is limited only by the target straightness. A combination of linear and rotational motion in the target mechanism provides the target replacement and polarization scans operation. Using of precision linear stages and rotational vacuum feed-through gives target position accuracy of ±0.2 mm. Time-of-flight and recoil carbon energy measurements are required for elastic scattering identification. Silicon-strip detectors are used in the polarimeters, which allow measurements of energy and arrival time of recoil Carbons in the RHIC ring vacuum environment. At full RHIC design intensity, the bunch width is about 8 ns and bunch spacing is 106 ns. To avoid prompt background, carbon nuclei should arrive at the detectors in the time window between two bunches.

Polarization and beam intensity profile measurements. The carbon target width of 5–15 μm is much smaller than the beam size. Therefore intensity and polarization profiles can be measured by the target scan. In scanning mode the counting rate dependence on the target position can be used for the beam intensity profile measurements in addition to polarization measurements. With high event rates, large statistics are accumulated in a very short time for fast target scans.

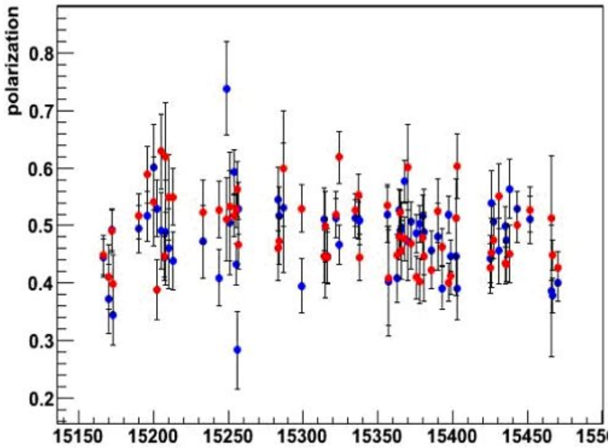

Figure 2: H-jet polarization measurements in RHIC in Run 2011.

The absolute (average) beam polarization at 100–250 GeV beam energy was measured with a polarized H-jet polarimeter, which is also based on elastic proton-proton scattering in the CNI region. Due to particle identity, polarization of the accelerated proton beam can be directly expressed in terms of proton target polarization, which can be precisely measured by Breit-Rabi polarimeter. With the record beam intensity of a 12.4×10^{16} atoms/s obtained in this atomic beam source [4], and with increased bunch intensities in Run 2011 a statistical error of about 6–7% was obtained for polarization measurement in each RHIC store (see Fig. 2). There is a plan for the H-jet polarimeter silicon detectors upgrade for larger solid angle, energy range and better resolution. The goal of upgrade is 2–3 times event rate increase, which will reduce statistical error to about 5% in a single 8 hours store.

The simultaneous measurements in p-Carbon and H-jet polarimeters provide the calibration for p-Carbon analyzing power. Fast pC polarimeter measures possible polarization losses during the store duration. Analyzing power of *pp* elastic scattering in CNI region has been accurately measured in experiments with H-jet polarimeter in energy range 24–250 GeV. This accuracy can be further improved after studies of molecular H_2 background and other systematic errors contributions. The statistical accuracy of the polarized H-jet polarimeter cannot be significantly improved because of strong intensity and density limitations for the polarized atomic beam target. But the accurately measured analyzing power can be used in the polarimeter with higher thickness un-polarized H_2-jet target and 100 times higher counting rate. It can be achieved with the un-polarized hydrogen jet target of a moderate about 10^{13} H_2/cm^2 thickness and increase of solid angle for recoil proton detection. This will result in less than 1% statistical accuracy for each fill.

3 Polarized beam in AGS and RHIC in Run 2011

In 2009 polarized Run the average polarization of about 55% was measured at 100 GeV beam energy. This polarization is equal to measured value at injection energy (within the systematic error of calibrations). It is expected, from spin dynamics simulations, that polarization losses from intrinsic resonances crossing at the energy ramp are higher at edge of beam, which should produce polarization distribution across the beam the polarization profile. These polarization profiles in RHIC were measured at injection energy, at 100 GeV and 250 GeV energies. The polarization profile values at 100 GeV were very close to the profile measurements at injection. This is another confirmation of small polarization losses at acceleration up to 100 GeV. In 2009 Run polarized protons was also for the first time successfully accelerated to 250 GeV beam energy and average polarization of a 36% was measured by the H-jet polarimeter. Significantly larger polarization profiles were also measured at 250 GeV beam energy.

A number of significant improvements in machine operation were implemented for 2011 Run. A "Jump-Quads" technique for polarization preservation during the passage of the week intrinsic resonances in AGS increased the beam polarization out of AGS for about 5–10% especially at the highest (2×10^{11} protons/bunch) beam intensity (see Fig. 3).

A new 9 MHz RF-cavity in RHIC improved the longitudinal matching in between AGS and RHIC and reduced the beam losses at the RHIC energy ramp. Spin tune stability was greatly improved with the implementation of the "tune feedback" system. This allowed the optimal choice of spin tune value to minimize depolarization and still keeping the stable machine operation. The beam position control system was also greatly improved, which reduced the vertical beam position motion to less than 0.1 mm, which is required for depolarization reduction [8]. As a result, the average polarization at 250 GeV was increased to 48% (see Fig. 2) and polarization profiles were reduced too accordingly. Another indicator of the improved machine control are the very close numbers for average polarization in Blue ($47.98 \pm 0.53\%$) and Yellow ($47.95 \pm 0.53\%$) rings, as measured by the H-jet polarimeter.

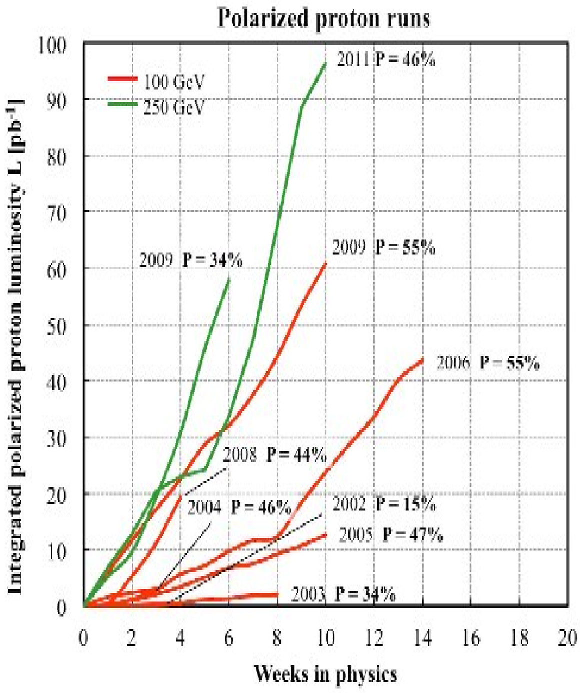

Figure 3: The polarized beam luminosity and polarization in Runs 2003-2011.

For colliding beams, the polarization profile is weighted with a product of two beam intensity profiles in transverse plane, therefore an "effective" polarization for colliding beams is somewhat higher than average polarization measured by the H-jet polarimeter [4]. In 2009 Run at 250 GeV beam energy these corrections were about 15% and "effective" polarization (as seen by colliding beams) was about 41%. In Run 2011 with the reduced polarization profiles the corrections were about 10% and "effective" polarization about

53%.

The RHIC upgrades allowed increase of the bunch intensity at injection to RHIC up to 2.0×10^{11} protons/bunch. The peak beam intensity accelerated to 250 GeV was increased to about 180×10^{11} protons in 109 bunches and peak beam luminosity 1.5×10^{32} cm^{-2}sec^{-1}. Average luminosity for the 8 hrs store was about 0.9×10^{32} cm^{-2}sec^{-1}. The RHIC performances in polarized Runs are shown in Fig. 3. In spite of 2 weeks downtime caused by technical problems (electrical power distribution system failure) the significant increase of integrated luminosity and polarization was achieved in Run 2011.

4 Summary and outlook

The RHIC spin program is a beneficiary of the latest development in the polarized ion source and polarized internal target technology. For the first time the polarized proton beam intensity in the high-energy accelerator is not limited by the polarized source intensity. In 2009-11 Runs polarized proton beam was successfully accelerated to 250 GeV energy. The beam polarization of a 55–60% at 100 GeV beam energy and 48% (53% as seen in collisions) at 250 GeV energy was measured with the polarized H-jet and p-Carbon CNI polarimeters. The plans for further polarization increase rely on polarized source upgrade to higher intensity and polarization [9]. Smaller beam emittance can be produced by strong beam scraping of the high-intensity beam after the Booster. This should reduce beam depolarization in AGS and RHIC and contribute to further luminosity increase. There is also a plan to eliminate a polarization decay (of about 10% during 8 hours store) which was observed in Run 11 by better choice of the operational tune value.

The depolarization studies and experimental data normalization are based on absolute polarization and polarization profiles measurement accuracy and ongoing program on polarimetry development and upgrades is an essential part of the RHIC spin program.

References

[1] T. Roser, AIP Conf. Proc **980** (2008) 15.

[2] I. Alekseev et al., NIM A **499** (2003) 392.

[3] A. Zelenski et al., “Precision absolute proton polarization measurements at 200 MeV beam energy”, SPIN 2011, Julich, Journal of Physics, Conf. Series **295** (2011) 012132.

[4] A. Bazilevskiy, et al, “Precision measurements of the proton beam absolute polarization in RHIC”, AIP Conf. Proc. **1149** (2009) 723.

[5] A. Zelenski et al., NIM A **536** (2005) 248.

[6] I. Nakagava et al., AIP Conf. Proc **980** (2008) 380.

[7] V. Schoefer et al., “Recent RHIC motivated polarized proton development in AGS”, PAC 2011, THP079.

[8] H.Huang et al., “RHIC polarized proton operation”, PAC 2011, MOOCN3.

[9] A.Zelenski et al., “The RHIC polarized source upgrade”, SPIN2010, Julich, Journal of Physics: Conference Series **295** (2011) 012147.