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DISCLAIMER

P-CARBON CNI POLARIMETRY IN THE AGS AND RHIC*

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Abstract

Proton polarization measurements in the AGS (Alternate Gradient Synchrotron) and RHIC (Relativistic Heavy Ion Collider) are based on proton-carbon(pC) and *proton-proton elastic scattering in the Coulomb Nuclear* Interference (CNI) region. The CNI polarimeters are the essential tools for polarized proton acceleration setup and operation. High intensity recoil nuclei from the scattering of the circulating proton beam in the thin carbon target is efficiently utilized in the silicon strip detectors and data acquisition system, which is capable to analyze the event rate up to a few millions/second. This makes it possible for the fast, practically non-destructive polarization measurements. The polarization measurement on the beam energy ramp was implemented in AGS and RHIC, providing locations of polarization losses. Polarimeter operation in the scanning mode also gives polarization profile and beam profile (including bunch by bunch values for the later one). This paper summarizes the recent modifications. Results of polarization measurements are also discussed.

I. INTRODUCTION

The collision of polarized proton beams at RHIC (at up to $\sqrt{S} = 500$ GeV CMS energy) provides a unique physics opportunity for studying spin effects in hard processes at high luminosities, including the measurement of the gluon polarization and the quark and anti-quark spin flavour composition[1].

The RHIC is the first collider where the Siberian snakes were successfully implemented to maintain polarization during beam acceleration [2]. Precise control of the AGS and RHIC machine parameters is required to eliminate residual depolarization (introduced for example by the snake itself). Therefore, fast polarization measurements are absolutely essential for the machine setup and physics programs during the physics stores.

The pC CNI polarimeters in AGS and RHIC are based on elastic proton scattering with low momentum transfer (CNI region) and measurement of asymmetry in recoil carbon nuclei production described in details in [3-4]. This process has a large cross-section and sizable analyzing power of a few percents which is expected to have weak energy dependence in the 24-250 GeV energy range. A very thin (5 μg/cm^2, 5-10 μm wide) carbon strip target in the high intensity circulating beam produces high collision rate and a highly efficient DAQ system acquires up to $5\cdot10^6$ carbon events /sec.

The absolute beam polarization at 100 GeV beam energy was measured with a polarized H-jet polarimeter which is also based on elastic proton-proton scattering in the CNI region [5].The simultaneous measurements in pC and H-jet polarimeters provide the calibration for pC analyzing power. Fast pC polarimeter measures possible polarization losses during the energy ramp and possible polarization decay during the RHIC store.

II. POLARIMETER HARWARE

Targets and Vacuum Chambers

The use of thin target in polarimeter is essential to reduce multiple scattering for recoil carbon ions and also keep the event rate within the detectors and DAQ capabilities. The carbon ribbons used in the polarimeters contain about 10^{14} carbon atoms/cm of target length (25 mm). High intensity circulating beam knocks out about 10^7-10^8 carbon nuclei, which cause the eventual target destruction. It is demonstrated that targets survive in the RHIC beam for 100-200 measurements at the full beam intensity which corresponds to a target lifetime of one-to-two weeks. Manufacturing of the ultra-thin carbon (amorphous graphite) targets requires high skill and is a time-consuming process[6]. Multiple targets (six vertical and four horizontal) are attached to a target ladder to extend the time between maintenance periods. The combination of translational and rotational motion in the target mechanism provides the target replacement and polarization scan operations. The target positioning accuracy is about ±0.5 mm and limited by the target straightness. This is required due to limited detector acceptance.

Two identical polarimeter vacuum chambers are located in the warm RHIC sections which are separated for the two circulating beams and have the separate vacuum systems. Due to the complexity of the chamber and the electronics, it is not practical to bake the chamber. To meet the RHIC vacuum requirement all polarimeter components were carefully measured for out-gassing rates. The high out-gassing rate ceramic material is replaced with low out-gassing rate material. A NEG (Non-Evaporable Getter) cartridge pump is added to each chamber to provide additional continuous pumping. As a result, the pump down speed is greatly improved. A full

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intensity physics store can be resumed within 24 hours (vacuum down to 10^{-9} Torr).

Detectors and Electronics

The time-of-flight and recoil carbon energy measurements are required for elastic scattering identification. The silicon-strip detectors are used in the polarimeters since they allow measurements of energy and arrival time of Carbons in the RHIC ring vacuum environment. The late arrival time of the recoiled carbons is advantageous since the detection can be done in almost noise-free environment after all beam-induced disturbances are gone. In addition to one pair of detector sitting in the horizontal plane, two pairs of detectors sitting at 45° are added, which allow measurement of both transverse polarization components (vertical and radial). At full RHIC designed intensity, the rms bunch length is about 2ns and bunch spacing is 106ns. To avoid the prompt background, the carbon nuclei should arrive the detectors between two bunches. The Si detector can detect carbons with kinetic energy as low as 200 keV, which can travel about 20cm in 100ns. The distance between detectors and interaction point is set as 18 cm. There are RF shields at the surface of the chamber to cover the detector ports to reduce the impedance impact. The same detectors and electronics are used in the AGS polarimeter, where just two left and right arms in horizontal plane are used.

The preamplifier boards are mounted on the polarimeter vacuum chamber directly connected to the vacuum feedthroughs to minimize the distance to the signal source. The amplified analogue signals are transferred through the RHIC tunnel on coaxial cables for about 300 feet to a counting room located next to the tunnel. The analogue signals are fed into hybrid shaper amplifiers; designed by the Brookhaven instrumentation division group. The shaping time is kept at 12ns from the original design for optimization of the timing resolution. The event rate per strip is estimated to be on the order of 100 kHz for normal RHIC running condition. A Wave Form Digitizer (WFD), which was originally developed by Yale University is utilized in the DAQ to handle the high-rate and minimize dead-time [7].

III. POLARIZATION MEASUREMENTS

Typical RHIC physics store is 8-10 hours. Polarization is measured in both rings at the beginning of the store and every 2-3 hours. Past experience shows that there are some gradual polarization losses over the store. The losses are driven by some high order depolarizing resonances, which are very weak but do show effect in the long time scale. Since every polarization measurement causes some beam loss (<0.5%) and physics run has to stop, we compromise to measure polarization every two to three hours.

The carbon target width is much smaller than the beam size therefore intensity and polarization profile can also be measured. The polarization measurement can be either a fixed target position or a profile measurement with target scanning through the beam. Significant polarization profiles were measured in RHIC beams. Part of these profiles is produced in AGS (which was measured directly in AGS). There are also some possible polarization profile generation in RHIC at the ramp and during the store. The effect depends on machine parameters and can be different for two rings. The example of polarization profile measurement is given in Fig. 1 for the Yellow ring.

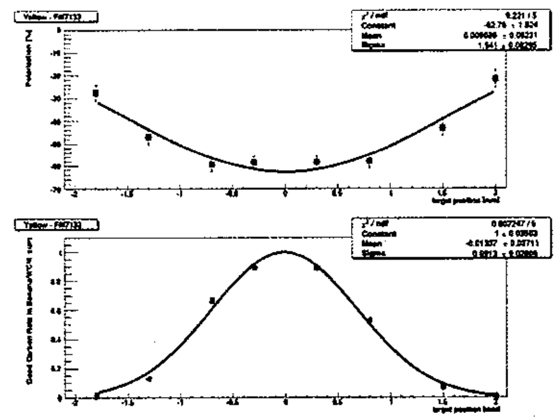

FIGURE 1. Top: polarization measurement across the beam profile. Bottom: beam profile. The measurements were done at fixed target position for each data point.

The RHIC collision experiments are sensitive to the convolution of the two beam polarization and polarization profiles therefore all polarization measurements for the physics stores were done in the scanning mode and polarization profiles were measured and correction to the polarization values as seen by the experiments were implemented [4]. The fixed target measurement gives a quick estimate of the polarization profile when compared with the regular scanning mode. If the profile measurement is significantly smaller than fixed target value, it is a warning that machine tunes have to be adjusted. To check the polarization sign pattern and stability of the pulse by pulse polarization the longer measurements were taken in dedicated stores or at the end of store. The accuracy of a few percents was obtained for each bunch polarization just in a one minute measurement (see Fig.2).

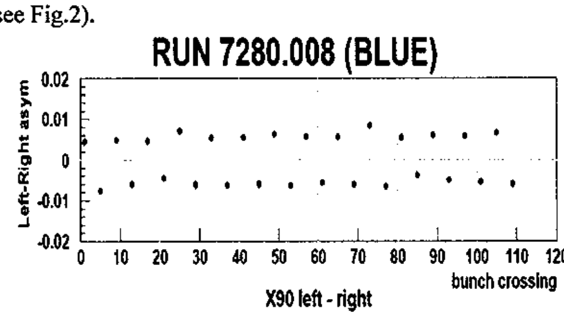

FIGURE 2. Example of a polarization plots for blue ring.

IV. BEAM PROFILE MEASUREMENTS

In a scanning mode of polarimeter operation the counting rate dependence on the target position can be used for the beam intensity profile measurements in addition to polarization measurements. With WFDs, every elastic event has a time stamp attached and each event is sorted by the bunch crossing. With the high event rate, a large statistics can be accumulated in a short time (of a few hundred milliseconds for the target scan through the beam), which were used for beam profile (emittance) bunch-by-bunch measurements (see Fig.3). These measurements have negligible effect to the beam losses and provide valuable tools for accelerator setup and monitoring. The absolute accuracy of these emittance measurements is limited by the target quality (straightness). The better quality measurements were obtained with the double thickness polarimeter targets (one of these targets was attached to each of multiple target holders) and these measurements were used for the Ionization Profile Monitors calibrations.

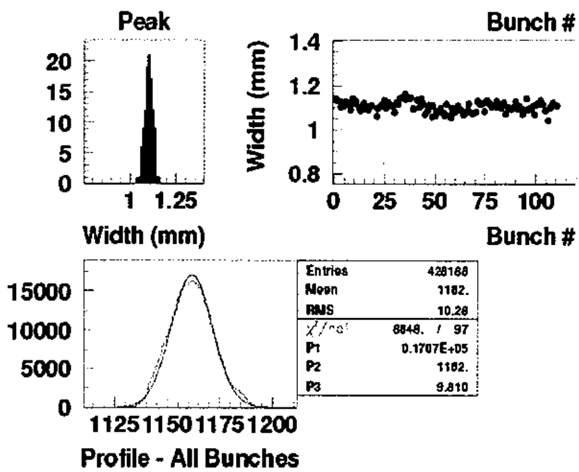

FIGURE 3. Emittance measurement in Blue ring. The profile at left bottom is for all 111 bunches, the beam width on the right top is for all individual bunches.

V. POLARIZATION MEASUREMENTS ON THE ACCELERATION RAMP

The capability of the fast polarization measurements was most spectacularly utilized in the polarization measurements on the acceleration ramps in AGS and RHIC. In the AGS the acceleration ramp duration is just 0.4 s but a few hundreds of cycles can be easily accumulated in the study time between the RHIC fill. These measurements provide the unique insight on polarization (and possible polarization loss) as a function of energy (see Fig. 4). In the AGS energy range 2.5-24 GeV, the pC CNI analyzing power is changing quite strongly but this change is expected to be monotonic. Therefore the observation of the polarization amplitude jump would be a suspect for local depolarization. The likely location of this depolarization is expected at the strongest intrinsic resonances energies, and polarization measurements on the ramp helped to identify the problems.

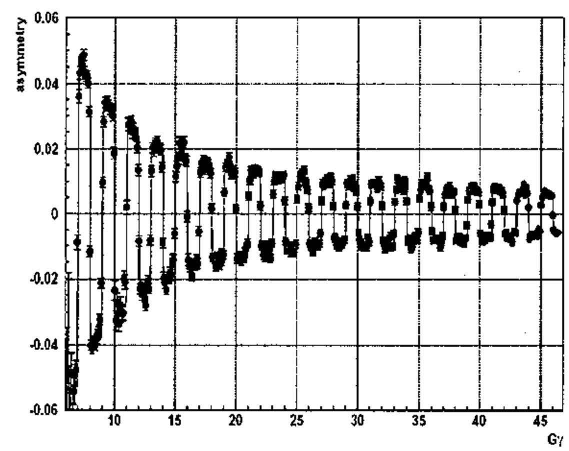

FIGURE 4. AGS asymmetries measured on the ramp. In the presence of partial snakes, the vertical component of polarization changes sign at every unit of Gγ.

The RHIC energy ramp is about 160 seconds at 100 GeV and 280 seconds at 250 GeV. In these cases the sufficient statistical accuracy can be obtained in a single ramp. These measurements were especially useful in the development of the 250 GeV energy ramps, where the polarization loss at the strong intrinsic resonance at 136.5 GeV was observed in the ramp measurements.

VI. SUMMARY

The pC CNI polarimeters at AGS and RHIC provide fast, practically non-destructive polarization and intensity profile measurements. The analyzing power of this polarimeter has been calibrated by the simultaneous polarization measurements in the absolute H-jet polarimeter at 100 GeV. It is expected that a weak analyzing power dependence on the beam energy will allow the polarimeter to operate at 250 GeV and beyond.

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