Polarization Measurements of RHIC-pp RUN05 Using CNI pC-Polarimeter

I. Nakagawa(1,2), I. Alekseev(3), A. Bravar(4,5), G. Bunce(2,5), S. Dhawan(6), K.O. Eyser(7), R. Gill(5), W. Haeberli(8), H. Huang(5), O. Jinnouchi(9), Y. Makdisi(5), A. Nass(10), H. Okada(1,11), E. Stephenson(12), D. Svirida(3), T. Wise(8), J. Wood(5), and A. Zelenski(5)

(1) RIKEN, Wako, Saitama 351-0198, Japan
(2) RIKEN BNL Research Center, Brookhaven National Laboratory, Upton, NY 11973-5000, U.S.A.
(3) Institute for Theoretical and Experimental Physics (ITEP), 117259, Moscow, Russia
(4) University of Geneva, 1205 Geneva, Switzerland
(5) Brookhaven National Laboratory, Upton, NY 11973, USA
(6) Yale University, New Haven, CT 06520, USA
(7) University of California, Riverside, CA 92951, USA
(8) University of Wisconsin, Madison, WI 53706, USA
(9) KEK, Tsukuba, Ibaraki 305-0801, Japan
(10) University of Erlangen, 91058 Erlangen, Germany
(11) Kyoto University, Kyoto 606-8502, Japan
(12) Indiana University, Bloomington, IN 47408, USA

Abstract. The 2005 run (RUN05) was the first extended operation of the polarized RHIC-pp program. Throughout 3 months of running, polarization measurements were regularly executed every 2 ~ 3 hours during the beams at storage energy 100GeV using RHIC pC-polarimeters. These measurements were performed under different beam conditions, i.e., intensity, emittance, backgrounds, cumulated radiation damage on detectors and so on. The stability of measurements under these various conditions is a major concern and is discussed in detail.

Keywords: spin, RHIC, polarimeter, CNI
PACS: 24.70.+s, 29.25.Lj, 29.27.Hj

RHIC CNI-POLARIMETERS

The polarization of the proton beams at the Relativistic Heavy Ion Collider (RHIC) is measured using both a hydrogen jet[1,2] and carbon polarimeters. These polarimeters are set up in the 12 o'clock area in the RHIC ring. The jet polarimeter is located at the collision point allowing measurements of both beams. Two identical pC-polarimeters are equipped in the yellow and blue rings, where the rings are separated. The pC-polarimeter measures relative polarization to a few percent statistical accuracy within 20 to 30 seconds using an ultra-thin (typically 10 ~ 20 $\mu g/cm^2$) carbon ribbon target, providing fast feedback to beam operations and experiments. As shown in Fig.1, six silicon sensors were mounted in a vacuum chamber at 45, 90, 135 degrees azimuthally in both left and right sides with respect to the beam. The sensor has 10×24 mm^2 total active area, divided into 12 strips of 10×2 mm^2 each. The thickness of the detector are 400 μm, fully depleted with the operation bias voltage of 100 – 150 V. The strips are made by the Boron implantation p^+-doping to a depth of 150 nm on the n-type Si bulk on the side facing the target. The distance from target to the silicon sensors was 18.5 cm. The absolute normalization is provided by the hydrogen polarimeter, which measures over 1~2 days to obtain ~5% statistical uncertainty (in 2005). Thus, the operation of the carbon polarimeters was focused on better control of relative stability between one measurement to another measurement rather than measuring the absolute polarization.

The analyzing power for elastic polarized proton-Carbon scattering is predicted to be maximized at the momentum transfer of (-t~0.003 [$(\mathrm{GeV}/c)^2$]) due to the interference between the electromagnetic and the strong amplitudes (this is known as the Coulomb-Nuclear Interference (CNI) region). In order to take advantage of relatively large sensitivity to the polarization, the recoil carbon atoms were detected near 90 degrees with respect to the beam direction. Kinetic energy range was from 400 to 900 keV, corresponding to a momentum transfer of $0.09 < -t < 0.23$ $(\mathrm{GeV}/c)^2$. The lower the kinetic energy, the larger the analyzing power and the more sensitivity we gain. However, in reality, the present range is constrained by the reliability of the low energy carbon detection as discussed later. Since there is a *t* dependence in the analyzing power even within the limited *t* coverage, absolute energy of recoil carbon ion needs to be measured to define the kinematics.

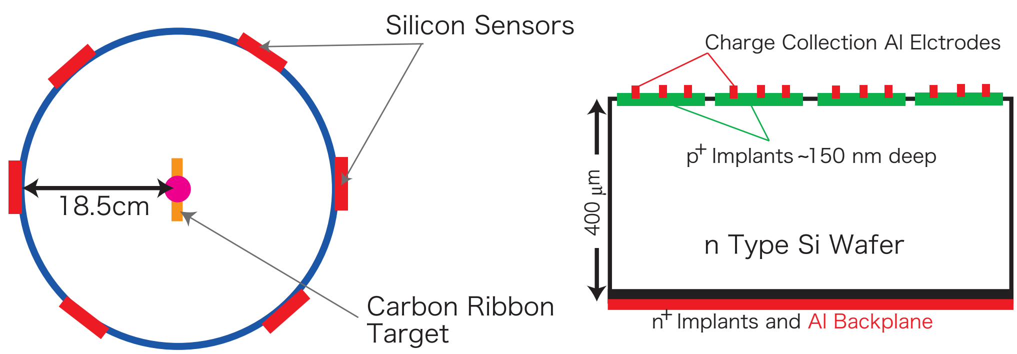

FIGURE 1. (Left) The RHIC pC-polarimeter setup. Silicon sensors are aligned 45, 90, and 135 degrees azimuthally in both left and right side with respect to the beam direction, which is pointing into the figure. Each sensor is segmented into 12 strips. (Right) The cross section of the silicon sensor.

RUN05 was the first extended operation of polarized proton-proton beams at RHIC. Polarization measurements were executed regularly every 2 ~ 3 hours while the beams are at storage energy 100 GeV using the pC-polarimeters throughout the three months of running. Continuous efforts were made in the accelerator tuning in order to improve the beam performance, such as polarization, intensity, emittance and backgrounds. Thus these measurements were not necessarily performed always under the same accelerator or detector conditions. The measured data have been carefully analyzed offline in order to estimate any instabilities induced by changed conditions between measurements. Slowly evolving changes, for example, accumulated radiation damage to the detectors is one of the major concerns because of longer exposure to the reactions with higher beam intensity than previous runs.

ENERGY CALIBRATION AND CORRECTION

The energy calibration of the silicon detectors is performed using an α source (^{241}Am, $E_\alpha = 5.486$ (85%), 5.443MeV (12%)). Dedicated calibration runs were executed several times throughout RUN05 and typically very minor gain changes were observed for all the strips.

The α calibration, however, does not effectively probe the surface region of the detectors where the sub-MeV carbon ions stop. These low energy carbon ions entering the silicon detector penetrate the p^+ doping layer (dead-layer) first, and then enter the sensitive part of the detector, stopping at a depth of <1.3 μm. The energy loss of the carbon in the dead-layer is energy dependent and can be described by a known function of energy[3].This energy loss is a significant fraction of the carbon energy, for example 30% for 400 keV carbon with a dead-layer thickness of 50 [μg/cm^2]. In addition to this energy loss, the charge collection near the surface dead-layer can be affected by radiation damage. We have been unable to separate whether a change in the detector response either comes from a changing charge collection or from energy-dependent energy loss in the dead-layer. We consider the net energy correction, due to both the dead-layer and reduced charge collection near the surface, as a varying dead-layer thickness with the energy-dependent energy loss. This "*effective dead-layer thickness*" can be determined through a fit to the kinematical correlation of measured time-of-flight and energy correlation for carbon recoils.

.

Shown in Fig.2 is an example of the fit using the non-relativistic kinematic formula,

$$t_{meas} + t_0 = L\sqrt{\frac{M}{2\{E_{meas.} + \Delta E(\Delta x)\}}} \ , \qquad (1)$$

where M, L, $t_{\text{meas.}}$ and $E_{\text{meas.}}$ are the mass, the flight path length, the measured time-of-flight, and the energy of the recoil carbon ion, respectively. A time offset t_0 and the effective thickness of the dead-layer Δx were set as free parameters. The empirical fit was applied to all polarization measurements during physics stores and evaluated the "*effective dead-layer thickness*" for each measurement independently to trace the stability.

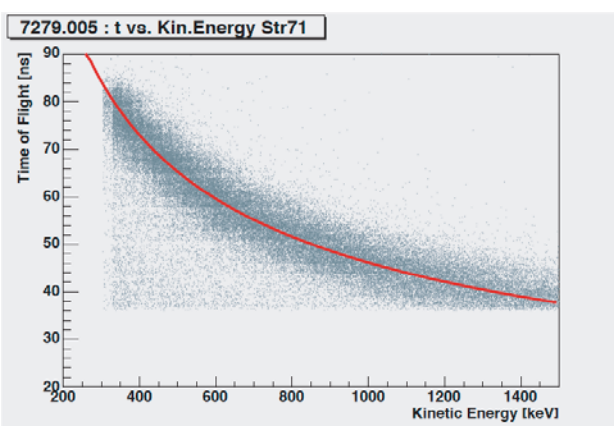

FIGURE 2. An example of the kinematical fit as the energy correction (dead-layer thickness) and time offset t_0 as free parameters.

STABILITY AND UNCERTAINTY

Shown in Fig.3 are the estimated *effective dead-layer thickness* in units of [μg/cm^2] averaged over all 72 strips. Each data point represents one measurement performed at the beam energy of 100 [GeV] in blue (left) and yellow (right) rings within physics stores. They are plotted as a function of the fill number. As can be seen from the figure, the resulting effective thicknesses of dead-layers are not constant and change from measurement to measurement.

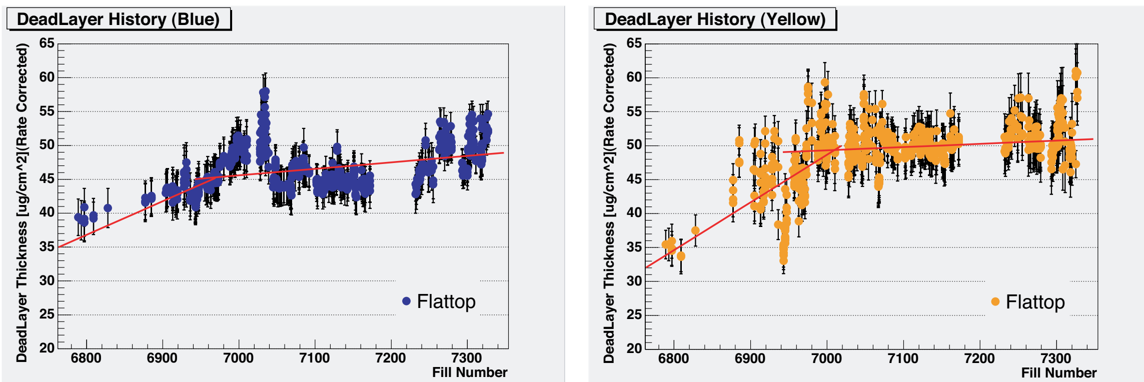

FIGURE 3. Stability of the *effective dead-layer thickness* averaged over 72 strips plotted as a function of fill number for blue (left) and yellow polarimeters, respectively.

As guided by the solid line in figures, the effective thickness of the dead-layer is growing as measurements go by. This growth of inefficiency can be interpreted as the deteriorated charge correction efficiency as a consequence of cumulated radiation damage in the surface region. Besides the precision limit of the fitting, the cause of varying dead-layer thickness is not known at this time, except for a small average rate dependence on the effective dead-layer thickness (data points in Fig.3 are already corrected for this). Also possible are change in the electronics noise or a baseline shift, which are not accounted in the present model. These fluctuations are thus accounted as uncertainty for the individual measurement. Taking 1σ of the fluctuations, 3[μg/cm^2] was estimated for both the blue and the yellow polarimeters, which corresponds to a few percent uncertainty of the beam polarization in relative scale for individual measurements. The average polarization will be determined by the jet measurements which is expected to be smaller uncertainties.

REFERENCES

[1] K.O. Eyser, these proceedings (2006).
[2] H. Okada *et al*, Phys. Lett. **B638**, 450 (2006) and these proceedings.
[3] H. Paul and A. Schinner, Nucl. Inst. Meth. **B195**, 166 (2002).