DRAFT: A Short Description of the RHIC proton-carbon CNI Polarimeter

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1 Introduction

A number of possible methods of measuring the polarization at RHIC were considered. The problem is that the method used for lower energy protons, pp elastic scattering at an experimentally observed maximum in analyzing power, at -t=0.15 $(GeV/c)^2$, appears to diminish as 1/energy, and is too small at RHIC energies. One new approach which is attractive uses the asymmetry of inclusive pion production at large x_F and moderate p_T. Such a polarimeter was designed, but was mothballed due to cost (roughly $1.5M).

pC CNI was a new suggestion which depended on the existence of very thin carbon targets. It is attractive because a significant (4%) analyzing power is predicted over the entire RHIC range, it would use a target which could survive in the RHIC beams, and the carbon recoil would be identified from both energy and time of flight. The figure of merit, at the maximum analyzing power at -t=0.003, is excellent compared to others. The very thin target is only available thru the development at IUCF and Bill Lozowski. The thickness, only 100 atoms, allows the slow carbon (150 KeV) to escape, it reduces the scattering rate to something which can be tolerated by detectors, and it survives the beam due to its large surface vs. volume. The target is also moved into the beam with a simple mechanism (i.e. not like a gas jet target or flying wire). A potential disadvantage is that the number of carbon atoms can actually become depleted, so it is important to use the scattering time efficiently. However, this also works out well, with an expected lifetime of hours in the beam, with measurements taking tens of seconds. It is also important to use the scattering efficiently to be able to measure the polarization many times during a RHIC fill without significantly increasing the beam emittance (and decreasing the collision luminosity). Lastly, the detector can be silicon, and, when located at 15 cm from the target, the interesting carbon atoms arrive 60-80 nanoseconds after a bunch passes the target. The signal is seen after prompt products are gone, and before the arrival of the next bunch (RHIC bunch spacing is 106 nsec.).

Coulomb Nuclear Interference involves scattering from the anomalous magnetic moment of the polarized proton, an electromagnetic spin-flip amplitude, and a non-flip hadronic amplitude. The magnitude of CNI at the maximum is proportional to (g-2)x(σ_{total}), and is about 4% for proton-carbon and also proton-proton scattering. There is also the opposite interference which was predicted to be very small, before we did our AGS experiment on this. It turns out that there is a significant hadronic spin-flip amplitude. The maximum in CNI analyzing power is about 3% at RHIC injection.

We first proposed, built and ran a CNI measurement at the AGS, at the RHIC injection energy. Silicon detectors were calibrated at low energy cyclotrons (Kyoto and IUCF) where pC elastic scattering was defined for both forward and recoil. The AGS experiment E950 ran in March 1999. This was very successful, and a paper on the result is being prepared.

A RHIC polarimeter, pC CNI, was then designed, built, installed in the Blue ring, and ran for the September 2000 polarized proton commissioning in RHIC.

2 The RHIC Polarimeter Collaboration

The groups in the RHIC polarimeter collaboration are BNL, the RIKEN BNL Research Center, RIKEN, Kyoto, New Mexico, Indiana, ITEP Moscow, Yale, Argonne, UCLA, New Mexico State. The funding has been from RIKEN (and RBRC), with DOE funds for the planned wave form digitizers from Yale. BNL Instrumentation has developed the silicon, shapers and amplifiers.

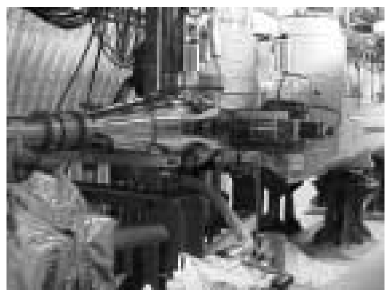

Figure 1: The RHIC polarimeter chamber as installed

Thomas Roser is the overall Spokesman, the detector work is led by Kazu Kurita of RBRC, and much of the geometry, special scattering chamber, target mechanisms, etc. by Haixin Huang of BNL. The readout and data analysis is led by Igor Alekseev and Dima Svirida of ITEP. The WFDs, required for the 60 and 120 bunch running (normal physics running), are developed by Satish Dhawan of Yale. Junji Tojo, a Kyoto student, has done much of the calibration work and analysis on E950.

3 Results from the September 2000 Commissioning

Figure 1 shows the scattering chamber as installed, and Figure 2 shows a schematic. Two target mechanisms were installed, to scan the target across the beam vertically and horizontally, although only a horizontal scan (vertical target) was used. Four silicon detectors were installed, each 15 cm from the target, at 45 degree angles as shown. These provided measures of both vertical polarization (left-right)=((1+2)-(3+4)), and radial polarization (up-down)=((1+3)-(2+4)), with the counters numbered as in Figure 2.

The identification of a carbon band is shown for an energy vs. time of flight scatterplot, for one of 12 strips on one silicon detector in Figure 3. There is

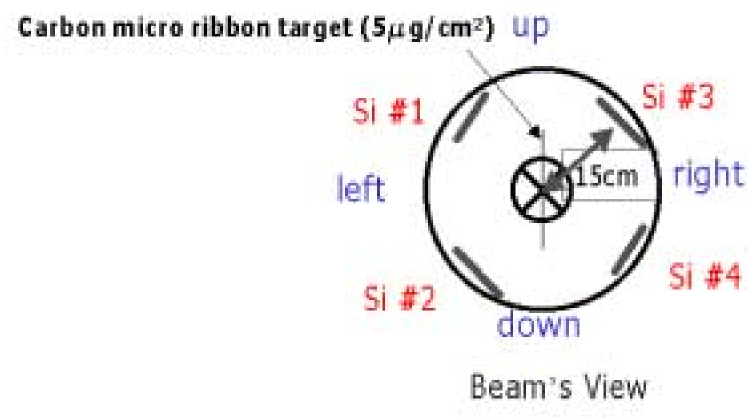

Figure 2: Schematic of the RHIC polarimeter Si arrangement

very little background, as shown for the reconstructed mass shown in Figure 4. We also see an alpha peak clearly (presumably quasielastic p-alpha scattering), and also a faint proton peak.

The commissioning showed that we can identify very clearly pC CNI scattering, with little background. When the data are combined as discussed above to measure vertical and radial polarization, we verified the vertical polarization of the injected beam (Figure 5a), we reversed the polarization and observed it reversed (Figure 5b), we turned off the polarization at the source and observed zero (Figure 5c). We observed the expected radial polarization after we adiabatically turned on the Siberian Snake (for the case of using only one snake, it is necessary to turn it on after injecting the beam, and the stable spin direction is in the horizontal plane) (Figure 6), we accelerated the beam so that the polarization should reverse radially and it did, we did this with the Siberian Snake off and observed no remaining polarization after the same acceleration (a 2.5 sigma statement). We also successfully accelerated to about 32 GeV. We were not successful in going above that, and we believe that was due to the large orbit errors that we had in acceleration–we did not have time in the commissioning to correct them. This is the first time that any of this has been done.

4 Rates and the Wave Form Digitizers

The commissioning was done by injecting 6 RHIC bunches with alternating polarization, for example +-+-+-. The spacing of the bunches was about 2 microseconds. We used the AGS E950 readout, FERA ADCs and TDCs. We triggered every bunch crossing, and then rejected a trigger if we did not have a silicon detector strip above threshold. Readout took about 20 microseconds

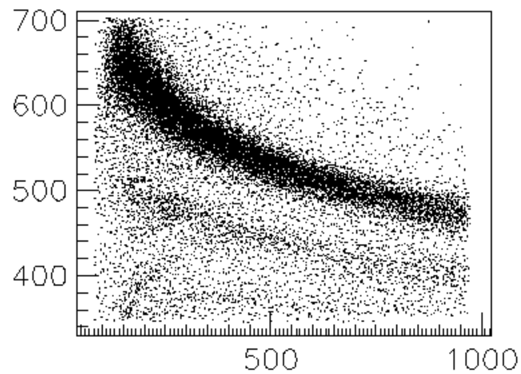

Figure 3: TDC vs. ADC of events in a Si strip

per event. There were about $2x10^{10}$ protons per bunch near the beginning of a fill and a typical run took 10 minutes to obtain 10^7 events. We had about 30% deadtime.

For next year, the first to take data with colliding polarized protons, we will have 60 bunches in each ring and expect 10^{11} polarized protons per bunch. The spacing will be 212 nsec. The rates in this run compared to commissioning will be about 10 times greater per bunch (from the larger number of protons per bunch and the decrease in beam size, accelerating to 100 GeV), and 100 times greater overall. The deadtime in this situation for the AGS-type readout would be 99%, and we also would not be able to distinguish 2 hits in the same strip, which will occur at roughly 0.2% frequency.

For these reasons, we plan to use wave form digitizer readout, with digitizations every 3 nsec, and no deadtime. WFD readout is ideal for this application, since we measure only energy and time (and strip number), with no other information on the event. Therefore the WFD data is exactly what is needed and is complete. The clock frequency is set according to the rise time, which is set to be short to improve double pulse resolution. We plan to take about 30 nsec of data for each pulse, and a pulse is defined as a change in pulse height (differential measurement). Prototype WFDs were used to test the plan in the September commissioning, and a digitized pulse is seen in Figure 7. In this figure, one can see a smaller bipolar pulse followed by a large pulse. The bipolar pulse is pickup from the beam at prompt time, and the large pulse is a carbon signal. A scatter plot for energy vs. time of flight for the WFD is shown in Figure 8, which matches the FERA readout plots. The prototype WFD worked.

A major issue for the WFD is to handle the large amount of data. We have been considering either writing to a local memory until the events needed for a measurement are collected, or developing a fast asynchronous readout. We were very pleasantly surprised be the cleanliness of the carbon signals at RHIC,

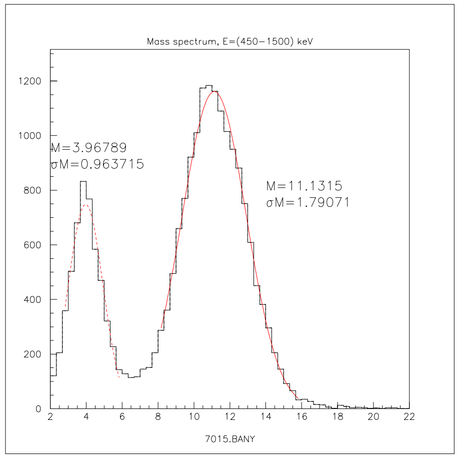

Figure 4: Mass distribution of events from a Si strip

and we are presently planning (although not implemented yet–this work will be done by ITEP next spring) to program the WFD to obtain energy and time (also for multiple pulses), and to then sum for scalar type information the WFD hits in the carbon band. This then reduces the data size to minimal levels, and the need for a fast readout would be alleviated. However, this idea is not yet implemented, and we need to first try it.

The silicon detectors each have 12 strips, with individual WFD readout, and 6 detectors are planned for each of two polarimeters. The detector locations will be +/- 45 degrees as for the commissioning, and also at left and right. The purpose of the detector locations are to measure radial and vertical polarization, as we did for the commissioning, and to have higher analyzing power for vertical polarization (the detectors at left and right). The rates will be about 1 event per bunch crossing per polarimeter for full luminosity and full energy. The number of bytes of data per event will be about 30, including bunch number. The data rate per detector will be 30x1/6x10^7 hertz, or 50 MBytes/second/detector, for 2002 and beyond. This is a very high rate. In considering whether an existing WFD could do this job, the requirement calls for differential measurements (for multiple pulses and varying pedestal), measurements every few nsec, and onboard memory to handle the rate. The new Yale/RHIC WFD is based on commercial integrated circuits, has an onboard FPGA to perform the differential trigger, and will include a beam crossing number with the data word. Its cost is $250 per channel (production cost).

For the first running year, 2001, we propose to use 48 WFD channels for the

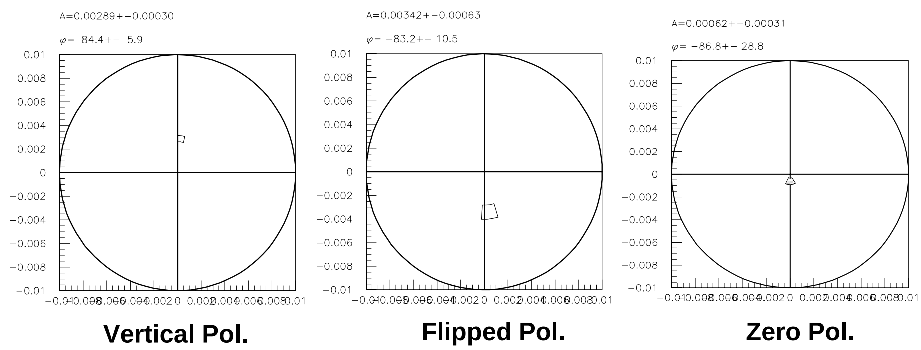

Figure 5: Establishment of vertical polarization

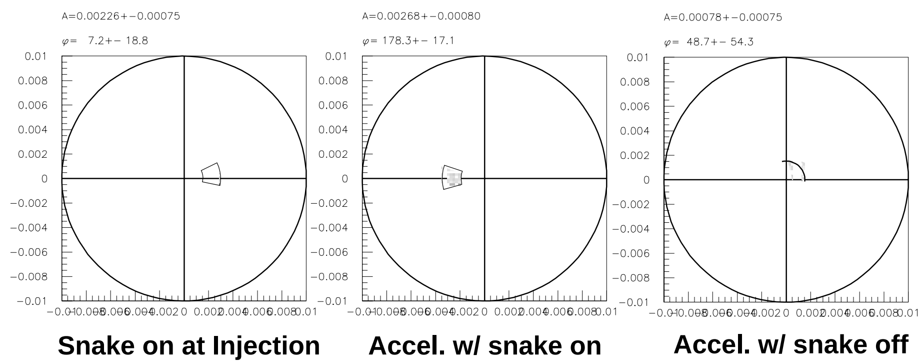

Figure 6: Study of the snake magnet behavior

two polarimeters. We will install the planned 6 detectors per polarimeter, and array the WFD channels over the detectors. We are considering sharing 2 strips per WFD channel for 2001.

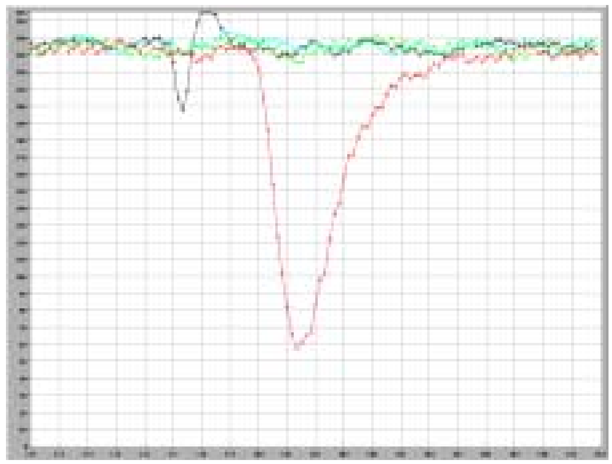

Figure 7: Digitized wave forms by our prototype WFD

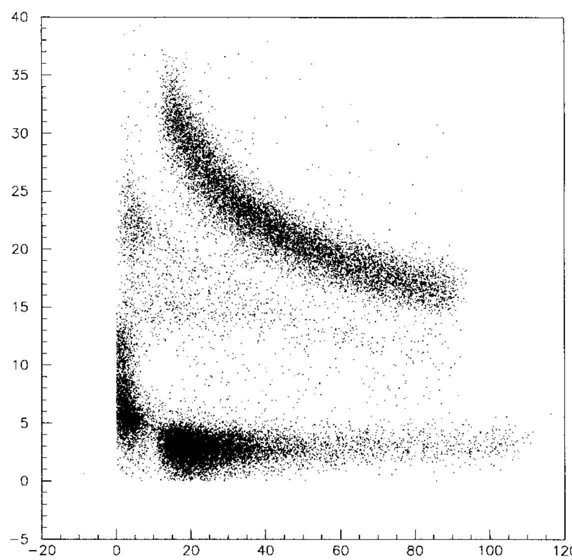

Figure 8: TOF vs. pulse height correlation obtained by our prototype WFD