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The RHIC polarized proton collider employs polarimeters in each of the Blue and Yellow rings that utilize the analyzing power in p-Carbon elastic scattering in the Coulomb Nuclear Interference region to measure the absolute beam polarization. These are calibrated by the polarized Hydrogen Jet Target that measures the absolute beam polarization in pp elastic scattering in the CNI region. This paper describes the status and performance of these polarimeters in the FY09 run which included both a 250 GeV/c and 100 GeV/c physics data taking periods. We will describe some of the difficulties encountered and the efforts underway to improve the performance in better energy resolution, rate handling capability, and reduced systematic uncertainties.

Keywords: Silicon; detectors; polarimeters; beam polarization; Polarized Hydrogen Jet.

1. Introduction

The RHIC polarimeter system relies on the analyzing power in both proton-proton as well as proton-Carbon elastic scattering in the Coulomb Nuclear Interference (CNI) region where the predictions without the presence of a hadronic spin flip amplitude reaches a maximum of the order of 5 and 4 %, respectively, and falls with increasing 4-momentum transfer [1][2] (Fig.1). The presence of this amplitude is difficult to estimate and is likely to change the predictions especially at lower beam energies. The analyzing power is predicted to change slowly With beam energy.

A polarized Hydrogen Jet Target [3][4][5] with high polarization that measures the analyzing power in pp elastic scattering in situ and then uses

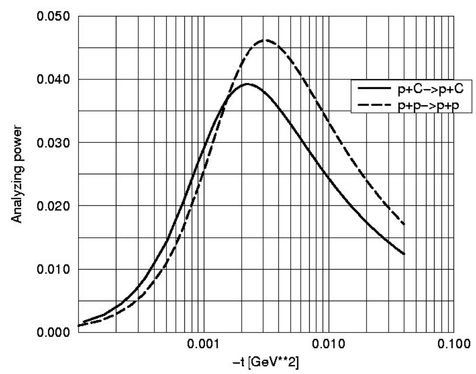

Fig. 1. The Analyzing Power in pp and p-carbon elastic scattering in the CNI region

the same data sample to measure the beam polarization over the respective store. This in turn calibrates the relative and faster beam polarimeters that measure the asymmetry from the p-carbon elastic scattering process.

The RHIC polarimeters utilize several thin carbon targets mounted on a special target drive operated by a motor to select horizontal or vertical targets for scanning across the beam to measure both the beam polarization and beam polarization profile. The targets are surrounded by three pairs of silicon detectors positioned 18 cm away with one pair at 90^0 in the horizontal plane and the other two at $\pm45^0$ above and below. (Fig.2).

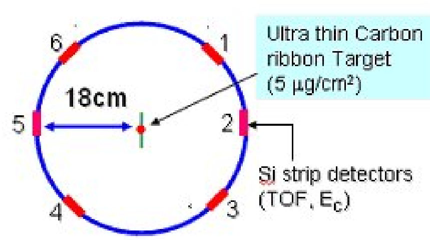

Fig. 2. A beam view of the silicon detectors in the RHIC polarimeters

The silicon detectors, manufactured by the BNL instrumentation division, comprise 12 strips each independently measuring the scattered recoil carbon energy and time of arrival. The left-right scattering asymmetry determines the degree of the beam polarization. The large p-carbon elastic scattering cross section provides a fast measurement with 2% statistical accuracy in less than one minute. The polarized jet target at an interaction region at 100 meters from the polarimeters and measures the absolute beam polarization to better than 10% in an 8-hour store. It takes a few stores to calibrate each polarimeter to an accuracy of 5%.

The polarimeters silicon detectors are calibrated using americium sources that emit alphas with energy of 5.5 MeV. This is large compared to that of the carbon recoils from 300 keV to about 1 MeV. This is a starting point followed by an involved process that relies on fitting the data to the time energy relation as well as data of the energy deposition of carbon in silicon[6]. This process resulted in a measured effective dead layer in the silicon 3 times larger than the physical one. Another issue facing the polarimeters is increasing rate as the RHIC bunch intensity moves upwards.

The polarized jet silicon energy calibration utilizes both Americium and Gadolinium sources, the latter emits a 3.2 MeV alpha particles at energies overlapping those of the recoil protons of interest from 1 to 5 MeV rendering a more comparable calibration. The jet measurement on the other hand is limited by the unpolarized molecular hydrogen background that at this stage is estimated at 3% and contributes a 2%systematic accuracy. In what follows we will describe the efforts to overcome some of these difficulties.

2. The Silicon Energy and Rate Response

The BNL Tandem complex has the capability to accelerate various ion species at prescribed energies and intensities. We used the Tandem to systematically scan energies of interest with varying intensities up to 4.10^6 ions/cm^2 to study the BNL manufactured silicon detectors response:

- The beam energy will span from 0.3 to 5 MeV wider than the recoil carbon range to understand detector response to the alpha energy from the americium source.
- Use beam carbon charges of +1, +2, and +3 to assess the detectors response and how soon charge equilibration occurs.
- Study any non-linearity to the energy response to help the calibration process.
- Check the energy resolution vs. beam energy.
- Use a foil to simulate the recoil carbon energy loss as it traverses the target.
- The tests utilized the readout system currently employed by the polarimeters in addition to alternate electronics to assess differences if any.

3. New Polarimeter Detectors and Electronics R&D

We used the Tandem carbon beams to test several Hamamatsu silicon photodiode detectors of several thicknesses, a 5μm S9724-005 (1x1cm^2) detector, a 300 μm S3590-19 (1x1 cm^2) detector and a strip-array S4114-35 without window-35 strips (4.4$\times$9mm^2) in an effort to attain better energy resolution and to develop an understanding of the detector sensitivity to the large number of prompt particles that stream through concurrently when the detectors are responding to the recoil carbon scatters.

- Test new photodiode detectors and array strip detectors under similar conditions to the BNL silicon detectors.
- Test a dual-silicon detector system with

  (a) a thin 5 μm followed by the 300 μm detectors to assess the charge equilibration process.
  (b) Identify the carbon charge with the thin detector at 10 MeV. This then drives the energy loss (dead layer) determination from the earlier data.
  (c) Assess the thin detector ability to provide a trigger as it is likely to be blind to minimum ionizing prompts, so less rate dependent.
  (d) Test the existing charge amplifier with a lower shaping time.
  (e) Test a new low capacitance cable between the detector and preamp

- Test a current amplifier concept which is better for high capacitance detectors (thin detectors) and high rate environment, and whether the associated noise level is acceptable.
- Study the effect of reduced silicon volume current by reducing the detector area and thickness.

The results of the measured energy resolution with carbon beams are shown in (Fig.3). The Hamamatsu detectors seem to indicate significantly better energy resolution. Using such detectors will allow us to reach a lower t value especially in the p-Carbon polarimeters.

4. InSitu Beam Tests at RHIC

The upgraded polarimeter vessels allowed for dual polarimeter set ups in each ring. In the Blue ring we installed a pair of photodiode strip detectors at 90^0 in the horizontal plane instrumented with the current readout system. With a vertical carbon target, this polarimeter response will be compared and contrasted with the two 45^0 BNL silicon polarimeters looking at the same target during the normal data taking. Similarly, one of the Yellow ring polarimeters utilized one 90^0 pair equipped with Hamamatsu

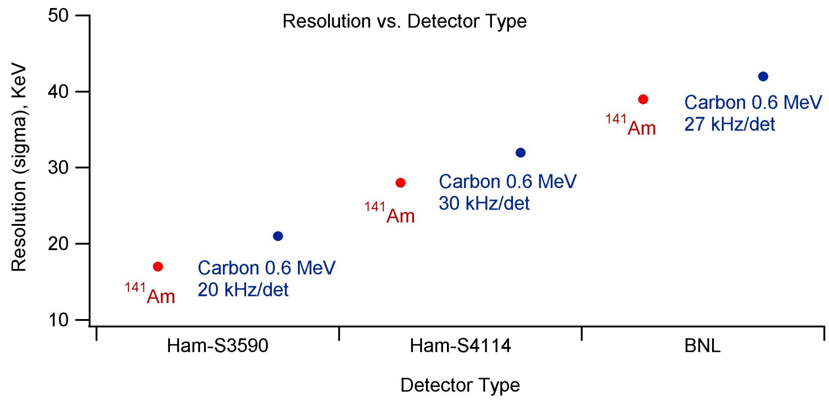

Fig. 3. Measured energy resolution for various types of silicon detectors using Carbon beams from the BNL Tandem

single photodiode detectors (two to a side) to carry out in situ comparisons. Dedicated studies compared the responses to varying the number of bunches and bunch intensities. Varying target thicknesses provided rate dependences. Another venue is to assess changes the detectors suffer due to radiation damage in a prolonged run. Run-9 provided a good test bed for our set up in that we ran for the first time with 250 GeV polarized proton beams for several weeks in addition to a ten week run with 100 GeV beams.

We also added a scintillation counter mounted on the outside of a thin 2mm flange to detect the arrival time of prompt particles in an attempt to better define $t0$ and better decouple the time and energy measurements. In practice this only served to count the overall rate seen at 90^0.

The dual polarimeters in each beam allowed the use of horizontal and vertical targets independently scanned across the beam and provided both a vertical and horizontal beam polarization profiles. A fast target scan also provided beam emittance measurements. These are used to help with machine tuning and more importantly to assess the actual beam polarization as seen by the experiments.

With the increased beam bunch intensities, the carbon polarimeters suffered measurable instabilities that, due to high beam rates, were further exacerbated at 250 GeV due to the smaller effective beam size. Dedicated beam studies were carried out with different target thicknesses to determine the cause of these problems. While data analysis continues, one potential culprit appears to be a 24 times amplification of a shaper stage on the preamp board. Parallel work was also carried out on the new Hamamatsu photodiode detectors using new amplifier shaper boards as well as a separate ADC and TDC system. The early analysis appears to indicate no rate issues and minimal increase in dark current.

5. The Polarized Jet Target Operation

Towards the end of Run-8, we tested the idea of having the two RHIC beams vertically separated by 5 mm and simultaneously impinging on the jet target. This was quite successful in that the data analysis did not reveal any more background under the elastic signal compared to running with one beam on target.

For Run-9 we re-aligned the jet with respect to the RHIC beam line, and along with an overhaul of the RHIC beam position monitors, we successfully ran with simultaneous measurement of both beams vertically separated by about 3.5 mm, consistent with acceptable beam-beam conditions to increase our vertical acceptance. An online plot showing the jet operating with two beams simultaneously on axis is shown in (Fig.4).

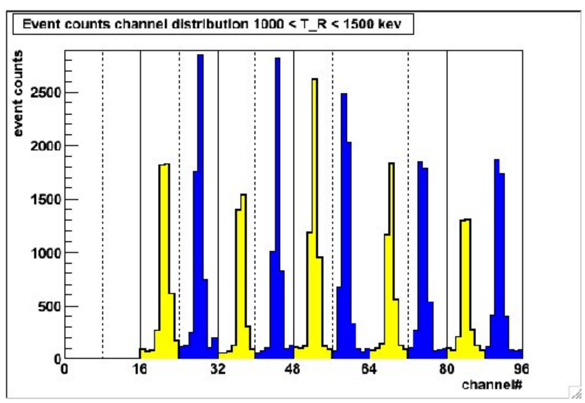

Fig. 4. An online plot of the activity on the 6 jet silicon strip detectors. The alternating peaks indicate the scattering due to the Yellow and the Blue, respectively. The level in-between indicated the attained background. Silicon detector 1 was off.

The jet took data in two running periods at 250 and 100 GeV respectively with continuous monitoring and calibration of both RHIC polarimeters and doubling the statistics. At 250 GeV and with 9 hour stores, the Jet provided a beam polarization measurement with 5% statistical accuracy. At 100 GeV, the statistical accuracy per 5 hour store was 7%.

Sofar, the polarized hydrogen target was able to measure the analyzing power in pp elastic scattering in the CNI region at 4 beam energies of 24

GeV, 31.2 GeV, 100 GeV and 250 GeV. The results are compiled in (Fig.5). It is interesting to note that the analyzing power appears to be the same over such a wide range spanning RHIC injection to top energy. The data at 24 GeV and 100 GeV with larger t coverage have been published[7] [8] in an attempt to measure the hadronic spin flip amplitude. While there is a discerned contribution at 24 GeV, it appears to be quite small at 100 GeV. Such plots show the capability of the jet system to self calibrate.

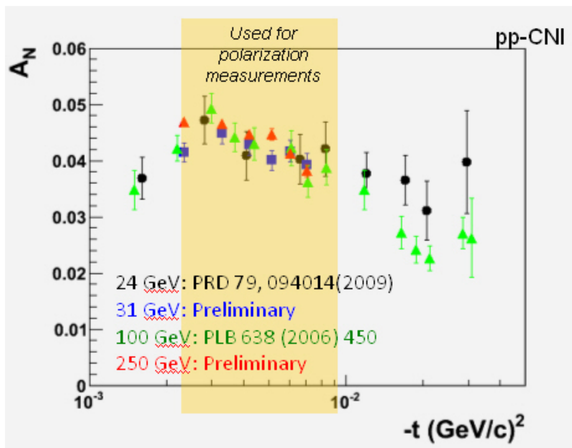

Fig. 5. The analyzing power in pp elastic scattering Vs. four momentum transfer. The Data at 250 GeV is preliminary.

An effort to monitor and understand the molecular hydrogen jet component *in situ* using luminescence monitoring was not successful. We continue to pursue ideas to quantify this background.

6. The Path Forward

There is no planned polarized proton running in Run-10. We plan to utilize the polarized proton beam at the AGS and its p-Carbon polarimeter to test our ideas for a path forward. We plan to use the 45^0 pairs to carry out the following studies: a) New Hamamtsu silicon photodiode detectors configured in strip geometry with new amplifier/shaper and separate TDC and ADC read out through VME. The preamp can be configured with a fall time down to 5 μsec which can increase its dynamic range b) A new current sensitive pre-amplifier with a short rise and fall time response to below 4 nsec in an attempt to reduce the pile up. These will plug into existing preamplifier boards. c) Should time allow we will also test a board with the 24× amplification reduced to 6× in an attempt to reduce saturation effects. d) While the AGS does not present the same environment as RHIC, namely the bunch to bunch timing as low as 114 nsec, we will use as high as 12 bunch fills and push on the intensity front and use different target thicknesses to approximate the RHIC rate conditions. e) Finally, at RHIC we will likely test moving the shaper and waveform digitizers into the RHIC tunnel to avoid the pulse spreading due to the 200 meters long cables.

7. Summary

We described the ongoing program to provide reliable beam polarimetry at RHIC and the efforts to improve our understanding of the energy responses, calibration, and rate capabilities of the current RHIC polarimeters. R&D is underway to test an improved set of silicon detectors that will provide better energy resolution, rate capabilities, and allow access to higher analyzing powers. Work continues to improve the polarized jet target calibration of the RHIC polarimeters. Of note is the maturing data analysis process and the improved ability to provide the RHIC experiments with results in a timely fashion.

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References

1. B.Z. Kopeliovich and L.I. Lapidus, in Sov. J. Nucl. Phys. 19, 114 (1974)
2. N.H. Buttimore, E. Gotsman, and E. Leader, in Phys. Rev. D 18, 694 (1978)
3. T. Wise et. al., in Spin 2004 Proc. 16th Int. Spin Phys. Symp. World Sc. Page 757 Aulenbacher, Bradamante, Bressan, and Martin, Eds.
4. A. Zelenski et al., in in Spin 2004 Proc. 16th Int. Spin Phys. Symp. World Sc. Page 761 Aulenbacher, Bradamante, Bressan, and Martin, Eds.
5. A. Nass et al., in in Spin 2004 Proc. 16th Int. Spin Phys. Symp. World Sc. Page 776 Aulenbacher, Bradamante, Bressan, and Martin, Eds.
6. I. Nakagawa et al., Proc. Of the 12th International Workshop on Polarized Ion Sources, Targets, and Polarimetry, Upton, NY, Sept. 10-14, 2007, p. 370.
7. H. Okada et. al., Phys.Lett. B 638, (2006)
8. I. G. Alekseev et. al., Phys. Rev. D79:094014,2009