A Proposal to Measure the Analyzing Power for Proton-Carbon Elastic Scattering in the Coulomb-Nuclear Interference Region at the RHIC Transfer Energy

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Abstract

We request a 24 hour run with the AGS polarized proton beam at 50% polarization, preceded by two weeks parasitic setup/testing to measure $A_N$ for proton-carbon elastic scattering at $-t=0.003-0.01$ GeV$^2$, at 23 GeV/c proton momentum. The experiment will use a very thin internal carbon target, with two recoil arms to observe the slow carbon recoil. The setup will be located upstream of the present internal AGS polarimeter. If the experiment is successful in detecting the 150 to 500 KeV carbon recoils in the AGS environment and we observe the expected analyzing power ($A_N$ of 0.02 or greater), we would expect to use this device as a RHIC polarimeter.

SUMMARY

A. Experiment: $^{12}$C(p,p)$^{12}$C; 10% measurement of the analyzing power between $-t = 0.003$-0.01 GeV$^2$, using information from the recoil alone.
B. Target: micro-ribbon carbon targets supplied by collaboration.
C. Detectors: silicon/micro channel plate recoil detection scheme. This will be designed and procured by the collaboration.
D. AGS internal polarimeter
E. Beam: 50% polarized protons at 23 GeV/c, $5 \times 10^9$/fill bunched beam.
F. Beam Time Request: 24 hours + two weeks parasitic.
G. The experiment will be ready by Spring of 1999.

1. Introduction

1.1. Scientific Justification

The collision of polarized proton beams at RHIC will provide qualitatively new and exciting physics. The RHIC spin project will collide 250 GeV polarized proton beams and will open up the unique physics opportunity of studying spin effects in hard processes [UND92] at high luminosities, including the measurement of the gluon polarization and the quark and anti-quark polarization by flavor. It will allow the study of the spin structure of the proton and also the verification of the well-documented expectations of spin effects in perturbative QCD and parity violation in W and Z production [BOU93]. This work will involve the PHENIX and STAR detectors with longitudinal and transverse polarization at these intersections. In addition, pp2pp and Brahms detectors at the 2 o’clock intersection and the Phobos detector at the 10 o’clock intersection will have transversely polarized proton collisions.

The RHIC spin program requires excellent polarimetry so that the knowledge of the beam polarization does not limit the errors on the experimental measurements. For the measurements taken at full luminosity, and hence high statistical accuracy, our goal is to know the polarization to
5% of itself.

However, polarimetry of proton beams with energies higher than about 30 GeV poses a difficult challenge. The analyzing power of only a few reactions have been measured so far [WRI80, IRO83, IGO83] and the value of the analyzing power is typically small. For a successful polarized beam program at RHIC we will need two types of polarimeters. For polarization monitoring during operation, a fast and reliable polarimeter is required that produces a polarization measurement with a 10% relative error within a few minutes. However, for the commissioning phase, the polarimeter is only required to give feedback to the accelerator facility for tuning purposes. At a workshop held by the RIKEN/BNL Research Center last summer, the idea of using $\vec{p} + C$ elastic scattering in the Coulomb-Nuclear Interference region was suggested. This proposed experiment will test low -t, $^{12}C(p,p)^{12}C$ to be used for such a polarimeter. Eventually the beam polarization will have to be calibrated absolutely with a second polarimeter to a precision of about 5%. In order to reach such a goal while keeping the spin program on schedule, we have proposed the following programmatic scheme:

1) Build and test at the AGS a $\vec{p} + C$ CNI polarimeter (This proposal).

2) If the AGS test is successful, the system would be installed in the 12 o’clock region of the RHIC ring as a commissioning polarimeter. With the same target, a $\vec{p} + C \rightarrow \pi^- + X$ polarimeter would serve as an independent polarimeter.

3) For the first spin physics running, we would install an unpolarized hydrogen jet target in the 4 o’clock region of the RHIC ring to look at the $\vec{p} + p$ elastic reaction in the CNI region. The $\vec{p} + C$ CNI polarimeter would remain as a backup and a fast "tuning" polarimeter.

4) As the luminosity, and hence the statistical accuracy of the spin physics measurements improve, we would upgrade the unpolarized hydrogen jet target to a polarized hydrogen jet target. This would allow the comparison of the beam polarization to the target polarization and thus achieve the 5% accuracy.

1.2. Coulomb-Nuclear Interference

Elastic scattering in the small angle Coulomb-Nuclear interference (CNI) region is predicted to have a calculable analyzing power of about 3-5% [BUT78, BUT83], as well as a large cross section over the whole RHIC energy range from 23 GeV to 250 GeV. The analyzing power is given by

$$A_{\gamma} = \sqrt{\frac{8 \pi Z \alpha}{m_p^2 \sigma_{pt}}} \frac{y^2}{1 + y^2} (\mu - 1 - 2\tau_A)$$

where m is the anomalous magnetic moment of the proton (1.7928), $m_p$ the proton mass,

$$y = \frac{\sigma_{pt}}{8 \pi Z \alpha}, \quad \tau_A = \frac{g}{\sqrt{m^2(g)}} \quad \text{and} \quad \frac{g}{m^2(g)} \text{ is the (unknown) contribution due to the hadronic spin-flip term g.}$$

The total cross section $\sigma_{pt}$ is only weakly energy dependent over the relevant energy range. Figure
The total cross section is only weakly energy dependent over the relevant energy range. Figure 1 shows the calculated analyzing power for a hydrogen target (\(Z = 1, \sigma_{\text{tot}} = 35 \text{ mb}\)) and a carbon target (\(Z = 6, \sigma_{\text{tot}} = 330 \text{ mb}\) [ROS75]) as a function of (-t) at 250 GeV/c. The uncertainty of the hadronic spin flip amplitude has been estimated to be smaller than 10% of the analyzing power from CNI [KOP97]. Using a carbon ribbon target will result in the high luminosities required for fast polarization measurements. A ribbon target will also allow for measurements of the polarization profile of the circulating polarized proton beam. The sizable analyzing power, the large cross section and the advantages of a ribbon target makes this process suitable for a fast primary polarimeter for RHIC.

![Analyzing power vs. -t](image)

**Figure 1.** Coulomb-Nuclear interference analyzing power for pp and pC scattering at 250 GeV.

### 2. Experimental Setup

#### 2.1. The proposed polarimeter scheme

The range \(-t = 0.003\) to \(0.01 \text{ GeV}^2\) corresponds to carbon recoil energies of 0.09 - 1.00 MeV. It will be impossible to measure the forward-scattered proton at RHIC without drastically reducing the beam divergence at the target, which would severely reduce the scattering rate and cause unacceptable beam emittance growth. It will therefore be necessary to rely only on the measurement of the recoil carbon nucleus to identify elastic scattering.

Direct measurement of the 0.1 - 1 MeV recoil carbon nucleus is only possible for a very thin carbon
target. A test at the IUCF Cooler has demonstrated the feasibility of detecting such low energy recoil carbon nuclei from a thin carbon target ribbon using a silicon surface-barrier detector. A description of that experiment and the results of the tests are included in Appendix A. In addition, the time-of-flight should be measured to discriminate against target fragments. Tests of a micro-channel plate detector, which provides precise time-of-flight information, have recently taken place at Kyoto University and are described in Appendix B. The two detector schemes will be combined for the AGS run in order to provide both the energy and TOF information for the recoil carbon, helping to resolve the elastic signal from the hadronic and inelastic. Figure 2 shows the expected energy-angle correlation for the recoil carbon at 25 GeV/c. The horizontal band shows the expected angular straggling from the target ribbon. Also shown is the well-separated kinematic range for producing the first excited carbon state at 4.4 MeV.

![Energy-angle correlation for the elastic and inelastic recoil carbon nucleus at 25 GeV.](image)

**2.2. Recoil Detector**

We employ silicon detectors and microchannel plates (MCP) for the detection of recoil carbon ions from the $\vec{p} + C$ elastic scattering. The schematic layout of the detector system is shown in Fig. 3. Detectors are placed on both left and right side (about 90 degree to the beam direction) of the beam.
The Si is used for measuring the recoil energy while the MCPs will provide time-of-flight information.

We will cover the inelastic channels in order to measure their $A_N$ as well. For this purpose, we will cover down to 86 degrees with our Silicon detectors (cf. Figure 2). That should cover the 4.44 MeV state. We will have six silicon channels per side each covering one-degree acceptance. We will begin with 92 degrees to avoid geometric biases.

![Figure 3. Proposed layout for one arm of the recoil detection system.](image)

2.3. The Target

As a target we will use carbon micro-ribbons of $\sim$5ug/cm$^2$ thickness, with a typical width of 10 m m and 3cm long. For the thinnest ribbons, there are $1.5 \times 10^{14}$ C nuclei per cm length. The manufacturing process for such ribbons has been developed at IUCF [LOZ91], and is now routine. The ribbons will be mounted perpendicular to the beam direction in free suspension between the ends of a fork. The fork can be moved by remote control such that the distance from the ribbon to the beam can be varied. Since the recoils are emitted in a very narrow range around 90$^\circ$, false asymmetries are minimal, and the target position need not be measured.

2.4. The Beam

We require high polarization, 50%, and our time request assumes $2 \times 10^9$ protons per AGS fill. The experiment will use bunched beam on a flattop chosen to match the RHIC transfer energy for polarized protons. All the setup can be done parasitically with E880 and E925 measurements. When taking data, we would measure $\vec{p} + C$ CNI over a one second flattop of bunched beam, followed by a 0.5 second measurement of the beam polarization with the AGS internal polarimeter using de-bunched beam. The purpose of the bunched beam is so that the recoil carbon nuclei arrive at the detector out of time with the prompt background from the target.
3. Measurements

3.1. Goal

We plan to measure the analyzing power in p+\(^{12}\)C elastic scattering at 23 GeV for the range of \(-t = 0.003\) to \(0.01\) GeV\(^2\) with a 10% statistical accuracy. Table 2 lists kinematic variables for this \(-t\) range. The measurement will be carried out with a carbon micro-ribbon target upstream of the existing AGS polarimeter. Only the recoil nuclei will be detected.

<table>
<thead>
<tr>
<th>(-t) [GeV(^2)]</th>
<th>(q_R) [deg]</th>
<th>(T_R) [MeV]</th>
<th>tof [ns]</th>
<th>tof(^\prime) [ns]</th>
<th>(A_N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.003</td>
<td>89.79</td>
<td>0.135</td>
<td>67.8</td>
<td>65.0</td>
<td>0.038</td>
</tr>
<tr>
<td>0.004</td>
<td>89.76</td>
<td>0.177</td>
<td>59.2</td>
<td>56.7</td>
<td>0.035</td>
</tr>
<tr>
<td>0.005</td>
<td>89.73</td>
<td>0.225</td>
<td>52.5</td>
<td>50.3</td>
<td>0.033</td>
</tr>
<tr>
<td>0.006</td>
<td>89.70</td>
<td>0.269</td>
<td>48.0</td>
<td>46.0</td>
<td>0.030</td>
</tr>
<tr>
<td>0.007</td>
<td>89.68</td>
<td>0.314</td>
<td>44.5</td>
<td>42.6</td>
<td>0.028</td>
</tr>
<tr>
<td>0.008</td>
<td>89.66</td>
<td>0.359</td>
<td>41.6</td>
<td>39.8</td>
<td>0.027</td>
</tr>
<tr>
<td>0.009</td>
<td>89.64</td>
<td>0.403</td>
<td>39.2</td>
<td>37.6</td>
<td>0.025</td>
</tr>
<tr>
<td>0.01</td>
<td>89.62</td>
<td>0.449</td>
<td>37.2</td>
<td>35.6</td>
<td>0.024</td>
</tr>
</tbody>
</table>

Table 1: p +\(^{12}\)C elastic scattering at 23 GeV. The columns are: momentum transfer squared, \(^{12}\)C recoil lab angle, kinetic energy of the \(^{12}\)C recoil, time of flight of \(^{12}\)C recoil for a 10 cm flight distance, as col.4 for a particle of same energy but mass 11, differential cross section, analyzing power.

3.2. Count Rate Estimate

The yield is estimated under the following assumptions. The beam intensity is \(2 \times 10^9\) protons/bunch and in total \(1.2 \times 10^{10}\) protons in the ring (6 bunches/ring). The size of the beam at 23 GeV and at the position of the target is 5mm in width. Then, the target efficiency for a 25mm wide ribbon target is \(5 \times 10^{-3}\). The number of carbon nuclei in the target is \(2.5 \times 10^{17}/\text{cm}^2\) for a 5mg/cm\(^2\) carbon ribbon. Thus, the luminosity is calculated as \(2.5 \times 10^{24}/\text{cm}^2/\text{bunch crossing and 7.5 \times 10^{30}/cm}^2/\text{sec.}\) The average cross-section for p +\(^{12}\)C elastic scattering from \(-t=0.003\) to \(0.01\) is estimated to be \(2.8 \times 10^{-24} \text{ cm}^2 / (\text{GeV/}c^2)^2\). If we assume the detection efficiency is 0.5, we expect the rate of the elastic p +\(^{12}\)C scattering in this t-range to be \(0.6 \times 10^{-3}\text{ event/bunch crossing and 1.8 x}\)
10^3 events/sec.

If we divide into 10 bins of -t, we expect to obtain the analyzing power with the statistical accuracy of about \( \Delta A_N = 0.002 \) for each -t bin in one hour (900 spill/hour). This represents a 10% measurement for the expected \( A_N \) in this -t region.

To summarize the calculation:

**Beam:** 2 x 10^9 protons/bunch, 6 bunches/ring, bunch crossing frequency of 3 MHz, 5mm wide at target.

**Target:** 5mg/cm^2 carbon ribbon = 2.5 x 10^{17}/cm^2, 25mm width.

**Luminosity:** 2.5 x 10^{24}/cm^2/bunch crossing and 7.5 x 10^{30}/cm^2/sec.

**Cross section:** \((ds/dt) = 2.8 \times 10^{-24} \text{cm}^2/(\text{GeV}/c)^2\).

**Binning:** \( dt = (0.01(\text{GeV}/c)^2 \).

**Acceptance:** \( df/2p = 6/360 \)

**Detection efficiency:** 0.5

**Count rate:** 0.6 x 10^{-3} event/bunch crossing, 1.8 x 10^3 events/sec.

**Shift request:**

Two weeks parasitic beam preparation, electronics adjustments, target manipulation, general overhead

3 shifts data acquisition at 23 GeV

**References**


[KOP97] B. Kopeliovich, Workshop on Hadron Spin-flip at RHIC Energies, E. Leader and L.
Appendix A. The IUCF Test Run CE75

We have performed a test of the use of silicon surface-barrier detectors in detecting low-energy carbon recoil nuclei in the elastic scattering of polarized protons from a thin carbon ribbon target at the Indiana University Cyclotron Facility (IUCF) Cooler. We installed a thin micro-ribbon carbon target in the A-region of the cooler in front of the existing forward-proton detection system in that region. On one side of the target, two silicon surface-barrier detectors were placed 10 cm from the target. Each detector was 3mm x 2.5cm x 300mm and used an Amptek 250 preamplifier and FET mounted in vacuum at close proximity. Events were selected with three separate trigger conditions: 1) requiring a hit in the forward proton detector alone, 2) requiring a signal in the silicon above noise in coincidence with a forward proton and, 3) requiring a signal in the silicon above threshold alone. Calibration of the energy deposition in the silicon was done offline by kinematics with the forward-scattered proton. The target used was a 3.7 mg/cm$^2$ thick x 10mm wide x 3cm long ribbon made at IUCF by Bill Lozowski. The ribbon target survived mounting, beam, and dismounting from the vacuum chamber, although much care was used in pumping down and letting up to air. We took data primarily with 200 MeV polarized protons (~70% polarization) bunched with ~100ns between bunches. The flight times of the recoil carbons were such that their arrival times were between bunches. Figure A1 shows the forward-scattered proton angle (x10) vs. the calibrated carbon recoil energy seen in the two silicon detectors using the silicon-only trigger. This figure clearly shows that it is possible to trigger on these carbons in silicon at energies as low as 200 KeV. Noise in the silicon channel closest to 90° prevented triggering at lower energies. We believe that with reduced noise (acoustic and 60 Hz) we could trigger as low as 150 KeV with high efficiency.
Appendix B. The Tests of the MCP at Kyoto


Department of Physics, Kyoto University

B1. Abstract

As a RHIC polarimeter, we have studied the $\bar{p} + C$ CNI polarimeter using the elastic proton-carbon scattering in the Coulomb-Nuclear interference region where recoil carbon ions are below 1 MeV. We have carried out test experiments to detect such low-energy carbon ions using a micro-channel plate (MCP) detector system. Carbon ions as low as 200 keV were successfully detected with the MCP. In order to design the polarimeter, we tested three configurations.
B2.1. MCP

The MCP (made by Hamamatsu) we used is double-layered and single-anode MCP of sensitive area 14.5mm in diameter. The gain of the MCP is $10^5$-$10^6$. The applied HV is 2100V. The MCP is sensitive to ions, electrons, X-rays etc.

B2.2. Configurations

We have two basic methods to detect carbon ions with the MCP. The first is the direct detection of carbon ions with the MCP. The second is to detect secondary electrons with the MCP. Secondary electrons are emitted from the material such as Au of a SSD surface, or a thin C foil through which the carbon ions pass. The emitted secondary electrons are transferred to the MCP by an electric field generated by an accelerating grid and electrostatic mirror. We used SUS wires of 0.05mm diameter with 50 mesh/inch (81% transparency). The applied voltage of the accelerating grid and the electrostatic mirror was 2.5 kV. We tested three configurations as a possible design of the polarimeter, as shown in Fig.1.

A. MCP (only).

B. Combination of MCP and SSD with electrostatic mirror.

C. Combination of two MCP with a thin carbon foil and electrostatic mirror.

![Fig. 1 Three Configurations](image-url)
B3. Experiment

We have used a 10 MeV proton beam from the Tandem Van de Graaff at Kyoto University to measure the elastic proton-carbon scattering. The target was a carbon foil of 5mg/cm\(^2\) in thickness and placed perpendicular to the beam. The scattered protons were detected with a plastic scintillator mounted on a photomultiplier (PMT). The recoil carbon ions were detected with the detector system in each configuration as shown in Fig.1. A schematic view of the setup is shown in Fig.2 only for the configuration (C). Each detector was fixed on a separate turntable so that the angle of each detector could be changed independently. Both TDC and ADC spectra were measured for both detectors. For configuration (B), the SSD was not read out. For the calibrations of the TOF spectra, we have also measured the elastic proton-proton scattering with a polyethylene target. We have measured the proton-carbon scattering at the angle settings as shown in the table below, in order to change the energy of the carbon ions.

<table>
<thead>
<tr>
<th>Proton Angle (degrees)</th>
<th>Carbon angle (degrees)</th>
<th>Calculated Carbon Energy (MeV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>22.17</td>
<td>77.0</td>
<td>0.1240</td>
</tr>
<tr>
<td>24.95</td>
<td>76.5</td>
<td>0.1554</td>
</tr>
<tr>
<td>27.74</td>
<td>75.0</td>
<td>0.1907</td>
</tr>
<tr>
<td>36.14</td>
<td>70.5</td>
<td>0.3176</td>
</tr>
<tr>
<td>40.83</td>
<td>68.0</td>
<td>0.4005</td>
</tr>
<tr>
<td>46.40</td>
<td>65.0</td>
<td>0.5102</td>
</tr>
<tr>
<td>53.12</td>
<td>61.5</td>
<td>0.6495</td>
</tr>
<tr>
<td>61.20</td>
<td>57.5</td>
<td>0.8240</td>
</tr>
</tbody>
</table>
B4. Results

After selecting the elastic scattering by the ADC (energy) spectrum of the plastic scintillator, the TOF spectra were obtained for each angle.

B4.1. TOF Resolution

The TOF resolution was obtained for the proton-proton run in each configuration. The TOF resolution for all configurations is shown in Fig.3.
**TOF Resolution**

Figure 3. TOF resolution for 1) Configuration A; 2) Configuration B; 3) Configuration C (electron); and 4) Configuration C (Carbon).

**B4.2. Energy Spectrum**

The TOF spectra can be converted to the energy spectra of the carbon ions, assuming the velocity of the proton is as calculated from kinematics. The possible small error in the proton velocity does not affect the TOF spectrum, since the velocity of the carbon ions is more than 10 times smaller than that of the protons. The energy spectra of the recoil carbon ions for all the configurations are shown in Figs.4-7. One can see that the carbon ions are successfully detected with the MCP detector in each configuration above.
Energy spectra for Configuration A.

Energy Spectrum: Configuration B

Figure 4.

Figure 5.
Figure 6.

Energy spectra for Configuration C. (Carbon)
Energy spectra for Configuration C. (electron)

B4.3. Efficiency

We have measured the efficiency of the detector system. The efficiency is defined as the ratio of the number of detected carbon ions to the number of detected protons from elastic p+C scattering. The dependence on the carbon energy is shown in Fig.8 for each configuration.
B5. Conclusion

Low energy carbon ions were successfully detected with the MCP detector in our three configurations. From the efficiency measurement, the method of detecting secondary electrons from a thin carbon foil is found suitable for detecting lower energy carbon ions. If we use finer wires and change the mesh by a plane of wires in one dimension, we can increase the efficiency by a factor of two. We conclude that this method is useful for a $\vec{p} + C$ CNI polarimeter for RHIC.