A p-Carbon CNI polarimeter for RHIC*

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Abstract

The RHIC spin program requires excellent polarimetry so that the knowledge of the beam polarization does not limit the errors on the experimental measurements. However, polarimetry of proton beams with energies higher than about 30GeV poses a difficult challenge. 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. The p-Carbon elastic scattering in the Coulomb-Nuclear-Scattering(CNI) region has a calculable and large analyzing power, but detecting the recoil carbon needs sophisticated detector system and a very thin target. Experiment has been planned in the AGS. This paper describes the experimental setup in the AGS.

1 INTRODUCTION

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 [1]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[2]. 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 elastic p-Carbon scattering at Coulomb-nuclear interference (CNI) region was recently proposed as a possible polarimeter for RHIC. It is quite attractive because measurement is compatible with the pion polarimeter and the detectors could be simple and inexpensive.

2 COULOMB-NUCLEAR INTERFERENCE

Small angle elastic scattering of hadrons in the CNI region has long been advocated for polarimetry. The predicted asymmetry is significant and largely independent of energy for energy above a few GeV. The prediction rests on hadronic spin flip being small, which is expected for high energies. Then the analyzing power can be reliably calculated and is about 3-5 %[3, 4] and a large cross section over the whole RHIC energy range from 23 GeV to 250 GeV is predicted. The analyzing power of p-p CNI was measured at 200GeV and was consistent with the theoretical values within the errors.

The CNI process has been proposed for RHIC polarimetry using a hydrogen jet target and in collider mode using the $pp2pp$ experiment. Both would be ppCNI. It is also possible to use a carbon target, pCCNI, which is simpler and cheaper than a hydrogen jet, and can be installed in the individual rings, vs. requiring collision of both rings as for the $pp2pp$ experiment. The analyzing power for pCCNI is similar to ppCNI and the cross section is high, giving a very large figure of merit NA^2. However, for pCCNI, the proton scattered forward is not easily detectable (it stays within the beam), and the energy of the recoil carbon nucleus is 100-600keV. The low energy carbon would stop in most targets. The pCCNI polarimeter becomes feasible with the development of very thin ribbon carbon targets at IUCF[5]. The slowness of the recoil carbon also makes detection difficult. However, the arrival time of the carbon can be set to be in between RHIC bunches, avoiding prompt background.

* Work supported in part by the U.S. Department of Energy.
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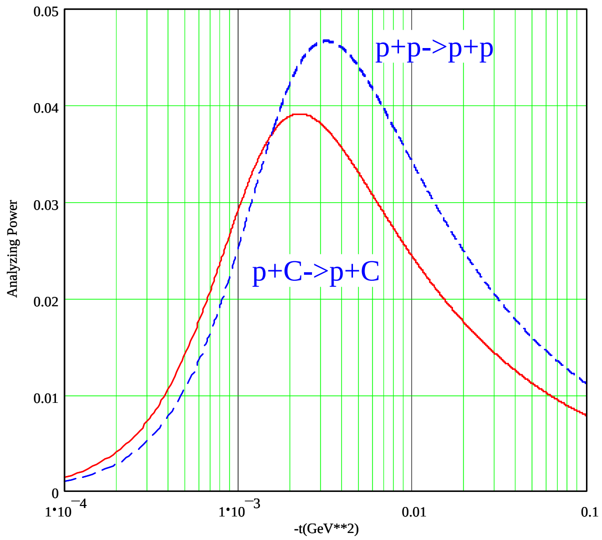

Figure 1: Coulomb-Nuclear interference analyzing power for pp and pC scattering at 250 GeV.

The analyzing power of CNI process is given by

$$A_N = \sqrt{\frac{8\pi Z\alpha}{m_p^2 \sigma_{tot}^{pA}}} \frac{y^{2/3}}{1+y^2}(\mu - 1 - 2\tau_A)$$

where μ is the anomalous magnetic moment of the proton (1.7928), m_p the proton mass, $y = \frac{\sigma_{tot} t}{8\pi Z\alpha}$, and $\tau_A = \frac{g}{\sqrt{\frac{-t}{m^2}(g)}}$ is the unknown contribution due to the hadronic spin-flip term g. The total cross section σ_{tot} is only weakly energy dependent over the relevant energy range. Fig. 1 shows the calculated analyzing power for a hydrogen target (Z = 1,σ_{tot}= 35 mb) and a carbon target (Z = 6,σ_{tot}= 330 mb [6]) as a function of (-t) at 250 GeV. The uncertainty of the hadronic spin flip amplitude has been estimated to be smaller than 10 % of the analyzing power from CNI [7]. 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.

3 EXPERIMENTAL SETUP

3.1 Polarimeter Scheme

The range $-t = 0.003$ to $0.01\ GeV^2$ 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.

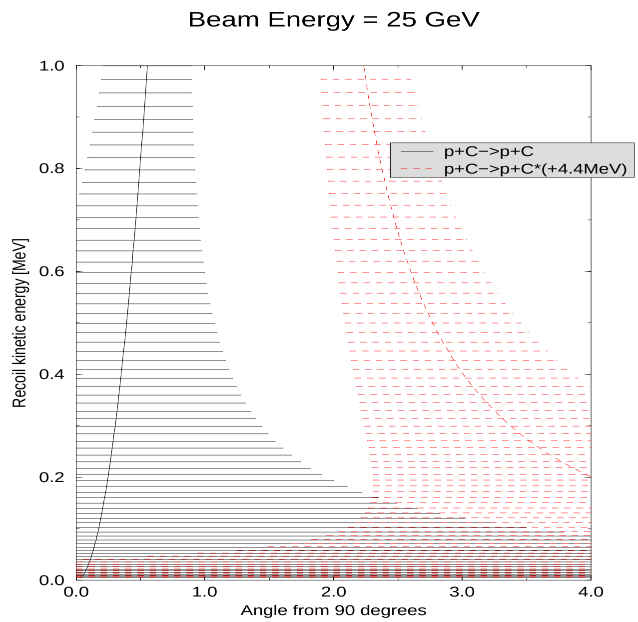

Figure 2: Energy-angle correlation for the elastic and inelastic recoil carbon nucleus at 25 GeV.

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. 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. A more sophisticated test has been done in the AGS in March, 1999. The two detector schemes are 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. Fig. 2 shows the expected energy-angle correlation for the recoil carbon at 25 GeV. 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.

3.2 Recoil Detectors and Target

We employ silicon strip detectors (SSD) and micro channel plates (MCP) for the detection of recoil carbon ions from the $\vec{p}+C$ elastic scattering. A vacuum chamber of 66cm diameter hosts the SSD and MCP detectors and target ladder. Two sets of SSDs and MCPs are mounted on left and right detector tables, respectively, which are perpendicular to the beam direction. The schematic layout of the one detector arm is shown in Fig. 3. The SSDs are used for measuring the recoil energy and time-of-flight while the MCPs will provide cross check of time-of-flight information.

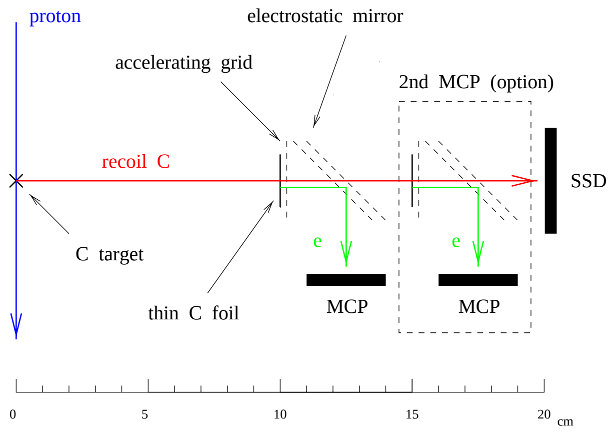

Figure 3: Layout for one arm of the recoil detection system.

Each SSD has 12 1cm×2mm strips. In the AGS experiment, every two strips are combined as one channel. The six silicon channels on each side cover six-degree acceptance. This covers the inelastic channels, too, so we can measure their A_N as well. For this purpose, SSDs cover down to 86 degrees and that should cover the 4.44 MeV state (see Fig. 2). Moreover, SSDs begin with 92 degrees to avoid geometric biases.

The pre-amplifiers is installed in the vacuum and the signals then travel 300 feet to the DAQ electronics. Since the noise is significantly high around AGS ring, special efforts are taken to reduce the noise from rf. The bias voltage power supply for the SSD is in the ring next to the vacuum chamber. A copper cage covers pre-amplifiers and reduces pick-up noise significantly. The analog signals are also differentiated before digitized to eliminate rf noise. A refrigerator keeps temperature of the SSDs down to -30^oC to reduce the leakage current.

The MCP is double-layered and has an effective area of 14mm diameter. The MCP is easy to handle like a photo multiplier due to its high gain especially against electronic noises. However, it is sensitive to the low energy electrons and X-rays. A thin carbon foil standing 10cm away from the target generates the electrons when hit by recoil carbon. The electrons are then accelerated by the accelerating grid and reflected to MCP by electrostatic mirror. A repeller is installed in front of the MCP to reflect electrons emitted from the target.

As a target we use carbon micro-ribbons of $5\mu g/cm^2$ thickness, with a width of 5μm and 2.5cm long. For the thinnest ribbons, there are 1.5×10^{14} C nuclei per cm length. The manufacturing process for such ribbons has been developed at IUCF [5], and is now routine. The ribbons are mounted perpendicular to the beam direction in free suspension between the ends of a fork. The fork can be moved into the beam in every AGS spill to a surveyed position, while the beam is shifted toward the target if necessary. This is to assure that the relative positions between detectors and target are fixed and no artificial asymmetry are introduced. Three targets can be mounted on the target ladder. Since the event rate is hard to estimate, two targets with different thickness are installed. The last ladder interval is left empty to check background. A limit switch is used to calibrate the target position after some running period.

4 EXPERIMENT

50% polarized beam has been successfully accelerated to the RHIC injection energy in the AGS, which is sufficient to measure the analyzing power at this energy. Such a polarimeter has been installed in the AGS and the data taking run has finished in March 1999. The experiment uses bunched beam with harmonic number $h = 12$. The analyzing power in $\vec{p} + C$ elastic scattering at 21.7 GeV/c for the range of -t = 0.003 to 0.01 GeV^2 is measured with a 10% statistical accuracy. Only the recoil nuclei are detected.

When taking data, $\vec{p} + C$ CNI is measured over a half second flattop of bunched beam, followed by a 0.85 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. Since the bunch length at 21.7GeV/c is about $25ns$, it is adequate to use SSD only to measure TOF.

The data analysis will give A_N for the RHIC injection energy. If this is a success, we plan to install the pC CNI polarimeter for the commissioning of RHIC in FY2000.

5 ACKNOWLEDGMENT

The authors would like to thank Dr. Z. Li, Dr. P. Rehak for their help on the design and production of the silicon strip detector. We are indebted to Dr. S. Rescia for providing the pre-amplifiers used in silicon detector electronics. We are grateful to G. Mahler for the mechanical design. We would like to thank T. Russo and his group for their enthusiastic work during installation and setup for the experiment.

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