Research Proposal to the Indiana University Cyclotron Facility

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Test of Small Angle Elastic Proton-Carbon Scattering as a High Energy Proton Beam Polarimeter for RHIC

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Abstract

p +^{12}C elastic scattering in the Coulomb-Nuclear Interference region could be used to measure the polarization of high-energy protons. Such a polarimeter must be capable of detecting recoiling Carbon nuclei of energies as low as 0.5 MeV or even lower. Micro-ribbon Carbon targets would be thin enough to allow the recoils to exit. We propose to use the Indiana Cooler to study the feasibility of using the low-energy recoil nuclei to measure p +^{12}C scattering in an accelerator environment. At 200 MeV in the IUCF Cooler a clean sample of scattering events will be prepared by requiring a coincidence with the forward scattered proton. This will allow us to investigate the energy spread of the recoil nuclei due to the thickness of the target and the insensitive entrance window of the detector.

SUMMARY

A. Experiment: $^{12}C(p,p)^{12}C$; measurement of the cross section and the analyzing power between 6 and 20 deg, using either a coincidence between the protons and the recoil nuclei, or the information from the recoil detector alone.

B. Target: micro-ribbon targets in skimming mode, supplied by IUCF.

C. Detectors: the standard detector stack in the A-region of the Cooler, supplemented with a new, cooled recoil detection scheme. The latter will be designed and procured by the collaboration.

D. Beam: polarized protons at 200 MeV and 450 MeV.

E. Beam Time Request: 11 shifts.

F. Ready Date: the experiment will be ready in the spring of 1998.

1. Introduction

1.1. Scientific Justification

The RHIC spin project of colliding 250 GeV polarized proton beams will open up the unique physics opportunity of studying spin effects in hard processes. 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.

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 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 the initial commissioning phase and for polarization monitoring during operation a fast and reliable polarimeter is required that produces a polarization measurement with a 5 -10 % relative error within a few minutes. This proposed experiment will test small angle $^{12}C(p,p)^{12}C$ 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 %. A possible candidate for such an absolute polarimeter would be elastic scattering from a polarized hydrogen target which would allow the comparison of the beam polarization to the target polarization.

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 25 GeV to 250 GeV. The analyzing power is given by

$$A_N = \frac{G t_0 t \sqrt{t}}{m_p\left(t^2 + t_0^2\right)}$$

where G is the anomalous magnetic moment of the proton (1.7928), m_p the proton mass, and $t_0 = \frac{8\pi\alpha Z}{\sigma_{tot}}$. The total cross section σ_{tot} is only weakly energy independent over the relevant energy range. Figure 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 [ROS75]) as a function of (-t). The uncertainty from a hadronic spin flip amplitude has been estimated to be smaller than 10 % of the analyzing power from CNI. Using a Carbon fiber target will result in the high luminosities required for fast polarization measurements. A fiber 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 solid fiber target makes this process ideal for a fast primary polarimeter for RHIC.

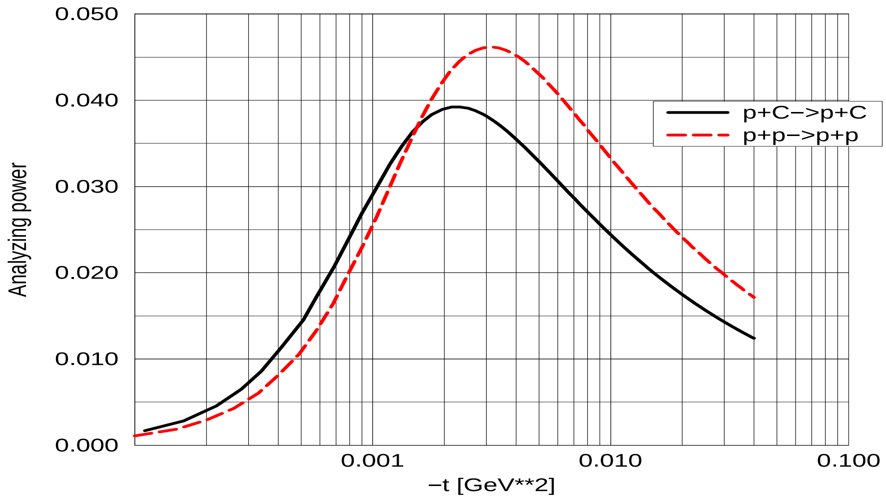

Figure 1. Coulomb-Nuclear interference analyzing power for pp and pC scattering.

1.2. The proposed polarimeter scheme

A typical (-t) value of 0.002 to 0.01 GeV2 results at high energy in a very small angle of the forward scattered proton relative to the beam direction and also a very low kinetic energy of the Carbon recoil of about 0.5 MeV. It will be impossible to measure the forward scattered proton without drastically reducing the beam divergence at the target which would severely reduce the scattering rate and also 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 to 1 MeV recoil Carbon nucleus is only possible for a very thin Carbon target. A test at IUCF cooler would demonstrate the feasibility detecting low energy recoil Carbon nuclei from a thin Carbon target ribbon. The determination of elastic scattering will be done be measuring both the energy and angle of the recoil Carbon. In addition the time-of-flight will be measured to discriminate against target fragments. Figure 2 shows the expected energy-angle correlation for the recoil Carbon. The horizontal lines show the expected angular straggling from the target ribbon. Also shown is the well sperated kinematic range for producing the first excited Carbon state at 4.4 MeV.

At the low beam energy of 200 MeV at the Cooler the forward proton can easily be measured and will allow for an easy confirmation of whether the recoil information alone is sufficient to determine elastic scattering.

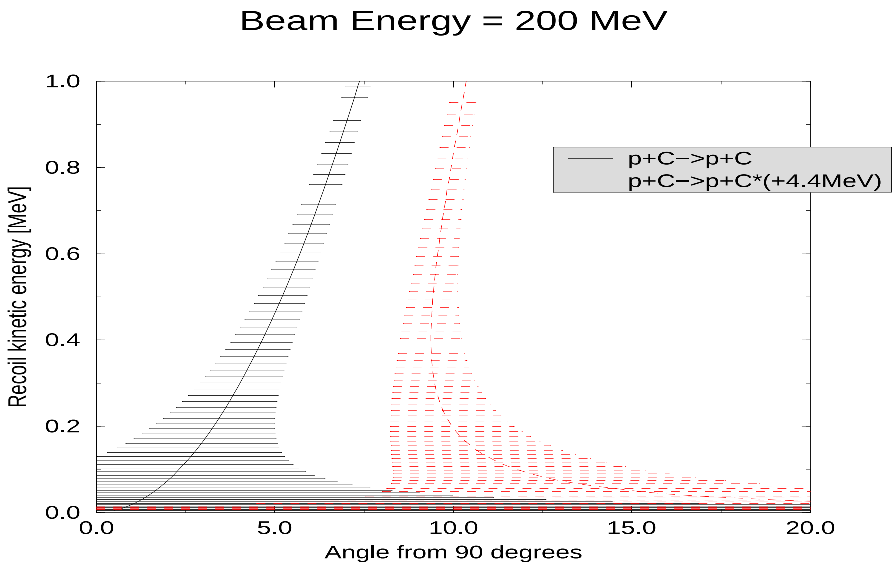

Figure 2. Energy-angle correlation for the elastic and inelastic recoil Carbon nucleus.

2. Equipment

2.1. Recoil Detector

2.1.1. Detection of Low-energy Heavy Ions

[Silicon detector (with energy information)? Micro-channel plate with only time information? Should we try both schemes?]

The detection of carbon ions with energy below 0.7-0.5MeV is not trivial. I would propose a smaller detector with say 0.5mm strips, positioned at a closer distance to avoid any wrap-around. The thin window detector will have to be cooled to about -20C. In order to get good TOF information for low energy ions, I would suggest that we combine the Si detector with a u-channel plate assembly (which will use secondary electrons ejected from the face of the Si). The whole system should probably be backed up by a segmented veto detector, in case the background from LCP's becomes too bothersome. The front detector will also be very sensitive to X-ray, and other background - so a preliminary test in 64" chamber and/or a low energy Van de Graaff may not hurt. Also, the actual run could be done in two installments, so there is time for improvements etc.

[There is also a question of allocation lab resources and especially manpower that to the design, construction and testing the recoil detector assembly. A Japanese group expressed interest in participating in that test - maybe they can help in that regard?]

2.1.2. Geometry of the Recoil Detector

For the purpose of judging the feasibility of the measurement we assume a detector for the ^{12}C recoils which is 4 cm long, 1 cm high, and is position sensitive in the direction of the long dimension with a position resolution of 1 mm. If we place the detector at a distance of 20 cm from the target, it covers an 11 deg wide recoil angle range, that is divided into 40 bins, each 0.3 deg wide. The solid angle of each bin is 2.5×10^{-4} sr.

2.2. Proton Detector

For the detection of the scattered protons we will use the scintillator and wire chamber stack in the A-region. This part of the apparatus is described for instance in ref. [HAE97]. We assume that the ribbon target will be mounted 35 cm upstream from the first wire chamber, which has an insensitive central hole of 5 cm diameter. Without any change in the present setup, we will thus be able to detect scattered protons between 4 and 25 deg with an angular resolution of about 0.3 deg. The data acquisition electronics is designed to accept a recoil signal in coincidence as a trigger condition, if desired.

2.3. The Target

As a target we will use Carbon micro-ribbons of 5-10 ug/cm2 thickness, with a typical width of 20 micro-meters. It is relatively easy to produce ribbons of up to 5 cm length. 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 [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 horizontally by remote control such that the distance from the fiber to the beam can be varied. The luminosity is a function of this distance, and can be adjusted to the desired level in this way. The ribbons will be mounted such that it can approach the beam either from the left or from the right, to evaluate instrumental asymmetries.

2.4. The Beam

We will use primarily a polarized 200 MeV proton beam, injected into the Cooler by cooling-assisted stacking. Fill rates of up to 150 uA/min have recently been recorded. We base our count rate estimate on a stored current of 200 uA, which can be easily accumulated with a fill time of a few minutes.

The time structure of the beam can be chosen at will. For better time resolution, we bunch the beam at harmonic number h = 6. The time separation of the bunches at 200 MeV is then 85 ns. Lately, we have experienced problems with the stability of the raw machine RF. It will therefore be necessary to improve the RF signal by phase-locking it to a signal from a pickup near the target. It is hoped that IUCF will provide such a device.

We anticipate that we also will also use beam accelerated to 450 MeV.

3. Measurements

3.1. Goal

We plan to measure cross section and analyzing power in p+^{12}C elastic scattering at 200 MeV for laboratory angles of the proton between 5 and 20 deg. Table 1 lists kinematical variables for this angle range. The measurement will be carried out in the A-region of the Cooler with a micro-ribbon target. Both the proton and the recoil nuclei will be detected. Data will also be acquired with a trigger that does not require a coincidence with the scattered proton, in order to study count rate limitations and problems in identifying elastic scattering events by using the energy, time of flight, and angle information measured with the recoil detector alone. Data on the time of flight of the recoil nuclei and neighboring-mass nuclei of the same energy can be found in table 1. The primary bombarding energy has been chosen to be 200 MeV because the proton angles of interest are well inside the detectable range, and because good cross section and analyzing power data are available down to 6 deg in the lab [MEY81]. However, an attempt to shed light on energy-dependent systematic effects, we plan to also take data with a 450 MeV beam.

3.2. Count Rate Estimate

It is difficult to estimate a luminosity with an inhomogeneous target in a stored beam. As a good guess, we assume that beam profile is a uniform rectangle with a width of 3 mm. A 200 μA beam then has a flux density of 1.8×10^{16} cm^{-2} s^{-1}. If we place the fiber in the center of the beam (i.e., 3 mm of its length, or 1.5×10^{14} nuclei, are illuminated), we get as an upper limit of the luminosity 2.6×10^{30} cm^{-2} s^{-1}. The cross section for p+^{12}C scattering ranges from 15 mb/sr at θ_p=20 deg to almost 400 mb/sr at 6 deg. Let us assume a differential cross section of 100 mb/sr. The ^{12}C (p,p) ^{12}C count rate for each of the 40 angle bins is then 60 Hz. The total rate is clearly much higher than 500 Hz which the data acquisition system is able to process. Thus, the luminosity must be adjusted to about 5×10^{29} cm^{-2} s^{-1} to conform to the acquisition limits. With this luminosity, the data rate at the largest angle of interest (with a cross section of 15 mb/sr) is now determined to be about 2 Hz. In other words, an angular distribution to a statistical accuracy of better than 0.01 can be carried out in about one hour. From the above, we conclude that the time for actual data taking under various conditions will be of the order of 2 - 3 shifts.

Shift request:

5 shifts	beam preparation, electronics adjustments, target manipulation, general overhead
3 shifts	data acquisition at 200 MeV
3 shifts	data acquisition at 450 MeV

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11 shifts total

References

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[LOZ91] W.R. Lozowski and J.D. Hudson, Nucl. Instr. Meth. A303, 34 (1991)
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[MEY81] H.O. Meyer et al. Phys. Rev. C23, 616 (1981)

Table 1. p + ^{12}C elastic scattering at 200 MeV

col.1: proton lab angle θ_p [deg]
col.2: ^{12}C recoil lab angle θ_R [deg]
col.3: kinetic energy of the ^{12}C recoil [MeV]
col.4: time of flight of ^{12}C recoil for a 20 cm flight distance
col.5: as col.4 for a particle of same energy but mass 11
col.6: differential cross section (mb/sr) [MEY81]
(refers to the lab solid ang. of scattered p)
col.7: analyzing power [MEY81]

θ_p [deg]	θ_R [deg]	T_R [MeV]	tof [ns]	tof' [ns]	$d\sigma/d\Omega$[mb/sr]	A_N
6	86.7	0.20	110.5	105.8	381	0.51
8	85.6	0.36	82.9	79.4	315	0.61
10	84.5	0.56	66.4	63.6	273	0.71
12	83.4	0.81	55.4	53.0	179	0.81
14	82.3	1.10	47.5	45.5	92	0.89
16	81.2	1.43	41.6	39.9	56	0.99
18	80.1	1.81	37.0	35.5	30	0.97
20	79.0	2.23	33.4	32.0	15	0.78