Absolute Polarimeter for the Proton-Beam Energy of 200 MeV

A. N. Zelenski¹), G. Atoian¹), A. A. Bogdanov²), S. B. Nurushev²), F. S. Pylaev²), D. Raparia¹), M. F. Runtso²)*, and E. Stephenson³)

Received June 10, 2013

Abstract—A polarimeter is upgraded and tested in a 200-MeV polarized-proton beam at the accelerator—collider facility of the Brookhaven National Laboratory. The polarimeter is based on the elastic polarized-proton scattering on a carbon target at an angle of 16.2°, in which case the analyzing power is close to unity and was measured to a very high degree of precision. It is shown that, in the energy range of 190–205 MeV, the absolute polarization can be measured to a precision better than ±0.5%.

DOI: 10.1134/S1063778813120156

A beam of polarized protons for the experimental spin-physics program at the Relativistic Heavy Ion Collider (RHIC) is created in an Optical Pumping Polarized Ion Source (OPPIS) of polarized negative hydrogen ions and is then accelerated in a linear accelerator (Linac) to a beam energy of 200 MeV and, after that, in a booster to an energy of 24.3 GeV for injection into the RHIC rings [1].

We recall that RHIC was the first collider of polarized particles where the Siberian snake procedure was successfully implemented in order to avoid resonance depolarization in the course of beam acceleration. Precise absolute measurements of polarizations over a broad range of energies from several keV units to 250 GeV at RHIC are required both for tuning the accelerator—operation mode (in order to minimize depolarization in the acceleration process) and for normalizing experimental data. Therefore, polarimetry is an important component of the polarization complex. A complete set of polarimeters includes a Lamb shift polarimeter at the outlet of the source of polarized protons, a polarimeter for the beam energy of 200 MeV downstream of the Linac, and polarimeters at AGS and RHIC on the basis of proton—carbon scattering in the region of Coulomb—nuclear interference. [2]. A polarimeter in a polarized hydrogen jet is used for absolute measurements of polarization at RHIC [3].

The present study is devoted to the polarimeter intended for application at the proton-beam energy of 200 MeV and positioned downstream of the Linac. Since the rate of beam injection to the booster of the AGS—RHIC complex is 1 Hz and since the source of polarized protons operates at a rate of 4 Hz, extra bunches are sent to the proton—carbon polarimeter.

Until recently, use was made of an inclusive proton—carbon polarimeter based on scattering at an angle 12°, described in [4], and calibrated to a precision of ±5% with the aid of a comparison with elastic proton—deuteron scattering. The analyzing power of the proton—carbon polarimeter—that is, the relative difference of the numbers of vertically polarized protons that were scattered to the right and to the left with respect to the beam-axis direction was 0.620 ± 0.004.

The currently implemented program of upgrading the source of polarized hydrogen ions to an intensity of 10 mA and a polarization degree of 85% [5] requires more precise absolute measurements of polarization at a very high peak intensity.

Owing to the increased beam intensity, it became possible to admit the reduction of the scattering cross section. At the same time, it was proposed to change the scattering angle, since, from the data published in the literature, it was known that, in the vicinity of 16°, the values of the analyzing power are close to unity and are expected to be stable over the measurement time.

One can readily show that, at a fixed beam polarization, the accuracy of its measurements becomes higher as the analyzing power approaches unity.

A feature that is peculiar to pC scattering and which complicates the application of pC polarimeters is that the carbon nucleus has the first excited state at an energy of 4.44 MeV [6].

Experimental dependences of the cross section (Fig. 1a) and analyzing power (Fig. 1b) for elastically
and inelastically scattered protons on the scattering angle in the laboratory frame (lab) were obtained in [7].

In order to perform estimations, we employed the parametrization from [6] for the experimental dependence of the analyzing power \( A_y \) in \( p^{12}\text{C} \) scattering on the projectile-proton kinetic energy \( T \) in the energy range of 180–200 MeV and on the laboratory scattering angle \( \theta \). The same parametrization is presented in [8] is given by

\[
A_y(\theta, T) = 1 - \alpha(T - T_0)^2 - \beta(T - T_0)(\theta - \theta_0) - \gamma(\theta - \theta_0)^2,
\]

where \( T_0 \) and \( \theta_0 \) are the interpolated values of the two parameters at one point where \( A_y \) takes the value of unity. Upon combining all known experimental results, it was found in [6] that, under the assumption of \( T_0 = 187.95 \text{ MeV} \) and \( \theta_0 = 17.16^\circ \), a least-squares fit to the data yielded the following coefficients in Eq. (1):

\[
\alpha = 1.19 (0.11) \times 10^{-4} \text{ MeV}^{-2},
\]

\[
\beta = 1.80 (0.16) \times 10^{-3} \text{ MeV}^{-1} \text{ deg}^{-1},
\]

\[
\gamma = 1.09 (0.08) \times 10^{-2} \text{ deg}^{-2}.
\]

The fitted results are given in Fig. 2 for the proton energies of 190, 198, 200, 202, and 205 MeV.

Thus, we can see that, according to the chosen parametrization, the maximum value of \( A_y \) at the proton energy of 200 MeV is 0.9935 at the angle of 16.2\(^\circ\). As the proton energy changes between 202 and 190 MeV, the analyzing power ranges between 0.990 and 0.995; that is, it changes by not more than 0.5%. At the same time, an increase in the energy above 205 MeV leads to a more substantial decrease in the analyzing power.

We will now estimate the possible effect of the admixture of inelastically scattered protons on the analyzing power. From the data in Fig. 1, it follows that, at a scattering angle of 16.2\(^\circ\), protons elastically scattered on carbon yield an analyzing power close to unity, while inelastically scattered protons yield an analyzing power of about 0.8. Thus, we have a mixture of two beams after scattering; for one of them, beam 1, which originates from elastic scattering, the analyzing power is \( A_1 \), while, for the other, beam 2, which owes its existence to the inelastic-scattering process, the analyzing power is \( A_2 \).

We can readily obtain an expression for determining the total analyzing power \( A_\Sigma \) of the polarimeter for two particle beams possessing, in the reaction with carbon, different analyzing powers \((A_1, A_2)\). The result is

\[
A_\Sigma = \frac{A_1 + A_2 k}{1 + k},
\]