Deuteron polarization determination at high energies

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Summary

- Partonic spin structure of the nucleon includes neutron
- Analyzing power for deuteron carbon elastic scattering
- Electromagnetic amplitudes for spin 1 - spin 0 collisions
- Glauber corrections and expectations for dC polarimetry

Introduction

Considerable progress has been made in using polarized protons to elicit the partonic spin structure of the nucleon. To provide a more compete picture of the isotopic spin sector it may be beneficial to use a probe more rich in the down quark such as the deuteron or a helium-three ion. The possibility of using deuteron carbon elastic scattering in the small angle interference region as a deuteron polarimeter is explored. Expectations for the anlyzing power are presented and discussed.

Coulomb helicity amplitudes

The parity conserving and time reversal invariant helicity amplitudes for a spin one deuteron of mass m scattering elastically off spinless carbon of mass M are

$$\begin{aligned} H_1 &= H_{++} = H_{--} \\ H_2 &= H_{+\,0} = H_{0\,-} = -H_{0\,+} = -H_{-\,0} \\ H_3 &= H_{+-} = H_{-+} \\ H_4 &= H_{0\,0} \end{aligned}$$

where the initial deuteron helicity appears to the right.

Amplitudes are normalized so that the spin averaged and spin aligned total cross sections may be written as

$$4\pi\,\mathrm{Im}\,[2H_1(s,0)+H_4(s,0)]/3 \;=\; k\,\sqrt{s}\,\sigma_{\rm tot}(s)$$

$$8\pi\,\mathrm{Im}\,[H_1(s,0)-H_4(s,0)]/3 \;=\; k\,\sqrt{s}\,\sigma_{\rm tot}^{\rm al}(s)$$

where k is the center of mass momentum variable. Noting a diffractive nature characterized by a slope parameter $b(s,t)$ the spin averaged amplitude may be exhibited in a form

$$\frac{2\,H_1+H_4}{3} \;=\; \frac{k\sqrt{s}}{4\pi}\,\sigma_{\rm tot}(s)\,(i+\rho)\,e^{bt}$$

The spin averaged differential cross section may therefore be expressed as

$$\frac{16\,\pi}{{\sigma_{\rm tot}}^2}\,\frac{d\sigma}{dt} \;=\; \left(1+\rho^{\,2}\right)\left(1+\beta^{\,2}\right)e^{2bt}$$

where $\beta(s,t)$ parametrizes the contribution from smaller spin dependent amplitudes all but $H_1 - H_4$ of which vanish in the forward direction so that, at $t = 0$,

$$\left[\,\beta(s,0)\,\right]^2 \;=\; \frac{1}{2}\left(\frac{\sigma_{\rm tot}^{\rm al}}{\sigma_{\rm tot}}\right)^2\frac{1+\rho_{\rm al}^{\,2}}{1+\rho^{\,2}}$$

The asymmetry parameter for vector polarized deuterons

$$\frac{i}{\sqrt{6}} t_{11}^{00} \; = \; - \frac{\mathrm{Im}\, H_2^*(H_1 - H_3 + H_4)}{2|H_1|^2 + 4|H_2|^2 + 2|H_3|^2 + |H_4|^2}$$

takes a simpler form in the case where the hadronic amplitudes $H_1 - H_4$ and H_3 are negligible at high energies

$$i\sqrt{3}\, t_{11}^{00} \; = \; - \frac{2\, \mathrm{Im}\, \sqrt{2}\, H_2^*\, H_1}{|H_1|^2 + \frac{2}{3}\, \left|\sqrt{2}\, H_2\right|^2} .$$

Interference phenomena result from the inclusion of electromagnetic effects due to one photon exchange. The corresponding amplitudes involve the three form factors of the deuteron, two of which are normalized according to

$$F_1^{\rm d}(0) = 1$$

$$G_1^{\rm d}(0) = \mu_d = 0.8574$$

in nuclear magneton units. The third quadrupole moment form factor of the deuteron $F_2^{\rm d}(t)$ appears with a multiplicative factor t and is therefore relatively unimportant in the small angle region under investigation. The electromagnetic helicity amplitudes for a spin one particle of unit charge and form factors $F_1^{\rm d}$ and $G_1^{\rm d}$ colliding with a spinless target of charge $6e$ and form factor $F_{\rm C}$ at high energy and low momentum transfer are approximately

$$
\begin{aligned}
H_1^{\rm em} &\approx 6\,\alpha\,F_{\rm C}\,F_1^{\rm d}\,\frac{s}{t} \\
\sqrt{2}\,H_2^{\rm em} &\approx 6\,\alpha\,F_{\rm C}\,F_1^{\rm d}\,\frac{s}{t}\left(\frac{\mu_d}{2} - \frac{m_p}{m}\right)\frac{\sqrt{-t}}{m_p} \\
H_3^{\rm em} &\approx 0 \\
H_4^{\rm em} &\approx 6\,\alpha\,F_{\rm C}\,F_1^{\rm d}\,\frac{s}{t}
\end{aligned}
$$

the correspondence with the proton carbon case is evident. It is convenient to introduce the following with kinematically scaled ratio τ between helicity flip and helicity non flip hadronic amplitudes

$$F = \frac{1}{2\,k\sqrt{s}} \frac{2H_1 + H_4}{3}, \qquad \frac{\sqrt{-t}}{m_p}\tau F = \frac{1}{2\,k\sqrt{s}}\sqrt{2}\,H_2$$

so that the analyzing power may be written compactly as

$$\frac{A_N}{4\pi}\frac{d\sigma}{dt} = \frac{\sqrt{-t}}{m} 2\,\mathrm{Im}\,(F + F^{\,\mathrm{em}})^* \left[\tau F + \left(\frac{\mu_d}{2} - \frac{m_p}{m}\right) F^{\,\mathrm{em}}\right]$$

where $F(s,t)$ refers to the hadronic part of d–C scattering.

The spin averaged differential cross section written as

$$\frac{1}{4\pi}\frac{d\sigma}{dt} \;=\; |F + F^{\,\rm em}|^2 + \frac{-2t}{3m_p^2}\left|\,\tau F + \left(\frac{\mu_d}{2} - \frac{m_p}{m}\right) F^{\,\rm em}\,\right|^2$$

involves the electromagnetic nonflip amplitude including Coulomb phase δ

$$F^{\,\rm em} \;=\; \frac{6\alpha}{t}\, F_d\, F_C\, e^{i\,\delta}$$

The deuteron carbon elastic scattering amplitude may be calculated approximately at momentum transfer $q = \sqrt{-t}$

using the Glauber formula

$$F(z) = 2f(q)f_d(q/2) + i\int \frac{d^2q'}{\pi} f(q/2+q')f(q/2-q')f_d(q')$$

where the proton carbon scattering amplitude $f(q)$ is assumed equal to the neutron carbon amplitude. The Gaussian form for $f(q) = F_d(q^2)$ is taken from Franco and Glauber, Phys Rev 142, 1195 (1966). The following figures indicate the expected values of the analyzing power for pC elastic scattering in the case of a number of values of the helicity flip parameter τ.

τ=0

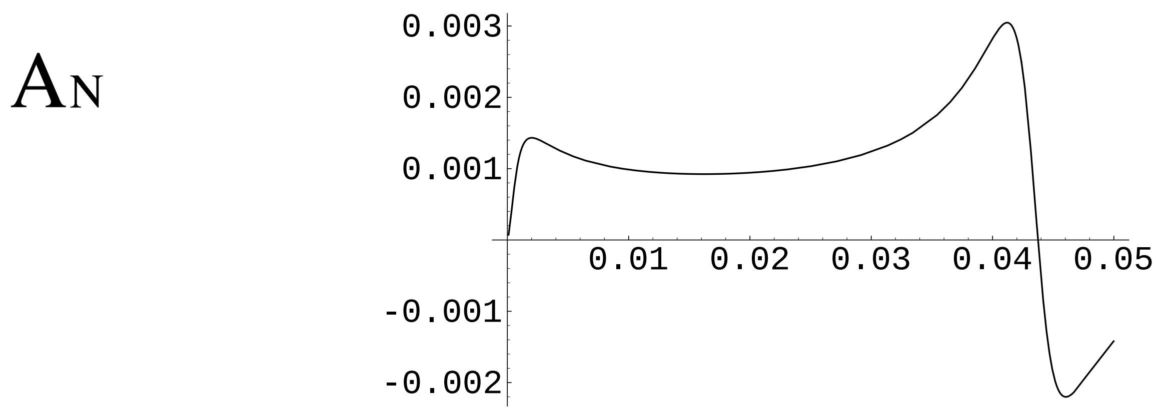

Figure 1: *The d-C* $i\sqrt{3}t_{11}^{00}/2$ *value.*

$\tau = -0.214 - 0.054\, i$

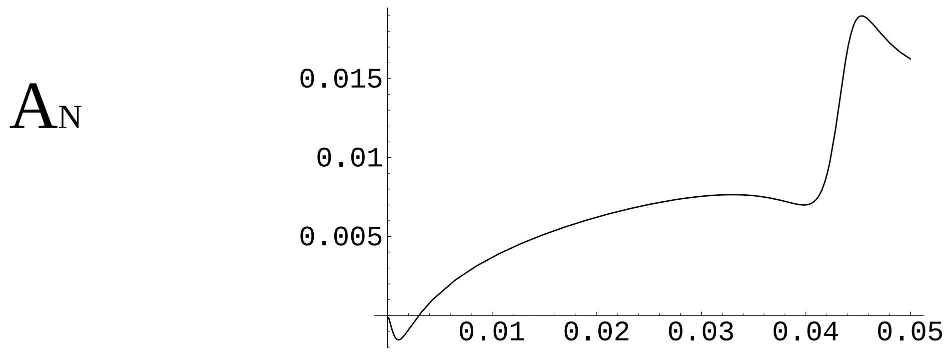

Figure 2: *The d-C* $i\sqrt{3}t_{11}^{00}/2$ *value*

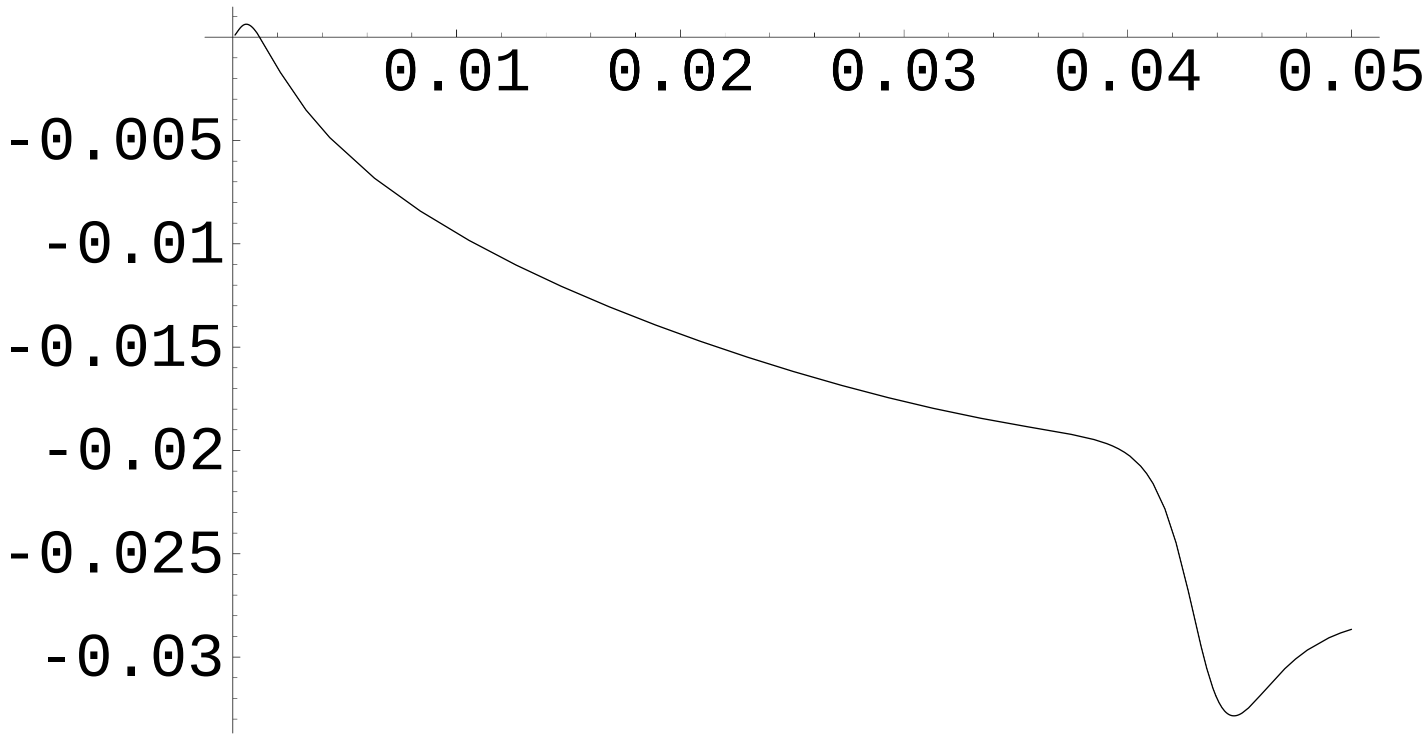

Figure 3: *The d-C* $i\sqrt{3}t_{11}^{00}$ *value with spin flip factor* $\tau = -0.130 - 0.053\,i$