Spin dynamics for high energy protons

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Lagrange

born at via Lagrange within Torino, 1736

worked in Torino, Berlin, and Paris, 1813

Hamilton

born in Dublin at 12pm, August 3, 1805

worked all his life near Dublin until 1865

events: www.hamilton.tcd.ie

Summary

- New spin frontier from RHIC pp collider
- Partonic spin structure of the nucleon
- Scaled proton proton helicity amplitudes
- Rôle in understanding analyzing powers
- Longitudinal and transverse asymmetries
- Spin dependence studies for polarimetry
- Conclusions

Introduction

Polarized proton beams facilitate a study of the spin dependent amplitudes of pp elastic scattering, particularly

$$\phi_+(s,0) \;\propto\; \sigma_{\rm tot}\,(i+\rho)$$

$$\phi_-(s,0) \;\propto\; \Delta\sigma_{_L}\,(i+\rho_-)$$

$$\phi_2(s,0) \;\propto\; \Delta\sigma_{_T}\,(i+\rho_2)$$

$$\phi_5(s,t) \;\propto\; \sqrt{-t}$$

with the definitions, $\phi_\pm = (\phi_1 \pm \phi_3)/2$ where ϕ_+ here refers to the dominant spin averaged proton proton amplitude.

Proton carbon elastic scattering has been successfully used by the E950 Collaboration as a polarimeter for RHIC. Polarized neutron studies could use forward deuteron carbon elastic scattering or helium-3 carbon elastic scattering for polarimetry. Understanding the hadronic spin dependence would increase the effectiveness of each polarimeter.

`Kopeliovich, Lapidus, YaF 19 (1974) 340`

`Bourrely, Soffer, DW, NP B91 (1974) 386`

`NHB, Gotsman, Leader, PR D18 (1978) 694`

`Akchurin, NHB, Penzo, PR D51 (1995) 3944`

`NHB, BK, EL, JS, TLT, PR D59 (1999) 114010`

`NHB, Leader, Trueman, PR D64 (2001) 094021`

`JT IA MB BB GB AD .., PRL 89 (2002) 052302`

Scaled amplitudes

Introduce ratios of amplitudes relative to the dominant imaginary proton proton amplitude $\mathrm{Im}\,\phi_+$

$$
\begin{aligned}
R_2 + i\, I_2 &= \frac{\phi_2}{2\,\mathrm{Im}\,\phi_+} \\
R_- + i\, I_- &= \frac{\phi_-}{\mathrm{Im}\,\phi_+} \\
R_5 + i\, I_5 &= \left(\frac{m}{\sqrt{-t}}\right) \frac{\phi_5}{\mathrm{Im}\,\phi_+}
\end{aligned}
$$

as such ratios are expected to have a variation in t that is less pronounced near the forward direction of scattering.

To first order in small quantities ρ, R_5, I_5, and Coulomb phase δ, the maximum of the pC asymmetry A_N occurs at t value

$$\frac{t_{\max}}{t_c} = \sqrt{3} - \rho - \delta - \frac{8}{\mu - 1} R_5 + \cdots$$

where $t_c = 8\,\pi\,\alpha/\sigma_{\rm tot}$ near interference. The maximum of $A_{\rm N}$ to first order is

$$\frac{4\,m\,A_{\max}}{\sqrt{-3\sqrt{3}\;t_c}} = (\mu - 1)\left[1 + \frac{\sqrt{3}}{2}(\rho + \delta)\right.$$

$$\left. - 2\sqrt{3}\,R_5 - 2\,I_5 + \cdots\right]$$

Similar expressions appear for the pp asymmetry A_N but with additional terms R_2, I_2, R_-, I_-, reflecting the more elaborate pp spin dependence.

- A positive value of ρ, about 0.10 over the RHIC energy range, would enhance the single spin asymmetry maximum

- A positive real or imaginary part of the single helicity flip amplitude would reduce the maximum of the asymmetry

- It would be helpful to know more about the augmented helicity flip amplitudes, R_5 and I_5, and generally R_2, I_2, R_-, I_- in the case of pp elastic scattering.

The spin dependent amplitudes of proton proton collisions are, in fact, accessible from asymmetry measurements undertaken in the interference region with both initial protons spin polarized.

Spin asymmetries

A_N, A_{NN}, A_{SS}, A_{LL}, A_{SL} have singular terms in t arising from CN interference. The scaled pp differential cross section

$$\mathcal{I}_0 \equiv \left(\frac{t}{e^{2Bt}\,\sigma_{\rm tot}}\right)\frac{d\sigma}{dt}$$

with a logarithmic slope parameter $2B$ has a singular expansion in powers of t

$$\mathcal{I}_0 = \frac{4\pi}{\sigma_{\rm tot}}\frac{\alpha^2}{t} + \alpha\, a_0 + \frac{\sigma_{\rm tot}}{8\pi}\, b_0\, t + \cdots$$

where it is assumed here that coefficients like a_0, b_0 are essentially t-independent.

For initial protons both polarized along axis, N (normal to the scattering plane), or L (longitudinal), the t expansion is

$$A_{NN}\,\mathcal{I}_0 \;=\; \alpha\, a_{NN} + \frac{\sigma_{\rm tot}}{8\pi}\, b_{NN}\, t\, + \cdots$$

$$A_{LL}\,\mathcal{I}_0 \;=\; \alpha\, a_{NN} \,+\, \frac{\sigma_{\rm tot}}{8\pi}\, b_{LL}\, t\, + \cdots$$

Spin observables with both initial protons polarized along perpendicular axes S, L have a similar power series expansion in t

$$-A_{SL}\,\mathcal{I}_1 \;=\; \alpha\, a_{SL} \,+\, \frac{\sigma_{\rm tot}}{8\pi}\, b_{SL}\, t\, + \cdots$$

In identical pp scattering, $A_{LS} = A_{SL}$ and near the forward direction one could check the expected equality $A_{NN} \approx A_{SS}$.

Like A_{SL}, the spin asymmetry with one of the initial protons polarized has a $\sqrt{-t}$ factor and so in

$$-A_N \mathcal{I}_1 \; = \; \alpha \, a_N \frac{\sigma_{\rm tot}}{8\pi} + b_N \, t + \cdots$$

it is convenient to define another scaled unpolarized differential cross section

$$\mathcal{I}_1 \; \equiv \; \frac{m\sqrt{-t}}{e^{2Bt}\sigma_{\rm tot}} \cdot \frac{d\sigma}{dt}$$

The eight expressions for the measurable coefficients, a_j, b_j, of the asymmetry expansions are sufficient to determine

$$R_j, \, I_j, \quad j = +, \, -, \, 2, \, 5$$

or at least bounds on these amplitudes.

Table 1: The expansion coefficients a_j

Observable	a_j
$\mathcal{I}_0$	ρ
$A_{NN}\mathcal{I}_0$	R_2
$A_{LL}\mathcal{I}_0$	R_-
$-A_{SL}\mathcal{I}_1$	$\kappa(R_2 + R_-)/2$
$-A_N\mathcal{I}_1$	$I_5 - \kappa(1 + I_2)/2$

Recall that for A_N , the occurence of the single helicity flip value I_5 in the coefficient a_N presented a difficulty for polarimeter normalization as does, incidentally, a non-zero value of I_2 .

Only the single helicity flip amplitude represents a problem for proton carbon elastic scattering with just two helicity amplitudes or for deuteron carbon elastic scattering with four helicity amplitudes.

Table 2: The expansion coefficients b_j

Observable	b_j
$\mathcal{I}_0$	$(1+\rho^2+R_-^2+I_-^2)/2+R_2^2+I_2^2$
$A_{NN}\mathcal{I}_0$	$R_2(\rho+R_-)+I_2(1+I_-)$
$A_{LL}\mathcal{I}_0$	$\rho R_- + I_- + R_2^2 + I_2^2$
$-A_{SL}\mathcal{I}_1$	$R_5(R_2+R_-)+I_5(I_2+I_-)$
$-A_N\mathcal{I}_1$	$I_5(\rho+R_2)-R_5(1+I_2)$

Analyzing power

- The analyzing power for polarized protons has a maximum in the Coulomb interference momentum transfer region.
- Spin effects change the value of the maximum expected on theoretical grounds in the absence of such effects.
- Many spin dependent terms can be obtained from double spin asymmetry measurements near forward angles.
- A study of the energy dependence of individual terms via interpolation, or

through the use of analyticity relations, would assist the understanding of their contribution to other processes such as deuterium or helion carbon elastic scattering

- The dipole magnetic moment of the deuteron $\mu_{\rm d} = 0.8574$ is less than the proton's $\mu_{\rm p} = 2.7928$ changing the maximum in the pC analyzing power to a small minimum in the dC analyzing power near the interference region.

- Isolating helicity dependent terms could elicit their energy and momentum transfer dependence and facilitate the understanding of proton spin structure.

Conclusions

- Understanding hadronic spin dependence assists polarimetry
- Change in maximum analyzing power at interference
- Implications for polarized deuteron and helion beams
- Causality test via analyticity of spin dependent amplitudes
- Measurement of double spin asymmetries near forward direction

Colours

pink mgnt prpl navy azur cyan teal