Pomeron spin-flip from single-spin asymmetry of forward protons

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Does the Pomeron flip proton helicity?

At first glance it does not, because treated perturbatively, the quark-gluon vertex conserves helicity. However, the sum the quark helicities is not equal to the proton one, since their momenta are not parallel. Besides, the anomalous color-magnetic moment of a quark generates a helicity-flip amplitude.

The fractional spin-flip:

\[ r_5 = \frac{2m_N \Phi_5}{\sqrt{-t} \text{Im}(\Phi_1 + \Phi_3)} \]

\[ \Phi_1 = \langle ++ | \hat{M} | ++ \rangle ; \quad \Phi_3 = \langle +- | \hat{M} | +- \rangle ; \quad \Phi_5 = \langle ++ | \hat{M} | +- \rangle . \]

Even if \( r_5 \) is sizable, it hardly can be seen in the hadronic single-spin asymmetry

\[ A_N \frac{d\sigma}{dt} = 2\text{Im}\{\Phi_5^* (\Phi_1 + \Phi_3)\} \]

Indeed, if Regge factorization holds, the relative phase shift vanishes.

Interference with Coulomb amplitude offers a unique possibility to measure \( r_5 \)


Coulomb-nuclear interference (CNI)

The Coulomb amplitude is known, both spin-flip and non-flip parts. The hadronic non-flip amplitude is known as well from data. Assuming $r_5=0$ the asymmetry $A_N(t)$ can be fully predicted.

$$A_N(t) = \frac{4(t/t_P)^{3/2}}{3(t/t_P)^2 + 1} A_N(t_P)$$

$$t_P = -8\sqrt{3} \frac{\pi \alpha}{\sigma_{\text{tot}}}$$

$$\mu_P - 1 \approx 1.79$$

anomalous magnetic moment of the proton


Coulomb-nuclear interference (CNI)
While accuracy is rather good, this is not an ultimate source of information about the Pomeron spin-flip. The energy is not high enough to neglect contribution to $r_5$ from iso-vector Reggeons ($\rho, a_2$) with large spin-flip.
CNI in pA elastic scattering

Nuclear targets strongly suppress, or completely exclude iso-vector Reggeons.

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\[ A_N^{pA}(s, t) \left( \frac{d\sigma_{el}^{pA}}{dt} \right) = \frac{Z\alpha\sigma_{tot}^{pA}}{2m_p q} F_A^C(q^2) F_A^H(q^2) [\mu_p - 1 - 2\text{Im} r_5] \]

\[ \frac{d\sigma_{el}^{pA}}{dt} = \left[ \frac{\sigma_{tot}^{pA} F_A^H(t)}{16\pi} \right]^2 + 4\pi \left( \frac{Z\alpha F_A^C(t)}{t} \right)^2 \]

\[ F_A^H(q^2) = \frac{1}{2\sigma_{tot}^{pA}} \int d^2b \ e^{i\vec{q}\vec{b}} \left[ 1 - e^{-\frac{1}{2}\sigma_{tot}^{pN} T(b)} \right] \]

\[ F_A^C(q^2) = \frac{1}{A} \int d^2b \ e^{i\vec{q}\vec{b}} T(b) \]
CNI in pC elastic scattering

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Calculations with a most realistic oscillatory parametrization for the nuclear density, including Coulomb phase shift, real parts, etc. Proposed as a parameter free polarimetry.

Crossing indeed is observed
CNI in pAu elastic scattering

Troubles are due to incorrect electromagnetic formfactor:

Preliminary
CNI in ultra-peripheral pA collisions

The electromagnetic amplitude gets the main contribution from ultra-peripheral collisions (UPC), while the hadronic amplitude is not zero only at small impact parameters, $b < R_A$

How can amplitudes with so different impact parameters interfere? - They do due to coherence.
CNI in ultra-peripheral pA collisions

Further adjustments are possible
r5 from pA elastic scattering

The global fit give a reasonable values for Re and Im of r5, but not reliable so far
While precise measurements of single-spin asymmetry of forward protons allows a rather accurate determination of the fractional spin-flip amplitude $r_5$, its interpretation is still questionable, because of the contribution of Reggeons with large spin-flip.

Nuclear targets suppress or completely eliminated the contribution of iso-vector Reggeons with a large spin-flip. Recent measurements in the CNI region for D, C, Al and Au open new opportunities for study of $r_5$.

A novel mechanism of interference of electromagnetic UPC with central hadronic collisions is proposed attempting at explanations of $p$-$Au$ data for CNI generated $A_N$.

Nevertheless, an accurate determination of $r_5$ from $pA$ data is still a challenge.