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SPIN EFFECTS IN HIGH-ENERGY NUCLEON-NUCLEON SCATTERING

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The polarization of the scattered nucleons in a scattering process where one of the initial nucleons is polarized is calculated with the assumption that the NN scattering at high energies is determined by singularities in the complex j plane with definite quantum numbers.

In the present paper we consider spin effects in NN scattering under the assumption that the leading singularity (or sequence of singularities) in the complex j plane determining the high-energy behavior of the scattering amplitude has definite quantum numbers: isospin T, G parity, signature P_j, and parity P. Whereas the behavior of the amplitude as a function of s and t depends on the type of singularity in the j plane, its spin structure is determined solely by the quantum numbers just enumerated. As to the type of singularities, there are indications that besides the Regge poles, moving branch points may occur in the j plane.[1]

To classify the states of the $N\overline{N}$ system (t channel), it is convenient to divide them into three groups:[2]

$$\text{a)}\ PP_j = +1,\quad (-1)^T P_j G = +1;$$
$$\text{b)}\ PP_j = -1,\quad (-1)^T P_j G = -1;$$
$$\text{c)}\ PP_j = -1,\quad (-1)^T P_j G = +1.$$

The spin structure of the scattering amplitude is different for these three cases and identical for states belonging to the same group.

Let us write the amplitude in the c.m.s. of the s channel in terms of two-component spinors (a relativistically invariant form of the amplitude is given by Volkov and Gribov[2]). For the states of group a) we have

$$M = A(s,t)1\cdot 1 + B(s,t)[i\sigma_2^{(1)}\cdot 1 + 1\cdot i\sigma_2^{(2)}] + C(s,t)i\sigma_2^{(1)}\cdot i\sigma_2^{(2)}. \tag{1}$$

The reaction plane is the xz plane. The indices 1, 2 refer to the initial nucleons, and 1′, 2′ to the final nucleons. The z axis is taken along the direction of the momentum $\mathbf{p}_1$ in the c.m.s. We consider the case of large $s = (p_1 + p_2)^2$ and small $t = (p_1 - p_1')$. When the leading state is a Regge pole, then $AC = B^2$, as is well known.[3]

For the states of group b)

$$M = D(s,t)\sigma_3^{(1)}\sigma_3^{(2)}, \tag{2}$$

and for the states of group c)

$$M = F(s,t)\sigma_1^{(1)}\sigma_1^{(2)}. \tag{3}$$

Since the states of type b) and c) only contribute to one invariant amplitude, the spin dependence of the matrix element is the same as in the corresponding single-pole case.

Let us now consider the polarization of the scattered nucleons in the case where one of the initial nucleons (for example, 1) is polarized. Let ξ be the polarization vector of the initial nucleon. Then the polarization of nucleon 2′ for the states b) and c) vanishes and the polarization of nucleon 1′ is

$$\boldsymbol{\xi}_1' = -\xi_x\mathbf{i} - \xi_y\mathbf{j} + \xi_z\mathbf{k}$$

for the states of type b), and

$$\boldsymbol{\xi}_1' = \xi_x\mathbf{i} - \xi_y\mathbf{j} - \xi_z\mathbf{k}$$

for the states of type c), where **i, j, k** are the basis vectors of the coordinate system.

In case a) both nucleons will in general be polarized:

$$\boldsymbol{\xi}_1' = \frac{1}{\sigma_0}\{[(|A|^2 - |C|^2)\xi_x - 2\xi_z \operatorname{Re} B(A+C)^*]\mathbf{i} + [(|A|^2 + 2|B|^2 + |C|^2)\xi_y - 2\operatorname{Im} B(A-C)^*]\mathbf{j} + [(|A|^2 - |C|^2)\xi_z + 2\xi_x \operatorname{Re} B(A+C)^*]\mathbf{k}\},$$

$$\boldsymbol{\xi}_2' = \frac{2}{\sigma_0}[\operatorname{Im} B^*(A-C) + \xi_y(|B|^2 - \operatorname{Re} A^*C)]\mathbf{j},$$

where

$$\sigma_0 = \{|A|^2 + 2|B|^2 + |C|^2 + 2\xi_y \operatorname{Im} B^*(A-C)\}.$$

If $\xi = 0$, then

$$\boldsymbol{\xi}_1' = \boldsymbol{\xi}_2' = \frac{2}{\sigma_0}\operatorname{Im} B^*(A-C)\mathbf{j},$$

where in the case of Regge poles the polarization can arise only from the interference of the vacuum pole with other poles,[3] and must hence vanish for $s \to \infty$. With our assumptions the polarization may, in general, be different from zero.

Let us consider scattering into the angle 0°. In general we have three nonvanishing amplitudes:

$$M = A(s,0)1\cdot 1 + D(s,0)\sigma_3^{(1)}\sigma_3^{(2)} + F_1(s,0)[\sigma_1^{(1)}\sigma_1^{(2)} + \sigma_2^{(1)}\sigma_2^{(2)}]. \qquad (4)$$

For the polarization we find

$$\xi_1' = \frac{1}{\sigma_0}\left\{(|A|^2-|D|^2)\xi + 2(|D|^2-|F_1|^2)\frac{(\xi\mathbf{p})\mathbf{p}}{|\mathbf{p}|^2}\right\},$$

$$\xi_2' = \frac{1}{\sigma_0}\left\{[2|F_1|^2 + 2\,\mathrm{Re}\,AD^*]\frac{(\xi\mathbf{p})\mathbf{p}}{|\mathbf{p}|^2} + 2\,\mathrm{Re}(A+D)F_1^*\left[\xi - \frac{(\xi\mathbf{p})\mathbf{p}}{|\mathbf{p}|^2}\right]\right\}, \qquad (5)$$

where

$$\sigma_0 = |A|^2 + 2|F_1|^2 + |D|^2.$$

The behavior of A(s, 0) and D(s, 0) is determined, analogously to (1) and (2), by the states of types a) and b), respectively. As far as $F_1(s,0)$ is concerned, we note the following. It follows from (1), (3), and (4) that $F(s,0) = -C(s,0)$; but since the behavior of C(s, t) is asymptotically determined by the states of type a) and that of F(s, t) by states of type c), the nonvanishing of $F_1(s,0)$ requires that the singularities with different PP_j (but the same signature and isospin) coincide for $t = 0$. Otherwise $F(s,0) = 0$. The problem of the coincidence of the Regge poles for $t = 0$ has been discussed in detail in [2]. There it was also noted that (for the case of Regge poles) if $C(s,0) \neq 0$ for some pole of type a) then the contribution of that pole to A(s, 0) vanishes, and vice versa. This is a consequence of the factorization of the residues at the pole, leading to the relation $AC = B^2$, taking account of the fact that $B(s,t) \sim \sqrt{t}$ for $t \to 0$. If the singularities different from Regge poles coincide for $t = 0$, then both C(s, 0) and A(s, 0) are in general different from zero.

Thus, if the asymptotic forward scattering amplitude is determined by states of the type a) then the function A(s, 0) is left in (5); if, on the other hand, the states of type b) dominate, then A(s, 0) and F(s, 0) can be neglected in comparison with D(s, 0). Finally, if the asymptotic amplitude is determined by the coincidence of singularities of types a) and b), then F(s, 0) and A(s, 0) are left in (5), where $A(s,0) = 0$ if the coinciding singularities are Regge poles. In particular, if the vacuum states of the t channel determine the asymptotic forward scattering amplitude without charge exchange, then $\xi_1' \to \xi$, $\xi_2' \to 0$ for $s \to \infty$.

Thus we find that if one of the initial nucleons is polarized, the measurement of the polarization of the scattered nucleons allows one to test the hypothesis that the leading singularities in the complex j plane are singularities with definite quantum numbers.

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[1] S. Mandelstam, Nuovo Cimento **30**, 1113, 1127, and 1148 (1963). V. N. Gribov, I. Ya. Pomeranchuk, and K. A. Ter-Martirosyan, Phys. Lett. **9**, 269 (1964).

[2] D. V. Volkov and V. N. Gribov, JETP **44**, 1068 (1963), Soviet Phys. JETP **17**, 720 (1963).

[3] V. N. Gribov and I. Ya. Pomeranchuk, JETP **42**, 1682 (1962), Soviet Phys. JETP **15**, 1168 (1962).

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87