Shrinking of the diffraction peak in elastic scattering by deuterons and light nuclei

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It is shown that the growth of the Glauber correction with energy causes a rapid shrinking of the diffraction peak (i.e., an increase of the effective value of $\alpha'_{\rm eff}$). Measurement of $\alpha'_{\rm eff}$ for a deuteron (or a light nucleus) can yield the rate of growth of the correction for screening with increasing energy and the value of the three-pomeron vertex in the region of very small momentum transfers $|t| < 0.2$ GeV^2.

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It was observed recently[1] that the shrinking of the diffraction cone in elastic *pd* scattering at energies 50 to 400 GeV/c is double that for *pp* scattering. In this paper we wish to call attention to the following: (a) a relatively small growth of the Glauber correction with increasing energy leads to a strong increase of the rate of shrinkage of the diffraction peak (i.e., of the effective value of $\alpha'_{\rm eff}$) for deuterons and nuclei; (b) the value of $\alpha'_{\rm eff}$ for the deuteron at high energies (>200 GeV/c) yields direct information and the three-pomeron vertex $G_{3I\!P}(t)$ at small momentum transfers $|t|$, or more accurately on the integral $\int G_{3I\!P}(t)S(4t)\,dt$, where $S(t)$ is the form factor of the deuteron ($S(t) = G_{ed}(t)/G_{ep}(t)$, and G_{ed} and G_{ep} are the form factors measured in the scattering of the electrons by the deuteron and the proton).

1. Let us analyze the amplitude of the *pd* scattering

$$A_{pd}(t) = S(t)[A_{pp}(t) + A_{pn}(t)] + A_G(s,\ t). \tag{1}$$

(Here A_G is the amplitude corresponding to the Glauber correction and s is the square of the total energy of the two nucleons.)

Inasmuch as at high energies the real parts of the amplitudes are small and, as shown in[1], they cannot noticeably influence the effect of interest to us, we consider only the imaginary part of A_{pd} and put

$$A_{pp} = A_{pn} = is\sigma_{pp}\exp(bt/2);\ \ (b = b_0 + 2a'\ln s),\ \ A_G = -is\,\Delta\sigma e^{ht};$$
$$(h = h_0 + h'\ln s). \tag{2}$$

The slope of the diffraction peak B then takes the form

$$B = \frac{2\partial\ln(A_{pd}(t))}{dt} = \frac{(2R^2 + b)S(t) - h\dfrac{\Delta\sigma}{\sigma_{pp}}\exp(ht - bt/2)}{S(t) - \dfrac{\Delta\sigma}{2\sigma_{pp}}\exp(ht - bt/2)}, \tag{3}$$

where the deuteron radius is $R^2 = \partial(\ln S(t))/\partial t$. The shrinking ($B'$) of the cone with energy is equal to

$$B' = 2\alpha'_{\text{eff}} = \frac{2\alpha' S(t) - h'(\Delta\sigma/\sigma_{pp})\exp(ht - bt/2) - h\frac{\partial}{\partial \ln s}\left(\frac{\Delta\sigma}{\sigma_{pp}}\exp(ht - bt/2)\right)}{+S(t) - \frac{\Delta\sigma}{2\sigma_{pp}}\exp(ht - bt/2)} \tag{4}$$

$$+\frac{(2R^2 + b)S(t) - h(\Delta\sigma/\sigma_{pp})\exp(ht - bt/2)}{\left[S(t) - \frac{\Delta\sigma}{2\sigma_{pp}}\exp(ht - bt/2)\right]^2}\frac{\partial}{\partial \ln s}\left(\frac{\Delta\sigma(s)}{2\sigma_{pp}(s)}\exp(ht - bt/2)\right)$$

and is determined in the main by two factors: the shrinking of the cone in nucleon-nucleon scattering (α') and the change of the relative magnitude of the Glauber correction. Even a small change of this quantity turns out to be very appreciable, since the derivative $(\partial/\partial \ln s)[(\Delta\sigma/2\sigma_{pp})\exp(ht - bt/2)]$ is multiplied by the large deuteron radius [R^2 in the second term of (4)]. Since the Glauber correction itself is small, the dependence of the amplitude $A_G(t)$ on the momentum transfer t has practically no effect on rate of shrinking B' of the cone [in formula (4), the slope h (h') is multiplied by the ratio $\Delta\sigma/2\sigma_{pp} \lesssim 0.05$]. We can therefore use the simple parametrization (2) for the amplitude A_G.

Neglecting the t-dependence of A_G in the region of small $|t| < 0.1$ GeV^2, we obtain

$$B'(t) = \frac{2\alpha' S(t)}{S(t) - \Delta\sigma/2\sigma_{pp}} + \frac{(2R^2 + b)S(t)}{[S(t) - \Delta\sigma/2\sigma_{pp}]^2}\frac{\partial}{\partial \ln s}\left(\frac{\Delta\sigma}{2\sigma_{pp}}\exp(ht - bt/2)\right). \tag{5}$$

A characteristic property of formulas (4) and (5) is the faster shrinking (B') of the cone at large momentum transfers $|t|$, this being due to the decrease of the denominators[1)] $(S(t) - \Delta\sigma/2\sigma_{pp})$. For example, even at $|t| = 0.07$ GeV^2 the second term of (5) increases 2.8 times. As a result, to explain the experimentally observed difference between the value of B' ($B' = 0.94$ GeV^{-2} over the interval $0.013 < |t| < 0.14$ GeV^2)[1] and $2\alpha' = 0.56$ GeV^{-2}, [2] it suffices to have the correction $\Delta\sigma$ increase by 0.25 mb when $\ln s$ is changed by unity.

We emphasize that measurement of the dependence of B' on the interval of t would make it possible to verify formulas (4) and (5) and to determine the value of $(\partial/\partial \ln s)[\Delta\sigma/(\sigma_{pp} + \sigma_{pn})]$.

2. It should be noted that the authors of[1] have themselves discussed the effect of the energy dependence of the Glauber correction $\Delta\sigma$ on the value of B'. They have arrived at the conclusion, however, that the possible growth of $\Delta\sigma$ changes B' only insignificantly (within ± 0.1 GeV^{-2}). The reason for this conclusion was that in[1] they used a concrete parametrization of the amplitude $A_G = -is(\Delta\sigma_{el} + \delta \ln s)$, where the coefficient δ was too small.

If it is assumed that, in accord with the exchange-degeneracy hypothesis[2)] $\sigma_{pp} = \sigma_{pn}$, then the data on the total pp and pd cross sections[3] indicate that, as seen from the figure, a rather fast growth of the Glauber correction

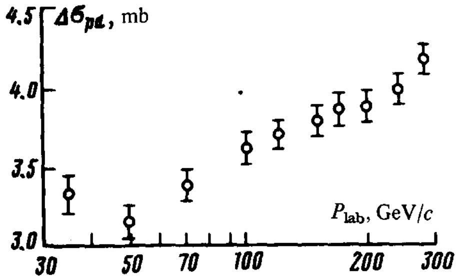

FIG. Energy dependence of the correction for the screening in the deuteron.

$(\partial(\Delta\sigma_{pd})/\partial \ln s \approx 0.4$ mb). This growth of $\Delta\sigma_{pd}$ explains readily the experimentally observed[1] shrinking of the peak in pd scattering.

3. We shall discuss briefly the cause of the growth of $\Delta\sigma$. The correction for the screening $\Delta\sigma = \Delta\sigma_{el} + \Delta\sigma_{in}$ consists of two parts: elastic $\Delta\sigma_{el}$ and inelastic $\Delta\sigma_{in}$. The elastic correction in pd scattering[5]

$$\Delta\sigma_d = \frac{\sigma_{pp}\sigma_{pn}}{8\pi}\int S(4t)\exp(bt)\,dt \tag{6}$$

increases quite slowly in the region 50—280 GeV/c, since the pp-interaction cross section increases only by 3% when the energy changes from 50 to 280 GeV/c. This change of the pp (pn) cross section increases $\Delta\sigma_{el}$ by approximately 0.08 mb.

The increase of the inelastic correction[7] at high energies (it begins already at 200 GeV/c, as shown in[6]) is determined entirely by the three-pomeron vertex $G_{3\mathbb{P}}(t)$, which can be obtained if one knows the inclusive spectra in the three-pomeron region

$$\Delta\sigma_{in}^{3\mathbb{P}} = 2\pi\int G_{3\mathbb{P}}(t)\,S(4t)\,dt\,\frac{dx}{1-x} = 2\int\frac{d\sigma^{3\mathbb{P}}}{dt\,dM^2}\,S(4t)\,dt\,dM^2, \tag{7}$$

If we use the parametrization of[8], then

$$\Delta\sigma_{in}^{3\mathbb{P}} = \text{const} + \ln s \cdot 0.13 \text{ mb} . \tag{8}$$

Some additional growth of $\Delta\sigma_{in}$ takes place at lower energies (50—150 GeV/c) because of non-pomeron contributions, e.g., because of the fading out of the $\pi\pi R$ contribution, the sign of which is negative. Consequently the change in the total inelastic correction in the interval of interest to us reaches $\delta = \partial(\Delta\sigma_{in})/\partial \ln s \approx 0.2$ mb, which is in fair agreement with the data on the shrinking of the cone in pd scattering.[1]

4. A similar effect (rapid shrinking of the cone) should be observed also for light nuclei, say He^4.[9] for He^4, however, the value of B' will turn out to be much larger. Indeed, in the region of small $|t|$, where triple rescatterings still do not matter, [at $|t| < 0.1$ GeV^2 the correction connected with the double elastic rescattering in the amplitude is $\approx 0.23/S_{He}(t)$, and is less than $0.04/S_{He}(t)$ in triple rescattering], formula (5) is valid with $S_d(t)$ replaced by $S_{He}(t)$, R_d^2 by R_{He}^2, and $\Delta\sigma/2\sigma_{pp}$ by $\Delta\sigma_{He}/4\sigma_{pp}$. And since the value of the double screening increases very rapidly for He^4 [$\Delta\sigma \propto C_2^2/4R_d^2$ for the deuteron and $\Delta\sigma \propto C_4^2/$

$(8/3)R^2_{He}$ for He^4], it follows that the second term of (5) increases by more than 4.5 times, and we expect $B'(0) \approx 0.35$ GeV^{-2} and B' ($|t| = 0.07$ GeV^2) ≈ 2.8 GeV^{-2} for pHe^4 scattering in the energy region 50—300 GeV/c.

5. Let us formulate the main conclusions: (a) Measurement of the shrinking of the peak B' in pd scattering makes it possible to assess the rate of growth of the Glauber correction with energy [formula (5)]. It is important to verify here that with increasing mean value of $\langle |t| \rangle$ (for the interval in which B' is measured) the value of B' increases. This growth of B' would be a confirmation of the fact that the large value of B' is indeed connected with the growth of the correction for screening, and not with some strange properties of the pn interaction. (b) Since the magnitude of the elastic screening $\Delta\sigma_{el}$ is easy to calculate[3)] [see (6)], it follows that knowing B' we can determine the value of the three-pomeron vertex[4)] in the region of very small momentum transfers. The reason is that the values of $|t|$ that matter in the integral (7) are determined by the deuteron form factor and do not exceed $|t| \approx 1/(4R_d^2) < 0.02$ GeV^2.

[1)]We consider here a region of not too large $|t|$, when $S(t) - \Delta\sigma/2\sigma_{pp} > 0$.

[2)]The equality $\sigma_{pp} - \sigma_{pn}$ does not contradict[4].

[3)]At high energies ($s > 600$ GeV^2) the elastic correction also begins to increase quite rapidly, owing to the growth of the total pp (pn) cross sections.

[4)]Since inclusive spectra in the three-reggeon region are described at present-day energies by the contributions of poles with $\alpha_{I\!P}(0) = 1$ and $\alpha_R(0) < 1$, the remaining three-reggeon vertices (except $G_{3I\!P}$) do not lead to a growth of $\Delta\sigma_{in}$. The influence of multipomeron cuts or of $\alpha_{I\!P}(0) \neq 1$ changes $\partial(\Delta\sigma_{in})/\partial \ln s$ little, and will be considered in detail in[6].

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