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ELECTROMAGNETIC CONTRIBUTIONS OF THE DIFFERENCE OF THE TOTAL CROSS SECTIONS FOR THE SCATTERING OF PARTICLES AND ANTIPARTICLES AT HIGH ENERGIES

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Many recent papers have been devoted to the electromagnetic contributions to hadron scattering cross sections [1 - 7]. We calculate here the differences, due to the interference between the electromagnetic and strong interactions at energies $E \gtrsim 300$ GeV, between the total cross sections for the scattering of particles and antiparticles. We show that the main contribution to the difference of the total cross sections of charged particles and antiparticles decreases logarithmically with increasing energy ($\sim 1/\ln s$) if the scattering cone narrows down logarithmically.

As is well known [3, 5], the radiative correction to the amplitude of elastic scattering of charged particles (we shall speak, for concreteness, of π^+p scattering), which takes correct account of the contribution of soft photons, is given at high energies by

$$A^{rad}_{\pi^+p}(s,\vec{\Delta}^2) = -\frac{i\alpha}{\pi}\int\frac{d^2q_\perp}{q_\perp^2+\lambda^2}A_{\pi^+p}(s,\vec{\Delta}-q_\perp), \qquad (1)$$

where λ is the photon mass and $\vec{\Delta}$ is the momentum transfer.

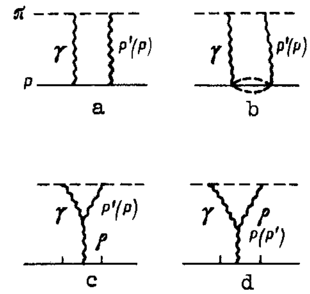
Expression (1) leads to the so-called Bethe phase [8], $\phi_B = -\alpha\ \ln(1/\lambda^{e\ell}t)$, where $t = \vec{\Delta}^2$, and $\lambda^{e\ell} = \alpha'_P \ln s + R_p^2$ is the slope in the amplitude of elastic scattering.

To obtain the contribution made to the difference between the total cross sections it is necessary to employ in (1) the optical theorem. At not too high energies (up to several dozen GeV), neglecting as a result the dependence of the phase of the amplitude on the momentum transfer, we thus obtain

$$r_{em} = 2\frac{\sigma^- - \sigma^+}{\sigma^- + \sigma^+} = 2\alpha\left.\frac{\mathrm{Re}(A_{\pi^+p} + A_{\pi^-p})}{\mathrm{Im}(A_{\pi^+p} + A_{\pi^-p})}\right|_{t=0}\left(\ln\frac{1}{\lambda^{e\ell}t_{min}} - \gamma\right), \qquad (2)$$

where t_{min} is the experimental resolution with respect to the momentum transfer and $\gamma = 0.58$ is Euler's constant.

We assume that the amplitude of the πN interaction has a Regge-like behavior. Then expression (2) corresponds to a $\gamma P'$ branch cut and decreases with increasing energy like $(1/s)^{1/2}$. Other contributions to the difference between the total cross sections also exist and decrease in power-law fashion with increasing s. These are the contributions of the beams to the $\gamma P'$ branch cuts (see Fig. a), and also the electromagnetic renormalization of the residue of the ρ pole (Fig. c). A rough estimate of such contributions was made in [6, 7] under the assumption that the mass spectrum of the inelastic intermediate states (see, e.g., Fig. b) is not bounded. According to this estimate [6], the contribution of the inelastic intermediate states to r_{em} can amount to 1.5% at $\mathrm{Re}\, A/\mathrm{Im}\, A|_{t=0} = -0.2$. We note that at a large beam mass Fig. b can be represented in the form c. The diagram d, which corresponds to electromagnetic renormalization of the residue of the vacuum pole, makes no contribution to the difference between the particle and antiparticle interaction cross sections. The validity of formulas (1) and (2) can be verified by measuring the difference between the total cross sections of $\pi^{\pm}d$ scattering, which is determined mainly by the radiative corrections to the πN amplitude [9].



As a result of the rapid decrease of expression (2) with increasing energy, an important role is played at high energies by the dependence of the phase of the amplitude on the momentum transfer. Recognizing that the signature factor of the vacuum pole is

$$\xi_P = -\frac{1 + e^{-i\pi\alpha_P(q_\perp^2)}}{\sin \pi\alpha_P(q_\perp^2)} \approx i - \frac{\pi}{2}\alpha'_P q_\perp^2 ,$$

we obtain for the contribution of the γP branch cut, by substituting ξ_P in (1) (Fig. a):

$$r^P_{em} = -\alpha \frac{\pi\alpha'_P}{\lambda^{el} + R^2_{em}} , \tag{3}$$

where R^2_{em} takes into account the electromagnetic form factors of the proton and pion.

Assuming that $\alpha'_P = 0.5$, we obtain $r^P_{em} = -1.5 \times 10^{-3}$ at $E_{lab} \sim 300$ GeV. Expression (3) represents the main contribution to the difference between the total cross sections, and is asymptotically independent of α_P: $r^P_{em} = -(\alpha\pi/\ln s)$ at $\alpha'_P \ln s >> R^2_P + R^2_{em}$.

Let us estimate also the contribution of the resonances to r_{em} (Fig. b), using for this purpose the experimental data on the diffraction production of resonances at high energy [10] and on electroproduction of resonances [11].

We parametrize the differential cross section of the elastic π^+p scattering and production of the resonances N* (1525) and N* (1690) by means of the formulas:

$$\frac{d\sigma^{el}}{dt} = A^{el}e^{-2\lambda^{el}t}; \quad \frac{d\sigma^*}{dt} = tA^* e^{-2\lambda^* t}; \quad A^{el} = 32\ \mathrm{mb/GeV^2}. \tag{4}$$

$A^* = 4.4\ \mathrm{mb/GeV^4}$ and $15\ \mathrm{mb/GeV^4}$ for N* (1525) and N* (1690), respectively, $\lambda^* = \alpha'_P \ln s + R^{*2} = 4\ \mathrm{GeV^{-2}}$ at 16 GeV, and we assume that the cross section for forward diffraction scattering vanishes.

For the contribution of each individual resonance we can obtain the following estimate

$$r_{em}^{P*} \lesssim \pi\alpha \frac{\beta_s^* \beta_\gamma^* \alpha_P'}{(\lambda^* + R_{em}^{*2})^2} \qquad (5)$$

where

$$\beta_s^{*2} = \frac{A^*}{A^{el}}, \quad \beta_\gamma^{*2} = \frac{1}{2m_p} \int \left(\lim_{q_\perp^2 \to 0} \frac{w_2(s_1, q_\perp^2)}{q_\perp^2} \right) ds_1 , \qquad (6)$$

$w_2(s_1, q_\perp^2)$ is the known structure function of the inelastic ep interaction, the integral with respect to ds_1 is taken over the given resonance, and $R_{em}^{*2} \simeq 1$ GeV^{-2} [11].

If we take the quantity

$$w_2(s_1, q_\perp^2) / q_\perp^2 = \frac{1}{4\pi^2\alpha} \frac{1}{s_1 - m_p^2} (\sigma_T + \sigma_L) \qquad (7)$$

from [11] at $s_1 = m^{*2}$ and then integrate with respect to ds_1, we obtain $\beta_\gamma^2(1525) = 0.55$ GeV^{-2} and $\beta_\gamma^2(1690) = 0.5$ GeV^{-2}. As a result we get

$$|r_{em}^P(1525)| \lesssim 10^{-4}; \quad |r_{em}^P(1690)| \lesssim 2 \cdot 10^{-4}. \qquad (8)$$

The differential cross section for the production of N* (1470) does not vanish at $t = 0$, but in this case the expression for $r_{em}(1470)$ takes the form (5), since the term linear in $q_\perp$ in the $\gamma P \to N^*(1470)$ amplitude vanishes upon integration with respect to $q_\perp$. For the contribution of N*(1470) we get the estimate $|r_{em}^P(1470)| \lesssim 0.8 \times 10^{-4}$.

If it is assumed that the contributions from the excited states of the pion and of the proton are approximately equal, then we have the following limitation for the summary contribution of the inelastic intermediate states:

$$|r_{em}^*| \lesssim 10^{-3} \text{ for } E \gtrsim 300 \text{ GeV}. \qquad (9)$$

The estimate (9) may turn out to be too high, since it is natural to expect a noticeable cancellation of the different contributions.

It should also be recognized that the quantity Re A/Im A, which enters in (2), contains at $t = 0$ terms $\sim 1/\ln^2 s$ that decrease slowly with increasing energy and result from the PP branching:

$$\left. \frac{\mathrm{Re} A_{\pi^\pm p}}{\mathrm{Im} A_{\pi^\pm p}} \right|_{t=0} = \frac{\sigma^\pm \alpha_P'}{64(\alpha_P' \ln s + R_P^2)^2} . \qquad (10)$$

The corresponding difference of the total cross sections is

$$r_{em}^{PP} = \alpha \frac{\alpha_P' \sigma}{(\alpha_P' \ln s + R_P^2)^2} \left[\ln \frac{2}{t_{min}(\lambda^{el} + 2R_{em}^2)} - 1 \right] \qquad (11)$$

and cancels out approximately 30% of the main contribution (3) at $E \sim 300$ GeV and $t_{min} = 0.05$ GeV^2.

Thus, at high energies ($E \gtrsim 300$ GeV) the electromagnetic contribution to the difference of the total cross sections of $\pi^{\pm}P$ interactions decreases with energy logarithmically and amounts to $\sim 10^{-3}$ of the total cross section. We emphasize that a similar energy dependence will be possessed by the electromagnetic contributions made to the difference of the total cross sections of the interaction of K^+ and K^- or p and $\bar{p}$ with any target. For hadrons that have no electric charge but are not truly neutral (K^+ and $\bar{K}$, n and $\bar{n}$), the electromagnetic difference of the total cross sections will decrease with energy like $1/\ln^2 s$. Modern experimental data favor the assumption that the contributions of the strong interaction to the difference of the total cross sections of the interactions of particles and antiparticles decreases with energy in power-law fashion. If this law does not change on going to higher energies (as is predicted within the framework of the theory of complex angular momenta), then at sufficiently high energies the difference of the total cross sections for the interaction of particles and antiparticles will be connected mainly with the interference of the electromagnetic and nuclear interactions, which is considered in the present paper. Then the electromagnetic contributions to the difference between the total cross sections of $\pi^{\pm}P$ interactions will become dominant already at energies typical of the Batavia accelerator.

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