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POSSIBLE METHODS OF STUDYING INTERFERENCE BETWEEN COULOMB AND NUCLEAR SCATTERING IN THE ELASTIC COLLISION OF PARTICLES OF ENERGY $> 10^{10}$ eV

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Two possible methods of studying the elastic scattering cross section of ultra-high energy particles are examined. The methods in question are not limited by the energy from above, and can be used for investigating elastic scattering in the region of low momentum transfer in which the Coulomb scattering cross section is comparable to the nuclear cross section. In particular, they make it possible to obtain information on the magnitude of the real part of the elastic scattering cross section by studying the interference effect between Coulomb and nuclear scattering.

INTRODUCTION

IT is possible to study the elastic scattering of particles by protons by recording the scattered particle or the recoil proton. In small-angle scattering, however, the recoil proton is of low energy, so that the velocity and direction of its escape are strongly distorted by the target material, impeding the kinematic separation of the elastic events. An increase in energy, in its turn, also causes difficulties in the investigation of elastic processes by studying the scattered particle. We shall make some estimates on the assumption that the square of the average momentum transfer in the elastic scattering of particles decreases with increase in the primary-particle energy no faster than logarithmically.

It is easily seen that for a primary energy of 10^{12} eV the average scattering angle in the laboratory system of coordinates $\psi = P_2/P_0$ is equal to 0.25×10^{-3} radian (P_2 = the average momentum of the recoil proton and P_0 = the momentum of the incident particle). It is found that the greater part of the cross section is concentrated in an angular range that is less than the angular resolving power of modern experiments. At high energies, this limits the possibility of investigating elastic scattering by studying the scattered proton.

The recoil proton behaves differently. The recoil proton momentum is related to its angle of emission ϑ in accordance with the formula

$$P_2 = 2m\beta \cos\vartheta \,/\, (1 - \beta^2 \cos^2\vartheta).$$

where m is the mass of the proton and β its center-of-mass velocity. In the case of small scattering angles the angle ϑ is close to 90° and we can write the following approximation:

$$P_2 \approx 2m\beta(\pi/2 - \vartheta) \equiv 2m\beta\varphi.$$

Since there is little change in the average momentum transfer and the center-of-mass velocity of the proton, there is very little variation in the average angle of emission of the recoil proton $\bar{\vartheta}$ or, consequently, the angle $\bar{\varphi} \approx \bar{P}_2/2m\beta$ with increase in energy. For example, $\varphi \approx 0.12$ radian for $E_0 = 10^{12}$ eV.

In addition to the absence of angular limitations, there are two further reasons which make it convenient to investigate elastic scattering by studying the recoil proton.

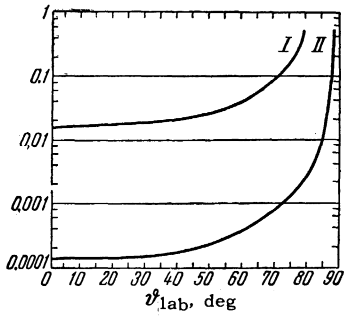
First, for the recoil proton in inelastic processes there is a maximum angle of escape $\vartheta_{\max}$, which makes the entire angular range $\Delta\varphi$ from 90° to $\vartheta_{\max}$ free from background (if a pure hydrogen target is used).

Second, for angles ϑ less than the maximum the relative distance between the boundary of the proton momentum spectrum in the inelastic process $P_{\text{in}}^{\max}(\vartheta)$ and the momentum $P_{el}(\vartheta)$ of the elastically scattered proton

$$\Delta P(\vartheta)/P_{el}(\vartheta) \equiv [P_{el}(\vartheta) - P_{in}^{max}(\vartheta)]/P_{el}(\vartheta)$$

is much greater for the recoil proton than for the scattered proton. Indeed, for pp scattering

$$\frac{\Delta P(\vartheta)}{P_{el}(\vartheta)} = 1 - \frac{1}{2}\left\{\beta\left[\frac{P_{in}^{*2}}{P_{el}^{*2}} + \frac{m^2}{P_{el}^{*2}}\right]^{1/2} + \frac{1}{\cos\vartheta}\left[\frac{P_{in}^{*2}}{P_{el}^{*2}} - \sin^2\vartheta\right]^{1/2}\right\}.$$



Relative distance between the maximum boundary of the proton momentum spectrum in inelastic pp-scattering and the proton momentum in elastic pp-scattering vs. laboratory angle for primary-proton energies of 10 GeV (curve I) and 1000 GeV (curve II).

where P^*_{el} is the center-of-mass momentum for the pp → pp process and P^*_{in} is the maximum center-of-mass momentum of the proton in the pp → ppπ reaction. The figure shows a plot of this function for $E_0 = 10$ GeV and $E_0 = 1000$ GeV.

It can be seen that $\Delta P(\vartheta)/P_{el}(\vartheta) \ll 1$ for low values of ϑ, and only varies from zero to any appreciable extent for values of ϑ close to ϑ_{max}. This means that the separation of the elastic and inelastic processes by using the angle—momentum criterion is easier in the range of values of the angle ϑ close to $\pi/2$ (corresponding to the recoil proton) than for low values of ϑ.

Thus, at ultra-high energies it is impossible to investigate small-angle elastic scattering by studying the scattered particle. A discussion is given below of two methods of eliminating the scattering of the slow recoil proton by the target material.

1. THE USE OF MULTIPLE PENETRATIONS OF THE PARTICLES THROUGH A THIN TARGET

The decrease in target thickness is limited by the value of the beam intensity. We used the method of multiple penetrations of the internal proton beam of the accelerator through the target, thereby increasing the number of interactions in the target several thousand times. It was possible to decrease the target thickness by the same factor. The problems posed by this technique and the results of an experiment carried out on the proton synchrotron at the Joint Institute for Nuclear Research have been described in [1-3]. The potential value of this method is even greater when the work is carried out on a strong-focusing accelerator. Since the angle spread and beam dimensions are smaller than in the case of a weak-focusing accelerator, it is possible to obtain an angular resolution of $\sim 10^{-4}$ radian and to use targets with a density of 10^{17}—18^{18} protons/cm^2, thereby almost entirely eliminating the scattering of the recoil proton by the target material.

2. INVESTIGATION OF SMALL-ANGLE ELASTIC SCATTERING ON EXTRACTED BEAMS

The thin target method is not effective with extracted beams of particles, where it is impossible to provide the conditions of multiple penetrations of the particles through the target. We therefore developed another method for measuring the scattering cross-section of π mesons with low momentum transfer (30 MeV/c < P_2 < 150 MeV/c). A well-defined beam of π mesons with an intensity of $\sim 10^4$ per pulse was passed through a hydrogen-filled cloud chamber. The operating conditions of the chamber were such that it was not sensitive to the relativistic π mesons, but recorded the recoil protons with momentum (30—150) MeV/c, which possessed a high ionizing power. In order to carry out the kinematic separation of the elastic events, we measured the proton momentum and the angle it formed with the direction of the meson beam at the point of interaction.

The meson beam direction field was determined when the chamber was operating under conditions such that it was sensitive to the relativistic protons, and several particles per frame were registered. The direction field was fed to the memory of an electronic computer, which calculated the momentum and angle of the recoil proton at the initial point from the curvature of the track in the magnetic field and the range in the gas. The center-of-mass scattering angle was determined with an error of not more than 0.5°.

In conclusion, it should be noted that the methods described make it possible to measure the elastic scattering cross section in a region in which interference may possibly occur between Coulomb and nuclear scattering for particles of such a suitably high order of energy. An interference effect is, in fact, observed in the angular range in which the Coulomb scattering amplitude is comparable to the nuclear amplitude, $A_C \approx A_N$. It is known that $A_C(\psi^*) \sim \mathrm{const}_1/P^*\beta_\Lambda\psi^{*2}$, and the nuclear amplitude for low values of ψ^* can be assumed to be equal to a value determined by the optical theorem

$$A_N^{(0)} = P^*\sigma_t\,\mathrm{const}_2.$$

where P^* and ψ^* are the center-of-mass scattering momentum and angle of the proton, β_Λ is the laboratory velocity of the incident proton, and

σ_t is the total proton interaction cross section. It is easily found, from the condition $A_C \sim A_N$, that $P_2 \equiv P^*\psi^* = \text{const}\sqrt{\sigma_t/\beta_\Lambda}$ and is only very slightly dependent upon the energy, i.e., that the conditions of measuring the elastic scattering cross section in the interference region hardly vary at all with increase in energy.

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