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In this Final Technical Report, we summarize the results obtained under NASA Grant NSG-8007: "Properties of Scattering Amplitudes at Very High Energies."

In Sections A, B, and C we give a discussion of results obtained on the following three questions: (1) Do total cross sections in the limit as the energy becomes infinite, increase? (2) What is the elastic scattering amplitude for non-forward directions? (3) Do neutrino scattering processes have an upper bound to their cross sections?

A. DO TOTAL CROSS SECTIONS INCREASE IN THE ASYMPTOTIC ENERGY REGION?

We obtained a partial answer to this question by using dimensional analysis and the following assumption: The asymptotic behavior of the total cross section is independent of any dimensional quantities, such as masses, elementary lengths, dimensional coupling constants, etc. Thus, the total cross section may be a function only of $\underline{S}$, which is the only kinematical variable available. ($\underline{S}$ is the square of the total energy in the center-of-mass system.) On the basis of dimensional analysis, we conclude that the asymptotic total cross section has the following functional form,

$$(1)\quad \sigma_t = C/S,$$

where $\underline{C}$ is a positive dimensionless constant.

Note that the result given by eq. (1), for the asymptotic behavior of the total cross section, does not depend on any specific dynamic mechanism and should apply to the strong, weak and certain types of electromagnetic interactions.

This type of behavior for the cross section implies that the effective number of partial waves contributing to the scattering process is constant. Following the methods used in references (1, 2), we were able to determine both upper and lower bounds on (i) the phase of the forward scattering amplitude, (ii) the elastic cross section, (iii) the forward differential cross section, and (iv) the diffraction width.

At present, we are extending this work to include various deep-inelastic scattering processes.

A summary of the above work[3] was presented at the conference on Physics at Ultra-High Energies at Westfield College, University of London (September 4-6, 1974) and at the Washington, D. C., American Physical Society Meeting (April 28-May 1, 1975).

B. WHAT IS THE ELASTIC SCATTERING AMPLITUDE FOR NON-FORWARD SCATTERING?

We have considered, in particular, pion-nucleon scattering at cosmic-ray energies. The amplitudes were obtained from a generalization of the total absorption model[5] to include both spin and phase effects. The helicity-flip amplitude was calculated from a derivative rule[6] and the phases of the amplitudes were determined by imposing on the amplitudes the condition that they be even under crossing.[7]

We have been able to calculate the following physical quantities: (i) the differential cross section for all scattering angles; (ii) the polarization of the nucleon in the near forward and near backward directions; and (iii) the phases of the various amplitudes.

In the future, we will apply these techniques to the case of proton-proton scattering.

This work has been presented at the Washington Meeting of the American Physical Society (April 28-May 1, 1975).[8] In addition, this work will be presented in oral and written form at the 14th International Cosmic Ray Conference to be held at Munchen, Germany (August 15-29, 1975).[9]

C. DO NEUTRINO SCATTERING PROCESSES HAVE AN UPPER BOUND TO THEIR CROSS SECTIONS?

It is well known, using analyticity and unitarity, that high-energy bounds may be derived for strong interaction scattering processes, e.g., the Froissart bound.[10] These bounds require for their proof a finite region of analyticity around the origin in the t-plane. Since all hadrons are massive, this condition is easily satisfied for the strong interactions. However, for the weak interactions, where pairs of massless neutrinos may be exchanged, the above reasoning breaks down, since the t-channel singularity begins at t=0.

We have shown, using the assumptions of analyticity, crossing, unitarity, polynomial boundedness, and a "zero-condition" on the absorptive part of the scattering amplitude, that all neutrino cross sections obey the following upper bound,[11]

$$\sigma(S) \leq \text{const.} \, (\text{Log } S)^2 .$$

In addition, we have obtained information on the functional form of the electric-charge form factor of the neutrino.[12]

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