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E1 - 3267

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ЛАБОРАТОРИЯ ВЫСОКИХ ЭНЕРГИЙ

1967.

E1 - 3267

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# THE REAL PART OF $\pi^- p$ ELASTIC SCATTERING AMPLITUDE IN THE COULOMB INTERFERENCE REGION AT 3.48 AND 6.13 Gev/c

Submitted to JETP Letters

It is known that a measurement of the real part of $\pi N$ elastic scattering amplitude at about zero angles is a good test for the validity of dispersion relations and, consequently, of the general principles of the local field theory. A number of recent papers have been devoted to this subject [1].

In the present paper some data are reported on measurement of the elastic scattering in the range of squared 4-momentum transfers $1.22 \times 10^{-3} \leq -t \leq 4.22 \times 10^{-3} (\mathrm{GeV}/c)^2$ (See Fig. 1). The results of our measurements at 3.48 and 6.13 GeV/c were already published in Prof. Van Hove's review paper presented at the 1966 International Conference on High Energy Physics in Berkeley. Since that time we have somewhat increased the statistics for 6.13 GeV/c, and repeated the most careful analysis of the data.

The ratio $\alpha = \frac{\mathrm{Re}\, A_n}{\mathrm{Im}\, A_n}$ for the real and the imaginary parts of nuclear elastic scattering amplitude has been determined from the Coulomb and nuclear scattering interference effect. Treatment of elastic differential cross section by Bethe's formula [2] gives values of $\alpha_B = -(0.17 \pm 0.07)$ at 3.48 GeV/c and $\alpha_B = -(0.22 \pm 0.09)$ at 6.13 GeV/c. Note that a mean relative phase shift between the Coulomb and nuclear scattering has been calculated in this formula in the framework of the nonrelativistic quantum mechanics. A similar formula is derived in Soloviev's paper [3] on the basis of the relativistic quantum field theory.

$$\frac{d\sigma}{d\Omega} = |A_c|^2 + |A_n|^2 + 2A_c\left(\alpha\, \mathrm{Im}\, A_n + 2\, \mathrm{Im}\, A_n \frac{1}{137\beta} \ln \frac{2}{\theta}\right),$$

where $A_c$ is the Coulomb scattering amplitude, $\alpha \operatorname{Im} A_n$ and $\operatorname{Im} A_n$ are the real and imaginary parts ot the nuclear ampitude respectively, $\beta$ is a lab. pion velocity, $\theta$ is a c.m. scattering angle, $k$ is the pion wave number in the center-of mass system, and a is the proton dimensions. In Bethe's formula we have $\frac{1,06}{k a \theta}$ under the sign of logarithm instead of $\frac{2}{\theta}$.

Treatment of the experimental data by Soloviev's formula gives values of $\alpha_s = -(0.12 \pm 0.07)$ at 3.48 GeV/c and $\alpha_s = -(0.17 \pm 0.09)$ at 6.13 GeV/c [x].

In order to detect small angle $\pi^- p$ scattering events, we have adopted a method using recoil protons [4,5]. Recoil protons were generated and recorded in a magnetic cloud chamber $50 \times 50 \times 15$ cm$^3$ in size filled with hydrogen at 3.5 atm., through which passed a pion flux of $(1-2) \times 10^4$ particles per expansion. The chamber was insensitive to individual relativistic particles of the beam. Use was made of the fact that, for our t-interval, recoil proton ionization losses exceeded those of beam pions 80 times or even more. A special exposure in which the chamber recorded relativistic particles has been made to determine the direction of the beam particles. 30 and 30 thousand pictures were scanned twice for 3.48 and 6.13 GeV/c, respectively. About 12.000 events which satisfied preliminary selection criteria have been analysed. In the main they turned out to be elastic events and 5% of all the cases were contained in our t-interval, in which an essential contribution was made by the interference effect. The single scanning efficiency was (90-94)%. Elastic events were separated from the background by momentum-angle kinematics. The selection of elastic scattering is shown in Fig. 2, which gives the distribution of events as a function of the deviation from kinematic line after the subtraction of the background. The background level is 9 times less than the height of the peak consisting of 355 at 3.48 GeV/c and 224 events at 6.13 GeV/c that satisfy the

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[x] In general, if both $\operatorname{Re} A_n(\pi^- p)$ and $\operatorname{Re} A_n(\pi^+ p)$ are negative, we have $|\alpha_B| > |\alpha_s|$ for $\pi^- p$ scattering while for $\pi^+ p$ scattering we would obtain $|\alpha_B| < |\alpha_s|$. The use of the formula from ref. [3] in the analysis of the data (1c) seems to give a better agreement between the experimental data and calculations on the basis of the forward dispersion relations.

selection criteria (the recoil proton comes to rest in the chamber gas, its momentum is $35 \leq p \leq 65$ MeV/c, track projection length exceeds 1 cm). The main source of background recoil protons were neutrons which are always present near an operating accelerator. Inelastic events made no contribution to the background for kinematic reasons. The weight of each event, which satisfies selection criteria, was determined taking into account azimuthal symmetry of $\pi p$ scattering. The momentum of recoil proton was measured with a high accuracy by its path in the chamber gas. As a result, we obtained a very good $t$-resolution $\Delta t \approx 1 \times 10^{-4} (GeV/c)^2$. Note that in this method the $t$-resolution does not vary with increasing energy of the incident particle. The condition $A_{Coulomb} \approx A_{nucl}$ necessary for observing an interference, does not practically depend on an incident particle energy, being a function of $t$ only. This makes it possible to use the above mentioned method at considerably higher energies.

An absolute measurement of the pion flux was made with the help of the nuclear emulsion placed behind the chamber to overlap the entire beam. An integral electronic system was also used to measure the pion flux in each expansion. The 3.48 GeV/c pion beam with momentum spread $\Delta p/p = 1.5\%$ consisted of $(7 \pm 1)\%$ of $\mu$-mesons and $(2.4 \pm 0.3)\%$ of electrons. The 6.13 GeV/c beam with $\frac{\Delta p}{p} = 2.2\%$ consisted of 6% $\mu$ and $e$. The contamination of $\bar{p}$ and $k^-$ was negligible. A value of $n_\pi \times n_H \times L$ was determined with an accuracy of 3% ($n_\pi$ is a pion flux, $n_H$ is hydrogen density, $L$ is a length of the chamber active volume).

For the chosen interval of momentum transfers, the cross section was obtained to be $\Delta\sigma = (0.244 \pm 0.017)$mb and $\Delta\sigma = (0.219 \pm 0.020)$mb at 3.48 GeV/c and 6.13 GeV/c, respectively. The values of $\alpha$ were deduced from the angular distributions by using the method of least squares. A good $\chi^2$ was obtained by using Bethe's formula as well as that of L.D.Soloviev. In the calculations the value $\sigma_{tot}^{\pi^- p}$ was taken from ref. /6/. The angular dependence for the real and the imaginary parts of the nuclear scattering amplitude was assumed to be equal and was determined from refs.[7,8]. Values of $\alpha$ slightly vary with varying the angular dependence of $A_n(\theta)$. For example, if vary $B$ in the formula $\frac{d\sigma}{dt} = \exp(Bt)$ in the limits of experimental errors we receive $\frac{\Delta\alpha}{\alpha} \lesssim 2\%$ for $\alpha \approx 0.2$. Suppose that $Re\,A_n$ and $Im\,A_n$ have different angular dependences. Then taking $B_{Re A_n}/B_{Im A_n} = 10$ and $\frac{B_{Re A_n}}{B_{Im A_n}} = \frac{1}{20}$ we obtain for our treatment the variation of $\alpha$ by 10% and 1%, respectively.

In this experiment, the main error in determing $\alpha$ is a statistical one.

The values of $\alpha$ listed in Fig. 3 obtained in this article correspond to the treatment by Soloviev's formula. The curve $\alpha(T)$ is calculated on the basis of the forward dispersion relations[9,14]. In these calculations the total cross sections at high energies were approximated by the function $\sigma = \sigma_\infty + \frac{c}{k^\beta}$. As is seen from Fig. 3 for a momentum of 3.48 GeV/c, and 6.13 GeV/c the results of calculations and values of $\alpha$ obtained in our experiment are in good agreement.

It has been shown in[10] for $\pi N$ scattering at energies up to several hundred MeV that the experimental data are consistent with dispersion relations. Papers[13,14,1g] indicate that up to 18 GeV there is consistence of the experimental data on elastic charge exchange $\pi^- p \to \pi^0 n$ with the forward dispersion-relation calculations. As in ref.[1h] and in our paper submitted to the Berkeley Conference[1i], here we conclude that there is no evidence for violation of dispersion relations for $\pi^- p$ forward scattering up to 6 GeV at least[x].

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Footnote [x] Recently, when this publication has been already in print, we found out that the authors of ref.[1c] have repeated the measurements of $\pi^\pm p$ and $pp$ scattering in the region of Coulomb interference in the energy range 8-26 GeV. After having treated their results by L.D.Soloviev's formula they obtained now complete agreement between the experimental values of $\alpha = Re\,A_n / Im\,A_n$ and the F.D.R. calculations. Thus, all the experimental data agree with the calculations made on the basis of forward dispersion relations.

We are deeply thankful to Academician V.I.Veksler and Prof. I.V.Chuvilo for their attention to the experiment, to Drs. V.A.Nikitin, V.A.Sviridov and N.N.Govorun for their direct participation in the first stage of the experiment, and to everybody who took part in the exposure of the chamber and experimental data treatment, particulary to N.I.Pavlov, L.P.Zinoviev, S.V.Feducov, N.I.Malashkevich, A.G.Muryzin, L.N.Belyaev, V.S.Grigorashenko, B.D.Omelchenko and O.N.Radin who provided a good operation of the accelerator and apparatus.

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Received by Publishing Department
on April 10, 1967.

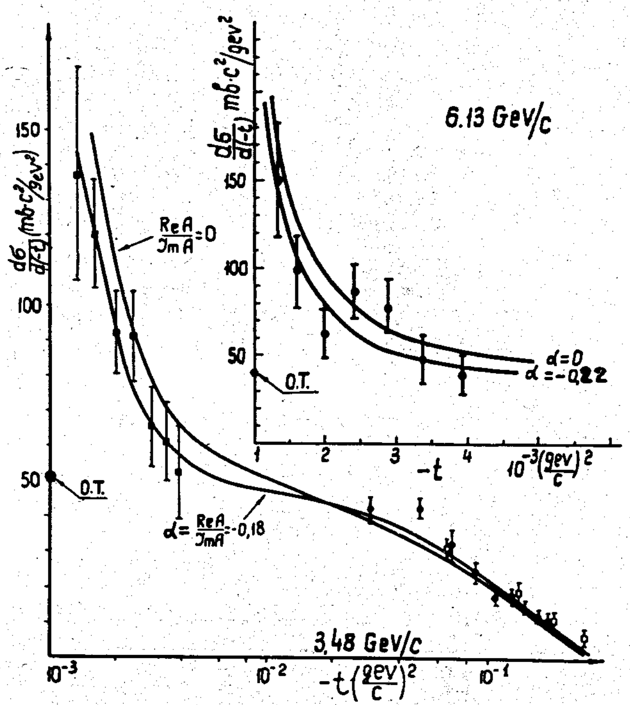


Fig. 1. $\pi^-p$ elastic scattering differential cross section. 3.48 GeV/c: ■ – our data, □ – data from ref./11/, ● – derived from the data of ref./8/. 6.13 GeV/c: ● – our data.

The curves calculated by Bethe's formula.

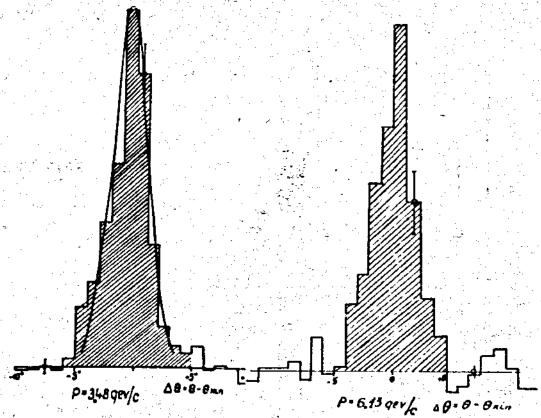


Fig. 2. Distribution of recoil protons by the deviations from the kinematic momentum-angle line.

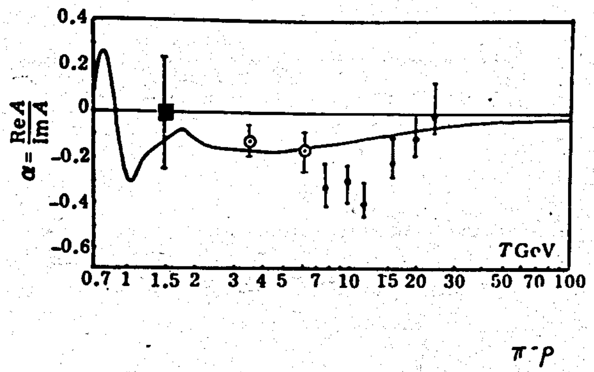


Fig. 3. The dependence of the ratio of the real to the imaginary part of the forward $\pi^- p$ elastic scattering nuclear amplitude upon lab. pion energy. ⊙ - our data, ● - data from ref./1c/, ■ - derived from the data of ref./12/. The theoretical curve is that calculated in ref./9/.