ELASTIC PROTON-PROTON SCATTERING AT 6.2 BeV

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Submitted to JETP editor December 1, 1962

J. Exptl. Theoret. Phys. (U.S.S.R.) **44**, 1470-1473 (May, 1963)

Elastic p-p scattering at 6.2 BeV was measured by perpendicular irradiation of nuclear emulsions. A total of 325 elastic scattering events were identified (including 141 events reported in [1]). The differential cross section in the 1.3—10.5° c.m.s. range is obtained; the elastic scattering cross section is 9.8 ± 0.9 mb. The experimental results are analyzed on the basis of a quasi-classical model.

INTRODUCTION

It is known[1] that the irradiation of a photographic emulsion in a direction perpendicular to its plane yields the events of interest more rapidly than the usual parallel irradiation when measuring differential cross sections for high-energy elastic scattering at small angles (to 1° in the c.m. system). We investigated proton-proton scattering at 6.2 BeV and c.m. angles ≤10.5°. Our data together with those in [2] give the differential cross section for elastic proton scattering at this energy within the broad c.m.s. range 1.3—27.6°. This is of decided interest in connection with the theory of Regge poles.

1. EXPERIMENT

Our work was performed with three emulsion stacks (A, B, and C), irradiated perpendicular to their planes with 6.2-BeV protons in the internal beam of the proton synchrotron of the Joint Institute for Nuclear Research. The 10×10×2-cm stacks consisted of NIKFI-BR pellicles 400 μ thick. The mean beam density in the central working zone (400 mm^2) was $(6.87 \pm 0.11) \times 10^5$, $(6.81 \pm 0.12) \times 10^5$, and $(4.84 \pm 0.07) \times 10^5$ protons/cm^2, respectively; the beam angle was 89.5° ± 0.5°, 89.3° ± 0.3°, and 88.9° ± 0.5°, respectively. One cubic centimeter of standard emulsion contained $(2.95 \pm 0.23) \times 10^{22}$ hydrogen atoms.[3]

Stack C was loaded with water; the rate at which the desired events were observed was thus increased several times.[4] The mean thickness of the loaded pellicles was 1000 μ, with 1 cm^3 containing $(5.33 \pm 0.27) \times 10^{22}$ hydrogen atoms. The sensitivity of stack C to positrons from $\pi^+ \to \mu^+ \to e^+$ decay was 14 grains/100 μ.

Elastic scattering events were sought by area scanning using microscopes giving ×420 total magnification. A single person scanned an average of 12 mm^2 per day. The total scanned area was 3.66 cm^3 (0.27 cm^3 in A, 1.89 cm^3 in B, and 1.50 cm^3 in C). In order to determine the scanning efficiency and to enhance the reliability of the results the entire volume was scanned twice.

2. IDENTIFICATION OF ELASTIC SCATTERING EVENTS

All two-prong stars outwardly resembling elastic proton-proton scattering events were registered. The actual elastic scattering events were then discriminated using kinematic criteria similar to those described in [1]. The technique of [1] was to measure R, φ, and ψ (the range and angle of the recoil proton, and the scattering angle of the incident proton). The angles ψ were measured accurately in only one pellicle. When a slow secondary proton undergoes interaction and its range cannot be determined, we compare its ionization with that of the slow secondary proton in another event with a similar scattering angle in the same pellicle.

From the distributions of events with respect to $|\Delta\varphi|$, the difference between the measured scattering angle of the slow secondary proton and the angle corresponding to its range kinematically, it was found that the mean error in measuring the angle φ was $\overline{|\Delta\varphi|} = 2°$ in A and B, and $\overline{|\Delta\varphi|} = 3°$ in C. From the distribution of events with respect to $|\Delta\psi|$, the difference between the measured scattering angle of the fast secondary proton and the angle corresponding kinematically to the given range for the slow proton, it was found that the mean value of $\overline{|\Delta\psi|}$ was 4′ in A and B, and 7′ in C.

$\theta_{c.m.}$, deg	Efficiency of double scanning			No. of events	$d\sigma/d\Omega$, mb/sr
	Stack A	Stack B	Stack C		
1.3 — 2.5	0.62±0.09	0.80±0.09	0.92±0.02	28	111±22
2.5 — 4.5	0.90±0.04	0.89±0.06	0.91±0.04	73	84±10
4.5 — 6.5	0.78±0.08	0.90±0.03	0.94±0.03	73	54± 7
6.5 — 8.5	0.76±0.07	0.83±0.04	0.83±0.05	73	41± 5
8.5 —10.5	—	0.68±0.09	0.79±0.08	50	28± 4
>10.5	—	—	—	28	—
			Total	325	

Quasi-elastic and other background events contributed about 1%.

3. RESULTS AND DISCUSSION

The analysis yielded 325 elastic scattering events: 20 in A, 160 in B, and 145 in the water-loaded stack C. The efficiency of double scanning, the number of events, and the differential cross sections for different c.m.s. angular intervals are given in the accompanying table.

The scanning efficiency was determined from the formulas in [5], and the statistical fluctuations were determined from the formulas in [6]. The efficiencies calculated by the procedures given in [5] and [7] agree within the error limits. The differential cross section is given with only its statistical error. For c.m. angles greater than 10.5° the scanning efficiency decreases rapidly to zero; 28 elastic scattering events were found in this region. The given number of events does not include those found at distances up to 30μ (in A and B) and up to 60μ (in C) from any surface of the undeveloped emulsions, because the efficiency cannot be determined accurately enough in this region.

The correct use of double scanning to determine the actual number of events has been discussed by several authors.[8] In order to check whether double scanning enabled a corrected evaluation of scanning efficiency in our work, we performed a third scanning of 600 mm^2 in stack C at the much slower rate of 3.5 mm^2 per day. The first two scannings had yielded 58 elastic scattering events in this area; the third scanning detected 52 of the previous events and 6 new events. The efficiency of the third scanning was 0.90, which is considerably above that of the first two scannings. However, the actual numbers of events counted from the first two scannings and from the third scanning do not differ by more than 2 or 3%, which is considerably smaller than the statistical error. This result indicates that in the present case the diversity of events has little effect on the scanning efficiency, and that the actual number of events was determined correctly from the first two scannings having 0.7 efficiency. With a still higher efficiency of a single scanning the actual number of events determined from double scanning would be established with even greater accuracy.

Our data and those in [2] yield 9.8 ± 0.9 mb as the cross section for elastic proton scattering at 6.2 BeV.

The results were analyzed according to the scheme given in [9], where it is assumed that the nuclear potential is a Gaussian function of separation, and that the ratio of the real part to the imaginary part is identical for the potentials of singlet and triplet states:

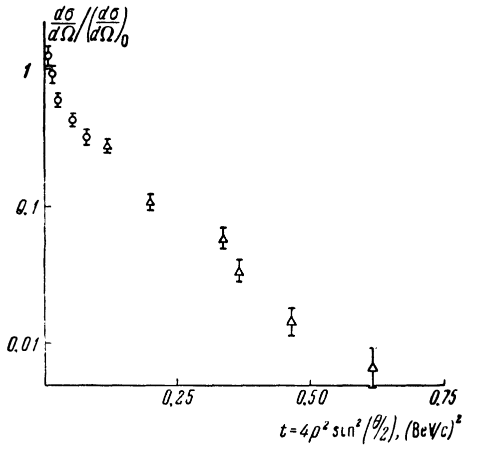
$$V_s = -(u + iw)\, e^{-\gamma^2 r^2}, \qquad V_t = \varkappa V_s.$$

The differential and total cross sections were calculated using phases computed from the given potential by means of expressions for the elements of the M matrix. The best curve and the corresponding values of the parameters κ, γ, u, and w were obtained by least squares. The calculated value of χ^2 characterized the deviation of a calculated curve from the experimental points. The calculated curves were plotted for three cases:

1) $\varkappa = 1,\ u = 0,$
2) $\varkappa \neq 1,\ u = 0,\ \sigma_t = 42$ mb,
3) $\varkappa = 1,\ u \neq 0,\ \sigma_t = 42$ mb.

The experimental data are represented equally well by all three cases, within statistical errors. Similar calculations were performed using our data combined with those in [2]; the results agree with experiment, but with doubling or tripling of the error limits. Our data yielded $(1.24 \pm 0.10) \times 10^{-13}$ cm for the mean interaction radius in all three cases, whereas the two investigations combined yielded $(0.94 \pm 0.10) \times 10^{-13}$ cm. For the effective interaction radius $r_{eff} = \sigma_t^2/4\pi\sigma_{el}$ [10] we obtained $(1.20 \pm 0.12) \times 10^{-13}$ cm.

The accompanying figure shows the dependence of the differential cross section on the square of the transferred transverse momentum (the Man-



Differential cross section for elastic proton-proton scattering at 6.2 BeV. o – present work, Δ – from [2].

delstam variable t). The analytic form of this dependence is [11]

$$\left(\frac{4\pi}{k\sigma_t}\right)^2 \frac{d\sigma}{d\Omega} = \frac{d\sigma}{d\Omega} \Big/ \left(\frac{d\sigma}{d\Omega}\right)_{0°} = F(t) = e^{-at+b}.$$

The coefficients a and b were calculated by least squares; the results are: using our present data, a = 15.0 ± 2.2, b = 0.1 ± 0.3; using the data in [2], a = 7.7 ± 1.0, b = −0.5 ± 0.3; using the combined data, a = 8.3 ± 0.7, b = −0.4 ± 0.1. In the calculations we omitted the first experimental point of the present work, which was affected by multiple Coulomb scattering, and the point at 7.6° (c.m.) in [2], where the authors mention a possible systematic error.

In conclusion we wish to thank the directors of the High Energy Laboratory of the Joint Institute for Nuclear Research for the irradiation and chemical processing of the emulsion stacks. We also wish to express our thanks to M. G. Shafranova, E. N. Tsyganov, B. A. Shakhbazyan, and I. N. Silin for participating in discussions of the results and for performing calculations on the M-20 computer, as well as to the laboratory staff which performed the work of scanning.

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Translated by I. Emin
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