THE REAL PART OF THE FORWARD AMPLITUDE IN PROTON-PROTON SCATTERING AT 1.7 GEV/c

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INTRODUCTION

Interference with the Coulomb amplitude which is mainly real, allows a determination of Re A (0) and the present experiment was carried out in order to clarify the situation at 1.7 GeV/c. Details of the experiment and preliminary results have already been given [1] showing that interference is small. In the present report final results are presented and compared with dispersion relation calculations and experimental results at other energies. Two sets of measurements were obtained under slightly different conditions of beam collimation and geometry and these have been analysed separately. The results are plotted in Fig. 1.

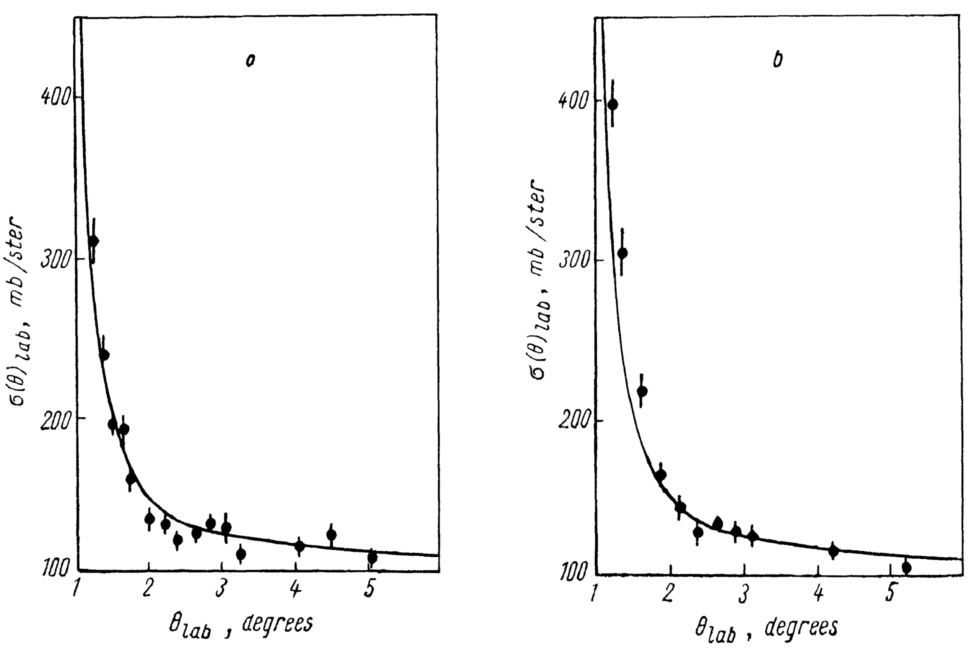

Fig. 1. Experimental results at 1.7 GeV/c. The curves represent the contribution of pure nuclear + pure Coulomb scattering.

TREATMENT OF RESULTS

The differential cross-section may be written ***

$$\sigma(\theta) = \sigma_N(\theta) + \sigma_C(\theta) + 2\mathrm{Re}\, A^*(\theta) f_C(\theta)$$

where the subscripts N and C refer to purely nuclear and purely Coulomb scattering and $f_C(\theta)$ is the Coulomb amplitude. $\sigma_N(\theta)$ is known at angles $\geqslant 7°$ lab. from the measurements of Dowell et al. [2] and McFarlane et al. [3] who fitted a series of Legendre polynomials to their data. For the present work we have combined the statistically more accurate data [8] with the absolute measurements [3]

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*** Strictly speaking one should add phase shifts and not amplitudes as has been done here. The difference should be unimportant in this case.

to give the laboratory system

$$\sigma_N(\theta) = 127.4\,(1 - 0.635\theta^2)\ \frac{\text{mb}}{\text{ster}}$$

which we have assumed may be extrapolated to zero. The uncertainty in the magnitude of this expression is $\pm$ 2.5%.

For the Coulomb amplitude we have used an approximate form of Mollers formula at small angles

$$f_C(\theta) = -\frac{2l^2}{p\beta c}\ \theta^{-2} e^{i\alpha}$$

where all quantities refer to the laboratory system and $e^{i\alpha}$ is a phase factor. For «α» we have used an effective value obtained from a formula given by Bethe [4] which approximately takes into account the difference in phase between the Coulomb and nuclear scattering. The imaginary part of the Coulomb amplitude is $\sim$ 3% of the real part in the region where interference is important and in this case gives a contribution to the interference term which is comparable to that arising from the real part. The resulting interference is destructive. For ImA (0) we have used the value of $3{\cdot}14 \times 10^{-13}$ cm obtained from the optical theorem [5] and assumed it to be constant over the region of interest. The effect of the nucleon form factor is estimated to be negligible at the momentum transfers of interest in this experiment. The Coulomb cross-section is given by

$$\sigma_C(\theta) = |f_C(\theta)|^2 = 412\theta^{-4}\ \frac{\text{mb}}{\text{ster}}$$

where θ is in degrees.

The simplest assumption that can be made about the real part of the nuclear amplitude $\mathrm{Re}A(\theta)$ and the only one that can be justified in our case is to assume that it is constant over the interference region (e. g. the nuclear cross-section changes by only 4% over the angular range 0.5° to 2.5° whilst the Coulomb amplitude changes by a factor of 25). The interference term is therefore proportional to θ^{-2}.

As was outlined in [1] we have adopted an approximate procedure in order to take account of the finite angular resolution ($\pm$ 0.25°). The only term in the expression for $\sigma(\theta)$ which seriously was affected by angular resolution is $\sigma_C(\theta)$ and it may be shown quite simply that one should replace $\sigma_C(\theta)$ by $\sigma_C(\theta)\ (1 + a,\ \theta^{-2} + a_2\theta^{-4} + \ldots)$ where a_1, a_2, etc. are measures of width and shape of the resolution function. We have therefore fitted an expression of the form $\sigma_N(\theta) + \sigma_C(\theta) + 21mA(\theta)\,Imf_C(\theta) + a(\theta)^{-6} + b(\theta)^{-2}$ to our data where we ignore terms higher than the second in the above expansion and leave a, the correction for finite angular resolution, to be determined by the least squares fit programme. The coefficient b gives the amount of interference between the real parts of the Coulomb and nuclear amplitudes. With our resolution we expect terms neglected to be smaller than our statistical errors.

DISCUSSION

The results of the preceeding analysis are presented in Table where the values of the

No. of points	a	b	χ^2/deg. of freedom	ReA (0)/ImA (0)
15	280$\pm$100	-46 ± 36	1,35	(13$\pm$9,5) %
11	266$\pm$60	-52 ± 25	0,52	($-11{,}5\pm9{,}5$)%

coefficients a and b and the goodness of fit (χ^2/ no. of degrees of freedom) are given, the experimental data having been normalized

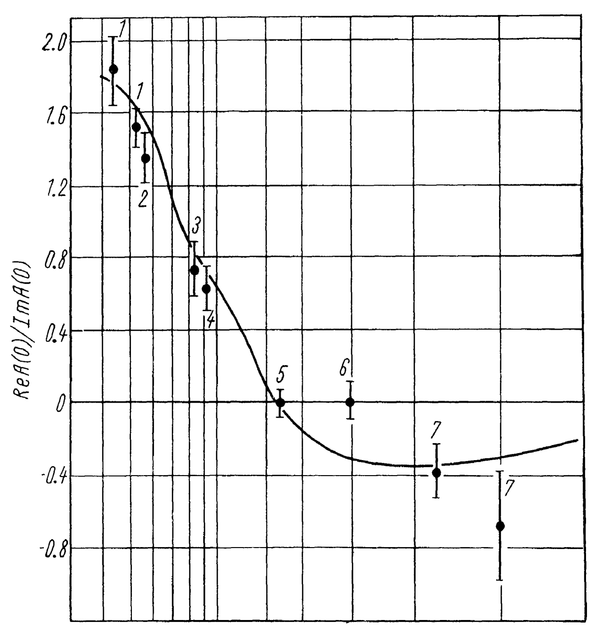

Fig. 2. The ratio Re A (0)/Im A (0) as a function of laboratory momentum.

Data below 1.7 GeV/c taken from R. R. Wilson «The two nucleon problem» 1. Taylor et al (98 MeV and 142 MeV); 2. Caversazio et al. (156 MeV); 3. Fischer et al. (330 MeV); 4. Holt et al (380 MeV); 5. Present experiment; 6. Preston et al [7]); 7. Kirillova et al. (Ref. [8]). The curve is the disperision relation calculation.

to the Coulomb and nuclear cross-sections by the programme. The ratio Re A (0)/Im A (0) derived from these results is given in the last column of Table. Contributions to the error on this quantity arise also from uncertainties in the zero angle and in the absolute value of the nuclear cross-section. The angular uncertainty was $\pm$ 0.025 on the first set of measurements and $\pm$ 0.05° on the second. Errors arising from these sources are included in the values quoted for Re A (0)/ Im A (0). Averaging these two gives a final result of (— 0.7 $\pm$ 7)%. Thus we may conclude that the real part of 1.7 GeV/c is certainly not large enough to account for the high value of the forward differential cross-section which must therefore result mainly from the spin dependent amplitudes.

Dispersion relation calculations of the real part of the spin independent amplitude [6] show that it is expected to change sign with increasing energy becoming fairly large at energies of several GeV (see Fig. 2), passing through zero at around 1.7 GeV/c in good agreement with our measurement.

In order to compare experimental results with the dispersion relation calculation as a function of momentum we have analysed several experiments in the energy range 100 — 380 MeV using an approximate method similar to that used for our own data. The results of this analysis * are plotted in Fig. 2. Also plotted are results from higher momenta [7, 8]. It should be noted that an alternative interpretation exists for the results at 6 and 10 GeV/c which does not require a real part. Although the quantitative agreement with experiment at higher energies is not good the general qualitative behaviour appears to follow the trend of the calculated curve. Further results at high energies would clearly be of interest.

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* This information can also be obtained from the phase shift analysis results. The ratio Re A(0)/Im A (0) calculated from the phase shifts at 98 MeV and 142 MeV agrees well with the results of our analysis.