SMALL-ANGLE ELASTIC SCATTERING OF 24.5 GeV/c PROTONS ON HYDROGEN NUCLEI *

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The present work is an investigation of 24.5 GeV/c p-p elastic scattering at momentum transfers between 49 MeV/c and 735 MeV/c, corresponding to $0.0024 \leqslant -t \leqslant 0.55$ (GeV/c)^2. No "anomalous" behaviour has been observed in this region.

The angular distribution at small angles has been studied by two different and complementary methods, (A) on the one hand with a liquid hydrogen bubble chamber, (B) on the other hand with perpendicularly exposed emulsions.

A) 17 000 pictures of the CERN 30 cm liquid hydrogen bubble chamber have been scanned for p-p interactions with two charged secondaries. Every event with a recoil track of projected length $l > 3$ mm on the scanning table (magnification 1.5 times) had to be noted, and the scanners were especially trained not to overlook events with short recoils. The geometrical reconstruction was performed with the graphical method described by Borelli et al [1]. The calculations were done with a computer of type "Bull Gamma 3".

Events accepted as elastic ones had to satisfy the following kinematical and geometrical conditions:

$$\text{a)}\quad F_1 = \varphi_1(\rho_1 \text{ or } R_1) - \frac{2m\cos\theta_1}{\sqrt{\frac{\gamma+1}{\gamma-1}} - \sqrt{\frac{\gamma-1}{\gamma+1}} \times \cos^2\theta_1} = 0\ ,$$

$$\text{b)}\quad F_2 = \operatorname{tg}\theta_1 \times \operatorname{tg}\theta_2 - (1-\beta^2\mathrm{cm}^2) = 0\ ,$$

$$\text{c)}\quad F_3 = |\alpha_1-\alpha_2| - \pi = 0$$

ρ, R, θ and α are the measured curvature, rest-range, polar angle and azimuthal angle respectively. Index 1 designates the slower particle β and γ are the velocity parameters of the c.m. in the L-system.

The separation of elastic from inelastic events was then performed with the distribution of the quantities: a) $F_1/\Delta F_1$, b) $F_2/\Delta F_2$, c) $F_3/\Delta F_3$, where the ΔF_i are the errors in F_i expected from measurement uncertainties. This procedure gave 658 elastic events in the angular interval 4 mrad $< \theta^L <$ 30 mrad at a total path of 25390 m. We concluded from the distributions that a possible systematic error of the number of elastic events should be smaller than about $\pm 3\%$.

In order to determine the scanning loss for events satisfying the scanning criteria a rescan has been performed. For inelastic events the loss was about 3%, while for elastic ones less than 0.5% new events were discovered.

Besides this "normal" scanning loss, the cut-off at 3 mm must necessarily give an inevitable scanning loss which is the stronger the shorter the recoil and the larger the dip angle. The estimate of this loss was performed by means of the target diagram shown in fig. 1. For the angular interval between 4 mrad and 8 mrad the resulting correction was +23% (4-6 mrad) and +9% (6-8 mrad). In addition the expected scanning loss can be calculated directly from the chosen cut-off value. The calculation confirms the corrections obtained from the target diagram inside the limits of statistical errors. Thus, including the corrections the bubble chamber gave 701 ± 35 elastic scatterings with 4 mrad $< \theta^L <$ 30 mrad.

Next, one had to account for Coulomb scattering. For the scattering amplitude we can write *

$$A(\theta) = C(\theta) + N(\theta) + \mathrm{i}\, I(\theta)\ ,$$

* Inelastic Coulomb scattering is neglected.

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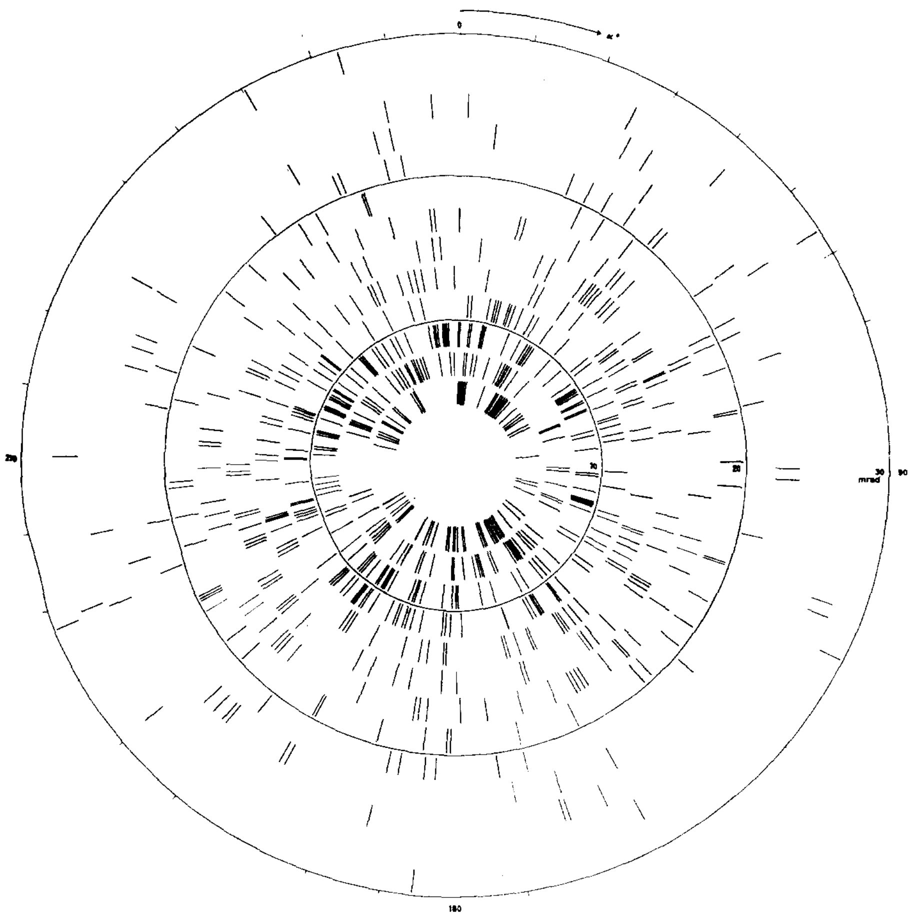

Fig. 1. Target diagram for 658 elastic scatterings with 4 mrad < θ < 30 mrad.

where $C(\theta)$ denotes the Coulomb scattering, $N(\theta)$ the nuclear real part and $I(\theta)$ the diffraction part. Then the elastic cross section becomes

$$\frac{d\sigma}{d\Omega} = \{C(\theta) + N(\theta)\}^2 + I^2(\theta) .$$

Presuming always $N(\theta) \ll I(\theta)$, one can investigate the behaviour of $d\sigma/d\Omega$ as a function of $C(\theta)$ and it can easily be shown that $N(\theta)$ has a maximum "effectiveness" on $d\sigma/d\Omega$ in the region where $C(\theta') = I(\theta')$*. At this angle the interference term produces a strong "Coulomb amplification" facilitating the detection of deviations from a pure diffraction pattern. For 24.5 GeV/c protons θ' becomes 1.8 mrad. From our measured distributions the pure Coulomb contribution $C(\theta)^2$ has been subtracted.

The distribution of $d\sigma/dt$ resulting from the bubble chamber pictures is shown in fig. 2. A function of type $a\,e^{At}$ has been fitted to the measured points. The two dashed curves are the envelopes to all "straight lines" with one standard deviation. The optical point calculated with $\sigma_T = 39.5 \pm 1$ mbarn obtained by Lindenbaum et al. [2] is well contained within the region defined by these envelopes and no larger irregularities appear. Brandt et al. [3] reported a possible upward curvature for 10 GeV/c π^--p scattering. It is possible that also in our case the real line is curved upwards. We have however no indication to assume on experimental grounds that it would then not converge to the optical point.

B) Simultaneously with the bubble chamber investigation the angular distribution of elastic p-p scatterings has been studied by means of perpendicularly exposed nuclear emulsions. Following a method first applied for this purpose by Lubimov et al. [4] we scanned for black and grey recoil tracks. The primary momentum was 24.4 GeV/c. Every apparent † end of a heavy track (with a length $R > 10\ \mu$) has been carefully investigated and has been noted down in the case that an ordinary primary and any number of secondary minimum tracks were connected with it. In this manner 2500 events with $n_h = 1$ and among them 954 events with $n_h = 1$, $n_s = 1$ have been found. To the

* For this consideration we assumed $N(\theta)$ = constant.

† This can be either the end or the beginning of the track.

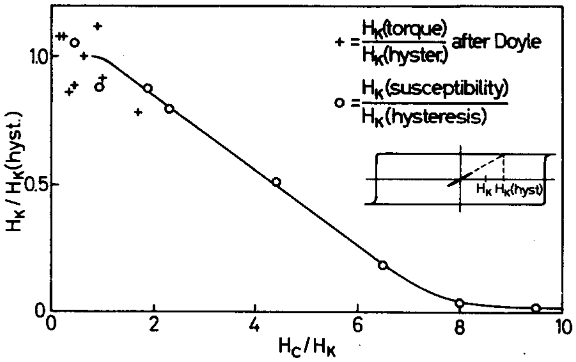

Fig. 2. Differential cross section for elastic scatterings.

954 stars with $n_h = 1$, $n_s = 1$ the same selection criteria have been applied as for the analysis of the bubble chamber data and 156 genuine elastic p-p scatterings have been obtained.

A rescan has been performed in order to estimate the scanning loss as function of the scattering angle. The average scanning efficiency was 70%. A cut-off near surface and glass has been taken into account. Again the pure Coulomb part of the cross section has been calculated and subtracted. The result is shown in fig. 2.

Inside the rather large errors the distribution obtained with emulsions agrees with that of the bubble chamber. In fact the emulsion investigation contributes primarily to the two inner points, the innermost one extending from 2-4 mrad, the next covering 4-6 mrad where the bubble chamber is already on its reliability limits of application. Results of counter measurement of Diddens et al. [5] and of Foley et al. [6] are shown for comparison in fig. 2. Most of their points are in our validity region. In order to get an idea about the magnitude of a real part in our angular region we took the measured $\alpha(t)$-dependence [6] and the theoretical consideration of Amati et al., and Hadjioannou et al. [7]. The predicted real-part contributes to $d\sigma/dt$ about 2‰ for $|t| < 0.5\ (\mathrm{GeV}/c)^2$. This is extremely small and it is today impossible to measure such a contribution directly, however it is clear that if one observed now any "bump" near the region $\theta = \theta'$ *, where the crossed term is especially effective, this would allow to put further restriction on the theory.

In the table we summarize finally the value of σ_{el}, A (from the fit $a\,e^{At}$) and σ_T as obtained with the bubble chamber (BC), BC and optical point (OP), BC and emulsion (EM), and with all three together.

* Such a "bump", naturally need, not necessarily appear precisely at $\theta = \theta'$. It could be shifted since as well as N the "Coulomb-amplification" varies with θ.

Table 1
Measured values from bubble chamber, emulsion and optical point.

	BC	BC+OP	BC+EM	BC+EM+OP
σ_{el}(mbarn)	8.7±0.4	8.8±0.3	8.7±0.4	8.8±0.3
$A(\mathrm{GeV}/c)^{-2}$	8.8±0.4	8.9±0.3	8.9±0.4	9.0±0.3
σ_T(mbarn)	38.8±1.2	39.2±0.8	38.9±1.2	39.3±0.8

The "best" values are

$$\sigma_{el} = 8.8 \pm 0.3 \text{ mbarn},$$
$$A = 9.0 \pm 0.3\ (\mathrm{GeV}/c)^{-2},$$
$$\sigma_T = 39.3 \pm 0.8 \text{ mbarn}.$$

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