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OBSERVATION OF A NARROW MINIMUM AND OF INELASTIC SHADOW EFFECTSIN DEUTERON-DEUTERON ELASTIC SCATTERING AT $\sqrt{s} = 53$ GeV

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ABSTRACT

We report on experimental results on deuteron-deuteron elastic scattering at a centre-of-mass energy of $\sqrt{s} = 53$ GeV. The data were obtained using the Split Field Magnet detector at the CERN Intersecting Storage Rings. The t -dependence of the elastic cross-section is measured up to $-t = 1.5 \text{ GeV}^2$. We observe a narrow interference minimum in the differential cross-section at $-t = 0.18 \text{ GeV}^2$. The inclusion of inelastic intermediate states in the multiple scattering Glauber theory is essential in the description of the data over the entire t -range where discrepancies of up to 25% are observed with the basic theory.

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The elastic scattering of high-energy hadrons on deuterons has revealed [1] distinctive features of double scattering processes contributing a rather complex structure to the differential cross-section. Once the deuteron degrees of freedom are properly taken into account these phenomena may provide new information on the basic nucleon scattering amplitudes since the details of any multiple scattering theoretical prediction appear to be dominated by interference phenomena. However, certain features of multiple scattering theories can be explored only when both colliding particles are composite; deuteron-deuteron elastic scattering is the simplest case of such a process. Higher order multiple scattering processes become in this case possible up to fourth order; their role in determining the structure of the differential cross-section is particularly relevant since they strongly interfere with the double scattering amplitude [2,3]. For these reasons coherent dd scattering provides new elements on the dynamics of processes involving the iterations of the elementary nucleon-nucleon interaction.

Besides these considerations, whose validity is independent of the energy region considered, new phenomena are expected to modify the simple Glauber picture at very high energies. Substantial corrections to multiple scattering diagrams arising from the propagation of virtual inelastic states are in fact expected [4] to become sizeable in the high-energy limit. Effects arising from contributions of inelastic propagators have been observed in proton-deuteron elastic scattering, as described in the preceding letter.

We are reporting here on experimental results on dd elastic scattering in the range $0.05 < -t < 1.5 \text{ GeV}^2$ at a centre-of-mass energy of $\sqrt{s} = 53 \text{ GeV}$. The data have been obtained using the Split Field Magnet detector (SFM) at the CERN Intersecting Storage Rings (ISR) and correspond to an integrated luminosity of $3292 \mu\text{b}^{-1}$.

The SFM detector has been described elsewhere [5]. As for the case of pd elastic scattering, events were selected within two narrow symmetric cones in the forward telescopes by requiring one track in each of the compensator spectrometers placed downstream of the main SFM magnetic system at about 7.5 m from the interaction region. A simple trigger layout could then be achieved due to the limited

t -interval interesting for this measurement. At the trigger level a rough collinearity selection and a t -dependent scaling of the input rate were applied.

After pattern recognition, geometrical reconstruction, and track fitting, a 20 GeV/c momentum cut on both tracks selected an almost pure dd coherent scattering sample. Figure 1 shows the correlation between the measured final-state momenta, in which the locus of elastic scattering events is clearly separated. Owing to the steep t -dependence of the deuteron form factor, inelastic interactions at any of the two vertices are dominated by deuteron break-up, the corresponding reaction products undergoing a discrete momentum loss of about one-half the initial beam momentum.

After a kinematical fit to the events in the elastic peak, the final sample was obtained selecting events with confidence level greater than 1%. The present results are based on a sample of 57443 events, of which 1925 events are beyond the diffraction minimum.

A study of the collinearity distribution as a function of four-momentum transfer indicates a t -independent background contamination of the order of 1%. Other background sources were below the 0.2% level.

The acceptance of the detector and of the reconstruction chain was evaluated with Monte Carlo methods following the same procedure as for pd elastic scattering. Also in this case the agreement between data and simulation is very good.

Using simulated events the experimental resolutions have been investigated in detail. For the invariant momentum transfer the distribution of $(t_{\text{true}} - t_{\text{measured}})$ is found to have a r.m.s. width of $\sigma_t = 0.014 \text{ GeV}^2$ at the position of the minimum and to increase roughly as $|t|^{0.6}$. Cross-section normalization was obtained by collecting monitor counts from two scintillation hodoscopes simultaneously with data taking. We estimate the over-all systematic accuracy of the data to be $\pm 7\%$. The results are shown in Fig. 2. The dominant property of the differential cross-section is a narrow interference minimum around $-t = 0.2 \text{ GeV}^2$.

The cross-section below the minimum and above the secondary maximum has approximately an exponential dependence on four-momentum transfer and the data

can be described with a slope $b = 56.8 \pm 0.3 \text{ GeV}^{-2}$ for $0.05 < -t < 0.09 \text{ GeV}^2$ and $b = 6.3 \pm 0.1 \text{ GeV}^{-2}$ for $0.41 < -t < 1.48 \text{ GeV}^2$. The true position and depth of the minimum in the cross-section have been determined by describing the data with a form

$$\frac{d\sigma}{dt} = |\sqrt{a_1} e^{(b_1/2)t} + \sqrt{a_2} e^{(b_2/2)t+i\phi}|^2 \quad (1)$$

folded with the experimental t -resolution. The best fit gives a minimum at

$$t = -(0.179 \pm 0.005) \text{ GeV}^2 \quad (2)$$

and a value of the corresponding differential cross-section of

$$\frac{d\sigma}{dt} = (37.28 \pm 7.86) \text{ } \mu\text{b/GeV} . \quad (3)$$

In Glauber theory [6] this minimum is generated by a subtle interference between the single scattering and a particular type of double scattering amplitude. At very high energies, however, the correction arising from the propagation of large virtual masses must be taken into account.

In the dd case one has to include them both in the double and in the triple scattering. Indeed, while in the forward direction the triple scattering is very small, it becomes very important [2,3] in the interference region. The Glauber formula for dd scattering then becomes

$$\begin{aligned} F = & 4S\left(\frac{q}{2}\right) \left\{ 2f(q)S\left(\frac{q}{2}\right) + \frac{2i}{\pi p_\ell} \left[\int S(q_1) f\left(\vec{q}_1 + \frac{\vec{q}}{2}\right) f\left(-\vec{q}_1 + \frac{\vec{q}}{2}\right) d^2q_1 + \right. \right. \\ & + \left. \int d^2q_1 dM^2 \Delta F_6(s + i\epsilon, s + i\epsilon, M^2) S(\vec{q}_1, q_{1L}) \right] \Big\} + \\ & + \frac{4i}{\pi p_\ell} \int d^2q_1 f\left(-\vec{q}_1 + \frac{\vec{q}}{2}\right) S(q_1) \left\{ S(q_1) f\left(\vec{q}_1 + \frac{\vec{q}}{2}\right) + \right. \\ & + \frac{2i}{\pi p_\ell} \left[\int d^2q_2 S(q_2) f(\vec{q}_1 + \vec{q}_2) f\left(\frac{\vec{q}}{2} - \vec{q}_2\right) + \right. \\ & + \left. \left. 2 \int d^2q_2 dM^2 \Delta F_6(s + i\epsilon, s + i\epsilon, M^2) S(\vec{q}_2, q_{2L}) \right] \right\} , \end{aligned} \quad (4)$$

where the notation is the same as in the preceding letter, with the difference that here we use the summed discontinuity of the six-point amplitude ΔF_6 which includes also the discrete part of the low-mass region [7].

Terms in square brackets are similar to those in Glauber formulae for the deuteron; the last term corresponds to the inclusion of inelastic intermediate states (IIS) in triple scattering. The factor 2 arises from the fact that there are two possible orderings for the inelastic propagator. The phenomenological input for ΔF_6 and the deuteron wave function are the same as for pd elastic scattering. The result, shown in Fig. 2, is in good agreement with the data. The curve is the absolute prediction of Eq. (4), folded with the experimental resolution in t . It is remarkable that the agreement is obtained through a substantial cancellation between the inelastic corrections in the triple and double scattering terms. This is shown in detail in Fig. 3a. The curve corresponding to the pure Glauber theory indicates clearly that, as for pd elastic scattering, the inclusion of inelastic intermediate states is necessary to get detailed quantitative agreement with the data. The lowest curve shows the effect of IIS in just the triple scattering term. It is then clear that the correction to the double scattering term is of opposite sign and of the right magnitude. Figure 3b shows the amount of the inelastic shadow effect over the full t -range of the experiment as the ratio of the differential cross-section to the pure Glauber term. This effect appears to be sizeable at all values of four-momentum transfer.

In conclusion, we have observed a narrow minimum in the dd elastic differential cross-section as theoretically predicted by the Glauber theory [2].

In the interference region the data can be described only by the extension of the basic theory with inelastic propagators both in the double and triple scattering terms. The sensitivity of this experiment to the details of the triple-Regge parametrizations is enhanced [8] by the delicate cancellation mechanisms apparently at play in the interference region.

Further experimental results at a different energy and a more detailed theoretical analysis will be the subject of a forthcoming paper [8].

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Figure captions

- Fig. 1 : Correlation between measured final-state momenta in the two spectrometer arms. Elastic scattering appears clearly separated from single and double break-up processes. Different peak heights arise from an interplay of trigger acceptance and deuteron form factors.
- Fig. 2 : Differential cross-section for dd elastic scattering at $\sqrt{s} = 53$ GeV. The curve is the absolute prediction of the modified Glauber model described in the text, convoluted with the experimental resolution.
- Fig. 3 : a) The elastic differential cross-section in the region of the minimum. The solid line is the full model, the dashed line the pure Glauber term. Also shown is the effect of inelastic intermediate states included in triple scattering only (dotted line).
b) The elastic differential cross-section normalized to the Glauber term. The line is the prediction of the full model including inelastic intermediate states.

Fig. 1

Fig. 2

Fig. 3