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PION-DEUTERON COHERENT SCATTERING AT 895 MeV/c

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ABSTRACT

The elastic scattering cross-section of π^- on deuterium at 895 MeV/c measured with counters and wire spark chambers is given in a region of momentum transfer between 0.16 and 0.96 $(GeV/c)^2$.

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In recent years much theoretical and experimental work has been devoted to the investigation of the coherent scattering of hadrons on nuclei. In the original approach of Franco and Glauber[1] a multiple scattering theory is proposed in which the interaction of the impinging hadron is solved in terms of the scattering amplitudes on the single nucleons, giving rise to a leading term, the so-called single-scattering term, plus higher order terms eventually interfering, whose importance increases with the momentum transferred to the nucleus. In the framework of this theory, the pion-deuteron scattering amplitude is expressed, at small momentum transfer t, mainly by a single and a double scattering term, which are expected to interfere at a value of $t \simeq -0.35\ [\mathrm{GeV/c}]^2$. Furthermore, a measurement of the πd differential cross-section in the region of the interference should give a knowledge of the t-dependence of the phase of the symmetric pion-proton amplitude in that region. So far, this appears to be the only method of measuring the phase of a scattering amplitude at non-zero momentum transfer at high energies, where no phase-shift analysis is possible.

A systematic investigation of pion-deuteron coherent scattering in the region of the interference at various pion momenta has been undertaken by our group[2]. We started with 0.9 GeV/c incident pions, since at this energy a good knowledge of the pion-nucleon scattering amplitude is available, and in principle one is able to calculate correctly the pion-

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deuteron differential cross-section in the multiple scattering theory. The measurement should in this way be a check of the assumption that we can express a many-body interaction in terms of the individual two-body amplitudes, when the particles are within a few fermi.

The elastic $\pi^- d$ differential cross-section has been measured[3] at 895 MeV/c incident π^- momentum in the momentum transfer interval from -0.16 to $-0.96\ [\mathrm{GeV/c}]^2$, corresponding to $38° \leq \Theta_d^{lab} \leq 71°$. The selection of the coherent events from the ones (about 100 times more frequent) in which the deuteron breaks-up (quasi-elastic πp scattering) was obtained requiring the angular correlation among the directions of all the particles involved in the reaction. The directions were measured with a system of wire spark chambers which were triggered when a scattering event, defined by a coincidence between the incoming and the outgoing pion counters, satisfied a suitable requirement with a time-of-flight (TOF) signal from the recoil particle.

The beam was produced at the CERN Proton Synchrotron on an internal target, at an angle of 31.3°; at the D_2 target the spot size was $14 \times 11\ \mathrm{mm}^2$, with an angular divergence of ± 13 mrad and ± 55 mrad in the horizontal and vertical planes, respectively. The incident pion momentum has been measured (by a range method, by TOF, and by magnetic analysis) to be 895 MeV/c $\pm 0.2\%$ at the centre of the target, and the momentum bite accepted was $\pm 0.3\%$, with an intensity of about 6×10^4 particles/burst.

The layout of the experiment is shown in Fig. 1. The beam was incident on a liquid deuterium target, 25 cm long and 3 cm in diameter. A scattering event was defined by the coincidence $(C_1 C_{1b} \bar{C}_2) \cdot (C_4 C_5) \cdot (C_7) \cdot (\overline{C_3 C_6})$. The position of C_7 was such that the pulses due to the elastically scattered deuterons with a good approximation arrived at the same time, regardless of the recoil angle[4]. In spite of the large dimensions of C_7, the TOF resolution has been 0.7 nsec.

All the chambers[5,6] had a wire spacing of 1 mm, and the magnetostrictive read-out system guaranteed an accuracy of 0.5 mm. The two pion-telescopes were composed of three spark chambers each; the three-gap spark chamber in the recoil branch has been specially built with the aim of reducing the material in the path of the deuterons, which could have a kinetic energy as low as 50 MeV. The chamber was fixed directly at the vacuum tank containing the liquid-deuterium target, so that the deuterons had to cross only a 0.16 mm mylar window to enter the chamber.

The read-out from the chambers and the data acquisition system have been described elsewhere[6,7]. The coordinates of every event are written down on a magnetic tape in about 40 msec, which is also the dead-time of the system. Typical figures for the reconstruction accuracy are ±1 mrad and ±4 mrad for the directions of the π-tracks and of the deuteron track, respectively, ±0.5 mm and ±1 mm for the vertex coordinate normal and parallel to the beam direction. This geometrical accuracy results in an energy resolution for the deuteron of 1 MeV at $t = -0.16$ $(\mathrm{GeV}/c)^2$, which increases almost linearly with t up to 4 MeV, at $t = -0.96$ $(\mathrm{GeV}/c)^2$. A periodical check on the alignment of the set-up guaranteed its long-term stability.

Account was taken in the reconstruction program of the multiple scattering, of the spark formation time and of the clearing field, the last two effects resulting in a drift of the spark positions.

About 12,000 events, which at an early stage of the program were found to be coplanar within 5°, were fully processed. The kinematical χ^2-distribution was fitted with the one expected for a 2C-fit plus a linear background, for bins of momentum transfer of ± 0.025 $[\mathrm{GeV}/c]^2$. The background filtered in the $\chi^2 \leq 6$ region goes from 2.5% at $t = -0.2$ $[\mathrm{GeV}/c]^2$ to 9% at $t = -0.9$ $[\mathrm{GeV}/c]^2$: this increase of the background with t is just what one would expect from the kinematical worsening of the energy resolution with momentum transfer.

The data have been corrected for: a) beam contamination, measured with a Čerenkov counter to be (5 ± 1)%; b) counting losses, estimated to be 6 ± 1%; c) nuclear absorption, always less than 1%; d) over-all efficiency of the spark chambers and of the data acquisition system, which was (90 ± 1)%; e) efficiency of the reconstruction program, limited by the small number of coordinates available for each track, and measured over a sample of events to be (80 ± 10)%. The results are shown in Table 1: the error in the absolute value of the cross-section is estimated to be less than ±15%. Integrating the cross-section over $\Delta t = 0.15$ (GeV/c^2)

intervals, we get values in good agreement with a cross-section measurement performed with a scanning counter during the setting up of the experiment, where the background was roughly evaluated from TOF spectra. In Fig. 2 the results are compared with a calculation[8]) in which the single and double π-nucleon scattering amplitudes, as determined from phase-shift analysis, were taken into account, both for spin-flip and for no spin-flip. The s-wave part of the Moravcsik/Gartenhaus form factor was used. Our data, like those from other similar experiments[9-11]), are at variance with the results of this calculation, as they do not show any evidence for the marked dip predicted for $-t \simeq 0.35\ (\mathrm{GeV/c})^2$. It should be pointed out that the effect of the Fermi motion of the nucleons in the deuteron was not taken into account. This could be important when, as in our case, the π-nucleon scattering amplitudes change rapidly with the energy. However, according to a recent paper by Coleman and Rhoades[12]), a behaviour of the differential cross-section presenting no dips and in agreement with the experimental results can be obtained when, besides the S-state, also the D-state of the deuteron is taken into account.

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Table 1

π^-d differential cross-section at 895 MeV/c absolute normalization error = ±15%			
-t (GeV/c)^2	Δt (GeV/c)^2	dσ/dt	Δ(dσ/dt)
		mb/(GeV/c)^2	
0.165	± 0.005	2.94	0.50
0.175	"	1.98	0.24
0.185	"	1.82	0.11
0.195	"	1.470	0.081
0.205	± 0.005	1.248	0.058
0.220	± 0.010	1.044	0.041
0.240	"	0.692	0.026
0.260	"	0.518	0.020
0.280	"	0.373	0.017
0.300	"	0.286	0.014
0.320	"	0.222	0.016
0.340	"	0.162	0.013
0.360	"	0.140	0.010
0.380	"	0.1071	0.0078
0.400	"	0.1056	0.0078
0.420	"	0.1008	0.0075
0.440	"	0.0911	0.0071
0.460	"	0.0989	0.0074
0.480	"	0.0853	0.0067
0.500	± 0.010	0.0886	0.0068
0.525	± 0.015	0.0812	0.0055
0.555	"	0.0924	0.0078
0.585	"	0.0853	0.0070
0.615	"	0.0905	0.0075
0.645	"	0.0789	0.0068
0.675	"	0.0682	0.0061
0.705	± 0.015	0.0644	0.0059
0.740	± 0.020	0.0684	0.0057
0.780	"	0.0679	0.0057
0.820	"	0.0581	0.0051
0.860	"	0.0526	0.0048
0.900	"	0.0486	0.0074
0.940	"	0.047	0.018

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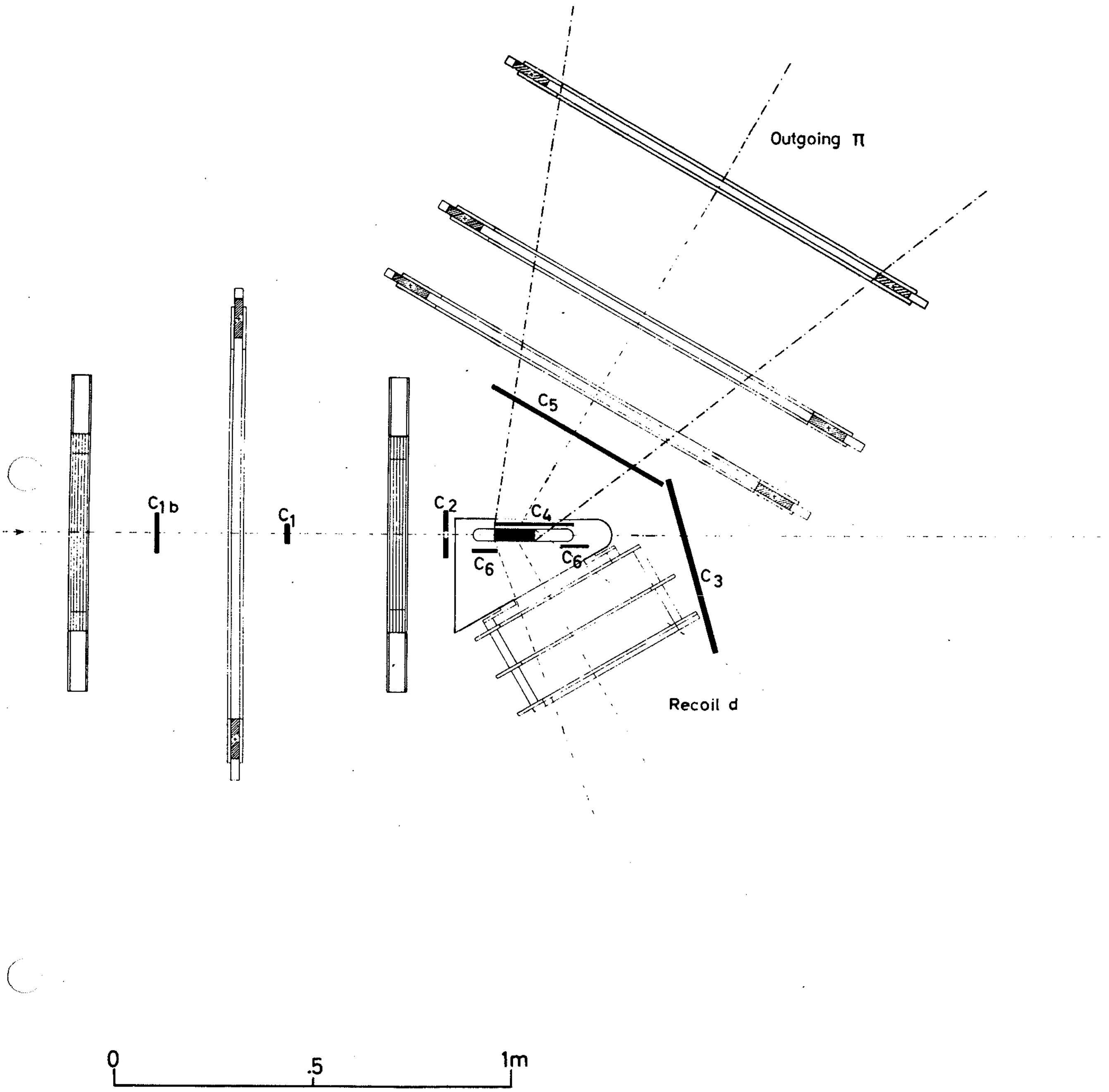
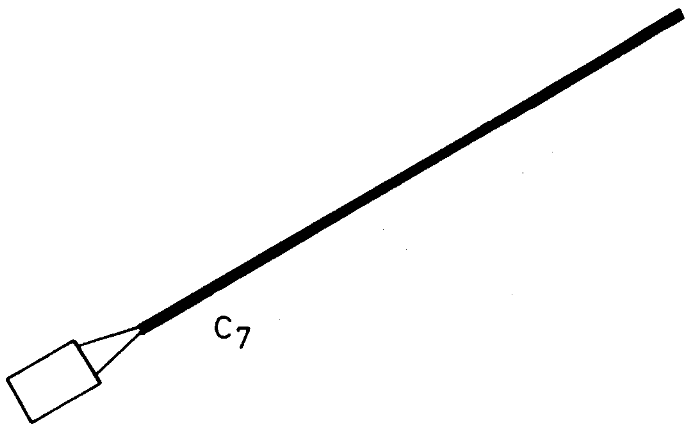
Figure captions

Fig. 1 : Experimental set-up.

Fig. 2 : $(d\sigma/dt)(\pi d \to \pi d)$ versus $|t|$. The solid curve is the one predicted from Ref. 8.





C_{1b} Φ 120 mm, 2 mm thick
C_1 Φ 50 mm, 2 mm thick
C_2 (120x120x10) mm, 18 mmΦ hole
C_3 460x400x10
C_4 (197x70x5) mm
C_5 special shape, 10 mm thick
C_6 (66x70x5) mm + (70x70x5) mm
C_7 10x(1300x100x10) mm

Fig. 1

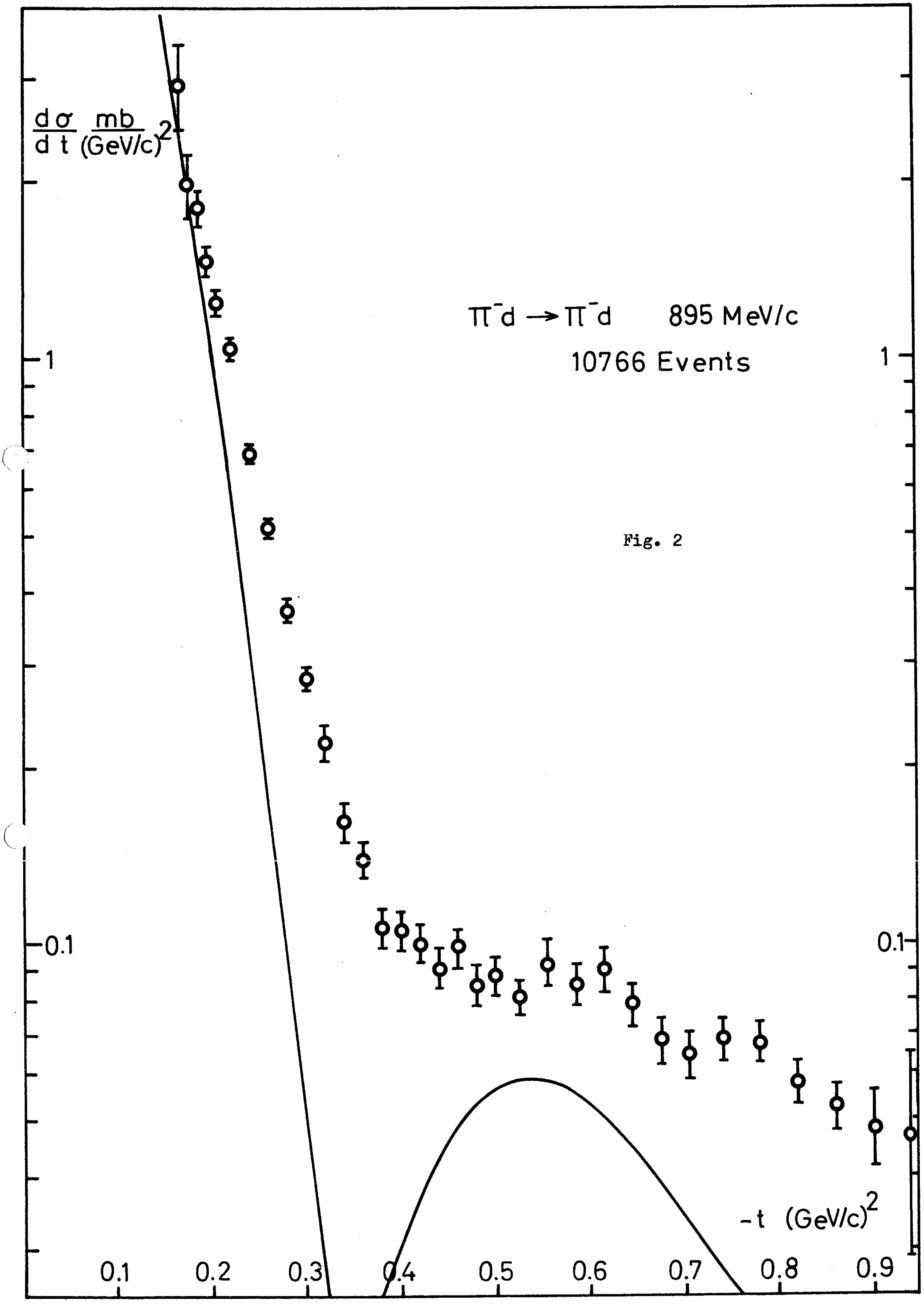

dσ/dt mb/(GeV/c)²
π⁻d → π⁻d 895 MeV/c
10766 Events
1
0.1
-t (GeV/c)²
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9

Fig. 2