EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

PH I/COM-68/11
22 February, 1968

PHYSICS I

ELECTRONICS EXPERIMENTS COMMITTEE

PROPOSAL

TO MEASURE THE PHASE OF THE PION-NUCLEON SCATTERING AT HIGH-ENERGY AND AT NON-ZERO MOMENTUM TRANSFER, BY STUDYING THE PION-DEUTERON ELASTIC SCATTERING

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(CERN-Trieste)

SUMMARY

This is the detailed description of the second part (high-energy) of the CERN-Trieste proposal of April 1967 to study pion-deuteron elastic scattering. The first part (low-energy) of this study is being completed at the CERN Proton Synchrotron (see the attached CERN-Trieste Progress Report of February 1968). The main change concerns the quality of the beam, which should be of the d-type. The geometry of the experiment is now somewhat different in order to take into account the changes in the kinematical configuration. The counters, spark chambers, and their related electronics stay essentially the same.

Geneva - 22 February 1968

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1 INTRODUCTION

The aim of the present paper is to give some experimental details on the high-energy part of the measurement of the πd elastic differential cross-section; we intend to work at incident pion momenta between 6 and 12 GeV/c, and in the region of momentum transfers to the deuteron $(0\ 15 \lesssim |t| \lesssim 1\ 35)(\mathrm{GeV}/c)^2$ For the theoretical justification of such an experiment we refer to our proposal of April 1967$^{1)}$ Here we want only to point out that in the framework of the Glauber theory the detailed knowledge of the πd elastic differential cross-section gives the possibility of measuring the ratio between the real and the imaginary parts of the pion-nucleon scattering amplitude in the non-forward direction. Our preliminary results$^{2)}$ at 0 9 GeV/c look quite promising in that sense, because a dip in the $d\sigma/dt$ versus t is shown to exist for the expected value of t (see Fig 8 of the attached Progress Report)

We want also to stress the following points:

i) Whilst until about 2 GeV/c it is possible to compute, from the known partial waves phase-shifts analysis$^{3)}$, the phase of the scattering amplitudes at momenta transfer different from zero, the method suggested in Ref 1 seems the only one possible at high energy, due to lack of phase-shift analysis.

ii) The behaviour of the pion-nucleon cross-sections shows that the pion-nucleon system does not seem to resonate strongly for energies above 4 GeV The absence of resonances should simplify the picture, since in the Glauber method it is implicitly assumed that the scattering amplitudes are slowly varying functions of the energy

iii) Some approximations in the Glauber theory are of the "high-energy" type and, therefore in the high-energy experiment one should be able to handle the experimental data in a more confident way; in particular, the same values of t correspond at high energy to smaller values of the scattering angle in the c m s , and therefore the goodness of the approximations is improved

iv) It is likely that at high energy the spin dependence of the scattering amplitude becomes less important; this fact helps the theoretical analysis of the data, since the πd differential cross-section becomes a function of a more limited number of parameters

v) There are some doubts about the validity of the Glauber approximations at very high energy, both from the theoretical side4) and from experimental results on pp, np, and pd total cross-sections5) These doubts concern the terms to be added to the single-scattering term (in the Glauber theory the double-scattering term) It should therefore be important to check the theory in a situation in which the projectile is spinless, and, more important, not in the forward direction where the double-scattering term is a small correction, but in the region of the second maximum [around 0 6 $(GeV/c)^2$ of momentum transfer], where the double-scattering contribution is supposed to give almost all the cross-section

The expected $d\sigma/dt$ was computed by introducing in the Glauber formula the experimental values of the total pion-nucleon cross-sections and of the slope of the diffraction peak in pion-nucleon scattering4) The ratio of the real to the imaginary part of the pion-nucleon scattering amplitudes was assumed constant with the momentum transfer and equal to the experimentally measured value in the forward direction6) The deuteron wave function was assumed to be of the Gartenhaus-Moravcsik type7) The results are given in Fig 1 for a pion momentum of 9 0 GeV/c

2. THE EXPERIMENTAL LAYOUT

Let us choose a pion momentum of 9 0 GeV/c The dependence of the momentum transfer and the scattering angle on the recoil angle for this momentum is given in Figs 2 and 3 for pion-deuteron and pion-proton scattering, respectively

We propose to use the layout sketched in Fig 4 The components of this set-up are essentially the same as the ones used in the low-energy experiment However, taking advantage of the fact that the scattered pions are concentrated in the forward direction, we propose to have a second symmetric deuteron detector; furthermore, in order to increase the pion detection efficiency, we would like to have one more chamber (which has already been built) in the scattered pion cone The C_i (i = 0, , 7) are scintillator counters, the S_j(j = 1, , 9) are spark chambers

A pion beam with the properties required in Section 4 hits a liquid deuterium target of 20 cm length and 3 cm diameter The beam signal will be the coincidence $C_1 C_{1b} \bar{C}_2$; if it is necessary to separate the negative pions from the antiprotons and the kaons, the coincidence with a Čerenkov counter could be required

The recoil deuterons are detected in the solid angles defined by the counters $\bar{C}_6 C_7$ and $\bar{C}'_6 C'_7$, respectively, which correspond to the wanted range of momentum transfers (0 15 $\leq$ t $\leq$ 1,35)$(\mathrm{GeV}/c)^2$ The C_7 and C'_7 are sets of 10 scintillators of (130 × 10 × 1) cm^3 each The scattered pions will be detected in the telescopes $C_4 C_5$ and $C'_4 C'_5$, respectively. Eventually, the trigger will be (beam) $\bar{C}_3 C_4 C_5 \bar{C}_6 C_7$ By time-of-flight selection on counters C_7 and C'_7, one will be able to separate roughly the deuterons from the background of quasi-elastic protons For the C_7 counter position indicated in Fig 4, the dependence of time-of-flight on the recoil angle is given in Fig 5 for the pion-deuteron and pion-proton scattering; the propagation time of the light in the scintillator is included Taking into account the angular correlation which forbids pions of less than 2 5° for momenta transfer less than 0 6 $(\mathrm{GeV}/c)^2$, it appears that a threshold for time-of-flight above 28 nsec will be sufficient to cut down the quasi-elastic proton background The block diagram of the trigger electronics is given in Fig 6 The elimination of the background will be completed through a geometrical and a kinematical fit of the tracks detected in the wire spark chamber system, with magnetostrictive read-out The general characteristics of the chambers were given elsewhere[8])

The accuracy in the reconstruction of the tracks will allow (as previously) a definition of the momentum transfer better than 2%.

3 MAGNETOSTRICTIVE SPARK CHAMBERS AND READ-OUT ELECTRONICS

As can be seen from Fig 4, nine wire spark chambers are used to measure the reaction; they are all already in operation In particular, two special multiple-gap spark chambers have been built for the recoil particle branch in order to have the least possible material along the trajectory of the recoil particle (with kinetic energy as low as ~30 MeV); only one mylar window (0 1 mm thick) lies between the target vacuum chamber and the three sensitive gaps; the chamber itself is filled with a conventional HeNe mixture, reducing the multiple scattering as much as possible

A total of 30 coordinates will be recorded on magnetic tape, using the already existing read-out electronics Some details of the acquisition system are shown in Fig 7; a more precise description can be found elsewhere[9)]

4 BEAM REQUIREMENTS

We propose to perform the high-energy experiment in the d-beam, putting the centre of the deuterium target in its first focus The momentum range will be between 4 and 12 (possibly 14) GeV/c. At 12 GeV/c, with 30% of 10^{12}/burst circulating protons on target 1 and a 40% target efficiency, one will expect, in a momentum bite of ±1%, a number of pions:

either 2 7 × 10^5/burst with a PS energy of 25 GeV and a repetition time of 2 3 sec

or 0 5 × 10^5/burst with a PS energy of 19 GeV and a repetition time of 1 6 sec

The image will have a diameter of 12 mm; a divergence of ±5 mrad in both the vertical and the horizontal planes could be reached[10)]

To observe a dip in the cross-section at a level of 1 $\mu b/(GeV/c)^2$ for a t-bite of 0 05$(GeV/c)^2$ (see Fig 1) and with a 10% statistical accuracy, we will need, for 20 cm D_2 target,

$$\frac{10^2}{0\ 6 \times 0\ 08 \times 20 \times 10^{-8} \times 0\ 6} \cong 1\ 5 \times 10^{10} \text{ pions,}$$

equivalent to two days with the PS working at 25 GeV, and to six days with the PS working at 19 GeV

We are limited in the triggering rate by the dead-time required to write an event onto magnetic tape (total dead-time ~ 40 nsec) This means that for a PS burst 200 msec long, only 5 events/burst can be recorded If we suppose a reasonable signal-to-noise ratio (extrapolated from our present experiment), we will be able to measure at the same time cross-sections less than 200 $\mu b/(GeV/c)^2$ (apart from a small part of the diffraction peak, seen in Fig 1, this is always our case) However, if the length of the beam were to be shortened or the signal-to-noise ratio became worse then the required time for the measurement would be longer

Therefore a reasonable schedule would be:

1 PS week for setting up the beam
2 PS weeks for setting up the experiment
2 PS weeks for data taking

5 DATA HANDLING

The reconstruction programme1) recognizes and selects the tracks in each wire chamber telescope and provides a geometrical fit of the interaction vertex; a second part of the programme fits our kinematical hypothesis and completes the analysis The basic set-up which the programme handles is a telescope of wire chambers, all orthogonal to some z axis, and each one with two magnetostrictive read-out lines (say x axis and y axis) at 90° to each other The number of telescopes, the number of chambers per telescope, the number of tracks per telescope, as well as the number of sparks per chamber, are all completely free The programme reads the data from a tape; it checks, reorders, and names the coordinates; then it picks up the tracks among the possible spurious sparks The xz and yz planes are kept separate Some additional information (in our case a wire chamber per telescope with a magnetostrictive read-out, t-axis at 45° with x axis and y axis) is needed to resolve ambiguities in the case of many tracks per telescope, i e to couple the xz plane and yz plane projected tracks A fit of the interaction vertex and of the track directions is then done by using a generalized least squares method, starting from the knowledge of the position of the read spark-points and their errors; the errors of the points in each telescope are assumed to be correlated by Coulomb scattering and other physical reasons

The programme is written in general form and incorporates many other facilities; it is now running both on the CERN CDC 6600/6400 under SCOPE and on University of Trieste IBM 7044 under IBSYS

Time Schedule

We are ready to start any time after the 1968 shut-down

* * *

REFERENCES

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2) CERN-Trieste High-Energy Group, Pion-deuteron elastic scattering (S63) — Progress Report, 2 February 1968

3) C Lovelace, Rapporteur's talk at the Int Conf on Elementary Particles, Heidelberg, 1967 CERN preprint TH 837

4) E S Abers, H Burkhardt, V L Teplitz and C Wilkin, Nuovo Cimento 42, 365 (1966)

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6) K J Foley, R S Gilmore, S J Lindenbaum, W A Love, S. Ozaki, T T Russel and L C L Yuan, Phys Rev Letters 15, 45 (1965).

7) M J Moravcsik, Nucl Phys 7, 113 (1958)

8) F Bradamante and F Sauli, Nucl Instrum and Methods 56, 268 (1967)

9) F Bradamante and F Sauli, INFN/TC - 67/5

10) G Petrucci, Private communication

11) P Schiavon, Bollettino SIF, 55, 109 (1967)

Figure Captions

Fig 1 : Theoretical $\pi d \rightarrow \pi d$ differential cross-section, computed for the following values of the parameters:

$$\sigma_{tot}(\pi p) = 26\ 8 \text{ mb}$$
$$\sigma_{tot}(\pi n) = 25\ 0 \text{ mb}$$
$$\alpha_{\pi p} = -0\ 15$$
$$\alpha_{\pi n} = -0\ 24$$

Fig 2 : Plot of momentum transfer versus recoil angle in pion-deuteron and pion-proton scattering

Fig 3 : Plot of recoil angle versus scattering angle in pion-deuteron and pion-proton scattering

Fig 4 : Experimental layout

Fig 5 : Times-of-flight of the recoil particles (including light propagation in scintillator) versus recoil angle, for pion-deuteron and pion-proton scattering

Fig 6 : Block diagram of the electronics for the trigger

Fig 7 : Block diagram of the read-out electronics for the spark chambers

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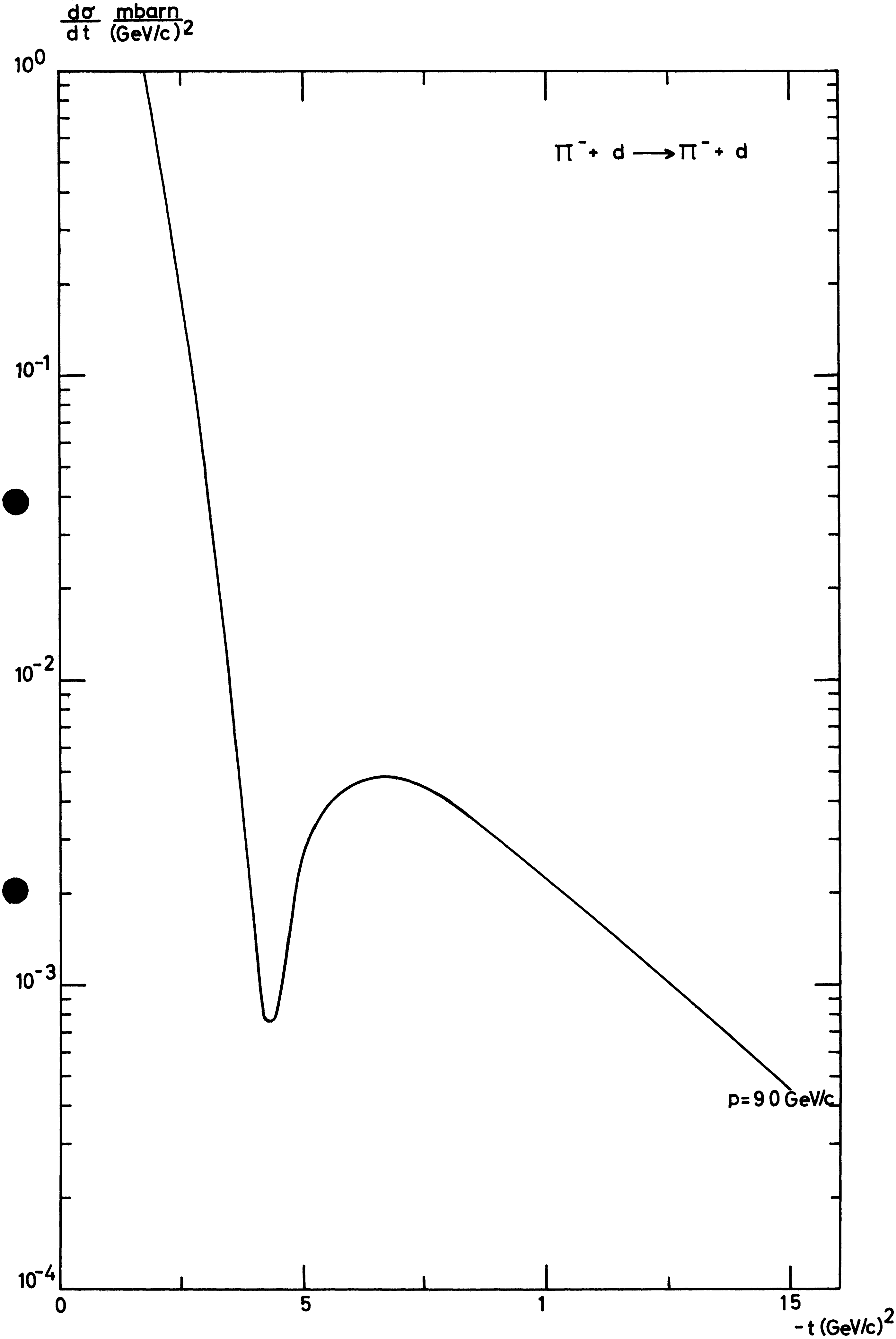
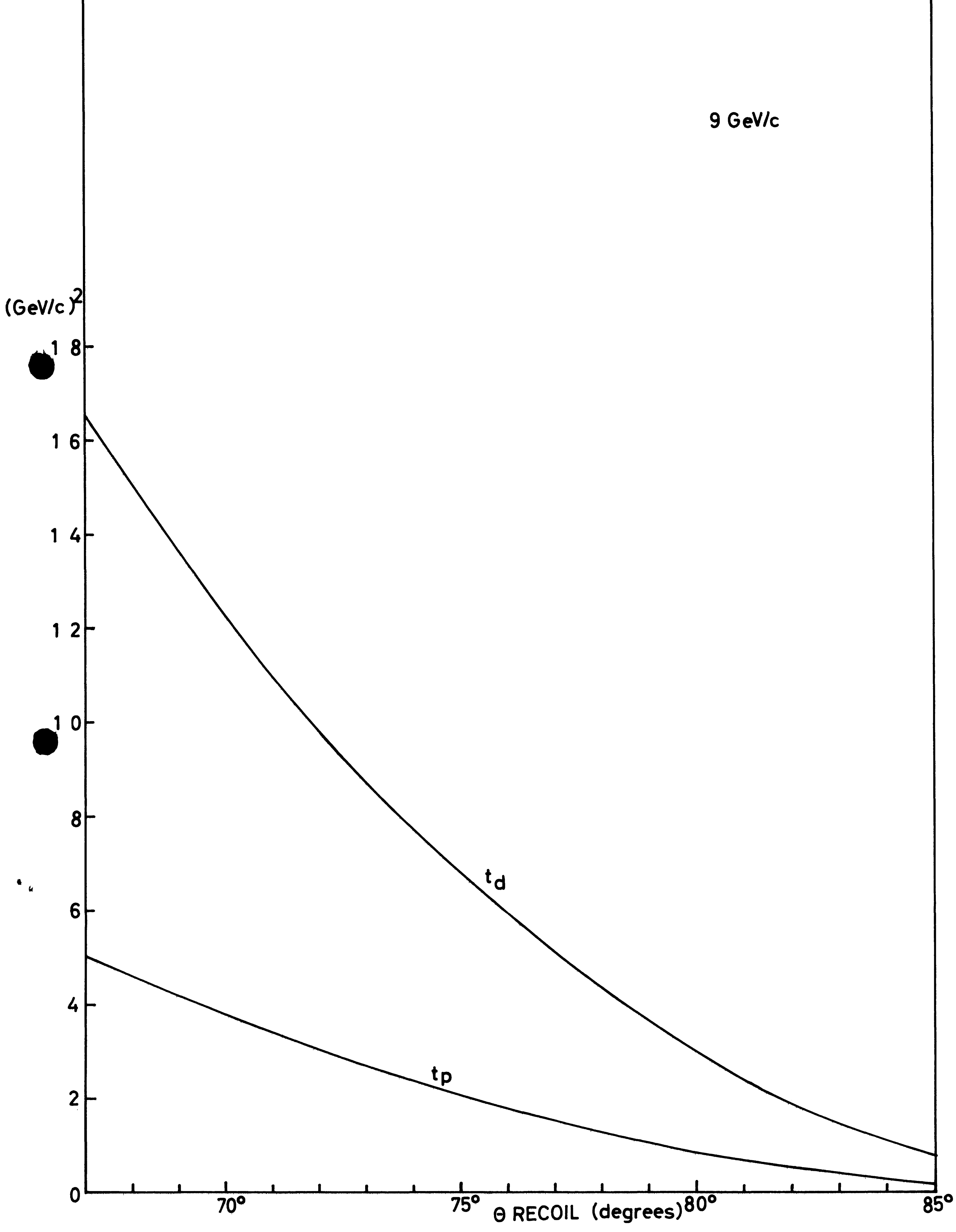
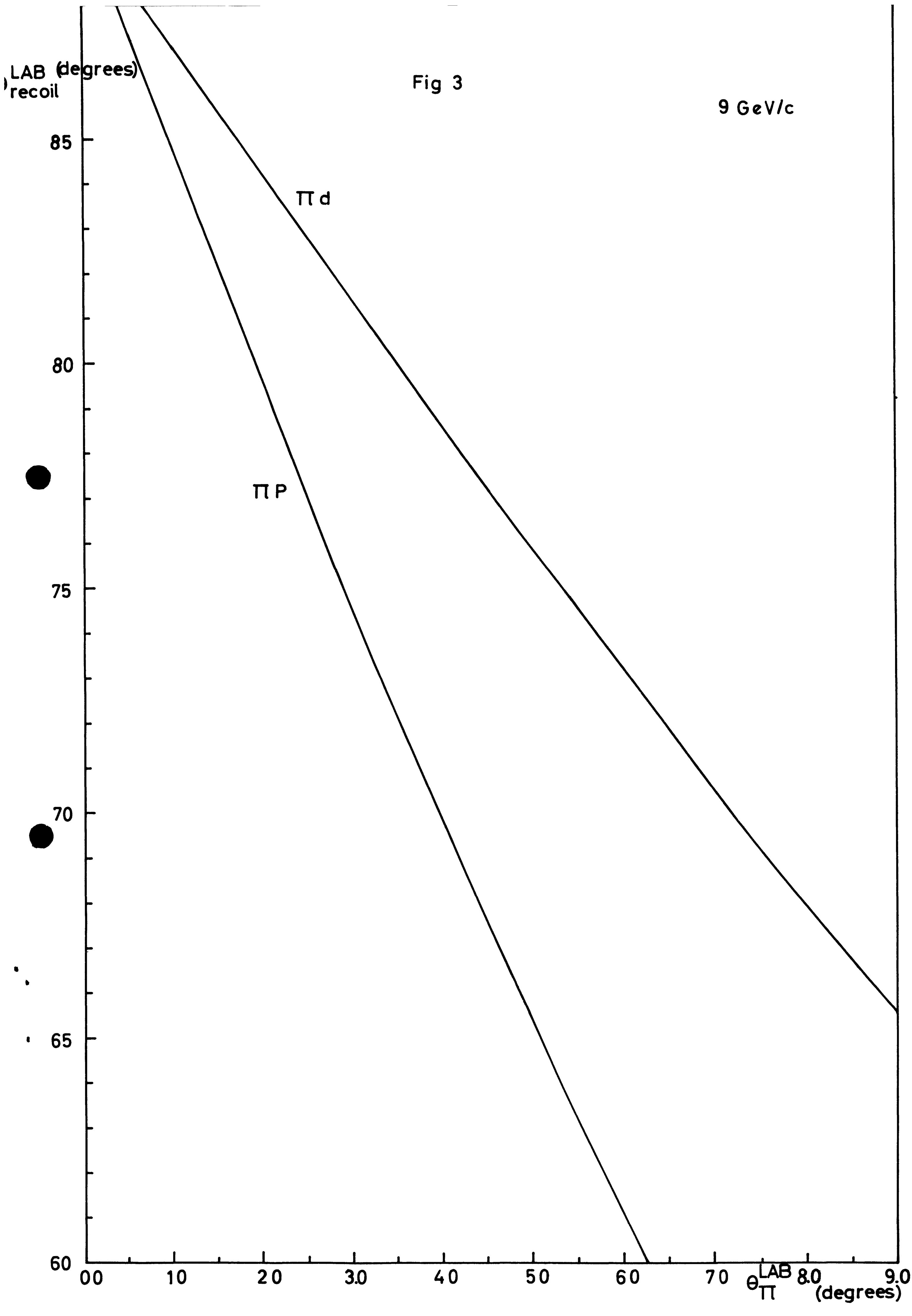

dσ/dt mbarn/(GeV/c)2
10^0
10^-1
10^-2
10^-3
10^-4
π^- + d ⟶ π^- + d
p=9 0 GeV/c
0
5
1
15
-t (GeV/c)2

Fig 1

Fig 2


9 GeV/c
(GeV/c)^2
1 8
1 6
1 4
1 2
1 0
8
6
4
2
0
t_d
t_p
70°
75°
80°
85°
Θ RECOIL (degrees)



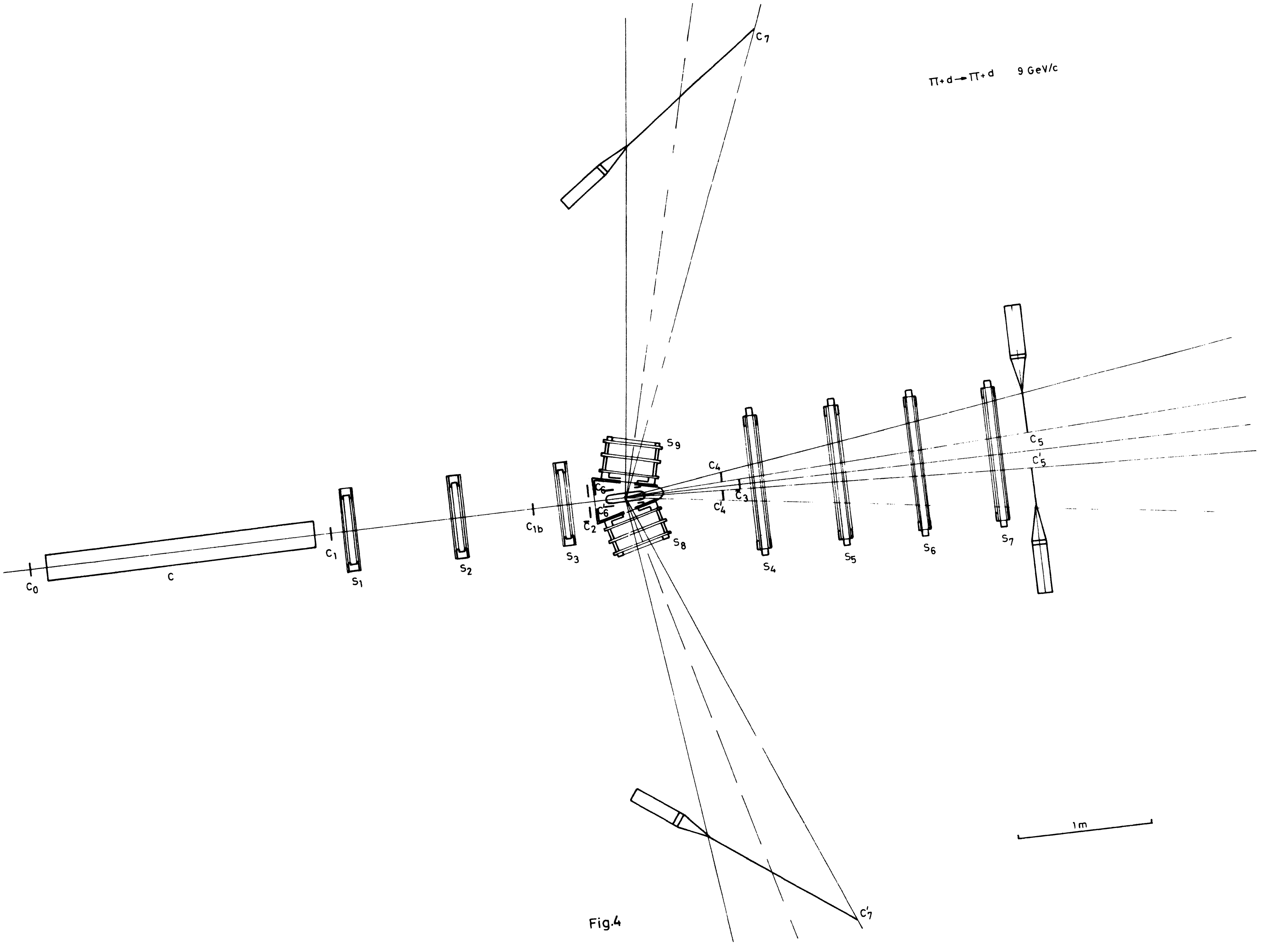
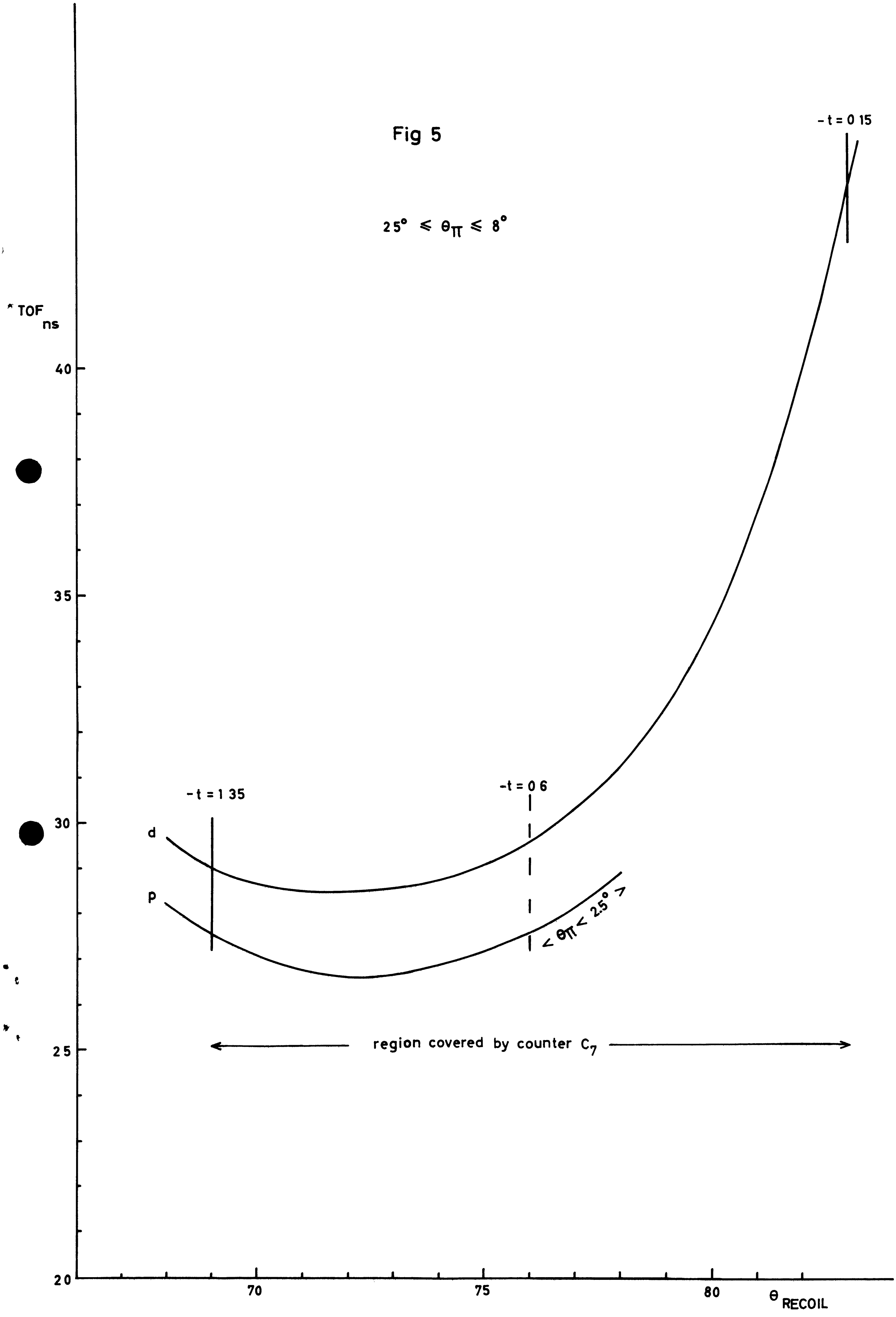

$\pi + d \rightarrow \pi + d$ 9 GeV/c
C_7
S_9
C_4
C_6
C_6'
C_2
C_3
C_4'
C_5
C_5'
C_0
C
C_1
S_1
S_2
C_{1b}
S_3
S_8
S_4
S_5
S_6
S_7
1m
C_7'

Fig.4

Fig 5


$25° \leqslant \theta_{\pi} \leqslant 8°$
TOF ns
40
35
30
25
20
70
75
80
θ_{RECOIL}
-t = 0 15
-t = 0 6
-t = 1 35
d
p
$< \theta_{\pi} < 2.5° >$
region covered by counter C_7

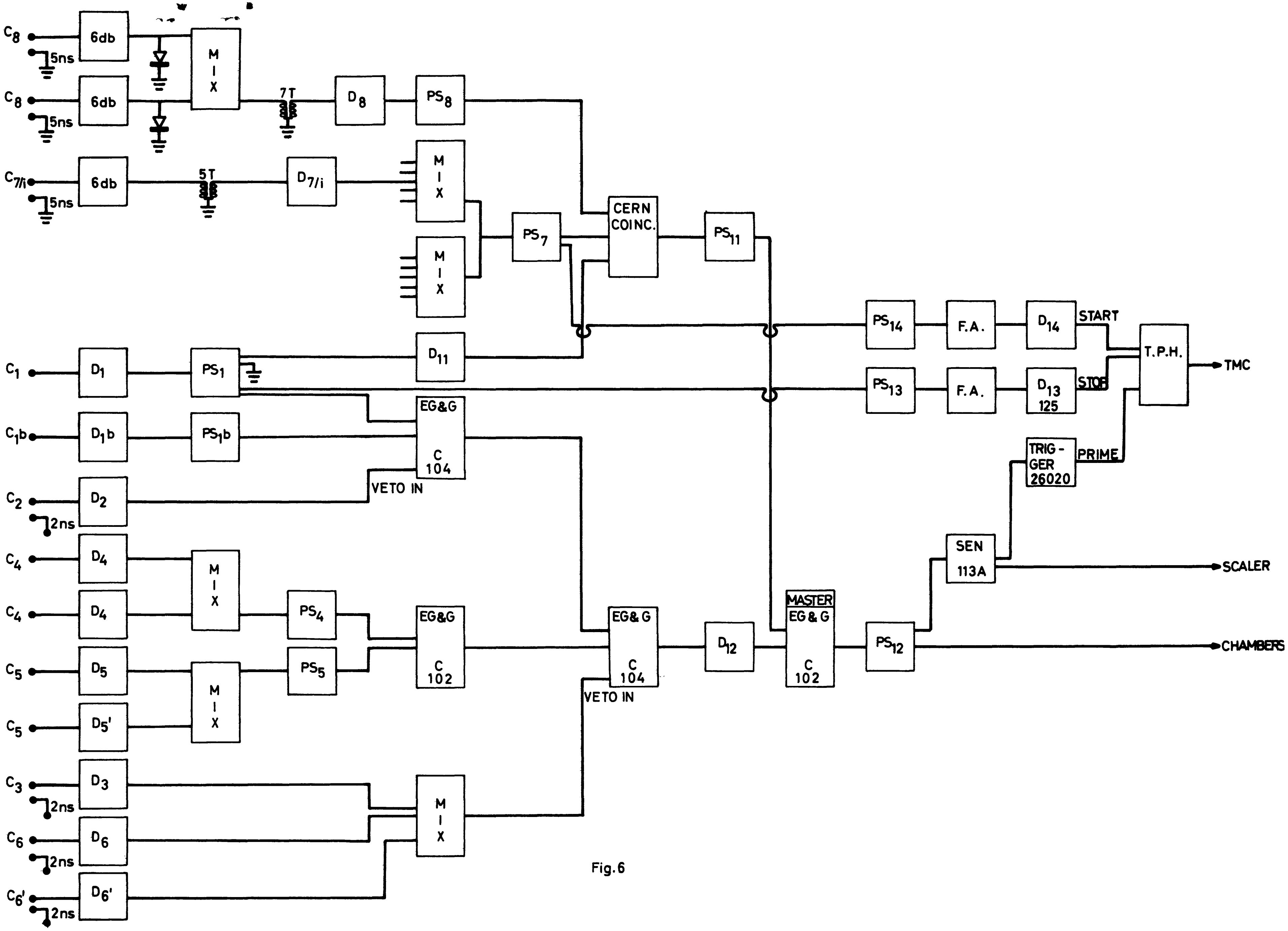

C8
5ns
6db
C8
5ns
6db
M I X
7T
D8
PS8
C7/i
5ns
6db
5T
D7/i
M I X
M I X
PS7
CERN COINC.
PS11
C1
D1
PS1
D11
C1b
D1b
PS1b
EG&G C 104
VETO IN
C2
2ns
D2
C4
D4
C4
D4
M I X
PS4
C5
D5
C5
D5'
M I X
PS5
EG&G C 102
C3
2ns
D3
C6
2ns
D6
C6'
2ns
D6'
M I X
EG&G C 104
VETO IN
D12
MASTER EG & G C 102
PS12
CHAMBERS
SEN 113A
SCALER
TRIG - GER 26020
PRIME
PS14
F.A.
D14
START
PS13
F.A.
D13 125
STOP
T.P.H.
TMC

Fig.6

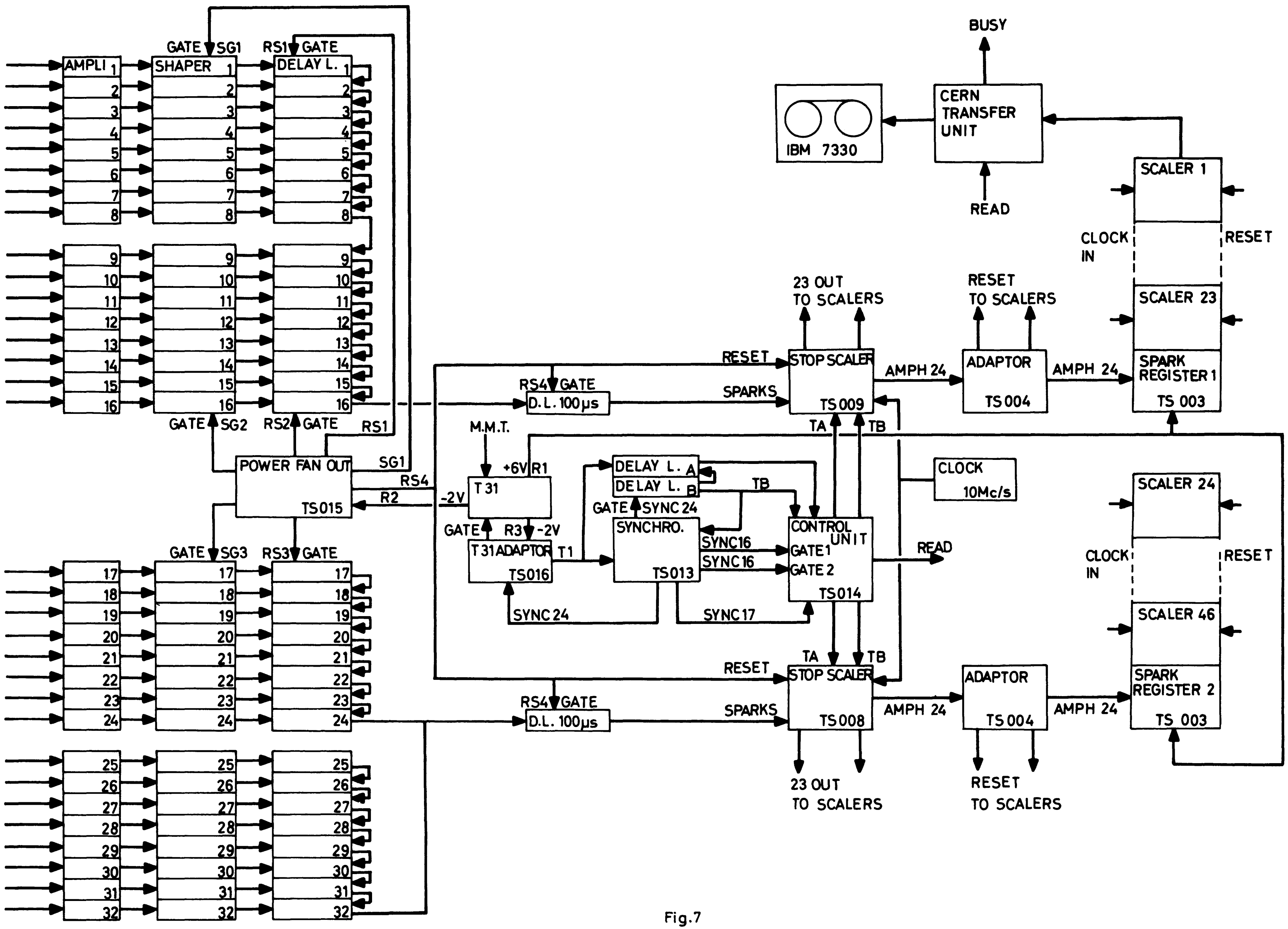

AMPLI
SHAPER
DELAY L.
GATE SG1
RS1 GATE
GATE SG2
RS2 GATE
GATE SG3
RS3 GATE
POWER FAN OUT
TS015
SG1
RS1
RS4
R2
-2V
M.M.T.
+6V R1
T 31
GATE
R3 -2V
T31ADAPTOR
TS016
T1
SYNC 24
DELAY L. A
DELAY L. B
GATE SYNC 24
SYNCHRO.
TS013
SYNC16
SYNC 16
SYNC17
TB
CONTROL UNIT
GATE1
GATE 2
TS014
READ
CLOCK
10Mc/s
RS4 GATE
D.L. 100μs
RESET
SPARKS
STOP SCALER
TS 009
TS 008
TA
TB
23 OUT
TO SCALERS
AMPH 24
ADAPTOR
TS 004
RESET
TO SCALERS
SPARK
REGISTER 1
SPARK
REGISTER 2
TS 003
SCALER 1
SCALER 23
SCALER 24
SCALER 46
CLOCK
IN
RESET
CERN
TRANSFER
UNIT
BUSY
READ
IBM 7330
1
2
3
4
5
6
7
8
9
10
11
12
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Fig.7