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PROPOSAL FOR AN EXPERIMENT ON COHERENT INTERACTIONS AND PRODUCTION PROCESSES FROM $\pi^{\pm}$ ON ^{4}He AND ^{3}He UP TO 5 GEV/c

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Abstract - We propose to study the coherent interaction of pions on ^{4}He (I = 0) and ^{3}He (I = 1/2) nuclei between 1 and 5 GeV/c. The main purpose of this experiment is to study the production of meson resonances with isotopic spin I = 1 and I = 0 at single ($t < 0.25$ (GeV/c)^2) and double scattering region ($t > 0.25$ (GeV/c)^2). The same experimental method (missing mass method) is used as in the p-He^4 coherent scattering experiment at 24 GeV/c : the recoiling nucleus is detected and identified by means of ΔE - E silicon detectors. For the use in secondary pion beams, the apparatus consists in large area ΔE - E solid state detectors, and the angle of the recoiling nucleus is determined by means of multiwire proportional counters (MWPC). This experiment could be performed in the m_9 beam, or partly in the m_7 beam.

I. INTRODUCTION

1) General interest

The interest of the coherent production processes has been already emphasised [1], in particular at the recent Uppsala Conference. Experimental data are now available for photoproduction coherent reactions [2], and for reactions involving hadrons [3] : most of them concern diffraction processes.

The study of a coherent reaction requires a good definition of the final state of the nucleus : charge, mass, spin and isospin even in an excited state, and a good description of the process, that means a high statistical accuracy in the region of the single and the double scattering, so as to obtain some information on the rescattering of the resonance, a precise idea of the variation of the phenomena with the energy, and its consequences on the character of the production (diffractive, non diffractive) and on the properties of the resonances in term of Regge pole analysis [4], [5].

We propose to study with two simple nuclei of isospin $I = 0$ and $I = 1/2$ the production processes of pionic resonances at different energies and in a region where their cross sections are high. With ^4He, only $I = 1$ pionic resonances can be produced. With ^3He using the charge exchange effect $^3He \rightarrow {}^3H$, $I = 0$ neutral pionic resonances can also be produced.

2) New technical possibilities

We propose to do this experiment using a gaseous target and making an intensive use of the recoil detection method. The large area (2 x 5 cm) semiconductor detectors now available, with associated cheap linear electronic system using integrated circuits, allow the use of a mosaïc of $\Delta E - E$ telescopes with a large solid angle which can be used in a secondary beam.

A recent experiment on the production of N^* from He^4 by 24 GeV/c protons have shown the powerful possibilities of this technique : the good separation of ^3He and ^4He allows a non ambiguous definition of the final state of the nucleus, and the study for momentum transfers corresponding to the single and the double scattering. [8]

A broader momentum transfer range could be explored by the use of Li drifted instead of surface barrier detectors as E detectors. This is particularly important when particles with charge 1 are to be detected.

In order to investigate very low momentum transfers, a special effort is developped concerning very thin ΔE detectors using a promising technique of electrochemical etching of epitaxial silicon [7]. This new possibility could be used in the future to study the production of resonances in the Coulomb field of the nucleus.

II. EXPERIMENTAL PROGRAMME

1) Elastic scattering

The study of elastic scattering will first provide a useful check of theoretical models which may then be used in production reactions.

Measurements for momentum transfer lying both in the single and the double scattering region lead to the phase of the pion nucleon scattering amplitude.

There are now many experimental results on pion nucleus scattering around the 3-3 resonance, but very few results beyond this region. And it would be interesting to compare $\pi^\pm$ scattering around the energy of the $I = 1/2$ (1688) resonance where the ratio of the $\pi^- p$ and $\pi^+ p$ cross sections is about 2, and at a higher energy (4 - 5 GeV/c) where they are similar (see Table 1). The interaction of pions with the protons and the neutrons of the nucleus could then be extracted. The situation is favoured compared to the situation at lower energies (around the 3-3 resonance) : i) the assumptions made in the multiple scattering models are better fulfilled; ii) the pion-nucleon cross sections are lower so that the incoming pion is expected to penetrate deeper into the nucleus.

The study of the charge exchange reaction from He^3 :

$$\pi^- + He^3 \rightarrow \pi^o + H^3$$

can provide a further information on these processes.

2) Coherent production from He^4

The reactions we propose to study are :

$$\pi^- + {}^4He \rightarrow X^- + {}^4He$$

where X^- is a pion system with isospin $I = 1$ (ρ, A_1, A_2).

The principal aims of these experiments are the following : i) the extraction of the meson-nucleon total cross sections in the double scattering region; ii) the study of the mechanisms of these reactions which are different for ρ production (ω exchange type) and for A_1 or A_2 for which diffraction processes are allowed; in particular, a comparison can be made between the production of ρ induced by pions and by photons which has been extensively studied.

So, we propose to make measurements at two different incident energies, about 3 GeV/c and 5 GeV/c, where cross sections for ρ production on nucleons are still high enough, and high missing masses can be yet detected (Figure 1).

3) Production from He^3

The same reactions can be studied from ^3He :

$$\pi^- + {}^3He \rightarrow X^- \ (I = 1) + {}^3He$$

But charge exchange and isospin exchange reactions are now allowed, leading in the final state to a ^3H nucleus and a missing mass system with $I = 1$ (ρ_o) or $I = 0$ (a scalar meson as η_o, ω_o, f_o) :

$$\pi^- + He^3 \rightarrow X^o \ (I = 1 \ \text{or} \ I = 0) + {}^3H$$

These reactions present a similar interest as the coherent reactions from ^4He, particularly the study of their mechanisms, and the rescattering, if the double scattering region can be experimentally explored.

4) Dissociation reactions

The experimental apparatus is designed in order to detect one or two charged recoiling particles in coïncidence. So the dissociation events are recorded in the same time as the single events from the former reactions. Thus we can get some information about the reactions:

$$\pi^- + {}^4He \rightarrow \pi^- + (n\,\pi) + \begin{array}{l} p + {}^3H \\ {}^2H + {}^2H \end{array}$$

$$\pi^- + {}^3He \rightarrow \pi^- + (n\,\pi) + p + {}^2H$$

in particular about incoherent production processes for which very few results are now available.

There is another interest of these reactions from a nuclear physics point of view, in particular : i) the study of the simple dissociation reactions without pion production; ii) the study of the final state interactions between the final products of these "three" body reactions (with and without production of pions) like :

$$\pi^- + {}^4He \rightarrow \Delta^o \ (\text{or} \ N^{*o}) + {}^3H.$$

III. EXPERIMENTAL SET UP

1. Description (Figure 3)

There are four detection planes around the beam axis. Every plane consists of eight $\Delta E - E$ telescopes (2 x 5 cm) of semiconductor detectors which give the identification and the energy of the recoiling nucleus. The angle of the detected particle with the beam axis is determined by means of two MWPC.

The detectors and the proportional chambers are located in a chamber filled with a gas mixture (A - CH_4 or A - CO_2) suitable for MWPC operation (with a pressure between 0 and 4 atmospheres). The gas target is contained in a small diameter cylindrical cell with very thin windows, at a pressure near that of the chamber. This gas target cell is necessary for experiments with ^3He. But the measurements from ^4He could be made using the gas both as target and working gas if it is possible to have a good operation of proportional chambers with helium (plus a few per cent of an organic gas).

The electronics is triggered, besides coincidences with suitable counters in the incident beam, by a fourfold coincidence between the ΔE and E detectors of one telescope and the groups of wires of the two MWPC located in front of this telescope, so that we can restrict the angular range for the recoiling particle (about 60^o $\leqslant \theta \leqslant +120^o$; negative angles can be found in the dissociation reactions). The pulses from the proportional gas chambers and the proportional silicon detectors are similar, and the resolution time is about 50 ns.

The wires are followed by a standard CERN modular system and the silicon detectors by a linear electronic system and an A.D. converter. Each event (ΔE - E - MWPC1 - MWPC 2) is recorded via CAMAC to a 2 100 A Hewlett Packard computer. The identification of the particles by means of the ΔE - E information is made off-line.

2) Experimental resolution

The energy resolution, which gives the momentum transfer resolution, is determined by the silicon detectors : $\sim$ .150 MeV.

The angular resolution, which is the most important parameter of the missing mass resolution (Figure 2) is determined by the proportional chambers. With standard electronics, each position is defined to about $\pm$ 1 mm. For a distance between the two MWPC of 10 cm, the uncertainty on the θ angle is $\sim \pm 1^o$) if the particles recoil at 90^o and $\pm 1.5^o$ at 60^o (this without any information on the azimuthal position. We hope to be able to have such an information on the cathode wires).

3) Counting rates

We calculate the counting rate for elastic $\pi^- He^4$ scattering at about 5 GeV/c from Glauber's multiple scattering theory (Figure 5) . In the range $.080 \leqslant t \leqslant .450$ (GeV/c), the estimated counting rate is about 2 elastic events per minute per detection plane, assuming a beam intensity of 10^6 pions per second and a gas pressure of 1 atmosphere.

For inelastic events, we have only reported on Table 1 the cross sections for π^- induced reactions on protons.

4) Tests

Tests are now beginning with this apparatus using 56 MeV particles on the S.C. of LYON and will be going on for about one year.

IV. BEAM

This experiment requires :

a) A focused beam on the gaseous target, with a common focus point both in the vertical and the horizontal plane.

b) A width at the focus point of the order of 1 cm. The angular divergence in both planes can be of the order of 12 m rad.

c) A momentum resolution of about 1% is sufficient. The maximum of the intensity of the beam is needed.

d) Three energies are needed : $\sim$ 1 GeV/c, mainly for the elastic scattering study, $\sim$ 3 GeV/c, and $\sim$ 5 GeV/c, and with pions of both sign π^+ and π^- for elastic scattering.

The 1 GeV/c and 3 GeV/c energies can be obtained in the m_7 beam, the three energies in the m_9 beam which has then more complete possibilities.

As this experiment is "transparent", another team could work behind. In this case, it is necessary to have two focus on the same beam and that needs some new installation of a quadrupole focusing system.

Another better solution (in the case of one focus) is the use of a beam in tandem with another group (runs are alternatively given to each group). Such a situation could be very interesting with the Trieste group, both groups having some common interest in the preparation of 300 GeV experiments and having in this perspective some complementarity in their technical possibilities.

V. TECHNICAL AND FINANCIAL SUPPORT

The preparation of this experiment is supported by the laboratories of Clermont-Ferrand (7 physicists, 1 engineer, 1 technician) and Lyon (6 physicists, 1 engineer, 2 technicians). *

The financial support has been guaranteed by the French Nuclear Research Authority (IN2P3), allowing the acquisition of a 2100 Hewlett Packard computer (and peripherals), and the construction of the detectors and the associated electronics.

* Two additional physicists from another team from Clermont-Ferrand could participate in this experiment.

VI. PLANNING

This experiment could start after the middle of 1974

Six runs are necessary for the data acquisition, 2 runs for each energy. It could be possible to work at the two lower energies (4 runs) in the m_7 beam and to end (2 runs) in the m_9 beam.

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2) K. GOTTFRIED, Proceedings of the 1971 Intern. Symposium on electron and photon interactions at high energy.

3) C. BEMPORAD et al., Nucl. Phys. B33 (1971) 397

4) J. FORMANEK and J.S. TREFIL, Nucl. Phys. B3(1967) 155.

5) L. STODOLSKY, Phys. Rev. 144 (1966) 1145.

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7) J.P. PONPON, P. SIFFERT and F. VAZEILLE, Thin dE/dx detectors of uniform thickness made on epitaxial silicon (To be published in Nucl. Instr. and Methods).

8) J. BERTHOT et al. (Collab. Clermont-Lyon-Strasbourg) p - ^4He coherent scattering at 24 GeV/c, observation of elastic scattering and production processes by a missing mass method. Intern. Conf. on High Energy Physics and Nuclear Structure, Uppsala, 18-22 juin 1973.

Reactions	Threshold (GeV/c)	Cross Sections (mb)		
		$p_\pi \sim 1$ GeV/c	$p_\pi \sim 2.5$ GeV/c	$p_\pi \sim 4.5$ GeV/c
$\pi^+ p \rightarrow \pi^+ p$	1.05	12.	6.9	5.8
$\pi^- p \rightarrow \pi^- p$		22.2	7.3	6.5
$\pi^- p \rightarrow \rho^- p$	1.05		1.3	0.6
$A_1^- p$				> 0.3
$A_2^- p$				> 0.2
$\pi^- p \rightarrow \pi^o n$		6.64	.53	.13
$\pi^- p \rightarrow \rho^o n$	1.05		2.	1.15
$\pi^- p \rightarrow \eta_o n$	.69	1.25	.09	.1
$\omega_o n$	1.09		1.4	
$\varphi_o n$	2.07		.2	.8
$f_o n$			2.	1.1

Table 1 - $\pi^\pm$ elastic and production cross sections taken from reference 6) for three incident momenta.

FIGURE CAPTIONS

Fig. 1 Kinematical curves with the outgoing mass m_x as parameter

1a) π - ^4He → X - ^4He at p_L = 3.0 GeV/c

1b) π - ^4He → X - ^4He at p_L = 5.0 GeV/c

The dotted curves show the acceptance limits of the detection system. The kinematics on ^3He is very close to that of this figure.

Fig. 2 Mass resolution for 5.0 GeV/c incident pions :

2a) Assuming an angular resolution of 1^o (it is the most important contribution)

2b) Assuming a momentum resolution of 1%

2c) Assuming a recoil energy resolution of 1 MeV.

Fig. 3 Diagrammatic view of the recoil spectrometer

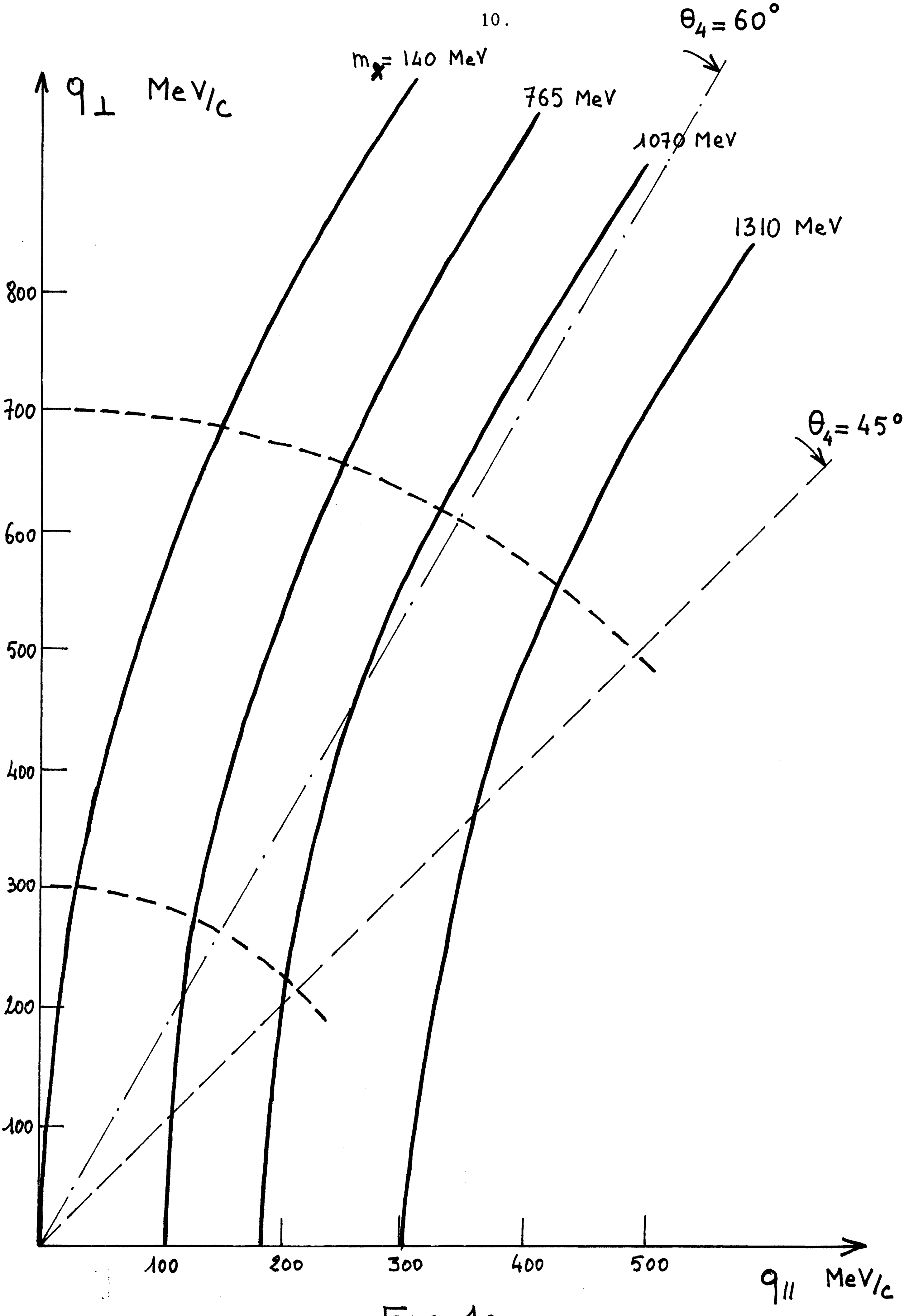
Fig. 4 View of one of the surface barrier detectors

Fig. 5 Theoretical distribution $d\sigma/dt$ in $mb/(GeV/c)^2$ of the elastic scattering $\pi^- + {}^4He \rightarrow \pi^- + {}^4He$ at p_L = 5.0 GeV/c computed from the Glauber's multiple scattering theory. Parameters : $R_{^4He}$ = 1.4 fm

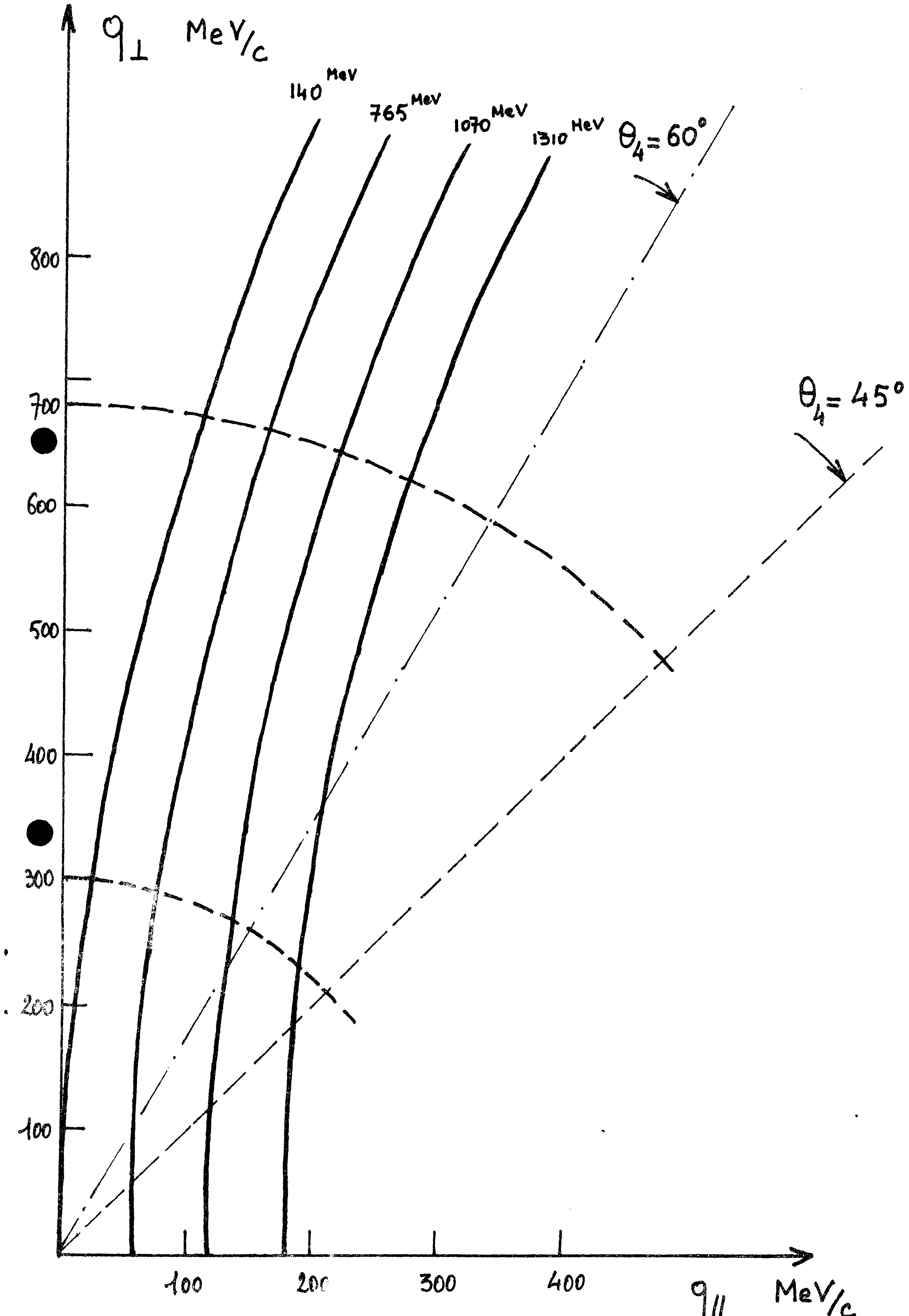
$\sigma_{\pi^- - N}$ = 29 mb

$$\alpha = \frac{Ref}{Imf} = -0.33$$

The two dotted lines are the limits of an investigated t-range : $0.080 < t < 0.450$ $(GeV/c)^2$.

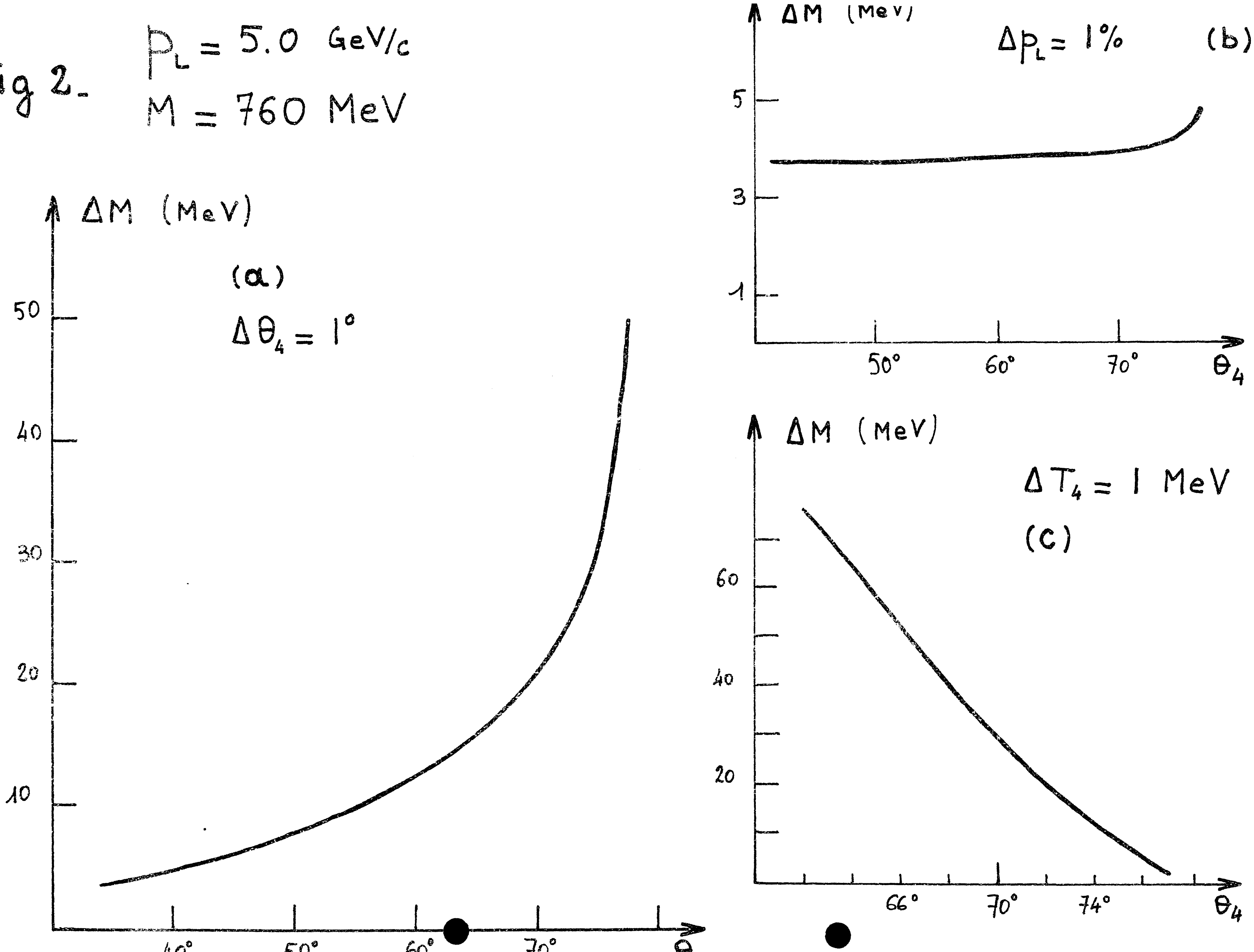

$\theta_4 = 60°$
m_x = 140 MeV
765 MeV
1070 MeV
1310 MeV
$\theta_4 = 45°$
$q_\perp$ MeV/c
800
700
600
500
400
300
200
100
100
200
300
400
500
$q_{\parallel}$ MeV/c

- Fig 1a -

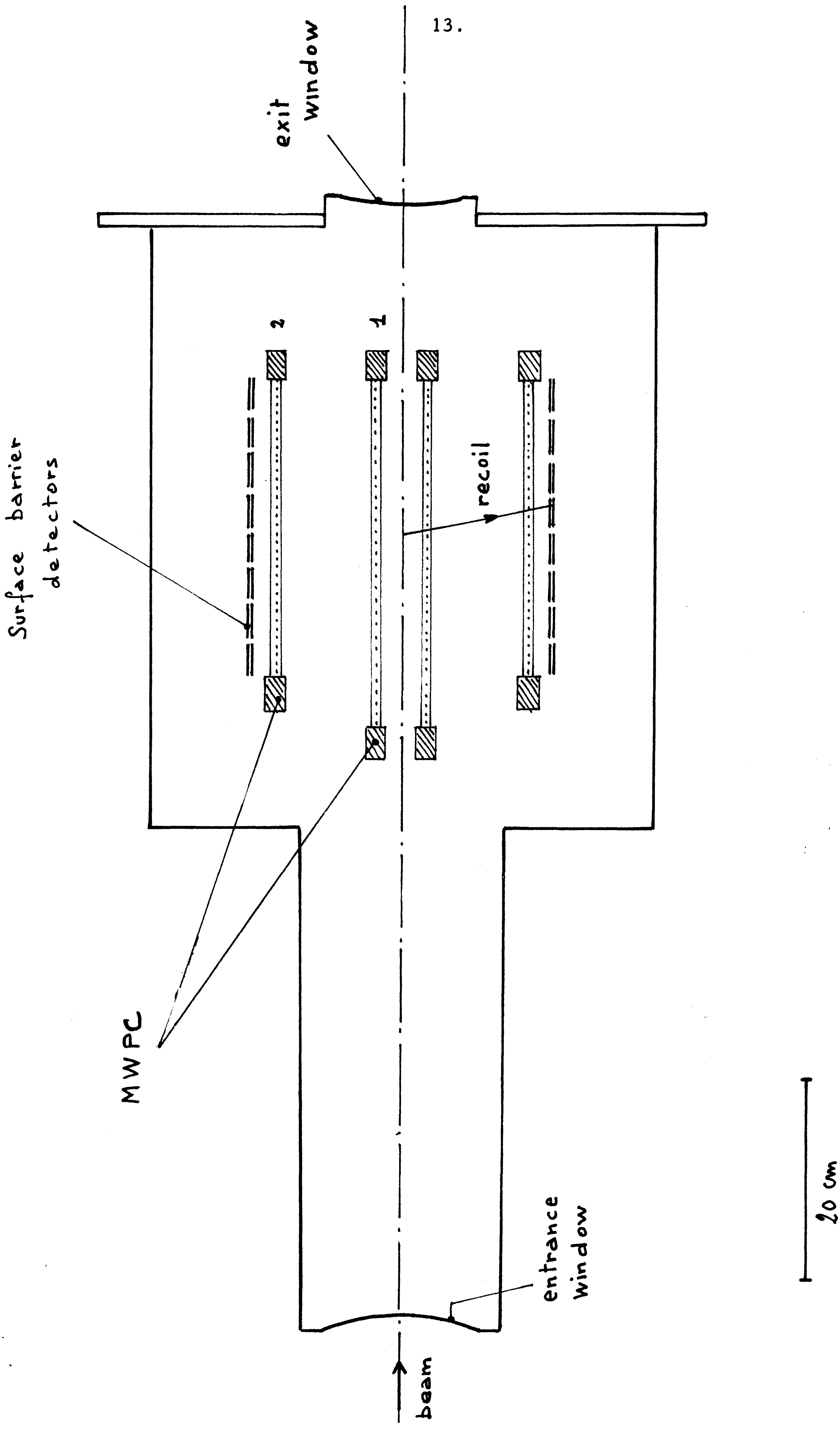

$q_\perp$ MeV/c
140 MeV
765 MeV
1070 MeV
1310 MeV
$\theta_4 = 60°$
$\theta_4 = 45°$
800
700
600
500
400
300
200
100
100
200
300
400
$q_{//}$ MeV/c

- Fig 1b -

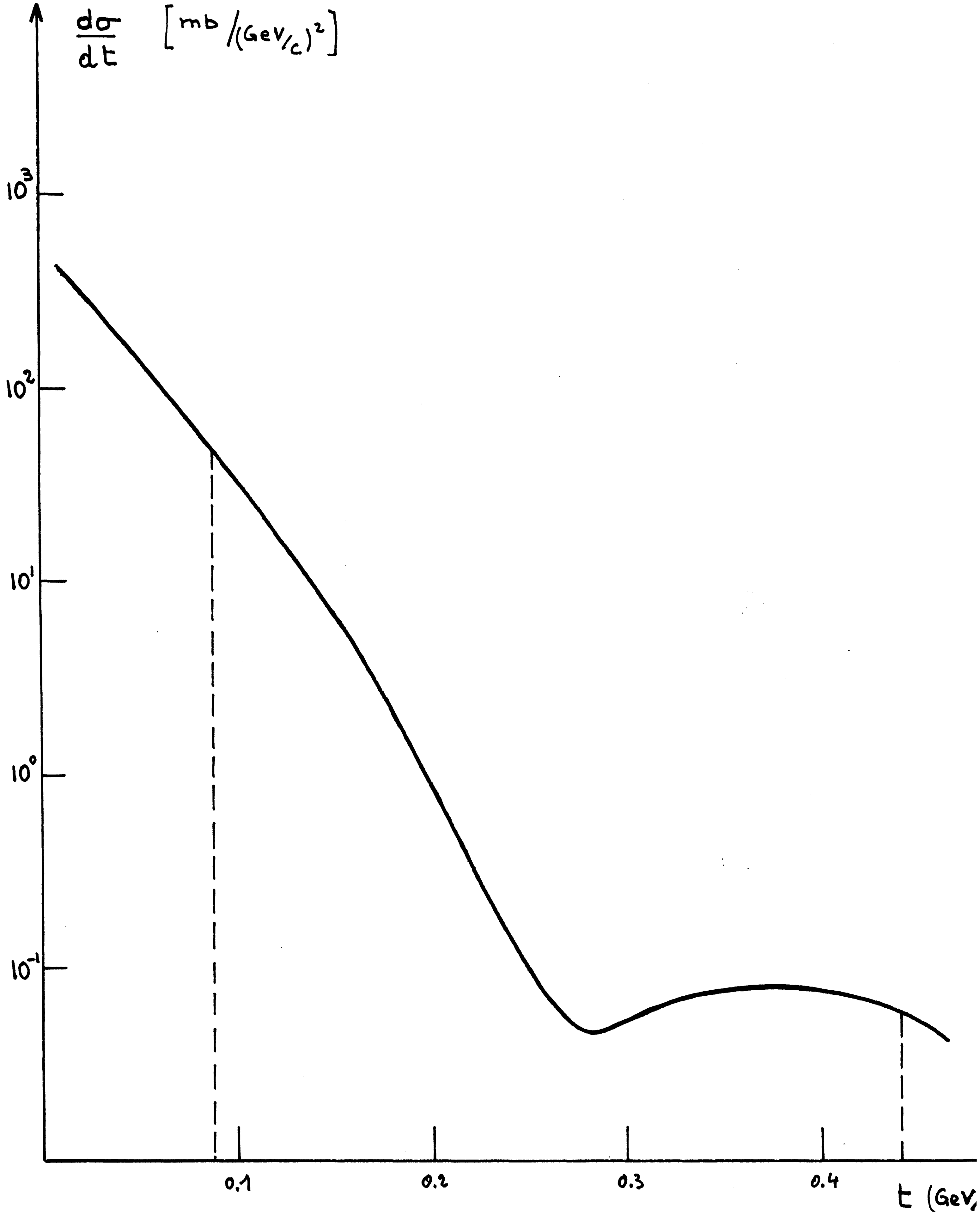
Fig 2.



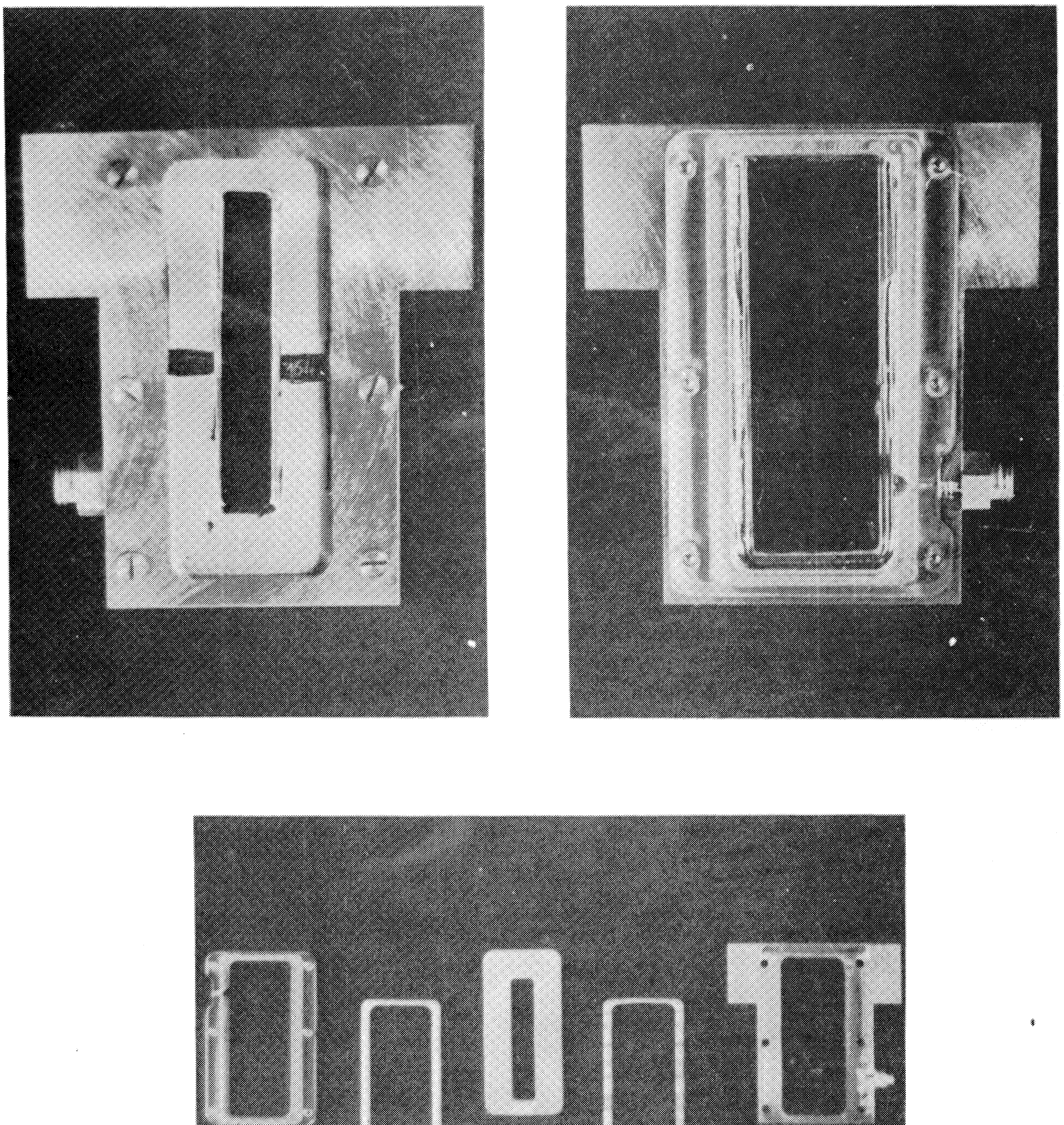
P_L = 5.0 GeV/c
M = 760 MeV
ΔM (MeV)
(a)
Δθ_4 = 1°
50
40
30
20
10
40°
50°
60°
70°
ΔM (MeV)
ΔP_L = 1%
(b)
5
3
1
50°
60°
70°
θ_4
ΔM (MeV)
ΔT_4 = 1 MeV
(c)
60
40
20
66°
70°
74°
θ_4


exit window
Surface barrier detectors
recoil
2
1
MWPC
entrance window
beam
20 cm

- Fig 3 -



- Fig 5 -



\- Fig. 4 -