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AN ISR PROPOSAL TO MEASURE PARTICLES WITH LARGE TRANSVERSE MOMENTUM AS A SEARCH FOR THE INTERMEDIATE BOSON

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1. INTRODUCTION

Two experiments[1] have been carried out to search for the intermediate boson by observation of muons of large transverse momentum. In both cases no muons were observed in excess of those expected from decay of K and π mesons. The experiments placed limits on the product $\sigma_W B$, where σ_W is the total cross-section for production of the intermediate boson and B is the muon branching ratio for the W meson. Burns et al.[1] place a limit of $\sigma_W B < 2 \times 10^{-34}$ cm^2 (99% confidence limit) for W masses between 2.5 and 6.0 GeV. The limits placed by Lamb et al.[1] are $B(d^2\sigma_W)/(dp d\Omega) \leq 4 \times 10^{-34}$ cm^2/sr GeV/c nucleon for W masses in the range 2-3 GeV.

It is not possible to make a reliable calculation of the cross-section expected for the production of intermediate bosons by nucleon-nucleon interactions. Table 1 summarizes the results of some order of magnitude calculations.

Yamaguchi[2] and Chilton et al.[3] have pointed out that, had the experiments[1] detected muons in excess of those expected from K and π decay, it would not have been evidence for the intermediate boson. Yamaguchi shows, on general grounds, that unless the W has a mass of 10 GeV or greater, the yield of muon pairs from virtual γ-rays of the mass of the intermediate boson is larger than the muon yield from the boson decay. Neither of the experiments referred to under Ref. 1 was able to tell if the muons detected were in reality members of a pair. A new experiment to look specifically for the production of meson pairs is currently in progress at the AGS.

2. THE AIMS OF THE PRESENT EXPERIMENT

The present experiment has three objectives:

a) To search for single muons with large transverse momentum, in excess of that from K and π decay, as evidence for production of the intermediate boson.

b) To search for the production of muon pairs. This is required to correct the single muon spectrum for contributions in which one muon escapes detection. A more important factor is that using the general arguments of Yamaguchi this will act as a normalization for the expected yield of intermediate bosons. Observation of muon pairs is of considerable interest in its own right as it will give the cross-section for production of virtual γ-rays of large mass. Subject to the validity of particular model calculations [for example the double peripheral calculation of Chilton[3]],this will give information on the $\pi\pi\gamma$ form factor. The effective mass spectrum of the muon pairs could also reveal new massive vector mesons if they are strongly produced and decay into muon pairs.

c) To search for general particle production at large transverse momentum: firstly, because the yield of K and π mesons is required in order to allow for muon contribution from decay; secondly, a significant yield of pions with large transverse momentum could be evidence for intermediate bosons decaying into hadrons; and, thirdly, the production of particles of large transverse momentum is of considerable direct experimental interest.

The experiment is envisaged as a primary search for the intermediate boson, using a technique that is sensitive to any production mechanism. If no evidence is found for excess muons from this experiment, it is not likely to be found in experiments requiring more specific production reactions. If excess muons are detected it will obviously be necessary to follow up this search with more specific experiments.

3. EXPERIMENTAL ARRANGEMENTS

The general arrangement for the experimental equipment is shown in Fig. 1. It consists of two major parts: i) a large solid-angle muon detector subtending 23% of 4π with a momentum resolution of about ±20%; and ii) a spectrometer with a solid angle of 30 msr, a momentum resolution of ±2% and two Čerenkov counters to separate π's, K's and protons, a range telescope to recognize muons and a shower chamber to recognize electrons.

3.1 Muon detector

Figure 2 shows a vertical section through the muon detector. A 30-50 cm thick tungsten absorber will be placed ∿15 cm from the intersecting region so as to absorb pions and kaons before they have an opportunity to decay. Data will be taken with the absorber at 10 cm to 20 cm, and with the absorber removed, in order to allow estimates to be made of the muon contribution from K and π decay. Thin-plate spark chambers will be placed around the intersecting region to record the direction of other charged particles produced. Magnetized iron plates, to a total thickness of 1 metre, will be used in the muon detector, with optical spark chambers between each plate. The optimum configuration of spark chambers and magnetized iron plates will not be decided until specimen modules have been made and tested. The momentum resolution will be approximately ±20%. The detector will cover horizontal angles between 20° and 160°, and a vertical angle of ±45°. The total weight of the spark chamber and magnetized iron detector will be about 150 tons. The optical chambers will be made in two-gap modules of approximately 2 m × 2 m area using 2 cm thick aluminium plates.

Trigger counters will be placed in the muon detector, and the spark chamber system will be triggered by muons with a range that assures them a transverse momentum of greater than 2 GeV/c. With this requirement, the trigger rate calculated using the yields predicted hy Hagedorn and Ranft[4]) is about one per minute, and hence no problem is envisaged when using optical spark chambers.

3.2 Spectrometer system

Figure 3 is a vertical section through the spectrometer. A one-metre magnet with an aperture of 16 cm × 200 cm will be used together with a trigger system of counter hodoscopes. Recognition of π, K, and p will be by two threshold gas Čerenkov counters with different pressures. These counters will not have the full acceptance of the magnet but will be moved to cover the angular range in several steps. The muon range chamber and the electron shower chamber will subtend the full aperture of the magnet. The magnet system will have a solid angle of 30 msr and a momentum resolution of ∿ ±2% at 5 GeV/c.

4. MUON BACKGROUND FROM K AND π DECAY

Calculations have been made of the muon background expected from the decay of K and π mesons, assuming primary yields predicted by the statistical model[4]). The interaction rate has been assumed to be 1.6×10^5/sec, corresponding to a luminosity of 4×10^{30} cm^2 sec^{-1} and a total cross-section of 40 mb.

The computed double differential muon rate ($d^2N/dpd\Omega$ in units of muons/hour sr GeV/c) for the decay of K^+ is shown in Fig. 4. Lines of constant muon momentum and constant muon transverse momentum p_T are shown. It is clear that p_T is a good parametrization, as the cross-section changes by only a factor of 3 between angles of emission of 20° and 90°. The values shown in Fig. 4 correspond to an absorber, with an interaction length of 8 cm, placed 10 cm from the interaction point. Changing the distance to 20 cm increases the yields by about a factor of 1.5.

This yield has been integrated over the solid angle of the detector (assumed to be θ_H = 20°-160° and θ_V = ±45° corresponding to 2.8 sr) and Fig. 5 shows the resulting yield dN/dp_T (in units of muons/hour GeV/c) plotted against p_T. The corresponding result from π^+ decay is also shown. The total μ^+ yield is seen to fall exponentially with p_T, with an exponent $p_T/0.147$. The total integrated rate for positive muons with transverse momentum greater than 2.4 GeV/c is one per hour.

5. MUON SPECTRUM EXPECTED FROM DECAY OF W

The muon spectrum from W decay has been calculated for three different models:

a) The reaction $p + p \to p + n + W^+$, assuming a momentum distribution given by phase space and an angular distribution chosen to give a mean transverse momentum for the W^+ of 0.5 GeV/c. The W is assumed to decay isotropically in its centre of mass.

b) A thermodynamic model of the Hagedorn type. An exponential distribution was assumed for the three components of the W momentum with a mean longitudinal momentum of 2.0 GeV/c and a mean transverse momentum of 1.0 GeV/c. The results are not sensitive to the exact values of these mean momenta, as the transverse momenta are small compared to the momenta of the muon in the W centre-of-mass system.

c) A double peripheral model calculation similar to that of Chilton et al.[3] for the reaction $p + p \to p + n + W^+$.

The predictions of these model calculations have been integrated over the detector, and the resulting μ^+ yields/hour are plotted against p_T in Figs. 6 to 8. For calculations (a) and (b) $\sigma_W B$ is assumed to be 10^{-32} cm^2

and the luminosity is taken as 4×10^{30} cm^{-2} sec^{-1}. Calculation (c) is an absolute calculation, and Fig. 9 gives the calculated values of $\sigma_W/F^2_{\pi\pi W}(m_W^2)$ where $F_{\pi\pi W}(m_W^2)$ is the $\pi\pi W$ form factor at the W mass. This form factor should be equal to the $\pi\pi\gamma$ form factor according to CVC theory. $F^2_{\pi\pi\gamma}(k^2)$ has been measured experimentally for k < 1 GeV. These results can be fitted by a ρ-dominance model and give

$$F^2_{\pi\pi\gamma}(k^2) = \frac{(55 \pm 7)\ m_\rho^2\ \Gamma_\rho^2}{(k^2-m_\rho^2)^2 + \Gamma_\rho^2 m_\rho^2}$$

where m_ρ and Γ_ρ are the mass and the width of ρ meson. It is certainly not justifiable to extrapolate this formula to masses of 5-20 GeV, but in the absence of any better guide we do this blindly, giving an $F^2_{\pi\pi W}(m_W^2)$ of 6.2×10^{-4}, 3.9×10^{-5}, and 2.5×10^{-6} for m_W = 5, 10, and 20 GeV, respectively. The results shown in Fig. 7 assume these values, and artificially assume that B = 1.

The same model can be used to calculate the yield and the angular distribution of μ pairs from virtual γ-rays. These calculations are in progress but are not yet complete.

6. CONCLUSIONS

The following conclusions can be drawn from Figs. 5 to 8:

a) If the yield of muons from K and π decay is confirmed by experimental measurement there should be no problem with muon background and, providing $\sigma_W B$ is large enough, a clean signal will be seen for $m_W \gtrsim 5$ GeV.

b) The limit that can be placed upon $\sigma_W B$ is dependent upon the production mechanism but will be limited by the counting rate. There should be no problem of signal to noise ratio. A luminosity of 4×10^{30} cm^2 sec^{-1} should enable a value of $\sigma_W B \lesssim$ a few $\times 10^{-34}$ to be reached for masses of 5 GeV to 50 GeV. The counting rates for $p_T > 2.5$ GeV/c for the different model calculations are summarized in Table 2.

c) Although the double peripheral model calculations including form factor estimates are very low, the only problem appears to be one of counting rate, and an improved ISR luminosity would enable one to detect even these very low cross-sections.

7. FURTHER OBJECTIVES

Whilst the search for single muons from the decay of intermediate bosons and the associated search for muon pairs from virtual γ-rays produced in accordance with current theory are significant objectives, we should also like to stress the following. A major justification for the experiment is that it is a search for the unexpected in a new energy region. The experiment is designed to look in a transverse momentum range where problems from strong interaction background are predicted to be a minimum. The energy region covered by the ISR is the region where interesting and unexpected results have recently been indicated by the cosmic-ray experiments at Utah[6]. Should these effects be genuine, they will give rise to easily discernible phenomena at the ISR.

REFERENCES

1) R. Burns, G. Danby, E. Hyman, L.M. Lederman, W. Lee, J. Rettberg and J. Sunderland, Phys.Rev.Letters 15, 830 (1965).
R.C. Lamb, R.A. Lundy, T.B. Novey, D.D. Yovanovitch, M.L. Good, R. Hartung, M.W. Peters and A. Subramanian, Phys.Rev. Letters 15, 800 (1965).

2) Y. Yamaguchi, Nuovo Cimento 43, 193 (1966).

3) F. Chilton, A.M. Saperstein and E. Shrauner, Phys.Rev. 148, 1380 (1966).

4) R. Hagedorn and J. Ranft, CERN-TH/851 (1967).

5) Private communication from J. Walker on an Orsay electron storage experiment.

6) J. Keuffel et al., paper presented to the 14th Int.Conf. on High-Energy Physics, Vienna (1968).

Table 1

Summary of calculations of cross-sections for the formation of the intermediate boson

Authors	Reference	Reaction	Energy	m_W	σ_W(total) cm^2
Chilton et al.	P.R. 148, 1380	$N + N \rightarrow N + N + W$	10-30	$1.5 \rightarrow 6.0$	10^{-31}-10^{-32}
Lee and Yang	P.R. 119, 1410	$N + N$ and $\pi + N$	order of magnitude only		$\sim 10^{-32}$
Bernstein	P.R. 129, 2323	$p + p \rightarrow D + W^+$	1.2-3.5	0.5-1.1	$\sim 10^{-34}$
Nearing	P.R. 132, 2323	$p + p \rightarrow D + W^+$	1.2-3.5	0.5-1.1	$\sim 5 \times 10^{-34}$
Bernstein and Feinberg	P.R. 125, 1741	$\pi^+ + p \rightarrow W^+ + p$	1.5	0.75	$\sim 10^{-33}$
Dombey	P.R.L. 6, 66	$\pi^+ + p \rightarrow W^+ + p$	2.4	?	$\sim 10^{-32}$
Mani	Ph.D. Thesis	$\bar{p} + p \rightarrow W + \pi$	?	2.0	$\sim 10^{-31}$

Note: In general the calculations have not made allowances for form factors.

Table 2

Calculated muon yield for different models

Assumptions: $L = 4 \times 10^{30}\ cm^2\ sec^{-1}$ $\sigma_T = 40$ mb

$B = 1$

Model	m_W GeV	Assumed σ_W	Counts/hour for $p_T \geq 2.5$
$p + p \rightarrow p + n + W^+$ with $\langle p_T \rangle_W = 0.5$ GeV/c and p_W distance as phase space	5	10^{-32}	11
	10	"	31
	20	"	36
"Thermodynamic"	5	"	16
	10	"	33
	20	"	39
Double peripheral model	5	calculated σ_W 2×10^{-34}	0.6
	10	1.4×10^{-35}	0.06
	20	1.4×10^{-36}	0.006
Contribution from decay of K^+ and π^+	-	-	0.6

APPENDIX

Present membership of the groups concerned with this proposal:

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*W.H. Range
*L.J. Carroll
*E. Williams

Note: The people who will participate in the experiment will not include all of those listed above. The number finally concerned will depend upon the requirements. Those currently working part-time on the experiment are marked with an asterisk.

Figure captions

Fig. 1 : General experimental arrangement.

Fig. 2 : Vertical section through the muon detector.

Fig. 3 : Vertical section through the spectrometer system.

Fig. 4 : $d^2N/dpd\Omega$ for muons produced from decay of K^+.

Fig. 5 : dN/dp_T for muons from K^+ and π^+ decay. The yield is integrated over the solid angle of the muon detector.

Fig. 6 : Muon yield dN/dp_T calculated for decay of W^+ produced by $p + p \rightarrow p + n + W^+$ assuming a mean transverse momentum for W^+ of 0.5 GeV/c. Assumed value of $\sigma_W B = 10^{-32}$ cm^2. The dotted line is the expected contribution from K^+ and π^+ decay.

Fig. 7 : Mean yield dN/dp_T calculated for the decay of W^+ using a thermodynamic model with the boson produced nearly at rest. Assumed value of $\sigma_W B = 10^{-32}$ cm^2. The dotted line is the expected contribution from K^+ and π^+ decay.

Fig. 8 : Muon yield dN/dp_T calculated for the reaction $p + p \rightarrow p + n + W^+$ using a double peripheral model. $F^2_{\pi\pi W}(m^2_W)$ has been estimated from experimental results for $F^2_{\pi\pi\gamma}(k^2)$. The dotted line is the expected contribution from K^+ and π^+ decay.

Fig. 9 : Values of $\sigma_W/F^2_{\pi\pi W}(m^2_W)$ calculated using the double peripheral model. Curve "a" is for 30 GeV protons in the ISR, and curve "b", which is given for comparison is for 30 GeV protons incident on a stationary proton.

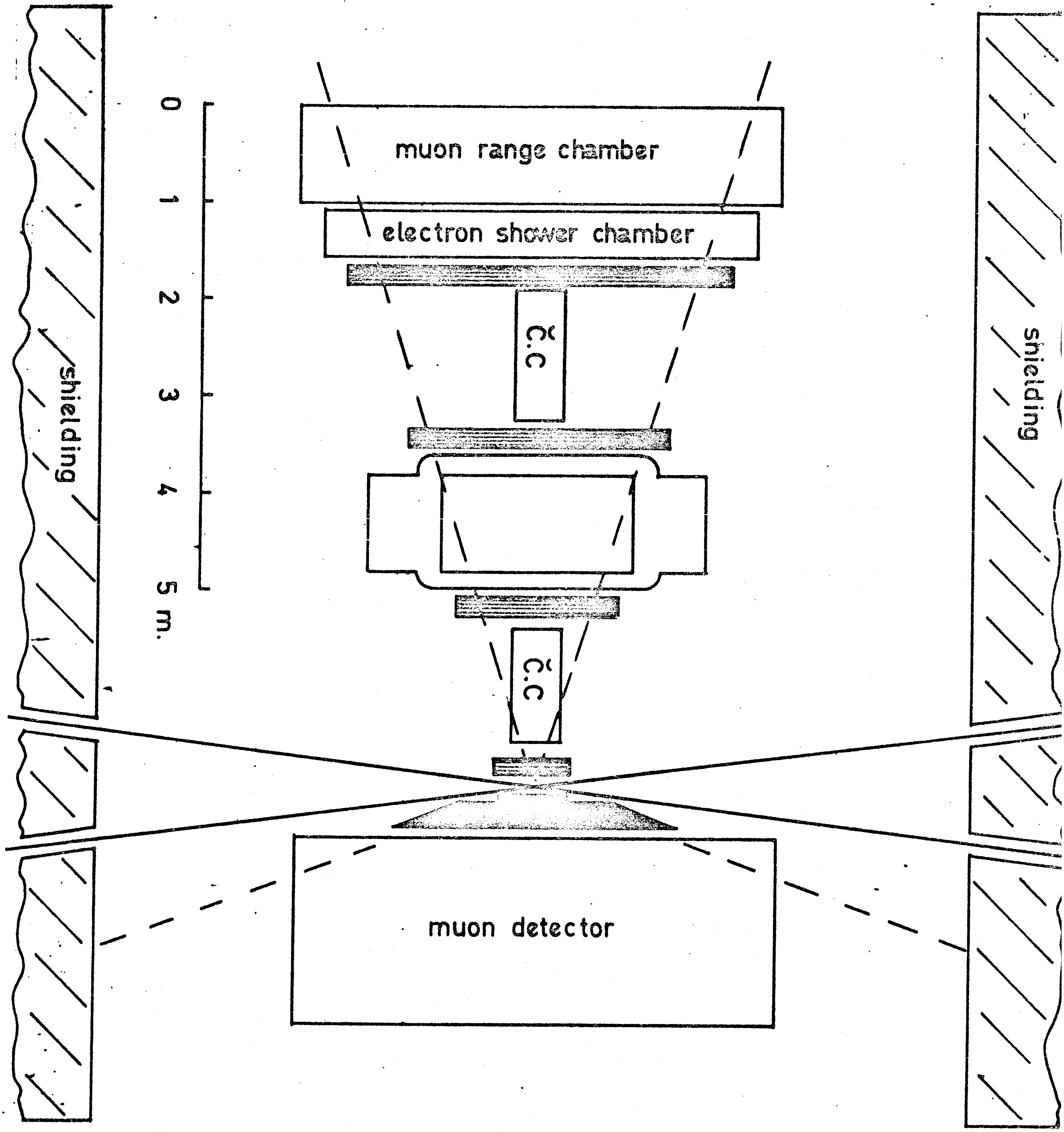

muon range chamber
electron shower chamber
Č.C
Č.C
shielding
shielding
0
1
2
3
4
5 m.
muon detector

FIG. 1

FIG. 2 Vertical section through muon detector.

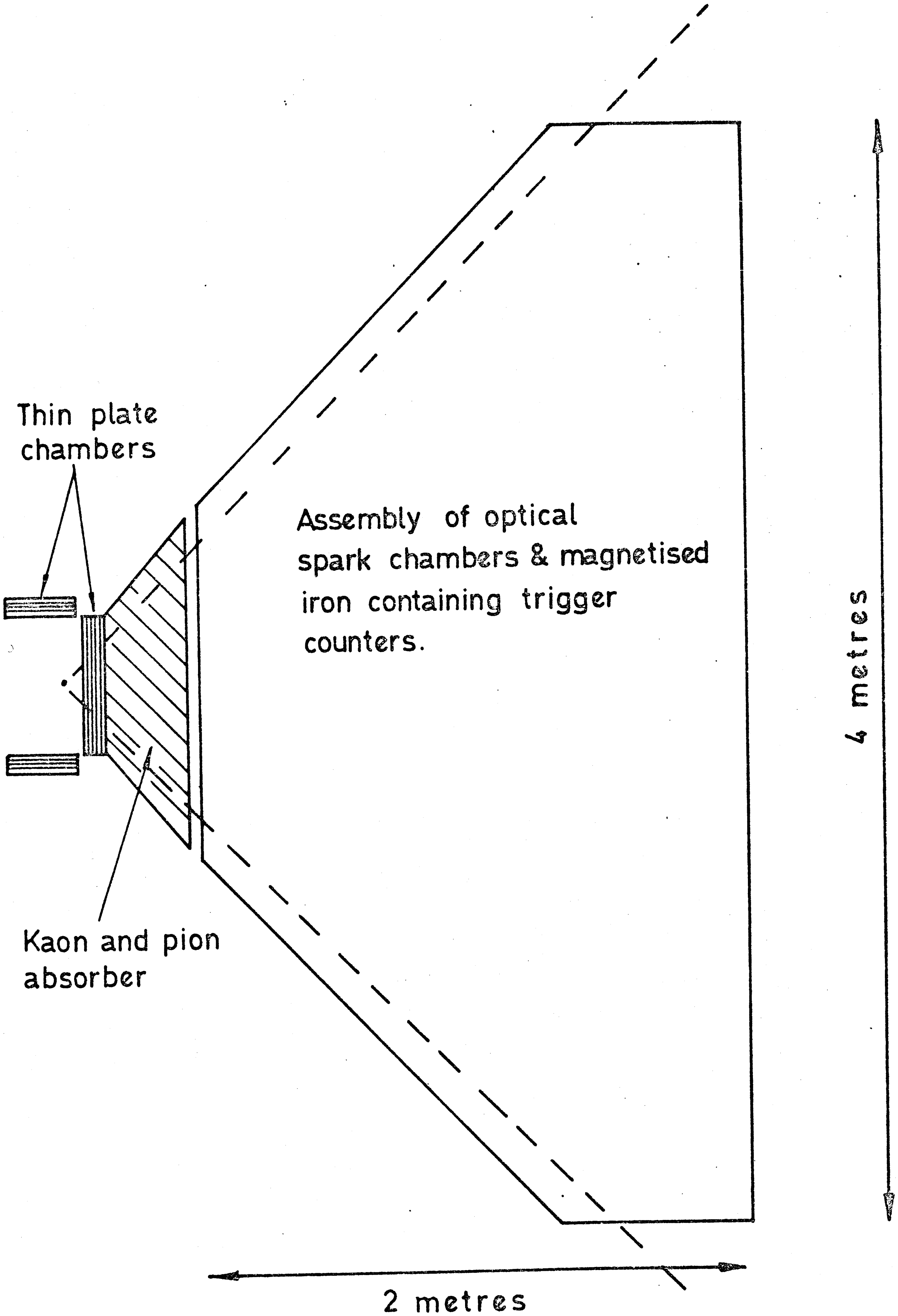
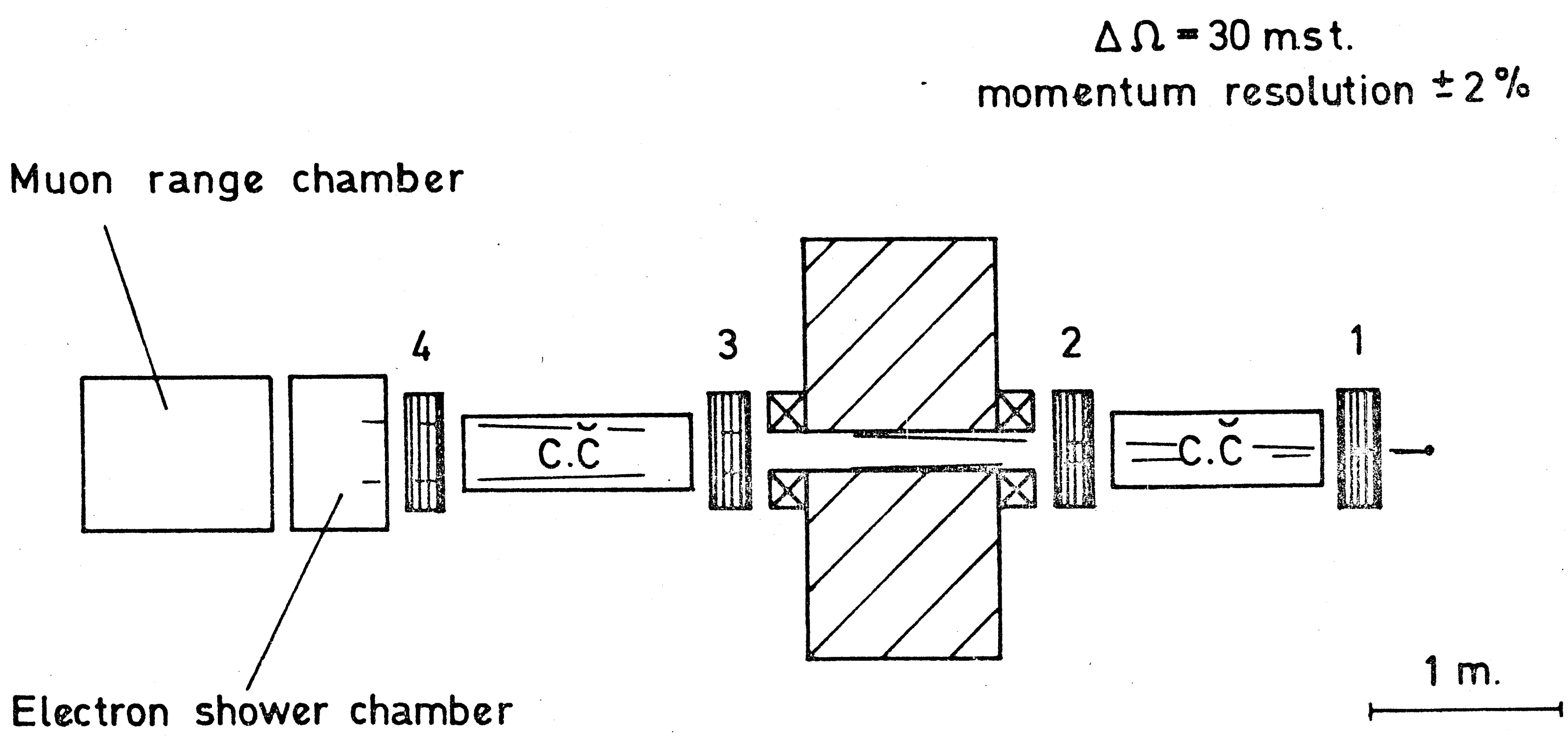
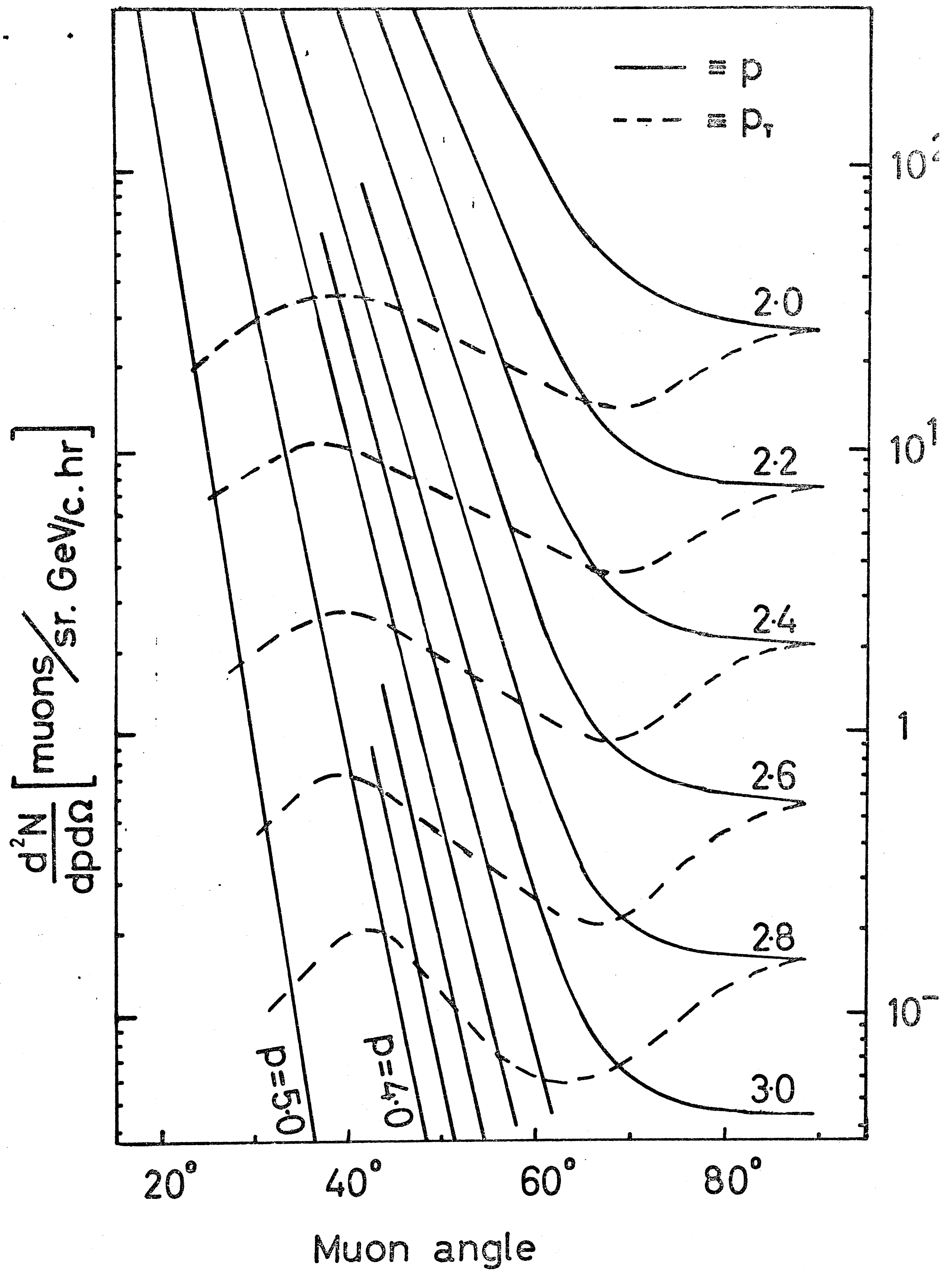


FIG. 3 Spectrometer system



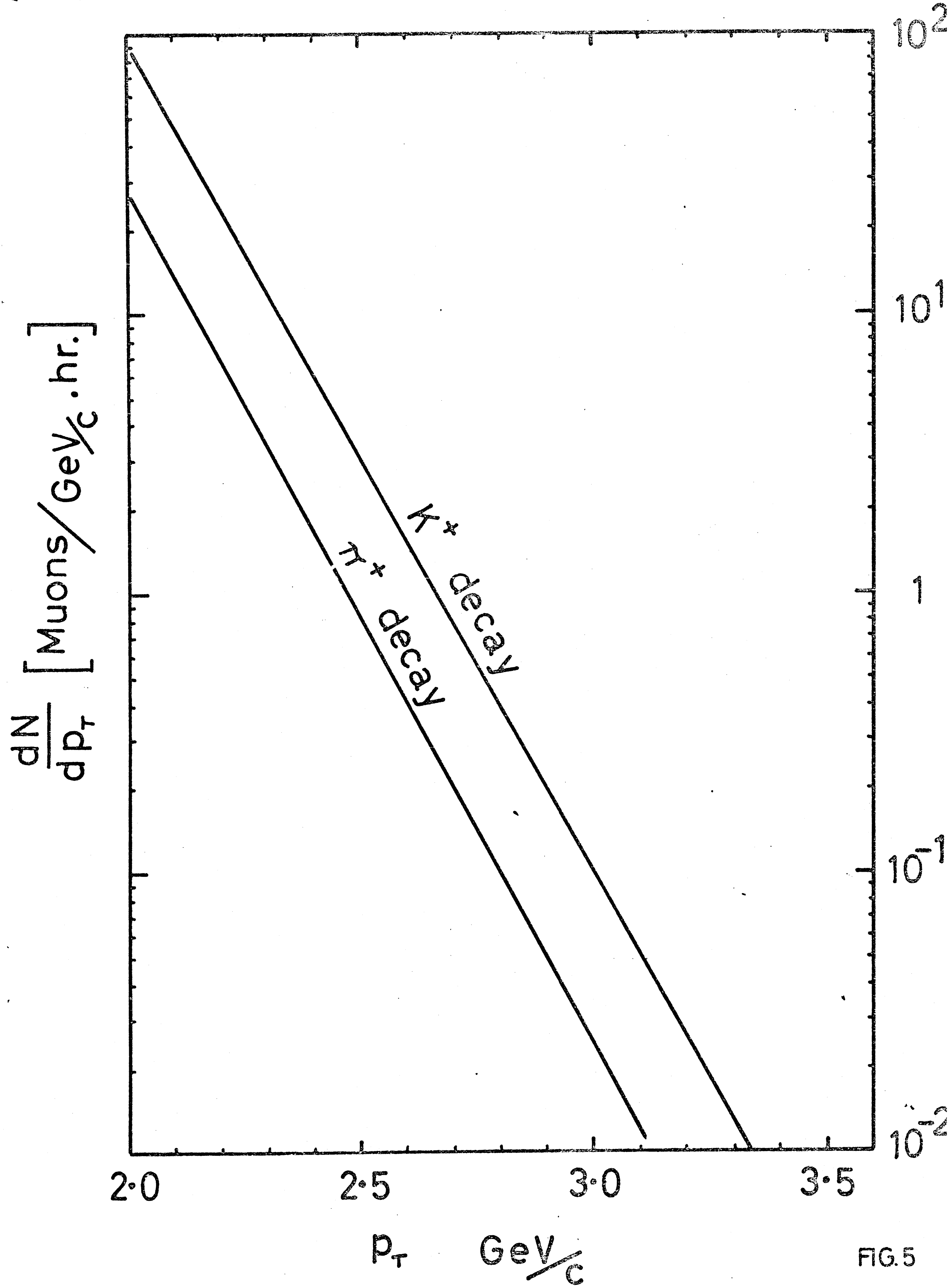
1–4 are spark chambers and hodoscope counters.

C.Č Threshold Cherenkov counters.



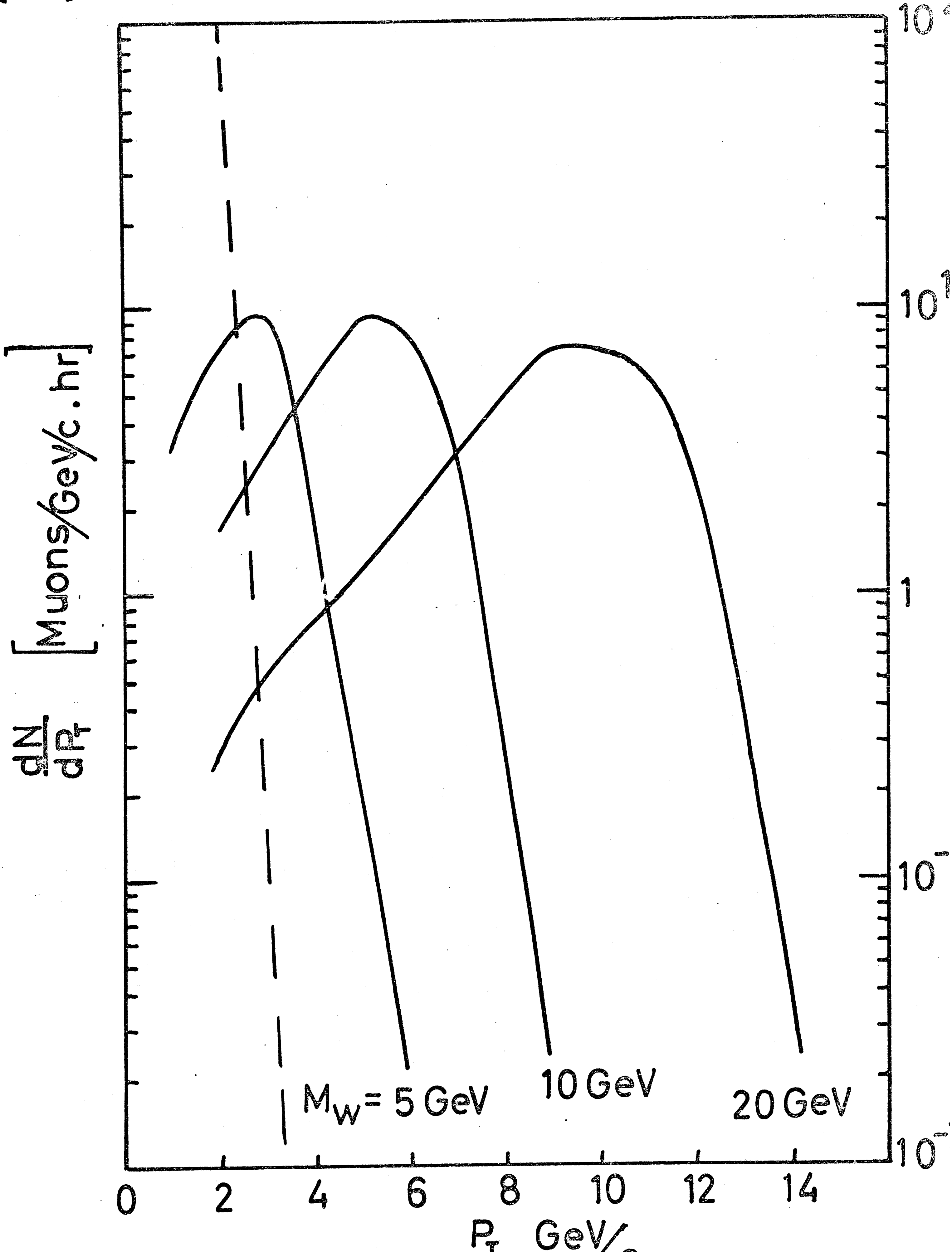
= p
= p_T
10^2
10^1
1
10^{-1}
2·0
2·2
2·4
2·6
2·8
3·0
p=5·0
p=4·0
20°
40°
60°
80°
Muon angle
$\frac{d^2N}{dpd\Omega}$ [muons/sr. GeV/c. hr]

FIG. 4



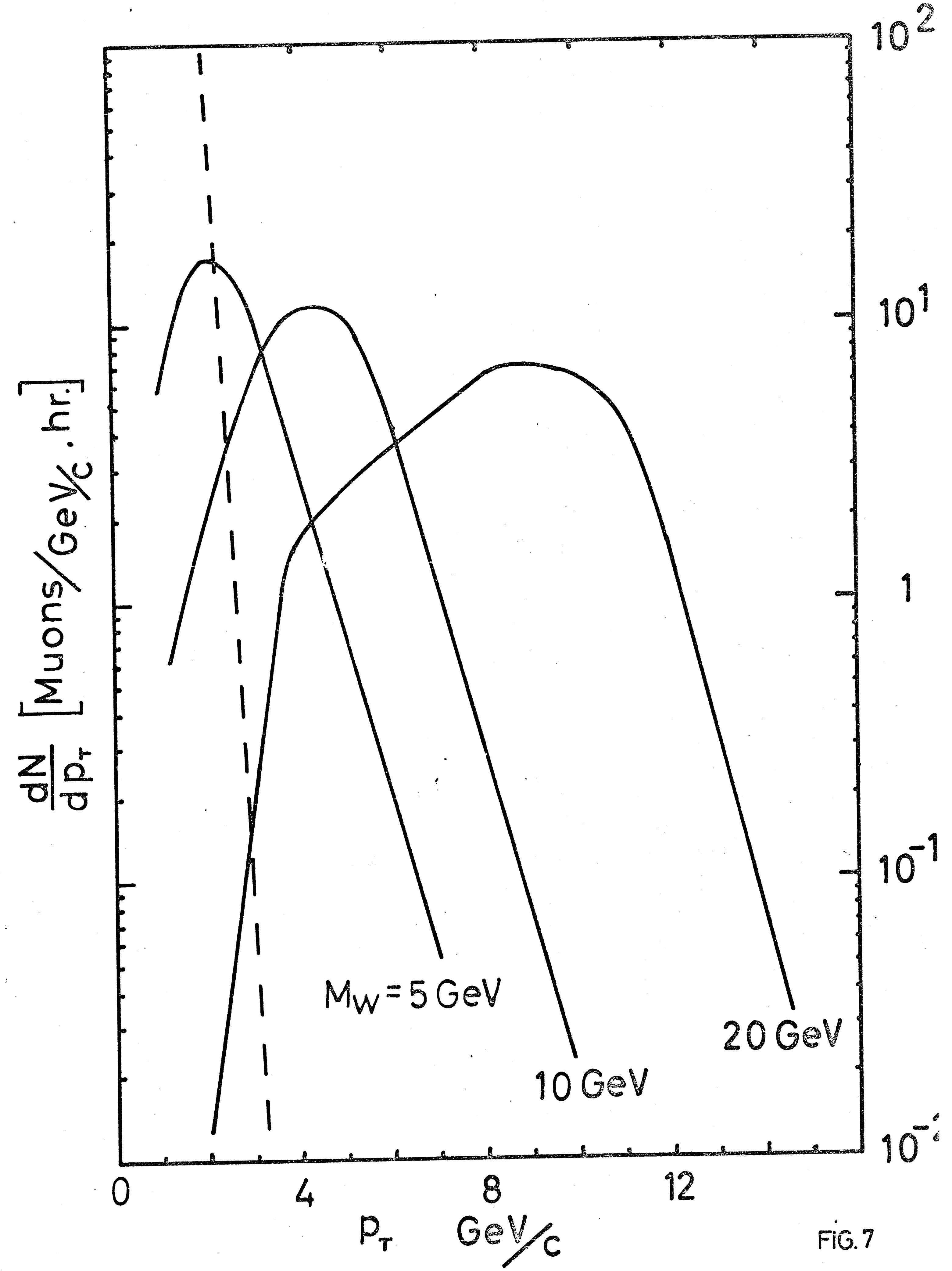
10^2
10^1
1
10^{-1}
10^{-2}
2·0
2·5
3·0
3·5
$\frac{dN}{dp_T}$ [Muons/GeV/c .hr.]
p_T GeV/c
K^+ decay
π^+ decay

FIG.5



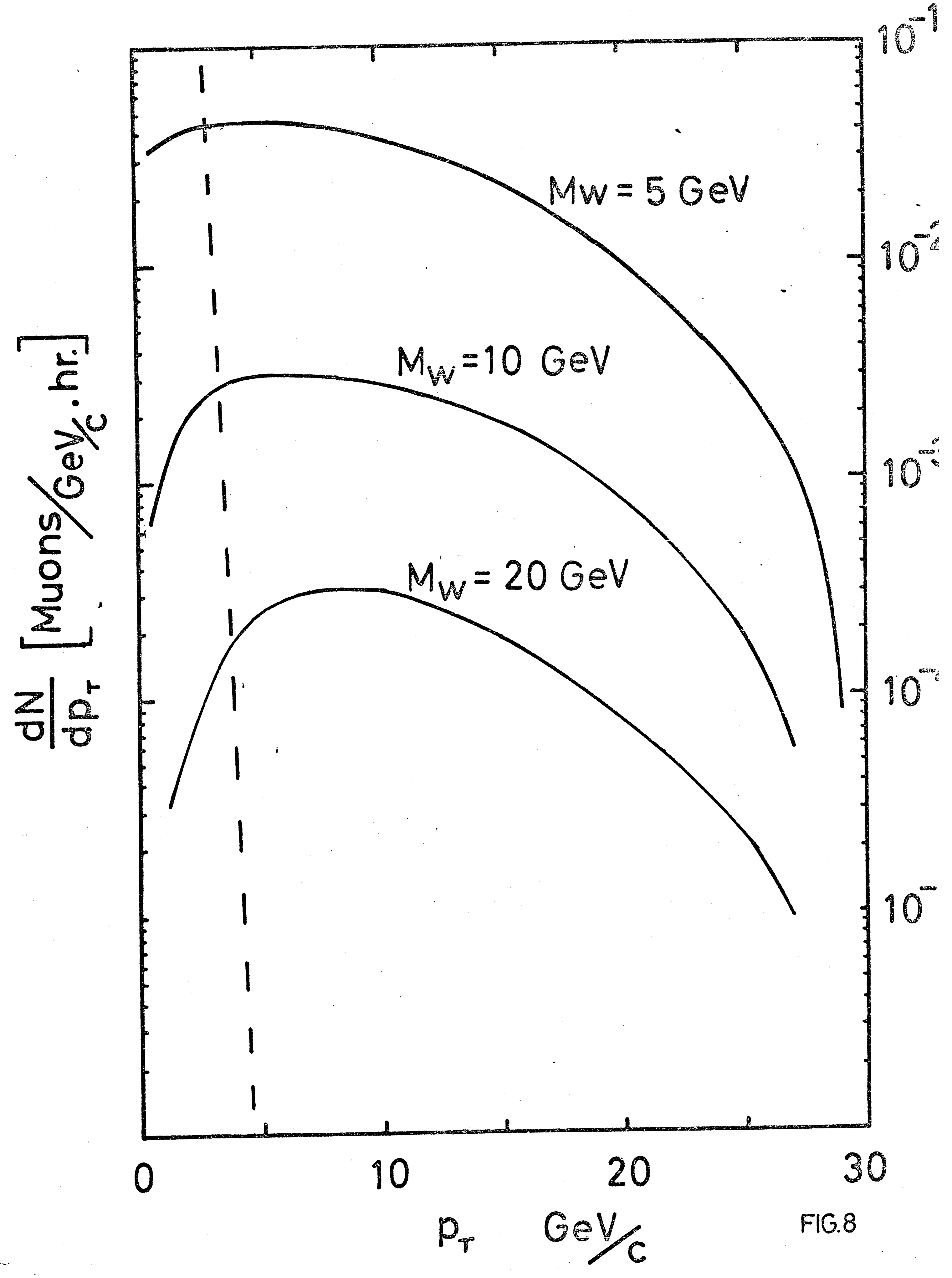
10^2
10^1
1
10^{-1}
10^{-2}
0
2
4
6
8
10
12
14
$\frac{dN}{dP_T}$ [Muons/GeV/c . hr]
P_T GeV/c
M_W = 5 GeV
10 GeV
20 GeV

FIG. 6



10^2
10^1
1
10^{-1}
10^{-2}
$\frac{dN}{dp_T}$ [Muons/GeV/c .hr.]
$M_W = 5$ GeV
10 GeV
20 GeV
0
4
8
12
p_T GeV/c

FIG. 7



10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
Mw = 5 GeV
M_W=10 GeV
M_W= 20 GeV
$\frac{dN}{dp_T}$ [Muons/GeV/c . hr.]
0
10
20
30
p_T GeV/c

FIG.8

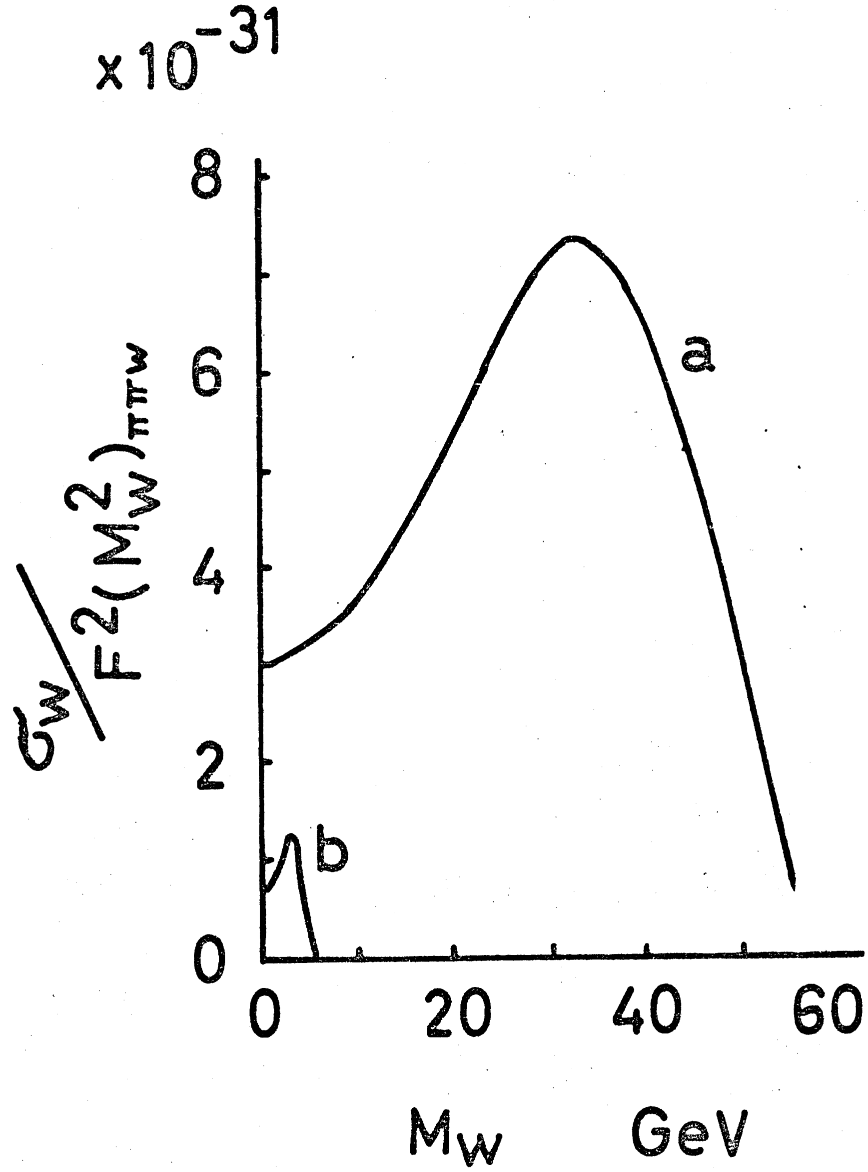


FIG. 9