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A STUDY OF THE K_L^O STRONG INTERACTIONS IN THE MOMENTUM REGION 60-360 GeV/c

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SUMMARY

We propose to design, build and use a tertiary $K_L{}^o$ beam produced using the high intensity pion beam being built in the proton area. The main advantage of this beam over previous beam is the low neutron background ($K_L/n > 3$). We propose to study the large transverse momentum dependence of the particles produced in the strong interactions of a K_L^o beam, and also the production of leptons, and lepton pairs.

Large transverse momentum phenomena has been a subject of intense theoretical[13] and experimental work[14,15]. This subject is important because of its possible implication on processes occurring at small distances. Up to the present in strong interactions only the large transverse momenta phenomena in p-p collisions has been studied. To see if the quark or parton picture is a good model of what is happening in these collisions then it seems reasonable to use as many other distinct particles colliding with nucleons. The differences or similarities in the fluxes and types of particles coming out at large transverse momenta for various colliding particles will help in our understanding of these processes.

To accomplish these objectives we propose first to do a beam survey by studying the decays $K_s \rightarrow \pi^+ \pi^-$ and $\Lambda \rightarrow \pi^- p$ in a "Vee magnetic spectrometer." This spectrometer will require a series of proportional chambers for time resolution and likely some drift chambers for spatial resolution. Later on we propose to study the large transverse momentum dependence in a one arm spectrometer which will consist of proportional chambers, a magnetic spectrometer, and an "ISIS" type device to determine the mass of the particle. This device will have a large enough solid angle to allow for adequate counting rates

in spite of the lower fluxes that exist in this beam.

We estimate a need of 400 hours testing, 200 hours data taking for the beam survey and about 400 hours data taking for the study of large transverse momentum phenomena.

BEAM DESIGN

The flux calculation of this neutral beam was carried out making use of the principles of scaling and a calculation of the pion flux in p-p collisions using the Wang formula.[1] Figure 1 shows the agreement between the empirical Wang formula and data obtained at NAL[2] for π^- production in p-p collisions. The Wang formula predicts rates which are too high by a factor of two or three. The curve in Figure 1 is ½ times the predicted Wang formula. We used this formula (even though it gives rise to fluxes too large by a factor of 2) to calculate the pion flux that should be observed in the present NAL beam design[3] for 400 and 500 Gev protons colliding with a stationary target. These fluxes are shown in Figure 2 and 3.

To calculate the fluxes of neutral particles produced by the collision of such a pion beam we assumed that scaling is obeyed by these interactions and made use of the following relations:

$$\frac{d^2\sigma}{dp\,d\cos\theta} = 2p^2 \frac{d^2\sigma}{dp_L\,dp_\perp^{\,2}}$$

$$= \frac{2p^2}{E}\left(E\frac{d\sigma}{dp_L}\right)\left(b\,e^{-bp_\perp^{\,2}}\right)$$

where $E\frac{d\sigma}{dp_L} = E^*\frac{d\sigma}{dp^*_L}(x) = \int_0^\infty E^*\frac{d^2\sigma}{dp^*_L\,dp_\perp^{\,2}}\,dp_\perp^{\,2}$

where p(E)is the momentum (energy) of the particle in the laboratory, p*(E*) is the momentum (energy) of the particle in the center of mass, p_L and $p_\perp$ is the longitudinal and transverse momentum of the particle and

$$-1 \le x = p^*_L / p^*_{L\ max} \le 1 .$$

The number of particles in the forward direction ($\theta = 0$) of momentum P in a momentum interval ΔP and angular interval $\Delta \cos \theta$ is given by

$$N(P, \theta=0, \Delta P, \Delta\cos\theta) = N(\pi^-, \text{ or } K^-) \frac{1}{\sigma_{tot}} \left. \frac{d^2\sigma}{dpd \cos \theta} \right|_{P, \cos \theta = 1.} \Delta P \Delta \cos\theta$$

where we assume that the full beam interacts in the target and $\Delta\cos\theta$ is very small. We also neglected to write down explicitly the energy dependence of the cross sections which were used to determine the fluxes at NAL energies. These dependence are shown in table 1. Also in table 1 are shown the value of b for the various reactions.

The differential cross section $E^*d\sigma/dp^*_L$ was obtained from various review articles and experiments carried out at lower energies (4-9). In Figure 4 we show the $E^*d\sigma/dp^*_L$ distributions for the various reactions under consideration. The cross section for π^0's is taken to be the average between π^+ and π^-. In addition the dashed part of the curve near x = +1 is our "artistic" conception of how the cross section would behave if there were no forward peak. In the flux calculations we assume this to be the case.

Table 1

Reaction	$b\,(\mathrm{Gev}/c)^{-2}$	E dependence
$\pi^-p\to K_s+X$	4.6	$P_{in}^{1/4}$
$\pi^-p\to\Lambda+X$	3.6	Const.
$\pi^-p\to n+X$	4.5	Const.
$\pi^-p\to\pi^o+X$	8.9	Const.
$K^-p\to K_s+X$	4.4	Const.
$K^-p\to\Lambda+X$	3.5	$P_{in}^{-1/2}$

The calculated flux of the various particles observed in the forward direction is shown in Figure 5. The difference in the π^o flux due to the change in the x = +1 region described in Figure 4 is seen as a dashed line in Figure 5. The outstanding features of this figure are the flatness of the K_L^o momentum spectrum up to almost the incident beam momentum and the relatively low neutron background. Neutron fluxes in neutral beams derived from p p collisions are about $10^4/K^o$. We should point out that in obtaining the neutron flux we assumed the neutron and proton spectra as produced in a π^-p collision to be the same. Furthermore there is only meager data from which we obtained the proton flux. One suspects in addition that at NAL energies the neutron flux in the higher momentum region should be substantially lower than predicted by our curves because the inclusive cross section $E^*d\sigma/dp^*_L$ should become more peaked towards the negative x region. Hence one of the primary purposes of the beam survey that we propose to carry out at the start will be to determine the neutron flux as a function of its momentum. If this flux is too high we may need to "harden the beam" to improve the K_L^o to neutron ratio.

Figure 6 shows the particle fluxes due to unstable particles at 40 meters from the target. It is clear that already at this distance the K_s and Λ component is quite small and the beam will consist of K_L, n, and γ's.

Figure 7 shows the flux of decay products of K_S, Λ, K_L into their charged modes in a 6 meter decay region. These curves show that there is sufficient flux of K's and Λ's to perform a beam survey in the full momentum region above 60 Gev.

BEAM SURVEY

The beam survey will hopefully be carried out at a distance of about 20 meters from the target where the pions interact. We will need immediately after the target large magnets (like 2 5" x 1½" x 10 ft. 16 kg magnets) to sweep the charged particles out. We are presently studying the muon flux associated with such a pion beam to determine the best way to remove most of the muons before it reaches our detector region. Before the sweeping magnet we expect to be able to move in by <u>remote control</u> up to 10 radiation lengths of lead to remove the gamma ray component of the beam.

<u>Study of the Gamma Flux</u> - It is useful to carry out the gamma flux in this beam in order to plan for future experiments in which this beam might be useful. (See Figure 6) Since this measurement can be done with a minimum of beam on target we are proposing it at this time. An arrangement to measure the gamma momentum spectrum is shown in Figure 8. A,B, and C are scintillation counters 1/8" thick. A radiator foil of about .02 radiation lengths between counters A and B would be next against the radiator. Counter banks D, E,F are lead glass counters of 8,8,20[10] radiation lengths

to measure the electron energy by observing the energy deposited in each bank. Between counters B and D we may plan to put two small proportional chambers to determine the direction of the gamma and see that it comes from the target. This measurement can be carried out with very low beam intensities on the target. We propose to put the whole arrangement on rails so that it can be moved back and forth away from the target.

<u>Study of the K_S^o and Λ Flux</u> - We plan to measure the $K_S \to \pi^+ \pi^-$ and $\Lambda \to \pi^- p$ decay momentum spectrum by using a V spectrometer as shown in Figure 9. In Figure 7 we show the number of decays expected at a distance of 20 to 30 meters from the target for 10^9 incident π's. It is quite clear that this measurement can be carried out with fluxes of 10^7, 10^8 π's on target.

The spectrometer will consist of one proportional chamber (A) in front followed by 2X and 2Y drift chambers where the sensing wires of the first and second X chamber alternate to avoid the right left ambiguity, similarly for the Y chambers. The sense wire spacing will be 1 cm, hence each of these chambers will have only 15 sense wires. This arrangement will hopefully give spatial resolution of .1 mm and the dead time due to ionization transit time will be only about .2 μsec.[11] which is quite sufficient for our needs. There will be a U-V proportional plane to overcome the double track ambiguity followed by another set of 2X, 2Y chambers near the magnet. The spectrometer should be a 10" x 10" x 6 ft 18 Kg magnet. Using the .1 mm spatial resolution leads to a 5% error in momentum measurement for a 400 Gev track sufficient to separate Λ's and K's. A similar arrangement of drift chambers will be used behind the magnet. Finally a scintillation counter hodoscope will be placed at the end. We may also put a lead glass calorimeter behind this arrangement to remove K_L^o decays which form a major source of background for momenta below 100 Gev/c.

<u>Study of Neutron Flux</u> - As can be seen from Figure 6 at distances from the target of greater than 40 meters the beam consists to within a few per cent of only K_L and neutrons. By studying the interactions of this beam to measure cross sections in the manner of Long et. al.[12] and knowing the K_L flux, neutron and K_L cross sections in hydrogen we can extract the neutron flux.

If we assume a K_L flux of 10^4 particles/pulse and a 10% neutron background interacting in a 1 meter hydrogen target we get 7×10^2 interactions per pulse which can be handled by a computer system. To get the neutron flux to 10% we need to know the number of interactions as a function of energy to 1%. Hence we need about 10^5 interactions at each energy which implies a total of a few $\times 10^6$ interactions. This implies no more than a few days of low intensity beam to obtain this result.

The Study of Large Transverse Mometum Phenomena in K_L Interactions

We would like to measure the fluxes of various particles produced at large transverse momentum in this collision. There are presently plans to study them in π-N collisions[16]. We propose to study these effects in K_L -N collisions. Because the K_L contains an admixture of strange quarks $\{K_L = \frac{1}{\sqrt{2}} (K^o - \bar{K^o}) = \frac{1}{\sqrt{2}} [(\lambda n) - (\bar{\lambda} n)]$ these are the only collisions besides charged K beams and hyperon beams where strange quarks will be directly involved. The advantage of this neutral over charged K beams is the non existence of an accompanying much larger π beam component, hence allowing for larger K fluxes to interact in the target without subjecting the electronics to high counting rates.

The arrangement to study the large $P_\perp$ phenomena is shown in Figure 10. It consists of a single arm spectrometer made up of 2 bending magnets, a series of preportional chambers at $\sim$ 80 mrad. to the beam direction. The beginning of this spectrometer is 20 meters from the target and is .5 x .5 meters in transverse dimension. The spectrometer will have a $\Delta p/p$ of about 25% or greater. At the end of the spectrometer will be an "ISIS" type device[17] to identify the mass of the particle or particles going through the spectrometer.

Using these values we are sensitive out to $P_\perp \approx 5$ Gev/c for moments of 300 Gev/c where we can observe 2 or more events/day. Hence we can study the scaling region up to $X_\perp = 2 P_\perp / \sqrt{s} \approx .55$. Table 2 shows a sample rate calculation. Using this we get the rates as shown in Table 3. Even though these rates are low there are theories[18] that predict much large fluxes at large transverse momenta for meson nucleon scattering than for proton nucleon scattering. Hence we can expect that our calculated flux for large transverse momentum particles is too low by a factor of 100 or more.

To study the direct muon production at large transverse momentum we plan to add a calorimeter at the back of our single arm spectrometer to separate the strongly interacting particles from the muons.

Because of the uncertainty surrounding the "ISIS" device relative to its ability to identify the masses of relativistic particles (since it is still to be tested) and because of the uncertainty of the fluxes of secondary particles expected at large transverse momentum we propose to perform our measurements in steps. We plan first to just measure the transverse momentum distribution of hadrons and leptons by using a calorimeter alone behind the single arm spectrometer. Knowing these facts we can plan how to determine the masses of the secondaries, either by using a Cherenkov counter or an "ISIS" device.

Comment

We are investigating the possibility of using a low intensity pion beam in the meson area to perform a preliminary test of our design calculations for the relative K_L/n flux so that we may determine whether we need a filter to improve the K_L/n ratio.

Table 2

Expected Rates Through Single Arm Spectrometer

$\sigma_T(Kn) = 21$ mb

From Cronin et. al[15] at $P_\perp = 5$ Gev $Ed^3\sigma/d^3p \approx 10^{-34} cm^2 Gev^{-2}$

$$\frac{\Delta P}{P} = .25$$

$$\Delta\Omega = \frac{.5 \times .5}{(20)^2} = \frac{.25}{4} \times 10^{-2} = .06 \times 10^{-2}$$

N = # of K_L (300 Gev/c ± 50) ≈ 10^5 for 6×10^{12} protons at 400 Gev/c

$$\text{Yield/pulse} = N\left(E\frac{d^3\sigma}{d^3p}\right)\left(\frac{1}{\sigma_T}\right) P^2 \frac{\Delta P}{P}\,\Delta\Omega \text{ (fraction of particles interacting)}$$

$$\text{Yield/pulse} = 10^5 \times 10^{-34} \frac{1}{21 \times 10^{-27}} \quad P^2 \quad .25 \times (.06 \times 10^{-2}) \times 1$$

$$\text{Yield/pulse} = \frac{1}{21} \times P^2 \; .015 \times 10^{-4}/\text{pulse}$$

$$= P^2 \times .75 \times .10^{-7}/\text{pulse}$$

Yield/day $= .75 \times 10^{-3}\, P^2$/day assuming 10^4 pulses/day.

= 2 /day at 100 mrad in angle. (p = 50 Gev/c)

TABLE 3

Rates

θ = 80 mrad ± 10 mrad ≅ 90º in the c.m. system

P(Gev/c)	P_t	$E\,d^3\sigma/d^3p$ (200 Gev/c)	$E\,d^3\sigma/d^3p$ (300 Gev/c)	$E\,d^3\sigma/d^3p$ (400 Gev/c)
10	.8	2×10^{-27}	2×10^{-27}	2×10^{-27}
20	1.6	8×10^{-29}	9×10^{-29}	10^{-28}
30	2.4	2×10^{-30}	3×10^{-30}	4×10^{-30}
40	3.2	1.6×10^{-31}	2.5×10^{-31}	3×10^{-31}
50	4.0	4.5×10^{-33}	1×10^{-32}	1.5×10^{-32}
60	4.8	1.5×10^{-34}	6×10^{-34}	1.5×10^{-33}
70	5.6	1.5×10^{-35}	8×10^{-35}	1.8×10^{-34}
80	6.4	6×10^{-37}	5×10^{-30}	1.5×10^{-35}

$$\frac{\Delta P}{P} = .25$$

$$\Delta\Omega = \frac{.5\ \times\ .5}{(20)^2} = .0625 \times 10^{-2} = 6.25 \times 10^{-4}$$

$\sigma(K_L n) \approx$ 21mb.

f = fraction of beam interacting = 1

N = $N(K_L) = 10^5$/pulse in a ΔP of 100 Gev/c = ±50 Gev/c.

$$\text{Flux/pulse} = N\,\frac{E\,d^3\sigma/d^3P}{\sigma_t}\,\Delta\Omega\,P^2\,\frac{\Delta P}{P}\,f = P^2\,\frac{E\,d^3\sigma/d^3P}{10^{-27}} \times \frac{10^5\times 6\times10^{-4}}{21}(.25)$$

$$\text{Flux/pulse} = .74\,P^2\,\frac{E\,d^3\sigma/d^3P}{10^{-27}}$$

P(Gev/c)	P_t(Gev/c)	200(Gev/c)	300(Gev/c)	400(Gev/c)
10	.8	148.0	148.0	148.0
20	1.6	23.6	26.6	29.6
30	2.4	1.3	2.0	2.7
40	3.2	.2	.3	.4
50	4.0	.008	.02	.03
60	4.8	4×10^{-4}	1.6×10^{-3}	4×10^{-3}
70	5.6	5.4×10^{-5}	2.9×10^{-4}	6.5×10^{-4}
80	6.4	2.8×10^{-6}	2.4×10^{-5}	7.2×10^{-5}

APPARATUS

We will need from NAL

1) 2 spectrometer type magnets 50 cm. x 50 cm x 6 ft. magnets
2) 1 hydrogen target
3) iron slabs for a calorimeter and shielding material
4) sweeping magnets for the beam line

Time Commitments

None of the experimentalists are presently committed to any other long range project at any other accelerator.
We are also presently looking for collaborators to work with us on this project.

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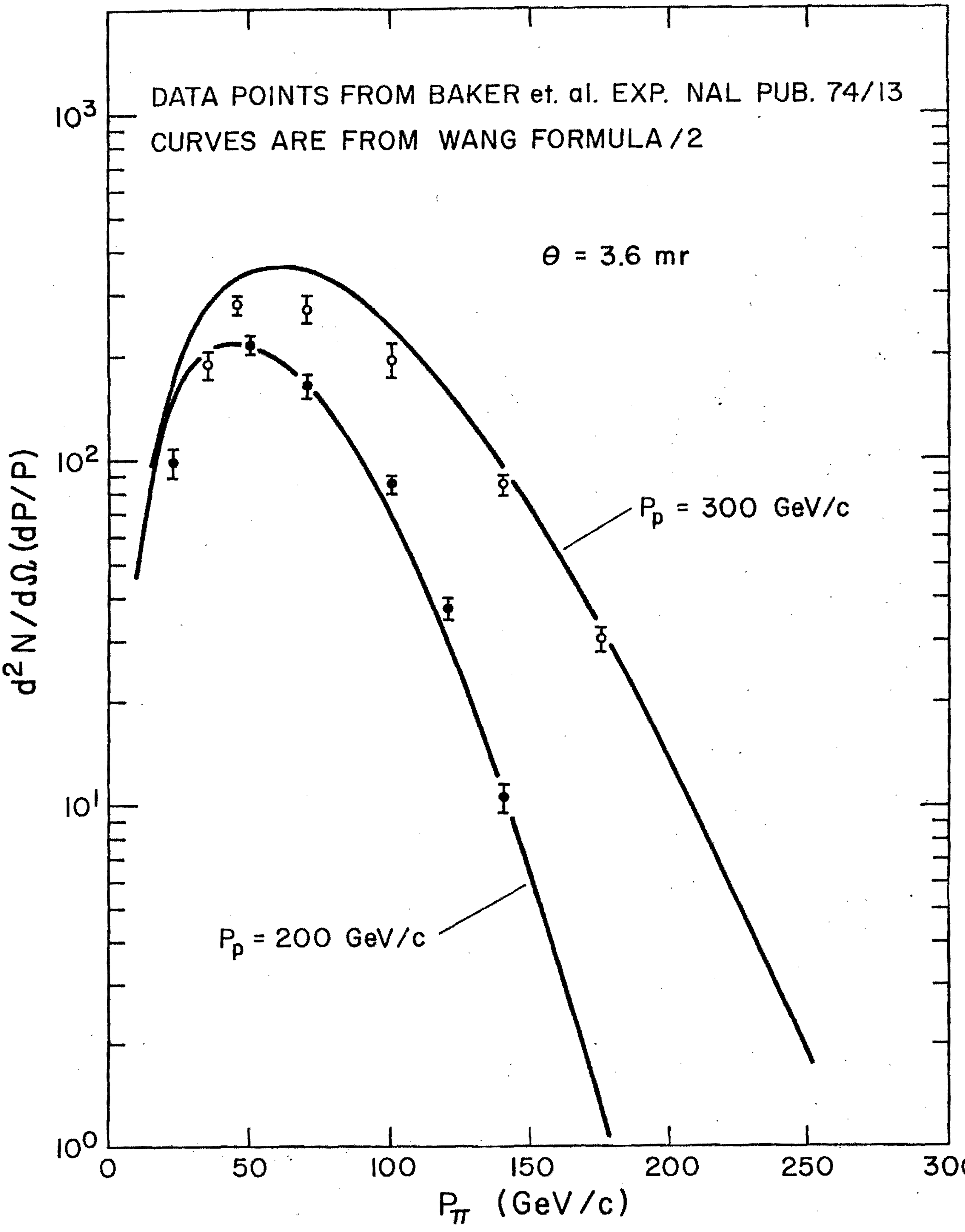
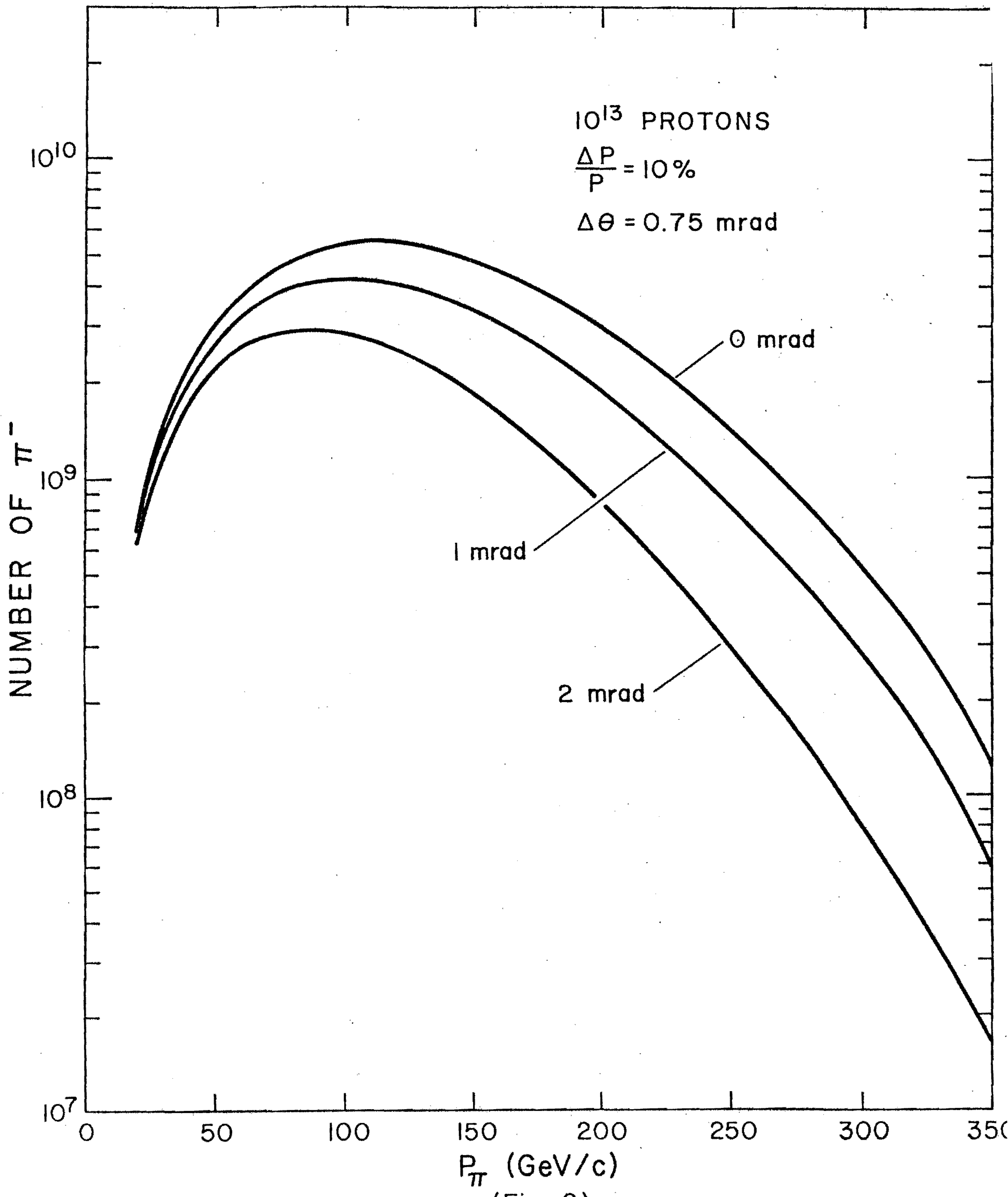
π^- PRODUCTION in P-P INTERACTIONS



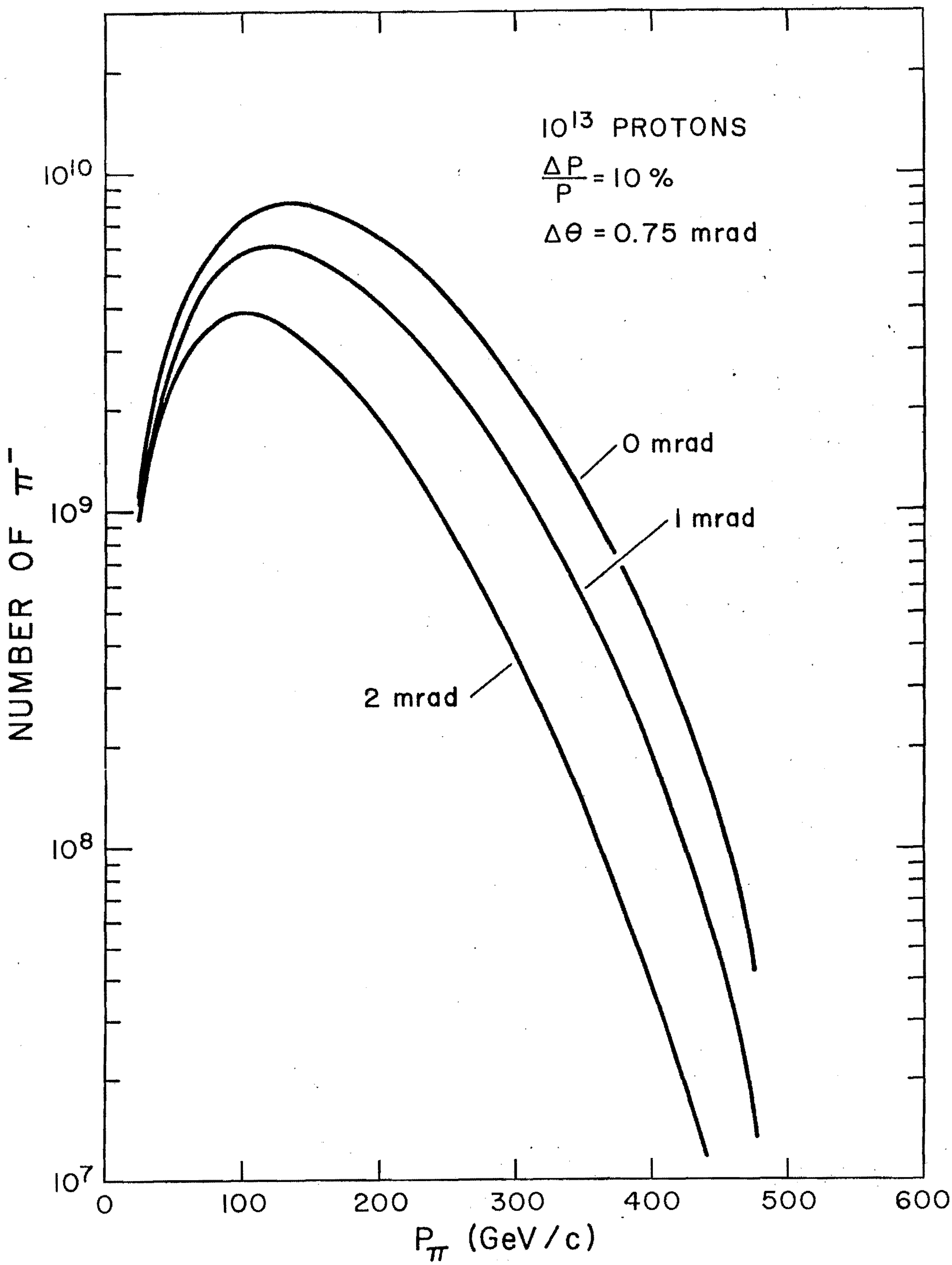
(Fig. 1)

π⁻ PRODUCTION in 400 GeV/c P-P INTERACTIONS



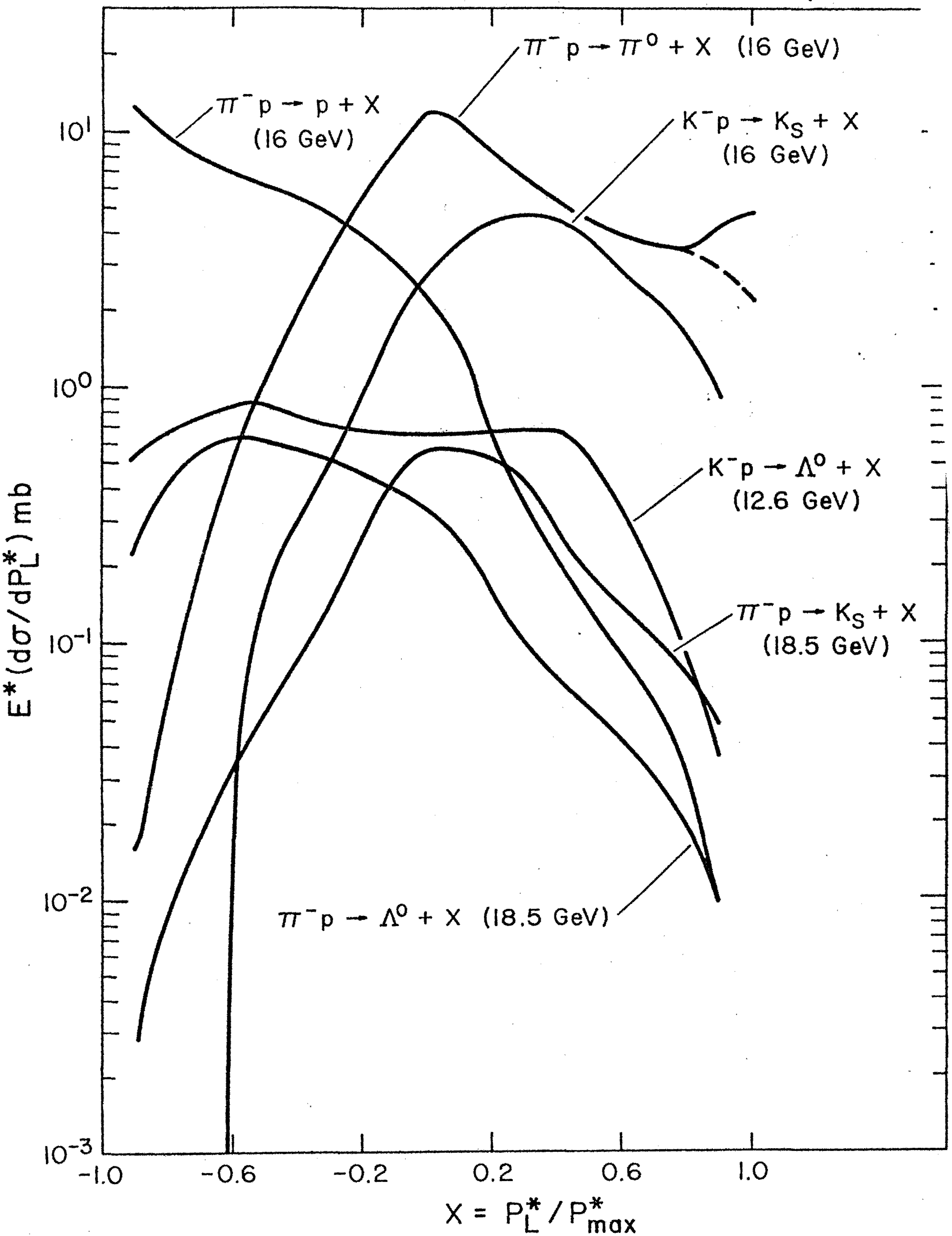
(Fig. 2)

π^- PRODUCTION in 500 GeV/c P-P INTERACTIONS



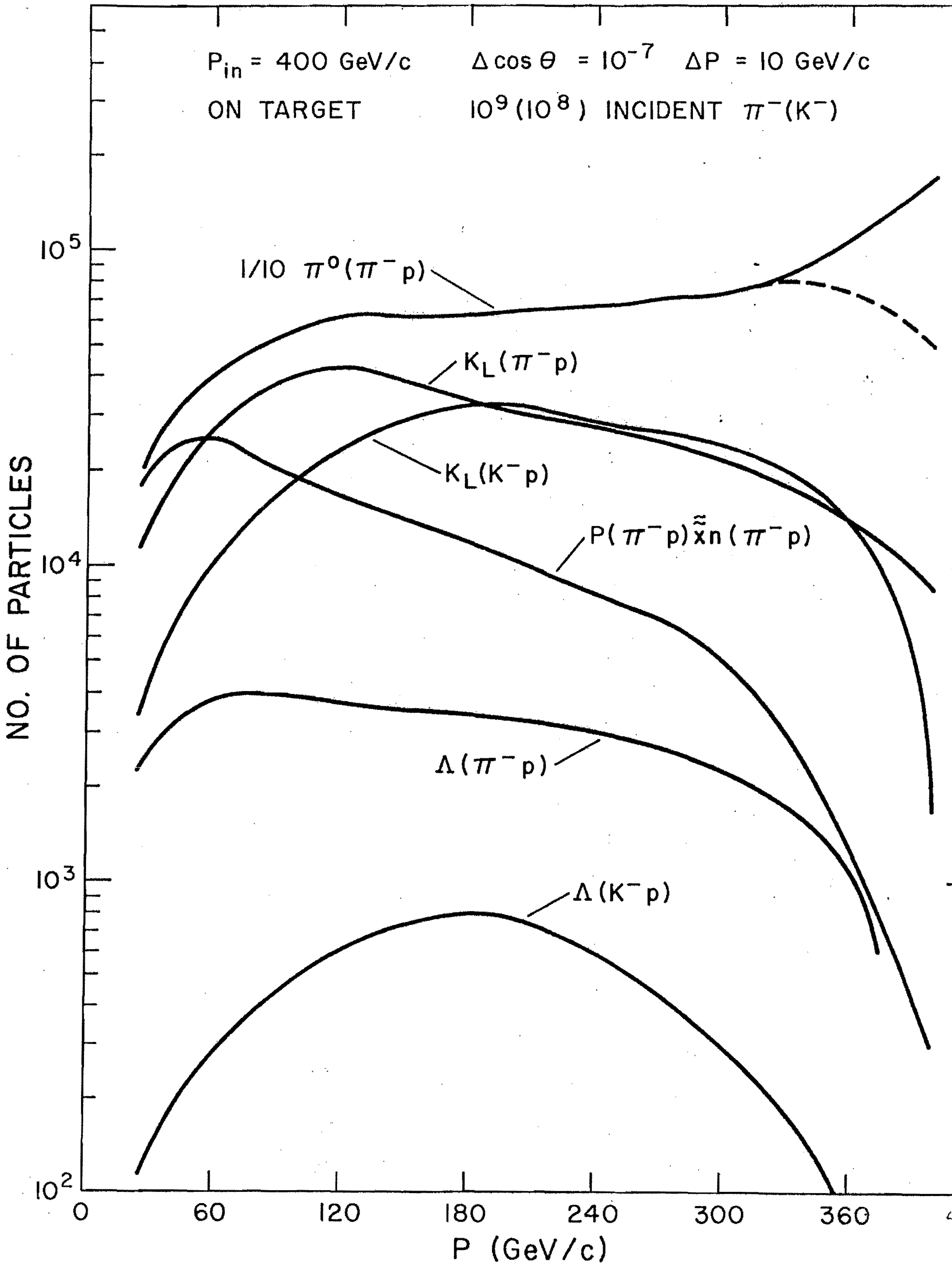
(Fig. 3)

E* dσ/dP*_L FOR VARIOUS INCLUSIVE REACTIONS

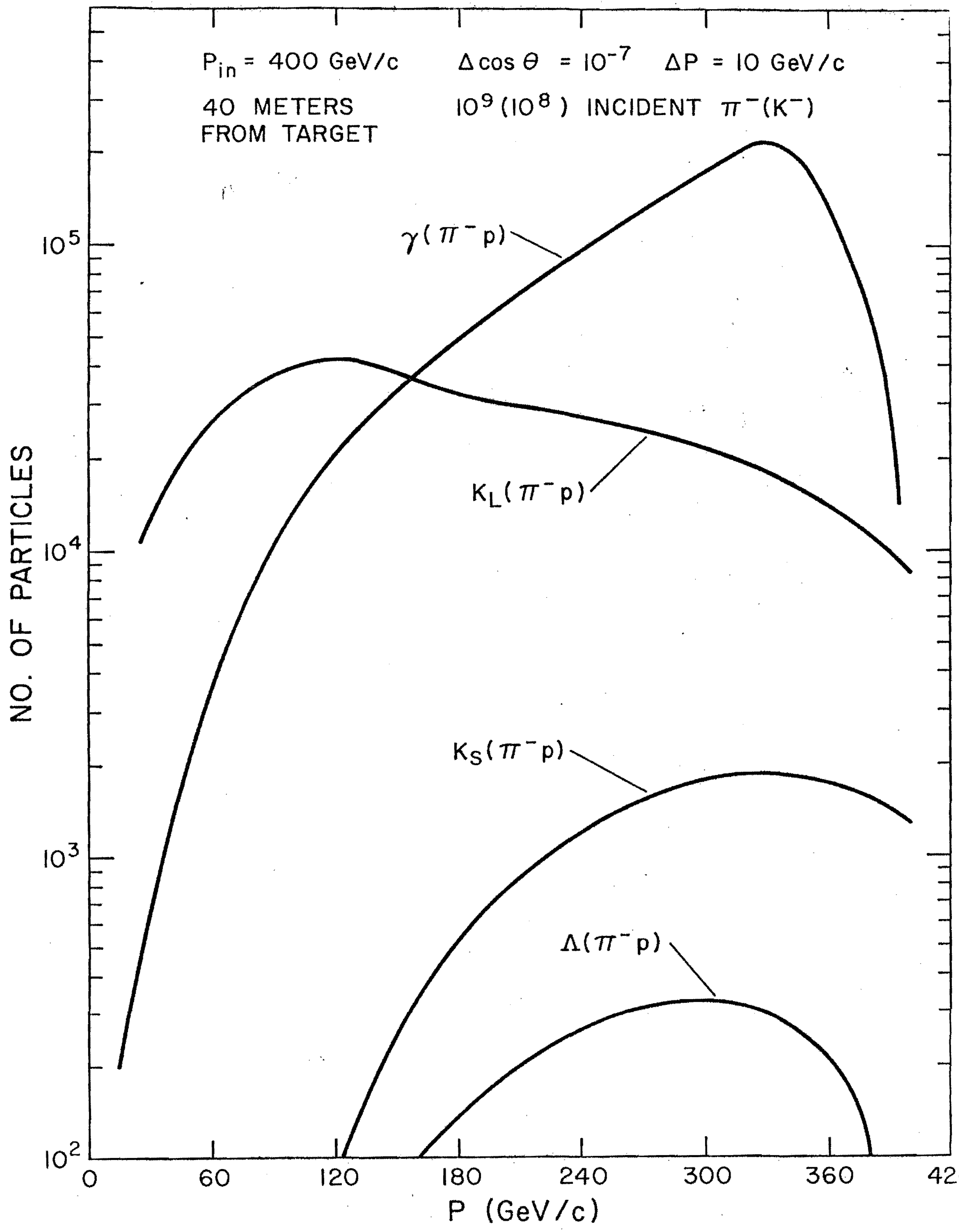


(Fig. 4)

PRODUCTION OF NEUTRALS AT 0 Mrad

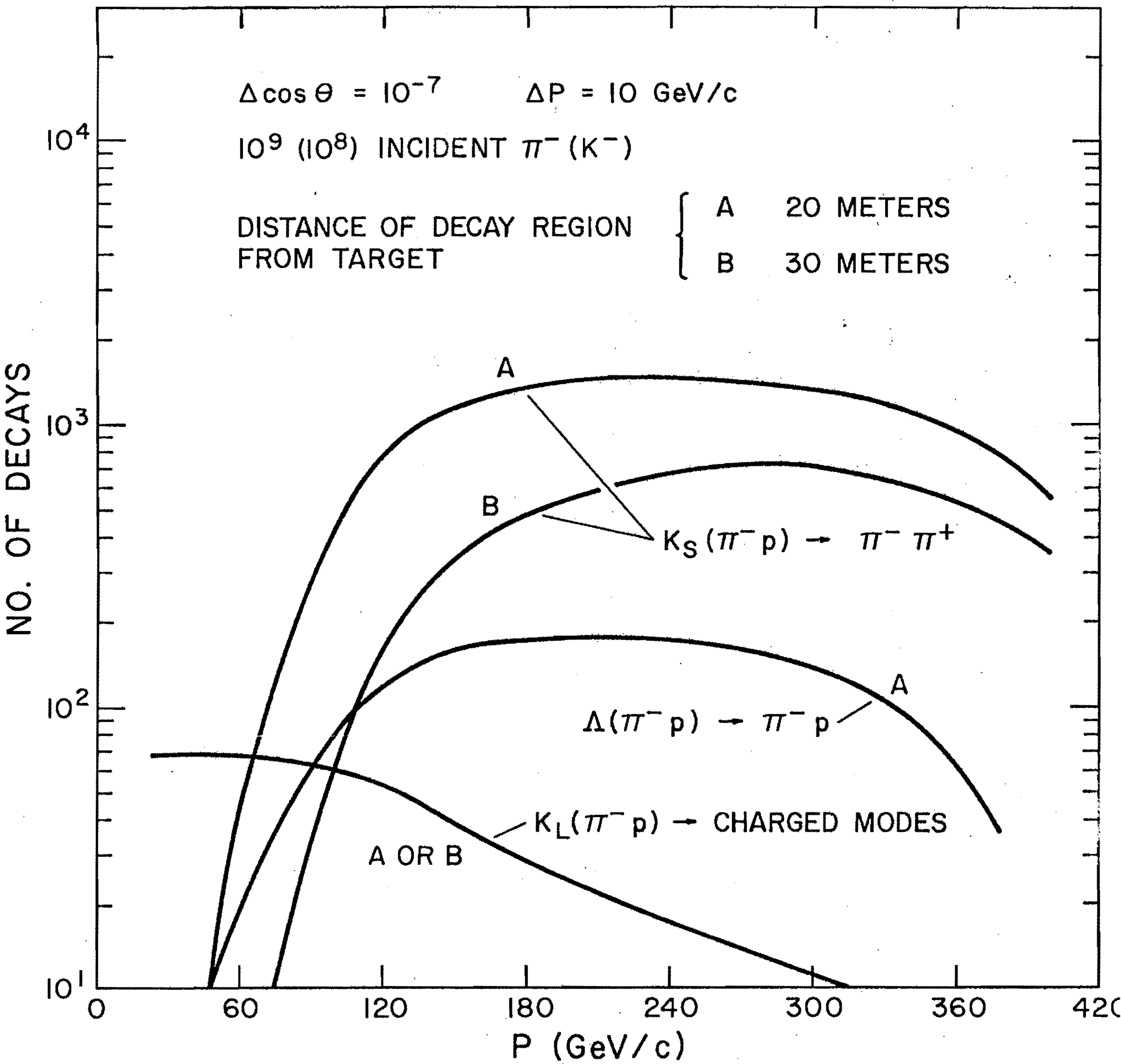


PRODUCTION OF NEUTRALS AT 0 Mrad



(Fig 6)

DECAY MOMENTUM SPECTRUM IN A 6 METER DECAY REGION



(Fig. 7)

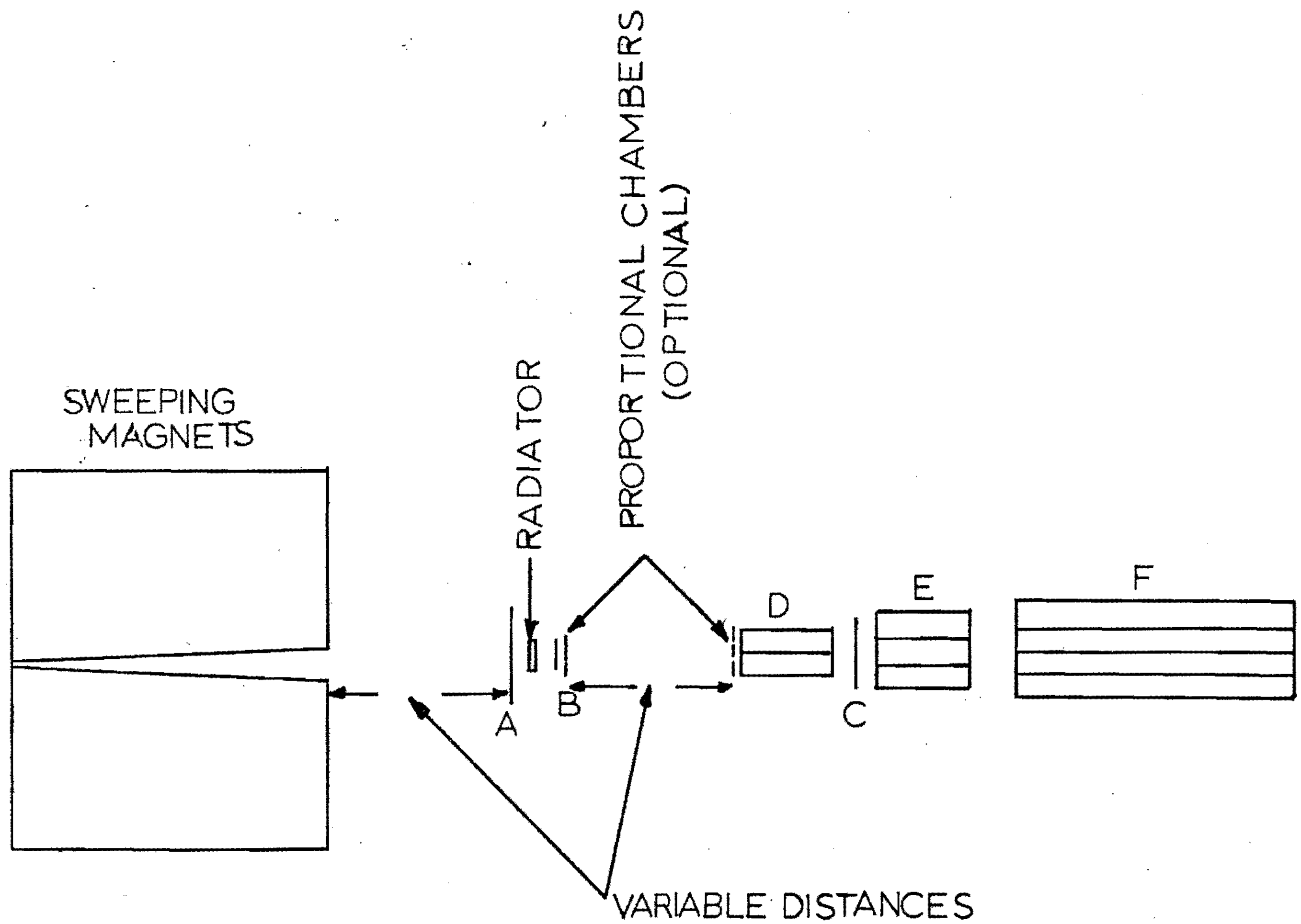

SWEEPING MAGNETS
RADIATOR
PROPORTIONAL CHAMBERS (OPTIONAL)
D
E
F
A
B
C
VARIABLE DISTANCES

FIG. 8

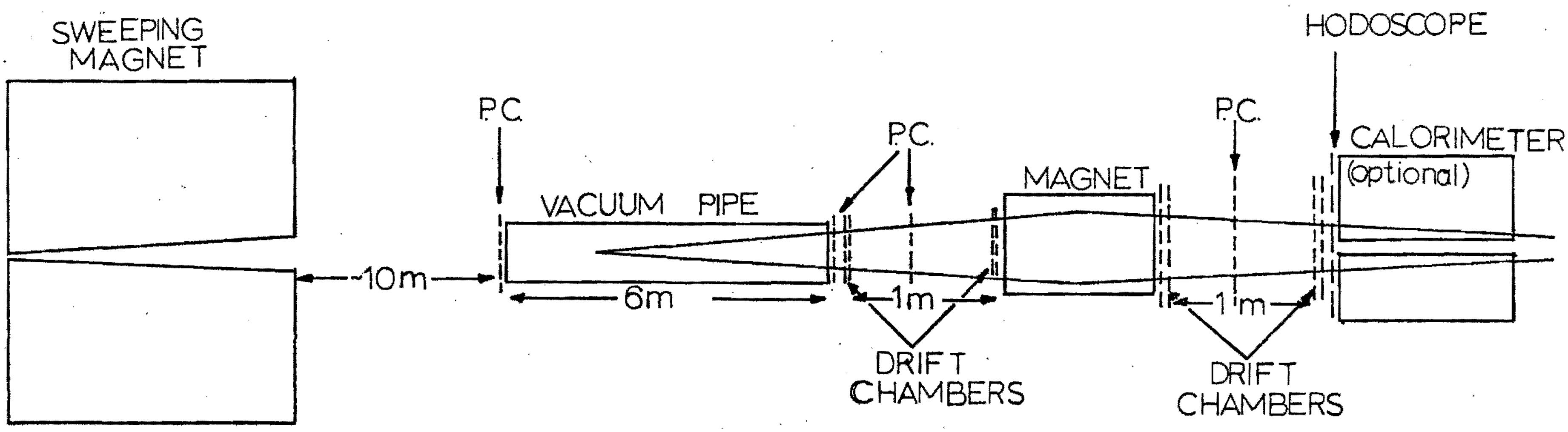

SWEEPING MAGNET
P.C.
VACUUM PIPE
P.C.
MAGNET
P.C.
HODOSCOPE
CALORIMETER (optional)
~10m
6m
1m
1m
DRIFT CHAMBERS
DRIFT CHAMBERS

FIG. 9

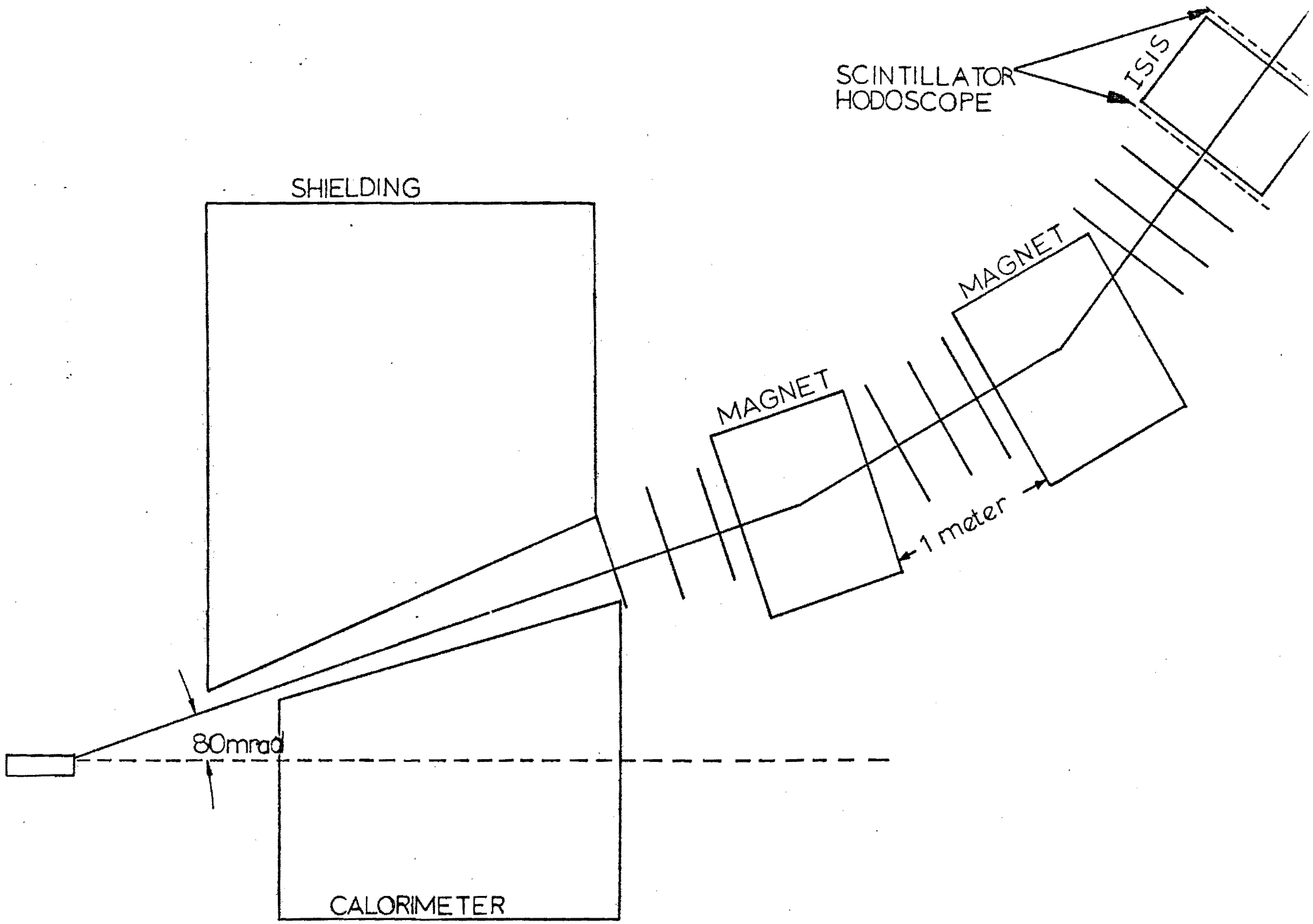

SCINTILLATOR
HODOSCOPE
ISIS
SHIELDING
MAGNET
MAGNET
1 meter
80mrad
CALORIMETER

FIG. 10