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Characteristics of the M-3 Neutral Beam at NAL[†]

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We present here a summary of the properties of the M-3 neutral beam that might be of interest to other experimenters. We have determined the spectra and yields of neutrons, photons, and kaons. These data were taken in conjunction with experiments E-4 and E-230.

The M-3 beam is taken off at an angle of approx. 1 mr from a target in the external proton beam. Most of the data presented here were taken with a 300 GeV proton beam incident on a beryllium target about 20 cm long. Charged particles are removed by several sweeping magnets. Two remotely-controlled lead filters can be placed in the beam to effectively remove photons from the beam (Figure 1). The beam is defined by a steel collimator 1.2 m long with a variable aperture. For the data shown here the defining aperture was 1.58 mm diameter at 198 m from the Be target and subtended 5×10^{-11} sr.

The main diagnostic tool used for the beam studies was a total absorption "calorimeter". The calorimeter and its properties are described in a separate article.[1] Briefly, it consists of 30 iron plates, each 30 g cm^{-2} thick, interspersed with 30 scintillators. The light output from the scintillators is optically added and brought to four 8575 photomultipliers. The summed output pulse from these is roughly proportional to the energy of the incident particle. Measurements taken with a monoenergetic proton beam show that the calorimeter has an energy resolution of ±15 GeV at 200 GeV and ±20 GeV at 300 GeV (i.e., ≈15% and 13% FWHM respectively). The average pulse height was also found to be a linear function of incident energy to within ±2%. Incident particles were required to interact in a converter just ahead of the calorimeter. This was normally a 2.5 cm thick iron plate.

Figure 2 shows the pulse height spectrum as measured with 6.35 cm of lead filters in the beam. Except for obvious limitations due to the energy resolution of the calorimeter, this is believed to be an accurate representation of the neutron spectrum of the beam. The energy scale is based on the assumption that the observed linearity between pulse-height and energy is true at energies below 200 GeV. A short run taken with a tungsten production target gave a spectrum more strongly peaked on the high end (Figure 3). No direct information is available on "low-energy" neutrons in the beam (i.e. <5 GeV). However, these did not seem to produce a troublesome background. The absolute neutron flux with a 1.58 mm diam. defining collimator at 198 m from the production target was ~1.6 x 10^{5} neutrons per 10^{12} protons incident on a 20 cm long Be target (corresponding to 3.2 x 10^{3} neutrons per sr per incident proton). An uncertainty of ±30% should probably be assigned to this because of uncertainties in targeting efficiency and in the effective collimator size.

The photon spectrum in the beam was studied by taking out all the lead filters in the beam and measuring the pulse-height spectrum. The neutron contribution was then removed by subtracting the pulse-height distribution with lead in the beam from that without. It was assumed that above 250 GeV the photon/neutron ratio is small. The resulting photon spectrum is shown in Fig. 4.

Note the huge peak at low energies and the sparsity of high-energy photons. In evaluating this spectrum the following "caveats" should be kept in mind:

1) In extracting the photon spectrum we assumed that the number of photons above 250 GeV was negligible compared with neutrons. This seems reasonable in view of the observed spectra shown in Figs. 4 and 6.

2) The photon energy scale was corrected relative to the neutrons by 25%. From the calorimeter calibration[1], it was determined that the instrument samples the energy loss of hadrons with only 72% efficiency relative to muons. In other words, a 200 GeV proton gave a pulse height 72% of that predicted from the observed pulse heights of high-energy muons traversing the calorimeter. This is because a significant fraction of the energy of an incident hadron eventually is lost in nuclear binding energy or in low-energy fragments which produce light less efficiently than muons. Photons which deposit their energy by producing $e^{\pm}$ pairs should give approximately the same amount of light per GeV deposited as muons.

3) Some fraction of the photons may be produced in the defining collimator and/or the last lead filter. The large spike below 20 GeV may be due to this, and may thus be sensitive to collimator details.

4) The calorimeter resolution deteriorates at lower energies and this may diffuse the low energy peak.

The total photon flux in the beam with no lead filters is ~0.9 times the neutron flux after taking into account the relative conversion in the iron plate. This corresponds to ~1.4 x 10^5 photons per 10^{12} protons through the 5 x 10^{-11} sr collimator with the 20 cm Be target. The uncertainty in absolute normalization is at least a factor of two. [Two separate attempts at absolute normalization did not agree; we have used the higher γ flux on the assumption that for the other some γ converter inadvertently remained in the beam.]

Neutral kaon production in the beam was studied by measuring the attenuation of the beam vs thickness of a carbon target. Since the kaon-carbon cross section is about half the neutron-carbon cross section, it was possible to fit the attenuation data by a sum of two exponentials. After correction for the relative conversion efficiencies in the iron plate, we find a K°/n ratio of approx. 0.25 in the energy interval 15-60 GeV and of 0.06 in the interval 60-105 GeV at our detector 415 m from the production target. A carbon filter of 286 g/cm^2 increases the K°/n ratio by almost an order of magnitude at the expense of a reduction of kaon flux by a factor of 10 (and of neutrons by a factor of 100). The spectra with and without the carbon filter are given in Fig. 5 together with the kaon spectrum found by subtraction.

In Fig. 6 we compare the absolute spectra of neutrons, kaons, and photons. The kaon flux is corrected for decay in flight to give K°_L yields at the production target. The absolute normalizations are uncertain as noted above.

No direct information is available on the $\bar{n}/n$ ratio in the beam. However, measurements of $\bar{p}/p$ fluxes in the M-1 beam[2] suggest that this ratio should be ~0.11 at 40 GeV and <<0.01 above 100 GeV.

We would like to thank the many people at NAL who contributed to the development and installation of the M-3 beam line, especially E. Bleser, R. Lundy and J. Sanford.

Figure Captions

1. The M-3 beam line (schematic). Note scales.
2. Neutron spectrum produced by 300 GeV protons on a beryllium target. Calorimeter energy resolution has not been unfolded.
3. Comparison of spectra from beryllium and tungsten targets.
4. Photon spectrum. See text for details.
5. Neutral hadron spectra with and without 286 g/cm^2 carbon filter normalized above 200 GeV. The difference between the two is ascribed to kaons.
6. Absolute fluxes of neutrons, kaons, and photons in the M3 beam line. Neutrons include antineutrons. Kaons are corrected for decay in flight. The normalizations are uncertain as follows: neutrons, ±30%; kaons, ±50%; photons, ± x 2 (see text).

References

1. L.W. Jones *et al.*, UMHE 73-24, to be published in Nucl. Instr. and Meth.
2. "Particle Survey in the M1 Beam Line", NALREP, February 1974.

M-3 BEAM

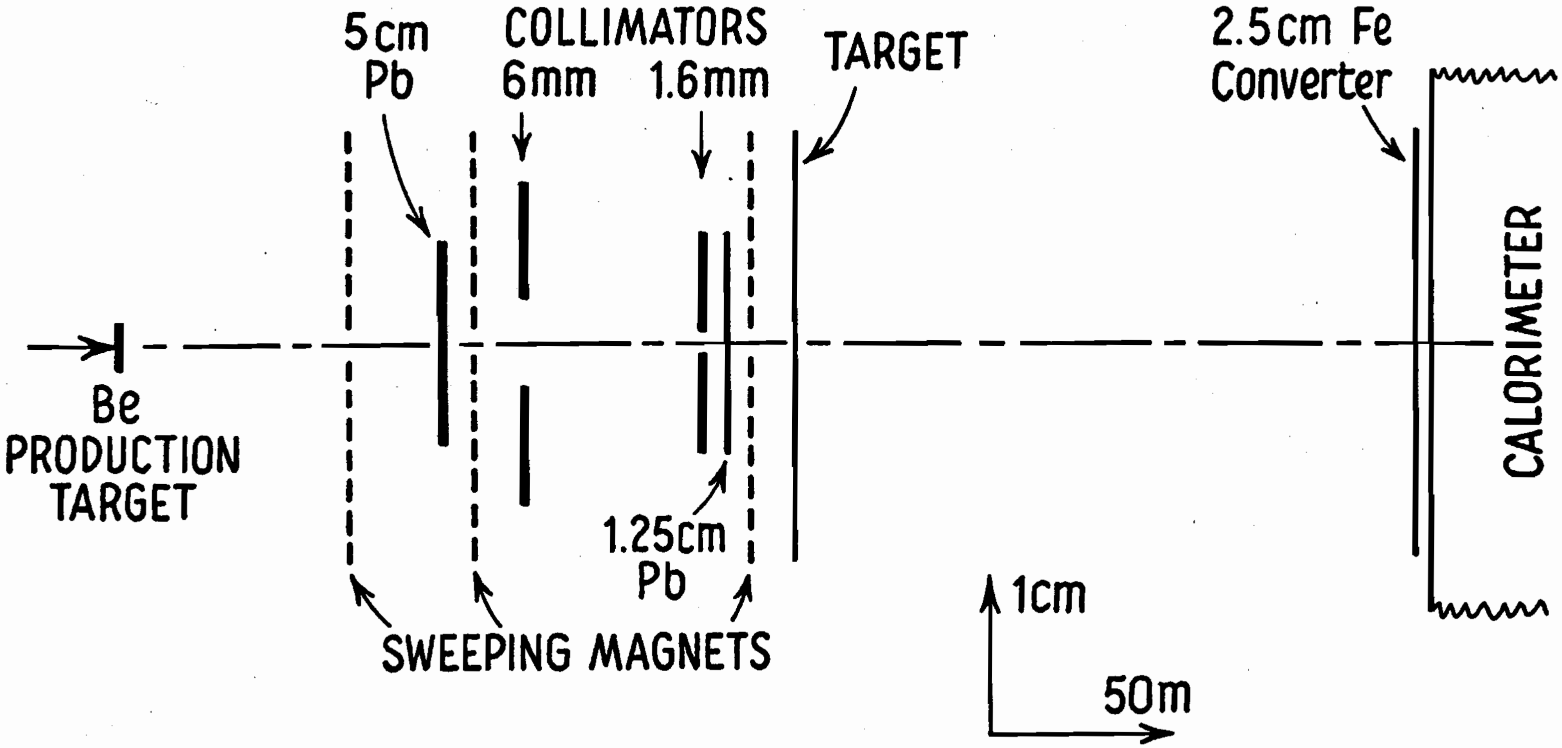


Figure 1

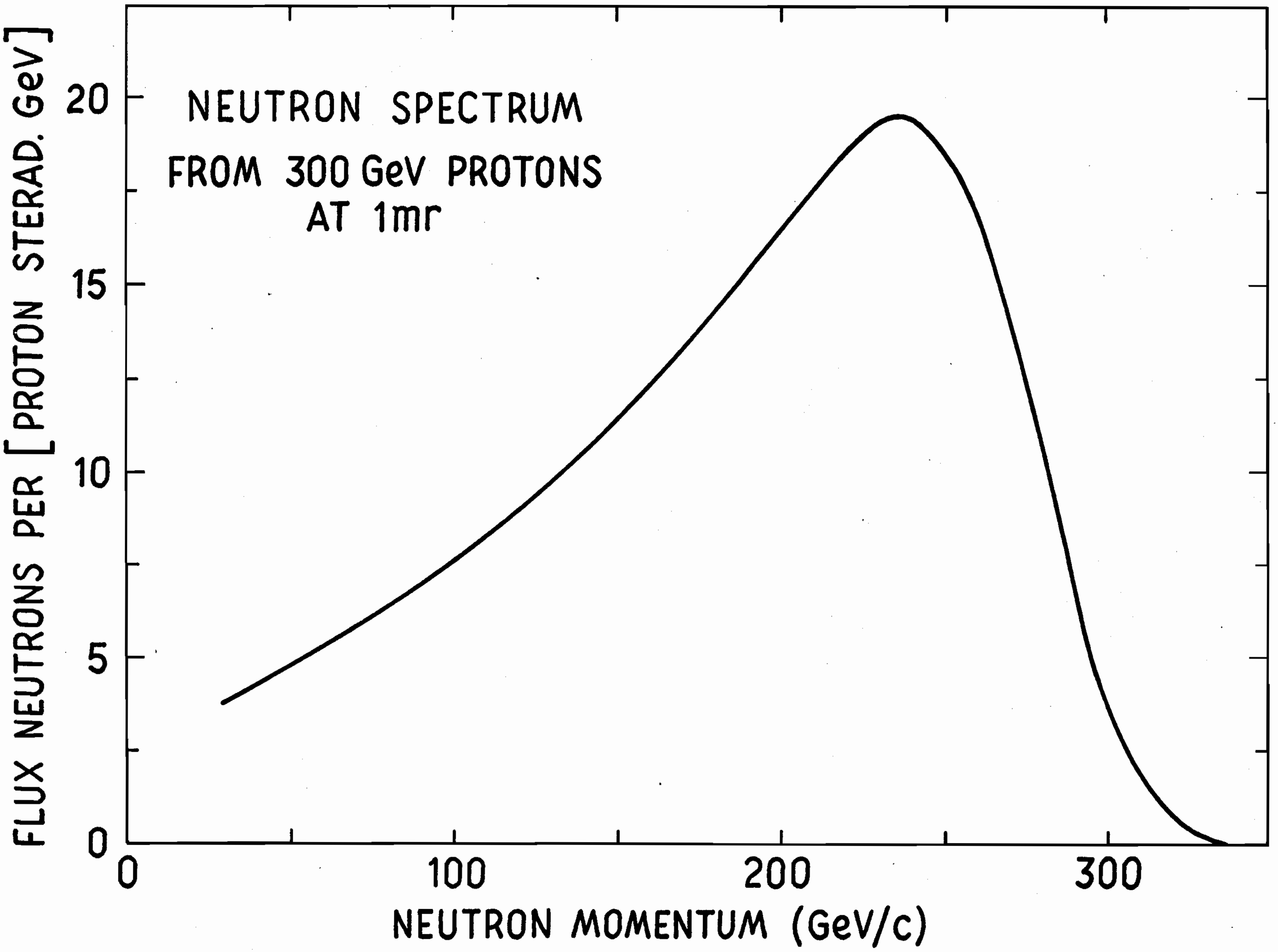

NEUTRON SPECTRUM
FROM 300 GeV PROTONS
AT 1mr
FLUX NEUTRONS PER [PROTON STERAD. GeV]
0
5
10
15
20
0
100
200
300
NEUTRON MOMENTUM (GeV/c)

Figure 2

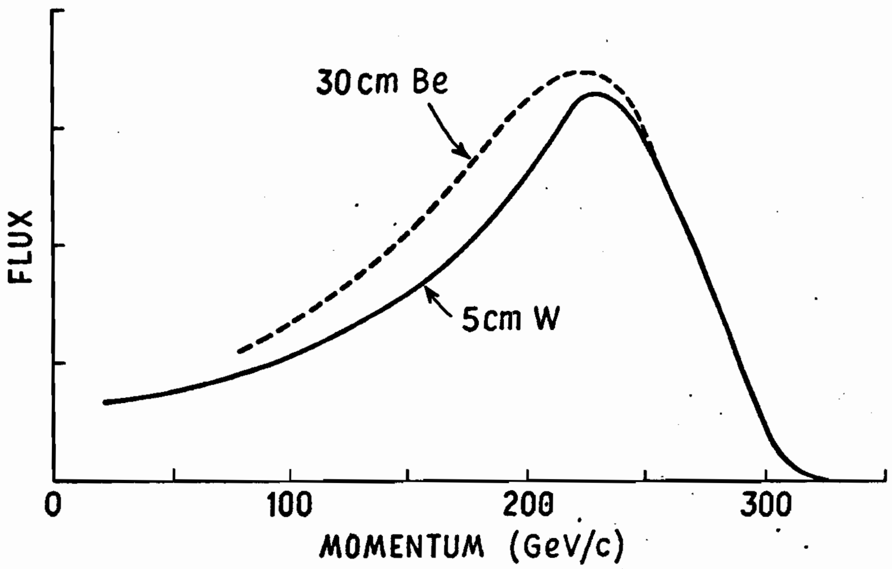


Figure 3

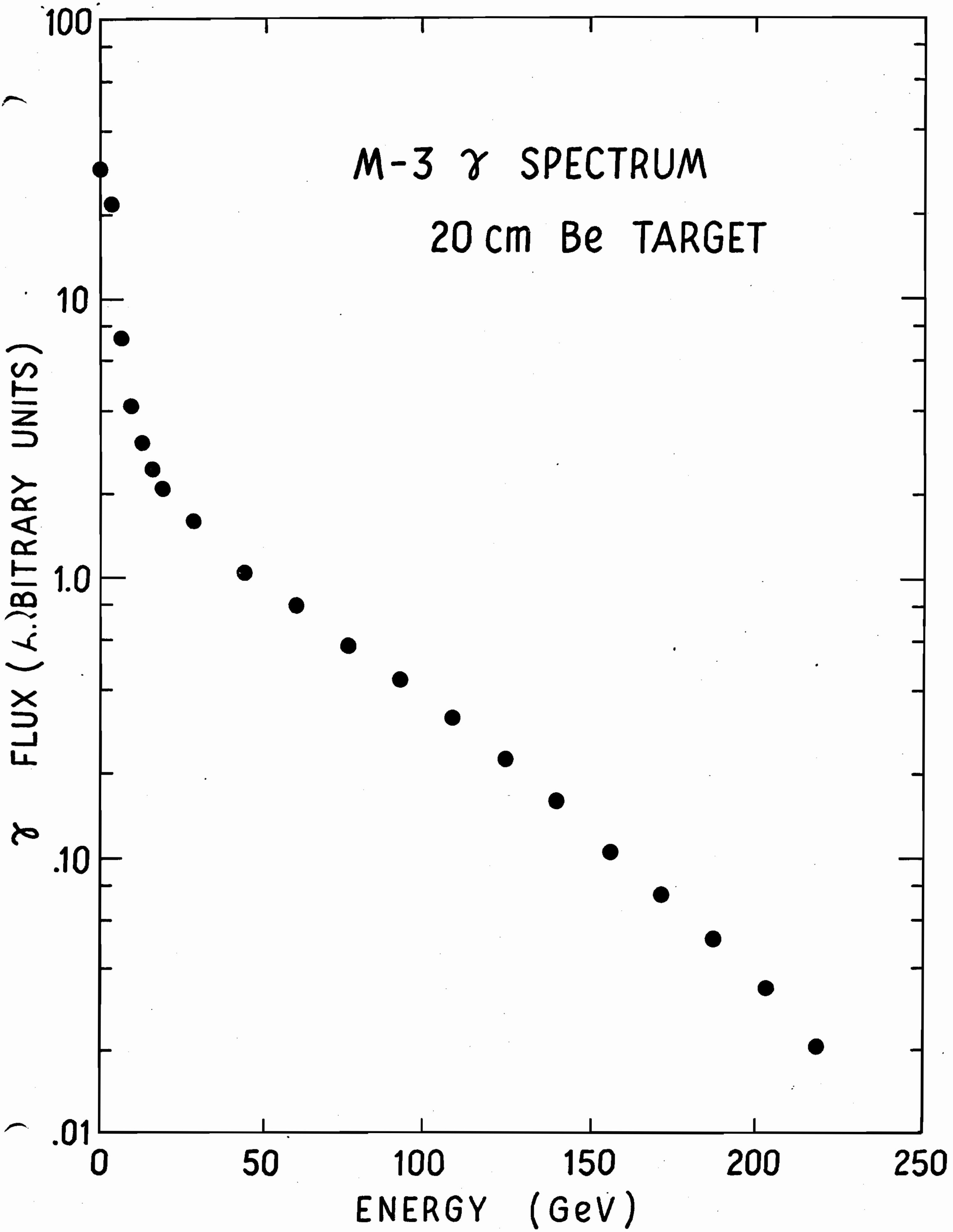

M-3 γ SPECTRUM
20 cm Be TARGET
γ FLUX (ARBITRARY UNITS)
100
10
1.0
.10
.01
0
50
100
150
200
250
ENERGY (GeV)

Figure 4

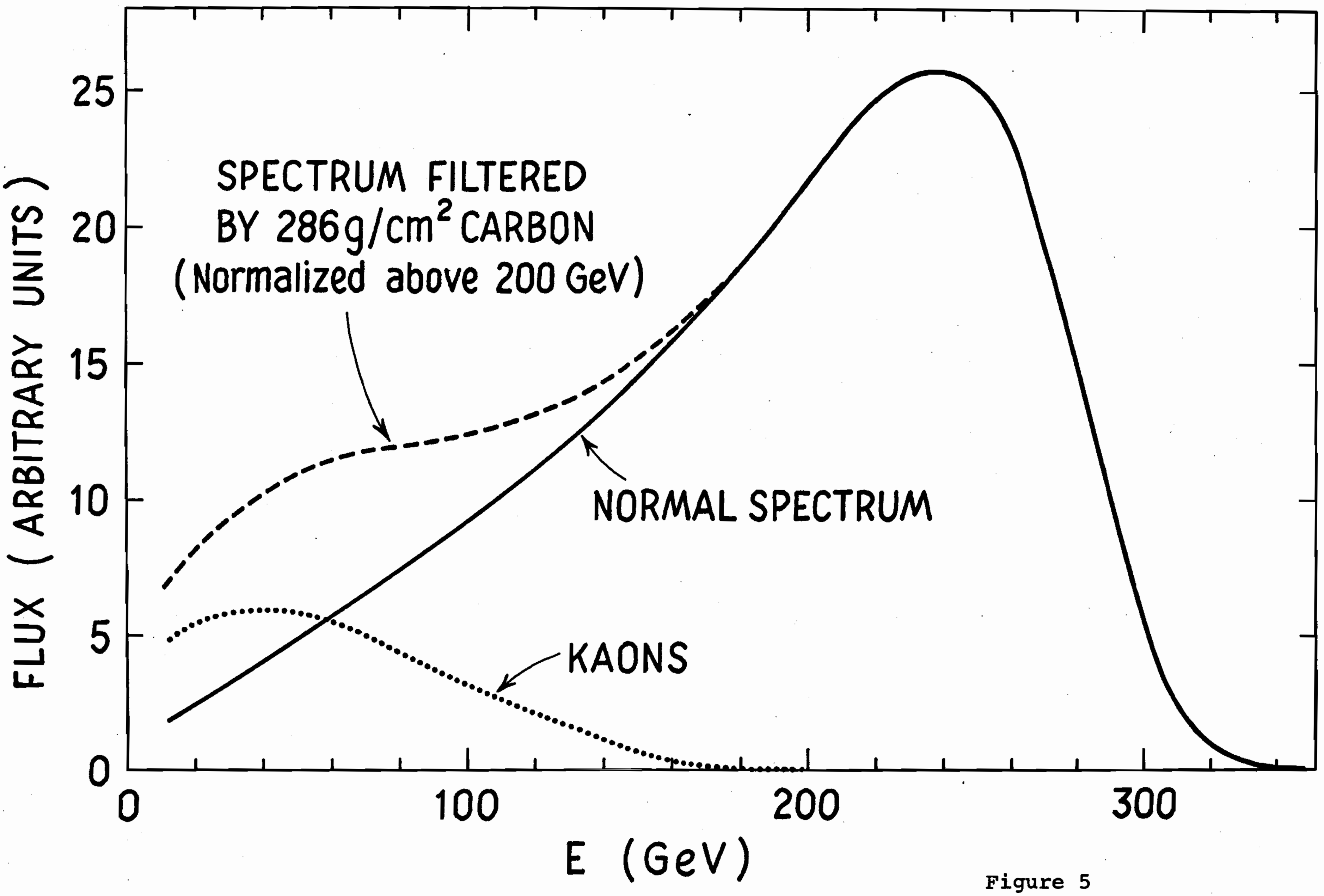
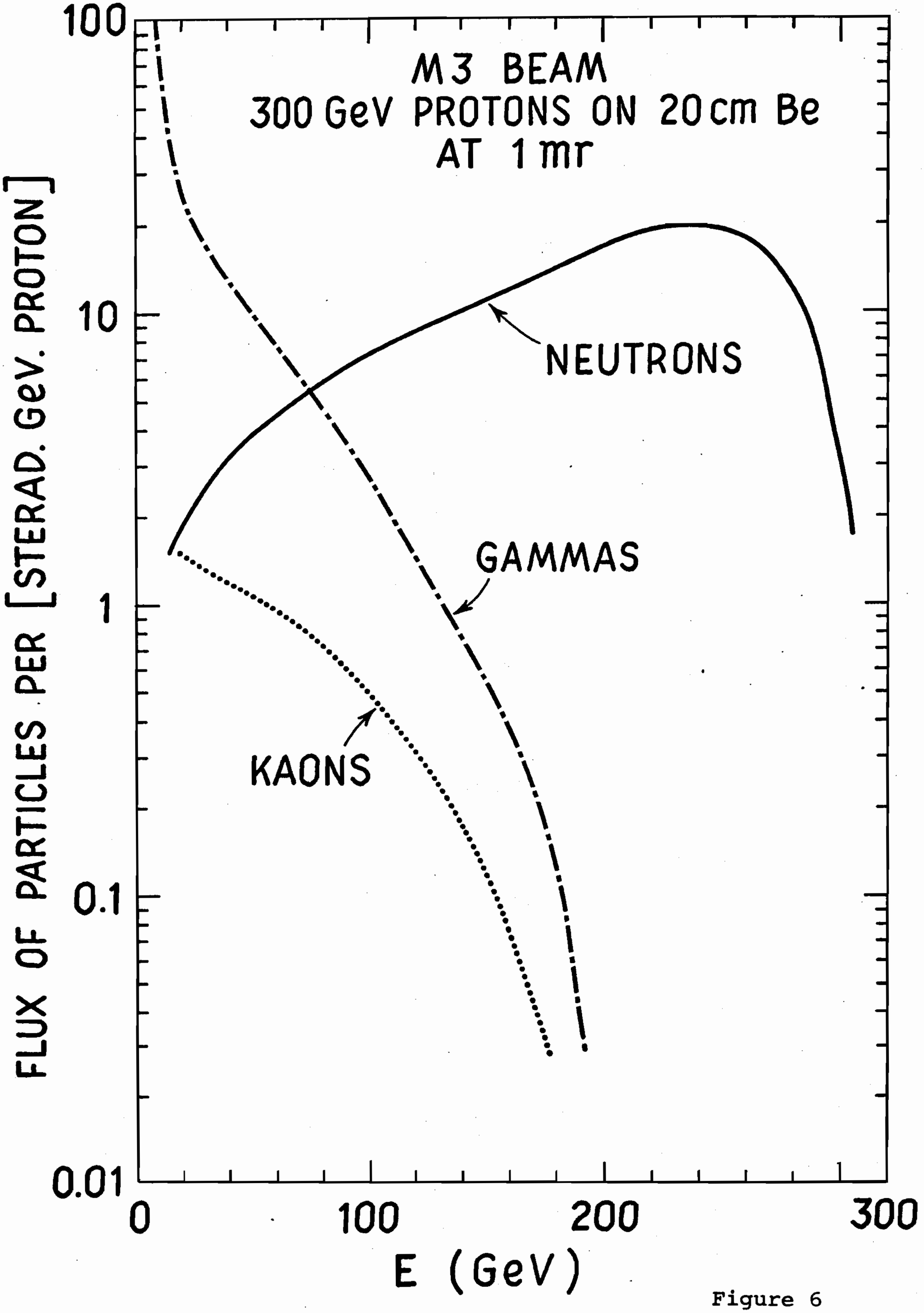

FLUX (ARBITRARY UNITS)
0
5
10
15
20
25
0
100
200
300
E (GeV)
SPECTRUM FILTERED
BY 286g/cm² CARBON
(Normalized above 200 GeV)
NORMAL SPECTRUM
KAONS

Figure 5



M3 BEAM
300 GeV PROTONS ON 20 cm Be
AT 1 mr
NEUTRONS
GAMMAS
KAONS
FLUX OF PARTICLES PER [STERAD. GeV. PROTON]
100
10
1
0.1
0.01
0
100
200
300
E (GeV)

Figure 6