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SEARCH FOR HEAVY MASS PARTICLES AND ANTIDEUTERON FLUX PRODUCED BY 300 GeV PROTONS ON BERYLLIUM

Single Arm Spectrometer Facility Group[†]

December 1973

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ABSTRACT

We have searched for heavy mass, long-lived particles and measured the antideuteron flux produced at 80 GeV/c by 300 GeV/c protons on beryllium.

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INTRODUCTION

With the new range of energies available at the National Accelerator Laboratory, the possibility of the observation of a particle heretofore unobserved is of high interest. Such a particle may be predicted, as is the case of the intermediate boson or completely unpredicted as was the case with the strange particles. In the testing of Cerenkov counters built for use in the NAL Single Arm Spectrometer Facility, it was realized that with the very high rejection ratios realized, 10^8, that we could with little extra effort both measure the beam constitution including antideuterons and make a search for high mass particles. The search was performed employing two Cerenkov counters detecting negative particles produced at a momentum of 80 GeV/c and an angle of 3 mrad by 300 GeV protons incident on a beryllium target. No new particles were found up to a mass of 4.4 GeV. The ratio of rates of production of particles at the target was found to be π:K:$\overline{\mathrm{P}}$:$\overline{\mathrm{D}}$: = 1:.071:.020:2.4×10^{-6}.

EXPERIMENTAL METHOD

The experiment was performed in the high resolution, M-6 beam line of the Meson Laboratory at NAL. The 300 GeV extracted proton beam of the NAL proton synchrotron was directed onto a 1/8" × 1/8" × 12" beryllium target. Typically, 10^{12} protons were contained in each beam pulse which was extracted over a period of about one-half-a-second every six seconds. The collimators at the beginning of the beam line (See Fig. 1) were adjusted to limit the number of particles in the beam line to 100,000 particles per pulse or less. The production angle was 3 mrad at a momentum of 80 GeV/c with a momentum bite of about one percent and was set for negative particles. The beam line was instrumented with various trigger and slit counters for diagnostic purposes for the checkout of the beam line which occurred concurrently with the mass search. Figure 1 shows the beam line and the elements related to the mass search. The three stage beam line is 448 meters long and serves as an ideal collimator, with its numerous small aperture elements, giving a very clean beam spot with very little halo at the third focus. The trigger counters used in the mass search were designated as BT1, Td, and BT2. BT1 and BT2 were located at the second and third foci of the beam line respectively. Td was located just after the differential Cerenkov counter. Td was a scintillator, one inch in diameter, and insured that the particle passed through the center of the counter.

A threshold Cerenkov counter, BGAS, was used to veto pions, kaons, and antiprotons. It had a radiating volume 18 meters long and 17 cm in diameter. [1] The Cerenkov light produced in the radiator at the small angles used, 35 miliradians or less, was contained in a black acrylic tube which, at these small grazing angles, is highly reflective. The light was collected and reflected by a thin lucite mirror onto an RCA 8850 photomultiplier with a quartz envelope, allowing its sensitivity to extend below 2000 Å.

The differential Cerenkov counter, SDIF, was used to identify the particle of interest. [2] This counter is shown in Fig. 2. Cerenkov light, produced by a particle traveling along the axis of the counter is focused by the primary mirror onto a ring at the focal point of the mirror whose radius is

$$R = f\theta$$

where f = 9.74 meters, the focal length of the mirror, and θ is the angle of emission of the Cerenkov light. At the focal plane, the counter has a remotely rotatable wheel on which six different mirrors can be placed (see sectional view in Fig. 2). Different mirrors can be installed without much difficulty by removing the cover plate. Light of the correct Cerenkov angle passes through the annulus removed in the mirror mounted on the wheel. It is reflected through

30 degrees by a mirror with a focal length of 58 cm, and is detected through a quartz window by a single two-inch diameter RCA 8850 photomultiplier with a quartz envelope which extends its response to about 1900 Å. The diameter of the disk of light focused on the face of the photomultiplier is about 1 cm. The counter was operated with a Cerenkov angle of 8.5 mrad which, for the 9.7 m radiator length of the counter, gave about 10 photoelectrons at the phototube. Light produced by a particle of the wrong mass, and therefore at an incorrect θ, or by a scattered particle, will not pass completely through the annulus, and some light will be reflected onto the veto photomultiplier.

The width ΔR of the annulus of light is predominately determined by the chromaticity of the gas. For nitrogen at pressures corresponding to a mass of 2 GeV, the ΔR due to the chromaticity, becomes comparable to the widest annulus we had available at the time, 2 cm. However, we operated the counter in a broad band mode, completely without the anti-coincidence feature above the pressure corresponding to a mass of 1.3 GeV. In this mode no veto mirror was in place allowing all the light to be collected by the coincidence mirror and focused onto the coincidence photomultiplier. The range of Cerenkov angles accepted was 5 to 15 mradians. The lower limit is set by the decrease in intensity of Cerenkov light with angle. The upper limit is set by the size of the light collecting mirror of the counter and by the counter's light baffling. Without a veto mirror in place, the counter accepts a much broader range of masses.

For detection of low mass particles, helium was used as a radiator, while for high mass particles, nitrogen was used. The maximum operating pressure of the counter is 75 PSIA. The temperature of the entire counter was regulated to better than one degree centigrade and was monitored to an accuracy of about 0.2 degrees. The pressure was monitored to an accuracy of .05 PSIA. The index of refraction of the radiating gas as obtained from pressure and temperature is determined to more than sufficient accuracy.

Two methods for aligning the primary mirror are indicated in Fig. 1. One involves an autocollimating telescope. The other involves the use of a point light source and four photo-resistors mounted at the veto mirror. We used the telescope system to align the primary mirror approximately, and then used the beam itself for the final alignment by remotely changing the primary mirror's angle. This method eliminates the need to survey the counter accurately along the beam line.

For the mass search, the three scintillation counters, BT1, Td and BT2 were put in coincidence, forming a trigger referred to as BT. The r.f. 50 MHZ structure of the NAL accelerator is maintained in the beam line. Thus, there is no merit to obtaining resolving times shorter than 5 to 10 N sec. In forming the trigger BT, a high bias was set on one counter, detecting whenever there was more than one particle in each r.f. bucket, and that bucket was vetoed. BT was put in coincidence with the coincidence photomultiplier of the differential Cerenkov counter with the veto photomultiplier in anticoincidence. The best rejection ratios were obtained with the veto photomultiplier set to count single photoelectrons while the coincidence photomultiplier was set to count with about 90% efficiency which corresponds to a bias of about four photoelectrons. The threshold counter was then put in directly in anticoincidence with the resulting signal. A significant increase in rejection of pions was obtained by using a LeCroy model 161 updating discriminator in place of a non-updating discriminator for the threshold Cerenkov counter.

In summary, the differential counter was operated in two ways. In the first mode, the standard differential mode, the veto mirror was in place using the rejection of the anticoincidence phototube against unwanted particles. From the pressure curves obtained in this mode, operating the counter at 8.5 mradians, the counter will be able to resolve pions and kaons up to a momentum of about 250 GeV/c. In the second mode, the broad-band mode, no veto mirror was used. In this mode a wide range of Cerenkov angles is accepted and focused onto the coincidence photomultiplier. Consequently, a wide range of particles is accepted at once.

RESULTS

Figure 3a shows our results for the low mass search up to a mass of 1.28 GeV. This search was made employing helium in both Cerenkov counters. The differential counter was operated with a veto mirror with an annulus of 1 1/2 cm width. For the data obtained above a pressure of 30 PSIA the threshold counter was in anticoincidence and its pressure was adjusted so that it counted π mesons with a high efficiency. The data obtained below 30 PSIA was obtained with the differential counter alone. The horizontal bars imply a measurement where no counts were observed but is plotted at a level as if one count had occurred. Thus we see the background in the neighborhood of the antiproton peak is less than one part in 10,000 of the antiproton flux. One notes at the very high pressure end we obtained a few counts; however, at the low pressure end of the pressure curve shown in Fig. 3b which corresponds to the same mass no counts are observed to a level twenty times lower.

Figure 3b shows the result of the higher mass search obtained using nitrogen in both Cerenkov counters. Below 8 PSIA only the differential counter was used employing a veto mirror with a 2 cm wide annulus. Above 8 PSIA no mirror at all was used in the veto mirror position. However, above 8 PSIA the threshold counter was used to veto with high efficiency π's, k's and $\bar{p}$'s. Thus we lost the potential rejection against stray particles but we gained in the range of mass accepted by the counter allowing the mass search to be made in much coarser steps. Since all light incident on the light collection mirror originating from the primary mirror is focused onto the phototube, we see the width of the antideuteron peak is a little over 5 PSIA wide with a neighboring background of less than 1/100 of the antideuteron peak. Again we see at the high pressure end several counts as in the data obtained with helium. We speculate that these counts are caused by knockons or interactions in the gas as the density of the gas increases in the upstream region of the counter which is viewed by the coincidence photomultiplier. This proposed background could be eliminated by splitting the coincidence mirror so that one-half of the light is collected by one phototube, the other half collected by a second phototube, and then the two tubes placed in coincidence. We would expect an added rejection factor against unwanted particles obtained in this way of between one to several decades. An additional rejection factor could have been obtained by raising the pressure in the threshold counter when the differential counter was set for high masses. Thus when the differential counter was tuned for masses above $M_{\overline{D}}$, the threshold counter could have been set to count and veto antideuterons. This was not done since at the time of the measurements we did not have a convenient remote fill system for the threshold counter.

The result of the mass search with nitrogen gives a negative result to about one part in 10^8 of the incident beam particles taking into account the resolution of the counter of about 5 PSIA when operated with no veto mirror. The result of the mass search obtained with helium as the radiating gas gave a negative result to one part in 10^6. Both mass searches were limited by statistics which could have been increased, especially in the low mass search employing helium.

One might ask what our efficiency for observing fractionally charged particles was. The biases on our counters were set liberally so that they would have counted 2/3 charged particles but with a reduced efficiency but not sufficiently liberal so that they would count 1/3 charged particles. No attempt was made to determine what these efficiencies were.

The relative rates of pions, kaons, and protons obtained corrected for decay in flight was $\pi:K:\overline{P}:\overline{D} = 1: .071: .020: 2.4\times 10^{-6}$. The estimated errors on these ratios including systematic errors is ten percent. This result is for negative particles produced at momentum of 80 GeV/c and an angle of 3 mrad by 300 GeV protons on a 12 inch long beryllium target.

Comparison data for the antideuteron flux are available at lower energies from the AGS and Serpukov and at higher energies from the ISR. Although our flux is roughly comparable in size, to those found at ISR and Serpukov, detailed comparison is difficult due to differences in target composites and in transverse momenta. Table I summarizes the comparison.

Comparison with the lower energy data of Serpukov and BNL on antideuteron fluxes leads to expected fluxes very similar to what we have observed. [3,4] Qualitatively antideuterons appear to be formed when an antiproton and antineutron are formed independently in the interaction and their respective wave functions overlap with a final deuteron state. This leads to an expectation that the fraction of antideuterons produced is proportional to the square of the fraction of antiprotons and antineutrons produced times an overlap factor which is independent of primary energy. This empirical rule seems clearly followed at NAL energies.

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REFERENCES

[1] The threshold Cerenkov counter was built at Argonne National Laboratory by D. S. Ayres, R. Diaz, R. Diebold, L. Filips, G.J. Maclay, and E. Walschon.

[2] The differential Cerenkov counter was constructed by the Stanford Group at the Stanford Linear Accelerator Center.

[3] F. Binon, *et al.*, Phys. Letters 30 B (1969) 510.

[4] D. Dorfan, *et al.*, Phys. Rev. Letters 14 (1965) 1003.

[5] B. Alper, *et al.*, AIP Conference Proceedings, Vol. 12 (1973) 169.

FIGURE CAPTIONS

1. Experimental layout. Shown is the M-6 beam line of the Meson Laboratory with the elements used in the mass search.

2. The differential Cerenkov counter. The counter has two photomultipliers, one used in coincidence and one used in anticoincidence. The veto mirror is mounted on a rotating wheel allowing various mirrors to be rotated into position. A cross-sectional view of the wheel is shown in the sectional view.

3. (a) Results of the low mass search using helium as the radiating gas in both Cerenkov counters. The search was made with an anticoincidence mirror with a 1 1/2 cm wide annulus. The data taken above 30 PSIA was obtained with the threshold counter in veto with its pressure set to count only π-mesons.

(b) High mass search. In this case, nitrogen was used as the radiator in both counters. Data below 8 PSIA was taken with a veto mirror with a 2 cm annulus and without the aid of the threshold counter. Data above 8 PSIA was taken with the threshold counter in veto with its pressure set to veto π's, K's and $\overline{\mathrm{P}}$'s. Above 8 PSIA no veto mirror was used allowing the pressure curve to be taken in larger steps. The absence of a defining annulus results in a much wider resolution curve for the antideuterons, but also gives a broad-band mass range acceptance.

TABLE I

Target	$P_{\overline{D}}$	$P_{coll.}$	$\overline{P}/\overline{D}$	$\pi^-/\overline{D}$	$P_\perp$	Ref.
Be	5 GeV/c	28 GeV/c	---	1.8×10^7	0.40 GeV/c	4
Al	40 GeV/c	70	5.5×10^4	2.0×10^7	(0°)	3
Be	80 GeV/c	300	8.3×10^3	4.2×10^5	0.2 GeV/c	This expt.
H (ISR)	<4 GeV/c	1500	1.2×10^3	---	0.7 GeV/c	5

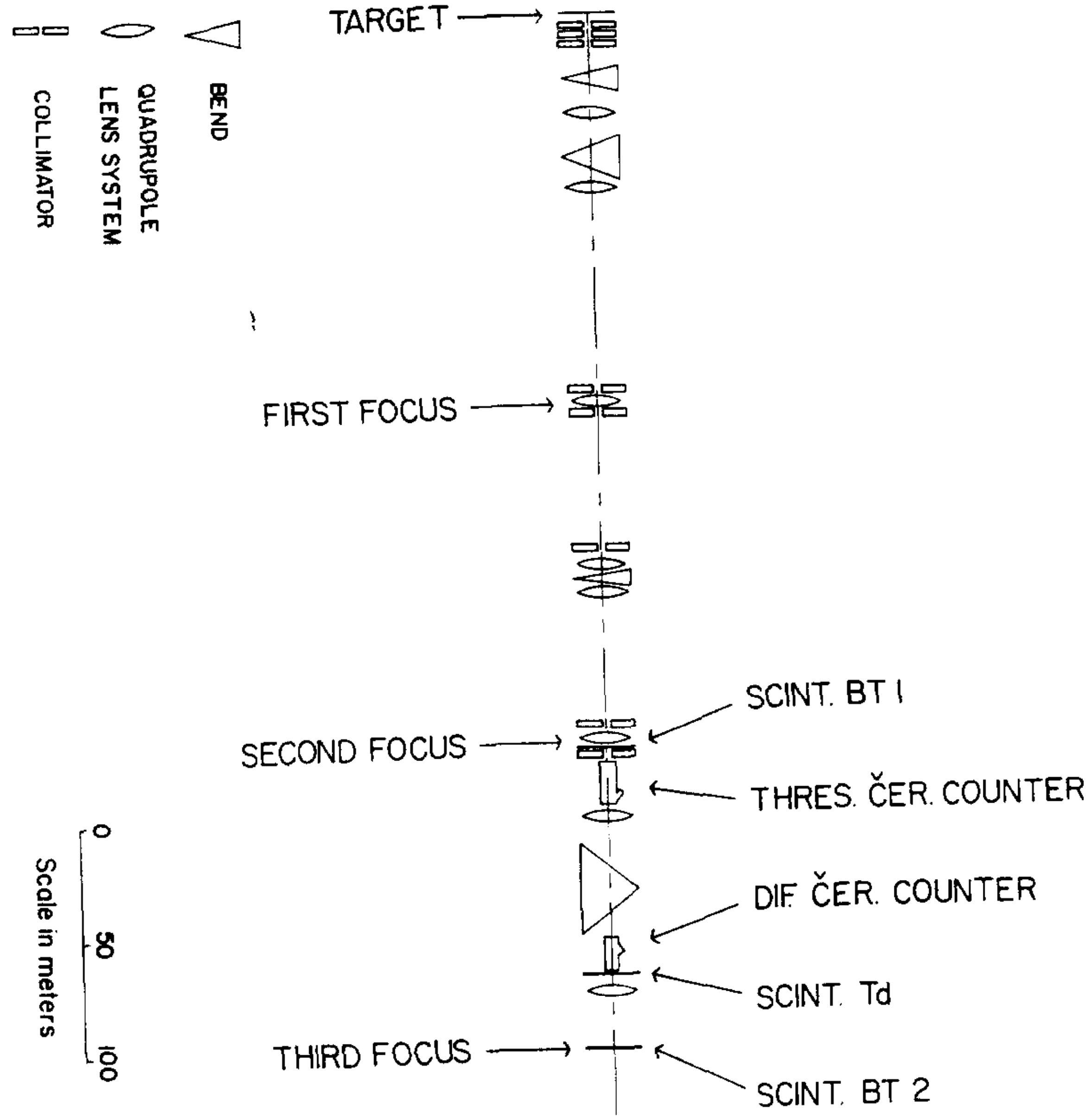
TARGET
FIRST FOCUS
SECOND FOCUS
THIRD FOCUS
SCINT. BT 1
THRES. ČER. COUNTER
DIF. ČER. COUNTER
SCINT. Td
SCINT. BT 2
BEND
QUADRUPOLE LENS SYSTEM
COLLIMATOR
0
50
100
Scale in meters

FIGURE 1

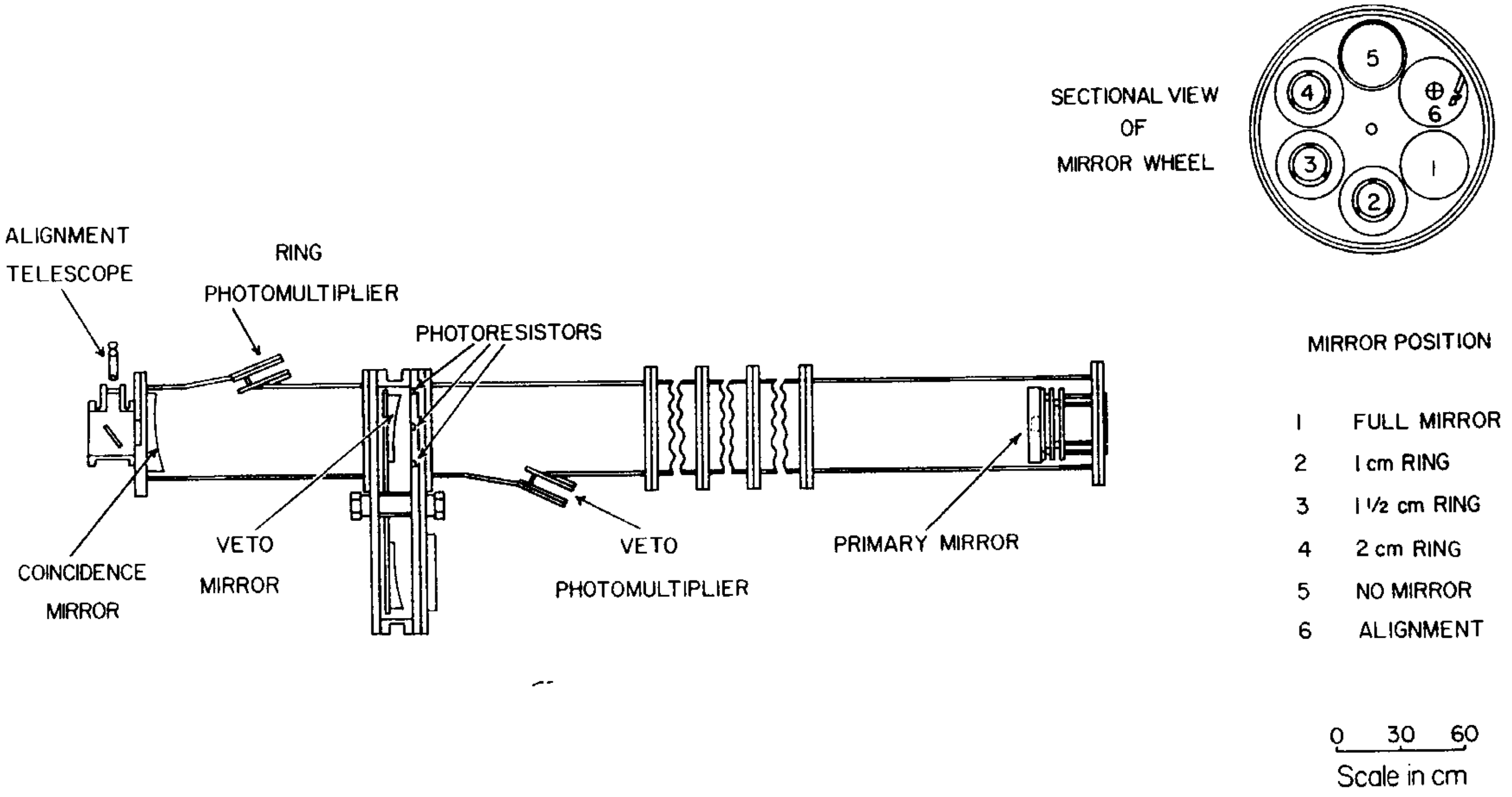
ALIGNMENT TELESCOPE
RING PHOTOMULTIPLIER
PHOTORESISTORS
COINCIDENCE MIRROR
VETO MIRROR
VETO PHOTOMULTIPLIER
PRIMARY MIRROR
SECTIONAL VIEW OF MIRROR WHEEL
1
2
3
4
5
6
MIRROR POSITION
1 FULL MIRROR
2 1 cm RING
3 1 1/2 cm RING
4 2 cm RING
5 NO MIRROR
6 ALIGNMENT
0
30
60
Scale in cm

FIGURE 2

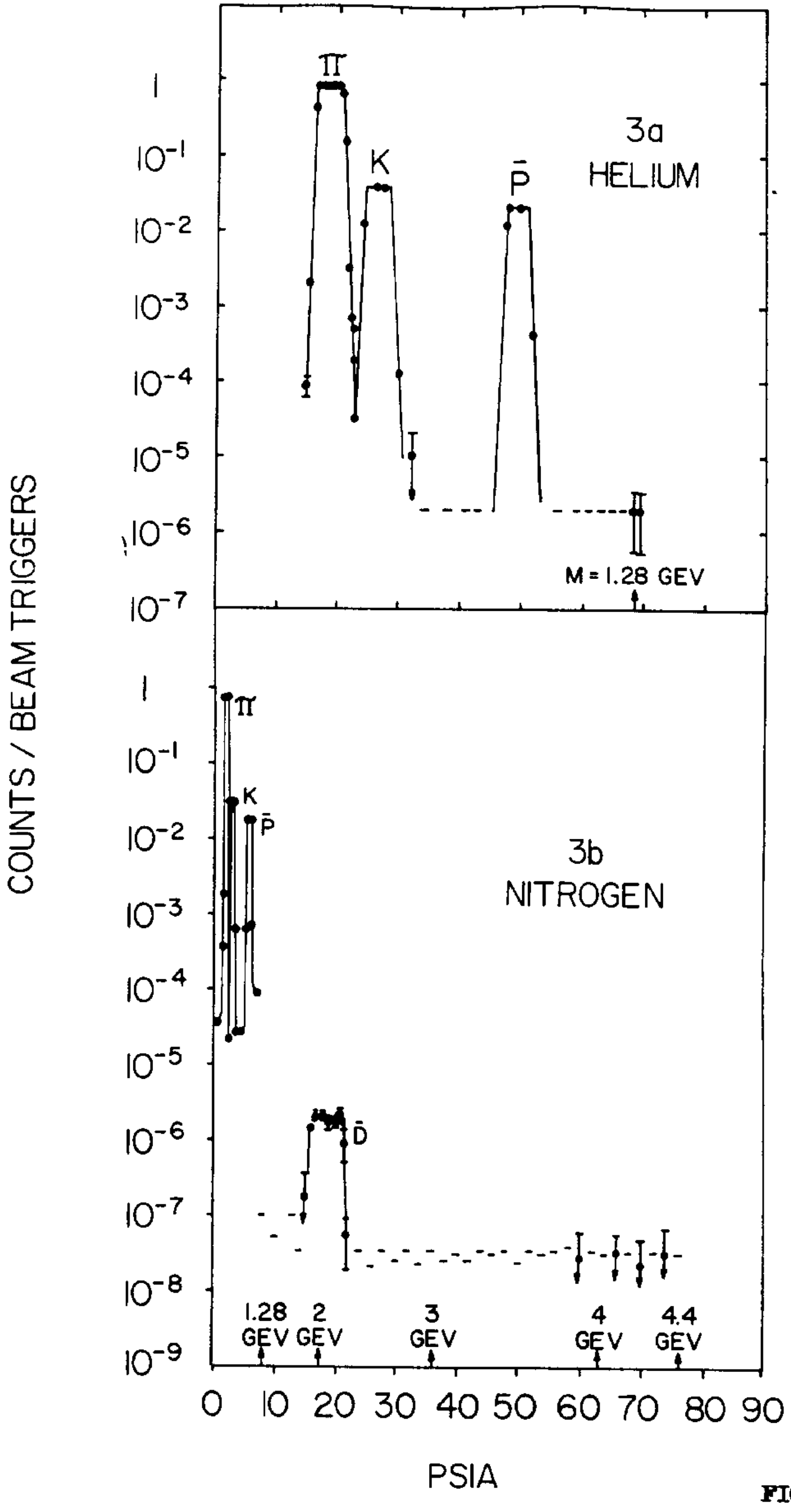
COUNTS / BEAM TRIGGERS
3a
HELIUM
π
K
P̄
M = 1.28 GEV
1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
3b
NITROGEN
π
K
P̄
D̄
1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-9}
1.28 GEV
2 GEV
3 GEV
4 GEV
4.4 GEV
0
10
20
30
40
50
60
70
80
90
PSIA

FIGURE 3