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A SURVEY FOR EXOTIC PARTICLES IN THE M1 BEAM

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1. Introduction

We request an extension of running time in order to achieve two goals: (i) To complete our beam survey by measuring the production of $\bar{d}$, $\bar{t}$, $\overline{He^3}$ and make a search for the as yet unobserved $\overline{He^4}$ and for quasi-stable leptons. (ii) Test of the ultimate capabilities of the two Brookhaven differential Cerenkov counters for rejection ratio and velocity separation. For these purposes we shall use our equipment in the M1 beam line, without modifications.

Very little time was spent until now to test the performance of the gas Cerenkov counters. Some tests of the selectivity will be performed when we make measurements of total cross sections at 220 and 250 GeV. Rejection ratios test will be better performed in conjunction with the study of the production of rare particles. Tests of the ultimate capabilities of these Cerenkov counters are needed for our future total cross section measurements at 400 GeV proton energy.

We have already perfomed, in the M1 beam, a particle survey for the production of $\pi^{\pm}$, $K^{\pm}$, p and $\bar{p}$ in p-Be collisions at 200 and 300 GeV/c[1]. The proposed measurements will extend the survey to more exotic types of particles. Three types of measurements will be made: (i) production of heavy particles with charge -1 ($\bar{d}$,$\bar{t}$, and search for unobserved ones); (ii) production of heavy particles with charge -2 ($\overline{He^3}$, and search for $\overline{He^4}$); (iii) search for heavy, muon-like particles. The as yet unobserved particles will be detected if their production rate is larger than 10^{-10} times the pion rate.

Heavy muons are required in certain gauge theories of weak interactions; they also have been proposed simply as higher states

of the electron and muon. The study of the production of antinuclei will offer a test of heavy particle production models[2].

It has been proven at Serpukhov, Fermilab and at the ISR that the efficient production of antinuclei requires that the bombarding proton energy be considerably greater than the threshold value. This is exemplified by the following increase in $\bar{d}$ production: $\bar{d}/\pi^- \simeq 10^{-7}$ at CERN[3] and BNL[4], $\sim 10^{-6}$ at Serpukhov[5], 10^{-5} at Fermilab[6-8] and $\sim 5\times 10^{-4}$ at the top ISR energy[9].

The experiment requires large beam fluxes, long beam spill and high rejection ratios against normal particles. The high intensities provided by the M1 beam, and the large amount of equipment of E104 provide unique possibilities for these searches. The equipment consists of 20 scintillation counters, 3 differential gas Cerenkov counters, 1 lead glass total absorption (plus a thin one) Cerenkov counter, iron shielding for muon detection and 3 sets of proportional wire chambers.

We propose to perform these measurements at the end of the present phase of the total cross section measurement. This will ensure the most efficient use of time since all the equipment is presently working and properly tested.

2. Detection of Charge 1 Particles with Heavy Mass

Fig. 1 is a compilation of antiparticle production at Serpukhov, Fermilab and the ISR. The Serpukhov results indicate that the production cross section for $\bar{p}$, $\bar{d}$, $\bar{t}$ and $\overline{He^3}$ are approximately exponential functions of the mass[5,10,11]. The slopes of the exponential curves become considerably smaller when one goes to higher energies. The graph suggests that at p_o=300 GeV one should have $\bar{t}/\pi^- \simeq \overline{He^3}/\pi^- \simeq 10^{-8}$ and $\overline{He^4}/\pi^- \sim 10^{-12}$-$10^{-10}$.

Fig. 2 shows particle ratios and absolute cross sections for the production of π^-, K^-, $\bar{p}$ and $\bar{d}$ at Serpukhov energies plotted versus the secondary beam momentum. These graphs and the graphs of Fig. 3, which shows the result of a phase space calculation for the production of $\bar{d}$ and $\overline{He^3}$, suggest that the optimum condition for the forward production of heavy particles is at a secondary momentum $p \simeq p_o/4 \sim 300/4 \sim 70\text{-}80$ GeV/c.

It is proposed to measure $\bar{d}$ production at three momenta, 60, 80 and 100 GeV/c and search for $\bar{t}$ and heavier nuclei at 80 GeV/c. We have already measured the $\bar{d}$ production at 120 GeV/c (see Fig. 4).

The $\bar{t}$ and higher masses search will be made with the following conditions:

(1) $p_o = 300$ GeV/c, $p = 80$ GeV/c, $\theta_{lab} = 3.5$ mr, $p_t = 0.28$ GeV/c, $x = 0.27$, 10^6 particles/burst (this corresponds to about 10^{10} particles per day).

(2) 6 scintillation counters in coincidence, set to detect minimum ionizing particles.

(3) 2 gas Cerenkov counters in anticoincidence (1 set on pions, and 1 on antiprotons).

(4) 1 differential Cerenkov counter will be used in coincidence for antideuterons, and antitritium in anticoincidence for the heavier particle search.

(5) Time of flight over a 200 meter flight path for events satisfying the previous three requirements. The equipment may be calibrated first with a positive beam.

The purpose of this measurement is to detect antideuterons at 3 momenta in order to better establish the energy dependence for their production cross section, to detect $\bar{t}$ and search for particles

of heavier mass, with a total sensitivity of 1 part in 10^{10} pions, corresponding to one day of running. The program outlined in this section requires approximately two days of running.

3. Detection of Antihelium Nuclei

The $\overline{He^3}$ measurement at Serpukhov was done under the following conditions:[10]

$p_o = 70$ GeV/c

$p_{beam,\ nominal} = 20$ GeV/c ($p_{beam}/e = 10$ GeV/c), $\frac{\Delta p}{p} \simeq \pm 2\%$

$\theta_{lab} = 27$ mr , $p_t = 0.54$, $x \simeq 0.29$,

beam flux $\simeq 3\times10^6$ particles/burst

$\overline{He^3}(20\ GeV)/\pi^-(20\ GeV) \simeq 1.3\times10^{-10}$ $\overline{He^3}(20\ GeV)/\pi^-(10\ GeV) = 2\times10^{-11}$

These values correspond to the following conditions at Fermilab:

$p_o = 300$ GeV/c

$p(\overline{He}) = 80$ GeV/c ($p_{beam}/e = 40$ GeV/c),

$\theta_{lab} = 3.5$ mr , $p_t = 0.28$, $x = 0.27$ ($p_{t\pi} = 0.14$, $x_\pi = 0.13$)

beam flux: 3×10^6 particles/burst, $\frac{\Delta p}{p} \gtrsim \pm 1\%$.

If we assume that we can handle 3×10^6 particles per burst we can have $\sim3\times10^{10}$ incoming particles per day. If at 300 GeV/c $\overline{He^3}/\pi^- \simeq 10^{-8}$ and $\overline{He^4}/\pi^- \sim 3\times10^{11}$, then we shall collect 300 $\overline{He^3}$ and 1 $\overline{He^4}$ events per day.

In order to perform such measurement we propose to use:

1. 15 scintillation counters with discriminator thresholds set about 10 db above minimum ionizing particles. In this way each counter could give about a factor of 10 rejection against minimum ionizing particles, while retaining full efficiency for particles which ionize four times the minimum value. However these rejections will not be all independent

and the total rejection will probably be at most $RF1 \simeq 10^{10}$.

2. Two gas Cerenkov counters used as threshold counters in anti-coincidence. Besides giving a further rejection against minimum ionizing particles, the main purpose of these counters is to reject accidentals, that is those cases where more than one particle comes within the resolving time of the electronics. Each Cerenkov counters should provide a rejection of almost 10^2 for a single particle and probably of 10^3 when 3-4 particles go through at once. ($RF2 \simeq 10^4 - 10^6$). The combination of requirements 1. and 2. should give a rejection ratio of at least 10^{12}. In addition to conditions 1. and 2. we shall have the extra requirements below:

3. One differential counter in coincidence, set first at the $\overline{He^3}$ pressure, then at the $\overline{He^4}$. The anti-ring of this counter will further reject lower mass particles. This requirement should yield a certain identification of either $\overline{He^3}$ and $\overline{He^4}$.

4. Time of flight measurement triggered by requirements 1. and 2. (and eventually by the anti-ring of point 3.). The time of flight does not really allow separation between $\overline{He^3}$ and $\overline{He^4}$, but should give redundancy in the particle identification as well as an exploration over a wider mass region for larger masses.

We may want to calibrate the whole system with a positive beam, observe a number of helium nuclei and then go to a negative beam.

From what is stated above it would seem that we have enough rejection ratio against non-helium particles and that the major problem is connected with having a very high intensity and thus with pile up effects in the counters. We thus require the longest spill possible.

It is estimated that this search will require about two days of stable running conditions.

4. Search for Heavy Quasi-Stable Muon

A search will be made for a heavy quasi-stable muon with a mass greater than the proton mass, a lifetime longer than 10^{-9} sec and a behaviour in matter like the μ-meson.

If heavy leptons participate in universal weak interactions, their lifetimes will be of the order of $\tau_\lambda \simeq 10^{-11}(m_p/m_\lambda)^5$ sec. The heavy lepton we are searching for would have a very long lifetime, which would violate this rule. On the other hand one could easily think of selection rules which would result in such long lifetimes[12].

For this search we plan to close the first beam collimator and open up all the apertures in the beam. If the first collimator would be open one would get beams with intensities of the order of 10^7-10^8 particles per burst. With the collimator closed the intensity will be between 10^4 and 10^5 particles per burst, most of which are muons. The following table gives the main parameters for this search:

p_o = 300 GeV/c

p = 80 GeV/c

θ = 3.5 mrad $\qquad p_\perp \simeq p\theta = 0.28$ GeV/c

$\Delta p/p \simeq \pm 4\%$

beam flux per burst $\simeq 10^7$ corresponding to about 10^{11} particles per day

beam flux with collimator closed $\sim 10^4$-10^5

mass limit 1-10 GeV.

The identification of the heavy lepton will be done with the following requirements:

1) Ability to pass through the first collimator (rejection factor of $RF1 \simeq 10^2$-10^3).

2) Counted in 5 scintillation counters (RF2=1) ($B_1B_2B_3\tau_6\tau_7$).

3) No counts in three gas Cerenkov counters, used as threshold counters, some set at the pion, some at the antiproton mass (RF3≃10^6).

4) A small pulse from the lead glass Cerenkov counter (RF4≃10).

5) Counts in two counters after the μ-shield (RF5≃10^2).

6) Time of flight if needed.

In one day of running, one will have 10^{11} effective particles incoming. The rejection ratio RF(1-6) will range between 10^{11}-10^{13} and will thus be adequate for measurement of up to a ratio

$$\frac{\text{heavy lepton}}{\text{muon}} = \lambda/\pi \lesssim 10^{-11}.$$

Two days of running will be needed for this search. This search has to be compared to the one performed at IHEP-Serpukhov[13] (p_o=70, p=25, (30), θ_{lab} = 2 mr, $p_\perp$=0.06, x=0.43, $1<m_\lambda<4.8$ GeV $\sigma_\lambda < \frac{1}{4\times10^{12}}\sigma_\pi$) and to the one performed at Fermilab[14] (p_o=300, $p_\perp$=2.38, θ_{cm}~94°=166°, $1<m_\lambda<6.8$ GeV, $\sigma_\lambda<10^{-9}\sigma_\pi$).

5. Conclusion

The program outlined in this note makes full use of the existing equipment and of the capabilities of the M1 beam; it may be carried out in one-two weeks of stable running conditions with 300 GeV primary protons. An additional week at 400 GeV is also requested provided that the beam spill characteristics prove to be adequate.

References

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(12) W. Alles, Private communication. Nuovo Cim. Lett. 10, 441 (74).

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(14) J.W. Cronin et al (Search for Massive Penetrating Particles produced by 300 GeV protons) (E100) 1974 London Conf.

Figure Captions

Fig. 1 Compilation of cross sections for the production of $\bar{p}$, $\bar{d}$, $\bar{t}$ and $\overline{He^3}$ versus mass.

Fig. 2 Particle ratios and absolute cross sections versus secondary momentum for p_o=70 GeV/c.

Fig. 3 Momentum spectra of d and $\overline{He^3}$ at p_o=70 GeV/c (phase space calculations).

Fig. 4 Pressure curve at 120 GeV/c.

ESTIMATES OF $\bar{d}$, $\bar{t}$, etc PRODUCTION

MODEL

DATE 8/27/74

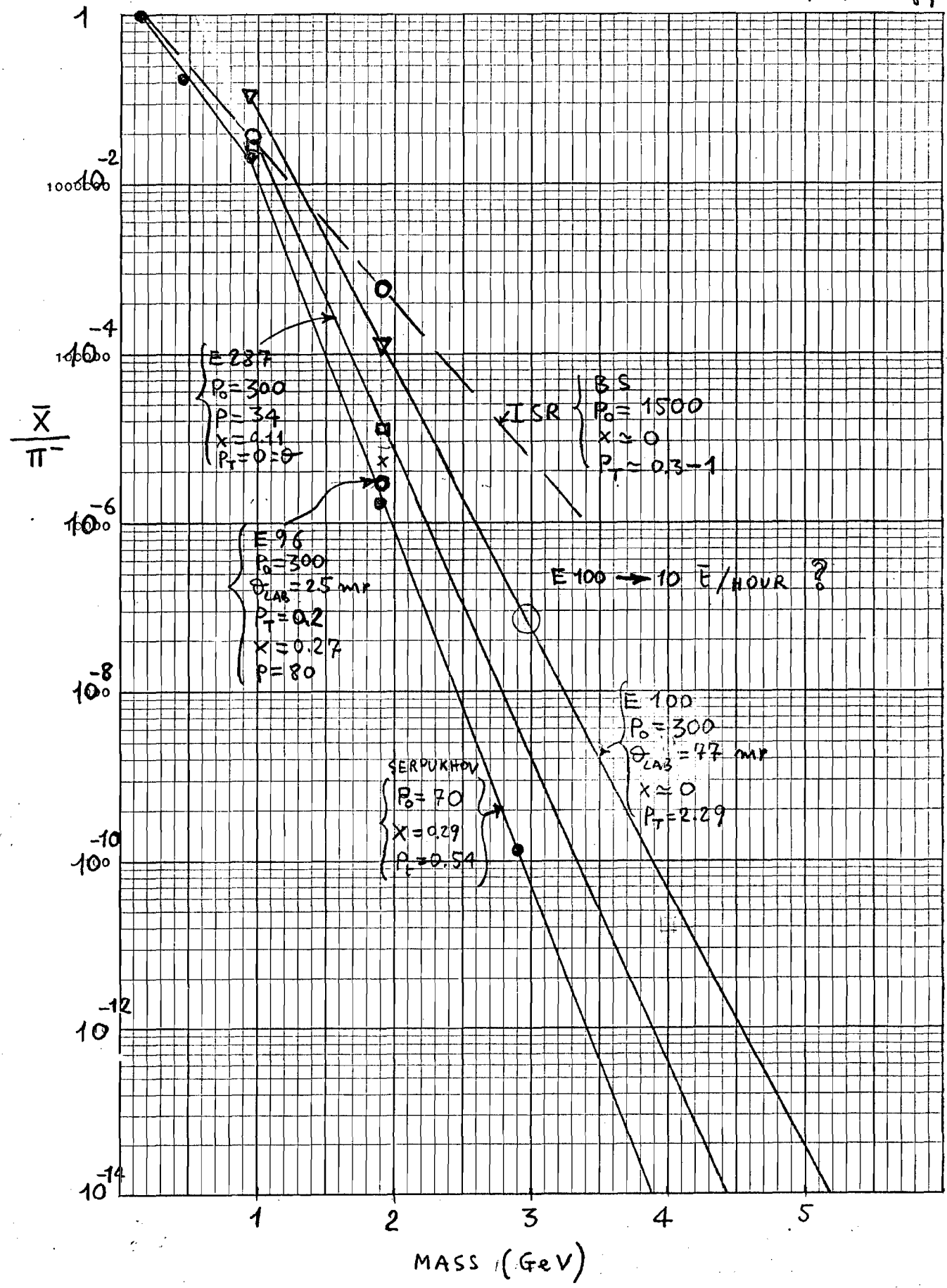

FIG. 1.

K+E SEMI-LOGARITHMIC 46 6460
7 CYCLES X 60 DIVISIONS MADE IN U.S.A.
KEUFFEL & ESSER CO.

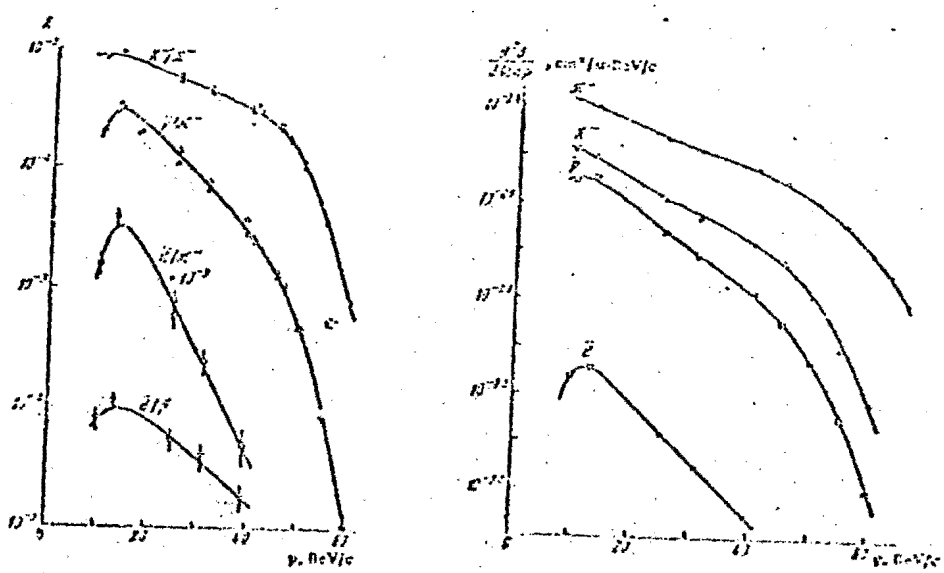

FIG. 2

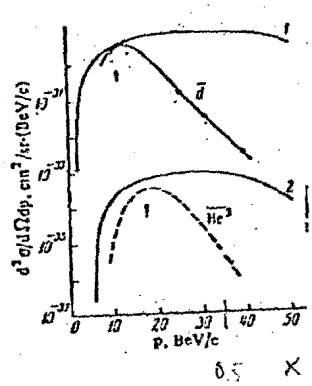

FIG. 1. Momentum spectra of antideuterons (experimental results) and He^3 nuclei (theory) produced by 70-BeV protons at an angle $\theta = 0$ in Al nuclei. The spectrum for $\overline{He^3}$ nuclei (dashed curve) was calculated with the "sticking" model:

$$\frac{d^2\sigma_{\overline{He^3}}}{d\Omega dp}(p) = \left[\frac{d^2\sigma_{\bar{d}}}{d\Omega dp}\left(\tfrac{2}{3}p\right)\right]^2 \Big/ \frac{d^2\sigma_{\bar{p}}}{d\Omega dp}\left(\tfrac{1}{3}p\right).$$

Curves 1 and 2 are spectra calculated on the basis of phase space for the reactions $pN \to pN\bar{d}d$ and $pN \to pN\overline{He^3}He^3$ (in relative units). The arrows indicate values of $p = \gamma_c\beta_c M$.

FIG. 3

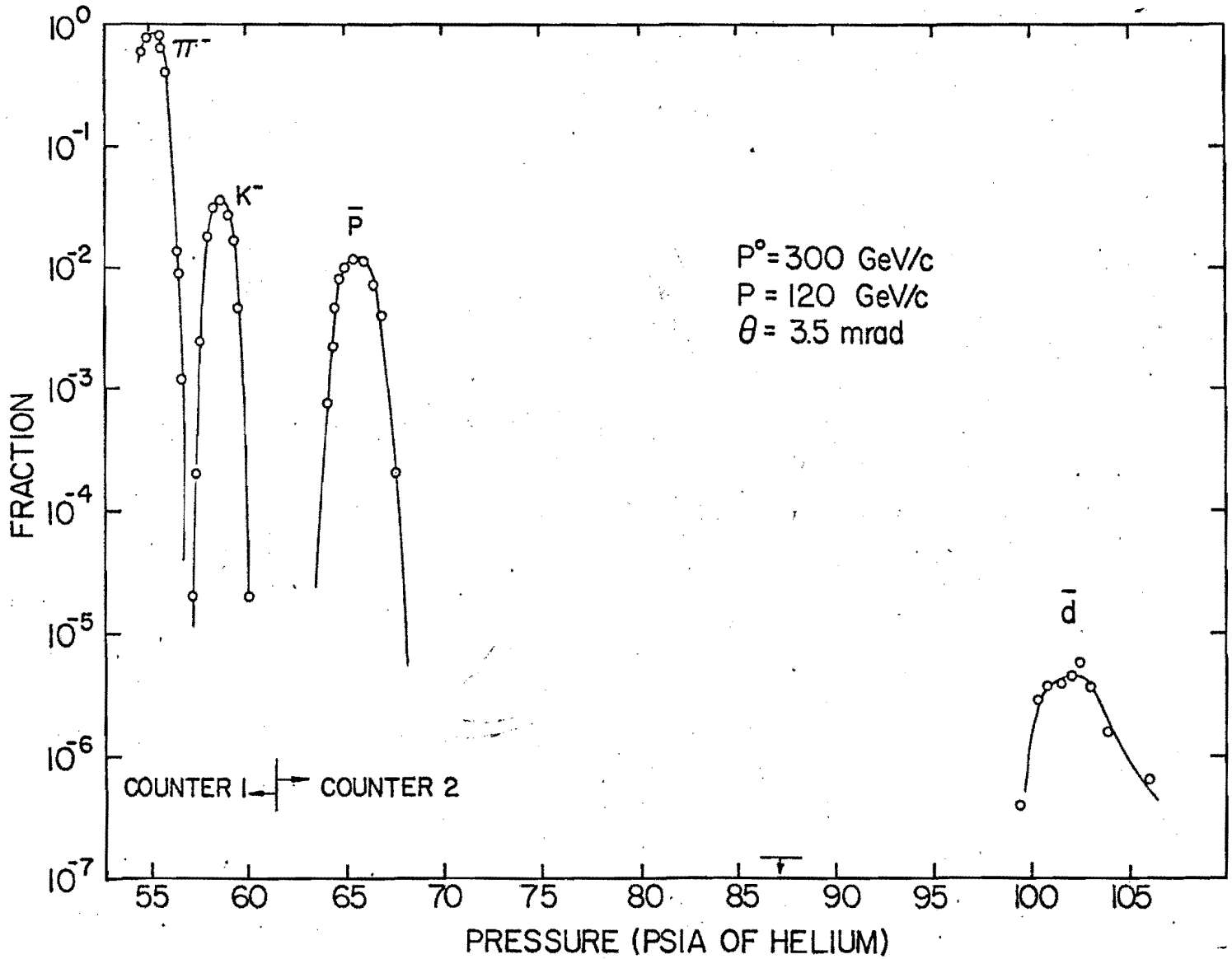
FRACTION
PRESSURE (PSIA OF HELIUM)
π^-
K^-
$\bar{p}$
$\bar{d}$
P^o = 300 GeV/c
P = 120 GeV/c
θ = 3.5 mrad
COUNTER 1
COUNTER 2

FIG. 4