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C. Richman, M. Skinner , J. Merritt, B. Youtz

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Berkeley, California

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PRODUCTION OF A π^+ MESON BEAM USING THE DEFLECTED PROTON BEAM OF THE 184-INCH SYNCHRO-CYCLOTRON

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August 30, 1950

ABSTRACT

The production of a meson beam using the deflected 340 Mev proton beam from the Berkeley 184-inch synchro-cyclotron is described. By making use of the large peak in the forward angle meson production cross section for protons on protons, an intense, fairly clean and monochromatic beam has been produced. With a CH_2 target 5 cm thick and magnetic separation of mesons and protons, a fairly well collimated beam of about 5000 mesons per second, issuing from a channel whose exit area is 2 inches by 2.5 inches has been obtained. The peak of the energy spectrum of the meson beam occurs at 53.5 Mev and the half-width of the peak is 5 Mev.

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*Atomic Energy Commission Post-Doctoral Research Fellow.

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The detailed measurement of the scattering and absorption cross sections of mesons on various elements should be of considerable help in understanding the nature of the interaction of mesons with nuclei. A great deal of work on these cross sections has already been done[1] using the charged π-mesons produced in penetrating showers. It would be very desirable, however, if such experiments could be done with an intense, monochromatic meson beam under the controlled conditions which would be available if the meson beam were produced by one of the present-day high-energy accelerators. This paper is concerned with some progress that has been made toward producing such a meson beam with the Berkeley 184-inch synchro-cyclotron.

The 340 Mev protons produced by the synchro-cyclotron are very suitable for meson production. Studies have been made on the cross sections for production of π^+- and π^- -mesons from carbon[2] and lead[3], and of π^+-mesons from hydrogen[4].

On examining this data one is immediately impressed by the large peak around 70 Mev in the differential production cross section for π^+-mesons at 0° by protons on protons. Fig. 1 shows some more recent data[5] on this cross section. The peak arises from the interaction of the heavy nucleons that come off from the collision[6]. Actually, two reaction are possible:

$$P + P \rightarrow P + N + \pi^+$$

and $$P + P \rightarrow D + \pi^+ .$$

If we take the mass of the π^+-meson to be 276 m_e, the first reaction gives a continuous meson energy spectrum with a maximum laboratory meson energy of 65.4 Mev for 340 Mev protons. The second reaction would lead to a line spectrum at 69.4 Mev. At the maximum meson energies the nucleons come off with low energies and about the same momenta in the center of mass system. Under these conditions they can interact strongly, giving rise to the peak in the spectrum. Because of the limited resolution of the apparatus[5] the existence of two separated peaks has not so far been verified.

The use of hydrogen for the production of a meson beam has many advantages. The most important of these in the interests of an intense, fairly monochromatic beam is that there are more mesons in an 8 or 10 Mev interval from hydrogen than from anything else that has been studied. Furthermore, use of a production target which is rich in hydrogen means that mesons are obtained with a minimum stopping of the primary proton beam in the target. A fairly thick target can therefore be used without working too far down on the excitation curve and decreasing the meson production per molecule. It may be noted further that, since the mesons in the hydrogen peak have an energy of 70 Mev, it is possible to build up the meson production using a thick target and still produce a meson beam with sufficiently high energy to be useful in scattering experiments.

A convenient target, rich in hydrogen and easy to handle, is polyethylene $(CH_2)_n$. The thickness of the target is determined by a compromise between the two competing requirements that a large number of mesons be produced and that their energy be approximately monochromatic and high enough for the desired use. Because of the hydrogen, the production from CH_2 for a thin target is strongly peaked at about 69 Mev (see Fig. 2). A 5 cm CH_2 target reduces the peak energy only to 53.5 Mev, and still, as we shall see, furnishes a considerable beam of mesons. There is one other advantage to using a hydrogen-rich target. One might expect that for a thick target the intense peak would be considerably broadened, and therefore lowered, because the mesons which are created in different parts of the target lose different amounts of energy before they leave the target. There is, however, a compensating effect since the peak energy of the mesons produced decreases as the proton beam energy is degraded going through the target. Fortunately, for a hydrogen rich target and 340 Mev protons this compensation is very nearly exact for the mesons in the peak of the spectrum. With a 5 cm CH_2 target, a 69 Mev meson created at the front of the target by a 340 Mev proton loses 15 Mev in the target and emerges with 54 Mev, whereas at the back of the target the protons have an energy of 323 Mev, having lost 17 Mev, and produce mesons with a peak energy of 54 Mev.

The scattering experiments envisioned for the meson beam require the use of the deflected proton beam of the 184-inch cyclotron. This beam has at present, a maximum intensity of about 6×10^{-10} amps, spread over a circular area of diameter 2 inches.

Since the mesons come off predominantly in the forward direction when the proton beam strikes a CH_2 target, it is necessary to bend them away from the proton beam using a channel placed inside a magnet. The attendant loss in solid angle is not so serious as one might think since this channel serves the additional purpose of a beam collimator which would be necessary with any arrangement.

A high magnetic field is desirable for the efficient separation of the mesons from the protons. Such separation was achieved with a field of 14,300 gauss giving a 54 Mev mesom a radius of curvature of 12.4 inches and a 340 Mev proton a radius of curvature of 80 inches.

The design of the channel was also determined by a compromise between conflicting requirements, to allow as many mesons to traverse the channel as possible while, however, giving a well-collimated meson beam uncontaminated by protons scattered from the CH_2 target or the magnet pole pieces.

The channel, whose walls were made of brass, was designed to accept all meson energies between 48 and 60 Mev: that is, mesons in this energy region from every point of the target have an unobstructed path to every point of the exit area of the channel. The channel was built so that a 54 Mev meson produced at 0° in the center of the target is turned through 85° by the magnetic field before emerging from the center of the channel. The exit area of the channel is 2 inches wide by 2.5 inches high. This means that the end of the channel subtends a solid angle of about 2.2×10^{-2} steradians at the CH_2 target.

The set-up is shown in Fig. 3. (The magnet was designed for a pair-spectrometer apparatus, which required the unusual pole face shape.) The position of the CH_2 target and the channel on the pole face were chosen so that both the proton and meson beams miss the yoke of the magnet. The magnet gap was 3.4 inches.

With this channel arrangment the meson beam collimation was such that $\theta_1 \cong \theta_2 \cong 9^\circ$ (see Fig. 3).

The mesons were detected by means of nuclear emulsions placed in aluminum absorbers in the usual way.[2] Both Ilford C_2 and Eastman Kodak NTB plates were used. The emulsion thicknesses were about 200μ. The exposures were made for about 10 minutes right at the end of the channel. A calibrated ionization chamber placed in front of the magnet in the proton beam was used to measure the current of protons through the target, and a suitable integrator then gave the total charge that had gone through the target. The scanning of the plates was very easy because of the high concentration of mesons with very little background.

Curve II of Fig. 4 shows the number of mesons per Mev per steradian leaving the 5 cm CH_2 target in the forward direction per incident proton. In order to obtain this curve, the meson density in the emulsions was corrected for the loss of a fraction of the mesons between the target and the emulsion due to a) decay in flight and b) nuclear scattering and absorption in the aluminum absorber holding the emulsions. The decay in flight correction is easily made and amounts to about 9 percent. To make the second correction we have used for the total nuclear cross section the geometrical area of the aluminum nucleus, with a nuclear radius of $1.5 \times 10^{-13}A^{1/3}$. With this cross section, one finds that 16 percent of the mesons are lost in the aluminum. Since the true correction is not known, although there is good reason to believe that the above is approximately right[1], Fig. 4 also shows the data before this correction was made. The errors indicated are statistical probable errors.

The peak of the spectrum occurs at 53.5 Mev, and the half-width of the peak is 5 Mev. Comparison of Fig. 4 with Fig. 2 shows that a thick target apparently does not spread the peak. The compensation of meson energy loss in the target by proton energy loss, as mentioned above, is clearly effective. Actually, even with exact compensation, one would expect some spread in the peak since those mesons made in a thin slice at the front of the target in a small energy interval traverse the target and leave it with a lower energy but in a larger energy interval. The fact that this spread is not observed leads one to believe that the peak of the thin target spectrum in Fig. 2 is thicker than that of the true production spectrum. This could easily be the case since the target used in that experiment was only 3/22 in. thick which made a long proton bombardment necessary. It is very likely that the proton beam energy changed somewhat during the long bombardment, thereby smearing out the peak.

Integrating curve I on Fig. 4 over the 12 Mev meson energy interval from 48 to 60 Mev one obtains 7.5×10^{-5} mesons leaving the target in the forward direction per steradian per incident proton. If one integrates the thin target spectrum of Fig. 2 (which has been similarly corrected for decay in flight and absorption) over the 12 Mev interval from 62 Mev to 74 Mev and multiplies this by the number of CH_2 molecules per cm^2 in the thick target one obtains 8.90×10^{-5} mesons per steradian per proton. The agreement between these figures shows clearly that in going from a thin to a thick target not many mesons are lost from the peak either due to absorption of protons and mesons in the CH_2 or to the effect of working down on the excitation curve. (One is tempted to try, by detailed comparison of the thin and thick target spectra, to draw further conclusions about the excitation function for protons with energy between 340 and 323 Mev. Such a detailed analysis is not warranted, however, for several reasons: 1) There are indications, mentioned above, that the true thin target spectrum is somewhat different from that given in Fig. 2. 2) One does not known how the shape of the meson energy spectrum changes with proton energy. 3) No examination has yet been made of the low energy wing of the thick target spectrum. (A direct measurement of the excitation function is being made by Mr. W. F. Cartwright.)

With a proton beam of 5×10^{-10} amp. there are about 5000 mesons per second with energies between 48 and 60 Mev issuing from the channel, or a meson current of 8×10^{-16} amp.

It is a pleasure to acknowledge the encouragement we have received from Professor R. L. Thornton. We also would like to thank Mr. J. Vale and the cyclotron crew for making the bombardments.

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LMB/9-21-50
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2. C. Richman and H. A. Wilcox, Phys. Rev. 78, 496 (~~1940~~ 1950)

3. M. Weisbluth, Ph. D. Thesis, University of California (1950) (UCRL-568)

4. W. F. Cartwright, C. Richman, M. N. Whitehead, and H. A. Wilcox, Phys. Rev. 78, 823 (1950)
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Figures

Fig. 1 The differential cross section per Mev for the production of mesons in the forward direction by 340 Mev protons on protons.

Fig. 2 The differential cross section per Mev per molecule for the production of mesons in the forward direction by 340 Mev protons on CH_2.

Fig. 3 Arrangement of the apparatus in the magnetic field.

Fig. 4 The number of mesons per Mev per steradian per incident proton leaving the 5 cm CH_2 target in the forward direction. Curve I: data not corrected for the absorption and scattering of mesons in the aluminum absorber. Curve II: corrected data. This curve is based on 706 π^+-mesons.

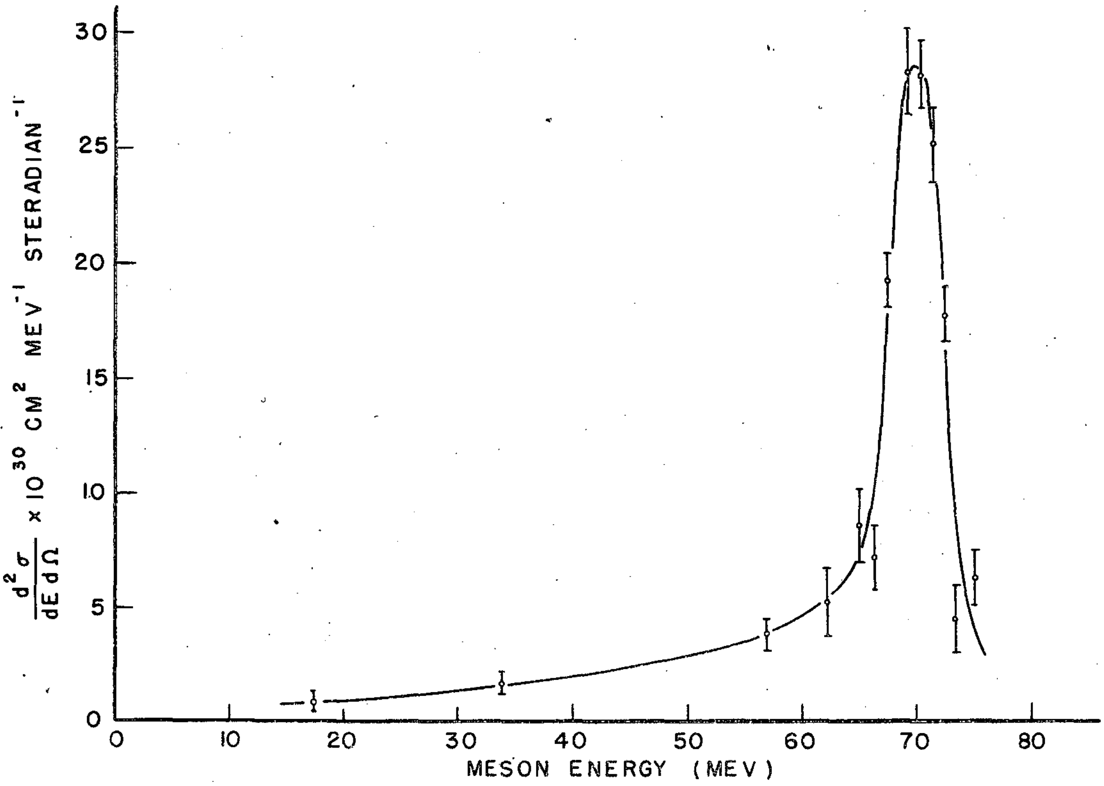
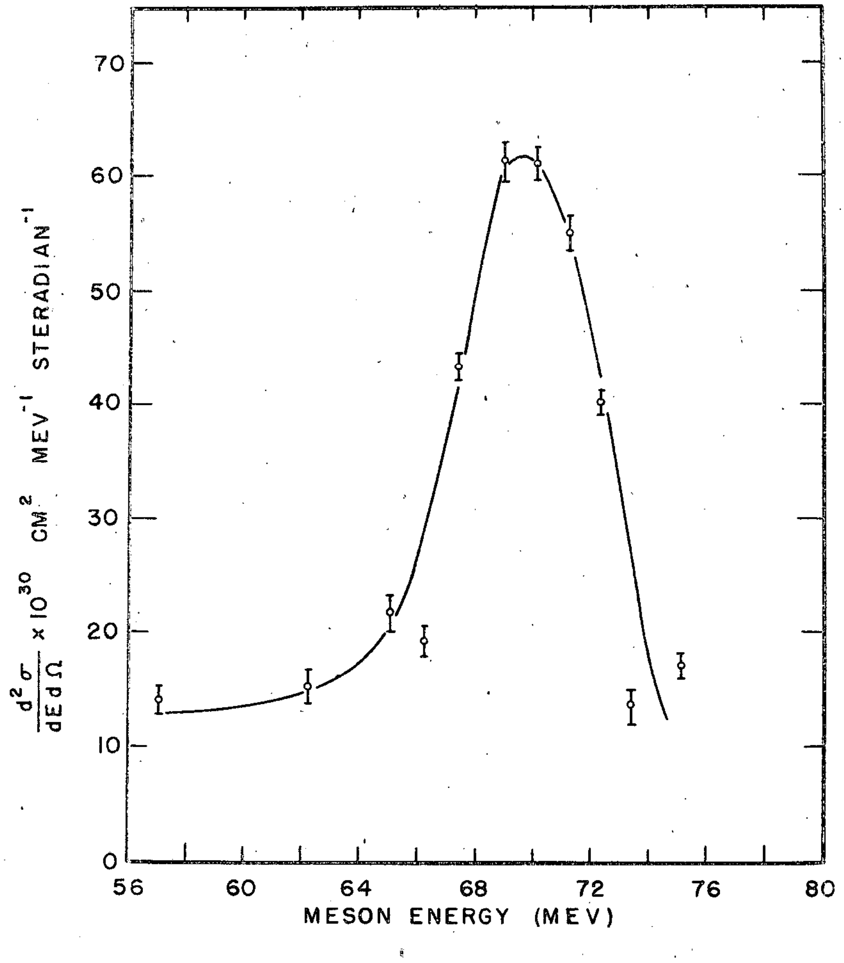

$\frac{d^2\sigma}{dE\,d\Omega} \times 10^{30}$ CM^2 MEV^{-1} STERADIAN^{-1}
30
25
20
15
10
5
0
0
10
20
30
40
50
60
70
80
MESON ENERGY (MEV)

FIG. 1

MU 782



$\frac{d^2\sigma}{dE\,d\Omega} \times 10^{30}$ CM^2 MEV^{-1} STERADIAN^{-1}
70
60
50
40
30
20
10
0
56
60
64
68
72
76
80
MESON ENERGY (MEV)

MU 783

FIG. 2

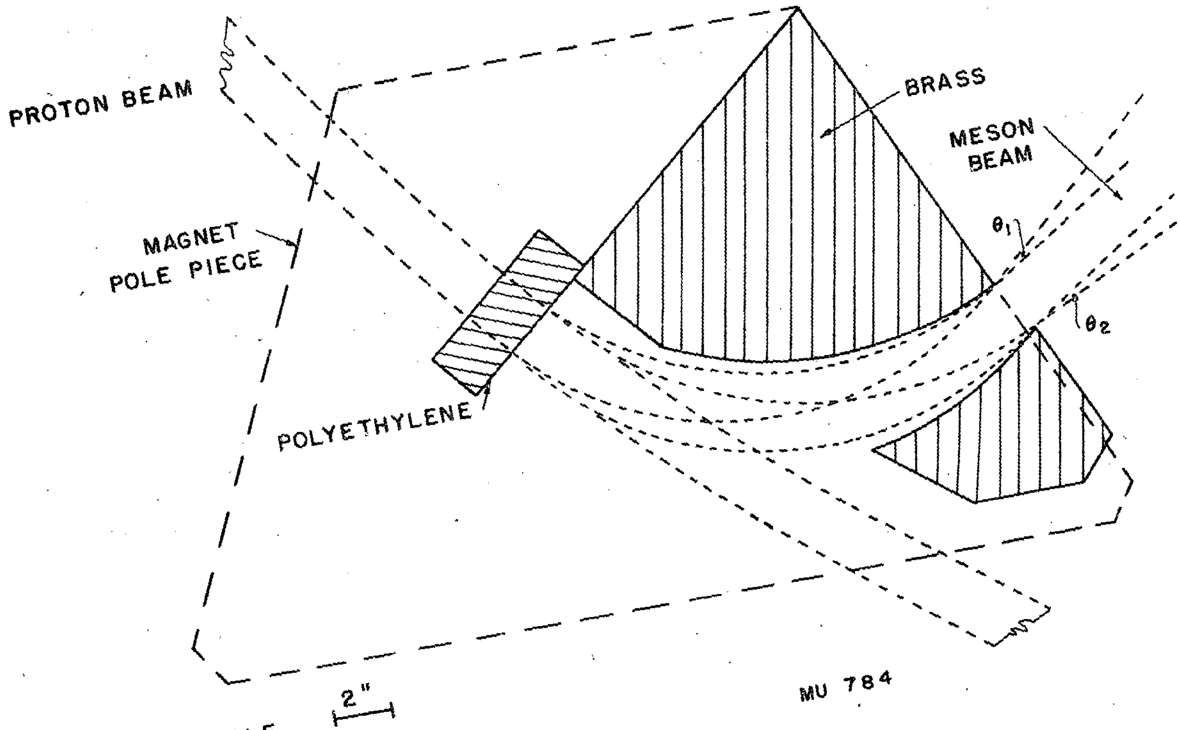
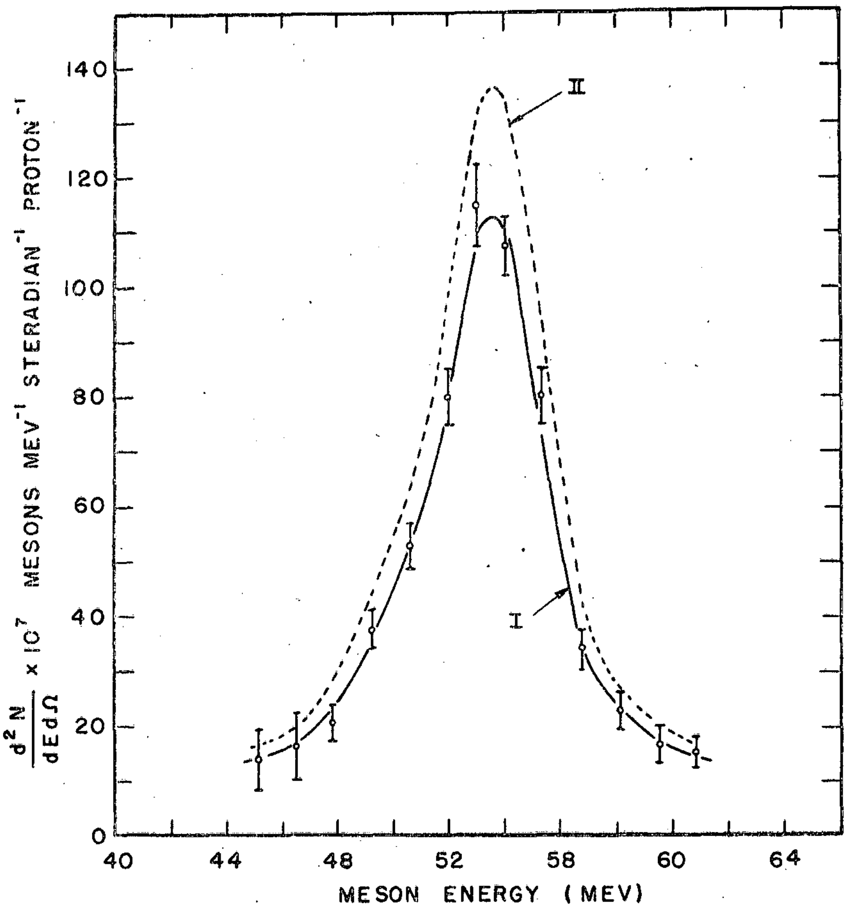

PROTON BEAM
BRASS
MESON BEAM
MAGNET POLE PIECE
θ_1
θ_2
POLYETHYLENE
MU 784
SCALE
2"

FIG. 3



140
120
100
80
60
40
20
0
$\frac{d^2N}{dE\,d\Omega} \times 10^7$ MESONS MEV^{-1} STERADIAN^{-1} PROTON^{-1}
40
44
48
52
58
60
64
MESON ENERGY (MEV)
II
I

FIG. 4

MU 785