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TOTAL AND DIFFERENTIAL CROSS SECTIONS FOR THE REACTION $\pi^- p \rightarrow \eta n$ *

W. Bruce Richards and Charles B. Chiu

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Nearing completion is the analysis of the pictures from an experiment by a collaboration of the Moyer-Helmholz group at the Lawrence Radiation Laboratory, Berkeley and the High Energy Physics group at the University of Hawaii, in which reactions of the type

$$\pi^- p \rightarrow \text{neutral final states}$$

were observed in 4π steel spark chambers. As the results for the reaction

$$\pi^- p \rightarrow \eta n$$

seem to be significantly better than the preliminary data published by another group,[1] this informal report has been written to make them available for study by interested workers. Since the data analysis is still in progress, the results should be regarded as preliminary, although no significant changes are expected.

Shown in Figure 1 is the layout of the experimental apparatus. A beam of negative pions from the Bevatron was focused onto a liquid hydrogen target located in the center of a cube of spark chambers. Monitor counters M_1, M_2, and M_3 in coincidence detected the incoming beam particles, and triggered the spark chambers in the absence of a signal from the anticounters A_1 through A_9. Placed around the target on the downstream side these anticounters were designed to detect and veto events containing charged particles in the final state. The six spark chambers, forming the six faces of a cube containing the hydrogen target and anticounters, each had 35 1/8-in. steel plates separated by 5/16-in. gaps to provide approximately six radiation lengths of conversion material. To enter the cube, the beam passed through a region 4 in. in diameter where the chamber plates were made of thin aluminum instead of steel, to minimize interactions of the beam particles in the chamber. Photons from the eta decay mode

$$\eta \rightarrow \gamma\gamma$$

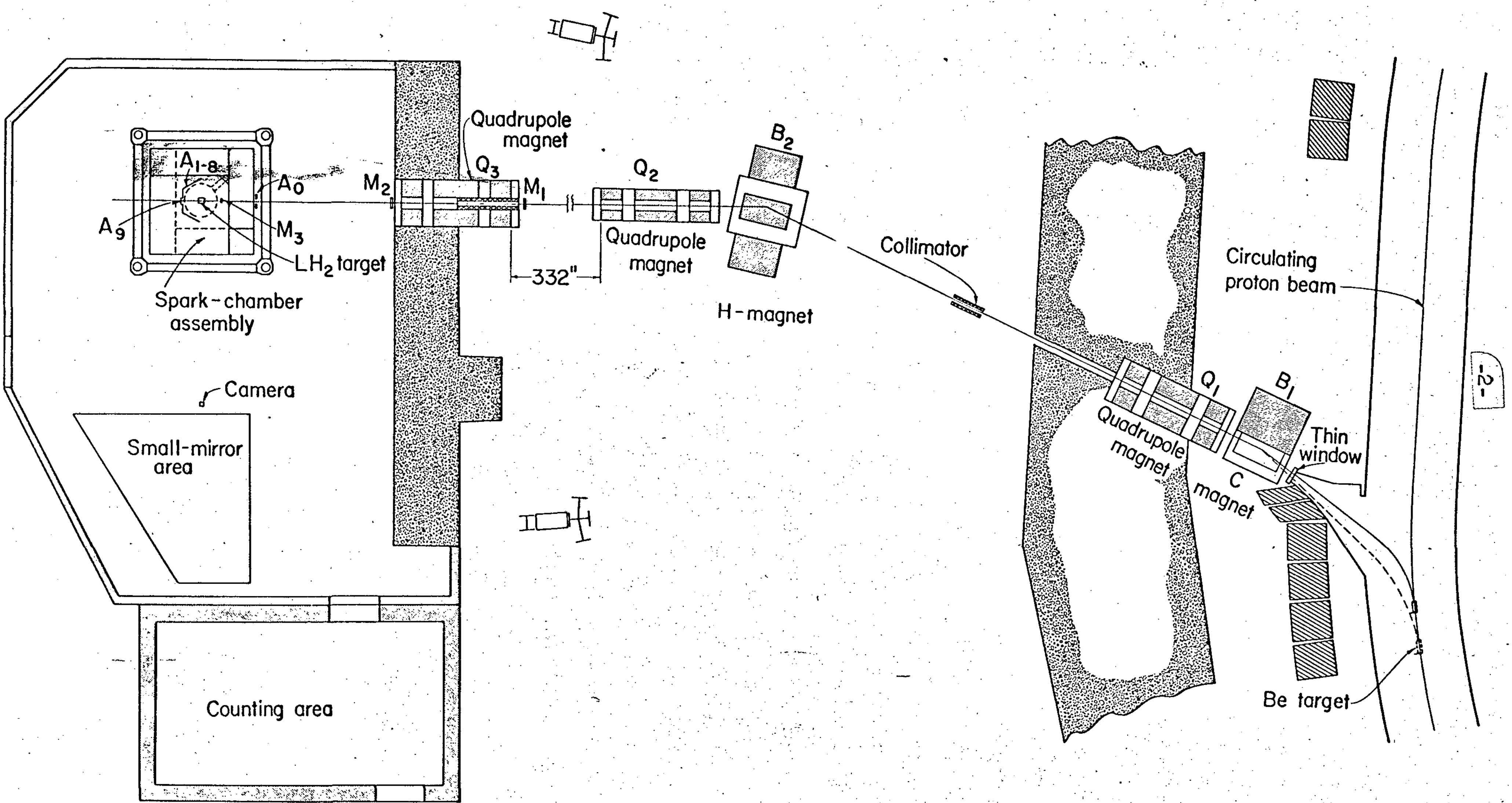


Fig. 1. Plan view of the experimental arrangement.

MUB-7092

as well as from the decay of other final state particles produced showers in the chambers which were photographed in two 90 deg stereo views of each chamber. A typical chamber was approximately $5 \times 5 \times 1.5$ ft., and weighed about 2.5 tons.

The events attributed to the decay of an η are separated from decay of π^0 mesons, the other main source of two-shower events, by consideration of the angle ϕ subtended by the two photons in the $\pi^- p$ center-of-mass system. The distribution in opening angle between the decay γ-rays from a particular type of meson is given by the well-known equation[2]

$$\frac{dn}{d\phi} = \frac{1}{2\gamma\beta} \frac{\cos \phi/2}{\sin^2 \phi/2 \sqrt{\gamma^2 \sin^2 \phi/2 - 1}} \qquad (1)$$

where β is the velocity of the particle in units of the speed of light, and $\gamma = \frac{1}{\sqrt{1 - \beta^2}}$. This distribution has a peak at a minimum angle given by

$$\cos \frac{\phi_{min}}{2} = \beta .$$

Since the η meson has a smaller center-of-mass velocity than the π^0, the peaks of the distribution functions occur at different angles, permitting the η's to be clearly separated from the π^0's.

Shown in Fig. 2 is the experimentally observed $\pi^- p$ center-of-mass opening angle distribution at one energy of the incoming pion. There the peak at 30 deg due to π^0 decay and the peak at 135 deg from η decay are clearly visible.

Since near threshold the position of the maximum of the opening angle distribution from η decay is an extremely sensitive function of the total energy, it was possible to fit the experimental distributions by

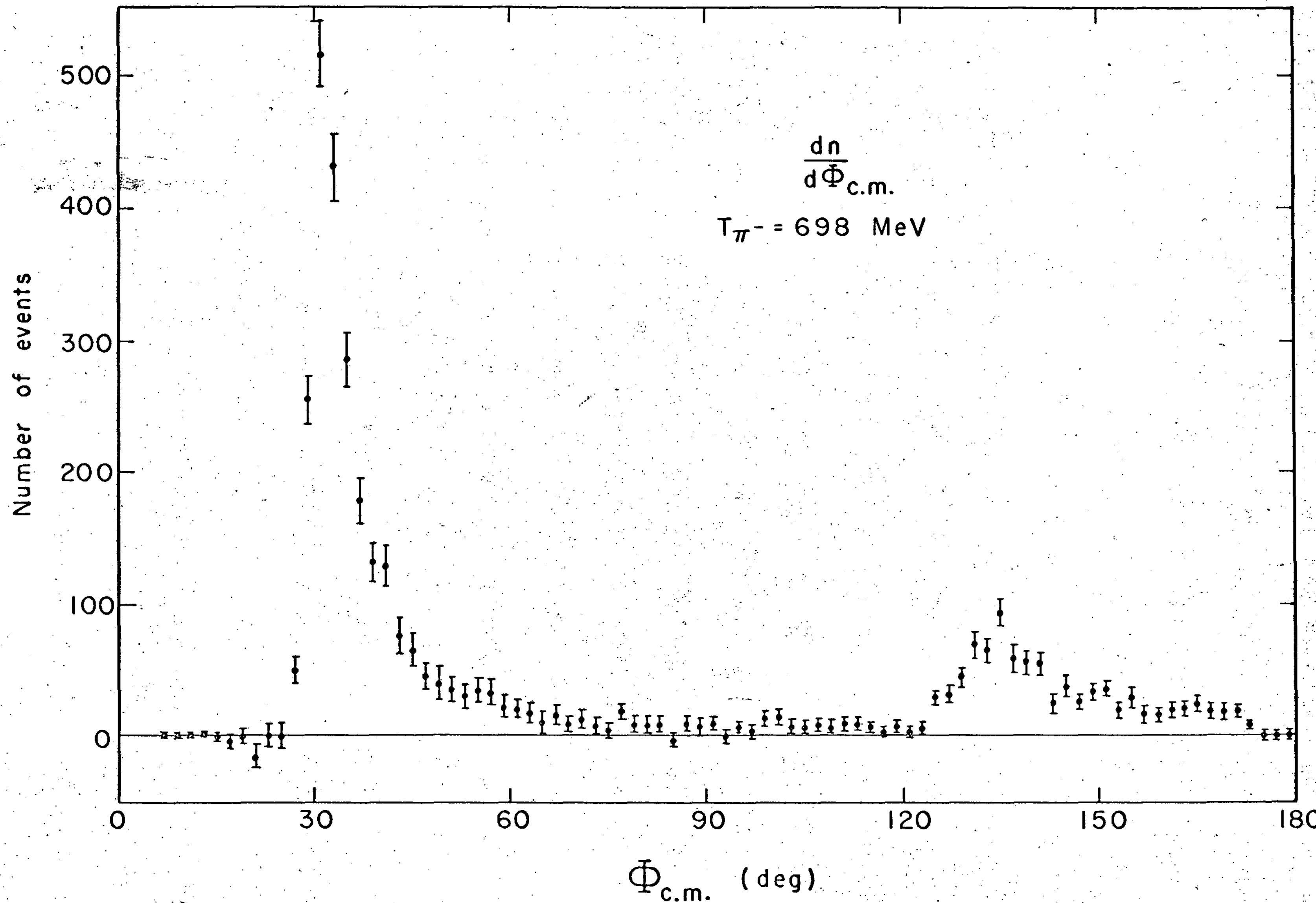


Fig. 2. Opening angle distribution. T_{π^-} was later corrected to 704 MeV by fitting the location of the η peak with theoretical curve.

MUB-7410

theoretical opening angle curves in which the incoming pion kinetic energy was varied as a parameter. Folded into the theoretical curves used were the angular resolution of the detector and the momentum spectrum of the beam. The best χ^2 fit to the data determined the energies of the experiment more accurately than the wire orbit measurements of the beam magnets.

In order to find out what fraction of the η and π^0 decays are observed as 0-, 1-, and 2-shower events, a study was made of the detection efficiency ϵ of the chambers. An exponential form for the energy dependence was assumed, and consideration of the number of events with one shower compared to the number of two-shower events in the π^0 peak permitted determination of E_c in the equation

$$\epsilon = 1 - e^{-\frac{(E_\gamma - 15)}{E_c}} \qquad (2)$$

at each energy of the experiment. E_γ is the photon energy. With a minimum acceptable shower consisting of 3 sparks, E_c was found to be within 7 MeV of 72 MeV at all but one energy, where E_c = 92 MeV.

Knowledge of the detection efficiency allows calculation of the production cross section. The number of events under the π^0 and η peaks are first multiplied by an efficiency factor to correct for the events in which one or both photons were not detected, and then compared. The charge exchange cross section, also measured in this experiment, was multiplied by the η/π^0 ratio to yield the partial cross section $f \cdot \sigma_T(\pi^- p \rightarrow \eta n)$ where f is the branching ratio

$$f = \frac{\Gamma(\eta \rightarrow 2\gamma)}{\Gamma(\eta \rightarrow \text{all decays})} \approx 1/3 \ .$$

In Table I the values for $f \cdot \sigma$ are given, and they are plotted in Figure 3 along with those from Ref 1, for comparison. The agreement is seen to be excellent.

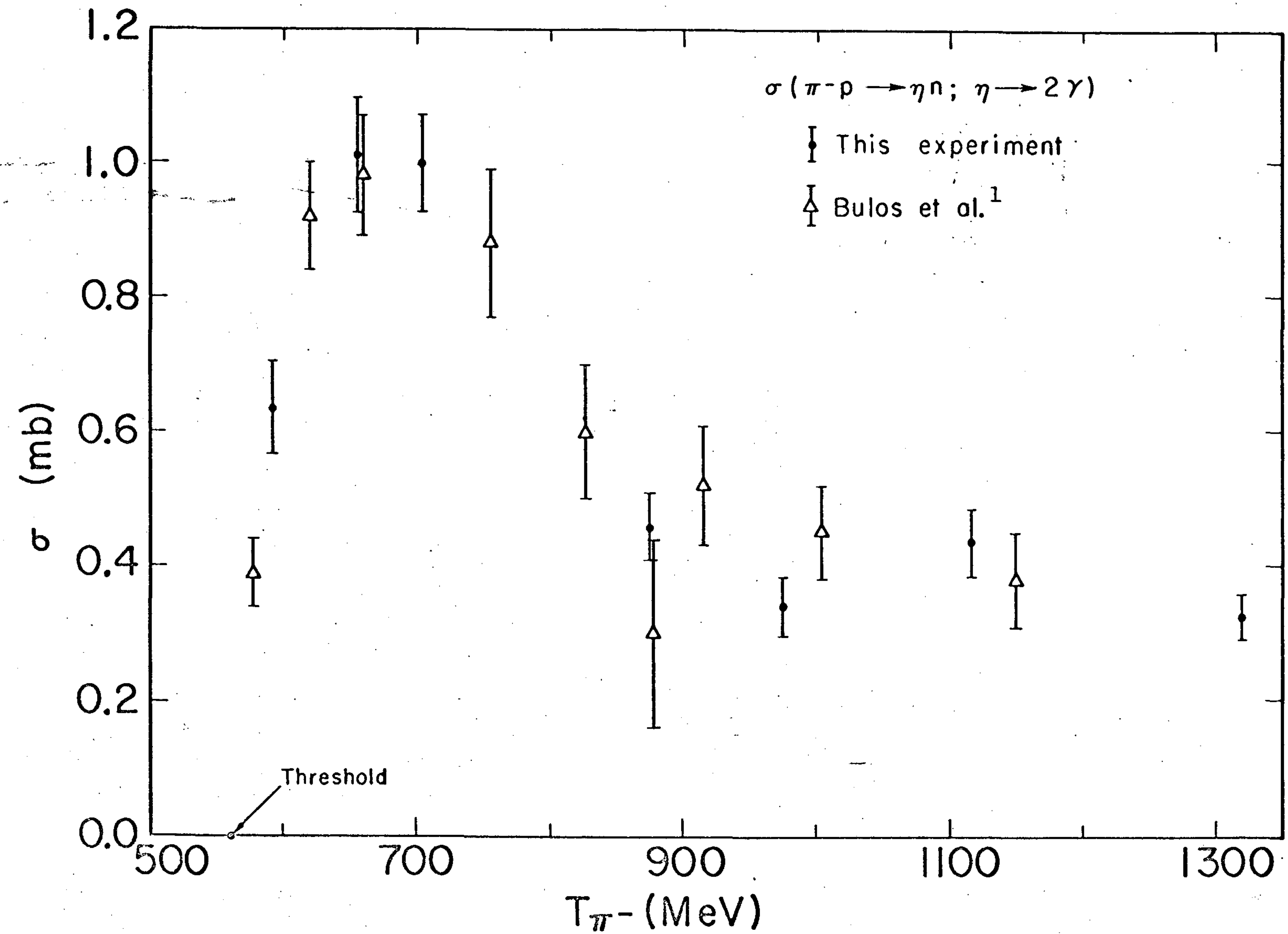
It should be emphasized that these numbers represent approximately one third of the total production cross section.

The angular distributions in the η production are formed by analysis of events with opening angles between the η minimum angle and an upper limit chosen to include approximately 75% of the events. Knowledge of the masses of the particles, the incoming pion energy, and the angular position of the two showers is sufficient to calculate the direction of travel of the η except for a quadratic ambiguity which results in a double solution. A sufficiently good observation of the relative energy in the two showers can resolve this ambiguity, but we were not able to do this in many cases.

Table I. Summary of partial cross section data

T_{π^-} (MeV)	P_η (c.m.) (MeV/c)	$f \cdot \sigma$ (mb)
592	116	0.64±.07
655	203	1.01±.09
704	251	1.00±.07
875	373	0.46±.05
975	429	0.34±.04
1117	499	0.44±.05
1319	584	0.33±.03

Therefore, it was necessary to use a slightly less direct method of analysis. Distributions were made of the direction of the bisector between the two showers. Because we used a γ-ray detector which covered a complete 4π solid angle, these distributions can then be converted to the true η angular distribution in the following way: If the distribution of the bisector has been fit by a sum of Legendre polynomials as



MUB-7470

Fig. 3. Results for partial cross section f · σ.

$$\left.\frac{d\sigma}{d\Omega}\right|_{Bis} = \sum_i A_i P_i \; (\cos \theta_{Bis}) \tag{3}$$

then the true η angular distribution is given by

$$\left.\frac{d\sigma}{d\Omega}\right|_{\eta} = \sum_i A_i/\xi_i \; P_i(\cos \theta_\eta) \; . \tag{4}$$

The A_i are the coefficients of the bisector fit, and

$$\xi_i = \int_{\frac{1}{\beta}\cos\frac{\phi_{max}}{2}}^{1} \frac{(1 - \beta^2)\; X\; P_i(X)dX}{\sqrt{1 - X^2}\left\{1 - \beta^2 X^2\right\}^{3/2}} \tag{5}$$

where ϕ_{max} is the upper limit of the opening angle interval from which the sample was taken, and β is the center-of-mass velocity of the meson.

In Figures 4a and 4b are presented the angular distributions, normalized to the partial cross section of Table I. Data points in the graphs are the experimental bisector distributions, corrected by a target-empty subtraction and a background subtraction. The distribution of background events was estimated by considering distributions from two out of three showers in the experimental sample of 3-shower events, in the limit that the third shower is very short. This distribution was isotropic within statistics.

The solid line in the graphs is the best χ^2 fit to the bisector data. The coefficients of this Legendre polynomial expansion were divided by the factors of Eq. (5) normalized in such a way that $\xi_0 = 1$, and the dotted line in each graph is a plot of the new expansion, representing the true η angular distribution. Table II contains the Legendre polynomial expansion coefficients of the η angular distribution.

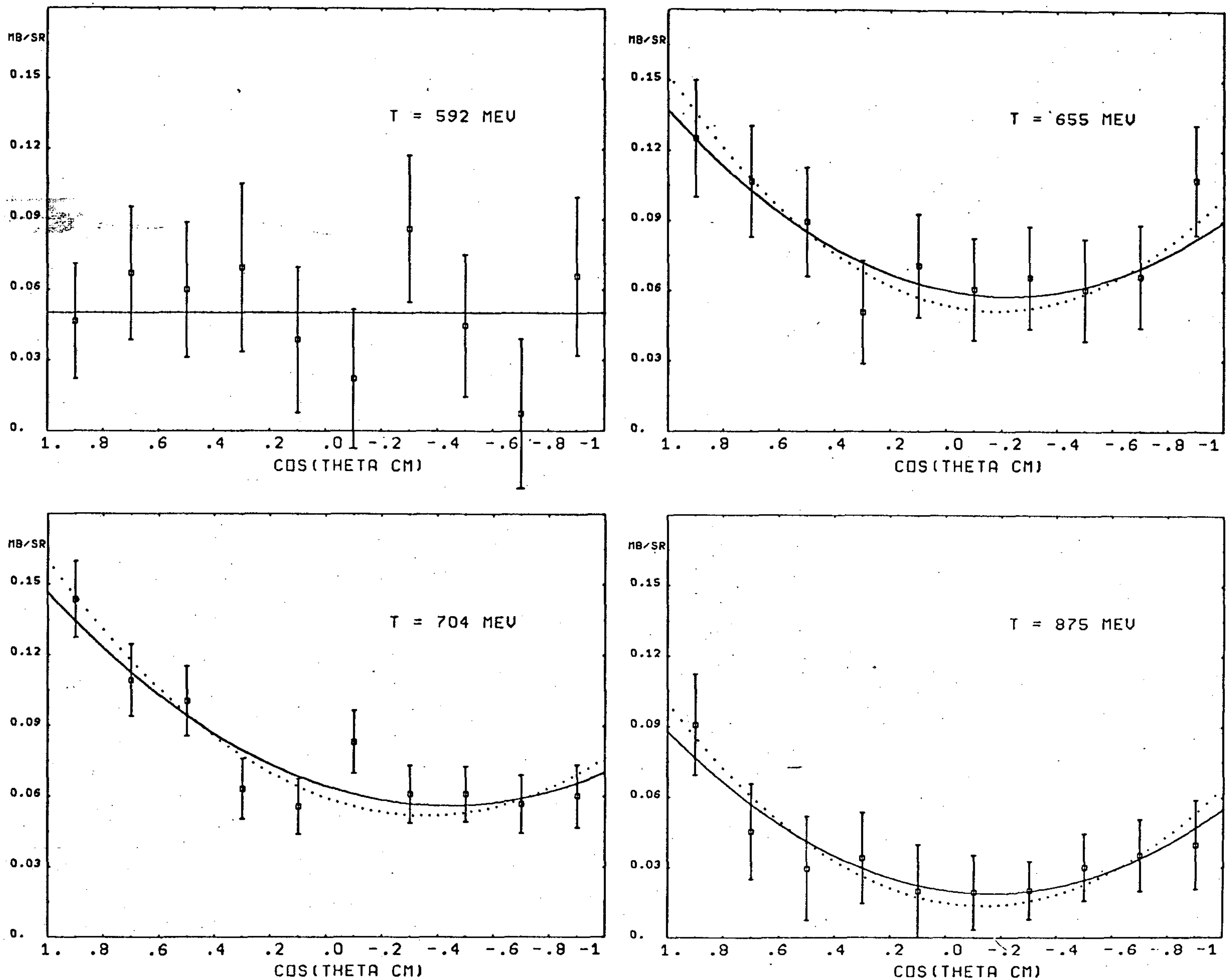


Fig. 4a. Differential cross sections. See text for explanation of curves.

MUB-7515

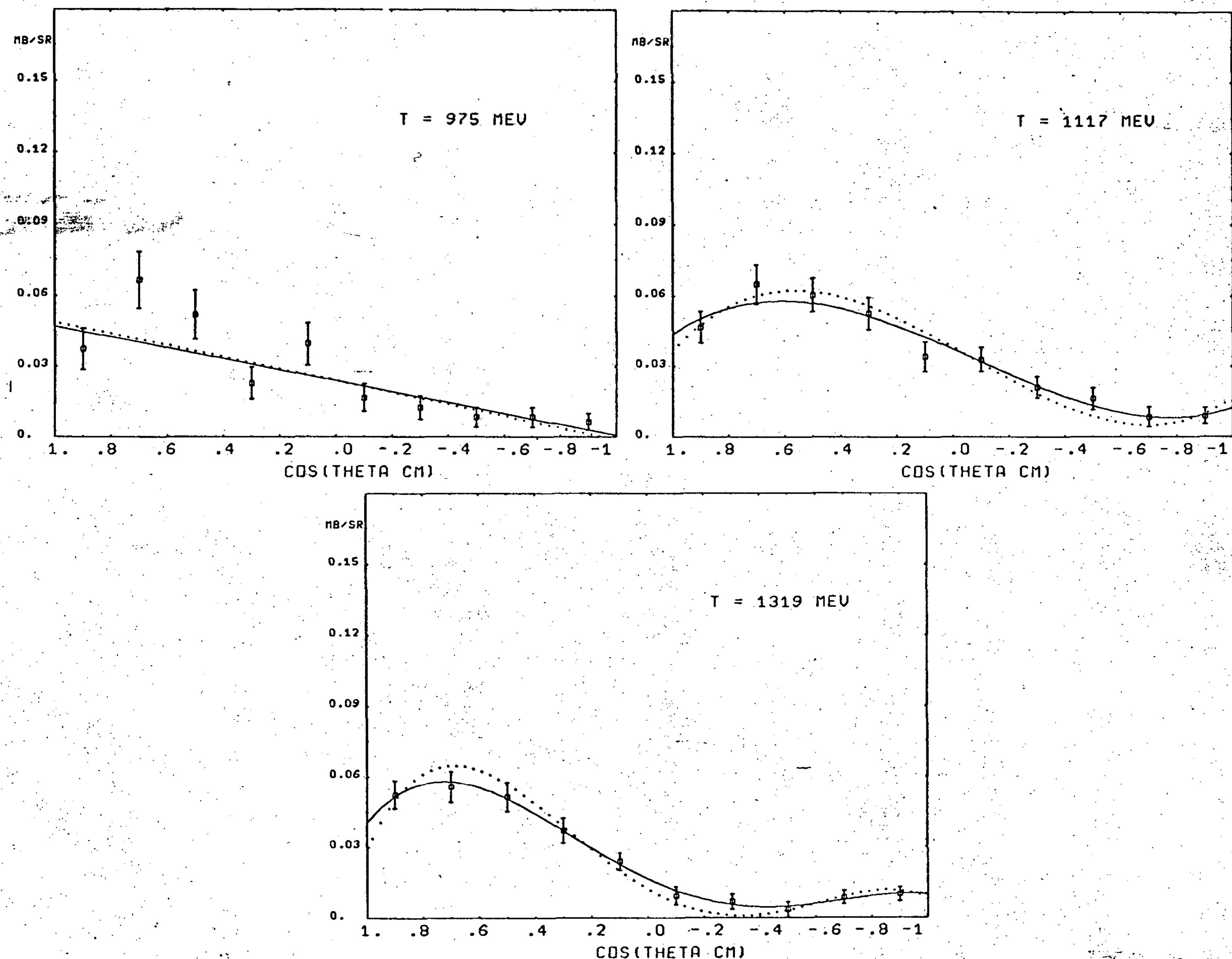


Fig. 4b. Differential cross sections. See text for explanation of curves.

MUB-7514

Table II. Coefficients of a Legendre polynomial expansion of the center-of-mass η production angular distribution.

T_{π^-} (MeV)	No. of events	A_0 (μb/sr)	A_1 (μb/sr)	A_2 (μb/sr)	A_3 (μb/sr)	A_4 (μb/sr)
592	49	50 ± 7				
655	460	78 ± 3	26 ± 8	48 ± 13		
704	536	79 ± 4	42 ± 8	39 ± 13		
875	114	37 ± 4	22 ± 9	40 ± 14		
975	130	24 ± 3	25 ± 5	(7 ± 8)		
1117	484	34 ± 2	33 ± 3	-7 ± 4	-23 ± 6	
1319	500	26 ± 1	33 ± 1	12 ± 2	-23 ± 6	-20 ± 4

Some comments on the data as presented are in order.

(a) Total Cross Section. The partial production cross section rises steeply from threshold to a peak of 1 mb, and then falls monotonically with increasing energy. Our first data point, and the first two points from Ref. 1, are closely proportional to the center-of-mass momentum of the η, suggesting strong S-wave production at threshold.

At $T_\pi \approx 900$ MeV the situation is slightly ambiguous, but there is certainly no clear evidence for any enhancement in the production cross section. This would indicate no major contribution from the decay of the $N^*_{1/2}$ (1688) via the η, which suggests, if true, that the $N^*_{1/2}$(1688) should be assigned to an SU(3) octet, rather than the $\underset{\sim}{27}$ multiplet.[3]

(b) Angular Distribution. Several theoretical calculations of the total cross section have been made assuming on the basis of the data from Ref. 1 that only the $S_{1/2}$ amplitude is important.[4,5,6] Our data show that although the production is through an S-wave amplitude at threshold, other partial waves become important quite quickly. One is tempted to explain these angular distributions by saying that in addition to the S wave there is a strong interaction in the $D_{3/2}$ state around 600 MeV, where there is a highly inelastic resonance in the π-nucleon isotopic spin 1/2 state. However, because exchange of all low-mass mesons is forbidden, it is hard to understand in any simple way how D-waves could be present in the η-N system so close to threshold, with such extremely short-range forces. Naturally, because of the Minami ambiguity, $P_{1/2}$ and $P_{3/2}$ amplitudes could lead to the same angular distributions as $S_{1/2}$ and $D_{3/2}$.

Again, in the angular distributions there is no evidence of unusual behavior in the vicinity of 900 MeV.

FOOTNOTES AND REFERENCES

* This work was done under the auspices of the U. S. Atomic Energy Commission.

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