Submitted to Physical Review Letters

UCRL-19253
Preprint

RECEIVED
LAWRENCE
RADIATION LABORATORY

JUL 29 1969

LIBRARY AND
DOCUMENTS SECTION

NoN

$\pi^+ n \to \eta p$: A REGGE FIT OVER A LARGE ENERGY RANGE USING VENEZIANO-TYPE RESIDUE FUNCTIONS

Jerome S. Danburg, Maris A. Abolins, Richard C. Brower, Orin I. Dahl,
Donald W. Davies, Paul L. Hoch, Janos Kirz,
Donald H. Miller and Robert K. Rader

AEC Contract No. W-7405-eng-48

TWO-WEEK LOAN COPY

This is a Library Circulating Copy which may be borrowed for two weeks. For a personal retention copy, call Tech. Info. Division, Ext. 5545

LAWRENCE RADIATION LABORATORY
UNIVERSITY of CALIFORNIA BERKELEY

UCRL-19253

DISCLAIMER

This document was prepared as an account of work sponsored by the United States Government. While this document is believed to contain correct information, neither the United States Government nor any agency thereof, nor the Regents of the University of California, nor any of their employees, makes any warranty, express or implied, or assumes any legal responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by its trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof, or the Regents of the University of California. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof or the Regents of the University of California.

$\pi^+ n \rightarrow \eta p$: A REGGE NON FIT OVER A LARGE ENERGY RANGE USING VENEZIANO-TYPE RESIDUE FUNCTIONS*

Jerome S. Danburg, Maris A. Abolins,+ Richard C. Brower, Orin I. Dahl, Donald W. Davies, Paul L. Hoch, Janos Kirz,‡ Donald H. Miller, and Robert K. Rader

Lawrence Radiation Laboratory, University of California, Berkeley, California 94720

July 4, 1969

ABSTRACT

A low-background sample of approximately 350 events from the reaction $\pi^+ n \rightarrow \eta p$ has been obtained from a study of the reaction $\pi^+ d \rightarrow p p \pi^+ \pi^- \pi^0$ in a bubble chamber experiment with incident pion momentum between 1.1 and 2.4 BeV/c. The η production angular distributions and the total cross section are very well fitted by a two-parameter Reggeized A_2- exchange model with Veneziano-type residue functions. The model is also compared with data from other experiments spanning the incident momentum range from near threshold to 18.2 BeV/c, and the agreement is very good.

HA!

We report an investigation of the reaction $\pi^+ d \rightarrow p p \pi^+ \pi^- \pi^0$ performed in the fall of 1966 in the deuterium-filled 72-inch bubble

chamber at the Lawrence Radiation Laboratory. The momentum of the incident pion beam from the Bevatron encompassed the range from 1.1 to 2.4 BeV/c at the eight momentum settings 1.10, 1.30, 1.53, 1.58, 1.70, 1.86, 2.15, and 2.37 BeV/c; the total exposure size was 14 events/μb. Because of the Fermi motion of the nucleons in the deuteron, a single beam momentum gives rise to a continuum of c.m. energies, and as a result our exposure gives continuous coverage of the c.m. energy range from 1.7 to 2.4 BeV.[1]

The events discussed here all have four visible outgoing tracks; that is, we do not report on events where the "spectator" proton (p) in the reaction

$$\pi^+ d \rightarrow (p)\ p\ \pi^+ \pi^- \pi^0 \qquad (1)$$

has momentum less than about 85 MeV/c in the laboratory. 128 000 four-pronged events were measured with the Spiral Reader and fitted with the standard LRL fitting programs TVGP and SQUAW. A sample of 8710 events assigned to reaction (1) and having at least one proton in the final state with laboratory momentum less than 300 MeV/c was obtained; the latter requirement is to insure that we are dealing with events in which only the neutron in the deuteron takes part in the interaction.

The $\pi^+\pi^-\pi^0$ mass spectrum from reaction (1) shows prominent η and ω peaks. The η peak contains about 350 events with little background; a maximum-likelihood fit using the program MURTLEBERT[2] was employed to estimate the number of η and ω events and to determine the cross sections for the reactions

$$\pi^+ n \rightarrow \eta\ p \qquad (2a)$$

$$\pi^+ n \rightarrow \omega\ p \qquad (2b)$$

as a function of c.m. energy by normalization to selected final states whose cross section is known from charge-symmetric data.[1] The background fraction in the η mass cut ($530\ \mathrm{MeV}/c^2 < m(\pi^+\pi^-\pi^0) < 570\ \mathrm{MeV}/c^2$) is 13 per cent.

The η production angular distributions and total cross sections have been fitted using a Regge-pole-exchange model involving the simplest allowed meson exchange, the A_2- or R-trajectory. The differential cross section, expressed in terms of the invariant amplitudes A and B, is

$$\frac{d\sigma}{d(\cos\theta)}\ (\mathrm{mb}) = \frac{.3895\ M^2\ q_f}{8\ \pi\ s\ q_i}\left\{\frac{|p|^2}{M^2}|A|^2 + \left[\left(\frac{s-u}{4\ M}\right)^2 + \frac{|k|^2\ t}{4\ M^2}\right]|B|^2 - \left(\frac{s-u}{2\ M}\right)\mathrm{Re}(A^*B)\right\}, \tag{3}$$

where M is the nucleon mass; s, t, and u are the usual Mandelstam variables; and q_i and q_f are the initial- and final-state c.m. momenta, respectively. k is the t-channel meson momentum, and p is the t-channel baryon momentum. (All momenta and masses are in BeV.) We have chosen to parametrize the invariant amplitudes A and B by the leading order in s of a Veneziano parametrization:

$$A\ (\mathrm{BeV}^{-1}) = a_o\Gamma(1-\alpha(t))(1+e^{-i\pi\alpha(t)})(b's)^{\alpha(t)} \tag{4a}$$

$$B\ (\mathrm{BeV}^{-2}) = b_o\Gamma(1-\alpha(t))(1+e^{-i\pi\alpha(t)})(b''s)^{\alpha(t)-1} \tag{4b}$$

Here $\alpha(t)$ is the A_2 trajectory function, which we take to be the straight-line form

$$\alpha(t) = 2 + (t - m_{A_2}^2)b \tag{5}$$

This parametrization is similar to the standard Regge parametrization of t-channel helicity amplitudes,[3] but the Veneziano model demands that

$b'' = b' = b$ be the universal slope of the linear trajectories. Hence, taking the trajectory slope b from experiment to be 1 BeV^{-2}, each residue function is determined up to an overall constant. The two real numbers a_o and b_o are consequently the only parameters in our fit.[4]

A least-squares fitting procedure to the shape only of the production angular distributions yields the best fit for

$$b_o/a_o = 2.4 \tag{6}$$

This fit is displayed upon the data for the production distributions at each of six c.m. energy intervals in Figures 1 a)-f). The production angular distributions are presented after subtraction of background; the three-pion production cosine distributions for three-pion masses adjacent to the η mass cut are fairly flat at all c.m. energies, so an isotropic background was subtracted. A small upward correction (the shaded events in Figure 1) has been made to the forwardmost two bins in each c.m. energy interval due to the effect of the Pauli exclusion principle in suppressing low-momentum-transfer events in reaction (1).[5]

The curves on the production distributions all satisfy equation (6), but they are normalized separately to have the same area as the respective histogram in Figure 1. It will be seen below, however, that a single choice of scale factor, i.e. a unique choice of a_o and b_o, fits both the shape and absolute scale of all distributions. The secondary zero in the curves of Figure 1 (at $t = -1.3$ BeV^2) occurs because the signature factors in equations (4) go to zero at $\alpha(t) = -1$.

The energy dependence of the total cross section for reaction (2a) and for its charge-symmetric counterpart, $\pi^- p \rightarrow \eta n$, have also been

compared to the model; the data points used span the c.m. energy interval from threshold for the reaction up to almost 6 BeV, the highest energy at which it has been studied. Figure 2 is a logarithmic plot of the total cross section for reaction (2a) and its charge-symmetric equivalent vs. c.m. energy, along with the predictions of the Reggeized A_2-exchange model. Figure 2 contains 13 cross-section points from this experiment and one point from another π^+-d experiment[6] for reaction (2a), and 15 points from two more experiments[7,8] done on the charge-symmetric reaction. Curves for three different ratios b_o/a_o are displayed on the data, all normalized to pass through the arbitrarily selected data point at $E_{c.m.} = 3.46$ BeV. For $b_o/a_o = 2.4$ the fit is seen to be very good over the entire range of energies; this is the same ratio which gives the best fit to the shape of the production angular distributions for our experiment.

The parameter values used to obtain the fit to the shape of our production angular distributions and to the total cross section over a wide range of energies are

$$a_o = 28.7, \quad b_o = 68.8 \tag{7}$$

From the two dotted curves in Figure 2 corresponding to $b_o/a_o = 2.2$ and 2.6, it is seen that a variation of only about 5 per cent in the ratio (6) is allowed in order to fit the cross section data. In order to fit the shape of the production cosine distributions, the tolerance is about 10 per cent. Furthermore, in order to fit the width of our experimental production cosine distributions, an A_2 trajectory slope of 1 BeV^{-2} $\pm$ 10 per cent is necessary; it should be noted that this value

is obtained under the restriction that $b = b' = b''$, which is not applied in a conventional Regge fit.

Figure 3 shows the differential cross section for

$$\pi^- p \longrightarrow \eta n, \quad \eta \longrightarrow \gamma \gamma \tag{8}$$

from reference 8 at c.m. energies above 2.50 BeV, along with the predictions of the Reggeized A_2-exchange model. The curves are normalized to have the same area as the histograms, which is not actually necessary because of the excellent agreement between the model and the total cross section points of this reference. The agreement between the differential cross sections and the model in Figure 3 is satisfactory.[9]

The model has also been compared with the differential cross section for reaction (2a) measured by Benson[10] at $E_{c.m.} = 2.78$ BeV and with that for reaction (8) measured by Wahlig and Mannelli[11] at $E_{c.m.} = 4.43$ BeV. (The comparison is shown in reference 1.) The data of Benson agree very well with the model, even better than the equivalent data of reference 8 shown in Figure 3b. The differential cross section of reference 11 is broader than the model and also broader than the distribution of reference 8 shown in Figure 3d, with which it should be identical. These discrepancies in the production distributions at high energy ($E_{c.m.} > 2.5$ BeV) should be kept in mind when making detailed comparisons with the model. Cross sections for reaction (8) have also been measured close to threshold by Richards et al.,[12] and at the energies where these measurements overlap with ours, the agreement between the two experiments is excellent. The model fails to describe the differential cross section only for $E_{c.m.}$ values near threshold, around the mass of the N(1550); the model has

been compared with the data of reference 12 in this region.

The simple two-parameter Regge exchange model described here is thus sufficient to predict accurately both the production angular distributions and the total cross section for reaction (2a) over a range of c.m. energies from 1.7 to 6 BeV (this corresponds to incident beam momentum between 1.1 and 18.2 BeV/c); this indicates that η production in reaction (2a) exhibits duality in the sense that the A_2 exchange which dominates the reaction for high energy and small t also gives a surprisingly good description at lower energy and at large angle.

We are indebted to the scanning and measuring staff of the Lawrence Radiation Laboratory for their industry and to the LRL computer center staff for their constant cooperation. We thank Prof. Luis W. Alvarez for his support and encouragement.

FOOTNOTES AND REFERENCES

* Work supported by the U. S. Atomic Energy Commission.

+ Now at Michigan State University, East Lansing, Michigan 48823.

‡ Now at State University of New York, Stony Brook, L.I., New York 11790.

1. For a more complete account of the experimental analysis and of the work reported here, see Jerome S. Danburg, Ph. D. thesis, University of California, 1969 (unpublished).

2. J. Friedman, Alvarez Programming Group Note P-156 (1966) (unpublished).

3. F. Arbab, N. F. Bali, and J. W. Dash, Phys. Rev. 158, 1515 (1967). Our use of A and B amplitudes automatically introduces an additional zero into the non-spin-flip helicity amplitude; the utility of such a zero for data fitting has been noted by these authors.

4. We note that our A_2 trajectory automatically follows the Gell-Mann mechanism at $\alpha_{A_2} = 0$; according to reference 3 this is preferred over the Chew mechanism for an A_2 trajectory with the standard slope ($b = 1$ BeV^{-2}).

5. I. Butterworth, J. L. Brown, G. Goldhaber, S. Goldhaber, A. A. Hirata, J. A. Kadyk, B. M. Schwarzschild, and G. H. Trilling, Phys. Rev. Letters 15, 734 (1965).

6. T. C. Bacon, W. J. Fickinger, D. G. Hill, H. W. K. Hopkins, D. K. Robinson, and E. O. Salant, Phys. Rev. 157, 1263 (1967).

7. F. Bulos *et al.* (Brown-Brandeis-Harvard-M.I.T.-Padua collaboration), Phys. Rev. Letters 13, 486 (1964).

8. O. Guisan, J. Kirz, P. Sonderegger, A. V. Stirling, P. Borgeaud, C. Bruneton, P. Falk-Vairant, B. Amblard, C. Caversasio, J. P. Guillaud, and M. Yvert, Phys. Letters 18, 200 (1965).

9. Examination of our model shows that the disappearance of the dip in the curves of Figure 3 at high energy is primarily due to shrinkage, in spite of the substantial spin-flip contribution to the cross section.

10. George C. Benson, Ph. D. thesis, University of Michigan, 1966 (unpublished); G. C. Benson, B. P. Roe, D. Sinclair, and J. C. Vander Velde, Phys. Rev. Letters 22, 1074 (1969).

11. M. A. Wahlig and I. Mannelli, Phys. Rev. 168, 1515 (1968).

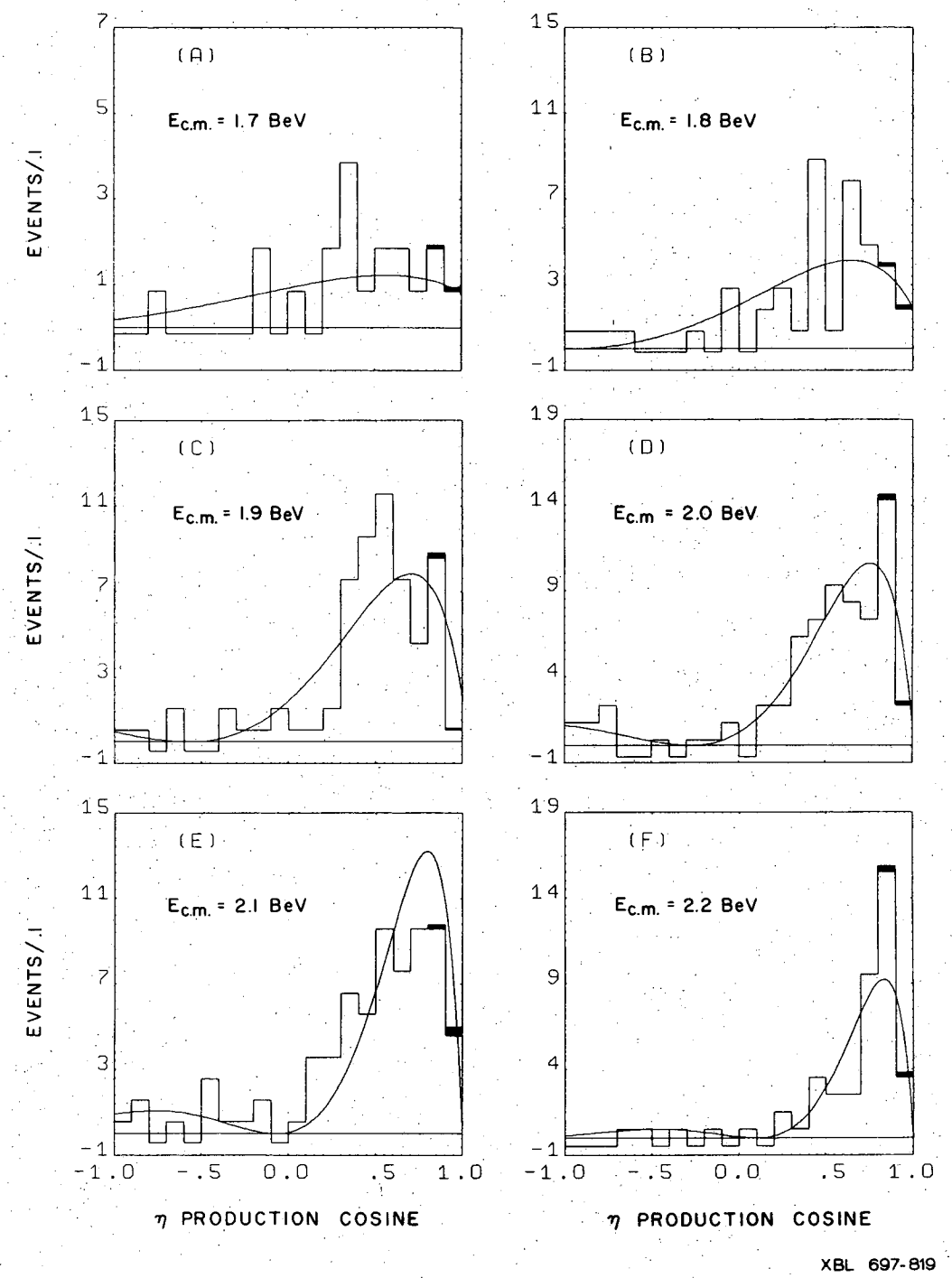
12. W. B. Richards, C. B. Chiu, R. D. Eandi, A. C. Helmholz, R. W. Kenney, B. J. Moyer, J. A. Poirier, R. J. Cence, V. Z. Peterson, N. K. Sehgal, and V. J. Stenger, Phys Rev. Letters 16, 1221 (1966).

FIGURE CAPTIONS

FIG. 1. η production cosine distributions for six 100-MeV-wide c.m. energy intervals centered at the values indicated. Shaded events are added to account for the effect of the Pauli exclusion principle. Some bins have negative contents because of the background subtraction. The curves are the predictions of the Reggeized A_2-exchange model with $b_o/a_o = 2.4$; they are normalized to have the same area as the histograms.

FIG. 2. Cross section for $\pi^+ n \rightarrow \eta p$ or $\pi^- p \rightarrow \eta n$ vs. c.m. energy. Three predictions of the Reggeized A_2-exchange model are plotted; all curves are normalized to pass through the data point at $E_{c.m.} = 3.46$ BeV.

FIG. 3. Differential cross sections for $\pi^- p \rightarrow \eta n$ from reference 8. The curves are the Reggeized A_2-exchange model predictions with $b_o/a_o = 2.4$ and are normalized to have the same area as the histograms.



XBL 697-819

FIGURE 1

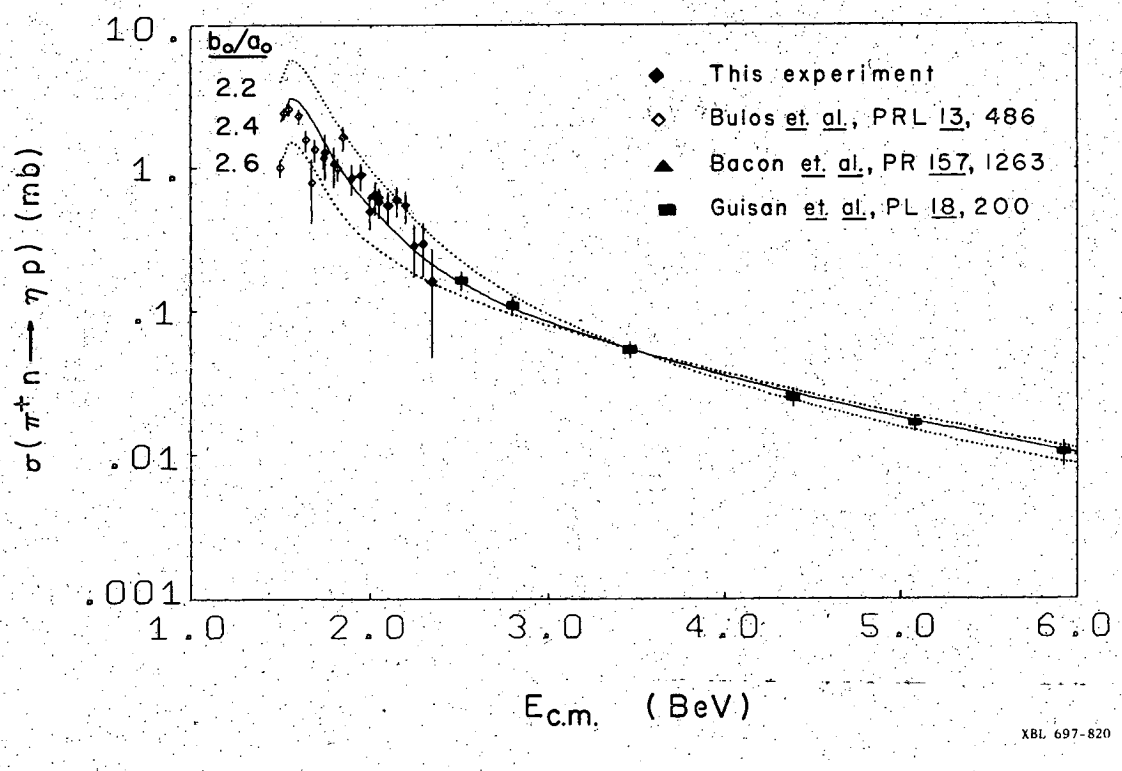

10.
1.
.1
.01
.001
b_0/a_0
2.2
2.4
2.6
This experiment
Bulos et. al., PRL 13, 486
Bacon et. al., PR 157, 1263
Guisan et. al., PL 18, 200
$\sigma(\pi^+ n \longrightarrow \eta p)$ (mb)
1.0
2.0
3.0
4.0
5.0
6.0
$E_{c.m.}$ (BeV)
XBL 697-820

FIGURE 2

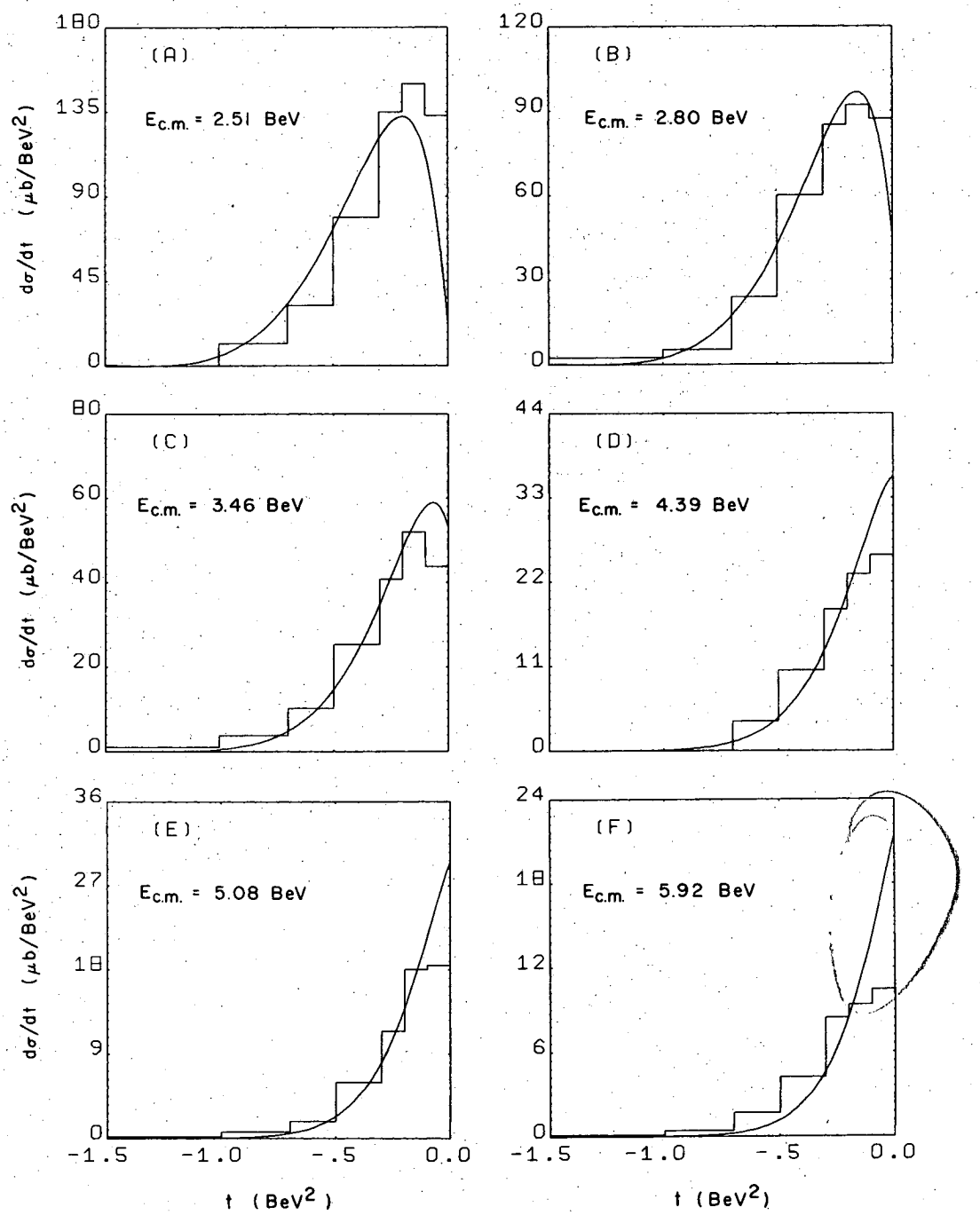

(A)
$E_{c.m.}$ = 2.51 BeV
(B)
$E_{c.m.}$ = 2.80 BeV
(C)
$E_{c.m.}$ = 3.46 BeV
(D)
$E_{c.m.}$ = 4.39 BeV
(E)
$E_{c.m.}$ = 5.08 BeV
(F)
$E_{c.m.}$ = 5.92 BeV
$d\sigma/dt$ ($\mu b/BeV^2$)
t (BeV^2)
XBL 697-818

FIGURE 3

LEGAL NOTICE

This report was prepared as an account of Government sponsored work. Neither the United States, nor the Commission, nor any person acting on behalf of the Commission:

A. Makes any warranty or representation, expressed or implied, with respect to the accuracy, completeness, or usefulness of the information contained in this report, or that the use of any information, apparatus, method, or process disclosed in this report may not infringe privately owned rights; or

B. Assumes any liabilities with respect to the use of, or for damages resulting from the use of any information, apparatus, method, or process disclosed in this report.

As used in the above, "person acting on behalf of the Commission" includes any employee or contractor of the Commission, or employee of such contractor, to the extent that such employee or contractor of the Commission, or employee of such contractor prepares, disseminates, or provides access to, any information pursuant to his employment or contract with the Commission, or his employment with such contractor.

TECHNICAL INFORMATION DIVISION
LAWRENCE RADIATION LABORATORY
UNIVERSITY OF CALIFORNIA
BERKELEY, CALIFORNIA 94720