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FINAL TECHNICAL PROGRESS REPORT for a Program in Medium-Energy Nuclear Physics Research

MASTER

1 May 1971 - 30 November 1981

H. B. Willard, Professor of Physics and Principal Investigator
P. R. Bevington,* Professor of Physics
R. A. Leskovec, Senior Staff Physicist

Department of Physics

CASE WESTERN RESERVE UNIVERSITY

Cleveland, Ohio 44106

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*Deceased

ABSTRACT

Final results are summarized for this program with the primary emphasis on measurement of ten independent parameters for proton-proton elastic scattering at 800 MeV and four independent such parameters at 650 MeV. Inelastic proton-proton reactions have also been measured at 800 MeV. Proton-deuteron elastic scattering cross sections and polarization analyzing powers have been obtained at 800 MeV. Proton-nucleus total and total reaction cross sections were measured at 700 MeV for a number of nuclei. Major instrumentation was designed and constructed to carry out this program.

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Notice

A. Nucleon-Nucleon Interaction at Intermediate Energies

Below 400 MeV the nucleon-nucleon interaction proceeds essentially by the elastic channel with recent phase shift analyses indicating that the data are reasonably consistent with only the finer details requiring further elucidation. Above 1 GeV (1.7 GeV/c) to the surprise of high energy physicists, the proton-proton interaction has revealed a wealth of spin dependent structure too complex to be adequately described by phase shift analyses and therefore fitted by various Regge and optical models. The intermediate energy region from 400 MeV to 1 GeV is of considerable importance to investigate thoroughly to bridge the gap in our descriptions of closely related phenomena. Precise nucleon-nucleon amplitudes and phase shifts are essential to our understanding of the basic interaction. In addition, the application to microscopic models of nucleon-nucleus interactions starts with the free nucleon-nucleon parameters to determine the effective interaction in nuclei. Finally, much interest in the last few years has been generated by observation of energy dependent structure in this energy range. Interpretations of this structure range from exotic dibaryon resonances to threshold effects within conventional models. It is generally agreed, however, that a definitive interpretation will not be possible without a complete set of measurements at a number of energies in this region.

The primary objective of the CWRU/LAMPF program has been to perform complete sets of precision measurements of the proton-proton interaction in the 400 - 800 MeV energy range. This will ultimately require investigation of the inelastic channels (including spin dependent effects) as well as the elastic scattering parameters we have obtained through polarized beams and targets. It is especially important that our studies overlap with the efforts at TRIUMF (T_{MAX} = 520 Mev) and SIN (T_{MAX} = 590 MeV). Our ability to measure the asymmetry with a polarized beam ($P(\Theta) = A_y(\Theta)$) with high precision and absolute accuracy is of particular interest as a method of calibrating all sets of data in this energy range.

As already indicated, above the pion threshold the nucleon-nucleon amplitudes are considerably more difficult to determine than at lower energies where unitarity allows simplifying assumptions. Five complex amplitudes are required to specify the interaction so that at least nine spin-dependent experiments are needed to determine five magnitudes and four phases. In collaboration with our Los Alamos and Argonne colleagues, we have measured at 800 MeV the cross section, (5) analyzing power, (11, 16) spin-correlation parameters (13, 15) A_{NN} and A_{LL}, and six spin transfer parameters (18) D_{NN}, D_{SS}, D_{LS}, K_{NN}, K_{SS}, K_{LS} to yield the total number of ten parameters. In addition, the first four parameters have been measured (5, 11, 13, 19) at 650 MeV and the six remaining parameters will be obtained by the Los Alamos group within the near future. Thus it is now possible for the first time to completely determine the proton-proton elastic (real) (isovector) phase shifts and amplitudes at 800 MeV. The complete set of data are shown in Figures 1-9 in comparision with Arndt's phase shift solutions (solid lines). Preliminary values of the data previously reported are included in the fits. Also shown for the spin transfer parameters are results from pre-existing solutions (dashed line). The impact of even the preliminary data on the pre-existing solutions was dramatic. The present phase shift predictions are reasonable; through the smaller uncertainties on the present data make it apparent that the predictions exhibit more structure than is observed in the data.

We have also obtained at 800 MeV unpolarized beam target inelastic data (9, 17) for the reactions

$$pp \to d\,\pi^+$$
$$\to pn\,\pi^+$$
$$\to pp\,\pi^+\pi^-$$

These results are not sufficient to determine the imaginary parts of the phase shifts. Further spin dependent data are required.

B. Proton-Nucleus Cross Section Measurement

Total and total reaction cross section data for 700 MeV protons have been obtained for samples of carbon, nickel, and lead with natural isotopic abundances and highly enriched samples of calcium 40, 44, and 48 and tin 116 and 124. The calcium data (12) provide information on matter radii differences of Δ (44-40) = (.05 $\pm$ .09)fm and Δ (48-40) = (.36 $\pm$ .09)fm.

C. Proton-Deuterum Elastic Scattering

The three nucleon system offers the simplest extension of nucleon-nucleon information to a real nucleus through the solution of Faddeev equations with separable potentials. We have measured (14) differential cross sections and polarization analyzing powers for proton-deuteron elastic scattering at 800 MeV.

D. Instrumentation

The precision of the measurements we have performed is nearly an order of magnitude superior to that of earlier work in this field. In order to achieve this level, a very careful evaluation of the instrumentation and analysis of data was required. At the time of initial funding of this program (May 31, 1971) we were in the process of terminating a long tradition of low energy nuclear physics research at Case Western Reserve University based on a 4 Mv pulsed beam Van de Graaff. In order to switch over to this new (to us) field of intermediate energy nuclear physics, it was necessary to design and construct.*

a) multi-wire proportional chambers (MWPC's),(2)

b) fast MWPC readout systems (8) which minimize the difficulties of performing coincidence experiments with the low duty factor (6%) beams available at LAMPF,

c) hardware and software interfaces with a PDP 11/45 computer system,

d) beam intensity monitors,(4)*

e) polarization monitors,*

f) polarized targets,*

g) π° spectrometer*

The MWPC's constructed for our experiments are 64 x 64 and 128 x 128 wires with 0.1 inch spacing. It is fair to state that they performed reasonably well but have not significantly advanced the state of the art. However, the readout system (8) is faster than anything available commercially even today and has functioned with increased reliability over the past several years. The hardware and software systems have been developed semi-independently of other systems at LAMPF and are among the most sophisticated currently in operation. It is unlikely that we would have been able to perform some of the experiments described earlier without our own system.

The Faraday cup, ionization chambers, and secondary emission monitors were developed primarily by our group (4) but with financial support from LAMPF. They are of course available to other groups working on the external proton beam line (EPB).

The Lamb shift polarized proton source developed and built for LAMPF by Drs. McKibben, Chamberlin, Stevens and others, at Los Alamos, allows one to measure the absolute beam polarization by atomic methods (quench ratio technique). We designed and constructed with LAMPF support a secondary calibration polarimeter to continuously monitor the beam polarization as required for high precision experiments. This combination of techniques has allowed absolute determinations (11) of the beam polarization to better than 1%.

The polarized proton target was constructed by Dr. Simmons (Los Alamos, P-Division) with Dr. McNaughton from our group assisting.

The π° spectrometer has been constructed with manpower input from LAMPF, Tel Aviv and CWRU, but fully funded by LAMPF. Following Professor Bevington's death in 1980, we discontinued our collaboration with the physics program associated with this spectrometer.

*Collaborative efforts required

Figure Captions

1. Differential cross section in mb/sr for proton-proton elastic scattering at 800 Mev (796 MeV)

2. Analyzing power A_y for proton-proton elastic scattering at 796 MeV

3. Spin correlation parameter A_{NN} for proton-proton elastic scattering at 796 MeV

4. Spin transfer parameter D_{NN} for proton-proton elastic scattering at 796 MeV

5. Spin transfer parameter D_{SS} for proton-proton elastic scattering at 796 MeV

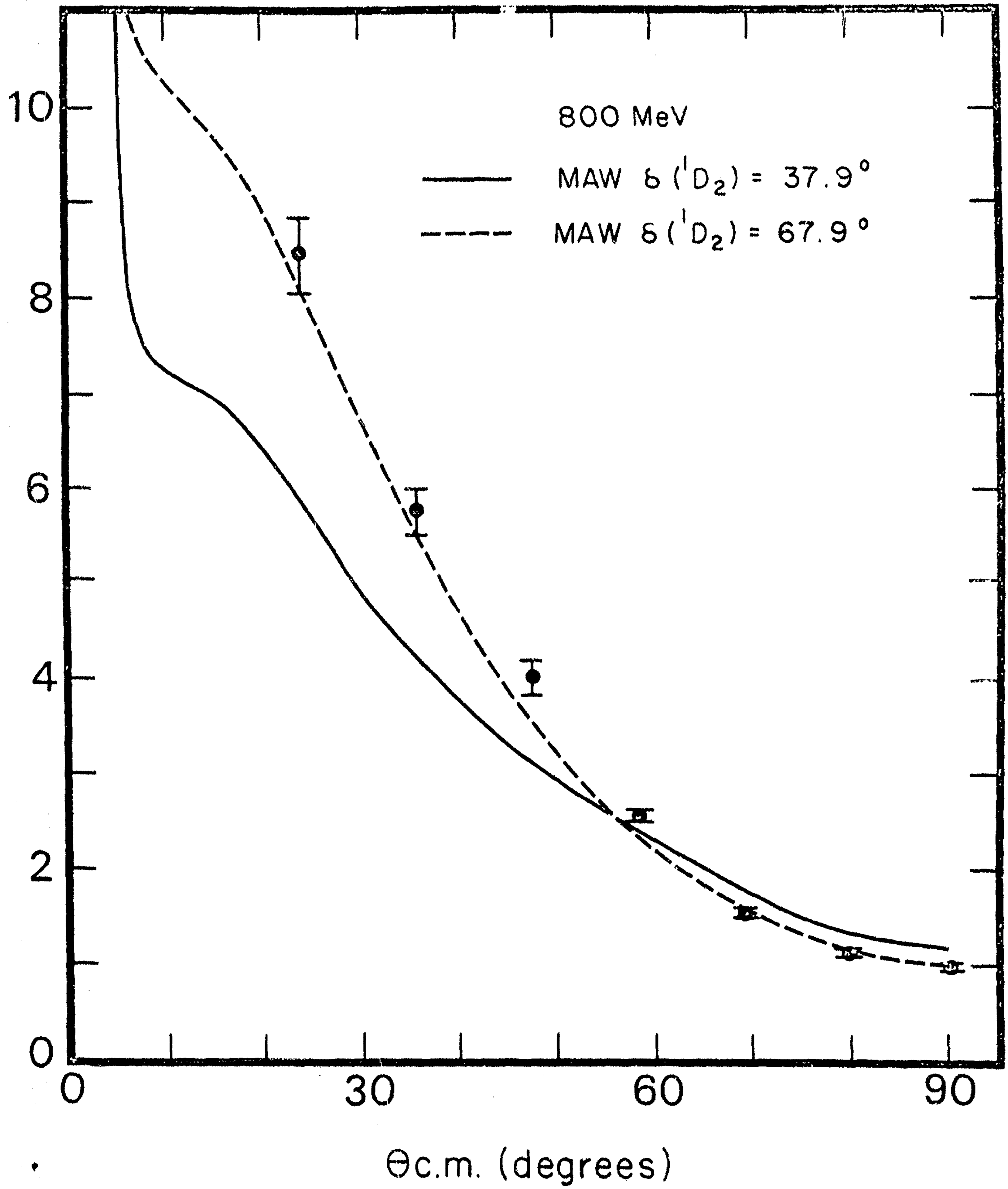
6. Spin transfer parameter D_{LS} for proton-proton elastic scattering at 796 MeV

7. Differential cross section in mb/sr for proton-proton elastic scattering at 647 MeV

8. Analyzing power A_y for proton-proton elastic scattering at 647 MeV

9. Spin correlation parameter A_{NN} for proton-proton elastic scattering at 647 MeV

(all parameters are plotted as a function of the center-of-mass scattering angle.)



800 MeV
MAW $\delta(^1D_2) = 37.9°$
MAW $\delta(^1D_2) = 67.9°$
0
2
4
6
8
10
0
30
60
90
Θc.m. (degrees)

Fig. 1

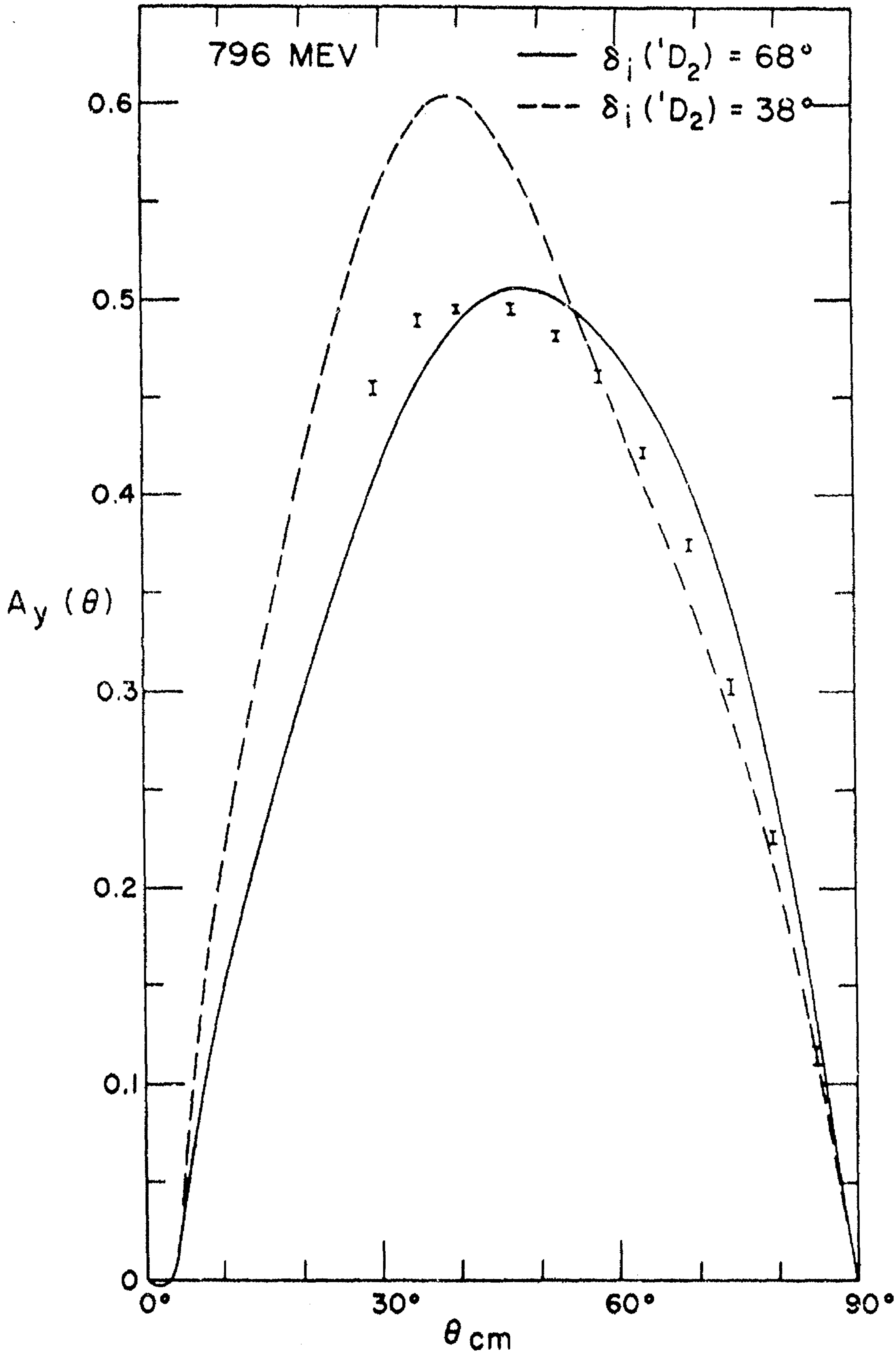

796 MEV
$\delta_i(^1D_2) = 68°$
$\delta_i(^1D_2) = 38°$
0.6
0.5
0.4
0.3
0.2
0.1
0
$A_y(\theta)$
0°
30°
60°
90°
θ_{cm}

Fig. 2

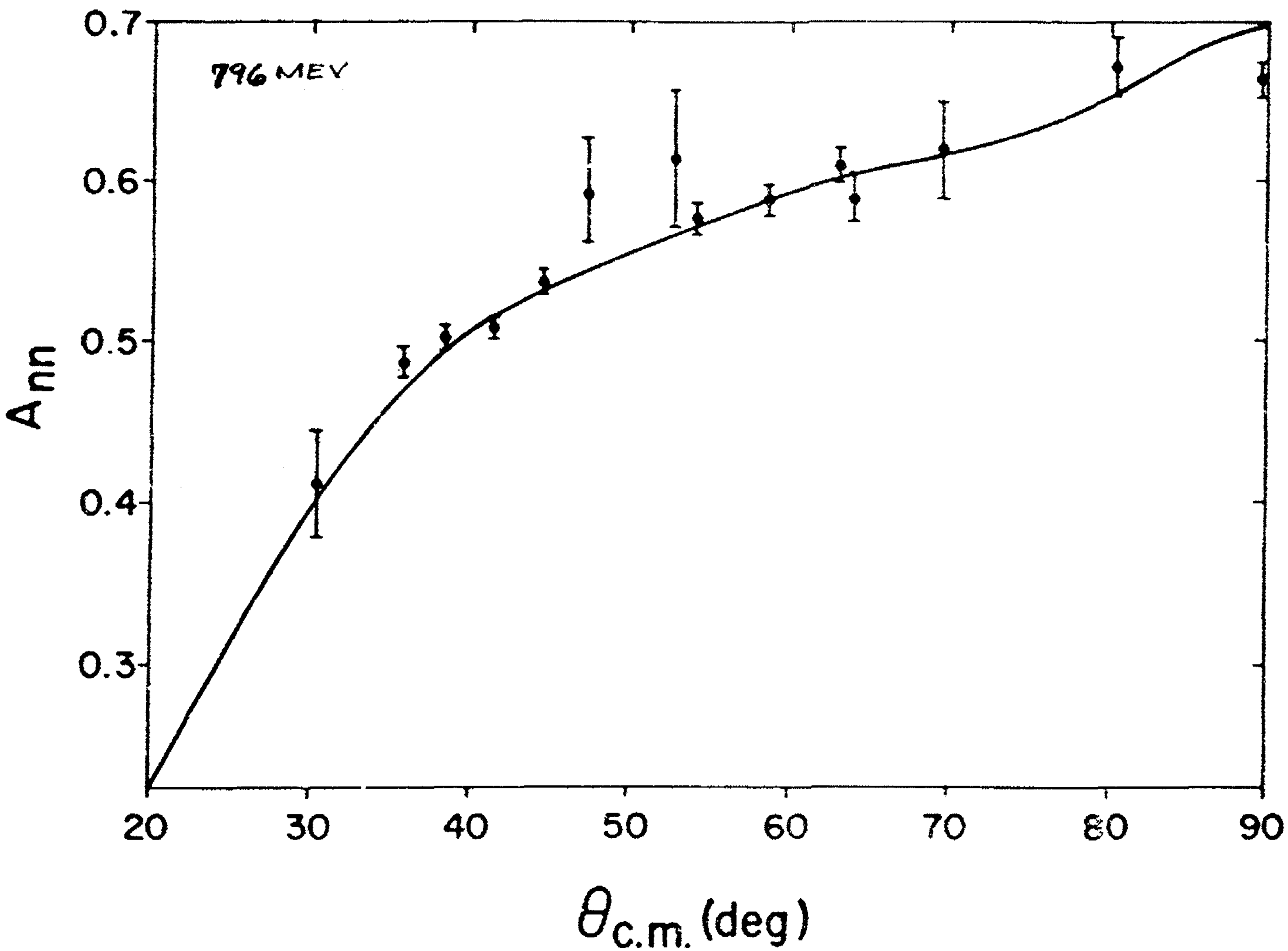


FIG. 3

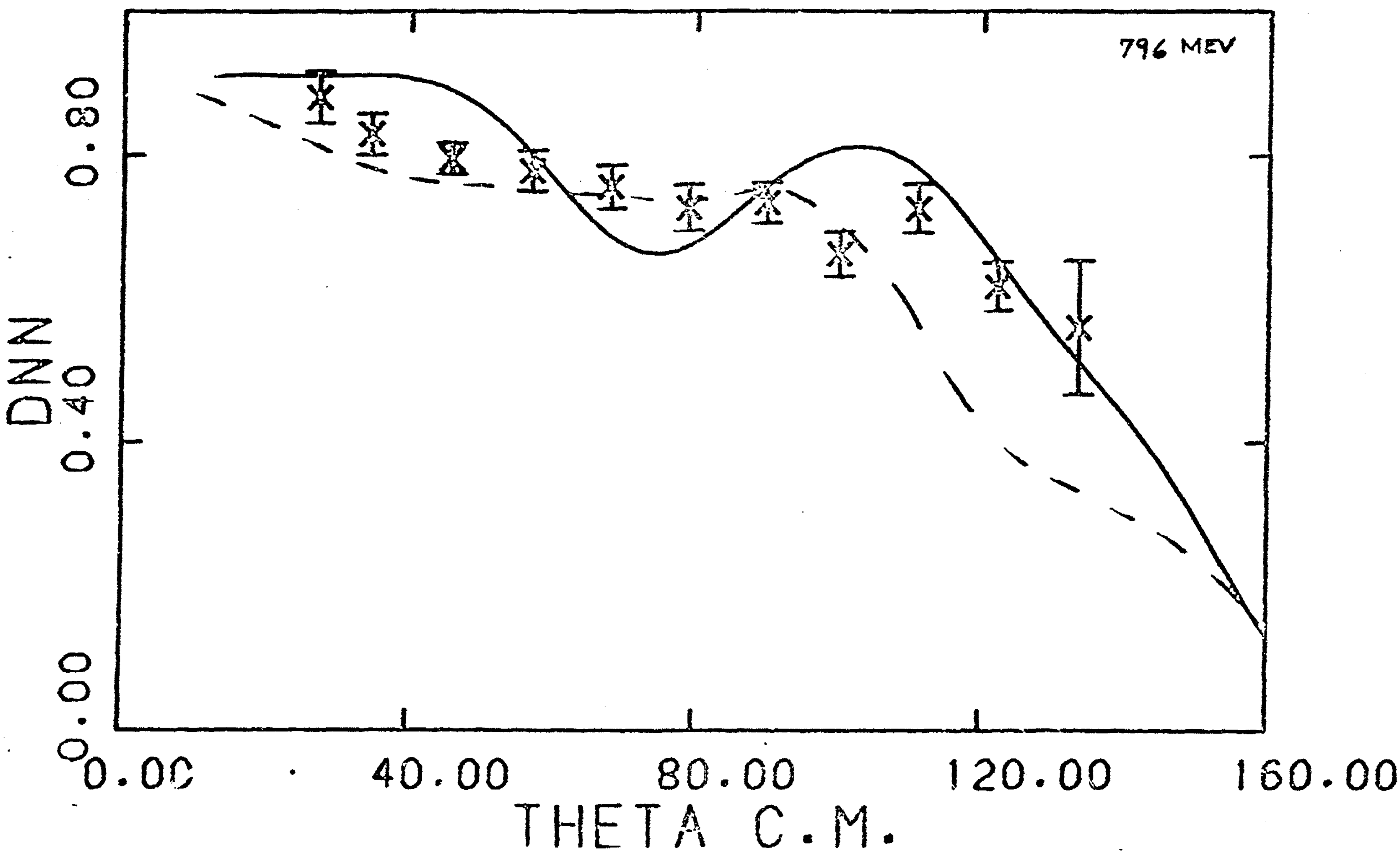


Fig. 4.

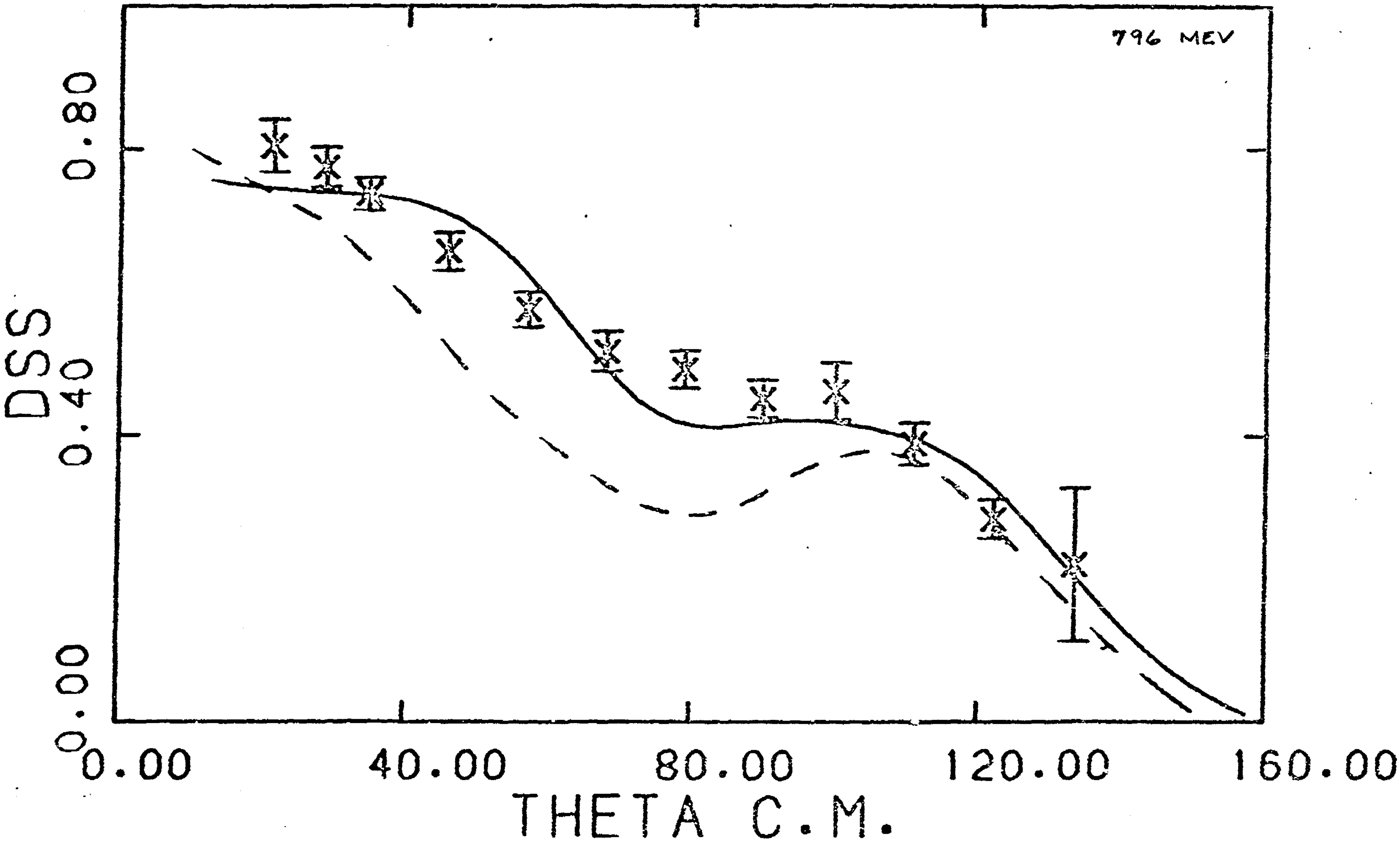


Fig. 5

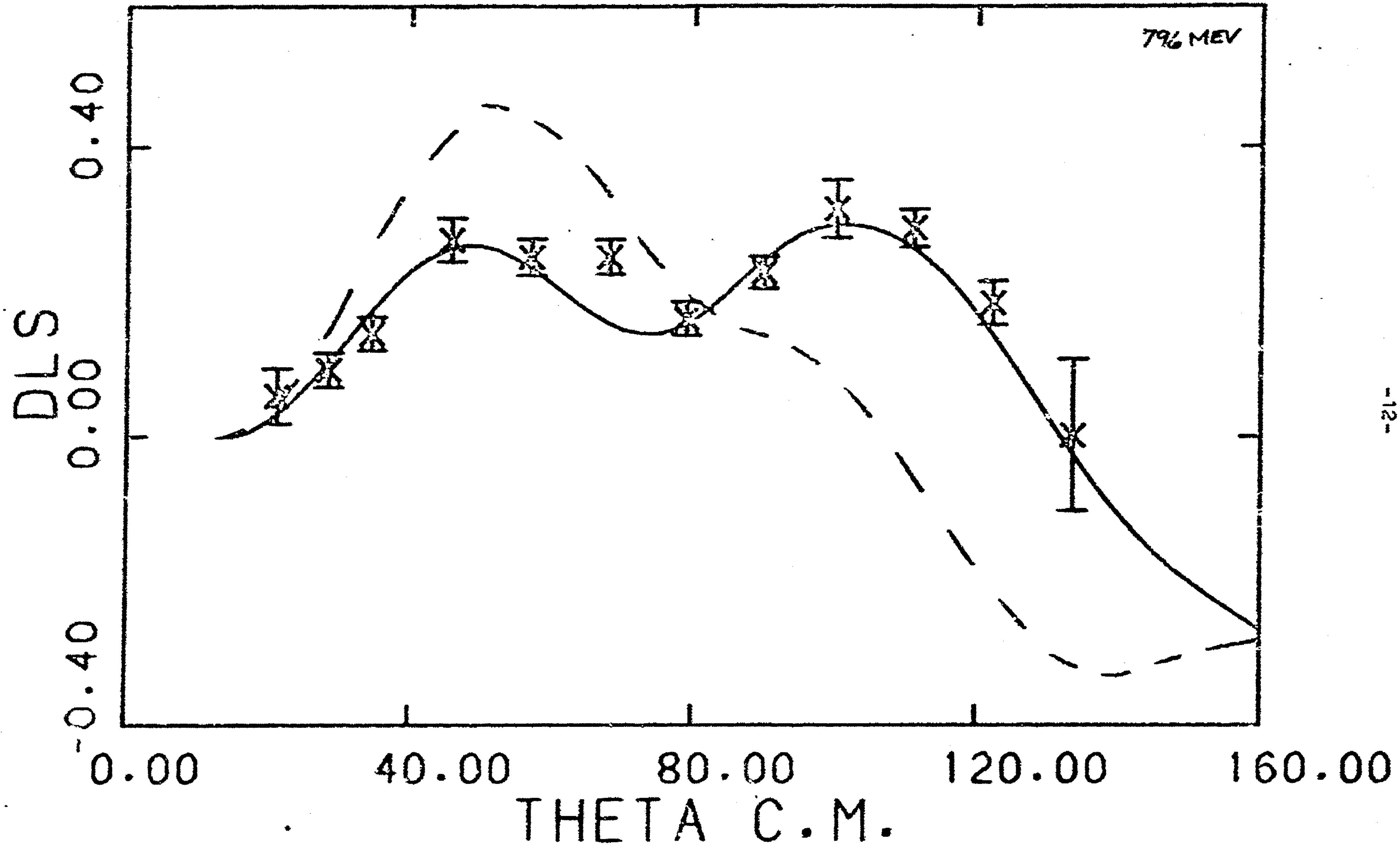


Fig. 6

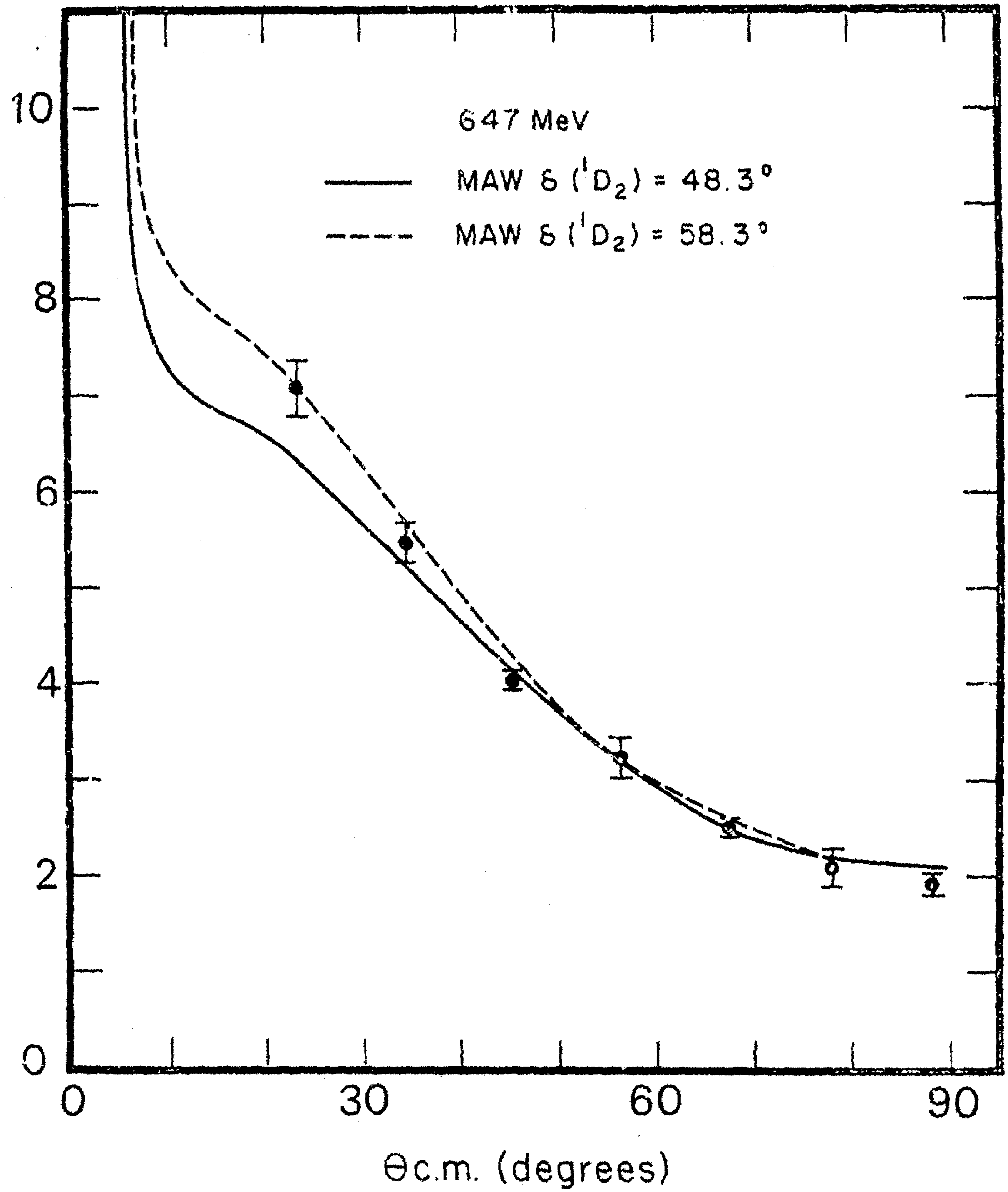

10
8
6
4
2
0
647 MeV
MAW δ ($^1D_2$) = 48.3°
MAW δ ($^1D_2$) = 58.3°
0
30
60
90
Θc.m. (degrees)

Fig. 7

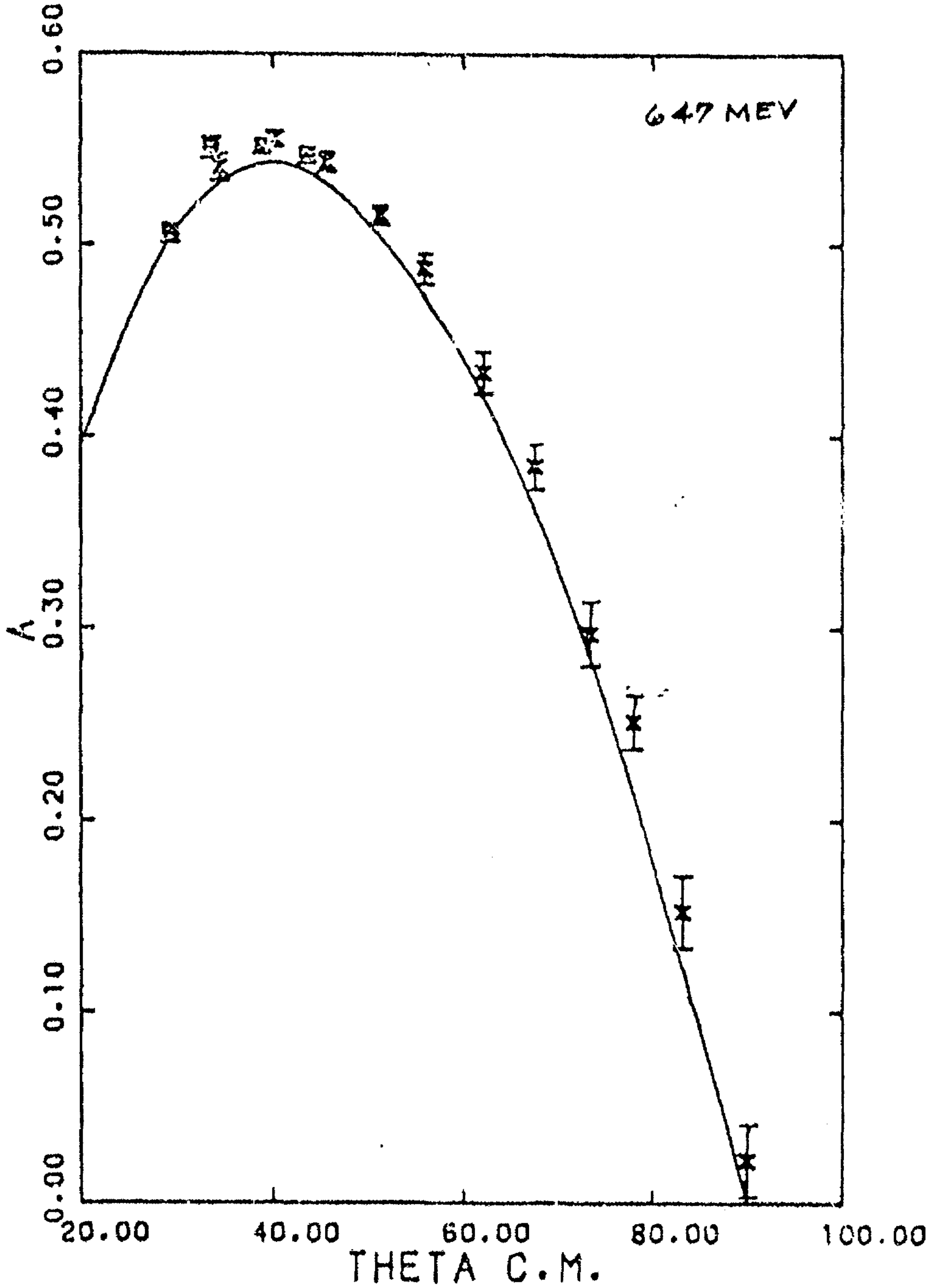

647 MEV
A
0.00
0.10
0.20
0.30
0.40
0.50
0.60
20.00
40.00
60.00
80.00
100.00
THETA C.M.

Fig. 8

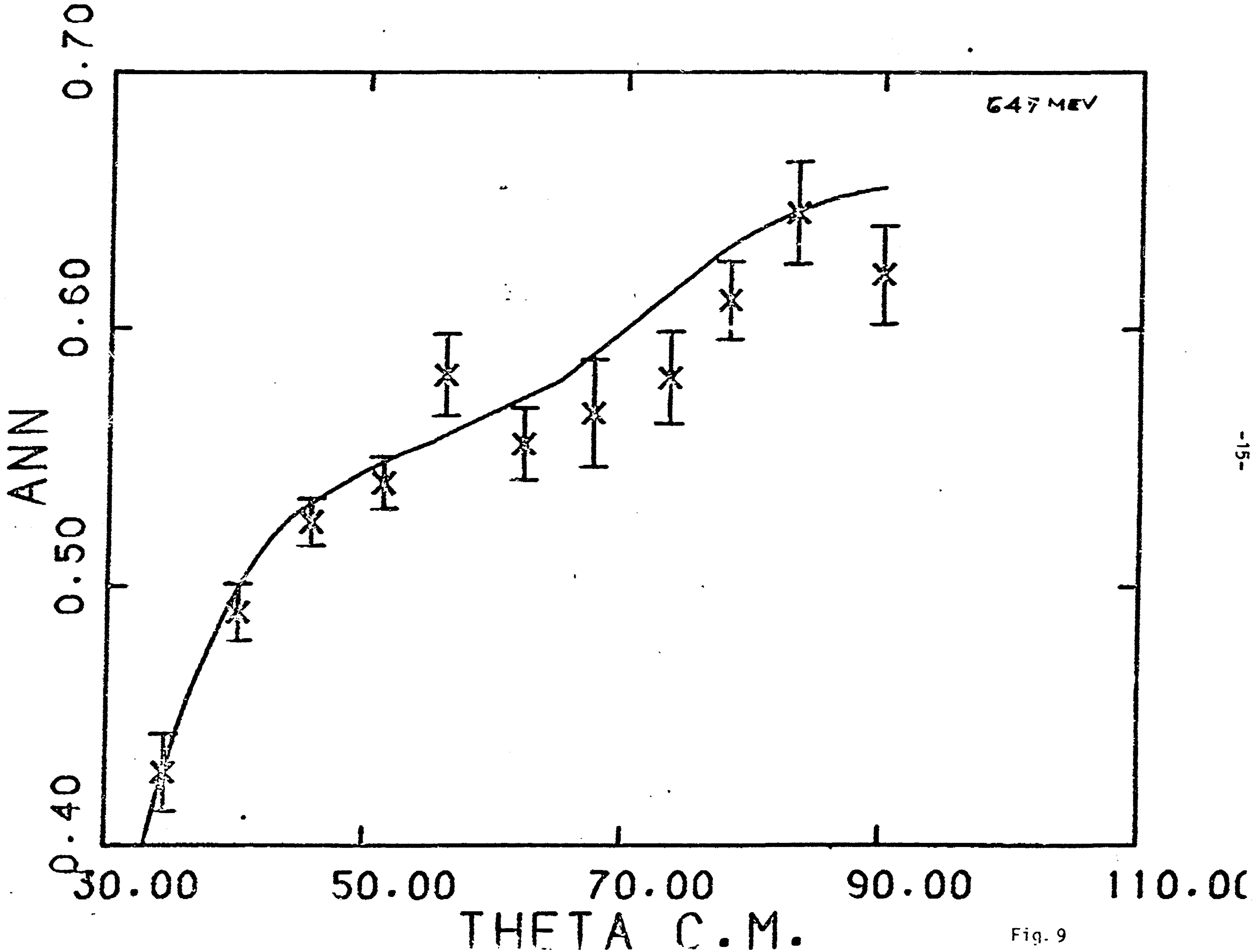


Fig. 9

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