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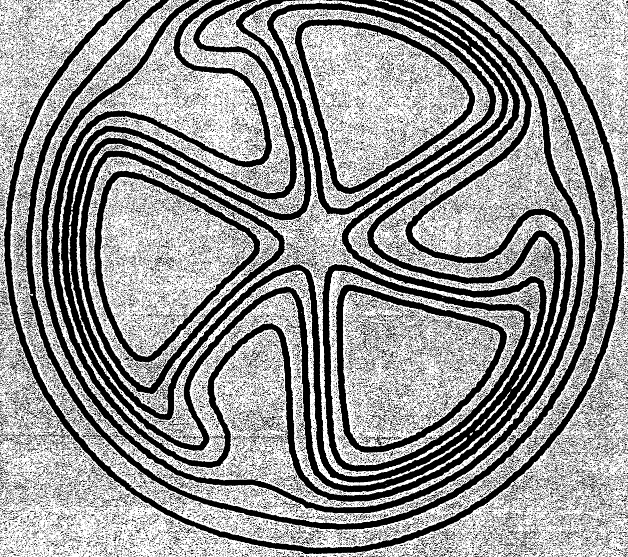

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A High Resolution Study of $^{48}Ca(p,t)^{46}Ca$ at E_p=39 MeV*

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ABSTRACT

The ^{46}Ca nucleus was studied using the (p,t) reaction. A number of spin-parity assignments are clarified for the low-lying states. Many new energy levels are reported up to an excitation energy of 6.3 MeV including an additional 0^+ state at 4.76 MeV. Distorted wave calculations with f-p shell wave functions give reasonable agreement for the first 0^+, 2^+, 4^+, and 6^+ states and for two weak 0^+ states near 5.5 MeV which were strongly excited in the $^{44}Ca(t,p)$ reaction.

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I. INTRODUCTION

There are still many difficulties in using two neutron transfer reactions to check detailed nuclear wave functions. One useful technique is to compare the cross sections for the excitation of the same states, particularly 0^+ states, in the same final nucleus reached by both (p,t) and (t,p) reactions.[1] This method was recently used by Broglia, Kolltveit, and Nilsson[2] in the Calcium isotopes to study 0^+ states. Such a study would benefit by more precise data on the ^{48}Ca(p,t) reaction since the complementary reaction ^{44}Ca(t,p) has already been carried out by Bjerregaard et al.[3] In this stripping experiment a number of 0^+ states were observed between 5 MeV and 6.5 MeV with cross sections from 9% to 55% of the ground state cross section. In the (p,t) experiments on ^{48}Ca[4-7] to date, the energy resolution has not been sufficient to extract these 0^+ states from the high density of states above 5 MeV. In addition the spin assignments for a number of states below 5 MeV from the ^{48}Ca(p,t) experiments did not agree with those from the ^{44}Ca(t,p) experiment.[3] Finally another (t,p) experiment[8] on ^{44}Ca with lower resolution suggested different 0^+ states above 6 MeV. It was therefore decided to carry out the ^{48}Ca(p,t) experiment to check these discrepancies and to compare with the ^{44}Ca(t,p) experiment. A preliminary report of this work has been presented elsewhere.[9]

II. EXPERIMENT

The experiment used the 39 MeV proton beam from the Michigan State University Cyclotron. This gave a maximum triton energy of about 30 MeV, the maximum rigidity particle which could be bent by the Enge split-pole spectrograph. The experiment was performed in two stages which nicely complemented each other. In one case, a single-wire proportional counter was used in the focal plane of the Enge spectrometer with a 1.1 mg/cm^2 self-supporting ^{48}Ca target (96.3% ^{48}Ca) obtained from the Oak Ridge National Laboratory. The energy resolution, primarily limited by the target thickness, was about 50 keV. However this arrangement allowed very accurate angular distributions to be obtained for a number of the strong low-lying excited states from 3° to 70° in the laboratory. Special care was taken to trace out the deep minima, particularly for the 0^+ angular distributions.

A high-resolution study was also carried out in which the tritons were detected in Kodak NTB photographic emulsions. In this case a 50 μg/cm^2 ^{48}Ca target was used. This metallic target was prepared from the carbonate by vacuum evaporation from a tantalum tube. The calcium (enriched to 97.2% ^{48}Ca) was deposited on a 20 μgm/cm^2 carbon foil which was supported by one layer of formvar. The target was stored and transferred to the scattering chamber under vacuum. The resolution of the system was optimized by observing tritons in the focal plane speculator system.[10] A total resolution of 11 keV FWHM was obtained. The plate data were not as extensive as those from the proportional counter because of the limitation of scanning many plates, and extended from 10° to 50° in 4° steps.

III. PROPORTIONAL COUNTER DATA

Angular distributions for a number of states observed using the proportional counter are shown in Fig. 1. At this energy, these angular distributions are quite characteristic of the ℓ-transfer in the reaction and can be used to assign spins and parities to states in ^{46}Ca. For example, the solid line through the angular distribution of the 3.86 MeV state represents the measured angular distribution for the known 4^+ states at 2.58 MeV. Since distorted wave calculations (Section V) give virtually identical angular distributions for an $\ell=4$ angular momentum transfer to states at these excitation energies, the similarity of the angular distributions observed indicates a J^π of 4^+ for the 3.86 MeV state.

The angular distributions for the 4.19 MeV and 4.73 MeV states are also very similar, as is indicated by the identical solid lines drawn through both. As can be noted from the plate data, there is a weak state within 30 keV of the 4.73 MeV state which is not resolved in the proportional counter data. However the plate data indicate that this weak satellite is always at least a factor of ten weaker than the 4.73 MeV state and so does not significantly affect the angular distribution. Spin and parity of 5^- have been assigned to the 4.74 MeV state from a previous (p,t) experiment.[4] The present angular distribution supports this assignment and is clearly inconsistent with spin and parity of 4^+ assigned tentatively from the (t,p) experiment.[3] A spin-parity of 5^- has therefore also been assigned to the 4.19 MeV state.

One more example, although somewhat less clear, is the pair of doublets at 3.6 MeV and 4.4 MeV. Both of these doublets are clearly resolved in the plate data but are combined in the proportional counter data. The doublet at 4.4 MeV has one very weak member so that the angular distribution for the strong member is practically unaffected.

But in the 3.6 MeV doublet, the 2^+ state at 3.64 MeV can modify the angular distribution, particularly near the maximum in the $\ell=2$ angular distribution at a center of mass angle of 32°. The similarity of the distributions except near 30° does however substantiate the spin assignments of 3^- to both the 3.61 MeV and 4.41 MeV states. This result is also confirmed by the plate data discussed in Section IV.

There are a few other points to note from these angular distributions. First the angular distributions of the two 0^+ states are very similar even down to a scattering angle of 3°. The ratio of the two cross sections is about 10.5 to 1. Another feature is the rather strong excitation of the high spin, $J^\pi=4^+$, 6^+, and 5^- states at 2.58 MeV, 2.98 MeV, and 4.73, MeV, particularly when compared to data taken at lower energies.[4,6]

IV. RESULTS USING PHOTOGRAPHIC EMULSIONS

A spectrum of tritons from the photographic plate data is shown in Fig. 2. The regions around 3.6 MeV, 4.4 MeV, and 4.7 MeV are also shown expanded to better illustrate the doublet structure. (Fig. 3) Note also the state at 3.987 MeV which has not been observed previously. No evidence is seen at any angle for the state at 3.780 MeV observed in an inelastic scattering on ^{46}Ca.[11] Many more states were observed above 5 MeV than had been observed previously.

A list of states including energies, and spin-parities are shown in Table I together with those from previous (p,t) and (t,p) experiments. Each run was calibrated using known energy levels up to

3.858 MeV in ^{46}Ca from a recent compilation.[12] Because of the small differences between the average excitation energies from a number of runs and the calibration points and because other measurements with the Enge spectrometer[13] indicate an accuracy of ≤ 2 keV, the errors on the excitation energies up to 3.9 MeV are given to ± 2 keV. Above 3.9 MeV, an additional error of 1 keV per MeV of excitation was added to allow for uncertainty in extrapolation.[13] The excitation energies were internally very consistent. The standard deviations of the mean energy values quoted in Table I were all less than 1 keV except for 5 levels where the standard deviation of the mean was less than 2 keV.

The spin-parity assignments in Table I, were made by comparison with the angular distributions for low-lying states of known spin, with the knowledge that the DWBA calculations of the shapes of the angular distributions with the same ℓ-value change very little up to an excitation energy of 7 MeV. The assignments shown in parentheses are less certain. Angular distributions for many of the levels are shown in Figs. 4 and 5 although some of the strong low-lying states, resolved in the counter data, are not repeated.

Spin-parity assignments can be made for nearly all the levels below an excitation energy of 5 MeV with good reliability because the different ℓ-transfers have quite characteristic angular distributions. Spin assignments of 6^+ and 2^+ were confirmed for the 2.98 MeV and 3.64 MeV states and a value of 4^+ would be assigned to the 3.86 MeV state. Some difficulty has been noted around 4.4 and 4.7 MeV where unresolved doublets have possibly confused previous analyses. A state at 4.43 MeV was assigned a J^π of 2^+ in previous (t,p)[3,8] measurements but was thought to be 3^- from the (p,t) reaction.[4] In the present experiment a close doublet is observed with states at 4.409 MeV and 4.431 MeV. The lower member was assigned $J^\pi=3^-$ but the state at 4.43 MeV does not have a characteristic ℓ-transfer. In particularly it does not appear to be a typical $\ell=2$ shape as required for a J^π of 2^+. Perhaps this state has unnatural parity and a second order process mediates the transfer.

A similar situation arises at 4.7 MeV where a J^π of 4^+ was tentatively assigned to a state at 4.74 MeV in the (t,p) reaction[3] but a $J^\pi=5^-$ in (p,t).[4] The present experiment shows two states, one at 4.73 MeV with $J^\pi=5^-$ and one at 4.76 MeV with $J^\pi=0^+$. This latter states is apparently not strongly excited in the (t,p) process,[3] since no forward angle peaking is observed in the angular distribution.

At excitation energies above 5 MeV very few spins have been even tentatively assigned from other experiments except for 0^+ states. The present (p,t) data suggests a number of J^π assignments including two possible 6^+ states at 5.86 MeV and 5.99 MeV. The 0^+ state observed at 5.32 MeV in the (t,p) reaction[3] is consistent with the few points obtained for a state seen at the same energy in this experiment. However, while states are observed near the energies of two other previously assigned 0^+ states at 5.60 MeV and 5.63 MeV,[3] we did not observe characteristic $\ell=0$ angular distributions for these states. The level at 5.60 MeV is very weak and was only observed at a few angles but the stronger state at 5.64 MeV appears more like an $\ell=4$ transfer than an $\ell=0$. We are only able therefore to assign upper limits to

$\ell=0$ states in this region. The other state at 6.05 MeV tentatively assigned $J^{\pi}=0^{+}$ in the (t,p) reaction[3] again appears to have a more characteristic $\ell=4$ shape in the present (p,t) experiment.

V. DISTORTED WAVE CALCULATIONS

Distorted wave calculations were carried out using the code DWUCK72.[14] Two different sets of proton parameters were used, one due to Becchetti and Greenlees[15] and the other due to Perey.[16] Almost thirty different sets of triton optical parameters, taken from a variety of sources,[2,17,18,19] with real well depths ranging from 113 MeV to 215 MeV were tried in an attempt to get a good fit to the low-lying states. The proton optical parameters and some of the more promising triton parameters are shown in Table II.

Some examples of the fits are shown in Fig. 6. For the ground state transition the comparison between theory and experiment is reasonable for angles greater than 10° but almost all the calculations have difficulty in fitting the forward angle data, which does not rise as rapidly as the calculations. One exception is the calculation with the S2 triton potential[17] but this fails to reproduce the deep minima observed experimentally near $\Theta_{cm}=9°$ and 37°. There is some evidence that this lack of a high maximum at very forward angles is not a sensitive function of the wave functions used. First, the shape of the $\ell=0$ angular distribution calculated using $(d_{3/2})^2$ wave functions is very similar to the angular distribution calculated with $(f_{7/2})^2$ wave functions although the magnitudes are very different. Secondly, the angular distributions for the excited 0^+ state at 2.42 MeV, which presumably has a very different structure from the ground state, has an observed angular distribution which is practically identical to the ground state.

Fits of comparable quality are obtained for the 2^+ and 4^+ states at 1.35 MeV and 2.58 MeV, with again the worst discrepancies being at forward angles. The S2 set of triton parameters again gives angular distributions with too little structure. The comparison of the theoretical and experimental distributions for the 6^+ state at 2.98 MeV is generally worse than for the lower spin states.

The wave functions used to obtain the spectroscopic amplitudes used in these calculations were taken from a paper by McGrory, Wildenthal, and Halbert.[20] These calculations (denoted f-p' in Ref. 20) placed particles in the $0f_{7/2}$, $1p_{3/2}$, $0f_{5/2}$, and $1p_{1/2}$ orbits and used a modified Kuo-Brown interaction. The calculated spectrum for ^{46}Ca was generally in good agreement with the observed low-lying positive parity states except for the second 0^+ and 2^+ states at 2.42 MeV and 3.02 MeV. Two 0^+ states were predicted at 5.13 MeV and 5.49 MeV and these wave functions were also used in distorted wave calculations in making comparisons with the possible 0^+ states observed in this region.

The cross section for the (p,t) reaction is given by[21]

$$\frac{d\sigma}{d\Omega} = \frac{D_o^2 x 9.72}{(2J+1)} \sigma_{DW}^{LSJ}$$

where σ_{DW} is the cross section calculated by the code DWUCK72 and J is the spin of the final state. D_o^2 is a normalization constant for the (p,t) reaction. The constant 9.72 comes from the choice of finite range parameters in the code DWUCK72.[21]

The values of D_o^2, obtained by comparing the theoretical calculation with the ground state cross section near $\Theta_{cm}=22°$, for the four sets of optical parameters which gave reasonable fits to the data, are given in Table III. These values differ by about a factor of three ranging from 22 to 65. The ratio of experimental to theoretical cross sections was calculated for a number of excited states which could be identified in the shell model calculation. These ratios are also presented in Table III. In spite of the substantial differences in the D_o^2 values, the predictions for the remaining states are fairly consistent for the different sets of optical parameters. An average value of the ratio of theoretical to experimental cross sections is therefore also presented in Table III. These values are smaller than unity for the high spin states which probably indicate that the predicted cross section for the ground state transition is too small, rather than that the predicted cross sections for the excited states are too large.

DWBA calculations were also carried out with the f-p' wave functions[20] for the two 0^+ states predicted around 5.5 MeV. In spite of the fact that the cross sections for these states are at least 300 times weaker than the ground state, the predictions are within about a factor of two of the experimental values. Since the states are so weak and basically serve as upper limits on the excitations, this is considered very reasonable agreement.

The main weakness in these calculations is the inability to predict the cross section for the remaining 0^+ states, one at 2.42 MeV and the other, a member of a close doublet at 4.76 MeV. These states have peak cross sections of 40 μb/sr and 10 μb/sr at 22° respectively, and so are much stronger than the states at around 5.5 MeV. These states, particularly the low-lying 0^+ at 2.42 MeV, presumably arise from two particle excitations from the 1s,0d shell, and it would therefore be interesting to attempt a shell model calculation of ^{46}Ca including these orbits.

In addition, these f-p' shell model calculations do not predict the negative parity states in ^{46}Ca, some of which are very strongly excited by the ^{48}Ca(p,t) reaction. Extended shell model calculations to include these states would therefore be of interest.

VI. SUMMARY

The ^{48}Ca(p,t)^{46}Ca experiment was carried out using both a proportional counter and nuclear emulsions to detect the tritons. Ambiguities in previous spin assignments to some low-lying states were resolved when these states were observed to be close doublets. Many new levels were observed up to an excitation energy of 6.3 MeV and a number of spin-parity assignments could be made. Distorted wave calculations using DWUCK72 and 0f,1p shell model wave functions were performed. The calculations were quite sensitive to the choice of optical parameters. For those parameters which gave reasonable fits to the 0^+, 2^+, 4^+, and 6^+ states, the predicted cross sections relative to the ground state were quite consistent with the data although the predictions were generally 20%-40% lower for the higher spin states. This probably reflects insufficient correlations in the ground state shell model wave functions. Calculations for 0^+ states near 5.5 MeV were also within factors of two to three of predictions even though the cross sections for these states were about 300 times weaker than the ground state transition. Further calculations for the remaining states, including two other low-lying 0^+ states await more extensive shell model calculations.

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FIGURE CAPTIONS

Fig. 1 Angular distributions for the $^{48}Ca(p,t)^{46}Ca$ reaction, measured with a position sensitive proportional counter in the spectrograph focal plane.

Fig. 2 A triton momentum spectrum obtained with a nuclear emulsion plate. The peak numbers correspond to those in Table I. The channel width represents a distance of 0.2 mm along the focal plane, or approximately 6 keV.

Fig. 3 Sections of a spectrum showing the details of the doublets observed at excitation energies of 3.6, 4.4. and 4.7 MeV.

Fig. 4 Angular distributions from the nuclear emulsion data for peak numbers 5-26.

Fig. 5 Angular distributions from the nuclear emulsion data for peak numbers 27-46.

Fig. 6 Comparison between distorted wave calculations and the measured angular distributions for four representative states that are excited strongly in the $^{48}Ca(p,t)^{46}Ca$ reaction. The optical model parameters are given in Table II (B-G;B1). The calculated curves have been normalized to fit the observed maximum cross section.

TABLE I: Levels in ^{46}Ca Below 6.4 MeV from (p,t) and (t,p) Experiments

Level No.	Present $E_x \pm E_x$ (MeV)	Expt. J^π	^{44}Ca(t,p) Ref 3		^{44}Ca(t,p) Ref 8		^{48}Ca(p,t) Ref 4	
			E_x (MeV)	J^π	E_x (MeV)	J^π	E_x (MeV)	J^π
1	0.0	0^+	0.0	0^+	0.0	0^+	0.0	0^+
2	1.347±0.002	2^+	1.350	2^+	1.347	2^+	1.35	2^+
3	2.423±0.002	0^+	2.427	0^+	2.425	0^+	2.43	0^+
4	2.576±0.002	4^+	2.573	4^+	2.578	4^+	2.57	4^+
5	2.978±0.002	6^+	2.980				2.98	(6^+)
6	3.024±0.002	2^+	3.024	2^+	3.022	2^+	3.02	(2^+)
7	3.613±0.002	3^-	3.611	3^-			3.62	
8	3.637±0.002	2^+	3.637	2^+				
9	3.860±0.002	4^+	3.857		3.858		3.86	
10	3.987±0.003	(3^-)						
11	4.185±0.003	5^-	4.280				4.19	(5^-)
12	4.409±0.003	3^-					4.43	3^-
13	4.431±0.003		4.429	2^+	4.433	2^+		
14	4.493±0.003	(4^+)						
15	4.734±0.003	5^-	4.742	(4^+)	4.754	4^+	4.74	5^-
16	4.758±0.003	0^+						
17	4.997±0.003	(4^+)	4.993	(2^+)				
18	5.056±0.004				5.011		5.07	
19	5.153±0.004							
20	5.218±0.004							
1	5.251±0.004	4^+						
22	5.316±0.004	$(0+)$	5.316	0^+	5.328	0^+		
23	5.380±0.004	$(3-)$	5.389					
24	5.418±0.004						5.40	
25	5.438±0.004	4^+						
26	5.474±0.004	(3^-)						
27	5.538±0.004		5.531		5.544			
28	5.601±0.004		5.595	0^+			5.60	
29	5.639±0.004		5.628	0^+	5.617		5.63	
30	5.691±0.004		5.682					
31	5.724±0.004							
32	5.785±0.004		5.776					
33	5.821±0.004							
34	5.852±0.004		5.850					
35	5.864±0.004	(6^+)					5.88	
36	5.959±0.004	(2^+)	5.954					
37	5.987±0.004	(6^+)						
38	6.010±0.005							
39	6.037±0.005	(4^+)	6.047	(0^+)				
40	6.077±0.005							
41	6.116±0.005	(2^+)						
42	6.156±0.005							
43	6.201±0.005							
44	6.252±0.005	(4^+)	6.264					
45	6.267±0.005				6.275	2^+		
46	6.309±0.005							

TABLE II: Optical Parameters

Proton Parameters	V_R (MeV)	r_R (fm)	a_R (fm)	W_V (MeV)	W_{SF}^{f} (MeV)	r_I (fm)	A_I (fm)	V_{SO}^{f} (MeV)	r_{SO} (fm)	a_{SO} (fm)
Becchetti-Greenlees[a] (B-G)	47.7	1.17	0.75	5.9	4.0	1.32	0.63	6.2	1.01	0.75
Perey[b] (Pe)	38.4	1.25	0.65	0	10.9	1.25	0.47	8.5	1.25	0.65

Triton Parameters	V_R (MeV)	r_R (fm)	a_R (fm)	W_V (MeV)	r_I (fm)	a_I (fm)
Satchler *et al.* (S1)[c]	203.3	1.048	0.745	14.1	1.604	0.866
Satchler *et al.* (S2)[c]	165.0	0.941	0.854	11.95	1.778	0.702
Flynn *et al.* (F5)[d]	170.1	1.16	0.752	17.0	1.498	0.817
Broglia *et al.* (B1)[e]	144.0	1.24	0.678	30.0	1.45	0.841

[a] Ref. 15

[b] Ref. 16

[c] Ref. 17

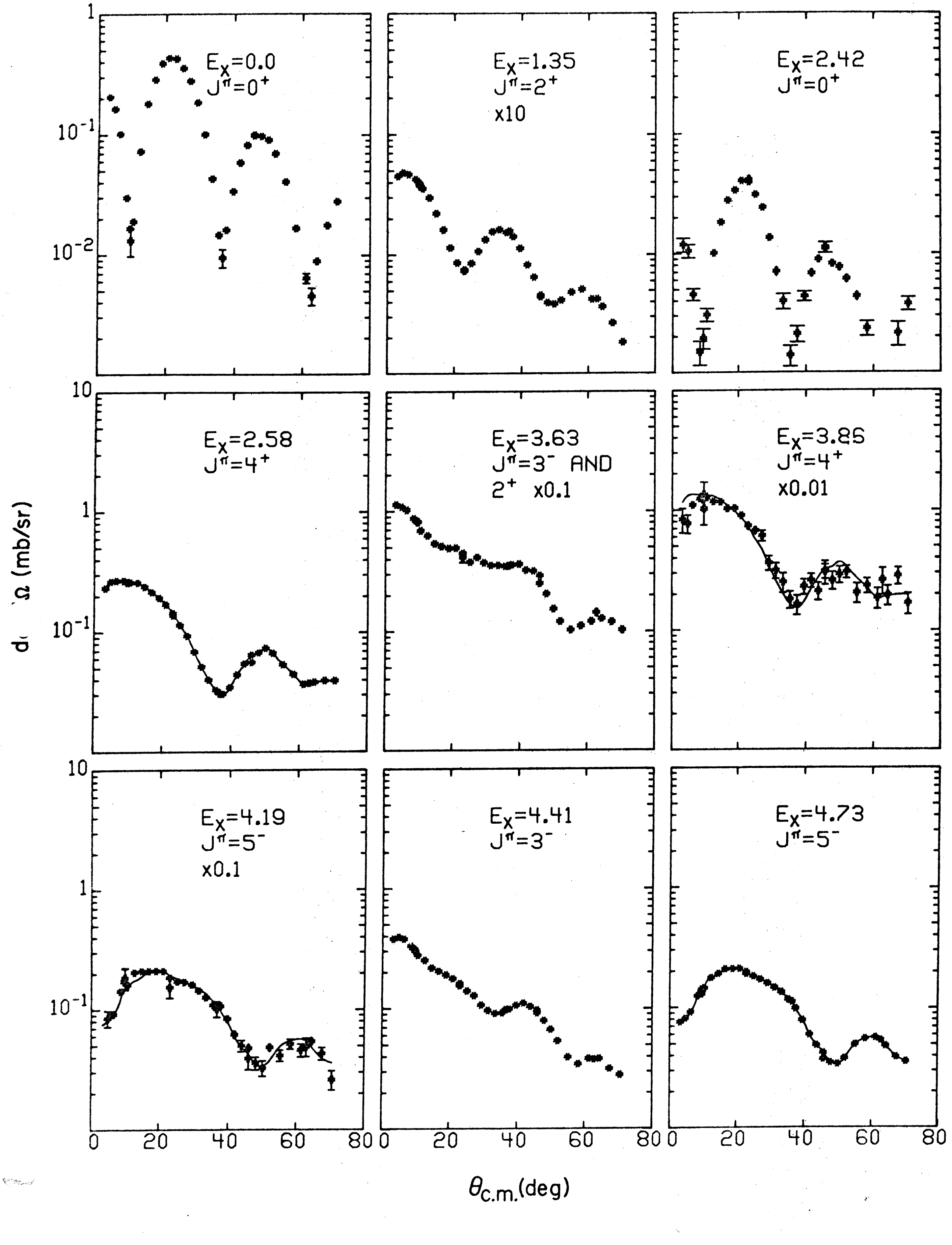
[d] Ref. 18

[e] Ref. 2

[f] DWUCK72 uses values $4W_{sf}$ and $4V_{SO}$

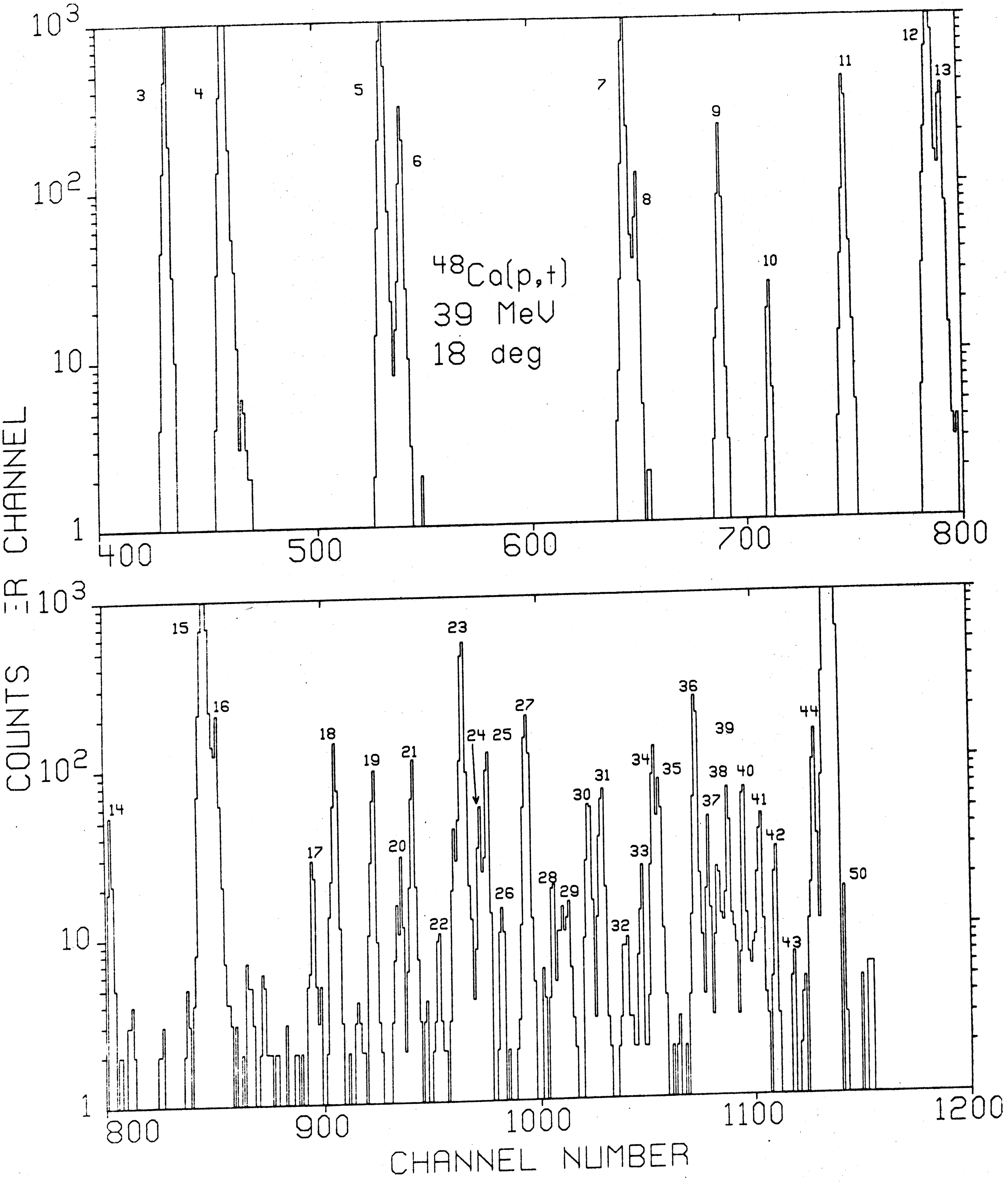
TABLE III: Ratios of $\frac{\sigma_{exp}}{\sigma_{theory}}$ compared using MHW wave functions.

J^π	D_o^2(g.s.)		21.8	65.4	27.3	29.7	
	E_x(theor)	E_x(exp)	Pe:S1	B-G:F5	B-G:S1	B-G:B1	Average
0^+	0.0	0.0	1.0	1.0	1.0	1.0	1.0
2^+	1.44	1.35	0.76	0.78	0.89	1.10	0.88
4^+	2.63	2.58	0.59	0.59	0.69	1.13	0.75
6^+	3.06	3.02	0.62	-	0.52	0.90	0.68
0^+	5.13	5.32	1.5	2.1	1.9	1.9	1.8
0^+	5.49	5.60	2.1	2.6	2.6	2.7	2.5



1
10⁻¹
10⁻²
10
1
10⁻¹
10
1
10⁻¹
Ex=0.0
Jπ=0+
Ex=1.35
Jπ=2+
x10
Ex=2.42
Jπ=0+
Ex=2.58
Jπ=4+
Ex=3.63
Jπ=3- AND
2+ x0.1
Ex=3.86
Jπ=4+
x0.01
Ex=4.19
Jπ=5-
x0.1
Ex=4.41
Jπ=3-
Ex=4.73
Jπ=5-
0
20
40
60
80
dσ/dΩ (mb/sr)
θc.m.(deg)

Figure 1



^{48}Ca(p,t)
39 MeV
18 deg
COUNTS ER CHANNEL
CHANNEL NUMBER
1
10
10^2
10^3
400
500
600
700
800
900
1000
1100
1200
3
4
5
6
7
8
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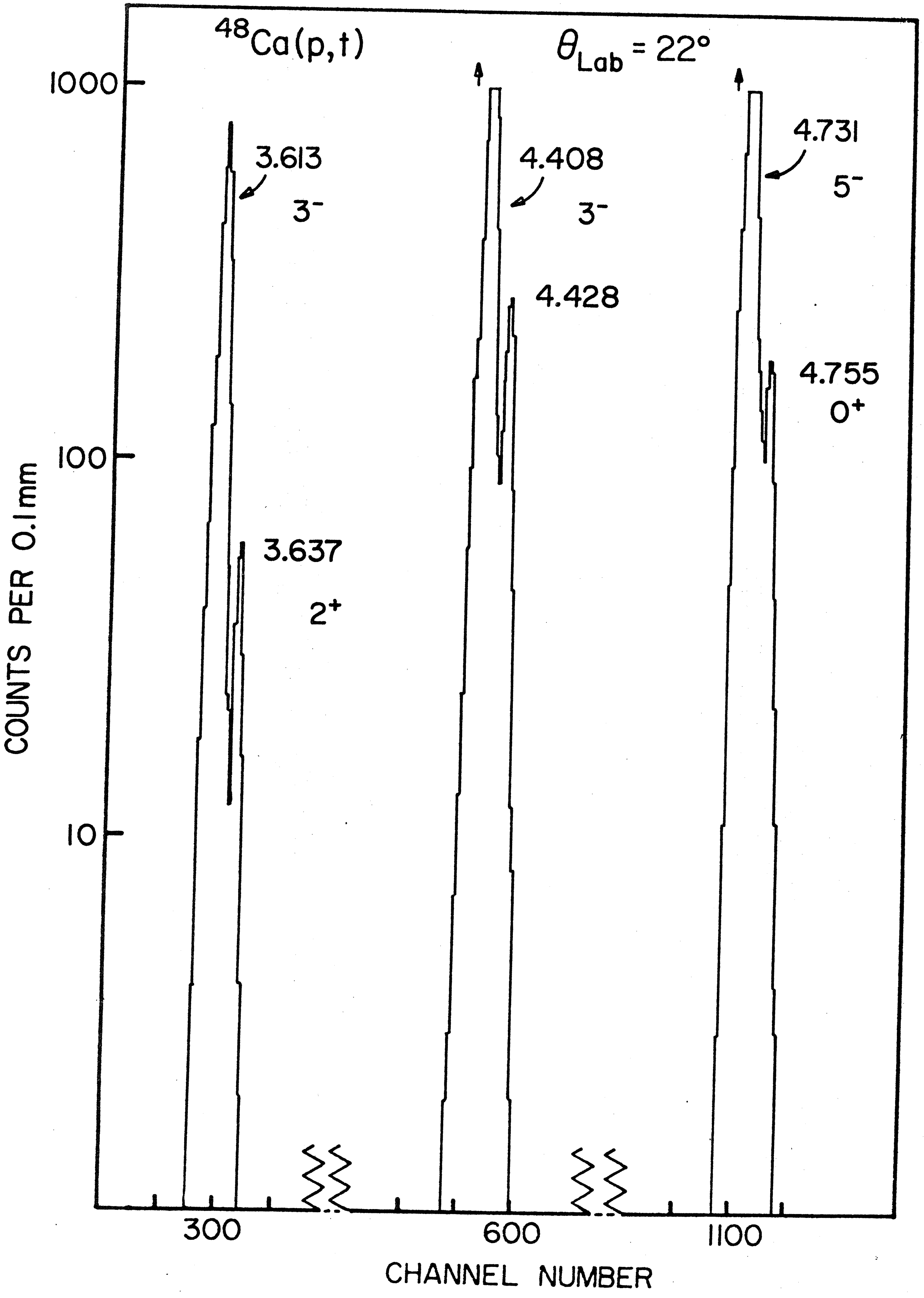
Figure 2



^{48}Ca(p,t)
θ_{Lab} = 22°
1000
100
10
COUNTS PER 0.1mm
3.613
3⁻
3.637
2⁺
4.408
3⁻
4.428
4.731
5⁻
4.755
0⁺
300
600
1100
CHANNEL NUMBER

Figure 3

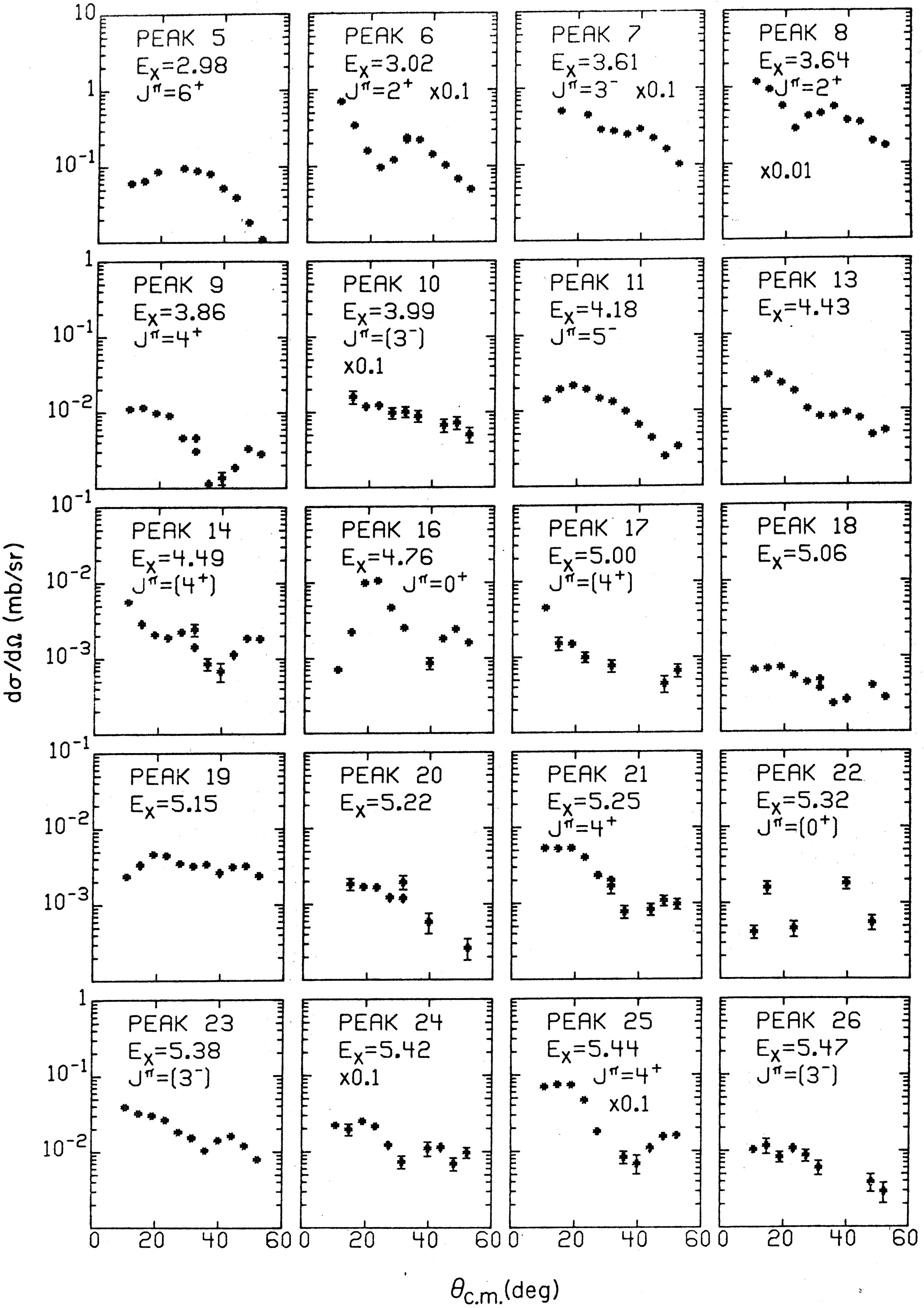

PEAK 5
Ex=2.98
Jπ=6+
PEAK 6
Ex=3.02
Jπ=2+ x0.1
PEAK 7
Ex=3.61
Jπ=3- x0.1
PEAK 8
Ex=3.64
Jπ=2+
x0.01
PEAK 9
Ex=3.86
Jπ=4+
PEAK 10
Ex=3.99
Jπ=(3-)
x0.1
PEAK 11
Ex=4.18
Jπ=5-
PEAK 13
Ex=4.43
PEAK 14
Ex=4.49
Jπ=(4+)
PEAK 16
Ex=4.76
Jπ=0+
PEAK 17
Ex=5.00
Jπ=(4+)
PEAK 18
Ex=5.06
PEAK 19
Ex=5.15
PEAK 20
Ex=5.22
PEAK 21
Ex=5.25
Jπ=4+
PEAK 22
Ex=5.32
Jπ=(0+)
PEAK 23
Ex=5.38
Jπ=(3-)
PEAK 24
Ex=5.42
x0.1
PEAK 25
Ex=5.44
Jπ=4+
x0.1
PEAK 26
Ex=5.47
Jπ=(3-)
10
1
10-1
10-2
10-3
dσ/dΩ (mb/sr)
0
20
40
60
θc.m.(deg)

Figure 4

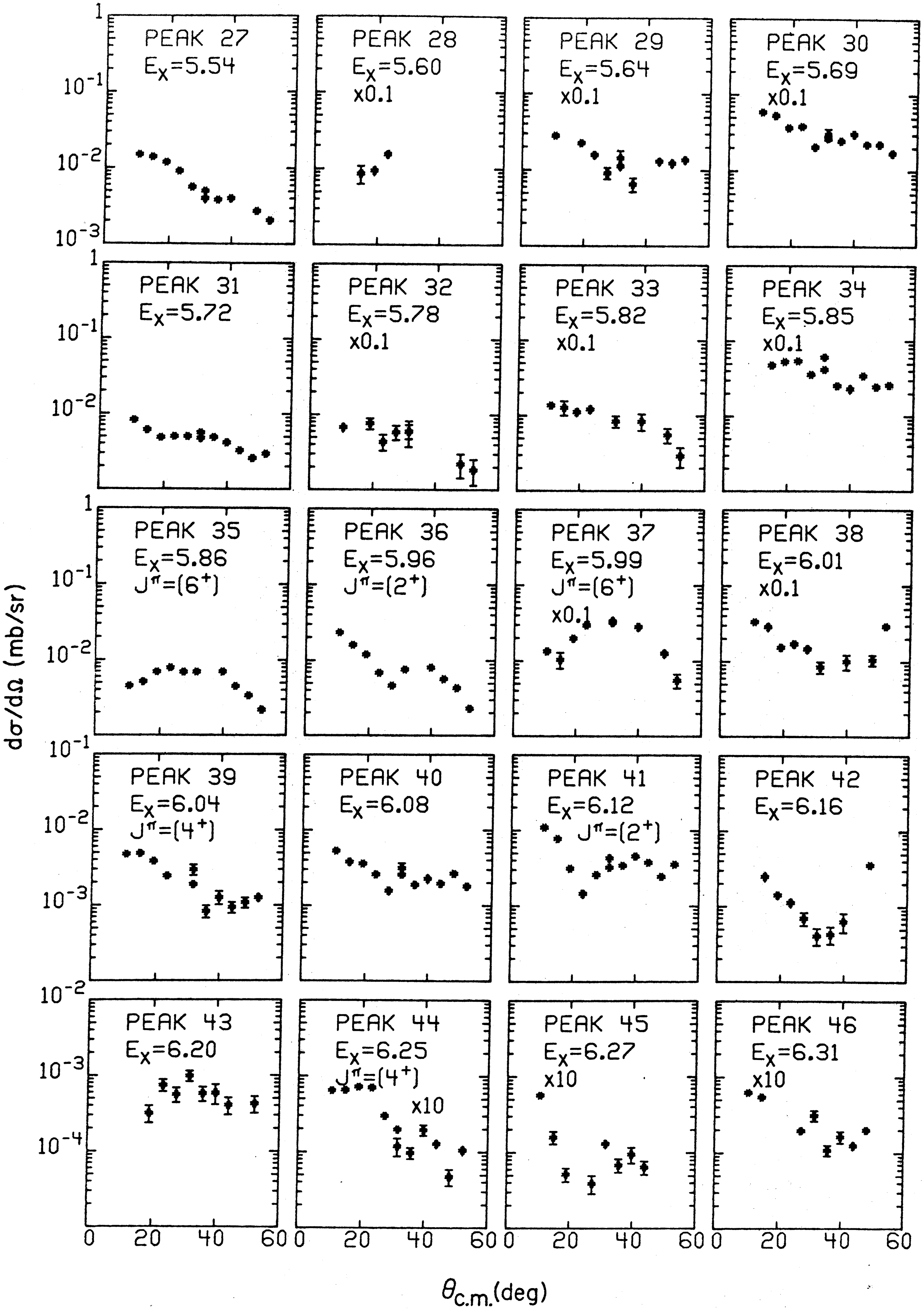
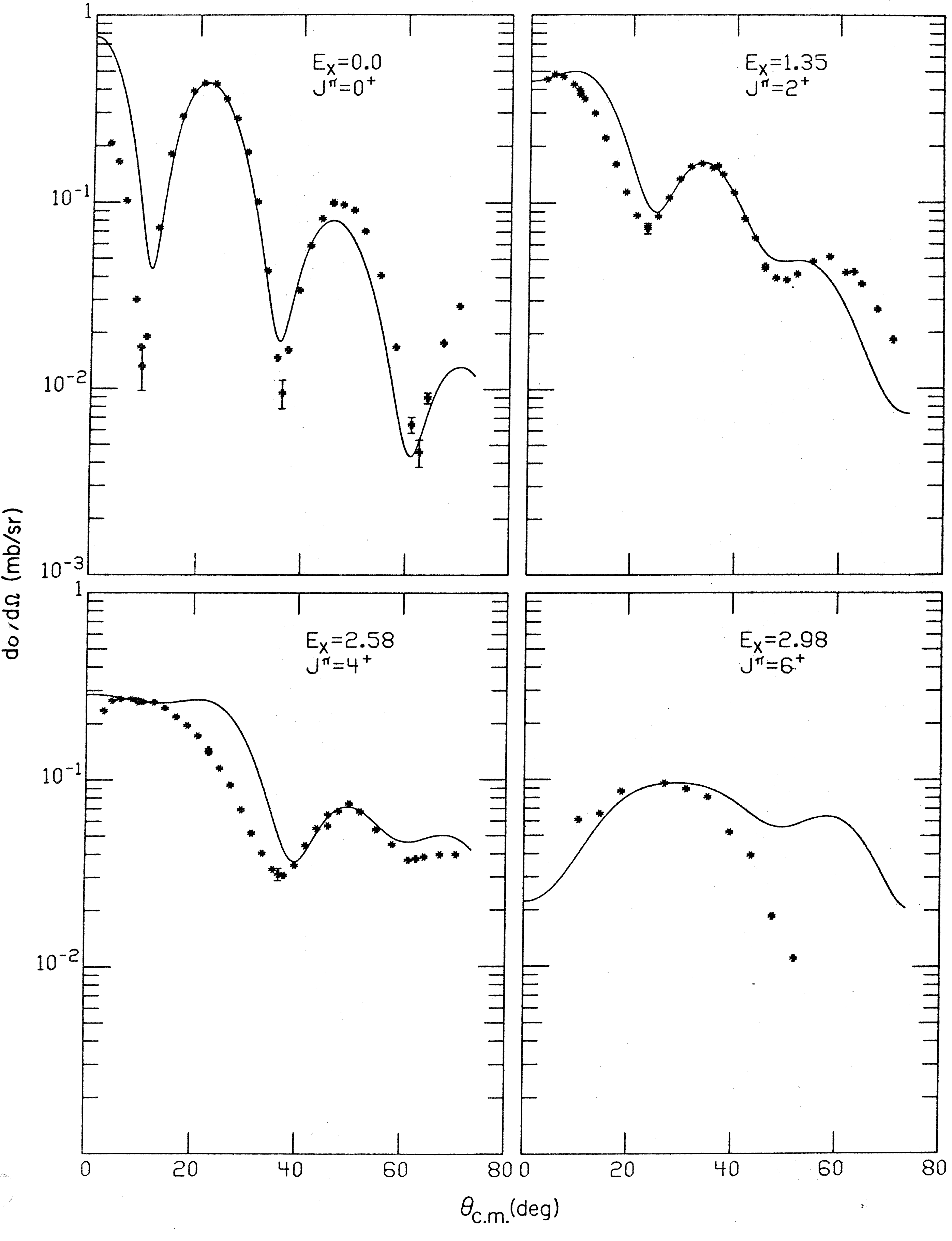

PEAK 27
E_X=5.54
PEAK 28
E_X=5.60
x0.1
PEAK 29
E_X=5.64
x0.1
PEAK 30
E_X=5.69
x0.1
PEAK 31
E_X=5.72
PEAK 32
E_X=5.78
x0.1
PEAK 33
E_X=5.82
x0.1
PEAK 34
E_X=5.85
x0.1
PEAK 35
E_X=5.86
J^π=(6^+)
PEAK 36
E_X=5.96
J^π=(2^+)
PEAK 37
E_X=5.99
J^π=(6^+)
x0.1
PEAK 38
E_X=6.01
x0.1
PEAK 39
E_X=6.04
J^π=(4^+)
PEAK 40
E_X=6.08
PEAK 41
E_X=6.12
J^π=(2^+)
PEAK 42
E_X=6.16
PEAK 43
E_X=6.20
PEAK 44
E_X=6.25
J^π=(4^+)
x10
PEAK 45
E_X=6.27
x10
PEAK 46
E_X=6.31
x10
1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
$d\sigma/d\Omega$ (mb/sr)
0
20
40
60
$\theta_{c.m.}$(deg)

Figure 5



E_x=0.0
J^π=0$^+$
E_x=1.35
J^π=2$^+$
E_x=2.58
J^π=4$^+$
E_x=2.98
J^π=6$^+$
1
10^{-1}
10^{-2}
10^{-3}
dσ/dΩ (mb/sr)
0
20
40
60
80
θ$_{c.m.}$(deg)

Figure 6