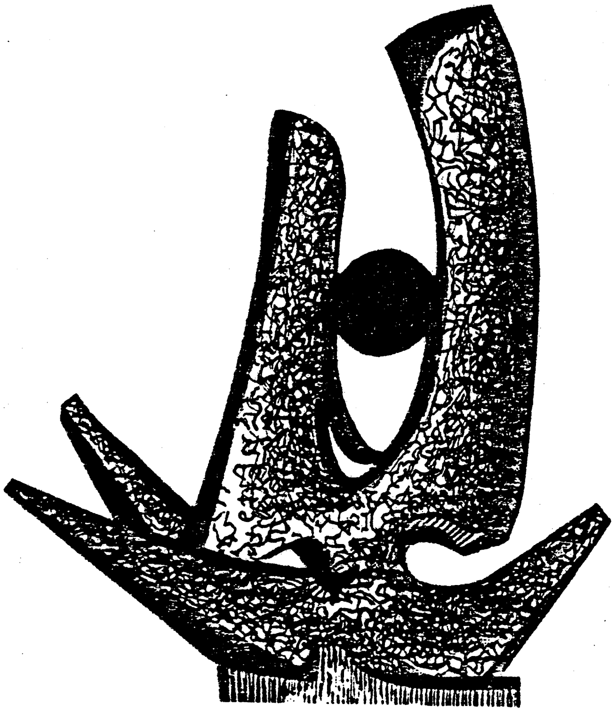
MICHIGAN STATE UNIVERSITY

CYCLOTRON LABORATORY

506

OBSERVATION OF QUENCHING IN ISOSCALAR AND ISOVECTOR $0^+ \rightarrow 1^+$ TRANSITIONS IN $^{28}Si(p,p')$

N. ANANTARAMAN, B.A. BROWN, G.M. CRAWLEY, A. GALONSKY,
B.H. WILDENTHAL, C. DJALALI, N. MARTY, M. MORLET,
A. WILLIS and J.-C. JOURDAIN



DECEMBER 1983

MSUCL-444

MSUCL-444
December 1983

Observation of Quenching in Isoscalar and Isovector $0^+ \rightarrow 1^+$ Transitions in ^{28}Si(p,p')

N. Anantaraman, B.A. Brown, G.M. Crawley, A. Galonsky,
and B.H. Wildenthal

National Superconducting Cyclotron Laboratory
Michigan State University, East Lansing, Michigan 48824

and

C. Djalali, N. Marty, M. Morlet, A. Willis, and J.-C. Jourdain

Institut de Physique Nucléaire, Orsay, France

ABSTRACT: In a study of ^{28}Si(p,p') at 201 MeV, one T=0 and nine T=1 1^+ states have been excited. The observed cross sections for the isoscalar and isovector transitions are about 24% and 33%, respectively, of the values predicted using sd shell-model wave functions and the Love-Franey effective interaction. The large reduction factor in the isoscalar channel, where Δ isobar effects are insignificant, suggests the importance of higher-order configuration mixing effects beyond those included in the full sd-shell calculation.

Submitted to Physical Review Letters

Recent (p,n) measurements of Gamow-Teller (GT) transitions[1,2] and (e,e')[3,4] and (p,p')[5,6] measurements of $0^+ \rightarrow 1^+$ transitions indicate a substantial quenching of isovector spin-flip strength in the low-excitation energy region relative to shell-model predictions which take into account configuration mixing only within a single major oscillator shell. The quenching of the GT strength occurs not only for the "giant" GT transitions observed in (p,n) reactions but also for GT beta decays[7,8] between individual states. Many authors have suggested that the quenching is primarily due to Δ isobar admixtures (ΔA) entering into the nuclear wave functions in first order.[9] While first-order nucleon configuration mixing effects between major shells vanish for the M1 and GT operators, second-order configuration mixing (CM) can give rise to significant quenching[10-13]. In spite of a 300-MeV energy denominator, the effect of ΔA may be greater than the second-order CM because, with no Pauli blocking of Δ's, all of the nucleons contribute coherently.[9,12,13]

In isoscalar $0^+ \rightarrow 1^+$ transitions the first-order ΔA contribution vanishes, since the isobar-to-nucleon coupling is purely isovector. Thus the corrections to isoscalar transitions should be dominated by CM. Comparison of quenching in isoscalar and isovector $0^+ \rightarrow 1^+$ transitions could be very useful in assessing the relative importance of ΔA and CM. In this Letter, we present such a comparison for $0^+ \rightarrow 1^+$ transitions excited in ^{28}Si by small-angle inelastic proton scattering at 201 MeV, which selectively excites such transitions.[5,6,14]

The measurement was carried out using the magnetic spectrometer and focal plane detection system[15] of the Orsay synchrocyclotron. With a natural Si target of 8.7 mg/cm^2 thickness, an energy resolution of 60 keV was obtained.

A spectrum measured at $\theta_{lab}=3.2^o$ is shown in Fig. 1. By combining information obtained from an energy-level tabulation for ^{28}Si,[16] from the measured (p,p') angular distribution shapes, and from a backward-angle (e,e') measurement,[17,18] we have been able to make J^π assignments to all of the indicated peaks in Fig. 1. There are four levels with the same angular distribution shape and that shape is steeper than for the 1^+ levels. Two of these, at 5.00 and 6.72 MeV, are known 0^+ levels, and we make the same J^π assignment for the other two, at 9.73 and 11.15 MeV. The peak at 9.50 MeV is an unresolved doublet, consisting of a known T=0, 2^+ level at 9.48 MeV and a level at 9.50 MeV with T=0 and a J^π assignment of 1^+, 1^- or 2^+. On the basis of its angular distribution, which is discussed below, we choose the 1^+ assignment for the latter level. In the excitation energy range between 10.59 and 15.50 MeV, we observe the eight 1^+, T=1 levels known from electron scattering[17,18] and a nineth one that is not seen in (e,e'). The measured angular distributions for six of the 1^+, T=1 levels and for the 1^+, T=0 level at 9.50 MeV are shown in Fig. 2.

Microscopic distorted-wave impulse approximation (DWIA) calculations for the $0^+\to1^+$ cross sections were carried out

with the code DWBA70[19] using transition amplitudes obtained from a recent shell-model calculation with a new sd-shell Hamiltonian,[20] an optical potential[6] determined from ^{40}Ca(p,p) data at 200 MeV which gave a reasonable fit to our ^{28}Si(p,p) data, harmonic-oscillator bound-state wave functions with an oscillator parameter of 1.82 fm, and the unpublished nucleon-nucleon interaction of Love and Franey (LF).[21] These calculations have been normalized to the data and are shown as the solid lines in Fig. 2. The calculated cross sections changed by <10% on using other available optical potentials or the published LF interaction.[14]

In Table I is shown the correspondence we have made between the experimental and calculated[20] energies of the 1^+ levels. The calculated (p,p') cross sections at a center-of-mass angle of 4^o and theoretical[20] B(M1) values are also listed. In the first of the three columns headed "Quenching" are given the normalization factors for (p,p') ($=\sigma_{exp}/\sigma_{calc}$) obtained from the overall matching between the experimental and calculated angular distributions; the other two columns list the ratios $B(M1)_{exp}/B(M1)_{th}$, using $B(M1)_{exp}$ values from (e,e')[17,18] and (γ,γ'),[22] respectively.

Let us first discuss the T=1 1^+ states. The measured (p,p') angular distributions all have nearly the same shape, which is somewhat steeper than the calculated shape, as was observed also for other nuclei.[5,6] The experimental counterpart of the 12.97 MeV level was not observed, probably because the cross section predicted is only 10^{-4} of that for the 11.52-MeV level. The quenching factor extracted for both the B(M1) values and the (p,p') cross sections varies greatly from level to level, implying that there is a misdistribution of the spin-flip strength in the model calculation. The summed strength given by the model should however be less sensitive to details of the calculation, since it depends principally only on the ground-state wave function. By summing the (p,p') cross sections, observed and calculated, for the nine transitions listed in Table I and taking the ratio, an overall quenching factor of 0.33 is obtained for the isovector channel.

We turn next to the isoscalar 1^+ states. Two states, at energies of 8.33 and 9.50 MeV, are known from gamma-decay systematics.[16] The T=0 assignment for these states is consistent with the fact that no corresponding parent states are known in ^{28}Al. In our experiment, only the second state is excited strongly. For the first state, an upper limit of one-tenth the cross section of the second state can be set. The angular distribution for the latter is shown at the bottom right-hand part of Fig. 2. It is much flatter than the angular distributions observed for the T=1 1^+ transitions. The DWIA calculations reproduce both the T=0 and T=1 data. The difference in the shapes can be understood qualitatively as being due to the strong, attractive $V_{\sigma\tau}$ interaction in the T=1 channel. The good fit obtained for the angular distribution of the 9.50-MeV state is an indication of the pure isoscalar nature of this state. (A known 2^+ level at 9.48 MeV is unresolved from the 9.50-MeV level. The dotted curve represents the contribution of the 2^+ level. Its shape is that which we measured for a known 2^+ doublet at 7.38-7.42 MeV, while its magnitude has been arbitrarily adjusted.)

Only the first, second, and fifth T=0 1^+ states of the model calculation are predicted to have measurable (p,p') cross sections, in the ratio of 1:4:1. The first two states correspond to the 8.33 and 9.50 MeV levels, but the fifth, at a predicted energy of 12.27 MeV, is not seen in our spectra. It is in the midst of several, much stronger T=1 1^+ states and presumably mixes with them through the Coulomb interaction. On omitting this state in both theory and experiment, the overall quenching in the isoscalar channel, obtained by summing the cross sections for the first and second states, is 0.24.

In order to compute the expected quenching, we have approximated the (p,p') $\Delta T=1$ and $\Delta T=0$ operators as being proportional to the GT and isoscalar M1 operators, respectively. It is important to note that the ratio of the summed strengths in the full $(sd)^n$ basis to that of the simple $d_{3/2}\text{-}d_{5/2}^{\;-1}$ model is already small: 0.36, 0.41, and 0.48 for the $\Delta T=0$ (p,p'), $\Delta T=1$ (p,p'), and $\Delta T=1$ M1 transitions, respectively. We have calculated the further quenching relative to the full $(sd)^n$ basis, due to both CM and ΔA effects, by using, in place of the free-nucleon matrix elements, the average of the effective single-particle matrix elements for the ^{16}O and ^{40}Ca closed shells calculated by Towner and

Khanna[13] (TK). This further quenching, for the summed strength below about 15 MeV in excitation, is 0.47, 0.65, and 0.79 for $\Delta T=0$ (p,p'), $\Delta T=1$ (p,p'), and $\Delta T=1$ M1, respectively. These theoretical values are to be compared with the experimental values (Table I) of 0.24, 0.33, and 0.77, respectively.

The difference between the theoretical $\Delta T=1$ M1 and $\Delta T=1$ (p,p') (GT) quenchings arises primarily from the positive contribution of the exchange current corrections to the M1 operator (the exchange current corrections to the (axial-vector) GT operator are relatively small). This explains part of the greater quenching observed in (p,p') relative to (e,e') for the T=1 states-- 0.33 vs. 0.77. The disagreement between experiment and theory for the $\Delta T=1$ (p,p') quenching would be less if we favored the forward-angle data more. The larger calculated quenching for the $\Delta T=0$ (p,p') strength relative to the $\Delta T=1$ (p,p') strength is consistent with that deduced from our experiment. In the isoscalar TK calculation the ΔA effect, of course, does not contribute and the quenching is due almost entirely to CM.

In summary, we find that the extent of quenching for $0^+ \rightarrow 1^+$ transitions in the isoscalar channel in ^{28}Si is comparable to or larger than that in the isovector channel. While the actual magnitude of this quenching is dependent on the details of the calculations we have used to extract it, the relative amounts of quenching in the two channels should be less sensitive to these details. The comparable

quenching in the two channels indicates that the Δ isobar admixture mechanism alone is not sufficient to explain the quenching. Our result, while not ruling out this mechanism, points to the importance of higher-order configuration mixing as a quenching mechanism. A specific calculation of the contribution of both these effects in ^{28}Si is highly desirable.

This work was partly supported by the U.S. National Science Foundation under grants PHY-80-17605 and INT-82-63242. One of the authors (GMC) thanks the University of Paris XI for financial support.

References

1. C.D. Goodman and S.D. Bloom, in "Spin Excitations in Nuclei: 1982", edited by F. Petrovich, (Plenum Press, New York, to be published).
2. C. Gaarde, Nucl. Phys. A396, 127 (1983).
3. W. Knupfer, M. Dillig, and A. Richter, Phys. Lett. 95B, 349 (1980).
4. A. Richter, Nucl. Phys. A374, 177 (1982).
5. C. Djalali et al., Nucl. Phys. A388, 1 (1982).
6. G.M. Crawley et al., Phys. Lett. 127B, 322 (1983).
7. B.A. Brown, W. Chung, and B.H. Wildenthal, Phys. Rev. Lett. 25, 1631 (1978).
8. B.A. Brown and B.H. Wildenthal, Phys. Rev. C 28, 2397 (1983).
9. M. Ericson, A. Figureau, and C. Thevenet, Phys. Lett. 45B, 19 (1973); E. Oset and M. Rho, Phys. Rev. Lett. 42, 47 (1979); H. Toki and W. Weise, Phys. Lett. 97B, 12 (1980); A. Bohr and B.R. Mottelson, Phys. Lett. 100B, 10 (1981).
10. K. Shimizu, M. Ichimura, and A. Arima, Nucl. Phys. A226, 282 (1974); and A. Arima and H. Hyuga, in "Mesons in Nuclei", edited by D.H. Wilkinson (North-Holland, Amsterdam, 1979), p. 683.
11. G.F. Bertsch and I. Hamamoto, Phys. Rev. C 26, 1323 (1982).

12. M. Kohno and D.W.L. Sprung, Phys. Rev. C 26, 297 (1982).
13. I.S. Towner and F.C. Khanna, Nucl. Phys. A399, 334 (1983).
14. W.G. Love and M.A. Franey, Phys. Rev. C 24, 1073 (1981).
15. C. Djalali et al., Nucl. Phys. A380, 42 (1982).
16. P.M. Endt and C. van der Leun, Nucl. Phys. A310, 1 (1978).
17. R. Schneider et al., Nucl. Phys. A323, 13 (1979).
18. A. Richter, in "Nuclear Structure", edited by K. Abrahams, K. Allaart, and A.E.L. Dieperink, (Plenum Press, New York, 1981), p. 241.
19. R. Schaeffer and J. Raynal (unpublished).
20. B.H. Wildenthal, in "Progress in Particle and Nuclear Physics", vol. 11, (Pergamon Press), to be published.
21. W.G. Love and M.A. Franey, private communication (1982).
22. U. Berg et al., 1982 Giessen Annual Report, and to be published.

Table I. Comparison of observed 1^+ levels in ^{28}Si with sd-shell model.

E_x (MeV)		$\sigma^{th}_{p,p'}$	$B_{th}(M1)\uparrow$	Quenching		
Exp	Th[a]	(mb/sr)	(μ_0^2)	(p,p')	(e,e')[b]	(γ,γ')[c]
T=0 States						
8.33	7.94	0.19	0.008	--	--	--
9.50	9.40	0.73	0.031	0.29	--	--
OVERALL (T=0)				0.24	--	--
T=1 States						
10.59	10.81	1.40	1.52	0.15	0.22	0.19
10.73	10.96[d]	0.009	0.003			
10.90	11.19	0.14	0.54	0.54	1.26	1.78
11.45	11.52	1.54	3.06	0.66	1.33	1.32
12.33	12.64	1.28	1.39	0.16	0.58	0.60
--	12.97	0.00	0.00	--	--	--
13.35	13.37	0.27	0.008	0.51	--	--
14.03	14.38	1.34	0.92	0.33	0.49	--
15.15	14.61	0.62	0.87	0.25	0.21	--
15.50	15.02	0.36	0.48	0.18	0.46	--
OVERALL (T=1)				0.33	0.77	0.78[e]

[a] Ref. 20.

[b] Refs. 17,18 and 20.

[c] Refs. 22 and 20

[d] Calculated to be a T=0 state. It appears in the experimental T=1 spectrum presumably due to isospin mixing.

[e] Based on the (γ,γ') data below 13 MeV and the (e,e') data above 13 MeV.

Figure Captions

Fig. 1. Inelastic proton spectrum for ^{28}Si at 3.2°. The arrows indicate the one T=0 and nine T=1 1^+ states observed.

Fig. 2. Angular distributions for seven 1^+ states, one (at E_x=9.50 MeV) with T=0 and the others with T=1. The solid curves are the results of DWIA calculations discussed in the text. The dotted curve for the 9.50-MeV doublet represents the experimental shape for a 2^+ state and the dashed line is the sum of the solid and dotted curves.

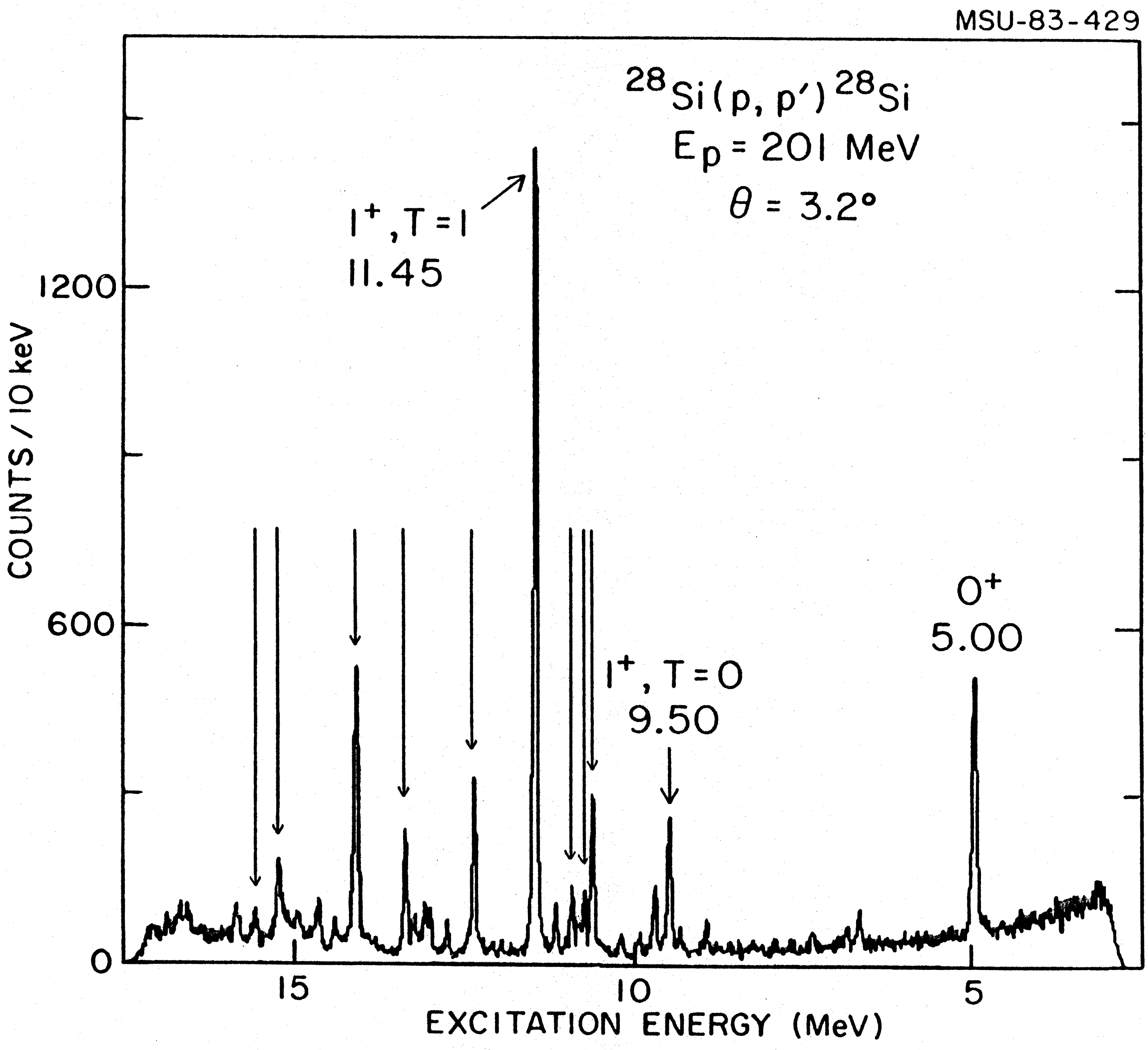

MSU-83-429
^{28}Si(p, p′)^{28}Si
E_p = 201 MeV
θ = 3.2°
1$^+$, T = 1
11.45
1$^+$, T = 0
9.50
0$^+$
5.00
COUNTS / 10 keV
1200
600
0
15
10
5
EXCITATION ENERGY (MeV)

Fig. 1

MSU-83-662

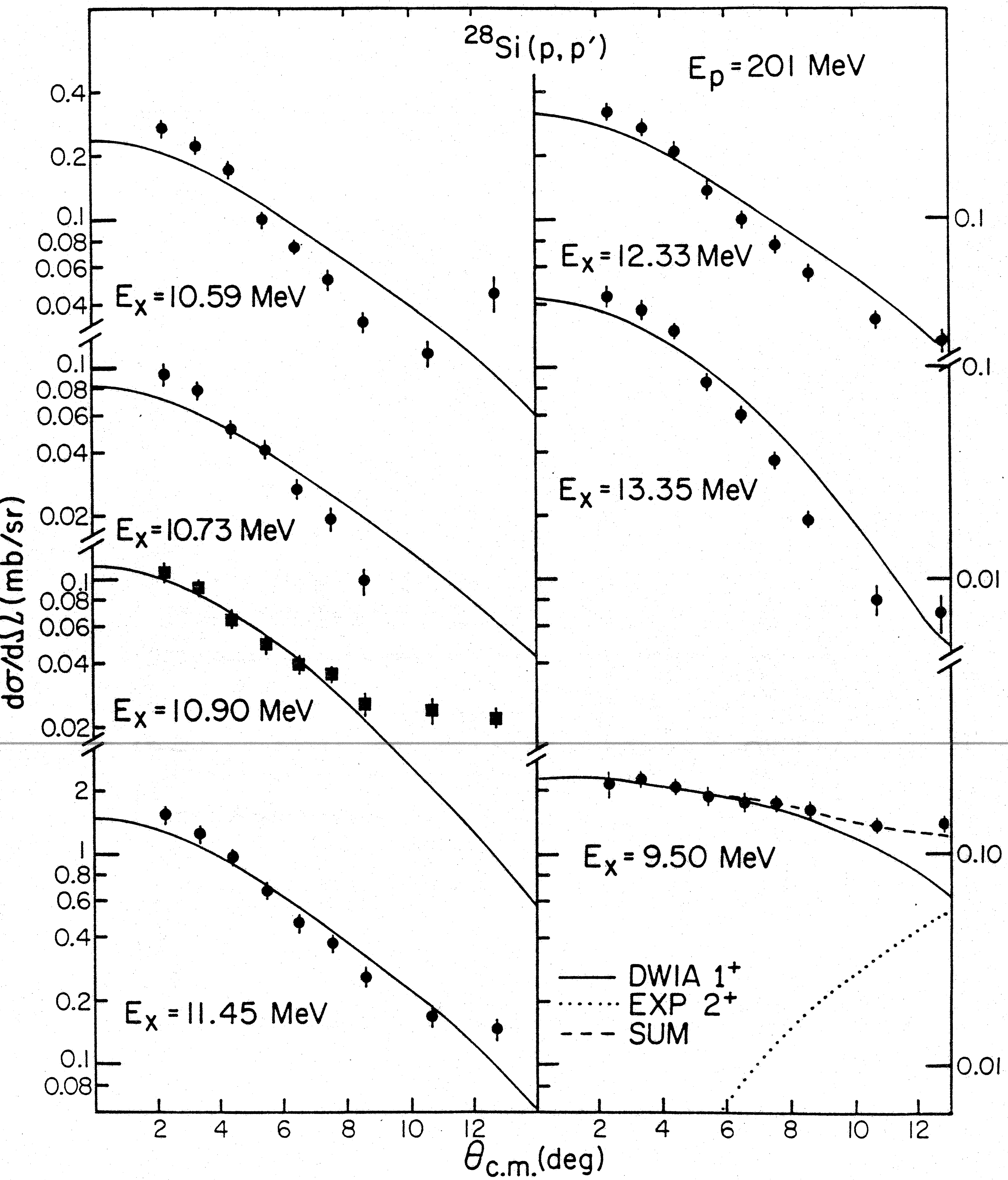


Fig. 2