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Evidence for narrow structure in the analyzing power of the ^{3}He($\vec{p}$,*d*)*X* reaction

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The differential cross section and the analyzing power A_y have been measured for the ^{3}He($\vec{p}$,*d*)*X* reaction at a deuteron angle of 22° (lab) and a proton momentum of 1.46 GeV/*c*. Evidence of narrow structure in the missing mass dependence of A_y was observed. The masses of the maxima are compared with other reports of narrow resonance-like structure and with the predictions of theory. Significant correspondence is found.

Reports of narrow ($\Gamma_{1/2} \leq 50$ MeV) structure in the $B=2$ missing mass spectra have attracted considerable interest in the past few years. Prominent among these for the systematic continuation of the work are those of $I=1$ structure in the ^{3}He(*p*,*d*)*X* reaction and its inverse. Missing mass spectra of the differential cross sections for these reactions, measured at Saclay,[1-4] have shown evidence of narrow structures at several energies and the credibility of these measurements is enhanced by agreement between these energies and resonance energies predicted by a rotation like model[5] inspired by theory.[6,7] Other structures, reported to occur in a variety of reactions,[8] appear to be well accommodated by this model. However, in most cases, reports are based on single, unverified (at times contested) measurements whose statistical significance is open to question and, in all cases the reported structure is small compared to that part of the cross section which varies smoothly with missing mass (which is usually referred to as the underlying "background"). Judging that the Saclay measurements would benefit from independent corroboration, it was decided to search for the reported structure at the Los Alamos Meson Physics Facility (LAMPF). Both the cross section $d\sigma/d\Omega$ and the analyzing power A_y were measured at a deuteron angle of 22° (lab) and at an incident proton momentum of 1.46 GeV/*c*. The latter was included in the hope that it might reveal a greater sensitivity to the effects of eventual resonances. The data obtained so far justify this decision and are reported here with emphasis on A_y.

The experiment was performed at LAMPF. An 8-mm-thick liquid ^{3}He cell was installed at the target position of the High Resolution Spectrometer[9] (HRS) which was used to detect the inclusively deuterons produced at 22° ± 1.4° (lab). A system of multiwire proportional chambers at the focal plane[10] determined momentum and scattering angle while a coincidence between scintillation counters, formed the trigger. Time of flight between the scintillation counters, together with the energy deposited in one of the counters, served to identify the deuterons after momentum analysis. Good particle identification (PID) was essential for rejecting protons which were produced copiously by elastic and inelastic interaction of the beam with all target components, i.e., both the liquid ^{3}He, target cell and cryostat walls. Proton contamination in the worst of cases was less than 2%. It was also necessary to account for deuterons produced by the target cell and the cryostat walls. This was done by means of a dummy-target run for each target-full run. The dummy-target was an empty cell, located immediately below the liquid ^{3}He cell and of identical construction, which could be moved remotely into position. The beam intensity was monitored by means of two argon-CO$_2$ ion chambers located about 1 m downstream of the target while a system of four scintillation telescopes was installed for the purpose of monitoring the luminosity and therefore (given the beam intensity) the target stability. The telescopes were arranged to monitor ^{3}He($\vec{p}$,*p*) elastic scattering at ±35° (lab) where accurate measurements have recently been performed.[11] The two telescopes (at ±35°) served to detect the scattered protons while the other two telescopes located at the conjugate angles (±65°) detected the recoiling ^{3}He in coincidence. Unfortunately, single rates in the monitor counters caused rate-dependent fluctuations at the 5% level. The target stability could therefore not be monitored to better than 5% using the monitor. The design can, however, easily be modified to obtain the desired stability. Beam polarization was monitored by means of a polarimeter[12] located upstream of the target and also by the quench method.[13] It could also be monitored, in principle, by the luminosity monitor using the recent measurements[11] of A_y for the elastic reaction.

The missing mass m_x was varied between 1.97 and 2.24 GeV by varying the spectrometer magnetic field in steps which were initially smaller than the physical spectrometer acceptance so that the data, which were divided in 2 MeV bins (our missing mass resolution), overlapped in one, or at most two, bins. [Only that part (0.8 to 0.5 depending on the field setting) of the acceptance ($\Delta p/p \approx 1\%$) where it does not vary with momentum was used for the differential cross section. Since the acceptance cancels out of the analyzing power the full acceptance could be used for A_y. Because of this larger acceptance a correspondingly larger overlap between the data from adjacent spectrometer magnetic-field settings as well as improved statistics are obtained.] From this overlap, one could conclude that the target thickness was stable to better than 1%. Unfortunately, due to lack of time, this overlap could not be maintained for $m_x \geq 2.16$ GeV and the range $2.07 \leq m_x \leq 2.10$ GeV (where we did not expect to observe structure) was omitted altogether. Furthermore, statistics were allowed to deteriorate with increasing missing mass as seen in Fig. 1 where the differential cross section data are presented, together with the Saclay data taken at the same angle but at 1.40 GeV/c. The uncertainty in the absolute normalization of our data, which was determined from the measurement of $^3\mathrm{He}(p,p)^3\mathrm{He}$ elastic scattering, was estimated to be ±20%. Differential cross sections were calculated assuming the target thickness to be stable as were the analyzing powers A_y which are shown in Figs. 2(a) and 2(b). This assumption was verified to better than 1% for $m_x \leq 2.16$ GeV and to 5% above that, as outlined above. Analyzing powers were calculated before and after dummy-target subtraction. They are shown in Figs. 2(a) and 2(b), respectively. Adjacent data points here have been averaged for the sake of clarity. Statistics are naturally better for the unsubtracted data.

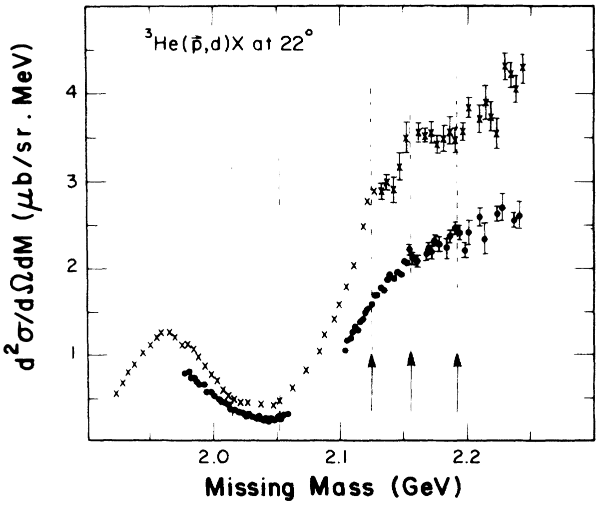

FIG. 1. Differential cross section (●) from this work compared with those from Saclay at 1.40 GeV/c (×). The vertical dashed lines correspond to predicted (Ref. 5) resonance energies. The arrows correspond to the energies at which structure was observed at Saclay.

Also indicated in both figures, by the vertical dashed lines, are the values of m_x given by the rotation-like expression

$$m_x = m_0 + m_1 J(J+1)\ , \qquad (1)$$

with $m_0 = 2.014$ GeV, $m_1 = 18.7$ MeV, $J = 0$–2 for the lowest energies (first band) and $m_0 = 2.155$ GeV, $m_1 = 18.7$ MeV, $J = 0$, 1 for the two highest (second band). This expression is predicted both by conventional models[6] (for $J = l$) as well as by bag models[7] (for $l = 0$).

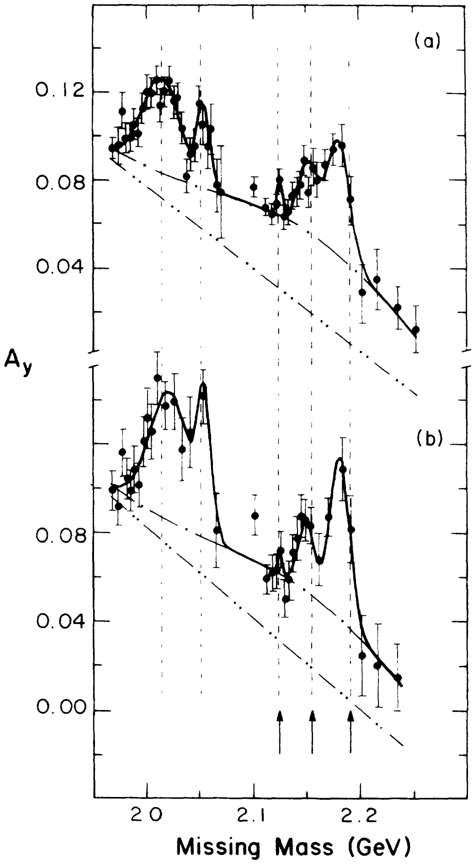

FIG. 2. (a) A_y calculated before dummy-target subtraction, together with the results of our fit (solid curve). The —··— curve represents a linear "background" term while the —·— curve represents the total nonresonant "background" (see text). (b) A_y after dummy-target subtraction. The curves are analogous to those in (a). The vertical dashed lines and the arrows have the same meaning as in Fig. 1.

The values of m_0 and m_1 used here were deduced by Tatischeff[5] from a fit to all reported structures and they are close to theoretical predictions (2.245 GeV and 19.6 MeV for the bag model or 2.015 GeV and 20.0 MeV for the conventional one, for m_0 and m_1, respectively) in the case of the first band. The energies at which structure was observed in $d\sigma/d\Omega$ at Saclay are indicated by the vertical arrows. Some indication of structure corresponding to states predicted at 2.120 and 2.155 GeV is seen in their data at 22° (see Fig. 1). No corresponding evidence is seen in our differential cross section data except perhaps at 2.155 GeV. On the other hand, the variation of A_y with m_x is anything but monotonic [see Figs. 2(a) and 2(b)] and the fact that the structure persists after dummy-target subtraction implies that it occurs in the $^3\mathrm{He}(p,d)m_x$ reaction. The analyzing powers in the contributions from the dummy target are compatible with a constant value of 0.08. These contributions comprise between ~0.2 of the total yield at either end of our data range and ~0.4 near the minimum in the differential cross section.

Interpretation of the A_y data is complicated by the limited energy range (particularly by the absence of data between 2.07 and 2.10 GeV) and by the lack of theoretical predictions. Guided only by the evidence that the *maxima* in the observed structure correspond to the predicted resonance positions, we have fitted a sum of 5 Gaussian functions and a nonresonant "background" term, consisting of a linear function and another Gaussian, to the data. All parameters of the first 5 Gaussians (i.e., amplitude, centroid, and width) were allowed to vary as was the slope of the linear "background" term. The Gaussian "background" term was included to allow for eventual effects of the Δ^{++} resonance so that only its amplitude was allowed to vary. Both the subtracted and unsubtracted data have been fitted and the results are shown with the data in Fig. 2. The peak positions and full widths at half maximum (FWHM) listed in Table I were obtained from the fit to the unsubtracted data, for which the statistics are better, but the results from the fit to the subtracted data are the same within statistics. These results are compared with the corresponding values reported by Saclay and those calculated using Eq. (1). We have not considered the states for $m \geq 2.240$ GeV as they are effectively outside our limits of sensitivity. (2.24 GeV is at the upper limit of our energy range where the bin-widths are increasing with missing mass because of the progressive deterioration in statistics. Statistics might also account for the discrepancy in the 2.192 GeV state.) Equation (1) may be considered representative of theory in so far as identical expressions are predicted by both conventional[6] and bag models[7] with parameters (m_0 and m_1) which differ little from the empirically determined ones. Note, however, that the bag model[7] only reduces to this form for spherical ($l=0$) bags and that the Pauli principle excludes ($I=1$, $J=$odd) states in this case. The odd-J states predicted by Eq. (1) cannot therefore be considered bag-model predictions. For $l\neq 0$ states the bag-model deviates from Eq. (1) as outlined in Ref. 7. These deviations are illustrated by the (scaled) predictions of Ref. 14, in column 6. The scaling factor (i.e., 0.90) applied is the ratio of the empirical[5] to bag-model[7] predictions of m_0 (see above).

Structures reported at Saclay are seen to occur in our A_y data at energies which, with the exception of our highest, agree within uncertainties. The same comment applies to the comparison with the values obtained using Eq. (1) from which one also notes that evidence for *all* resonances predicted in our range of sensitivity is observed in A_y. The scaled values of the bag model predictions also agree reasonably well with the data with the exception of the second state. Naturally, this comparison does not distinguish between predictions which could not be resolved by this experiment. It might also be noted for completeness that the scaled value (1.98 GeV) of the lowest state ($l=1$, $s=0$) predicted by Ref. 14 could correspond to the structure reported recently[4] below the $pp\pi$ threshold at 1.969 GeV.

In conclusion, structure has been observed in the missing mass spectra of A_y for deuterons produced inclusively at 22° (lab) from the incidence of 1.46 GeV/c polarized protons on ^{3}He. All but one of the maxima in this structure correspond to resonance energies predicted in our range of sensitivity. Interpretation of the data is, however, not free from ambiguity because of the smallness of

TABLE I. Position and FWHM (in GeV) for the structures in A_y as obtained from the fit to our data (see text), compared with Saclay results (Ref. 8) and predicted resonance masses. Total χ^2 for the fit was 56 for $n=74$° of freedom.

Fit results		Saclay results		From Eq. (1) (Ref. 5)	Bag model (Ref. 14)
Peak position	Peak FWHM	Peak position	Peak FWHM	Resonance mass	Resonance mass
2.015 ± 0.005	0.034 ± 0.014			2.015	2.015 ($l=0,s=0$) 2.017 ($l=1,s=1$)
2.054 ± 0.004	0.011 ± 0.006			2.052	2.098 ($l=1,s=2$) 2.100 ($l=1,s=0,1,2$)
2.125 ± 0.003	0.006 ± 0.007	2.124 ± 0.003	0.025 ± 0.002	2.124	2.121 ($l=0,s=2$) 2.129 ($l=1,s=0,1$)
2.152 ± 0.004	0.020 ± 0.010	2.155 (?)	0.018 (?)	2.155	2.164 ($l=1,s=1$)
2.181 ± 0.005	0.020 ± 0.008	2.192 ± 0.003	0.025 ± 0.006	2.192	2.175 ($l=2,s=0$) 2.180 ($l=1,s=0,1,2$) 2.185 ($l=1,s=1,2$)

this range and because of the lack of theoretical predictions as to the manner in which eventual resonances might affect A_y. Nevertheless, the fact that as many peaks are observed as resolvable resonances predicted in our range of sensitivity and that the maxima generally correspond to the predicted resonance energies is certainly grounds for speculation and provides stimulus for more measurements with better statistics over a wider range of missing mass. Some are presently being planned at LAMPF. In the meantime, some attempt at calculating the effect of $B=2$ resonances on A_y would certainly be helpful in interpreting the data.

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