Triple angular correlations in the decay of $^{110}Ag^{m}$

K. S. Krane and N. S. Schulz
Department of Physics, Oregon State University, Corvallis, Oregon 97331
(Received 13 October 1987)

Double and triple gamma-ray angular correlations are reported for cascades in ^{110}Cd following the decay of ^{110}Ag. The 764-1505-658 keV triple correlation helps to resolve a long-standing ambiguity concerning the $E2/M1$ multipole mixing ratio of the 1505-keV transition. The potential of triple correlations to contribute to nuclear spectroscopy is thereby demonstrated.

I. INTRODUCTION

In a recent work summarizing triple angular correlations,[1] it was pointed out that the previously published work on triple gamma correlations had produced results that were generally inferior to the results of conventional studies of double correlations. In particular, for triple gamma correlations $\gamma_0\gamma_1\gamma_2$, the precision of the multipole mixing ratio δ_1 of γ_1 deduced from the triple correlation was usually worse than the precision of δ_1 that could be obtained from the double correlation $\gamma_0\gamma_1$ or $\gamma_1\gamma_2$. Purely from the standpoint of counting statistics, the correlation coefficients obtained in a triple correlation are at least a factor of 3 less precise than those that can be obtained in the same counting time in a double correlation (that is, the coincidence rate is at least an order of magnitude smaller). Thus the triple correlation will be a superior method only if the sensitivity of the triple correlation coefficients to δ_1 is at least a factor of 3 greater than the sensitivity of the double correlation coefficients to δ_1. (In general, the triple correlation provides no significant advantage in measuring the multipole mixing ratios of γ_0 or γ_2.)

In the present work, results are reported for triple correlations involving the 1505-keV transition in ^{110}Cd emitted following the decay of $^{110}Ag^{m}$. This case satisfies the above criteria owing to the extreme lack of sensitivity of the double correlations involving that transition. Remeasurements of the double correlations are also reported, and disagreements among the various measurements are resolved.

A preliminary version of this work, based on measurements with three NaI detectors, was previously reported.[2]

II. 1505-keV TRANSITION IN ^{110}Cd

Figure 1 shows the decay scheme of $^{110}Ag^{m}$ to ^{110}Cd. The 1505-keV $E2+M1$ transition is strongly populated in the decay, and is in strong coincidence with the previous 764-keV $E2$ transition and the subsequent 658-keV $E2$ transition. The present work is concerned with the 764-1505 ($\gamma_0\gamma_1$) and 1505-658 ($\gamma_1\gamma_2$) double correlations and with the 764-1505-658 triple correlations.

Owing to the complexity of the decay scheme, older double correlation work using NaI detectors is unreliable in measuring these correlations. There are three published works[3-5] on these double correlations using two Ge detectors; Table I shows the reported correlation coefficients, and Figs. 2 and 3 show the relationships of the measured correlation coefficients to the 1505-keV $E2/M1$ multipole mixing ratio.

The three previous values of the 764-1505 keV correlation coefficients are in good mutual agreement and indicate values of δ near -1.0. The weighted average of the three results is $A_{22}=-0.201\pm0.011$, $A_{44}=-0.006\pm0.016$. From the mean A_{22} it is possible to deduce two values of δ: -0.46 ± 0.07 and -1.28 ± 0.16, where the uncertainties correspond to one standard deviation of the mean A_{22}. However, these uncertainties are not realistic; as shown in Fig. 2, the A_{22} vs δ curve is flat near $\delta\approx-1$, and $1\frac{1}{2}$ standard deviations include the entire region from $\delta=-0.3$ to $\delta=-1.7$. The A_{44} is small and gives no information about δ.

In contrast, the three measured 1505-658 keV correlation coefficients are not in good mutual agreement. The previous results of Krane and Steffen[3] would give values of $\delta(1505)$ either in the range of -0.6 to -0.7 or beyond -2.1, and thus would seem to favor the smaller of the values deduced above from the 764-1505 keV correlation. The results of Gardulski and Wiedenbeck span the range -0.75 to -1.9 and would favor the larger of the values deduced above. The results of Ruhter are beyond the maximum permitted A_{22}, but within two standard deviations would be consistent with values in the range -0.95 to -1.4. From a simultaneous chi-squared analysis of the 764-1505 and 1505-658 keV correlations, Ruhter deduced $\delta=-1.24\pm0.32$. This value has a relatively large uncertainty, owing to the small slope of the A_{22} vs δ curves and the corresponding poor sensitivity of δ to A_{22}.

Two nuclear orientation studies have reported values for the 1505-keV mixing ratio. The dependence of the A_2 obtained in nuclear orientation on δ is identical with that of the A_{22} of the 764-1505 keV correlation shown in Fig. 2; the nuclear orientation data therefore suffer from the same ambiguity in δ values as the 764-1505 keV correlation. Johnston and Stone[6] report two values, -0.48 ± 0.03 and -1.26 ± 0.06 determined from A_2, with A_4 favoring the larger value but only within about

 ©1988 The American Physical Society

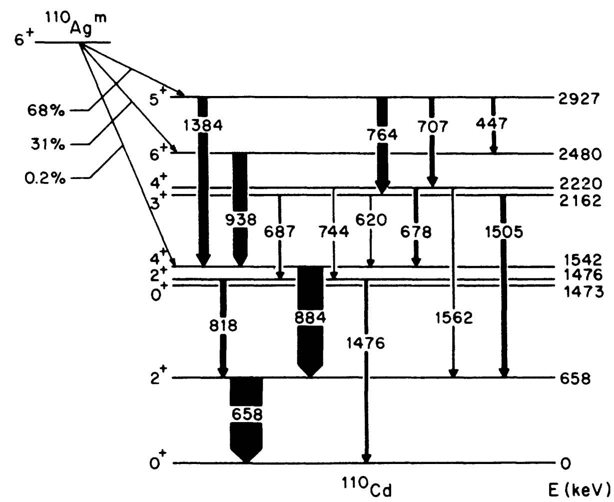

FIG. 1. Decay of ^{110}Ag to ^{110}Cd.

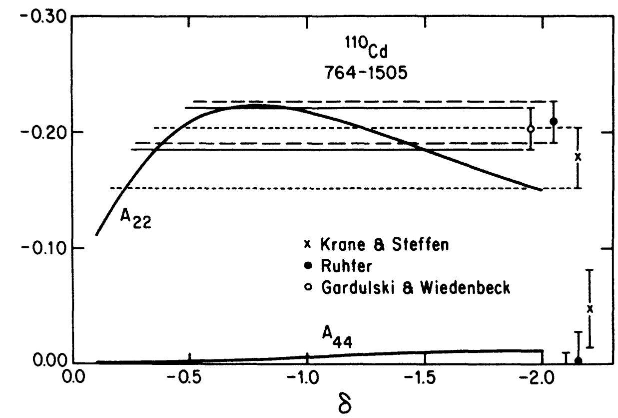

FIG. 2. Angular correlation coefficients A_{22} and A_{44} vs δ for the 764-1505 keV cascade in ^{110}Cd.

two standard deviations. Wang *et al.*[7] reported the smaller value -0.51 ± 0.05, but after the results of Ruhter[5] were reported, they reported[8] the larger value $\delta=-1.09\pm0.10$.

Summarizing the above angular correlation and nuclear orientation results, the 764-1505 keV angular correlation and the nuclear orientation angular distribution are consistent with two values of δ(1505), one near −0.5 and another near −1.2; a mild preference exists for the larger value. The 1505-658 keV correlation cannot resolve the ambiguity, as it is extremely insensitive to δ and the three reported correlations do not agree, possibly owning to a source of systematic uncertainty (to be discussed below).

Figures 4 and 5 show the dependence of the *triple* angular correlation coefficients on the 1505-keV mixing ratio, in the two geometries chosen for this experiment. The difference between the functional dependences of the double and triple correlation coefficients is striking. The triple correlation coefficients do not lose their sensitivity to δ until values beyond −1.2. In the $N2$ geometry, there is a factor of 2 difference between the Γ_2 correlation coefficient at $\delta=-0.5$ and $\delta=-1.2$; even a relatively imprecise measurement of the triple correlation should be able to distinguish between these possible values for δ. This experiment should therefore provide a demonstration of the use of triple correlations to resolve an essential ambiguity that does not seem resolvable with other techniques.

III. EXPERIMENTAL DETAILS

The 764-1505-658 keV triple coincidence is particularly strong in the $^{110}Ag^m$ decay, but there are competing cascades that would not be resolved if two or three NaI detectors were used. With two Ge detectors to select clearly two of the transitions in the cascade, none of the interfering cascades can contribute even if an NaI detector is used for the third radiation. The triple correlation was therefore measured with a system consisting of one NaI (7.5 cm by 7.5 cm) and two Ge ($\sim$40 cm^3) detectors. Source-to-detector distances were about 5 cm for the Ge detectors and 8 cm for NaI.

The coincidences were observed using a conventional fast-slow system with single-channel analyzers (SCA's) selecting the gamma-ray transitions from the pulse-height spectrum [gating a multichannel analyzer (MCA) spectrum provides no advantage in the triples measurement].

The coincidence resolving time was 30 ns, and with a source strength of about 10 μCi, the triple coincidence rate was about 0.06 min^{-1}; the double rates for the 764-1505 and 1505-658 keV cascades were of the order of 4 min^{-1} for the Ge-Ge combination and 40 min^{-1} for the Ge-NaI combinations.

The correction to the triple coincidence rate for chance coincidences includes four contributions: three of the form of a true double with a random triple, and one in which all three signals are random (that is, in the first case, two of the three gammas originate from the same nucleus and the third comes from a different nu-

TABLE I. Gamma-ray double correlations in ^{110}Cd involving the 1505-keV transition.

	764–1505		1505–658	
Ref.	A_{22}	A_{44}	A_{22}	A_{44}
3	−0.178(26)	−0.047(33)	−0.471(10)	−0.040(20)
4	−0.203(18)	+0.017(27)	−0.512(19)	−0.003(27)
5	−0.209(18)	−0.003(25)	−0.557(15)	−0.060(18)

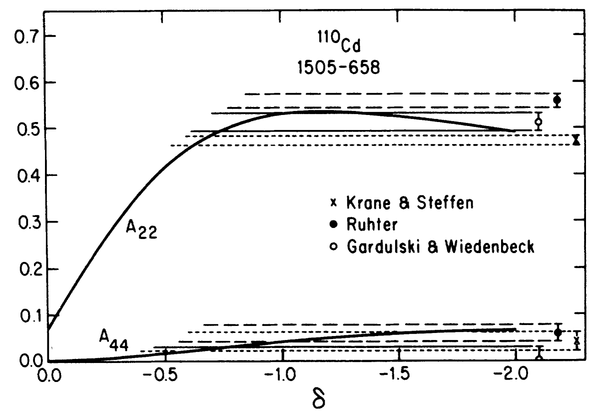

FIG. 3. Angular correlation coefficients A_{22} and A_{44} vs δ for the 1505-658 keV cascade in ^{110}Cd.

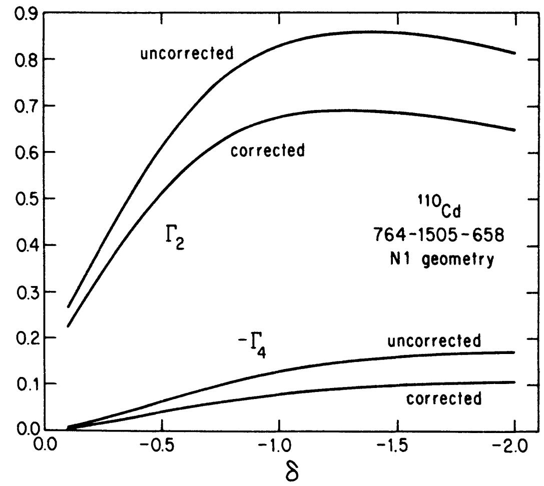

FIG. 4. Triple angular distribution coefficients Γ_2 and Γ_4 for the 764-1505-658 keV cascade in ^{110}Cd in the $N1$ geometry. Note that the negative of Γ_4 is plotted.

cleus, while in the second case all three gammas come from different nuclei). The accidental rate can be measured by introducing delays into the individual fast channels one by one and measuring the rate $R_{(ij)k}$, in which i and j are in time coincidence and k is delayed (by about 200 ns) so as to be outside the timing window. Each of the three such measured ratios, however, also includes a contribution R_{ijk} from the *random* coincidences of i and j in random coincidence with k (the contribution of the second type discussed above). The complete accidental rate for the triple coincidences can thus be determined as

$$R_{\rm acc}=R_{(12)3}+R_{(13)2}+R_{(23)1}-2R_{123} \ . \qquad (1)$$

At the resolving time (30 ns) used in the present experiment, the three rates $R_{(ij)k}$ were of the order of 10^{-3} min^{-1} and the rate R_{123} was of the order of 2×10^{-5} min^{-1} and therefore negligible. The total rate $R_{\rm acc}$ was about 0.0024 min^{-1}, that is, about 4% of the true rate. It should also be noted that only the rate R_{123} is isotropic; the accidental rates $R_{(ij)k}$ have an angular dependence owing to the angular correlation of i and j.

The geometrical configuration of the three detectors determines the anisotropy of the triple correlation and thus its sensitivity to δ of γ_1. The general theory of the triple correlation can be obtained from the formalism for directional correlations from oriented states as given by Krane, Steffen, and Wheeler;[9] the orientation axis is determined by the direction of emission of the first radiation in the triple cascade, which is denoted γ_0 to preserve the notation of Ref. 9. The orientation parameters appearing in the formalism then become the ordinary gamma-ray directional orientation parameters given in Eq. (4) of Ref. 9.

Radiations γ_1 and γ_2 are observed at polar angles θ_1 and θ_2 relative to γ_0, and the azimuthal angle ϕ is the angle between the planes determined by $\gamma_0\gamma_1$ and $\gamma_0\gamma_2$. The triple correlation is then

$$W(\theta_1\theta_2\phi)=\sum_{\lambda_0\lambda_1\lambda_2} B_{\lambda_0}(\gamma_0)A_{\lambda_1}^{\lambda_2\lambda_0}(\gamma_1) \times A_{\lambda_2}(\gamma_2)H_{\lambda_0\lambda_1\lambda_2}(\theta_1\theta_2\phi) \ , \qquad (2)$$

where the indices $\lambda_1\lambda\lambda_2$ of Ref. 9 have been respectively replaced with the indices $\lambda_0\lambda_1\lambda_2$ which are more representative for the triple $\gamma_0\gamma_1\gamma_2$ gamma-ray correlation. Expressions for the generalized angular distribution coefficient $A_{\lambda_1}^{\lambda_2\lambda_0}$ and the angular function $H_{\lambda_0\lambda_1\lambda_2}$ can be found in Ref. 9.

The analysis and interpretation of triple correlation data are simplified if one of a number of possible normal or parallel geometries is chosen as described in Ref. 9. After evaluating Eq. (2) for these simple geometries as well as for a number of other geometrical arrangements, the conclusion was reached that the $N1$ and $N2$ geometries provided the greatest sensitivity to δ. In the $N1$ geometry, θ_1 is fixed at 90°, while in the $N2$ geometry, θ_2 is fixed at 90°. For these geometries, the angular distribution reduces to an expansion in terms of

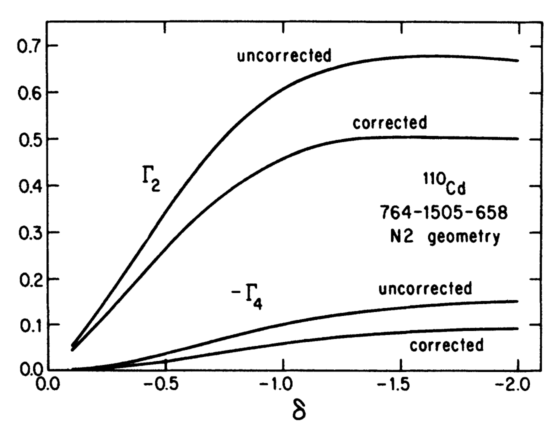

FIG. 5. Triple angular distribution coefficients Γ_2 and Γ_4 for the 764-1505-658 keV cascade in ^{110}Cd in the $N2$ geometry. Note that the negative of Γ_4 is plotted.

ordinary Legendre polynomials

$$W(\theta)=\sum_{\Lambda}\Gamma_{\Lambda}P_{\Lambda}(\cos\theta) \ . \quad (3)$$

Here either θ_1 or θ_2 is fixed at 90° and the other is the variable θ; the angle ϕ is fixed at a conveniently chosen value (180°). The normalized correlation coefficients are

$$\Gamma_{\Lambda}=\frac{\sum_{\lambda_0\lambda_1\lambda_2} Q_{\lambda_0}(\gamma_0)Q_{\lambda_1}(\gamma_1)Q_{\lambda_2}(\gamma_2)B_{\lambda_0}(\gamma_0)A_{\lambda_1}^{\lambda_2\lambda_0}(\gamma_2)g_{\Lambda}^{\lambda_0\lambda_1\lambda_2}}{\sum_{\lambda_0\lambda_1\lambda_2} Q_{\lambda_0}(\gamma_0)Q_{\lambda_1}(\gamma_1)Q_{\lambda_2}(\gamma_2)B_{\lambda_0}(\gamma_0)A_{\lambda_1}^{\lambda_2\lambda_0}(\gamma_2)g_{0}^{\lambda_0\lambda_1\lambda_2}} \ . \quad (4)$$

The geometrical coefficients $g_{\Lambda}^{\lambda_0\lambda_1\lambda_2}$ are tabulated in Ref. 9 for the $N1$ and $N2$ geometries for the case $\phi=0$ or π (in which case the detectors lie in a plane). In Eq. (4), the detector solid-angle correction factors have been included. Figures 4 and 5 show plots of Γ_2 and Γ_4 calculated for the $N1$ and $N2$ geometries, including the solid-angle corrections. For triple correlations, it is not possible to correct experimental correlation coefficients for the solid-angle factors as is normally done in double correlation experiments.

Figure 6 shows the geometrical arrangement used in the present experiments. Detector 1 is a Ge in a fixed position, detector 3 is a NaI fixed at 90° to detector 1, and detector 2 is a Ge that can move in the quadrant indicated. Each detector signal is processed by four SCA's, permitting four simultaneous experiments to be done, two in the $N1$ geometry and two in the $N2$ geometry, as shown in Fig. 6.

IV. RESULTS AND ANALYSIS

In order to check the operation of the triple correlation system, it was first used to measure two other relatively strong cascades in the decay of $^{110}\mathrm{Ag}^m$: 937-885-658 keV and 1384-885-658 keV. The first cascade is 6^+-4^+-2^+-0^+ with three pure $E2$ transitions. The measured values for this cascade in the two geometries from about 8 d of coincidence counting were:

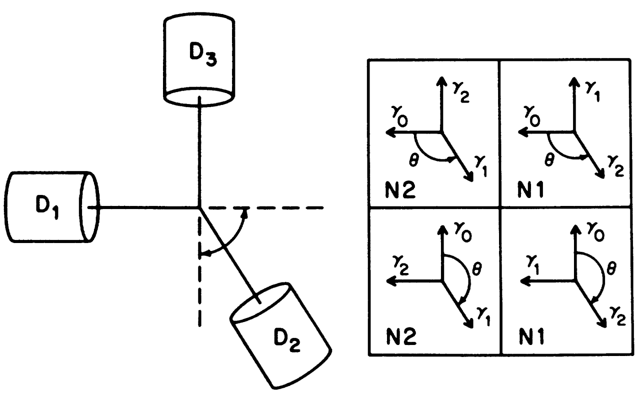

FIG. 6. Geometry of the triple correlation experiment. The three detectors lie in a plane with D_1 (Ge) and D_3 (NaI) at 90° to one another and D_2 (Ge) moving in the quadrant shown. By accepting different gammas in the energy windows, the four configurations shown at right can be achieved.

$N1$: $\Gamma_2=-0.020\pm0.025$, $\Gamma_4=0.030\pm0.028$,

$N2$: $\Gamma_2=-0.009\pm0.023$, $\Gamma_4=0.047\pm0.029$.

The theoretical values computed from Eq. (4) are

$N1$: $\Gamma_2=-0.008$, $\Gamma_4=+0.015$,

$N2$: $\Gamma_2=-0.005$, $\Gamma_4=+0.016$.

For the second cascade (5^+-4^+-2^+-0^+), which was previously measured in the $N1$ geometry by Singh *et al.*,[10] the results, after about 10 d of coincidence counting, were

$N1$: $\Gamma_2=-0.289\pm0.031$, $\Gamma_4=0.009\pm0.036$,

$N2$: $\Gamma_2=-0.316\pm0.027$, $\Gamma_4=0.018\pm0.031$,

which compare well with the theoretical values:

$N1$: $\Gamma_2=-0.307$, $\Gamma_4=-0.013$,

$N2$: $\Gamma_2=-0.314$, $\Gamma_4=-0.015$.

The above theoretical values were calculated with the precisely known result $\delta(1384)=-0.42$.

The excellent agreement between theory and experiment in these test cases, one with a nearly vanishing anisotropy and the other with a reasonably large anisotropy, suggests that there are neither spurious contributions to the triple correlations nor unexpected attenuations.

The 764-1505-658 keV triple correlation was measured for about 4 weeks. The results, corrected for accidental coincidences, are as follows:

$N1$: $\Gamma_2=0.72\pm0.03$, $\Gamma_4=-0.11\pm0.03$,

$N2$: $\Gamma_2=0.41\pm0.03$, $\Gamma_4=-0.04\pm0.03$.

For the $N1$ geometry, the results can be compared with the curves plotted in Fig. 4. The experimental result overlaps a broad section of the Γ_2 curve between about -1.1 and -1.6, but is clearly inconsistent with $\delta\approx-0.5$, for which $\Gamma_2=0.51$. The results for the $N2$ geometry would be consistent with $-0.8\le\delta\le-1.1$ and again inconsistent with $\delta\approx-0.5$ ($\Gamma_2=0.26$).

An alternative approach to the analysis of these data is to produce a χ^2 plot of the type described by James *et al.*[11] Figure 7 shows the χ^2 values for the $N1$ and $N2$ geometries. Adopting the conservative criteria of James *et al.* for the assignment of the limit corresponding to one standard deviation, the results are $\delta=-1.33\pm0.35$

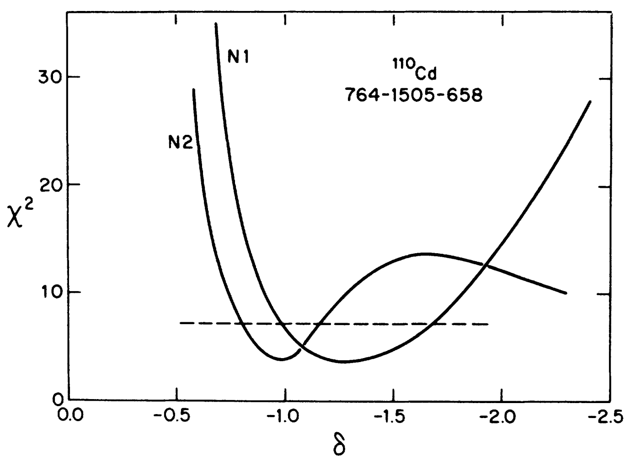

FIG. 7. Chi-squared analysis of triple-correlation data. The dashed horizontal line shows the limit corresponding to one standard deviation.

from the $N1$ geometry and $\delta=-0.98\pm0.18$ from the $N2$ geometry; the allowed regions overlap nicely and the weighted average is $\delta=-1.05\pm0.16$. Figure 7 also illustrates that the triple correlation data do not permit a solution near $\delta=-0.5$.

The triple correlation data therefore support the choice of the larger of the two δ values obtained from the 764-1505 keV correlation and the nuclear orientation angular distribution. The double correlations will be examined in more detail in the next section.

V. REMEASUREMENT OF DOUBLE CORRELATIONS

To resolve the discrepancies among the previously reported results for the 1505-658 keV correlation, the two double correlations involved in the present work were remeasured using the two Ge detectors. With the detectors at about 5 cm distant from the source, the measured correlation coefficients, corrected for geometry, were

$$\text{764-1505 keV:}\quad A_{22}=-0.199\pm0.005\ ,$$
$$A_{44}=-0.005\pm0.006\ ,$$
$$\text{1505-658 keV:}\quad A_{22}=-0.492\pm0.004\ ,$$
$$A_{44}=-0.042\pm0.005\ .$$

In accumulating these data, special care was taken with detector alignment and shielding to eliminate two sources of systematic error. The errors are statistical only and were computed at the level of one standard deviation.

The 764-1505 keV results are in good agreement with the previous values listed in Table I. The 1505 keV mixing ratios corresponding to these results, calculated from a χ^2 analysis, are -0.48 ± 0.04 and -1.24 ± 0.07. The errors correspond to one standard deviation and are essentially identical with the values of δ that would be obtained directly from A_{22}.

The 1505-658 keV results agree rather poorly with the previous results listed in Table I, and would lead to 1505-keV mixing ratios of -0.75 ± 0.02 or -2.1 ± 0.1, in poor agreement with the now well established value of -1.2. The questions therefore follow as to why this discrepancy occurs and why the results for this correlation seem to be in such poor agreement.

Ruhter[5] has speculated that the source of this discrepancy is the effect of gamma-ray summing in the 1505 keV transition. The 687 + 818 keV branch competes with the direct 1505-keV transition; the relative intensity of the summing branch is about 24% compared with the direct branch of 76%, and it is plausible that such summing could indeed play a role. The measured 1505-658 keV correlation has such a large anisotropy and such a small relative statistical uncertainty that even a small correction could have a substantial effect in altering the anisotropy. However, this speculation is inconsistent with both experimental and theoretical analysis. Since the summing correction ought to be reduced as the source-to-detector distance increases, the double correlations were repeated with the distance increased from 5 cm to 8 cm. The correlation coefficients at 8 cm, corrected for geometry, are

$$\text{764-1505 keV:}\quad A_{22}=-0.197\pm0.007\ ,$$
$$A_{44}=-0.005\pm0.009\ ,$$
$$\text{1505-658 keV:}\quad A_{22}=-0.501\pm0.007\ ,$$
$$A_{44}=-0.049\pm0.008\ .$$

The probability of summing can be estimated as the ratio of the relative intensities of the summed and nonsummed correlations:

$$\frac{I(\text{764-687+818})}{I(\text{764-1505})}=\frac{0.31\epsilon_{687}\epsilon_{818}\Omega}{\epsilon_{1505}}\ ,$$

where the ϵ's represent relative detector efficiencies and Ω is the detector solid angle (which introduces the dependence on the distance between the source and detector). The factor of 0.31 originates from the relative intensity of the 687 + 818 keV branch. Estimating the detector efficiencies to vary with energy roughly as $E^{-1.2}$, the ratio can be written as $1.7\epsilon_{1505}\Omega$ which evaluates to 2×10^{-3} at 5 cm or 0.8×10^{-3} at 8 cm. The effect of the summing correction on the observed angular correlation requires the calculation of the *triple* correlation in which the 687- and 818-keV radiations are emitted in the same direction. The triple correlation 764-687-818 keV in which 687 and 818 keV are emitted in the same direction can be computed from Eq. (2) with $\phi=0$, and $\theta_1=\theta_2$. The result, calculated with $\delta(687)=-1.76$ and $\delta(818)=-1.29$, is of the form of Eq. (3) with $\Gamma_2=-0.175$ and $\Gamma_4=-0.007$, thus indicating a negligible effect on the measured 764-1505 keV double correlation. For the correction to the 1505-658 keV correlation, it is necessary to evaluate the 687-818-658 keV triple correlation from Eq. (2) with $\phi=0$, $\theta_1=0$, and $\theta_2=\theta$; this is just the $P1$ geometry of Ref. 9. The resulting correlation coefficients are $\Gamma_2=0.26$, $\Gamma_4=0.56$.

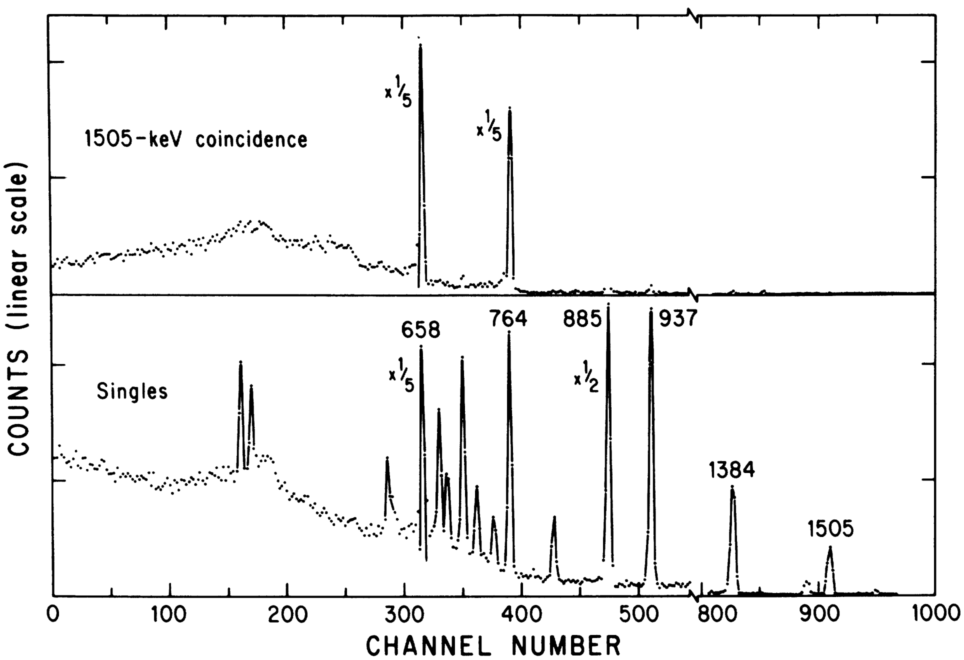

FIG. 8. Singles (bottom) and 1505-keV coincidence spectra of $^{110}Ag^m$ decay. The small peaks in the coincidence spectrum are from accidental coincidences.

Even at 5 cm, the 2×10^{-3} correction will not influence the measured correlation coefficients beyond the statistical uncertainty, and the Γ_4 correction ought to affect the measured A_{44} more than the Γ_2 correction affects the A_{22}. This seems not to be the case, as the 8-cm data for the 1505-658 keV correlation agree with the 5-cm data and in neither case agree with the expected value for $\delta=-1.2$ ($A_{22}=-0.535$).

A more likely explanation for the discrepancy is the presence in the 658-keV window of events associated with the Compton distribution of the 764-keV transition (see Fig. 8). Gating windows set on the background adjacent to the 658-keV peak showed anisotropies characteristic of the 764-1505 keV correlation. The background correction in the 658-keV window is estimated to be $8\pm1\%$; the 8-cm correlation data are thereby corrected to $A_{22}=-0.527\pm0.008$, which agrees with the expected value for $\delta=-1.2$. This background correction appears to account for the disagreement between the 1505-658 keV correlation and the other results, and it can finally be concluded that all results for the 1505-keV correlation are in good agreement: -1.05 ± 0.16 from the present triple correlation, -1.24 ± 0.07 from the present 764-1505 keV correlation, -1.09 ± 0.09 and -1.26 ± 0.06 from the nuclear orientation data of (respectively) Wang[8] and Johnston and Stone,[6] and -1.24 ± 0.32 from the simultaneous 764-1505 keV and 1505-658 keV analysis of Ruhter,[5] which by virtue of the use of two-dimensional coincidences should be unaffected by these background corrections. The weighted average of these results is -1.21 ± 0.04 (normalized chi-square = 0.9), suggesting that this result should be adopted as the best value for the 1505-keV mixing ratio.

VI. SUMMARY AND CONCLUSIONS

The present work has demonstrated the potential of the triple correlation technique for deriving significant nuclear spectroscopic information in certain selected cases. If a decay scheme has a relatively strong triple cascade, it will therefore have two strong double cascades involving the same transitions. In most cases, the double correlations will yield the better and more precise information, owing to their superior precision resulting from counting statistics. In a few rare cases such as the present one, in which the correlations are strong but ambiguous, the triple correlation may provide the critical information needed.

The precise knowledge of $E2/M1$ multipole mixing ratios is often essential for the analysis and interpretation of the results of calculations of nuclear parameters from a particular theory or model. In the case of the transitions in ^{110}Cd, Arima and Iachello[12] have used the vibrational limit of interacting boson approximation (IBA) to calculate the $E2/M1$ multipole mixing ratios of eight transitions for which precise experimental values are available for comparison. In general, the agreement between theory and experiment is quite good. However, the 1505-keV transition is forbidden in the "pure" d-boson limit, and its mixing ratio is thus a sensitive measure of the mixing of terms in the IBA Hamiltonian. Precise knowledge of the $E2/M1$ mixing ratio of this transition therefore is of particular importance, and the present resolution of the previous discrepancies provides improved input for such calculations.

The present work was supported in part by the U. S. Department of Energy under Contract DE-FG06-87ER40345.

[1]K. S. Krane, Nucl. Instrum. Methods **214**, 321 (1983).
[2]K. S. Krane and N. S. Schulz, Bull. Am. Phys. Soc. **30**, 1258 (1985).
[3]K. S. Krane and R. M. Steffen, Phys. Rev. C **2**, 724 (1970).
[4]P. L. Gardulski and M. L. Wiedenbeck, Phys. Rev. C **7**, 2080 (1973).
[5]W. D. Ruhter, Ph.D. thesis, University of California, 1977, Report No. UCRL-523360; see also W. D. Ruhter and D. C. Camp, Nucl. Instrum. Methods **173**, 489 (1980).
[6]P. D. Johnston and N. J. Stone, Nucl. Phys. **A206**, 273 (1973).
[7]G. W. Wang, A. J. Becker, J. L. Groves, L. M. Chirovsky, and C. S. Wu, Bull. Am. Phys. Soc. **22**, 566 (1977).
[8]G. W. Wang, A. J. Becker, L. M. Chirovsky, J. L. Groves, and C. S. Wu, Phys. Rev. C **18**, 476 (1978); see also G. W. Wang, Ph. D. thesis, Columbia University, 1977 (unpublished), available from University Microfilms No. 77-24,131.
[9]K. S. Krane, R. M. Steffen, and R. M. Wheeler, Nucl. Data Tables **11**, 351 (1973).
[10]B. P. Singh, H. S. Dahiya, and U. S. Pande, Phys. Rev. C **4**, 1510 (1971).
[11]A. N. James, P. J. Twin, and P. A. Butler, Nucl. Instrum. Methods **115**, 105 (1974).
[12]A. Arima and F. Iachello, Am. Phys. (NY) **99**, 253 (1976).