A NEW METHOD FOR THE CORRECTION OF $\gamma$-$\gamma$ CORRELATION MATRICES

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A new method for the correction of $\gamma$-$\gamma$ correlation matrices based on the unfolding of the detector response function is presented. Results from this unfolding method are given for coincidence data from the reaction $^{238}$U + $^{238}$U at a beam energy of 44 MeV. The method is compared with the standard correction method introduced by Andersen.

1. Introduction

Information about the structure of rotational nuclei at high rotational frequencies can be obtained from the study of $\gamma$-ray transitions in the quasi-continuous energy region. Although, due to the high density of states in this energy region, these transitions cannot be associated with discrete peaks in the $\gamma$-ray spectra, it is of great interest to search for correlations in the decay pattern. Usually the data are obtained by means of coincidence experiments in which different types of $\gamma$-ray detectors are employed (large-volume NaI(Tl), Ge(Li) detectors or Compton-suppression spectrometers). In order to extract the photopeak-photopeak events from a large background of Compton-scattered and random events, a reduction method is commonly used which has been proposed by Andersen [1,2].

Table 1

<table>
<thead>
<tr>
<th>Detector System</th>
<th>Peak to Compton ratio</th>
<th>Peak-peak coincidences (%)</th>
<th>Compton-Compton coincidences (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ge x Ge</td>
<td>15</td>
<td>2</td>
<td>72</td>
</tr>
<tr>
<td>NaI x NaI</td>
<td>40</td>
<td>16</td>
<td>36</td>
</tr>
<tr>
<td>CSS x CSS</td>
<td>26</td>
<td>24</td>
<td>36</td>
</tr>
</tbody>
</table>

2. Formulation

A method for the correction of Compton-scattered events has been developed which is based on the response function of Compton-suppression spectrometers. At first instance we have restricted ourselves to the correction of the photopeak-Compton ridges only. This limitation mainly was imposed by the fact that the program had to be implemented on a PDP-11/34 minicomputer and therefore the correction of all scattered events would have increased the already large
computation times beyond reasonable limits. An extension of the method, however, to the correction of Compton-Compton events should be straightforward. Secondly we decided to use as few parameters as possible in the description of the Compton ridges, again in order to minimize calculation times. From the form of the Compton ridge in singles spectra we deduced that an exponential function will fit the ridge in a reasonable way.

For the contribution to the background $N_{\text{bg}}$ at an energy $E_0$, resulting from a photopeak with intensity $N$ at energy $E_0$, therefore we have taken:

$$N_{\text{bg}}(E_0) = N(E_0) \exp(-\alpha (E_0 - \beta)).$$

where $\alpha = E_0/E_1$. To correct for the energy-dependent detector efficiency $\epsilon = \exp(-\gamma E)$ has been used. In this formalism $\alpha$, $\beta$ and $\gamma$ are adjustable parameters. (Note that $\gamma$ is a measure for the "step function" which is usually applied when a spectrum slice with a peak is fitted with a Gaussian function superposed on a polynomial background.) The corrected number of events with energy $E_0$ will then be:

$$N_{\text{corr}}(E_0) = N(E_0) - \sum_{E_i} N_{\text{bg}}(E_i - E_0).$$

where we sum over all energies higher than $E_0$. The parameters $\alpha$, $\beta$ and $\gamma$ are determined from the require-

\begin{figure}
\centering
\includegraphics[width=\textwidth]{fig1.png}
\caption{Contour plot of a part of the symmetrical $y$-$y$ coincidence matrix resulting from the $^{12}$C + $^{12}$Mg reaction. Levels shown are 200, 400, 1200, 2000, 3000 and 4000 counts, respectively.}
\end{figure}
It is important that the parameterization of the detector response function has to be extracted from data obtained from a setup with a geometry similar to the one used in the actual experiment. The geometry of the setup usually can introduce effects different from those encountered when only a single Compton-suppression spectrometer is used (e.g., the "back-scatter" peaks).

Although in principle the correction could be extended to experiments with other types of detectors (by applying a different response function), the method is especially suited for Compton-suppression spectrometers. The worse resolution of large NaI(Tl) detectors introduces larger errors in the form of the Compton edge, whereas for large Ge detectors the relatively small number of photopeak-photopeak events, compared to the background, makes the method highly unreliable.

Fig. 2. Same as fig. 1, corrected using the unfolding method discussed in this article.
due to the large errors introduced by the subtraction process.

3. Results

The correction method has been tested on a $\gamma-\gamma$ correlation matrix from a coincidence experiment on $^{16}$Er [6] with the $^{24}$Mg + $^{40}$Ar reaction at a beam energy $E_{\text{beam}} = 44$ MeV. The two spectrometers used in the experiment were positioned at 90° with respect to the beam direction. Due to the fact that the spectrometers were directly facing each other in this setup, the 511 keV annihilation line is very pronounced in the coincidence matrix. For both spectrometers the suppression factor was already better than 10. Compared to reactions producing heavier nuclei at higher incident energies, this reaction has the advantage that the resulting matrix should be free from the continuum $\gamma$-rays due to unresolved transitions between high-energy states in the formed nuclei. Therefore only discrete peaks should remain in the matrix after the correction has been applied. The continuous background would make conclusions about the correctness of the method much harder to draw.

Prior to the application of both methods the matrix was partly corrected for random events using a timegate in the $E_{\gamma}$-spectrum. To enhance visual appearance the

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**Fig. 3.** Same as in Fig. 1, corrected using the iterative method from Anderson [1,2].
matrix was also symmetrised. Contour plots of a part of the matrix before and after the correction are shown in Figs. 1 and 2. The Andersen-corrected matrix is displayed in Fig. 3. For all three matrices the dispersion is 9.23 keV per channel, resulting from a compression of 4 K ADC data to a 256 x 256 channel matrix. A comparison of both corrected matrices (Figs. 2 and 3) shows their similarity. Although experience has learned that a one-pass Andersen correction of a coincidence matrix from two Compton-suppression spectrometers results in an overcorrection of the Compton ridges (especially at the positions where two ridges meet), the iterative procedure smoothes this effect. Obviously the method is sensitive enough to handle the discrete ridges well. The unfolding method corrects the ridges somewhat better (see also below), but performs worse at energies above the photopeak-peak intensity where coincidences are random.

Both methods are compared in more detail by means of the projection of a slice around 1350 keV onto the horizontal axis, as illustrated in Fig. 4. For comparison a spectrum which has been corrected for random events

![Projection of a slice around 1350 keV onto the horizontal axis](image)

Fig. 4. Spectra resulting from a projection of a slice around 1350 keV onto the horizontal axis. Presented from the bottom upward are (a) a projection in the original matrix; (b) a projection in the unfolded matrix; (c) a projection in the Andersen corrected matrix; (d) the background corrected spectrum. Lines which are present also in the background corrected spectrum are hatched. The last spectrum is included for reference purposes only. See text.
in the "usual" way (by subtracting a "background"
spectrum resulting from the projection of an adjacent
slice) is also included. This last spectrum may be used
as a reference as to which peaks should be suppressed in
the corrected spectra when compared to the original. In
the spectrum only the 223, 398, 1181 and 1611 keV lines
consistent with the 2648 keV transition in $^{36}$Ar [6] are
still present (the hatched peaks in fig. 4). The 795 keV
peak also present is consistent with the 1622 keV transi-
tion in $^{39}$K [7], which is also contained in the projection
gate. In both the unfolded and iterated spectra (indied
the other peaks (notably the 396, 670 and 1044 keV
lines from $^{36}$Ar [6]), and the 511 keV annihilation line) are
reduced relative to the $^{36}$Ar lines, as a result from
the partial removal of the Compton background present
in the slice. With the exception of the 511 keV line all
contaminating peaks are better suppressed in the un-
folded spectrum. As has been stressed before this con-
taminant cannot be properly corrected by the unfolding
method because it does not consist of Compton-scattered
events. That the ridges stretching from the annihilation
peak towards higher energies are nevertheless partially
suppressed is a result from the unfolding procedure
which corrects for the spurious intensity in the ridges as
if those consisted of photopeaks. It should be noted that
this problem is noticeably present only in the case of the
511 keV peak which height is larger than all other peaks
present in the matrix by a factor of at least 15.

4. Conclusions

The results from the two correction methods clearly
indicate that they are at least comparable in perfor-
mance. The unfolding method, however, has the ad-
antage that it is more transparent, physically speaking,
and still is susceptible for improvements. In theory the
unfolding method as it is should be able to increase the
relative number of photopeak-photopeak coincidences
to about 70% of the total contents of the matrix, a
number which will be somewhat lower in practice due to
the presence of random events and the fact that the
response function which we use can only be an ap-
proximation. Because random events seem to be rea-
sonably well corrected by the iterative method without
affecting the photopeaks too much, a combination of
both methods will probably produce even better results.
Further improvements could include a better param-
terisation of the response function and a correction
for the backscatter peak. Obviously another set-up than
the face-to-face geometry used in this experiment would
reduce the dominant 511 keV peak considerably.

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