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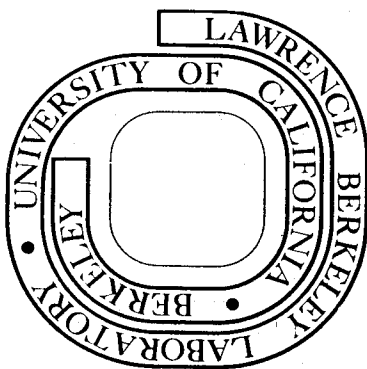
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IDENTIFICATION OF ATOMIC NUMBERS UP TO $Z = 60$

BY MEANS OF $\Delta E - E$ TELESCOPES AND A COMPUTERIZED METHOD**

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ABSTRACT

A very sensitive method for the location of individual atomic numbers in $\Delta E - E$ telescope data is presented. Identification of elements up to $Z = 60$ can be obtained for fragments from heavy ion deep inelastic processes in the energy range of 1 to 3 MeV/amu using a telescope with ionization chamber ΔE and solid state E detector.¹

1. INTRODUCTION

ΔE -E telescopes have become quite popular for studying heavy ion reactions because they are so simple to use. In experiments with solid state ΔE and E counters, the nonuniformities of the ΔE detector thickness limit the Z resolution to fairly low atomic numbers. Range-energy tables, normalized to some experimental values are often used to define Z-bins, as areas in the two-dimensional ΔE -E spectra which are supposed to contain the events of the same atomic number. However, this method gives questionable results since the commonly used range-energy tables² are extrapolations which lead to sizable errors in the region of interest for heavy ions. A more accurate and reliable method is to determine the Z-bins from the reaction data themselves, provided that identification of individual atomic numbers can be achieved. The performance of combined gas-ionization ΔE and solid state E detector systems has been much improved,¹ and the Z resolution has been greatly extended.

In this paper we present a simple computerized method to determine the Z-bins from the data. It works on marginal statistics and for the highest Z's where the resolution approaches 1 Z unit (fwhm).

2. SEARCH FOR Z-RIDGES

The first step is to search the data for Z-ridges. The data are assembled into two-dimensional ΔE -E-arrays (100 E-channels, 960 ΔE -channels). An example of such a map is shown in Fig. 1. The pattern of Z-ridges crossing the map is clearly seen. In less favorable cases, e.g., higher Z's or poor statistics, it is quite difficult to see the ridges by eye.

The new program scans E-columns ($E = \text{const}$) for peaks to locate the ridges. In order to improve statistics, a number of columns (odd,

so the center will coincide with an original column) is compressed into one. Adjacent columns are added vertically displaced according to the slope of the Z-lines. The assumption of one average slope throughout the map has proven sufficient even for rather large ranges of Z. The slope is optimized for the high-Z region, where the Z resolution is most critical. Figure 2 shows a compressed column. The nearly equidistant peaks of successive Z's show clearly in the lower part. For higher Z's, the peak-to-valley-ratio deteriorates.

A most efficient method for detecting these peaks in the E-columns involves the use of a triangle-shaped "test-function". A normalized convolution of the column with the test-function is carried out. As the test-function is moved along the column, a maximum in the convolution sum results, wherever a peak is matched; a minimum is obtained, when a valley is matched. The basewidth $2w+1$ of the test triangle

$$t(i) = w - |i| \quad i = -w, \dots, +w$$

is chosen to correspond to the average spacing of the Z-lines. (The basewidth is odd, so the centroid of the triangle will not fall between column channels). The normalized convolution is defined as

$$c(n) = \sum_{i=-w}^w f(n-i) t(i) / \sum_{i=-w}^w t(i) \left(\sum_{j=-w}^w \frac{f(n-j)}{(2w+1)} \right)$$

where $f(i)$ are the data in the compressed column. A flat background would yield $c(n) \equiv 1$. The resulting vector $c(n)$ is smoothed, then scanned for peaks. The smoothing is done in order to avoid multiple peaking due to statistical fluctuations. The peaks are simply detected as local maxima of $c(n)$ with the condition

$$c(n-1) < c(n) \geq c(n+1)$$

The significance of each peak is determined in the following way: the relative standard deviation σ of $c(n)$ (unsmoothed) is calculated, assuming uniform distribution of the counts in the area covered by the test-function. This standard deviation, compared to the actual deviation of $c(n)$ from unity

$$p = \frac{c(n) - 1}{\sigma(n)}$$

is called a significance value. Due to the non-uniform distribution of counts and the smoothing process, p is not a true significance value, but a reasonable estimate of it. The actual significance is generally slightly better. Usually, peaks with $p < 1.4$ are not considered significant. In Fig. 3 the peak value of the normalized convolution of overlapping equidistant Gaussians is plotted vs the FWHM of one Gaussian. The valley-to-peak-ratio of the superposition of Gaussians is also shown. Figure 4 shows the result of a convolution on real data.

The first set of ridge points is improved in a second pass with a three-fold triangular test-function which exploits the experimentally observed periodicity of the structures and increases statistical accuracy. The spacing of the triple triangle test-function is varied according to a fit of the spacings obtained in the first pass. The fit-function used is

$$S(i) = a - b \exp(-c \cdot i) ;$$

b and c are forced to be positive. This fit function has the important feature of leveling off to a constant for increasing i , which is the

observed behavior of the Z-line spacing. For the fit, only spacings deviating less than a factor of 1.4 from a guess are considered. For the first guess, $a = 1.25 (2w+1)$, $b = a/2$ and $c = a/200$ are assumed, for subsequent columns, the previous fit is used as a guess. In order to get a good first fit, the search is to be started at a column where the statistics of the data is good.

The normalized convolution with the triple triangle is checked for significant peaks in the same way as above. The two-pass search procedure is carried out over the whole range of E-columns containing data. The result is a grid of ridge points and of their significance values. It should be emphasized, that up to here, the program works completely automatically, using only three input parameters: the spacing guess $2w+1$, the average slope of the Z-lines and the number of columns to compress into one. Figure 5 shows an example of the grid of ridge points obtained with the single and triple triangle convolution.

3. FITTING OF Z-LINES TO RIDGE POINTS

The part of the program which defines the Z-lines is interactive and uses a CRT-display for control. From the matrix of ridge points previously found, sets of points are selected which belong to the same Z-ridge. These are fitted with a 4th order polynomial. The first set of points is selected from the grid by an algorithm which uses the guessed average slope of the Z-lines and which starts at the most significant ridge point. In some cases, e.g., if ridge points are missing due to low statistics, or if the Z-line is strongly curved with respect to the distance of compressed columns, this algorithm may fail and the first set of points to be fitted must be specified. A guess for the second

Z-line is obtained by displacing the first Z-line one average spacing $2w+1$. Ridge points close to this guess are collected and fitted. For subsequent lines, the spacing between previous lines is used in order to obtain a guess. Thus the whole grid of ridge points is ordered in Z-lines and fitted with 4th order polynomials. At the high-Z end of the grid, an extrapolation to additional Z's can be accomplished by extrapolating the spacing of the previous lines. The display facilitates control of the smooth behavior of the Z-line spacing. In the later data analysis, median lines between the Z-lines define the boundaries of the Z-bins.

4. CONCLUSION

The method of Z-identification described above has shown its power in the successful treatment of a large amount of data for various deep inelastic heavy ion reactions,³ ranging from Ne+Ag to Xe+Au. It has enabled us to identify Z's up to 60 and given us confidence in our results. Our version of the code is tailored for the use on a PDP-9 computer with 32 k memory and custom display. The authors will be pleased to make the code available to anyone interested.

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* Nato Fellow

+ Sloan Fellow 1974-1976.

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P. Russo, B. Cauvin, P. Glässel, R. C. Jared, R. P. Schmitt, G. G. Wozniak, L. G. Moretto, LBL-4362, to be published.

FIGURE CAPTIONS

- Fig. 1 ΔE -E-Map from the reaction of 340 MeV Ar on Ag.
- Fig. 2 Compressed E-column from the reaction of 620 MeV Kr + ^{159}Tb .
- Fig. 3 Peak value of the convolution sum for overlapping equidistant equal-area Gaussian peaks vs widths of the Gaussians. The valley-to-peak ratio of the overlapping Gaussians is also shown.
- Fig. 4 Normalized convolution sum for the reaction of 980 MeV Xe on ^{197}Au .
- Fig. 5 Ridge points found with the single and triple triangle test function for data from the reaction of 980 MeV Xe on ^{197}Au . The lines connecting Z-lines are eye-guides. Shown are all points with a significance value $p \geq 1.0$.

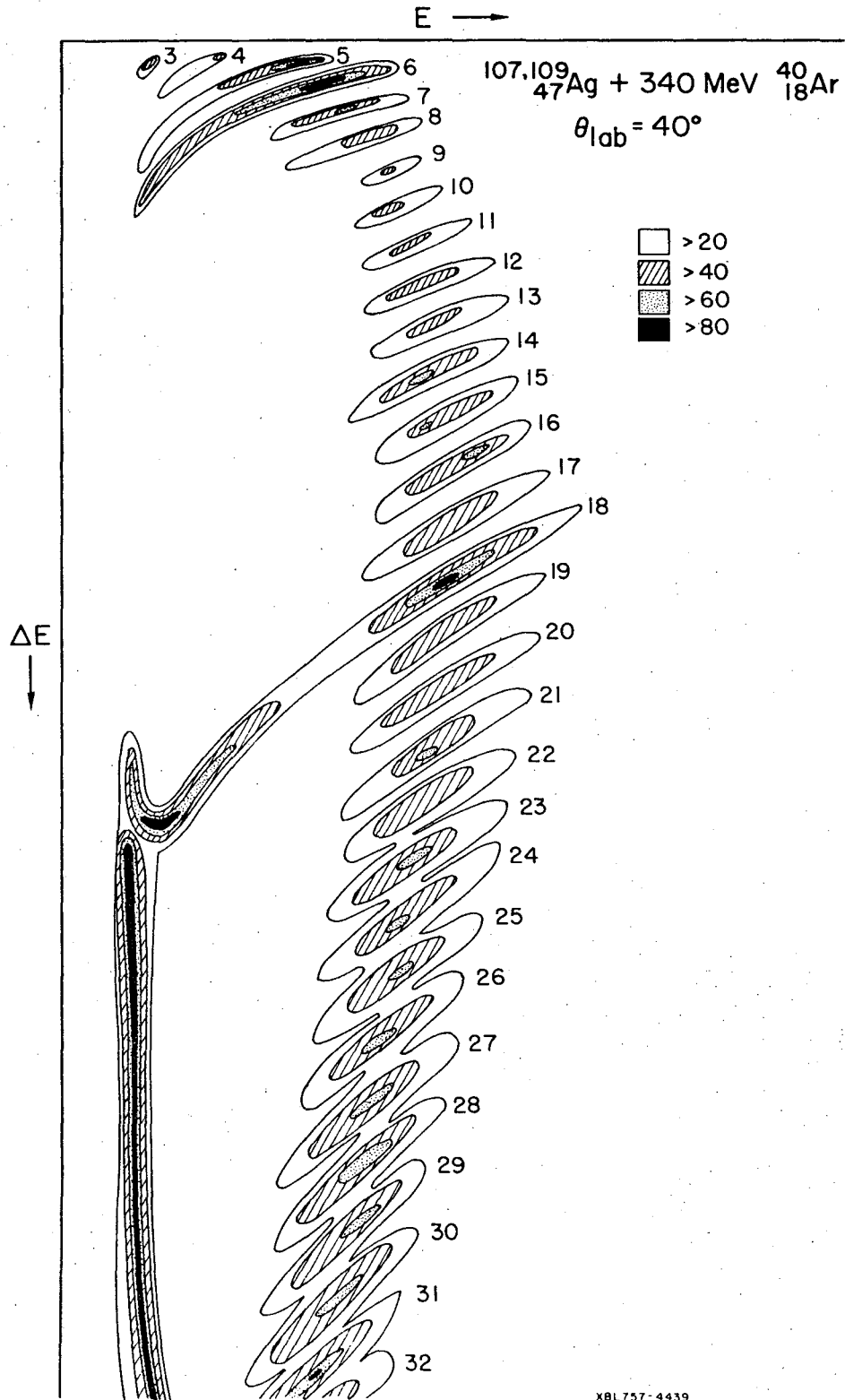
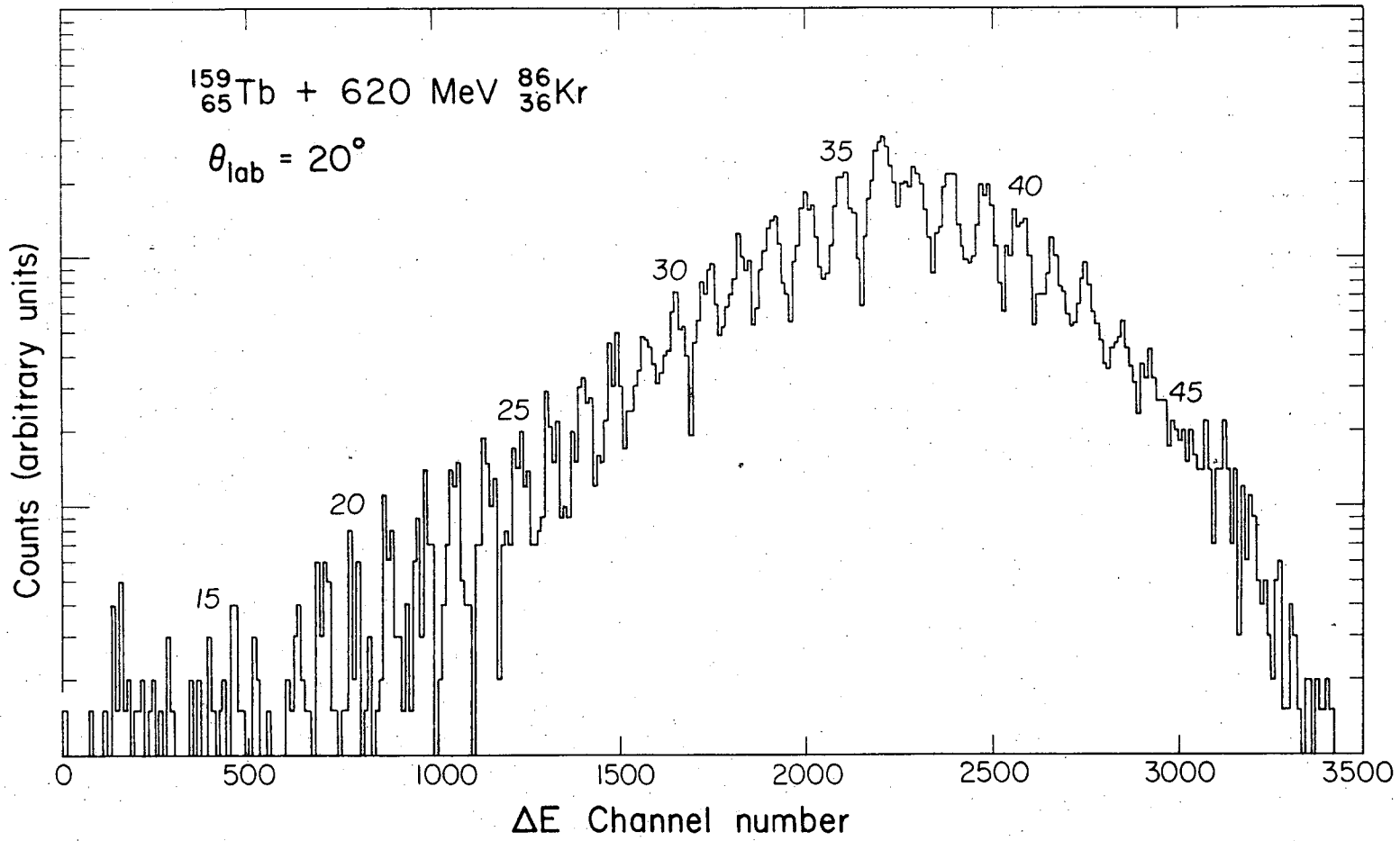
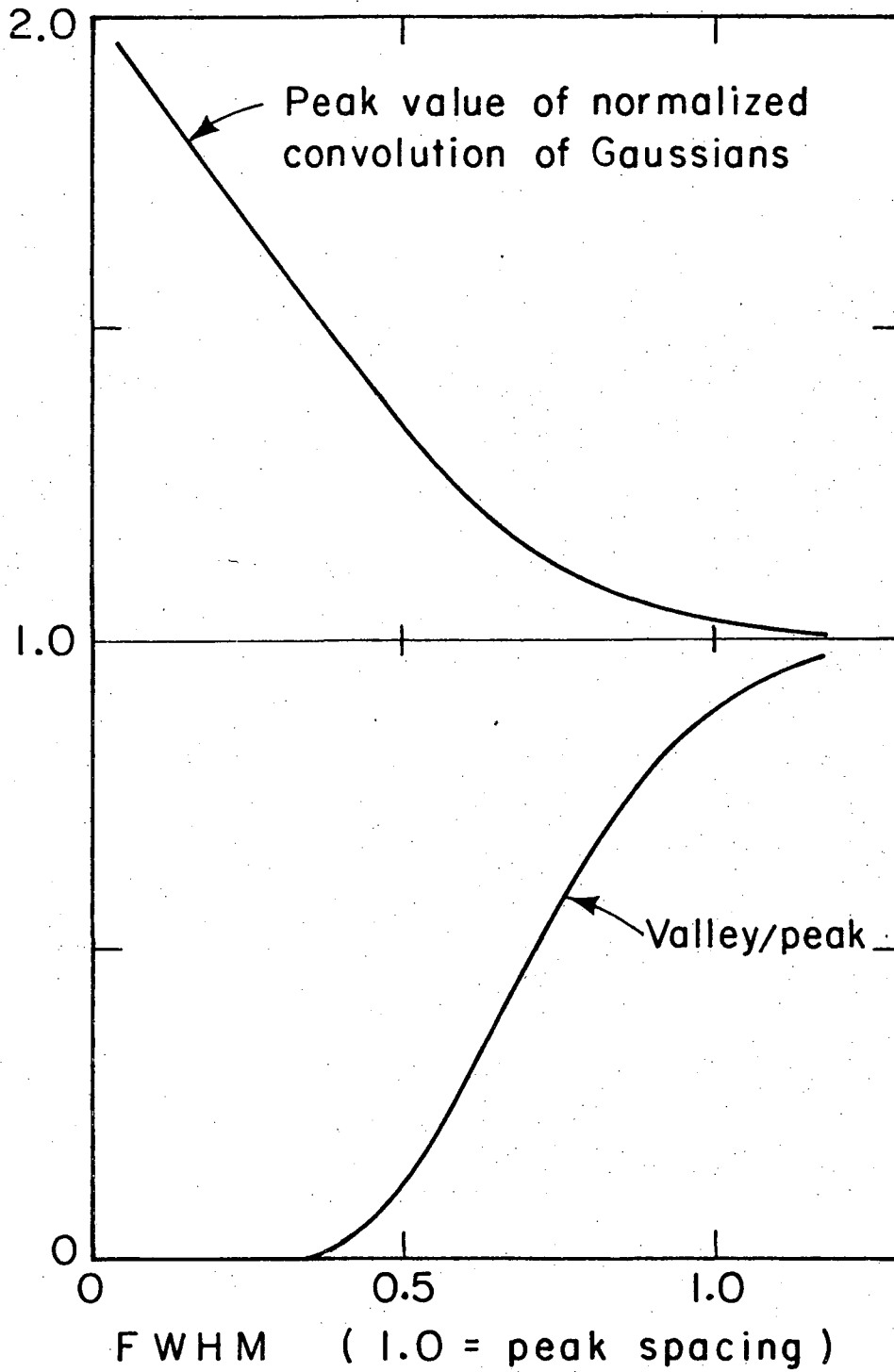


Fig. 1



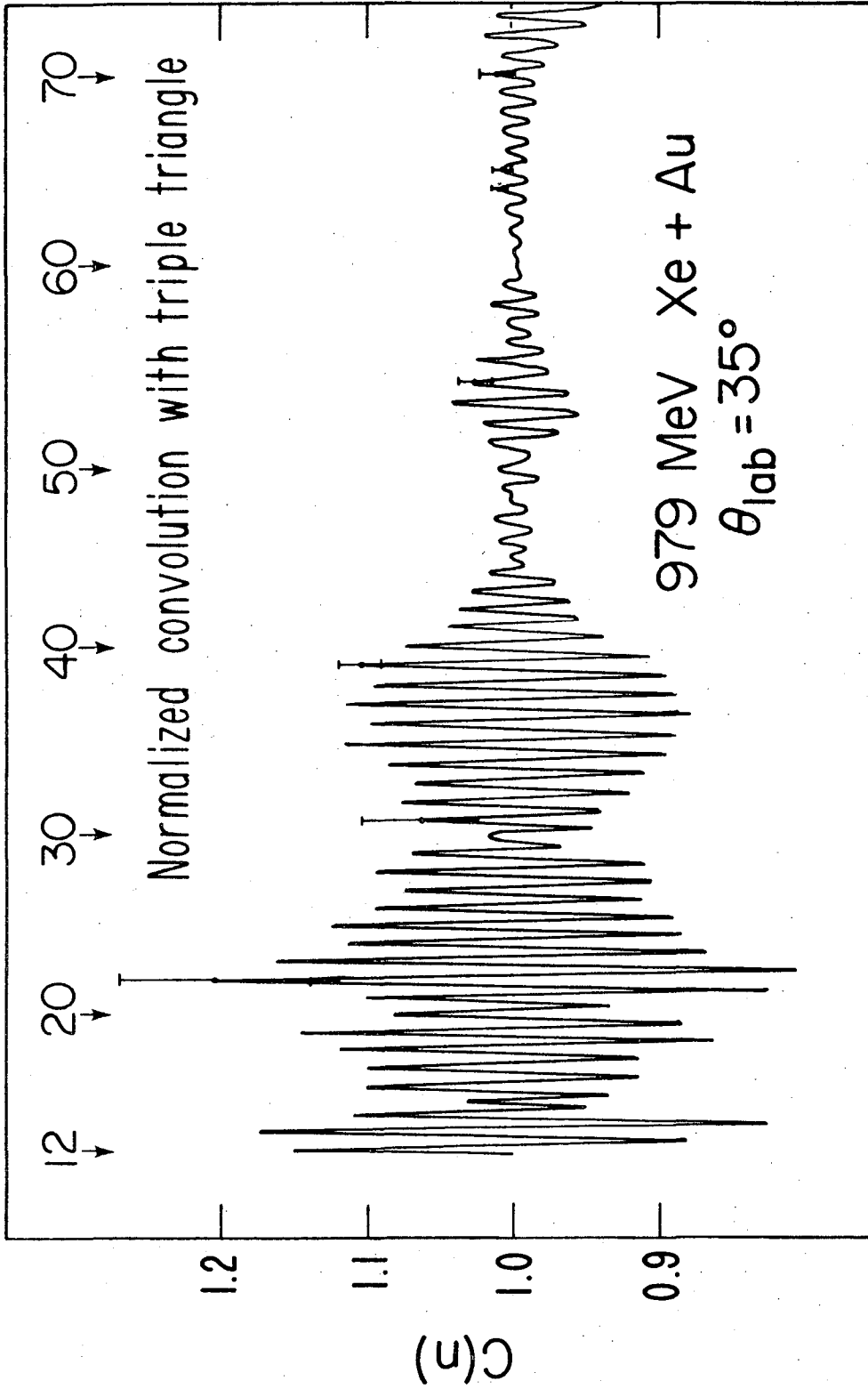
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Fig. 2



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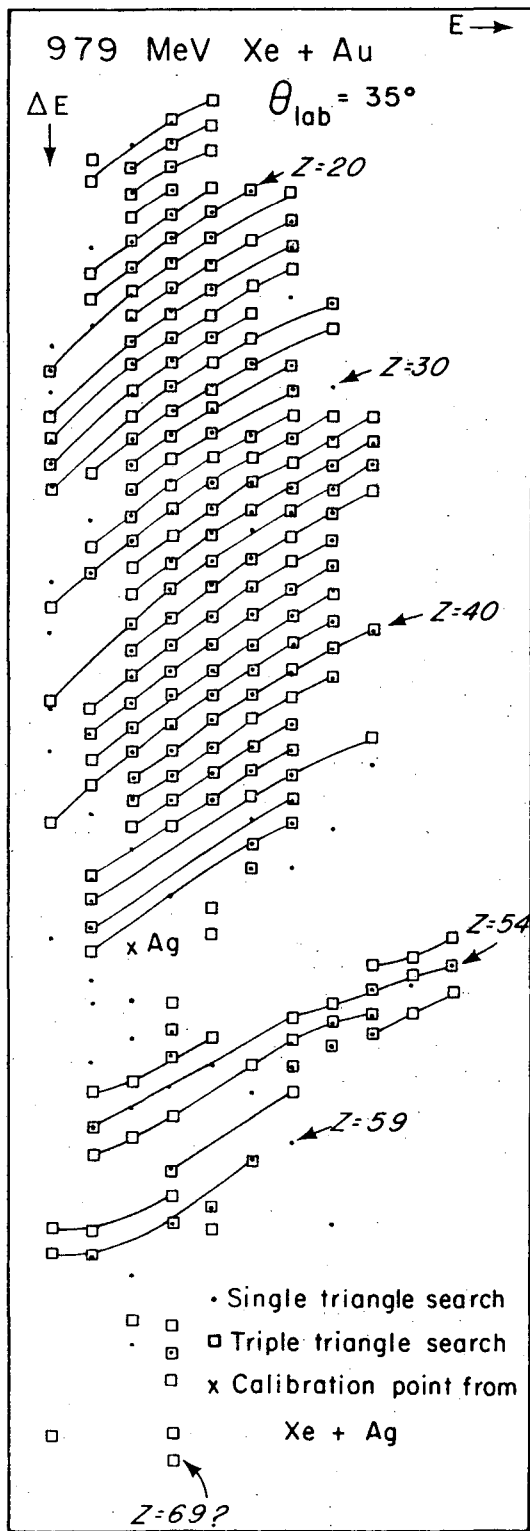
Fig. 3



ΔE - channel

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Fig. 4



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Fig. 5

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