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New Apparatus and Measuring Techniques

THE MEASUREMENT OF MULTIDIMENSIONAL SPECTRA IN NUCLEAR PHYSICS

G. P. MEL'NIKOV

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IN this article we set forth the basic techniques for measuring multidimensional spectra in experimental nuclear physics and describe a new method for obtaining multidimensional spectra, based on the use of a multichannel analyzer with potentialoscope [= electrostatic memory tube] registration. This method provides a high efficiency for counting the events of interest and the possibility of observing during the experiment the results of the multidimensional analysis displayed as a family of plane sections of the multidimensional space under investigation or as stereoscopic relief spectra.

The single-channel or multichannel analyzer usually used in experimental nuclear physics allows the pulse-height or time of electrical pulses to be determined. In the final analysis, this corresponds to the energy, mass, time-of-flight, or other spectrum of elementary particles. However, no matter which dependence is determined in this manner, it is always a relation between two quantities and represents a plane curve; consequently all these amplitude, time, energy, or other spectra can be called plane spectra.

However, in contemporary experimental physics it is increasingly necessary to study the distribution of elementary particles in not just one variable, but in two or more variables, i.e., the problem is to obtain spectra represented not by a plane curve, but by a surface in three-dimensional, or generally multidimensional, space. For example, a three-dimensional problem arises in studying the dependence of neutron and gamma spectra on the energy of fission fragments. Three-dimensional spectra can be represented by a family of plane sections of the three-dimensional space; each section is an ordinary two-dimensional spectrum. In practice, this family is obtained by using a single multichannel analyzer to register only events coincident or correlated with a given value of a second parameter, for example, a given pulse height in a second counter, selected by a supplementary single-channel differential analyzer.[11] By setting the requisite number of levels of discrimination of the single-channel analyzer, the experimenter sequentially, spectrum by spectrum, obtains a collection of plane sections of the three-dimensional spectrum under investigation. However, the counting efficiency is low with this technique, since only events belonging to only the one fixed section are registered and other events are excluded. Thus, a complete collection of plane sections requires a large amount of time and the probability of apparatus failure is high; in practice, this method of obtaining three-dimensional spectra is only used when it is not necessary to determine the whole three-dimensional spectral surface and a few selected plane sections are sufficient. This method is hardly acceptable for spectra with more than three coordinates, since each three-dimensional spectrum is just a single point in a space with a large number of dimensions. Finally, in principle it would be possible to obtain a multidimensional spectrum by the simultaneous use of many multichannel analyzers, each taking a two-dimensional spectrum in a different plane section; however, in practice this procedure is unrealistic since even one multichannel analyzer is a sufficiently complicated and expensive device.

In order to sharply increase the counting efficiency in multidimensional (actually three-dimensional) spectra and register as many of the events on the spectral surface under investigation as possible, the method of preliminary memorization[1-5] has been widely applied. The main feature of this method is a two-stage technique for obtaining multidimensional spectra; first stage — memorization of the data during the physical experiment, second stage — processing the memorized data after the end of the experiment.

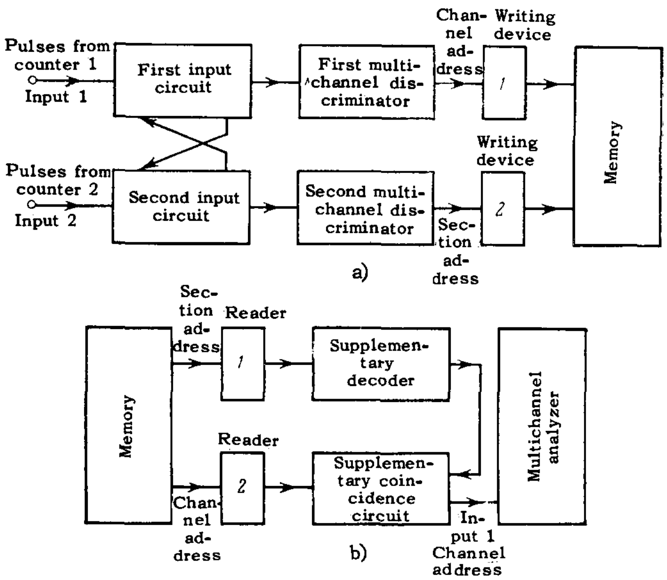

FIG. 1. An apparatus used to measure multidimensional spectra: a) first stage; b) second stage.

i.e., sorting the data and representing it as a family of plane sections of the multidimensional spectrum.

To illustrate better the operational particulars of this three-dimensional spectral apparatus, we consider the block diagram of a typical representative of all the devices[2–5] used for this purpose.

We start with the first stage — memorization. A block-diagram of the interacting circuits used in this stage is shown in Fig. 1a.

The signals from two radiation detectors, counters 1 and 2, enter inputs 1 and 2, respectively, of the special input circuits which are connected in a "mutual resolution" arrangement so that each of the input circuits produces an output pulse only if the input pulses from the counters arrive in coincidence. This process selects only coincident "paired" events. The selected pulses proceed further into circuits which transform the analog form of the pulses into a discrete form, for example, a binary code. These transforming circuits are called multichannel discriminators. The binary code signals then are fed into a registering device, such as the electromagnets of a punch, which inscribes the binary numbers on two tracks of a memory device, such as punched paper tape. This memorization of the data after preliminary processing proceeds throughout the course of the experiment as the pulses arrive from the counters. The first stage of operation of the apparatus ends with the cessation of the experiment. Thus, it is perfectly clear that this sort of apparatus is not an analyzer in the usual sense of the word, since neither during the experiment nor at the moment of its cessation are the results of the analysis exhibited to the experimenter. They become known only in the second stage, after additional processing of the memorized data; then the signals from the memory are transferred either to a digital computer or else, as in the apparatus of reference 1 and in many others, are analyzed in a special manner with a standard multichannel pulse-height analyzer, in which a registration device is the principal element.

This second stage in obtaining a three-dimensional spectrum is illustrated in Fig. 1b, which shows the block-diagram of the apparatus used in reference 1. The signals from the memory, in this case punched paper tape, obtained from readers 1 and 2 enter the supplementary circuits. The code from reader 1 goes to a supplementary decoder designed to give an output pulse only if a definite code prescribed by the operator, i.e., a definite binary number, enters. The signal from this decoder is used as a gate pulse in a supplementary coincidence circuit which passes the code for the second, paired event as read from the second track of the memory. The codes passed by the coincidence circuit proceed into a multichannel analyzer and give the addresses of the channels in which the events sorted out by this process are to be registered.

Consequently, the spectrum collected in the multichannel analyzer is an ordinary two-dimensional plane spectrum of events from the second counter corresponding to only a particular paired event in the first counter which is selected from all the other events by the supplementary decoder. This two-dimensional spectrum is one of the plane sections of the three-dimensional spectrum under consideration. To obtain the other sections it is necessary to "filter out" in a similar manner the appropriate number of plane spectra, each time resetting the supplementary decoder to select a different value of the third coordinate of the volume spectrum.

Thus, the merit of the preliminary memorization technique is apparent: it has a high efficiency for registering events. This is especially important when the intensity of correlated events is low. The defects of this technique are also apparent: the use of two stages, the necessity for repeated inspection of the same data in order to sort out a sufficient number of plane sections of the three-dimensional spectrum, the long time required for this sorting, and the large number of pieces of equipment required (memory, writing apparatus, reading apparatus, variable decoder, supplementary coincidence circuit).

We describe below a new method for taking multidimensional spectra; this method preserves the merit of the preliminary memorization technique and avoids its disadvantages. This method is most easily accomplished with a multichannel analyzer using a potentialoscope multichannel register of the type described in reference 6. Each of the various modifications of this analyzer[7–9] is very fast, has a rather large number of channels, and can easily be turned into a device for obtaining and stereoscopically observing multidimensional spectra. As is known, the potentialoscope exhibits the analysis results as a histogram in which illuminated dots give the number of pulses registered in each channel in binary form. For an inspection of the spectrum, the binary representation can be switched to a linear one so that a histogram of the spectrum is visible. Since the number of binary bits per channel is much larger than the number of channels, the histogram is divided into several "stages" for efficient use of the elements of the register. For example, in the 1024 channel register of the ÉLA-3 analyzer the histogram is split into eight "stages" with 128 channels in each.[9]

To use an analyzer of the ÉLA type for three-dimensional spectra, it is also necessary to insert a second input circuit which allows only signals in coincidence to enter the analyzer and a second multichannel discriminator with an output signal which gives the address of the channel in which a given event is to be registered (Fig. 2). The pulses from the two counters which detect the parameters of the correlated events under investigation enter the input circuits; the input circuits operate in mutual coincidence. Pulses which arrive from just one counter are not passed on for analysis and consequently give no address signal to the register. If the whole register is divided into

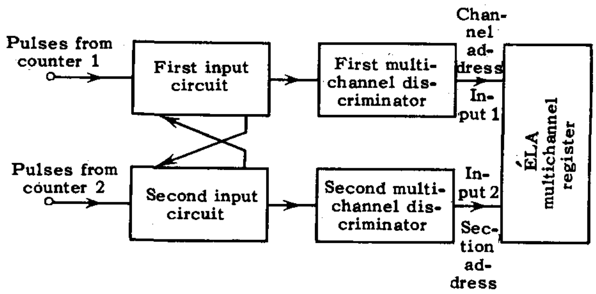

FIG. 2. Block diagram of the multidimensional analyzer.

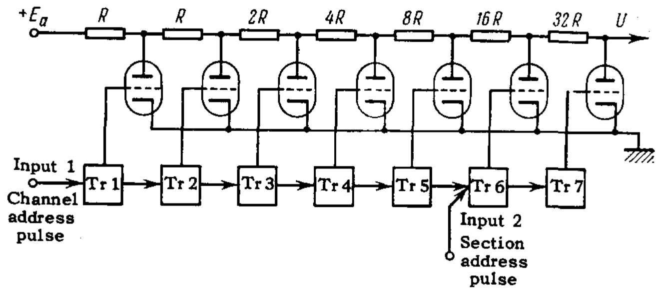

FIG. 3. Principle used to obtain step voltages in the multidimensional analyzer.

separate parts, for example "stages", and the address signals from the second counter's pulses are used as the "stage" address, then each registered event will have two coordinates: channel number and "stage" number. Consequently, each "stage" will represent just a two-dimensional plane section of the three-dimensional spectrum, i.e., just what is required. The splitting into groups need not be by "stages". For example, a 1024-channel register can be used to obtain a "space cube" consisting of 32 sections with 32 channels per section. For four-dimensional spectra, three input circuits and three discriminators are needed, etc.

Thus, this technique for measuring multidimensional spectra eliminates the second stage in processing the data and at the same time makes it possible to split the multidimensional spectrum into plane sections and watch their growth during the course of the experiment.

By excluding the second stage, which consists of processing the memorized data, the circuitry for multidimensional analysis is greatly simplified. This is most easily seen by comparing the block diagram of an apparatus like that of reference 1 (Fig. 1) with the block diagram in Fig. 2.

What changes must be made in the ÉLA analyzer in order to transform it from a plane spectrum analyzer into an analyzer for multidimensional, and particularly three-dimensional, "volume", spectra?

Besides the insertion of a second input circuit and a second multichannel discriminator, the only alteration to be made in the ÉLA circuit is the addition of input No. 2 in the address system of the analyzer. The standard address system for deflecting the beam into the memory tubes of the ÉLA analyzer is described in references 7 — 11. Figure 3 shows the address system as modified for three-dimensional analysis; it differs from the standard one only in the addition of input No. 2, through which the pulses giving the section address code enter from the second multichannel discriminator.

Two additional inputs would be needed for four-dimensional spectra, etc.

Now we consider the question of observing the results of the analysis.

The collection of sections of the multidimensional spectrum shown on the screen of the register is a sufficiently explicit description of the physical phenomenon being investigated. A stereoscopic representation of the three-dimensional volume gives an even clearer picture than the disjoint sections and can also be obtained without serious difficulties. For this purpose an extra switch is inserted in the sawtooth circuit of the oscillograph so that two traces, two groups, are obtained on the screen instead of one, and a vertical displacement regulator and two independent horizontal displacement regulators for the plane sections are installed. With these controls, the relative position of the two groups of sections on the oscilloscope screen can be adjusted so that the spectrum is seen in relief when observed through a stereoscope (Fig. 4).

If the dimensionality of the spectrum is greater than three, then any three of the coordinates can be chosen for stereoscopic observation.

The details of the address circuit for the analyzer which is suitable not only for obtaining a collection of plane sections of a volume spectrum but also for stereoscopic representation of the results are not presented here, since it also differs little from the usual circuit and uses just some extra switching between the cascades in the circuit. An oscillating mirror can also be used to obtain a representation of volume spectra, but this process will not be discussed either, since it is convenient only for observing the results and is not important from the point of view of the principles of multidimensional analysis. The technical details of an apparatus suited for stereoscopic observation of the results of multidimensional analysis will be described in a separate paper.

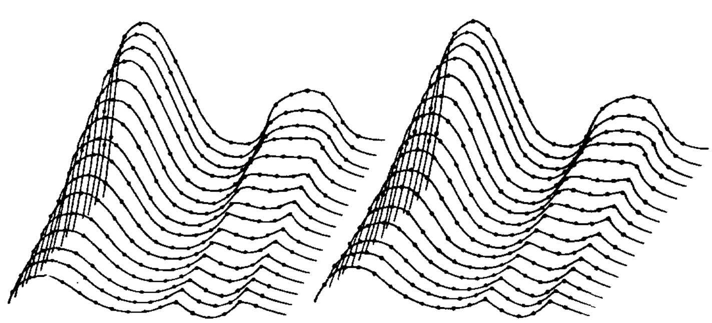

FIG. 4. Example of a three-dimensional spectrum (256 channel analyzer with 16 sections of 16 channels each).

Since the position of a spectral surface with respect to the coordinate axes can vary greatly, a maximal "volume" of spectrum is necessary for a preliminary survey of the form of the surface; this is obtained by choosing the number of channels and the number of sections to be as nearly equal as possible. If the variation of the spectrum along one of the axes is found to be slow, then the number of channels in this direction can be decreased; this makes it possible to increase the number of channels for the more interesting coordinate or else to increase the width of the channels so as to decrease the time required for obtaining the volume spectrum.

The address system for analyzers of the ÉLA type allows a great variety of switching arrangements so that the required number of sections and channels for multidimensional spectra can be set up.

Thus, this method makes it possible to obtain multidimensional spectra with high counting efficiency and to observe the results of the analysis during the experiment; if desired the volume spectra can be viewed through a stereoscope. Since many research organizations in this country are using analyzers of the ÉLA type, it is really possible to apply this method. The first three-dimensional analyzer of this type was constructed using an ÉLA-2 and successfully tested at the end of 1959. This principle of multidimensional analysis can also be applied with other types of analyzer, but then difficulties arise due to the limited number of channels, speed of operation, etc.

A wide adoption of multichannel analyzers opens significant new possibilities for high-resolution experiments in nuclear physics and other branches of science. Reference 11 gives a clear illustration of the interesting physical data that can be obtained by using multichannel analysis. From the example of the same work the great amount of labor involved in obtaining one volume spectrum with the usual spectral techniques is also clear. The use of a multidimensional analyzer would have reduced this amount by a factor of 10 or so.

[1] Birc, Braid, and Detenbeck, Rev. Sci. Instr. **29**, 203 (1958).

[2] D. Maeder and P. Stachelin, Helv. Phys. Acta **28**, 193 (1955).

[3] MIT Annual Progress Report, May 1955, p. 165.

[4] L. Grodziens, Rev. Sci. Instr. **26**, 1208 (1955).

[5] Multichannel Pulse Height Analyzers, edited by H. W. Kochand and R. W. Johnston, NAS NRC Nuclear Science Series, Report No. 20, 1957.

[6] G. P. Mel'nikov, Description of Author's Claim [= patent disclosure] No. 707516/01237, 1953; Author's Certificate No. 21421.

[7] Mel'nikov, Artemenkov, and Golubev, Приборы и техника эксперимента (Instruments and Experimental Techniques) **6**, 57 (1957).

[8] V. O. Vyazemskii and V. V. Trifonov, Амплитудный анализатор импульсов с регистрацией на потенциалоскопе АМА-2 (Pulse Height Analyzer with AMA-2 Potentialoscope Registration) 1957.

[9] Voronin, Golubev, Levin, et al., ÉLA-3 1024 Channel Pulse-Height and Time Analyzer, published in Передовой научно-технический и производственный опыт (Progressive Technological and Industrial Experience), M. 1959.

[10] R. L. Becker, Phys. Rev. **119**, 1076 (1960).

[11] Проблемы кибернетики (Problems in Cybernetics) No. 2, Fizmatgiz 1959, p. 192.

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