The 8-Parameter List Mode for γ-γ Perturbed Angular Correlation Measurements

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A new TDPAC spectrometer which is based on the principle of event by event data acquisition (list mode) in order to reduce a background, avoid systematic errors and increase efficiency of the setup is described. The principal demand on the new spectrometer is the simultaneous measurement of all events containing the time and energy signals of the four detectors appearing in a preset common time window. For this purpose an 8-parameter list mode data acquisition system has been developed.

Key words: Time Differential Perturbed Angular Correlations (TDPAC); Spectrometers; List Mode; Event by Event; Data Acquisition.

Introduction

Among different hyperfine interaction methods used for obtaining structural and dynamic information on solids, time differential perturbed angular correlation (TDPAC) spectroscopy has become well developed. The measured coupling of a nuclear spin system with magnetic and/or electric hyperfine fields gives specific information about such problems as point defects in metal or insulating systems, atomic diffusion in solids, phase transitions in solids, surface and interface effects and types of magnetic ordering [1].

The method is based on the observation of the anisotropic γ radiation emitted from an isomeric nuclear state with a non-random nuclear spin orientation. The requirement of spin alignment is achieved by using nuclei with a γ-γ cascade, where the detection of the emission direction of the first γ-quantum determines the set of nuclei with the same defined nuclear spin orientation. Then the intensity distribution of the second γ radiation is anisotropic in space and correlated to the direction of the first one. This is the substantial advantage of this method; otherwise very strong magnetic fields or mK temperatures have to be used to obtain nuclear spin alignment.

The measurements are performed in a coincidence regime of a multi-detector arrangement. Usually TDPAC multi-detector (three [2], four [3], and six [4]) setups have two independent measurement paths: the timing signal is analyzed in a fast line, whereas the energy signal needs about 1 µs to be electronically shaped in the slow part of the system. Next, both time and energy signals have to be combined to produce the coincidence event. This operation is performed either in a slow-fast coincidence system [5] or, less often, in a fast-slow [6] coincidence setup. The number of coincidence spectra which can be measured increases nonlinearly with the number of detectors and is between 4 and 30, depending on the number of detectors and the chosen coincidence system. In both above-mentioned cases it is necessary to use a large a number of electronic modules, which are susceptible to instabilities and breakdowns and temperature sensitive, and in the case of the slow-fast regime a passive delay in the range of µs also has to be used. This can deteriorate the timing properties of the system, and also can lead to a loss of data, because any thermal drift of the electronics or other failures during the relatively long time which is necessary to collect sufficient statistics can ruin many hours of experiment.

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The experimental limits are given by the time resolution of the setup, which should be sufficient for a time differential measurement, and by the energy resolution of the detectors, which should give a possibility of distinguishing two gamma radiations with their respective energies, and by the real-to-random ratio of coincidences defined by the source activity. To obtain a good and reliable PAC spectrum, a high efficiency is required to reduce statistical errors and pick up high statistics in a reasonable measurement time. The problem of duration of the measurement is particularly important in surface and interface studies performed in ultrahigh vacuum conditions because in this case sample and vacuum preparation take most of the time reserved for the experiment [7].

Here we present a new TDPAC spectrometer designed for work with samples kept in ultrahigh vacuum, based on the principle of event by event data acquisition (list mode) in order to reduce background, avoid systematic errors and increase efficiency of the setup. The principal demand on the new spectrometer is the simultaneous measurement of all events containing the time and energy signals of the four detectors appearing in a preset common window time. For this purpose an 8-parameter list mode data acquisition system has been developed.

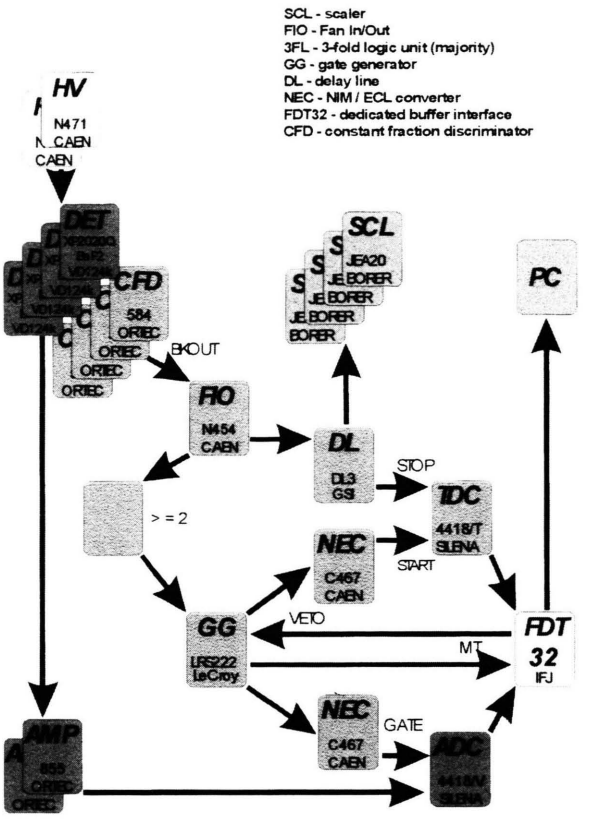

Fig. 1. Schematic block diagram of the data acquisition system.

Description of the Setup

The outstanding features of BaF_2 scintillators in respect to fast timing applications are already well known [8]. The very fast (600 ps half life) scintillation component makes it possible to obtain a time resolution comparable to the fastest plastic scintillator. On the other hand, very pure BaF_2 crystals provide also an energy resolution of about 10% for the 662 keV γ-quanta of ^{137}Cs, which is sufficient to distinguish between γ-quanta of a cascade of most PAC probes [9].

Our detection system consists of four cylindrical BaF_2 scintillation crystals (1.5" $\times$ 1.5") equipped with XP 2020 Q photomultipliers and Philips voltage dividers, VD 124K. It is known [10] that conically shaped scintillation crystals have better timing performance than cylindrical ones. However, the present setup was designed for PAC measurements of samples kept in ultrahigh vacuum conditions, and this fact put strong limitations on the geometry of the space around the sample. The sample in this case is kept inside a tubulated UHV viewport of 50 mm diameter terminating our PAC chamber, and it is surrounded by four detectors. Therefore the minimum distance between the sample and crystal is about 30 mm. This fact does not allow for a reasonable, as to experimental conditions and cost, optimization of the crystal size.

The signal from the photomultiplier anode is sent to a constant fraction discriminator, ORTEC 584, to create the timing signal, whereas the energy output from the last photomultiplier dynode is amplified by a standard spectroscopy amplifier, ORTEC 855. Time-to-digital (TDC) and energy-to-digital (ADC) conversions are performed by two fast CAMAC-FERAbus converters SILENA 4418/T and SILENA 4418/V. In the TDC converter all eight input channels acquire the time delay of the arrival of the input signals with respect to the common start signal given by the common gate unit. The ADC converter registers the pulse amplitude of the input signals which occur within the time interval marked by a common gate signal. Both blocks were chosen because of their high resolution of

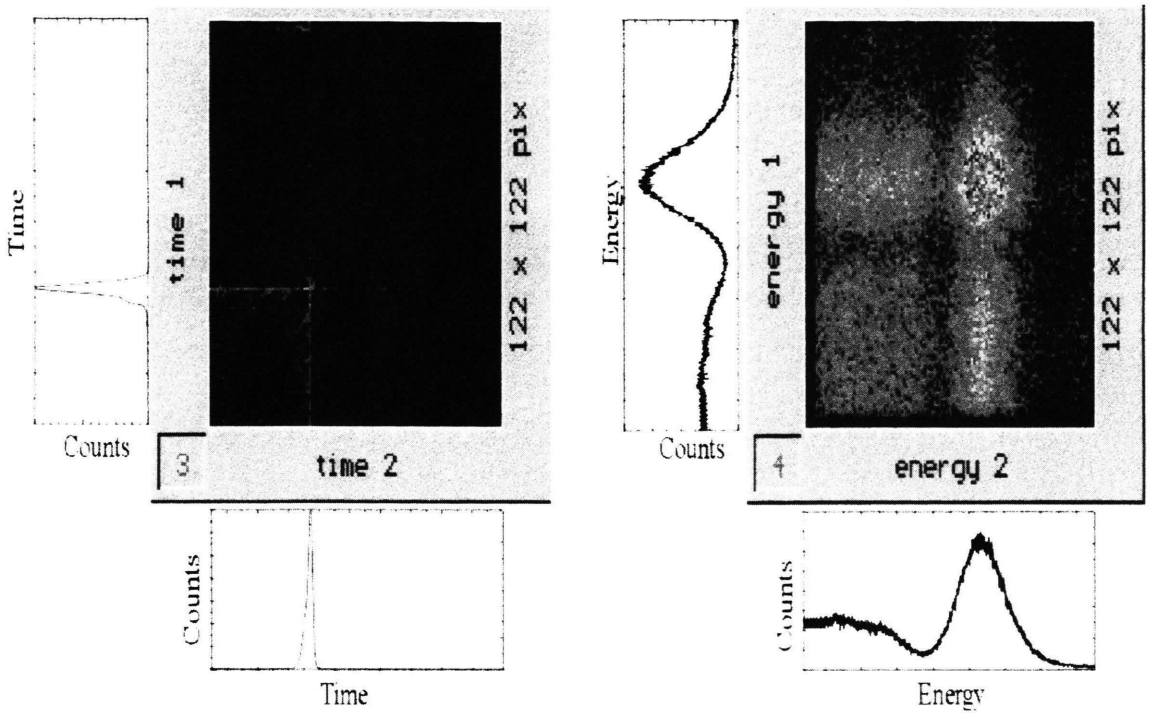

Fig. 2. The time-time coincidence matrix and energy-energy coincidence matrix for a pair of detectors measured with ^{22}Na together with the projections of data on corresponding axes.

analog-to-digital conversion (12 bits), fast conversion time and fast ECL readout logic of the data through the FERAbus. Both converter blocks can be controlled through the CAMAC. The lower and upper threshold, offset and common threshold for noise rejection can be defined. The systems block diagram is shown in Figure 1.

The event by event data acquisition is driven by a common coincidence timing signal (common gate) produced by a majority unit CAEN N405 from the undelayed timing signals, with the logical condition that at least two detectors were registering γ-quanta. The delayed timing signal of each detector is transferred to the corresponding TDC channel, and the energy signal which belongs to it is taken by the corresponding ADC channel. The acceptance of the common gate signal by the digital converters is equivalent to the beginning of the acquisition process. From this moment the TDC converter registers all inputs arriving in a time equal to its range (in our case 1 μs), whereas the time window in which energy signals are acquired is determined by the width of the gating signal. After this time has passed, the conversion of data signals to digits is performed and the signal is sent,

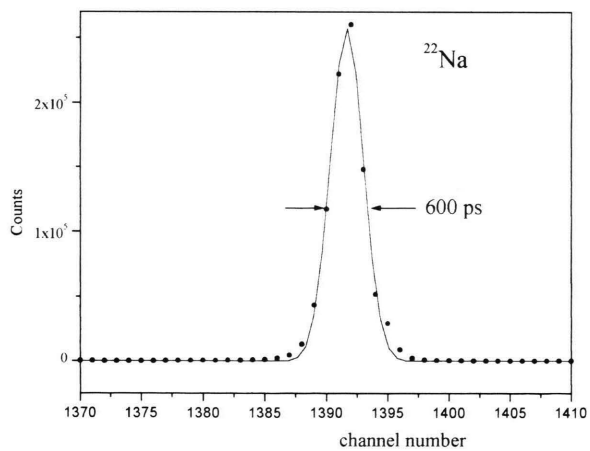

Fig. 3. Typical time resolution curve obtained with our setup for ^{22}Na.

through a FERAbus driver FDT32 recently developed in our laboratory, to a PC computer. The FERAbus module distributes control signals like gate, clear and handshake signals via the command bus. This kind of connection accomplishes the readout of data as time-energy coincidences of all detectors which are active at the same moment in one piece of informa-

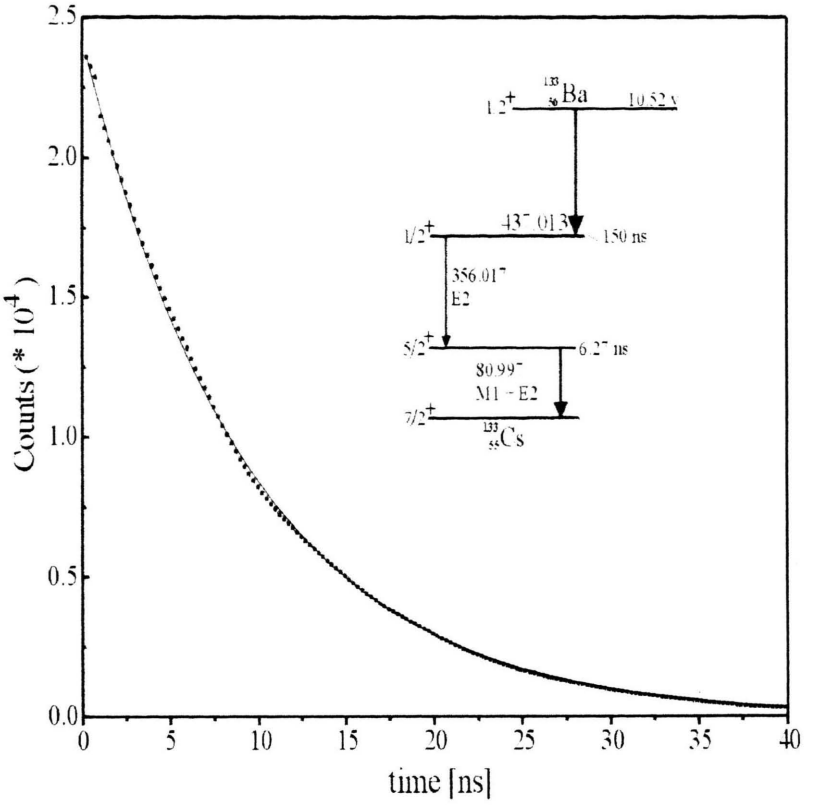

Fig. 4. Time coincidence spectrum measured for ^{133}Ba with four BaF_2 detectors in the list mode data acquisition system. The solid line shows the results of a least-squares fit to the halflife. The inset shows the simplified decay scheme of ^{133}Ba.

tion, called an event. The FERAbus principle assures that to one event belong only data corresponding to the same gating signal, which in our case is produced by coincidence of at least two detectors. The possibility that the next gating input could be accepted is blocked by the FERAbus driver to the moment when both converters are read. The buffer of 2 kWords in the FERAbus driver is used to store data temporarily before sending them through the CAMAC controller to the PC computer. Additionally the FERA driver sends an INHIBIT REQUEST signal to the majority unit to prevent creation of any new gating signals before the current data acquisition is completed. The event word consists of information about the identity of every active detector, energy of any γ-quanta registered through it and the time delay between the timing and the common gate signal.

The data acquisition system is controlled by the measuring and data evaluation software EURYDICE written especially for this purpose. This software provides all CAMAC commands, the preliminary sorting of the events in the PC and storing them to the hard disk. To allow control of data acquisition, while the experiment is running, the program shows the TDC and energy spectra of all four detectors. Also coincidence matrices can be displayed for any combination of detectors and signals (time or energy). The example of time-time and energy-energy coincidence matrices of 256x256 channels taken with a ^{22}Na source for a pair of detectors is shown in Figure 2.

Additionally, data from each detector are displayed as a projection separately on time and energy axes. These data were collected without any conditions, so it is clear that in the time coincidence matrix, in addition to prompt peak, coincidences between Compton-scattering and photopeaks are also visible. For the energy spectrum, in addition to the photopeaks and Compton-scattering coincidences, one also observes the broad background resulting from the moderate energy resolution of our detectors.

EURYDICE software also allows for sorting the list of events by different sorting conditions in order to get the coincidence spectra necessary to determine the γ-γ correlation function. To sort the registered events offline, another sorting subroutine is used which allows the sorting process to be controlled at any step

of data reading. In this way, during sorting one can eliminate data artefacts related to temperature shift of electronic blocks, jittering of signals or other perturbations of measurement.

Results

The good quality of our fast timing signal is demonstrated in Fig. 3 by the measured time spectrum of coincidences between the 511 keV annihilation quanta of a ^{22}Na source. The time resolution of our system, measured for ^{22}Na, did not exceed 600 ps.

In order to verify the proper working conditions of the data acquisition system we measured the spectrum of a calibration source of ^{133}Ba which has a γ-γ cascade of 356-81keV with halflife time of 6.27(2) ns [11]. An event-by-event spectrum was collected for this source and sorted offline for proper energy conditions. Thereby we obtained 12 coincidence spectra from which we determined the halflife of the intermediate state of the γ-γ cascade. An example of such a spectrum is shown in Figure 4. The lifetime of the intermediate level determined this way was 6.47(3) ns, which is in reasonable agreement with the known value.

Conclusions

After preliminary testing we can conclude that our system has the following advantages: it can record all coincidence spectra possible for a chosen isotope, which allows the use of radioactive probes with more complicated decay schemes; it avoids the use of passive delays resulting in signal reflections and deterioration of the time resolution; in case of any failure or damage, one can save the part of the spectrum collected in proper experimental conditions; it is flexible and can be easily extended to a larger number of detectors. The extension of the system to five detectors is already in progress.

During testing of the list mode spectrometer we noticed that the speed of data readout through the CAMAC does not allow to use all the advantages of the FERAbus. This is a primary limitation of the efficiency of the system. Then we decided to apply an entirely different approach to processing data which should facilitate all on-line computing and disk-write operations especially from the point of view of speed and the real time approach. Therefore, direct communication between the FERAbus driver FDT32 and a DSP board is under development.

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