Triple coincidence PALS setup based on fast pulse digitizers

D. Bosnar¹, B. Đurđević¹, L. Pavelić¹ and S. Bosnar²

¹ Department of Physics, Faculty of Science, University of Zagreb, Zagreb, Croatia
² Division of Materials Chemistry, Ruđer Bošković Institute, Zagreb, Croatia

E-mail: bosnar@phy.hr

Abstract. We have assembled positron annihilation lifetime spectroscopy system that consists of three BaF₂ detectors with XP2020URQ PMTs which are directly coupled to DRS4 evaluation board. Both time and energy information of the detected gamma rays are reconstructed. In the off-line analysis, by using selected cuts on energies of gamma rays, double, as well as triple coincidence events can be extracted. The setup is very suitable for the determination of contributions of positronium three gamma annihilations which can be of interest in the investigations of various porous materials.

1. Introduction

Positron annihilation lifetime spectroscopy (PALS) systems are usually based on classical, analog, electronics, and they extract only time information from the registered gamma rays, see eg. [1]. One of the improvements of such setups, but still relying on the analog electronics, includes simultaneous recording of time and energy information of the detected gamma rays and this additional information can be used in investigations of contributions of three gamma positronium annihilations [2]. A new approach to PALS measurements has been recently introduced by the employment of fast pulse digitizers, see eg. [3]. We have used a low-cost DRS4 evaluation board [4], similarly as in [5], in order to further investigate properties and possibilities of PALS measuring systems based on fast pulse digitizers. Our focus is on the determination of contributions of positronium three gamma annihilations. Our PALS setup comprises three BaF₂ detectors directly coupled to the DRS4 evaluation board. Both time and energy information of the detected gamma rays are reconstructed. In the off-line analysis double coincidence events can be selected by choosing 1.27 MeV gamma as a start signal in one detector and 0.511 MeV gamma as a stop signal in one of the other two detectors. Triple coincidence events can be selected by demanding coincidences among 1.27 MeV gamma in one detector and two annihilation gamma rays from positronium decay in the remaining detectors. The setup is now being used in the investigations of selected samples with large voids and for the determination of contributions of three gamma positronium annihilations. These contributions can be of special interest for various porous materials [6,7,8].

In the second section we give brief overview of the PALS setup, the third section is devoted to the energy and time determination from the data collected by the digitizer, the fourth section briefly describes ongoing measurements of the selected samples and the fifth section gives summary and conclusion.
2. PALS setup

Our positron annihilation lifetime spectroscopy system comprises three BaF$_2$ scintillation detectors. The BaF$_2$ scintillators have cylindrical shape with the base diameter of 1 inch and height of 1 inch. All sides of the scintillators, except one base, are wrapped with aluminum foil. The scintillators are placed inside aluminum housings and are coupled to XP2020URQ PMTs which are protected by mu-metal shieldings. All three detectors are in one plane and each detector is positioned on an aluminum holder that can be rotated around the fix central point at which sample with $^{22}$Na source is placed. The angles among the detectors and the distances of the detectors from the source can be varied. Three Ortec 556 HV suppliers are used for the BaF$_2$ detectors. Anode outputs of the PMTs are directly coupled to the inputs of the DRS4 evaluation board. The board has four input channels and it is connected with the USB cable to the computer. Linux based control and data acquisition software supplied by the producer of DRS4 board is used for display of signals on the computer screen and for the data acquisition. The sampling rate can be varied in the interval 0.7-5 GS/s and it is possible to collect 1024 sampling points for each channel, covering the signal time range of 1.4 µs - 200 ns, respectively. The software allows selection of thresholds for the used channels. Also, selection of a combination of AND / OR conditions among the used channels for the data acquisition trigger is possible. In the measurements complete signals from the detectors in the selected time range and for selected trigger conditions are stored.

![Figure 1. The PALS setup with three BaF$_2$ detectors and DRS4 evaluation board.](image)

3. Energy and time determination

Algorithms in Root software [9] for timing and energy determination from the recorded signal pulses have been developed. For timing determination an emulation of constant fraction method was applied.

![Figure 2. Determination of the time difference by using emulation of constant fraction method.](image)
A Gaussian fit on the rising edge of the signal was made and the height of the signal was determined. The time point at a selected fraction of signal height was taken as the time of signal appearance and time differences for coincidence gammas were determined, Figure 2. The selected fraction had been varied until the best time resolution in measurements with $^{60}$Co was obtained.

For energy determination the integration of the signal pulse in the whole range of recorded signal has been made, and it clearly allows separation of gammas in the photo-peak and Compton gamma rays, Figure 3.

![Figure 3. Energy reconstruction by integration of the recorded signal, left. Spectrum of $^{22}$Na Gamma rays recorded by one of BaF$_2$ detectors, right.](image)

In the measurements with $^{60}$Co source and maximal sampling rate of 5GS/s by selecting only gamma rays from photo-peak the achieved time resolution was 145 ps (FWHM), and by using both Compton gamma rays and gamma rays from photo-peak time resolution was 153 ps. Achieved time resolution at the sampling rate of 2 GS/s with $^{60}$Co source was 153 ps when we used gammas from photo-peak, and 185 ps when we used both Compton gamma rays and gamma rays from photo-peak, Figure 4.

![Figure 4. Time resolution determined in the measurements with $^{60}$Co at the sampling rate of 2 GS/s: 153 ps, only gamma rays from photo-peak, left; 185 ps, both Compton gamma rays and gamma rays from photo-peak, right.](image)

The time resolution at the minimal sampling rate of 0.7 GS/s becomes much worse and it is not suitable for PALS measurements. In our measurements, in order to also measure positronium three gamma decays, we use the sampling rate of 2 GS/s.
4. Measurements of selected samples

The setup is currently being used for PALS measurements of some selected samples of porous materials, in particular hierarchical zeolites and mesoporous materials. In larger sample voids a portion of positronium can directly decay in three gammas. Due to these decays the intensities of longer lifetimes from positronium pick-up annihilations determined by standard PALS measurements are lower and eventually they suggest lower relative concentrations of such voids. In order to determine this portion we are currently investigating mesoporous materials in which lifetimes up to 41 ns have been observed, and zeolite samples with hierarchical porosity in which lifetimes up to 36 ns have been observed with our standard PALS setup [10]. In the measurements we are collecting data from which double and triple coincidences can be extracted. Procedures for the determination of contributions of three gamma positronium annihilations which take into account different efficiencies for two- and three- gamma detections are being developed. In these measurements we also are examining the stability of the employed evaluation board for the long term measurements.

5. Summary and conclusion

We have assembled PALS setup based on three BaF$_2$ detectors and DRS4 evaluation board and the software for timing and energy determination of recorded gamma rays has been developed. It can be used for double and triple coincidence measurements. Excellent properties regarding time resolution have been achieved. In the off-line analysis energy selection of the detected gamma rays can be done. These features of the setup can be used for the determination of contributions of positronium three gamma annihilations. On the hardware side this is very simple setup, but the complexity of the relevant information extraction has been shifted toward the software for the data reconstruction and analysis. Also, the amount of collected data substantially increases. The stability of this particular board in long term PALS measurements is being examined. The achieved results clearly demonstrate some of possible advantages of PALS system based on such kind of fast pulse digitizers.

Acknowledgments

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