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Introduction

Positron Annihilation Lifetime Spectroscopy (PALS) is a well-known non-destructive radiological technique widely used in material science studies. PALS typically relies on an analog coincidence measurement setup and allows the estimate of the positron lifetime in the material sample under investigation **[1]**. Depending on the detector used, different kinds of measurement are possible:

1. **Lifetime measurement**: high-speed pulse signals from fast scintillators like BaF_2 scintillator or EJ-309 liquid, EJ-276 and BC-418 plastic scintillator detectors are input to a time analysis spectrum board to calculate the positron annihilation lifetime. The positronium trapping at vacancies in the material results in an increased lifetime **[1]**.
2. **Coincidence Doppler Broadening (CDB)**: while the annihilation lifetime provides information about the size of open volume defects, the Doppler broadening of annihilation radiation tells about the local electron-positron pair momentum distribution at the annihilation site **[2][3]**. In such a case, the coincidence of signals from two HPGe detectors is detected and a corresponding two-dimensional energy histogram is generated.
3. Combining the data from the previous measurement, it is possible to get the **Age-MOmentum Correlation (AMOC)** that allows the user to detect changes in the positron-electron pair momentum distribution in a specific positron state (positron slow-down) or transitions between different positron states (trapping of positrons) **[4][5]**.

In this Application Note, we will describe a demonstrative measurement setup composed by CAEN digital electronics and how these measurements can be easily performed thanks to the CAEN multiparametric acquisition software CoMPASS **[13]**. The analysis of the results is beyond the scope of this measurement and it is usually performed by user designed code or by the well-established *PALSfit3* analysis software provided by the Technical University of Denmark **[6]** or other similar specific software.

Material and methods

The PALS experimental setup is usually composed by a ^{22}Na source (10µCi in our case) sealed between two identical Kapton foils and placed in sandwich geometry between two identical samples **[1]**. Since our experimental setup is just a demonstrative one, the source that we used is constructed using a Plexiglas® disk **[7]** and we did not used any specific sample to be investigated.

The experimental setup shown in **Figure 1** is composed by:

- n°1 10µCi ^{22}Na source **[7]**
- n°2 1" x 1" BaF_2 detectors Mod. 38A38/2M-E1-BAF-X-N, V_{bias} = -1800V **[8]**
- n°1 Canberra HPGE Model 7229P, 20% Efficiency, V_{bias} = +3500V
- n°1 DT5780M – Dual Digital Multi Channel Analyzer (with HV & Preamplifier power supply) **[9]**
- n°1 DT5730 – 8 Channel 14 bit 500 MS/s Digitizer with DPP-PSD firmware **[10]**
- n°1 DT5533N – 4 Channel 4 kV/3 mA (4 W) Desktop HV Power Supply **[11]**
- n°1 DT4700 – Clock Generator and FAN-OUT **[12]**
- CoMPASS Multiparametric Acquisition software **[13][14]**

Figure 1: Overview of the PALS demonstrative experimental setup in the CAEN laboratories.

The detail on the electronics is shown in the picture below.

Figure 2: Detail on the CAEN DAQ setup and connections.

In the above shown experimental setup, the DT5533EN provides the -1800V bias voltage to the BaF_2 scintillators while the DT5780P MCA provides the +3500V to the HPGe.

The BaF_2 signals are readout by the DT5730 digitizer running the DPP-PSD firmware that provides the energy information by means of a charge integration and a high precision timing information through a digital CFD. The HPGe signals are readout by the DT5780P MCA that provides the energy information through a trapezoidal filter and a timing information through a CFD-like (RC-CR2) timing filter.

A common reference clock for the event synchronization is provided to the DT5730 and to the DT5780P by a DT4700 clock generator.

A 10 uCi ^{22}Na source is placed in the middle of the 3 detectors at close distance providing an input rate of about 9 kcps for the BaF_2 detectors and about 20 kcps for the HPGe.

The parameter setting and the data readout, plotting and saving are done by the multiparametric acquisition software CoMPASS that allows the user to perform an easy management and synchronization of multiple a not homogeneous boards running different digital pulse processing firmware, to perform online data selection (eg energy selection) and to perform runtime detector correlation as well.

The energy spectrum acquired with the HPGe detector and one of the BaF_2 detectors are shown in **Figure 3** and in **Figure 4** respectively.

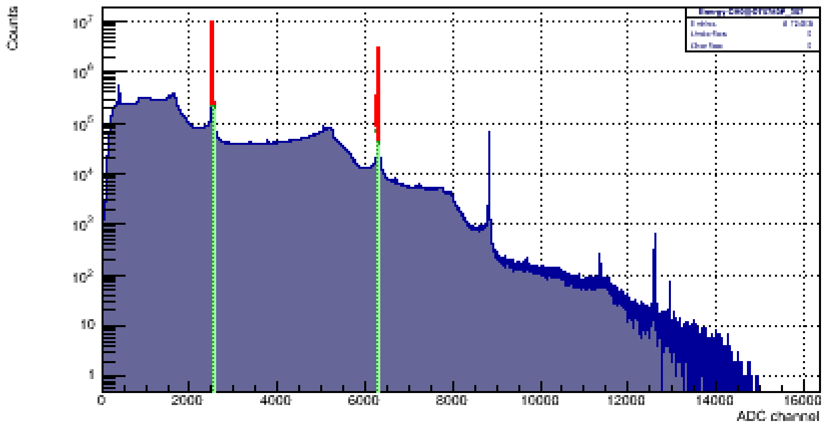

Figure 3: Spectrum acquired with the HPGe detector.

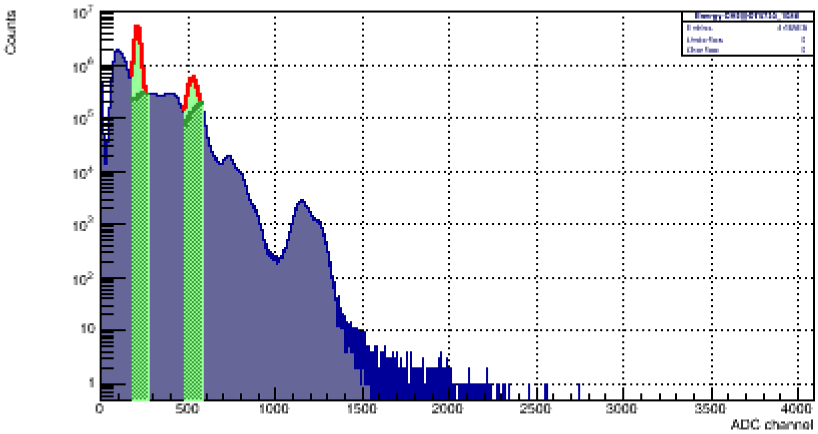

Figure 4: Spectrum acquired with one of the BaF_2 detectors.

The energy resolution achieved with the HPGe at the 511 keV and 1275 keV is 2.8 keV and 2 keV respectively, that are in agreement with previously taken measurement with the same detector at this input rate **[15]**.

The energy resolution achieved with the BaF_2 at the 511 keV and 1275 keV is 12% and 8% respectively, which are within the expectation for this kind of detectors **[8]**.

Lifetime measurements

In order to perform a Lifetime measurement, a BaF_2 - BaF_2 correlation is required.

One BaF_2 detector, in which an energy selection on the 1275 keV ^{22}Na peak is set, provides the correlation start time while the stop is provided by the second BaF_2 detector on which an energy selection on the 511 keV ^{22}Na peak is set (**Figure 5**)

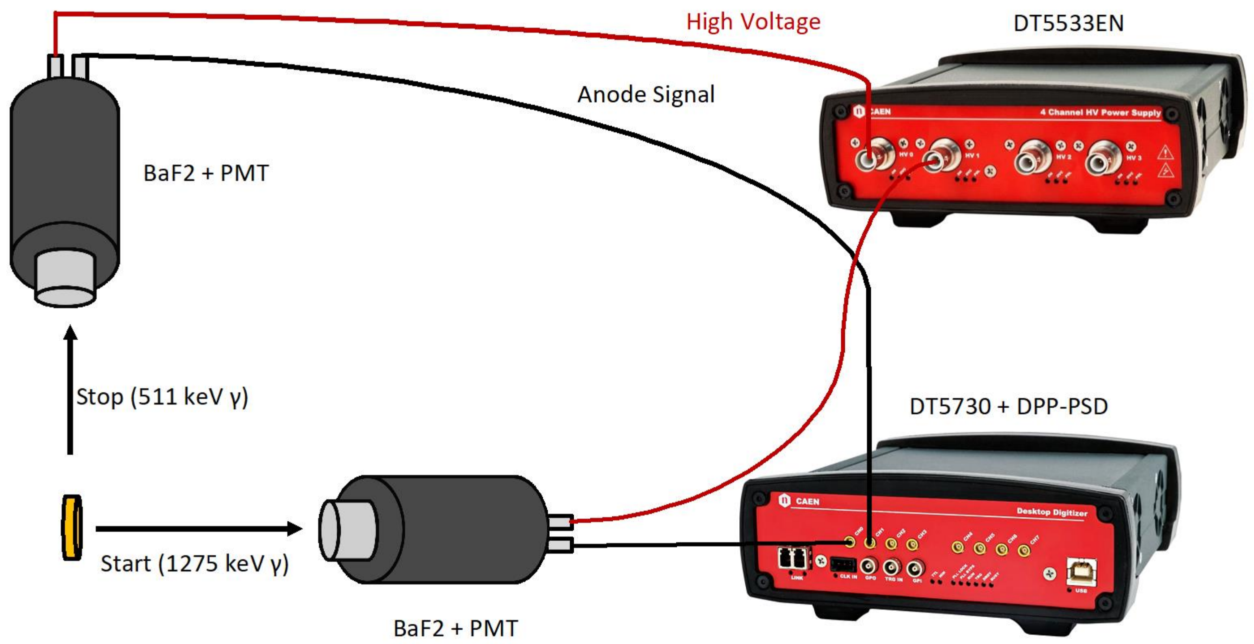

Figure 5: Lifetime measurement scheme.

The BaF_2 - BaF_2 ΔT plot is shown in **Figure 6**, which is the starting point for the following positron lifetime estimation analysis.

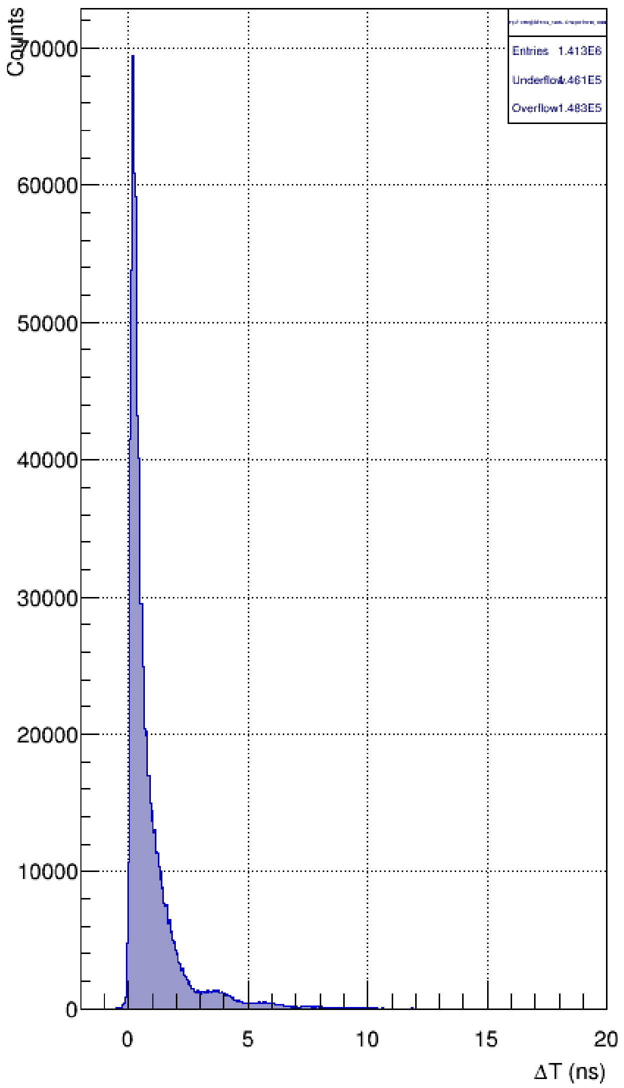

Figure 6: ΔT between the start signal of 1275 keV gamma in the first BaF_2 and 511 keV gamma in the second BaF_2.

Age-MOmentum Correlation measurements

In order to perform a Lifetime measurement, a BaF_2 - BaF_2 - HPGe correlations is required. One BaF_2 detector, in which an energy selection on the 1275 keV ^{22}Na peak is set, provides the correlation common start time while the correlation stop are provided by the second BaF_2 detector and the HPGe on which an energy selection on the 511 keV ^{22}Na peak is set (**Figure 7**).

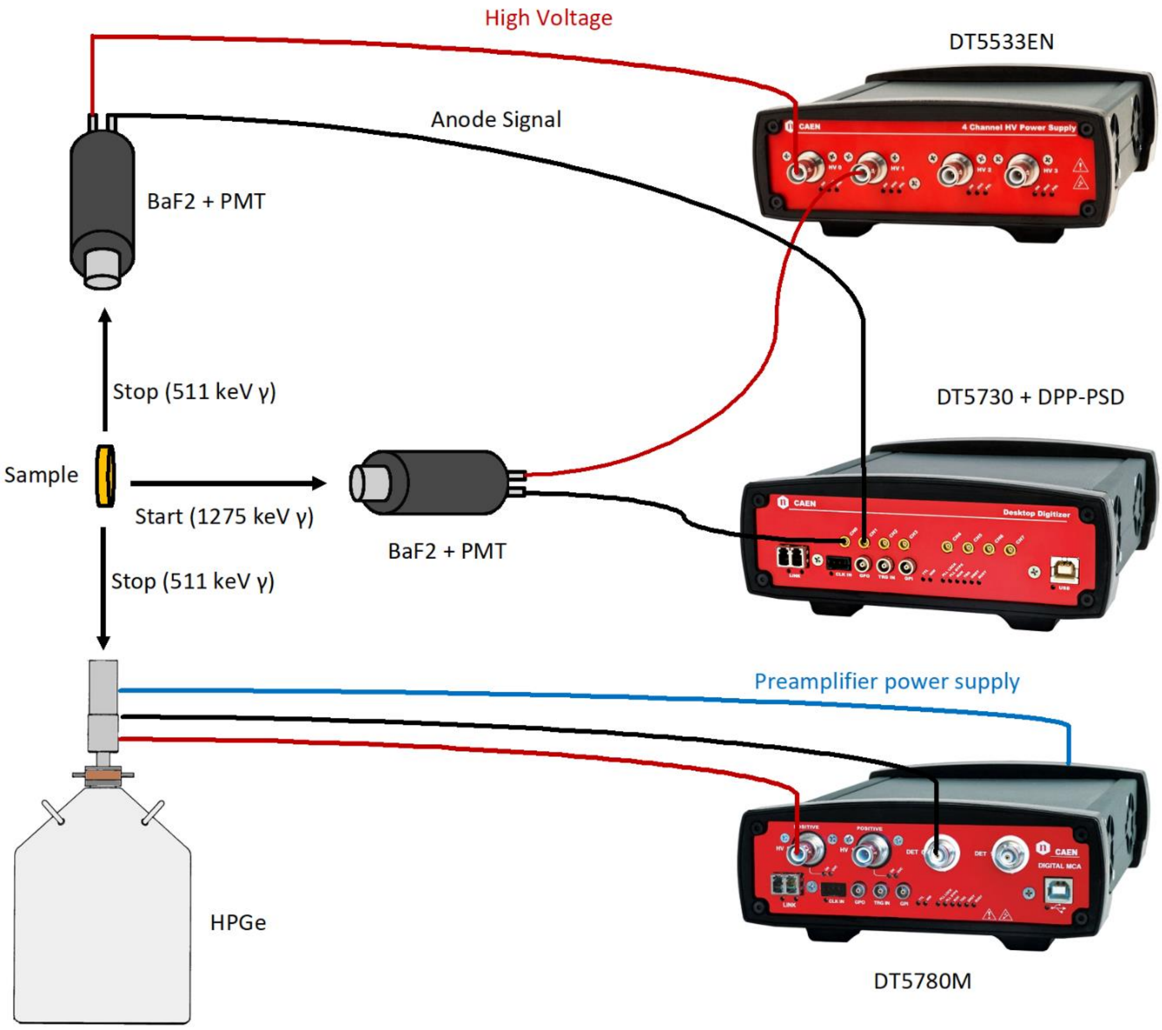

Figure 7: Age-MOmentum Correlation measurement scheme.

To demonstrate the correlation between the measurements obtained with the BaF_2 detector and the HPGe detector the ΔT plot between the 1275 keV gamma in the scintillator detector and the 511 keV in the semiconductor detector is shown in **Figure 8**. The positron lifetime-momentum correlation plot can be obtained with the offline analysis on the saved time-stamped list of energy measurements.

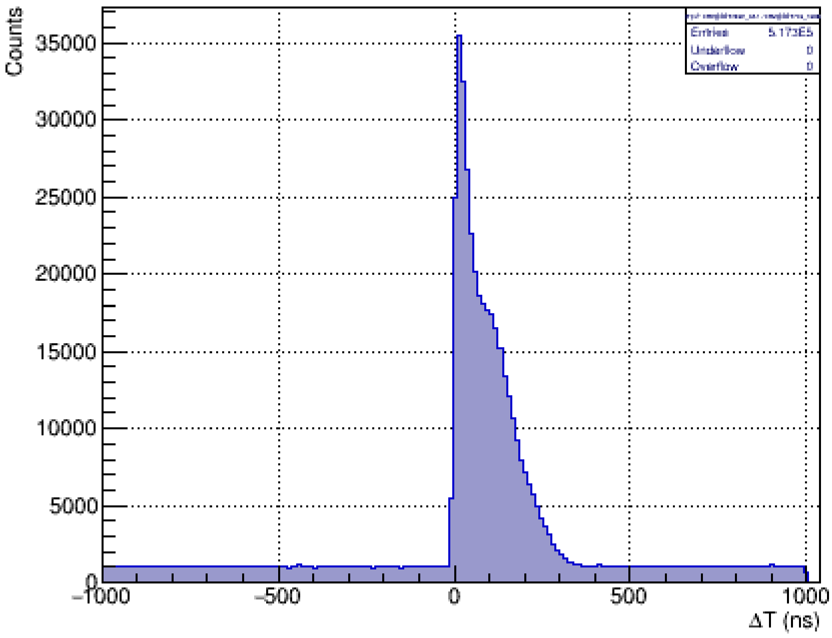

Figure 8: ΔT between the start signal of 1275 keV gamma in the first BaF_2 and 511 keV gamma in HPGe.

Results discussion

In order to show the usability of the dataset provided by our DAQ system, a very simple analysis has been attempted with the demo version of the *PALSfit3* analysis software. The demo has limited functionality (only the PositronFit part is available, the number of channels and lifetimes are limited etc) so a complete and realistic data analysis is out of the scope of this Application Note.
The BaF_2 - BaF_2 ΔT plot has been used. As mentioned in the introduction, the used ^{22}Na source is not of the standard type used in such measurements (i.e. sealed in thin Kapton foils) but a Plexiglas® (PMMA) disk surrounded source and no specific sample to investigate has used. However, it is still possible to try extract the Plexiglas lifetime components.

The results of this analysis are shown in **Figure 9** and **Figure 10**.

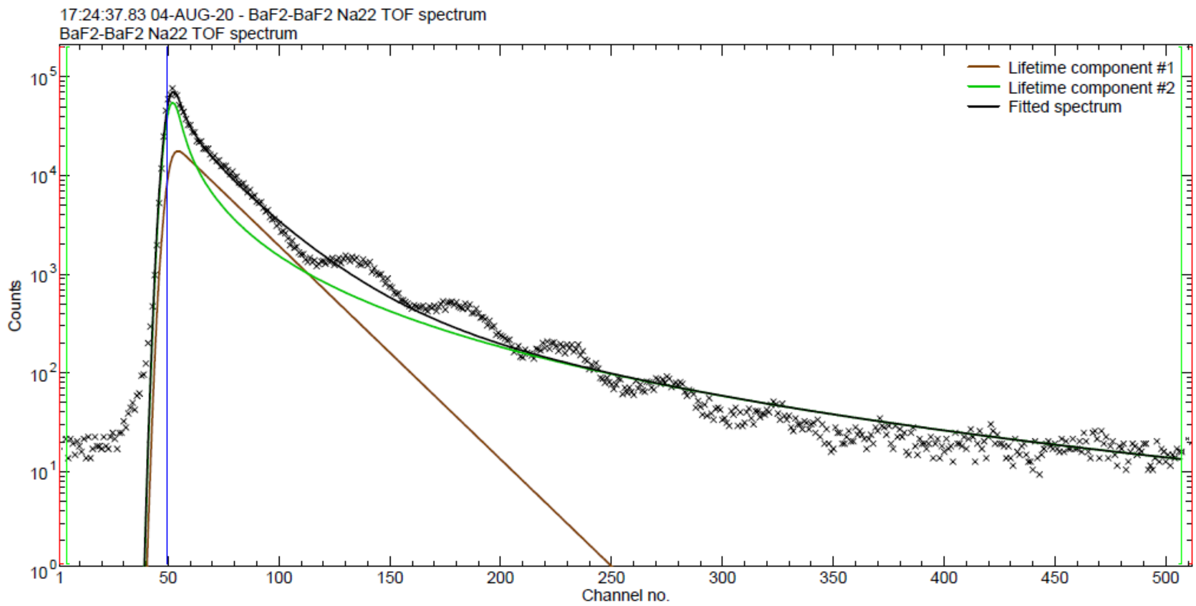

Figure 9: PALS fitted spectrum as shown by *PALSfit3* demo software.

```
####################### F i n a l   R e s u l t s #######################
Dataset 1

Convergence obtained after 36 iterations
Chi-square =      18564.41   with 497 degrees of freedom
Reduced chi-square = chi-square/dof =    37.353   with std deviation 0.063
Significance of imperfect model = 100.00 %

Lifetimes (ns)       :    0.8620    0.9842
Std deviations       :    0.0035    0.0107

Intensities (%)      :   38.0731   61.9269
Std deviations       :    0.4236    0.4236

Mean lifetime(ns)    :    0.9376
Std deviation        :    0.0055
```

Figure 10: PALS results report as shown by *PALSfit3* demo software.

In case of PMMA, usually the measured lifetime spectra are resolved into three lifetime components τ_1, τ_2, and τ_3 with corresponding intensities I_1, I_2, and I_3 because this analysis better fit results however, as mentioned the *PALSfit3* demo version allows to use only 2 components. This results in a high χ^2 fit value and probably in not realistic results.

Conclusions

In this Application Note the demonstration of how easily a PALS measurement setup can be built and operated has been shown. Thanks to the multiboard and multiparametric capabilities of the CoMPASS software it is possible to easily get at the same time the energy and the high resolution correlated time information from different detectors (BaF_2 and HPGe in this case) connected to different acquisition boards. Energy and Time-of-Flight spectra and List files with event by event time and energy information for a subsequent more advanced analysis can be easily saved as well.

References

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