Advanced positron lifetime spectroscopy for pulsed positron beams

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Motivation

- Conventional positron lifetime (Fig. 1) suffers from a relatively bad time resolution (FWHM=180...250 ps).
- The source activity must be limited for small background: collection of high-statistics spectra (>10^7 counts) is very time-consuming.
- The resolution function is often very complex (approximated as sum of gaussians).
- A further disadvantage is the fraction of positrons annihilating in the source, which must be substracted from the spectra.

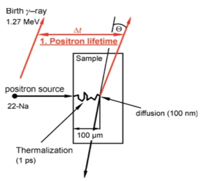

Fig. 1: Conventional positron lifetime is measured as time difference between a γ quantum from the β^+ decay and only one of the two annihilation 511-keV γ quanta.

Triple coincidence improves time resolution

- When measuring also the lifetime by using the second 511 keV γ quantum (times t_1 and t_2, Fig. 2), the time resolution can be improved by averaging the two values (improvement factor: $1/\sqrt{2}$)
- By substracting t_2-t_1, the resolution function itself could be measured. The background should be strongly suppressed.
- Monte-Carlo simulations show the improvement for the resolution function and for the lifetime spectrum (Fig. 3).
- Both improvements are only possible for the fraction of the resolution function which originates from the stop channel.
- Hence, best application is expected for pulsed beams with small time spread of incoming positron beam.

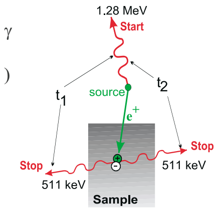

Fig. 2

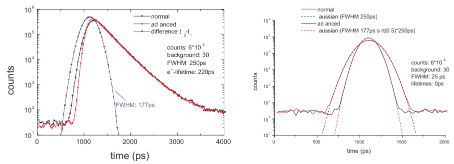

Fig. 3

Realization using a ^{22}Na source

- For testing the principle, the advanced positron lifetime was realized by using an ^{22}Na source and detectors for all three γ quanta (Fig. 4)..
- Data collection was done using a FAST-ComTec two-dimensional coincidence system in list mode (t_1 and t_2 are stored together as a pair).
- The calculation of $(t_1+t_2)/2$ and t_2-t_1 was performed after completing the measurement.

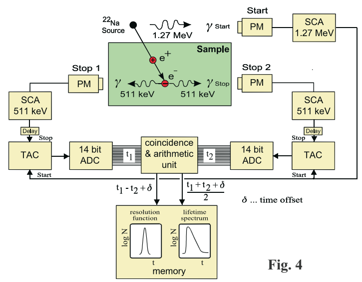

Fig. 4

Results of experiments

- Fig.5 shows the result of the above described test measurements as a 3D-plot. As expected, the coincident spectrum showed only a slight improvement of the time resolution from 240 to 220 ps (FWHM) due to the non-neglectable contribution of the start detector to the resolution function.
- The background was low in the complete t_1-t_2-plane, but surprisingly high in the diagonal. This is due to backscattered 1.27 MeV γ quanta which start the time measurement and still causes a stop pulse. This can be avoided in a beam system where no such high-energy quanta are present at the sample position. Then, a strong background suppression is possible even for a high-brigthness positron source.

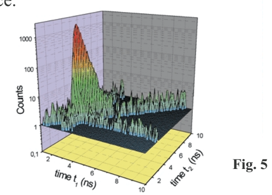

Fig. 5

Application at a high-brightness pulsed beam

- The ideal application is a pulsed positron beam at a strong source. Here, one can make use of all advantages of the triple-coincidence technique. Fig. 6 shows a possible setup.
- A multidetector system is necessary for a high counting rate.

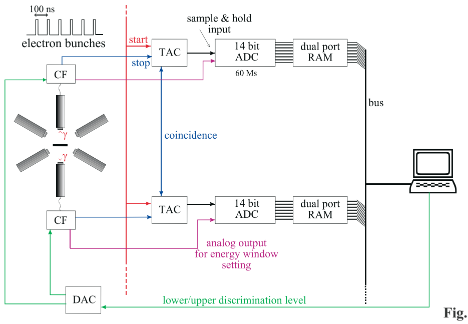

Fig. 6

Conclusions

- The detection of both annihilation γ quanta allows the improvement of the time resolution of a positron lifetime measurement. This is especially useful when a pulsed positron beam with a small time spread of the positron bunches is used.
- The fraction of the resolution function originating from the stop pulse can be measured directly.
- The background can be suppressed strongly by the additional coincidence circuit when the 1.27 MeV quanta are not present at the sample position (at a positron beam).
- The advanced positron lifetime technique is not suiatable for a laboratory system using a ^{22}Na source (low counting rate and only partially realization of improvements).
- The application of this technique is strongly recommended for the positron lifetime spectroscopy at a high-brightness positron source. Then, also the source contribution to the spectrum is avoided.

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