An approach towards digital positron annihilation coincidence Doppler broadening spectroscopy

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Introduction

The first steps towards a digital Coincidence Doppler Broadening Spectrometer (CDBS) which is also suitable for Age-Momentum Correlation (AMOC) for use in material research is presented. Analyzing Doppler broadening of annihilation radiation is one of the fundamental methods in positron annihilation spectroscopy and due to it's simple and compact setup one of the most spread techniques in positron material research. The most significant improvement in the last years is the usage of digital technology [1,2] and the availability of high intense positron beam sources. We try to make use of both of them by developing a fully digital CDBS for the upcoming high intense positron beam source EPOS at the Research Center Dresden-Rossendorf. The experimental data will be analyzed and evaluated by an own sophisticated open source software suite and is presented to the user in an online manner while the user obtains fully remote control.

Basics

The fundamental fact of conservation of momentum and energy taking place at the annihilation process enables methods to study defects and the electronic structure in solid materials [3]. During the annihilation process the entire momentum p of the electron-positron pair is transferred to the photon pair, which is emitted with a total energy of $2m_0c^2 - E_B$ whereas m_0 is the rest mass of the electron and E_B is the binding energy of the electron. The measured Doppler shift (broadening of the line) in the annihilation quantum energy originates from the longitudinal component of the electron-positron momentum and is used for chemical and electronical identification of atoms on the annihilation site.

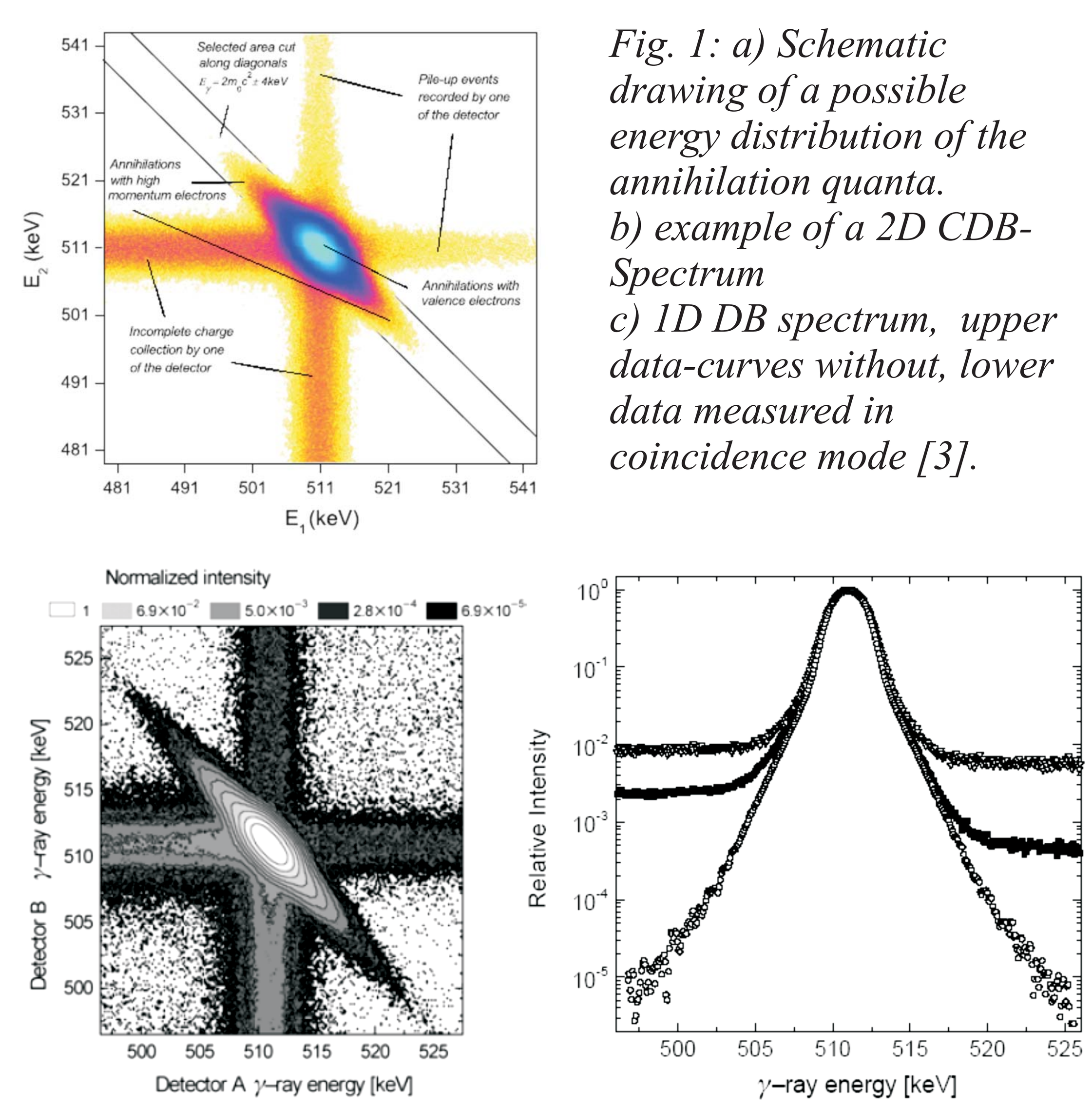

Fig. 1: a) Schematic drawing of a possible energy distribution of the annihilation quanta. b) example of a 2D CDB-Spectrum c) 1D DB spectrum, upper data-curves without, lower data measured in coincidence mode [3].

Digital measurement setup

As proposed by Lynn and others [4] two high purity germanium scintillators (efficiency about 20%) face each other in a short distance to detect both 511 keV γ-quanta in coincidence. Shortly after the annihilation, the signals of the photons are converted into electrical pulses by state-of-the-art digitizers. We use always two coupled digitizers (CompuScope 14100C, bandwith of 100MHz, up to 100 MS/s in single detection mode and 50 MS/s simultaneous sampling in coincidence mode.) to realize one ultrafast two-channel digitizer.

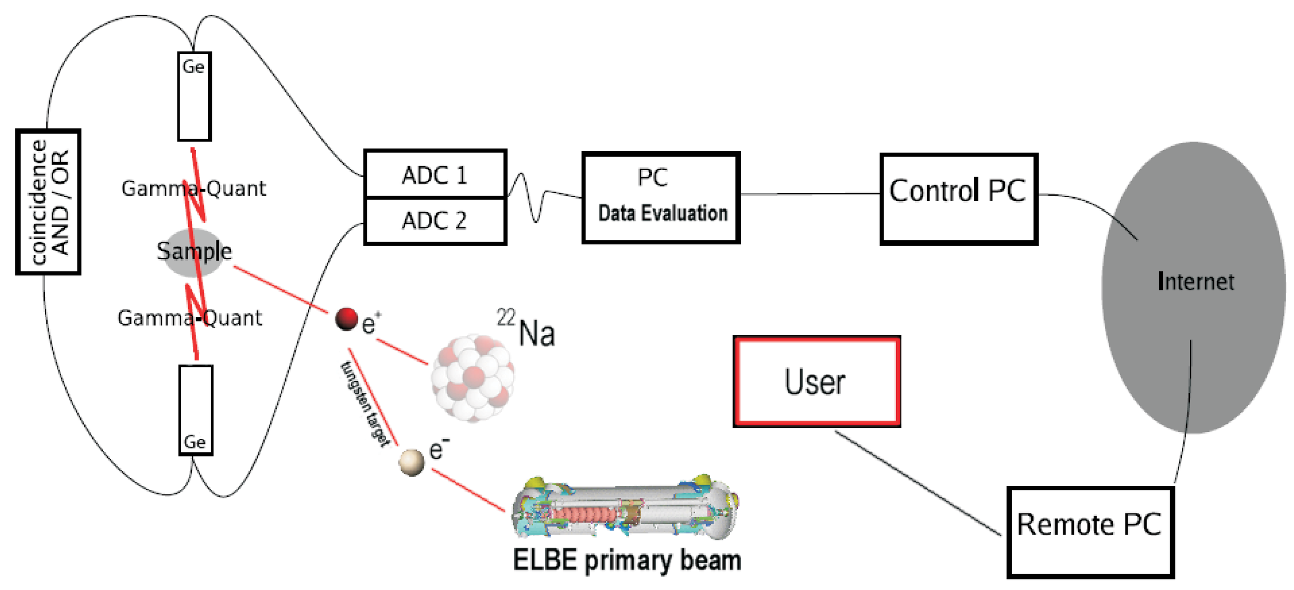

Fig. 2: Schematic overview of the digital CDBS setup (PM=photomultiplier, ADC=Digitizer) like it will be used at EPOS

The fetched digitalized pulses are evaluated through exchangable plugins in the data-acquisation-chain and are sent by network to the server. Different plugins and filters can be applied/reapplied during the acquisition without recompiling the software e.g.:

- Grading of pulse-shape quality (noise, pile-up's)
- Constant fraction modules for coincidence time window
- Analysis of rise/decay-time of the pulse
- Different methods of energy determination (pulse amplitude, different integrations of the pulse)
- Interpolation methods for higher accuracy

As the digitizer delivers a resolution of 14 bit and we are using new methods to determine the energy of the γ-quanta we expect at an energy 40-50 eV per channel an estimated FWHM below 1 keV for the system resolution function (514 keV gamma ray line of ^{85}Sr) for one detector. Moreover, it has been demonstrated that by additional deconvolution techniques an effective resolution below 400eV can be reached [5]. It will be a task in the near future to implement different additional methods (least square, iterative Newton) to substract the background in the CDB spectra in our software.

As EPOS provides a counting rate of about $1x10^5$ s^{-1} on the detector we have to confess that we will not benefit of them all, as the online signal processing software limits us to $1x10^4$ events per second for a single detector.

Pulse shape discrimination

Even though a simple coincident set-up enables peak-to-background ratios up to 10^5 [3,4], one of the main drawbacks of CDBS still is the distortion of the spectra by background events, mainly arising from Compton scattering, incomplete charge collections by the detectors, environmental radiation and pulse pile-up's. With Compton scattering of high energetic gammas being banned by using a positron beam instead of a conventional β^+-emitter, the last two events can easily be suppressed by using different software filters during pulse acquisation (see fig. 3). With additional suppression of chance coincidences one will obtain high resolution energy spectra from which even information of core electrons can be obtained.

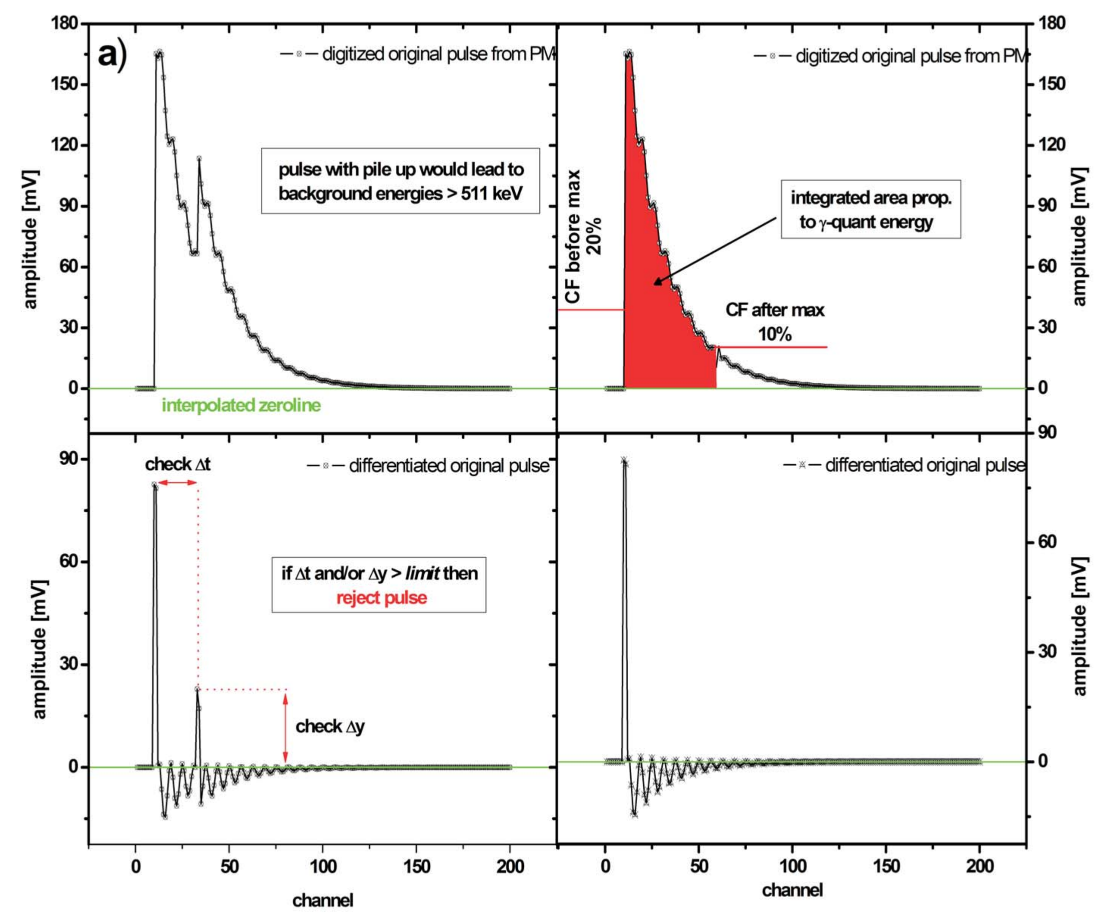

Fig. 3: Examples for pulse shape discrimination and energy determination of the digitized pulses .

Advantages and drawbacks

- No electronic adjustments
- Faster measurement, better energy- and time resolution expected
- Flexible evaluation and analysis of the data by specialized software
- Limitation of pulse rate due to online processing
- Calibration and universality of the software

References

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This poster and the described open-source software can be downloaded from our hompage:

http://positron.physik.uni-halle.de/

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