Development of a new time and position resolving detector for the pulsed low energy positron system PLEPS

2013 J. Phys.: Conf. Ser. 443 012095

(http://iopscience.iop.org/1742-6596/443/1/012095)

Development of a new time and position resolving detector for the pulsed low energy positron system PLEPS

U Ackermann[1], W Egger[1], P Sperr[1], B Löwe[1], L Ravelli[1], G Kögel[1], G Dollinger[1] and O Jagutzki[2]

[1] Universität der Bundeswehr München, Institut für Angewandte Physik und Messtechnik, Werner-Heisenberg-Weg 39, Neubiberg, 85577, Germany
[2] Universität Frankfurt, RoentDek GmbH c/o Institut für Kernphysik, Frankfurt am Main, 60438, Germany

ulrich.ackermann@unibw.de

Abstract. The pulsed low energy positron system PLEPS at the Munich research reactor FRM-II is a user facility for depth resolved positron lifetime measurements. Besides positron lifetime measurements 2D-AMOC (Two Dimensional Age Momentum Correlation) experiments are also possible. 2D-AMOC provides in coincidence the lifetime of the positron and the longitudinal momentum distribution of the annihilated electron. It would be of great scientific concern to measure simultaneously the entire 3D-momentum distribution of the electron annihilating with the positron and the corresponding lifetime of the positron (4D-AMOC). To perform 4D-AMOC measurements a time and position resolving detector is required in coincidence with a pixelated Germanium detector. Therefore a time and spatially resolving detector is currently developed at our institute with envisaged time resolution of 100 ps (FWHM) and a spatial resolution of about 2.6 mm (FWHM) over an area of 12 cm². First test measurements have been carried out with a 25 mm diameter MCP (Micro Channel Plate) image intensifier and with special delay-line anode readout for the spatial information. Up to now 178 ps (FWHM) time resolution and on average 3.4 mm (FWHM) position resolution have been achieved with BaF_2 as scintillator material and a ^{60}Co source.

1. Introduction

The pulsed low energy positron system [1] (PLEPS) at the high intensity neutron induced positron source [2] (NEPOMUC) at the Munich research reactor FRM-II is a very powerful user facility to perform depth-dependent high-quality positron annihilation lifetime spectroscopy (PALS) measurements. To enhance its defect identification potential a setup to perform two dimensional age momentum correlation (2D-AMOC) measurements has been recently commissioned [1]. In addition to the lifetime of the positron 2D-AMOC measurements provide information about the correlated longitudinal momentum of the electron annihilating with the positron and thus about the chemical environment at the location of annihilation. It would be of great scientific concern to measure the full three dimensional momentum distribution of the electron annihilating with the positron together with the positron's lifetime (4D-AMOC).

In the 2D-AMOC setup the two almost collinearly emitted gamma quanta from the annihilation process are registered with a photomultiplier tube (PMT) to measure the lifetime of the positron in coincidence with a Germanium detector to measure the longitudinal momentum of the electron.

4D-AMOC measurements require a time and position resolving detector operating in coincidence with an energy and position resolving detector. In our 4D-AMOC setup we use a commercially available pixelated Germanium detector from Canberra as position and energy resolving detector. The time and spatially resolving detector is currently under development. The pixelated Germanium detector has an energy resolution of 1.35 keV (FWHM) at 662 keV. For the time and position resolving detector a time resolution of about 100 ps (FWHM) is envisaged. The required angular resolution for both detectors is 2.6 mrad (FWHM). This corresponds to 2.6 mm position resolution (FWHM) at a distance of 1 m from the specimen.

To meet these constraints, a new approach for the time and position resolving detector has been chosen using a specially designed MCP image intensifier with a BaF_2 scintillator and a capacitively coupled delay-line anode readout providing the spatial information. First time and position resolution tests have been made with a prototype. The results are presented in this paper.

2. Experimental setup and results

To figure out the optimum design parameters for the new time and position resolving detector, we used an MCP image intensifier from Proxitronic (active diameter 25 mm) with a fused silica entrance window and a bialkali photocathode evaporated on the inner side of the window. For the time resolution measurements a cylindrical BaF_2 scintillator of 15 mm diameter and 10 mm height was coupled to the entrance window. For the position resolution measurements two identical BaF_2 scintillators (4 mm diameter, 8 mm height) were mounted at a distance of 7.5 mm. The time signal was taken directly from the MCPs. The electron cloud produced in the channels of the MCP image intensifier is collected on a so-called resistive screen anode which is capacitance-coupled to a commercial position-encoding delay-line anode (RoentDek GmbH) placed outside the MCP image intensifier. Figure 1 shows a schematic drawing of the MCP detector setup.

2.1. Time resolution measurement

A conventional fast-slow configuration was used for the time resolution measurement (see figure 2). Start and stop signals for the time to amplitude converter were derived from a PMT (Photonis, XP2020 URQ) and the MCP image intensifier using constant fraction triggers. In the measurements a ^{60}Co (1.17 MeV and 1.33 MeV) point source was placed between the MCP image intensifier and the PMT.

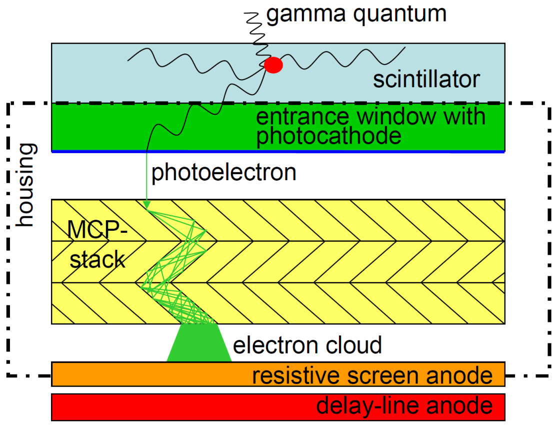

Figure 1. Principle drawing of the MCP detector setup.

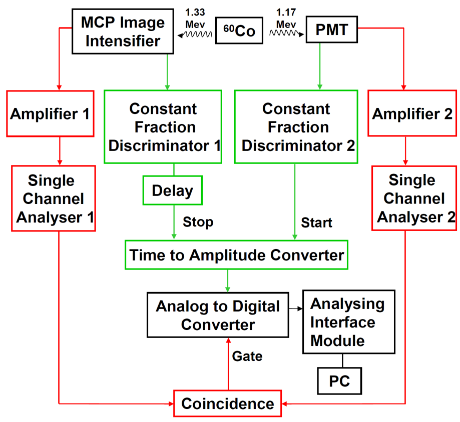

Figure 2. Scheme of the time resolution measurement setup.

The energy window was set on the 1.17 MeV energy peak for the PMT and on the 1.33 MeV energy peak for the MCP image intensifier. The measured coincidence resolving time was 206 ps ± 1 ps (FWHM). From the known time resolution of the PMT the MCP image intensifier time resolution of 178 ps ± 1 ps (FWHM) could be deduced. In figure 3 the recorded time spectrum is shown.

2.2. Position resolution measurement

The 2D-position information of the interaction of the gamma quantum in the scintillator is deduced from a RoentDek delay-line anode readout. The delay-line anode in this setup consists of a three layer structure with LC-delay configuration. A detailed description of the delay-line anode could be found in [3]. An electron cloud hitting the resistive screen anode will induce a signal on the three layers of the delay-line anode. This signal goes to the endings of the respective LC-delays leading to six signals - two signals per layer - with different arrival times. From the differences of the arrival times relative to the signal taken directly at the MCPs the centroid information of the electron cloud and hence the 2D-position of the interaction of the gamma quantum in the scintillator is derived.

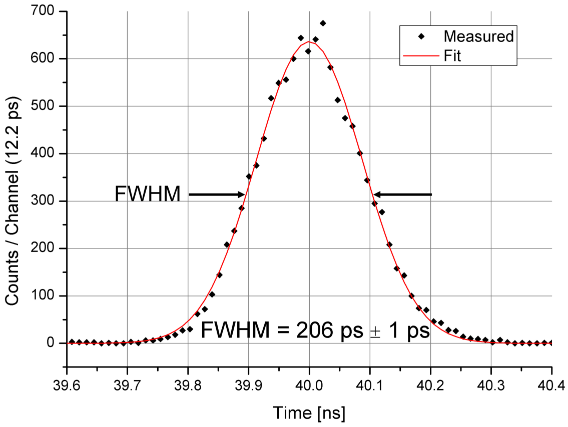

Figure 3. Observed coincidence resolving time spectrum with the MCP image intensifier and PMT.

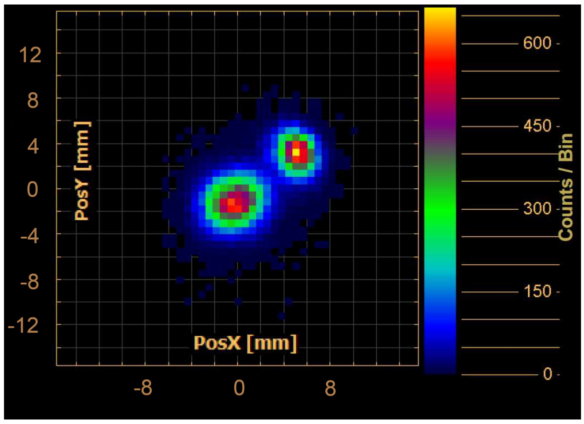

Figure 4. Recorded detector signals as function of position. The two BaF_2 crystals can be clearly separated.

Two identical BaF_2 scintillator cylinders (4 mm diameter, 8 mm height) were mounted with a plastic holder on the entrance window of the MCP image intensifier, one in the center of the entrance window, the other in a distance of 7.5 mm (center to center). The ^{60}Co point source was placed on top of the plastic holder between the scintillators. Figure 4 shows the recorded detector signals as a function of position. The position of the two BaF_2 cylinders is clearly resolved. The projection of the counts to the x-axis results in an average position resolution (FWHM) of approximately 3.3 mm and for the projection to the y-axis of 3.4 mm, respectively.

3. Conclusion and outlook

A new detector approach with a MCP image intensifier and additional delay-line anode readout for reaching the goal of 100 ps time resolution and 2.6 mm position resolution, FWHM respectively, was presented in this paper. The aim is to upgrade PLEPS in the near future with a position and time resolving detector fulfilling the above mentioned constraints and thus enabling in coincidence with a pixelated Germanium detector 4D-AMOC measurements. We have reached with a 25 mm active diameter MCP image intensifier a time resolution of 178 ps (FWHM) and on average a 3.4 mm position resolution (FWHM) in our first experiment with BaF_2 as scintillator material. This result seems very promising to achieve the above stated required position and time resolution. Tests will be made with a MCP image intensifier with 40 mm active diameter and delay-line anode readout and different shaped scintillators.

The so far measured time resolution with the 25 mm active diameter MCP image intensifier is in the order of the until now achieved time resolution at PLEPS. Already at this moment it would be possible to implement the MCP image intensifier at PLEPS and to perform time resolution measurements. Due to the fact that we used for the time resolution measurements already at our institute existing instrumentation the goal of 100 ps (FWHM) seems feasible with especially for the MCP image intensifier adapted electronics. Also the position resolution of 2.6 mm (FWHM) should be obtainable by performing further experimental position resolution tests with different shaped scintillator materials.

Acknowledgement
Funding from the BMBF (Project 05K10WNA-Posimethod) is gratefully acknowledged.

References

[1] Egger W 2010 Pulsed low-energy positron beams in materials sciences *Proc. Int. School of Physics Enrico Fermi Course CLXXIV* ed R S Brusa, A Dupasquier and A P Mills Jr (Amsterdam: IOS Press) pp 419–449
[2] Hugenschmidt C 2010 Positron sources and positron beams *Proc. Int. School of Physics Enrico Fermi Course CLXXIV* ed R S Brusa, A Dupasquier and A P Mills Jr (Amsterdam: IOS Press) pp 399–418
[3] Schössler S, Bromberger B, Brandis M, Schmidt L Ph H, Tittelmeier K, Czasch A, Dangendorf V and Jagutzki O 2012 Time and position sensitive single photon detector for scintillator read-out *J. Instrum.* 2012 JINST 7 C02048