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Timing resolution of fast gamma detectors

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<p> Positron Annihilation Lifetime Spectroscopy (PALS) technique enables atomic-scale investigation of a wide range of phenomena and material characteristics. It is based on measuring the time interval between positron production and annihilation and reflects the characteristics of the environment in which the annihilation takes place. The timing resolution of the PALS spectrometer is influenced mainly by the performance of its detectors. Barium fluoride (BaF₂) inorganic crystals assembled with fast photomultiplier tubes (PMTs) are often used in PALS measurements due to their high density, short radiation wavelength, and short decay time of 600 - 800 ps. </p>

<p>Experiments that are going to be performed at Extreme Light Infrastructure - Nuclear Physics will use a PALS system where slow positron beams will be guided by magnetic field. In this respect, this study presents the investigation of the timing resolution of BaF₂ detectors to determine their performance when subjected to magnetic fields. The results were compared with the timing resolution of the detectors that were not influenced by magnetic field. </p>

<p>The experimental equipment was a digital PALS system. It consisted of different combinations of two fast BaF₂ scintillation detectors in face-to-face geometry, the corresponding electronics, and a source of ⁶⁰Co. Five Hamamatsu H3378-50 PMTs with linear-focused dynodes were coupled to five polished BaF₂ crystals. Four of them had truncated pyramidal shapes (45 mm diameter x 27 mm height) and the fifth was cylindrical (50 mm diameter x 50 mm height). The spectrometer timing resolution function was well-represented by a Gaussian and as a quantitative estimation, the full width at half maximum (FWHM) was taken. FWHM represents the value of the spectrometer resulting from both detectors and the electronics. To obtain the timing resolution of the detectors, one should first determine that of the electronics. The timing resolution of the electronics was obtained through two methods. The first method used a single detector and a passive splitter that divided the anode signal of the PMT into two identical signals considered as start and stop and the second one used a wave generator that created two artificial and synchronized signals. </p>

The results from this study showed that the timing resolution values of the electronics were quite similar for both methods. Within the first method, a value of 25 ps resulted and for the second one of 25.5 ps. For the experiments where the detectors were not subjected to magnetic fields, their timing resolution as a function of the voltage applied to PMTs, showed a linear improvement. The timing resolutions of the four detectors (BaF₂ truncated pyramidal shape) felt between 64 and 86 ps, indicating a good consistency among them. Instead, but the fifth detector (BaF₂ cylindrical shape) had a worse timing resolution corresponding to 96 - 107 ps. In addition, by performing a stability test (using ²²Na source) over longer periods of time (45h), the system proved to be extremely stable.

<p>In order to mimic the magnetic field of the slow positron beam line around the detectors, coils were added to the experimental set-up configuration. Longitudinal magnetic field was created by a coil placed parallel to the axis of the detectors. Both timing resolution of the detectors and their energy spectrum were measured. The energy spectra were collected to determine how the magnetic field affects the strength of the detector signals. For the creation of transversal magnetic field, two Helmholtz coils were added one on top of each other and oriented perpendicularly to the detectors. Similarly, the timing resolution and energy spectra were evaluated. The results showed that the timing resolution values increased with the magnetic flux density and the longitudinal field has stronger effect. </p>

<p>Measurement was performed within transversal magnetic field. First, the energy spectra of the detectors were collected by individually rotating one of the detectors with an α angle along their axis, i.e., one detector was fixed at 0^o angle, meanwhile the other was rotated with different angles (0^o, 45^o, 90^o, 180^o, 270^o, and 315^o). From this data, it was determined the best and worse axial detector orientation. The configuration at which the strongest and the weakest signals resulted from the energy spectra of both detectors correspond to different rotation angles, such as 180^o and 315^o for detector 1 and to 0^o and 90^o for detector 2. Then, to demonstrate the importance of the axial rotation orientation of the detectors, the spectrometer timing resolution was obtained for the best and worse orientations, showing a FWHM value of 293 ps and 384 ps correspondingly. </p>

<p>In conclusion, the similar timing resolution of the BaF₂ truncated pyramidal shape detectors indicated a good consistency among them. When the detectors were placed in longitudinal or transversal magnetic fields, their performance and, by default, their timing resolution values deteriorated due to the helical motion of the charged particles (the electrons between the dynodes of the PMT) within magnetic field. Moreover, the PMTs in transversal magnetic field need individual optimization of the axial angle to obtain their best performances.</p>

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