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Compton Telescope for hadron therapy range monitoring: update on characterization results and beam tests.

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The detection of prompt gammas to assess range variations in real time during hadron therapy is being investigated as an alternative to PET techniques. The use of prompt gammas can be advantageous given the larger amount produced as compared to positron emitters and the fact that they are produced within nanoseconds after irradiation. However, their detection is challenging due to the continuous emission spectrum at high energies (useful up to about 10 MeV).

The IRIS group of the Instituto de Fisica Corpuscular (IFIC-CSIC/UVEG, Valencia) has developed a three-layer Compton telescope based on LaBr3 scintillator crystals and Silicon photomultipliers for this purpose. The system aims at combining two- and three-layer events. For the latter, the energy is determined by event kinematics and thus they provide high precision. Two-layer events without requiring absorption of the photons provide high efficiency. In order to use both types of events, an image reconstruction code capable of estimating the energy of the incoming gamma ray has been developed.

The telescope is made of LaBr3 continuous crystals coupled to MPPC arrays in order to obtain high spatial resolution and fast timing response, together with compactness and operation simplicity. The VATA64HDR16 ASIC is employed in the front-end readout. A custom-made data acquisition system drives the ASIC and controls the acquisition. A programmable coincidences board makes it possible to acquire data with any two or three planes simultaneously.

The system has been characterized in the laboratory with radioactive sources of different energies (Na-22, Y-88). Data have been acquired in several geometrical configurations with two and three planes. With the Y-88 source, a preliminary spatial resolution of 3.1 mm FWHM has been obtained with two planes, and of 5.2 mm FWHM with three planes.

The system has also been tested in beam facilities. At KVI-CART (Groningen), data were taken with a 150 MeV proton beam with an intensity of about 1E8 protons/s and a lateral beam spread of 5.3 mm impinging on a PMMA phantom. The PMMA target was placed in two different positions along the beam separated by 10 mm. A shift in the Bragg peak consistent with the phantom position was observed. At HZDR (Dresden) the system was placed in different positions to image 4.4 MeV photons. The distance between the centers of the reconstructed images corresponds to the telescope shift.

The telescope shows promising results both in laboratory and in beam tests. Further optimization of the device is ongoing in order to achieve the specifications necessary for the application.

Summary

Hadron therapy is a promising radiotherapy technique for certain types of cancer, in particular for ocular tumours, radioresistant tumours, paediatric patients, or tumours close to critical organs. The benefits of sparing healthy tissue from irradiation have been demonstrated[1,2]. However, the lack of precise methods to monitor the treatment online is hindering its further application. PET techniques currently applied have strong limitations, such as low efficiency, late emission of positrons and biological washout, complicating its use for real time monitoring.

The detection of prompt gammas to assess range variations in real time during hadron therapy is being investigated as an alternative to PET techniques. The use of prompt gammas can be advantageous given the larger

amount produced as compared to positron emitters and the fact that they are produced within nanoseconds after irradiation. However, their detection is challenging due to the continuous emission spectrum at high energies (useful up to about 10 MeV).

Collimated and Compton Cameras with different configurations and materials are being employed for this purpose. The IRIS group of the Instituto de Física Corpuscular (IFIC-CSIC/UVEG, Valencia) has developed a three-layer Compton telescope based on LaBr3 scintillator crystals and Silicon photomultipliers[3]. The system aims at combining two- and three-layer events. For the latter, the energy is determined by event kinematics and thus they provide high precision. Two-layer events without requiring absorption of the photons provide high efficiency. In order to use both types of events, an image reconstruction code capable of estimating the energy of the incoming gamma ray has been developed[4].

The telescope is made of LaBr3 continuous crystals coupled to MPPC arrays in order to obtain high spatial resolution and fast timing response, together with compactness and simplified operation. Each crystal is coupled to four arrays with 4x4 pixels of 3 mm x 3 mm size. The first layer is made of a 27.2 mm × 26.8 mm × 5 mm crystal coupled to four Hamamatsu MPPC S11830-3340MF monolithic arrays. The arrays are biased individually. The second and third layers are composed of crystals of size 32 mm × 36 mm and thickness of 5 and 10 mm, respectively, coupled to four S11064-050P(X1) arrays (an older version with larger gaps between the pixels), with a common bias for all of them.

The ASIC VATA64HDR16 is employed in the front-end readout to process the signals of the 64 channels and provide the detector trigger. The trigger signals are fed to a programmable coincidences board which makes it possible to acquire data with any two or the three planes simultaneously. Custom-made data acquisition system and software are employed to drive the ASIC and control the acquisition.

The system has been characterized in the laboratory with radioactive sources of different energies (Na-22, Y-88). The uniformity of the channel response is within 5% for the first detector and the energy resolution around 7% FWHM at 511 keV. For the second and third detectors, the uniformity is about 10% and the energy resolution 7.5% FWHM at 511 keV. Coincidence data have been acquired in several geometrical configurations with two and three planes and with the two radioactive sources in different positions. With the Y-88 source, a preliminary spatial resolution of 3.1 mm FWHM has been obtained with two planes, and of 5.2 mm FWHM with three planes.

The system has also been tested in beam facilities. At KVI-CART (Groningen), data were taken with a 150 MeV proton beam with an intensity of about 1E8 protons/s and a lateral beam spread of 5.3 mm impinging on a PMMA phantom. The PMMA target was placed in two different positions along the beam separated by 10 mm. A shift in the Bragg peak consistent with the phantom position was observed[5].
At HZDR (Dresden) the system was placed in different position to image 4.4 MeV photons. The distance between the centers of the reconstructed images corresponds to the telescope shift.

The telescope shows promising results both in laboratory and in beam tests. Further optimization of the device is ongoing in order to achieve the specifications necessary for the application.

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