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#9-238 Range monitoring in proton and carbon therapy with the TIARA detector

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Hadron therapy offers a significant advantage over conventional gamma-ray radiotherapy: its specific dose deposition profile with a maximum, called Bragg peak, at the end of the hadron range allows for more precise tumour targeting while sparing the healthy tissues. However, uncertainties in the prediction of the range in the patient leads to the use of relatively large safety margins, thus hindering the potential of this kind of therapy. In this context, we have developed a range monitoring detector, the Time-of-Flight Imaging ARrAy (TIARA), dedicated to Prompt Gamma Imaging. Prompt Gammas (PG) are secondary radiation resulting from the nuclear interactions occurring in the patient. TIARA exploits the existing correlations between the proton + PG Time-Of-Flight (TOF) distribution and the distribution of PG emission vertices, which reflects dose deposition along the proton path.

The current TIARA prototype consists of 8 Cherenkov detectors placed around the patient, which are readout in time coincidence with a fast beam monitor placed upstream. The beam monitor is composed of a plastic scintillator read-out by four strips of SiPMs placed on the sides, used to tag in time the incident particle with a time resolution of 120 ps FWHM with 63 MeV protons. The Cherenkov detectors are composed of $2 \times 1.5 \times 1.5$ cm^3 PbF_2 crystals, coupled to a 2×2 SiPM array to determine the PG time of arrival. These detectors have the advantage of being insensitive to neutrons, which represent the main source of background for this application. The system coincidence time resolution is of the order of 250 ps FWHM, allowing to precisely measure the proton + PG TOF.

The prototype has been tested extensively at cyclotron, synchro-cyclotron and synchrotron facilities, with proton and carbon ions. The system has proven its adaptability to the peculiar time structures of these accelerators. The different approaches proposed for the determination of the hadron-gamma coincidences and the different performances obtained will be described, by discussing the main experimental campaigns.

The prototype was tested at the Centre Antoine Lacassagne (CAL) in Nice, France using the S2C2 proton synchro-cyclotron. An anthropomorphic head phantom was irradiated with 148 MeV protons at the level of one of the sinuses. In a first experiment, the sinus was left empty, while in a second irradiation it was filled with ultrasound gel, mimicking an anatomical change in the patient. These two irradiations provided noticeably different proton + PG TOF distributions, providing information on the proton range shift and on the density of irradiated tissues. In general, proton range accuracies of the order of 2 mm or less (at 2 σ) have been obtained at the level of a single irradiation spot of approximately 10^7 protons.

More recently, the adaptability of the TIARA prototype to 12C beams delivered by the CNAO synchrotron in Pavia, Italy was studied. The use of 12C beams poses several challenges. Carbon ions may go through fragmentation, generating lighter and faster secondary particles which, in turn, may create PGs beyond the Bragg peak, making the proton + PG TOF distribution less sharp and the projectile range more difficult to measure. Moreover, energetic secondary particles produced by the patient/target may also be directly detected by the TIARA modules, especially those placed downstream, thus leading to background contamination and a degradation of the measurement SNR. Despite these challenges, CTRs of around 250 ps FWHM, close to the one obtained with synchro-cyclotron protons, was obtained in a comparable low intensity configuration.

A large PMMA target was employed to estimate the sensitivity of the system by slightly varying the beam incident energy. For energy variations corresponding to millimetric range shifts, TIARA provided small (~ 10 ps), but measurable time differences. The analysis of these data is currently on-going and will provide a quantitative measurement of the system range measurement accuracy with carbon ions.

Primary author: PINSON, Maxime (LPSC)

Co-authors: ANDRÉ, Adélie (LPSC); Mrs GARNIER, Alicia (CPPM); Dr MOREL, Christian (CPPM); Dr HOARAU, Christophe (LPSC); Dr MANEVAL, Daniel (CAL); Dr MURAZ, Jean-François (LPSC); Dr HERAULT, Joel (CAL); Dr HOFVERBERG, Johan-Petter (CAL); Dr GALLIN-MARTEL, Laurent (LPSC); Dr PULLIA, Marco (CNAO); Dr GALLIN-MARTEL, Marie-Laure (LPSC); Dr DUPONT, Matheiu (CPPM); Dr KAVRIGIN, Pavel (LPSC); Dr MARCATILI, Sara (LPSC); Dr BOURSIER, Yannick (CPPM)

Presenter: PINSON, Maxime (LPSC)

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