Contribution ID: **14** Type: **not specified**

Characterization of thin silicon detectors for applications in conventional and flash irradiations

Detector technology based on thin (~ 50 µm) silicon sensors is gaining interest for the possible applications in beam monitoring, quality assurance, treatment verification and dosimetry in radiation therapy. Compared to gas ionization chambers, thin silicon sensors feature superior sensitivity, allowing to measure single particles, increased spatial resolution, much faster signal collection times and crossing time resolutions of tens of picoseconds. In addition, the large electric field in the small thickness limits the effects of charge volume recombination at the ultra-high dose rates foreseen in FLASH modalities.
Thanks to the INFN-CSN5 projects MoVeIT, SIG and FRIDA, the University and INFN group of Torino has been exploring various applications aimed at enhancing treatment delivery or contributing to new developments in this field. Several sensors of various thicknesses (15, 25, 45 and 60 µm), both with and without moderate gain, were designed and characterized on particle beams both at TIFPA and CNAO, demonstrating the capability of tracking single protons and carbon ions with crossing time resolutions as good as 20 ps. The applicability to beam monitoring at FLASH dose rates has been verified with electron beams at the CPFR facility in Pisa, where good signal linearity has been observed up to doses of 10 Gy in 4 µs pulses.
Large area sensors (2.7x2.7 cm^2) segmented in strips and a custom front-end readout chip (ABACUS) were developed to build a detector for counting beam particles over the cross section of a pencil beam, demonstrating the capability of operating up to clinical rates and measuring the beam position and profile with resolutions comparable to radiochromic films.
Smaller sensors and a custom analog readout were employed to develop a self-calibrating system to measure, with negligible beam perturbation, the particle's energy through a time-of-flight technique, allowing the measurement in a few milliseconds with an uncertainty of less than 1 mm range in water.
The excellent time resolution has been exploited developing readout systems based on fast Time to Digital converters to provide a full 4D tracking of beam particles at high rates. This has allowed to perform measurements of the CNAO beam time structure at the nanosecond level as well as acquiring Prompt Gamma Timing distributions, a useful technique for the in vivo verification of the particle range in the patient correlating in time the detection of the primary particle and of the emitted photon.

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