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**Monitoring of a therapeutic proton beam: preliminary tests of innovative thin silicon detectors.**

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**Title:** Monitoring of a therapeutic proton beam: preliminary tests of innovative thin silicon detectors.

**Purpose.** For on-line monitoring of the prescribed dose in particle-therapy with active beam scanning, new silicon detectors could overcome the limits of ionization chambers (such as response dependence on beam energy, slow collection time, reduced sensitivity).

Based on limited internal charge multiplication, Low-Gain Avalanche Detectors (LGADs) provide high signal-to-noise ratio and fast collection time in small thickness (1 ns in 50  $\mu\text{m}$ ), allowing direct single particle counting at high rates, if properly segmented. LGADs optimized for excellent time resolutions (Ultra Fast Silicon Detectors, UFSDs) can also measure the beam energy using time-of-flight techniques. The preliminary tests of UFSD sensors on therapeutic beams are presented.

**Methods.** Particle fluxes and time resolutions are preliminarily evaluated using two UFSD pads (1,2 x 1,2  $\text{mm}^2$  x 50  $\text{mm}$ ) aligned along the proton beam (intensity=  $10^9$  p/s, FWHM=1 cm). Based on the results, dedicated UFSDs for beam monitoring are being designed and produced, together with custom VLSI chips for the readout. Different doping possibilities will be investigated to extend the radiation resistance of the sensors.

**Results.** The sensors signals show well separated contributions from single particles, with low pile-up probability up to almost  $10^9$  p/( $\text{cm}^2 \cdot \text{s}$ ). Number of particles, beam flux, and crossing time are determined via offline analysis of collected waveforms. The obtained time resolution is 70 ps for single crossing, thus allowing precise beam energy measurements within few mm of data taking, using the timing difference between two sensors at a mutual distance < 1 meter. The measured numbers of counts from two aligned detectors are very well correlated, and the beam structure is resolved at the nanosecond level.

**Conclusion.** UFSDs are demonstrated to be suitable for on-line monitoring of therapeutic proton beams, by directly counting the number of particles. This information will improve the indirect measurements provided nowadays by ionization chambers.