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Silicon sensors for beam monitoring: first characterization with Ultra-High Dose-Rate electron beams

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Introduction:
A normal tissue sparing effect (FLASH effect) has been observed in Ultra-High Dose-Rate electron and proton irradiation (UHDR). In this extreme regime, conventional transmission chambers show non-linear effects due to very high flux of particles. Therefore, the real time beam monitoring in UHDR requires the adaptation of detector technologies and the investigation of new approaches, to be capable of measuring the integrated flux of each FLASH pulse. In this contribution, thin silicon planar sensors studied by the University and INFN Turin within the INFN FRIDA project will be described. The first tests on pulsed electron FLASH beams at the SIT ElectronFLASH Linac (EF) installed at the Centro Pisano for Flash RadioTherapy (CPRF, through a special funding from the Fondazione Pisa) will be reported.

Materials and methods:
Silicon p-i-n sensors of 45 µm active thickness, segmented into 2 mm^2 strips and inversely polarized, were irradiated with 9MeV FLASH electron beams. Two different systems were used to readout the signal generated in the silicon and compared with each other: one sensor strip was connected to an oscilloscope (with a sampling frequency of 10 GS/s) and a second strip was connected to a TERA08 chip, a 64-channel current-frequency converter (20 MHz/channel maximum output frequency, 200 fC charge quantum). The clinical dose per pulse (DPP) was varied up to a value of 4 Gy in each pulse of 4µs duration.

Results:
It was observed that TERA08 saturates under EF irradiation. To overcome this issue, an RC circuit (R=2kOhm, C=1µF) was placed between the sensor and the chip to reduce the instantaneous charge input to the chip, keeping the integrated charge constant. In this way, the charge measured by a silicon strip (polarized at 200V) in each EF pulse is linear (R value > 0.99) up to ˜ 4 Gy/pulse for both readout systems (oscilloscope and TERA08). In condition of full depletion of the active thickness and lower bias voltage applied (i.e. 50 V), the collected charge vs dose per pulse deviates from linearity. This is due to the creation of an electric field opposite to the applied one (caused by the high charge density released in the silicon), inhibiting charge collection. Simulations with the TCAD Sentaurus software are being performed to reproduce the experimental results and to characterize this effect.

Conclusions:
Initial tests with delivered EF beams have demonstrated the potential of thin planar silicon sensors to monitor UHDR electron beams up to a few Gy/pulse. A lower charge collection was observed with sensor polarization <200V and is being studied through simulations. New sensor geometries will be tested on both electron and proton beams.

Authors: MEDINA, Elisabetta (Università degli Studi di Torino, Dipartimento di Fisica, via P. Giuria 1, Torino, Italy & National Institute of Nuclear Physics (INFN), sezione di Torino, via P. Giuria 1, Torino, Italy); CAMPERI, Aurora (Università degli Studi di Torino, Dipartimento di Fisica, via P. Giuria 1, Torino, Italy); CENTIS VIGNALI, Matteo (Fondazione Bruno Kessler, Center for Sensors and Devices, Trento, Italy); DEUT, Umberto (Università degli Studi di Torino, Dipartimento di Fisica, via P. Giuria 1, Torino, Italy); DI MARTINO, Fabio (Fisica Sanitaria, Azienda

Ospedaliera Universitaria Pisa AOUP, ed.18 via Roma 67, Pisa, Italy & Università di Pisa, Centro Pisano ricerca e implementazione clinica Flash Radiotherapy (CPFR@CISUP), Presidio S. Chiara, ed. 18 via Roma 67, Pisa Italy & INFN, sezione di Pisa, Largo B. Pontecorvo 3 I-57127, Pisa, Italy); FERRERO, Veronica (National Institute of Nuclear Physics (INFN), sezione di Torino, via P. Giuria 1, Torino, Italy); FERRO, Arianna (Università degli Studi di Torino, Dipartimento di Fisica, via P. Giuria 1, Torino, Italy & National Institute of Nuclear Physics (INFN), sezione di Torino, via P. Giuria 1, Torino, Italy); GIORDANENGO, Simona (National Institute of Nuclear Physics (INFN), sezione di Torino, via P. Giuria 1, Torino, Italy); HAMMAD ALI, Omar (Fondazione Bruno Kessler, Center for Sensors and Devices, Trento, Italy); MARTÌ VILLARREAL, Oscar Ariel (Fondazione Bruno Kessler, Center for Sensors and Devices, Trento, Italy); MAS MILIAN, Felix (Università degli Studi di Torino, Dipartimento di Fisica, via P. Giuria 1, Torino, Italy & National Institute of Nuclear Physics (INFN), sezione di Torino, via P. Giuria 1, Torino, Italy & Universidade Estadual de Santa Cruz, Department of Exact and Technological Sciences, Ilhéus, Brazil); MILLUZZO, Giuliana (INFN, sezione di Catania, Via Santa Sofia, 64, 95123 Catania, Italy); MONTALVAN OLIVARES, Diango (Università degli Studi di Torino, Dipartimento di Fisica, via P. Giuria 1, Torino, Italy & National Institute of Nuclear Physics (INFN), sezione di Torino, via P. Giuria 1, Torino, Italy); ROMANO, Francesco (INFN, sezione di Catania, Via Santa Sofia, 64, 95123 Catania, Italy); CIRIO, Roberto (Università degli Studi di Torino, Dipartimento di Fisica, via P. Giuria 1, Torino, Italy & National Institute of Nuclear Physics (INFN), sezione di Torino, via P. Giuria 1, Torino, Italy); SACCHI, Roberto (Università degli Studi di Torino, Dipartimento di Fisica, via P. Giuria 1, Torino, Italy & National Institute of Nuclear Physics (INFN), sezione di Torino, via P. Giuria 1, Torino, Italy); VIGNATI, Anna (Università degli Studi di Torino, Dipartimento di Fisica, via P. Giuria 1, Torino, Italy & National Institute of Nuclear Physics (INFN), sezione di Torino, via P. Giuria 1, Torino, Italy)

Presenter: MEDINA, Elisabetta (Università degli Studi di Torino, Dipartimento di Fisica, via P. Giuria 1, Torino, Italy & National Institute of Nuclear Physics (INFN), sezione di Torino, via P. Giuria 1, Torino, Italy)

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