Investigating the high energy response of Timepix detectors for applications in ion-beam therapy

Maike Saphörster[1,2,3,4], Marcos Fernandez Garcia, Michael Moll[1], Tim Gehrke[2,3,5], Mária Martišíková[2,3], Michael Campbell[1], Lukas Tlustos[1,61]

[1]EP Department CERN, 1211 Geneva 23, Switzerland
[2]Division of Medical Physics in Radiation Oncology, German Cancer Research Center (DKFZ), Heidelberg, Germany
[3]Heidelberg Institute for Radiation Oncology (HIRO) and National Center for Radiation Research in Oncology (NCRO), Heidelberg, Germany
[4]Department of Physics and Astronomy, Heidelberg University, Heidelberg, Germany
[5]Instituto de FÂŽÄ±$sicadeCantabria(CSIC-UC), Spain$
[5]Department of Radiation Oncology, Heidelberg University Hospital, Heidelberg, Germany.
[6]Institute of Experimental and Applied Physics, Czech Technical University of Prague, Husova 240/5, 110 000 Prague 1, Czech Republic

Members of the Timepix family of detectors [1], [2] have been successfully used as single-layer particle identification devices in space dosimetry. The advantage of this approach over standard absorbed dose measurements is that it enables a more accurate estimate of biological dose because in addition to absorbed dose, the composition of the radiation field can be analyzed simultaneously. This is made possible by the analysis of signal characteristics, i.e. the shape of so-called clusters of multiple hit pixels that are formed under ion irradiation and the charge measured in each pixel of the cluster.

A similar situation arises in hadrontherapy with heavy ions and the particle identification and energy-deposition measurement capabilities of Timepix detectors are of interest for hadrontherapy dosimetry and treatment monitoring. The biological effects of radiation on tissues are closely linked to the linear energy transfer (LET) value of the radiation. In hadrontherapy, the increased biological effectiveness of protons and especially heavier ions such as He, C and O is concentrated in the Bragg peak region. Treatment planning depends to a large extent on accurate estimations of ions' stopping power in the tissue to correctly determine the local LET and consequently the local biological effect, and also the range of the ions. In this context, the Timepix family is a promising detector technology, since it could be used to measure LET spectra in different depths along the Bragg curve. Furthermore, the stopping power distribution along the beam direction,which translates to the ions' range, could be measured by means of ion-beam imaging right before the treatment. Here, high-energetic ion beams that can traverse the patient at very low doses are used [3].

However, accurate measurement of the charge deposited by the heavy ions in the Bragg peak remains a challenge, as the amount of charge deposited per pixel often exceeds the linear response range of the pixel's front electronics. Timepix [1] and Timepix3 [2] in particular suffer from the so-called volcano effect, which manifests itself in a corruption of the charge information in the center of the pixel cluster.

A systematic investigation of the pixel response to high input charge (>>100ke) is difficult due to the limited availability of ion pencil beams with a diameter in the µm-range and low fluence rates. High intensity laser pulses provide a well-controlled and scalable alternative mechanism to generate high LET charge deposition events in the sensor. The aim of this work is to characterize the non-linear behavior of the Timepix3 pixel front end using high intensity laser pulses and to derive corrections for the charge lost in the volcano. Cluster parameters such as cluster size, total ToT and the hit of secondary pixels generated in the Timepix3 nonlinear regime are analyzed and assessed with respect to their potential benefit in volcano correction strategies.

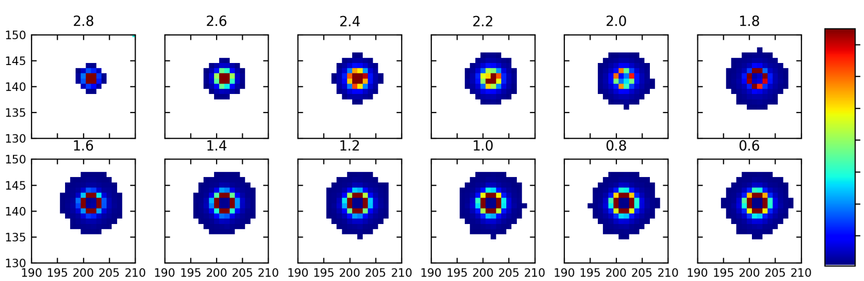

Figure 1: Mean cluster representing the typical cluster shape at different laser attenuation (0.6-2.8)

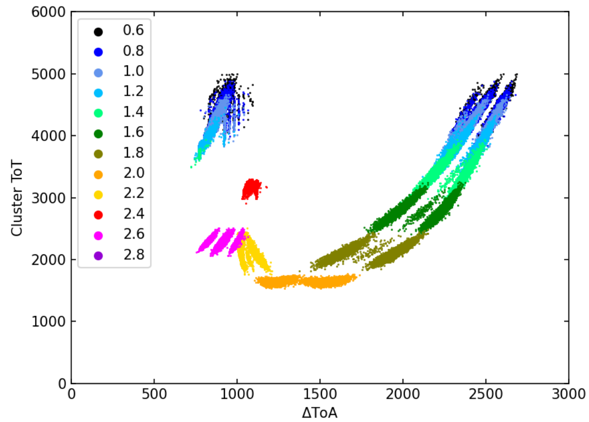

Figure 2: Time between the first and second pulse in the same pixel (ΔToA) in relation to the total ToT in the corresponding cluster, colours represent laser attenuation.

References

[1] X. Llopart, R. Ballabriga, M. Campbell, L. Tlustos, and W. Wong. Timepix, a 65k programmable pixel readout chip for arrival time, energy and/or photon counting measurements. *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment*, 581(1):485–494, 2007. VCI 2007.

[2] T Poikela, J Plosila, T Westerlund, M Campbell, M De Gaspari, X Llopart, V Gromov, R Kluit, M van Beuzekom, F Zappon, V Zivkovic, C Brezina, K Desch, Y Fu, and A Kruth. Timepix3: a 65k channel hybrid pixel readout chip with simultaneous toa/tot and sparse readout. *Journal of Instrumentation*, 9(05):C05013, may 2014.

[3] M Martišiková, T Gehrke, S Berke, G Aricò, and O Jäkel. Helium ion beam imaging for image guided ion radiotherapy. *Radiat Oncol.*, 13(1):109, june 2018.