3D silicon sensor optimization for high resolution time measurements

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Introduction:

Looking forward to future High Luminosity LHC experiments, efforts are being made to develop new tracking detectors are increasing. A common approach to improve track reconstruction efficiency in high pile-up conditions is to add time measurements per pixel with a resolution smaller than 50 ps. The INFN R&D project TIMESPOT (for Time and Space real time Operating Tracker) focuses on the development and realization of a first 4D tracking detector, based on 3D silicon and diamond sensors. This poster covers the current state of the silicon sensor development, the design approach used to define the geometry and the developed tools to simulate the response of the sensor.

Timing optimized 3D-Si sensors: Development and first fabrication

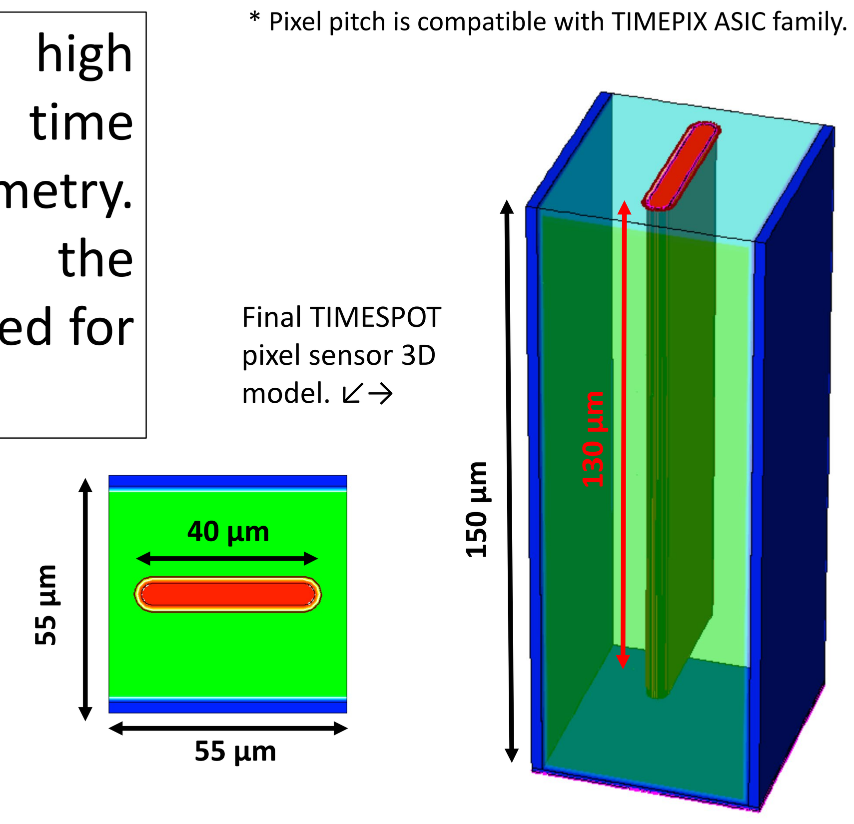
Main tasks: 3D silicon sensors presents intrinsic high radiation tolerance and fast charge collection but time response is strongly dependent on their electrode geometry. Multiple configurations were explored and the configurations with the best performances were selected for a final prototype production.

Ramo Map: Is a quantitative representation of the amount of charge induced instantaneously by a single electron-hole pair generated in a specific position and traveling at drift velocity.

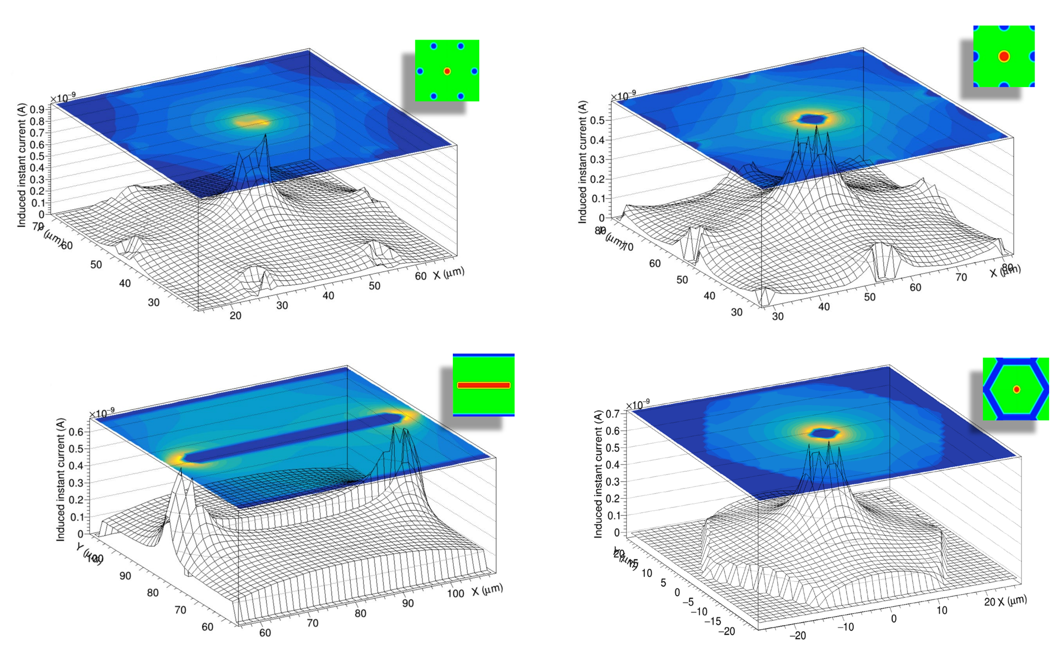
A Ramo map is an effective way to make first estimates about timing properties and sensor response.

Uniformity and high current values are good properties for a timing optimized sensor.

* Pixel pitch is compatible with TIMEPIX ASIC family.

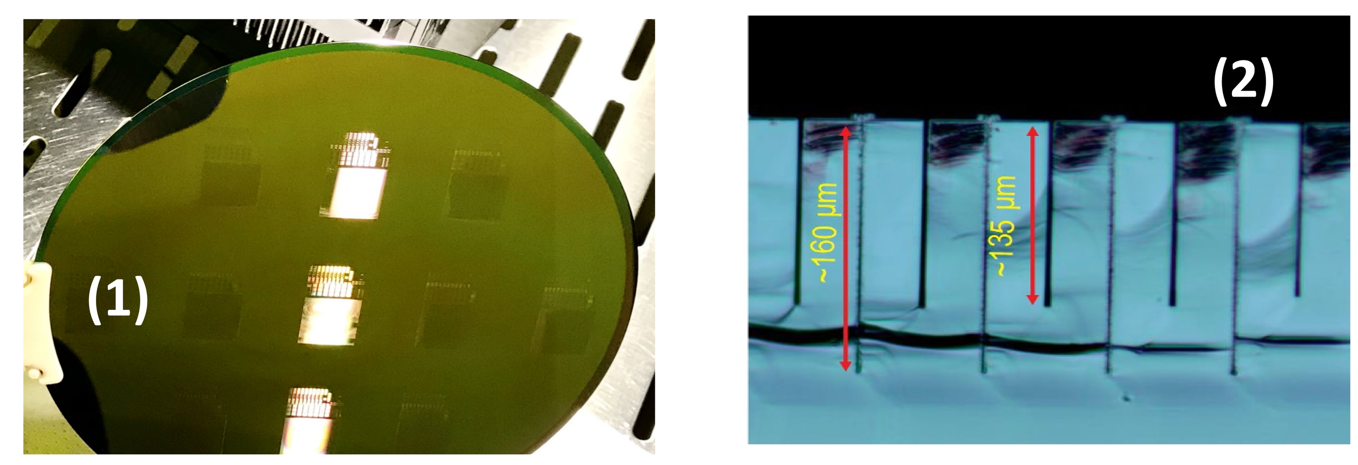


Final TIMESPOT pixel sensor 3D model. ↙→

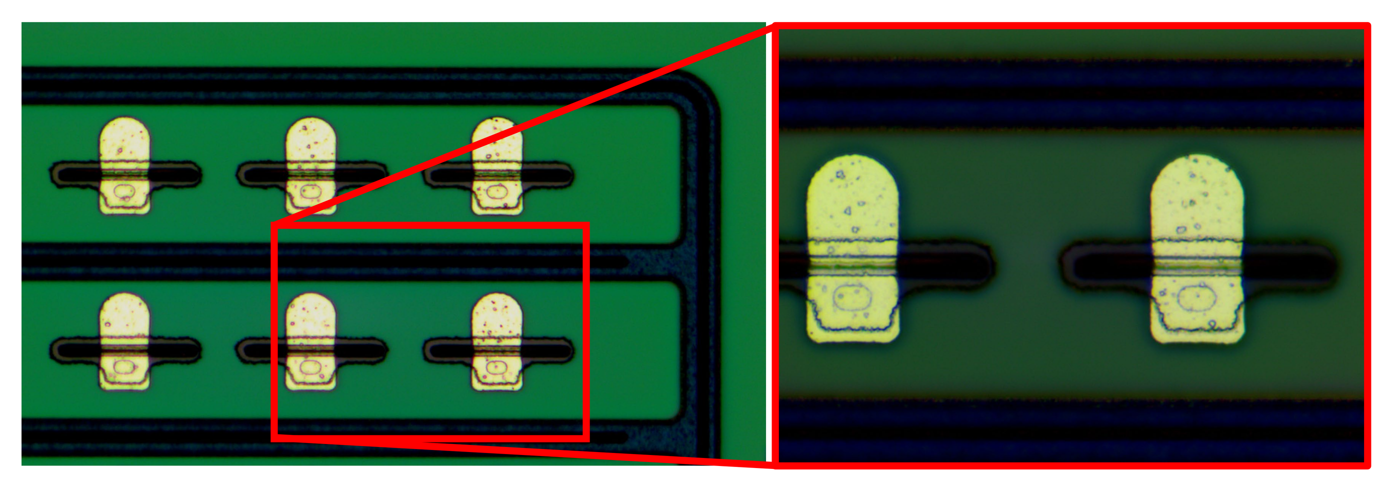


4 Ramo maps showing the effects of current induction inside a 3D silicon sensor. The 3D geometry with parallel trench configuration presents the highest and most uniform response over the entire volume. →

Fabrication: (1) Wafer containing first prototype sensor. (2) Cut through a first test structure of parallel trench sensors.



Magnification of some bonding pad for the parallel trench sensors.



* Photos: Fondazione Bruno Kessler (FBK), Trento.

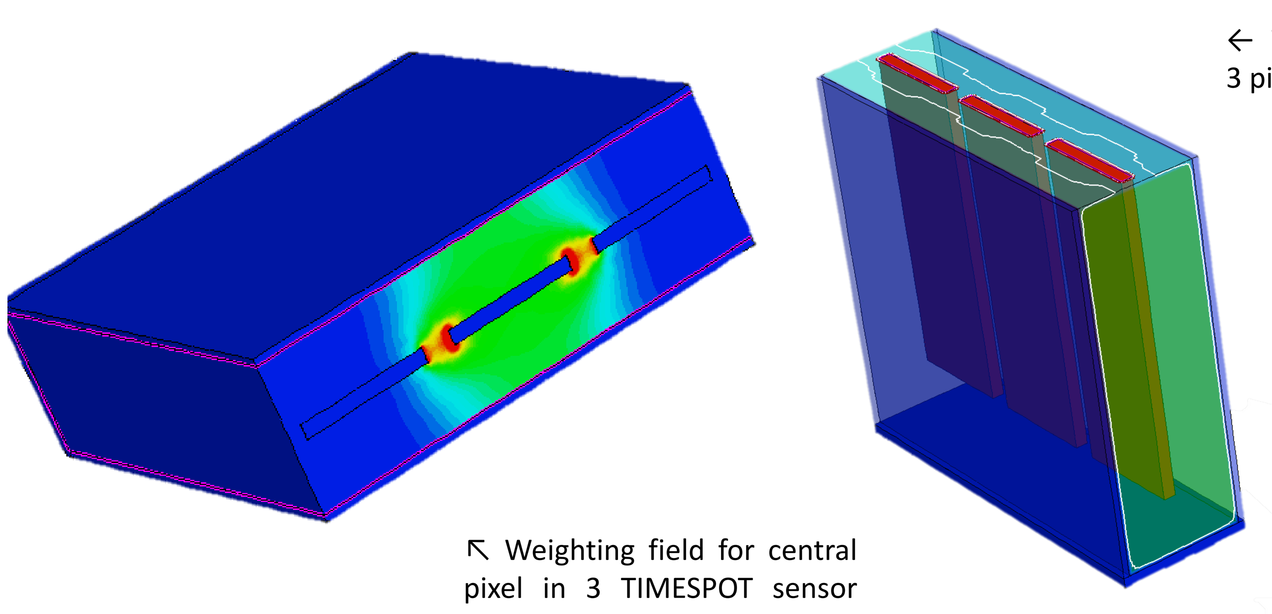
Sensor operation: The TCODE simulator

General description: TCode is a C++14 compliant application to simulate the response of solid state sensors in massively parallel platforms on Linux systems. TCode is implemented on top of Hydra [1] and as such, it can run on OpenMP, CUDA and TBB compatible devices.

Current status: TCODE is still in its alpha version and the repository it is taking shape. You can download it on the following path: https://github.com/MultithreadCorner/TCode

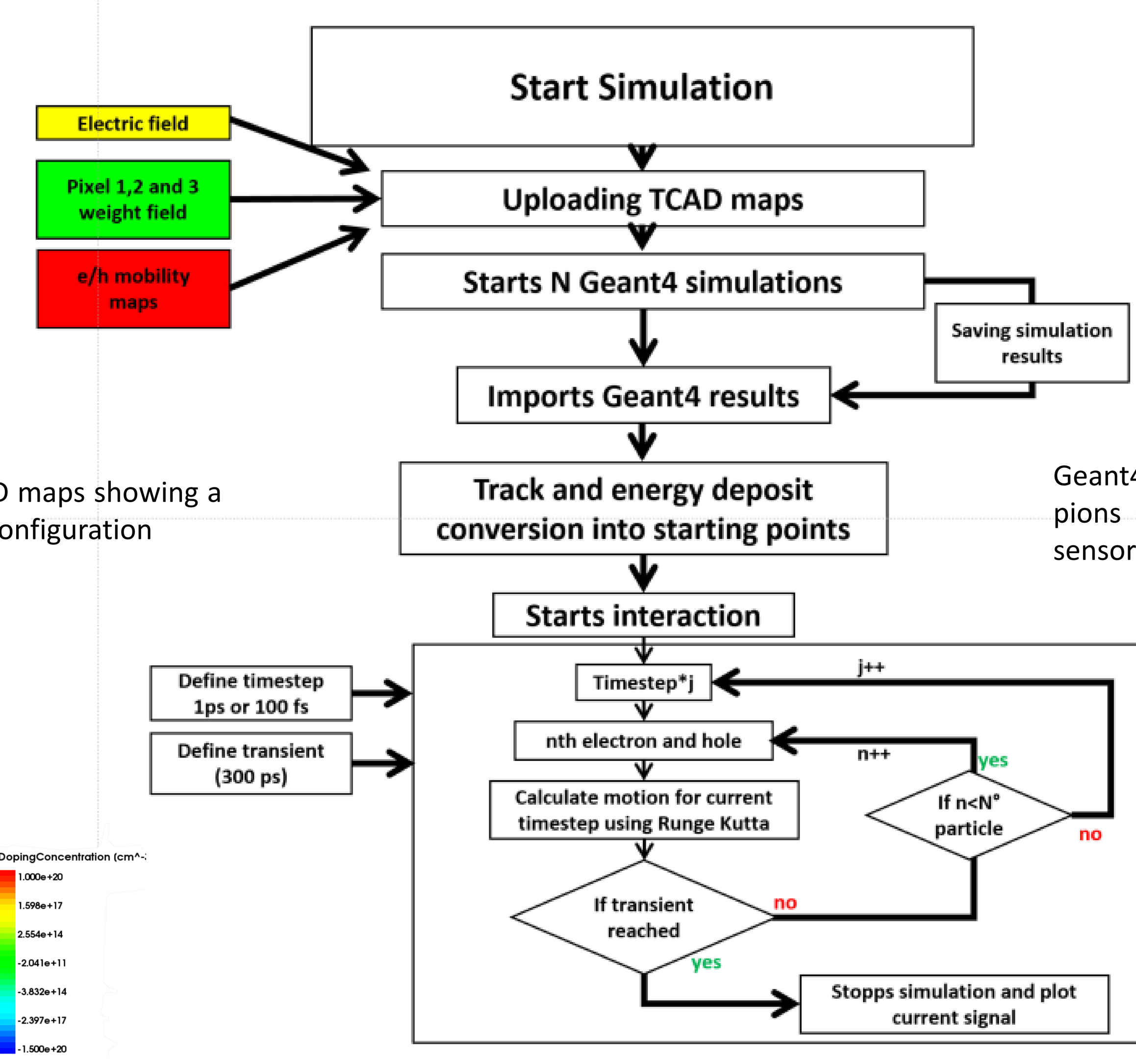
TimeSPOT Code for Detector simulation

The physics TCode uses external 3D maps, containing information about electric/weighting field and carrier mobilities of the sensor, and energy deposits. Maps can be generated using TCAD [3] or other tools.



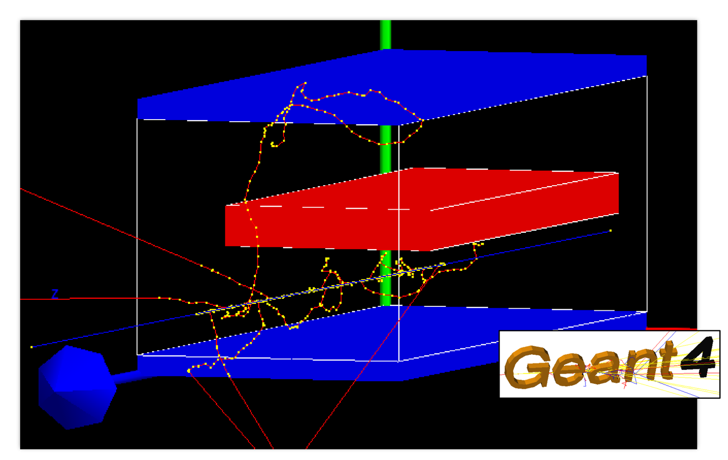
↖ Weighting field for central pixel in 3 TIMESPOT sensor pixel matrix.

← TCAD maps showing a 3 pixel configuration



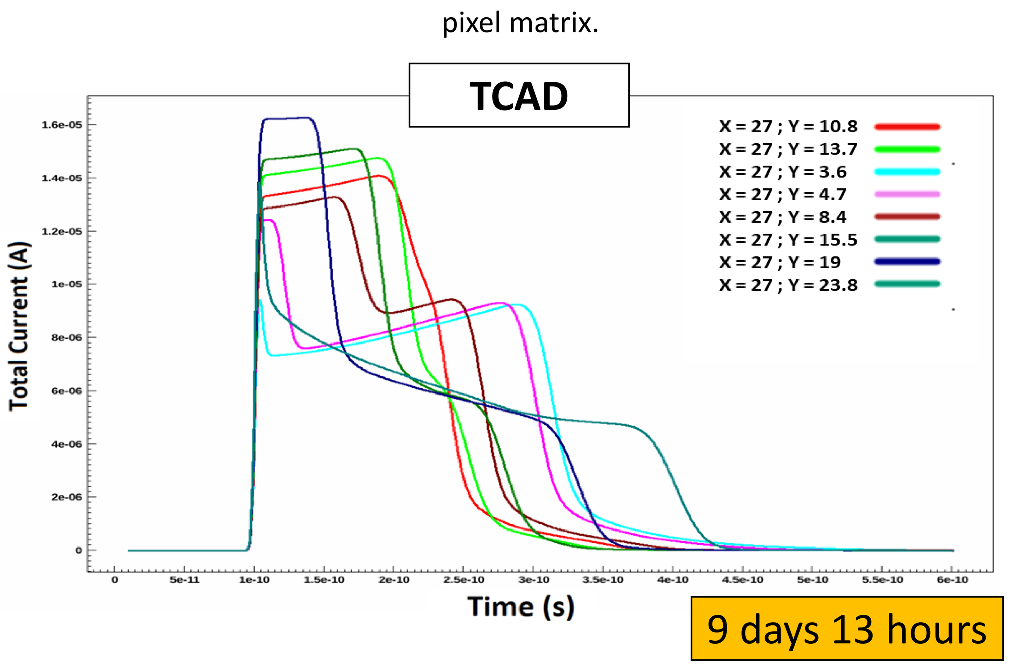
Energy deposits can be generated from other tools, like Geant4 and than converted in TCODE in equivalent electron-hole pairs

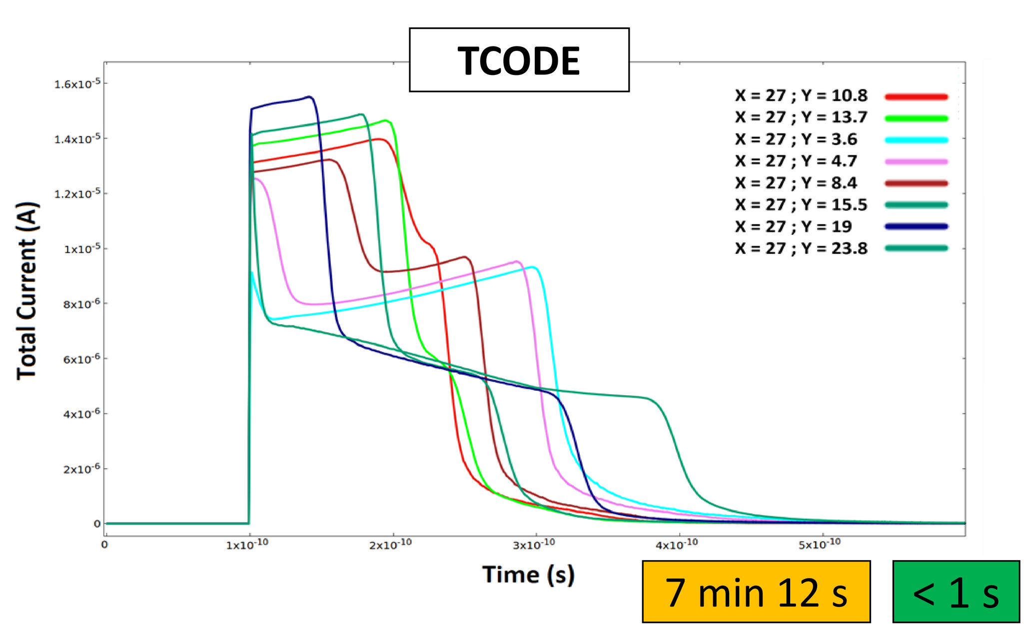
Geant4 simulation showing multiple pions crossing throug a silicon pixel sensor →



The motion of the individual carriers produced in the initial deposit is determined using a 4th order Runge-Kutta algorithm. This operation is parallelized using Hydra.

At each time interval the current induced on a specific electrode is calculated using the Shockley-Ramo theorem [2].





TCAD [3] vs TCODE performance: TCAD transient simulation were executed with 20 CPU threads. TCODE signals were simulated in single thread mode (yellow time) and GPU multithread mode (green time).

Further developments

Further developments will include:

1) Front-end response (work in progress)
2) Effects due to radiation damage
3) Charge amplification (for LGAD-type sensors)
4) Compatibility with diamond sensors

[1] Alves Junior, MultithreadCorner/Hydra, March2018, 10.5281/zenodo.1206261, https://doi.org/10.5281/zenodo.1206261
[2] S. Ramo (1939), **"Currents Induced by Electron Motion"**, in Proceedings of the IRE, vol. 27, nº 9, 1939, pp. 584–585
[3] Synopsys Inc. 2015 Synopsys Sentaurus TCAD Version 2015.06, https://www.synopsys.com/silicon/tcad.html

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