3D detectors for timing applications

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Introduction

The increase of proton flux in the upcoming LHC upgrade, as well as the upcoming colliders like the FCC, are going to push the requirements of its radiation detectors to further limits, specially demanding good performance of two specific parameters:

- Radiation hardness: The detectors must be able to withstand the high amount of radiation at which they will be exposed. High energy particles hitting the detector, in addition to induce charge which is collected and used to obtain the desired information, they create defects in the silicon lattice, which create energy levels that contribute to increase the noise and the leakage current when biased in reverse. So, these new detectors must have good charge collection efficiency with acceptable levels of leakage current at reverse bias.
- Time resolution: The higher proton flux implies a higher amount of events per unit time. In order to tell apart which track comes from which event, a higher time resolution is required so that all the possible data is collected and correctly interpreted. The timing resolution strongly depends on the noise of the detector and the walk time of the induced particles before reaching the electrodes.

This poster will focus on showcasing that 3D silicon detectors are good candidates for timing applications since they fulfil the aforementioned requirements.

3D silicon detectors

3D silicon detectors consist of columnar electrodes etched perpendicularly to a silicon wafer. This architecture proposed by Parker et al [1] allows a short interelectrode distance that gives the sensor the capability to withstand high amounts of radiation while operating at considerably low bias voltages. In addition, since charges are created close to the electrodes, very short travel time of the charge is expected making them good candidates as timing detectors, as long as the noise can be kept low.

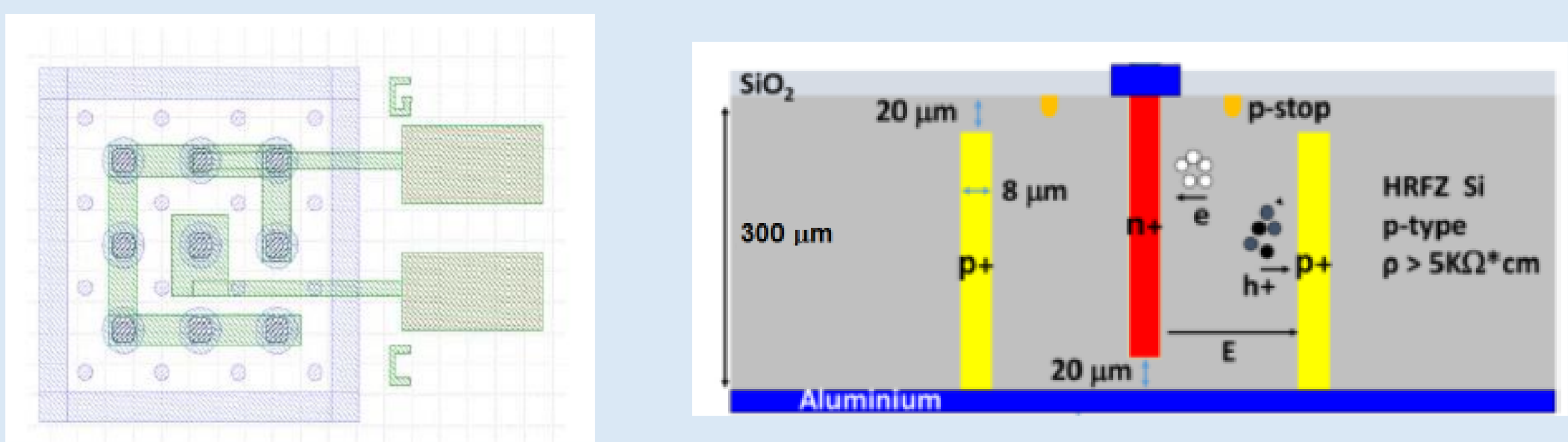

Fig 1. top view of the mask (left) and vertical cross section (right) of the 3D technology used for timing measurements [2].

Radiation Hardness

High doses of radiation create lattice defects in the silicon wafer that act as charge traps. Those traps may decrease the charge collection efficiency as well as increase the leakage current because of the new energy levels created in the band gap.

Measurements of 3D detectors produced at CNM for a readout ATLAS FE-I4 chip have shown charge collection efficiencies of 97% @ 100V at a fluence of approximately 10^{16}Neq/cm^2.

In addition, as it can be seen in Fig. 2, the detector has a leakage current of 20-40uA with a breakdown voltage below 40V before irradiation. After being irradiated, the leakage current generally increases, but so does the breakdown voltage, making it still operable beyond the capacity before being irradiated.

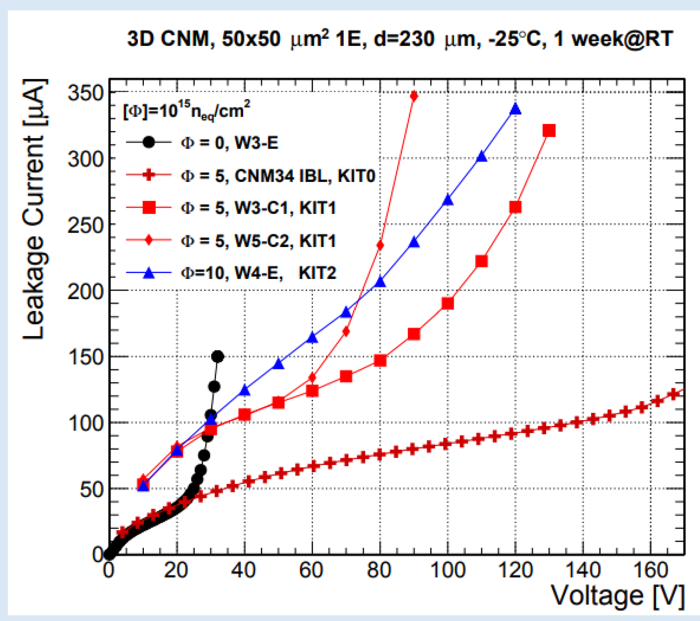

Fig 2. I-V for different 3D devices before irradiation (black) and after, with fluences of 5·10^{15}Neq/cm^2 (red) and 10^{16}Neq/cm^2 (blue) [3]

Simulations

The response of a 3D pixel silicon sensor when being hit by a MIP can be simulated by using the software KDetSim. Simulations show the short path that ions have to travel to get to the electrodes (Fig 3 a), and that the charge collection is very fast, with a rise time of the order of the nanosecond when also taking into factor the electronics response.

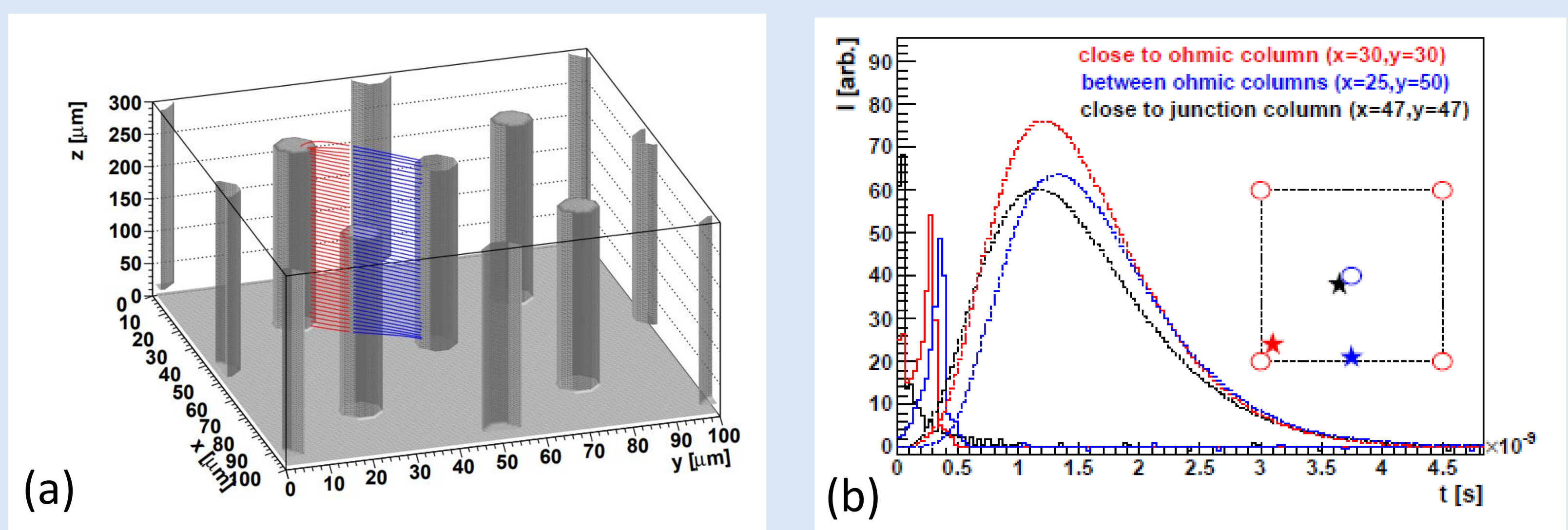

Fig 3. (a) Simulation of the paths of the electrons (blue) and holes (red) created by the perpendicular track of a MIP. (b) Simulation of the waveform induced with different hit positions before (solid lines) and after (dashed) the electronics response. [2]

Timing measurements

Small diode arrays fabricated at CNM have been used for measuring the timing performance of the 3D technology at Jožef Stefan Institute using a Sr90 source and an unirradiated LGAD as a reference detector. In Fig 4 we can see the histograms on the rise times (a) which shows to be better for the 3D detector while the noise levels (b) shows to be better for the reference LGAD. The resulting time resolution for the 3D at a bias voltage of 150V at -30ºC is around 30ps, close to the one from the reference LGAD (26 ps)

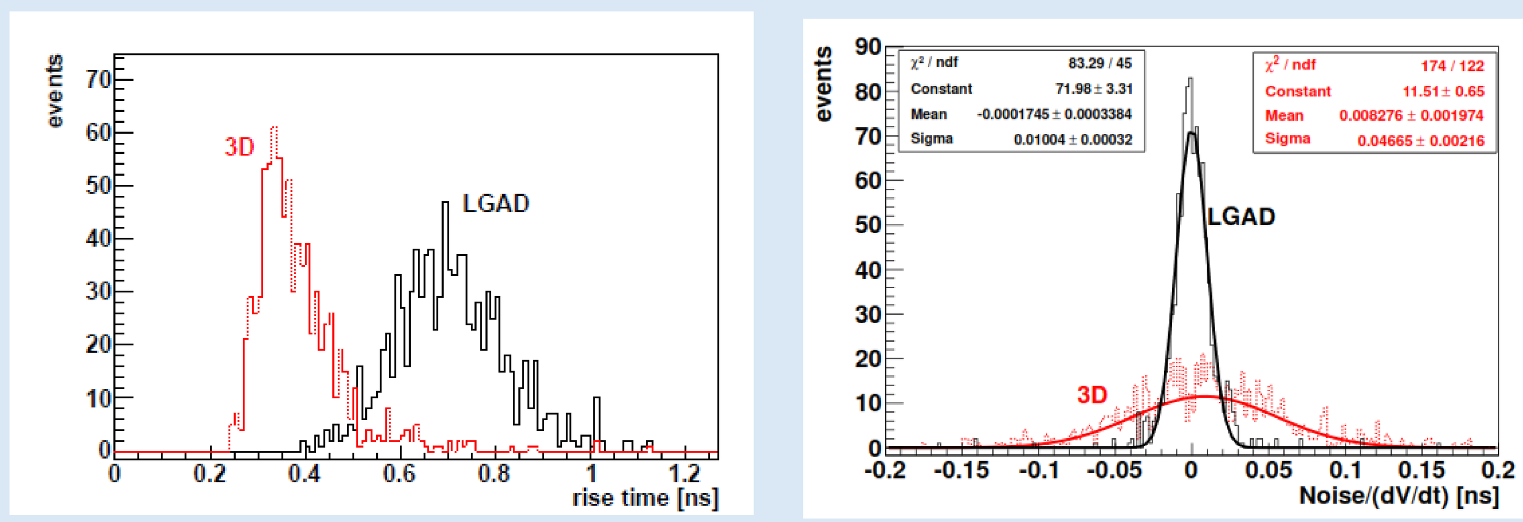

Fig 4. Timing measurements that show a better rise time from 3D with respect to LGAD (planar) [2]

Conclusions

3D detectors have been proven to be good candidates for timing applications for future colliders since they show good timing resolution while withstanding high amounts of radiation. For future work, 3D detectors optimized for timing applications will be fabricated with a thinner wafer and an optimized geometry in order to have a better timing resolution.

References

[1] S. Parker, C. Kenney, and J. Segal, 3D - A proposed new architecture for solid-state radiation detectors, Nucl. Instrum. Meth. A 395 no. 3, (1997) 328 - 343.

[2] G. Kramberger, et al.,"Timing performance of small cell 3D silicon detectors", Nuclear Inst. And Methods in Physics Research, A, Volume 934, p. 26-32, 2019.

[3] J. Lange et al., Radiation hardness of small-pitch 3D pixel sensors up to a fluence $2x10^{16}$ neq/cm^2, JINST 13 (2018) P09009.