3D SEMICONDUCTOR RADIATION DETECTOR R&D AT HIP

SiLC MEETING
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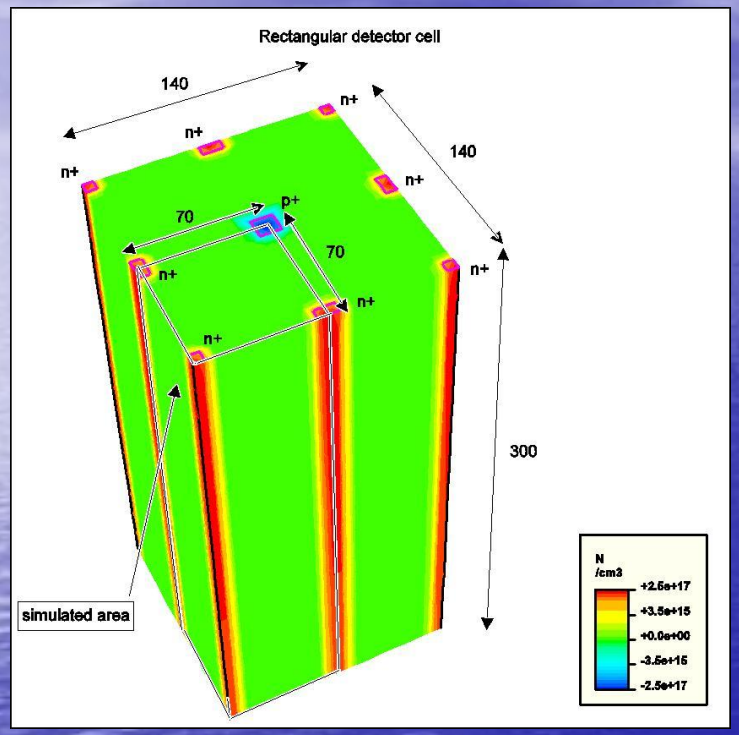
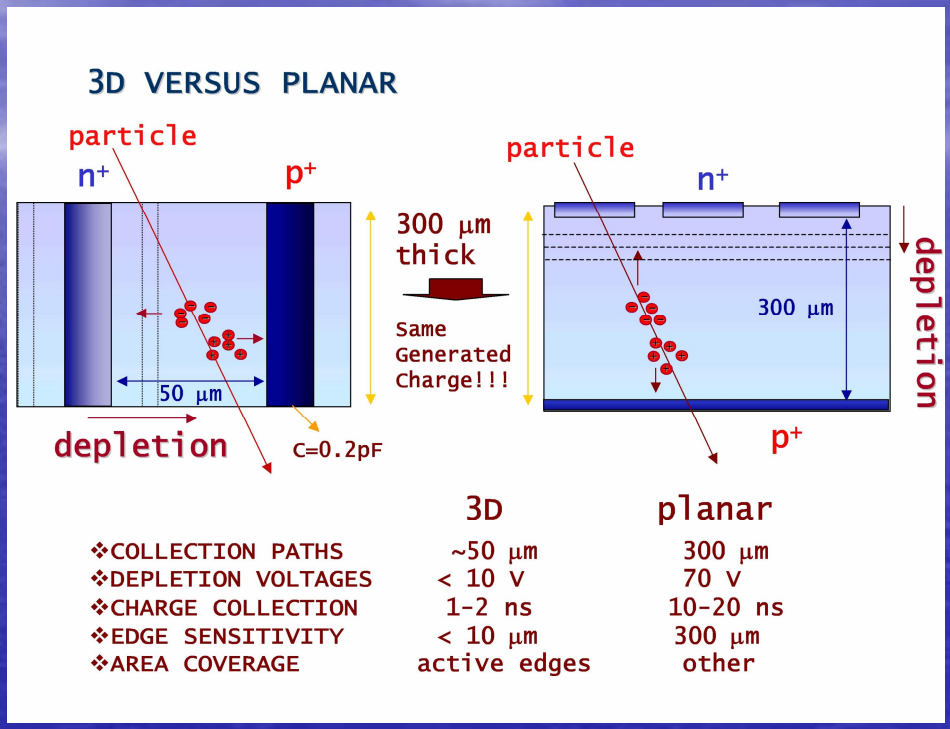
Outline:

- 3D detectors overview
- 3D detector structure simulations in 3D
- Electrical and transient characteristics
- Semi 3D detector structure
- Measurements vs. 3D simulations
- Electric fields and charge collection characteristics
- Publications
- Conclusions

3D detectors overview

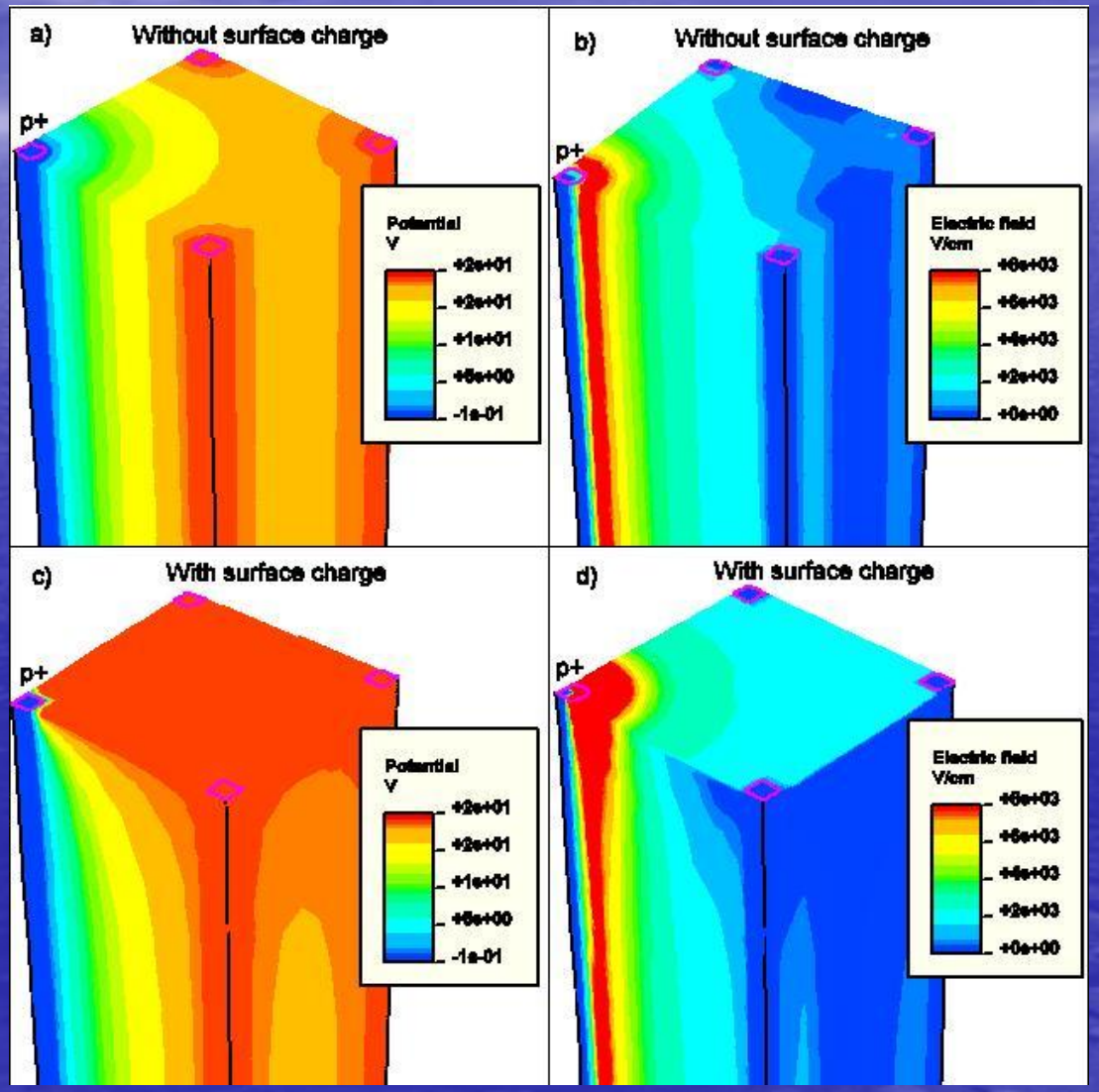




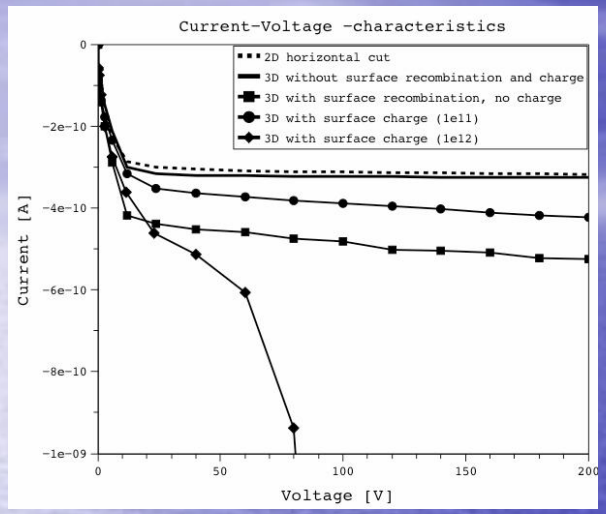
- Due to short electrode spacing, 3D structures posses small leakage currents, capacitances and small depletion voltages.
- Short charge collection distances permit small charge collection times and radiation hard detectors.
- Radiation sensitive area can be extended close to the physical edges of the 3D detector.

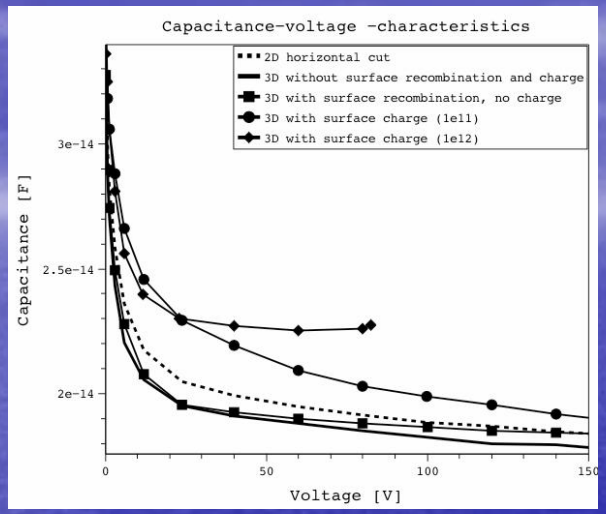
3D detector structure simulations in 3D

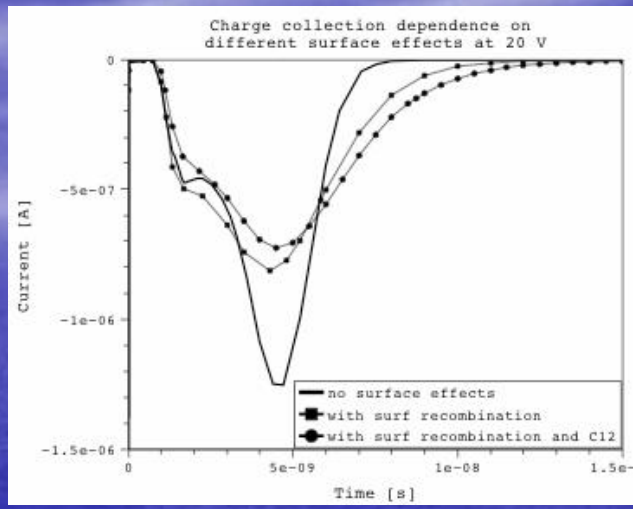
- 3D potential and electric field distributions modified due to surface effects.
- Presence of the surface charge increases the electric field by one order of magnitude on the surface near the p+ electrode and causes eventually the pn-junction breakdown at this point.

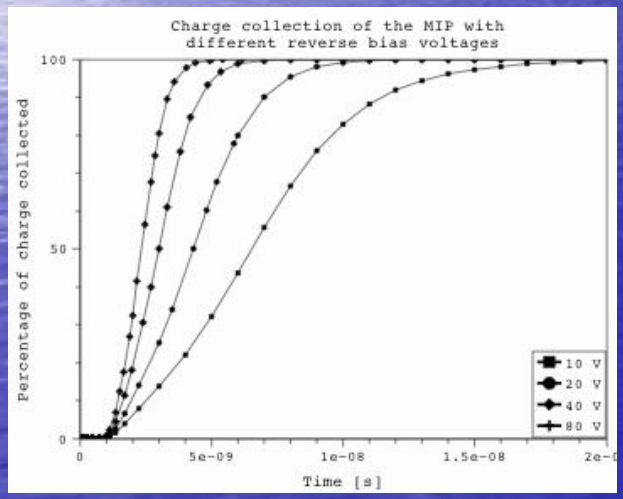


Electrical and transient characteristics



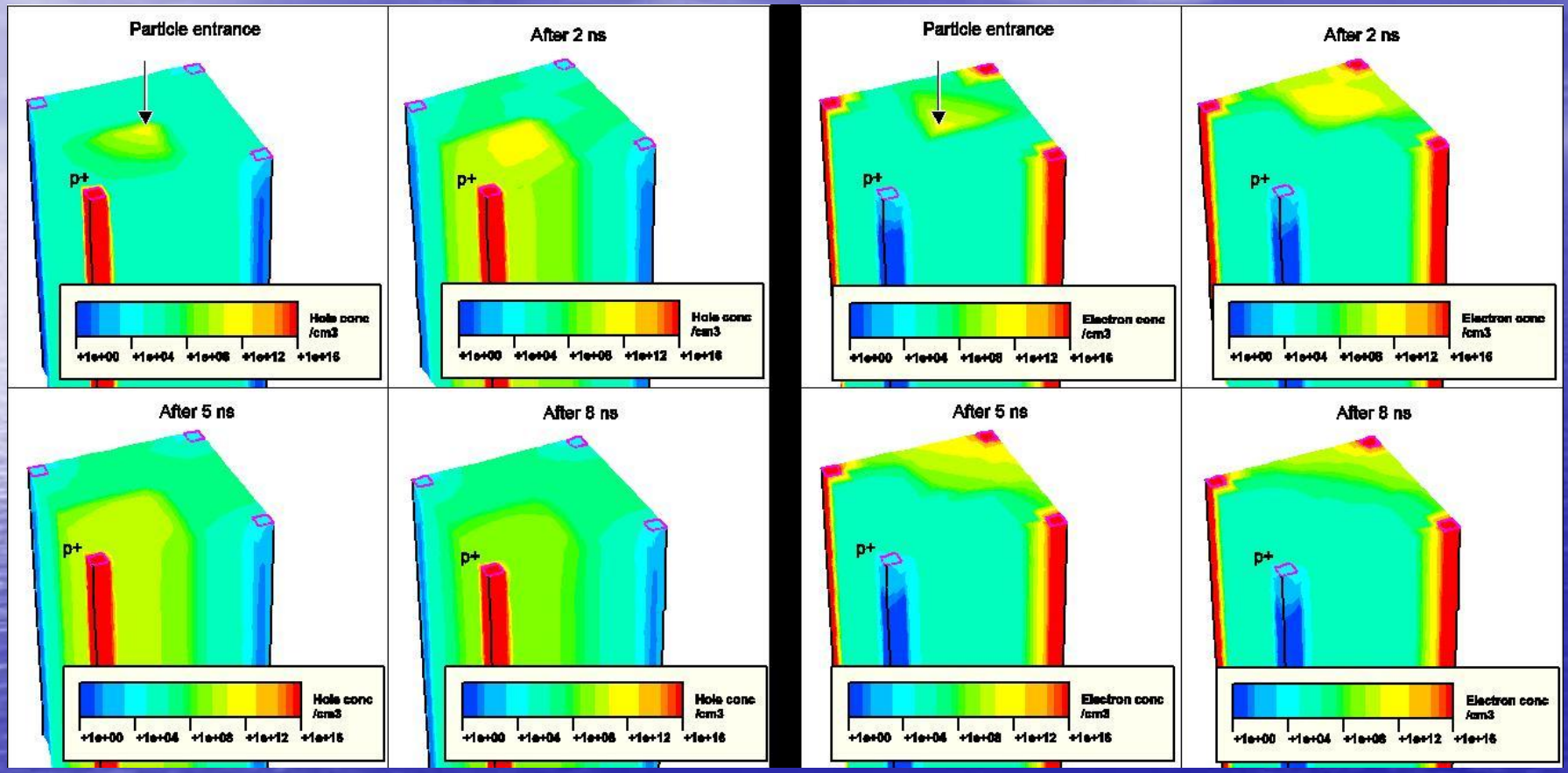






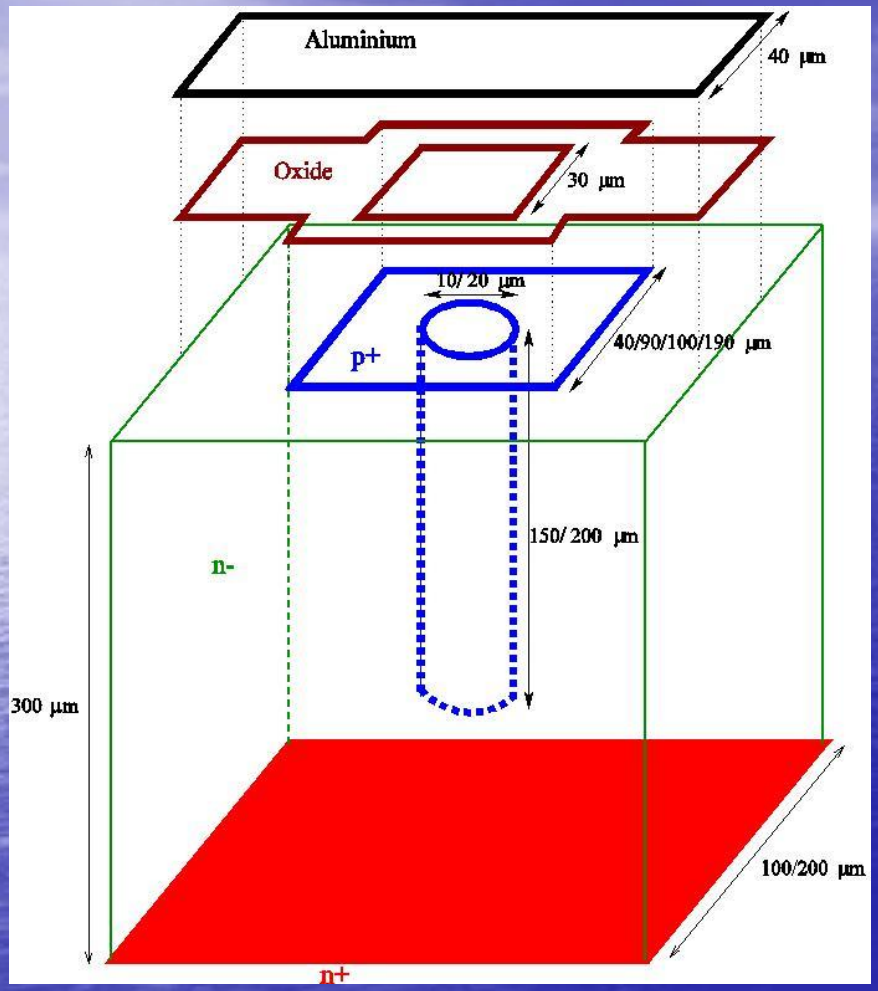
- Capacitance is increased due to surface effects and the current-plot indicates a full depletion about at 20 V.
- Theoretically calculated saturation current and capacitance, 0.33 nA and 20.8 fF, respectively, agree well with the simulations.
- Charge collection time is increased due to surface effects and it can be decreased by increasing the bias voltage.

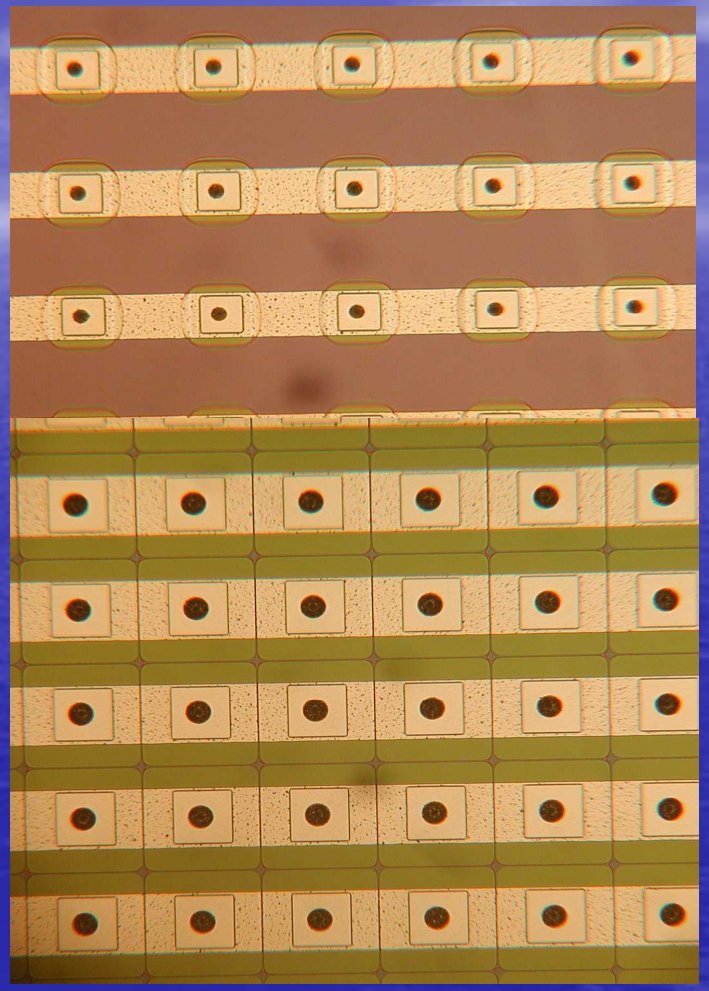
Electrical and transient characteristics



- A minimum ionising particle (MIP) creates about 24000 electron-hole –pairs when passing through 300 µm thick silicon wafer.

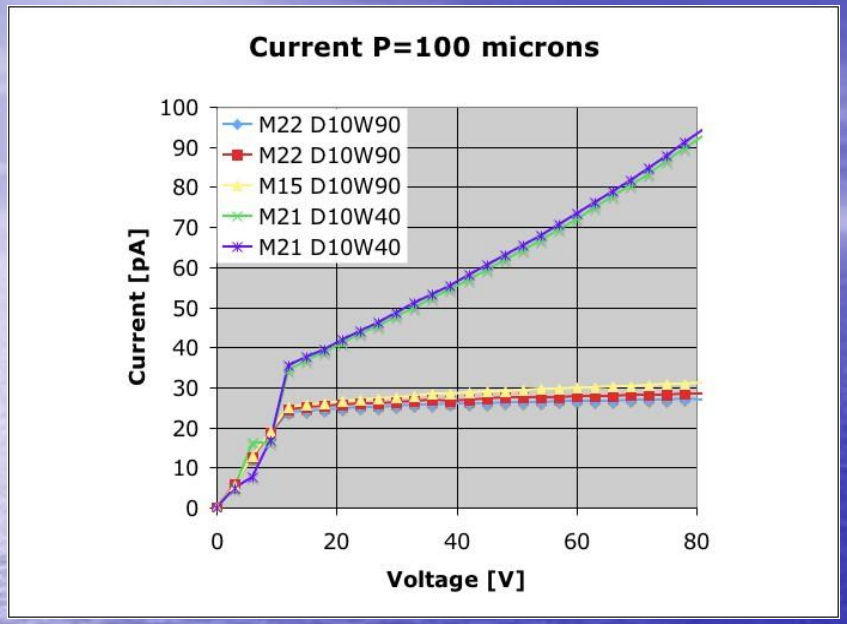
Semi 3D detector structure

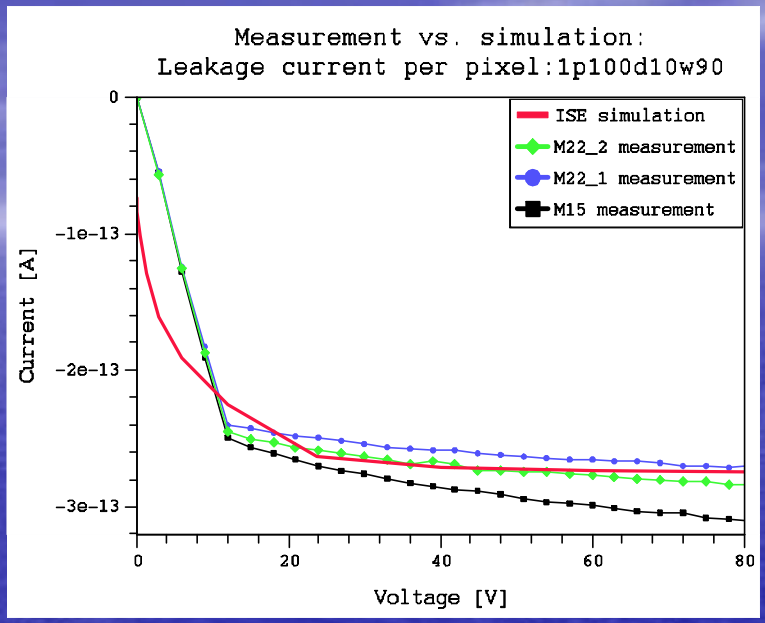


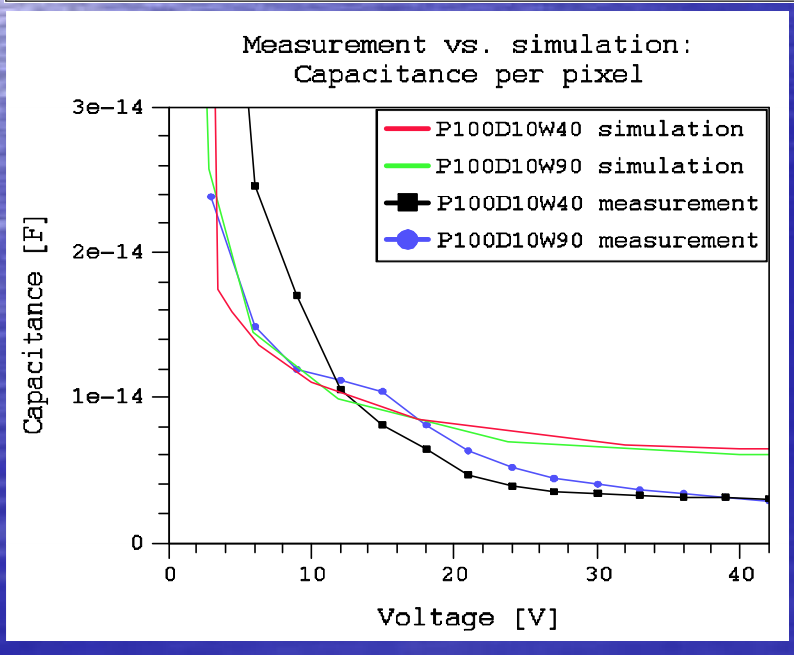


- The semi 3D structures where processed at VTT.
- The biggest structures: 1-4 cm^2 (DC) and 9 cm^2 (AC).
- MediPix2 compatible pixel sensors have been fabricated.

Measurements vs. 3D simulations: Electrical characteristics & Radiation hardness

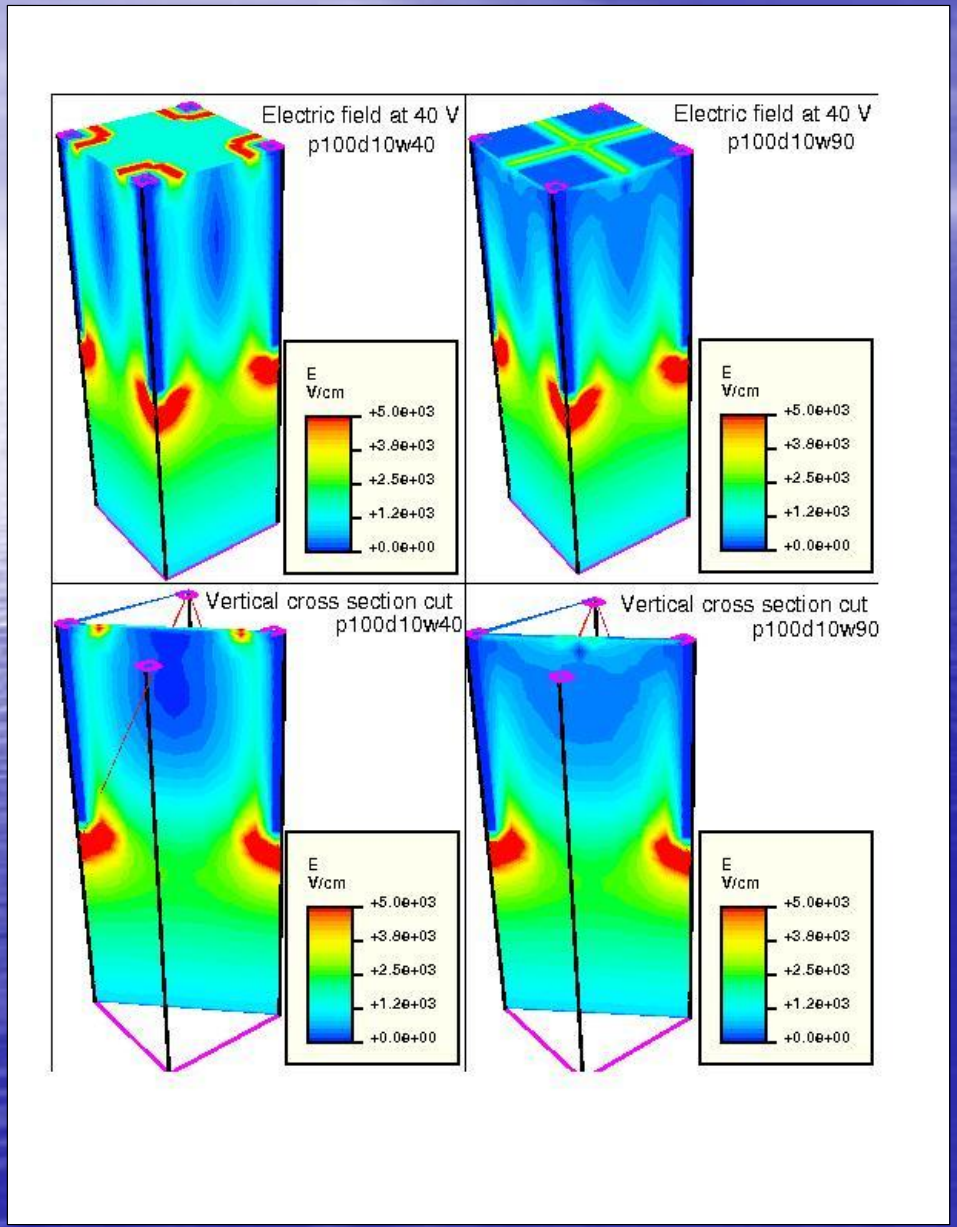


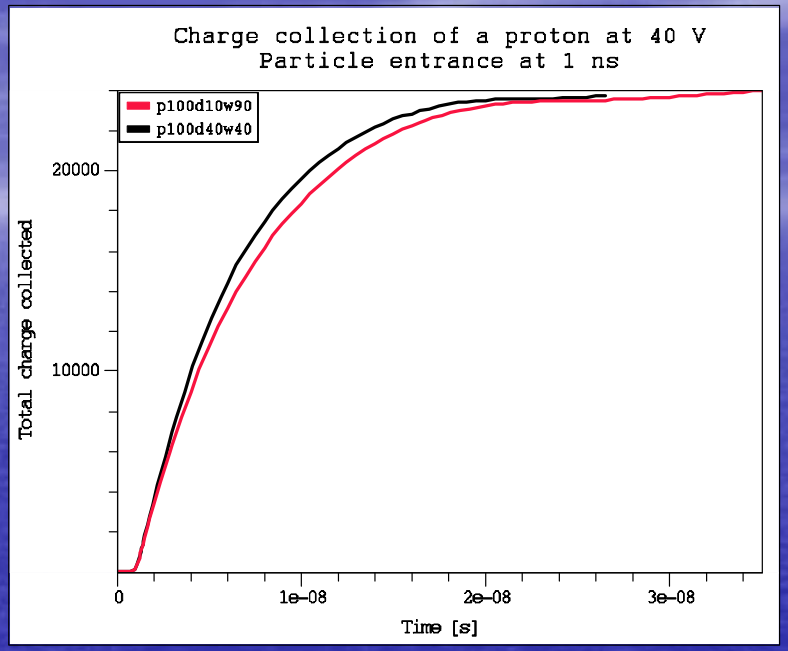




- Leakage currents from 250 to 300 fA/pixel at 80 V.
- Detector fully depleted at 30 V.
- Full depletion capacitances from 3 to 4 fF/pixel.
- Radiation hardness demonstrated (24 GeV/c protons at CERN): depletion voltage below 100 V at fluencies $6 \cdot 10^{15}$ cm^{-2}.

Electric fields and charge collection





- Charge collection of a proton hitting the low electric field region, ”worst case scenario”, at 40 V.
- 90% of the charge is collected in 10 ns.

Publications:

- S. Eränen et al., “Silicon semi 3d radiation detectors,” in Nuclear Science Symposium (NSS) Conference Record, vol. 2, Rome, Italy, 16-22. Oct. 2004, pp. 1231–1235.
- J.Kalliopuska, S. Eränen, and R. Orava, “3d simulations of 3d silicon radiation detector structures,” in Proc. of 10th European Symposium on Semiconductor Detectors, Munchen, Germany, June 2005.
- J.Kalliopuska and S. Eränen, “Measurements and simulations of 3d silicon radiation detector structures,” in Proc. of 10th European Symposium on Semiconductor Detectors, Munchen, Germany, June 2005.
- J.Kalliopuska, S. Eränen, and R. Orava, “Simulations of 3d silicon radiation detector structures in 2d and 3d: Transient simulations,” in Nuclear Science Symposium (NSS) Conference Record, Fajardo, Puerto Rico, 23-29. Oct. 2005.

Conclusion

- The 3D detector structures have multiple advantages compared to the planar ones: low depletion voltage, leakage current and capacitance; radiation hardness and fast charge collection.
- Large scale 3D detectors have been fabricated and tested successfully.
- The measured and simulated electrical characteristics give similar results for the Semi 3D structure.