Advanced simulation tools are required to simulate, model and optimise the complex sensor designs evaluated in this work package. A combination of finite-element and transient Monte Carlo simulations is employed to enable a precise sensor modelling and high statistics of the simulation samples. For this purpose, the Monte Carlo frameworks Allpix Squared [1] and Garfield++ [2] are developed and maintained within the work package.

In the past year, several new features and improvements were implemented in Allpix Squared, such as refined multi-threading capabilities or advanced models for the parameterization of charge carrier mobility and recombination. An Allpix Squared User Workshop took place in 2021 [3], bringing together the Allpix Squared community to discuss new features and share results.

The transient simulation capabilities of the Allpix Squared framework were investigated extensively in the past year by benchmarking them against stand-alone transient 3D TCAD simulations and test-beam data [4, 5].

The comparison of transient current pulses is illustrated in Fig. 1 for CLICTD sensors using three different pixel flavors. A charge injection in the pixel corners is simulated, which takes approximately 8 hours using transient 3D TCAD simulations and 0.1 – 0.2 s for the transient Monte Carlo simulations on the same machine using the same number of threads. Despite the different charge collection times and field configurations in the different pixel flavors, the two simulation approaches yield compatible results in all cases without the need for prior tuning.

The small computation times for the MC simulations also enable the consideration of statistical fluctuations and secondary particles as depicted in Fig. 2, where the transient pulse...
distribution is displayed. The pulse-by-pulse variations underline the importance of including statistical fluctuations in the simulation setup to guarantee a realistic modelling of the sensor response.

A comparison between test-beam data and transient Allpix Squared simulations is shown in Fig. 3 for the mean cluster size as a function of the detection threshold. The shaded band reflects the systematic uncertainties related to uncertainties in the doping profiles. The agreement between data and simulation is well within the uncertainties over the full threshold range, which confirms the validity of the simulation approach. The simulations are used for further development of silicon sensors, e.g. for the optimization of monolithic 65 nm CMOS silicon sensors in WP 1.2.

![Continuous n-implant](image)

**Figure 3. Mean cluster size as a function of the detection threshold for data and transient Allpix Squared simulations.**

References

[1] D.Dannheim et al., Combining TCAD and Monte Carlo methods to simulate CMOS pixel sensors with a small collection electrode using the Allpix framework, NIMA964, 2020, 163784


