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CMOS Strip Chip Simulation with RASER

Chenxi Fu[1,2], Sen Zhao[1], Xin Shi[1]

1. Institute of High Energy Physics, Chinese Academy of Science, Beijing, China;

2. University of Chinese Academy of Science, Beijing, China.

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Abstract

The CMOS strip sensor is a key component of the CEPC Inner Tracker. We have simulated CMOS Strip Chip (CSC), including the electric properties of the sensor, the front-end electronics and the detector responce of beta ray and laser.

Simulation Work Flow

First, a detector geometry is designed, from which a suitable mesh is created. Using the open-source TCAD software DevSim, the electric field and carrier distribution can be calculated.

Next, an incoming particle is generated by Geant4, and the deposited energy is converted into carrier excitation. After the charge carriers drift and diffuse, an induced current is generated on the readout electrode, followed by amplification and waveform shaping simulated by NGSpice front-end electronics.

With noise simulation, statistical results for arrival time, hit position, and dE/dx can be evaluated, allowing for the determination of the detector's time, spatial, and energy resolution.

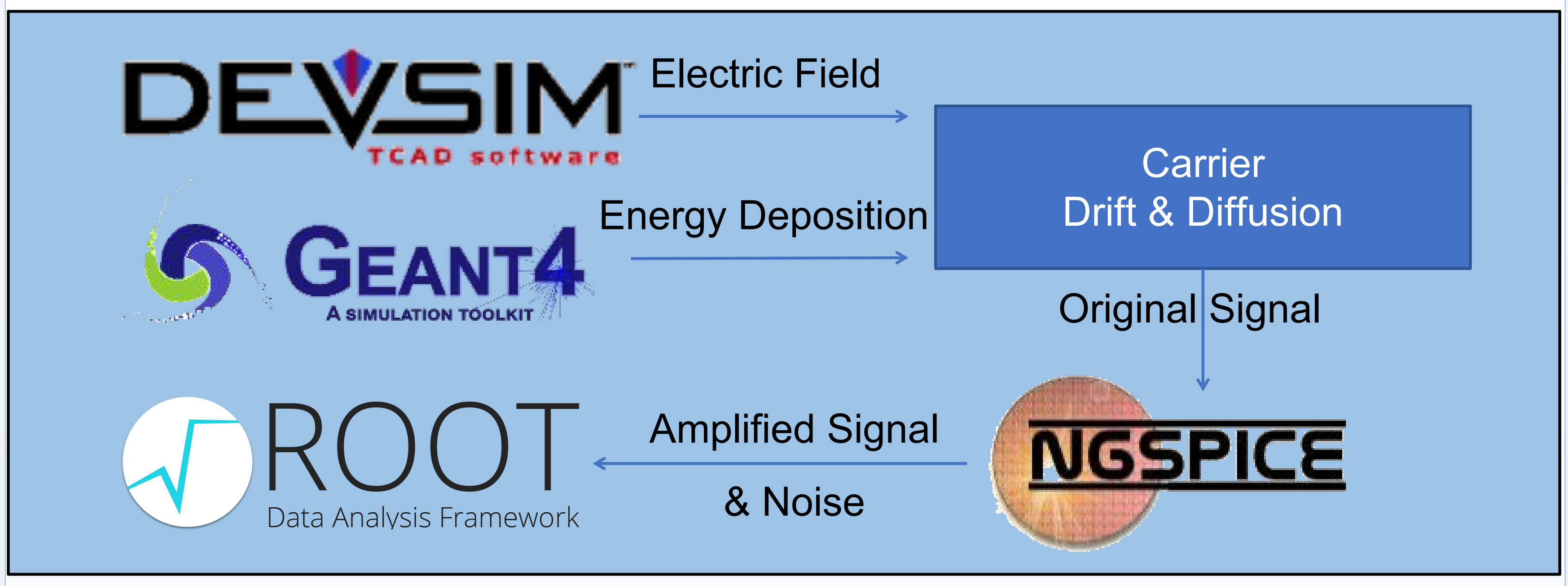

Figure 1. Simulation work flow by RASER [1].

CSC Detector Modelling

We have developed a strip detector model based on [2], integrated with a CMOS processing design, as illustrated in Fig. 2. In our simulation, each strip readout is equipped with an n-plus well connected to the cathode, along with two p-stops shared by neighboring readouts to reduce the charge sharing effect.

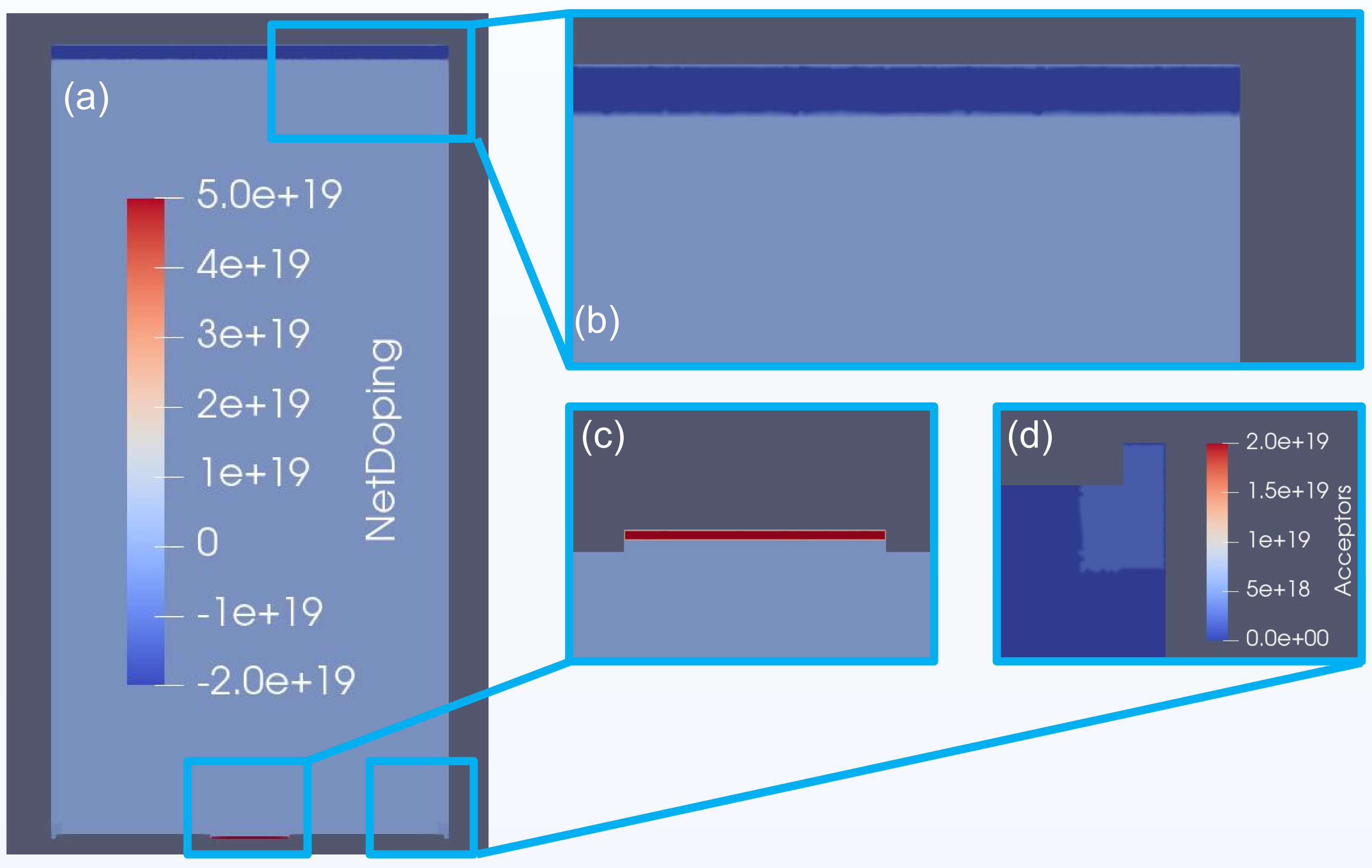

Figure 2. Doping profile of (a) the sensor, (b) p-contact (c) n-well, (d) and p-stop.

Electric Performance

We have evaluated the in-circuit properties of the detector, including the current-voltage (I-V) and capacitance-voltage (C-V) relations. The C-V relationship indicates that the detector reaches full depletion at 30 V. Meanwhile, the I-V relationship shows a relatively mild leakage current of 1 μA at operating voltages.

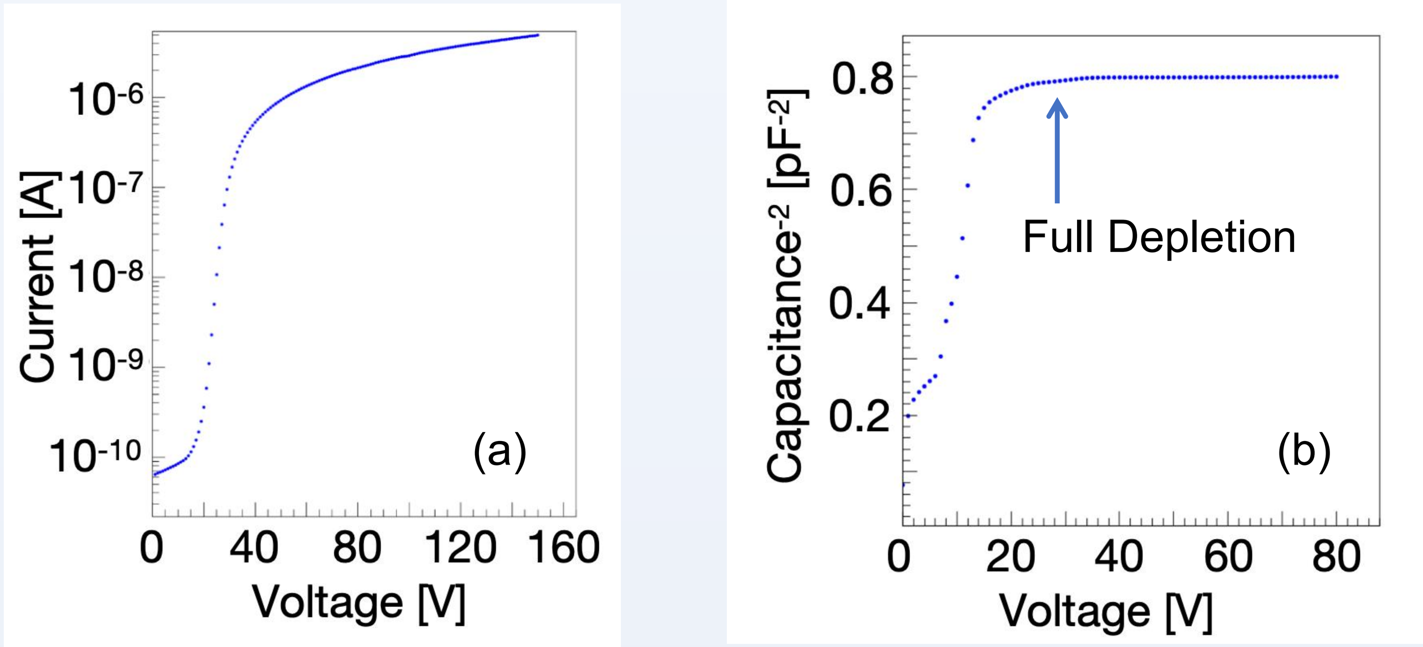

Figure 3. (a) I-V and (b) C-V relations of CSC sensor.

Electronics

We have simulated the ATLAS ABCStar amplifier, which consists of three stages: a preamplifier, a first boost amplifier, and a second amplifier with a shaper. This design is with good noise tolerance.

The circuit achieves a gain of 87.7 mV/fC, a rise time of 21.7 ns, and a waveform full width at half maximum (FWHM) of approximately 32 ns. These results are consistent with the ABCStar data, which reports a gain of 85 mV/fC, a rise time of 22 ns, and an FWHM of 34 ns.

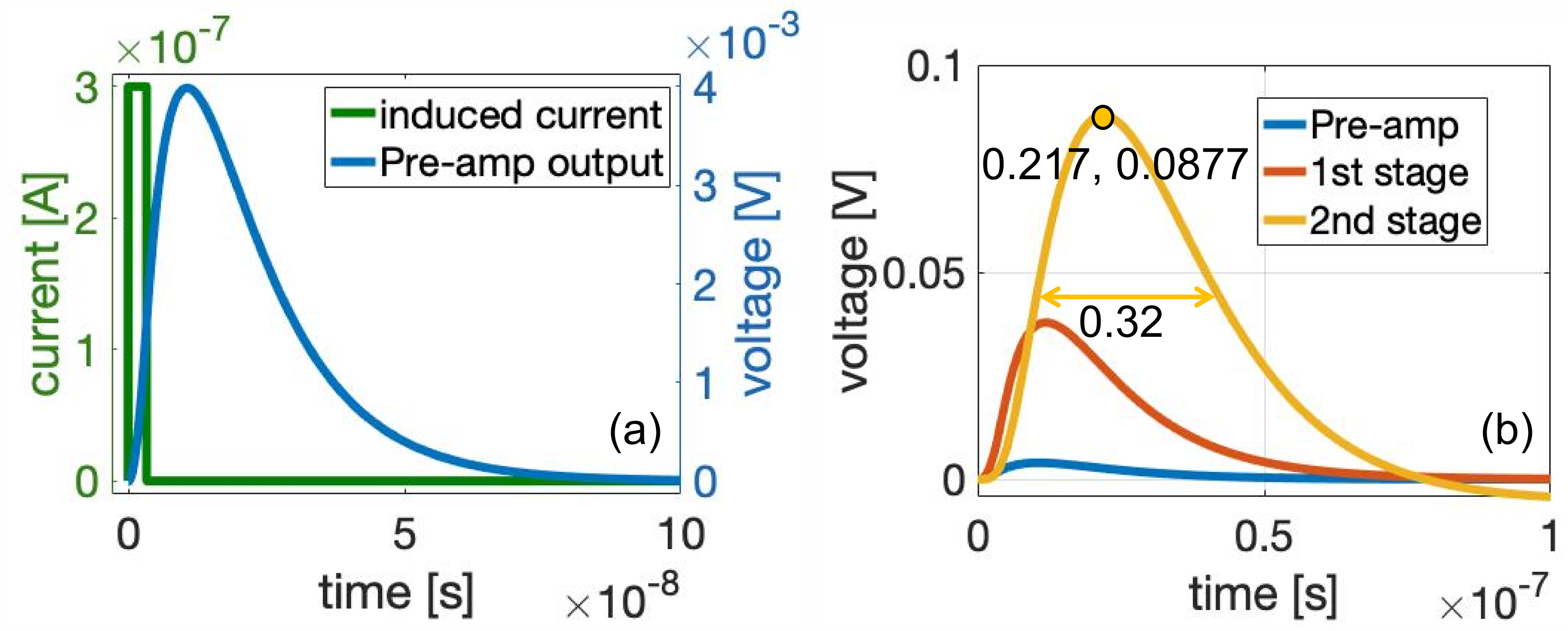

Figure 4. Signals (a) before and after the Pre-amp, (b) after every stage. Input 1 fC.

Responce Simulation

We use a ^{90}Sr beta source in Geant4 as minimum ionizing particle (MIP) source, with the emitted electrons having an energy of 0.546 MeV.

Similarly, we also simulated the response of the detector to a 660 nm wavelength laser. The laser is incident from the n-well side of the detector, with a beam width of 5 μm and a pulse duration of 5 ns.

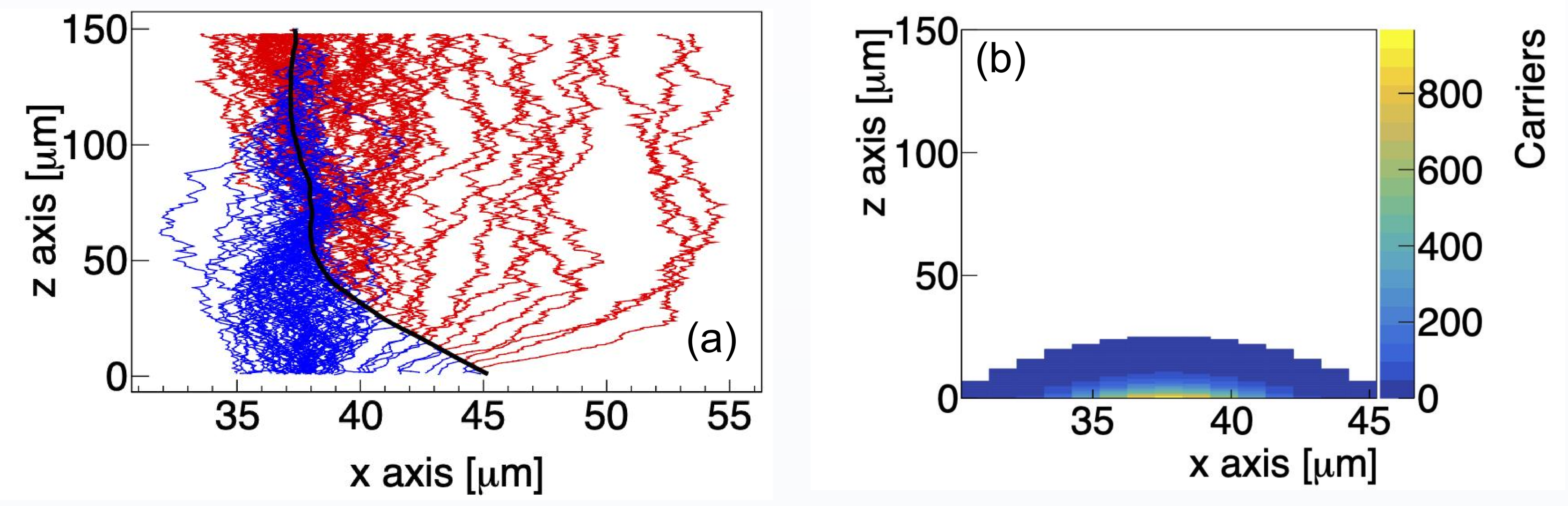

Figure 5. Visualization of (a) carrier drift paths after beta ray injection and (b) carrier distribution after laser injection.

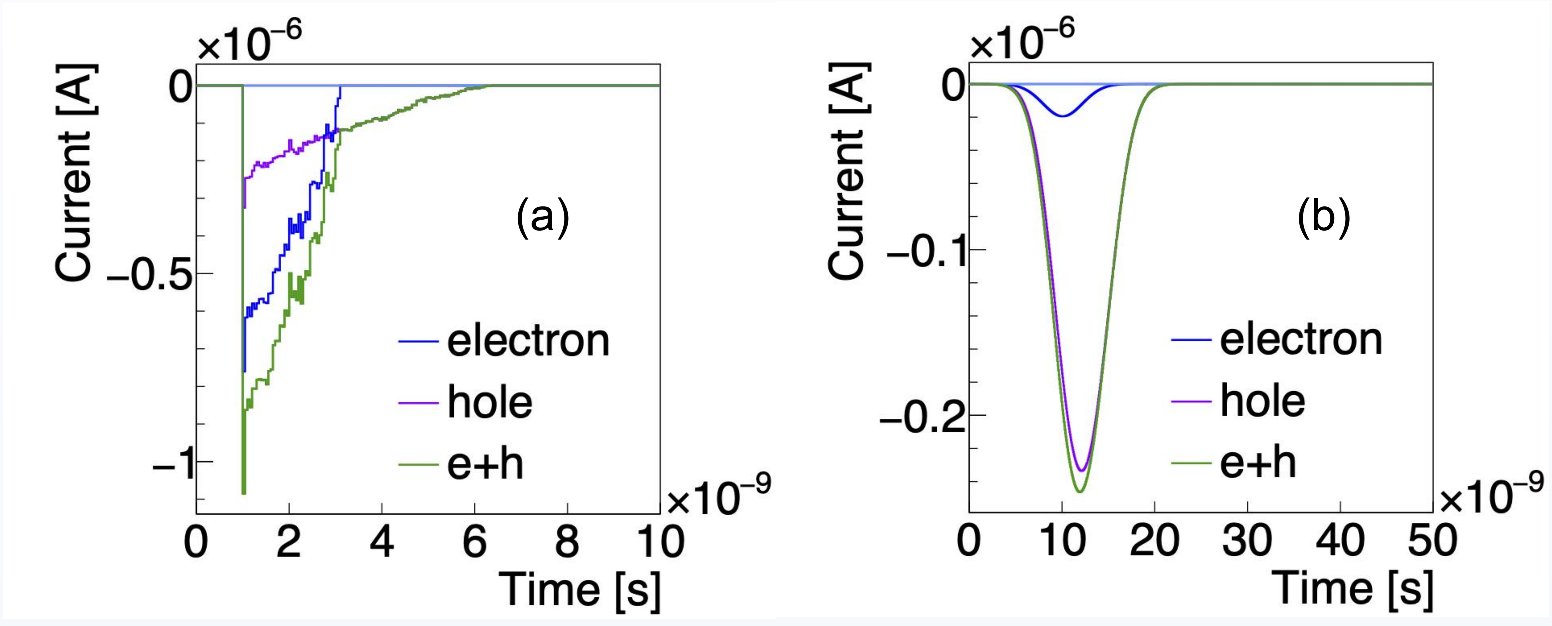

Figure 6. Sensor responce of (a) beta ray and (b) laser injection.

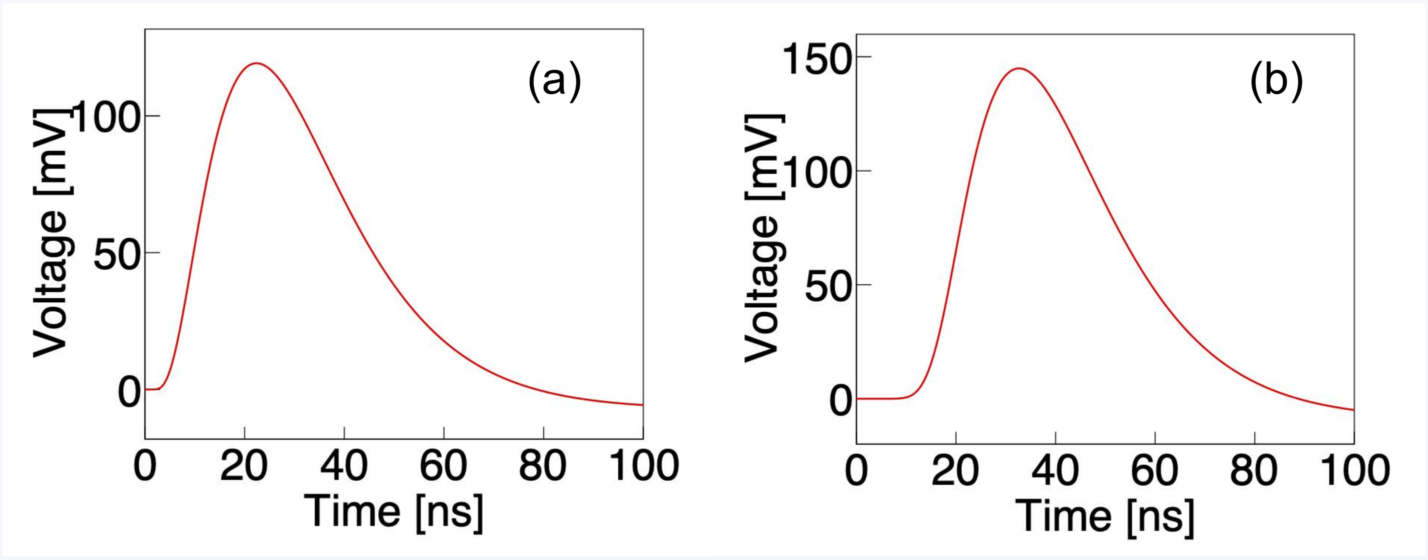

Figure 7. Amplified waveform of (a) beta ray and (b) laser injection.

Summary

Based on the fully open-source software RASER that we developed, we conducted a comprehensive simulation of the minimum ionizing particle (MIP) and laser response signals for the CMOS Strip Chip used in the CEPC inner tracker. This simulation provides an effective reference for the subsequent development and testing of the device.

Reference

[1] raser, https://pypi.org/project/raser/.

[2] Diehl, L., et al, 2022. Characterization of passive CMOS strip sensors. Nucl. Inst. Meth. A. 2022, 166671.

[3] Cormier, K.J.R., et al, 2021. Development of the front end amplifier circuit for the ATLAS ITk silicon strip detector. J. Inst. 16, P07061.