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Research on Performance and Applications of SiC on RASER

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June 5th, 2025

3rd DRD3 week on Solid State Detectors R&D

Outline

- **Simulation needs in SiC detector applications**
- **Functions and advantages of RASER**
- **Applications of RASER in simulating SiC detectors**
  - **Basic electrical performance simulation**
  - **Application simulation on Beam Monitoring**
  - **Particle identification**
  - **Irradiation damage research**
- **Summary and Outlook**

Simulation Needs in Silicon Carbide Detector Applications

1. ## Full-chain Simulation from Detector Structure to Electronics Output

   Requires integration of detector structure design, process simulation, charge transport, signal generation, and electronics circuit optimization.

2. ## Multivariable Coupling Simulation in Application Scenarios

   Models for temperature, irradiation energy, dose rate, time, and particle types to analyze coupled effects.

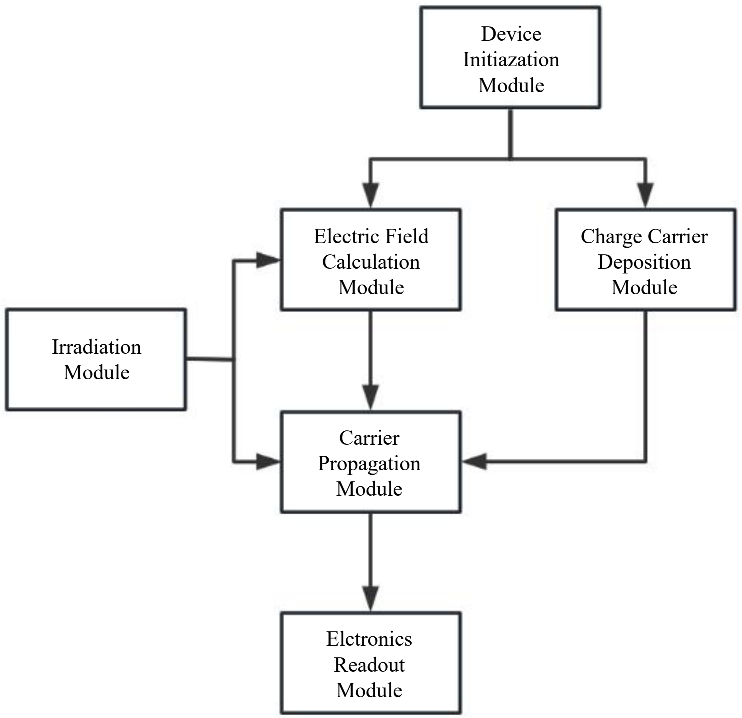
3. ## Reliability Validation of Simulation Results

   Experimental feedback and model iteration to ensure accuracy, such as comparing with DLTS/TRPL measurements.

Functions and Advantages of RASER

- **Cross-Platform Integration: Links GEANT4 (particle transport), DEVSIM (electrical field solving), and NGSpice (electronics simulation) via Python.**
- **Modular Architecture:**
  - **DEVSIM: Solves electric fields and weighting fields for detector structures.**
  - **GEANT4: Simulates particle trajectories and energy deposition.**
  - **NGSpice: Models current-sensitive amplifiers and readout circuits.**
- **User-Friendly Development: Python-based framework suitable for beginners and collaborative development.**

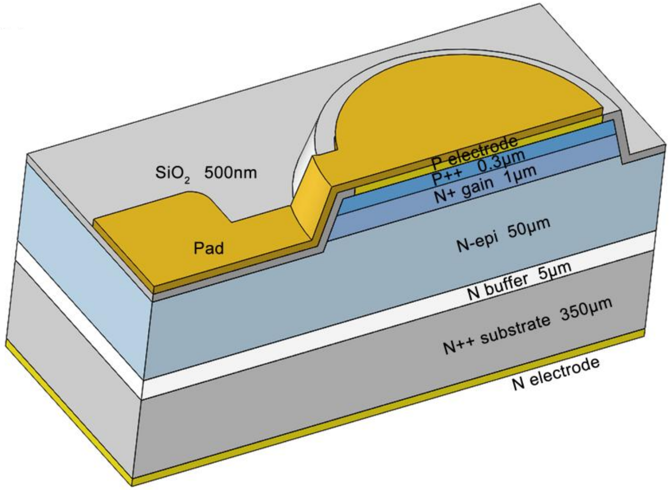
$$I(t) = -q\vec{v}(\vec{r}(t)) \cdot \vec{E}_w(\vec{r}(t))$$



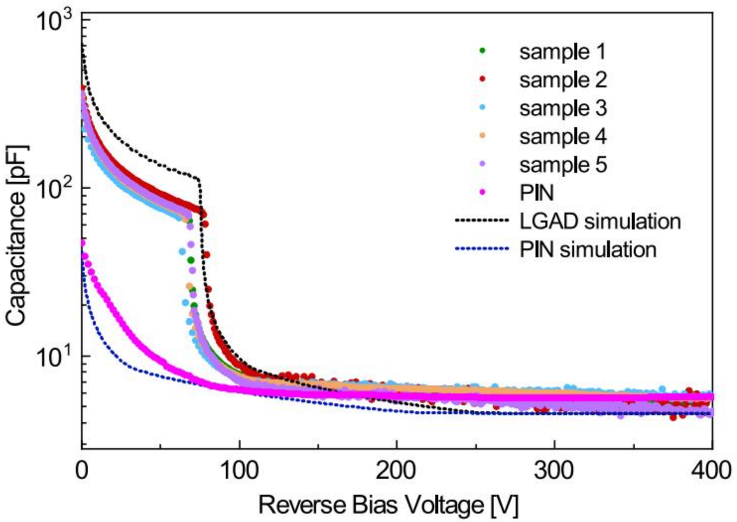
Composition and functions of sub-module in RASER

Basic Electrical Performance Simulation

- **LGAD Technology**



SiC LGAD strip cross-section



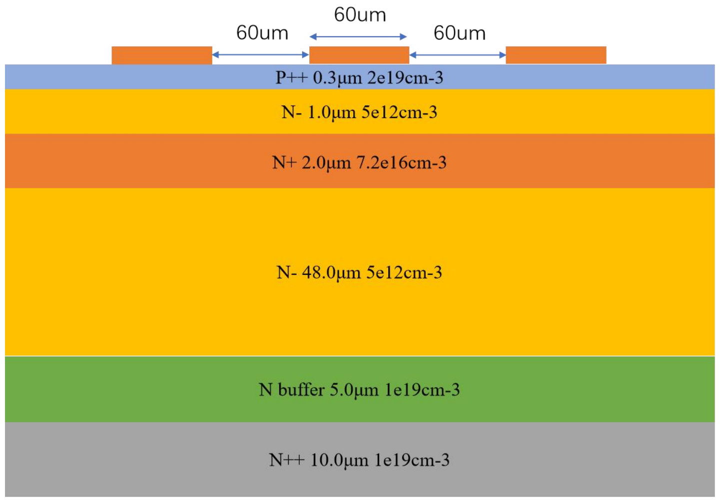
CV curves of SiC LGAD

- **Introduced in SiC detectors (SICAR structure) to achieve avalanche multiplication for signal amplification.**
- **Key Layer: N++ gain layer (1 μm, 1.4×10^{17} cm^{-3}) for charge multiplication.**
- **Electrode Design: Graphene-metal composite electrodes for laser penetration and wire bonding.**

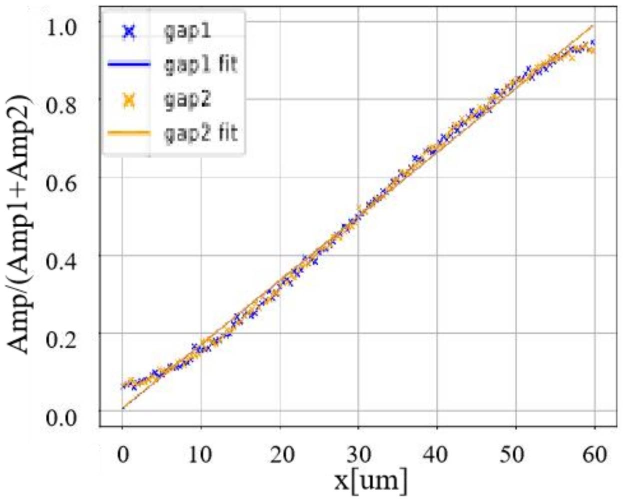
10.1109/TNS.2024.3471863

Basic Electrical Performance Simulation

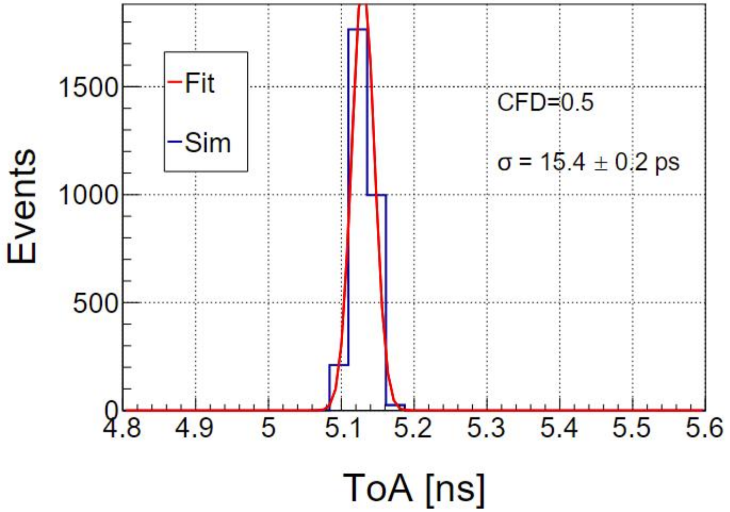
- **SiC LGAD strip Resolution Simulation**



Schematic diagram of SiC LGAD strip



Electrode amplitude with position scanning



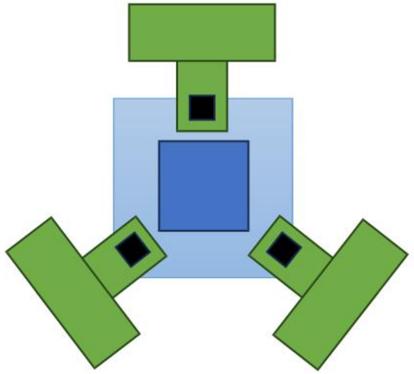
Time resolution of near electrode, worse than direct injection 9.0±1.6ps

- **Position resolution: Studied via 375 nm laser scanning.**
- **Time resolution: near electrodes σ = 15.4 ps (direct incidence), σ = 31.0 ps (adjacent strips), worse than direct injection 9.0 ps.**

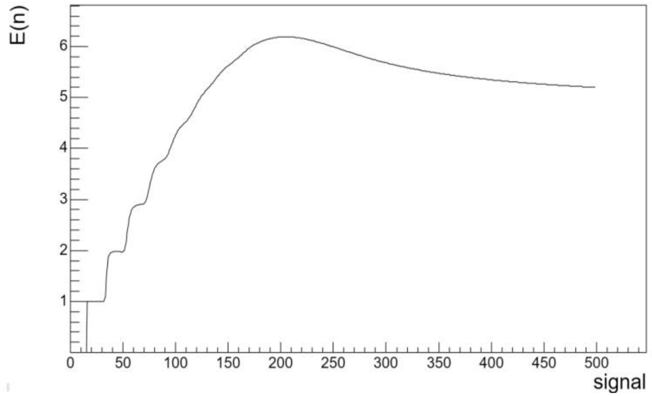
Application Simulation in Beam Monitoring

- **Design a high-precision beam monitor system for China Spallation Neutron Source's 1.6 GeV proton beam, ensuring ≤1% uncertainty in fluence measurement under extreme radiation conditions.**

SiC → T-shape plate → Amp → DT5742 → Data



Schematic of detector-beam position



Electronic signals and incident particle count

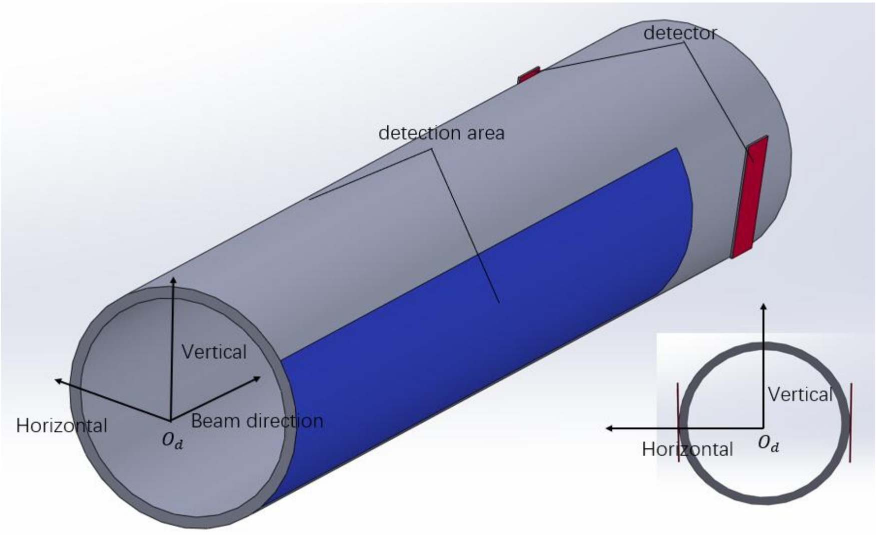
- **RASER is used to simulate the signal output of SiC detector in proton beam, and evaluate the distribution of the signal peak voltage through Gaussian fitting.**

- **Calculate the statistical fluctruations of the proton beam energy deposition, and verify the impact of factors such as electronic noise and irradiation damage.**

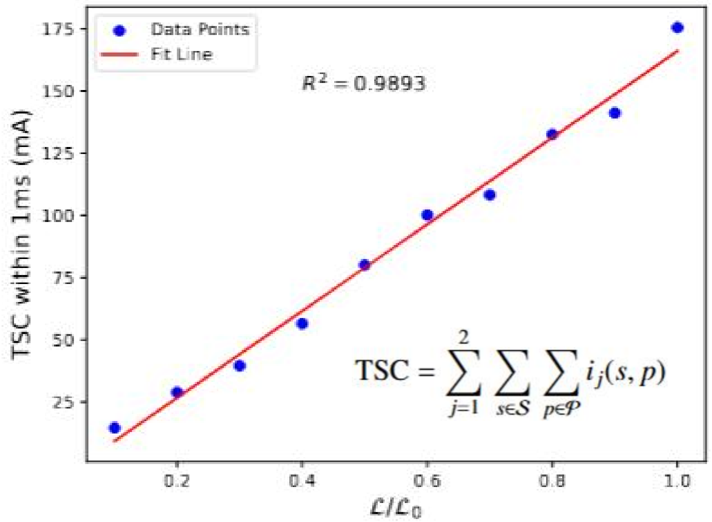
10.1007/s41605-024-00487-4

Application Simulation in Beam Monitoring

- **Circular Electron-Positron Collider Collision Point Monitoring**



Position of detector(red)

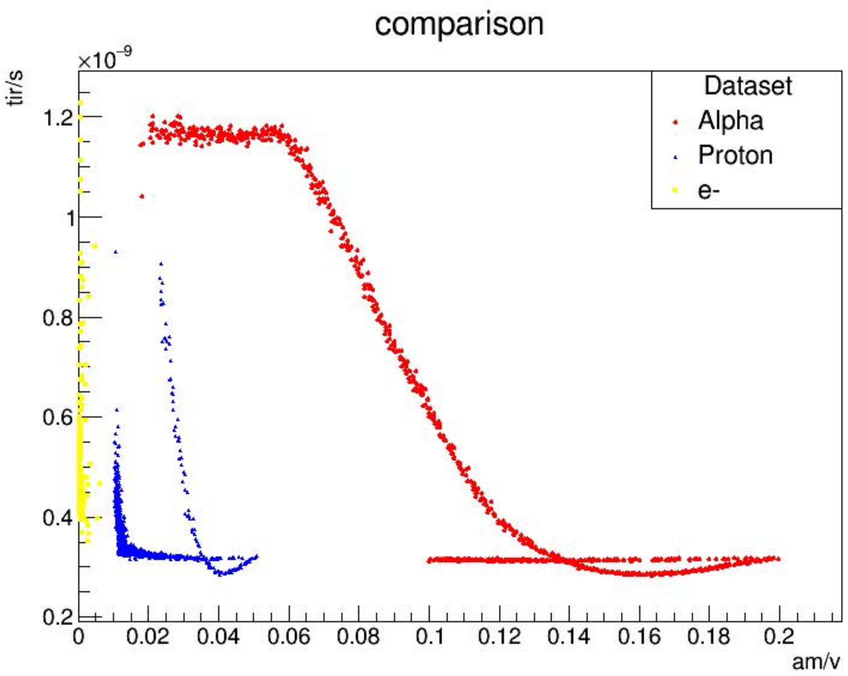


Simulation of TSC under different luminosity

- **Estimates beam intensity by detecting secondary particles (γ, e⁻) downstream.**
- **Linear relationship between total sample current and beam brightness ($R^2 = 0.9893$).**

Particle identification

- **Particle identification**

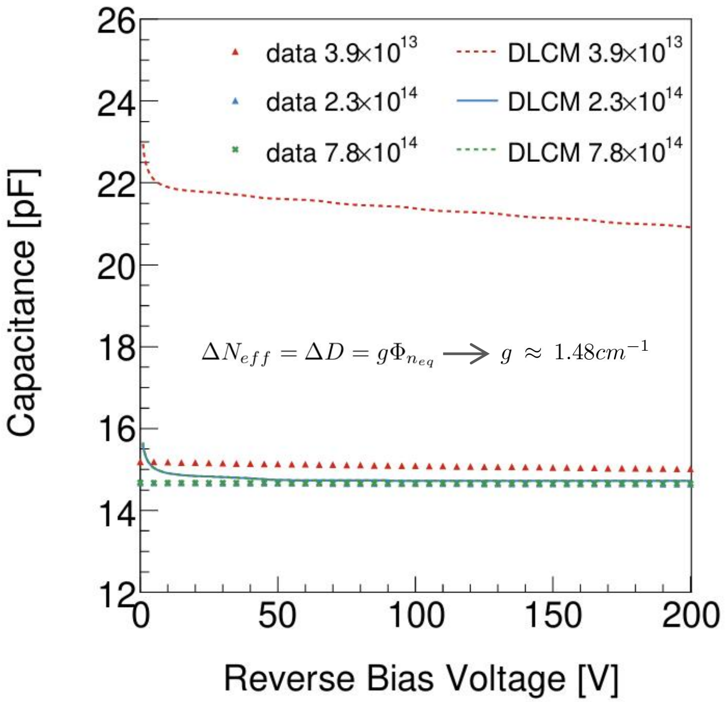


Amplitude - rise time of alpha, proton and electron

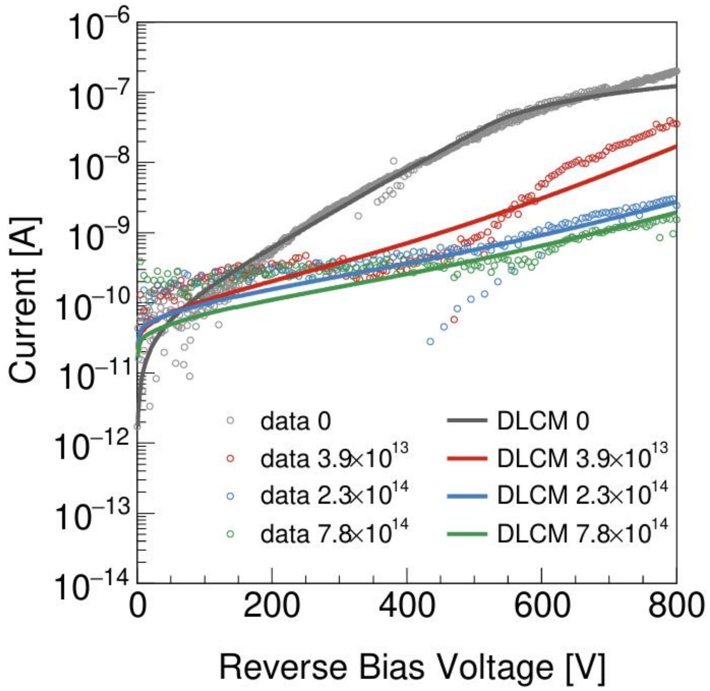
- **Using RASER to simulate the energy deposition of protons, alpha particles, and electrons with energies below 20 MeV in a SiC detector. Particle identification is achieved by distinguishing the incident particles based on the differences in waveform information (amplitude-rise time).**

Irradiation Damage Research

Deep - Level Compensation Model



Simulation of CV of irradiated detectors considering DLCM



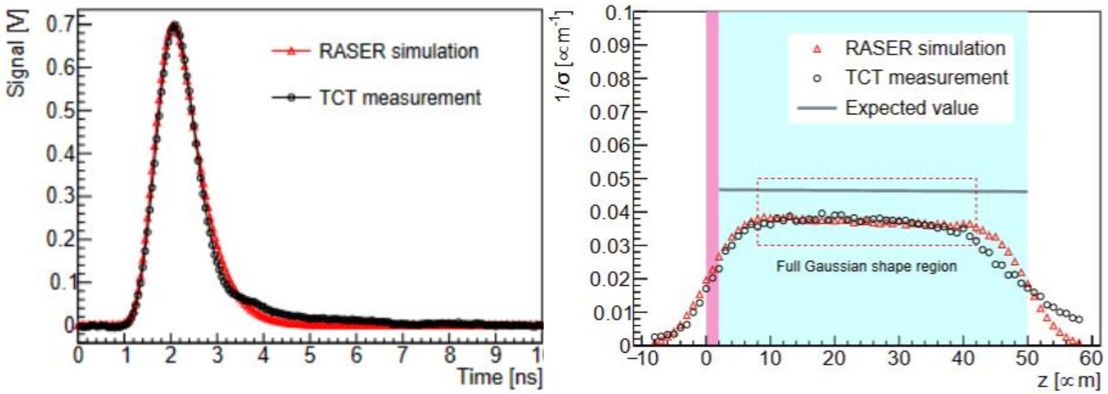
Simulation of IV of irradiated detectors considering DLCM

- **CV curve simulations considering EH3 defects(from DLTS) match experimental data, validating the model.**
- **IV simulations considering tunneling effects and irradiation-induced lifetime degradation.**

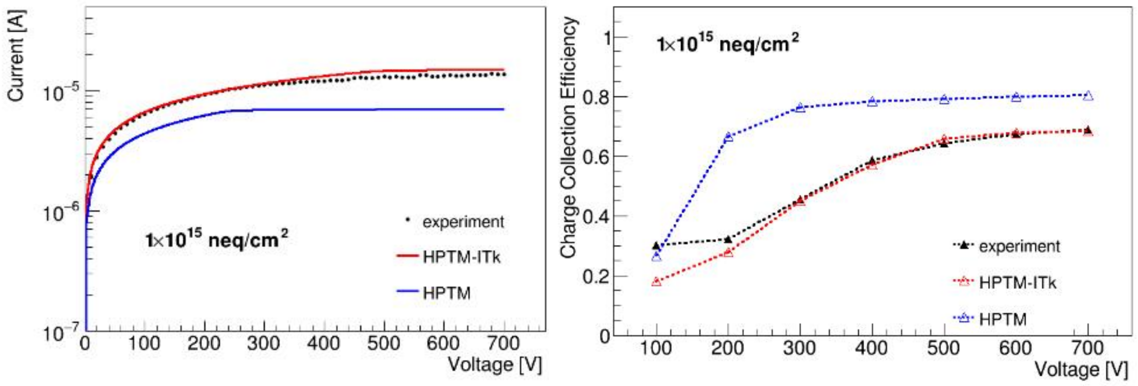
Details in Zaiyi's report

Summary and Outlook

- Full-Chain Simulation: Integrated detector physics, charge transport, and electronics for SiC devices.
- Irradiation Modeling: DLCM accurately predicts defect-driven performance changes in irradiated SiC.
- Multi-Material Support: Extended to silicon detectors and scintillators (e.g., Si LGAD edge-TCT simulation).



Si LGAD waveform from RASER(left) and electric field by diffusion method(right)



IV(left) and CCE(right) of Si strip using optimized irradation model

10.1016/j.nima.2024.169479

Summary and Outlook

- Optimize the time and spatial resolution algorithms for strip detectors
- Implement three-dimensional field solving and simulate the resolution performance of pixel detectors
- Optimize the modeling of SiC LGAD irradiation damage
- Expand the application scenarios of SiC detectors

Thanks for your attention!