TCAD Simulation Studies for the Development of LGADs and AC-LGADs

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Overview

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- ➢ Gain Suppression in LGADs:
  - Gain suppression has been observed experimentally from large energy deposition.
  - Explore and characterize the gain suppression effects using TCAD simulation.

- ➢ Charge Sharing in AC-LGADs:
  - Effects of charge sharing in neighbouring channels for different n+ layer resistivity, channel pitch, and strip length.

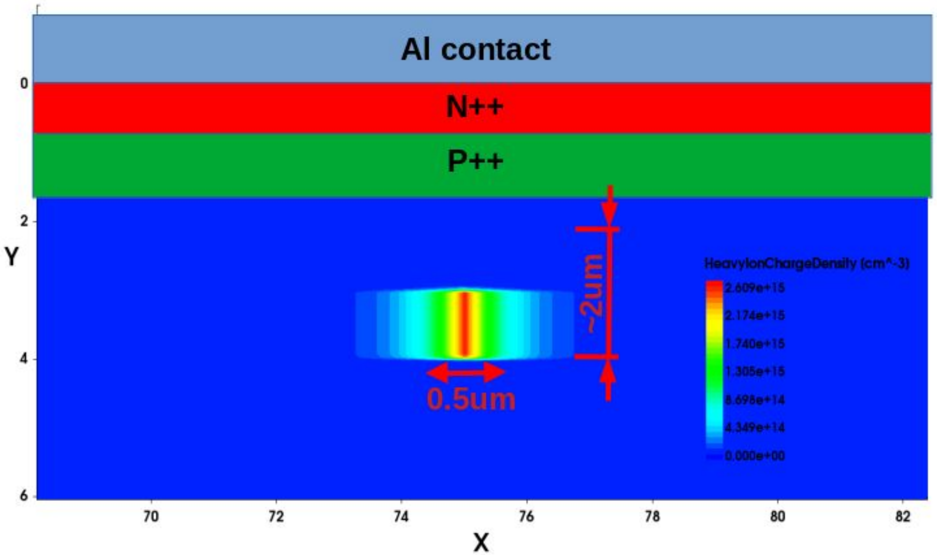
- ➢ Backup

Gain suppression in LGADs

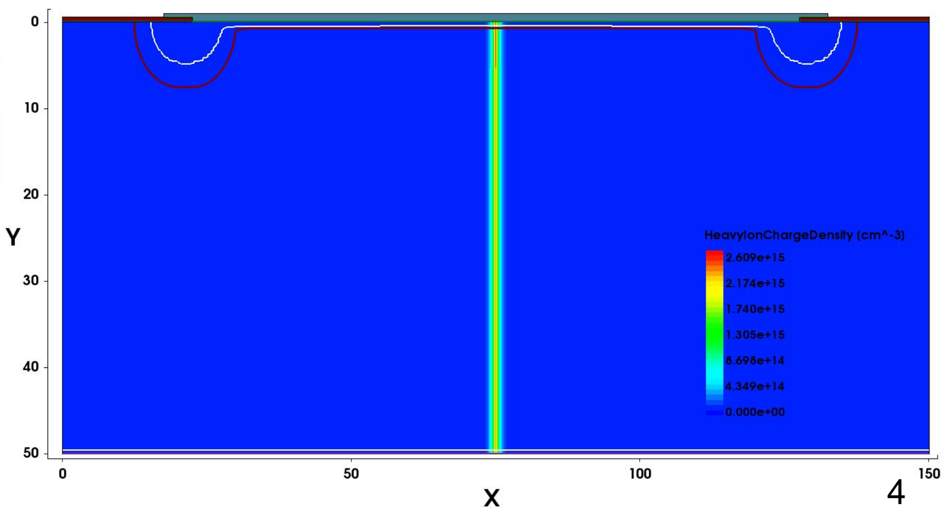
Configuration of Input Charges

- Two configurations of input charges are used for studying the gain suppression effect:
  - **1) approximately localized charges:**
    - Generated input charges below the gain layer,
    - Extend with length of 1um into the device.
  - **2) track of charges:**
    - Track of generated charge with constant density per um
    - Total track length equals the thickness of the device.

Localized charges

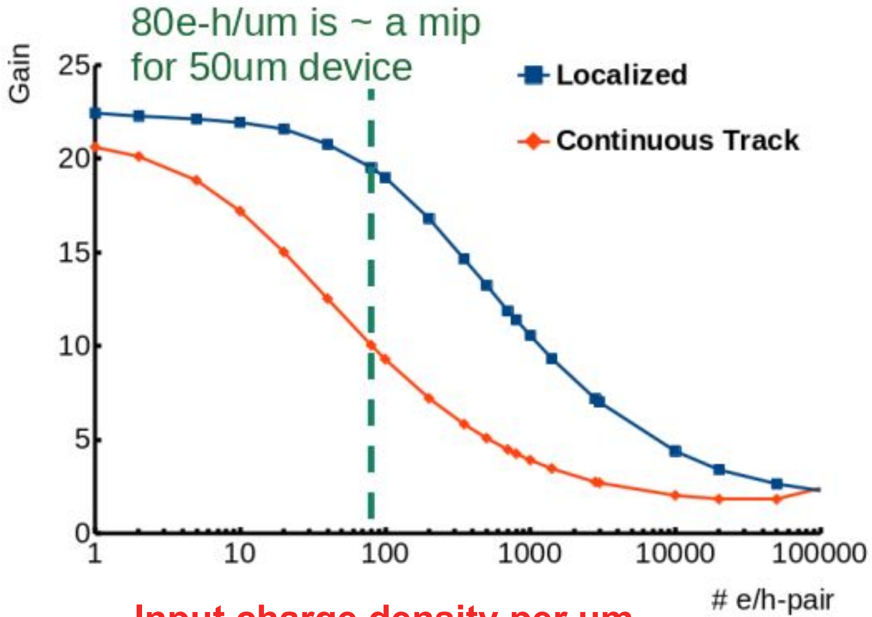


Track of charges

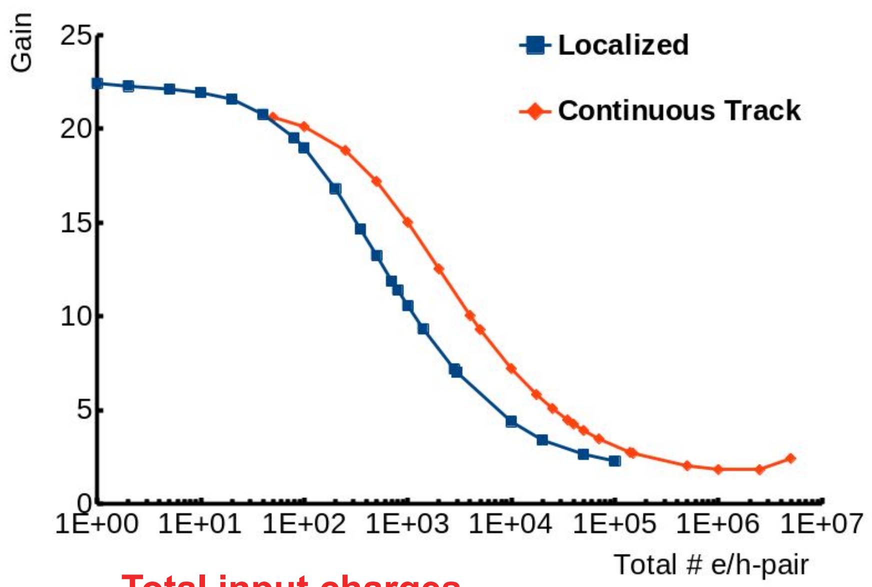


Gain Suppression and Input Charge Density

- The simulation shows the gain suppression effect is significant when the input charge density is high.
- The simulated gain can be characterized in terms of the generated charge density in the direction of trajectory.
- The gain can also be expressed in terms of total input charges.
    - For the same amount of total input charges, the gain suppression is reduced if the input charges are spread even.



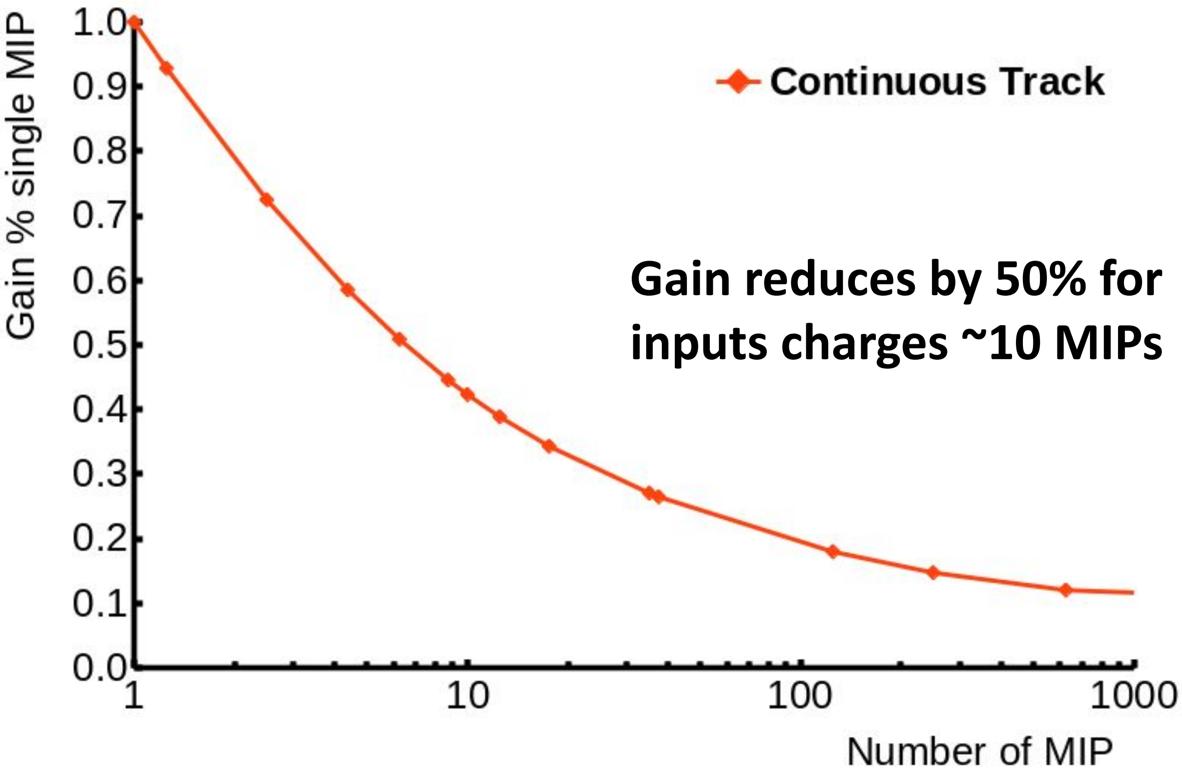
Input charge density per um



Total input charges.

Gain Suppression and Input Charge Density

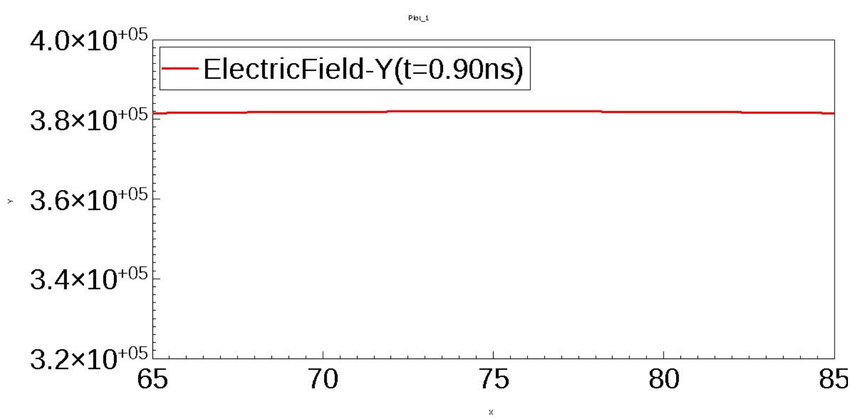
- The simulated fractional gain with respect to single MIP is shown. (Only the case of continuous track is considered here)



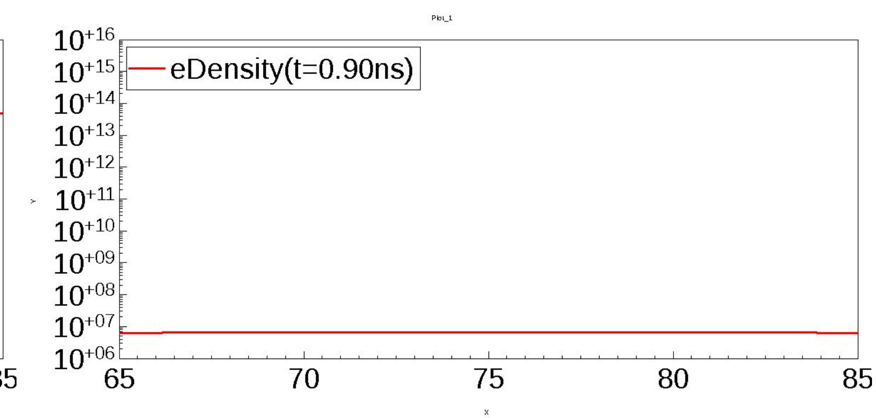
Time Evolution of Electric Field in Gain Layer

- The gain of a LGAD device is produced by impact ionization in the high field region of the gain layer.
- Impact ionization is very sensitive to the magnitude of the electric field.
- To understand the gain suppression effects, the time evolution of electric field within the gain layer is simulation

Electric field time evolution for localized input charges.



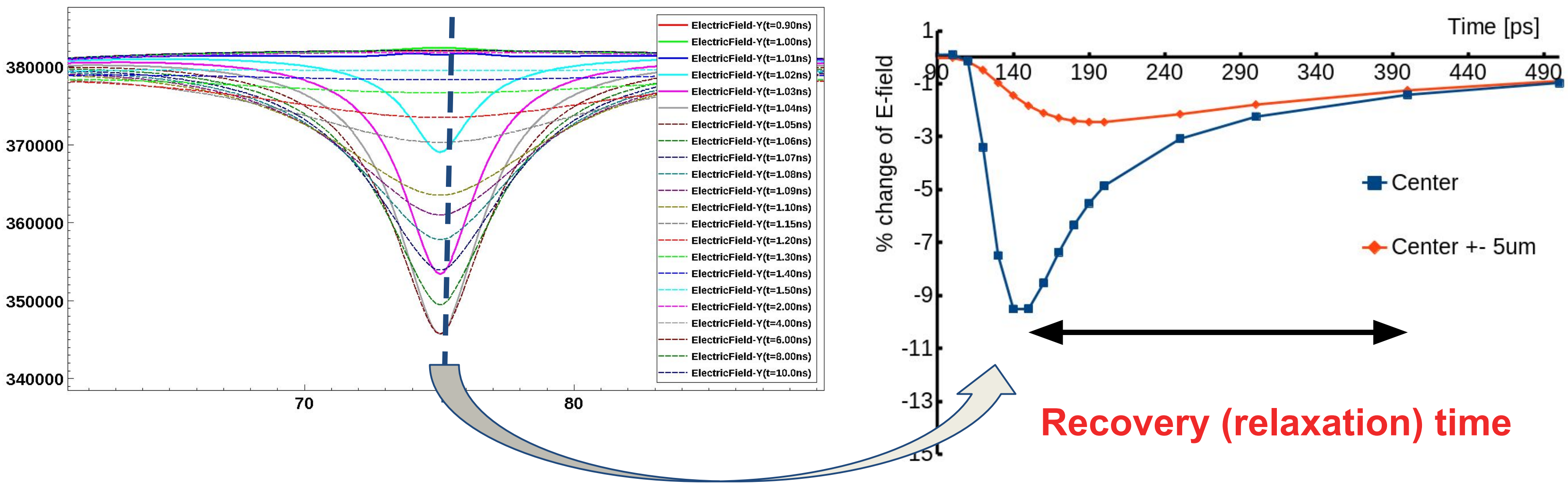
Electron density within the gain layer.



(animated electric field & e-density time snapshot)

Recovery (Relaxation) time of Electric Field

- In order to connect the gain suppression effects to the electric field within the gain layer, a concept of **recovery (relaxation) time** of the electric field is introduced:
  - **Recovery (relaxation) time: the required time duration for the electric field within the gain layer to recover to steady state after the impact ionization process**



Snapshot of the electric field within the gain layer at different time for localized input charge.

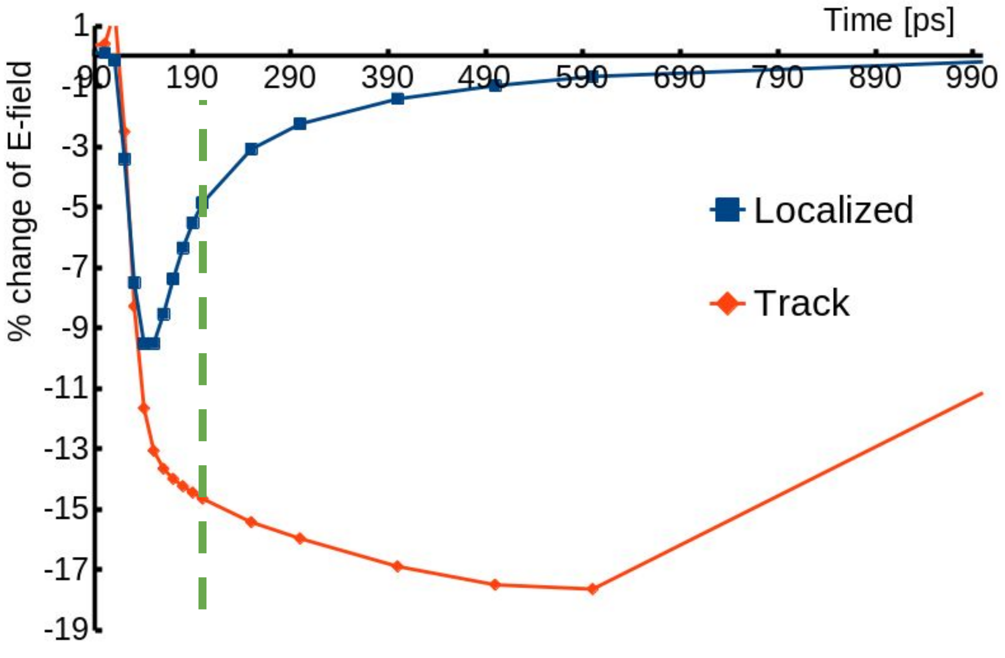
Note: the impact ionization has exponential dependence on the field.

Recovery Time for
Localized vs Track of Input Charges

- The variation of the electric field within the gain layer over time for localized and track of charges are shown. (Same charge density per unit distance are used in both cases.)
- The degree of electric field degradation approaches equilibrium as the impact ionization and recovery processes compete.
- Note:

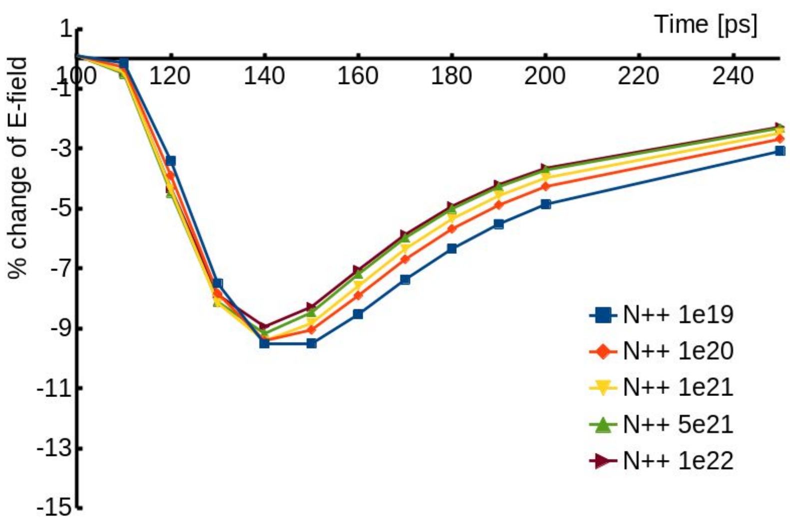
  1) charge arrived at the gain layer at later time see a relatively lower field due to the previous impact ionization process.
  –> gain suppression

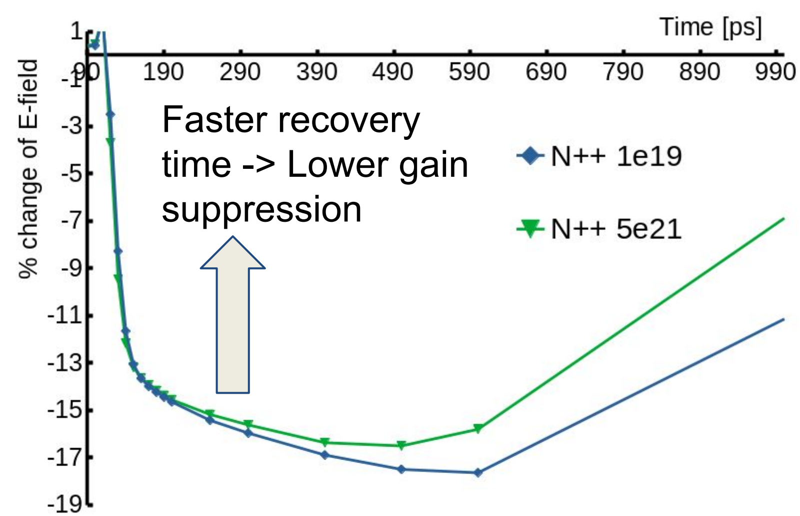
  2) **Faster recovery time should reduce the gain suppression effects.**



Attempt on Improving the Recovery Time

- The recovery time of the electric field depends on how fast the generated charges from impact ionization process are "drain" away.
- One approach is to increase the conductivity of the gain layer profile configuration. E.g. increasing the n++ doping concentration.
    - No more changes above doping of 5e21 N/cm^3
- Reach limitation from transport of space charge in the gain layer itself.
- We are open to other ideas about how to improve this.

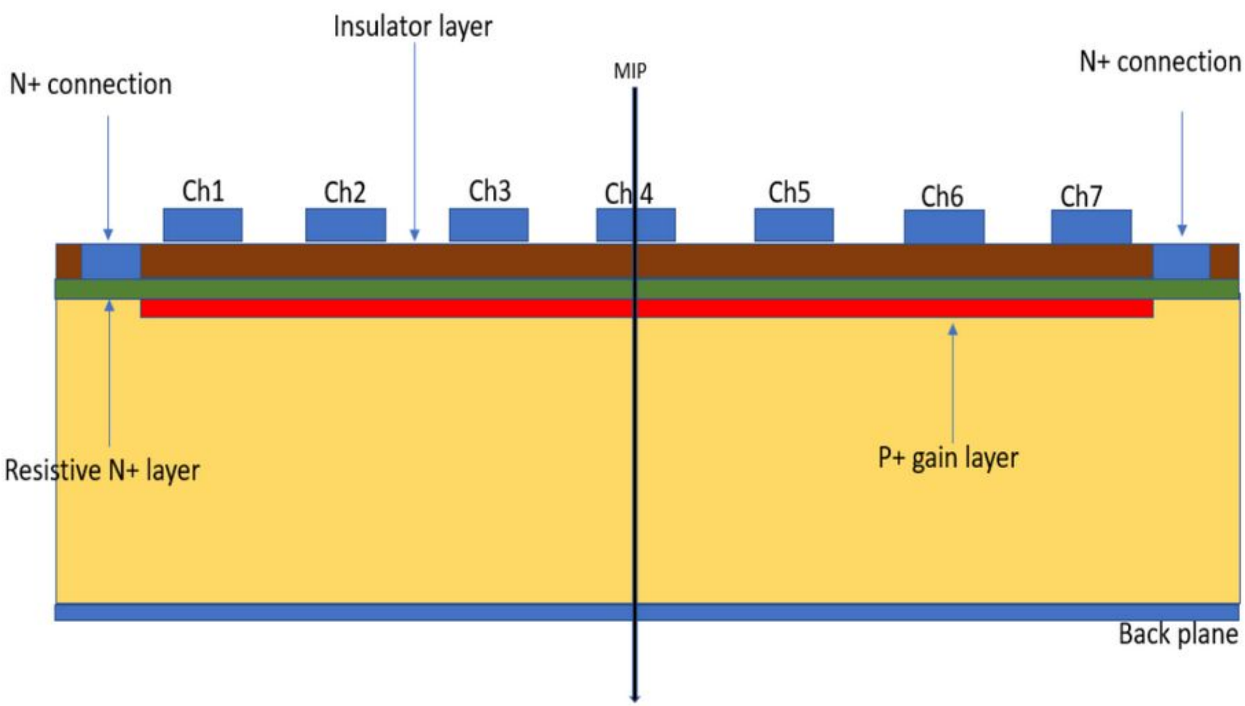




Charge Sharing in AC-LGADs

Review of AC-LGADs Structure

- AC-LGADs contain a resistivity n+ layer, with AC coupled readout channels as shown below.
- Charge sharing property in the resistive layer allows neighboring channels to pick up signal.
- The effect of charge sharing for different n+ resistivity, channel pitch, and strip length are studied with TCAD simulation.

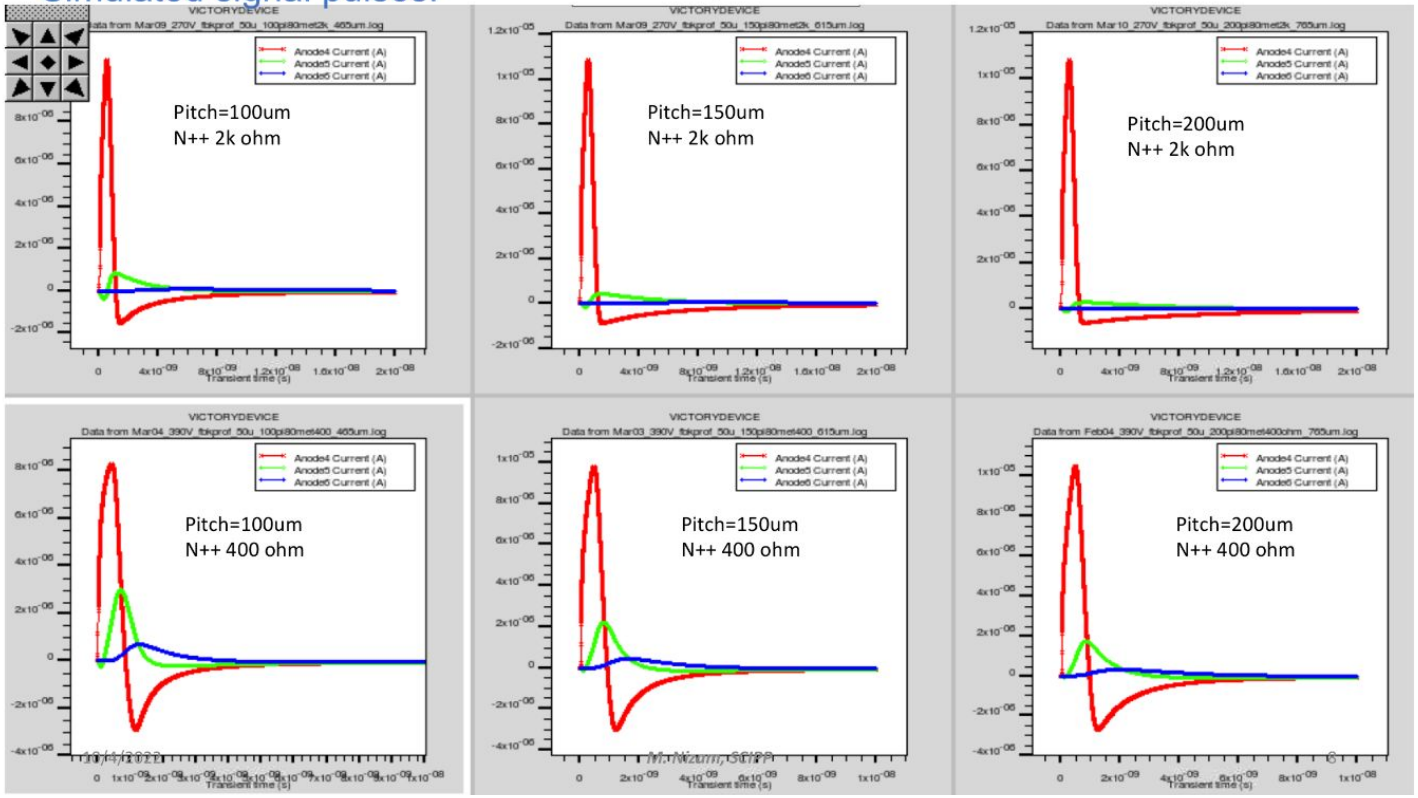


N+ Layer Resistivity and Channel Pitch

- The signal from 3 channels for different n+ resistivity and pitch are shown:
  - The **red** signal is the channel where the mip is entered.
- Large channel pitch reduces the signal sharing in the nearby channels.
- N+ layer with higher resistivity reduces the signal in nearby channels.

Simulated signal pulses:

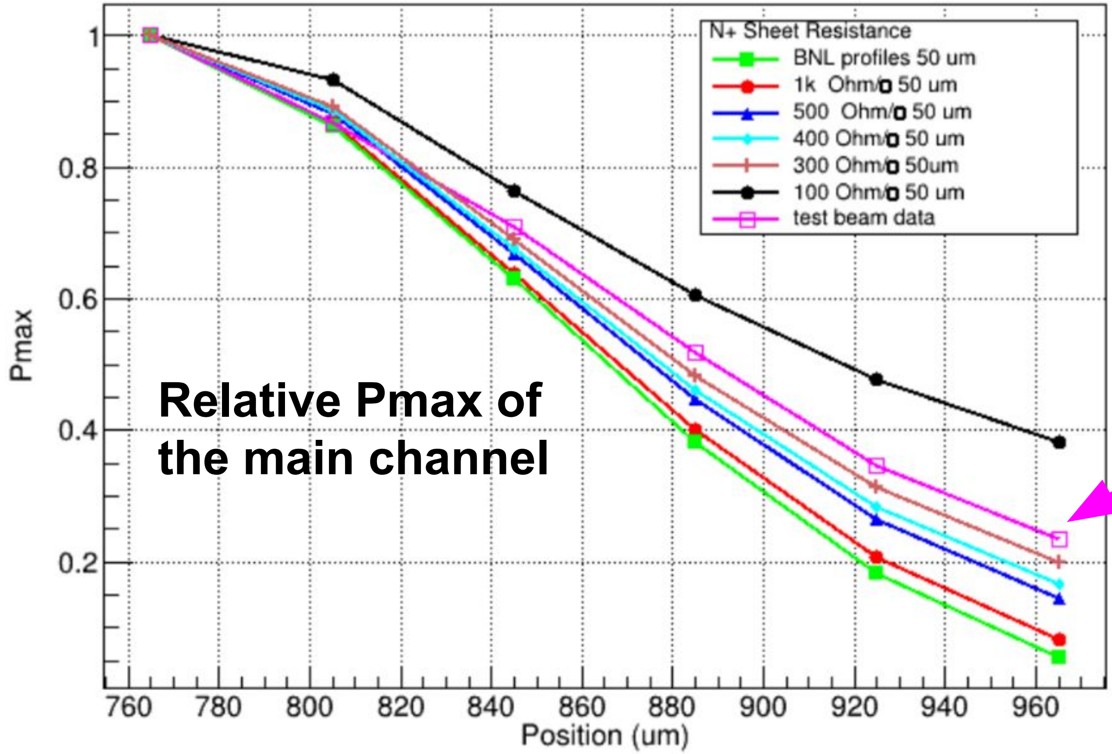
Bulk=50 um, Metal=80 um



Simulation by M. Nizam

N+ Layer Resistivity and Channel Pitch

- Mip scan at different locations were also simulated for different N+ resistivity. (with fixed channel pitch)
- The relative pulse maximum at different mip incident location are shown
  - The charge sharing effects becomes wider as the resistivity of the N+ layer increases.

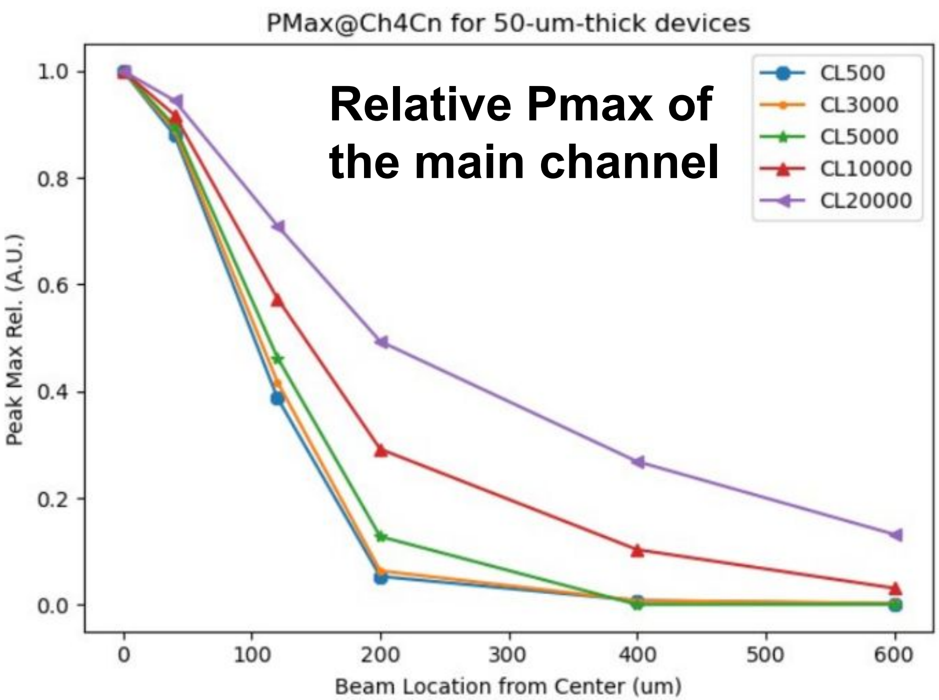


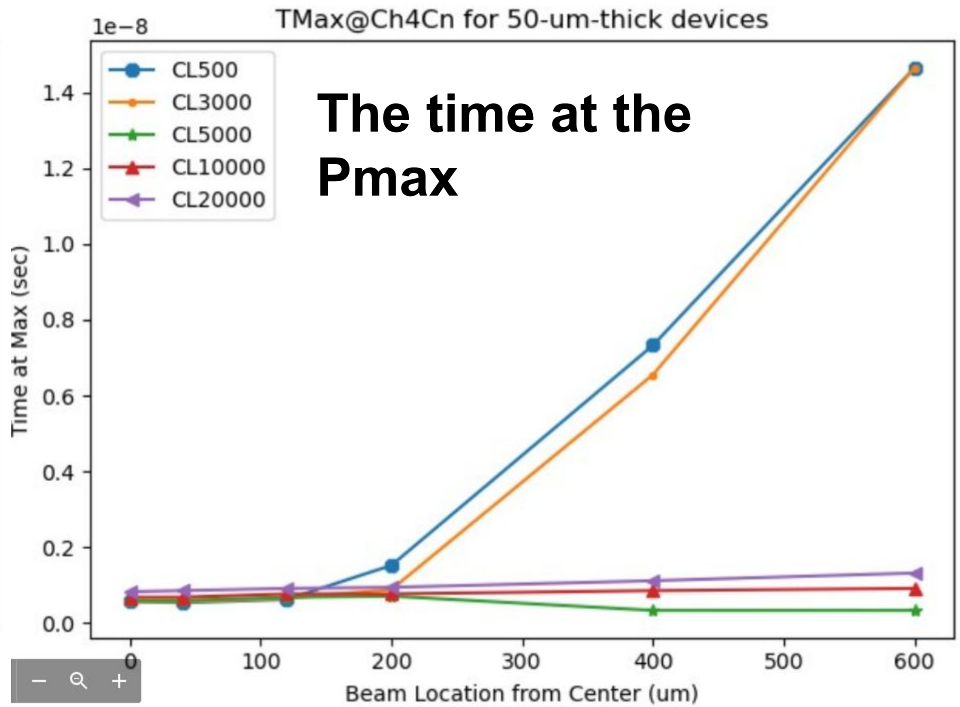
Simulation by M. Nizam

Testbeam data by M. Wong

Charge Sharing and Channel Strip Length

- Different channel strip length are studied in the simulation.
- Relatively small signal pickup for strip length < 5000 um.
- Large signal peak was observed for strip length > 20,000um, and the signal paek is also more align in time.

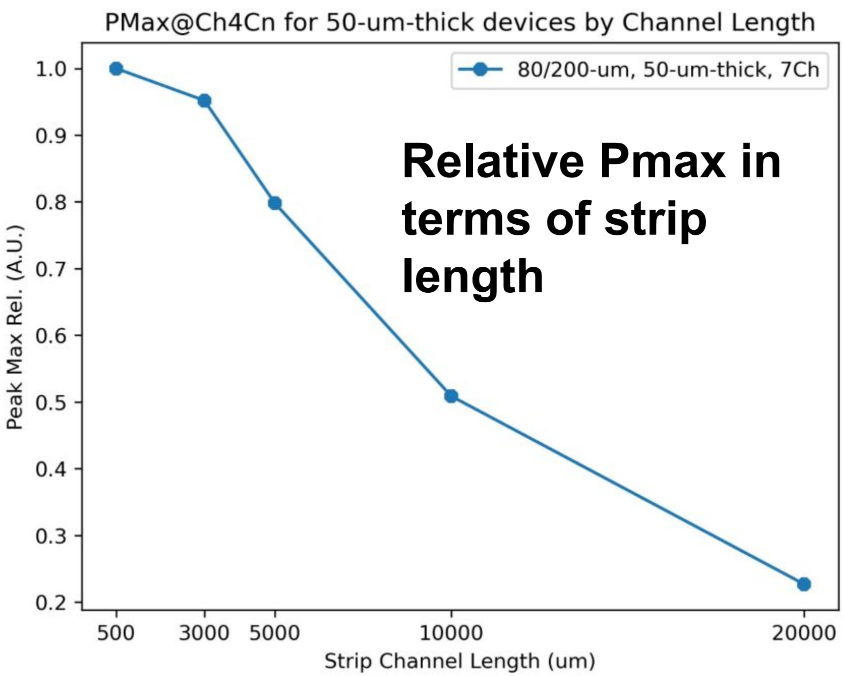


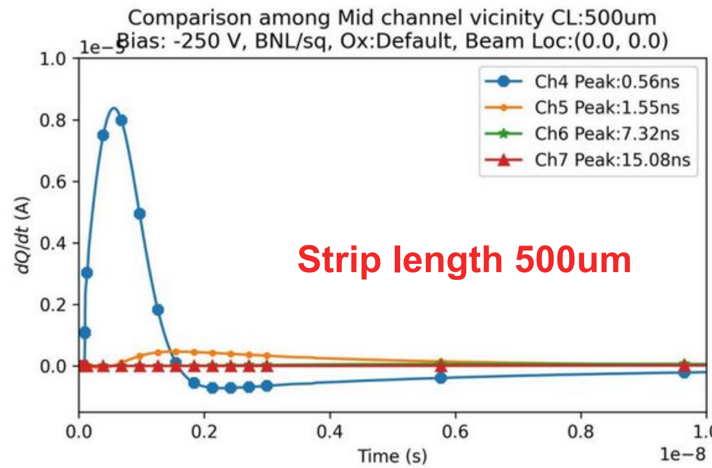


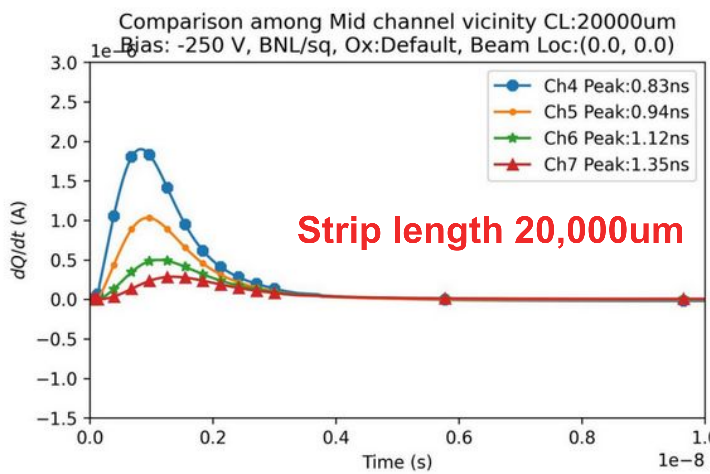
Simulation by T. Shin

Charge Sharing and Channel Strip Length

- As the channel strip length increases, the signal of the channel, where the particle is entered, is reduced.







Simulation by T. Shin

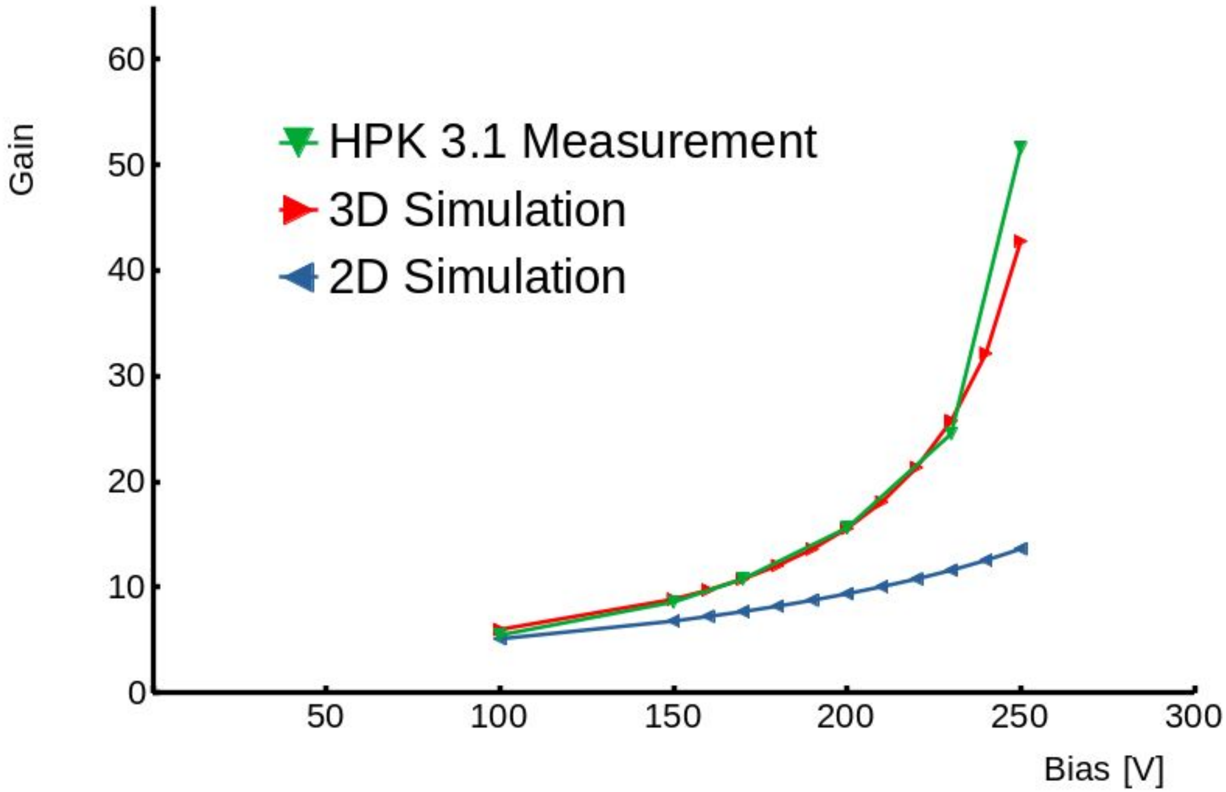
Summary

- **Presented TCAD simulation studies for gain suppression in LGADs:**
  - The gain suppression effect depends on the input charge density.
  - The the same amount of total input charges, spreading them evenly will reduce the gain suppression effects. (the charge density is lower).
  - The recovery time of the electric field within the gain layer is introduced: Faster recovery time could help reducing the gain suppression effect.
- **Presented TCAD simulation studies for AC-LGADs charge sharing with different N+ resistivity, channel pitch, and channel length:**
  - Strong correlation between the N+ layer resistivity and sharing between the neighboring channels.
  - Increasing channel strip length too much yields detrimental result in terms of signal strength and crosstalk.

Backup

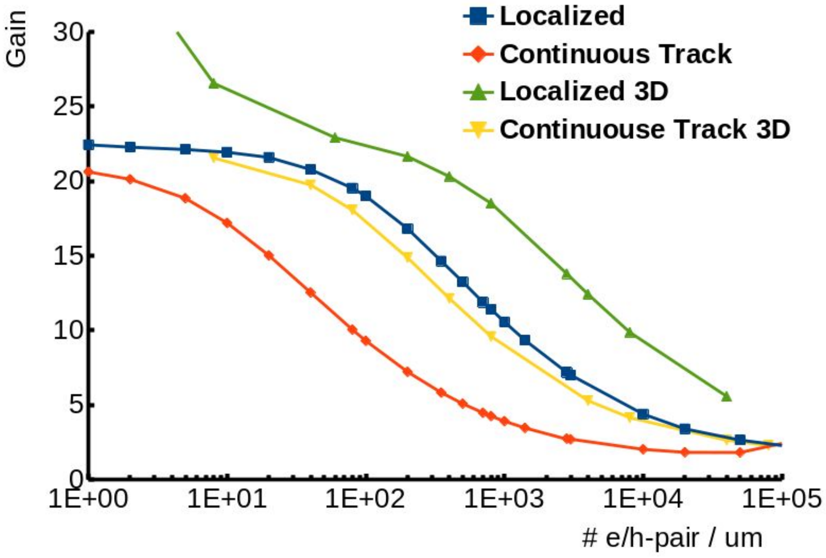
Gain Simulation: 2D vs 3D

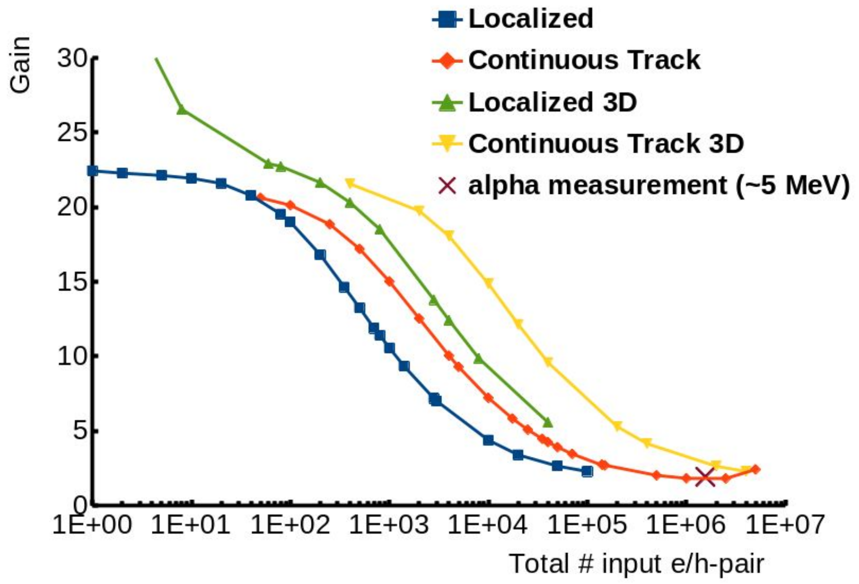
- The doping profile used in the simulation is closed to the HPK 3.1 LGAD.
- 3D Simulation give more accurate gain when comparing to measurement.



Gain Suppression: 2D vs 3D Simulation

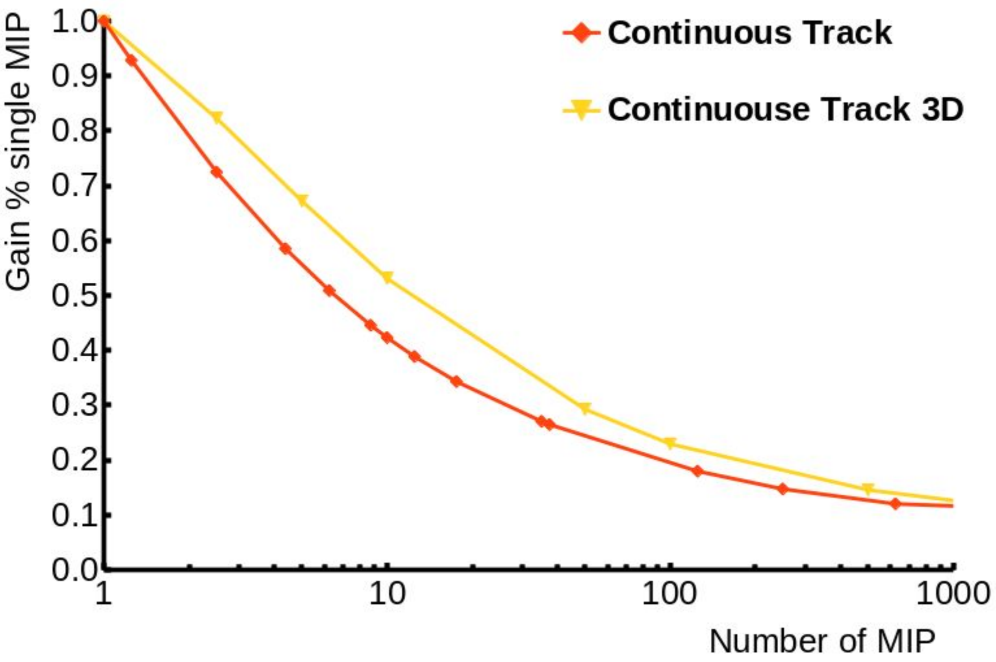
- Although there is an overall difference in gain for 2D vs 3D simulation, the gain suppression effect still exists for large input charge desnsity.
- Measurement with alpha particle (similar to localized input charge) are also show agreement with simulation





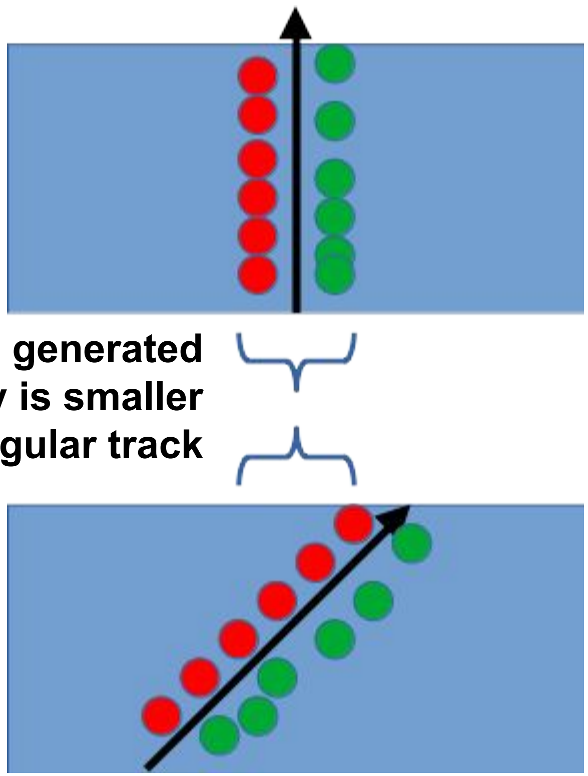
Gain Suppression: 2D vs 3D Simulation

- Both 2D vs 3D simulated fractional gain changes for N input MIPs are shown.
-

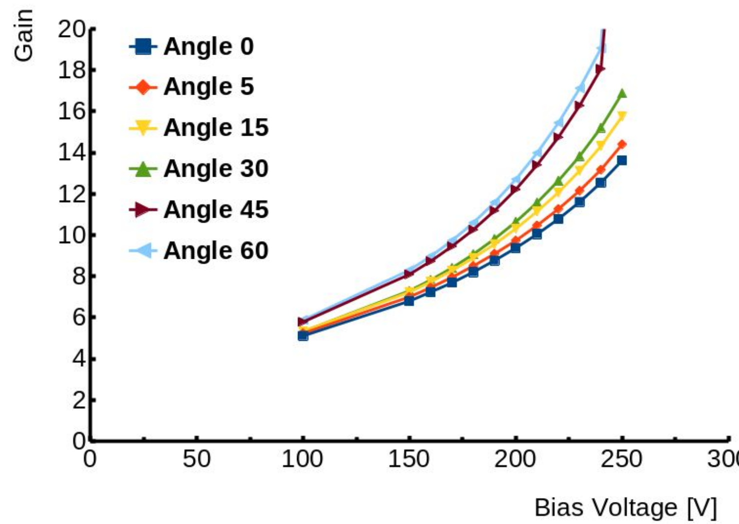


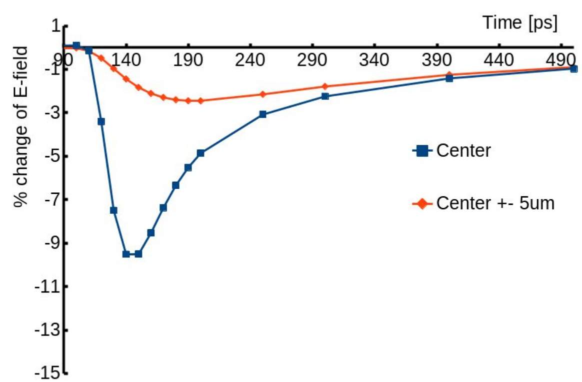
Gain Suppression for Angular Track

- The effective density per um is smaller for angular track.
- However, the range of field degradation extends more than 5um in the lateral direction. It’s a more complicated effect to be characterized.



The effective generated charge density is smaller for angular track





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