TCAD Simulation of AC-LGAD

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RARE PION DECAY WORKSHOP – UCSC

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Outline

- Motivation
- 2D Simulation in Silvaco Victory device
- Comparison with the test beam data
- 3D Simulation in Synopsis Sentaurus
- Effect of strip length
- Gain Suppression study in Sentaurus

Motivation

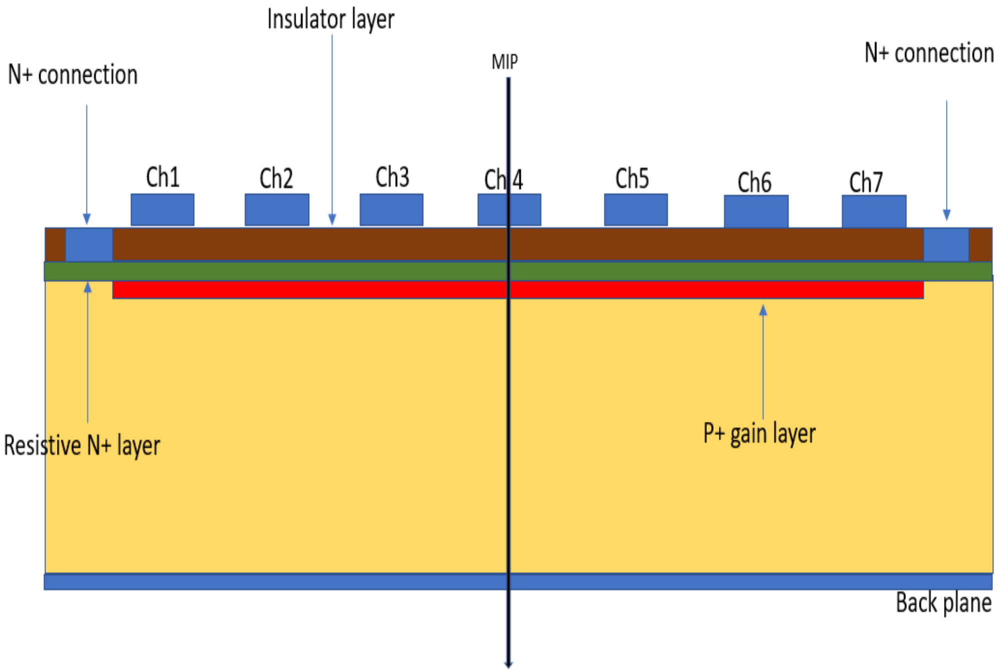
- Technology Computer Aided Design (TCAD) extensively used in semiconductor industry

- The goal of TCAD simulation of LGADs is to reproduce the existing results from the test beam data and optimize various parameters (e.g., N+ sheet resistance, bulk thickness, pitch size, strip size etc) for the PIONEER to provide input to the production.

2D Simulation

AC-coupled Low Gain Avalanche Diode (AC-LGAD)

- ❑ A variant of LGAD with an insulating layer between the read-out pads/strips and the N+ layer.
- ❑ N+ layer is contacted only by a separate grounding electrode.
- ❑ The signal on the metal pad/strip is a mirror image of the charges reaching the N+ layer.



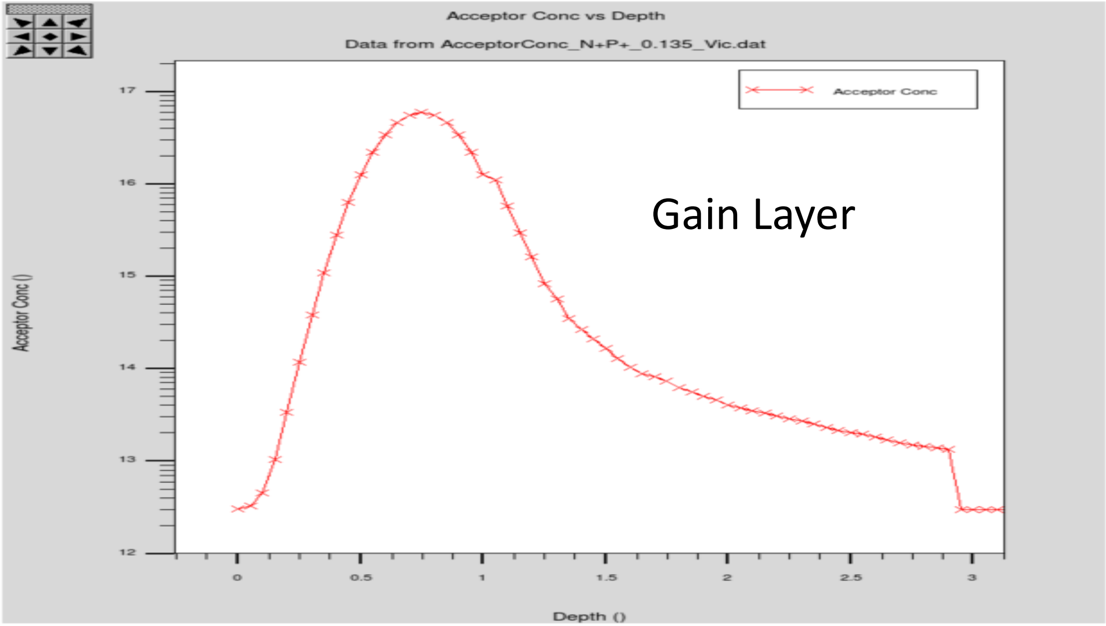
Simulation Framework

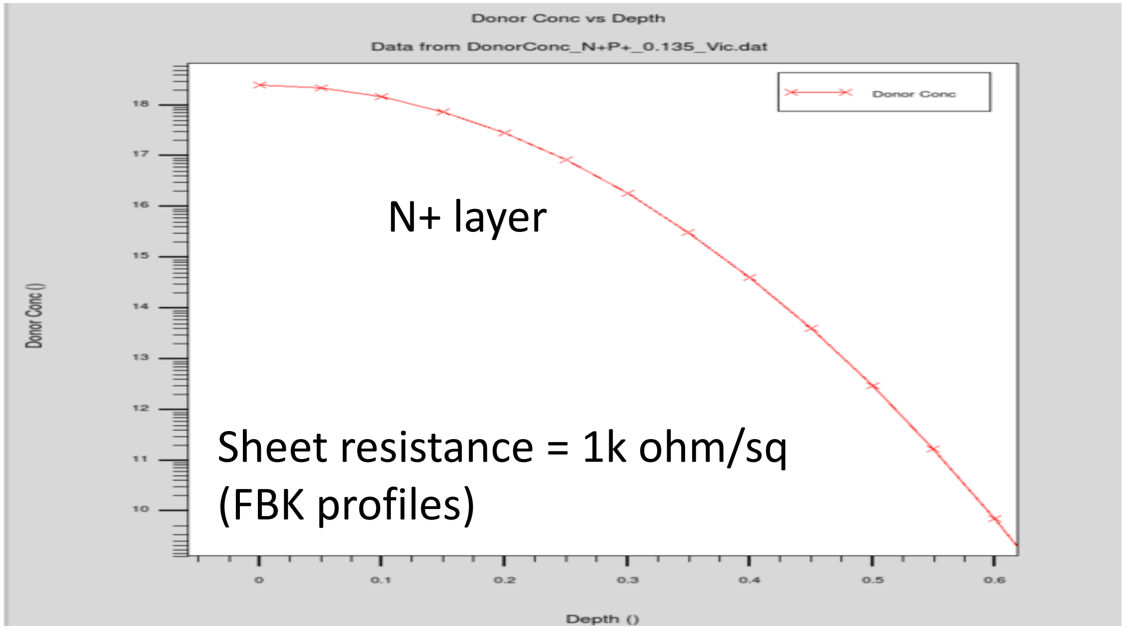
- 2D Silvaco© Victorydevice
- Impact Ionization = Grant (has a low-field, an intermediate-field, and a high-field region, there is no temperature dependence)
- Mobility Models:
  - Conmob (the concentration dependent mobility model)
  - Fldmob (the lateral electric field-dependent mobility model)
- Recombination model = Shockley – Read –Hall Recombination model (SRH)
  Method = Newton (Nonlinear solutions are obtained using the Newton method)
- Charge deposition (MIP) using singleeventupset method (80 e/h pairs per micron)
- X-mesh size = 5 um
- Y-mesh size= 0.01 um – 1.0 um

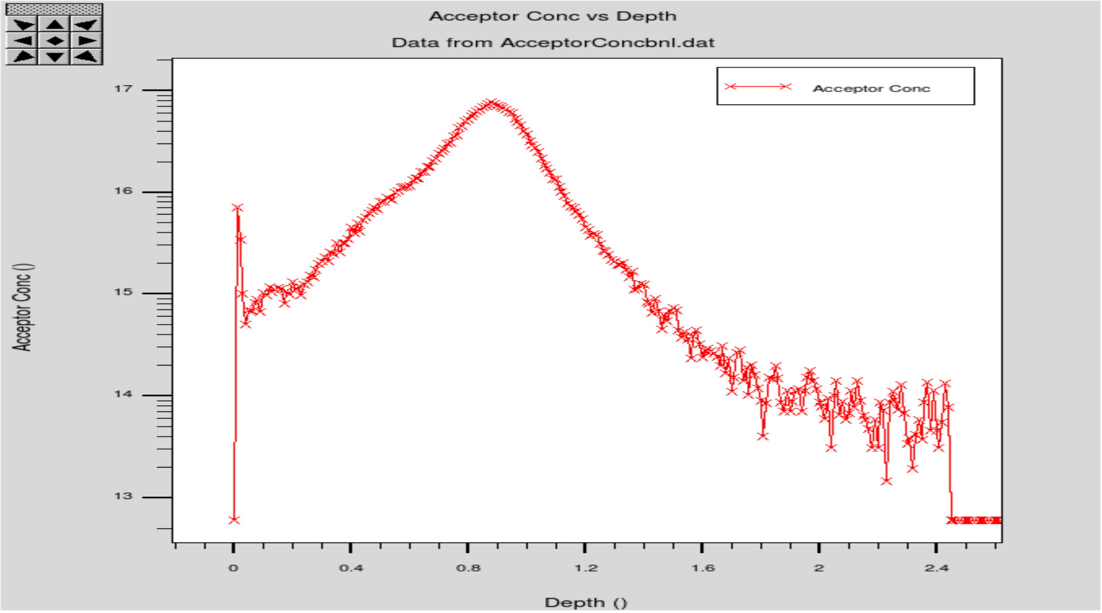
Simulated Device Parameters

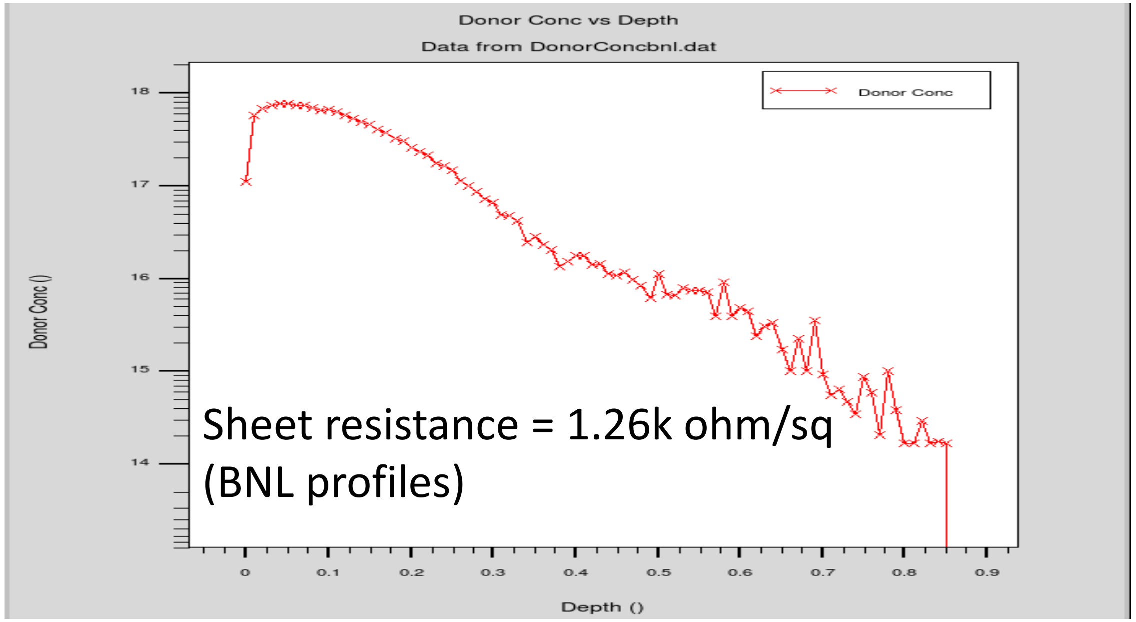
	Device 1	Device 2	Device 3
Pitch (um)	100	150	200
Metal size (um)	80	80	80
Channels	7	7	7
Oxide layer (nm)	20	20	20
Nitride layer (nm)	85	85	85
Bulk thickness (um)	50	50	50
Doping Profiles	FBK/BNL	FBK/BNL	FBK/BNL

Doping profiles (per cm^3): Gain Layer and the N+ layer (Bulk= 50um, metal = 80 um, Pitch = 200 um

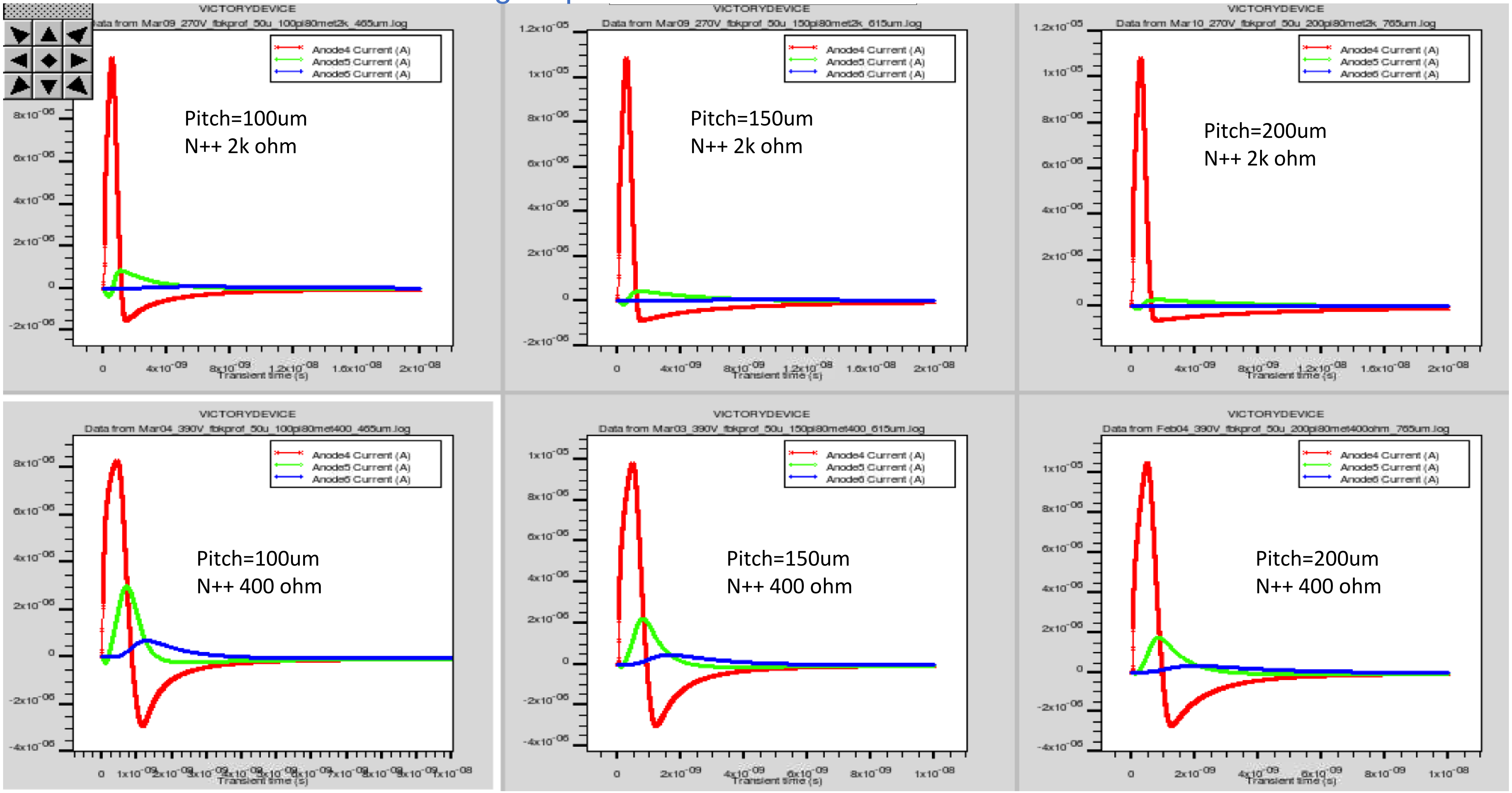




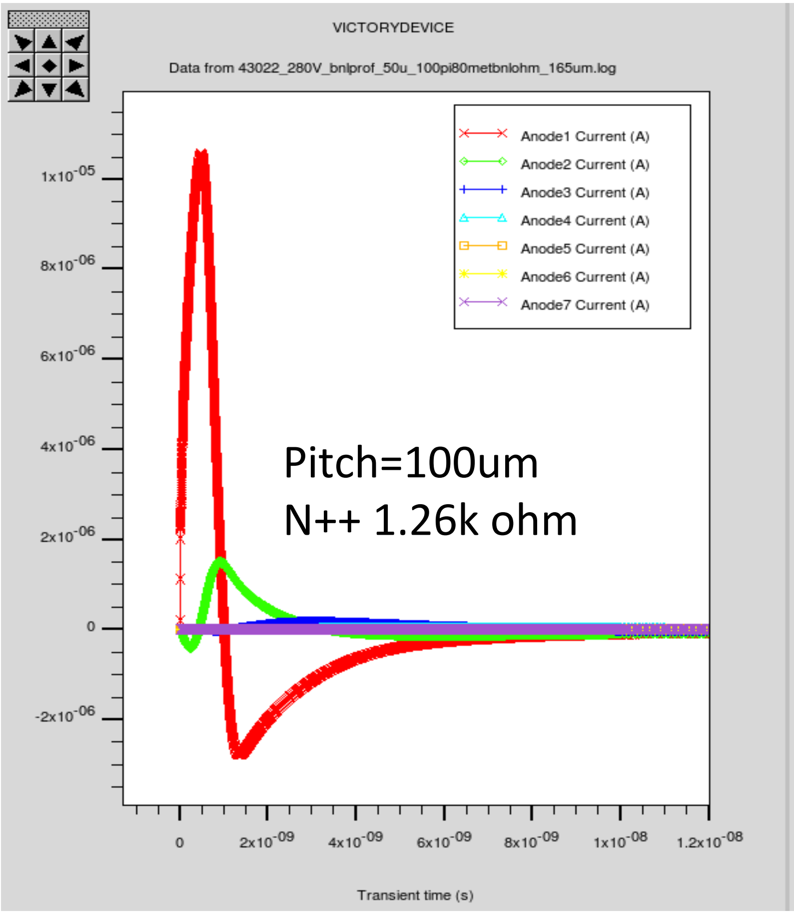


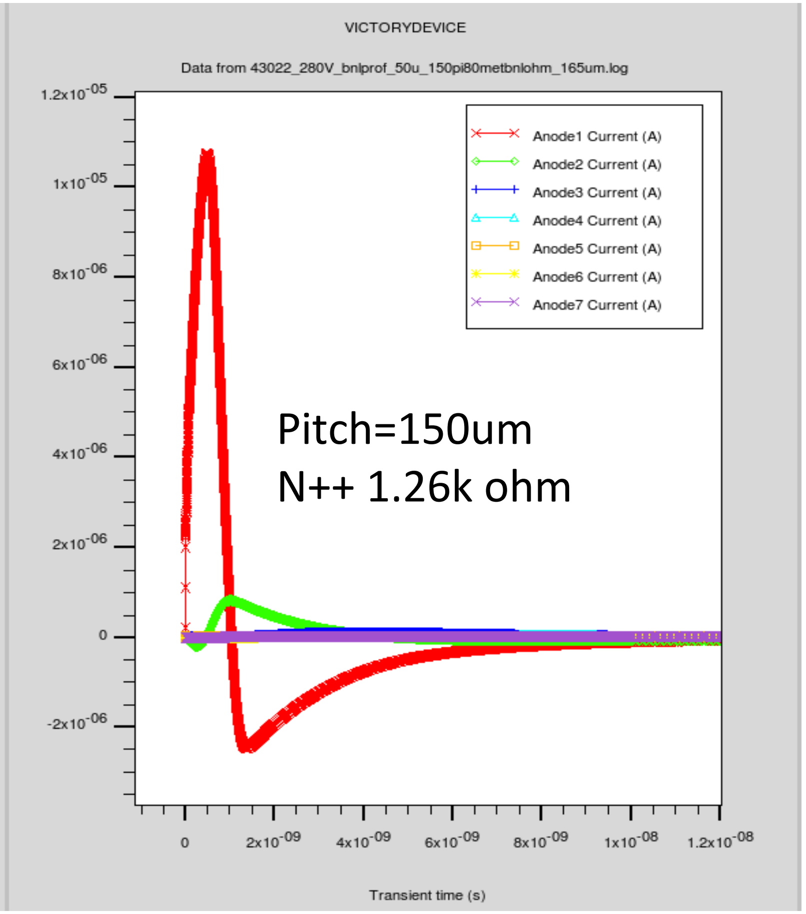


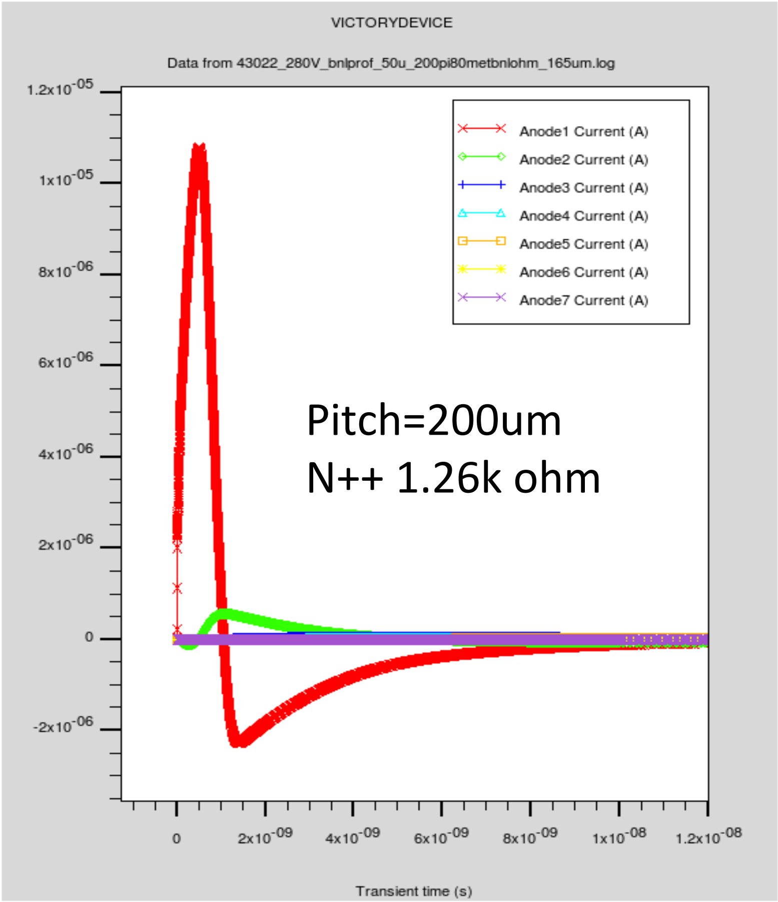
Simulated signal pulses: Bulk=50 um, Metal=80 um, FBK doping profiles



Simulated signal pulses: Bulk=50 um, Metal=80 um, BNL doping profiles

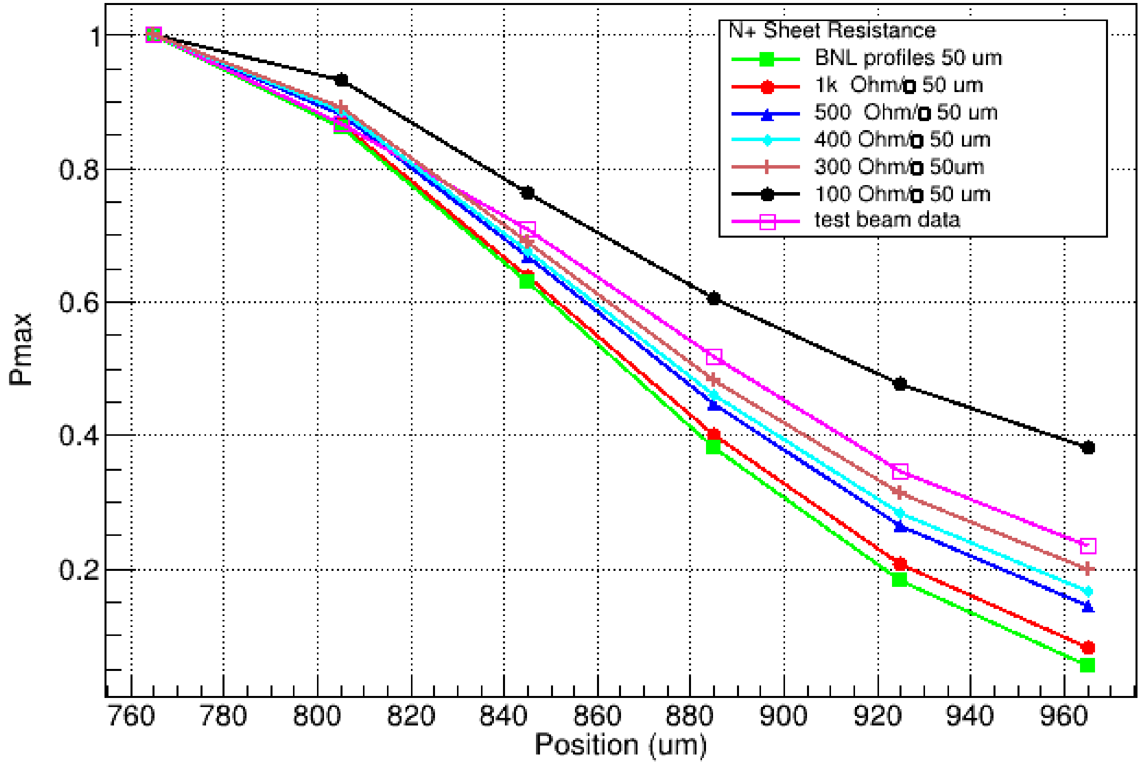






Comparison with the test beam data

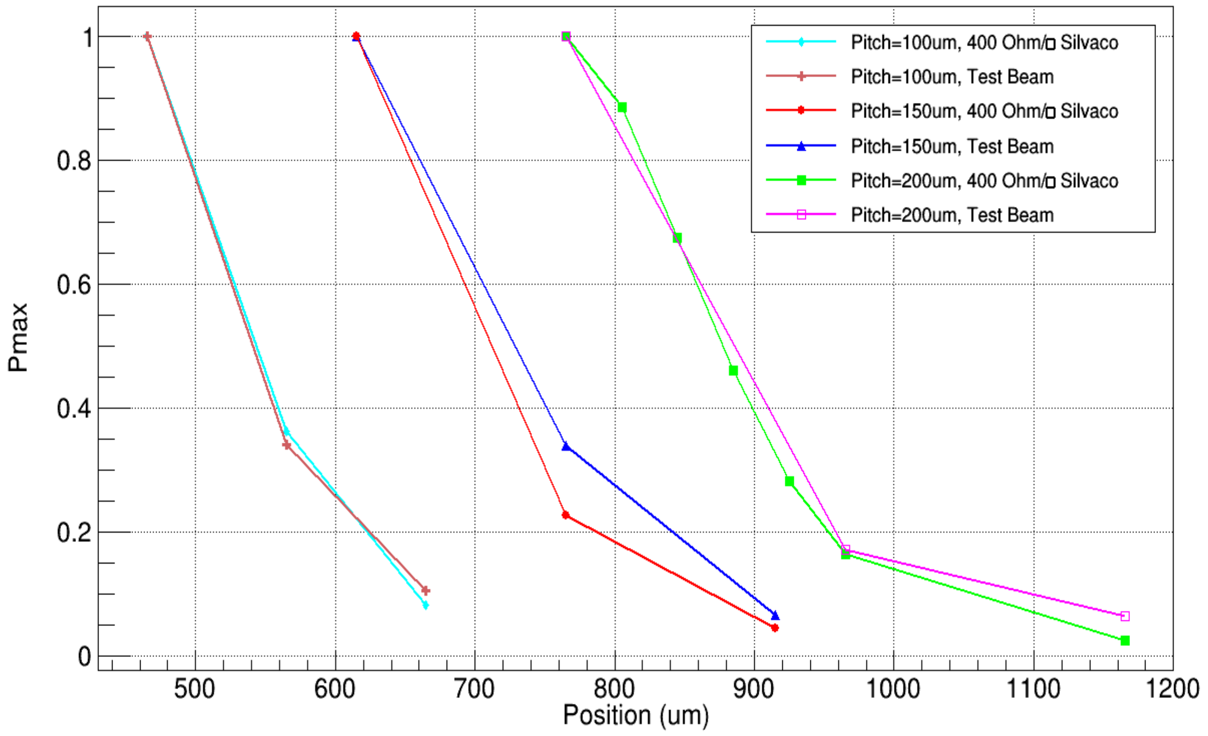
Bulk=50 um, Pitch=200 um Metal=80 um



Test Beam data analysis by Marcus Wong

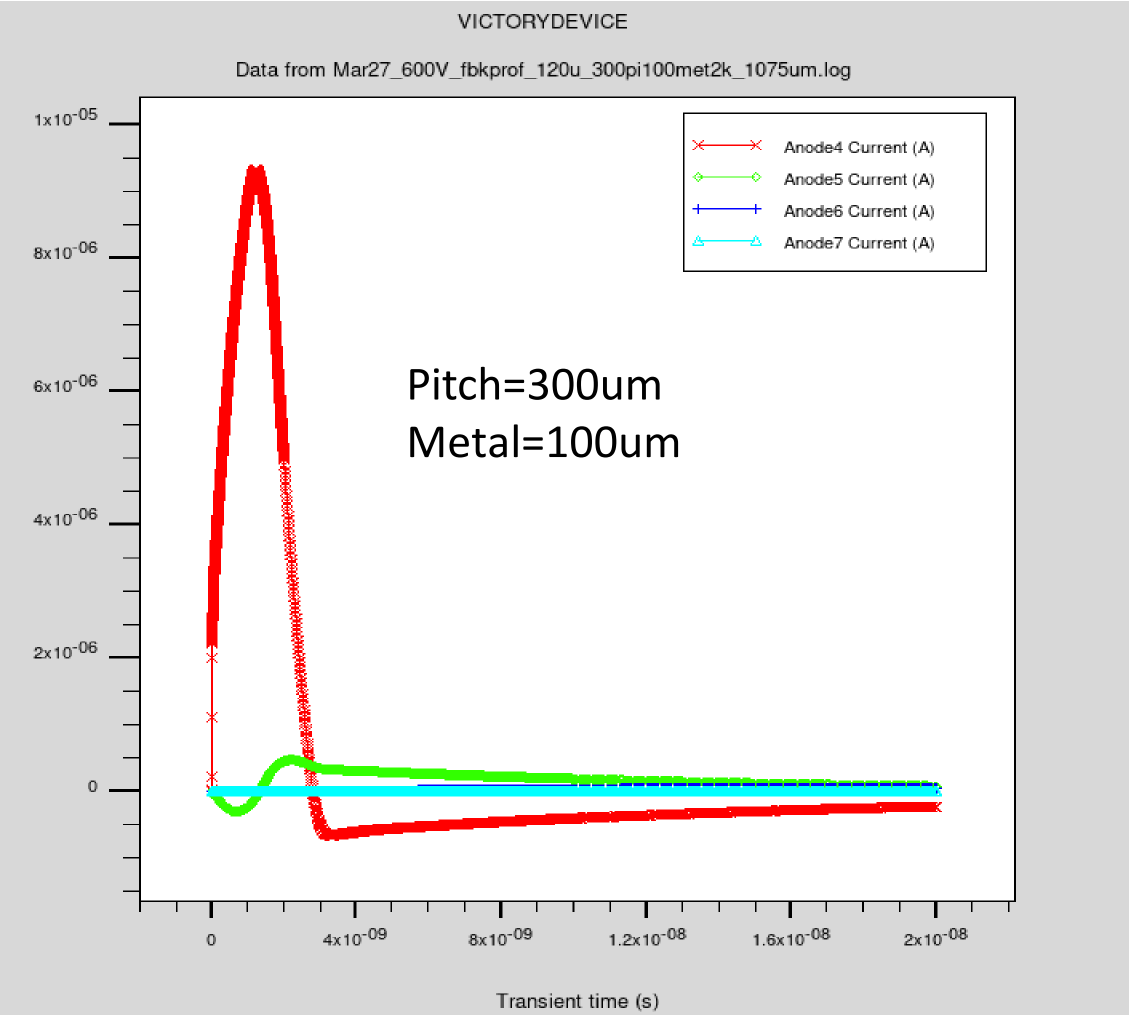
Pitch = 100um, 150um, 200um

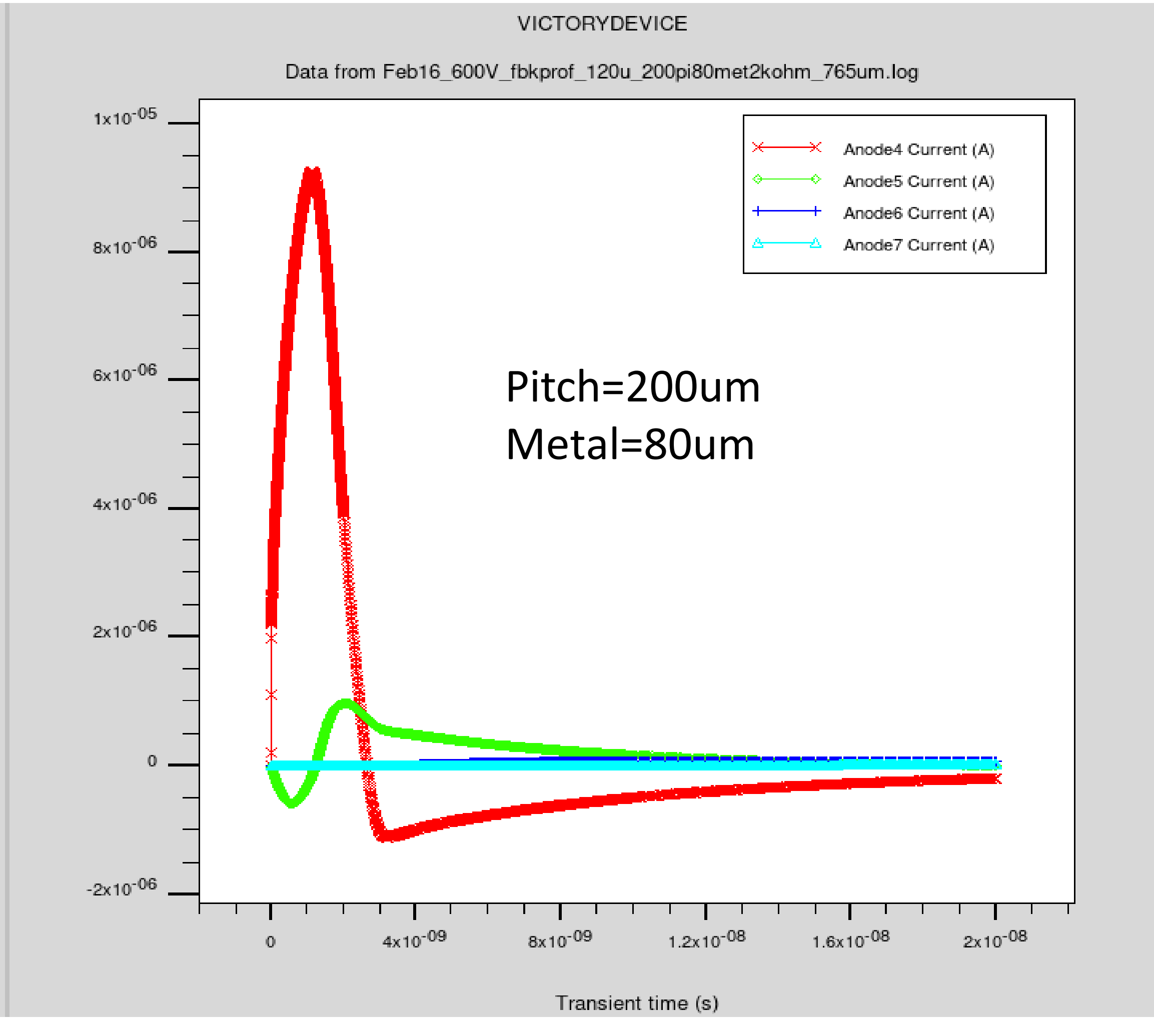
Bulk=50 um, Metal=80 um



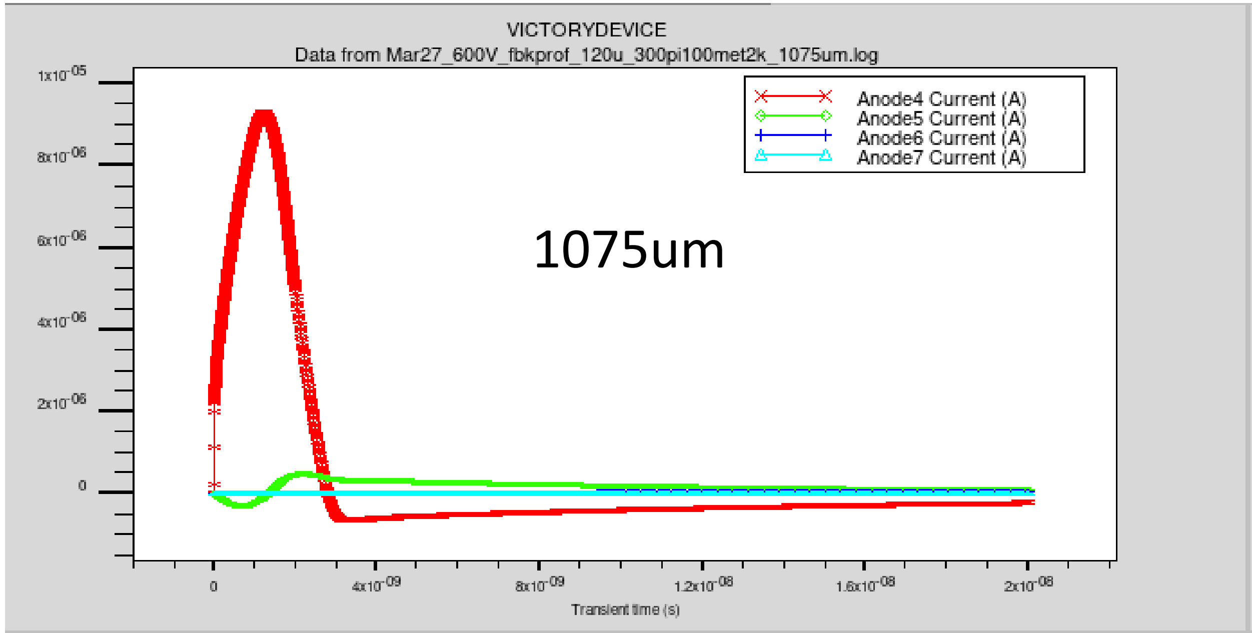
Test Beam data analysis by Jennifer Ott

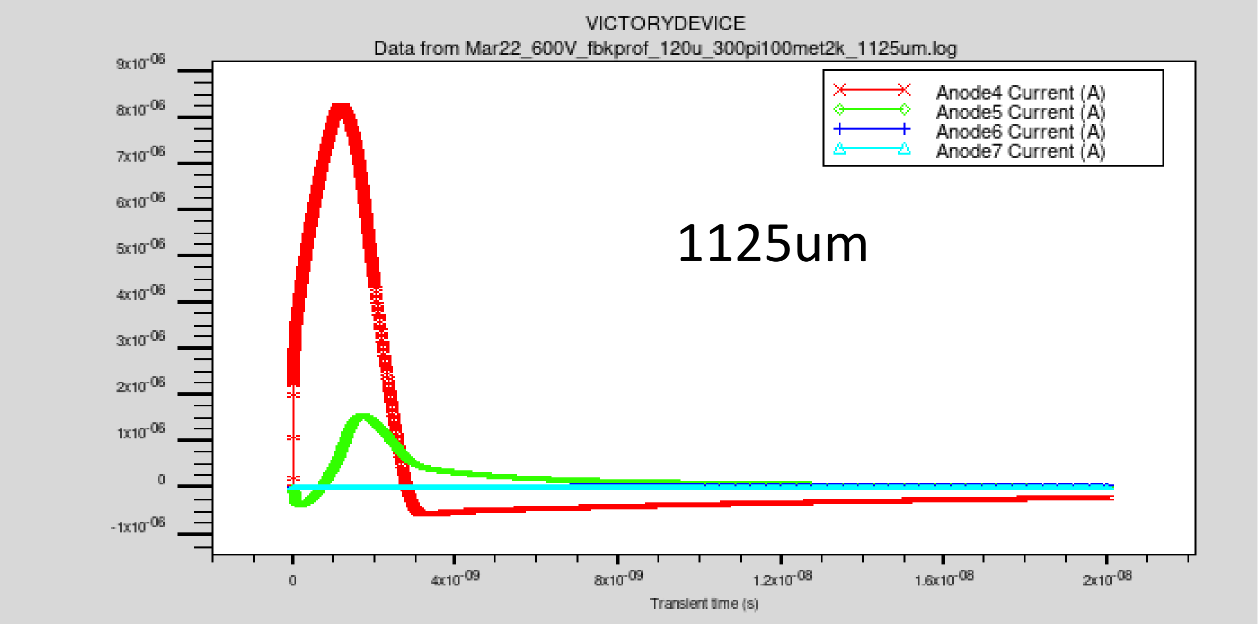
Simulation of 120um bulk sensor: N+ sheet resistance = 2k Ω/□

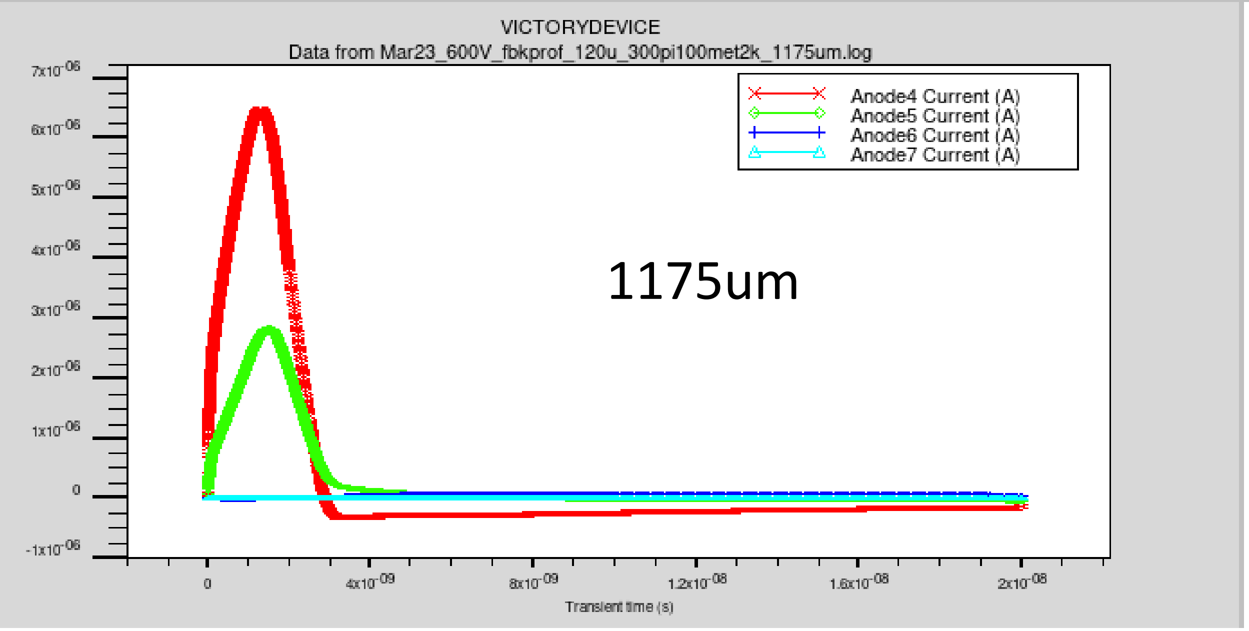


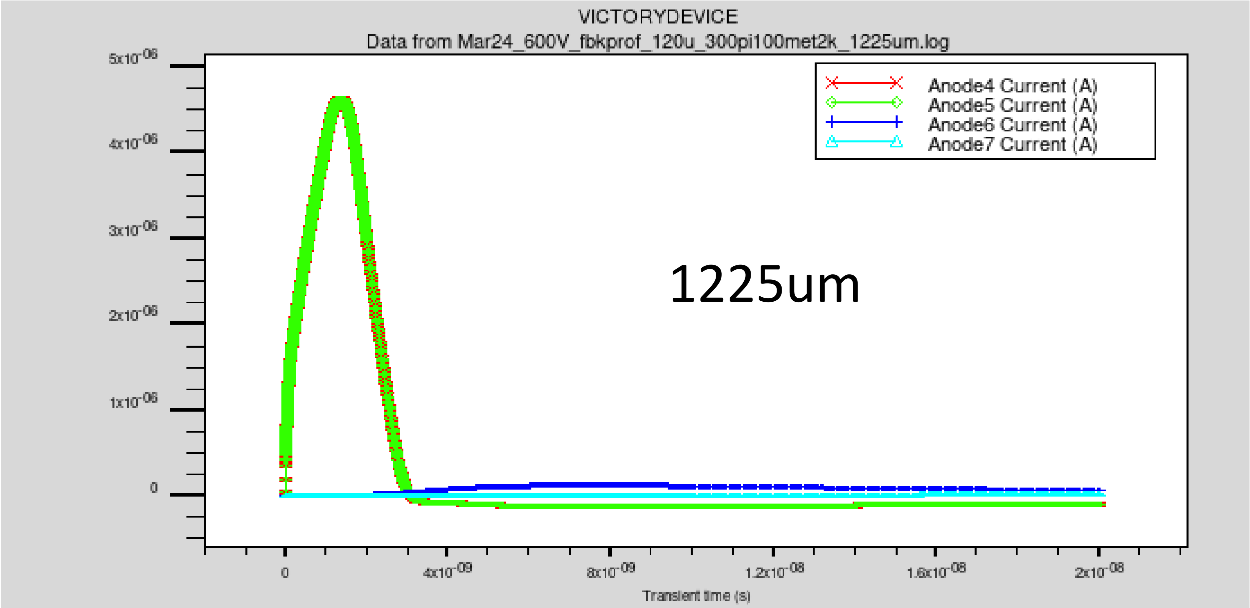


Bulk=120 um, Pitch=300 um, Metal=100 um, N++ 2k ohm









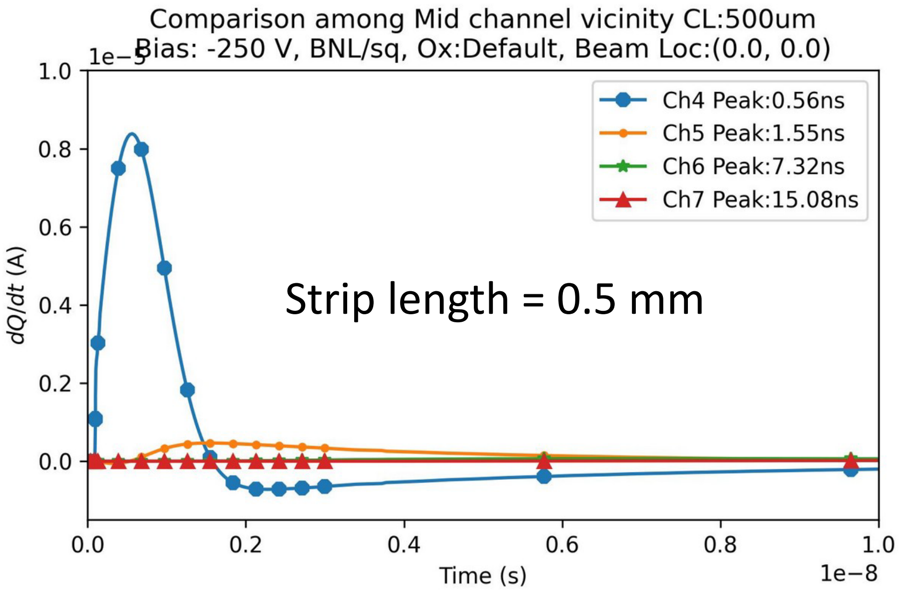
Sharing between the channels: 120um bulk, N+ sheet resistance = 2k Ω/□

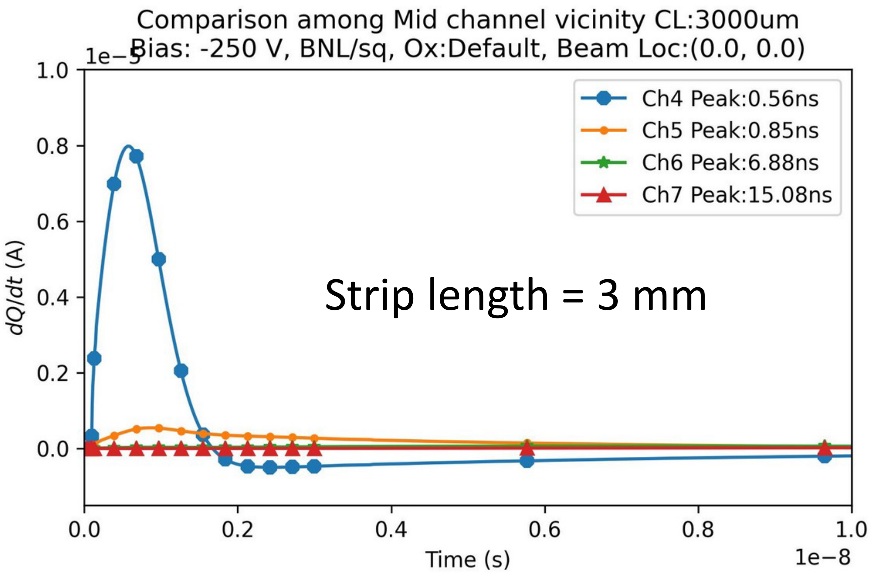
Pitch, metal,MIP LOC → Channel ratio ↓	300,100,ch4	200,80,ch4	300,100, mid ch4&ch5	200,80, mid ch4&ch5
Ch4/ch4	9.33E-06/9.33E-06=1	9.25E-06/9.25E-06=1	4.63E-06/4.63E-06=1	4.64E-06/4.64E-06=1
Ch5/ch4	4.66E-07/9.33E-06=0.05	9.75E-07/9.25E-06=0.11	4.62E-06/4.63E-06=0.99	4.64E-06/4.64E-06=1
Ch6/ch4	4.01E-08/9.33E-06=0.004	7.84E-08/9.25E-06=0.008	1.23E-07/4.63E-06=0.026	2.26E-07/4.64E-06=0.05
Ch7/ch4			1.67E-08/4.63E-06=0.0036	3.59E-08/4.64E-06=0.0077

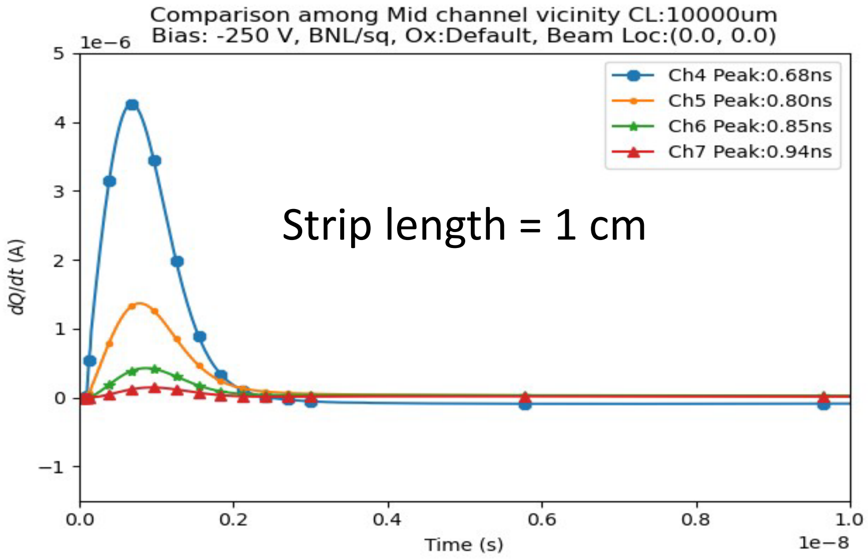
3D Simulation
@ Synopsis Sentaurus™

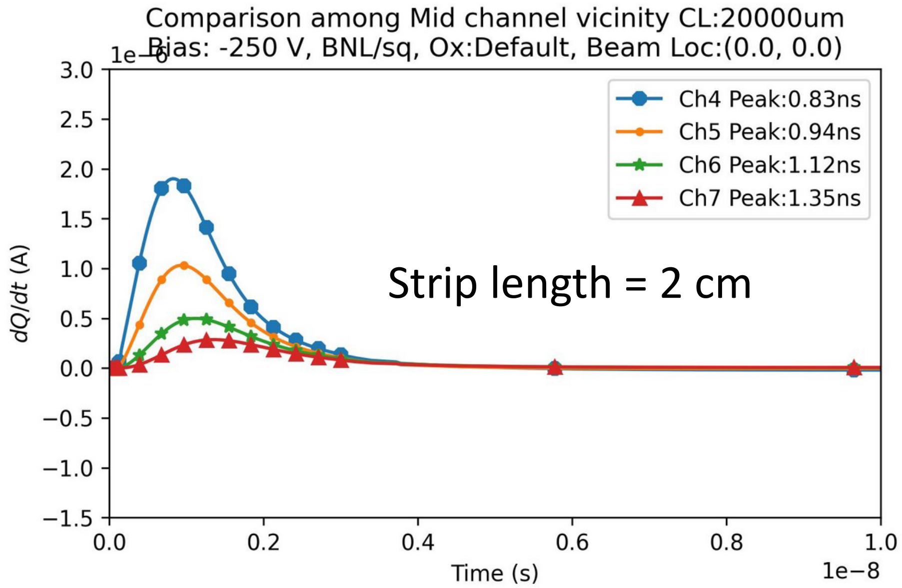
--Taylor Shin

Effect of strip length on signal sharing between the neighbouring channels



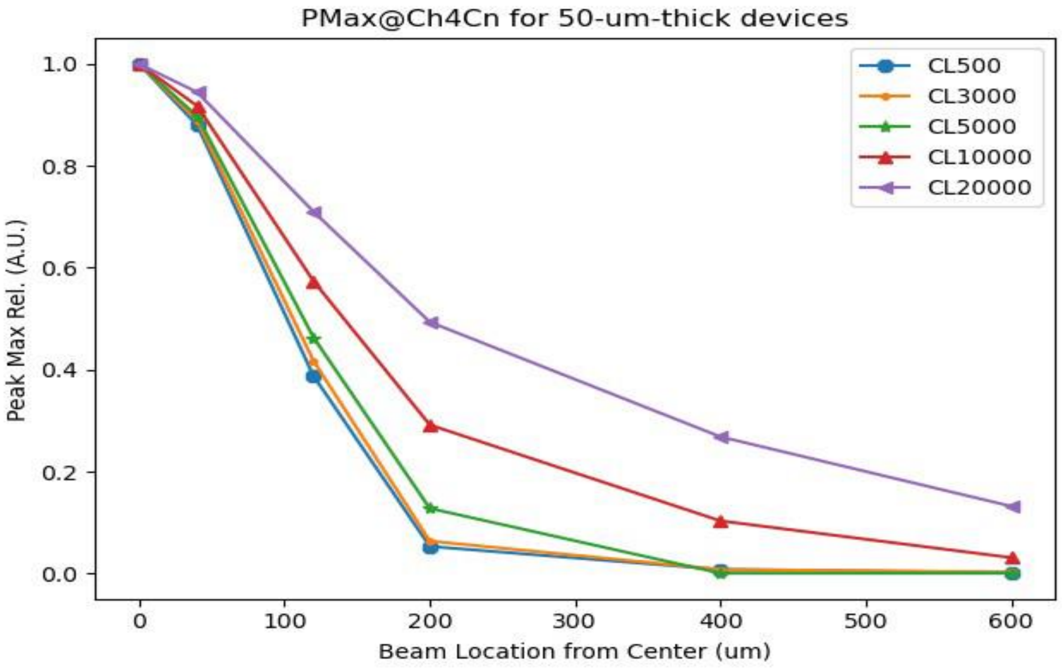


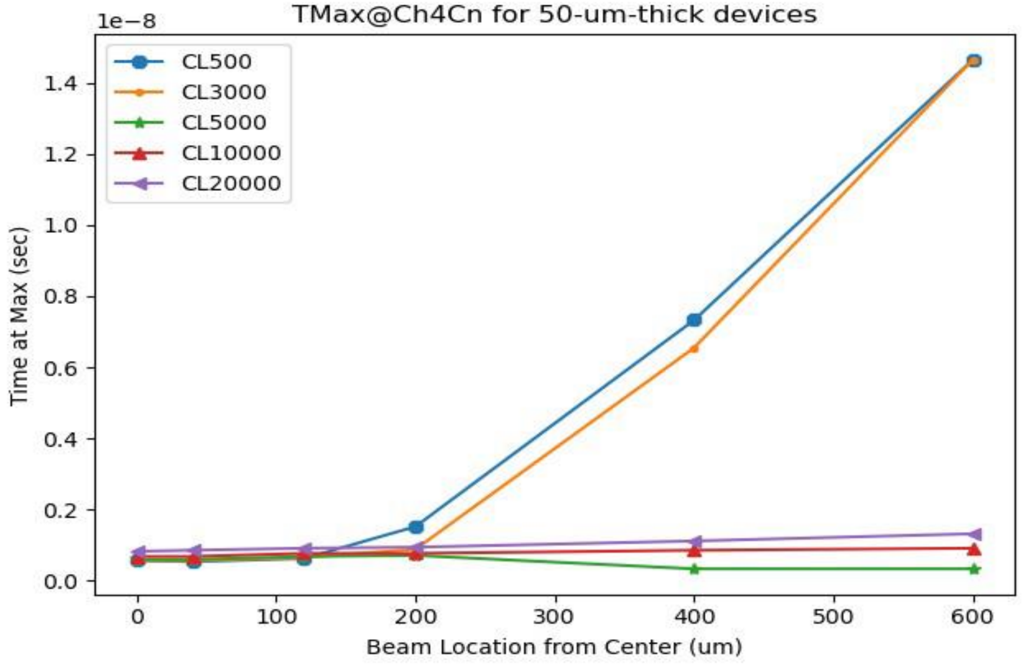




--Taylor Shin

Effect of strip length on signal sharing between the neighbouring channels





--Taylor Shin

Gain Suppression Study
@ Synopsis Sentaurus™

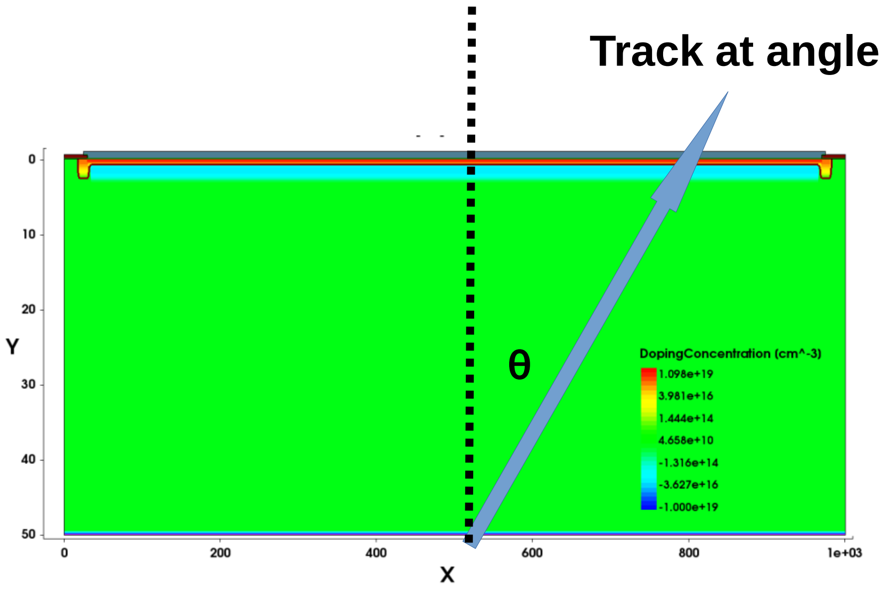
--Yuzhan Zhao

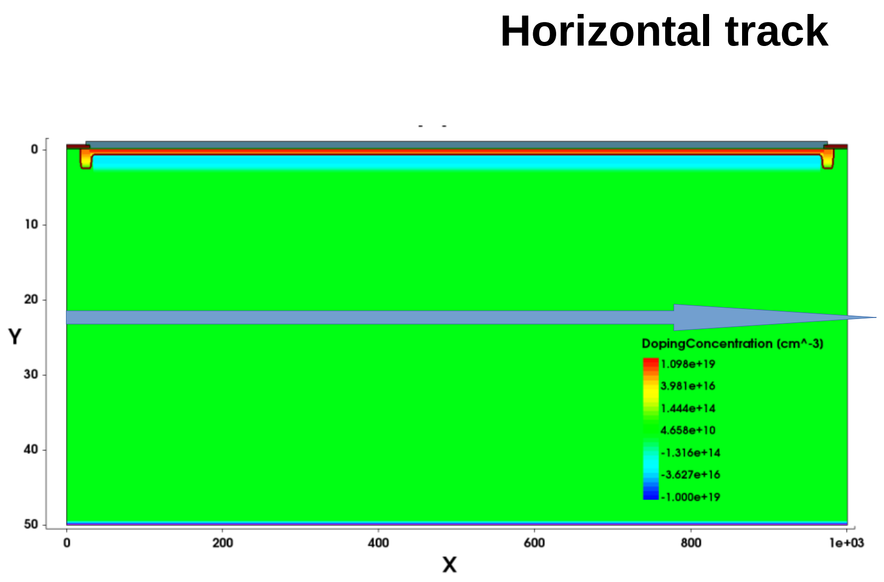
Simulation Setup

For ion track injection, the following scans were simulated:

– Scan over different angles

– Complete horizontal track





--Yuzhan Zhao

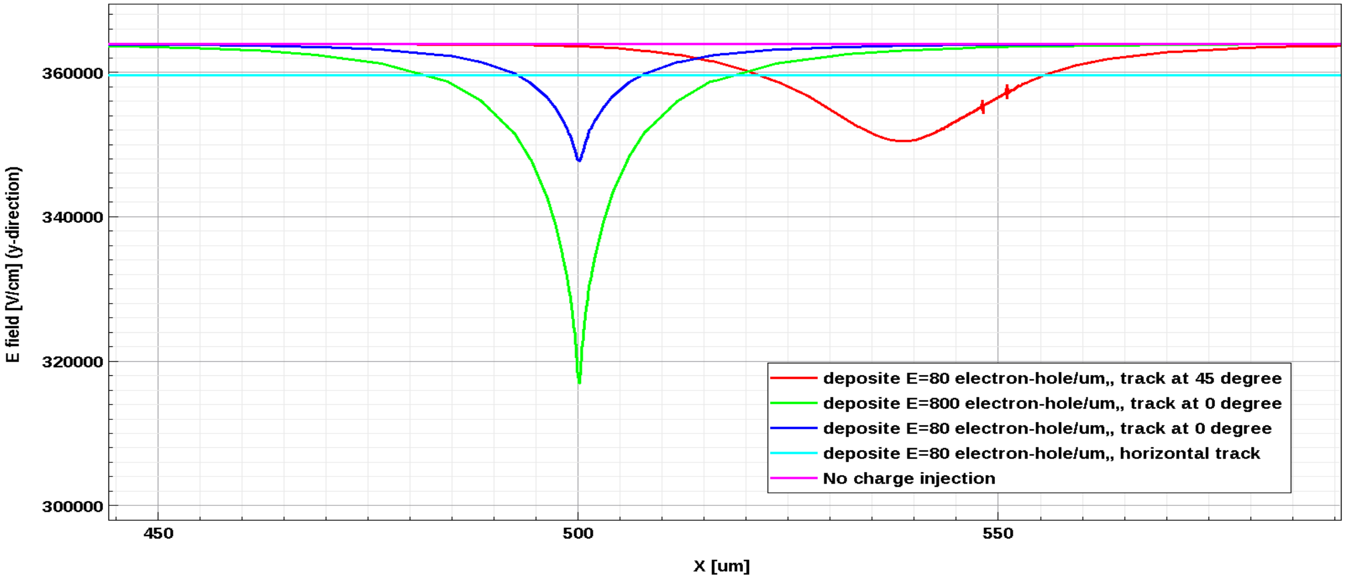
Electric Field within the Gain Layer

- Since the gain, or avalanche mechanism, depends on the high electric field in the gain layer region, it would be interesting to study the E-field for various tracks.
- The following plot show the time snapshot of the E-field within the gain layer.

– The E-field decreases as more charges were put in, and the affected location is large for track at angle.

– In the case of horizontal track, the field is generally lower across the entire gain layer.

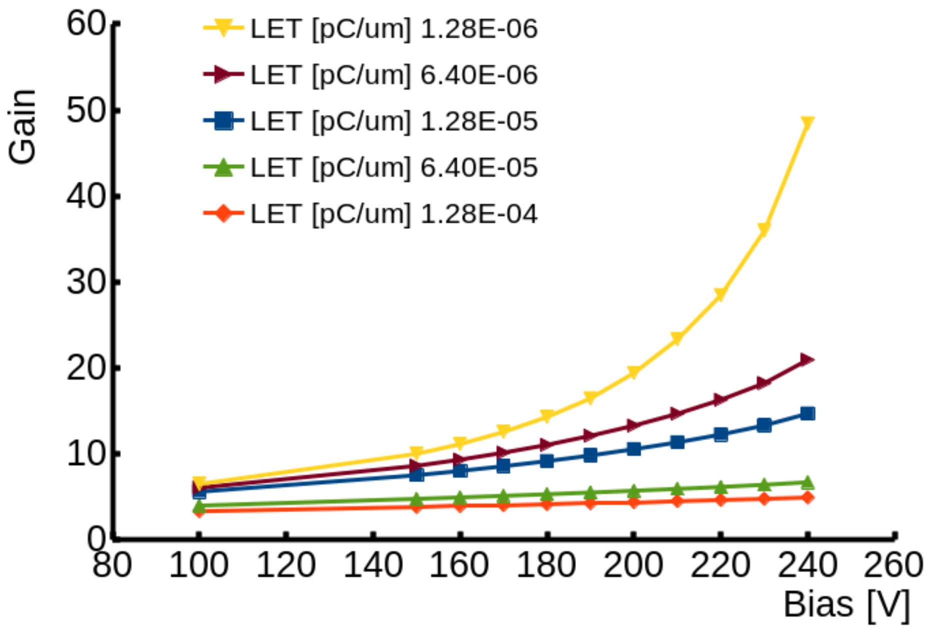
- NOTE: this process is dynamic, which is not covered in the single time snapshot.

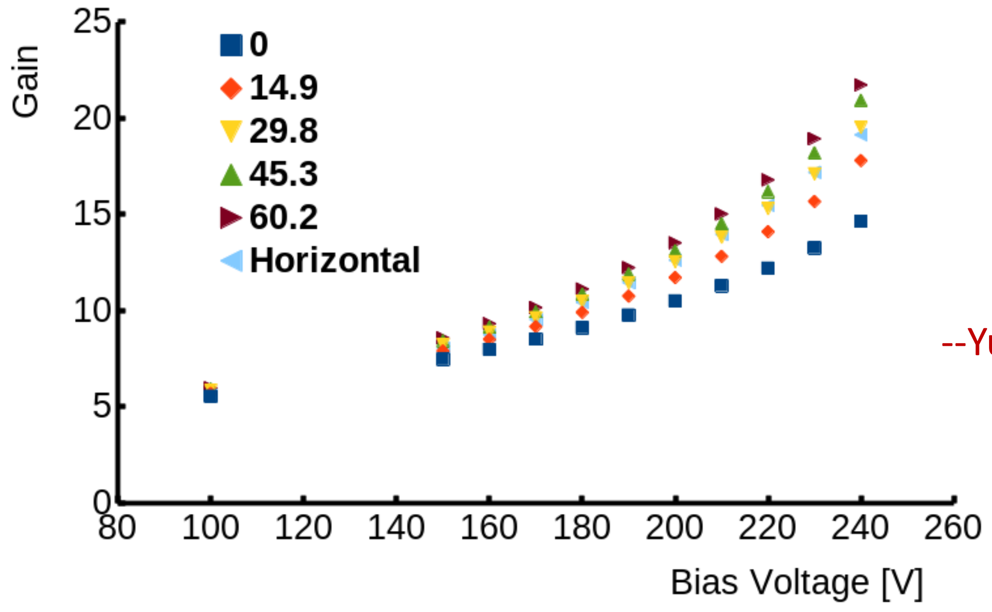


--Yuzhan Zhao

Particle Injection with different energies and at different angles

- **One of the tunable parameters of the partcle track is the Linear energy transfer (LET)**
  - For LET=1.28e-5 pC/um, which corresponds to generated ~80 eh/um
- **The following plot shows for vertical track injection (0 degree), the gain is reduced as more charge is injected.**
  - The difference is more significant at high bias voltage.

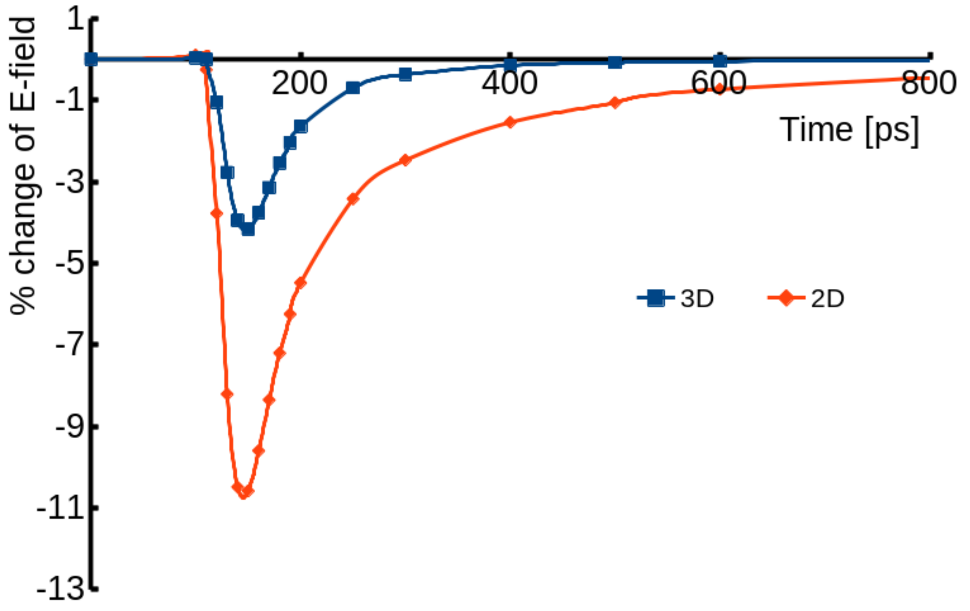


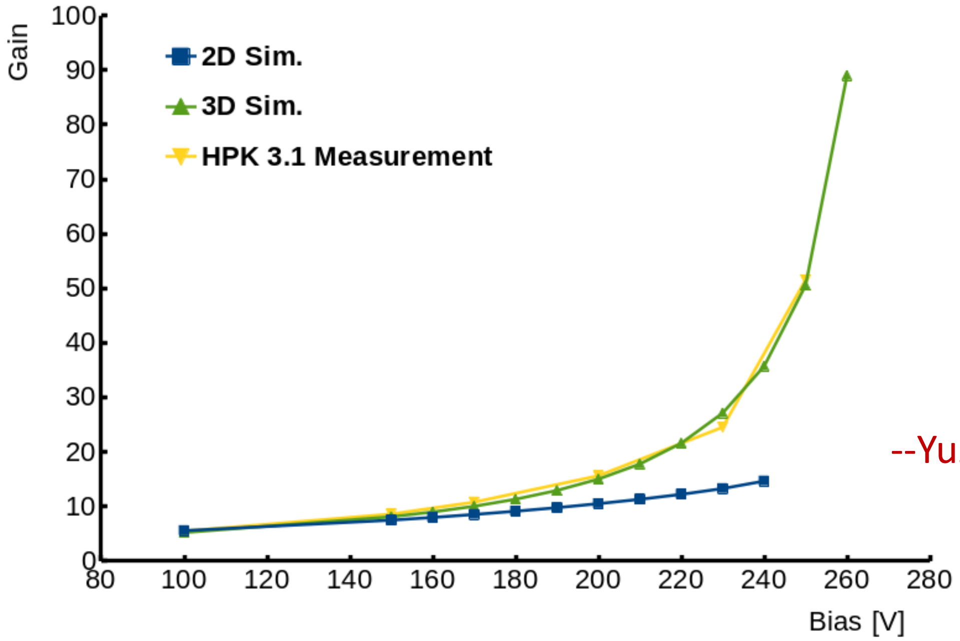


--Yuzhan Zhao

3D simulation for localized charge

- Device size : 250 um x 250um x 50um
- The change of E-field is much smaller for 3D case??



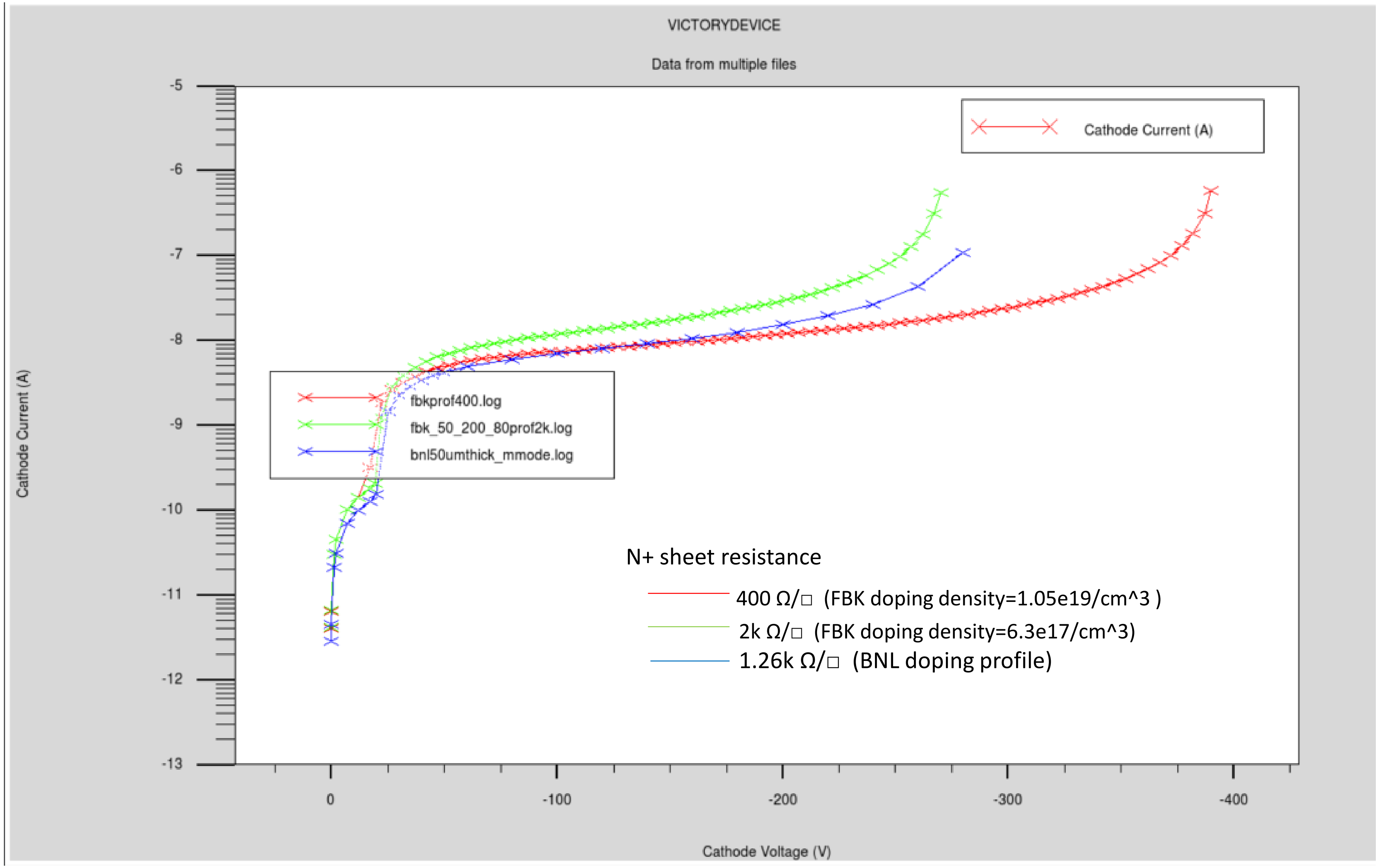


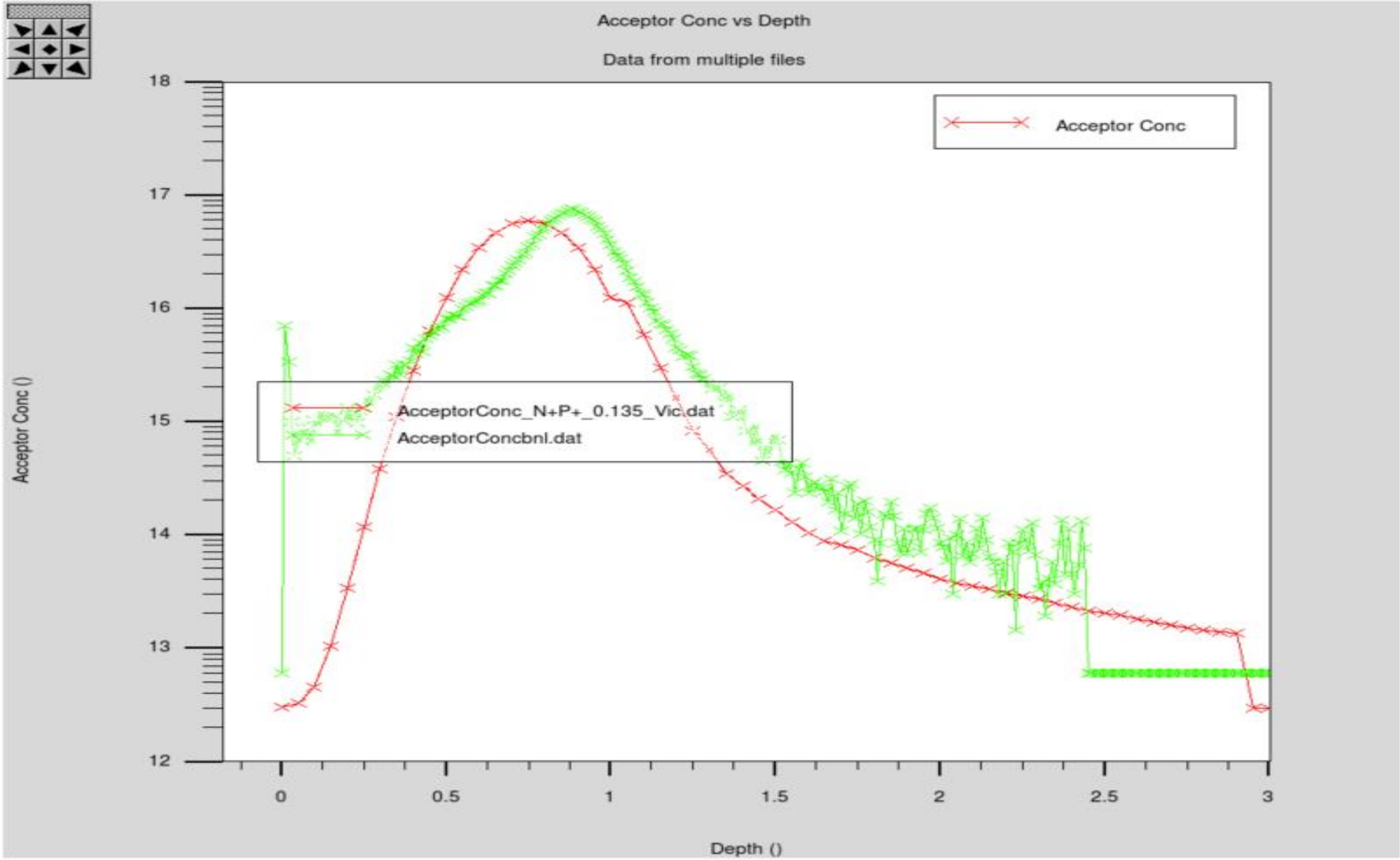
--Yuzhan Zhao

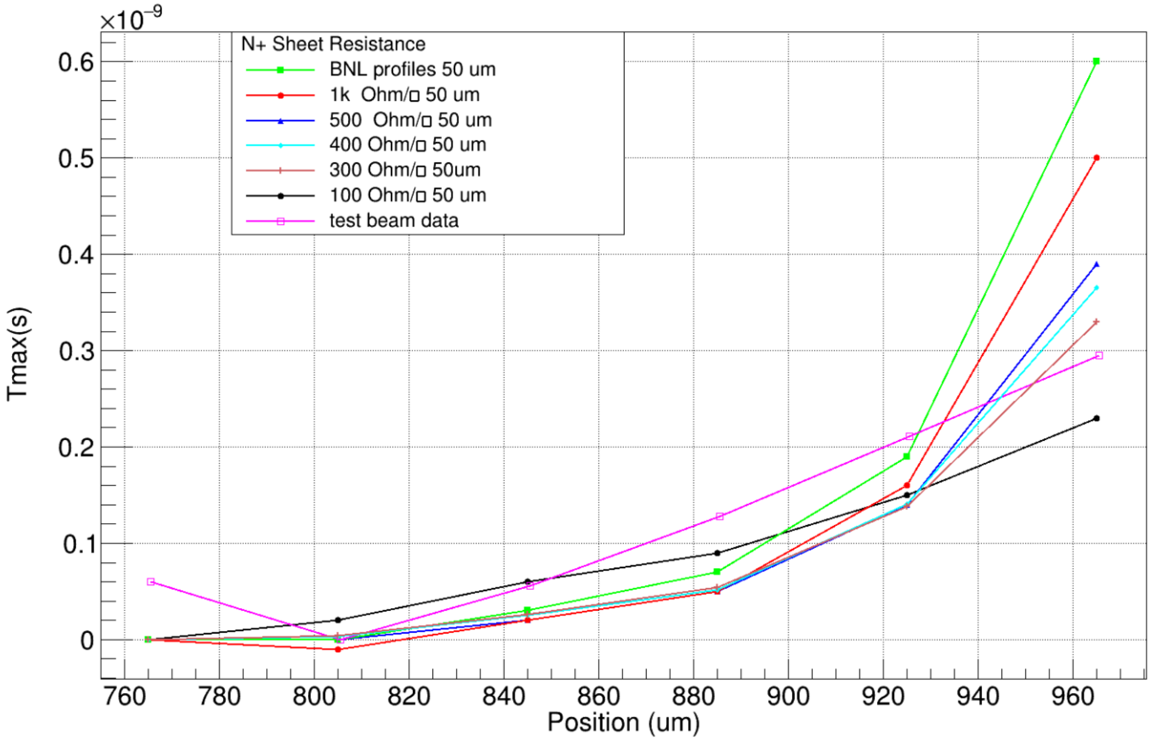
Summary

- In 2D TCAD simulation, we have characterized effects of N+ resistivity, strip metal size a, pitch size and substrate thickness.
- Sharing between the neighbouring channels depends on N+ resistivity, pitch size and the bulk thickness.
- 3D TCAD simulation gives more realistic results in terms of strip length, but we have benchmark it with the existing test beam results (by Taylor Shin)
- It seems Sentaurus can simulate the gain suppression and the work is in progress (by Yuzhan Zhao)

IV characteristics




Acceptor Conc vs Depth
Data from multiple files
Acceptor Conc
AcceptorConc_N+P+_0.135_Vic.dat
AcceptorConcbnl.dat
Acceptor Conc ()
Depth ()
18
17
16
15
14
13
12
0
0.5
1
1.5
2
2.5
3


×10^-9
N+ Sheet Resistance
BNL profiles 50 um
1k Ohm/□ 50 um
500 Ohm/□ 50 um
400 Ohm/□ 50 um
300 Ohm/□ 50um
100 Ohm/□ 50 um
test beam data
Tmax(s)
0.6
0.5
0.4
0.3
0.2
0.1
0
760
780
800
820
840
860
880
900
920
940
960
Position (um)

Sharing between the channels

120um bulk, N+ sheet resistance = 2k Ω/□