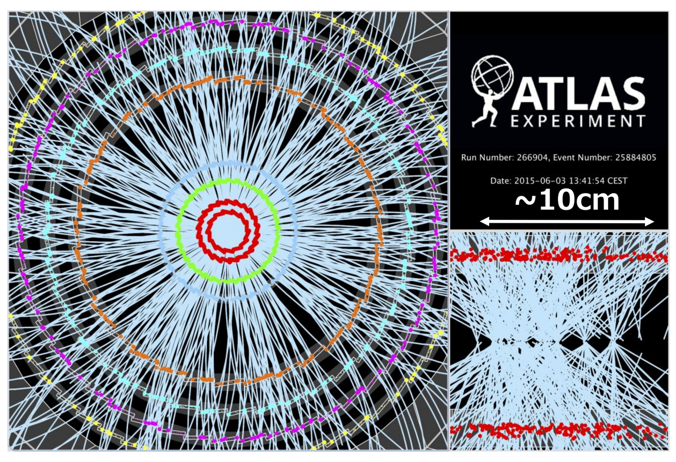
Design of a Segmented LGAD Sensor for Development of 4-D Tracking Detector

筑波大学 宇宙史研究センター Tomonaga Center for the History of the Universe

KEK

University of Tsukuba WADA Sayaka, ONARU Kyoji, HARA Kazuhiko, KEK-INPS UNNO Yoshinobu, NAKAMURA Koji

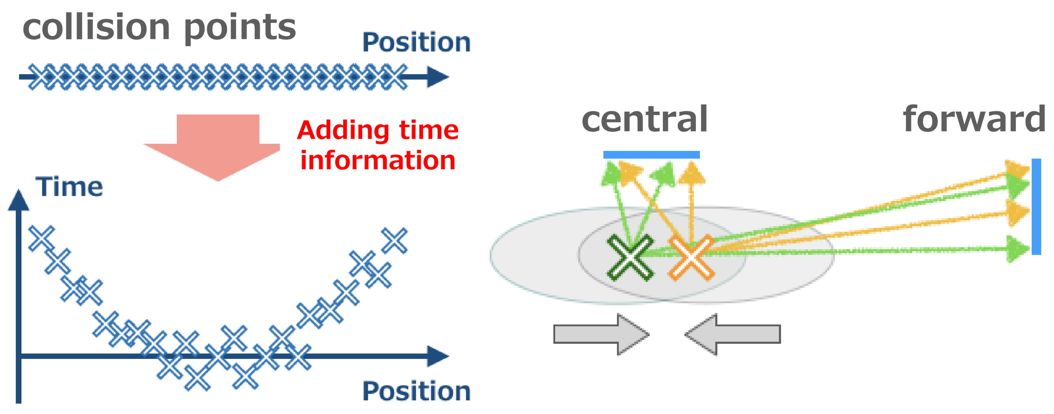
4D Tracker

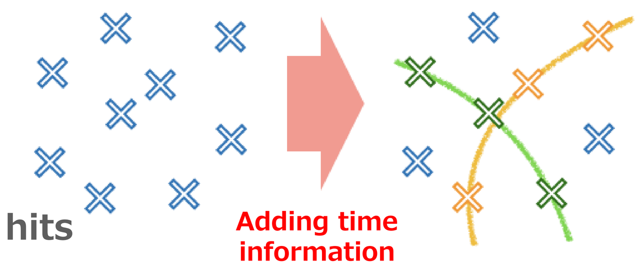


Tracks reconstructed by ATLAS (event with 17 interactions)
➡ Expect 200/crossing at HL-LHC

- Should we add time information to the hits,
  - Identify vertices otherwise difficult using position information only
  - Effective in forward regions where vertexing precision is limited

(Δt=10ps ⇄ Δz=3mm)





- Should we add time information to each hit,
  - Reconstruct tracks using proper time differences
  - Help reduce wrong hit combinations and effective in reducing the track reconstruction CPU

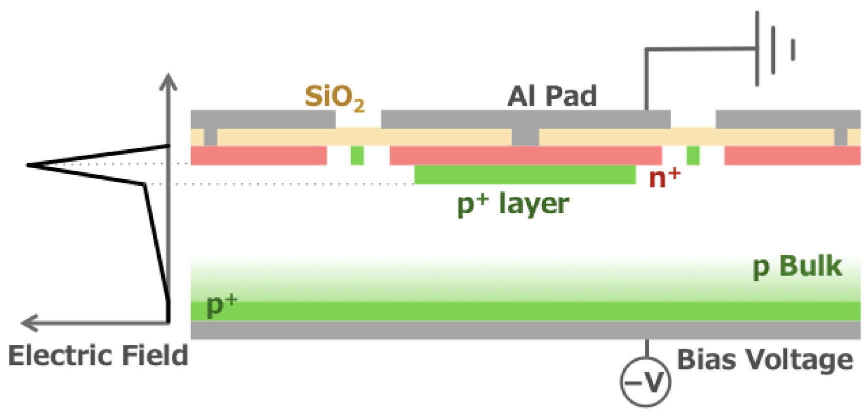
→ **Innovation in tracking**

Low-Gain Avalanche Detector (LGAD)

Add p⁺ layer underneath the n⁺ readout electrode
High E-field induces avalanche multiplication

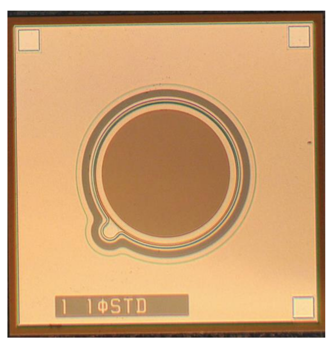
- thin (50µm) substrate is effective for signal creation
- short charge collection time with fast signal shape

→ **good time resolution O(10ps)**



with superior position resolution **O(10µm) achievable** with semiconductor, LGAD is a good candidate for realizing 4-D tracker.

HPK LGAD samples



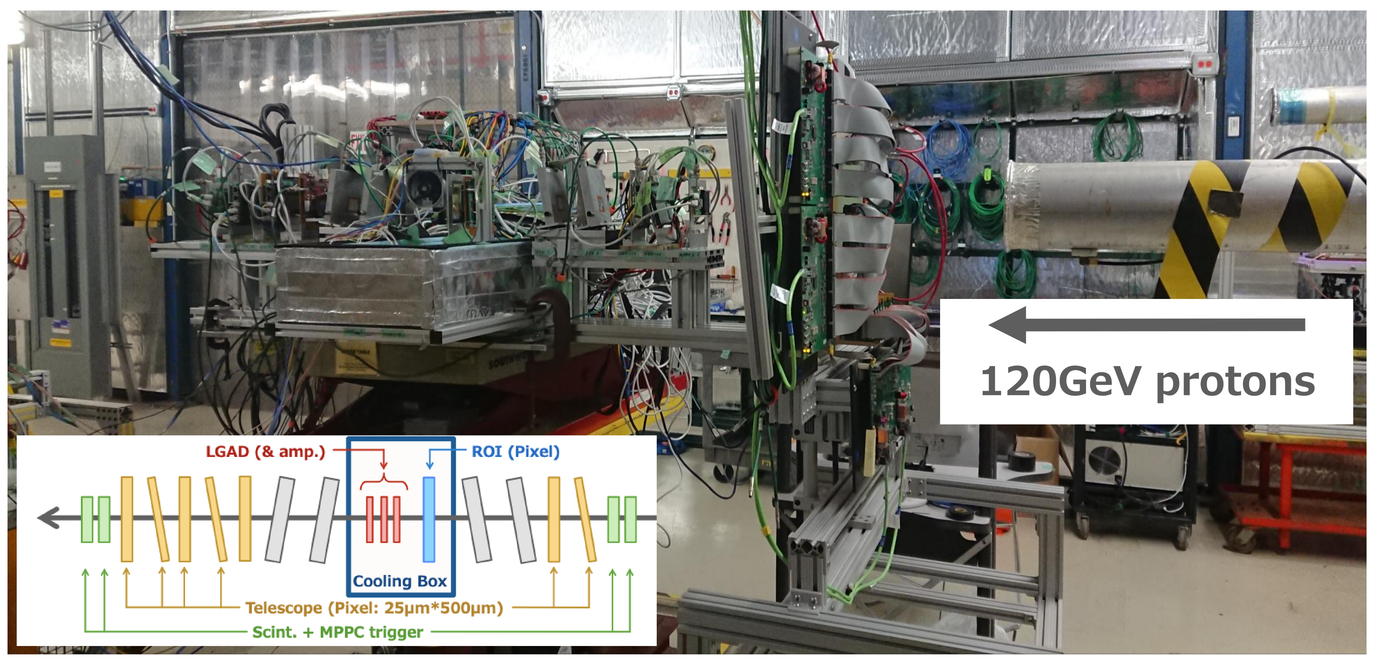
Pad type window : 1mmD

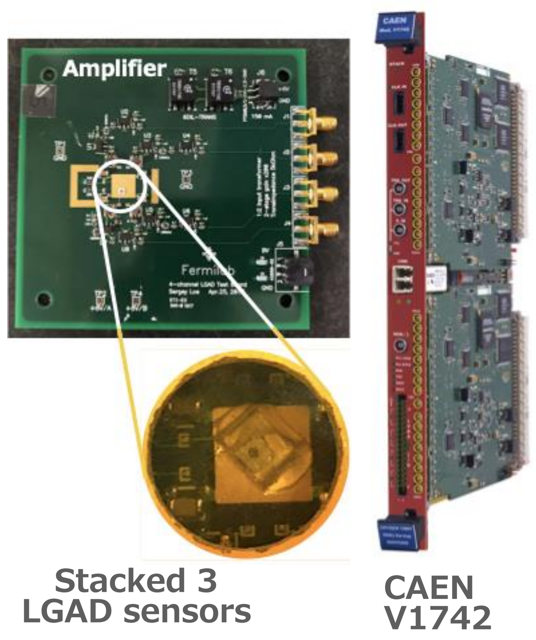
Strip type strip pitch : 80µm

Active thickness : 50 or 80µm (150µm physical)
p⁺ layer concentration : 4 steps (A<B<C<D)

Evaluation of Timing Precision in High-Energy Beam

Feb 20-Mar 4, 2018 @FNAL FTBF

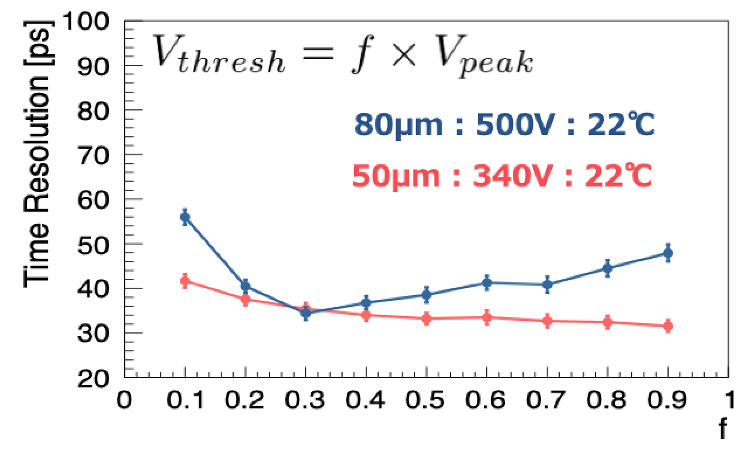


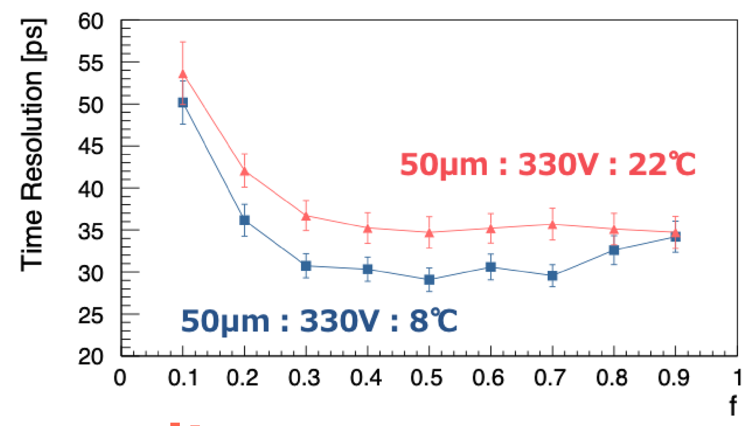


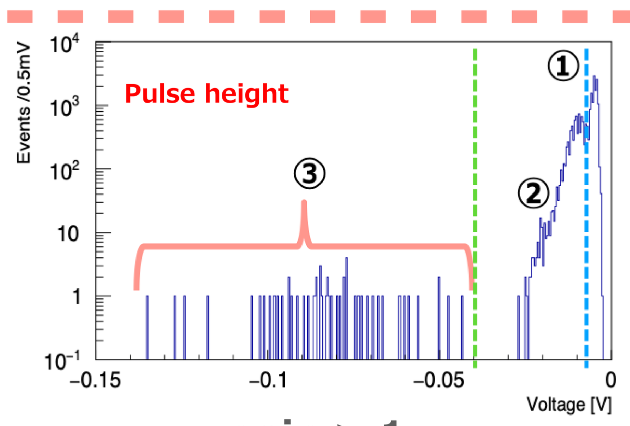
Signal readout

LGAD signal is amplified (using high-speed amps) and digitized using DRS4 flash ADCs (5GS/s)

- Pulse height : 12bit, 1Vpp (1V/4096 ~ 0.25mV)
- Time bins : 10bit, 5GS/s (200ps*1024~200ns F.S.)

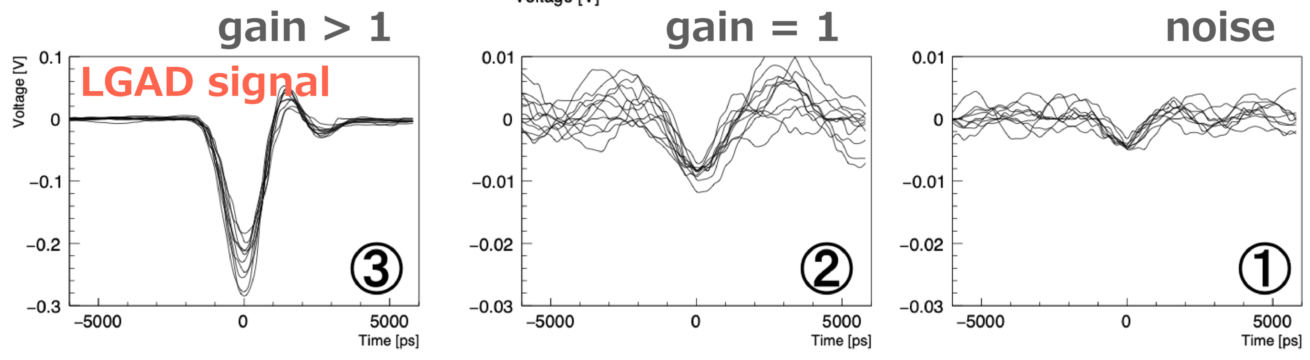




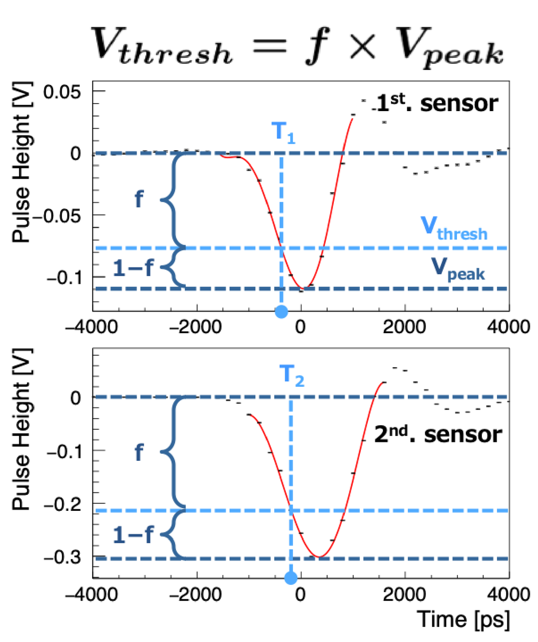


① noise only
② beam hit the gain=1 region
③ beam hit the LGAD region

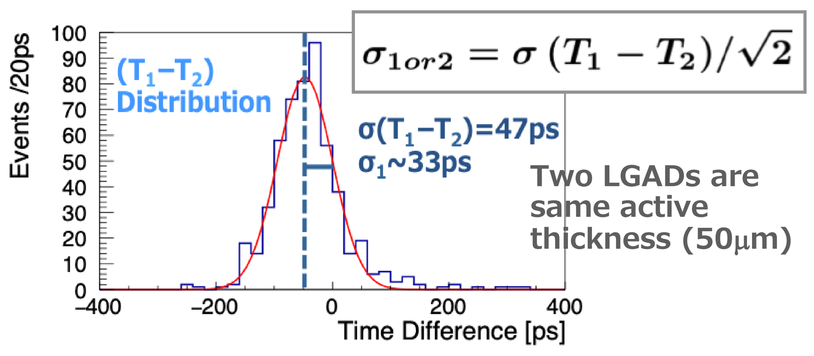
③ → timing resolution evaluated



evaluation



Flash ADC data are fitted to a polynomial function to extract the time when the signal exceeds $f\times$(signal peak), where f is an arbitral coefficient.
Extract the timing resolution from the measured time differences for the two sensors.



results

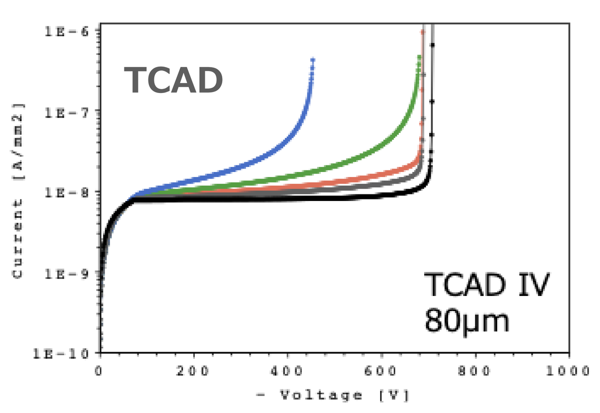
Better timing precision achieved

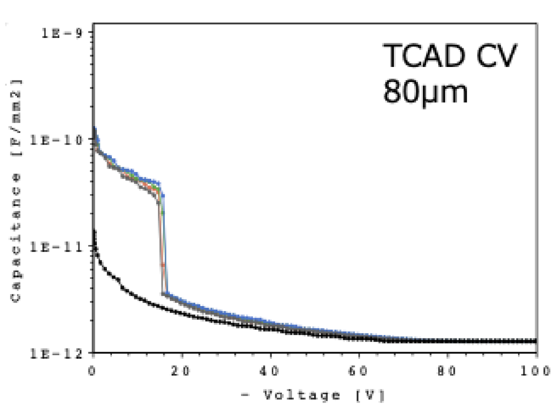
- for thinner active thickness
  - 50µm : ~30ps @340V (f=0.9)
  - 80µm : ~40ps @500V (f=0.3)
- at lower temperature
  - 22℃ : ~35ps @330V (f=0.5)
  - 8℃ : ~28ps @330V (f=0.5)

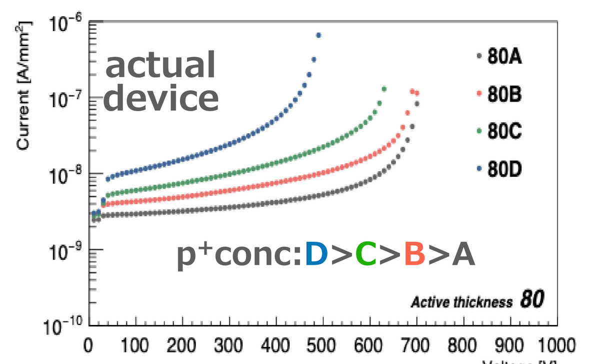
as expected for higher LGAD gain

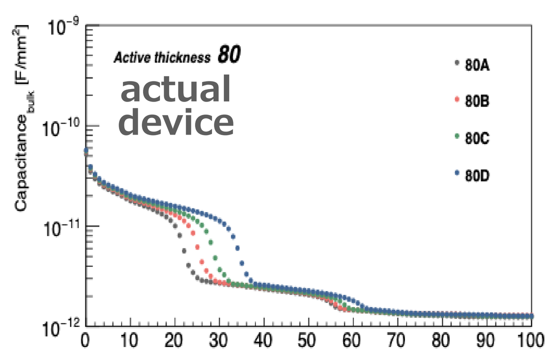
TCAD Simulation for Segmented LGADs

TCAD Sentaurus™ (synopsys)

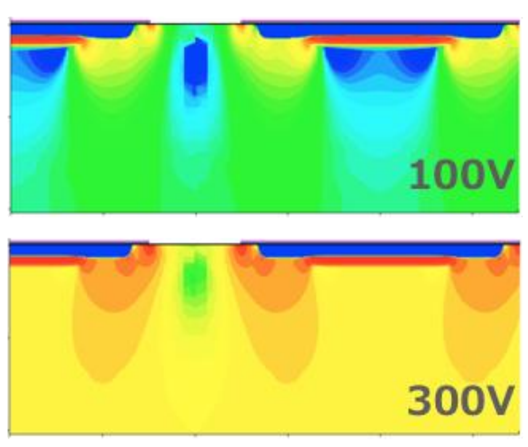








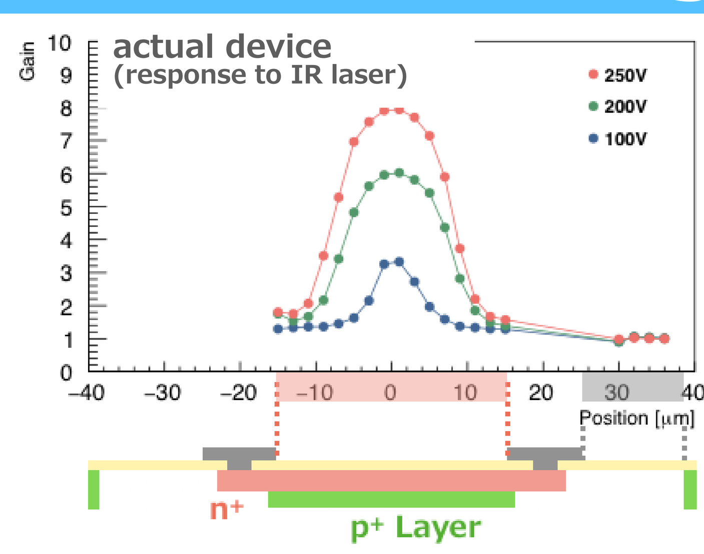
Measured IV and CV are reproduced by TCAD at a precision reasonably well

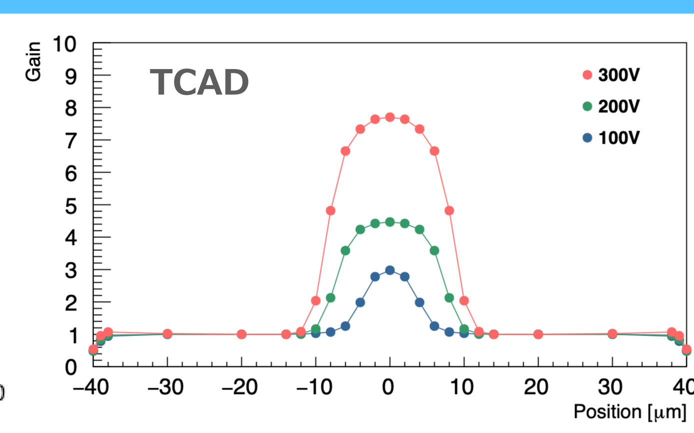


Impact ionization map

at 100V, E-field in the junction is not high and multiplication is not large.

at 300V, E-field in the junction is high but too large at the ends of the multiplication layers, causing sensor breakdown.



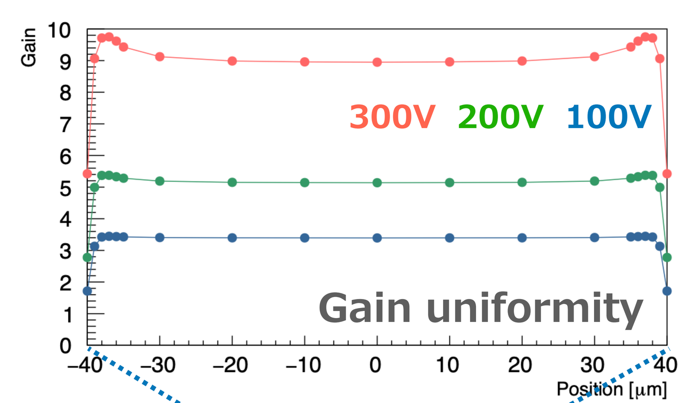


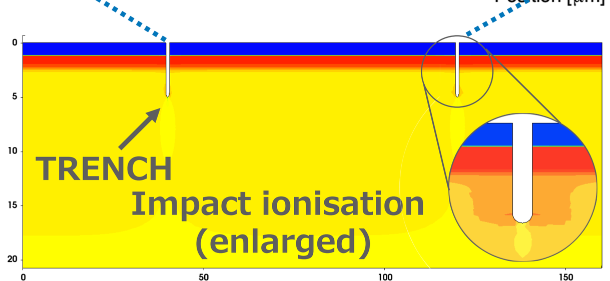
Gain non-uniformity of strip is also reproduced by TCAD

TCAD with parameters tuned to reproduce the measurements is used to simulate new segmented devices with least non-uniformity

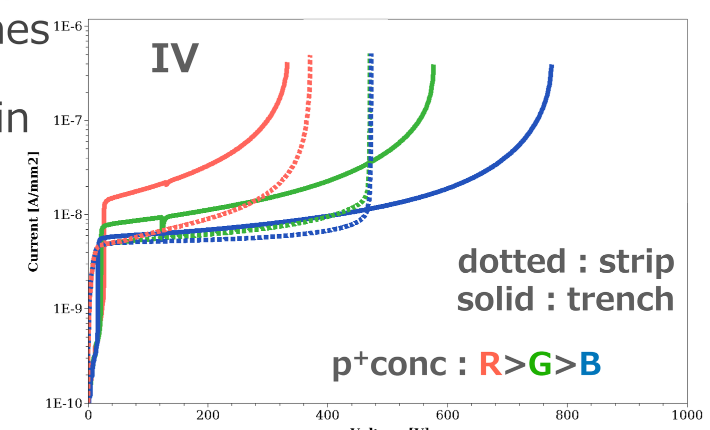
candidate : deep trench

To separate electrodes physical by deep and thin trenches





- Uniform gain~10 is obtainable in wider region except a few µm around trenches
- IV characteristics is more stable than in the strip type
- E-field concentration around the trenches causes the breakdown. Needs optimization of neutralisation process around the trenches



→ **trench is a good candidate for the LGAD segmentation, but need further process optimisation**

Summary

We are developing LGAD sensors to realise 4-D tracking detector

➡ Time precision better than 30 ps is obtained from test beam measurements

➡ TCAD simulation tuned to reproduce measured characteristics is used to design segmented LGAD sensors. Trench is a good candidate. Continue to optimize the electrode structure and trench process

Acknowledgement

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Fermilab