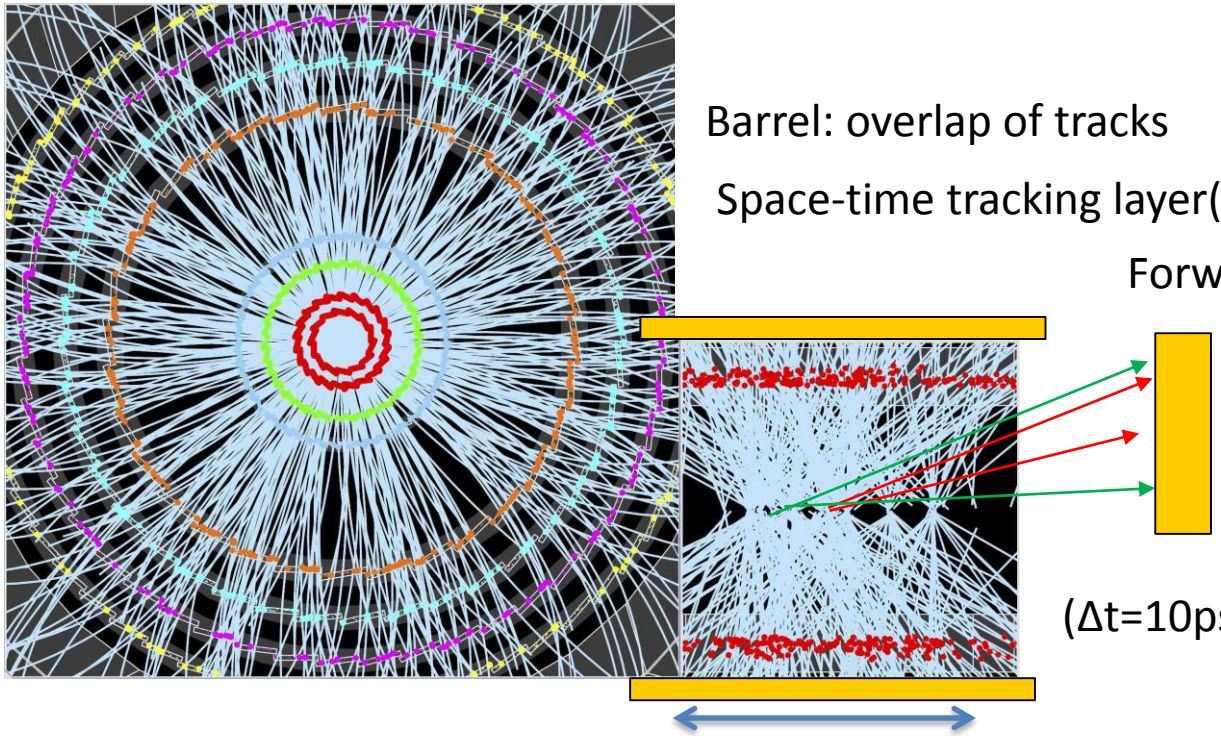
Development of Strip-type Low-Gain-Avalanche Detectors

Y. Unno (KEK)

Motivation/Application



Barrel: overlap of tracks

Space-time tracking layer(s)

Forward: highly collimated jets

ATLAS: High Granularity Timing Detector (HGTD)

(Δt=10ps$\Leftrightarrow\Delta z$=3mm)

interaction region: $2\sigma_z$=15 cm=500 ps

in HL-LHC, max. 200 interactions at a collision

- A detector for tracking in HL-LHC
- Reduction of fake tracks with precision space-time (4D) info.
  - For the barrel region, strip detector is a cost-effective solution.

Motivation/Application II

- Application to medical instrumentation
  - Positron Emission Tomography (PET)
  - A novel detection element, replacing conventional scintillator crystals
  - Similar application as in the “barrel” region, with γ detection

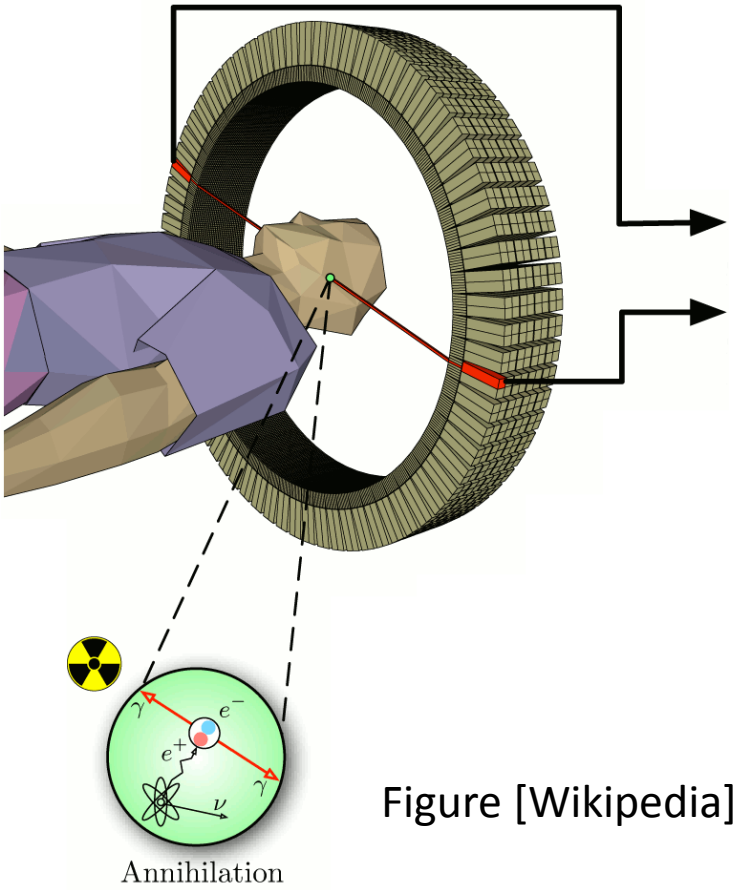


Figure [Wikipedia]

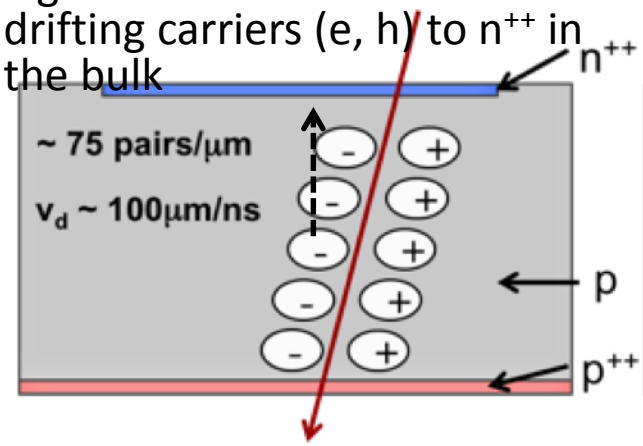
Coincidence in space-time

- Precision space info. -
  - high resolution in “line of sight”
  - $\Delta x \sim 20\ \mu m$
- Precision time info.
  - reduction of fake lines
  - $\Delta t \sim 10$ ps = $\Delta r \sim 3$ mm
  - which may reduce a requirement for photon energy measurement

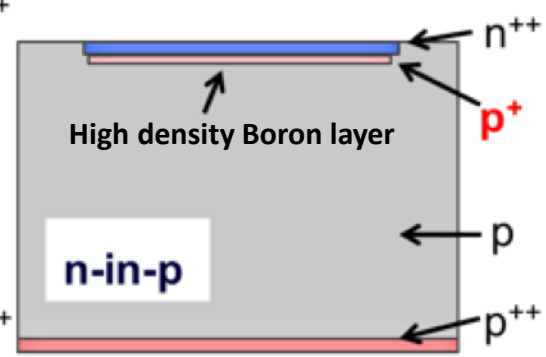
LGAD: Strip Sample

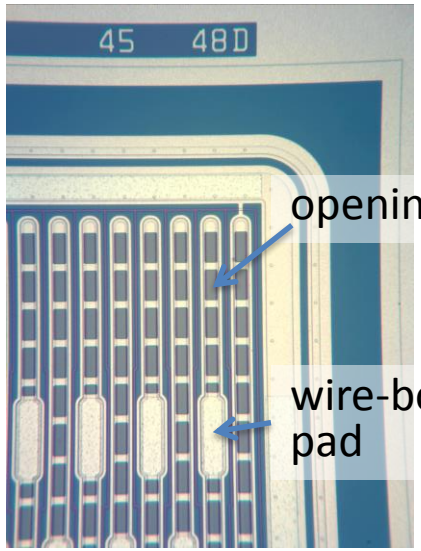
Traditional

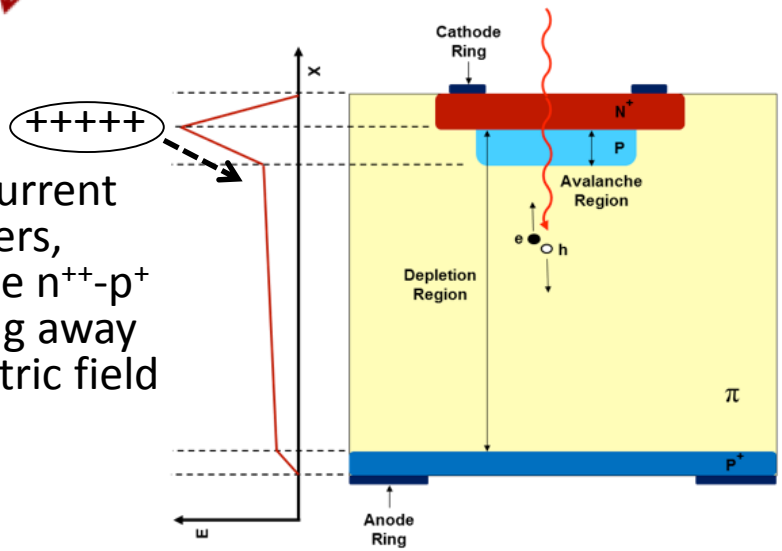
Signal: mirror current of drifting carriers (e, h) to n^{++} in the bulk



LGAD



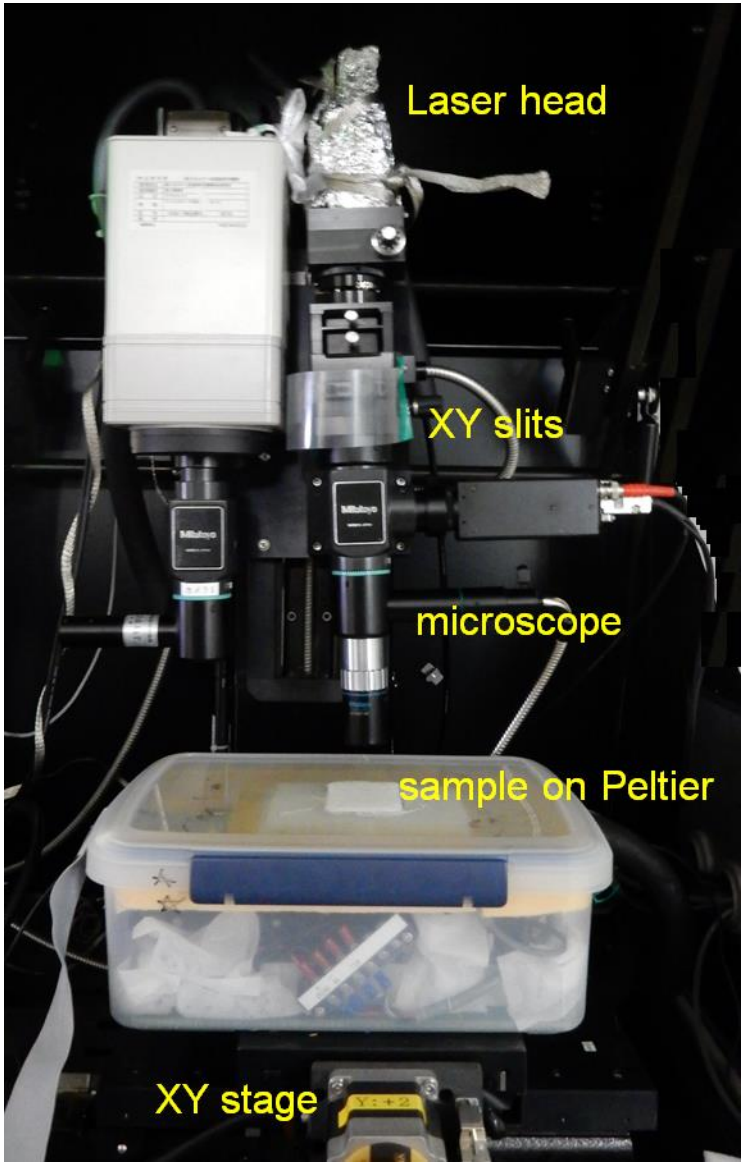




Signal: mirror current of drifting carriers, multiplied at the n^{++}-p^{+} junction, drifting away in the high electric field in p+ layer

- Geometry
  - Strip pitch: 80 μm
  - Readout metal: DC-coupled (although AC should be possible)(
  - Opening (30 μm wide) in the metal for laser injection
- Density of p^{+} gain layer
  - 4 densities: A, B, C, D as ↗
  - 2 Active thicknesses: 50, 80 μm

Gain Measurement with Laser



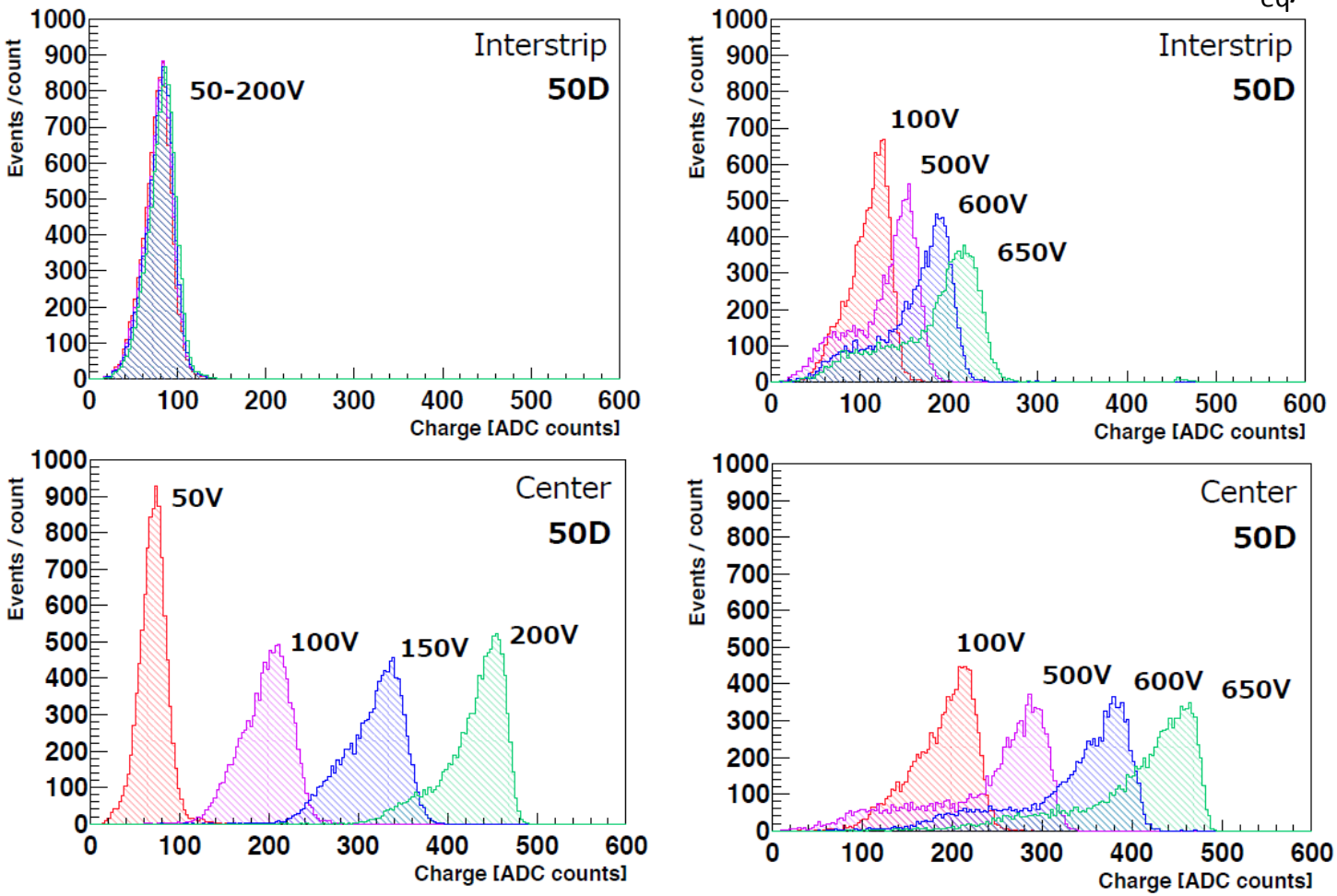
- Irradiation with neutrons
  - TRIGA reactor of JSI, with V. Cindro et al.
  - Supported by the H2020 project AIDA-2020, GA no. 654168
  - Fluences: 0.3, 1.0, 3×10^{15} 1-MeV n_{eq}/cm^2
- Infrared laser (Nd:YAG)
  - λ = 1064 nm
  - Focused at surface, collimated to 2×2 μm^2
  - uniform *e-h* generation in depth, mimicking the traverse of charged particle

Responses to Laser

S. Wada et al., HSTD11 (2017)

Before irradiation

After irradiation of 1×10^{15} n_{eq}/cm^2

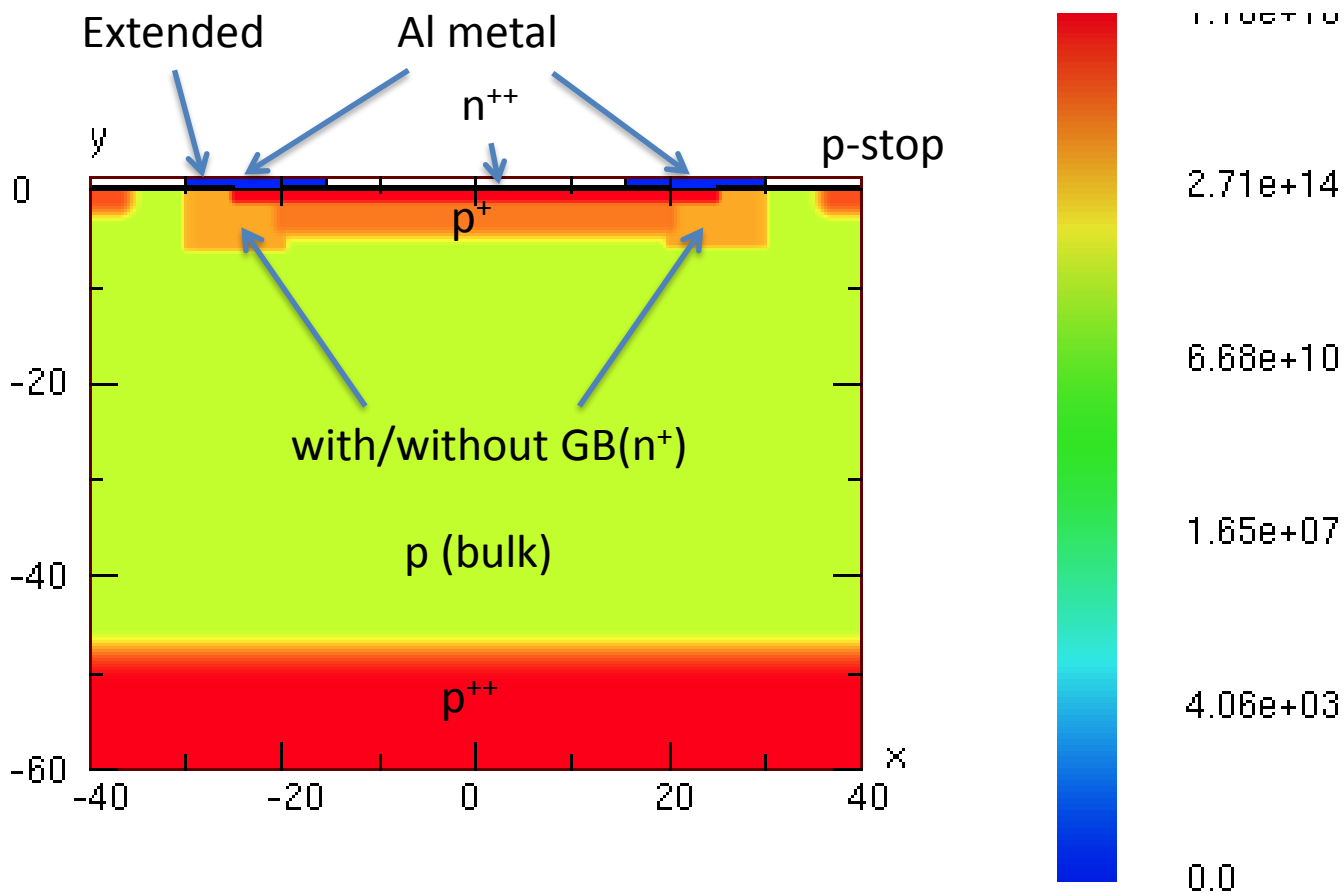


- At the center of strips (bottom figs.) – observed gain both before and after irradiation, as expected.
- At the interstrip (top figs.) – no gain before irrad. as expected; non-zero gain after irradiation, surprising, but, in retrospect, confirming “charge multiplication”

How to Make a Usable Device?

- Present sample:
  - No gain in the interstrip region, although a small gain has appeared after irradiation.
  - As is, it is not usable, with a design as same as the conventional strip sensor (narrow strip with wide interstrip region)
- Improvement(?):
  - “AC LGAD” might be a way to go for (see other talk)
  - Here, we pursue to introduce gain in the interstrip region before irradiation.
  - In the next slides we show how, with TCAD simulations...

TCAD Simulations – Strips in General

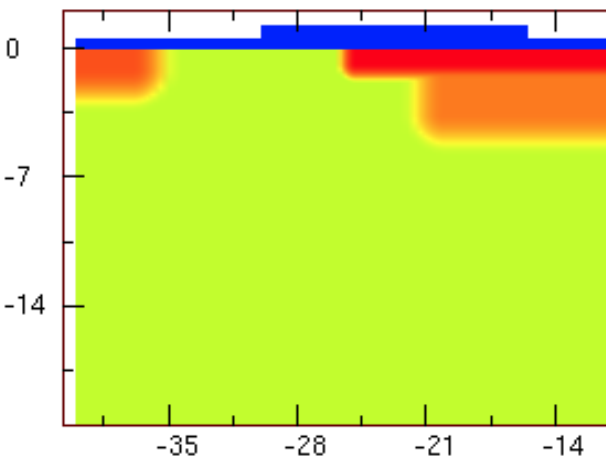


- A few factors that are affecting electric field
  - Guard band (GB): usually n^+ implantation, noted as GB(n^+)
  - Extended Al (XA)
  - Staggering of n^{++} and p^+ layers

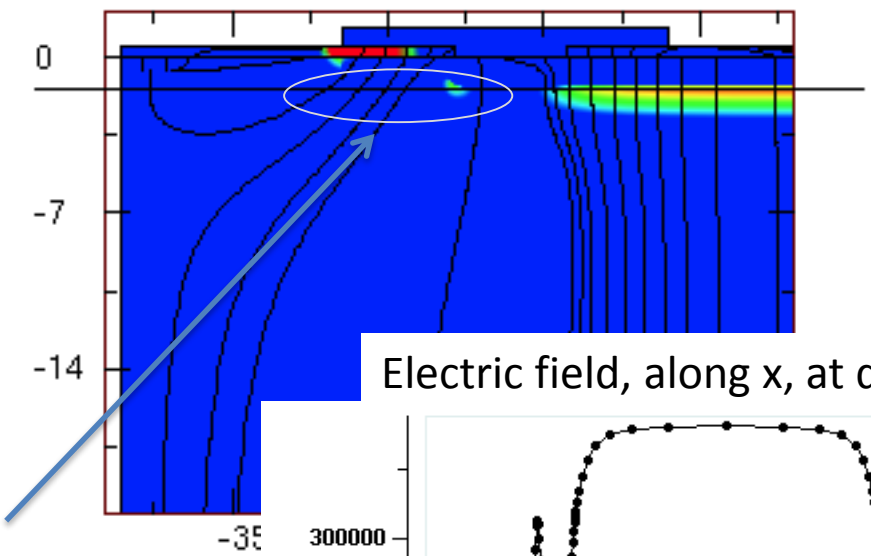
Electric Field and Flow lines

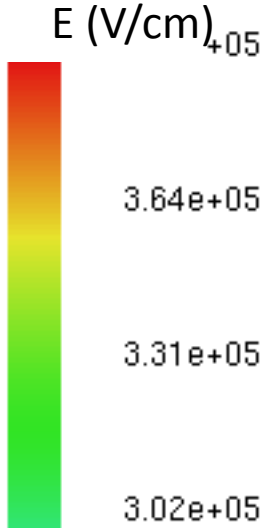
- Case2.0 – as is, No GB(n^+)

Geometry



Electric field E > 250 kV/cm

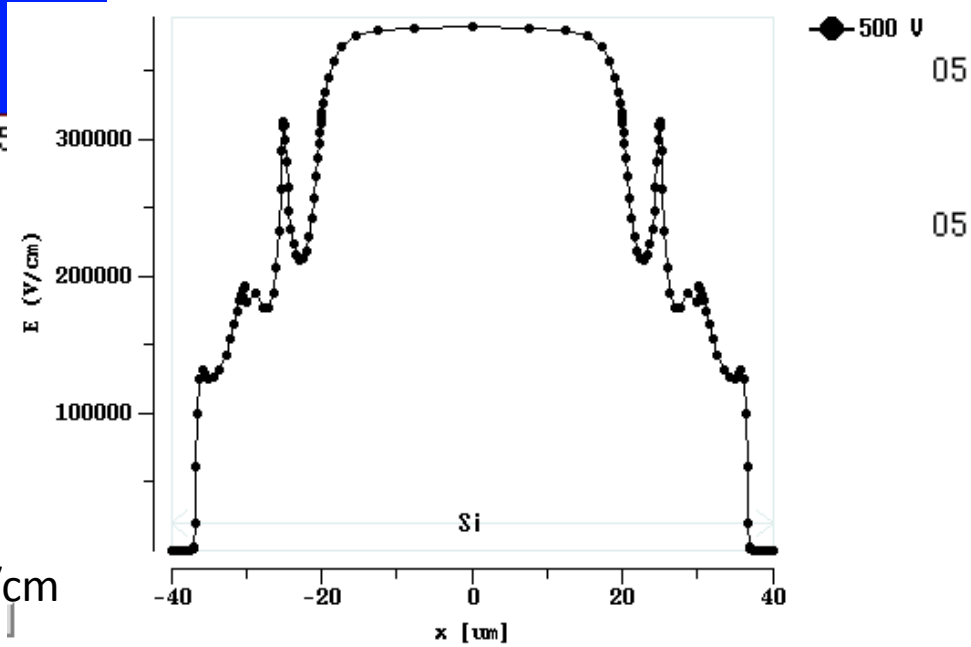




Carries drifting along these flow lines will not go avalanche, except ...

- A corner of n^{++} electrode with E>300 kV/cm may have become effective to go avalanche after irradiation.

Electric field, along x, at depth 1.4 µm

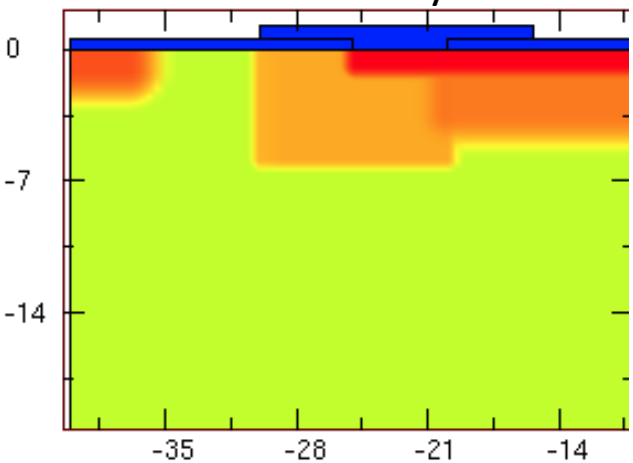


Avalanche breakdown field – 300 kV/cm

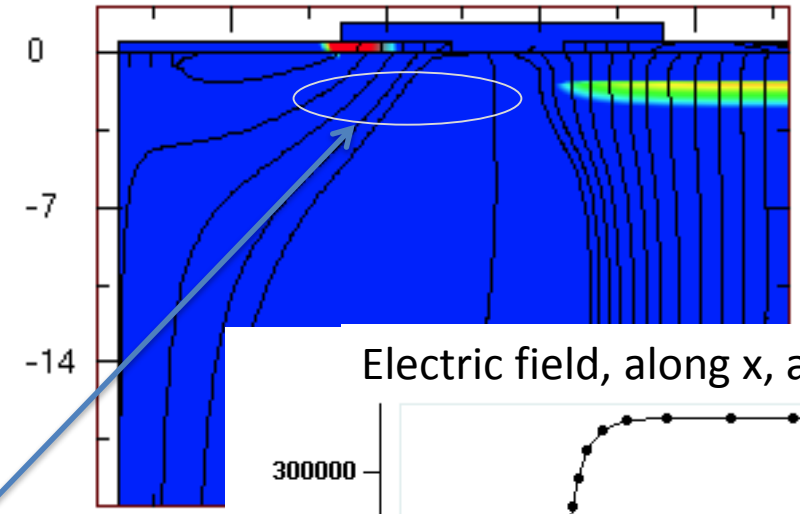
Electric Field and Flow lines

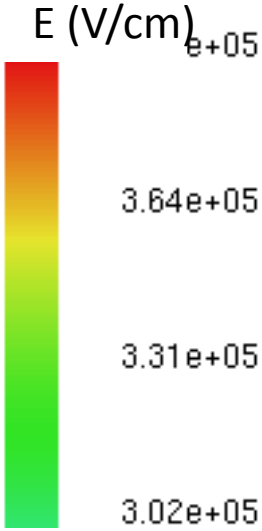
- Case1.5 – as is, with GB(n+)

Geometry



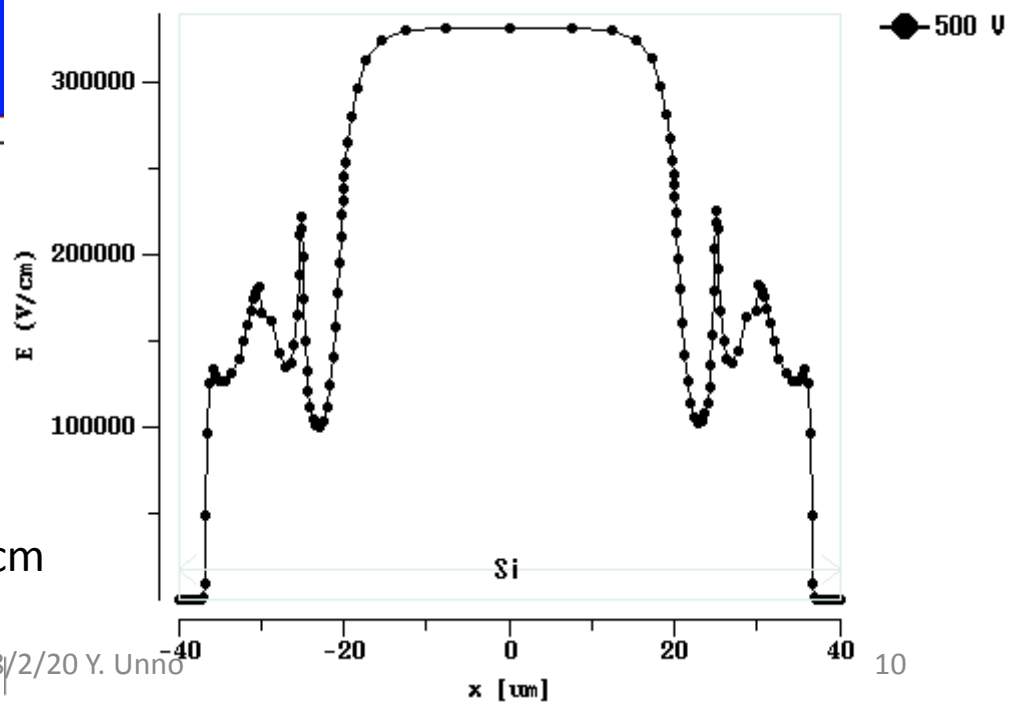
Electric field E > 250 kV/cm





Carries drifting along these flow lines will not go avalanche

Electric field, along x, at depth 1.4 µm



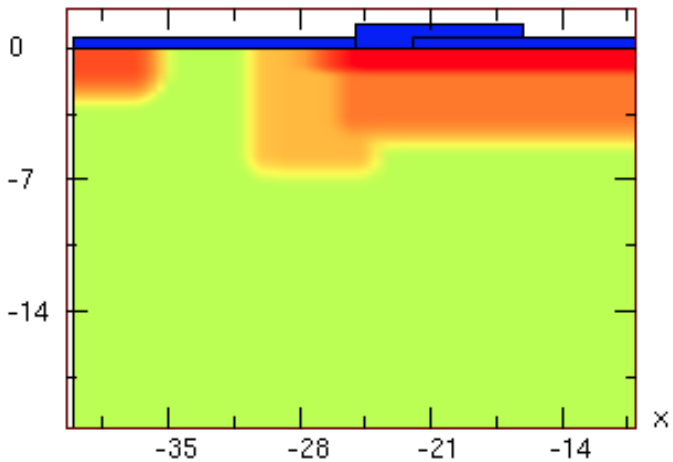
- GB(n^+) suppresses a region with E>300 kV/cm at a corner of n+ electrode, making the device safer for micro-discharge breakdown.

Avalanche breakdown field – 300 kV/cm

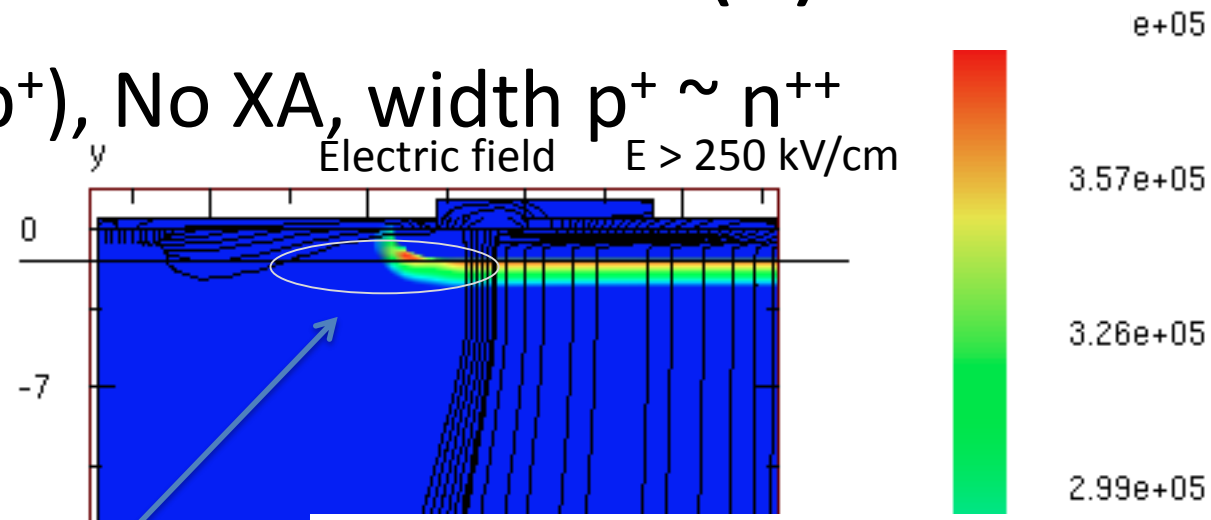
A Proposed Solution (?)

- Case3.1 – GB(p^+), No XA, width p^+ ~ n^{++}

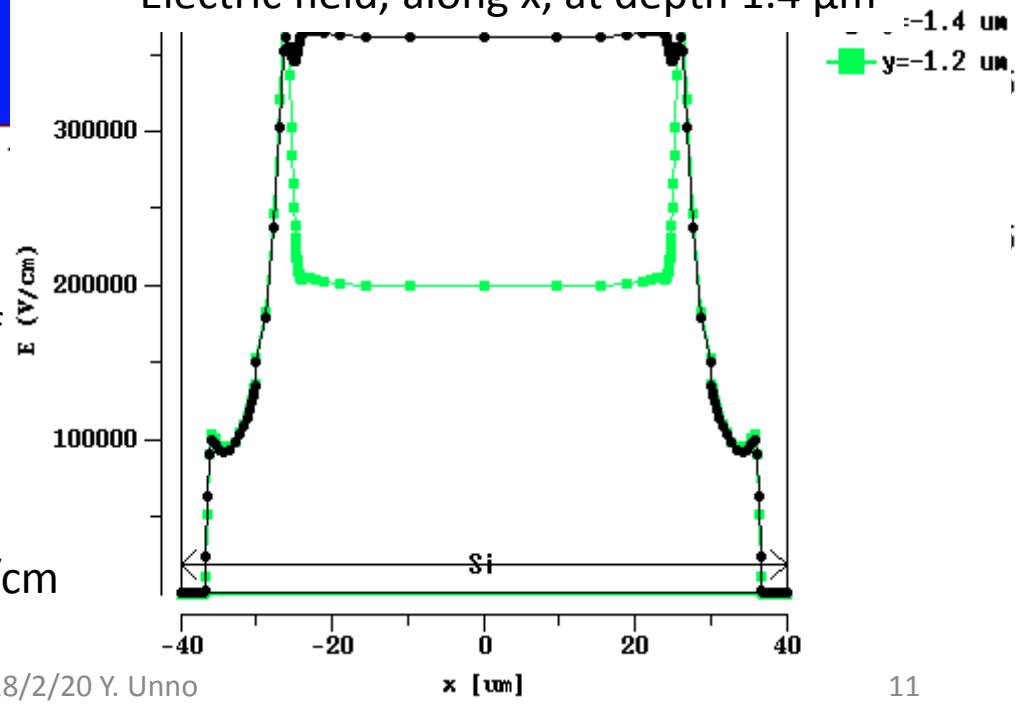
Geometry



Electric field E > 250 kV/cm



Electric field, along x, at depth 1.4 µm



Carries drifting towards the corner along flow lines (not drawn) will go avalanche

- GB(p^+), no extended Al, same width of n^{++} and p^+ enhance electric field along the edge of n^+ electrode to have E>300 kV/cm, making the n^{++} electrode sensitive to avalanche in all faces.

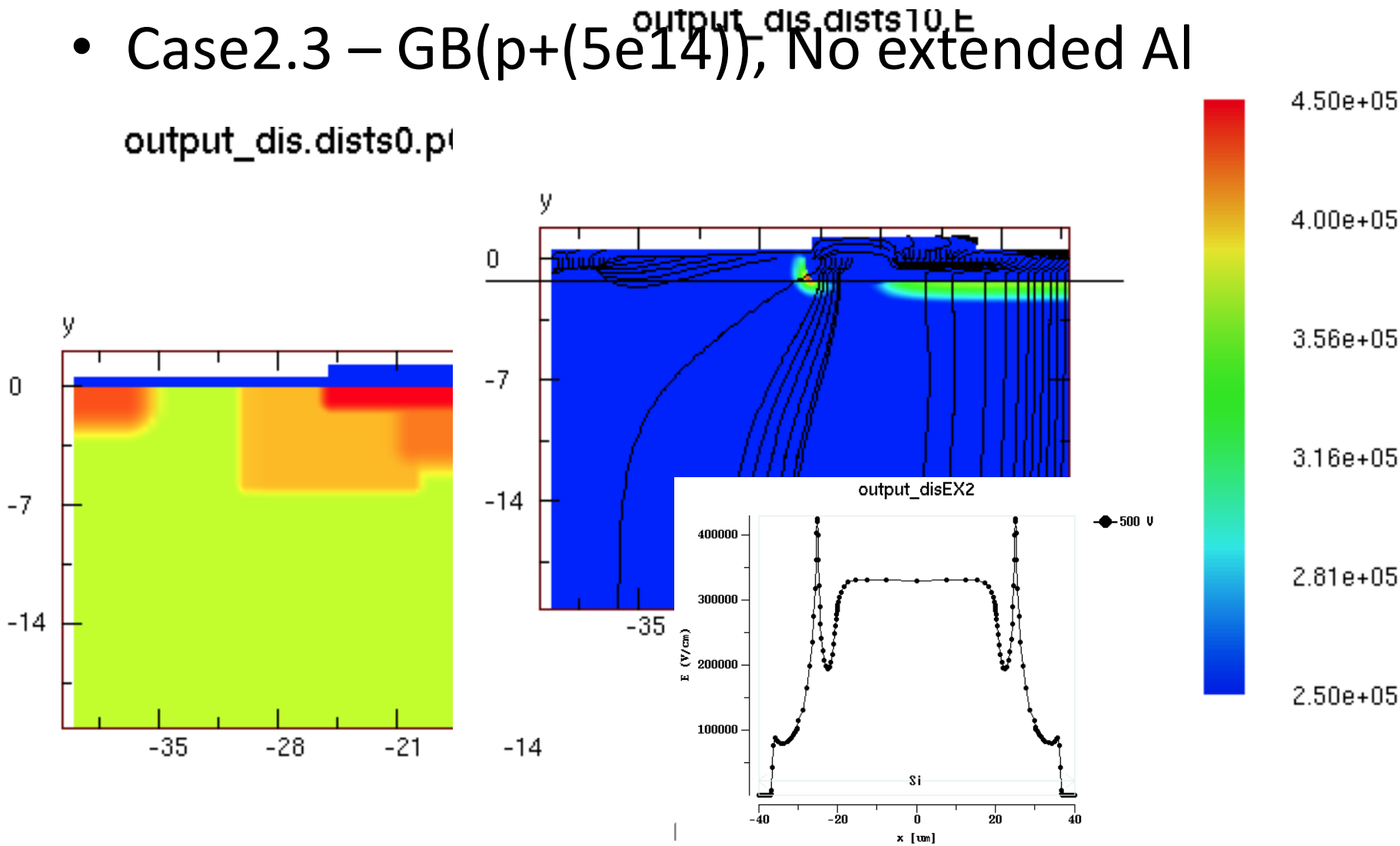
Avalanche breakdown field – 300 kV/cm

Summary

- We have evaluated strip-type LGAD (DC-coupled), by implementing high density p^+ gain layer in the conventional strip structure.
- The strip region where the gain layer is showed gain of ≥10, before and after irradiation to neutrons, as expected.
- The interstrip region did not show gain, before irradiation as expected, showed small gain after irradiation, a confirmation of “charge multiplication”.
- We have pursued and propose a design to introduce gain in the interstrip region before irradiation, verified with TCAD simulations.
- A next step is to fabricate a device.

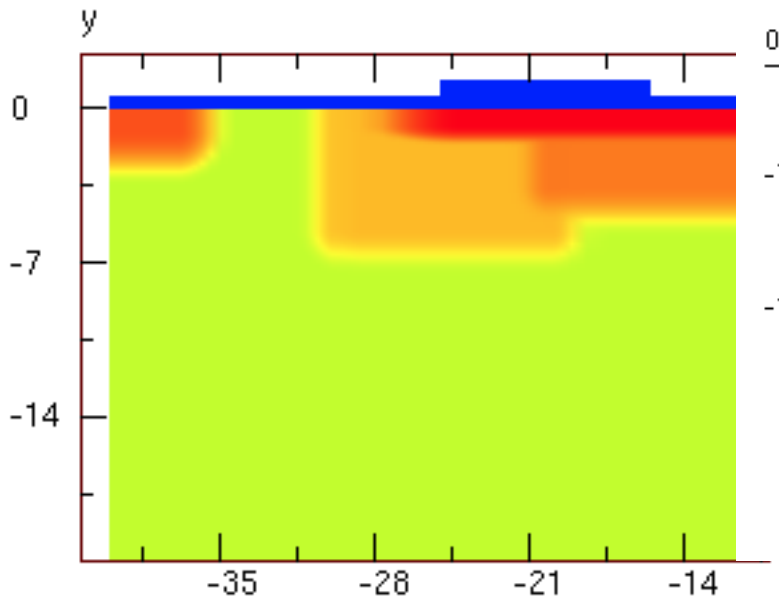
Backup

- Case2.3 – GB(p+(5e14)), No extended Al

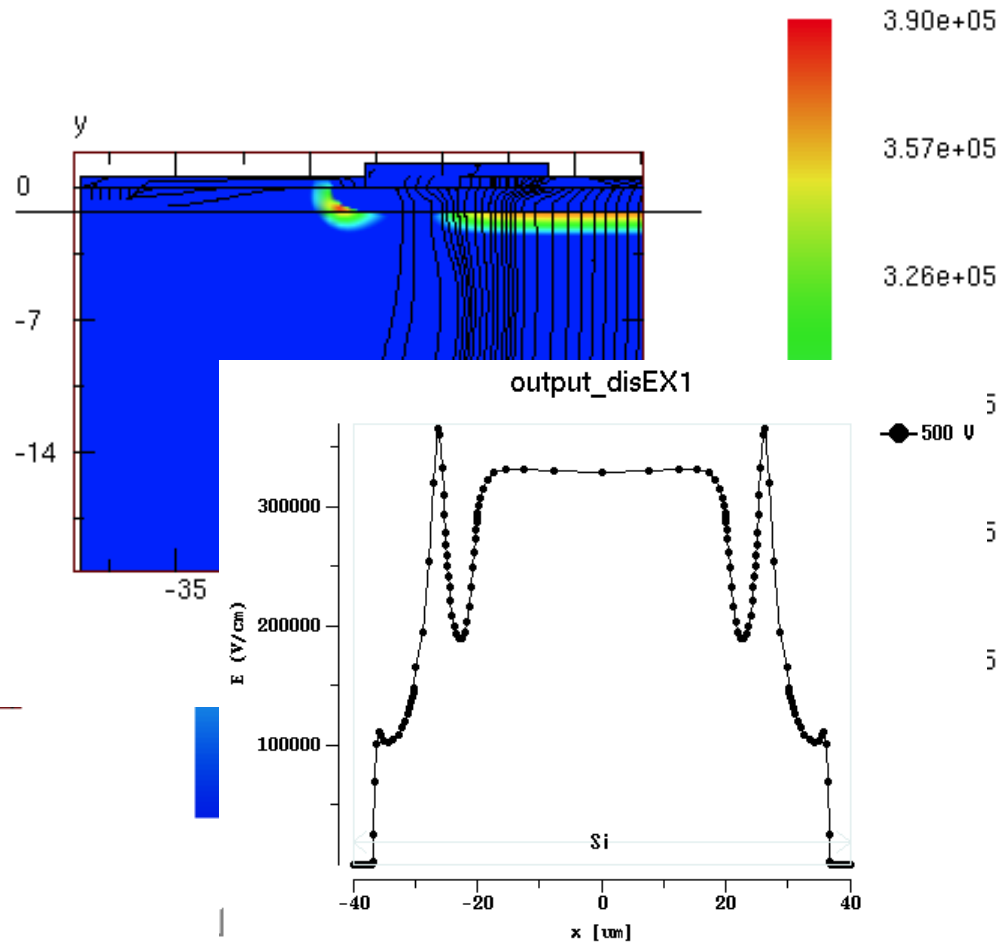


- Case3.0 – GB(p+(5e14)-XA, n+ side-smearing(1

output_dis.dists0.pCnet



output_dis.dists10.E



- Case2.05 – No GB, No extended Al (XA)