DJ-LGAD

(Deep-Junction LGAD)

A new approach to higher granularity fast timing detectors

15° Trento Workshop (2020, Wien)

Dr. Simone M. Mazza (SCIPP, UC Santa Cruz),
on behalf of the SCIPP UCSC group

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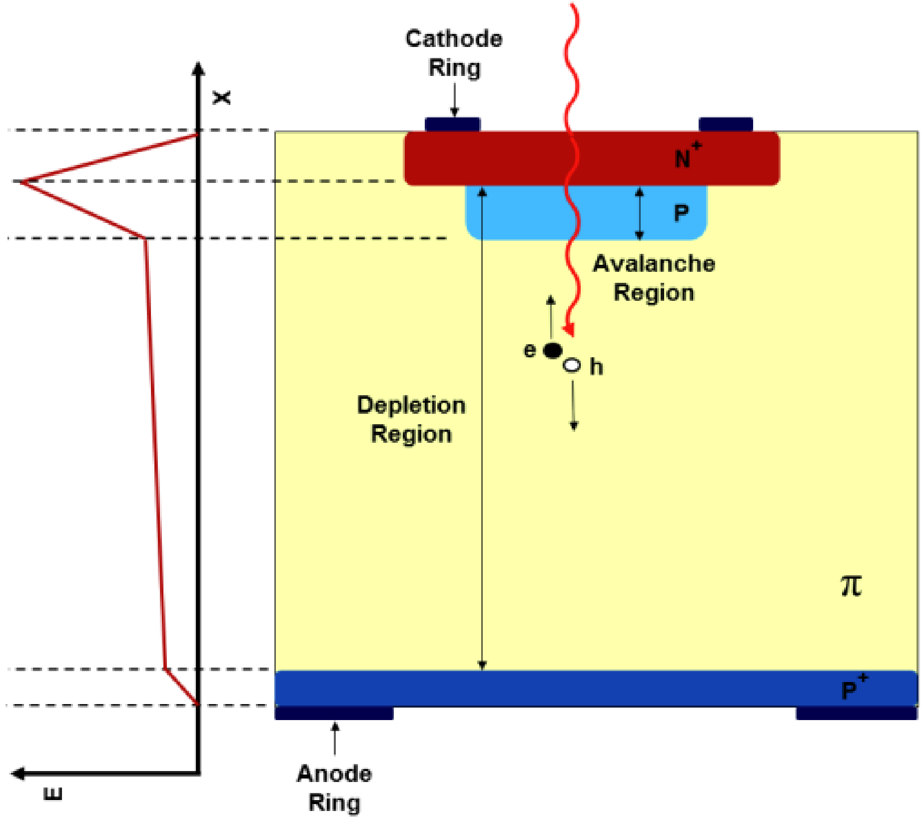
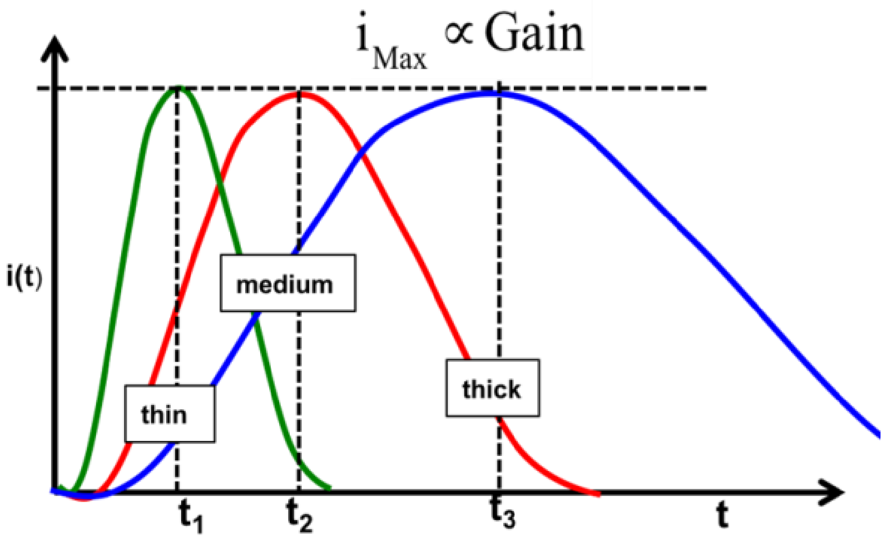
LGADs

- LGAD: silicon detector with a thin (<5μm) and highly doped ($\sim 10^{16}$ P++) multiplication (gain) layer
  - High electric field in the multiplication layer
- LGADs have intrinsic modest internal gain (10-50)
  - $G = \frac{Q_{LGAD}}{Q_{PiN}}$ (collected charge of LGAD vs same size PiN)
  - Better signal to noise ratio, sharp rise edge
- Allows thin detectors (50 μm, 35 μm, 20 μm)
  - Thinner detectors have shorter rise time and less Landau fluctuations
- **Time resolution < 30 ps**

$$\sigma^2_{timing} = \sigma^2_{time\,walk} + \sigma^2_{Landau\,noise} + \sigma^2_{Jitter} + \sigma^2_{TDC}$$

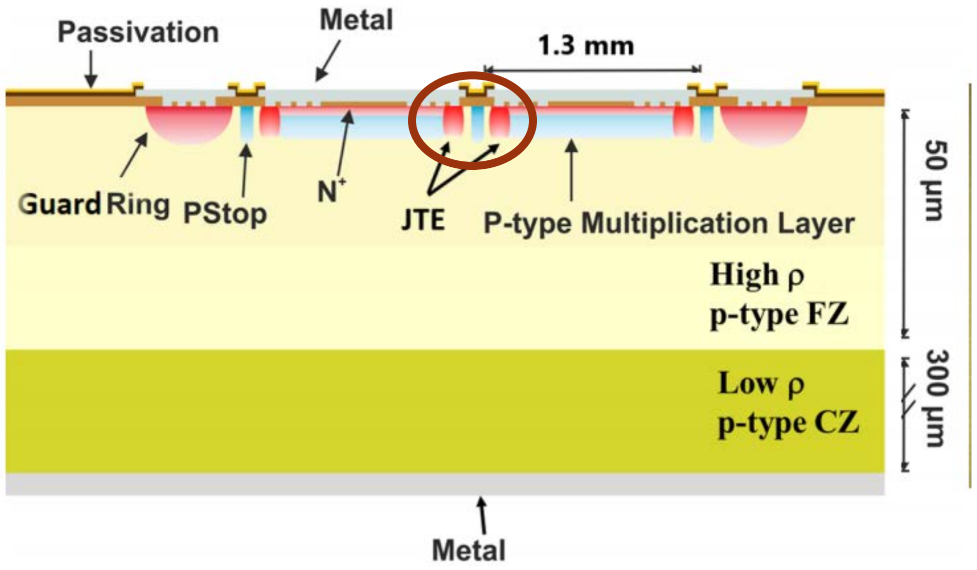
- Several vendors of thin LGADs under study
  - HPK (Japan), FBK (Italy), CNM (Spain), BNL (USA), NDL (China)





LGAD arrays

- Current limitation of LGADs:
  - High fluence radiation hardness → but we're getting there!
  - Granularity
- Due to high fields in the multiplication layer the pads needs electrical insulation
  - Protection structure: Junction Termination Extension (JTE)
  - Causes inter pad (IP) gap to 50-150um, also changes with applied bias voltage
  - Limits LGAD granularity to mm scale
- However 50um pitch (and lower) is required for next generation colliders and 4D tracking
  - At least same level as the ATLAS new inner tracker (ITk) needed



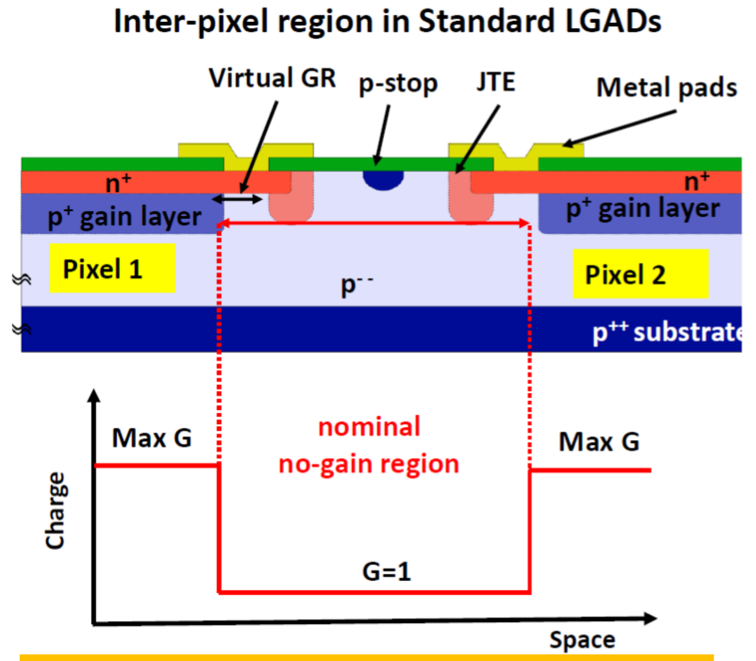
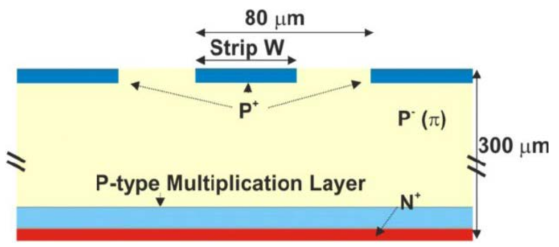
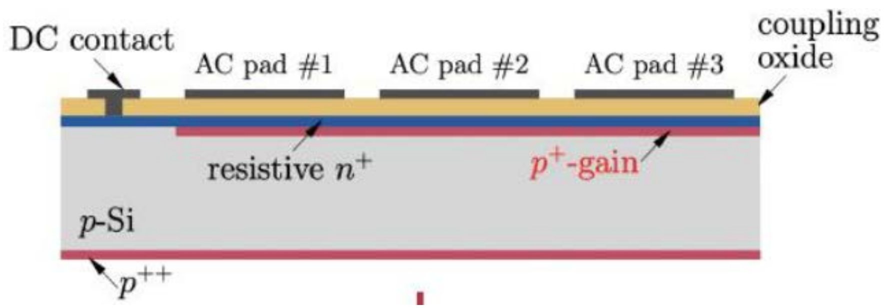
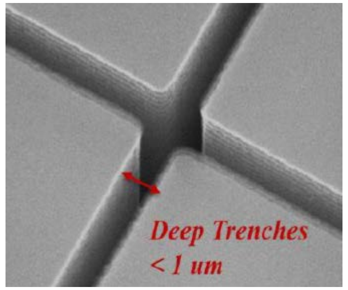


Diagram credit: FBK, Trento, Italy

Higher granularity LGADs





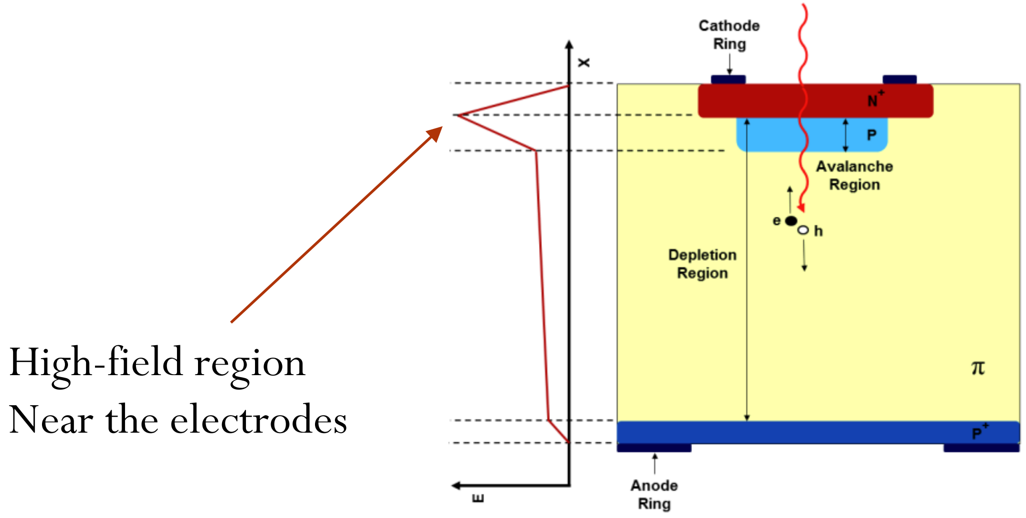


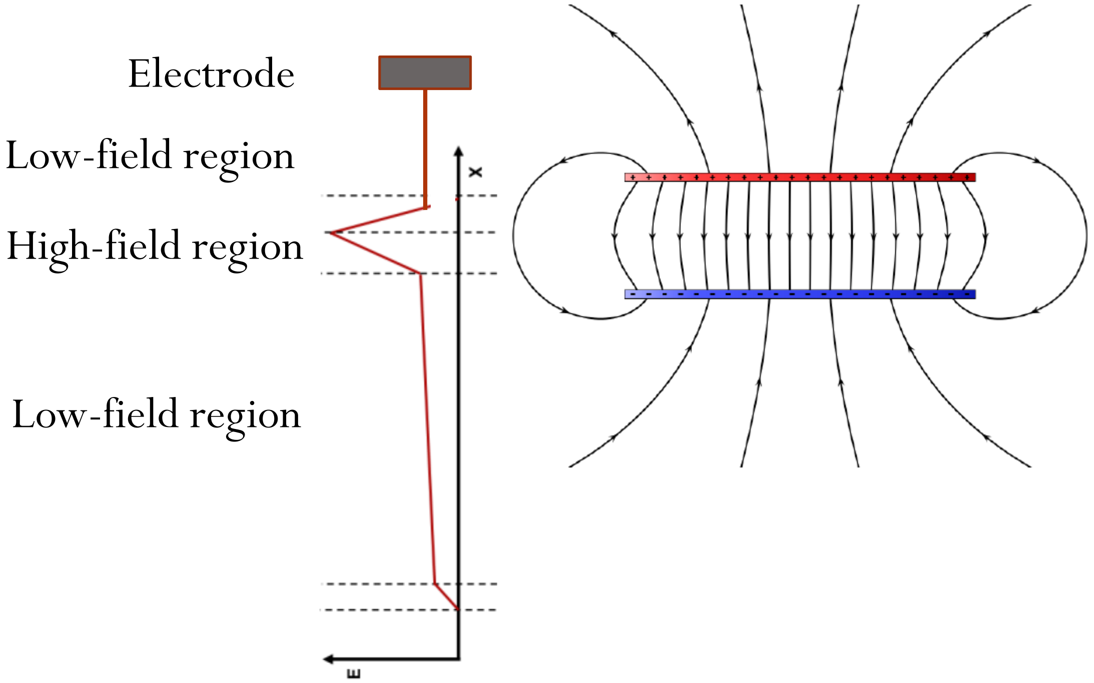
Several promising approaches to overcome this limit:

- Reverse position of gain layer → iLGAD
- AC coupling with output → AC-LGAD (UCSC - US patent N. 9,613,993 B2, granted Apr. 4, 2017)
- Trench insulation of pads → TI-LGAD
- Some will be discussed in this workshop!

A new approach: deep junction

- Granularity limit is caused by high field near the electrodes
  - What if the field is kept low while maintaining gain?
- Basic inspiration is that of the capacitive field:
  - Large between plates, but surrounded by low-field region beyond the plates
- Use symmetric P-N junction to act as an effective capacitor
- Localized high field in junction region creates impact ionization
- Bury the P-N junction so that fields are low at the surface, allowing conventional granularity
- → **"Deep Junction" LGAD (DJ-LGAD)**





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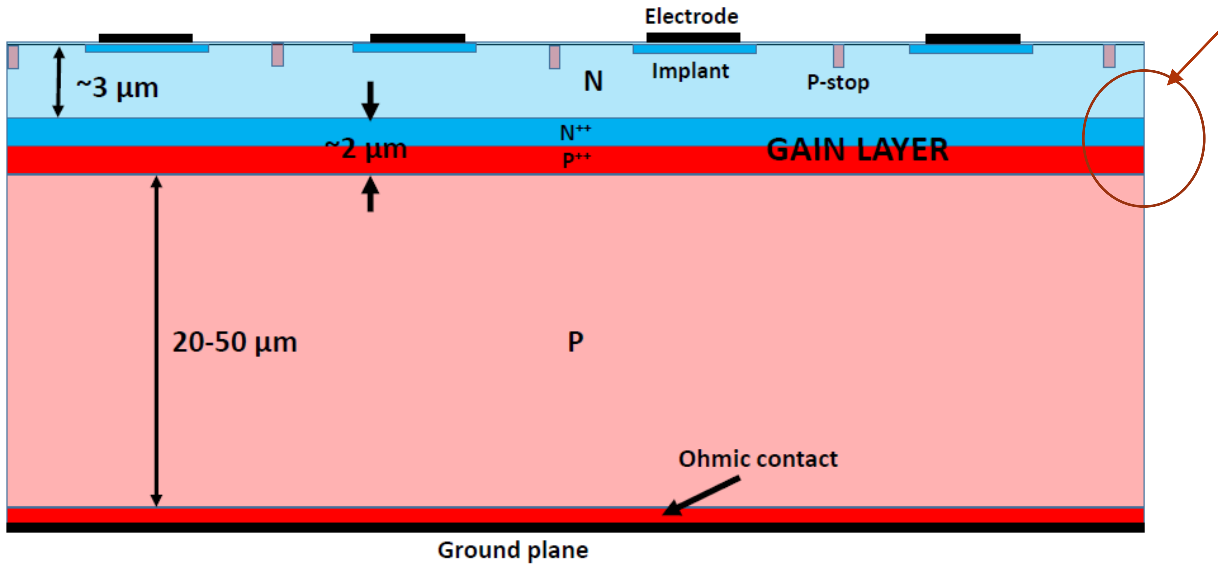
DJ-LGAD

A structure is being studied to be added at edge for the termination of the gain layer



Element	Doping Level	Extent in Depth
N isolation layer	Constant doping of density 3e10 N/cm^3	From 0 µm (surface) to 4 µm
N^{++} gain plate (upper half of gain layer)	Gaussian doping, peak of 3e16 N/cm^3	Peak at 3 µm, falling to 5e12 at 4 µm (sigma = 0.17 µm, FWHM=0.4 µm)
P^{++} gain plate (lower half of gain layer)	Gaussian doping, peak of 3e16 N/cm^3	Peak @ 4.5 µm, falling to 5e12 at 5.5 µm (sigma = 0.17 µm, FWHM=0.4 µm)
P drift region	Constant doping of density 3e12 N/cm^3	4 µm to 50 µm

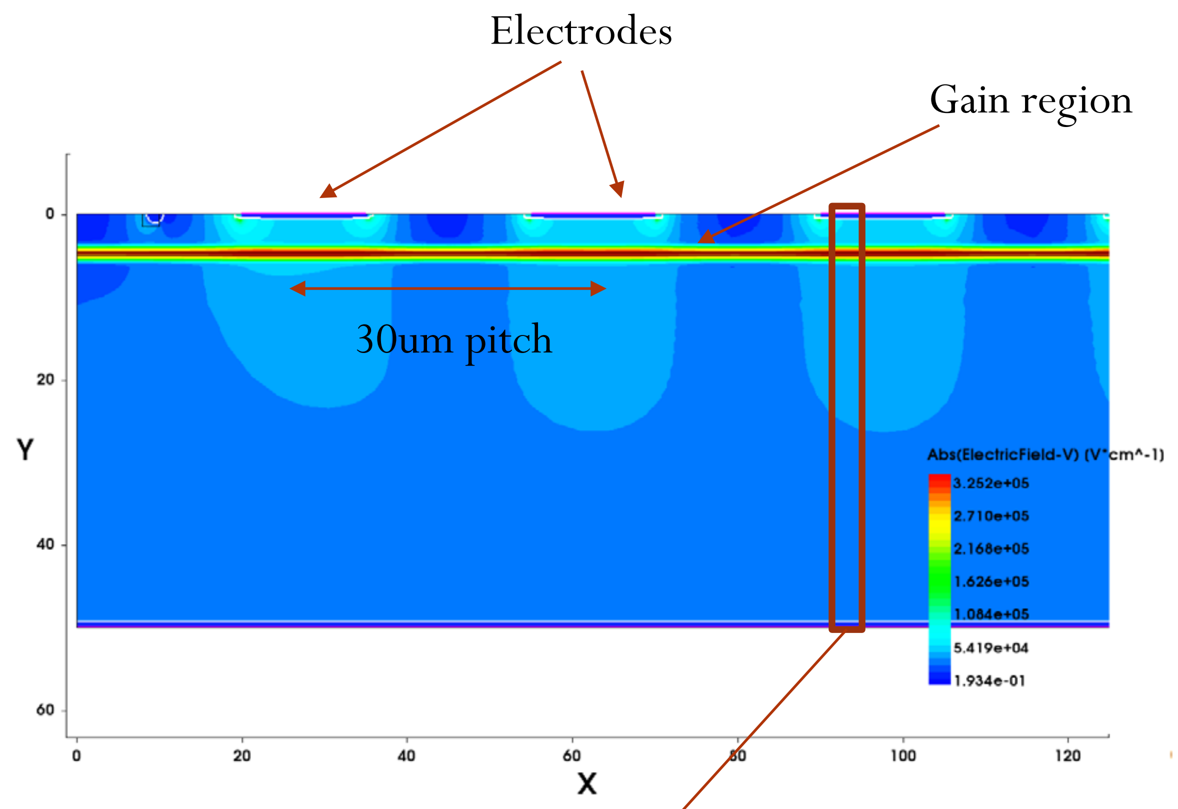
- P++ gain layer is paired with a N++ layer that lowers the field
  - Junction is buried ~5 um inside the detector
- Tuning of N+ and P+ parameters important
  - Low field outside of the electrodes while maintaining sufficient gain
  - No need for a JTE
- Termination of gain layer at the edge under study
- DJ-LGAD Baseline design studied with TCAD Sentaurus

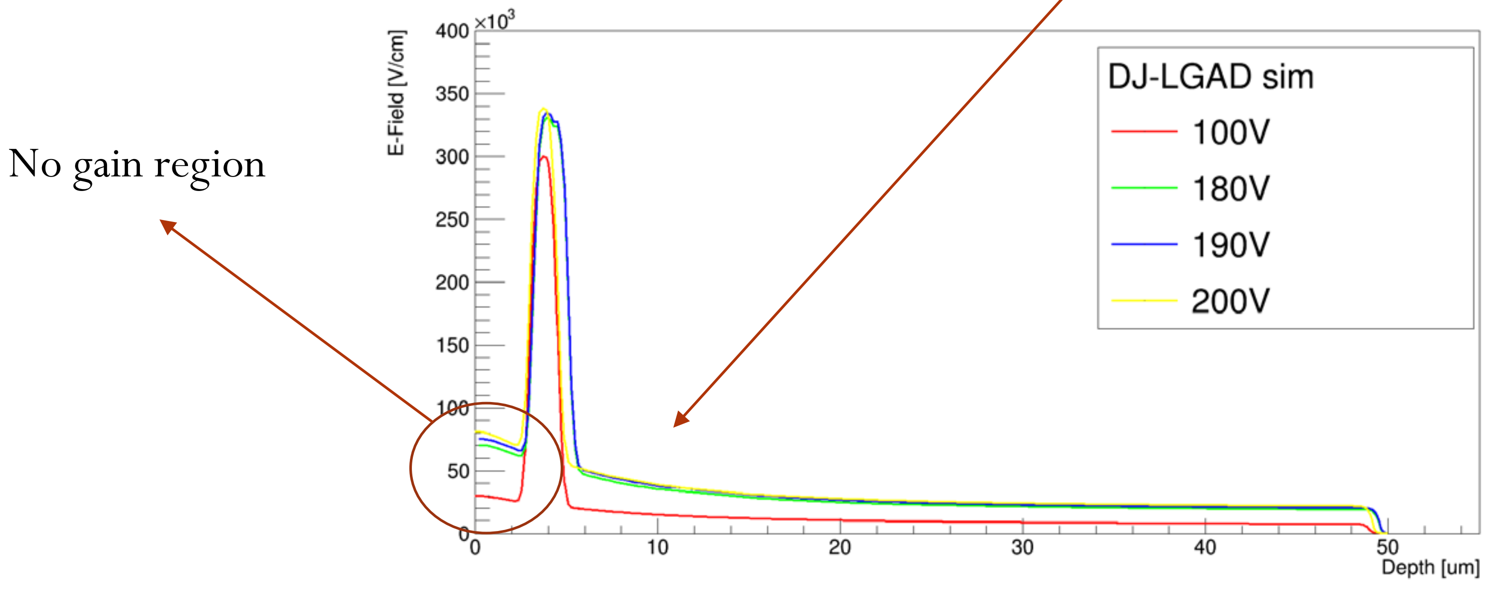
- Patent Application SC 2019-978 (UCSC)
  - C. Gee, S. M. Mazza, B. Schumm, Y. Zhao

Electric field configuration

- High field in the buried N++ and P++ junction generates gain
  - Only charge deposited in the P bulk is multiplied
  - (can't be too deep)
- In the P and N bulk electric field is lower
  - But drift speed is saturated

- Simulation example
  - 50um thick device
  - 30um pixel pitch
  - Pads are DC coupled

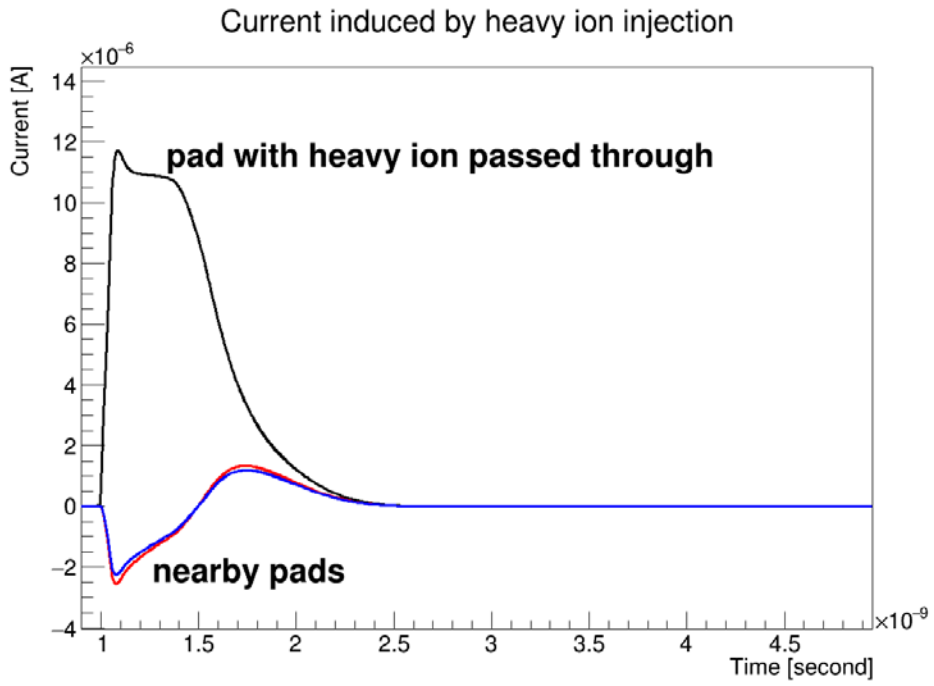


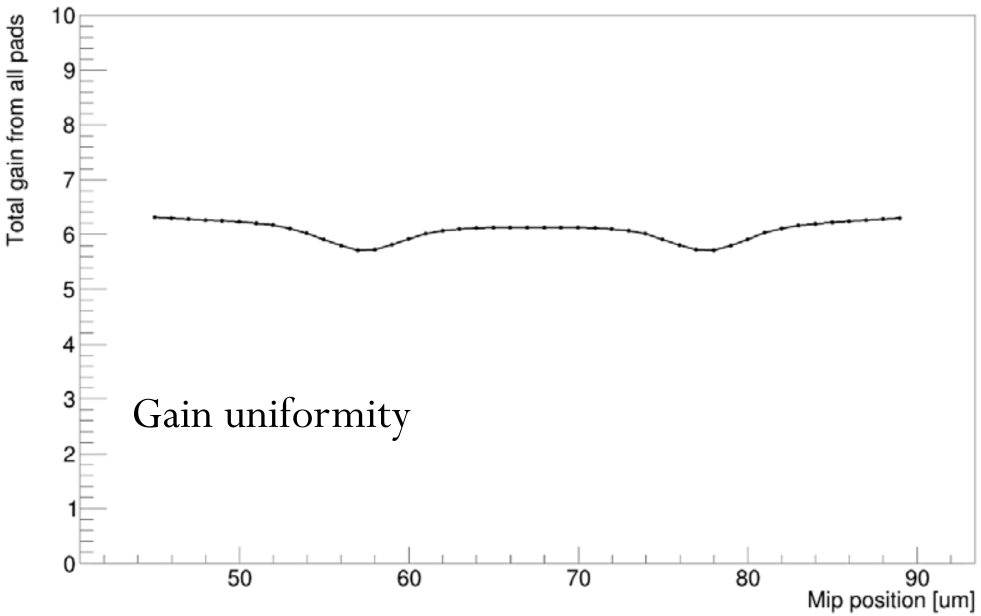


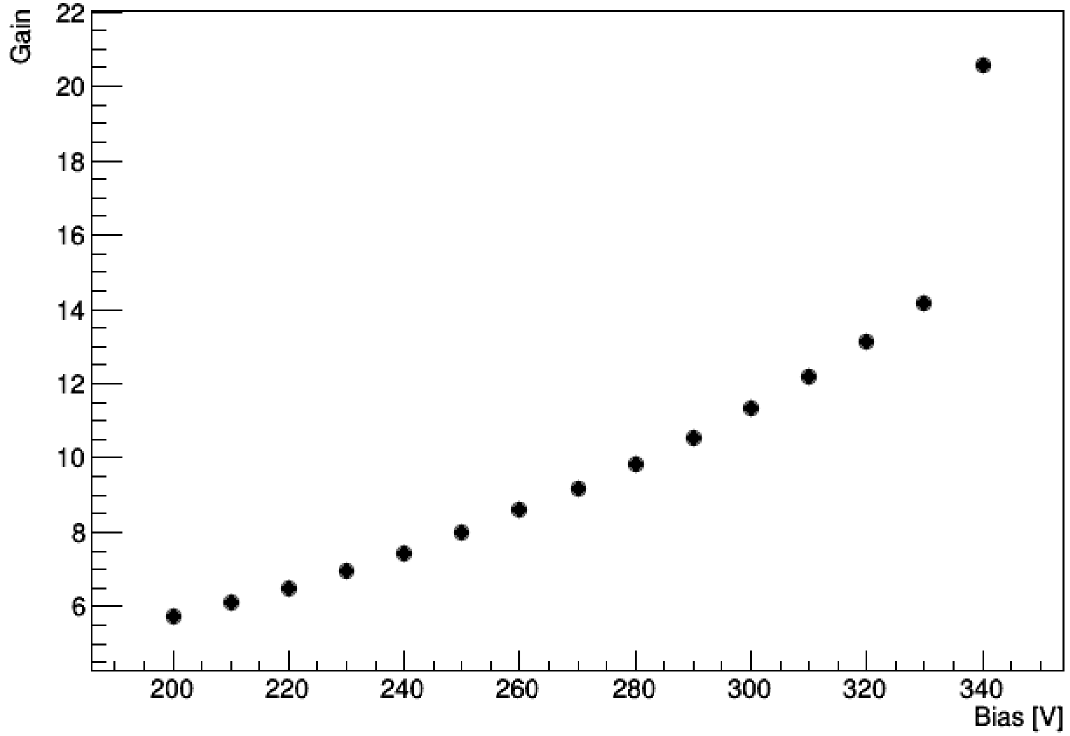
Electric field configuration

- High field in the buried N++ and P++ junction generates gain
  - Only charge deposited in the P bulk is multiplied
  - (can't be too deep)
- In the P and N bulk electric field is lower
  - But drift speed is saturated

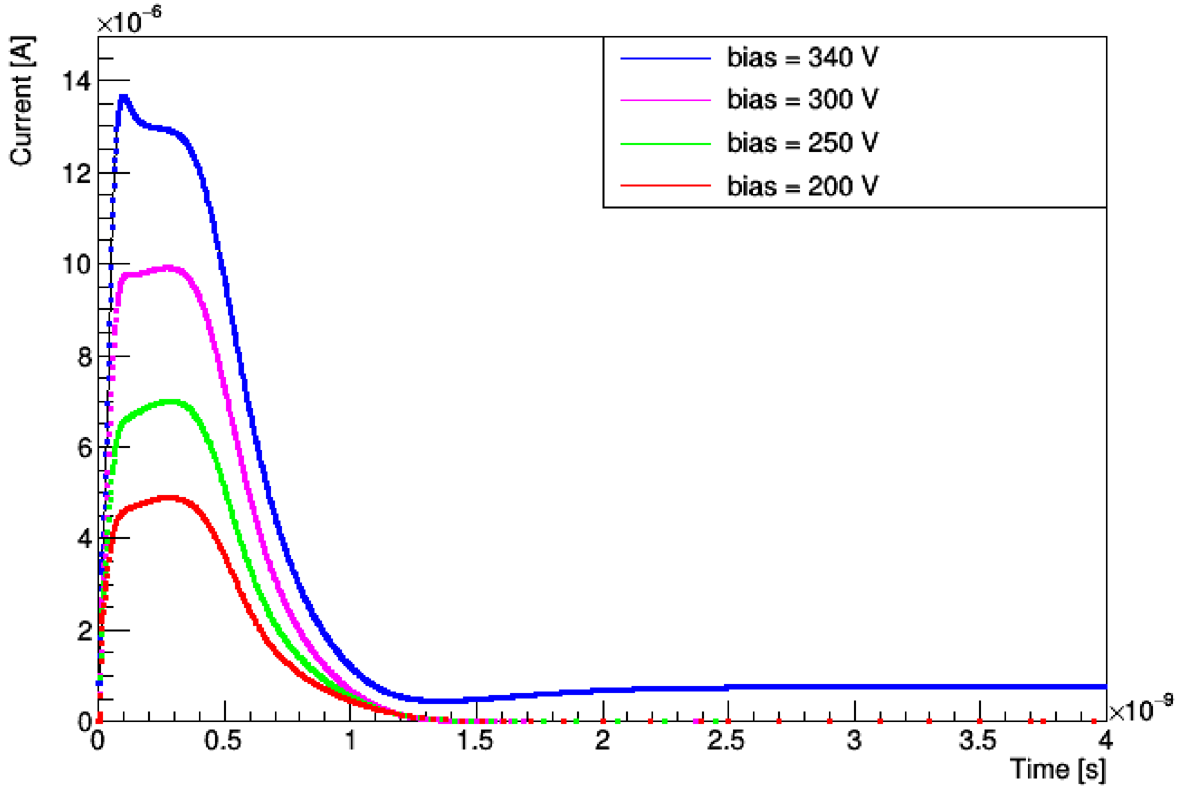
- Simulation example
  - 50um thick device
  - 20um pixel pitch
  - Pads are DC coupled
  - Small cross talk between pads
  - Gain uniformity of ±4%





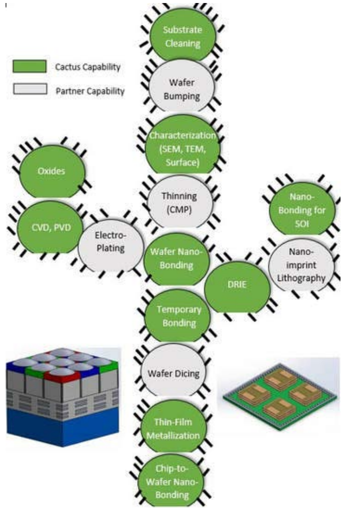


- Breakdown voltage over 300V
- Stable simulated gain up to 15
- Studies are ongoing to increase the gain reach



- Pulse shape temporal profile
- Fast rise time (100ps)
- Full charge collection within 1 ns

Fabrication of the device



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- Fabrication will probably involve epitaxial layer growth
  - For the deposition of the deep junction
  - Needed precision for the deposition to be studied (probably % level)
- First prototype will be produced with in collaboration with **Cactus Material** (AZ)
  - Founded by DoE SBIR “A New Approach to Achieving High Granularity in Low Gain Avalanche Detectors” (34b)
  - Phase-I approved: fabrication of single pad planar device
- Also collaborating with **Brookhaven National Laboratory** for a first production of DJ-LGADs
  - Segmented device but farther in the future
- Also discussing with IHEP Beijing for simulation cross-checks

Conclusions

- DJ-LGAD: a device with deep junction
  - Avoid high field near the electrodes while maintaining modest gain
  - High field region with multiplication ~5um deep
  - Velocity is saturated in the low field regions (P and N)

- TCAD simulation show very promising results
  - Stable gain up to 15
  - 8% gain variation over 30um pitch pads
- First fabrication will be done at BNL and Cactus material (funded by DoE SBIR)

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This work was supported by the United States Department of Energy, grant DE-FG02-04ER41286

This work was partially performed within the CERN RD50 collaboration.

Part of this work has been financed by the European Union's Horizon 2020 Research and Innovation funding program, under Grant Agreement no. 654168 (AIDA-2020) and Grant Agreement no. 669529 (ERC UFSD669529), and by the Italian Ministero degli Affari Esteri and INFN Gruppo V.

This project was supported in part by a Launchpad Grant awarded by the Industry Alliances & Technology Commercialization office from the University of California, Santa Cruz.