On Strike! See: https://www.goodmorningamerica.com/news/video/48000-university-california-academic-workers-strike-93324508

First prototype production of DJ-LGAD:

a new approach to high granularity LGADs

45° RD50 Workshop (2022, Sevilla, Spain)

Dr. Simone M. Mazza, B. Schumm, Y. Zhao, C. Gee

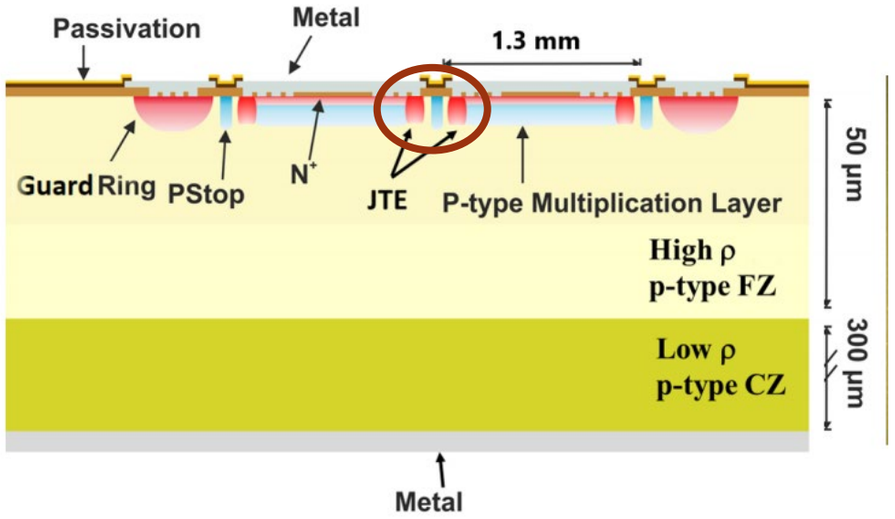
~~(SCIPP, UC Santa Cruz)~~

G. Giacomini (BNL), R. Islam, I. Ali (CACTUS)

LGAD arrays

- Granularity is a current limitation for LGADs
- 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
- Several possible solutions are being investigated by the community
  - AC-coupled (RSD) LGADs, Trench insulated LGADs, inverted LGADS…



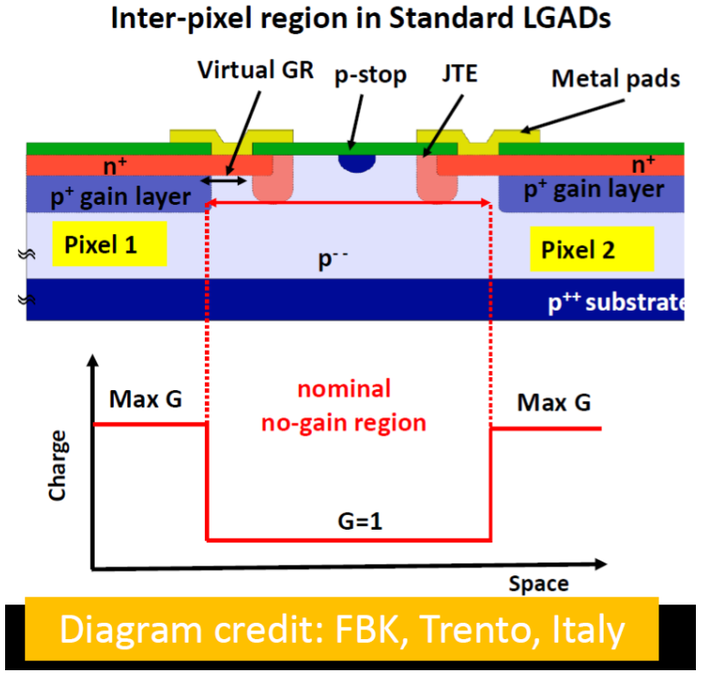


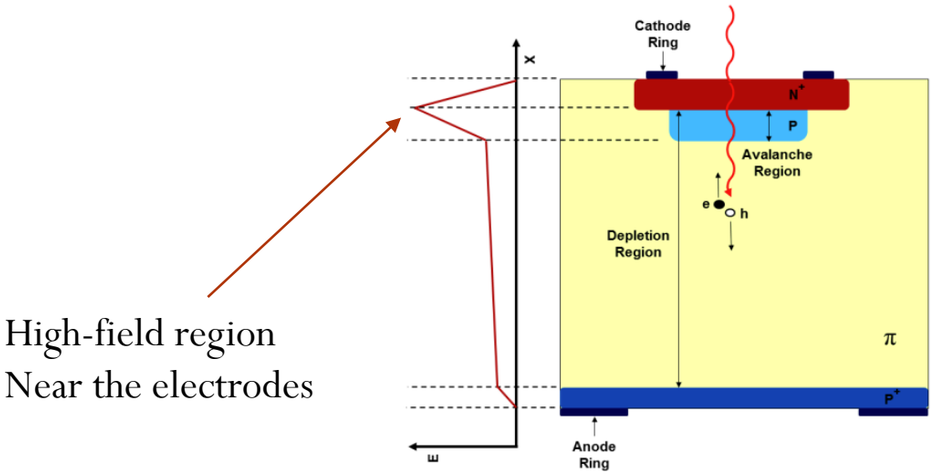
Diagram credit: FBK, Trento, Italy

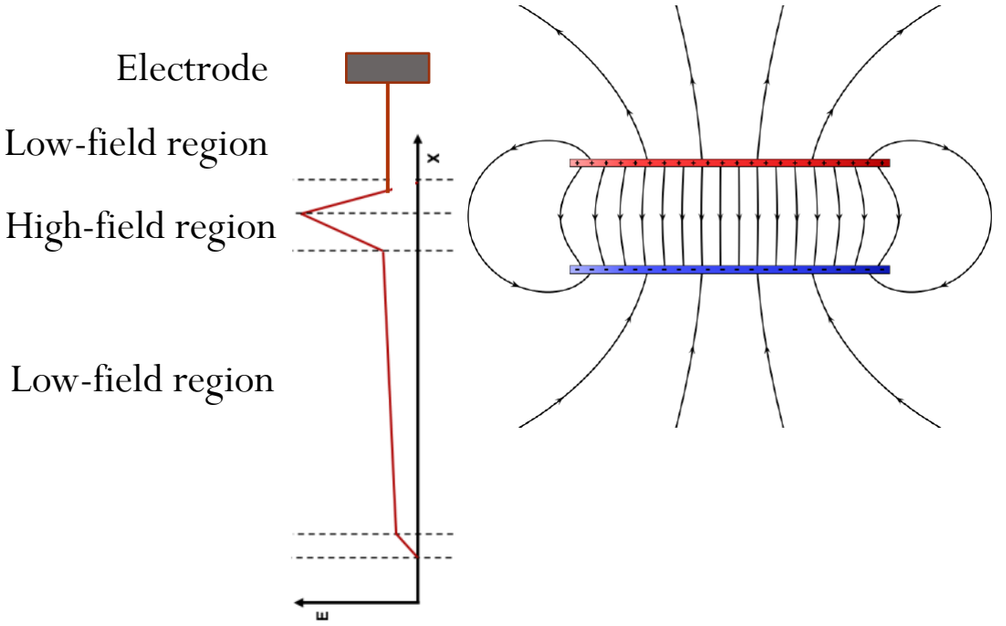
A new approach: deep junction

- 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

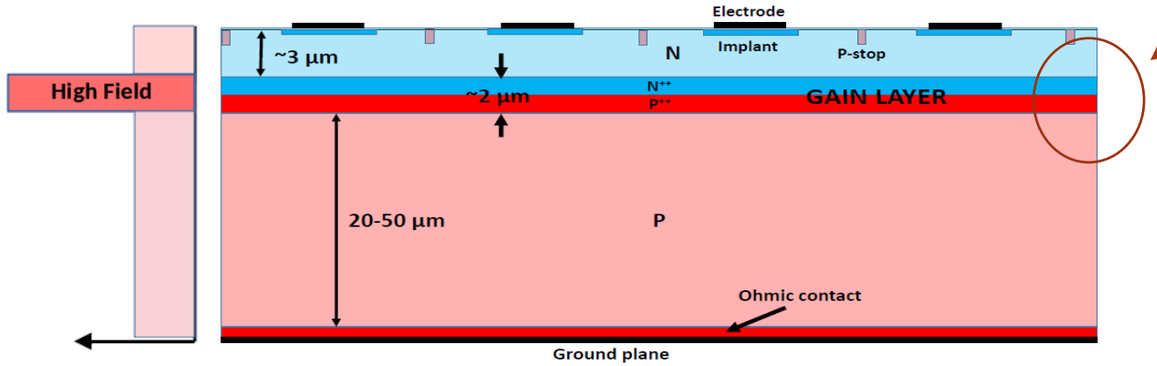
- → **"Deep Junction" LGAD (DJ-LGAD)**
- Concept presented at TREDI 2020
  - https://indico.cern.ch/event/813597/contributions/3727775/

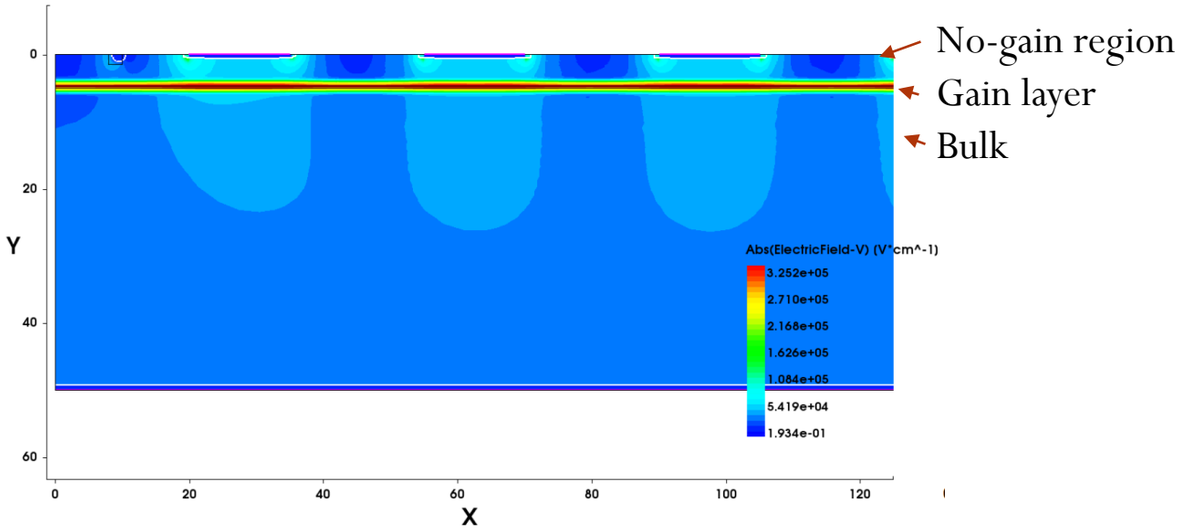




DJ-LGAD

Termination of the gain layer was studied in the first production

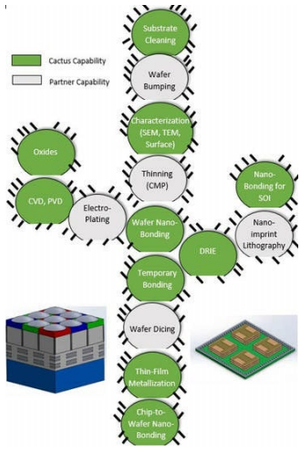


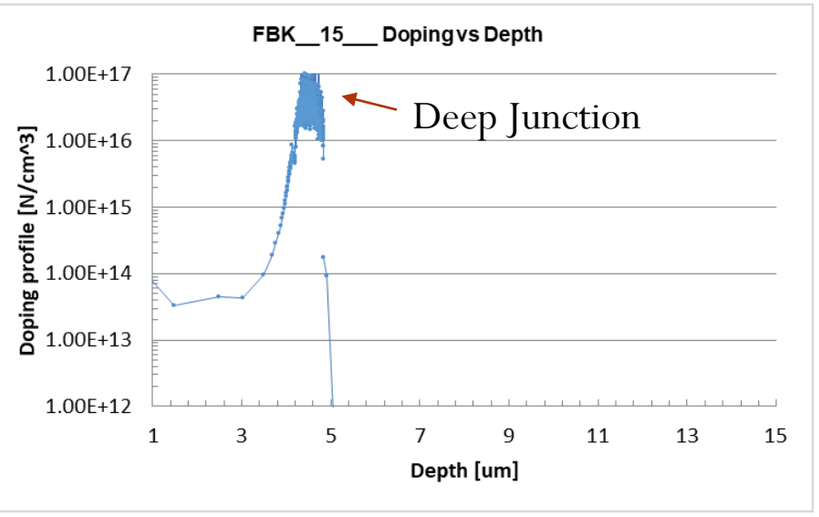


- **P++ gain layer is paired with a N++ layer that lowers the field**
  - Junction is buried ~5 um inside the detector
- Tuning of N+ and P+ parameters important
  - Low field outside of the electrodes while maintaining sufficient gain
  - No need for a JTE
  - Different termination of the gain layer designed
- DJ-LGAD design studied with TCAD Sentaurus
- First production in collaboration with BNL and CACTUS materials is ready!

- **Patent WO2021087237A1**
  - C. Gee, S. M. Mazza, B. Schumm, Y. Zhao
  - https://patents.google.com/patent/WO2021087237A1/en

Fabrication of the device



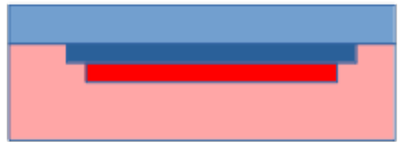


- Two productions funded by phase I SBIR were recently completed
  - UCSC in collaboration with **Cactus Material** (AZ) and **BNL**
  - Founded by DoE SBIR "A New Approach to Achieving High Granularity in Low Gain Avalanche Detectors" (34b)
  - Phase I finished, Phase II started
- **First prototype using Epitaxial layer growth**
  - Deep layer implanted and the buried by the growth
  - The prototypes breaks down early in voltage
  - However, deep junction placement was successful
  - Signal observed with high ionizing particles (alpha)
- **Second prototype using w2w bonding**
  - The production was successful with many wafers reaching completion
  - Some wafers had issues with processing after w2w bonding procedure
  - Standard PiNs but with deep junction work as well
  - High current for most prototypes to be addressed in the next production

Fabrication process for prototype run 1 and 2

Gain Layer Implantation
Similar to Conventional LGAD, but with higher energy

Epitaxial growth of high resistivity N type layer



Deposit electrodes and implants

Gain Layer Implantation
on N and P type substrate

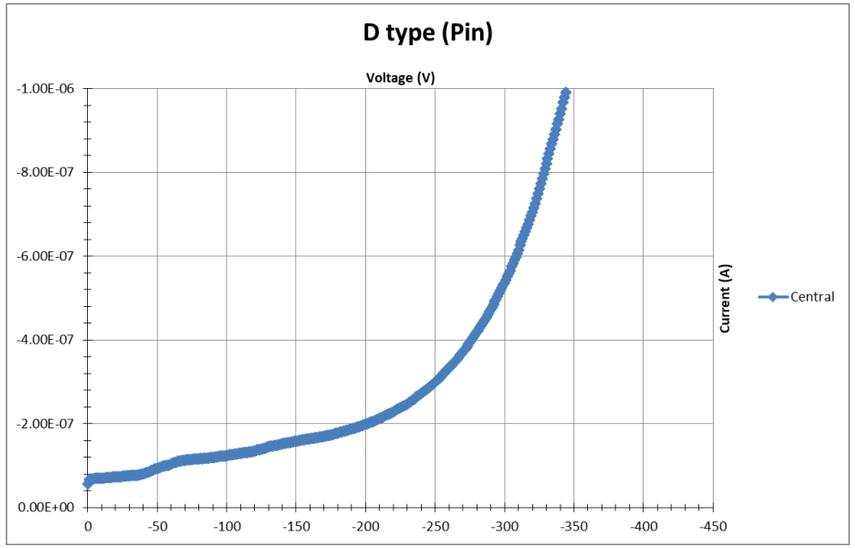
Wafer-wafer bonding

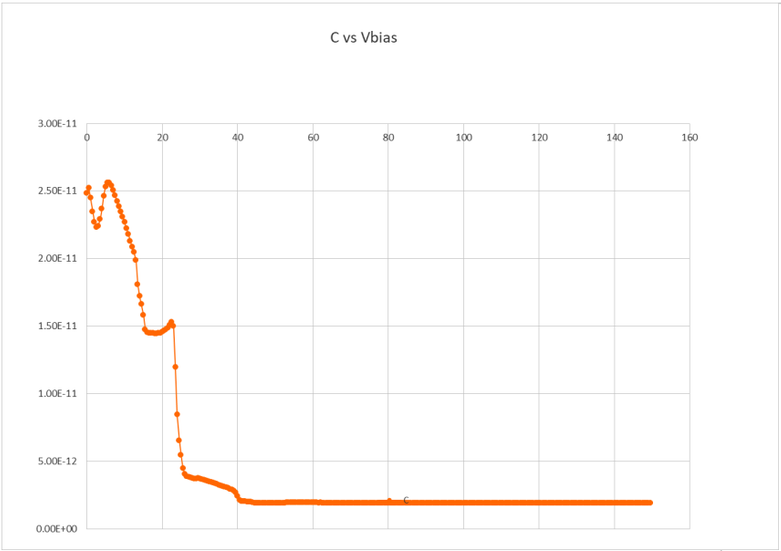
In the production there are two different ways to terminate the junction: symmetric and asymmetric

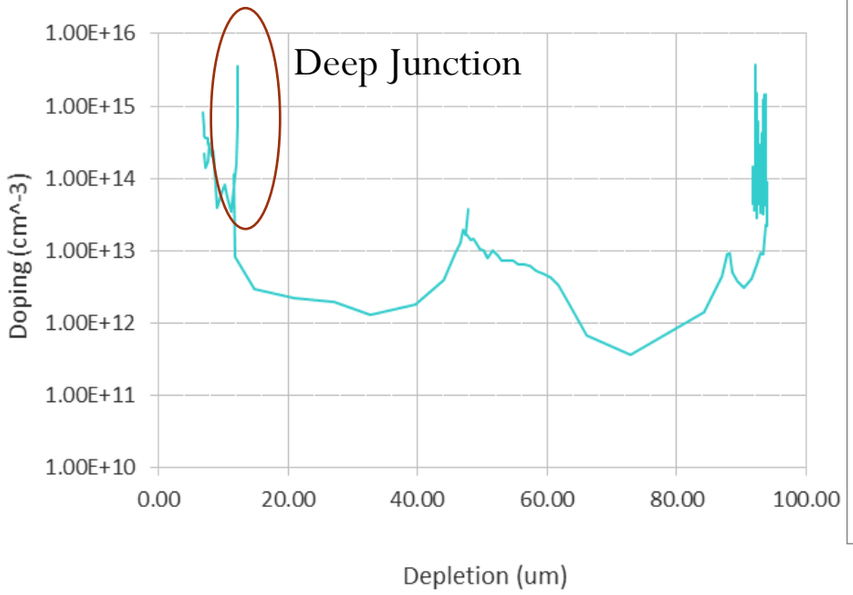
2x1 arrays were also produced and show minimal IP gap

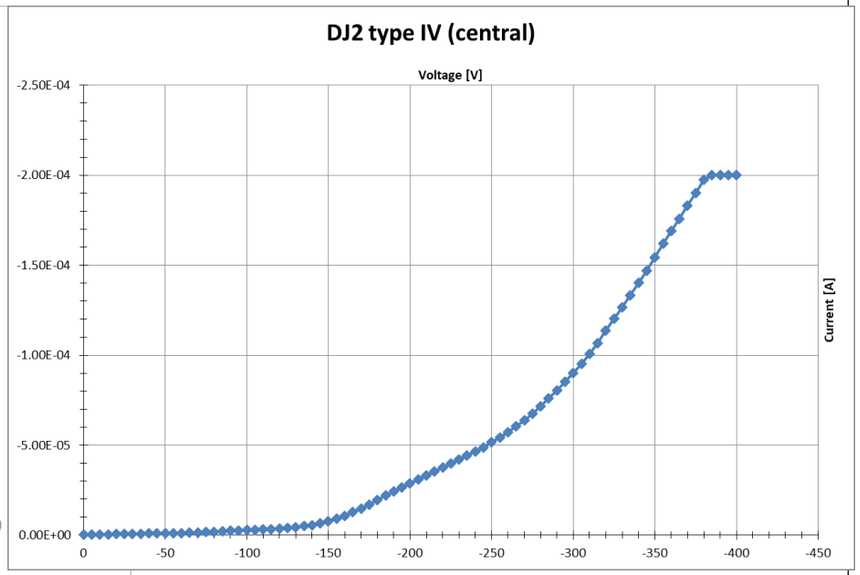
DJ-LGAD 2nd prototype run

- D-type, standard PiN with deep junction, Current <1uA
- DJ-type, deep junction ending below the active area, High current (100s uA)
  - The sensor is also very noisy, not usable
- DJ2-type, deep junction ending under the Guard ring
  - Manageable current (10s uA), BV seems to be very high
  - CV shows deep junction structure, thickness seems higher than expected
- DJ3-type, 2x1 array, termination as DJ2, Manageable current (10s uA)





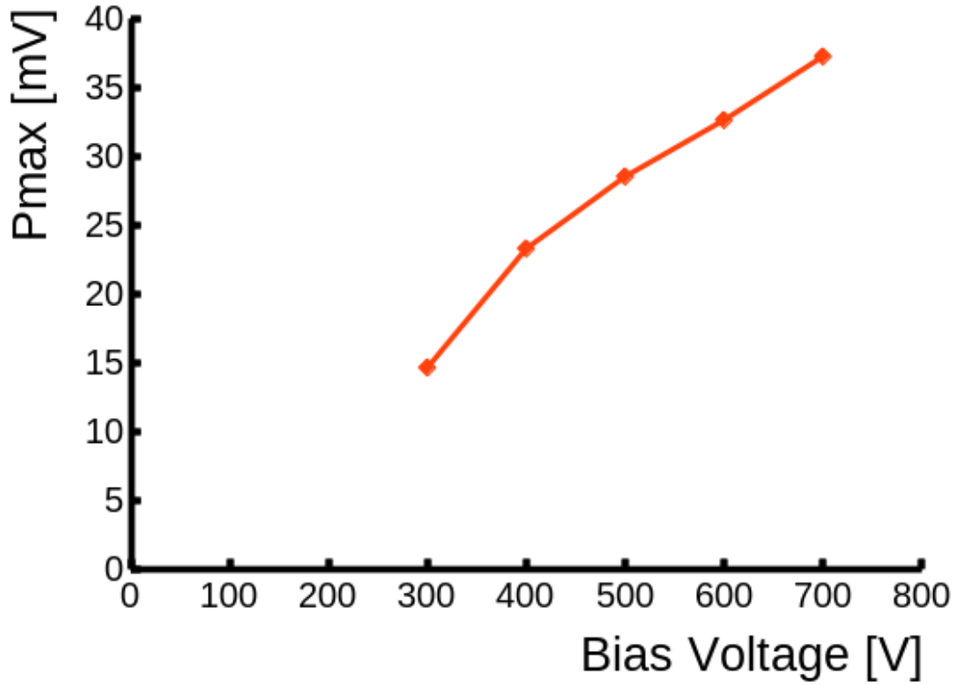


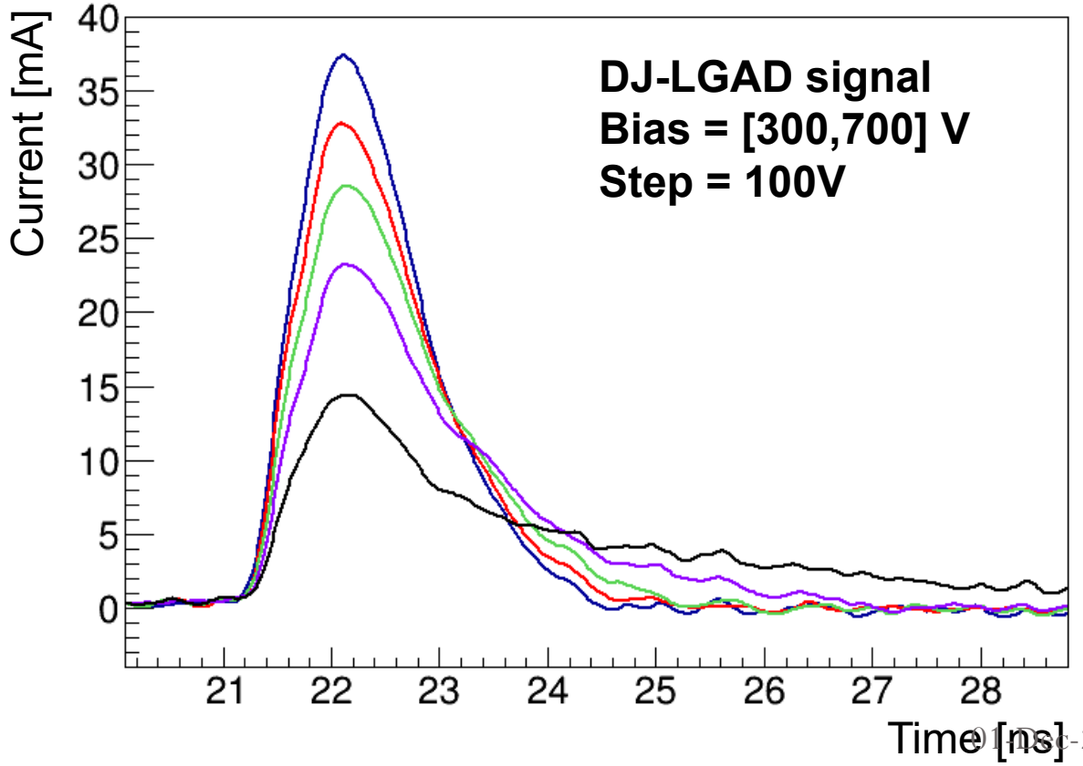


Charge collection studies

Data taken by Miguel Godoy

- Sensor mounted on UCSC 1ch and 4ch board, test with Sr90 source with know trigger sensor to study MiP response
  - Read out by fast oscilloscope, trigger on the trigger sensor
- **Rise time ~ 580 ps, similar to a typical 50-60um LGAD,** Breakdown >700V
- **Measured gain of ~ 3 to 5**
  - Lower than conventional LGAD
  - Optimization of the gain layer doping is required for future prototype

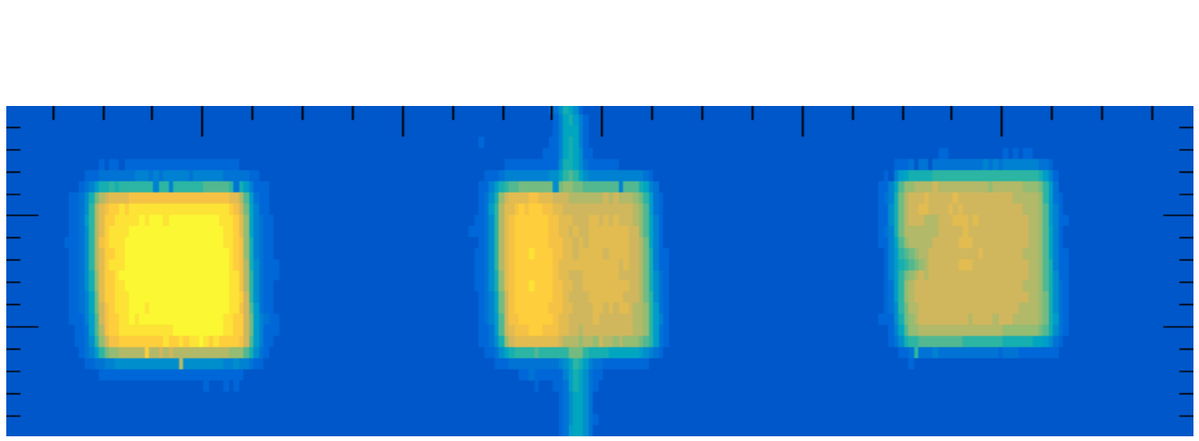


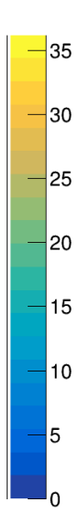


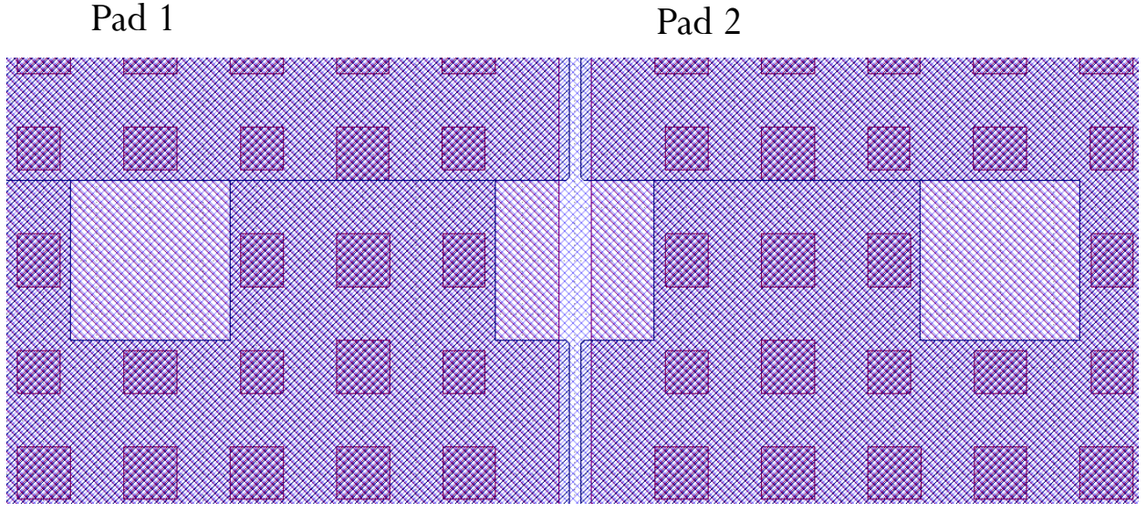
Laser studies

Data taken by Yuzhan Zhao

- **DJ-LGAD 2x1 array prototype is studied with IR Laser scan**
  - Digitized by fast scope, laser spot size is 10-20 um
- Pmax values in terms of the laser beam location are shown for sum of channels
  - Sensors have 3 open areas in the metal, one in each pad and in between pads
  - In the scan the blue low signal region corresponds to the metal
  - The sum of the two signals is more or less constant on the sensor (no gain loss in between pads)







Laser studies

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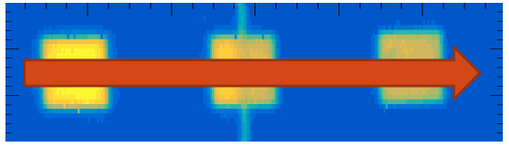
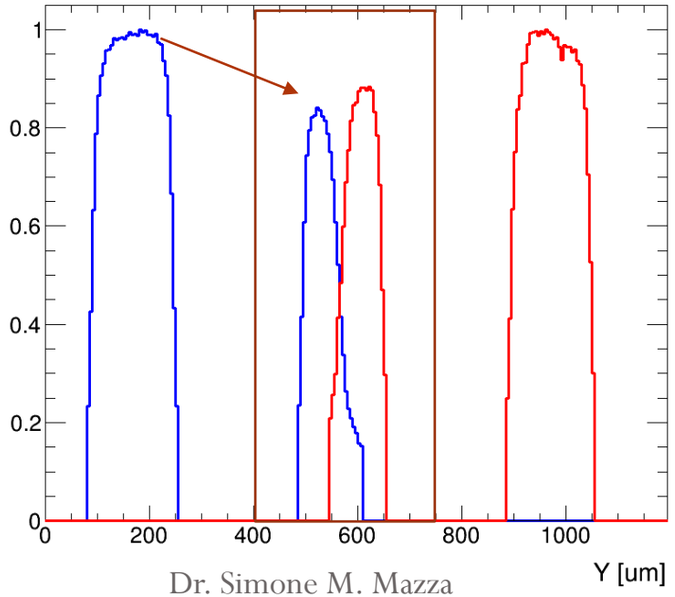


- **1D profile fractions shows a slightly lower signal next to the gap**
  - 2D simulation shows the field in the gain layer is reduced in the inter pad region
- Zoom in the inter pad region (nominal electrode gap is 30um)
  - Sum of signal show almost no reduction in the gain
  - Minor cross talk in a 50 um region between pads

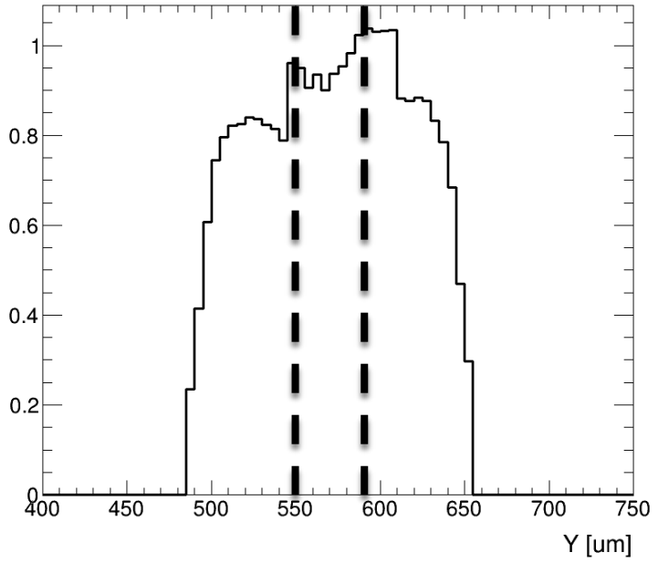
The pmax fraction of an individual strip is defined as:

$$pmax\ fraction\ (channel) = \frac{pmax\ (channel)}{\sum pmax}$$

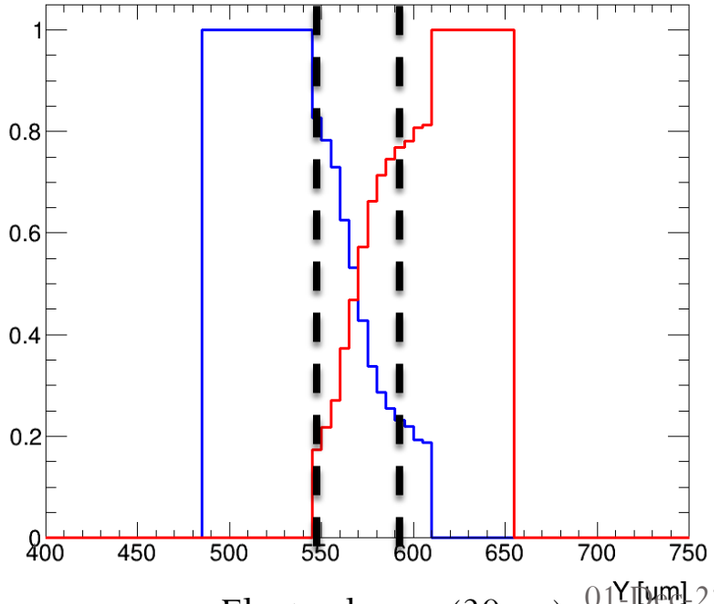
Normalized profile for Pad 1 and 2



Normalized sum of Pad 1 and 2



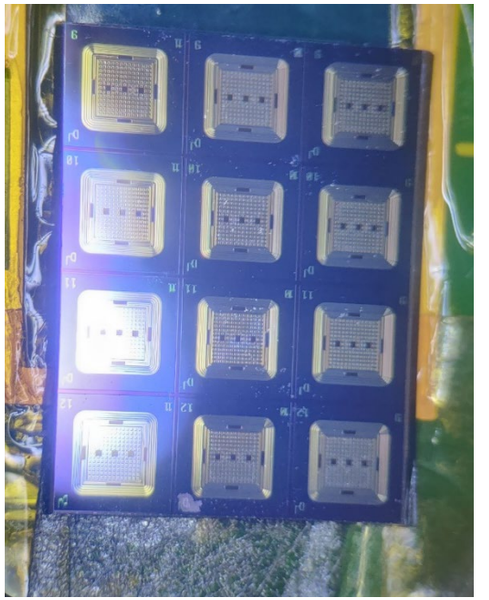
Fractional Pmax profile between Pad 1 and 2

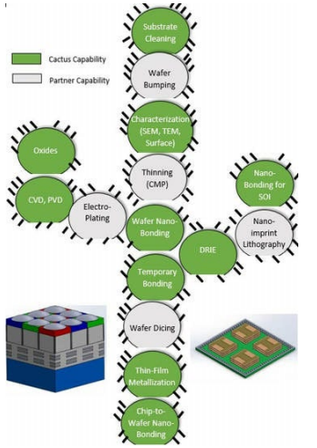


Electrode gap (30um)

Conclusions

- **DJ-LGAD: a device with deep gain layer**
  - Avoid high field near the electrodes while maintaining gain
- Presented the results of first working DJ-LGAD prototype
  - **Demonstrated that the Deep-Junction can be fabricated with epitaxial growth and w2w bonding**
  - Shows very good signal/charge uniformity across channels
  - Almost no IP-gap is present between pads, small cross talk
- Future production for DJ-LGAD has already started (funded by phase II SBIR), issues to solve:
  - Very large leakage current → reduce the current to level of conventional LGAD
  - The gain is lower than conventional LGAD → optimize the doping in the future prototype
- **DJ-LGAD technology can be used as the base concept for many other new types of devices!**





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