Sensor testing updates at UCSC

Simone Mazza (SCIPP, UC Santa Cruz)

Update on sensor testing at UCSC

- Comparison of HPK devices from 2023, 2024 and 2025 productions to investigate time resolution loss
  - Laser TCT
  - Beta source telescope (see next contribution)
- Testing of new batch of irradiated devices (2 weeks ago)
  - Irradiated at FNAL with low to high fluence
  - Full size sensors irradiated
  - Plans: IV/CV/N+ change/Laser TCT
- Test of new double metal HPK strip sensor
  - Laser TCT

Irradiated full sensors

FNAL irradiated sensors

- Irradiated full size sensors and test structures at FNAL
- <u>1e13</u>, 1e14, 5e14, 1e15Neq
- Important to check effect on large devices:
  - Increase of leakage current (relevant)
  - Performance change (likely not for ePIC)
  - Secondary effects

- Testing ongoing
  - IV/CV almost done
  - N+ resistivity from test structures
  - Laser TCT

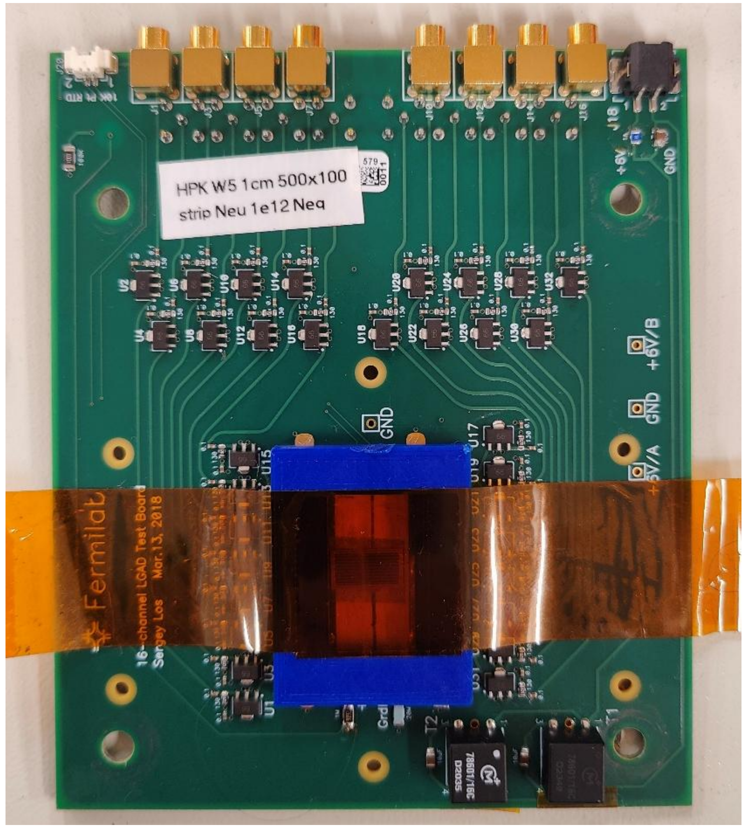
- Also testing extremely irradiated devices
- Not of interest for ePIC, towards FCC

Strip sensor 2023, 2024, 2025 comparison

Comparison of HPK devices from 2023, 2024 and 2025

- Laser TCT data comparison, using same laser power, maximum voltage
  - Note: same laser power is not same injected charge (variations occur)
  - Scans over a single strip electrode

2023



2024 (S16694)

2025 (ePIC1)

Comparison of HPK devices from 2023, 2024 and 2025

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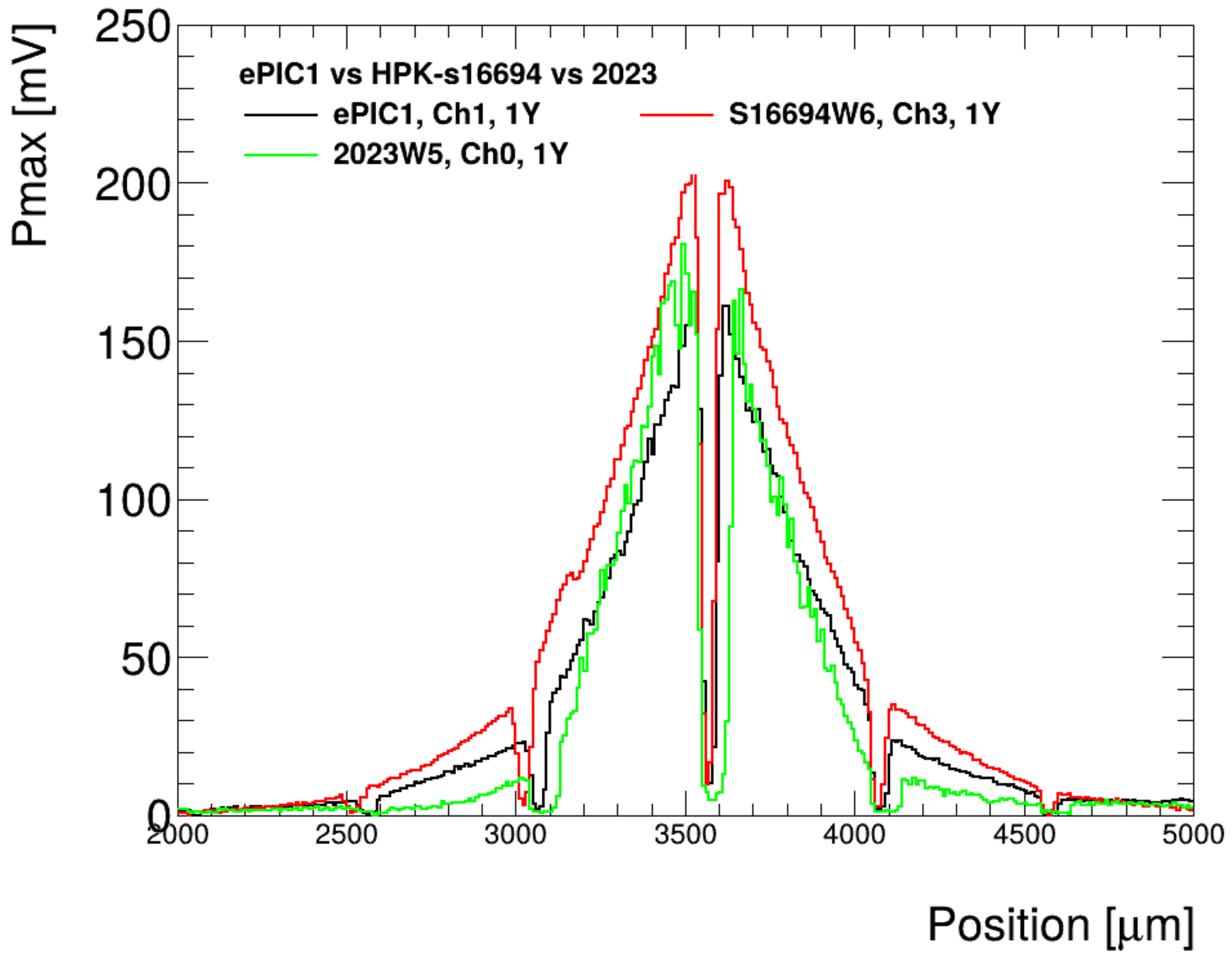
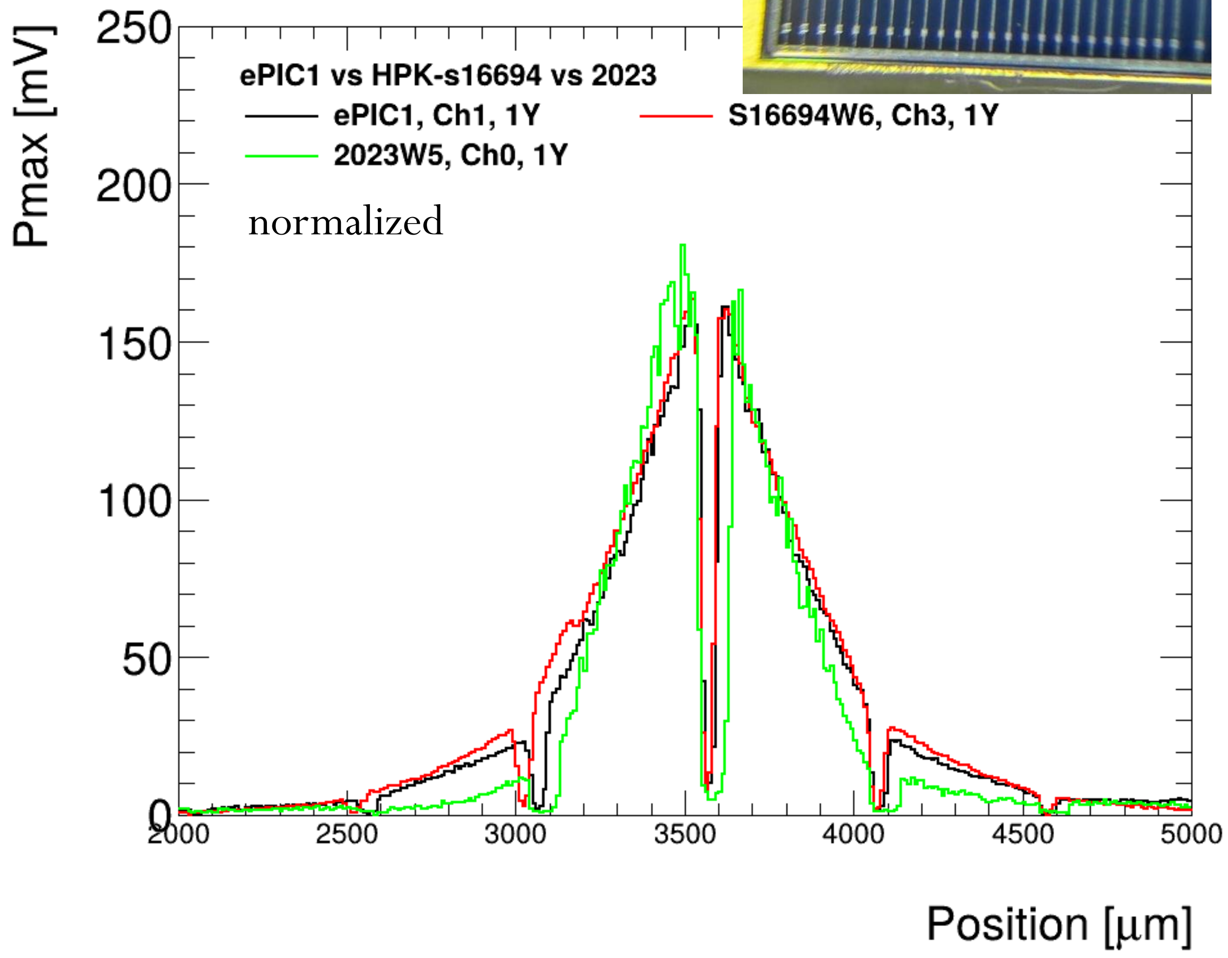
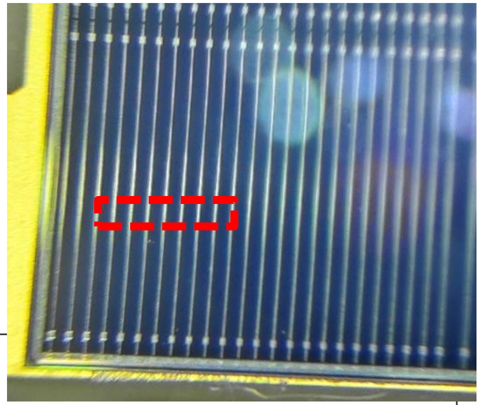
  - Note: same laser power is not same injected charge (variations occur)







Comparison of HPK devices from 2023, 2024 and 2025

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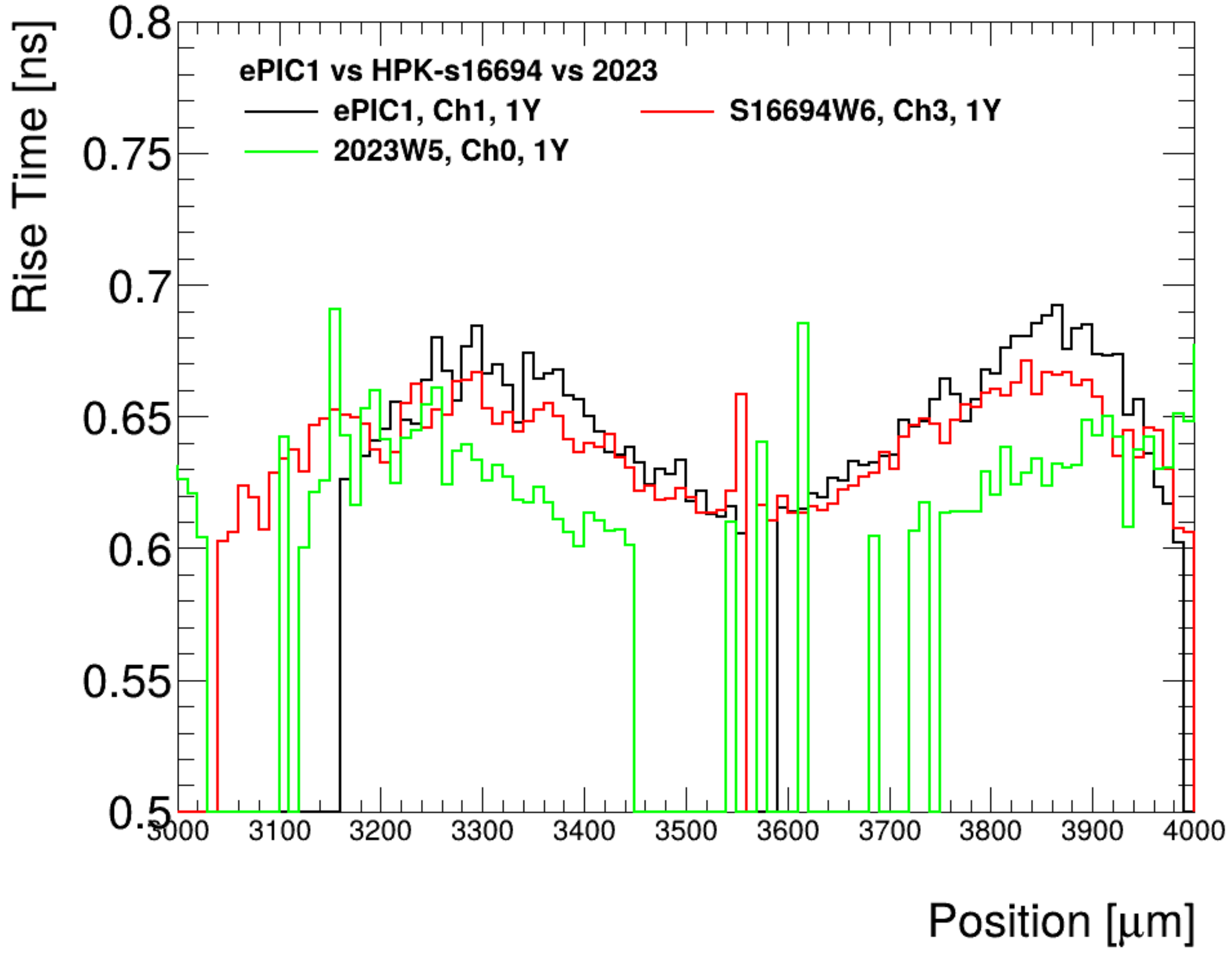
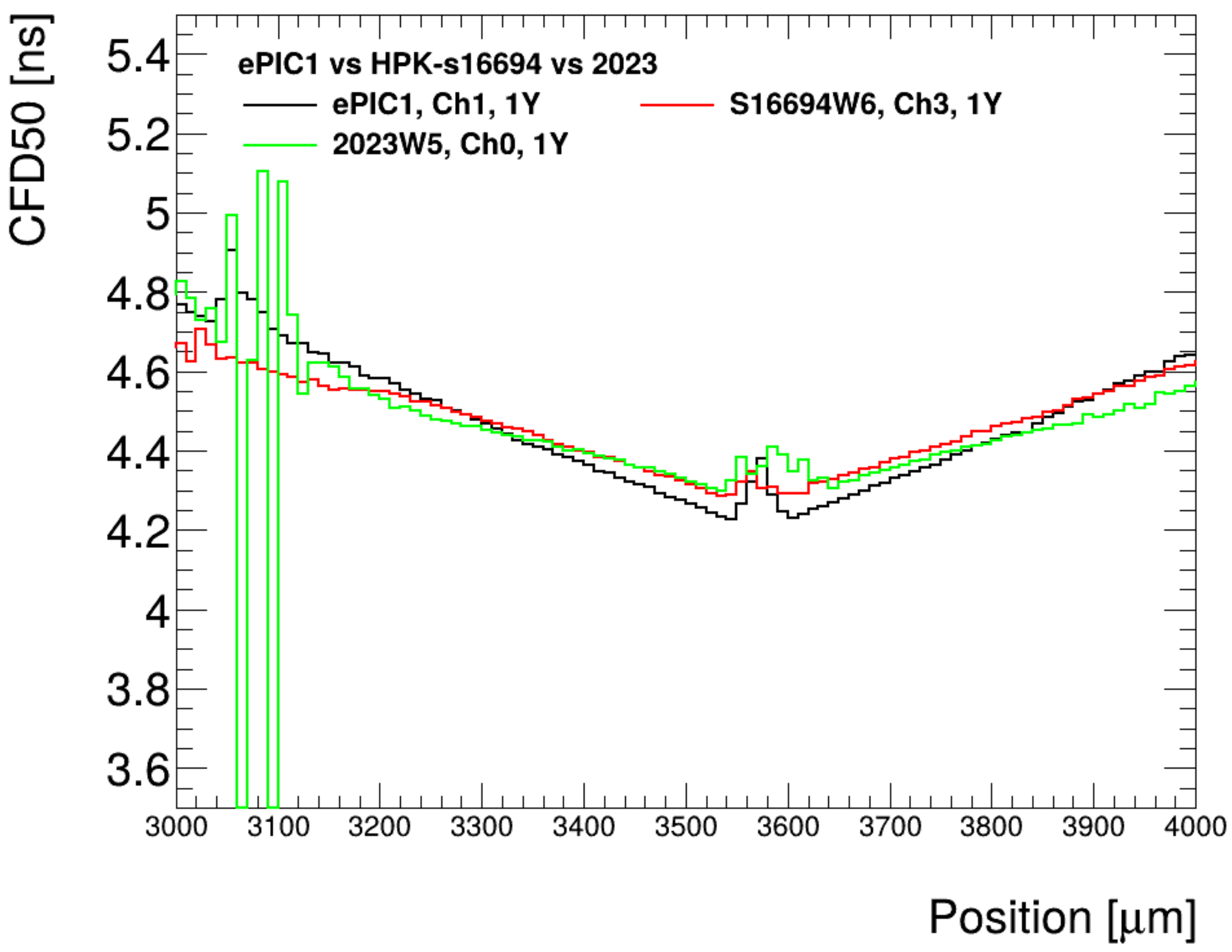




Comparison of HPK devices from 2023, 2024 and 2025

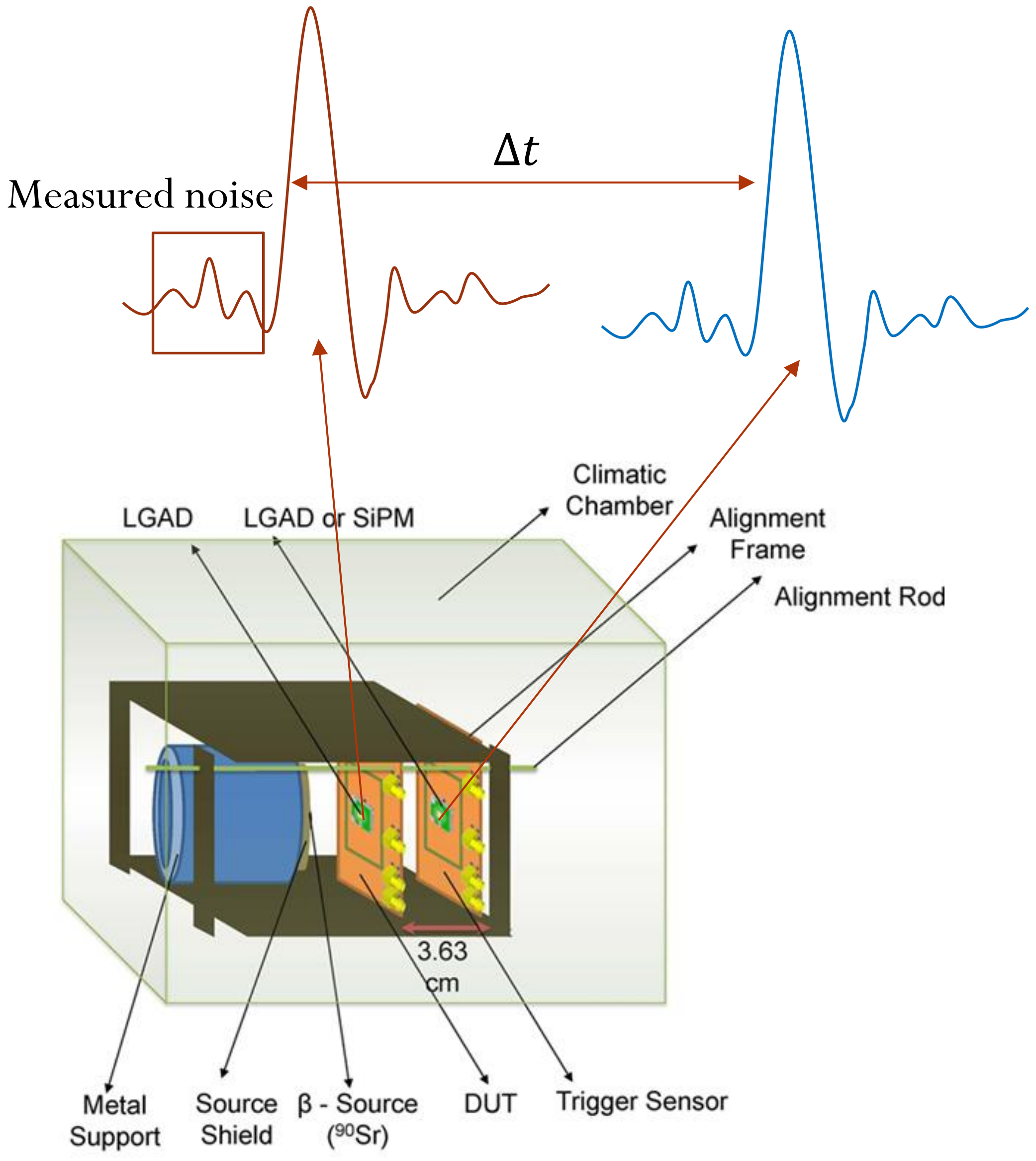
- Laser TCT data comparison, using same laser power, maximum voltage
  - Note: same laser power is not same injected charge (variations occur)

- Comments:
  - Using the same laser power we get roughly the same signal for the three devices
  - Rise time is comparable
  - Time of arrival correction is comparable

- Notes:
  - The 2023 sensor has the same thickness, N+ resistivity and oxide as S16694
  - The 2025 has a different oxide thickness (thicker)
  - The 2024 and 2025 sensors have the same geometry 500x50um
  - The 2023 is 500x100um, I can’t find a 500x50um anymore
  - The 2023 is also very lightly irradiated, but that should not affect performance

Sensor testing – Sr90 telescope

Details: S.M. Mazza et al. arXiv:1804.05449



- **Same sensors tested with beta source with coincidence trigger**
- Two sensors are aligned with a beta source
  - DUT (Device Under Test) to characterize: **on 16ch board, readout 3 strips. Use to reconstruct event position**
  - Trigger with known performance, **1mm size**
- Sensors mounted on fast amplifier boards (~2Ghz) and read out by a fast oscilloscope (2Ghz, 20Gs)

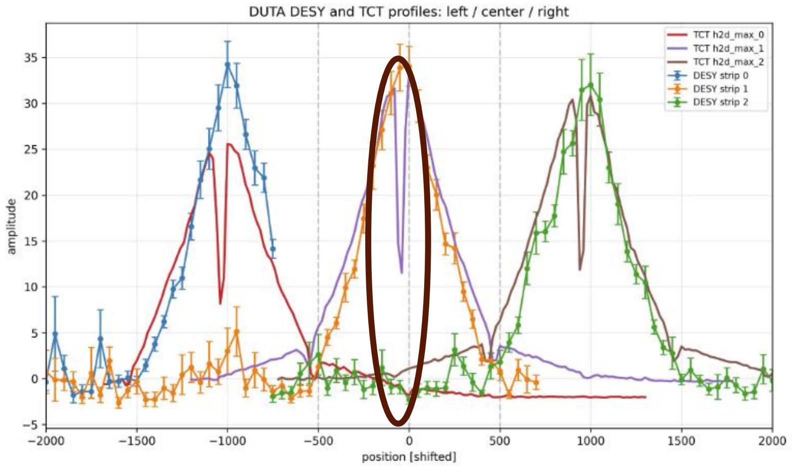
- **Collected charge**
- **Time resolution**: sigma of time difference between trigger sensor (with known time resolution) and DUT,
- **Gain**: collected charge divided by collected charge in same thickness PiN

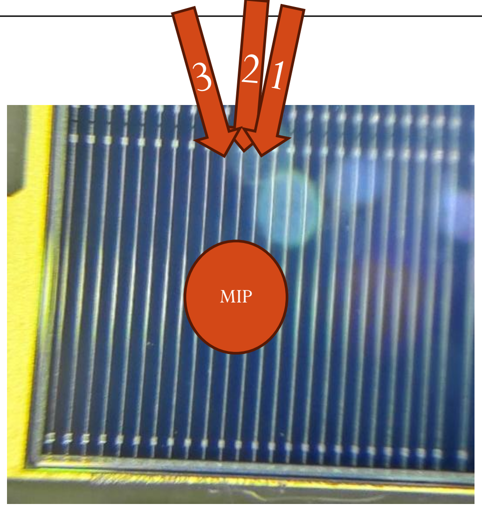
- **Data taking still ongoing**
- **See next talk!**

Pmax under center strip

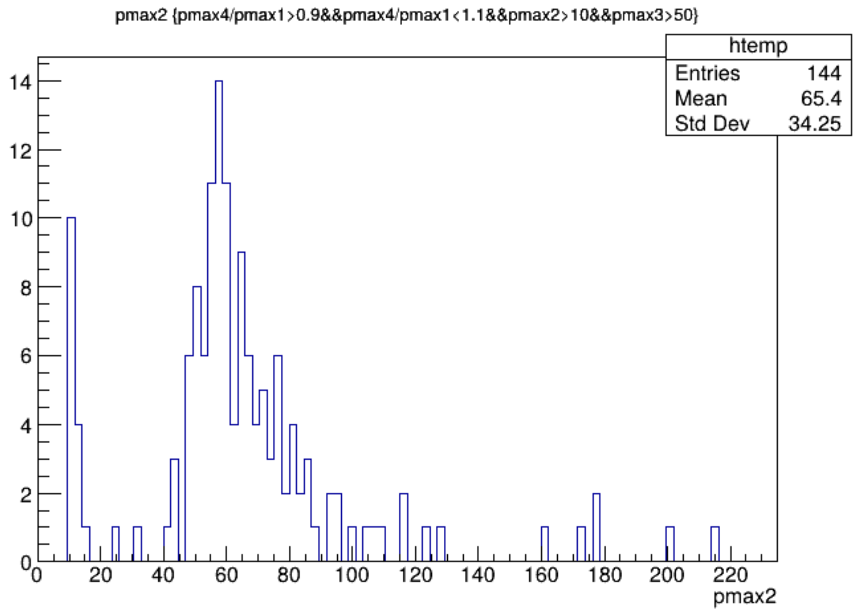
"Dumb" quick analysis: select events under strip 2 by assuming same signal from Strip 1 and strip 3

Laser TCT was off by ~50% of 1 MIP
Signal for 2024 and 2025 ~same, 2023 has lower signal?
Trying higher voltage for 2023 (190V --> 210V) data taking ongoing

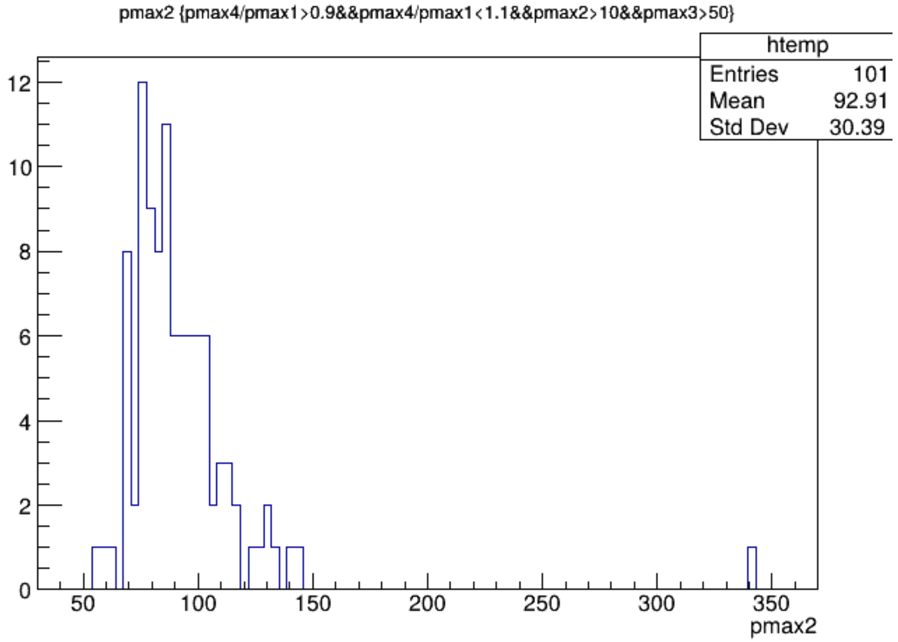




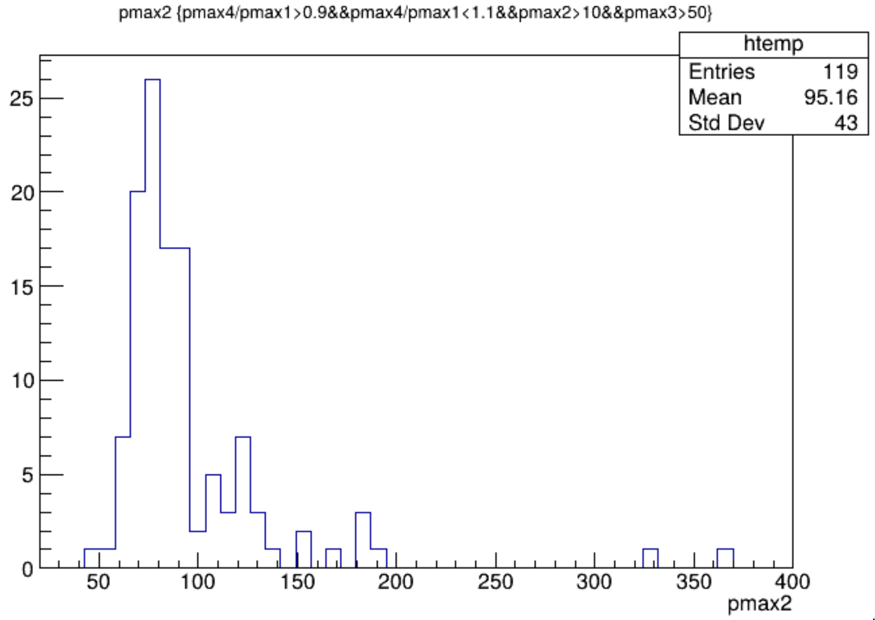
2023



2024



2025

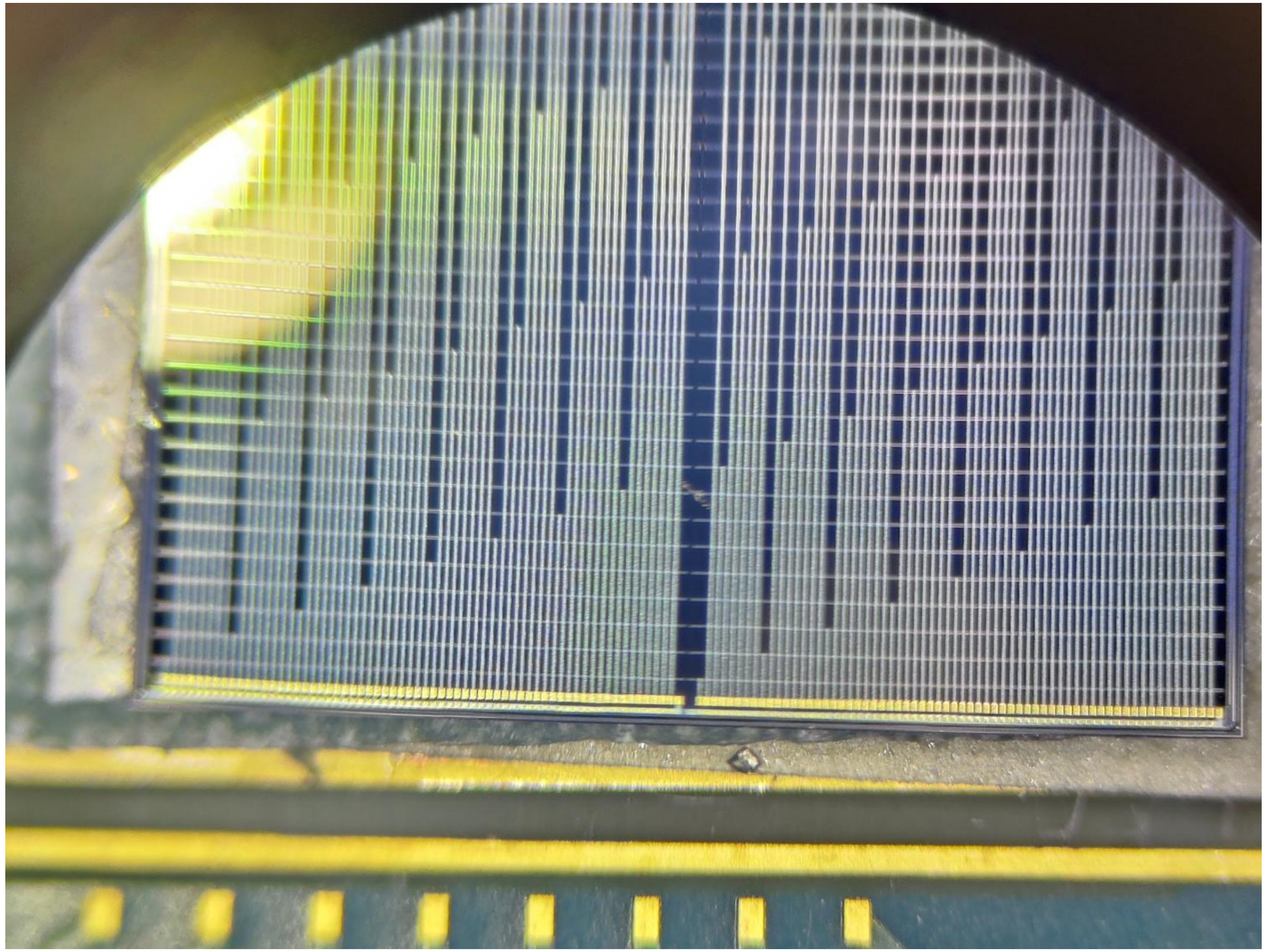


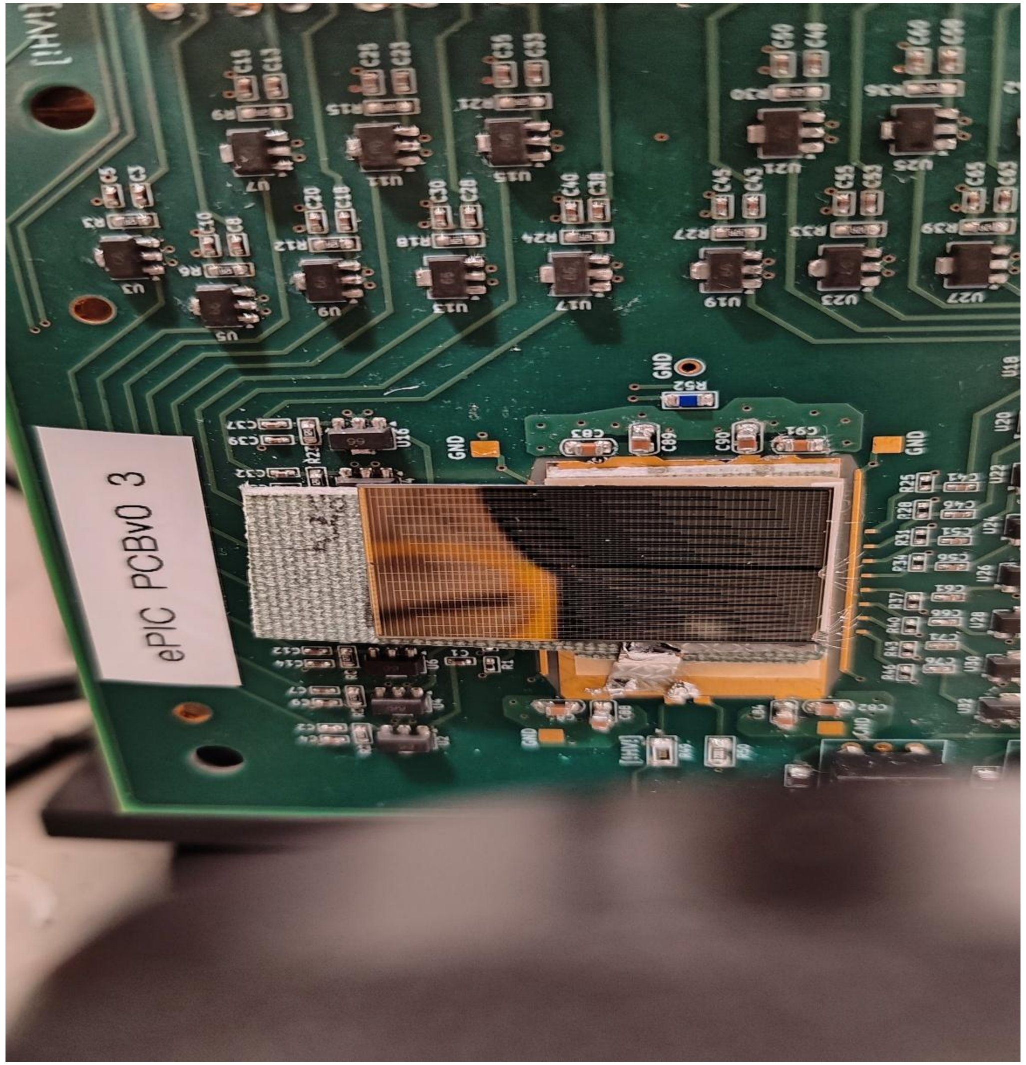

```
wfm->Draw("pmax2","pmax4/pmax1>0.9&&pmax4/pmax1<1.1&&pmax2>10&&pmax3>50")
```

Pmax3 is trigger

Double metal sensor

New double metal sensor





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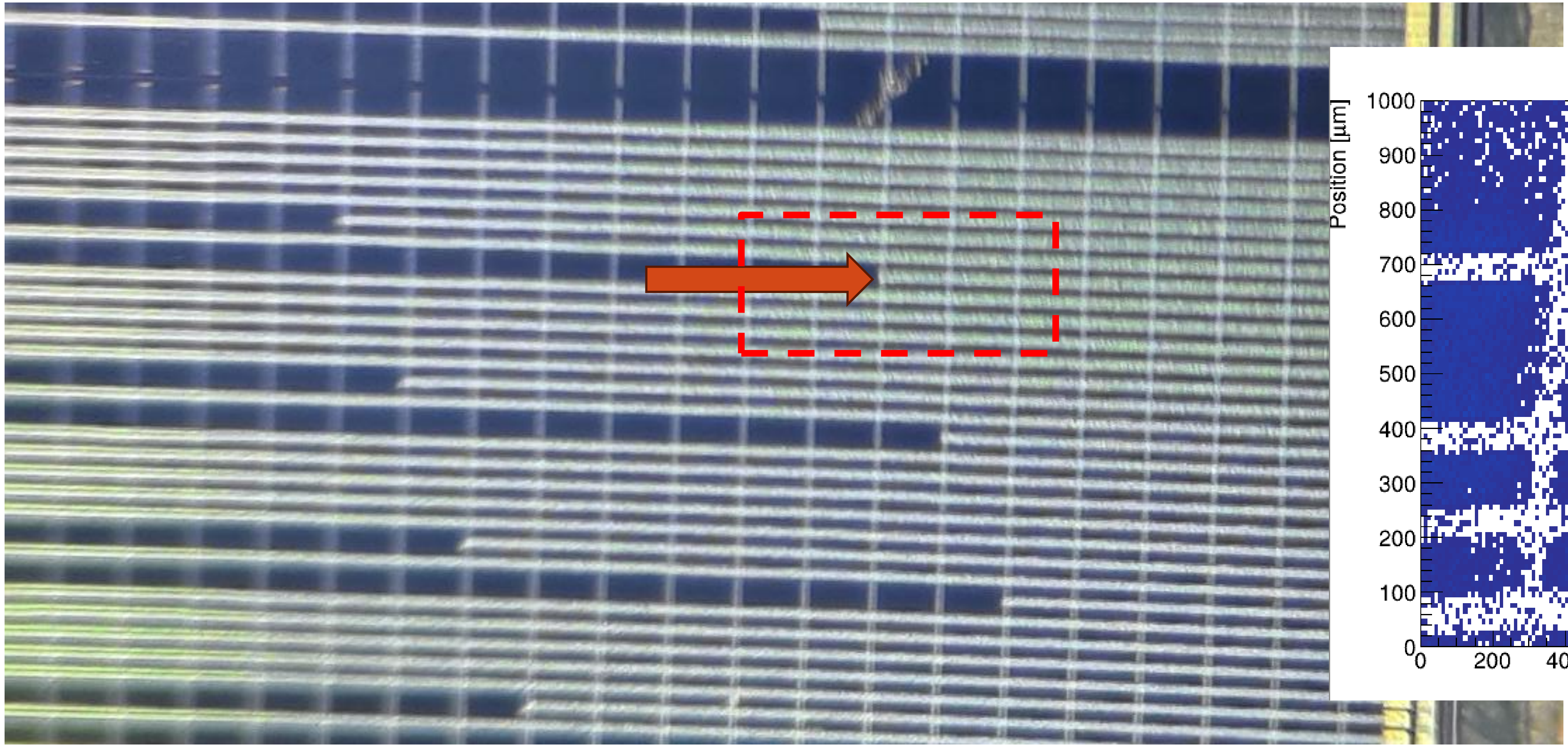

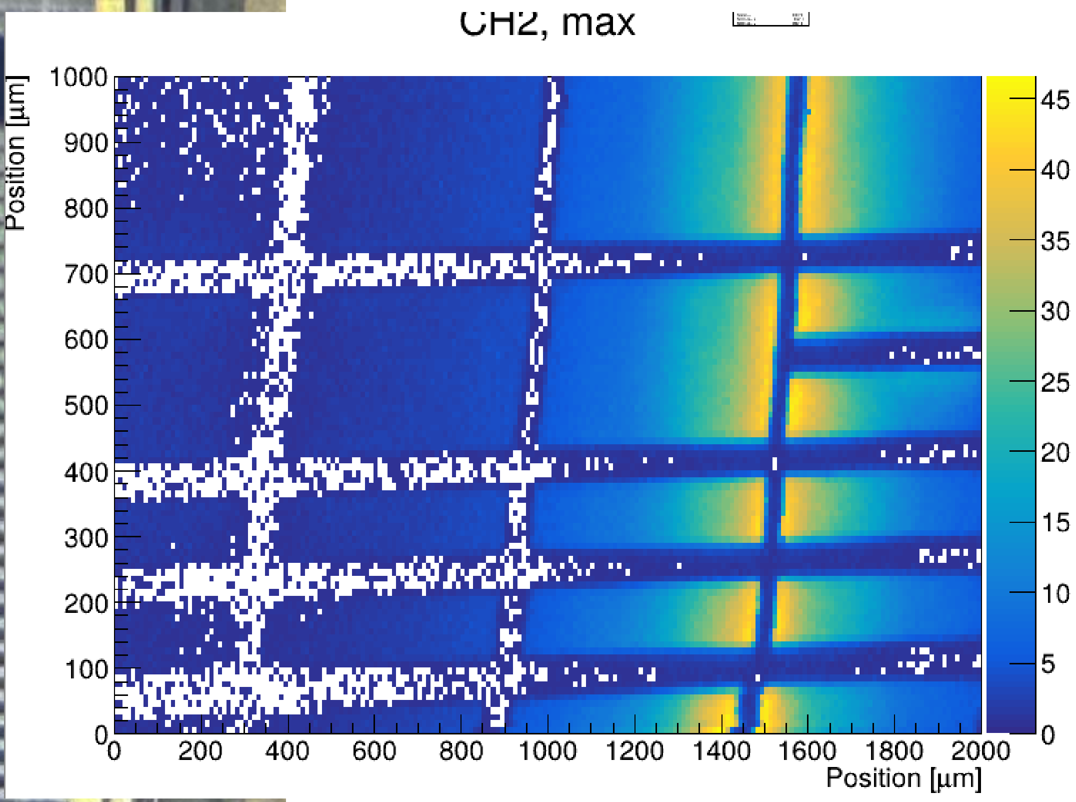

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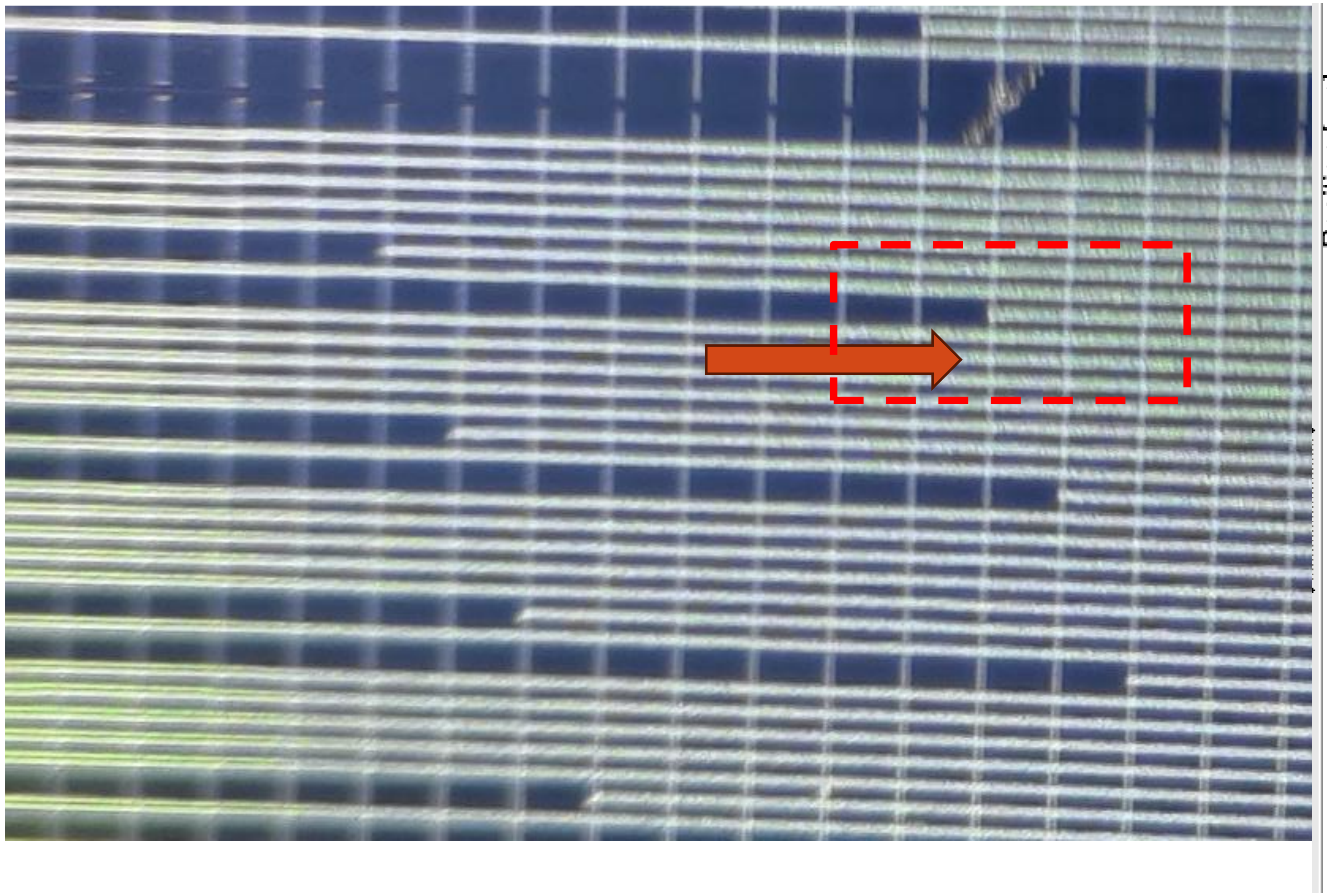
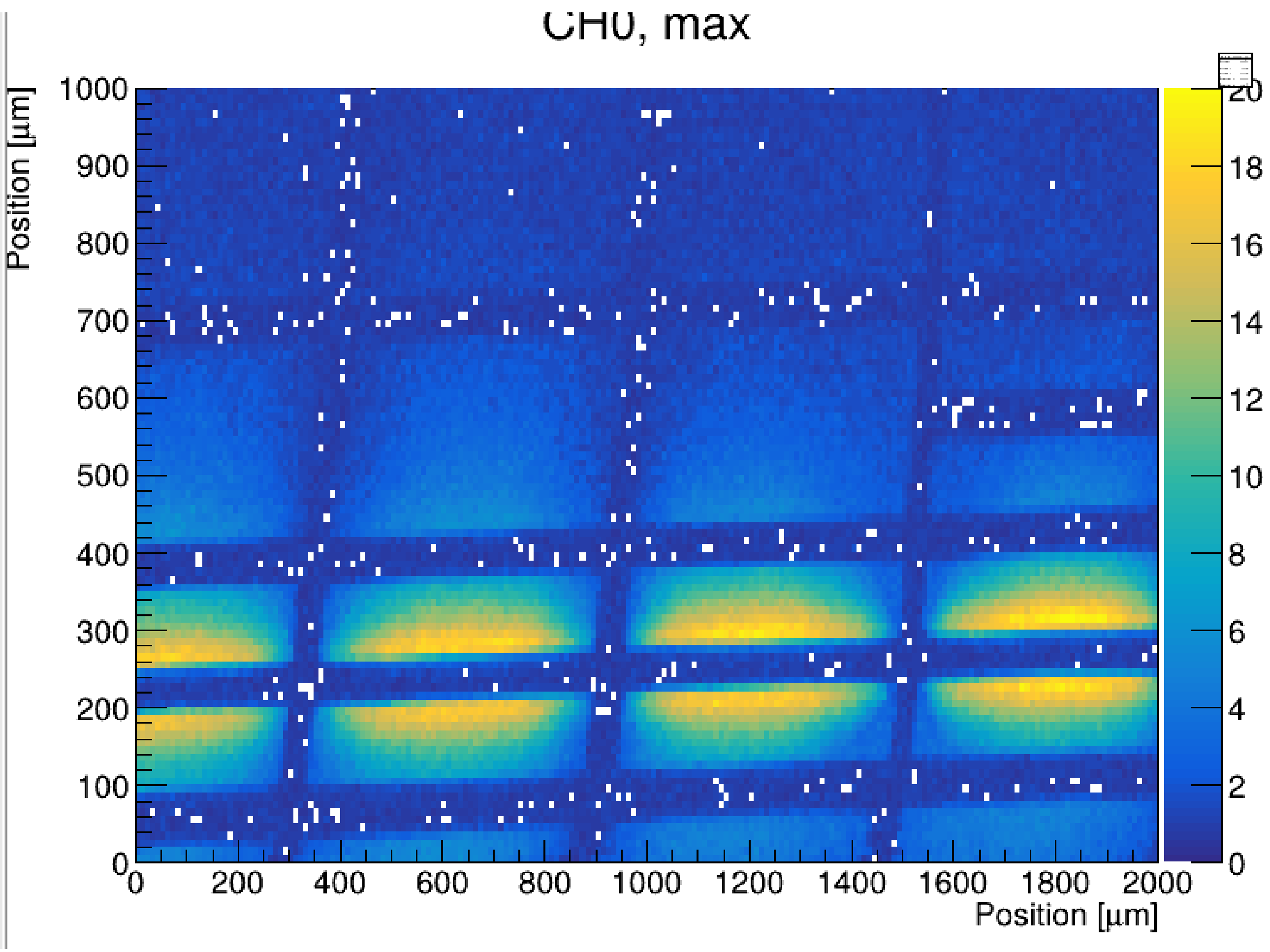


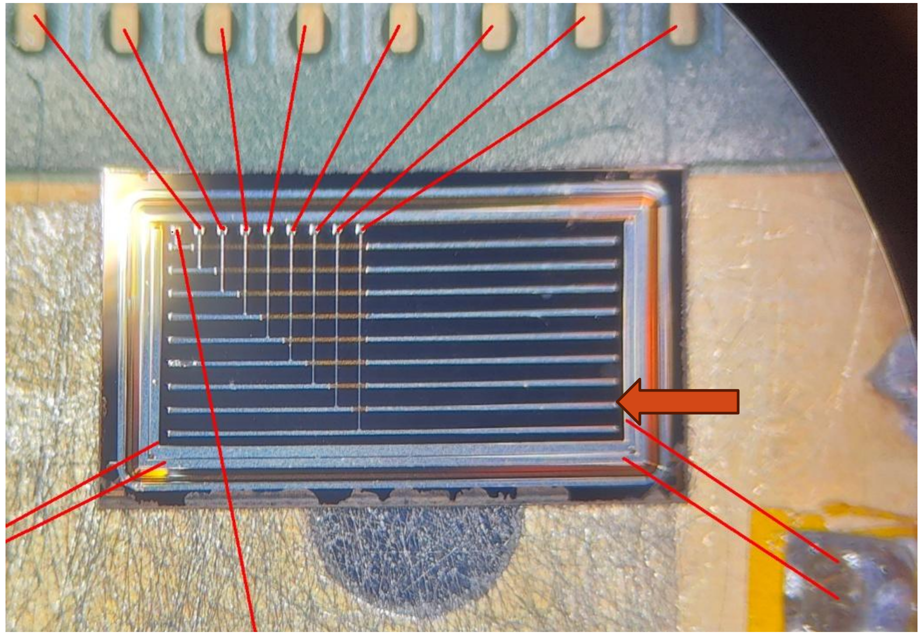


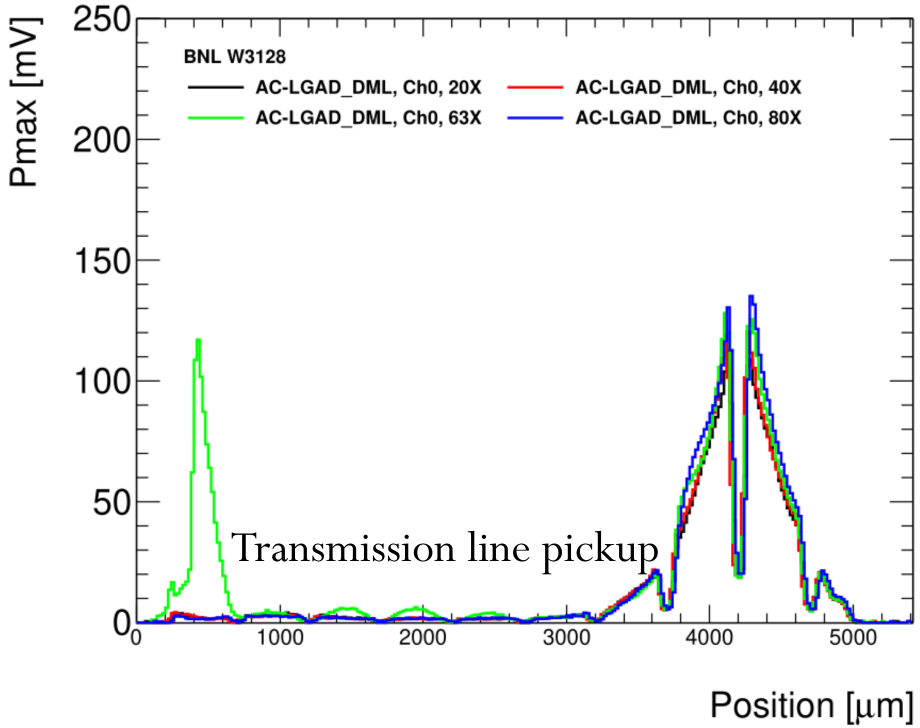
New double metal sensor

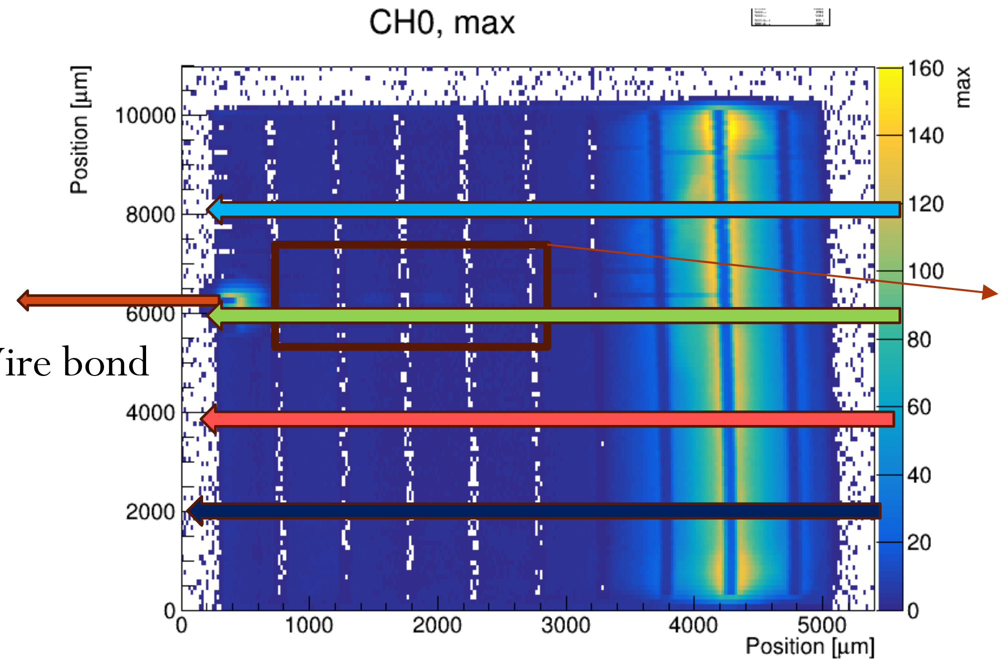
- Transmission lines pick up a lot of signal, around ½ of real electrodes
- Probably too wide or 2nd oxide too thin
- BNL device had much less transmission line pickup (~4%)
- Analysis ongoing, probably need better connection scheme

DML AC-LGADs

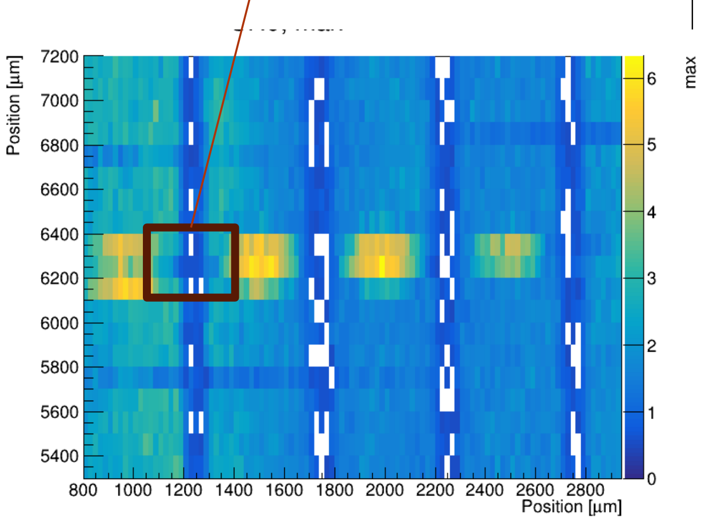
- Proof of principle works! Behaves as standard AC-LGAD
- Pickup of the cross strip is minimal, extra pickup at the bonding pad
  - Pickup on the line is ~4%
  - Cross talk with perpendicular strip hard to test with laser
- Behavior across the strip is homogeneous
  - Both Pmax and rise time are ok
- **Signal delays are complex to correct for**
  - Large delays due to transmission lines
  - Signal propagation in strip and transmission line is different







Can’t test crosstalk under metal

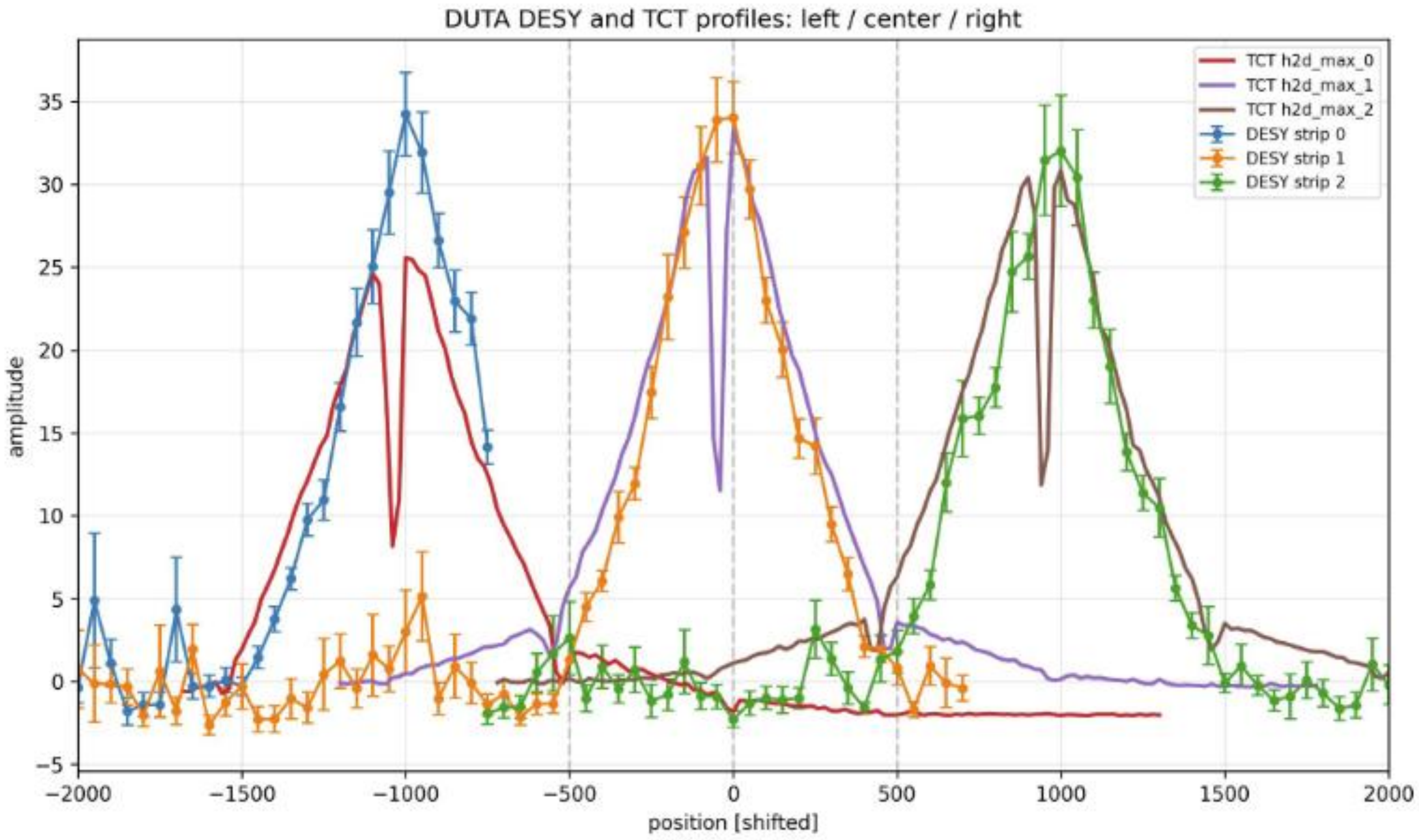


Student: A. Molnar, C. Altafulla

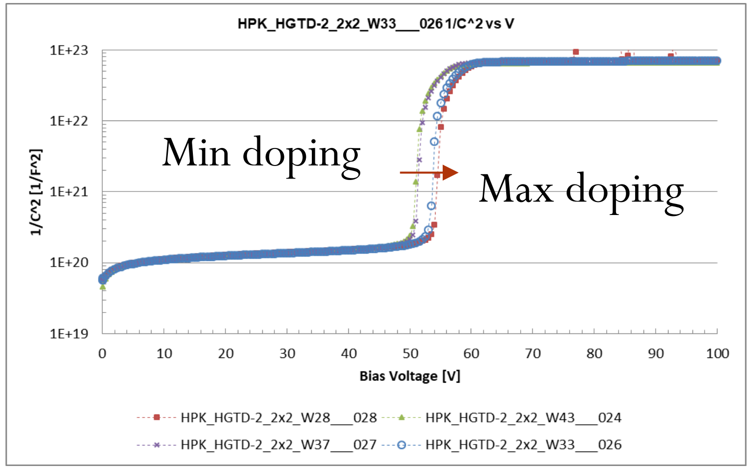
Backup

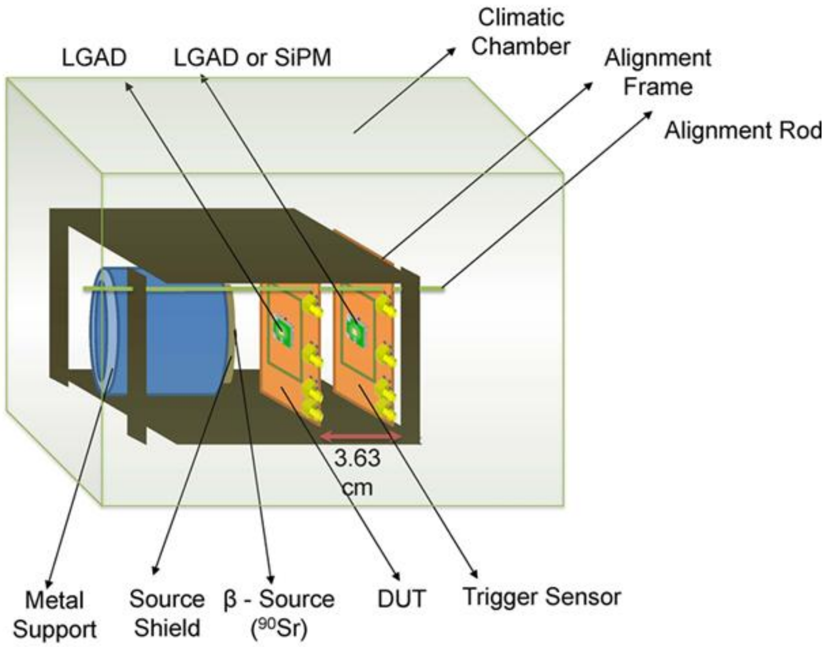
Laser TCT and testbeam comparison

- Pretty good agreement!



Sensor testing –probe station, charge collection





- **Probe station electrical testing**
- Current of voltage (IV) and Capacitance over voltage (CV)
- CV is used to probe the doping profile of the gain layer

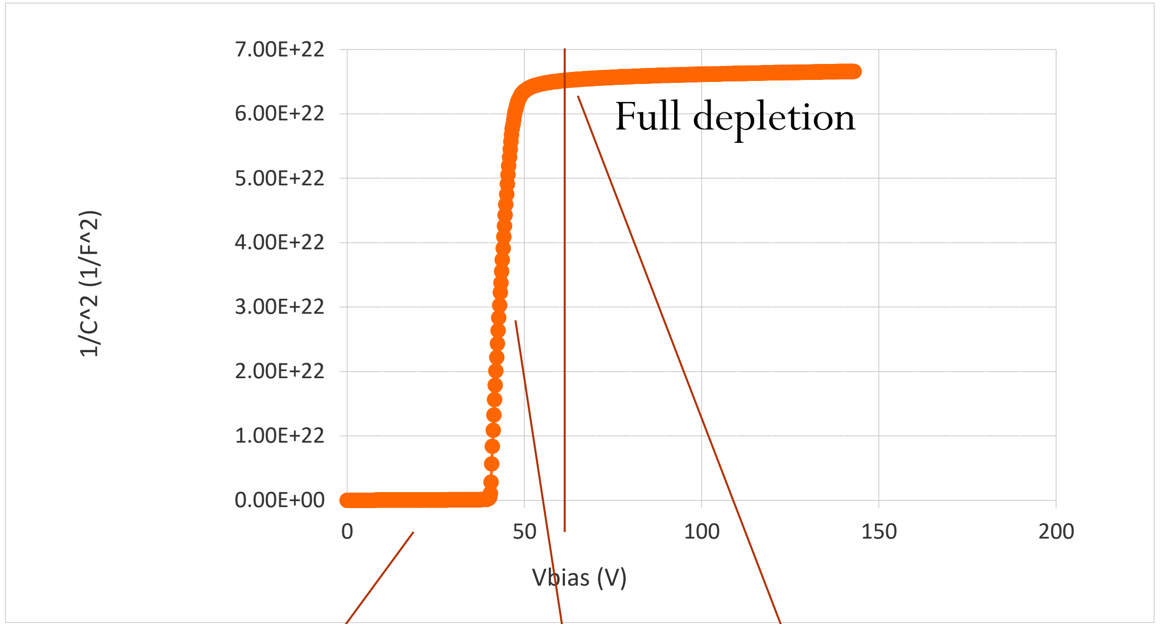
- **Laboratory charge collection**
- Using MiP electrons from a Sr90 β-source (β-telescope)
  - Signal shape, noise, **collected charge**, gain, **time resolution**
- Using Alpha source in vacuum (Am237), ~100 MIPs deposition
- Using X-ray gun

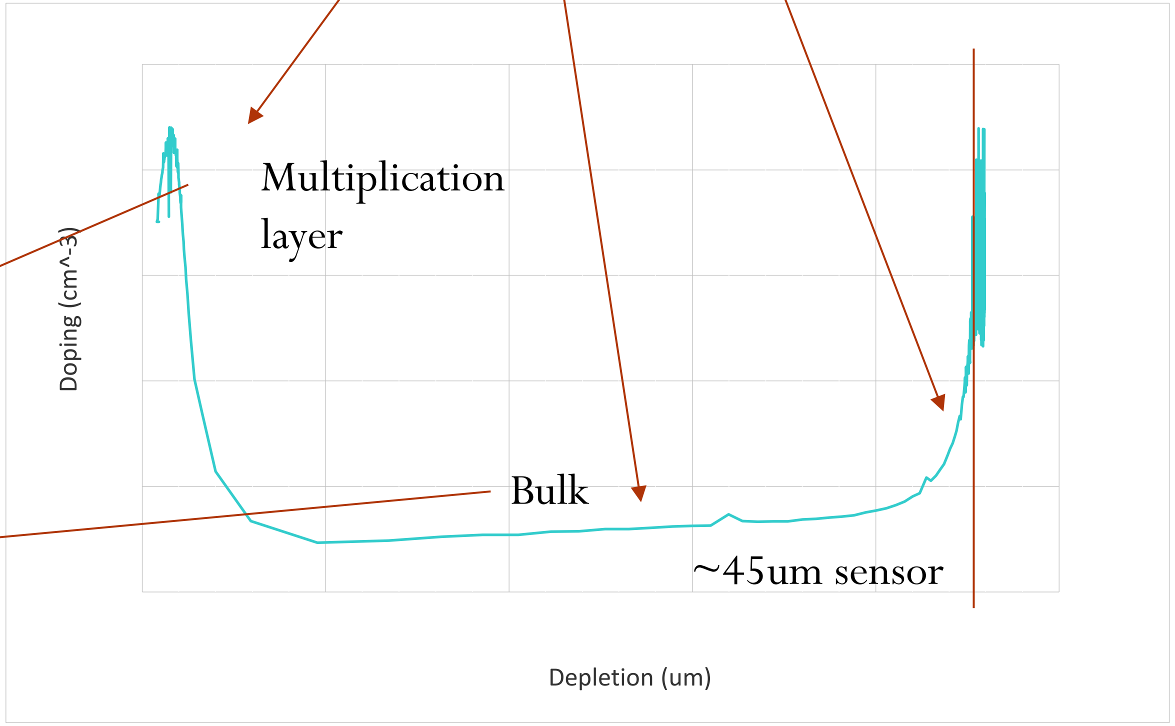
- **Laser TCT studies**
  - IR laser mimics a MiP response and allows charge injection as a function of position
  - Particularly useful to test arrays and AC-LGADs (see later)

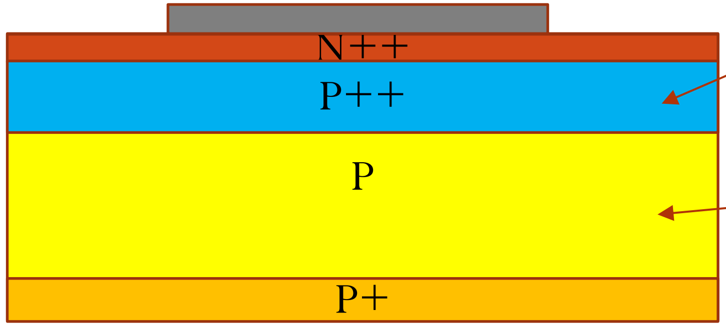
- **Test beam at facilities (CERN, DESY, FNAL)**
  - Allows the study of MiP response with position information through an external tracker

Sensor testing – IV/CV

- Capacitance over voltage (CV)
  - Study doping concentration profile and full depletion of the sensor
  - Doping profile can be extracted from the $1/C^2$ derivative
- Study of the “foot” for LGADs on $1/C^2$
  - $1/C^2$ is flat until depletion of multiplication layer because of the high doping concentration
  - Proportional to gain layer active concentration
- Bulk doping concentration proportional to the derivative of $1/C^2$ before depletion







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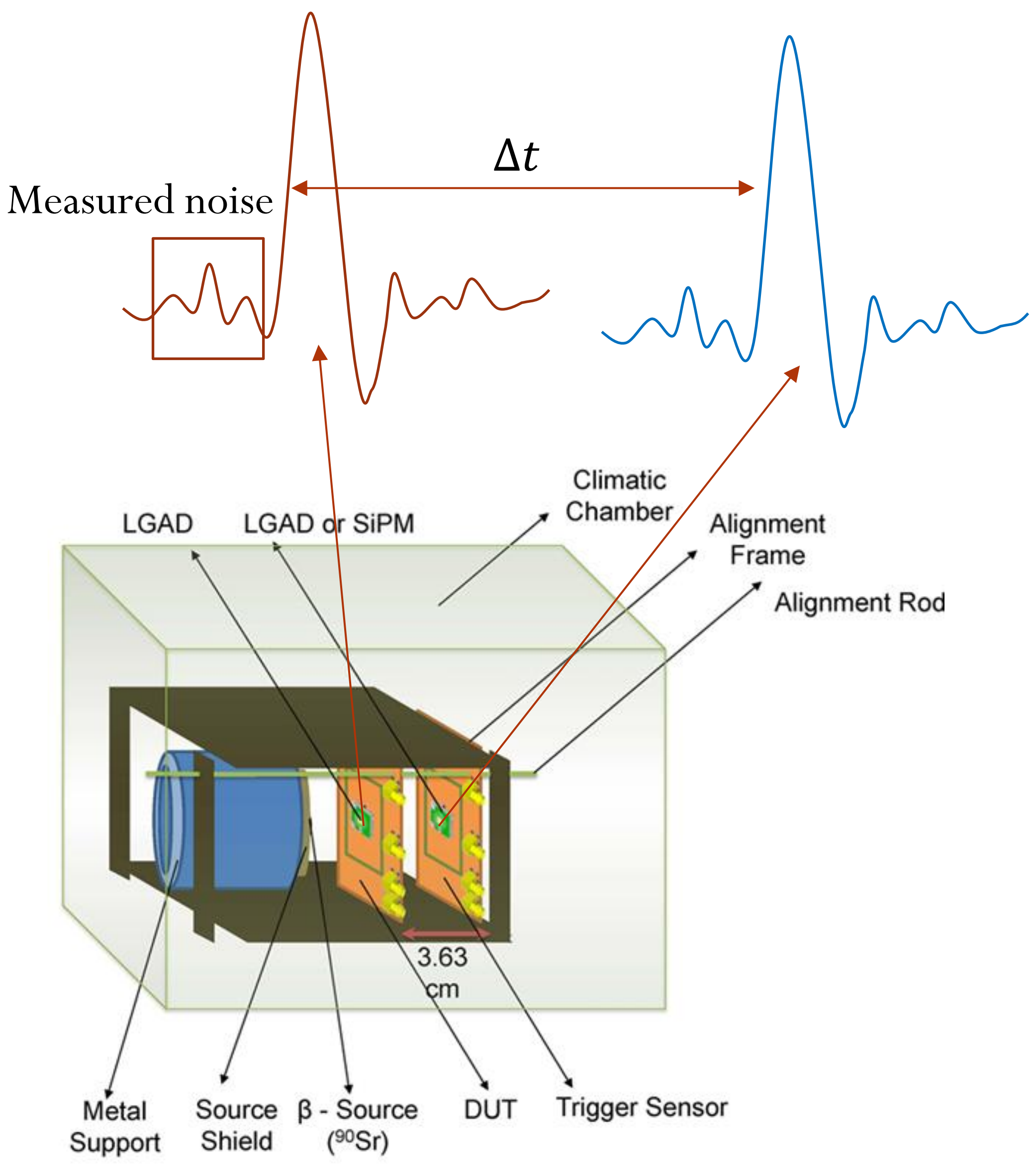
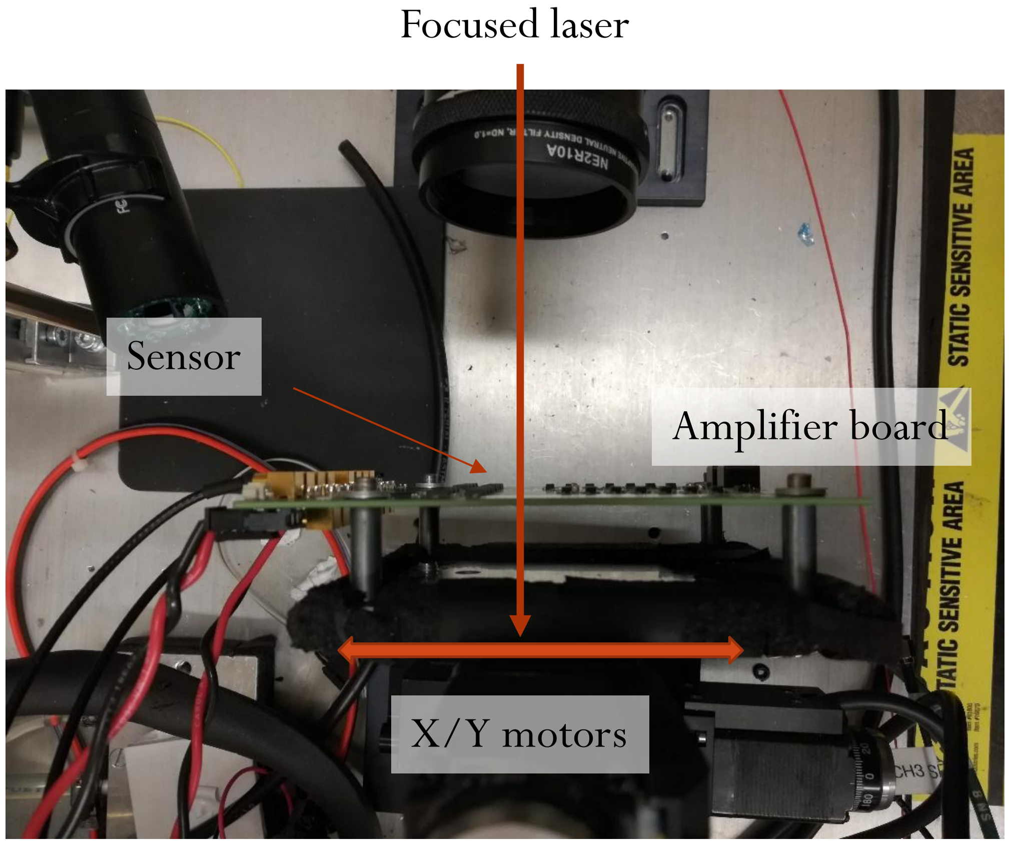


- Two sensors are aligned with a beta source
  - DUT (Device Under Test) to characterize
  - Trigger with known performance
- Sensors mounted on fast amplifier boards (~2Ghz) and read out by a fast oscilloscope (2Ghz, 20Gs)

- **Collected charge**
- **Time resolution**: sigma of time difference between trigger sensor (with known time resolution) and DUT,
- **Gain**: collected charge divided by collected charge in same thickness PiN
- **Signal to Noise ratio**

Sensor testing –Laser TCT setup

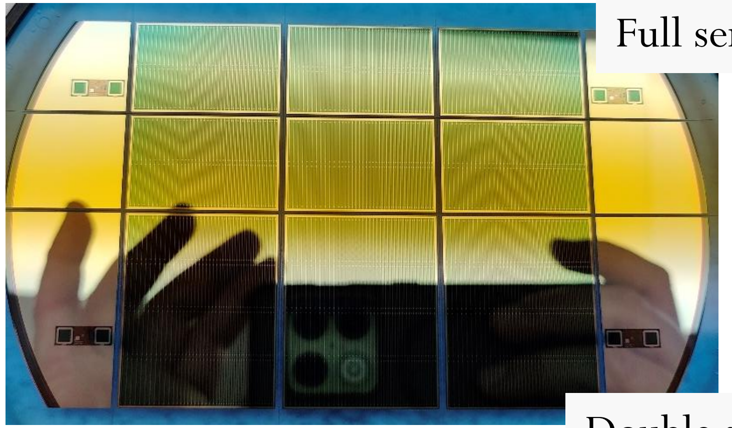


- Sensors are mounted on a multi-channel analog amplifier board with bandwidth ~1 GHz
  - Response is readout by 2 GHz/20 Gs oscilloscope
- **IR laser (1064 nm)** mimics charge deposit of a Minimum Ionizing Particle (MiP)
  - Focused laser beam with spot width ~20 um
- Amplifier board is mounted on X/Y moving stages
  - Charge injection as a function of position
- Metal is not transparent to IR so no response can be seen when laser is on top of metal
  - Only the sensor response in-between metal pads is visible

HPK s16694 production – 2024/2025

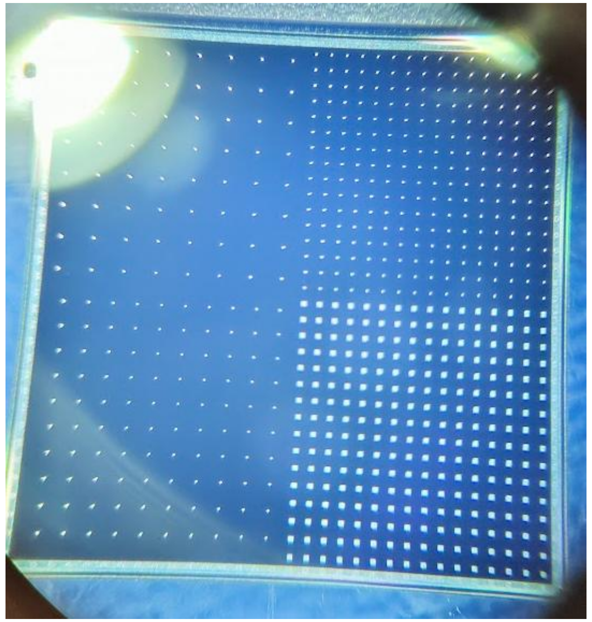
- ePIC full-size production of HPK strip and pixel AC-LGADs
  - Multi-pitch and multi-electrode size
- 8 strip wafers, 50um and 30um thick
- 4 pixel wafers, 30um and 20um thick
- Fully tested electrically and sample tested with laser and test beams
  - Measured parameters variation

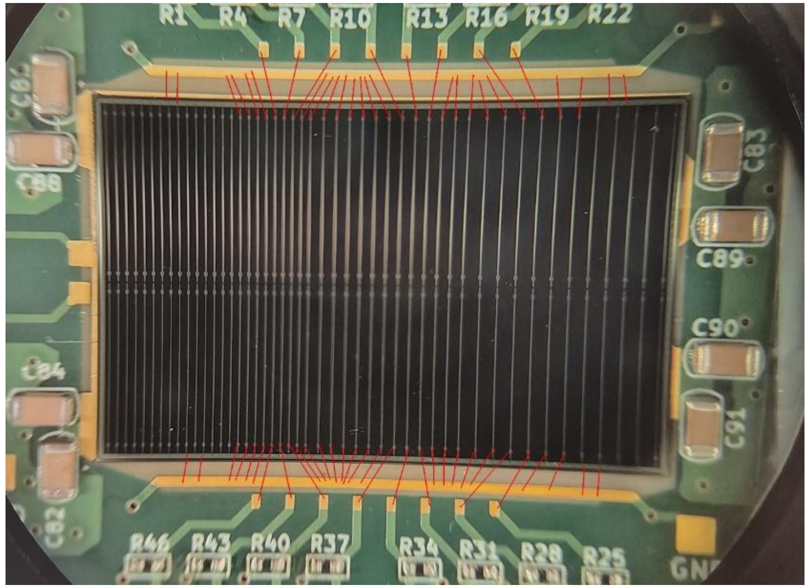
Half sensors

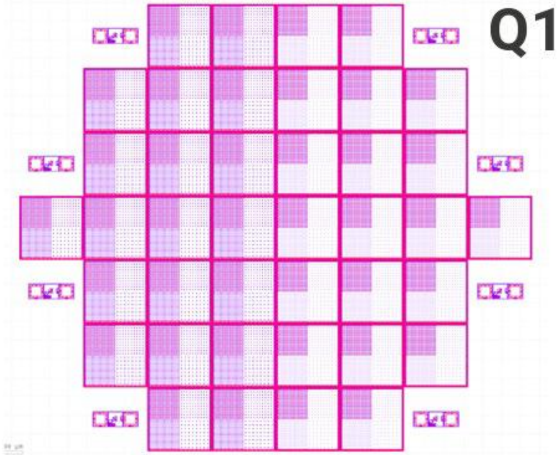


Full sensors

Double sensors







HPK Sensor production for pixel ongoing, first trials with EICROC1 when available (Q4 2025)