

Status of CNM Developments on LGAD and iLGAD Detectors

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CERN, Geneva, Switzerland

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Outline

1

- **Technological** Developments @ CNM on **LGAD** & **iLGAD** Detectors

2

- **PAD** & **microStrips** LGAD Characterization
 - ✓ I-V, C-V
 - ✓ Gain Measurements
 - Laser
 - Alpha Particles
 - ✓ Gamma Irradiations

3

- **New iLGAD.** Low Gain P on P Detector
 - ✓ Position-Sensitive Detectors
 - ✓ Timing
 - Thin Detectors
 - ✓ Double-Sided LGAD
 - Pad LGAD @ Back-side
 - Ohmic Read Out @ Front-side
- microStrip **iLGAD Simulation**
 - ✓ Optimization
 - Technological
 - Electrical
 - Thinner Substrates for Timing
- **First iLGAD Mask Set**
- **First iLGAD Run @ CNM**

RD50 Institutes Participating

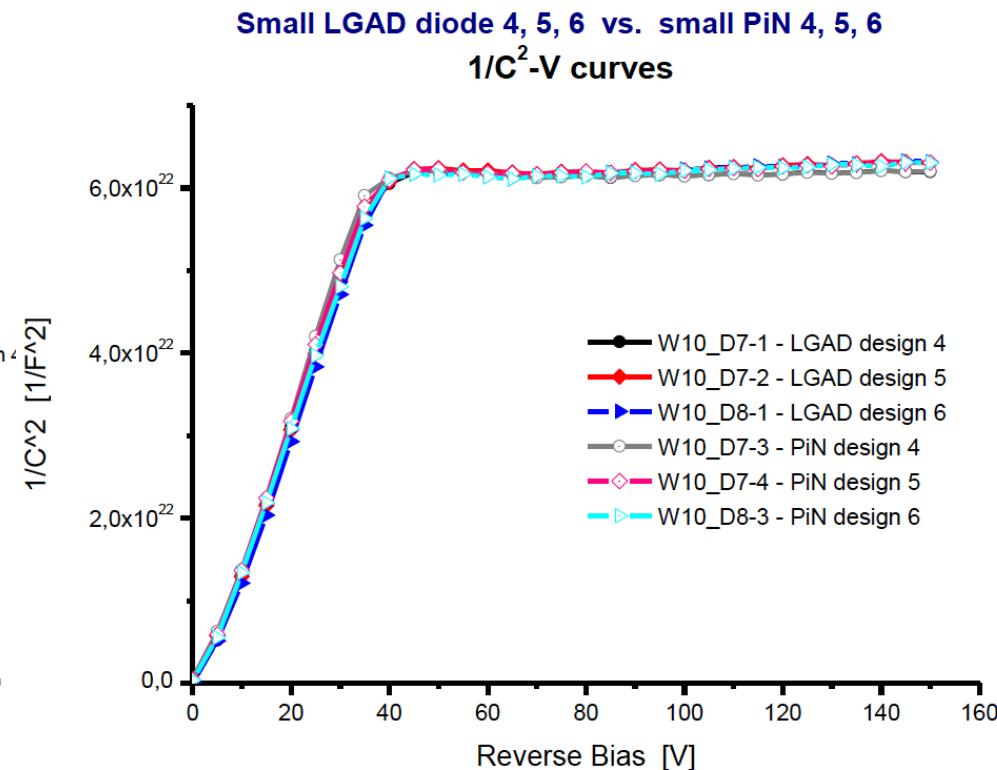
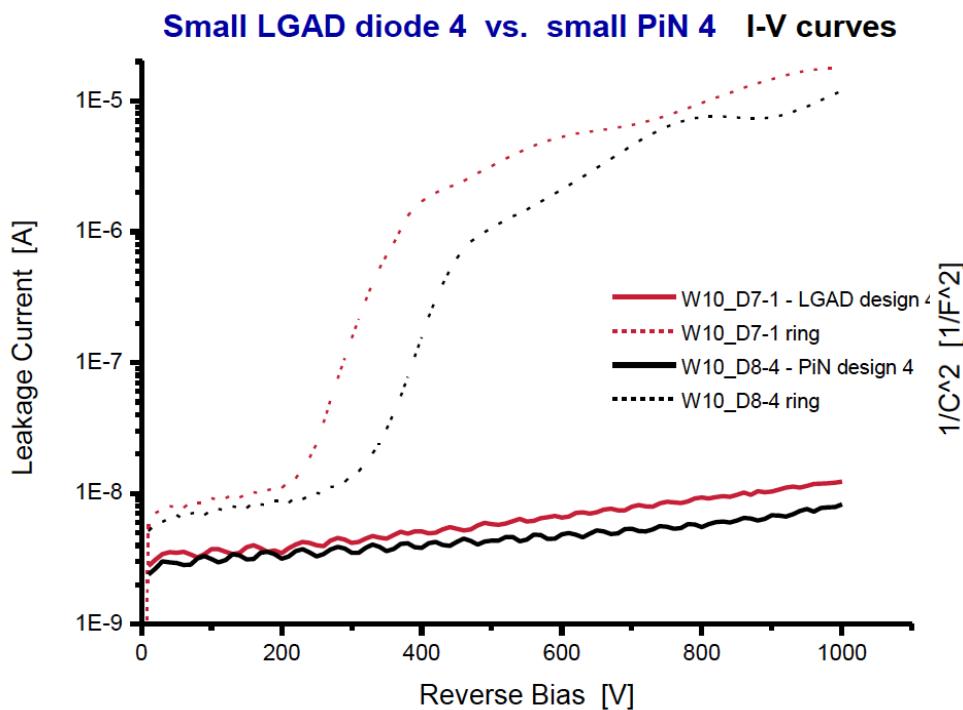
1. CNM Barcelona, G. Pellegrini, giulio.pellegrini@cnm-imb.csic.es
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3. UC Santa Cruz, Hartmut Sadrozinski, hartmut@ucsc.edu
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LGAD and iLGAD Fabrication Runs Status

- **2 Runs** with **Boron** Multiplication Layer and **300 µm** Substrate: **Finished**
 - ✓ Run 7509
 - ✓ Run 7859
- **1 Run** with **Boron** Multiplication Layer and **200 µm** Substrate: **Finished**
 - ✓ Run 7782
- **1 Run** with **Gallium** Multiplication Layer and **300 µm** Substrate: **Finished**
 - ✓ Run 7735
- **1 Run** with **Boron** Multiplication Layer and **300 µm** Substrate: **On Going**
 - ✓ Run 8622. LGAD. **3 Gallium Wafers**. It will end during the second week of **January**
- **1 Run** with **Boron** Multiplication Layer and **300 µm** Substrate: **On Going**
 - ✓ Run 8533. iLGAD. **3 Gallium Wafers**. **50 %** Run steps done
- **1 Run** with **Boron** Multiplication Layer and **6"-500 µm** Substrate: **On Going**
 - ✓ Run 8373. LGAD. It will end during **June**
- **New Run** with **Boron** Multiplication Layer and **200 µm** Substrate: **Waiting**
- **New Run** with **Gallium** Multiplication Layer and **300 µm** Substrate: **Waiting**

LGAD. Gallium Multiplication Layer. 300 μm Substrate

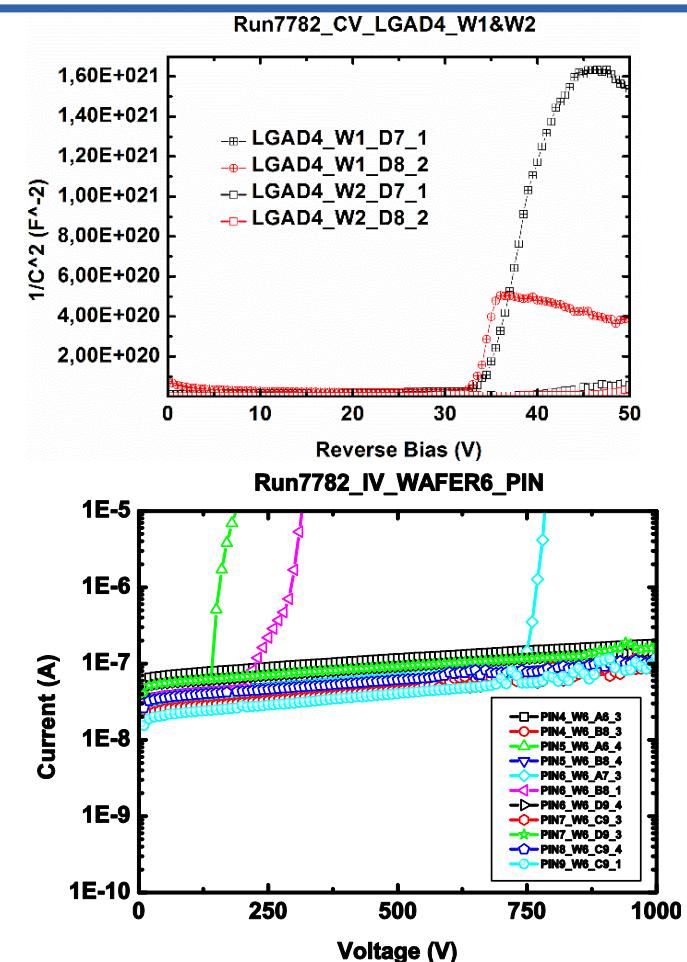
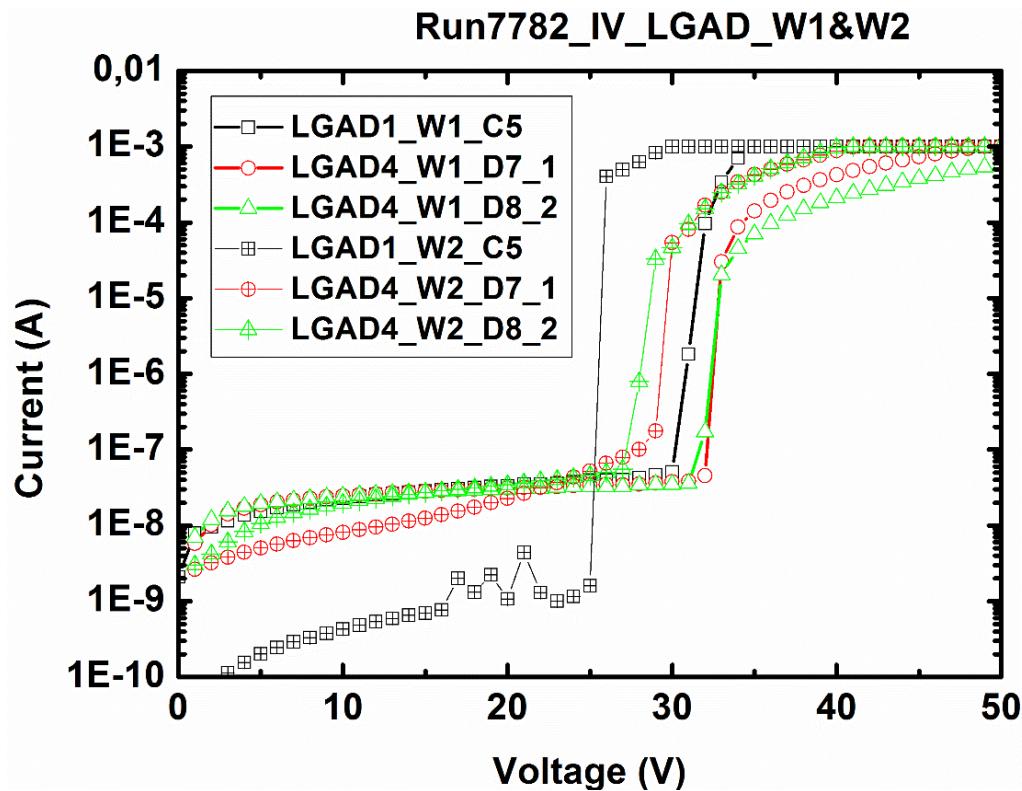
- I-V, C-V on Wafer



- LGAD Devices with Gallium Multiplication Layer have Similar I-V and C-V Characteristics than PiN Detectors. We do not Observe the Multiplication Layer Depletion

LGAD. Boron Multiplication Layer. 200 μm Substrate

- I-V, C-V on Wafer



- LGAD devices with 200 μm substrate have Low Breakdown Voltage Characteristics than 300 μm substrate Equivalent LGAD Detectors
- Doping Level of the Boron Multiplication Layer is Higher than Expected by Simulations
- Neutron Irradiation at JSI Ljubljana to Reduce Boron Peak Concentration

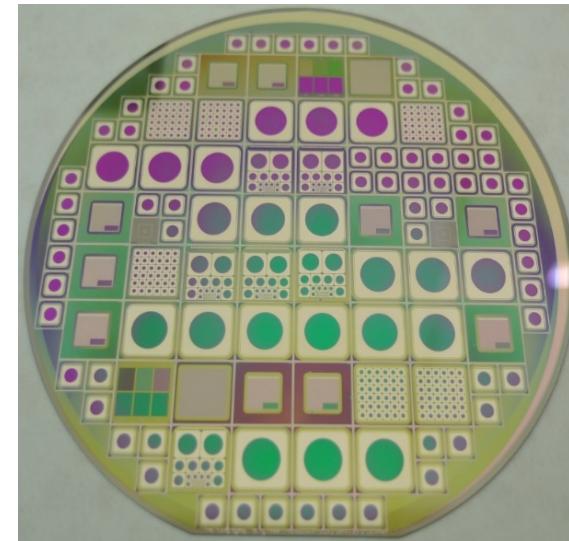
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LGAD and iLGAD Fabrication Runs. At Glance

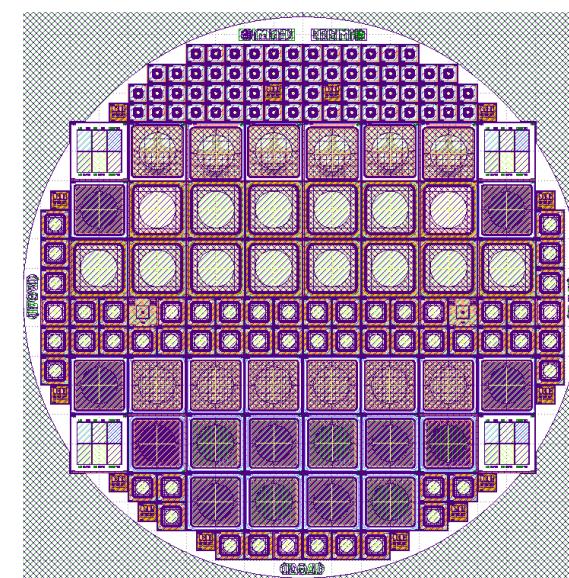
- **LGAD Run Basic Information:**

- ✓ **Cnm761** Mask Set
- ✓ **8** Mask Levels
- ✓ **70** Technological Steps
- ✓ **Single** Side Process
- ✓ Only **Electron** Collection



- **iLGAD Run Basic Information:**

- ✓ **Cnm809** Mask Set
- ✓ **12** Mask Levels
- ✓ **100** Technological Steps
- ✓ **Double** Side Process
- ✓ Only **Hole** Collection



- **Common** Information:

- ✓ Improve **Surface Isolation (P-Stop)**. iLGAD @ Multiplication Side)
- ✓ Different **Terminations**
- ✓ **Pad** Detectors with Different Sizes
- ✓ **Strips** and **Pixel** Detectors (iLGAD @ Front Side)
- ✓ Detectors for **Timing** Applications
- ✓ **Test Structures** to Measure the Multiplication Layer

RD50 Samples Distribution

RD50 Institution	7509	7859
CERN + IFCA, Santander	38	30
SCIPP, Santa Cruz	36	13
LAL, Orsay	4	6
INFN, Torino	18	17
Jozef Stefan Institute, Ljubljana	43	22
IFAE, Barcelona	10	30

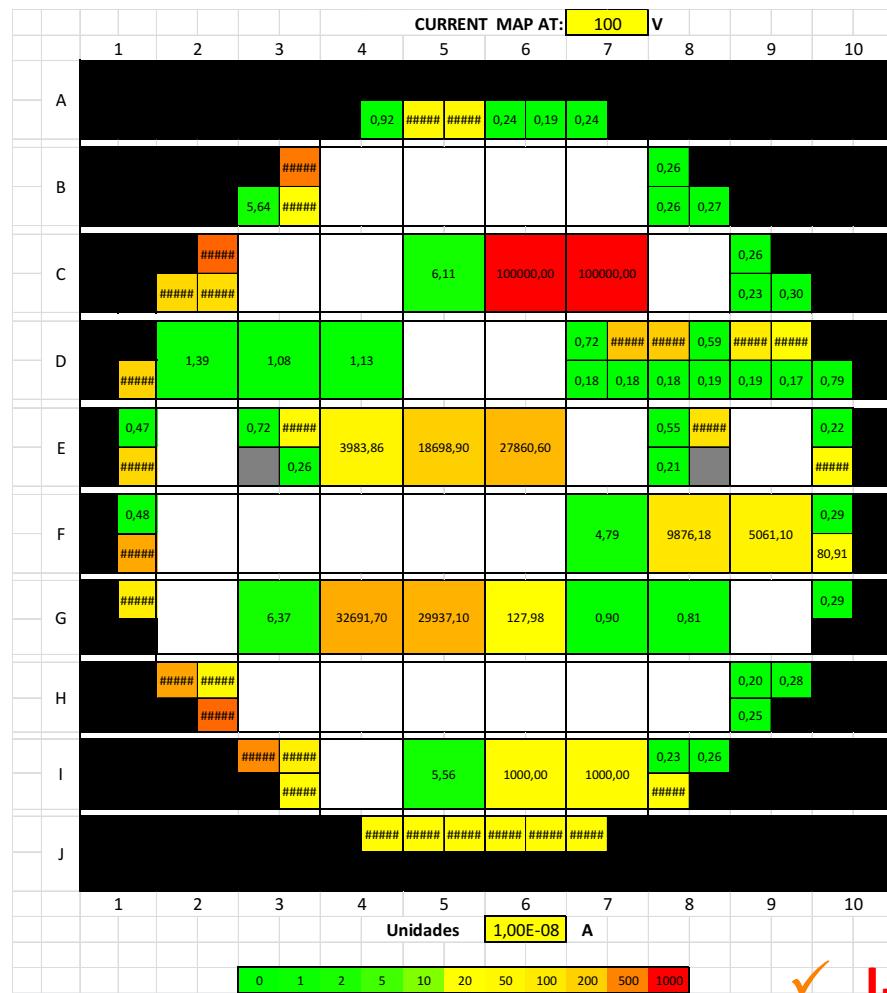


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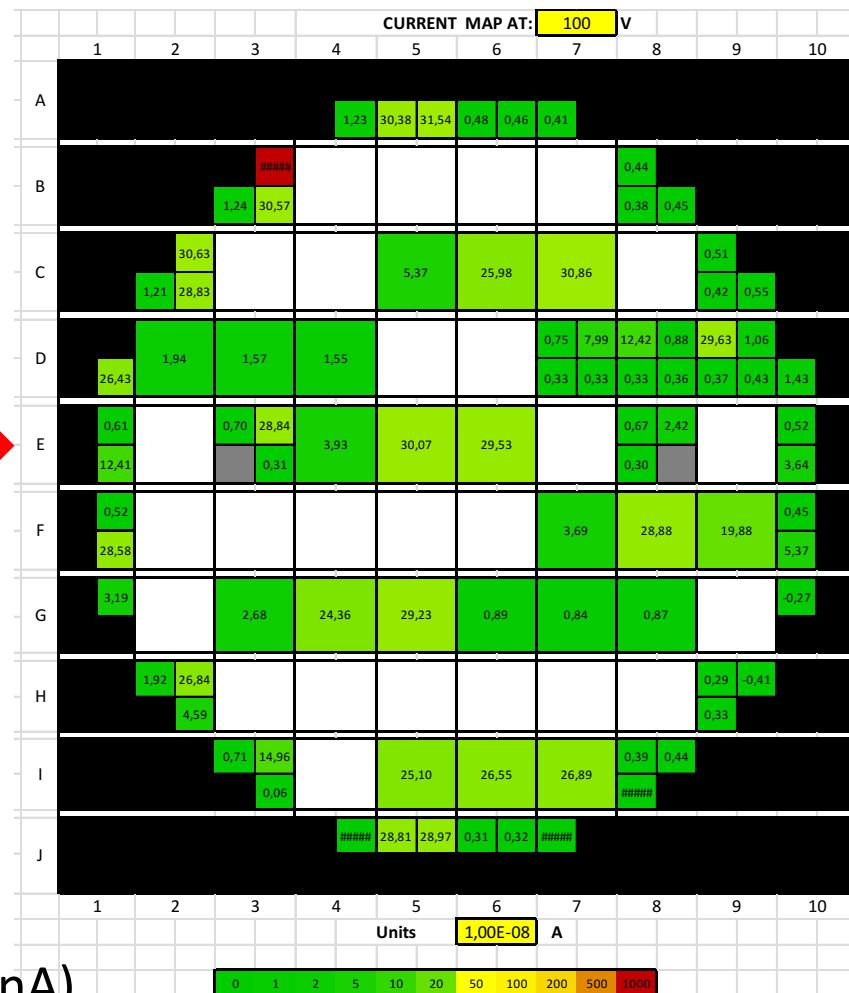
LGAD. Boron Multiplication Layer. 300 µm Substrate

○ Yield Improved

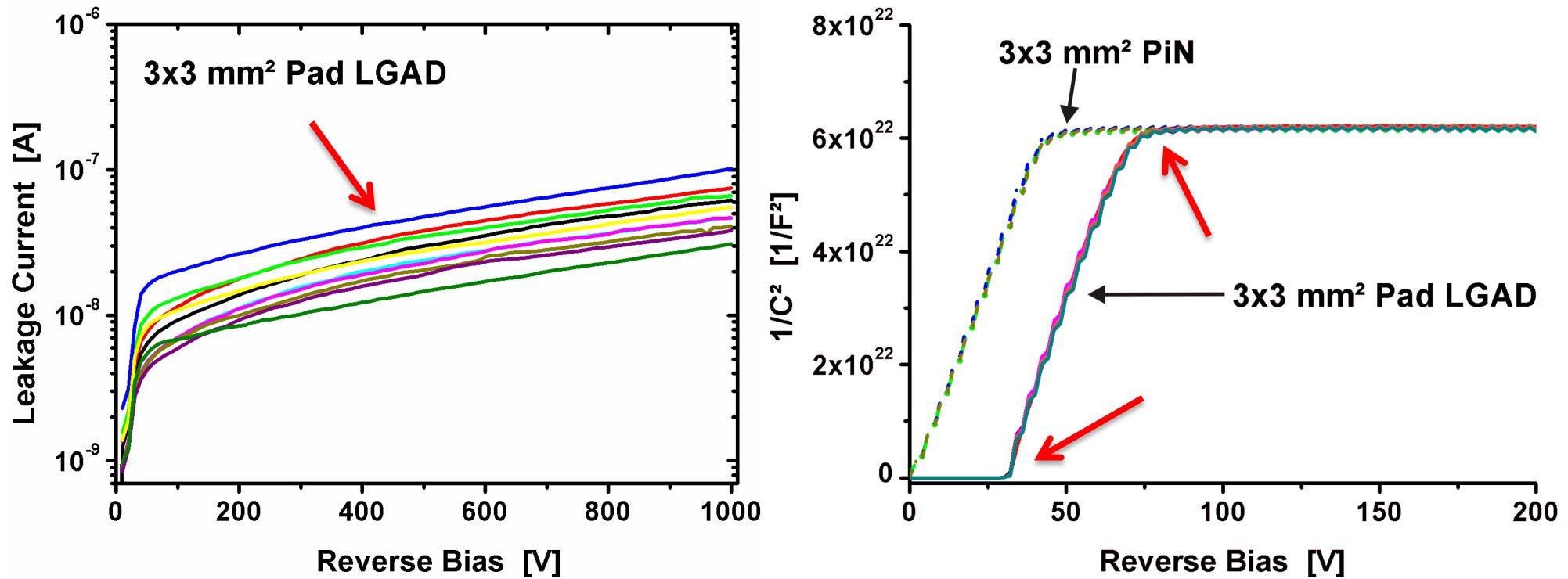
✓ Run 7509



✓ Run 7859



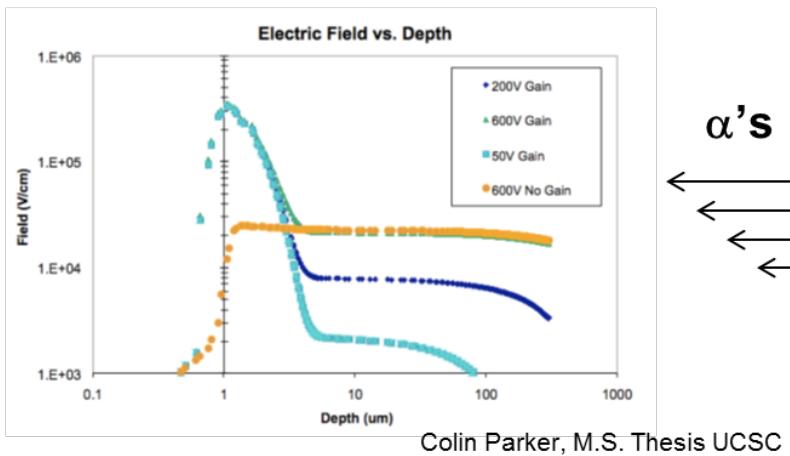
LGAD. Run 7859. $I(V)$ and $1/C^2(V)$



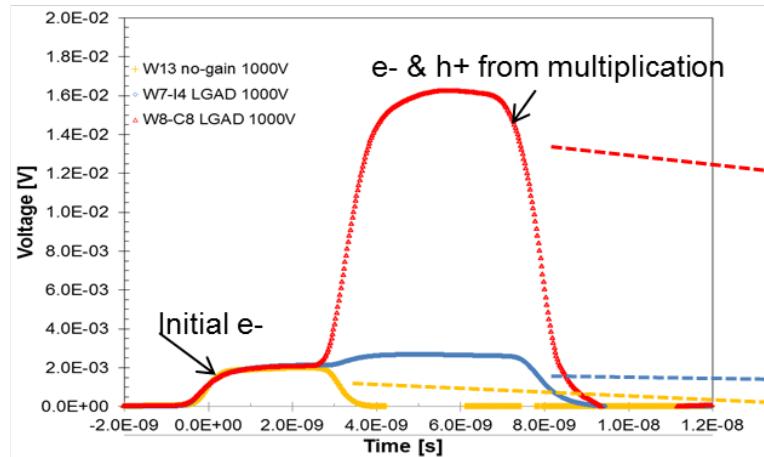
- **Wafer 2.** Multiplication Layer Dose $1.8 \times 10^{13} \text{ atm/cm}^2$
- Low **Leakage Current.** $10\text{-}30 \text{ nA}$ @ 500 V
- Multiplication Layer **Depletion Voltage** $\sim 30 \text{ V}$. **Full Depletion Voltage** $\sim 80 \text{ V}$

LGAD. Run 6474. Gain Calibration with α 's from Am(241)

Hartmut F.-W. Sadrozinski, Ultra-Fast Silicon Detectors. CPAD



Pulse shapes for high-gain (red), low-gain (blue) LGAD and no-gain sensor (yellow)

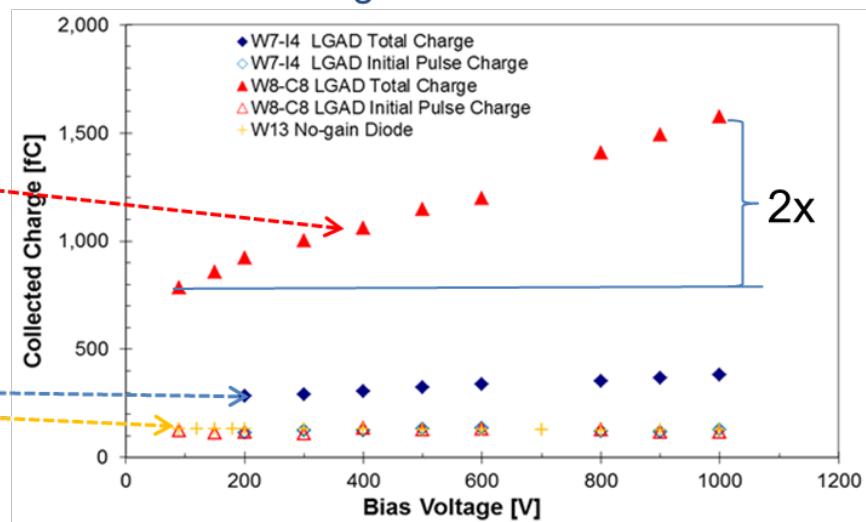


$$\text{Gain} = \frac{\text{electrons + holes}}{\text{initial} \cdot \text{electrons}}$$

“Electron injection” with α 's from Am(241) or with red laser illuminating the back side, range \sim few μm 's, electron signal drifts and is then amplified in high field, holes drift back.

Large bias voltages reach.

Gain of 15, can be tuned within factor 2x with bias voltage.

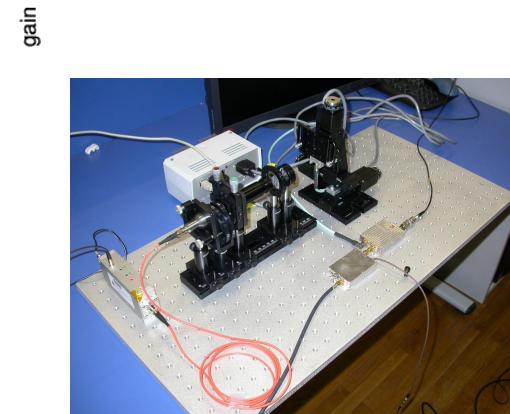
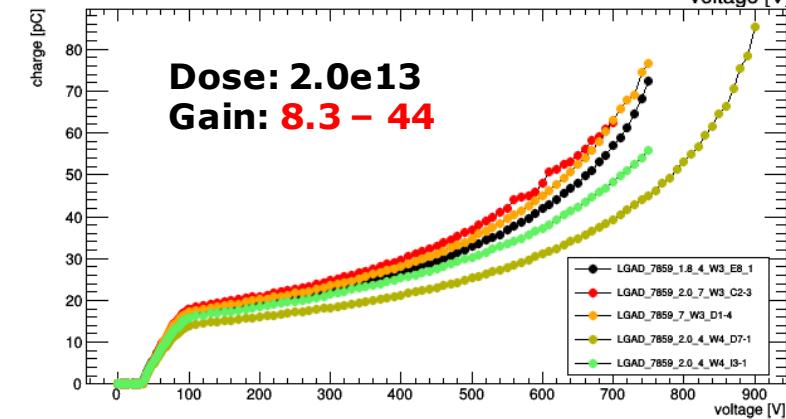
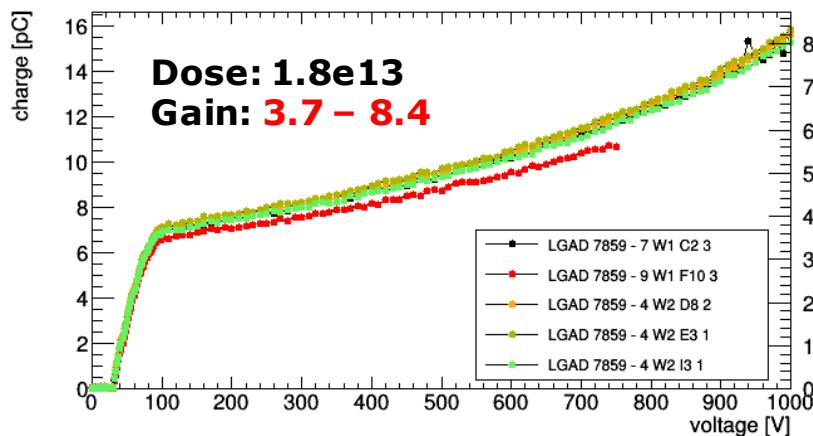


○ **Wafer 8.** Multiplication Layer Dose $1.8\text{e}13 \text{ atm}/\text{cm}^2$ 12/40



LGAD. Run 7859. TCT Measurements. IR. Back

- See Next Presentation by Sofia Otero Ugobono (CERN)

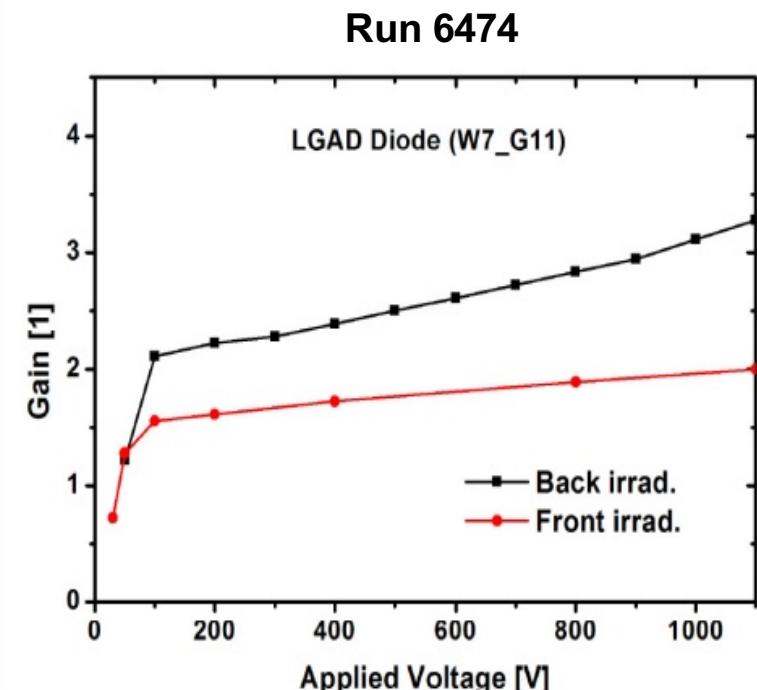
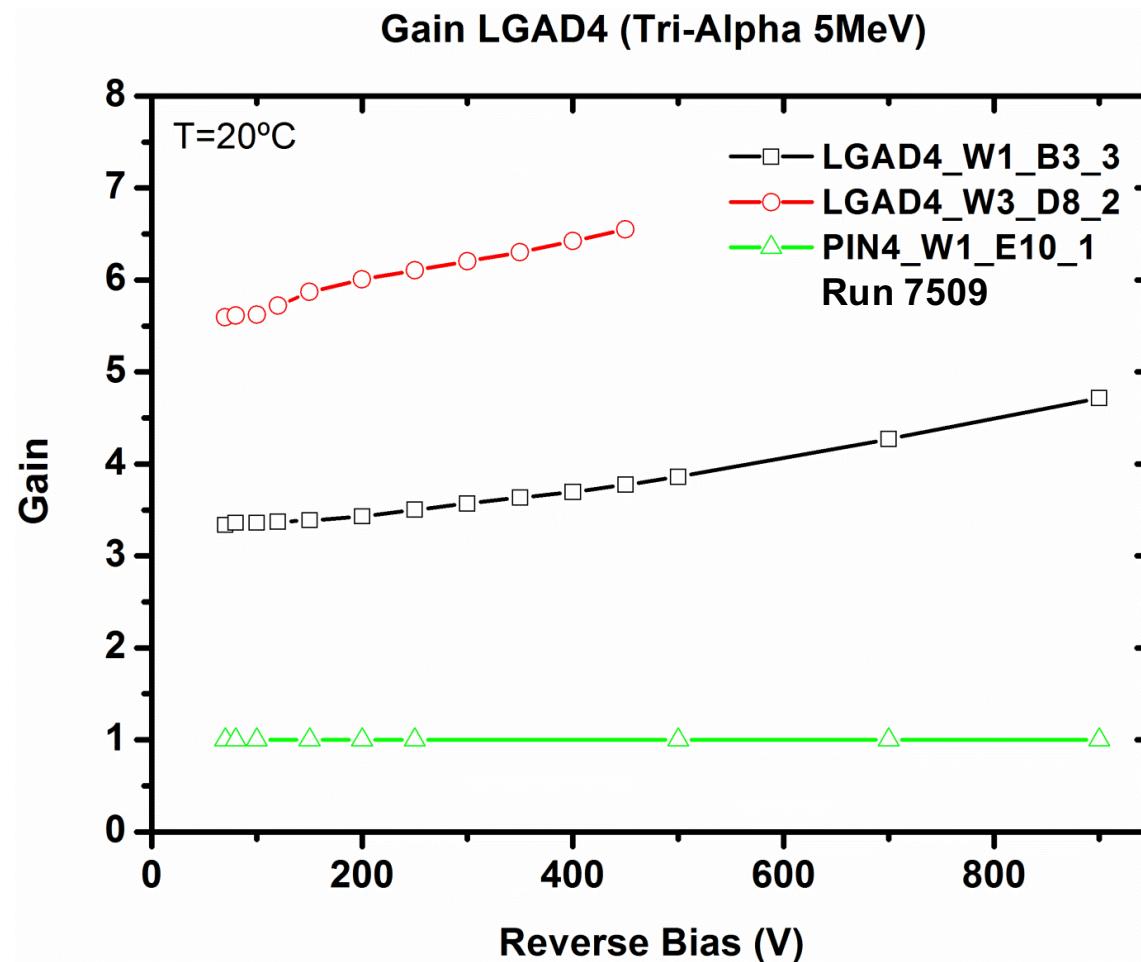


G. Kramberger, 20th RD50 Workshop, Bari, 2012

- Measurements done at **CERN Silicon Lab** by C. Gallrapp, M. Stricker, M. Fernandez and M. Moll.

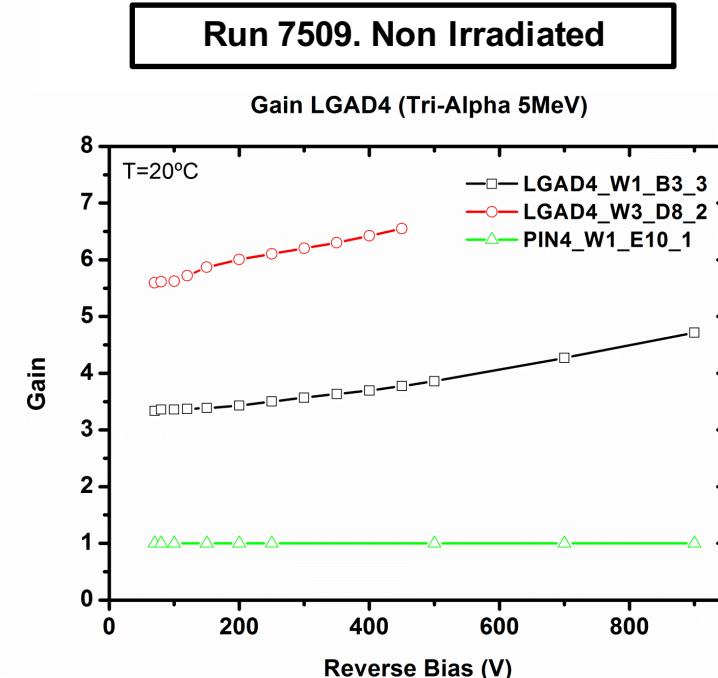
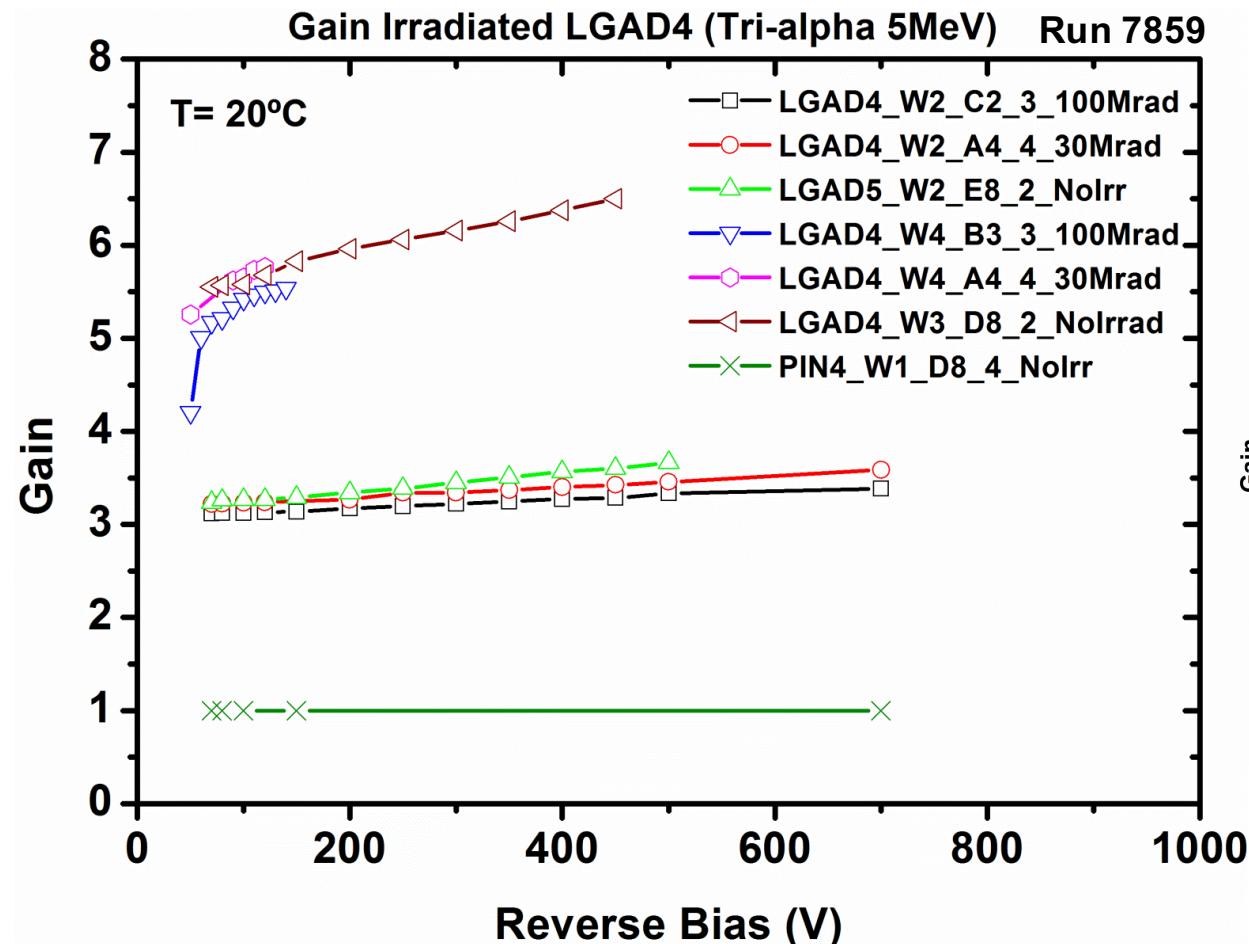


LGAD. Run 7509. Charge Collection. Alpha. Back Illumination



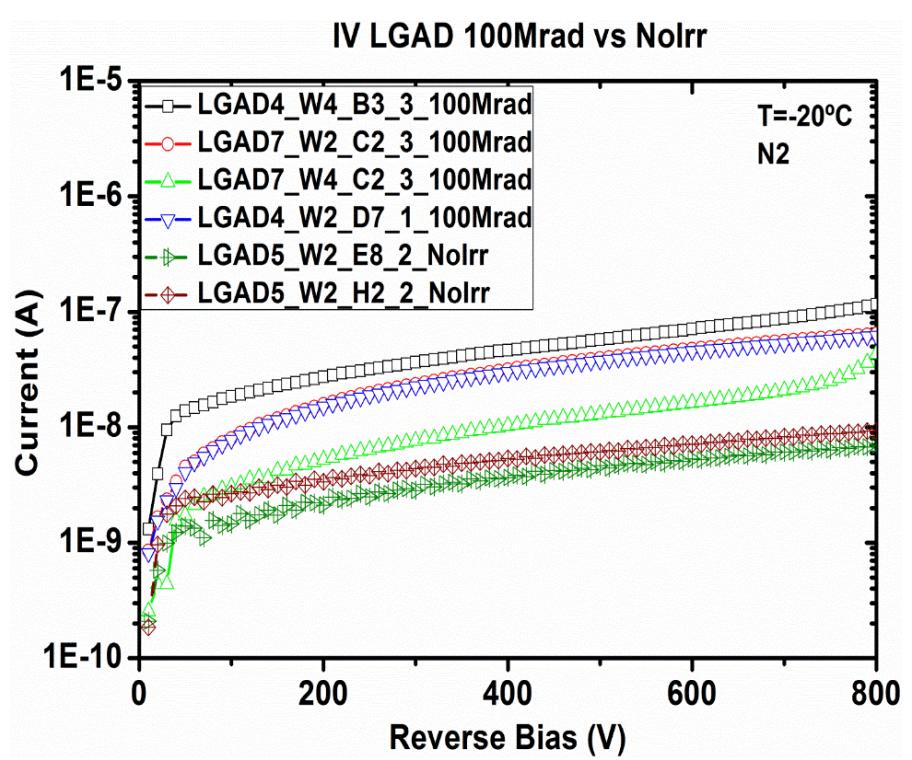
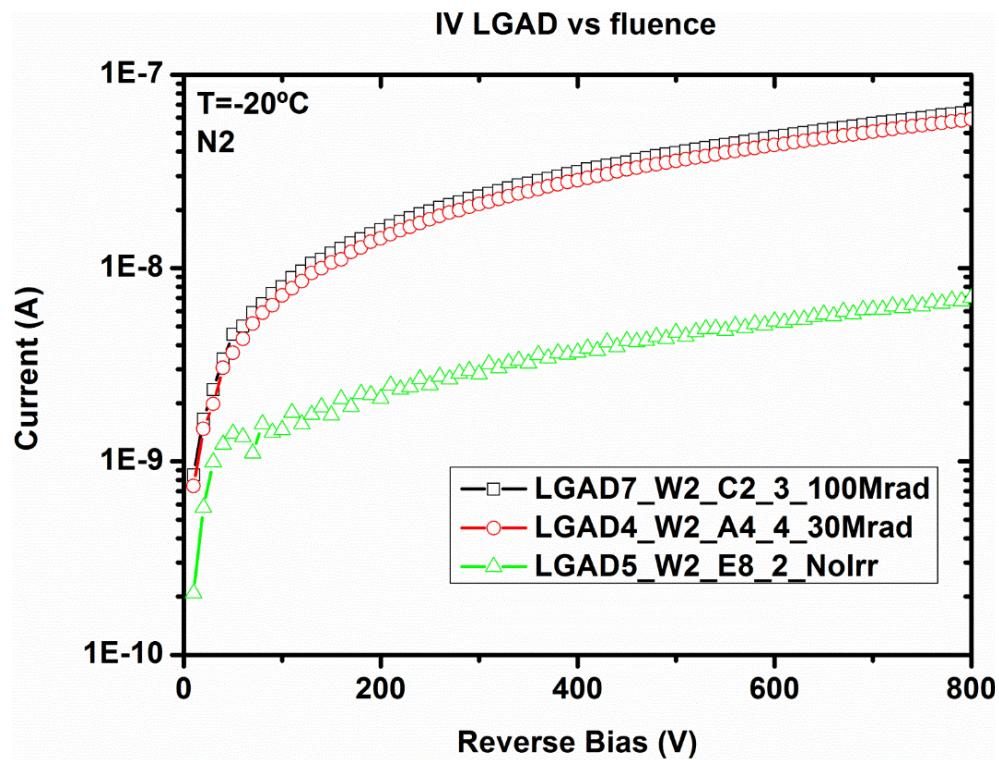
- **Wafer 1.** Multiplication Layer Dose **1.8e13 atm/cm²**
- **Wafer 3.** Multiplication Layer Dose **2.0e13 atm/cm²**

Gamma Irradiated LGAD. Run 7859. Charge Collection. Alpha



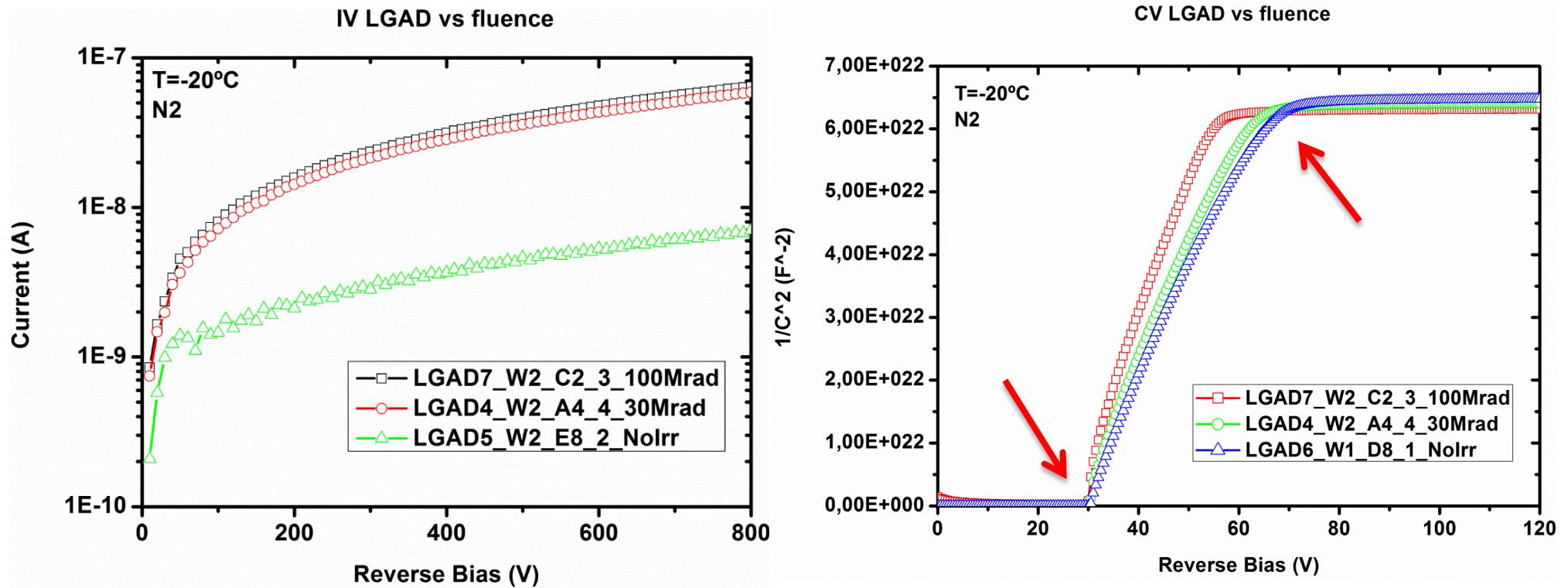
- **Wafers 1, 2.** Multiplication Layer Dose **1.8e13 atm/cm²**
- **Wafers 3, 4.** Multiplication Layer Dose **2.0e13 atm/cm²**
- **Gamma Irradiation with ⁶⁰Co**

Gamma Irradiated LGAD. Run 7859. I(V)



- **Wafer 2.** Multiplication Layer Dose $1.8\text{e}13 \text{ atm/cm}^2$
- **Wafer 4.** Multiplication Layer Dose $2.0\text{e}13 \text{ atm/cm}^2$
- **Gamma Irradiation with ^{60}Co**
- Leakage Current **Moderate Increase**. From 10 nA to 100 nA @ 800 V

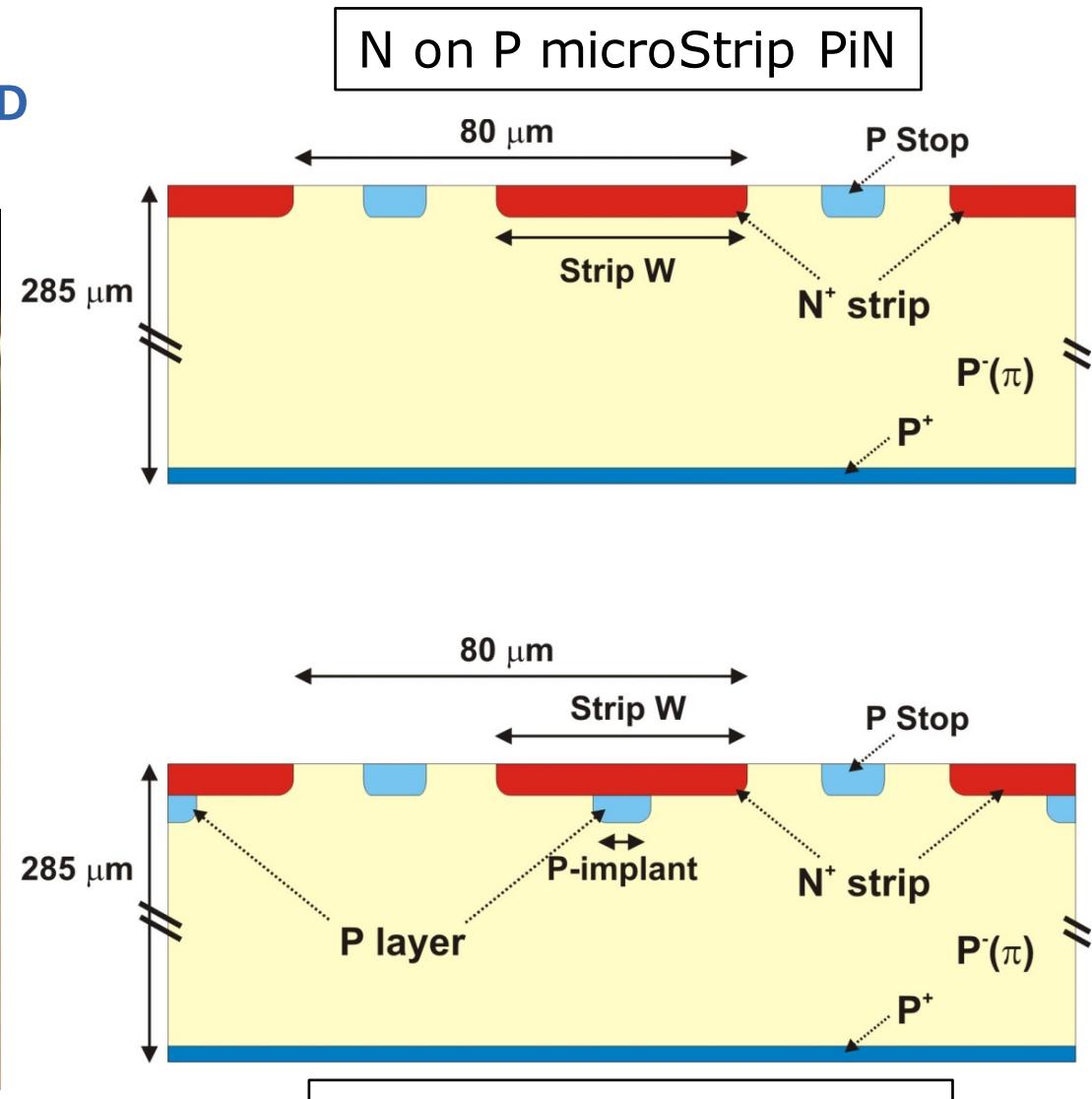
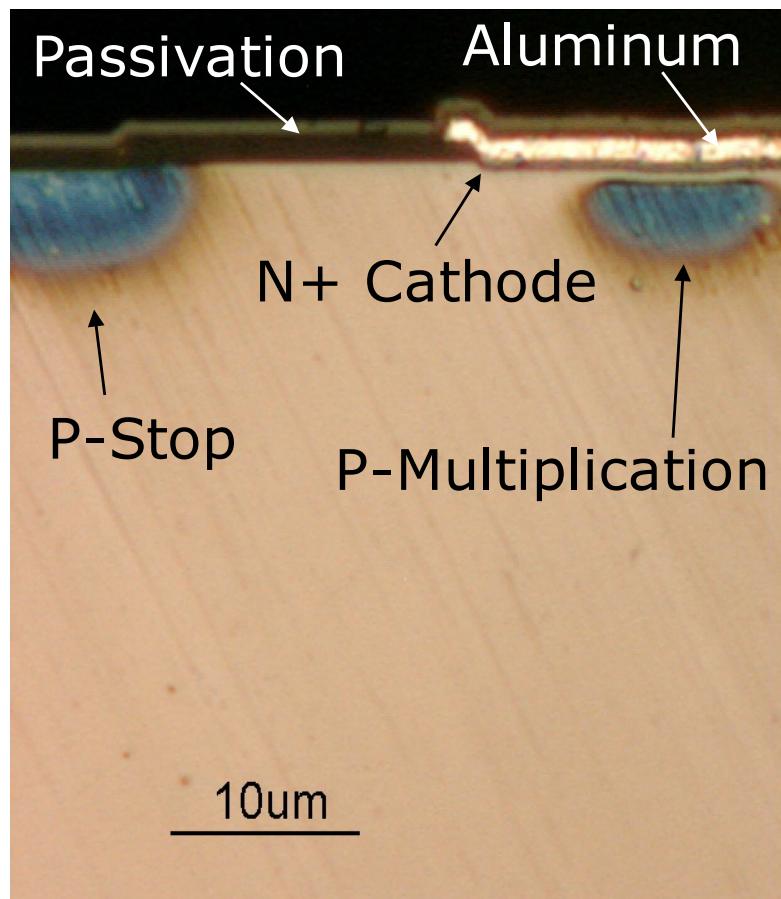
Gamma Irradiated LGAD. Run 7859. $I(V)$ and $1/C^2(V)$



- **Gamma** Irradiation with ^{60}Co
- Leakage Current **Moderate Increase**. From **10 nA** to **100 nA** @ 800 V
- Multiplication Layer Depletion Voltage $\sim 30 \text{ V}$ for **All Fluences**
- Full Depletion Voltage **Decreases if Fluence Increases**

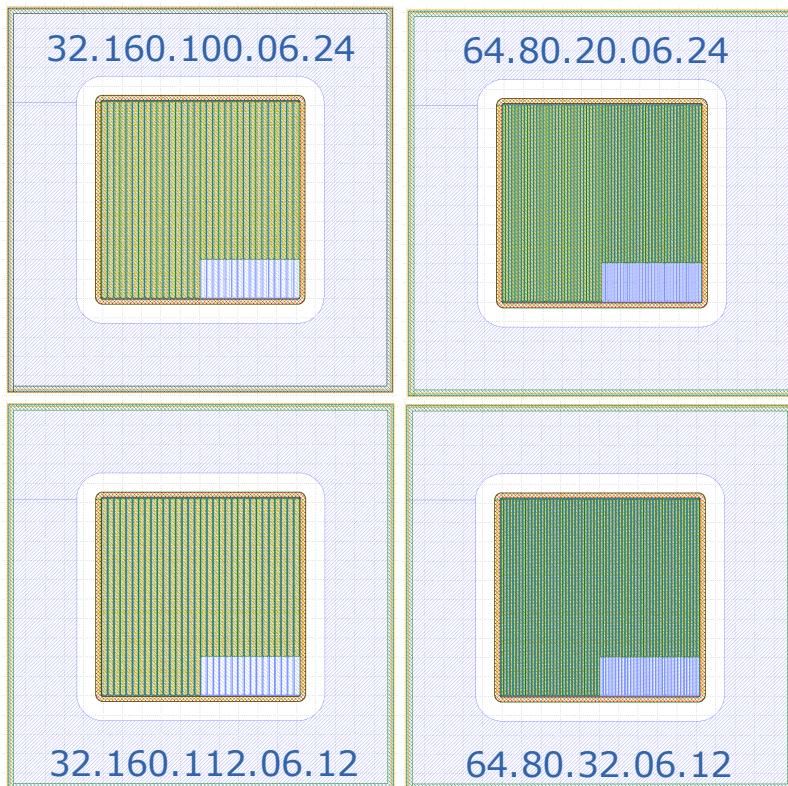
Strip LGAD. Segmented Amplification

- N on P microStrips. PiN vs LGAD

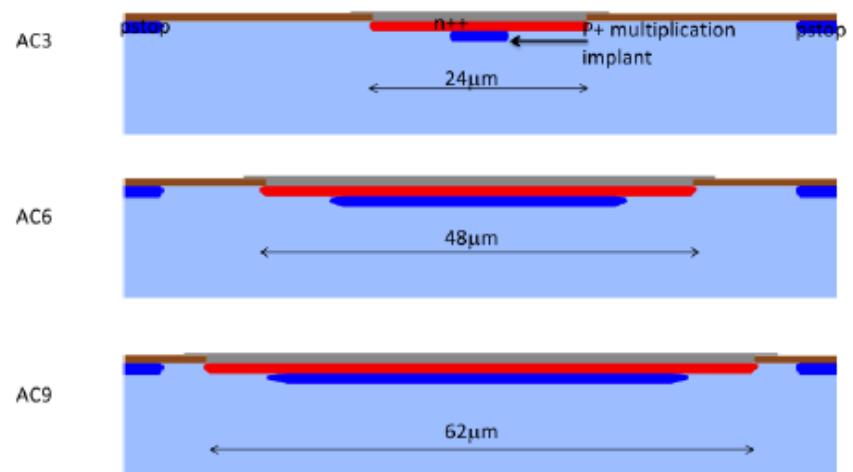


First Approach. Strip LGAD. Segmented Amplification

- Runs **7509** and **7859**, with **Optimized P-well** Engineering
 - ✓ First prototypes characterization **On Going**
- Several** Layouts with **Different P-well Width** and **N-well Depth**
- Constant Pixel Size**

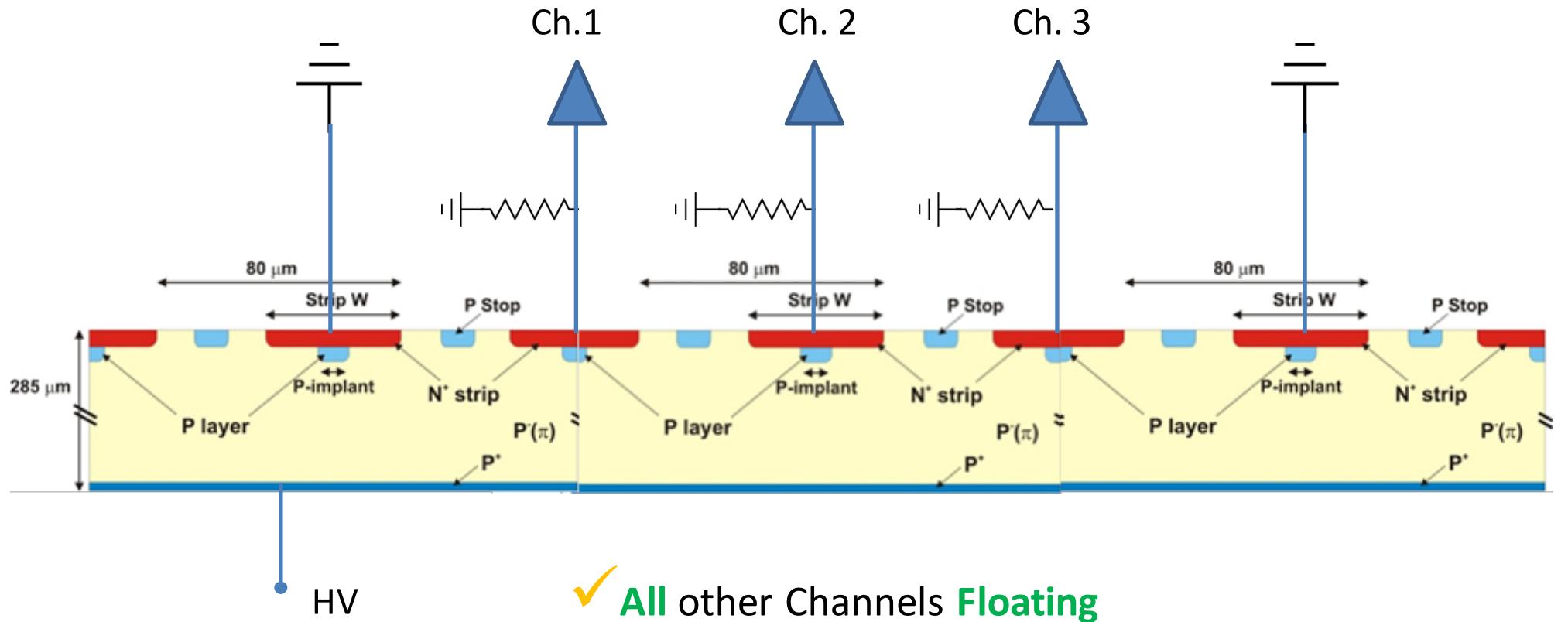


Strip outline



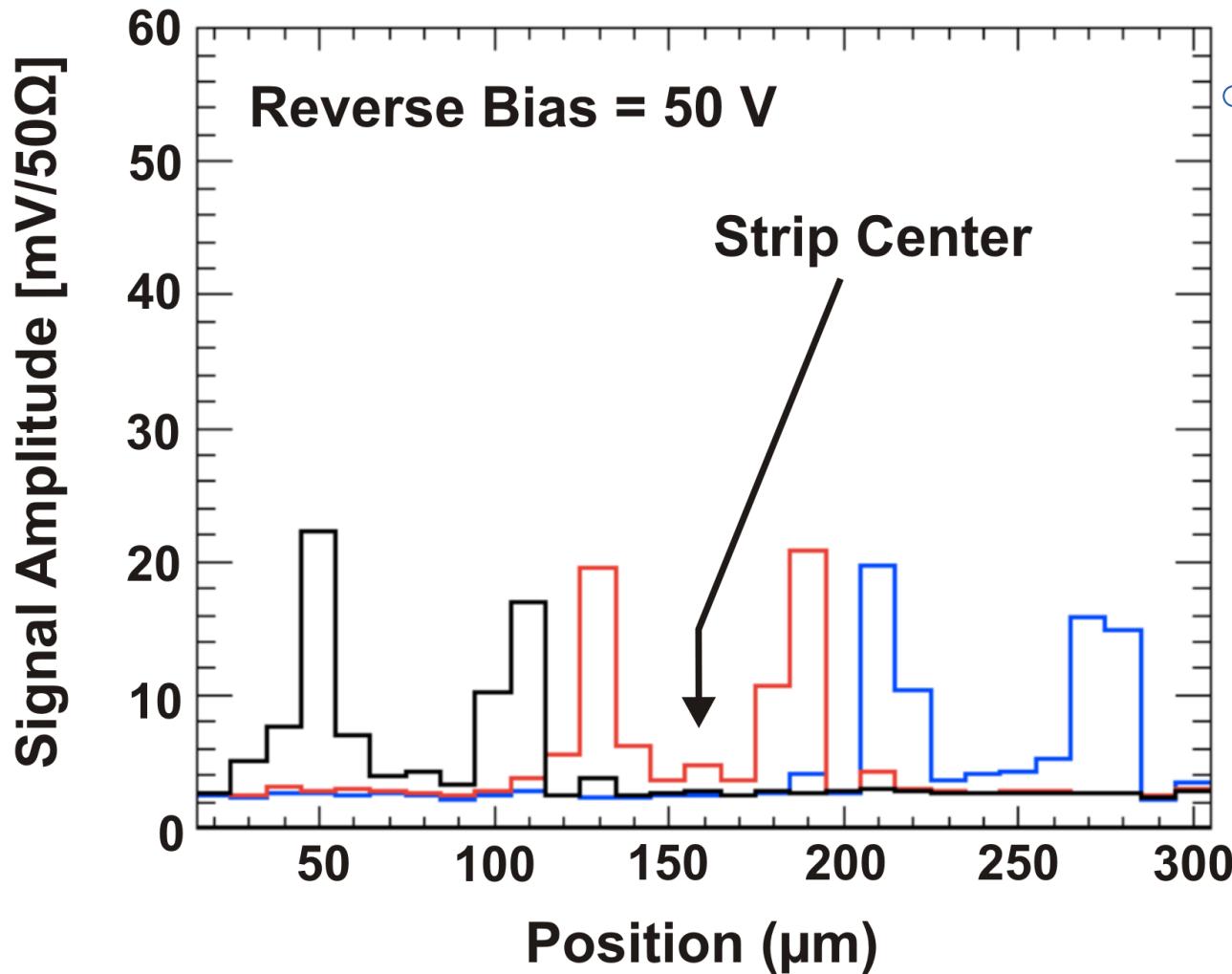
- Key Legend**
 - ✓ **AA-BB-CC-DD-EE**
 - ✓ **AA**, Channels
 - ✓ **BB**, Pixel Size
 - ✓ **CC**, Multiplication Width
 - ✓ **DD**, P-Stop Width
 - ✓ **EE**, P-Stop Position

First Approach. Strip LGAD. SCIPP TCT Set Up

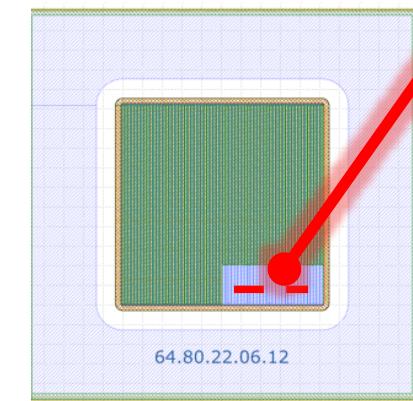


- Measurements done at **SCIPP** by Zachary Galloway, Giulio Pellegrini and Zhijun Liang

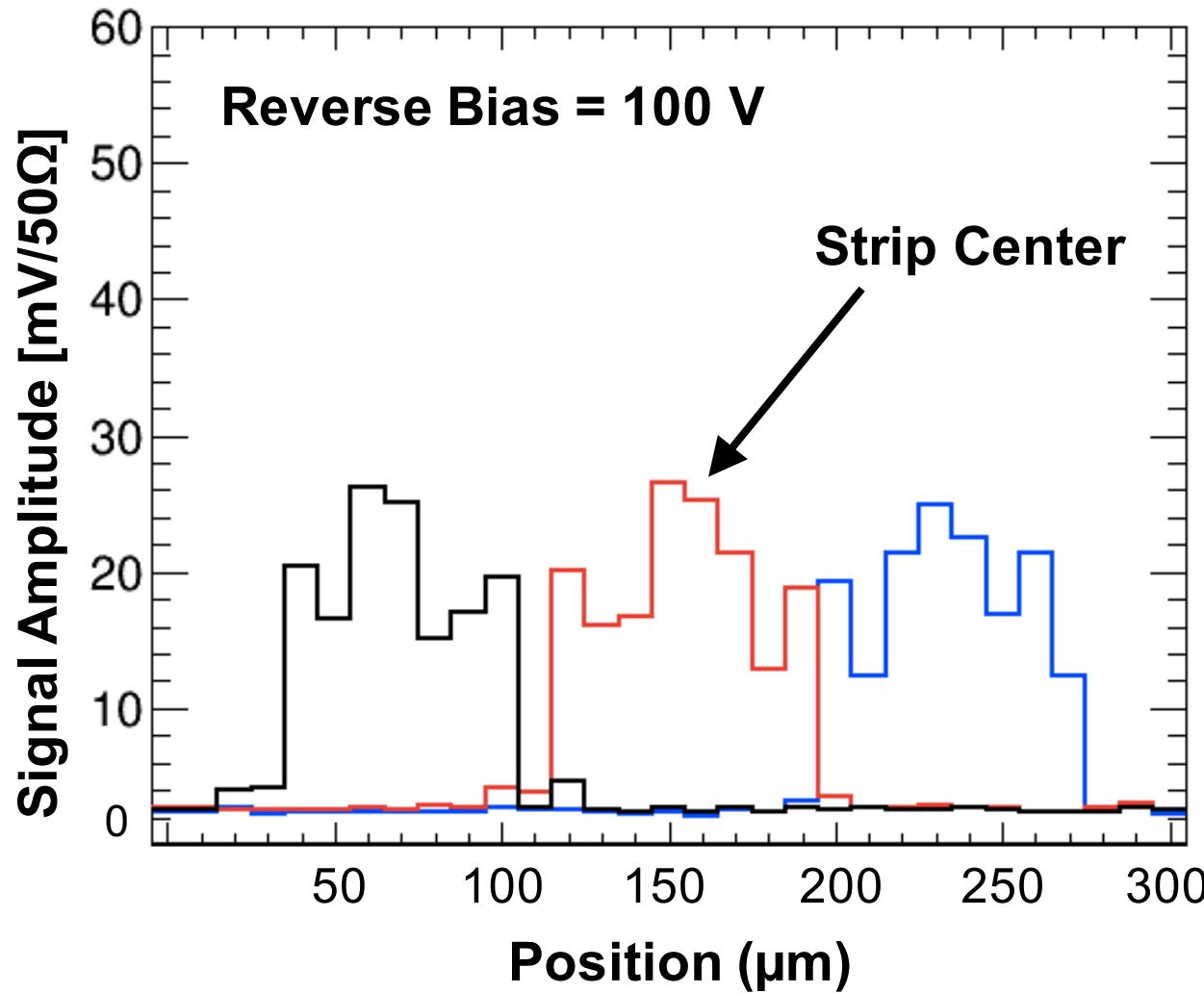
First Approach. Strip LGAD. SCIPP TCT. X Scan vs Voltage



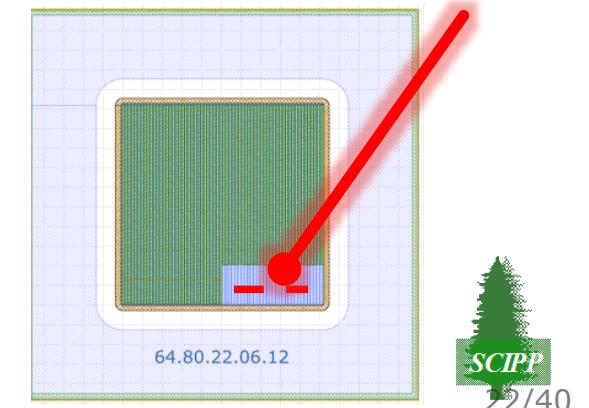
- **TCT Basic Information:**
 - ✓ Run 7859. W4-E2. 50 V
 - ✓ Red Laser from Top
 - ✓ All 3 Channels Connected
 - ✓ DRS4 Circuit Amplifier
 - ✓ Strips Without Metal
 - ✓ No Signal in the Middle of the Strip. No Gain



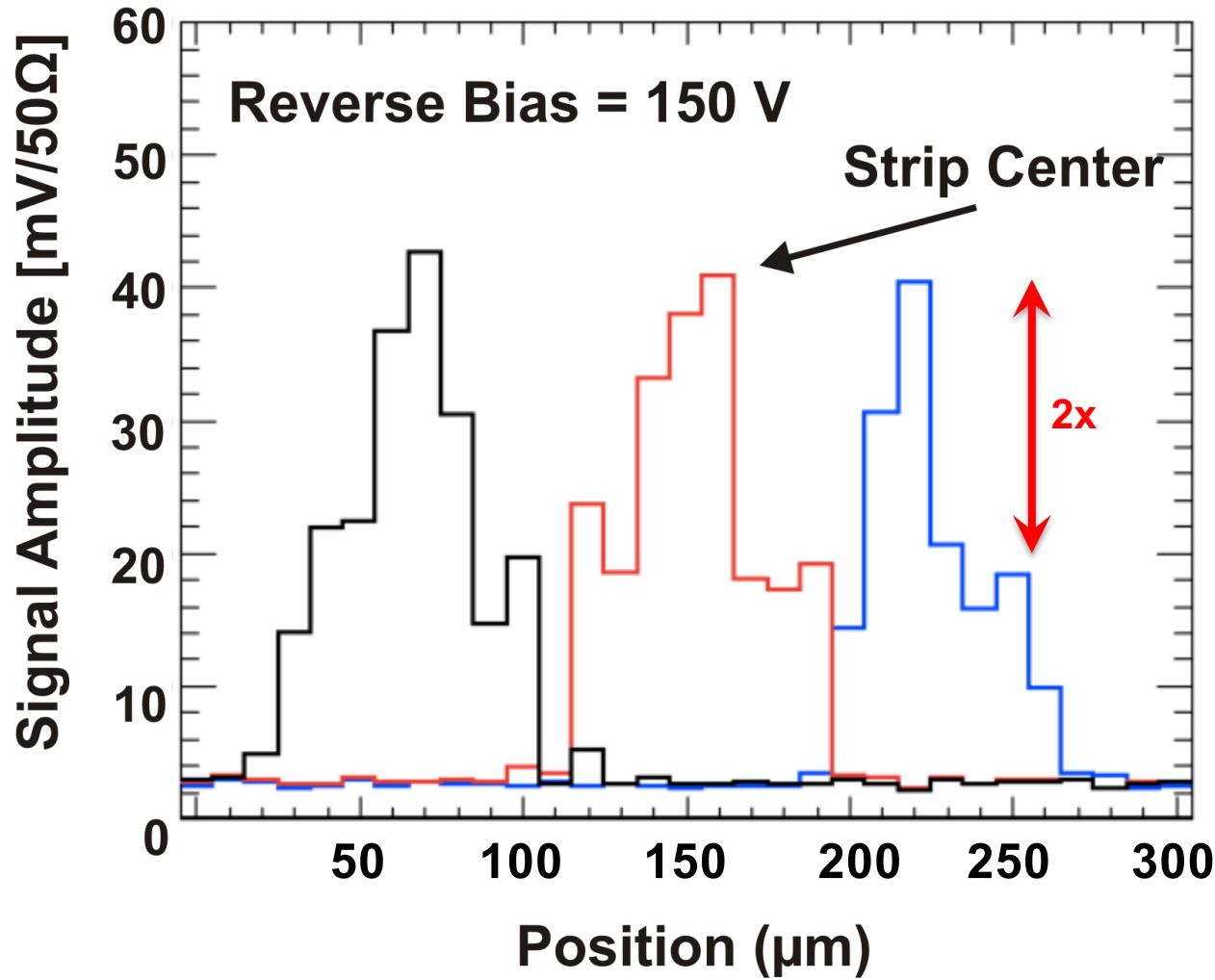
First Approach. Strip LGAD. SCIPP TCT. X Scan vs Voltage



- **TCT Basic Information:**
 - ✓ Run 7859. W4-E2. 100 V
 - ✓ Red Laser from Top
 - ✓ All 3 Channels Connected
 - ✓ DRS4 Circuit Amplifier
 - ✓ Strips Without Metal
 - ✓ Low Signal in the Middle of the Strip. Low Gain

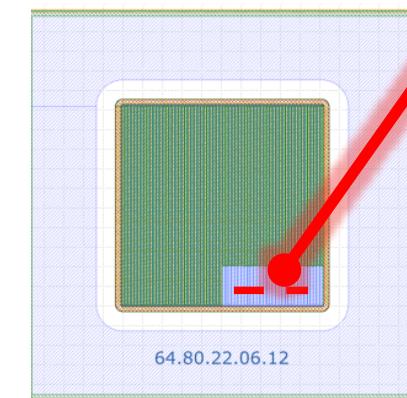


First Approach. Strip LGAD. SCIPP TCT. X Scan vs Voltage

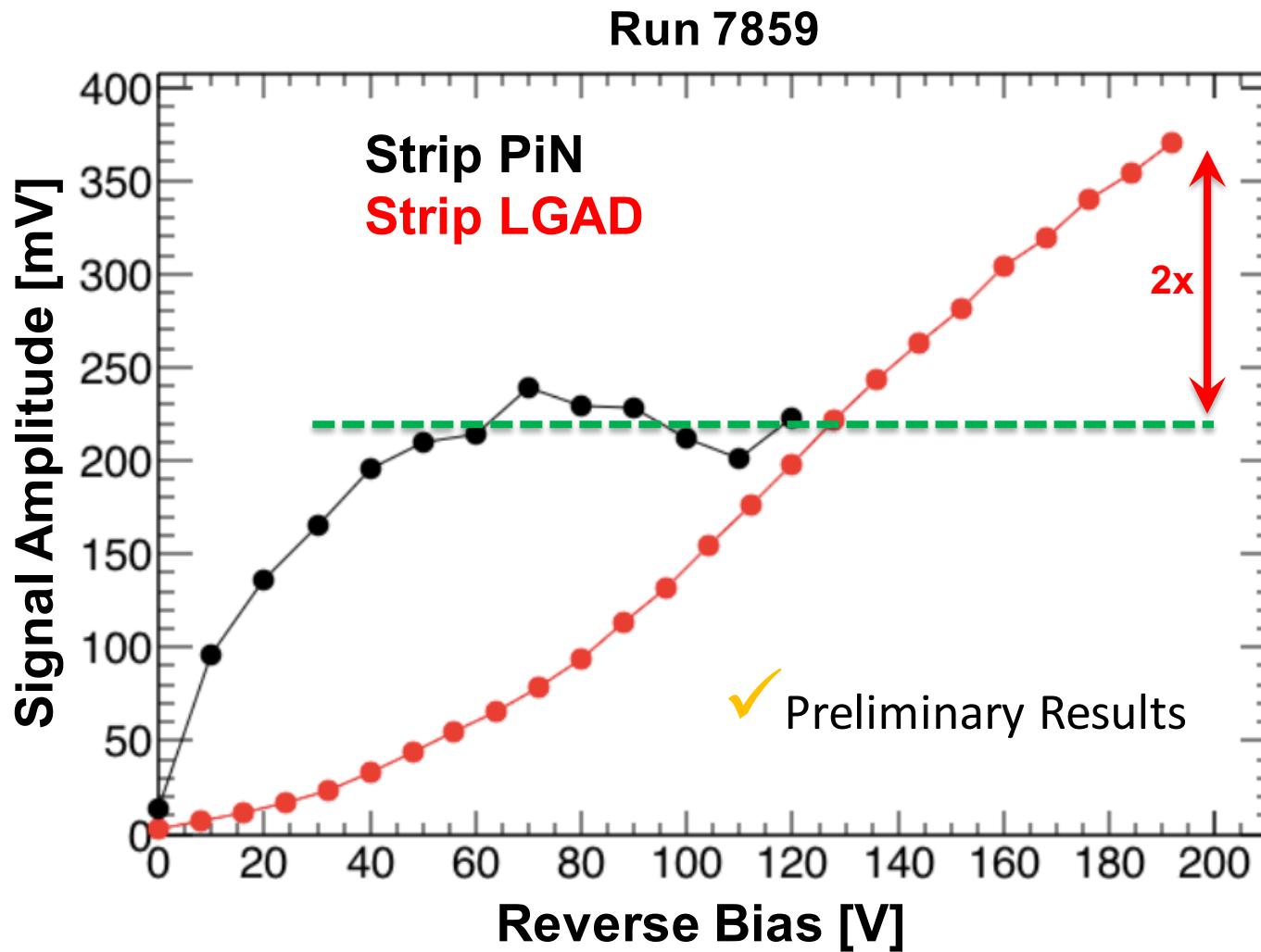


- TCT Basic Information:

- ✓ Run 7859. W4-E2. 150 V
- ✓ Red Laser from Top
- ✓ All 3 Channels Connected
- ✓ DRS4 Circuit Amplifier
- ✓ Strips Without Metal
- ✓ High Signal in the Middle of the Strip. High Gain



First Approach. Strip LGAD. SCIPP TCT. Signal Amp vs Bias

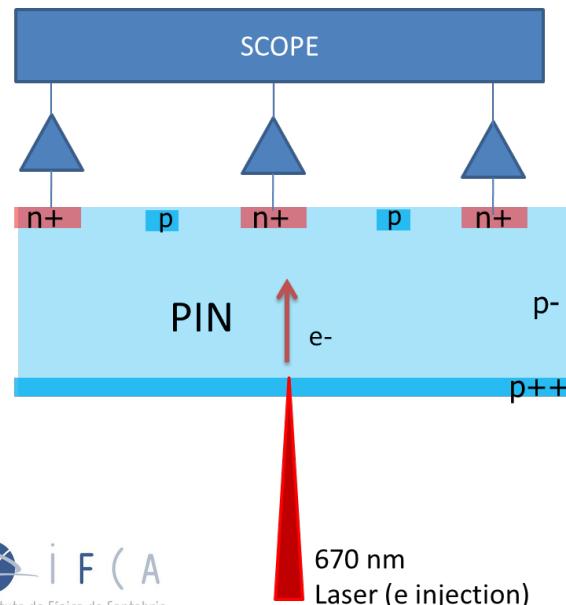


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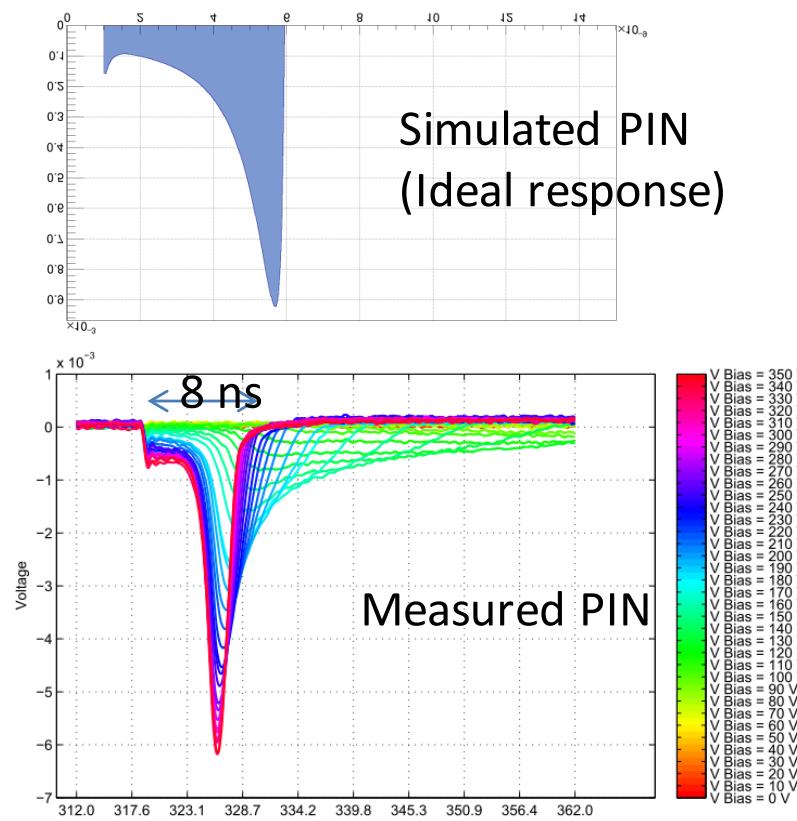
First Approach. Strip LGAD. IFCA TCT. PiN Strip

- See Next Presentation by Sofia Otero Ugobono (CERN)

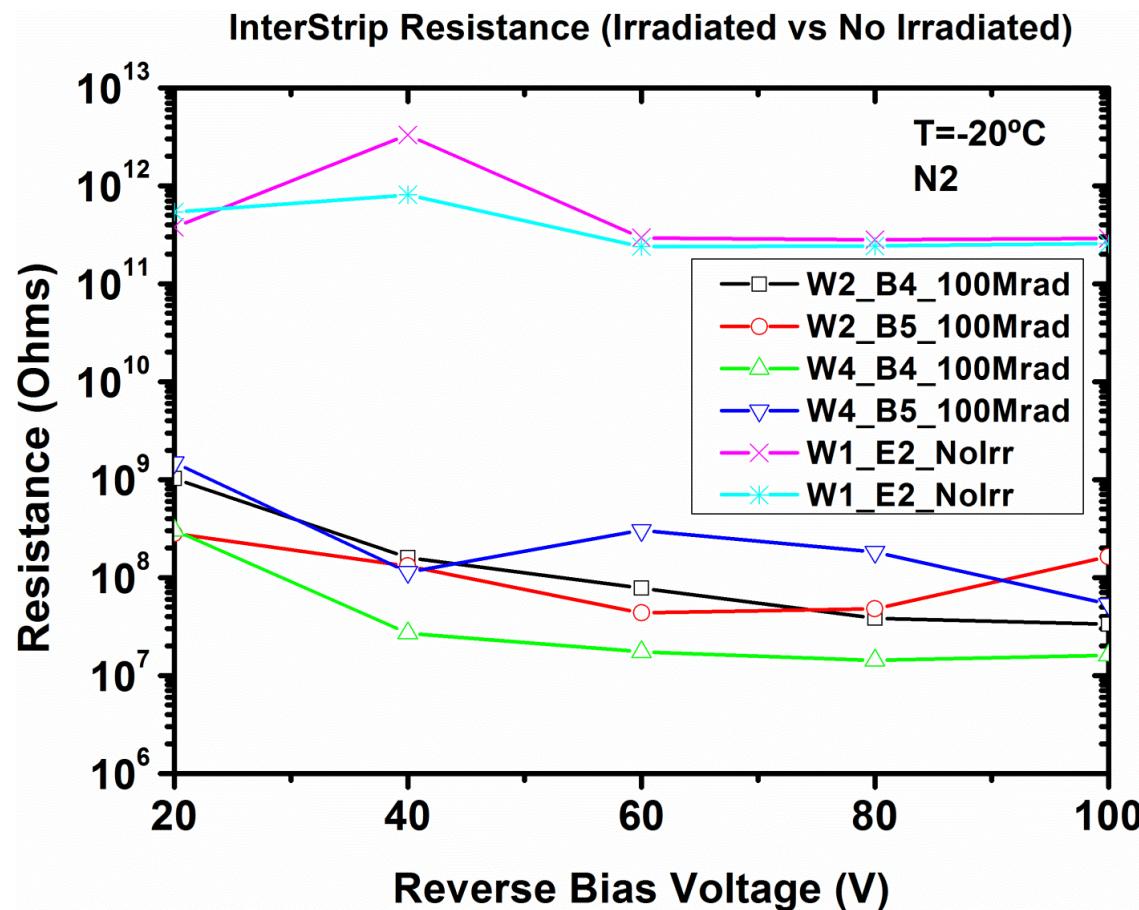
- Comparing **LGAD** microStrips vs microStrip **PIN**
- **Red Laser, Bottom Illumination (Electron Injection)**



W2-G9 Strp.32,160,100,06,24,PiN



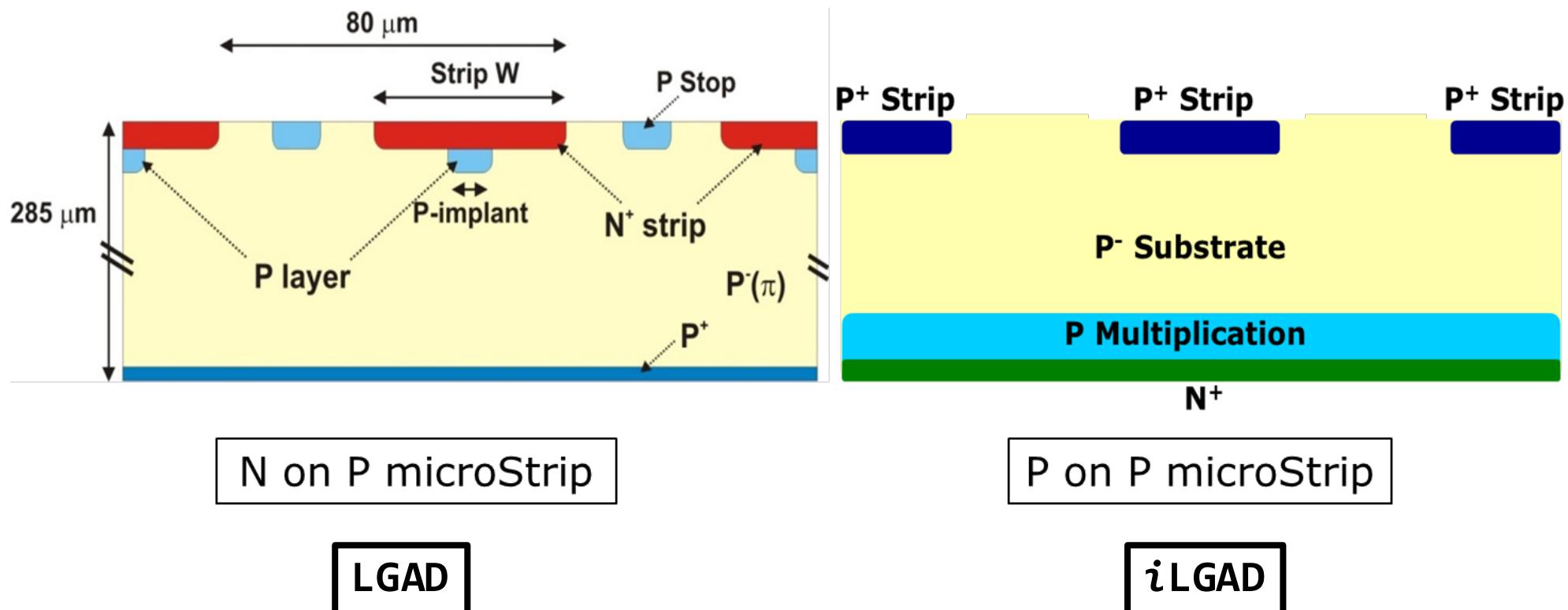
Gamma Irradiated LGAD. Run 7859. Inter-Strip Resistance



- Gamma Irradiation with ^{60}Co
- Inter-Strip Resistance Reduction @ 100 Mrad, for Every Reverse Bias and Sample

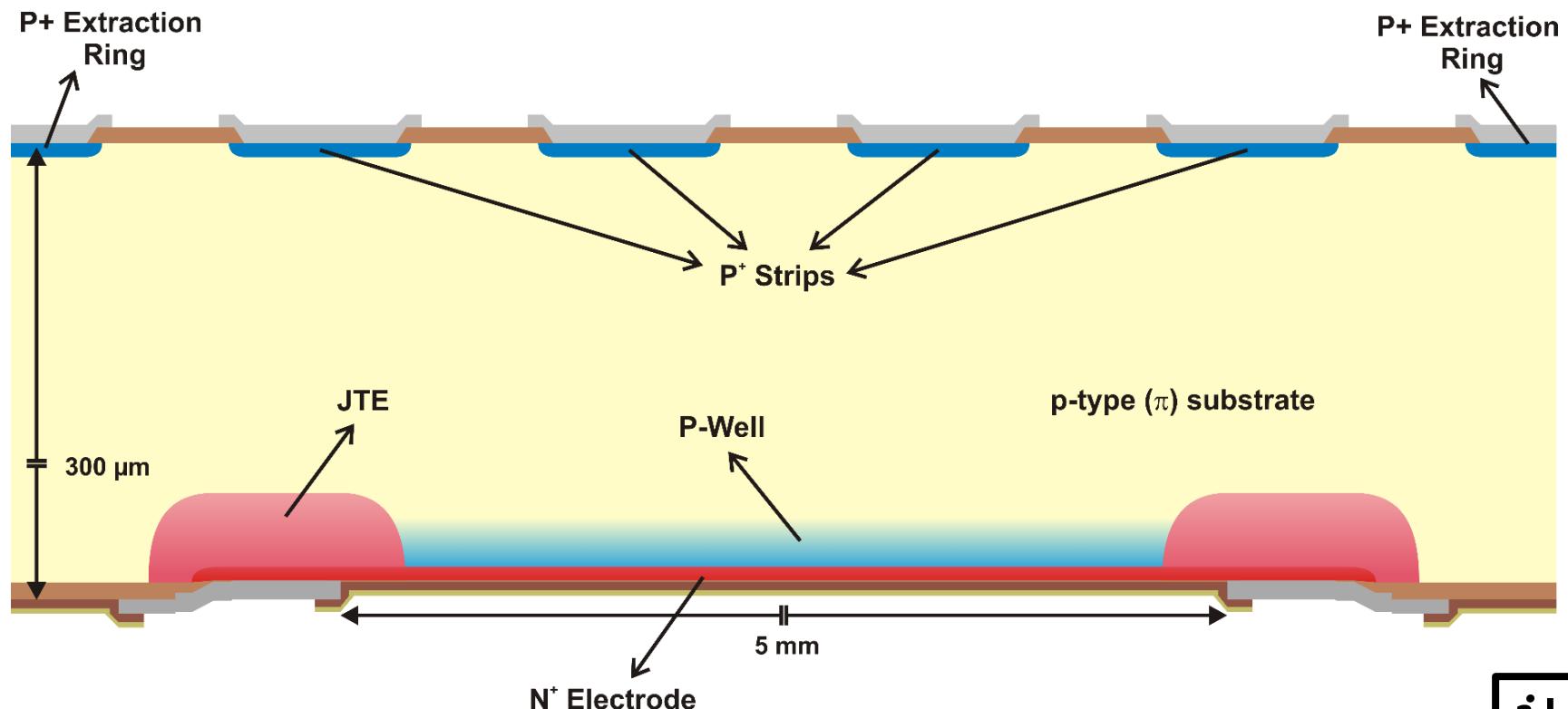
Second Approach. P on P Strip iLGAD: The "Inverse" LGAD

- Double-sided LGAD with pad-like multiplication structure in the back-side and ohmic read out strips, or pixels, in the front-side
- N on P vs P on P LGAD microStrips Comparison



P on P Strip iLGAD: The "Inverse" LGAD

- Double-sided LGAD with pad-like multiplication structure in the back-side and ohmic read out strips, or pixels, in the front-side
- First Design and Run. Include Pads, microStrips and pixelated iLGADs



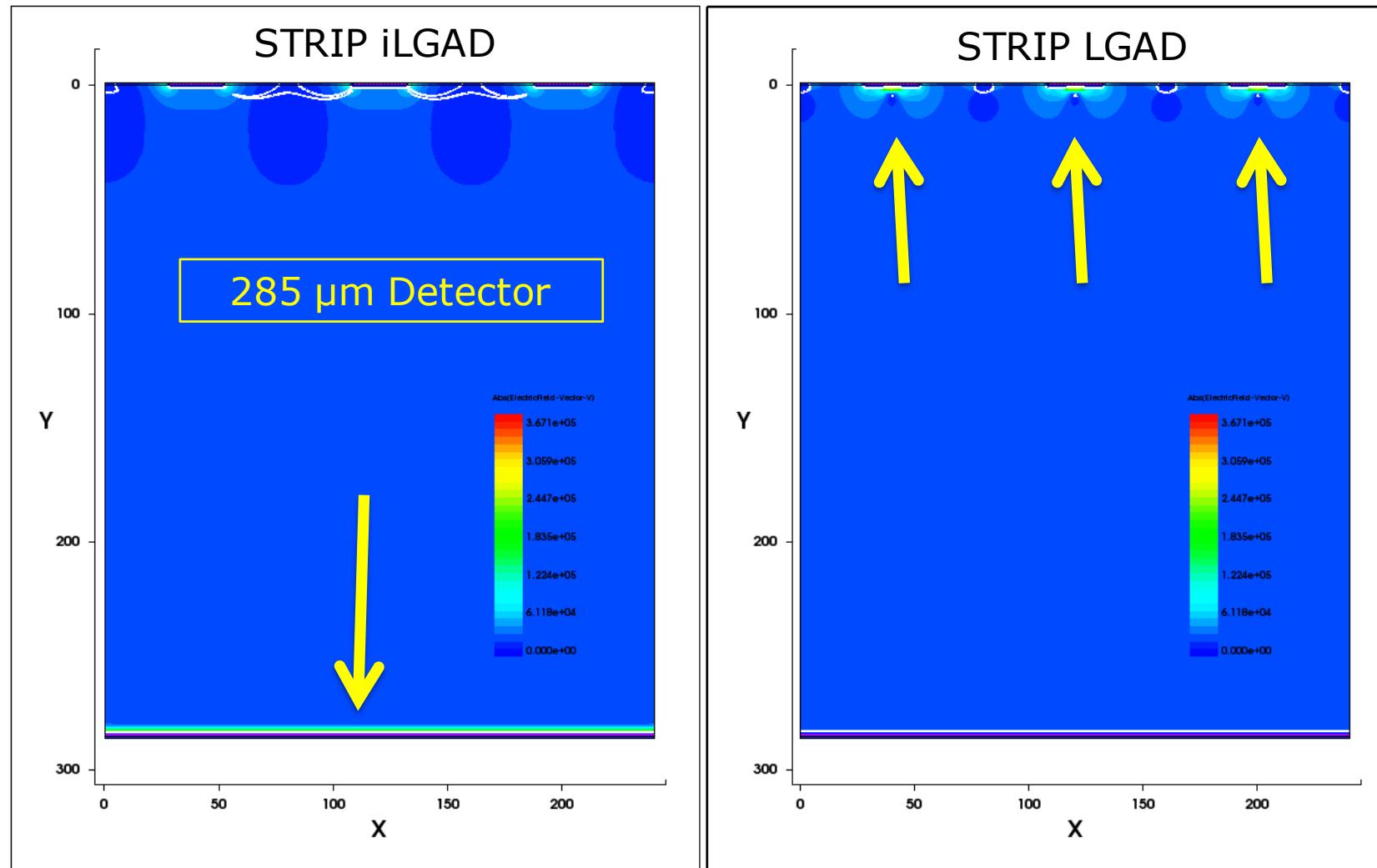
1987 United States Patent. Paul P. Webb et al. RCA Inc. "Avalanche photodiode"

iLGAD

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iLGAD. P on P MicroStrips. 2D Simulation

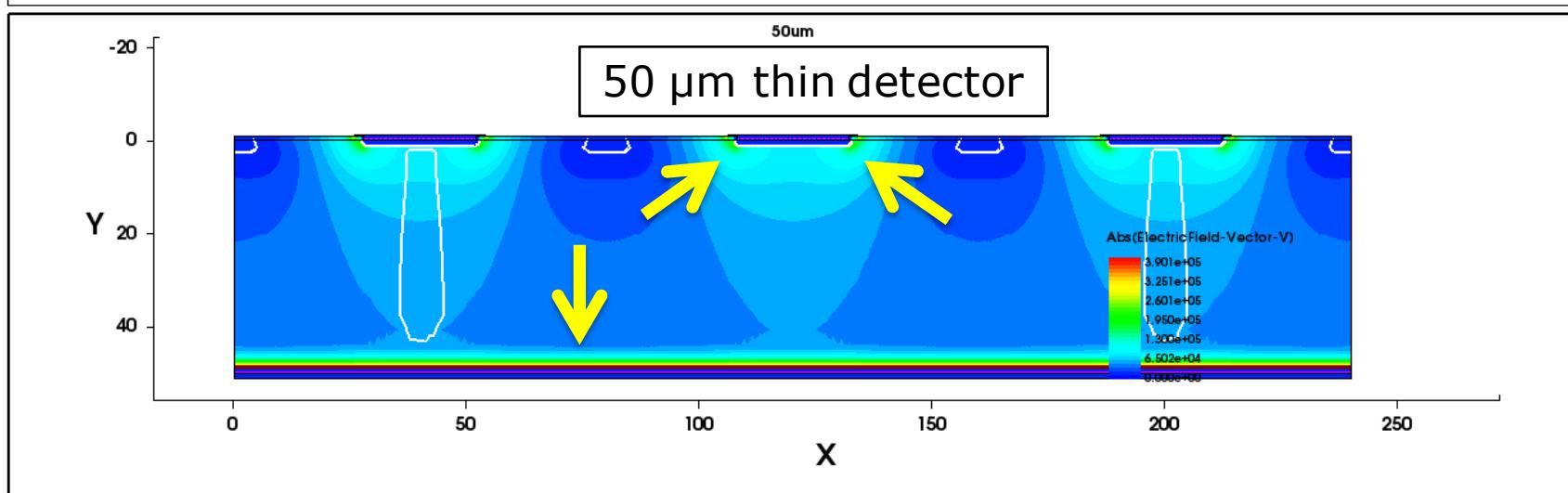
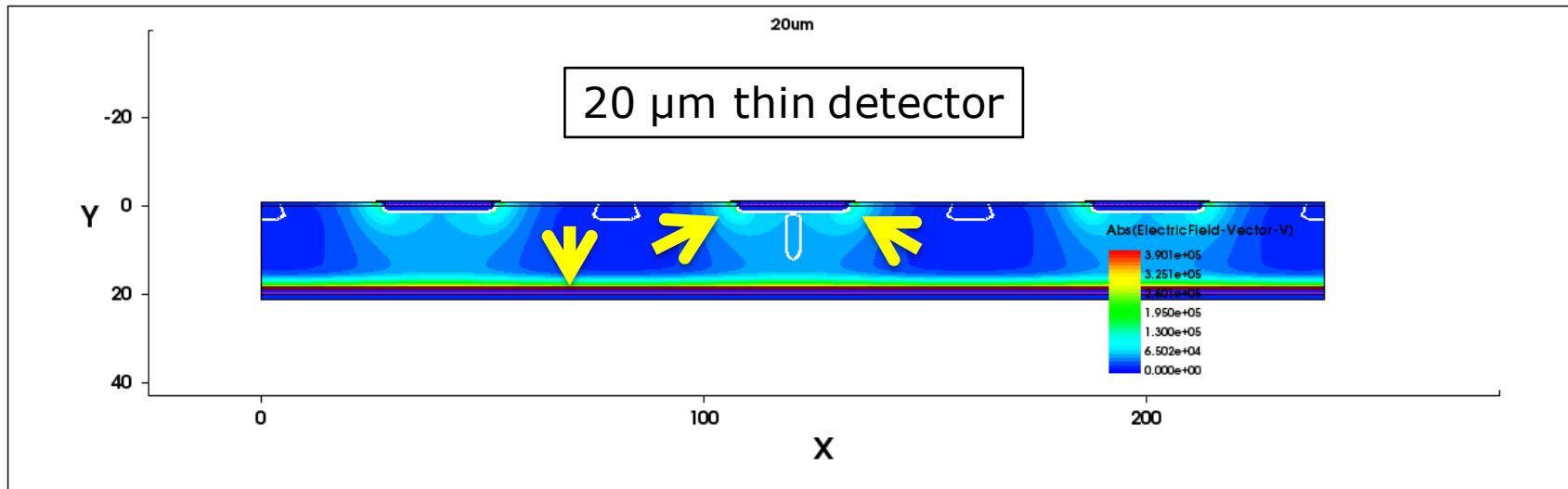
- Three microStrips. Electric Field Distribution: Maximum value @ P-N Junctions



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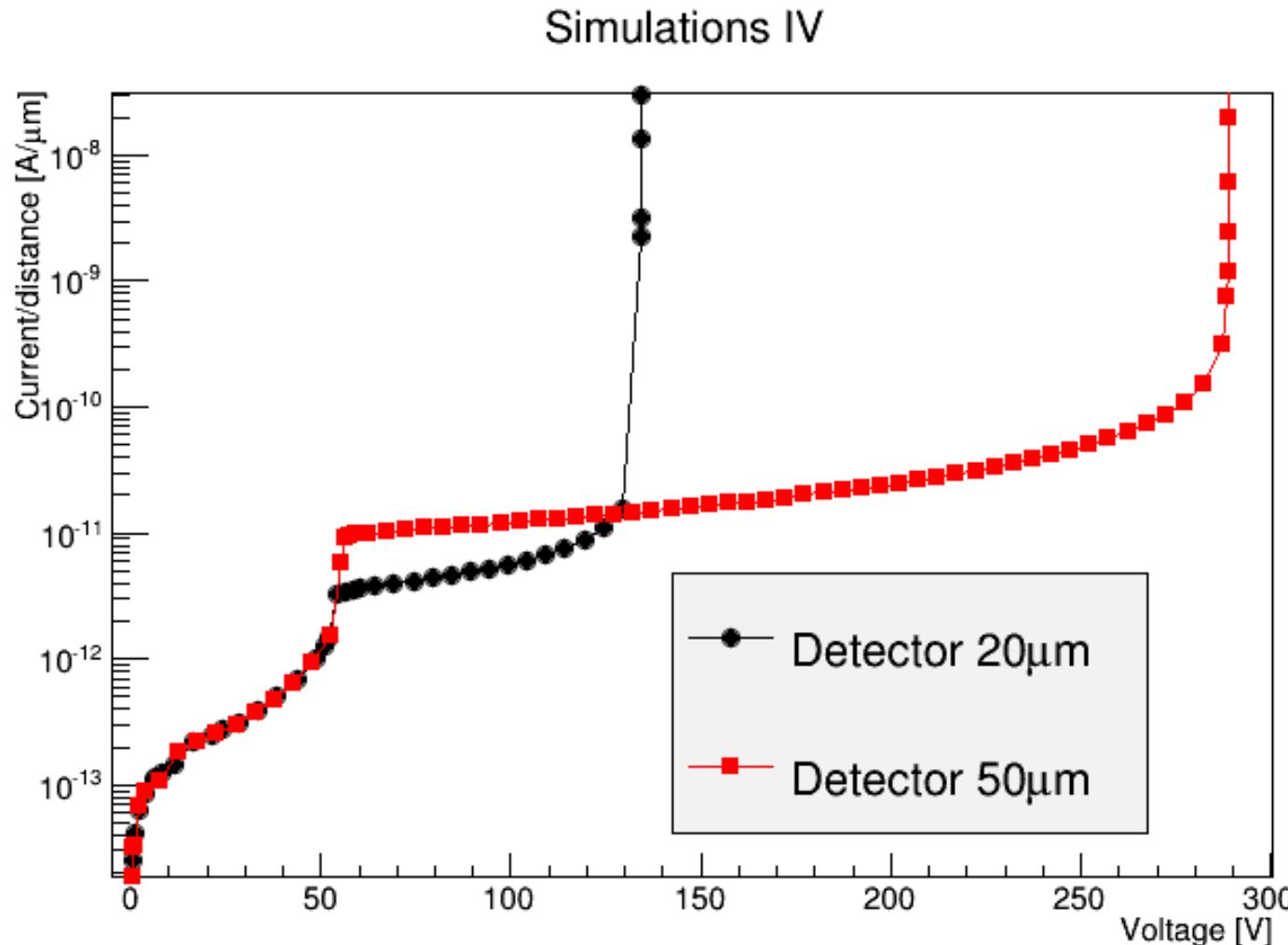
iLGAD. P on P MicroStrips. 2D Simulation

- MicroStrips Simulation. **Electric Field** 2D Distribution @ V_{BR}



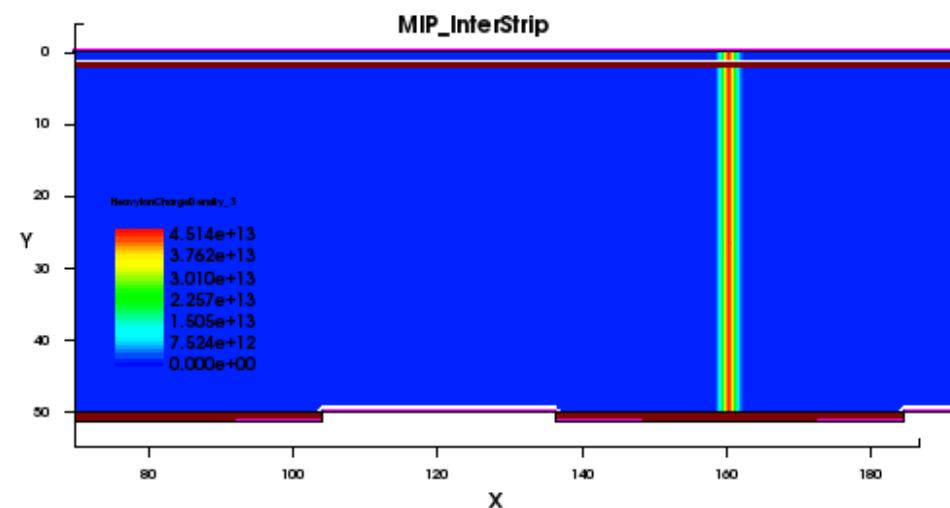
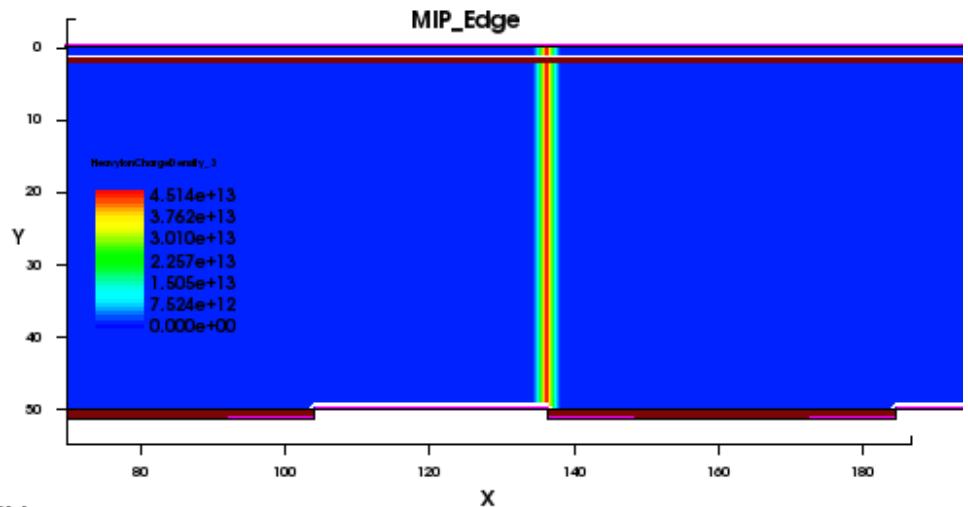
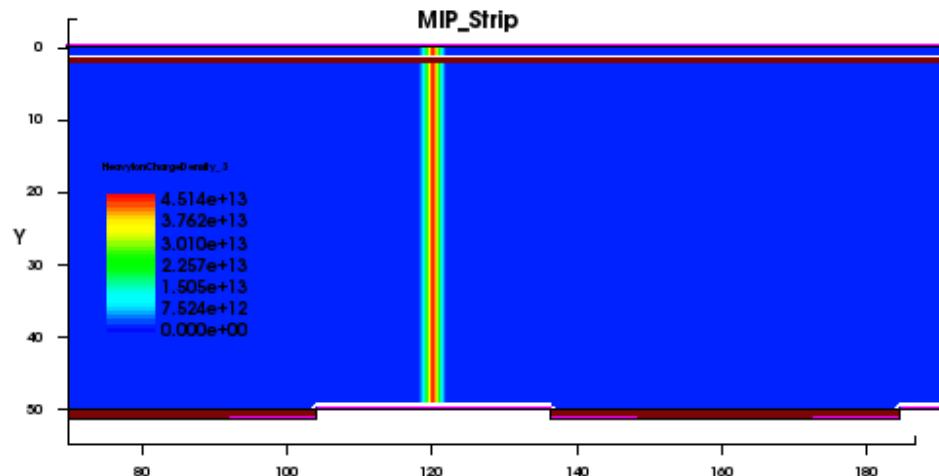
iLGAD. P on P MicroStrips. 2D Simulation

- MicroStrips I(V). Breakdown performances **limited** by **Thickness**

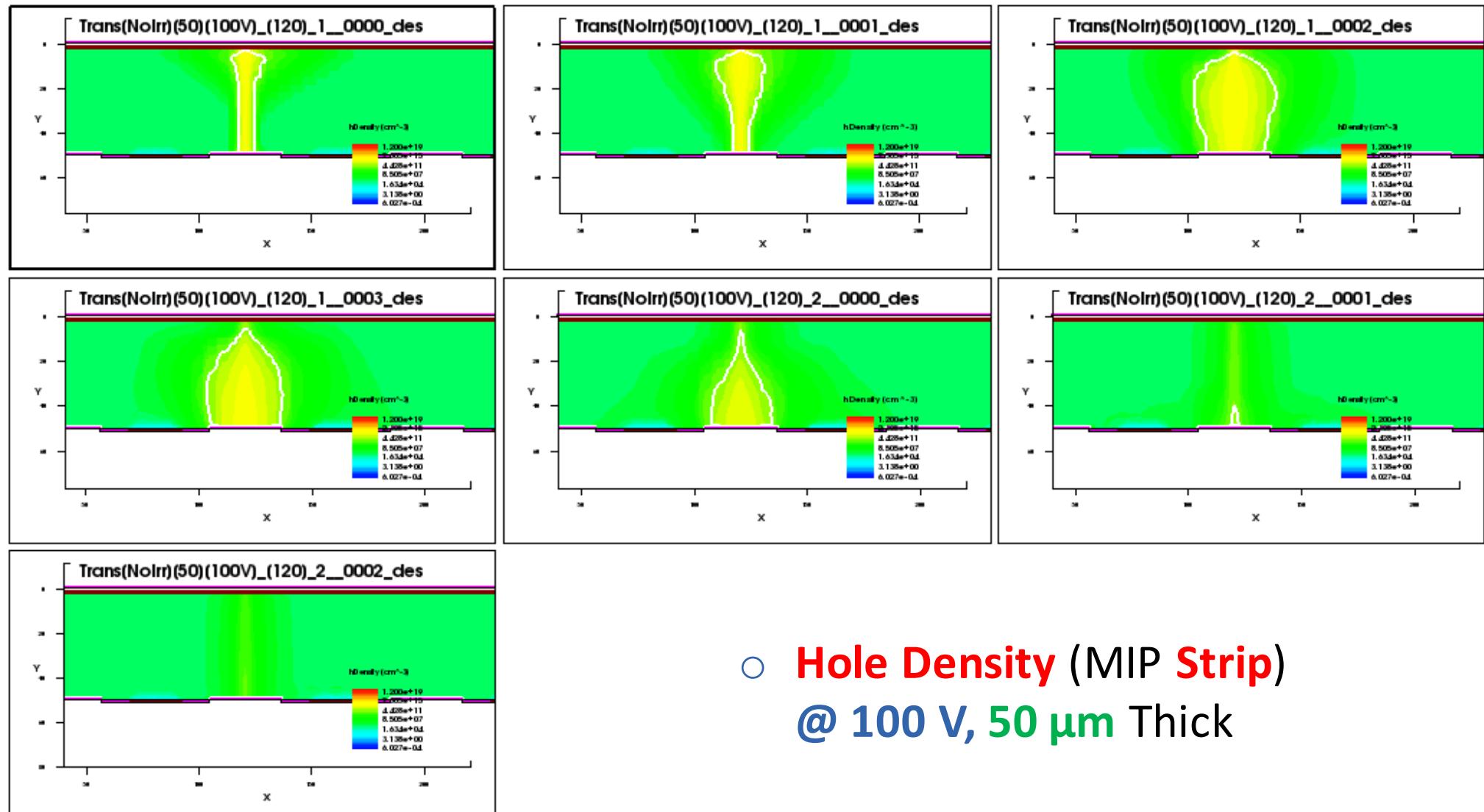


iLGAD. P on P MicroStrips. 2D Simulation. MIP

- Charge Collection (MIP) @ 100 V, 50 μm Thick

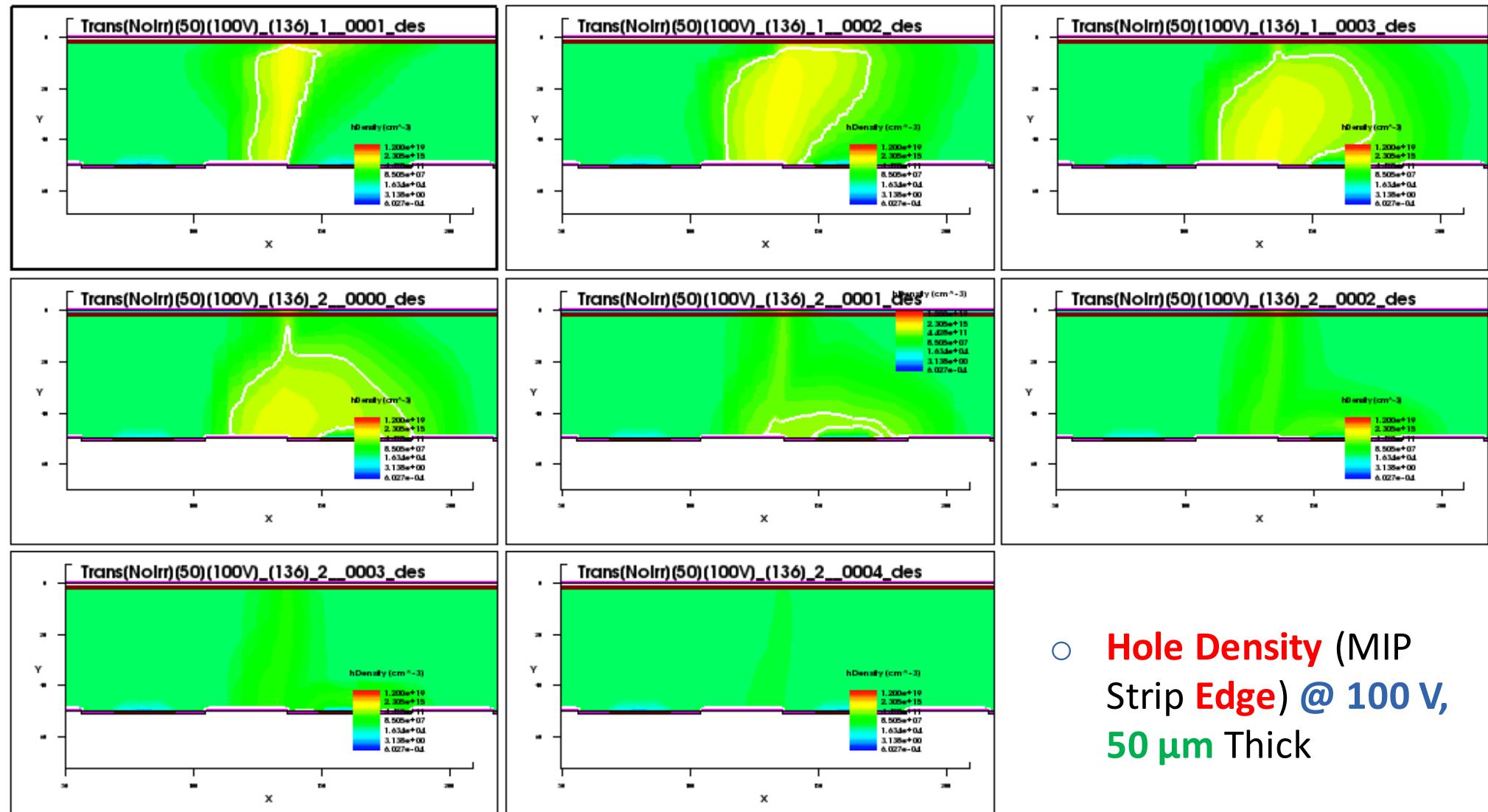


iLGAD. P on P MicroStrips. 2D Simulation. MIP. Strip Center



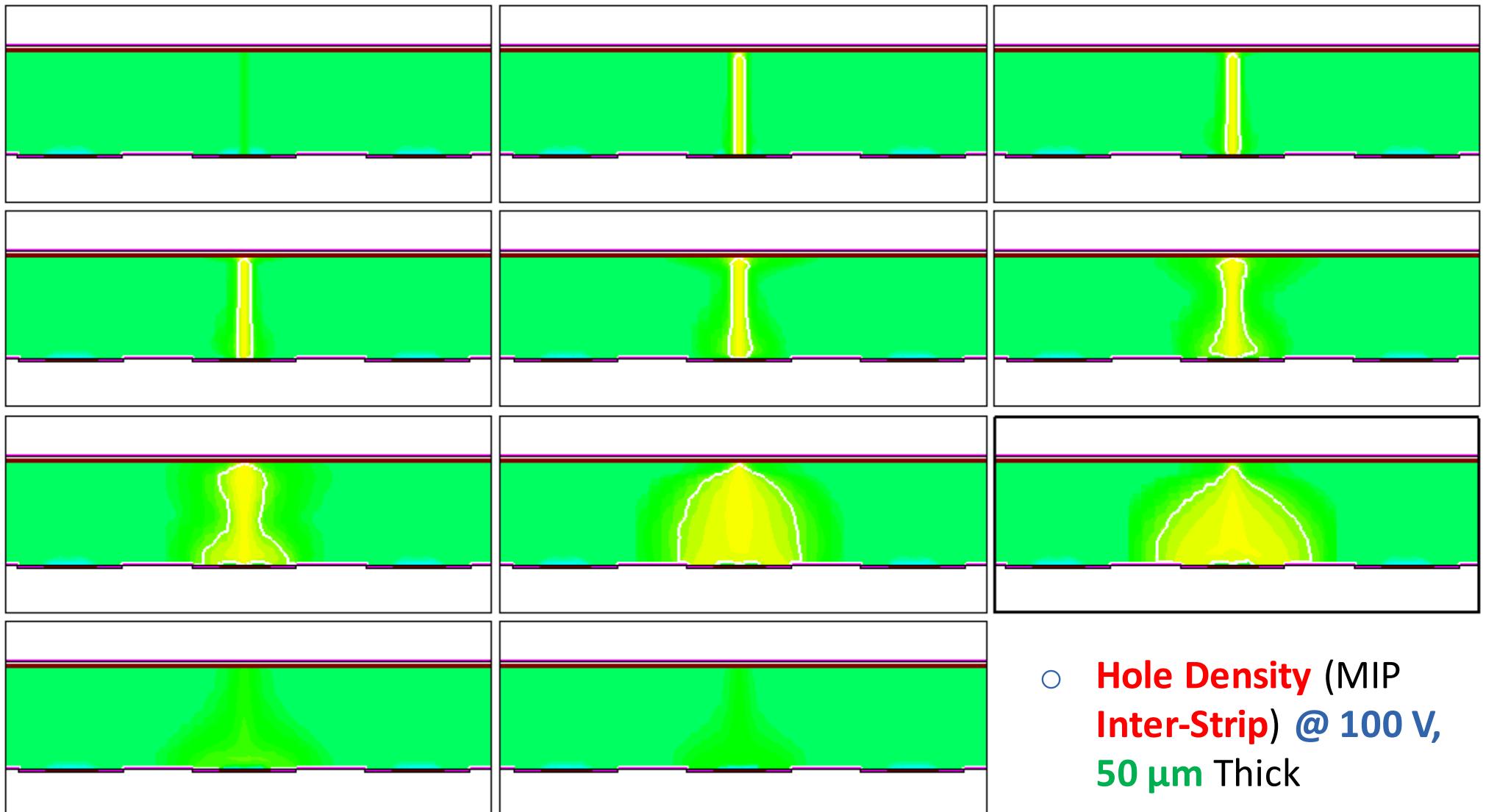
- Hole Density (MIP Strip)
@ 100 V, 50 μm Thick

iLGAD. P on P MicroStrips. 2D Simulation. MIP. Strip Edge



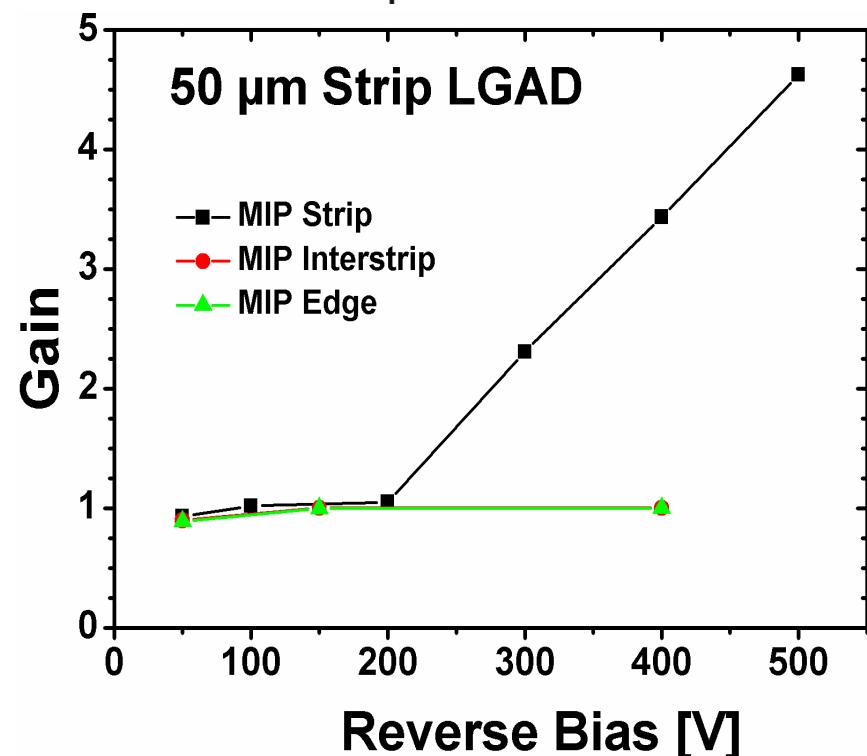
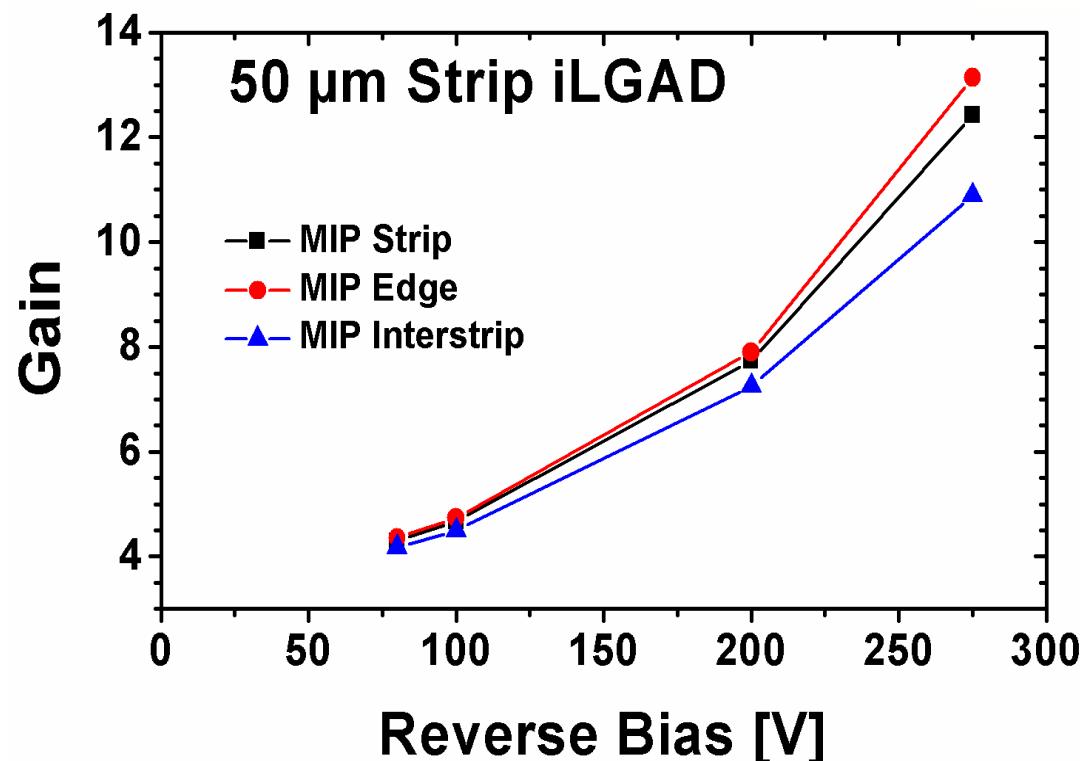
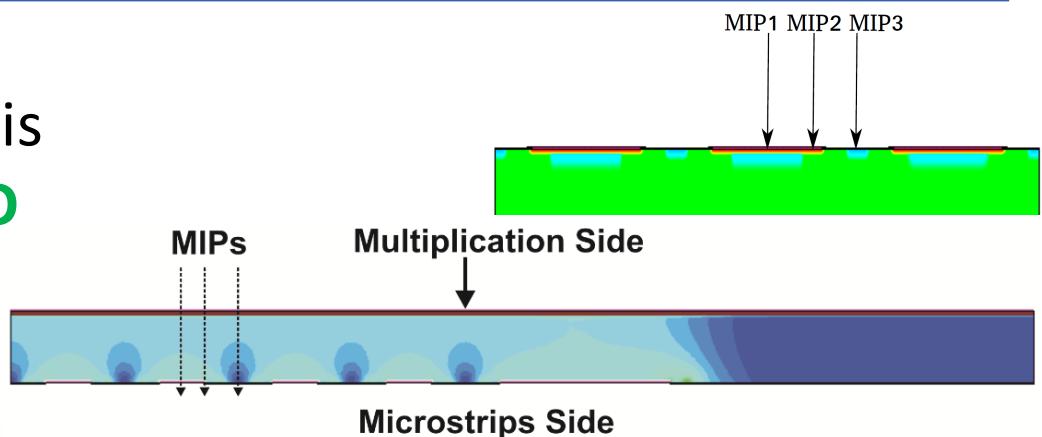
- Hole Density (MIP Strip Edge) @ 100 V, 50 μm Thick

iLGAD. P on P MicroStrips. 2D Simulation. MIP. Inter-Strip



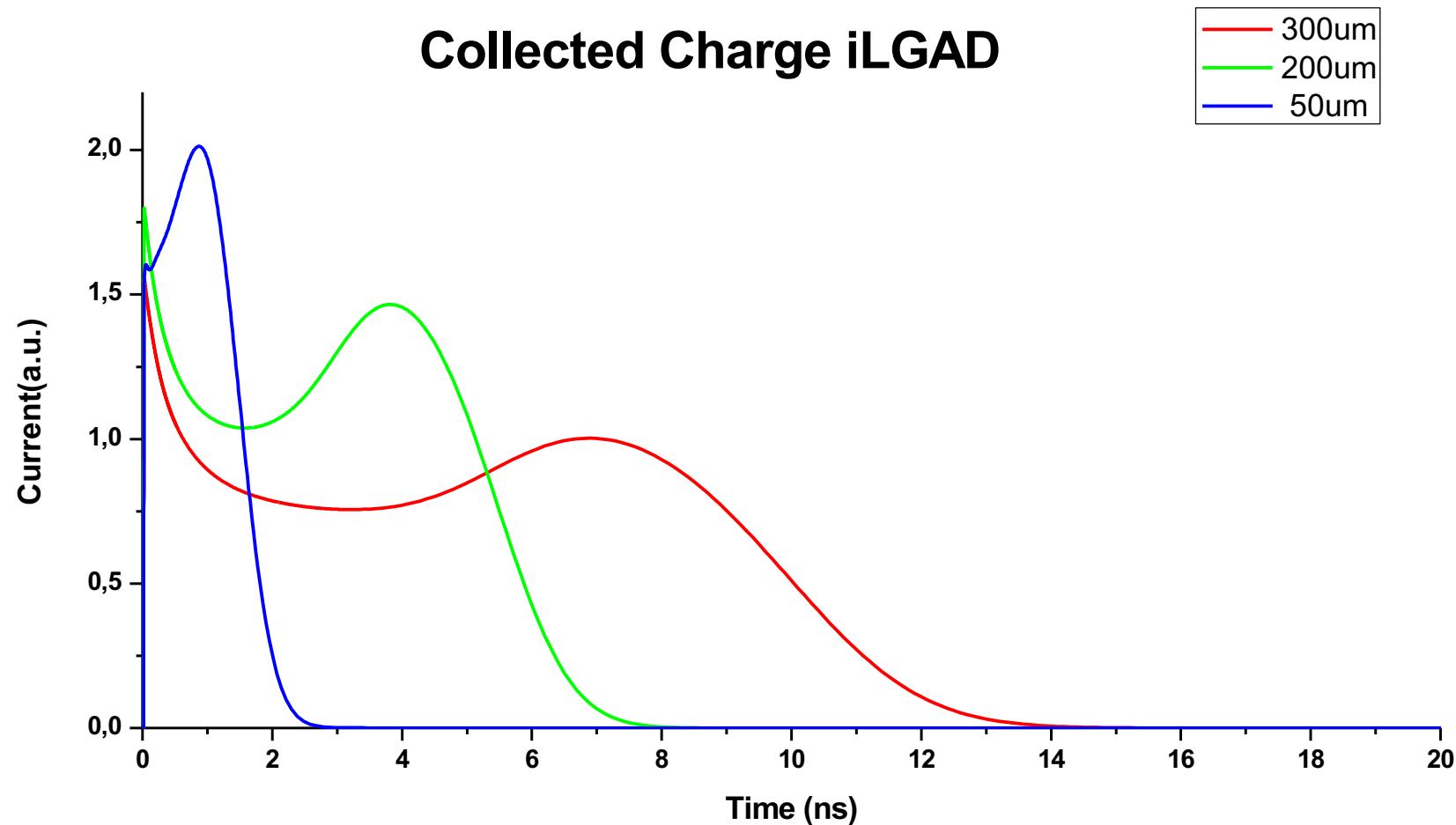
Strip LGAD vs iLGAD. MIP Simulation. Gain Evolution

- μStrip iLGAD Charge Collection is More Efficient than μStrip LGAD



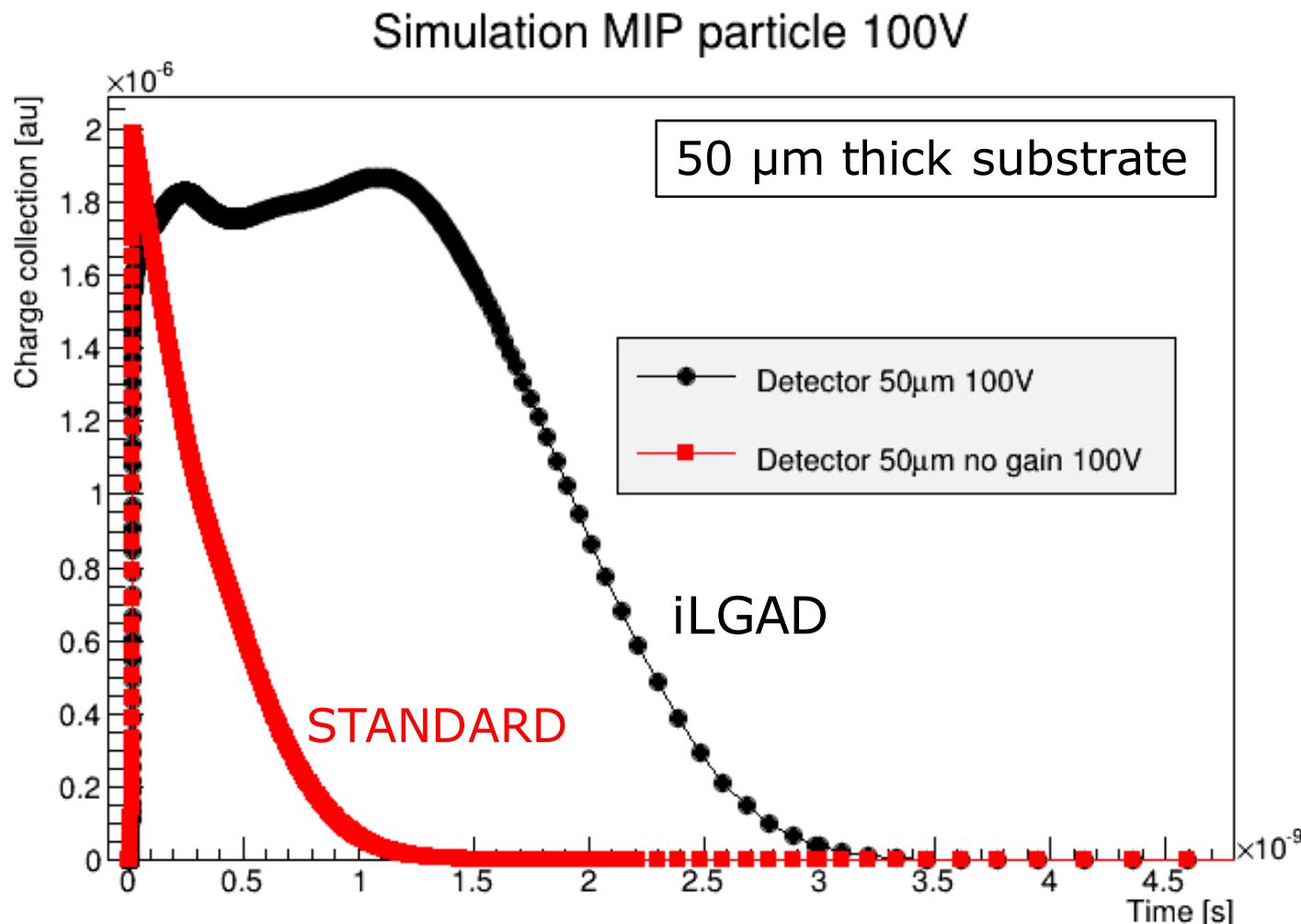
iLGAD. P on P MicroStrips. 2D Simulation. Timing

- MIP through the middle of the sensors (central strip) @ 500 V and 300 V (50 μm)



iLGAD. P on P MicroStrips. 2D Simulation. Timing

- MIP through the middle of the sensors (central strip) @ 100 V



Conclusions

- **Technological** Developments @ CNM on **LGAD & iLGAD** Detectors
- **PAD** LGAD Shows
 - ✓ Gain: 3.7 – 8.4, Dose: 1.8e13
 - ✓ Gain: 8.3 – 44, Dose: 2.0e13
 - ✓ Good Homogeneity
- **microStrips** LGAD Shows
 - ✓ Low Gain: 2.0 @ 200 V
 - ✓ Charge Collection. Center of Multiplication Area
- **New iLGAD**. Low Gain P on P Detector
 - ✓ Position-Sensitive Detectors
 - Thin Detectors
 - Fine Pitch
 - ✓ Timing
 - Thin Detectors
- **Double-Sided** LGAD
 - ✓ Pad LGAD @ Back-side
 - ✓ Ohmic Read Out @ Front-side
- **microStrip iLGAD Simulation**
 - ✓ Optimization
 - Technological
 - Electrical
 - Thinner Substrates for Timing
 - ✓ Detectors Shown **Good Performances**
 - ✓ **μStrip iLGAD charge collection is better** than **μStrip LGAD**
- **First Mask Set**
 - ✓ microStrips
 - ✓ Pixels
- **First iLGAD Prototypes**
 - ✓ 12 Mask
 - ✓ 100 Steps
 - ✓ 5-6 Months
- **First iLGAD Run Already Started**
@ CNM

Thank you for your attention !!!!



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