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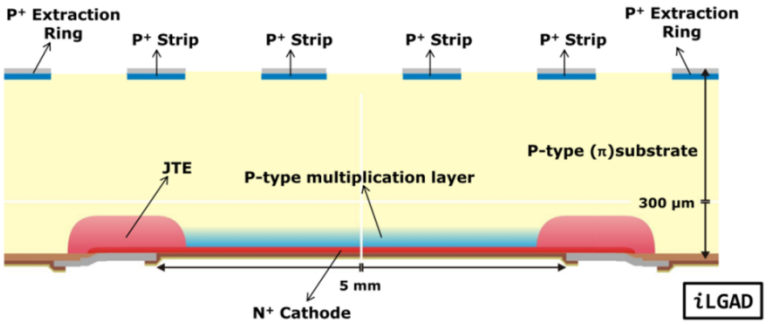
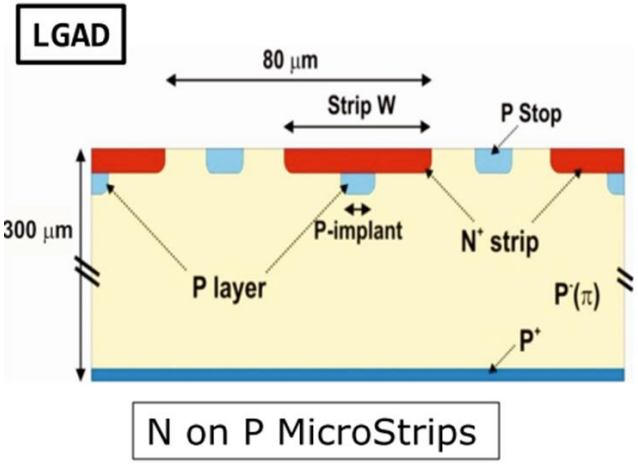
Developed inside the RD50 collaboration & AIDA -2020 WP7 on Advanced Hybrid Detectors.

This project has received funding from the European Union's Horizon 2020 Research and Innovation programme under Grant Agreement no. 654168.

Towards an ultralight tracking system: the strip-LGAD & the i-LGAD sensor





Linear Collider Workshop 2016, Morioka, Dec 2016

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Instituto de Física de Cantabria

CSIC Consejo Superior de Investigaciones Científicas

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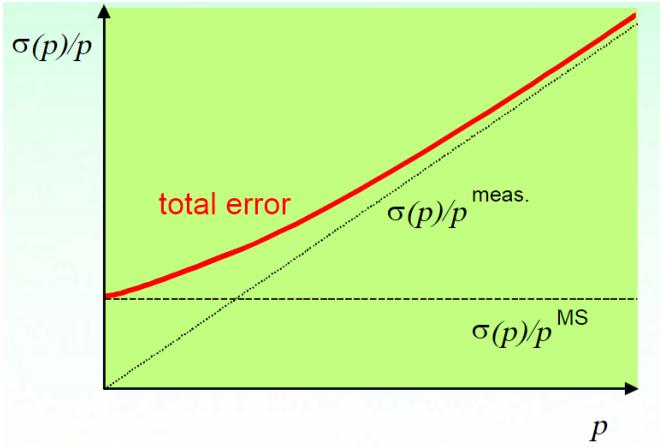
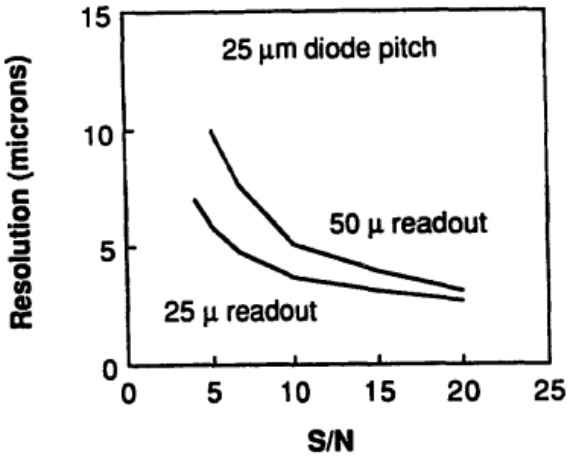
Outline

- Low Gain Avalanche Detector (LGAD) Motivation & basics
- Strip LGAD & Inverse LGAD Proof-of-concept: Transient Current Caracterization of s-LGAD (n-in-p) and i-LGAD (p-in-p)
- I-LGAD Test beam characterization
- Summary and outlook.

Motivation for a strip detector with integrated signal gain

- Integrated signal amplification increases the Signal-to-Noise ratio increasing the tracking resolution:
  - Thinner detectors (reduction of the **multiple scattering**)
  - Improved **intrinsic hit resolution**.





Low Gain Avalanche Detectors 101

– Signal amplification implemented as reach-trough Avalanche Diode structure [Web74].

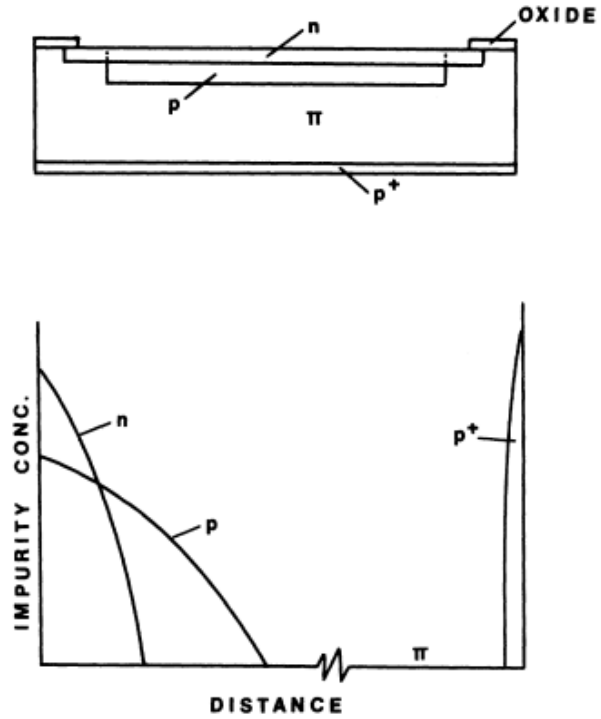


Fig. 1 - Reach-through avalanche diode structure and impurity concentration profile. The starting material is p-type silicon of about 5000 ohm-cm, resistivity. The p and n diffusions are, respectively, boron and phosphorus.

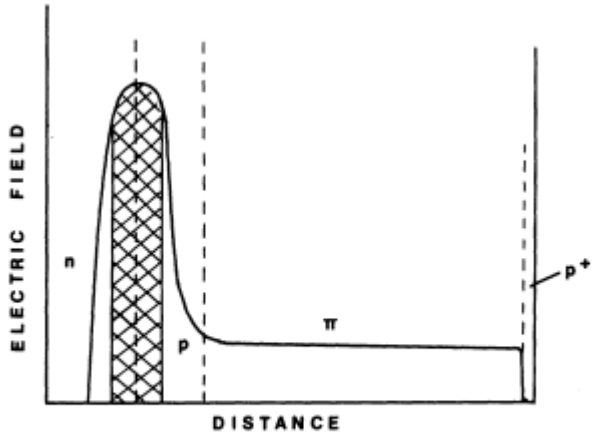
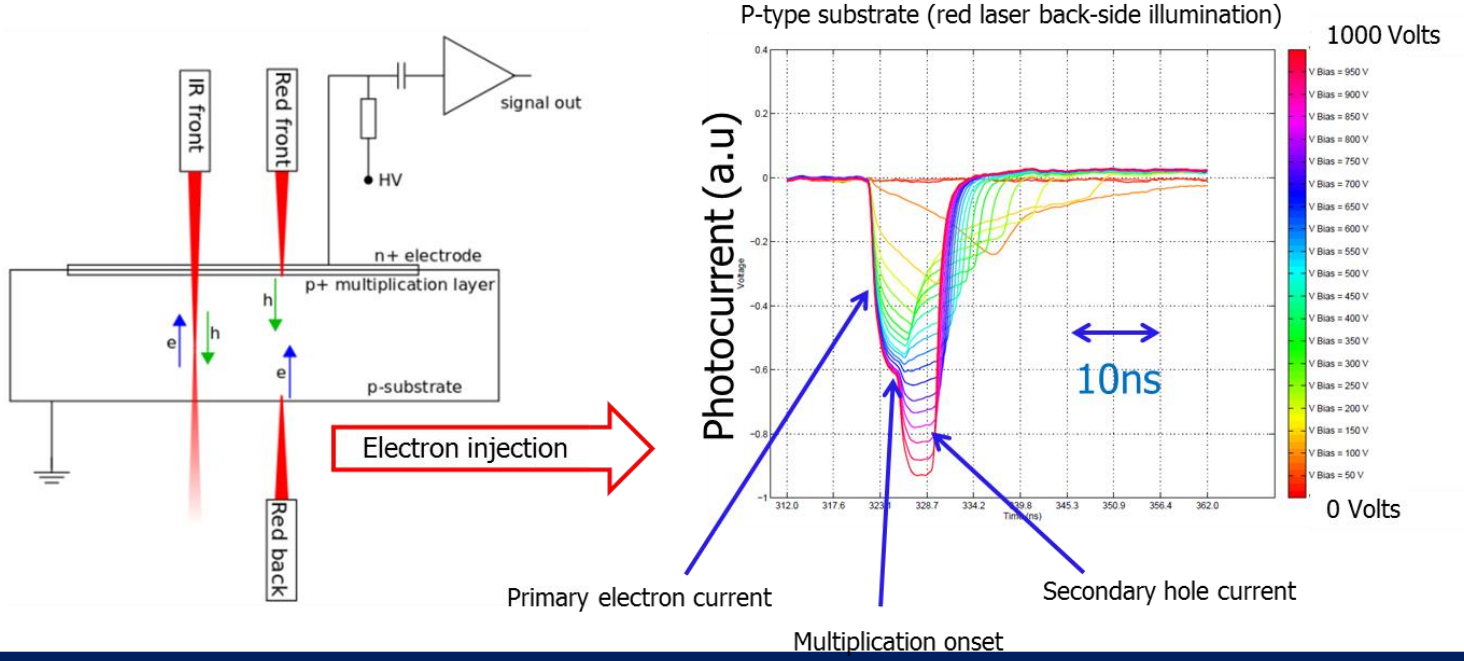


Fig. 2 - Electric field profile for a reach-through avalanche diode.

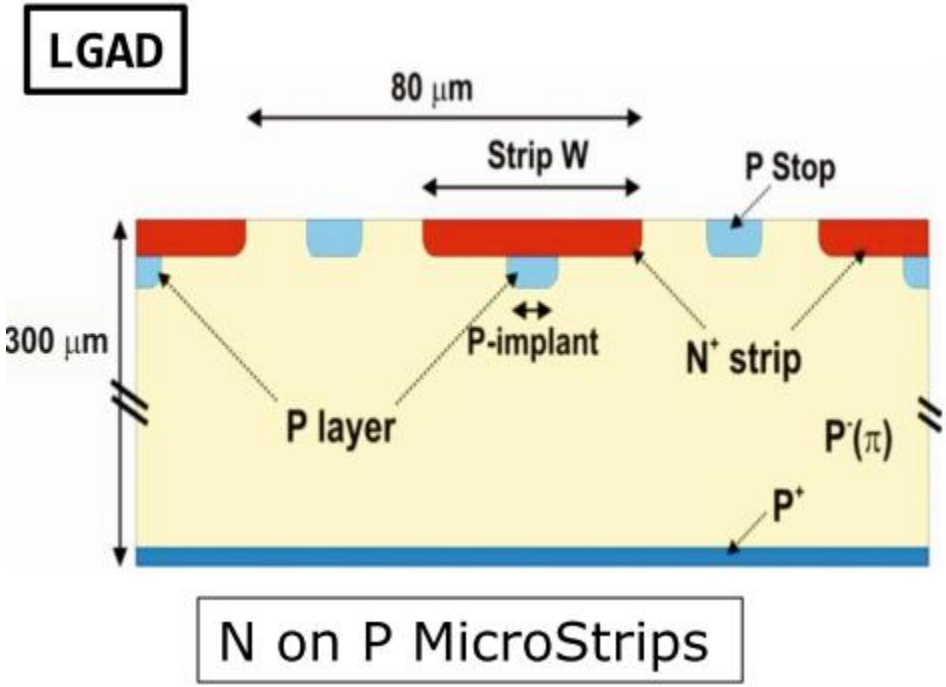
High electric field to trigger the production of secondary carriers by impact ionization.

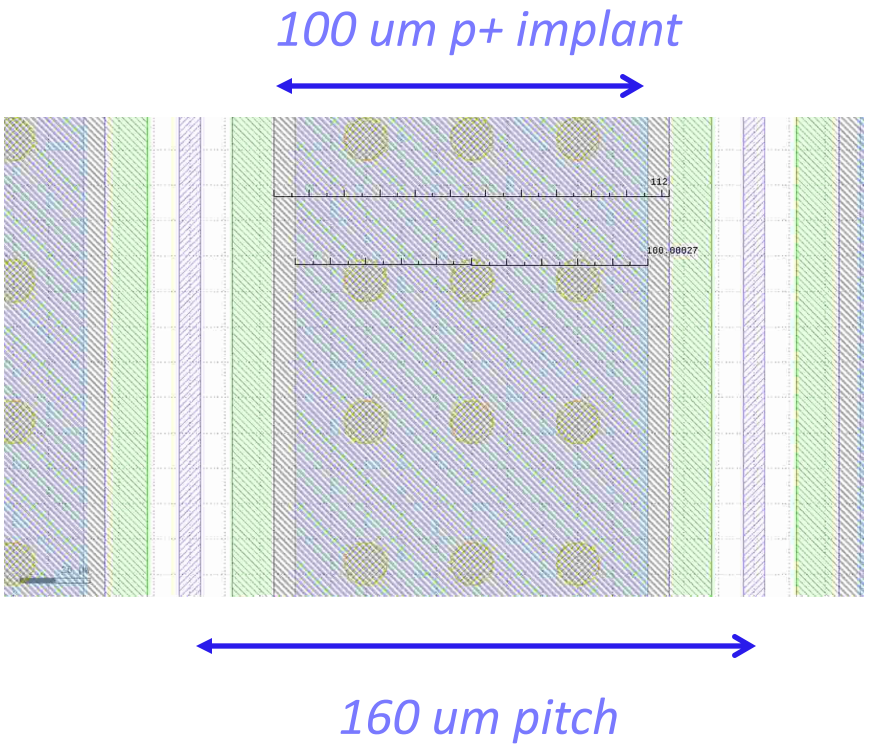
Methodology: Signal amplification footprint

- Distinct signature of signal amplification.
- Injections of electron into the anode: resulting transient current is a sequential contribution of primary electrons reaching the amplification layer and secondary holes drifting towards the anode.



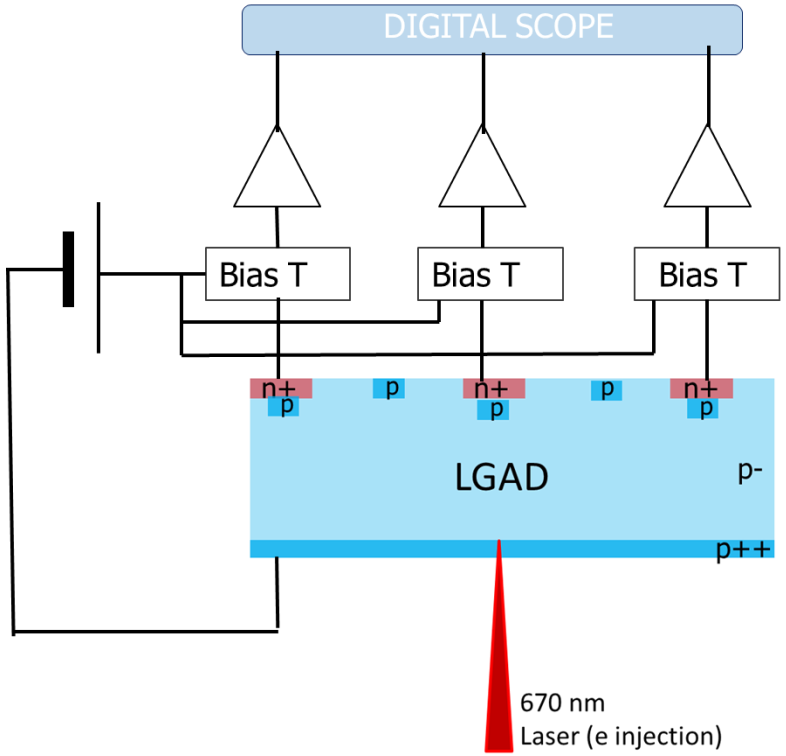
Strip LGAD Characterization (r#7859)





Multi-channel TCT on DC strips.

– All Strip LGAD (r#7859) and I-LGAD (r#8533) manufactured as DC mini sensors (biasing through decoupling capacitor).



Simultaneous read out

of up to three strips

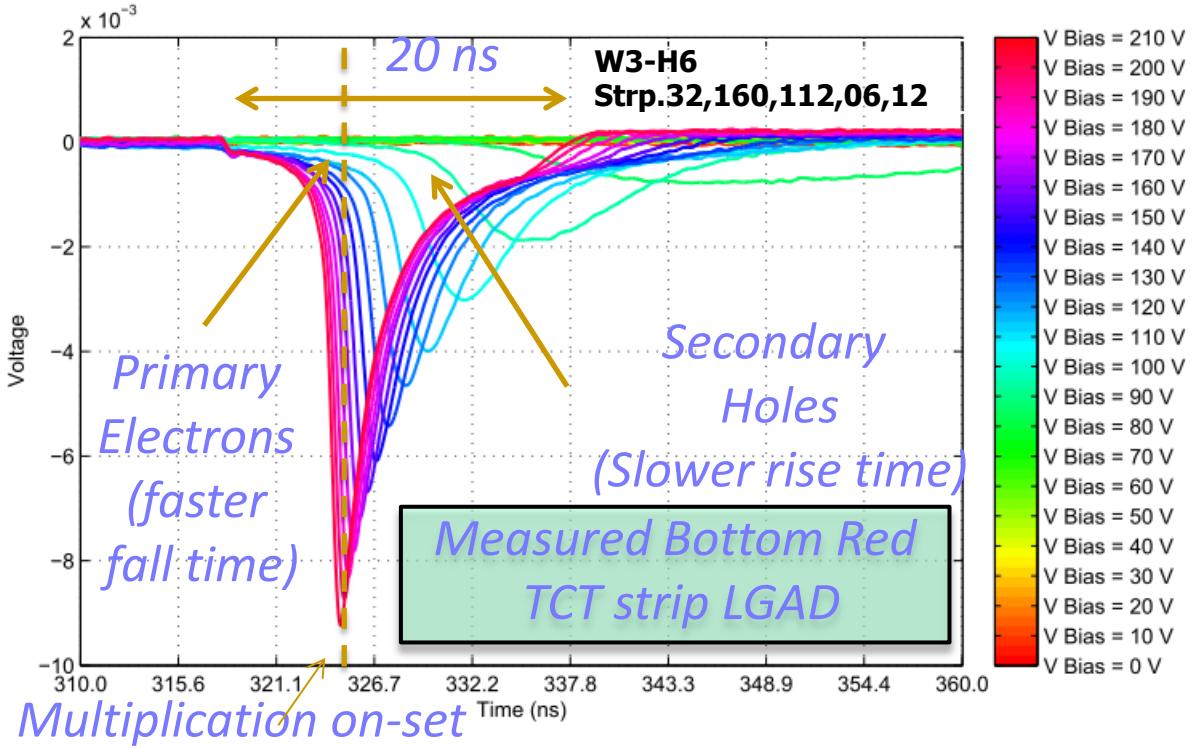
Electron injection

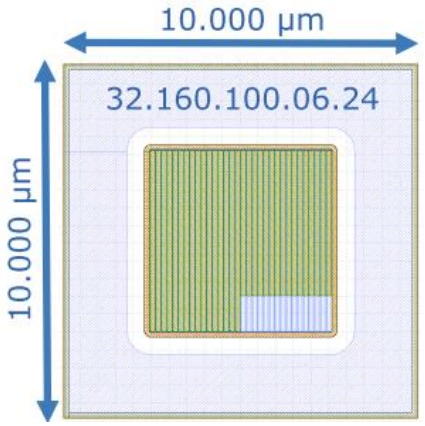
(red laser back-side

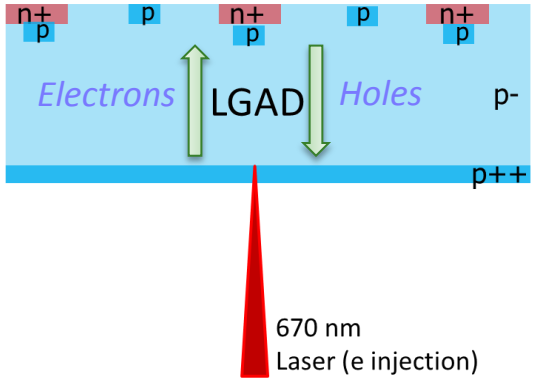
illumination)

LGAD strip: electron injection

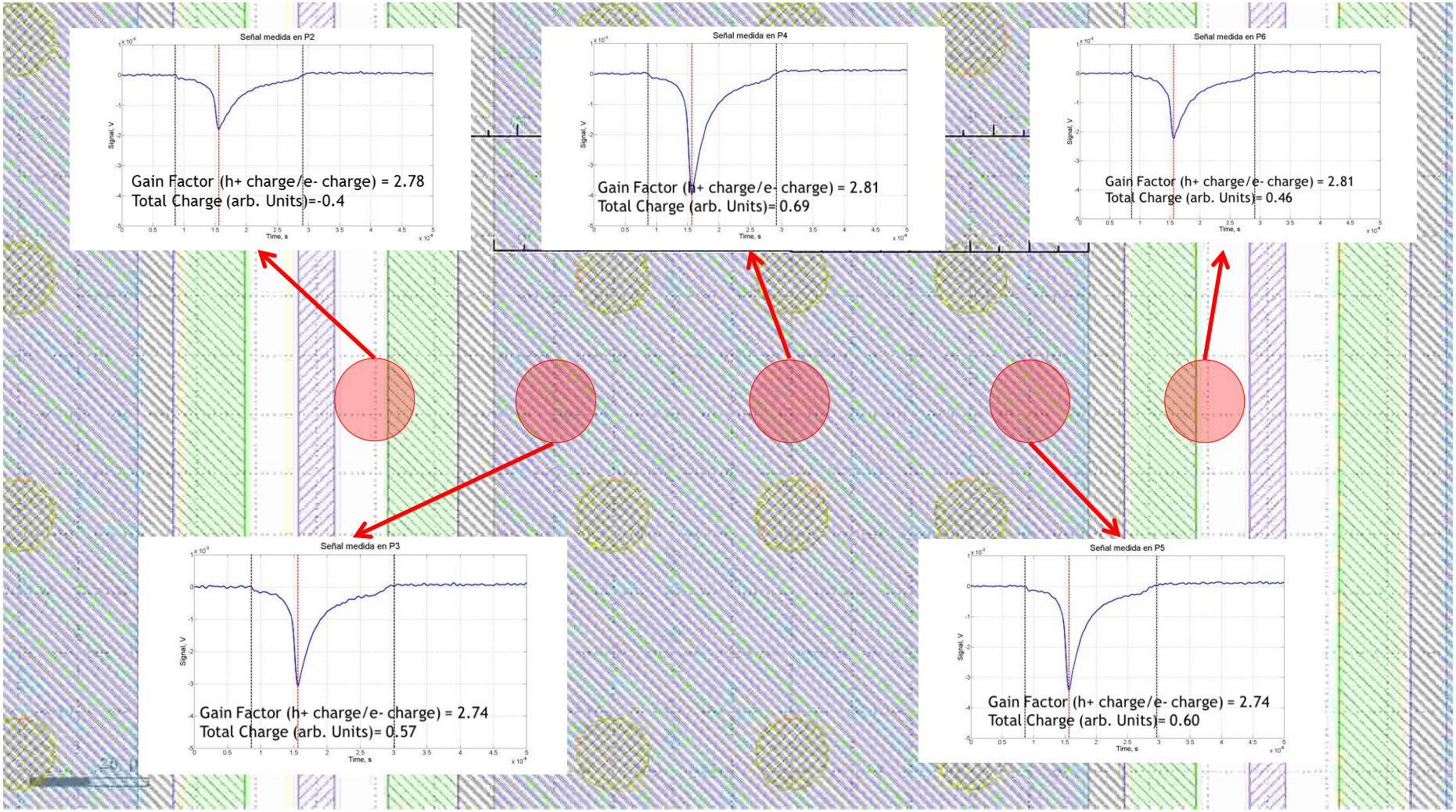
- Signal gain observed:
  - Wider TCT pulses wrt to PIN
  - Charge increases vs HV
- Strip current waveform shows clear sequential electron and hole drift





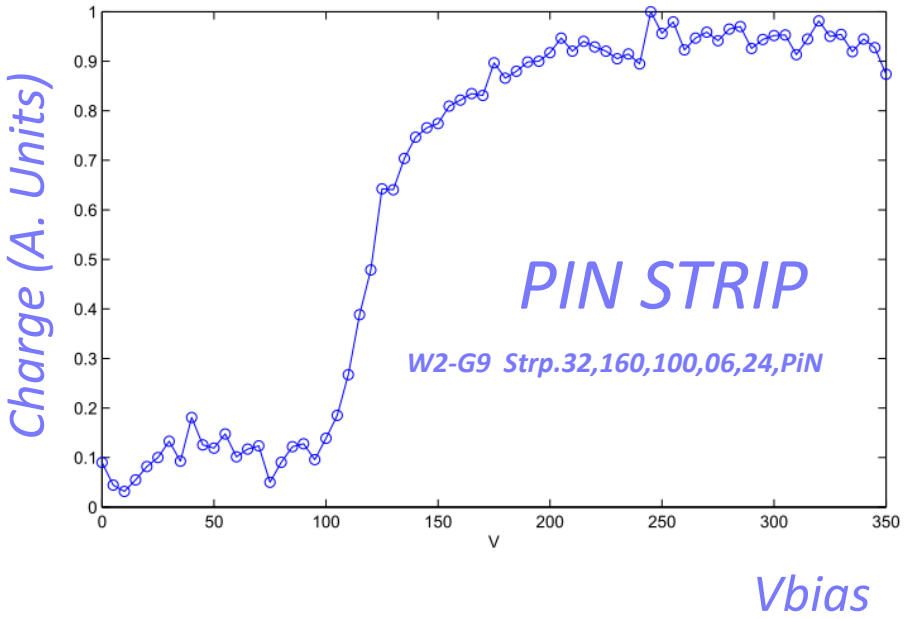


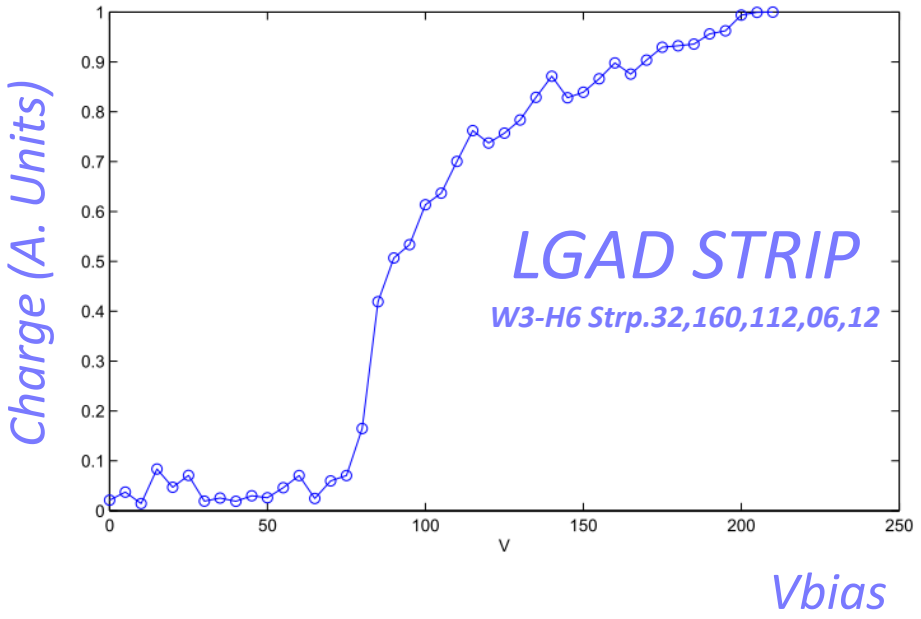
Strip LGAD: Gain Factor Uniformity:



LGAD Strip: Signal vs V_{bias}

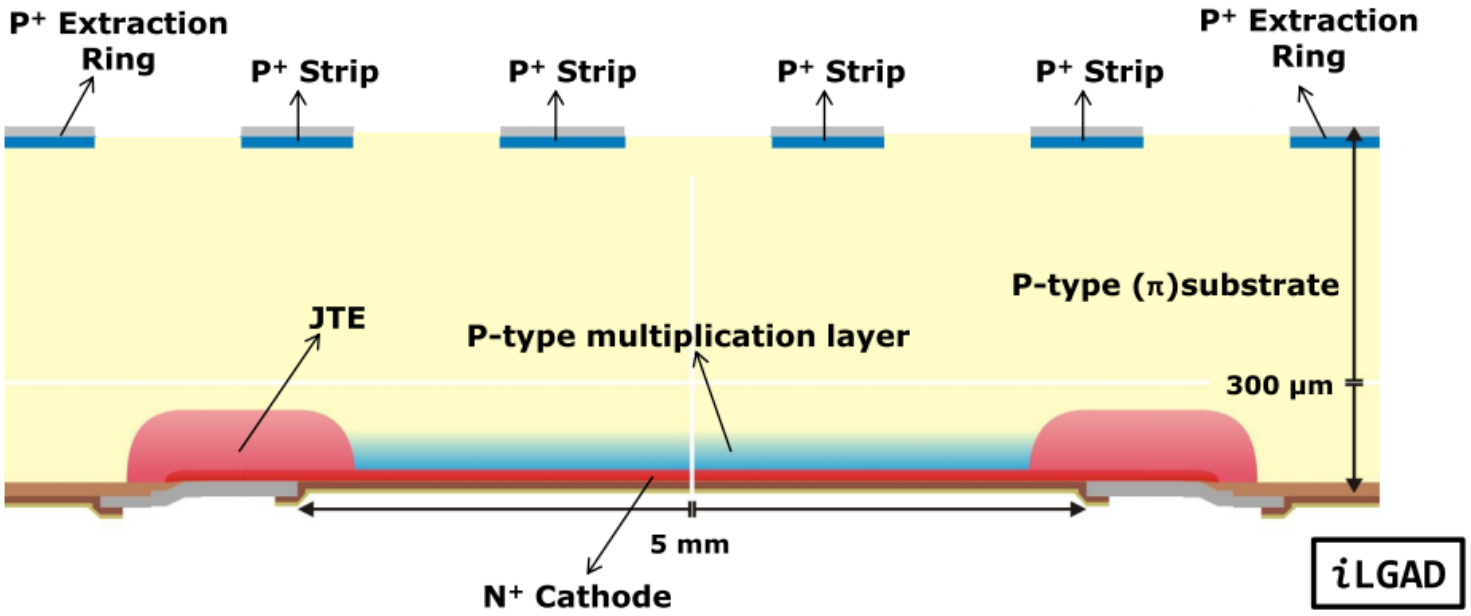
– Red laser, bottom TCT, electron injection (Integrated current transient curves)





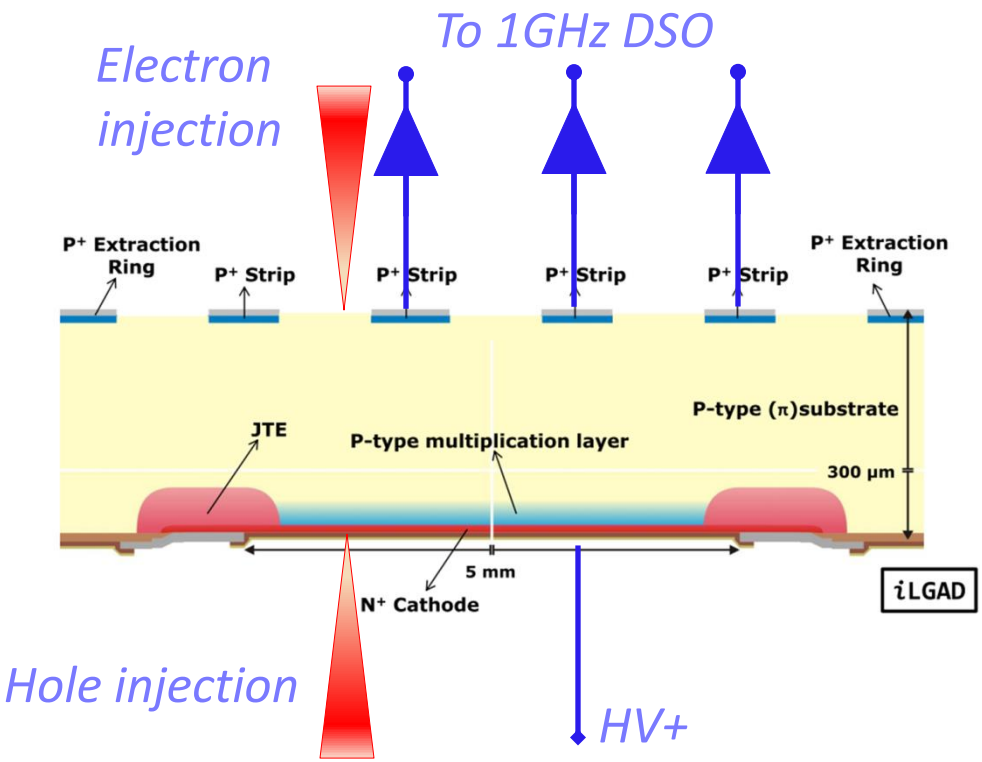
Inverse- LGAD (CNM run #8533)

- P-in-P LGAD with hole readout (ohmic contact segmented)
- W1-K037 STR.45.160.8000.06.12



Multi-channel TCT on DC strips.

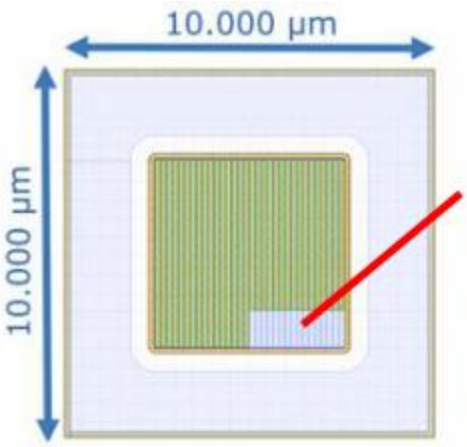
– I-LGAD (r#8533) manufactured as DC mini sensors



Simultaneous transient current acquisition (up to three strips)

Electron/hole injection (670nm red laser back-side illumination)

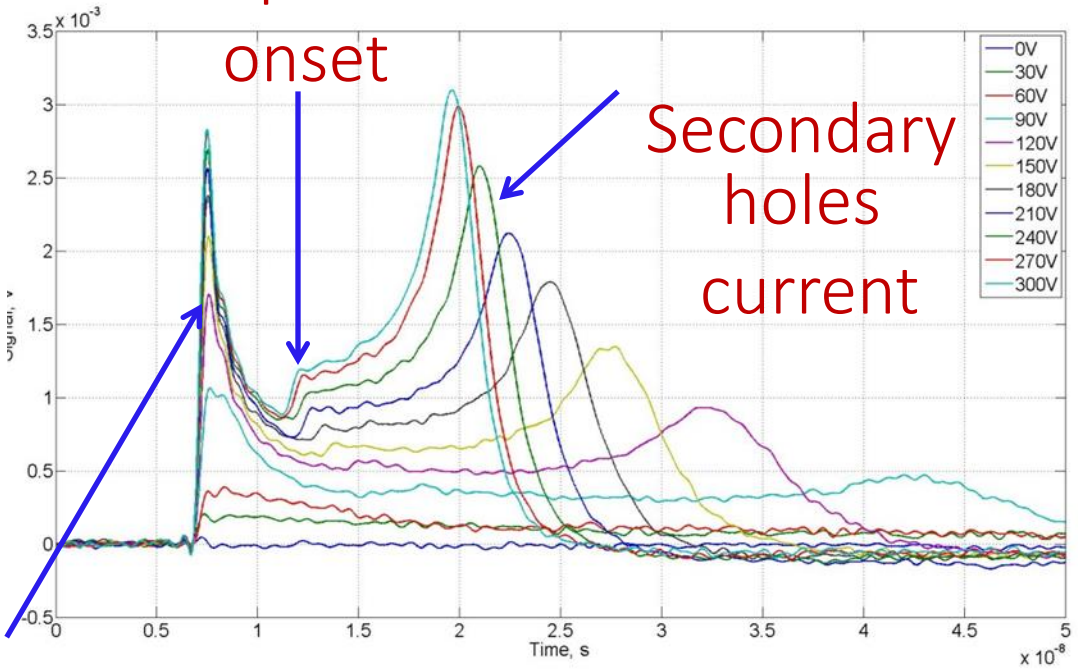
Inverse-LGAD TCT: Electron injection
first observation of signal amplification (June 2016)



Primary electrons current

Multiplication onset

Secondary holes current



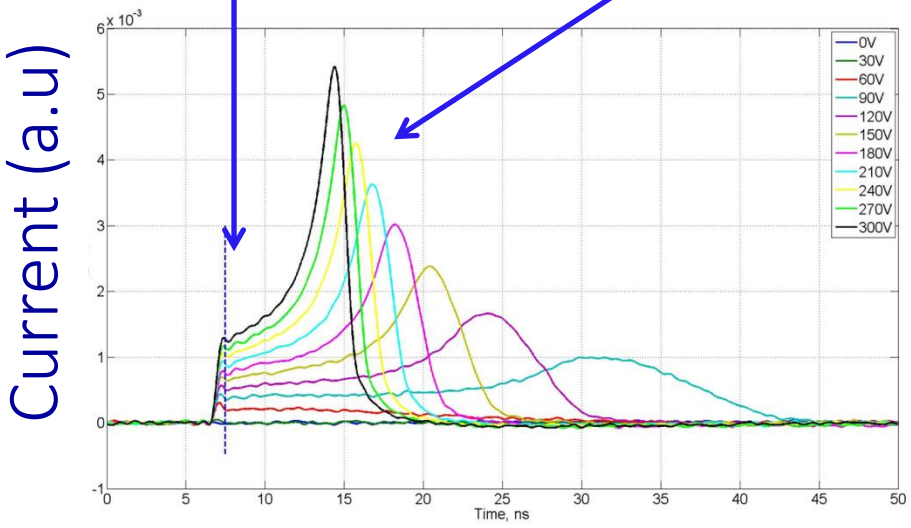
Time (ns)

– Electron injection (ohmic contact)

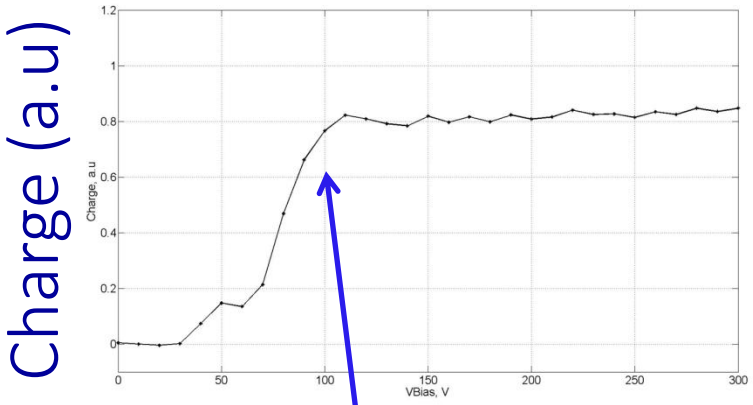
Inverse-LGAD TCT: Hole injection
Collectec charge vs. Vbias

Multiplication onset

Primary & secondary hole current



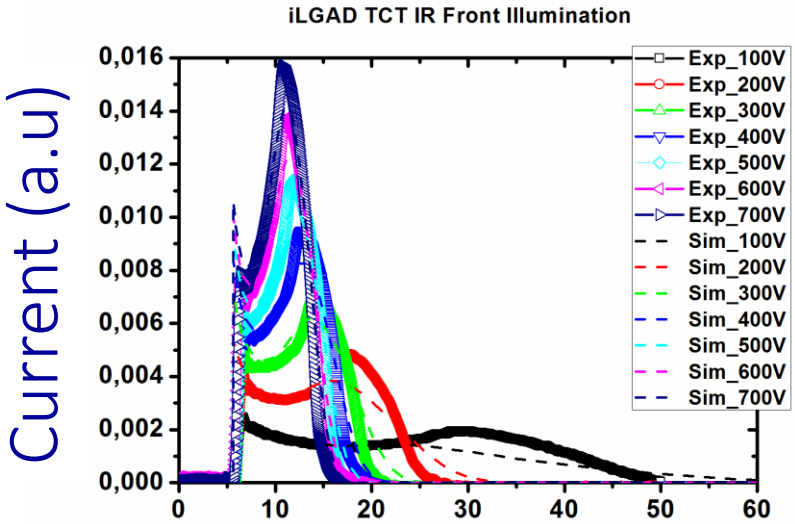
Time (ns)



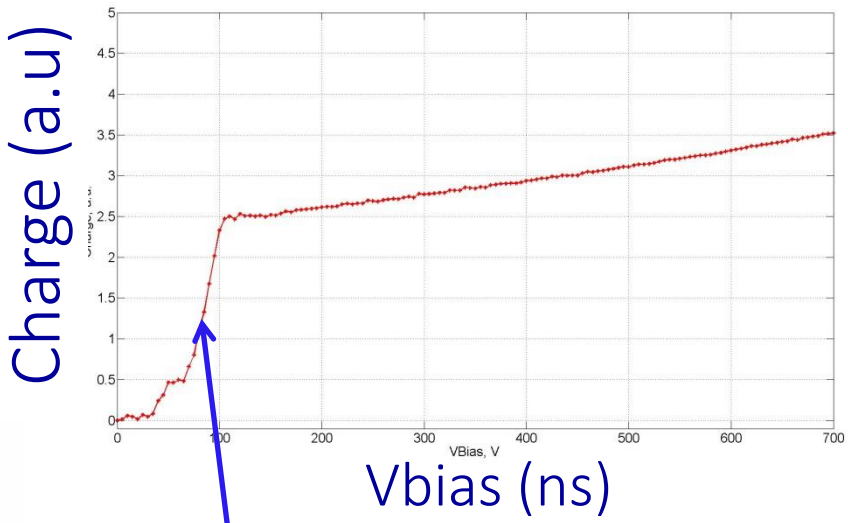
Vbias (ns)

Coherent with CV characterization

Inverse-LGAD TCT: MIP Response Emulation Infrared laser



Preliminary result (arbitrary data/simulation normalization)

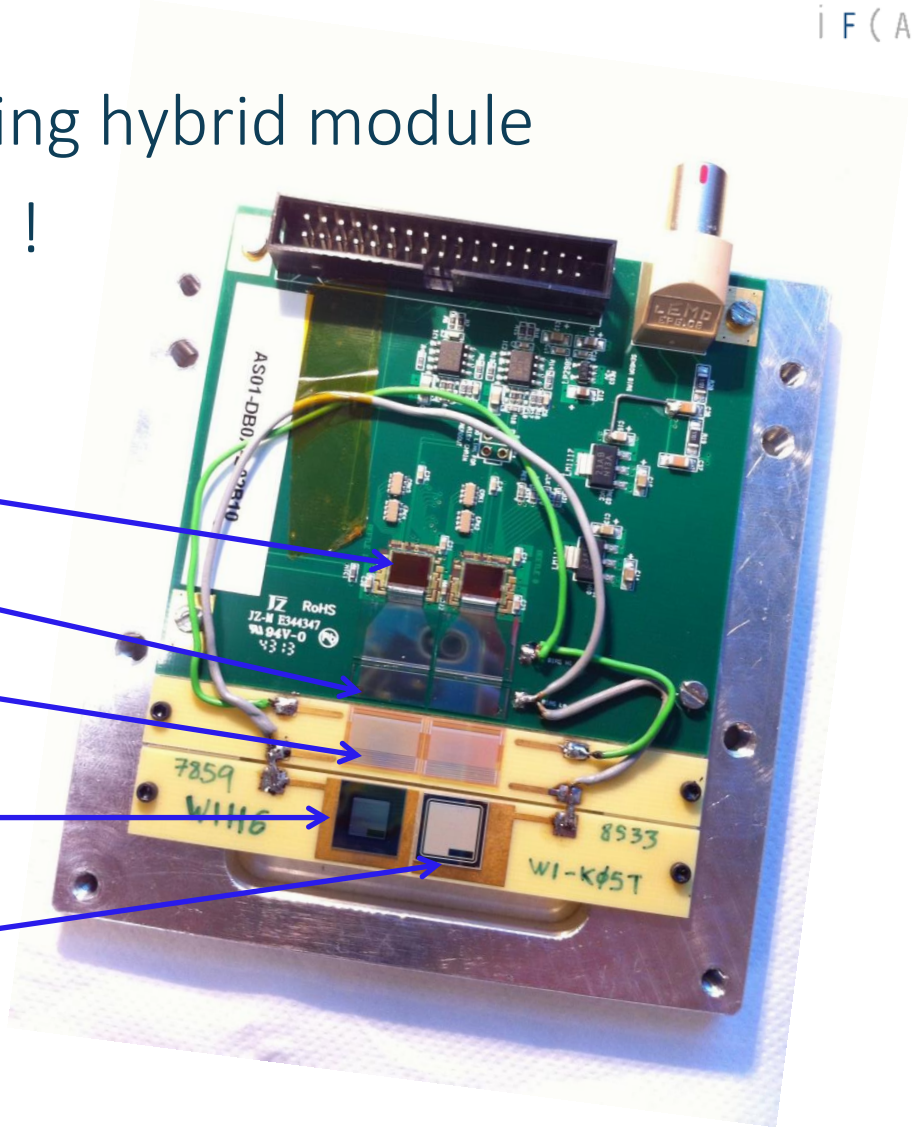


Signal rise Coherent with CV characterization

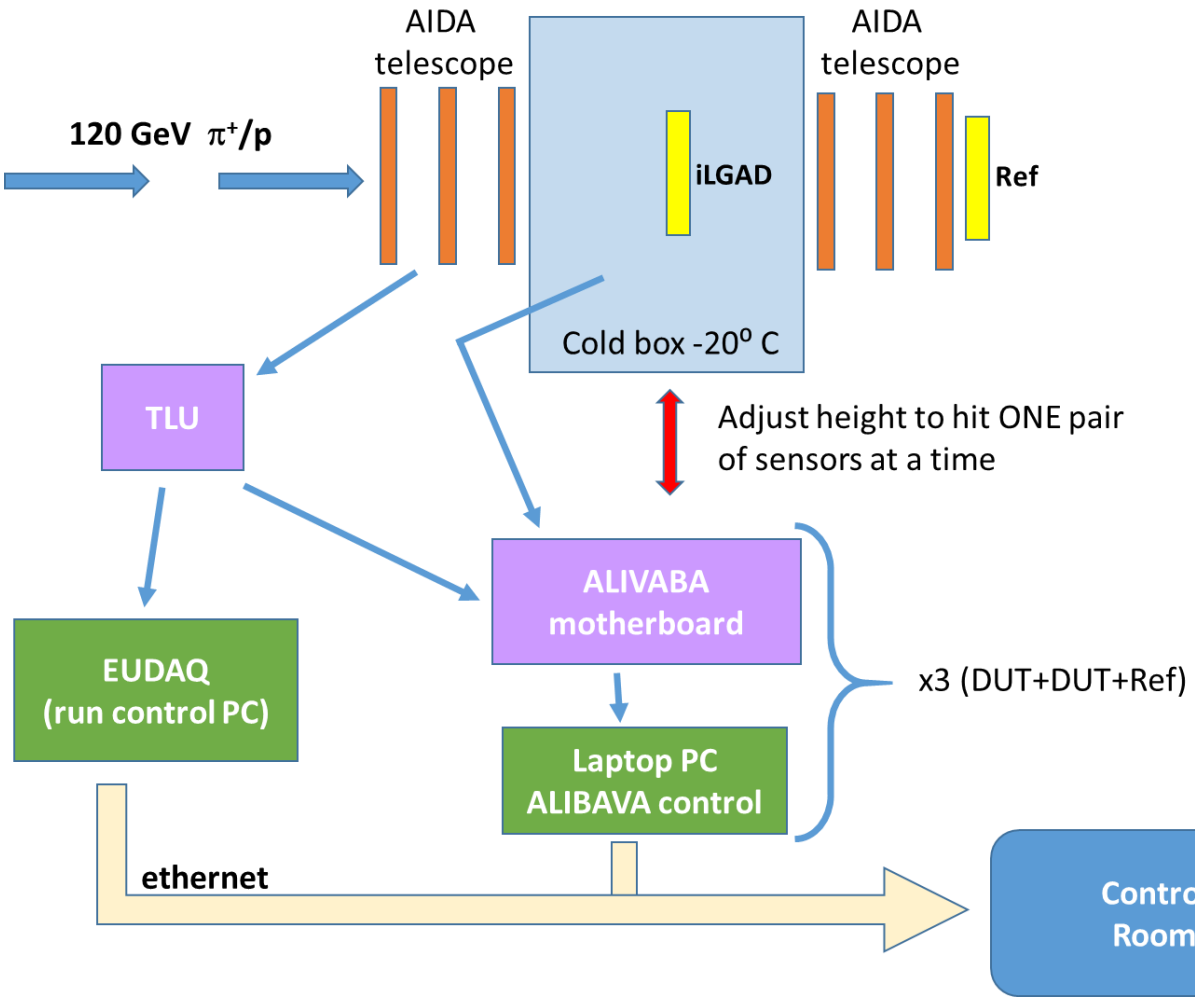
Inverse-LGAD Test Beam testing.

First ever multi-channel tracking hybrid module

Based on I-LGAD & Strip LGAD !

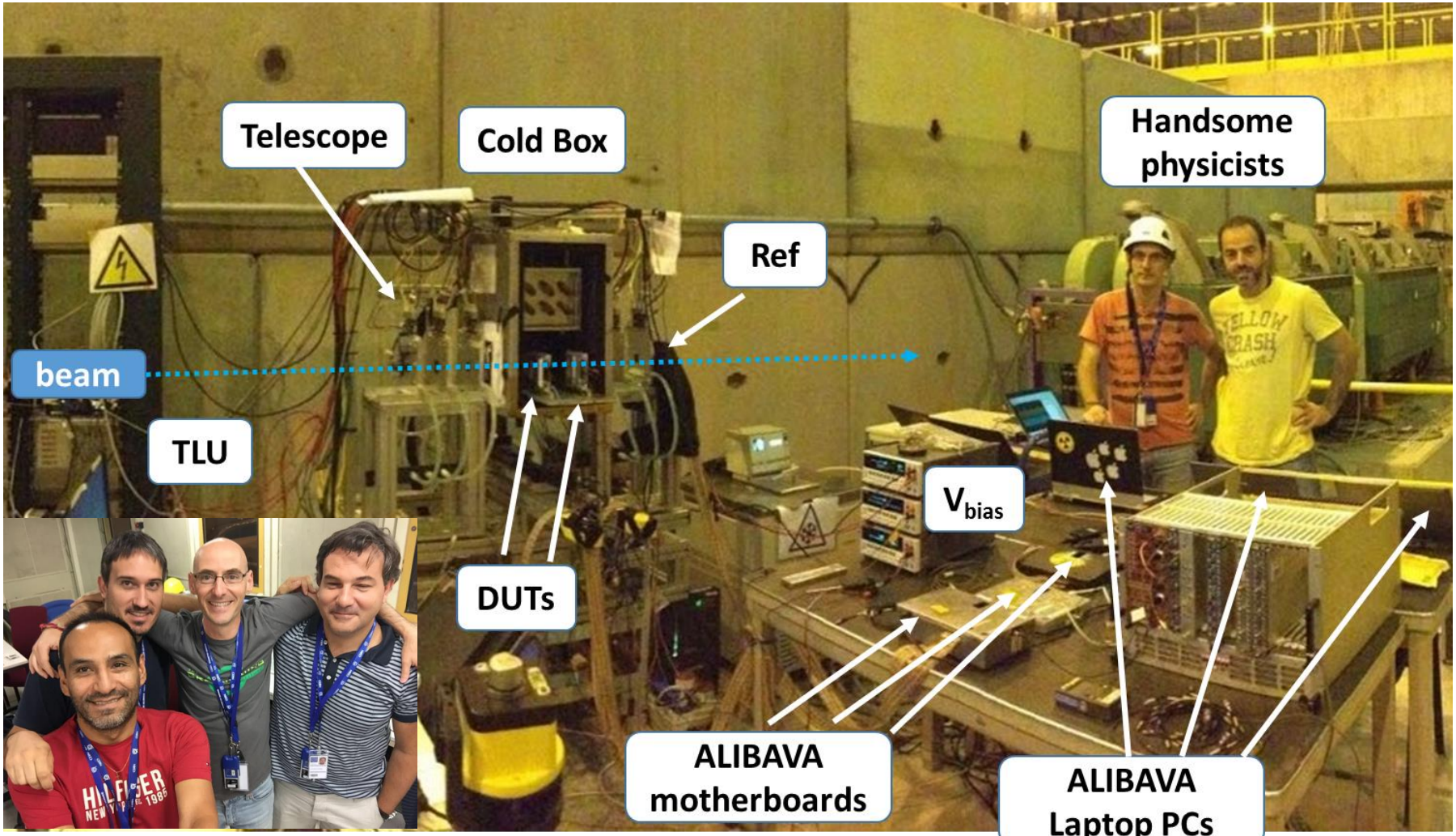


Inverse-LGAD TB: AIDA-2020 WP7 Setup AKA as Atlas ITK setup ☺



This project has received funding from the European Union's Horizon 2020 Research and Innovation programme under Grant Agreement no. 654168.

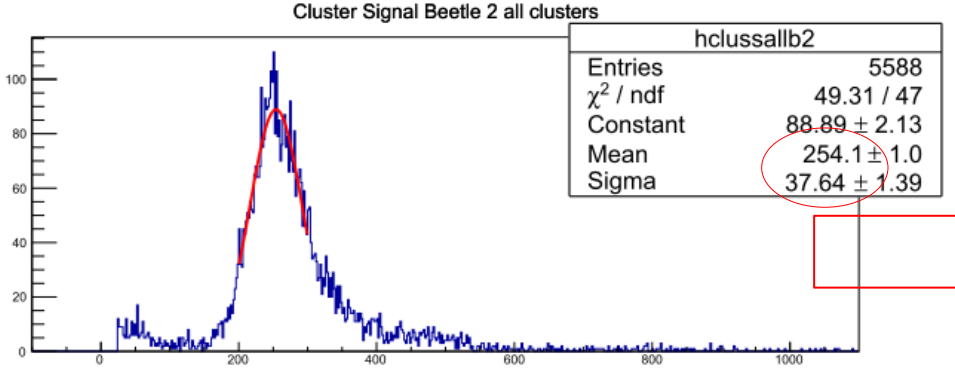
Inverse-LGAD TB: Set-upo



Inverse-LGAD TB: Gain determination

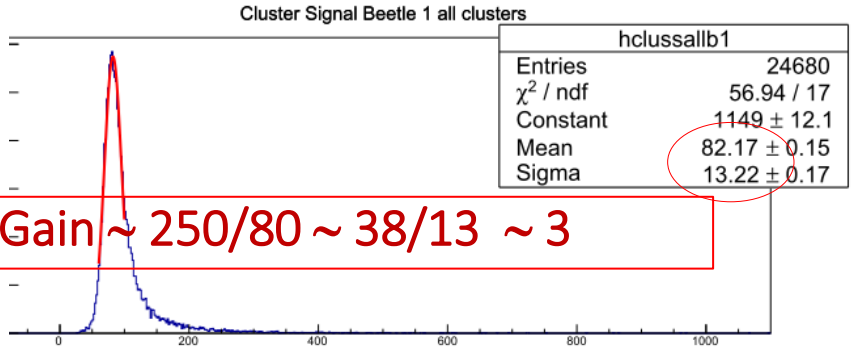
- Gain ≡ Charge Most Probable Value I-LGAD/ MPV Reference PIN
- Reference sensor and I-LGAD same thickness

I-LGAD
(Room temp. 400 Volts)



Cluster Charge (arb. Units)

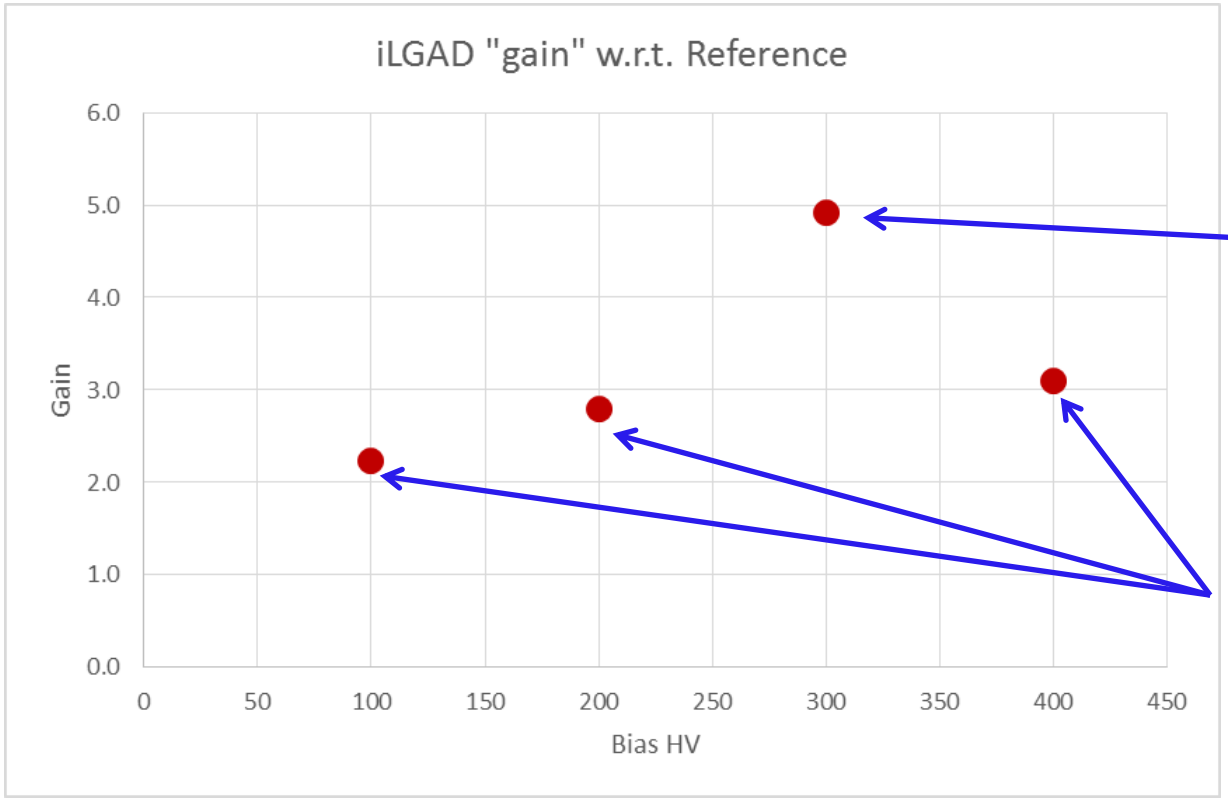
Standard Strip
(Room temp. 200 Volts)



Gain ~ 250/80 ~ 38/13 ~ 3

Cluster Charge (arb. Units)

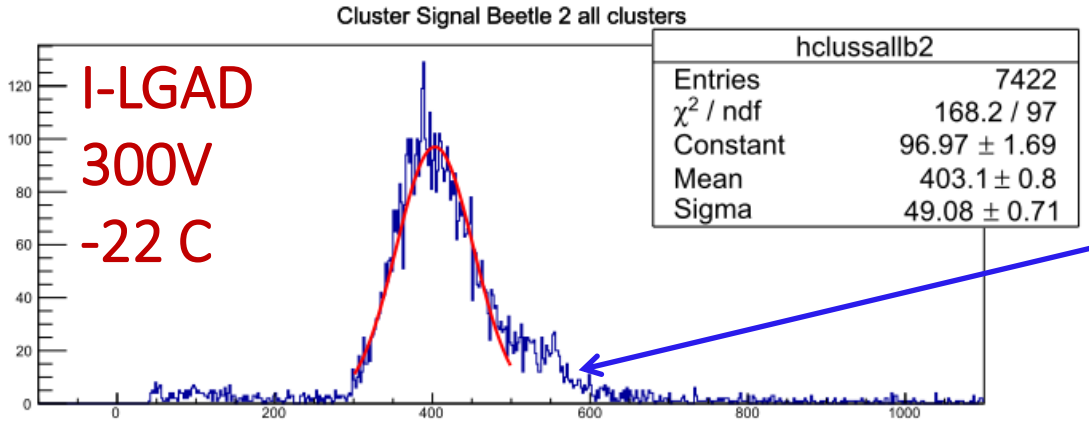
Inverse-LGAD TB: Gain vs V_{bias}



@ -22 C
(Biased by
The gain temperature
Dependence of the
beetle ROC)

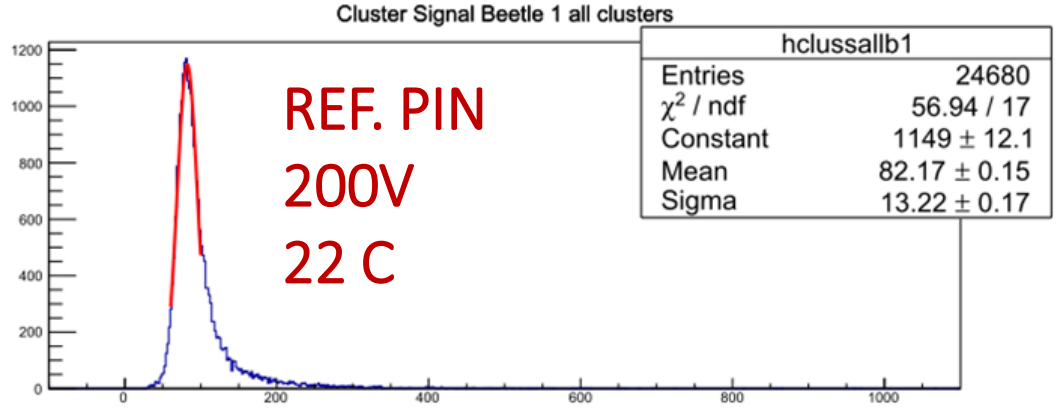
@Room temp.

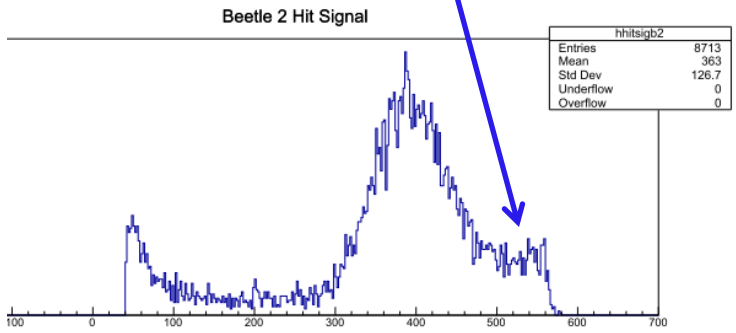
Inverse-LGAD TB: Charge spectrum shape @ -22 C



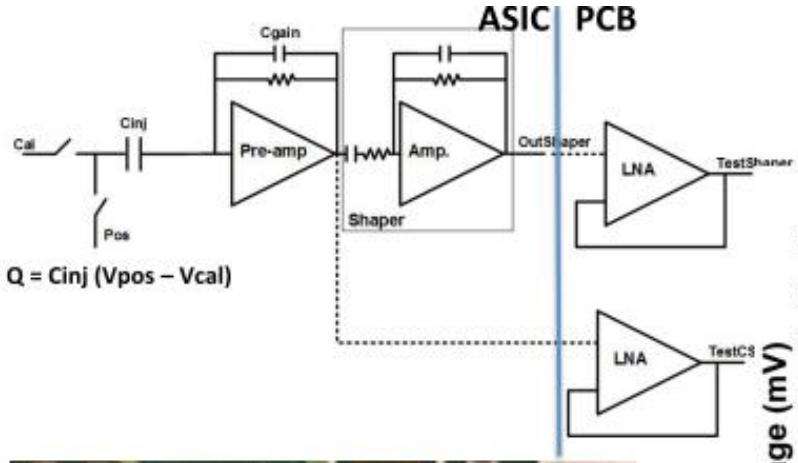
Spectrum shape modified by sub-optimal front-end

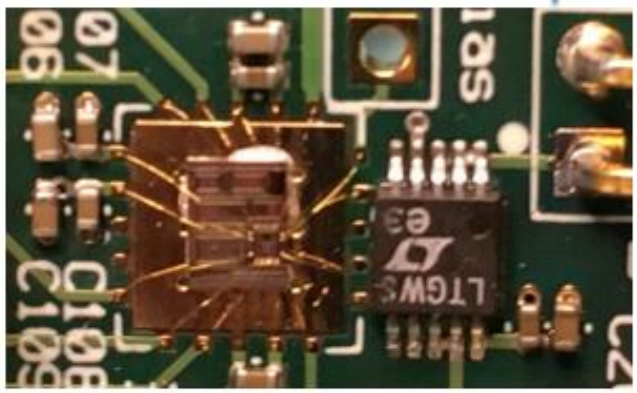
Sharp drop in charge spectrum originated by ADC saturation



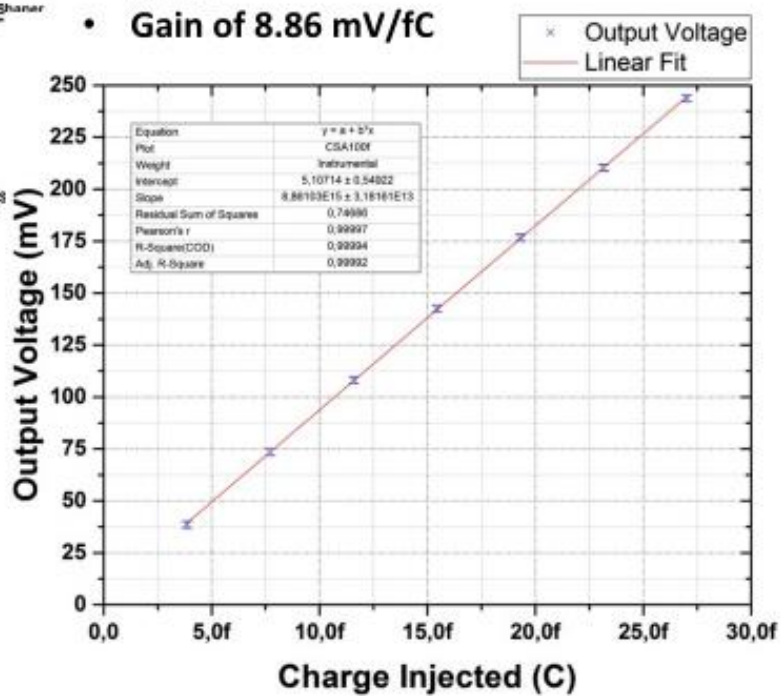


Dedicated front-end electronics: preamp+shaper





- **Amplitude of the output pulse for the CSA when the injected charge is below 30 fC**
- **Gain of 8.86 mV/fC**



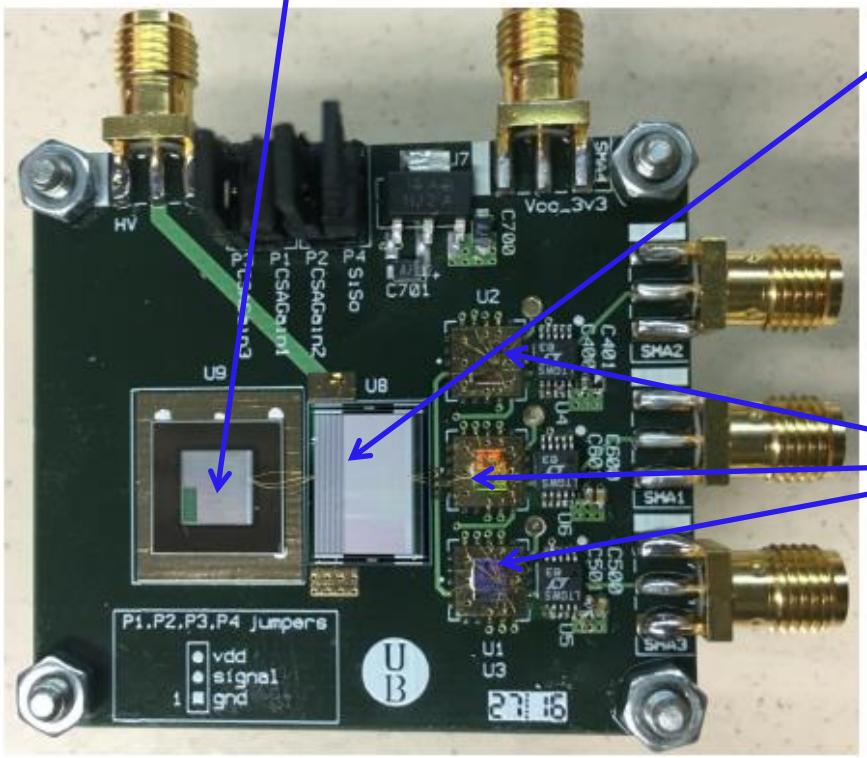
Two gain ranges: 100fC and 500fC

Fron-end electronics: s-LGAD integration

Strip LGAD (three strips bonded)

Fan-in with integrated coupling capacitors

Single channel preamp+shaper



Summary

- Detailed laser-based characterization of strip- LGADs and inverse-LGAD.
- First i-LGAD and s-LGAD based hybrid module for tracking.
- Test beam at SPS (AIDA-2020) with Alibava readout (non-optimal for relatively large gain regimes).
- Very preliminary results confirm typical LGAD characteristics: signal amplification, gain vs Vbias dependence, etc.
- Tracking performance in progress

Outlook (borrowed from Salvador Hidalgo)

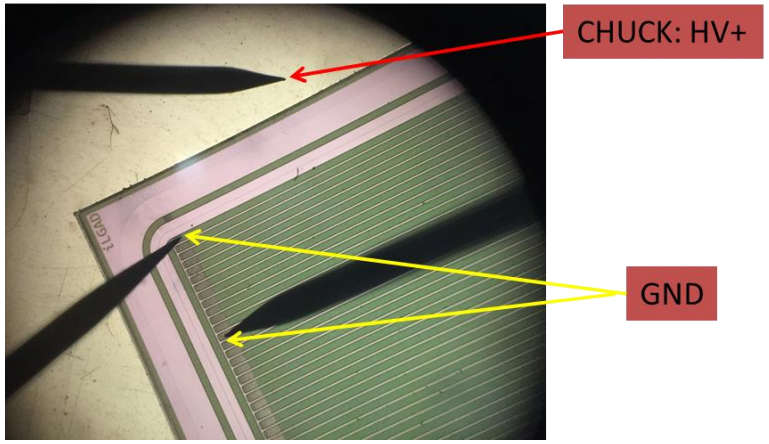
– First promising steps towards a very high-precision tracking detector with built-in timing but still… a road full of bumps ahead, that is, plenty of fun.

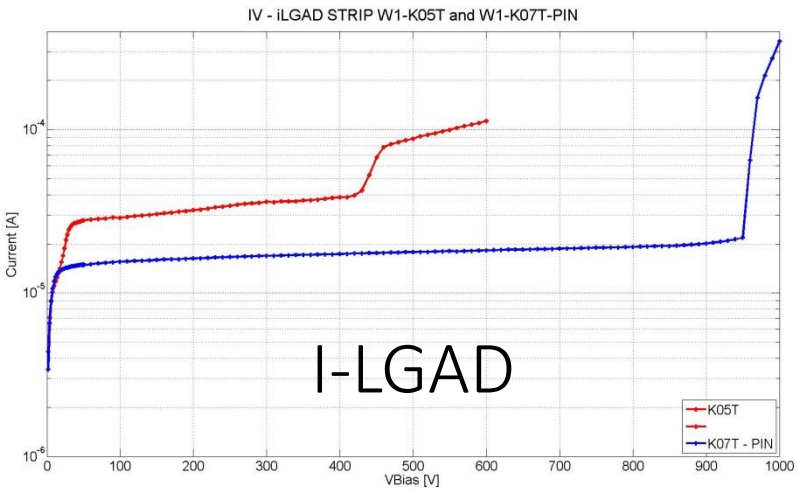
- **Double Side** Technological Process
- Using **4 inch** Wafers
- **Higher** Active Area. **6 inch** Wafers
- **Lower** Pitch Size. 50 µm
- **Thin** Devices (< 200 µm)
  - ✓ **SOI, SOS** Wafers
  - ✓ **Timing** Applications
- **Radiation Hardness**
  - ✓ **Gallium** Implantation
  - ✓ **Carbon** Doping
- **AC** Design
  - ✓ **Polysilicon** Layer
  - ✓ **1-2 Additional Mask** Levels
- **More Complex** than **3D** Fabrication Process

THANK YOU!

Special thanks to Florentina Manolescu (bonding lab), Federico Ravotti (irrad facility@CERN), Esteban Currás and Sofia Otero (SSD@CERN)

I-LGAD: Electrical Characterization

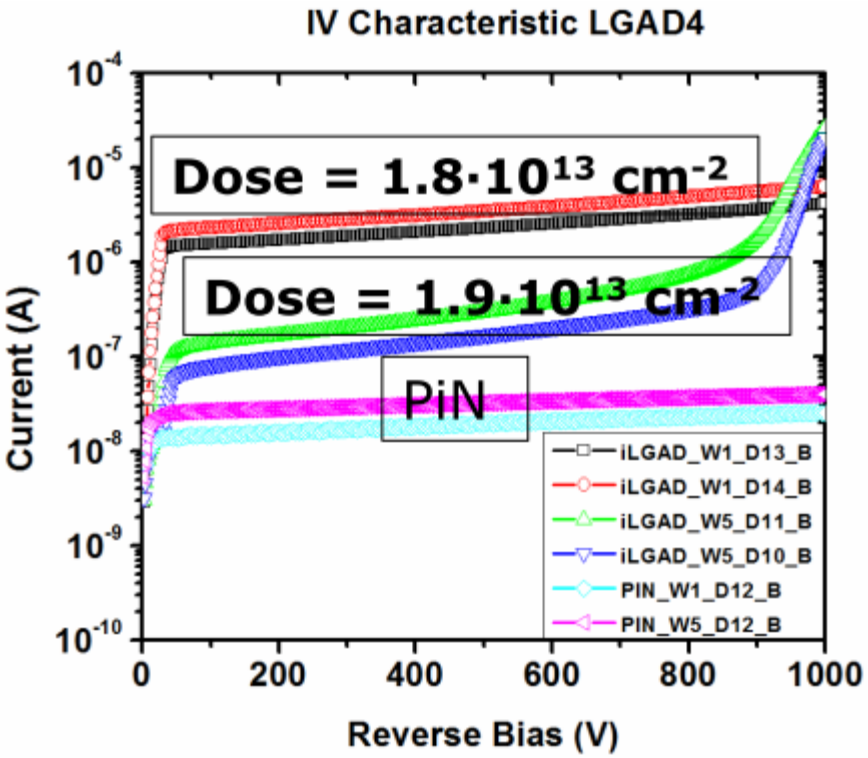




Current (A)

I-LGAD

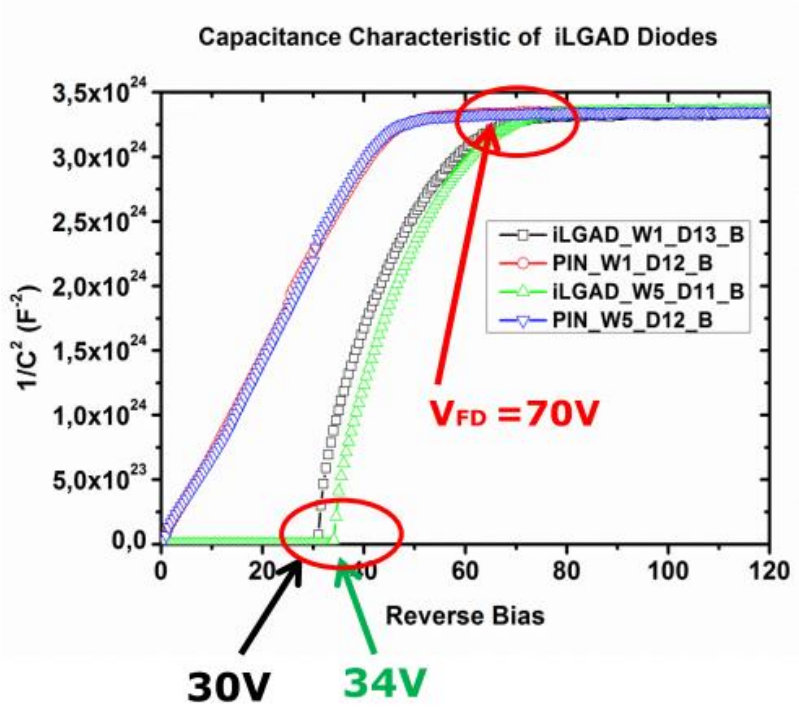
BIAS (Volts)

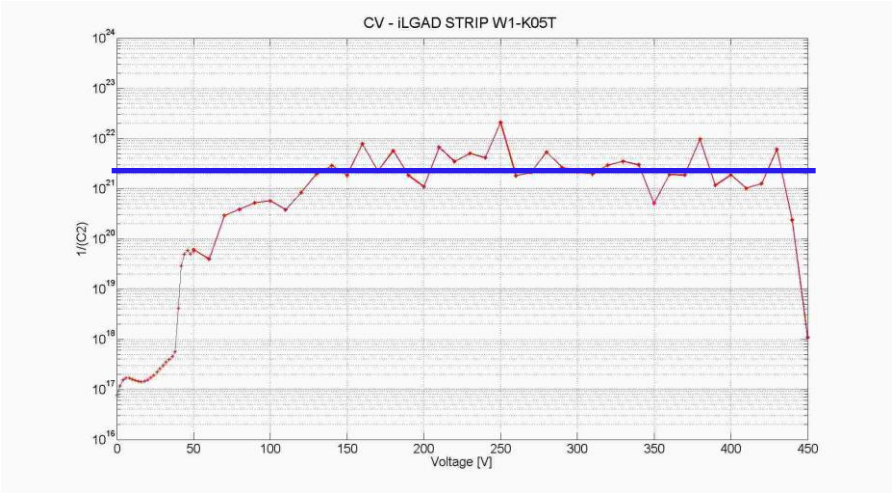


PAD DIODE

Inverse-LGAD: CV

– PADs vs I-LGAD depletion

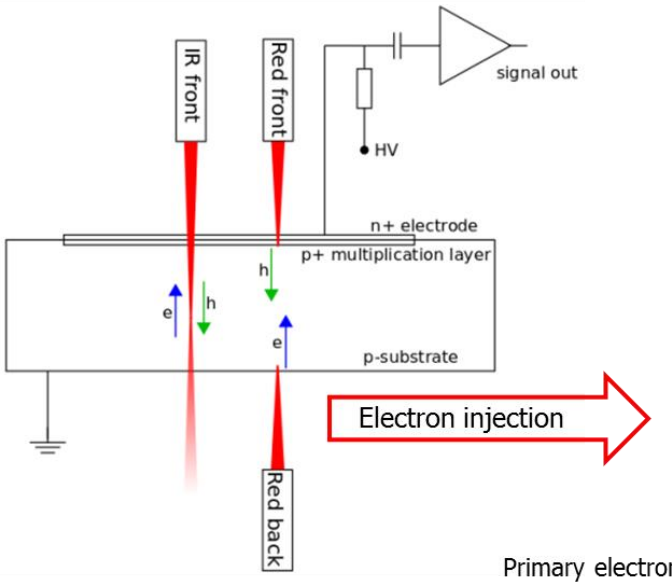




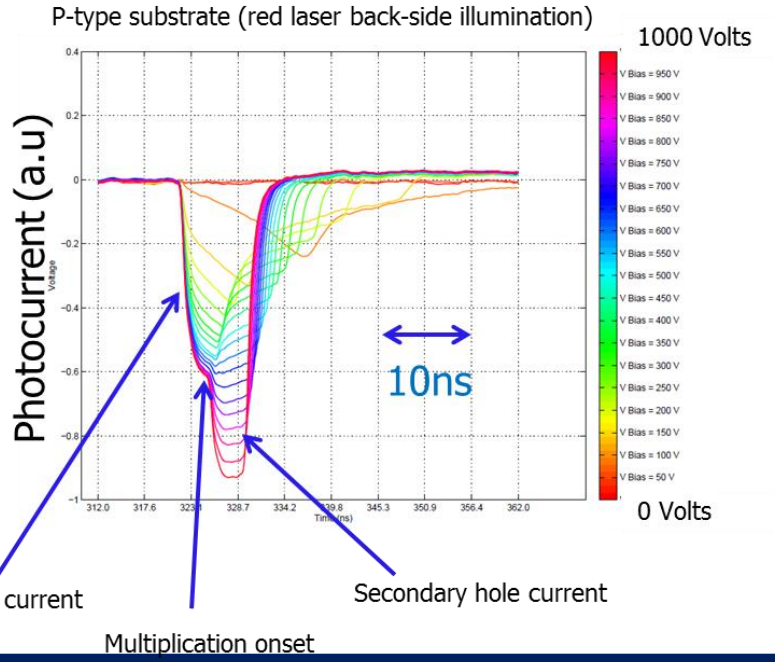
Single strip capacitance

Methodology: Signal amplification footprint

- Distinct signature of signal amplification.
- Injections of electron into the anode: resulting transient current is a sequential contribution of primary electrons reaching the amplification layer and secondary holes drifting towards the anode.

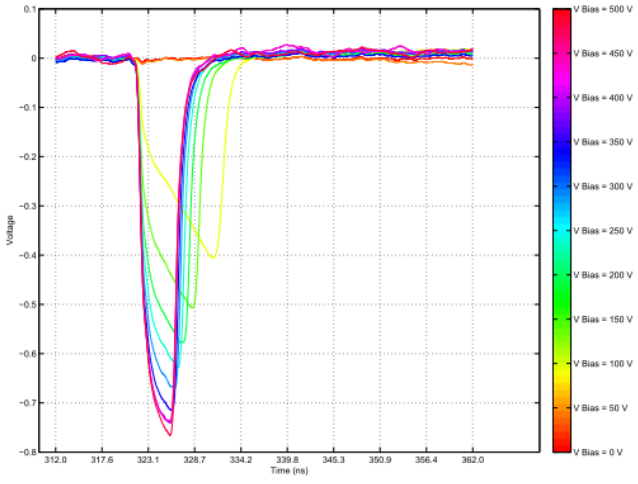


Electron injection

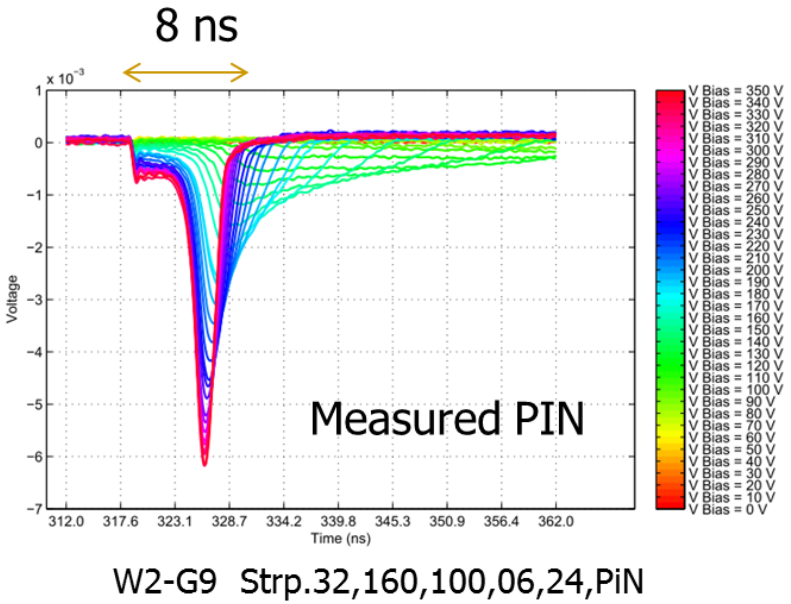


Transient currents: pad vs microstrips

– Transient current waveform shape dominated by weighting field (peaked at the collecting electrode):



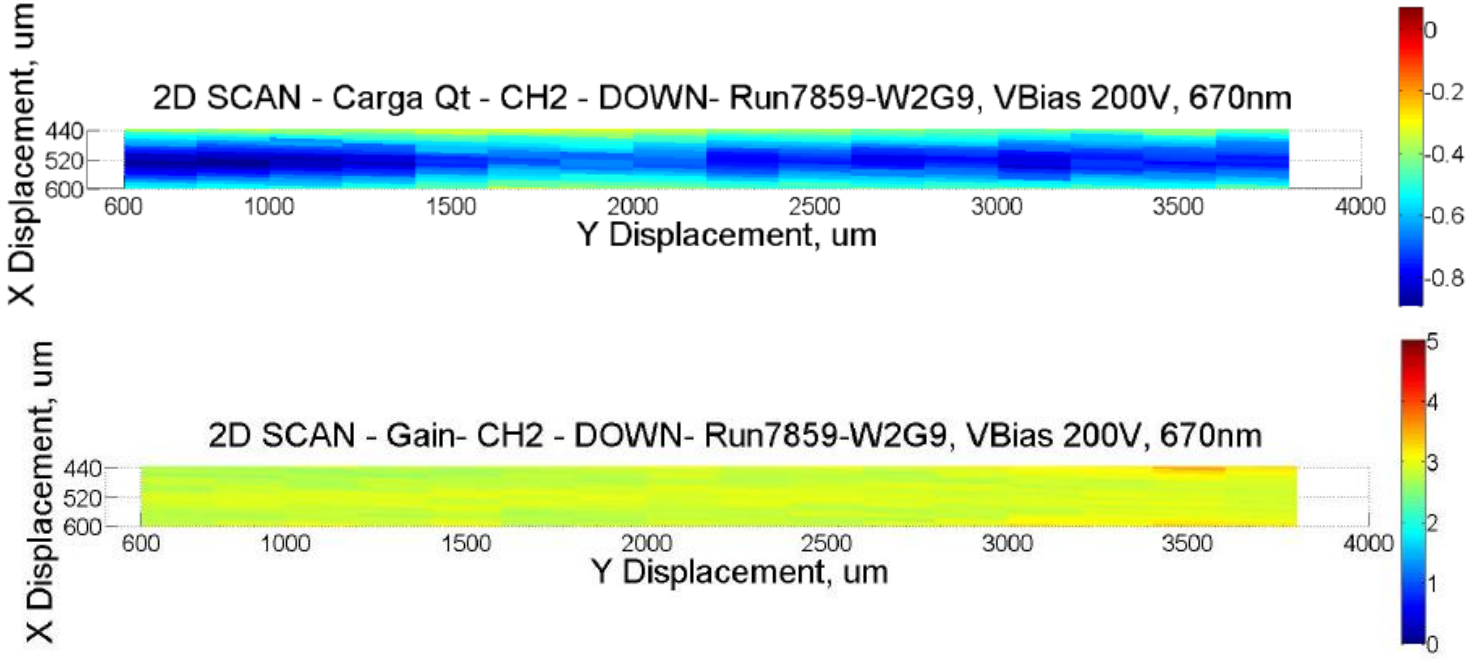
Pad like diode



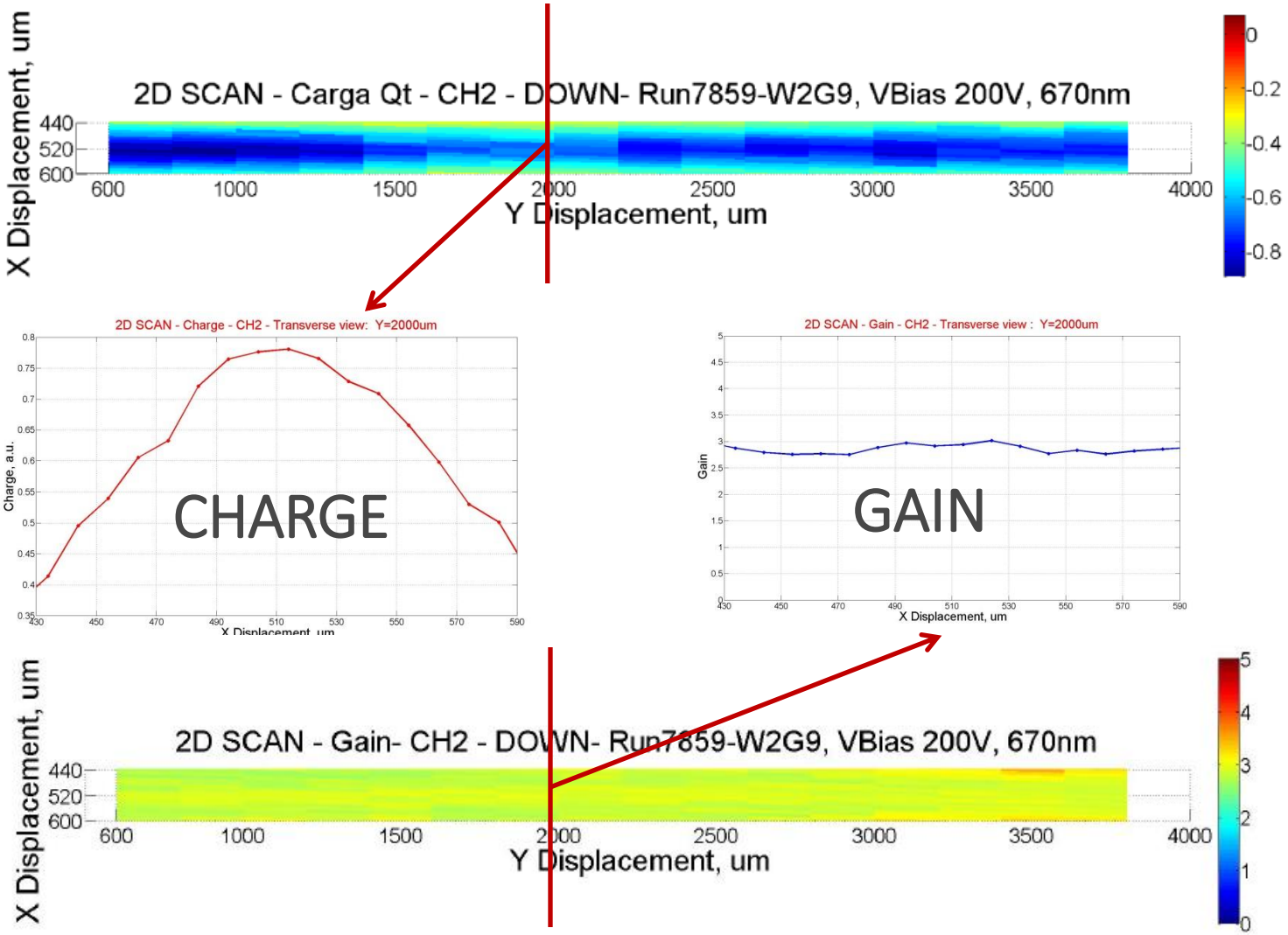
microstrip diode

Strip LGAD: Mapping the strip gain (1)

– Raster scan: electron injection into the anode at each point of the strip collecting charge back side area (+-80um around the strip center)



CHARGE MAP

GAIN MAP

Strip LGAD: Mapping the strip gain (2)