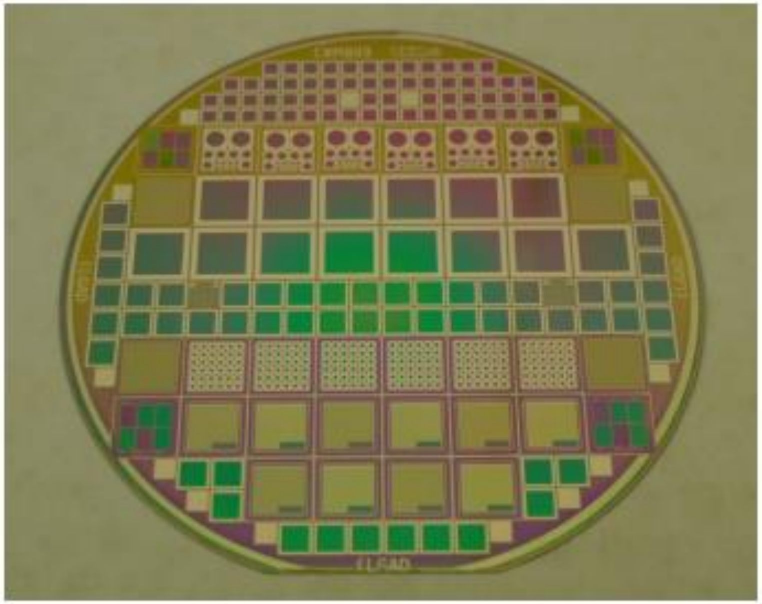
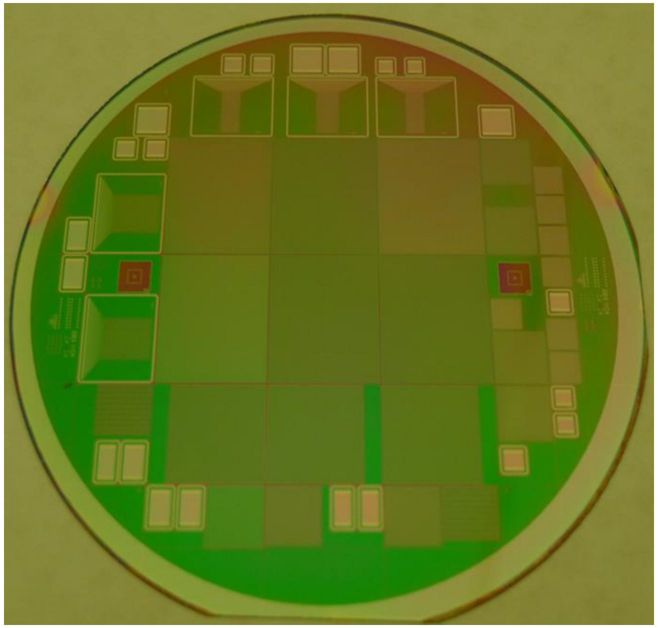
Santander's Activities Update on 3D and LGAD sensors





AIDA-2020 Second Annual Meeting
Paris, April 2017

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Instituto de Física de Cantabria (CSIC-UC)

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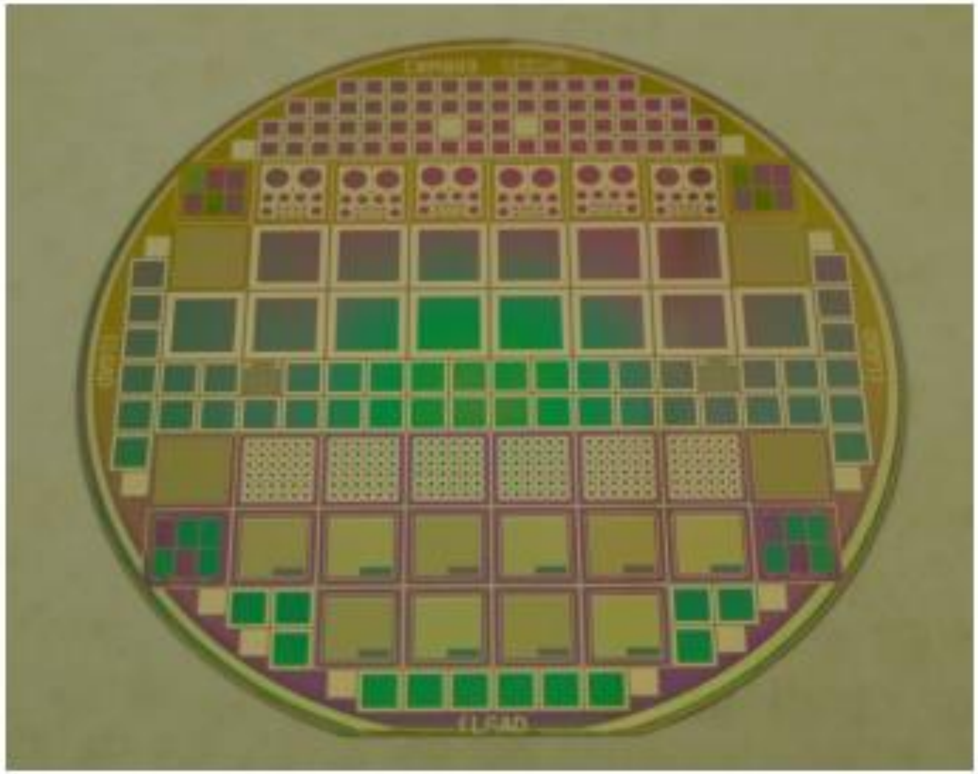
Developed inside the RD50 collaboration & AIDA -2020 WP7 on Advanced Hybrid Detectors.

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

Outline

- Overview on activities on LGADs
  - TCT characterization comparison vs TCAD
  - Test beam at SPS(August 2016) .
- Overview on activities on 3D sensors.
  - Test beam at SPS(August 2016)
- Summary

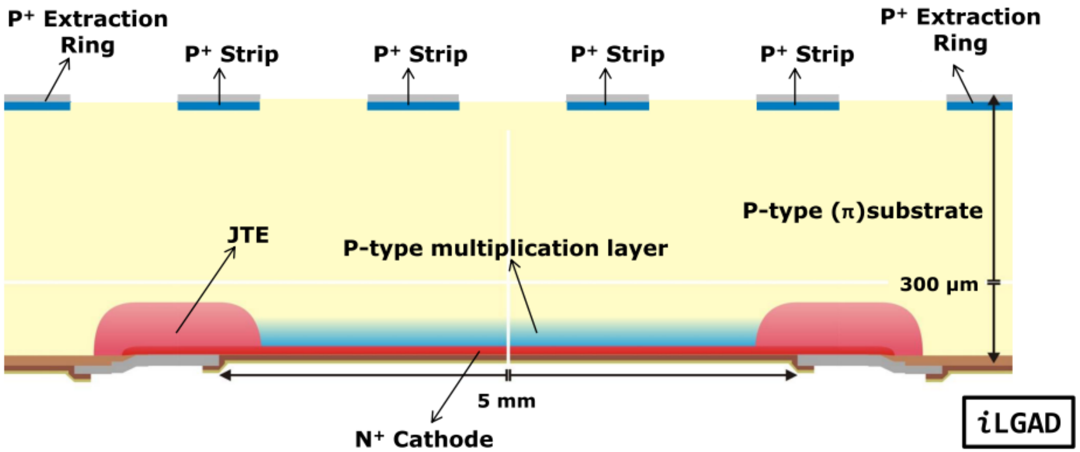
LGAD



Prototype description (CNM run #8533)

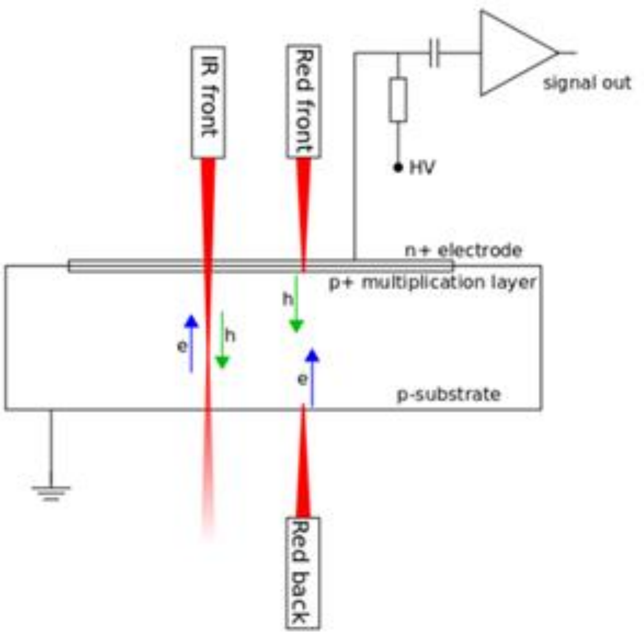
- P-in-P LGAD with segmented cathode (ohmic contact, “readout of holes”)
- DC strips, 160um pitch, 1.8E13/cm^2 imp. dose

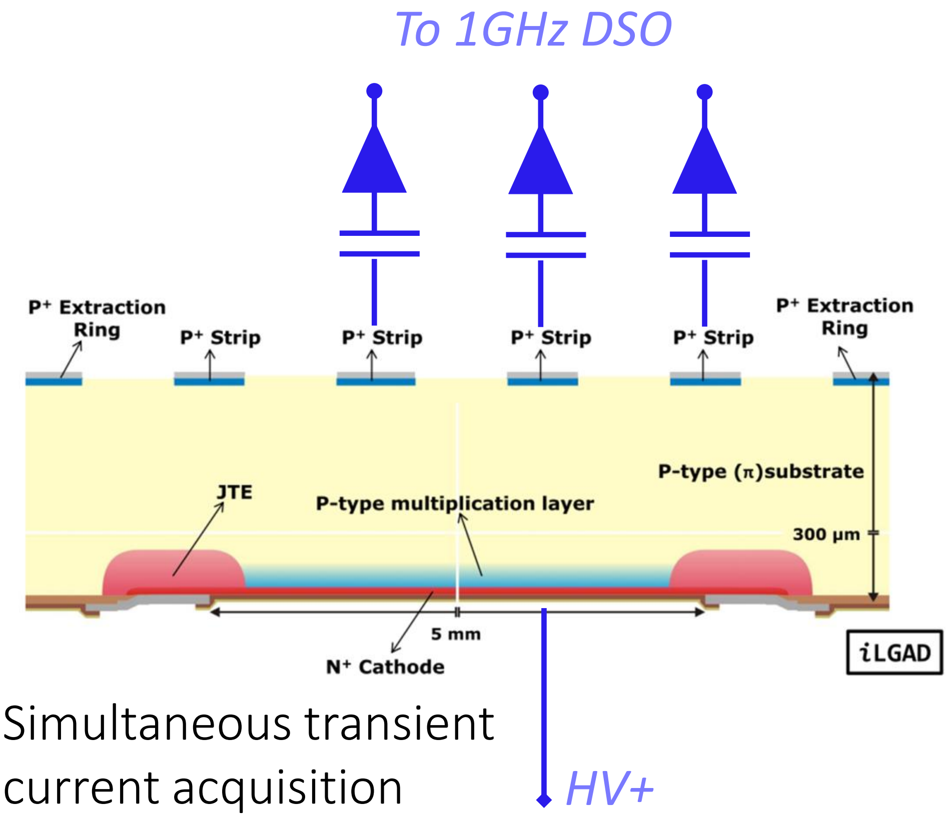
(W1-K05 & W1-K03 STR.45.160.8000.06.12)



Laser Characterization: TCT

– Transient Current Distinct signature of signal amplification.
– Comparison of measured transient vs. TCAD simulations.

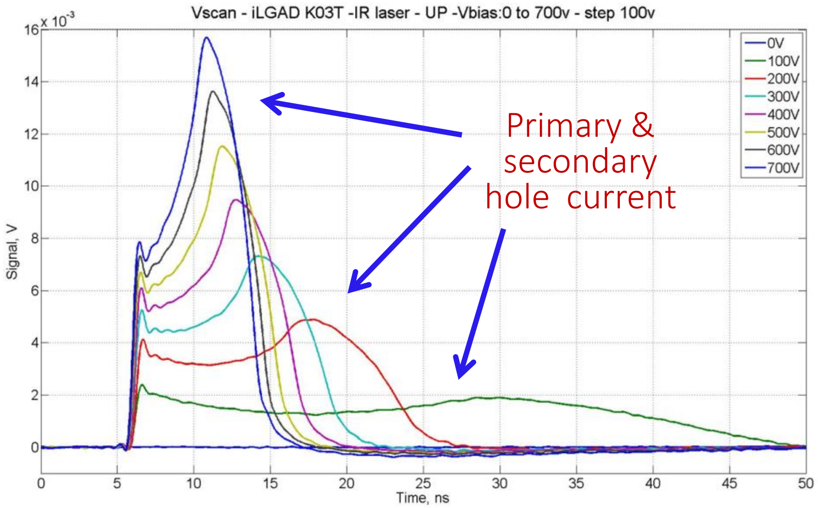




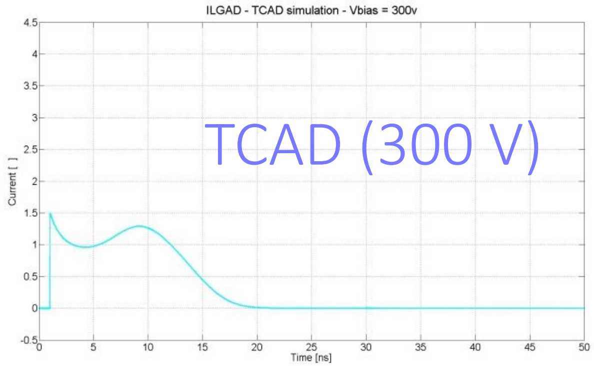
Simultaneous transient current acquisition

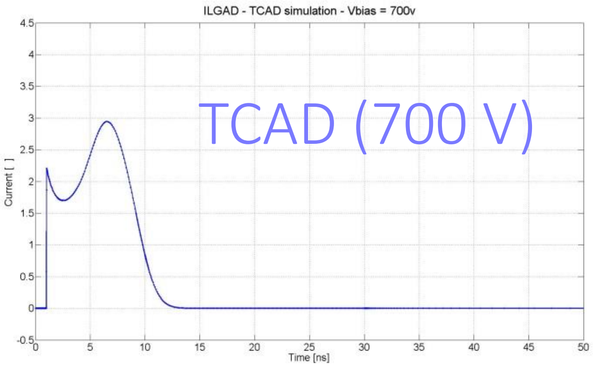
(up to three strips)

MIP Response Emulation: Infrared laser vs TCAD Simulation



Infrared laser Transient Current (MIP emulation)

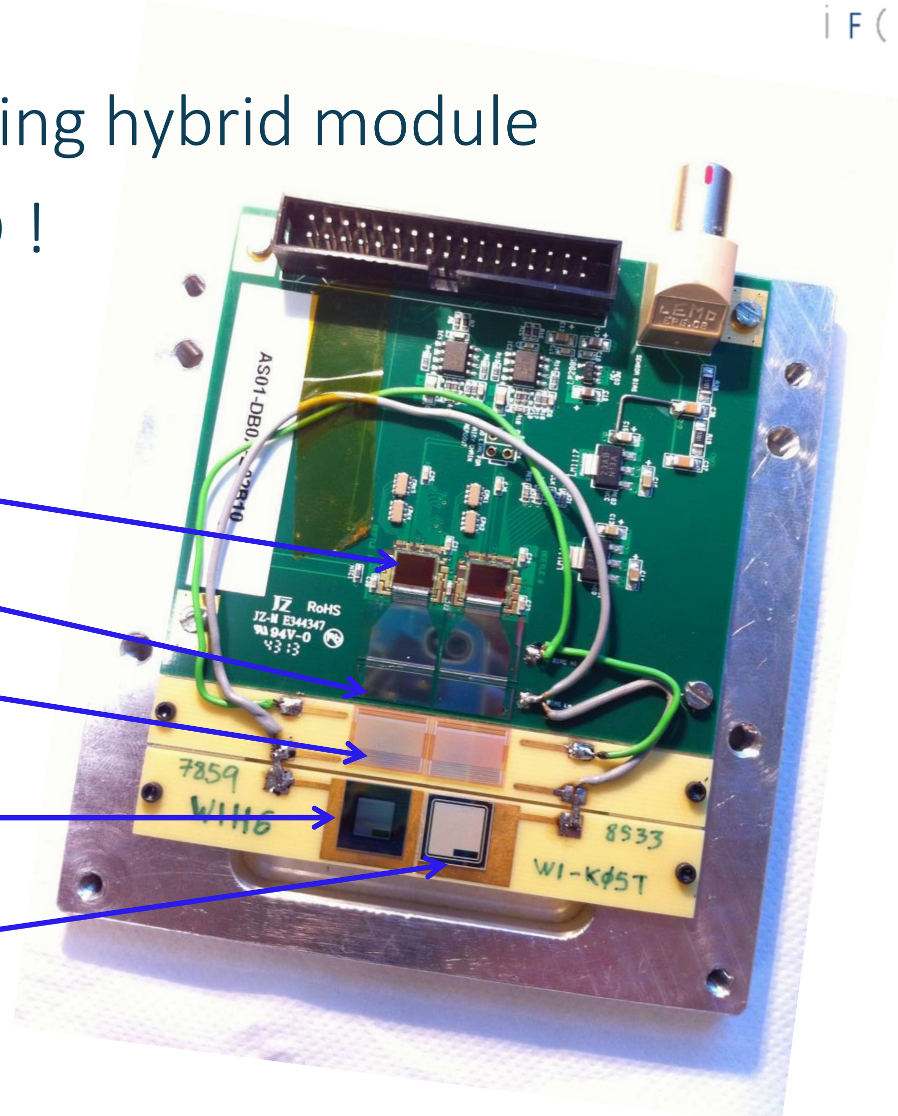




MIP Response: Test Beam testing.

First ever multi-channel tracking hybrid module

Based on I-LGAD & Strip LGAD !



Beetle ROC

Fan in DC

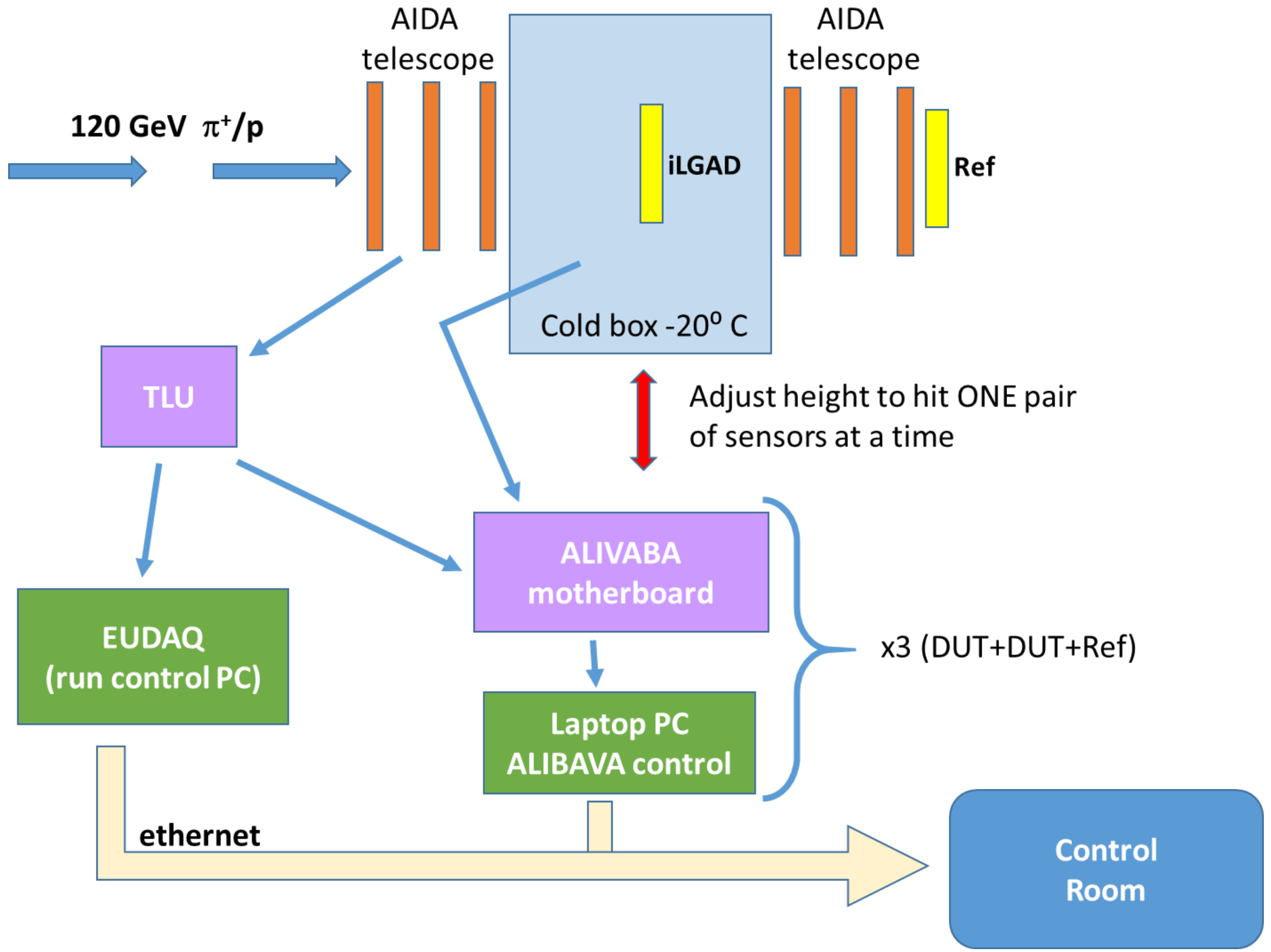
Fan in AC

Strip LGAD

I-LGAD

(8533W1K05T, 45 strips
160 mm, non-irradiated)

Test beam: AIDA-2020 WP7 Setup AKA as Atlas ITK setup ☺

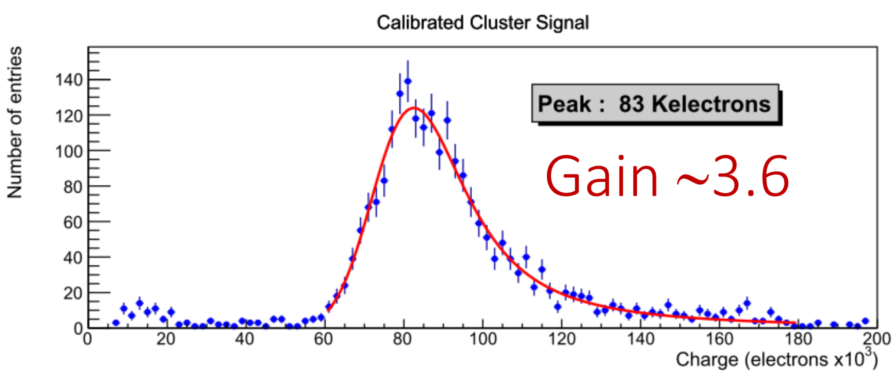


This project has received funding from the European Union's Horizon 2020 Research and Innovation programme under Grant Agreement no. 654168.

Test beam: Gain determination

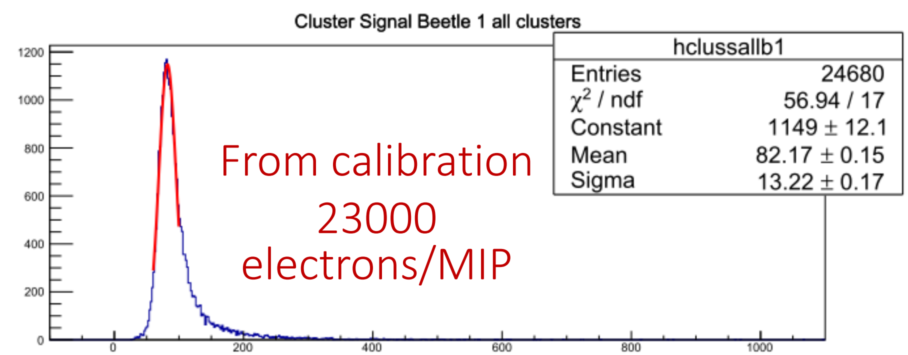
- Gain ≡ Charge Most Probable Value I-LGAD/ MPV Reference PIN
- Reference sensor and I-LGAD same thickness
- Dependence of the beetle gain (electrons/ADU) corrected (see **G. Gomez** talk on 3D sensors)

I-LGAD
(Room temp. 400 Volts)



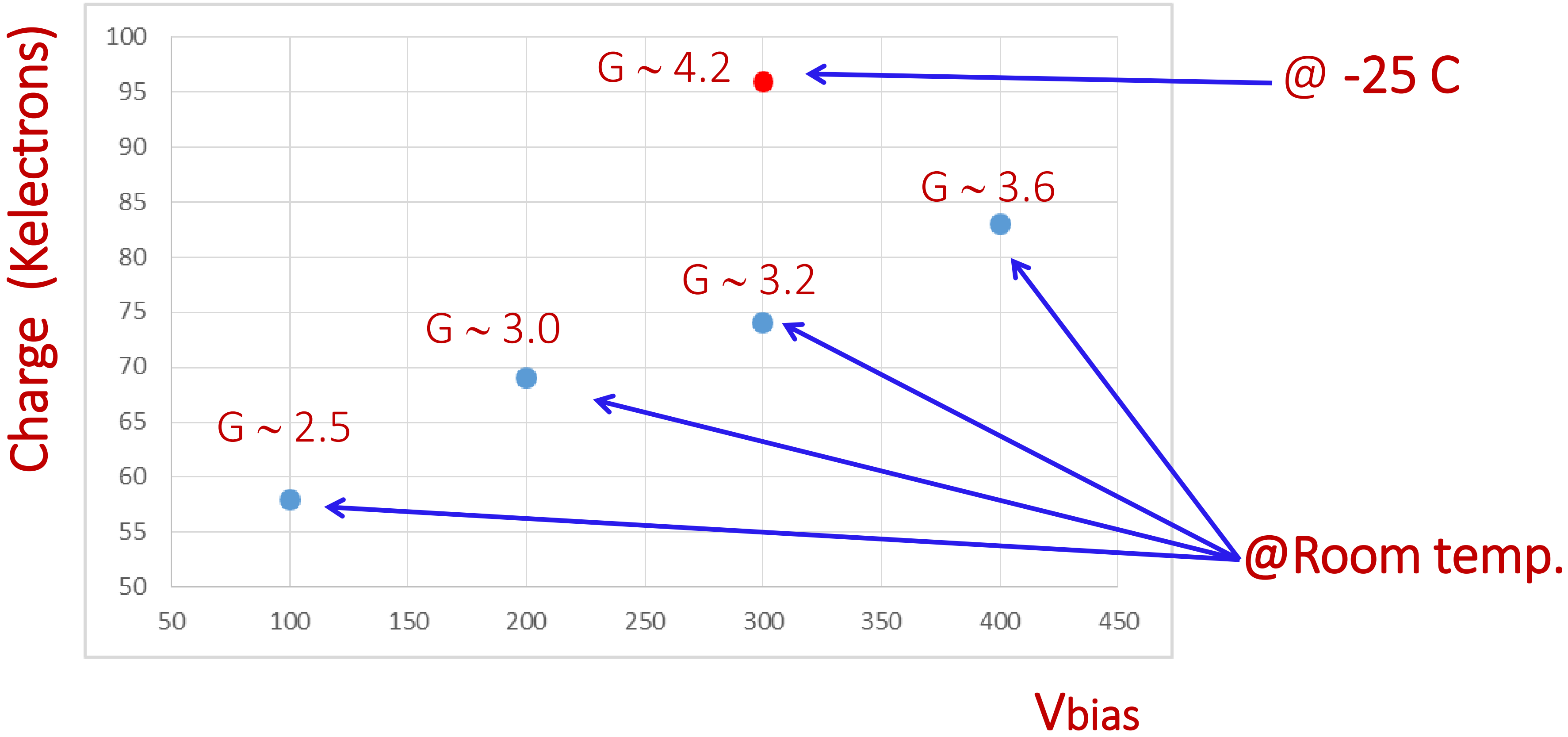
Cluster Charge

Standard Strip
(Room temp. 200 Volts)

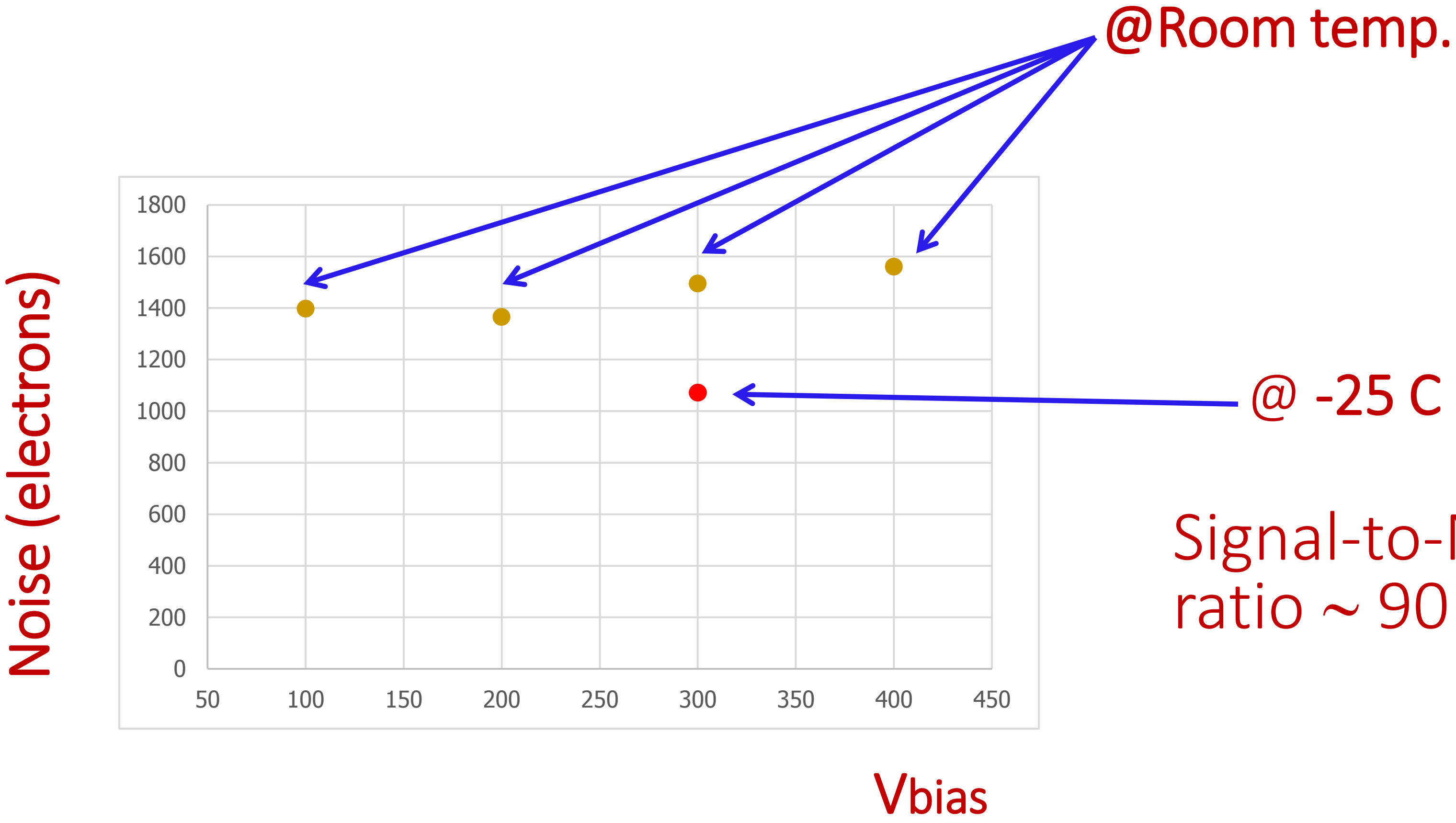


Cluster Charge (ADU)

Test beam: Charge vs V_{bias}

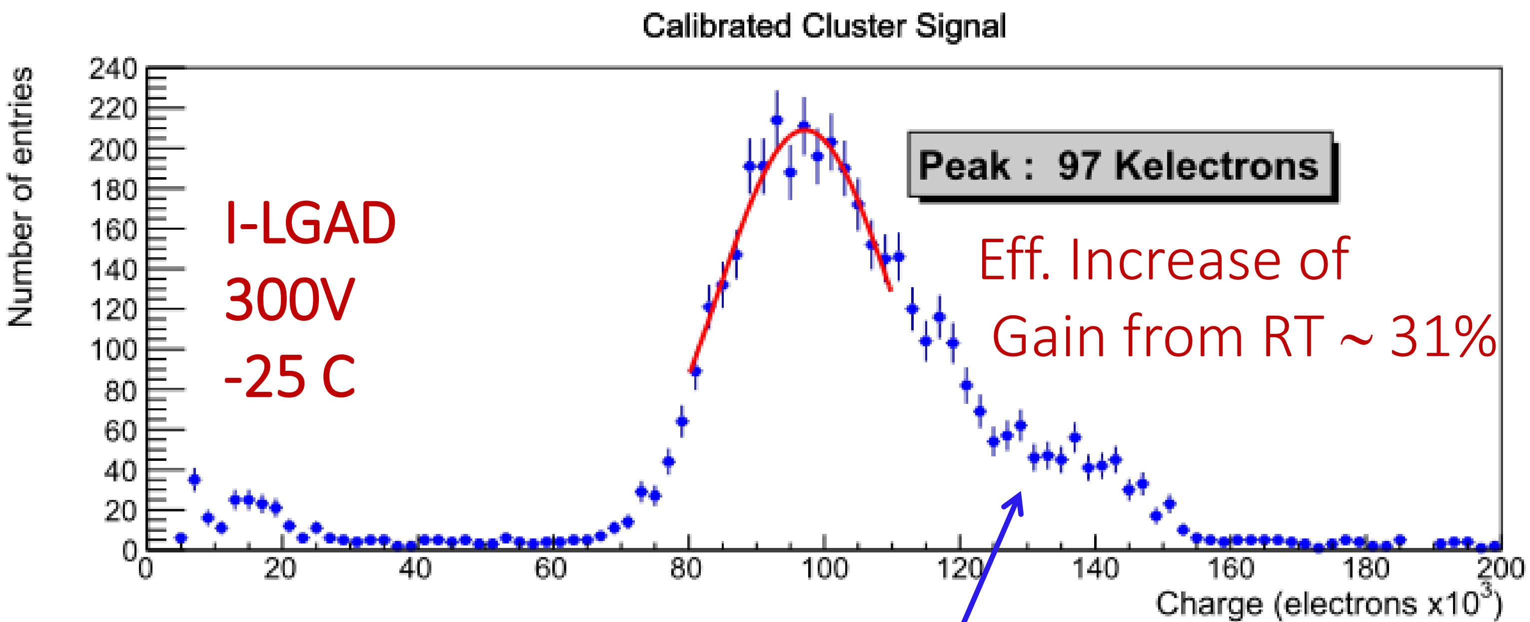


Test beam: Noise vs. V_{bias}



Signal-to-Noise ratio ~ 90 !!!

Test beam: readout front-end saturation.



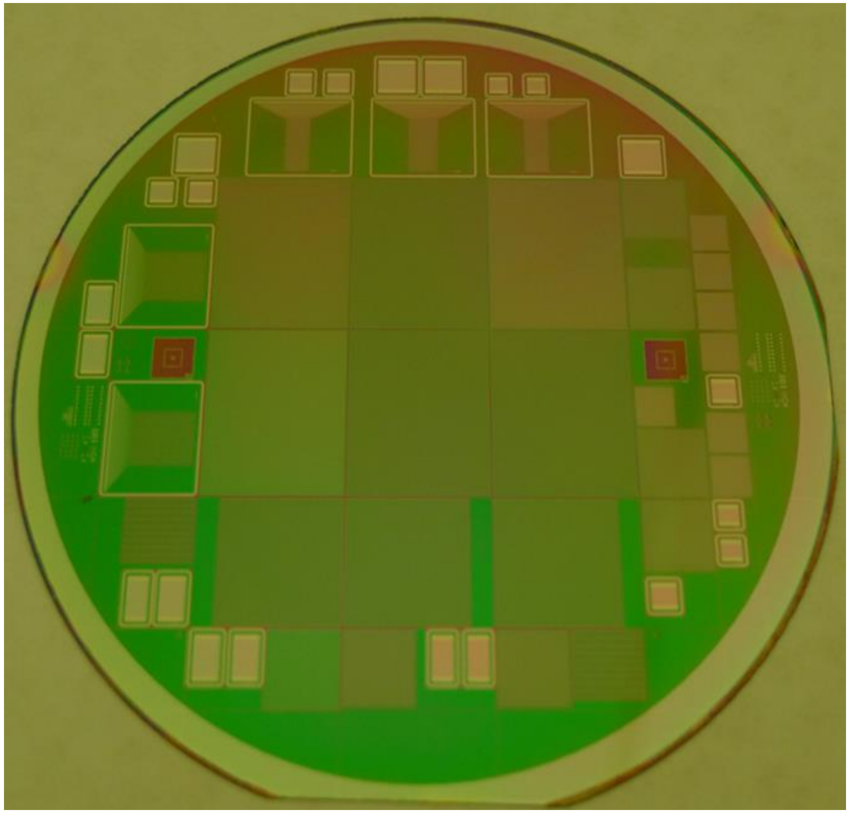
I-LGAD
300V
-25 C

Eff. Increase of Gain from RT ~ 31%

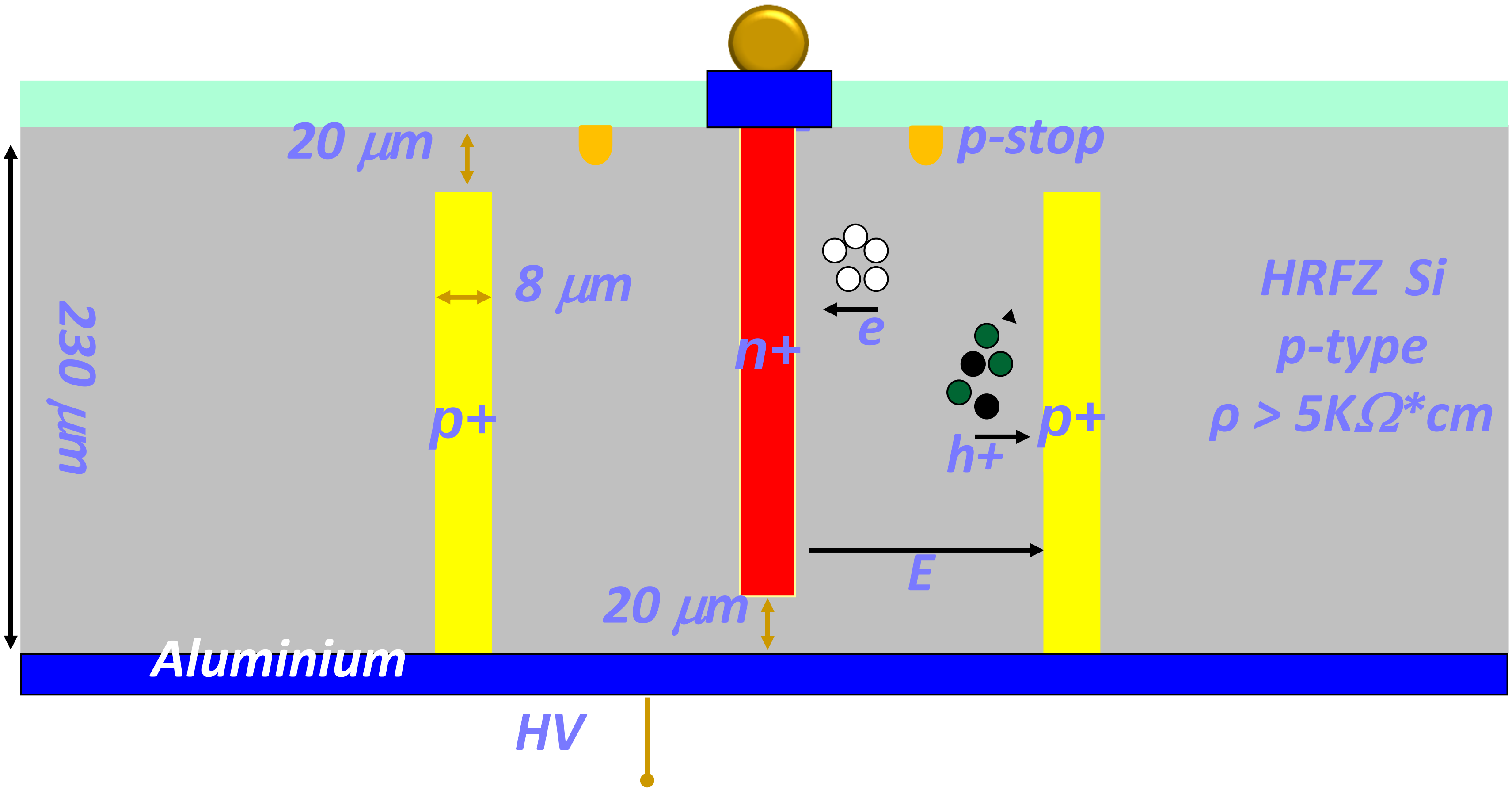
Spectrum shape modified by sub-optimal front-end

Sharp drop in charge spectrum originated by ADC saturation

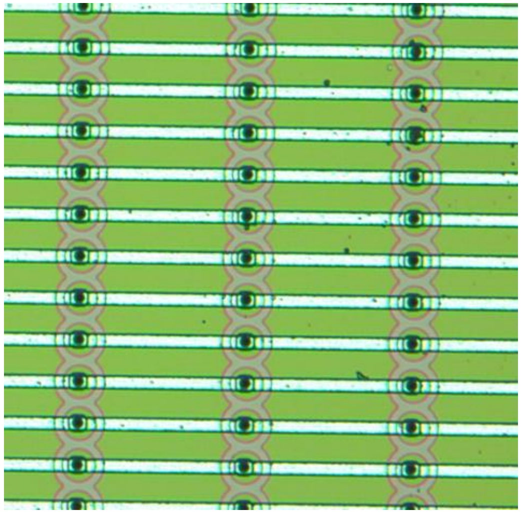
3D pixel sensors

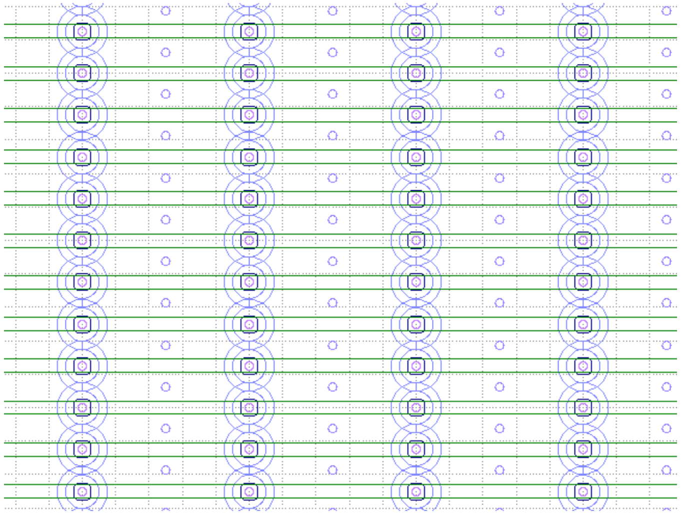


CNM Double sided 3D process: cross section

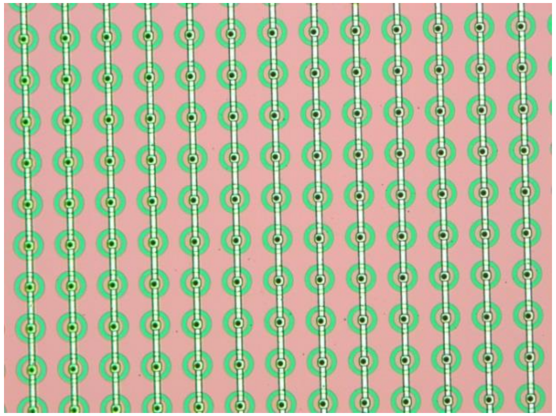


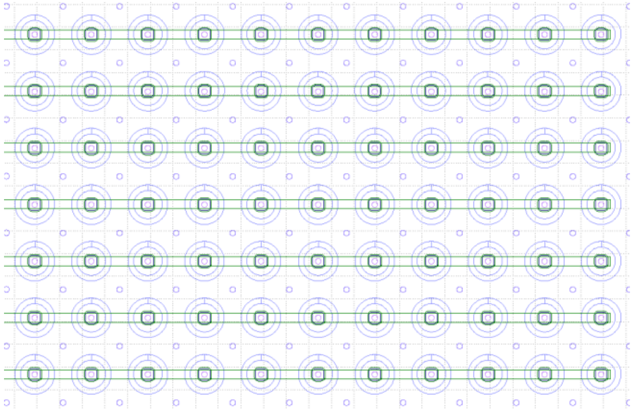
3D pixel strips: layout





25x100 (1E) μm²





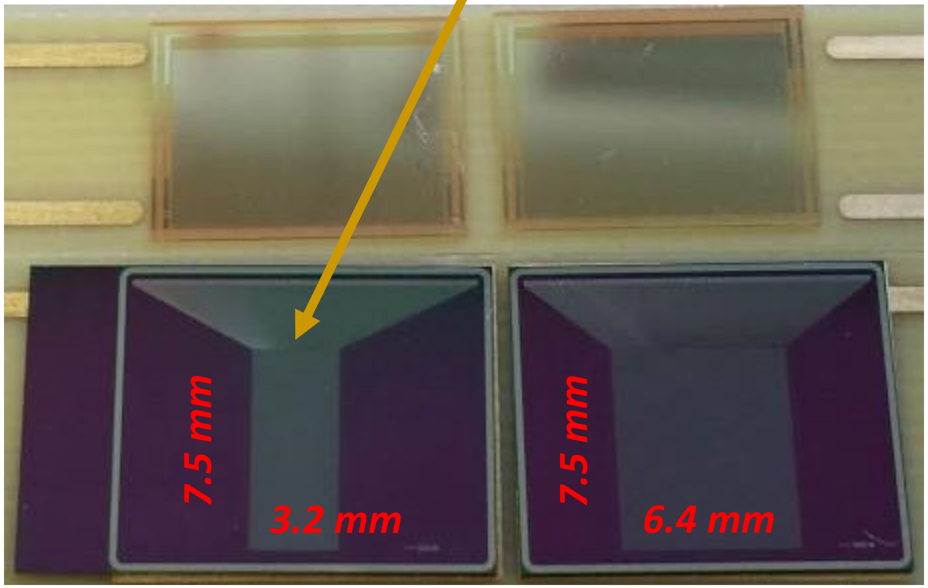
50x50 (1E) μm²

DUT:3D strips

Metal routing to fit 80 μm pitch electronics (Alibava Systems). Connected through fan AC.

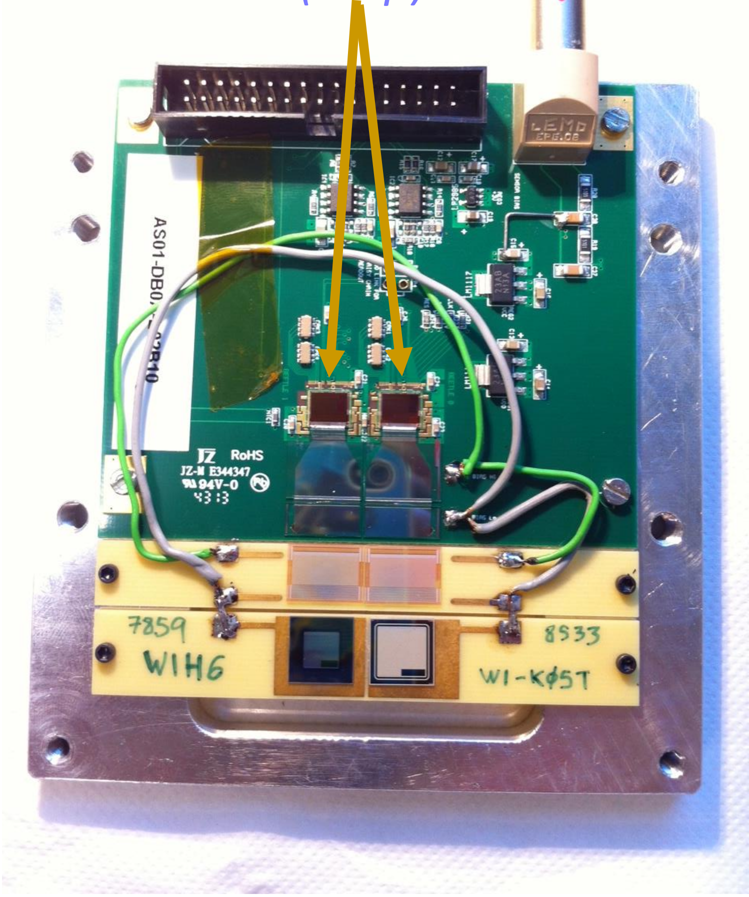
Alibava daughter board with 2 beetle (strip) ROCs

FAN AC *FAN AC*



25x100
128 75-pixel strips

50x50
128 150-pixel strips

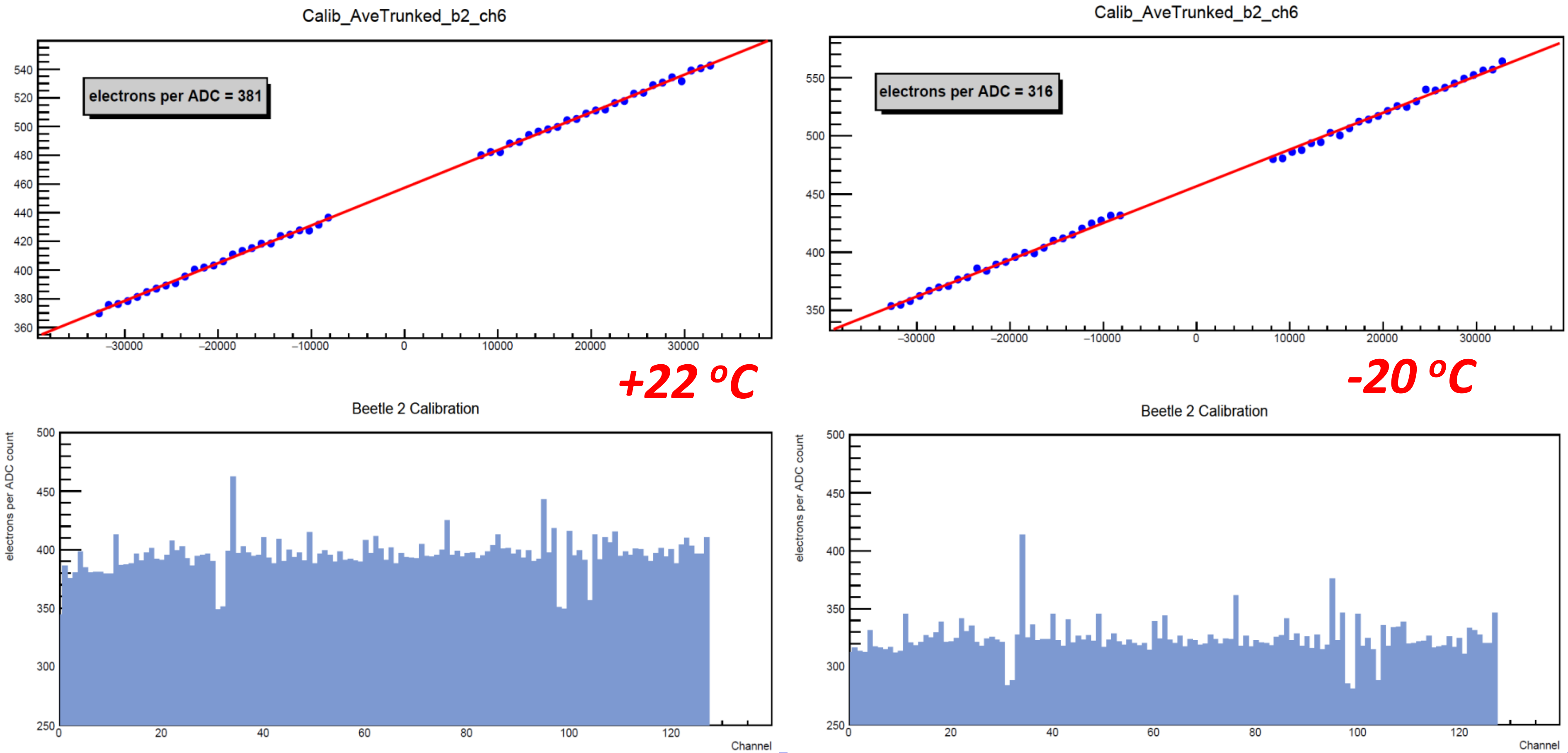


Irradiation

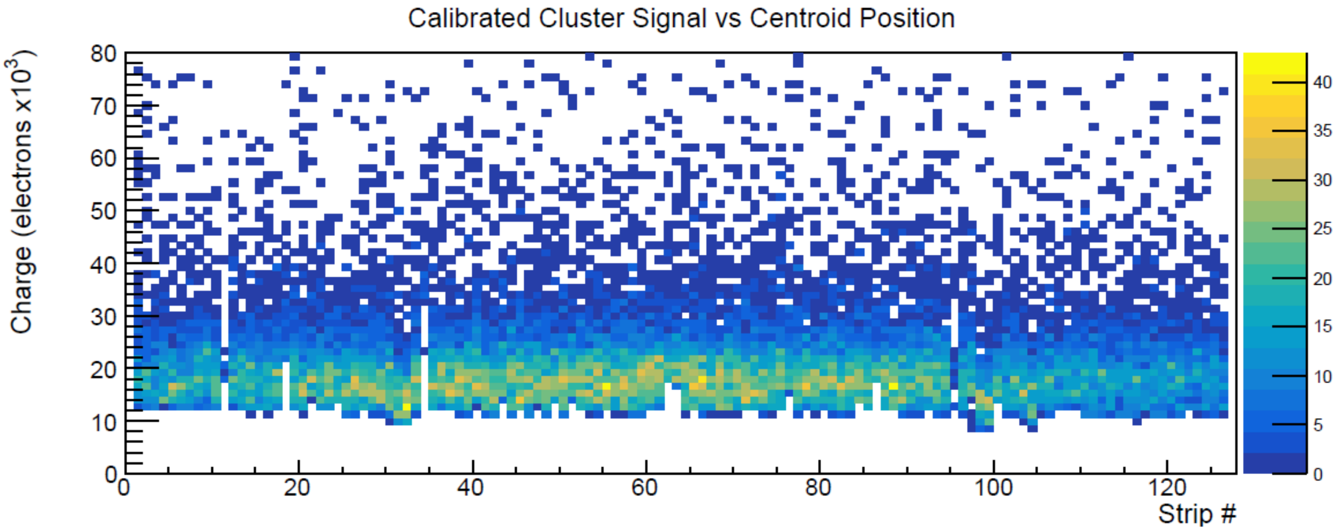
- CERN PS: 24 GeV protons
- Devices
  - 25x100 “pixel strips” 9.43e15 ± 7% p/cm2 = 5.7e15 neq/cm2
  - 50x50 “pixel strips” 9.43e15 ± 7% p/cm2 = 5.7e15 neq/cm2
  - 25x100 “pixel strips” 1.72e16 ± 7% p/cm2 = 1.0e16 neq/cm2
  - 50x50 “pixel strips” 1.72e16 ± 7% p/cm2 = 1.0e16 neq/cm2
- NO annealing (yet)
- 1e16 devices were NOT in time for test beam

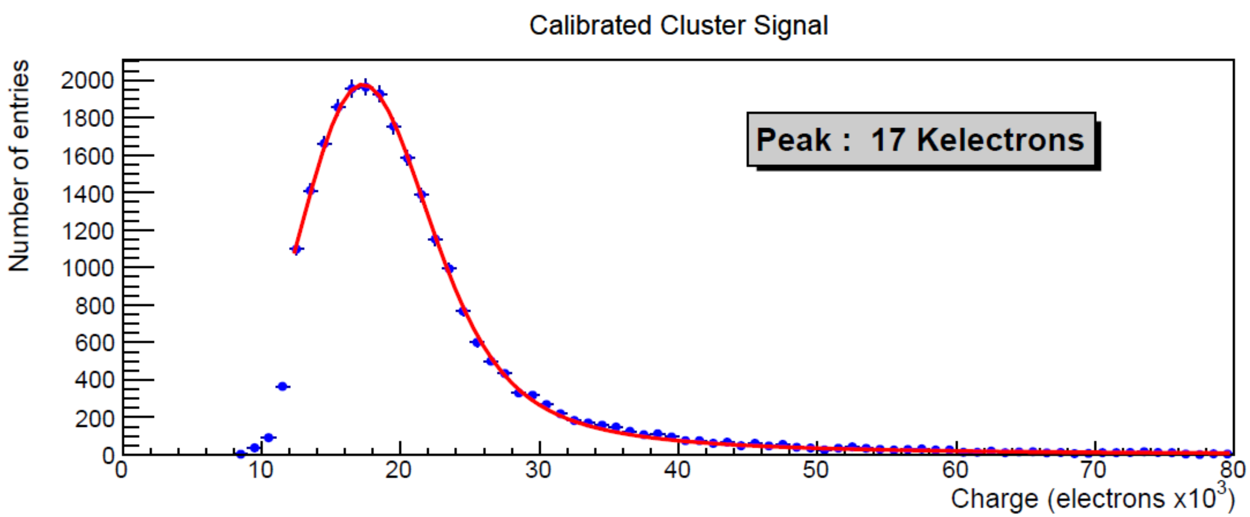
Data Analysis summary

Calibrate ALIBAVA beetle chips.
Charge injection circuit non-linear at small charges: exclude from linear fit.
***Strong temperature dependence**: repeated all calibrations in climatic chamber.*
Calibrations and data are matched both in temperature and in bias voltage.
*Although calibrations are insensitive to bias V: **inter-strip capacitance dominates**.*



Unirradiated sensor, 3D 50x50x230 μm^3, 22°C, -25V, π/p beam





50x50x230 μm^3

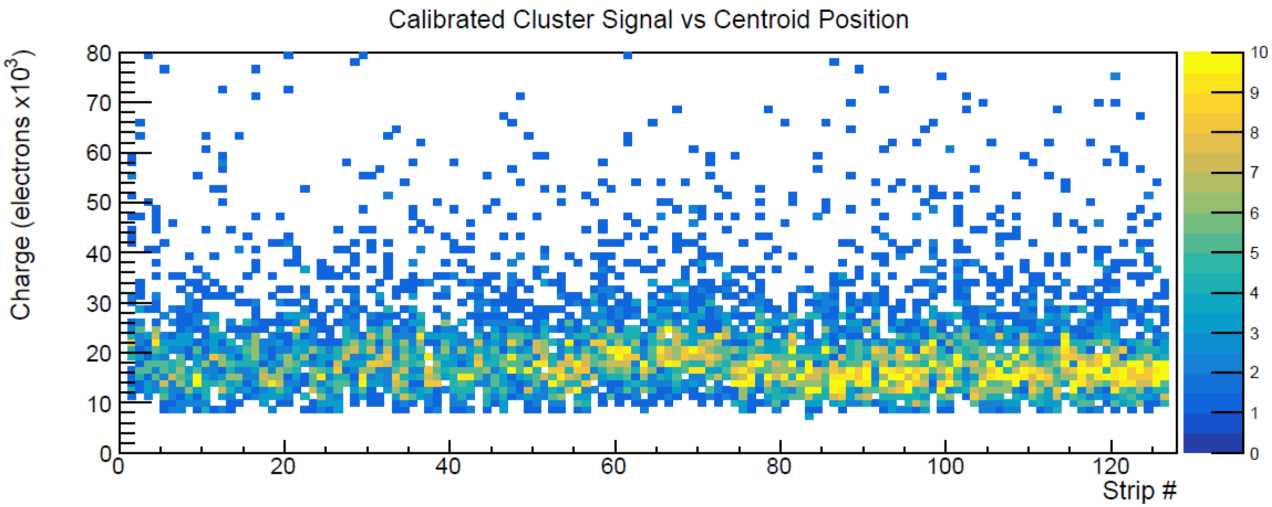
Unirradiated

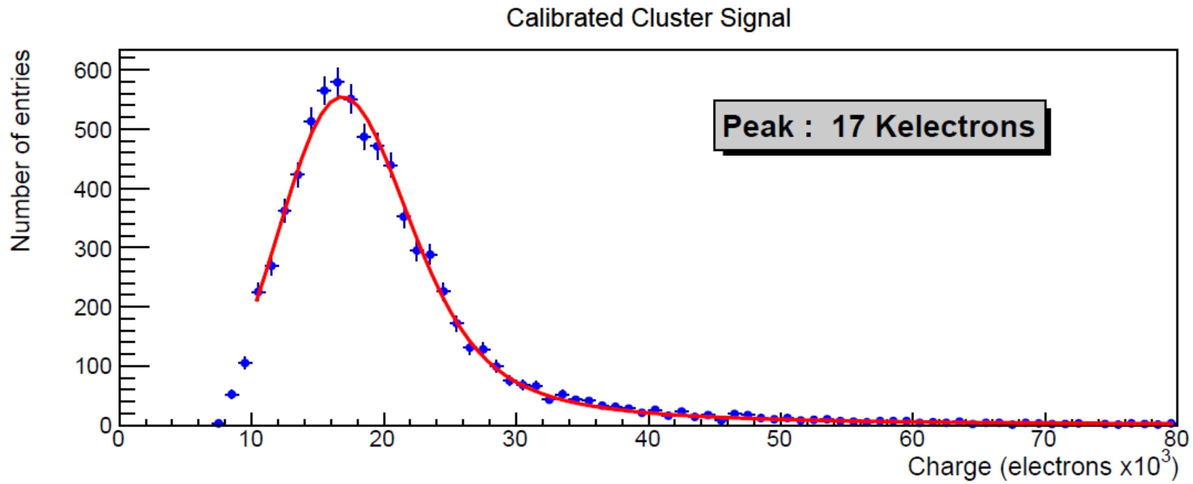
Vbias = -25 V

Temperature = +22 °C

120 GeV π^+/p

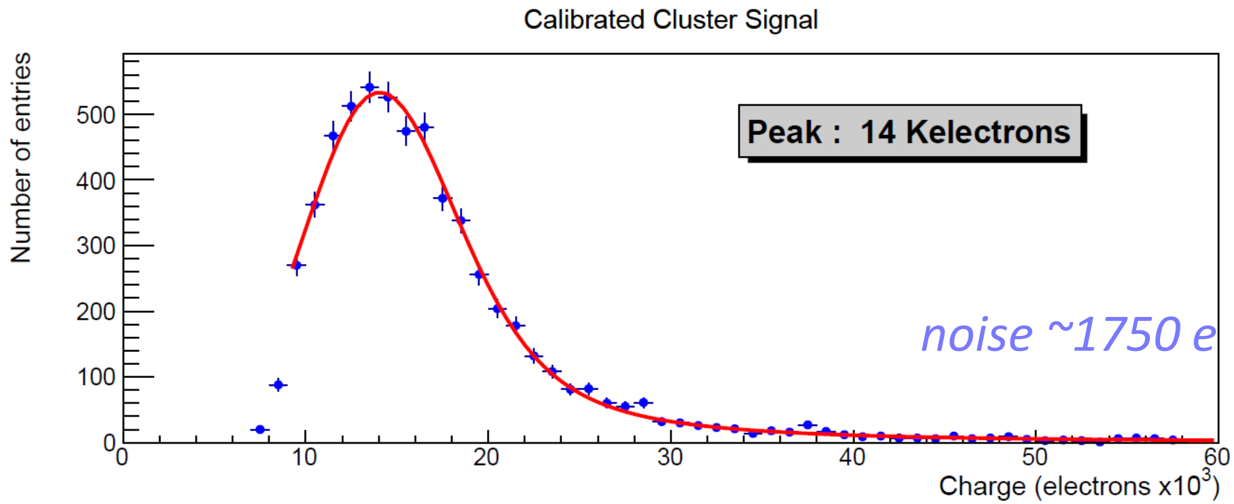
Unirradiated sensor, 3D 25x100x230 μm^3, -25°C, -30V, π/p beam





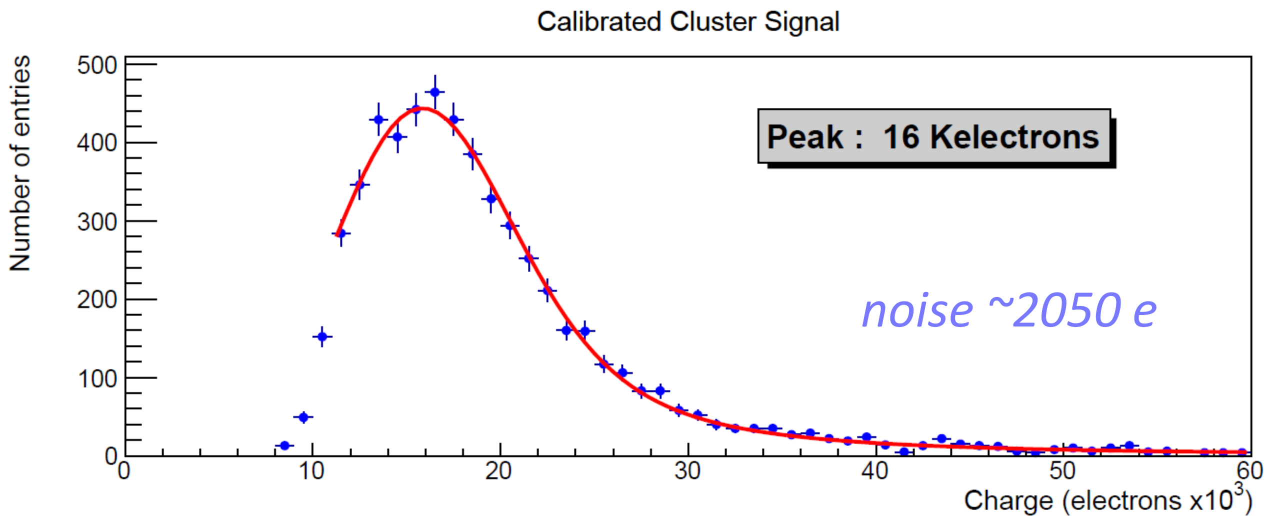
25x100x230 μm^3
Unirradiated
Vbias = -30 V
Temperature = -25 °C
120 GeV π^+/p

Φ = 5.7e15 n_{eq}/cm^2, 3D 25x100x230 μm^3, -25°C, -150V and -180V, π/p beam



noise ~1750 e

25x100x230 μm^3
p^+ irrad to 5.7e15 n_{eq}/cm^2
Vbias = -150 V
Temperature = -25 °C
120 GeV π^+/p



noise ~2050 e

25x100x230 μm^3
p^+ irrad to 5.7e15 n_{eq}/cm^2
Vbias = -180 V
Temperature = -25 °C
120 GeV π^+/p

Collected charge summary

Sensor Geometry	Operating Conditions	Fluence (protons) (n_{eq}/cm^2)	Charge (electrons x 10^3)	CCE* (%)
3D 50 x 50 x 230 μm^3	-25 V, 22 °C	0	17	100
3D 25 x 100 x 230 μm^3	-30 V, -25 °C	0	17	100
3D 25 x 100 x 230 μm^3	-150 V, -25 °C	$5.7x10^{15}$	14	82
3D 25 x 100 x 230 μm^3	-180 V, -25 °C	$5.7x10^{15}$	16	94

***** CCE with respect to non-irradiated sensor*

Hint of charge multiplication for irradiated sensor at high V

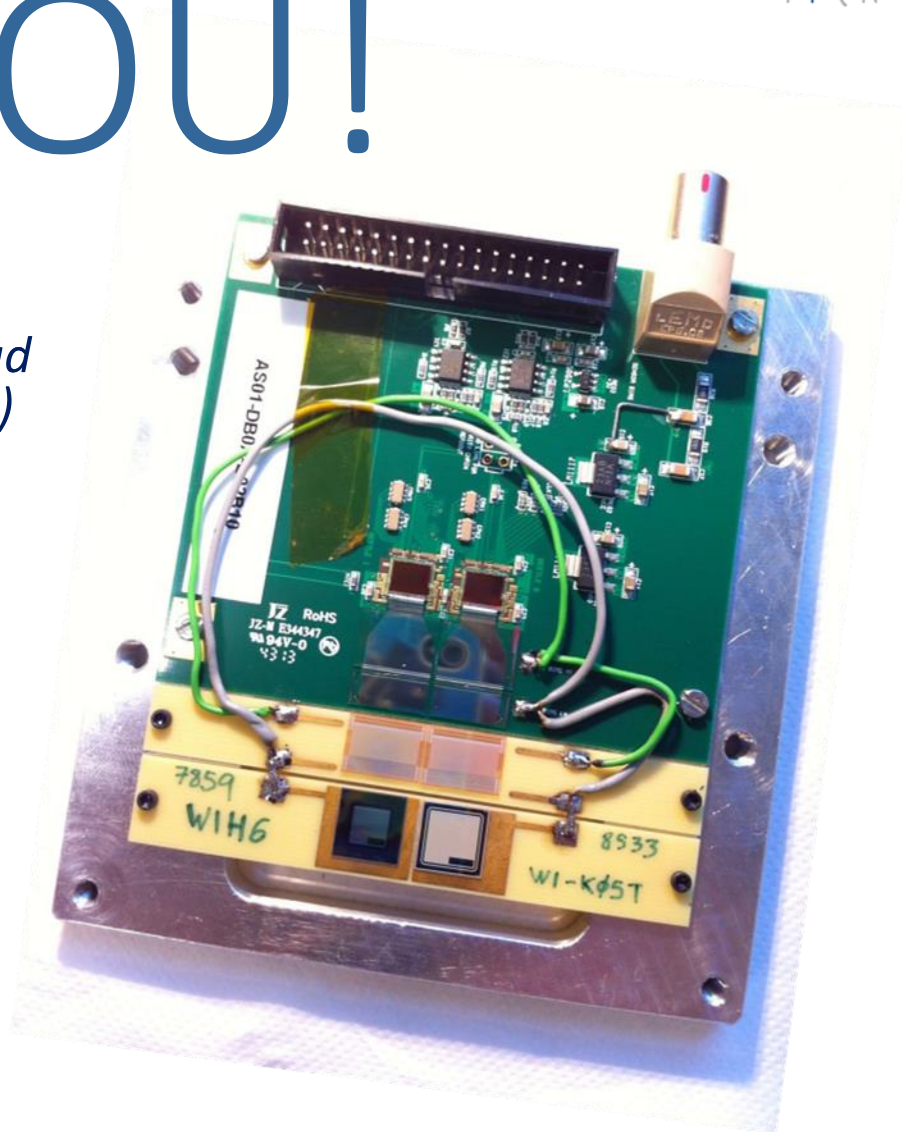
Typical Q ~ 76 $e^-/\mu m$ ~17480 e^- for 230 μm thickness

Summary

- I-LGAD
  - First characterization of a module with at SPS (AIDA-2020) with Alibava readout
  - Overall performance matches TCAD simulations and expectation.
  - Promising technology for achieving an ultra-low material budget tracking + built-in timing.
- 3D
  - Studied small-pitch 3D pixel strips from CNM
  - Proton irradiation at CERN PS. Three sensors tested
  - Fresh and irrdiated samples CCE as expected.
  - CCE after Φ of 5.7e15 n_{eq}/cm^2 82% @ 150 V, 94% @ 180 V

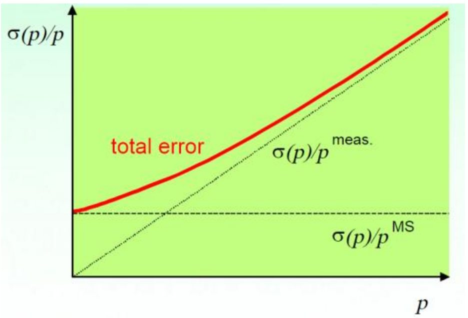
THANK YOU!

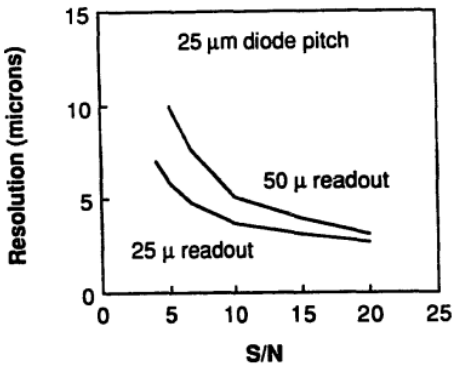
Special thanks to Florentina Manolescu (bonding lab @ CERN), Federico Ravotti (irrad facility@CERN) and Sofia Otero (SSD@CERN)

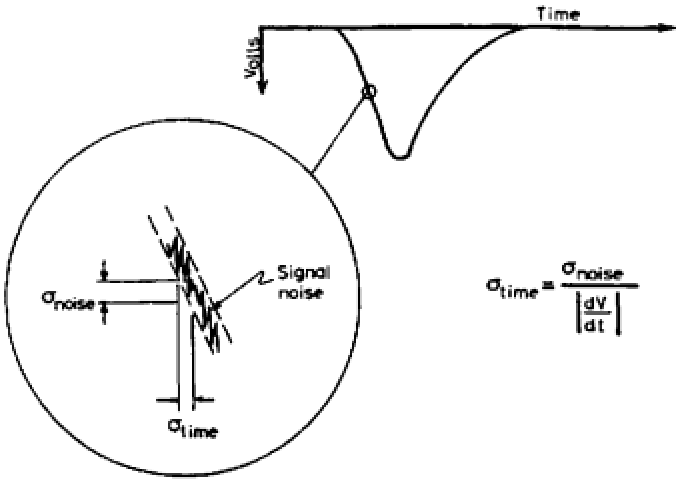


Motivation:

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

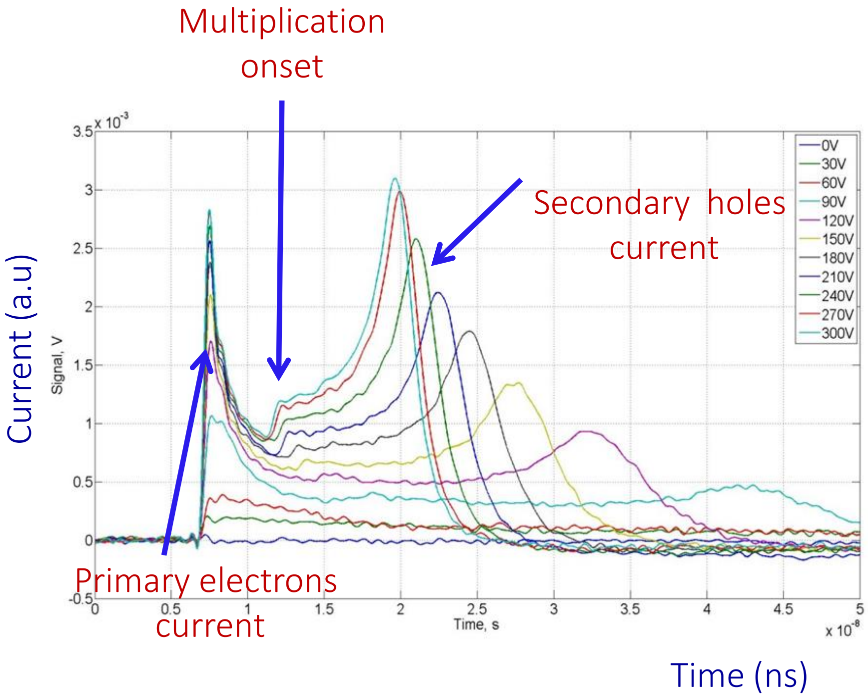




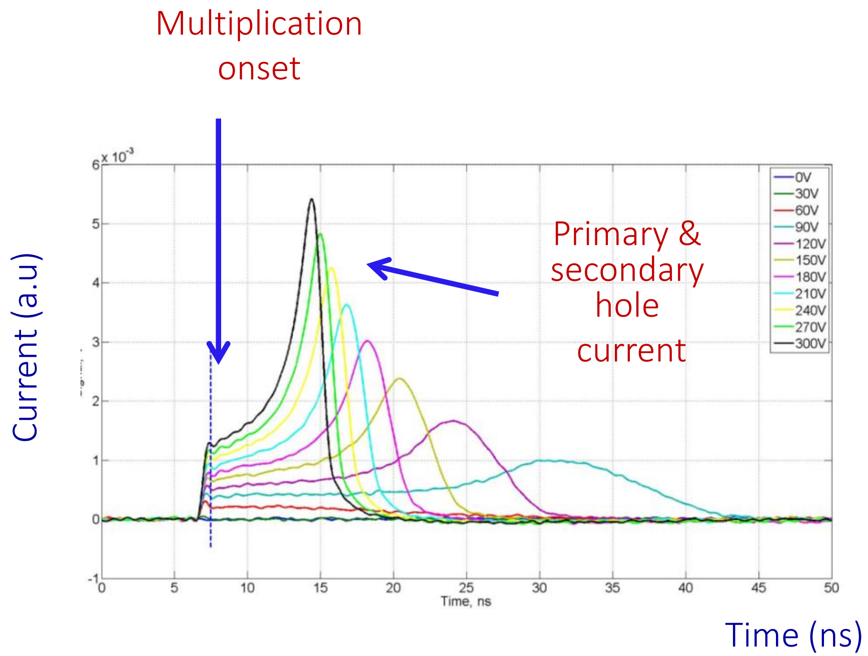


Transient Current: Red laser TCT.

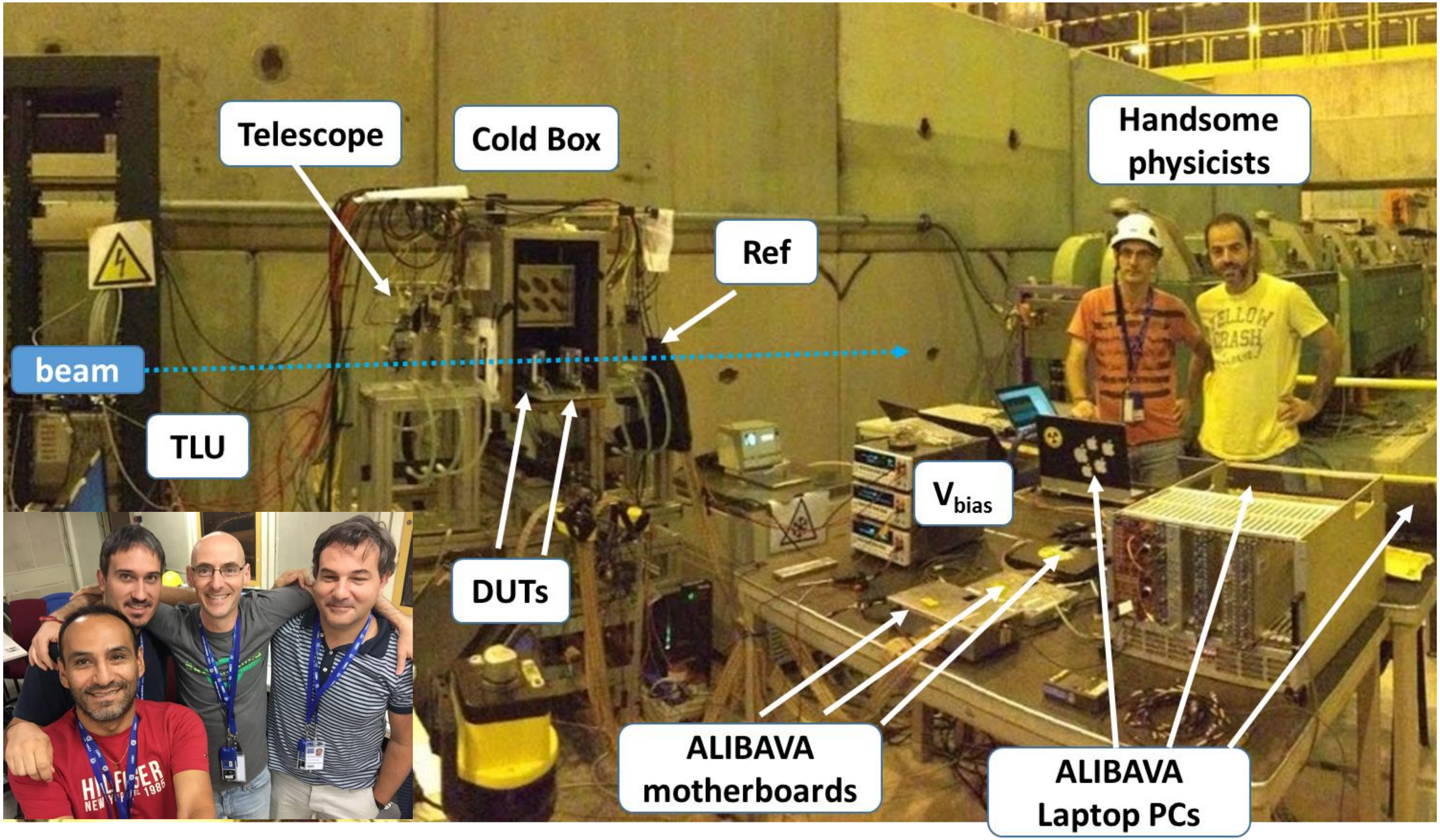
Electron Injection



Hole injection

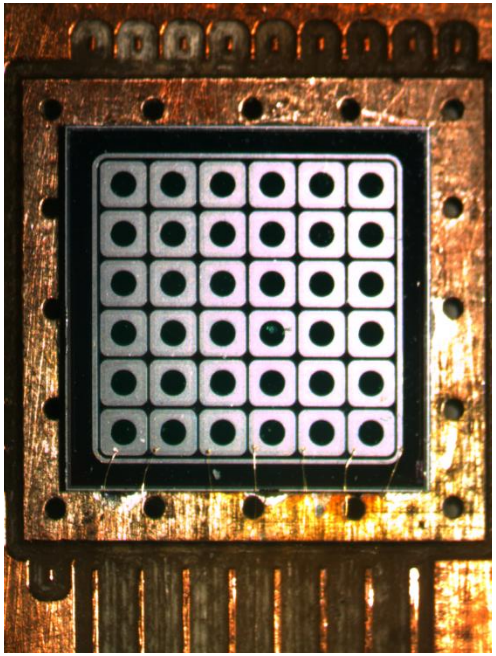


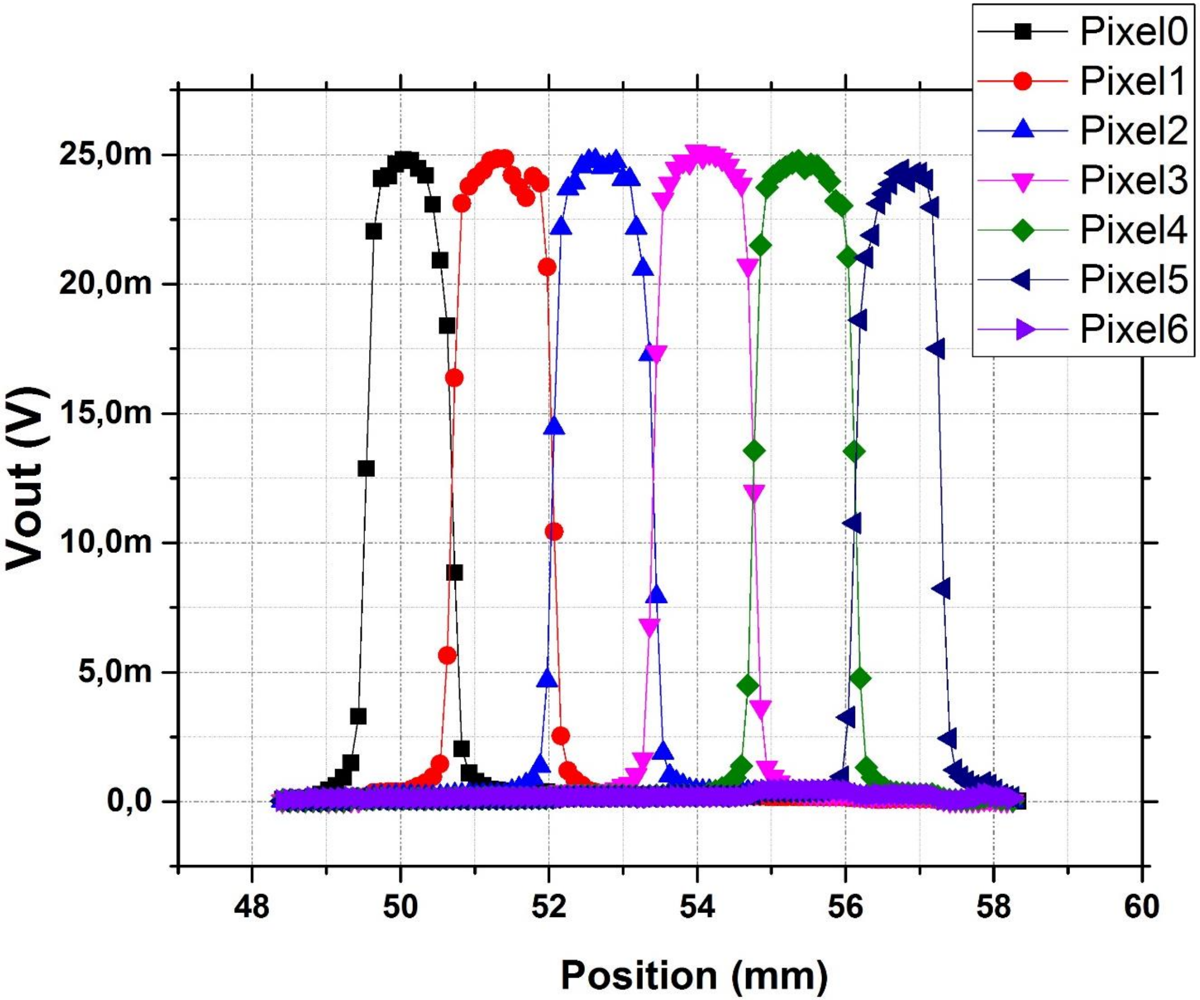
Test beam: Set-up



LGAD matrix characterization

- **LGAD back illuminated**
- **Ring included (Pixel6)**
- **Pulsed laser**
- **LGAD biased @ 420V**
- **100 um pinhole**
- **Vrms noise 0.73 mV**



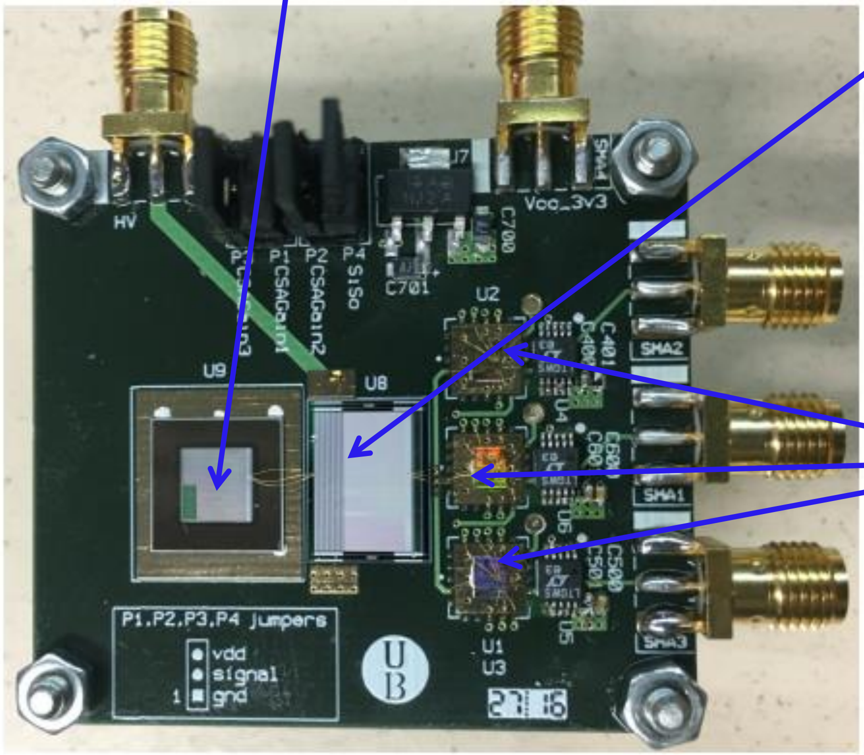


Fron-end electronics: s-LGAD integration

Strip LGAD (three strips bonded)

Fan-in with integrated coupling capacitors

Single channel preamp+shaper



Outlook

– I-LGAD prototypes (very limited sample tested) performing as designed.

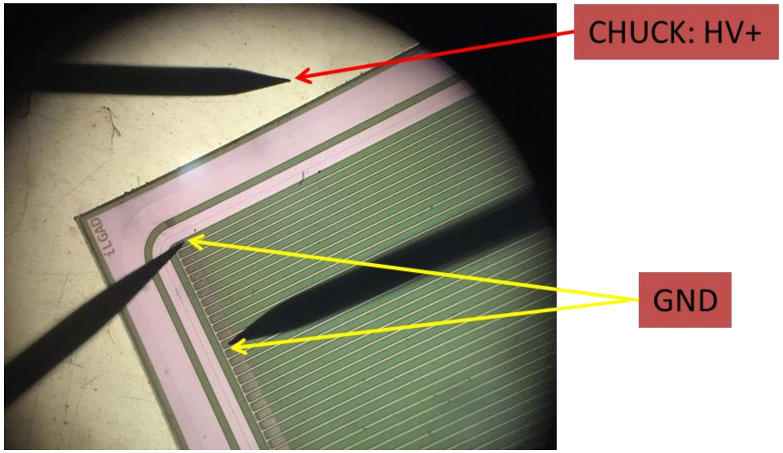
- Double Side Technological Process
- Using 4 inch Wafers
- Higher Active Area. 6 inch Wafers
- Lower Pitch Size. 50 µm
- Thin Devices (< 200 µm)
  - ✓ SOI, SOS Wafers
  - ✓ Timing Applications
- Radiation Hardness
  - ✓ Gallium Implantation
  - ✓ Carbon Doping

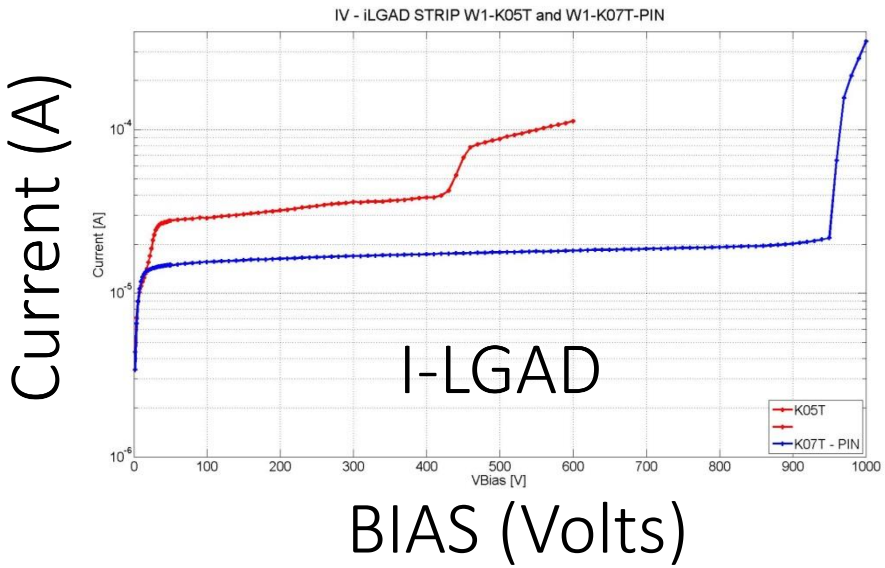
(See Talk from Mar Carulla)

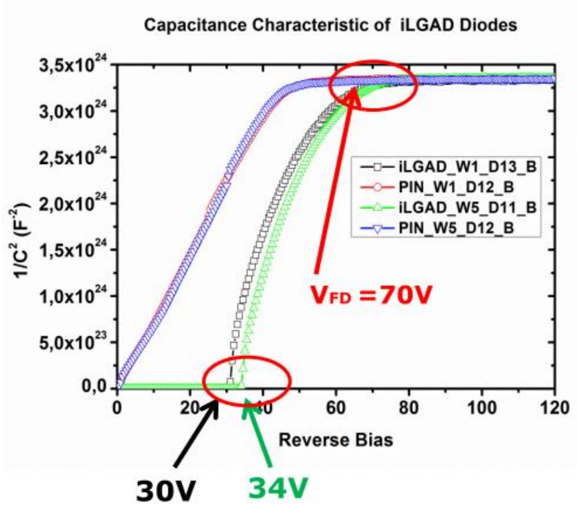
- AC Design
  - ✓ Polysilicon Layer
  - ✓ 1-2 Additional Mask Levels

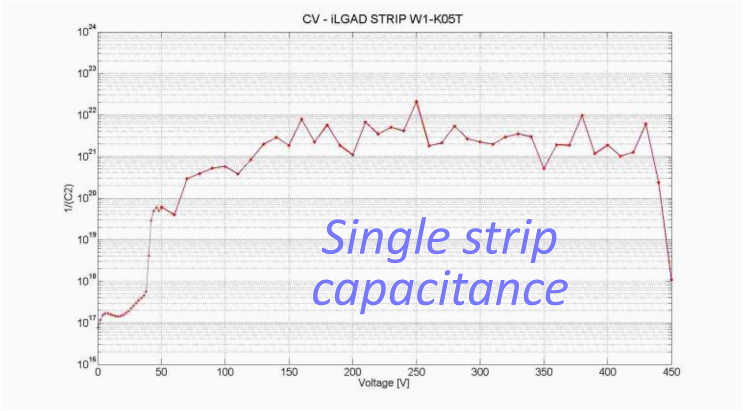
(from Salvador Hidalgo)

Electrical Characterization

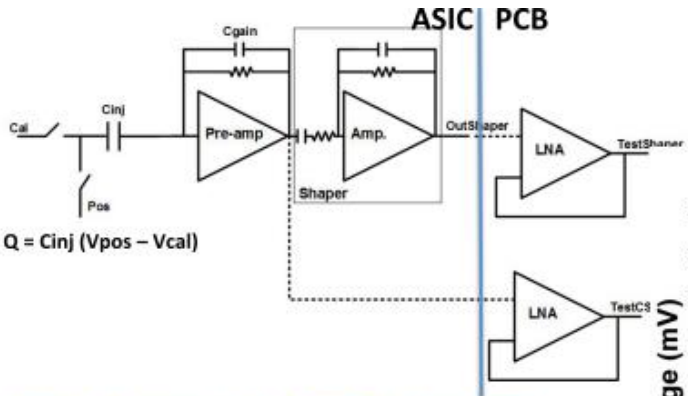




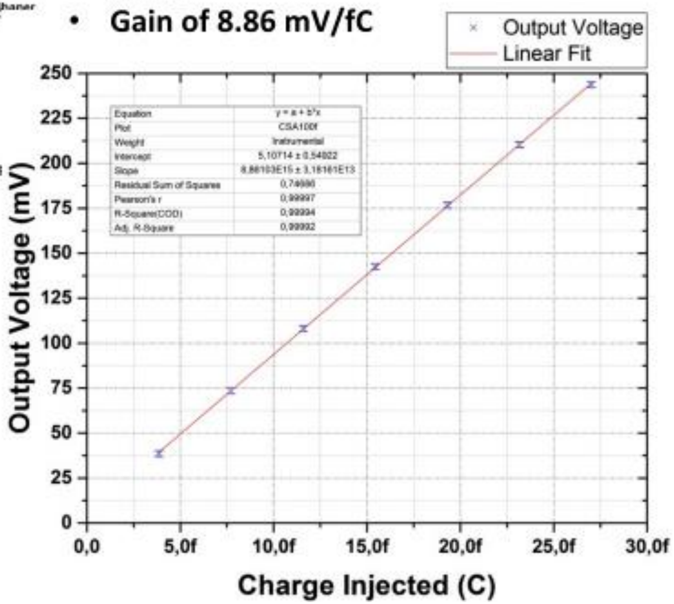


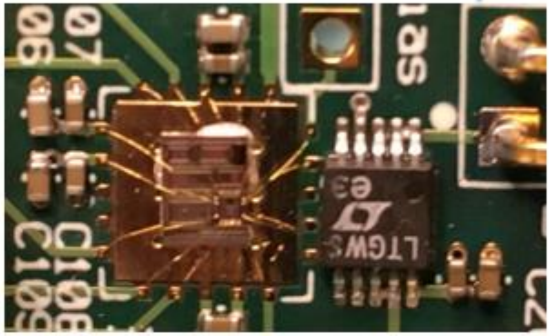


Dedicated front-end electronics: preamp+shaper



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





Optimized to maintain ENC below 700 e- with a C_d of 20 pF

CSA with two gains (100fC, 500fC)

Two gain ranges: 100fC and 500fC