I-LGAD
A thin microstrip sensor with signal amplification for ILD tracking

M. Fernández, J. González, R. Jaramillo,
D. Moya, A. Ruiz, **I. Vila**.
Instituto de Física de Cantabria(CSIC-UC)
P. Fernández, S. Hidalgo, G. Pellegrini, M. Vaselga.
Centro Nacional de Microelectrónica at Barcelona (CSIC)
C. Gallrapp, M. Moll, M. Stricker
CERN
H. Sadrozinski, Zachary Galloway, Zhijun Liang
UCSC - SCIPP
G. Kramberger
Josef Stefan Institute, Ljubljana
R.Palomo
Univesidad de Sevilla

… an RD50 project of the LGAD community.

Work supported by RD50 - Radiation hard semiconductor devices for very high luminosity colliders.

RD50 participating Institutes in this project:

1. CNM-Barcelona, G. Pellegrini, Giulio.Pellegrini@cnm-imb.csic.es
2. Liverpool University, Gianluigi Casse, gcasse@hep.ph.liv.ac.uk
3. UC Santa Cruz, Hartmut Sadrozinki, hartmut@ucsc.edu
4. IFCA Santander, Ivan Vila, ivan.vila@csic.es
5. University of Glasgow, Richard Bates, richard.bates@glasgow.ac.uk
6. INFN Florence, Mara Bruzzi, mara.bruzzi@unifi.it
7. CERN, M. Moll, Michael.Moll@cern.ch
8. Jozef Stefan Institute , G. Kramberger, Gregor.Kramberger@ijs.si

http://rd50.web.cern.ch/

Outline

- Low Gain Avalanche Detector Basics:
  - motivation and technology description
- Pad devices characterization (See S. Hidalgo talk)
  - Gain, noise, uniformity.
  - Neutron radiation tolerance.
- Microstrip devices:
  - Single sided n-in-p strips (results and simulations)
  - Double sided p-in-p strips (simulation and design)
- Inverted-LGAD (I-LGAD) manufacturing run description
- Summary and Plans

Motivation(s)

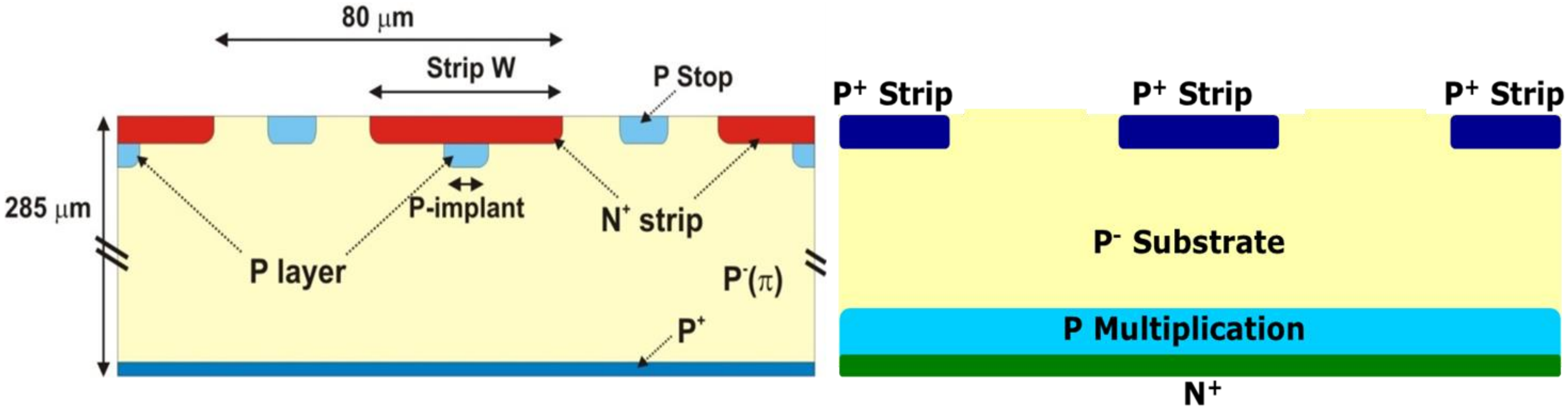
- **Proposal:** a small signal (5-10) gain integrated in the sensor while maintaining similar noise levels and avoiding readout front-end saturation.
- **Low-mass and low-power tracking systems** with thinner microstrips sensors conserving the same SNR (Covered here)
- **Timing:** ToF, primary interaction vertex timestamping (high pileup environments), medical, etc.

  (Not covered here, see H. Sadrozinski, talk on Ultra-Fast Silicon Detectors at the CPAD Instrumentation Frontier Meeting 2015)

Microstrips LGAD

– Based on the technology adjustments from the pad LGAD run now aiming to strips and pixel like segmentation of the readout electrodes.

– Two options:



N on P microStrip

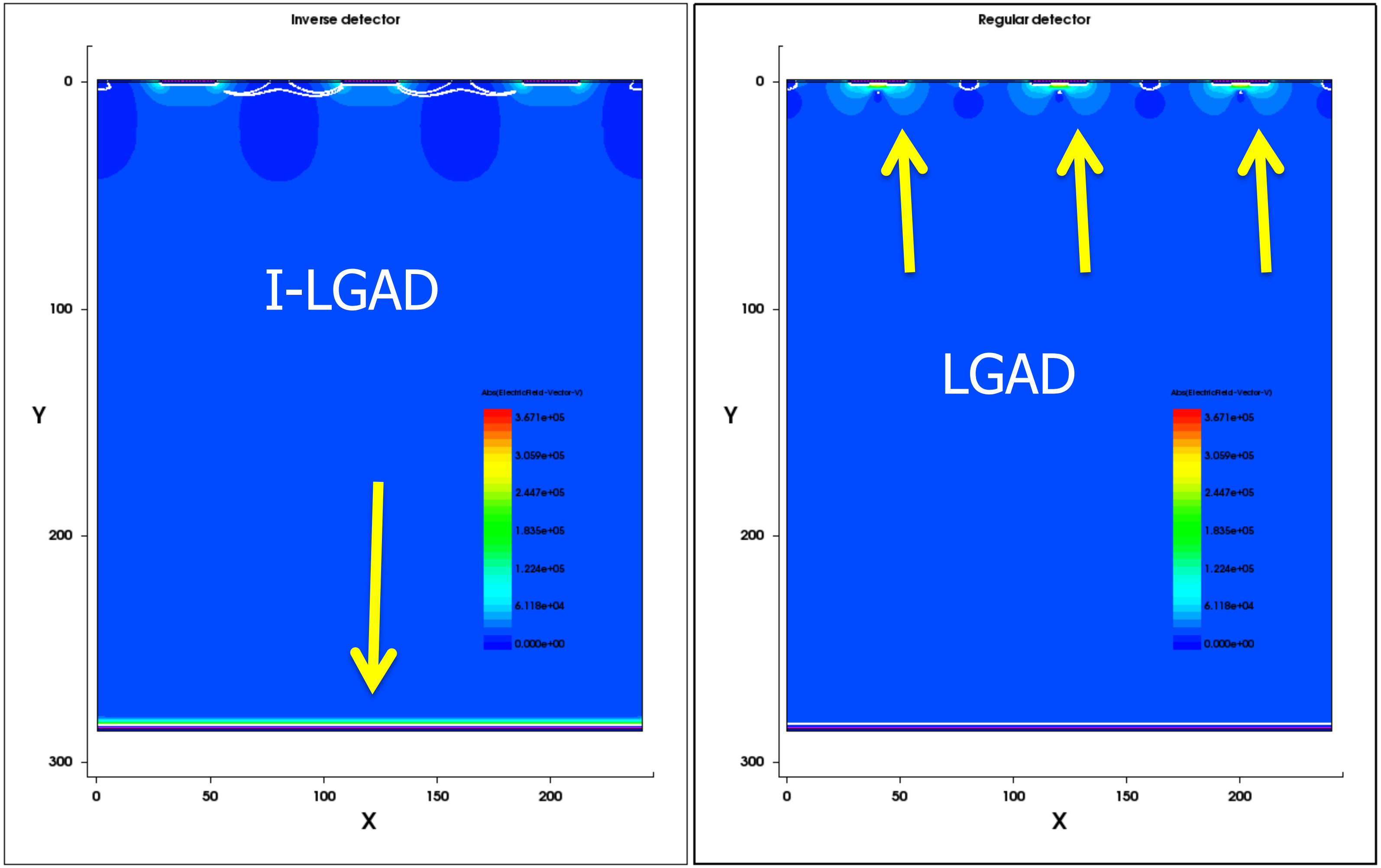
LGAD

P on P microStrip

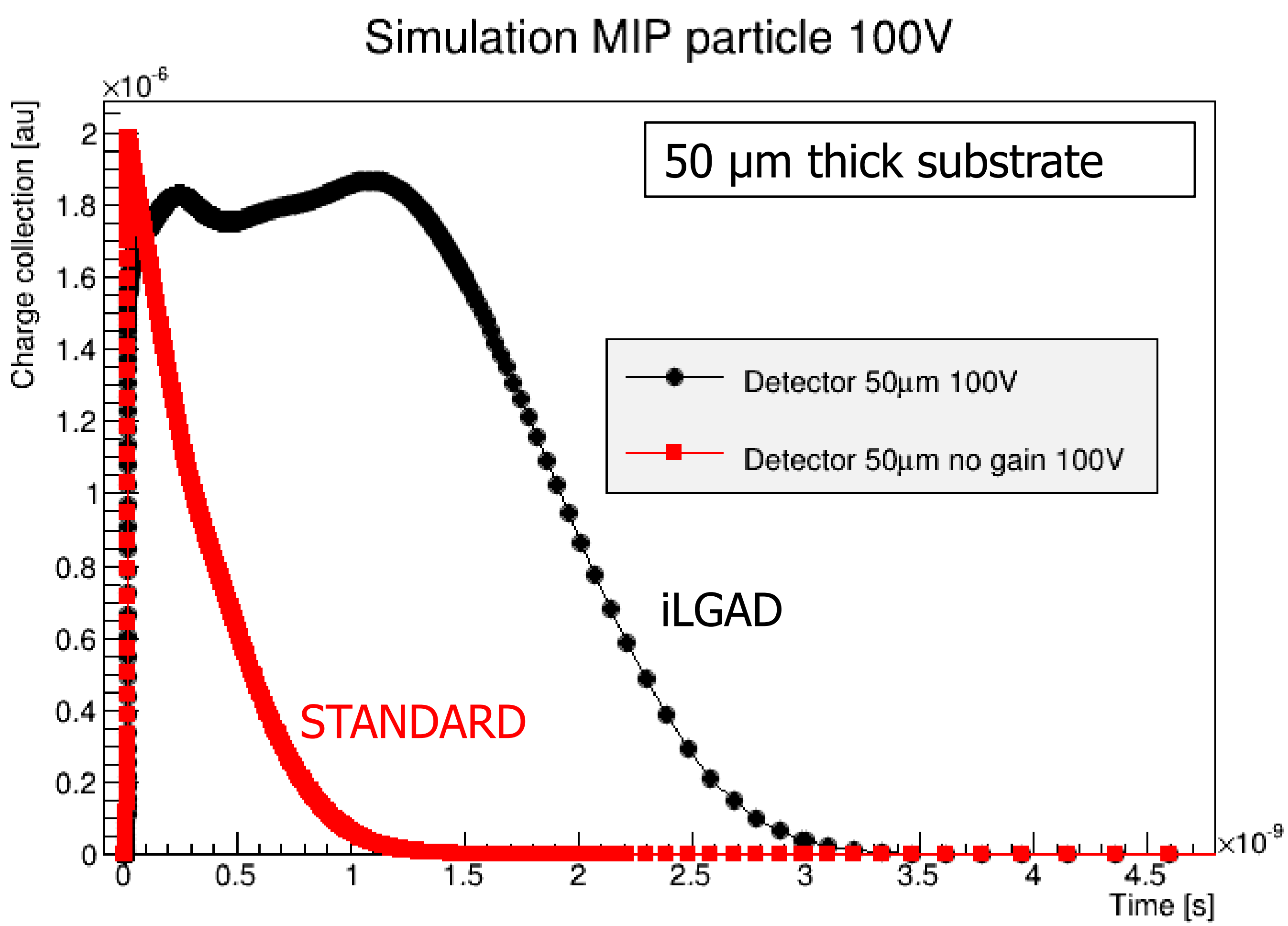
iLGAD

ustrips LGAD comparison: V_{BD} voltage

– I-LGAD design ensures that the maximum field remains in the multiplication layer.

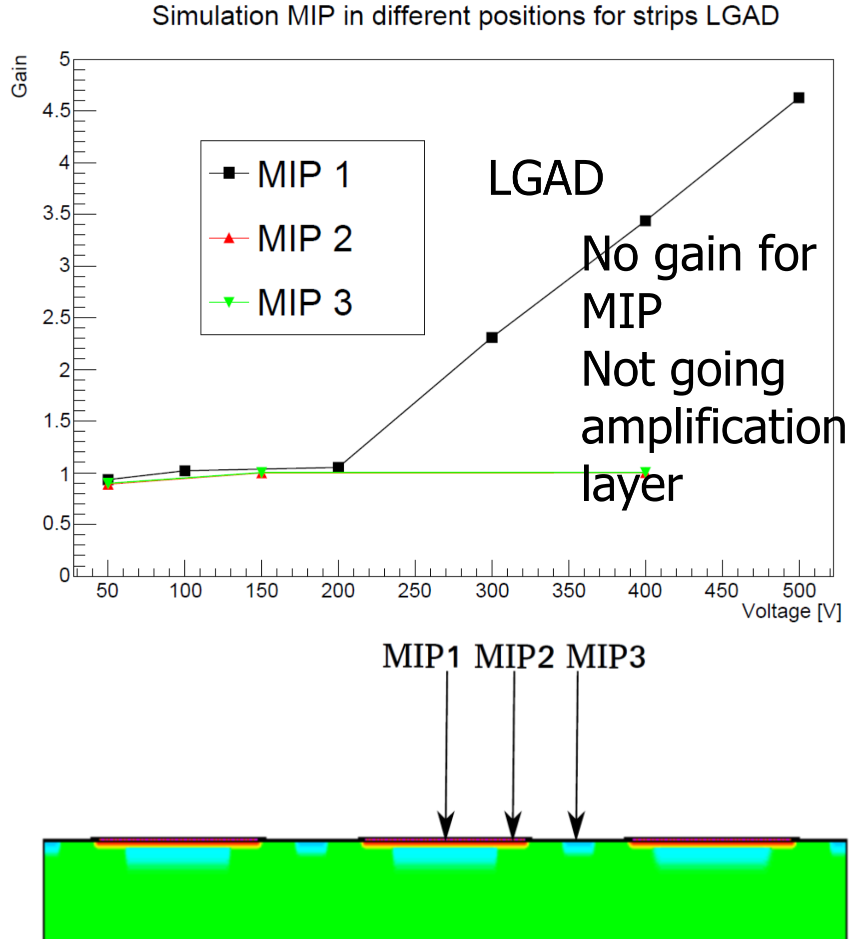


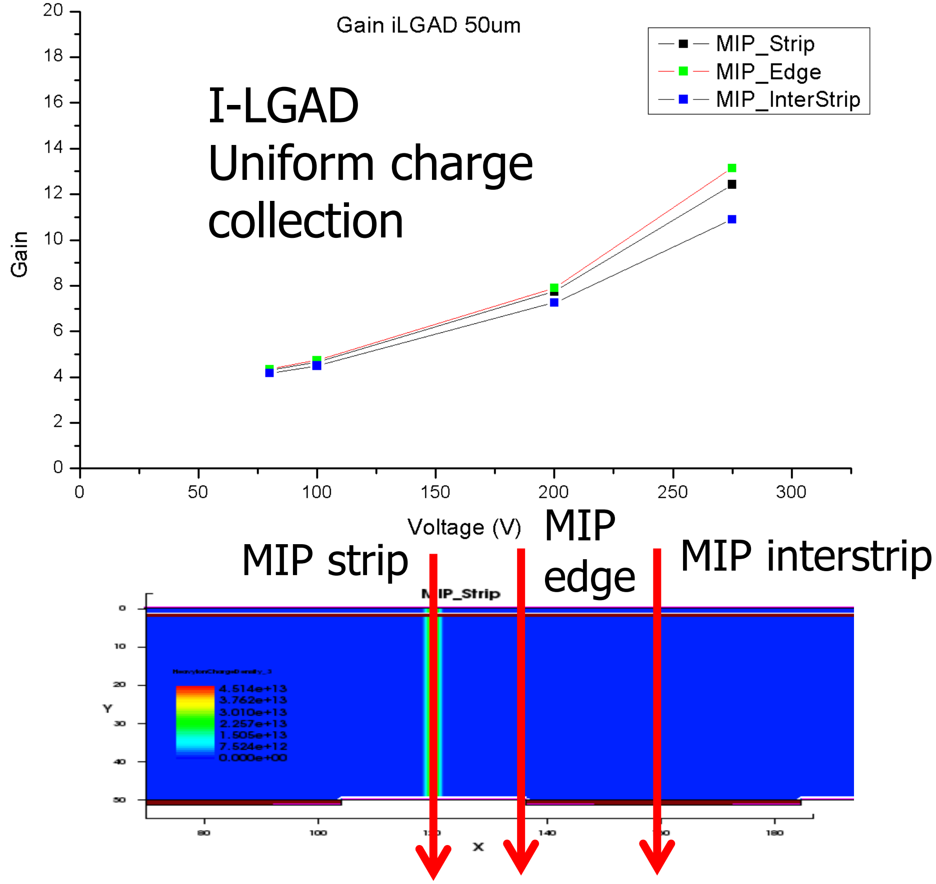
MIP through central strip @ 100 V



ustrips LGAD comparison: response spatial uniformity.

I-LGAD design provides signal response uniformity

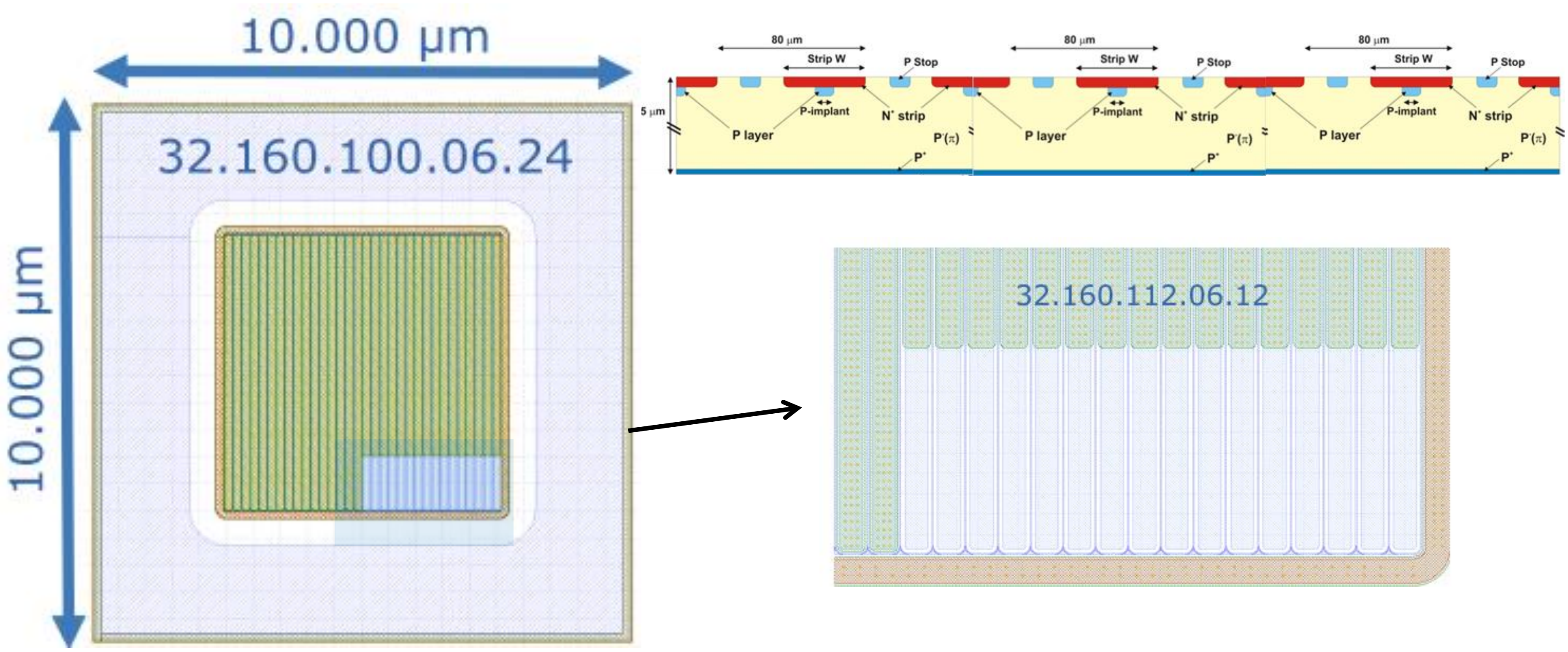




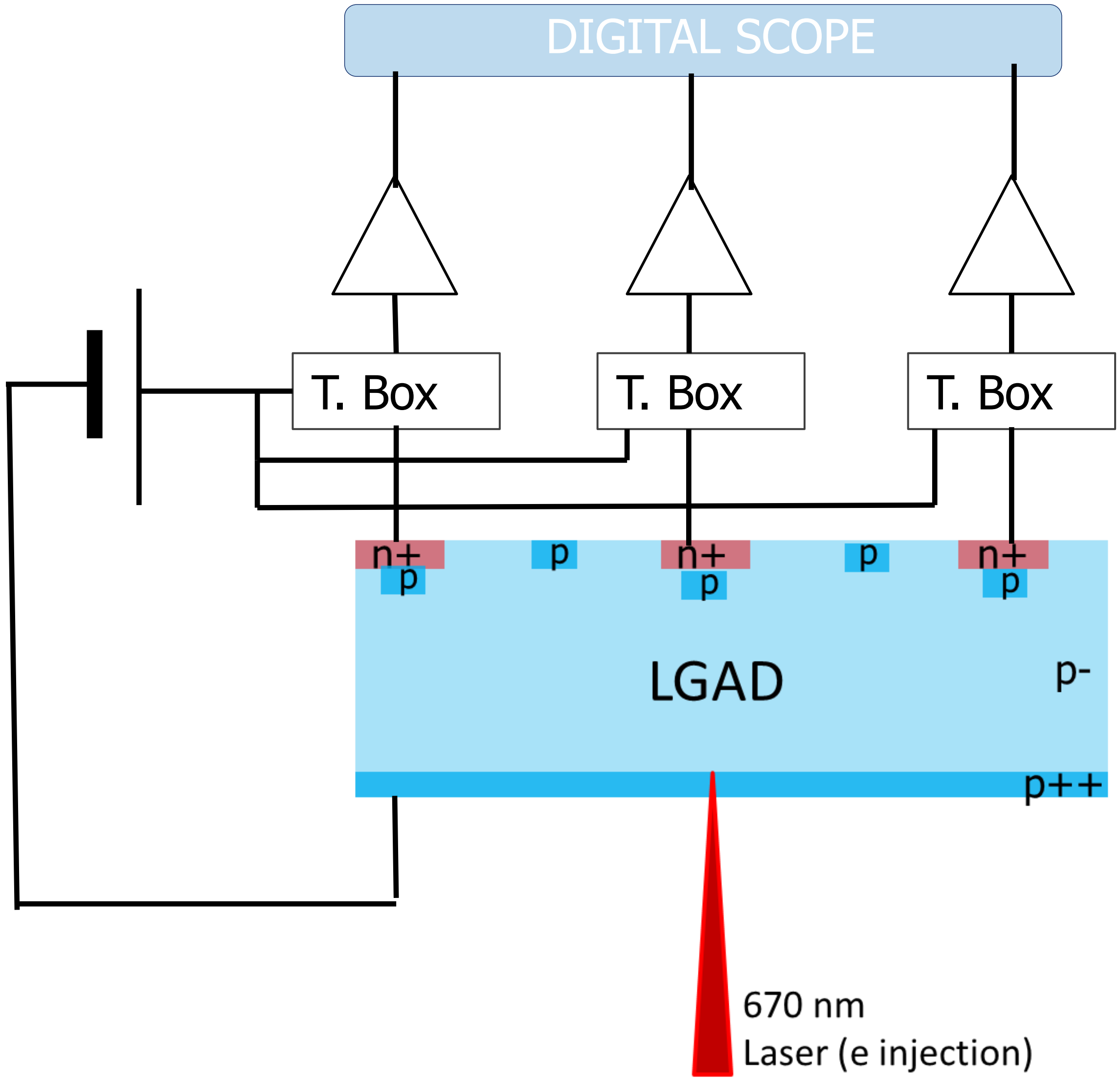
uscript LGAD vs ILGAD: in brief.

- ILGAD avantages:
  - more uniform charge amplification.
  - Breakdown voltage at the main diffusion
  - Combination of well stablished technologies.
- ILGAD drawbacks:
  - More complex (double-sided) processing.
  - Relatively slower collecting time (holes dominated).
- Action taken:
  - First, manufacturing of much simpler ustrip LGAD (existing photolithographic masks).
  - Detailed design of dedicated mask set for a new I-LGAD production run (under production).

Microstrip LGAD



Characterization lay-out

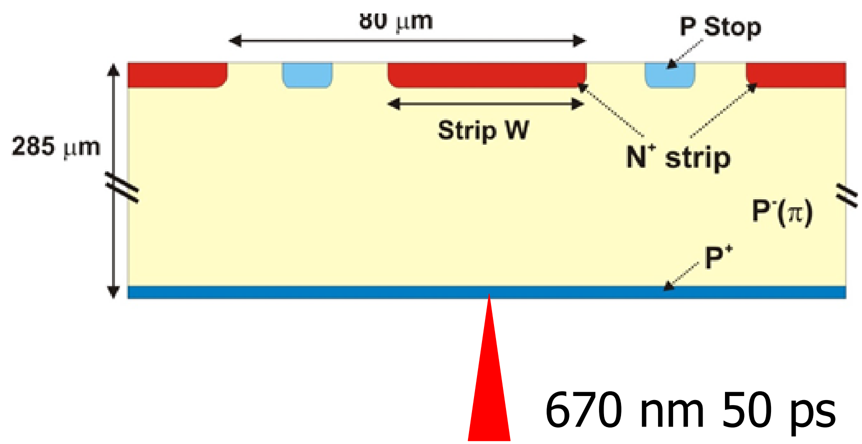


Simultaneous read out of three strips

Comparing PIN strip vs LGAD Strip transient Photoiduced currents

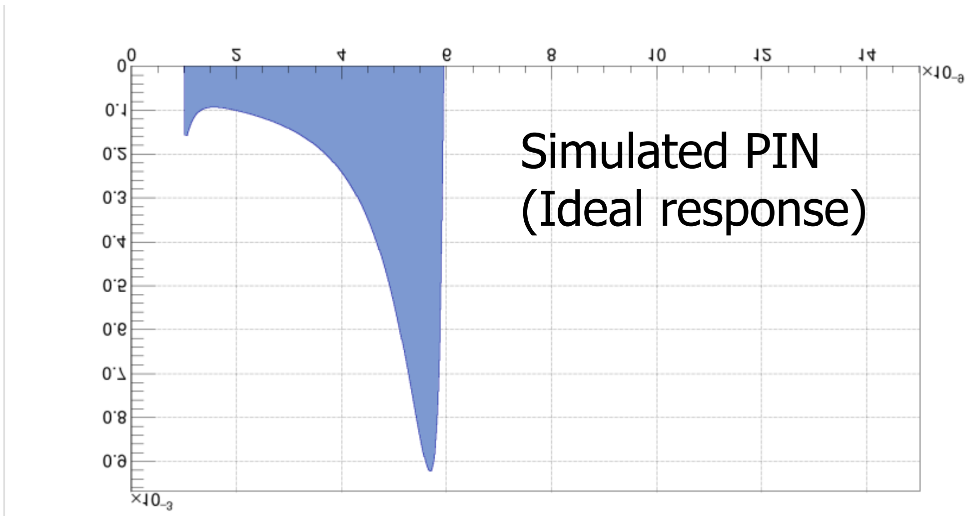
Electron injection (read Laser back-side ilumination

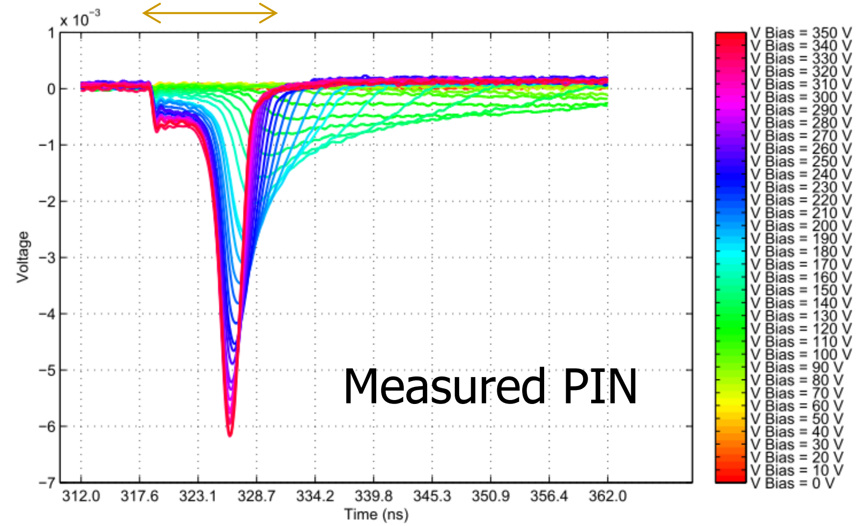
Microstrip LGAD: TCT PIN strip



670 nm 50 ps laser

8 ns

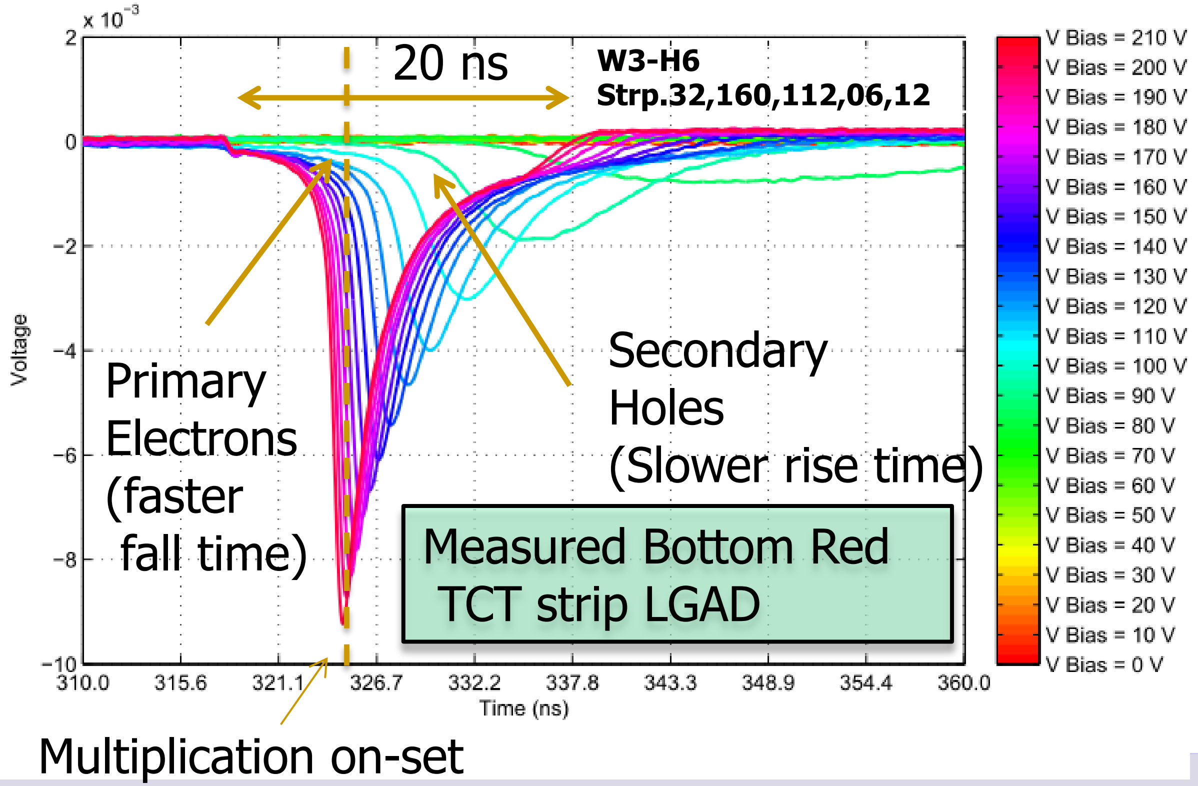


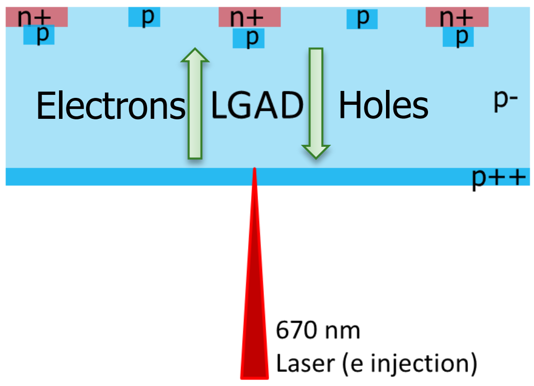


W2-G9 Strp.32,160,100,06,24,PiN

Microstrip LGAD: TCT LGAD strip

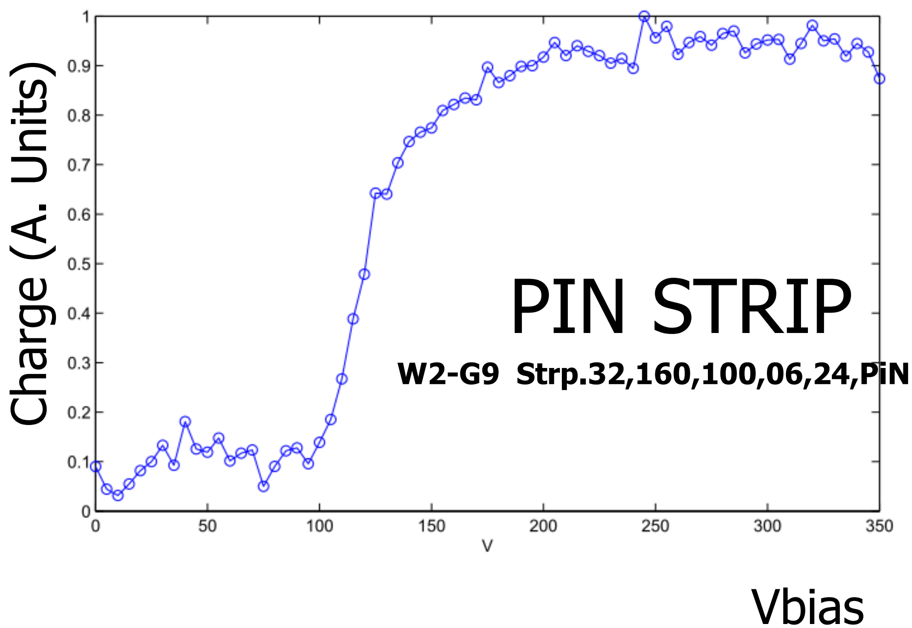
- Signal gain requires:
  - Wider TCT pulses wrt to PIN
  - Charge increases vs HV
- Strip current waveform shows clear sequential electron and hole drift (handle to extract the signal gain)

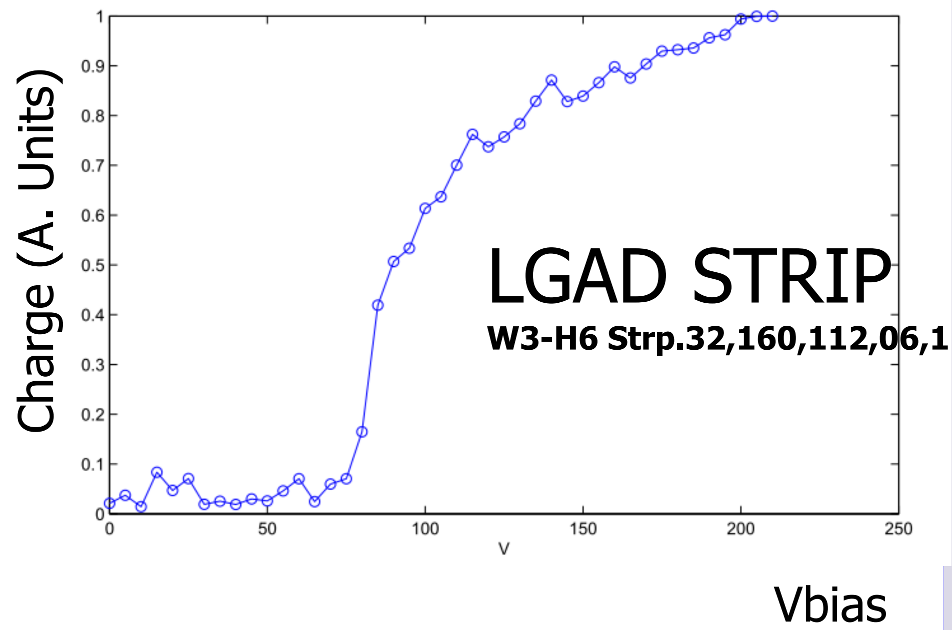




Microstrip LGAD: Charge vs Vbias

– Red laser – bottom TCT (Integrated current waveforms)

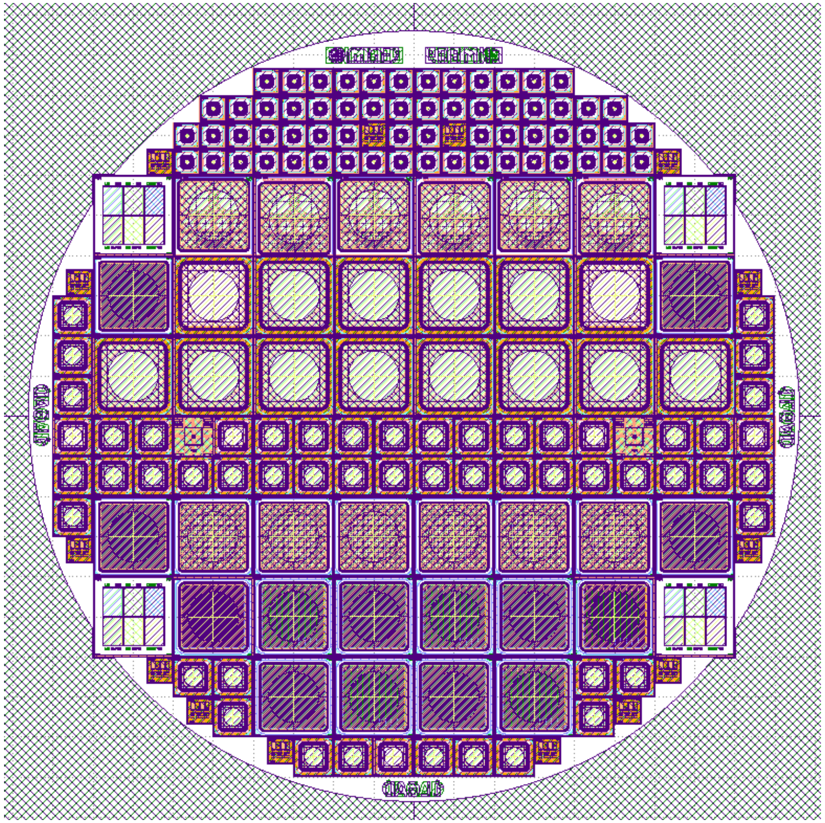




I-LGAD Run: Mask description

iLGAD

- 176 Chips
  - ✓ 44 (10 x 10 mm, total area)
  - ✓ 56 (5 x 5 mm, total area)
  - ✓ 76 (3.3 x 3.3 mm, total area)



- 113 LGAD Pad Detectors
  - ✓ 12 (8 x 8 mm mult area)
  - ✓ 49 (3 x 3 mm mult area)
  - ✓ 52 (1 x 1 mm mult area)
- 17 PiN Detectors
  - ✓ 2 (8 x 8 mm active area)
  - ✓ 5 (3 x 3 mm active area)
  - ✓ 10 (1 x 1 mm active area)
- 8 iLGAD pStrips Detectors
  - ✓ 4 (45 Channels)
  - ✓ 4 (90 Channels)
- 2 PiN pStrips Detectors
  - ✓ 1 (45 Channels)
  - ✓ 1 (90 Channels)
- 6 Pixelated iLGAD Detector (6 x 6 pixels)
- 4 Pixelated iLGAD MediPix Detector (145 x 145 pixels)
- 6 iLGAD for Timing Applications
  - ✓ 3 (720 µm to cut line)
  - ✓ 3 (370 µm to cut line)
- 4 Specific Test Structure (SPR,SIMS,XPS)
- 16 CNM Test Structures (Microsection, CBR, Kelvin, Capacitors, Diodes)

Summary

- Low Gain Avalanche Detectors implemented as reach-trough avalanche diodes as a way to maintain the SNR while reducing very significantly material budget.
- Tuning of the technological process (at IMB-CNM) using pad LGAD devices: Proven gain reproducibility and uniformity; radiation resistance (up to 1E13 neq/cm2, gamma tolerance assessment in progress); and no significant excess noise.
- Preliminary results on n-in-p strips LGAD showed non-uniform gain (behavior reproduced by TCAD simulation).
- New design of a p-in-p strip sensor with pad-like multiplication layer to solve the non uniformity issue

Next year foreseen activities.

- New batch of LGADs detectors on a 200um substrate available (since last week).
- Complete the p-n-p strip run (ILGAD) by May 2016
- Dedicated gamma irradiation campaign.
- Full test of I-LGAD devices.
- Design of a new devices integrating LGAD technology and resistive electrodes (Charge division for longitudinal position resolution

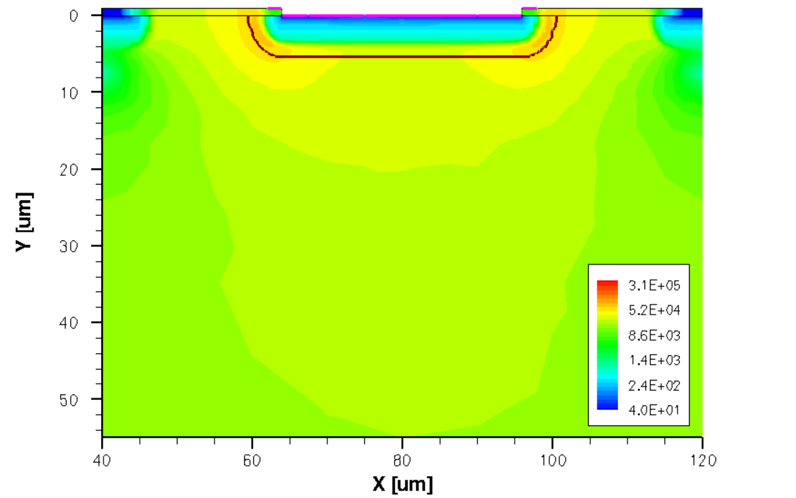
THANK YOU !

BACK UP

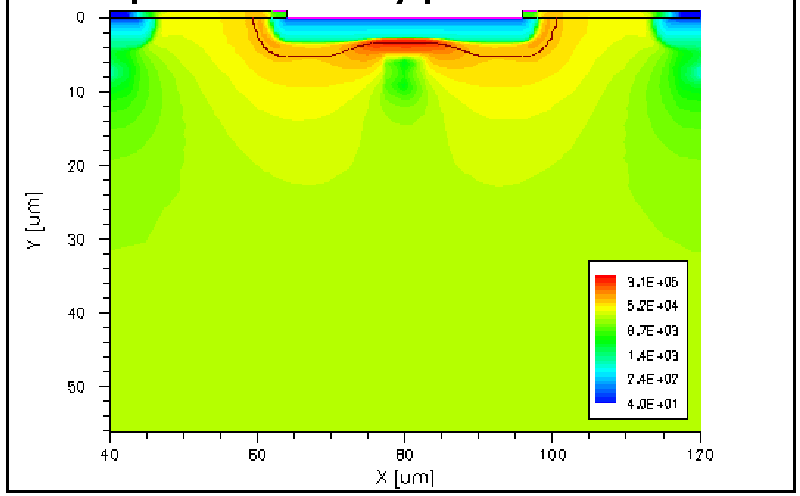
Strip LGAD: Electric Field

- To obtain the manufacture parameters (doping profiles)

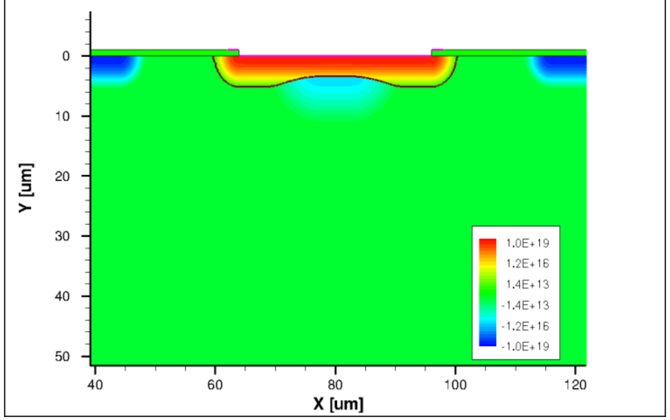
Standard Strip

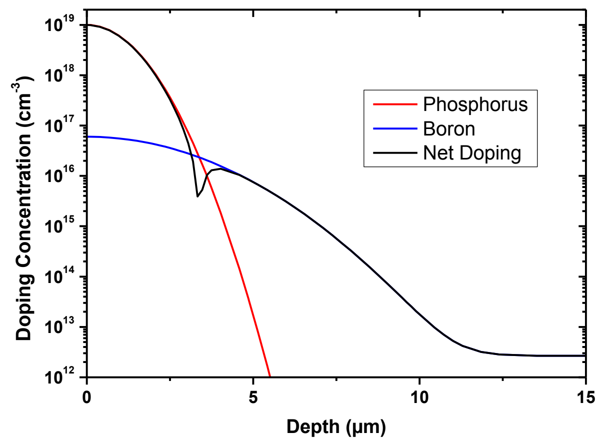


Strip with P-type diffusion

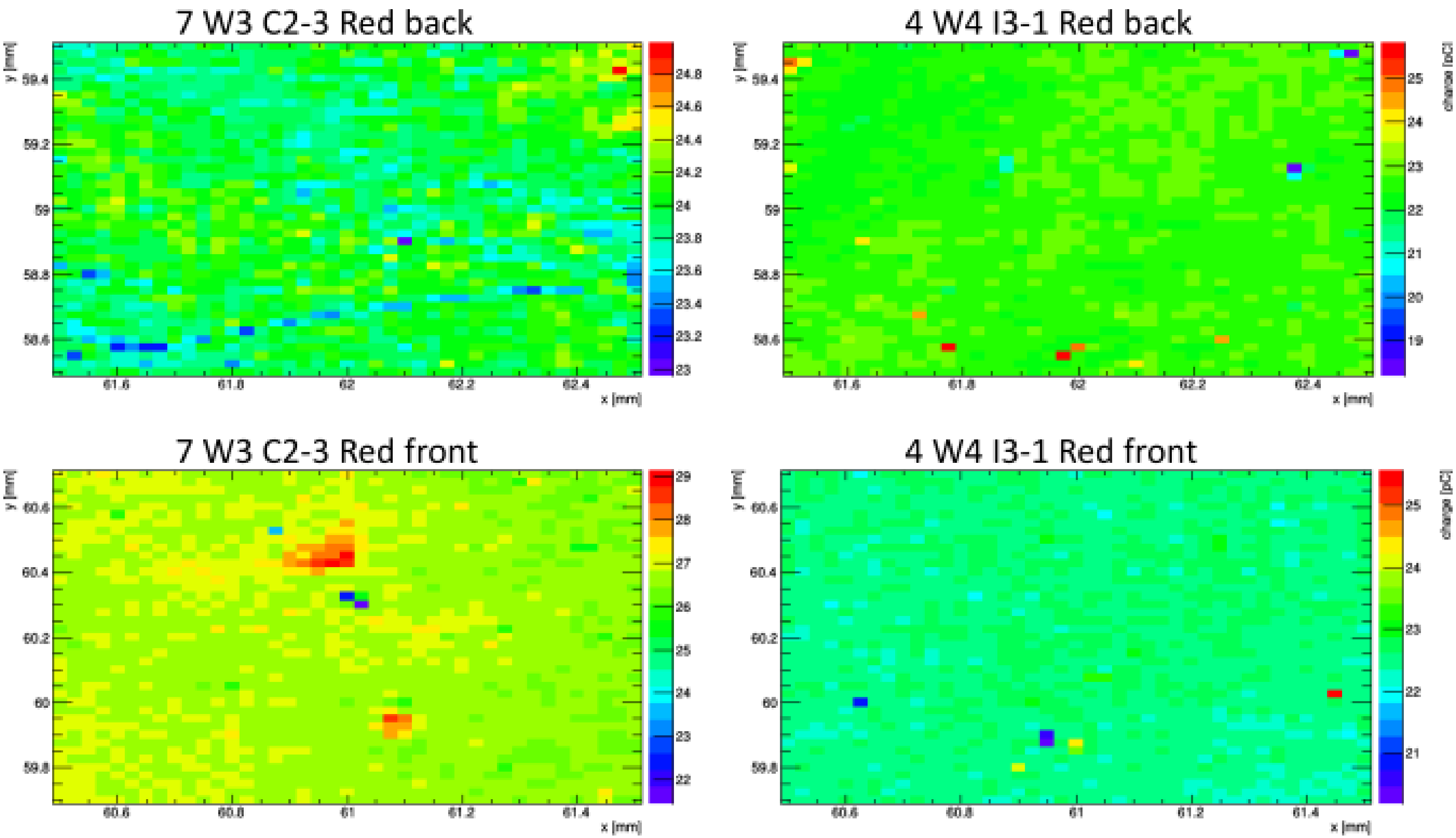


Strip with P-type diffusion: 2D and 1D doping profiles





Gain Uniformity: LGAD 2.0 at 100Vs



Low Gain Avalanche Detectors 101

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

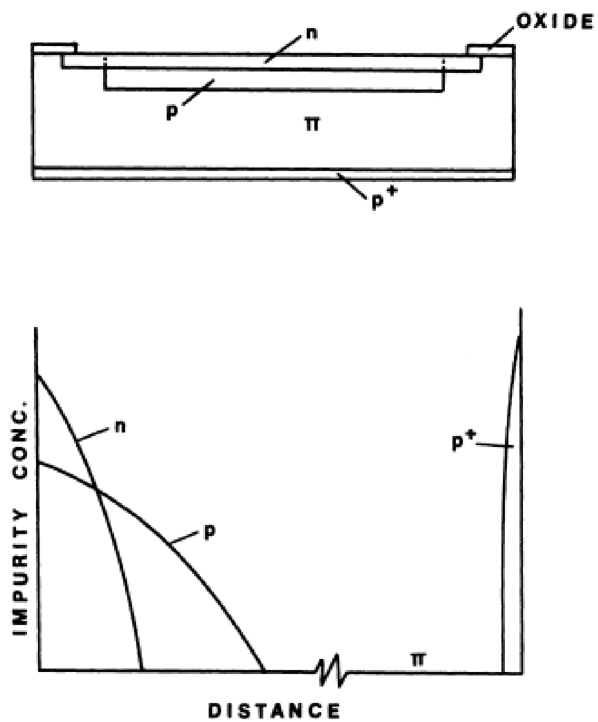


Fig. 1 - Reach-through avalanche diode structure and impurity concentration profile. The starting material is p-type silicon of about 5000 ohm-cm, resistivity. The p and n diffusions are, respectively, boron and phosphorus.

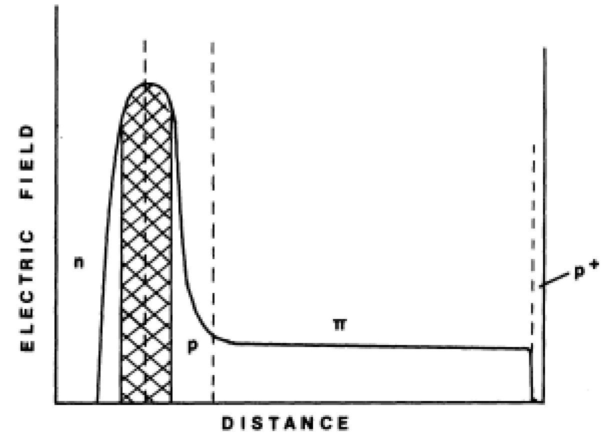
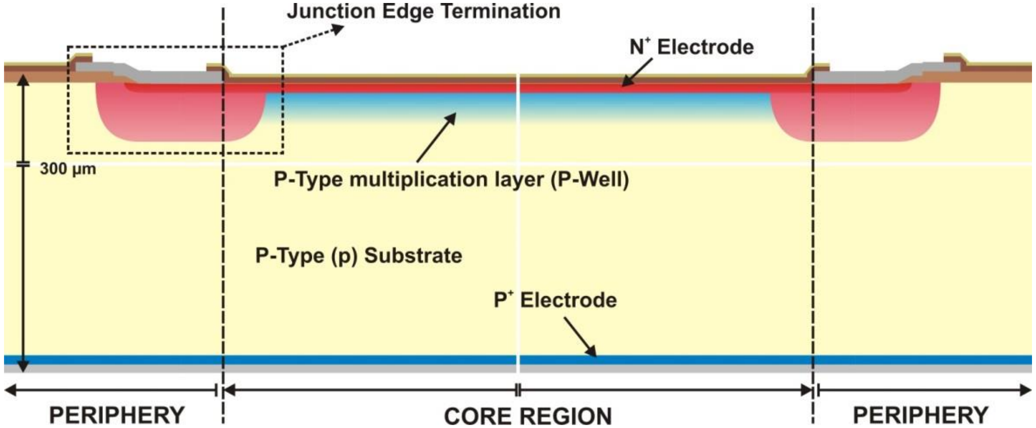


Fig. 2 - Electric field profile for a reach-through avalanche diode.

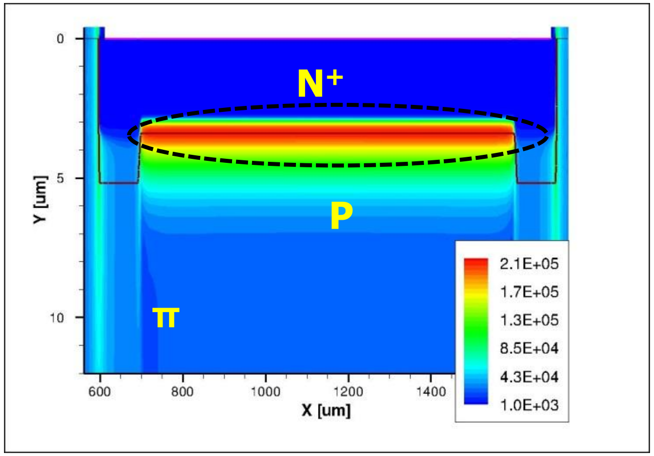
High electric field to trigger the production of secondary carriers by impact ionization.

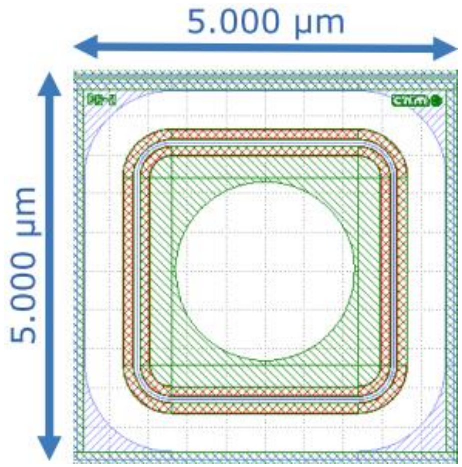
Low Gain Avalanche Detectors 101 (2)

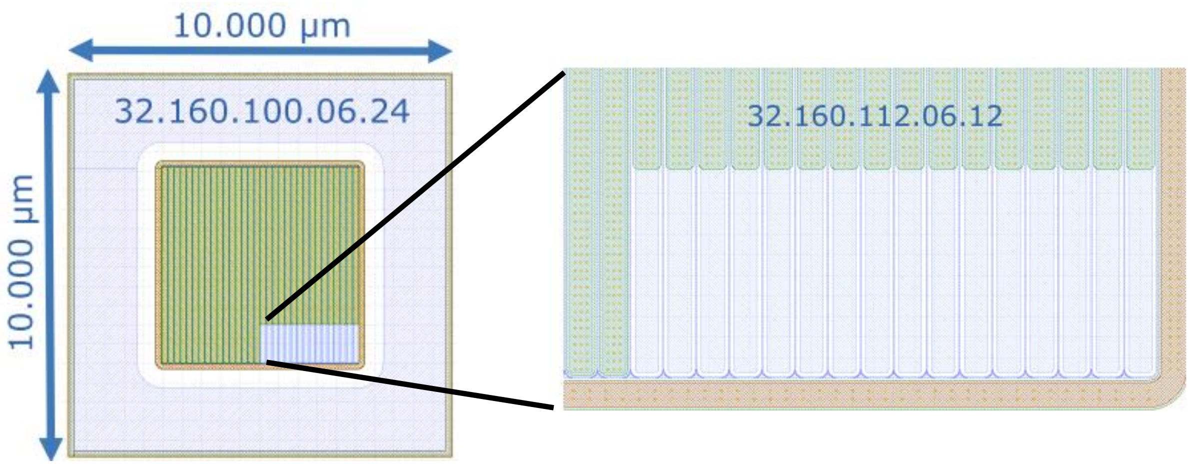
Implementation @ IMB-CNM as pad and microstrips



Electric Field @ 400 V

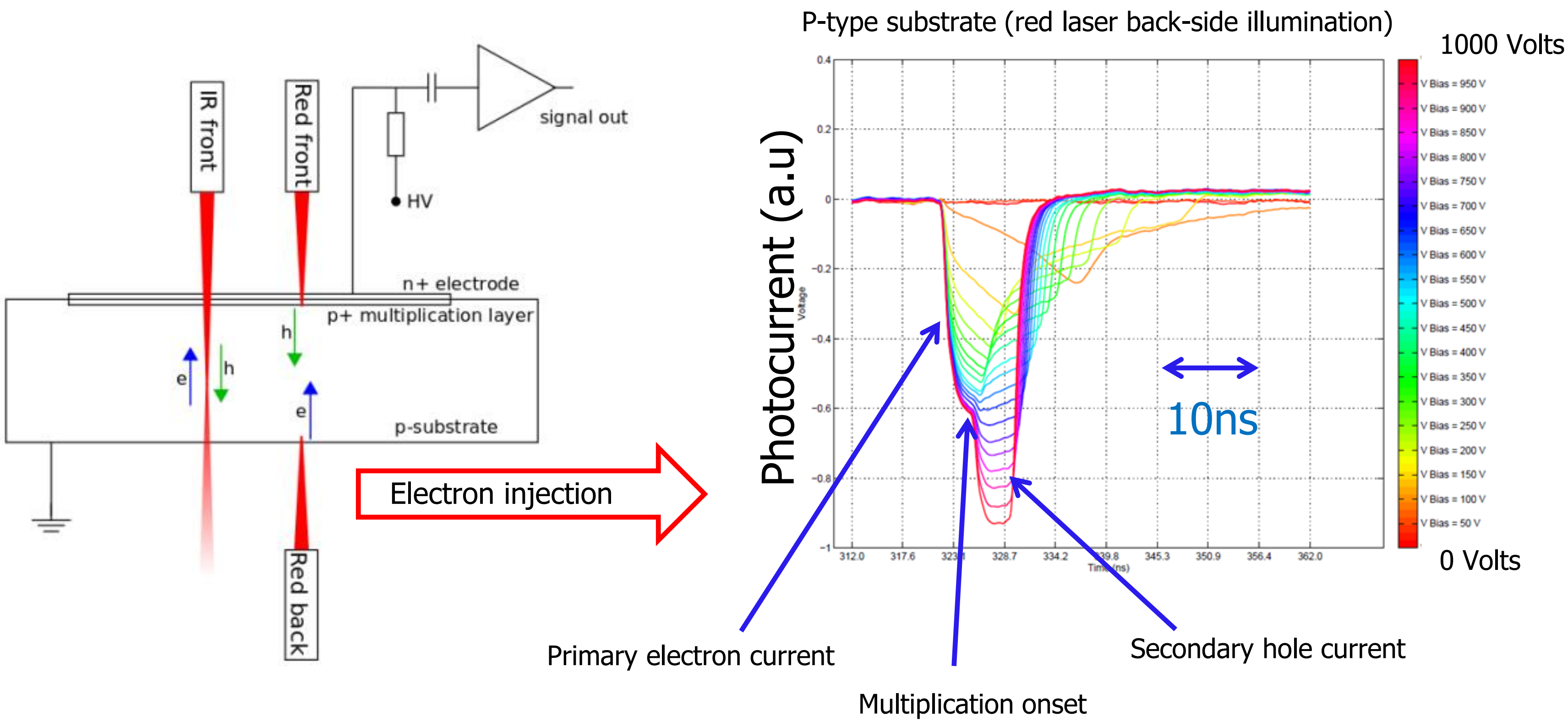






Charge multiplication in pad LGAD

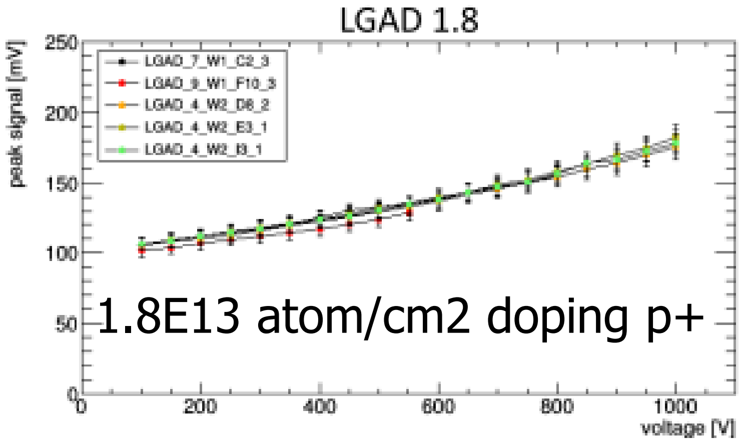
– Time-resolved photo-current generated by low penetration depth (670nm, red) picosecond laser pulses (TCT technique) shows a clear charge multiplication footprint.

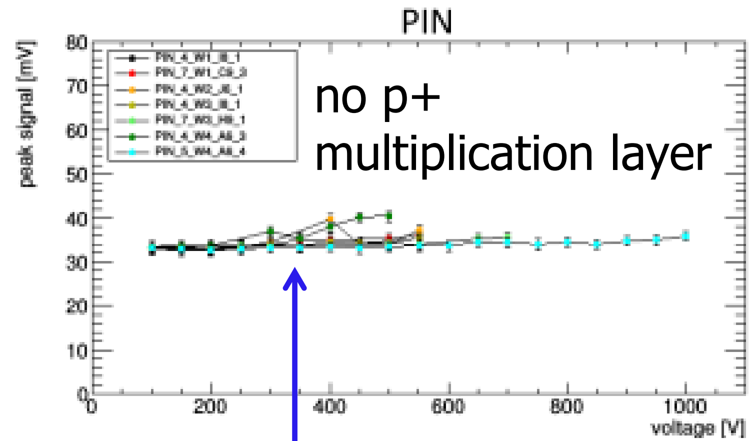


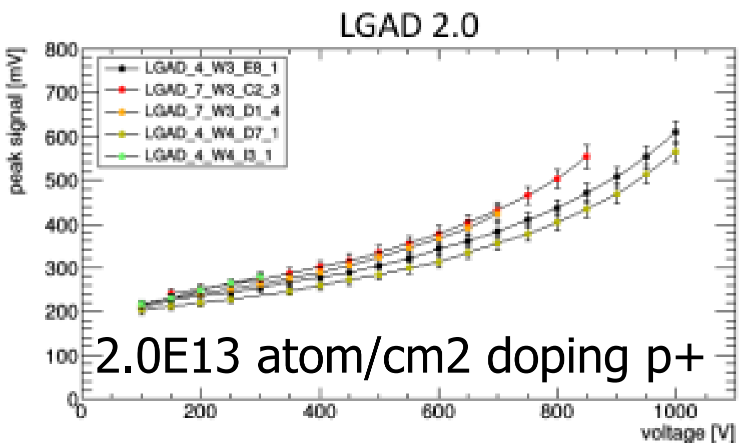
Charge multiplication in Pad LGAD(2)

Collected charge vs voltage

Sr90 radioactive source + CSA

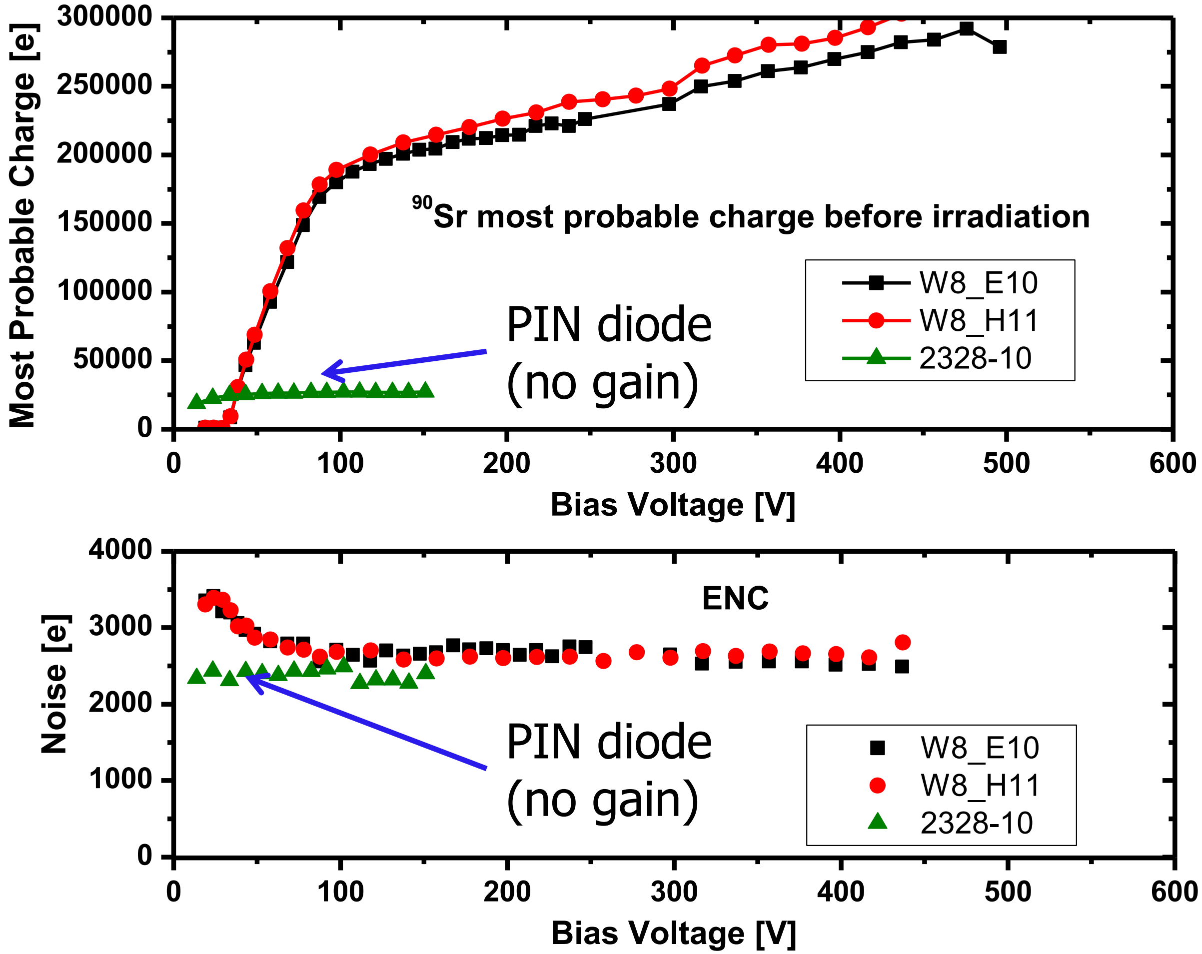






- Reference signal in PIN diode
  - About 34mV
- Gain in LGAD1.8
  - 200V -> about 3.2
  - 1000V -> about 5.3
- Gain in LGAD2.0
  - 200V → about 7.3
  - 1000V → about 17.6

Excess noise in pad LGAD.



90Sr Setup (done at JSI):

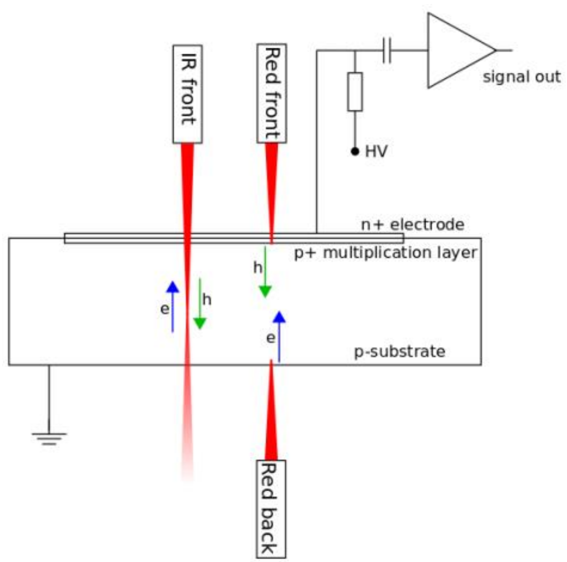
Measuring absolute charge collection for MIP with LHC-type electronics.

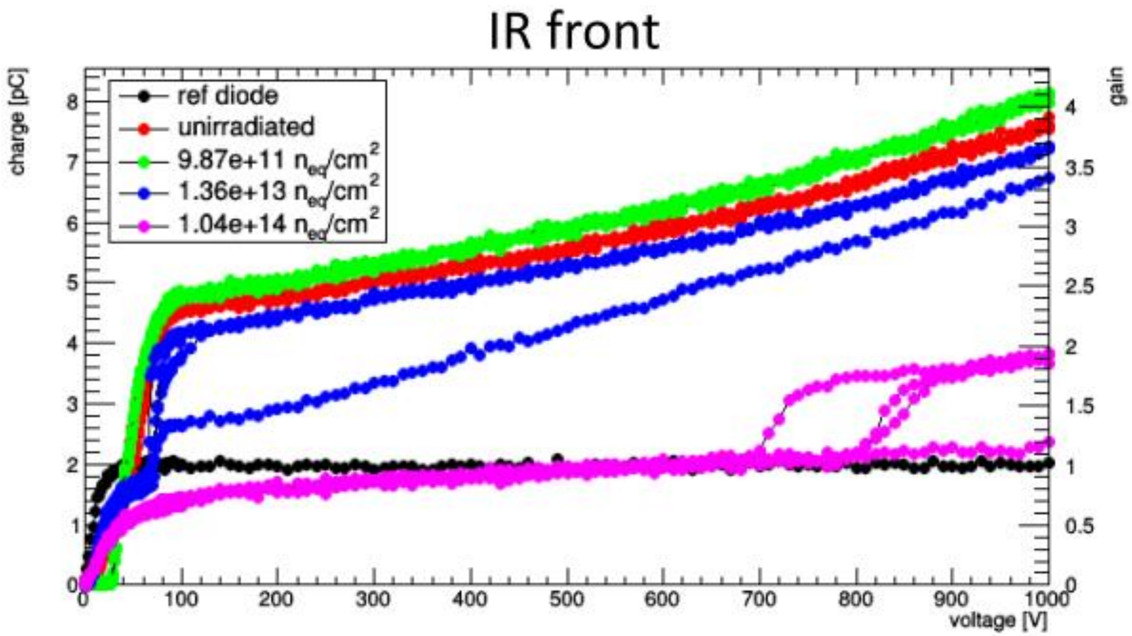
Improvement of signal for a **factor 8** at 300 V before irradiation

No significant increase of noise – dominated by series noise

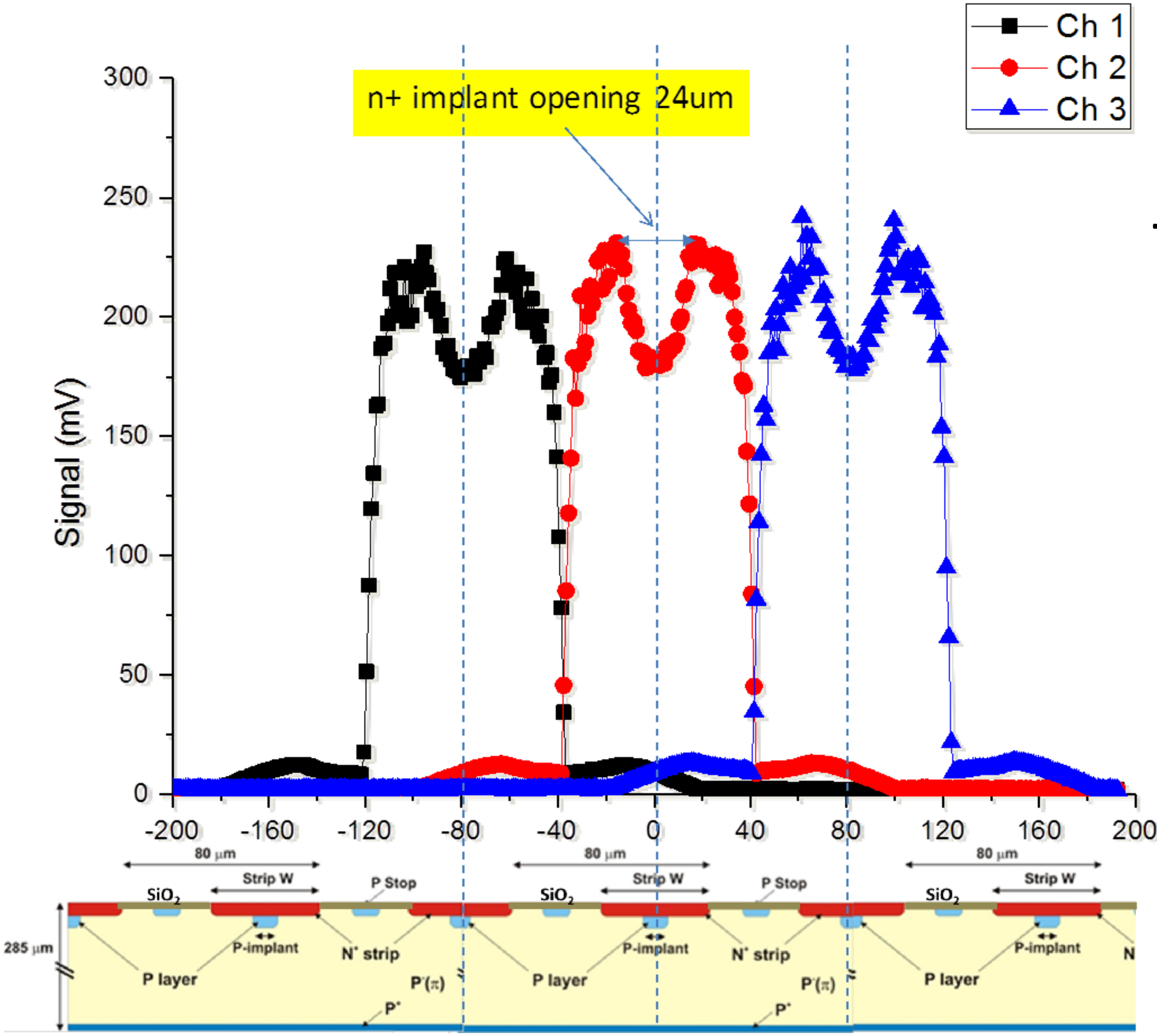
Pad LGAD radiation tolerance (neutrons)

– Neutron radiation tolerance assessment with IR laser measurement (gamma campaign in preparation).
– No gain degradation observed up to 1E13 n_{eq}/cm^2





ustrip PIN: Laser transversal scan



PIN structure no p++ layer

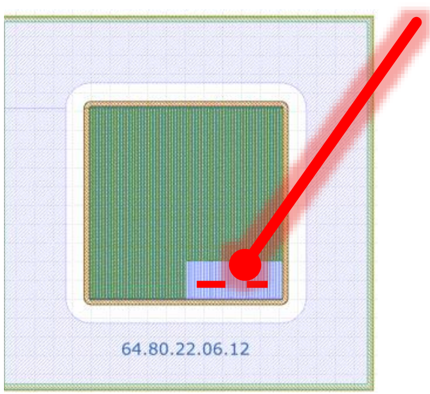
TCT Basic Information:

100 V

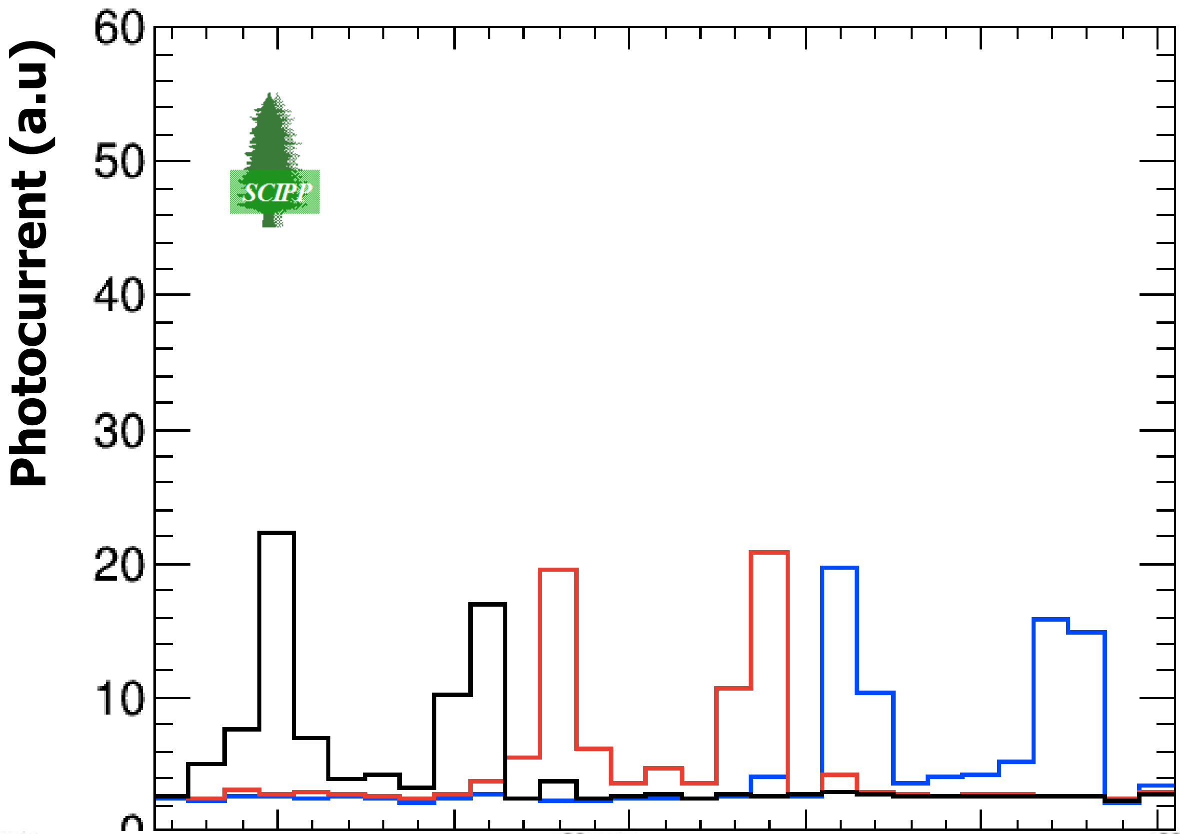
Red Laser from **Top**

All 3 Channels Connected to CSA

Strips **Without Metal**

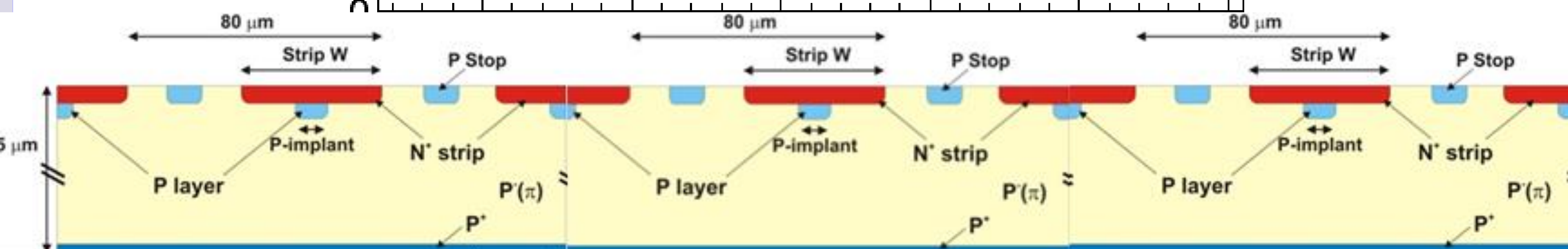


ustrip LGAD: Transversal Red laser scan

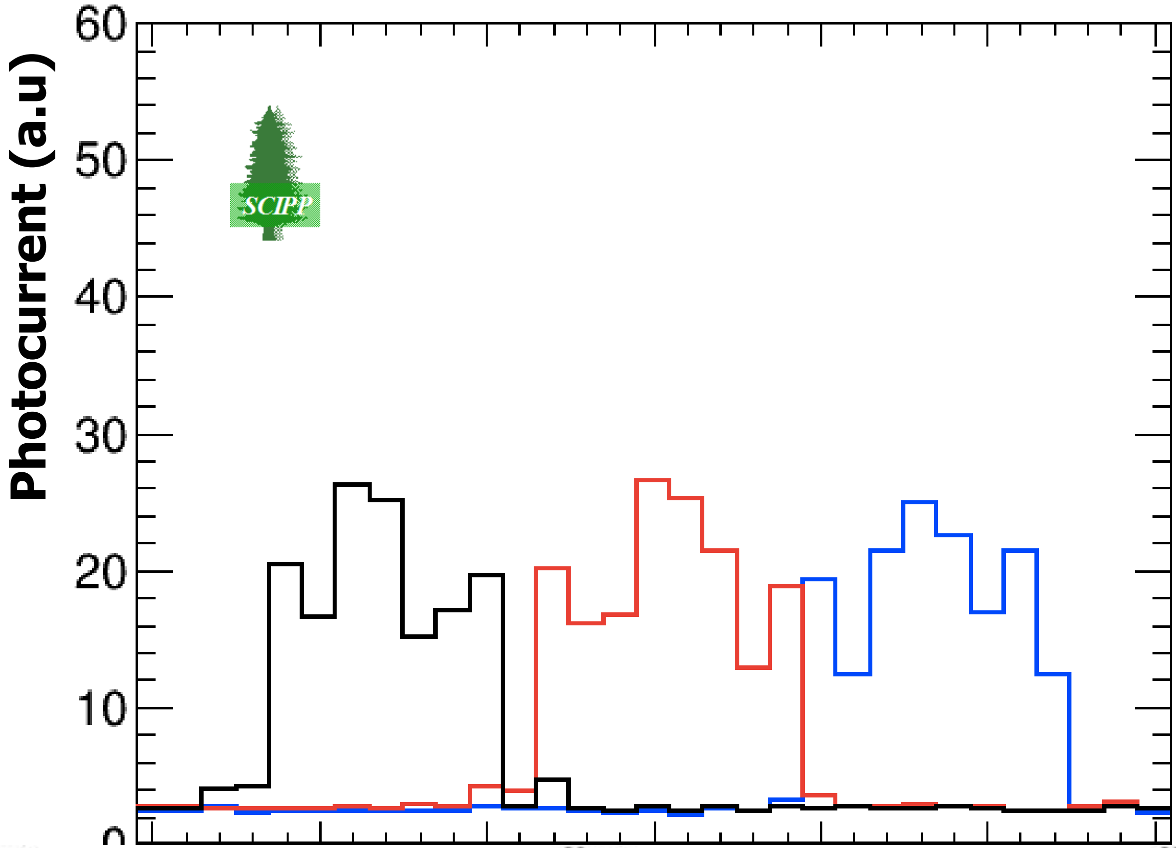


Vbias
50 V

Small signal
Drop at center of the strip (n++ doping)

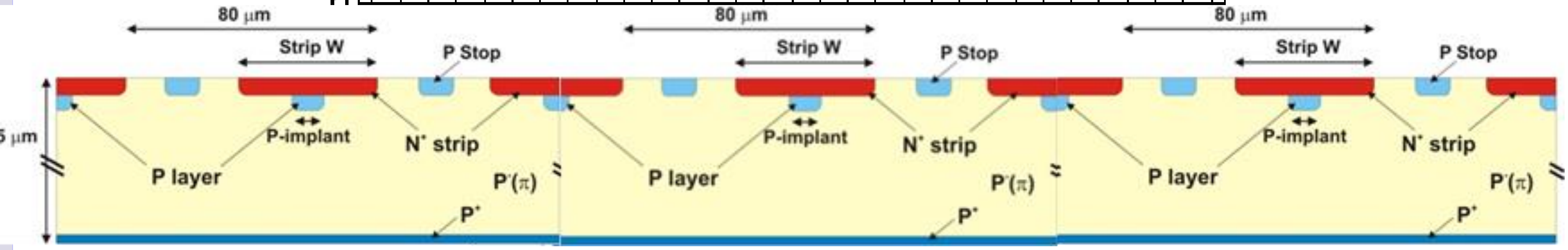


ustrip LGAD: Transversal Red laser scan

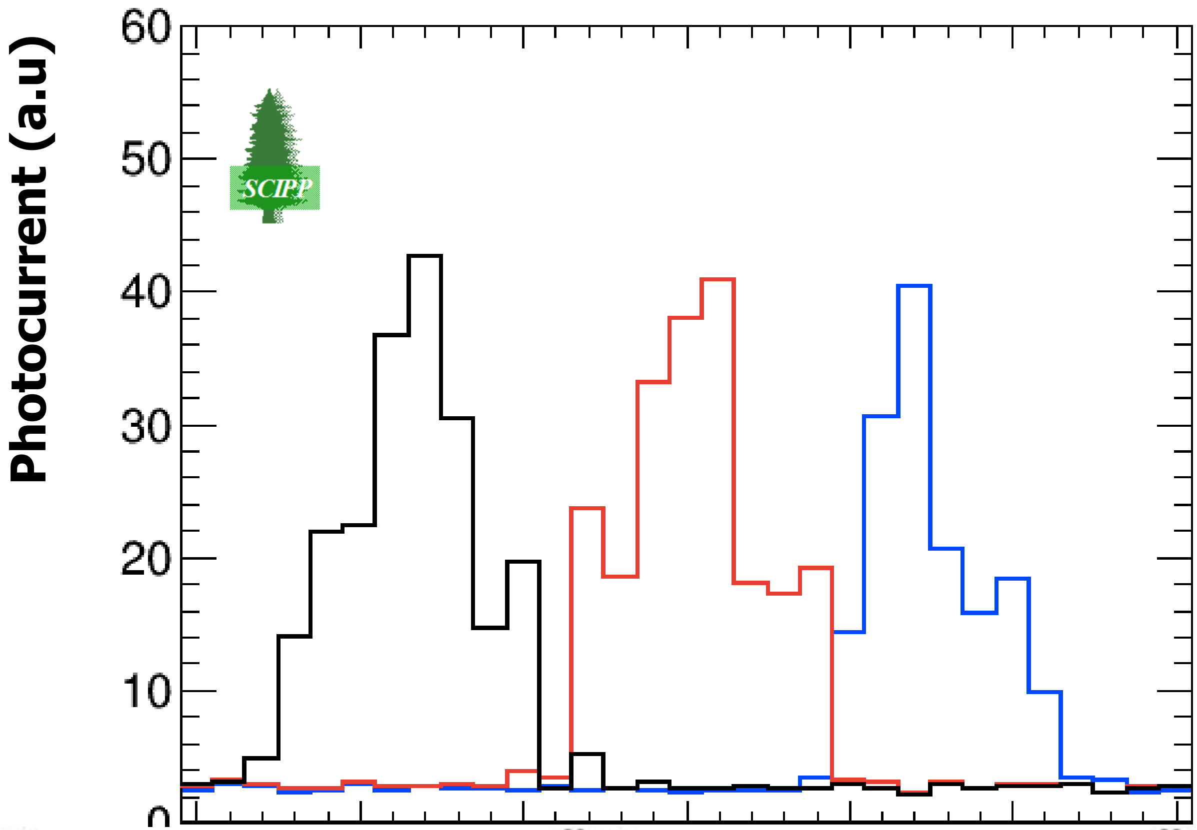


Vbias
100 V

Clear signal at center of the strip (multiplication layer)



ustrip LGAD: Transversal Red laser scan



Vbias
150 V

Larger signal at center of the strip (multiplication layer)