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Institut des Nanotechnologies de Lyon UMR 5270

New developments on Avalanche Pixels and R&D results

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Outline

- Avalanche Pixel concept
- Development
- Characterization
- Ongoing work

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➢ **Avalanche Pixel concept**

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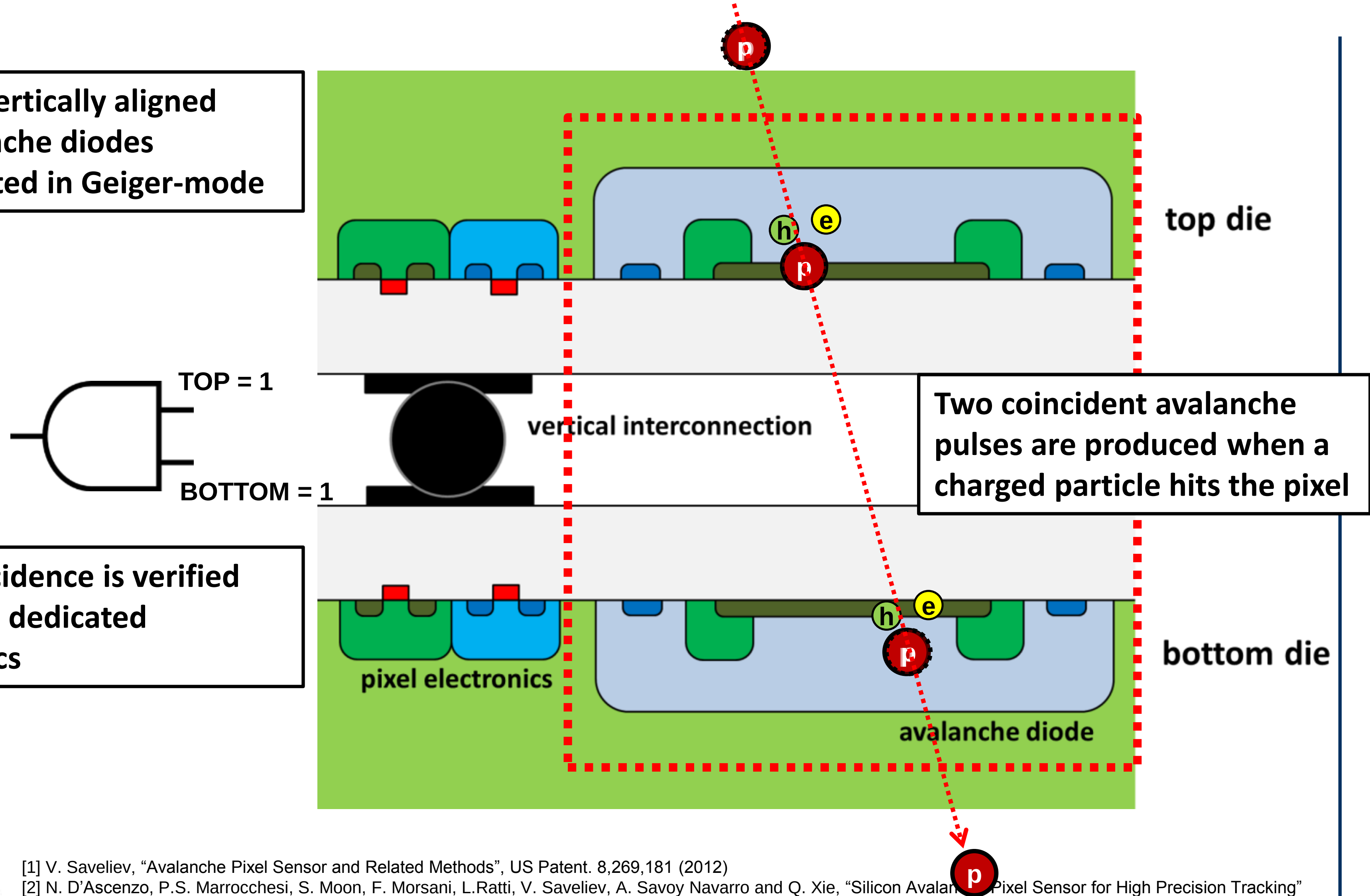
Introduction

A novel 3D pixelated detector suitable for particle tracking and imaging

Two vertically aligned avalanche diodes operated in Geiger-mode



Two coincident avalanche pulses are produced when a charged particle hits the pixel

The coincidence is verified thanks to dedicated electronics

[1] V. Saveliev, "Avalanche Pixel Sensor and Related Methods", US Patent. 8,269,181 (2012)
[2] N. D'Ascenzo, P.S. Marrocchesi, S. Moon, F. Morsani, L.Ratti, V. Saveliev, A. Savoy Navarro and Q. Xie, "Silicon Avalanche Pixel Sensor for High Precision Tracking" 13th Topical Seminar on Innovative Particle and Radiation Detectors IPRD13

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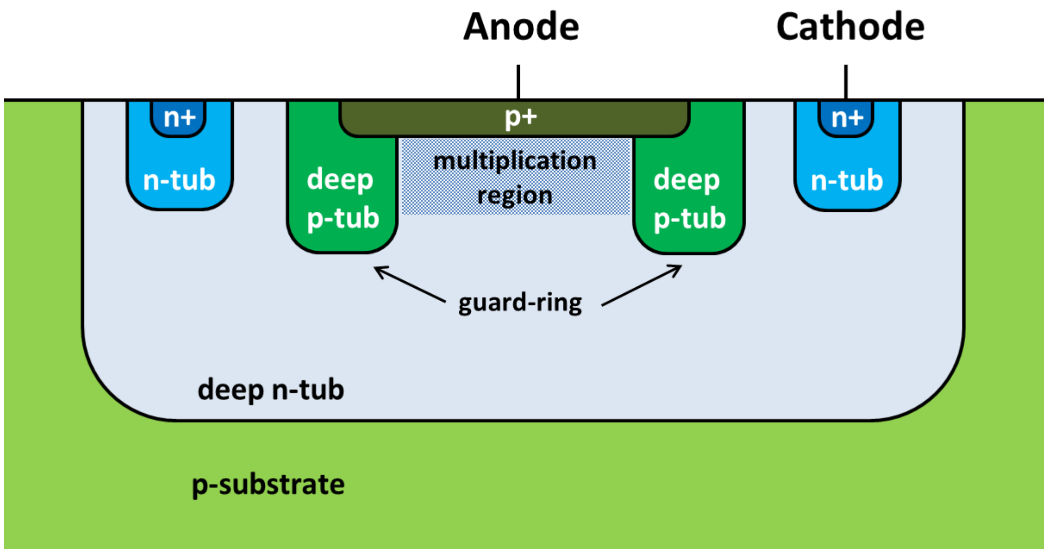
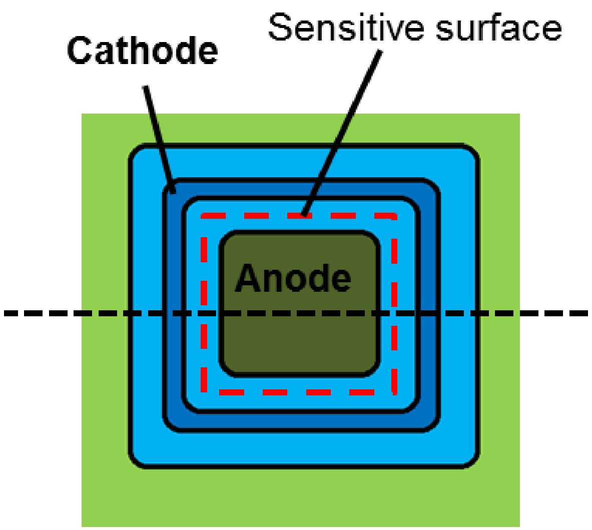
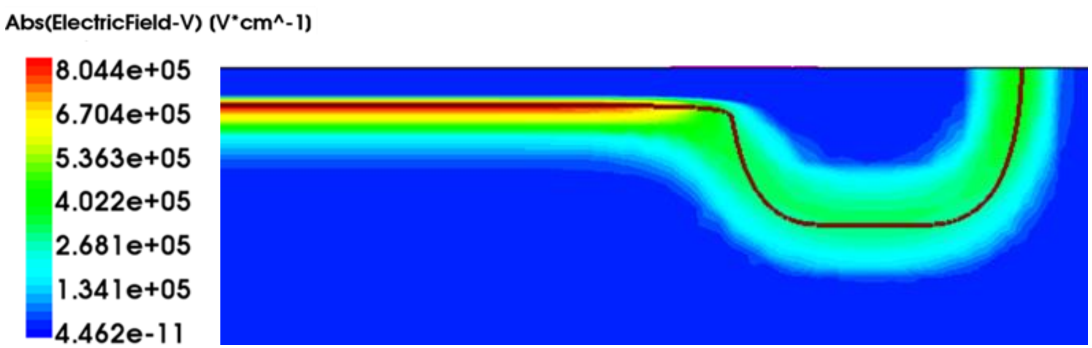
Design of the avalanche diode

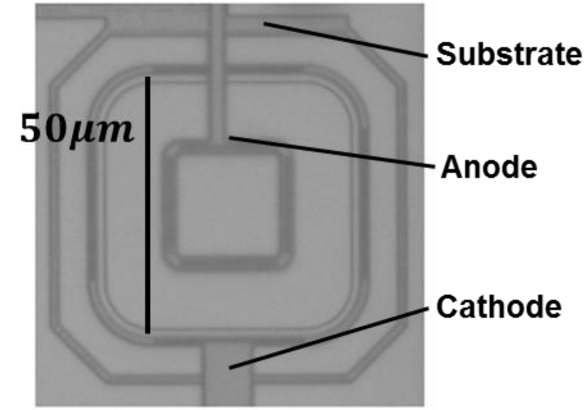
AMS HV-CMOS 0,35µm technology







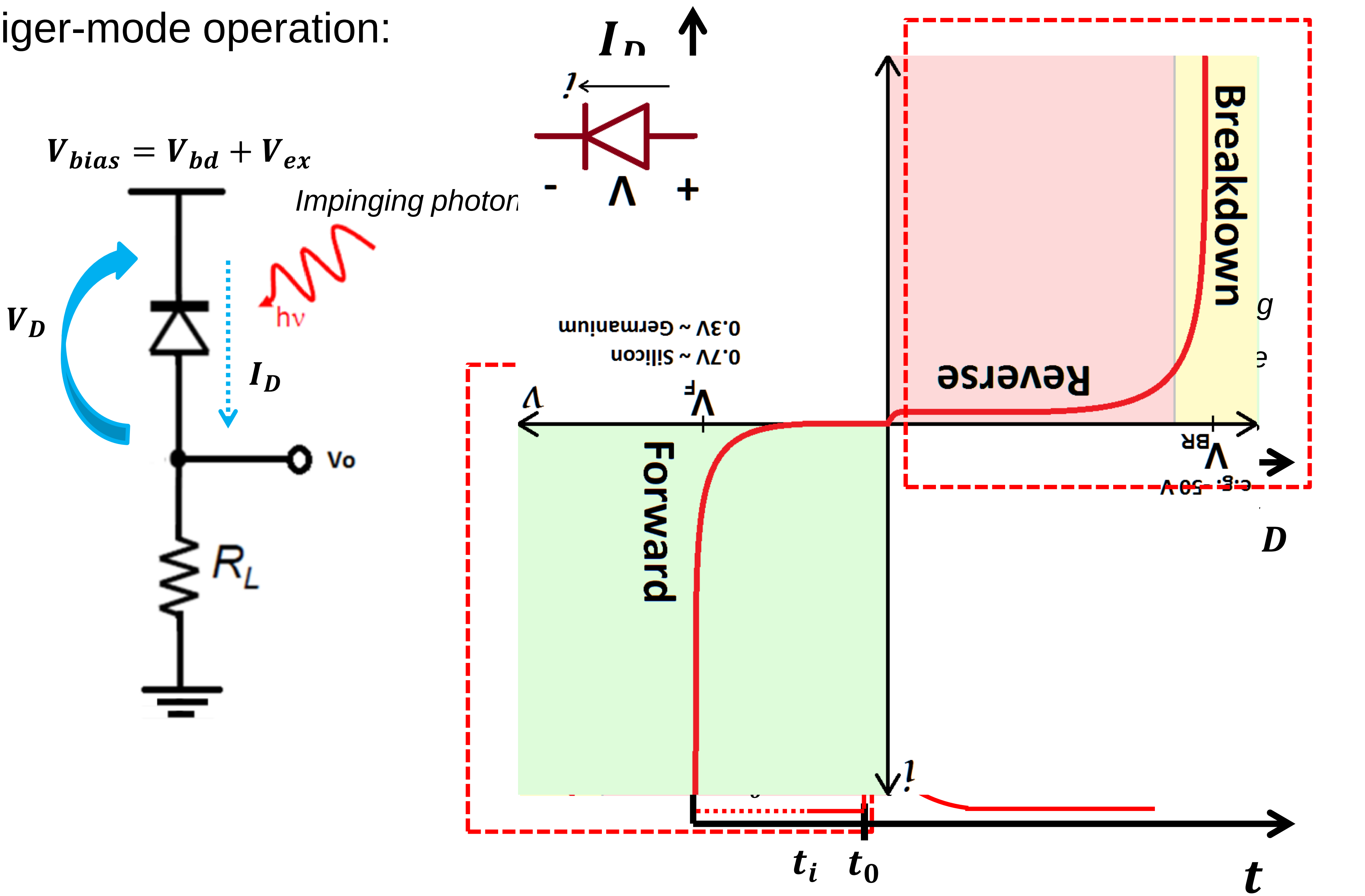
Premature edge breakdown (PEB) prevention



Design of the pixel electronics for Geiger-mode

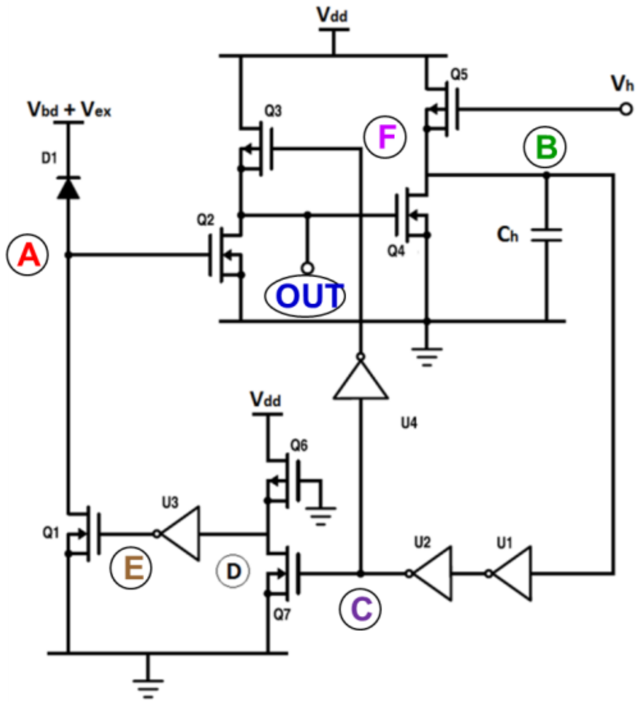
Geiger-mode operation:

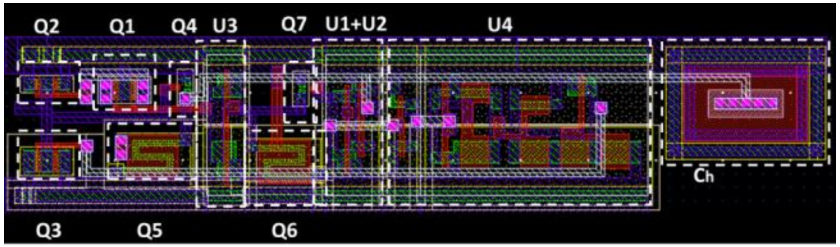
$$V_{bias} = V_{bd} + V_{ex}$$



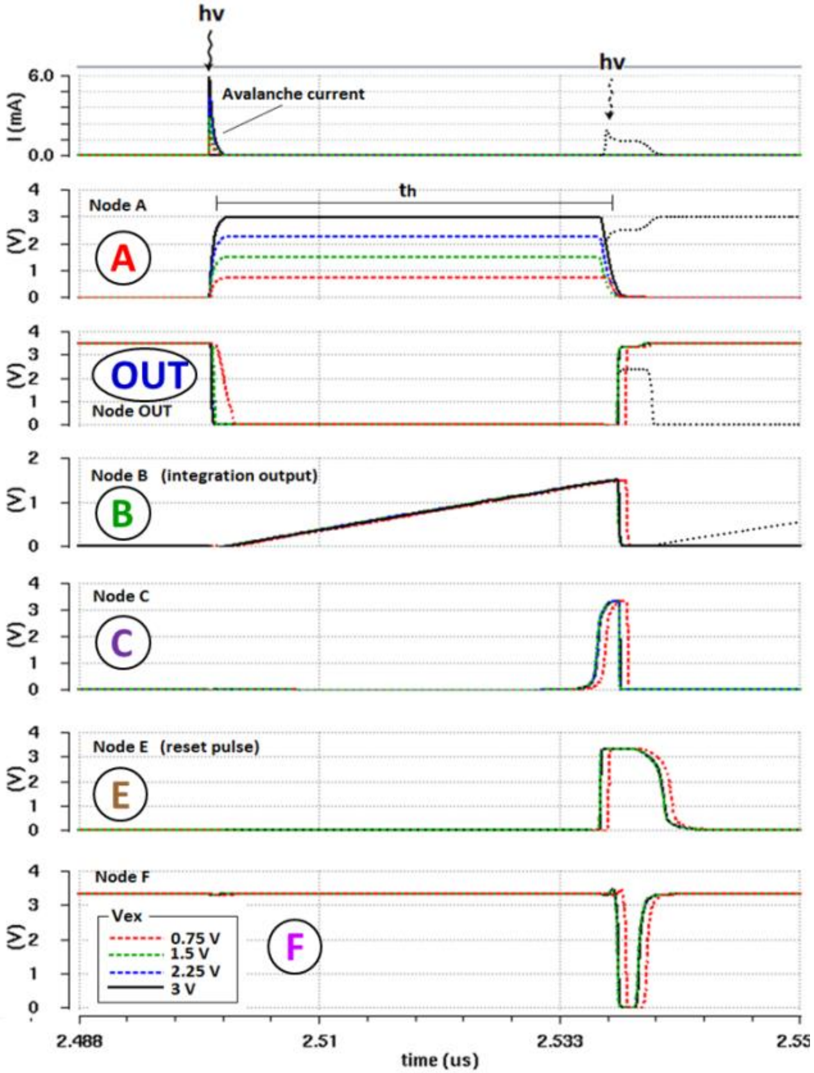
Design of the pixel electronics – 2D level

A time integration-based passive quench - active recharge circuit

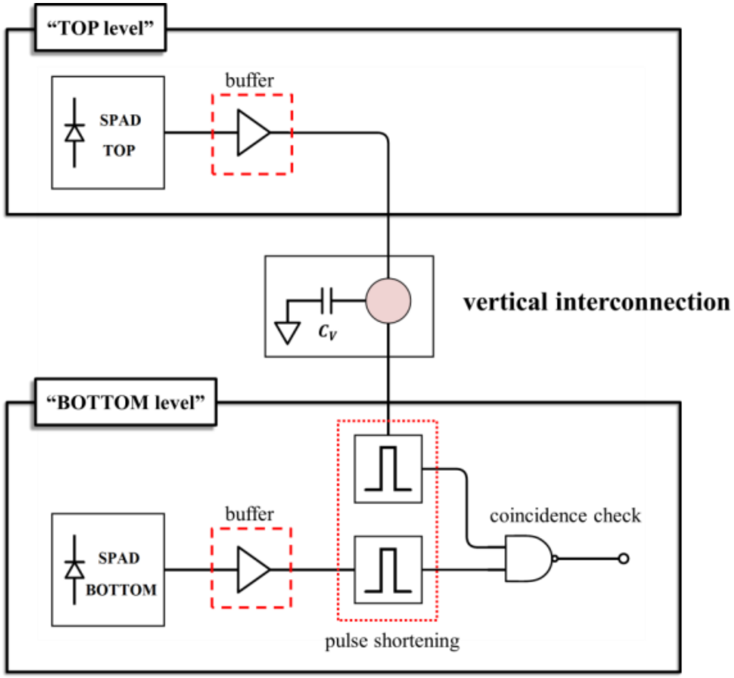


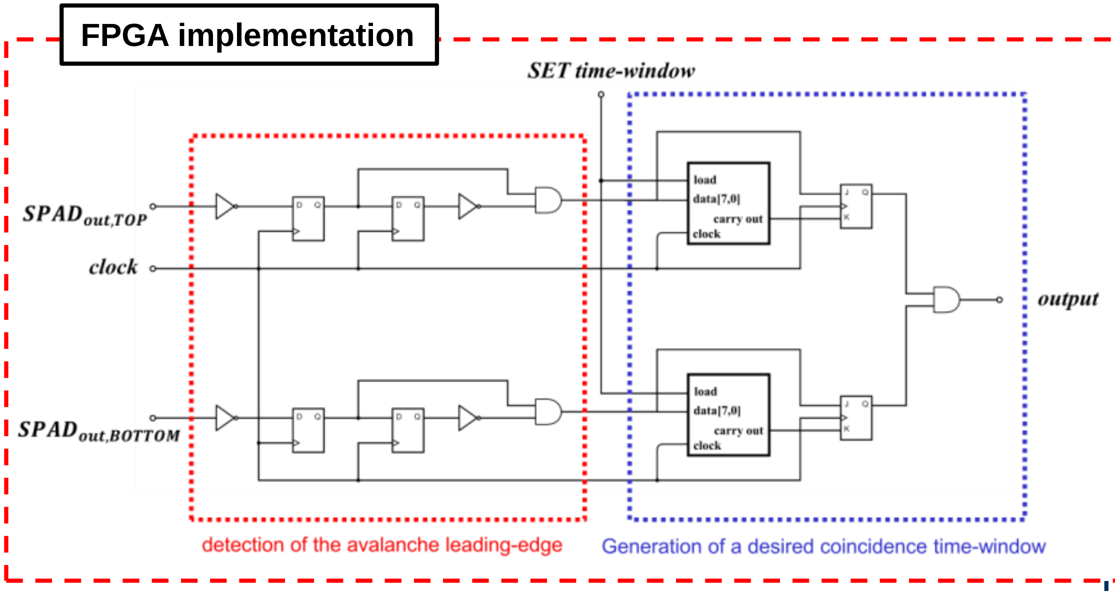


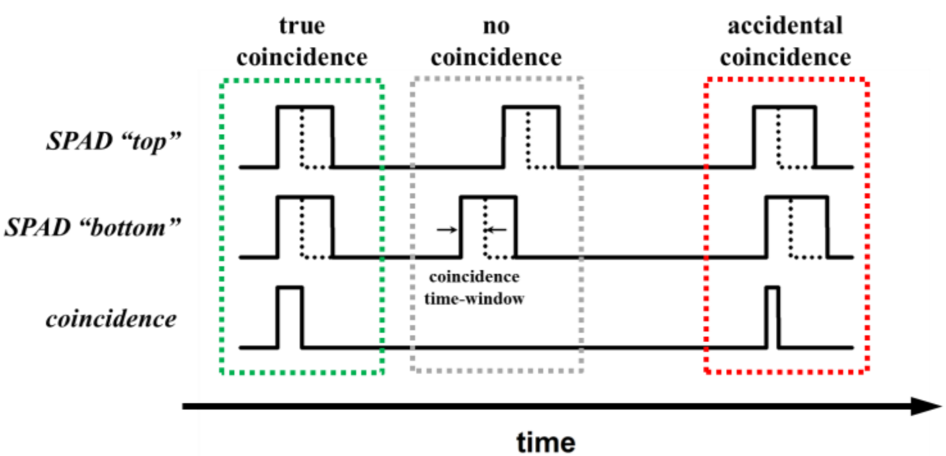
Vignetti M. et al "A time-integration based quenching circuit for Geiger-mode avalanche diodes" 13th IEEE International New Circuits and Systems Conference (NEWCAS 2015) June 7-10, 2015 Grenoble, France (2015)

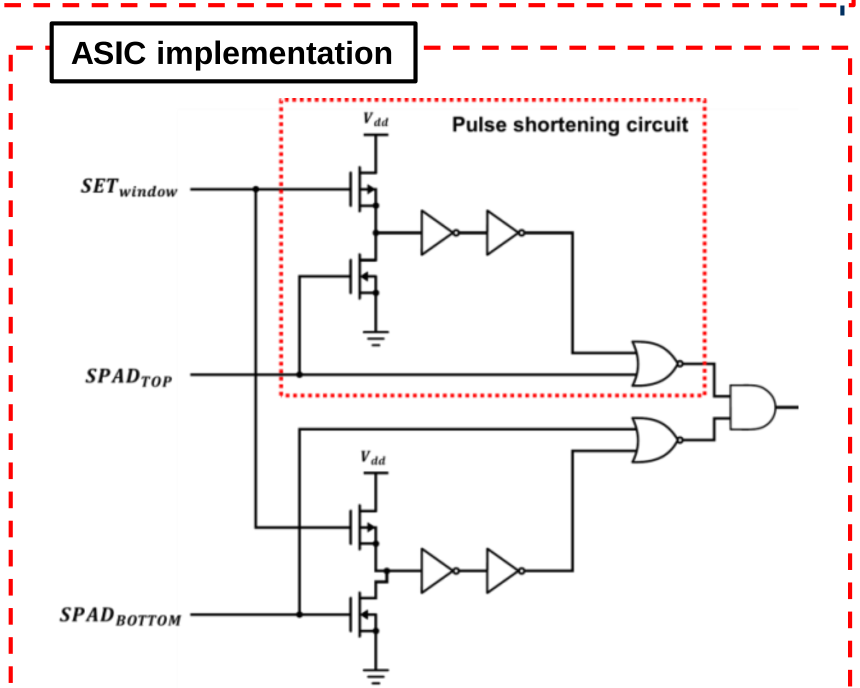


Design of the pixel electronics – 3D level

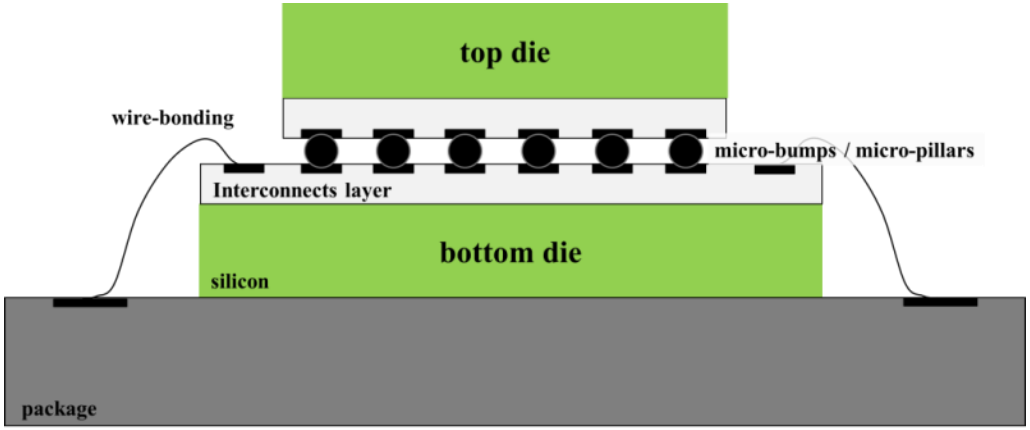








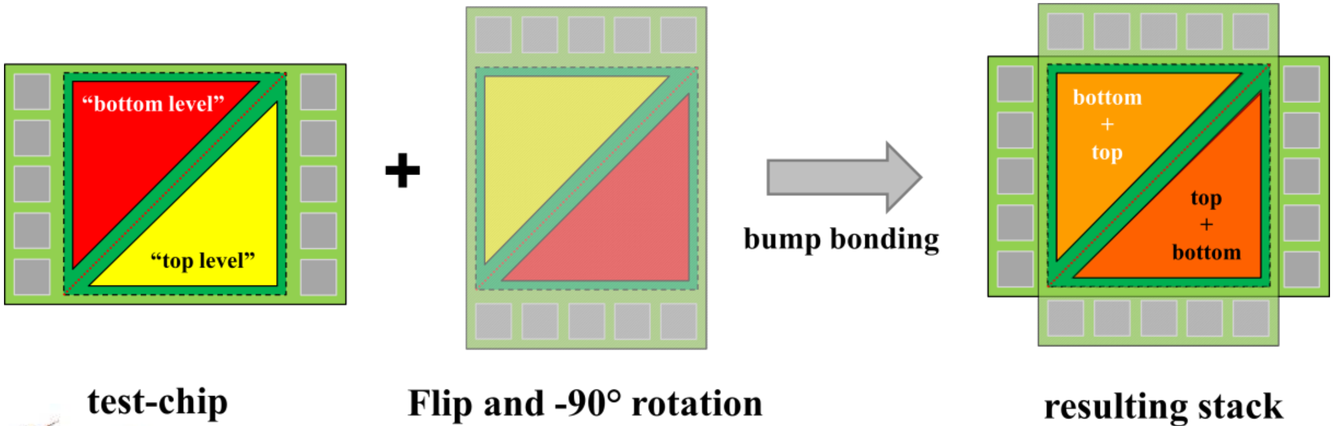
3D vertical stacking: flip-chip assembly



Gold stud bump based assembly

- ☺ *Die-to-die assembly: **<u>not costly</u>***
- ☺ *Gold bumps deposition "by hand"*
- ☹ *Large bump diameter (70 um)*
- ☹ *Parasitics and low-degree of integration*

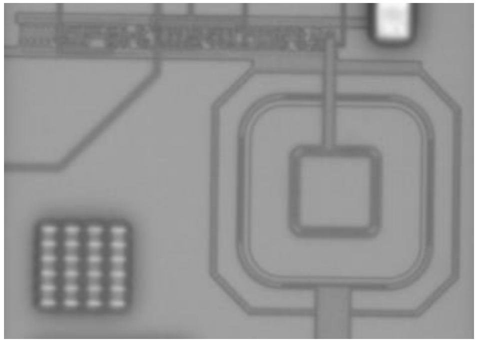
Assembling strategy: ***TOP level and BOTTOM level on the same test-chip***



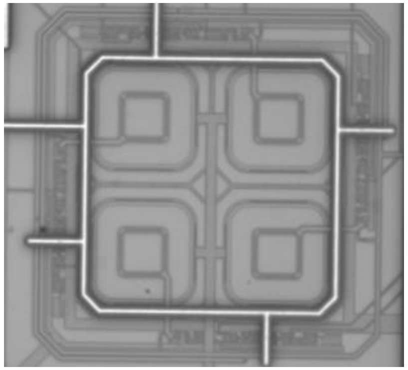
Only external PADs on BOTTOM die will be wire-bonded

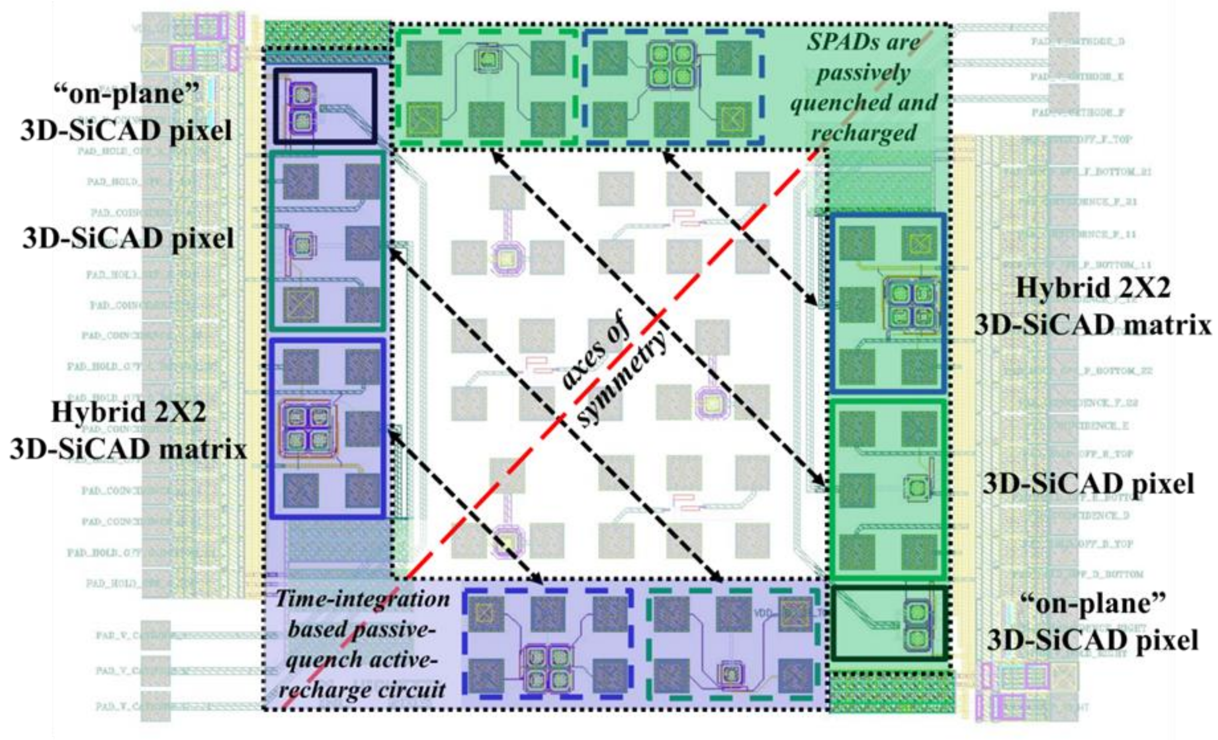
Tape-out: CMP run – AMS HV-CMOS 0,35um

3D pixels cells

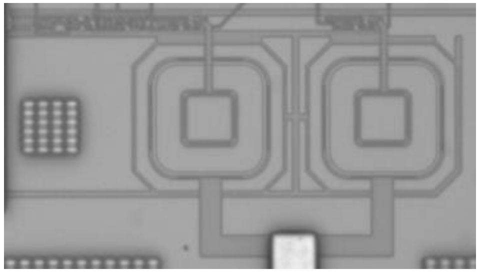


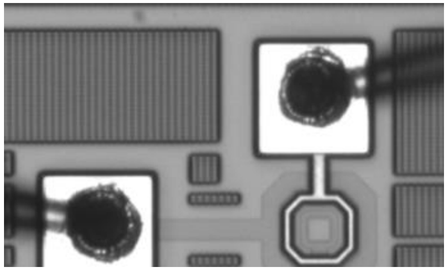
2x2 hybrid matrix cells





Test structures





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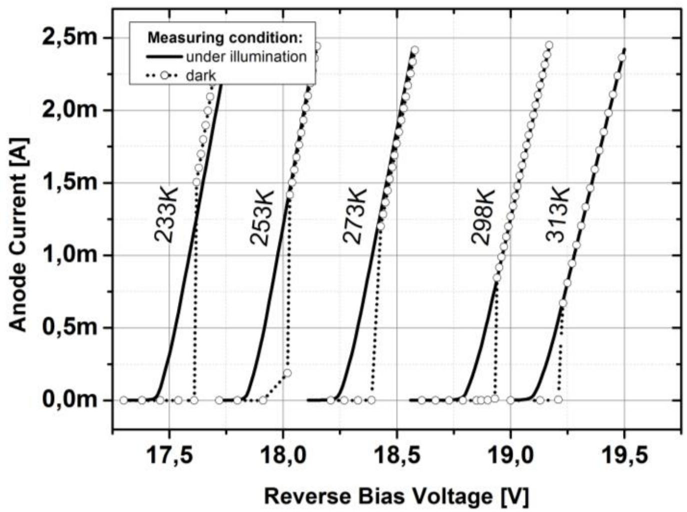
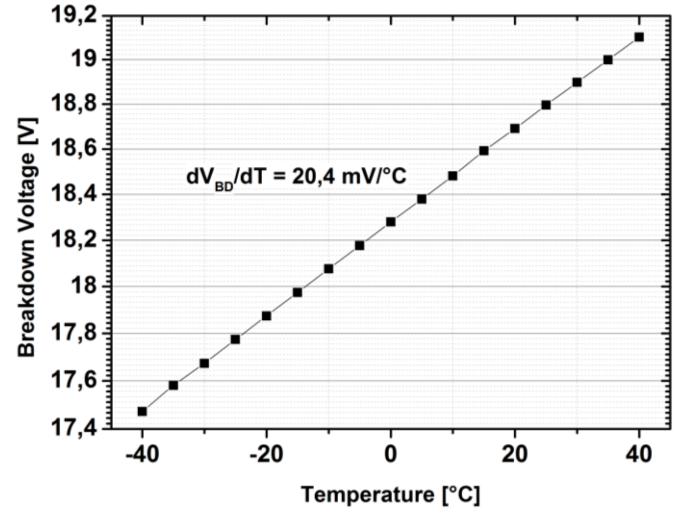
Characterization: avalanche diode validation

Breakdown voltage

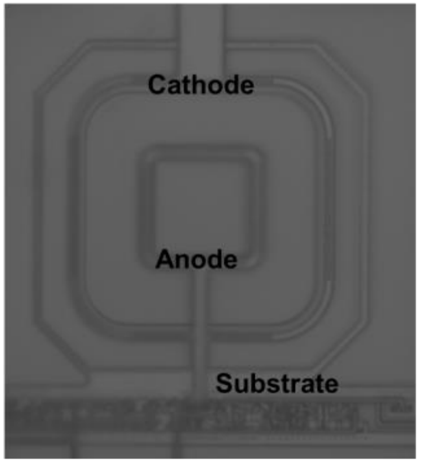


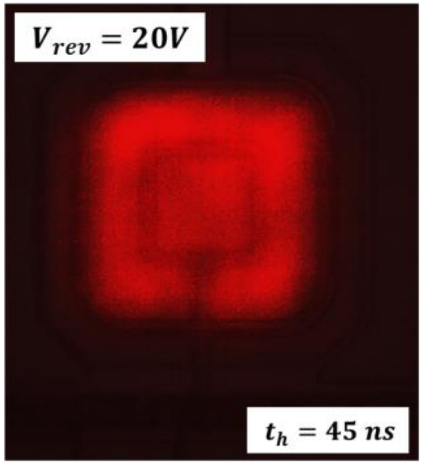


Luminescence imaging

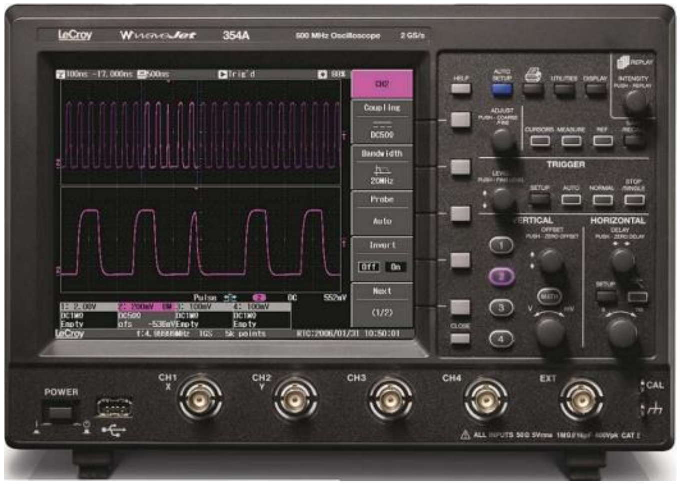
Breakdown bias in Si diodes is accompanied with light emission in the visible spectrum range

- *Uniform light emission picture is obtained: uniform electric field distribution all over the active area*
- *Dark "rings" over the diode active area are due to shadowing effect by the anode metal ring.*
- *No PEB observed*



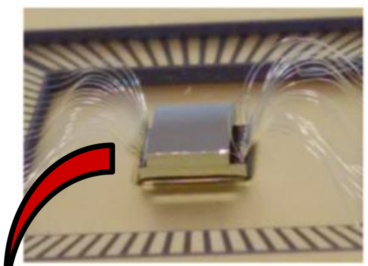


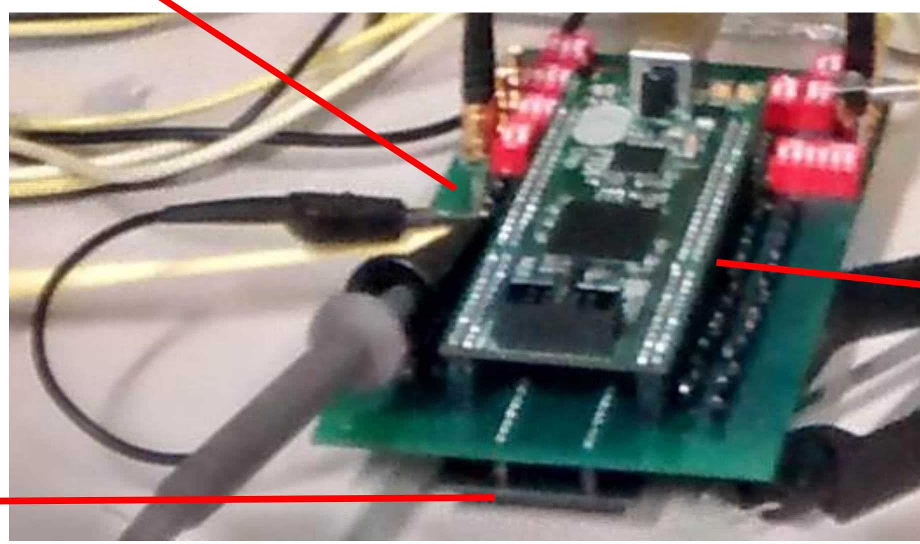
Characterization: geiger-mode operation

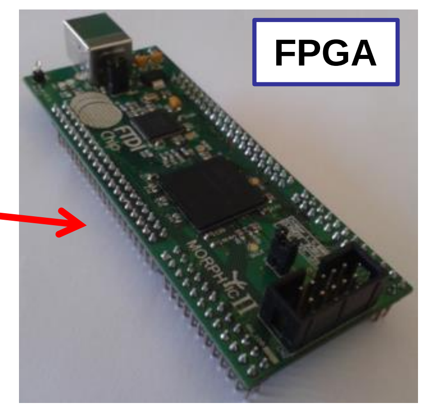


signal analysis

data acquisition
(via USB)



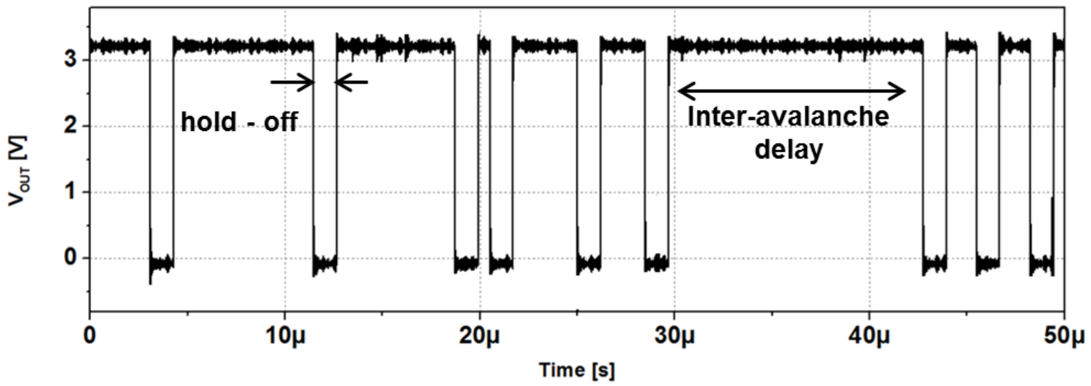


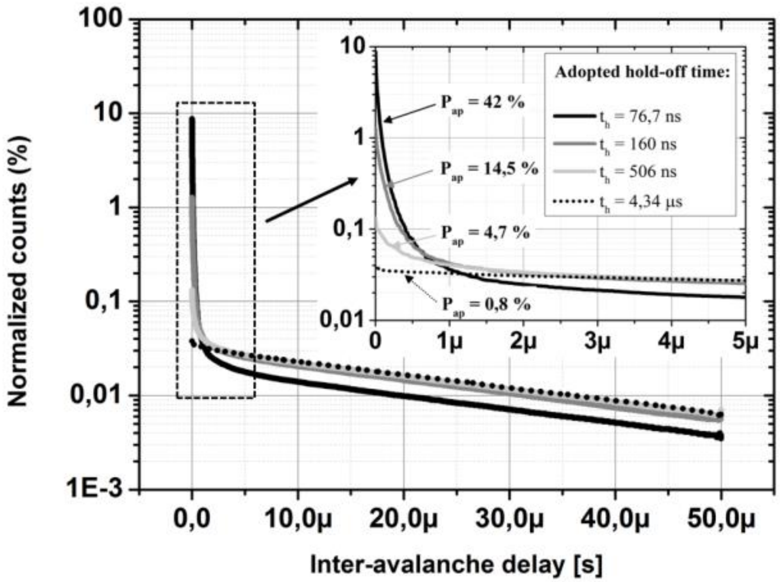


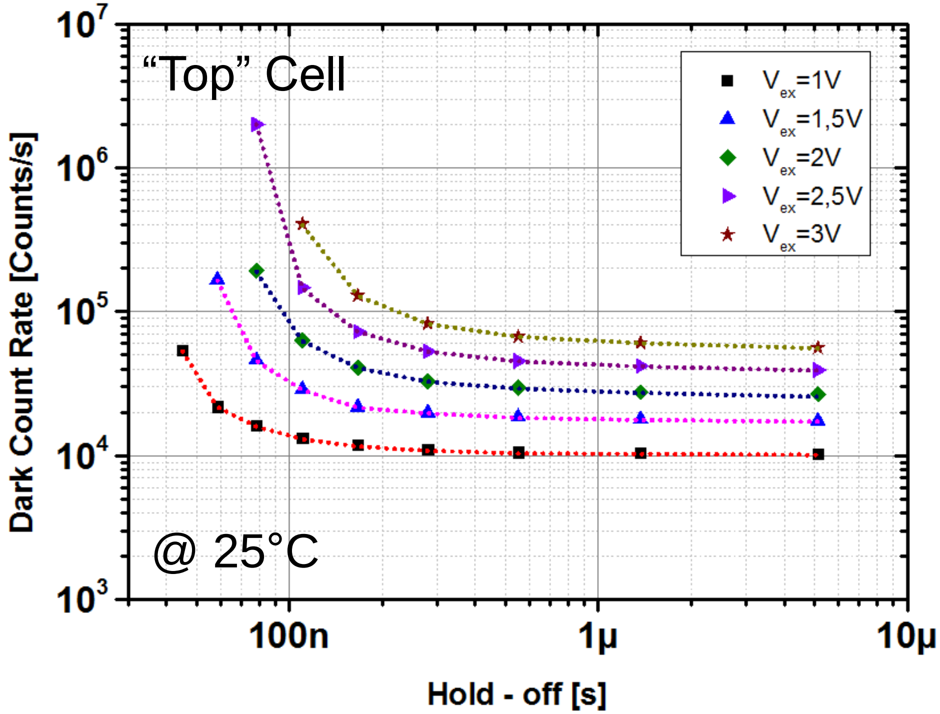
FPGA

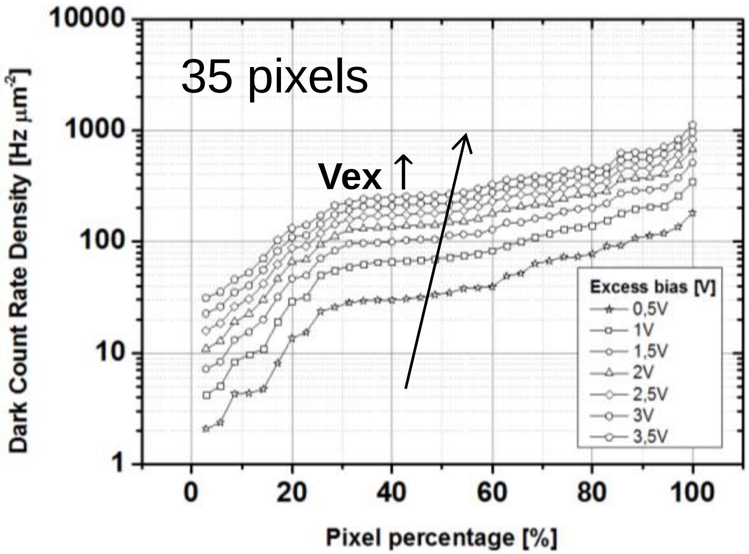
Daughter board

Characterization: DCR evaluation



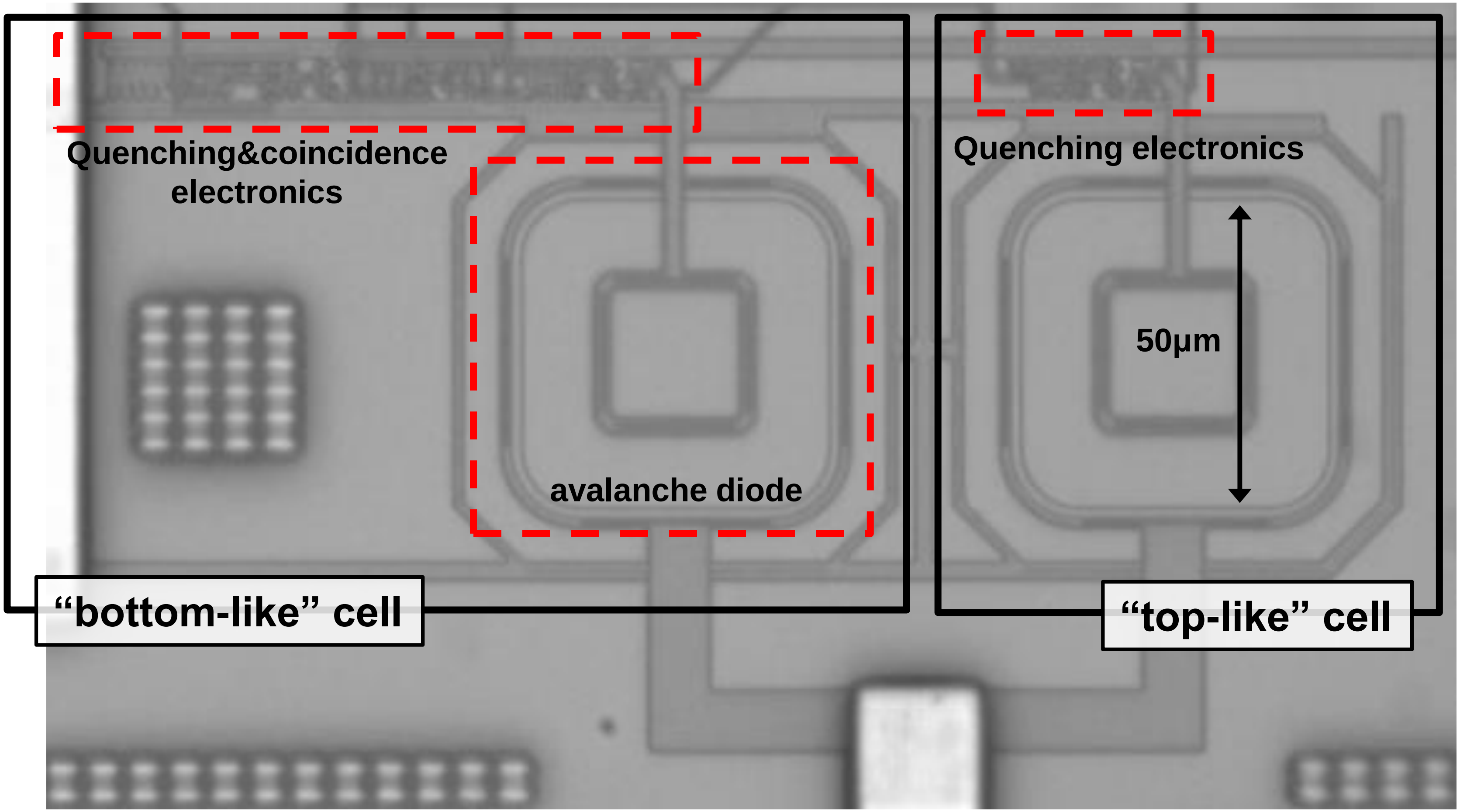






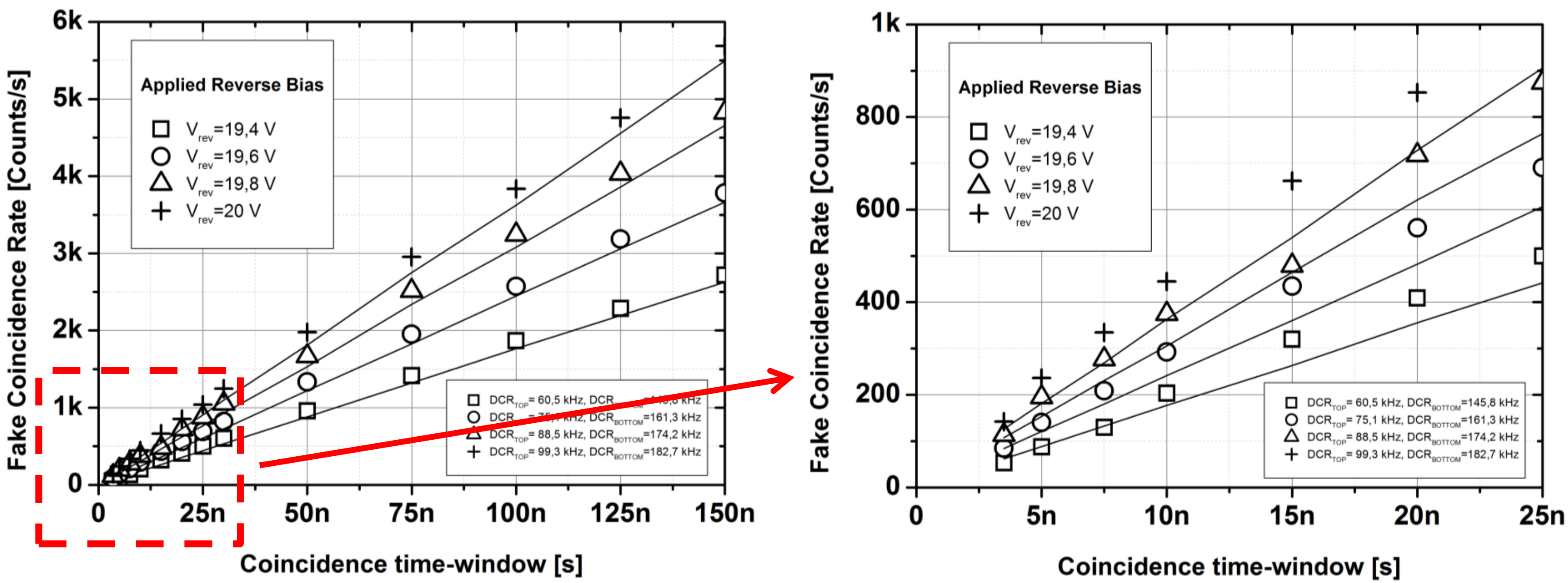
Characterization: on-plane coincidence

Check the coincidence between two adjacent SPAD pixel cells



Characterization: on-plane coincidence

Noise evaluation: Fake Coincidence Rate (**FCR**) via FPGA

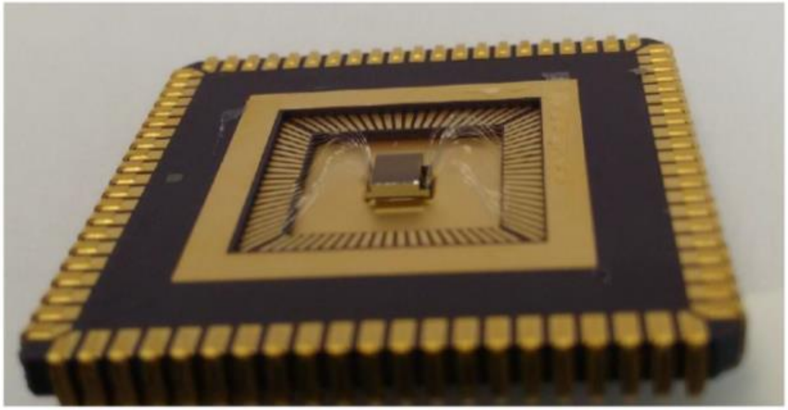


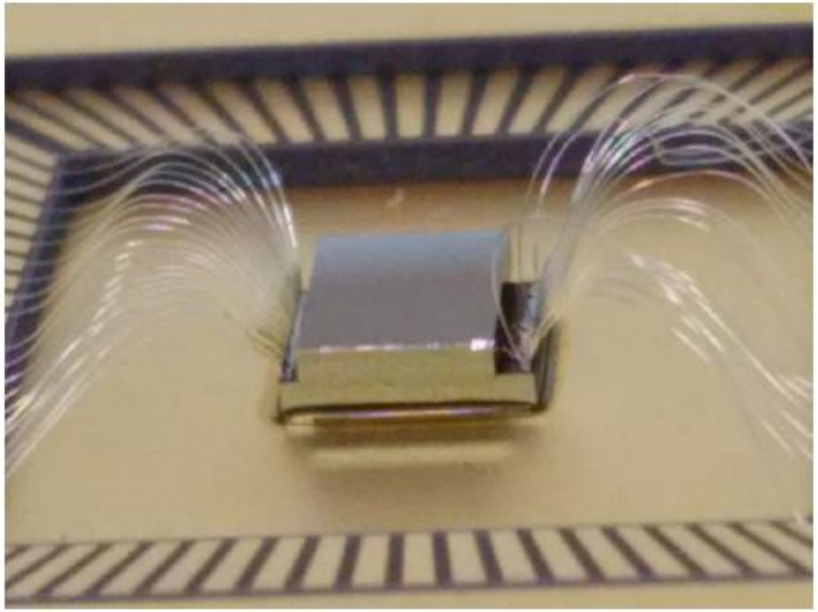
- □ DCR_{TOP}= 60,5 kHz, DCR_{BOTTOM}=145,8 kHz
- ○ DCR_{TOP}= 75,1 kHz, DCR_{BOTTOM}=161,3 kHz
- △ DCR_{TOP}= 88,5 kHz, DCR_{BOTTOM}=174,2 kHz
- + DCR_{TOP}= 99,3 kHz, DCR_{BOTTOM}=182,7 kHz

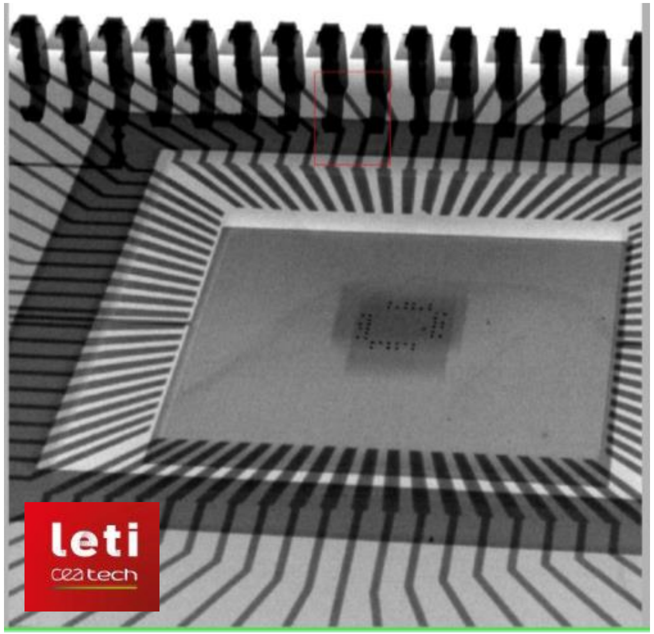
✓ Experimental data is in agreement with the predicted FCR

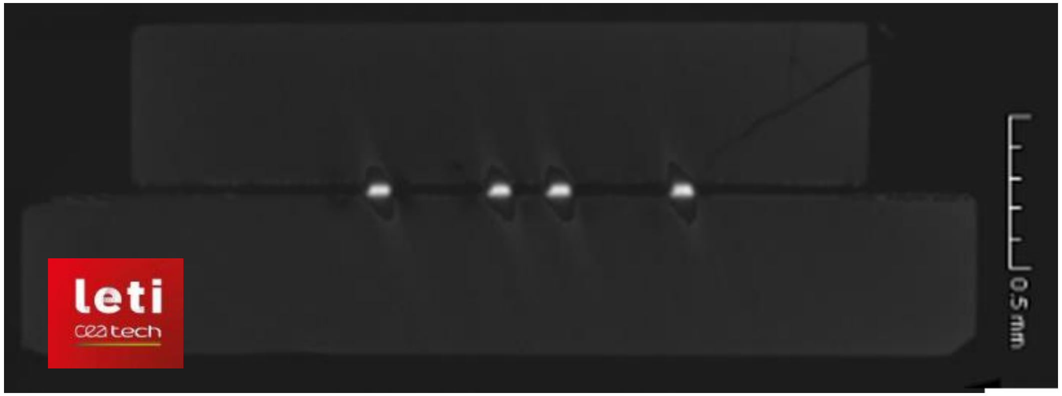
✓ NRF $\sim 10^3$ for small coincidence time-window

3D prototype at CEA-LETI and CIME nanotech



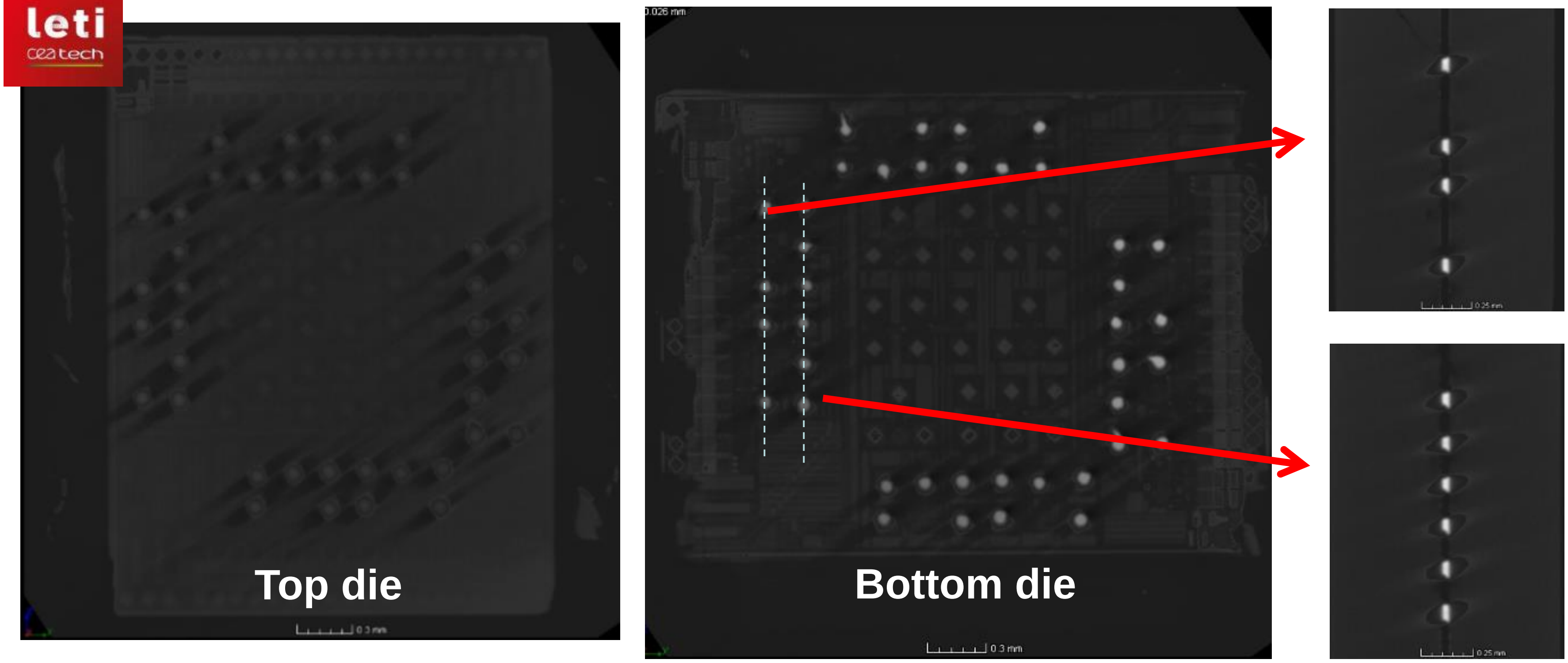






3D prototype at CEA-LETI and CIME nanotech

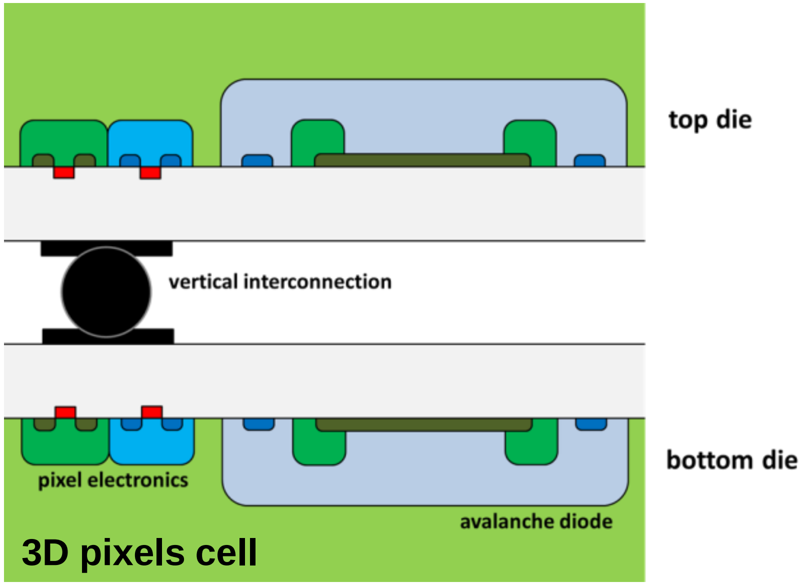
X-ray tomography of the assembled prototype

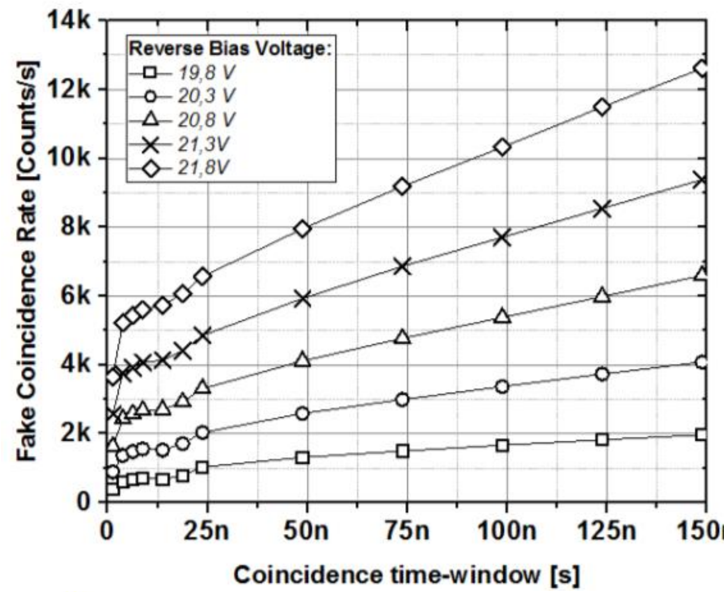


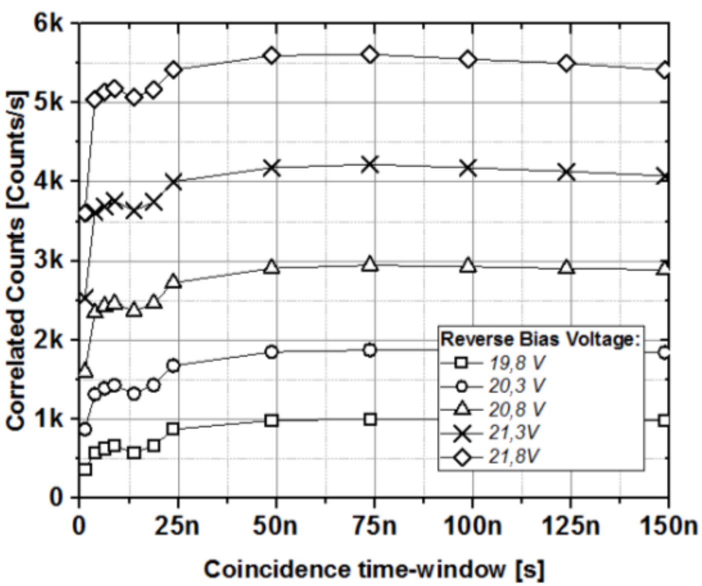
- *The two dies looks perfectly aligned*
- *The electrical connection cannot be validated because of a shadowing effect in proximity to the bonding surface due to gold bumps.*

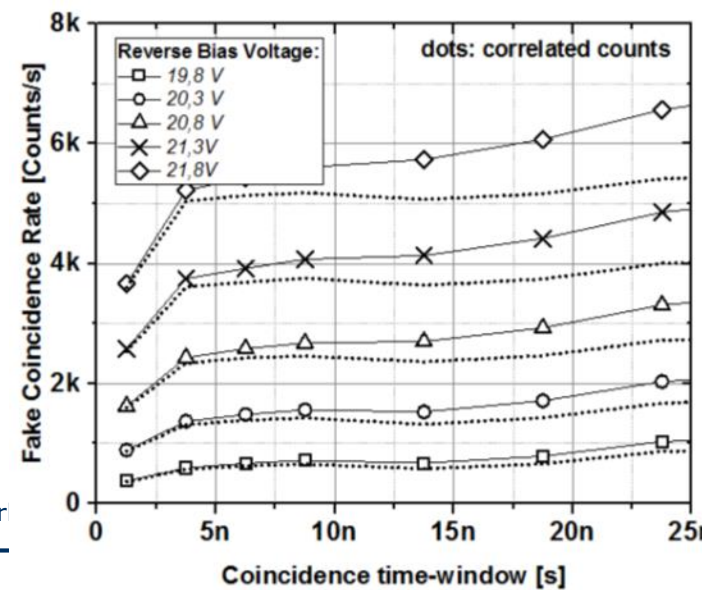
Characterization: 3D prototype

Noise evaluation: Fake Coincidence Rate (**FCR**) via FPGA









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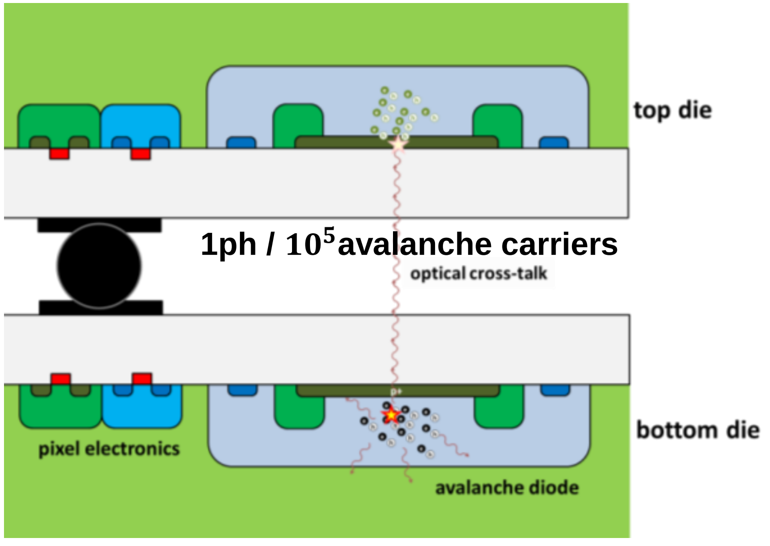
Characterization: 3D prototype

Possible source of correlated counts: optical cross-talk between the 2 sensing levels

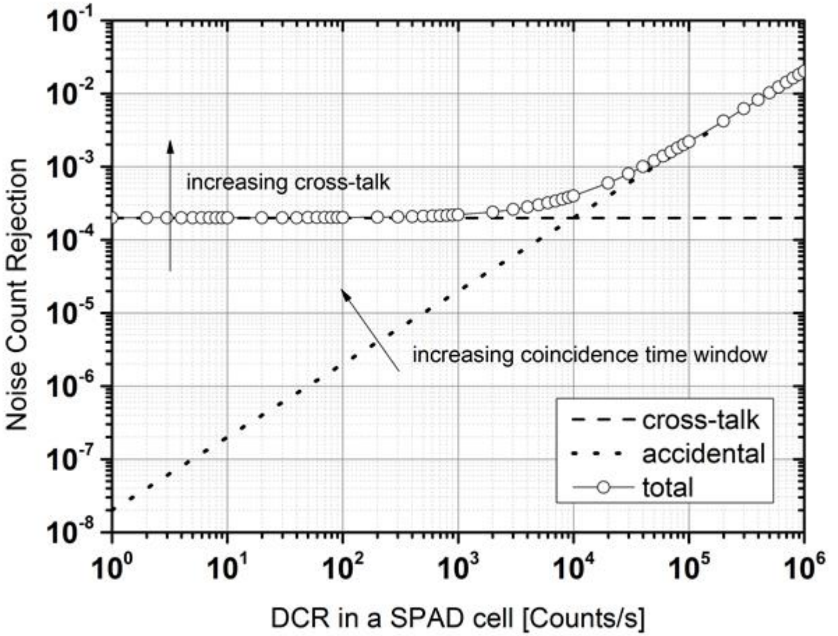


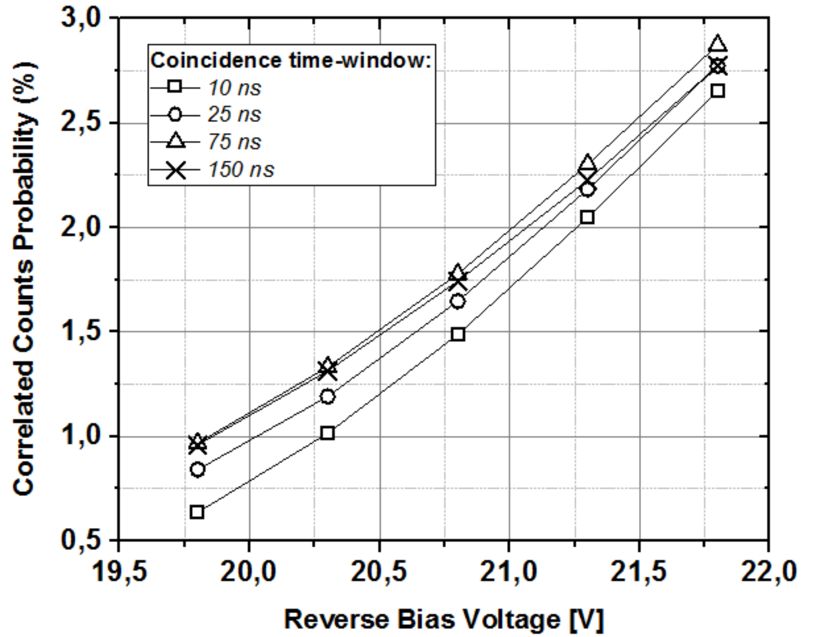
- ***Optical cross-talk between the two sensing levels produces correlated coincidence events.***
- ***Even very weak optical cross-talk*** ($p_X \approx 0.01\%$) *can impact a lot when in coincidence*

FCR correction:

$$\lambda_{coinc} = 2\Delta t \lambda_T \lambda_B + \frac{p_X}{1+p_X}(\lambda_T + \lambda_B)$$

$$\boldsymbol{\lambda_{coinc} \approx \lambda_{dark,coinc} + \lambda_{X,coinc}}$$





Ongoing work and perspectives

- **Further characterization and data analysis on the available prototypes**
- **Understanding of the physical nature of the correlated counts**
- **3D prototype test under a Sr 90 radioactive source (β− decay) @ IPNL (Lyon – France)**
- **65 MeV proton beam test @ “Lacassagne” hospital (Nice - France)**

Thanks