Developments on ARCADIA

State of the art and future perspectives

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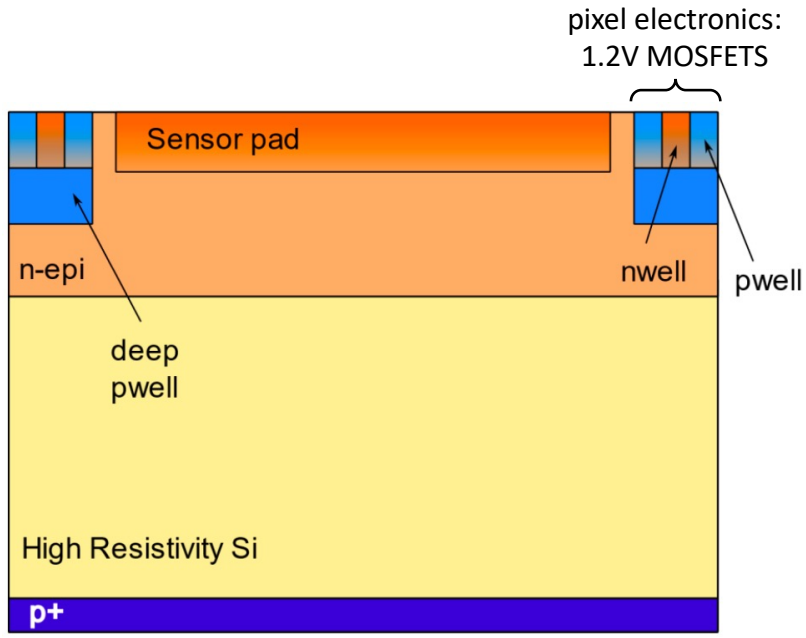
The ARCADIA sensor concept

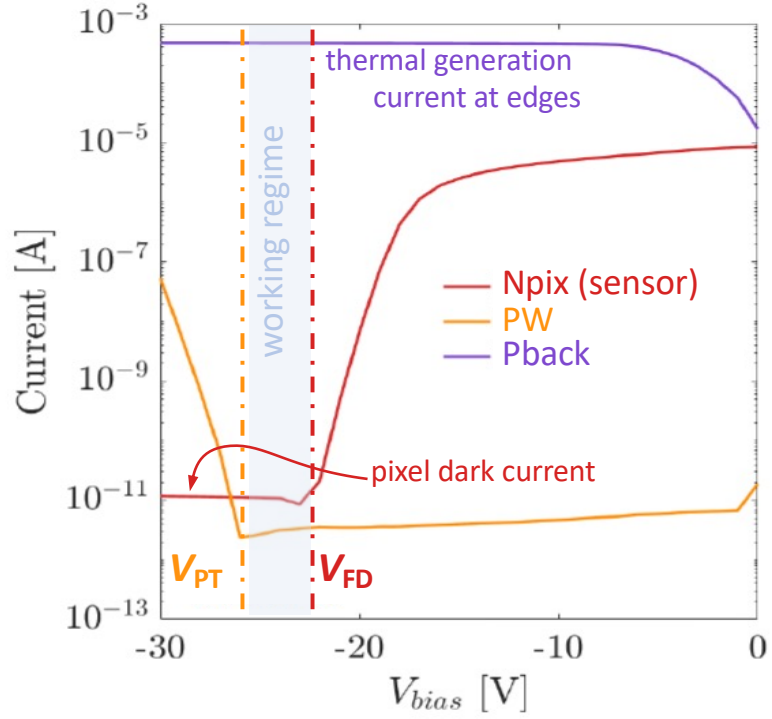
Fully-depleted Monolithic Active Pixel Sensors



- ***n*-type high resistivity** substrate with ***n*-type epitaxial** active volume
- **110 nm** CMOS process (LFoundry)
- **deep-*p*-wells** shielding *n*-wells with electronics
- **reverse-biased** junction: depletion grows from back to top

Main constraints:

- **full-depletion** condition
- **edge breakdown** induced by the **topside voltage**
- **punch-through** due to the **backside bias**

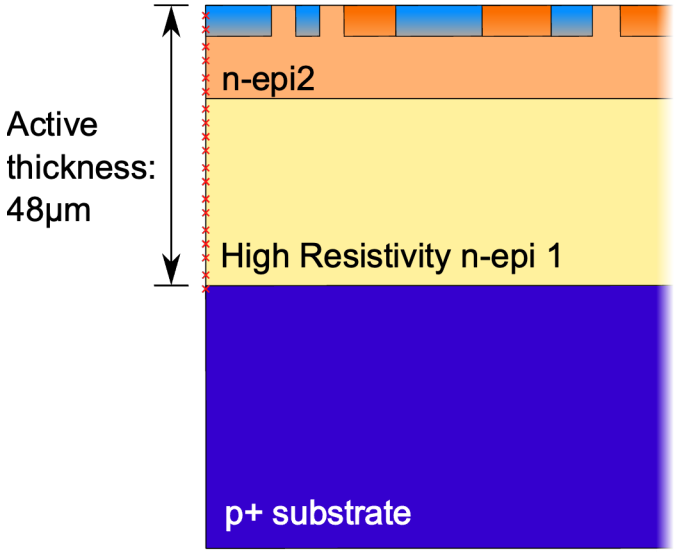


The ARCADIA sensor concept

Substrates and post-processing

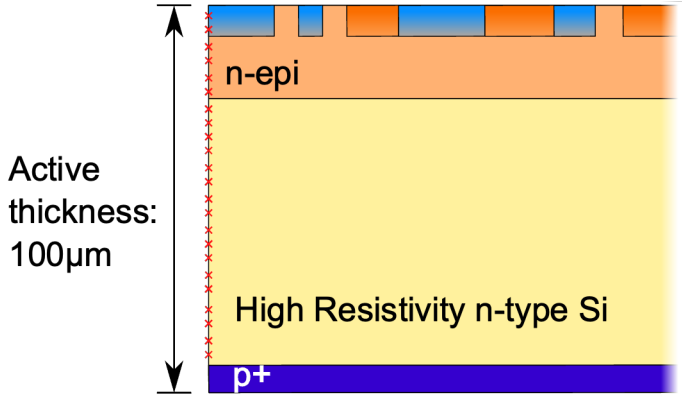
Type 1:

thinning to 100 or 300 µm total thickness



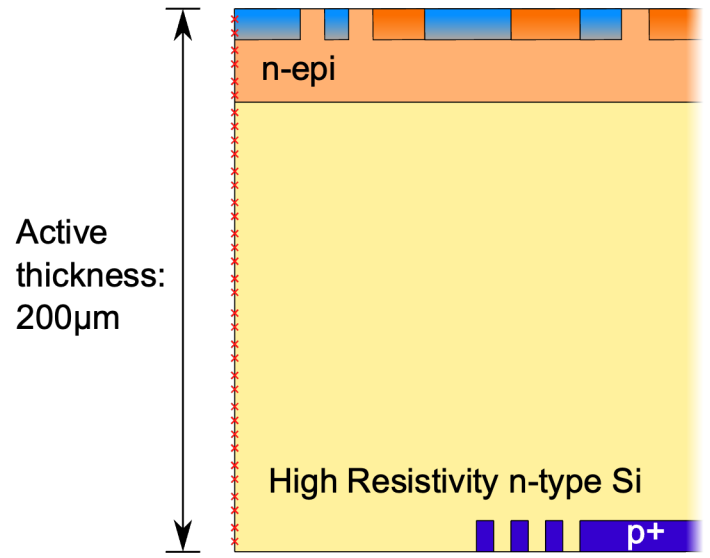
Type 2:

thinning, backside ***p*⁺ implantation** and laser annealing



Type 3:

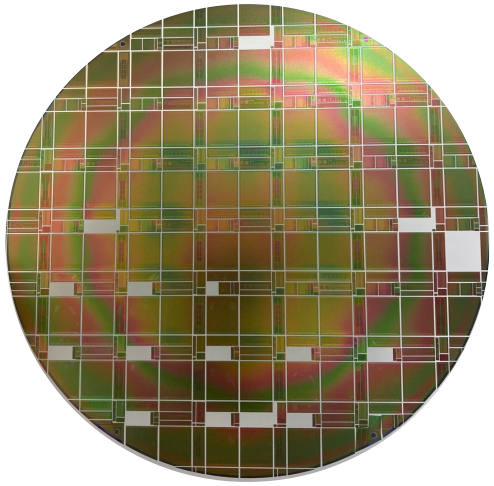
thinning, **lithography**, backside ***p*⁺ implantation** and laser annealing, **insulators/metal** deposition and patterning



First ARCADIA engineering runs

8” wafers

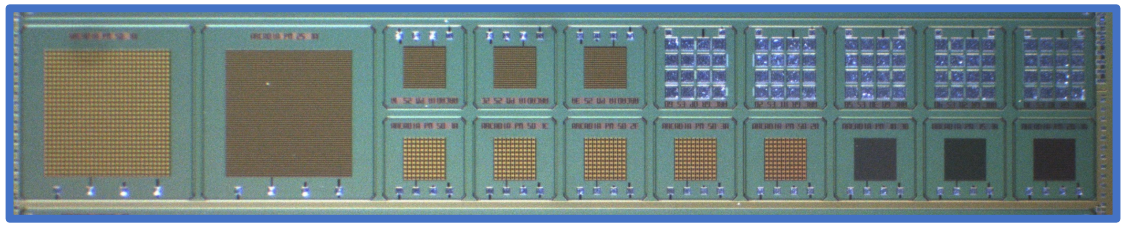
front side



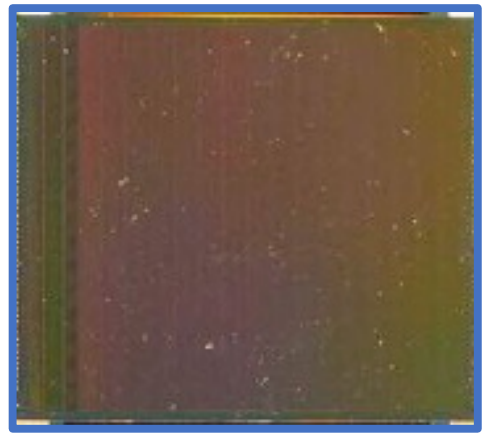
back side (type 3)

Structures:

- small **pixel arrays** with **different pitch** (10 µm - 25 µm - 50 µm) with and w/o active readout
- **strip detectors** with and w/o active readout
- **passive test structures** for sensors characterization and process qualification
- **Main Demonstrator**: **25-µm-pitch** pixel sensor, **512 × 512** array



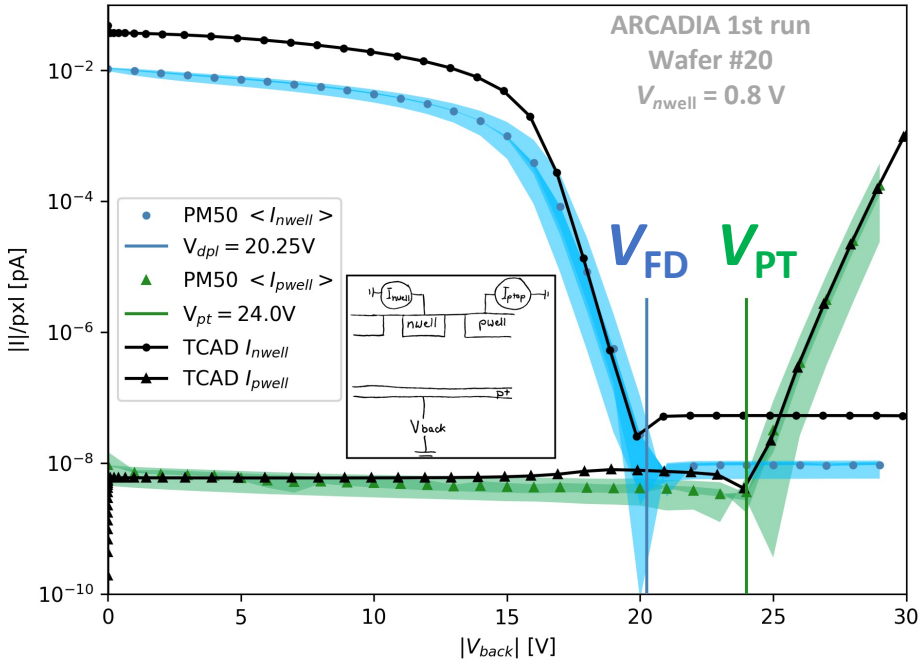
passive test structures block

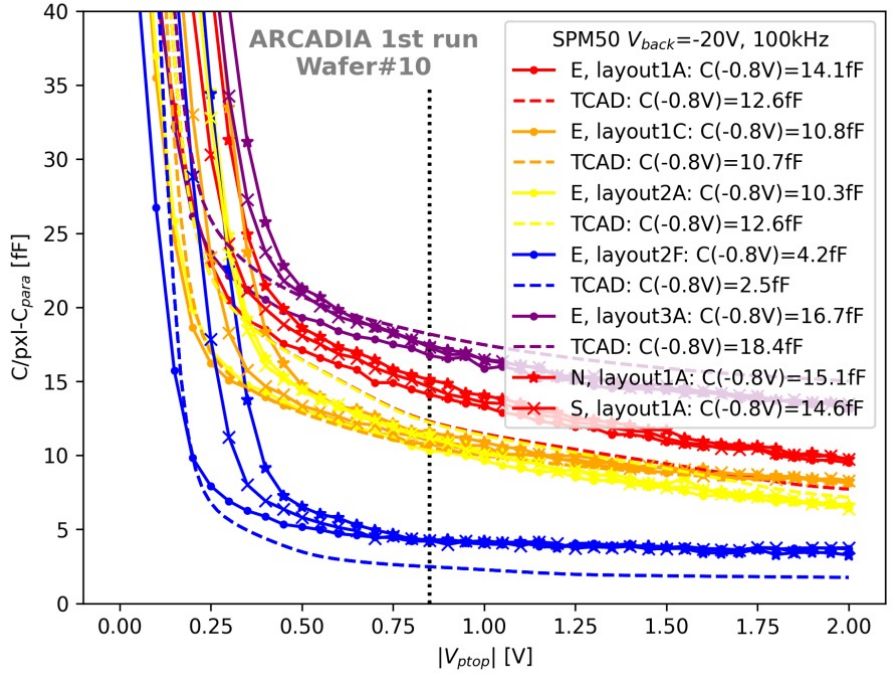


ARCADIA
Main Demonstrator

First ARCADIA engineering runs

Electrical characterizations



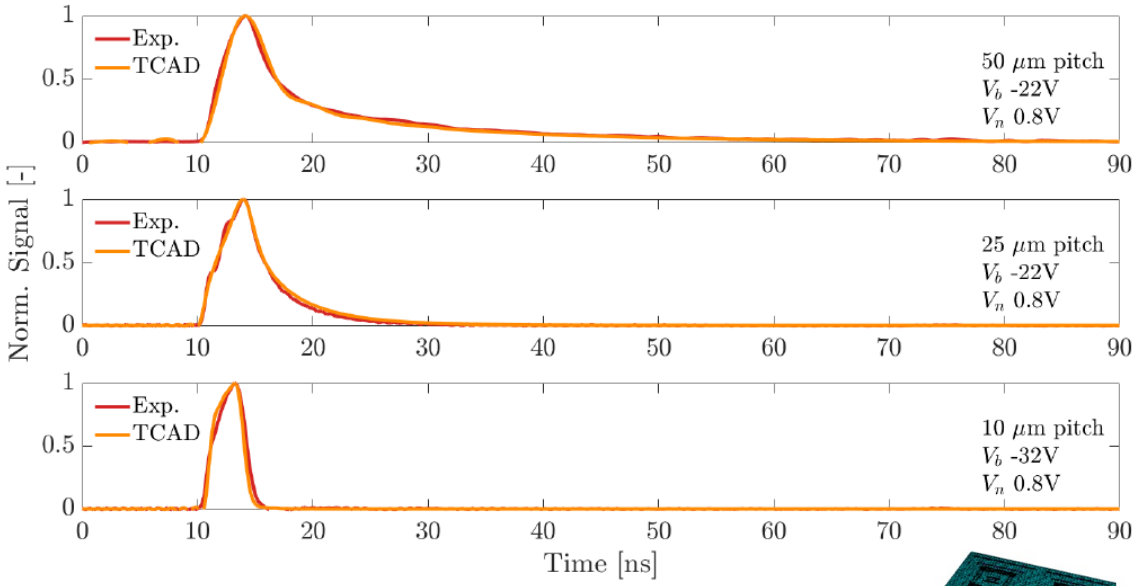


- different **pixel layouts** have been tested
- **intra-** and **inter-wafer uniformity** evaluated
- **TCAD parameters** adjusted on experimental results

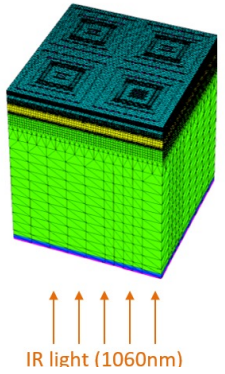
- **capacitance** dominated by the **sensor perimeter**

First ARCADIA engineering runs

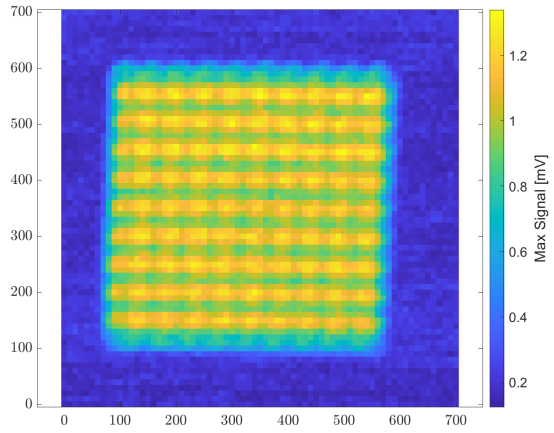
Dynamic response with laser



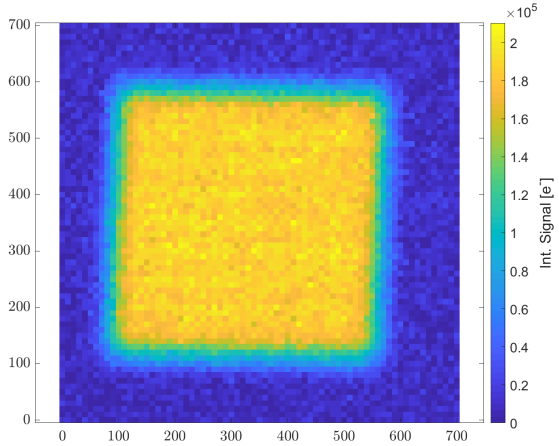
- < **100 ps** FWHM IR laser pulse
- passive **pixel array** test structures
- **100 µm** active thickness
- different **pixel pitch**: **50 µm** - **25 µm** - **10 µm**



signal peak amplitude



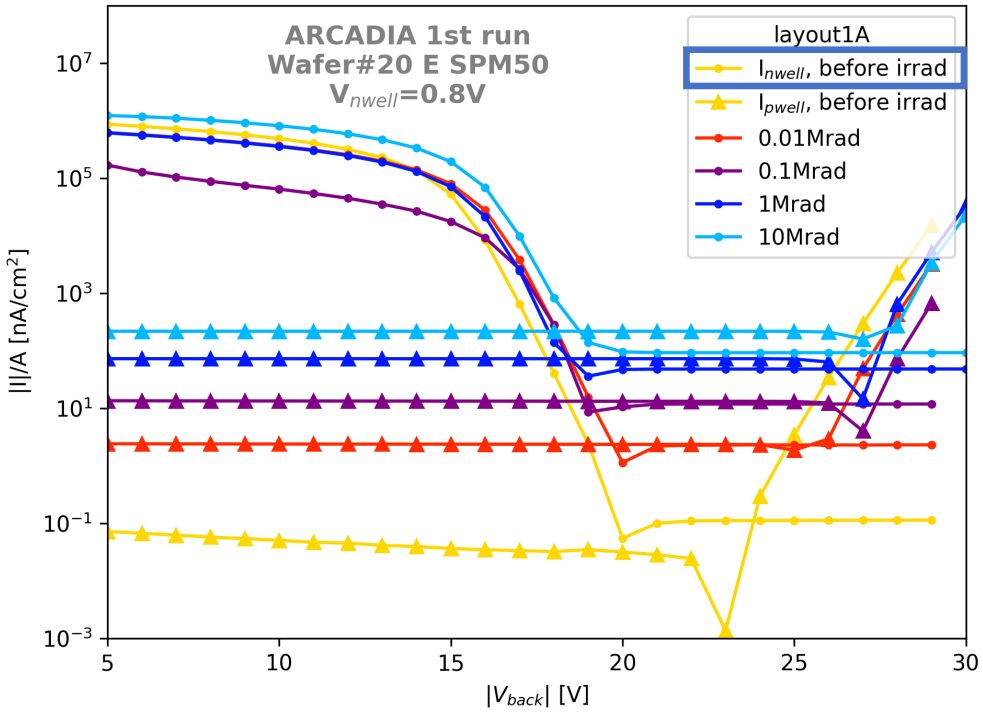
integrated charge

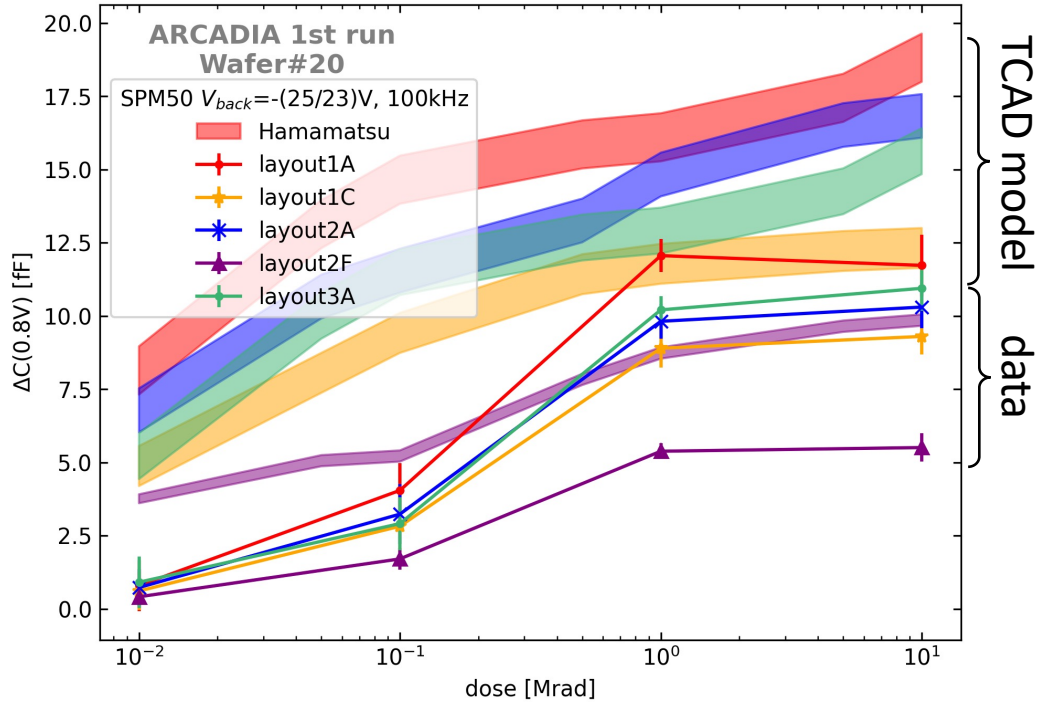


- **10 µm** FWHM focused IR laser
- **50-µm-pitch** test structure
- V_{top} **= 0.8 V** and V_{back} **= –22 V**
- **10 µm** steps in *X* and *Y* directions

First ARCADIA engineering runs

Pixel radiation hardness: X-rays @ University of Padova, Italy

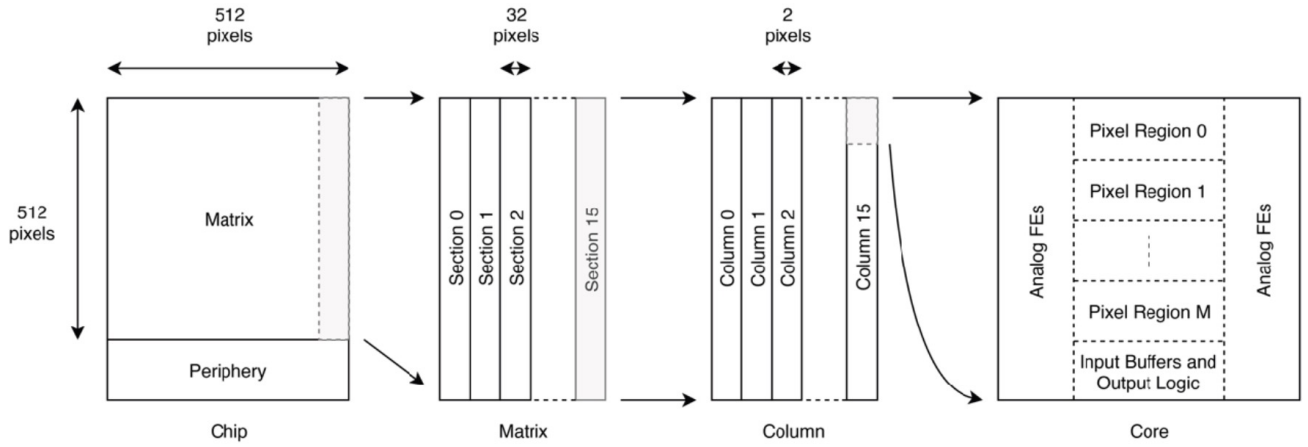


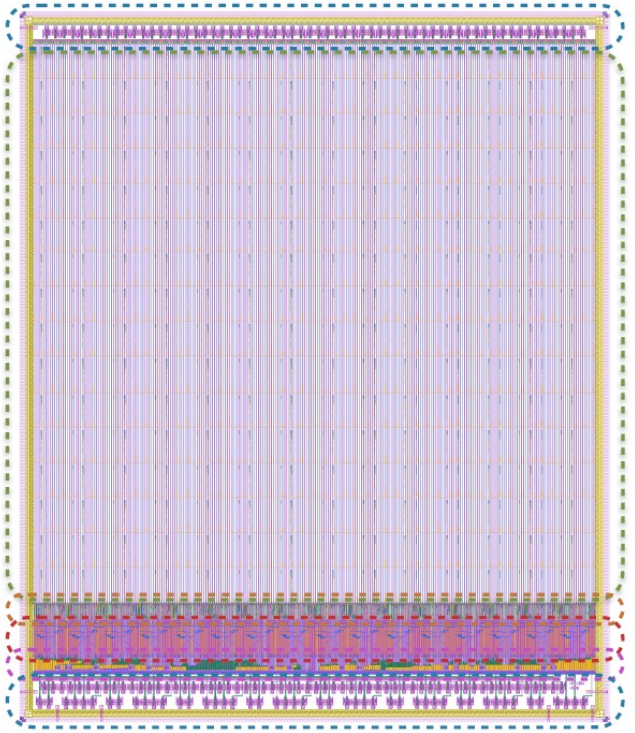


- increase of **pixel leakage** current with **Total Ionizing Dose** (TID) due to **surface generation**
- capacitance post-irradiation overestimated by the Perugia model with Hamamatsu parametrization

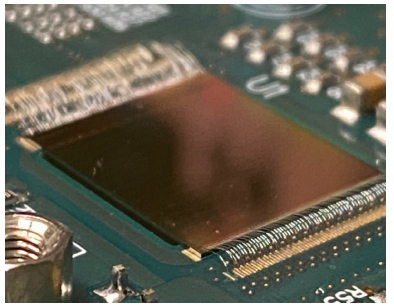
First ARCADIA engineering runs

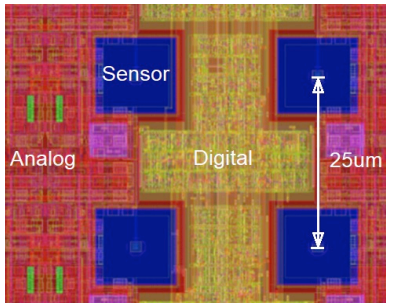
Main Demonstrator - architecture





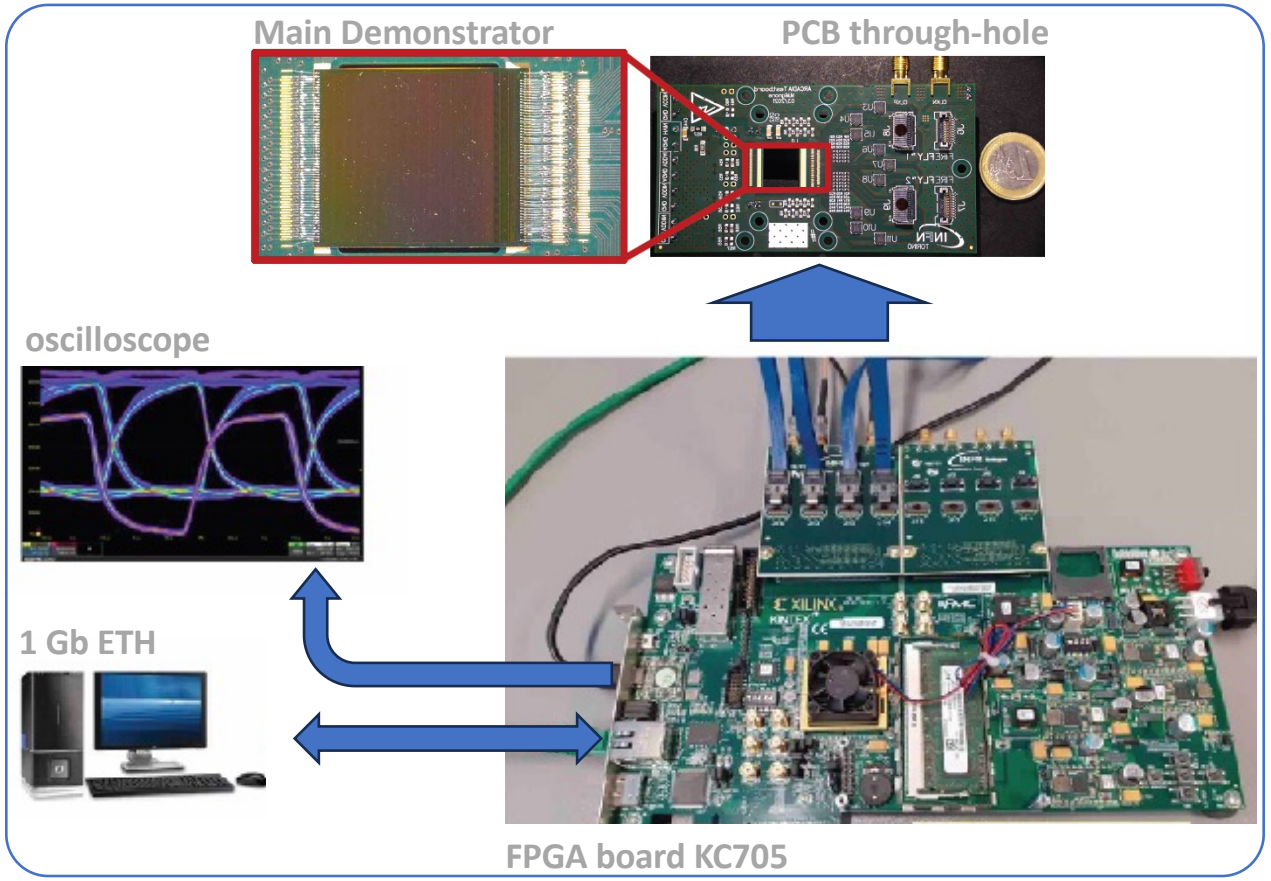
- Pixel **pitch**: **25 µm**
- Array core **area**: **1.28 cm × 1.28 cm** (262144 pixels)
- Electronics: **analog** and **digital**, with in-pixel **threshold** and **data storage**
- Architecture: **event-driven**, with active pixels sending their address to the chip peripheral circuits
- (Low) **power**: **20 mW/cm^2**
- (High) **event rate**: **100 MHz/cm^2**

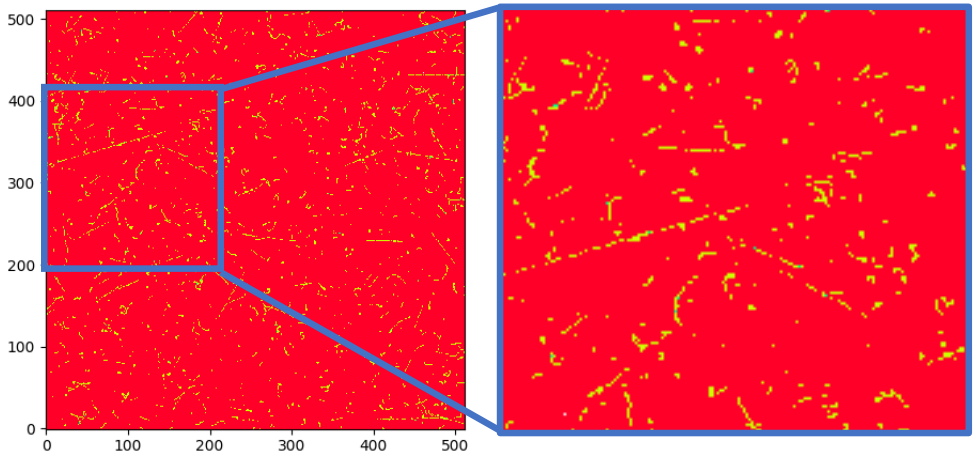




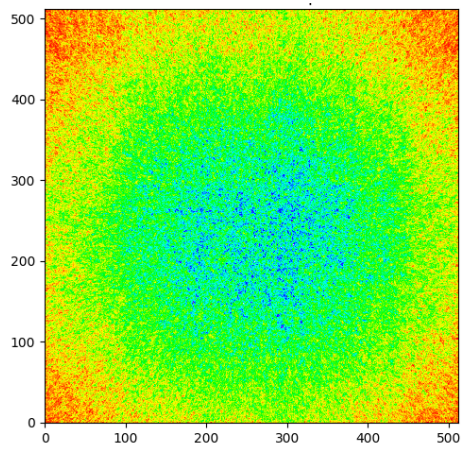
First ARCADIA engineering runs

Main Demonstrator - acquisition setup

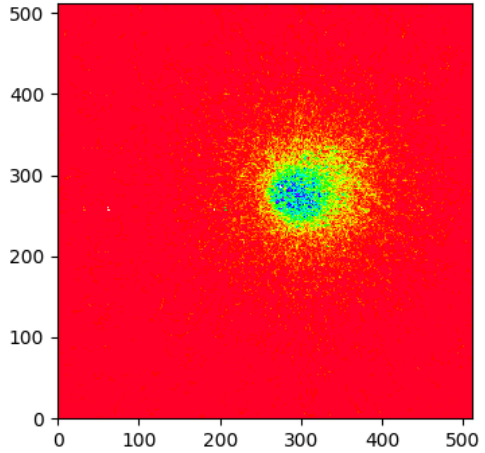




Cosmic rays acquisition (4h)



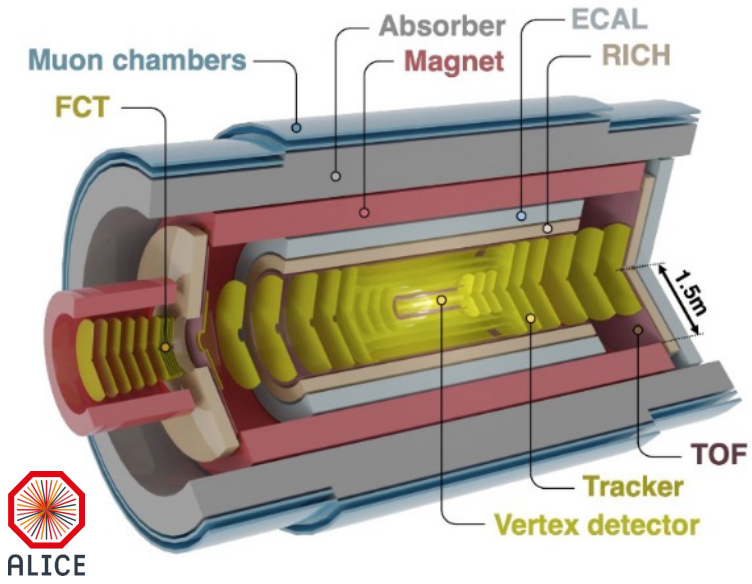
^{90}Sr beta source (1cm^2) 8 mm from the sensor surface



Collimated ^{90}Sr beta source
Collimator diameter: 1mm

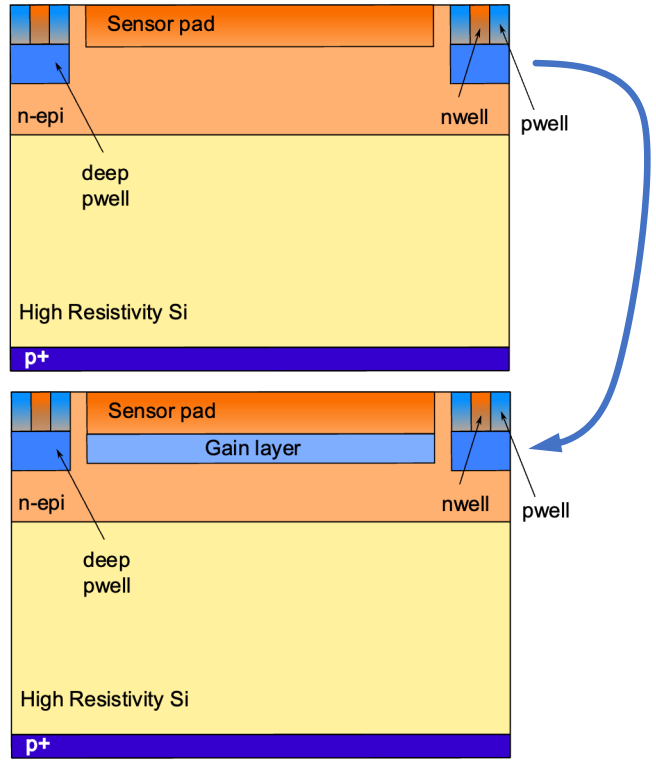
- Total **power consumption**: **10 mW/cm^2** at low event rates
- **Design specification**: **20 mW/cm^2** at rates up to 100 Mevents/cm^2

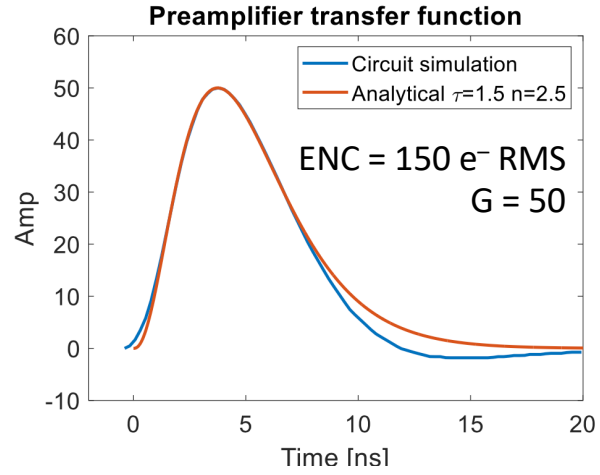
The ARCADIA run-3

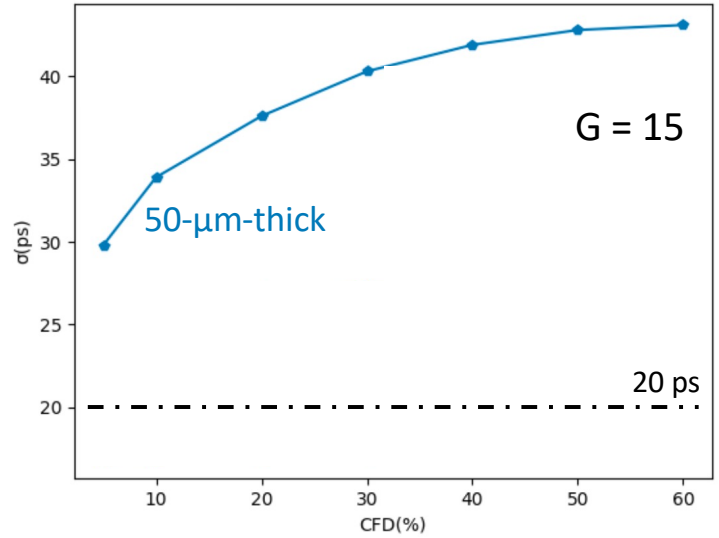


ALICE 3 **TOF** detector:

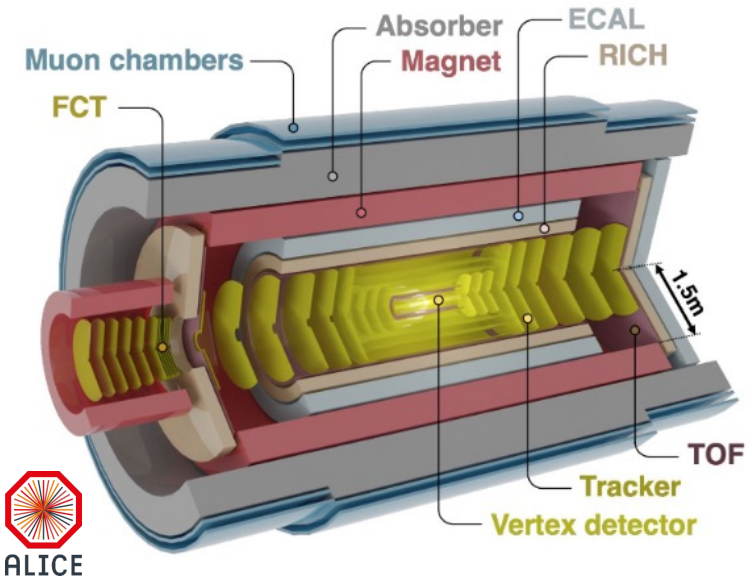
- high-resolution tracking and vertexing
- particle ID with low $p_T \Rightarrow \sigma_t \sim 20$ ps







The ARCADIA run-3



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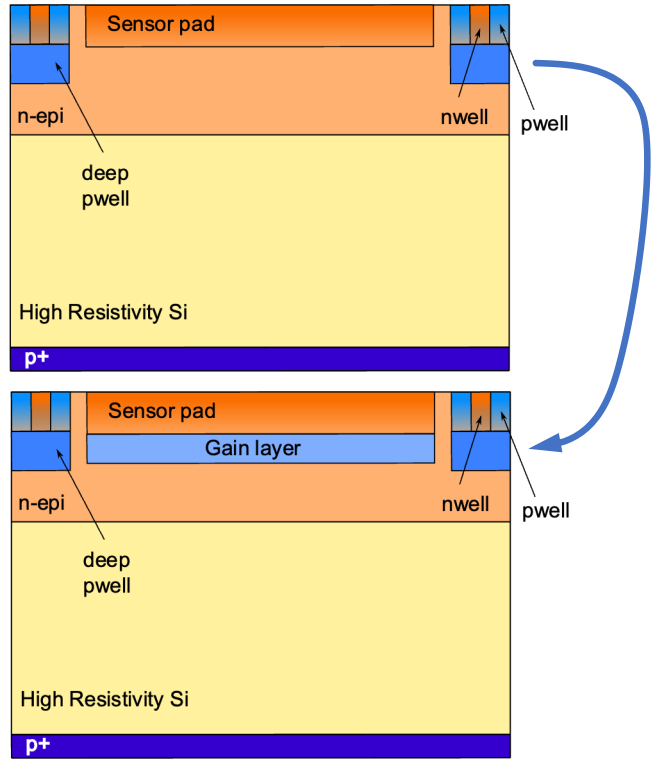
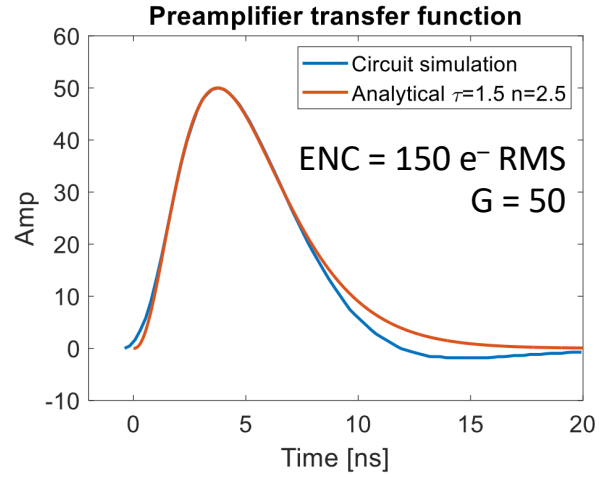
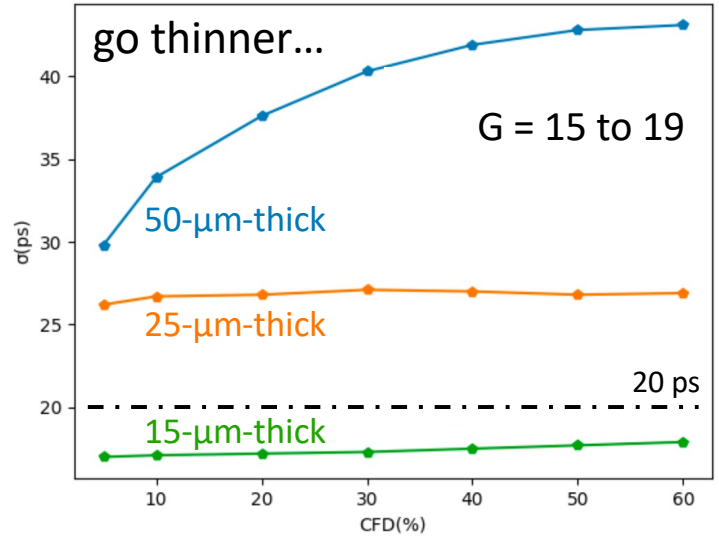
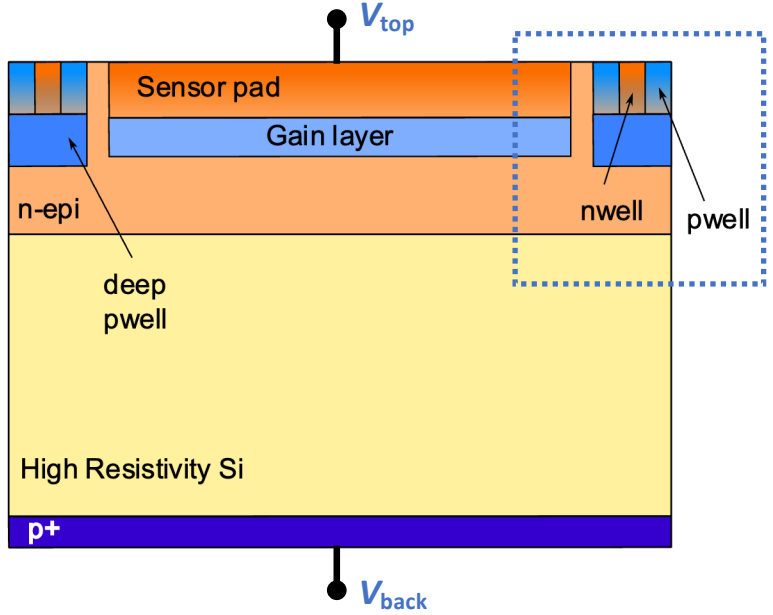






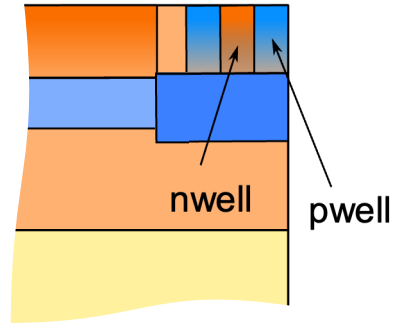
The ARCADIA run-3

Sensor structure and layout



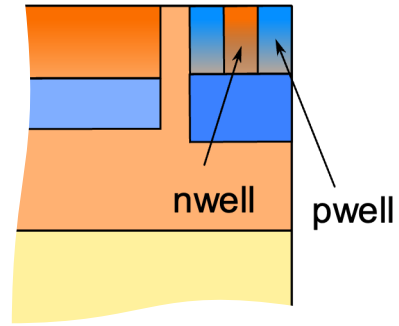
Layout A1:

deep-*p*-wells are in connection with the ***p*-gain** implant ⇒ more **uniform charge multiplication**



Layout A2:

standard solution: **direct path** to the n^+ collection electrode ⇒ more **uniform time response**; NO multiplication of charges at borders



V_{top} (30-40 V) determines the **gain**, while V_{back} (–30 V) defines the **drift field** in the substrate

top voltage limited by **edge breakdown**
backplane bias limited by **punch-through**

- four **gain dose splittings** to cope with implantation uncertainties
- target: **gain** in the range **10 – 30**
- **50**, **100** and **200 µm** active **thicknesses**

The ARCADIA run-3

MadPix: first small-scale (**4 × 16 mm²**) demonstrator with **gain** and **integrated electronics**

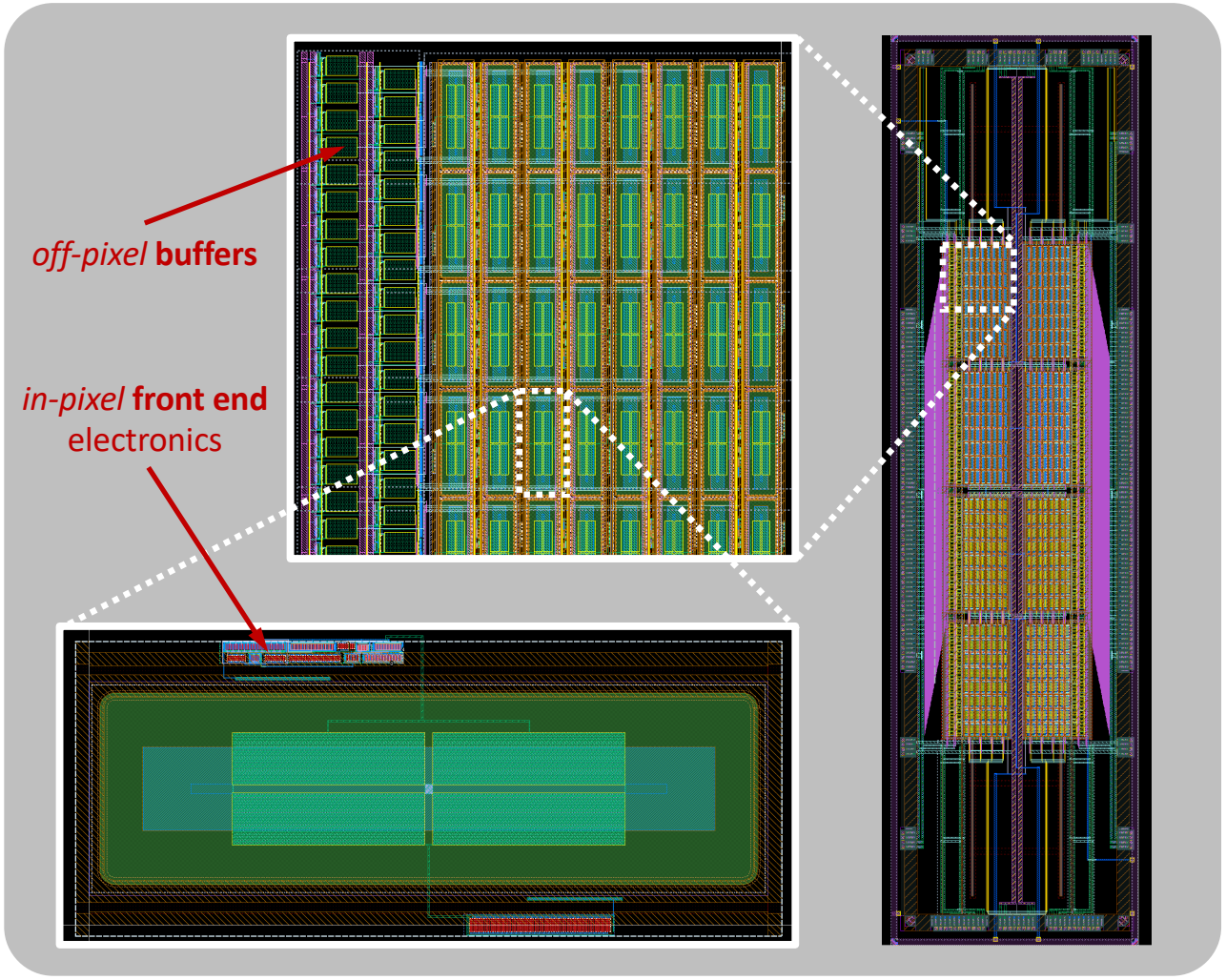
- **8 matrices** (**64 pixel pads** each) implementing different sensor and front-end flavours
- pads of **250 × 100 µm²**
- readout: **64 × 2 analog outputs** on each side
- **rolling shutter** of single matrix readout

Front-end (*in-pixel*)

- **Cascoded common source** amplifier, followed by a **differential buffer** (1.2V)
- **AC-coupled** with **sensor** (in order to decouple it from the sensor top voltage)
- **Power** consumption: **0.18 mW/ch**

Source follower *off-pixel* buffers (3.3V)

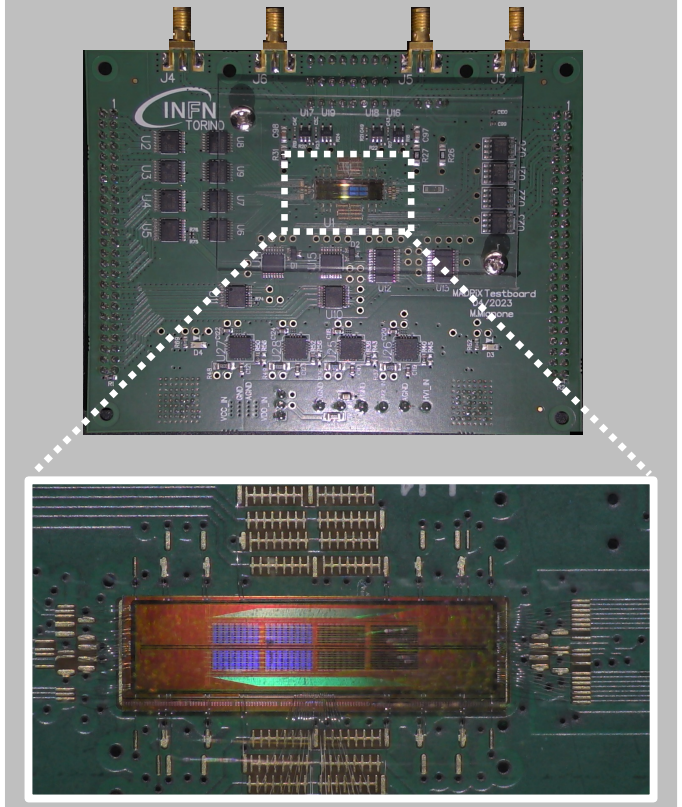
- **AC-coupled** with **FE**
- **Power** consumption: **1.65 mW/ch**



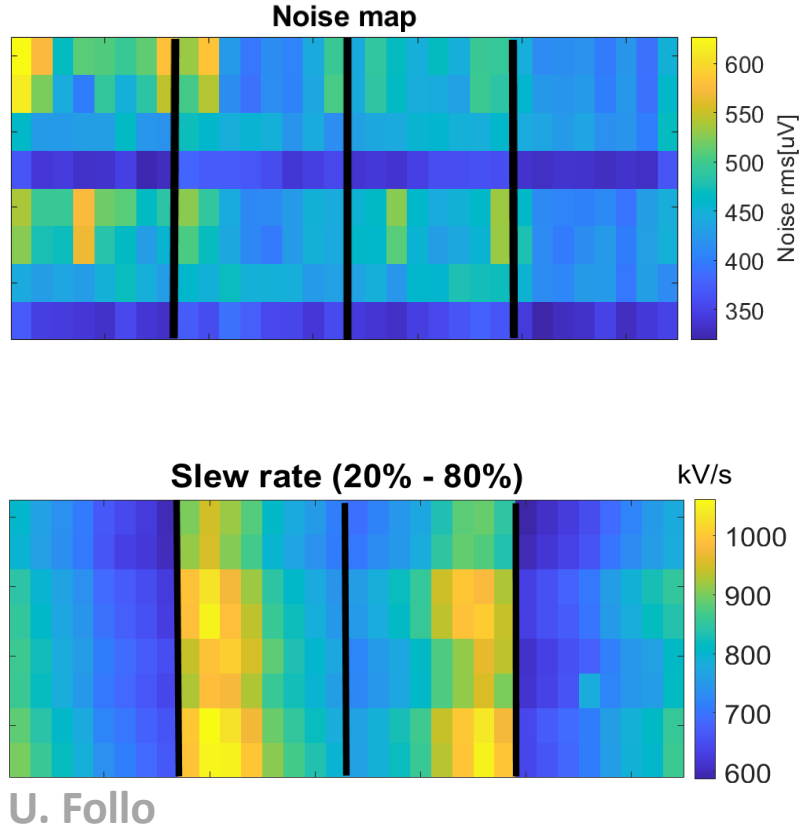
The ARCADIA run-3

MadPix: first small-scale (**4 × 16 mm²**) demonstrator with **gain** and **integrated electronics**

MadPix testboard

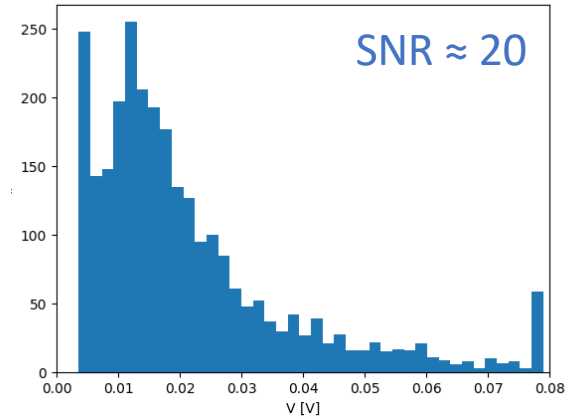


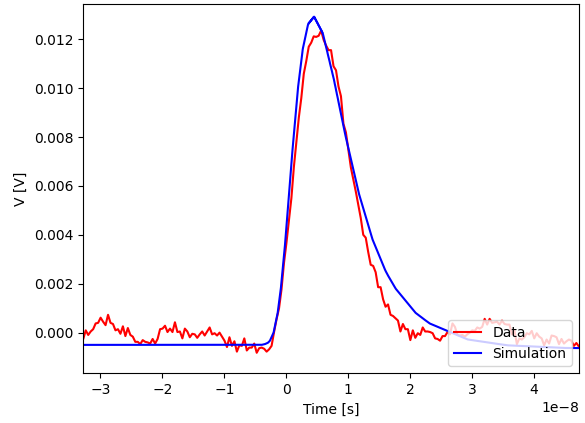
Noise and **slew-rate** characterization with external **test-pulse** injection



U. Follo

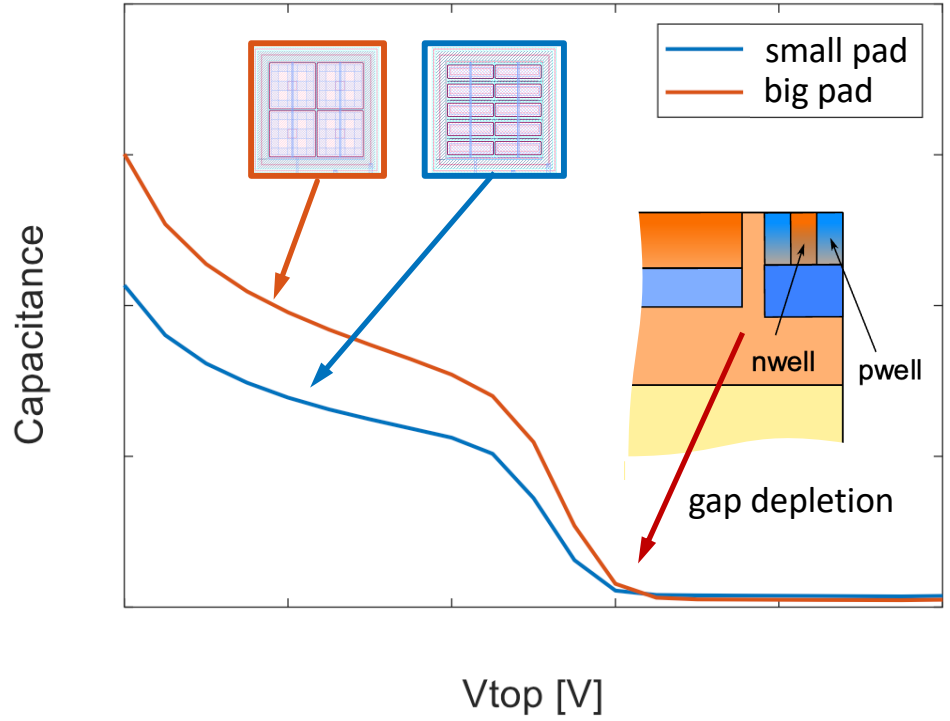
First data with **beta source** (^{90}**Sr**)



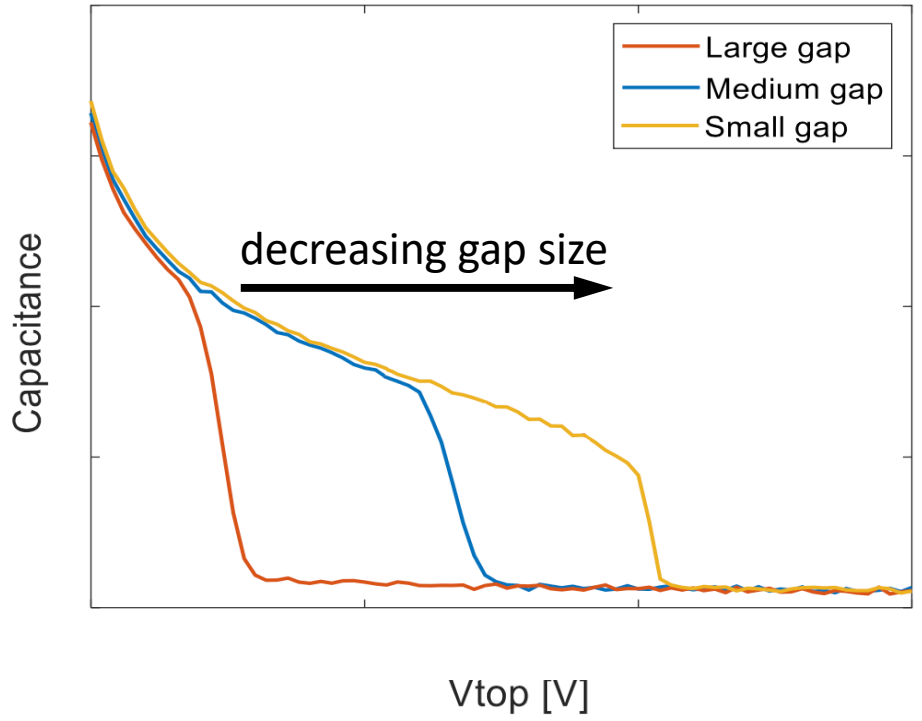


The ARCADIA run-3

Electrical characterization – standalone **passive test-structures**



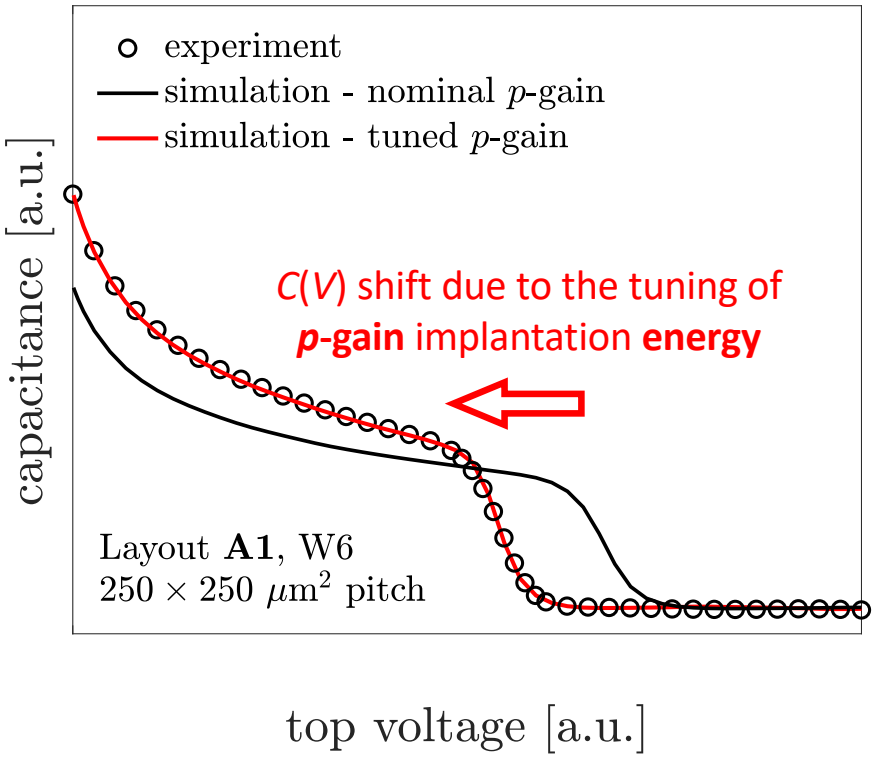
Differently from standard LGADs, the *C*(*V*) does not allow to reconstruct the whole gain implant profile, since the **gaps** between **deep-*p*-well** and ***p*-gain** are depleted earlier



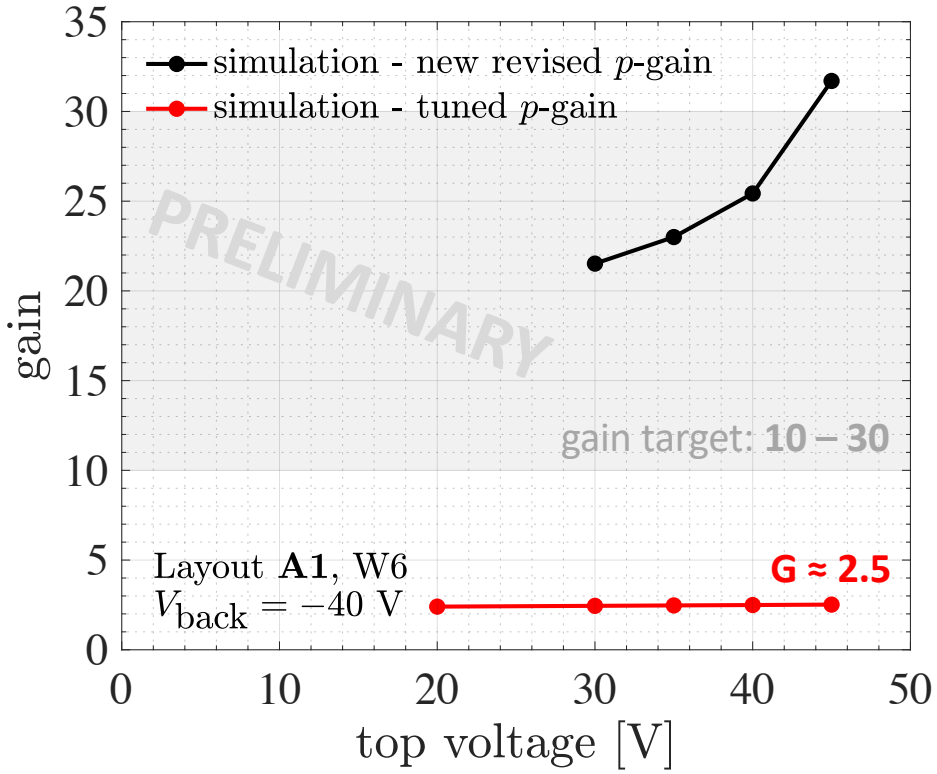
The **foot/knee** observed in the *C*(*V*) curves depends on the **size** of the gap. A **larger gaps** are fully **depleted** at **lower voltage**

The ARCADIA run-3

Investigations about the gain (target: **10 – 30**)



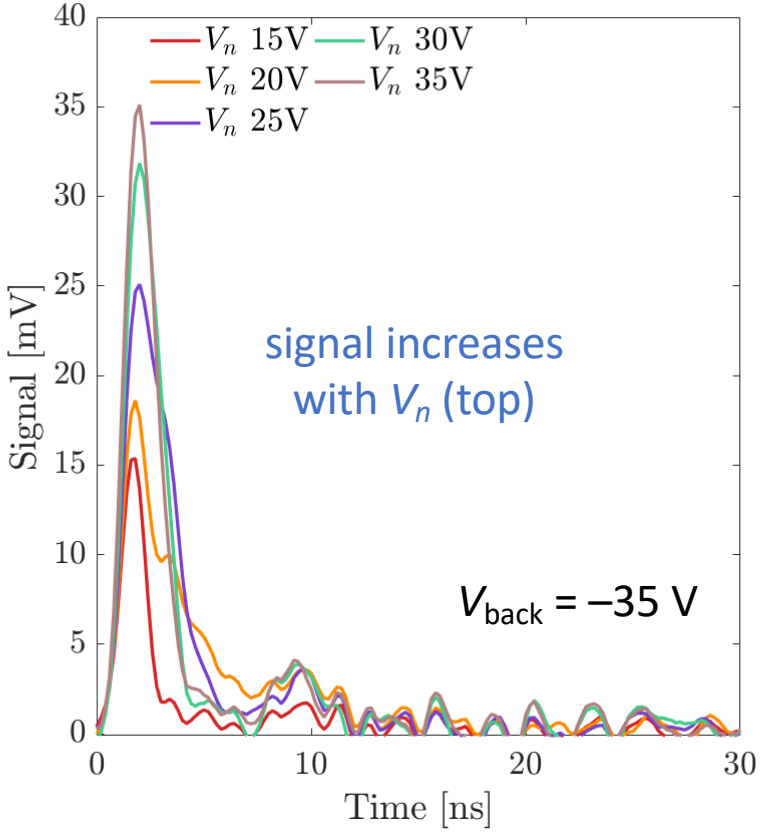
the ***p*-gain implant energy** must be reduced
by **~30%** to recover the mismatch

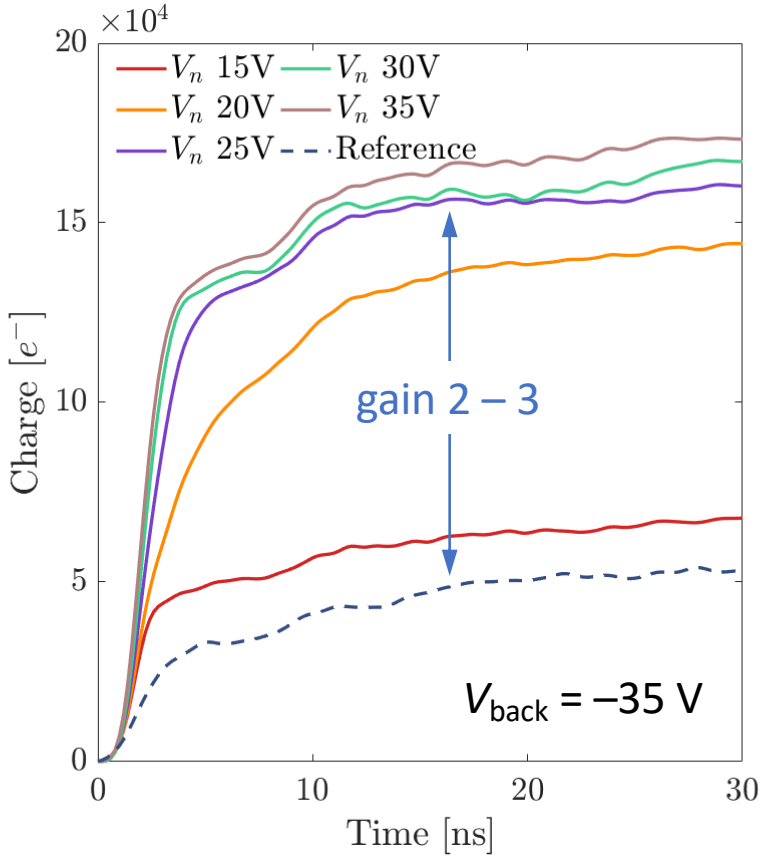


The ARCADIA run-3

Dynamic characterization – standalone **passive test-structures**

Focused IR laser spot (~10 µm)
Backside illumination





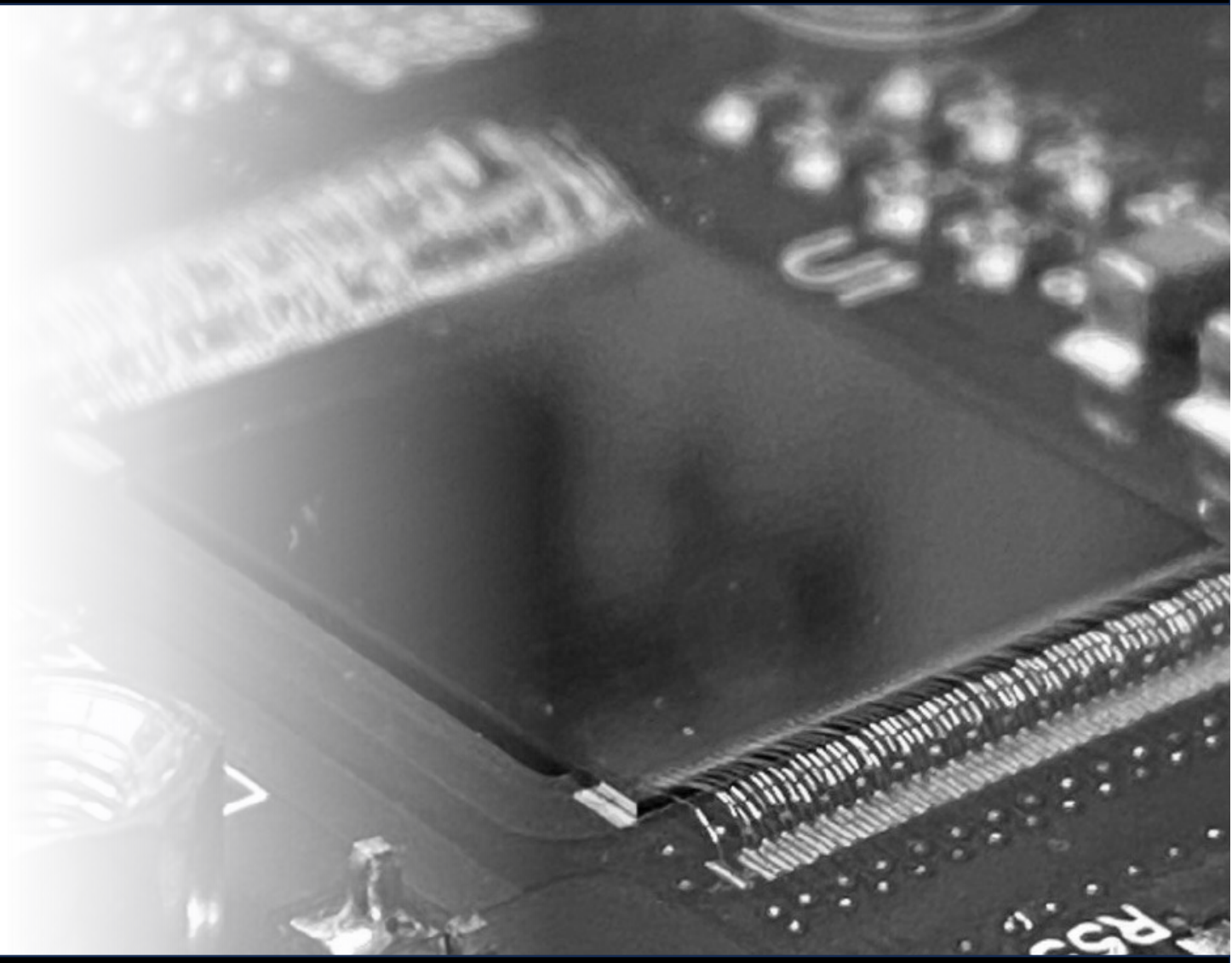
Conclusions

- We proved the **compatibility** between the **LGAD technology** and the 110-nm **CMOS process**, thanks to the **3rd ARCADIA production**
- This engineering run has been **characterized** through **static** and **dynamic laboratory tests**, as well as **numerical simulations**, allowing to find the ***p*-gain implantation error**

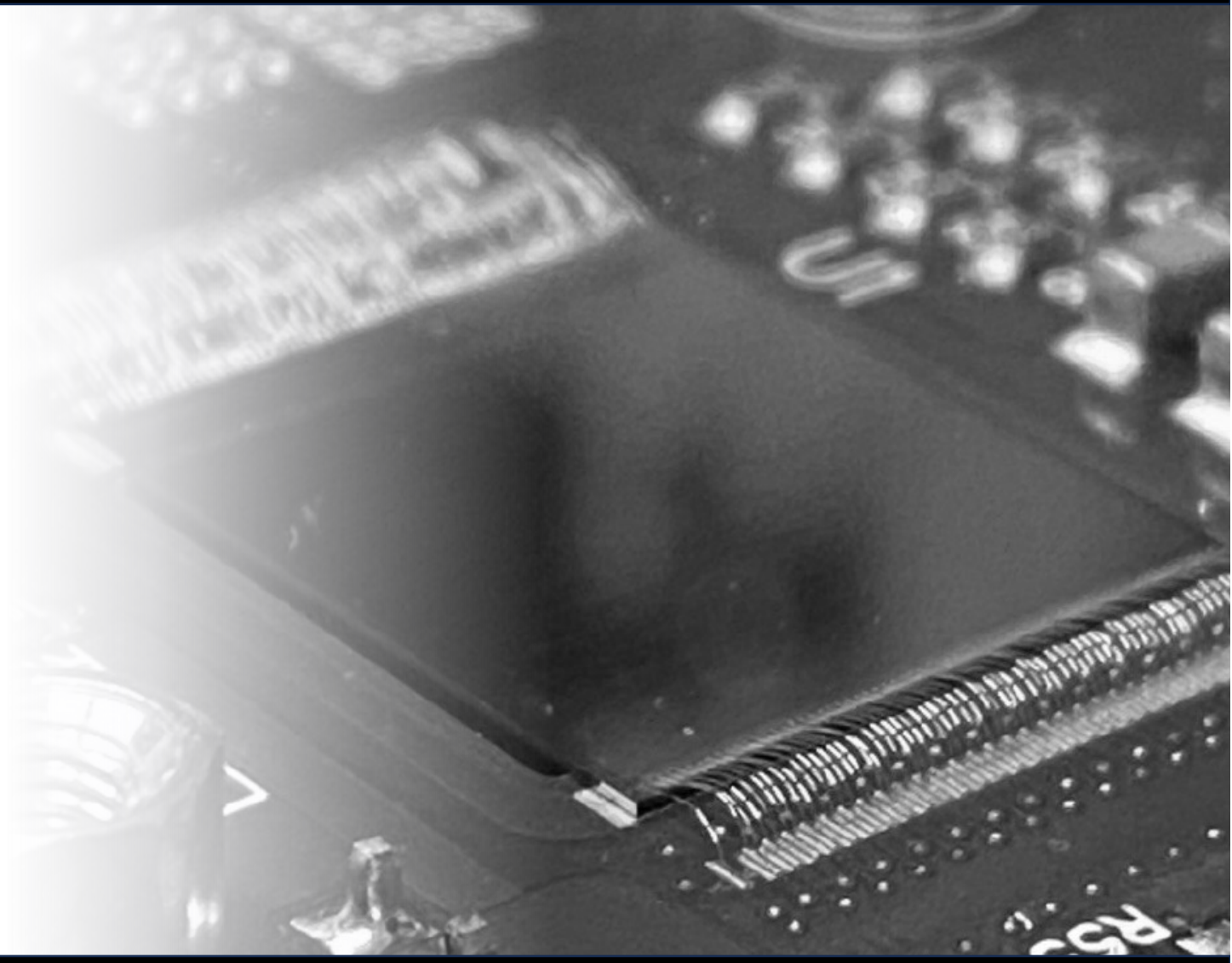
… *what's next* ?

- Laboratory **characterizations** of the incoming **short-loop run** as a testbench for next test beams
- Optimize the sensor in view of **timing applications** (improvement of periphery layout, new substrates, pad area / active thickness ratio, …)
- New **sensor concepts** on the way: follow our next contributions (e.g. *Pisa Meeting*)

Thank you for the attention!



backup



First ARCADIA engineering runs

Pixel characterization

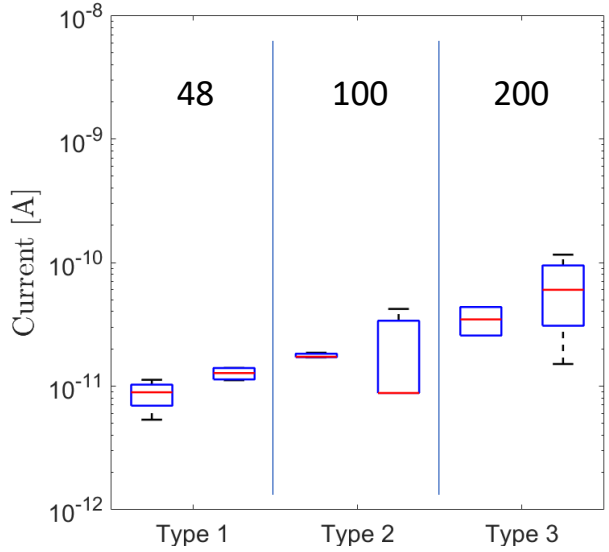
static characteristics

Active thickness (µm)	48	100	200
bias voltage (V)	25	20-35	60-100
dark current density (pA/cm^2)	100-350	230 - 500	650 - 2000

dynamic characteristics

Pixel pitch (µm) @ 100-µm-thick	10	25	50
capacitance (fF)	1.9	3	12.7
time for 90% charge collection with picosecond IR laser (ns)	4	10	31

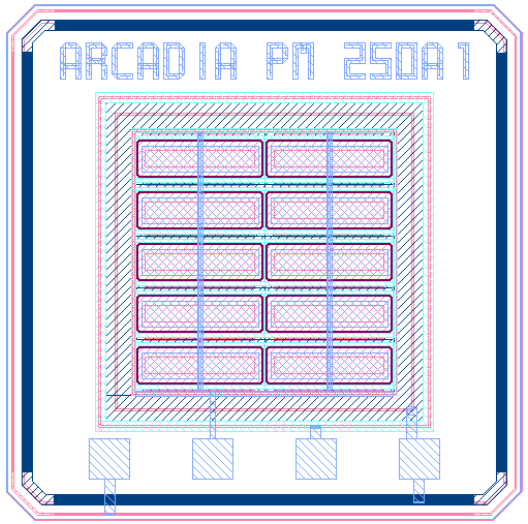
dark currents in **1.5 mm × 1.5 mm pixel** arrays with different active **thicknesses**



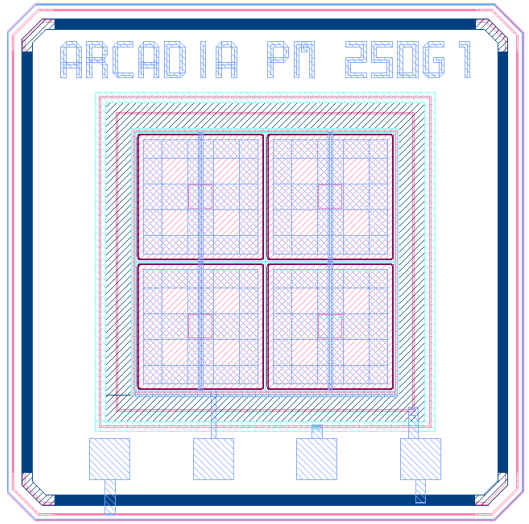
The ARCADIA run-3

Electrical characterization – standalone **passive test-structures**

Designed for test at the probe station and with external amplifiers



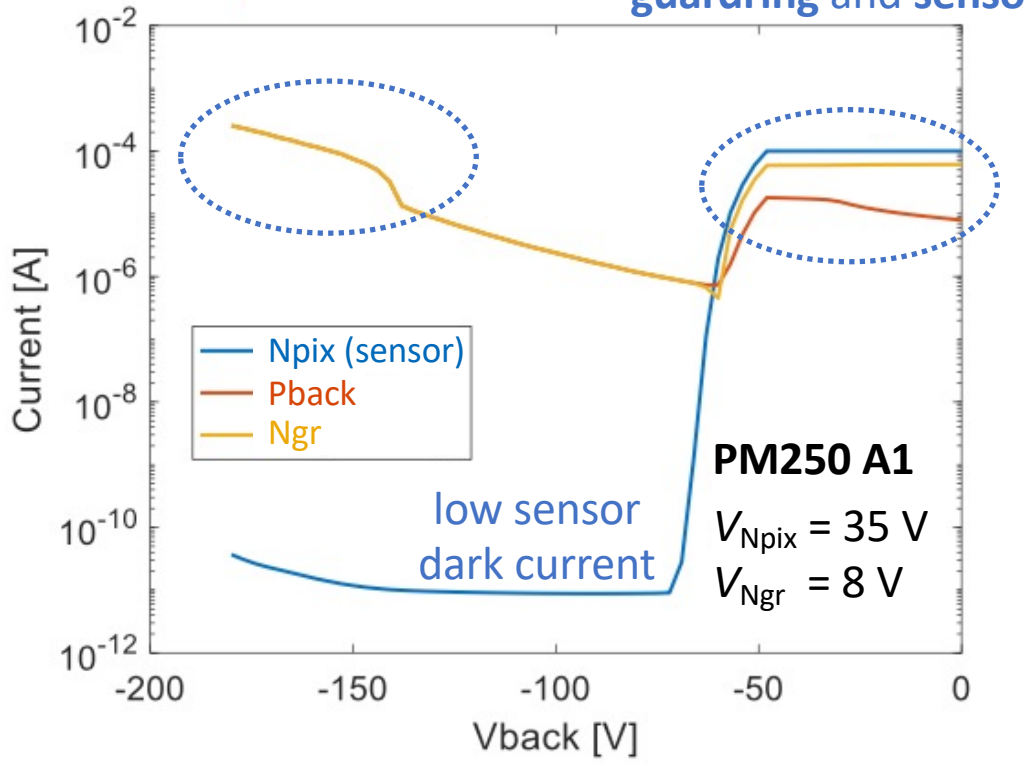
Rectangular passive pads:
70 µm × 250 µm



Square passive pads with large fill-factor: 250 µm × 250 µm

dark current between **guardring** and **backside**

current mostly flowing between **guardring** and **sensor**

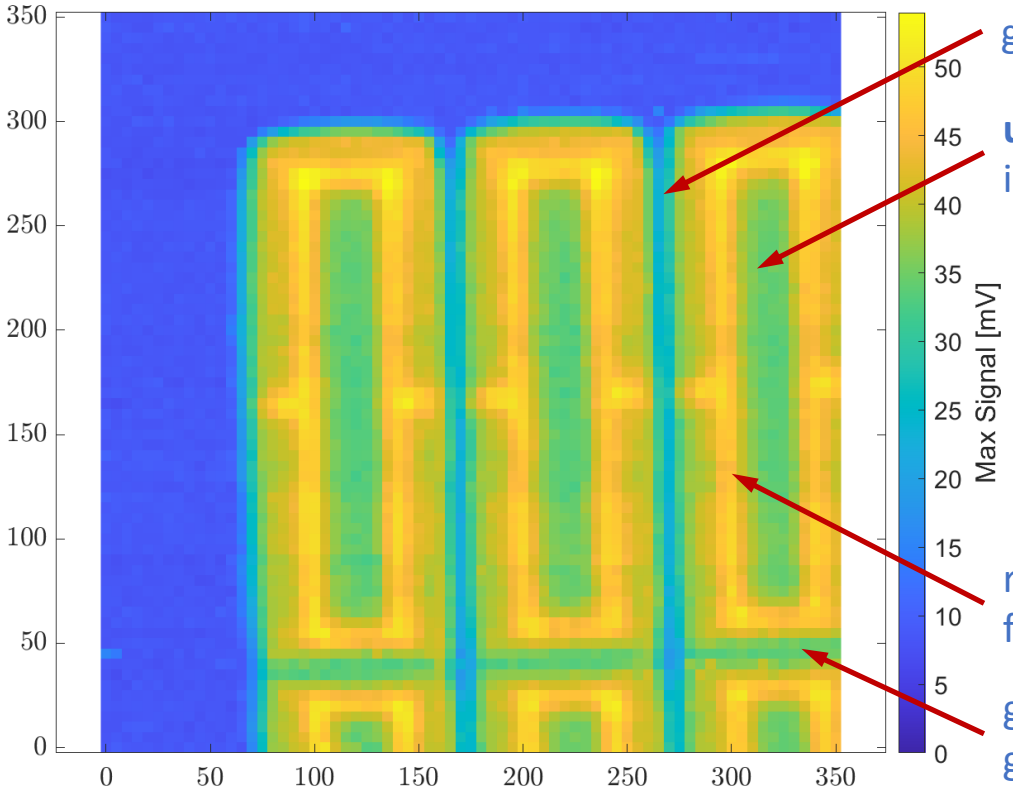


The ARCADIA run-3

Dynamic characterization – standalone **passive test-structures**

Focused IR laser spot (~10 µm)
Frontside illumination

Maximum signal amplitude map



gap w/ guard-ring

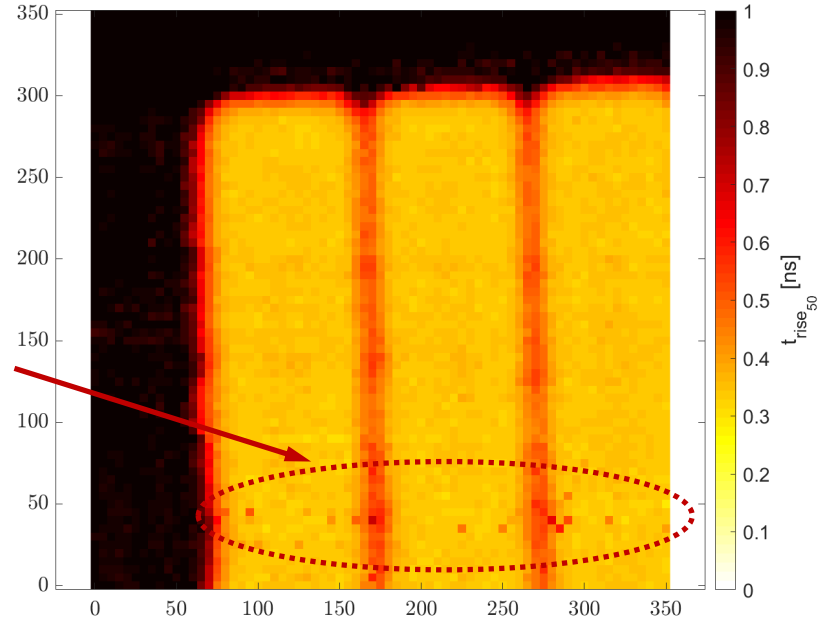
uniform response inside the pad

no discontinuities at gaps w/o guard-ring

reflection in the frontside metal

gap w/o guard-ring

Signal risetime map

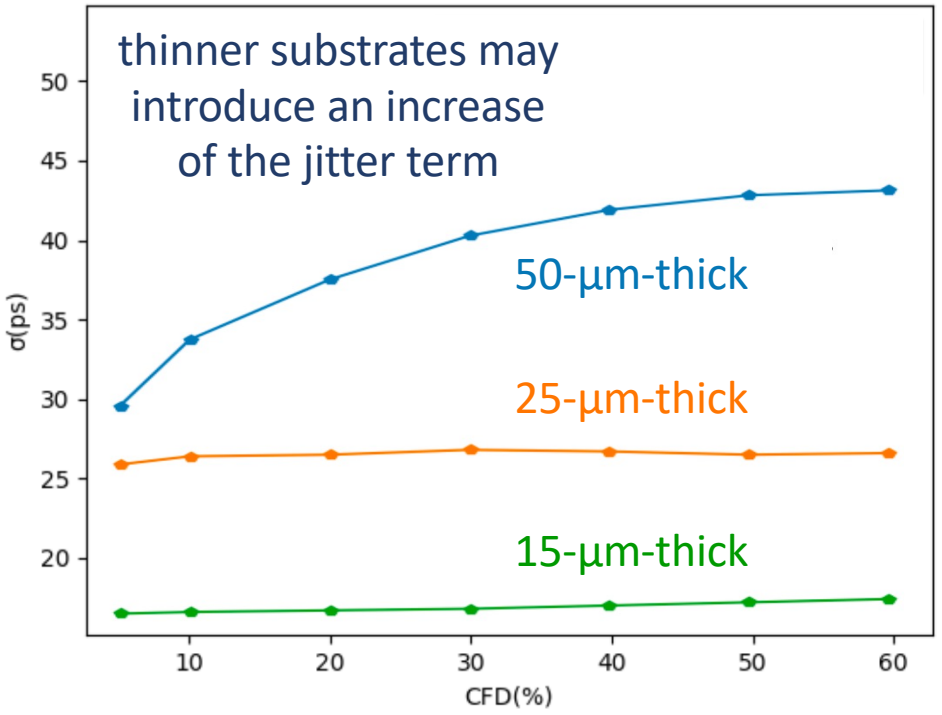


- 70 × 250 µm² **PM250 A1** array
- V_{pix} = 40 V, V_{back} = –35 V
- Focused laser spot (~10 µm)
- 5 µm motor step

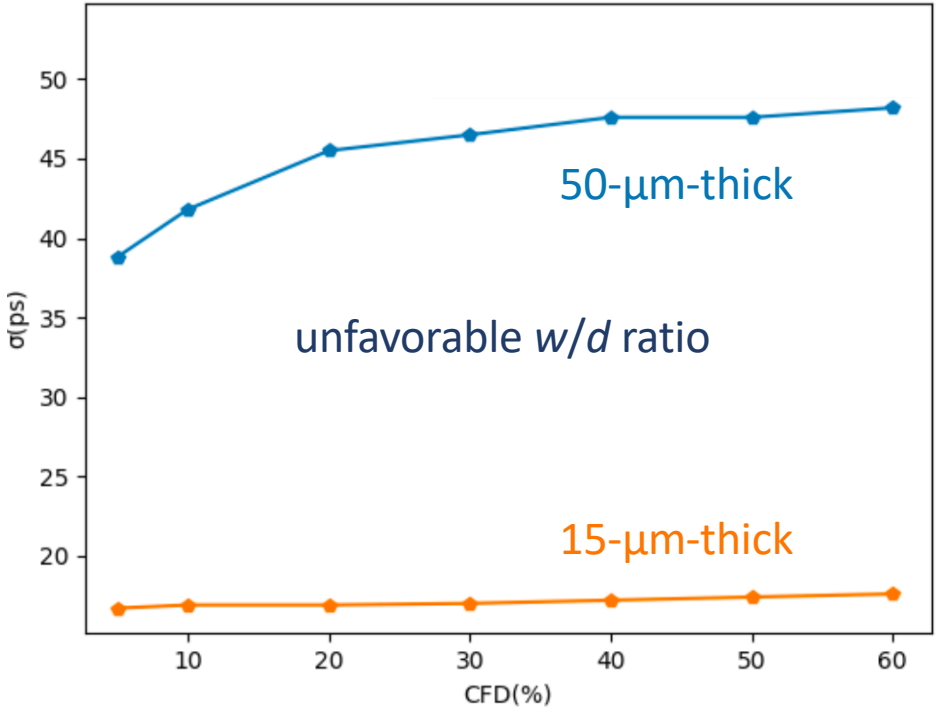
σ_t simulations with MC

Time resolution vs. sensor width

noise: **150 e⁻ RMS**
width: **40 µm**

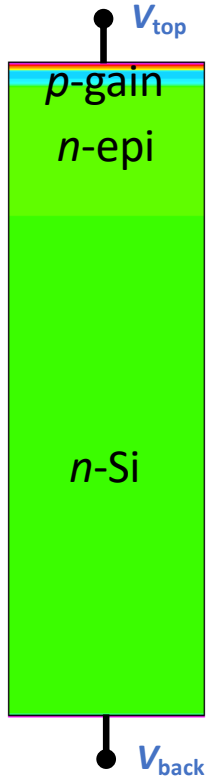


noise: **150 e⁻ RMS**
width: **70 µm**

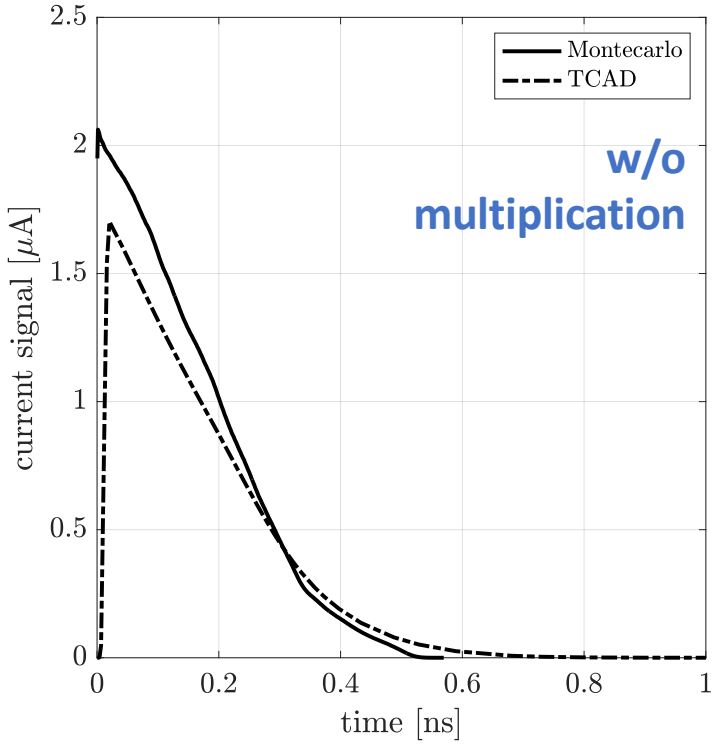


Optimization of simulation tools

Signal simulations w/ and w/o default models (and parameters) for **TCAD** and **Montecarlo**



PRE-optimization

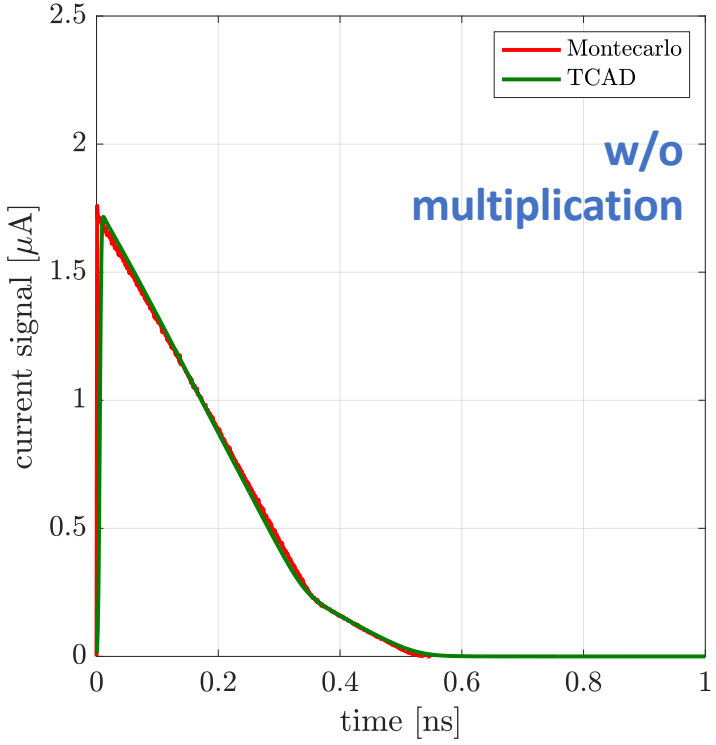


Elements involved in the tuning:

- **Masetti-Canali** mobility model
- transient **timestep** (~ 1 ps)
- **mesh** spacing
- number of **pairs/µm** (~ 80)

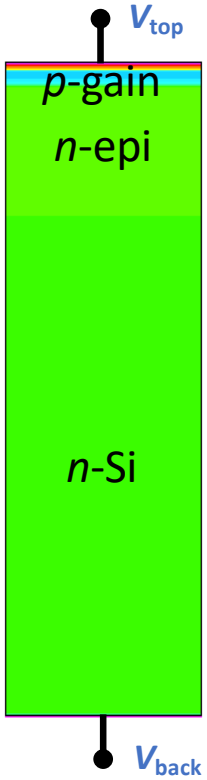
- **extended-Canali** mobility model
- transient **MaxStep** (~ 1 ps)
- **track width**
- number of **pairs/µm** (~ 70)

POST-optimization

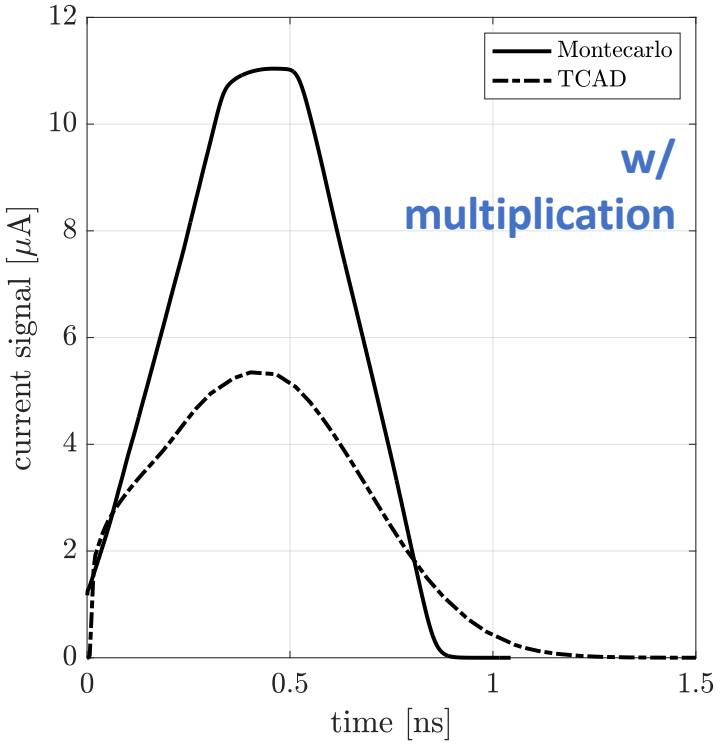


Optimization of simulation tools

Signal simulations w/ and w/o default models (and parameters) for **TCAD** and **Montecarlo**



PRE-optimization



Elements involved in the tuning:

- **Masetti-Canali** mobility model
- transient **timestep** (~ 0.1 ps)
- **mesh** spacing
- number of **pairs/μm** (~ 80)

- **extended-Canali** mobility model
- transient **MaxStep** (~ 0.5 ps)
- **track width**
- number of **pairs/μm** (drastically reduced to get rid of *space-charge effects*)

POST-optimization