Next generation silicon pixel detectors: towards **picosecond timing**

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UNIVERSITÉ DE GENÈVE

Swiss National Science Foundation

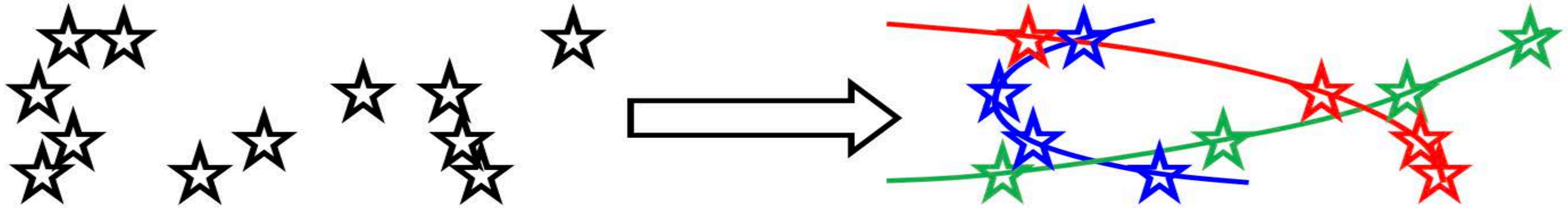
European Research Council
Established by the European Commission

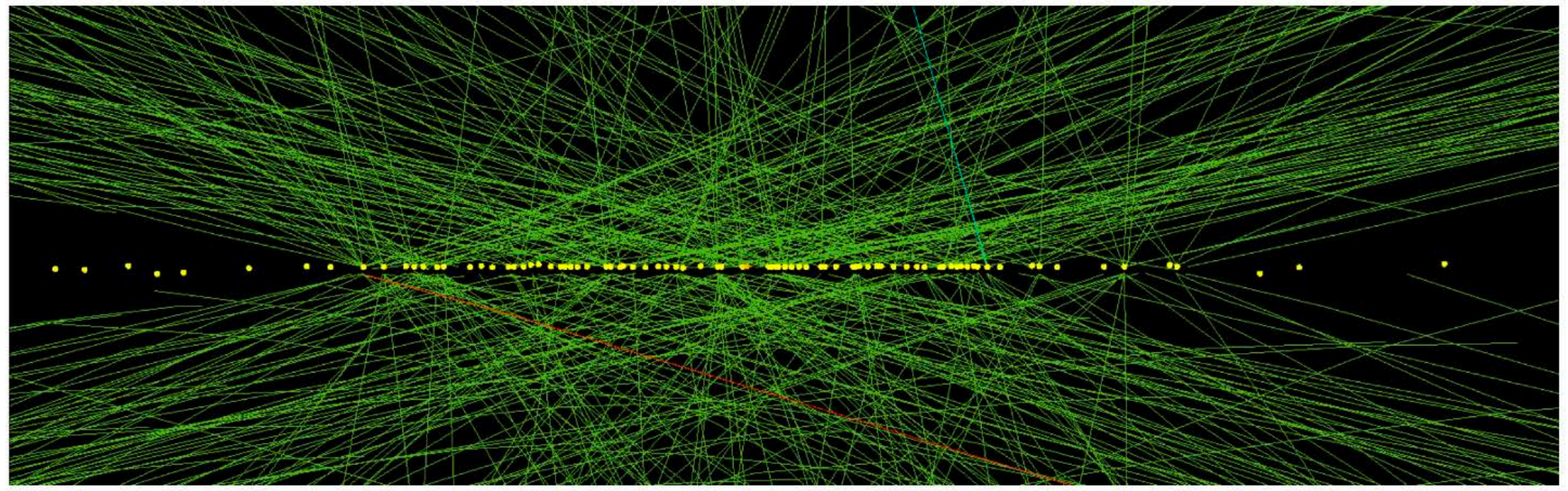
Precise timing measurement at HL-LHC

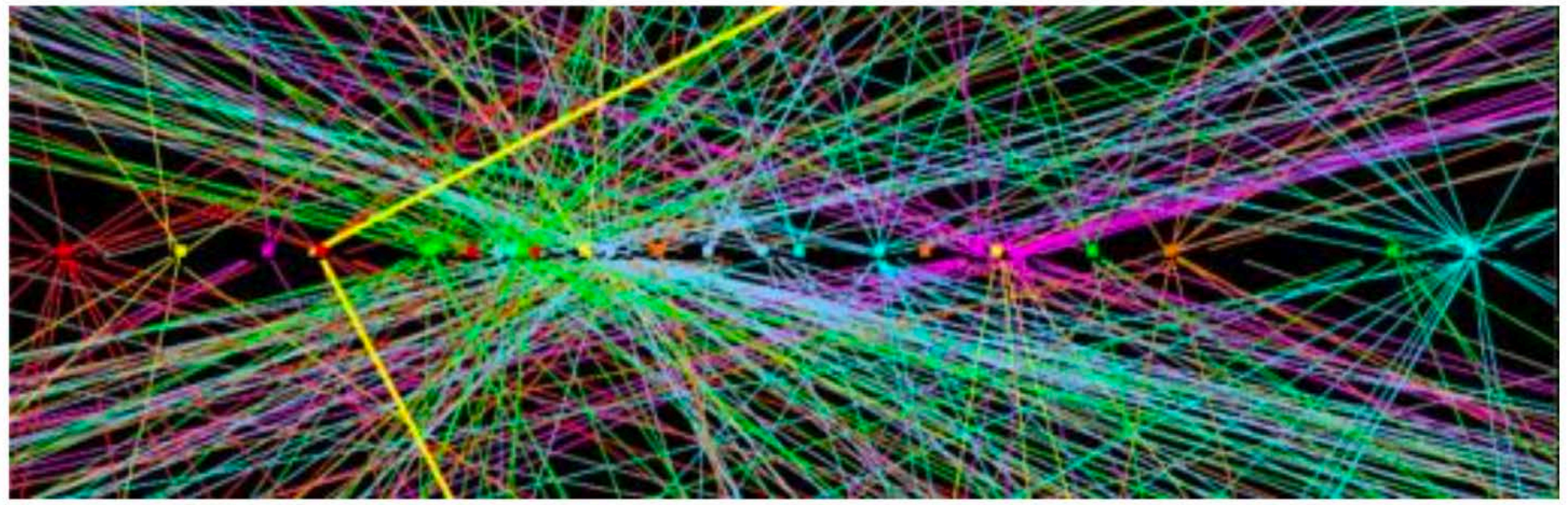
- High Luminosity LHC (**HL-LHC**, starting in 2029): expect a pile-up of **150-200 events per bunch crossing**
- Timing and spatial resolution of standard silicon trackers not sufficient: *10-15% of vertexes composed of 2 events*

Pile-up without timing:

Pile-up with precise timing – 4D tracking:







H. Sadrozinski, A. Seiden and N. Cartiglia, 2018 Rep. Prog. Phys. ***81*** *026101*

Requirements for silicon detectors for **4D tracking at the HL-LHC:**

- Time resolution: ***30 ps***
- Spatial granularity: **~1 mm** (timing information assigned to the track)
- Radiation tolerance: $\gtrsim 10^{15}\ n_{eq}\cdot cm^{-2}$

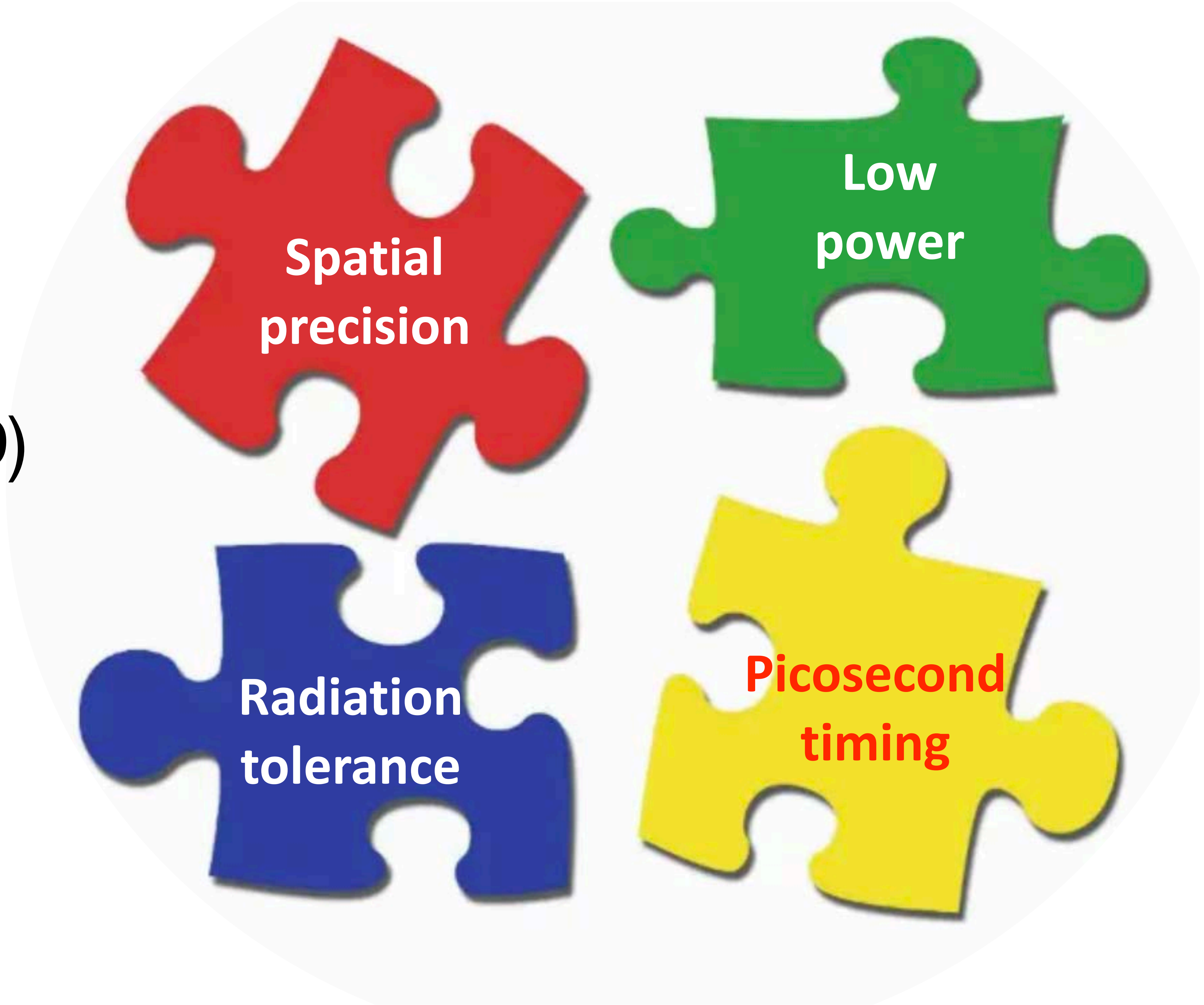
Precise timing with silicon

Timing resolution in silicon pixel detectors mainly determined by:

1. Sensor **geometry and fields**
2. **Charge-collection** (Landau) noise
3. **Electronic** noise
4. **Gain**: Internal charge multiplication (except 3D)

Challenge:

Optimise these parameters for **picosecond timing** while maintaining **other performance requirements**



1. Sensor geometry and fields

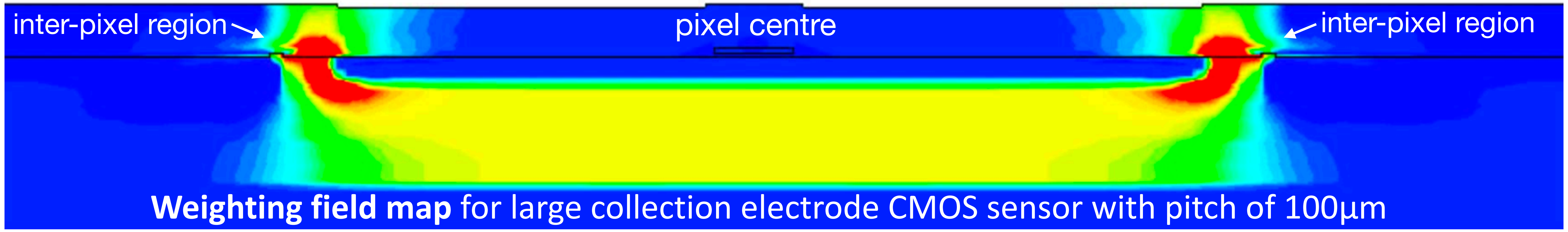
Sensor geometry needs to guarantee ***fast and uniform time response***:

- High and uniform **electric field** (charge transport with uniform and saturated **drift velocity**)
- High and uniform **weighting field** (fast and uniform **signal induction**)

$$I_{ind} = \sum_i q_i \, \overrightarrow{v}_{drift,i} \cdot \overrightarrow{E}_{w,i}$$

Challenge:

- **Small pixels** introduce **low and non-uniform electric and weighting field** regions:



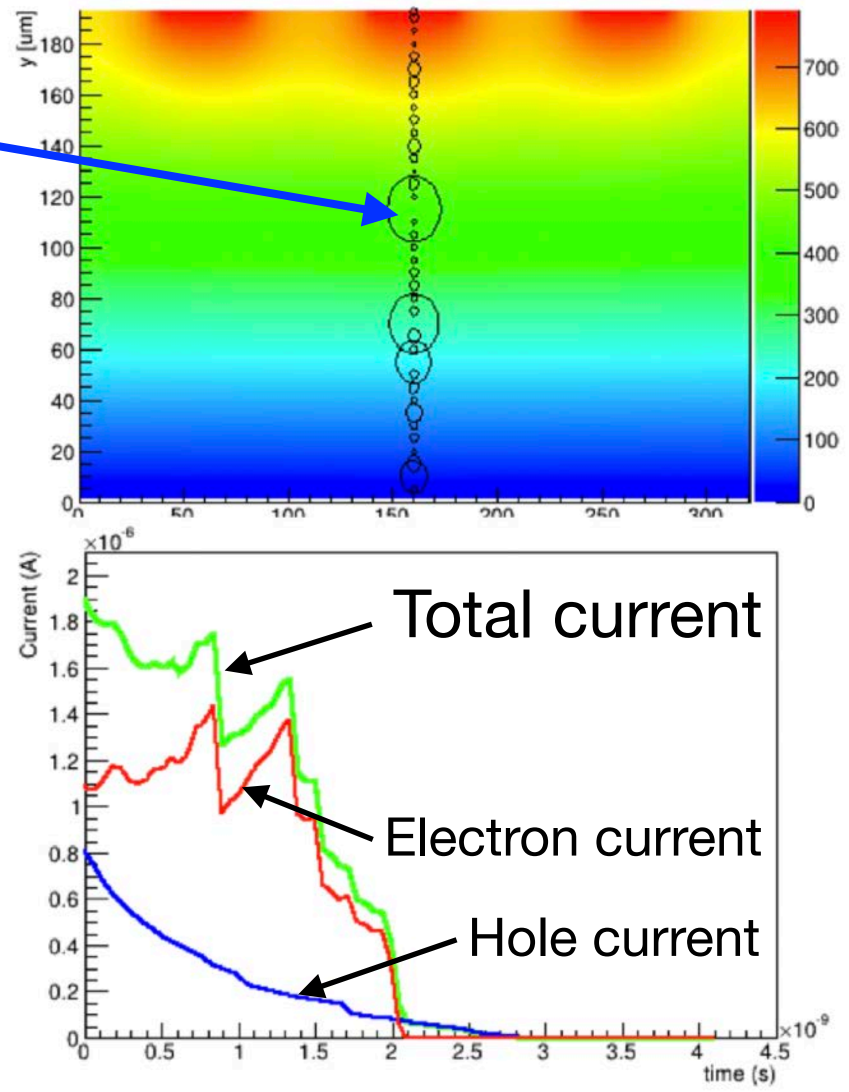
Red = high
Blue = low

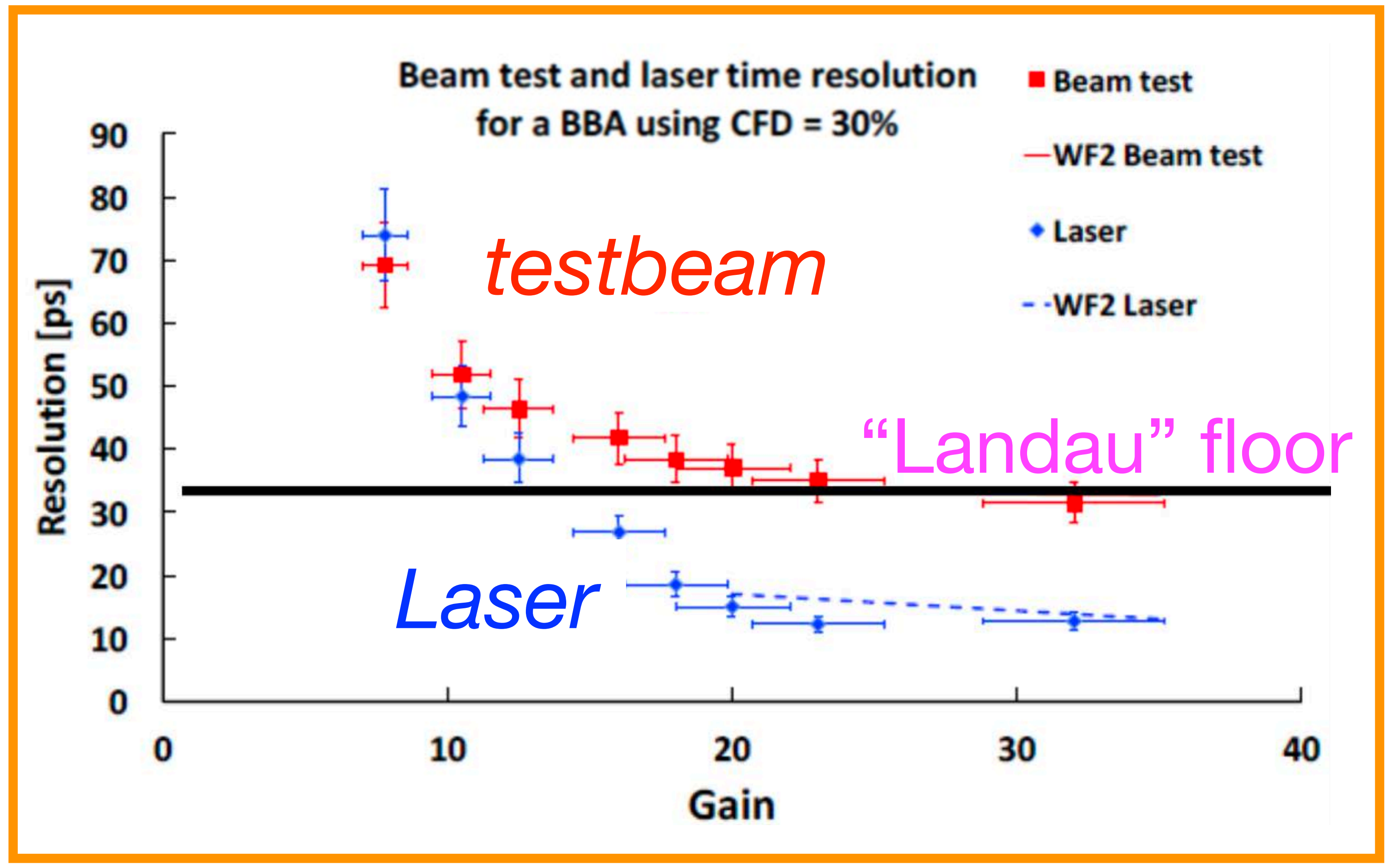
L. Paolozzi PhD thesis, 2014 – http://www.infn.it/thesis/thesis_dettaglio.php?tid=11828

Sensor design needs to reduce **charge-collection noise**:

Non uniform charge deposition along particle track induces a **jitter in the current pulse**

$$I_{ind} = \sum_i q_i \vec{v}_{drift,i} \cdot \vec{E}_{w,i}$$





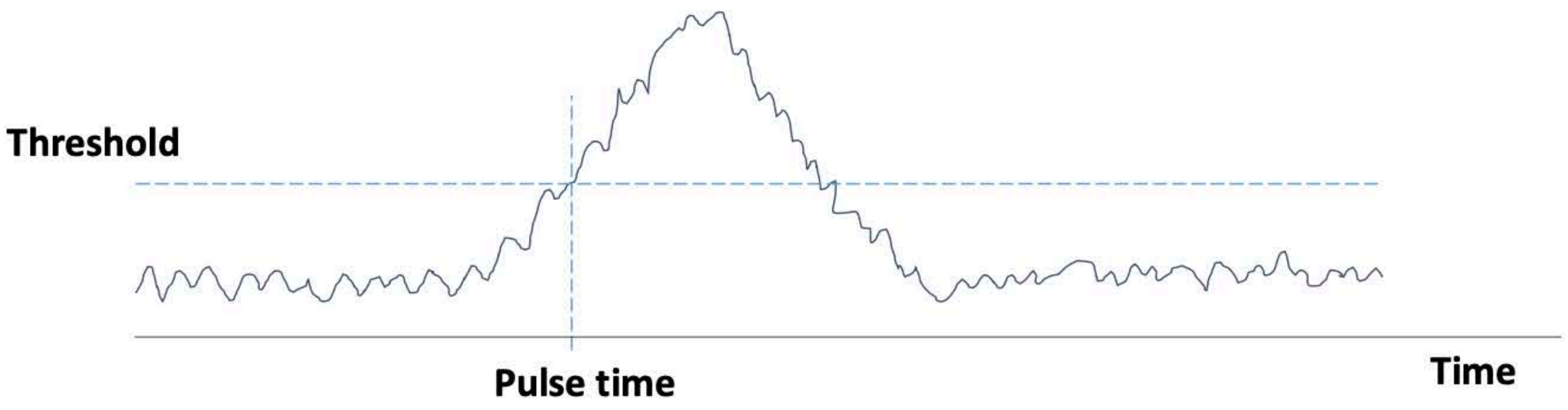
The **statistical origin** of this variability of I_{ind} makes this effect **irreducible in PN-junction sensors**

H. Sadrozinski, A. Seiden and N. Cartiglia, 2018 Rep. Prog. Phys. ***81*** *026101*

Way out: **thinning** of the sensor

Challenge: although thin sensors reduce charge collection noise, they are typically bad for Signal/Noise (less ionization + increased capacitive coupling to sensor backside)

Once the geometry has been fixed, the time resolution depends mostly on the **amplifier performance:**



$$\sigma_t = \frac{\sigma_V}{\frac{dV}{dt}} = \frac{A_{Gain} \cdot ENC}{A_{Gain} \cdot I_{ind}} \cong \frac{t_{rise}}{\frac{Q}{ENC}} = \frac{t_{rise}}{Signal/_{Noise}}$$

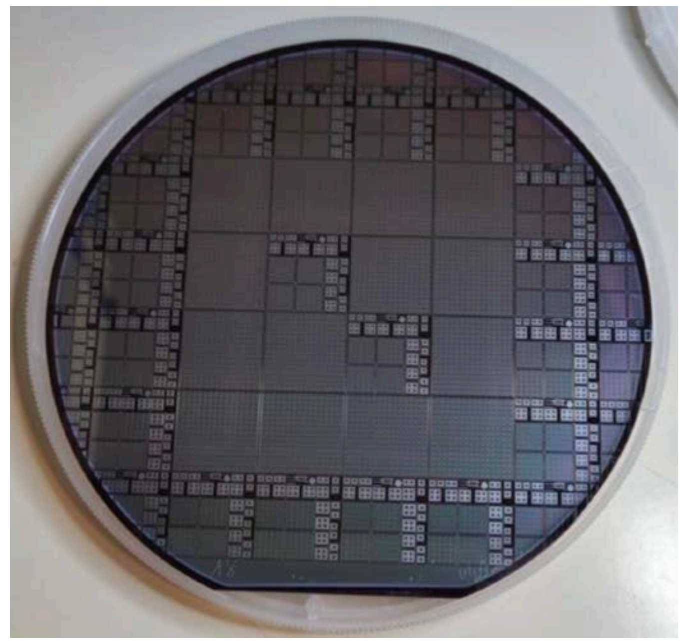
➔ Need an **ultra-fast**, **high-gain**, **low-noise** (low power-consumption) electronics with **fast risetime** and **small capacitance**

Towards ps timing: Outline

Under the impulse of the High Energy Physics community, a new generation of silicon sensors for timing is being developed:

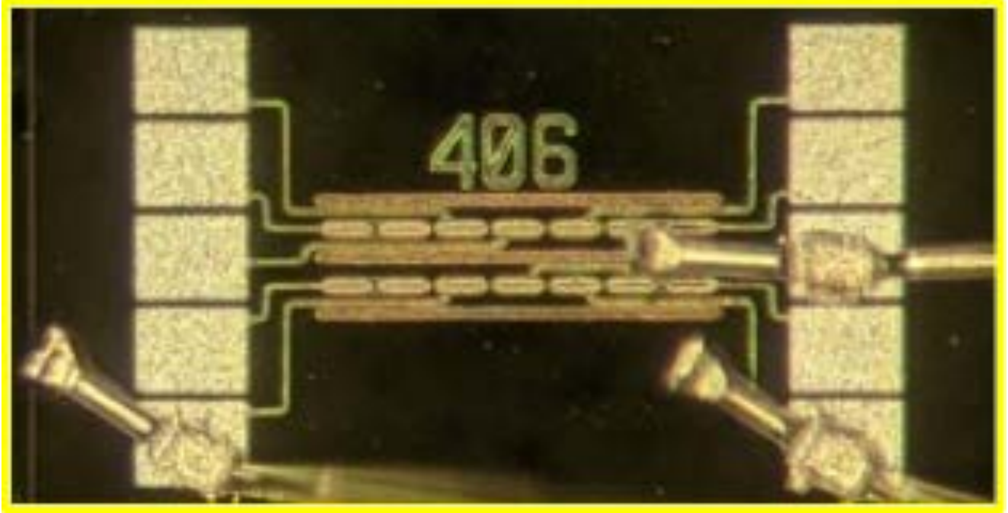
30 ps sensors:

- **LGAD** (Low-Gain Avalanche Detector)
  - ➡ TI-LGAD (Trench-Isolated LGAD)
  - ➡ AC-Coupled (Resistive) LGAD

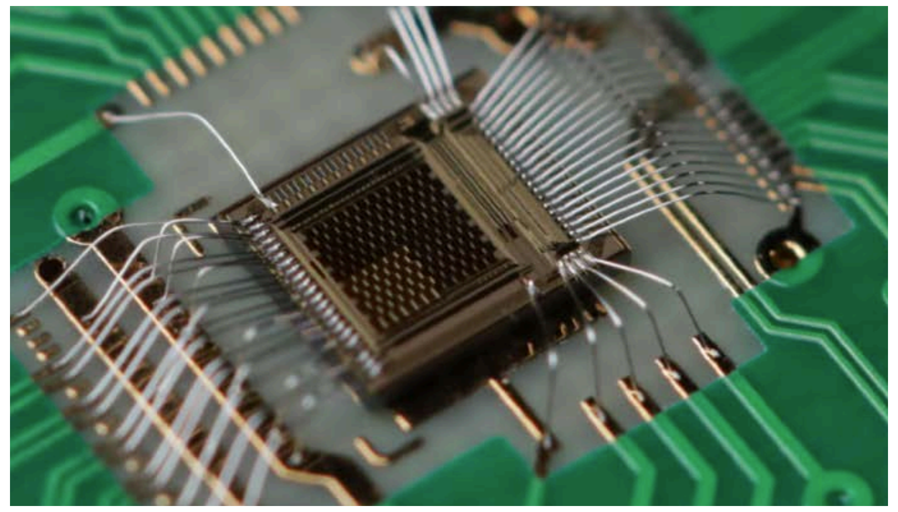


10 ps sensors:

- **3D** sensors (TIMESPOT Project)



- **PicoAD** (MONOLITH Project)



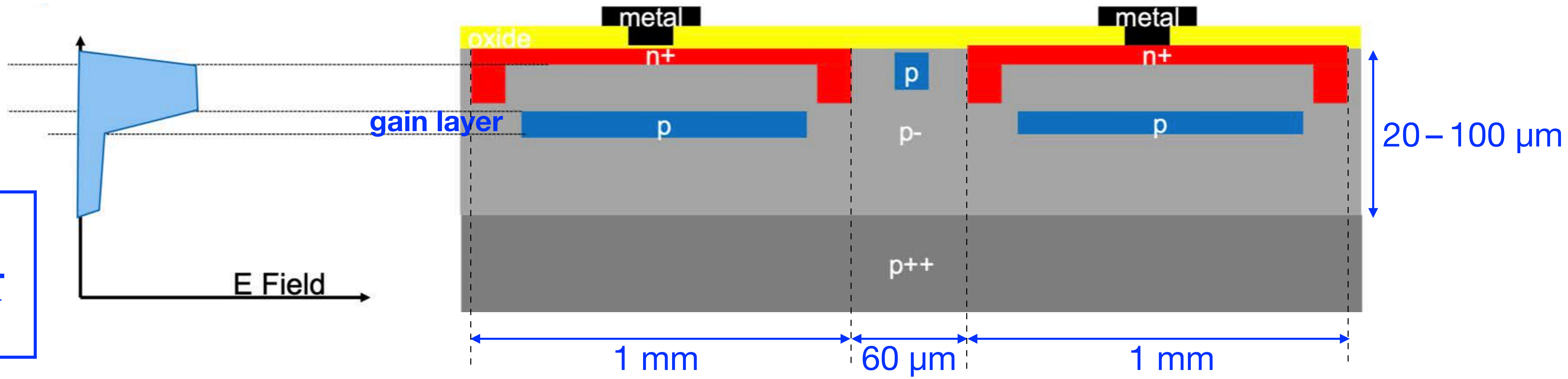
Low Gain Avalanche Detectors

LGAD

Low Gain Avalanche Detectors

LGADs: developed and being produced for HL-LHC

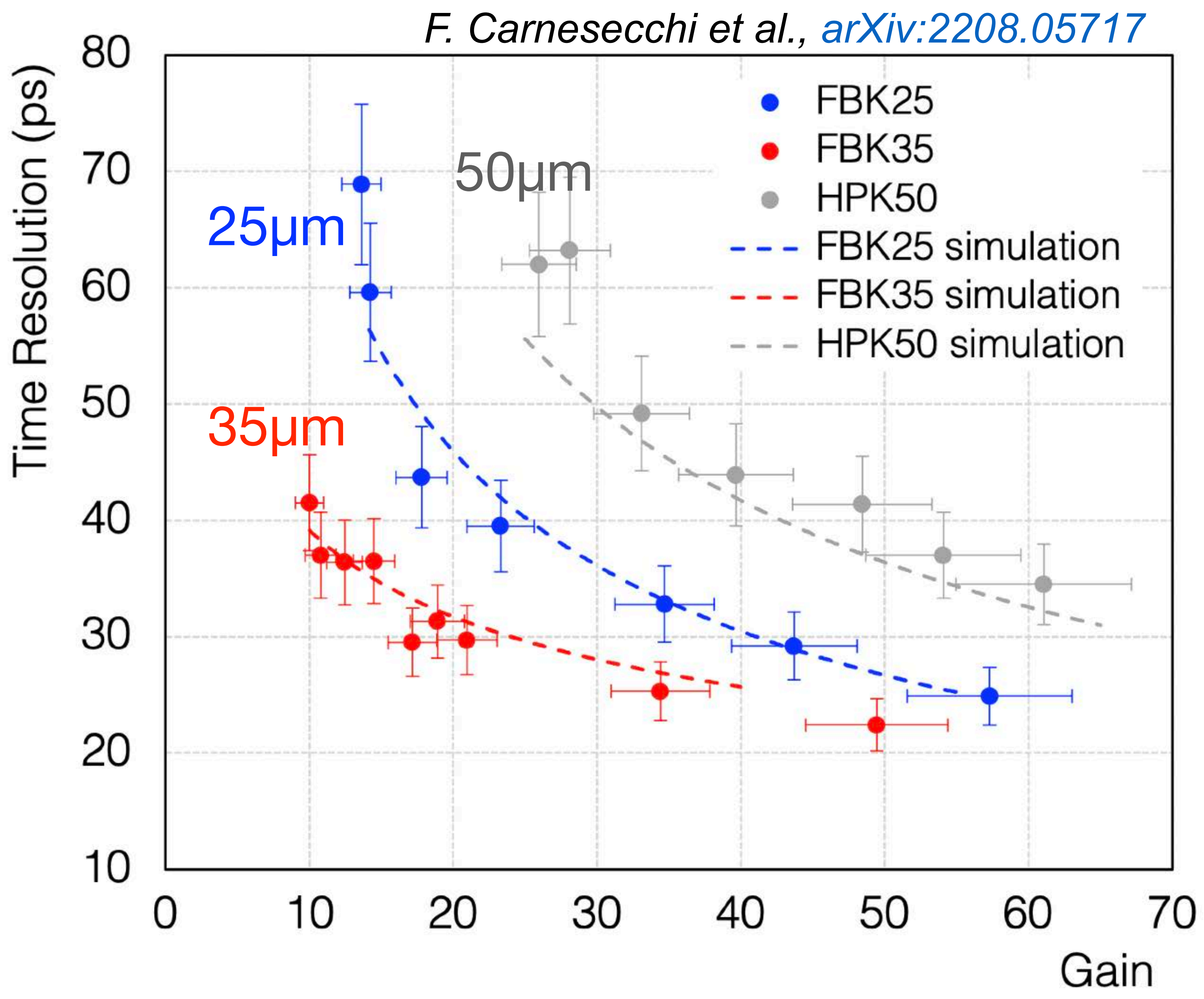
$$\sigma_{time} \approx \frac{t_{rise}}{S/N}$$



- Internal charge multiplication (**gain** = 10 – 20) ⇒ S/N increases and gives better σ_{time}
- **Hybrid** silicon "pad" sensors; 1 mm pads, with ≲100µm inactive inter-pad region
- Depleted thickness 20 – 100 µm
- Time resolution: **25 – 35 ps** (depending on the thickness)

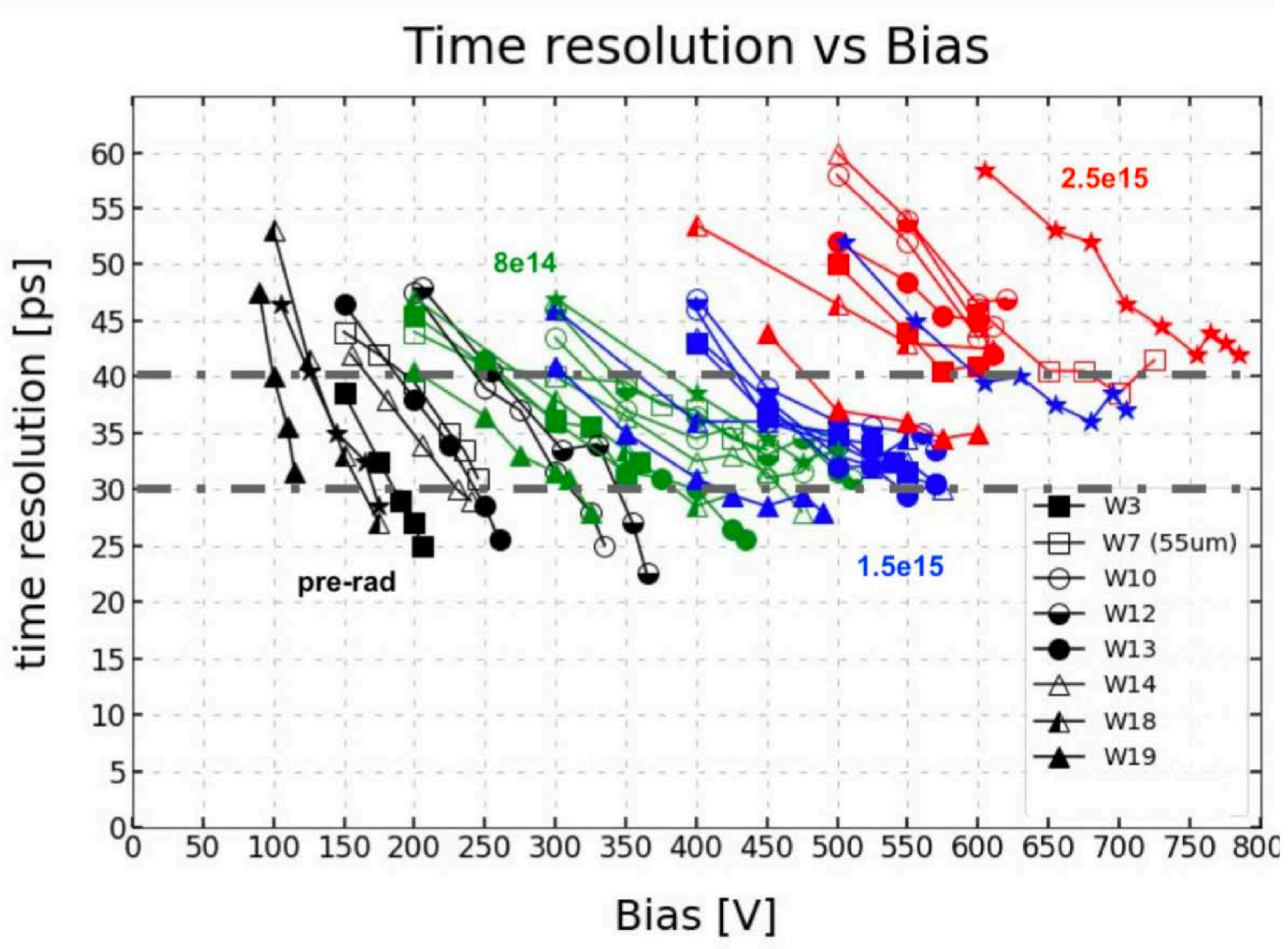
Low Gain Avalanche Detectors

Recent test of **ultra-thin** FBK LGADs :



35 µm thick LGADs approach 25 ps time resolution (mostly due to reduction of Landau-noise jitter)

Demonstrated **radiation tolerance** and time resolution for HL-LHC:

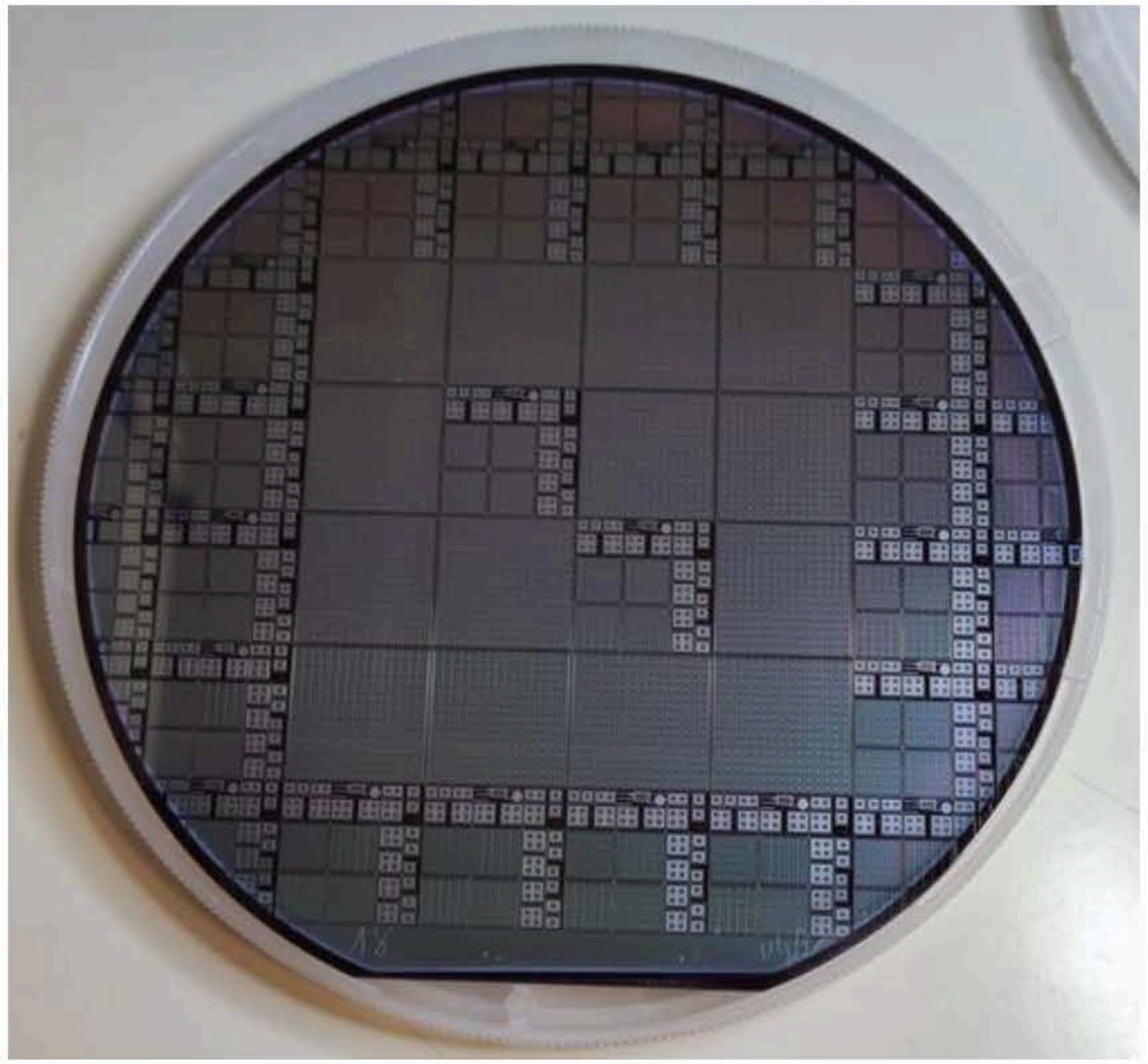


σ_T [ps]	NIEL [n_{eq}/cm^2]
30	$1 \cdot 10^{15}$
40	$2.5 \cdot 10^{15}$

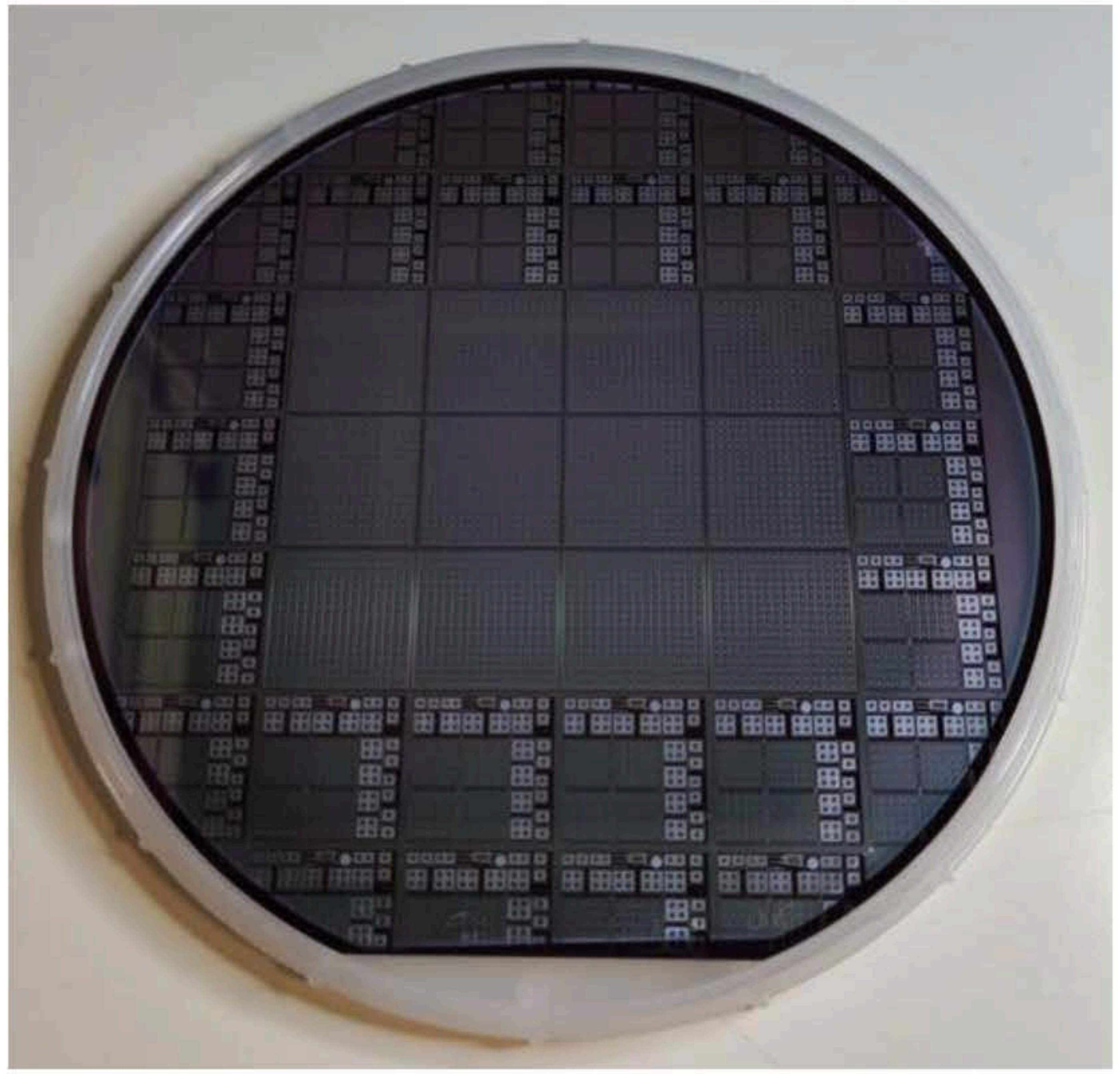
Low Gain Avalanche Detectors

LGADs now being fabricated for the HL-LHC experiments:

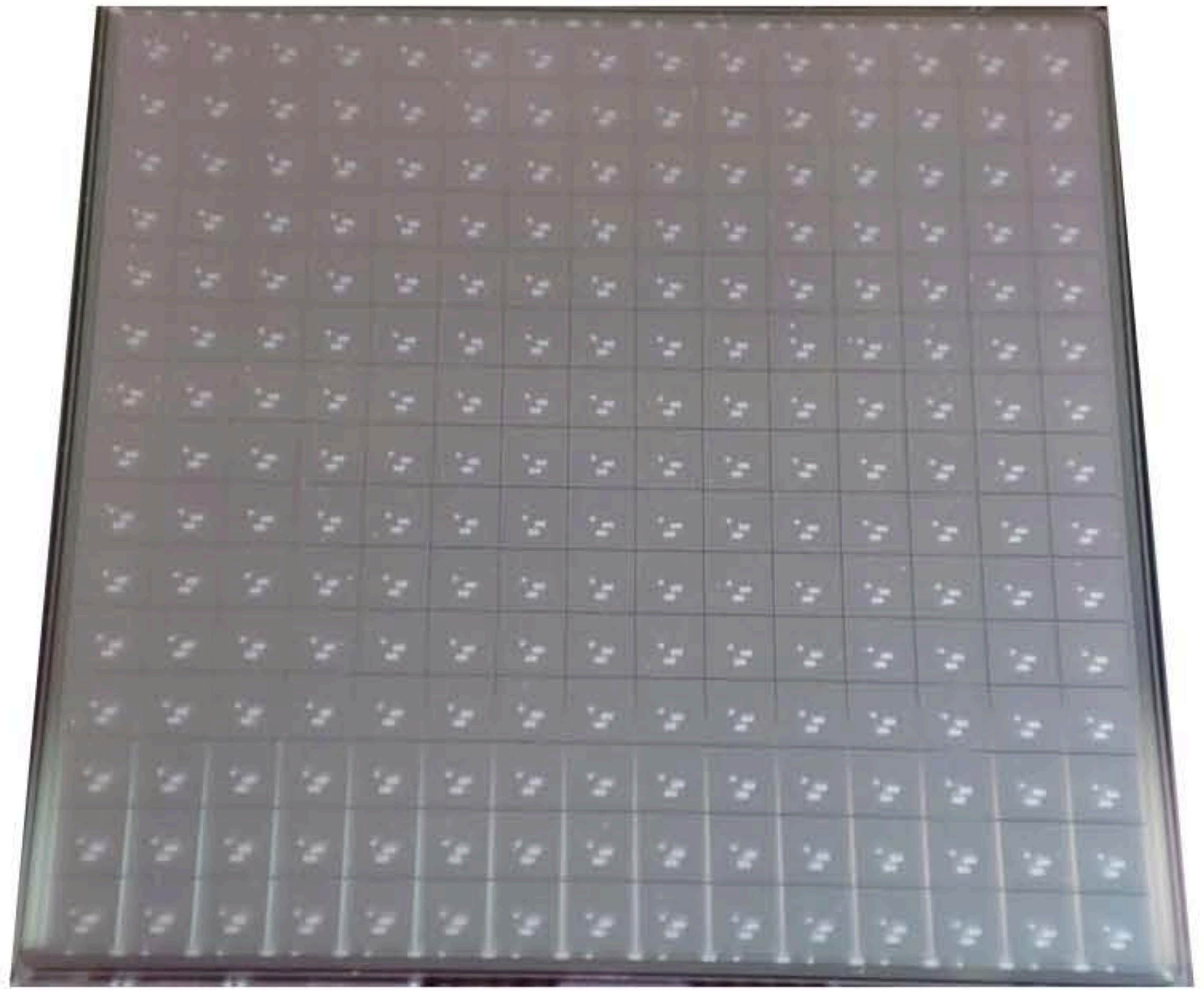
ATLAS - HGTD



CMS - ETL



- Full sensors ~ 2 x 2 cm^2
- 15 x 15 and 16 x 16 arrays
- 1.3 mm^2 pads



UFSD 4 batch for final sensor qualification

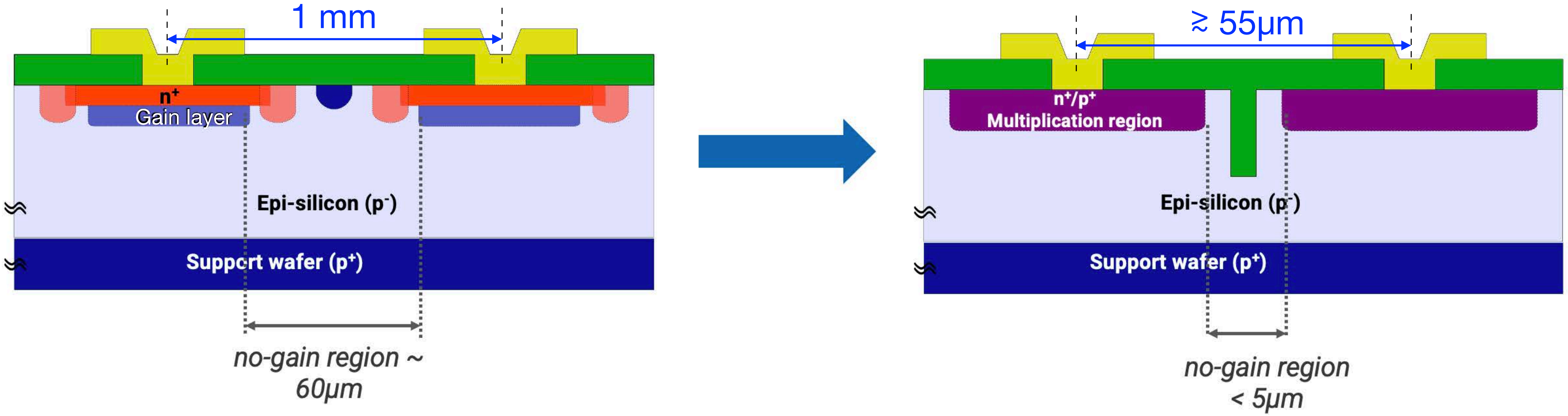
FBK SENSORS AND DEVICES
FONDAZIONE BRUNO KESSLER

(Courtesy of G. Paternoster)

LGAD: from pads to pixels

Standard LGAD

TRENCH-ISOLATED LGAD

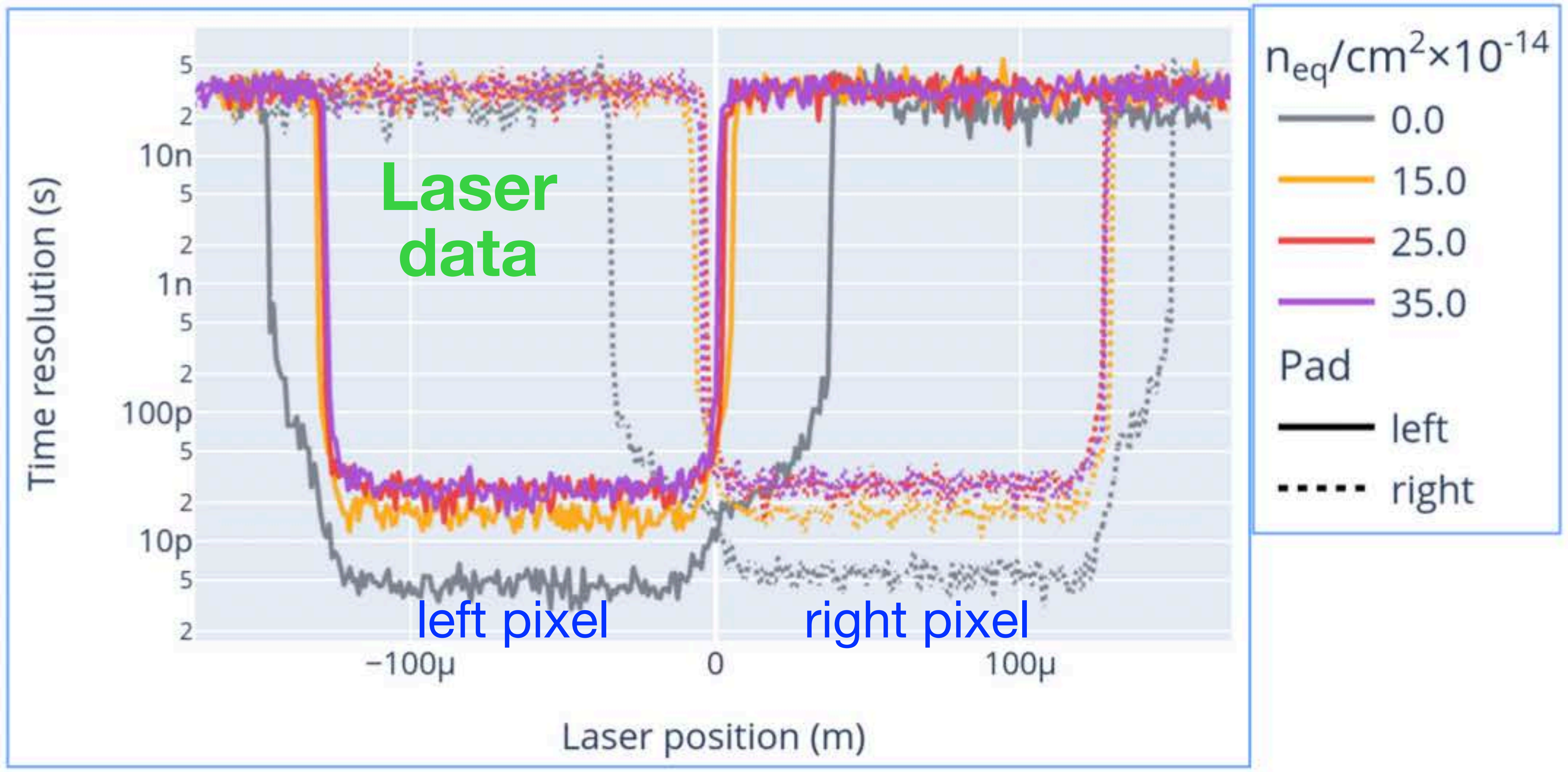


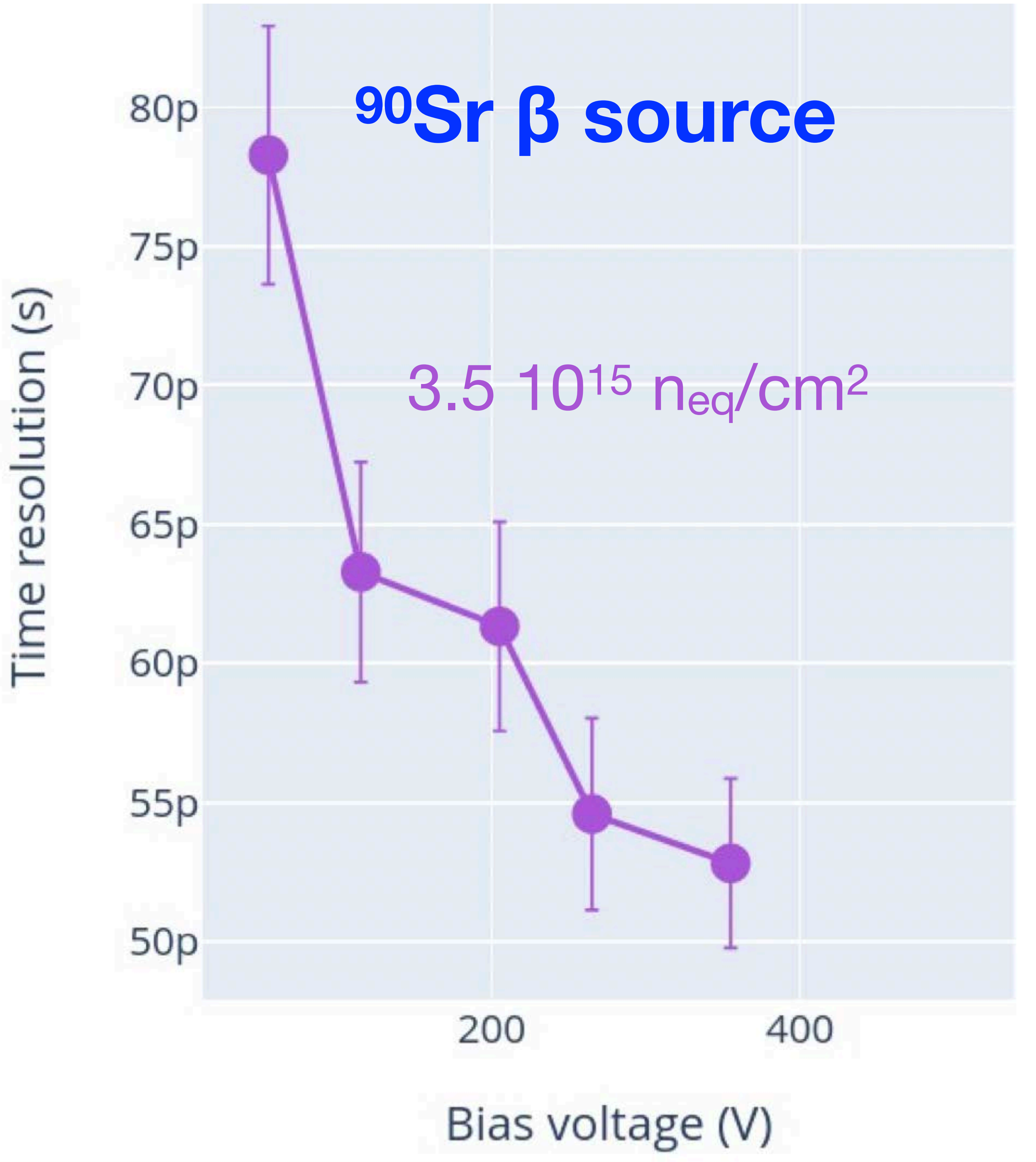
Pixel isolation and termination structures are replaced by a **trench** that:

- is a **few µm deep** and **~1 µm wide**, filled with silicon oxide
- acts as a **drift/diffusion barrier for electrons** and **isolates adjacent pixels**
- reduces the **inactive region in-between pixels** from ~60 µm to **few µm**

Prototypes already produced with pixel pitch down to 55µm

TI-LGAD radiation tolerance





Pixel isolation by **trenches**: good before and after irradiation

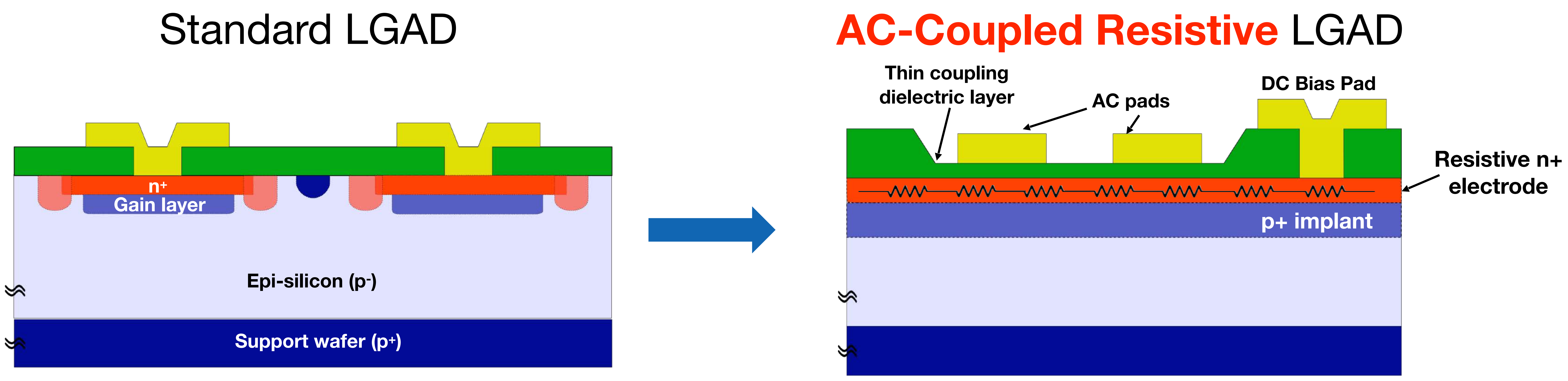
Inter-pixel distance remains of few μm before and after irradiation

Time resolution degraded after irradiation, but still uniform until the edges:

NIEL level:	0	$3.5\cdot10^{15}$ n_{eq}/cm^2
with **laser**:	5ps →	30ps
with **^{90}Sr**:	35ps →	60ps

M. Senger – VCI 2022

Resistive AC-Coupled LGADs



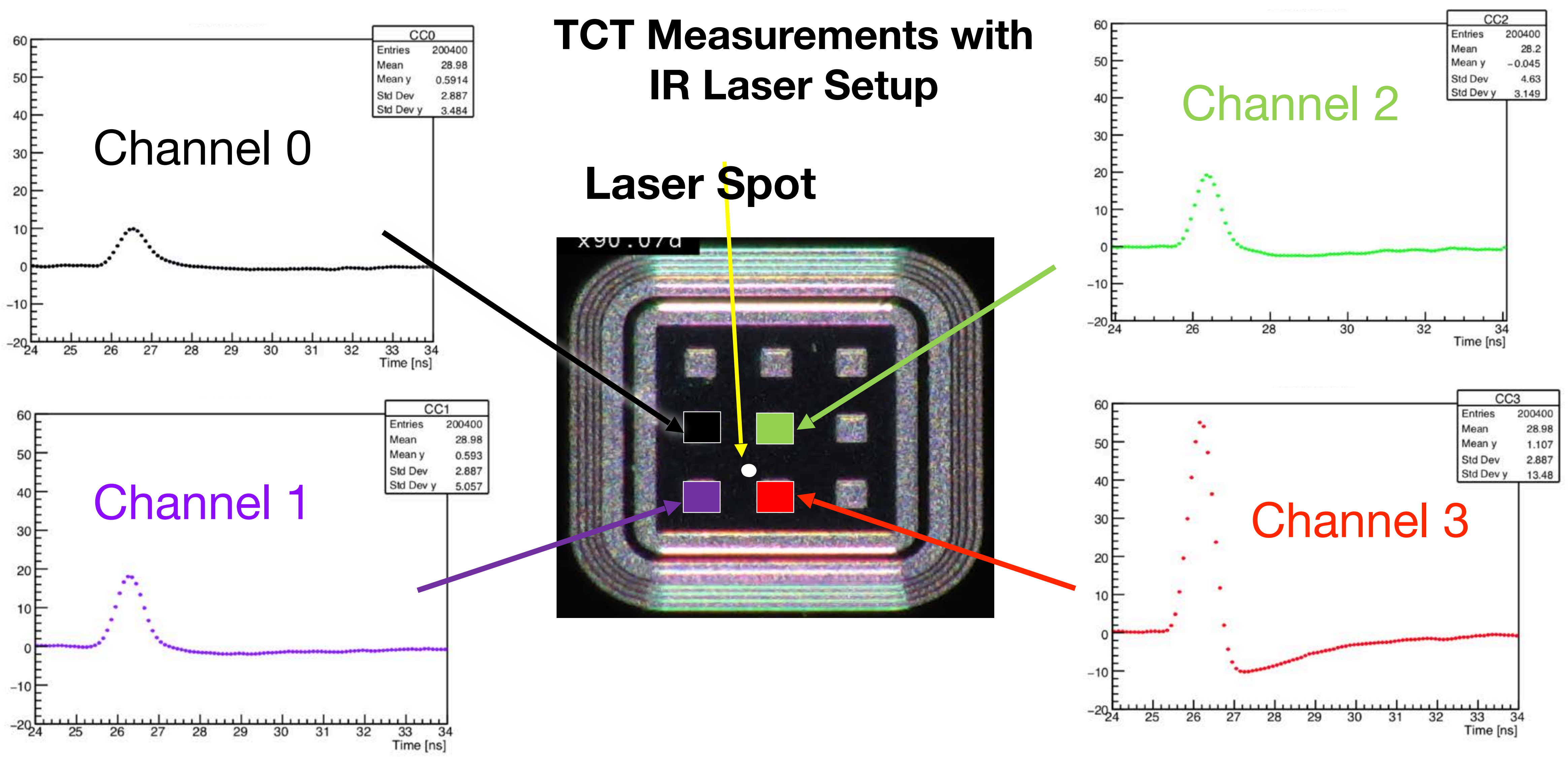
- **AC-coupled** to the **resistive n+ layer** via dielectric coupling
- Gain layer **NOT** segmented: **100% fill factor**

- Note that it is a **different way** to read out the signal and segment the sensor, since the **signal spreads over adjacent pixels**

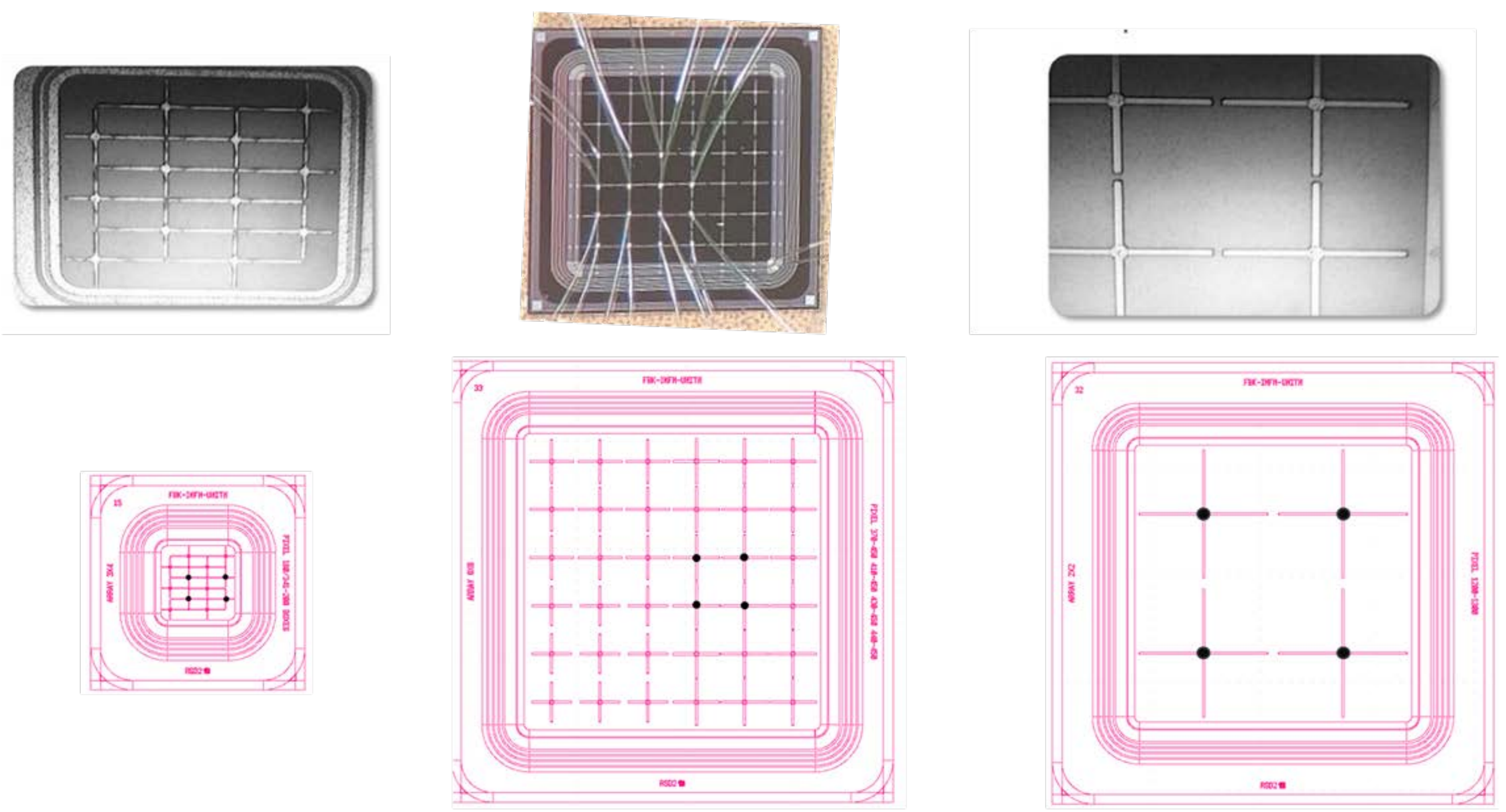
AC-Coupled LGAD: How does it work ?

Signal spreads over adjacent pixels, with **amplitude inversely proportional to the hit distance**

M. Tornago et al., NIMA 1003 (2021) 165319

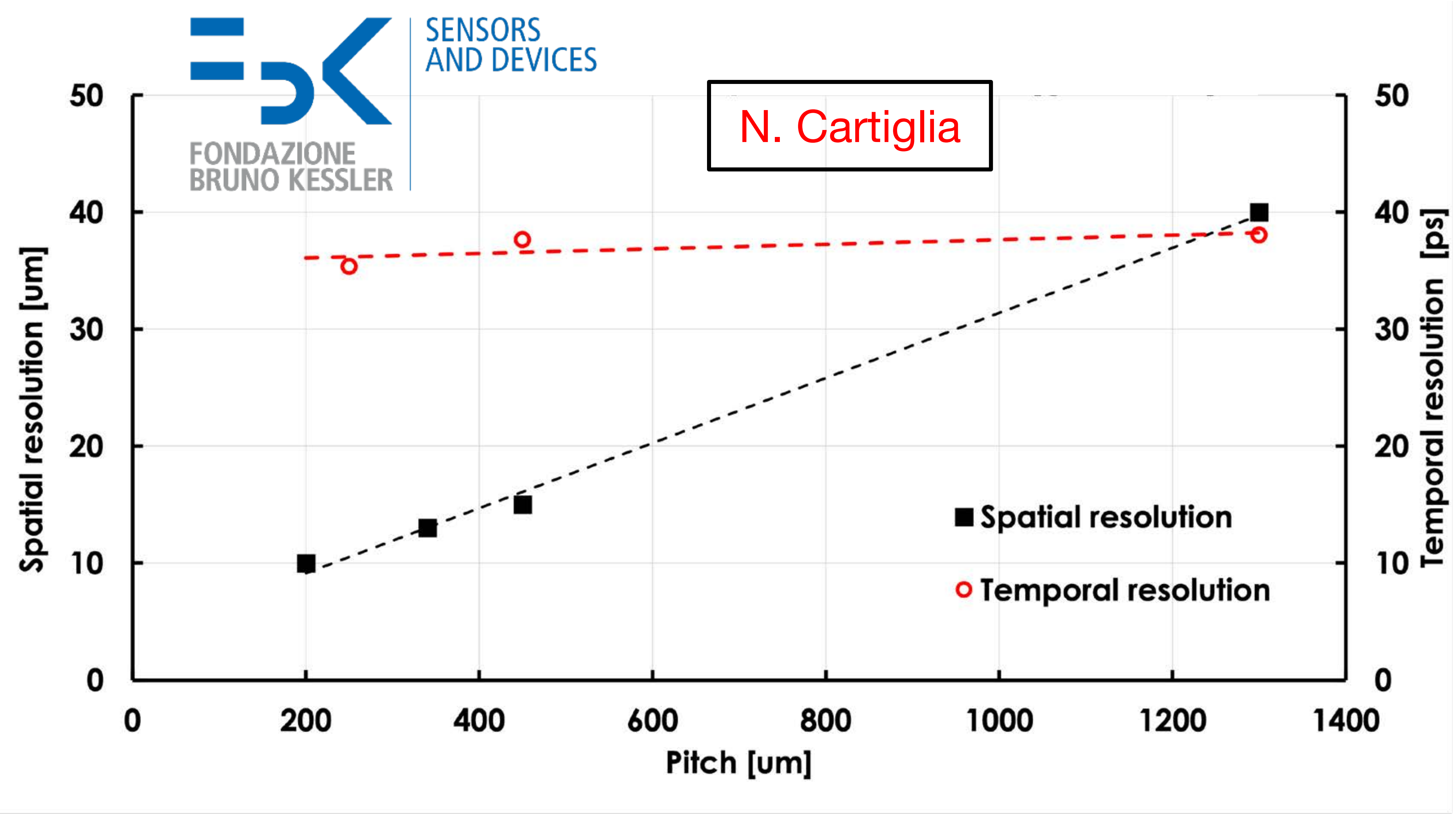


RSD2 production

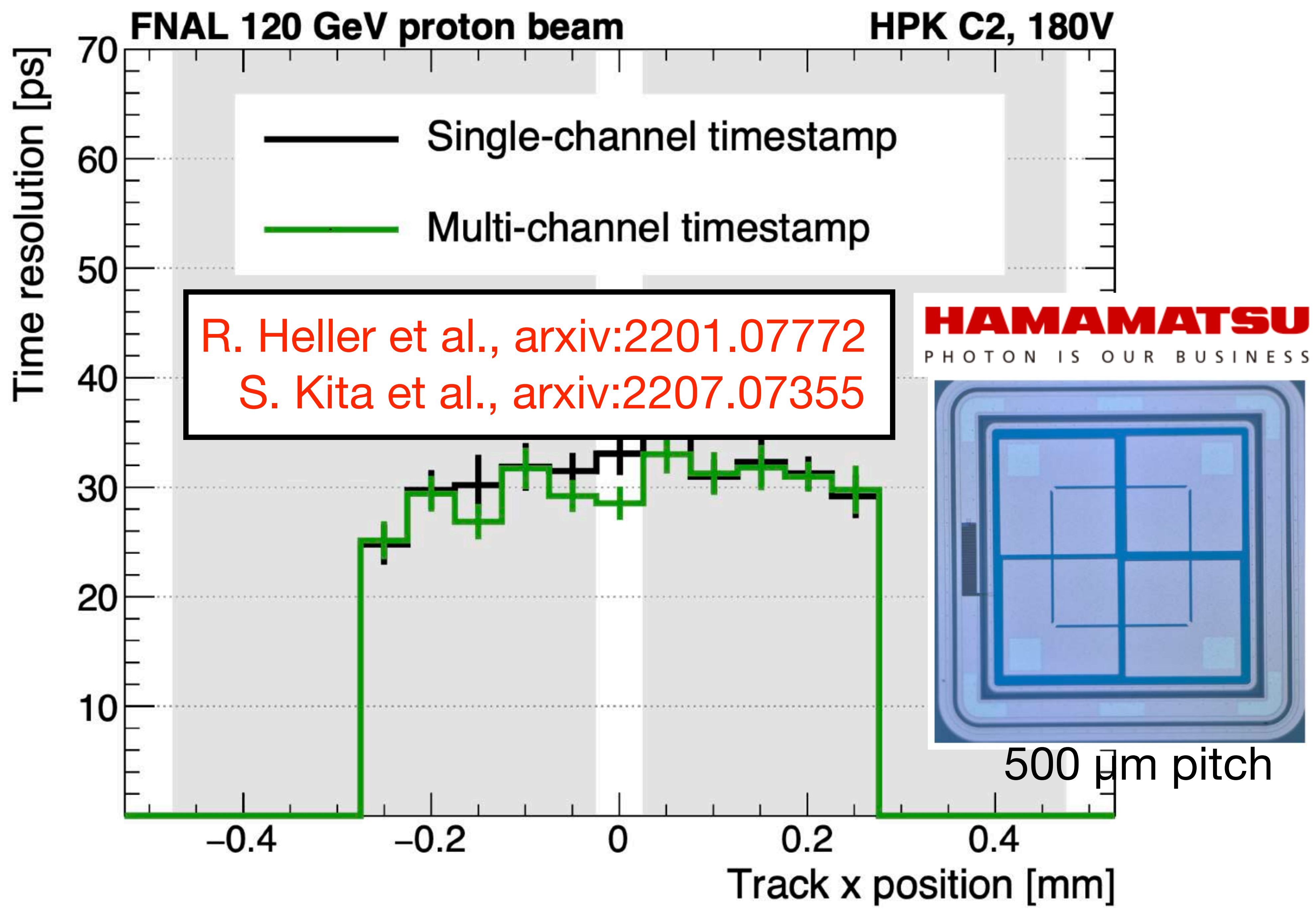


AC-Coupled LGAD

Pixel AC-LGAD by **FBK**



Pixel AC-LGAD by



Time resolution: **30-35 ps**, regardless of pixel pitch

Spatial resolution: **≈ 4μm + 3% of pixel pitch**

AC-Coupled Resistive LGAD

AC-Coupled LGAD is a candidate to combine in future experiments
30ps timing and few μm spatial resolution with a **reduced number of readout channels**

Figure from N. Cartiglia et al., arxiv:2204.06536

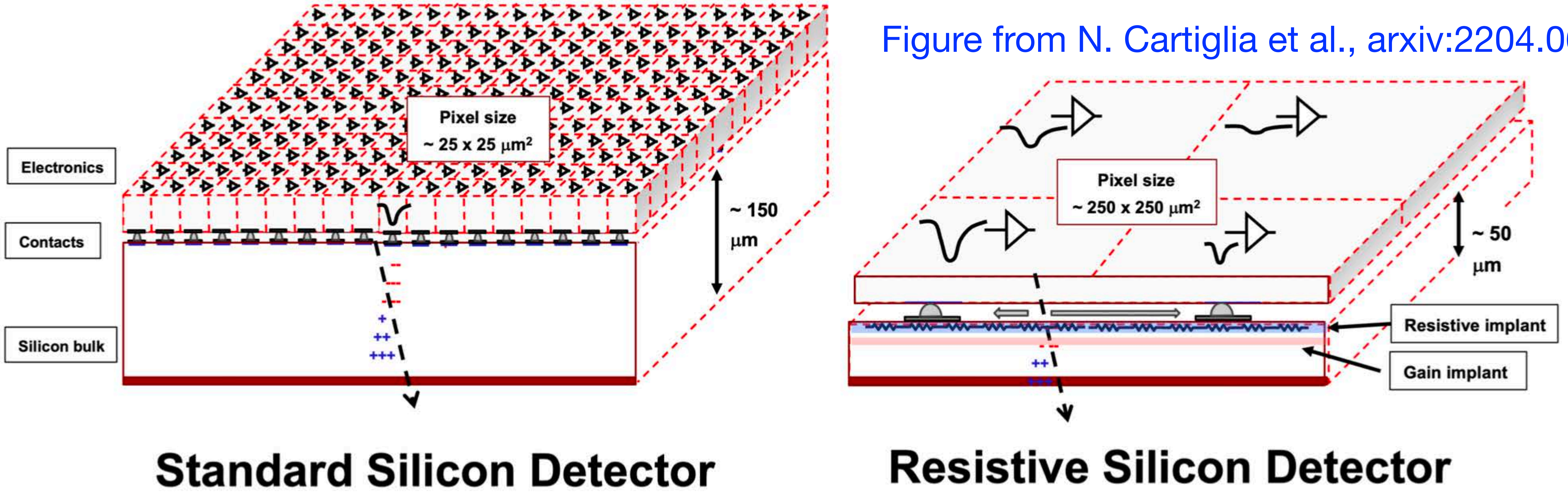


Figure 10: Sketches of a standard silicon detector and of an RSD with the same spatial resolution of about 5-10 μm.

The TIMESPOT Project
3D sensors

"Gain? no thanks! go… Geometric ! "

(A. Lai, INFN)

3D sensors: no gain, but geometry

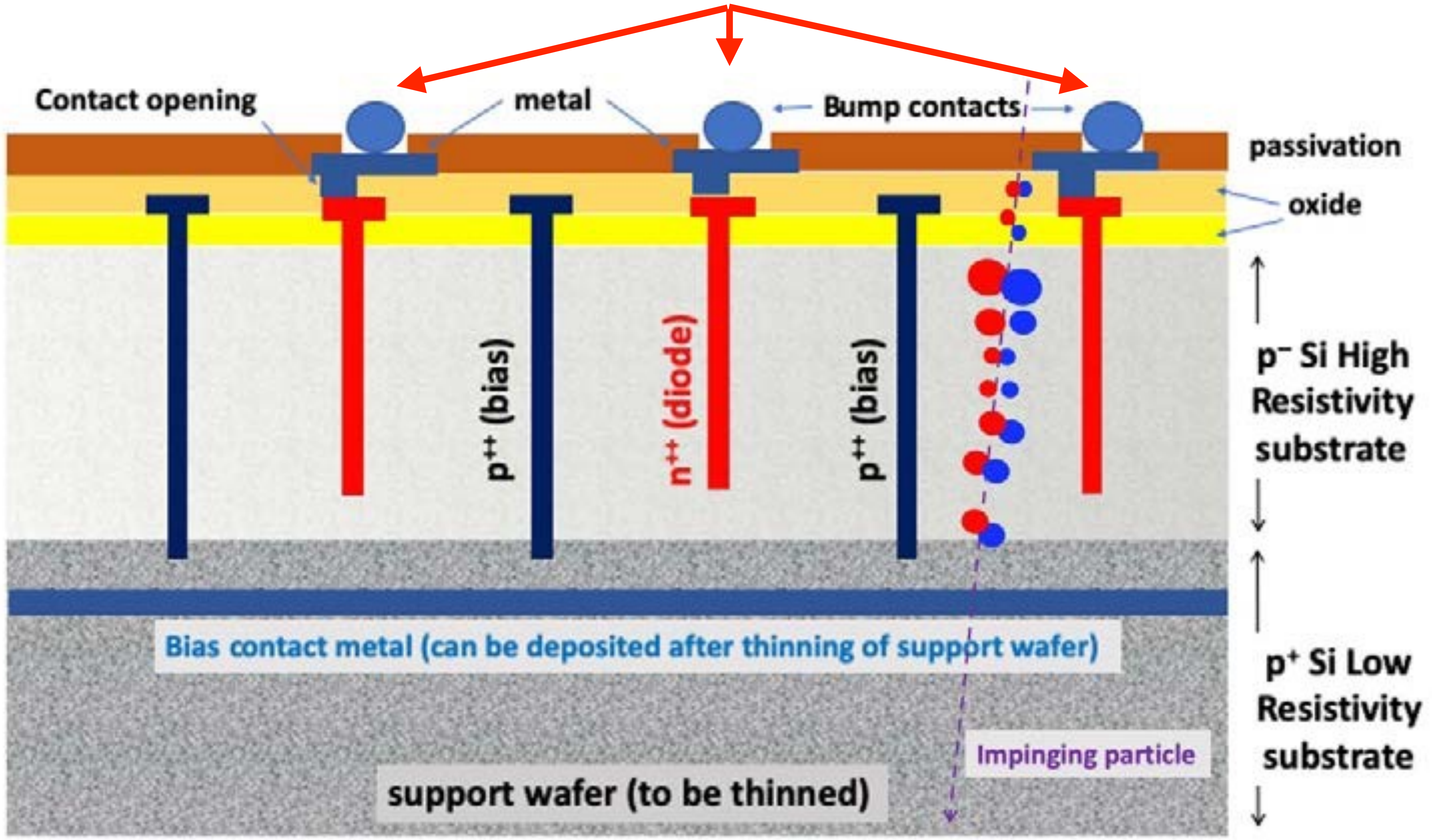
Original idea by Sherwood Parker (1997)

Hybrid sensor in which **collection electrodes** **are vertical highly doped** **columns**

1. Very short drift distance to collection electrode
   ➡ *Fast charge collection*

2. Reduced distance to ohmic contacts
   ➡ *High drift field*
   ➡ *High weighting field*

⇒ *Precise timing*



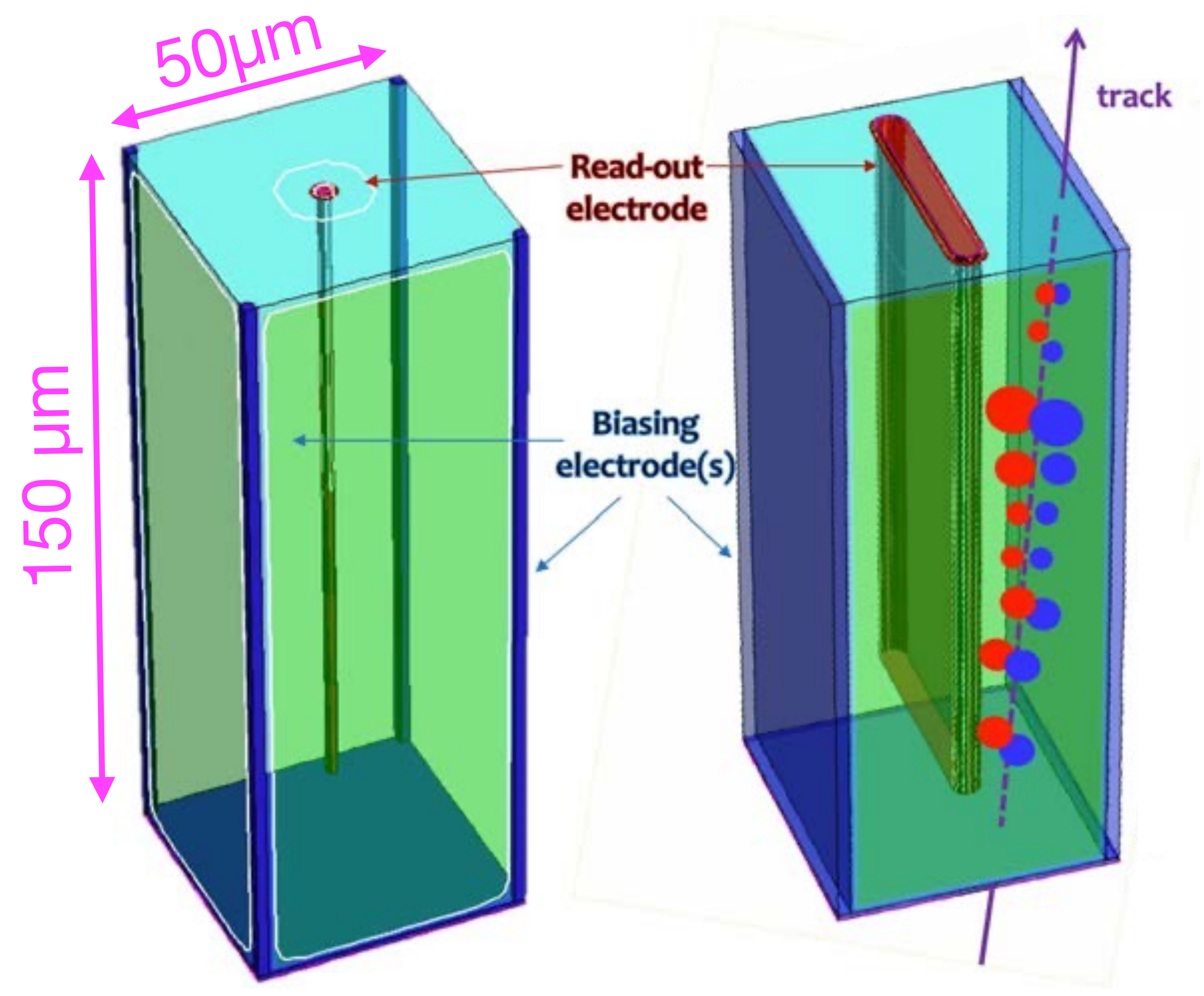
Columns produced by Deep Reactive Ion Etching
(Bosch technology developed for MEMS)

Challenge:

Inefficiency in region of collection electrode at perpendicular particle incidence

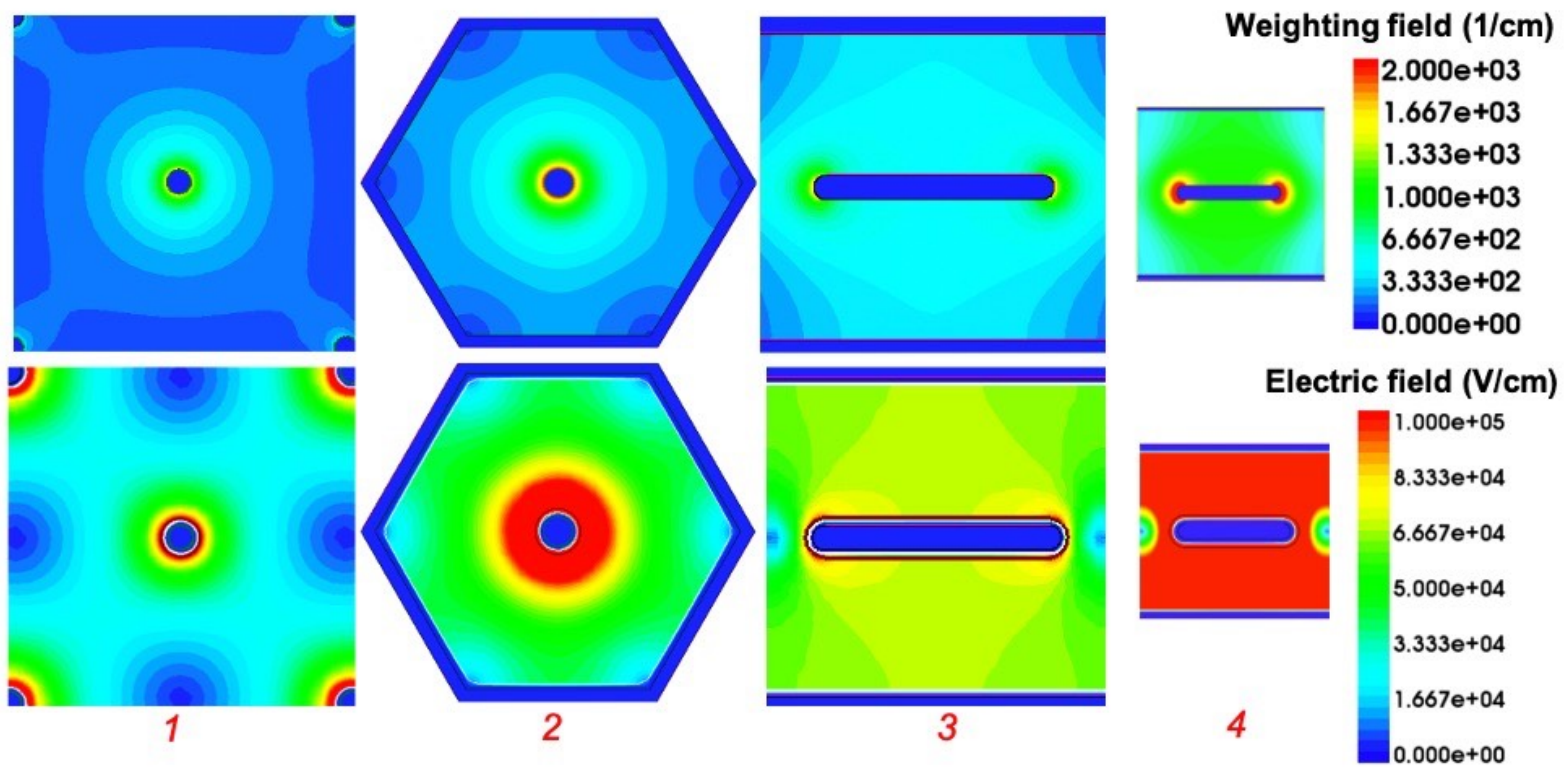
3D sensors

Sensitive volume and electrode shapes designed for maximum performance:



Columns **Trenches**

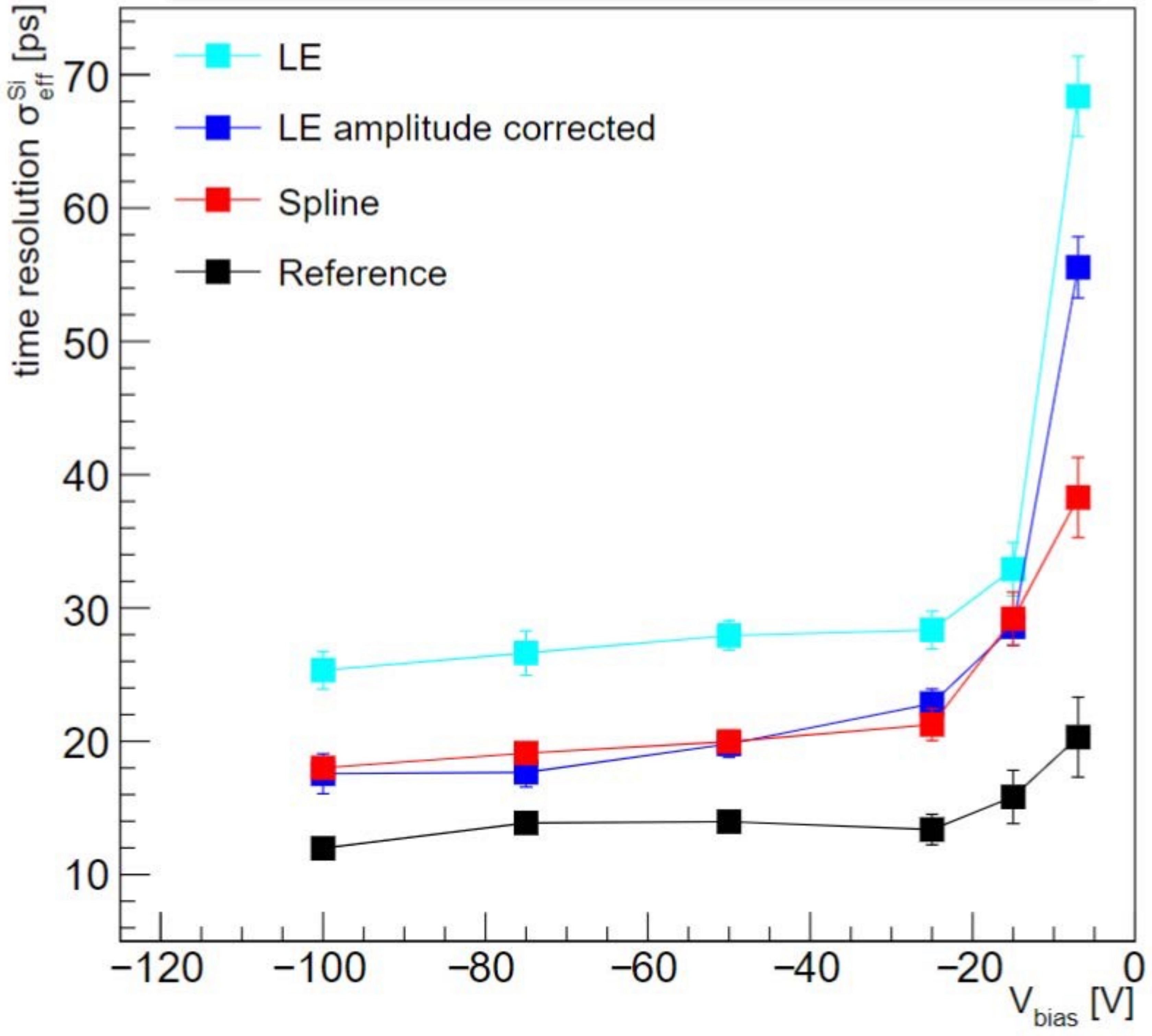
TCAD simulation of three electrode geometries:

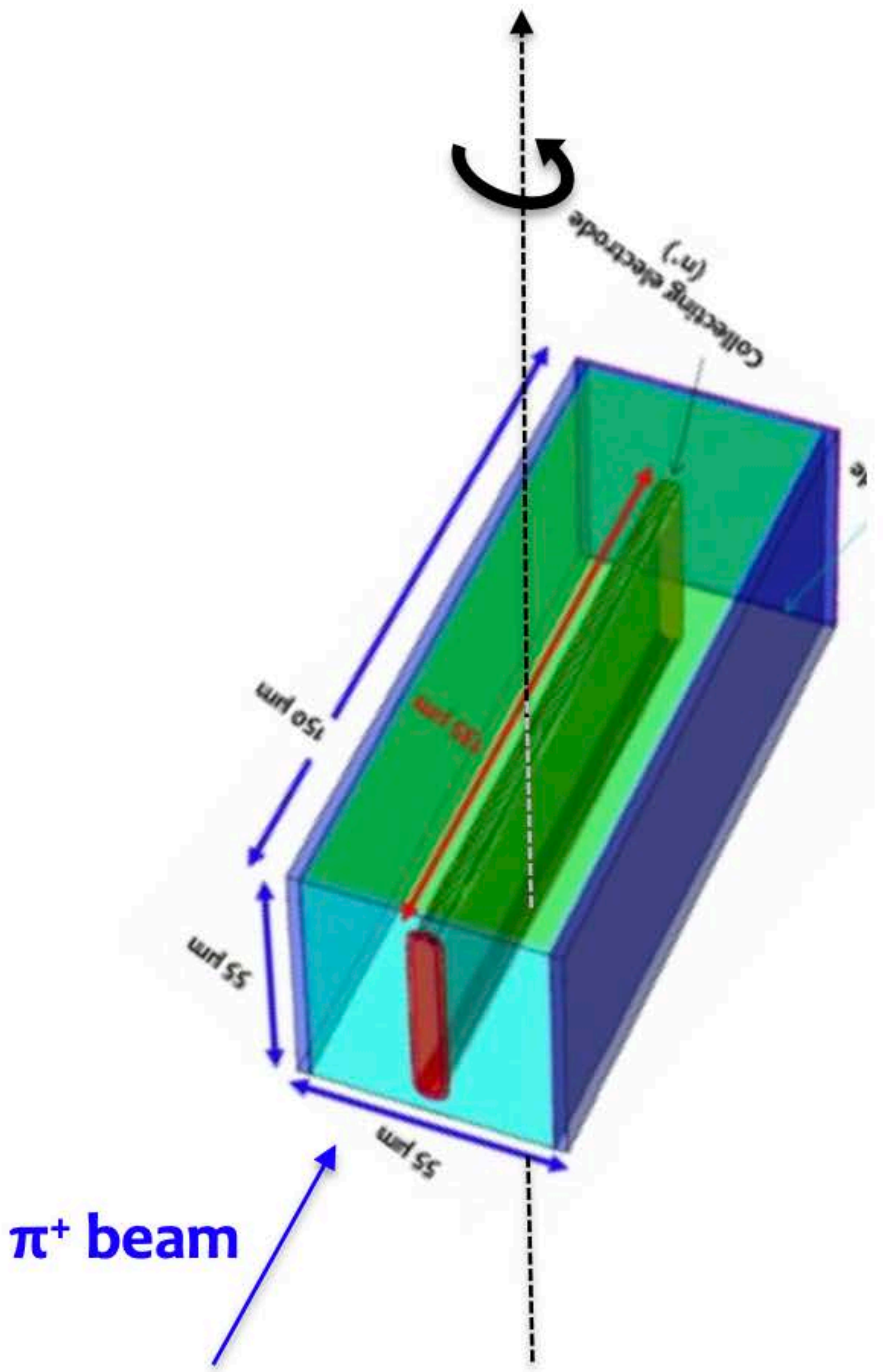


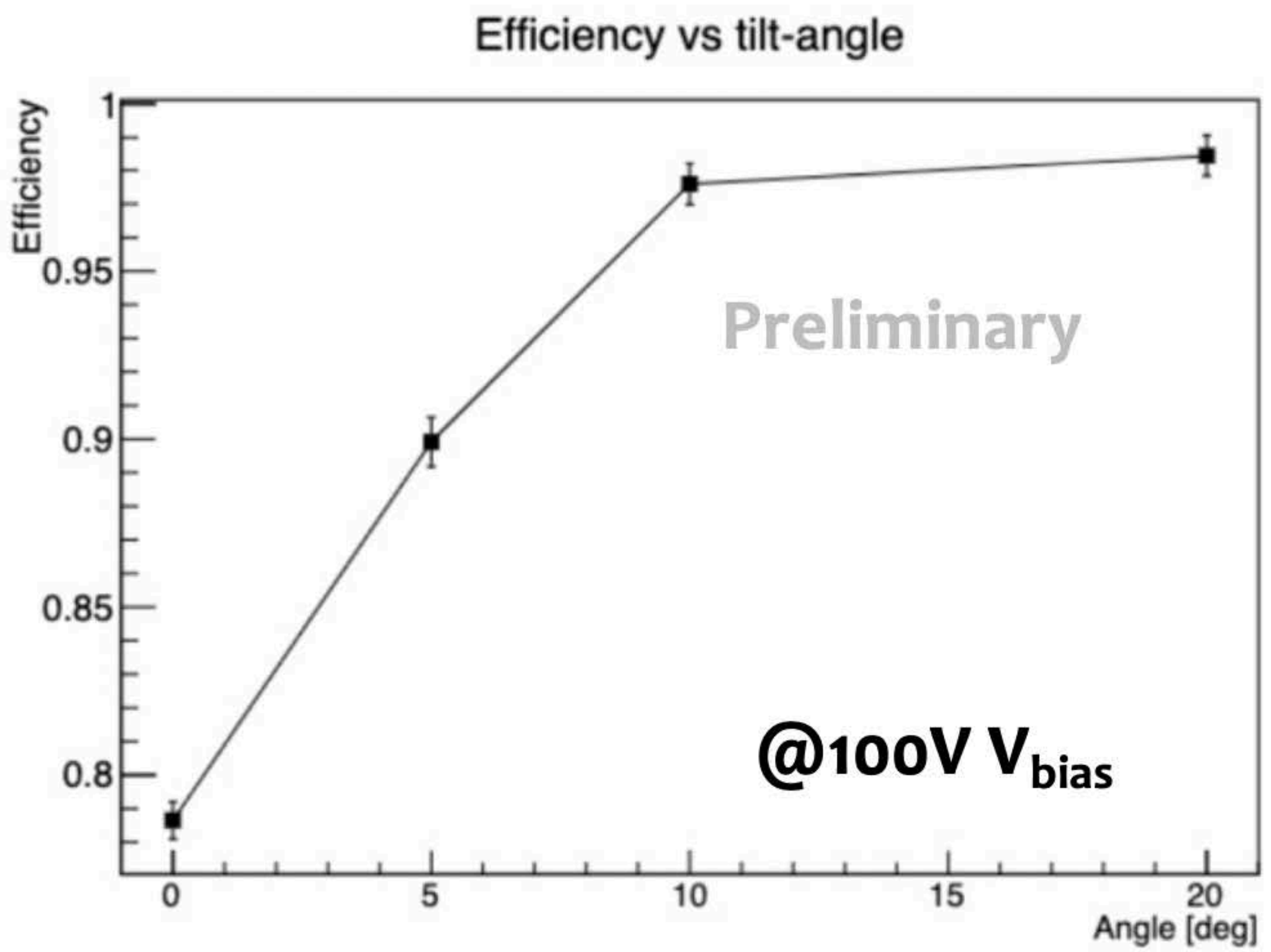
Thrench geometry offers the best configuration

Timespot: testbeam results

LE: Leading edge, NO ToT correction
LE: Leading edge, ToT correction
Spline: Classic CFD
Reference: Differentiation + CFD



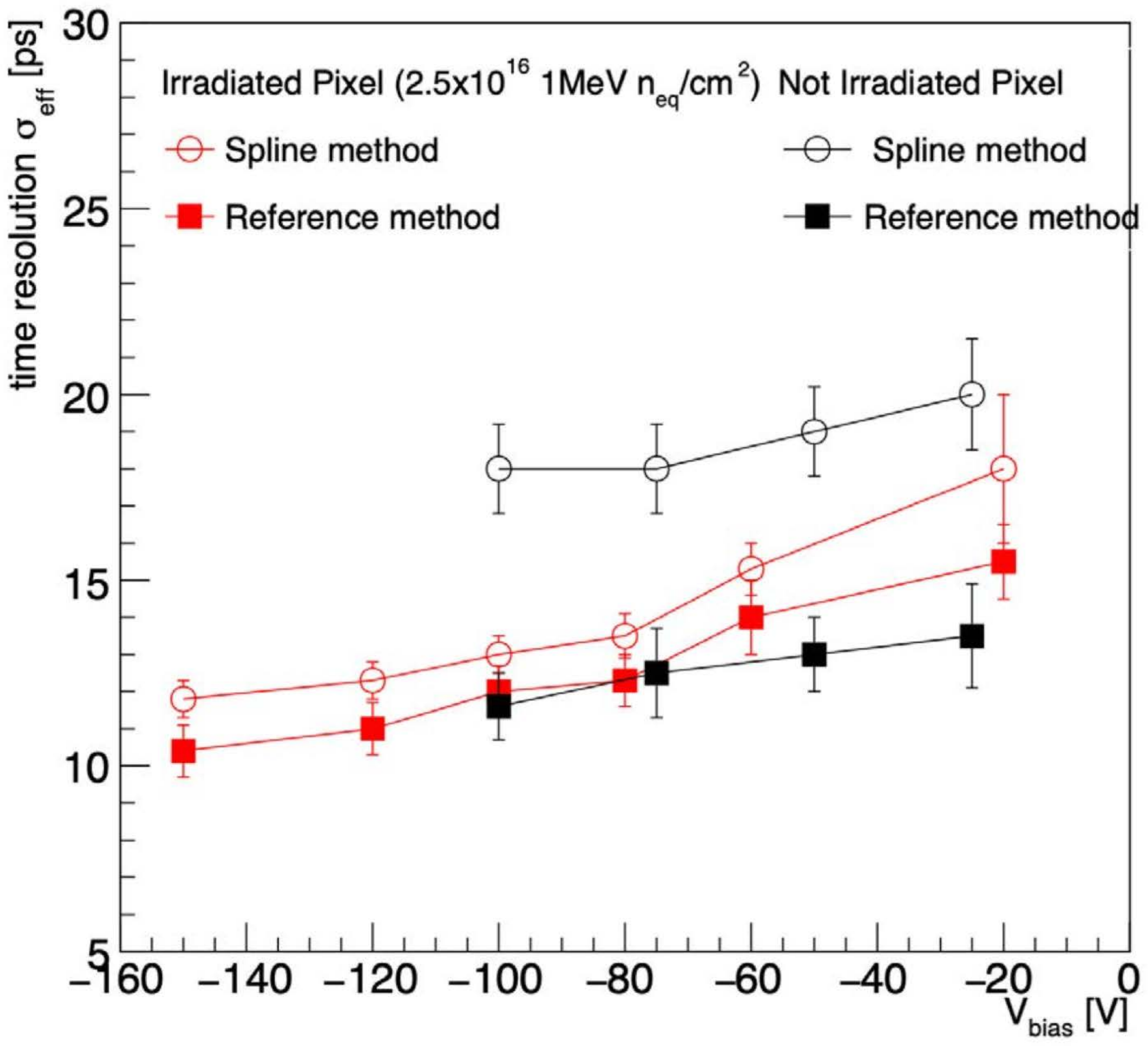


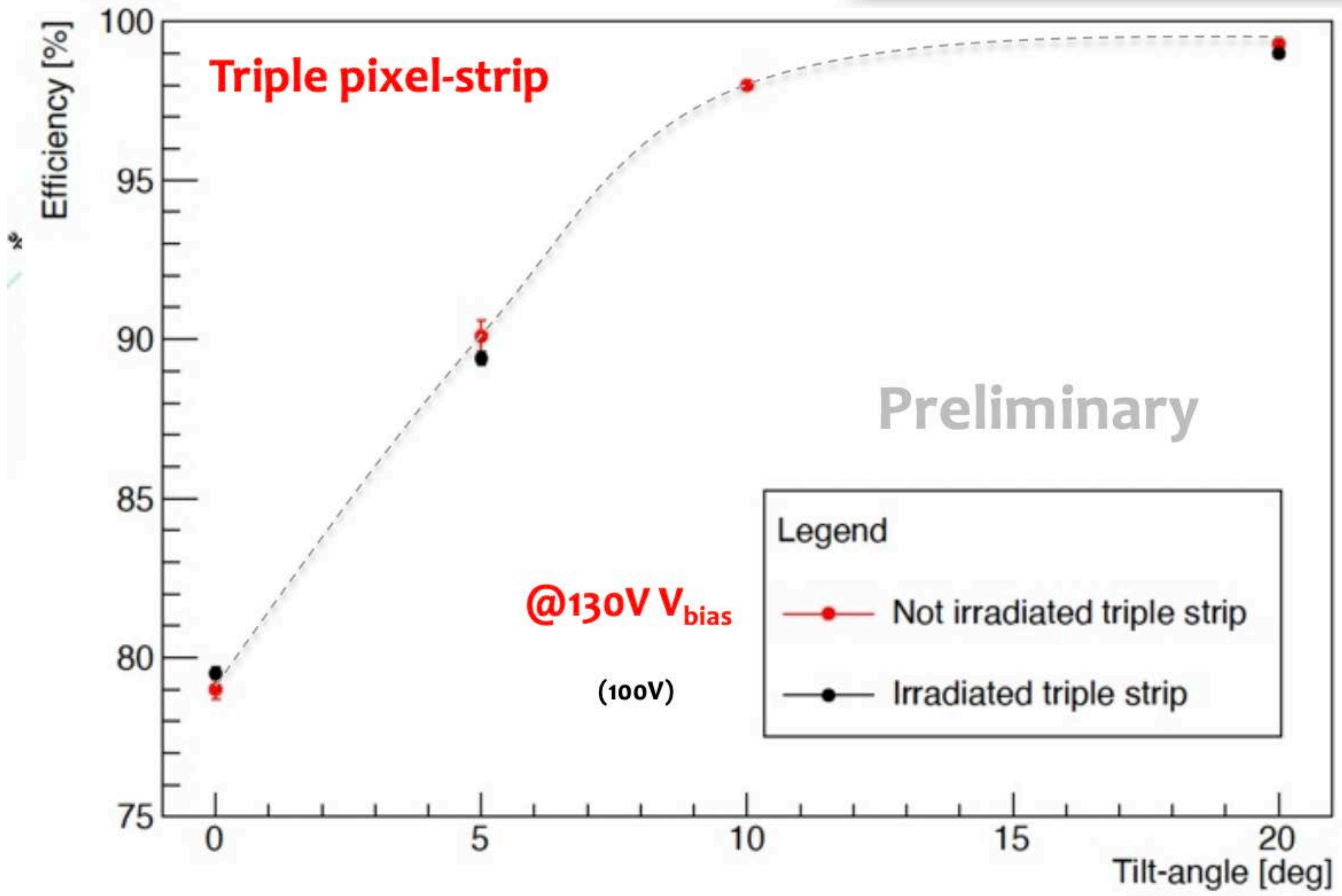


Time Resolution: down to ≈ **12 ps**

Efficiency ~80% for particle angle = 0°,
due to **trenches dead area.**
Recovered for angles ≳10°

Timespot: irradiated sensors





3D sensors are **intrinsically radiation hard**:

time resolution and efficiency maintained even after the extreme fluence of $2.5\cdot10^{16}$ n_{eq}/cm^2

The MONOLITH Project

European Research Council
Established by the European Commission

Our recepy for picosecond timing with silicon:

MONOLITHIC

SiGe BiCMOS

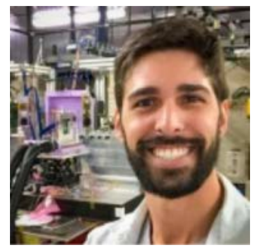
PicoAD: Picosecond Avalanche Detector

The UniGe Silicon Team


Giuseppe Iacobucci
- project P.I.
- System design


Thanushan Kugathasan
- Lead chip design
- Digital electronics


Roberto Cardella
- Sensor design
- Laboratory test


Mateus Vicente
- System integration
- Laboratory test


Matteo Milanesio
- Laboratory test
- Data analysis


Antonio Picardi
- Chip design
- Firmware


Jihad Saidi
- Laboratory test
- Data analysis


Carlo Alberto Fenoglio
- Chip design
- Firmware


Lorenzo Paolozzi
- Sensor design
- Analog electronics

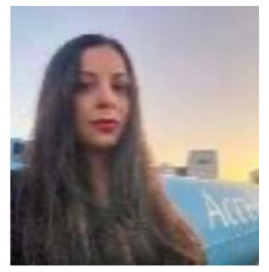

Magdalena Munker
- Sensor design
- Laboratory test


Stefano Zambito
- Laboratory test
- Data analysis


Fulvio Martinelli
- Chip design
- Firmware


Théo Moretti
- Laboratory test
- Data analysis


Chiara Magliocca
- Laboratory test
- Data analysis


Rafaella Kotitsa
- Sensor simulation


Luca Iodice
- Chip design
- Firmware


Didier Ferrere
- System integration
- Laboratory test


Sergio Gonzalez-Sevilla
- System integration
- Laboratory test


Yannick Favre
- Board design
- RO system


Stéphane Débieux
- Board design
- RO system

Main research partners: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INFN Rome2 & UNIGE


Holger Rücker
IHP Mikroelektronik


Marzio Nessi
CERN & UNIGE


Bernd Heinemann
IHP Mikroelektronik

Funded by:

Swiss National Science Foundation

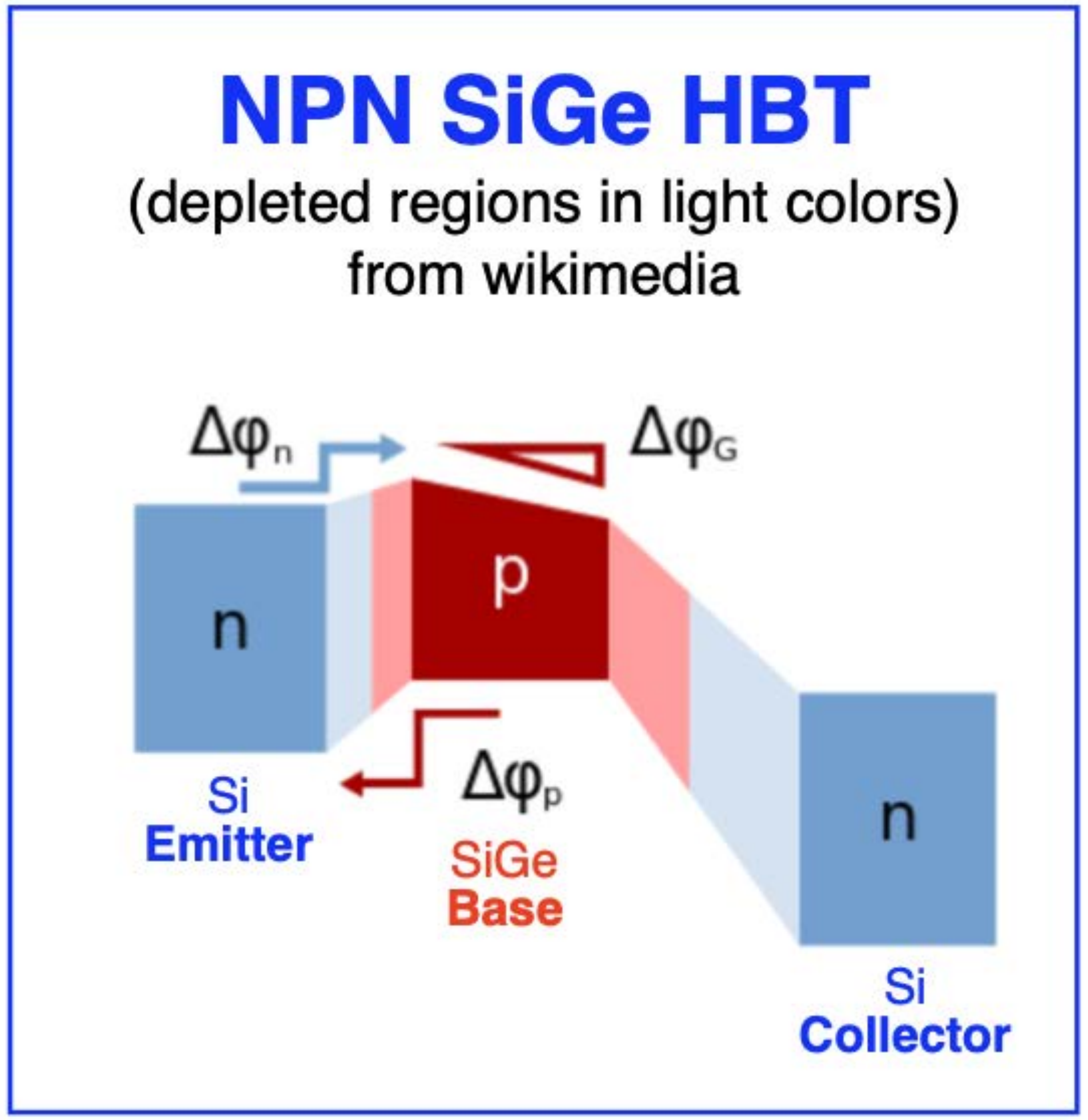
European Research Council
Established by the European Commission

Sinergia

ATTRACT

UNIVERSITÉ DE GENÈVE UNITEC

SiGe BiCMOS Front-End Electronics



SiGe HBT = BJT with Germanium as base material.

Grading of Ge doping in base:

- charge-transport in base via **drift**
  - reduced charge-transit-time in base
  - **high current gain** β
- **Higher doping** in base is possible:
  - thinner base
  - **reduced base resistance** R_b

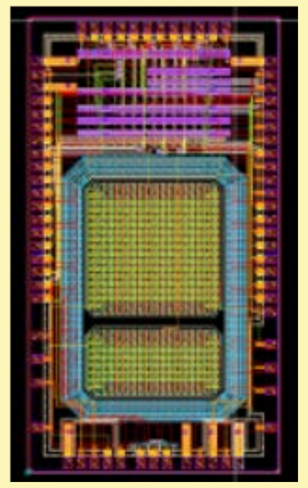
$$ENC_{series\ noise} \propto \sqrt{k_1 \frac{C_{tot}^2}{\beta} + k_2 R_b C_{tot}^2}$$

Leading-edge **IHP SG13G2** technology, **130 nm** process featuring **SiGe HBT**

Monolithic SiGe BiCMOS for timing

Monolithic prototypes with SiGe BiCMOS (without internal gain layer)

2016



200ps

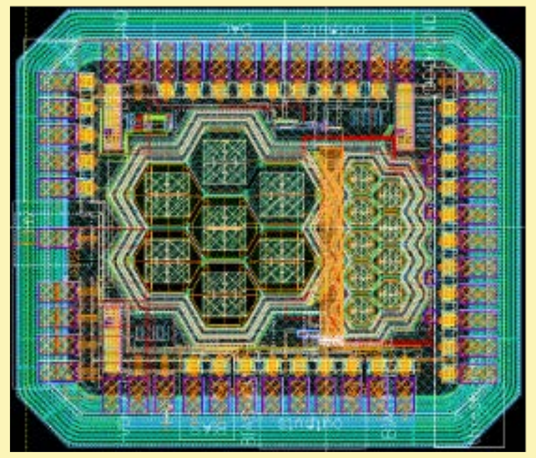
- 1 and 0.5 mm² pixels
- Discriminator output

2017

110ps

- 30 pixels 500x500µm²
- 100ps TDC +I/O logic

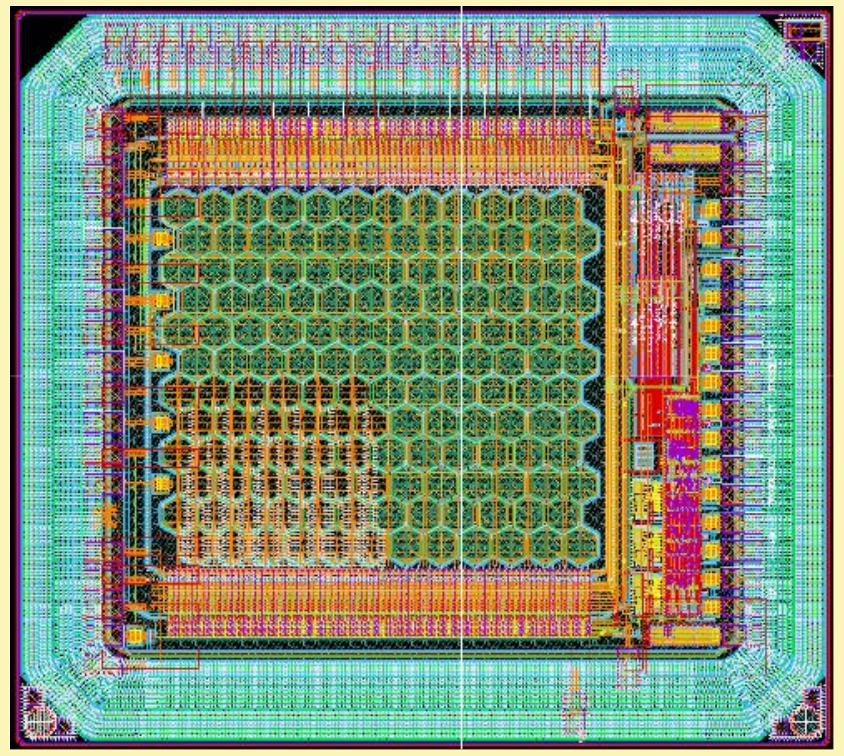
2018



50ps

- Hexagonal pixels 65µm and 130µm side
- Discriminator output

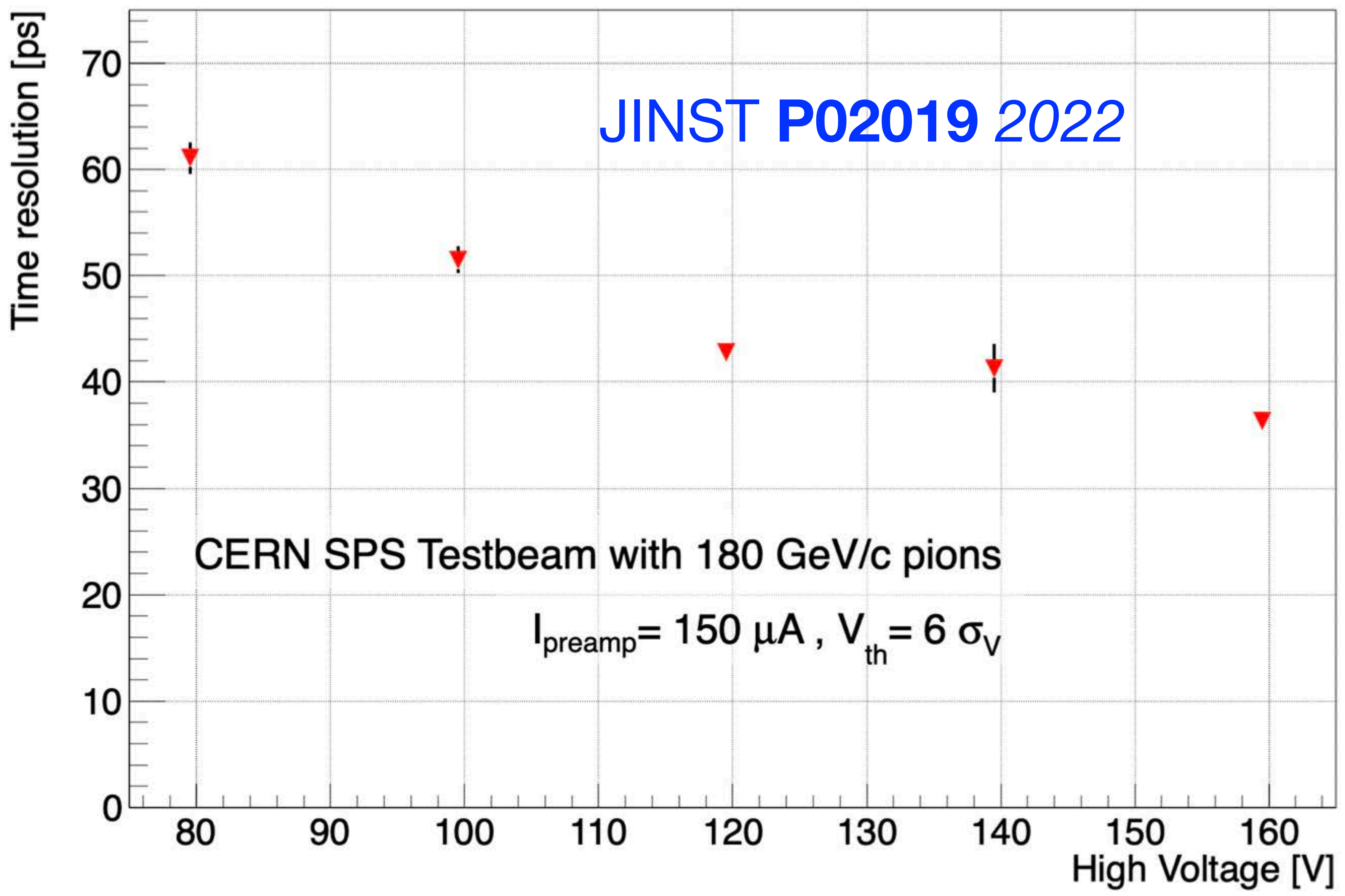
2019



36 ps

- Hexagonal pixels 65µm side
- 30ps TDC +I/O logic
- Analog channels

Test beam results of 2019 prototype



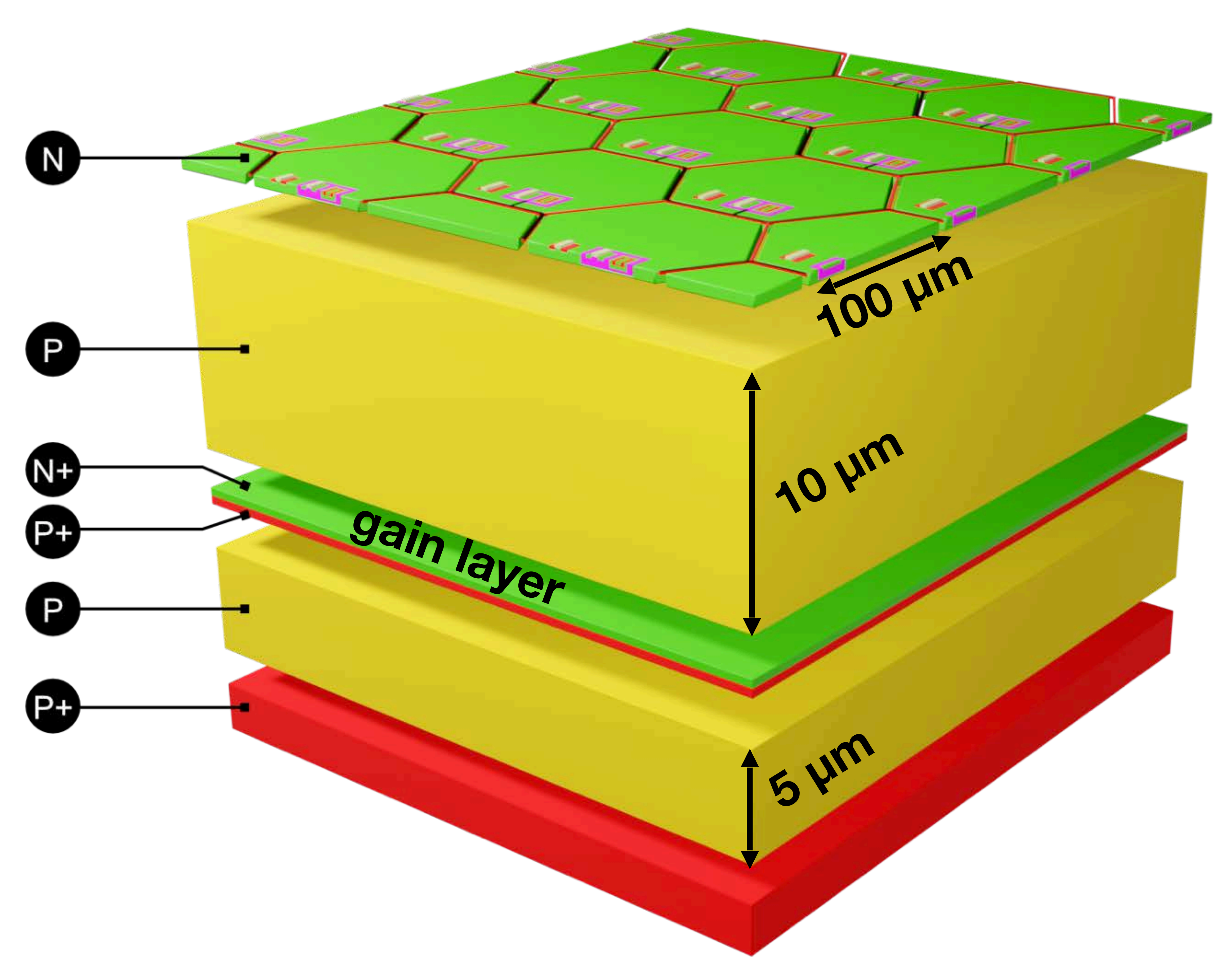
PicoAD Sensor Concept

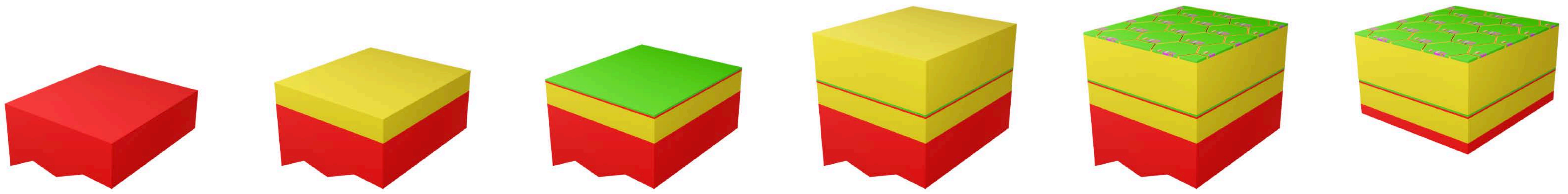
© G. Iacobucci, L. Paolozzi and P. Valerio. Multi-junction pico-avalanche detector;
European Patent EP3654376A1, US Patent US2021280734A1, Nov 2018

PicoAD:

Multi-Junction Picosecond-Avalanche Detector©
with continuous and deep gain layer:

- De-correlation from implant size/geometry
  → **high pixel granularity and full fill factor**
  (high spatial resolution)
- Only small fraction of charge gets amplified
  → **reduced charge-collection noise**
  (enhance timing resolution)

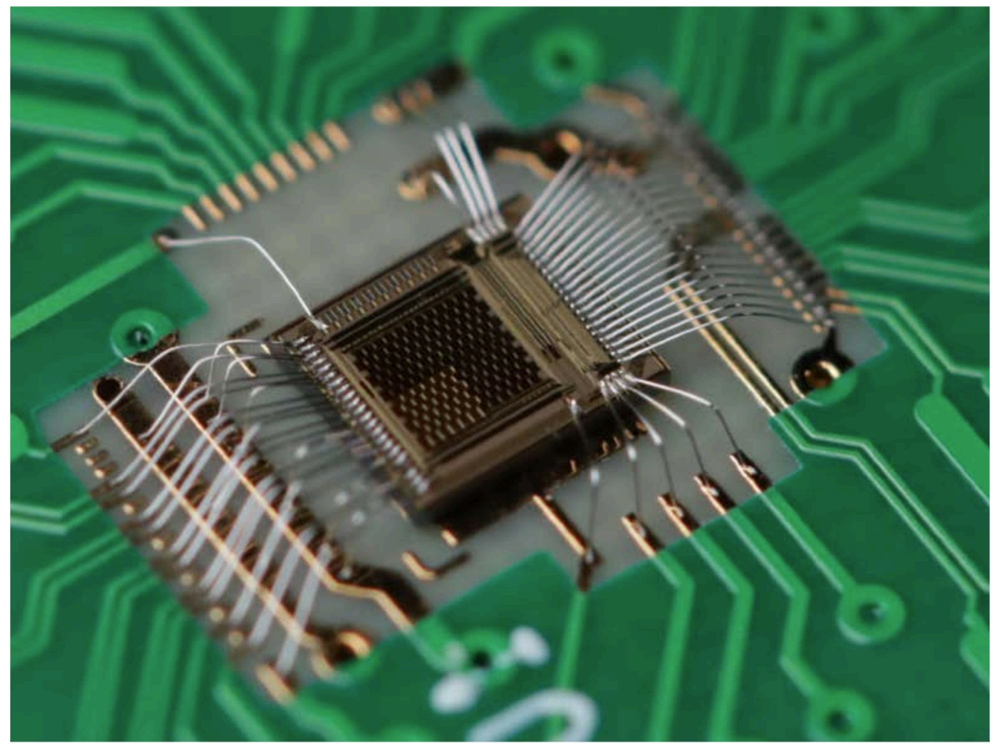




Step 1 Step 2 Step 3 Step 4 Step 5 Step 6

PicoAD monolithic proof-of-concept prototype

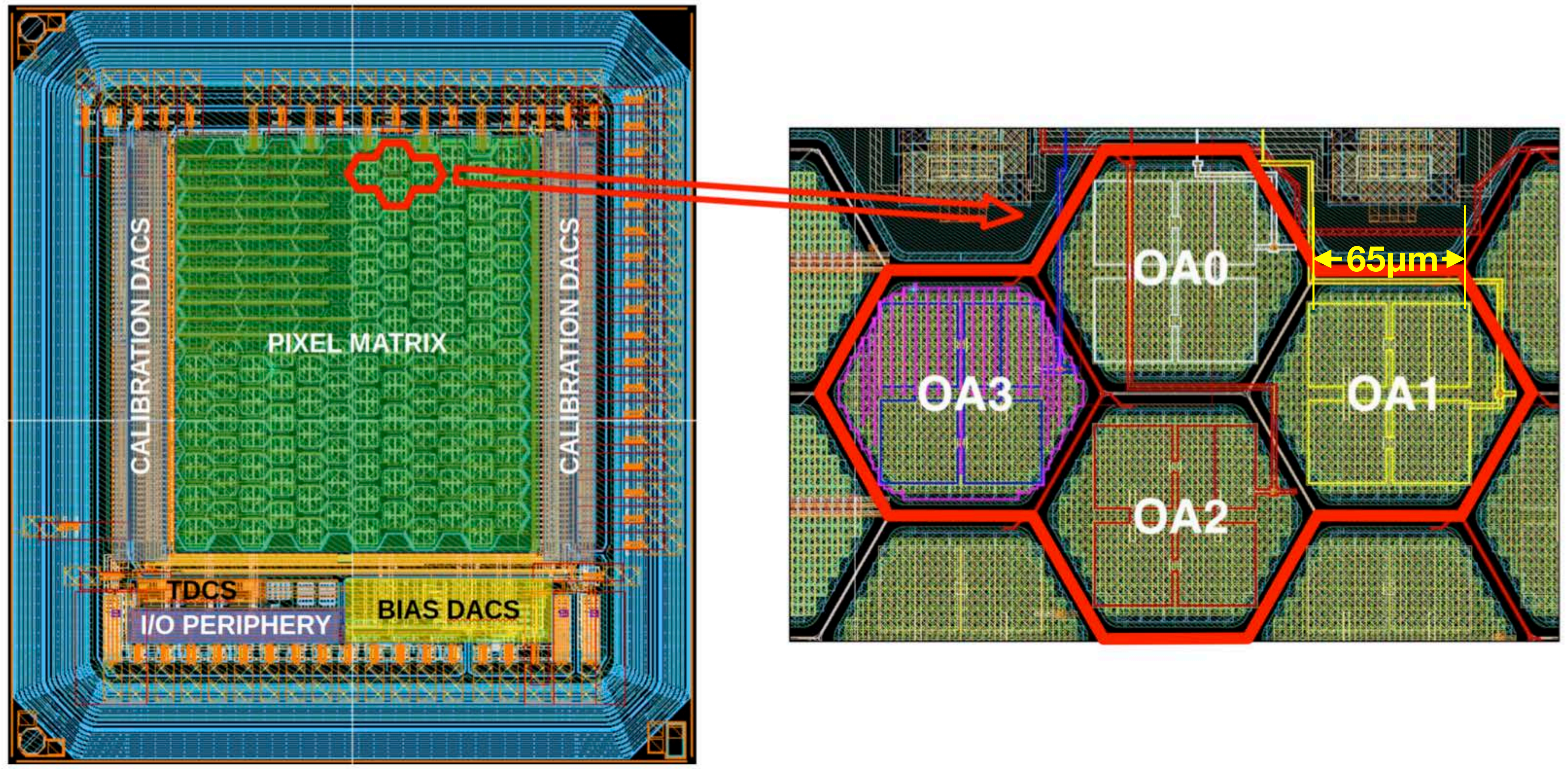
The proof-of-concept monolithic ASIC was produced by IHP in their SG13G2 SiGe BiCMOS process.



The ASIC contains:

- **Four matrices** of hexagonal pixels with ≈ 100μm pitch
  - with different electronics configurations
- **Four analog pixels**
  - tested with ^{55}Fe source and in testbeam

PicoAD Proof-Of-Concept Prototype (2021)



IHP also produced **PicoAD special wafers** with four different gain-layer implant doses

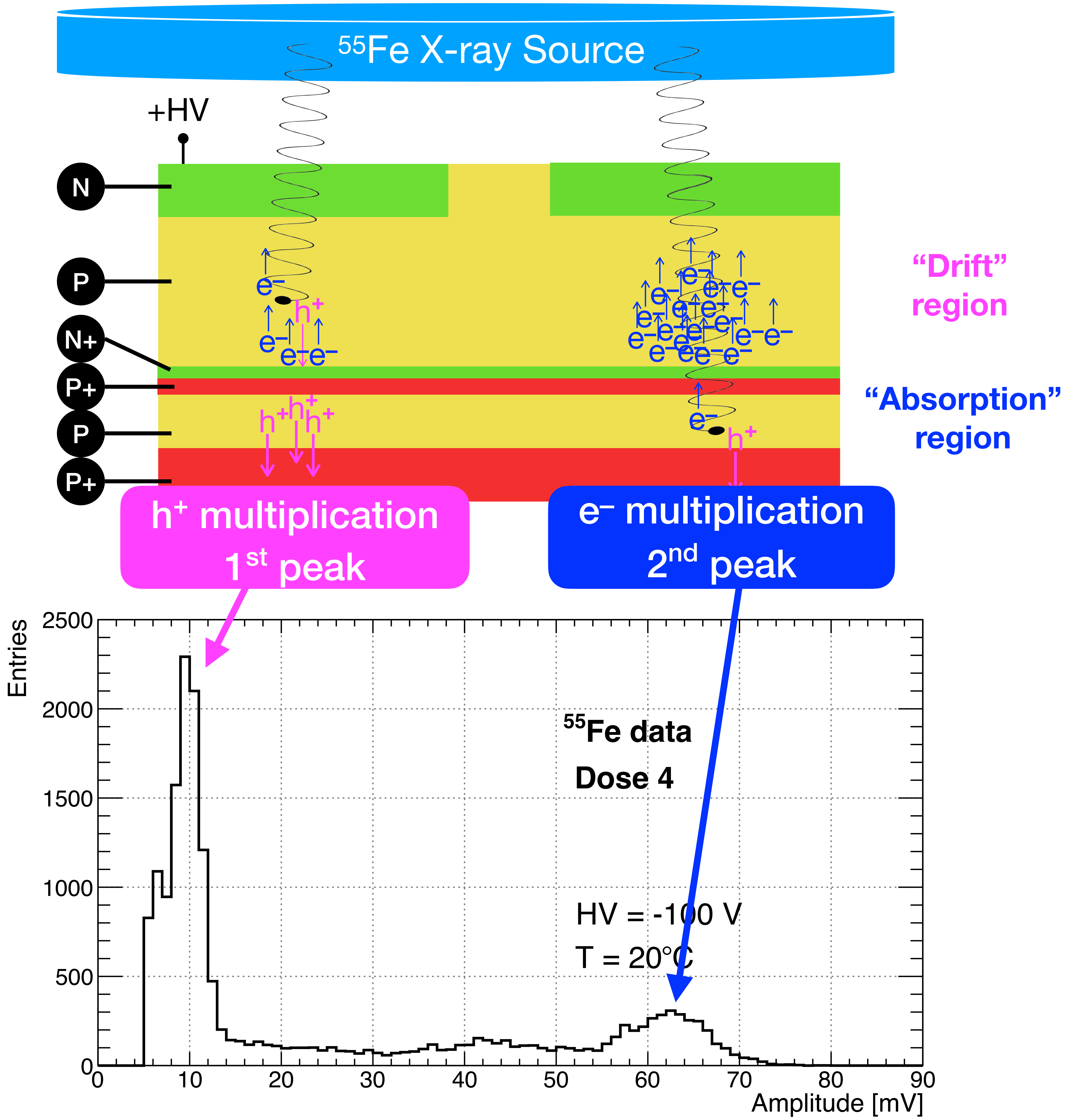
Gain Measurement with ^{55}Fe source

X-rays from ^{55}Fe radioactive source:

- mainly ~5.9 keV photons
- point-like charge deposition

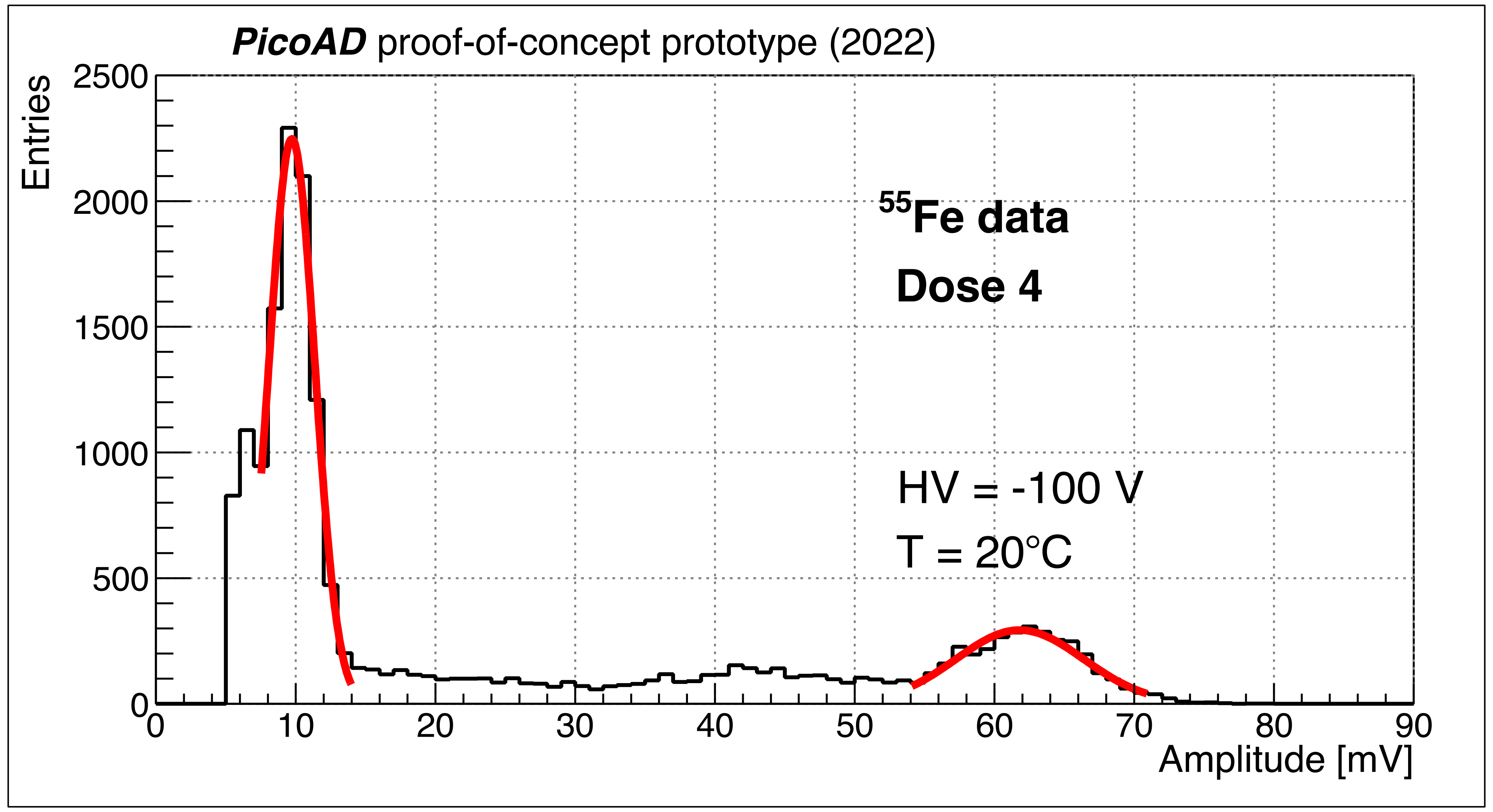
Characteristic double-peak spectrum

- photon absorbed in **drift region**
  - ➡ holes drift through gain layer & multiplied
  - ➡ first peak in the spectrum
- photon absorbed in **absorption region**
  - ➡ electrons through gain layer & multiplied
  - ➡ second peak in the spectrum



Gain Measurement with ^{55}Fe source

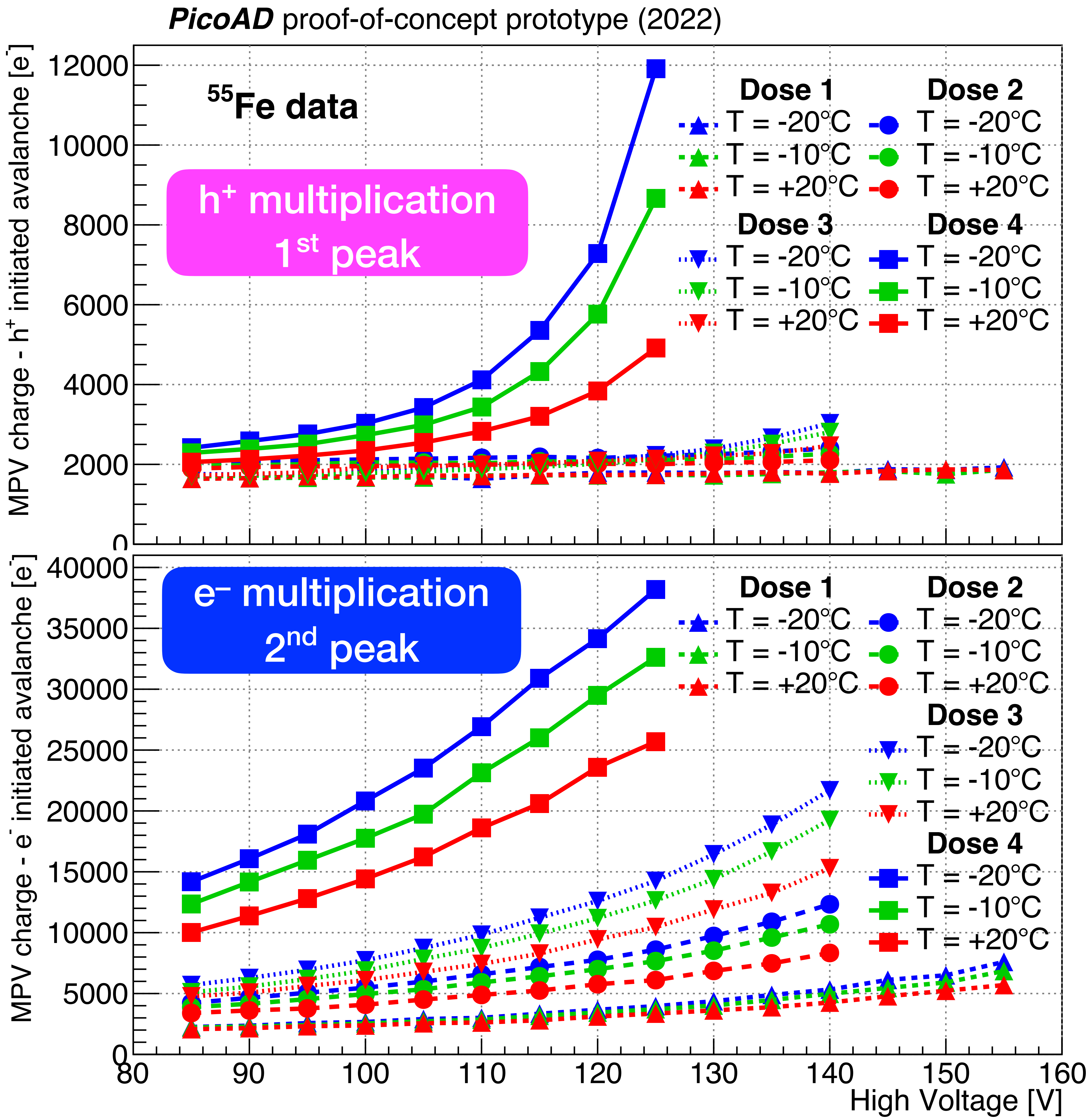
Average amplitudes of h+ and e- gains extracted via gaussian fit around local maxima



Assumption of no gain multiplication when:

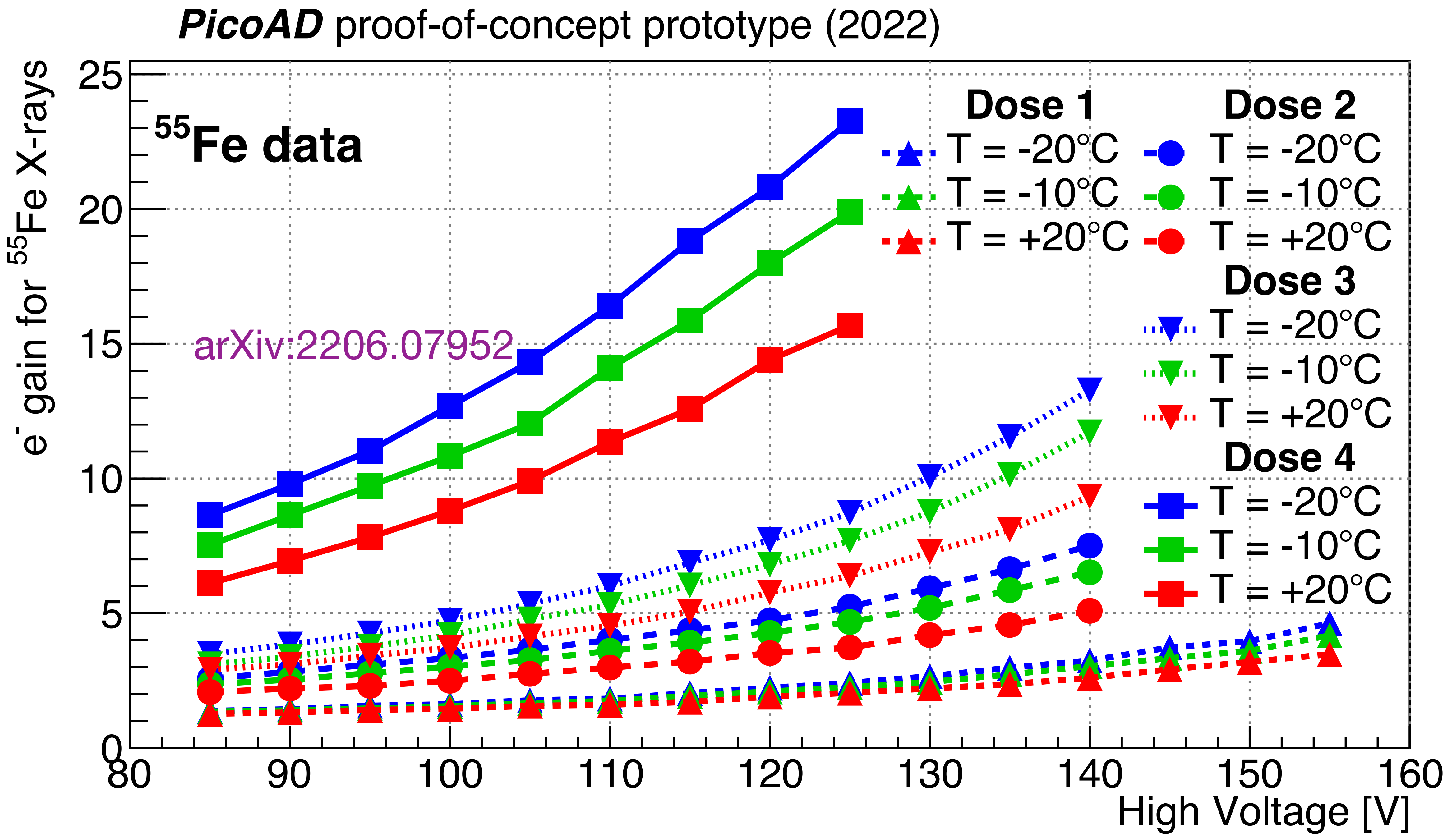
- photon absorbed in drift region
- lowest voltage (85 V)
- lowest dose (dose 1)

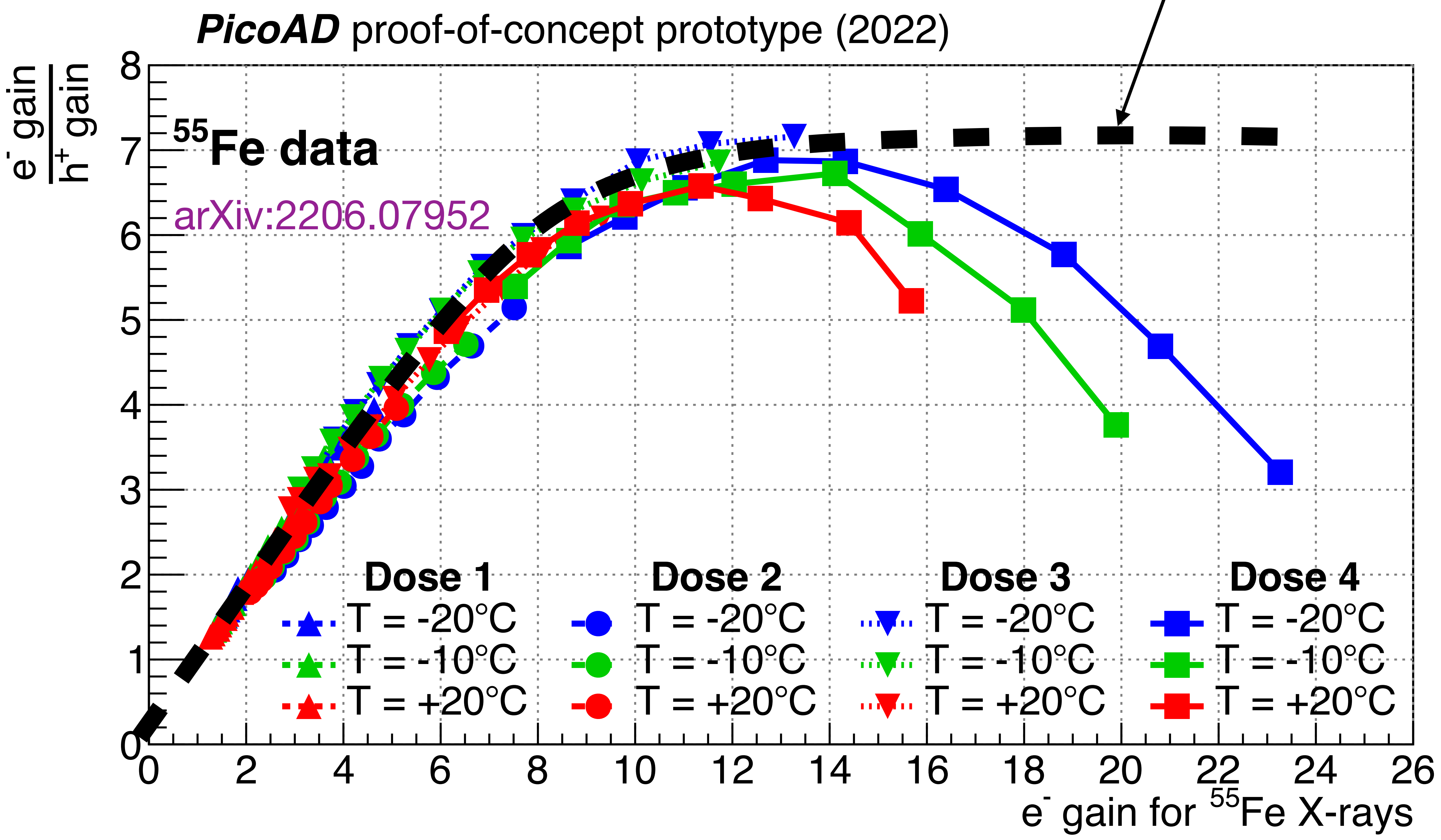
⇒ **normalization value**



Gain Measurement with ^{55}Fe source

R. J. McIntyre, IEEE Trans. Electr. Dev., Vol. 46, no. 8, 1623-1631, Aug. 1999



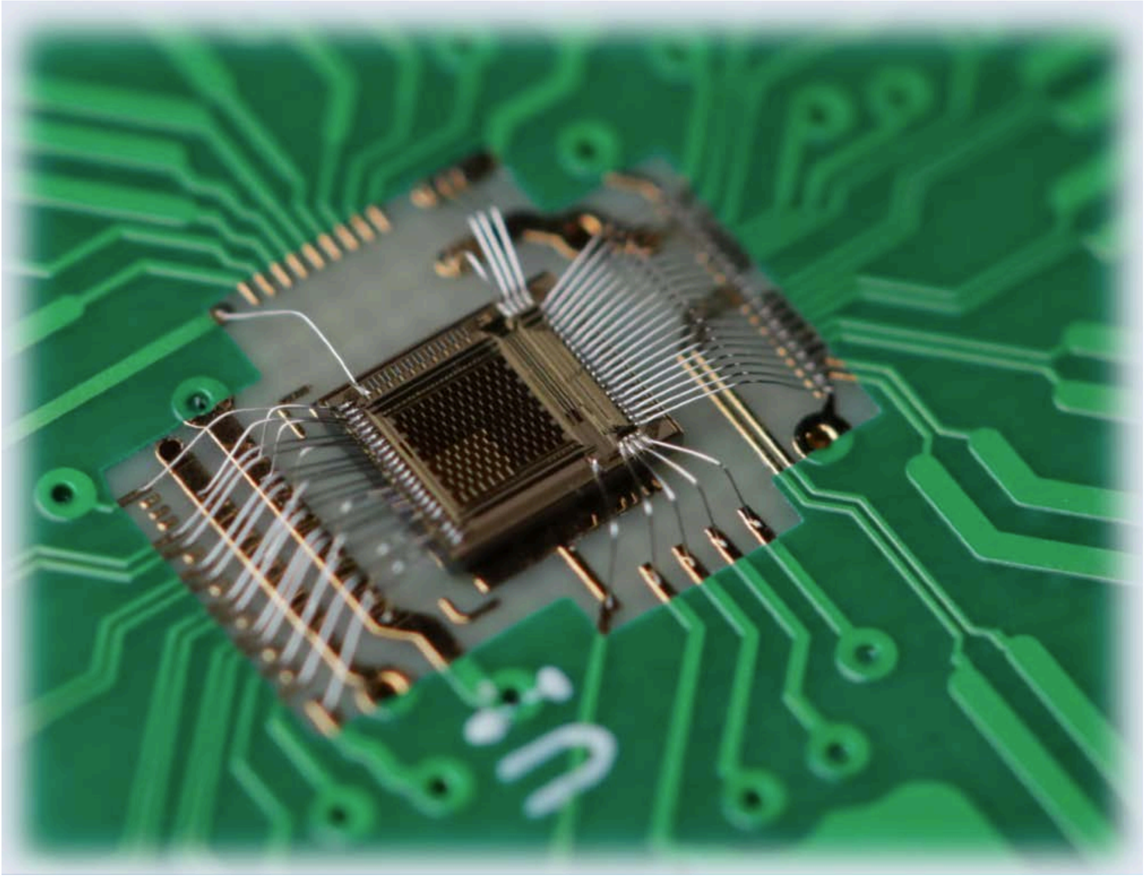


A **gain up to ≈ 20 for ^{55}Fe X-rays** obtained at HV = 120 V and T = -20 °C

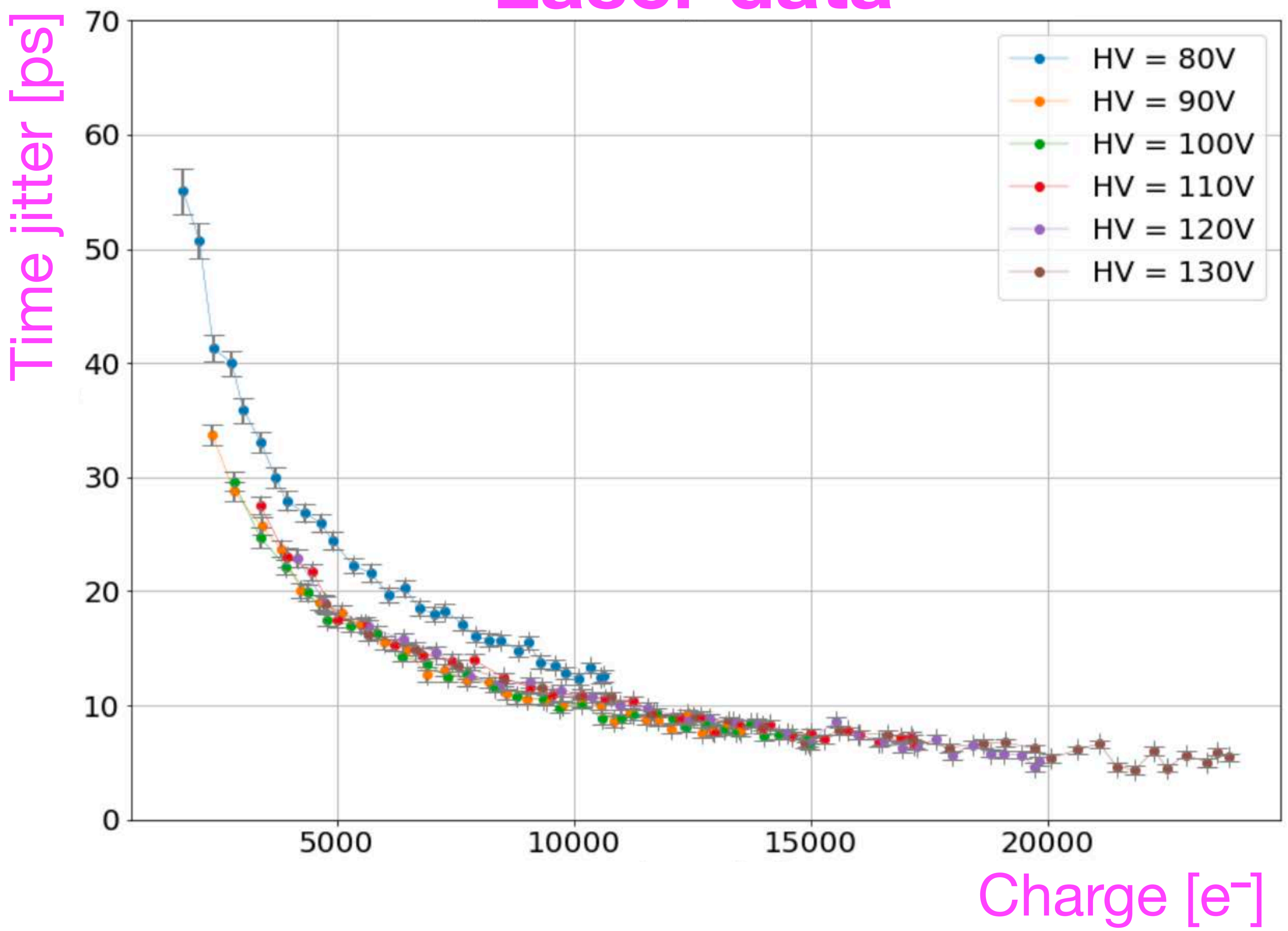
Evidence for **gain suppression** due to space-charge effects **in the case of ^{55}Fe X-rays**

PicoAD: laser measurements

PicoAD proof-of-concept prototype:

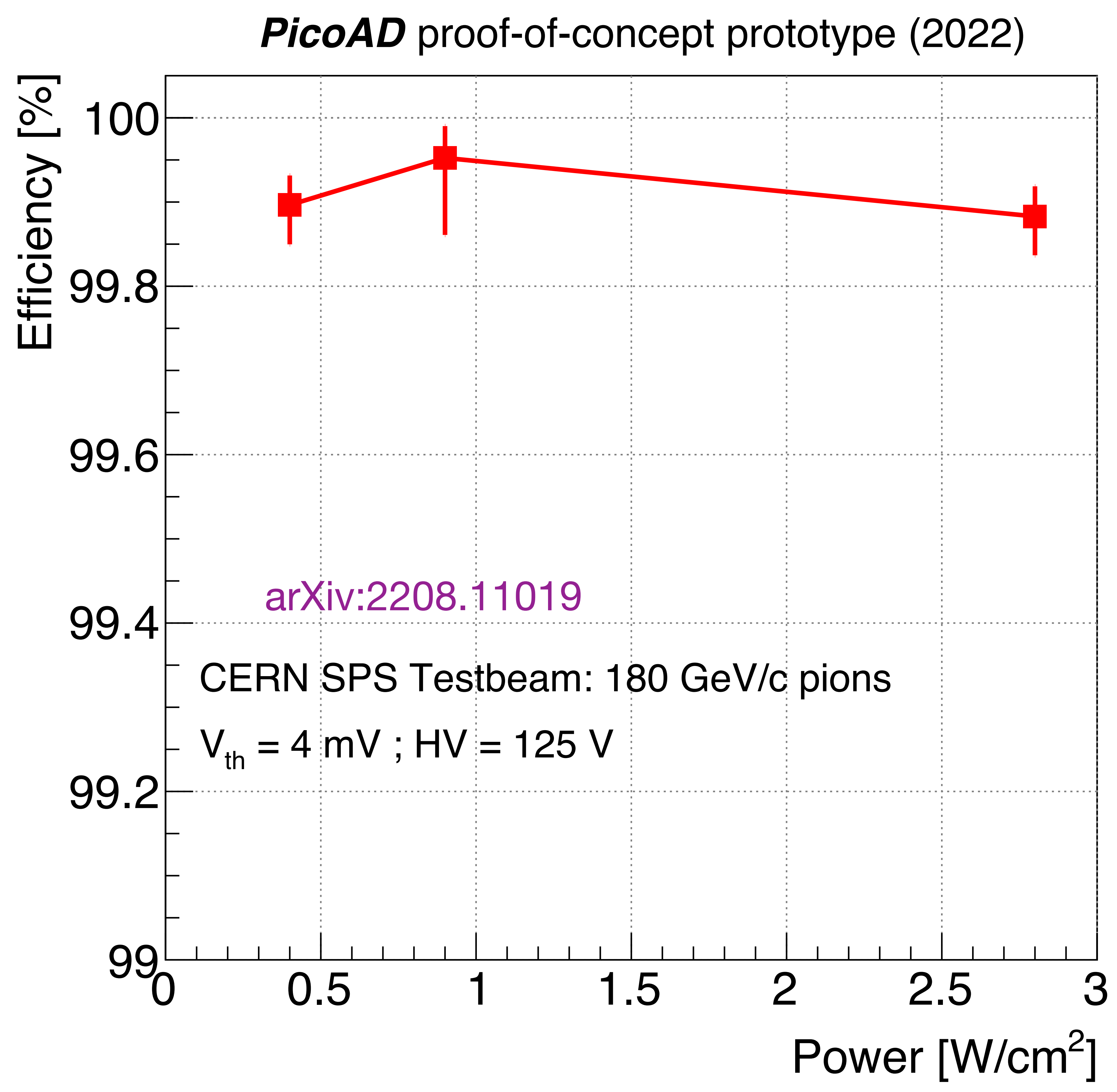


Laser data

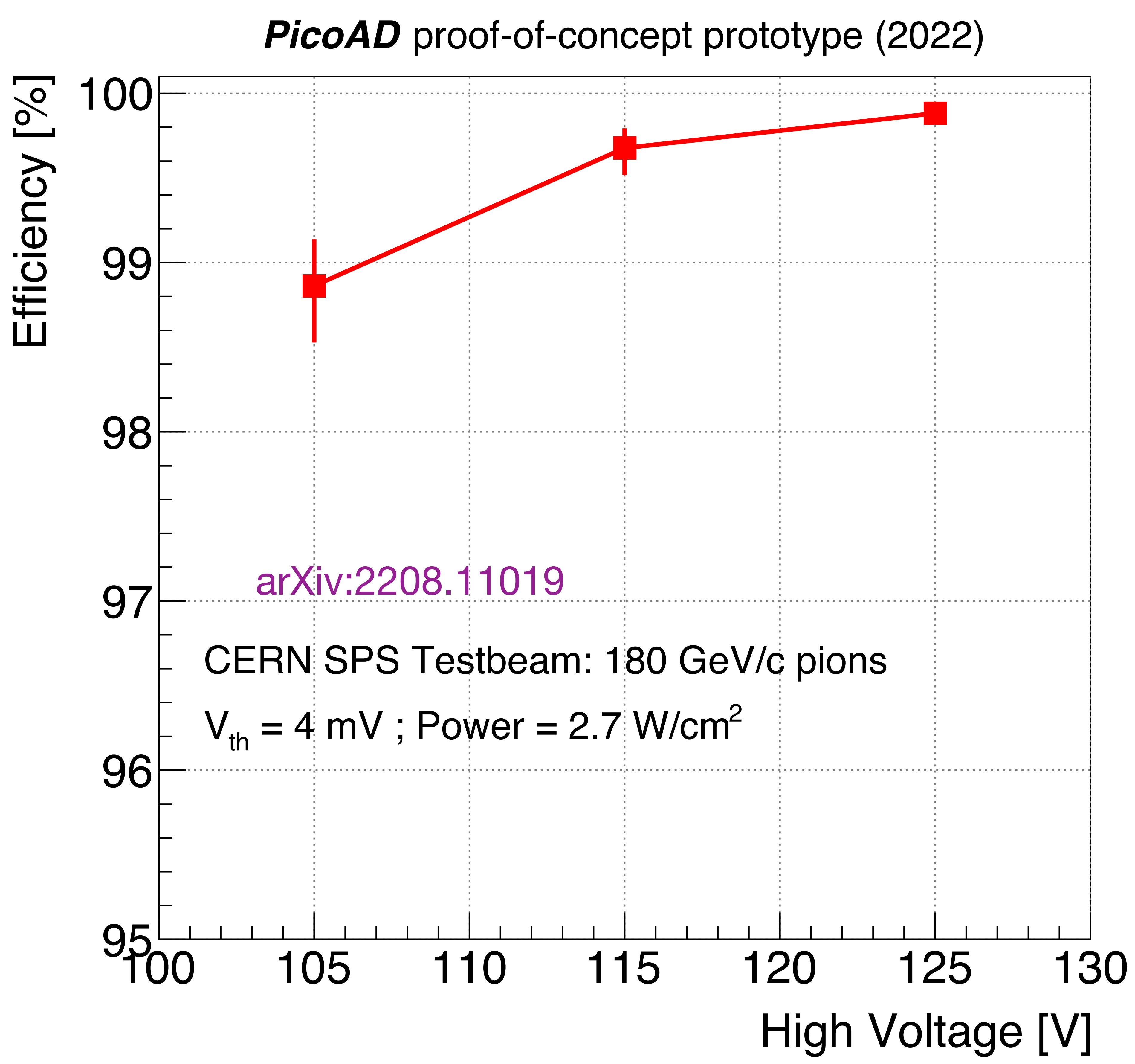


Testbeam results: Detection Efficiency

99.9% for all power consumptions

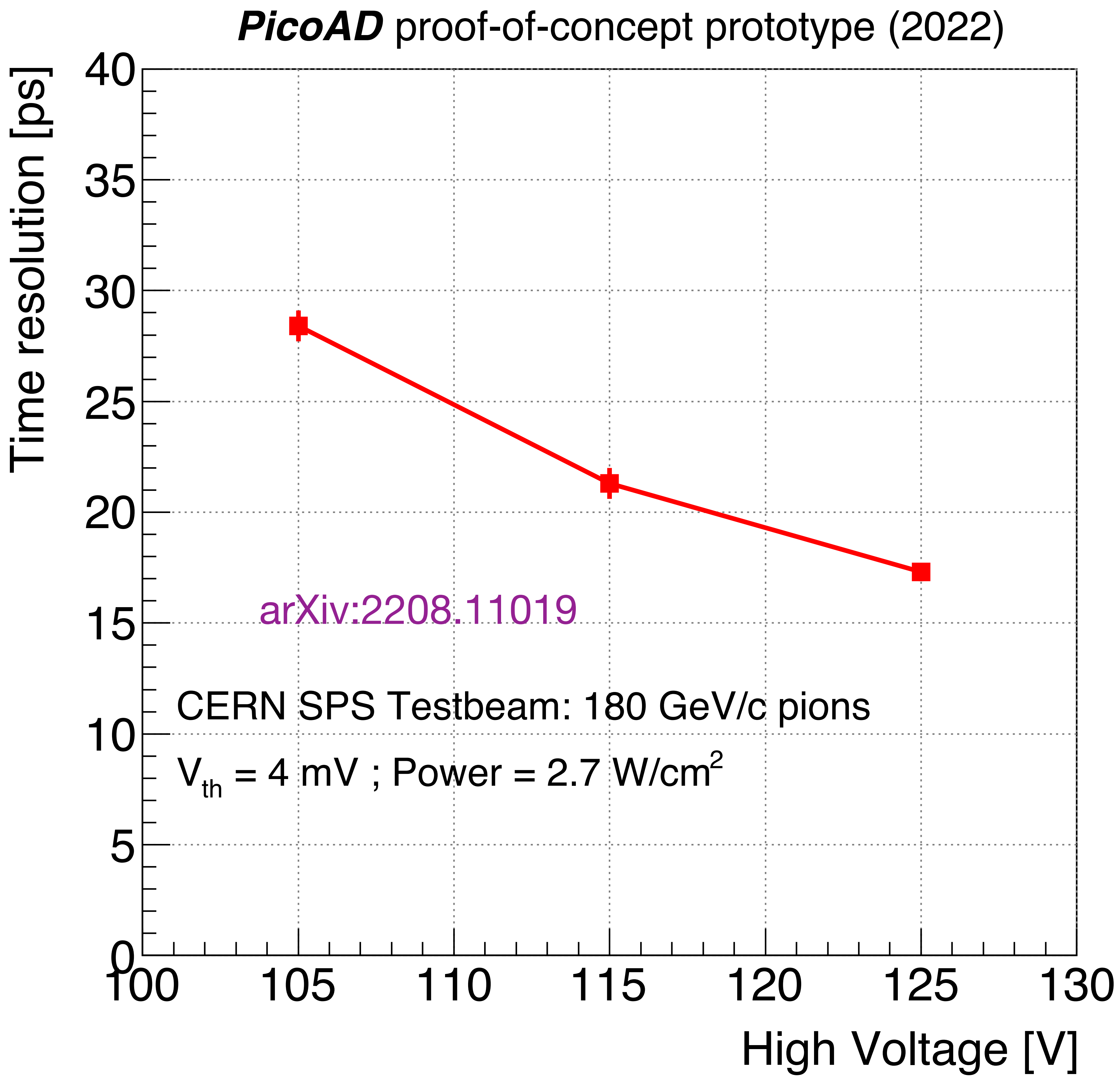


Drops to 99% for HV=105 V

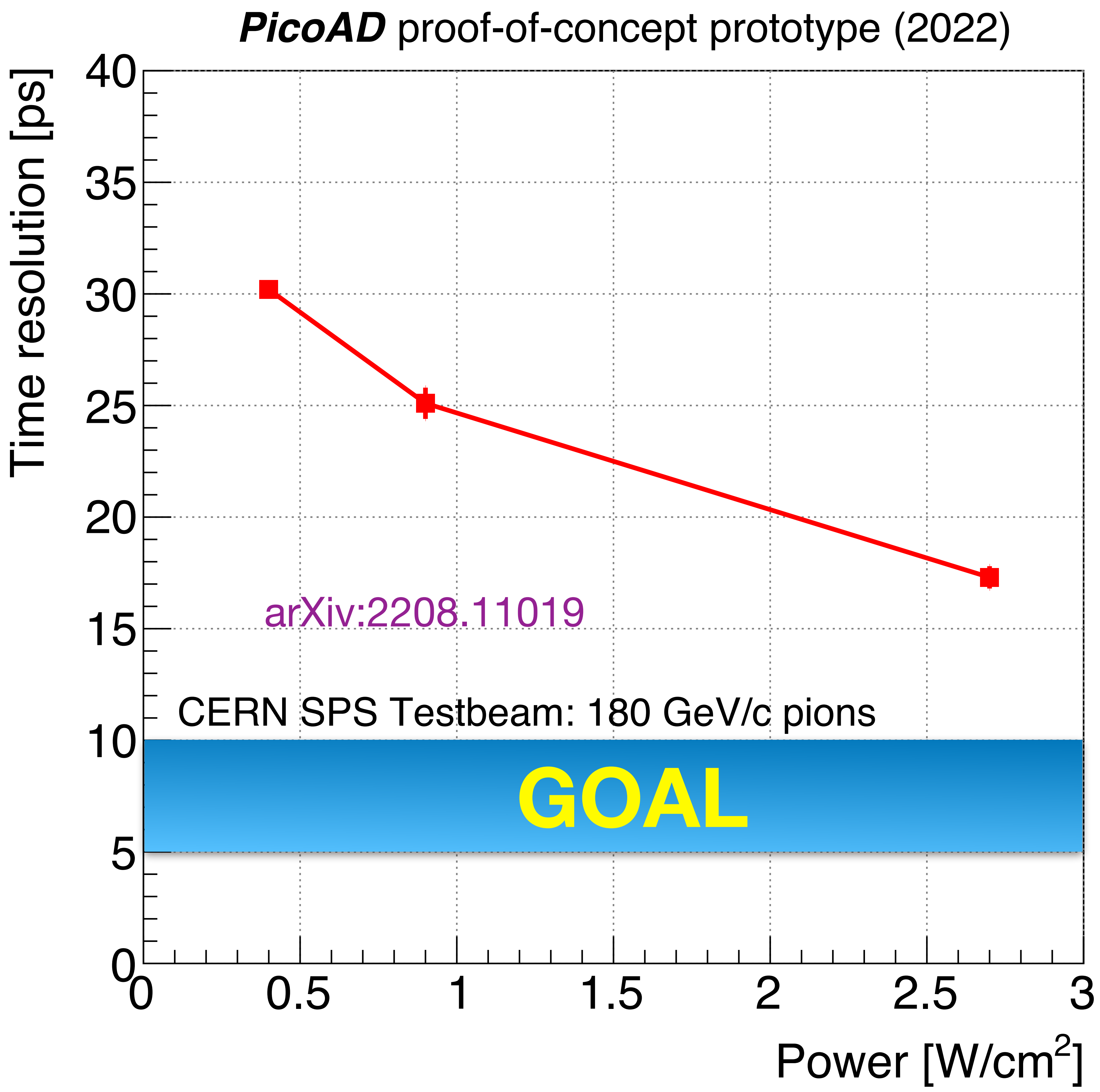


Testbeam results: Time Resolution[6]

Best performance: (17.3±0.4) ps
for HV=125 V and Power = **2.7 W/cm²**

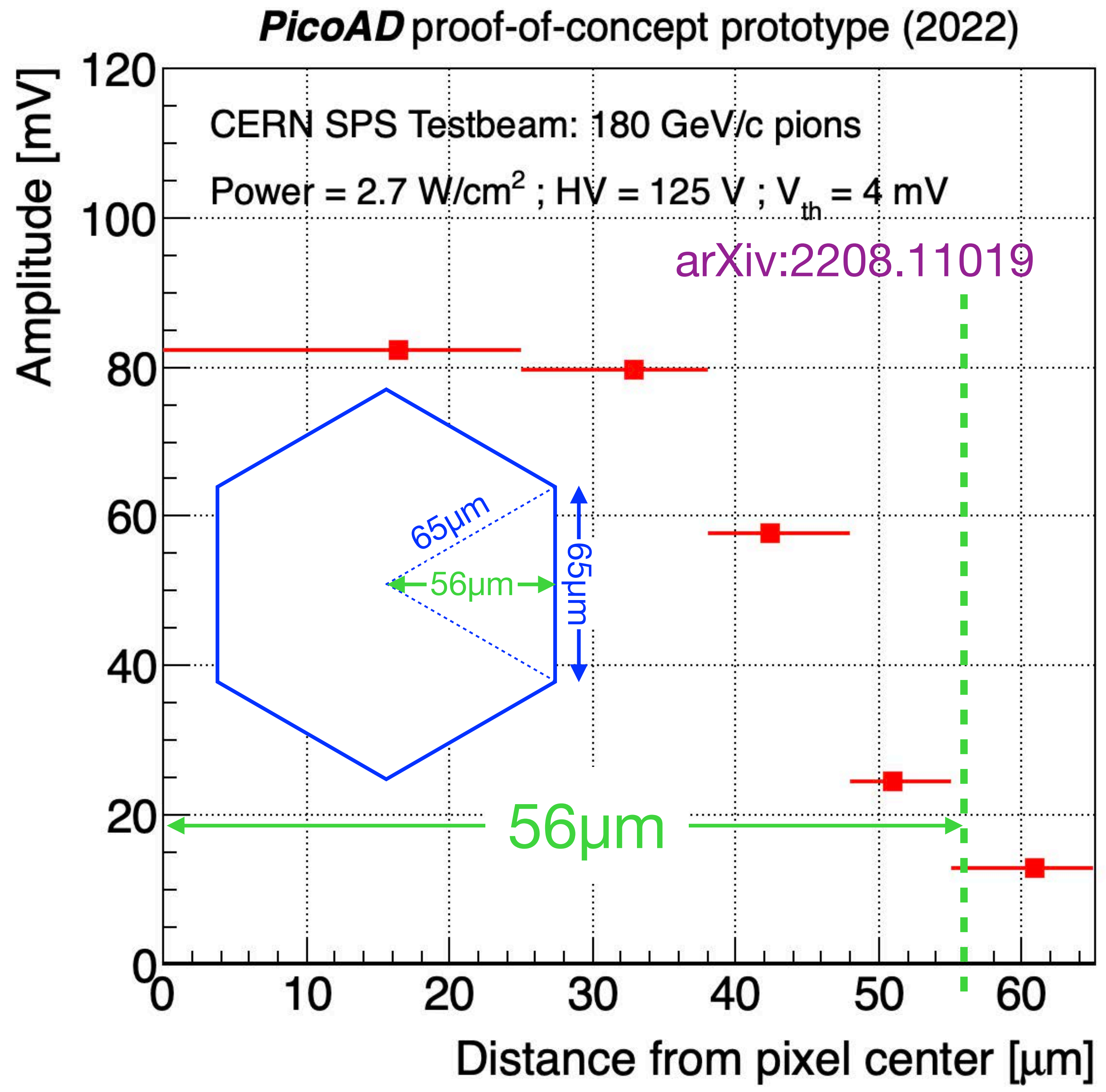


Timing resolution of **30 ps** even
at power consumption of **0.4 W/cm²**

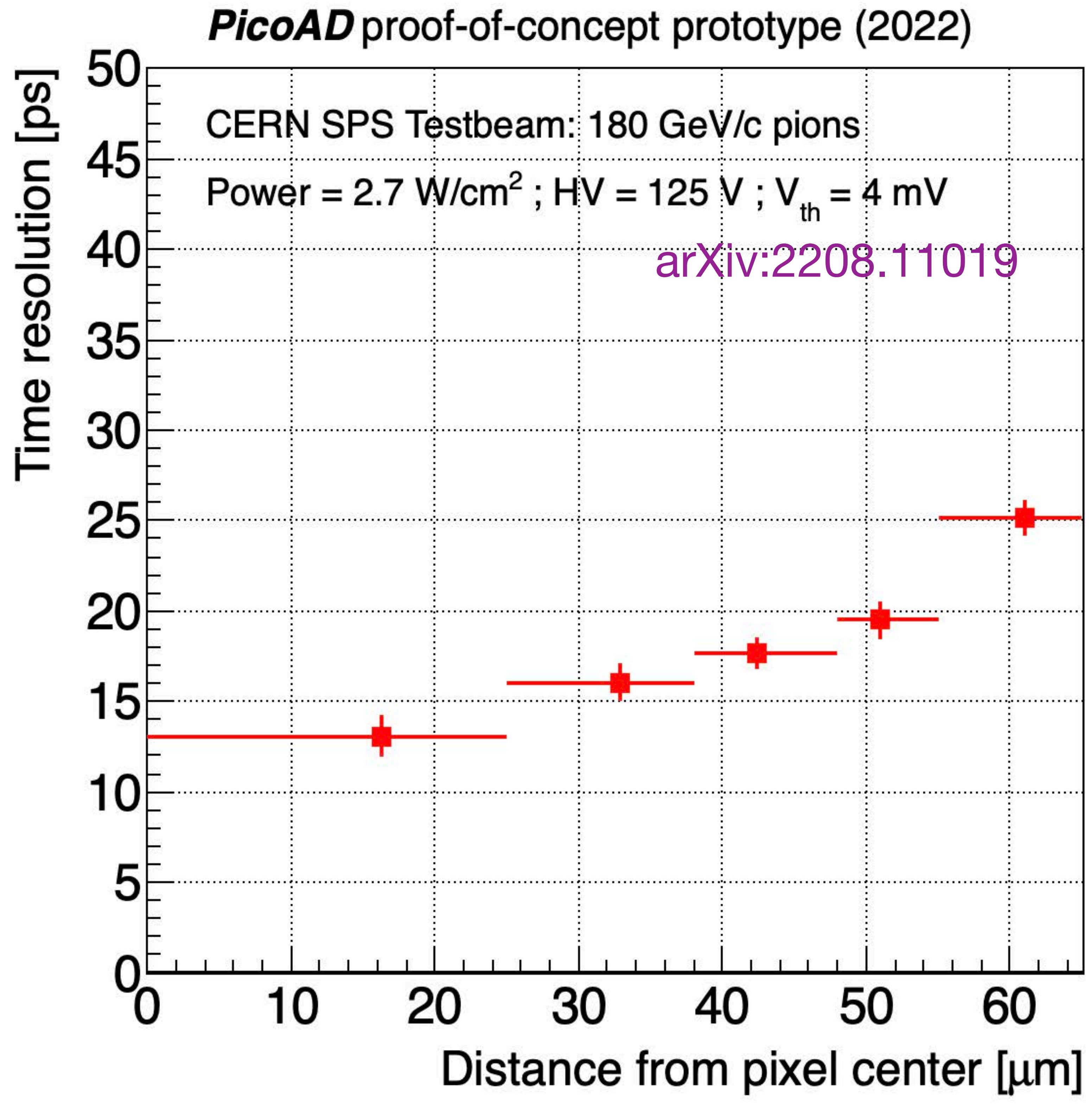


Testbeam results: dependence on position

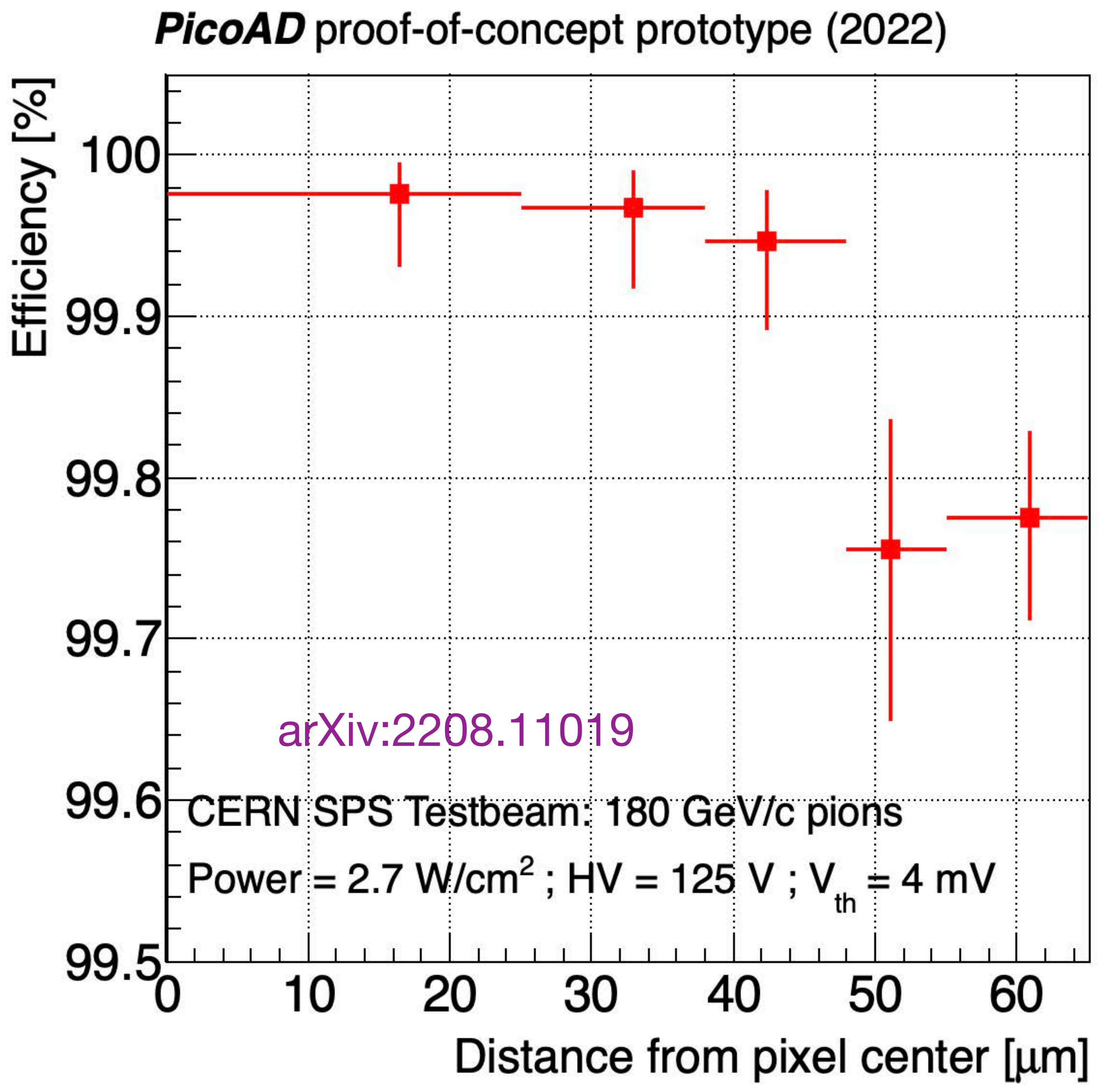
Signal MPV amplitude



Time resolution



Efficiency

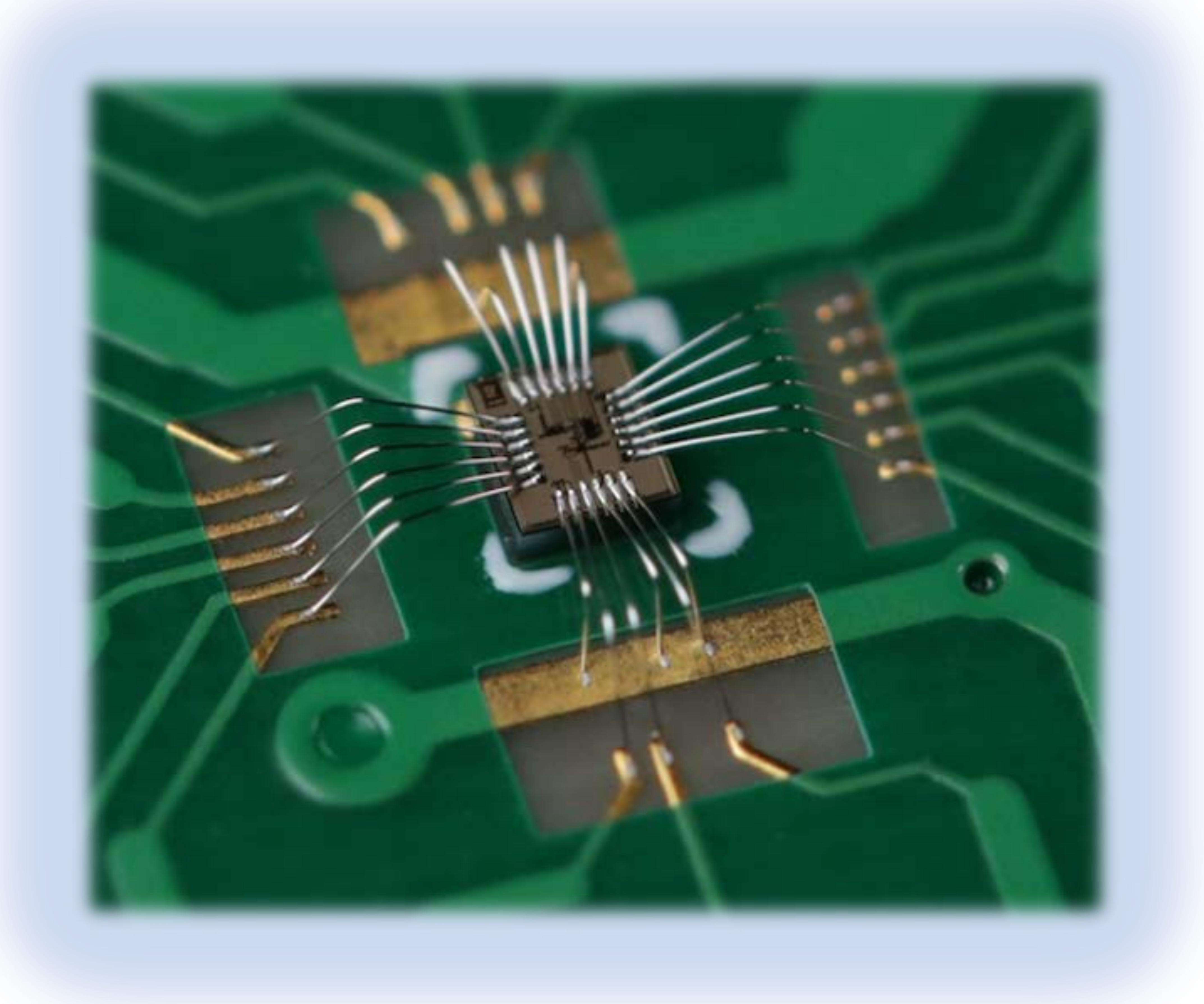


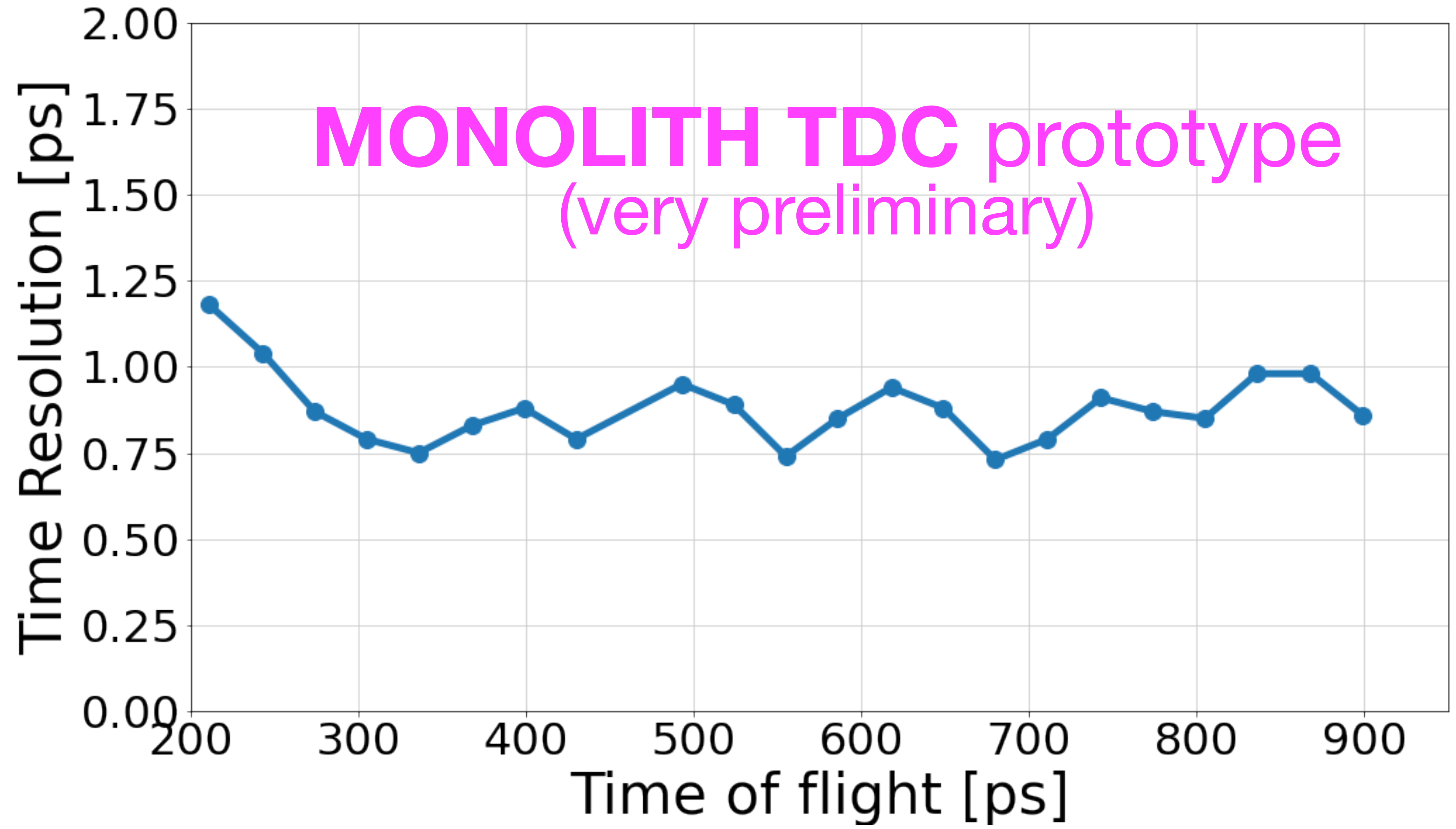
(13.2 ± 0.8) ps at the pixel center

Sub-picosecond TDC

We are developing a sub-picosecond TDC based on a novel design (our patent© & more):

© R. Cardarelli, L. Paolozzi, P. Valerio and G. Iacobucci, European Patent Application / Filing - UGKP-P-001-EP, Europe Patent EP 18181123.3. 2 July 2018.





Standalone prototype still under test at UNIGE.
Integrated in MONOLITH 2022 monolithic ASIC.

Summary

Triggered by the needs of the **HL-LHC and beyond**, the HEP community is working on precise timing with silicon to produce **4D trackers.**

Hybrid **LGAD** pads will be used in ATLAS & CMS, with **30 ps time capabilities**

Evolving towards :
- **TI-LGAD** to obtain small-pitch pixels
- **resistive AC-Coupled LGAD** to reduce the number of channels

Two projects are producing results at the level of **10 ps** (below the Landau limit):

- **TIMESPOT**, featuring the intrinsically rad-hard **hybrid 3D sensors**
- **MONOLITH**, featuring **monolithic** implementation of **SiGe BiCMOS** electronics on the novel **PicoAD** sensor

Production of **full systems** with 10µm and 10ps resolutions is a long way ahead of us

Extra Material

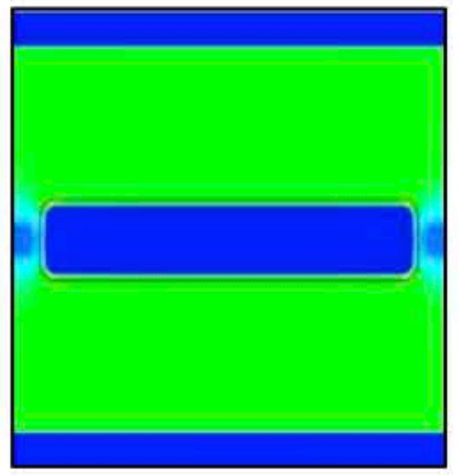
3D trench sensors

Sensor fabrication @ FBK

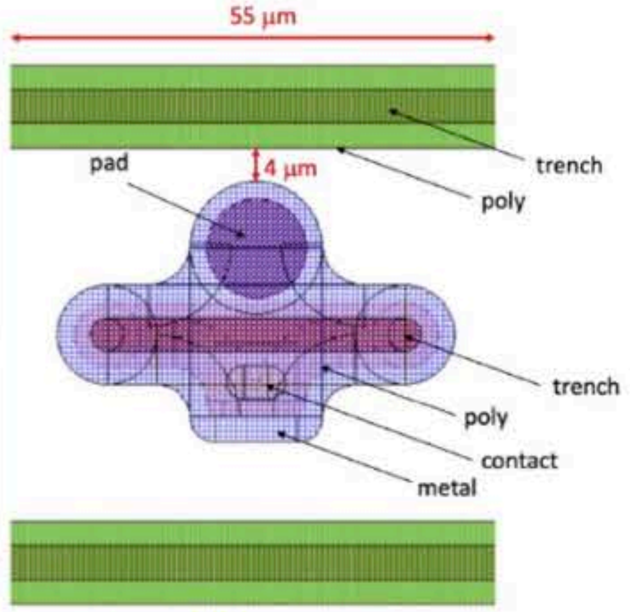
2 batches (2019 and 2020)

The optimal geometry

- 3D-trench
- 5 x 40 x 135 μm³ trench
- 150 μm pixel depth



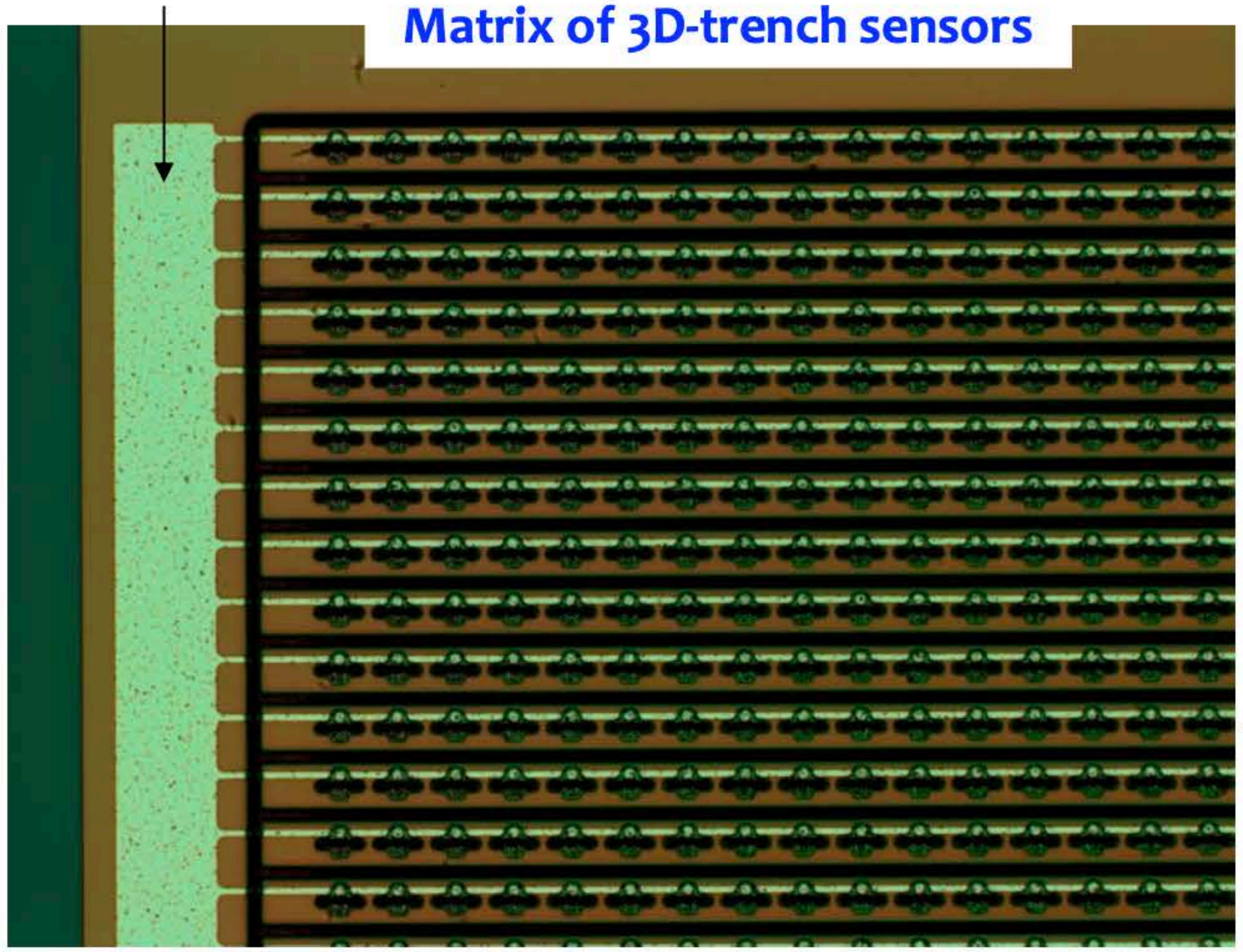
Pixel geometry



Pixel layout

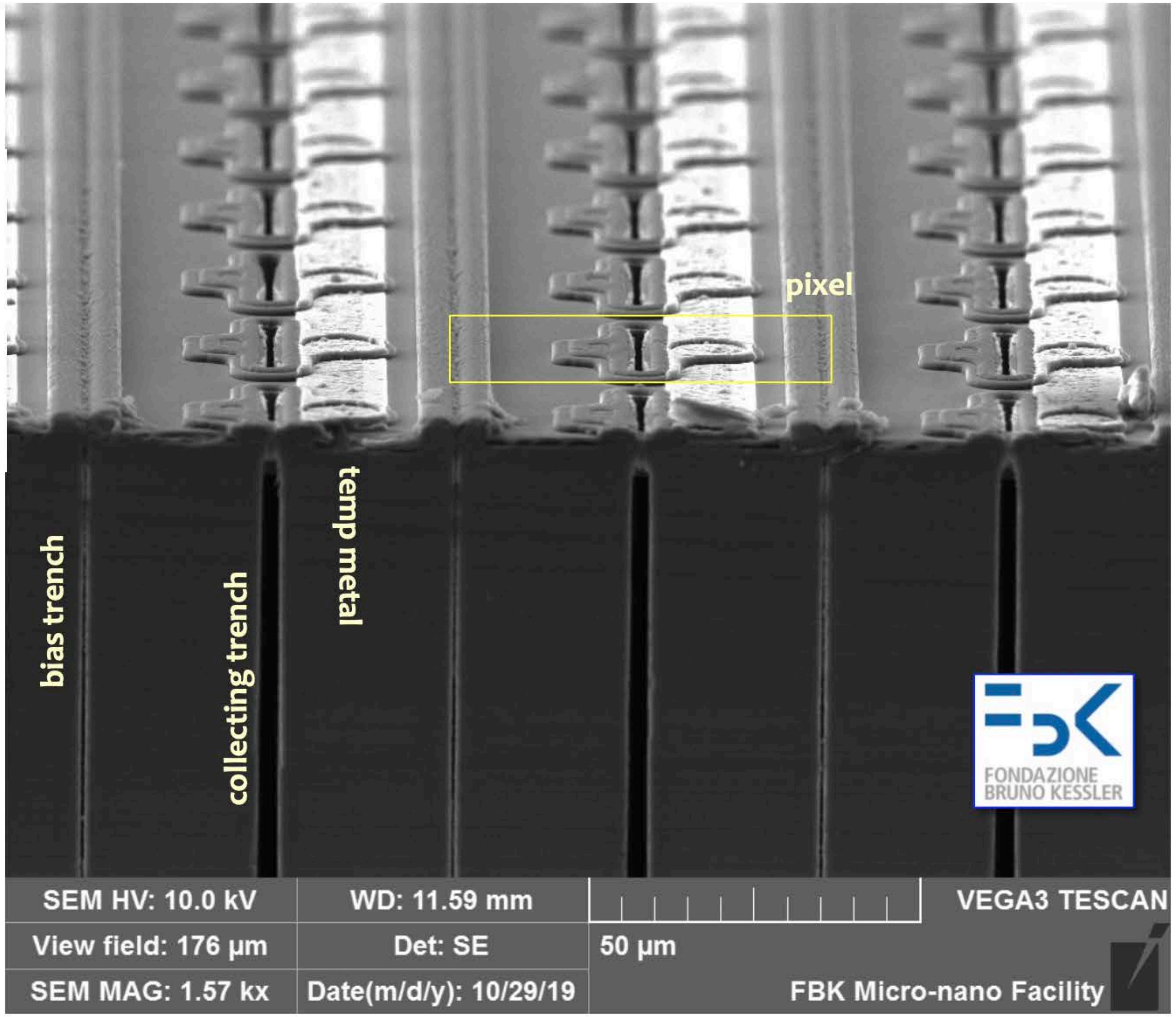
temp metal
for static tests

Matrix of 3D-trench sensors



collecting trench

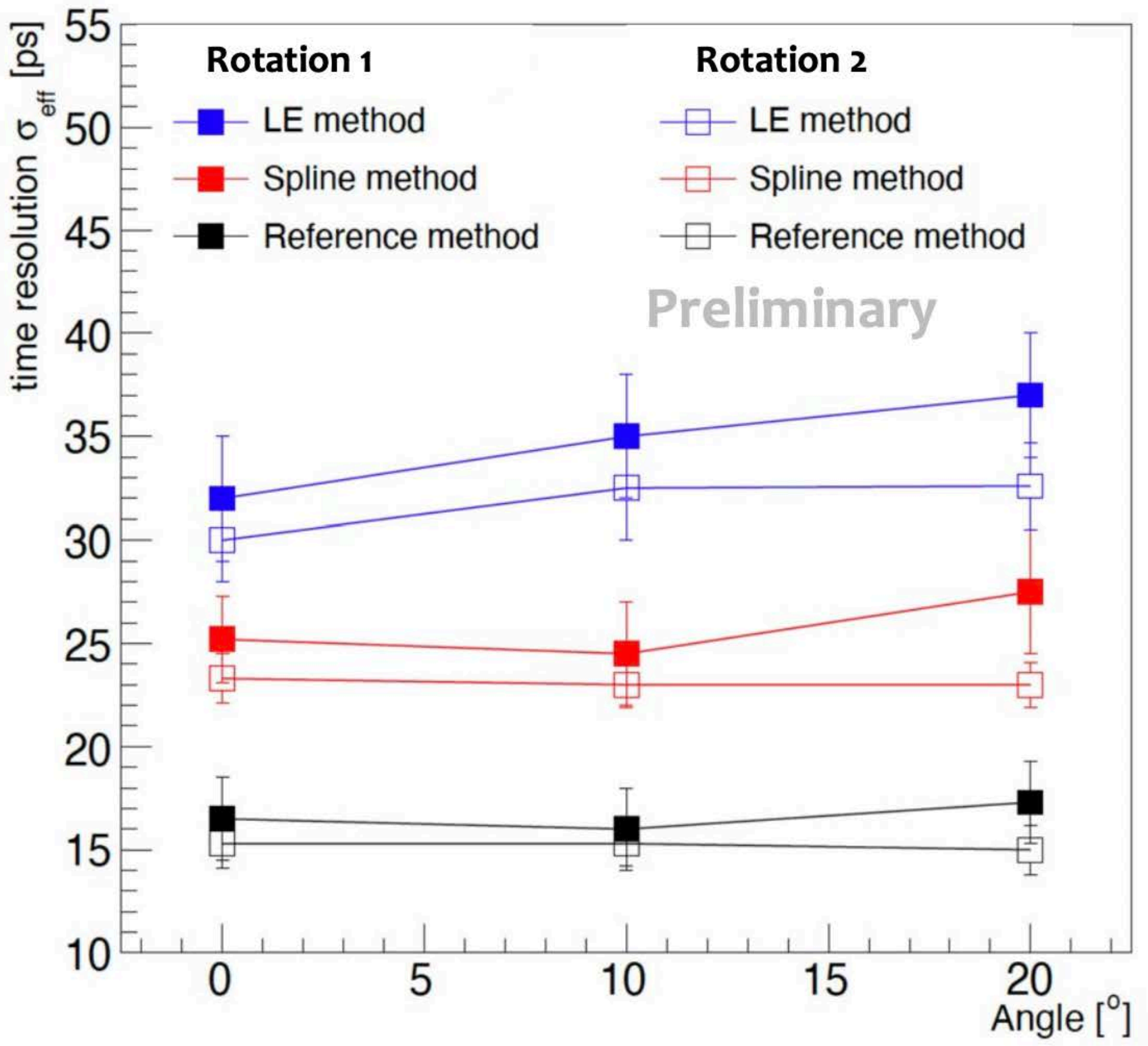
bias trench



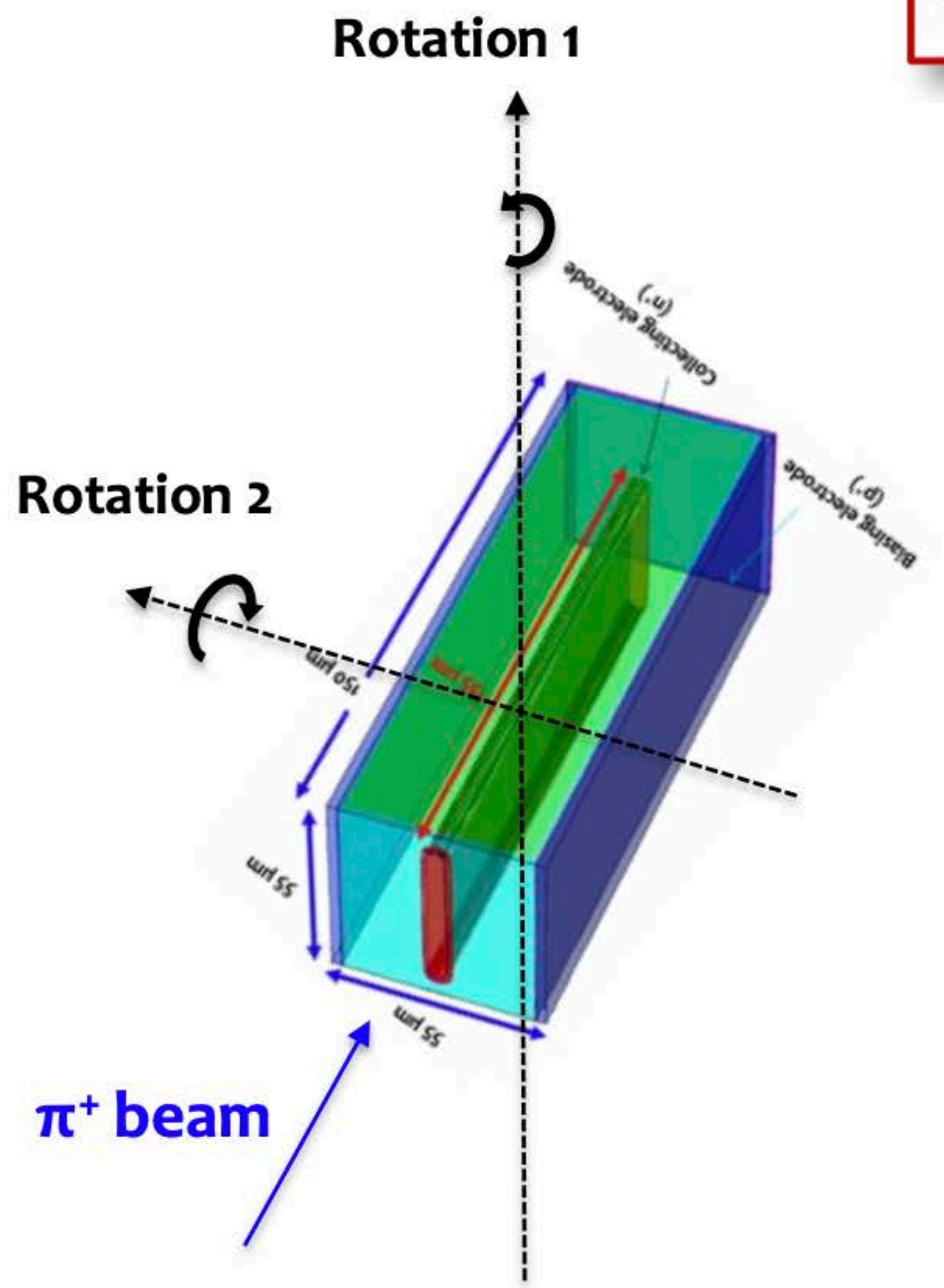
Deep Reactive Ion Etching
Bosch technology
(developed for MicroElectroMechanicalSystem technology)

TimeSPOT results – A. Lai – 1st MONOLITH Wshop – UniGeneve, 5-6th September 2022

Timespot: timing tilted sensors



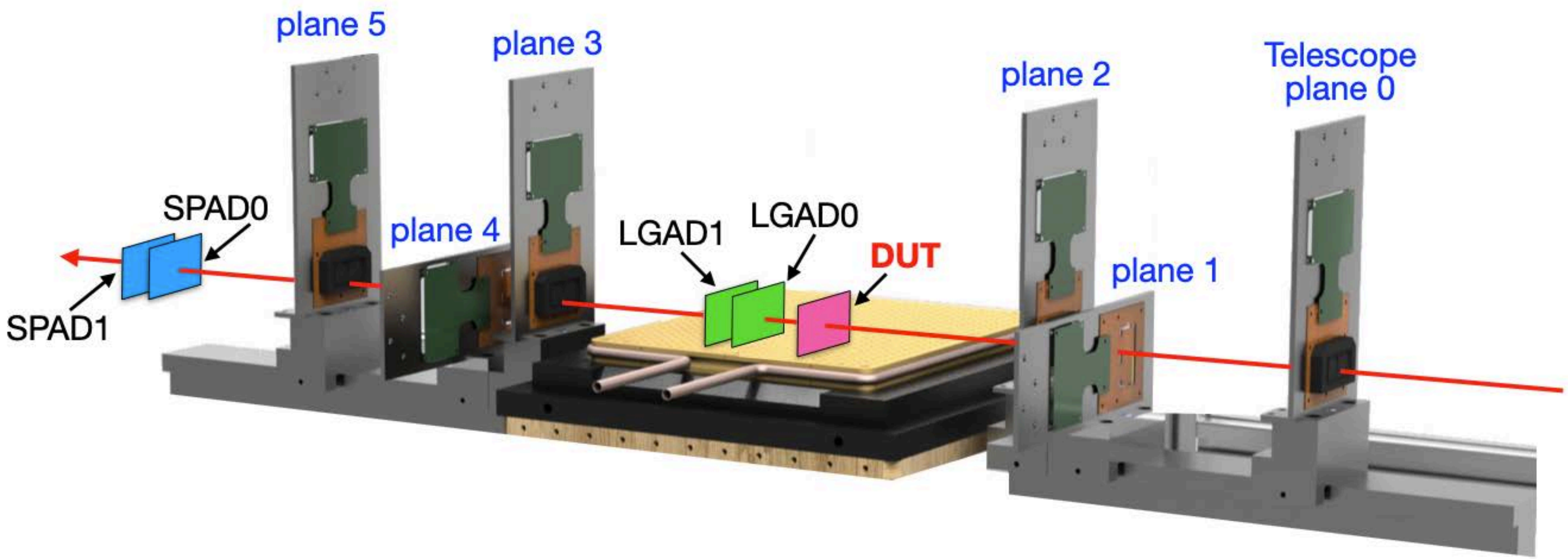
Single Pixel @ 50V



25

Test Beam: Experimental Setup

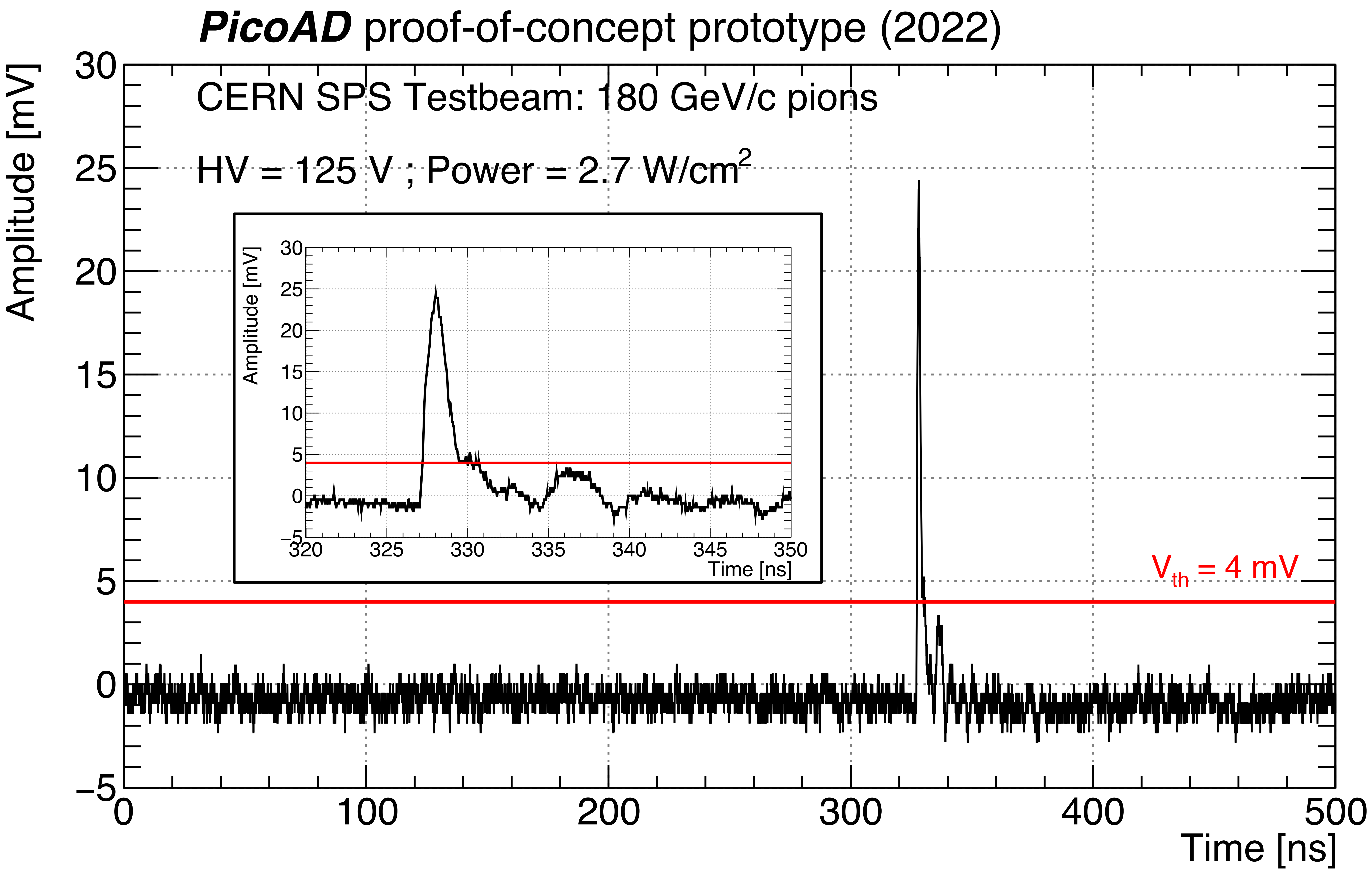
CERN SPS Testbeam with 180 GeV/c pions to measure **efficiency** and **time resolution**



UNIGE FE-I4 telescope to provide spatial information ($\sigma_{x,y} \approx$10 µm)

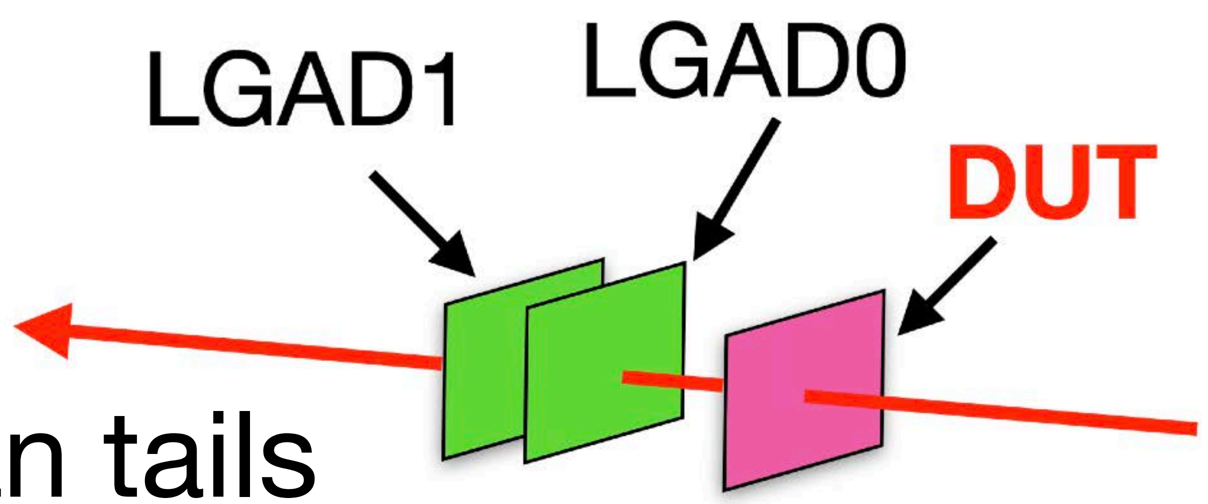
Two LGADs ($\sigma_t \approx$35 ps) to provide the timing reference (and **two SPADs** with $\sigma_t \approx$20 ps)

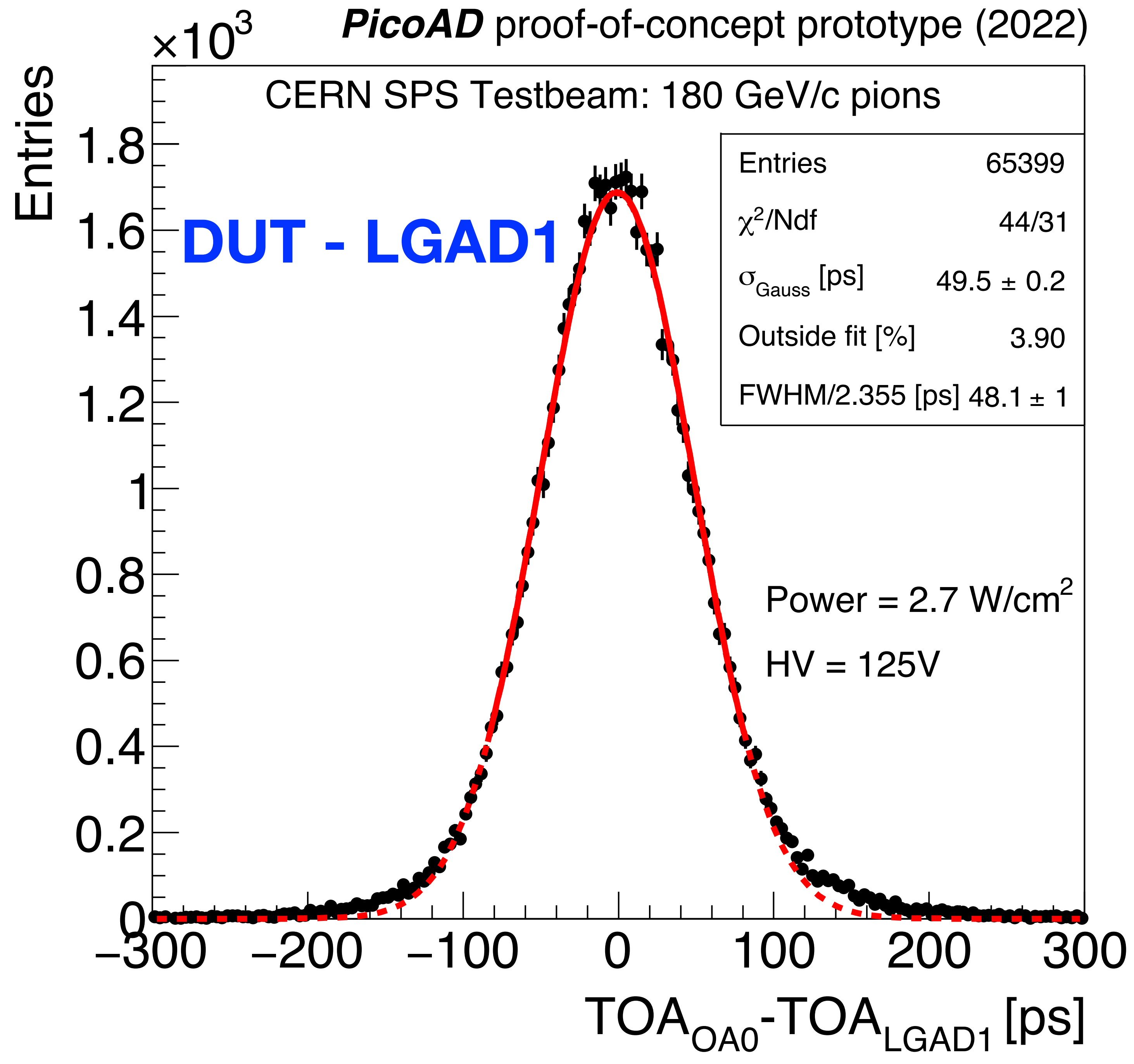
Waveform Example

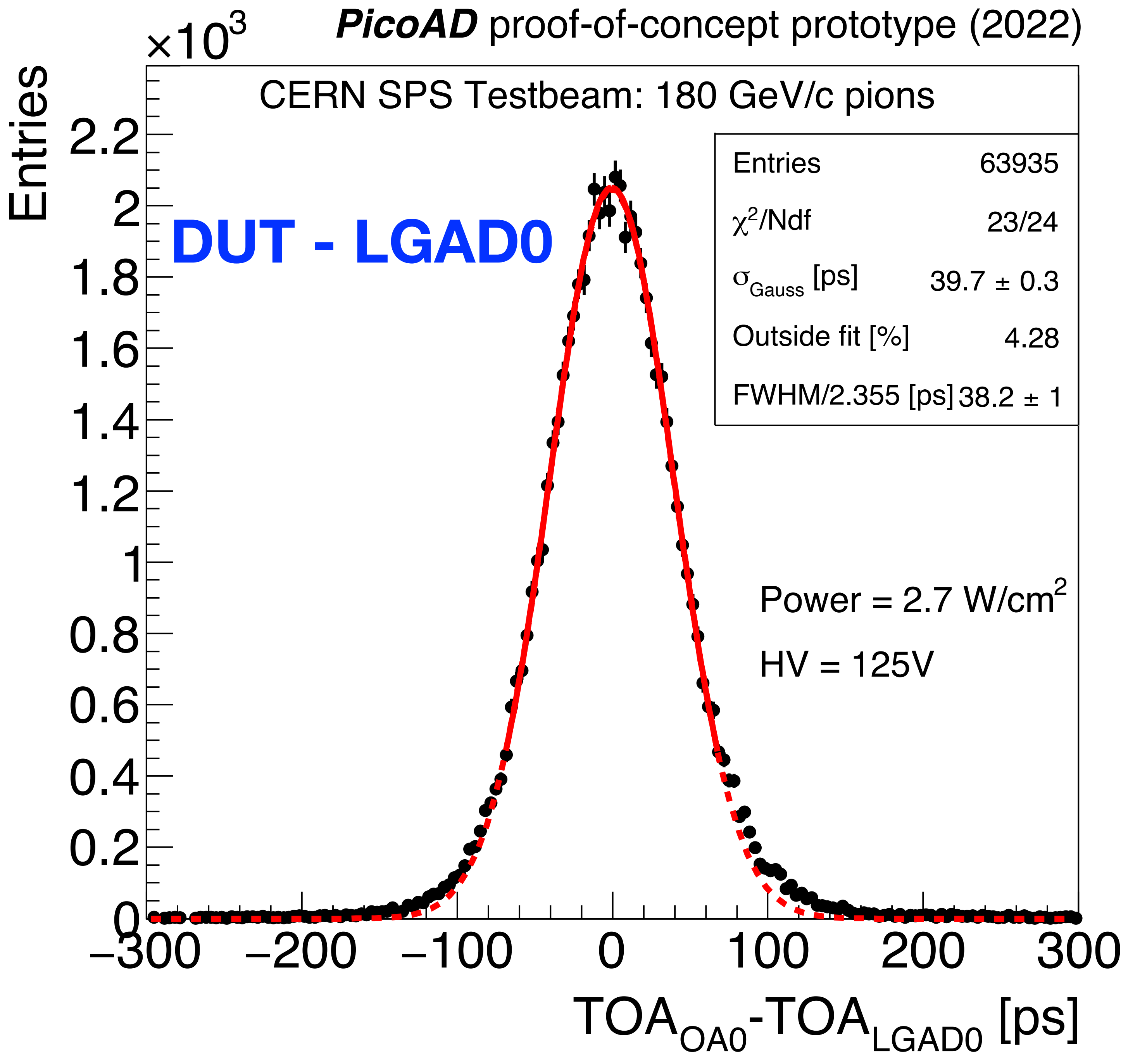


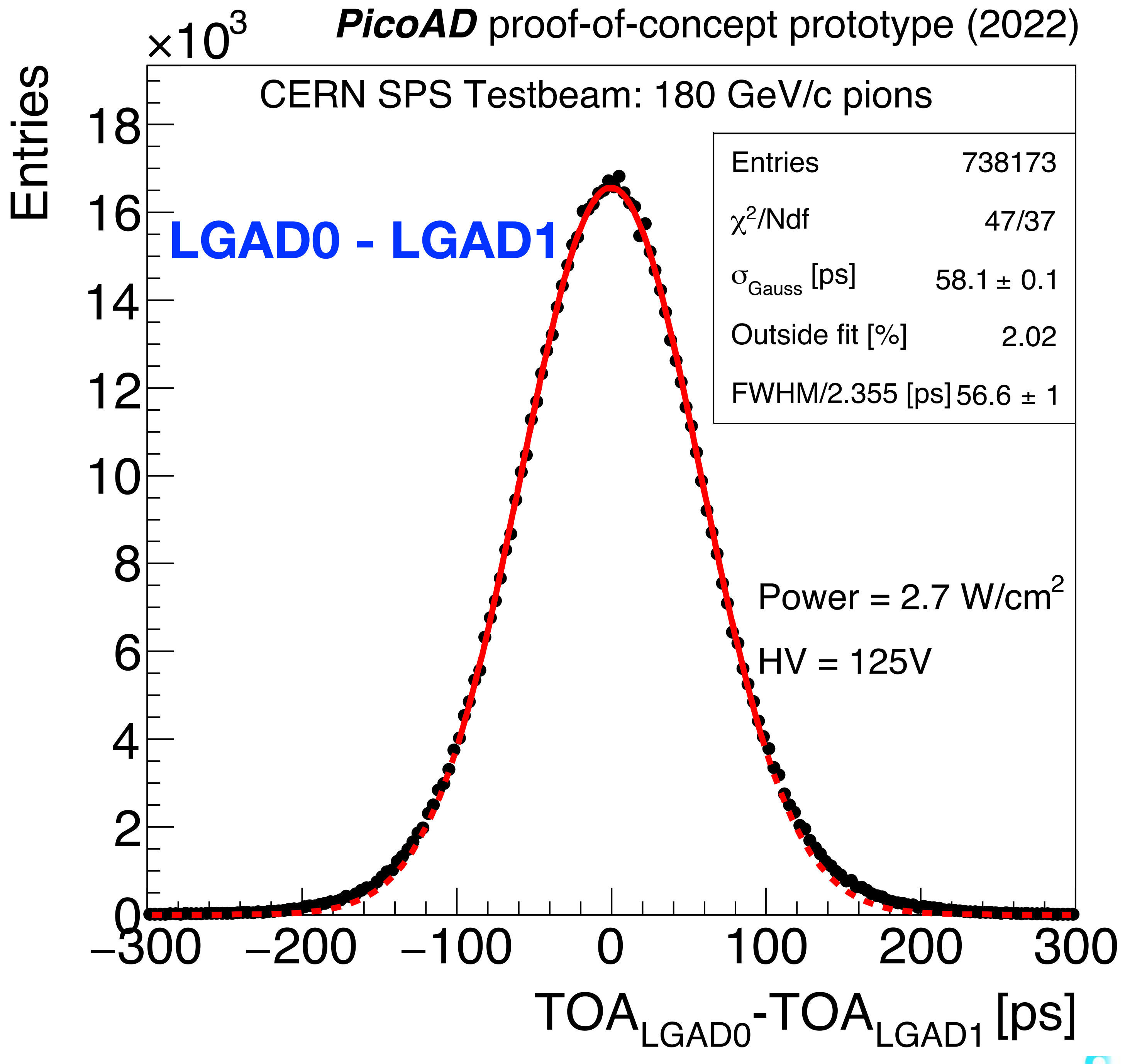
Testbeam results: Time Resolution

- Time Of Arrival (TOA) as a **time at constant fraction**
- Distributions after **time-walk correction**
- Distributions are **Gaussian:** only ≈2-4 % of entries in non-gaussian tails
- Simultaneous fit to extract time resolutions of the DUT, LGAD0, LGAD1





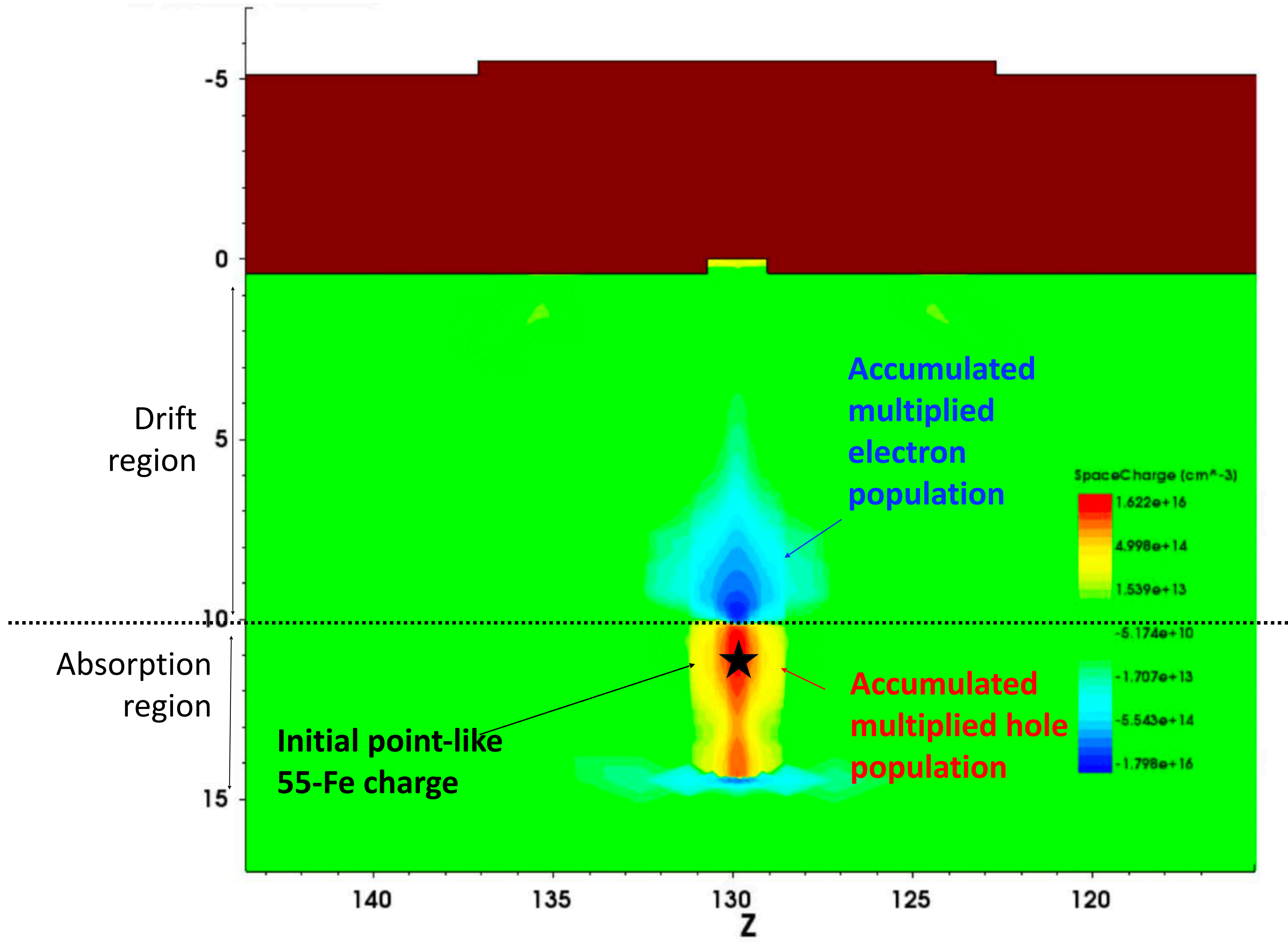




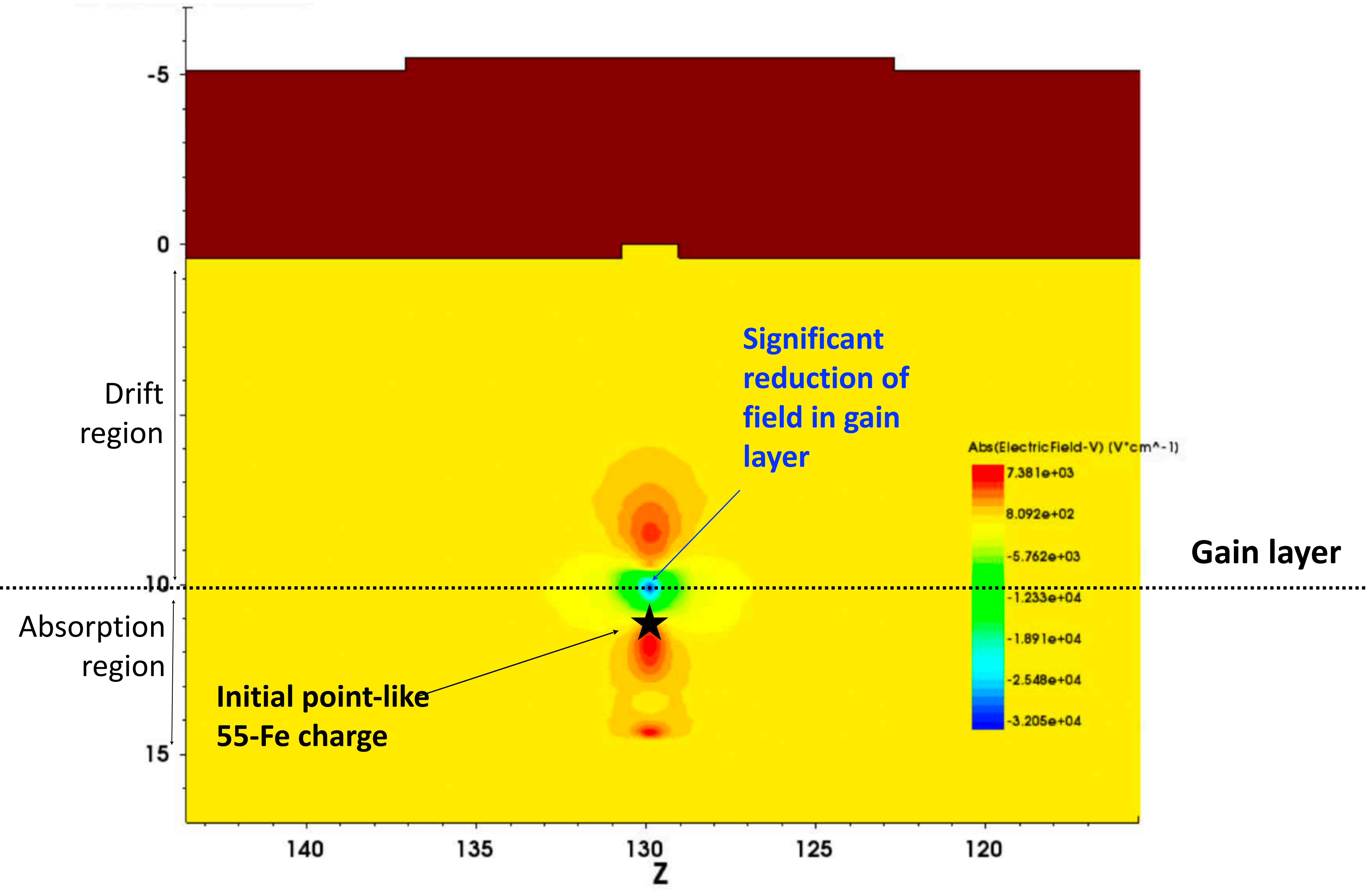
TCAD: transient space-charge effect

Transient 3D TCAD simulation of point like 55-Fe charge deposition in absorption layer:

Space charge:
10ps after charge generation – before charge generation:

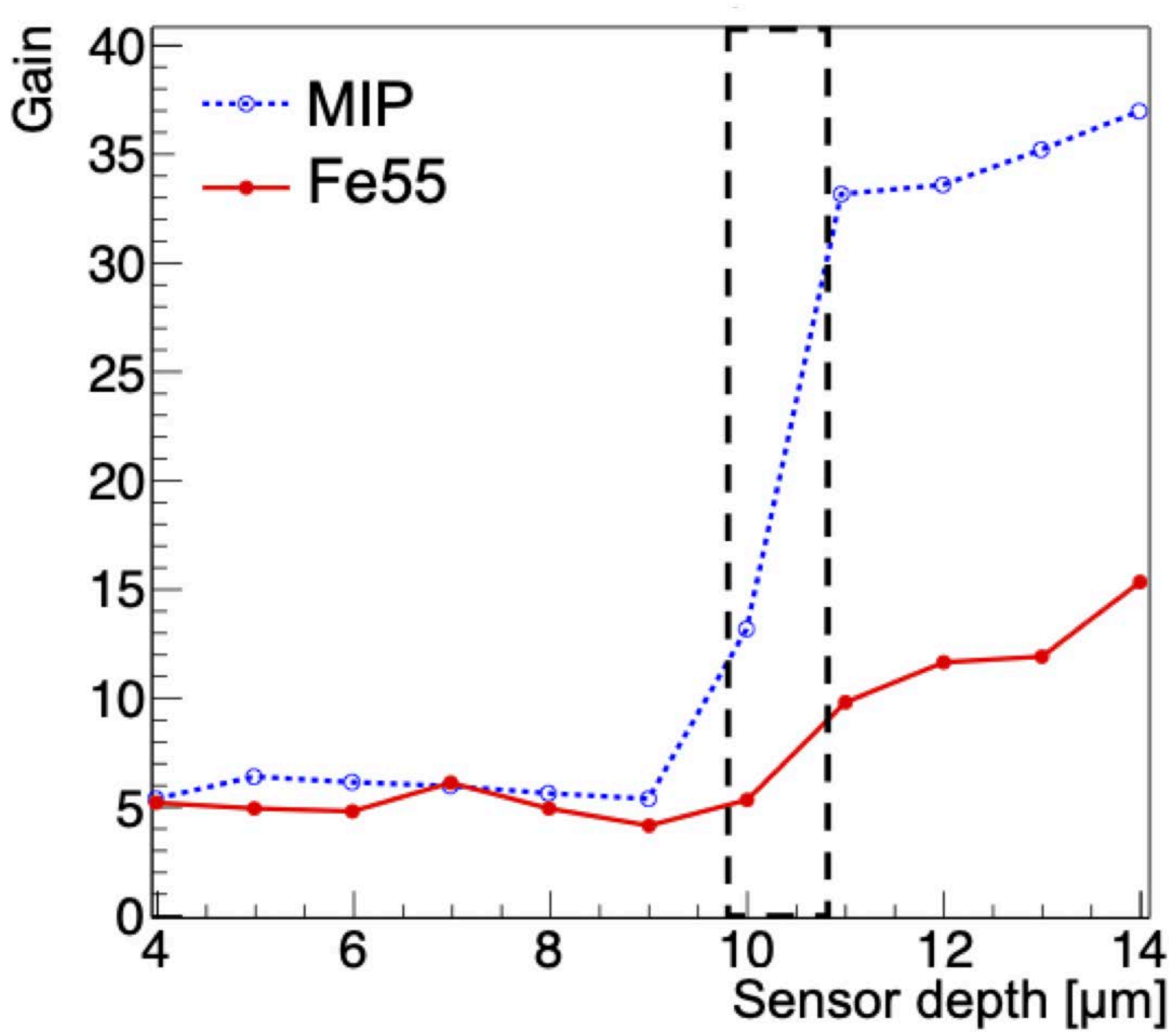


Electric field:
10ps after charge generation – before charge generation



TCAD: transient space-charge effect

Gain as function of sensor depth for different primary charge carrier densities:



- For high charge carrier densities (Fe55) the gain is suppressed compared to lower charge carrier densities (MIPs).

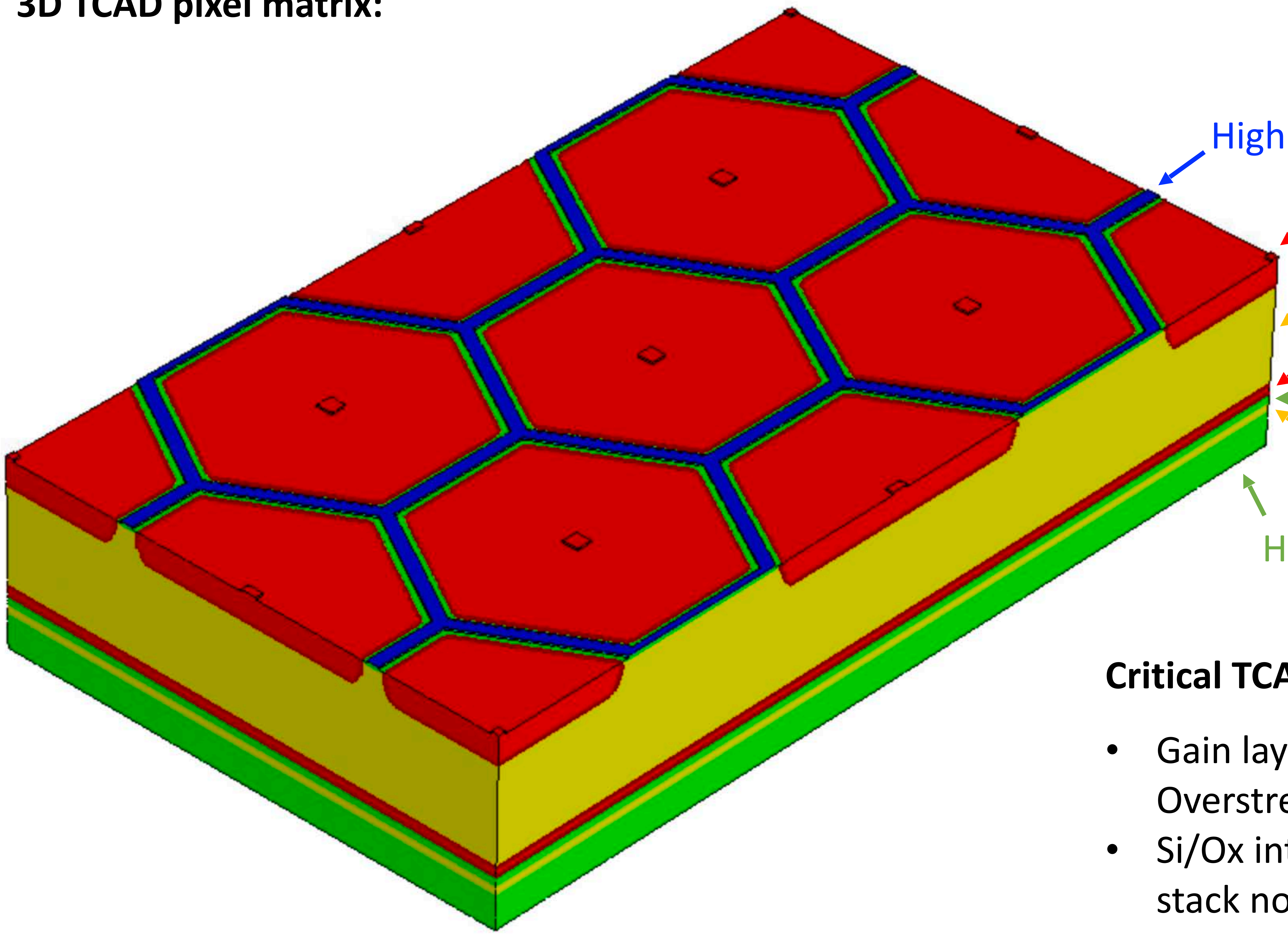
- Simulated suppression factor of Fe55 w.r.t. MIP charge compatible to calculation of compression factor from test-beam and Fe55 measurements.

→Measured gain for Fe55 significantly supressed by transient space charge effect.

→Need of fully self consistent transient TCAD simulations.

PicoAD simulation - 3D TCAD setup

3D TCAD pixel matrix:

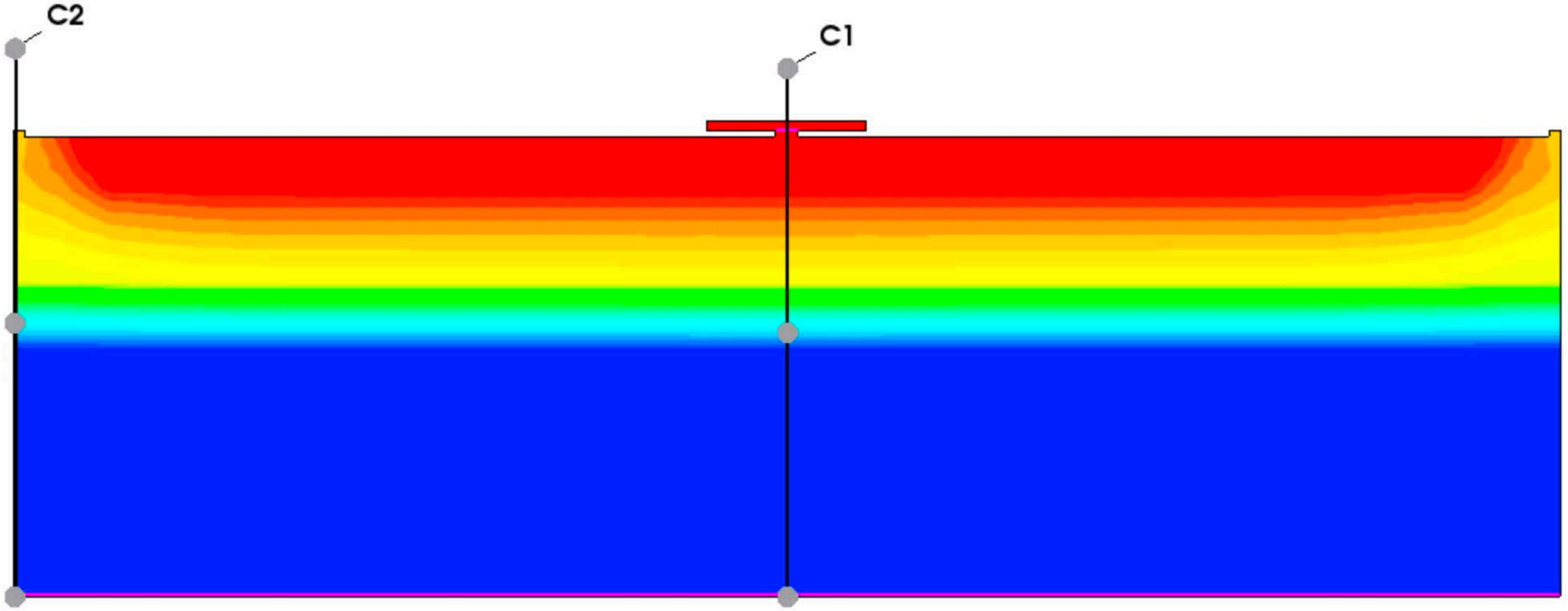


Critical TCAD aspects:

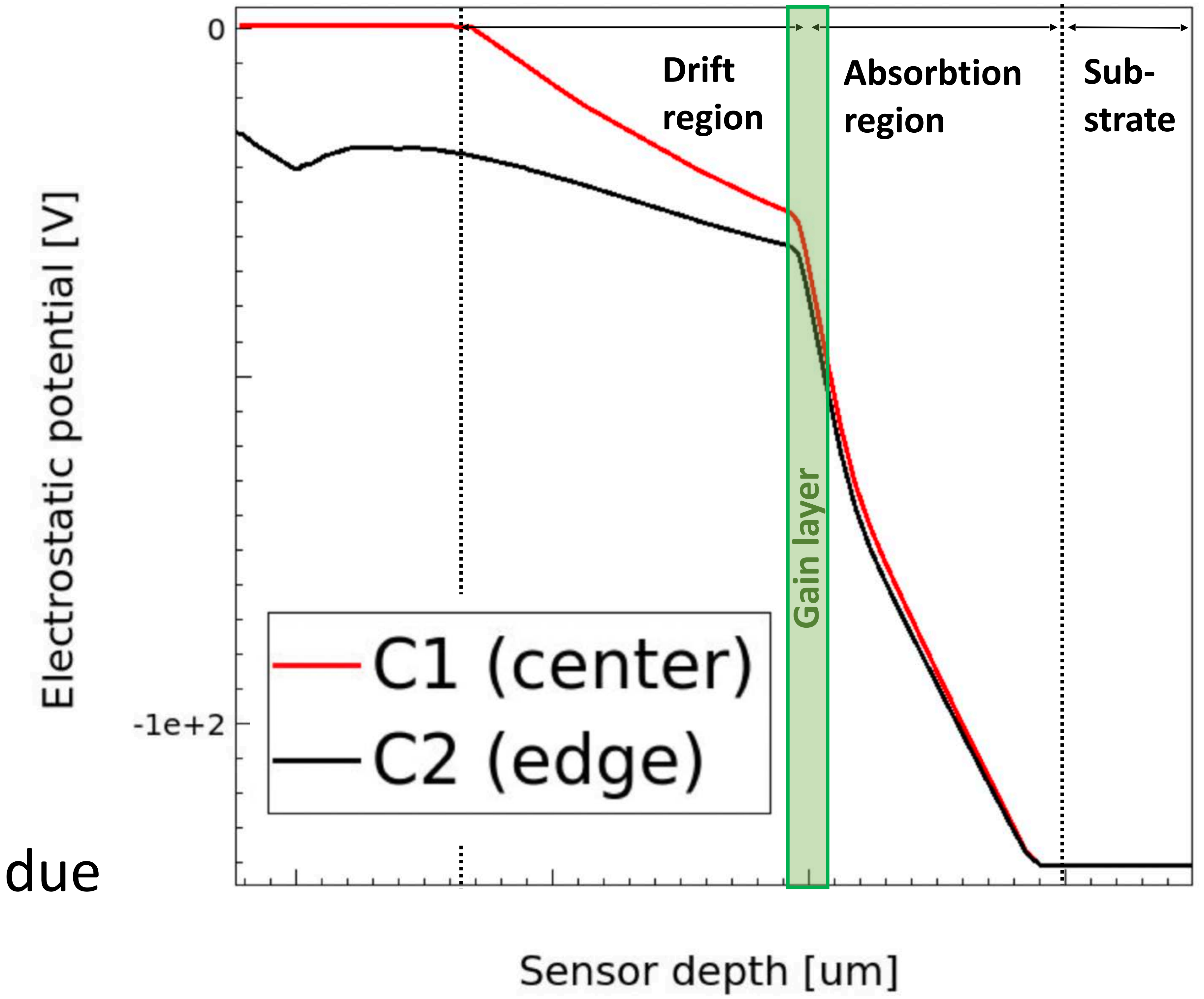
- Gain layer: meshing & modelling (Okuto, van Overstreaten etc…)
- Si/Ox interface in inter pixel region (top layer oxide stack not shown here)

PicoAD 3D TCAD - electrostatic potential

Electrostatic potential – 2D map:



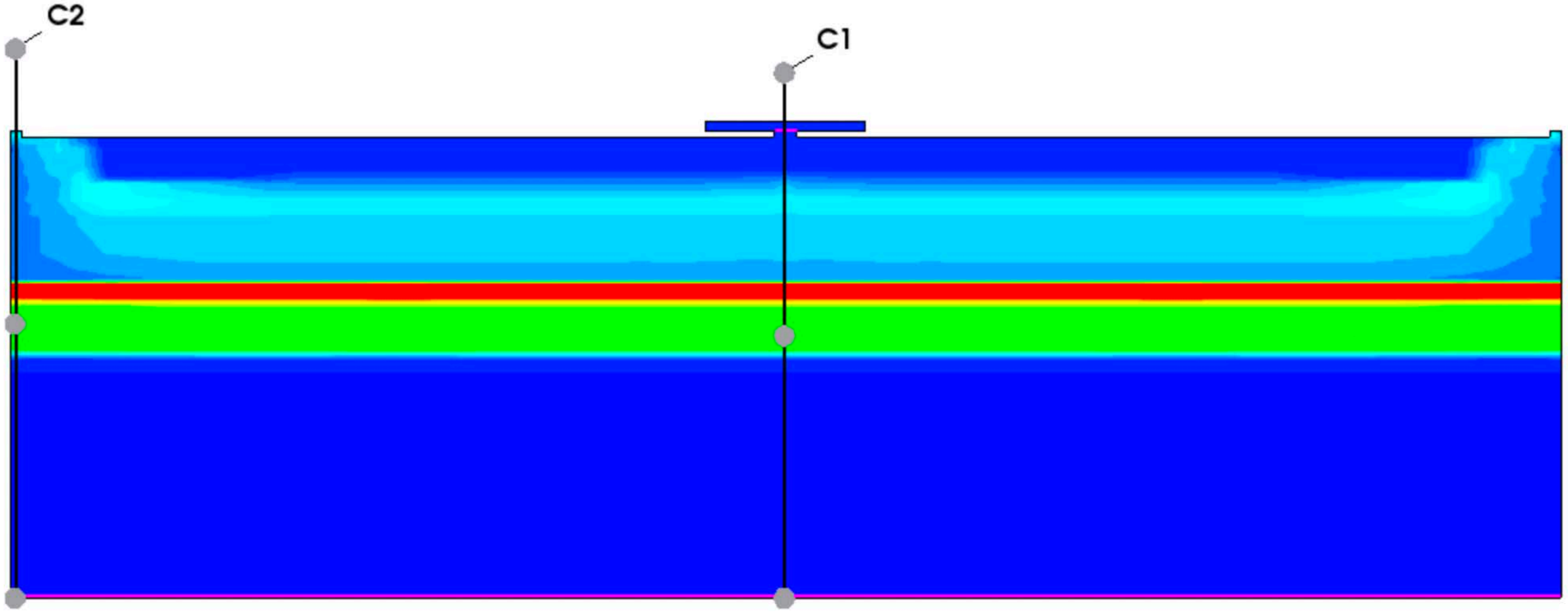
Electrostatic potential – cuts C1, C2:



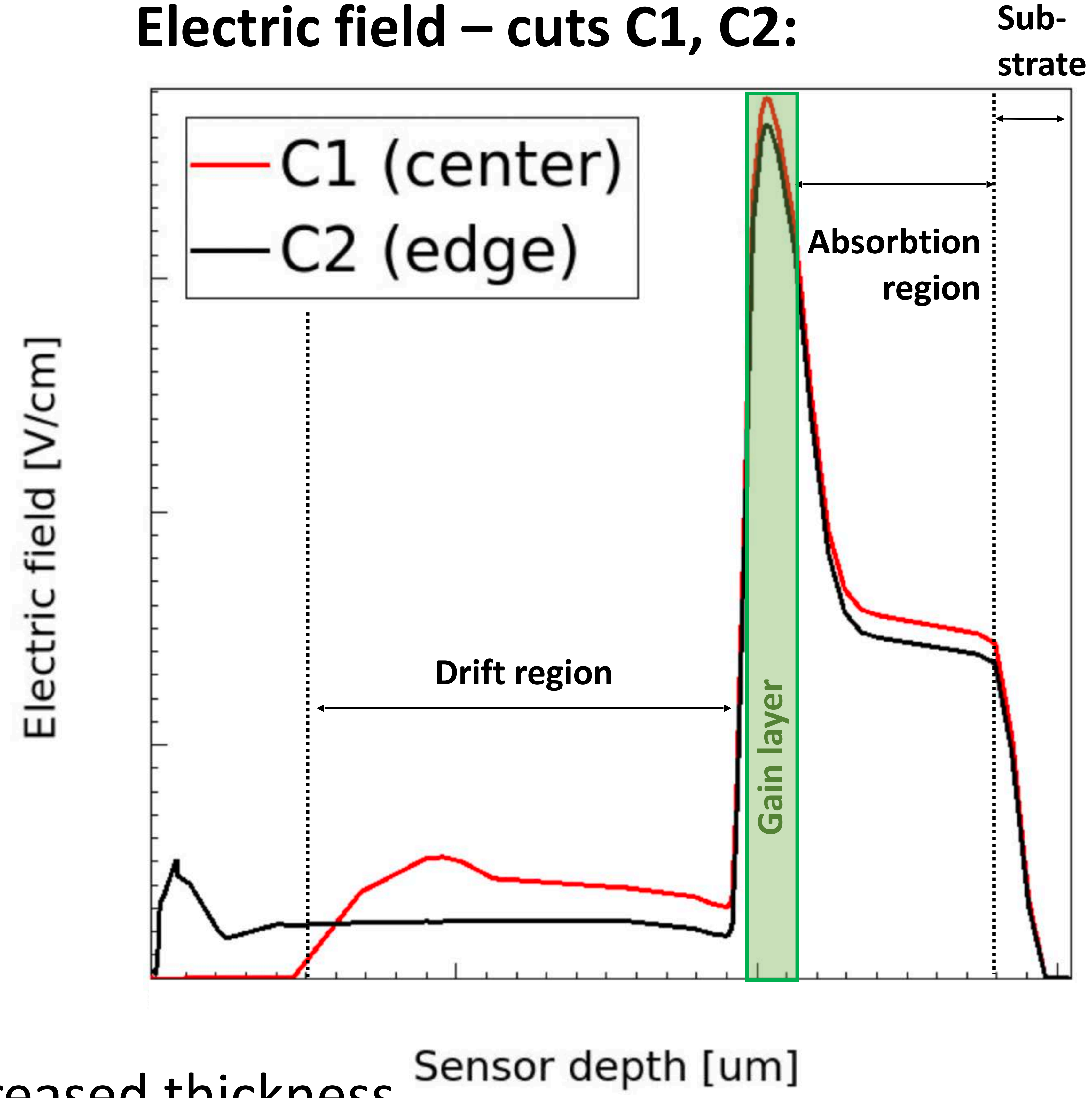
- Highest potential drop in gain layer (as expected)
- Significant potential drop in drift region, less compared to absorbtion region due to increased thickness
- In inter-pixel region:
  - Potential maximum close to surface
  - Reduced potential drop in drift & gain layer region

PicoAD 3D TCAD - Electric field

Electric field – 2D map:



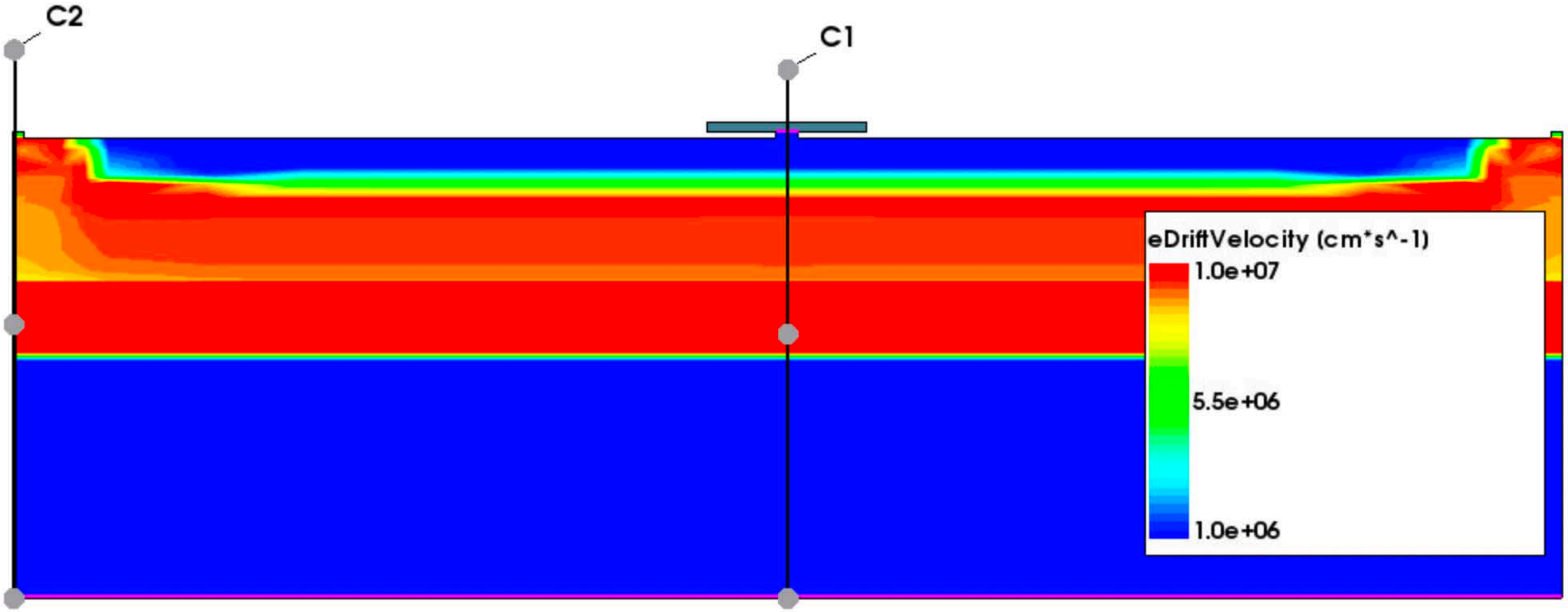
Electric field – cuts C1, C2:



- Highest elecric field in gain layer (as expected)
- Significant E field in drift region, less compared to absorbtion region due to increased thickness
- In inter-pixel region:
  - Field minimum close to surface
  - Reduced field in drift & gain layer region → lower gain in inter pixel region

Electron drift velocity

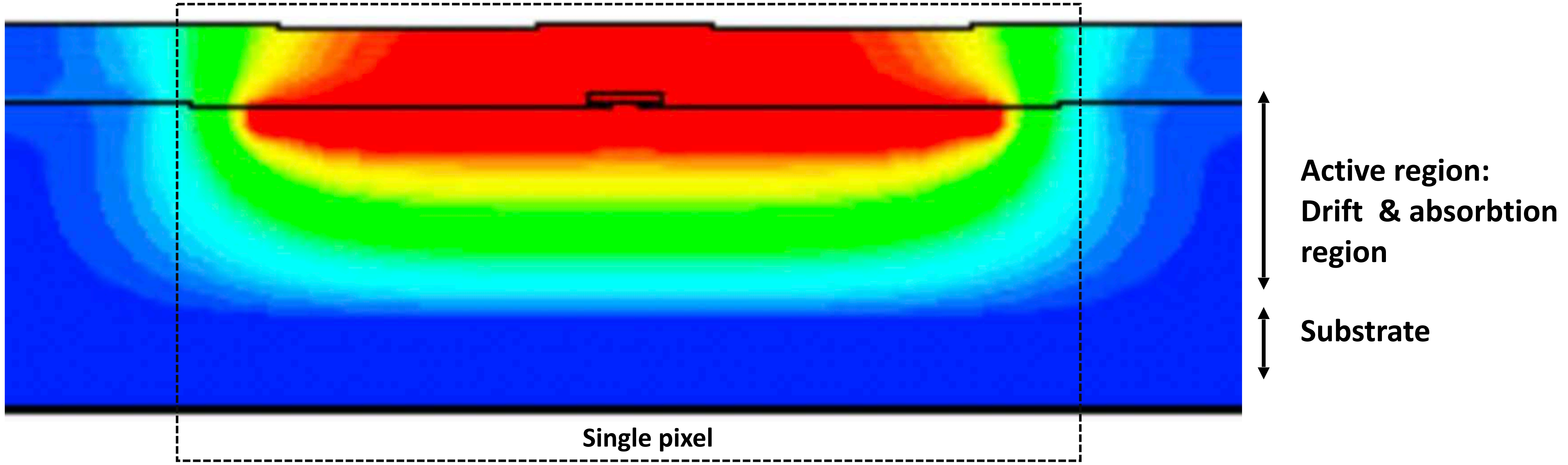
Electron drift velocity – 2D map:



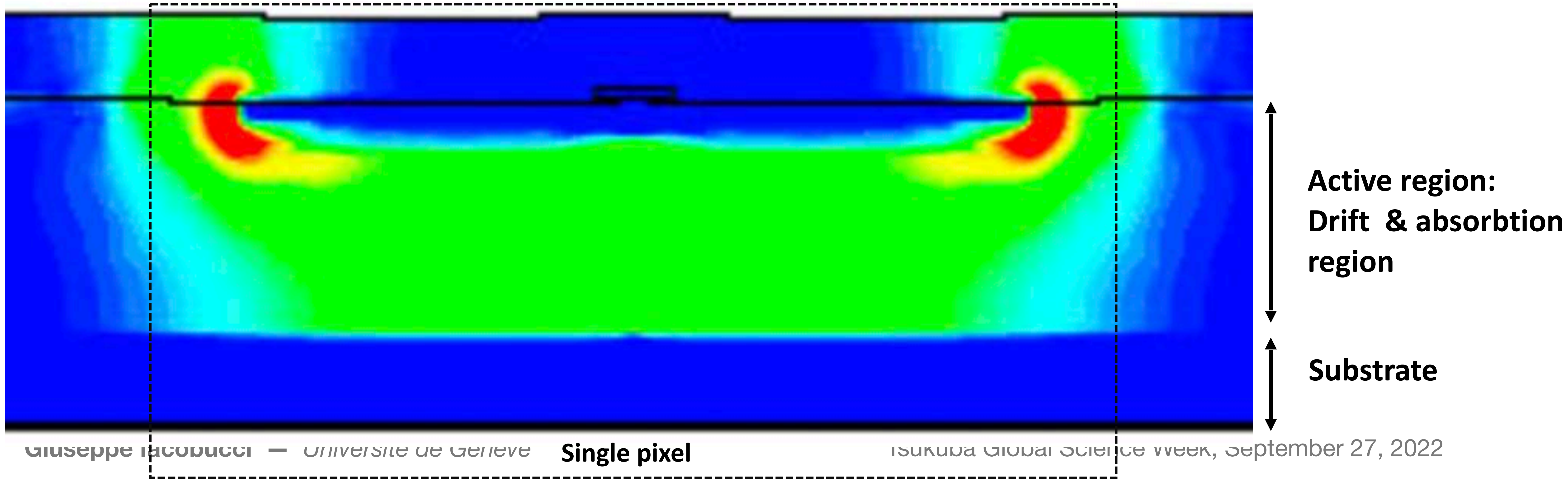
→ Electron drift velocity very close to saturation in full pixel volume (note the scale!)
→ Important for precise timing

Weighting potential & field

Weighting potential – 2D map:



Weighting field – 2D map:



- No impact of gain layer on weighting potential & field
- High weighting field over full active thickeness

→ Important for precise timing

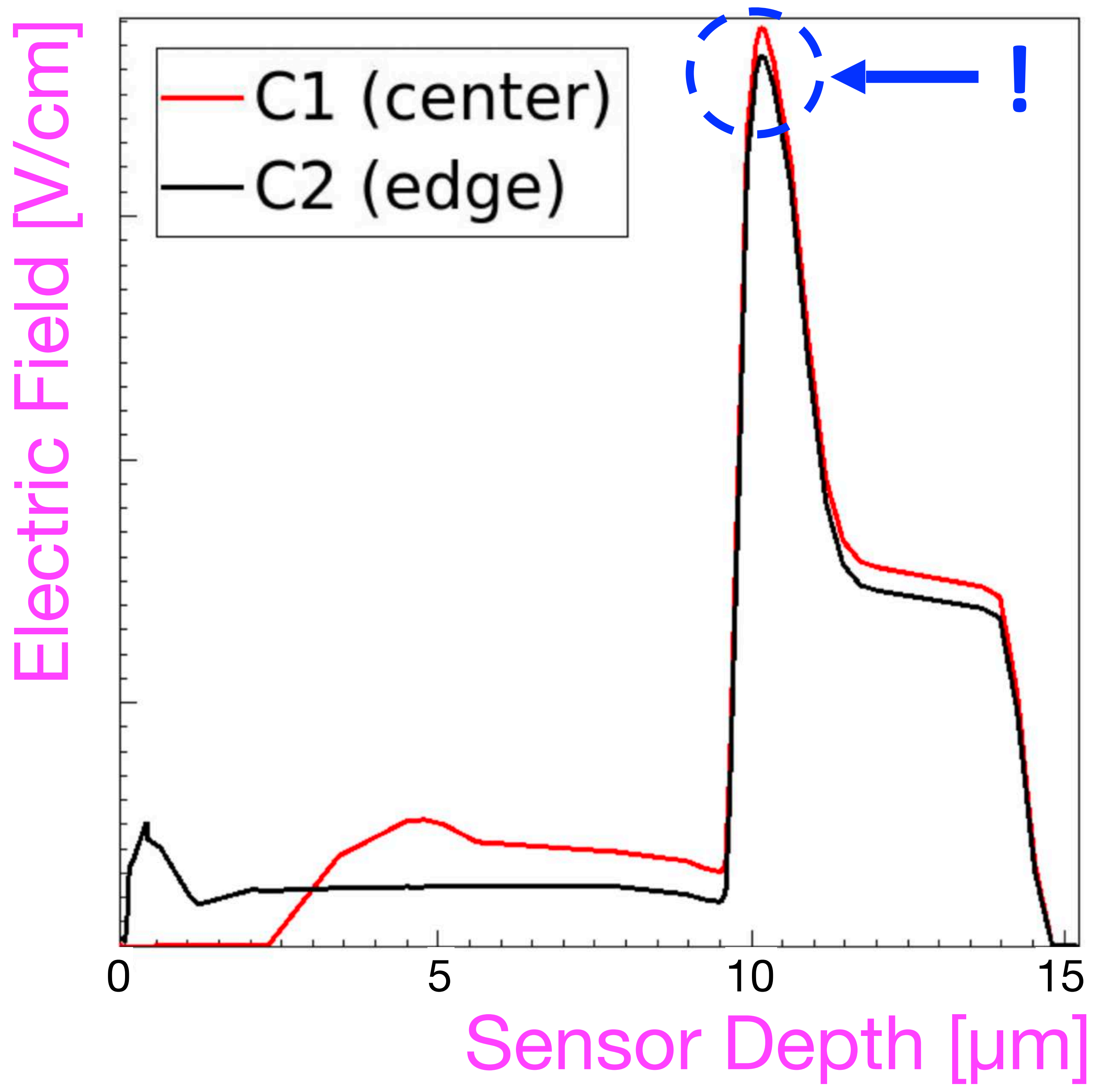
- Highest weighting field in pixel implant corners due to largest potential drop

Next submission – optimisation of drift region

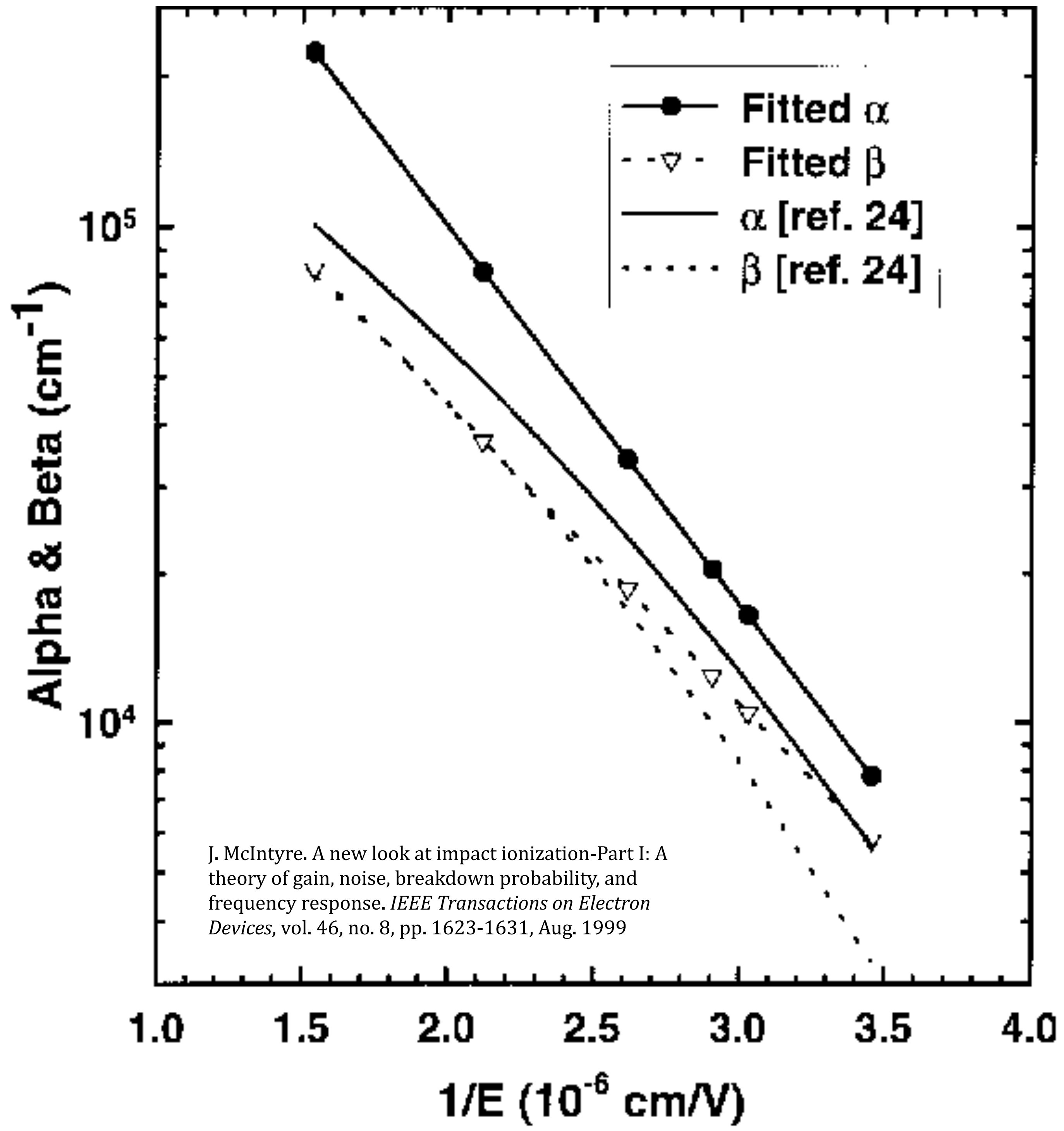
First proof of concept prototype with non-optimal drift region thickness:

Thickness of epi-layer limited by production process
→ Significant gain variations in inter-pixel region:

E_{field}, 1st prototype, 10µm drift region:

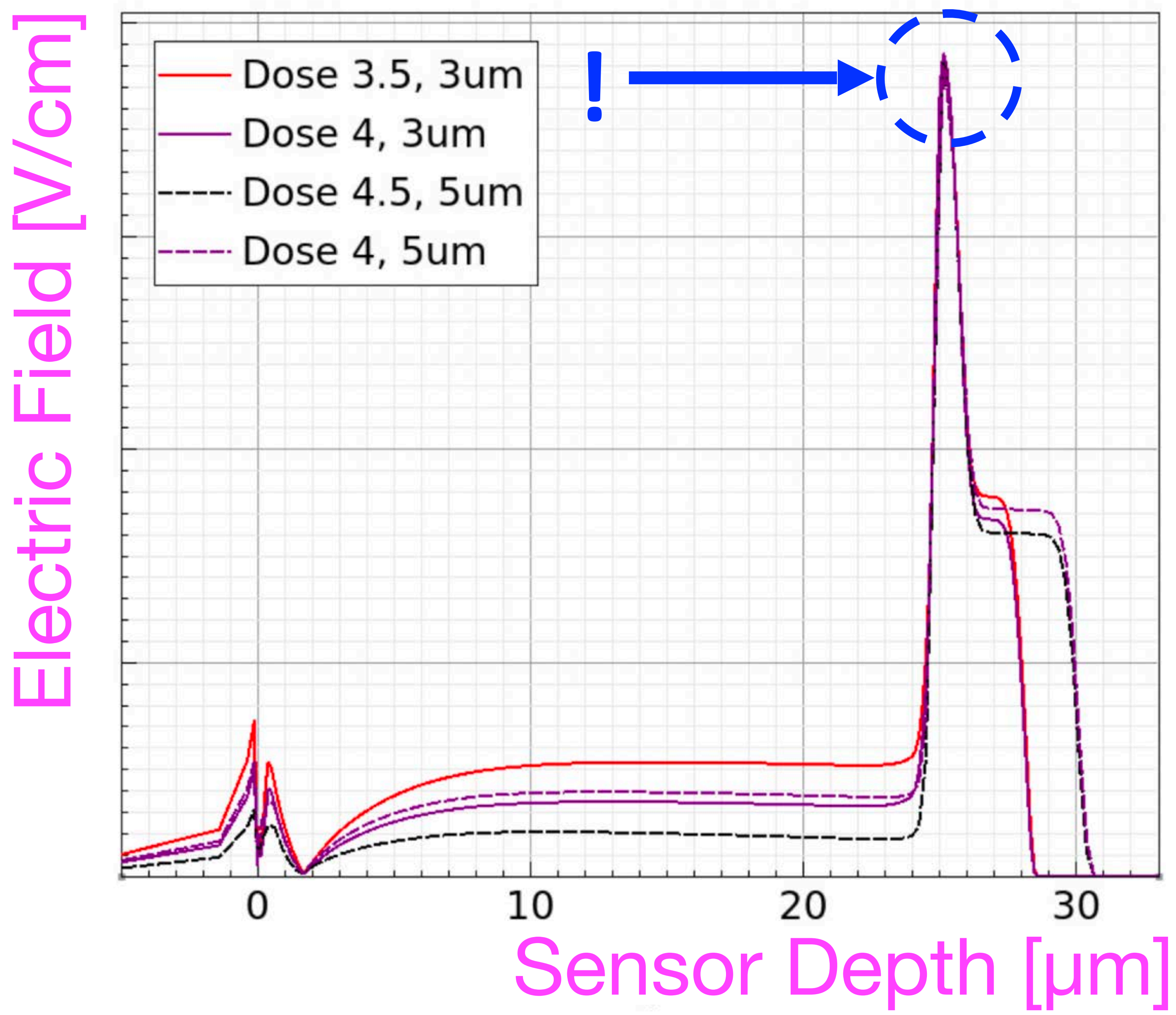


At high voltage, small variations of the electric field in the gain layer result in large gain variations:



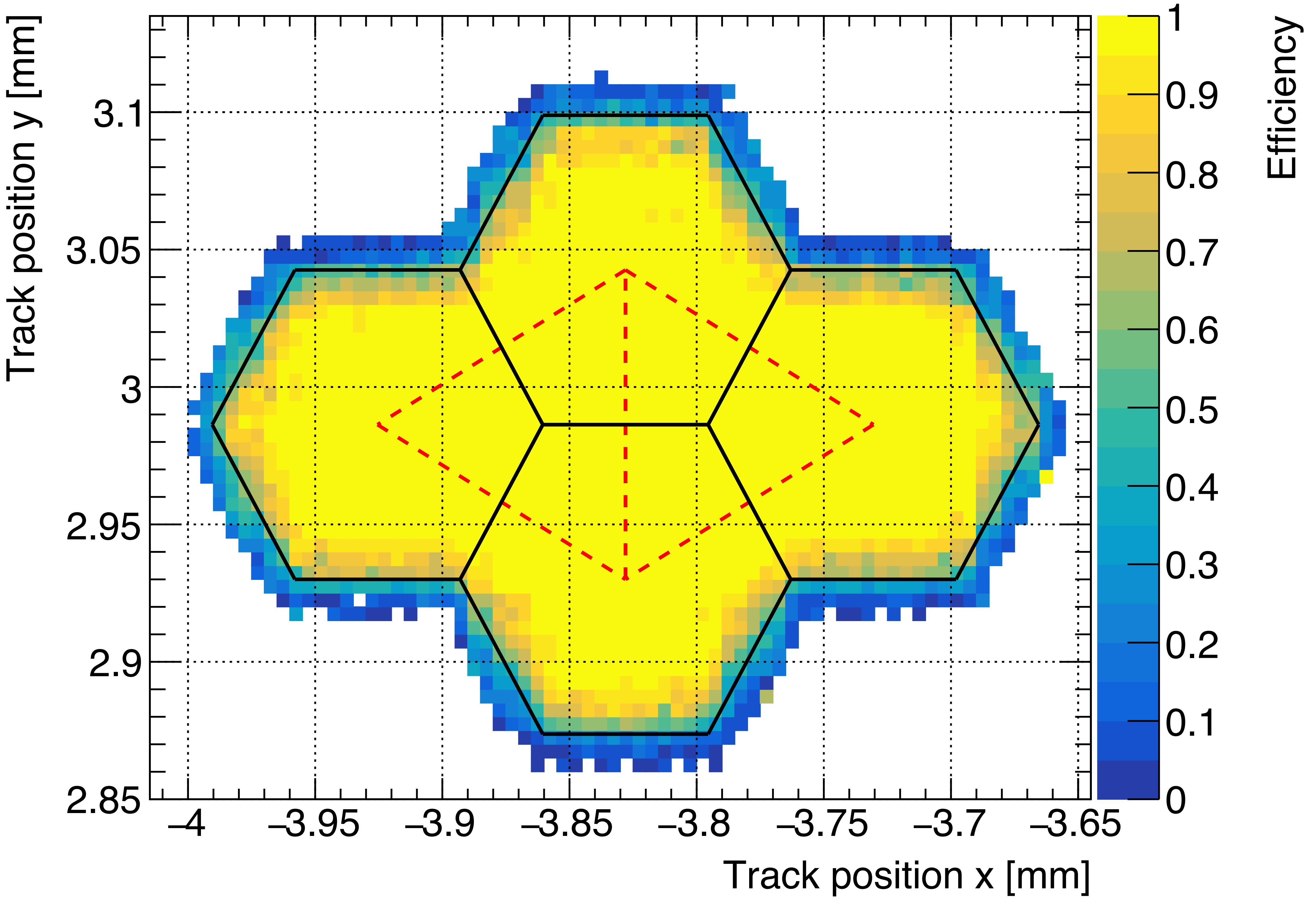
→ Next production (with external company): thicker epitaxial layer for drift region

E_{field}, 2nd prototype, 25µm drift region:



Detection Efficiency

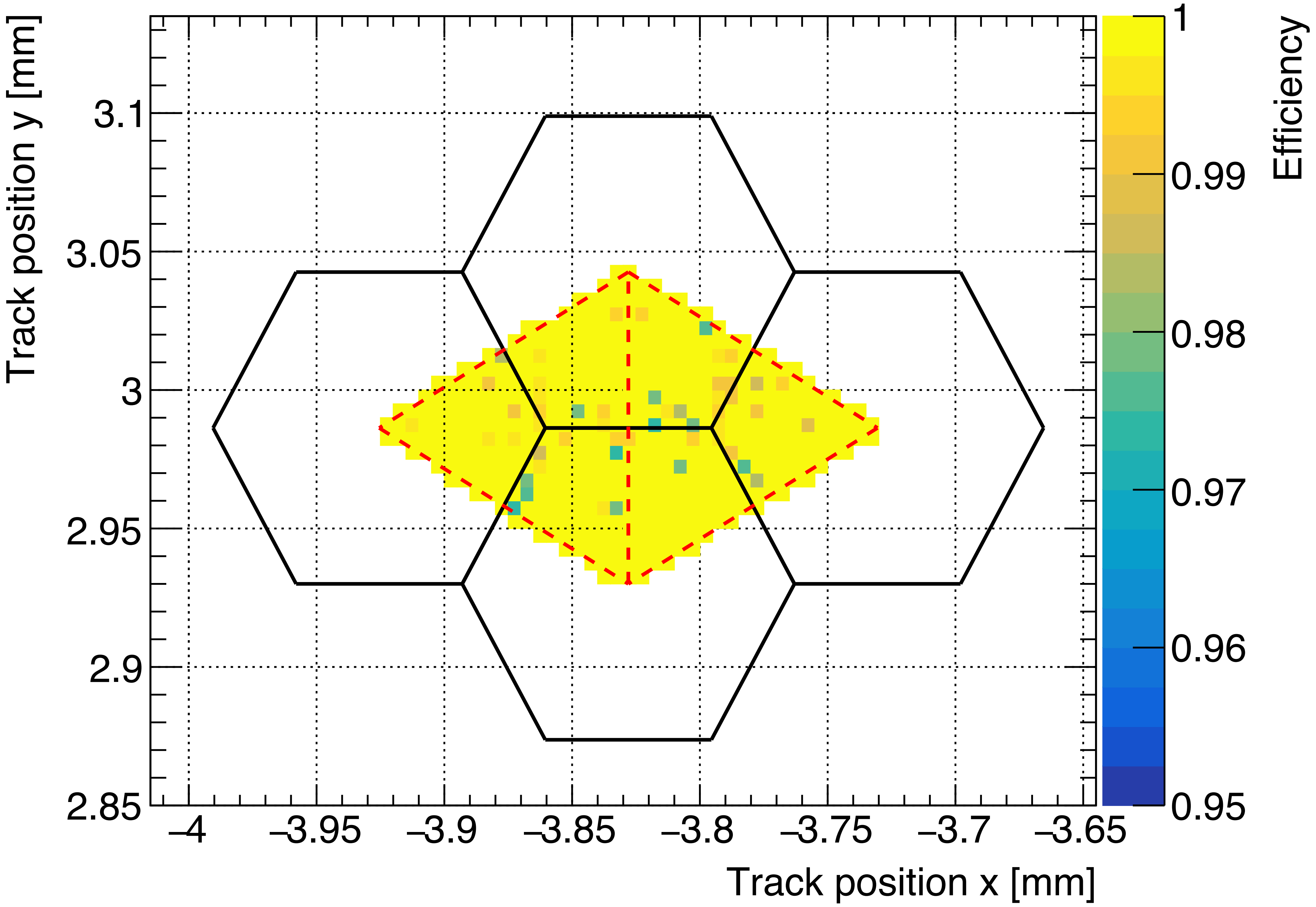
PicoAD proof-of-concept prototype (2022)

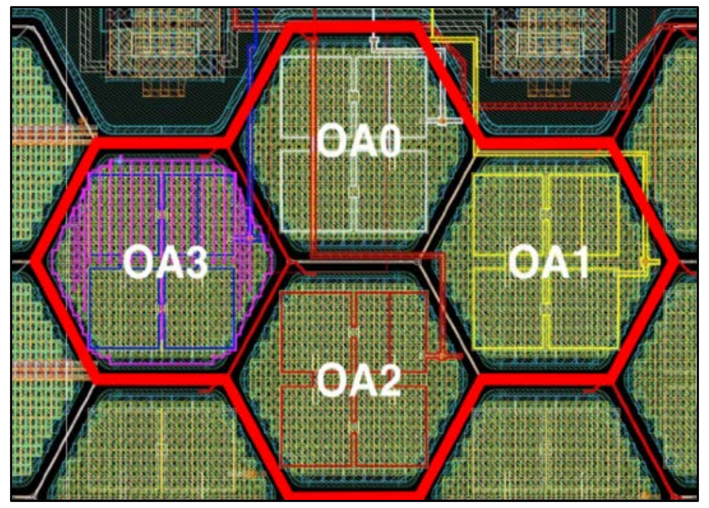


of tl

CERN SPS Testbeam: 180 GeV/c pions

V_{th} = 4 mV ; HV = 125 V ; Power = 2.7 W/cm^2

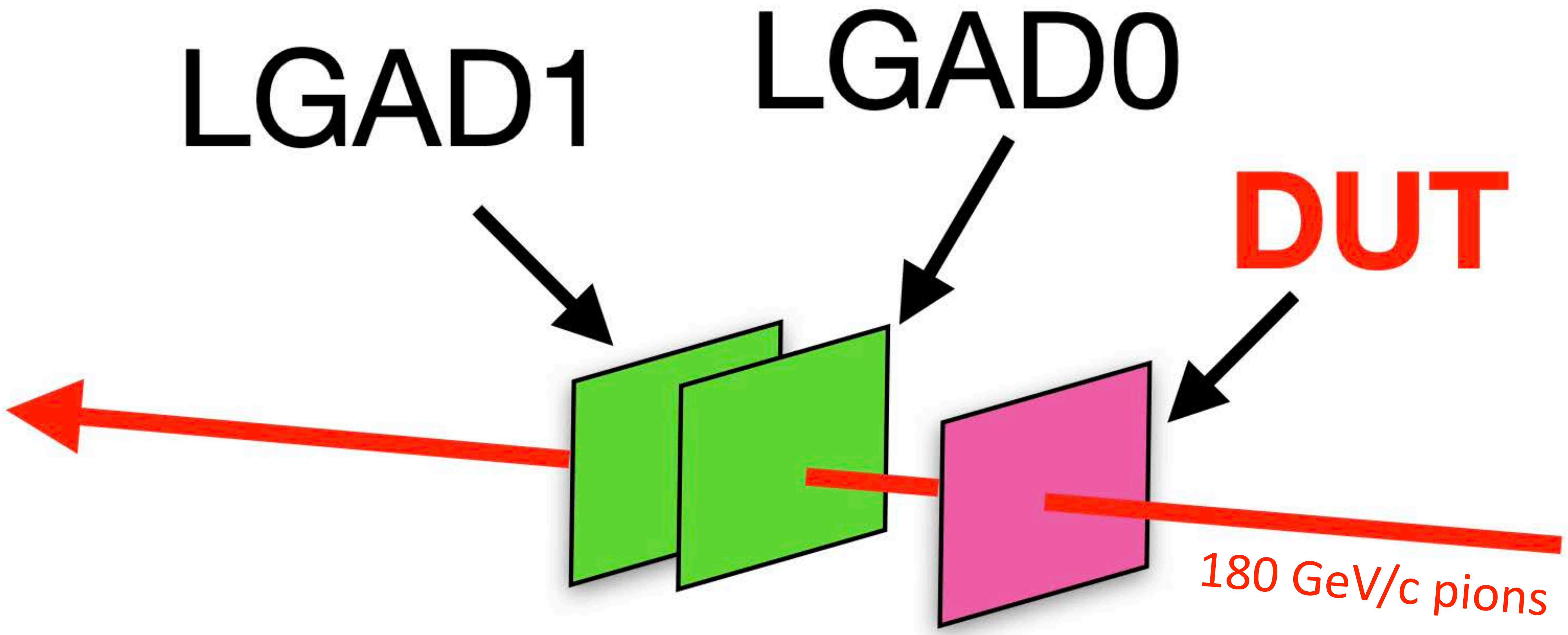




Selection of two **triangles**:

- representative of a whole pixel
- **unbiased** by telescope resolution

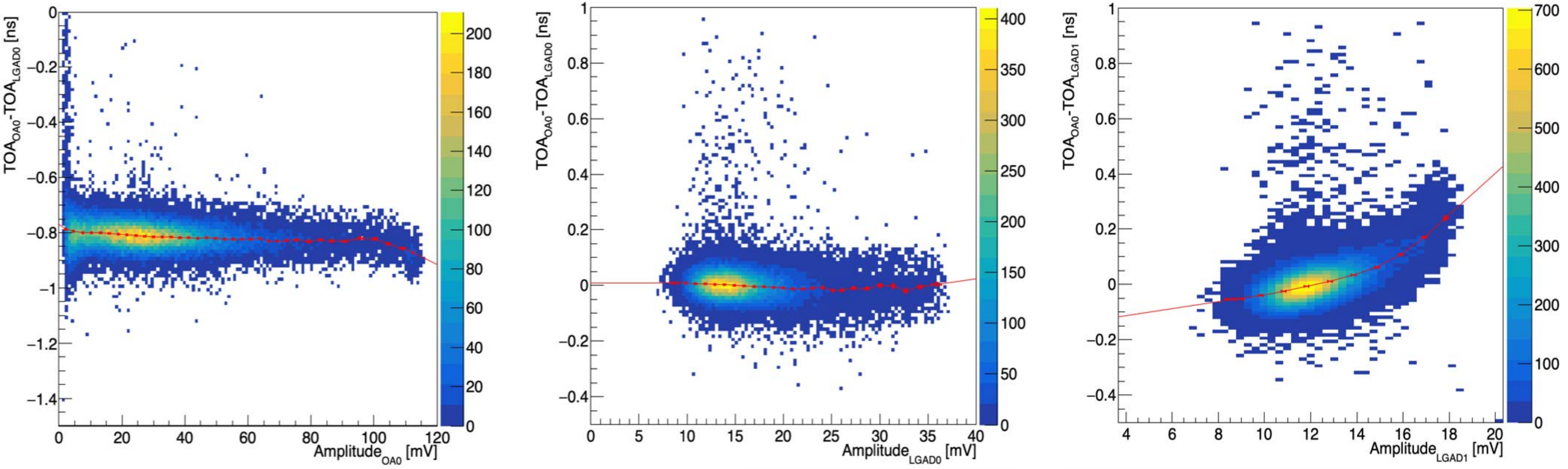
Time Resolution



Results were also verified using **two SPADs** (but with much smaller statistics)

Time-walk Correction

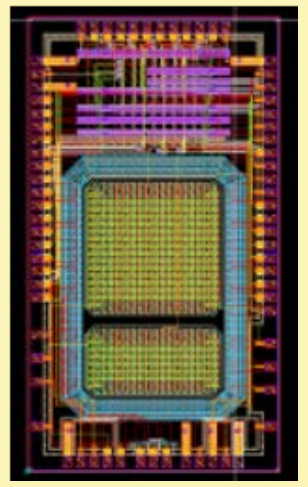
- Shift at 200 ps of the waveform to subtract low-frequency noise
- Time at constant fraction: 25% of max amplitude
- Amplitude-based time-walk correction for residual time walk



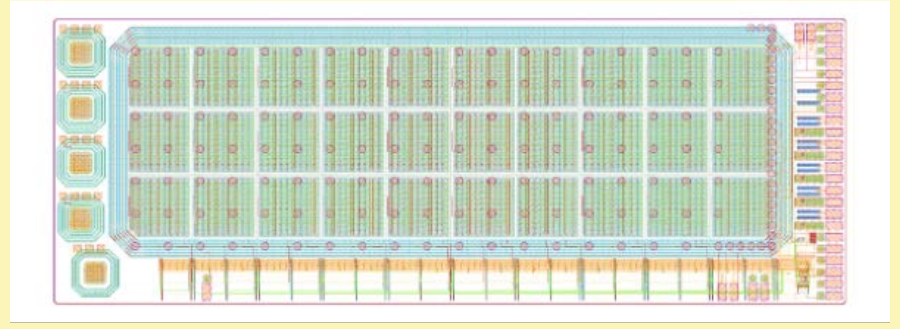
MONOLITH: First PicoAD Prototype

Prototypes without internal gain layer

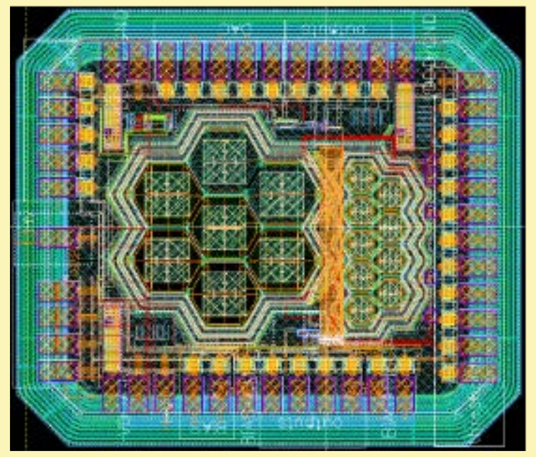
2016



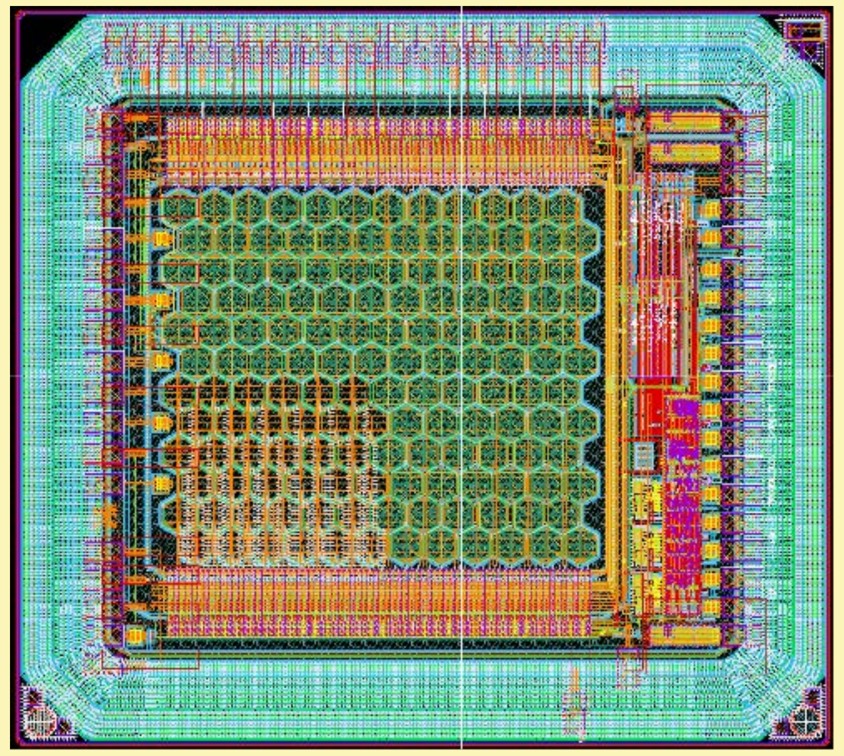
2017



2018



2019



200ps
- 1 and 0.5 mm^2 pixels
- Discriminator output

110ps
- 30 pixels 500x500µm^2
- 100ps TDC +I/O logic

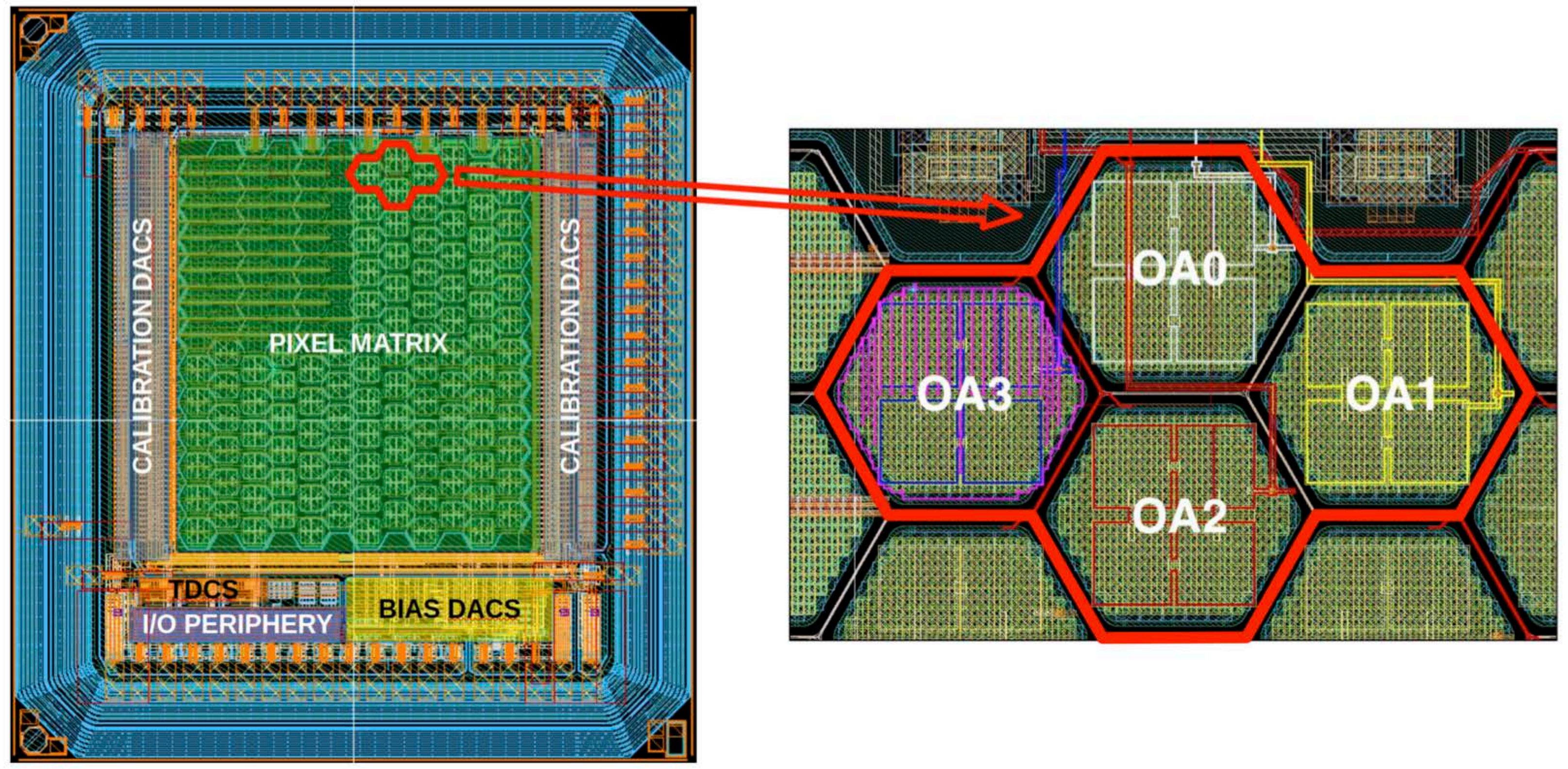
50ps
- Hexagonal pixels 65µm and 130µm side
- Discriminator output

36 ps
- Hexagonal pixels 65µm side
- 30ps TDC +I/O logic
- Analog channels

Sensor with no gain test beam results: JINST **P02019** *2022*

PicoAD Proof-Of-Concept Prototype

2021



17 ps
- **Same electronics as 2019 prototype**
- **Epitaxial layers + gain layer**
- **4 different gain-layer doses**

PicoAD proof-of-concept prototype

Gain measurements: arXiv:2206.07952, June 2022

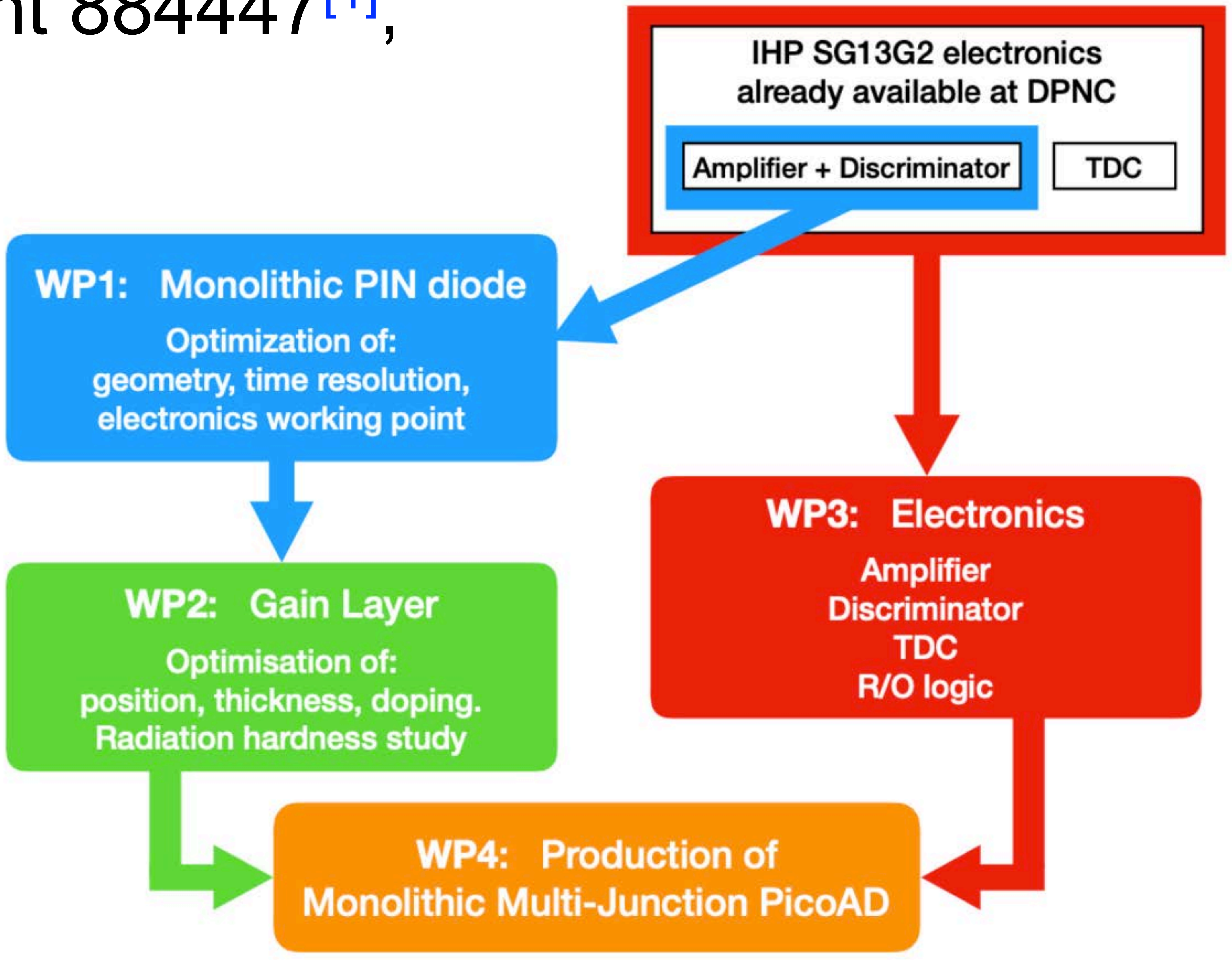
Testbeam results: arXiv:2208.11019, August 2022

The MONOLITH ERC Project

- Funded by the H2020 ERC Advanced grant 884447[1], July 2020 - June 2025

- Monolithic silicon sensor able to:
  - precisely measure 3D spatial position
  - provide picosecond-level time resolution

- Implements:
  - Fast and low-noise **SiGe BiCMOS electronics**
  - Novel sensor concept: the Picosecond Avalanche Detector (**PicoAD**)



[1] MONOLITH H2020 ERC Advanced Project Web Page - https://www.unige.ch/dpnc/en/groups/giuseppe-iacobucci/research/monolith-erc-advanced-project/

Other UNIGE projects that use monolithic SiGe BiCMOS

1. 100µPET SNSF SINERGIA
2. FASER W-Si pre-shower

The 100µPET SNSF SINERGIA project

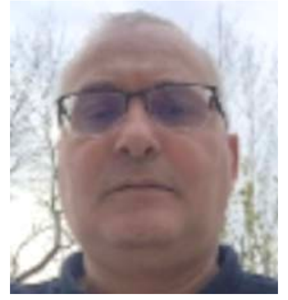
European Research Council
Established by the European Commission

UNIVERSITÉ DE GENÈVE
FACULTÉ DES SCIENCES

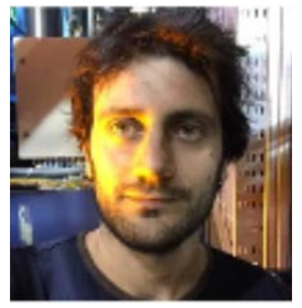
Giuseppe Iacobucci
- P.I.

Mateus Vicente
- System integration
- Laboratory test

Jihad Saidi
- System simulation
- Laboratory test



Didier Ferrere
- System integration
- Laboratory test



Lorenzo Paolozzi
- Sensor design
- Analog electronics

Yannick Favre
- Board design
- RO system

Franck Cadoux
- Mechanics
- FEA calculations

EPFL

Michäel Unser
- P. I.

Pol del Aguila Pla
- Statistical signal processing

Aleix Boquet-Pujadas
- Signal/image processing
- Physical modeling

UNI LU

Martin Walter
- P. I.

Pablo Jané
- Nuclear Medicine
- PET imaging
- Translational imaging

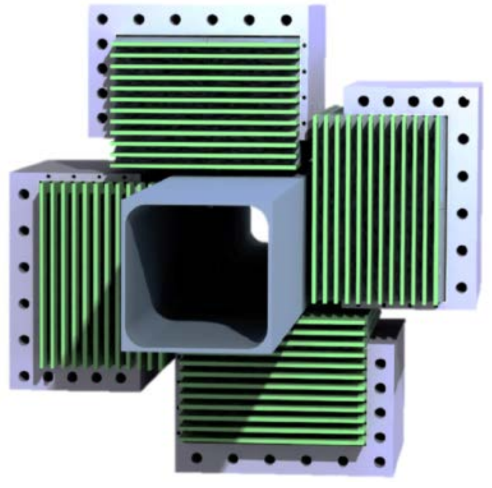
Xiaoying Xu
- Molecular Biology
- In vivo studies
- Bioinformatics

The 100μPET SNSF SINERGIA project

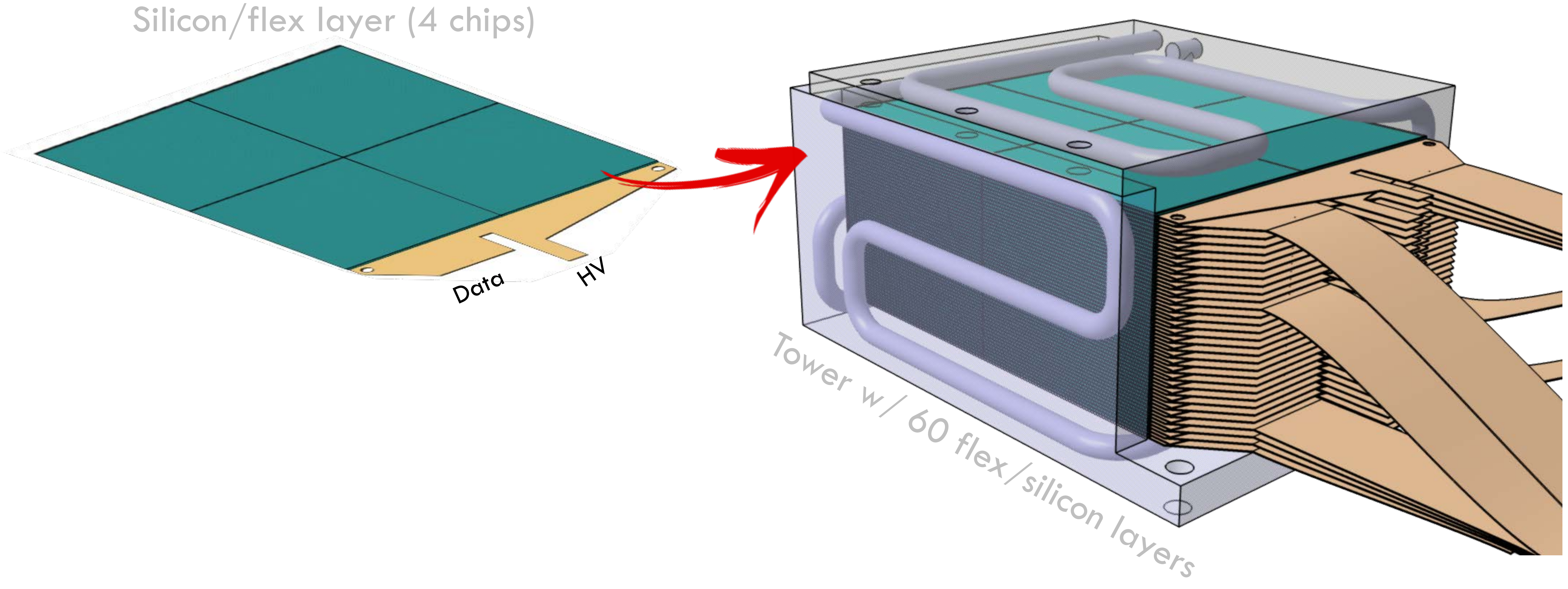
Swiss National Science Foundation

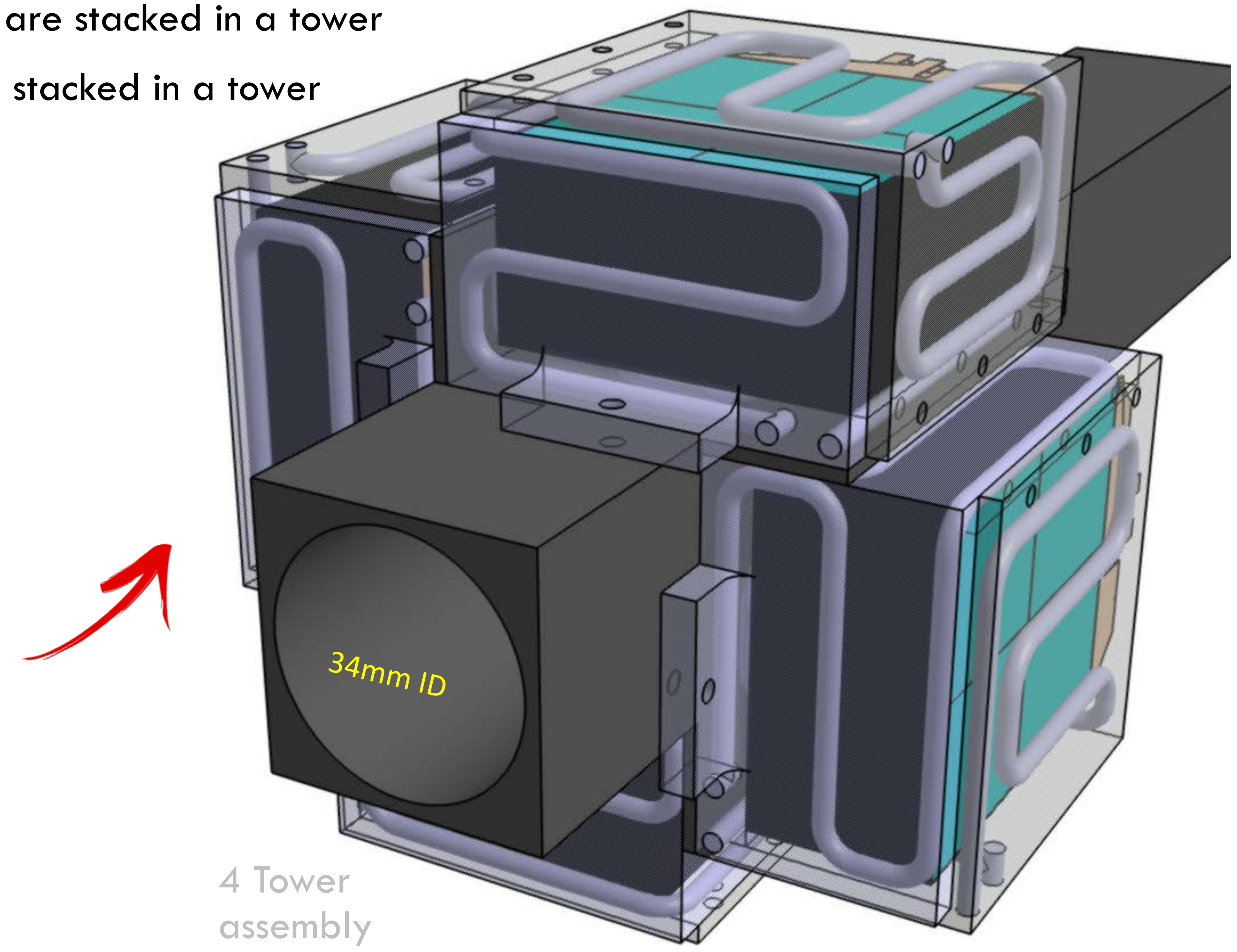
UNIVERSITÉ DE GENÈVE
FACULTÉ DES SCIENCES
Département de physique nucléaire et corpusculaire

- **Simplified** and **improved** scanner design, <u>avoiding acceptance holes</u> from cooling blocks
- <u>Monolithic</u> **100μPET** detector ASIC: **2.5 x 3 cm^2** active pixel matrix; **100 μm** pixel pitch; **250 μm** thick active silicon sensor
- Single silicon detection layer composed by **2x2 chips** assembled, covering **30 cm^2**
- **4 "towers"** compose the scanner. **60** detection layers on each tower = <u>**960 chips!**</u>
  - Large number of services and interconnections, requiring **innovative** design. <u>Two possible designs</u> under study
    - **5 silicon detector layers** (20 chips) stacked on a **PCB**, staggered for **wire-bonding**. **12 modules** are stacked in a tower
    - **1 detection layer** (2x2 chips) are interfaced to a **FPC** via <u>ACF bonding</u>. **60 FPC/ASIC layers** are stacked in a tower



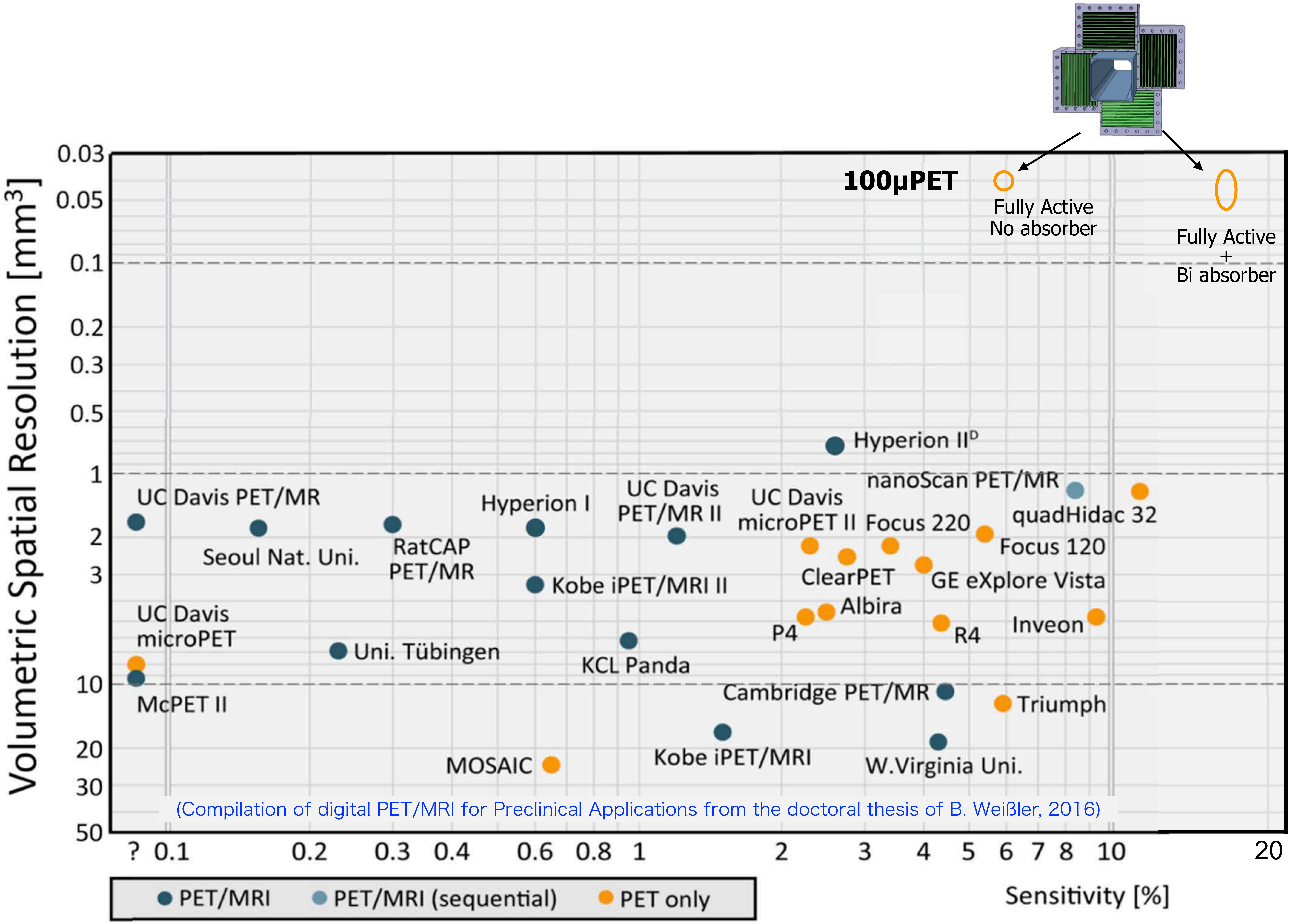
4 Tower assembly





4 Tower assembly

The 100μPET Performance

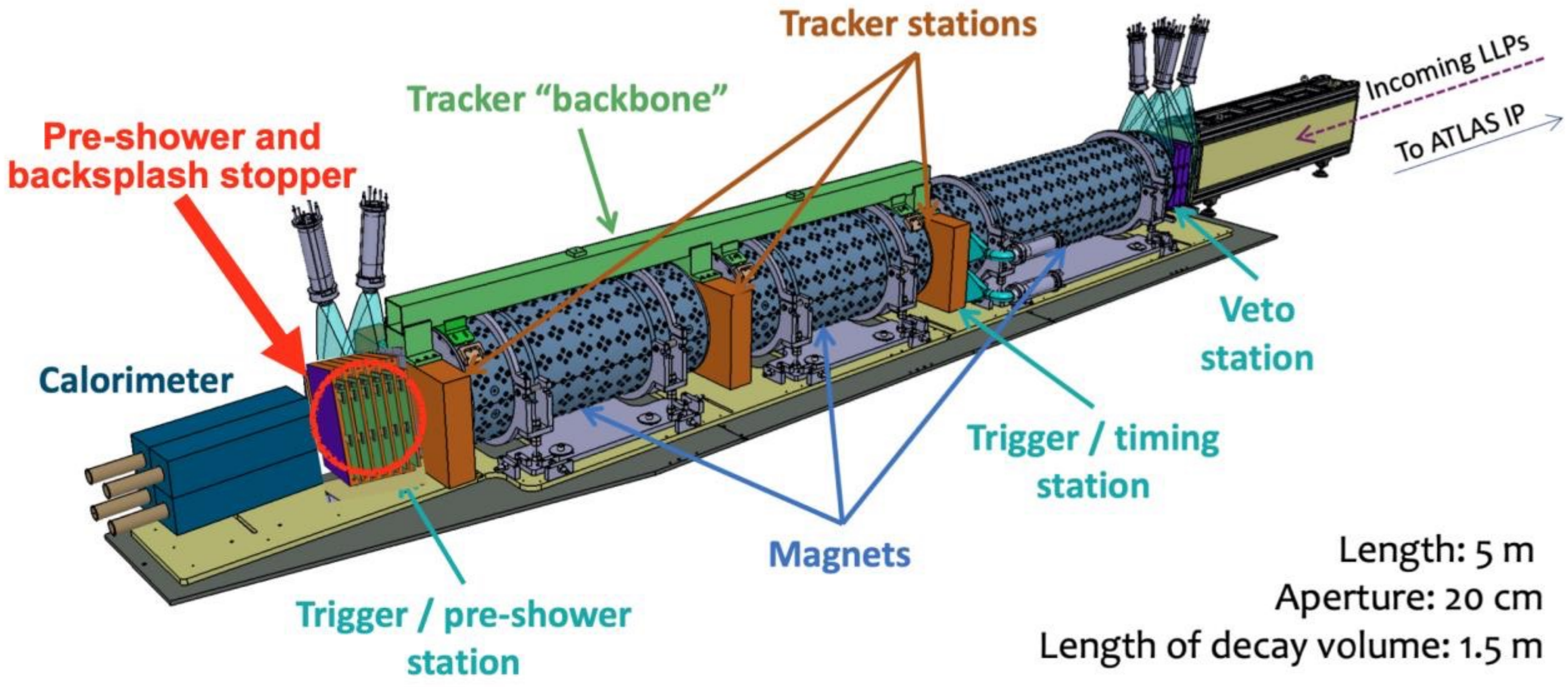


High granularity FASER W-Si pre-shower

A. Sfyrla and G. Iacobucci groups

Current FASER pre-shower:

2 layers of tungsten + scintillating detectors $\Longrightarrow$ no XY granularity



To have access to **two-photon final states**:

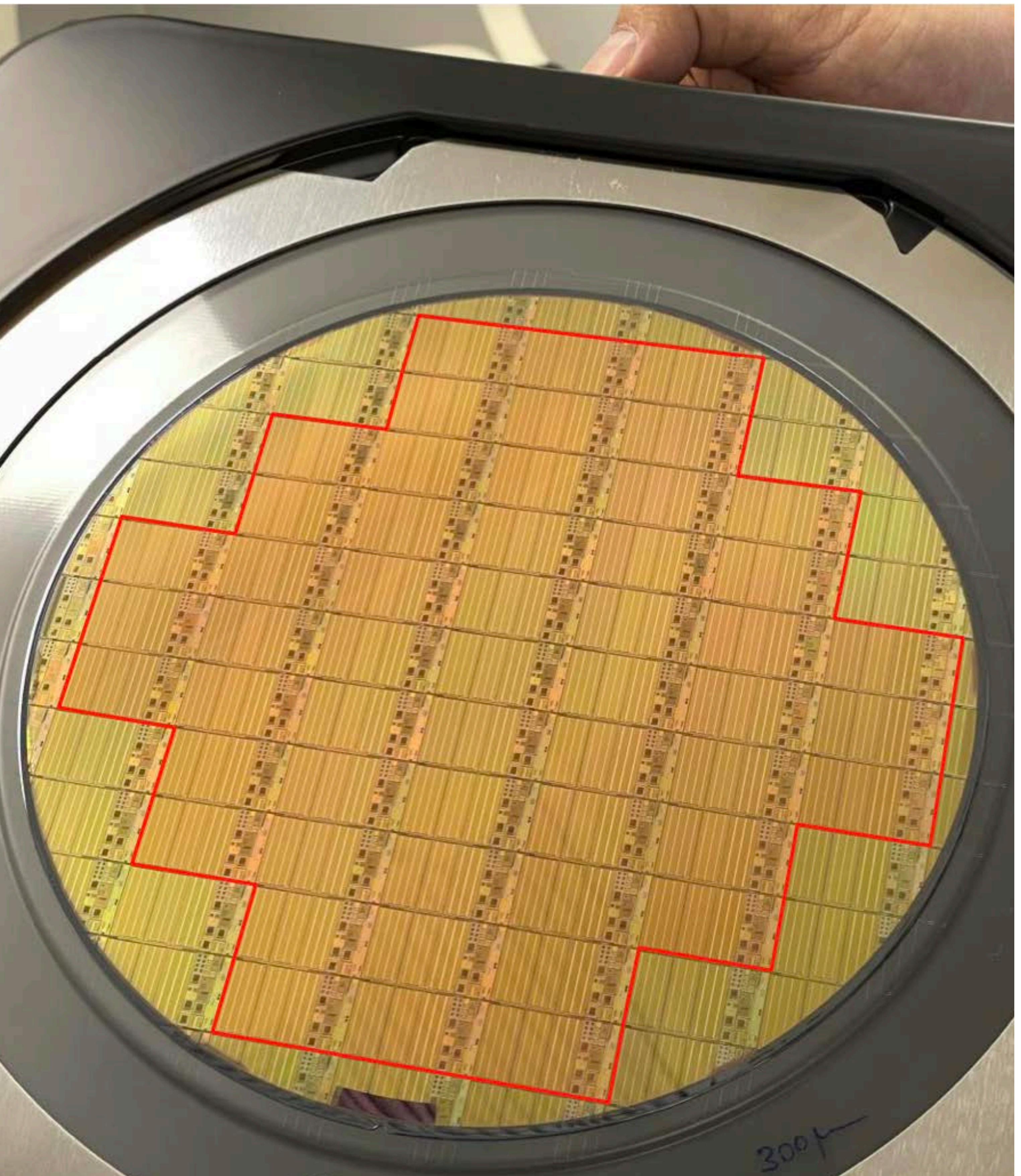
- **High granularity and high dinamic range** pre-shower based on six planes of monolithic pixels
- Discriminate **TeV-scale EM showers**
- Targeting data taking in 2024-2026 and during HL-LHC

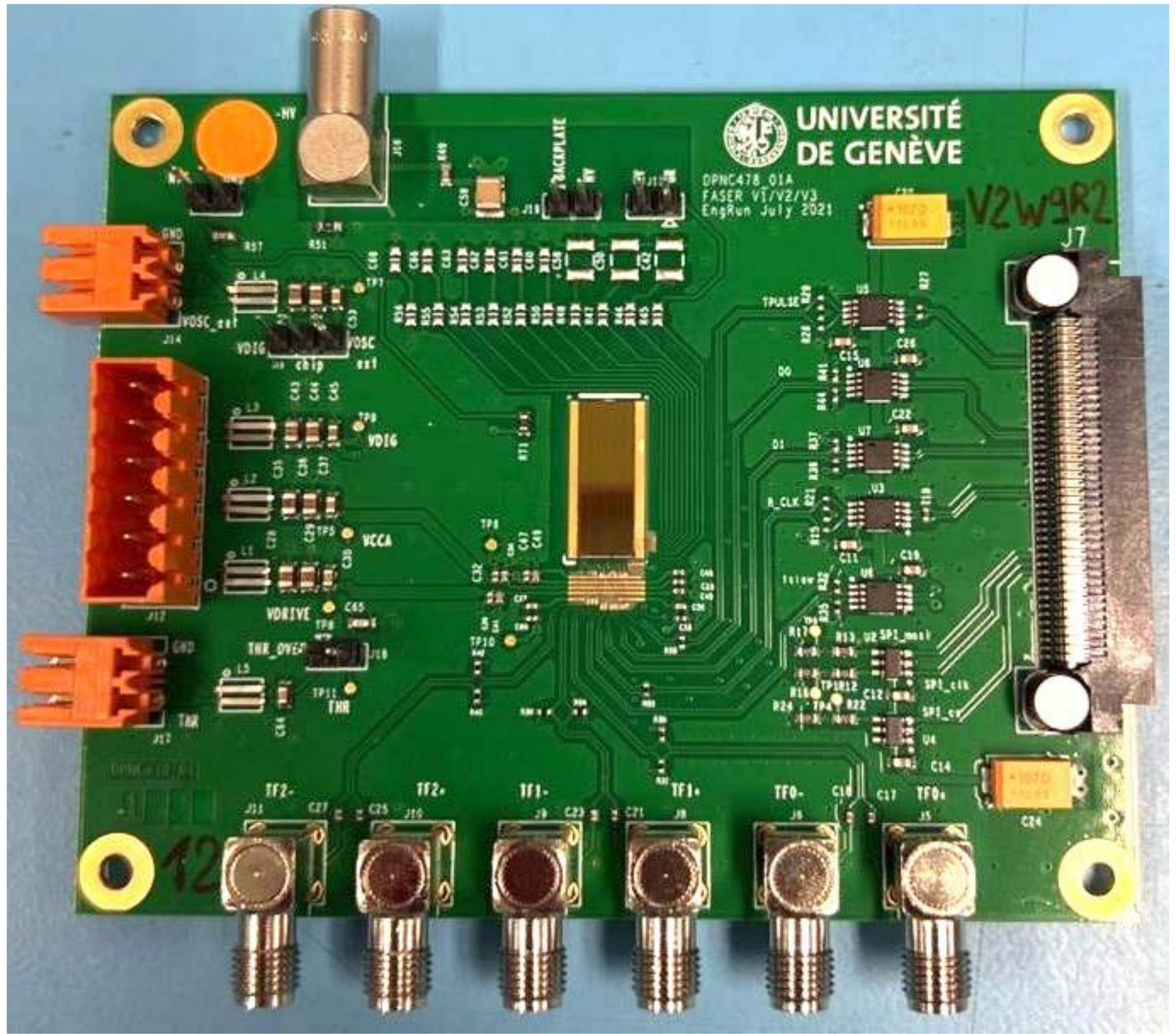
FLARE

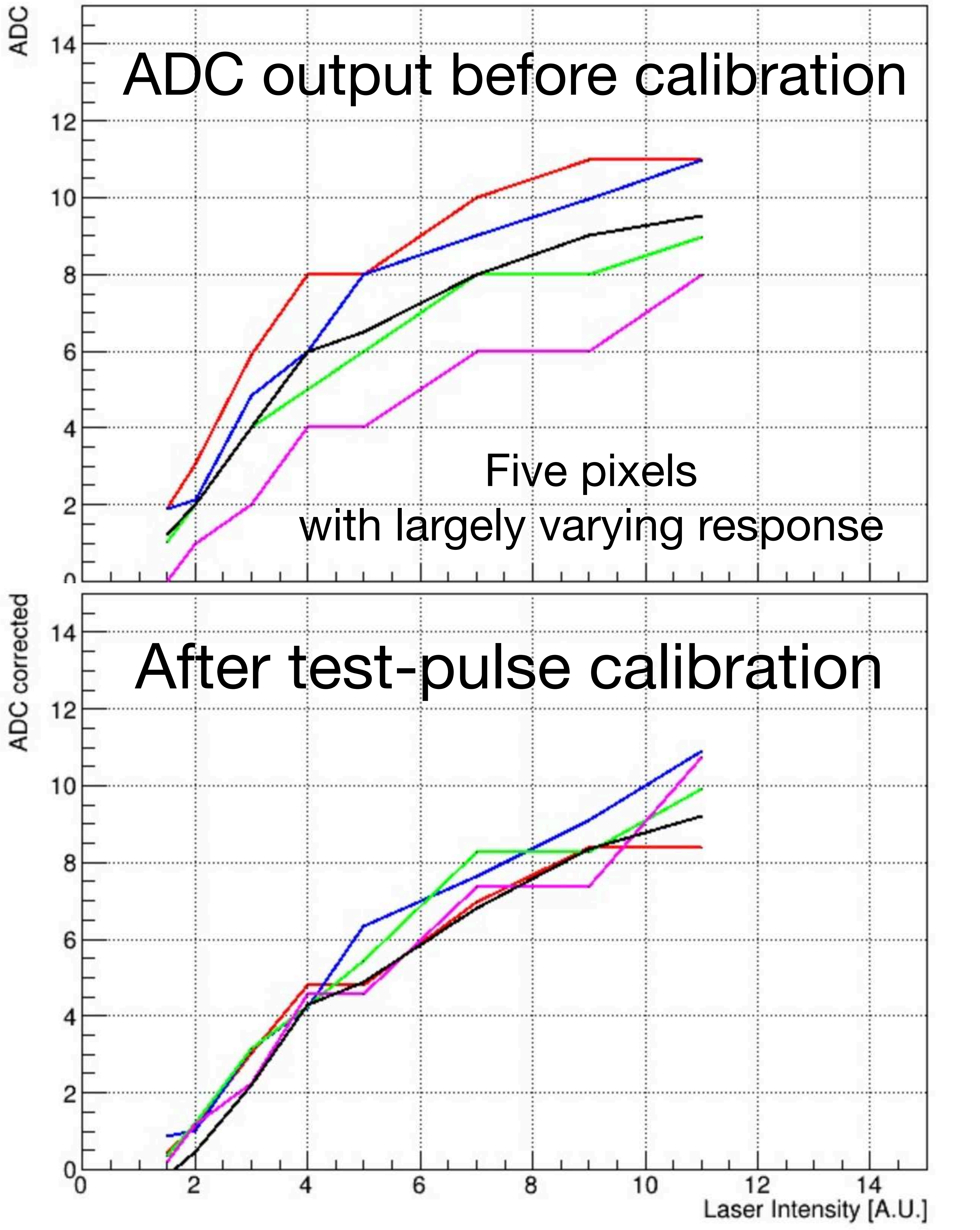
High granularity FASER W-Si pre-shower

FASER preshower pre-production chip:

- **First engineering run produced by UNIGE in SiGe BiCMOS**
- Three large ASIC (15x7.5 mm^2) with alternative designs
- pixels with 65μm side (~100μm pitch)
- Delivered in July; presently under test







Summary & Outlook

The PicoAD© Monolithic <u>proof-of-concept</u> prototype works:

- **Gain ≈ 20** for ^{55}Fe X-rays (space-charge effects, for X-rays, measured)
- **Efficiency = 99.9 %** at full sensor-bias voltage
- **Time resolution σ_t = (17.3 ± 0.4) ps** (although sensor not yet optimized for timing)

Ongoing activities include:

- Optimization for timing of the PicoAD sensor design with TCAD to achieve $\lesssim$10 ps (smaller pixel pitch; thicker drift layer; improved inter-pixel region)
- Development of picosecond TDC for fully monolithic chip

Deliverable of MONOLITH project:

- Full-reticle chip with 50µm pitch and sub-10ps timing in Summer 2025