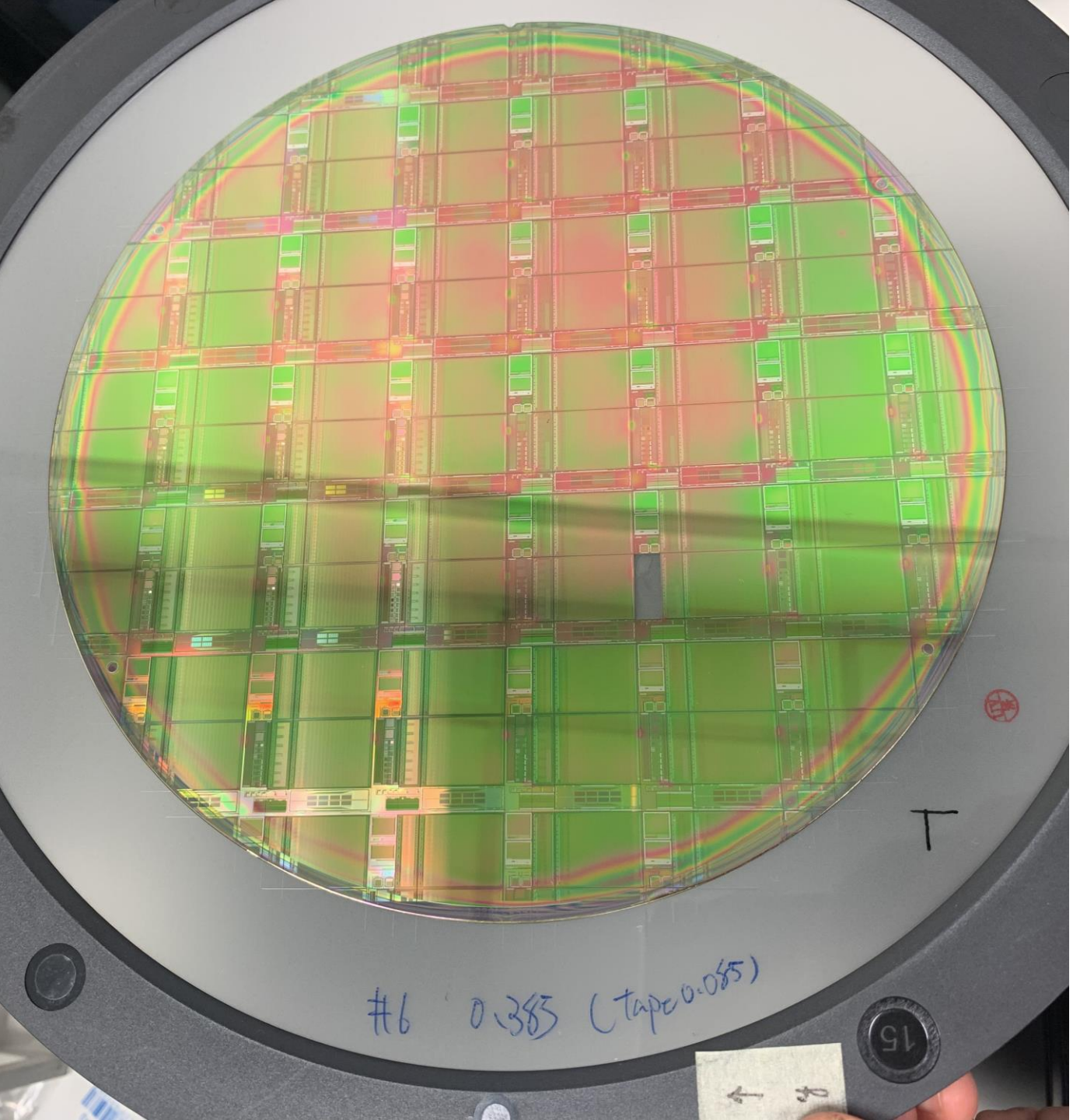


Latest results on the first monolithic CMOS LGAD implemented in 110 nm

IFD 2025 – INFN Workshop on Future Detectors

Sestri Levante - 19/03/2025

Giulia Gioachin

on behalf of the ALICE Collaboration

ALICE 3: a next generation heavy ion experiment

Main driver: ALICE Time-of-Flight detectors

TOF requirements from simulations:

- Material budget < 3% of X_0
- Time resolution ≈ 20 ps

See B. Sabiu talk

SiPM

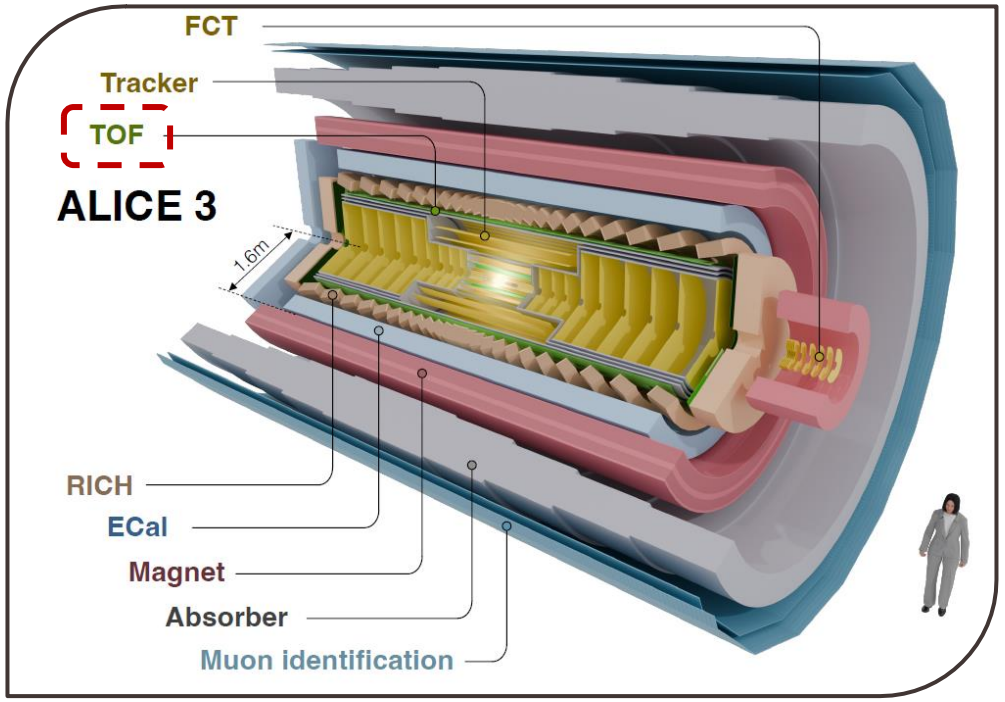
LGAD

CMOS LGAD

Advantages of CMOS LGAD:

- Less material and costs
- Simpler and cheaper assembly

Monolithic approach



Other fields:

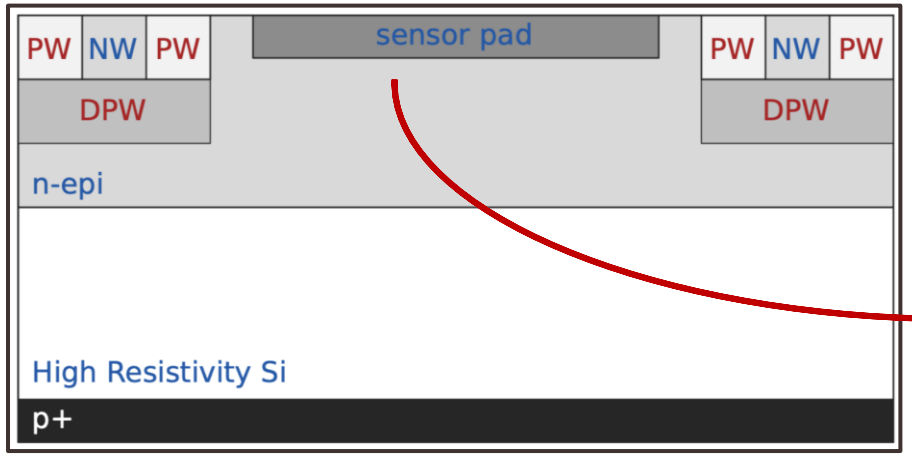
4D tracking

very low power pixel sensors → space

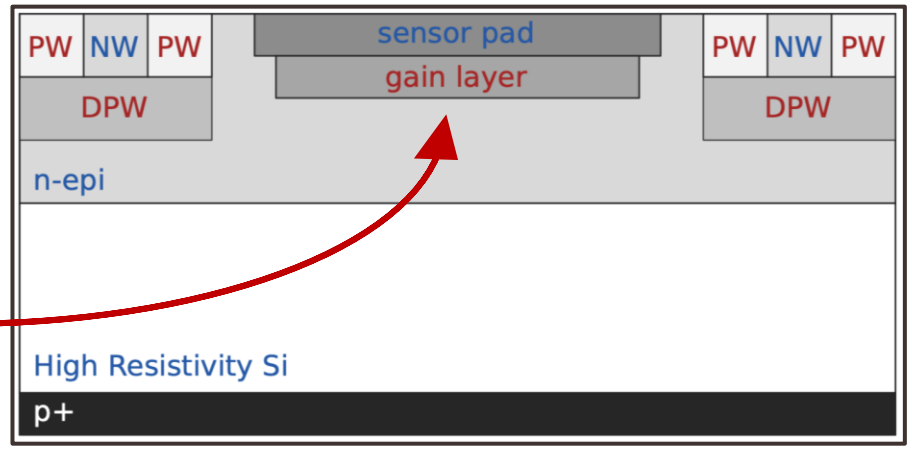
medical applications

Monolithic sensors - ARCADIA sensor concept

ARCADIA pad sensor



ARCADIA pad sensor with gain



- ARCADIA ER3 production: → See A. Zingaretti talk
  - ↳ **passive** and **monolithic structures**
- **Lfoundry CMOS 110nm** with 48um active thickness
- Fully depleted monolithic sensor from the bottom
- Add-on p+-gain layer below the collecting electrode
- Expected gain from detailed simulations:
  - ↳ **5-20**

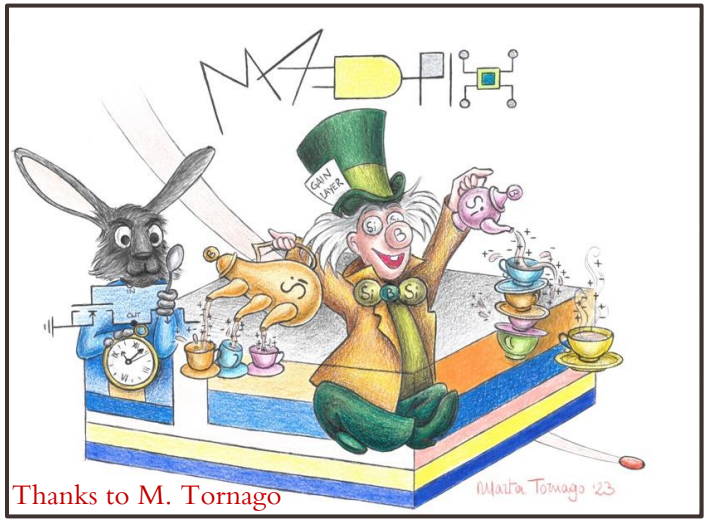
MADPix

***M**onolithic CMOS **A**valanche **D**etector **PIX**elated Prototype*

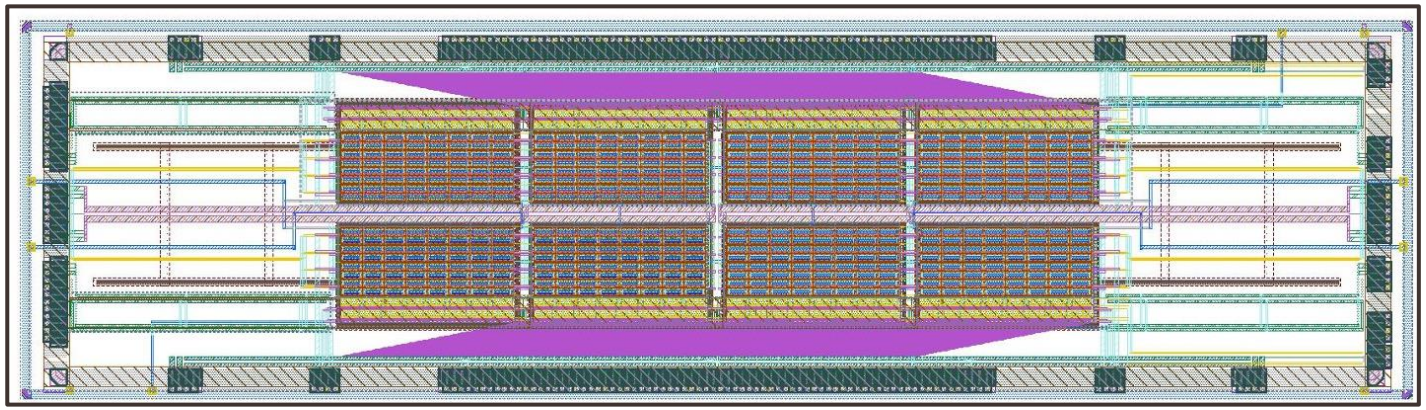
First prototype with **integrated electronics** and **gain layer**

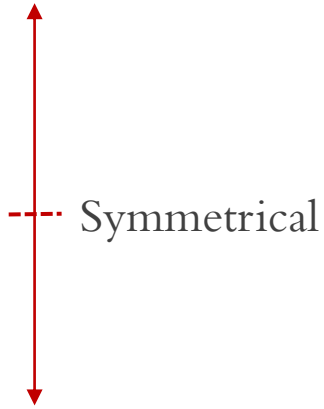
Active thickness: 48 µm

- **Backside HV**: allow full depletion → -20 V to -40 v
- **Topside HV**: manage the gain → 35 V to 65 V



- 8 matrices of 64 pixels each
- 4 flavours
- 64 x 2 analogue outputs
- Pixels of 250 µm x 100 µm

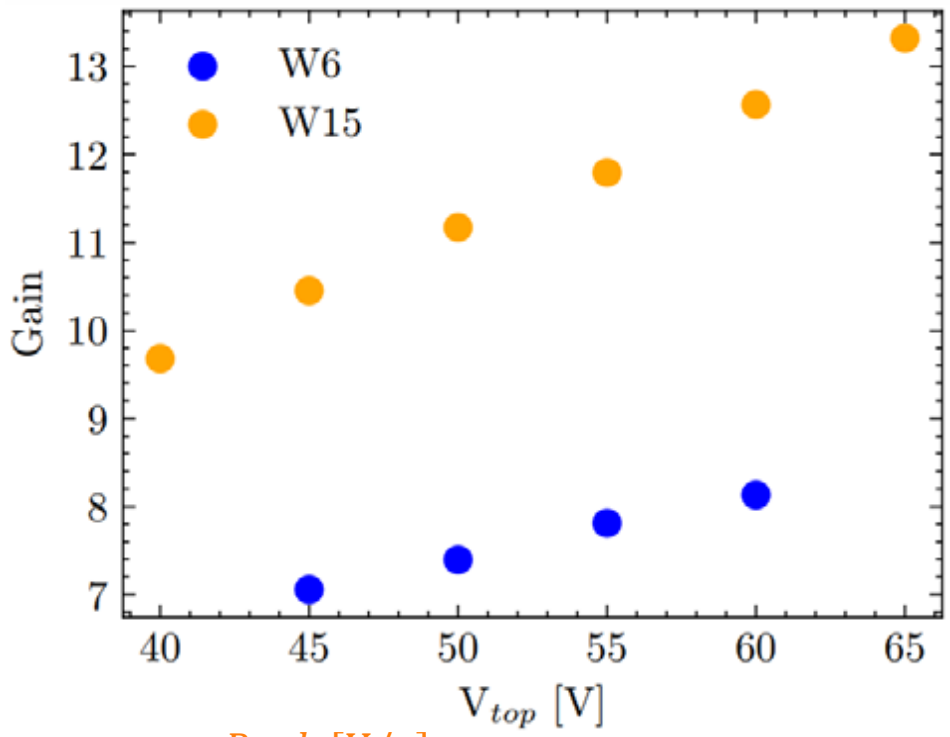




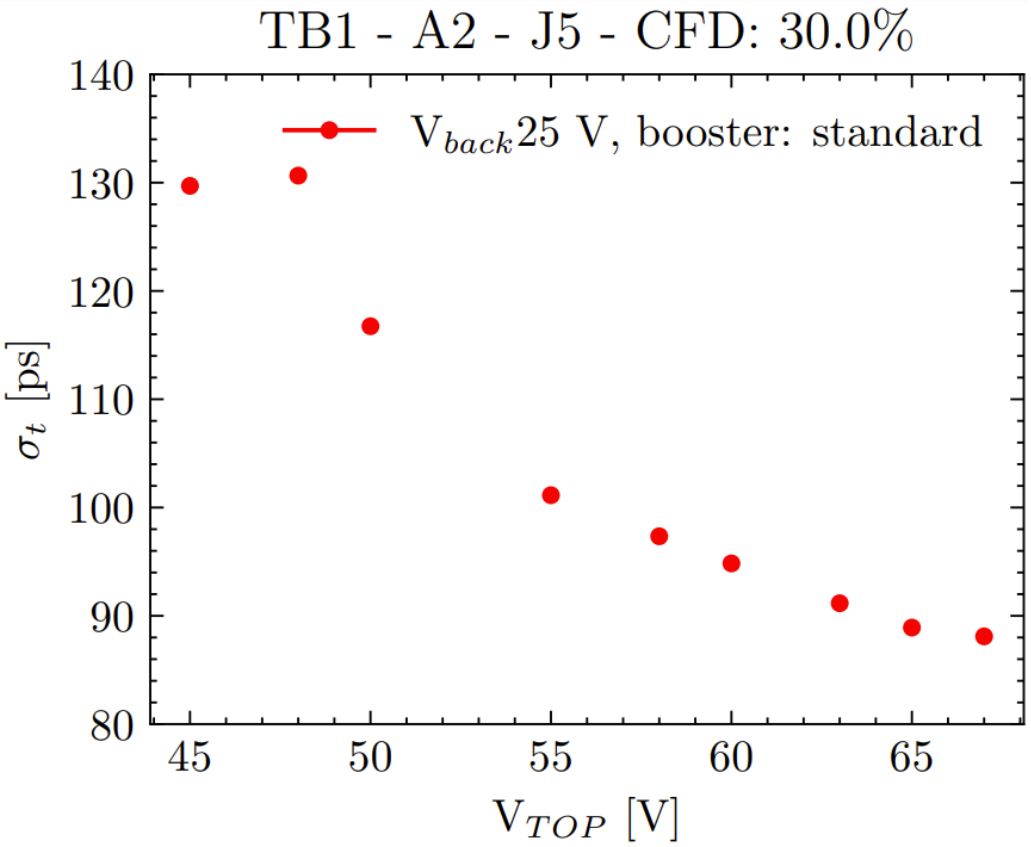
MADPix new short loop 3.2

New production: higher gain

Short loop: same mask set with different implant dose → optimization of sensor at low price
New **sensor production** with **higher gain** arrived last September 2024
Expected **gain range: 5-20**



Fist gain estimation using a no collimated radiation source of 55Fe

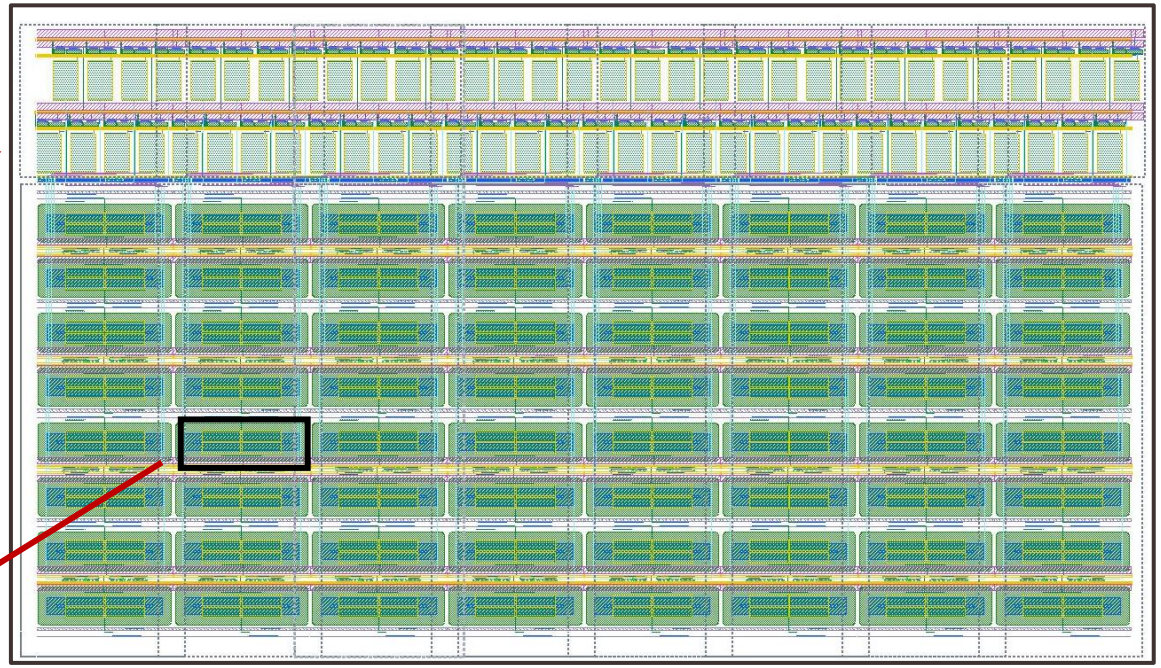


$$Gain = \frac{Peak\ [V/e]}{Electronics_{gain}[V/e]}$$ → From electronics simulations matched with data

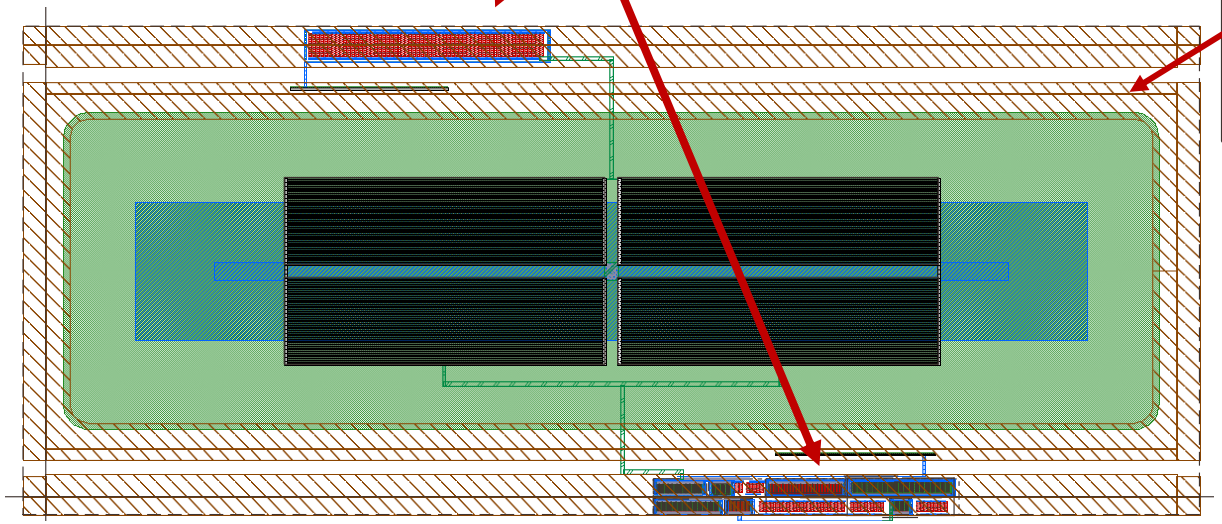
Time resolution sensor + front end (@0.18mW/ch): **88 ps**
Time resolution sensor ≈ 75 ps

MADPix Layout

- Active thickness: 48 µm

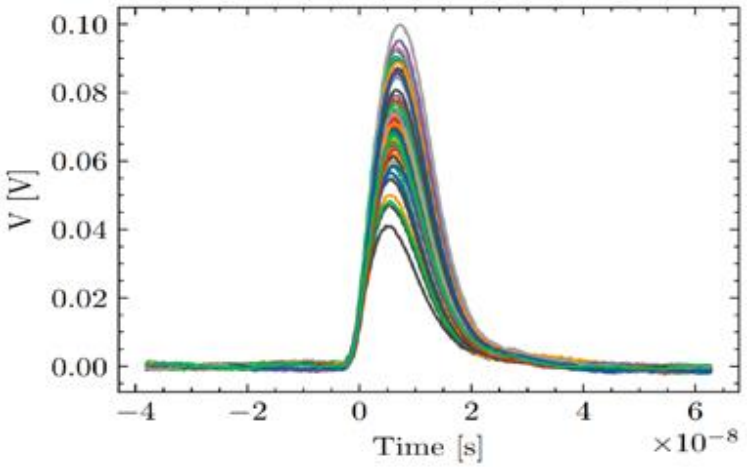


- 3.3V buffer out-pixel
- 1.2V **FE electronics in-pixel**



- 8x8 pixels in one matrix
- 250µm x 100µm pixel, non optimal for timing (Distortion term) but crucial in this R&D phase
  - Bigger pixels can be implemented in dedicated run

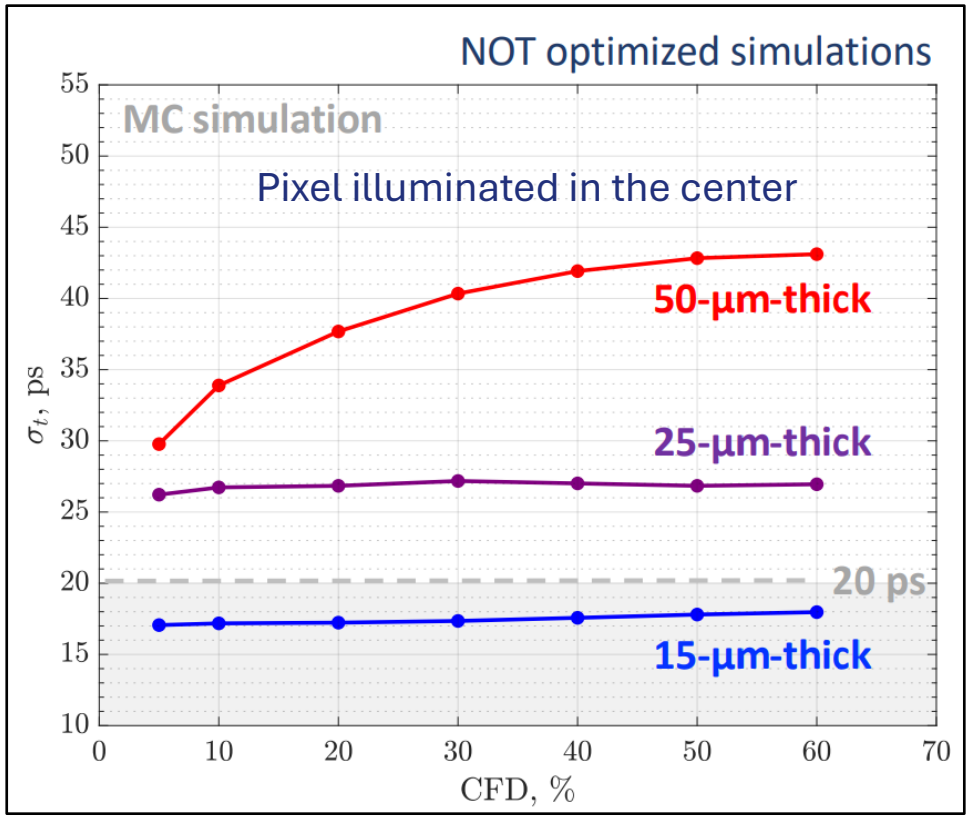
Where we are and what's next…



Signals observed in last test beam,
MadPix with gain - 48um thick
Oct 2024

Time resolution sensor ≈ 75 ps

Not final thickness and optimized geometry



Need to implement new pixels design to mitigate edge effects and distortion term

→ new engineering run

Summary

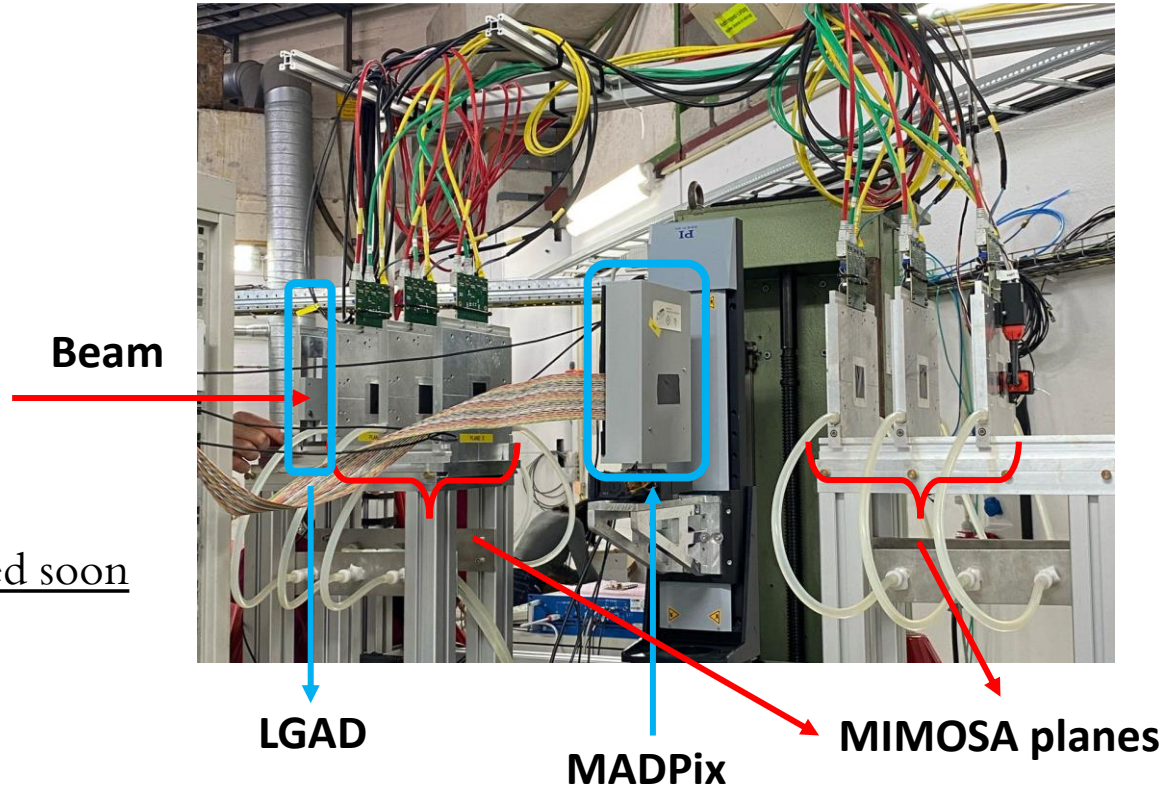
→ Prototype for timing application in 110nm technology design in the ARCADIA project: **MADPix**

- Laboratory characterization of structure from the short loop 3.2
  Gain of the sensor between **5 and 13**
- Total time resolution below 90ps (@ 0.18mW/ch)
  Sensor time resolution ≈ 75ps

What's next?

- Position – time resolution correlation of MadPix soon
  → thanks to a test beam @ DESY
- Irradiation campaign soon
- Simulation activities to match test beam results

- New short loop with lower active thicknesses will be submitted soon

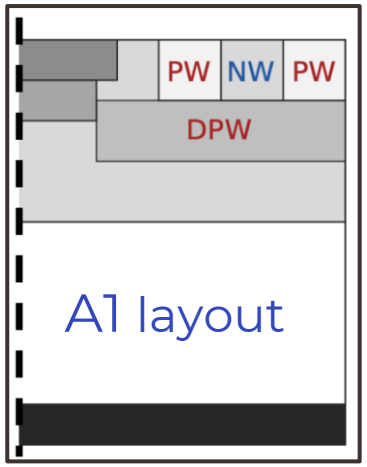


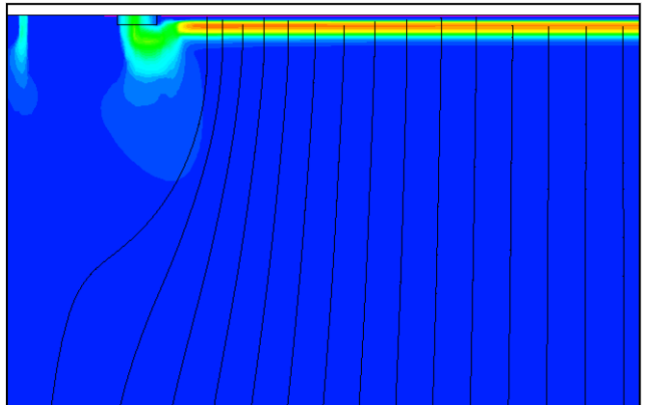
Thank you for the attention!

Backup slides

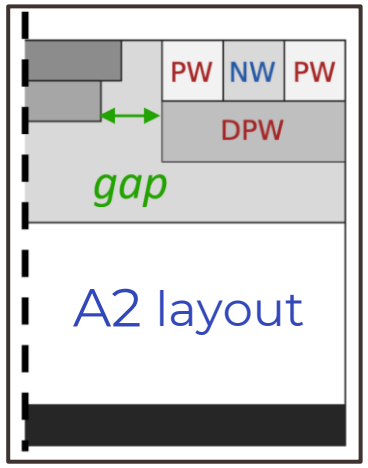
Monolithic sensors - ARCADIA sensor concept

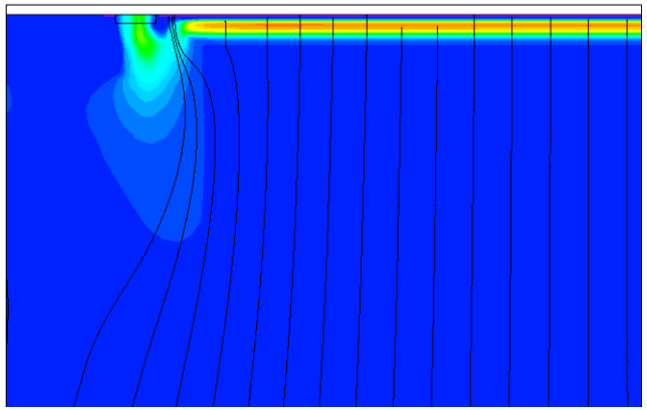
- Different sensor layouts to test the charge collection properties at borders
- Two sensor layout: A1 and A2





► **deep-*p*-well** connected to the ***p*-gain**
- all the field lines cross the gain region
- **charges** generated at **borders** are **multiplied**
  - 100% fill factor
  - extended collection volume
  - non-uniform gain and timing

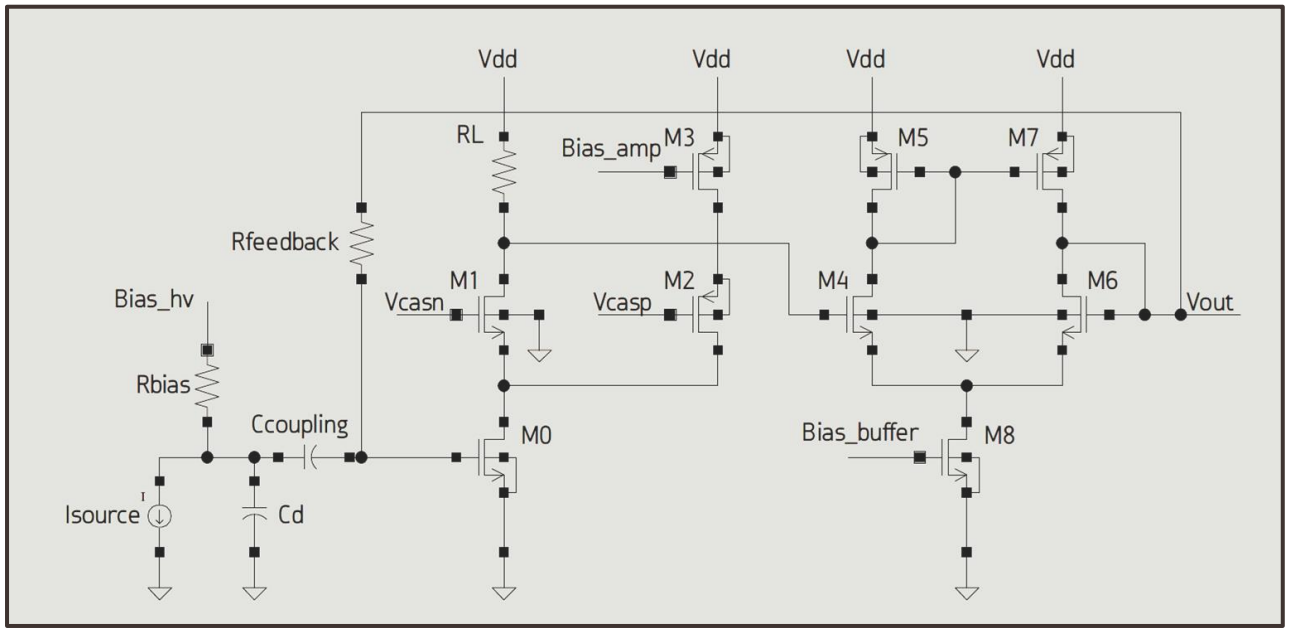




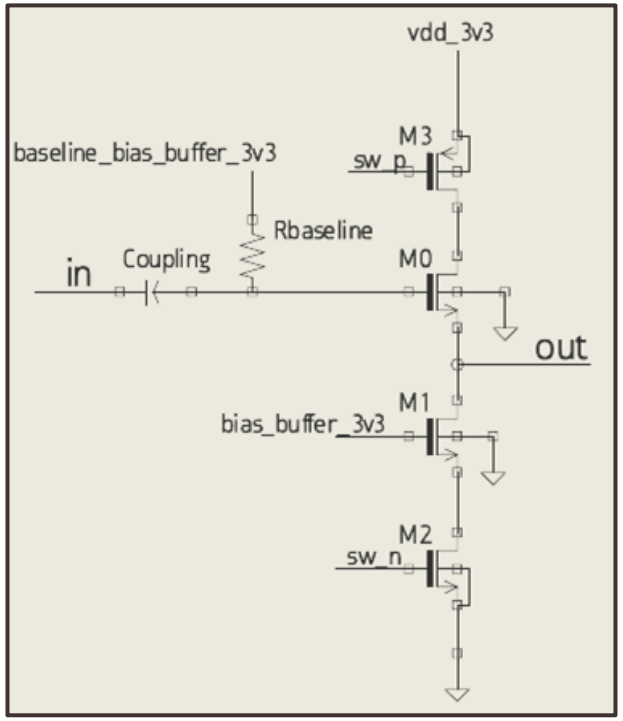
► "standard" termination implants → Gap
- peripheral field lines don't cross the gain region
- **charges** collected at **borders** are **NOT multiplied**
  - direct path to the p-gain
  - «dead area» at the borders with gain 1
  - more uniform time response

MADPix Electronics

- Cascoded common source + differential buffer (1.2V)
- FE **AC coupled** with sensor
- Power: **0.18mW/ch**



- Source follower (3.3V)
- AC coupled with FE
- Power: 1.65mW/ch



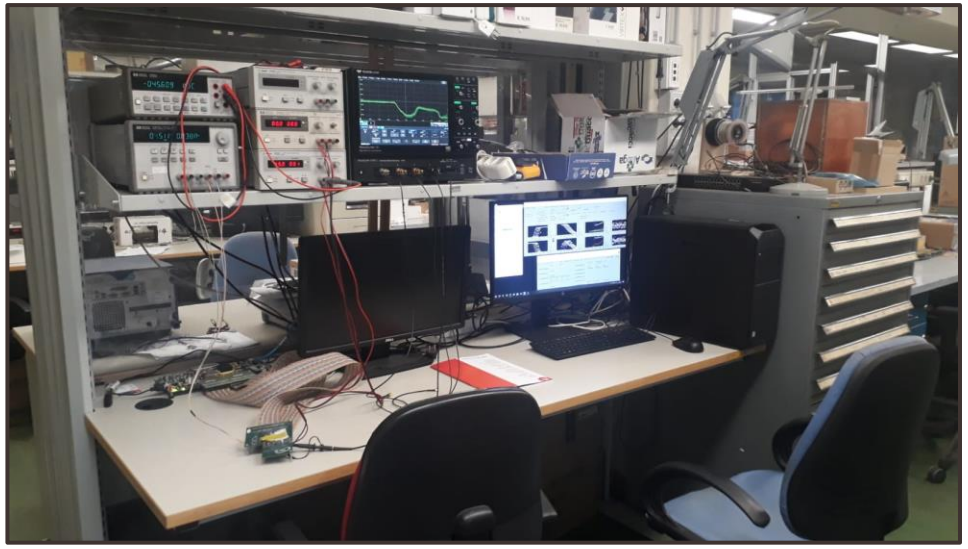
S. Durando e U. Follo

MADPix Test Board

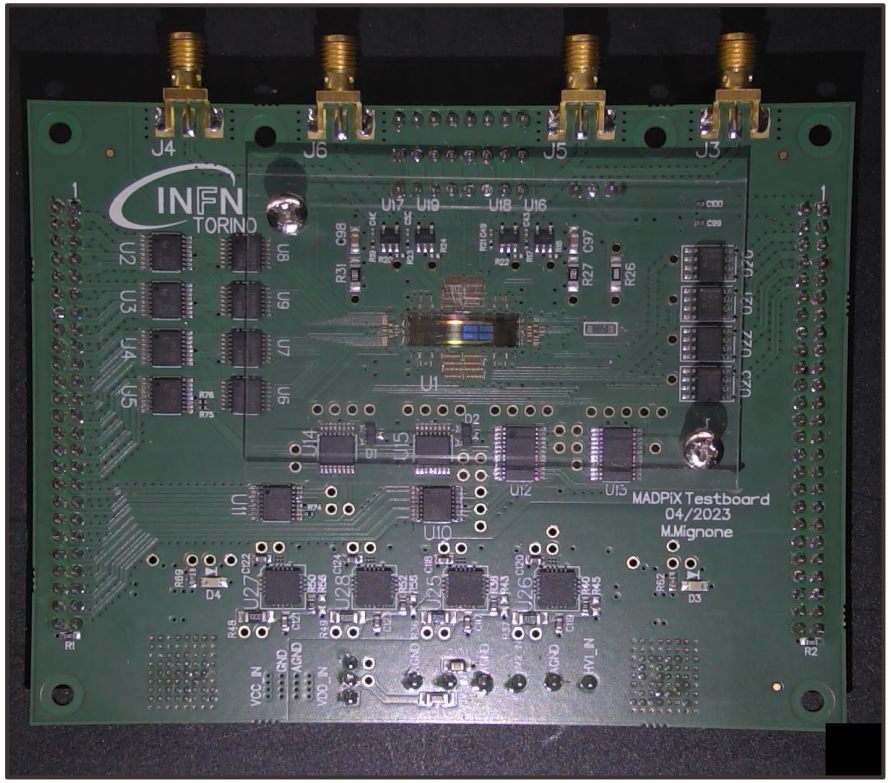
Controlled through FPGA (DACs, Digital potentiometers, Test pulse)

- 4 SMA driving 50Ω line (top 4 matrices) → **Analogue** read-out (Oscilloscope/Digitizer)
- 4 Discriminator (bottom 4 matrices) → **Digital** read-out (FPGA)

Electrical characterisation at INFN Torino

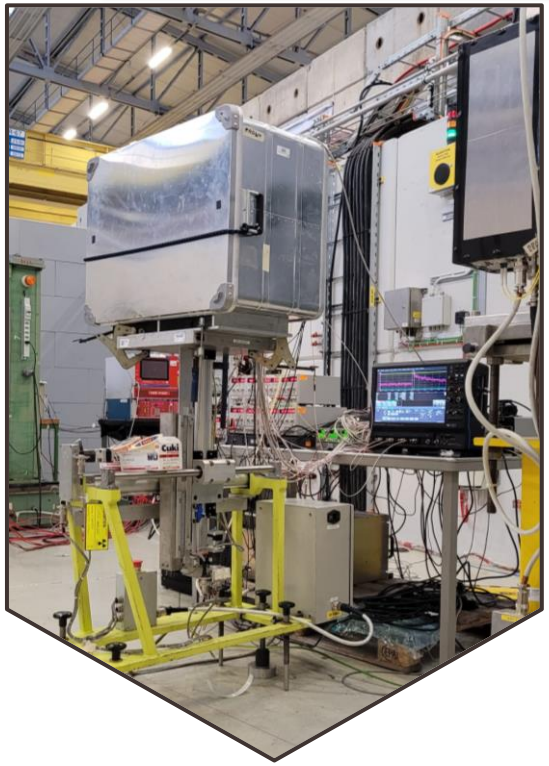


Only **four adjacent pixels** can be read simultaneously



- Board designed by Marco Mignone (INFN Torino)
- Firmware written by Richard Weadon (INFN Torino)

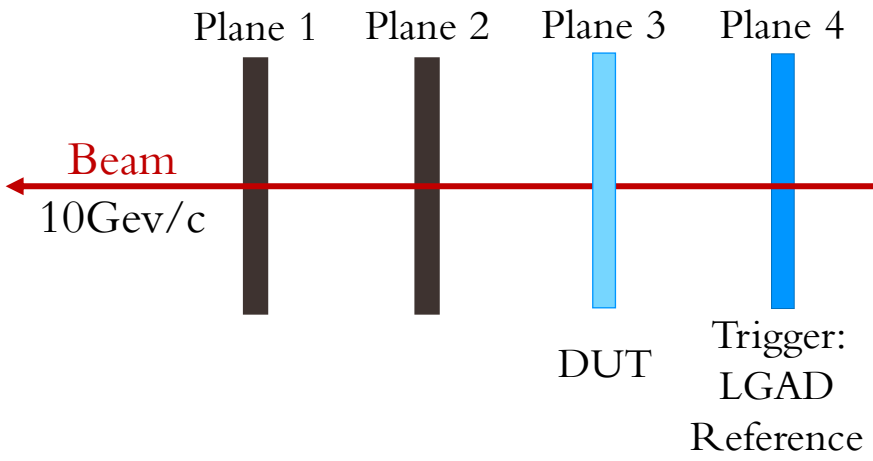
MADPix at the Test Beam

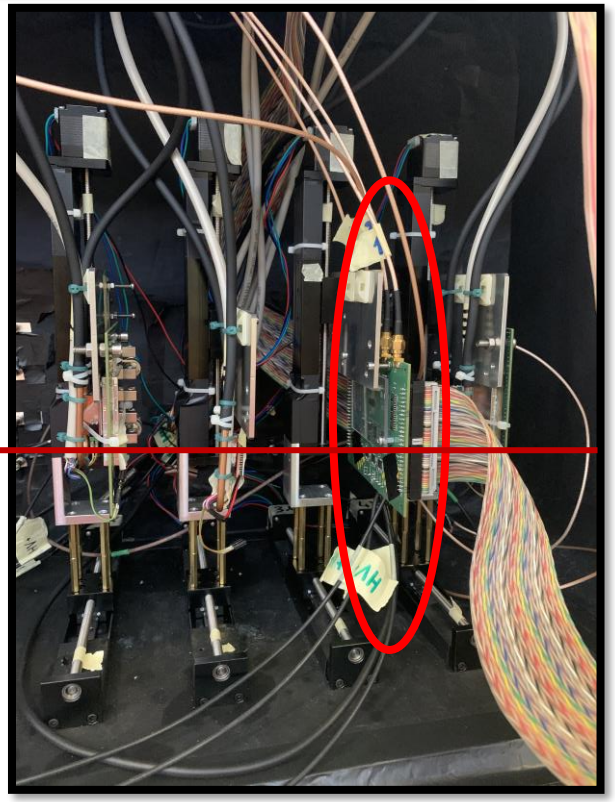


Test beam setup in collaboration with INFN Bologna

→ at CERN Proton Synchrotron (PS)

→ with p/π of 10 GeV/c





M. Bregant, S. Bufalino, Z. Buthelezi, D. Cavazza, M. Colocci, G. Fabbri, C. Ferrero, U. Follo, J. Goodhead, S. Förtsch, G. Gioachin, M. Mandurrino, R. Nania, B. Sabiu, G. Souza, S. Strazzi, S. Wimberg

INFN Torino,
INFN Bologna,
iThemba LABS,
Universidade de São Paulo

4 planes telescope:

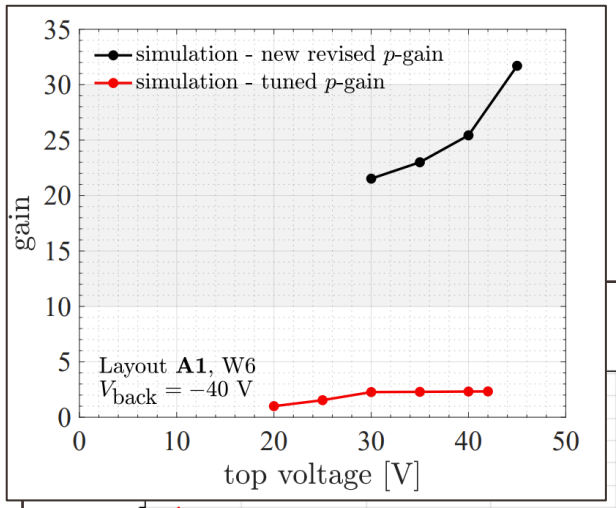
→ LGAD: 1mm x 1mm sensor used as trigger reference

→ MADPix: 16.4mm x 4.4 mm divided in matrices

Readout → Oscilloscope for signal acquisition

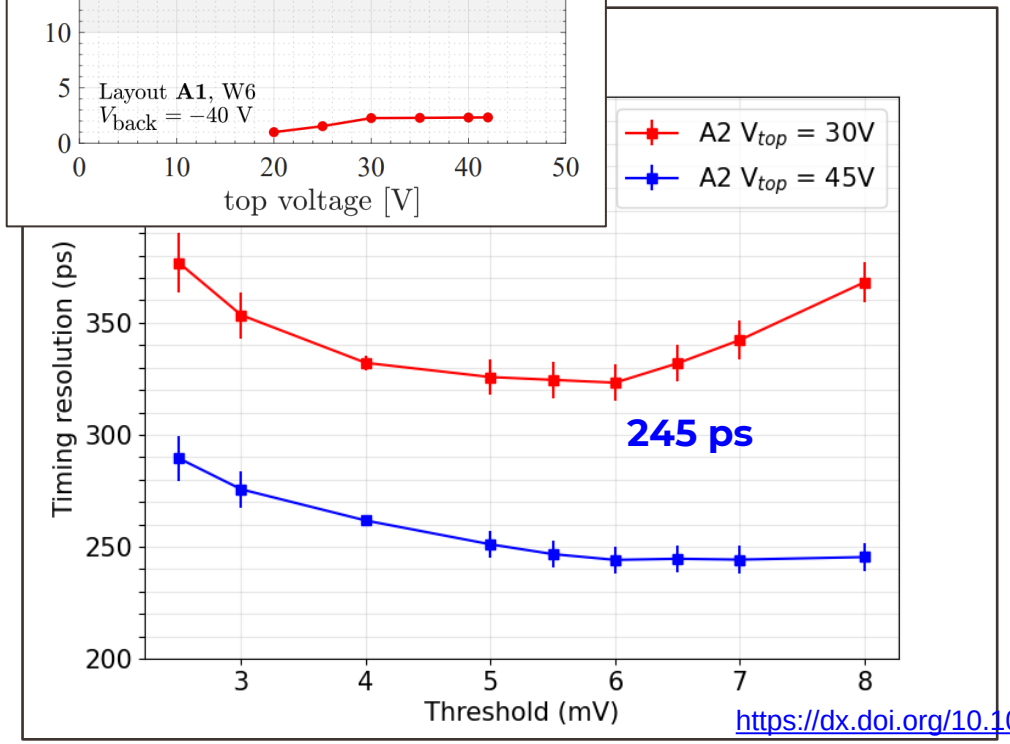
First test beam results: Time resolution

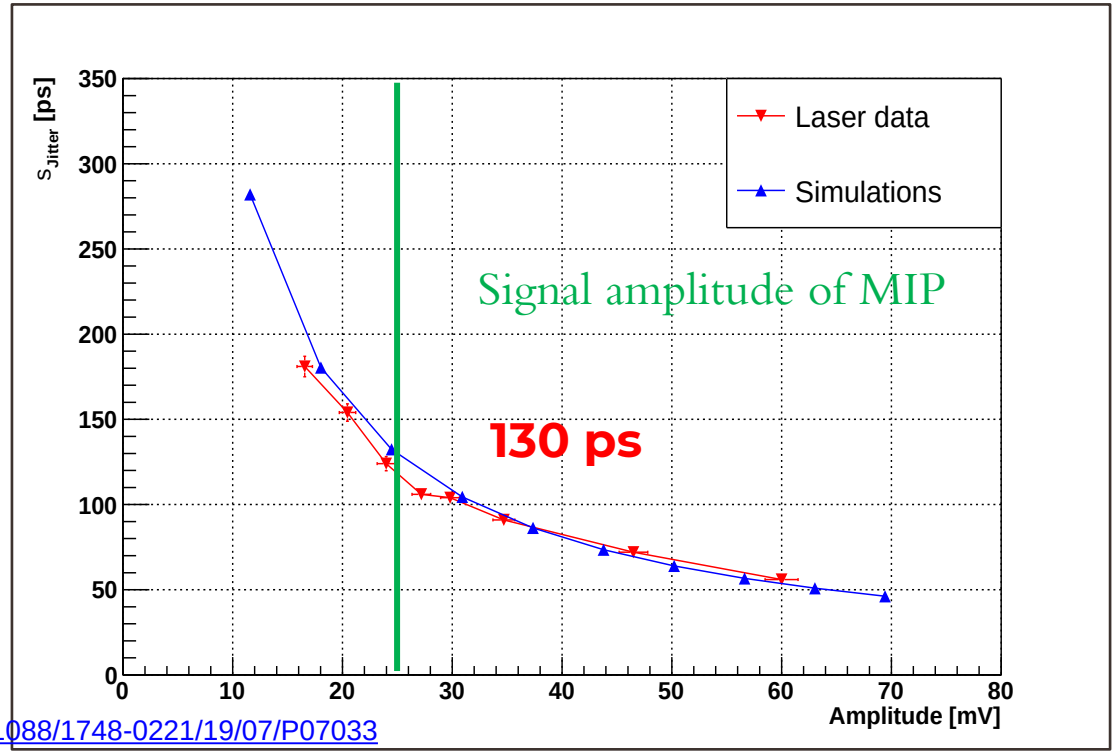
First production: sensor gain ≈ 2.5



First estimation of **jitter**:

- RMS of the time difference between laser trigger out (TTL) and analogue output of MadPix (@ 50% signal amplitude)





https://dx.doi.org/10.1088/1748-0221/19/07/P07033

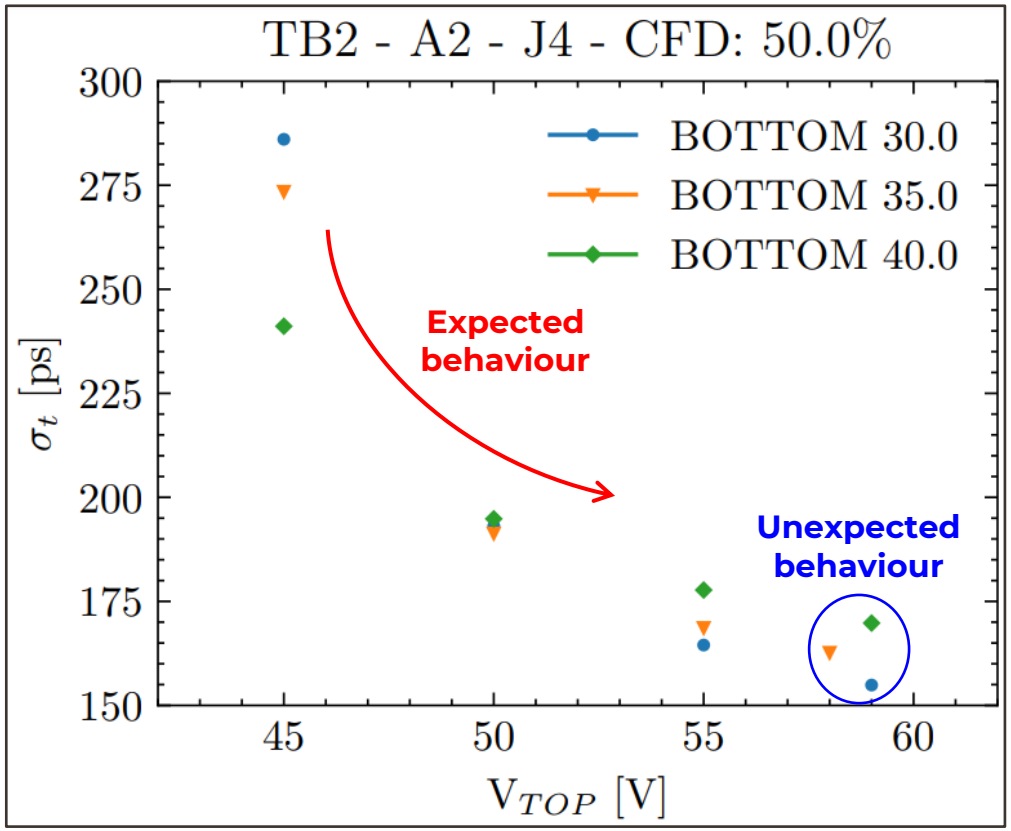
$$\sigma_{Jitter} \propto \frac{\sigma_V}{\frac{dV}{dt}}$$

Increased by raising output power of the laser

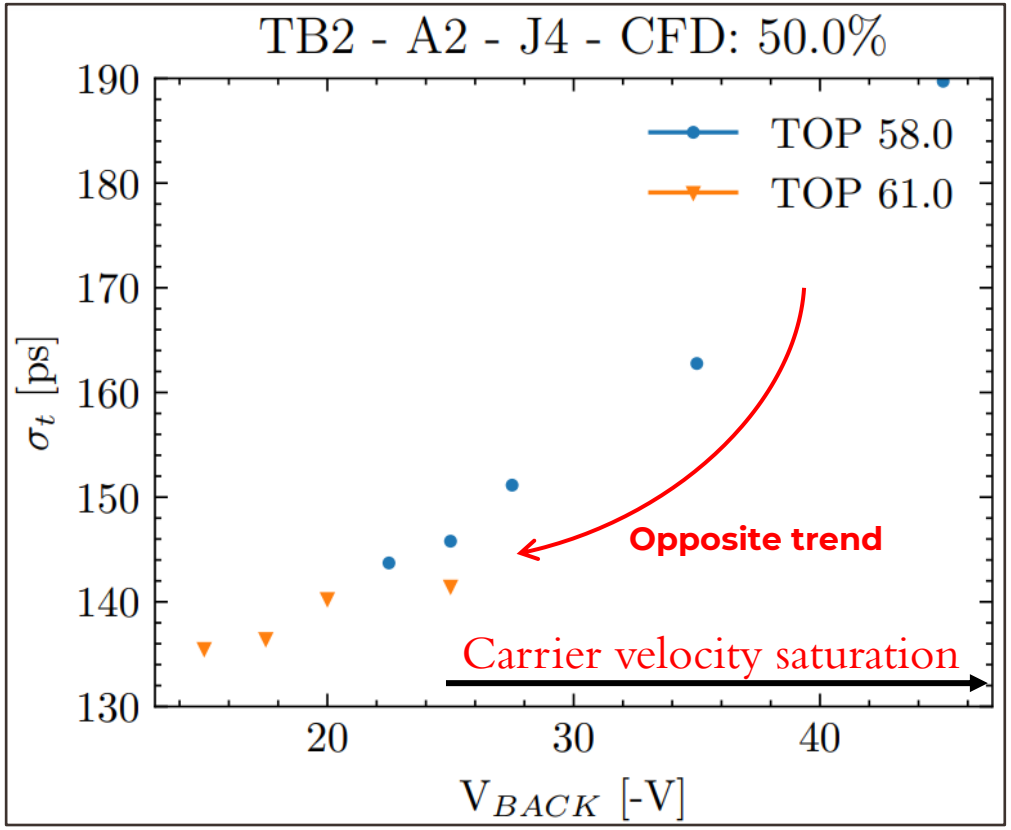
Time resolution of **245 ps** can **not** be explained with **jitter** → **Main contributor: Sensor**

MADPix 2nd test beam: new learnings

First production: sensor gain ≈ 2.5



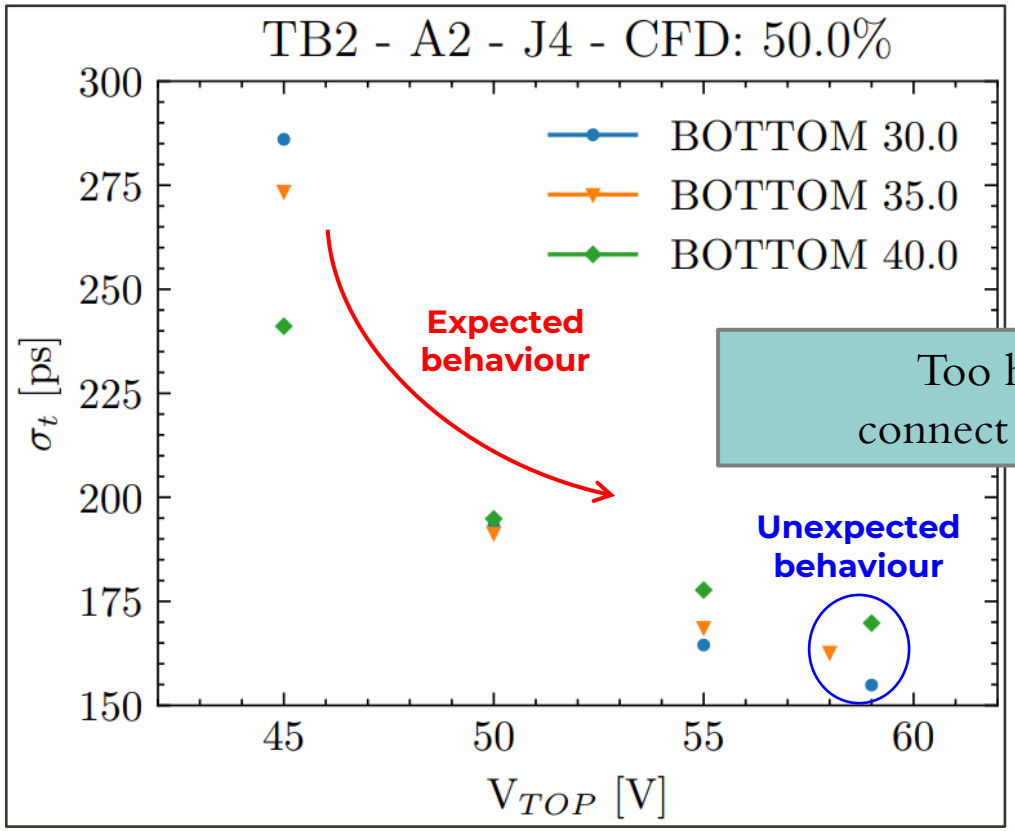
Increasing the collection electrode voltage → the time resolution improves



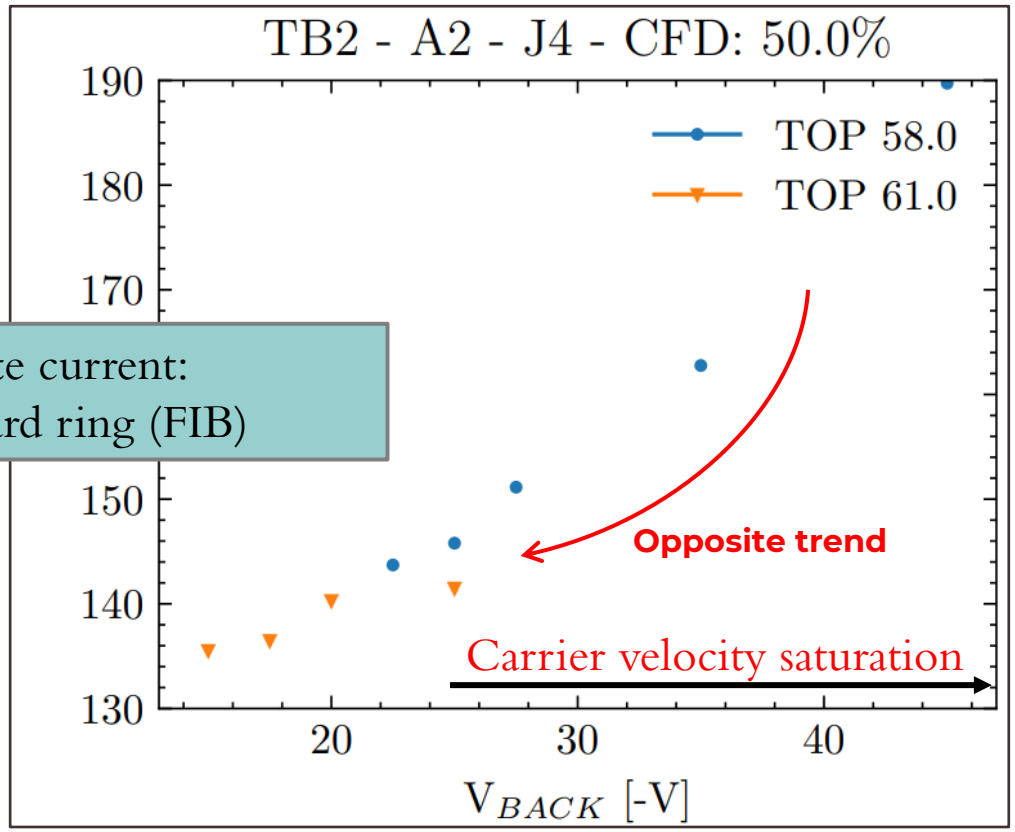
Decreasing the substrate voltage → the time resolution improves

MADPix 2nd test beam: new learnings

First production: sensor gain ≈ 2.5



Too high substrate current:
connect floating guard ring (FIB)

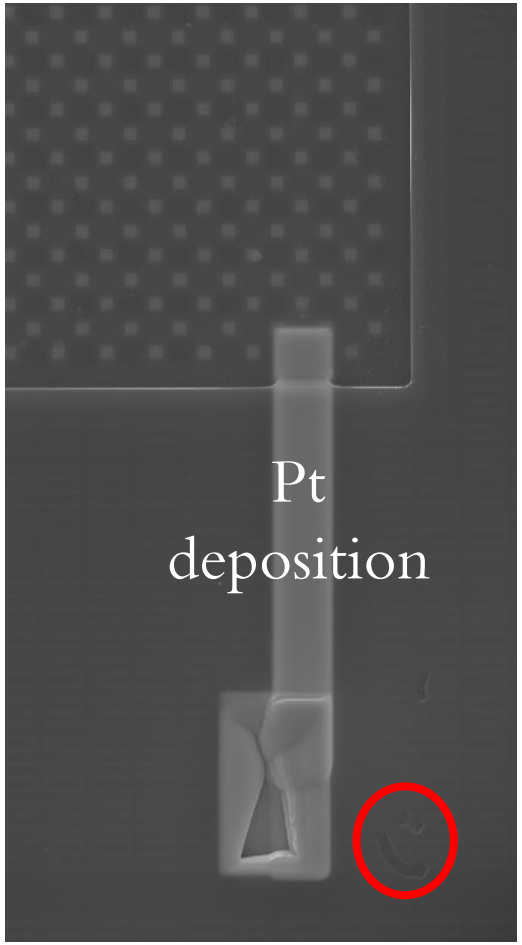


Increasing the collection electrode voltage → the time resolution improves

Decreasing the substrate voltage → the time resolution improves

Focused Ion Beam Technique

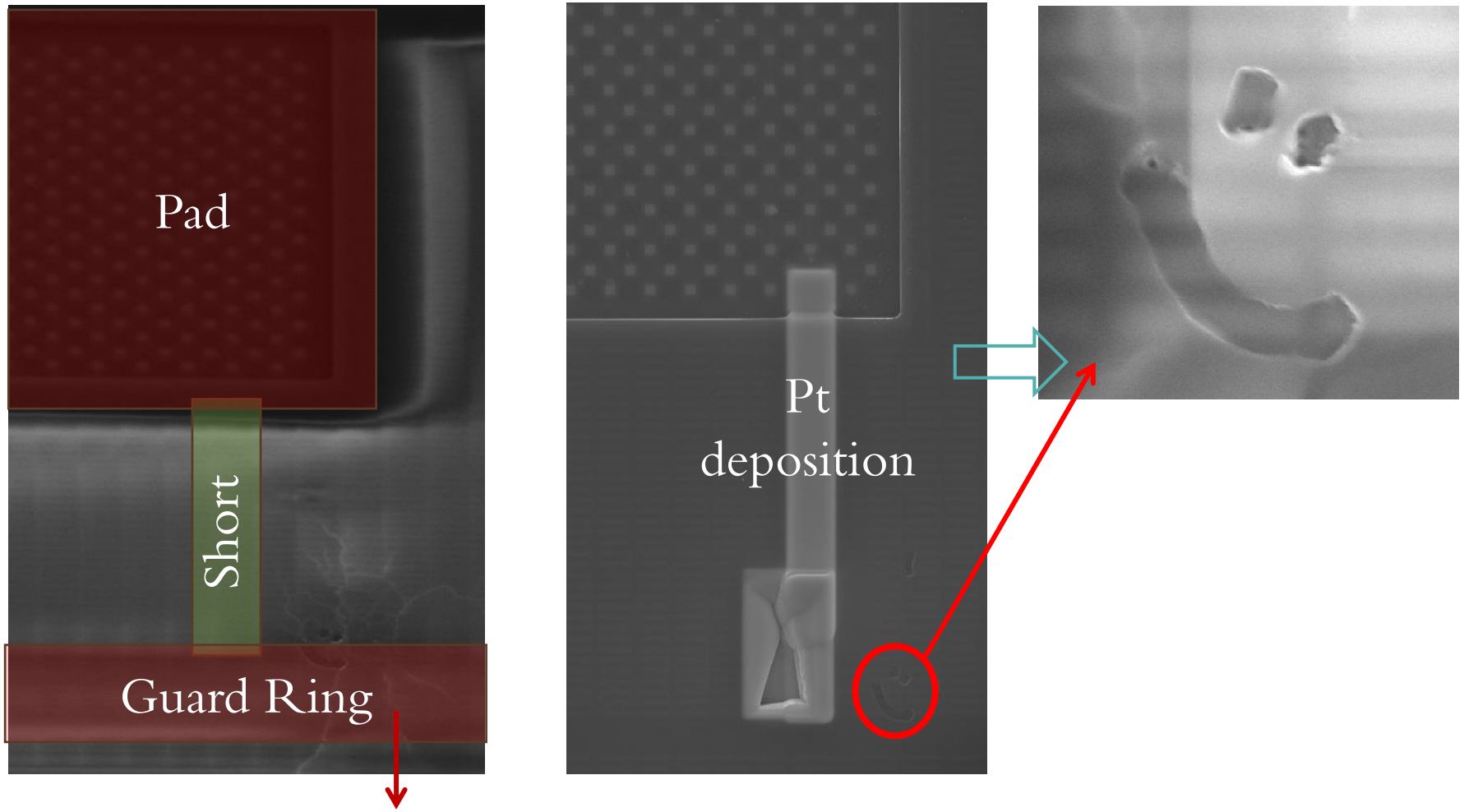
Focused Ion Beam Facility at INRIM Torino



Floating guard ring to be shorted

Focused Ion Beam Technique

Focused Ion Beam Facility at INRIM Torino



Floating guard ring to be shorted

Focused Ion Beam Technique

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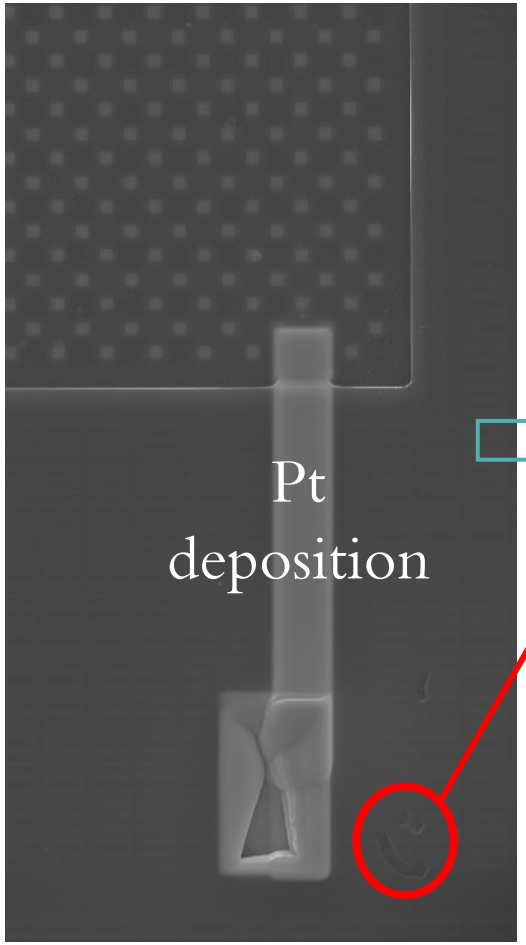
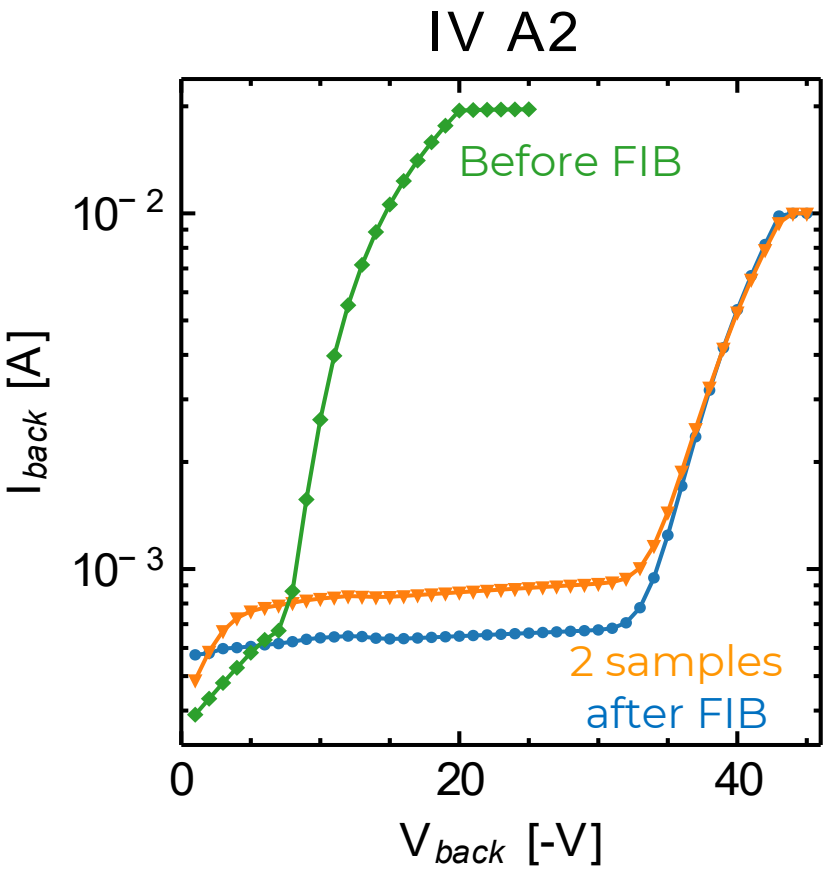
Floating guard ring to be shorted



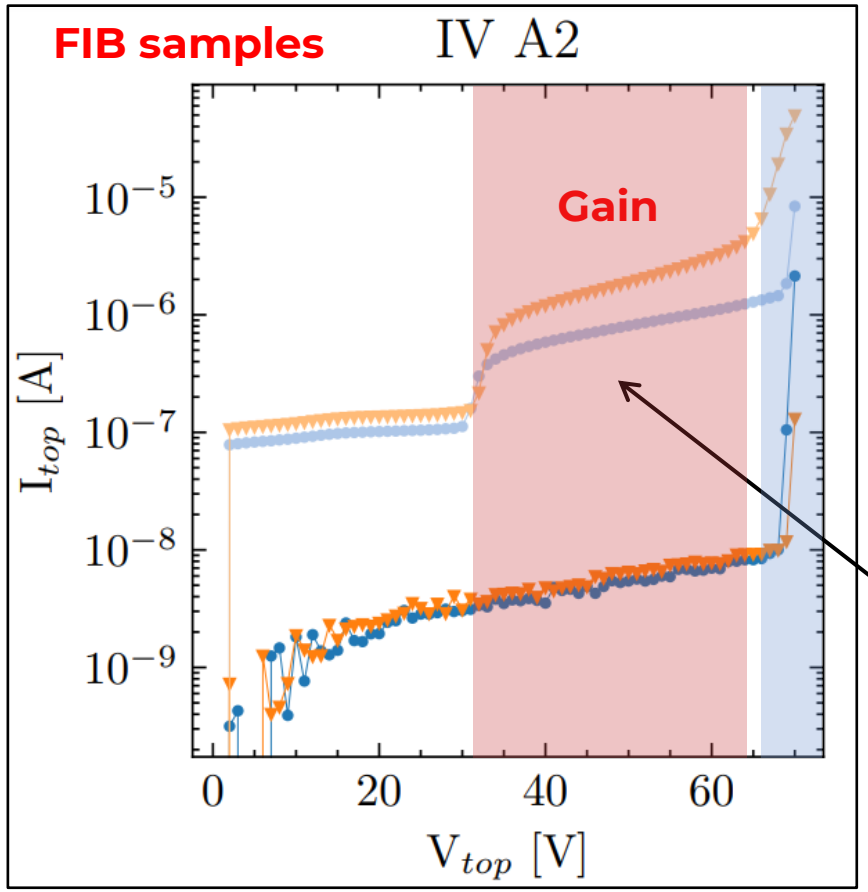


Backside current lowered of
2 order of magnitude

MADPix new short loop 3.2

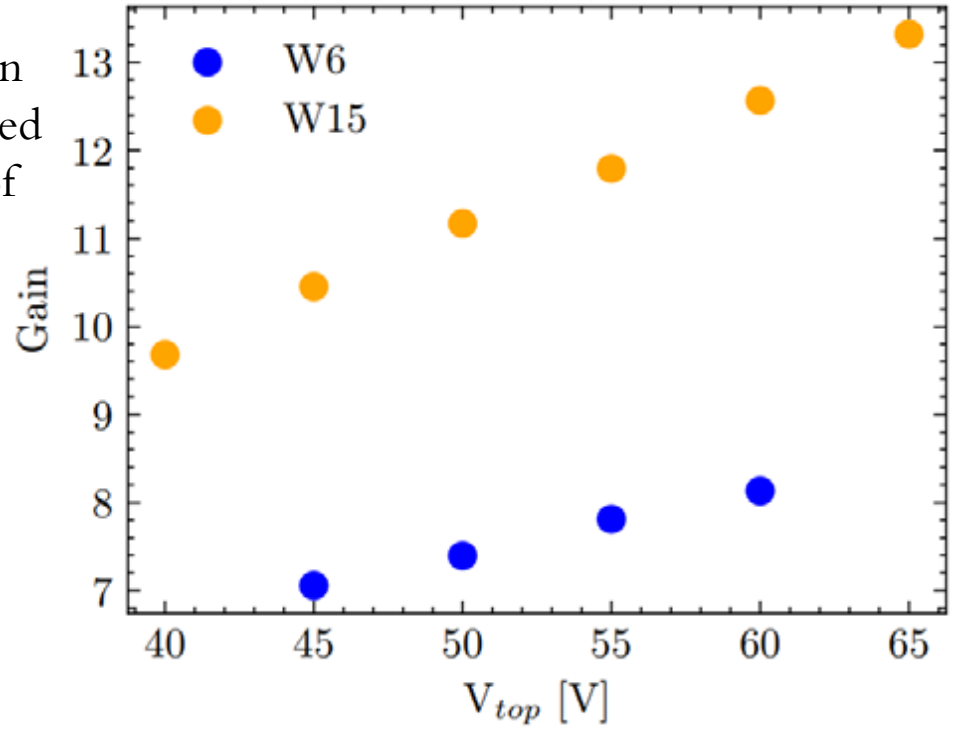
New production: higher gain

Short loop: same mask set with different implant dose → optimization of sensor at low price
New **sensor production** with **higher gain** arrived last September 2024
Expected **gain range: 5-20**



Curves with continuous IR laser on samples

Fist gain estimation using a no collimated radiation source of 55Fe

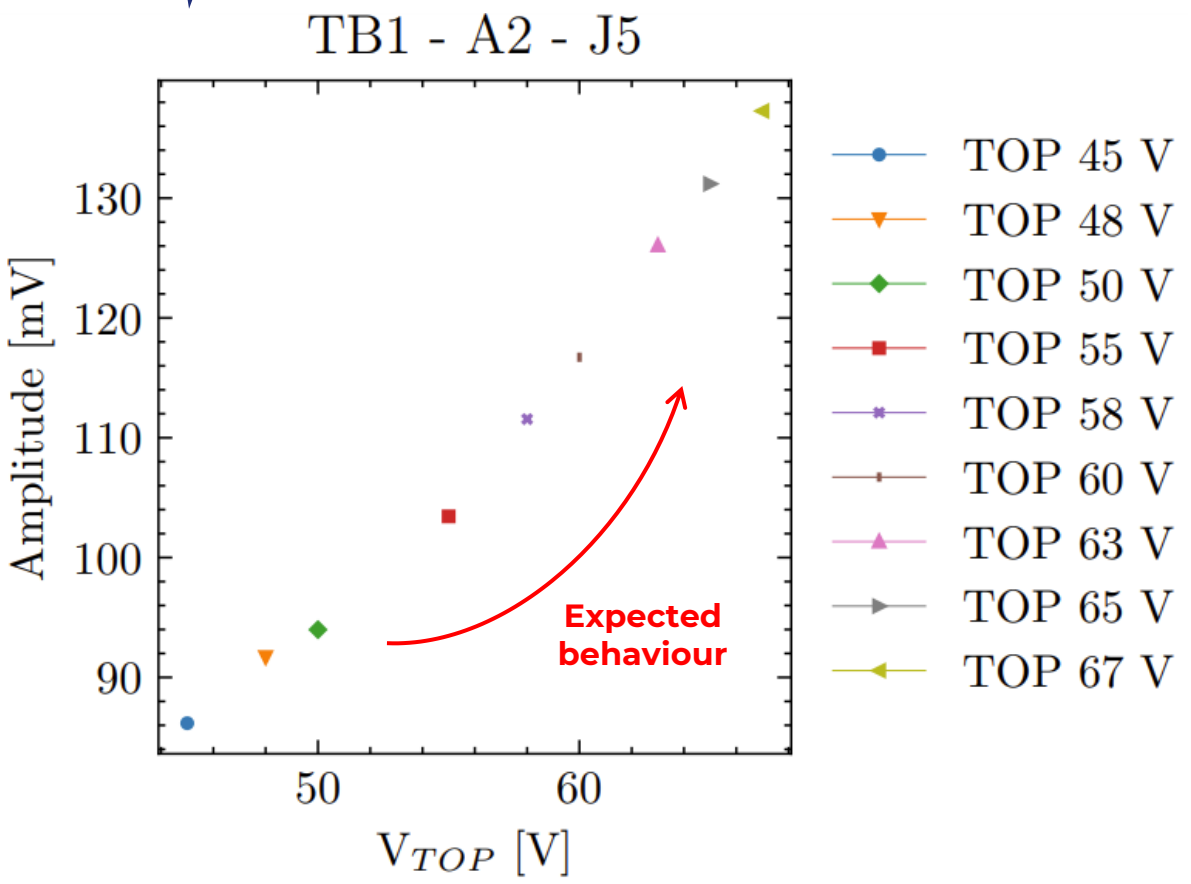


$$Gain = \frac{Peak\ [V/e]}{Electronics_{gain}[V/e]}$$ → From electronics simulations matched with data

New Results

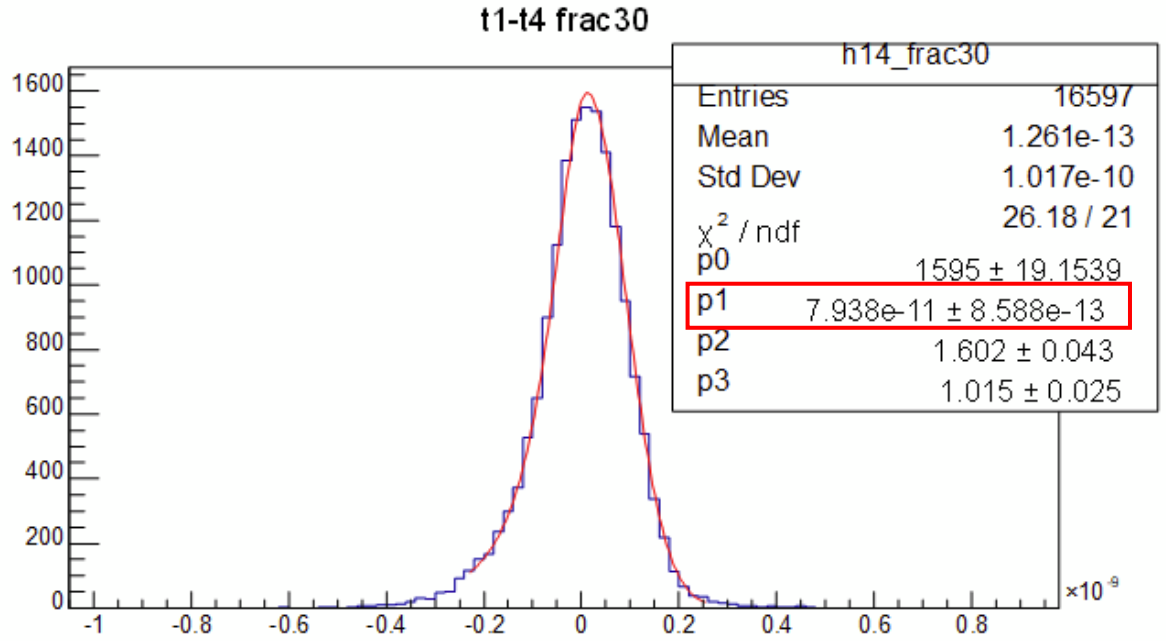
Latest test beam results

New production: higher gain



Most Probable Value of the Landau

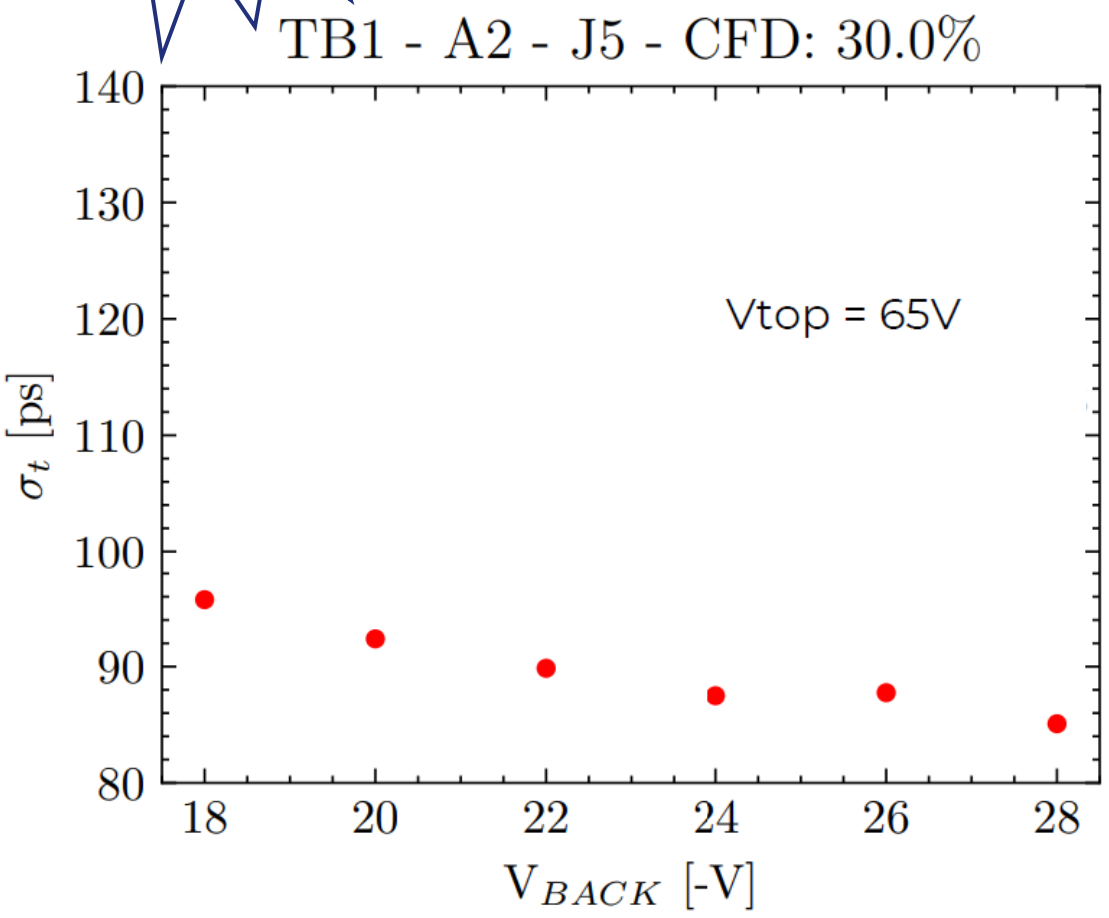
Time difference distribution

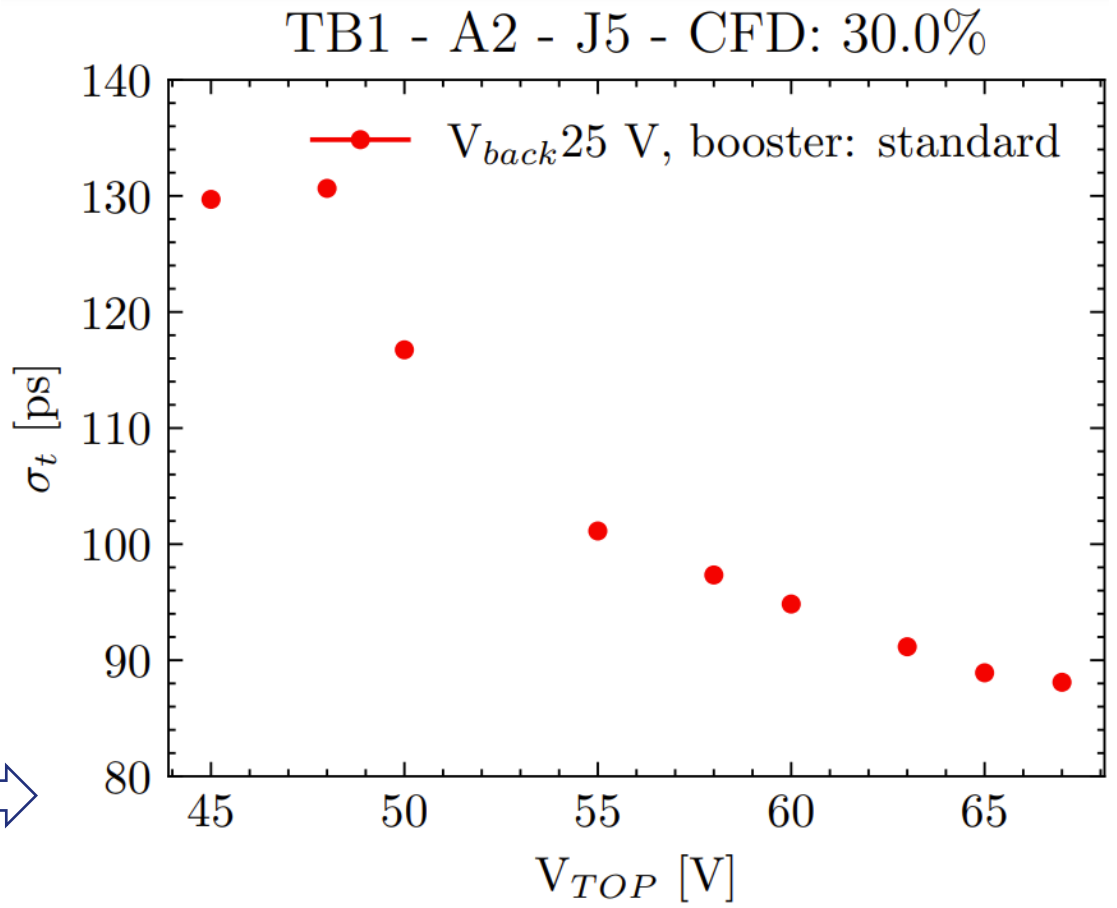


New Results

Latest test beam results

New production: higher gain



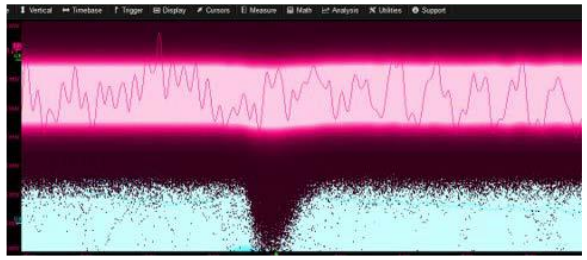


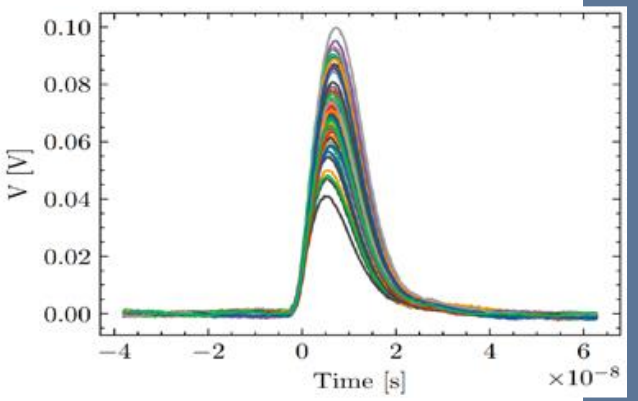
Time resolution sensor + front end (@0.18mW/ch): **88 ps**

Time resolution sensor: ≈ 75 ps

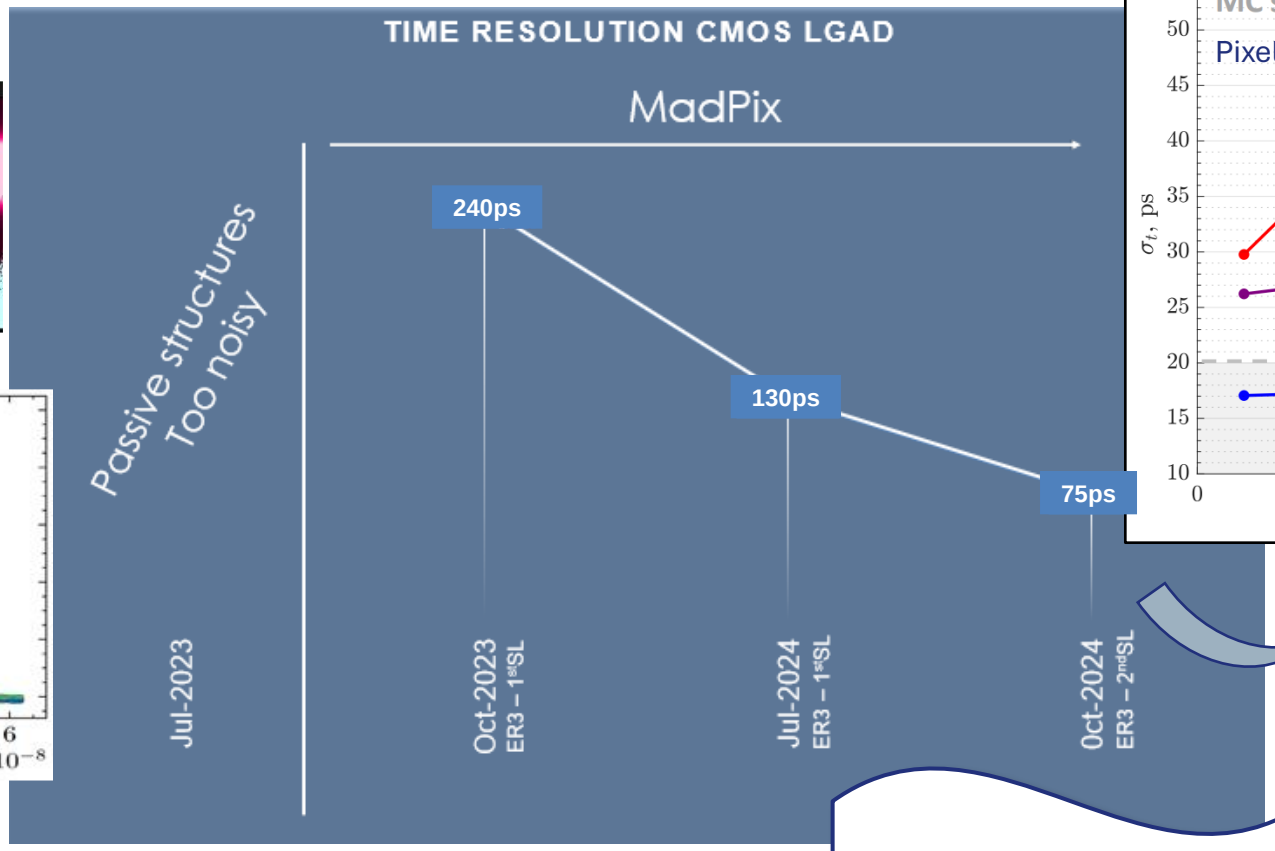
Where we started from…

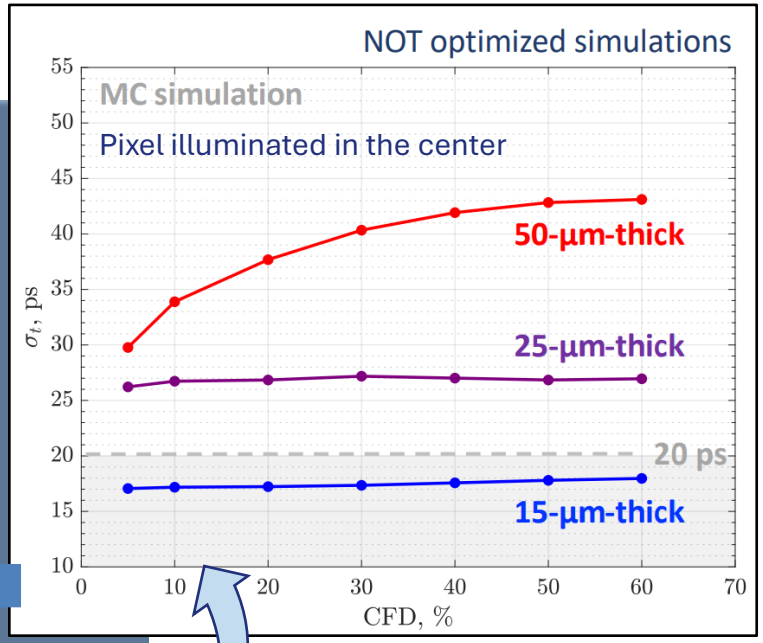
First signals observed in a test beam,
passive structure with gain - 50um thick
July 2023





Signals observed in last test beam,
MadPix with gain - 50um thick
Oct 2024





Need to implement new pixels design to mitigate edge effects and distortion term

→ new engineering run

Not final thickness and optimized geometry