INFN TORINO

ARCADIA

Politecnico di Torino 1859

ALICE

First results on Timing Performance of Monolithic sensors with additional gain for the future ALICE 3 experiment

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on behalf of the ALICE and the ARCADIA Collaborations

Politecnico di Torino & INFN sezione di Torino

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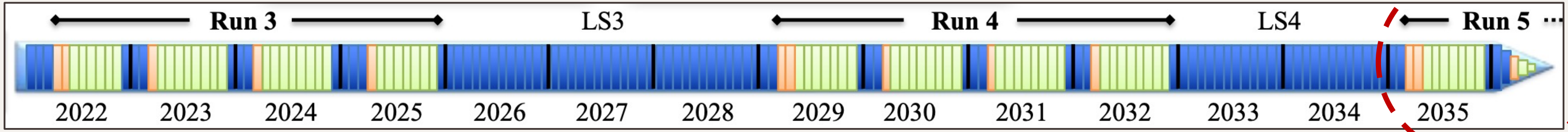
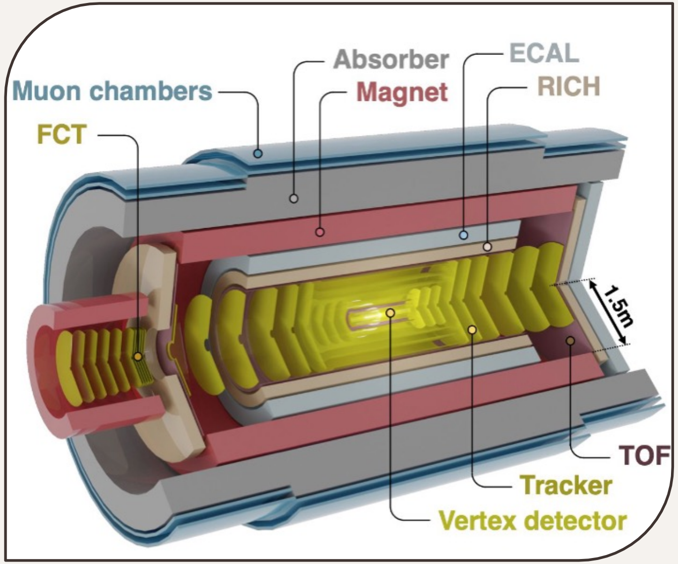
Introduction

ALICE 3: a next generation heavy ion experiment



ALICE 3



Key features:

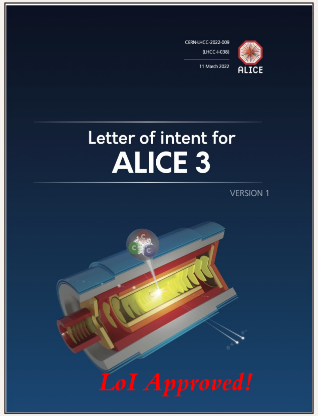
- exceptional pointing resolution
- excellent Particle IDentification (PID)
  - TOF
  - ECal
  - RICH
  - MID

Time-Of-Flight (TOF) system with silicon sensor

→ electrons and hadrons ID at low p_T

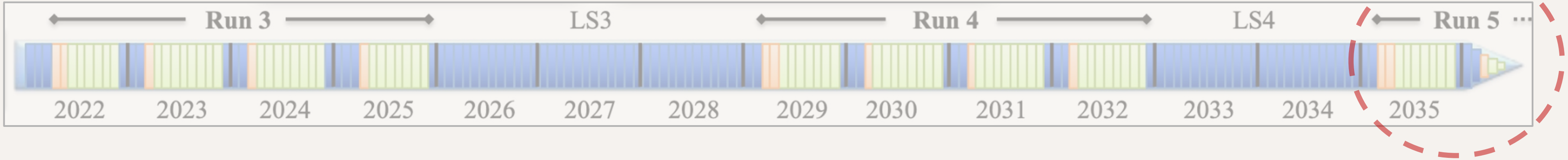
Requirements:

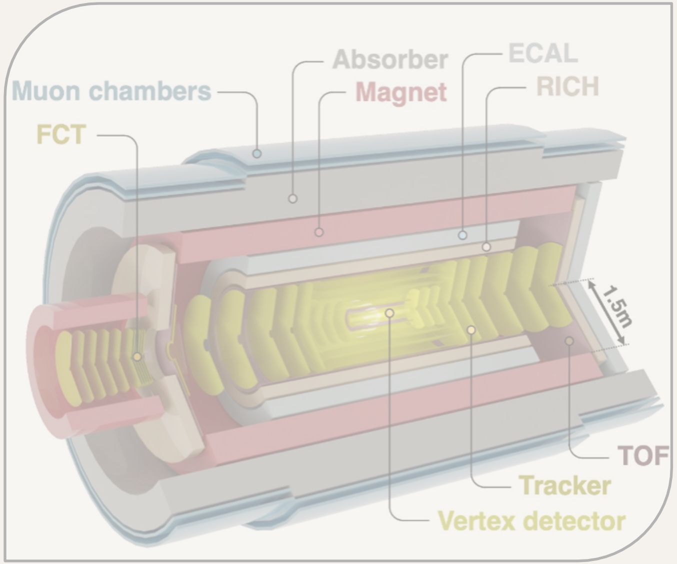
- time resolution of 20 ps
- low material budget ~1-3% X_0 per layer
- low power density 50 mW/cm^2



https://cds.cern.ch/record/2803563

ALICE 3: a next generation heavy ion experiment





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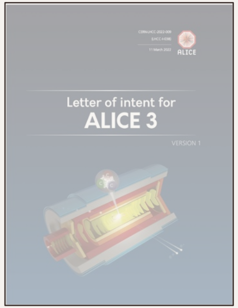

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HOW?

3 options considered in LoI:

- CMOS Sensors
- LGADs
- SPADs

Monolithic sensors – ARCADIA Project

https://web.infn.it/ARCADIA/index.php/en

Advanced Readout CMOS Architectures with Depleted Integrated sensor Arrays

- **Front-end electronics** is embedded in the same silicon substrate → **Lower material budget** + **Cheaper**
- **Fully depleted monolithic sensor** → fast charge collection by drift → good time performance
- **Large electrode** → uniform $\vec{E}$ necessary for timing measures

  → higher capacitance → **Signal-to-Noise Ratio decreases**

- ***Drawback***: current time resolution is too low (~ns)

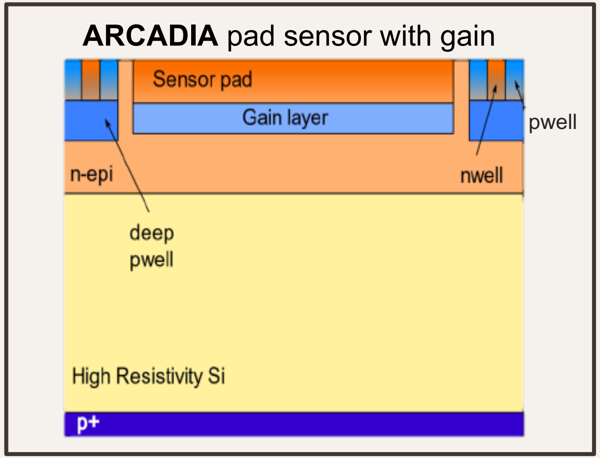
Solution: ***gain layer*** with low multiplication introduction

↓

charge multiplication → avalanche process

↓

increase the signal/noise ratio (SNR)



Lucio Pancheri

MadPix

Monolithic CMOS Avalanche Detector PIXelated Prototype

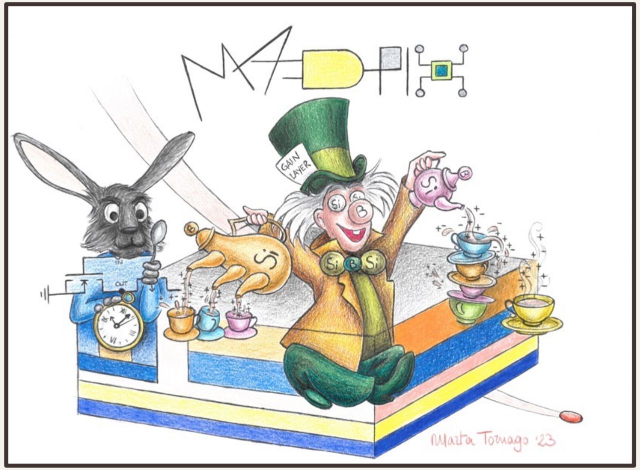
First prototype with **integrated electronics** and **gain layer**

↳ LFoundry in 110 nm commercial CMOS Process

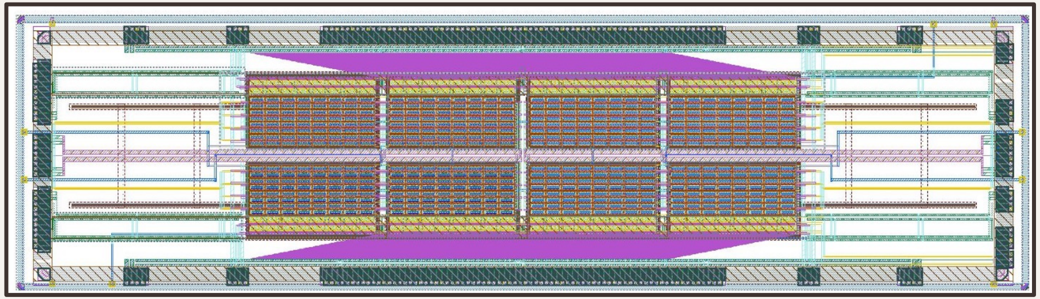
Active thickness: 48 μm

- **Backside HV**: allow full depletion → -25 V to -40 V
- **Topside HV**: manage the gain → 30 V to 50 V

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



Thanks to M. Tornago



Symmetrical

ALICE

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Monte Carlo Simulation

ALICE

Allpix^2 tool

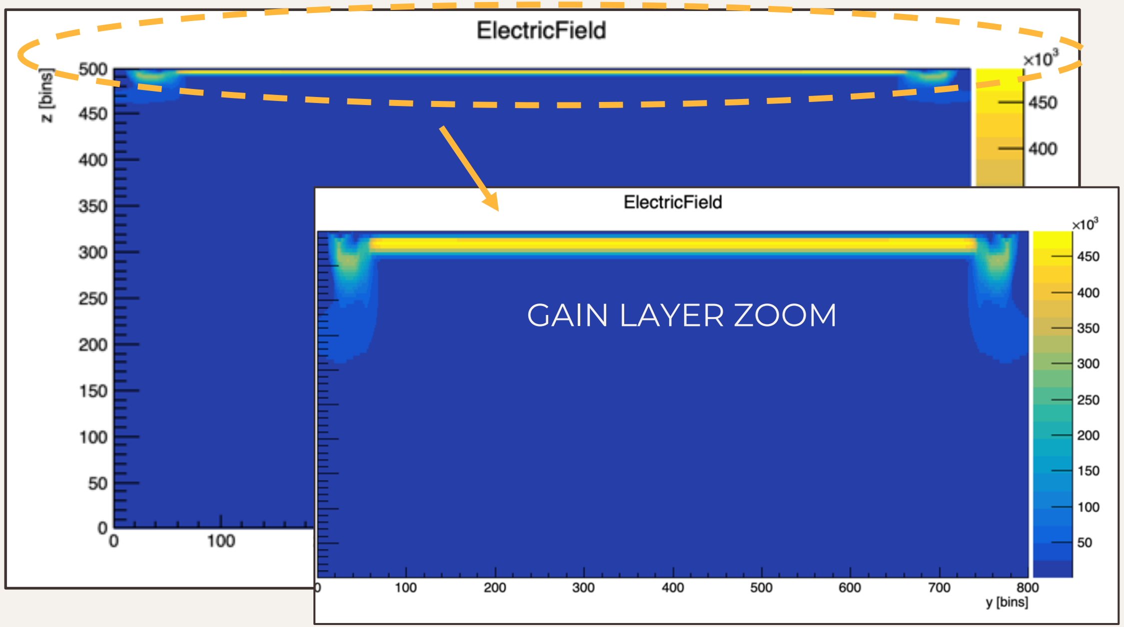
https://allpix-squared.docs.cern.ch/

TCAD
- Simulation tool for sensor modeling
- Describes electromagnetic fields
- Long computing time

Allpix^2
- Monte Carlo simulations for detectors
- High statistics
- Less computing time

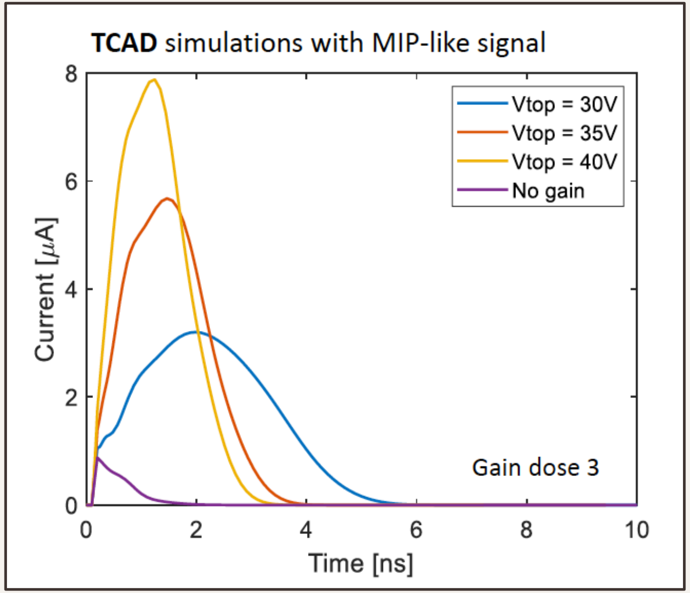
2D Simulation

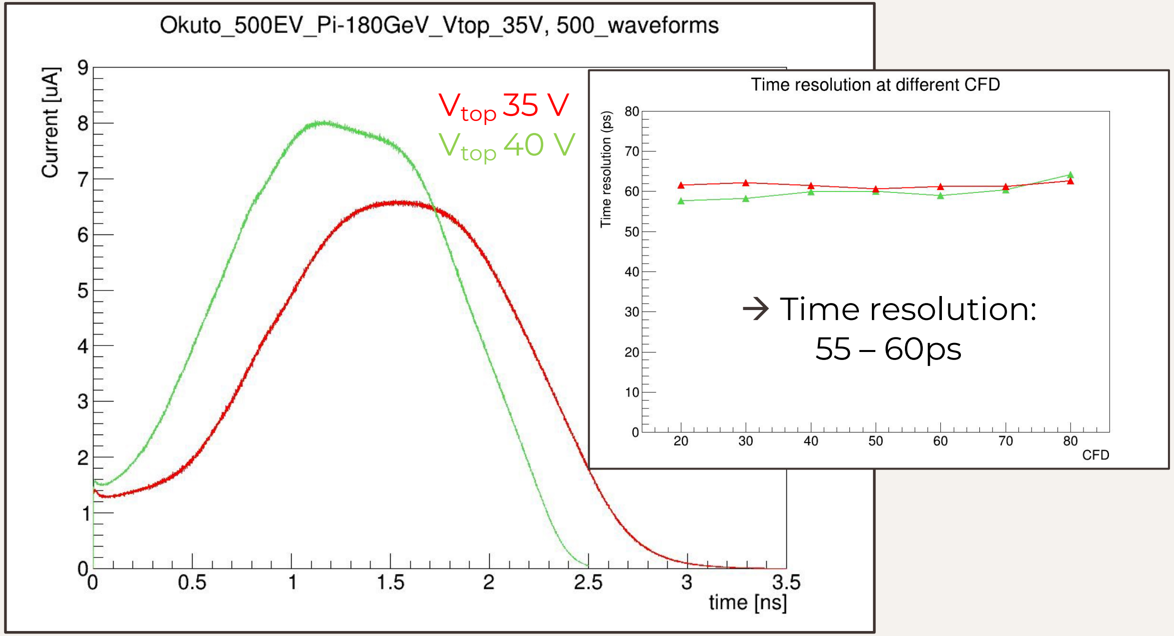
- Pixel size: 80 x 50 μm^2
  80μm width → 68μm effective width of the gain layer
  50μm thickness
- Mesh division: 0.1 x 0.1 μm^2
- Squared source with 2 μm square side
- Charged particle: **180 GeV π**
- **Masetti-Canali** mobility model
- Multiplication model: **Okuto**



Allpix^2 tool

Comparison between Allpix^2 and TCAD signals at different V_{top} bias





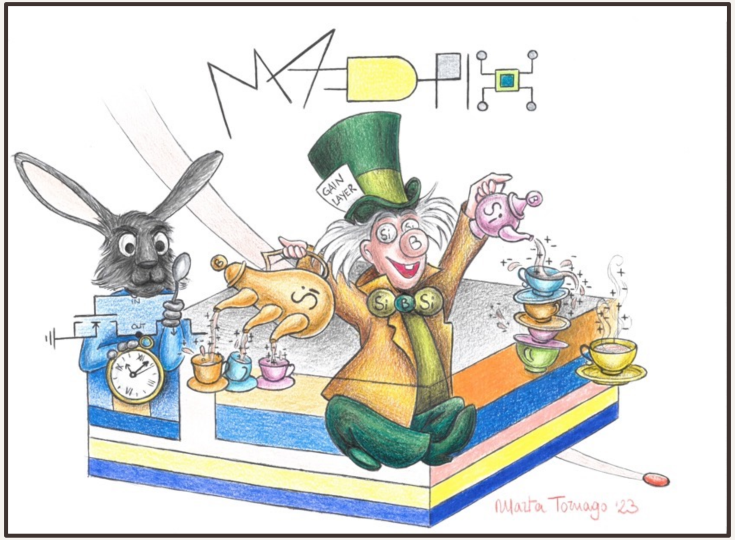
We are a bit far from the time resolution required by ALICE 3

→ the electric field will be more uniform increasing the sensor width → improves the time resolution

→ thickness reduction (25 -15 μm) is needed to reach the 20ps target

03

Laboratory Tests

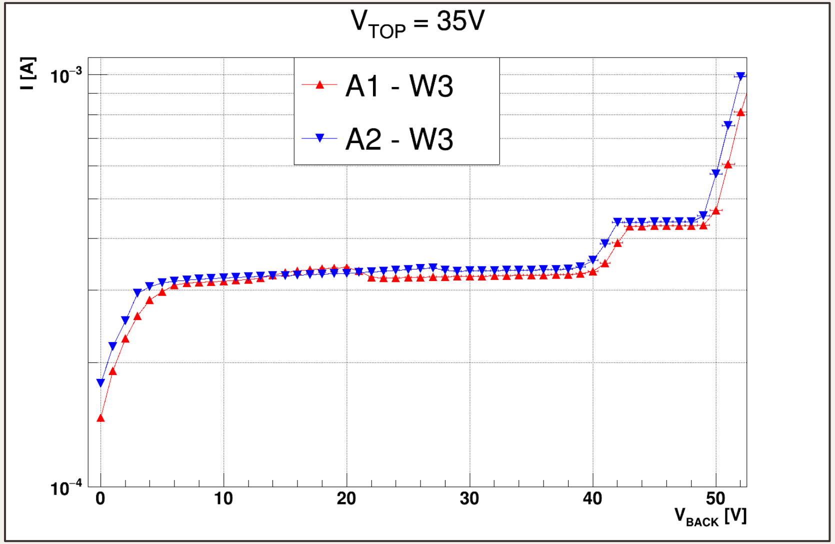


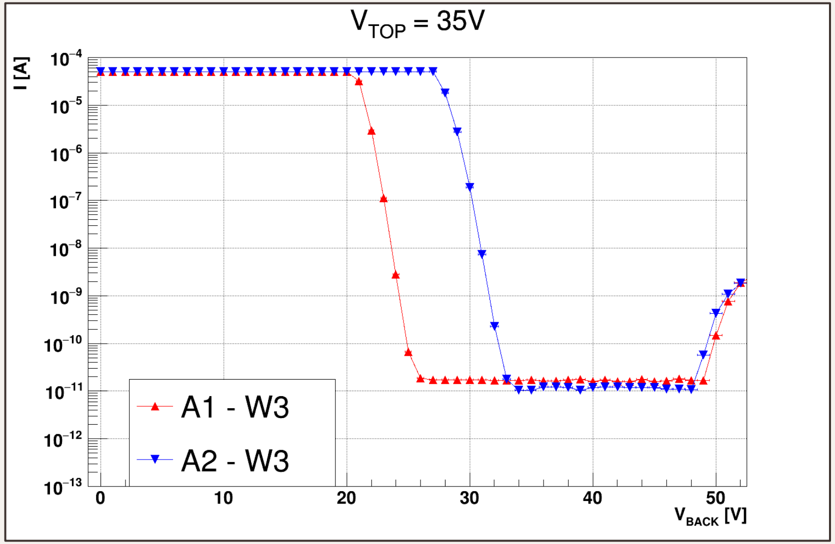
Passive structures characterization

I(V) scan to study the sensor behavior

I_{back} → current between p^+ on the backside and the p-wells
→ Punch through for HV back > 45V

I_{top} → current between n^+ collection electrode and guard ring
→ Depletion for HV back > 35V





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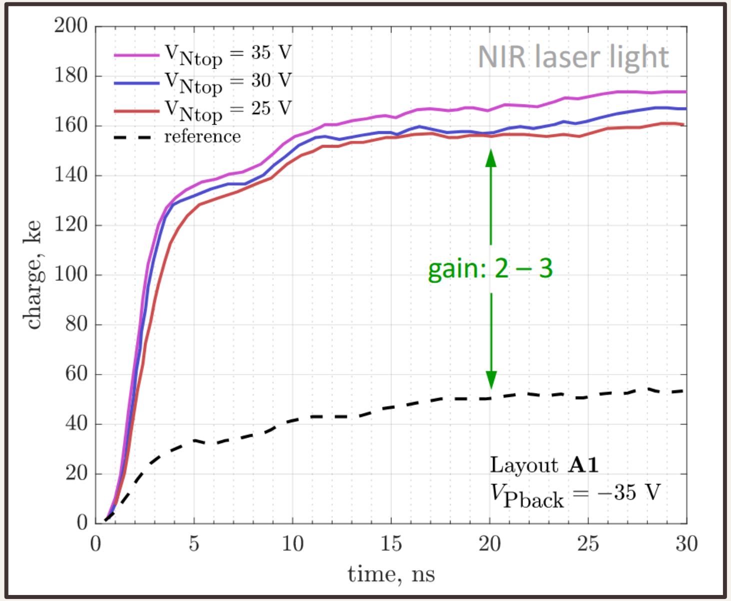
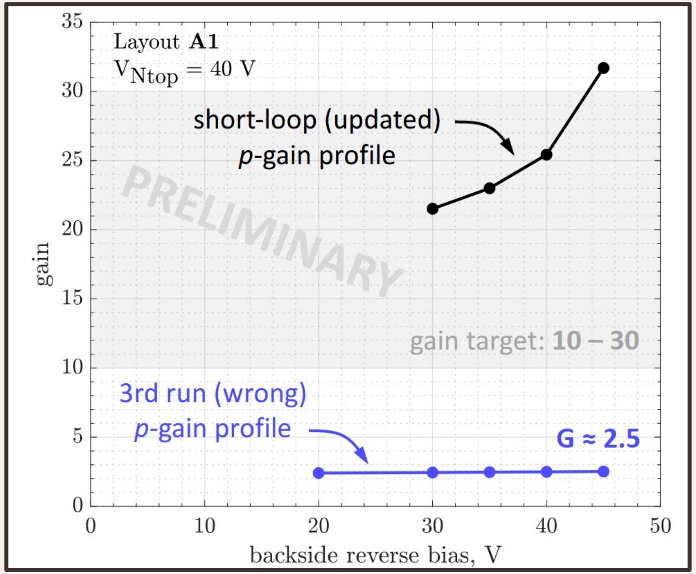
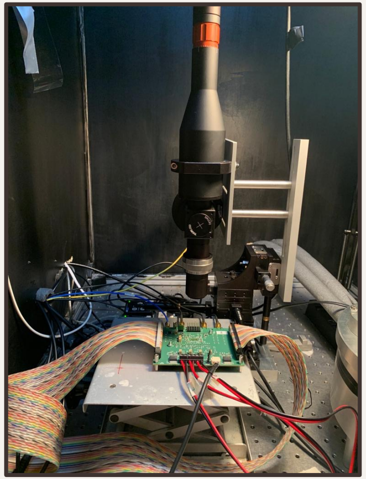
Laser Measurements

Optical characterization at UNITN (Trento)
- → IR laser from the back of the sensor
- → laser spot ~ 20 μm

Integral of the charge ⟹ Gain ≈ 2.5 ↳ Investigation of the p-gain profile with TCAD







Implantation energy lower by 30% with respect to the design

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Conclusions

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Conclusions and Outlook

→ A new innovative sensor is being designed and tested to meet the timing requirement of ALICE 3 Project

↳ **Monolithic sensors with additional gain**

→ Using a Monte Carlo simulation tool **Allpix²**

↳ the electrical behavior and the timing performance are being simulated

A time resolution of about *50 ps* is obtained → thinning the sensor we could achieve the required 20 ps

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

↳ **MadPix**

→ Laboratory tests show that the sensors are **fully functional**

What's next?

→ Simulation activities in parallel with tests

→ Short loop run will arrive in the next weeks: new sensors with increased gain to be tested

Thank you for the attention!

Spare

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Monolithic sensors – ARCADIA Project

ARCADIA

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  → higher capacitance → **noise increases**

$$\sigma_t^2 = \sigma_{\text{Time Walk}}^2 + \sigma_{\text{Landau Noise}}^2 + \sigma_{\text{Distortion}}^2 + \sigma_{\text{Jitter}}^2 + \sigma_{\text{TDC}}^2$$

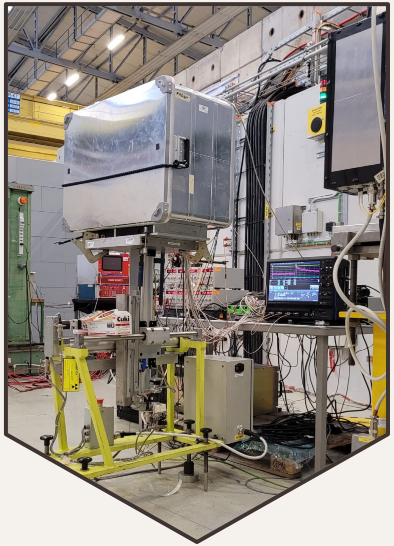
- $\sigma_{\text{Time Walk}}^2$: Can be **corrected** (e.g. with Constant Fraction Discriminator, CFD)
- $\sigma_{\text{Landau Noise}}^2$: Fundamental limit
- $\sigma_{\text{Distortion}}^2$: Non saturated velocity and non-uniform weighting field
- σ_{TDC}^2: Can be made **negligible**
- σ_{Jitter}^2:

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

- σ_V: Low input capacitance, High preamp. transconductance
- dV: Large signal (gain)
- dt: Short signal rise time

H. F.-W. Sadrozinski et al 2018 Rep. Prog. Phys. 81 026101

Test Beam Setup

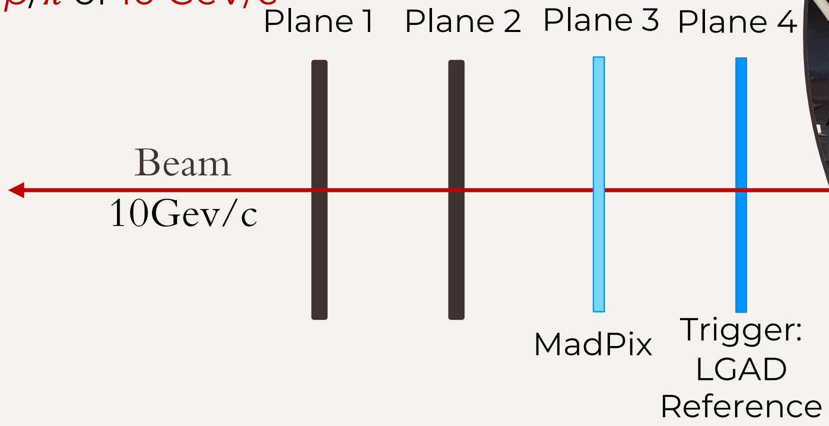


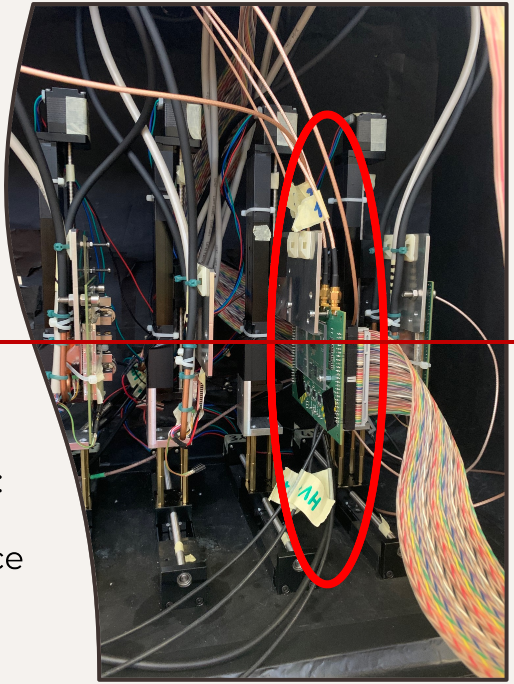
📍 Test beam setup realized at INFN Bologna

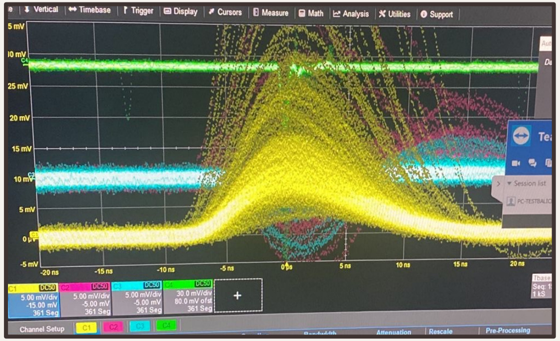
In October 2023 ***first test beam*** with ***MadPix***

→ at CERN Proton Synchrotron (PS)

→ with *p*/π of 10 GeV/c







First MIP signals of MadPix