Preliminary results on monolithic CMOS sensors with gain layer in 110 nm technology for the ALICE 3 experiment

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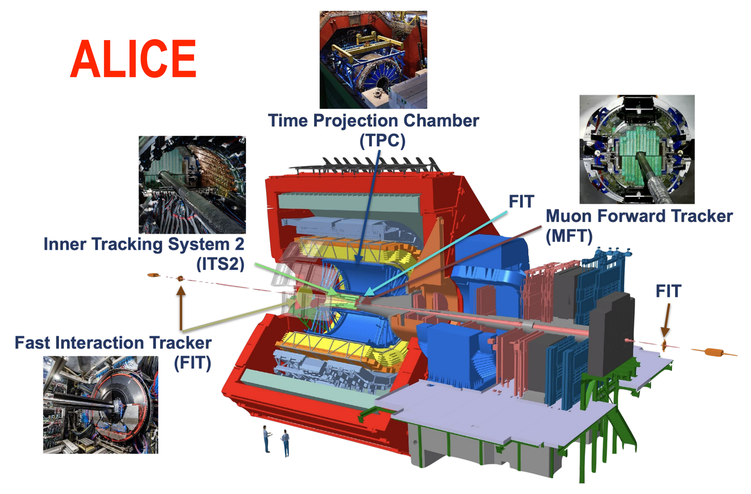
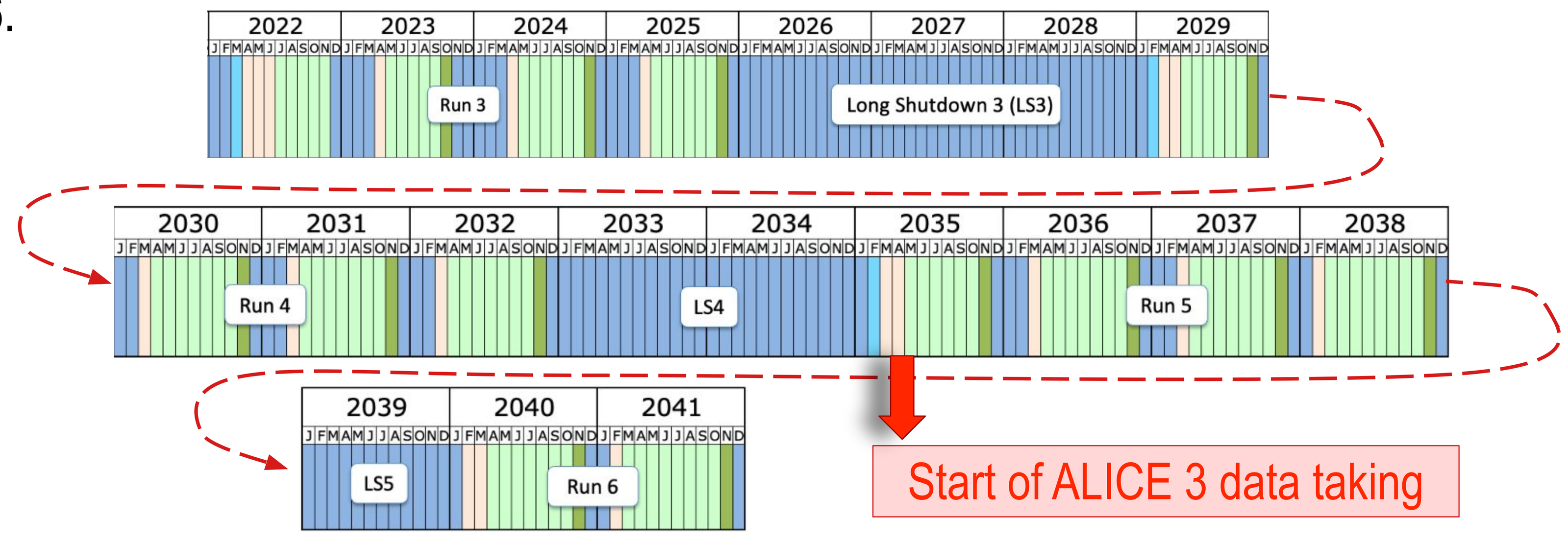
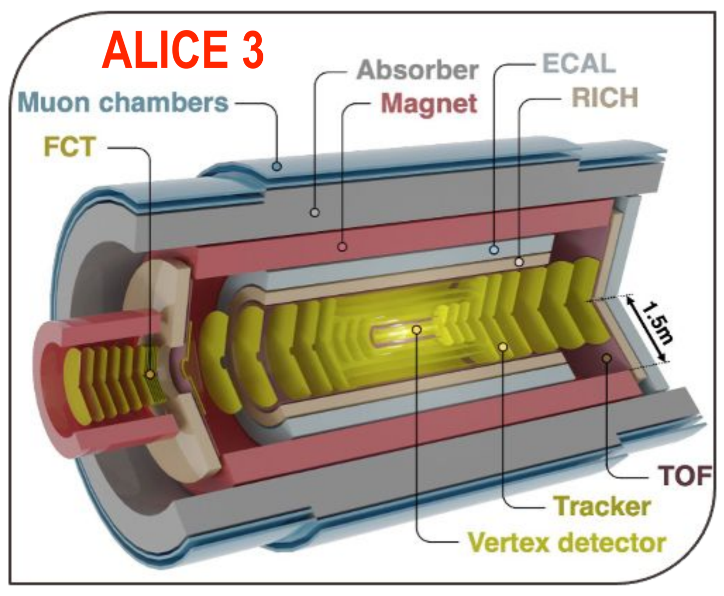
Context and motivation: the ALICE 3 upgrade

- **M**onolithic **A**ctive **P**ixel **S**ensors (**MAPS**) based on the CMOS Imaging Sensor (CIS) technology are used in ultra-light large tracking systems of various high-energy physics (HEP) experiments like **ALICE** (**A** **L**arge **I**on **C**ollider **E**xperiment) at the CERN LHC. They are considered for many future HEP applications, in particular for **ALICE 3**, the next-generation heavy-ion physics experiment proposed for the LHC Run 5 and 6.







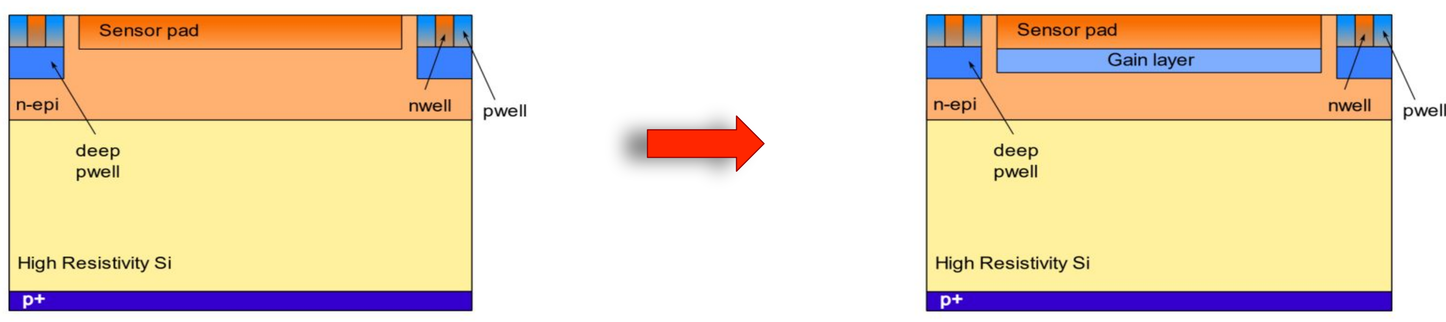
- **ALICE 3 TOF** detector: dedicated to **T**ime **O**f **F**light measurements. The required time resolution of **20 ps** will provide accurate particle identification information. Other TOF requirements: material budget 1-3% X_0 per layer, power consumption limit: 50 mW/cm^2

The sensor concept

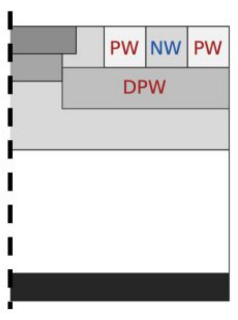
- Different silicon-based technologies are under study for the ALICE 3 timing layer: LGAD, SPAD or MAPS with gain. Timing with silicon sensors:

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

Structures developed by the **ARCADIA** (**A**dvanced **R**eadout **C**MOS **A**rchitectures with **D**epleted **I**ntegrated sensor **A**rrays) collaboration: **LFoundry 110 CIS technology**

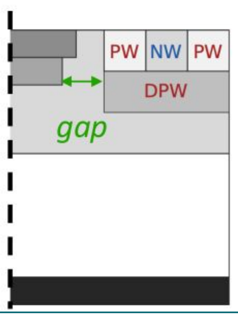


- Additional p-gain implant below the n+ collecting electrode to improve the time performance
- Different sensor layouts to test the charge collection properties at borders: **A1** and **A2**



Layout A1

- no space between deep-p-well and p-gain
- charges from the borders are multiplied: extended collection volume; more uniform multiplication

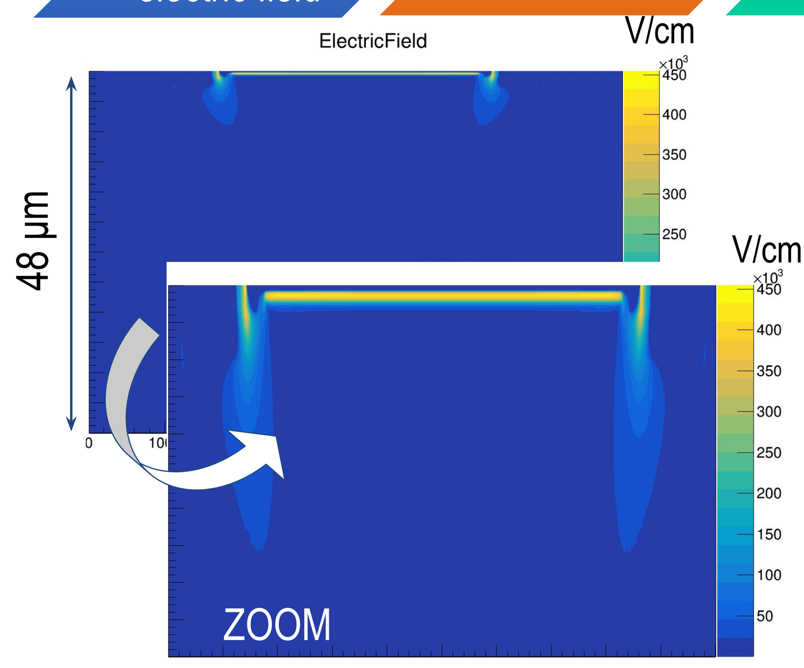


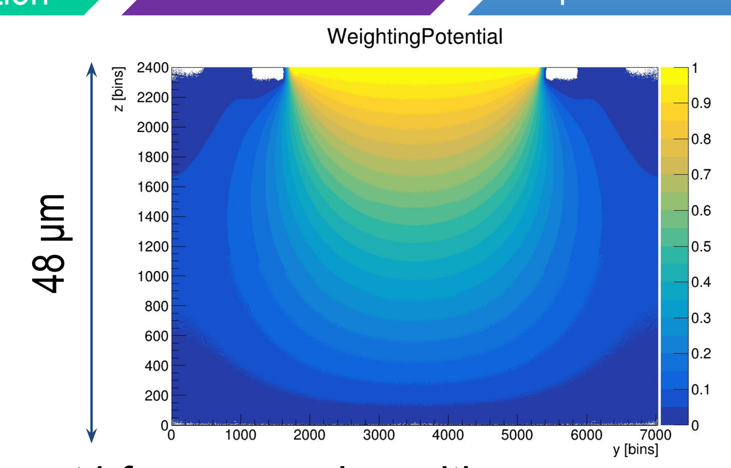
Layout A2

- "standard LGAD" termination implants
- charges collected at borders are NOT multiplied: direct path to the p-gain/n+ region; more uniform time response

TCAD and Monte Carlo simulations

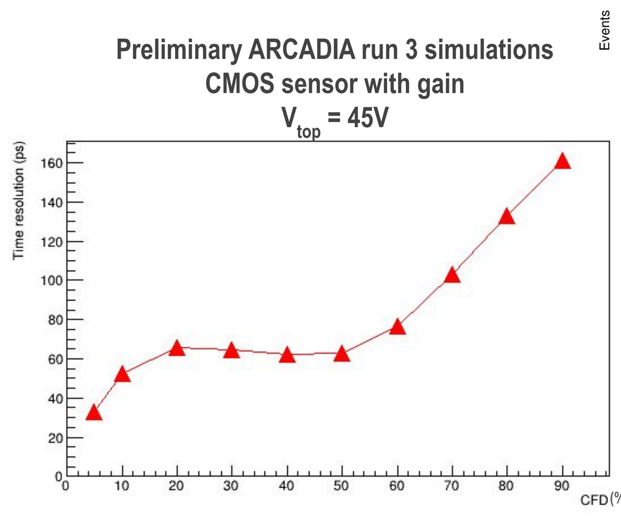
TCAD simulated electric field → Mesh Converter tool → Allpix2 Signal simulation → High statistic of particle-sensor interaction → Comparison of simulations and experimental data

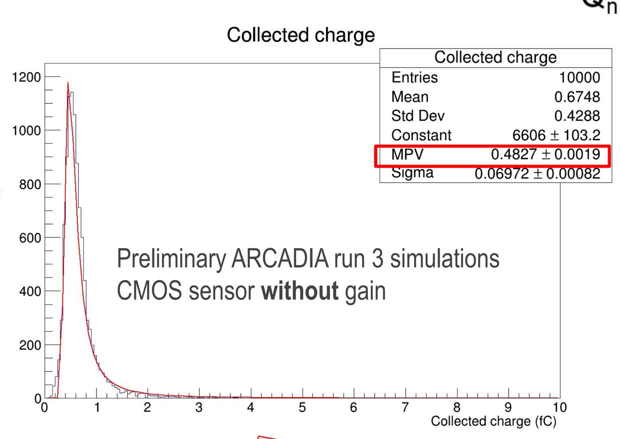


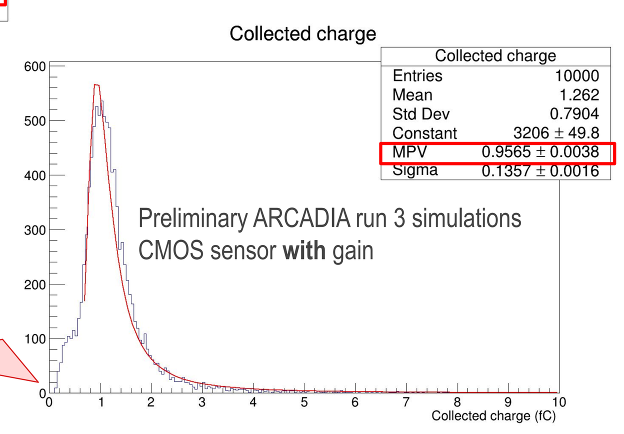


- Geant4 for energy deposition
- Induced charge computed using the weighting potential $\psi_n(x)$

$$Q_n = \int_{t_0}^{t_1} dt\, I_n^{ind}(t) = -\frac{q}{V_w}\int_{t_0}^{t_1} dt\, \boldsymbol{E}_n(\boldsymbol{x}(t))\dot{x}(t) = \frac{q}{V_w}[\psi_n(\mathbf{x}_1) - \psi_n(\mathbf{x}_0)]$$





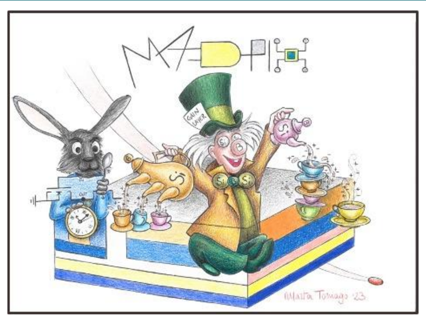


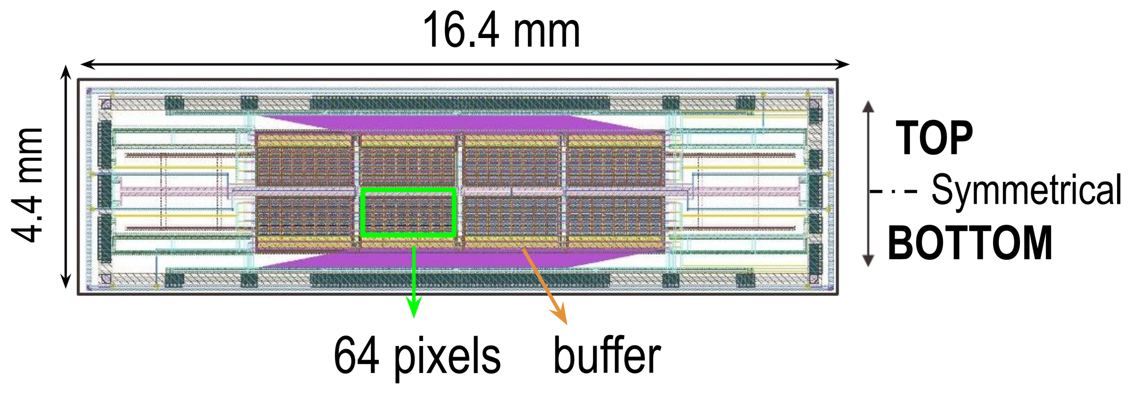
Gain ~ 2

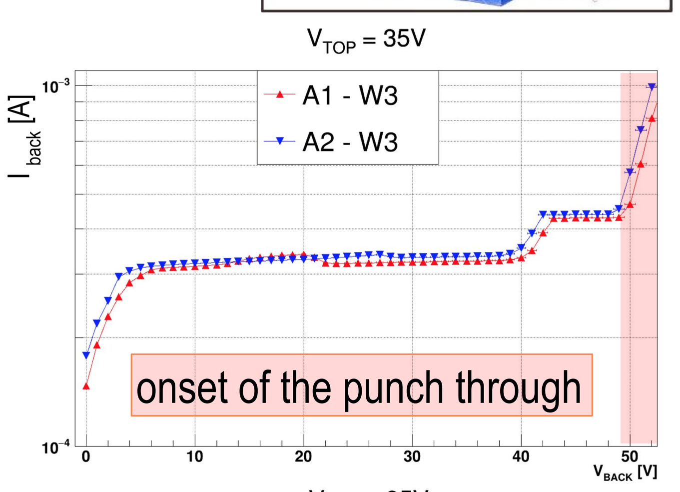
MadPix : a Monolithic CMOS Avalanche Detector PIXelated

<u>First prototype with integrated electronics and gain layer</u>

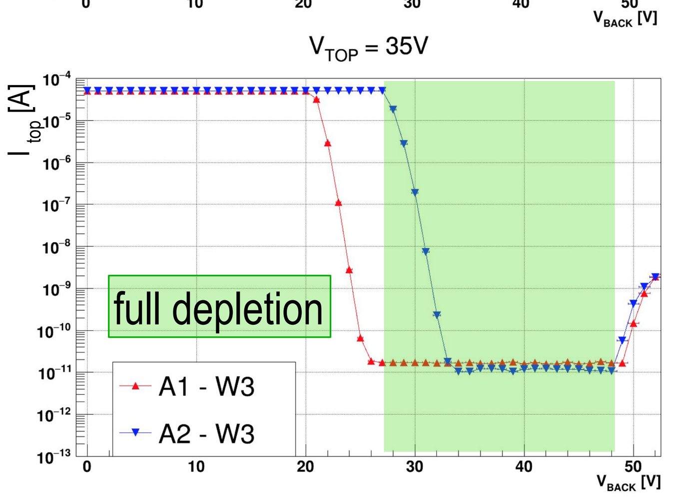
- Active thickness: 48 µm
- V_{back} allows full depletion (-25 V ÷ -40 V) ⟶ drift field in the substrate
- V_{top} (30 V ÷ 50 V) ⟶ defines the gain







- Each side has 4 matrices of 64 pixels divided in 8 rows and 8 columns
- Pixels size: 100 µm x 250 µm
- Maximum applicable backside voltage limited by punch-through current (power consumption increases exponentially above a certain threshold)

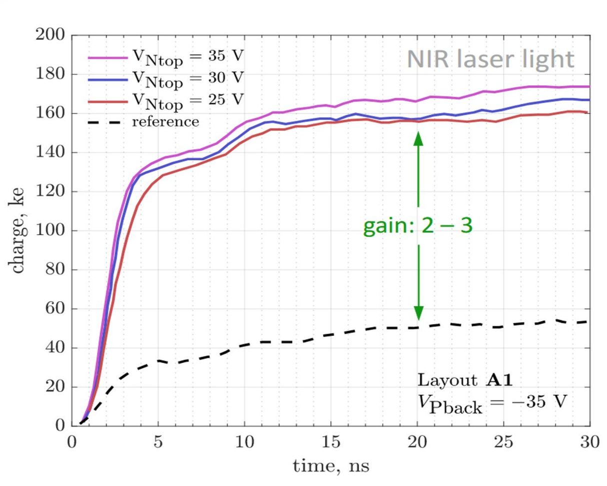


Future plans: test beam and laboratory measurements

- Validation of **MadPix** + **LIROC** (front-end ASIC designed to discriminate SiPM signals) + **picoTDC** (resolution of 3 – 12 ps) ⟶ acquisition of 4 analog outputs
- Validation of **MadPix + picoTDC** to acquire 4 discriminated outputs
- Electrical and optical characterization of the <u>monolithic devices with higher gain</u> and test beam to evaluate the timing resolution (foreseen in July 2024)

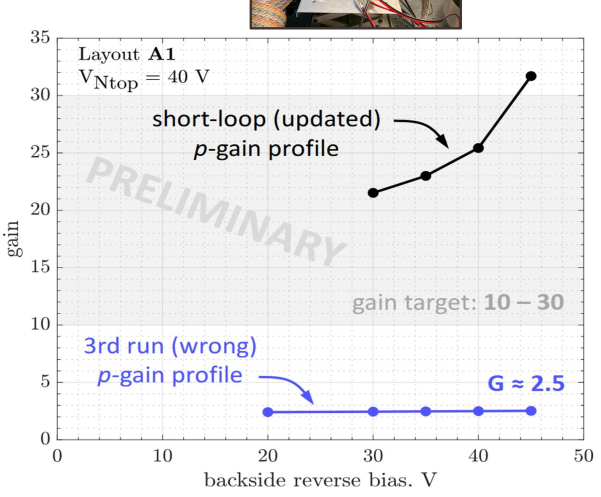
Laboratory measurements

- Optical characterization of passive structures at University of Trento
- IR laser from the back of the sensor simulating the passage of a MIP
- laser spot ~ 20 µm



TCAD simulations to investigate the p-gain profile mismatch

Implantation energy lower by 30% with respect to the design



In-beam measurements

- Proton Synchrotron - CERN, October 2023
- p/π beam with momentum 10 GeV/c
- setup in collaboration with INFN Bologna
- MadPix read out via 3 oscilloscope channels