First results on Monolithic sensors with additional gain with a 110 nm technology for the ALICE 3 Time of Flight detector

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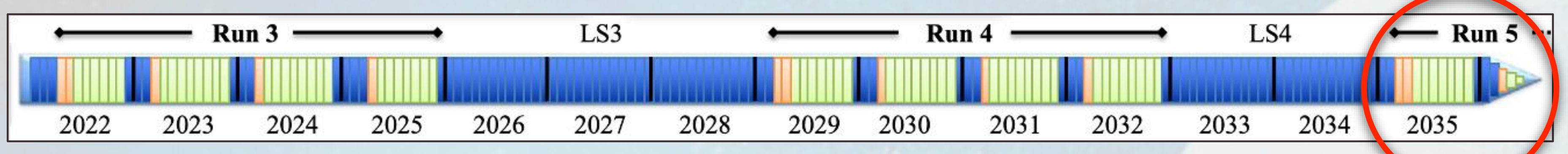
ALICE 3: a next generation heavy ion experiment

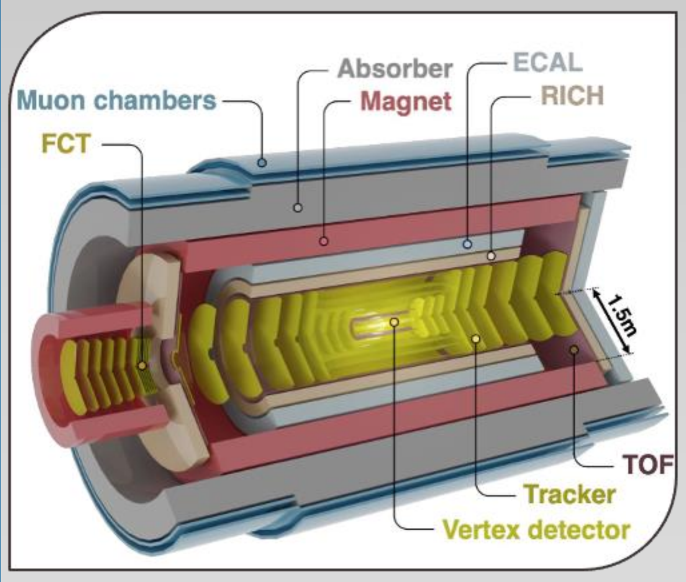


The key features of the compact next-generation detector in LHC will be:

- an exceptional pointing resolution
- an excellent Particle IDentification (PID)

- TOF - ECal
- RICH - MID

Time-Of-Flight (TOF) System → for electrons and hadrons ID at low p_T



TOF requires:

- *Time resolution of 20 ps*
- Low material budget ~1-3% X_0 per layer
- Low power density 50 mW/cm²

Advantages to choose the CMOS Technology

1. Less material and costs
2. Simpler and cheaper assembly

3 options considered in the LoI:

- **CMOS Sensors**
- LGADs
- SPADs

From the monolithic sensors to MadPix

The monolithic sensors of ARCADIA Project (**A**dvanced **R**eadout **C**MOS **A**rchitectures with **D**epleted **I**ntegrated sensor **A**rrays) present some peculiar and innovative characteristics:

- Fully depleted monolithic sensor → fast charge collection by drift
- Large electrode → uniform electric field

Drawback: the present time resolution (some *ns*) is too low due to limited SNR (no gain)

Solution: integration of the LGAD concept in the design of fully depleted Monolithic Active Pixel Sensors (MAPS)

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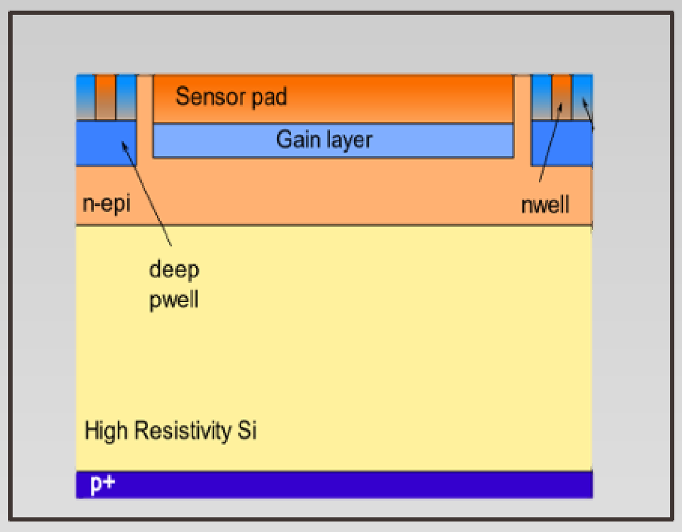
highly doped p-type region (*gain layer*)

⇩

avalanche process

⇩

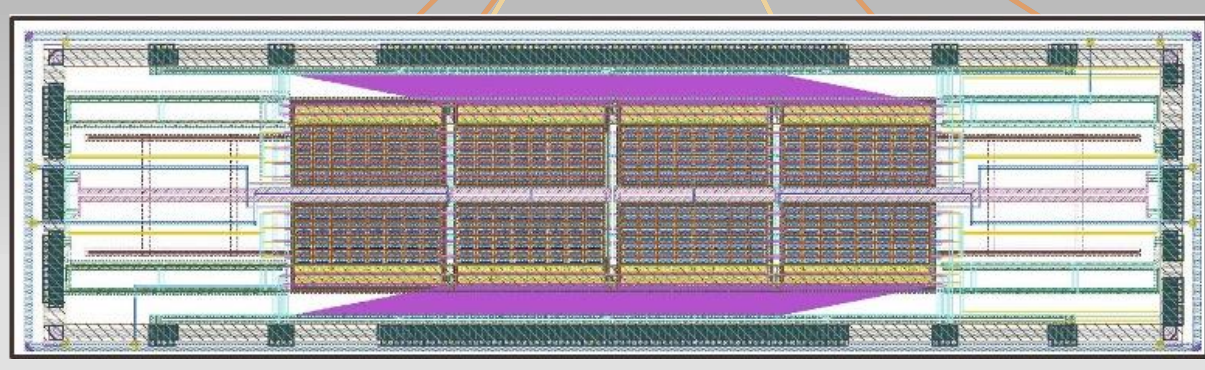
larger SNR → improved the time resolution



MadPix : a Monolithic CMOS Avalanche Detector PIXelated

First prototype with integrated electronics and gain layer produced by LFoundry in 110 nm commercial CMOS Process

- Active thickness: 48 µm
- Presence of deep-p-wells hosting the front-end electronics
- Backside HV allows full depletion -25 V to -40 V
- Topside HV manages the gain 30 V to 50 V

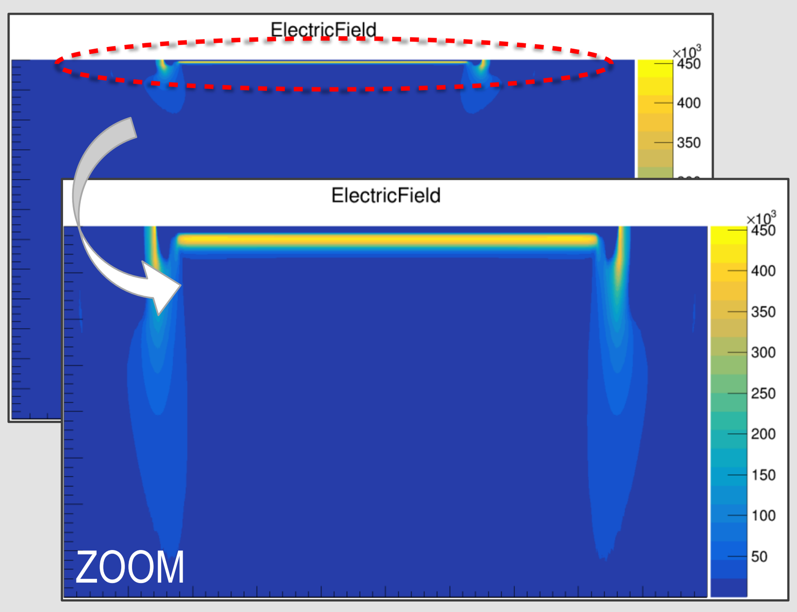


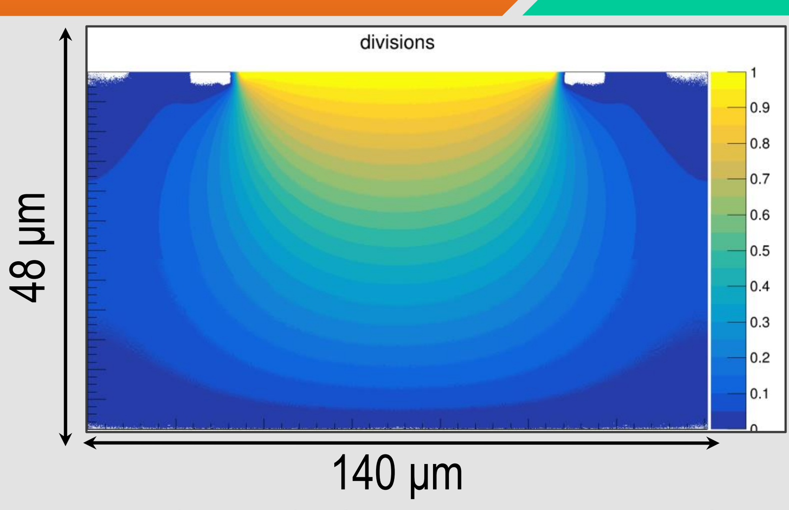
MadPix is 16.4 x 4.4 mm² large

- 8 matrices of 64 pixels divided in: 8 rows and 8 columns
- Pixels size of 250µm x 100µm

Monte Carlo Simulations

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

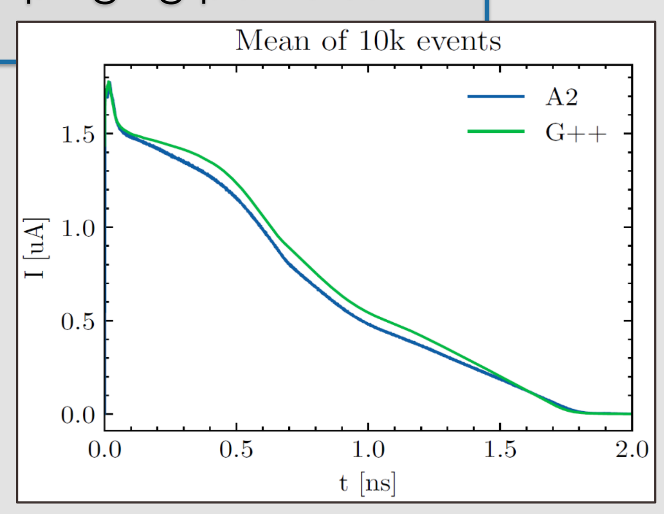




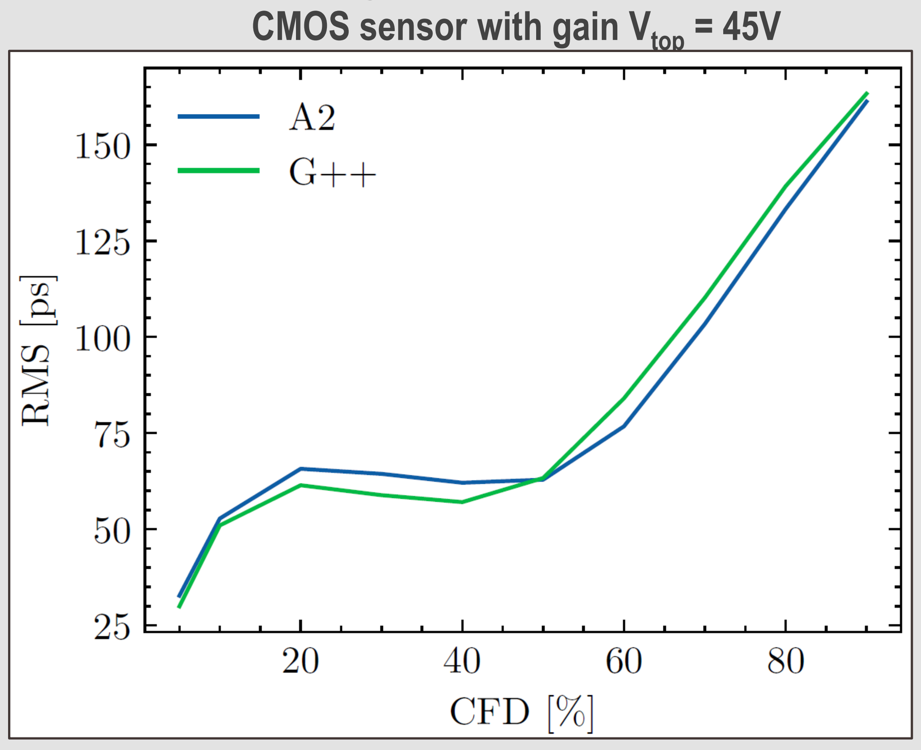
➢ Induced charge computed using the weighting potential via the Shockley-Ramo theorem

2D Simulation

- Pixel size
  140µm width → gain layer 68µm
  48µm thickness
- Randomly impinging particles
- 180 GeV π

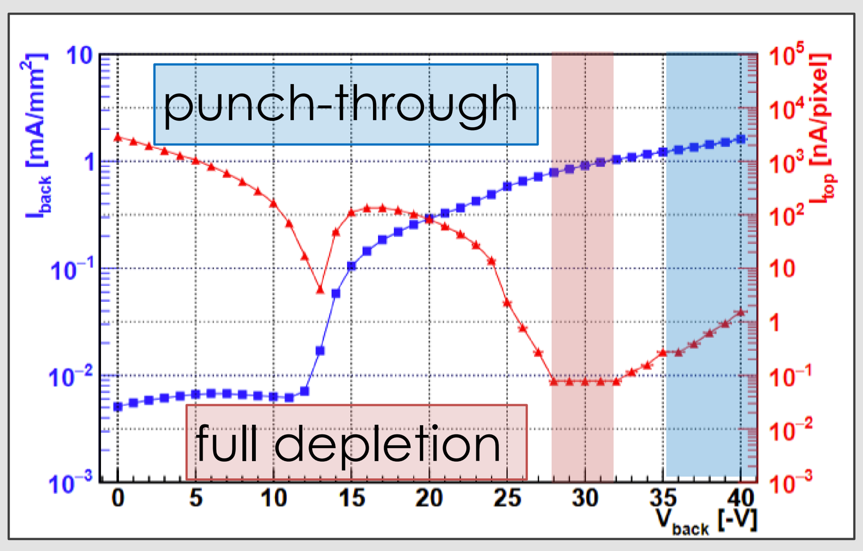


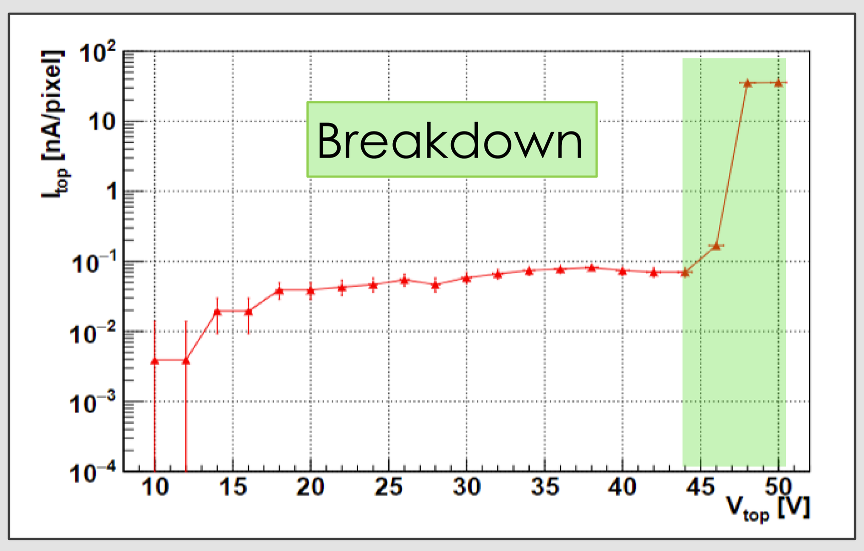
Preliminary ARCADIA run 3 simulations
CMOS sensor with gain V_{top} = 45V



Laboratory Measurements

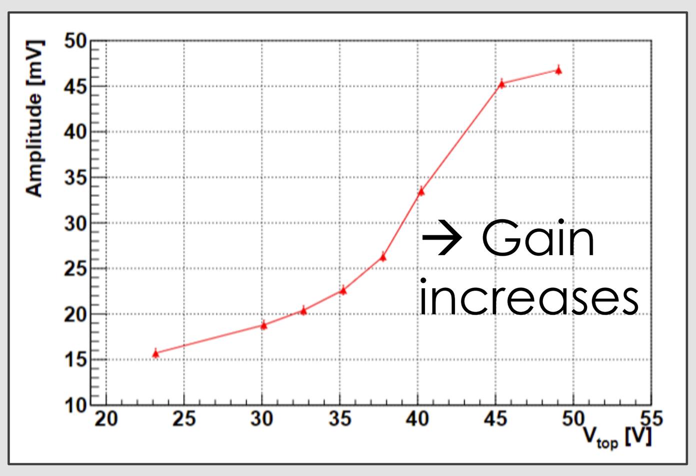
I(V) scan to study the sensor behavior

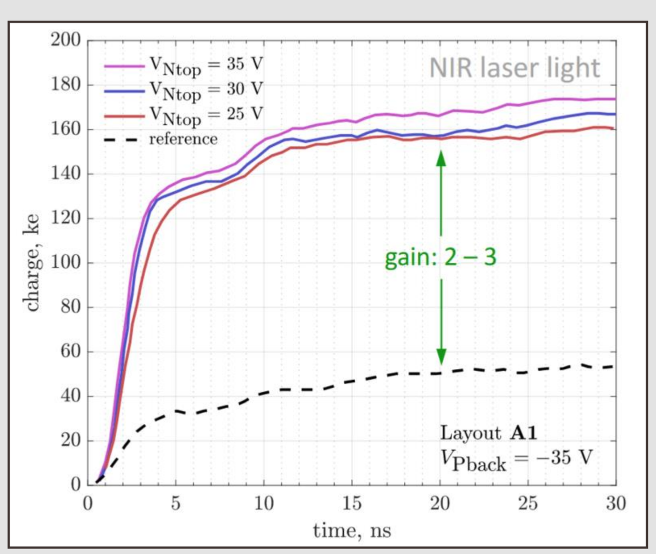




Optical characterization at University of Trento

- IR laser from the back of the sensor
- laser spot: 20 µm





TCAD simulations to investigate the gain mismatch

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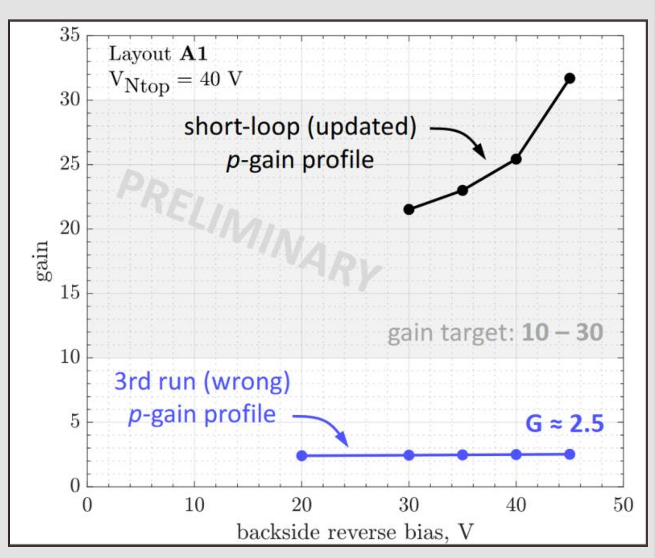
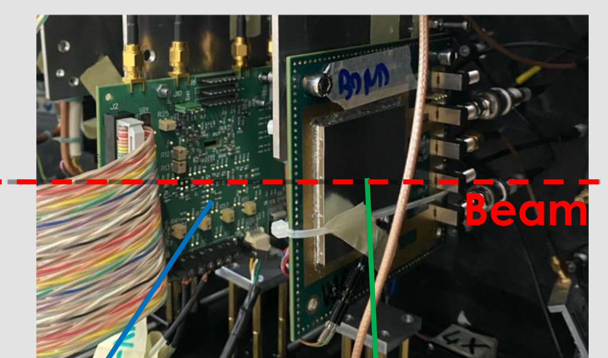
p-gain implantation energy lower by 30% with respect to the design



In-beam measurements

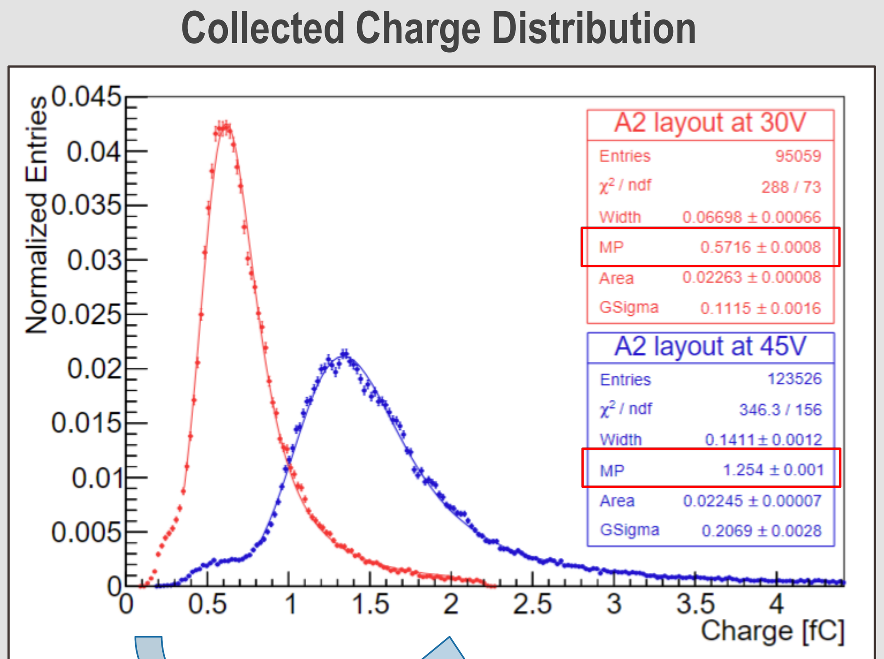
Proton Synchrotron - CERN
p/π beam with momentum 10 GeV/c

MadPix read out via 3 oscilloscope channels

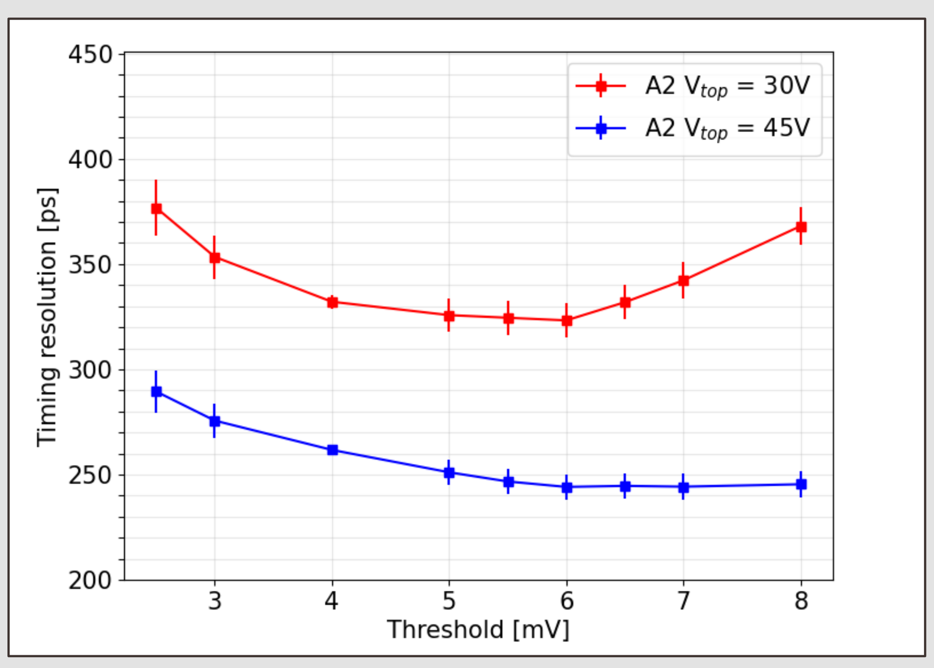


MadPix (DUT)
LGAD (Trigger reference)

Collected Charge Distribution



Gain ~ 2



Future Plans: Simulations and Measurements

➢ Simulations of the new short-loop structures
➢ Electrical and optical characterization of the monolithic devices with higher gain and test beam to evaluate the timing resolution → July 2024