First results on monolithic CMOS sensor with internal gain in 110nm technology node

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Introduction

ALICE 3 - TOF

TOF requirements from simulations:

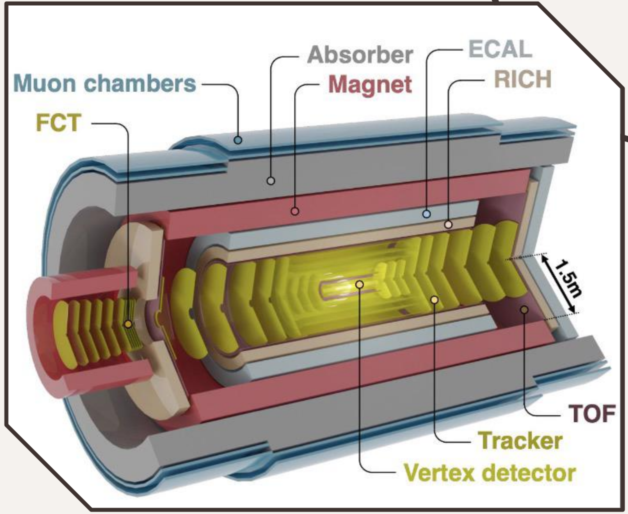
- **Material budget < 3% of X_0**
- **Time resolution ≈ 20 ps**

→ SiPM / LGAD / **CMOS LGAD**

Advantages of CMOS LGAD:

- **Less material and costs**
- **Simpler and cheaper assembly**

→ Monolithic approach



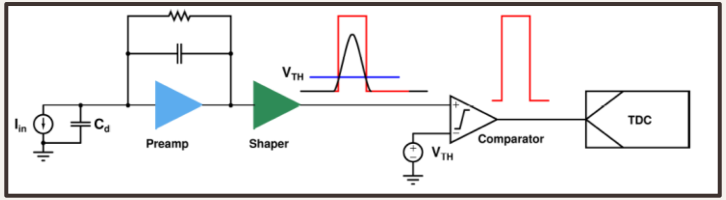
$$\sigma_t^2 = \sigma^2_{\text{Time Walk}} + \sigma^2_{\text{Landau Noise}} + \sigma^2_{\text{Distortion}} + \sigma^2_{\text{Jitter}} + \sigma^2_{\text{TDC}}$$

- Time Walk: Can be **corrected** (e.g. with Constant Fraction Discriminator, CFD)
- Landau Noise: Fundamental limit
- Distortion: Non saturated velocity and non-uniform weighting field
- TDC: Can be made **negligible**

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

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

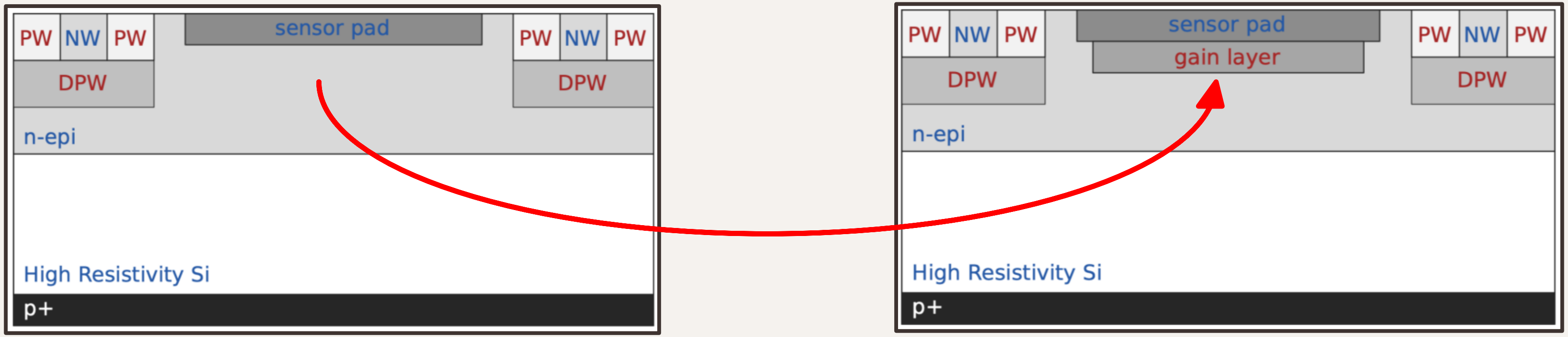
H. F.-W. Sadrozinski et al 2018 Rep. Prog. Phys. 81 026101



Contributions to the time resolution

ARCADIA SENSOR CONCEPT

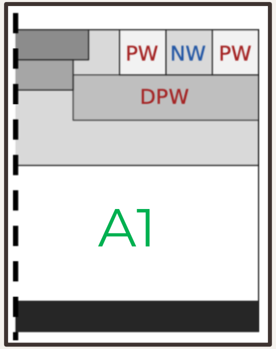
ARCADIA pad sensor — **ARCADIA** pad sensor with gain

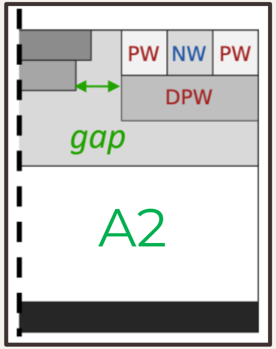


- Active thicknesses: 48 μm – 100 μm – 200 μm
- Add-on **p-gain** below the collecting electrode
- ARCADIA-run3: passive and monolithic structures
- Expected gain: 10-30
- Two sensor layout: **A1** and **A2**

A1:
- Extended collection volume
- More uniform multiplication

A2:
- Direct path to the p-gain
- More uniform time response



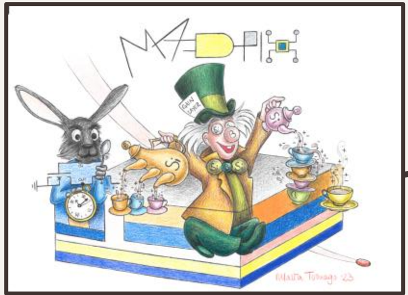


MadPix

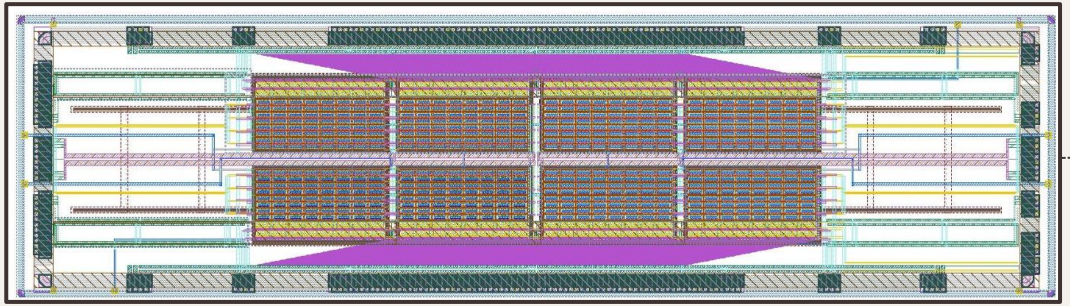
***M**onolithic CMOS **A**valanche **D**etector **PIX**elated Prototype for ps Timing Application*

First prototype with **integrated electronics** (LFoundry 110 nm) and **gain layer**
Active thickness: 48µm

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

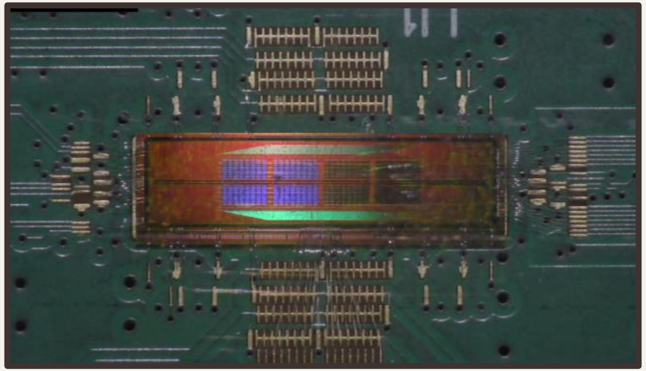


- 8 matrices of 64 pixels each
- 4 flavours
- 64 x 2 analogue outputs
- Pixels of 250µm x 100µm



Symmetrical

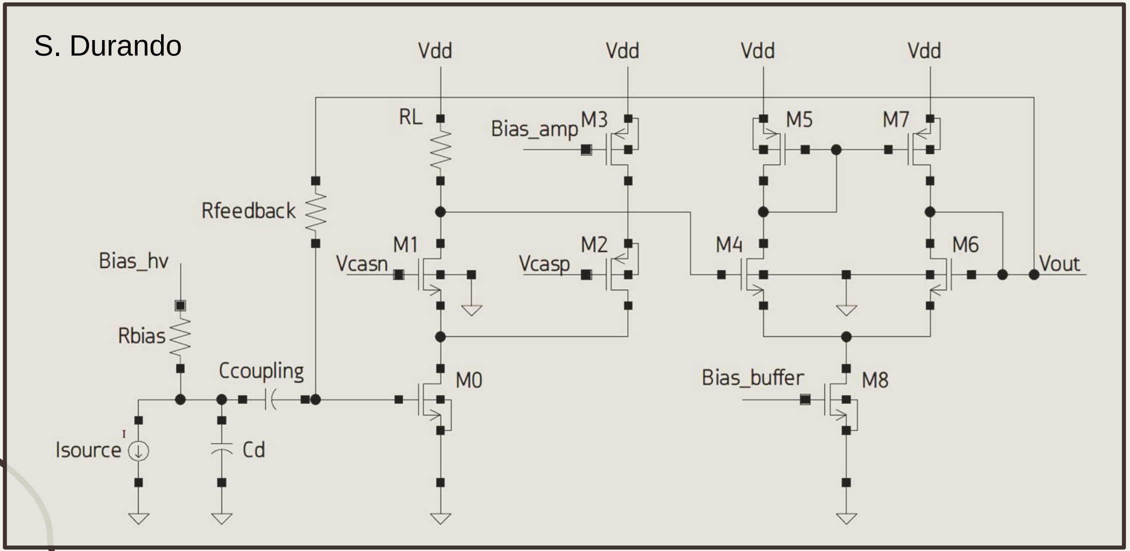
02
MadPix Design

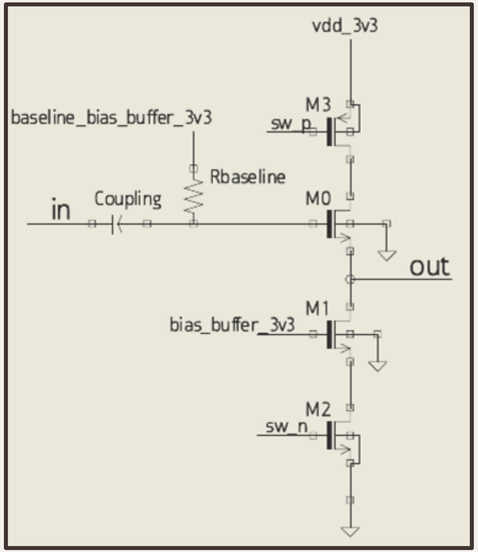


MadPix Electronics

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

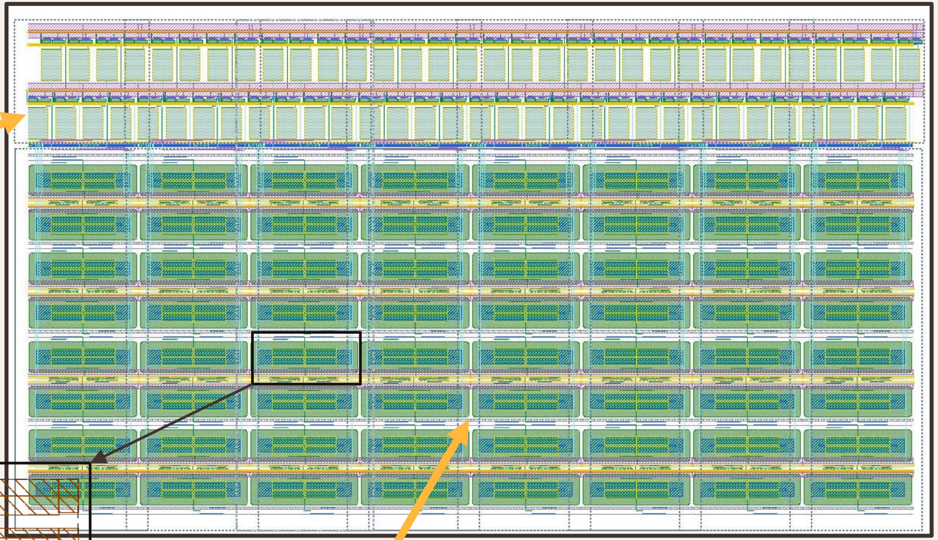
- Source follower (3.3V)
- AC coupled with FE
- Power: 1.65mW/ch

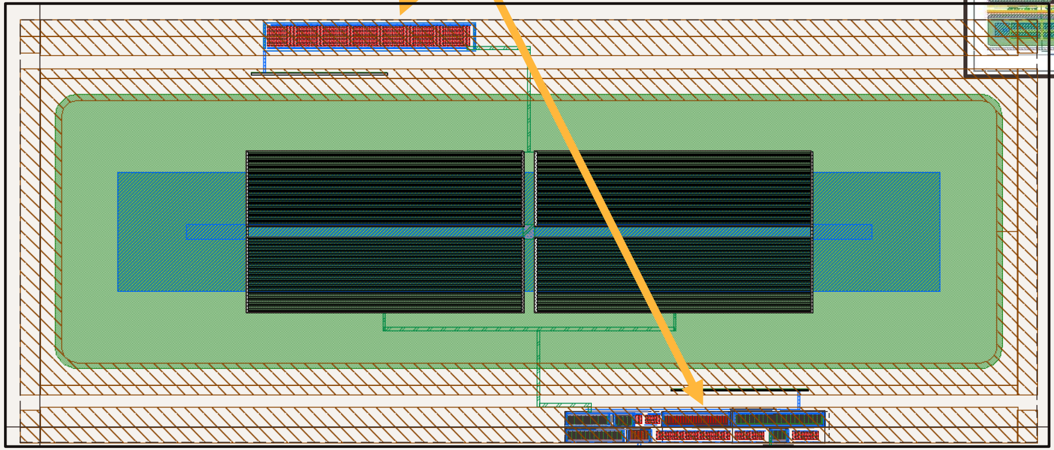




MadPix Layout

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





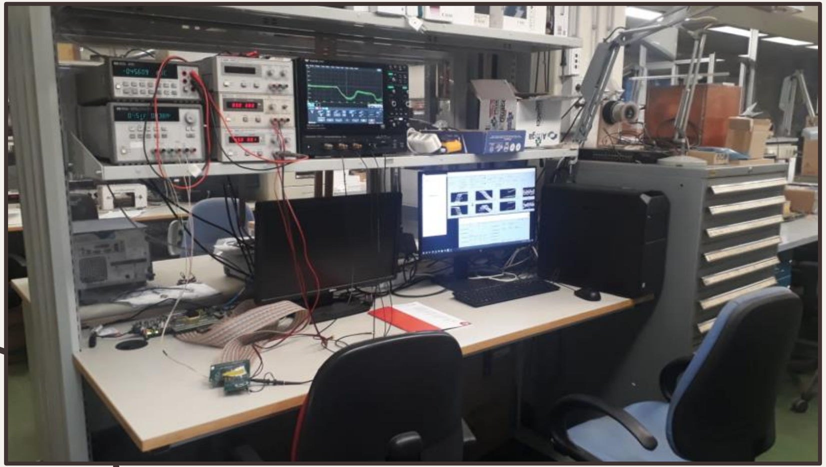
- 8x8 pixels in one matrix
- 250μmx100μm pixel, non optimal for timing (Distortion term) but crucial in this R&D phase
  - ↳ Bigger pixels can be implemented in dedicated run

MadPix Test Board

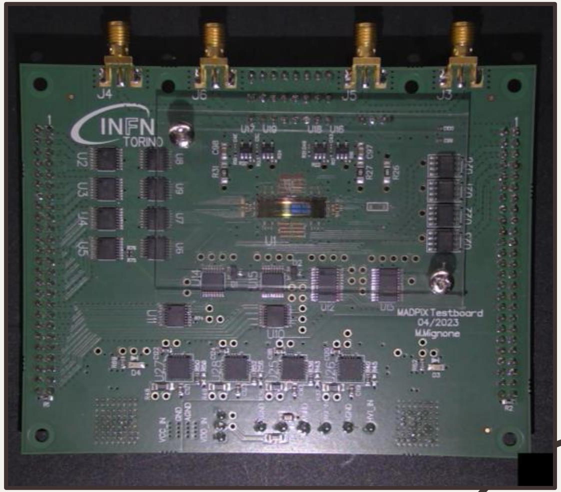
Controlled through FPGA (DACs, Digital potentiometers, Test pulse)

- **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)

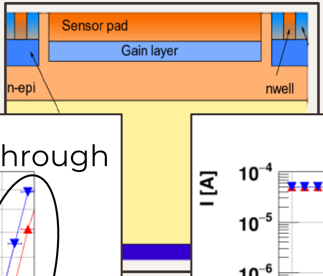
03
Laboratory Tests

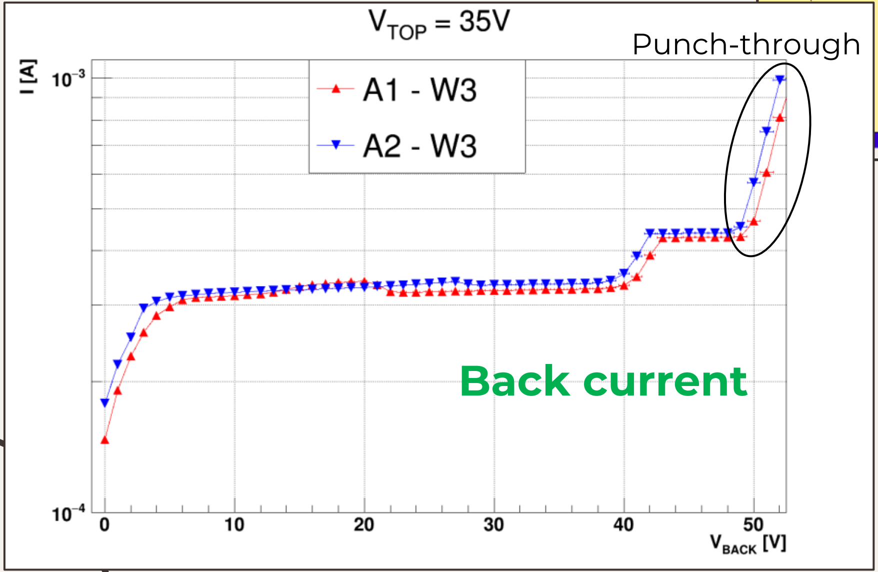
Passive structures characterization

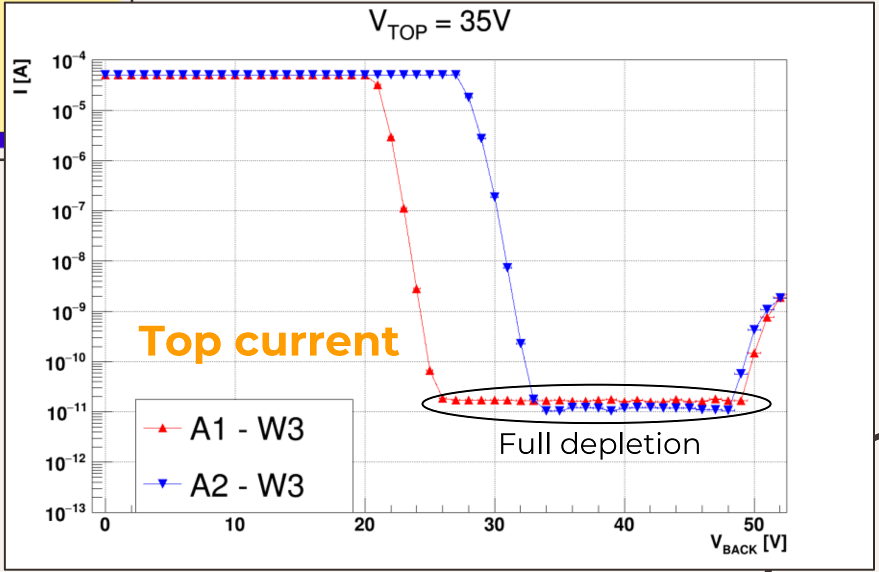
I(V) scan to study the sensor behavior

Punch through for HV back > 45V

Depletion HV back > 35V



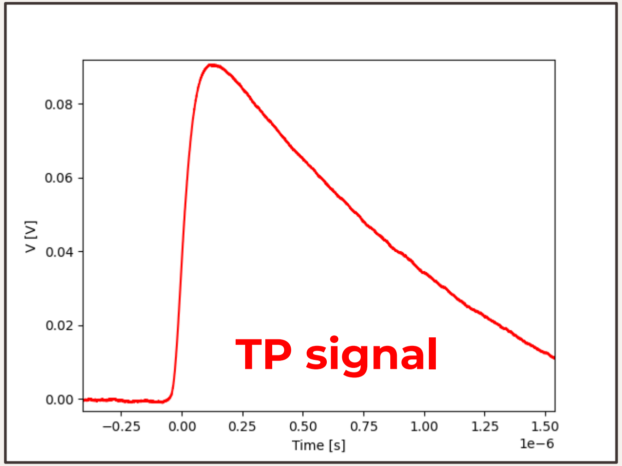


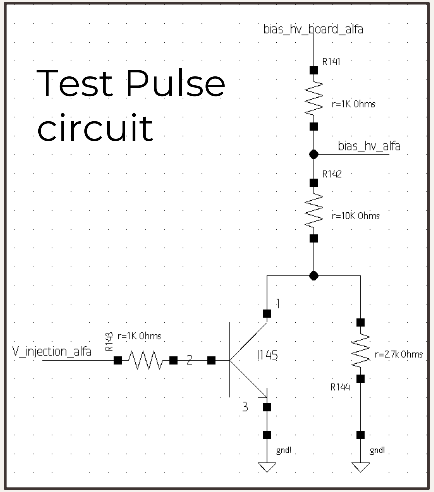


MadPix Test pulse

Response of the four top matrices using test pulse

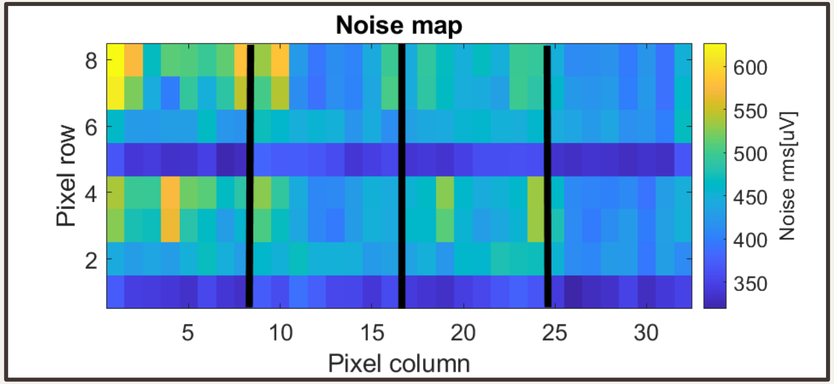
- HV top = 35V
- HV back = 30V





Test pulse generated through the TB:

- Signals on HV → All pixels receive TP
- Duration of the signal > 100ns
- Analogue measurements with oscilloscope

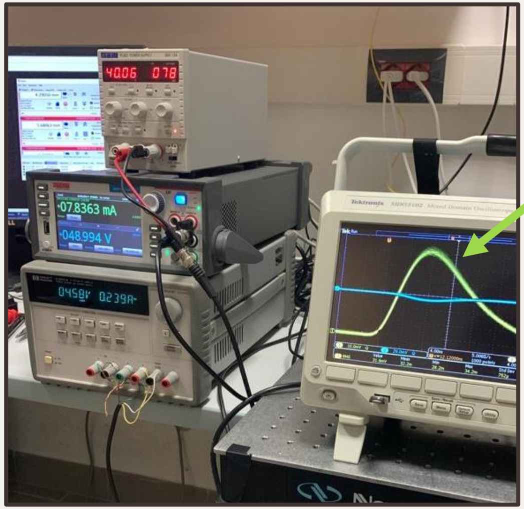


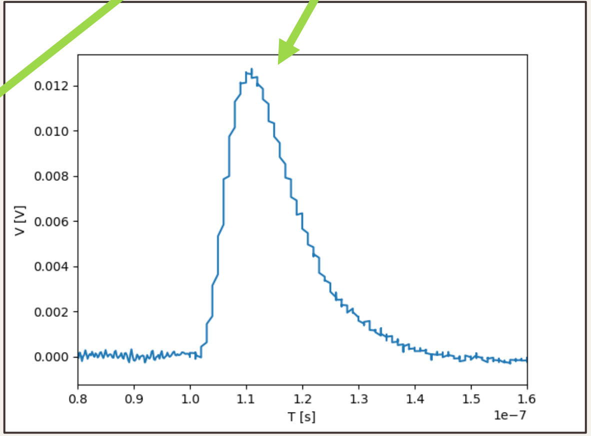
Laser setup

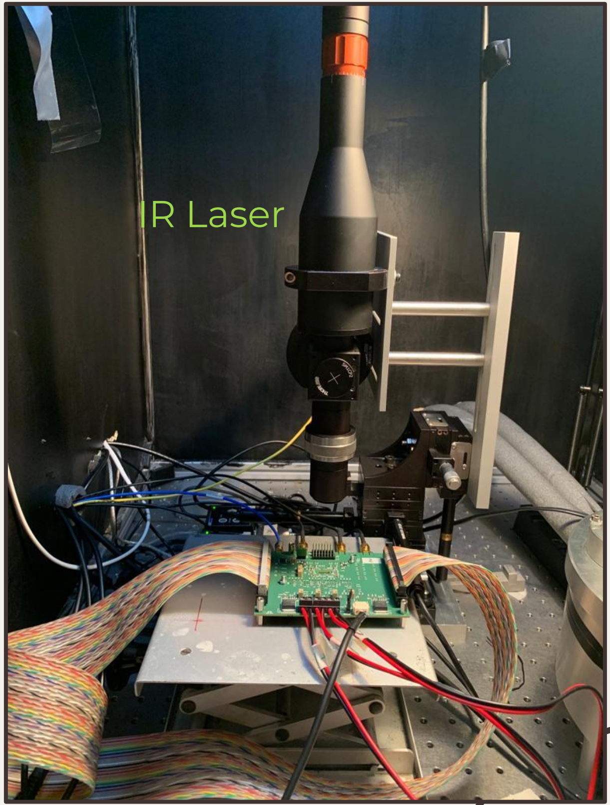
Optical characterization at UNITN (Trento)

- → IR laser from the back of the sensor
- → laser pulse ~ 100 ps
- → laser spot ~ 20 μm

MadPix
Output signals
(ΔV_{out})







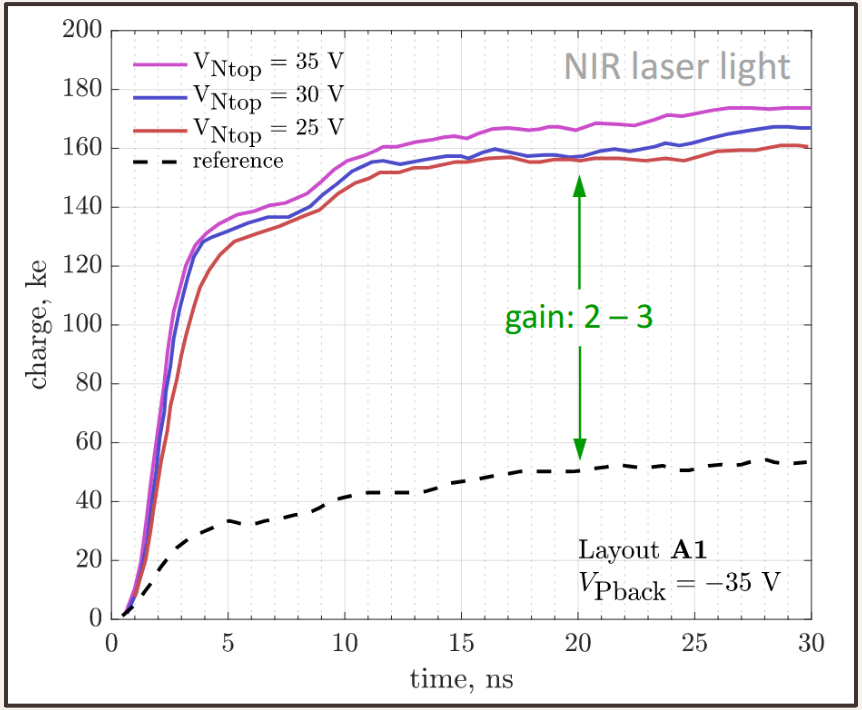
T. Corradino

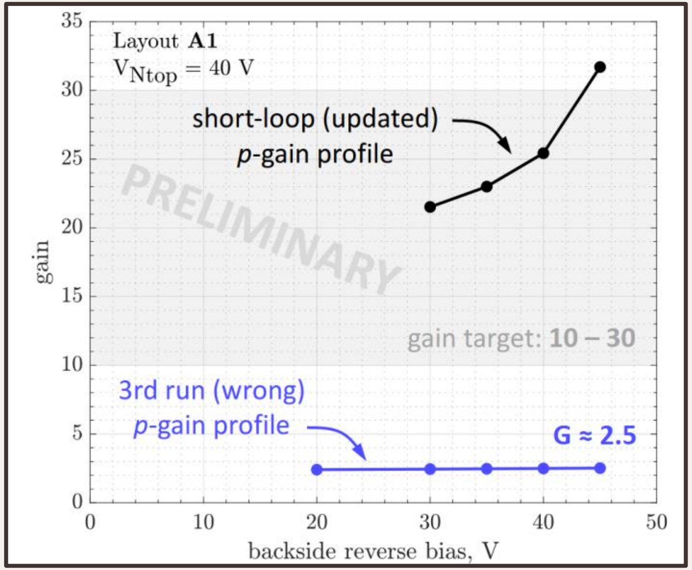
Laser – Passive structures

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

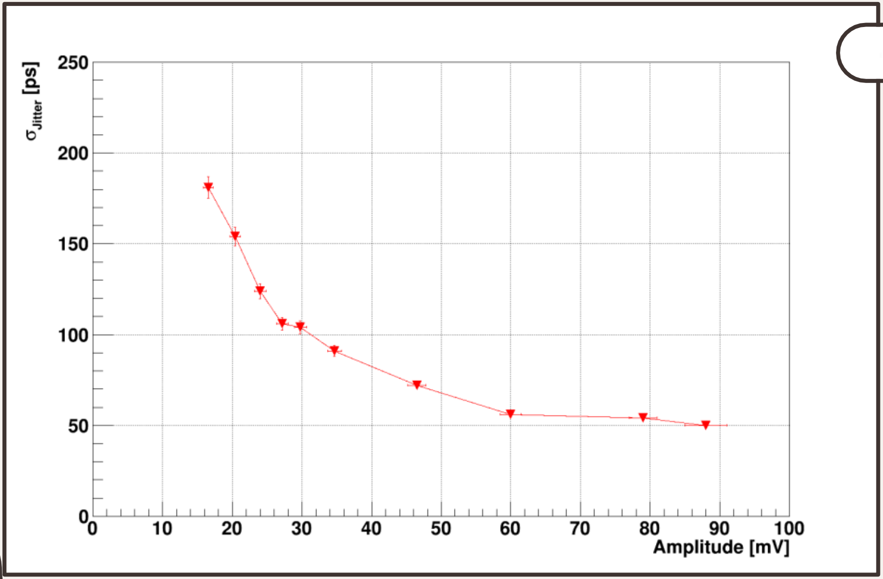




Laser - MadPix

First estimation of **jitter**:

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



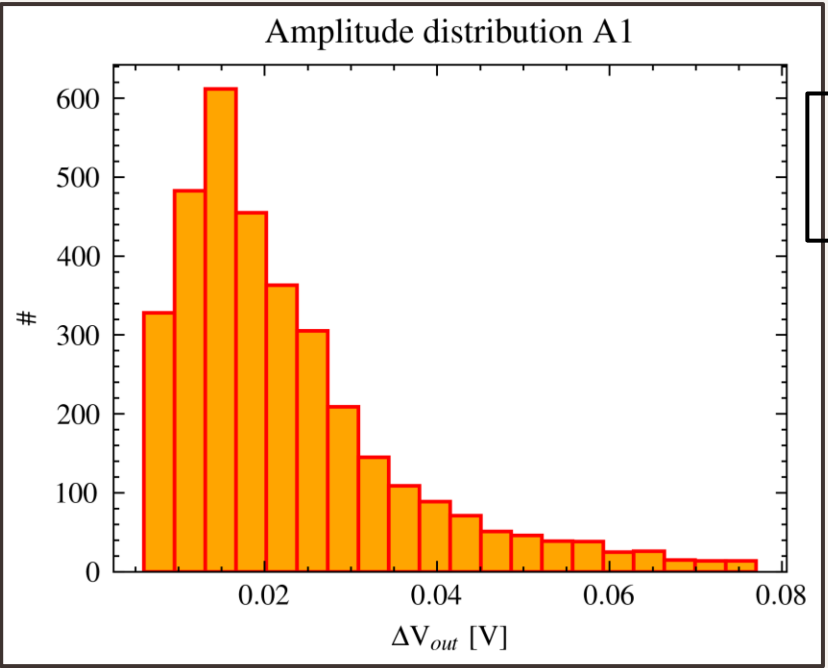
$$\sigma_t^2 = \sigma_{\text{Time Walk}}^2 + \sigma_{\text{Landau Noise}}^2 + \sigma_{\text{Distortion}}^2 + \sigma_{\text{Jitter}}^2 + \sigma_{\text{TDC}}^2$$

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

Increased raising output power of the laser

Sr90 - MadPix

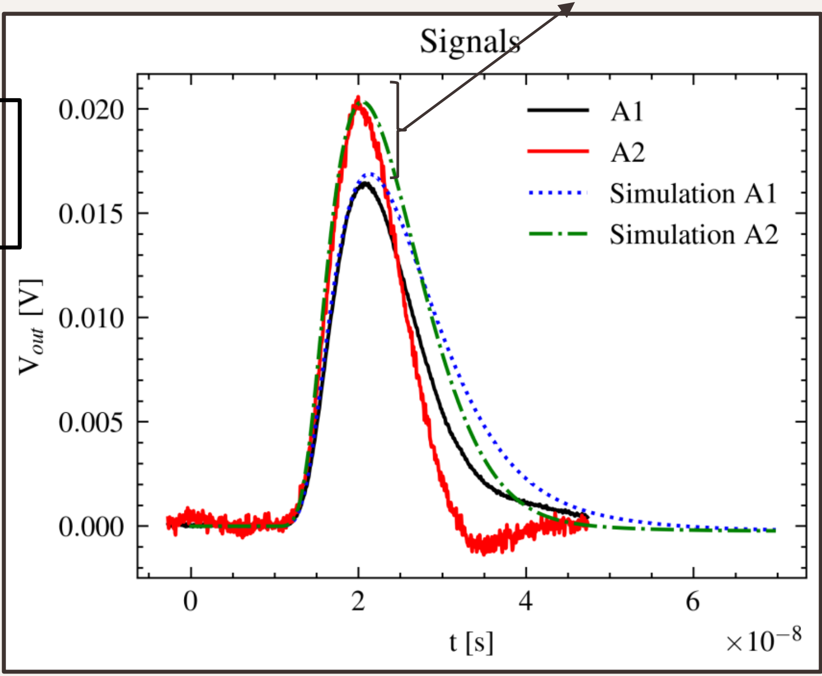
First estimation of **MPV** i.e. 16mV (A1) and 20mV (A2) and **SNR** using a non collimated radiation source



$SNR_{A1} \approx 25$

$SNR_{A2} \approx 30$

Different sensor capacitances



06
Conclusions

Conclusions and Outlook

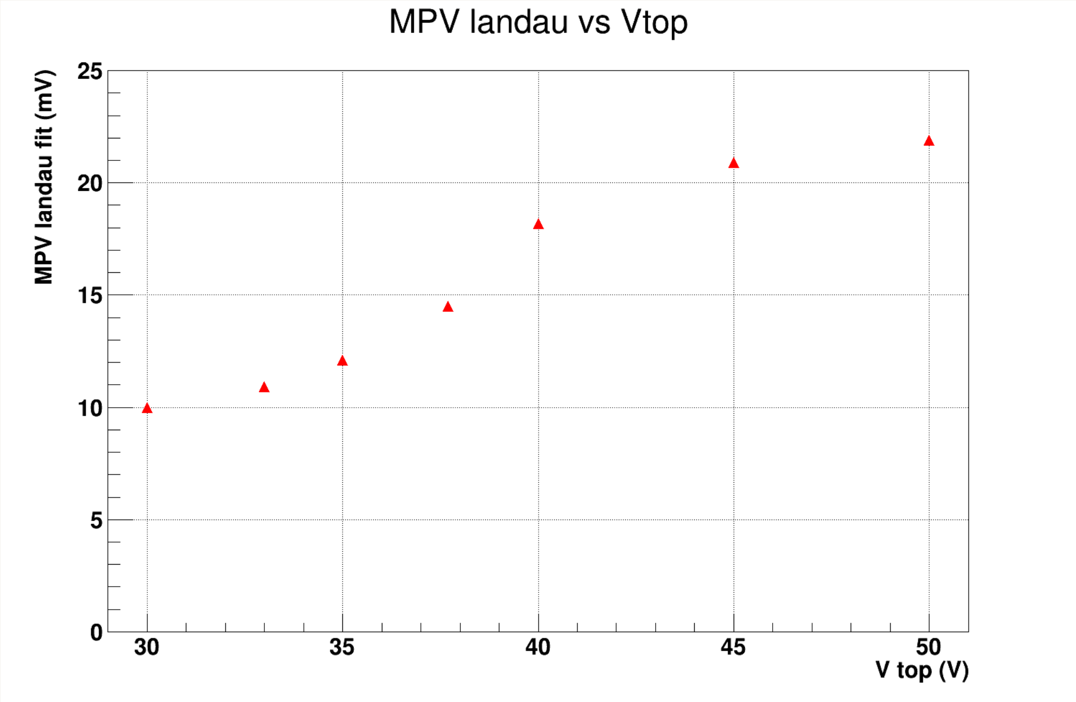
- Prototype for timing application in 110nm technology design in the ARCADIA project
  - **MadPix**
- Electrical test shown that MadPix is **fully functional**
- First estimation of electronics **jitter** with laser
  - **≈ 50ps** for signal with 90mV of amplitude
- Sr90 study
  - SNR **≈ 25/30** and MPV **≈ 16/20mV** depending on the sensor layout

What's next?

- Test beam analysis is ongoing
- Simulation activities in parallel with tests
- Short loop run requested: new sensors with increased gain to be tested in the next months
- Planning of 2024 test beams

Thank you for the attention!

Amp max (MIP) CMOS vs HV top



TOF specifications – ALICE3

	Inner TOF	Outer TOF	Forward TOF
Radius (m)	0.19	0.85	0.15–1.5
z range (m)	–0.62–0.62	–2.79–2.79	4.05
Surface (m^2)	1.5	30	14
Granularity (mm^2)	1×1	5×5	1×1 to 5×5
Hit rate (kHz/cm^2)	74	4	122
NIEL (1 MeV n_{eq}/cm^2) / month	1.3×10^{11}	6.2×10^9	2.1×10^{11}
TID (rad) / month	4×10^3	2×10^2	6.6×10^3
Material budget ($\%X_0$)	1–3	1–3	1–3
Power density (mW/cm^2)	50	50	50
Time resolution (ps)	20	20	20