Innovative silicon timing sensors for the future ALICE 3 experiment

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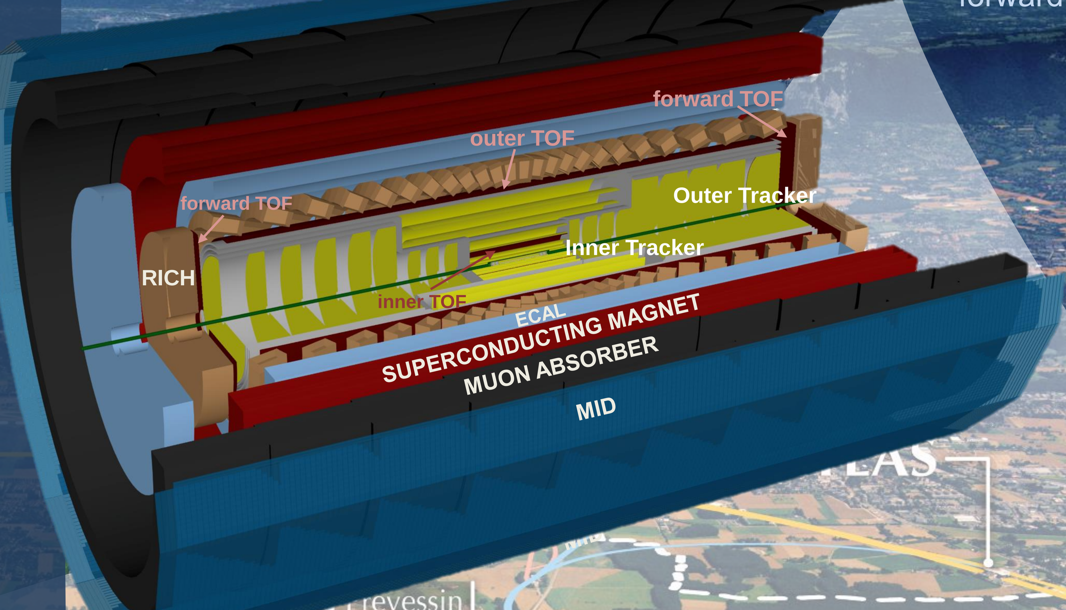
ALICE 3 - A next generation heavy ion experiment

ALICE3
concept layout

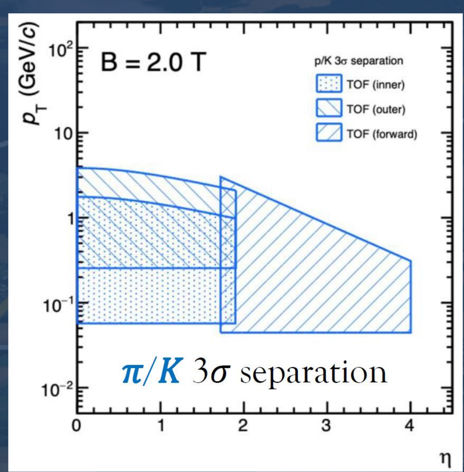


inner TOF R ≈ 19 cm, |z| < 62 cm
outer TOF R ≈ 85 cm, |z| < 350 cm
forward TOF z ≈ ±370 cm, R ≈ 15-100 cm

ALICE3-TOF will be part of an **extensive PID system**, together with a RICH detector, a muon identifier (MID) and an electromagnetic calorimeter (ECal)

Requirements:

- Rad. hardness
  - outer TOF: NIEL ~ $9\cdot10^{11}$ MeV n_{eq} /cm^2
  - inner TOF: NIEL ~ $6.1\cdot10^{12}$ MeV n_{eq} /cm^2
  - forward TOF: NIEL ~ $8.5\cdot10^{12}$ MeV n_{eq} /cm^2
- Time resolution of 20 ps
- Low material budget 1-3% X_0



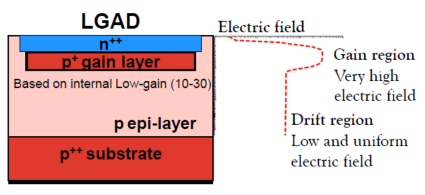
Extensive **R&D** on advanced silicon technologies: ***LGADs, CMOS-LGADs and SiPMs***

SUISSE
FRANCE
CERN Meyrin
SPS 7 km
ALICE 3
ALICE

2022-2025	2026-2028	2029-2032	2033-2034	2035-2038	2039	2040-2041
LHC Run 3	LHC LS3	LHC Run 4	LHC LS4	LHC Run 5	LHC LS5	LHC Run 6

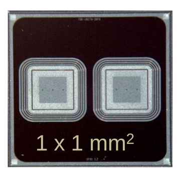
ALICE 3 LoI: *https://arxiv.org/abs/2211.02491*

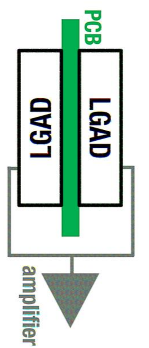
LGADs (Low Gain Avalanche Detectors)



Evolution of *n*-on-*p* sensors, obtained by implanting a doped **gain layer** just below the *p-n* junction

Structures under test (1 x 1 mm²) ←

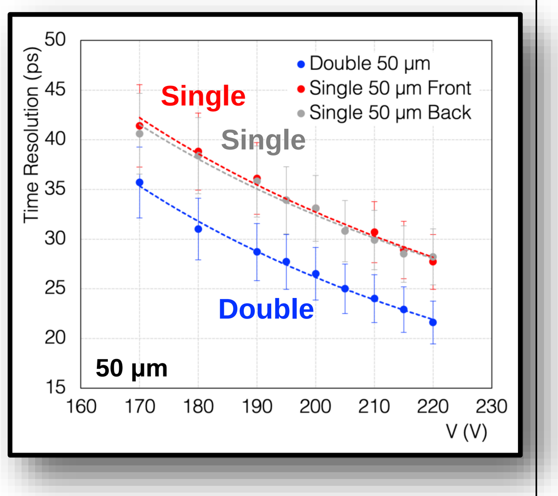


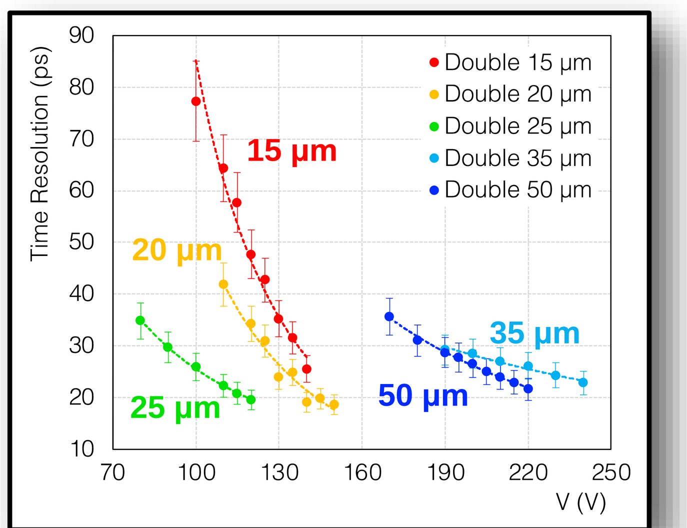


double-LGAD introduced and tested for the first time
https://doi.org/10.1140/epjp/s13360-024-04621-x

→ signals of both layers sum up resulting in a *larger* signal (charge) using a *single* front-end amplifier

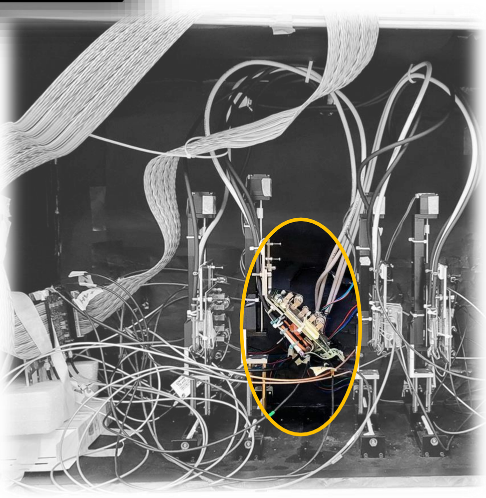
consistent improvement of the time resolution for the double-LGAD w.r.t. single LGAD ←

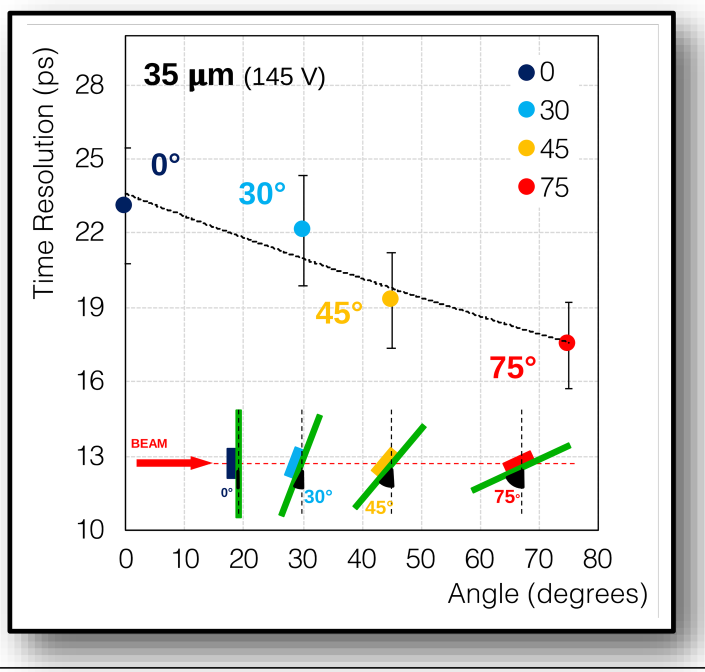




Pioneering tests of **very thin LGADs**
down to 20, 15 µm in 2023

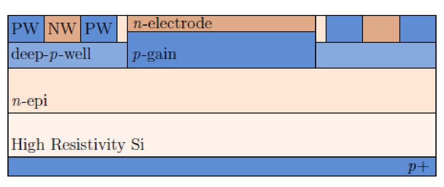
→ better timing by going to thinner LGAD design
(different doping concentration in different thicknesses)





LGAD inclined w.r.t. the beam direction ←
probe sensors at the edges of outer TOF ($\eta \simeq 2$)
Small dependence on tracks inclination ←

CMOS-LGADs

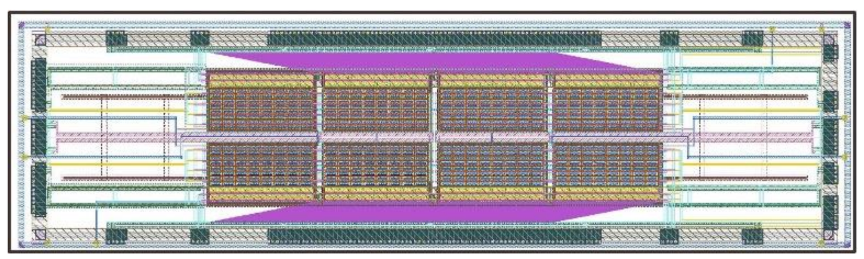


Advantages of a **monolithic** approach: lower material budget, cheaper and easier assembly, lower power consumption

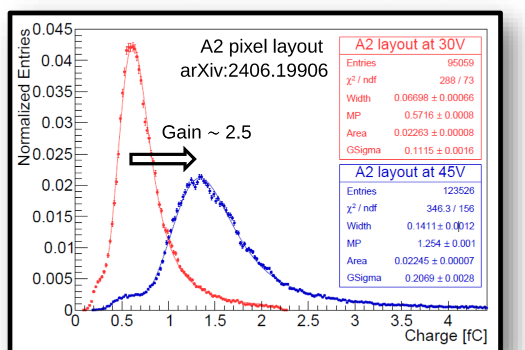
→ LGAD technology has been integrated in INFN-ARCADIA production of MAPS produced with a commercial 110 nm CIS process by LFoundry

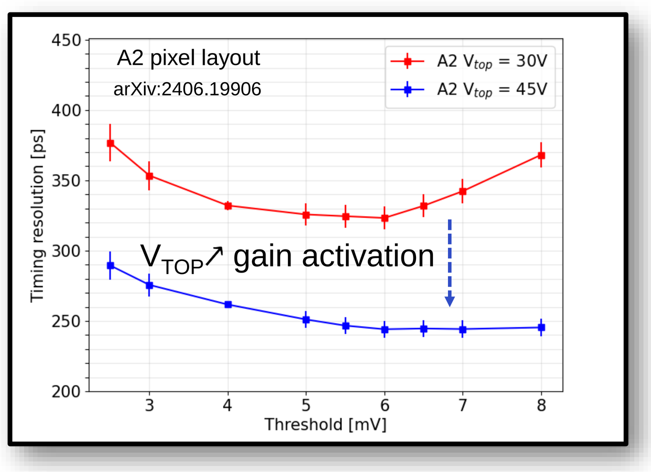
First prototype (**MadPix**) with integrated electronics and gain layer produced by LFoundry in 110 nm commercial process

- Active thickness: 48 µm
- Backside HV allows full depletion -25 V to -40 V
- Topside HV controls the gain 30 V to 60 V

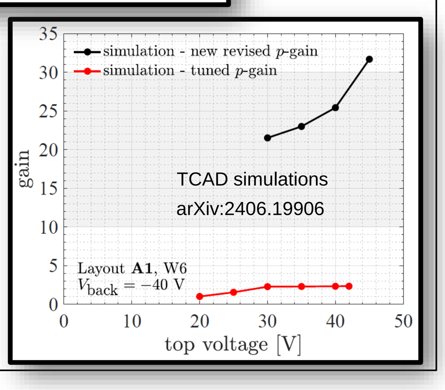


MadPix (Monolithic CMOS Avalanche Detector PIXelated)
1.6 x 4.4 mm² large, 8 matrices of 64 pixels, 250 x 100 µm² pixel size





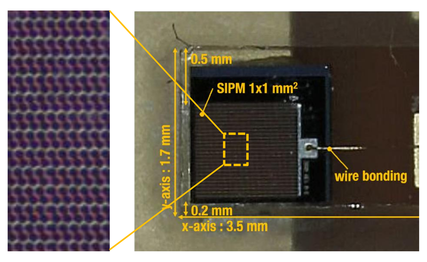
Unexpected limited gain of 2.5
→ **short-loop run scheduled** and new structures with higher sensor gain expected later in 2024



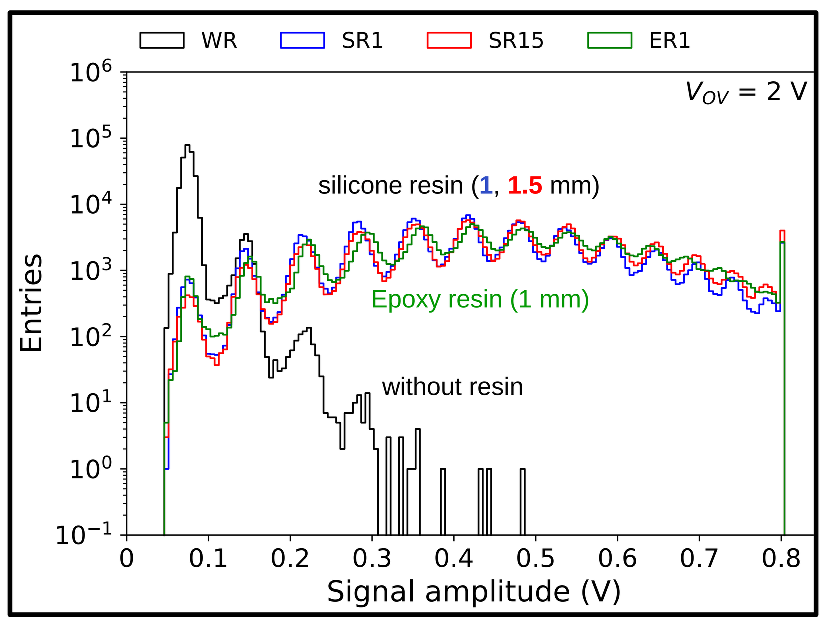
SiPMs (Silicon Photomultipliers)

SiPM as array of O(10^4) **SPAD**s (Single Photon Avalanche Detectors) in Geiger mode (gain 10^6) above breakdown

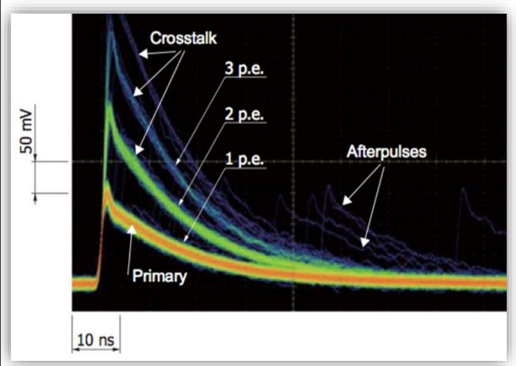
Direct response of SiPMs to the passage of **charged particles** was studied for the first time
https://doi.org/10.1140/epjp/s13360-023-04397-0



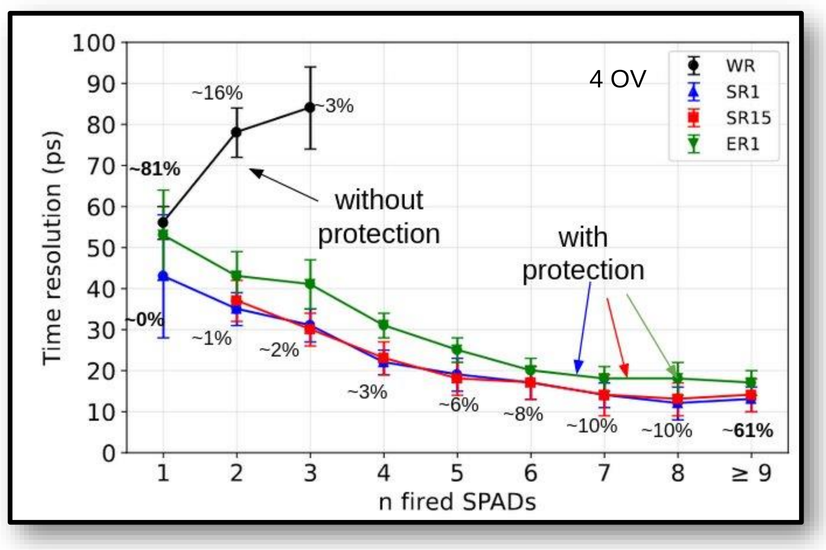
FBK NUV-HD-RH technology
20 µm pixel pitch, 72% FF
(2444 SPADs in 1 x 1 mm²)



high crosstalk with the protection resin ←
→ large contribution of the **Cherenkov light** produced in the resin (acting as Cherenkov radiator!)



← without protection layer →
mainly 1 SPAD firing, up to 4-5 SPADs compatible with intrinsic crosstalk

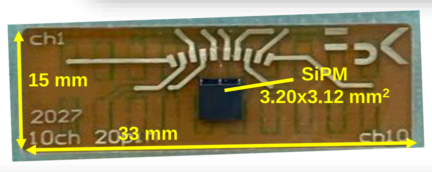


The increased number of firing SPADs improves significantly the time resolution ←

Large fraction of multi SPADs events
→ huge noise rejection w.r.t. standard SiPMs

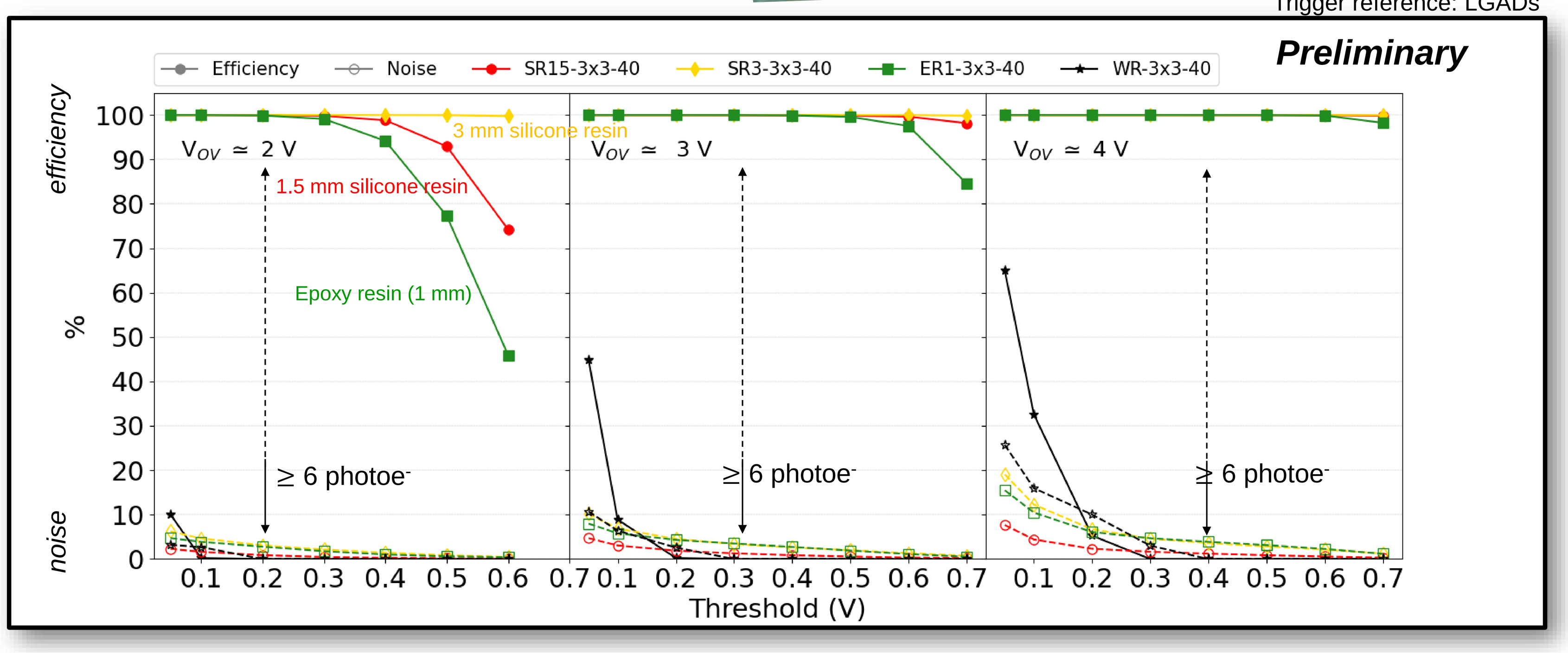
[%] percentage of events with 1, 2, 3, etc firing SPADs

Larger area SiPMs (3.2 x 3.12 mm²) – enough to collect all produced Cherenkov photons – **tested in October 2023**



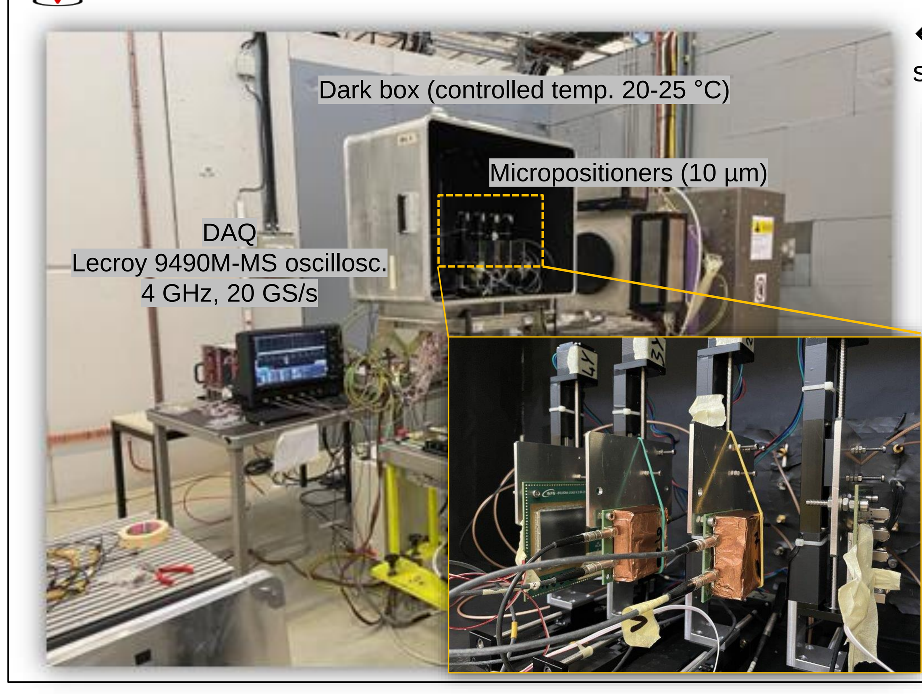
NUV-HD SiPMs produced by **FBK**
40 µm pixel pitch, 83% FF
(6200 SPADs in 3.2 x 3.12 mm²)

Trigger reference: LGADs

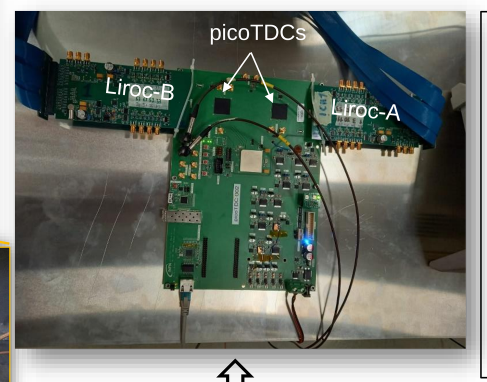


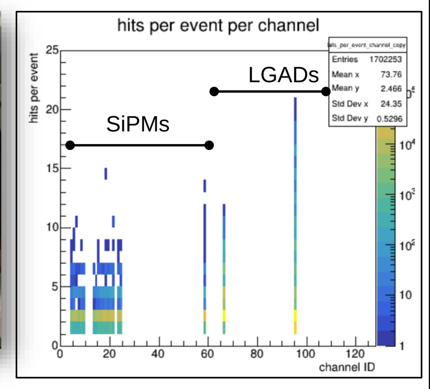
→ SiPMs can be operated at large npe threshold i.e. above the dark count
→ *Large variety of applications* from space experiments to colliders, potentially also the **outer TOF layer** (only), as alternative to (CMOS-)LGADs

In-beam measurements at CERN PS (T10), p/π^+ beam - 10 GeV/c



← **beam-test setup**
signal waveforms acquired with Lecroy 9490M-MS oscilloscope.





New front-end and readout since April 2024
- discrimination by 2 *Liroc* boards (based on Weroc front-end ASIC for SiPMs)
- *picoTDC* board (based on CERN picoTDC)

→ data analysis in progress