ADA_5D (nuova sigla)

Avalanche Diodes Array for position, charge and timing (5D) measurements

RL – Lodovico Ratti

RN - Pier Simone Marrocchesi (INFN PI)

Personnel involved in the experiment

Sezioni coinvolte:

PD (G. Collazuol, 1.2 FTE)
PI (P.S. Marrocchesi, 4.8 FTE)
PV (L. Ratti, 3.5 FTE)
TIFPA (L. Pancheri, 2.2 FTE)

TOTALE: 11.7 FTE

Anagrafica di Pavia

Simone Giroletti (dott.): 100%
Marco Grassi (RTDb): 50%
Piero Malcovati (PO): 30%
Joana Minga (dott.): 100%
Ratti Lodovico (PO): 30%
Vacchi Carla (RU): 40%

Goal of the project

Overall plan:

develop a new LGAD based detector capable of simultaneously measuring position, charge and time of arrival of the impinging particle – application to charge identification of individual cosmic ray elements for the next generation of space-borne experiments

Role of the Pavia group:

design and characterize the front-end circuit for the detector

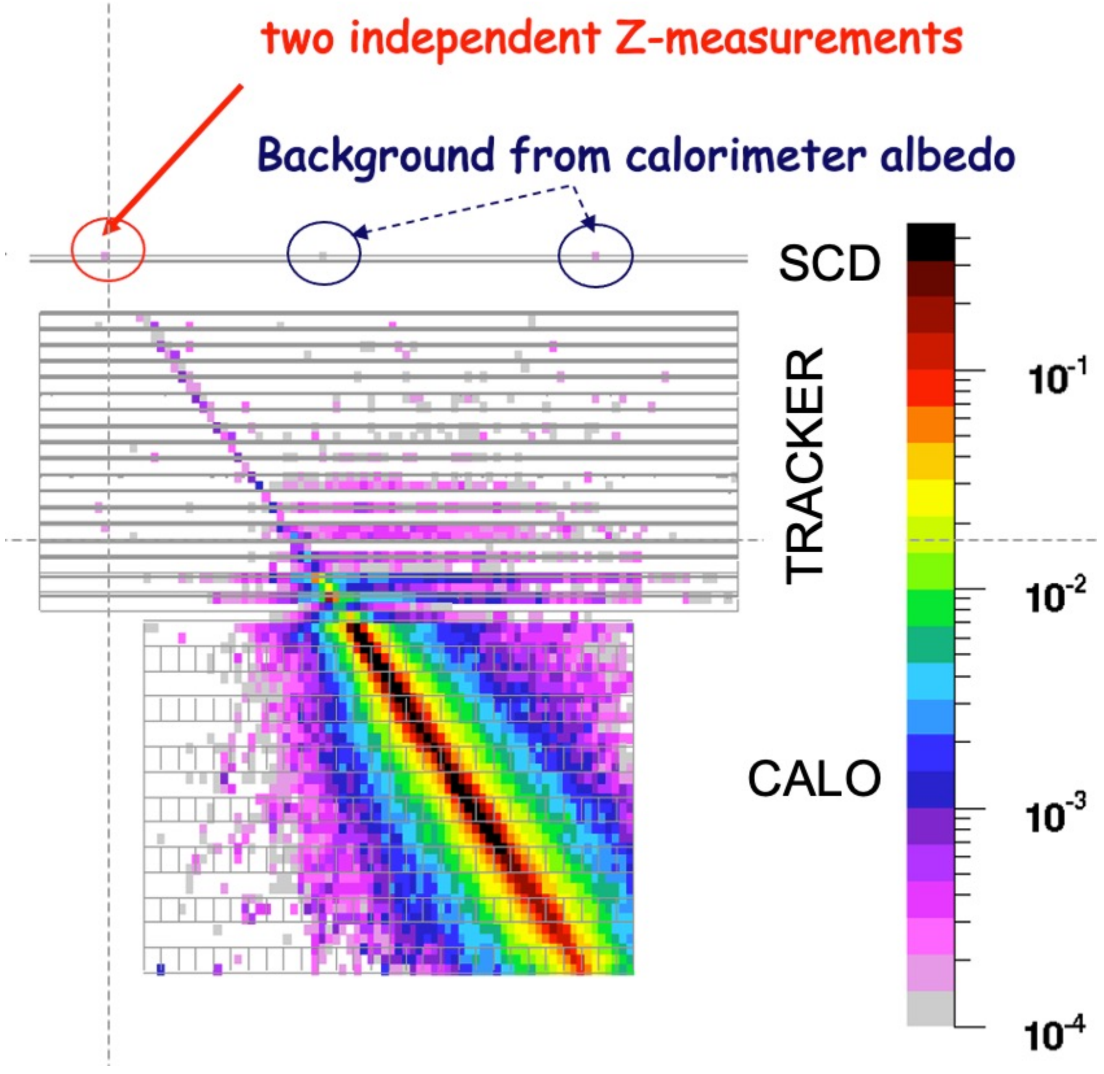
- 2x2 array of processing channels performing preamplification, shaping and analog to digital conversion
- 65 nm CMOS technology

The ADA_5D concept

CHARGE IDENTIFICATION of cosmic-ray (CR) ions with charge $1 \leq Z \leq 30$ with $dE/dx \propto Z^2$ measurements in a **silicon charge detector** (SCD) at the top of the instrument

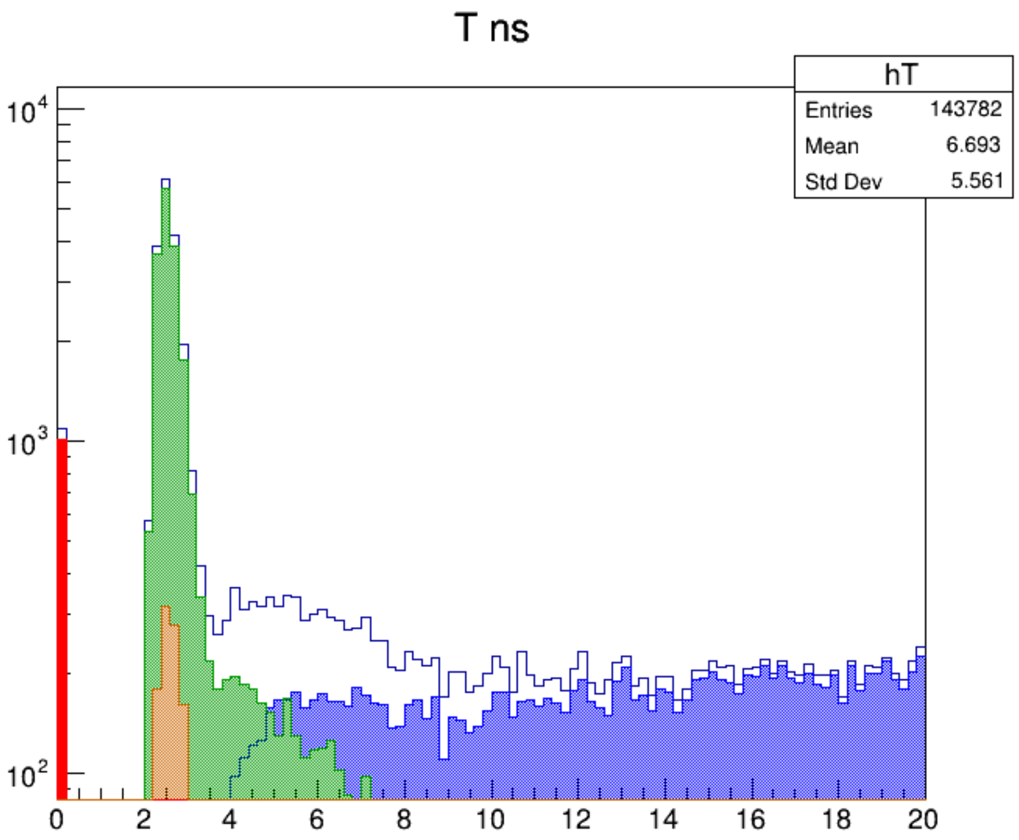
- **Backscattering (BS)** from the calorimeter generates fake hits in the charge detectors and in the tracker.
- The tracker back extrapolates to the SCD with an impact point IP resolution ~ 150 - 200 um
- BS increases with energy and deteriorates the charge ID of individual CR elements.

ADA-5D concept: reject BS with a high resolution ToF measurement



FLUKA simulation of 1 TeV incident carbon nucleus

Arrival time of BS particles



- ToF of incident particle to CALO ~ 1ns
- BS flight time:
  - ~ 1ns for ultra-relativistic particles (e, γ)
  - > 1ns for NR (neutrons)

Total time > 2ns

Geometry

Calorimeter: 50x50 cm^2 Pb 30 X_0

300 micron Silicon array (50x50 cm^2)

e.g.: 30 cm distance to calorimeter

- filled-green: back-scattered **photons** (create ionizing secondaries → fake hits in SCD);
- filled-blue: back-scattered **neutrons**;
- filled-orange: back-scattered **electrons** depositing energy in the charge detector;
- filled-red: **incident protons** on charge detector (generated at t=0);
- blue non-filled: histogram inclusive of all above..

Detector specifications

VERY stringent requirements for a space experiment:

Charge measurement:
- large dynamic range > 1000 m.i.p.
- charge resolution for proton < 0.1 => 200-300 μm sensors for primary ionization

Timing measurement:
- sub-ns resolution (e.g., for 10 – 20 cm flight path → 100 ps)

Space resolution and granularity:
- modest granularity (3mm x 3mm pixels) to cover large O(m^2) sensitive area
- an independent TRACKER is in charge of the fine spatial resolution

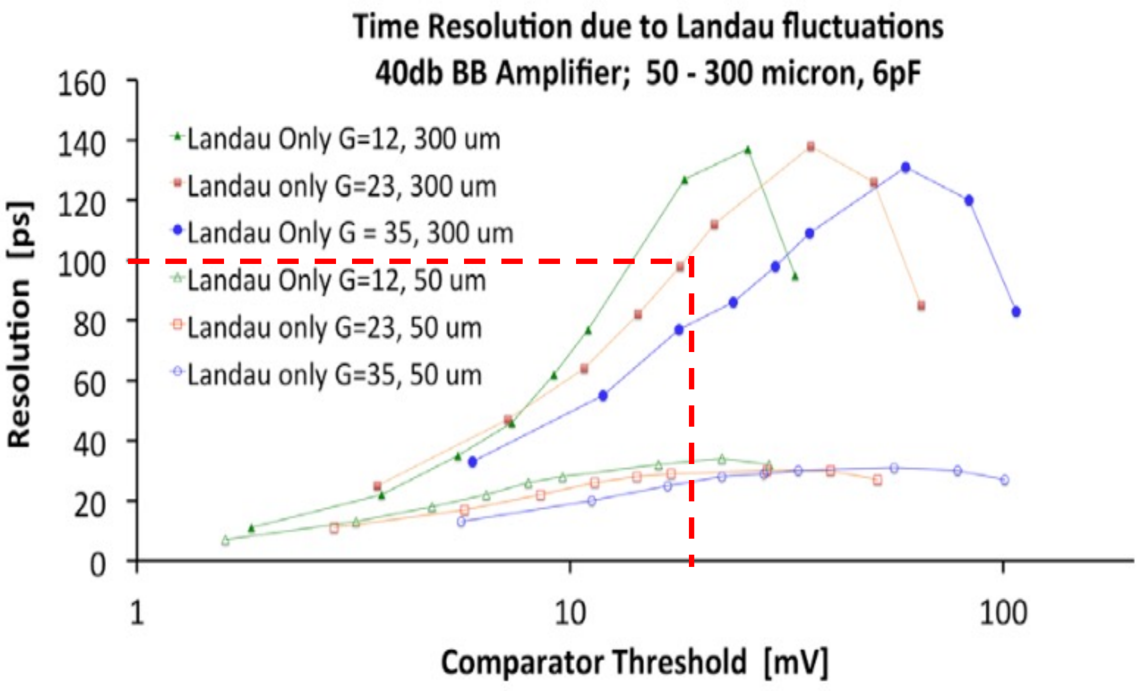
Power budget:
- VERY challenging < 150 W/m^2

Radiation hardness:
- modest problem for space experiments < 10^{11} 1 MeV neq (TID ~100 krad)

Development of LGADs at FBK

- large pixels (e.g.: 3mm x 3mm)
- sensor thickness 200-300 um

with G~ 10-20 the dominant term for the time resolution is the jitter => 100 ps feasible with a low threshold



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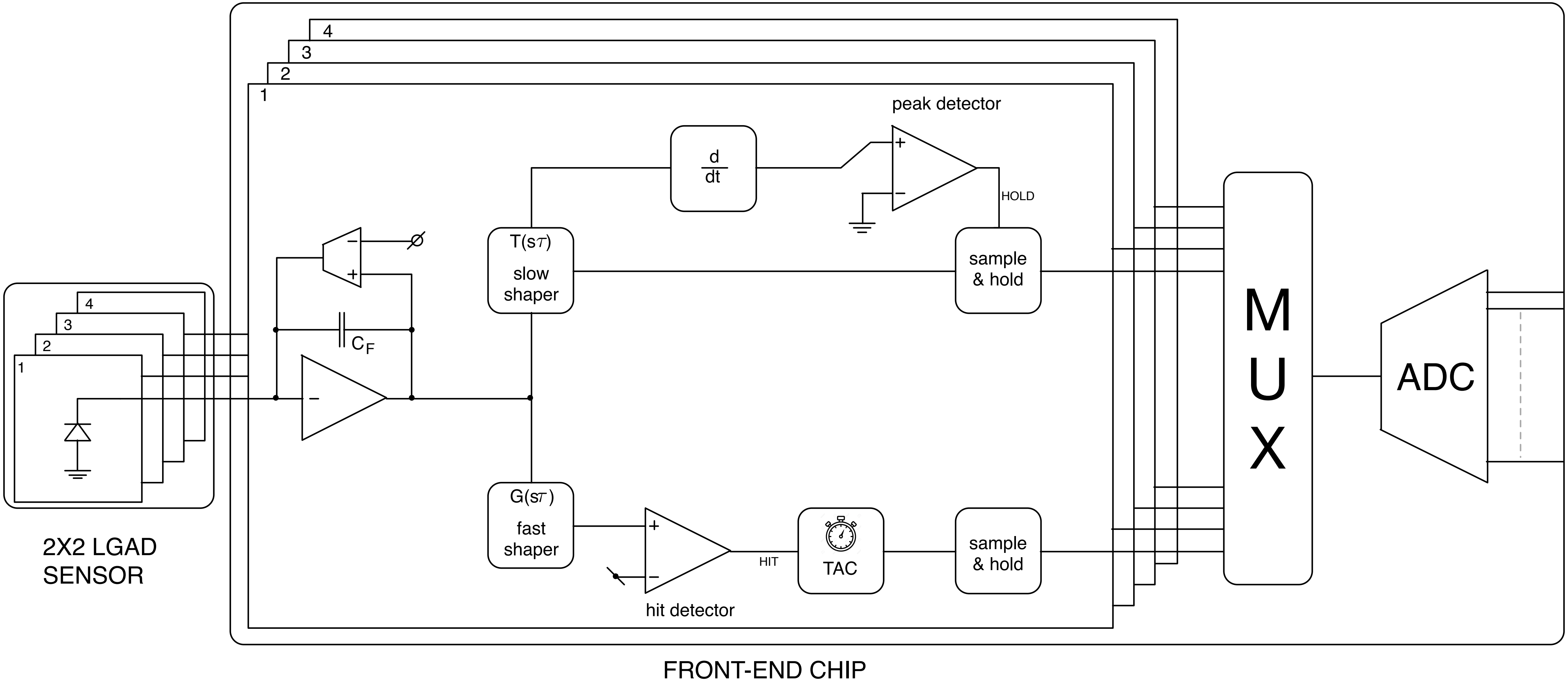
e.g.: 100 ps resolution with:

- 300 um thickness
- G=23
- threshold ~ 20 – 30 mV

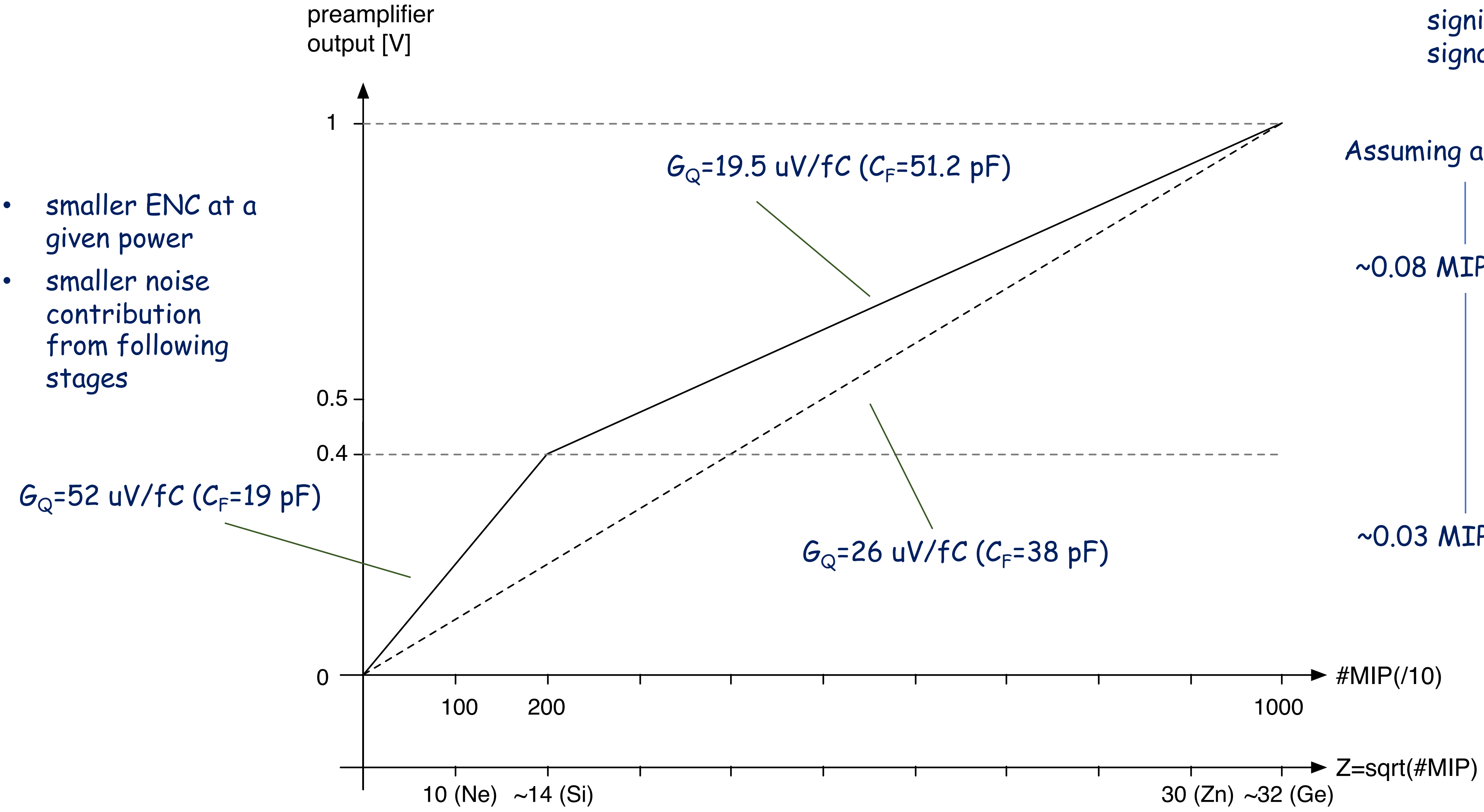
Front-end chip for LGAD detector



Bi-linear compression

- large transient current required to drive the feedback capacitance
- resolution degrades significantly for large signals

- smaller ENC at a given power
- smaller noise contribution from following stages



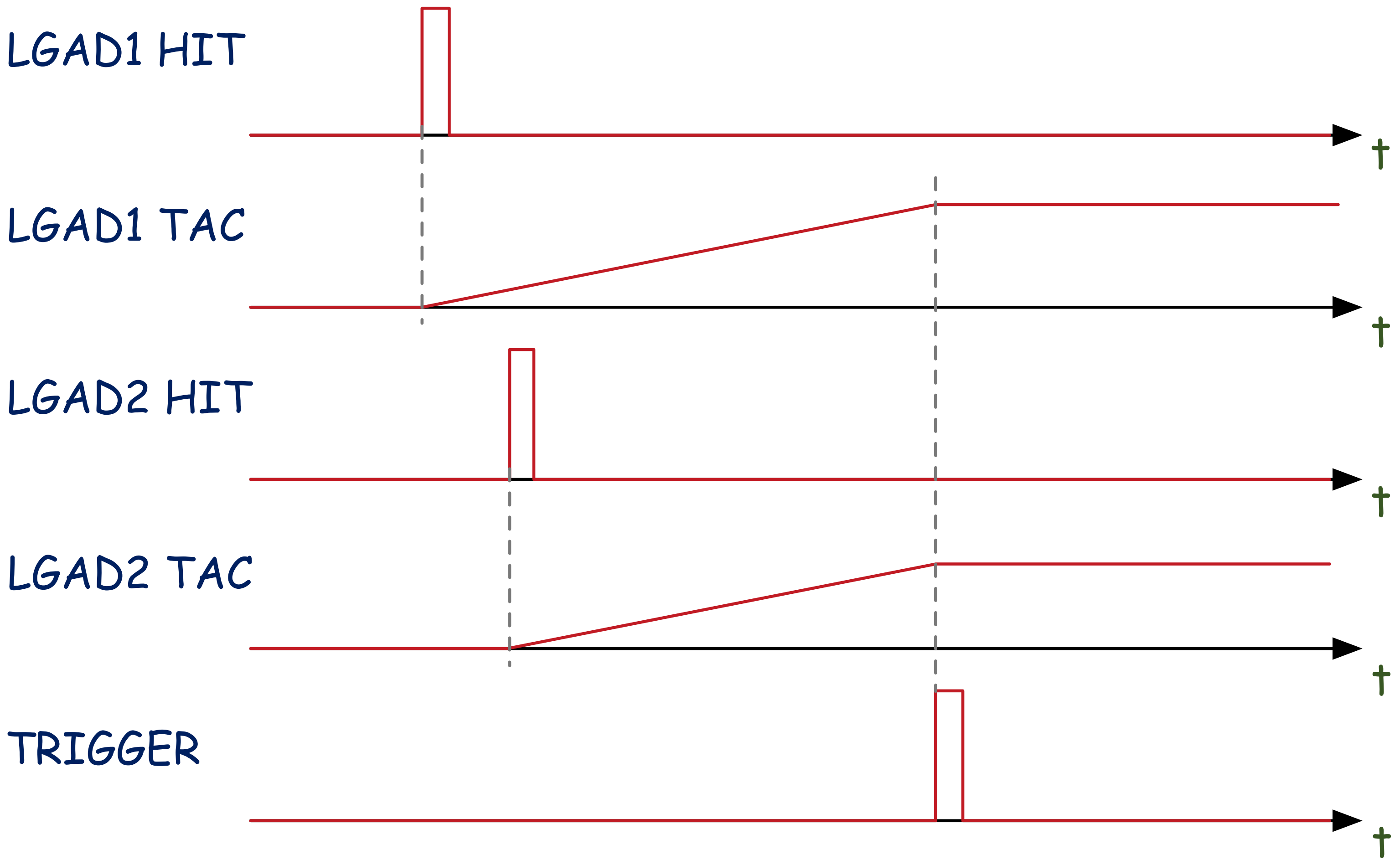
Assuming a 14 bit ADC

~0.08 MIP/LSB

~0.03 MIP/LSB

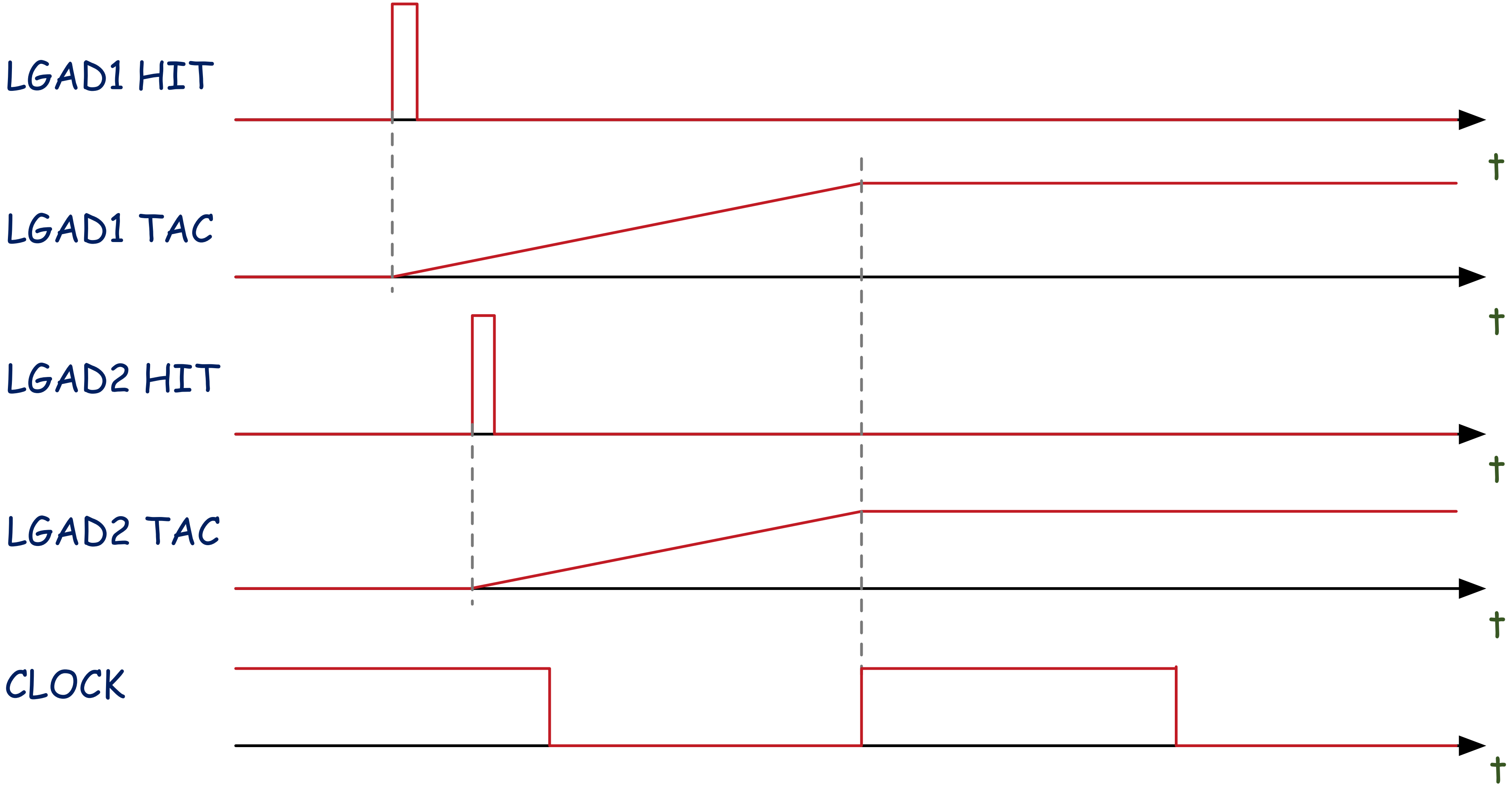
Timing

- Clock-less operation
  - TAC (TDC) starts when an LGAD (pixel) is hit
  - TAC (TDC) stops when a trigger signal is received

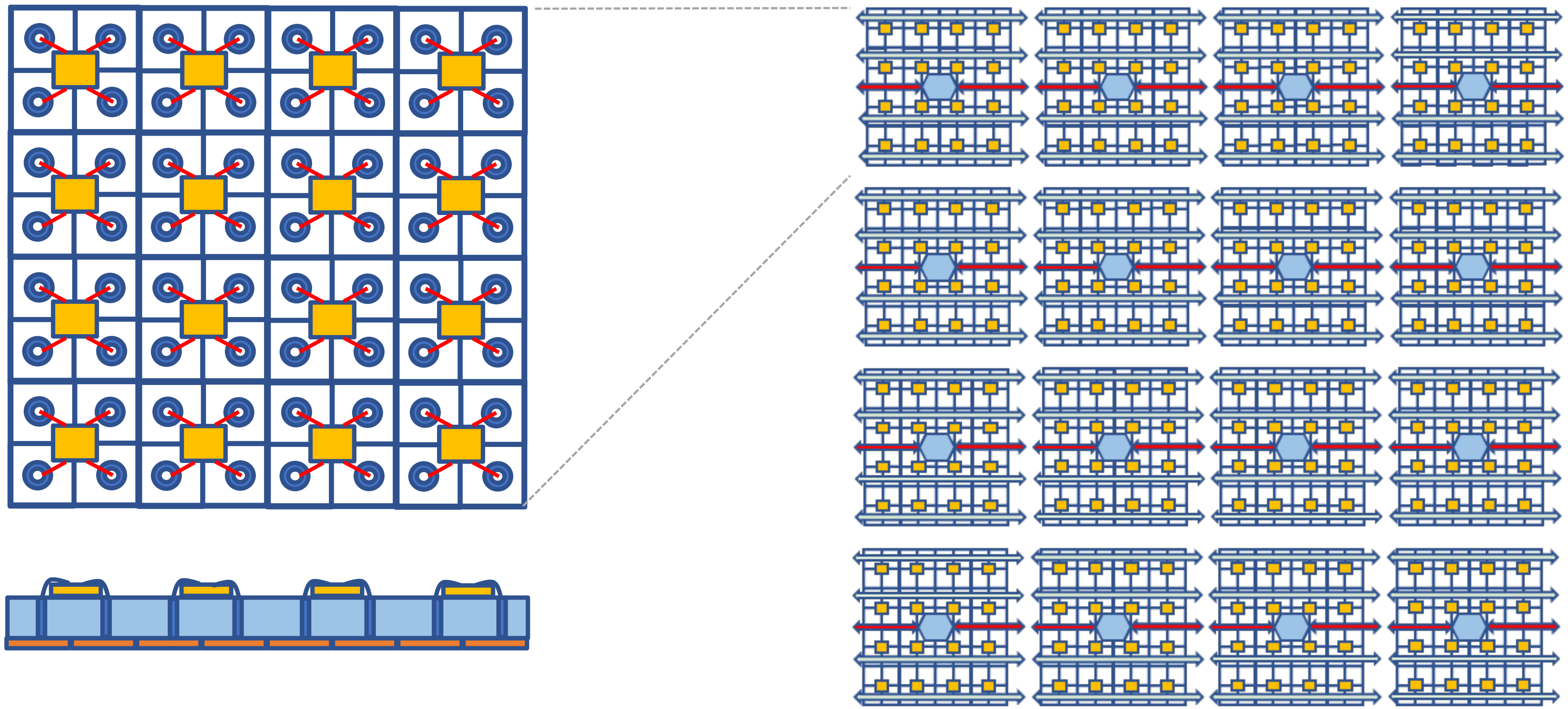


Timing

- Clocked operation
  - TAC (TDC) starts when an LGAD (pixel) is hit
  - TAC (TDC) stops at the next clock rising edge



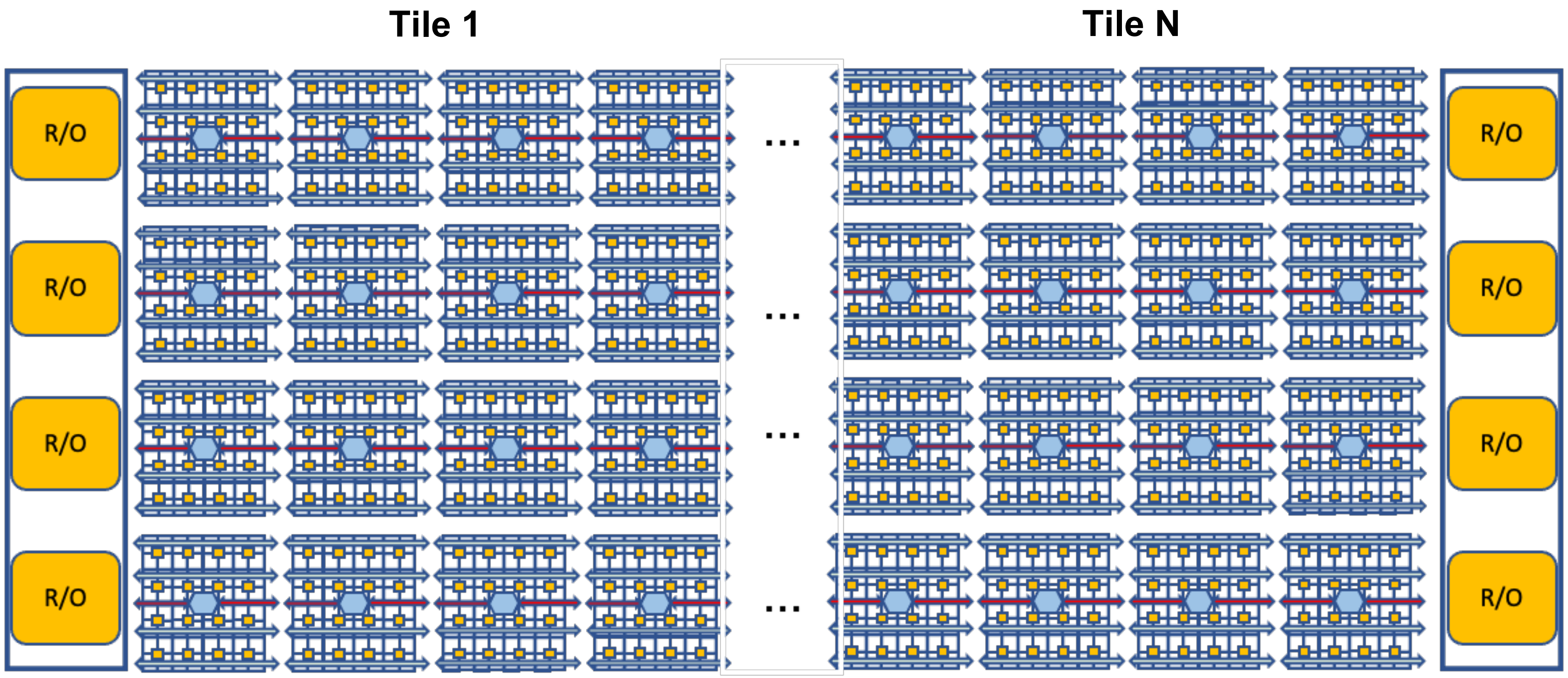
Detector architecture

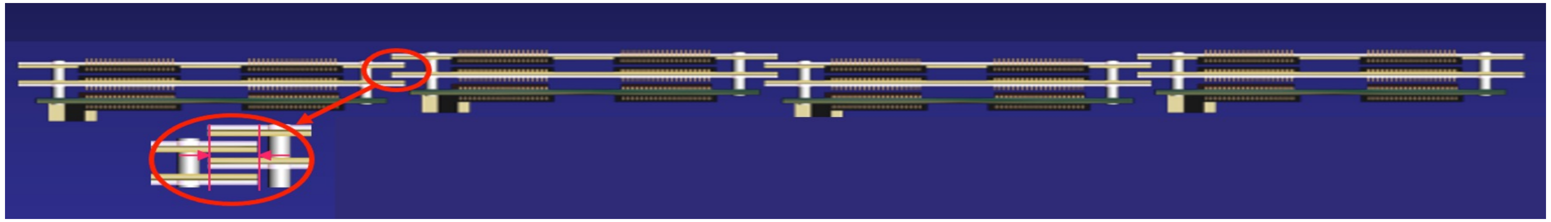


mini-TILE (2.4 cm x 2.4 cm):
16 FE = 8 x 8 LGADs

TILE (9.6 cm x 9.6 cm): 16 mini-tiles
= 256 FE = 16 x 8 x 8 = 1024 LGADs

Detector architecture





overlapping staggered layers

ADA-5D goal is limited to the development of one TILE (or mini-TILE)

Financial request (PV, 2023)

	2023 - Sez. di Pavia	k€
Missioni	Missione a Trento presso FBK per meeting su progettazione dell'elettronica di front-end e sua interconnessione con sensori LGAD (2 persone – 2gg)	1
	Missione a Pisa presso INFN per meeting su elettronica di front-end e suo interfacciamento con elettronica di reaodut digitale (2 persone – 2gg).	1
Consumi	Componenti elettronici (inclusi microcontrollori ed FPGA con schede di collaudo) per la caratterizzazione dei prototipi dell'elettronica di front-end.	2
	Run mini@sic, attraverso il consorzio Europractice, per la produzione di prototipi del canale di lettura in tecnologia CMOS 65 nm (il costo dei run mini@asic è dettagliato sul sito del consorzio all'indirizzo https://europractice-ic.com/schedules-prices-2022/). Costo IVA inclusa.	24
Apparati	Produzione di schede di test per la caratterizzazione dei prototipi del canale di lettura	2
	PV-TOTAL	30

Overall cost estimate (2023-2025)

	ADA_5D 2023 - 2025	2023	2024	2025
Missioni	beam tests (sj)		15	15
	missioni in italia	10.5	6	6
Consumi	componentistica elettronica + meccanica + schede	26	25	28
	tracker upgrade	3.5	6	
Apparati	runs di produzione del chip di front-end	24	42	
	runs di produzione di LGADs a FBK	27.5	27.5	
	TOTAL 262	**91.5**	**121.5**	**49**