SMART-ReAD: AI-driven detector readout for physics experiments

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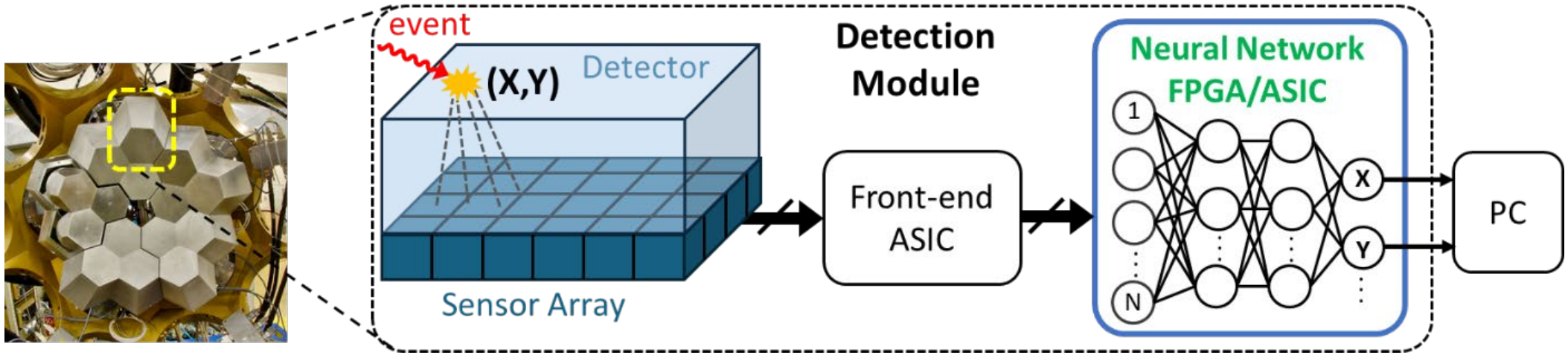
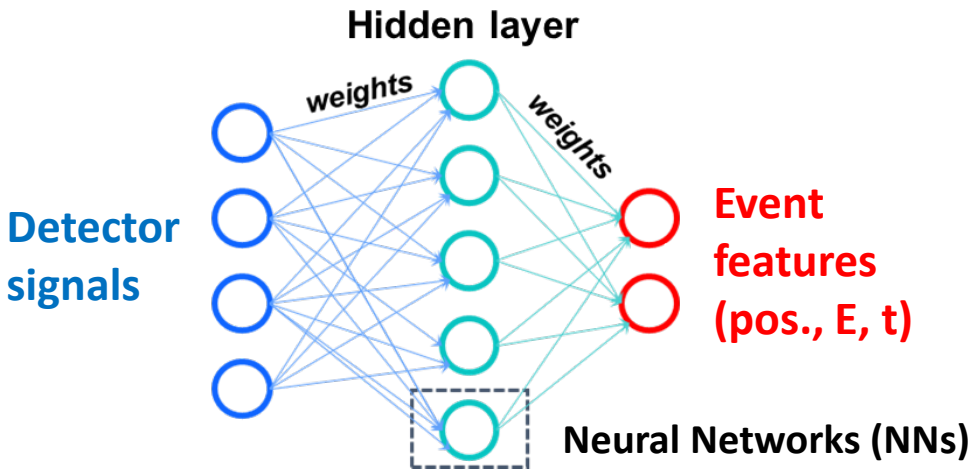
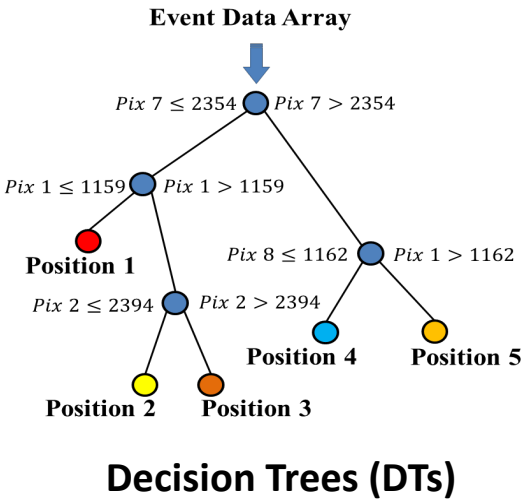


- **Goal:** Development of an **electronics platform** to implement an **embedded processing of detector signals** by means of **AI techniques** and its deployment in **experiments infrastructures**
- **Detector types:** segmented detectors where **event signals are distributed over several units**
- **Advantages:** **simplify** the event processing still keeping **performances**, **reduction** the computational **resources** and **power**, compared to event processing by external computational units

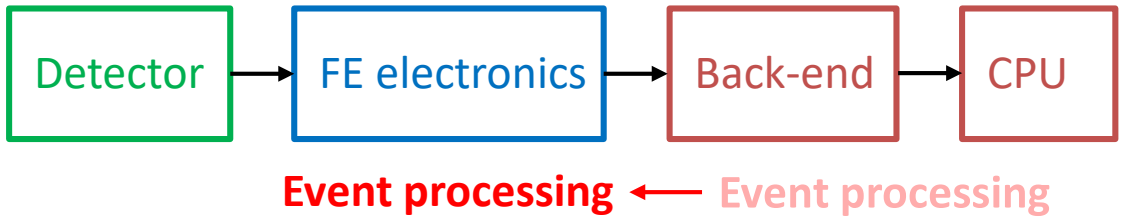
Development approaches

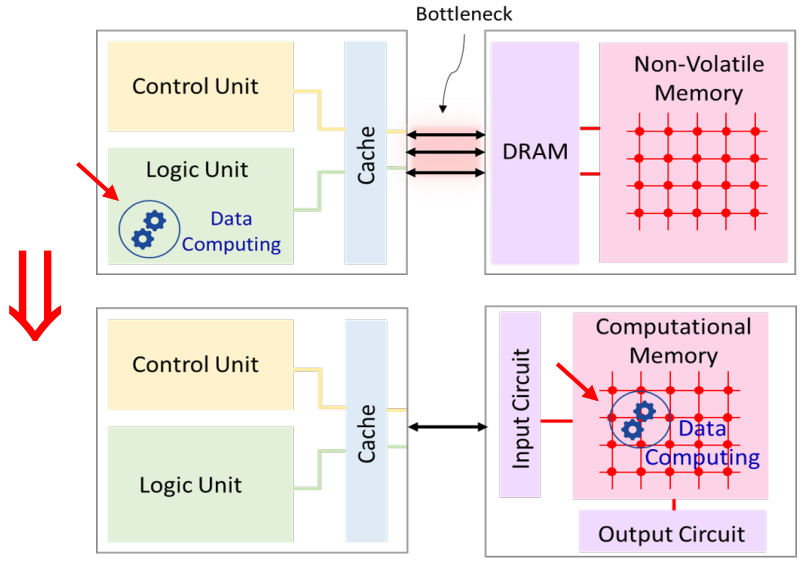
1) Processing the detector signals by means of **AI algorithms**, in particular **Machine Learning (ML)**:



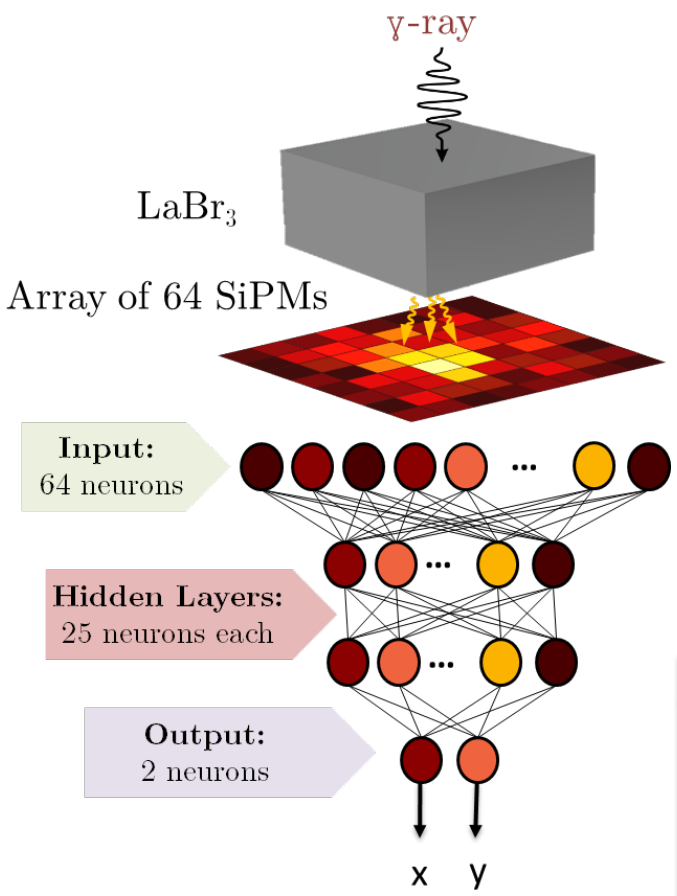


2) Moving the **processing of the event** for feature extraction (position, energy, timing) **closer to the detector and FE electronics**. Employment of **In-Memory Computing** approach:

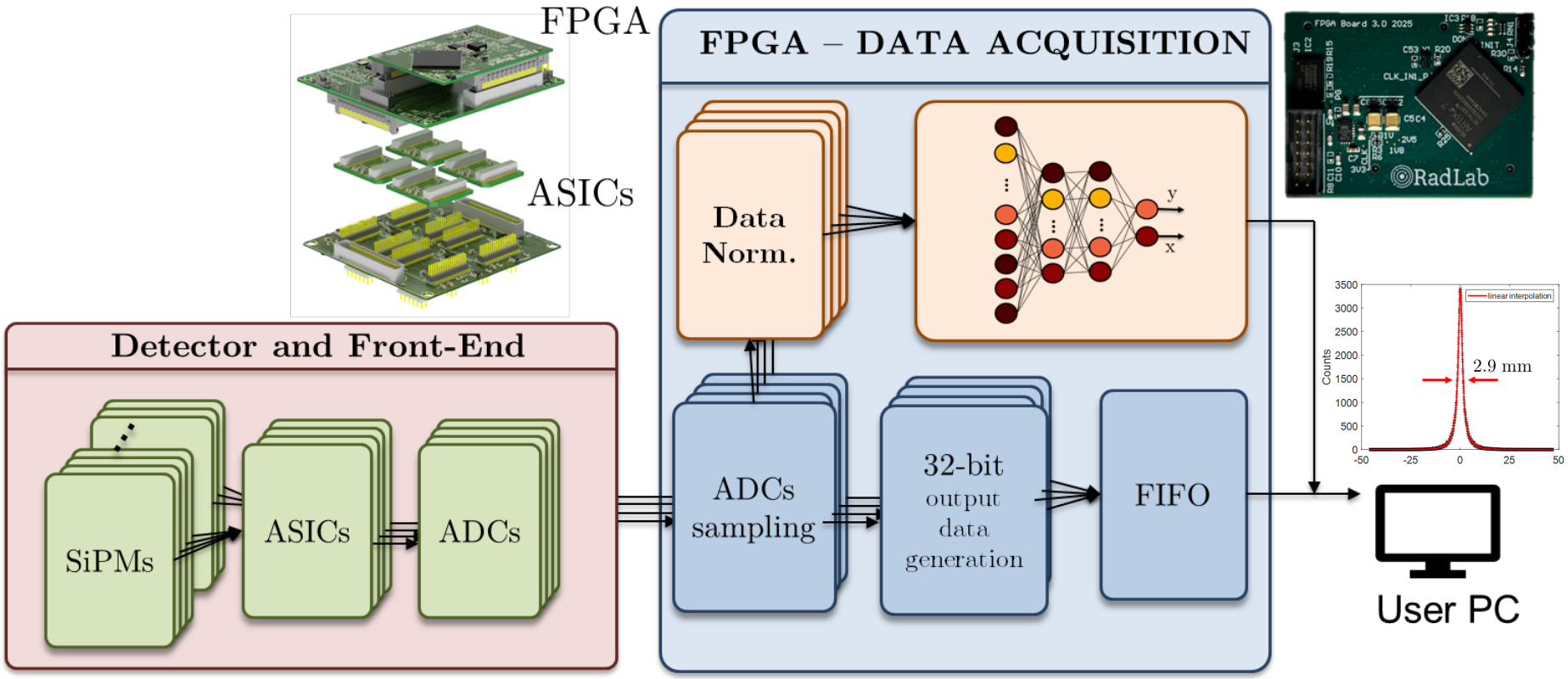




Real-time event reconstruction in FPGA



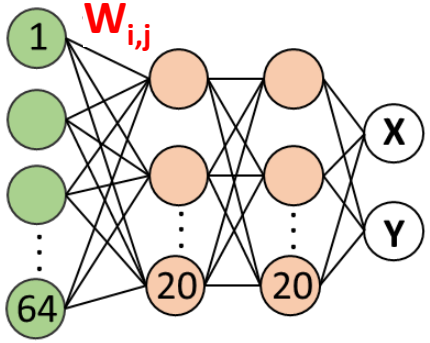
- Implementation of a **Artificial Neural Network in FPGA** for real-time reconstruction of gamma-ray events (energy, position) in **thick scintillators**
- **2.9mm spatial resolution**, **5us/event processing time**



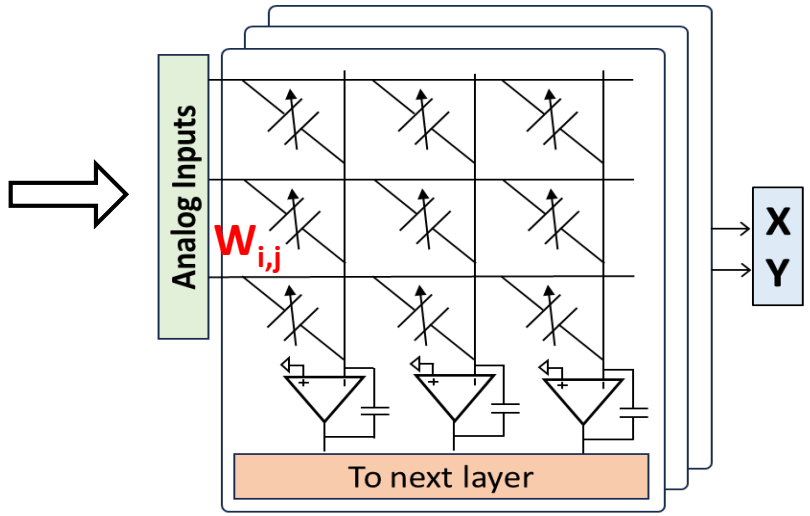
T. Ferri et al., IEEE TRPMS, vol. 9, no. 3, pp. 284-295, 2025.

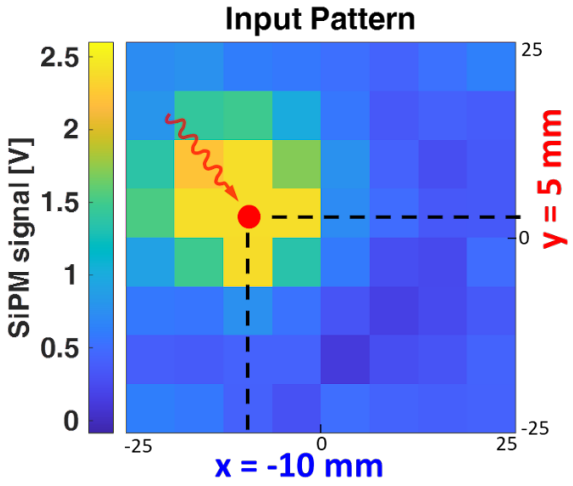
ANNA (Analog Neural Network ASIC)

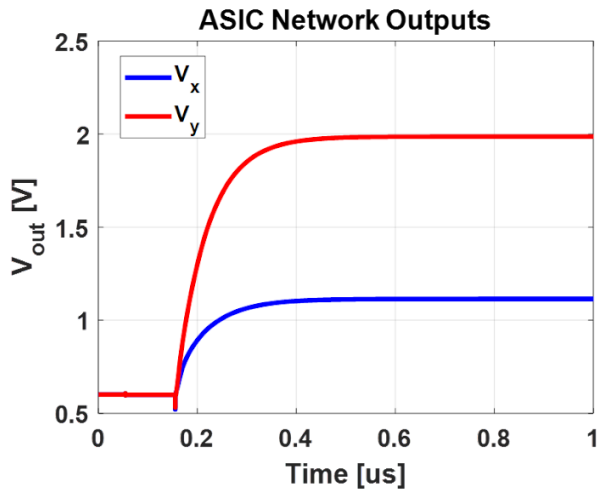
Detector signals



Interaction coordinates

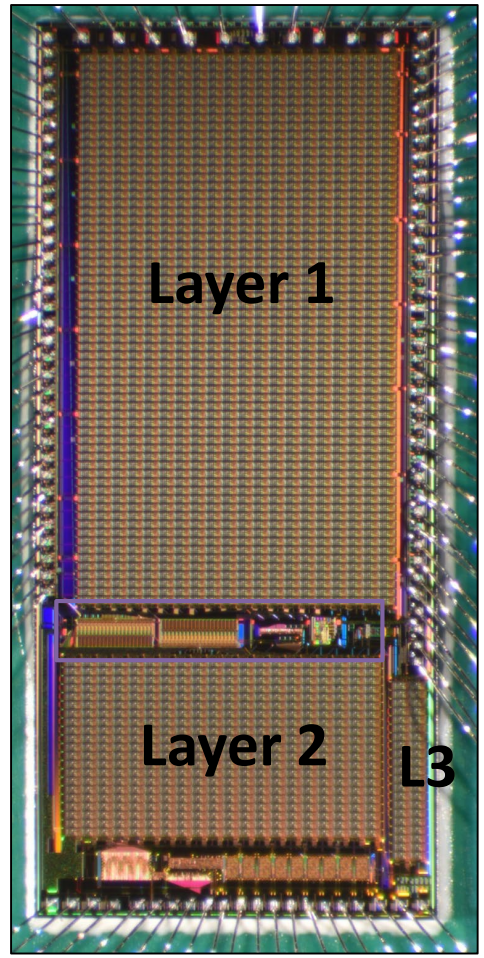






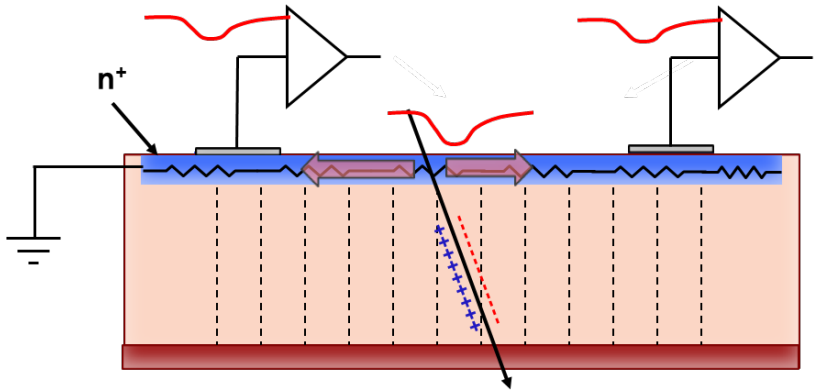
→ **No need for ADC and FPGA** for embedded processing

→ **Interaction coordinates (X,Y)** directly at the output of the **ASIC**

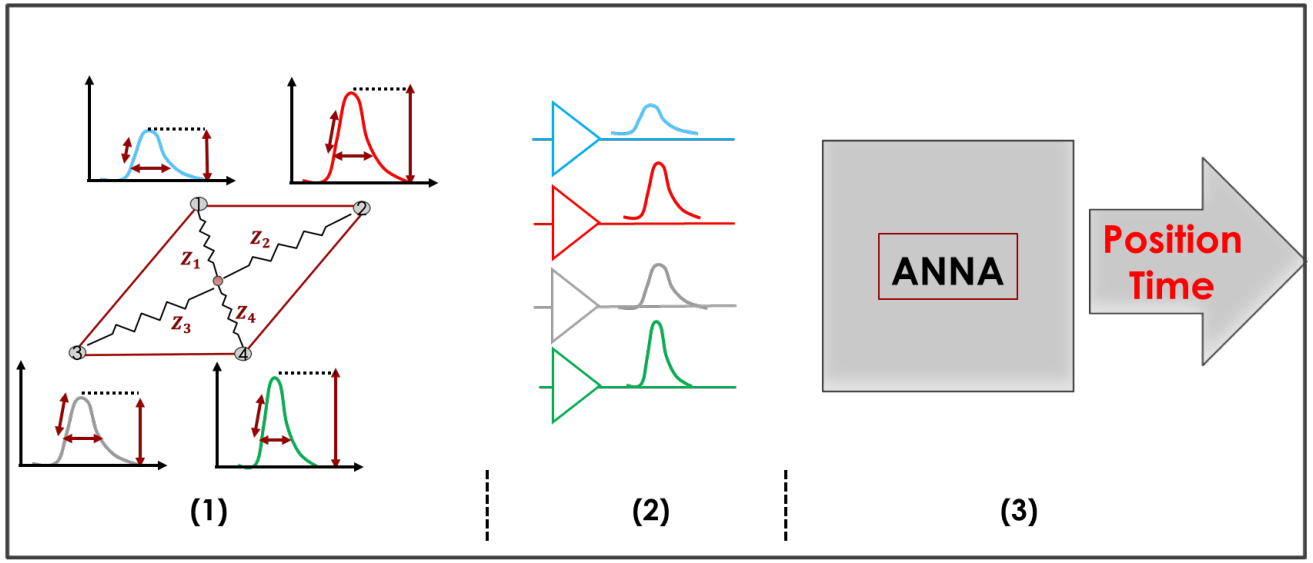


S. Di Giacomo, et al., in IEEE TRPMS, vol. 9, no. 5, pp. 542-552, 2025.

LGAD Resistive Silicon Sensors (RDS)



- the **resistive implant** collecting the charge acts as a **signal divider**;
- information about **position**, **energy**, and **timing** is **encoded** in how the **signal** is **split** among nearby readout electrodes;
- **RSDs reduce** the **number** of readout **channels** of a factor of **~100** compared to standard sensors;
- **machine-learning** techniques provide better results than analytical algorithms in **reconstructing** the **events**.

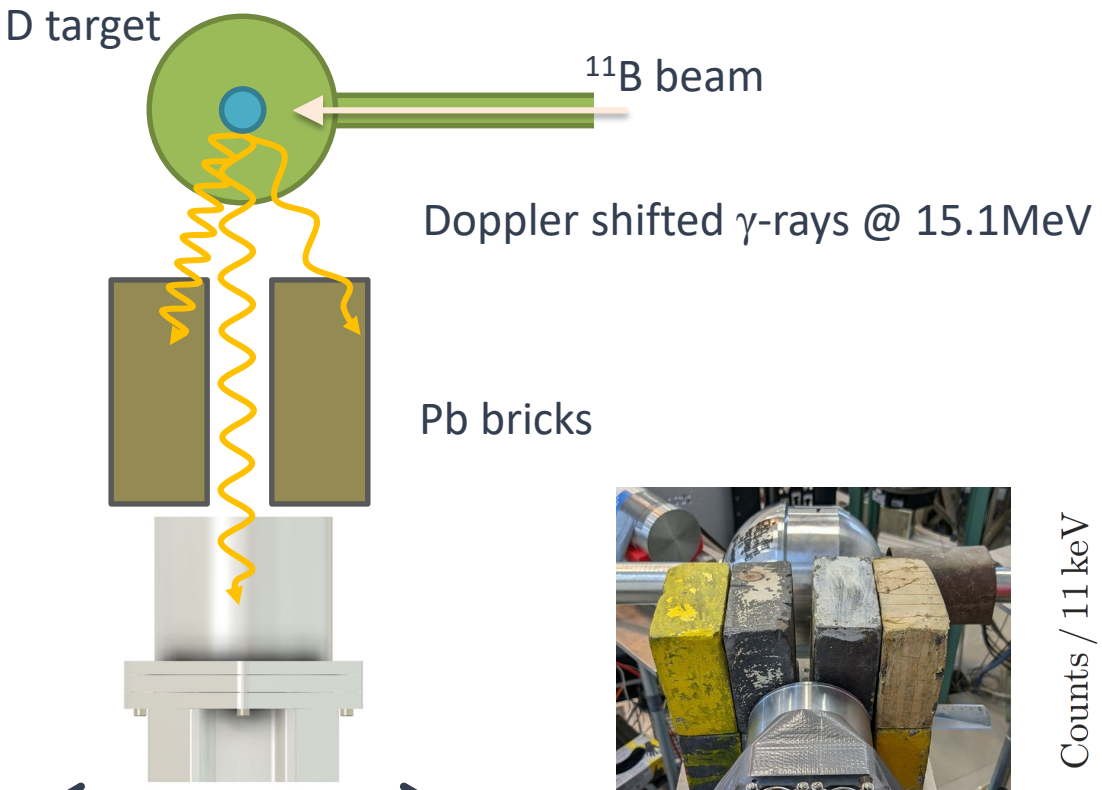


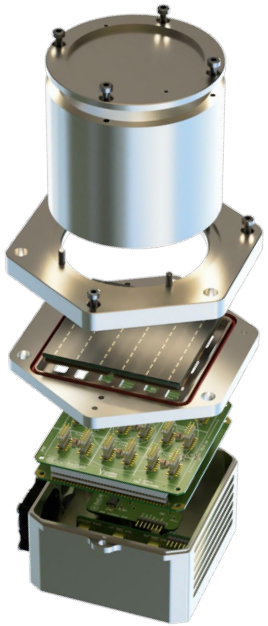
Goals:

- Develop a proof-of-concept **low-power ML-RSD tracker** to be tested in **beam test facilities (spatial res. ≠ pixel dimensions!)**. Low-power 4D detector: an ECFA milestone.
- Prototype of a **new telescope detector** to be **installed in beam test facilities**

F. Siviero, et al., JINST, 19 C01028.

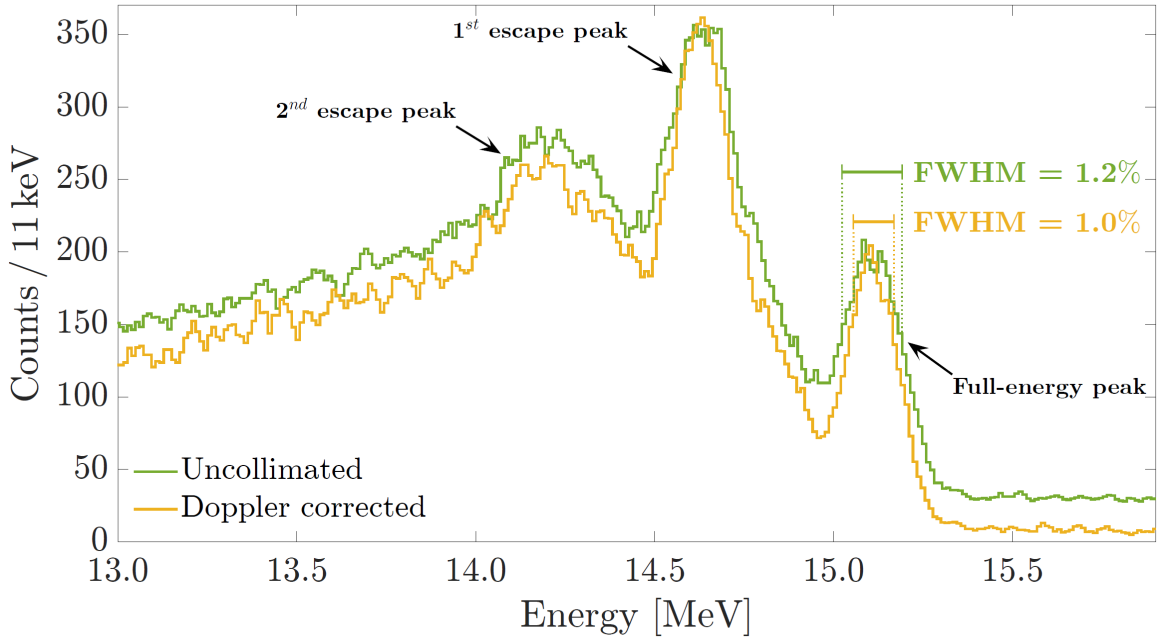
Scintillator detectors for gamma-ray spectroscopy, imaging, calorimetry





GAMMA Detector

- Experiments performed at **IFIN-HH** Tandem accelerator (Bucarest, Romania)
- **Position sensitivity** by Decision Tree reconstruction algorithm allows to **correct for Doppler broadening**



M. Agnolin et al., IEEE TNS, vol. 70, no. 10, p. 2337, 2023.

Project plan

Project activities

- Development of an **electronics platform** for **AI-processing of detector signals**, based on **FPGAs** and **ASICs**, available both as **stand-alone units** and **integrated in the detector module**
- Compatible with **different detector types**: LGAD-RDS, scintillators, Ge, CdTe/CZT,..
- **Event features extraction** (position, energy, timing), **particle identification** by PSA
- **Integration and validation in experiment facilities** (see next slide)

Topics of interest in the call

- ***Short-term R&D, AI technologies, Applications and links with industry***.
- Aim to contribute to **improve the efficiency of the infrastructures in complex detection apparatus of hadron physics experiments** (Work programme: .. *improve the services the infrastructures provide and to further develop their on-line services).*
- Potential impact also in **applied physics applications**, as nuclear medical imaging (e.g. PET, Range Verification in Hadron Therapy), as well as towards **innovative industrial instruments**.

Transnational Access to Infrastructures

RSD detectors

Beam test facilities

- CERN SPS, Geneve
  - 120 GeV/c pions & protons beams
  - Particle tracker available upon request
- LNF, Beam Test Facility, Frascati
  - e+ 50 - 550 MeV
  - e- 50 - 750 MeV
- MAMI, Mainz
  - e- 0.2 - 1.6 GeV

Irradiation facilities

- Neutron irradiation: Liubjiana TRIGA reactor,
- Proton irradiation: IRRAD, CERN
- Low energy hadron: KIT, Karlsruhe

Scintillator detectors

Beam test facilities

- IFIN-HH, Bucarest
  - >10 MeV protons
- LNL, Legnaro
  - 28 MeV protons
- IFJ-PAN, Krakow
  - 70 - 230 MeV protons

Participants and budget

Participating institutions

- Politecnico di Milano, Dipartimento di Elettronica, Informazione e Bioingegneria
- Università degli Studi di Milano, Dipartimento di Fisica
- INFN, Sezione di Milano / INFN Sezione di Torino
- UPO, Università del Piemonte Orientale

Estimated budget request

- 4 FTEs for designers (140k), 1 FTE for detector development (35k)
- ASIC runs (80k), sensors production (60k)
- FPGAs, PCBs, el. components (30k),
- beam tests and travels (40k)
- overheads (60k)
- Tot. 445k