EUROPEAN AI FOR FUNDAMENTAL PHYSICS CONFERENCE
EuCAIFCon 2025

Neuromorphic Readout for Hadron Calorimeter

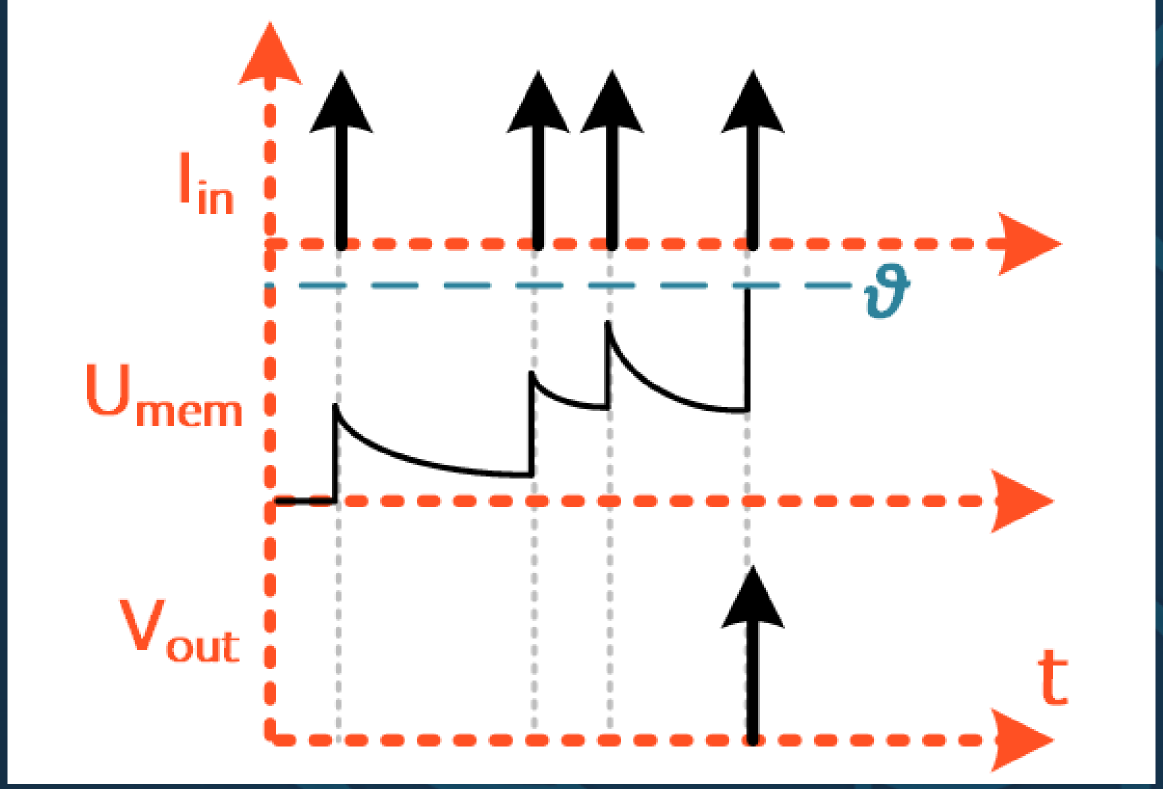
Enrico Lupi, Alessandro Breccia, Riccardo Carroccio, Tommaso Dorigo, *et al.*

MCCXXII

Istituto Nazionale di Fisica Nucleare

Introduction:
Our Goal

- Hadron calorimeters rely on high segmentation to extract topological information and improve performances
  ⇒ This leads to high cost, high power, massive data volumes, and very fast processing requirements
- We propose a **neuromorphic readout** of the light signals to provide low-latency, low-power consumption local computation to generate high-level primitives



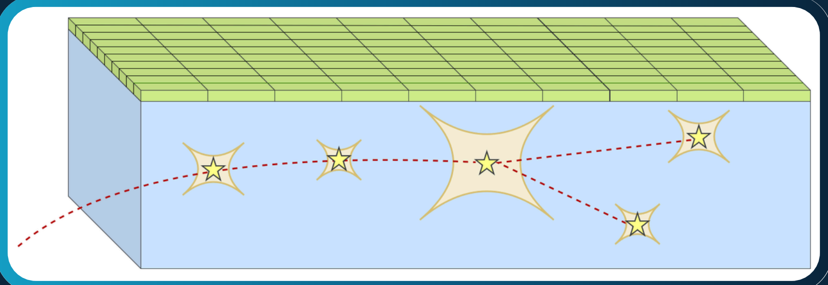
Neuromorphic Computing

- Computing approach that **mimics the human brain** using artificial neurons and synapses
- We use a **Spiking Neural Network**, in which neurons:
  - communicate using “spikes” (discrete signals)
  - have an internal membrane potential that evolves in time and integrates incoming spikes
  - fire output spikes whenever the potential reaches a threshold

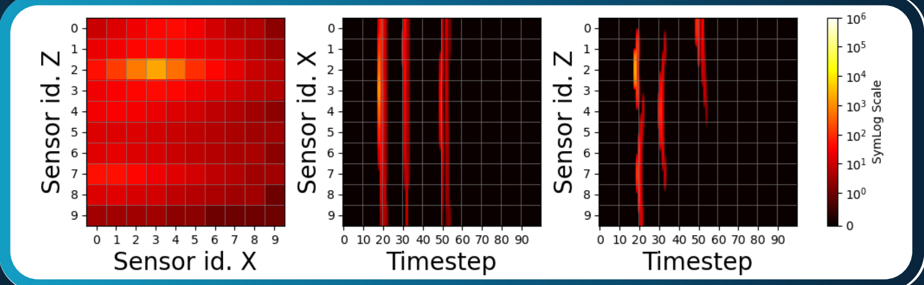
Processing Pipeline:

1. Data Generation

Simulated using GEANT4 + custom light propagation model

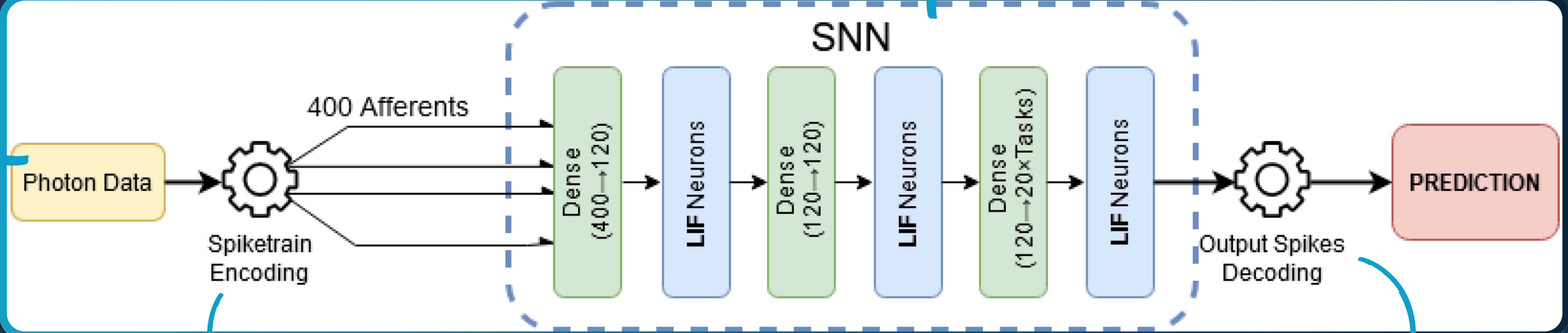


Light Signals



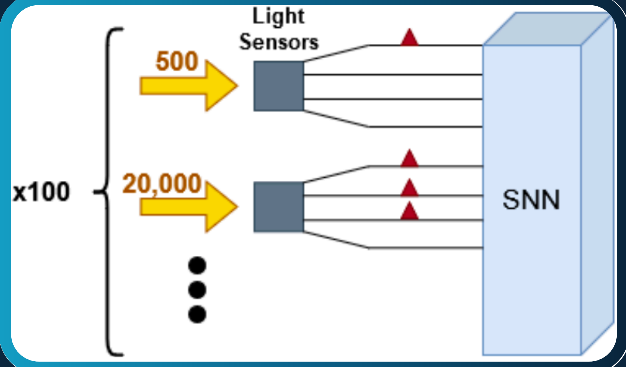
3. Spiking Network

- Feed-forward NN with dense layers
- Leaky-Integrate-and-Fire (LIF) neurons implemented in *snnTorch*



2. Spike Encoding

Create spiketrain depending on photon intensity



4. Output Spike Decoding

Spike rate decoding scheme

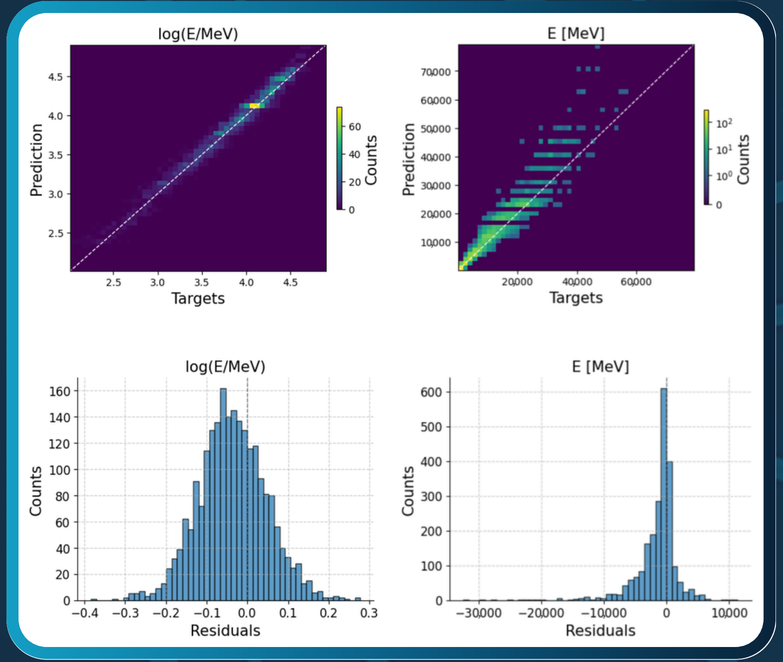
$$\hat{X} = \frac{1}{N_{pop}} \sum_{i=1}^{N_{pop}} \sum_{t=1}^{T} S^{(i)}[t]$$

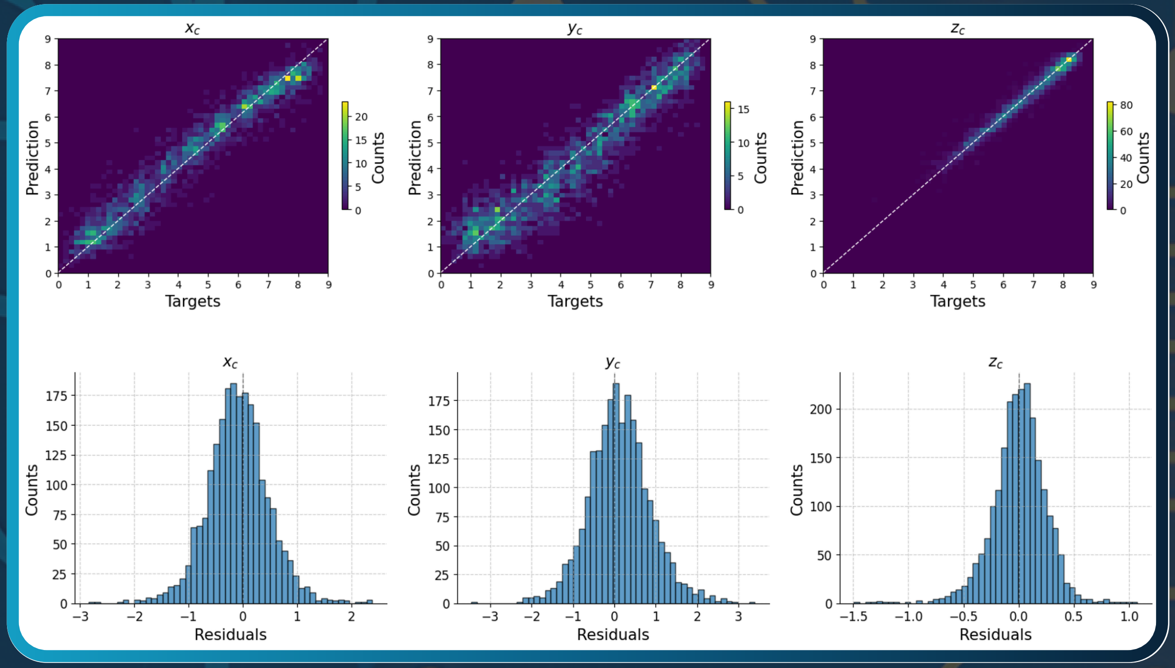
Results:

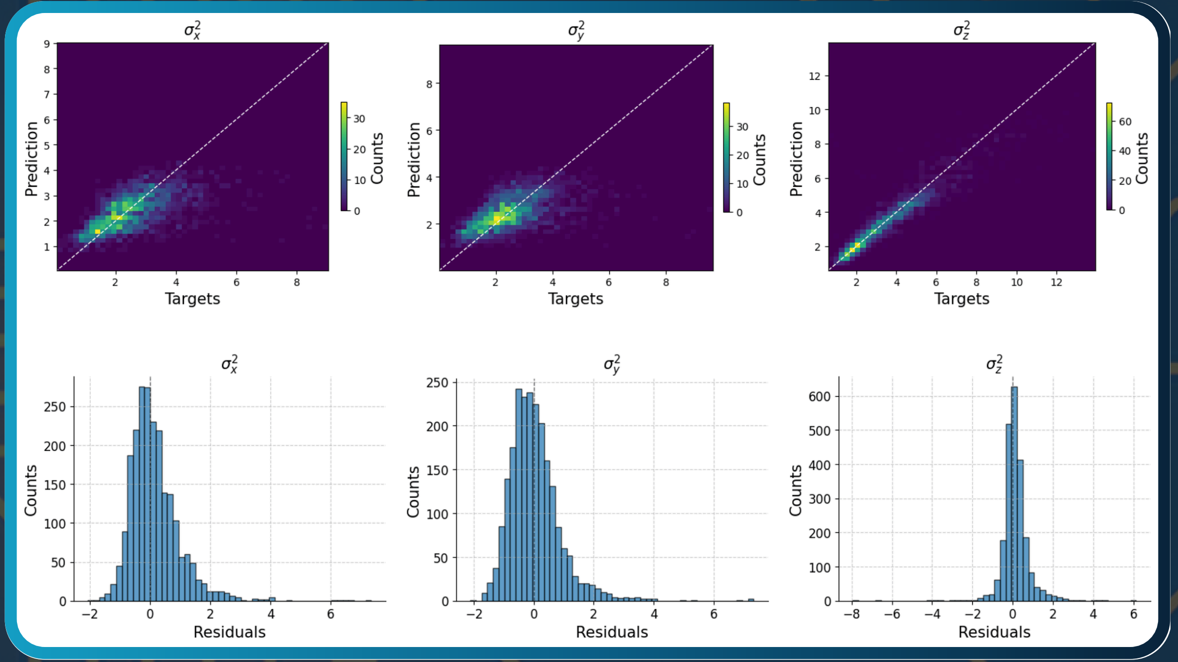
We apply this processing pipeline to three quantities:

a. *log* of total energy released
b. Position of energy depositions centroid
c. Dispersion of energy depositions

	log(E/MeV)	E	x_c	y_c	z_c	σ_x^2	σ_y^2	σ_z^2
ϵ_{rel} (%)	1.975	18.37	18.13	24.74	2.85	26.07	31.39	12.04
ϵ_{abs}	0.073	2039 MeV	0.44	0.58	0.18	0.58	0.62	0.41







It is possible to build network that regress mutiple values at once by specializing populations of output neurons, obtaining comparable results.