

Introduction & Motivation

- **Neuromorphic sensing & computing (NSC)** emerges as an alternative to conventional digital computing with several potentially advantageous characteristics, in particular its high energy efficiency and the exploitation of temporal structure of input signals.
- Today or tomorrow detectors are pushing the challenges of low latency and highly complex data and thus creates a new paradigm of Computing and Sensing.
- Neuromorphic Sensing & Computing spans diverse applications from fundamental Physics research to next-generation particle detectors.

Material Study: Memristive Memory Devices

- Resistive Random Access Memory (ReRAM) is a promising candidate for building brain-like memory (synapses) and learning in NSC hardware



Fig. 1 a) Schematic of ReRAM device as switching layer b) Band gaps of Na₃SbX₄

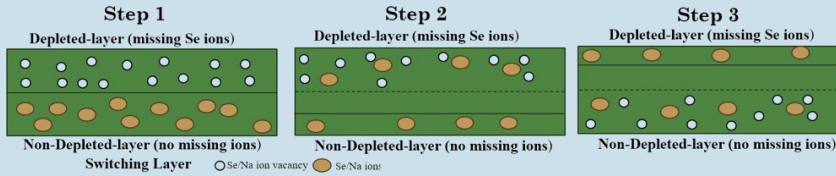


Fig. 2 Ion migration process in the switching layer of ReRAM

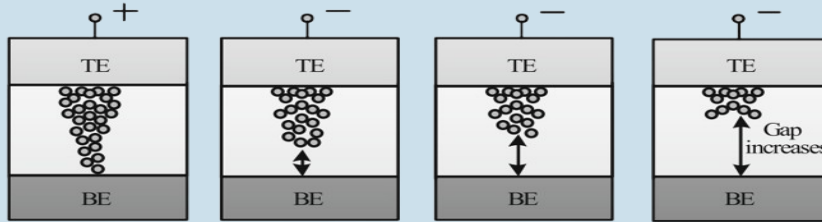


Fig. 3 Resistive switching in ReRAM under varying voltage between Top/Bottom Electrodes (TE/BE)

Results: Novel chalcogen composites with suitable optoelectronic properties for NSC devices

Application 1: Track Reconstruction

Challenge: In future collider experiments, particle collisions will generate massively complex data and high background noise levels where traditional sensing and computing may struggle to reconstruct tracks efficiently.

Neuromorphic Solution: Encoding of position of hits in silicon detectors layers as temporal events (spikes) and use of Spiking Neural Network (SNN) trained with unsupervised learning proven to reconstruct particle trajectories.

Results: 98% Track reconstruction accuracy, <3% false positives, and demonstrated low-latency, energy-efficient tracking

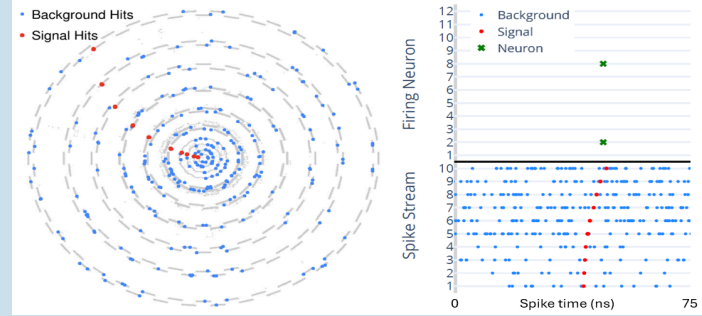


Fig. 4 Left: Side view of silicon detector with recorded hits. Right: Neuron activations (top) resulting from spike-timing encoding of hit positions (bottom)

Application 2: Granular Hadron Calorimeters

Challenge: Next-generation Hadron Calorimeters will need to provide high granularity and time resolution, posing stringent engineering and electronics demands.

Neuromorphic Solution: Application of SNN to regress energy and spatial information from physical space-time distribution of scintillation signals using spike-based input encoding.

Results: High-resolution regression, low-power & learnt spatio-temporal patterns, power benefits, and reduced needs of physical granularity.

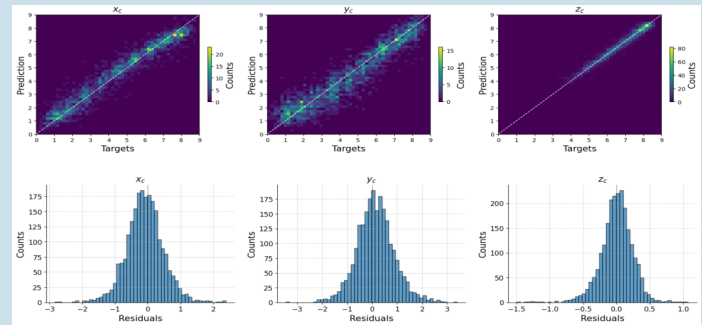


Fig. 5 Predicted vs True positions of light emission centroids (Top) and residuals (Bottom)

Summary

- NSC opens new horizons in the design of next-generation of particle detectors
- Exploration of ReRAM materials for neuromorphic memory devices, Sb-based chalcogens identified to have suitable structural, and optoelectronic properties
- Considered in two applications: **a)** Accurate track reconstruction in silicon detectors with unsupervised learning
b) High-resolution Energy/position regression in calorimeters with reduced needs of physical granularity

