Integration of Squid/Memristor Neurons with Precision Space and Time Particle Physics Detectors for 4D Image Reconstruction using Neuromorphic Computing

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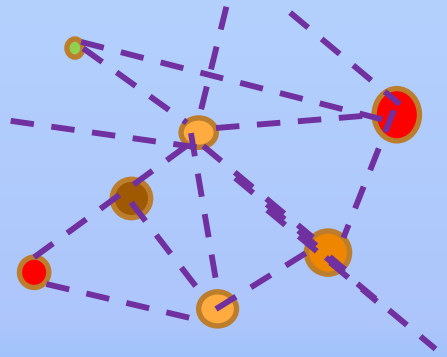
Neuromorphic computing (NC) could tackle Tracking Challenges

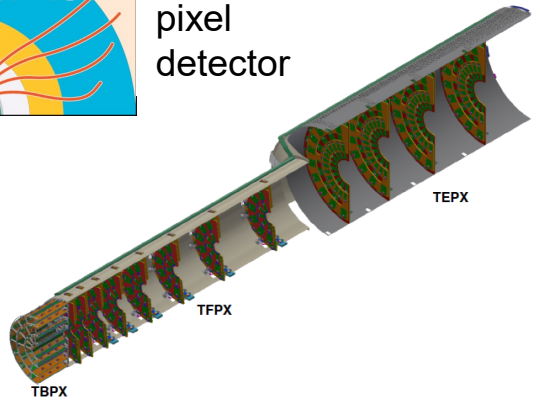


NC Emulates human brain

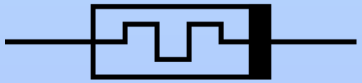
- Memory and computing elements aren't separated
- Neurons communicate in parallel architecture

- Challenge: HL-LHC CMS pixel detector
  - 2 billion readout channels!

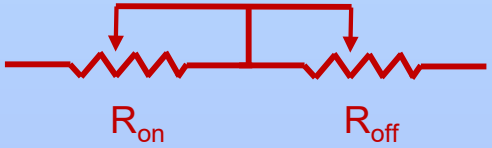
HL-LHC pixel detector



Neuron System Development



MEMRISTOR: resistor with memory
- passive device with a state (on/off)
- non-volatile
- adjustable resistance
- Can act as logic gate as well

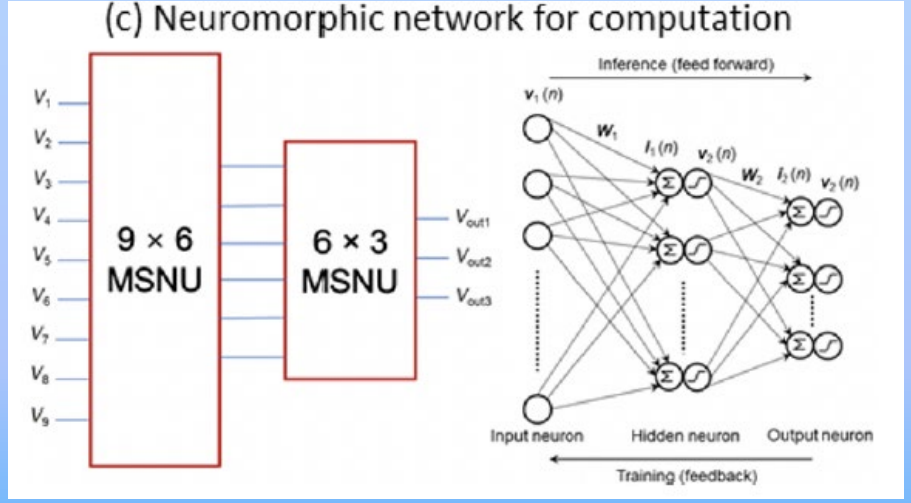


- Report from DOE Office of Science 2015
- https://science.osti.gov/-/media/ascr/pdf/programdocuments/docs/Neuromorphic-Computing-Report_FNLBLP.pdf
- Intel has 8M neuron system (100M soon) with 64 Loihi 14nm chip
- https://spectrum.ieee.org/tech-talk/robotics/artificial-intelligence/intels-neuromorphic-system-hits-8-million-neurons-100-million-coming-by-2020.amp.html
- Present applications use CMOS technology (2D)

  Possibility of petabits/cm^2

Neuromorphic Computing Readout Electronics

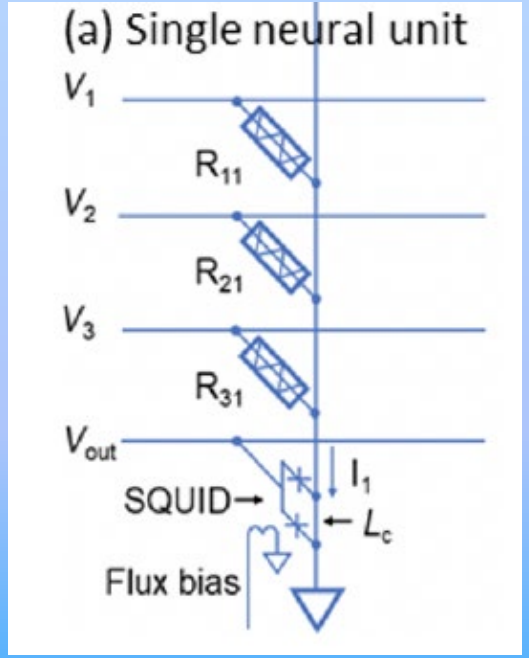
- Downstream implementation of Deep Neural Networks is available already as part of Neuromorphic Computing
- Layout architecture more flexible
- Can add temporal characteristics to implement Spiking Neural Network



KU CMP group NC development

- Atomically tunable memristors with superconductor electrodes paired with Superconducting SQUID for neuronal units
  - IP disclosure filed

  SQUID has 1 pA/Hz$^{1/2}$ reading out 0.1μA signal in 0.1 ns
- Reduced power from ~NxN to ~N for N(row) x N(column) network of NC circuit, 3D scalability
- Logic gates can be implemented



Timing detectors: LGADs

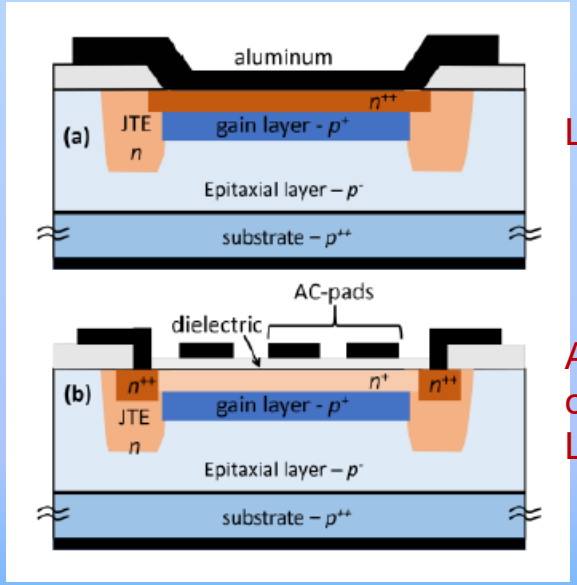
AC coupling: remove pixilation and add n+ implant, di-electric layer, as well as AC coupling to readout pads

Expected 100% fill factor gives fast timing per pixel (now ~30ps), and spatial resolution (currently ~50μm spatial)

- sparse readout at lower power

Charge is shared between multiple pads cross talk is expected

Need new readout to exploit this property



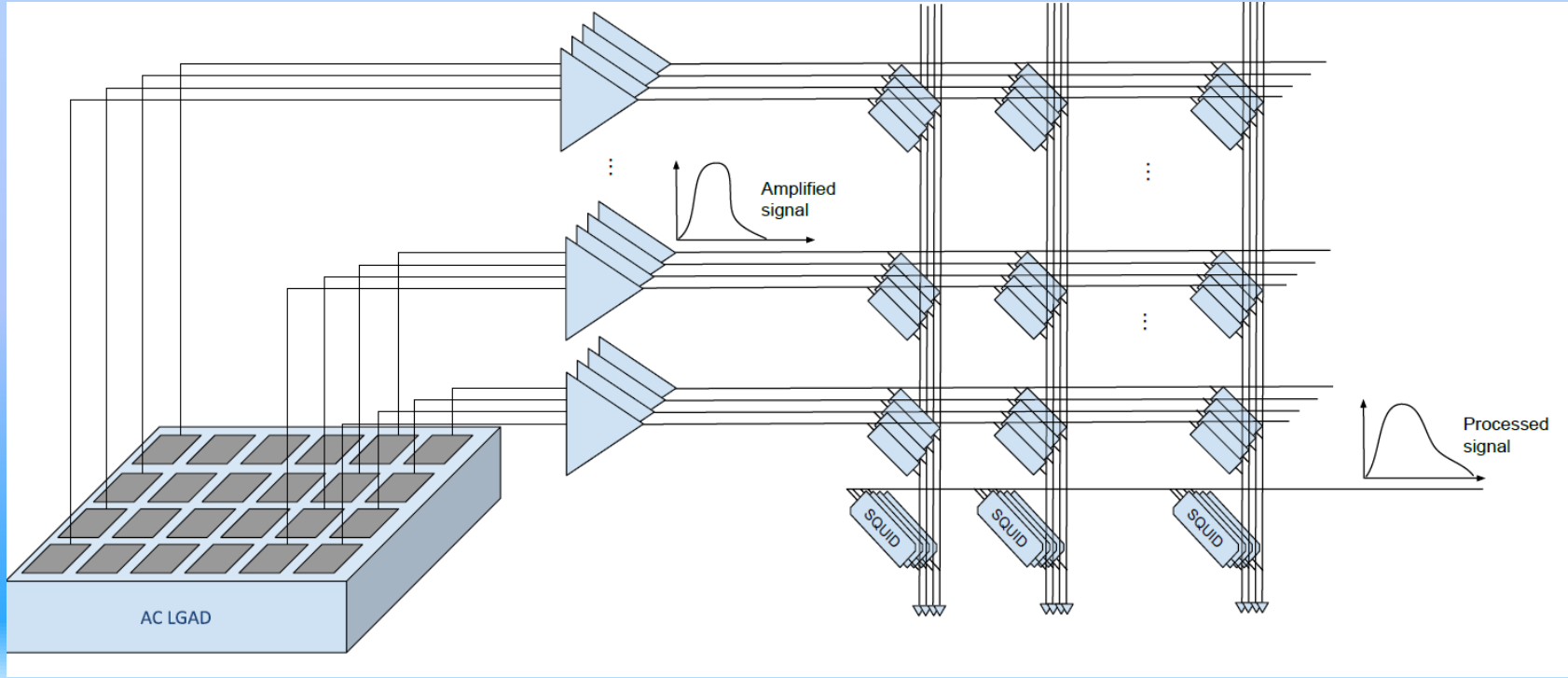
LGAD

AC coupled LGAD

G. Giacomini, W. Chen, G. D'Amen, and A. Tricoli, Journal of Instrumentation 14 no. 09 (Sept 2019) P09004.

Make Cross Talk work for you - Processing intrinsic to readout electronics

- Essentially you have an analog readout



Integrate NC backend with AC LGAD

- Hardware exists now to start:
  CMOS NC units commercially available → Superconducting NC at KU
- Need new algorithms to exploit 4D spatial and temporal info
  Deep Neural Network → Spiking Neural Network

- Future promises:
  better usage of analog signals → LESS POWER