Quasi-Instantaneous online trigger based on optical neural network

Daniele Sanvitto

CNR Nanotec Lecce

INFN - CSN4 FIELDTURB

Daniele Sanvitto

CNR staff, researcher

group coordinator

Talk prepared by G. Chiodini - INFN Lecce

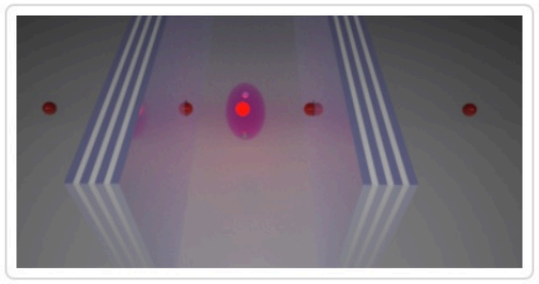
Overview

1. Advance Photonic Group in Lecce
2. Polaritons condensate
3. Ultrafast and low power optical neuromorphic computer
4. Trends in Machine Learning

Excellence in NANOTEC Lecce in polaritons quantum systems

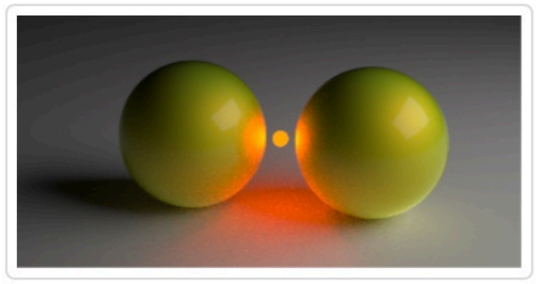
Advanced Photonics Group: Daniele Sanvitto is the coordinator.

http://polaritonics.nanotec.cnr.it



QUANTUM POLARITON

Generation and manipulation of polaritons at the single particle level by using the tools provided by quantum optics.

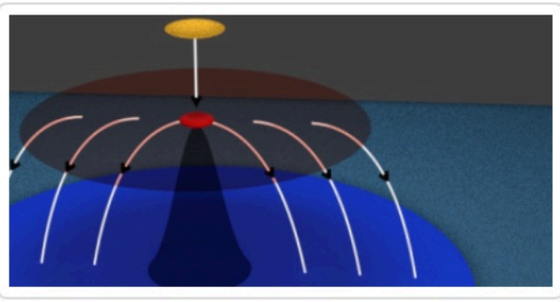


PLASMON POLARITON

Plasmons are extremely sensitive to the geometry of the metallic nanostructures and allow the study of the interaction of polaritons and geometric structures.

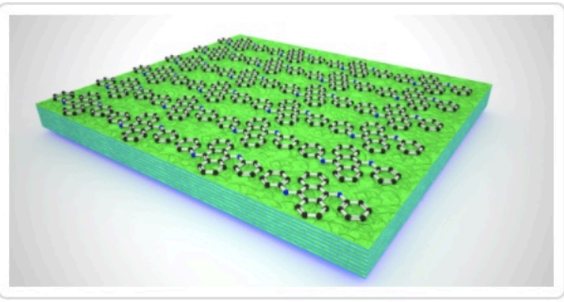
Demonstrated proof of principle of polariton devices, such as logic gates, switches, routers and transistors with femtojoule energy cost per operation and few tens of picosecond recovery time.

More recently, lattices of localized polariton condensates have been used to form topological protected states and solving many-body hamiltonians.



QUANTUM GASES

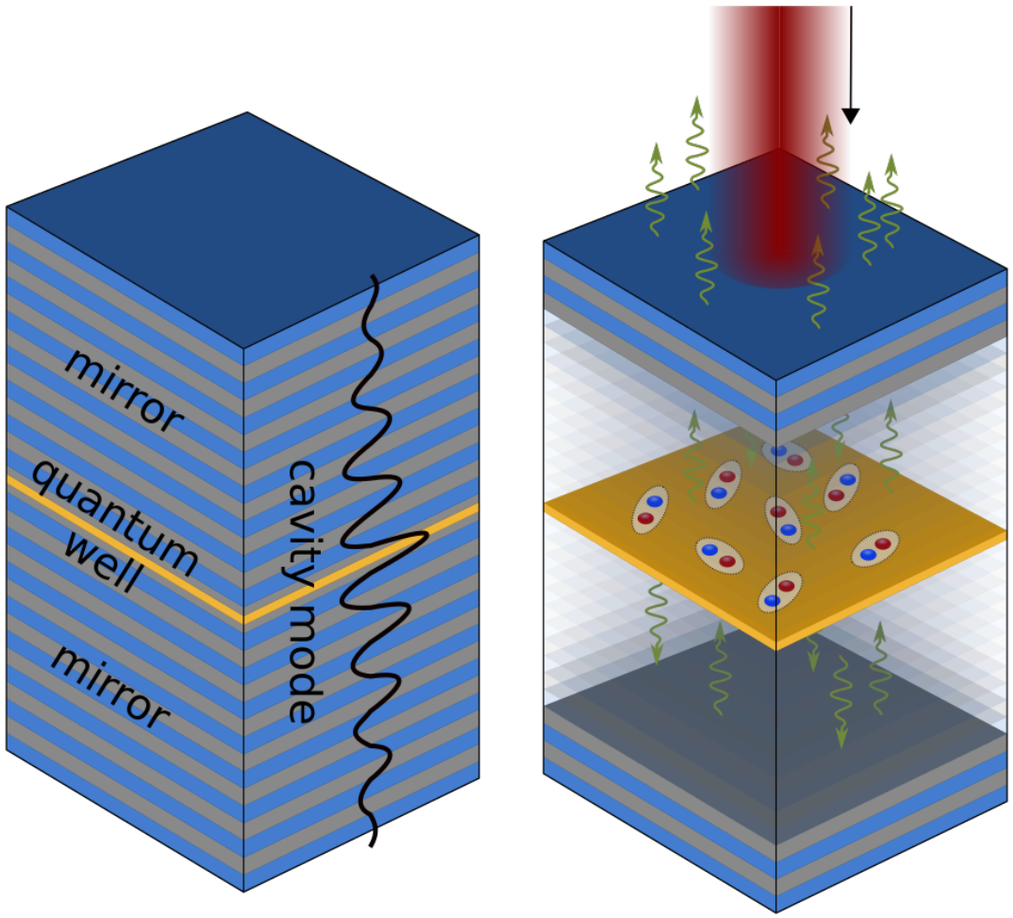
By utilizing the polariton fluid properties we study what are the physical laws behind the physics of these bosons gases.



HYBRID POLARITON

The use of organic materials let us study the interaction between light and matter also at room temperature.

Polaritons condensate



Polaritons are bosonic quasiparticles formed when excitons (electron-hole atoms) hybridize with photons (dressed photons with an effective mass).

Polaritons can be created by a pump laser in an optical cavity when the energy of the optical resonance is near to the exciton energy of the medium inside the cavity,

The photons become strongly interacting (Kerr nonlinearities) and can approach equilibrium and undergo Bose-Einstein condensation (BEC) at high density or low temperature.

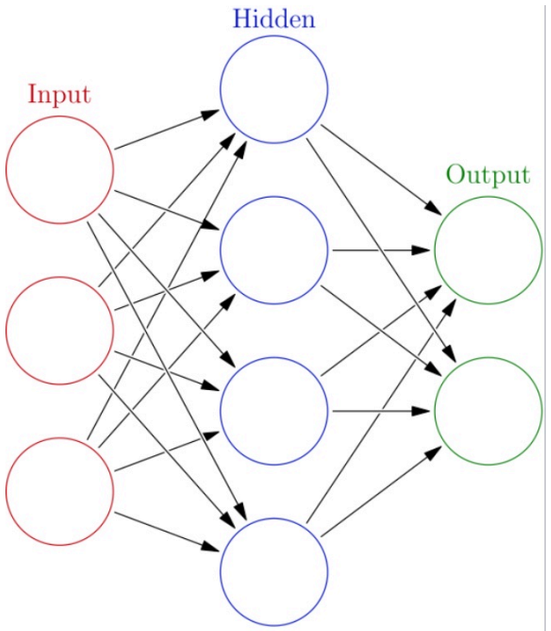
Quantum fluids of light are an emerging platform for energy-efficient signal processing, ultrasensitive interferometry and quantum simulators at elevated temperatures.

Polaritons network as optical neutral network

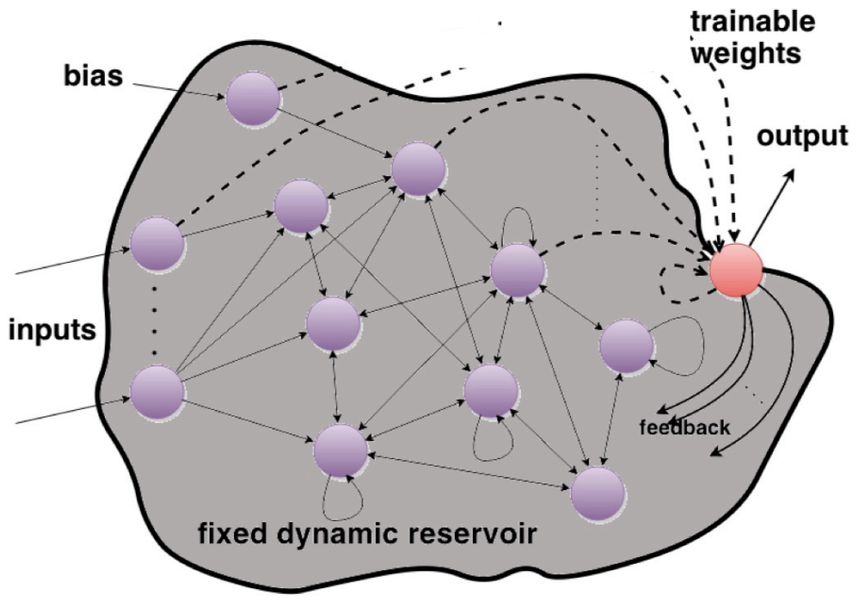
Rather than reproduce binary logic systems, an alternative approach here is demonstrated:

NEUROMORPHIC PROCESSING architecture having as RESERVOIR a POLARITON CONDENSATE to perform very efficient PATTERN RECOGNITION.

Artificial Neural Network vs Reservoir computing



In an Artificial Neural Network the training and the control of many weights between nodes is a challenging requirement on hardware.

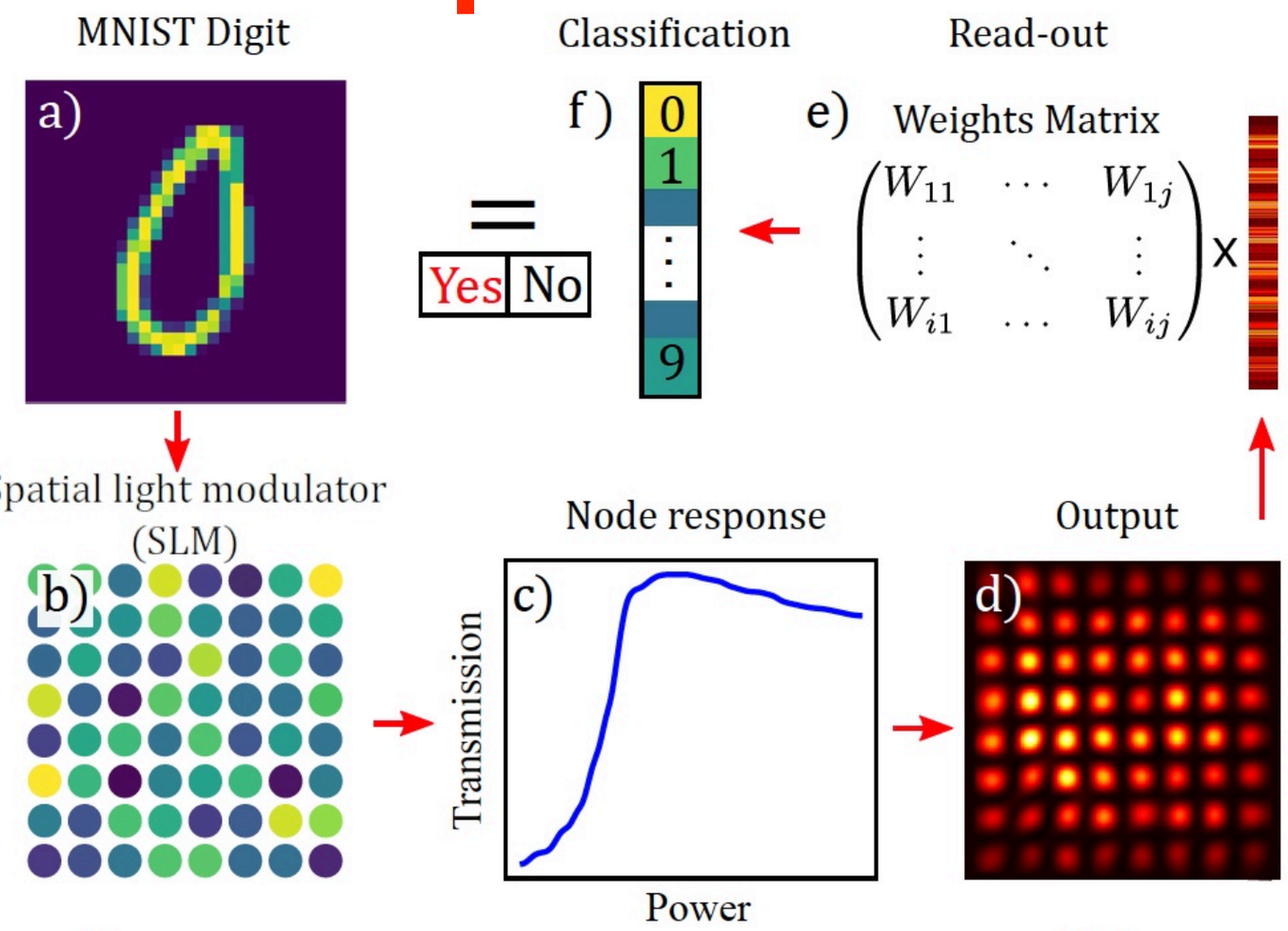


Reservoir Computing eliminate training and control of the neural network.
A input signal is fed into a fixed dynamical system called a reservoir and the dynamics of the reservoir map the input to a higher dimension.
The simple readout mechanism is trained to read the state of the reservoir and map it to the desired output.

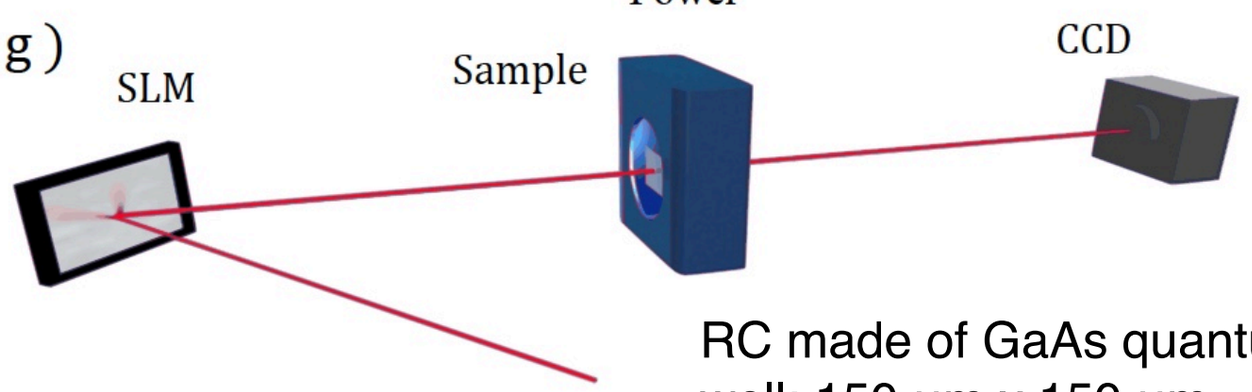
Optical Neural Network based on polaritons

28x28 handwritten

$28^2 \times 8^2$ random matrix



SLM used to generate an 8x8 array of polariton nodes with digit encoded in intensity and junction created by opposite phase for adjacent nodes.



774 nm pump laser threshold power few meV/nodes

RC made of GaAs quantum well: 150 µm x 150 µm fingerprint and steady state reached in 50 ps.

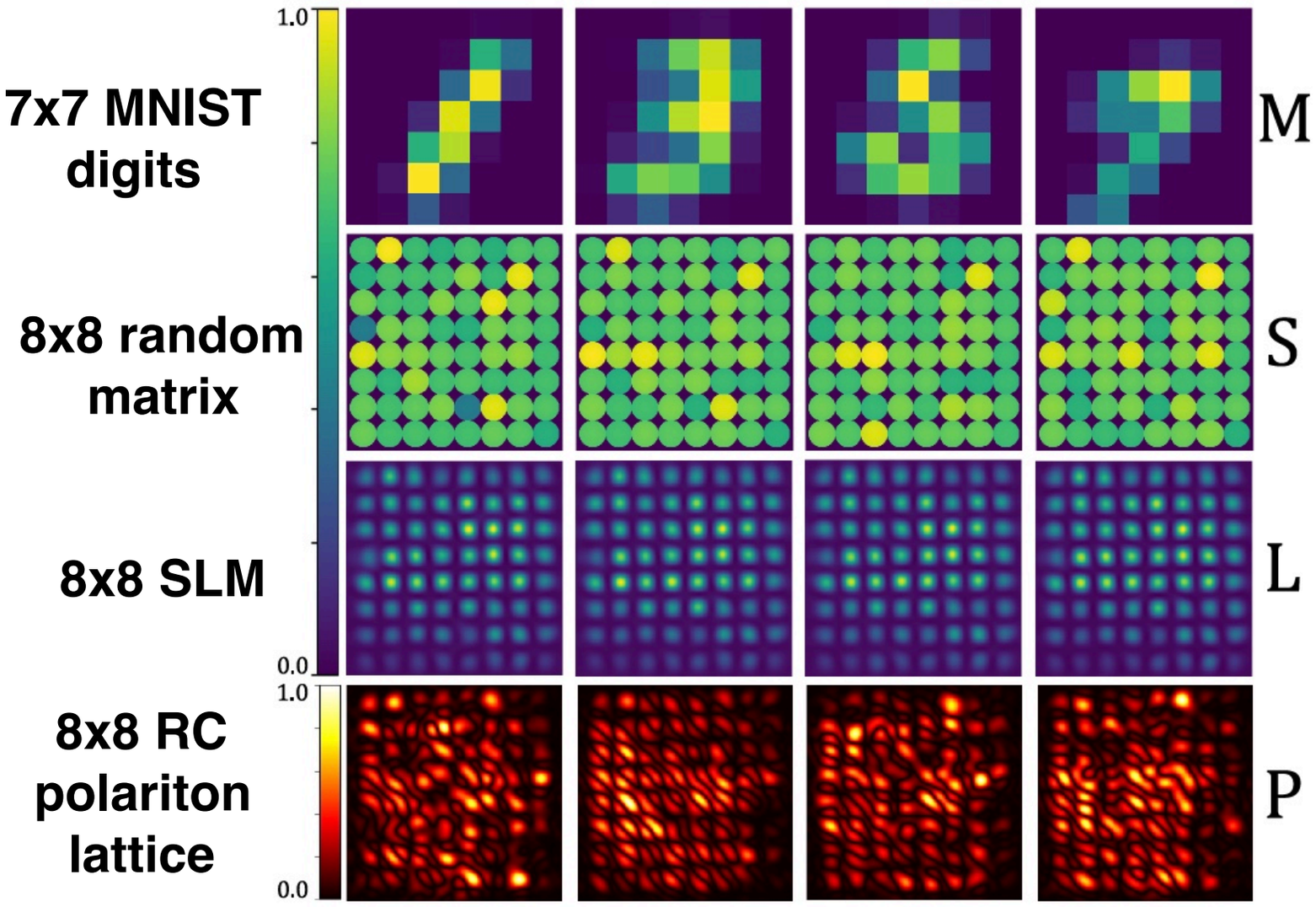
The PC in the readout stage could be replaced by an all-optical device performing a linear vector-matrix multiplication operation.

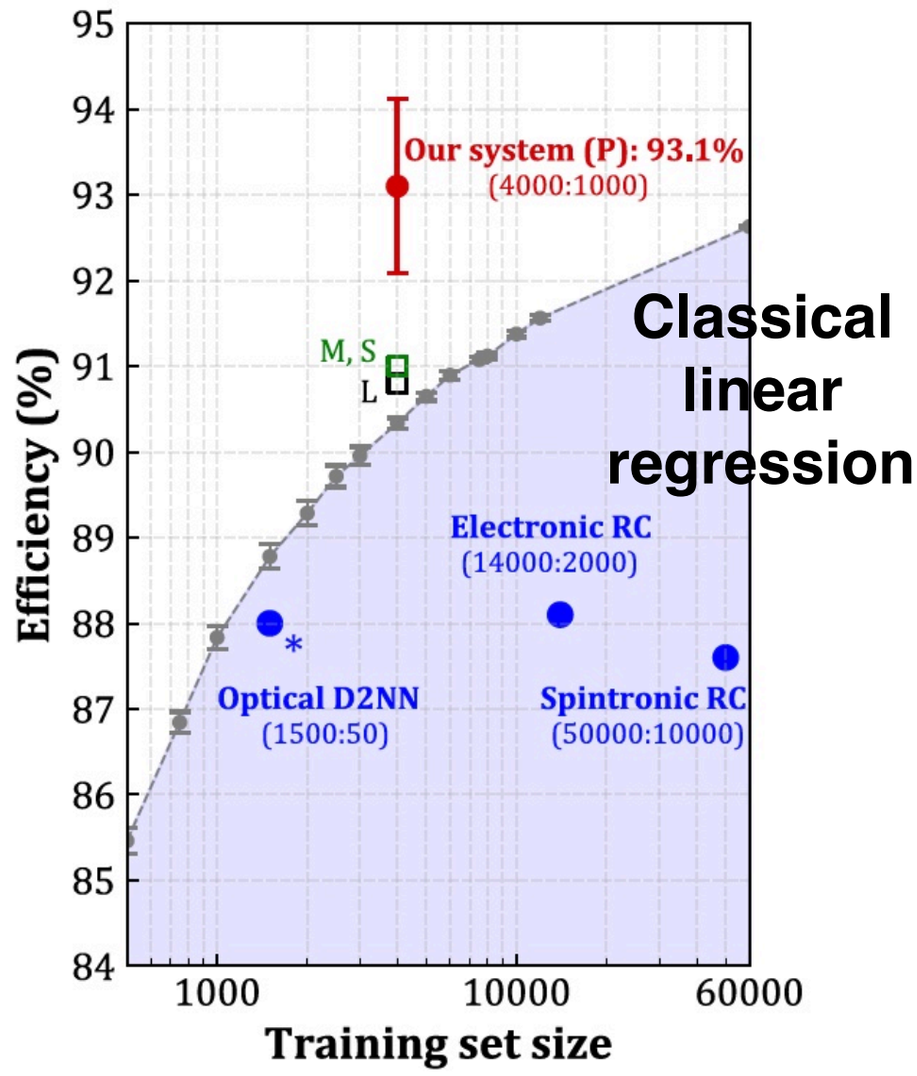
Polariton lattices of a few thousands nodes can be integrated on-chip with direct optical excitation with a repetition rates up to THz.

Polariton RC outperform linear classifier

A random choice of 5000 digits (80% for the training stage, 20% for the testing stage).

Training is realized on computer by finding weights for the readout matrix that minimize the error rate of predictions by a logistic regression.



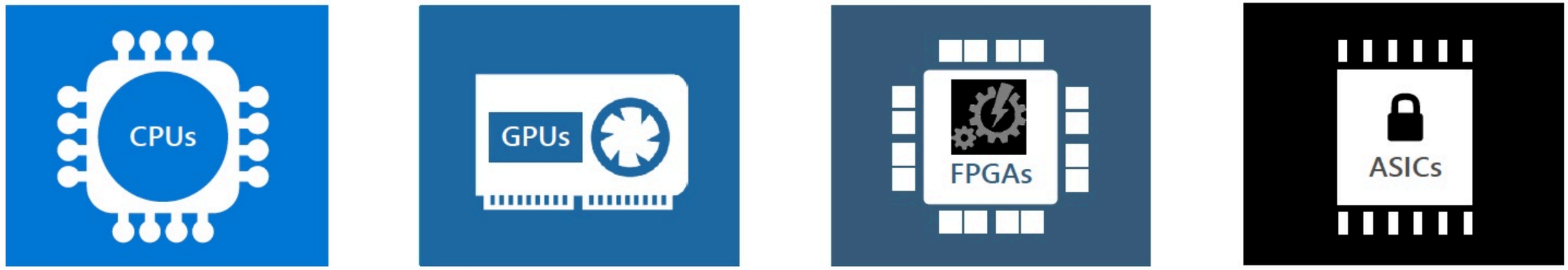


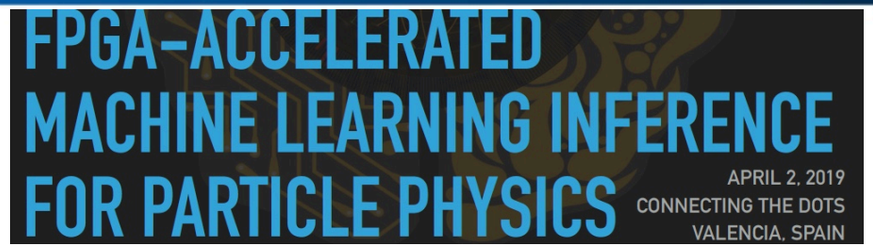
The network node is an artificial neuron with a nonlinear response function, while the fast polariton propagation within the cavity plane provides the effective connectivity between nodes.

Trends in Machine Learning

Focus in HEP

Focus in Industry





Javier Duarte
Fermilab

Could we go beyond with a realistic integration of ultrafast and low power artificial intelligence based on optical systems with present technologies?

Back-up

Von Neumann computing vs Neuromorphic computing

Von Neumann bottleneck: physical separation of memory and processing units → the data transfer increase the latency and idle time and decrease performance.

Neuromorphic computer mimic neuro-biological architectures present in the nervous system → native parallelism of tasks, avoiding the bottleneck of the von Neumann architecture.

Recap

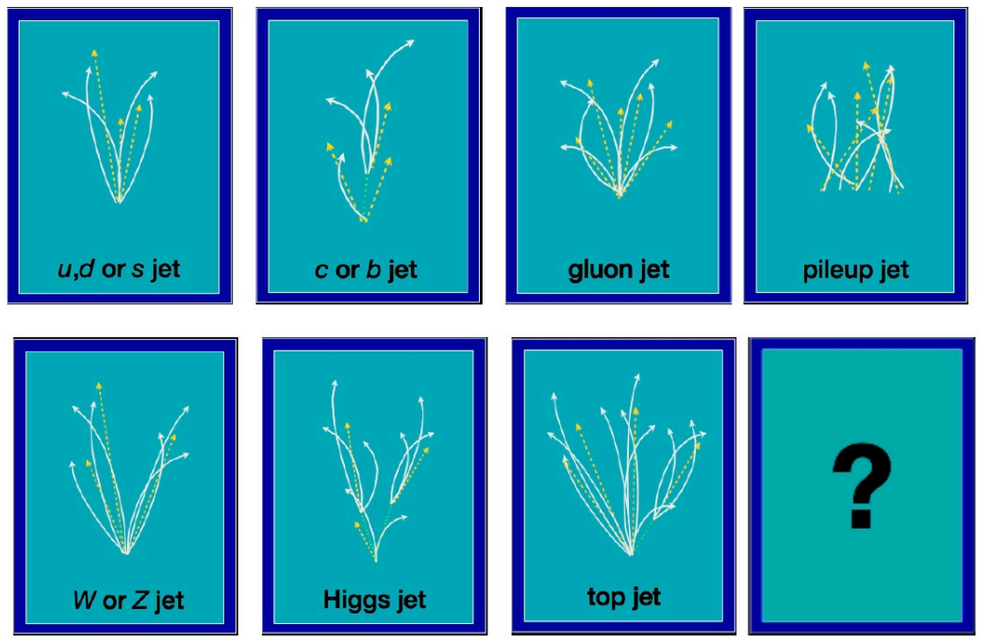
Up to now, all optical implementations of artificial neural networks have been limited by weak nonlinearities. This is one of the most challenging obstacles to overcome before photon-based neural networks can outperform standard computers.

Exciton-polaritons are a suited system thanks to their mixed light-matter components: polariton-polariton interactions brings the desired strong nonlinearities while the photonic component assures the connectivity between nodes and high operational speeds.

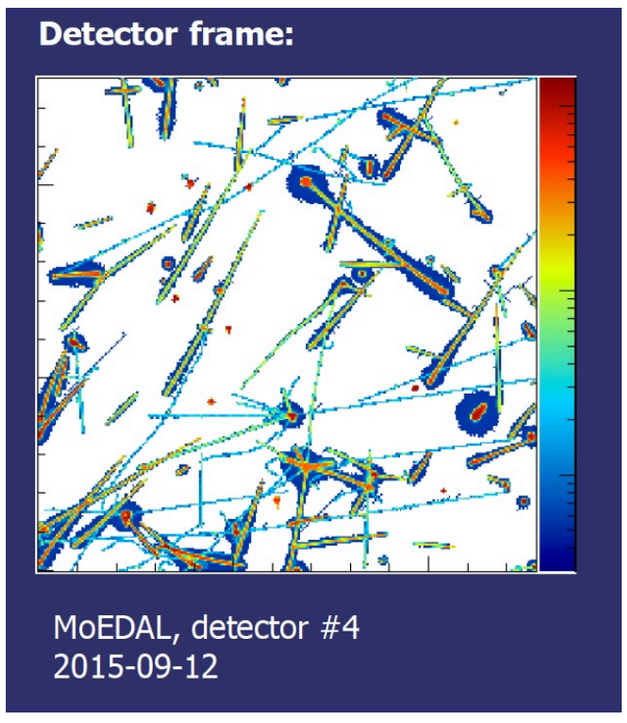
Highly efficient and ultrafast pattern recognition is achieved by exploiting the exceptional properties of exciton-polaritons lattice where data representing a single digit is processed simultaneously instead of sequentially.

Machine Learning in HEP

Partons and boosted object identification in jets

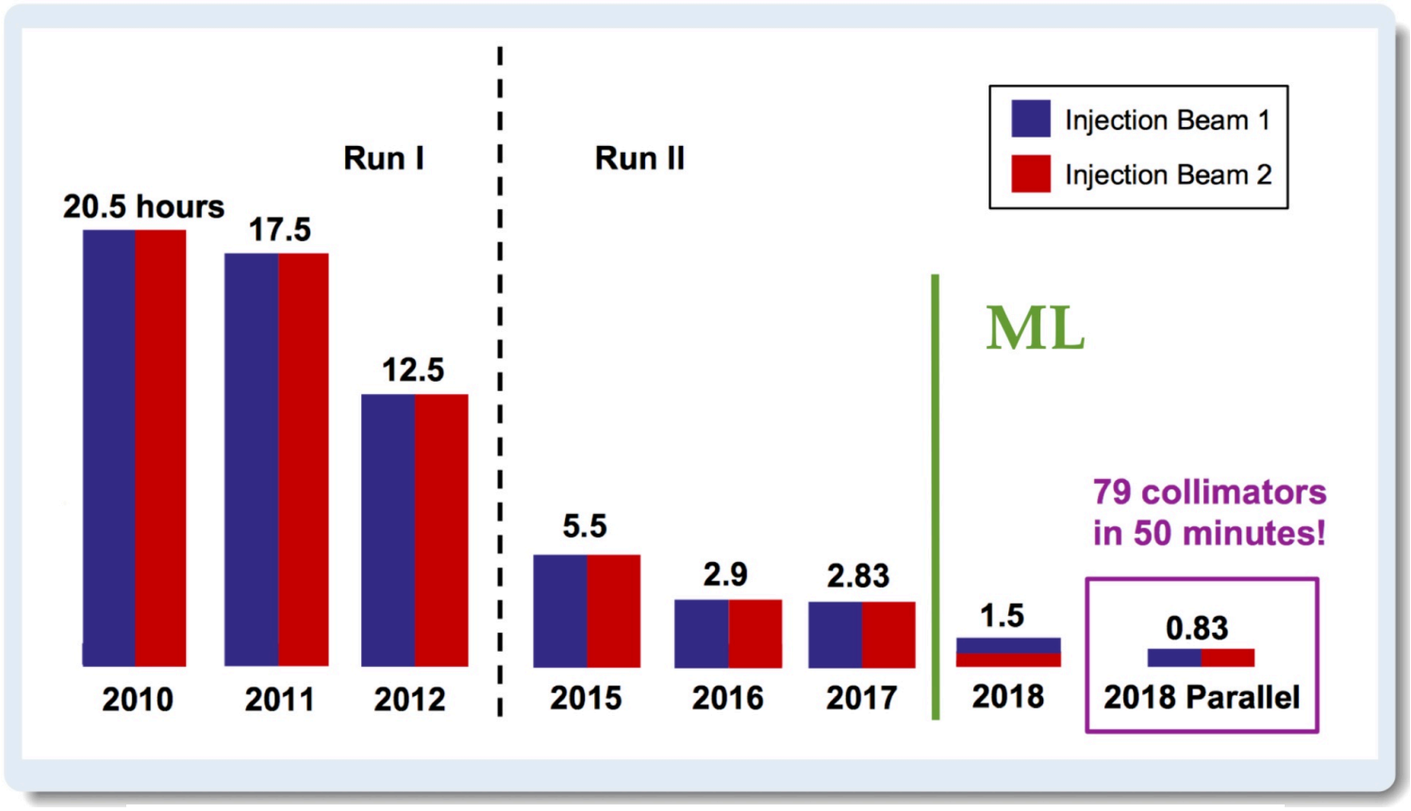


Particle identiication with TIMEPIX



CTD/WIT 2019
Valencia-
Petr Mánek

Application at LHC: collimator, optics, and beam lifetime.
EPS-HEP 2019 Ghent - F.F. Van der Veken



Topology classification with deep learning to improve real-time event selection at the LHC

Thong Q. Nguyen*[1], Daniel Weitekamp III[2], Dustin Anderson[1], Roberto Castello[3], Olmo Cerri[1], Maurizio Pierini[3], Maria Spiropulu[1], and Jean-Roch Vlimant[1]

[1]California Institute of Technology (USA)
[2]University of California at Berkeley (USA)
[3]Experimental Physics Department, CERN (CH)