CERN QTI Community Workshop

Friday, December 10, 2021 - Friday, December 10, 2021

Book of Abstracts

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R&D: Quantum Theory and Simulation

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R&D: Quantum Sensing, Metrology and Materials

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R&D: Quantum Communication and Networks

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CERN group or section submitting a project proposal:

Description:

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Introduction to Quantum Computing for High School Students

Author: Maria Alandes Pradillo[1]

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Description:

CERN participates in many outreach events in the local area. These events are a great opportunity to reach out to young students and bring science and technology closer to them. Teaching the basic concepts of quantum computing to high school students could contribute to build up on their interest for this technology that is still very much unknown to the general public. The workshop aims at stimulating student's interest on quantum technologies and demystifying the complexity of quantum physics by explaining basic concepts without using algebra or mathematical formulas.

CERN group or section submitting a project proposal:

Women in Technology

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An INFN-CERN collaboration towards the usage of IBM quantum resources

Author: Concezio Bozzi[1]

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Description:

An agreement between IBM and CERN grants CERN a license to access the IBM Q System, join the IBM Q Network, operate the CERN Hub and sublicense access to the same for purposes of research-level engagements. A collaboration agreement between CERN and INFN has been subsequently signed, whereby INFN researchers will access the IBM quantum systems and software technologies. Research topics include: studies of the dynamics of QCD-inspired theoretical models; the investigation of thermodynamical properties of simple theory models; a quantum simulation of the nucleon-nucleon potential; quantum machine learning for event classification at the LHC; the exploitation of Quantum graph networks for particle track reconstruction.

CERN group or section submitting a project proposal:

no

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Co-designing near-term quantum architecture for HEP applications

Authors: Junichi Tanaka[1]; Koji Terashi[1]; Lento Nagano[1]; Morino Terao[1]; Ryu Sawada[1]; Ryunosuke Okubo[1]; Sanmay Ganguly[1]; Shinichi Mizuhara[1]; Wonho Jang[1]; Yutaro Iiyama[1]

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Description:

Our project proposal is summarized in a set of slides linked from
https://cernbox.cern.ch/index.php/s/4q3uNWVy0NNaMrZ
We are open to work together with anyone in CERN community who is interested in this project.

CERN group or section submitting a project proposal:

ICEPP, The University of Tokyo

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Application of the quantum machine learning on the particle identification at the BESIII experiment

Authors: Jiaheng Zou[None]; Teng LI[1]; Tao Lin[None]; Weidong Li[2]; Xingtao Huang[3]; Zhipeng Yao[3]

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Description:

Particle identification is one of most fundamental tools in various HEP experiments. For the BESIII experiment on the BEPCII, the realization of numerous physical goals heavily relies on advanced particle identification algorithms. In recent years, the emerging of quantum machine learning could potentially arm HEP experiments with a powerful new toolbox. In this proposal, targeting at the PID problem at BESIII, we are developing quantum classifiers based on quantum machine learning algorithms under the Noisy Intermediate-Scale Quantum (NISQ) device. The first algorithm we developed is a SVM classifier based on quantum kernel methods, while the second algorithm we are developing is a variational quantum classifier, also known as a quantum neural network. For the quantum SVM classifier, we mainly study the expressiveness of different feature maps by optimizing the encoding circutis, while for the quantum neural network, we mainly study different variational circuits and optimization methods. By simulating these models using the IBM quantum simulator, as well as deploying the models to the Wuyuan quantum hardware system, we found that the quantum classifiers show comparable discrimination power with other traditional machine learning models. This has demonstrated the potential of using quantum machine learning techniques to form a new approach for particle identification in HEP experiments.

CERN group or section submitting a project proposal:

ATLAS

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Quantum walks in high energy physics

Author: Sarah Malik[1]

[1] *Imperial College (GB)*

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Description:

We've shown that quantum computers can be used to calculate helicity amplitudes for simple scattering processes at the LHC and also to model the subsequent parton shower using a quantum walk framework. This project aims to explore other applications of the quantum walk within high energy physics

CERN group or section submitting a project proposal:

Physics

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Development of quantum machine learning algorithms to study Higgs boson decays with the LHCb detector

Authors: Alessio Gianelle[1]; Davide Nicotra[1]; Donatella Lucchesi[None]; Carlos Vazquez Sierra[2]; Davide Zuliani[1]; Eduardo Rodrigues[3]; Jacco Andreas De Vries[4]; Lorenzo Sestini[1]

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CERN group or section submitting a project proposal:

quantum computing and algorithms

Description:

Quantum Machine Learning (QML) algorithms are proposed as an exciting prospective application of quantum technologies. Problems that are classically hard to compute have potential to be solved faster by such new algorithms. The LHCb collaboration has already made a first step by studying the identification of b and b-bar jets showing new possibilities opened by these algorithms.
This new project proposes to demonstrate how QML can improve the determination of the Higgs boson decay rates to b and c jets by exploiting the different b and c jet sub-structure.

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Noise Gates

Authors: Angelo Bassi[1]; Francesco Cesa[2]; Giovanni Di Bartolomeo [1]; Michele Vischi [2]; Sandro Donadi[2]

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Description:

Assessing the effect of noises in quantum computers is a major task for understanding their practical applicability for solving real-life problems. In quantum mechanics, and in particular in quantum computation, noises emerging from the interaction of a system with its surrounding environment is formulated in terms of the density matrix. The theory is well developed, but from the computational point of view resorting to the density matrix instead of the state vector makes the problem quadratically more difficult to solve.

We propose a scheme called Noise Gates, that uses state vectors evolving according to a stochastic Schrödinger equation. This descriptions is statistically equivalent to the density matrix formulation: by taking the average over different noise realizations, one recovers the evolution of the density matrix. At the same time, it presents the computational advantage of working with the state vector.

Thanks to stochastic Schrödinger equations, the effects of the noise are described by a linear and stochastic matrix, mathematically equivalent to a quantum gate that includes the effects of the noise. This gives our method its name, Noise gates. By finding the expressions for these noise gates, we will perform classical simulations of noisy quantum algorithms on quantum computers, in order to analyze error propagation and devise strategies to mitigate them.

CERN group or section submitting a project proposal:

Angelo Bassi's group

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Quantum Algorithms for Manifold Learning

Author: Akshat Kumar[None]

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Description:

The Manifold Hypothesis (MH) states that naturally occurring, real-world data is intrinsically low-dimensional and thus provides a guideline for the success of most machine learning techniques. Manifold learning is a sub-field of machine learning that aims to reduce dimensionality and recover the relevant geometry underlying high-dimensional datasets. Data analysis tasks involving tracking, clustering, anomaly/signal detection and classification are prime applications of manifold learning, since they are most effectively solved once the data is transformed to a low-dimensional and well-organized representation. Through the MH, applications go beyond these: Generative Adversarial Networks are widely used for fast simulations and their training and stability issues are directly linked to the persistence of the confinement of data to low-dimensional manifolds; a priori dimensionality reduction is thus an oft-proposed regularization step. The LHC requires such data analyses at scales so demanding that recently, attention has turned to quantum computing; however, the effective formulation of quantum algorithms to achieve a significant speed-up is highly non-trivial. We have recently showed that manifold learning can be achieved with purely quantum primitives: evolving certain localized wavepackets through data-derived Hamiltonian dynamics produces states localized along geodesics of the latent space; then, for example, taking expectations yields geodesic coordinates that serve to transform the data into latent degrees of freedom. We propose to use these results to devise quantum algorithms for manifold learning and subsequent data analysis tasks that are required of particle physics experiments at the LHC.

CERN group or section submitting a project proposal:

CERN Openlab

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Simulating a quantum battery on an quantum computer

Authors: Dario Ferraro[1]; Michele Grossi[2]

[1] *University of Genova*

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Description:

Aim of this project is to characterize the functioning of a quantum battery made by one or more qubits. In this kind of devices the charging phase can be achieved by means of a classical time dependent drive [1]. By using the tools provided for the pulse engineering [2] the optimal profile of the drive able to minimize the charging time, still leading to a full charge of the quantum battery (arbitrary initial state to excited state transition), will be determined. The energy fluctuation associated to this charging process will be considered in order to determine the stability and the efficiency of the device [3]. The typical discharging time of the battery towards the ground state once the drive is switched off will be also estimated. In the case of a quantum battery made by more than one qubit the role of mutual interaction among these subunits in the performance of the device will be also investigated [4].

[1] A. Crescente, M, Carrega, M. Sassetti, D. Ferraro, New J. Phys. 22, 063057 (2020).
[2] T. Alexander et al., Quantum Sci. Technol. 5, 044006 (2020).
[3] S. Gherardini, A. Belechia, M. Paternostro, A. Trombettoni, Phys. Rev. A 104, L050203 (2021).

[4] Y.-Y. Zhang, T.-R. Yang, L. Fu, X. Wang, Phys. Rev. E 99, 052106 (2019).

CERN group or section submitting a project proposal:

Algorithm

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Particle ID with timing using quantum algorithms

Authors: Karolos Potamianos[1]; Daniel Dobos[2]; Bilge Demirkoz[3]; Kristiane Novotny[4]

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Description:

Can quantum machine learning algorithms tackle particle identification challenges, do they provide any kind of new insights ?

In the high pileup conditions at the High-Luminosity LHC, particle identification using vertex detectors in combination with calorimetry becomes a challenging task. The use of detector hit timing information, through high precision (pico-second) time resolved tracking (4D tracking detectors) and fast calorimetry, is a promising possibility to resolve combinatorial ambiguities in the tracking. So is the use of extended classical and Quantum Machine Learning (QML) algorithms. We propose to compare the results obtained using QML techniques with results using available classical ML algorithms.

CERN group or section submitting a project proposal:

gluoNNet & METU & CERN openlab

Project and collaboration proposals / 22

theory-informed classification of proton-proton collisions with quantum machine learning tools

Authors: Andrea Giachero[1]; Pietro Govoni[1]

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Description:

The data analysis of the results of proton-proton collisions performed at the CERN LHC is currently heavily relying on classical machine learning algorithms for optimal separation between signal and backgrounds. The training of these discriminants, that in the vast majority of the cases are either boosted decision trees or deep neural networks, relies of large samples of simulated events, while the discriminants architecture is usually based on empirical trial-and-error-based techniques to choose the algorithm hyperparameters.
The aim of this project is to perform a fully blown comparative study between classical and quantum machine learning (QML) in the proton collisions case, in order to quantify the differences in performances

between the two techniques. In fact, the elementary particle interaction is an ideal environment due to the relatively limited number of features that characterise the physics events, the highest degree of reproducibility of the initial conditions, the availability of simulations linked to theory calculations with high precision and quantitative estimates of their availability, the extreme quality of the simulated events.

The study will focus on the electroweak production of vector boson pairs, which is of fundamental importance for the understanding of the electroweak symmetry breaking (EWSB), which is the theoretical corner stone of the standard model of particle physics. This kind of interaction is characterised by an unfavourable signal-over-background ratio and yet a very distinct signature, due to the presence of six fermions in the final state, which have distinct kinematical and topological behaviours dictated by the theoretical properties of the events.

We will test the performances of classical and quantum machine learning in several different conditions, with fully comparable benchmark scenarios and figures of merit. Studies will be performed as a function of the initial conditions, as for example the number of available training simulated events; as a function of the classical and quantum model design and hyperparameters; with different theoretical precision in the signal and backgrounds calculation, with respect to the full interaction description. When possible, we will confront the results to real LHC data, either in agreement with the experimental Collaborations, or making use of Open Data.

Thanks to the deep theoretical understanding of the process, we will build the QML model with a quantum circuit architecture adapted to the expected physical correlations among the model input features, to either verify whether the QML training would be able to single out expected entanglements, or check whether context-aware architectural choices may generate significative improvements in the circuit performances. In particular, we will investigate the advantages of such an approach in the isolation of the longitudinal component of the scattering, which is by far the most sensitive one to the EWSB physics.

The proponents are for the time being by Pietro Govoni and Andrea Giachero. Pietro Govoni is Associate Professor at Milano - Bicocca University and works in the field of experimental particle physics: he is member of the CMS Collaboration, where he works in the study of standard model processes, in particular on vector boson scattering. He is currently one of the CMS SMP Physics Analysis Group conveners and he lead the COST Action CA16108 named VBSCan and dedicated to the study of vector boson scattering at hadron colliders.

Andrea Giachero is Assistant Professor at Milano - Bicocca University and works in the fields of experimental particle physics and quantum technologies. He is the Principal Investigator of the DARTWARS project (https://dartwars.unimib.it/) and member of the HOLMES and CUORE collaborations. Starting from October 2021 is a Marie Skłodowska-Curie IF Researcher. He leads the Quantum Information Science - Milano Bicocca University (QISMIB) program (https://github.com/qismib) that aims to introduce students to quantum computing.

We would like to collaborate with the CERN Quantum Computing group to create a stronger team, and propose a thesis for a brilliant master student to be the main player of the project. The tools needed for the project to start are well established in the fields of QML and high-energy physics, therefore the project may start very quickly. The student would be selected based on excellence in the academic history and prior knowledge of quantum computing and particle physics, so to become operative in a short time, with a limited needed preliminary training. The duration of the project is expected to be less than a year.

The final results will show a systematic quantitative comparison between classical and quantum machine learning with respect to the various possible architectures and initial conditions, investigating the new interesting avenue of context-aware QML training.

CERN group or section submitting a project proposal:

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