QuantHEP: Quantum and Tensor Network Solutions for High-Energy and T-NiSQ Workshop

Monday, January 30, 2023 - Tuesday, January 31, 2023

Dept. of Physics and Astronomy - Univ. of Padova

Scientific Program

QuantHEP Workshop

Monday, January 30 (Venue: Aula Voci - Galilei building):

11:00 - Yasser Omar: Overview of QuantHEP project
11:15 - Sofia Vallecorsa: Quantum algorithms for anomaly detection at LHC
12:00 - Hannes Pichler: Quantum Optimization with Rydberg Atom Arrays beyond Unit Disk Graphs

12:45 - Lunch at Osteria La Sofia (Via Aristide Gabelli, 2b)

14:30 - Sunny Pradhan: Hamiltonians and gauge-invariant Hilbert space for lattice gauge theories with finite non- Abelian group
15:00 - Matteo Turco: Preparation of interacting wavepackets for quantum simulation of scattering

15:30 - Coffee break (Room R)

16:00 - Enrique Rico Ortega: Quantum Simulation of Light-Front Parton Correlators
16:45 - Giovanni Cataldi: Tensor Network Simulations of (2+1)D SU(2) Yang Mills Lattice Gauge Theory
17:15 - Open Discussion

20:00 - Social dinner at La Gourmetteria (via Zabarella 23, https://www.gourmetteria.com)

Tuesday, January 31 (Venue: Room P4C - Paolotti building)

9:30 - QuantHEP Board Meeting
10:15 - Marco Pezzutto: Energetics of quantum technologies: quantum dynamics for energetic advantage in a charge-based classical full-adder

11:00 - Coffee break (outside Room P4C)

11:30 - Saverio Pascazio: Dimensional reduction of field theories
12:15 - Alice Pagano: Ab-initio two-dimensional digital twin for quantum computer benchmarking

13:00 - Lunch at Casa Vecchiato Pane e Vino (inside Centro Culturale San Gaetano)

14:15 - Domenico Pomarico: Dynamical quantum phase transitions of the Schwinger model: real-time dynamics on IBM Quantum
15:00 - Open Discussion

Book of Abstracts

Title: Quantum algorithms for anomaly detection at LHC
Speaker: Sofia Vallecorsa (CERN)
Abstract: One of the main goals of the LHC physics program is the search for new physics phenomena Beyond the Standard Model (BSM). Typical BSM searches are model-dependent and, exploiting at best the difference between the expected signal and known background process, achieve remarkable discrimination power. Unfortunately, this approach suffers from intrinsic limitations with respect to any other kind of physics deviating from the theoretical model under study. Consequently, if an unexpected signature is present in the data, it might not be identified due to this inherent bias. In order to avoid this limitation, an unsupervised approach can be used to frame the search for new physics as an Anomaly Detection (AD) problem. Unsupervised algorithms for AD rely on less information than supervised methods and are currently widely studied in the context of LHC experiments. This talk describes a new strategy for anomaly detection at the LHC based on unsupervised quantum machine learning algorithms. To accommodate the constraints on the problem size dictated by limitations of current quantum hardware a classical convolutional autoencoder is trained for data compression. Quantum anomaly detection models, namely an unsupervised kernel machine and two clustering algorithms, are then trained to find new-physics events in the latent representation of LHC data produced by the autoencoder. The performance of the quantum algorithms is benchmarked against classical counterparts on different BSM scenarios and the dependence on different model hyper-parameters is studied.

Title: Quantum Optimization with Rydberg Atom Arrays beyond Unit Disk Graphs
Speaker: Hannes Pichler (University of Innsbruck & IQOQI)
Abstract: Programmable quantum systems based on Rydberg atom arrays are a promising platform for tests of quantum optimization algorithms with hundreds of qubits. In particular, the maximum independent set problem on so-called unit-disk graphs has a natural realization in such systems. In this talk I discuss strategies to extend the classes of problems that can be efficiently encoded in Rydberg arrays by constructing explicit mappings from several generic optimization problems to maximum weighted independent set problems on unit-disk graphs, with at most a quadratic overhead in the number of qubits. This includes: maximum weighted independent set on graphs with arbitrary connectivity, quadratic unconstrained binary optimization problems with arbitrary connectivity, and integer factorization formulated as an optimization problem. This provides a blueprint for using Rydberg atom arrays to solve a wide range of combinatorial optimization problems with arbitrary connectivity.
Title: Hamiltonians and gauge-invariant Hilbert space for lattice gauge theories with finite non-Abelian group Speaker: Sunny Pradhan (University of Bologna)
Abstract: Motivated by quantum simulation, we consider Hamiltonians for lattice gauge theories with finite non- Abelian group. We show that the electric Hamiltonian admits an interpretation as a certain natural Laplacian operator on the finite group. Independently of the chosen Hamiltonian, we provide a full explicit description of the physical, gauge-invariant Hilbert space using spin networks and derive a simple formula for computing its dimension. We illustrate the use of the gauge-invariant basis to diagonalize a dihedral gauge theory on a small periodic lattice.

Title: Preparation of interacting wavepackets for quantum simulation of scattering
Speaker: Matteo Turco (CeFEMA Lisbon)
Abstract: In their seminal paper, Jordan, Lee and Preskill provided for the first time an efficient algorithm for quantum simulation of scattering in (scalar) quantum field theory. State preparation is the most resource- consuming part of the algorithm and can be organized as follows:
1) free ground-state preparation
2) excitation of non interacting single-particle wavepackets
3) adiabatic transformation to interacting wavepackets.
Assuming the capability to prepare the ground-state of the interacting theory, in this work we present a method, based on results from axiomatic quantum field theory, to prepare interacting single-particle wavepackets starting directly from the interacting vacuum. With some caveat this method can be used to prepare also incoming bound states for the scattering simulation, which is

not possible with the algorithm presented by Jordan, Lee and Preskill.

Title: Quantum Simulation of Light-Front Parton Correlators
Speaker: Enrique Rico Ortega (Ikerbasque & UPV/EHU)
Abstract: The physics of high-energy colliders relies on the knowledge of different non-perturbative parton correlators, such as parton distribution functions, that encode the information on universal hadron structure and are thus the main building blocks of any factorization theorem of the underlying process in such collision. These functions are given in terms of gauge-invariant light-front operators, they are non-local in both space and real time, and are thus intractable by standard lattice techniques due to the well-known sign problem. In this talk, we present a quantum algorithm to perform a quantum simulation of these type of correlators, and illustrate it by considering a space-time Wilson loop. We discuss the implementation of the quantum algorithm in terms of quantum gates that are accessible within actual quantum technologies such as cold atoms setups, trapped ions or superconducting circuits.
Reference: Phys. Rev. D 104, 014512 (2021)

Title: Tensor Network Simulations of (2+1)D SU(2) Yang Mills Lattice Gauge Theory
Speaker: Giovanni Cataldi (University of Padua)
Abstract: Exploiting Tensor Network simulations, we study a (2+1)D SU(2) Yang-Mills lattice gauge theory in the Hamiltonian formulation. Within the Quantum Link Model approach, we develop a sign-problem-free formalism that allows for simulating the Hamiltonian in both zero and finite charge densities. Correspondingly, we address a qualitative description of the whole phase diagram of the model, including small and large regimes of gauge and mass couplings. In both the charge sectors, gauge fields display a transition between electric and magnetic phases. Besides, the dynamical matter locally freezes in both gauge phases while fluctuating at criticality. Ultimately, we find the model behaving as a topological insulator, with the same topology as the Toric Code but energy-separated topological sectors.

Title: Energetics of quantum technologies: quantum dynamics for energetic advantage in a charge-based classical full-adder
Speaker: Marco Pezzutto (University of Lisbon)
Abstract: Conventional classical computers are becoming increasingly energy demanding. Beside the costs, this is becoming a limiting factor on their performance. On the other hand, quantum computers are a reality and are improving constantly, but quantum supremacy is still debated, scalability is a challenge, and few applications to relevant practical computational problems exist. Most of the efforts have been focused on achieving increasingly better computational performance and accuracy; the question of energy performance of quantum computers, however, has been playing a secondary role so far, and it has only gained some attention recently, and has opened the possibility for a quantum advantage from the energy point of view. In fact, quantum computers require many accessory systems whose energy demand is significant but should not grow substantially with the size of quantum processors. In addition, quantum unitary dynamics is reversible, therefore not subjected to the intrinsic minimal energy dissipation required by the Landauer principle. The question arises: can quantum technologies, originally developed for quantum computers, also be employed to perform classical computations more efficiently? We address this question with a proposal for a one-bit full-adder to process classical information based on a few electrons in a triple quantum dot system, serving as a proof of principle for the development of energy-efficient information technologies operating through coherent quantum dynamics. The device works via the repeated execution of a Fredkin gate implemented through the dynamics of a single time-independent Hamiltonian. Our proposal uses realistic parameter values and could be implemented on currently available quantum dot architectures. We compare the estimated energetic costs for operating our full-adder with those of well-known fully classical devices, and identify a few important factors for the future success of this technology.

Title: Dimensional reduction of field theories
Speaker: Saverio Pascazio (University of Bari)
Abstract: We derive and discuss one- and two-dimensional (classical) field-theoretical models by making use of Hadamard’s method of descent. We focus on electromagnetism (Maxwell) and spin-1/2 fields (Dirac). Low-dimensional field models are conceived as a specialization of the higher dimensional ones, in which the fields are uniform along the additional spatial directions. We consider the free situation and then the interacting fields. The basic properties of these theories, as well as their relation with existing models for two-dimensional matter, are discussed. We focus on the relevance of these findings for the quantum simulation of (lattice) gauge theories.

Title: Ab-initio two-dimensional digital twin for quantum computer benchmarking
Speaker: Alice Pagano (University of Padua)
Abstract: Large-scale numerical simulations of the Hamiltonian dynamics of a Noisy Intermediate Scale Quantum (NISQ) computer - a digital twin - could play a major role in developing efficient and scalable strategies for tuning quantum algorithms for specific hardware. Via a two-dimensional tensor network digital twin of a Rydberg atom quantum computer, we demonstrate the feasibility of such a program. In particular, we quantify the effects of gate crosstalks induced by the van der Waals interaction between Rydberg atoms: according to an 8x8 digital twin simulation based on the current state-of-the-art experimental setups, the initial state of a five-qubit repetition code can be prepared with a high fidelity, a first indicator for a compatibility with fault-tolerant quantum computing. The preparation of a 64-qubit Greenberger-Horne-Zeilinger (GHZ) state with about 700 gates yields a 99.9% fidelity in a closed system while achieving a speedup of 35% via parallelization.

Title: Dynamical quantum phase transitions of the Schwinger model: real-time dynamics on IBM Quantum
Speaker: Domenico Pomarico (University of Bari)
Abstract: Simulating real-time dynamics of gauge theories represents a paradigmatic use case to test the hardware capabilities of a quantum computer, since it can involve non-trivial input states preparation, discretized time evolution, long-distance entanglement, and measurement in a noisy environment. We implement an algorithm to simulate the real-time dynamics of a few-qubit system that approximates the Schwinger model in the framework of lattice gauge theories, with specific attention to the occurrence of a dynamical quantum phase transition. Limitations in the simulation capabilities on IBM Quantum are imposed by noise affecting the application of single-qubit and two-qubit gates, which combine in the decomposition of Trotter evolution. The experimental results collected in quantum algorithm runs on IBM Quantum are compared with noise models to characterize the performance in the absence of error mitigation.