Quantum Computing and Machine Learning Workshop 2025

Report of Contributions

Contribution ID: **2** Type: **not specified**

基于机器学习的 eXTP 卫星 PFA 载荷地面和在轨数光电子径迹重建

eXTP 卫星是我国下一代旗舰级 X 射线天文台，其中的 PFA 载荷对能量为 2-10 keV 的 X 射线进行可成像的偏振、时变和能谱观测。PFA 载荷的气体 X 射线偏振探测器基于 X 射线在气体探测器中发生光电效应时光电子出射方向在垂直于 X 射线入射方向的平面内的角分布来测量偏振。在这类探测器的数据分析中，最关键的就是光电子径迹的重建。由于光电子径迹是通过测量光电子在气体探测器内与气体分子碰撞而产生的电离电子所描绘的径迹而获得的。光电子在运动过程中，除了电离出电子，还会因为和气体分子中的原子核发生库里散射而改变方向，同时还会伴随有俄歇电子的产生，所有这些因素增加了光电子径迹重建的复杂性。传统的光电子径迹重建方法是力矩法，随着机器学习技术的发展，我们开展了基于深度学习的地面和在轨光电子径迹重建方法的研究，本报告将介绍相关研究情况。

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Contribution ID: **4** Type: **not specified**

Machine Learning for Parton-Level Studies of Quantum Entanglement Using pp→ττ

Quantum entanglement is a hallmark feature of quantum mechanics, manifesting as correlations between subsystems that cannot be fully described without one another, regardless of spatial separation. While entanglement has been observed in processes such as $pp \to t\bar{t}$ and thoroughly analyzed in Higgs decay channels ($H \to VV$) at the Large Hadron Collider (LHC), it remains comparatively underexplored in the $pp \to \tau\tau$ system. In this study, we adapt OmniLearn, a foundational model for solving all jet physics tasks, to reconstruct the neutrino information in the final state of $pp \to \tau\tau$ system, which is an essential step toward probing quantum entanglement in this channel. Good neutrino reconstruction has reached now, which is the key to the following steps in the reconstruction level study.

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Contribution ID: **5** Type: **not specified**

Quantum simulations of quantum electrodynamics in Coulomb gauge

In recent years, the quantum computing method has been used to address the sign problem in traditional Monte Carlo lattice gauge theory (LGT) simulations. We propose that the Coulomb gauge (CG) should be used in quantum simulations of LGT. Since the redundant degrees of freedom of gauge fields can be eliminated in CG, the Hamiltonian in CG does not need to be gauge invariance, allowing the gauge field to be discretized naively. Then the discretized gauge fields and fermion fields should be placed on momentum and position lattices, respectively. Under this scheme, the CG condition and Gauss's law can be conveniently preserved by solving for the polarization vectors from algebraic equations. Furthermore, we discuss the mapping of gauge fields to qubits and evaluate the associated qubit and gate cost of this framework. We point out that this formalism is efficient for simulating hadron scattering processes on future fault-tolerant quantum computers. Finally, we calculate the vacuum expectation value of the U(1) plaquette operator and the Wilson loop on a classical device to test the performance of our discretization scheme.

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Contribution ID: **6** Type: **not specified**

Computing n-time correlation functions without ancilla qubits

The n-time correlation function is pivotal for establishing connections between theoretical predictions and experimental observations of a quantum system. Conventional methods for computing n-time correlation functions on quantum computers, such as the Hadamard test, generally require an ancilla qubit that controls the entire system – an approach that poses challenges for digital quantum devices with limited qubit connectivity, as well as for analog quantum platforms lacking controlled operations. Here, we introduce a method to compute n-time correlation functions using only unitary evolutions on the system of interest, thereby eliminating the need for ancillas and the control operations. This approach substantially relaxes hardware connectivity requirements for digital processors and enables more practical measurements of n-time correlation functions on analog platforms. We demonstrate our protocol on IBM quantum hardware up to 12 qubits to measure the single-particle spectrum of the Schwinger model and the out-of-time-order correlator in the transverse-field Ising model. In the demonstration, we further introduce an error mitigation procedure based on signal processing that integrates signal filtering and correlation analysis, and successfully reproduces the noiseless simulation results from the noisy hardware. Our work highlights a route to exploring complex quantum many-body correlation functions in practice, even in the presence of realistic hardware limitations and noise.

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Contribution ID: **7** Type: **not specified**

Transfer learning empowers material Z classification with muon tomography

Cosmic-ray muon sources exhibit distinct scattering angle distributions when interacting with materials of different atomic numbers (Z values), facilitating the identification of various Z-class materials, particularly those radioactive high-Z nuclear elements. Most of the traditional identification methods are based on complex statistical iterative reconstruction or simple trajectory approximation. Supervised machine learning methods offer some improvement but rely heavily on prior knowledge of target materials, significantly limiting their practical applicability in detecting concealed materials. For the first time, transfer learning is introduced into the field of muon tomography in this work. We propose two lightweight neural network models for fine-tuning and adversarial transfer learning, utilizing muon scattering data of bare materials to predict the Z-class of materials coated by typical shieldings (e.g., aluminum or polyethylene), simulating practical scenarios like cargo inspection and arms control. By introducing a novel inverse cumulative distribution-based sampling method, more accurate scattering angle distributions could be obtained from data, leading to an improvement by nearly 4% in prediction accuracy compared with the traditional random sampling-based training. When applied to coated materials with limited labeled or even unlabeled muon tomography data, the proposed method achieves an overall prediction accuracy exceeding 96%, with high-Z materials reaching nearly 99%. Simulation results indicate that transfer learning improves prediction accuracy by approximately 10% compared to direct prediction without transfer. This study demonstrates the effectiveness of transfer learning in overcoming the physical challenges associated with limited labeled/unlabeled data, and highlights the promising potential of transfer learning in the field of muon tomography.

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Contribution ID: **8** Type: **not specified**

Studying Hadronic Shower Development in HERD CALO with Machine Learning

The High Energy cosmic-Radiation Detection (HERD) facility will be installed as a space astronomy payload on the China Space Station in 2028. The three-dimensional imaging calorimeter (CALO) of HERD comprises about 7500 lutetium yttrium oxy-orthosilicate (LYSO:Ce) cubes, where the topological development of hadronic showers can be measured. Over the years, advancements in deep learning, particularly Convolutional Neural Networks (CNNs) and Transformers, have demonstrated state-of-the-art performance in high energy physics. These deep learning architectures are designed to exploit large datasets to reduce complexity and find new features in data. In this seminar, I will discuss the application of the CNN and Transformer techniques to precisely reconstruct the parameters of a hadronic shower initiated in HERD CALO. Both models are optimized using isotropic proton simulations and demonstrate superior performance over a wide energy range from 30 GeV up to 1 TeV. After some adaptation, these architectures could be applied for different types of calorimeters.

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Contribution ID: **9** Type: **not specified**

The Neural Networks with Tensor Weights and the Corresponding Fermionic Quantum Field Theory

In this paper, we establish a theoretical connection between complex-valued neural networks (CVNNs) and fermionic quantum field theory (QFT), bridging a fundamental gap in the emerging framework of neural network quantum field theory (NN-QFT). While prior NN-QFT works have linked real-valued architectures to bosonic fields, we demonstrate that CVNNs equipped with tensor-valued weights intrinsically generate fermionic quantum fields. By promoting hidden-to-output weights to Clifford algebra-valued tensors, we induce anticommutation relations essential for fermionic statistics. Through analytical study of the generating functional, we obtain the exact quantum state in the infinite-width limit, revealing that the parameters between the input layer and the last hidden layer correspond to the eigenvalues of the quantum system, and the tensor weighting parameters in the hidden-to-output layer map to dynamical fermionic fields. The continuum limit reproduces free fermion correlators, with diagrammatic expansions confirming anticommutation. The work provides the first explicit mapping from neural architectures to fermionic QFT at the level of correlation functions and generating functional. It extends NN-QFT beyond bosonic theories and opens avenues for encoding fermionic symmetries into machine learning models, with potential applications in quantum simulation and lattice field theory.

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基于量子计算的 (2) 规范理论中的手性不平衡研究

We implement a variational quantum algorithm to investigate the chiral condensate in a 1+1 dimensional SU(2) non-Abelian gauge theory. The algorithm is evaluated using a proposed Monte Carlo sampling method, which allows the extension to large qubit systems. The obtained results through quantum simulations on classical and actual quantum hardware are in good agreement with exact diagonalization of the lattice Hamiltonian, revealing the phenomena of chiral symmetry breaking and restoration as functions of both temperature and chemical potential. Our findings underscore the potential of near-term quantum computing for exploring QCD systems at finite temperature and density in non-Abelian gauge theories.

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