Theoretical and Computational Physics highlights in November 2024

The international workshop on "Parton Distribution Functions and Lattice Calculations (PDFLattice 2024)" took place at Jefferson Lab from 18-20 November with the aim of advancing our understanding of the internal structure of hadrons through the amalgam of lattice QCD calculation, global analysis, and theoretical advances. This workshop was the third in the series, following those at the University of Oxford in 2017 and Michigan State University in 2019. The workshop had over 45 participants from across the US, South America, Europe and Australia, and members of the Theory Center gave presentations across lattice QCD, global analysis, and theoretical developments within QCD. A particular focus of this workshop was Uncertainty Quantification, reflecting the increasing precision availabl in our understanding of PDFs. Following the previous workshops, the outcome will be a white paper reflecting the advances in the field, and in particular the progress at uncertainty quantification in PDFs.

There is enormous interest in developing and utilizing Quantum Computing for calculations relevant for Nuclear Physics. In FY21, a two-year LDRD project was initiated between JLab/Theory, JLab/Cryogenics and the Atomic/Molecular/Optics group in UVA/Physics to extend the UVA optics-based Quantum Computing system for Nuclear Physics research. JLab provided expertise and detector equipment that enhanced the system in a crucial direction, namely, the new capability to resolve up to 100 photons in their quantum detector system. An early paper highlighting the result was published in Nature Photonics [17 (2023) 1, 106]. The group has subsequently developed the theory and computational formalism along with the experimental setup to utilize the Continuous Variable optics-based system. A new paper describing the methods was recently published in Physical Review Research [6 (2024) 4, 043065] with funding support from the LDRD project and the Center for Quantum Advantage (C2QA). In collaboration with members of the UVA Electrical Engineering Dept, the group is continuing to develop a new version of the Quantum Computing system using semiconductor based optics and is pursuing funding opportunities from NSF and DOE.

Optimizing stochastic algorithms for hadron correlation function computations in lattice QCD
Distillation is a quark-smearing method for the construction of a broad class of hadron operators useful in lattice QCD computations. A paper by Dr. Robert Edwards and the Hadron Spectrum Collaboration [arXiv:2411.10395] presents a new orthonormal basis for the distillation method, which builds in the property of locality. This basis is useful for the construction of stochastic methods to estimate the correlation functions computed in Monte Carlo calculations relevant for hadronic physics.

Finite-volume quantization condition from the N/D representation
A new model-independent method for determining hadronic resonances from lattice QCD has been proposed by Dr. Adam Szczepaniak and colleagues [arXiv:2411.15730], derived from the general principles of unitarity and analyticity. The method generalizes the Luescher approach, or the quantization condition, which relates the finite volume energy spectrum to infinite volume scattering amplitude to all energies, including energies below thresholds. This is particularly important when analyzing exotic bound states formed near thresholds where forces due to light meson exchanges, such as pion exchange, are important and could not be included with the standard quantization condition.

Chiral-odd generalized parton distributions in the large-Nc limit of QCD: Spin-flavor structure, polynomiality, sum rules

In Quantum Chromodynamics the quarks are endowed with a property of left/right handedness (so-called chirality), which is entangled with their motion and interactions and expresses itself in the complex spin structure of the proton. A recent theoretical study establishes the properties of the chiral-odd generalized parton distributions in the proton, using systematic analytic methods based on the semiclassical limit of QCD ($1/N_c$ expansion) [arXiv:2411.17634]. The results of this study explain the spin-flavor dependence observed in lattice QCD calculations of the chiral-odd distributions and enable predictions for exclusive pion production experiments at JLab 12 GeV and EIC.