Theory and computation highlights in April, 2023

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Modern lattice QCD analyses provide accurate information on the dynamics of strongly interacting processes. The modeling of scattering amplitudes allows us to find unstable particles appearing in the QCD spectrum. The identification of light, non-ordinary hadrons has been subject to fierce debate, and it is one of the main goals of the HadSpec collaboration. For most of these states, their nature is barely known. In our recent work [arXiv:2303.10701], Drs.~Dudek, Edwards and Rodas studied the pion-pion interaction and extracted the elusive sigma resonance. Furthermore, they observed its dependence on the quark mass and found it compatible with a non-ordinary meson. However, they also observed that the error induced by modeling the amplitudes could be many times larger than the statistical error associated with our lattice QCD computations. This hinders the extraction of such an object. In their subsequent analysis [arXiv:2304.03762], by making use of mathematical techniques, known as dispersion relations, they eliminated this systematic uncertainty and reduced the error in the sigma extraction. They also constrained the pion-pion interactions even further and provided an approach that can be reproduced by future lattice QCD works. These dispersive analyses set the groundwork for future studies of non-ordinary mesons.

Phenomena caused by higher-order electromagnetic interactions in electron scattering (two-photon exchange processes) present unique challenges to theory and experiments, and mark the precision frontier in hadronic physics. A recent theoretical study [arXiv:2303.12681] by Dr. Jose Goity and Dr. Christian Weiss has computed the target normal single-spin asymmetry produced by two-photon exchange in inclusive electron-nucleon scattering in the resonance region, using an effective field theory method (1/Nc expansion) that provides a systematic treatment with controlled uncertainties. Measurements of this spin observable and related two-photon exchange effects are planned in next-generation experiments at Jefferson Lab with a positron beam.

Transverse momentum dependent (TMD) distributions describe the distribution of quarks and gluons inside the proton and other hadrons with respect to both their longitudinal and transverse momenta. Understanding TMDs requires a combination of theoretical techniques from quantum field theory, nonperturbative calculations using lattce QCD and phenomenological analysis of experimental data. Dr. Jianwei Qiu and the TMD Collaboration have just released a comprehensive new TMD Handbook [arXiv:2304.03302] covering a wide range of topics on TMDs, from theoretical foundations to experimental analyses, as well as recent developments and future directions.

The $N \to \Delta$ transitions offer new possibilities for exploring the isovector component of the QCD quark angular momentum (AM) operator causing the J^{u-d} flavor asymmetry in the nucleon. Dr. Kim and other JLab theorists extended the concept of QCD AM to transitions between baryon states, using light-front densities of the energy-momentum tensor in transversely localized states [arXiv:2304.08575]. They calculated the $N \to \Delta$ transition AM in the $1/N_c$ expansion, connected it with the J^{u-d} flavor asymmetry in the nucleon, and estimated the values using lattice QCD results. In the same setup they connected the transition AM to the transition GPDs sampled in hard exclusive electroproduction processes with $N \to \Delta$ transitions, enabling experimental study of the transition AM.