Theoretical and Computational Physics highlights in July 2024

Timelike meson form factors beyond the elastic region from lattice QCD

In a recent paper [arXiv:2407.20617] Drs. Jo Dudek and Robert Edwards presented a QCD calculation of the timelike form factor of the pion in a kinematic region where the final state interactions are sensitive to the rescattering of coupled $\pi\pi$ and $K^*\bar{K}$ systems. The formalism correcting for the finite spatial volume of the lattice necessarily gives access to both the timelike pion and kaon form factors, and it was found that a dispersive representation could describe simultaneously both the spacelike and timelike pion form factor.

Solving the homogeneous Bethe-Salpeter equation with a quantum annealer

A recent analysis by Dr. Alex Gnech and collaborators [arXiv:2406.18669] solved for the first time the Bethe-Salpeter equation that describes the bound state of a particle in Minkowski space using a quantum annealer. The four-dimensional space was discretized, mapping the equation onto a minimization problem, and a quantum algorithm was developed to exploit the 5,000 qubits of the D-wave quantum annealer to find the minima of the problem for the bound state of the system. The work demonstrates how the quantum annealer can be used for solving the Bethe-Salpeter equation, obtaining reliable physical results, and providing a baseline for future work using quantum computers to tackle bound-state problems.

A unitary coupled-channel three-body amplitude with pions and kaons

Three-body dynamics above threshold is required for the reliable extraction of many amplitudes and resonances from experiment and lattice QCD. The S-matrix principle of unitarity can be used to construct dynamical coupled-channel approaches in which three particles scatter off each other, rearranging two-body subsystems by particle exchange. A new paper by Dr. Adam Szczepaniak and collaborators [arXiv:2407.08721] reports the development of a three-body, coupled-channel amplitude including pions and kaons.

State preparation of lattice field theories using quantum optimal control

Advances in quantum computing are expected to enable the simulations of real-time dynamics of QCD, which is one of the most challenging open problems in nuclear physics. New work by Dr. Felix Ringer and collaborators [arXiv:2407.17556] explores for the first time the use of Quantum Optimal Control techniques for state preparation of lattice field theories. By controlling qubits at the pulse level, one is able to achieve a gate-free state preparation, resulting in significantly reduced coherence time requirements, which is an important ingredient for achieving a quantum advantage in fundamental physics applications.

Non-local nucleon matrix elements in the rest frame

Non-local matrix elements of nucleons are used in a new paper by Drs. Joe Karpie, Christopher Monahan, and Anatoly Radyushkin [arXiv:2407.16577] to study their internal partonic structure. The matrix elements in the rest frame are calculated with lattice QCD at multiple lattice spacings, and are shown to be described by the ultraviolet renormalization constant up to a few percent up, even at distances over 0.5 fm. The residual dependence can be described by the long distance behavior created by the finite size of the nucleon.

Revisiting gauge invariance and Reggeization of pion exchange

While the Reggeized pion is expected to provide the main contribution to the forward cross section in light meson photoproduction reactions with charge exchange at high energies, the pion exchange mechanism has only been studied using phenomenological approaches so far. With new and forthcoming high-precision data from JLab, the JPAC Collaboration has published a new paper [arXiv:2407.19577] that takes a more fundamental approach to revisit the pion exchange mechanism focusing on the Reggeization of pion exchange in charged pion photoproduction and its consistency with current conservation. The paper shows that the gauge-invariant amplitude for the exchange of a particle with generic even spin $J \geq 2$ in the t-channel is analytic at $J=0$, and can be interpreted in terms of the nucleon electric current, reconciling the dynamics in the s- and u-channel with the amplitude expressed in terms of t-channel partial waves as required by Regge theory.