Theoretical and Computational Physics highlights in May 2024

The LQCD computing initiatives, including DOE/HEP supporting FNAL/BNL and DOE/NP supporting JLab, recently underwent a successful renewal on May 29-30. The new initiatives cover the period FY25-29 with a total 5-year budget of $22.5M. The in-person review covered the science and business plans for the HEP & NP initiatives. There were 15 presentations on the science and operations of the LQCD clusters, with HEP & NP program managers advised by eight expert reviewers. The collaboration was praised for the science plan, allocations, management and operations of the computing facilities.

Electromagnetic pion form factor at high energies

The structure of hadronic form factors at high energies and their deviations from perturbative quantum chromodynamics (QCD) provide insight into nonperturbative QCD dynamics. A new paper by the Joint Physics Analysis Center [arXiv:2405.09517] uses an approach that is consistent with dispersion relations to construct a model which simultaneously accounts for the pion wave function, gluonic exchanges, and quark Reggeization. In particular, the study finds that quark Reggeization can be investigated at high energies by studying scaling violation of the form factor.

Pion gravitational form factors in the QCD instanton vacuum

The emergence of the light hadron masses from QCD is connected with the quantum fluctuations of the gluon fields (so-called trace anomaly) and expressed in the measurable gluonic structure of the hadrons. Recent work by Dr. Christian Weiss and collaborators [arXiv:2405.14026] has computed the mass decomposition and gluonic form factors of the pion in the instanton liquid model of the QCD vacuum, which implements the topological vacuum fluctuations of the gluon fields observed in lattice QCD and explicitly realizes the trace anomaly. It is found that half of the pion mass arises from the gluon trace anomaly, and the other half from the quark-mass-dependent sigma term.

Towards Unpolarized GPDs from Pseudo-Distributions

The generalized parton distributions (GPDs) can unravel the tomographic, mechanic, mass, and spin structures of hadrons. A group of JLab theorists led by Drs. H. Dutrieux and J. Karpie [arXiv:2405.10304] have presented an exploration of the unpolarized isovector proton GPDs $H^{u-d}(x,\xi,t)$ and $E^{u-d}(x,\xi,t)$ in the pseudo-distribution formalism using distillation. Taking advantage of the large kinematic coverage made possible by this approach, they presented results on the moments of GPDs up to the order x^3 – including their skewness dependence – at a pion mass $m_\pi = 358$ MeV and a lattice spacing $a = 0.094$ fm.

White Paper on "Exploring baryon resonances with transition GPDs"

QCD gives rise to a rich spectrum of excited baryon states. Understanding their internal structure is important for many areas of nuclear physics, such as nuclear forces, dense matter, and neutrino-nucleus interactions. Recent developments in theory have made it possible to extend the concept of generalized parton distributions (GPDs) from the ground-state nucleon to excited states and employ them for next-generation studies of the structure of excited baryons. The "transition GPDs" make it possible to construct 3D images of the quark/gluon distributions in excited baryons and quantify their mechanical properties such as the distributions of mass, angular momentum, and forces in the system. A White Paper [arXiv:2405.15386], compiled by a group of researchers led by Dr. C. Weiss (JLab Theory), outlined the emerging physics program in connection with transition GPDs. It describes the properties and interpretation of the transition GPDs, theoretical methods for structures and processes, first experimental results from JLab 12 GeV, and future measurements with existing and planned facilities (JLab detector and 22 GeV energy upgrades, COMPASS/AMBER, EIC, J-PARC, LHC ultraperihperal collisions).