Theoretical and Computational Physics highlights in September 2024

The program of "hadron femtography" – imaging the three-dimensional spatial structure of subnuclear particles – employs a unique set of methods in theoretical, computational, and experimental physics as well as data science. Training the next generation of researchers in these special methods is a priority for JLab and DOE NP and supported by the DOE Topical Collaboration program. The "First International School of Hadron Femtography" was held at Jefferson Lab on Sep. 16-25, organized jointly by the Quark-Gluon Tomography Topical Collaboration and the Center for Nuclear Femtography at JLab [https://www.jlab.org/conference/HadronFemtographySchool]. It attracted 35 junior researchers (graduate student and postdoc level) from US and foreign institutions and provided intensive training in femtography methods as well as networking and mentoring opportunities. Members of the Theory Center developed the Scientific Program (W. Melnitchouk, D. Richards, C. Weiss), gave core lectures and seminars (R. Edwards, J. Karpie, J-W Qiu, C. Weiss, Zh. Yu), and provided the key administrative support (B. Whitehead). The school was regarded as very successful, representing a seminal event in the scientific community, and will be followed up by further similar initiatives.

Partial-wave projection of relativistic three-body amplitudes

A new paper by Drs. C. Costa, A. Jackura and collaborators [arXiv:2409.15577] presents the theoretical and practical application of partial-wave three-body scattering amplitudes, building on previous results for accessing three-hadron reactions using lattice QCD. The paper presents a class of flexible parameterizations for the short-distance interactions which are to be constrained from lattice QCD data. Finally, the authors explore a toy model system of three pions at various isospins at unphysical heavy pion masses.

Towards a unified description of hadron scattering at all energies

New work by Drs. A. Rodas, G. Montana, A. Szczepaniak and colleagues [arXiv:2409.09172] presents a parameterization which fulfills many expectations of S-matrix and Regge theory principles, connecting the essential physics of hadron scattering in the resonance region and in asymptotic limits in closed algebraic form. In this construction, dynamical information is entirely contained in Regge trajectories that generalize resonance poles in the complex energy plane to moving poles in the angular momentum plane. The paper highlights the salient features of the model, comparing with existing literature on dispersive and dual amplitudes, and benchmarking the formalism with an initial numerical application to the ρ and $\sigma/f_0(500)$ mesons in $\pi\pi$ scattering.

Azimuthal modulations and extraction of generalized parton distributions

Azimuthal modulations are crucial for the phenomenological extraction and separation of various generalized parton distributions (GPDs). In a new paper [arXiv:2409.06882], Drs. J.-W. Qiu, N. Sato and Z. Yu provide a new choice of frame and the corresponding formalism, which describes azimuthal distributions in a unified way for all 2-to-3 exclusive processes involving GPDs, including deeply virtual and time-like Compton scattering. The new description is well suited for experimental analysis, and is advantageous in separating contributions from different subprocesses that contribute to the same physical reaction.

Factorization for jet production in heavy-ion collisions

Dr. Felix Ringer and collaborators have developed an effective field theory approach to QCD factorization of jet quenching observables in heavy-ion collisions [arXiv:2409.05957]. The jet, which loses energy due to the presence of the hot and dense QCD medium, is described as an open quantum system. The work provides a systematic framework for computing jet observables at higher order and understanding their nonperturbative aspects, paving the way for future applications in heavy-ion phenomenology.

Role of data embedding in quantum autoencoders for improved anomaly detection

The performance of Quantum Autoencoders (QAEs) in anomaly detection tasks is critically dependent on the choice of data embedding and ansatz design. A study by Dr. J. Araz and collaborators [arXiv:2409.04519] explores the effects of three data embedding techniques – data re-uploading, parallel embedding, and alternate embedding – on the representability and effectiveness of QAEs in detecting anomalies. The findings reveal that even with relatively simple variational circuits, enhanced data embedding strategies can substantially improve anomaly detection accuracy and the representability of underlying data across different datasets.