Theoretical and Computational Physics highlights in December 2024

Leading-twist flavor singlet quark TMDs at small x

In the standard transverse momentum dependent (TMD) factorization framework, the description of the TMDs breaks down at small parton momentum fractions x, as large logarithms in x start to dominate over the resummed logarithms in the four-momentum transfer squared, Q^2. In the light-cone operator treatment, one is able to resum these logarithms and predict their small-x evolution and behavior. A paper by Dr. Daniel Adamiak and collaborators [arXiv:2412.14154] derives and solves six novel evolution equations and presents the full table of quark-singlet TMD small-x asymptotics.

Kernel methods for evolution of generalized parton distributions

Generalized parton distributions (GPDs) characterize the 3-dimensional structure of hadrons, combining information about their internal quark and gluon longitudinal momentum distributions and transverse position within the hadron. The dependence of GPDs on the factorization scale Q2 allows one to connect hard exclusive processes involving GPDs at disparate energy and momentum scales, which is needed in global analyses of experimental data. In a new paper [arXiv:2412.13450] members of the JAM Collaboration (GPD Analysis Group) and colleagues explore how finite element methods can be used to construct fast and differentiable Q^2 evolution codes for GPDs in momentum space, which can be used in a machine learning framework. The study shows numerical benchmarks of the methods' accuracy, including a comparison to an existing evolution code from PARTONS/APFEL++, and provides a repository where the code can be accessed.

Quantum stresses in the hydrogen atom

Work by Dr. Adam Freese [arXiv:2412.09664] studies the quantum stress tensor and gravitational form factors in the hydrogen atom as a simple case, to better understand the physical meaning of these quantities in more complicated systems like the proton. With the help of the de Broglie-Bohm pilot wave interpretation, the stress tensor of matter particles can be understood to quantify forces exerted by the wave function on the particles. A major finding of the study is that the c-bar gravitational form factor, rather than D, encodes the force law binding the system.

A simple non-parametric reconstruction of parton distributions from limited Fourier information

In order to obtain parton distributions from lattice QCD calculations, one must infer the inverse Fourier transform of a finite amount of statistically noisy data. Gaussian Process Regression allows for a non-parametric description of an arbitrary unknown function. In a recent paper [arXiv:2412.05227], Dr. Joe Karpie and collaborators applied this technique to real and fictitious lattice QCD matrix elements. Using the data and physical intuition to select a few hyperparameters, estimates of the parton distribution and its error can be learned both more efficiently and more accurately than the standard non-linear minimization used in previous studies and global analysis of experimental data. Compared to other machine learning techniques, the impact of these few hyperparameters are transparent allowing for the user to make informed choices on the unavoidable trade off between bias and variance.

Jet substructure of light and heavy flavor jets at RHIC

Jet substructure studies at the Large Hadron Collider have been used to constrain parton distribution functions, test perturbative QCD, measure the strong-coupling constant, and probe the properties of the quark-gluon plasma. In a new study [arXiv:2412.08682], Dr. Oleh Fedkevych and collaborators extend these studies to lower energies at the Relativistic Heavy Ion Collider that would additionally allow us to test

existing models of nonperturbative physics. In particular, the paper presents a PYTHIA-based Monte Carlo study of substructure of jets produced in proton-proton collisions at 200 GeV. Jet substructure observables of different types are considered, and their sensitivity to the dead cone effect (suppression of collinear radiation in the vicinity of massive quarks) is investigated.