2025 SURGE Collaboration Meeting and Workshop

Monday 23 June 2025 - Wednesday 25 June 2025

Physics and Astronomy Building

Book of Abstracts

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Probing orbital angular momentum distributions with elastic dijet production in ep collisions

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We calculate the elastic production of dijets from electron collisions with a longitudinally polarized proton target at small values of the Bjorken x variable. Building on the pioneering proposals of Hatta et al and Bhattacharya et al for measuring the quark and gluon orbital angular momentum (OAM) distributions, our focus is on both the longitudinal double spin asymmetry (DSA) and longitudinal single spin asymmetry (SSA). We compute the numerators of these asymmetries in the small-x formalism of the light cone operator treatment. Utilizing the small-x expressions for the OAM distributions derived earlier, we demonstrate that the DSA provides a robust probe for both the quark and gluon OAM distributions within the proton. In contrast, we find that while the SSA is also sensitive to the OAM distributions, extraction of the latter from the SSA would require new developments in small-x theory and phenomenology, and is probably not feasible at this point in time. These findings highlight the potential of DSA measurements in elastic dijet production at the future Electron-Ion Collider to provide the first-ever direct access to the quark and gluon OAM distributions at small x, paving the way for new insights into the proton spin puzzle.

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Probing the Sivers Asymmetry with Transverse Energy-Energy Correlators in the Small-x Regime

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We investigate transverse energy-energy correlators (TEECs) for both polarized and unpolarized targets in the small-x regime at the Electron-Ion Collider (EIC). Focusing on the approximately back-to-back electroproduction of a hadron-electron pair, we apply transverse-momentum-dependent (TMD) factorization formulas that incorporate TMD evolution for both event-shape observables and expand them in terms of the small-x dipole amplitude. This allows us to write the TEEC off the transversely polarized proton in terms of a C-odd interaction, corresponding to an odderon exchange. Due to the charge-conjugation-odd nature of the small-x quark Sivers function, we restrict the sum over final hadronic states to positively and negatively charged hadrons separately. We present numerical predictions for the TEEC Sivers asymmetry at the EIC and find the magnitude of the asymmetry to be on the 0.1% level. This channel offers a promising avenue for benchmarking the still largely unconstrained odderon amplitude.

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Small-x Helicity Evolution: First Study on the Impact of Polarized pp Scattering Data

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We perform a phenomenological study of helicity-dependent parton distribution functions (hPDFs) using the KPS-CTT small-x helicity evolution equations. Specifically, this new work presents the first study of the influence of polarized proton-proton (pp) scattering data whilst simultaneously analyzing inclusive and semi-inclusive deep-inelastic scattering data, all at $x < 0.1$. Polarized pp data in this analysis is limited to double-longitudinal spin asymmetries in single-inclusive jet production, for which we approximate it via the polarized small-x pure-glue calculation of $pp \to gX$. We use a variant of the large-N_c evolution equations by taking the large-$N_c\&N_f$ KPS-CTT evolution equations and setting $N_f = 0$ to replicate a pure-glue limit that retains external quark flavor dependence for the spinor field operators. We observe that the pp data have a substantial impact on the helicity PDFs at small x, leading to reduced uncertainties and an updated total quark and gluon helicity contribution to the proton for $x < 0.1$ of -0.04 ± 0.23. Comparing our analysis with a recent JAM analysis of world polarized data, including data at $x > 0.1$, we estimate a total parton helicity contribution for $x > 10^{-7}$ of between 0.02 and 0.51.

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Energy-energy correlators inside jets in pp and pA collisions

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Energy-energy correlators (EEC) are event-shape observables that have gained renewed interest in the recent years, due to them being less sensitive to the non-perturbative hadronization of the final-state particles. In this talk, I will discuss the EEC in pp and pA collisions in the collinear limit where the studied particles are inside the same jet. This type of EEC allows us to probe jet formation and effects of the cold nuclear medium. I will present a framework for studying EEC in both perturbative and non-perturbative regions simultaneously and discuss the importance of nuclear effects in describing the recent LHC data [1].

[1] João Barata, Zhong-Bo Kang, Xoán Mayo López, Jani Penttala (arXiv: 2411.11782 [hep-ph])

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A Neural-Network Extraction of Unpolarized Transverse-Momentum Distributions from Drell-Yan data

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We present the first proof of concept extraction using neural networks (NNs) of the unpolarised transverse-momentum distributions (TMDs) at next-to-next-to-next-to- leading logarithmic (N3LL) accuracy. By offering a more flexible and adaptable approach, NNs overcome some of the limitations of traditional functional forms, providing a better description of data. This work focuses exclusively on Drell-Yan (DY) data and establishes the feasibility of NN-based TMD extractions.

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Welcome

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SURGE: Status Overview and Progress

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Overview of Initial Stage working group

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Breakout Session: Small x and NLO WG

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Closing Remarks

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Wednesday Session / 20

Weizs\"acker-Williams Gluon Helicity Distribution and Inclusive Dijet Production in Longitudinally Polarized Electron-Proton Collisions

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It is well-known that the back-to-back (correlation) limit of inclusive quark–antiquark dijet production in unpolarized high energy electron–proton collisions can probe the Weizs\"{a}cker-Williams (WW) gluon transverse momentum-dependent distribution (TMD) at small x. In this paper, we consider a helicity-dependent version of the same process: we study the double-spin asymmetry for inclusive quark–antiquark dijet production in longitudinally polarized electron–proton scattering at high energies. We show that in the back-to-back limit this process probes the WW gluon helicity TMD. Furthermore, we derive the small-x evolution equation for the operator related to the WW gluon helicity distribution. We find that in the double-logarithmic approximation and in the large-N_c limit, the small-x asymptotics of the WW gluon helicity distribution is governed by exactly the same evolution equation as that for the dipole gluon helicity distribution. The longitudinal double-spin asymmetry for inclusive dijet production in the longitudinally polarized electron–proton collisions can thus test the small-x helicity evolution equations and facilitate constraining the initial conditions for phenomenology based on these equations.

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Born-Oppenheimer Renormalization group for High Energy Scattering

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We develop an approach to QCD evolution based on the sequential Born-Oppenheimer approximations that include higher and higher frequency modes as the evolution parameter is increased. This Born-Oppenheimer renormalization group is a general approach which is valid for the high energy evolution as well as the evolution in transverse resolution scale Q^2. We found that the evolution equation for the TMD contains a linear and a nonlinear term. The linear term reproduces the Collins-Soper-Sterman (CSS) equation with a physical relation between the transverse and longitudinal resolution scales. We explain how this equivalence arises, even though the BO and CSS cascades are somewhat different in structures. The nonlinear term in the evolution has a very appealing physical meaning: it is a correction due to stimulated emission, which enhances emission of gluons (bosons) into states with a nonzero occupation.

Tuesday Session / 22

Jet Energy-Energy Correlators in Deep Inelastic Scatterings

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The jet energy-energy correlator (EEC), which measures angular correlations of energy flow inside jets, provides a sensitive probe of jet substructure and its modification by the nuclear medium. We compute the EEC for jets produced in electron-proton and electron-nucleus deep inelastic scattering, focusing on medium-induced corrections arising from final-state interactions in cold nuclear matter. Working at leading order in the QCD coupling and the jet-medium interaction, we derive an analytical expression for the modification of the jet EEC as a function of the opening angle and show that the modification is strongest at large angles within the jet cone. We further obtain explicit parametric dependencies on the jet energy, path length, and the characteristic scattering power of the nuclear medium, providing a new approach to study cold nuclear matter effects at a future Electron-Ion Collider.

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Gluonic Gravitational Form Factors and Near-Threshold J/ψ Photoproduction in Holographic QCD

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Abstract:

Gravitational form factors (GFFs) of the nucleon furnish a three–dimensional map of the energy, momentum, pressure, and shear carried by QCD constituents, with gluonic contributions playing a decisive role. Complementing lattice QCD results, we employ a confining bottom-up AdS/QCD model in which the bulk dilaton background simultaneously generates linear Regge trajectories for 2^{++} and 0^{++} glueballs, and implements the QCD trace anomaly. Analytical expressions for the gluon $A(t)$ (energy–momentum) and $D(t)$ (mechanical) form factors are derived, revealing a consistent picture of the nucleon's mass, pressure, and shear distributions.

The same holographic wave functions determine the near-threshold photoproduction amplitude of heavy quarkonia through Witten diagrams. We discuss the recent extraction of gluonic GFFs by the $J/\psi-007$ collaboration at Jefferson Lab (published in Nature 615,813–816 (2023)) , which analyzed exclusive J/ψ production on the proton close to threshold using our holographic amplitude. The experimentally determined tensor (A) and scalar (D) form factors exhibit excellent agreement with lattice gluonic GFFs, reinforcing the validity of the holographic description in the non-perturbative regime. These developments highlight the synergy between gauge/gravity duality, lattice computations, and precision experiments, advancing our understanding of how gluons generate the visible mass and mechanical structure of hadronic matter.

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Small-x asympototics of GPDs

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We study the small-x asymptotics of unpolarized generalized parton distributions (GPDs). Unlike the previous works in the literature, we consider the case of non-zero skewness. We show that the unpolarized GPDs at small x are related to the eikonal dipole amplitude N, whose small-x evolution is given by the BK/JIMWLK evolution equations. We show that the effect of non-zero skewness $\xi \neq 0$ is to modify the value of the evolution parameter (rapidity) in the argument for the dipole amplitude from $Y = \ln(1/x)$ to $Y = \ln \min \{1/x, 1/|\xi|\}$.

Further, we address the question of calculating the real part of the scattering amplitude at high energies, corresponding to the imaginary part of the dipole amplitude N. In phenomenology, this real part is often accounted for by a multiplicative R-factor, often used in elastic vector meson production calculations. We study the origin of the R-factor in the shock wave picture and find that the real part of the scattering amplitude originates from multiple t-channel gluon exchanges in the initial conditions for the small-x evolution. We show that such exchanges are the origin of the signature factor in the scattering amplitudes in the shock wave approach to high-energy scattering.

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Towards 3-loop Balitsky–Kovchegov: the non-conformal part

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The Balitsky–Kovchegov (BK) equation offers a tractable description of the high-energy growth of gauge-theory scattering amplitudes and the nonlinear saturation effects that eventually tame this growth. Motivated by the upcoming precision era at the Electron–Ion Collider (EIC)—whose extended kinematic reach promises decisive tests of saturation—we present a framework based on the timelike-spacelike correspondence that streamlines the computation of multiloop corrections to the BK equation. We predict the full nonconformal part of the NNLO BK Hamiltonian in the planar limit of a generic gauge theory, treating the numbers of fermions and scalars as free parameters. As a byproduct of this three-loop computation, we introduce novel Feynman-calculus techniques for the explicit evaluation of dimensionally regulated Fourier transforms.

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SIDIS in the target fragmentation region at small x

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Single inclusive hadron production in Deep Inelastic Scattering serves as standard candle observable for probing the 3D partonic structure of proton or nuclear targets. In this talk, I will focus on particle production in the target fragmentation region. At moderate Bjorken-x, this kinematic regime is described by the framework of transverse momentum dependent (TMD) fracture functions. To extend the study of fracture functions into the small-x region, we consider the differential cross-section for single-inclusive jet/hadron production with transverse momentum Pt in DIS, mediated by a longitudinally polarized virtual photon of virtuality Qˆ2»Ptˆ2. We show that this cross-section is not power-suppressed in Pt/Q, and can be factorized in terms of TMD quark and gluon fracture functions at small x, for which the Color Glass Condensate provides explicit analytic expressions.

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Sea quark TMD distributions at small-x

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The Color Glass Condensate (CGC) is an effective field theory that describes the behavior of hadrons and nuclei at high energies (corresponding to small values of Bjorken-x), where the rapid growth of gluon densities is expected to be moderated by saturation effects. In this talk I will show that within the CGC dilute-dense formalism, the cross section for dijet production involving a small-x quark from the nuclear target admits factorization in the back-to-back limit, where the cross section is expressed in terms of the usual perturbative hard factors and TMD sea quark distributions. We present explicit expressions for these quark TMD distributions in terms of two fundamental distributions: the dipole correlator and the quark operator appearing in SIDIS and Drell-Yan processes.

Monday Session / **29**

nCTEQ25: Overview and Preliminary Results

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We discuss the preliminary results of the new global nCTEQ25 nuclear PDF analysis, combining a number of our previous analyses into one consistent framework with updates to the underlying theoretical treatment as well as the addition of new available data. In particular, the nCTEQ24 global release will be the first nCTEQ release containing neutrino DIS scattering data in a consistent manner together with JLab high-x DIS data and new LHC p-Pb data. These additions will allow to improve the data-driven description of nuclear PDFs in new regions such as the gluon for very low-x or the nuclear strange quark PDF.

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Revisiting the Dihadron Angular Correlations in Forward pA collisions

Authors: Bjoern Schenke[1]; Farid Salazar[2]; Paul Caucal[3]; Piotr Korcyl[4]; Raju Venugopalan[None]; Tomasz Stebel[5]; Wenbin Zhao[6]; Zhongbo Kang[7]

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Dihadron angular correlations in forward pA collisions provide a sensitive probe of gluon saturation effects. In these processes, both gluon saturation and parton shower dynamics contribute to the observed de-correlation between back-to-back dihadron pairs. In our study, we employ the Color Glass Condensate (CGC) framework to perform a detailed numerical investigation of dihadron correlations at forward rapidities. We utilize the improved Transverse Momentum Dependent (ITMD) factorization scheme designed for small-x physics and incorporate parton shower effects by including the corresponding Sudakov factor. Our results show good agreement with STAR data in both pp and pAu collisions. Additionally, we present predictions for dihadron correlations within the FOCAL kinematic ranges to be explored at the LHC. We will also discuss the progress on developing an event generator that couples CGC calculations with Pythia to further study these correlations.

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Recent experimental progress in searching for gluon saturation

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Understanding gluon saturation at small x is a central question in high-energy nuclear physics, with deep implications for the non-linear regime of QCD. This talk presents an overview of recent experimental efforts aimed at uncovering signatures of gluon saturation, with a focus on two-particle azimuthal correlations in p+p, p+A, and d+A collisions. Despite theoretical predictions from the CGC framework suggesting broadening and suppression in the away-side peak, no definitive experimental observation of saturation-induced broadening has been confirmed. Multiple confounding effects, such as Sudakov radiation and fragmentation, complicate the interpretation of the correlation widths.

Recent simulation studies incorporating saturation, Sudakov effects, and next-leading-order contributions highlight the subtle interplay between these mechanisms. We also review the role of nuclear PDFs, such as EPPS21 with the extracted gluon densities vanishing at low Q^2.

Looking ahead, the EIC offers unprecedented opportunities to isolate initial-state effects using observables like F_2, F_L, and diffractive processes. We outline prospects for early science measurements at the EIC and the potential for clarifying the non-linear QCD dynamics underlying gluon saturation.

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Calculation of sub-eikonal corrections for the dijet production in the background field method

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The search of the signatures of saturation is one of the main goals of the future Electron-Ion Collider (EIC). In this regime the background field of the target is characterized by the shock-wave structure defined by the eikonal interactions. However, we expect that this limit will be hard to achieve at EIC, due to the moderate values of the scattering energies. Instead, the leading eikonal picture of scattering will be spoiled by so-called sub-eikonal corrections that effectively describe the transition between the limits of large- and small-x. For this reason, understanding the sub-eikonal corrections is essential for the search of saturation at EIC. In the talk, I will describe application of the background field method to calculating of the sub-eikonal corrections for the dijet production process. I will describe advantages of the method comparing to other available calculation schemes, in particular, its efficiency in determination of the structure of QCD operators defining interaction between the dijet pair and the background field of the target, which leads to important physical conclusions.

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Recent jet-based measurements sensitive to TMDs in ep collisions

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Experimental probes of gluon saturation in UPCs

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Gluon GPDs at small-x and global analysis

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Event Generator at the EIC

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Regge Factorization for ep Diffraction from EFT

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Modification of EEC in cold and hot nuclear medium

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What do we talk about when we talk about saturation?

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CSS evolution as renormalization of a non-local composite operator

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