

Session Q Abstracts

Designing a digital twin for Brookhaven National Laboratory's Rapid Cycling Synchrotron as part of the Electron-Ion Collider project

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The Electron-Ion Collider (EIC), currently in design at Brookhaven National Laboratory, will be a first-of-its-kind particle accelerator capable of colliding beams of electrons and heavy nuclei to illuminate the answers to central questions in nuclear physics. The EIC will use a Rapid Cycling Synchrotron (RCS) to accelerate electron beams from 750 MeV to 18 GeV; this acceleration is essential to successful experimentation in the EIC. To ensure the stability of beams within the RCS, the effect of quadrupole strength misalignments on beam motion must be rigorously understood. However, quantifying optical response to such deviations is prohibitively slow using standard exhaustive tracking studies. Thus, we present a digital twin of the RCS: a machine-learning surrogate model that maps inputted quadrupole strengths to key twiss parameters at every element within the RCS lattice in real time. The model is trained on MAD-X simulation data and learns directly from the accelerator optics, enabling rapid optics studies, misalignment tolerance evaluations, and magnet setting optimization that would otherwise be computationally expensive. The resulting model augments conventional modeling by providing fast, physics-consistent optics estimates for design exploration and prospective online tuning during commissioning and operations, with the approach generalizing to other accelerators.

Shadow celestial OPEs in 4D asymptotically flat holography

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An effort to realise an analogous correspondence to AdS/CFT exploits the isomorphism $SO(3,1) \cong SL(2, \mathbb{C})$ to posit a duality between 4D asymptotically flat spacetime and a 2D Conformal Field Theory (CFT). In this framework, the linearised massless wave equation admits two distinct highest-weight families of solutions under $SL(2, \mathbb{C})$, related through a shadow transformation. The first is built by Mellin-transforming standard momentum eigenstates to yield so-called *celestial primaries* whose operator product expansion (OPE) directly encodes the collinear limits of momentum space amplitudes, giving rise to a local 2D OPE structure similar to conventional CFT correlators. The second is *a priori* non-local and does not bear the fruit of such an OPE on the celestial sphere, due to its mixing with global descendants. We release this tension by providing a general prescription that endows shadow operators with a local OPE. In particular, we derive how OPE coefficients of collinear limits transform under a shadow map for arbitrary n -point functions using OPE blocks, with applications to $U(1)$ currents and stress tensors discussed therein. Further work includes generalising this construction from $(3,1)$ to $(2,2)$ signature, and more broadly, assembling an algebraic framework that both encodes the bulk RG flow and harnesses the non-locality of shadow operators to probe the UV/IR mixing crucial for any UV completion of gravity in the bulk.

Categorification of Stokes coefficients for Brieskorn sphere invariants

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We construct a homology theory $H^{\{*,*\}}(\Sigma(p,q,r))$ for Brieskorn spheres $\Sigma(p,q,r)$, whose graded Euler characteristic matches the power-series invariant Z_b of Gukov–Pei–Putrov–Vafa. This invariant, defined via resurgence in complex Chern–Simons theory, encodes Stokes coefficients from steepest-descent expansions around flat connections. Using plumbing descriptions, we compute integer series $I^{\{S\}}_{\{S'\}}(q)$ and categorify them into Poincaré polynomials representing candidate homology

groups. Initial computations agree with known cases but show discrepancies in higher examples, suggesting refinements are needed. The project advances the categorification of quantum invariants of 3-manifolds.

Lambda-Gray Molasses cooling on the Cesium-133 D_1 transition line for enhanced loading of atoms in optical tweezer arrays

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Neutral atoms in optical tweezer arrays are gaining prominence as qubits for quantum computation due to their highly scalable nature and long coherence times. However, due to the stochastic nature of atom loading processes, atom arrays typically host only 50% of their total atom capacity, which limits their overall scaling and the complexity of the algorithms that can be implemented. Lambda-enhanced Gray Molasses (LGM) is a laser cooling procedure that uses dark states, i.e., states decoupled from light, which has been previously shown to result in enhanced loading on the order of 80% in other alkali atoms, by reducing atom losses and decoherence due to scattering. We present our methodology for implementing LGM on the D_1 transition line ($6^2S_{1/2} \rightarrow 6^2P_{1/2}$) of ^{133}Cs , with enhanced controllability of important scanning parameters necessary for further study of cooling and enhanced loading capabilities in our atom arrays.

Probing the weak interaction with early universe physics: The effects of sterile neutrinos in hot and dense environments

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Neutrinos are tiny, nearly massless fundamental particles. Despite only interacting weakly, they strongly influence the evolution of our universe. We analyze the observational consequences of a model that introduces a population of sterile neutrinos that decay roughly one second after the Big Bang, when the early universe was hot, dense, and the weak interaction played an important role in the dynamics of the universe. Sterile neutrinos are hypothetical electrically neutral particles that interact only through gravity. The hot and dense early universe provides an optimal setting to study sterile neutrinos because the conditions at this time allow for more interactions between elusive particles. In this work, we examine this model's effects on large-scale structure formation and cosmologically-inferred neutrino mass measurements. At the same time, we explore how the model influences the formation of the first light elements during Big Bang Nucleosynthesis.

Analysis of optical timescales based on ultrastable cryogenic silicon resonators referenced by a strontium lattice clock

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Timescales, such as UTC and its physical realizations, allow for the synchronization and timing of events such as financial transactions and observations for Very-Long-Baseline Interferometry, with modern timescales being measured by counting the period of a stable oscillator referenced to an atomic transition. While current timescales typically utilize the microwave frequency produced by hydrogen masers referenced to the hyperfine transition of Cesium to achieve fractional frequency uncertainties around 10^{-15} or 10^{-16} , cryogenic silicon resonators have demonstrated fractional stability around 10^{-17} and strontium lattice clocks referenced to the $^1S_0 \rightarrow ^3P_0$ transition below 10^{-18} systematic uncertainty at optical frequencies, giving the potential for a substantial improvement in timing accuracy. This work builds on a previous effort by the group demonstrating the feasibility of such an optical timescale over a 34-day campaign and aims to develop a toolchain to produce a continuously generated optically oscillating signal from using a two-cavity ensemble, including a method of analyzing the timescale accuracy from the cavity – Sr clock comparison. This also provides an opportunity to continually track the difference between this timescale and the NIST realization of UTC over a fiber link, with the goal of making optical contributions to official timescales.

Determining the extent to which the subgroup of computable elements in the Galois group of the algebraic closure of the rationals is elementary

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The Galois Group of the Algebraic Closure of the Rationals is regarded as a complex and poorly understood structure. We investigate the extent to which one can compute the square roots of computable automorphisms in this group. Key aspects of this question reduce to the purely group theoretic question of when, given two groups H and N , there exists a group G such that $G/N \cong H$ and distinct square elements of G have distinct square roots in H . We examine subgroups of the wreath product described by the Krasner-Kaloujnine Theorem to understand how and when groups can be constructed with these properties. Answering the question of when square roots of computable automorphisms are computable is a step towards determining the extent to which the subgroup of computable elements is elementary, which will provide insight into the overall structure of the Galois group.

Time-dependent Schrödinger equation simulations of Floquet-driven exciton dynamics in monolayer WS_2 as a platform for carrier-envelope phase-controlled light-matter interaction

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We present time-dependent Schrödinger equation (TDSE) simulations of Floquet-driven exciton dynamics in monolayer WS_2 under mid-infrared optical driving. By modeling the optical response in the absence of carrier-envelope phase (CEP) stabilization, we recover key experimental features of the transient absorption spectrum and reveal signatures of strong-field-induced exciton resonances and sideband formation. These results establish a computational framework for probing the interplay between strong periodic driving fields and excitonic wave packet evolution in two-dimensional semiconductors. This platform enables a systematic investigation of CEP-sensitive phenomena, wherein the absolute optical phase of few-cycle pulses can induce subcycle exciton dynamics. Our approach lays the groundwork for exploring a broader class of CEP-governed light-matter interactions in solid-state systems, with potential implications for ultrafast quantum control and optoelectronic applications. Planned experimental upgrades to incorporate a CEP-stable laser will allow for direct validation of these predictions and enable quantitative comparisons between simulation and experiment.

Impact of oscillating magnetic fields on skyrmion configurations

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Magnetic skyrmions are topologically protected spin textures that offer promise for next-generation data storage and spintronic devices. While the behavior of individual skyrmions under applied fields is well characterized, the collective dynamics of multiple skyrmions remain poorly understood. This project investigates how groups of skyrmions behave when subjected to oscillating magnetic fields, with a focus on their rotational motion, stability, and energy dynamics. To establish a theoretical foundation, we derived the continuous free energy of a chiral magnet from the discrete spin Hamiltonian, including contributions from exchange interactions, the Dzyaloshinskii-Moriya interaction, and external magnetic fields. We then used micromagnetic simulations in MuMax3 to study the driven dynamics of one and two skyrmions under resonant and off-resonant magnetic fields. Simulations show a strong resonance response characterized by periodic breathing behavior. Future work will extend to systems of two or more skyrmions, using stroboscopic sampling to isolate collective motion and determine whether skyrmions rotate with constant radius and linearly increasing angular displacement. These results will inform analytical modeling of skyrmion torque and interaction under weak periodic driving.

Pion form factor from a three-point function in lattice quantum chromodynamics

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Mentors: Frank Lee and Mark B. Wise

Quantum chromodynamics (QCD) is the field theory which describes the strong interaction between quarks. Lattice QCD is a method of solving equations in quantum chromodynamics by formulating space and time as a lattice of points. We aim to verify that a three-point function in lattice QCD can be used to calculate the form factor of a pion. The form factor is a function of momentum transfer that describes how the distribution of charge within a particle changes as the energy level of the particle changes. We used the Perlmutter supercomputer at NERSC as the platform for the computation of our three-point function. We will extract the form factor from our data with a covariance fitting function called a jackknife function that accounts for correlation and error propagation. We used Mathematica to perform our data analysis. Previous work in the field has utilized four-point functions to calculate important quantities. Computational evaluation of four-point functions is time- and energy-intensive. By demonstrating that a three-point function can determine the pion form factor, we aim to present a more efficient alternative to the current standard computational method.