(+91) 7319218645
debsubhra.chakraborty@tifr.res.in
Department of Theoretical Physics,
Tata Institute of Fundamental Research,
Dr. Homi Bhabha road, Mumbai, 400005

Debsubhra Chakraborty

Education

Department of Theoretical Physics, TIFR — Mumbai, India
Integrated Ph.D. in Physics — 2021 - 2027 *(expected)*
- Advisor: Prof. Nilmani Mathur
- Research area: Computation of Nuclear Matrix Elements using Lattice QCD

Ramakrishna Mission Vidyamandira, University of Calcutta — Kolkata, India
B.Sc.(Honors) in Physics — 2018 - 2021
- CGPA: 9.66/10.

Publications and Preprints

1. Nilmani Mathur, M. Padmanath and Debsubhra Chakraborty, “Strongly Bound Dibaryon with Maximal Beauty Flavor from Lattice QCD”. In: Phys. Rev. Lett. 130 (11 Mar. 2023), p. 111901. doi: 10.1103/PhysRevLett.130. 111901.
2. Debsubhra Chakraborty, Piyush Srivastava, Arpith Kumar and Nilmani Mathur, ”Nuclear correlation functions using first-principle calculations of lattice quantum chromodynamics”. In: Phys.Rev.D. 110 (Dec. 2024), p.114505. doi: 10.1103/PhysRevD.110.114505.
3. N. S. Dhindsa, D. Chakraborty, A. Radhakrishnan, N, Mathur and M. Padmanath, ”Precise study of triply charmed baryons (Ω_{ccc})”,arXiv: 2411.12729, (Nov. 2024).
4. D. Chakraborty, D. Sood, A. Radhakrishnan and N. Mathur, ”Estimating energy levels from lattice QCD correlation functions using a transfer matrix formalism”, arXiv: 2412.01900, (Dec. 2024).
5. D. Chakraborty, S. Chattopadhyay and R.S. Gupta, ”Towards the HEFT-hedron: the complete set of positivity constraints at NLO”, arXiv:2412.14155, (Dec. 2024).

Talks

- D. Chakraborty*, S. Chattopadhyay and R.S. Gupta, Towards the HEFT-hedron: the complete set of positivity constraints on HEFT operators at NLO. Presented at the 8th General Meeting of the LHC EFT Working Group, December, 2024, Link to talk.
- D. Chakraborty*, D. Sood, A. Radhakrishnan and N. Mathur, Estimating Energy Levels from Lattice QCD Correlation Functions Using a Transfer Matrix Formalism. Presented at the χQCD annual meeting 2024, 15 December, 2024.
- D. Chakraborty*, P. Srivastava, A. Kumar and N. mathur, Nuclear Spectroscopy from Lattice QCD, at Institute of Theoretical Physics, Universtat Bern, 26$^{\text{th}}$ June, 2025.

Awards and Honors

- JBNSTS Senior Scholar, batch of 2018.
- National Graduate Physics Examination (NGPE)-2020 Gold medal.
- Satyendranath Bose gold medal for first rank in B.Sc. (Physics Honours).

Skills

Languages: Bengali, English, Hindi.
Programming: `Python`, `C`, `Mathematica`, `Cuda C`.

Teaching

Graduate Teaching Assistant PHY 107.1; Classical Electrodynamics I; Instructor: Prof. Rick Sandeepan Gupta, Spring 2024.

Research Experience

Lattice QCD Study of a Fully Bottom Dibaryon

Collaborators: Prof. Nilmani Mathur and Prof. Padmanath Madanagopalan

Conducted the first lattice QCD study of a fully bottom dibaryon ($\Omega_{bbb} - \Omega_{bbb}$), revealing a deeply bound state in the $^1S_0$ channel with a binding energy of -81^{+14}_{-16} MeV. Using state-of-the-art lattice techniques, computed the $\Omega_{bbb} - \Omega_{bbb}$ scattering amplitude and identified a pole singularity, confirming the strong interaction forms a deeply bound state. With such a large binding energy, Coulomb repulsion contributes only as a small perturbation, shifting the strong binding by a few percent. This suggests that the strong force dominates in this system, making it the most deeply bound dibaryon composed of a single quark flavor. The study provides critical insights into the behavior of multi-baryon systems at the heaviest quark sector, offering new constraints on phenomenological models of strong interactions in extreme regimes. These findings also have implications for the study of exotic hadronic states and may provide guidance for future experimental searches in high-energy physics. This work establishes the heaviest possible and most deeply bound dibaryon in the visible universe, pushing the frontiers of lattice QCD calculations and enhancing our understanding of the fundamental forces governing the structure of matter.

Advancing Nuclear Physics with Lattice QCD and Novel Computational Methods

Collaborators: Prof. Piyush Srivastava, Dr. Arpith Kumar and Prof. Nilmani Mathur

Exploring nuclear physics at the quark-gluon level presents significant computational challenges, particularly due to the exponential growth of Wick contractions in multi-nucleon systems. In this work, we developed two novel approaches to address this problem efficiently. First, we applied randomized algorithms inspired by computational number theory to detect and eliminate redundancies in Wick contraction computations. Second, we leveraged machine learning-inspired programming models (e.g., TensorFlow) to automate tensor contractions, optimize algorithmic efficiency, and facilitate implementation on GPU accelerators. Using these methods, we computed two-point correlation functions for Deuteron, Helium-3, Helium-4, and Lithium-7, achieving at least an order-of-magnitude improvement over existing algorithms. Additionally, we identified a striking feature in nuclear correlation functions: specific spin-color combinations consistently dominate, suggesting a potential underlying symmetry in nuclear systems. Exploiting this property further could significantly reduce computational costs. Our results demonstrate the feasibility of extending these methods to larger nuclei ($A \sim 12$ and beyond), broadening the scope of lattice QCD in nuclear physics. These advancements provide a powerful framework for future studies of nuclear structure and interactions, pushing the frontiers of computational hadron and nuclear physics.

Precise Determination of the Triply-Charmed Baryon Mass Using Lattice QCD

Collaborators: Dr. Navdeep S. Dhindsa, Dr. Archana Radhakrishnan, Prof. Nilmani Mathur and Prof. Padmanath Madanagopalan

Conducted the most precise lattice QCD calculation of the ground-state mass of the triply-charmed spin-3/2 baryon (Ω_{ccc}). The study utilized six $N_f = 2 + 1 + 1$ Highly Improved Staggered Quark (HISQ) ensembles generated by the MILC collaboration, employing two distinct lattice setups. In the first setup, a fully dynamical HISQ action was used for all quark flavors, while in the second, an overlap action was applied for the valence charm quark. The calculations spanned five different lattice spacings, two different volumes, and two distinct fermion actions, allowing for a robust continuum extrapolation. Our final prediction for the mass of the lowest $\Omega_{ccc}(3/2^+)$ state is $4793(5)(7)$ MeV, representing the most precise determination to date with full control over systematic uncertainties. Additionally, we predict the $\Omega_{ccc}(3/2^-)$ mass to be $5094(12)(13)$ MeV. These results provide key theoretical inputs for future experimental searches and deepen our understanding of heavy baryon spectroscopy. The study also demonstrates the effectiveness of using mixed-action approaches in precision lattice QCD calculations.

Efficient Energy Estimation from Lattice QCD Correlation Functions

Collaborators: Mr. Dhruv Sood, Dr. Archana Radhakrishnan and Prof. Nilmani Mathur

Developed an efficient method for estimating energy levels from lattice QCD correlation functions by computing the eigenvalues of the transfer matrix. This method generalizes the recently introduced Lanczos procedure while being simpler to implement. Applied to various hadrons and light nuclei, it provides more reliable energy extractions than conventional methods. While the signal-to-noise ratio remains a challenge, the method effectively accounts for statistical uncertainties and systematic errors, including fitting window effects. This approach enhances precision in lattice QCD calculations and offers a robust framework for future studies of hadronic and nuclear spectra.

Positivity Bounds on the Higgs Effective Field Theory at NLO

Collaborators: Prof. Rick S. Gupta and Mr. Susobhan Chattopadhyay

Performed a comprehensive analysis of positivity bounds on the Higgs Effective Field Theory (HEFT) at next-to-leading order (NLO). Identified 15 operators contributing to s^2-growth in longitudinal gauge-Higgs scattering amplitudes, constraining all possible $2 \to 2$ processes involving longitudinal gauge bosons ($V_L = W_L^{\pm}, Z_L$) and the Higgs boson (h). Derived two types of constraints: (i) specific linear combinations of CP-even Wilson coefficients (WCs) must be positive, and (ii) the magnitudes of certain WCs, including all CP-odd ones, must be bounded by products of other CP-even WCs. Exploited unitarity and crossing symmetry to obtain double-sided bounds on these coefficients. Our final constraints significantly refine the 15-dimensional HEFT parameter space, with only 5% of the Wilson coefficient space satisfying positivity. We demonstrated how known positivity bounds on the 3-dimensional space of dimension-8 SMEFT can be recovered from our results. For vector boson scattering, our constraints are often substantially stronger than current experimental limits. Furthermore, for processes such as $V_L V_L, hh \to hh$ and $V_L V_L, hh \to V_L h$, where no experimental limits exist, our results provide the first theoretical bounds.

Nuclear Spectroscopy of light Nuclei upto ^{4}He from Lattice QCD

Collaborators: Prof. Nilmani Mathur, Dr. Xiang Gao and Prof. Swagato Mukherjee

In this project, we investigate the binding energies of light nuclei — including the deuteron, dineutron, ^{3}He, and ^{4}He — using first-principles Lattice QCD simulations. The calculations are performed on $N_f = 2 + 1$ Highly Improved Staggered Quark (HISQ) ensembles generated by the MILC collaboration, with a lattice spacing of $a \approx 0.076$ fm. For the valence quarks, we employ the clover fermion action. A key focus of this work is to examine how the binding energies of these few-nucleon systems vary with the valence pion mass, while keeping the sea quark sector fixed at the physical point. This allows us to isolate the effect of valence quark mass on nuclear interactions within a QCD framework. We perform simulations at three different valence pion masses: $m_\pi \approx 700$ MeV, 300 MeV, and 140 MeV. This study contributes to a deeper understanding of nuclear forces from QCD, and may provide valuable insight into the nature of binding in light nuclei, particularly in regions away from the physical point.

Precise Determination of Heavy Baryon Masses with Relativistic Bottom Quarks from Lattice QCD

Collaborators: Prof. Nilmani Mathur and Dr. Archana Radhakrishnan

In this ongoing work, we compute the spectrum of heavy baryons and mesons using relativistic bottom quarks in Lattice QCD simulations for the first time. The study employs $N_f = 2 + 1 + 1$ Highly Improved Staggered Quark (HISQ) ensembles generated by the MILC collaboration, with a fine lattice spacing of $a \approx 0.0327$ fm. We use the HISQ action for all valence quarks, including strange, charm, and bottom flavors. As many of these heavy baryons are expected to be discovered in the coming decades, our precise mass determinations will aid ongoing and future experimental efforts. To date, all studies of such heavy baryons have relied on non-relativistic QCD (NRQCD) actions for bottom quarks. Our work thus provides a fully relativistic alternative and offers a valuable cross-check of NRQCD-based results.