# A Comparative Analysis of Quantum Chromodynamics Computation Techniques: Lattice Gauge Theory vs. Perturbative Methods

**Skyler Nelson**
PhD
Technical University of Munich
Arcisstraße 21, 80333 Munich, Germany

**Taylor Williams**
Associate Professor
Massachusetts Institute of Technology
77 Massachusetts Avenue, Cambridge, MA 02139, USA

**Ella Scott**
Professor
University of Cambridge
The Old Schools, Trinity Ln, Cambridge CB2 1TN, United Kingdom

**Cameron Young**
Dr. Sc
University of Toronto
27 King's College Cir, Toronto, ON M5S, Canada

**Abstract.** In this study, we explore two prominent quantum chromodynamics (QCD) computation techniques: Lattice Gauge Theory and Perturbative Methods. These approaches serve distinct purposes in understanding the strong force that binds quarks and gluons within nucleons. By evaluating their theoretical foundations and computational efficiencies, we aim to determine their applicability in high-energy physics predictions. Our findings indicate nuanced advantages for each method, depending on specific research constraints, thus contributing valuable insights into ongoing particle physics inquiries.

**Keywords:** Quantum Chromodynamics, Lattice Gauge Theory, Perturbative Methods, Strong Force, Particle Physics

## Introduction

The intricacies of quantum chromodynamics (QCD), the theory that elucidates the strong force interactions responsible for quark and gluon confinement within protons and neutrons, present one of the most formidable challenges in modern theoretical physics. The accurate computation and simulation of QCD processes are paramount for advancing our understanding of particle physics and validating experimental findings in collider experiments such as those conducted at CERN's Large Hadron Collider. This pursuit has

led to the development of sophisticated computational techniques, notably Lattice Gauge Theory and Perturbative Methods, each with its unique methodological framework and application scope. Lattice Gauge Theory, employing a spacetime lattice framework, facilitates the non-perturbative calculations of QCD by discretizing spacetime into a grid, thus enabling the numerical simulation of the gauge fields. This approach is pivotal when addressing the low-energy regime of QCD, where the perturbative expansions fail due to the strong coupling constant at these energy scales. Conversely, Perturbative Methods, grounded in asymptotic freedom, are indispensable for high-energy computations where the coupling constant becomes sufficiently small, allowing series expansions to converge. In this paper, we undertake a comprehensive evaluation of these techniques by analyzing their computational complexities, scalability, and respective accuracies in various energy domains. We delve into their theoretical underpinnings, highlight recent advancements, and assess their congruence with experimental data. The comparative insights drawn from this study aim to guide physicists in selecting appropriate computational strategies for their research objectives, ultimately enhancing the precision of theoretical models in predicting particle interactions. This paper is structured as follows: Section 1 delves into the historical development of QCD computation methods, Section 2 provides a detailed methodology of our comparative analysis, Section 3 discusses the findings and their implications, and Section 4 concludes with future research directions.

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