FROM CURRENT ALGEBRA TO QUANTUM CHROMODYNAMICS

A Case for Structural Realism

The advent of quantum chromodynamics (QCD) in the early 1970s was one of the most important events in twentieth-century science. This book examines the conceptual steps that were crucial to the rise of QCD, placing them in historical context against the background of debates that were ongoing between the bootstrap approach and composite modeling, and between mathematical and realistic conceptions of quarks. It explains the origins of QCD in current algebra and its development through high energy experiments, model-building, mathematical analysis, and conceptual synthesis. Addressing a range of complex physical, philosophical, and historiographical issues in detail, this book will interest graduate students and researchers in physics and in the history and philosophy of science.

TIAN YU CAO is the author of *Conceptual Developments of 20th Century Field Theories* (1997) and the editor of *Conceptual Foundations of Quantum Field Theory* (1999), also published by Cambridge University Press.

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In memory of
Dia-dia and M-ma

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Preface

This volume is the first part of a large project which has its origin in conversations with Cecilia Jarlskog and Anders Barany in December 1999, in which the difficulties and confusions in understanding various issues related to the discovery of QCD were highly appreciated.

While the forthcoming part will be a comprehensive historical study of the evolution of various conceptions about the strong interactions from the late 1940s to the late 1970s, covering the meson theory, Pauli's non-abelian gauge theory, S-matrix theory (from dispersion relation, Regge trajectories to bootstrap program), current algebra, dual resonance model and string theory for the strong interactions, QCD, lattice gauge theory, and also briefly the supersymmetry approach, the D-brane approach, and the string–gauge theory duality approach, titled *The Making of QCD*, this volume is a brief treatment, from a structural realist perspective, of the conceptual development from 1962 to 1972, covering the major advances in the current algebraic approach to QCD, and philosophical analysis of the historical movement.

The division of labor between the two parts of the project is as follows. This volume is more philosophically oriented and deals mainly with those conceptual developments within the scope of current algebra and QCD that are philosophically interesting from the perspective of structural realism; while the whole history and all the historical complexity in the making of QCD will be properly dealt with in the longer historical treatise. They will be mutually supportive but have minimal overlap and no repetition.

After the project was conceived, I have visited Santa Barbara, Princeton, Santa Fe, DESY in Hamburg, the Max Planck Institute of Munich, University of Bern, and CERN, and talked to theorists Stephen Adler, Luis Alvarez-Gaume, James Bjorken, Curtis Callan, Sidney Coleman, Richard Dalitz, Freeman Dyson, Harold Fritzsch, Murray Gell-Mann, Sheldon Glashow,

Peter Goddard, David Gross, Roman Jackiw, Heinrich Leutwyler, Juan Maldacena, Peter Minkowski, David Olive, Nathan Seiberg, Arthur Wightman, and Edward Witten, on various issues related to the project. I have learnt numerous conceptual and technical details and many deep insights from them and also from other theorists who were active in the early 1970s through email exchanges. I also had long conversations with two experimenters Jerome Friedman of MIT and Gunter Wolf of DESY, and learnt from them various details of crucial experiments which led to the discovery of scaling and three-jet events. The SLAC archives was very helpful and provided me with the whole set of the original documents without which I would have no way to know how the deep inelastic scattering experiments were actually conceived, planned, performed, and interpreted. Critical exchanges with two historians of science, Charles Gillispie of Princeton and Paul Forman of the Smithsonian Institution greatly helped me in the general conception of the project.

Over years, parts of the research were presented at Harvard, Princeton, DESY, MPI of Munich, University of Bern and other places. Most memorable was a whole-day small workshop (around 20 participants) at Princeton, on April 20, 2005, chaired by Stephen Adler, at which I reported my preliminary researches on the history of QCD. Murray Gell-Mann, Arthur Wightman, Charles Gillispie and Paul Benacerraf, together with those from the Institute, took an active part, examined various issues raised by those preliminary results, made helpful comments, provided much background information, and had interesting exchanges of judgments.

To all those institutions and scholars I owe my most sincere gratitude. My research was interrupted several times by emotional turbulences caused by my mother's death and several deaths of close relatives and friends in the last few years. In the difficult times unfailing support from my wife Lin Chun and sister Nanwei helped me recover from depression and carry the project ahead. I am deeply grateful to them.