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Quantum Chromodynamics on the Light-Cone*

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One of the most challenging problems in particle physics theory is to compute the bound state structure of the proton and other hadrons from first principles in quantum chromodynamics. The goal is to calculate not only the hadron spectrum, but also to derive the momentum and spin distributions of the quarks and gluons which control hadronic reactions.

Recently, several new methods based on light-cone quantization have been proposed as an alternative to lattice gauge theory for solving non-perturbative problems in QCD and other gauge field theories. The foundations of light-cone quantization date back to Dirac, who in 1949 showed that there are remarkable advantages of quantizing relativistic field theories at fixed "light-cone time" $\tau = t + z/c$ rather than ordinary time. In the traditional equal-time Hamiltonian formulation, computing the wavefunction of a moving bound state is as complicated a dynamical problem as diagonalizing the Hamiltonian itself. On the other hand, quantization on the light-cone can be formulated without reference to the choice of a specific Lorentz frame; the eigensolutions of the light-cone Hamiltonian thus describe bound states of arbitrary four-momentum.

Another remarkable feature of this formalism is the apparent simplicity of the light-cone vacuum. In principle, the Fock expansion constructed on the vacuum state provides a complete relativistic many-particle basis for diagonalizing the full theory and a consistent definition of hadron wavefunctions, the amplitudes which describe a composite system consisting of an arbitrary number of confined relativistic quarks and gluons. One thus obtains a precise definition of the parton model and a general calculus for the computation of scattering amplitudes, form factors, electroweak transition amplitudes, and other hadronic matrix elements.

In the "discretized light-cone quantization method," the problem of computing the hadronic spectrum and the corresponding light-cone wavefunctions of QCD can be reduced to the diagonalization of a discrete finite matrix representation of the light-cone Hamiltonian. This method has been successfully applied to a number of quantum field theories, including QCD, QED, and Yukawa models in one-space and one-time dimension, two-dimensional matrix models occurring in superstring theory, as well as to gauge and scalar field theories in physical space-time. In the case of QCD(1+1), complete numerical solutions for the spectrum and light-cone wavefunctions can be obtained as a function of the coupling strength, the quark masses, and the number of flavors and color. Other methods have also been developed using effective light-cone Hamiltonians with Tamm-Dancoff Fock Space truncation, or a combination of a transverse lattice with light-cone quantization. References and further discussion may be found in a recent review, "The Challenge of Light Cone Quantization of Gauge Field Theory," by S. J. Brodsky, G. McCartor, H. C. Pauli, and S. S. Pinsky (SLAC-PUB-5811, June, 1992), to appear in *Particle World.*

The application of the light-cone quantization to QCD in physical space-time is unavoidably a highly challenging numerical computational problem. The size of the quark and gluon Fock space and the discretization of the transverse momenta leads quickly to very large matrices, and the effective Hamiltonian must also be supplemented by terms specified by the ultraviolet renormalization procedure. The most subtle problem now confronting the light-cone quantization method is how to understand the spontaneous symmetry breaking normally associated with the structure of the vacuum. In light-cone quantization the zero modes of the quantum fields are determined from constraint equations derived from the equations of motion of the theory. The zero modes can thus have non-zero vacuum expectation value and determine the phase and physics of the theory. There are other fundamental renormalization and gauge invariance issues that still have to be completely understood, such as how symmetries lost in the Fock space truncation can be restored, how to deal consistently with massless particles, and how to best regulate the infrared as well as ultraviolet singularities. All of these problems make the field quite exciting and challenging.

In addition to its potential for solving the problems of the hadronic spectrum and wavefunctions of QCD, light-cone quantization has already led to many new insights into the quantization of gauge theories. Light-cone quantization not only provides a consistent language for representing hadrons as QCD bound-states of relativistic quarks and gluons, but it also provides a novel method for simulating quantum field theory on a computer and understanding features of QCD phenomena at the amplitude level.

The appealing features of light-cone quantization for quantum field theory have brought together a new community of theorists interested in solving both the practical and formal problems. A series of conferences were held in 1991 and 1992 at Heidelberg, Aspen, Telluride, and Dallas. Two light-cone meetings in this series are being planned for this summer. Daniel Wyler of Zurich University (wyler@forty2.physik.unizh.ch) is organizing a conference June 14-18, 1993 at the Paul Scherrer Institute near Zurich, and Antonio Bassetto (bassetto@ipdinfn) under the support of the Istituto Nazionale di Fisica Nucleare (INFN) is organizing a workshop at the Gran Sasso laboratory August 17-27, 1993. Those interested in participating should contact the organizers.

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