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The one loop gluon emission light cone wave function

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HIGHLIGHTS

- The full light cone wave function for one gluon emission from a quark is calculated.
- The calculation uses an efficient helicity basis method to simplify the denominators.
- The 1-loop QCD beta function is recovered, and the finite contributions to the process calculated for the first time.

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ABSTRACT

Light cone perturbation theory has become an essential tool to calculate cross sections for various small-x dilute-dense processes such as deep inelastic scattering and forward proton–proton and proton–nucleus collisions. Here we set out to do one loop calculations in an explicit helicity basis in the four dimensional helicity scheme. As a first process we calculate light cone wave function for one gluon emission to one-loop order in Hamiltonian perturbation theory on the light front. We regulate ultraviolet divergences with transverse dimensional regularization and soft divergences using a cut-off on longitudinal momentum. We show that when all the renormalization constants are combined, the ultraviolet divergences can be absorbed into the standard QCD running coupling constant, and give an explicit expression for the remaining finite part.

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1. Introduction

Hamiltonian perturbation theory in the light cone (or light front) form [1–4] has become a standard tool in understanding hadronic scattering processes within a first-principles QCD approach. The calculational inconveniences of light cone perturbation theory (LCPT) compared to standard covariant perturbation theory are balanced by several features that make its physical interpretation more transparent. Light cone gauge LCPT only involves physical degrees of freedom, i.e. spin-or helicity states of partons, enabling an interpretation in terms of a constituent picture of hadrons. The factorization between long distance hadronic physics both in the incoming and final state hadrons on one hand, and hard perturbative QCD scattering on the other hand, is naturally implemented in LCPT. This allows for a simultaneous description of inclusive and exclusive processes in a consistent framework.

More recently LCPT has found a new area of application in understanding the nonlinear QCD physics of gluon saturation. Gluon saturation is most naturally understood in the "color glass condensate" (CGC) effective theory [5–8], which describes the soft small-x degrees of freedom in the high energy hadron as a classical field, radiated by color sources representing the large momentum partons. This classical color field can then be probed in various scattering processes by different dilute probes, whose interactions with the target are described in the high energy limit by an eikonal Wilson line on the light cone. The most natural way to describe the structure of the dilute probe (a real or virtual photon, or a quark or gluon from a probe hadron) in terms of a Fock state decomposition of partonic states is the light cone wave function of LCPT. This provides a formalism to factorize cross sections into light-cone wave functions describing the structure of the probe developing on a long timescale before the interaction, and Wilson line operators that describe the instantaneous scattering of the probe Fock state on the target.

Early loop calculations in LCPT [9–14] explored the structure of divergences in the longitudinal and transverse momentum integrals and recovered the one-loop renormalization constants known from covariant theory. Due to the more complicated mathematical structure resulting from the breaking of explicit rotational symmetry, LCPT has never been the formulation of choice for high order loop calculations. More recently, however, calculations of dilute-dense scattering processes in the CGC picture have increasingly started advancing to the NLO level, for example for the small-x evolution equations [15–24], inclusive DIS cross sections [25–27] and single [28–33] and double [34–36] inclusive particle production in the hybrid formalism. Many of these calculations have been, or could be, performed very naturally in LCPT. In particular, the concept of "light-cone wave function" appears frequently in calculations that are factorized into the partonic structure of the probe, and its eikonal interaction with the target.

The primary purpose of this paper is to develop techniques for systematically performing loop calculations in light cone perturbation theory. As a first step in this program we will calculate to one loop order the quark-to-quark–gluon splitting light cone wave function, i.e. the probability amplitude for finding a quark and a gluon state component in the quantum state of an interacting quark. Although the expressions for the diagrammatic rules for LCPT calculations can be found in many references (see in particular [37,38]), we find that they can be given in a particularly simple form using an explicit spin/helicity basis for both quarks and gluons. This is natural to combine with the four dimensional helicity (FDH) scheme for dimensional regularization, as will be discussed in more detail in Section 2.5.

We start this paper by a brief exposition of the LCPT rules and the concept of the light cone wave function in Section 2. We then calculate the one-loop contributions, both divergent and finite parts, in Section 3, assembling the results in Section 4. We finally end with a discussion of applications and future extensions of this calculation in Section 5.

2. LC conventions and LCPT rules

2.1. LC coordinates

In light-cone coordinates a four-vector x^μ is given by the components

$$x^\mu = (x^+, x^-, \mathbf{x}) \quad \text{with } \mathbf{x} = (x^1, x^2). \tag{1}$$