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Self Energy Correction in Light Front QED And Coherent State Basis[☆]

Jai More[a,*], Anuradha Misra[a]

[a]*Department of Physics,University of Mumbai,
Santa Cruz(E), Mumbai, India-400098*

Abstract

We discuss the calculation of fermion self energy correction in Light Front QED using a coherent state basis. We show that if one uses coherent state basis instead of fock basis to calculate the transition matrix elements, the true infrared divergences in electron mass renormalization δm^2 get canceled up to $O(e^4)$ in Light Front gauge. We have also verified this cancellation in Feynman gauge up to $O(e^2)$.

Keywords:
Light Front QED, Coherent State Formalism

1. INTRODUCTION

LSZ formalism of quantum field theory is based on the assumption that at large times, the dynamics of incoming and outgoing particles in a scattering process is governed by the free Hamiltonian, i.e. the asymptotic Hamiltonian H_{as} is the same as free Hamiltonian:

$$H_{as} = \lim_{|t|\to\infty} H = H_0 \tag{1}$$

However, it was pointed out by Kulish and Faddeev [1] that this assumption does not hold for theories in which either

- long range interactions like QED are present or
- the incoming and outgoing states are bound states like in QCD.

Kulish and Faddeev (KF) proposed the method of asymptotic dynamics and showed that in QED, at large times, when one takes into account the long range interaction between the incoming and outgoing states, then

$$H_{as} = H_0 + V_{as} \tag{2}$$

V_{as} was shown to be non-zero in QED and was used to construct the asymptotic Möller operators

$$\Omega^A_{\pm} = T\ exp\Big[-i\int_{\mp\infty}^{0} V_{as}(t)dt\Big]$$

which leads to the coherent states

$$|n\colon coh\rangle = \Omega^A_{\pm}|n\rangle\ ,$$

as the asymptotic states, where $|n\rangle$ is the n particle Fock state. It was then shown that the transition matrix elements evaluated between these coherent states are infra-red (IR) divergence free.

In this talk, I will discuss the issue of cancellation of IR divergences in the electron mass renormalization in light front QED.

For the sake of completeness, we state the notation

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[*]Speaker of the talk

Email addresses: more.physics@gmail.com (Jai More), anuradha.misra@gmail.com (Anuradha Misra)

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followed by us [2]. Our metric tensor is

$$g^{\mu\nu} = \begin{bmatrix} 0 & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 \\ 0 & 0 & -1 & 0 \\ 0 & 0 & 0 & -1 \end{bmatrix}$$

so that the four vector is defined as

$$x^\mu = (x^+, x^-, \mathbf{x}^\perp)$$

where

$$x^+ = \frac{(x^0 + x^3)}{\sqrt{2}}, x^- = \frac{(x^0 - x^3)}{\sqrt{2}}, \mathbf{x}_\perp = (x^1, x^2)$$

Four momentum is $p = (p^+, p^-, \mathbf{p}_\perp)$ and the mass shell condition is

$$p^- = \frac{p_\perp^2 + m^2}{2p^+}$$

In LFFT, there are two kinds of IR divergences

1) Spurious IR divergences, which are divergences arising due to $k^+ \to 0$ and are actually a manifestation of UV divergences of equal time theory. These can be regularized by an infrared cutoff on small values of longitudinal momentum.

2) True IR divergences are the actual IR divergences of equal time theory and are present because of the particles being on mass shell. The coherent state method is one possible way to deal with this kind of divergences.

A coherent state approach based on the method of asymptotic dynamics has been developed and applied to lowest order calculations in LFFT [3, 4, 5]. It was shown [3, 5] that the true IR divergences do not appear when one uses these coherent states to calculate the transition matrix elements for evaluating one loop vertex correction both in LFQED and LFQCD.

Light-front QED Hamiltonian in the light-front gauge consists of the free part, the standard three point QED vertex and two 4-point instantaneous interactions.

$$P^- = H \equiv H_0 + V_1 + V_2 + V_3 \ ,$$

Here

$$H_0 = \int d^2\mathbf{x}_\perp dx^- \{\frac{i}{2}\bar{\xi}\gamma^- \overleftrightarrow{\partial}_- \xi + \frac{1}{2}(F_{12})^2 - \frac{1}{2}a_+\partial_-\partial_k a_k\}$$

$$V_1 = e\int d^2\mathbf{x}_\perp dx^- \bar{\xi}\gamma^\mu \xi a_\mu$$

$$V_2 = -\frac{ie^2}{4}\int d^2\mathbf{x}_\perp dx^- dy^- \epsilon(x^- - y^-)(\bar{\xi}a_k\gamma^k)(x)\gamma^+(a_j\gamma^j\xi)(y)$$

$$V_3 = -\frac{e^2}{4}\int d^2\mathbf{x}_\perp dx^- dy^- (\bar{\xi}\gamma^+\xi)(x)|x^- - y^-|(\bar{\xi}\gamma^+\xi)(y)$$

$\xi(x)$ and $a_\mu(x)$ can be expanded in terms of creation and annihilation operators as

$$\xi(x) = \int \frac{d^2\mathbf{p}_\perp}{(2\pi)^{3/2}} \int \frac{dp^+}{\sqrt{2p^+}} \sum_{s=\pm\frac{1}{2}} [u(p,s)e^{-i(p^+x^- - \mathbf{p}_\perp x_\perp)} \times b(p,s,x^+) + v(p,s)e^{i(p^+x^- - \mathbf{p}_\perp x_\perp)} d^\dagger(p,s,x^+)],$$

$$a_\mu(x) = \int \frac{d^2\mathbf{q}_\perp}{(2\pi)^{3/2}} \int \frac{dq^+}{\sqrt{2q^+}} \sum_{\lambda=1,2} \epsilon_\mu^\lambda(q)[e^{-i(q^+x^- - \mathbf{q}_\perp x_\perp)} \times a(q,\lambda,x^+) + e^{i(q^+x^- - \mathbf{q}_\perp x_\perp)} a^\dagger(q,\lambda,x^+)],$$

The creation and annihilation operator satisfy

$$\{b(p,s), b^\dagger(p',s')\} = \delta(p^+ - p'^+)\delta^2(\mathbf{p}_\perp - \mathbf{p}'_\perp)\delta_{ss'} = \{d(p,s), d^\dagger(p',s')\}, \tag{3}$$

$$[a(q,\lambda), a^\dagger(q',\lambda')] = \delta(q^+ - q'^+)\delta^2(\mathbf{q}_\perp - \mathbf{q}'_\perp)\delta_{\lambda\lambda'}. \tag{4}$$

The light cone time dependence of the interaction Hamiltonian is given by

$$H_I(x^+) = V_1(x^+) + V_2(x^+) + V_3(x^+)$$

where

$$V_1(x^+) = e\sum_{i=1}^4 \int d\nu_i^{(1)}[e^{-i\nu_i^{(1)}x^+}\tilde{h}_i^{(1)}(\nu_i^{(1)}) + e^{i\nu_i^{(1)}x^+}\tilde{h}_i^{(1)\dagger}(\nu_i^{(1)})] \tag{5}$$

$\tilde{h}_i^{(1)}(\nu_i^{(1)})$'s are the three point QED interaction vertices and $\nu_i^{(1)}$ is the light-front energy transferred at the vertex $\tilde{h}_i^{(1)}$. $d\nu_i^{(1)}$ is the integration measure. For example,

$$\int d\nu_1^{(1)} = \frac{1}{(2\pi)^{3/2}}\int \frac{[dp][dk]}{\sqrt{2p^+}} \tag{6}$$

and $\nu_1^{(1)} = p^- - k^- - (p-k)^-$. The expressions for $V_2(x^+)$ and $V_3(x^+)$ can be found in Ref. [7]. Following the KF method, H_{as} is evaluated by taking the limit $x^+ \to \infty$ in $exp[-i\nu_i^{(1)}x^+]$, which contains the time dependence of this term in the interaction Hamiltonian H_{int}. If $\nu_i^{(1)} \to 0$ for some vertex, then the corresponding term in H_{int} does not vanish in large x^+ limit. One can then use KF method to obtain the asymptotic Hamiltonian and to construct the asymptotic Möller operator which leads to the coherent states.

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