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NONPERTURBATIVE VACUUM AND HARD SCATTERING PROCESSES

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ABSTRACT

A number of interesting suggestions for the QCD nonperturbative vacuum have been advocated in recent years by a group of people in Copenhagen. I review briefly some of the main ideas. I also describe an attempt to obtain the physical effects of the nonperturbative vacuum by studying hard scattering processes such as $e^+e^- \to$hadrons.

NONPERTURBATIVE VACUUM

To explore the nontrivial structure of the QCD vacuum, many people have calculated the effective potential (=vacuum energy density) V for the gluon field A_μ^a by using a simplifying Ansatz of constant chromomagnetic field (a = color index, μ = Lorentz index)[1-5]

$$A_y^{a=3} = Hx, \quad A_\mu^a = 0 \quad \text{otherwise.} \tag{1}$$

In the one-loop approximation Savvidy has found that this effective potential has a minimum for $H \neq 0$ and the perturbative vacuum ($H=0$) is unstable[1] as shown in Fig. 1. The nonperturbative vacuum at the minimum has a constant chromomagnetic field and may be called "color-ferromagnetic vacuum." However, N.K. Nielsen and P. Olesen pointed out that the effective potential actually has an imaginary part and the color-ferromagnetic state is unstable.[3] They found that the large anomalous color magnetic moment of non-Abelian gluons causes the unstable mode when the gluon spin is parellel to the chromomagnetic field H. By giving nonvanishing vacuum expectation values for the unstable mode,[6] one can further lower the vacuum energy. To lower the energy density by a finite amount, H.B. Nielsen and M. Ninomiya noticed that the lowering of the vacuum energy density requires an unstable mode field configuration which is extended all over the space.[7]

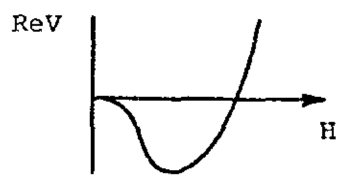

Fig. 1 Real part of the effective potential in the one-loop approximation.

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Thus they were naturally led to consider a periodic field configuration which exhibits domains of chromomagnetic flux. They also obtained an estimate of bag constant in agreement with the phenomenological value. Closer correspondence with the superconductor and with the flux concept of 'tHooft has also been discussed recently.[8]

One of the serious problems of the proposed nonperturbative vacuum is the lack of rotational or Lorentz invariance. H.B. Nielsen and P. Olesen estimated the quantum fluctuations of the chromomagnetic flux and proposed a "quantum liquid picture" to restore the invariance: quantum fluctuations are so large that the QCD vacuum looks like a "liquid."[9] The resulting picture is a random distribution of chromomagnetic flux tubes like spaghetti, although it is not yet well-formulated in detail.

HARD SCATTERING PHENOMENA

In extracting physical effects, we make two basic observations: i) Hard scattering processes probe a small space-time region which is likely to be well-approximated by constant chromomagnetic field. ii) By considering the total cross section we circumvent the difficult task of constructing hadrons explicitly.[10]

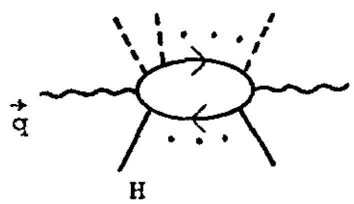

Fig. 2 Vacuum polarization in the field H.

The effect of the nonperturbative vacuum in $e^+e^- \to$hadrons can be obtained by calculating the vacuum polarization $\pi^{\mu\nu}$ due to quarks in the constant chromomagnetic field H (see Fig. 2). If we separate $\pi^{\mu\nu}$ into perturbative part $\pi^{\mu\nu}(H=0)$ and nonperturbative part $\Delta\pi^{\mu\nu}$, we find no ultraviolet divergence in $\Delta\pi^{\mu\nu}$ in the one-loop order. We evaluate the asymptotic behavior of the nonperturbative effect $\Delta\pi^{\mu\nu}$ for $-q^2 \gg gH \gg m^2$ (m:quark mass). For instance the longitudinal vacuum polarization in the rest frame of photon is given by (H is along the z-direction)

$$\Delta\pi^{zz} \simeq \frac{(gH)^2}{3\pi^2 q^2} \ln \frac{-q^2}{2gH} \quad , \tag{2}$$

If one naively calculates $\Delta\pi^{zz}$ with only two H field insertions attached to the quark loop instead of summing all H field insersions, one obtains a mass singularity (2gH in the logarithm is replaced by m^2). The correct asymptotic behavior (2) can be interpreted in terms of parton language: If a quark is produced in the nonperturbative vacuum, the virtuality of the quark extends from order q^2 down only to the nonperturbative mass scale gH (quarks tend to be off-shell by an amount gH).

To restore the rotational and Lorentz invariance we use the Nielson-Olesen proprosal[9] and average over the rotated and boosted color field configuration. If we average over spacial directons of H only (rotational averaging), we obtain the nonperturbative correction ΔR for $R=\sigma_{had}/\sigma_{\mu\bar{\mu}}$

$$\Delta R/R_{parton} \simeq -\frac{2}{9}\left(\frac{gH}{q^2}\right)^2, \tag{3}$$

which is about the same order of magnitude as the perturbative g^4 order corrections around $q^2=1\sim3$ GeV^2 ($gH\simeq3.42\Lambda^2$, $\Lambda\simeq0.5$ GeV). If we take the Lorentz invariant averaging, we obtain only real part for $(gH)^2$ order of $\Delta\pi^{\mu\nu}$. This result agrees with that of the ITEP group.[11] In this case the nonperturbative effect to R can behave at most as $(gH/q^2)^4$.

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