INSTANTON INFRA-RED STABILIZATION IN THE NONPERTURBATIVE QCD VACUUM

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The influence of nonperturbative fields on instantons in quantum chromodynamics is studied. Nonperturbative vacuum is described in terms of nonlocal gauge invariant vacuum averages of gluon field strength. Effective action for instanton is derived in bilocal approximation and it is demonstrated that stochastic background gluon fields are responsible for infra-red (IR) stabilization of instantons. Comparison of obtained instanton size distribution with lattice data is made.

1. Instantons were introduced in 1975 by Polyakov and coauthors. Instanton gas as a model of QCD vacuum was proposed in works by Callan, Dashen and Gross. Instanton liquid model of QCD vacuum was developed by Shuryak. These topologically nontrivial field configurations are essential for the solution of some problems of quantum chromodynamics. Spontaneous chiral symmetry breaking (SCSB) can be explained with the help of instanton and anti-instanton field configurations in QCD vacuum. Taking into account instantons is of crucial importance for many phenomena of QCD.

At the same time, there is a number of problems in instanton physics. The first is the divergence of integrals over instanton size $\rho$ at big $\rho$. This makes it impossible to calculate instantons' contribution to some physical quantities, such as vacuum gluon condensate. Second, "area law" for Wilson loop can not be explained in instanton gas model, hence quasiclassical instanton anti-instanton vacuum lacks confinement which is responsible for hadron spectra.

In our approach we make a natural assumption that there exist other nonperturbative fields apart from instantons in the vacuum, which allow...
to explain listed above problems. In this talk we will demonstrate that
instanton can be stabilized in nonperturbative vacuum and exist as a sta-
ble topologically nontrivial field configuration against the background of
stochastic nonperturbative fields, which are responsible for confinement,
and will find quantitatively it’s size.

2. Standard euclidian action of gluodynamics has the form

\[ S[A] = \frac{1}{2g^2} \int d^4x \text{tr}(F^2_{\mu\nu}[A]) = \frac{1}{4} \int d^4xF_{\mu\nu}^a[A]F_{\mu\nu}^a[A], \]  

(1)

where \( F_{\mu\nu}^a[A] = \partial_\mu A_\nu^a - \partial_\nu A_\mu^a - i[A_\mu^a, A_\nu^a] \) is the strength of gluon field. We
decompose \( A_\mu \) as \( A_\mu = A_\mu^{\text{inst}} + B_\mu + a_\mu \), where \( A_\mu^{\text{inst}} \) is an instanton-like field
configuration with a unit topological charge \( Q_T[A_{\text{inst}}] = 1 \); \( a_\mu \) is quantum
field and \( B_\mu \) is nonperturbative background field (with zero topological
charge), which can be parametrized by gauge invariant nonlocal vacuum
averages of gluon field strength (correlators).

In general case effective action for instanton in NP vacuum takes the
form

\[ Z = e^{-S_{\text{eff}}[A_{\text{inst}}]} = \int [Da_\mu] \langle e^{-S[A_{\text{inst}}+B+a]} \rangle, \]  

(2)

where \( \langle ... \rangle \) implies averaging over background field \( B_\mu \).

Integrating over \( a_\mu \) we arrive at the following expression for effective
instanton action:

\[ S_{\text{eff}}[A_{\text{inst}}] = S_{\text{eff}}^{\text{P}}[A_{\text{inst}}] + S_{\text{eff}}^{\text{NP}}[A_{\text{inst}}] \]

\[ S_{\text{eff}}^{\text{P}}(\rho) = \frac{b}{2} \ln \frac{1/\rho^2 + m^2}{\Lambda^2} \]

\[ S_{\text{eff}}^{\text{NP}}[A_{\text{inst}}] = -\ln(Z_2(B)) = -\ln \langle \exp\{-S[A_{\text{inst}}+B]+S[A_{\text{inst}}]\} \rangle \]  

(3)

3. We calculated effective instanton action (see 10) in bilocal approxi-
mation (i.e. we considered only bilocal correlator). In many cases this
approximation appears to be sufficient for qualitative description of various
physical phenomena in QCD. Moreover, there are indications that correc-
tions due to higher correlators are small and amount to several percent.

Numerical results for effective instanton action are shown in Fig. 1. It is
clear that nonperturbative part of effective action \( S_{\text{eff}}^{\text{NP}} \) leads to IR sta-
bilization of instanton. Numerical results for instanton size distribution
\( dn/d\sigma \sim \exp(-S_{\text{eff}}) \) and corresponding lattice data are presented in
Fig. 2. We can make a conclusion that our results for \( \rho_c \) are consistent
with phenomenological value \( \bar{\rho} \simeq 1/3 \) fm and with lattice data. We
have also studied dependence of instanton size on gluon condensate \( \langle G^2 \rangle \)
and correlation length \( T_g \). We have found that, as it should be, big values
of \( \langle G^2 \rangle \) and \( T_g \) lead to the suppression of large-size instantons.
Figure 1. Effective action $S_{\text{eff}}^P$ (dotted line), $S_{\text{eff}}^{NP}$ (dashed line) and $S_{\text{eff}} = S_{\text{eff}}^P + S_{\text{eff}}^{NP}$ (solid line).

Figure 2. Instanton density $dn/d^4zd\rho$ and lattice data.

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