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Probing Confined-Quark Dynamics via Nucleon Form Factors

Axel Bender
Physics Division, Bldg. 203, Argonne National Laboratory
Argonne, IL 60439-4843, USA

The QCD Dyson-Schwinger equations [DSEs] provide the basis for a phenomenology, in which the known large-q^2 behaviour of the gluon propagator is extrapolated to small-q^2 via a parametrisation that incorporates the qualitative features of many studies of the gluon DSE. This phenomenology has been successfully applied in the calculation of a wide range of hadron observables; for example: the meson ground-state spectrum; the elastic scattering and anomalous transition form factors of pseudoscalar mesons; and the electroproduction of vector mesons.[1] In this approach, applicable at *all* momentum scales, these observables probe the nonperturbative, confined-quark, bound state structure of the hadrons, which is their dominant, determining characteristic.[2]

The nonperturbative dressing of quarks and gluons, of which condensate formation is but one part, is of particular importance in QCD. For example, it ensures the absence of quark and gluon production thresholds in colour-singlet to singlet $\mathcal{S}$-matrix amplitudes, which is a sufficient condition for confinement. This in itself, however, neither precludes nor entails the existence of bound states, whether coloured or not. The existence of hadronic bound states can only be established via the Bethe-Salpeter equation (mesons) or the covariant Fadde'ev equation (baryons). These homogeneous bound state equations are derived from the inhomogeneous DSEs for the 4-point or 6-point quark Schwinger functions under the assumption that the associated $\mathcal{T}$-matrix has a pole in a given channel. The complex nature of the QCD vacuum and the intrinsically nonperturbative nature of bound-state problems suggest that one should employ dressed gluon and quark propagators in constructing the kernels of these equations. The DSEs facilitate this since they provide a natural framework for the unified treatment of the structure of the QCD vacuum and bound states, in which the global symmetries of QCD are manifestly preserved.

The simplest (lowest order) truncation of the two-body Bethe-Salpeter equation [BSE] is ladder approximation, in which the kernel is constructed from the model dressed gluon propagator and dressed-quark propagators obtained in rainbow approximation. With this kernel Goldstone's theorem is manifest and one can obtain a good description of the ground-state meson spectrum. However, it has the defect that it is purely attractive in the q-$\bar{q}$ colour-singlet and q-q colour-antitriplet channels. This entails the existence of colour-antitriplet quark-quark bound states, which are not observed, and can be said to underly the diquark-pole approximation to the 2-body $\mathcal{T}$-matrix in the solution of the covariant 3-body Fadde'ev equation for the baryon.

A systematic, Goldstone theorem preserving improvement of the ladder truncation demonstrates that repulsive terms appear in the kernel at every higher order.[3] In the meson channel these terms are cancelled by additional attractive terms that also appear. However, in the colour-antitriplet quark-quark channel they are not and act to eliminate the diquark bound states completely. It is this that provides for the absence of such coloured bound states in the strong interaction spectrum. Nevertheless, it is possible to simplify the study of the Fadde'ev equation by neglecting explicit 3-body interactions and approximating the 2-body $\mathcal{T}$-matrix as a sum of confined-diquark contributions.

In order to explore the efficacy of such a simplification, the electromagnetic form factors of the nucleon are calculated using a product Ansatz for the nucleon Fadde'ev amplitude: $\Psi = \sum_I \Gamma_I^{qq}\, D_I^{qq}\, \psi_I^{qq-q}$, where: Γ_I^{qq} is a quark-quark (confined-diquark) correlation amplitude; D_I^{qq} is the confined-diquark propagator; ψ_I^{qq-q} is the confined-diquark–quark correlation amplitude; and the index I ranges over all allowed colour-antitriplet, flavour and Dirac quark-quark correlations. The functions Γ_I^{qq}, D_I^{qq} and ψ_I^{qq-q} are parametrised such that no quark production thresholds occur in the kernel of the 6-point quark Schwinger function.

The preliminary results are encouraging.[4] Isoscalar-scalar and isovector-pseudovector confined-diquark correlations are found to provide the dominant contribution to the form factors. An isoscalar-scalar confined-diquark correlation alone is insufficient to describe both the electric and magnetic properties of the nucleon. The preliminary calculations indicate that the inclusion of the isovector-pseudovector correlation can remedy this problem. It is important to note that the length-scales that characterise Γ_I^{qq} and ψ_I^{qq-q} are approximately equal, which means that the diquark correlation and the nucleon itself have the same space-time extent.

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