Vision of QCD Vacuum Structure Response to Strong EM Fields ◇

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Our study of QCD in strong electromagnetic (EM) fields focuses onto the basic non-perturbative objects of the theory, which are the quark, and gluon, condensates. During the past year we have accomplished a major goal of in principle relating the condensate properties to the self-consistent treatment of the glue propagator in covariant gauge, based on a system of Dyson–Schwinger equations involving ghost fields [1]. Given this result we have devised [2] a completely novel technique of a priory calculations of condensate in pure gluodynamics. Not only we have rendered the amplitude of the gluon condensate, but also its correlation scales at large and small distances have also been determined. Our results are in good agreement with lattice calculations, and the amplitude and shape of the gluon condensate is comparable to the experimental values. The spatial form of the non-local condensate obtained in our Dyson-Schwinger Equation solution (DSE) approach is shown in Fig. 1.

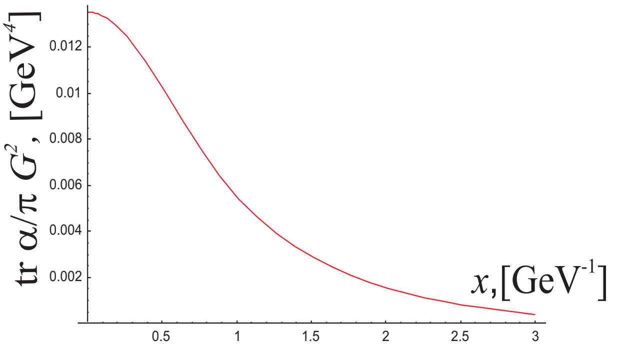

Fig. 1: The non local gluon condensate in $3+1$-dimensional $SU_c(3)$ from DSE approach, scale fixed at 10 GeV.

Having implemented pure 2-loop gluodynamics, we aim presently at taming full QCD with quarks. It is generally recognized that quark fluctuations are driven by gluon fluctuations, therefore, hence the pure gluodynamics treatment is necessarily precedent to studying the quark sector and the chiral symmetry breaking. We are in early stage of this effort, but the methods we developed for gluodynamics are applicable to the quark domain and no new in principle complications are expected.

Our solution of the condensate problem opens to study the behavior of quark condensate by impacting it with an external electromagnetic field, a milestone objective in this research area. Another milestone objective in our studies of non-local gluon condensate is the understanding of the (small) long-range field correlation which is expected to respond strongly to the ordering effect of, in this context long-range, external field. As shown by lattice methods such a long-range gauge field correlation can arise due to presence of topological monopoles. By way of this mechanism, a strong QED-QCD coupling in the vacuum arises, and it is rendered invisible in the infrared QED limit by the process of renormalization. However, considering the strength of quark fluctuations in the vacuum, as expressed by their condensate, is it a literal miracle of Poincaré symmetry that a plane wave of light can pass unimpeded through these.

However high intensity focused relativistic light pulse are not protected by translational symmetry, and should undergo hadronization when threshold intensity is reached. This can occur in the same way as ionization effects in atoms, here through the virtual quark re-collision process: a quark pulled out of the vacuum state is returned by the oscillating light pulse wave to the remaining color-ion domain, in so far the color string is not already broken – in either case hadronization of light occurs. Theoretical demonstration, and experimental implementation of this phenomenon is the primary objective of our research program, since it creates a connection of quantum optics with hadron physics.

Constant magnetic field offers another probe to analyzing the structure of the vacuum, being an alternative to a plane wave laser field in the sense that a field configuration of any strength is stable, i.e. does not lead to vacuum decay. One of us (A.Z.) developed within so called AdS/CFT method [3] an analytical approach to describe the chiral condensate in strong magnetic fields of a strength exceeding the quark mass scale The key result of this analysis is a condensate shift quadratic in the magnetic field. This result contrasts with the standard result of chiral perturbation theory, where a linear effect in field strength is found. The AdS/CFT method is viewed by many as a novel nonperturbative approach yet it fails this test comparison with a more established QCD method. This result needs deserves verification within our DSE method.

Another theoretical objective we pursue is a nonperturbative formulation of the evaluation of the quark and gauge condensate. These objects being completely nonperturbative, deserve improved treatment, free of any series expansions. In the current evaluation we still have to resort to a perturbative representation of Wilson lines. Therefore we are working to implement a Bethe-Salpeter-like 'bound' state type re-summation of ladder diagrams for the Wilson line correlator. This will allow us to close the chain of self-consistent equations defining in full the structure of the QCD-QED vacuum characteristics. With this accomplished we should be able to proceed to quantitative predictions on vacuum melting and hadronization by external electromagnetic fields.

References

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