Anderson Localization transition in QCD spectrum

Abstract

Lattice QCD is currently our best numerical approach to the non-perturbative regime of strong interaction. Asymptotic freedom guarantees that at high energy scales, the theory is weakly interacting and a perturbative treatment is possible.
Through Monte Carlo simulations of the Path Integral, it's possible to investigate numerous non-perturbative effects arising from low energy scales. One such effect is Anderson localization, initially described in the context of disordered electronic systems. It seems to be related to the behavior of low-energy fermionic states when we couple Dirac fermions to the QCD non-Abelian $SU(3)$ gauge field.
In the following work, we use Rational Hybrid Monte Carlo sampling techniques to generate gauge configurations to couple with the staggered Dirac fermion operator and analyze the statistical properties of the spectrum. The aim is to visualize a transition in the distribution of the unfolded level spacings of the Dirac modes, from a Poissonian to a Wigner-Dyson distribution proceeding towards higher eigenvalues. The Poissonian behavior of the spectrum indicates the presence of localized modes, while a GUE distribution is expected for the eigenvalues up to a mobility edge.
By computing the integral of the unfolded level spacing distribution I_{s_0}, up to the first intersection point between the two statistics, we can identify the mobility edge as the critical value of I_{s_0}, at which the spacings switch distribution and localization/delocalization appears. We will investigate the behavior of the Participation Ratio (PR), a measure of the fraction of the system occupied by a certain mode, looking for evidence of localization.
Furthermore, the localization transition seems to be related to the transition to deconfinement and the restoration of chiral symmetry, which is spontaneously broken at low temperatures. Numerical simulations suggest a relation between these phenomena, occurring at very close temperatures, but it is not well understood if the presence of localized modes affects both chiral symmetry restoration and deconfinement.
Moreover, the Anderson localization transition should be linked to topological excitations of the gauge field and the associated fermionic zero modes. In light of this, given that the QCD vacuum is thought to be populated by fluctuations of a dense liquid of topological objects (instantons and anti-instantons), we can explore the conjectured relation between certain gauge configurations and the presence of localized modes. Instanton solutions of the Yang-Mills equation are always associated with zero energy modes of the Dirac operator. However, the liquid instanton–anti-instanton model is not an exact solution. So, we can investigate the potential relation between topological charges (carried by instantons associated with the lowest modes of the spectrum) and chiral symmetry restoration, providing a possible connection scenario between localization and chirality phenomena.

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