Unification of QCD Running Coupling and $\beta$-function on any $Q^2$ scale

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I. ABSTRACT

In this work, we investigate QCD-like running coupling $\alpha_{s}^{AdS}(Q^2)$ and its associated $\beta$-function $\beta(Q^2)$ in the spirit of tachyonic AdS/QCD. We distort the AdS$_5$ conformal symmetry using a color dielectric function $G(\phi(z))$ associated with tachyons, with $\phi(z)$ the tachyon field. The $G(\phi(z))$ presents different properties of $\alpha_{s}^{AdS}(Q^2)$ at small and large values of the fifth-dimensional holographic variable $z$. The $G(\phi(z))$ distorts the AdS$_5$ space, giving $\alpha_{s}^{AdS}(Q^2)$ and its $\beta(Q^2)$ at any $Q^2$ scale. The result obtained for large value of $z$ shows characteristics similar to nonperturbative QCD. On the other hand, the result obtained for a small value of $z$ shows characteristics similar to perturbative QCD. Free tachyons are responsible for distortions at small $z$. On the contrary, condensed tachyon states lead to large $z$ distortion. This provides a unified background for determining $\alpha_{s}^{AdS}(Q^2)$ and its $\beta(Q^2)$ in both the ultraviolet (UV) and infrared (IR) regions in a unified framework.

Furthermore, we show that the tachyonic field $\phi$ is associated with glueball field $\varphi$, and the color dielectric function is associated with higher dimensional operator $H_{\mu\nu}H^{\mu\nu}$ coupled to a Standard Model (SM) gauge field $O_{SM}$ that leads to strongly interacting light glueballs. The results obtained from the study are compared with effective couplings determined from different observables such as; lattice QCD, QCD phenomenology, and $g_1$ scheme extracted from the well-measured Bjorken sum rule. Our approach brings new perspective to AdS/QCD, where pQCD coupling characteristics can be determined through direct UV deformation of the AdS$_5$ space instead of extrapolation from the IR deformation of the AdS space. Again, we determine the parameter that controls the transition from the pQCD to nonperturbative QCD.

Finally, we show that $\alpha_{s}(Q^2)$ and $\beta(Q^2)$ are related to strongly interacting scalar glueballs with mass $m_{\phi}$ and discuss its effect. Landau singularity that marks the failure of perturbative QCD was examined in the model framework. The $\alpha_{s}(Q^2)$ is a subject of active research due to its limited understanding in the low momentum transfer region. A good knowledge of $\alpha_{s}(Q^2)$ at $Q \rightarrow \infty$ is also necessary to match the growing precision of hadron scattering experiments and enhance the understanding of high energy unification of strongly interacting and electroweak theories. Nonetheless, a precise understanding of $\alpha_{s}(Q^2)$ at $Q \rightarrow 0$ on the scale of proton mass enables us to understand hadron structure, confinement, and hadronization.


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