GLUON PROPAGATOR IN MAXIMALLY ABELIAN GAUGE AND ABELIAN DOMINANCE FOR LONG-RANGE INTERACTION

K. Amemiya and H. Suganuma

Research Center for Nuclear Physics (RCNP), Ibaraki, Osaka 567-0047, Japan

The dual-superconductor picture[1] for the confinement mechanism is one of the most an interesting current topics in the hadron physics. In this picture, the color-magnetic monopoles condense and the color-electric flux is sqeezed through a dual Meissner effect. The key point is the use of the maximally abelian (MA) gauge, where QCD reduces into the abelian gauge theory including QCD-monopoles[2]. In the MA gauge, the diagonal part of gluon field plays a dominant role to the nonperturbative quantities like confinement and chiral-symmetry breaking[3]. On the other hand, the off-diagonal part of gluon field behaves as a charged matter field and does not contribute to the long-range phenomena. This is called as the abelian dominance[4]. The abelian dominance is strongly supported by the recent lattice QCD simulation. However, the origin of the abelian dominance in the MA gauge is not understood yet.

As a possible physical interpretation for the abelian dominance, the effective mass of the charged gluon may be induced in the MA gauge, and therefore the charged gluon propagation is limited within the short-range region because the massive particle propagates within the inverse of its mass. Here, to understand the origin of the abelian dominance, we study the gluon propagator in the MA gauge in terms of the interaction range and strength using the lattice QCD Monte-Carlo simulation.

To estimate the effective mass of the off-diagonal (charged) gluon in the MA gauge, we consider the massive gauge boson propagator for the off-diagonal (charged) gluon propagator in the MA gauge. In momentum space, the massive gauge boson propagator is

$$\tilde{G}_{\mu\nu}(k) \equiv \frac{-\mathrm{i}}{k^2 - M^2 + \mathrm{i}\varepsilon}\left[g_{\mu\nu} + (\xi - 1)\frac{k_\mu k_\nu}{k^2 - \xi M^2}\right] , \qquad (1)$$

where the gauge fixing parameter ξ is the residual U(1) gauge freedom after the MA gauge fixing. We impose the U(1) Landau gauge fixing $\xi = 0$ to extract most continuous gauge configuration and to compare lattice QCD results with the continuum theory. In coordinate space, the propagator becomes the Yukawa-type function through the Fourier transformation,

$$G_{\mu\mu}(r) \equiv \frac{3}{4\pi^2}\frac{\exp(-M\ r)}{r^2} \qquad \left(r \equiv \sum_{\mu=1}^{4}(x_\mu x_\mu)^{\frac{1}{2}}\right) ,$$

and shows the short-range interaction, where $G_{\mu\mu} \equiv G_{11} + G_{22} + G_{33} + G_{44}$ in the Euclidean metric. On the other hand, for the massless gauge boson, the long-range Coulomb-type interaction is showed,

$$G_{\mu\mu}(r) \equiv \frac{3}{4\pi^2}\frac{1}{r^2}.$$

In the lattice QCD, the MA gauge is defined by maximizing

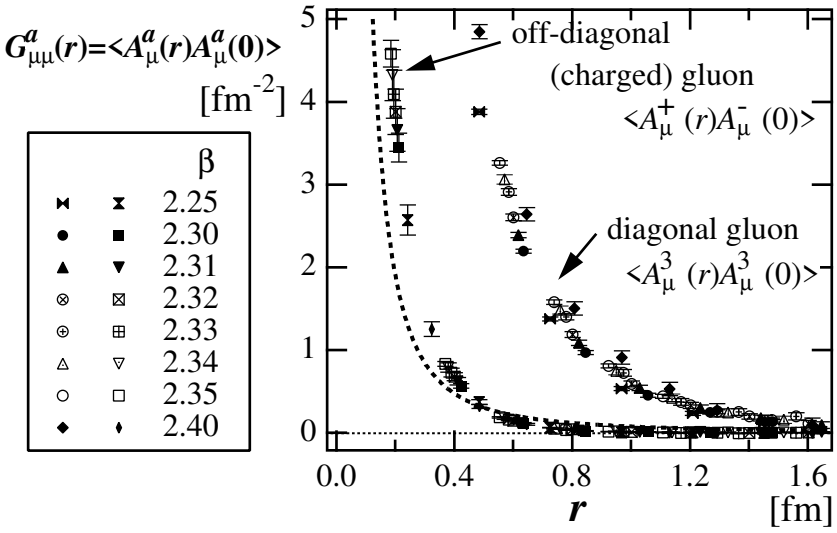

Figure 1: The gluon propagator in the MA gauge. The separation of the diagonal part of the propagator and the off-diagonal part is observed. In the MA gauge, the only diagonal-gluon is dominant in the long-range region, $r \gtrsim 0.4$ fm. The charged gluon is defined by $A^\pm_\mu \equiv \frac{1}{\sqrt{2}}(A^1_\mu \pm \mathrm{i}A^2_\mu)$.

$R_{MA} \equiv \sum_{s,\mu} \mathrm{Tr}\left[U_\mu(s)\tau^3 U^\dagger_\mu(s)\tau^3\right]$ using the SU(2) gauge transformation. In the MA gauge, the SU(2) link variable $U_\mu(s)$ becomes U(1)-like due to the suppression of the off-diagonal component.

We calculate the gluon propagator in the MA gauge with the U(1) Landau gauge by the SU(2) lattice QCD Monte Carlo simulation with $12^3 \times 24$ and $\beta = 2.25$ to 2.40. The gluon propagator is calculated considering the scalar combination, $G^a_{\mu\mu}(r) \equiv \sum_{\mu=1}^4 \langle A^a_\mu(r)A^a_\mu(0)\rangle$ ($a = 1,2,3$). Here the scalar combination $G^a_{\mu\mu}(r)$ is useful to observe the interaction range of the gluon, because it depends only on the four-dimensional Euclidean radial coordinate $r \equiv \sum_\mu (x_\mu x_\mu)^{\frac{1}{2}}$ [5, 6].

In Fig.1, in the MA gauge, the off-diagonal (charged) gluon propagates within the short-range region $r \lesssim 0.4$ fm. The charged gluon behaves as the massive particle and does not contribute to the long-range physics in the MA gauge. On the other hand, the diagonal gluon propagates over the long distance and influences the long-range physics. Thus, the only diagonal gluon field is relevant for the long-range physics in the MA gauge, and we find the abelian dominance for the gluon propagator in the MA gauge. This is the origin of the abelian dominance for the long-range physics [5, 6].

The off-diagonal (charged) gluon propagator decreases more strongly than the massless gauge-boson propagator $G_{\mu\mu}(r) = \frac{3}{4\pi^2}\frac{1}{r^2}$. Therefore, the charged gluon is expected to have an effective mass in the MA gauge. We estimate the effective mass of the charged gluon from the scalar combination $G_{\mu\mu}(r)$ of the gluon propagator. Since the propagator of the massive gauge boson with mass M behaves as the Yukawa-type function $G_{\mu\mu}(r) = \frac{3}{4\pi^2}\frac{1}{r^2}\exp(-M\ r)$, we can estimate the effective mass of gluons M_{eff} from the slope of the logarithmic plot

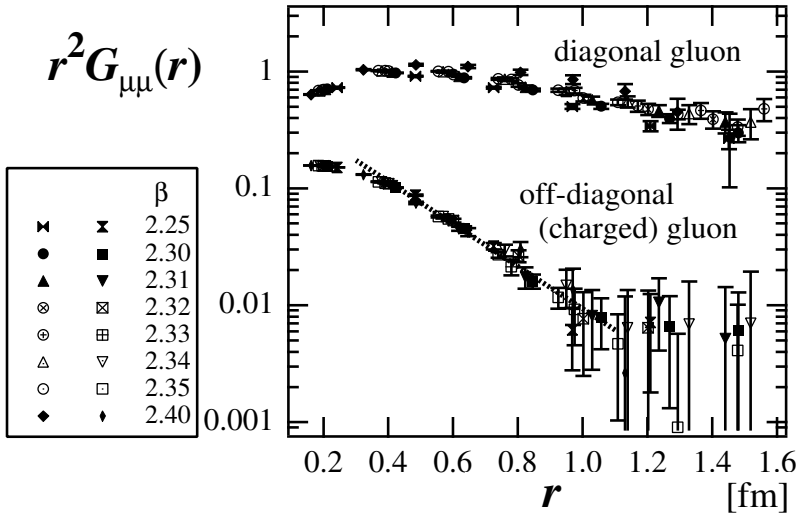

Figure 2: The logarithmic plot of $r^2G_{\mu\mu}(r)$ as the function of the distance r in the MA gauge. The charged gluon propagator behaves as the Yukawa-type function, $G_{\mu\mu}(r) \sim \frac{\exp(-Mr)}{r^2}$. The effective mass of the charged gluon can be estimated by the slope of the dotted line.

of $r^2G_{\mu\mu}(r) \sim \exp(-M_{\rm eff}\ r)$. In Fig.2, the charged gluon correlation $r^2G_{\mu\mu}(r)$ decreases linearly in the long-range region $r \gtrsim 0.4$ fm. We obtain the effective mass of the charged gluon from this slope in the intermediate region $r = 0.35 \sim 1.0$ fm as $M_{\rm eff} \simeq 4.5$ fm^{-1} $= 0.9$ GeV [5, 6].

To summarize, in the MA gauge, the propagator of the off-diagonal (charged) gluon follows the Yukawa-type function, and the effective mass of the off-diagonal (charged) gluon is induced as $M_{\rm eff} \simeq 1$ GeV in the infrared region. Accordingly, the off-diagonal gluon can be neglected and does not contribute to the long-range physics as $r \gtrsim 0.4$ fm, although its effect appears in the short distance as $r \lesssim 0.4$ fm. Thus, only the diagonal gluon propagates the long distance, which leads to the origin of the abelian dominance for nonperturbative QCD[5, 6].

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