Experimental Verification of Two types of Gluon Jets in QCD

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The Abelian decomposition of QCD tells that there are two types of gluons, the color neutral neurons and colored chromons. We propose to test the Abelian decomposition confirming the existence of two types of gluon jets experimentally. We predict that a quarter of the gluon jet is made of the neuron jet which has the color factor 3/4 and has the sharpest jet radius and smallest particle multiplicity, while the four-third of the gluon jet is made of the chromon jet with the color factor 9/4 which has the broadest jet (broader than the quark jet). Moreover, we argue that the neuron jet has a distinct color flow which forms an ideal color dipole, while the quark and chromon jets have distorted dipole pattern. To test the plausibility of this proposal we suggest to renalize the existing gluon jet events and look for the jet pattern which does not fit to the known charateristics of the gluon jet.

Keywords: Abelian decomposition, two types of gluons, neuron, chromon, decomposition of Feynman diagram in QCD, neuron jet, chromon jet, color factors of neuron and chromon jets, quark and chromon model

I. INTRODUCTION

A common misunderstanding on QCD is that the non-Abelian color gauge symmetry is so tight that it defines the theory almost uniquely, and thus does not allow any simplification. This is not true. The Abelian decomposition of QCD tells that we can construct the restricted QCD (RCD) which inherits the full non-Abelian color gauge symmetry with the restricted potential obtained by the Abelian projection. This tells that QCD has a non-trivial core, RCD, which describes the Abelian subdynamics of QCD but has the full color gauge symmetry. Moreover, it tells that QCD can be viewed as RCD which has the gauge covariant valence gluons as the colored source [1, 2]. This is because the Abelian decomposition decomposed the color gauge potential to the restricted potential made of the color neutral gluon potential and monopole potential and the gauge covariant valence potential which describes the colored gluons gauge independently.

There are ample motivations for the Abelian decomposition. Consider the proton made of three quarks. Obviously we need the gluons to bind the quarks in the proton. However, the quark model tells that the proton has no valence gluon. If so, what is the binding gluon which bind the quarks in proton, and how do we distinguish it from the valence gluon?

Another motivation is the color confinement in QCD. Two popular proposals for the confinement are the monopole condensation [2, 3] and the Abelian dominance [4, 5]. To prove the monopole condensation, we first have to separate the monopole potential gauge independently. Similarly, to prove the Abelian dominance we have to know what is the Abelian part and how to separate it.

Actually, the simple group theory tells that the color gauge group has the Abelian subgroup generated by the diagonal generators, and that the gauge potential which correspond to these generators must be color neutral while the potential which correspond to the off-diagonal generators must carry the color. This strongly implies that there are two types of gluon, the color neutral ones and colored ones. And they should behave differently. If so, how can we separate them?

The Abelian decomposition tells how to do this. It decomposes the non-Abelian gauge potential to two parts, the restricted Abelian part which has the full non-Abelian gauge symmetry and the gauge covariant valence part which describes the colored gluons. Moreover, it separates the restricted potential to the non-topological Maxwell part which describes the colorless binding gluons and the topological Dirac part which describes the non-Abelian monopole [1, 2].

This has deep consequences. It tells that QCD has two types of gluons, the color neutral binding gluons (the neurons) and the colored valence gluons (the chromons), which play totally different roles. The neurons, just like the photon in QED, plays the role of the binding gluon. On the other hand the neurons, kike the quarks, play the role of the constituent gluon.

This allows us to prove the Abelian dominance, that RCD is responsible for the confinement [4, 5]. This is because the chromons, being colored, have to be confined. So it can not play any role in the confinement. More-

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over, this allows us to prove the monopole condensation. Integrating out the chromons under the monopole background, we can demonstrate that the true QCD vacuum is given by stable monopole condensation [6–8].

This makes the experimental verification of the Abelian decomposition an urgent issue. The prediction and subsequent confirmation of the gluon jet was a great success of QCD [9–11]. To promote QCD further we need the experimental confirmation of the existence of two types of gluons. The purpose of this communication is to show how to do this at LHC.

II. ABELIAN DECOMPOSITION: A REVIEW

To show QCD has two types of gluons, consider the SU(2) QCD first. Let $(\hat{n}_1, \hat{n}_2, \hat{n}_3 = \hat{n})$ be an arbitrary SU(2) basis and select $\hat{n}$ to be the Abelian direction. Project out the restricted potential $\hat{A}_\mu$ which parallelizes $\hat{n}$ [1, 2]

$$\begin{gathered} D_\mu \hat{n} = (\partial_\mu + g\vec{A}_\mu \times)\hat{n} = 0, \\ \vec{A}_\mu \rightarrow \hat{A}_\mu = A_\mu \hat{n} - \frac{1}{g}\hat{n} \times \partial_\mu \hat{n} = \tilde{A}_\mu + \tilde{C}_\mu, \\ \tilde{A}_\mu = A_\mu \hat{n}, \quad \tilde{C}_\mu = -\frac{1}{g}\hat{n} \times \partial_\mu \hat{n}. \end{gathered} \tag{1}$$

The restricted potential is made of two parts, the non-topological (Maxwellian) $\tilde{A}_\mu$ which describes the colorless neuron and the topological (Diracian) $\tilde{C}_\mu$ which describes the non-Abelian monopole [12, 13]. Moreover, it has the full SU(2) gauge degrees of freedom.

With this we have

$$\begin{gathered} \hat{F}_{\mu\nu} = (F_{\mu\nu} + H_{\mu\nu})\hat{n} = F'_{\mu\nu}\hat{n}, \\ F_{\mu\nu} = \partial_\mu A_\nu - \partial_\nu A_\mu, \\ H_{\mu\nu} = -\frac{1}{g}\hat{n} \cdot (\partial_\mu \hat{n} \times \partial_\nu \hat{n}) = \partial_\mu C_\nu - \partial_\nu C_\mu, \\ C_\mu = -\frac{1}{g}\hat{n}_1 \cdot \partial_\mu \hat{n}_2, \\ F'_{\mu\nu} = \partial_\mu A'_\nu - \partial_\nu A'_\mu, \quad A'_\mu = A_\mu + C_\mu. \end{gathered} \tag{2}$$

From this we can construct RCD which has the full non-Abelian gauge symmetry,

$$\begin{gathered} \mathcal{L}_{RCD} = -\frac{1}{4}\hat{F}^2_{\mu\nu} = -\frac{1}{4}F^2_{\mu\nu} \\ +\frac{1}{2g}F_{\mu\nu}\hat{n} \cdot (\partial_\mu \hat{n} \times \partial_\nu \hat{n}) - \frac{1}{4g^2}(\partial_\mu \hat{n} \times \partial_\nu \hat{n})^2, \end{gathered} \tag{3}$$

which describes the Abelian sub-dynamics of QCD.

We can express the full SU(2) potential adding the gauge covariant chromon $\vec{X}_\mu$ to $\hat{A}_\mu$ [1, 2]

$$\vec{A}_\mu = \hat{A}_\mu + \vec{X}_\mu, \quad \hat{n} \cdot \vec{X}_\mu = 0. \tag{4}$$

Moreover, with

$$\vec{F}_{\mu\nu} = \hat{F}_{\mu\nu} + \hat{D}_\mu \vec{X}_\nu - \hat{D}_\nu \vec{X}_\mu + g\vec{X}_\mu \times \vec{X}_\nu, \tag{5}$$

we recover the full SU(2) QCD

$$\begin{gathered} \mathcal{L}_{QCD} = -\frac{1}{4}\hat{F}^2_{\mu\nu} - \frac{1}{4}(\hat{D}_\mu \vec{X}_\nu - \hat{D}_\nu \vec{X}_\mu)^2 \\ -\frac{g}{2}\hat{F}_{\mu\nu} \cdot (\vec{X}_\mu \times \vec{X}_\nu) - \frac{g^2}{4}(\vec{X}_\mu \times \vec{X}_\nu)^2, \end{gathered} \tag{6}$$

This shows that QCD can be viewed as RCD which has the chromon as the colored source [1, 2].

The Abelian decomposition of SU(3) QCD is similar [6–8]. Let $\hat{n}_i$ $(i = 1, 2, ..., 8)$ be the orthonormal SU(3) basis and choose $\hat{n}_3 = \hat{n}$ and $\hat{n}_8 = \hat{n}'$ to be the two Abelian directions, and make the Abelian projection imposing the condition

$$\begin{gathered} D_\mu \hat{n} = 0, \quad D_\mu \hat{n}' = 0, \\ \vec{A}_\mu \rightarrow \hat{A}_\mu = A_\mu \hat{n} + A'_\mu \hat{n}' - \frac{1}{g}\hat{n} \times \partial_\mu \hat{n} - \frac{1}{g}\hat{n}' \times \partial_\mu \hat{n}' \\ = \sum_p \frac{2}{3}\hat{A}^p_\mu, \quad (p = 1, 2, 3), \\ \hat{A}^p_\mu = A^p_\mu \hat{n}^p - \frac{1}{g}\hat{n}^p \times \partial_\mu \hat{n}^p = \mathcal{A}^p_\mu + \mathcal{C}^p_\mu, \\ A^1_\mu = A_\mu, \quad A^2_\mu = -\frac{1}{2}A_\mu + \frac{\sqrt{3}}{2}A'_\mu, \\ A^3_\mu = -\frac{1}{2}A_\mu - \frac{\sqrt{3}}{2}A'_\mu, \\ \hat{n}^1 = \hat{n}, \ \hat{n}^2 = -\frac{1}{2}\hat{n} + \frac{\sqrt{3}}{2}\hat{n}', \ \hat{n}^3 = -\frac{1}{2}\hat{n} - \frac{\sqrt{3}}{2}\hat{n}'. \end{gathered} \tag{7}$$

Notice that, although SU(3) has only two Abelian directions, $\hat{A}_\mu$ can be expressed by three SU(2) restricted potential $\hat{A}^i_\mu$ $(i = 1, 2, 3)$ in Weyl symmetric way, symmetric under the permutation of three SU(2) subgroups (or equivalently permutation of three Abelian directions $\hat{n}^i$). With this we have the Weyl symmetric SU(3) RCD

$$\mathcal{L}_{RCD} = -\frac{1}{4}\hat{F}^2_{\mu\nu} = -\sum_p \frac{1}{6}(\hat{F}^p_{\mu\nu})^2, \tag{8}$$

which has the full SU(3) gauge symmetry.

Adding the valence part $\vec{X}_\mu$ to $\hat{A}_\mu$ we have the SU(3) Abelian decomposition,

$$\begin{gathered} \vec{A}_\mu = \hat{A}_\mu + \vec{X}_\mu = \sum_p (\frac{2}{3}\hat{A}^p_\mu + \vec{W}^p_\mu), \\ \vec{W}^1_\mu = X^1_\mu \hat{n}_1 + X^2_\mu \hat{n}_2, \quad \vec{W}^2_\mu = X^6_\mu \hat{n}_6 + X^7_\mu \hat{n}_7, \\ \vec{W}^3_\mu = X^4_\mu \hat{n}_4 + X^5_\mu \hat{n}_5, \\ \vec{F}_{\mu\nu} = \hat{F}_{\mu\nu} + \hat{D}_\mu \vec{X}_\nu - \hat{D}_\nu \vec{X}_\mu + g\vec{X}_\mu \times \vec{X}_\nu \\ = \sum_p \big[\frac{2}{3}\hat{F}^p_{\mu\nu} + (\hat{D}^p_\mu \vec{W}^p_\nu - \hat{D}^p_\mu \vec{W}^p_\nu)\big] \\ + \sum_{p,q} \vec{W}^p_\mu \times \vec{W}^q_\nu, \end{gathered} \tag{9}$$

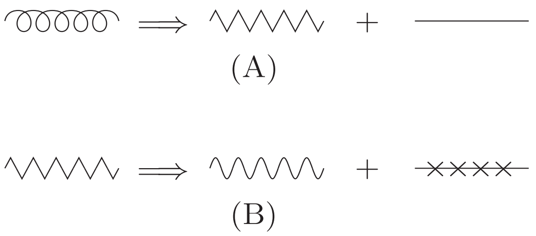

FIG. 1: The Abelian decomposition of the gauge potential. In (A) it is decomposed to the restricted potential (kinked line) and the chromon (straight line). In (B) the restricted potential is further decomposed to the neuron (wiggly line) and the monopole (spiked line).

where $\hat{D}^p_\mu = \partial_\mu + g\hat{A}^p_\mu \times$. Notice that $\vec{X}_\mu$ is decomposed to three (red, blue, and green) SU(2) chromons $(\vec{W}^1_\mu, \vec{W}^2_\mu, \vec{W}^3_\mu)$. Here again $\vec{A}_\mu$ is expressed in a Weyl symmetric way, but unlike $\hat{A}^i_\mu$, the three chromons are completely independent.

From this we obtain the Weyl symmetric SU(3) QCD [6–8]

$$\mathcal{L}_{QCD} = \sum_p \Big\{ -\frac{1}{6}(\hat{F}^p_{\mu\nu})^2 \\ -\frac{1}{4}(\hat{D}^p_\mu \vec{W}^p_\nu - \hat{D}^p_\nu \vec{W}^p_\mu)^2 - \frac{g}{2}\hat{F}^p_{\mu\nu}\cdot(\vec{W}^p_\mu \times \vec{W}^p_\nu)\Big\} \\ -\sum_{p,q}\frac{g^2}{4}(\vec{W}^p_\mu \times \vec{W}^q_\mu)^2 \\ -\sum_{p,q,r}\frac{g}{2}(\hat{D}^p_\mu \vec{W}^p_\nu - \hat{D}^p_\nu \vec{W}^p_\mu)\cdot(\vec{W}^q_\mu \times \vec{W}^r_\mu) \\ -\sum_{p\neq q}\frac{g^2}{4}\Big[(\vec{W}^p_\mu \times \vec{W}^q_\nu)\cdot(\vec{W}^q_\mu \times \vec{W}^p_\nu) \\ +(\vec{W}^p_\mu \times \vec{W}^p_\nu)\cdot(\vec{W}^q_\mu \times \vec{W}^q_\nu)\Big]. \quad (10)$$

We can easily add the quark triplet (r, g, b) in the Abelian decomposition, and express the quark Lagrangian in Weyl-symmetric in three SU(2) quark doublets (r, b), (b, g), and (g, r) [6, 8]. In the literature the Abelian decomposition is known as the Cho decomposition, Cho-Duan-Ge (CDG) decomposition, or Cho-Faddeev-Niemi (CFN) decomposition [14–17].

The Abelian decomposition is expressed graphically in Fig. 1. Although the decomposition does not change QCD, it reveals the important hidden structures of QCD. In particular, it shows the existence of two types of gluons, the neuron and chromon.

This has deep implications. In the perturbative regime this tells that the Feynman diagram can be decomposed in such a way that the color conservation is explicit. This is graphically shown in Fig. 2. Notice that there are no three-point vertex made of two or three neuron legs, and no four-point vertex made of three or four neuron legs.

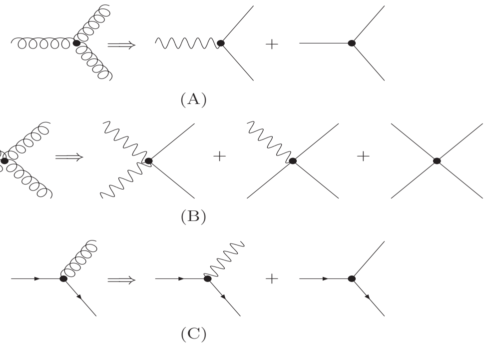

FIG. 2: The decomposition of the Feynman diagrams in SU(3) QCD. In (A) and (B) the three-point and four-point gluon vertices are decomposed, and in (C) the quark-gluon vertices are decomposed. Notice that the monopole does not appear in the Feynman diagrams because it describes topological degree, not dynamical degree.

As importantly this shows that neurons and chromons play totally different roles. The neuron, just like the photon in QED, provides the binding. But the chromons, just like the quarks, become the colored source. This is evident in Feynman diagrams of two gluon binding shown in Fig. 3. Clearly the neuron binding looks very much like two photon binding in QED, while the chromon binding look just like the quark-antiquark binding in QCD. This strongly implies that the neurons may not be viewed as the constituent of hadrons. However, the chromon binding strongly implies that they, just like the quarks, become the constituent of hadrons. This generalizes the quark model to the quark and chromon model, which provides a new picture of hadrons [18, 19].

III. MONOPOLE CONDENSATION

In the non-perturbative regime, the Abelian decomposition proves the Abelian dominance, or more precisely the monopole dominance. Theoretically we can show rigorously that only the restricted potential contributes to the Wilson loop integral which produces the area law for the confinenent [5]. Moreover, we can argue that the neurons (just like the photon in QED) provide the binding force and do not play an important role in the confinement. This strongly implies that the monopole potential plays the central role in the confinement.

This can be confirmed in lattice QCD. Implementing the Abelian decomposition on lattice we can calculate the Wilson loop integral with the full potential, the restricted potential, and the monopole potential separately, and show that all three potentials produce exactly the same linear confining force [20, 21]. The lattice result for SU(3) QCD is shown in Fig. 4. This tells that the monopole potential plays the crucial role in the confinement.

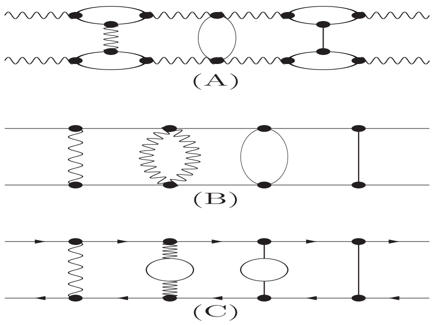

FIG. 3: The possible Feynman diagrams of the neurons and chromons. Two neuron interaction is shown in (A), two chromon interaction is shown in (B), and quark-antiquark interaction is shown in (C).

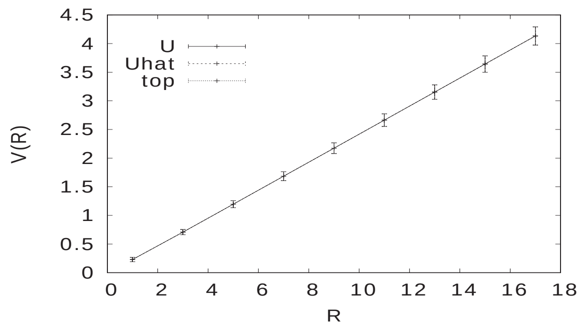

FIG. 4: The SU(3) lattice QCD calculation which establishes the monopole dominance in the confining force in Wilson loop. Here the confining forces shown in full, dashed, and dotted lines are obtained with the full potential, the Abelian potential, and the monopole potential, respectively.

As importantly the Abelian decomposition naturally puts QCD to the background field formalism, because the restricted part and the valence part can be treated as the classical background and the fast moving quantum fluctuation [22, 23]. So the decomposition provides us an ideal platform to calculate the QCD effective potential and prove the monopole condensation gauge independently. Indeed, choosing the monopole potential as the background and integrating out the chromons gauge invariantly, we can prove that the true QCD vacuum is given by the gauge invariant monopole condensation [6–8].

IV. NEURON JET AND CHROMON JET

The Abelian decomposition is not just a theoretical proposition. There are many ways to test it experimentally. For example, we can test it by showing the quark and chromon model describes the correct hadron spectrum. Or we can test it by demonstrating that the monopole condensation does describe the true QCD vacuum. But these are the indirect tests. If QCD really has two types of gluons, we should be able to confirm it directly by experiment.

During the last twenty years there has been huge progress on jet structure in QCD. New features of the quark and gluon jet substructures have been known [24–27]. Moreover, new ways to tag different jets have been developed [28–30]. Now, we argue that these progresses could allow us to confirm the existence of two types of gluon jets experimentally at LHC.

Early experiments which established the existence of the gluon are based on planar three jet events made of two quark jets and one gluon jet [10, 11]. So the problem here is to devide the gluon jets to neuron jet and chromon jet. For this we have two questions. First, how many of them are the neuron jet? Second, how can we identify the neuorn jet?

The first question is easy. Since two of the eight gluons are neurons, one quarter of the gluon jet should be the neuron jet and three quarters of them should be the chromon jet. The difficult problem is the second question. Actually the problem here is not just how to separate the neuron jet from the chromon jet. Since we have the quark jet as well in QCD, we have to tell how to tag all three jets, the neuron jet, the chromon jet, and the quark jet, separately. So we have to know the difference of each jet from the other two.

To tell the difference it is important to remember that the gluons and quarks emitted in the p-p collisions evolve into hadron jets in two steps, the parton shower described by the perturbative process and the hadronization described by the non-perturbative process. The hadronization in the second step is basically the same in all three jets. The difference comes from the parton shower in the first step [31]. This is shown in Fig. 5 in the first order interaction.

Clearly the neuron jet shown in (A) has no parton shower made of neuron emission which exists in both the chromon jet (B) and the quark jet (C). But the chromon and quark jets have the neuron and chromon jets, and qualitatively look similar. This is because the three-point vertex made of three neurons is forbidden, as shown in Fig. 2. This strongly suggests that the neuron jet must have different jet shape, sharp with relatively small radius compared to the chromon and quark jets.

Of course, there are other differences. The neuron jet should have different (charged) particle multiplicity, considerably smaller than that of the quark and/or chromon jets. This again must be clear from Fig. 5, which shows that chromon and quark couple to neurons which make secondary showers but the neuron jet is not allowed to have such interaction.

Another important feature of the neuron jet is that

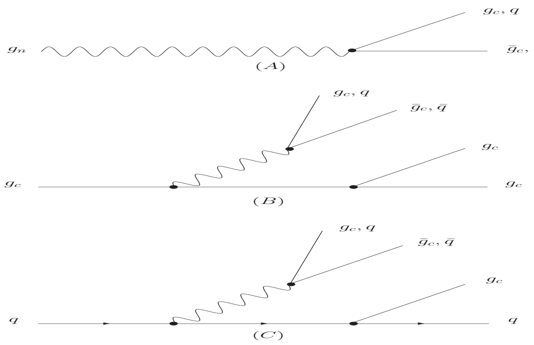

FIG. 5: The first order perturbative diagrams of neuron, chromon, and quark jets. The neuron jet described in (A) is qualitatively different from the chromon jet and the quark jet shown in (B) and (C), while the chromon and quark jets are similar.

it has has different color flow. Clearly the chromons and quarks carry color charge, but the neurons are color neutral. So the neuron jet must have different color flow. In fact, Fig. 5 tells that the color flow of the neuron jet generates an ideal color dipole pattern, but the other two jets have distorted dipole pattern. We could check this prediction using Pythia and FastJet. This means that the neuron jet must be quantitatively different from the chromon and quark jets. To tell more detailed differences, of course, we need more serious theoretical calculations and numerical simulations. But from the above observations it must be clear that the neuron jet is different from the other two.

To quantify the difference, we have to know the color factors of the neuron and chromon jets, a most important quantity that determines the characters of the jet. Since the soft gluon radiation of the hard quark and the hard gluon are proportional to their color factors $C_F = 4/3$ and $C_A = 3$ in the eikonal approximation, the quark/gluon tagging performance crucially depends on their ratio C_A/C_F. So it is important to know the neuron and chromon color factors.

One might think that the neurons have no color factor, but this is not so. Although they are color neutral, they are not color singlet. So they have finite color factor. But at the moment it appears unclear if one can calculate the neuron and chromon color factors from the first principle, because the color gauge symmetry is replaced to the 24-element color reflection symmetry after the Abelian decomposition [1, 2, 6–8]. On the other hand, from the fact that the gluon color factor is given by the trace of the quadratic Casimir invariant made of the eight gluon generators, we could assume the neuron color factor to be the part of the trace of the quadratic Casimir invariant corresponding to the neuron generators. Since each of the eight gluon generators contributes equally to the gluon color factor, we can deduce the neuron color factors to be 3/4, one quarter of the gluon color factor 3. By the same reason we can say that the chromon color factor must be 9/4. A more intuitive way to understand this comes from the simple democracy of the gauge interaction. Since the neurons constitute one quarter of eight gluons their color factor must be one quarter of the gluon color factor 3, that is 3/4.

According to the above reasoning the color factor ratio of the quark, chromon, and neuron jets should be $C_q : C_c : C_n = 4/3 : 9/4 : 3/4 \simeq 1.78 : 3 : 1$, since the quark color factor is given by $C_F = 4/3$. If this is so, the recent experiments which separated the quark jet from the gluon jet based on the color factor ratio $C_A/C_F = 9/4$ need to be completely re-analysed [28–30].

In this respect we notice two interesting reports which could support the above interpretation. The re-analysis of DELPHI e^+e^- three jet data at LEP strongly indicates that actual C_A/C_F could be around 1.74, much less than the popular value 2.25 but close to our prediction 1.69 [32, 33]. Moreover, the $p\bar{p}$ DØ jets experiment at Fermilab Tevatron shows that the quark to gluon jets particle multiplicity ratio is around 1.84, again close to our prediction 1,69 [34]. They could be an indication that the observed gluon jets are indeed the chromon jets.

Actually we could concentrate on the gluon jet. In an idealized setup with e^+e^- colliion we can have the quark and gluon jets separately,

$$\begin{aligned} &quark\ jet: \quad e^+e^- \to \gamma/Z \to u\bar{u}, \\ &gluon\ jet: \quad e^+e^- \to H \to gg, \end{aligned} \tag{11}$$

or in the pp collision

$$\begin{aligned} &quark\ enriched\ jet: \quad pp \to Z + jet, \\ &gluon\ enriched\ jet: \quad pp \to dijet, \end{aligned} \tag{12}$$

In this case we could forget about the quark jet and concentrate on the gluon (enriched) jet, and try to separate the neuron jet from the chromon jet. In principle this could be simpler because in this case the ratio of the color factor becomes bigger $C_c/C_n = 3$. This strongly implies that about one quarter of the gluon (enriched) jet must be the neuron jet, which has sharper shape than the other and has an ideal color dipole pattern

At this point one might ask what are the gluon jets identified by ATLAS and CMS? Probably they are the chromon jets, because the chromon jet has the characteristics of the known gluon jet. This is evident from Fig. 5. Perhaps a more interesting question is why they have not found the neuron jet? There could be two explanations. They have not searched for the neuron jet yet, because they had no motivation to do that. Or they might have misidentified some of the neuron jets as the quark jet. This is because the color factor of neuron and chromon jets are not much different. This tells that we need a more careful analysis of quark and gluon jets.

One advantage in searching for the neuron jet is that we do not need any new experiment. LHC produces billions of hadron jets in a second, and ATLAS and CMS have already filed up huge data on jets. Moreover, DESY, LEP, and Tevatron have old data on three jet events (the gluon jets) which we could use. Here again the simple number counting strongly suggests that one-quarter of the gluon jets coming from the three jets events could actually be the neuron jets which do not fit to the conventional gluon jet category.

V. DISCUSSION

The gauge potential of QCD is thought to represent the gluons, but the role of gluons in QCD has been confusing. On the one hand they are supposed to provide the binding of the (colored) quarks. But at the same time they are supposed to play the role of the constituent of hadrons, because they are colored. The Abelian decomposition tells that there are two types of gluons, the binding gluons and the valence gluons, that play different roles.

As we have emphasized, the fact that there should be two types of gluons is evident from the simple group theory. Group theory tells that two of eight gluons must be neutral. The question is how to separate the neutral gluons gauge independently. The Abelian decomposition does the job [1, 2]. As importantly, it tells that the Abelian (restricted) potential contains not only the neurons but also the topological monopole part which plays the crucial role to retain the full non-Abelian gauge degrees of freedom to the restricted potential.

This clarifies the role of gauge potential in QCD. The neurons and monopole potential together bind and confine the colored objects with the monopole condensation [6–8], but the chromons play the role of constituent of hadrons [18, 19].

The experimental confirmation of the gluon jet was a triumphant in the history of QCD. It proved that QCD is indeed the right theory of strong interaction. Moreover, it justified the asymptotic freedom and extended our understanding of QCD very much [35]. Clearly the experimental confirmation of two types of gluon jets should play at least as important role as this. It will shed a new light on QCD, revealing the hidden structures of QCD.

It will justify the decomposition of Feynman diagram and solve the long standing problem of the glueball, providing a correct picture of the glueball and its mixing with the quarkonium. Moreover, it will prove the quark and chromon model is the correct picture of hadron spectroscopy [18, 19].

In this paper we have argued that the existence of two types of gluon could actually be established by expariment, and proposed intuitive idea to verify this experimentally. Of course, to verify this experimentally we need more concrete predictions and numerical simulations. But this is beyond the scpoe of this paper, because our aim here is to present the theoretical foundation why QCD must have two types of gluon, discuss the experimental plausibility of neuron and chromon jet tagging, and suggest basic idea how we can actually do this.

In fact experimentally the quark/gluon tagging is a very complicated and ongoing issue which is not completely settled yet. In particular, the gluon tagging has many unclear and unresolved problems [26, 27]. We believe that this could be, at least partly, due to the existence of two types of gluon jet. To test the plausibility of this suggestion we could look at the existing gluon jet data and check if there are events which do not fit to the well known predicted characters of the gluon jet.

Our prediction tells that about one quarter of the gluon jets should actually be the neuron jets which have sharper jet shape and ideal color dipole pattern. This could be done without much difficulty. After we confirm this, we could try to do the neuron and chromon jets tagging. A nice thing about this proposal is that we do not need any new experiment. All that we have to do is to re-analyse the existing data at LHC.

The experimental confirmation of the gluon jet was a great achievement in high energy physics. It had established QCD as the correct theory of strong interaction [9, 35]. Obviously the experimental confirmation of two types of gluon jet will be as important as the confirmation of the gluon jet in QCD. We hope that the recent machine learning algorithm could help us to verify the existence of the neuron and chromon jets experimentally [26, 27]

Acknowledgements

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