In addition, the radiative transitions of the neutral Z_b/Z_b' to $\eta_b(nS)$, $(n=1,2)$ are also considered

$$\begin{aligned}
\mathcal{B}(Z_b \to \eta_b(1S)\gamma) &= (0.43 \sim 2.71) \times 10^{-5}, \\
\mathcal{B}(Z_b \to \eta_b(2S)\gamma) &= (0.34 \sim 1.47) \times 10^{-4}, \\
\mathcal{B}(Z_b' \to \eta_b(1S)\gamma) &= (0.78 \sim 13.0) \times 10^{-6}, \\
\mathcal{B}(Z_b' \to \eta_b(2S)\gamma) &= (0.38 \sim 4.26) \times 10^{-5},
\end{aligned} \tag{2}$$

which is of order of $10^{-6} \sim 10^{-4}$. With the running of the Belle II in the near future, the predicted branching ratios of $Z_b^{(\prime)} \to \eta_b(mS)\rho/\gamma$, $(m=1,2)$ could be further tested.

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1 - 9 Light-front Approach to Hadron Structure

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Although Quantum chromodynamics (QCD) has been accepted as the fundamental theory for strong interaction, it remains a curious fact and a longstanding puzzle that strong interaction exhibits distinct pictures at different energy regimes: at high energy the particles behave as bound states consisting of quarks and gluons (partons) interacting through the fundamental QCD interactions, whereas at low energy protons and neutrons (nucleons) become the relevant degrees of freedom and they interact via the effective nucleon-nucleon interactions. Understanding the connection between these different pictures will significantly enhance our understanding of strong interaction and answer many fundamental questions such as the origin of the mass and spin of hadrons, the mechanism for confinement of quarks and gluons. The key to these connections lies in the structure of hadrons on the parton level. The major challenge here is that the hadron structure is mostly determined by the nonperturbative domain of QCD. Although enormous progress has been made in understanding QCD in the perturbative domain, in the nonperturbative domain our knowledge is still rather limited. Recently new tools have been continually developed which probe the nonperturbative structure of QCD, for example, hard diffractive reactions, semi-inclusive deep inelastic scattering (SIDIS) and deep virtual Compton scattering (DVCS). The Electron Ion Colliders (EICs) will be the most effective facility for realizing these processes and measuring the pertinent observables characterizing the structure of hadrons. The proposed EIC facilities include eRHIC at the BNL, JLEIC at JLab in USA, LHeC at CERN in Europe and the future EicC in China.

In order to efficiently utilize the experimental facility and interpret data, one needs to develop theoretical approaches linking the QCD theory with experimental data. In view of the recent developments on both the experimental and the theory sides, we propose to explore the hadron structure from the first-principle approach based on light-front quantization[1], which provides an alternative nonperturbative tool to lattice formalism and a direct way to calculate the QCD observables. One of the main advantages of light-front quantization is that by adopting Hamiltonian formalism it provides access to the wavefunction of bound states, which encodes the complete information of hadron structure.

Based on light-front quantization, the Basis Light-front Quantization (BLFQ)[2] has been developed over the last ten years as a numerical nonperturbative approach to quantum field theory. This method combines the advantages of light-front dynamics with modern developments in *ab initio* nuclear structure calculations. The diagonalization of the light-front Hamiltonian in a Fock-space basis yields the mass eigenstates of the system, along with wavefunctions which can then be applied to determine spin structures, electromagnetic form factors and generalized parton distributions (GPDs) of hadrons and other observables. The ultimate goal of BLFQ is to study hadron structure from first-principles of QCD. So far, BLFQ has been successfully applied in QED system such as the physical electron[3] and the strong coupling positronium[4]. Recently, this formalism has been applied to the heavy quarkonium system to investigate the spectroscopy and decay constants which are are comparable to experimental measurements. However, most of the current applications of BLFQ are restricted to the leading Fock sector and with effective interactions. Besides, the studies of systems like the baryons and light-mesons remain unsolved. Thus we propose to continue the development of BLFQ in both the method itself and its applications. Specifically we will carry out research in the following two directions:

1. Inclusion of higher Fock sectors in the basis. Including high Fock sectors on the one hand makes the BLFQ basis more complete and potentially leads to more accurate representation of the hadron states, on the other hand it opens the channels for self-energy corrections which necessitates appropriate renormalization procedures in order to generate results with prediction power. Since developing a nonperturbative renormalization procedure directly in QCD is challenging, we plan to first carry out the studies in Quantum Electrodynamics (QED) which can be considered as a model for QCD but in many aspects simpler. Specifically we intend to study the following systems:

1) Positronium: As the simplest bound state in QED, it is an ideal laboratory for testing renormalization procedures in BLFQ. We will continue the ongoing study of the positronium system in $|e\bar{e}\rangle$ and $|e\bar{e}\gamma\rangle$ Fock sectors and further examine the convergence of the observables with respect to basis truncation parameters. After this is finished, we further include the higher Fock sector: $|e\bar{e}\gamma\gamma\rangle$.

2) Physical photon: The photon, as a gauge boson, is important for studying and understanding the gauge theory in light-front quantization. We plan to solve the physical photon system in $|\gamma\rangle$ and $|e\bar{e}\rangle$ Fock sectors. Developing the renormalization procedure for this system will help us understand the behavior of the gauge theory in truncated bases. Besides, the similar techniques can be used in other systems (such as the positronium and the physical electron) where the photon appears as a component.

2. Application to broader systems and observables. In addition to the fundamental interactions, we will also adopt effective interactions in BLFQ. These effective interactions are usually simpler than the fundamental interactions (such as QED and QCD) and restricted to the leading Fock sector. Nevertheless, they are often able to provide decent first-order descriptions of the structure of the bound states. Performing calculation with effective theories not only allows us to have quick calculations of the observables which are comparable with experimental data, but also provides guidance and baselines for future first-principle calculations. Specifically, we plan to work on the following systems:

1) Baryon: Baryons are the building blocks of the atomic nuclei. Their structure will be measured by the EICs. In the first step, we will consider the baryon system in the leading Fock sector $|qqq\rangle$ only with an effective Hamiltonian, which consists of the light-front kinetic energy term, a confining potential in the transverse direction based on the light-front holographic QCD, as well as a longitudinal confining potential for the completeness, and a one-gluon exchange interaction with fixed coupling[5].

2) Heavy quarkonium: Based on the similarity between the positronium system and the heavy quarkonium system, we plan to extend the study of the positronium system in QED to the heavy quarkonium system in QCD by including additional confining interactions in both the transverse and the longitudinal directions. The heavy quarkonium system will be investigated in $|q\bar{q}\rangle$ and $|q\bar{q}g\rangle$ Fock sectors so that we will be able to access the gluon distribution.

3) Heavy-light and light mesons: Based on the method for the heavy quarkonium, we will investigate the structure and spectrum of the light meson (such as the pion and rho meson), and heavy-light meson (such as the B and D meson), in $|q\bar{q}\rangle$ and $|q\bar{q}g\rangle$ Fock sectors.

Since BLFQ is based on Hamiltonian formalism, it can be straightforwardly extended to the time-dependent regime: the time-dependent Basis Light-front Quantization (tBLFQ)[6] has been developed to simulate the nonperturbative time-evolution of quantum field configurations, which describes the hadron scattering processes. The ultimate goal of tBLFQ is to understand hadronization where hadrons are formed out of quarks and gluons, which is a nonperturbative and time-dependent process in QCD.

Besides hadron scattering the tBLFQ approach also finds applications in treating systems in time-dependent/strong background fields. One of the important applications of tBLFQ is in strong-field QED: although QED has been verified to high precision, most of the tests so far are performed in the cases of weak electromagnetic fields ($eE \ll m_e^2$, m_e is the electron mass). In recent years increasing interest has been seen in testing QED in strong electromagnetic field ($eE \sim m_e^2$) through laser-particle scattering, where the laser fields are typically made of several pulses in time. We plan to employ tBLFQ to study the acceleration and radiation process of an electron placed in such time-dependent strong laser fields. Similar approaches can be used to study quark-jet propagation in the hot medium created by relativistic heavy-ion collisions. Another application is in atomic physics where we will study the time-dependence of the momentum distribution of the photons emitted in the decay process of an excited atom. This work will help us understand the decay process of unstable bound states from a time-dependent perspective.

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1 - 10 Skyrme Model and New Topologies*

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Skyrmions has been shown that carries two independent topologies, the baryon topologies and the monopole topology[1]. The baryon number B of skyrmions could be expressed as $B=mn$, where m is the monopole number and n is the shell nubmer. These two topological numbers describe the topologies $\pi_1(S^1)$ and $\pi_2 S^2$, respectively.

In this report, we briefly review that topological structures in Skyrme model. Skyrme model is an effective model of quantum choromodynamics (QCD) at low energy, which could be understood from QCD lagrangian with Duan-Ge-Cho decomposition theory. With this and the the monopole topology in QCD, we discuss the decomposition of baryon topology in standard Skyrme model and Bogomol'nyi-Prasad-Sommerfield(BPS) Skyrme model. New BPS skyrmion solution is shown with different monopole topology and shell topology.

Duan-Ge-Cho decomposition tells that the QCD gauge field can be decomposed as

$$\hat{A}_\mu = A_\mu \hat{n} + \vec{C}_\mu, \quad \vec{C}_\mu = -\frac{1}{g}\hat{n}\times\partial_\mu\hat{n}. \tag{1}$$

$\hat{A}_\mu$ is the restricted potential which has the full non-Abelian gauge transformation

$$\delta\hat{A}_\mu = \frac{1}{g}\hat{D}_\mu\vec{\alpha}, \ \delta\hat{n} = -\vec{\alpha}\times\hat{n}. \tag{2}$$

More importantly, the restricted potential retains all of the topological properties of QCD filed that represented by vector filed $\hat{n}$. To recover full dynamics of QCD we need to introduce the valence filed $\vec{X}_\mu$

$$\vec{A}_\mu = \hat{A}_\mu + \vec{X}_\mu = A_\mu\hat{n} - \frac{1}{g}\hat{n}\times\partial_\mu\hat{n} + \vec{X}_\mu. \tag{3}$$

so that we have

$$\vec{F}_{\mu\nu} = \partial_\mu\vec{A}_\nu - \partial_\nu\vec{A}_\mu + g\vec{A}_\mu\times\vec{A}_\nu = \hat{F}_{\mu\nu} + \hat{D}_\mu\vec{X}_\nu - \hat{D}_\nu\vec{X}_\mu + g\vec{X}_\mu\times\vec{X}_\nu, \tag{4}$$

and the QCD Lagragian is

$$\mathcal{L} = -\frac{1}{4}\hat{F}_{\mu\nu} - \frac{1}{4}(\hat{D}_\mu\vec{X}_\nu - \hat{D}_\nu\vec{X}_\mu)^2 - \frac{g}{2}\hat{F}_{\mu\nu}\cdot(\vec{X}_\mu\times\vec{X}_\nu) - \frac{g^2}{4}(\vec{X}_\mu\times\vec{X}_\nu)^2. \tag{5}$$

Moreover, since the restricted gluon filed $\hat{A}_\mu$ obtains mass due to confinement, QCD Lagrangian could be effectively expressed as

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

Let us introduce

$$\vec{X}_\mu = f_1\partial_\mu\hat{n} + f_2\hat{n}\times\partial_\mu\hat{n}, \ \phi = f_1 + if_2. \tag{7}$$