Generalized Parton Distributions from Lattice QCD

(Letter of Interest for Snowmass 2021)

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Generalized parton distributions (GPDs) provide, together with the transverse-momentum-dependent parton distributions, a more comprehensive picture of hadron structure. They were introduced in [1], and rediscovered [2] from their connection to the spin structure of the proton. Experimentally, the GPDs can be accessed in hard exclusive processes such as the deeply-virtual Compton scattering or meson production [2, 3], but extracting them from these data is very challenging because of their complicated kinematic dependence and relation to experimental observables. On the other hand, one can also extract certain information on the GPDs from lattice calculations of their moments (for a recent calculation see, e.g., [4]). This is also very limited due to technical difficulties. However, given the importance of the GPDs for the JLab 12 GeV program and future ElC, it is highly desirable to have first-principle calculations of them with much better understanding of the physical landscape in different kinematic variables.

Here we propose to perform a systematic study of the GPDs from lattice QCD, based on the large momentum effective theory (LaMET) approach proposed in [5, 6]. In the usual formulation of parton physics, the GPDs are defined as the hadron matrix elements of lightcone correlators. LaMET provides an alternative formulation in which the same parton physics can be obtained from matrix elements of time-independent operators in infinite-momentum hadrons. This allows to extract parton properties of hadrons from static correlations at finite momentum, where the latter can be calculated on the lattice and converted to the usual parton quantities through a factorization formula. In the following, we list the important issues that we will investigate:

1. Systematic lattice studies of flavor non-singlet GPDs in the pion and the nucleon. There have been exploratory studies on the isovector quark GPDs in the pion [7] and in the nucleon [8], either at zero skewness or at nonzero skewness with limited momentum transfer. We plan to extend these studies to more lattice ensembles and analyze the relevant systematics.

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2. Renormalization strategy. Currently, the most commonly used renormalization in LaMET calculations includes the RI/MOM and the ratio scheme, where the former requires calculating off-shell quark matrix elements while the latter requires zero-momentum hadron matrix elements. Both of them introduce extra nonperturbative (infrared) effects at large distance. In Ref. [9], a hybrid renormalization scheme that avoids this has been proposed for lattice studies of quark PDFs. In this proposal, we will extend it to the GPD case and calculate the relevant theory inputs to high accuracy.

3. Theory and lattice studies of flavor singlet and gluon GPDs. There have been theory studies on how to extract the singlet quark PDF and gluon PDF, where a detailed discussion on the renormalization and matching has been given. We plan to extend those analyses to the GPDs in the hybrid scheme and apply the results to lattice calculations.

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