High energy soft scattering from lattice QCD

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Introduction

In the process of high-energy scattering, when the transferred momentum is small, it is called high-energy soft scattering. This process has two energy scales, the center–of–mass total energy squared s, which is a hard scale, and the transferred momentum squared t, which is a soft scale. So it can only be studied by non-perturbation methods. A quenched lattice study was carried out in 2008 [2]. In this work, we calculate the loop-loop correlation function on full-QCD configurations, which can be used to reconstruct the hadron-hadron scattering cross section after analytic continuation [1,3]. Also, by utilizing the crossing symmetry, a clear signal of the odderon exchange is found in the angular dependence of correlation function, which provides a hint of the C-odd glueball as recently observed in the experiment [5].

Loop-loop correlator on the lattice

Nachtmann(1991) [2] proved that hadron-hadron scattering amplitudes can be reconstructed in terms of certain correlation function of two Wilson loops. First, the hadron-hadron scattering amplitude can be represented by the dipole-dipole scattering amplitude. Second, the dipole-dipole scattering amplitude can be represented by the loop-loop correlation function.

$$\mathcal{M}_{(hh)}(s,t) = \int d^2\mathbf{R_1}\int_0^1 df_1|\psi_1(\mathbf{R_1},f_1)|^2\int d^2\mathbf{R_2}\int_0^1 df_2|\psi_2(\mathbf{R_2},f_2)|^2 \times \mathcal{M}_{(dd)}(s,t;\mathbf{R_1},f_1,\mathbf{R_2},f_2). \quad (1)$$

$$\mathcal{M}_{(dd)}(s,t;\mathbf{R_1},f_1,\mathbf{R_2},f_2) = -i2s\int d^2z e^{iqz}\left[\frac{\langle W_1W_2\rangle}{\langle W_1\rangle\langle W_2\rangle}-1\right]. \quad (2)$$

All the above refers to the theory in the Minkowski space-time. It is proved that, one can get the corresponding Euclidean forms by analytic continuation [3]. Then we can calculate the loop-loop correlator on the lattice. We define the correlator

$$\mathrm{GL} \equiv \frac{\langle\widetilde{\mathcal{W}}_L(\mathbf{l}_{1\parallel};\mathbf{R}_{1\perp};d)\widetilde{\mathcal{W}}_L(\mathbf{l}_{2\parallel};\mathbf{R}_{2\perp};0)\rangle}{\langle\widetilde{\mathcal{W}}_L(\mathbf{l}_{1\parallel};\mathbf{R}_{1\perp};d)\rangle\langle\widetilde{\mathcal{W}}_L(\mathbf{l}_{2\parallel};\mathbf{R}_{2\perp};0)\rangle}-1. \quad (3)$$

The loops involved in the calculation have one side in the x-t (longitudinal) plain, and the other in the y-z (transverse) plane and their centers are separated by d in the transverse plane (Fig. 1). Specifically, $\mathbf{l}_{1\parallel}=(L_1,0)$ is on axis and of length $L_1=6$ or 8 lattice spacing while $\mathbf{l}_{2\parallel}$ is off axis (Tab. 1), so more relative angles θ can be obtained. We label the loop-loop correlator as 61, 62, 81 and 82 where the first number is for L_1 and the second is for the sets of L_2.

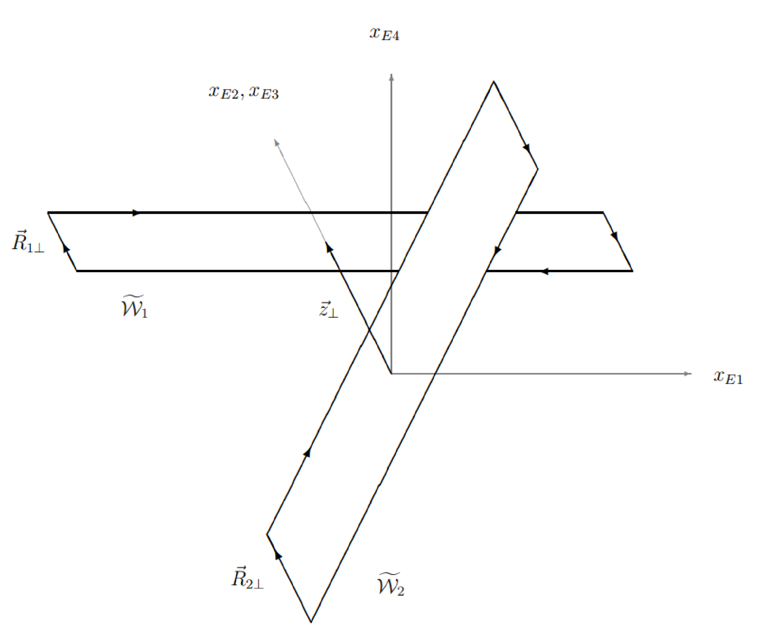

Figure 1: Lattice setup.

θ		26.565°	45°	63.435°	90°	116.565°	135°	153.435°
$\vec{l}_{2\parallel}$	set 1	$(4,2)$	$(4,4)$	$(2,4)$	$(0,6)$	$(-2,4)$	$(-4,4)$	$(-4,2)$
	set 2	$(8,4)$	$(6,6)$	$(4,8)$	$(0,8)$	$(-4,8)$	$(-6,6)$	$(-8,4)$
L_2	set 1	$2\sqrt{5}$	$4\sqrt{2}$	$2\sqrt{5}$	6	$2\sqrt{5}$	$4\sqrt{2}$	$2\sqrt{5}$
	set 2	$4\sqrt{5}$	$6\sqrt{2}$	$4\sqrt{5}$	8	$4\sqrt{5}$	$6\sqrt{2}$	$4\sqrt{5}$

Table 1: Length and various angles for off-axis loops.

Numerical results

We calculate the loop-loop correlation function on 1600 full-QCD configurations with pion mass ~ 330 MeV. The numerical results are shown in Fig. 2. We can see that the angular dependence of the loop-loop correlation function is asymmetric, which is actually a hint of the odderons or oddeballs exchange due to the crossing symmetry [4]. We define the asymmetry $C_E{}^-(\theta)$ as

$$\mathcal{C}_E^-(\theta) \equiv \frac{\mathcal{C}_E(\theta)-\mathcal{C}_E(\pi-\theta)}{2}. \quad (4)$$

As shown in the right panel of Fig. 2, a clear signal of nonzero $C_E{}^-(\theta)$ is present in our data. which proves that the C-odd interaction is important in the dipole–dipole scattering amplitude.

Besides, we get a notably larger GL on full-QCD configurations than that on quenched configurations. The numerical results are shown in Fig. 3. This is of special interest and further analysis is on going.

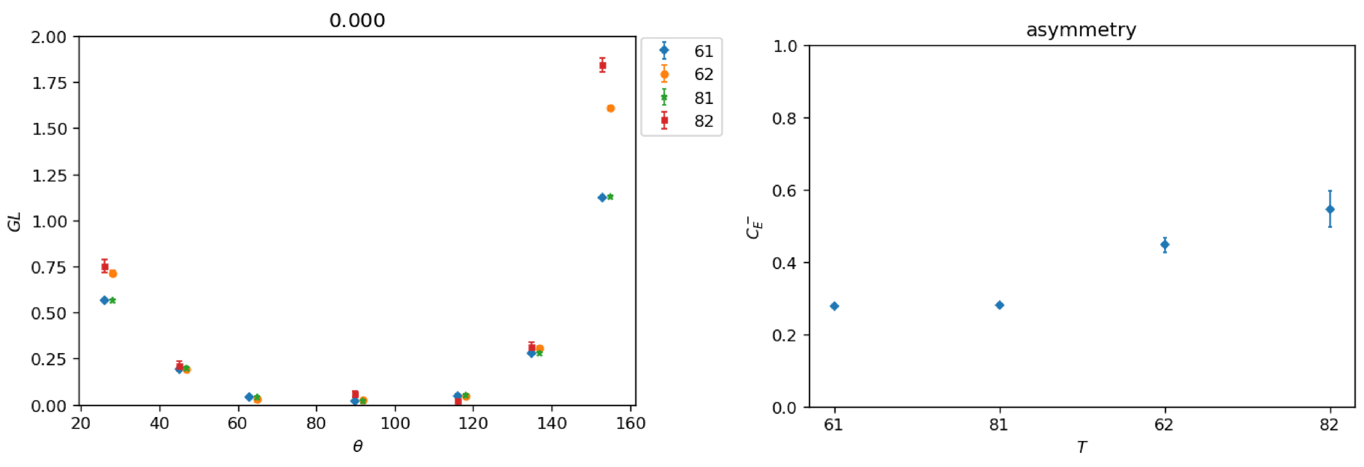

Figure 2: Angular dependence of GL for various lengths of the loops.

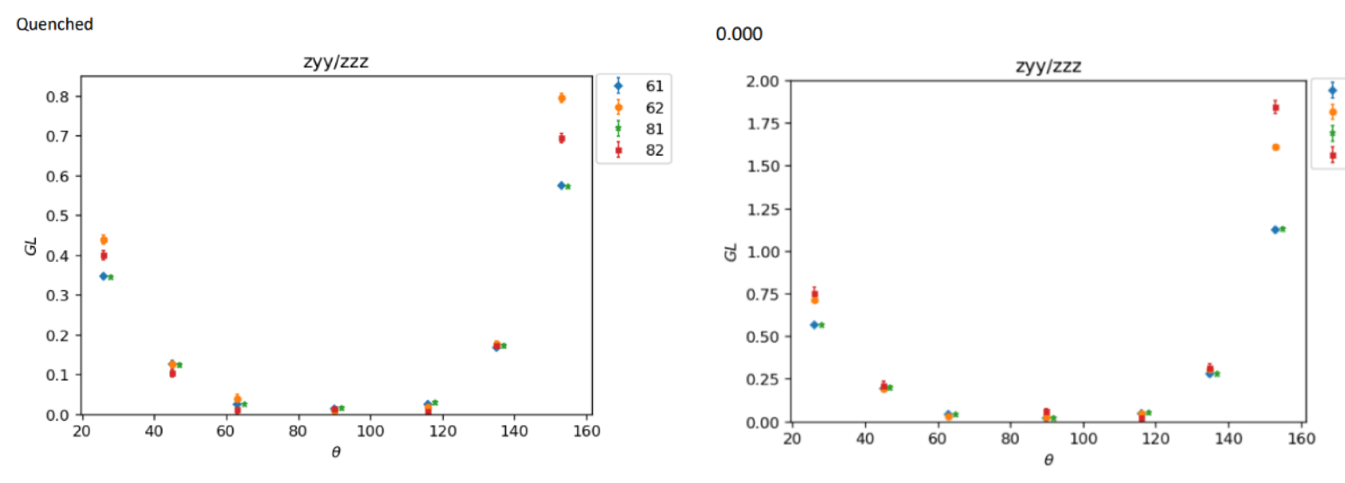

Figure 3: Contrast with quenched and full-QCD configuratons.

Summary and perspectives

We calculate the loop-loop correlation function on full-QCD configurations, which can be used to reconstruct the high-energy soft scattering cross section. Considering theoretical analysis such as the crossing symmetry, our results provide a demonstration of the existence of odderons or oddballs. Besides, a larger GL on full-QCD configurations is discovered, compared with that on quenched configurations.

We are now calculating the loop-loop correlation function on configurations with the physical pion mass. We believe this to be so far the best lattice calculation for this problem. Tripole-tripole correlation function is also waht we are interested in. It can represent the baryon-baryon interaction.

References

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