String effect in 4D compact U(1) lattice gauge theory

Y. Koma, M. Koma, P. Majumdar

Max-Planck-Institut für Physik, Föhringer Ring 6, D-80805 München, Germany

If the confining gauge theory is related to an effective bosonic string theory, the long range behavior of the potential between static two charges separated by distance r is expected to have the form:

$$V(r) = \sigma r + \mu + \frac{\gamma}{r} + O(\frac{1}{r^2}) \ , \tag{1}$$

where σ is the string tension and μ a constant. The third term is known as the Lüscher term [1] and the coefficient γ is considered to be universal, such that it does not depend on the gauge group but only on the space-time dimension d through $\gamma = -\pi(d-2)/24$. The effective bosonic string theory also predicts that the width of the field energy distribution of the flux tube diverges logarithmically as $r \to \infty$ [2]. Recent Monte-Carlo simulations of various lattice gauge theories (LGTs) support Eq. (1) with high accuracy: the confinement phase of $\mathbb{Z}_2$ LGT [3], SU(2) LGT [4] and SU(3) LGT [5].

We report here the study on the long range properties of 4D compact U(1) LGT in the confinement phase. From the Polyakov loop correlation function (PLCF), we extract the potential and force to see whether this theory also supports the presence of the universal correction to the static potential. We then measure the profile of the flux tube induced by the PLCF, and see the behavior of its width as a function of r. However, due to its strong coupling nature, the Monte Carlo simulation of compact U(1) LGT is numerically difficult, when its long range properties are of interest. To obtain reliable signals, we apply here the multi-level algorithm proposed by Lüscher and Weisz originally for SU(3) LGT [6], which helps to reduce statistical errors exponentially. The detail of the numerical procedures, see Ref. [7].

We generate configurations by using the Wilson gauge action on a 16^4 lattice at $\beta = 0.98$, 0.99, 1.00, 1.005 and 1.01. In Fig. 1, we show the static potential and force from all β values. The scale is introduced by Sommer's relation $r_0^2 F(r_0) = 1.65$. We also plot the theoretical prediction for the force based on Eq. (1). We find that the long distance behavior is well-described by the function, $F = dV/dr = \sigma - \gamma/r^2$ with $\sigma r_0^2 = 1.65 - \gamma = 1.39$, which contains no fitting parameter. This supports the universality of γ/r correction to the static potential. Surprisingly, another feature in common with non-Abelian gauge theories is that this function also fits the data down to relatively short distance to $r/r_0 \sim 0.3$. For this, there is as yet no explanation.

In Fig. 2, we then show the profiles of electric field and monopole current for various r's measured at the mid-plane between two charges. We have taken the cylindrical average: $\rho = \sqrt{x^2 + y^2}$ and $\varphi = \tan^{-1}(y/x)$. We find that the tail of the electric field profile ($\rho/r_0 > 0.4$) seems to fall into one curve, indicating its r independence. Moreover, although the monopole current profile shows squeezed shape for small r,

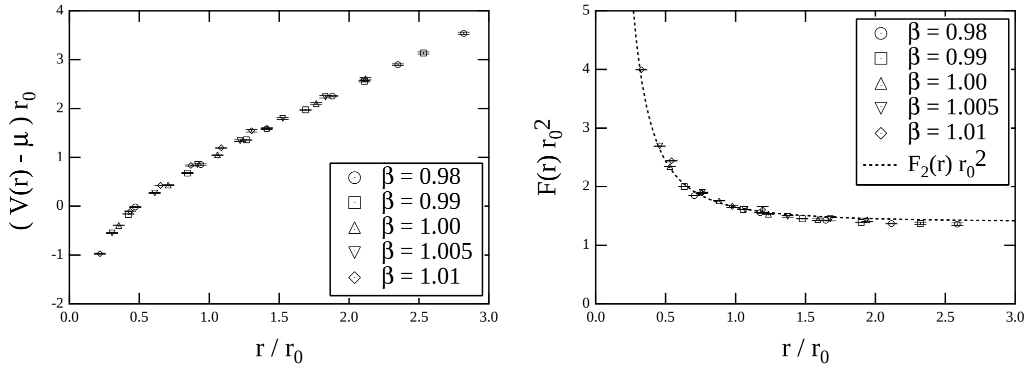

Figure 1: The static potential (left) and force (right) as a function of r/r_0. The dotted line corresponds to the theoretical prediction of Eq. (1) up to $O(1/r^2)$ corrections.

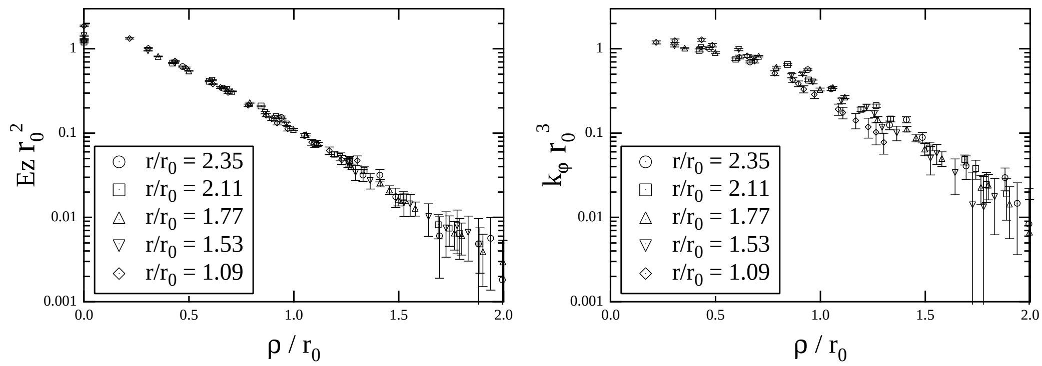

Figure 2: Profiles of the electric field (left) and the monopole current (right) from different r.

it becomes wider as r increases and seems to converge again into one curve. In fact, a quantitative analysis of the width based on the dual Ginzburg-Landau theory has indicated that the width remains almost constant at long distances [7]. To check whether a logarithmic growth of the width is hidden in our data, a further detailed investigation especially for the range $r/r_0 > 1.77$ is needed.

The calculations were done on the NEC SX5 at the RCNP, Osaka University.

References

[1] M. Lüscher, K. Symanzik and P. Weisz, Nucl. Phys. B173 (1980) 365.

[2] M. Lüscher, G. Münster and P. Weisz, Nucl. Phys. B180 (1981) 1.

[3] M. Caselle, M. Hasenbusch and M. Panero, JHEP 01 (2003) 057.

[4] G.S. Bali, K. Schilling and C. Schlichter, Phys. Rev. D51 (1995) 5165; P. Majumdar, Nucl. Phys. B664 (2003) 213; S. Kratochvila and Ph. de Forcrand, Nucl. Phys. B671 (2003) 103.

[5] K.J. Juge, J. Kuti and C. Morningstar, Phys. Rev. Lett. 90 (2003) 161601; M. Lüscher and P. Weisz, JHEP 07 (2002) 049.

[6] M. Lüscher and P. Weisz, JHEP 09 (2001) 010.

[7] Y. Koma, M. Koma, and P. Majumdar, Nucl. Phys. B in press, hep-lat/0311016.