SPECTRUM OF VERY EXCITED FLUX TUBES IN SU(3) GAUGE THEORY

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ABSTRACT

As gluons, the force carriers of strong interactions, have color charge; the gluonic field is squeezed in space-time due to the self-interaction and forms a flux tube in the vacuum; this is in contrast to the electromagnetic field spreading out in space. The flux tube can be modeled as a relativistic string which its quantization leads to a tower of levels. The simplest model of a quantum string is known as the Nambu-Goto string model. We used lattice QCD to study the spectrum of the flux tube with different symmetries. We could get a significant number of excitations by using different types of action, smearing techniques, large operator basis, and solving generalized eigenvalue problem. Moreover, we compare our results with the Nambu-Goto string model to see its deviation, which could be a signal for novel phenomena beyond the model.

ACTIONS, OPERATORS

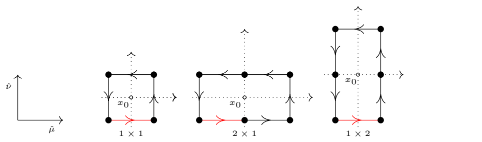


Fig. 1: Action is sum over the smallest close loop, called plaquatte

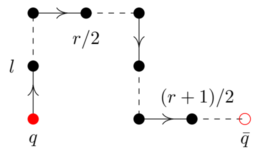


Fig. 2: An example of operators

$$C(t)\nu = \lambda(t)C(t_0)\nu \quad (4)$$

$$E_n = \log \frac{\lambda_n(t)}{\lambda_n(t+1)} \quad (5)$$

Generalized eigenvalue problem.

NAMBU-GOTO STRING MODEL

The Nambu-Goto string model, predict the tower of excitation for flux tube energy

$$V(R) = \sqrt{\sigma^2 R^2 + 2\pi\sigma(N - (D-2)/24)} \quad (1)$$

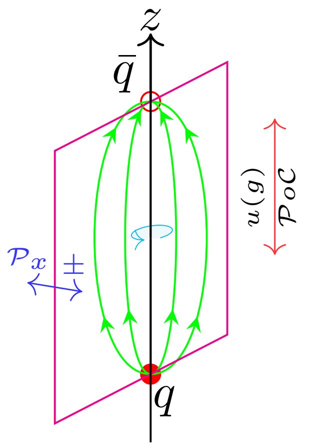
Modified ansatz to search for deviation:

$$V_1(R) = \sigma R\sqrt{1 + \frac{2\pi}{\sigma_2 R^2}(N - (D-2)/24)} \quad (2)$$

$$V_2(R) = V_0 + \sigma_1 R\sqrt{1 + \frac{2\pi}{\sigma_2 R^2}(N - (D-2)/24)} \quad (3)$$

QUNATUM NAMBER OF FLUX TUBE

- z-component of angular momentum: $\Lambda = 0, 1, 2, 3, \ldots \rightarrow \Sigma, \Pi, \Delta, \Phi, \ldots$
- Charge conjugation & spatial inversion, eigenvalues: $\eta = 1, -1 \rightarrow g,\ u$
- For $\Sigma(\Lambda = 0)$, plane inversion, eigenvalues: $\epsilon = +, -$



All the quantum numbers: Σ_g^+, Σ_g^-, Σ_u^+, Σ_u^-, Π_g, Π_u, Δ_u, Δ_g, ...

RESULTS

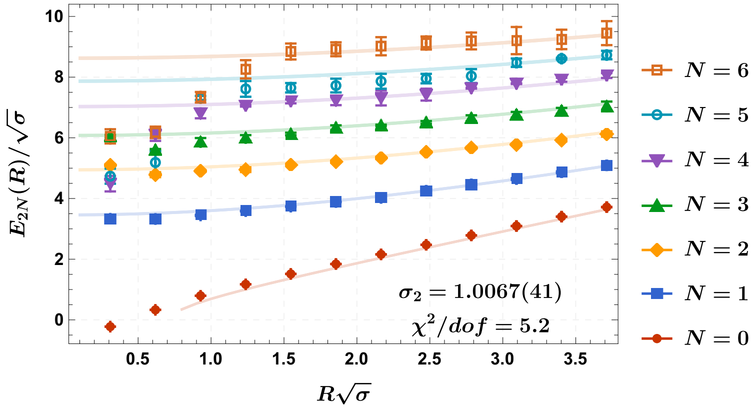


Fig. 3: Σ_g^+, W_2, $\beta = 5.9$, $lat = 24^3 \times 48$

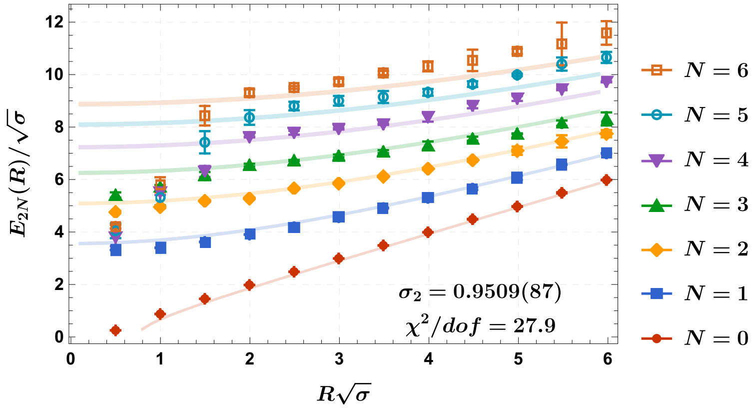


Fig. 4: Σ_g^+, W_4, $\beta = 5.6$, $lat = 24^3 \times 96$

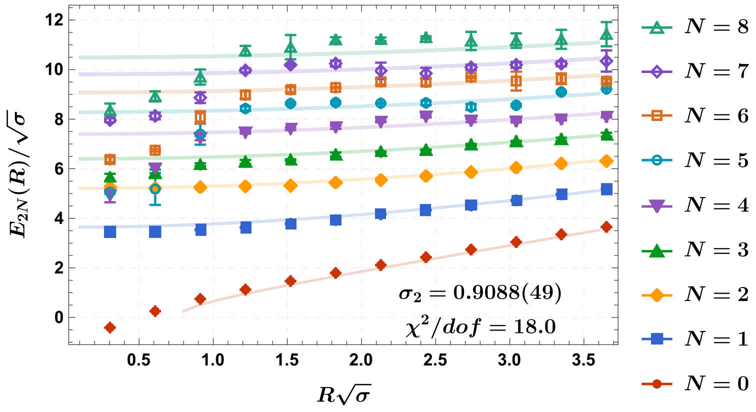


Fig. 5: Σ_g^+, S_4, $\beta = 4$, $lat = 24^3 \times 96$

S_4, Π_u, $Fit: 1 \rightarrow 13$

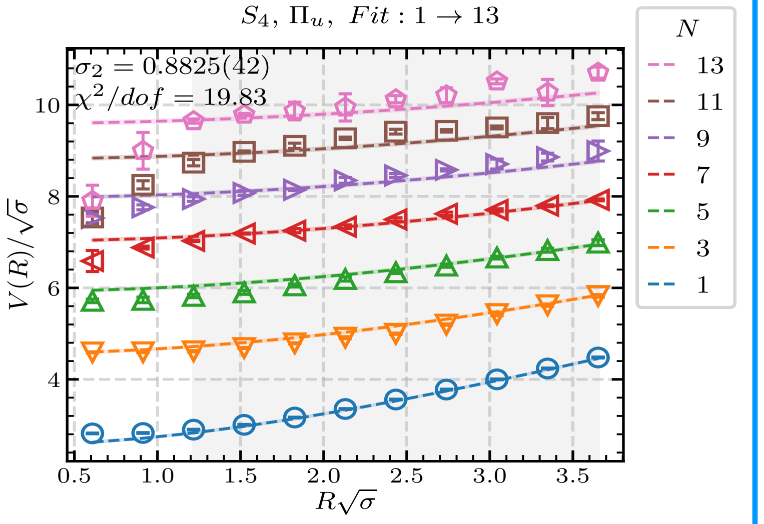


Fig. 6: S_4, Π_u

W denotes to Wilson lattice action and S indicates tadpole improved action. The index of W and S show anisotropic factor ξ where ξ =spatial lattice spacing/temporal lattice spacing

CONCLUSION

Λ_η^+	Σ_g^+	Σ_g^-	Σ_u^+	Σ_u^-	Π_g	Π_u	Δ_g	Δ_u
S_{II}	2	0	0	0	1	1	1	0
	8	5	5	3	5	6	6	5

Table 1: First row: Number of excitations reported in the literature, highlighted row: our result, with improved action S_4

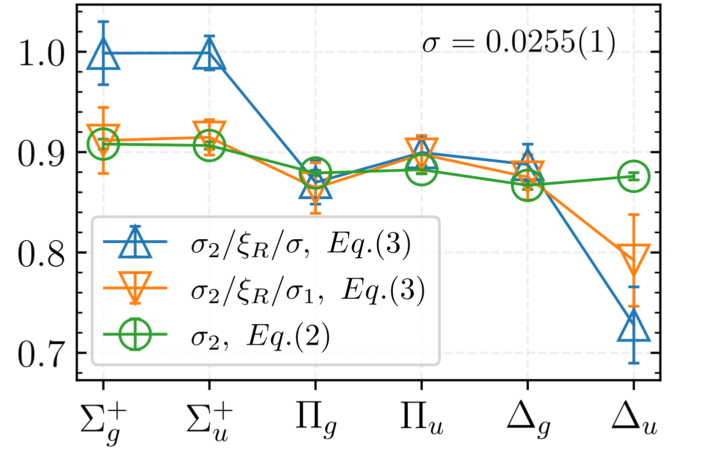


Fig. 7: Almost 10% deviation from the string tension σ of Nambu-Goto string model

REFERENCES

[1] P. Bicudo, N. Cardoso, and A. Sharifian. Spectrum of very excited σ_g^+ flux tubes in su(3) gauge theory, 2021.

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