Spatial structure of the color field in the SU(3) flux tube

Marshall Baker, Paolo Cea, Volodymyr Chelnokov, Leonardo Cosmai, Francesca Cuteri, Alessandro Papa

23 July 2018

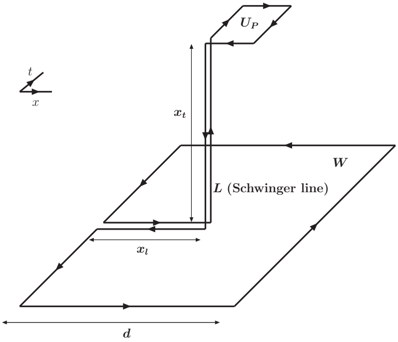
Outline

Introduction

The chromoelectric field between static quark-antiquark pair is concentrated in a flux tube that connects quark and antiquark. This creates a linear potential between quark and antiquark, causing color confinement.

We measure full profile of the flux tube in $SU(3)$ LGT and propose a way of separating the field into short-range perturbative and long-range nonperturbative parts.

Field operator



$$\rho_W^{\text{conn}} = \frac{\left\langle \mathrm{tr}\left(W L U_P L^{\dagger}\right)\right\rangle}{\langle \mathrm{tr}(W)\rangle} - \frac{1}{N}\frac{\langle \mathrm{tr}(U_P)\mathrm{tr}(W)\rangle}{\langle \mathrm{tr}(W)\rangle} .$$

Smearing procedure

For the Monte-Carlo simulations we used the MILC code, modified to calculate the relevant observables.

To improve the signal-to-noise ratio the smearing procedure was applied, which consisted of one HYP smearing step with parameters $(1.0, 0.5, 0.5)$ for the links in time direction, followed by a set of APE smearing steps with parameter $\alpha_{\rm APE} = 0.167$.

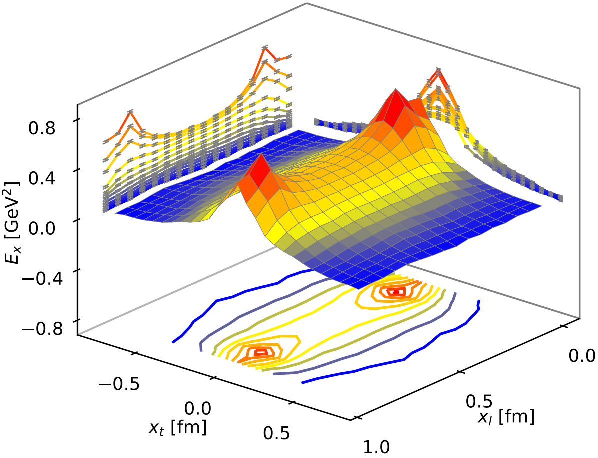
Field measurements

We have measured all field components using the operator $\rho_W^{\rm conn}$ for the following lattice setups:

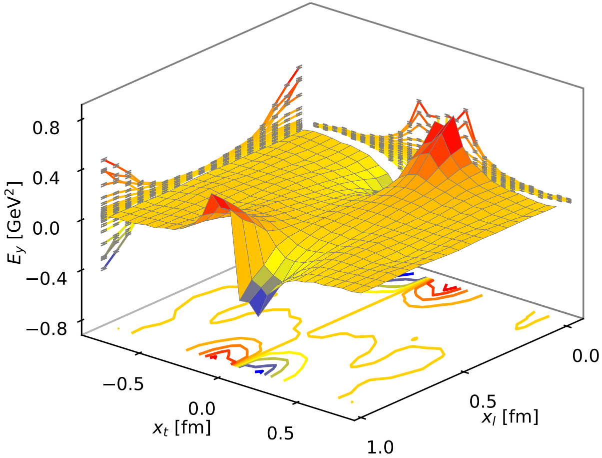
Table: Summary of the runs performed in the SU(3) pure gauge theory (measurements are taken every 100 upgrades of the lattice configuration).

β	lattice	distance d	statistics	smearing steps
6.370	48^4	0.95 fm	1000	80
6.240	48^4	1.14 fm	4000	100
6.136	48^4	1.33 fm	16000	120

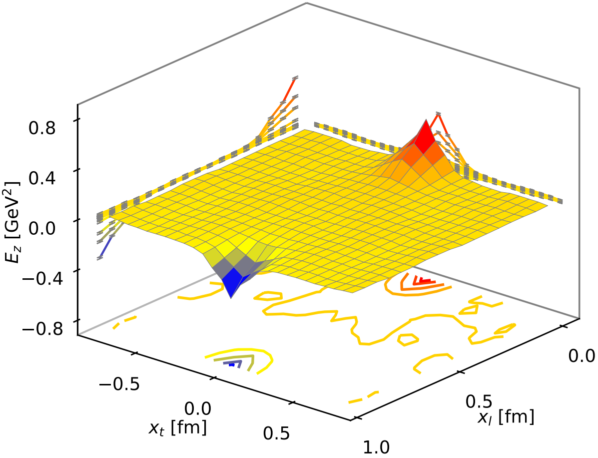
E_x field, $d = 0.95$ fm



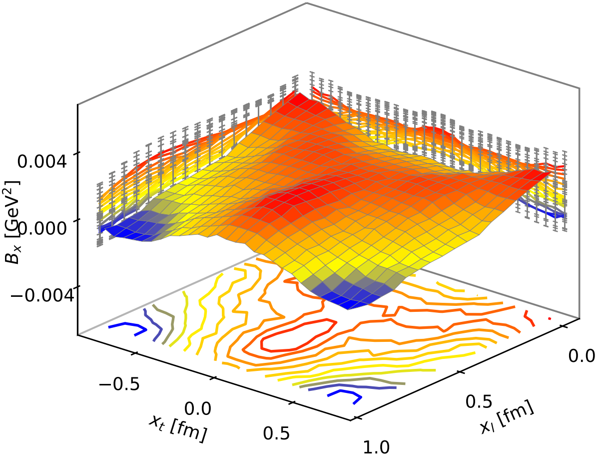
E_y field, $d = 0.95$ fm



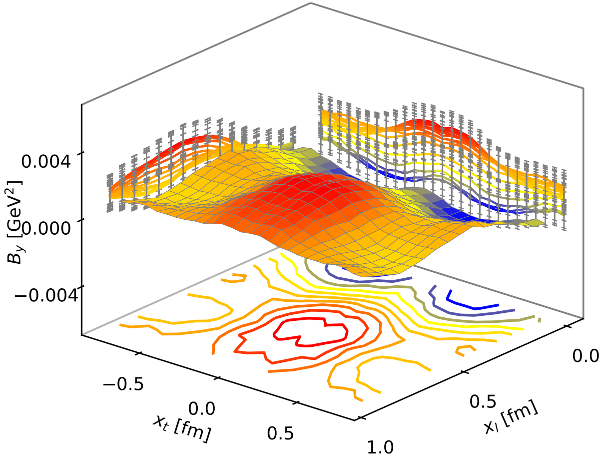
E_z field, $d = 0.95$ fm



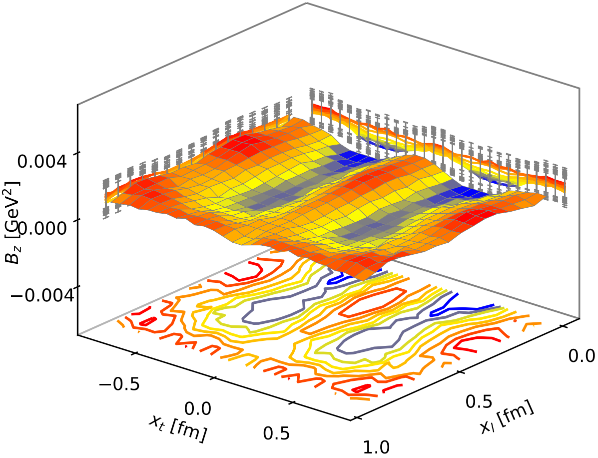
B_x field, $d = 0.95$ fm



B_y field, $d = 0.95$ fm



B_z field, $d = 0.95$ fm



Chromoelectric field structure

We expect that the measured chromoelectric field is composed from two parts – the perturbative part, which behaves like a Coulomb electrostatic field and the nonperturbative confining part which should be purely longitudinal, at least far away from field sources.

$$\vec{E}(\vec{r}) = \vec{E}_C(\vec{r}) + \vec{E}_{\mathrm{np}}(\vec{r})$$

Chromoelectric field structure

The Coulomb part is just sum of the fields of two sources with charge Q and $-Q$. To be able to partially explain the behaviour of the field close to the sources – specifically that the maximum of longitudinal field component is located at nonzero distance from the sources, we take the field to be the field of a uniformly charged sphere of a radius R.

$$\vec{E}_C(\vec{r}) = \vec{E}_R(\vec{r} - \vec{r_1}, q) + \vec{E}_R(\vec{r} - \vec{r_2}, -q)$$

$$\vec{E}_R(r, q) = \frac{q\vec{r}}{\max(r^3, R^3)}$$

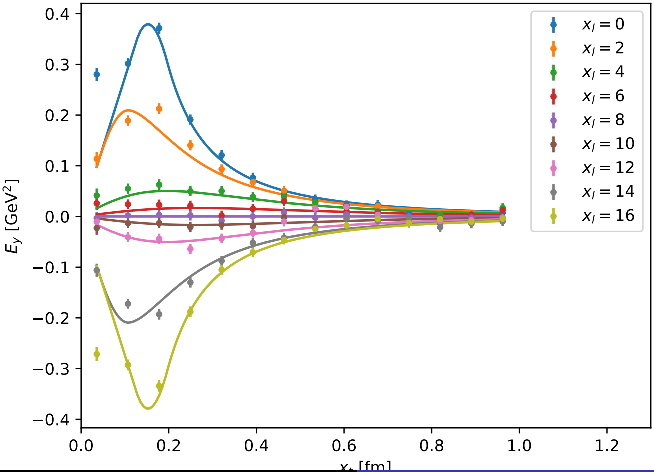
Extracting the nonperturbative part

To extract the nonperturbative part, we make a fit of the transverse field component E_y to the Coulomb field $\vec{E}_C(\vec{r})$. To take into account that the field is measured using a plaquette of a finite size, we take

$$\rho_W^{\mathrm{conn}}(r_l, r_t) = \int_{r_t}^{r_t+1} \vec{E}(r_l, y, 0) dy$$

From the fit we determine the parameters q – "electrostatic" charge for the quark and antiqark, and R – radius for the perturbative field.

Extracting the nonperturbative part $d = 1.14$ fm

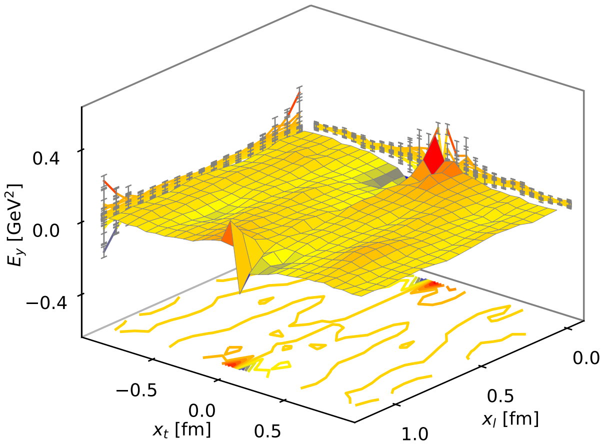


Extracting the nonperturbative part

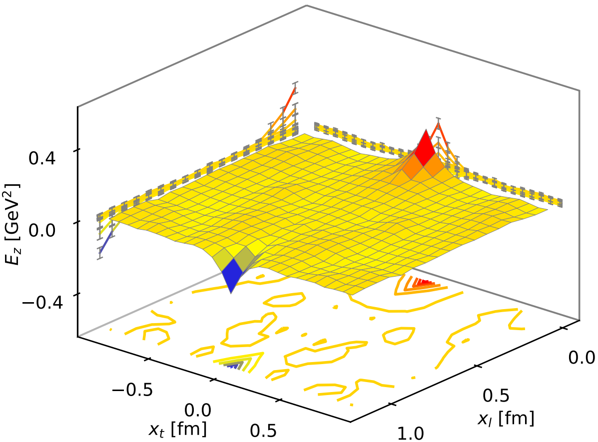
Table: Results of the fits extracting Coulomb part of the chromoelectric field

β	q	R	χ_r^2
6.370	0.26(3)	0.13(3)	6.3
6.240	0.29(5)	0.161(18)	3.43
6.136	0.29(17)	0.21(13)	1.09

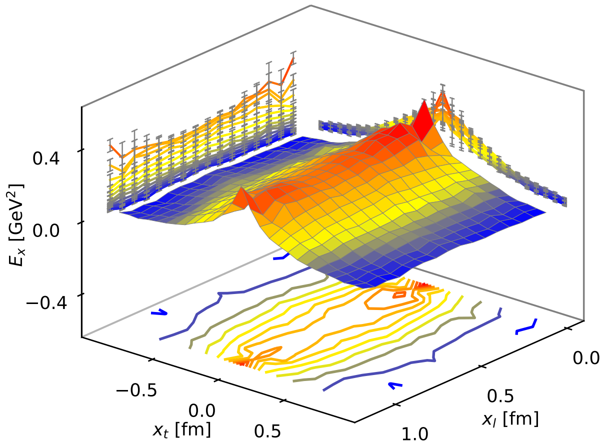
Nonperturbative field E_y, $d = 1.14$ fm



Nonperturbative field E_z, $d = 1.14$ fm



Nonperturbative field E_x, $d = 1.14$ fm



Conclusions

- For four dimensional $SU(3)$ pure gauge model full profile of chromoelectromagnetic field in presence of two static charges is measured using Monte Carlo simulations.
- All the components of measured chromomagnetic field are compatible with zero. The chromoelectric field has radial symmetry.
- The transverse components of the electromagnetic field can be described (when not too close to the sources) by the Coulomb-type field.
- After subtracting the Coulomb field the longitudinal component of electric field does not change with longitudinal displacement (away from sources).

Thank you for attention