The confining color field in the SU(3) gauge theory

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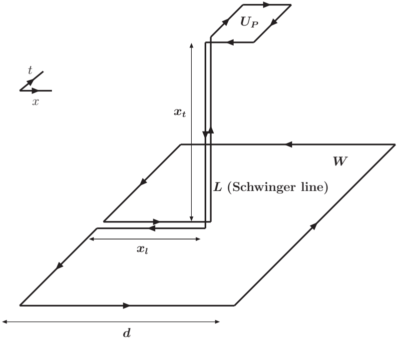
Introduction

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



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

Smearing procedure

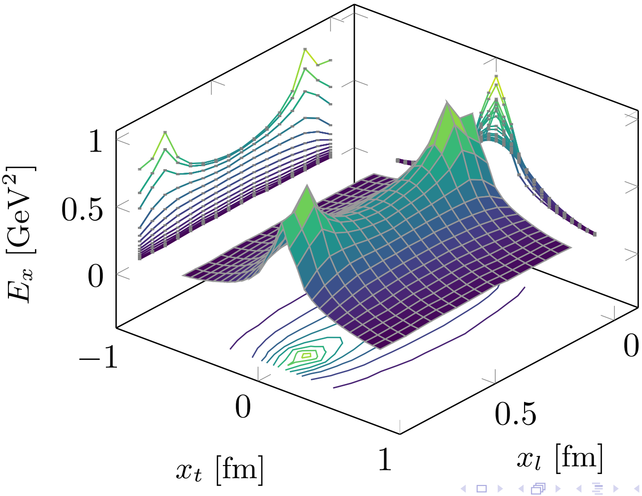
For the Monte-Carlo simulations we used the MILC code, modified to calculate the relevant observables.
To improve the signal-to-noise ratio the smearing procedure was applied, which consisted of one HYP smearing step with parameters $(1.0, 0.5, 0.5)$ for the links in time direction, followed by a set of APE smearing steps with parameter $\alpha_{\mathrm{APE}} = 0.167$.

Field measurements

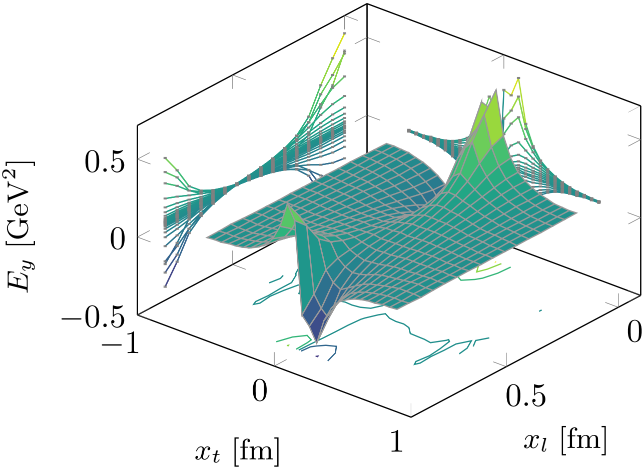
We have measured all field components using the operator $\rho_W^{\rm conn}$ for the following lattice setups:

β	lattice	d [fm]	statistics	$N_{\rm APE}$
6.47466	36^4	0.37	12900	100
6.333	48^4	0.45	180	80
6.240	48^4	0.51	1300	60
6.500	48^4	0.54	3900	100
6.539	48^4	0.69	6300	100
6.370	48^4	0.85	5300	100
6.299	48^4	0.94	10700	100
6.240	48^4	1.02	21000	100
6.218	48^4	1.06	32000	100
6.136	48^4	1.19	84000	120

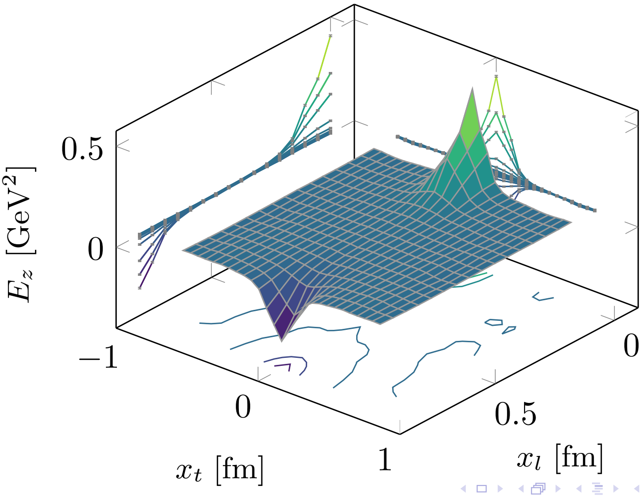
E_x field, $d = 0.85$ fm



E_y field, $d = 0.85$ fm



E_z field, $d = 0.85$ 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.

$$\vec{E}(\vec{r}) \; = \; \vec{E}_C(\vec{r}) \, + \, \vec{E}_{\rm np}(\vec{r})$$

Chromoelectric field structure

The Coulomb part is just sum of the fields of two sources with charge Q and $-Q$. To try 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.

$$\vec{E}_C(\vec{r}) = \vec{E}_R(\vec{r} - \vec{r}_1, q) + \vec{E}_R(\vec{r} - \vec{r}_2, -q)$$

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

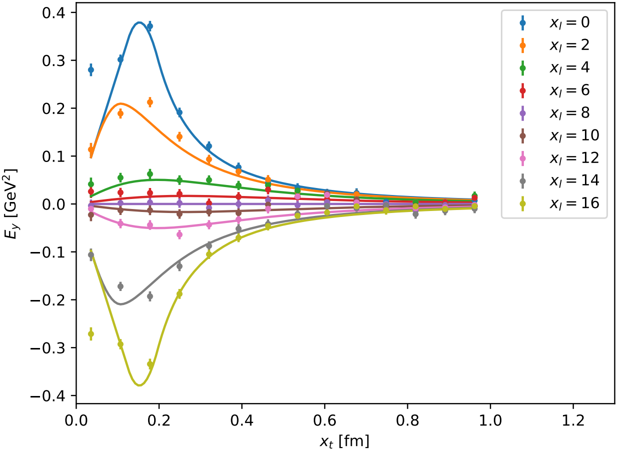
Extracting the nonperturbative part

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

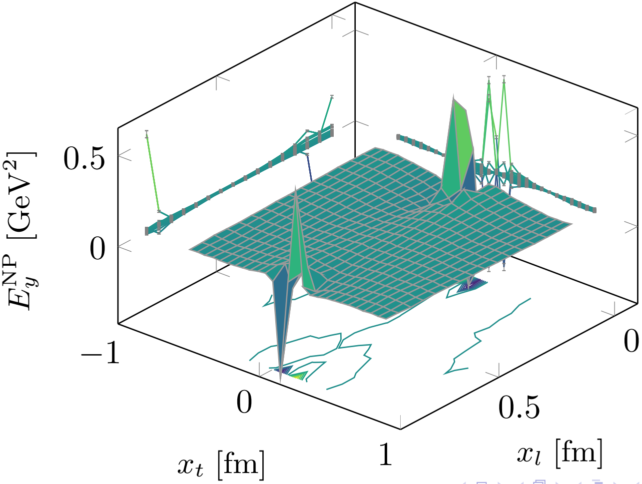
$$\rho_W^{\mathrm{conn}}(r_l, r_t) = \int_{r_t}^{r_t+1} \vec{E}(r_l, y, 0) dy$$

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

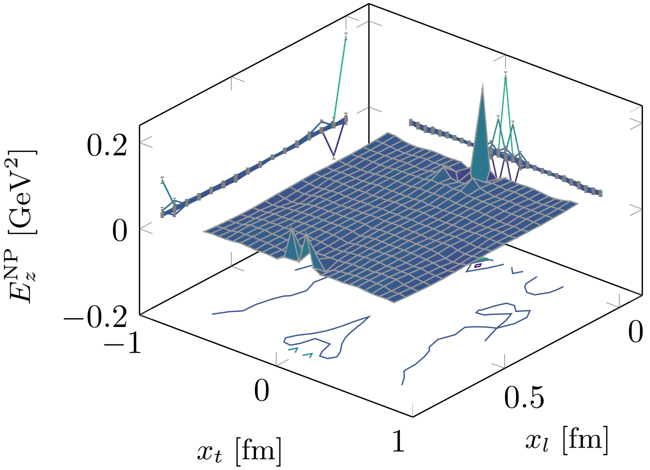
Extracting the nonperturbative part $d = 1.14$ fm



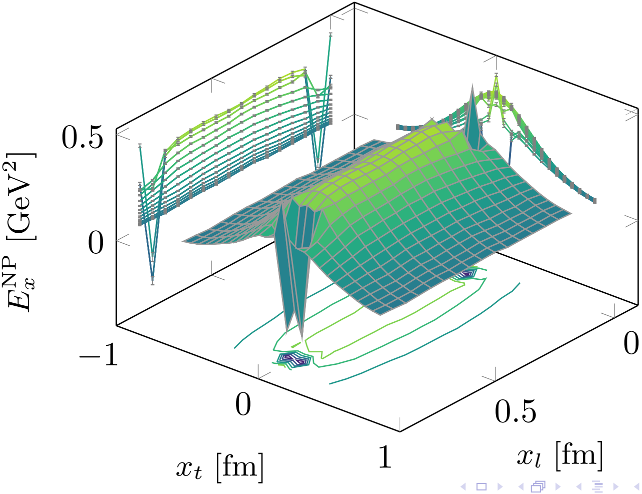
Nonperturbative field E_y, $d = 0.85$ fm



Nonperturbative field E_z, $d = 0.85$ fm



Nonperturbative field E_x, $d = 0.85$ fm



Irrotational property

Instead of postulating the Coulomb form of the perturbative field, and having to introduce the explicit distribution of charge we can just consider that the pertorbative field is irrotational.

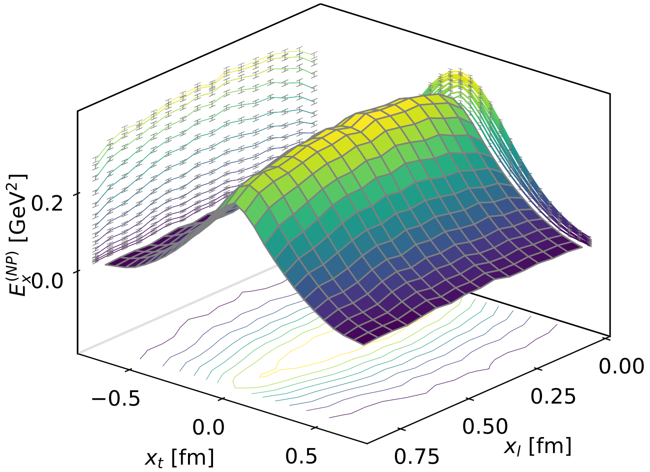
$$\vec{\nabla} \times \vec{E}^C(\vec{r}) = 0$$

On the lattice that would mean

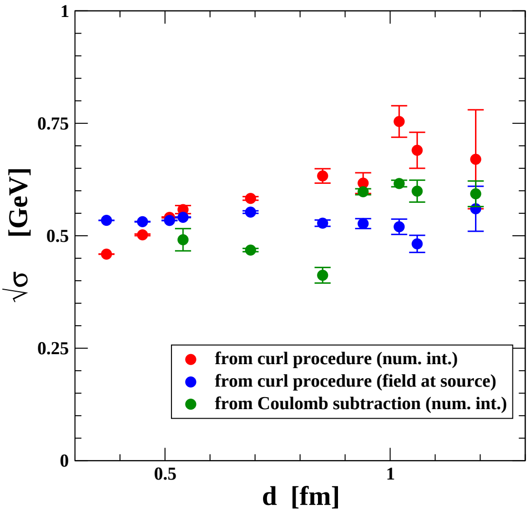
$$E_x^C(x,y) + E_y^C(x+1,y) - E_x^C(x,y+1) - E_y^C(x,y) = 0$$

Taking $E_y^C = E_y$, and considering that for $y = y_{\max}$
$E_x^C(x, y_{\max}) = 0$ we can restore E_x^C.

Nonperturbative field E_x, $d = 0.85$ fm



String tension extracted from the nonperturbative field



Conclusions

- For four dimensional $SU(3)$ pure gauge model the 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 by the Coulomb-type field. It can be extracted using its irrotational property from the transverse components of the full field.
- After subtracting the Coulomb field the longitudinal component of electric field is stable with respect to longitudinal displacement

Problems

- The behavior of the field in finite temperature case. String breaking transition.
- Applicability of this description to the QCD with dynamic quarks.
- Color structure of the field.
- Effect of the smearing procedure on the results (compared with explicit renormalization or Wilson flow).

Thank you for attention