The sound of the center - deconfinement in QCD

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What is QCD? What is deconfinement?

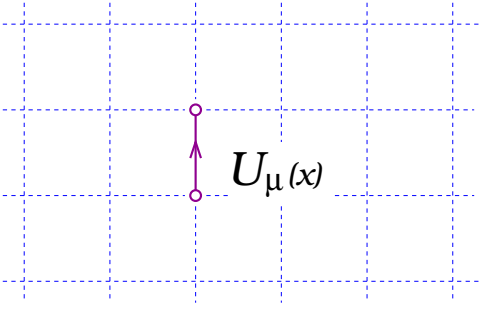
- Quantum Chromo Dynamics (QCD) is the theory of quarks and gluons.
- Usually quarks are confined in bound states, such as protons or neutrons which are basic building blocks of matter.
- At very high temperatures ($\sim$ 2,000,000,000,000 K) the quarks can escape their bound states and become deconfined.
- The gluons are the carriers of the strong force and are responsible for confinement and the deconfinement transition.
- For understanding confinement and the deconfinement transition often the theory of only gluons (gluodynamics) is studied.

Gluodynamics on the lattice

- A powerful approach to QCD is its formulation on a space-time lattice.
- To each link of the lattice a 3×3 complex matrix $U_\mu(x)$ is attached, which describes the gluons.
- The gluon configurations U follow a Boltzmann distribution:

$$P[U] \ \sim \ e^{-S[U]}$$

- We can use Monte Carlo techniques to generate gluon configurations with this distribution numerically.

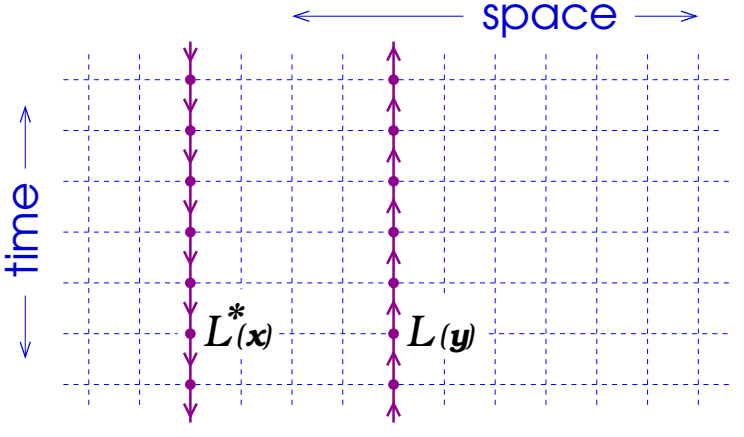


Quark sources

- We introduce quark sources $L(\mathbf{x})$ and study their correlator:

$$\langle L(\mathbf{x})^* L(\mathbf{y}) \rangle$$

- If the correlator is non-vanishing for large distances $|\ \mathbf{x} - \mathbf{y}\ |$ then quarks can move freely, i.e., they are deconfined.



Reduction to center elements

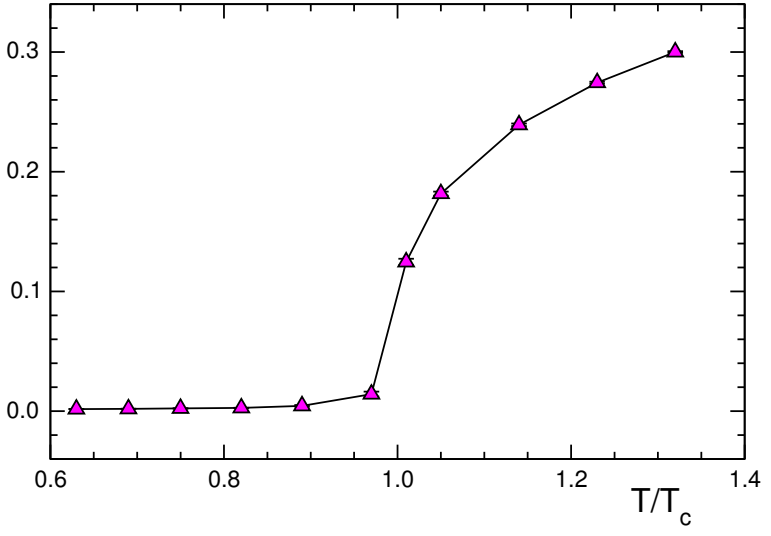
- It was conjectured, that the dynamics at the QCD phase transition may be described by an effective spin system where at each space time point the quark sources $L(\mathbf{x})$ assume only one of the three center values $1, e^{+i2\pi/3}, e^{-i2\pi/3}$.

- We filter and project the quark sources $L(\mathbf{x})$ to the nearest center element.

- If neighboring lattice points have the same center element, we put them in the same cluster.

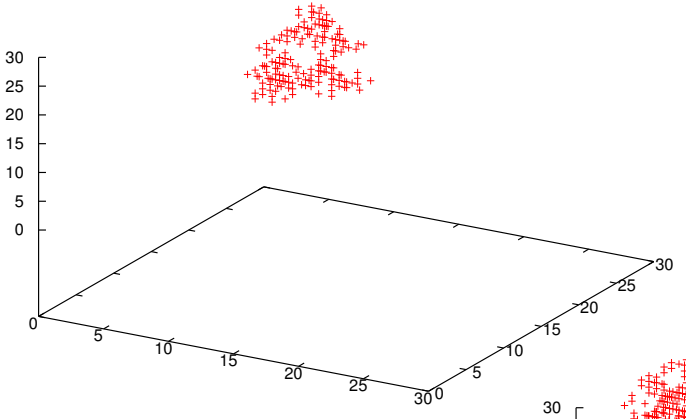
- Properties of the clusters are studied for different temperatures.

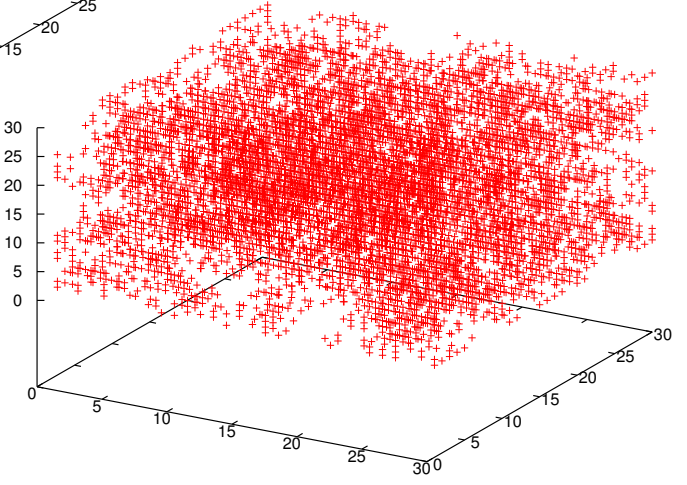
Size of the largest cluster normalized with the volume



We find that at the deconfinement temperature T_c a percolating cluster forms which spans all of the lattice.

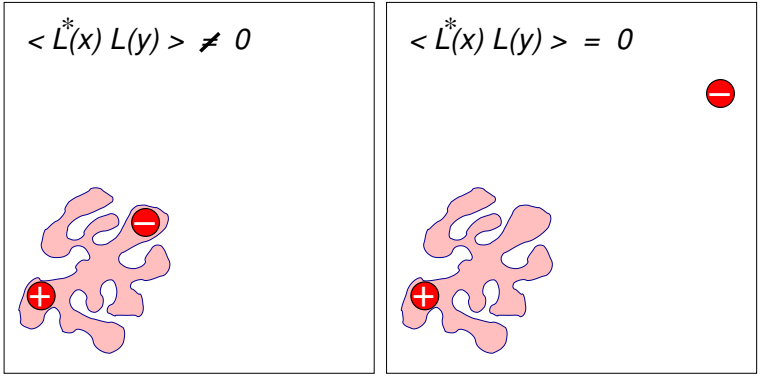
Clusters below and above T_c





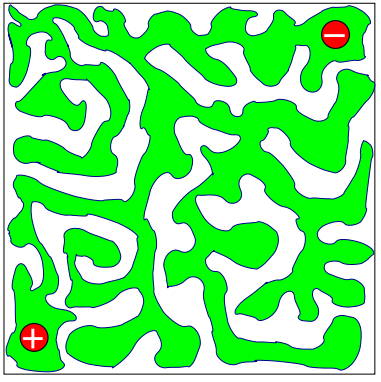
A mechanism for confinement and the deconfinement transition

T < T$_c$



Below T_c two static sources (= local loops) have a non–vanishing expectation value only if they fit into the same cluster, such that the phases cancel.

T > T$_c$



When the clusters percolate the sources can be put at arbitrary distances.

$$1 + e^{+i2\pi/3} + e^{-i2\pi/3} = 0$$

Suggestions and questions for sonification

- Is it possible to sonify the clusters?
- Can one distinguish the confined low temperature phase from the hot deconfined phase?
- Can one acoustically locate the transition temperature T_c?

Data format

- For several temperatures below and above T_c I have prepared 10 files intsect_TTC_X.XX_conf_NN.dat with the cluster information for 10 configurations.

- The volume is 40^3, and for each one of the 40^3 lattice points I stored a number, $-1, 0, 1$ or 2. The value 2 is used for lattice points that were filtered out, the other values correspond to the three possible center elements.

- Each file consists of 40^3 lines, each line containing $-1, 0, 1$ or 2. A C++ program is provided to read the numbers into an array `intsect[x][y][z]`.

- The coordinates `x`, `y`, `z` run from 0 to 39, and periodic boundary conditions are used.