



The Schwinger model in a bosonic version

A team of researchers from the Jagiellonian Univ. of Cracow, the University of Barcelona and ICFO report on a new theoretical method to understand bosonic behavior in quantum simulations.

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Relativistic quantum gauge theories are fundamental theories of matter describing nature. Paradigmatic examples are quantum electrodynamics (describing electromagnetic interactions of charged particles and photons), chromodynamics (describing strong interactions of quarks and gluons), and the Standard Model, unifying the latter two with the weak interactions.

Despite enormous progress in our understanding of quantum gauge theories, the questions concerning the behaviors of systems described by such theories in the presence of strong correlations remain widely open: from the very nature of the quark confinement to the behavior of quark-gluon-plasma at high densities and temperatures. Moreover, quantum out-of-equilibrium dynamics of quantum gauge theories is out of reach of the present

computers. For these reasons, there is a lot of effort to design and investigate quantum simulators of such systems. The paradigmatic model of quantum gauge theory in one spatial dimension and time is the Schwinger model, in which $i\frac{1}{2}$ charged $i\frac{1}{2}$ electrons (fermions) interact with photons (bosons) in one dimension. Since quantum simulations with fermions are notoriously difficult, Titas Chanda with Jakub Zakrzewski from Jagiellonian University in Cracow, Luca Tagliacozzo from UB and ICREA professor Maciej Lewenstein from ICFO, proposed in a recent study published in Phys. Rev. Lett. a bosonic version of the Schwinger model.

Using state-of-the-art methods of theoretical physics, they investigated in their work how the bosonic matter behaves when it is driven out-of-equilibrium by creating a pair of particle and antiparticle on top of the vacuum of the system. They obtain three results important for the understanding of quantum gauge theories in general:

- i) The bosons undergo evolution dominated by strong confinement of charges, responsible for only a partial screening of electric field, even in the massless limit;
- ii) The extended $i\frac{1}{2}$ meson $i\frac{1}{2}$ formed by the two charges and the electric-flux tube connecting them is very robust. It leaves a strong footprint in the entanglement of the system;
- iii) The systems fails to thermalize and generate exotic states at long times, characterized by two distinct space-time regions -- one external region made by thermal mesons, and a central region between the two initial charges, where their quantum correlations obey the, so called, area-law of entanglement.

This work opens a path towards quantum simulations of quantum gauge theories in novel, unexplored regimes.

Caption: (a) In the lattice version of bosonic Schwinger Model (BSM), sites are occupied by two kinds of bosons, corresponding to particles (red dots) and antiparticles (blue dots), which are coupled to U(1) gauge fields residing on bonds. Tunneling of bosons across a given bond change the internal state of corresponding gauge field as dictated by arrows. (b) Time-dynamics of BSM is greatly affected by strong confinement, where the light-cone of the particles bends inwards, producing exotic asymptotic states made of a central core of strongly correlated bosons and external regions populated by free mesons. Image Credit: Titas Chanda