Experimental linear optical quantum computing:
from fundamental tests to quantum simulation of frustrated Heisenberg spin systems

Abstract:
Photons have an intrinsic lack of decoherence and are simple to control by standard off-the-shelf components. Therefore optical qubits are playing an important role in investigating foundations of quantum information processing. Furthermore, photonic qubits for quantum computation are particularly attractive because they could interface to various quantum communication applications [1]. In recent years, one-way quantum computing has become an exciting alternative to existing proposals for quantum computers. In this specific model, coherent quantum information processing is accomplished via a sequence of single-qubit measurements applied to an entangled resource known as cluster state. Here I will review experiments realizations of various quantum algorithms on a photonic four-qubit cluster state, which is generated by means of parametric down-conversion [2-3]. Finally I will present the capability of using entangled photonic systems for the simulation of the ground-state wave function of four spin-1/2 particles interacting via any Heisenberg-type Hamiltonian.. The ground state properties of such quantum magnets may be important for the understanding of high-Tc superconductors, thus raising significant interest in the so-called valence-bond states. As such, experimental groups are in strong competition to perform the first quantum simulation to probe the entanglement dynamics of such states. The studied spin tetramer is the two-dimensional archetype system with the valence-bond state as a ground state. Depending on the interaction strength, frustration within the system emerges such that the ground state evolves from a localized to a resonating valence-bond state, which belongs to the class of spin liquid states. Experimentally, this spin tetramer is created using the polarization states of four photons. The high level of single-particle quantum control allows us to obtain fundamental insights by studying entanglement dynamics among individual particles [4].
[1] Nature Photonics 4, 553 (2010).
[2] Nature 434, 169 (2005)
[3] Nature 445, 65 (2007).
[4] Nature Physics (in press)