From Entangled Quantum Puzzles to Quantum Information

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In the talk I will first give an introduction to quantum entanglement. Then its puzzling features for the foundations of quantum physics will be presented along some typical experiments. To date entangled photons have become an essential workhorse for experiments on the foundations of quantum mechanics. Tests of Bell's Inequality (cf. the Einstein-Podolsky-Rosen Paradox) have with increasing sophistication ruled out more and more alternative views to quantum mechanics. Besides that, they emerged to be also essential for a number of quantum communication tasks.

In most experiments, entanglement of two qubits, that is, of two photons in two states, e.f. polarization are employed. Going beyond two particles, and beyond two dimensions interesting novel phenomena arise. One of them is the GHZ contradiction, where a conflict between an objective local (i.e. classical) view in quantum mechanics arises even for non-statistical predictions of the theory. A most fascinating subject is entanglement swapping, where photons can be entangled which share no common past. In delayed-choice entanglement swapping, the decision whether two photons are entangled or not can be made at a time after they have already been detected and their measurement results (e.g. their polarization) has been registered.

Going beyond qubits, states of orbital angular momentum (OAM) of photons provide an in principle unlimited discrete state space where the photons can also be entangled in many different ways. That way, entanglement has been confirmed for quantum numbers above 10.000 and between two photons, each carrying more than 100-dimensional states.

A Cosmic Bell Test employed very distant quasars. Also, quantum communication was established between Europe and China using the Chinese satellite Micius. I will conclude with the Big Bell Test, an experiment to test quantum entanglement employing human free will with twelve laboratories on five continents and a hundred million human participants.