EXPERIMENTAL MEASUREMENT OF NONLINEAR ENTANGLEMENT WITNESS FOR HYPER-ENTANGLED STATES

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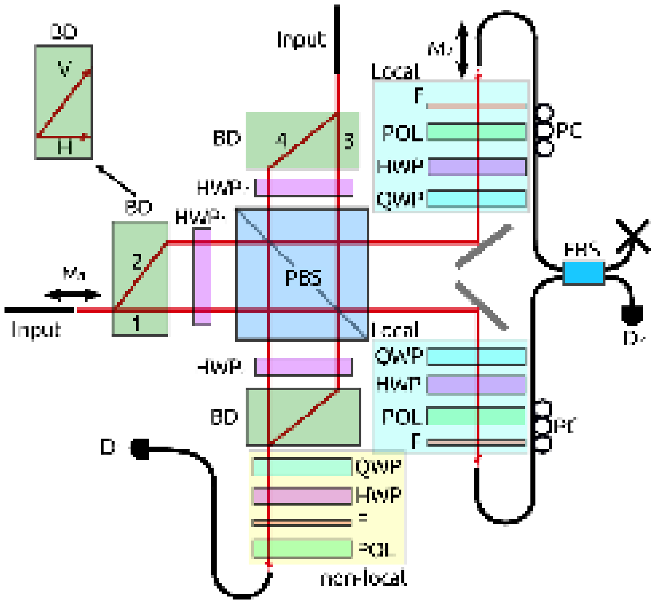
Quantum entanglement is one of the most useful tools of quantum technologies. Therefore it is no surprise that a lot of work has been dedicated to its investigation. Entanglement in more than one degree of freedom - the hyper-entanglement, has been found an invaluable asset for a number of quantum protocols. Quantum state tomography with density matrix estimation [1] and entanglement witnesses [2,3] are the commonly used methods for entanglement detection and quantification. The latter is more efficient since it does not require a large number of measurements, however one needs to have some *a priori* information about the input state. Several non-linear witnesses have been proposed to detect entanglement in one degree of freedom *e.g.* [4]. In this contribution we adopt this concept to test hyper-entangled states. Instead of multiple copies of investigated state, we use only one copy of the hyper-entangled state, but address all degrees of freedom simultaneously.



Fugure 1: Scheme of the experimental setup. M - motorized translation, HWP - half-wave plate, QWP - quarter-wave plate, PBS - polarizing beam splitter, BD - beam divider, POL - polarizer, F - interference filter, Loc. - local measurements, nLoc. non-local measurements , D - detector, FBS - fiber beam splitter, PC - polarization controller.

Experimental implementation - The simplified construction of the experimental setup is depicted in Fig. 1. Two polarization-entangled photons are generated in a BBO crystal cascade and each brought to one input port. The beam dividers then transform polarization entanglement into spatial entanglement and the two photons interact on a~polarizing beam splitter where they get entangled in polarization again. The hyper-entangled state is consequently subjected to local and non-local polarization projective measurements in mode A and B respectively. Local or non-local in our concept stands for measurements implemented separately respectively jointly on the two degrees of freedom. The amount of entanglement, in terms of collectibility [4], is then derived from correlations between coincidence rates of individual projections.

Tested states - We have tested the setup on a set of three fundamental quantum states namely: maximally hyper-entangled Bell state, pure separable state and mixed state.

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