Experimental preparation of two-photon Knill-Laflamme-Milburn states

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Several years ago Knill, Laflamme and Milburn have shown how a specific class of states can be useful for quantum information processing [1]. Their proposal has been subsequently generalized by Franson et al. [2]. Here we present experimental preparation of such quantum states based on our recent theoretical proposal [3].

$$|\psi\rangle_{\mathrm{KLM}} = \gamma|1100\rangle + \delta|1001\rangle - \gamma|0011\rangle$$

encoding into 4 spatial modes

PBS

$$|\psi\rangle_{\mathrm{KLM}} = \gamma|H_1V_1\rangle + \delta|H_1V_2\rangle - \gamma|H_2V_2\rangle$$

encoding into 2 spatial and 2 polarization modes

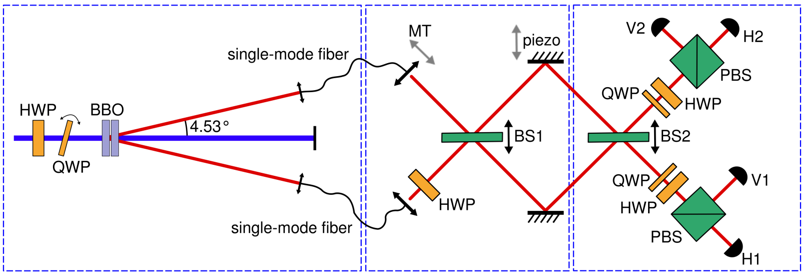
The experimental setup can be divided into **three main parts:**

a) **source of entangled photon pairs** using the SPDC source proposed by Kwiat et al. [4] composed of two BBO type I crystals rotated perpendicularly one with respect to the other pumped by CW Krypton laser beam at 413 nm,

b) **KLM state preparation** using beam splitter BS1 with tunable effective splitting ratio,

c) **KLM state analysis** using second beam splitter BS2 followed by polarization analysis.

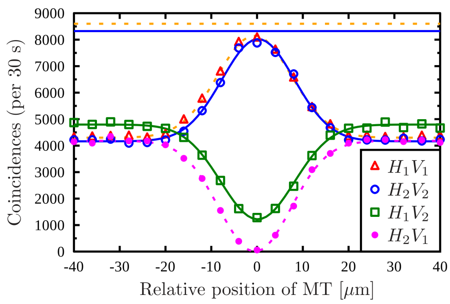
Both beam splitters BS1 and BS2 can be shifted as depicted by arrows. This shifting strongly affects reflected beam path, but leaves the path of the transmitted beam unaffected. At the expense of losses we are thus able to tune the reflectivity/transmissivity ratio in the range from 50:50 to 0:100.

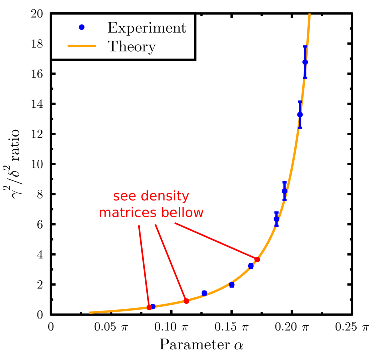


a) source of entangled photon pairs

b) KLM state preparation

c) KLM state analysis





The photon source generates entangled two-photon states in the form of

$$|\psi_{\mathrm{SOURCE}}\rangle = \sin\alpha|VH\rangle + \cos\alpha|HV\rangle,$$

where parameter α can be set by rotating the HWP in the pumping beam. The QWP in the pumping beam is used to tune the relative phase between VH and HV terms. **The KLM state is then prepared on the first beam splitter BS1**, whose amplitude reflectivity/transmissivity ratio σ has to be set according to theoretical calculations [3]

$$\sigma = \sqrt{\tan\alpha}.$$

By changing the relative path of the two input modes using motorized translation MT we have observed dip in the coincidences H2V1, when both incoming wave packets overlap in time on the beam splitter. The visibility typically about 95% indicates that the **undesired term H2V1 practically vanish**.

We have investigated the **relative intensity ratio** γ^2/δ^2. Theory suggests that amplitudes should depend on the source parameter via relations

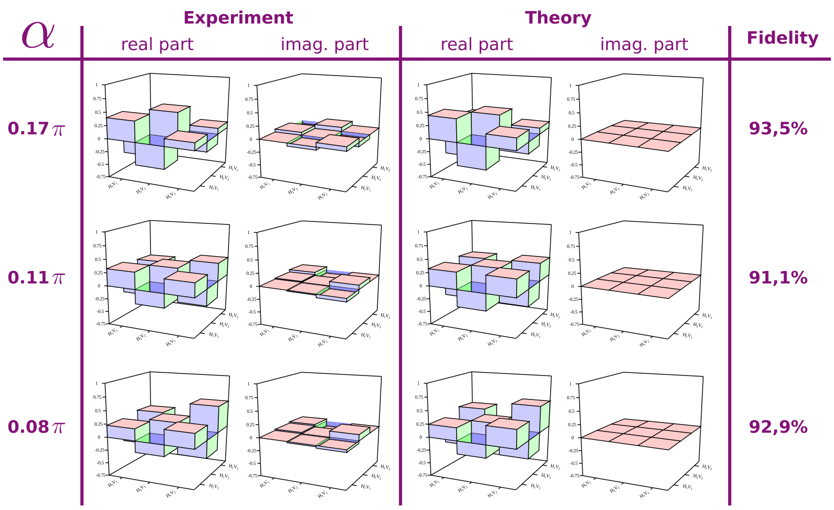
$$\gamma = \tfrac{1}{2}\sqrt{\tan\alpha}\,(\sin\alpha + \cos\alpha)\,,\ \delta = \cos 2\alpha/(2\cos\alpha).$$

Figure above shows theoretical relation as well as experimentally detemined values.

For complete KLM state analysis we have to employ the second beam splitter and thus form a Mach-Zehnder interferometer.

The position of the beam splitter BS2 is tuned so it becomes a balanced beam splitter. All possible coincidences are measured for relative phases 0 and $\pi/4$ between the two arms of the interferometer. Such measurement in combination with the coincidence measurement with BS2 shifted to the 0:100 ratio represents full state tomography and allows us to estimate the 3x3 density matrix of the KLM state using the maximum likelihood method described in [5]. Three examples of obtained matrices are depicted each with the theoretical prediction for comparison.

Fidelity of prepared state is calculated as the overlap of estimated density matrix with its theoretical counterpart. **States with fidelity about 92% were prepared.**



[1] Knill, Laflamme, Milburn; Nature **406**, 46 (2001)
[2] Franson et al.; Phys. Rev. Lett. **89**, 137901 (2002)
[3] Lemr, Fiurasek; Phys. Rev. A **77**, 023802 (2008)
[4] Kwiat et al.; Phys. Rev. A **60**, R773 (1999)
[5] Jezek et al.; Phys. Rev. A **68**, 012305 (2003)

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