Quadripartite CV entanglement and cluster states

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This work is a continuation of research into multipartite continuous variable entanglement, where ACQAO and the Jack Dodd Centre have provided theoretical support for the quantum optics experiments undertaken at the University of Virginia.

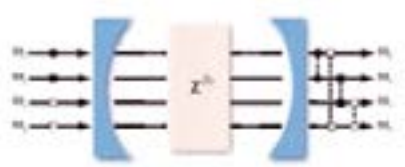

Figure 1: Schematic of the $\chi^{(2)}$ crystal inside a pumped cavity. The inputs are on the left and the output downconverted modes on the right.

Olivier Pfister is able to use intracavity systems which produce quadruply concurrent downconversion. With four pump lasers, as shown in Fig. 1, this results in four downconverted output modes which are inseparable [1] and will find many uses in quantum information technologies. The system as shown in Fig. 2, with only two pumps, provides a continuous variable cluster state in the limit of strong squeezing, which is a proposed resource for one-way quantum computing, but may also be useful for more viable tasks.

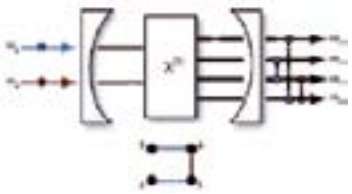

Figure 2: Schematic of the cluster state system and graph state representation of the outputs.

To demonstrate the existence of quadripartite entanglement, where none of the four output subsystems may be described separately from the others, we calculated an optimised form of the van Loock-Furusawa correlations [3], finding that both systems we considered exhibited entanglement for a wide range of parameters, both above and below threshold. The four-pump scheme showed almost complete violation of the inequalities around the oscillation threshold when all the nonlinearities were equal and, more importantly for experimental realisations, still exhibited genuine inseparability with differences among the interaction strengths. An important advantage of this scheme is that the entanglement is present well above threshold, where the outputs are of truly macroscopic intensity.

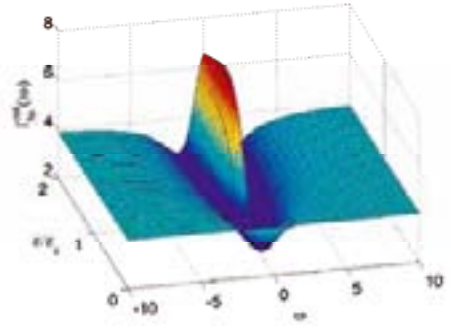

Figure 3: Output spectral correlation for the cluster scheme. A value of less than one signifies entanglement.

The cluster state also provided entanglement both above and below threshold, with a small injected coherent signal necessary above threshold to prevent phase diffusion. There are three inequalities which must all be violated to demonstrate full inseparability, with one of them being shown in Fig. 3. The other two are equal to each other, but different from I_{56} for the same parameters. This is unlike the four pump system, where for equal parameters the spectra are identical and no injected signal is required. We found that both schemes are potential sources of bright entangled states and that the usefulness of the two-pump scheme as a cluster state will depend on whether less than perfect squeezing is acceptable.

References

[1] S. L. W. Midgley, A. S. Bradley, O. Pfister, and M. K. Olsen, Phys. Rev. A **81**, 063834 (2010).
[2] S. L. W. Midgley, M. K. Olsen, A. S. Bradley, and O. Pfister, Phys. Rev. A **82**, 053826 (2010).
[3] P. van Loock and A. Furusawa, Phys. Rev. A **67**, 052315 (2003).