Examining Light-Matter Interactions Through Two Photon Entanglement

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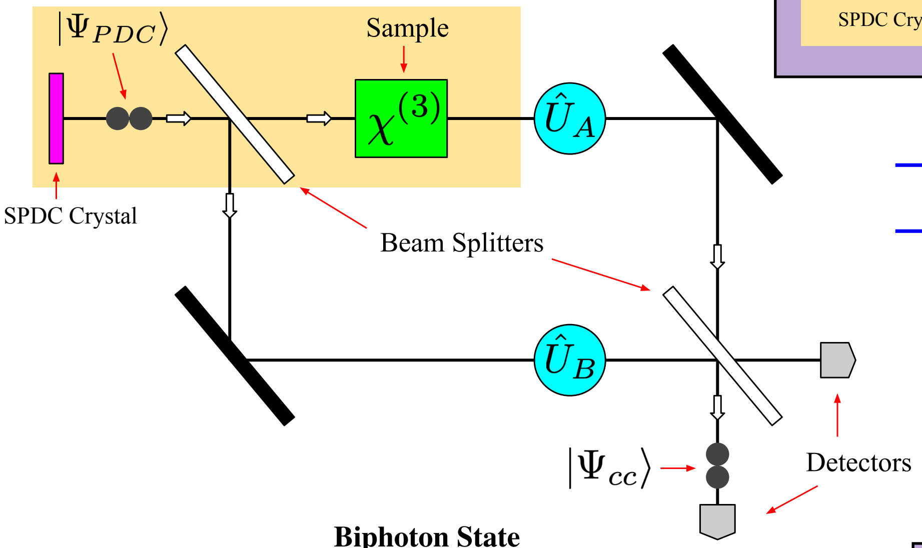
Abstract

In this thesis we model two-photon interference with a nonlinear sample in a Mach Zehnder interferometer to calculate a coincidence signal that can be compared with ongoing experimentation. Specifically, we use entangled biphoton states created by Type I collinear spontaneous parametric down conversion (SPDC).

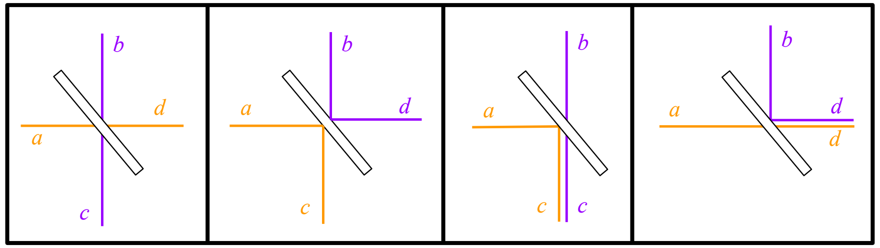
Mach Zehnder (MZ) Interferometer



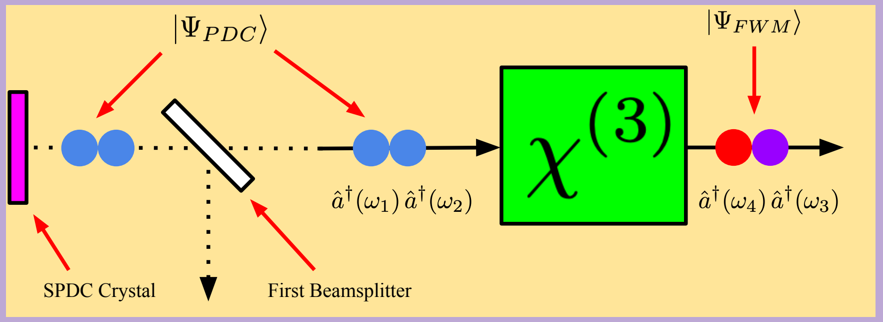
Biphoton State

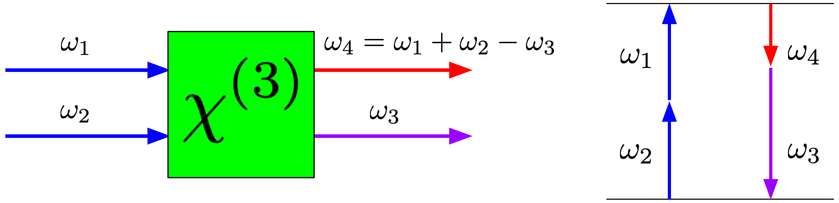
$$|\Psi_{PDC}\rangle = \int d\omega_1 \int d\omega_2 \; \psi_{PDC}(\omega_1,\omega_2)\; \hat{a}^\dagger(\omega_1)\hat{a}^\dagger(\omega_2)\,|0\rangle$$

Beam Splitter Paths



Four-wave-mixing





$$|\Psi_{PDC}\rangle \rightarrow |\Psi_{FWM}\rangle \rightarrow |\Psi_{cc}\rangle$$

The fully evolved state can be organized into linear and nonlinear contributions.

$$|\Psi_{cc}\rangle = \left[\cos\left(\frac{\alpha}{2}\right)(\text{linear}) + e^{i\beta}\,\sin\left(\frac{\alpha}{2}\right)(\text{nonlinear})\right]|0\rangle$$

Joint Detection Model [1]

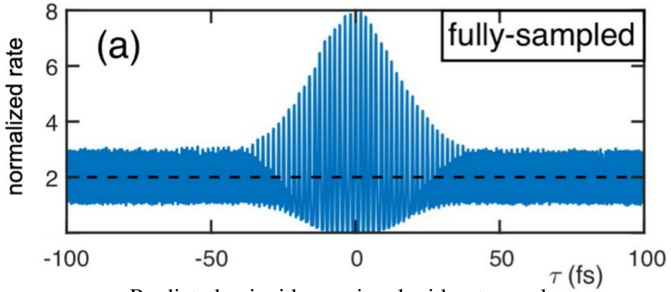
$$R_{cc}(\tau) \propto \int d\omega_1 \int d\omega_2 \left|\,\langle 0|\,\hat{c}(\omega_1)\hat{c}(\omega_2)\,|\Psi_{cc}\rangle\,\right|^2$$

The predicted coincidence signal can be broken up into three contributions.

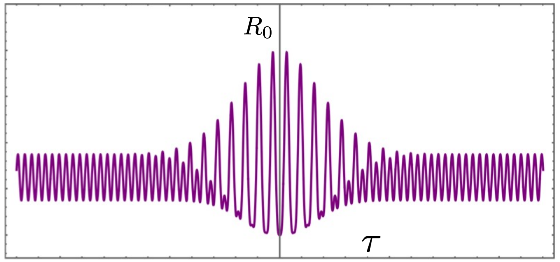
$$R_{cc} \propto R_0 + R_1 + R_2$$

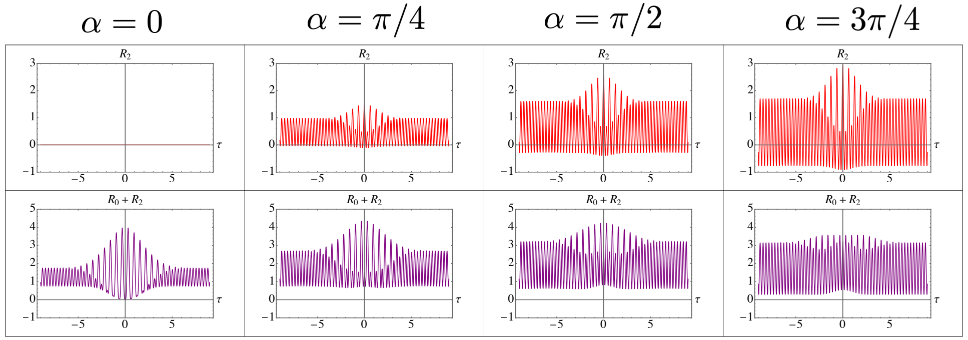
Only the first and last terms have been calculated for this MZ interferometer

Measured coincidence signal without sample. [1]



Predicted coincidence signal without sample.





Conclusion

At least one part of the nonlinear contribution for sample interaction impacts the coincidence signal at all ranges of efficiency. Further work should include an examination of the other nonlinear contribution and scaling the parameter space to match those used in experiment.

[1] Jonathan Lavoie, Tiemo Landes, Amr Tamimi, Brian J Smith, Andrew H Marcus, and Michael G Raymer. Phase-modulated interferometry, spectroscopy, and refractometry using entangled photon pairs. *Advanced Quantum Technologies*, page 1900114.

Acknowledgments

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