Entangled Photon-Pair Generation in BiBO Crystal

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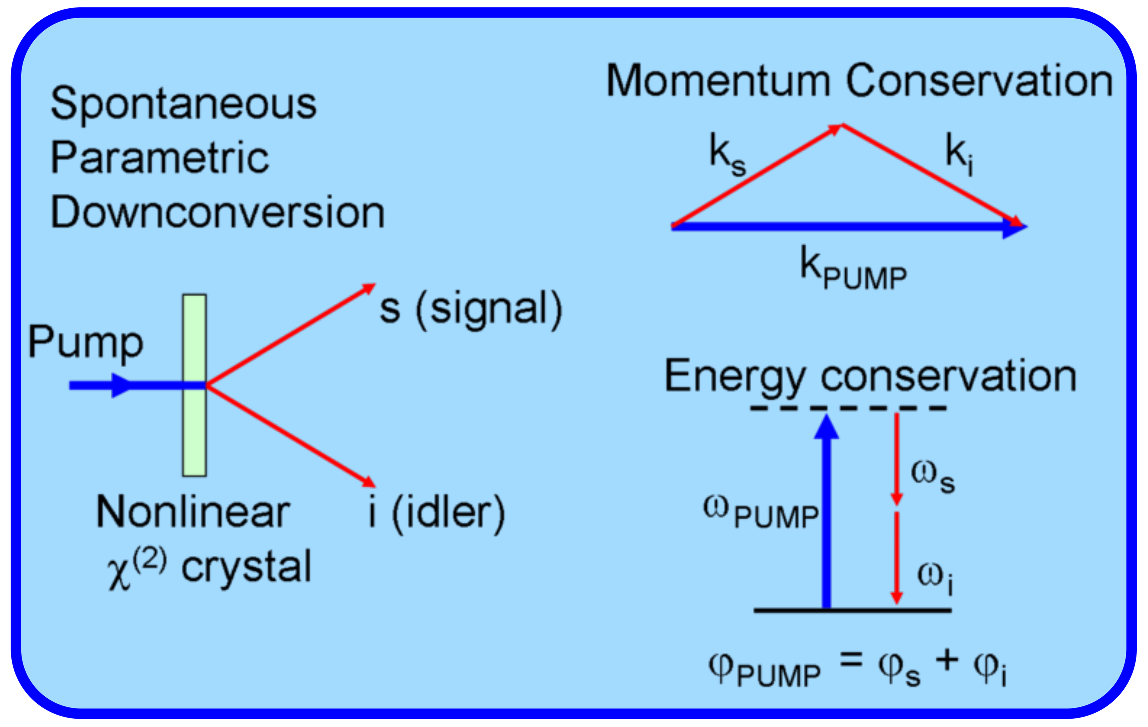
Introduction — Quantum State Generation

Entanglement is a fundamental resource for quantum information processing; entangled photons are essential for many quantum communication and quantum cryptography protocols. In order to create entangled photon pairs, we exploit the phenomenon of **spontaneous parametric down-conversion (SPDC)** in nonlinear birefringent BiB_3O_6 (BiBO) crystal.

Entangled states are **intrinsically correlated yet random, and nonlocal**. They cannot be factored into product states.

$$|\Phi\rangle_{\alpha,\beta} \neq \sum_i c_i |i\rangle_\alpha \otimes \sum_j c_j |j\rangle_\beta$$



SPDC, with very small probability, will generate entangled photon pairs. BiBO's type-I phase matching ensures the signal and idler polarizations are orthogonal to the pump. Pumping two crystals back to back, with orthogonal principal axes leads to:

$$|H\rangle_I \rightarrow |V\rangle_s + |V\rangle_i$$
$$|V\rangle_{II} \rightarrow |H\rangle_s + |H\rangle_i$$

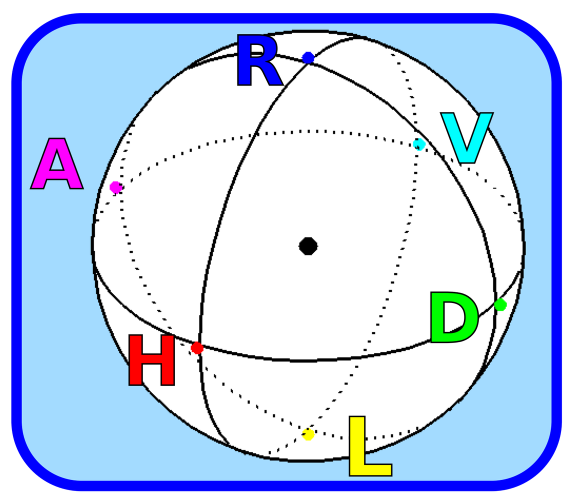
Pumping these two crystals with the proper delay will give:

$$|D\rangle_{\text{pump}} \rightarrow \frac{1}{\sqrt{2}}\left[|H_s H_i\rangle + e^{i\phi}|V_s V_i\rangle\right]$$

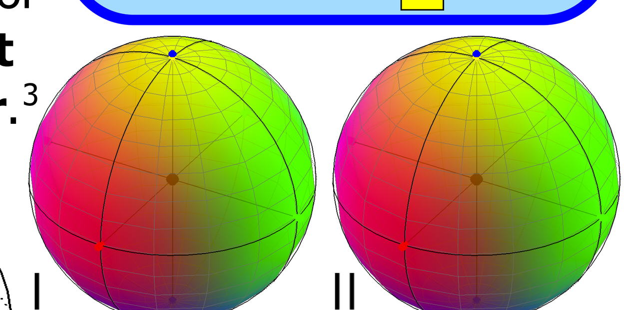
Quantum State Representation

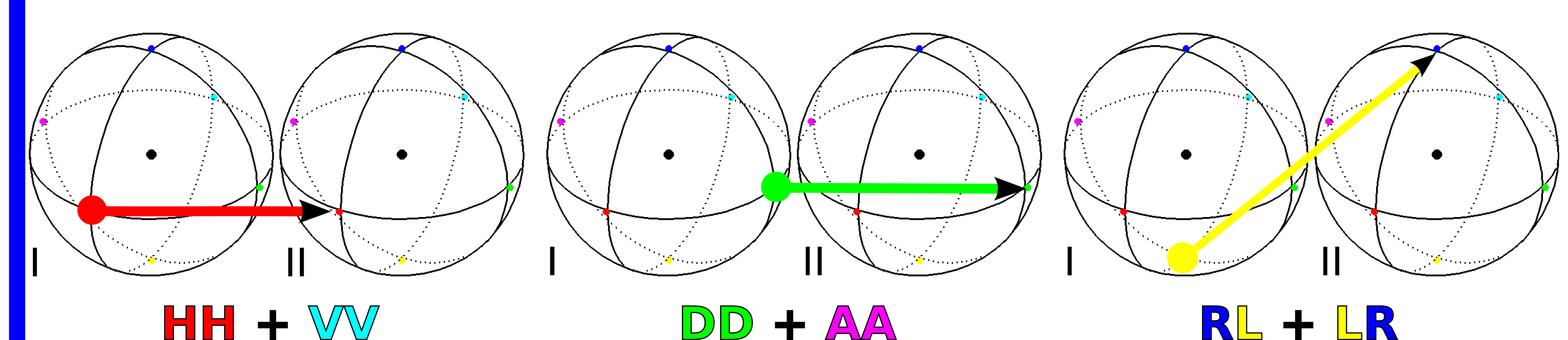
Any **polarization-based single-qubit quantum state** can be represented on the **Poincaré sphere** by the following coordinates; any combination will lead to a valid density matrix:

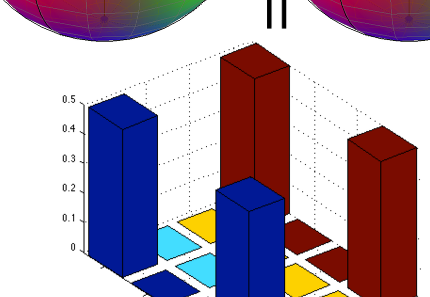
$$[\rho] = \frac{1}{2}\left(\begin{bmatrix}1 & 0\\0 & 1\end{bmatrix} + x\begin{bmatrix}1 & 0\\0 & -1\end{bmatrix} + y\begin{bmatrix}0 & 1\\1 & 0\end{bmatrix} + z\begin{bmatrix}0 & -i\\i & 0\end{bmatrix}\right) \longrightarrow$$



To represent entangled states of **two qubits, two ellipsoids** are needed.[3] The **positions** of points are **states which can be remotely prepared**, while **measurements which must be performed on the other qubit to remotely perpare them** are represented by **color**.[3]



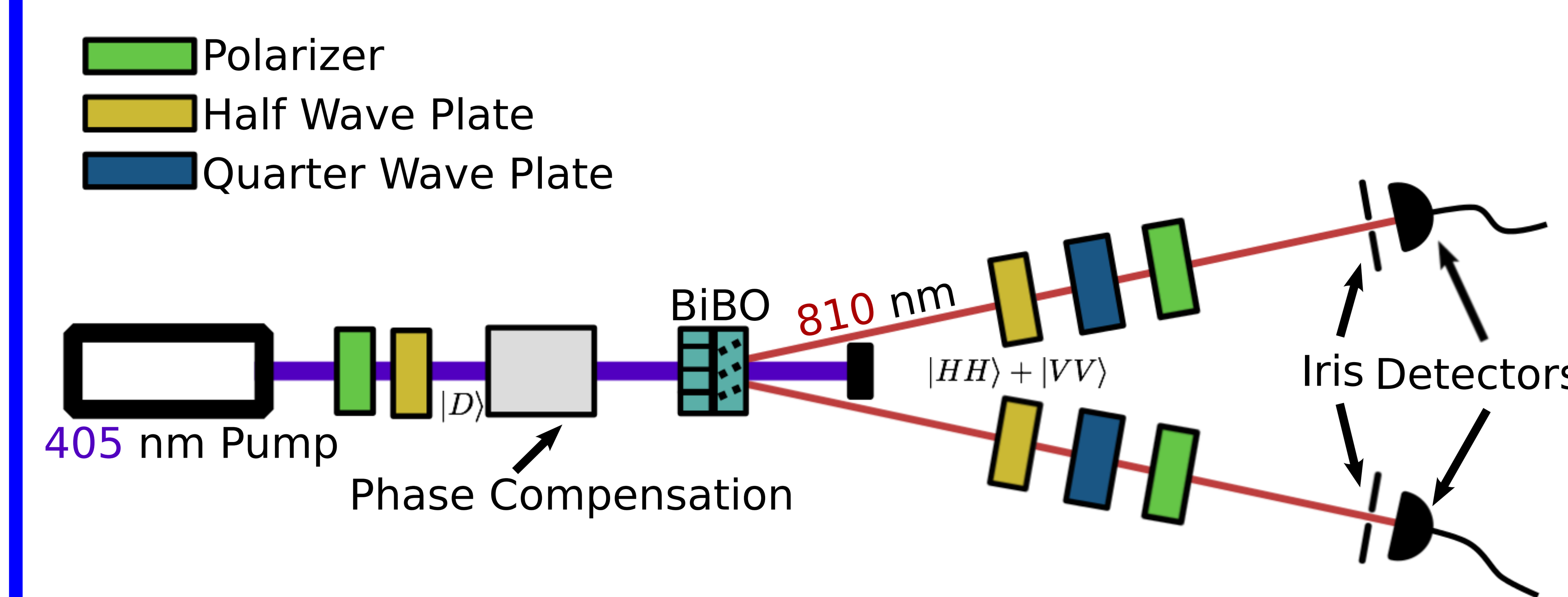




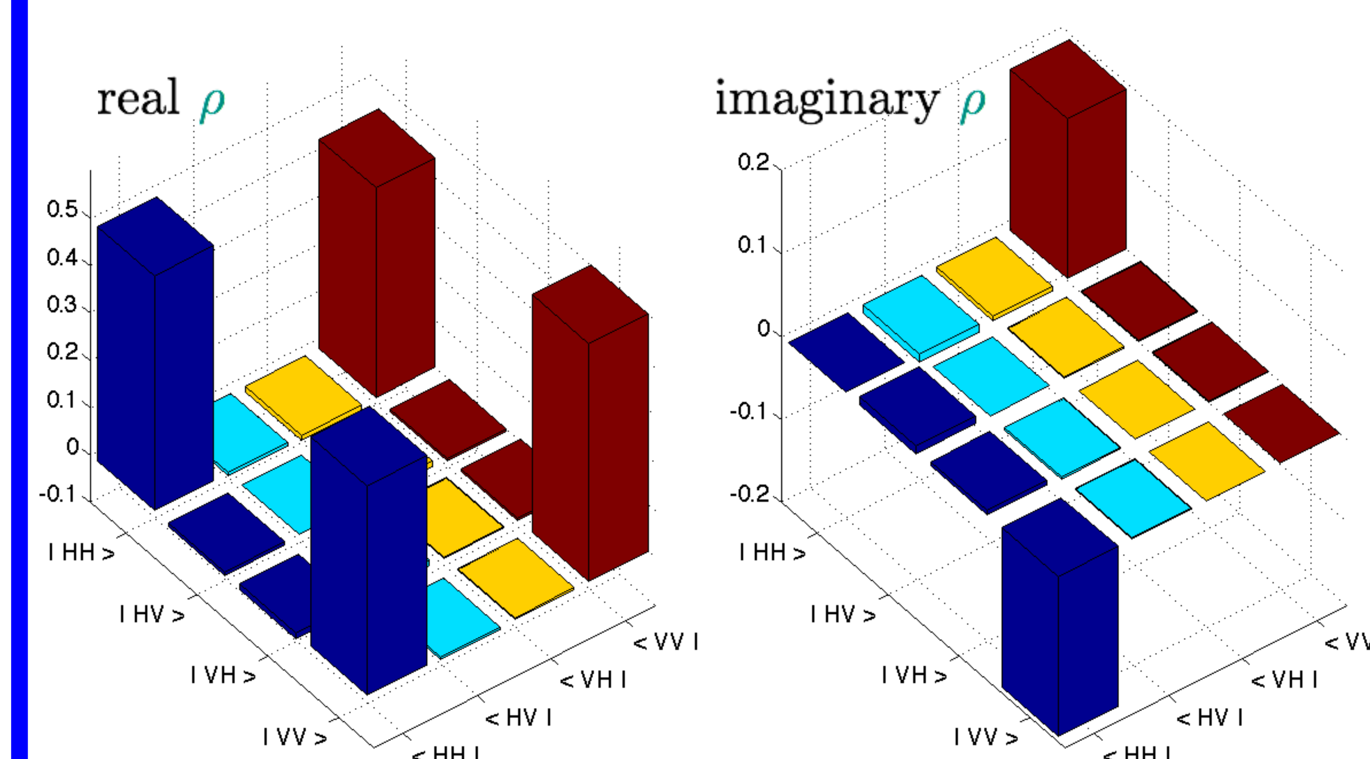
The Bell state $|\Phi^+\rangle$ features these transformations which manifest themselves in the following complete ellipsoids. The density matrix is also shown.

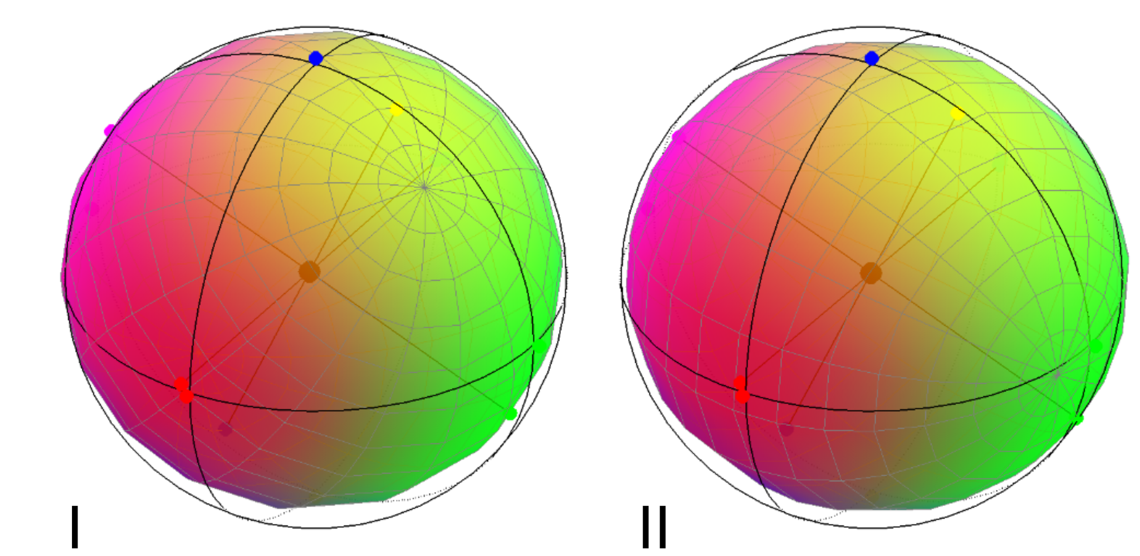
$$|\Phi^+\rangle = \frac{1}{\sqrt{2}}\left[|HH\rangle + |VV\rangle\right]$$

Apparatus and Results



The BiBO crystal used for entangled photon pair generation was pumped with a **405 nm laser.** A block of **quartz was needed for phase compensation** due to the large birefringence of the BiBO. Silicon avalanche photodiode detectors, wave plates and polarizers were set up at the cone opening angle in order to perform a tomography[2] of the state. The waveplates allow us to project any polarization state.





The state generated by the apparatus is shown above.[2] The **Bell fidelity** (a measure of the state overlap of ρ with the Bell-like state $1/\sqrt{2}\left[|HH\rangle + e^{i\phi}|VV\rangle\right]$) of the state is **0.9807 ± 0.0048**, while the **tangle** (a measure of the non-classical properties of a quantum state, 0 for product states to a maximum value of 1 for Bell states) of the state is **0.885 ± 0.028**. This measurement was taken with an **iris size of 2mm and 20 nm filters** centerd at 810 nm in the signal, idler arms. In the future we plan on using 4 nm filtering to get a better tangle.[1]

We have shown entangled photon-pair generation by using a BiBO crystal with **high Bell fidelity**, and with further improvements this type of source **has many uses in the field of quantum communication**. This setup will also used in a quantum information teaching lab to **showcase entanglement to advanced undergraduate students**, stimulating interest in the subject.

References

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[3]J. B. Altepeter, E. R. Jeffrey, M. Medic, and P. Kumar, "Multiple-Qubit Quantum State Visualization," in Conference on Lasers and Electro-Optics/International Quantum Electronics Conference, OSA Technical Digest (CD) (Optical Society of America, 2009), paper IWC1. a

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