Direct Observation of Conservation of OAM in Collinear Type-I SPDC

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Abstract

Here we implement a direct measurement of the Spatial modes distribution carrying Orbital Angular Momentum (OAM) generated in collinear type I SPDC, by using a triggered ICCD camera. Modes up to $l = \pm 10$ were observed, and the probability amplitude of generation of each mode is reported. We also present a method to observe the topological charge of these modes, which we used for the modes $l = \pm 1$ and $l = \pm 2$, proving conservation of OAM.

Theory

We can express the individual photonic state in the LG basis:

$$\left|1\right\rangle_i = \sum_{l_i} c_{l_i} \left|LG_{l_i}\right\rangle_i \tag{1}$$

Analogously for the case of the signal photon, and using the selection rule for the transfer of OAM from the pump to the idler and signal photons ($l_p = l_i + l_s$), that always holds for collinear type-I SPDC[2], that clearly tells us that the OAM is conserved, we can write the bi-photonic state $\left|1\right\rangle_i \left|1\right\rangle_s$ as:

$$\left|\psi\right\rangle_{spdc} = \sum_{l} C_l (\left|LG_l\right\rangle_i \left|LG_{l_p - l}\right\rangle_s + \left|LG_{l_p - l}\right\rangle_i \left|LG_l\right\rangle_s) \tag{2}$$

Spatial Modes carrying OAM

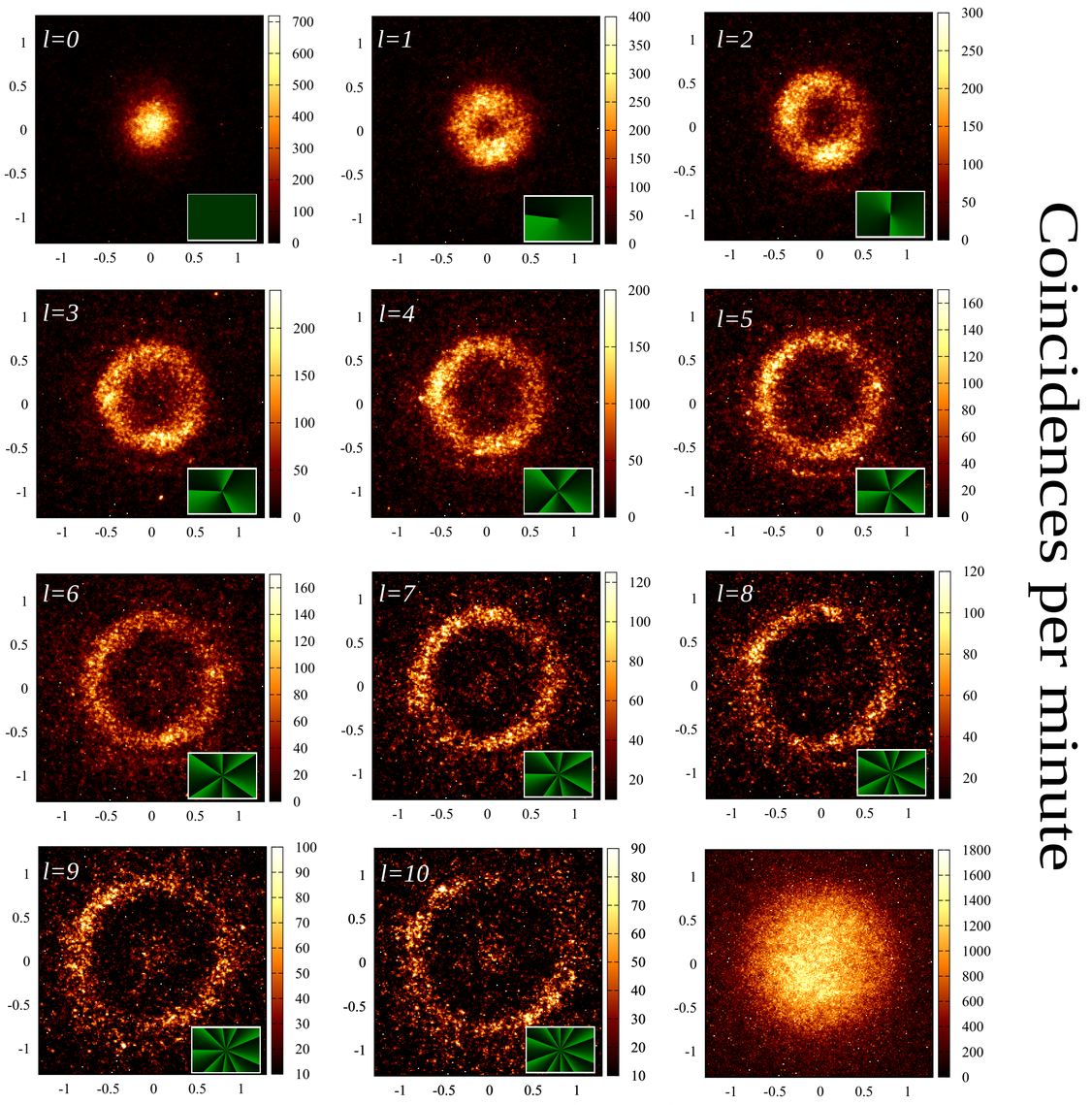

Fig. 3: Far- field conditional picture of the spatial mode of the idler photon, for different projected LG modes of the signal photon

Probability Amplitude

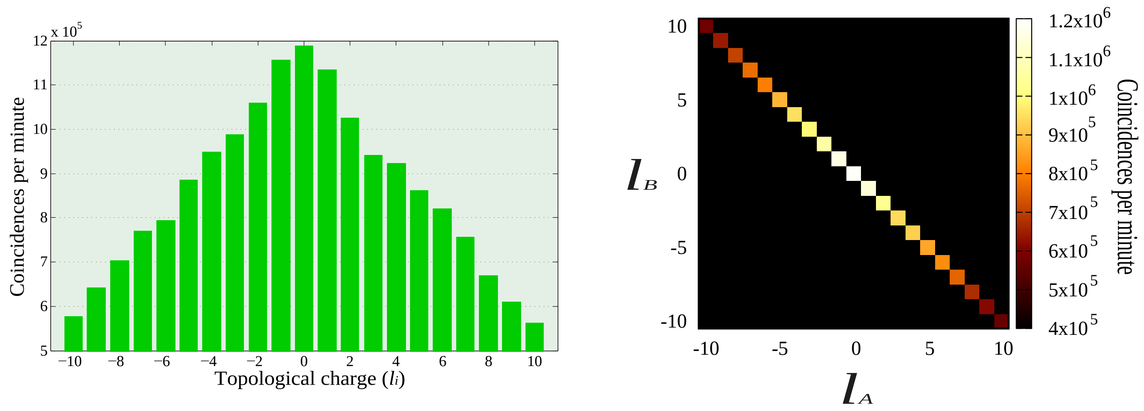

Fig. 6: Probability amplitude of generation of each mode $\left|c_l\right|^2$

Set-Up

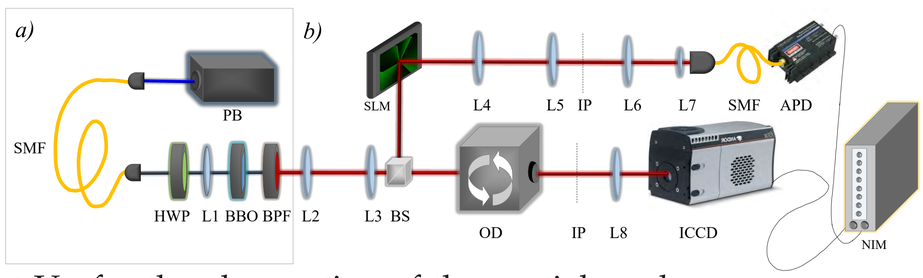

Fig. 1: Set-Up for the observation of the spatial modes. We use a $405nm$ laser spatially filtered by a single mode fiber (SMF) to ensure a Gaussian beam profile, that is focused in a 2 mm thick type I β-BBO crystal in collinear configuration. To select the degenerate photon pair, the down converted photons pass through a $10nm$ bandpass filter centered at $810nm$). For selecting a specific mode in the signal photon, we use a 4f system (l_2 and l_3) to image the crystal plane onto the SLM where a phase mask with $\mp l$ projects the $\pm l$ LG mode of signal photon that wants to be measured, into a Gaussian mode collected with a single mode fiber attached to an APD. The idler photon, formed as a superposition of LG modes, goes through an image preserving optical delay line [4] to an ICCD camera triggered by the detection of the Gaussian filtered signal photon.

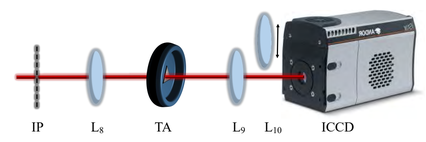

Fig. 2: Set-Up for the observation of the Topological charge

Topological Charge

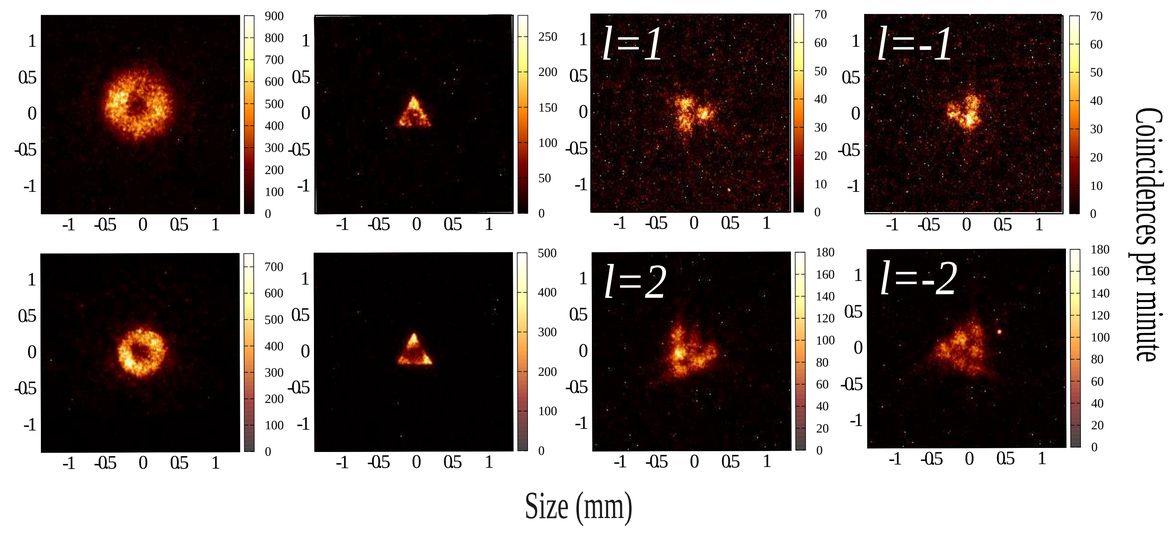

Fig. 4: Pictures of the spatial modes in the far-field for the cases of $l = \pm 1, \pm 2$, spatial modes on the TA plane, and diffraction patterns showing the topological charge carried by modes.

Classical LG_l

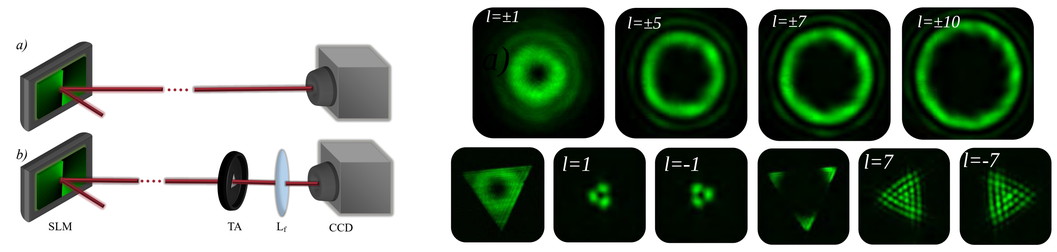

Fig. 5: (a) show the setup for the generation of spatial modes carrying a defined TC, and (b) to observe it directly. The pictures show the modes generated and the diffraction patterns indicating the sign and magnitude of the TC

Conclusion

We implemented a source of pairs of photons that carry Orbital Angular Momentum, and we directly observed and proved, for our set-up configuration, that the topological charges which the pair of photons are generated with, meet a selection rule, that states a full transfer of OAM from the pump photon to the idler and signal photons, at least for the cases $l = \pm 1, \pm 2$. And since the state of one photon depends on the state of the other they are entangled in OAM.

Referencias

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