# Temporal properties of counter-propagating twin beams in a Mirrorless Optical Parametric Oscillator

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Twin photon pairs generated through parametric down-conversion (PDC) in a $\chi^2$ medium is one of the most widely used source of entanglement. We focus here on a non-conventional geometry in which one of the twin photons propagates in the opposite direction with respect to the pump beam exploiting quasi-phase-matching in a periodically poled crystal. Through predicted almost 50 years ago, this new PDC configuration has been realized experimentally only recently [1] thanks to new fabrication techniques achieving the required sub-micrometer poling period. Because of the presence of distributed feedback, the optical system has been shown to behave as a Mirrorless Optical Parametric Oscillator (MOPO) and exhibits peculiar spectral properties which strongly differ from those found in more common geometries involving co-propagating beams.

In this work we provide a detailed analysis of the correlation and coherence properties of counter-propagating twin beams both in the purely spontaneous regime and in the neighborhood of the MOPO threshold.

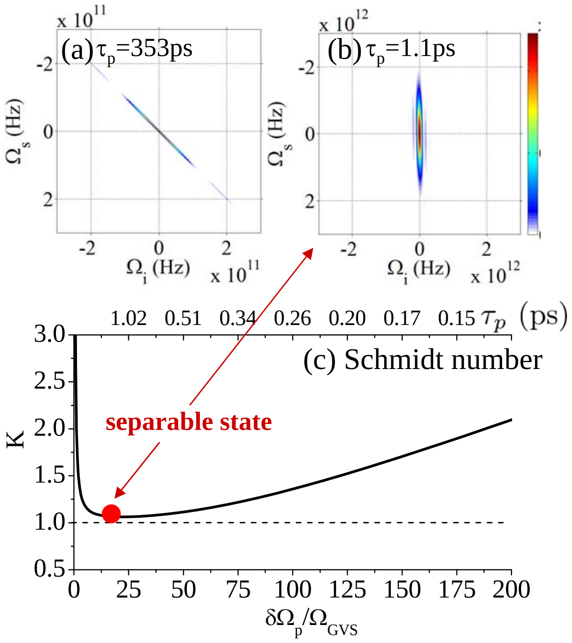


FIG. 1. (a) Biphoton spectral correlation $\langle A_s(\Omega_s)A_i(\Omega_i)\rangle$ displaying signal-idler frequency entanglement for $\tau_p \gg \tau_{GVS}$, (b) nearly separable state for $\tau_{GVM} \ll \tau_p \ll \tau_{GVS}$. (c) Schmidt number as a function of the pump pulse bandwidth $\Delta\Omega_p = 1/\tau_p$. The red dot corresponds to the separable state shown in (b). 4mm PP-KTP crystal pumped at 821.4mm, $\lambda_s = 1141$nm, $\lambda_i = 2932$nm, $\tau_{GVM} = 0.27$ps, $\tau_{GVS} = 25.2$ps.

We consider on the on side the regime of spontaneous pair production where the characteristic narrow band of the counter-propagating twin beams offers the unique opportunity of generating heralded single photon states with a high degree of purity, a relevant property for applications in quantum communication [2]. In this context, we investigate how the degree of separability of the twin photon state varies with the pump pulse duration $\tau_p$. We find that two well separated time scales characterize the system dynamics: a *short* time scale $\tau_{GVM}$, in the picoseconds range, corresponding to the typical temporal delay of co-propagating waves due to group-velocity mismatch, and a much longer time scale $\tau_{GVS}$ associated with the temporal separation of counter-propagating waves. We show that a high degree of separability can be achieved when the pump pulse duration satisfy the condition $\tau_{GVM} \ll \tau_p \ll \tau_{GVS}$, as illustrated by the behaviour of the Schmidt number which reaches a minimum close to unity in this region (see red dot in Fig.1c). The separability is lost when the pump pulse duration falls outside this interval, as shown in the long pump pulse example illustrated in Fig 1a, where the entanglement between the signal and idler frequencies can be inferred by the non factorable shape of the spectral biphoton amplitude. We offer a physical interpretation of such a behaviour, and a detailed analysis of the Schmidt number characterizing the entanglement of the state.

We also considered a completely different regime of operation, close to the MOPO threshold, where the combined effect of stimulated PDC and distributed feedback affects dramatically the property of coherence of the field. Our analysis put in evidence a progressive narrowing of both the spectral twin beam correlation and the intensity spectra as the pump field intensity approaches its threshold value. This translates into a drastic increase of the correlation and coherence times in the temporal domain, a feature which can be attributed to the critical slowing down of the fluctuation dynamics characterizing the transition toward coherent emission occurring at the MOPO threshold.

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