# Two-photons interferences in fiber interferometers

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*We present two experiments using photon pairs and fiber interferometers. The first one is the Hong-Ou-Mandel experiment highlighting the bosonic nature of photons through photon bunching. The photon pairs are created at 1556 nm by degenerate parametric fluorescence in a periodically poled silica fiber and sent to a balanced fiber interferometer thermally stabilized. At the interferometer output, we measured a dip in the coincidence rate with 40% visibility and 8,4 µm width. The second experiment involves an unbalanced fiber interferometer. Photon pairs where created using a PPLN waveguide and a two-photon interference was observed at the output of the interferometer.*

## Photon pair source based on periodically poled silica fibre (PPSF)

One of the photon pair sources we are using in this paper is based on the use of parametric fluorescence in a special kind of silica fibre. Indeed since silica glass presents a vanishing second-order nonlinearity owing to its centro-symmetric structure on a macroscopic scale, the technique of thermal poling has been applied to a twin-hole glass optical fiber in order to induce a permanent $\chi^{(2)}$, thereby enabling parametric second order non-linear optical processes[1-2]. The twin-hole fiber owes its name to a pair of holes running parallel to the core along the fiber length (Fig.1(a)). During the poling process a high voltage (~ 4 kV) is applied across the core thanks to two thin 25 mm-diameter wire electrodes that are inserted into the holes. Simultaneously the fiber is heated to 250°C. Under the action of the applied electric field, impurities ions, typically $Na^{+}$, drift away from the anode leaving behind a negatively charged region. Sudden cool down of the glass freezes the ions in their new position and an intense electric field (~ kV/ µm) is consequently frozen in the glass (Fig.1(a)). This electric field couples with the existing third-order nonlinearity to give an effective $\chi^{(2)}$ through the relationship $\chi^{(2)} = 3\,\chi^{(3)}E_{dc}$, where $E_{dc}$ is the frozen field induced by poling. A 8 cm long uniform $\chi^{(2)}$ nonlinear region was produced in this way . Quasi-phase matching for efficient growth of the parametric fluorescence power was implemented by periodic UV erasure of the uniform frozen-in field as described in [2]. More information about this fibre can be found in [3-4].

Using this fibre we were able to generate photon pairs around 1556 nm at a rate of 146 MHz using 43 mW of pump power. The photon pair's bandwidth was around 17 THz and the conversion efficiency around 1.2 $10^{-11}$ [4].

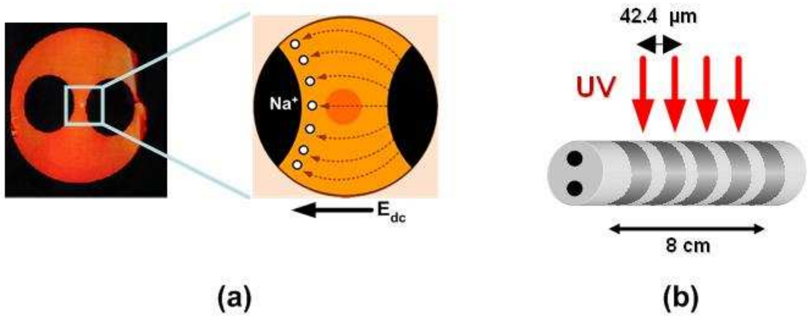


Fig.1: (a) Cross section image of a twin-hole silica fibre. The enlargement on the core region shows the drift of the Na+ ions as a result of the process of thermal poling. (b) UV erasure of the thermally poled silica fibre to achieve quasi-phase matching condition during parametric fluorescence.

## Hong-Ou-Mandel experiment

Using photon pairs produced in the periodically poled silica fiber as described above we performed the Hong-Ou-Mandel experiment [5] using an all-fiber Michelson interferometer (Fig.2).

As shown in Fig.2, photon pairs enter the interferometer via an optical circulator (C). The circulator sends the photon pairs on a 50/50 beam-splitter (BS1) (in practice a 3dB fibre coupler) where they can be separated. The photons then propagate towards Faraday mirrors (FM) placed at the end of each arm of the interferometer. After reflection, they come back to the beam-splitter (BS1). One arm is slightly longer, and introduces a total extra optical path $\Delta L$. If $\Delta L$ is set to zero the two photons that come back to the beam-splitter are indistinguishable, and they experience photon bunching [5]. As in the original Hong-Ou-Mandel experiment, detectors (APD) are put at the beam-splitter outputs, and the number of coincidences is measured as a function of the delay $\Delta L$. In our experiment the fiber in each arm was individually temperature controlled thanks to two Peltier modules powered by PID temperature controllers. Thus $\Delta L$ could be tuned using the fibre thermal expansion.

Fig3 shows coincidence measurements at the Michelson interferometer outputs (black dot) for 45 mW pump power measured at the output of the PPSF and a gaussian fit of the experimental data's (red curve). The coincidence rate is calculated over a 3 ns time window. The error on the coincidence number is due to the dark counts. Blue points show the accidental events. The theoretical curve (grey) shows one-photon interference fringes superposed on the dip with interfringe spacing related to the pump wavelength [4,6]. As our goal was to observe the Mandel dip and not the one photon interference we periodically induced a small variation on the delay $\Delta L$ with amplitude of approximately $\lambda_p/2$. As a result the fringes were averaged during acquisition time. This slight variation was achieved thanks to a ±0.01°C temperature variation of one arm induced every 30 s by a pattern generator.

With this averaging the coincidence rate shows a clear 8.4 µm dip as shown in Fig.3. As a consequence of the averaging the dip is slightly broader than the expected value (7.3 µm). When the noise is subtracted, the net visibility is 40%.

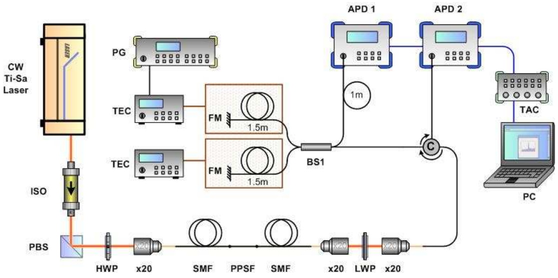


Fig.2: Experimental setup for the Hong-Ou-Mandel experiment : ISO, isolator; PBS, polarizing beam splitter; HWP, half-waveplate; X20, microscope objective; SMF, single mode fiber; PPSF, periodically poled silica fiber; LWP, long-wave pass filter; C, circulator; BS1, 50/50 beamsplitter; FM, Faraday mirror; APD, avalanche photodiode; TAC, time to amplitude converter; TEC, temperature controller; PG, pattern generator.

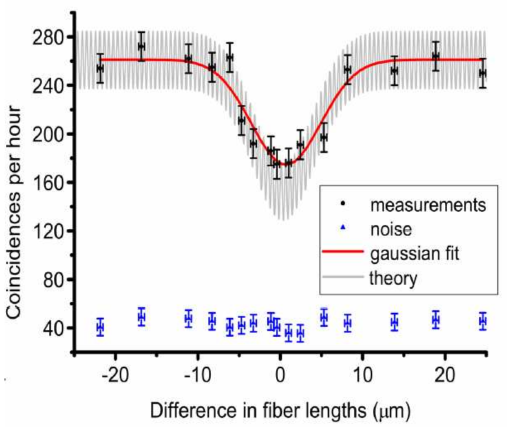


Fig.3: Coincidence rate at the output of the Michelson interferometer with respect to the difference in fibre length between the two arms of the interferometer. The coincidence rate shows a clear dip for simultaneous arrival of the photons on the beamsplitter.

## Two photon interference in an unbalanced interferometer

We performed another two photon interference experiment. As depicted in Fig.4 the photon pair source is this time based on a periodically poled lithium niobate waveguide [7]. Photon pairs are filtrated from the pump using fiber wavelength demultiplexers (CWDM) and sent to the same kind of interferometer as for the Hong-Ou-Mandel experiment. However this time we use an unbalanced Michelson interferometer ($\Delta L \approx 60$ cm) that was still put in an insulated box where temperature was kept constant within 0.01°C. Another temperature controller allows us to heat a short portion of fibre inside the interferometer and thus vary $\Delta L$.

In this set-up the possibility that both photons of the pair travel along the short arm of the interferometer interfere with the possibility that both photons travels along the long arm [8]. This results in interference fringes in the coincidence rate at the output of the interferometer when $\Delta L$ is being varied.

Fig.5 represents the coincidence rate at the output of our interferometer with respect to the phase difference between the two arms of the interferometer. We clearly see two sets of interference fringes. Actually our pump laser seems to switch between two discrete wavelengths separated by 1 pm. The phase difference in the interferometer is related to ΔL of course but also to the pump wavelength that's why having two discrete pump wavelengths results in two distinct oscillations in the coincidence rate. The phase shift between the two oscillations can be calculated as $\delta_\phi = \frac{2\pi\delta_\lambda \Delta L}{\lambda^2} \sim \frac{8\pi}{9}$ with $\delta_\lambda$ = 1 pm and $\Delta L$ = 60 cm which corresponds to the observed phase shift in Fig.5.

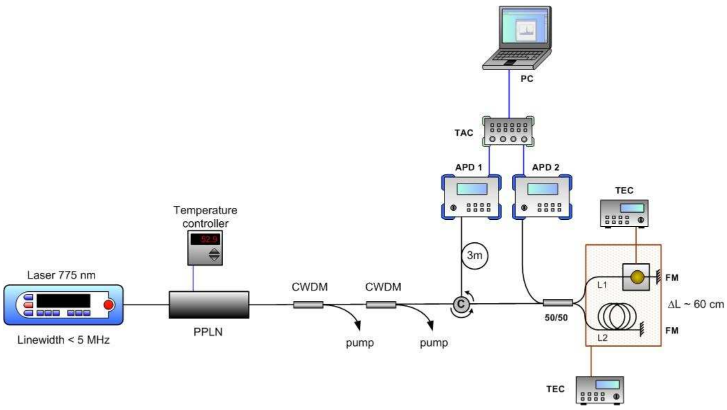


Fig.4: Experiment setup leading to two photon interferences in an unbalanced Michelson interferometer. See Fig.2 for components enumeration.

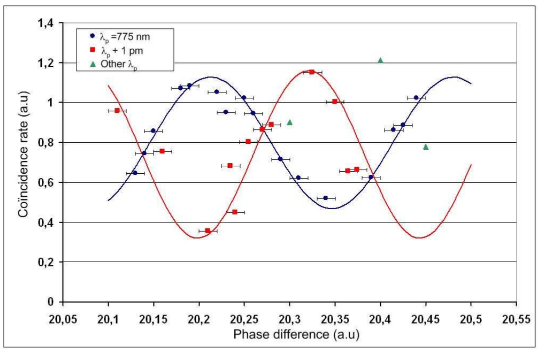


Fig.5: Two photon interferences at the output of the unbalanced interferometer. The two curves are due to two discrete pump wavelengths used in our photon pair source and separated by 1 pm.

The authors acknowledge the support of the Fonds pour la formation `a la Recherche dans l'Industrie et dans l'Agriculture (FRIA, Belgium), of the Interuniversity Attraction Pole program of the Belgian government under Grant IAP6-10 and of the EU project QAP contact number 015848.

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