We report the observation of interference in position and transverse momentum variables between two parallel-propagating gaussian beams separated by an arbitrary distance [1]. This resembles the Alford and Gold effect that has been reported for the time-frequency degree of freedom [2], and constitutes a method for spatial intensity shaping of light beams. We observe this interference by using a tunable beam displacer [1], which plays the role of a Michelson interferometer for the transverse spatial variables. We propose this method for engineering environments in the study of dynamics of open quantum systems, in particular, generation of Markovian and non-Markovian dynamics [3].

Motivation

We introduce a Tunable Beam Displacer to change arbitrarily the transverse distance between two parallel-propagating beams.

![Figure 1: (a) Tunable Beam Displacer Sketch (TBD), with a controllable separation of 2d. (b) Experimental setup of a physical realization of a TBD [1].](image)

Experimental setup

The experimental setup in Fig. 2 was implemented using:

- A CW laser that produces a Gaussian beam with $w_0 = 0.87$m.
- Tunable Beam Displacer
- A 50-50 beam splitter, to measure position and momentum distributions simultaneously.
- A power meter, for measuring the position interference.
- A 2f-system, with $f=75$cm, to generate the transverse momentum distribution.
- A CCD camera, to register the positions of the beam in the momentum variables.

![Figure 2: Experimental setup with measurement and tunability of separation.](image)

Interference in Position

Following the setup of Fig. 2, we set an incoming gaussian beam:

$$E_i(y) = E_0 \exp \left( -\frac{y^2}{w_0^2} \right) \exp \left( iq_0y \right).$$  \hspace{1cm} (1)

where

- $w_0$ is the beam waist.
- $q_0$ will be determined from our measurements.

The output electric field is

$$E_{out}(y, d) \propto E_i(y - d) + e^{i\phi}E_i(y + d).$$  \hspace{1cm} (2)

After the TBD, the intensity will be

$$I_{out}(d) = \left| \frac{E_0^2}{2} \right|^2 \left( 1 + \exp \left( -\frac{2d^2}{w_0^2} \right) \cos(2q_0d + \phi) \right).$$  \hspace{1cm} (3)

Eq. (3) shows interference in position modulated by $d$.

Interference in Transverse momentum

The interference in the conjugate variable is obtained by taking the Fourier transform of $E_{out}(y, d)$. The intensity $S_{out}(q, d)$ in the Fourier plane yields:

$$S_{out}(q, d) \propto \exp \left[ -\frac{w_0^2 (q - q_0)^2}{2} \right] \left[ 1 + \cos(2q_0d + \phi) \right].$$  \hspace{1cm} (4)

We see:

- There is a modulation of the intensity in the Fourier plane, which is given by the cosine term.
- If $d = 0$ and $\phi = \pi$, the spectral intensity will vanish.
- As $d$ becomes larger than $w_0$, there will appear a set of oscillations within the Gaussian envelope.

Experimental results

![Figure 3: Experimental results (circles) of two-beam interference in position (a,b) and momentum (c,d,e) variables. Insets in (c), (d), (e) correspond to the images recorded in the CCD camera](image)

- Interferences are seen in Fig. 3(a), but not in (b), when the two beams do not overlap in position.
- In the Fourier plane, the intensity modulation appears when $d > w_0$, as can be seen in Fig. 3(e), but not in Fig. 3(c), where $d < w_0$. These results show a modulation in the transverse momentum distribution.
- Environments like in Fig. 3 (d,e) are used in Poster QT6A.32 to explore the transition between Markovian and non–Markovian quantum dynamics.

Conclusions

- We report the interference of light in its spatial degree of freedom for an arbitrary, tunable separation of two beams.
- We introduce a method for the spatial intensity shaping of laser beams, which permit environment engineering for Open Quantum Systems.

References