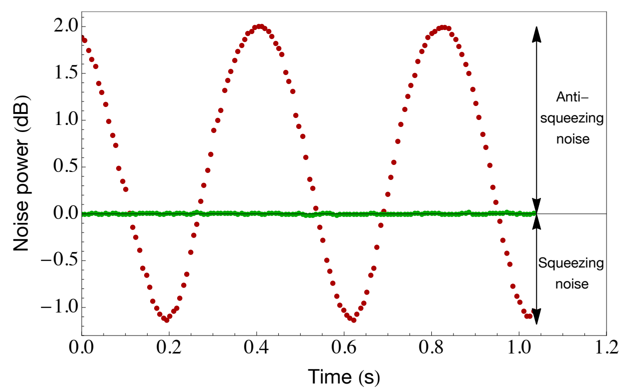
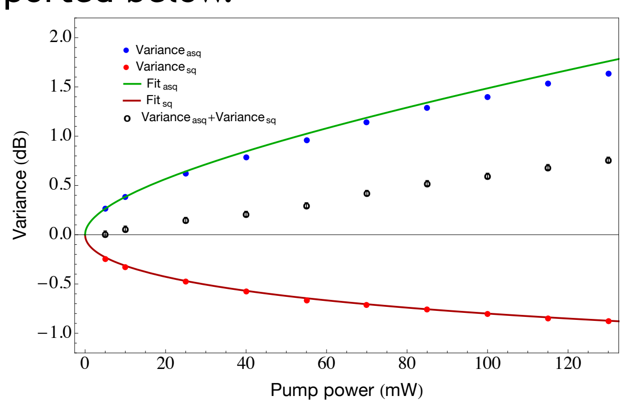
vacuum state has thus been generated. The squeezed signal is analyzed by means of the *homodyne detection*, that is a detection technique in which the signal to analyze is mixed on a 50:50 beam-splitter with a strong coherent field called *local oscillator* (LO) at 786 nm. Then, the difference between the photocurrents induced on two photodetectors placed along the output paths of the beam-splitter is measured. From this measure, it is demonstrated that we can directly measure the quadratures of the signal to analyze. Scanning over the LO phase, we observe an amplification/de-amplification (anti-squeezing - *asq* - or squeezing - *sq* -, respectively) of the generated signal noise with respect to the vacuum noise (*shot noise*), as shown in the following figure. The green line is the shot noise, whereas the red curve is the amplified or de-amplified squeezed signal noise.



The variance versus the pump power is reported below.

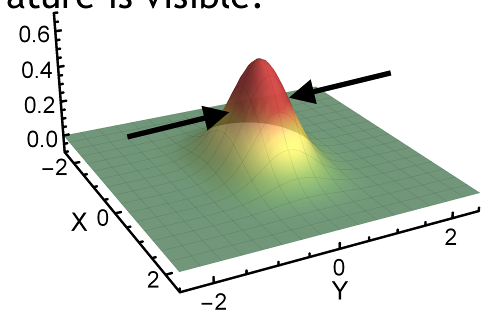


The blue and red dots are the maximum and minimum variances with respect to the shot noise. The sum between them should be equal to zero, but a deviation is observed. This fact is included in what we call *overall detection efficiency* η, and thus we fit with the model

$$S_m^{\{asq,sq\}} = \eta\,[e^{\pm 2\cdot 1.4\sqrt{P}}\,0.44 + (1-0.44)] + (1-\eta)$$

with S_m the measured variance. From the fit we find $\eta = 0.65 \pm 0.01$, in good agreement with the expected value. The best obtained squeezing value is (-1.13 ± 0.01) dB.

Moreover, the Wigner function for the generated squeezed vacuum state has been reconstructed by means of the so-called *quantum tomography*. The Wigner function is shown in the following figure. The squeezing along the Y quadrature is visible.



Conclusion

The property of having a reduced noise along one quadrature makes squeezed states useful in many quantum information protocols. The generated squeezed states will form a basis for advanced quantum state engineering for fundamental research and applications.

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Generation of squeezed states by single-pass optical parametric amplification

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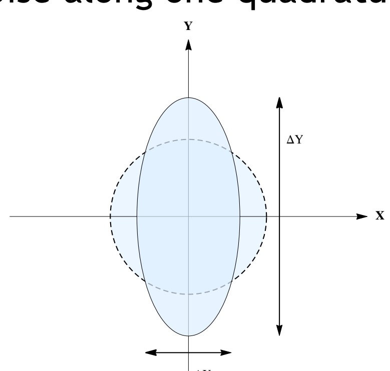
Introduction

Quantum mechanics is one of the most interesting and successful theory in physics. One interesting aspect is represented by the generation and manipulation of *non-classical states* of light, that are states showing purely quantum-mechanical properties. Examples of non-classical states are *squeezed states*, whose fluctuations along one quadrature of the light field are lower than those of the vacuum, with a consequent increase of fluctuations along the other quadrature. The dashed circle in the following figure is the uncertainty area associated to the vacuum state, where the fluctuations are the same for both the *X* and *Y* quadratures, whereas the solid ellipse represents the uncertainty area associated to a *squeezed* vacuum state. It is clearly visible that the fluctuations are not the same for both the quadratures, so squeezed states have reduced noise along one quadrature.



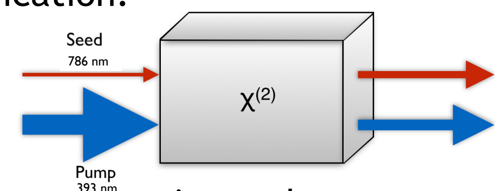
This work aims to generate squeezed states of light in a single-pass configuration - i.e. without any needs of optical cavities - and in a pulsed regime - i.e. by using pulsed laser light - by means of the so-called *optical parametric amplification* process.

Optical parametric amplification

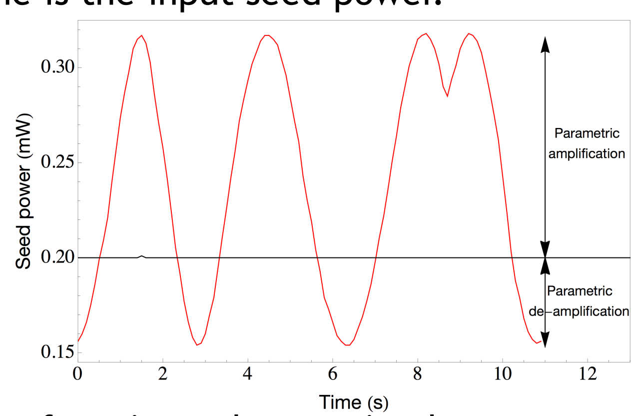
Optical parametric amplification (OPA) is a non-linear process that takes place in non-linear crystals. We here characterize this process by taking into account classical and quantum approaches.

- Classical characterization

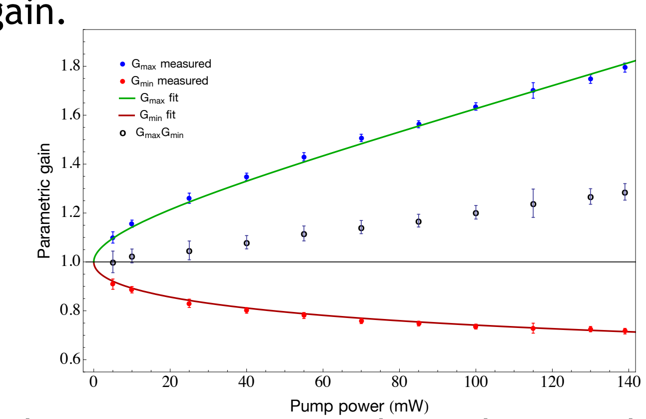
When injecting two beams called *pump* and *seed*, at frequencies 2ω and ω respectively, into a non-linear crystal, the output seed results amplified or de-amplified with respect to the input seed, depending on the relative phase between pump and seed. By way of illustration, the figure below shows the seed amplification.



Sending a triangular ramp to a piezoelectric stage placed along the pump path, thus scanning the pump phase, the output seed power results amplified or de-amplified, as shown in the figure below (red curve). The black line is the input seed power.



Performing the ratio between the maximum/minimum seed power and the input seed power, we obtain the maximum/minimum parametric gain. In the following figure, maximum and minimum gain versus pump power are reported (red and blue dots, respectively). The temperature of the crystal is varied point by point, in order to maximize the maximum and minimum gain.



What we note is that the product between the maximum and minimum gain is not 1, as expected in the ideal case. This is explained with a simple model taking into account other effects, for example thermal effects, not included in the theory we use to explain the measured data.
Fitting the data with

$$G_{\{max,min\}} = \varepsilon e^{\pm 2r} + (1-\varepsilon)$$

where $r \equiv \gamma\sqrt{p}$, with γ certain constant dependent from the experimental parameters, p is the pump power, and ε is a parameter which accounts for the deviation from 1. From the fit, we find

$\varepsilon = 0.44 \pm 0.01$,

$\gamma = (1.40 \pm 0.02)\ \mathrm{W}^{-1/2}$.

The value of γ is in good agreement with that estimated by using the experimental parameters.

- Quantum characterization

To explain this approach, we have to take into account that the OPA takes place not only for field amplitudes but also for quantum uncertainties. Keeping this in mind, when only the pump is injected into the crystal, i.e. the seed is taken from the vacuum, the OPA results in a compression/de-compression of the uncertainty circle associated to the vacuum state. By definition, a squeezed