Mid-Infrared balanced detector for quantum light characterization

Tecla Gabbrielli[a] *,Francesco Cappelli[a], Natalia Bruno[a], Nicola Corrias[a], Simone Borri[a], Paolo De Natale[a], and Alessandro Zavatta[a]

[a] European Laboratory for Non-linear Spectroscopy (LENS), Via nello Carrara 1, 50019 Sesto Fiorentino, Florence, Italy & Istituto Nazionale di Ottica (CNR-INO), Largo Enrico Fermi 6, 50125 Florence, Italy

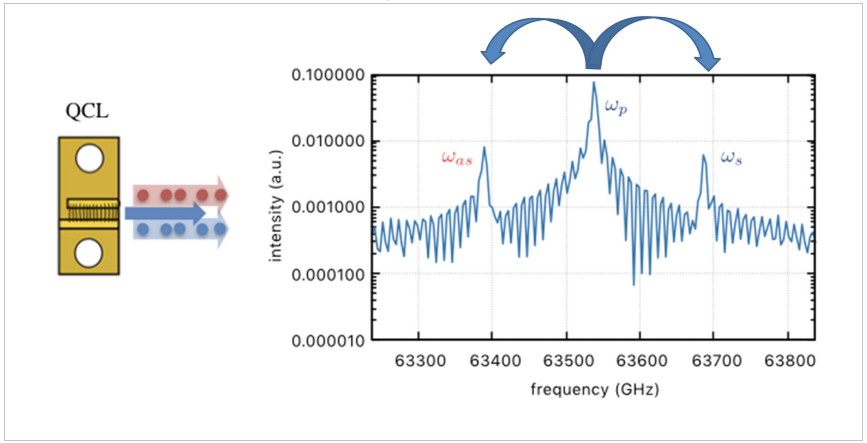
*gabbrielli@lens.unifi.it

ABSTRACT

We present a novel shot-noise-limited mid-infrared balanced detector suitable for revealing non-classicality in the light emitted by Quantum Cascade Lasers (QCLs). QCLs are promising emitters of non-classical light states due to the presence of a non-linear parametric process of photon generation in their active medium. Their non-classical properties have not been demonstrated yet. In this scenario, our detector is the first step in this experimental investigation.

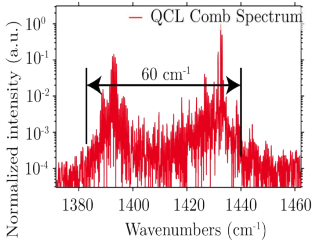
Four-Wave Mixing in Quantum Cascade Lasers

QCL $\chi^{(3)}$ ⇨ Four-Wave Mixing (FWM)



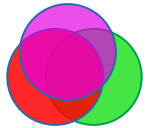
Frequency Comb

J. Faist et al, Nanophotonics **5**, 272–291 (2016)

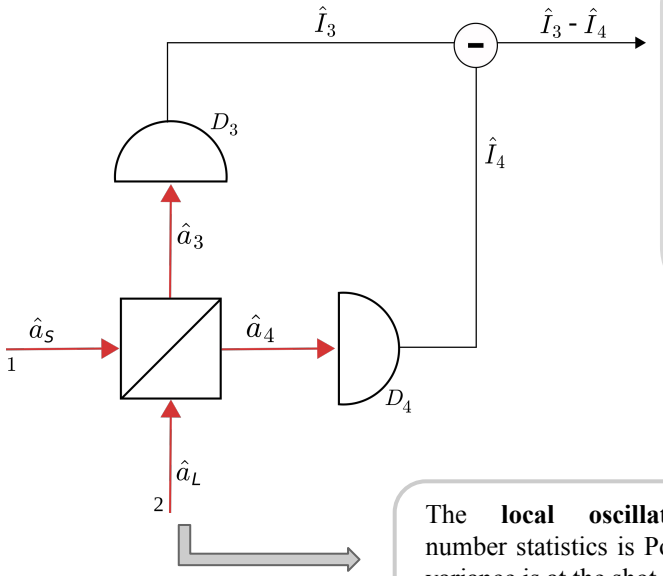


?

Squeezing & color entanglement



Balanced homodyne detection



In the linear responsivity regime:

$$\int_0^T (\hat{I}_3 - \hat{I}_4)\,\mathrm{dt} \propto \hat{n}_3 - \hat{n}_4 = \hat{n}_{34}$$

And for a high intensity local oscillator:

$$\hat{n}_{34} \propto \hat{E} \qquad \Delta^2 n_{34} \propto \Delta^2 E$$

The **local oscillator** photon number statistics is Poissonian. Its variance is at the shot-noise level:

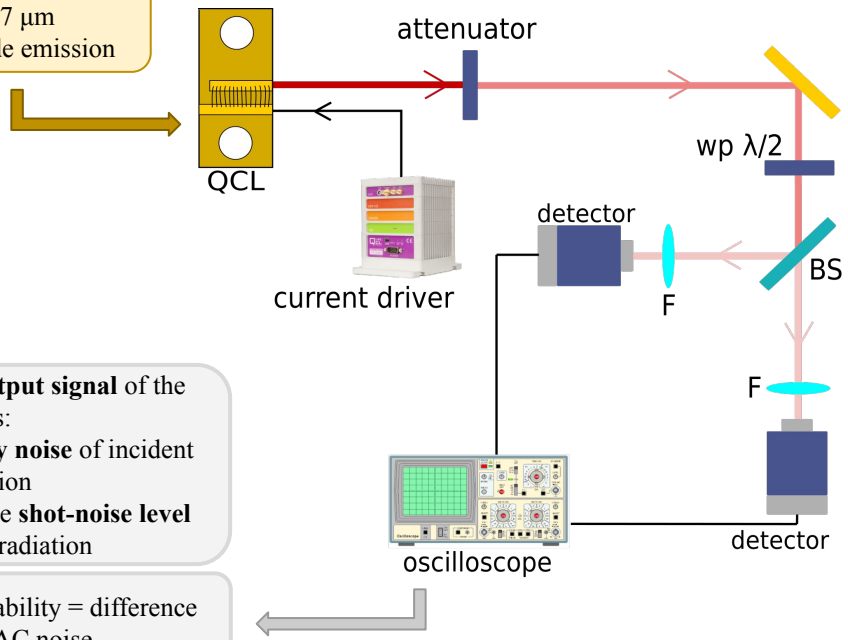
$$\Delta^2 N \propto N$$

With this technique it is possible to **test** a **radiation at the quantum level**.

We have to build up a **balanced detector** and test its ability in reaching the **shot-noise level** of the incident radiation

Mid-infrared balanced detector

Local oscillator:
$\lambda = 4.7\ \mu m$
Single-mode emission

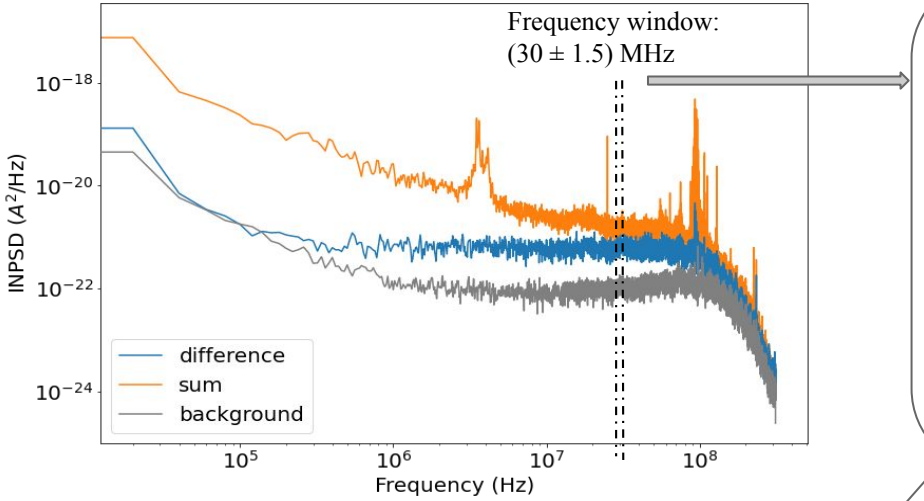


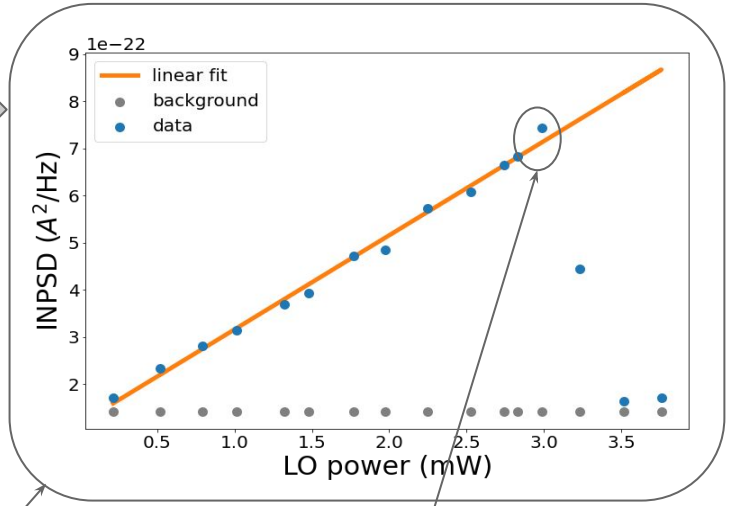
We have acquired the **AC output signal** of the two detectors:

1. The **sum** ⇒ **intensity noise** of incident radiation
2. The **difference** ⇒ the **shot-noise level** of incident radiation

The **limit** of shot-noise detectability = difference of the **background** AC noise

Data analysis and results



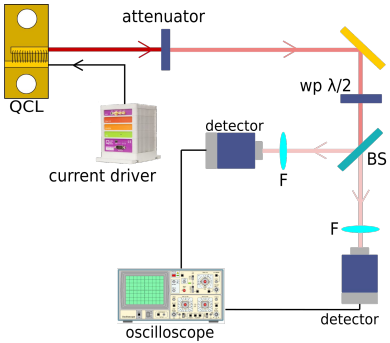


The detector is shot-noise limited:
The differential noise (INPSD) ∝ incident power

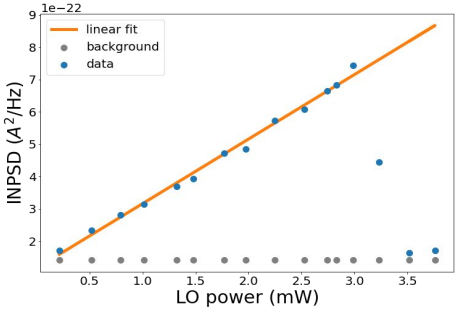
Maximum ratio between data and background noise

Conclusion

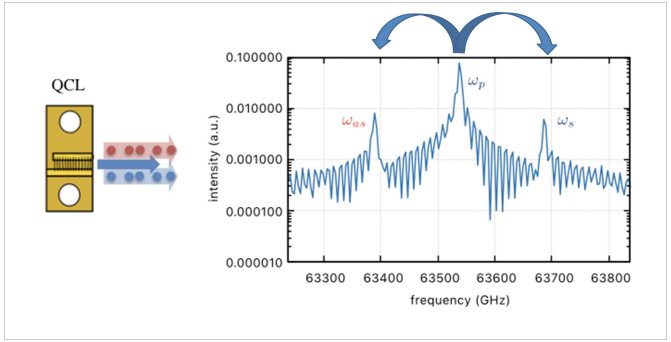
1. We built up a mid-infrared balanced detector



2. We proved that it can reach the shot-noise level



3. With our detector we will test quantum cascade lasers emission at the quantum level



ACKNOWLEDGMENTS

The authors acknowledge financial support from the European Union's Horizon 2020 research and innovation programme - Qombs Project, FET Flagship on Quantum Technologies grant no. 820419.