A light source for quantum-enhanced single molecule detection schemes using whispering gallery modes

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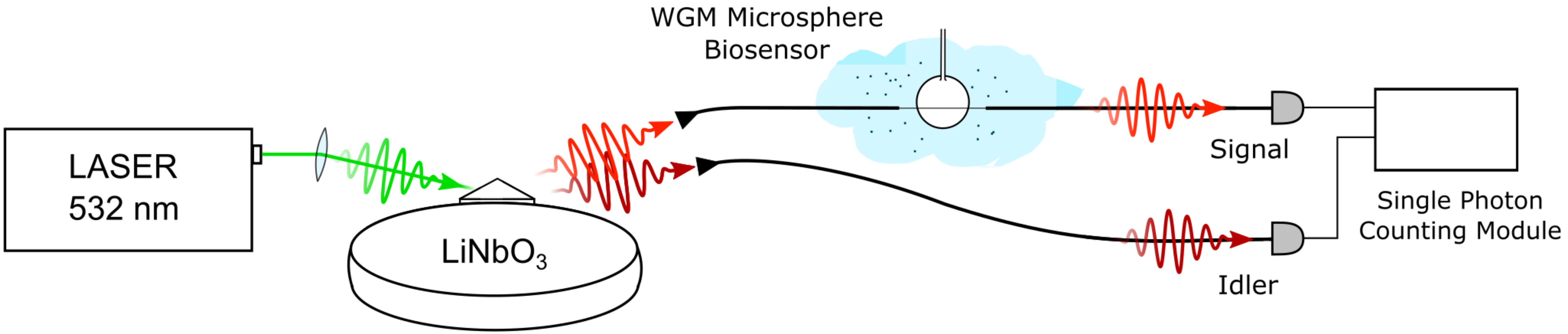


1. Introduction

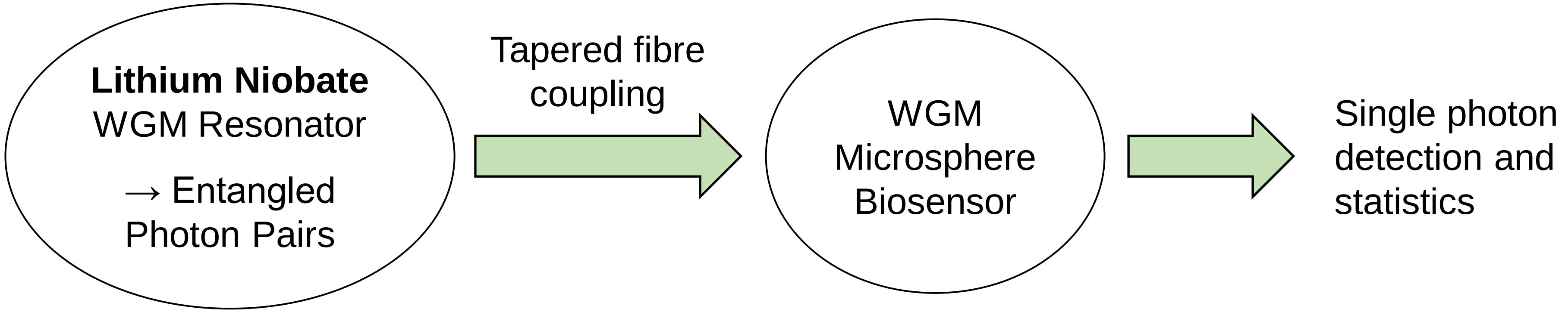
Motivation:

Quantum optical states of light including **entangled photon pairs** and **squeezed light** have allowed enhanced precision in several biosensing experiments, e.g. refractive index sensing [1] and particle tracking [2].

We aim to extend the use of quantum optical probe states to probe **whispering gallery mode (WGM) biosensors**, which have become a versatile platform for many single molecule experiments [3,4].

Requirements:

- Stable source of entangled photon pairs
- Wavelength tunability
- Narrow spectral width
- Low optical losses



[1] A. Crespi et al. Applied Physics Letters 100, 233704 (2012)
[2] M. A. Taylor et al. Nature Photonics 7 (2013)
[3] S. Subramanian et al. Advanced Materials 30, 1801246 (2018)
[4] J. Xavier et al. Nanophotonics, NANOPH-2020-0593 (2020, In review)

2. Experimental Setup

Lithium Niobate disk resonators have been demonstrated as robust, highly tuneable sources of entangled photon pairs using **Type-I Spontaneous Parametric Down-Conversion (SPDC)**; a second order nonlinear process [5].

[5] M. Förtsch et al. Nature Communications 4, 1818 (2013)

Efficient SPDC occurs for WGMs satisfying phase matching conditions:

$$n_p^e \omega_p = n_s^o \omega_s + n_i^o \omega_i$$

Energy conservation

$$\vec{J}_p = \vec{J}_s + \vec{J}_i$$

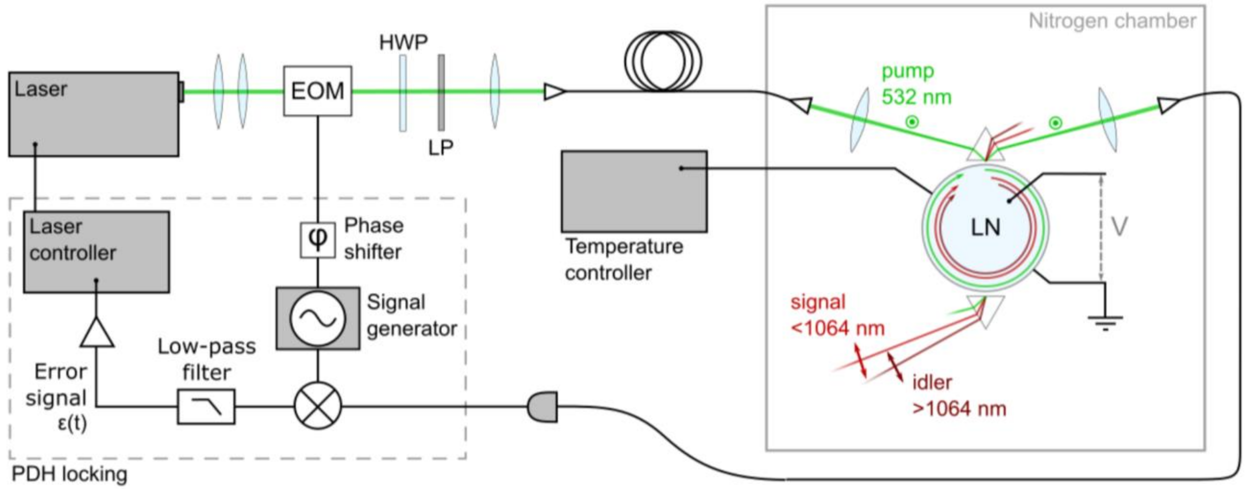
Angular momentum conservation

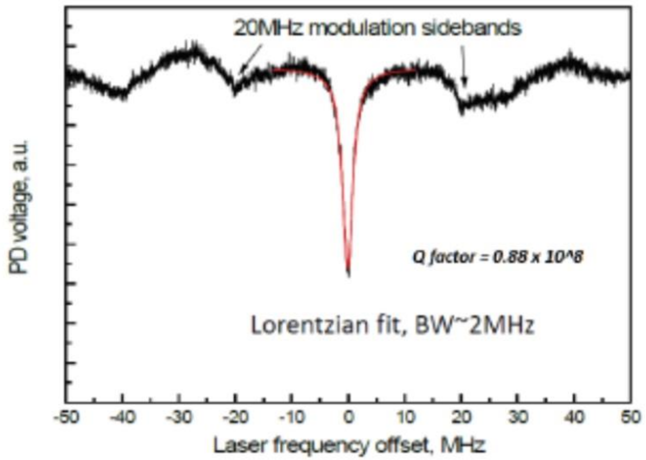
Pump (p): TE mode; polarised along extraordinary axis (z axis)

Signal, idler (s, i): TM modes polarised along ordinary axis (in plane)

Signal, idler wavelengths tuned by:

- **Crystal temperature**; coarse tuning in discrete steps
- **Voltage**; fine, continuous tuning



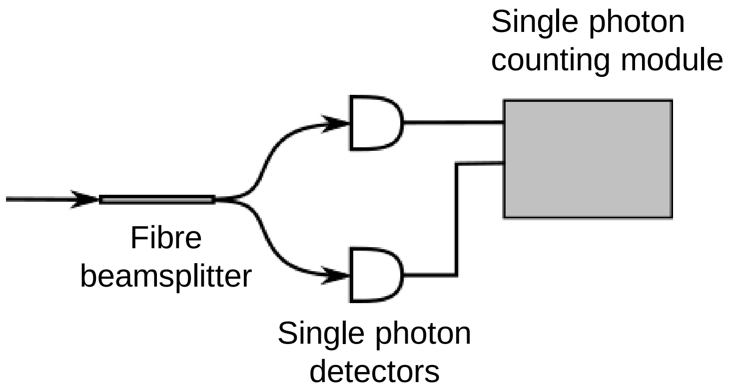


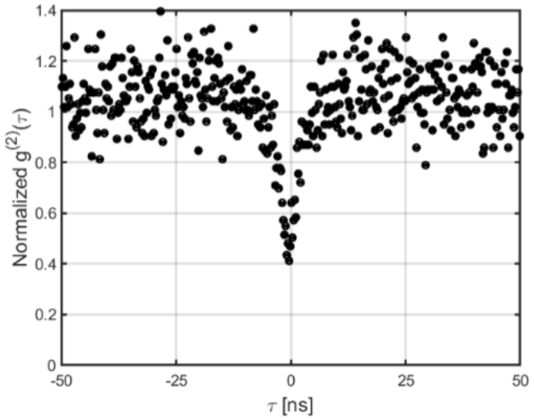
Setup developed by Dr Jolly Xavier in LSI for SPDC in lithium niobate (LN) disk WGM resonator

3. Characterising Heralded Single Photons

Detecting coincidences between signal and idler photons allows the signal photons to be post-selected and used as **heralded single photons**.

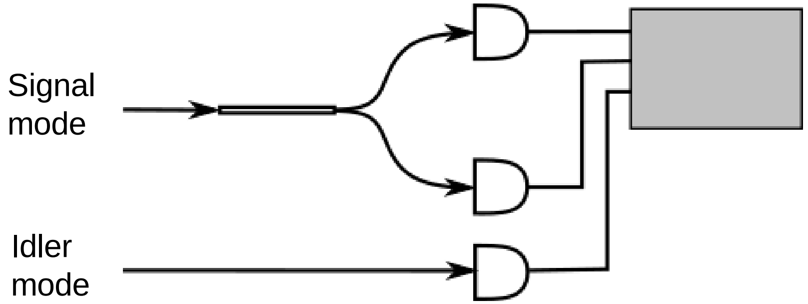
Hanbury Brown and Twiss (HBT) Measurement





Example $g^{(2)}$ function measured on a hexagonal boron nitride (hBN) quantum emitter in our lab

HBT on Heralded Single Photons



Record triple coincidence events as a function of delay between signal detections τ

Second-order correlation function ≡ histogram of delay time between detections τ

$$g_{si}^{(2)}(\tau) = \frac{\langle N_s(0) N_i(\tau)\rangle}{\langle N_s(0)\rangle\langle N_i(\tau)\rangle}$$

Indication of antibunched single photon emission:

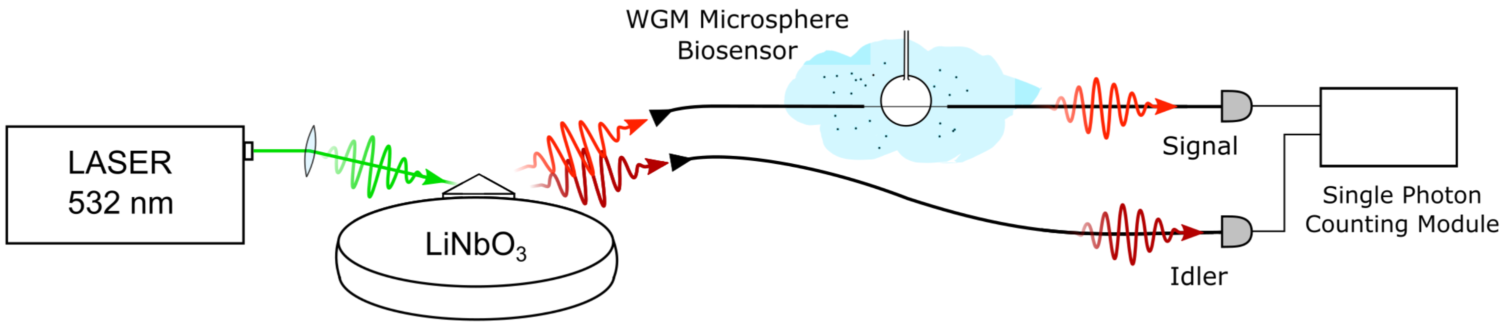
$$g^{(2)}(0) < 0.5$$

4. Biosensing Method

Heralded single photons generated in lithium niobate **coupled to a WGM microsphere**

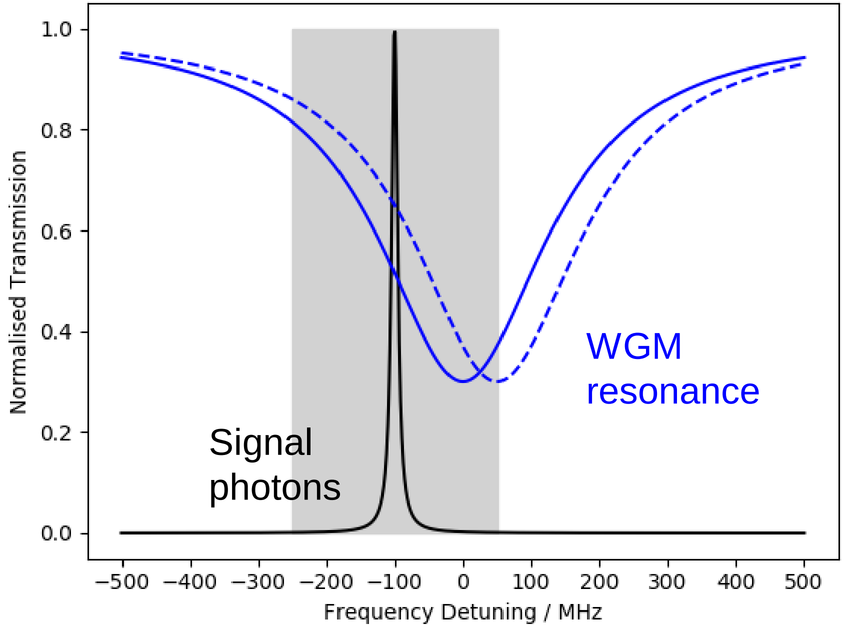
Wavelength tuned with combination of **temperature and voltage tuning**

High efficiency **tapered fibre coupling** to minimise optical losses



Schematic of sensing scheme

Local **refractive index** change	➞	**WGM resonance** shift	➞	Signal photon **transmission**	➞	**Coincidence count rate** change



Estimated photon bandwidth (black) and tuning range (grey) compared to WGM resonance (blue).

Based on literature values [5,6]:

Signal mode bandwidth ~10 MHz
Voltage tuning range ~300 MHz

Assumed WGM wavelength 980 nm; Q factor 10^6

[5] M. Förtsch et al. Nature Communications 4, 1818 (2013)
[6] G. Schunk et al. Journal of Modern Optics 63, 20 (2016)

5. Summary

Source of **entangled photon pairs**: a lithium niobate disk resonator supporting Type-I spontaneous parametric down-conversion

Key qualities of the source:
- Wavelength tunability
- Narrow spectral width
- Stable count rate

We propose to couple heralded single photons to a whispering gallery mode microsphere biosensor

Potential for **quantum-enhanced precision** in non-invasive biosensing with low probe power

Working towards **probing single molecules** with heralded **single photons**

References:

[1] A. Crespi et al. Applied Physics Letters 100, 233704 (2012)

[2] M. A. Taylor et al. Nature Photonics 7 (2013)

[3] S. Subramanian et al. Advanced Materials 30, 1801246 (2018)

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