IEEE/CSC & ESAS SUPERCONDUCTIVITY NEWS FORUM (global edition), October 2014 (Preview 1).
ASC 2014 presentation and paper 1EOr1B-05; 3rd Prize in Best Student Paper

ASC 2014, Charlotte, North Carolina, USA

Singlet oxygen luminescence detection with a fiber-coupled superconducting nanowire

Nathan Gemmell

Heriot-Watt University

Aongus McCarthy, Baochang Liu, Mike Tanner, Val Zwiller, Sander Dorenbos, Mike Patterson, Gerald Buller, Brian Wilson, Robert Hadfield

Collaborators

University of Glasgow, McMaster University, Heriot Watt University, University of Toronto, TU Delft

Sponsors

EPSRC, The Royal Society, SUPA, University Health Network — Achieving Global Impact

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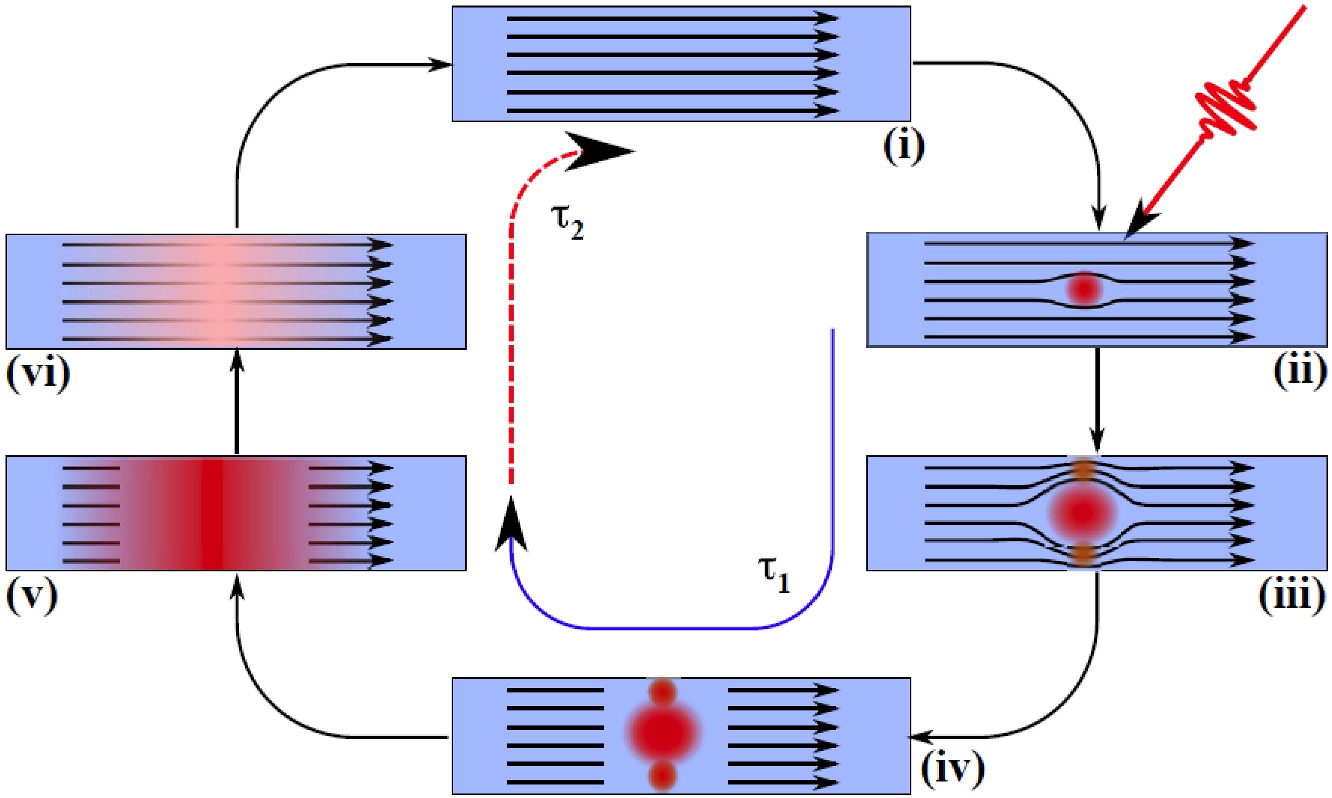
Superconducting Nanowire Single-Photon Detectors



G. N. Gol'tsman *et al*, *Applied Physics Letters* **79**, 705 (2001)

C. M. Natarajan, M. G. Tanner, and R. H. Hadfield 2012 *Superconductor Science and Technology* 25 063001

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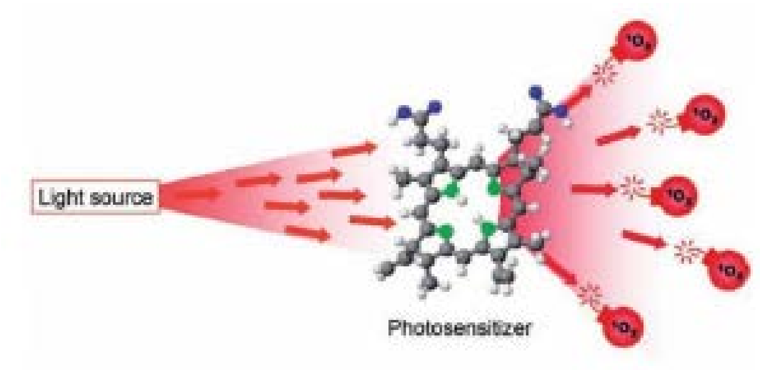
Photodynamic therapy in the treatment of cancer



PDT treatment:

- A photosensitzer drug is introduced into the cancerous tissue
- Targeted illumination releases $^1O_2$
- $^1O_2$ kills the tumor

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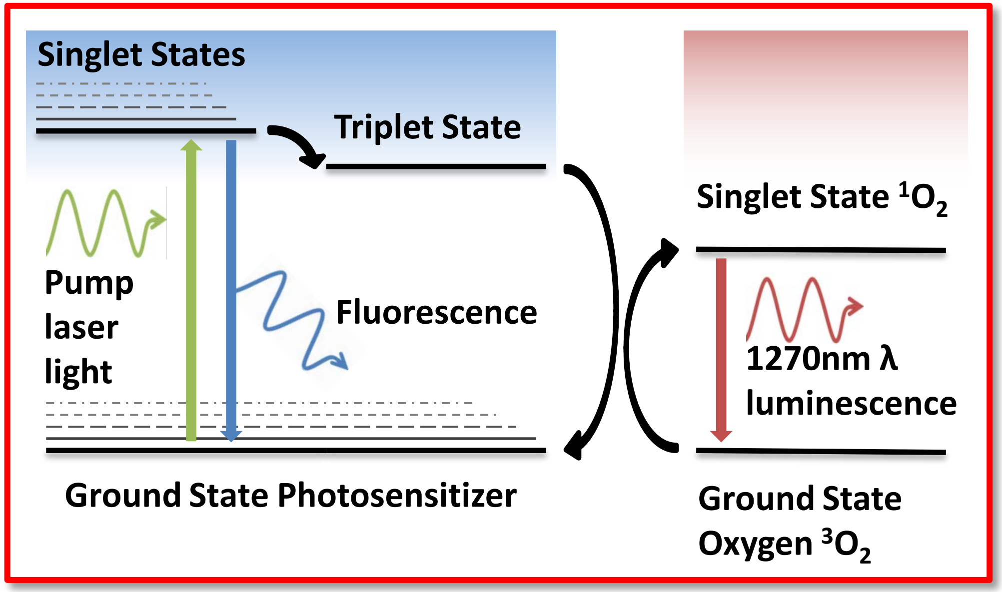
Photodynamic therapy in the treatment of cancer



Detection of a single photon at 1270 nm wavelength allows **direct monitoring** of the realise of $^1O_2$ – a powerful dosimetry technique for **photodynamic therapy in the treatment of cancer.**

Jarvi *et al.* Photochem & Photobiol. **82** 1198 (2006)

- The lowest excited state of the oxygen molecule ($^1\Delta_g$), is commonly referred to as **Singlet Oxygen** ($^1O_2$).
- Singlet oxygen lies at the heart of many biological and physiological processes – and hence has a wealth of potential applications.

  Ogilby Chemical Society Reviews **39** 3181 (2010)
- A direct signature of $^1O_2$ is the emission of a **single photon** at 1270 nm wavelength.

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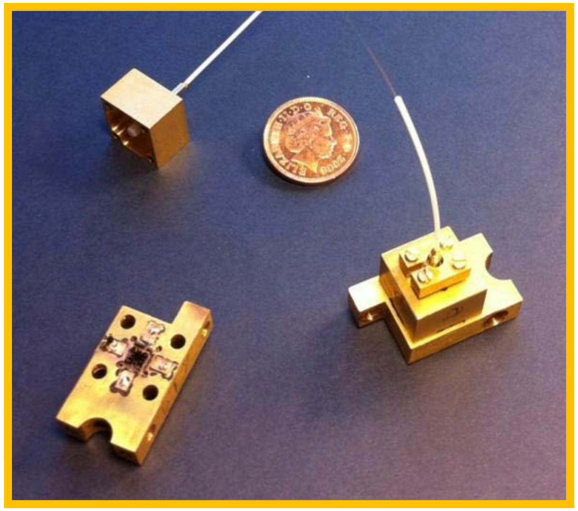
Comparison of detectors for singlet oxygen luminescence detection

	IR Photomultiplier	SNSPD
Study	Niedre *et al.* Photochem & Photobiol. **75** 382 (2002)	Gemmell *et al.* Optics Express **21** 5005 (2013)
Operating Temp.	200 K	3 K
Detection Efficiency	1 % @1300 nm	30% @1310 nm
Dark Count Rate	16 kHz	1 kHz
Active Area (mm^2)	24	1×10^{-4}
Optical Coupling	Free Space	Single Mode Fiber



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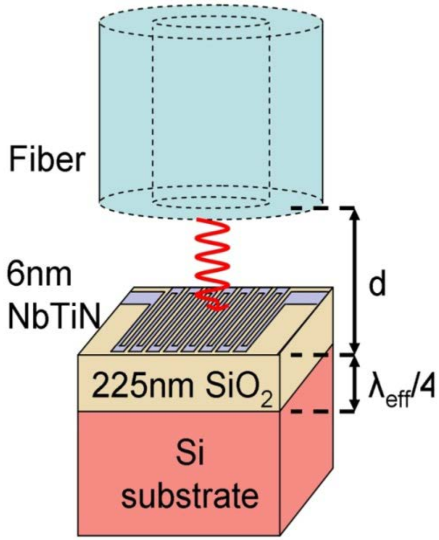
Underpinning capability: superconducting nanowire single-photon detectors

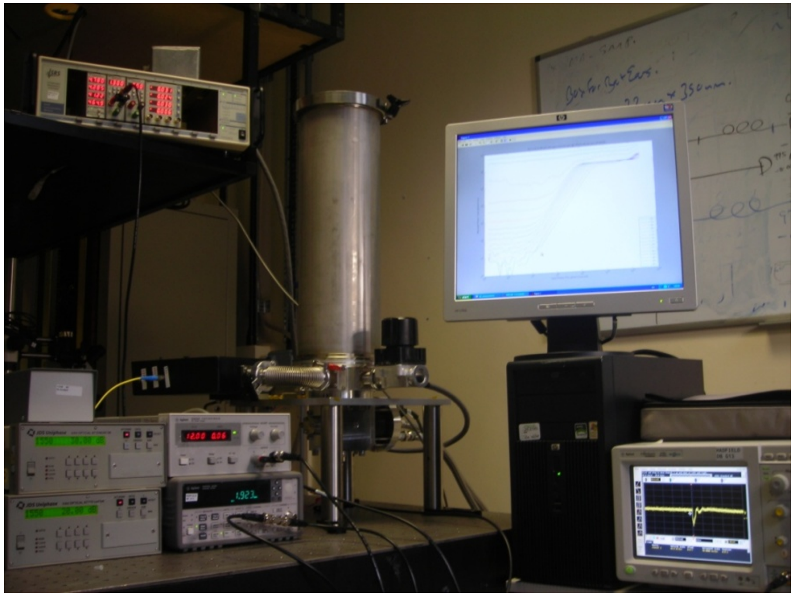
- Superconducting nanowire single-photon detectors (SNSPDs) are an important emerging infrared single photon detector technology.

  Natarajan *et al* Superconductor Science & Technology **25** 063001 (2012) – **Open Access**
- High efficiency superconducting nanowire single photon detectors (SNSPDs) from TU Delft

  Tanner *et al* Applied Physics Letters **96** 221109 (2010)
- 4 or more fiber-coupled SNSPDs can be placed in a closed-cycle refrigerator system

  Hadfield *et al* Optics Express **13** (26) 10864 (2005)





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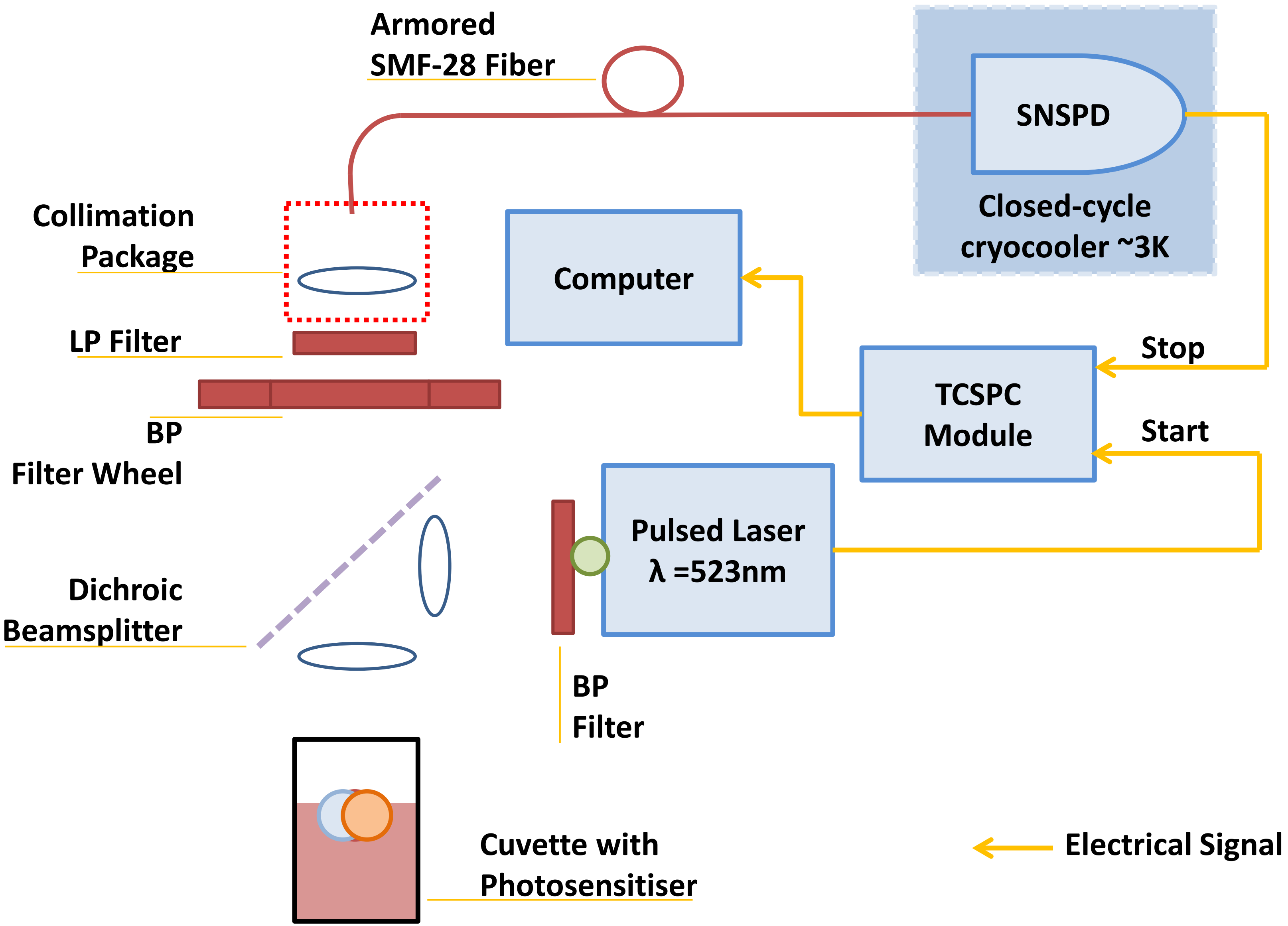
Singlet oxygen luminescence detection: free space optical setup



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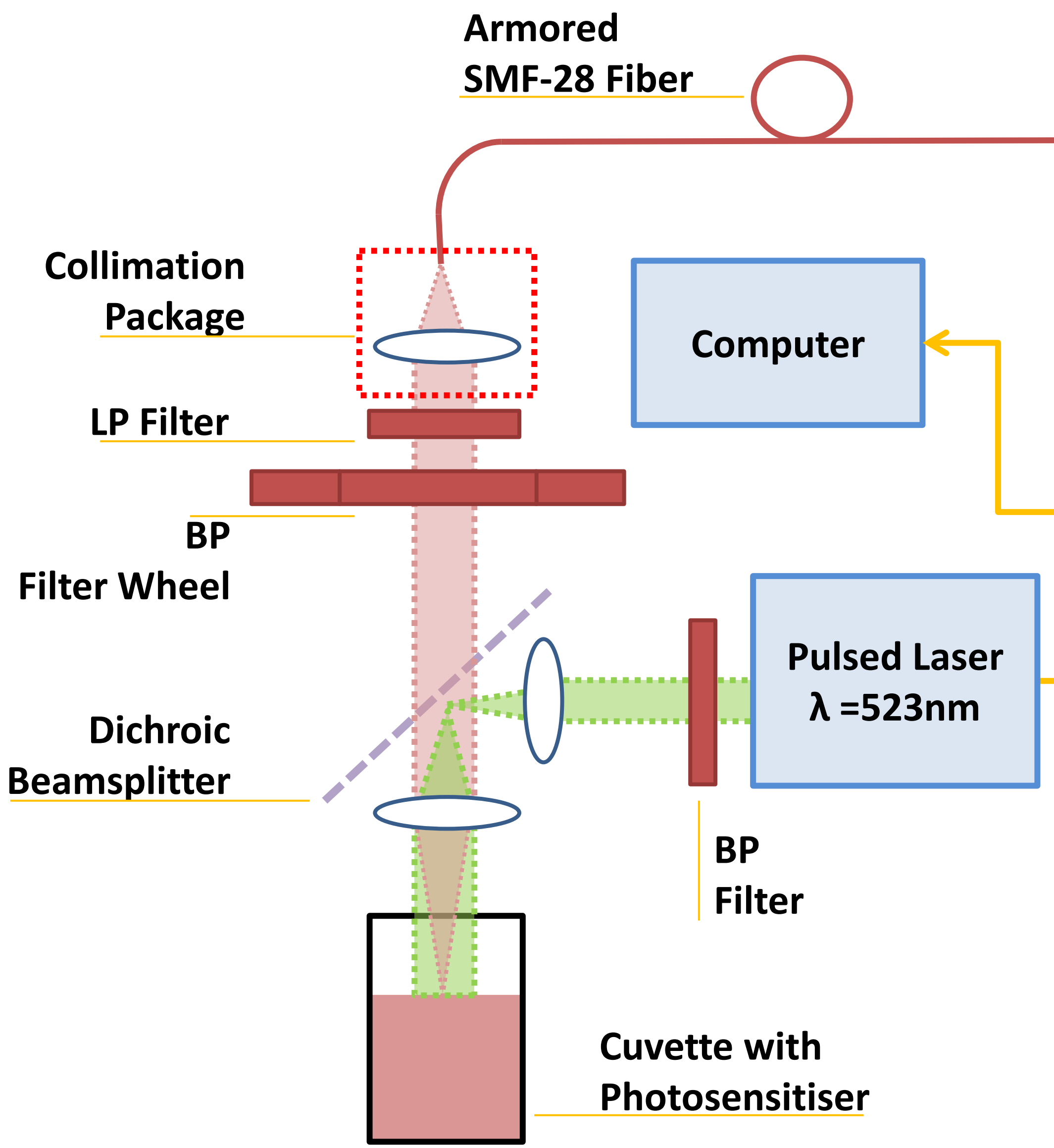
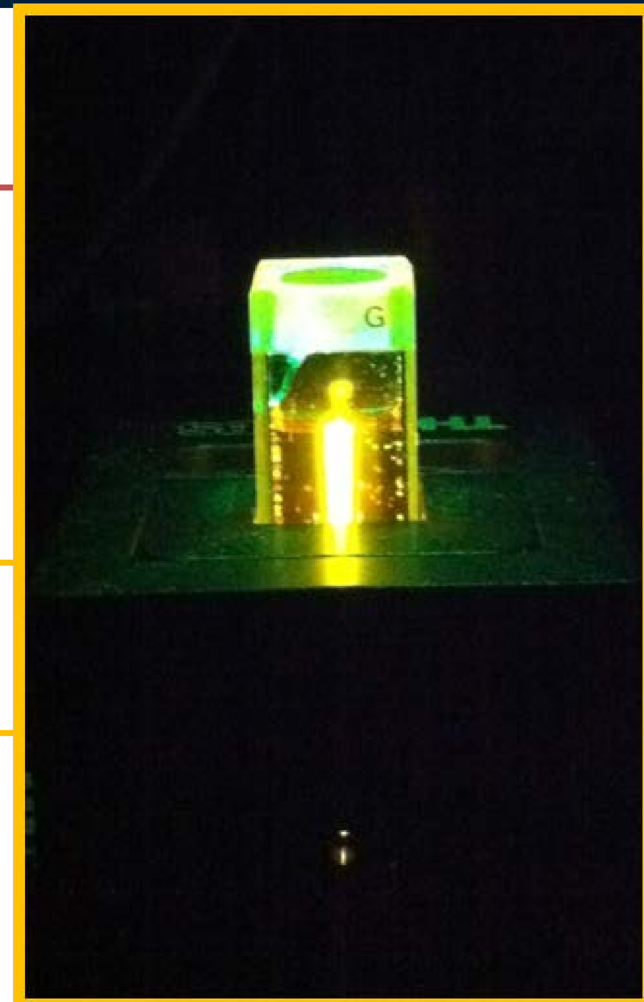
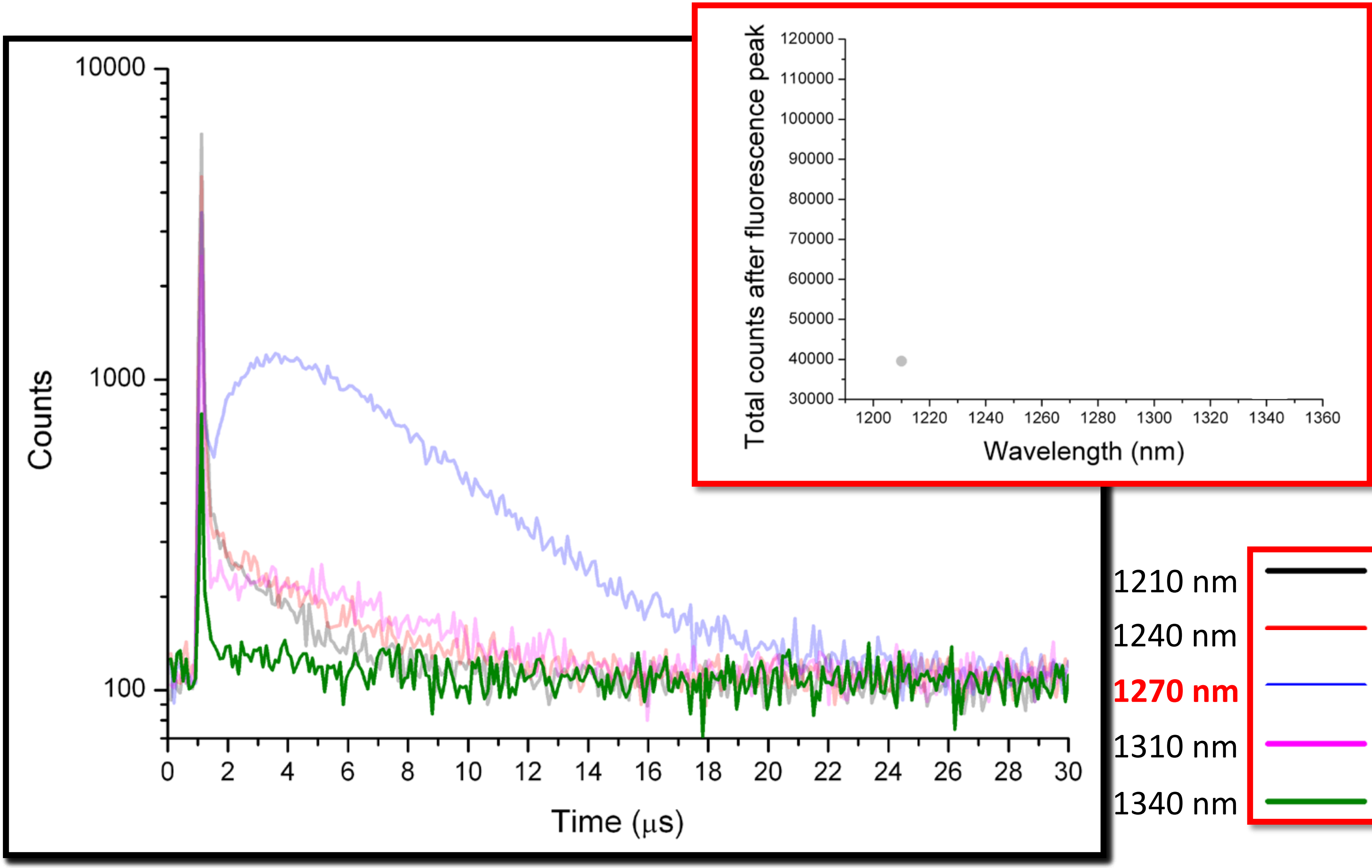




Histograms of Singlet Oxygen luminescence



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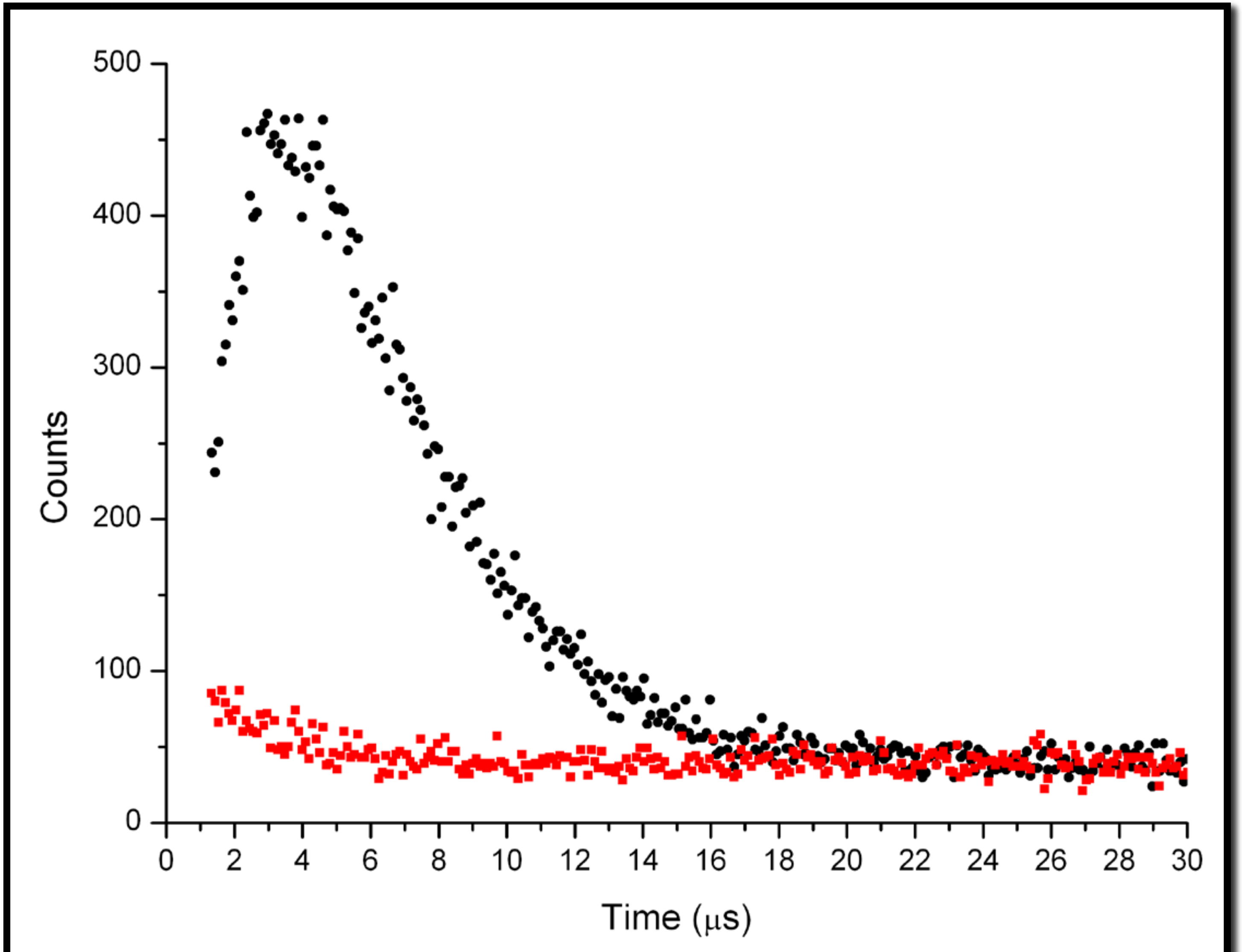
Confirmation of Singlet Oxygen luminescence signature



A known singlet oxygen quencher **Sodium Azide** was also added to the sample cuvette of photosensitizer as confirmation that the 1270 nm signal was from singlet oxygen rather than another fluorescence source.

A least squares fit of the temporal profile of the detected signal to the equation below gives lifetimes of:

$\tau_D = 3.0 \pm 0.3$ µs

$\tau_T = 2.3 \pm 0.3$ µs

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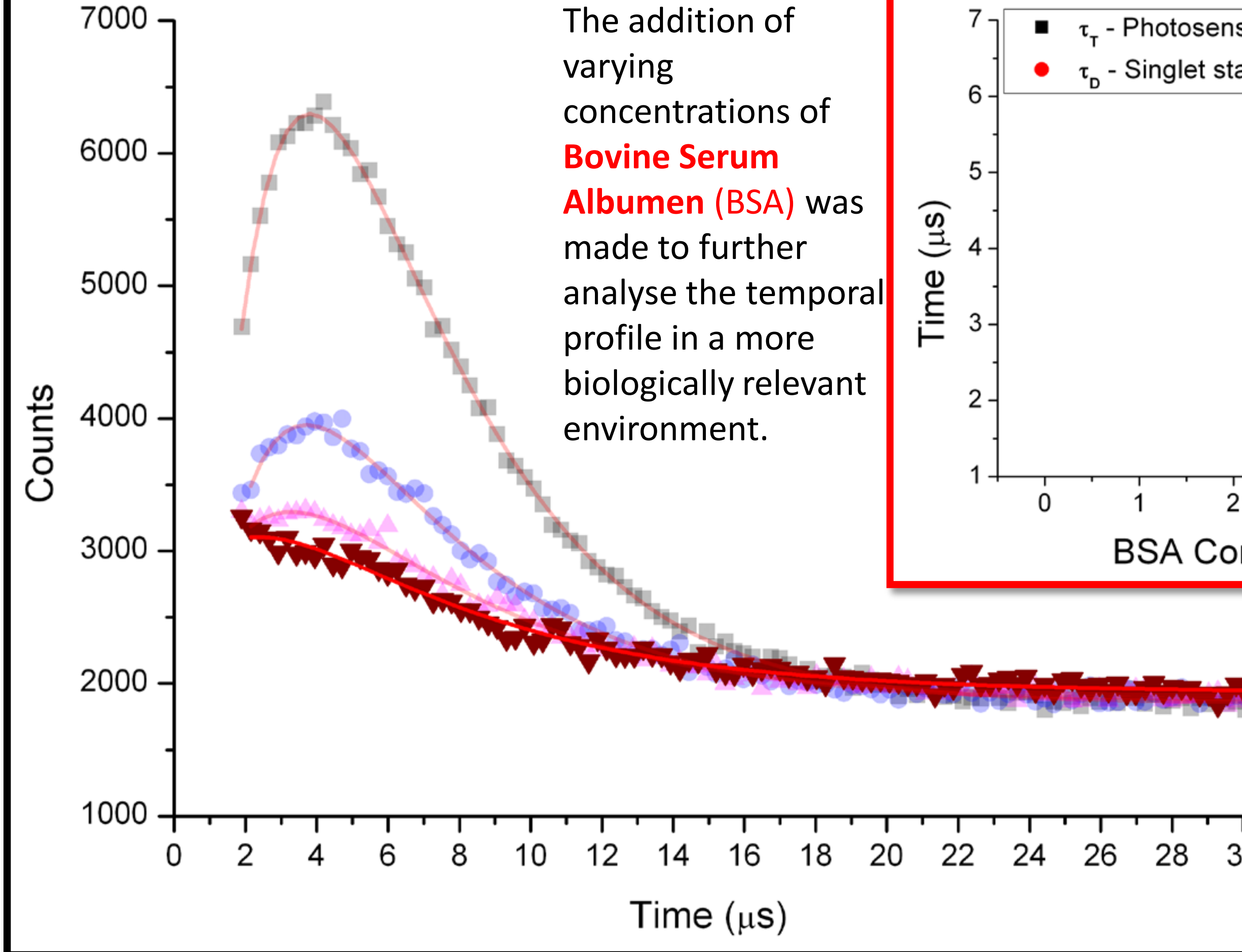
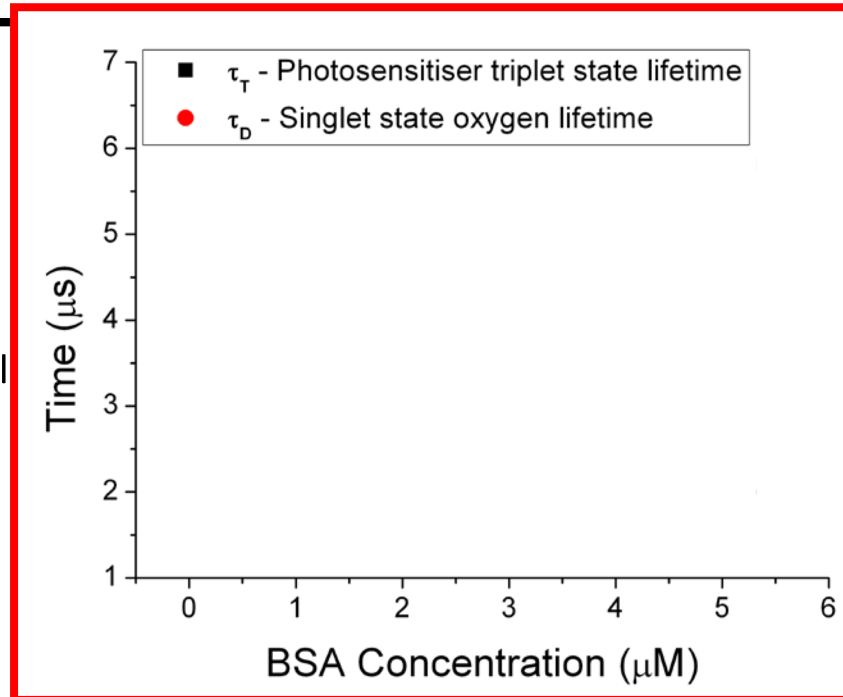
Simulating a physiological environment: addition of protein

The addition of varying concentrations of **Bovine Serum Albumen** (BSA) was made to further analyse the temporal profile in a more biologically relevant environment.





BSA Concentration:
■ 0 μM

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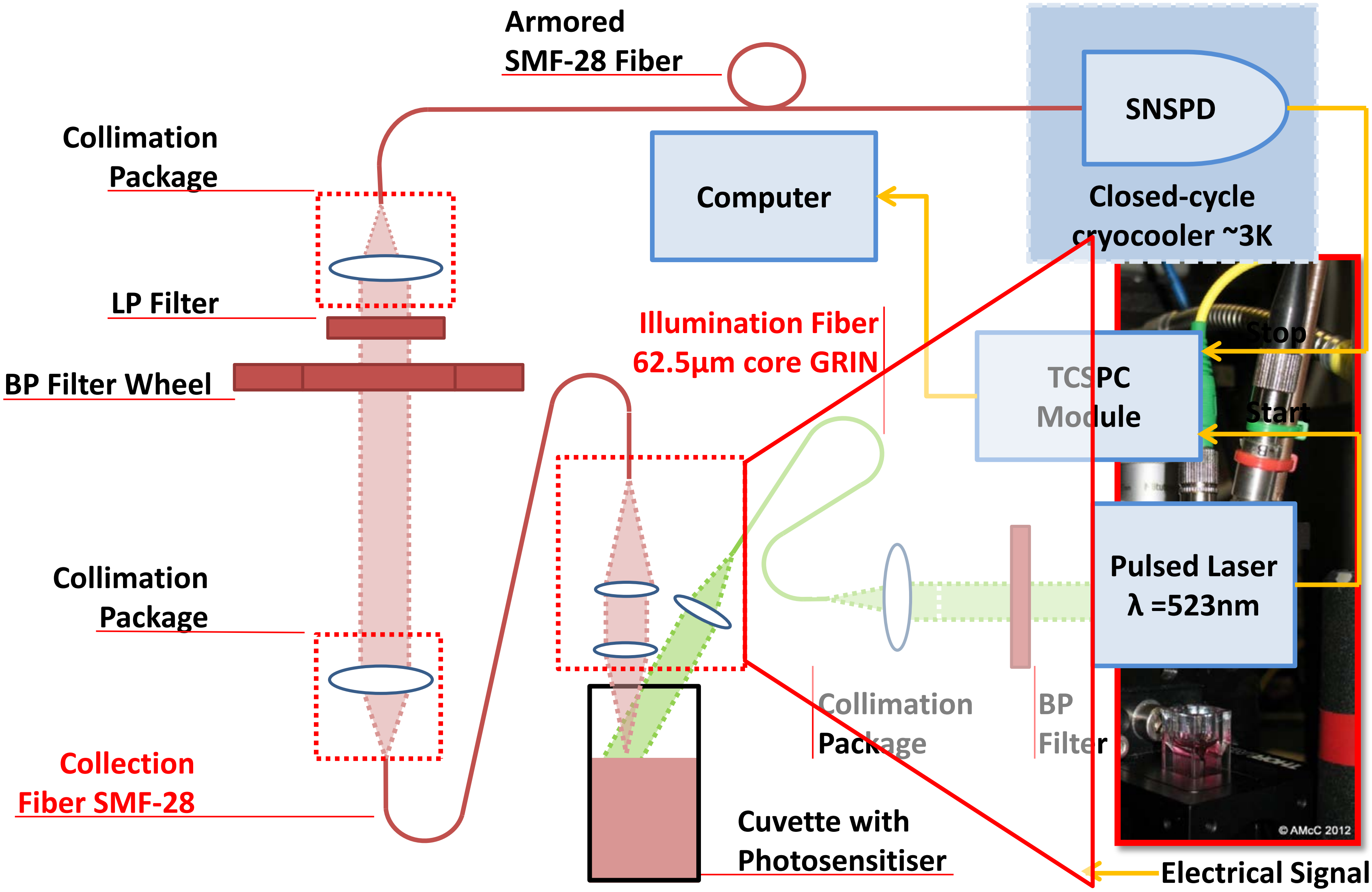
Singlet Oxygen luminescence detection: optical fiber setup



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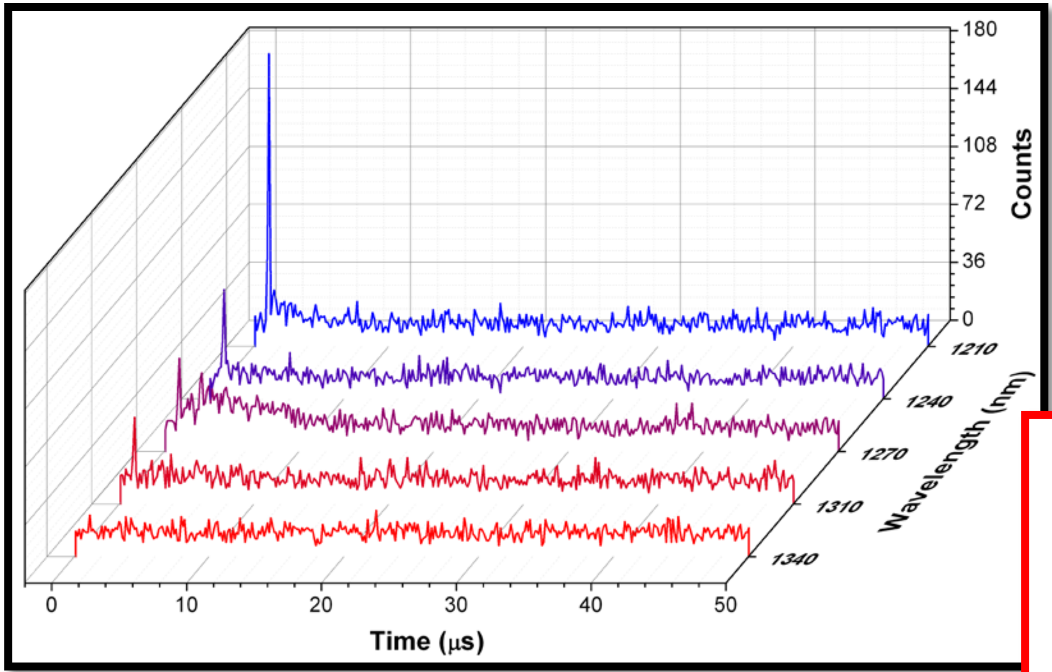
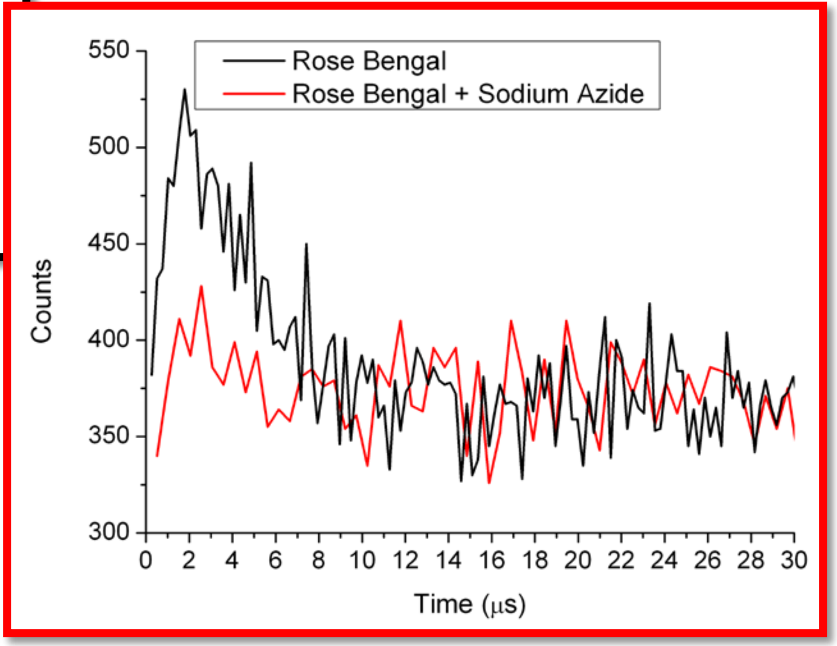
Verification of Singlet Oxygen luminescence via optical fiber



[97.367 nM Rose Bengal Solution
30 min acquisition time, 0.128 µs bin size]

Sodium Azide quenching:

[97.367 nM Rose Bengal Solution 60 min acquisition time, 0.512 µs bin size
97.367 nM Rose Bengal Solution + 2 M Sodium Azide 60 min acquisition time, 0.512 µs bin size]



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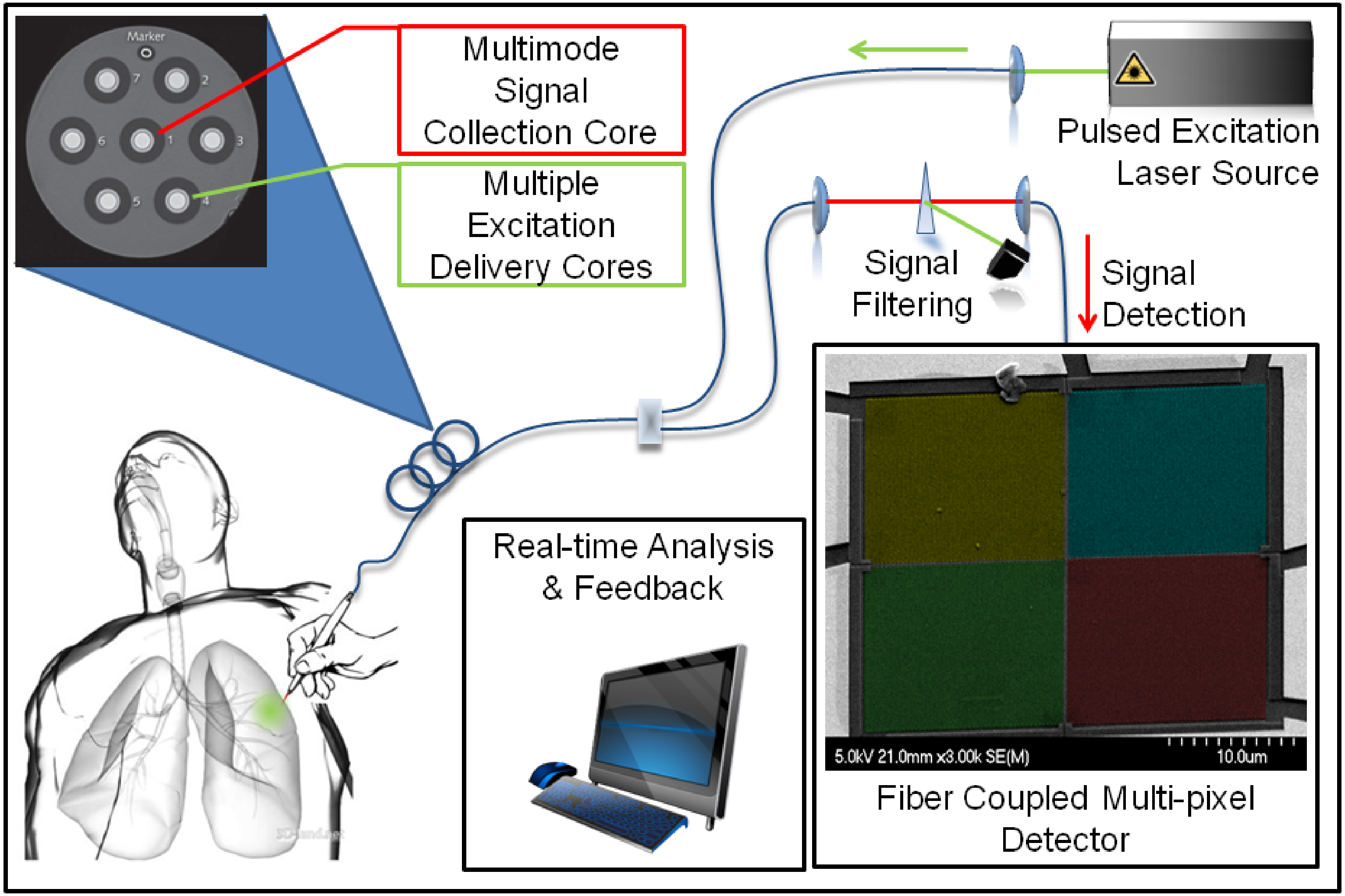
NIH Proposal for Singlet Oxygen Luminescence detection via optical fiber



A Casaburi, A Pizzone, RH Hadfield,
Photonics Technologies, 2014 Fotonica AEIT Italian Conference on, 1-4

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Singlet oxygen luminescence detection with a superconducting single-photon detector

- In summary, we have demonstrated for the first time the feasibility of detecting **singlet oxygen** ($^1O_2$) luminescence using a superconducting nanowire single photon detector (SNSPD).
- We have performed a complete set of canonical laboratory experiments using Rose Bengal photosensitizer dye (quenching, addition of BSA).
- The superconducting detector is fiber coupled. For the first time we have performed **singlet oxygen luminescence detection via optical fiber**
- Possible improvements to the setup : next generation SNSPDs with increased active area allow multimode fiber collection could drive down acquisition times by orders of magnitude; delivery and collection via a single tailored fiber.
- This study is a crucial step towards clinical applications in **photodynamic therapy** .

Gemmell *et al.* 'Singlet oxygen luminescence detection with a fiber-coupled superonducting nanowire single-photon detector' Optics Express 21 5005 (2013)

See also: Nature Photonics Research Highlight, BioOptics World, May 2013