Optical Characterization of Erbium Doped Cerium Dioxide:

Photoluminescence and Lifetime Measurements

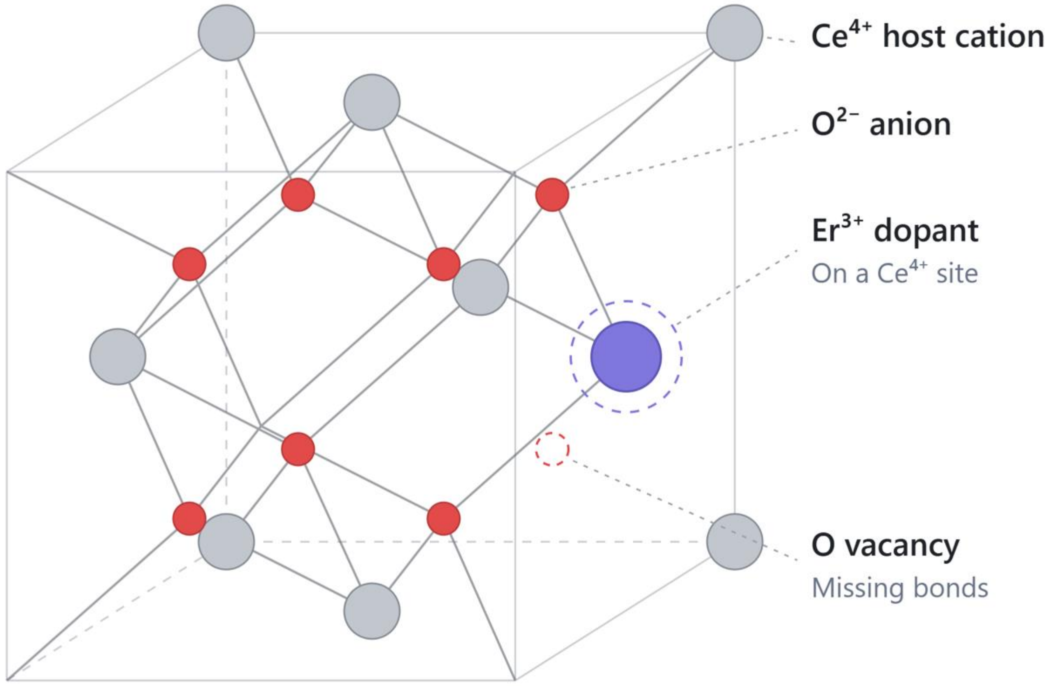
PQT
PHOTONIC QUANTUM
TECHNOLOGIES LABORATORY

Photonic Quantum Technologies Group
Dr. Alisa Javadi

Adam Powell – July 23, 2026

Rare Earth Dopant Ion Quantum Emitters: Erbium Doped Cerium Dioxide

- Rare earth dopant-ion emitters (such as Er3+) possess discrete atomic energy levels and can act as **qubits (quantum computational bits).**
- Embedding them in a wide band-gap host (such as Cerium Dioxide) allows their internal optical transitions to be excited at energies below the host band gap, so the surrounding host is not excited across its valence and conduction bands.



Why Erbium 3+ Ion?

- Erbium, like all Lanthanides (atomic numbers 57 – 71) , has good orbital shielding from the 5s^2 5p^6 Xenon core
- 4f – 4f electronic transitions produce clean emissions in the telecom band
- **Ion can function as a qubit!**
- Telecom band: 1260 nm to 1675 nm
- Er^0 – [Xe] 4f^12 6s^2 (disrupted 4f transitions)
- Er^3+ = [Xe] 4f^11 (nicely shielded 4f transitions)

Why Cerium Dioxide?

- Cerium Dioxide is a low magnetic noise host as seen by Magnetic Natural Isotope Abundance: Cerium Dioxide host has very few magnetic nuclei and produces a very quiet magnetic environment for Erbium ion spins.
- Stable crystalline structure
- Wide bandgap
- Compatible with wide range of substrates including silicon

Element	Magnetic Natural Isotope Abundance
Carbon	1%
Silicon	4.6%
Cerium	0%
Calcium	0.13%
Oxygen	0.04%

Kanai, S.; et al, Proc. Natl. Acad. Sci. U.S.A. 2022, 119, e2121808119.

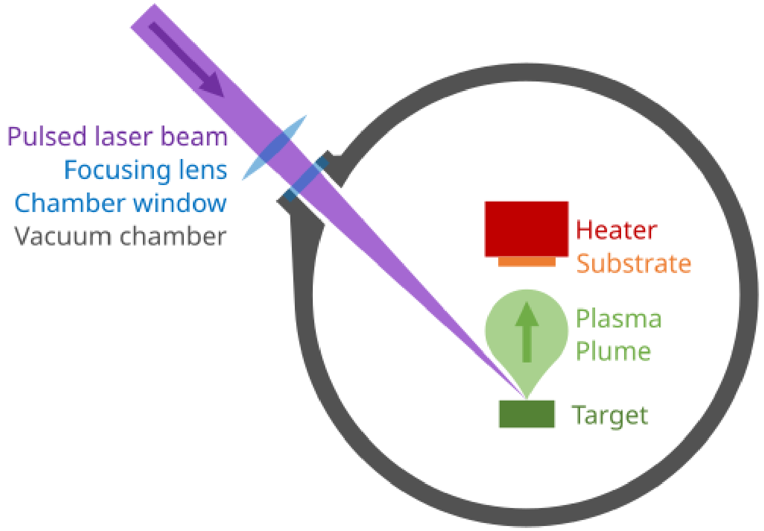
Sample Preparation: PLD Laboratory, OU

Dr. Thirumalai Venkatesan

Dr. Pralay Paul

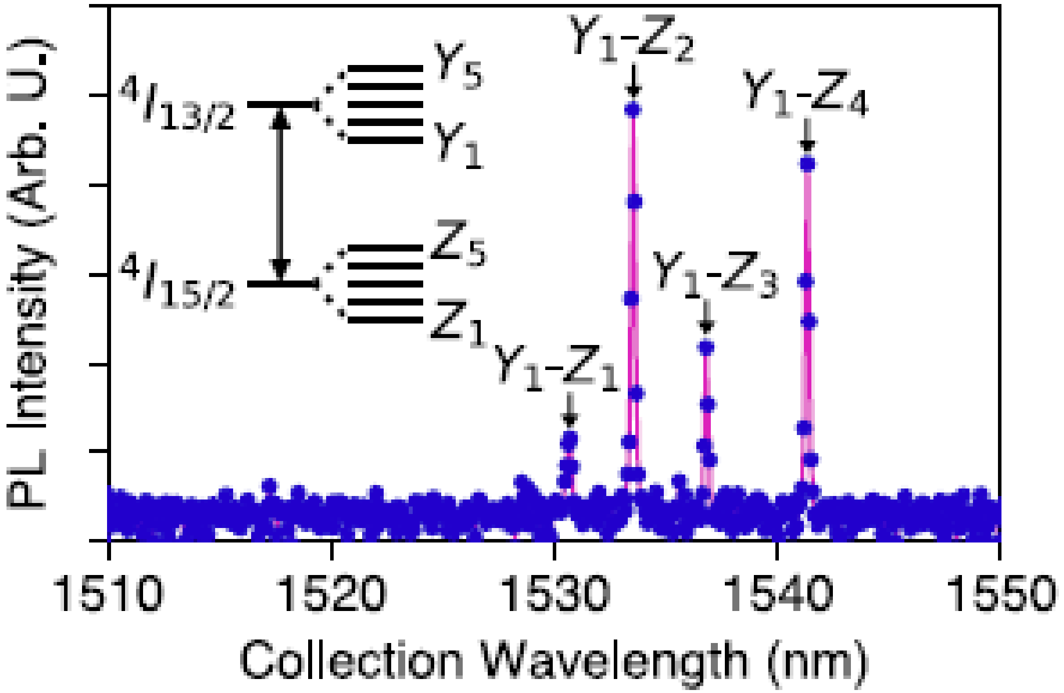
(No Picture) Phu-Trong Nguyen

- PLD: Pulsed Laser Deposition



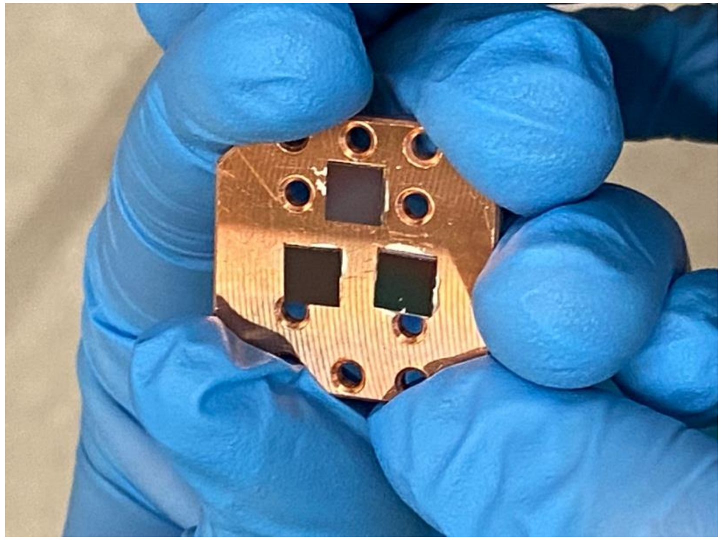
Characterization: Photoluminescence and Lifetime Measurements

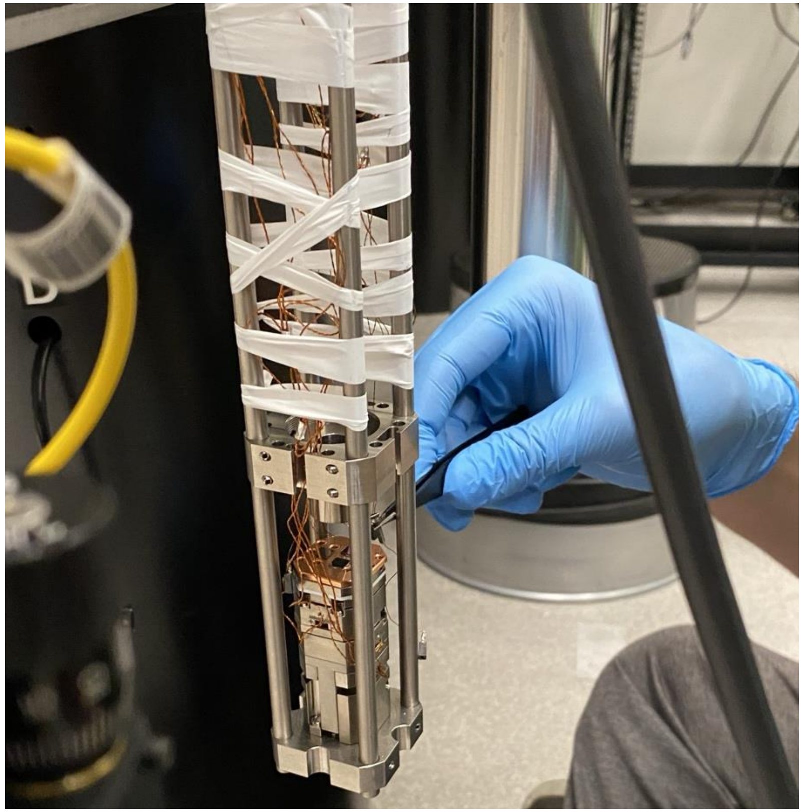
- Photoluminescence (PL): We excite our sample with a laser and measure the light emissions (wavelength).
- Lifetime: We excite the sample with a pulse and then measure how the emission intensity decays over time.
- From Lifetime Histogram, we extract **tau τ** lifetime

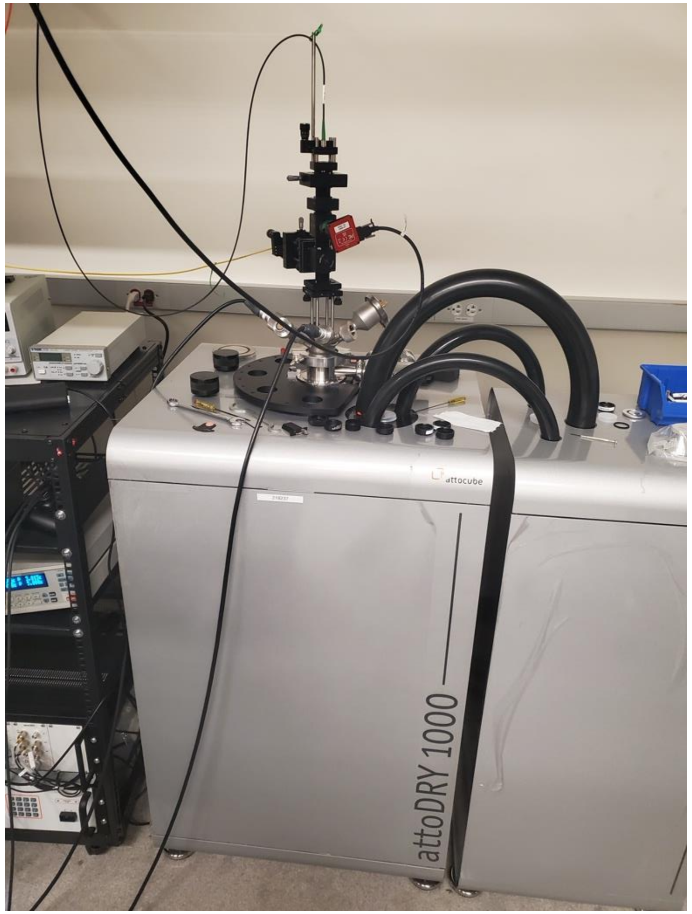


Grant, Zhang, et al.

Three Samples: Preparation for the Cryostat

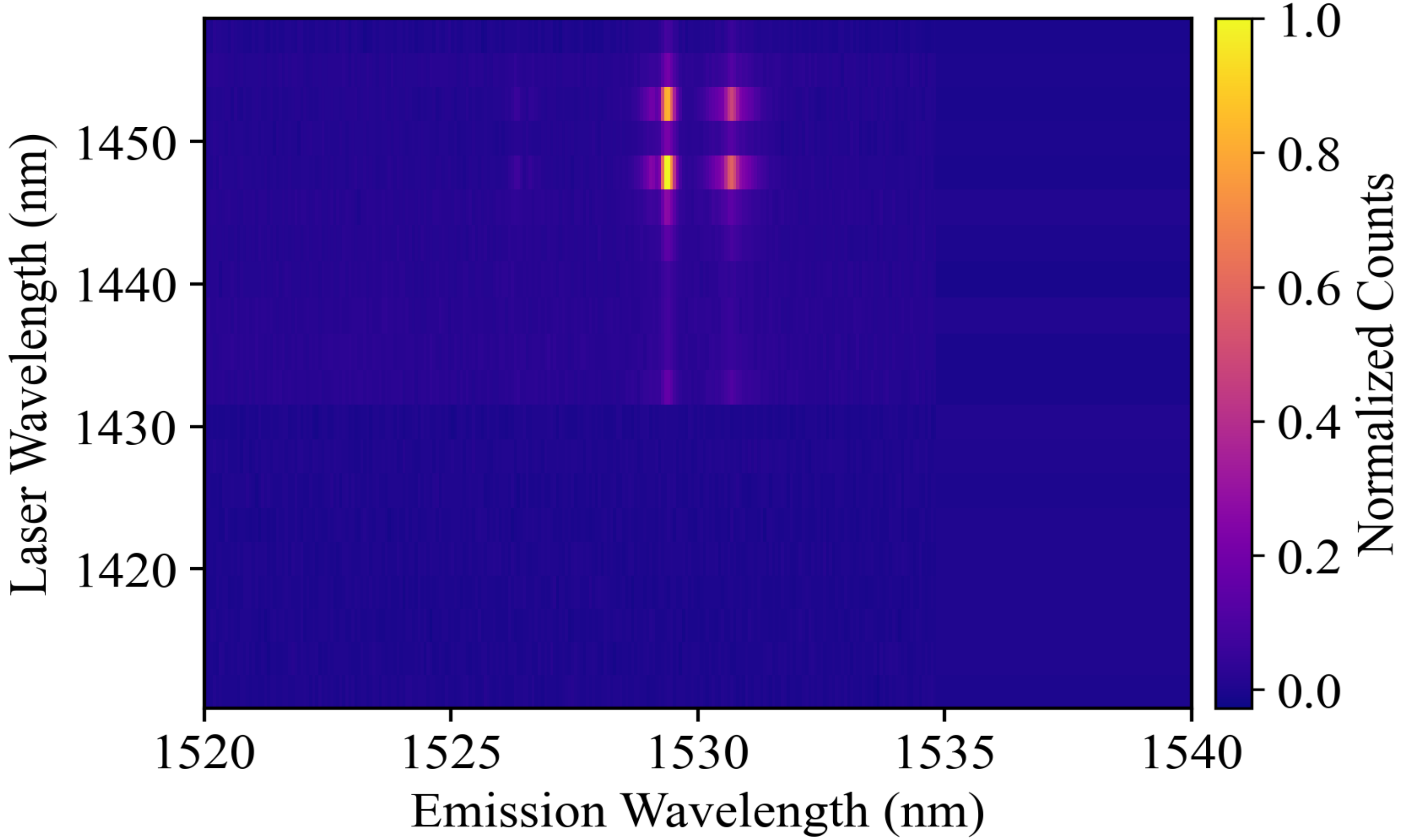






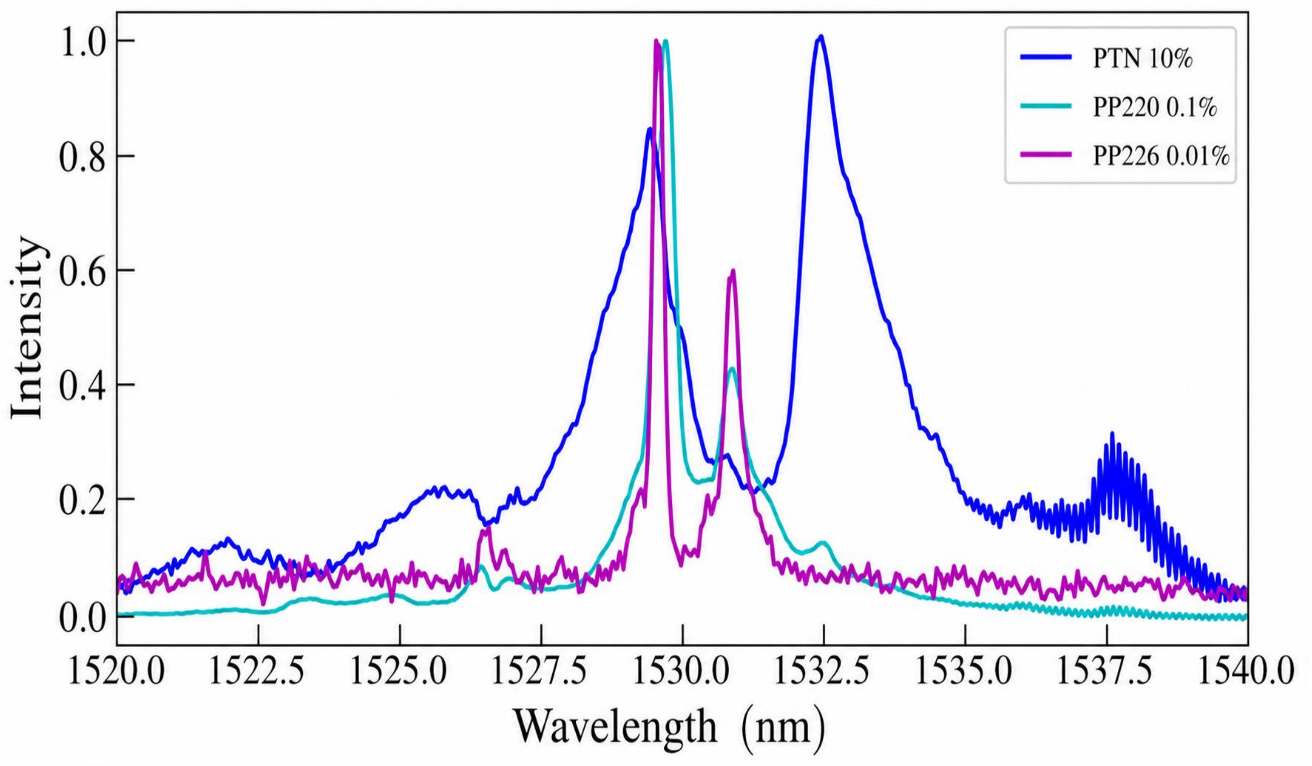
- PP220: 0.01% Erbium
- PP226: 0.1% Erbium
- PTN: 10% Erbium

Photoluminescence:
Excitation VS Emission Spectrum Mapping (1445 nm)

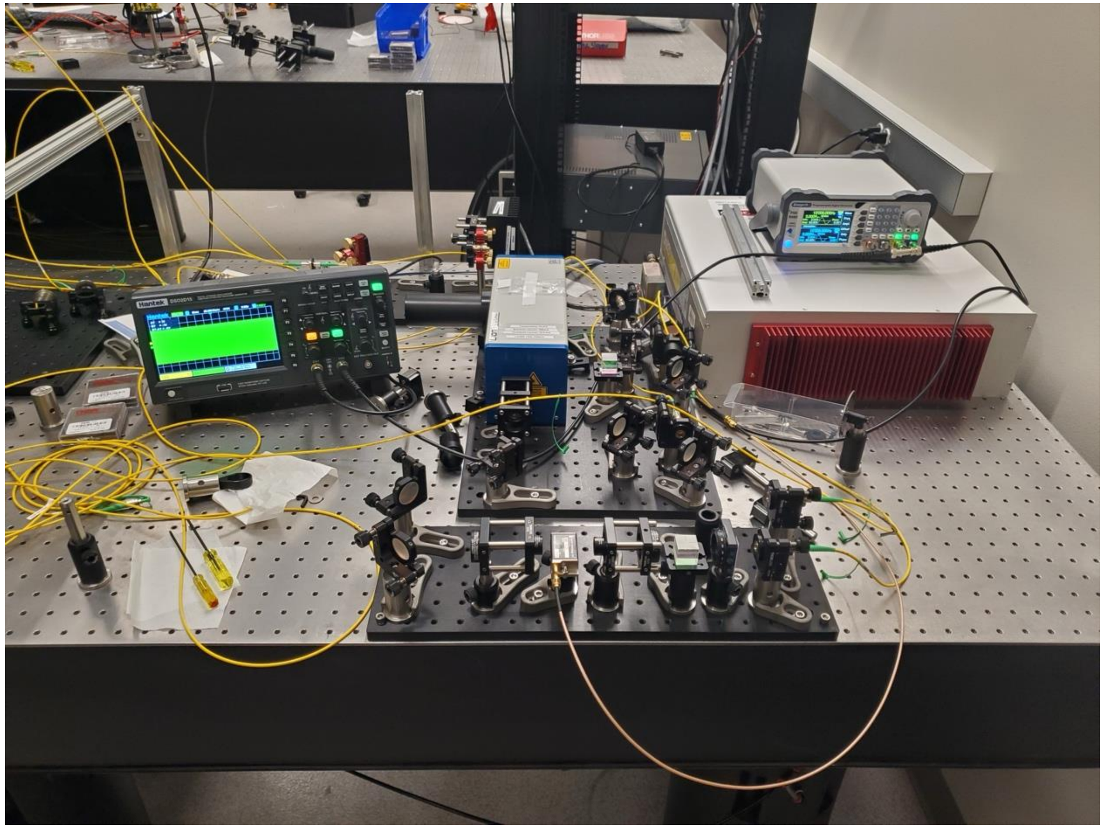


Photoluminescence Measurements

- 1445 nm excitation wavelength
- Signal-to-noise ratio more important than simply having massive intensity
- Higher concentrations → inhomogeneous broadening
- This is due to local strain, lattice defects and impurities, etc.



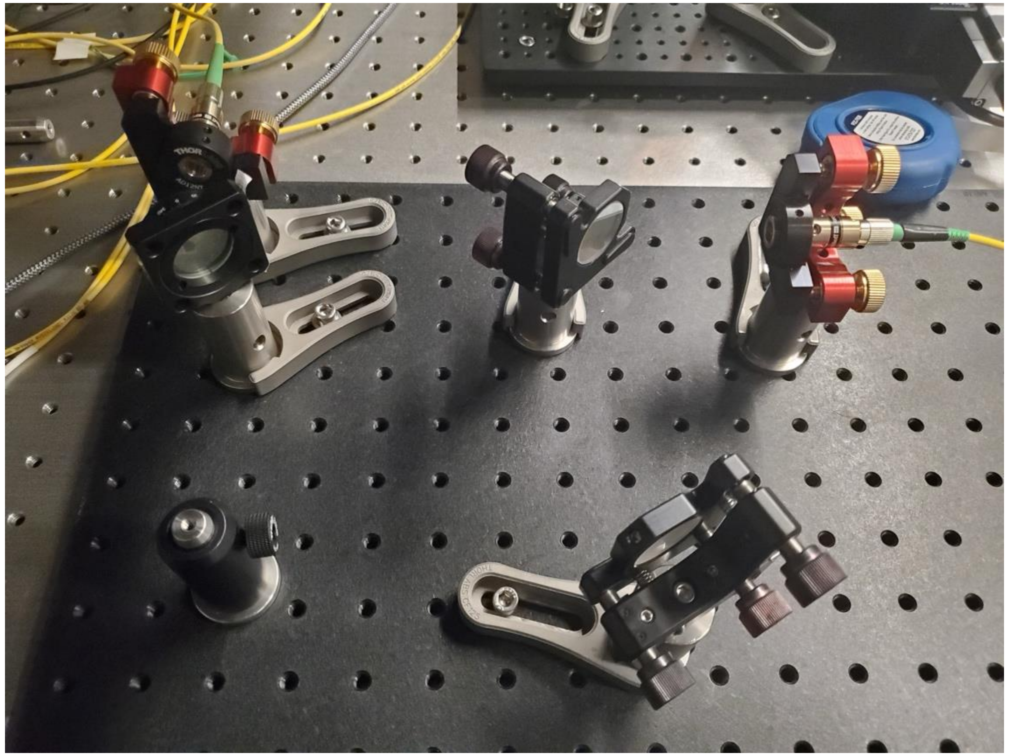
Lifetime Measurement Laboratory Setup



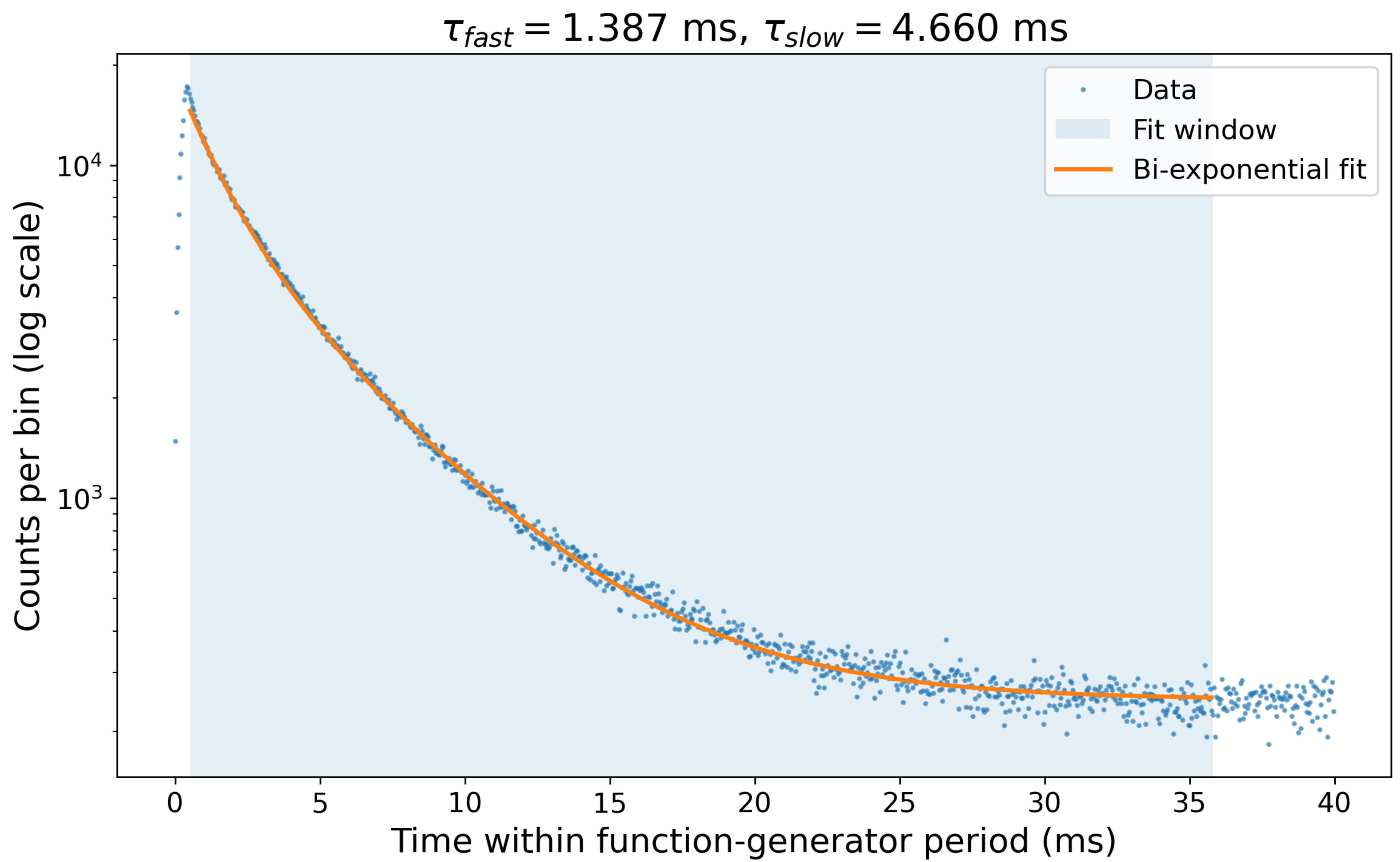
- Laser → AOM → Excitation Arm of Microscope
- Collection Arm of Microscope → Diffraction Grating (Spectral Filter) → SNSPD (Superconducting Nanowire Single-Photon Detector)
- Function Generator (which is synced with Time Tagger) creates low Duty pulse sequence for AOM, then AOM administers pulsed excitation sequence to sample

Diffraction Grating (Spectral Filter)

- We calibrate the diffraction grating with the exact wavelength of the emission spike we are trying to filter for.
- A diffraction grating spatially separates different wavelengths into different diffraction angles.
- We use the first diffraction order and then send the filtered emission to the SNSPD.

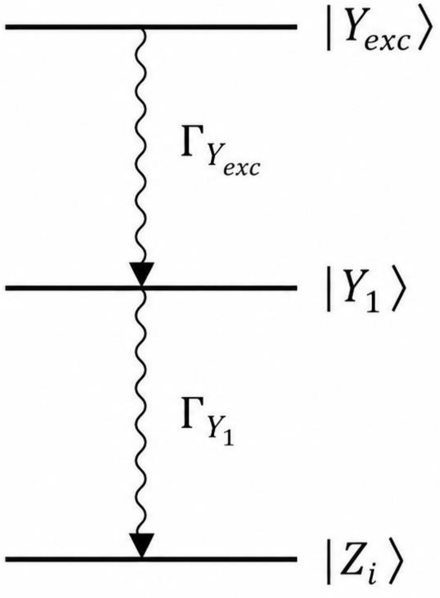


PP220: Lifetime Decay Plot with Tau Values



Data Analysis: How did ground these τ values?

$$R_{Z_i}(t) = \begin{cases} R_{Z_i} & \text{pump on} \\ 0 & \text{pump off} \end{cases}$$



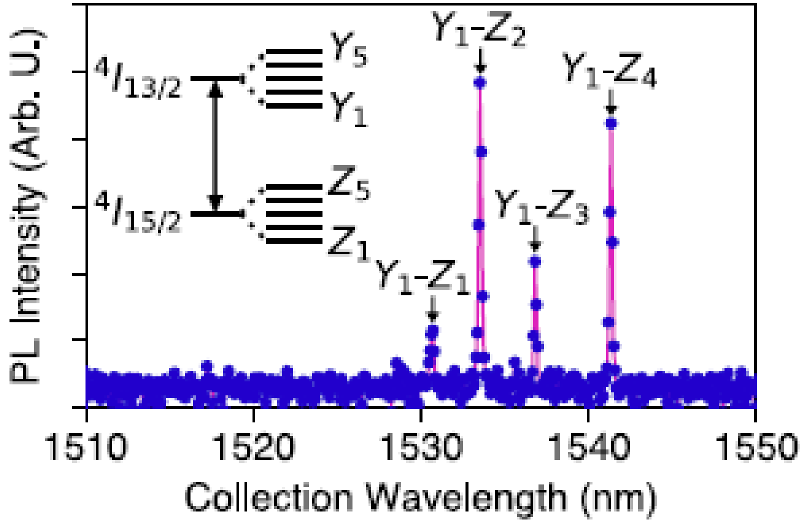
$$\frac{dP_{Y_{exc}}}{dt} = R_{Z_i} P_{Z_i} - \Gamma_{Y_{exc}} P_{Y_{exc}}$$

$$\frac{dP_{Y_1}}{dt} = \Gamma_{Y_{exc}} P_{Y_{exc}} - \Gamma_{Y_1} P_{Y_1}$$

$$\frac{dP_{Z_i}}{dt} = \Gamma_{Y_1} P_{Y_1} - R_{Z_i} P_{Z_i}$$

$$I(t) = \underbrace{\alpha e^{-t/\tau_f}}_{\text{fast}} + \underbrace{\beta e^{-t/\tau_s}}_{\text{slow}}$$

$$\Gamma = 1/\tau$$



Special Thank You.

- I would like to give a special thank you to Dr. Javadi and all the members of the Photonic Quantum Technologies Group. You have helped me tremendously in this learning process and you are very much appreciated.