

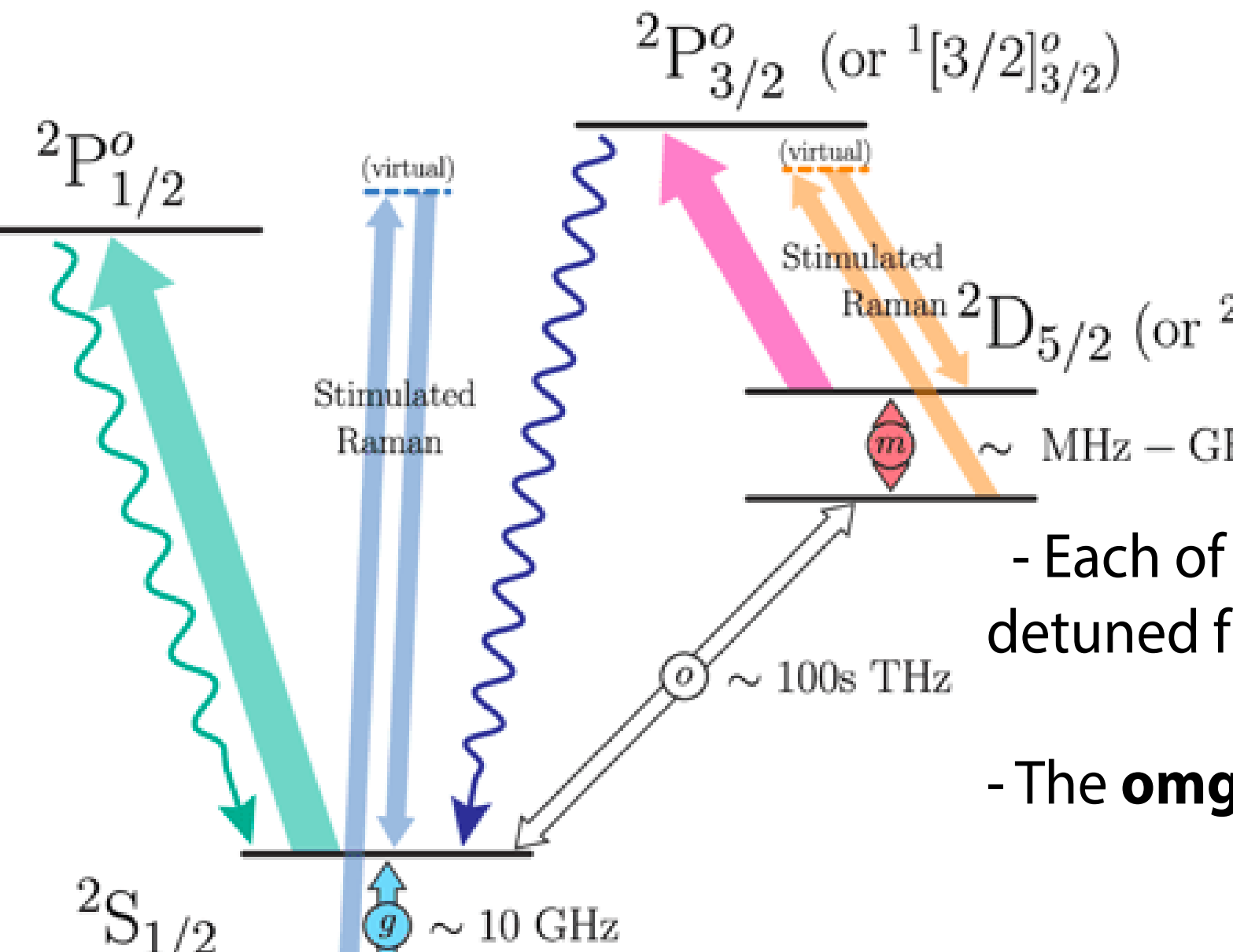
$^{133}\text{Ba}^+$ Ion

$^{133}\text{Ba}^+$ Hyperfine Qubits:

- Spin 1/2 nucleus
- Native hyperfine and optical qubit clock-states
- Visible and IR wavelength transitions
- Long-lived D state lifetime ($\tau \sim 30\text{s}$)
- High fidelity electron shelving scheme
- High ground state SPAM Fidelity >0.999
- 10.5 year half-life

omg Qubit Architecture

- o**: Optical Qubit
- m**: Metastable Qubit
- g**: Ground Qubit



- Each of the **omg** qubit type is far detuned from other **omg** qubit types
- The **omg** qubits have equal mass

-omg qubit operation analogous to dual-species operations

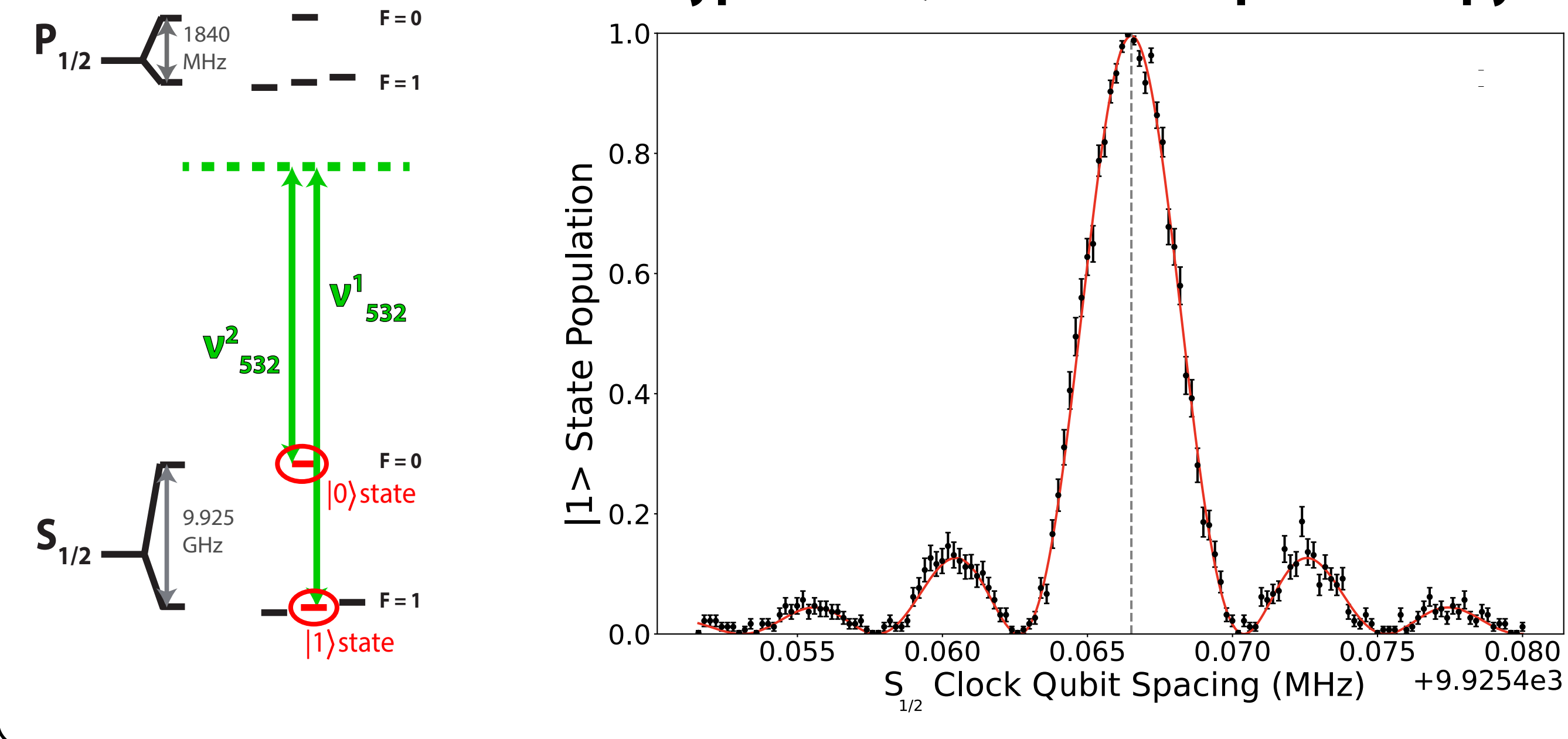
$^{133}\text{Ba}^+$ omg qubits states:

$$\mathbf{o} = \{S_{1/2}, D_{5/2}\}; \mathbf{m} = D_{5/2}\{F=2,3\}; \mathbf{g} = S_{1/2}\{F=0,1\}$$

Single Qubit Raman Gate Operations

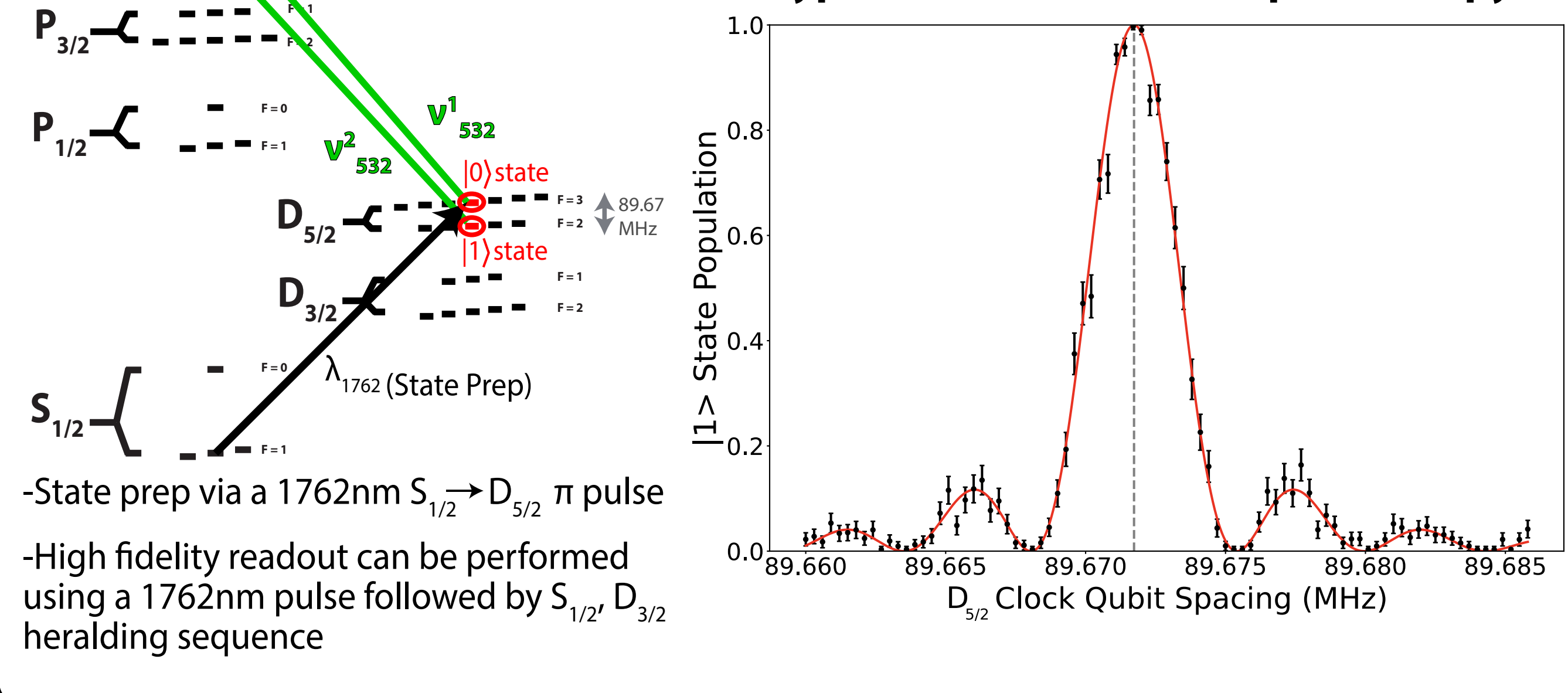
Ground State (g) Qubit

Hyperfine Qubit Raman Spectroscopy



Metastable State (m) Qubit

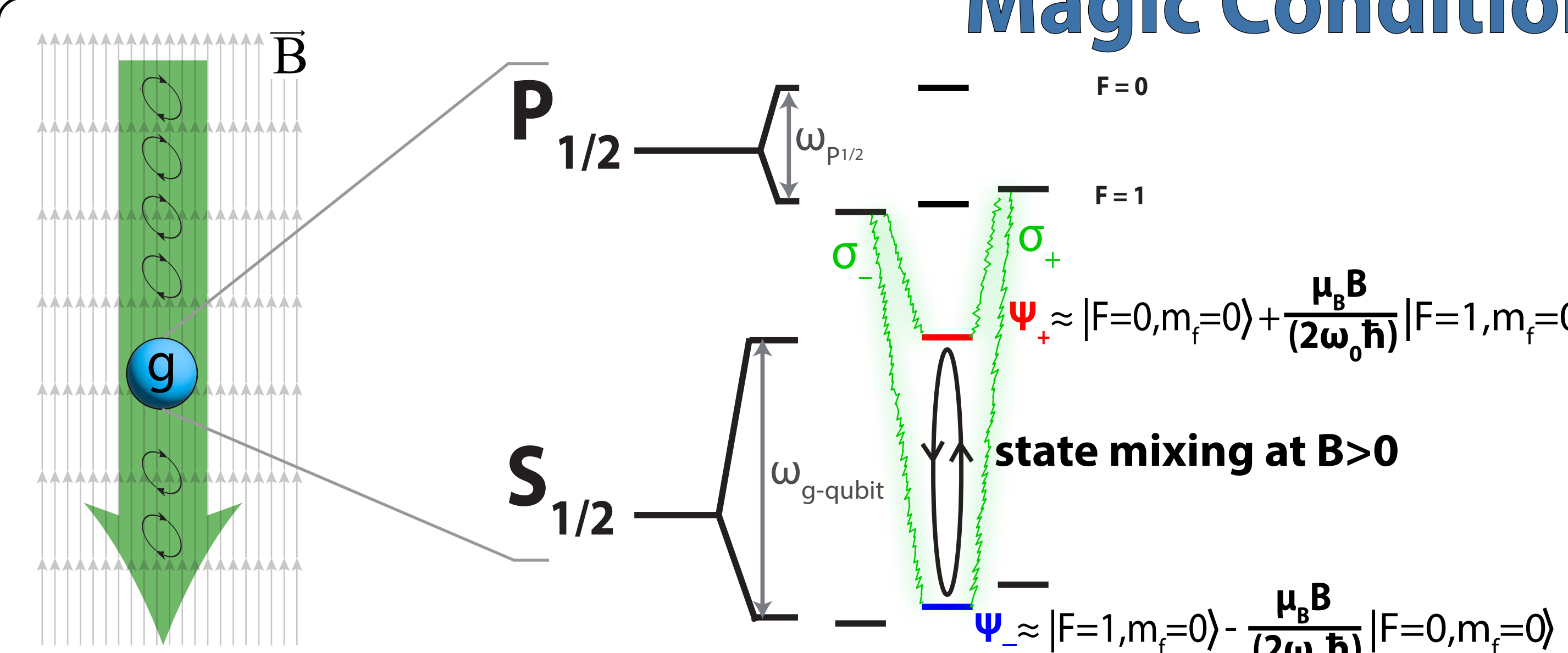
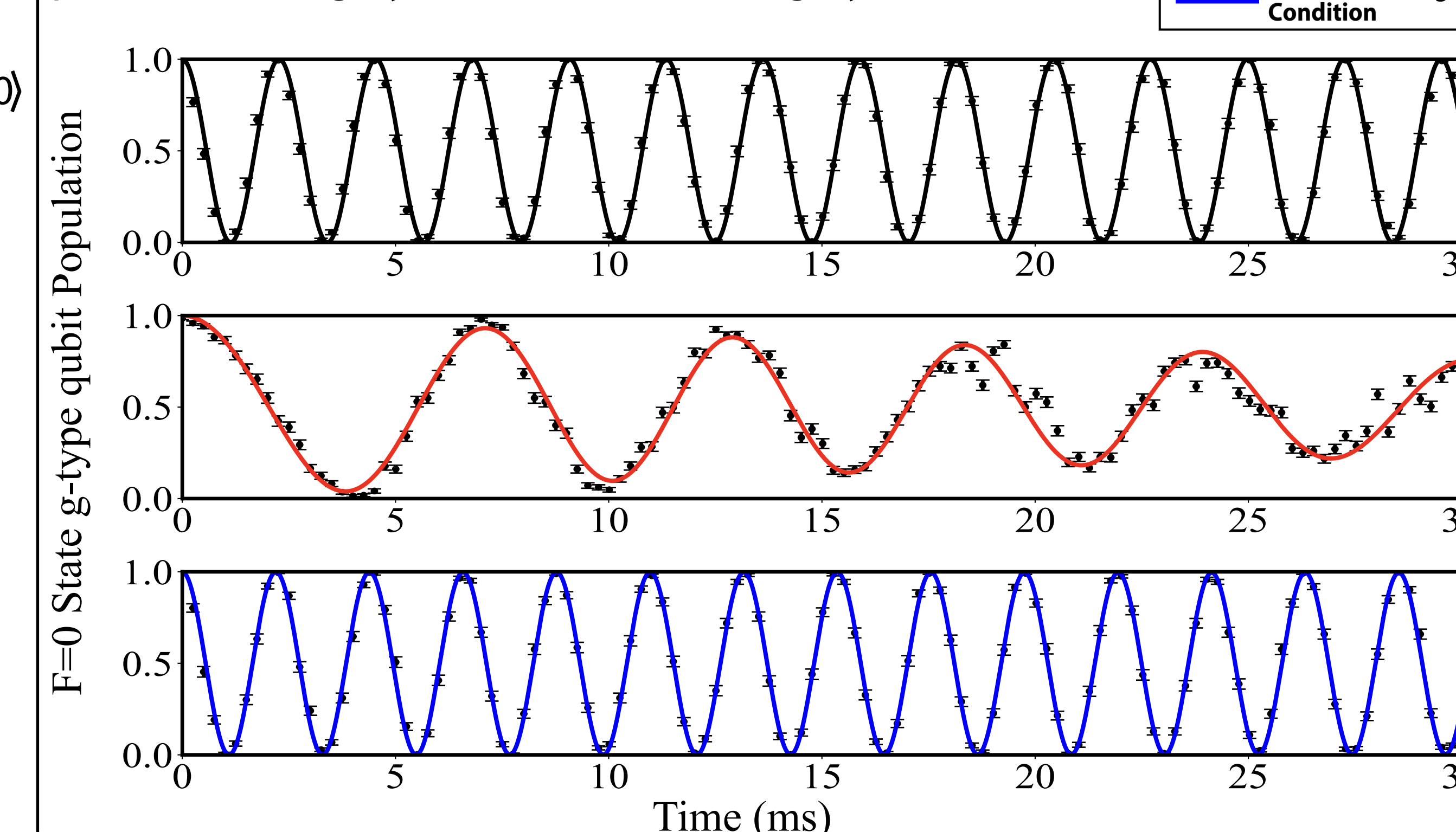
Hyperfine Qubit Raman Spectroscopy



Magic Conditions in g-State Qubit

Improved Cross-talk Fidelity

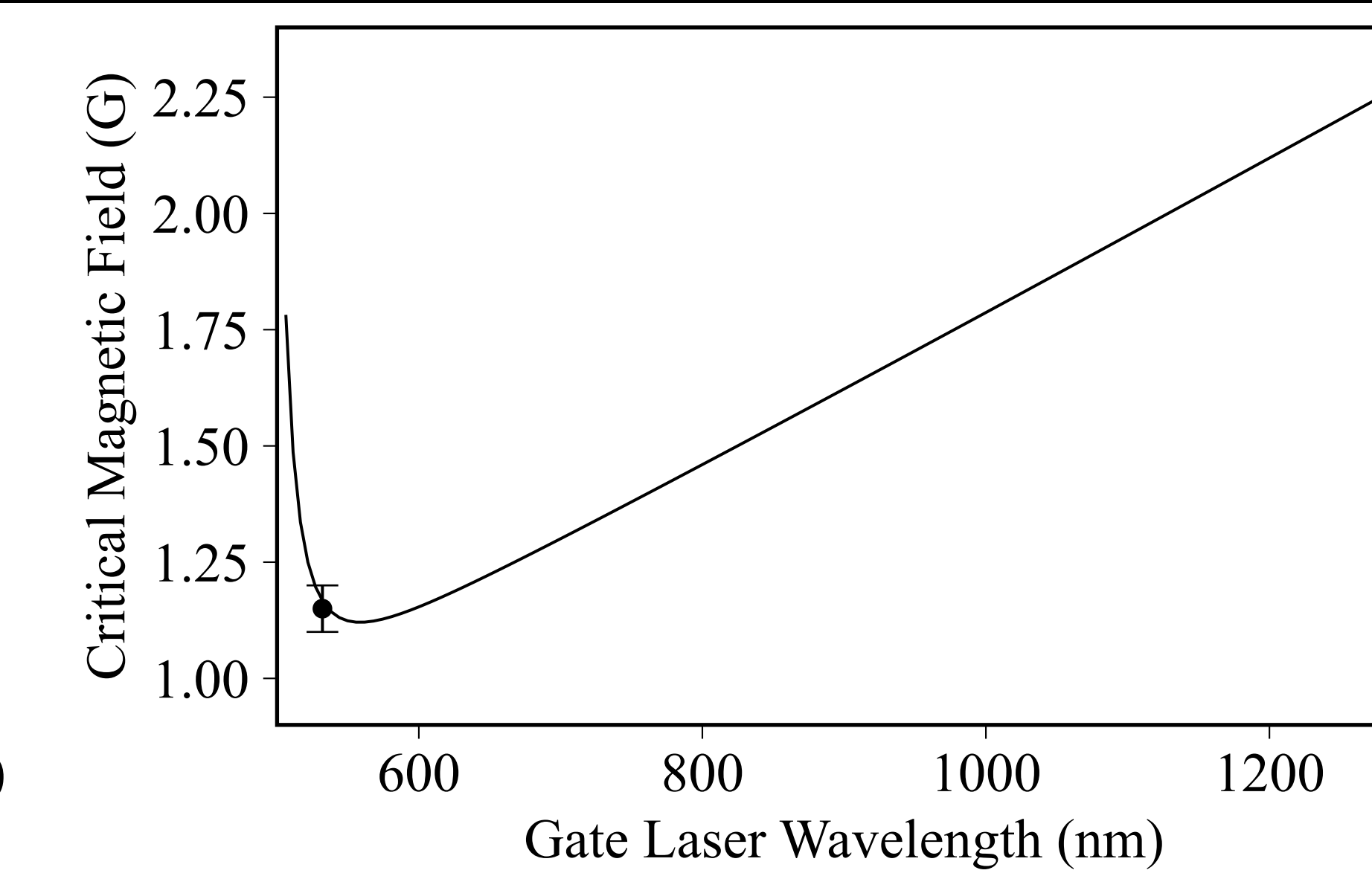
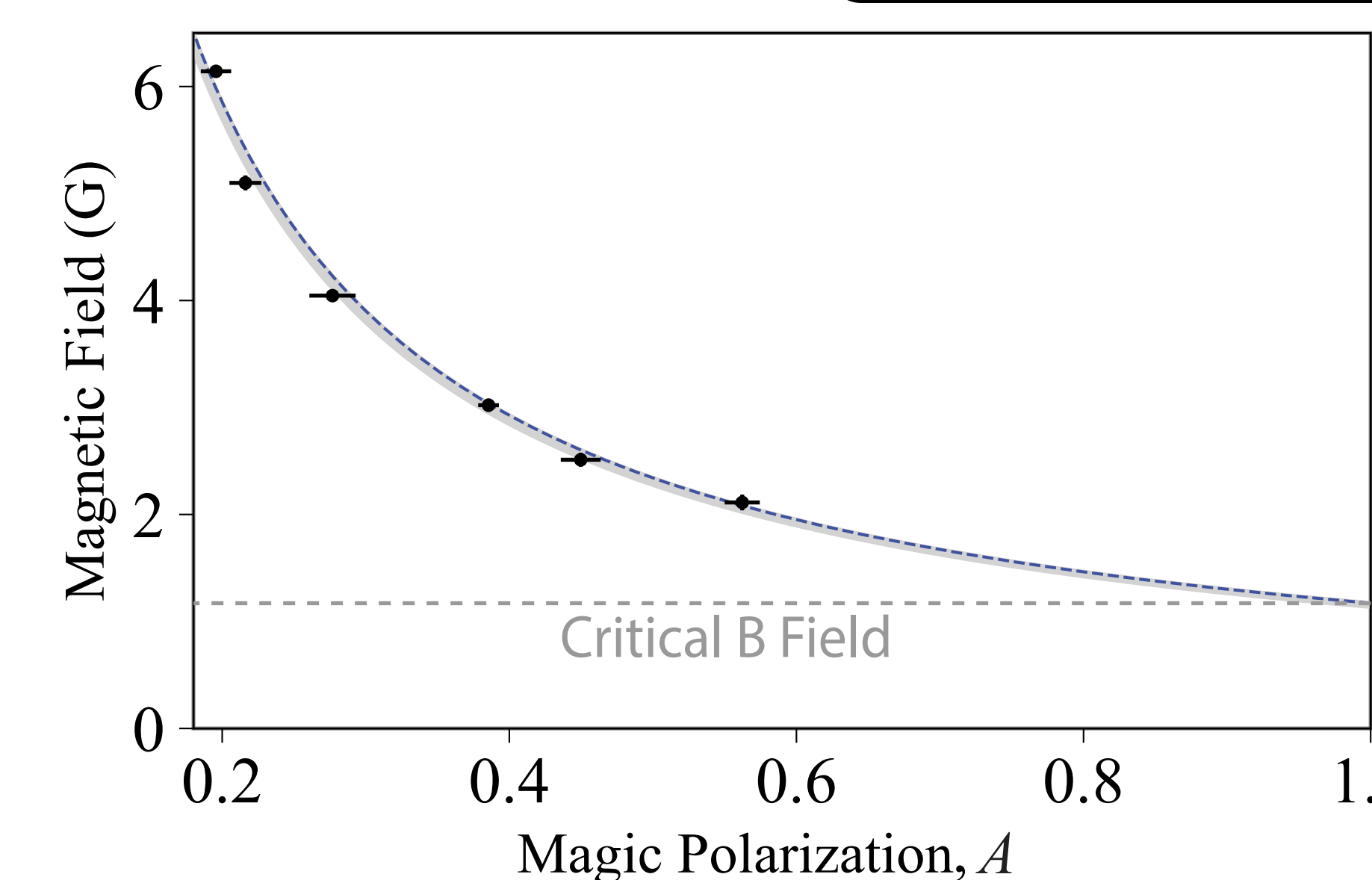
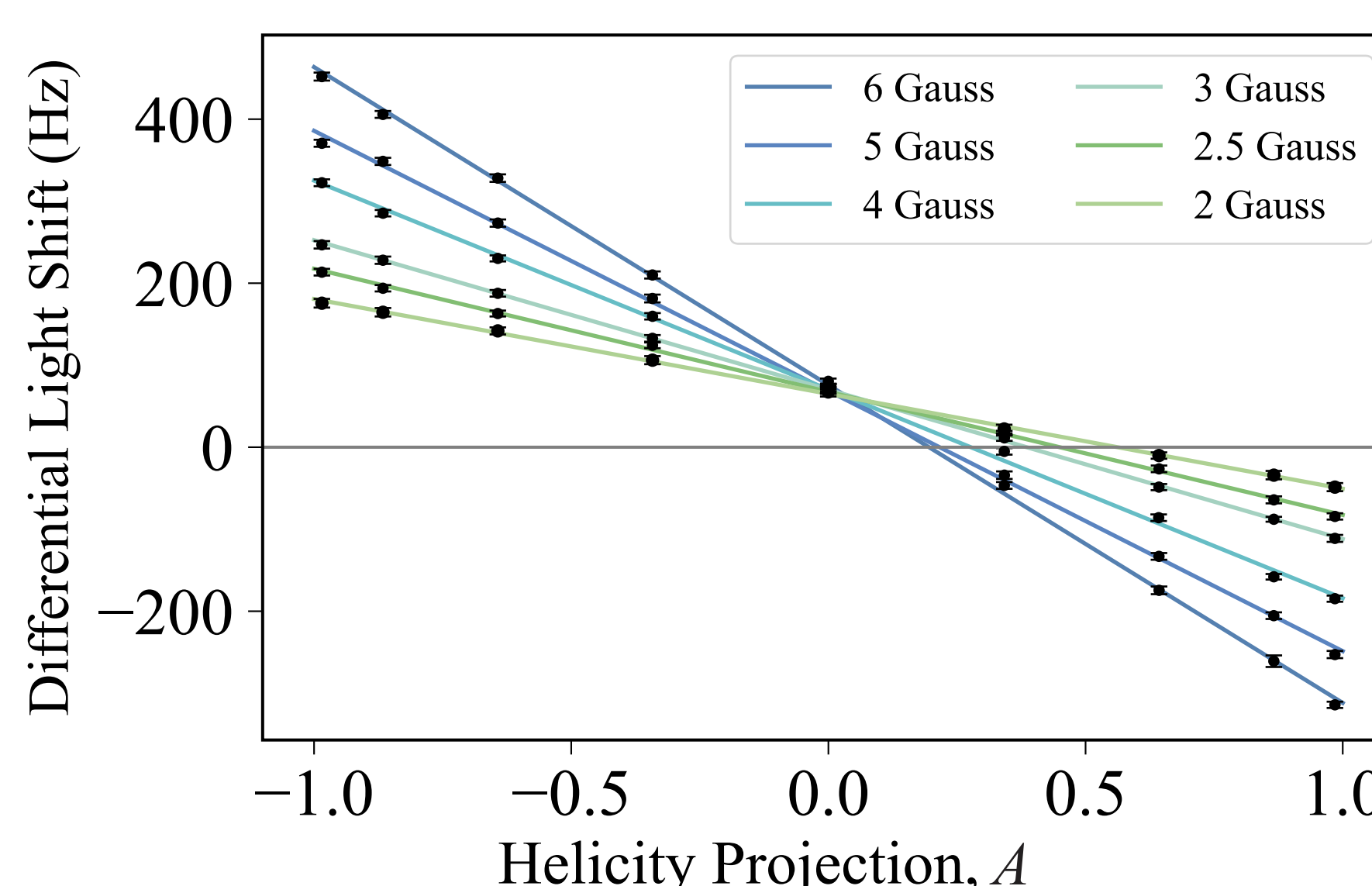
-Decreases the g-qubit cross-talk error per m-qubit π pulse from roughly $2.7(2) \times 10^{-5}$ to roughly $3(2) \times 10^{-7}$



At B=0: Global m-qubit gate laser light causes the g-qubit states to shift different amounts creating a differential light shift

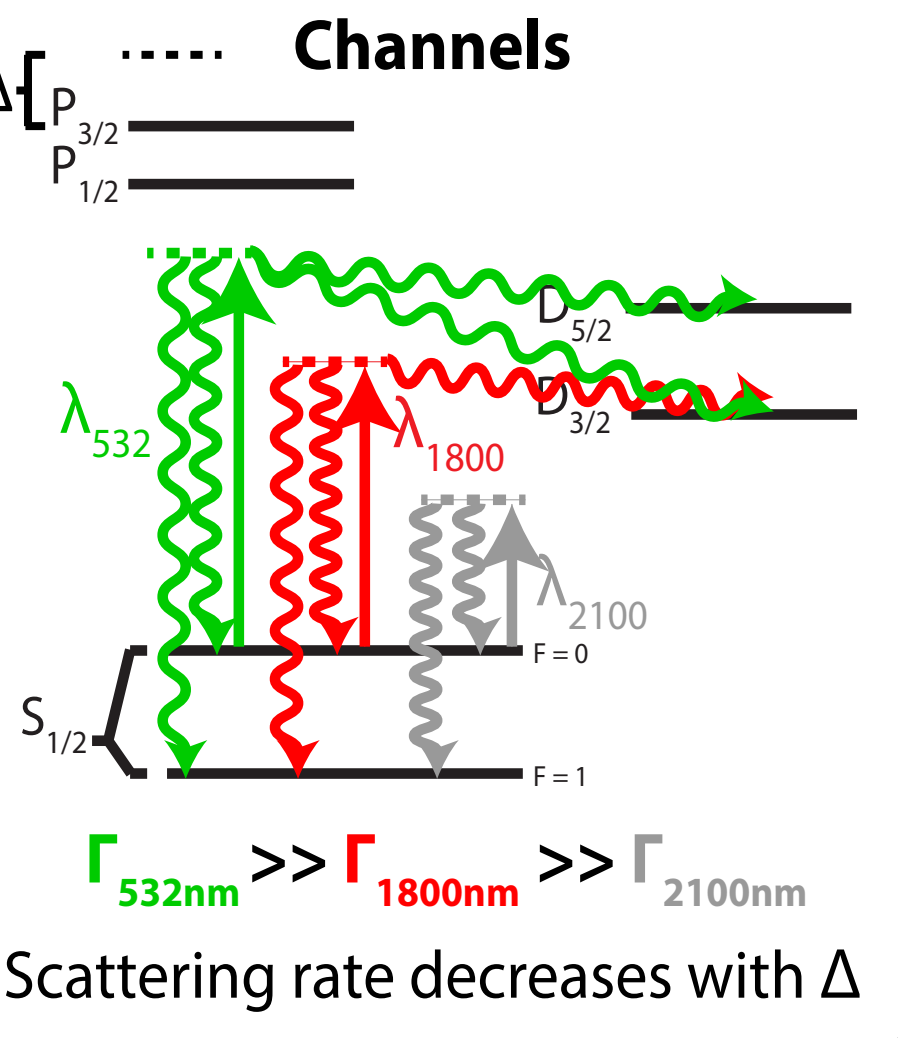
At B > 0: Hyperfine clock states mix, leading to B field and polarization dependent differential light shift

At B > B_{critical} ≈ 1.2 G: Combinations of σ_+ and σ_- light lead to **Magic Conditions** where the differential light shift is removed at any laser intensity



Fundamental Limits of Raman Gates

Gate Laser Photon Scattering Channels



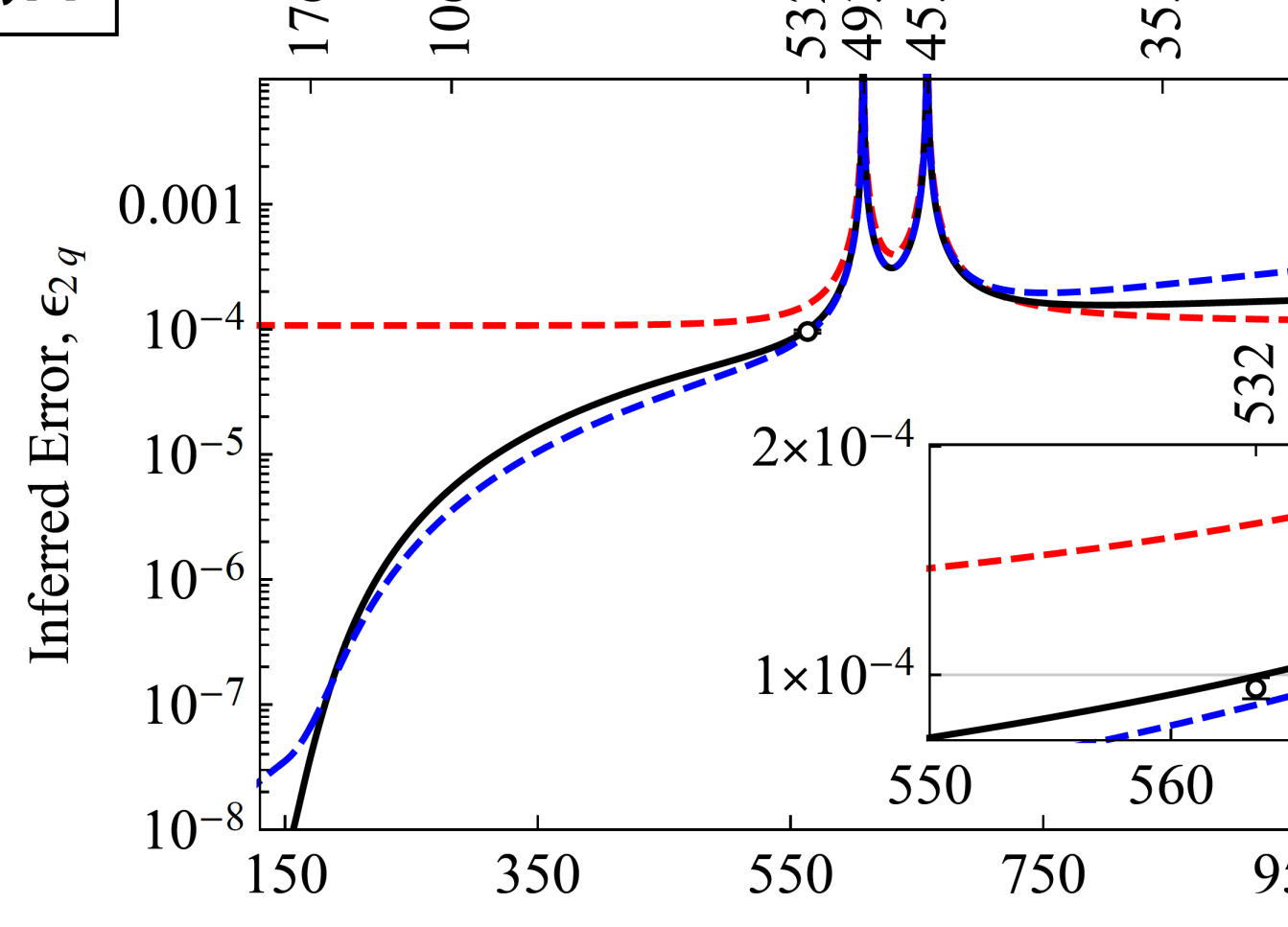
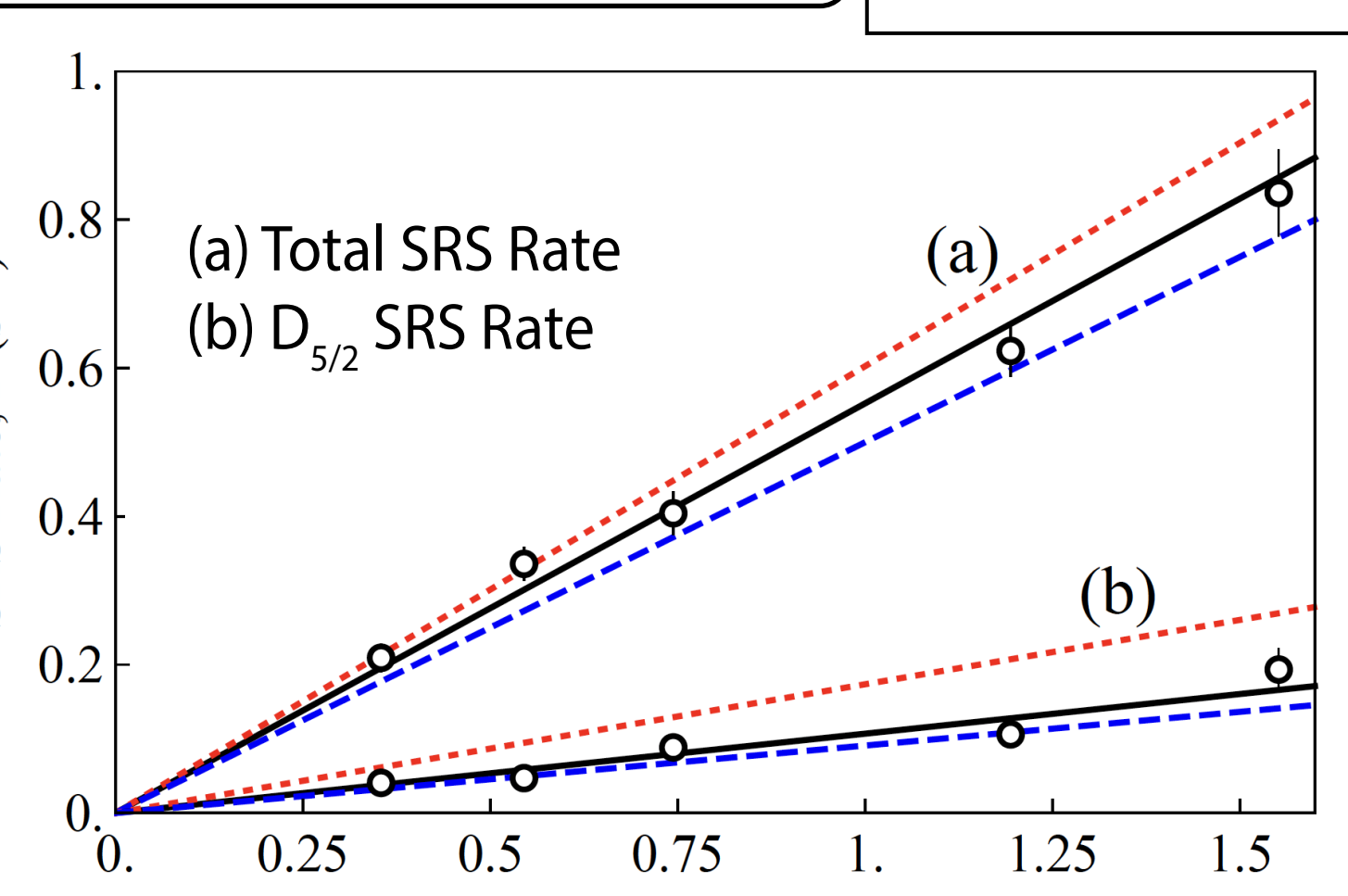
-Raman Gate fidelity is fundamentally limited by Stimulated Raman (SR) Scattering

Simplified Theory: (at large detuning Δ)

- SR transition rate: $\Omega_R \sim 1/\Delta^2$
- Photon scattering rate: $R \sim 1/\Delta^2$
- Probability of scattering photon: $R/\Omega_R \sim \text{constant}$

New Theory:

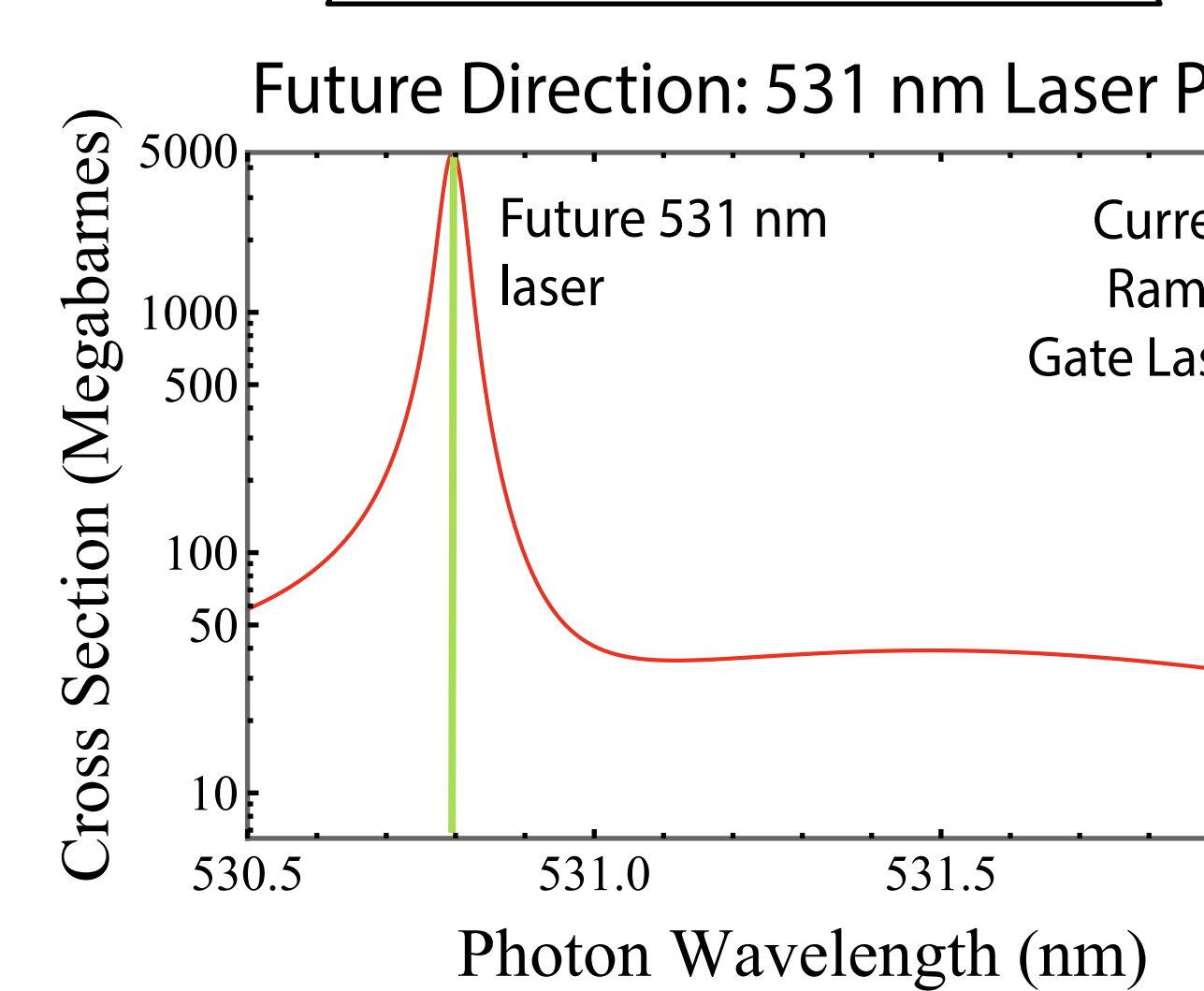
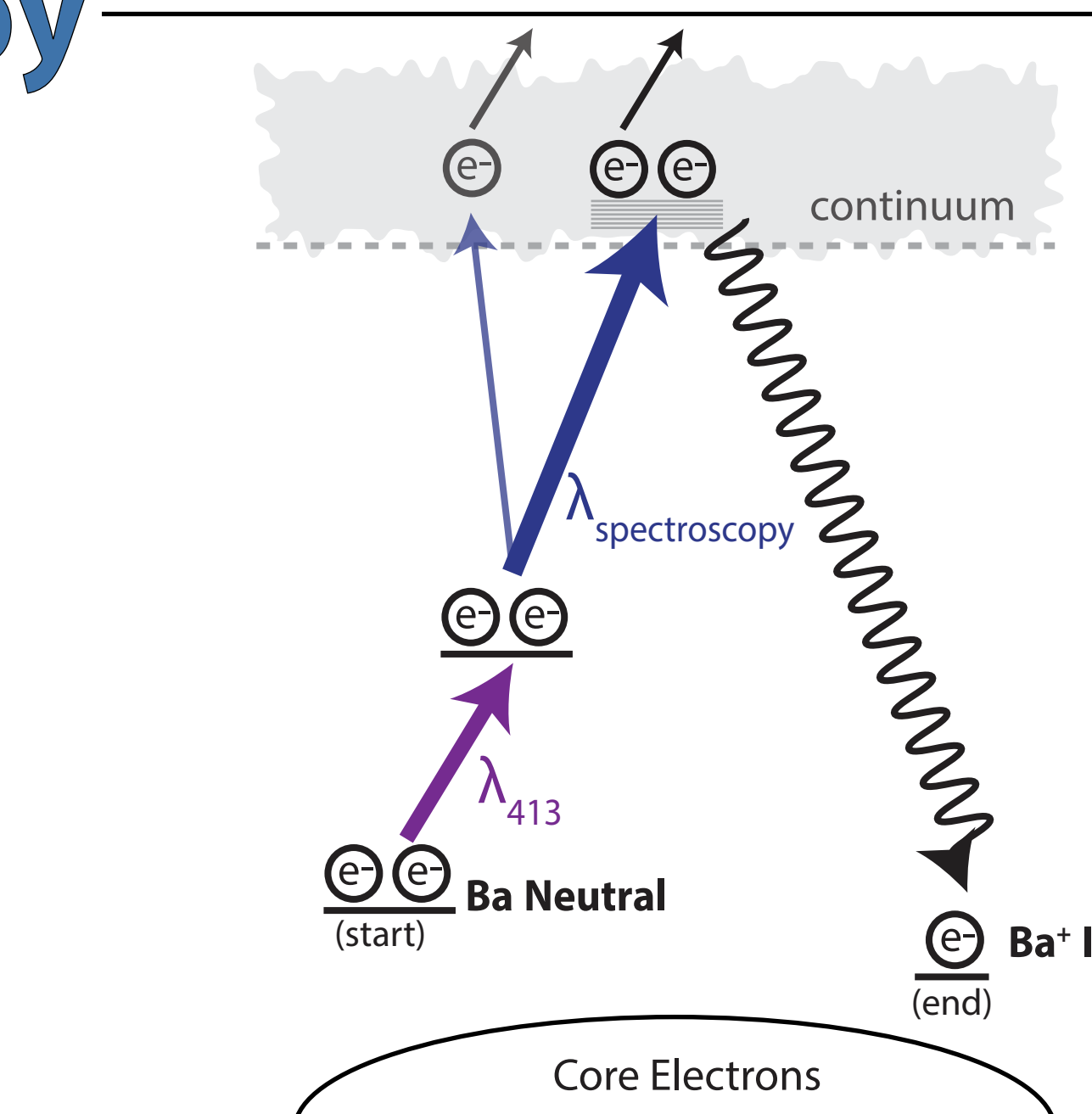
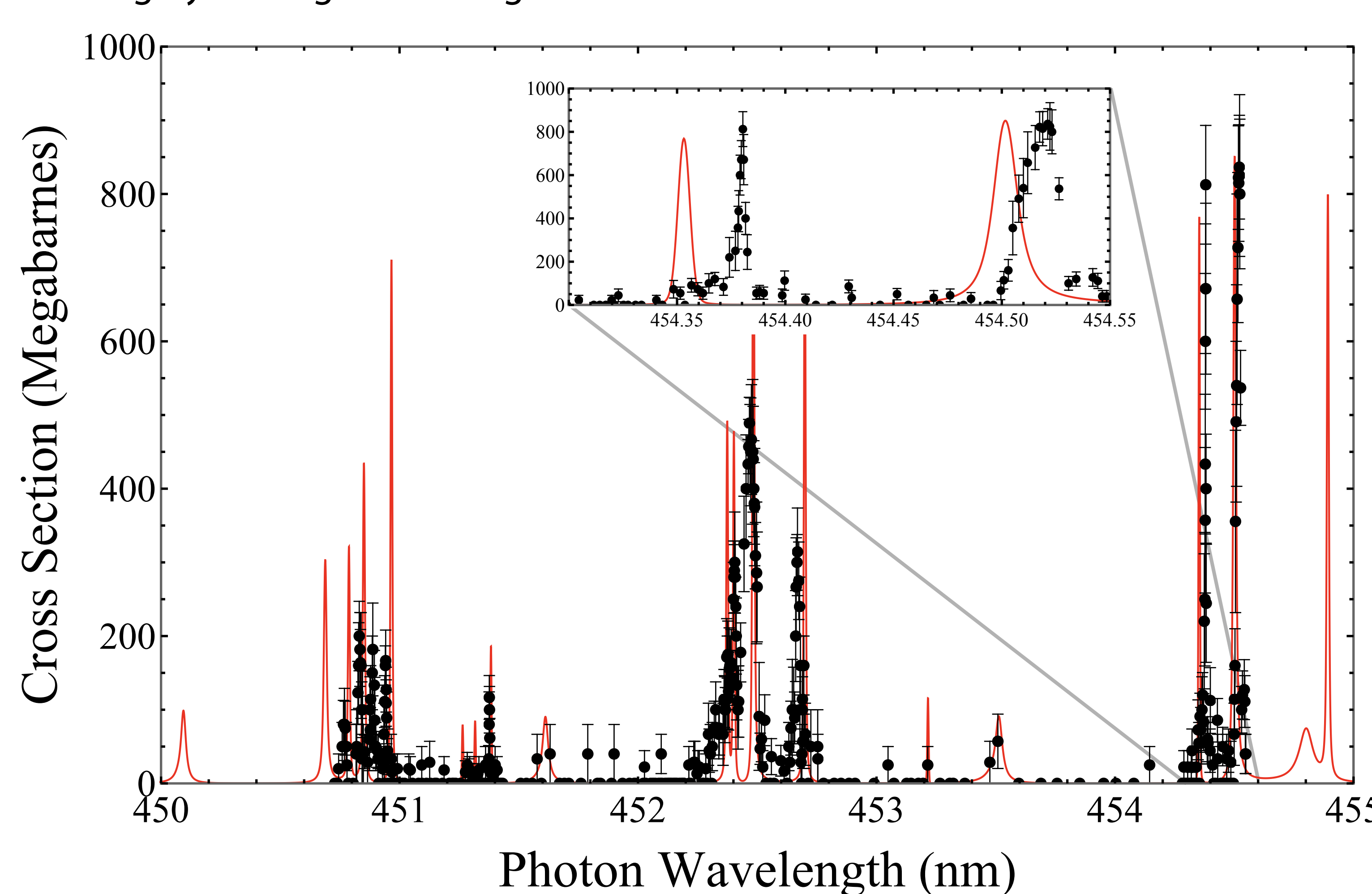
- Allows for variable density of states of the photon scattered frequency, ω_{sc} : $R \sim \omega_{sc}^3/\Delta^2$
- Scattering **not** constant as a function of wavelength



PhysRevLett.131.063001

Autoionization Spectroscopy

- Highly efficient loading with 413 + 454 to autoionizing state
- Roughly 60x higher loading rate over 413 + 413 scheme



Integrated Photonics Trap

- Nanofabricated surface trap with on-chip waveguides
- Printed micro-reflectors to address ions for single or two qubit gate operations
- Al₂O₃ waveguide core engineered for all Barium wavelengths in single waveguide

