Simulation of Optical Pumping in Laser Spectroscopy of Ga at TRIUMF

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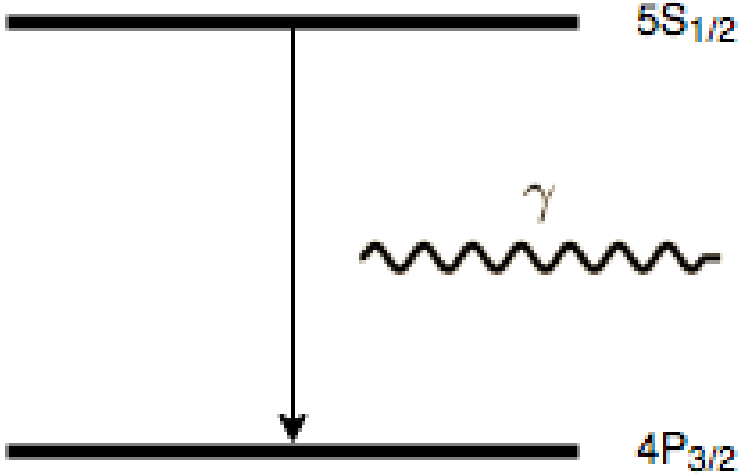
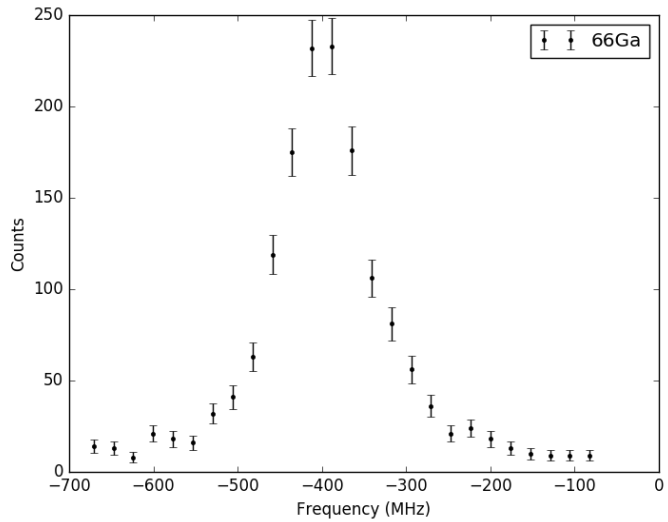
February 16, 2017

Laser Spectroscopy

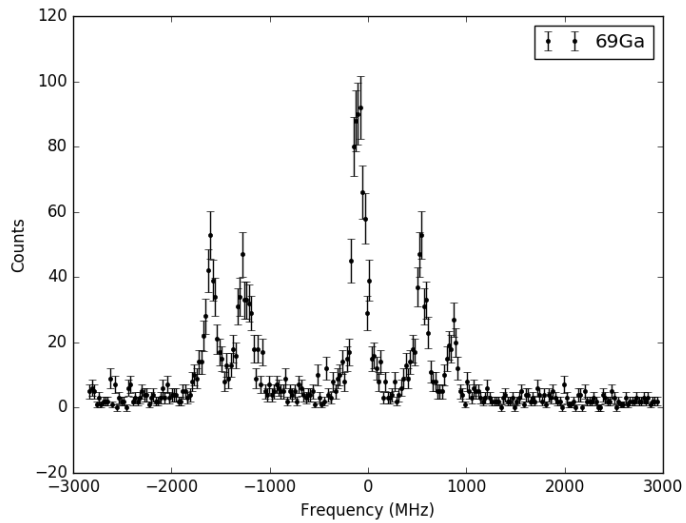
- Use a laser to drive electron transitions in atoms. Measure photons released on de-excitation.





Laser Spectroscopy: Hyperfine Atomic Structure

- The nuclear spin couples with the orbital angular momentum of the electron, giving additional structure to atomic spectra.

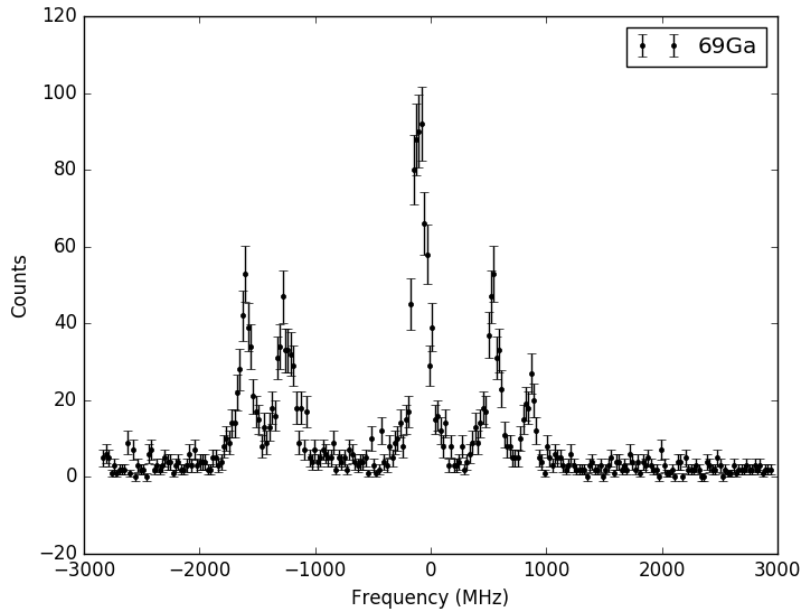


Hyperfine Spectra: Peak Locations

$$\Delta E = \text{I.S.} + \frac{K}{2}A + \frac{3K(K+1) - 4I(I+1)J(J+1)}{8I(2I-1)(2J-1)}B$$

$$K = F(F+1) - I(I+1) - J(J+1)$$

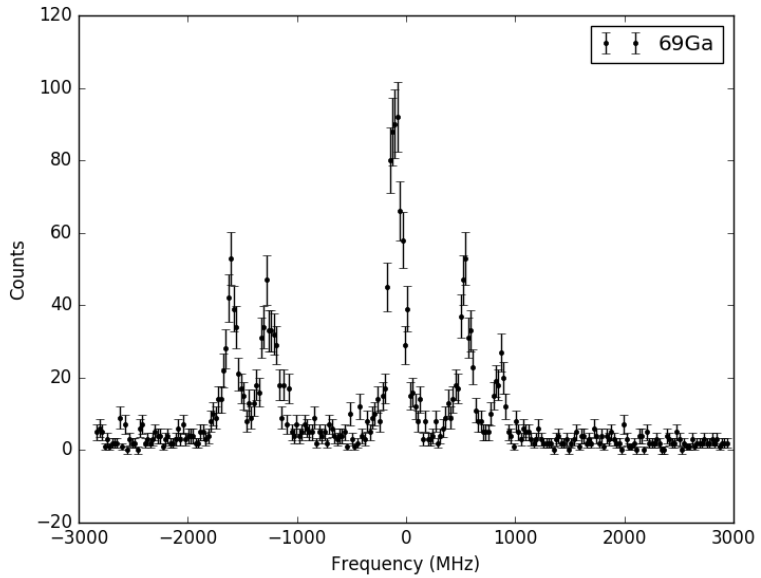
- Isotope Shift
  $\rightarrow \delta < r^2 >$
- Magnetic Dipole Moment: A $\rightarrow \mu_M$
- Electric Quadrupole Moment: B $\rightarrow Q$



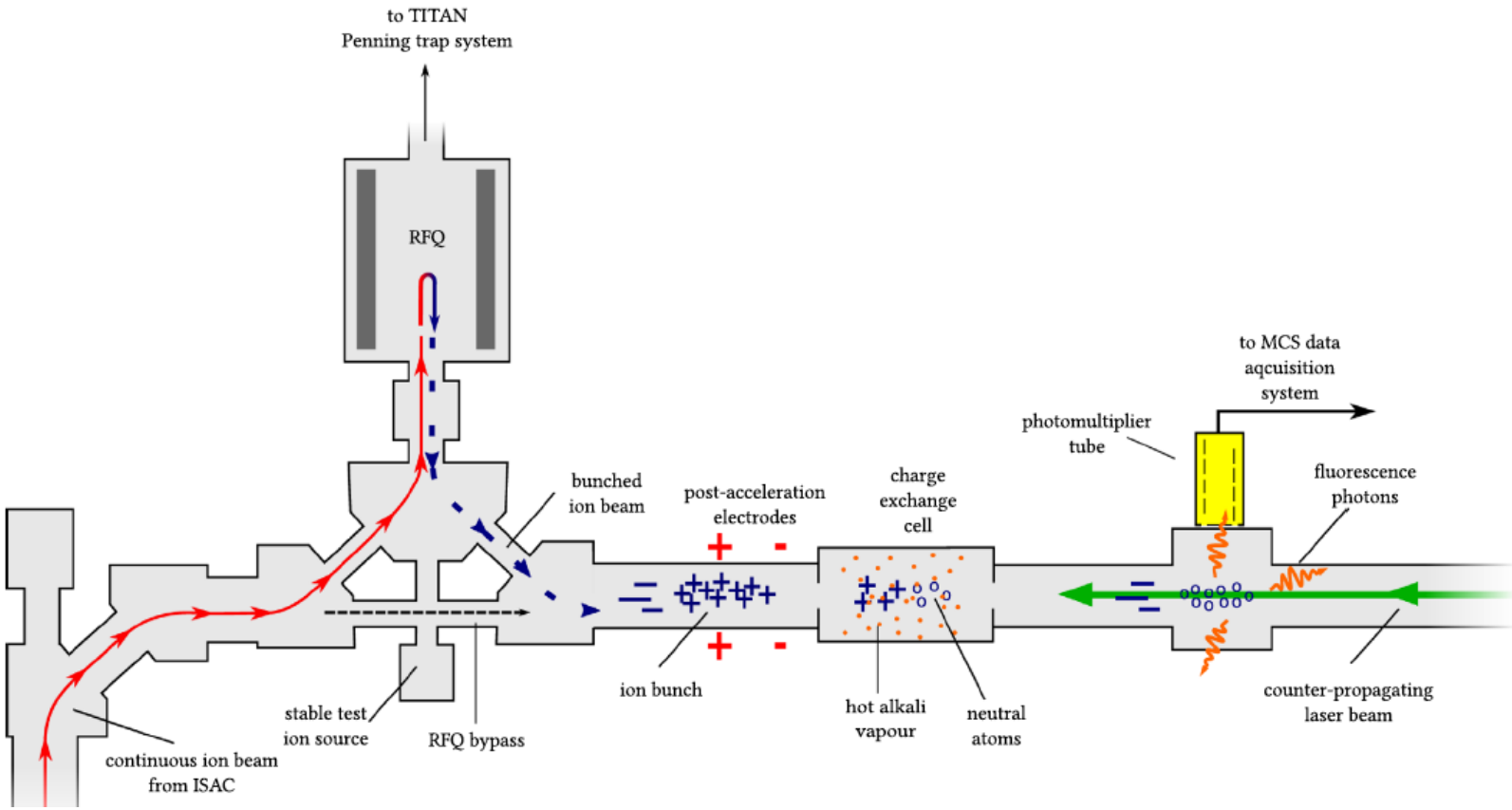
Hyperfine Spectra: Peak Heights

$$\text{Intensity} = (2F_{\text{lower}} + 1)((2F_{\text{upper}} + 1) \begin{Bmatrix} F_{\text{lower}} & F_{\text{upper}} & 1 \\ J_{\text{upper}} & J_{\text{lower}} & I \end{Bmatrix}^2$$

- Relative peak heights give I
- Main reason to simulate full hyperfine spectra



Laser Spectroscopy at TRIUMF



Challenges

- Optical Pumping
  - Between CEC and LCR, electron goes through several excitation/de-excitation cycles
  - Electron is less likely to be in its original ground state at entry of LCR

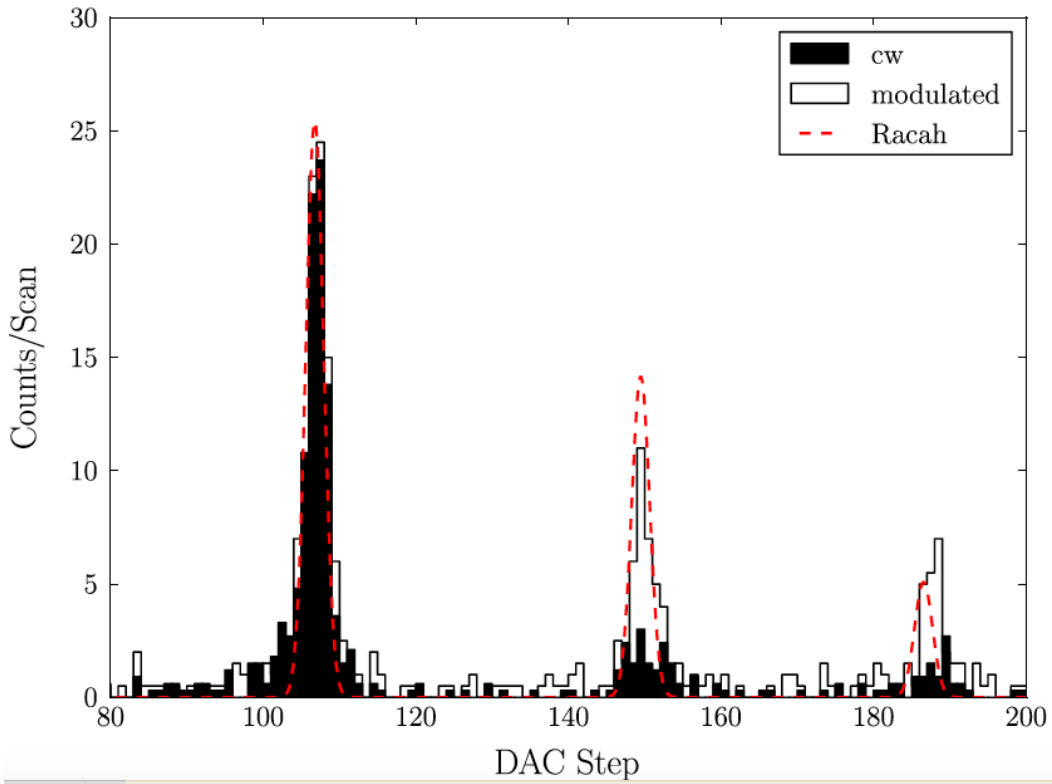


Figure: Spectrum of francium showing the effects of optical pumping.

Simulating Hyperfine Spectra

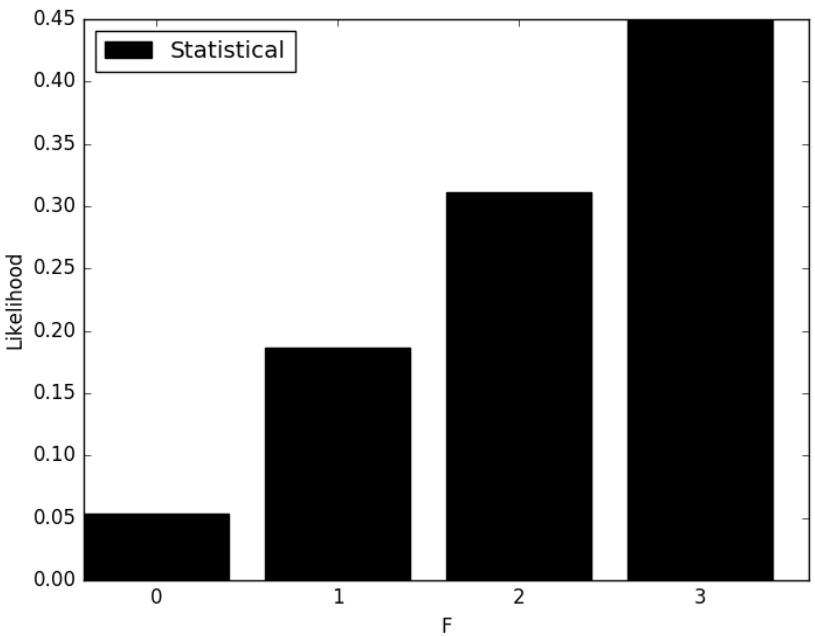
Goal: Follow atoms as they pass between the CEC and LCR and reproduce spectrum measured in LCR

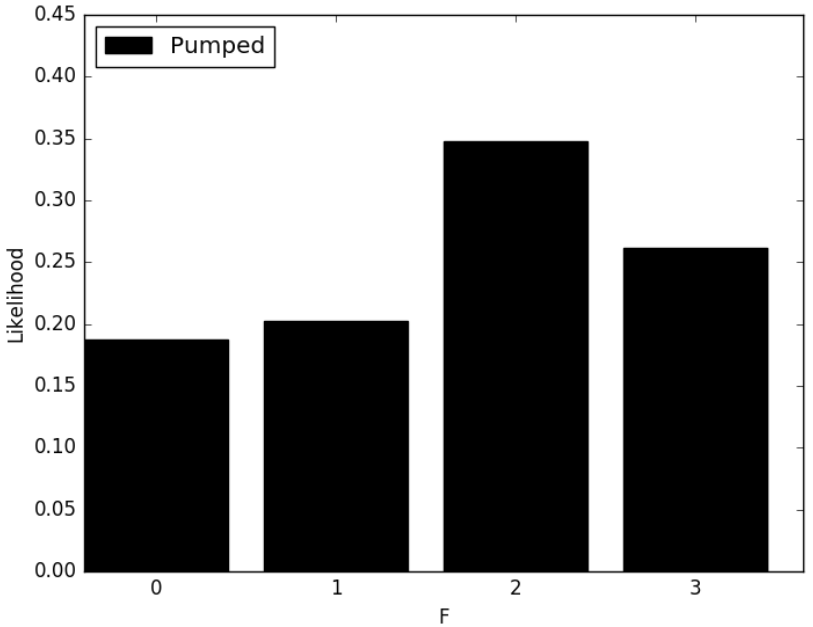
Relevant Quantities

- Transition energies, decay rate (γ), lifetimes(τ) and natural line widths (σ_E)
  - $\gamma = \frac{\omega^3 \mu^2}{3\pi\epsilon_0 \hbar c^3}$, $\tau = 1/\gamma$, $\sigma_E = \frac{1}{2\pi\tau}$
- Temperature of Beam (Affects peak width)
- Ground state distributions at beginning of CEC
  - Statistical distribution is assumed. Electrons populate ground states according to $2F + 1$

Current Results

- Modified ground state distribution at entrance of LCR





Current Results

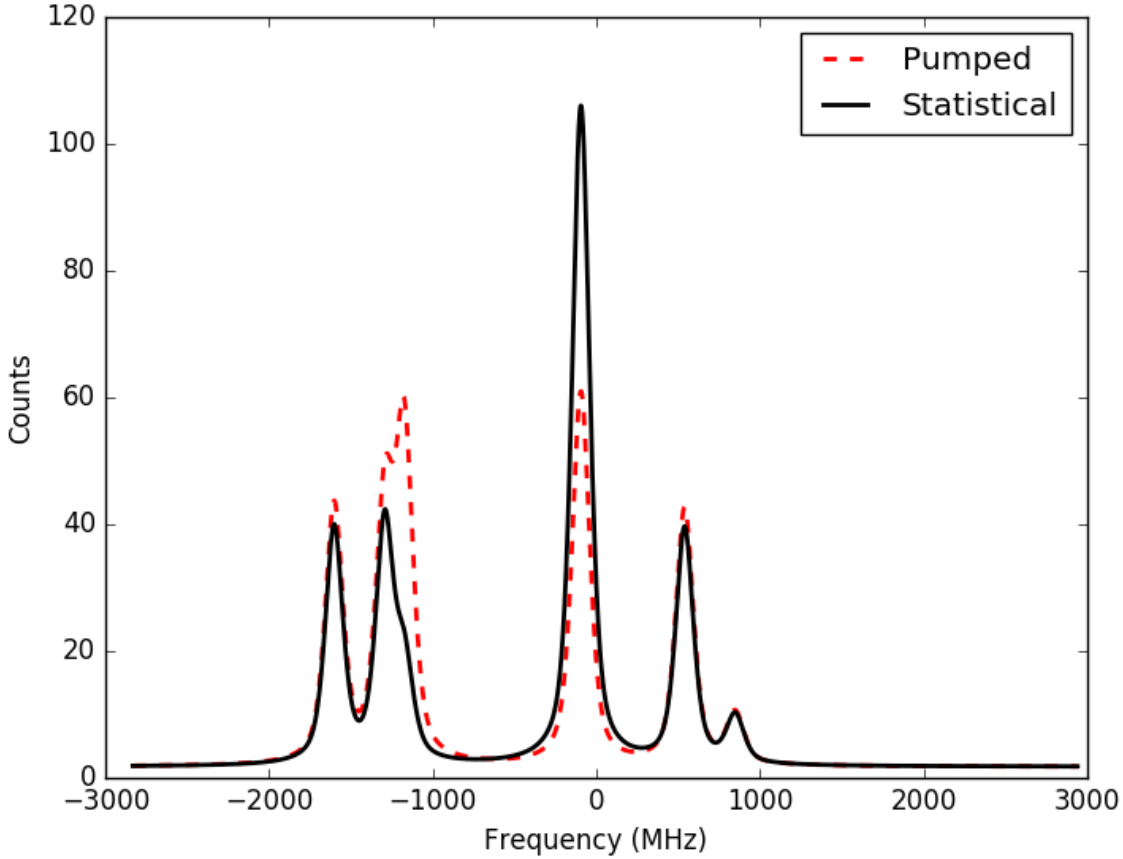


Figure: Ga69 spectrum assuming a statistical distribution of the ground states (black) compared to a theoretical spectrum produced from a pumped ground state distribution (red)

Conclusion

- Optical pumping affects the results of laser spectroscopy (Relative peak intensity)
- Set up at TRIUMF is susceptible to the effects of optical pumping
- Simulation of hyperfine spectra can lead to a better prediction of nuclear spin (I)
- So far, simulation shows a change in the ground state distributions of the atoms as they enter the LCR

Questions?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