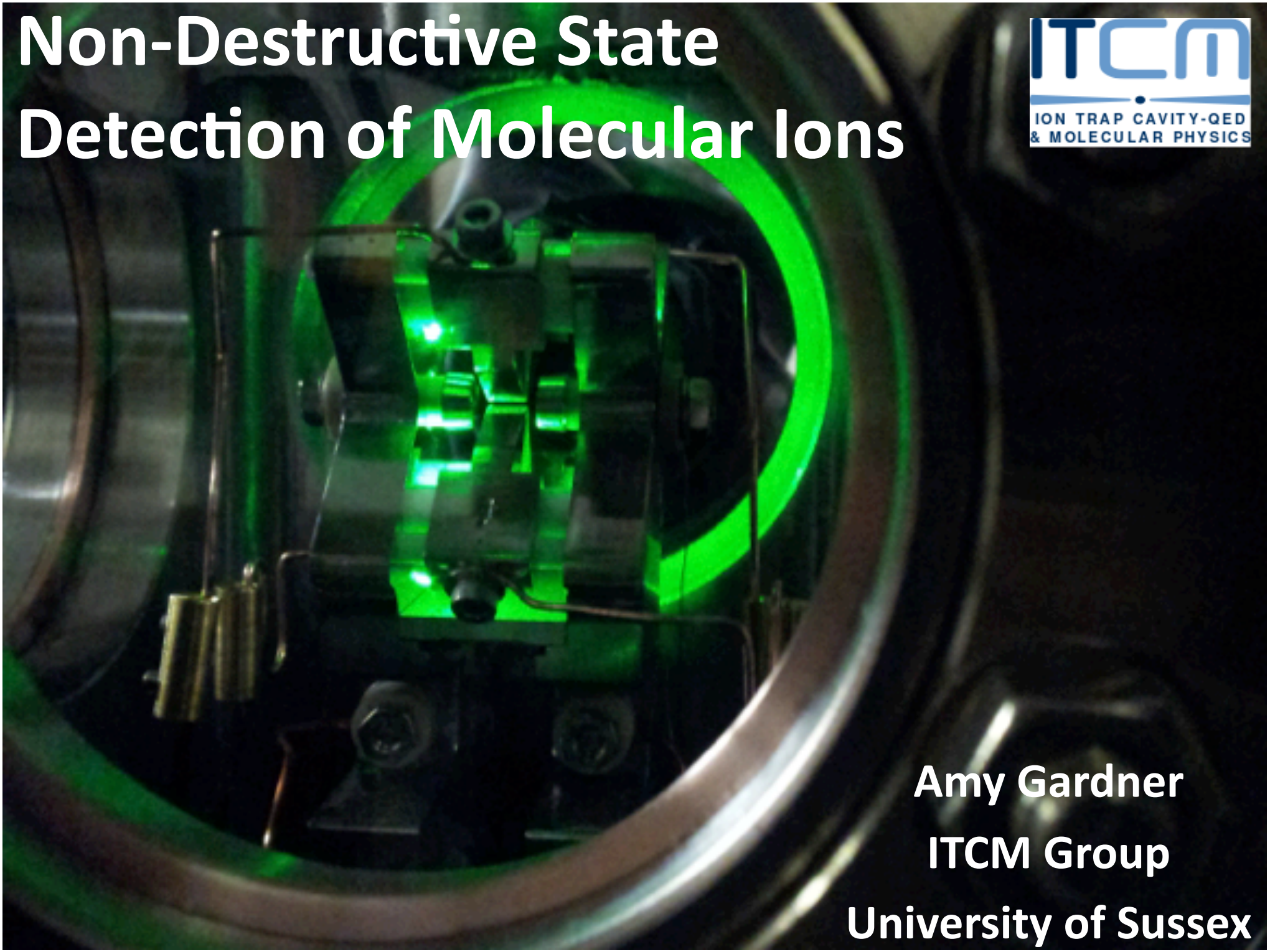
Non-Destructive State Detection of Molecular Ions



ITCM
ION TRAP CAVITY-QED & MOLECULAR PHYSICS

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University of Sussex

Outlook

- **Non-Destructive State Detection:**
  - -Molecules
  - -Dipole force
- **Experimental Set-up:**
  - -Ion Trapping
  - -Molecular Beam Line
- **Requirements:**
  - -State Readout
  - -Optical Excitation and Amplification
  - -Tuned Damping

Challenges in Molecular Ion Physics

Localized molecular ions in well-defined internal states are of broad interest for physics and chemistry:

- **Test of fundamental physics**
  - ***-Time variation of fundamental constants***
  - ***-Electron EDM***

J.Hudson PRL 89, 023003

- **High precision spectroscopy of molecular ions**
  - ***-Alternative frequency references***
  - ***-Molecular structure calculations***
- **Quantum Computation**
  - ***-Possible qubit***

D.DeMille PRL 88, 067901

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D.DeMille PRL 88, 067901

Challenges:

Cooling Molecules:

~~Laser Cooling~~

Sympathetic Cooling

State detection:

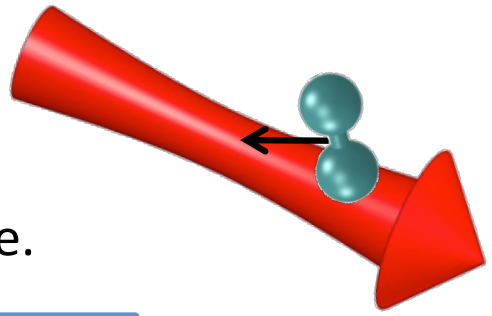
~~REMPD~~

Non-destructively

State Detection: Laser-induced Dipole Force

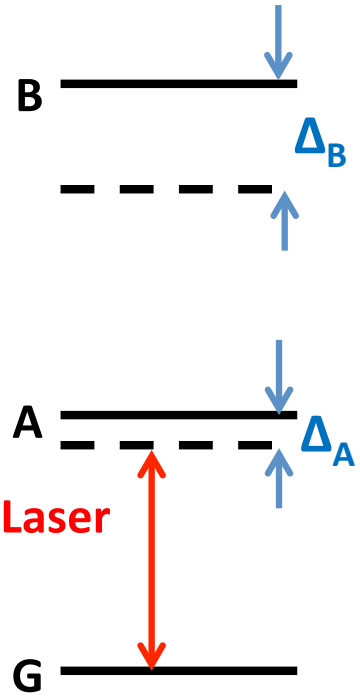
Laser-Induced dipole force:

$$\vec{F} = -\frac{\hbar}{2}\nabla\Omega$$



For Large detuning, ie.

$$\Delta >> \Omega$$



State-Dependence:

$$\vec{F} = -\frac{\mu^2}{\varepsilon_0 c \hbar \Delta}\nabla I$$

State selective

$$\Delta_B >> \Delta_A$$

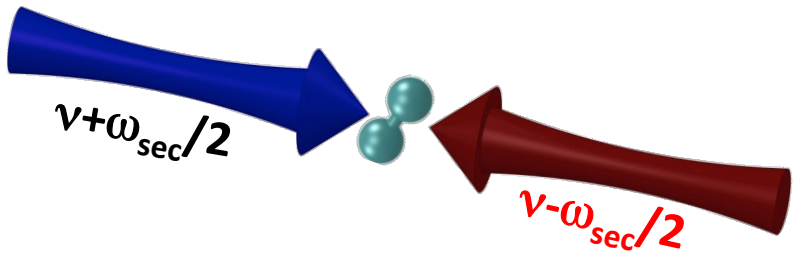
$$F_G >> F_A$$

Well separated transisions!

Create a Walking Wave with two Counter-propagating lasers:

- Dipole force will oscillate at ω_{sec} if this is the frequency difference

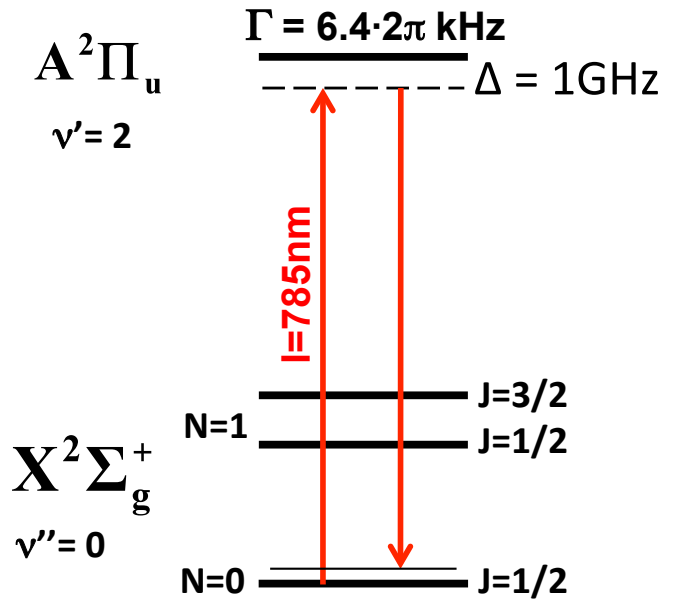
-The motion of the ion is then resonantly excited at its secular frequency

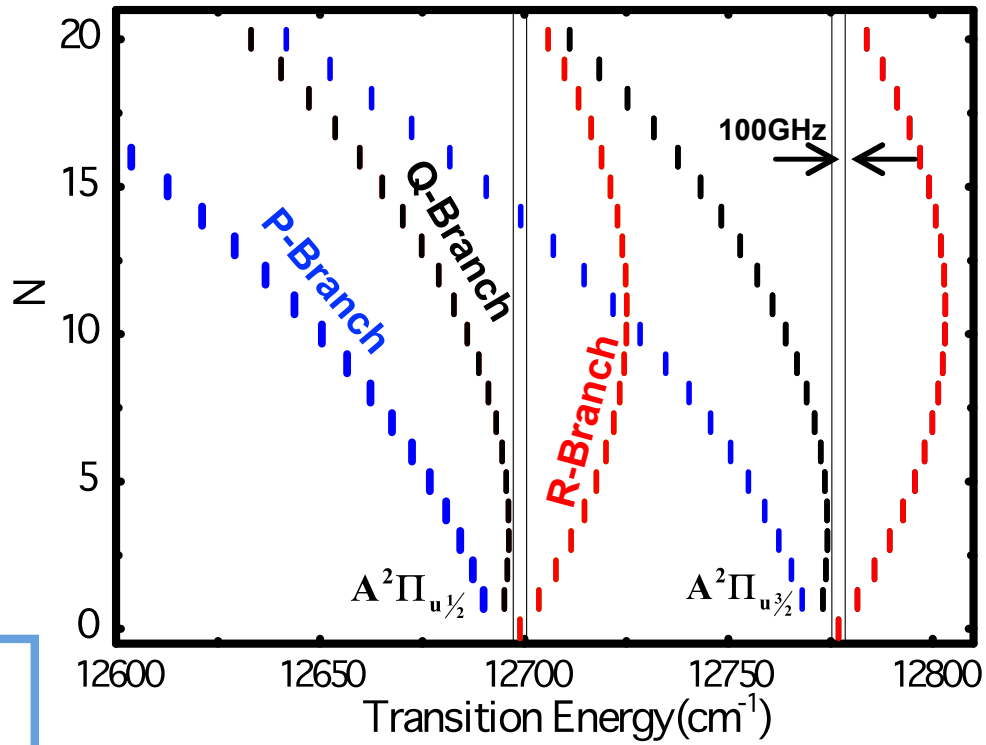


Walking wave

Transition separation for N_2^+

State detection requires **large separation of transitions:**





Splitting of rotational transitions (R-branch) : **> 100 GHz**

Ratio of dipole forces between adjacent states: **> 500**

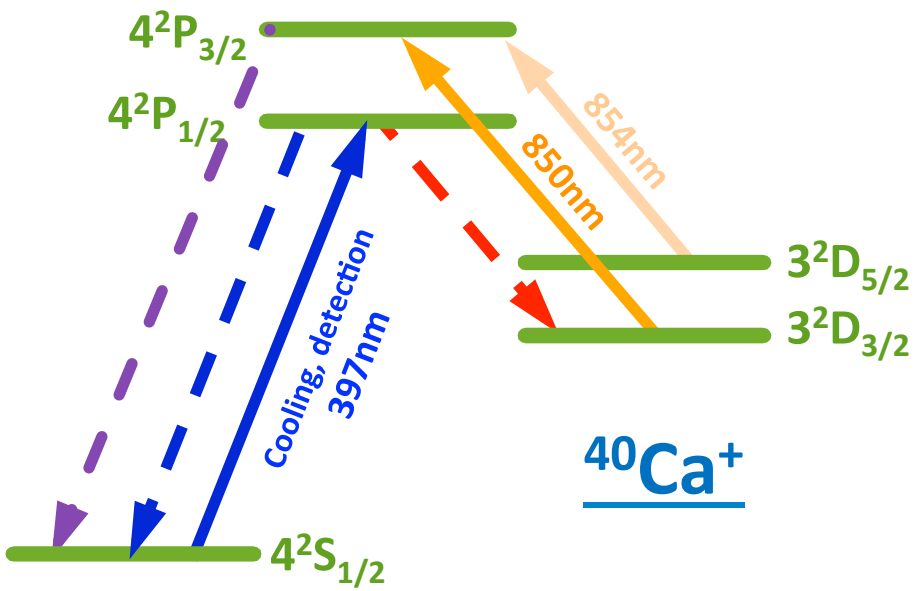
Spontaneous decay probability (~1ms): **< 0.1%**

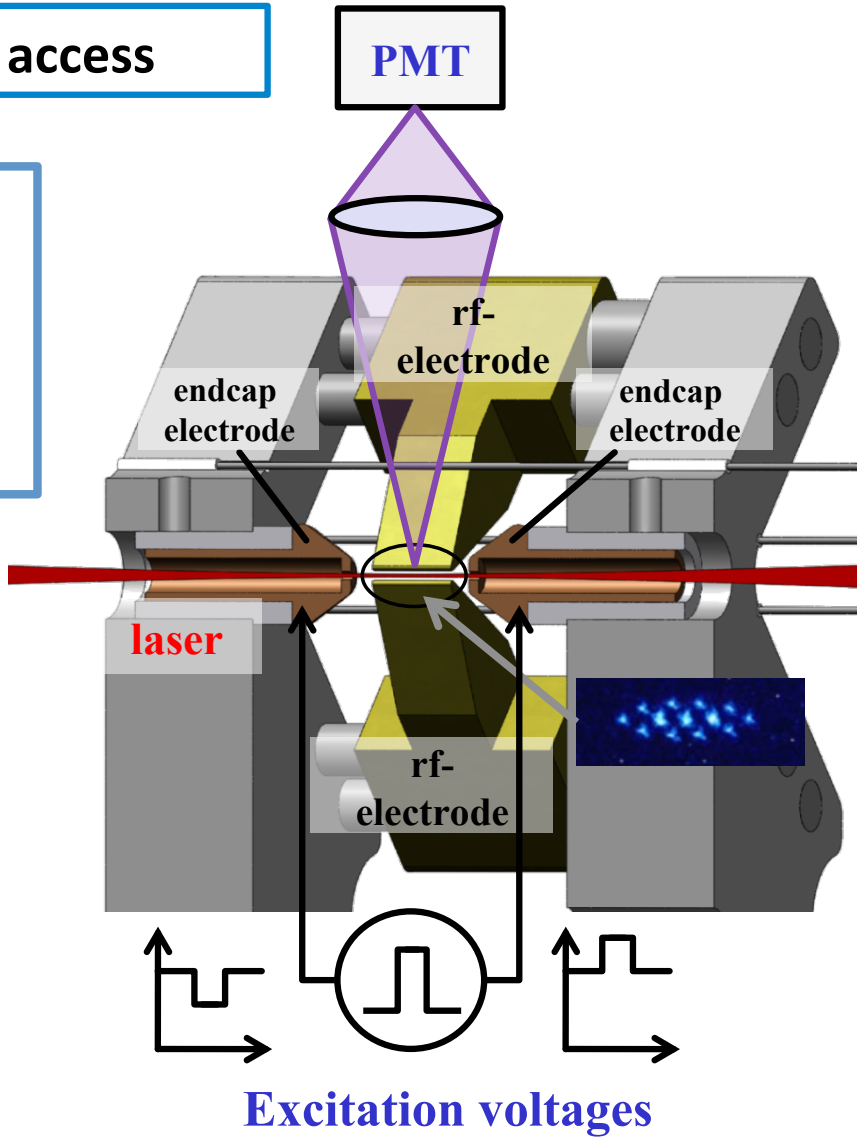
P: ΔJ = -1
Q: ΔJ = 0
R: ΔJ = 1

Ion Trap setup

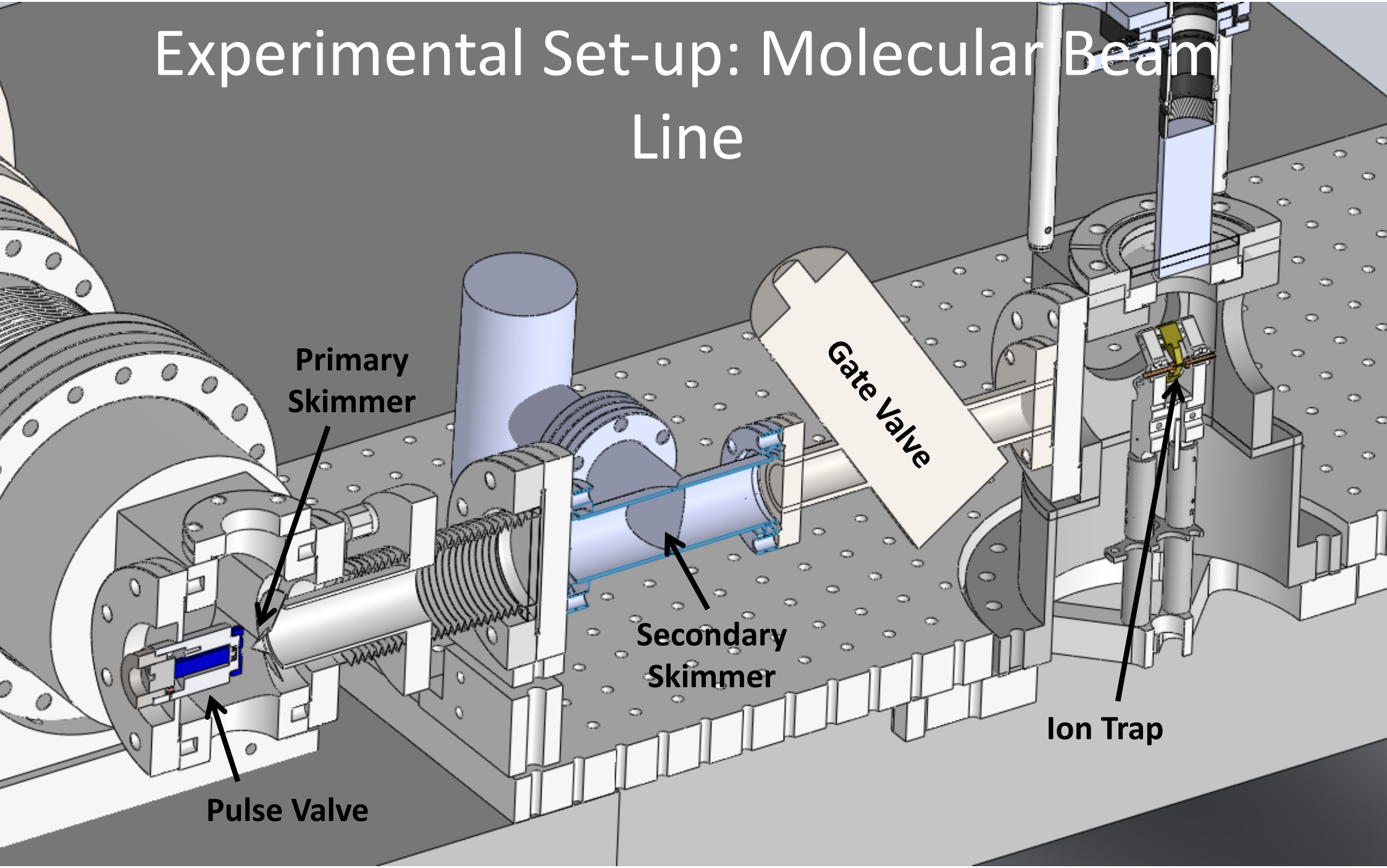
Linear Paul Trap design with good optical access

Trap Parameters:
Trap Frequency: 34.5 MHz
Ion-Electrode Distance: 460 µm
Trap length: 6mm
Radial Confinement: 2 MHz





Experimental Set-up: Molecular Beam Line



So far...

- **Non-Destructive State Detection:**
  - -Molecules
  - -Dipole force
- **Experimental Set-up:**
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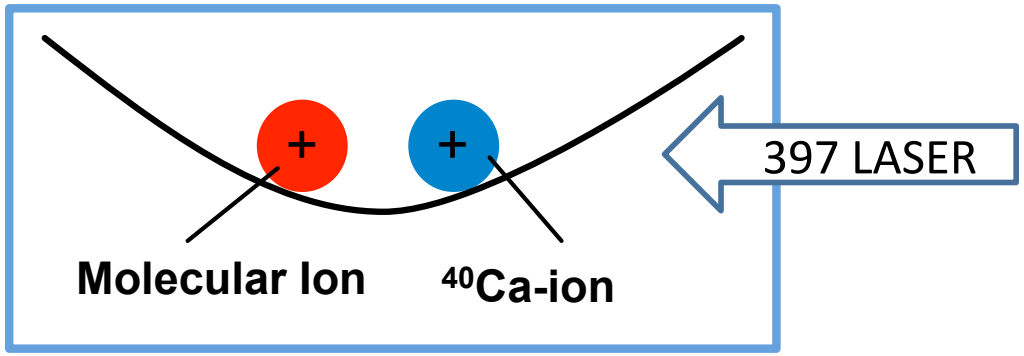
  - -State Readout
  - -Optical Excitation and Amplification
  - -Tuned Damping

State Readout\Requirements

State readout through ^{40}Ca-ions, trapped alongside the molecule.



State Readout\Requirements

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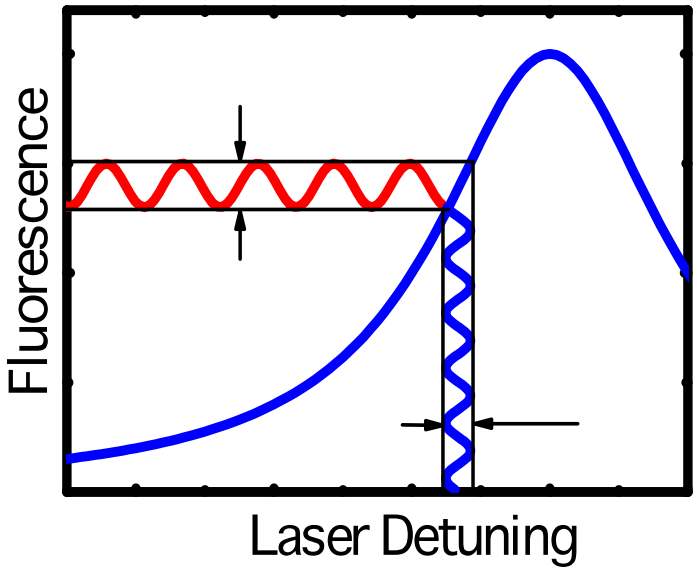
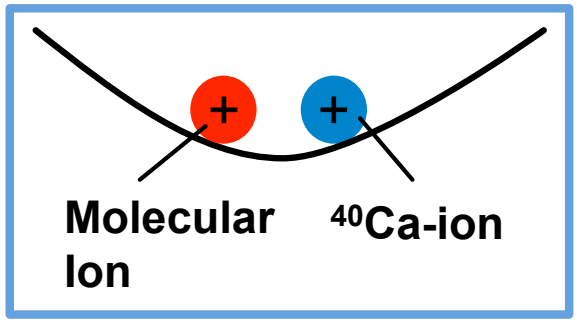
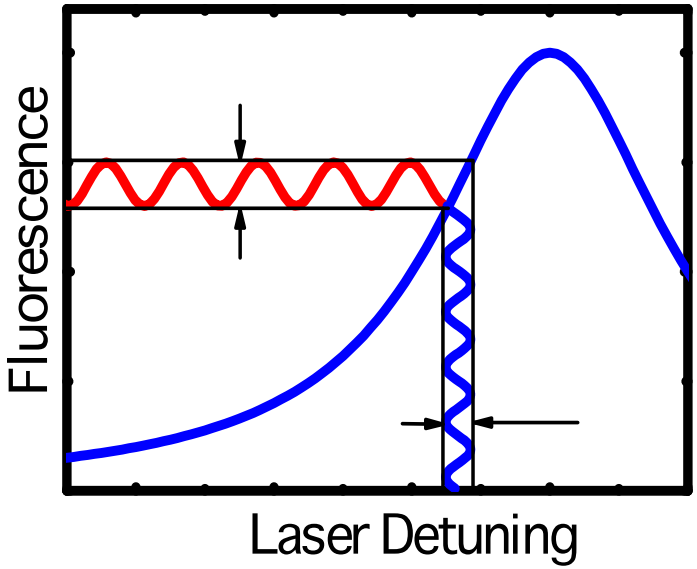


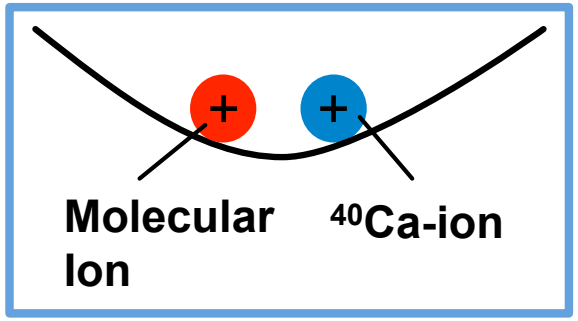


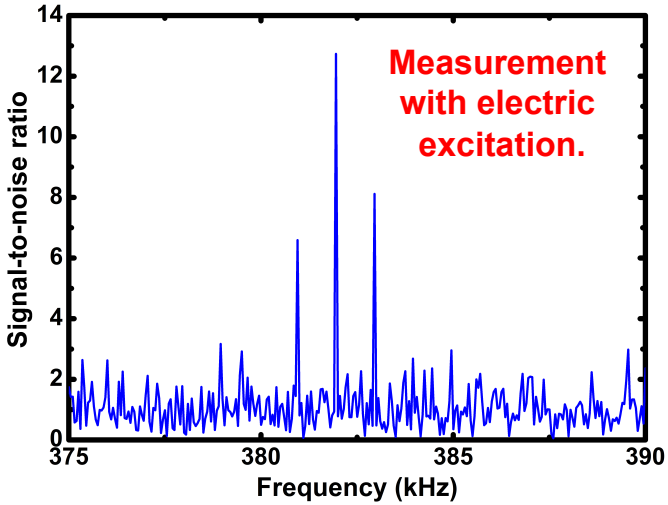
State Readout\Requirements

State readout through ^{40}Ca-ions, trapped alongside the molecule.

Doppler Velocimetry → **FFT of auto-correlation**







Parameters:

10 ^{40}Ca-ions

100 excitation pulses

→

Required:

~1 ^{40}Ca-ions

1 excitation pulse

- Increase in fluorescence collection efficiency:

currently **< 0.25%** → **~5%**

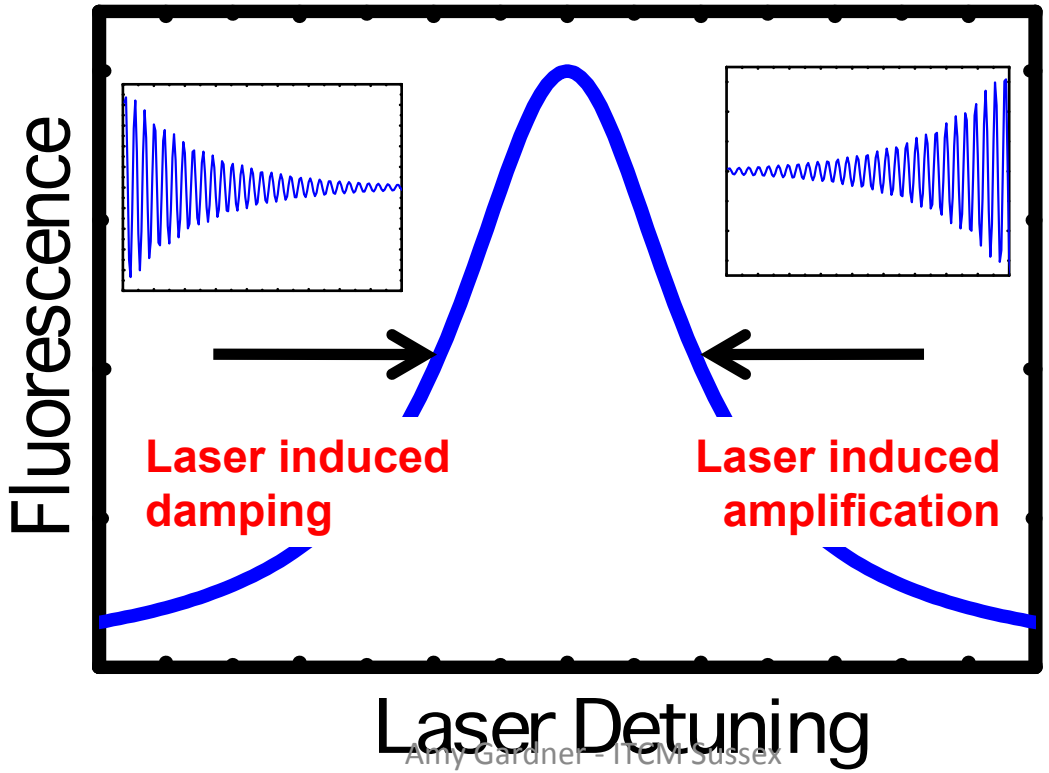
- Amplification of motion…

Optical Excitation and Amplification

Problem: typical force ~zN
(~100-1000 x smaller than electric excitation)

Use radiation pressure to excite motion of ions to simulate dipole force

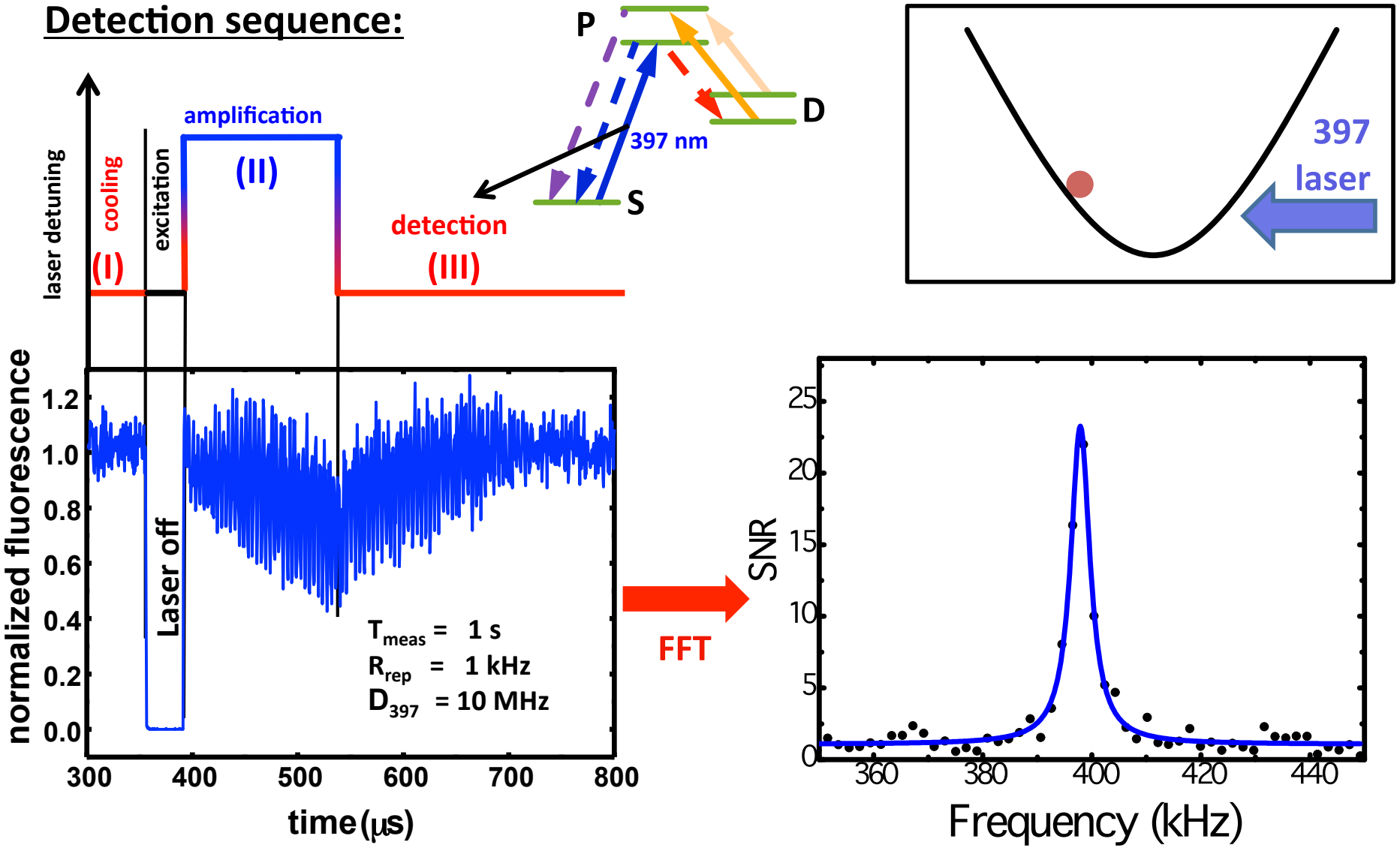
Signal enhancement by amplifying the coherent motion required



Velocity dependent laser induced radiation pressure leads to damping / enhancement of ion's motion.

D.B. Hume PRL

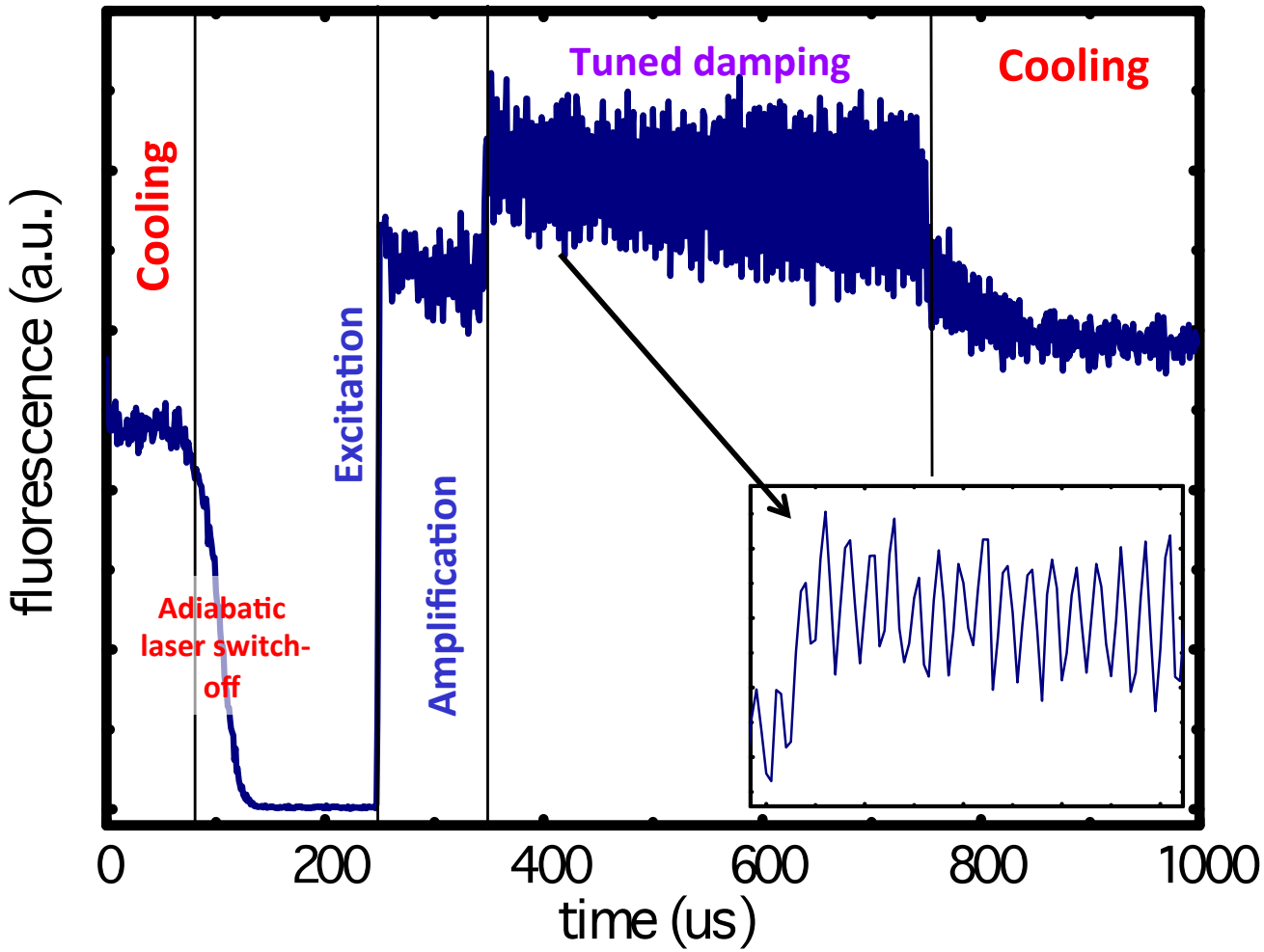
Optical Excitation and Coherent Amplification



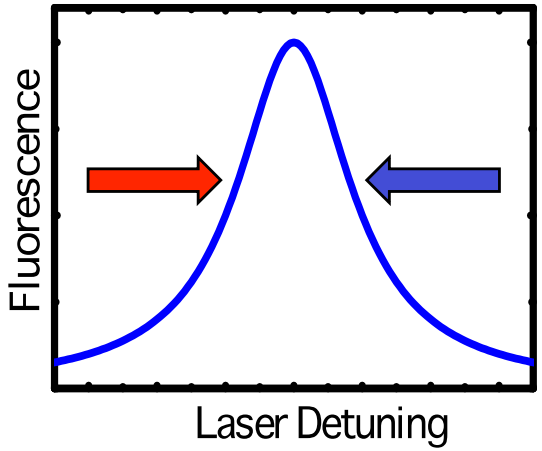
Eur. Phys. J. D 66:289 (2012)

Tuned Damping

Effective damping tuned by changing ratio of laser intensities



Laser pulse sequence to test tuning of damping



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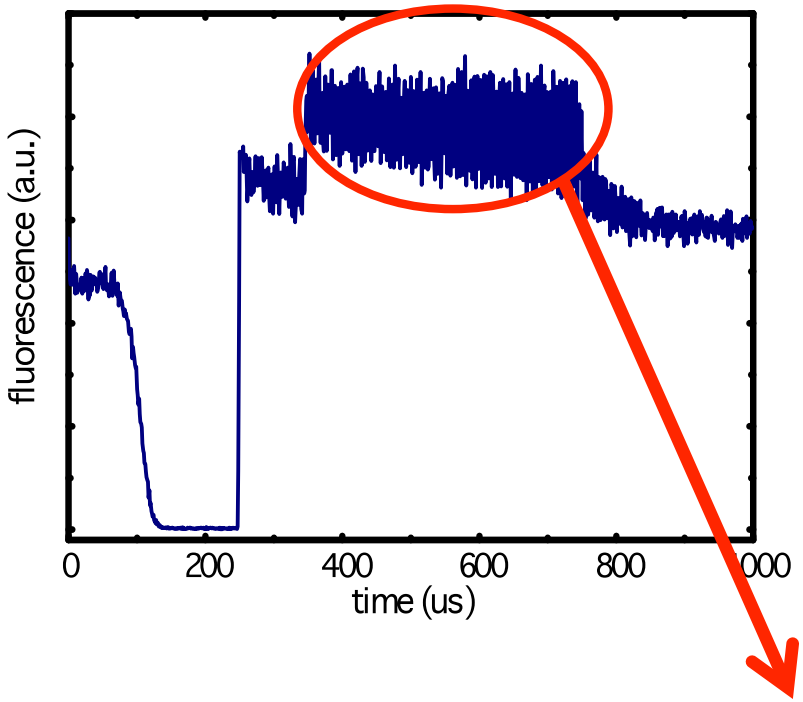
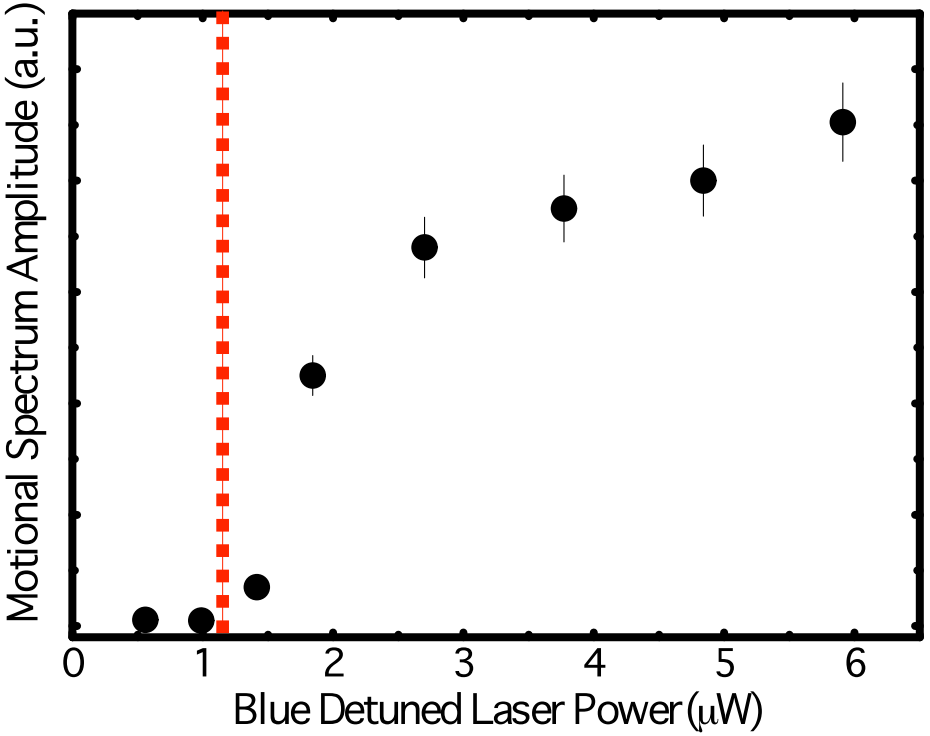
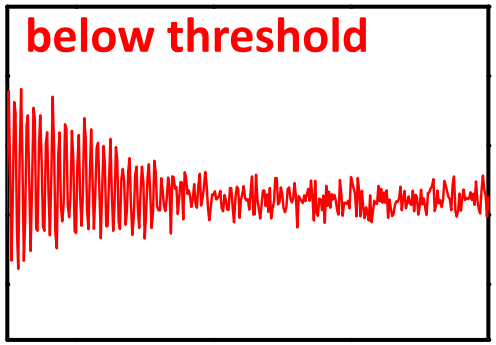
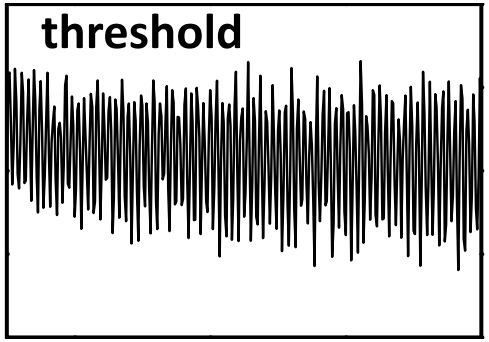


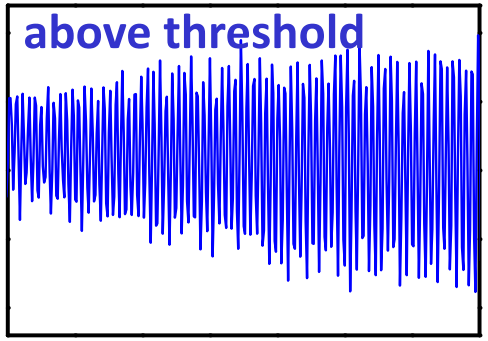




Strong damping of ion's motion



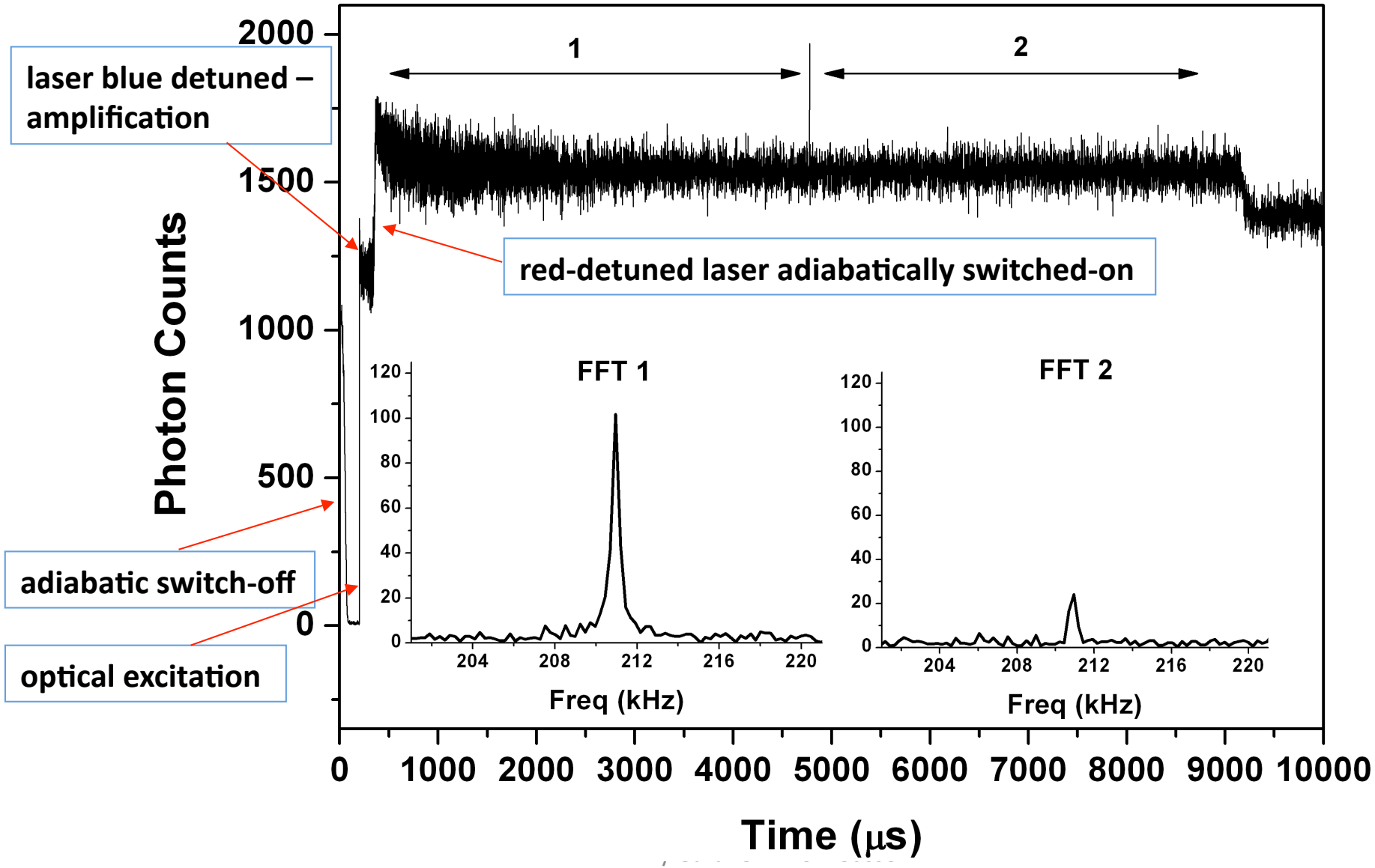
Initial oscillation amplitude maintained



Increase of oscillation amplitude until saturation

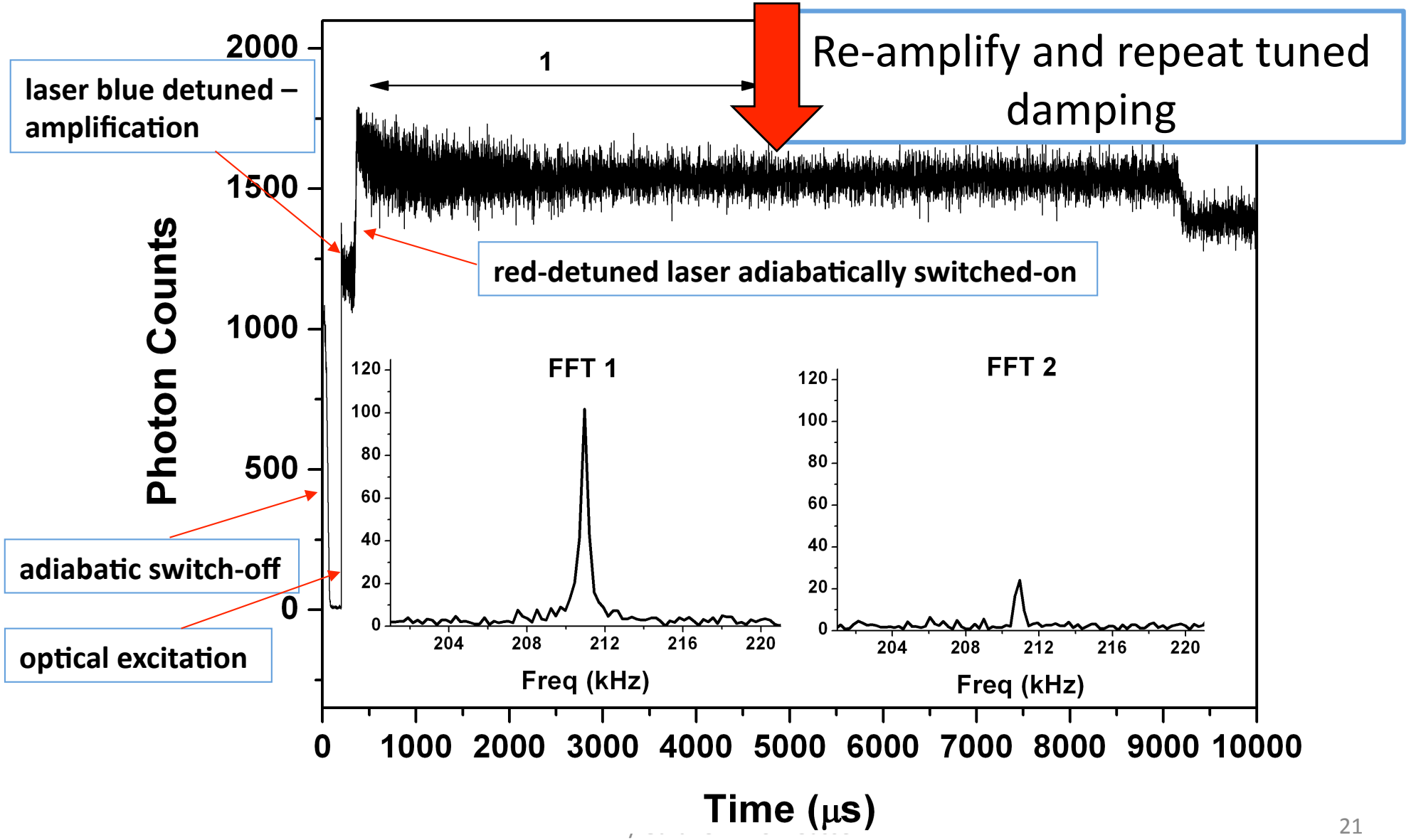
Single shot measurement

Prolong the damping period for ~ms ➡ repeat amplification/damping



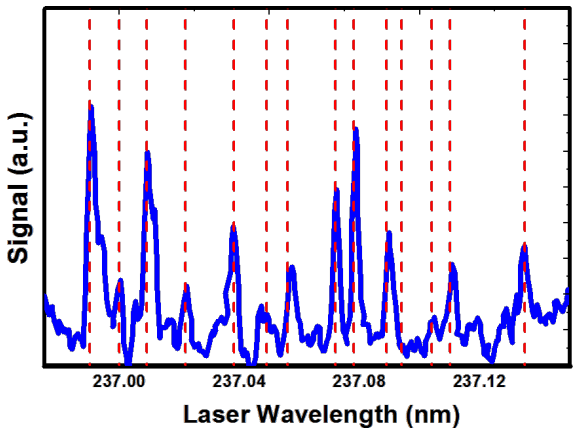
Single shot measurement

Prolong the damping period for ~ms → repeat amplification/damping

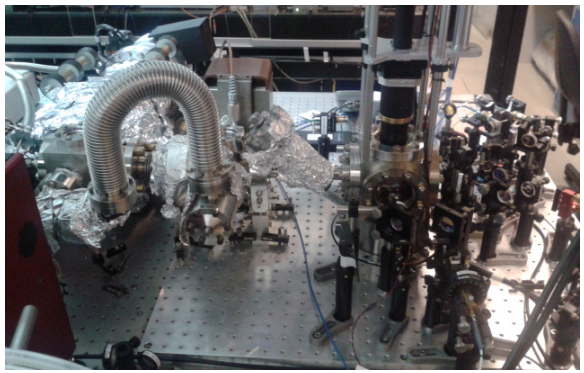


Outlook

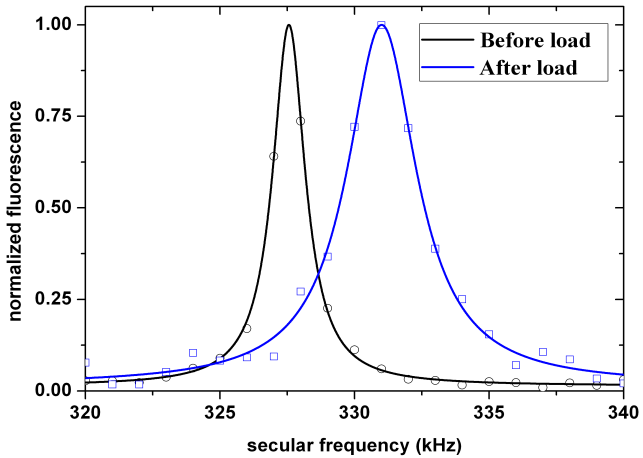
N_2 Ionisation spectrum found



Molecular beamline and Ion trap constructed

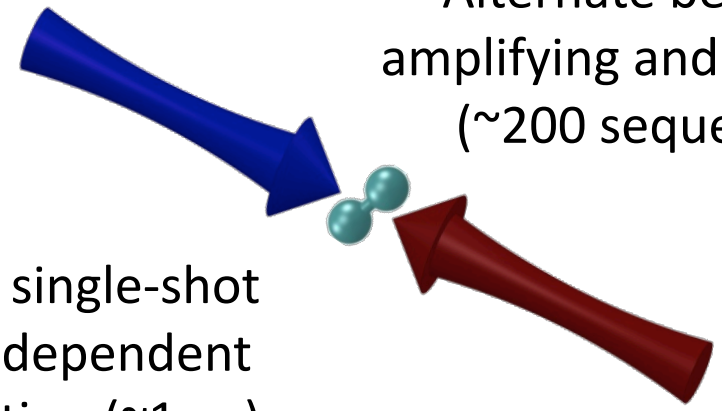


N_2 successfully loaded into trap alongside $^{40}Ca^+$

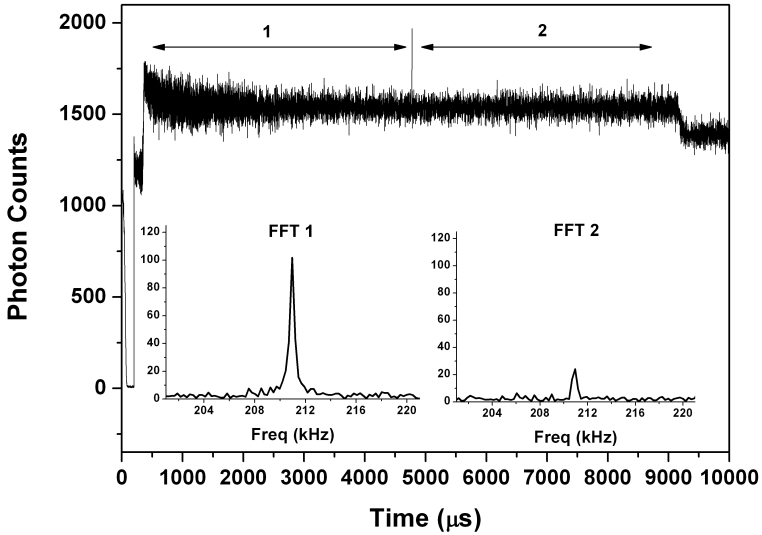


Next…

Alternate between amplifying and damping (~200 sequences)



Apply single-shot state dependent excitation (~1ms)



EPSRC

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