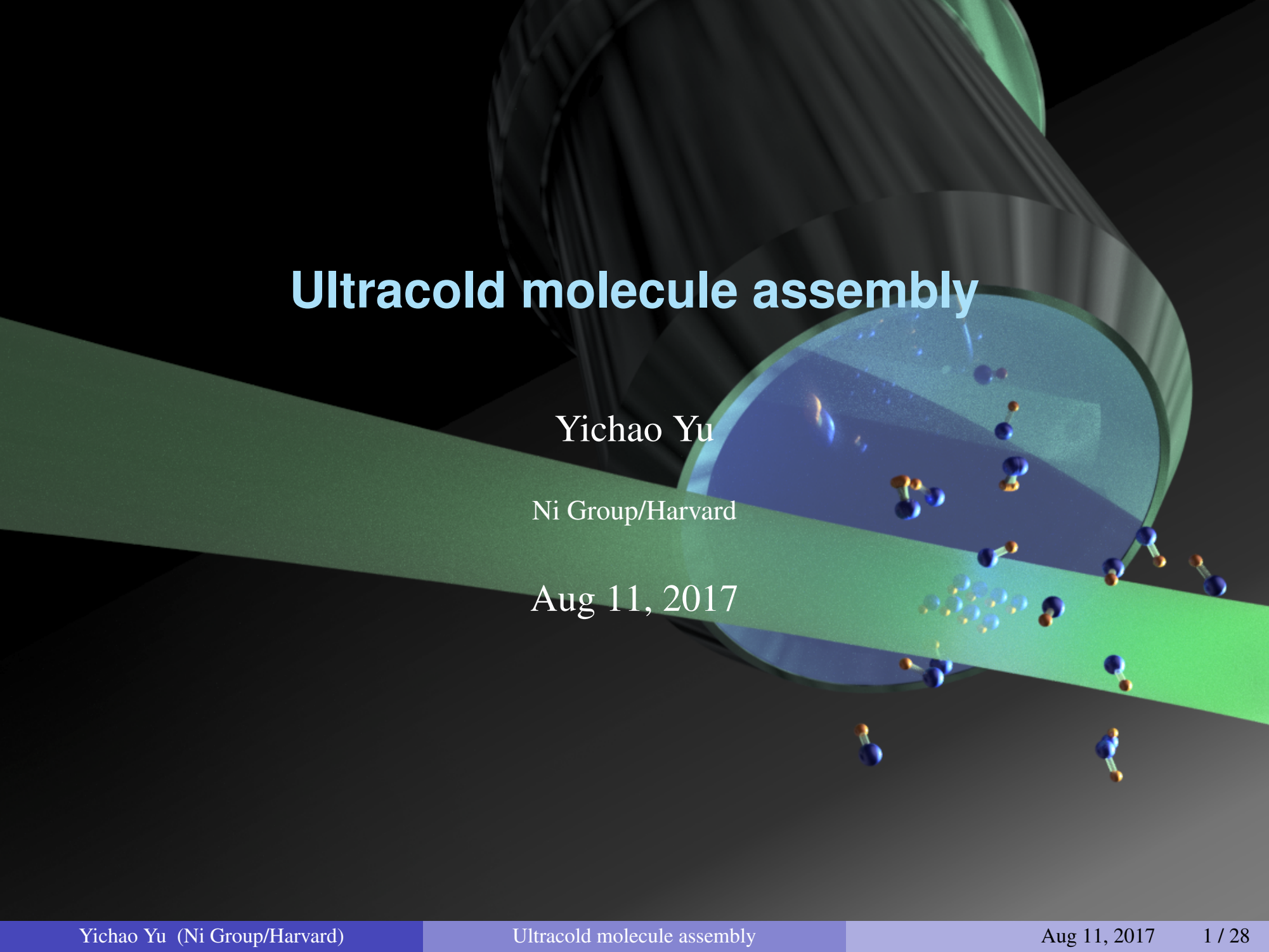


Ultracold molecule assembly

Yichao Yu

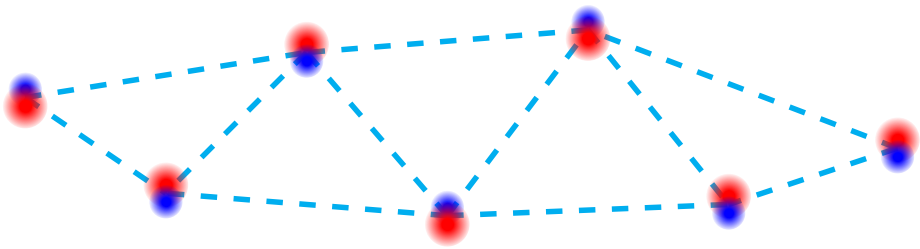
Ni Group/Harvard

Aug 11, 2017

Molecules in optical tweezer

Features

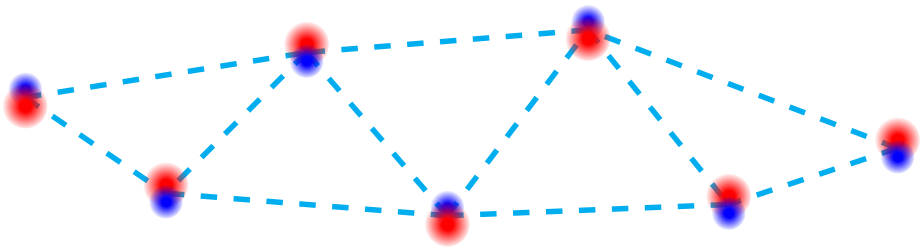
- Strong and tunable interaction
- Rich internal energy levels
- High filling fraction
- Single site detection and manipulation



Molecules in optical tweezer

Features

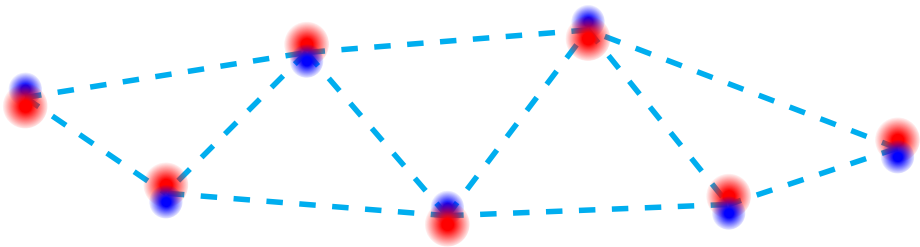
- Strong and tunable interaction
- Rich internal energy levels
- High filling fraction
- Single site detection and manipulation



Molecules in optical tweezer

Features

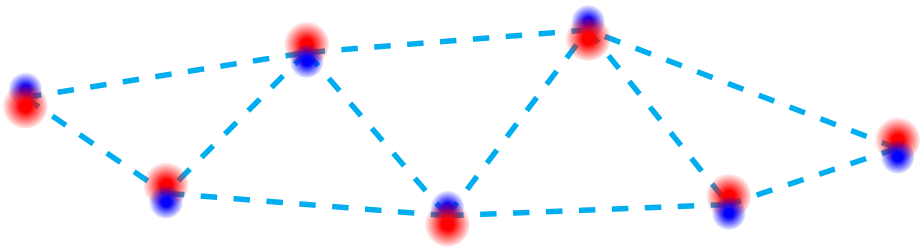
- Strong and tunable interaction
- Rich internal energy levels
- High filling fraction
- Single site detection and manipulation



Molecules in optical tweezer

Features

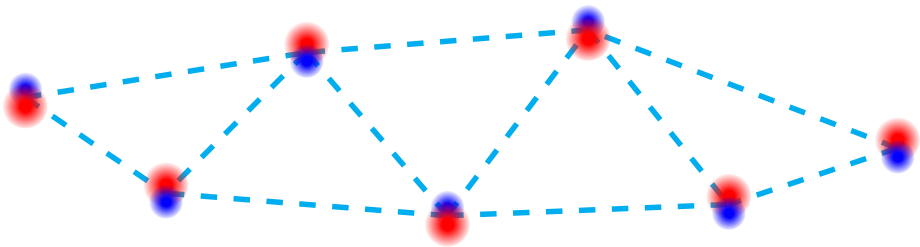
- Strong and tunable interaction
- Rich internal energy levels
- High filling fraction
- Single site detection and manipulation



Molecules in optical tweezer

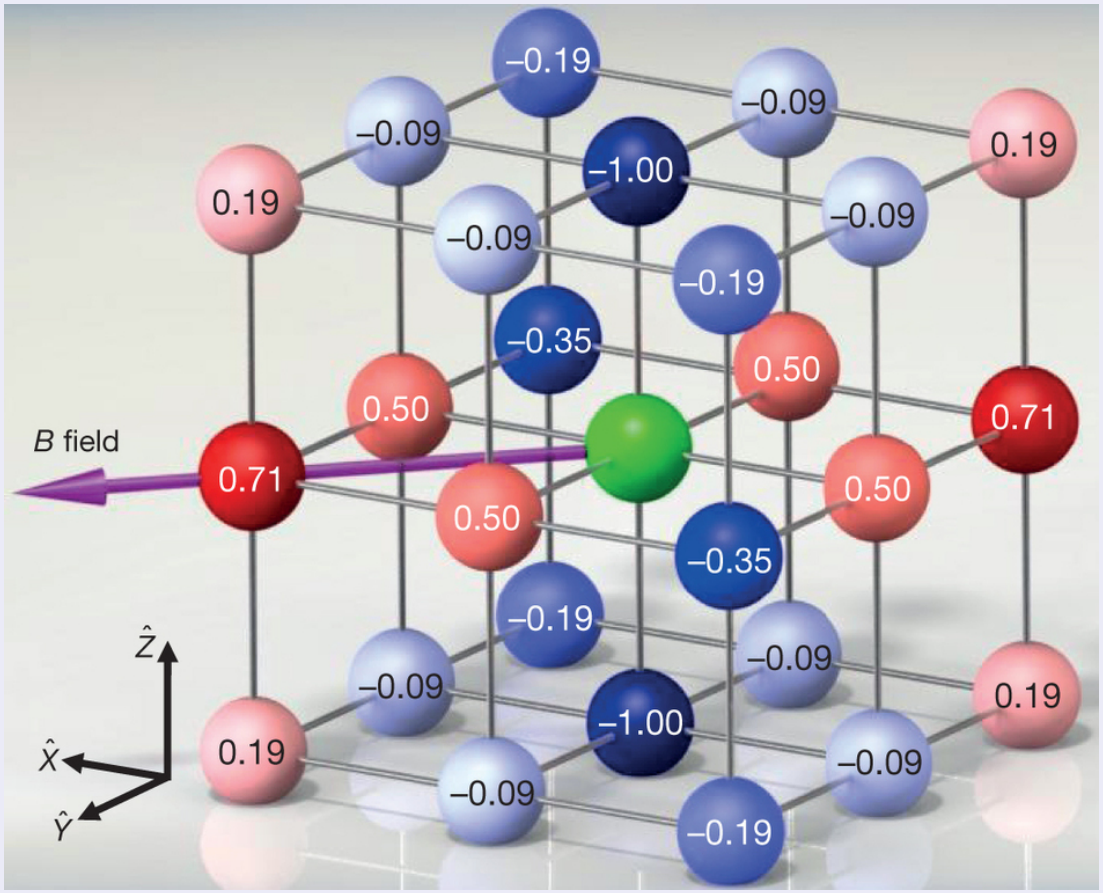
Features

- Strong and tunable interaction
- Rich internal energy levels
- High filling fraction
- Single site detection and manipulation



Applications

Simulation of many-body system[1]

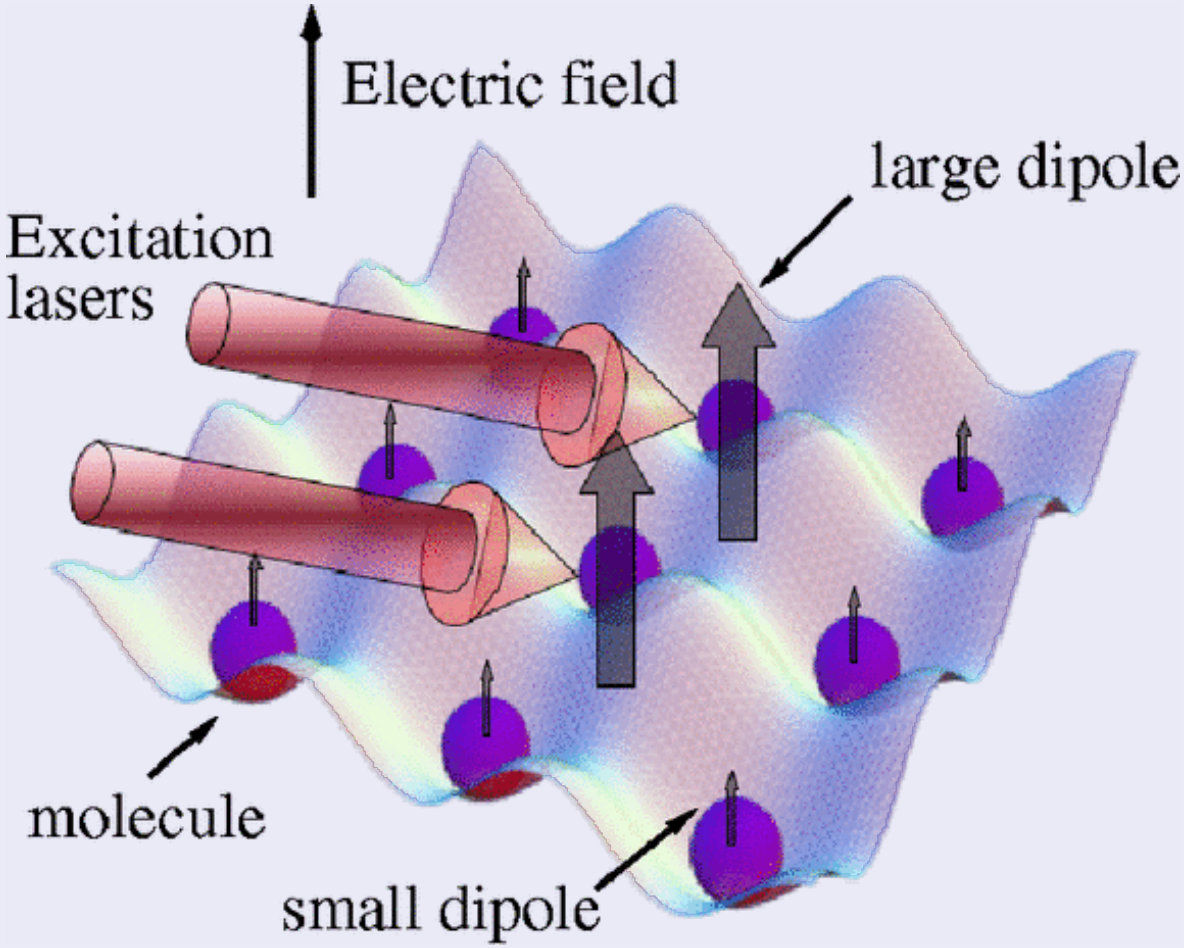


$$H \propto \sum V_{ij}\left(S_i^+ S_j^- + S_i^- S_j^+\right)$$

[1] B. Yan et al., "Observation of dipolar spin-exchange interactions with lattice-confined polar molecules.", Nature **501**, 521–5 (2013).

Applications

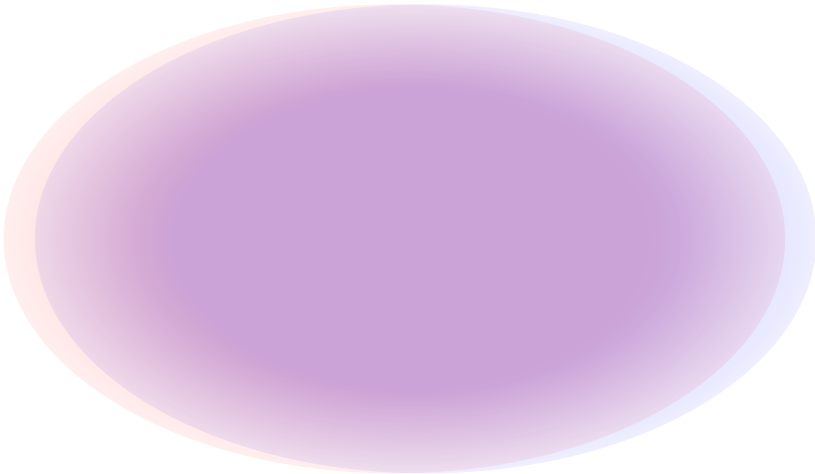
Quantum computation[2]



[2] S. F. Yelin et al., "Schemes for robust quantum computation with polar molecules", Phys. Rev. A **74**, 050301 (2006).

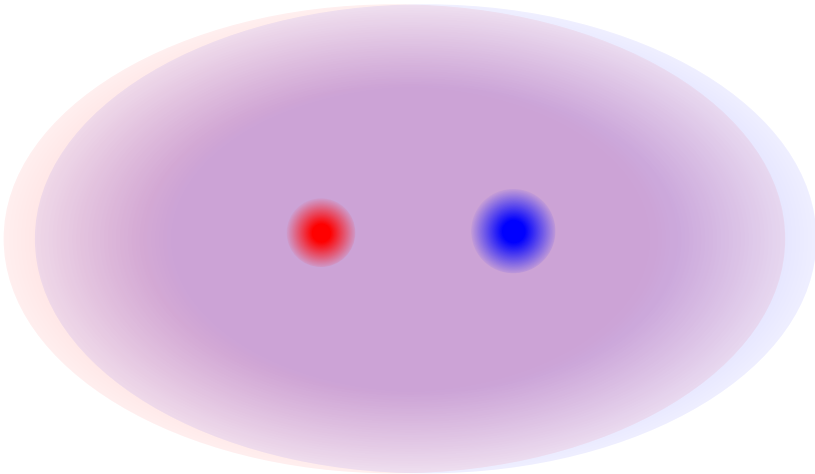
Making molecules from atoms

- MOT (Na + Cs)
- Loading single atoms
- Raman sideband cooling
- Merge traps
- Make molecules!



Making molecules from atoms

- MOT (Na + Cs)
- Loading single atoms
- Raman sideband cooling
- Merge traps
- Make molecules!



Making molecules from atoms

- MOT (Na + Cs)
- Loading single atoms
- Raman sideband cooling
- Merge traps
- Make molecules!

Making molecules from atoms

- MOT (Na + Cs)
- Loading single atoms
- Raman sideband cooling
- Merge traps
- Make molecules!

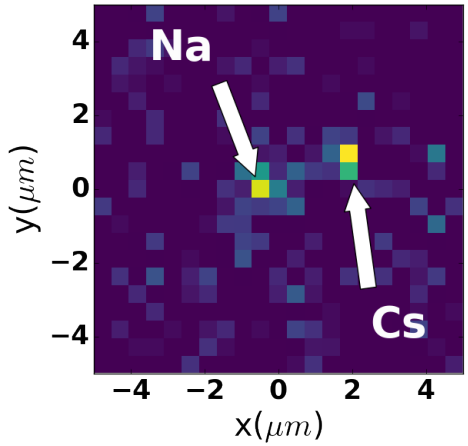
Making molecules from atoms

- MOT (Na + Cs)
- Loading single atoms
- Raman sideband cooling
- Merge traps
- Make molecules!

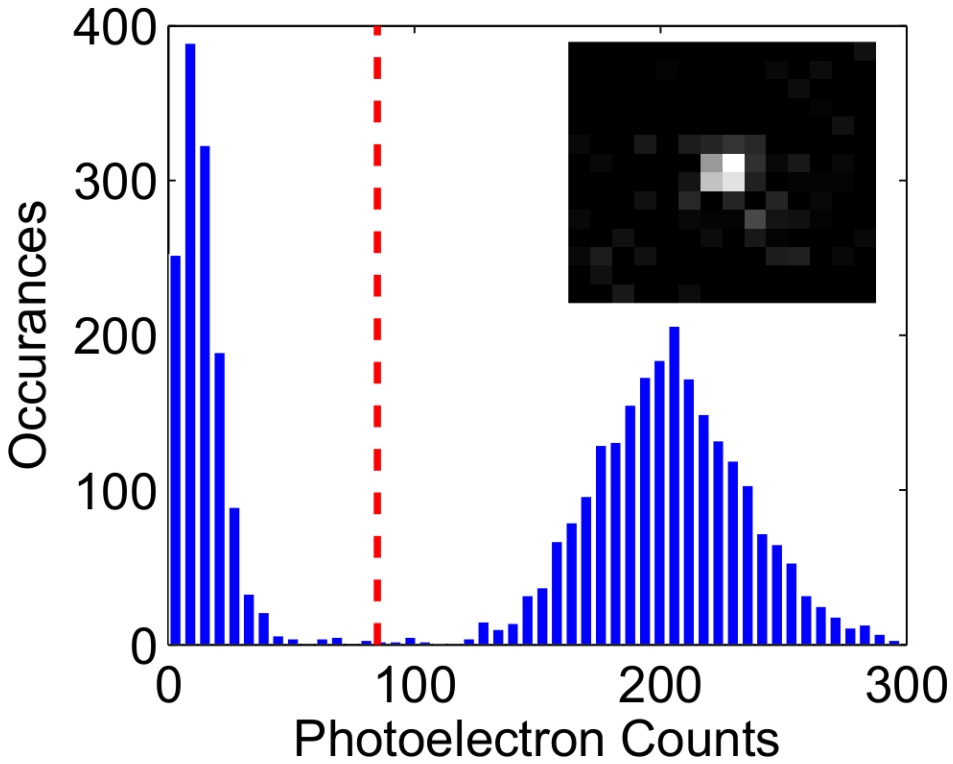
Making molecules from atoms

- MOT (Na + Cs)
- Loading single atoms
- Raman sideband cooling
- Merge traps
- Make molecules!

Atom loading and cooling

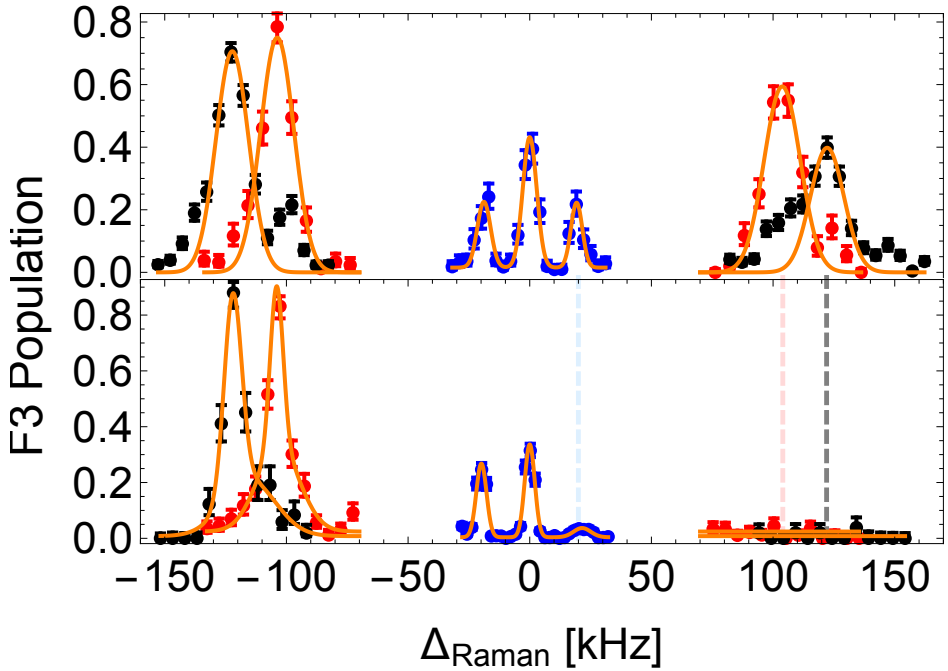


- Single atoms
- 85% ground state after Cesium Raman sideband cooling

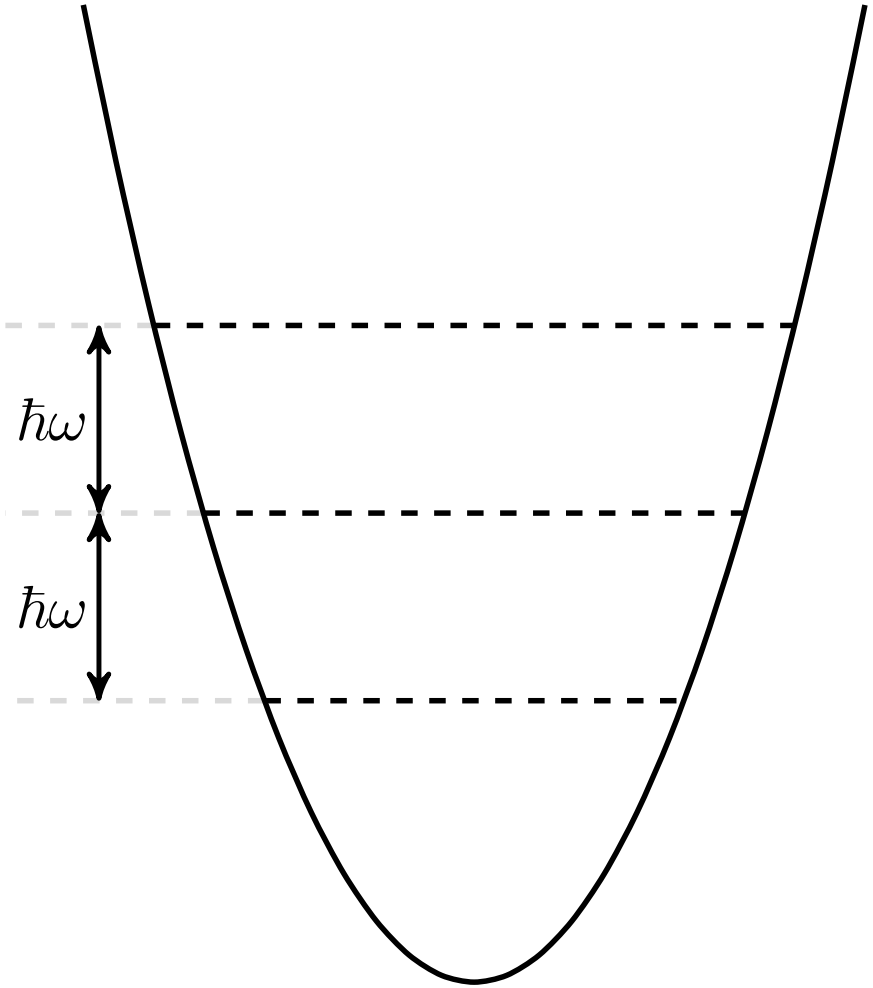


Atom loading and cooling

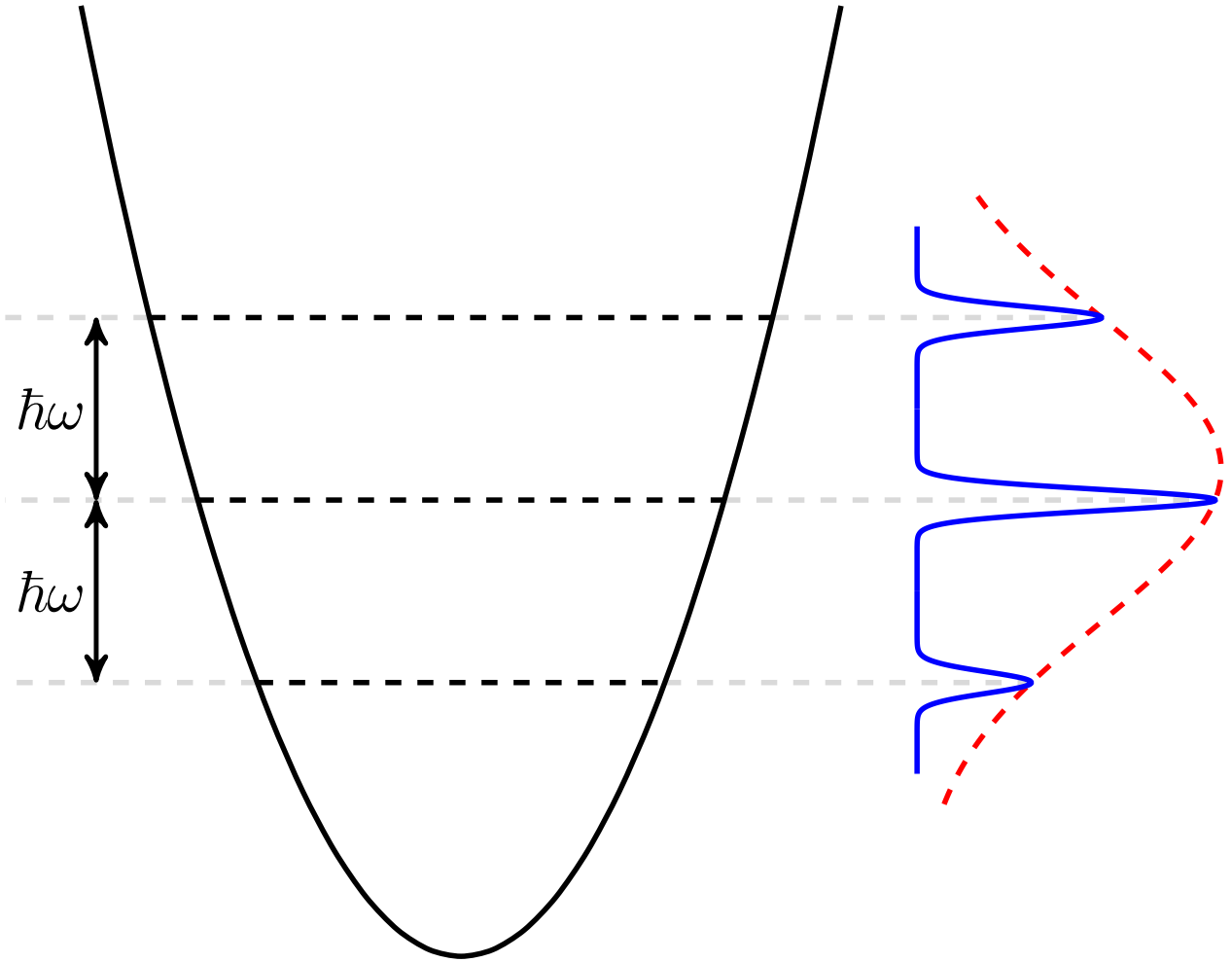
- Single atoms
- 85% ground state after Cesium Raman sideband cooling



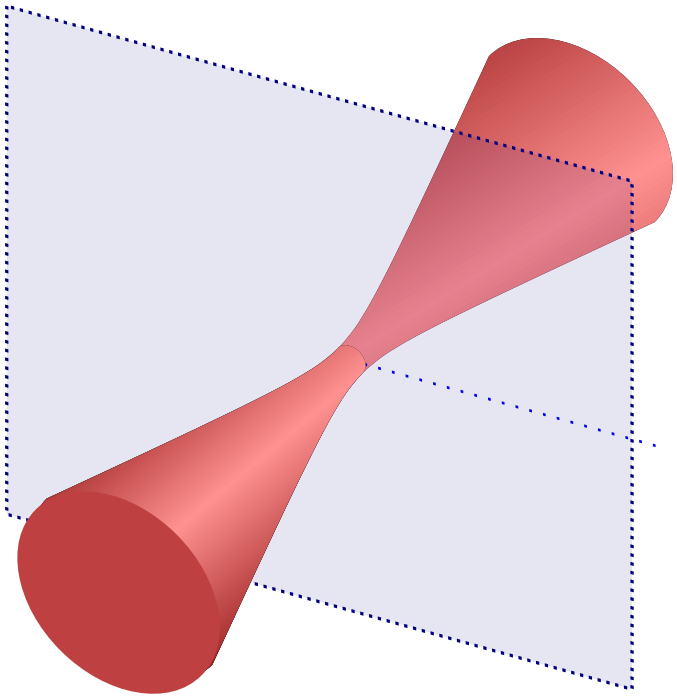
Raman sideband cooling

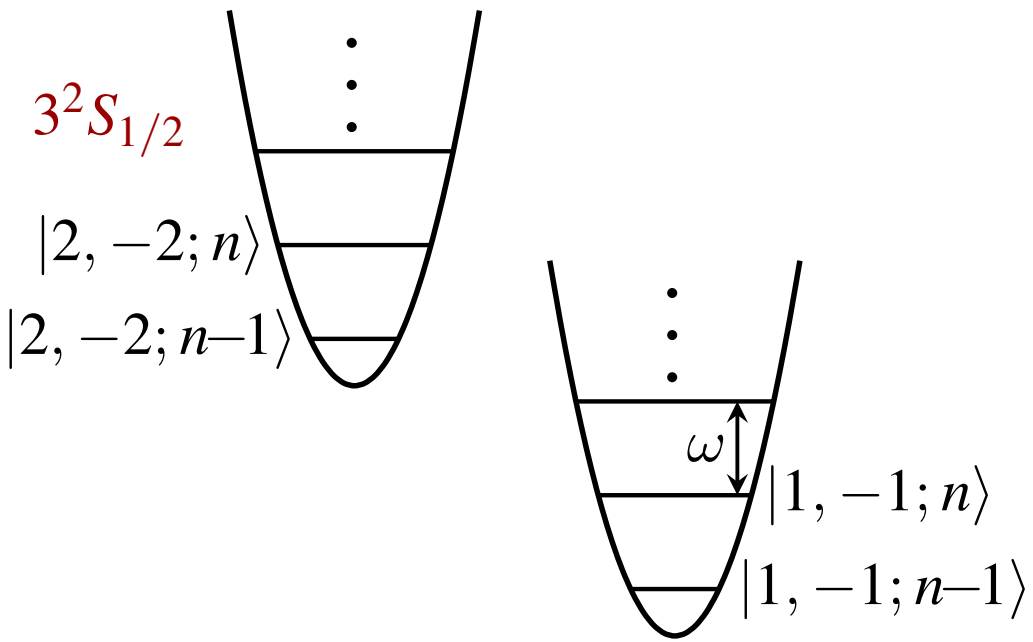


Raman sideband cooling

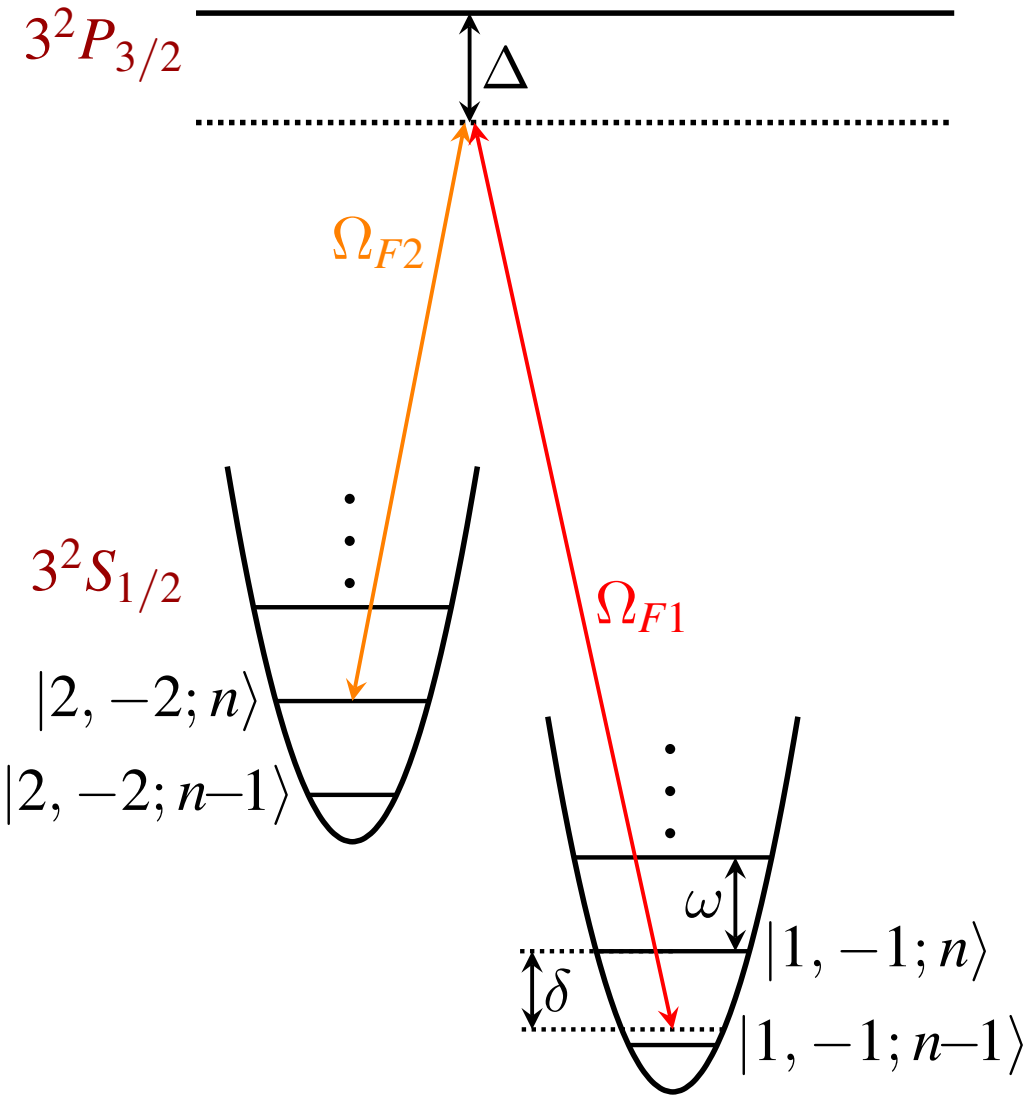


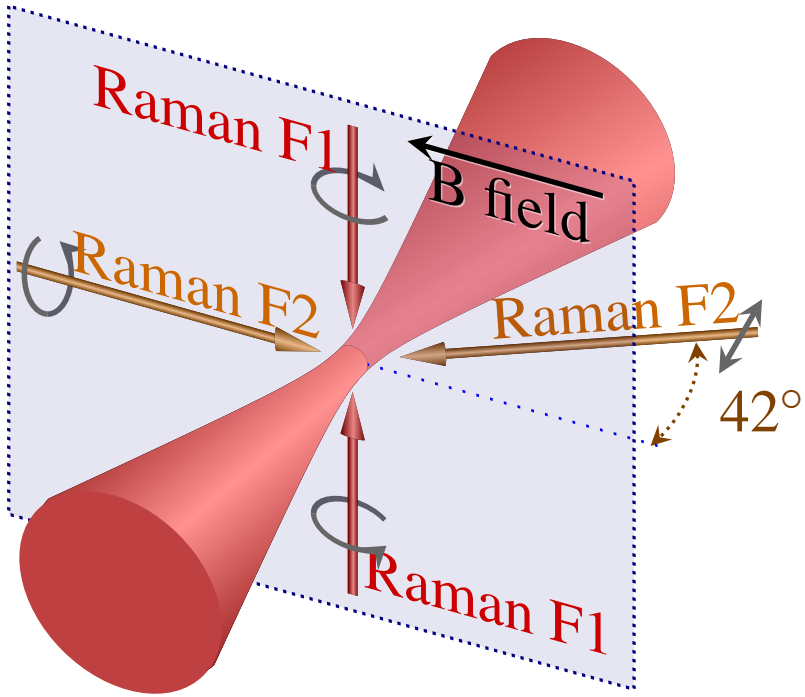
Raman sideband cooling



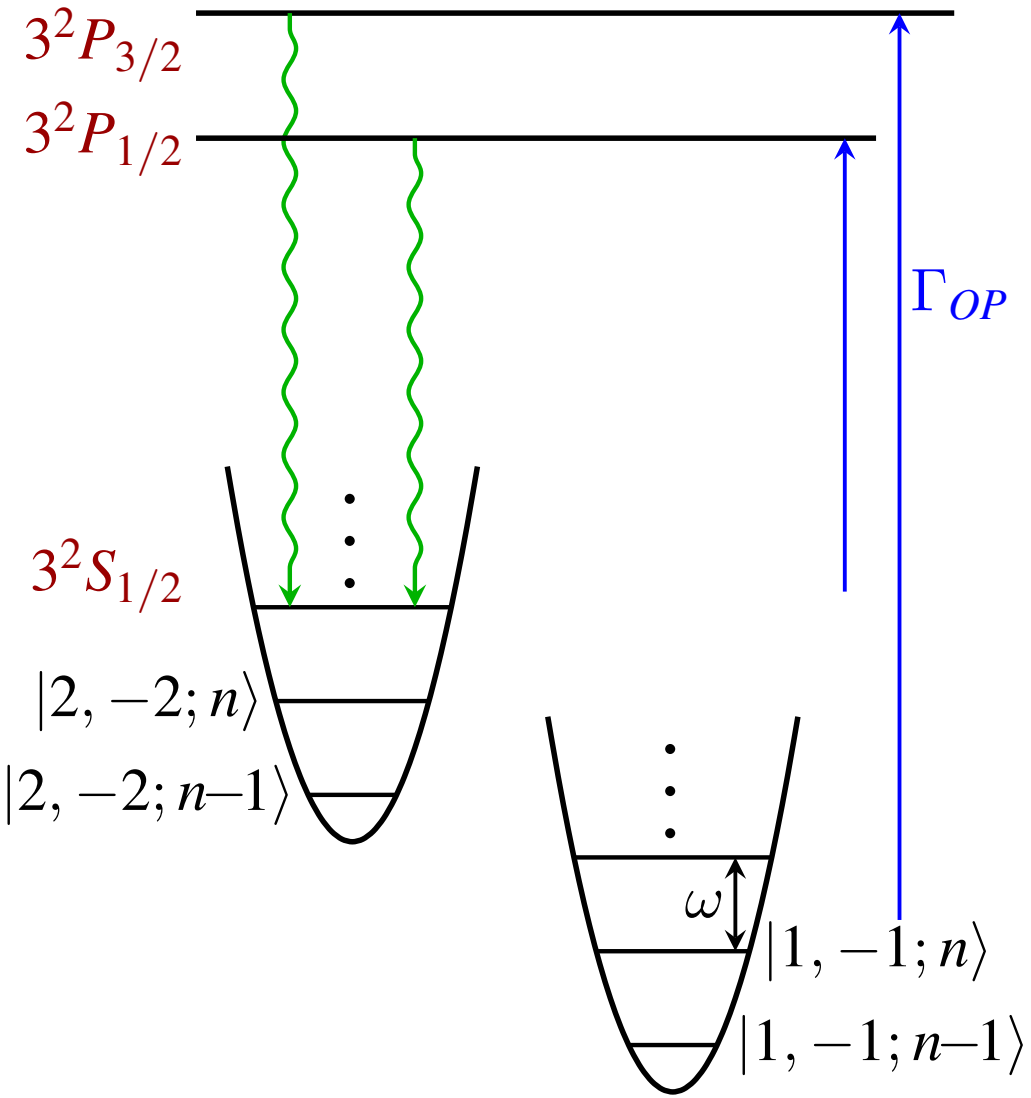


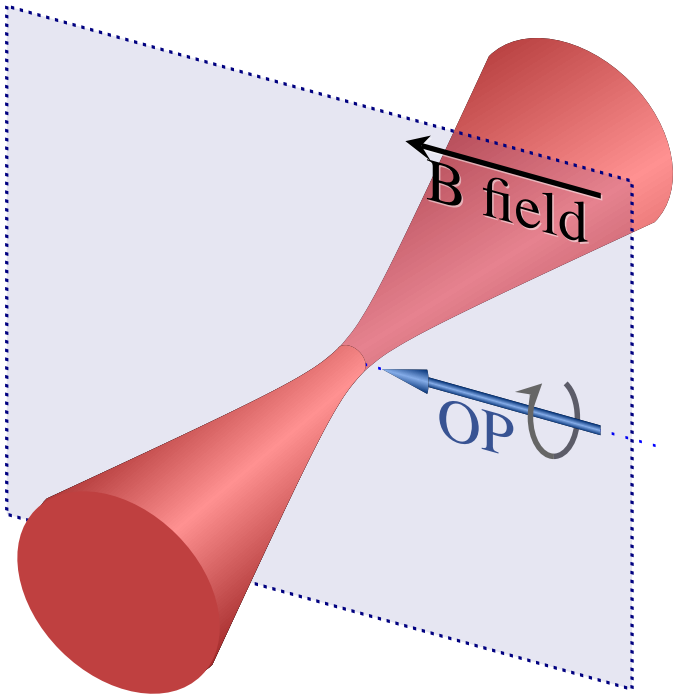
Raman sideband cooling



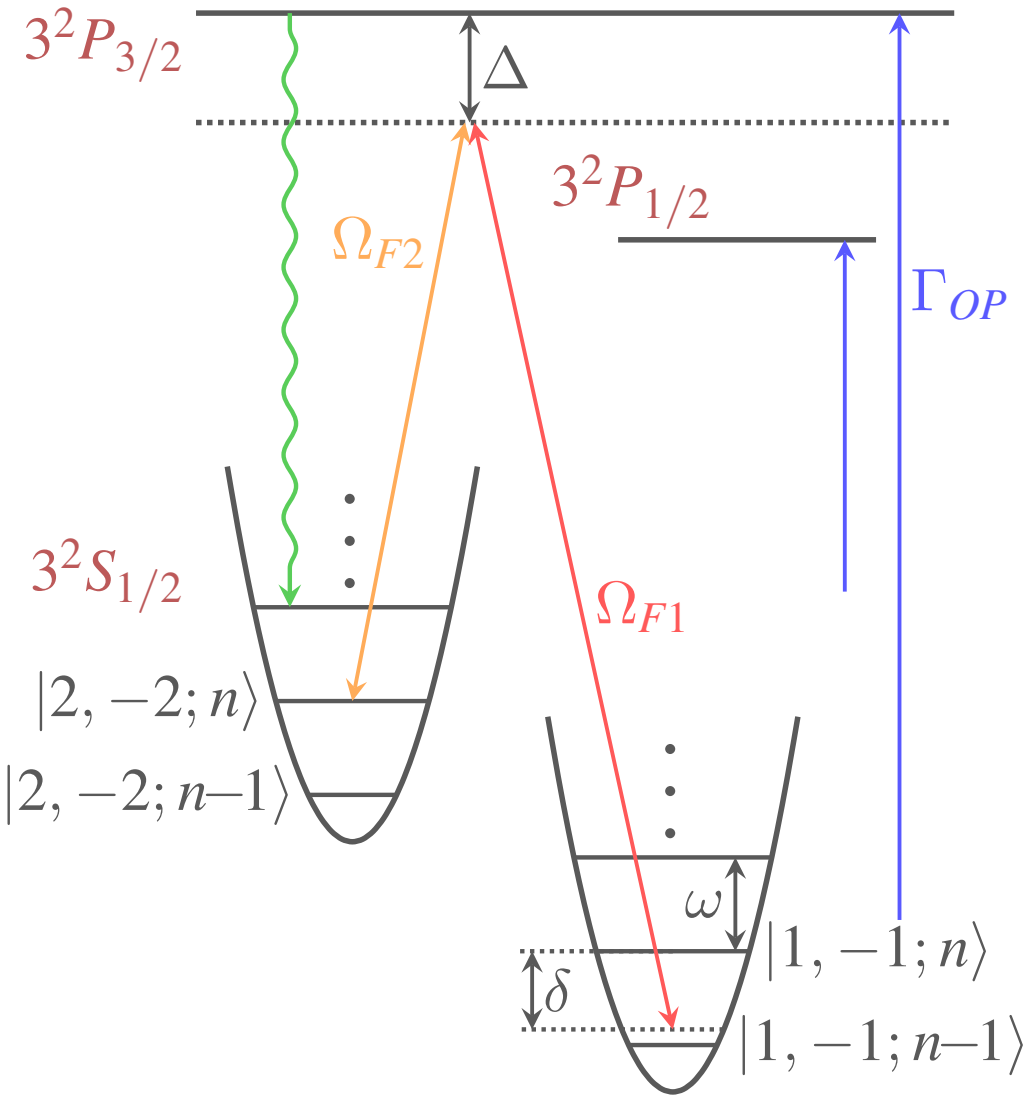


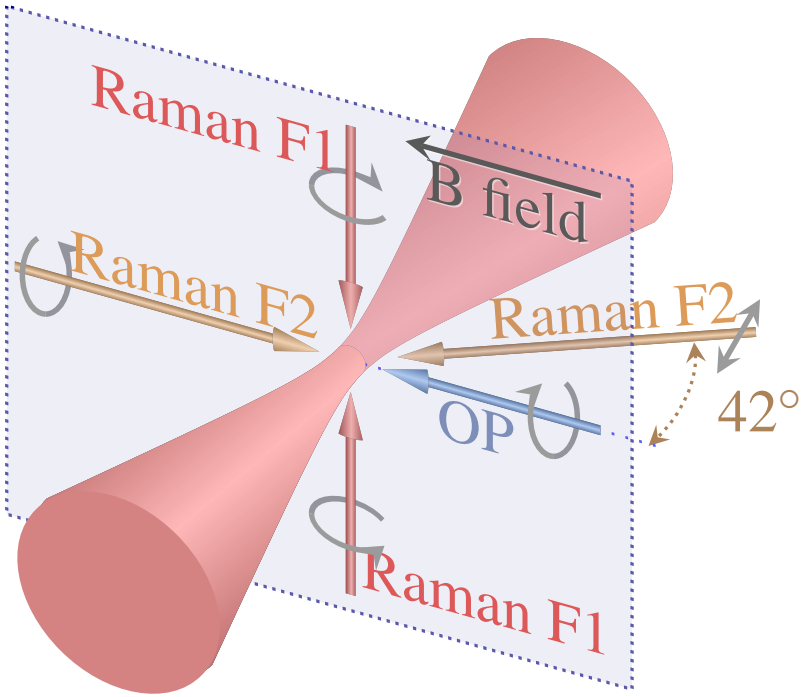
Raman sideband cooling





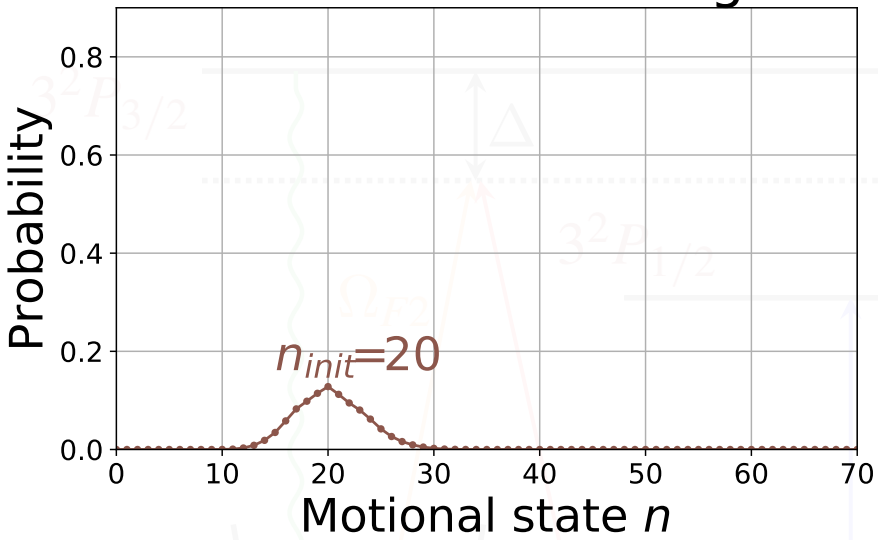
Raman sideband cooling



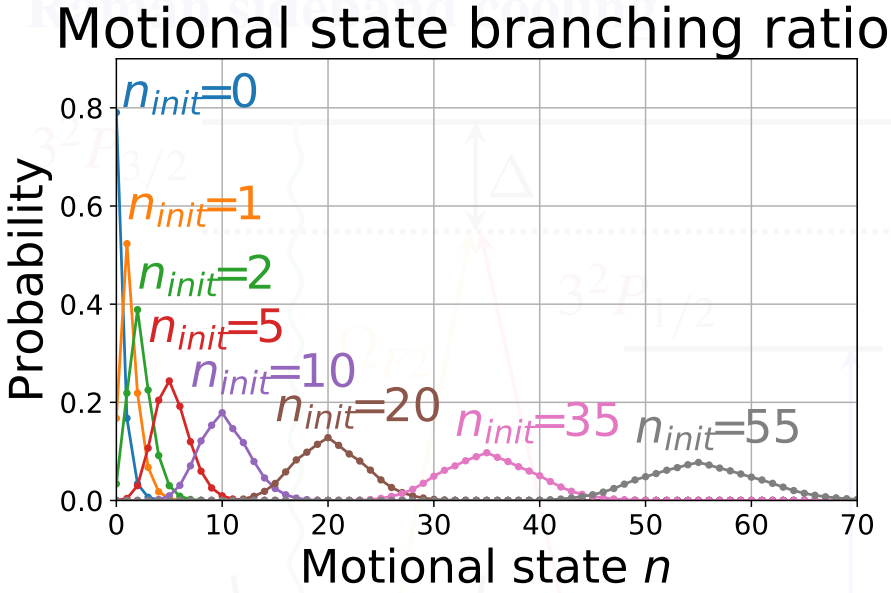


- High initial temperature ($70\mu K$)
- High Lamb Dicke parameter
  $\eta \equiv kz_0$
- Large light shift
- Trap anharmonicity
- Off resonance scattering
  $\approx 3 \sim 15$kHz

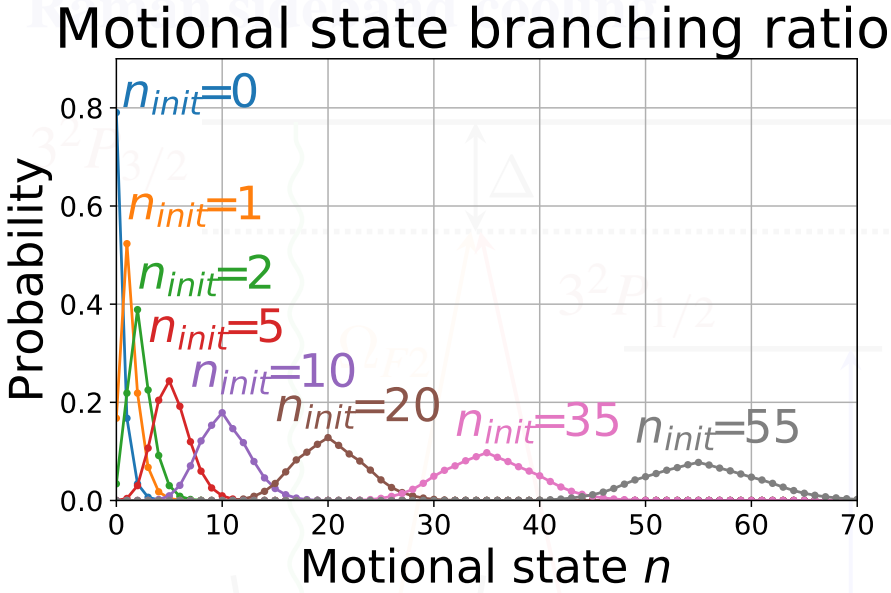
Motional state branching ratios

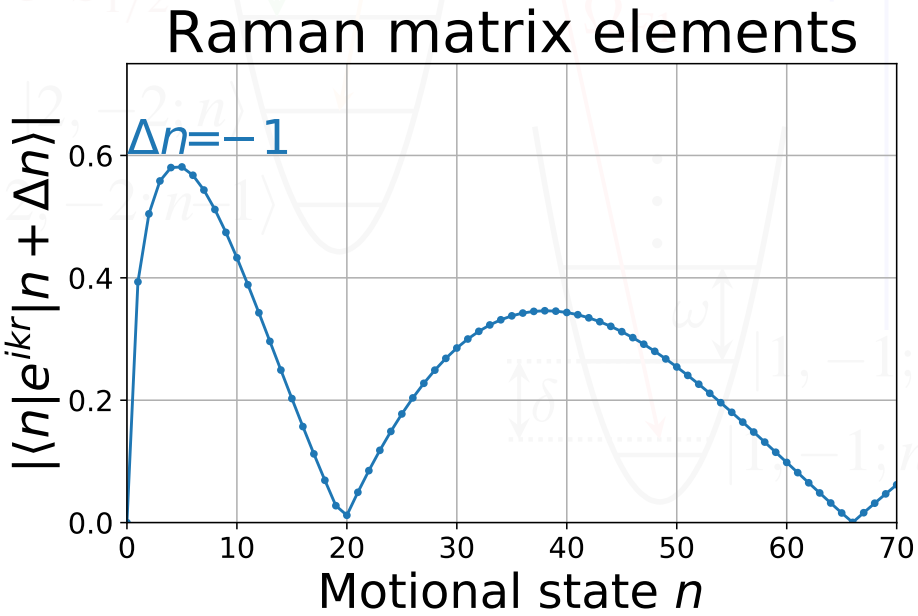


- High initial temperature ($70\mu K$)
- High Lamb Dicke parameter $\eta \equiv kz_0$
- Large light shift
- Trap anharmonicity
- Off resonance scattering $\approx 3 \sim 15$kHz

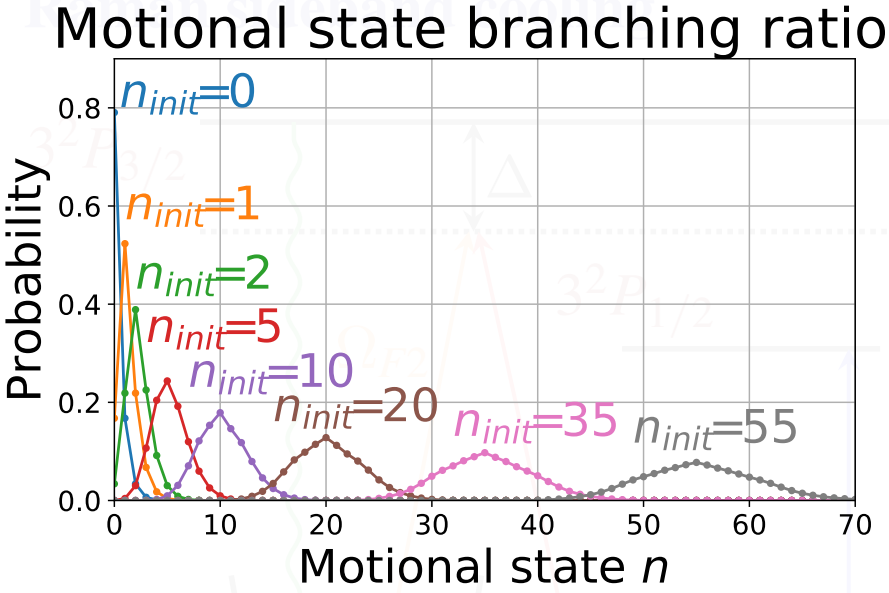


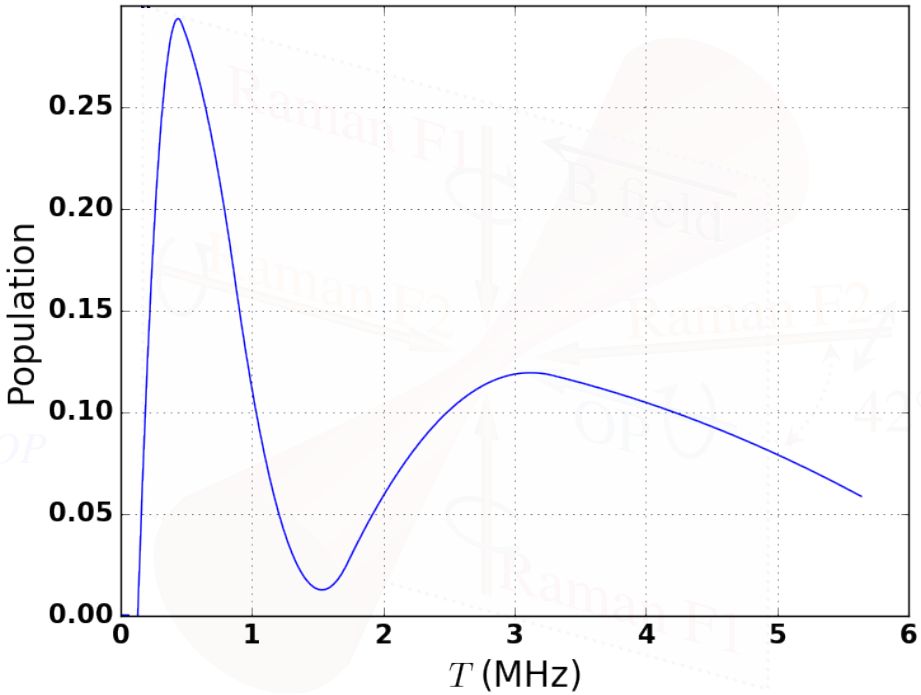
- High initial temperature ($70\mu K$)
- High Lamb Dicke parameter $\eta \equiv kz_0$
- Large light shift
- Trap anharmonicity
- Off resonance scattering $\approx 3 \sim 15$kHz

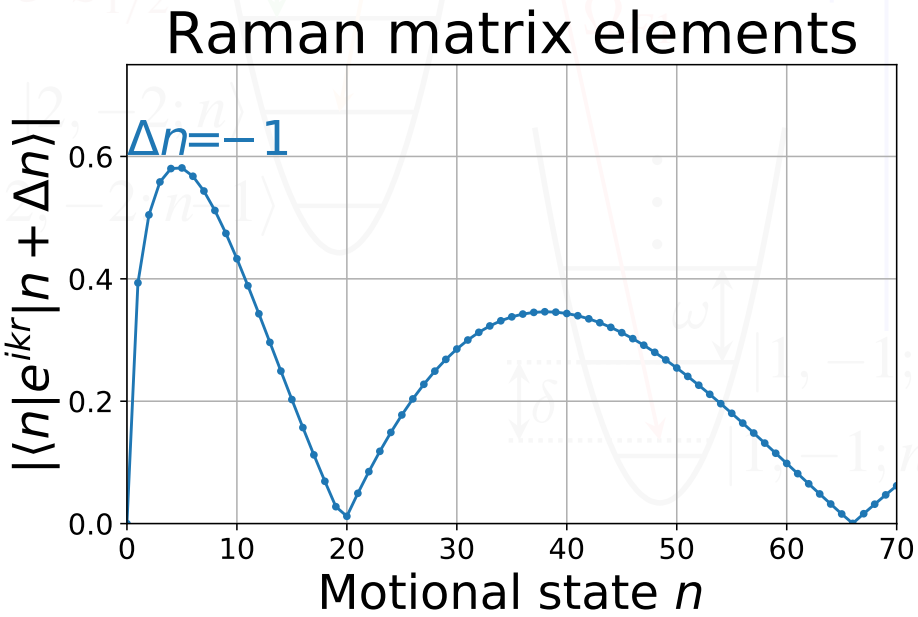




- High initial temperature ($70\mu K$)
- High Lamb Dicke parameter $\eta \equiv kz_0$
- Large light shift
- Trap anharmonicity
- Off resonance scattering $\approx 3 \sim 15$kHz

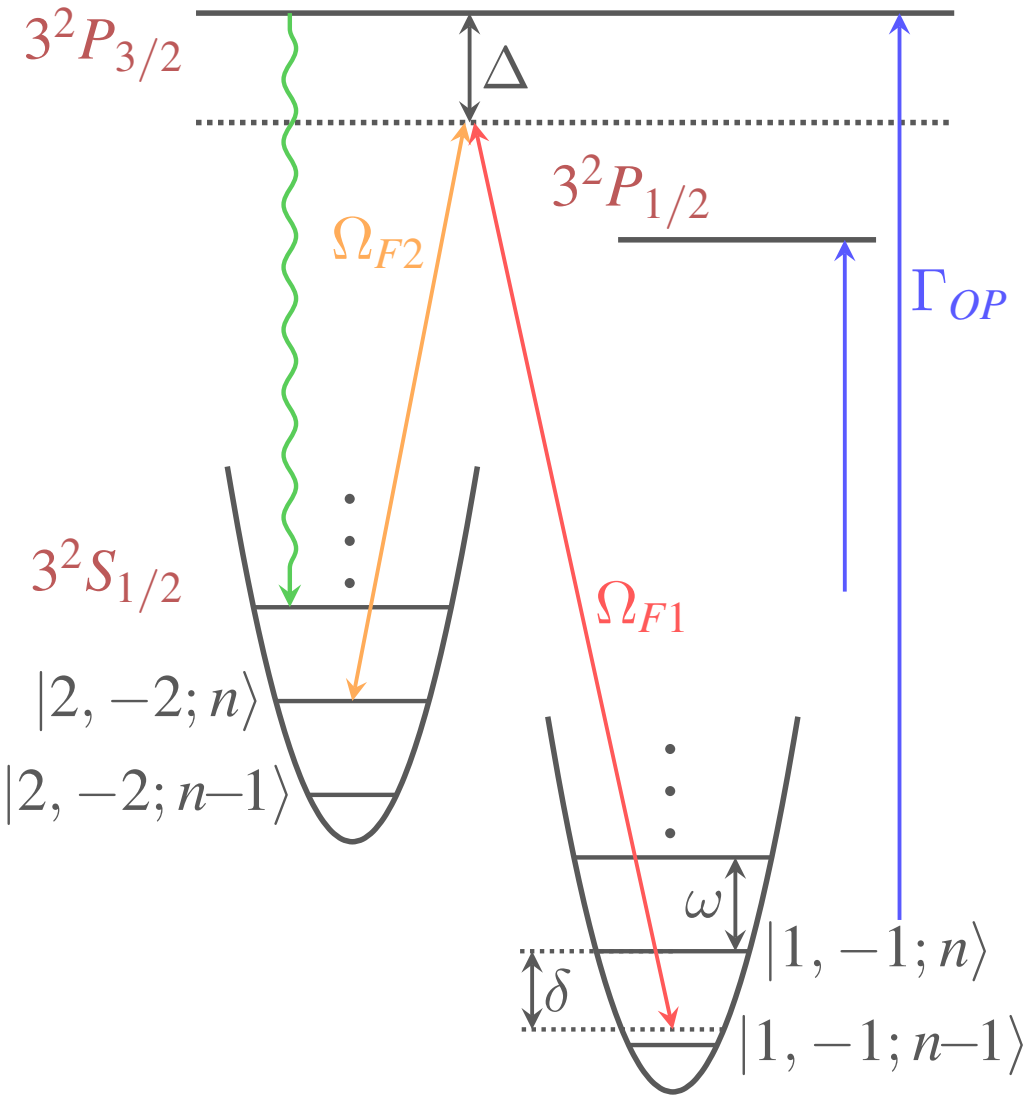


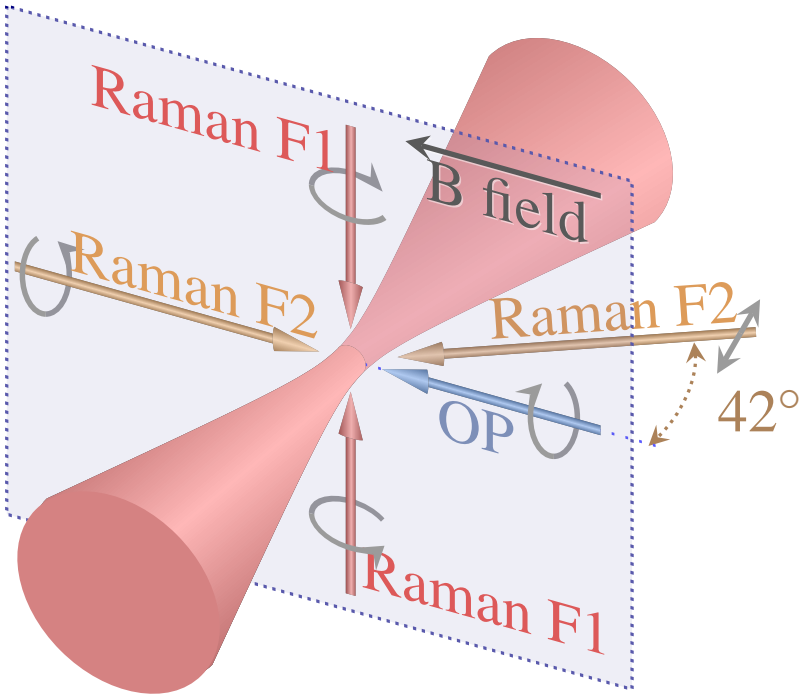




- High initial temperature ($70\mu K$)
- High Lamb Dicke parameter
  $\eta \equiv kz_0$
- Large light shift
- Trap anharmonicity
- Off resonance scattering
  $\approx 3 \sim 15$kHz

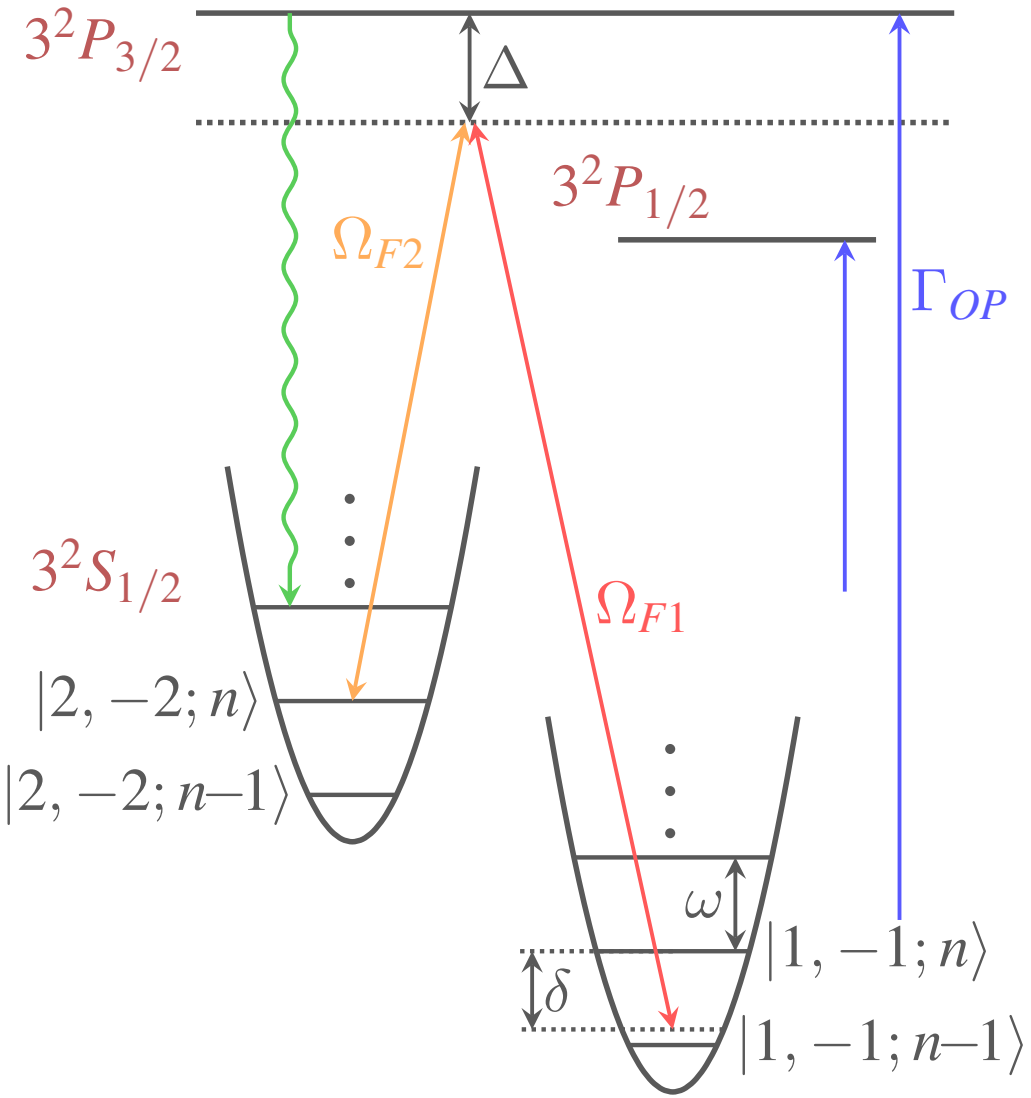
Raman sideband cooling

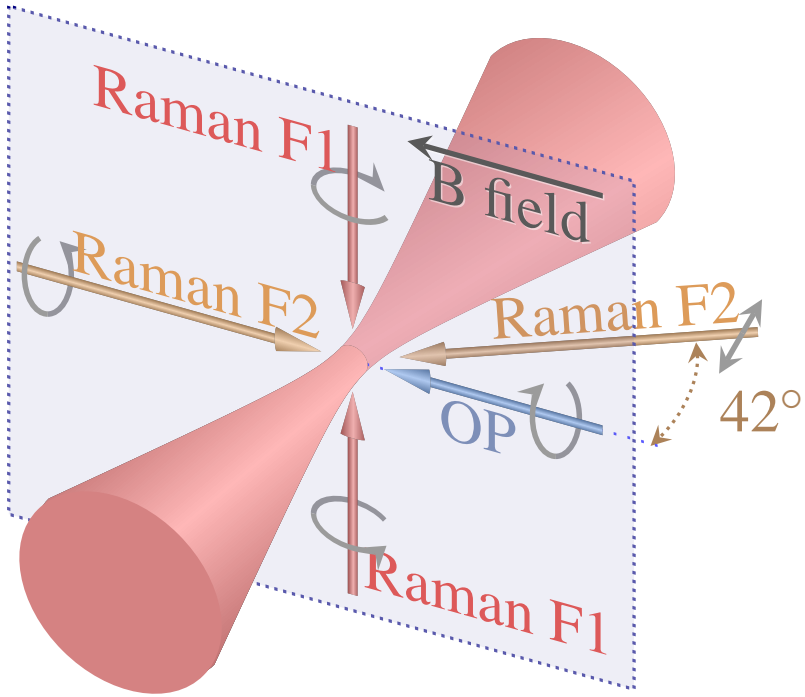




- High initial temperature ($70\mu K$)
- High Lamb Dicke parameter
  $\eta \equiv kz_0$
- Large light shift
- Trap anharmonicity
- Off resonance scattering
  $\approx 3 \sim 15$kHz

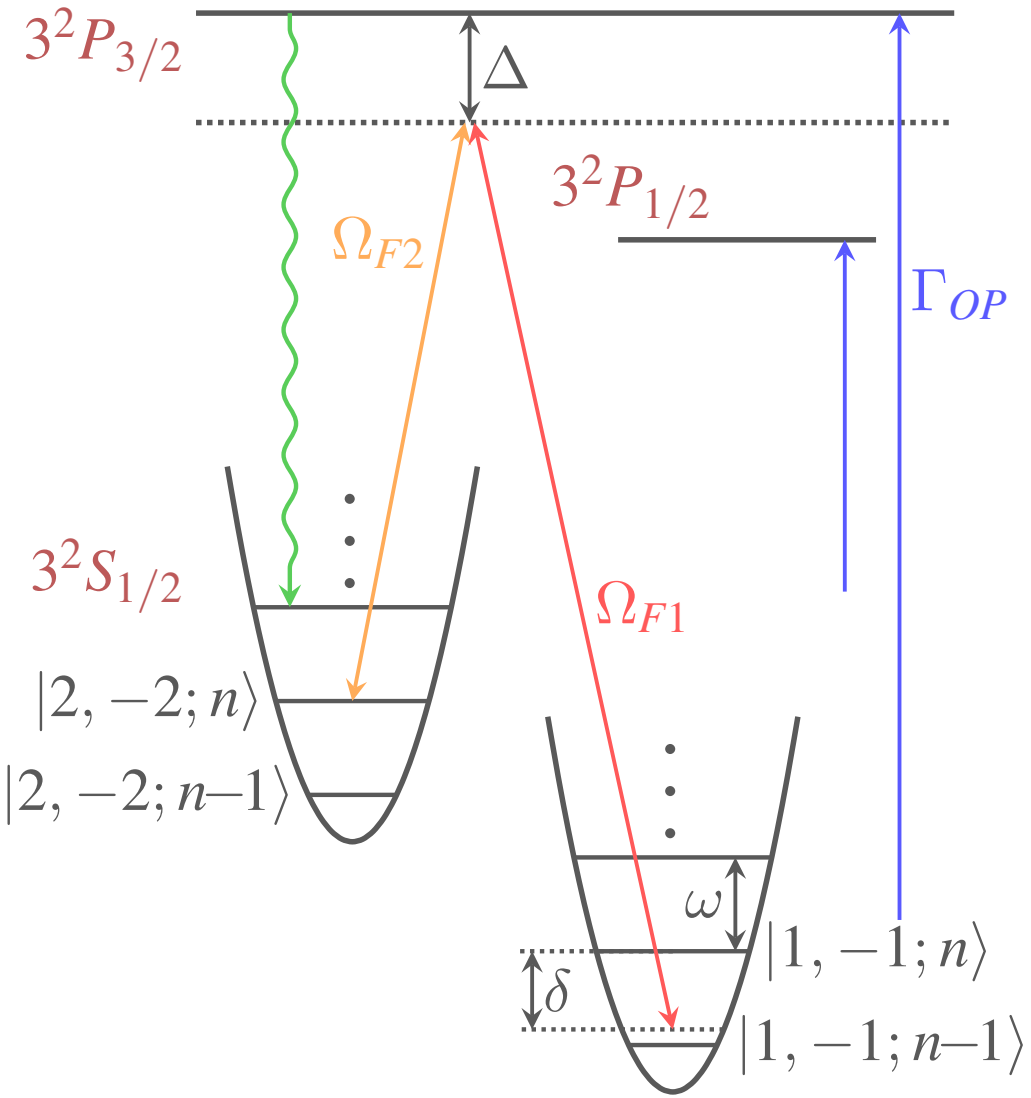
Raman sideband cooling

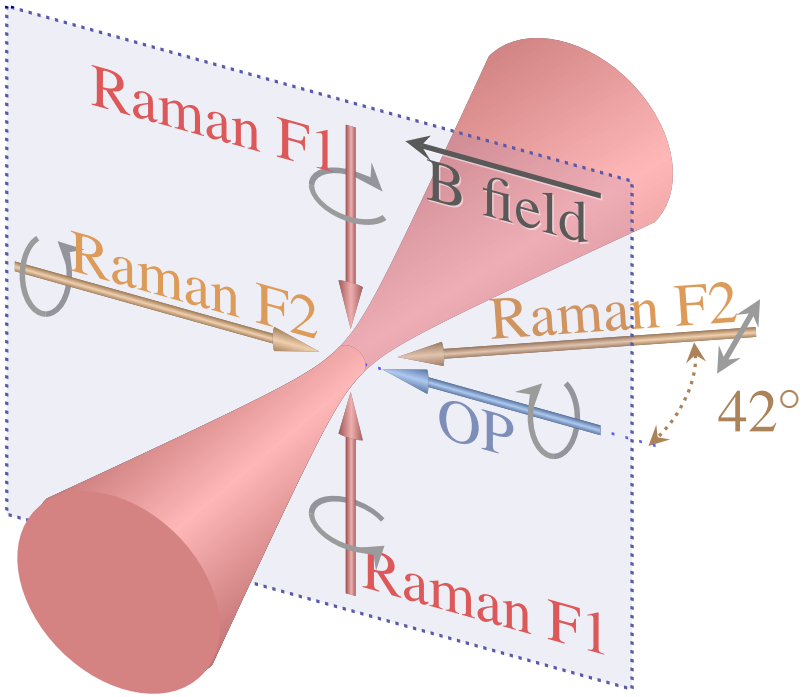




- High initial temperature ($70\mu K$)
- High Lamb Dicke parameter $\eta \equiv kz_0$
- Large light shift
- Trap anharmonicity
- Off resonance scattering $\approx 3 \sim 15$kHz

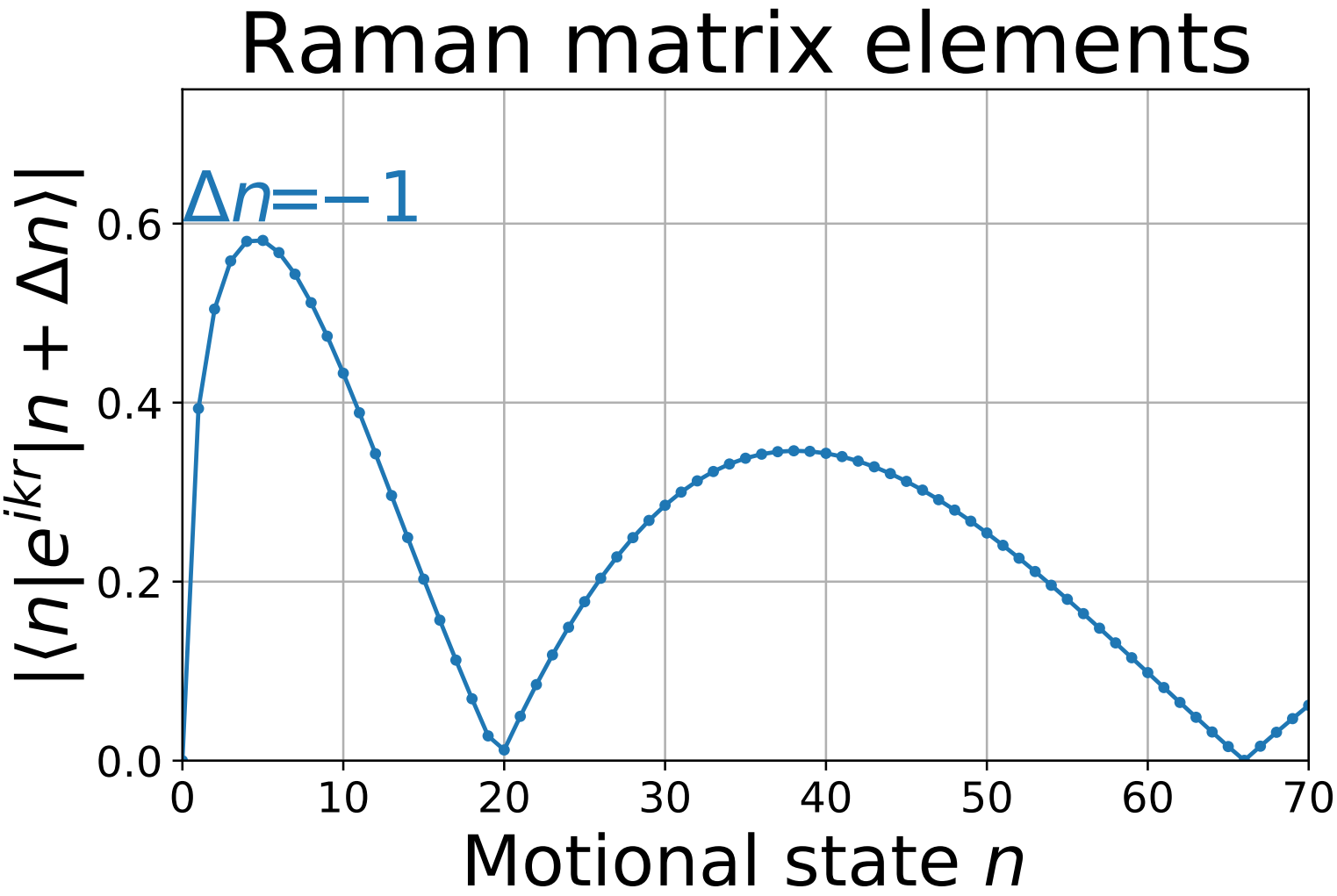
Raman sideband cooling



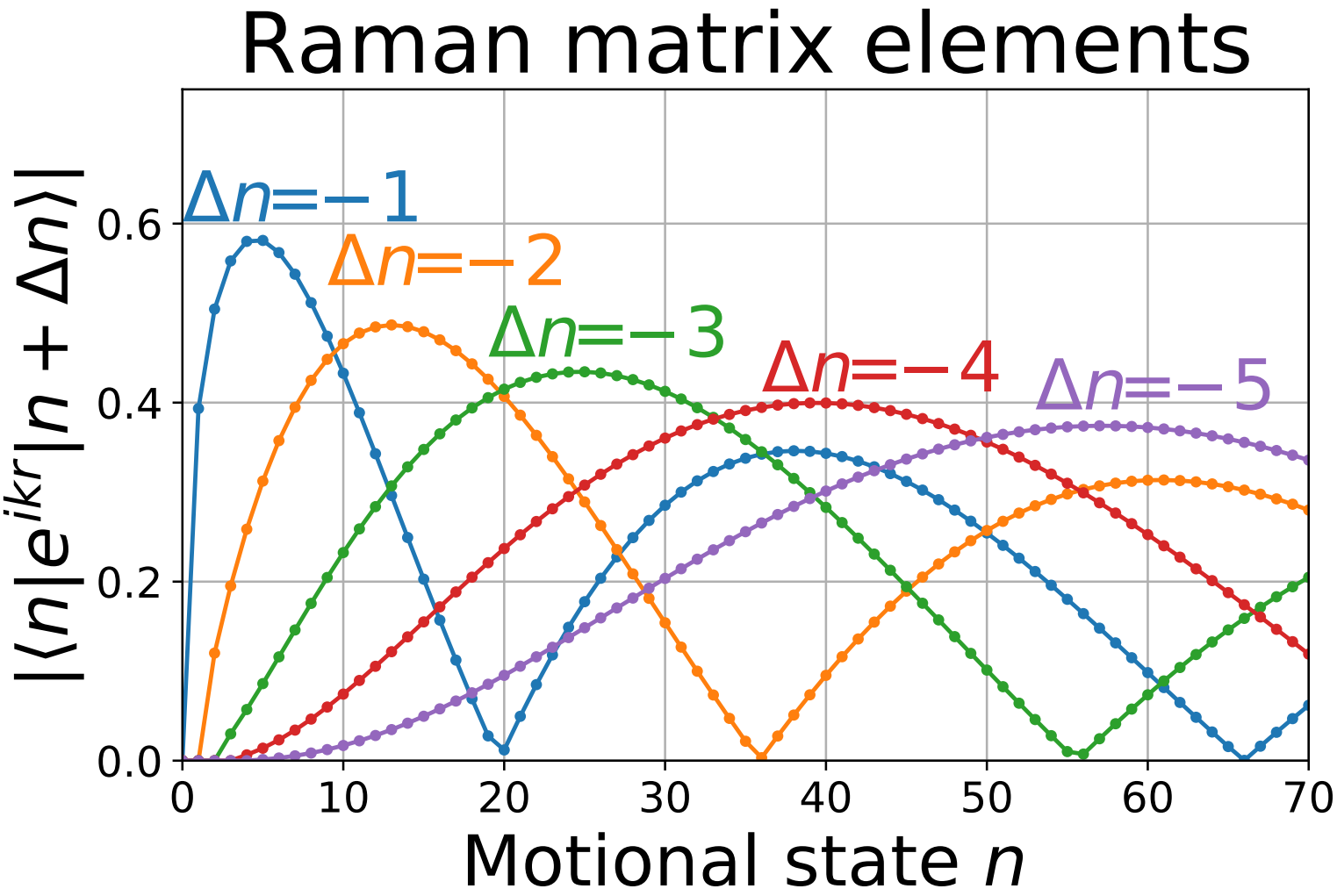


- High initial temperature ($70\mu K$)
- High Lamb Dicke parameter $\eta \equiv kz_0$
- Large light shift
- Trap anharmonicity
- Off resonance scattering $\approx 3 \sim 15$kHz

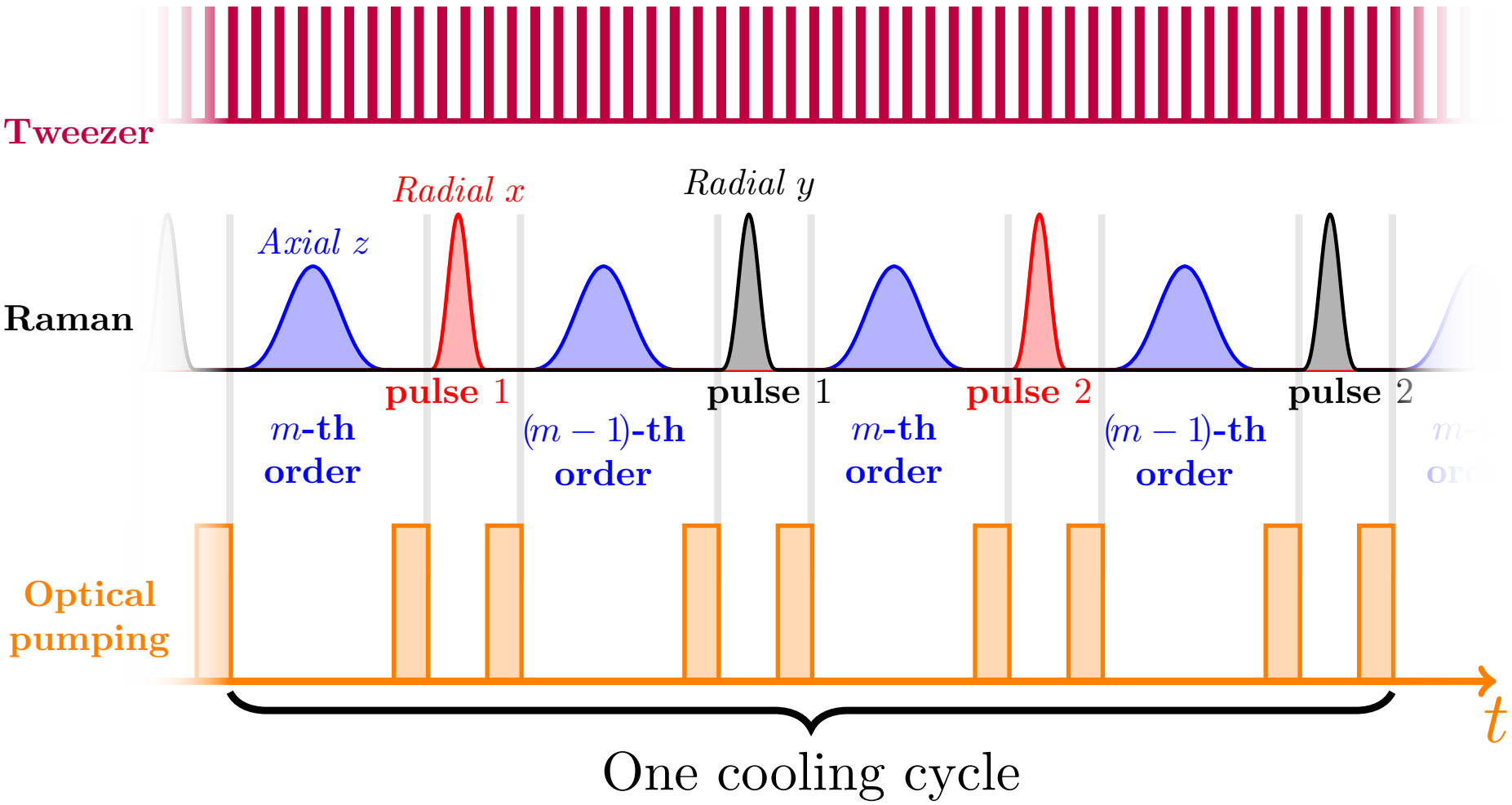
Sequence and simulation



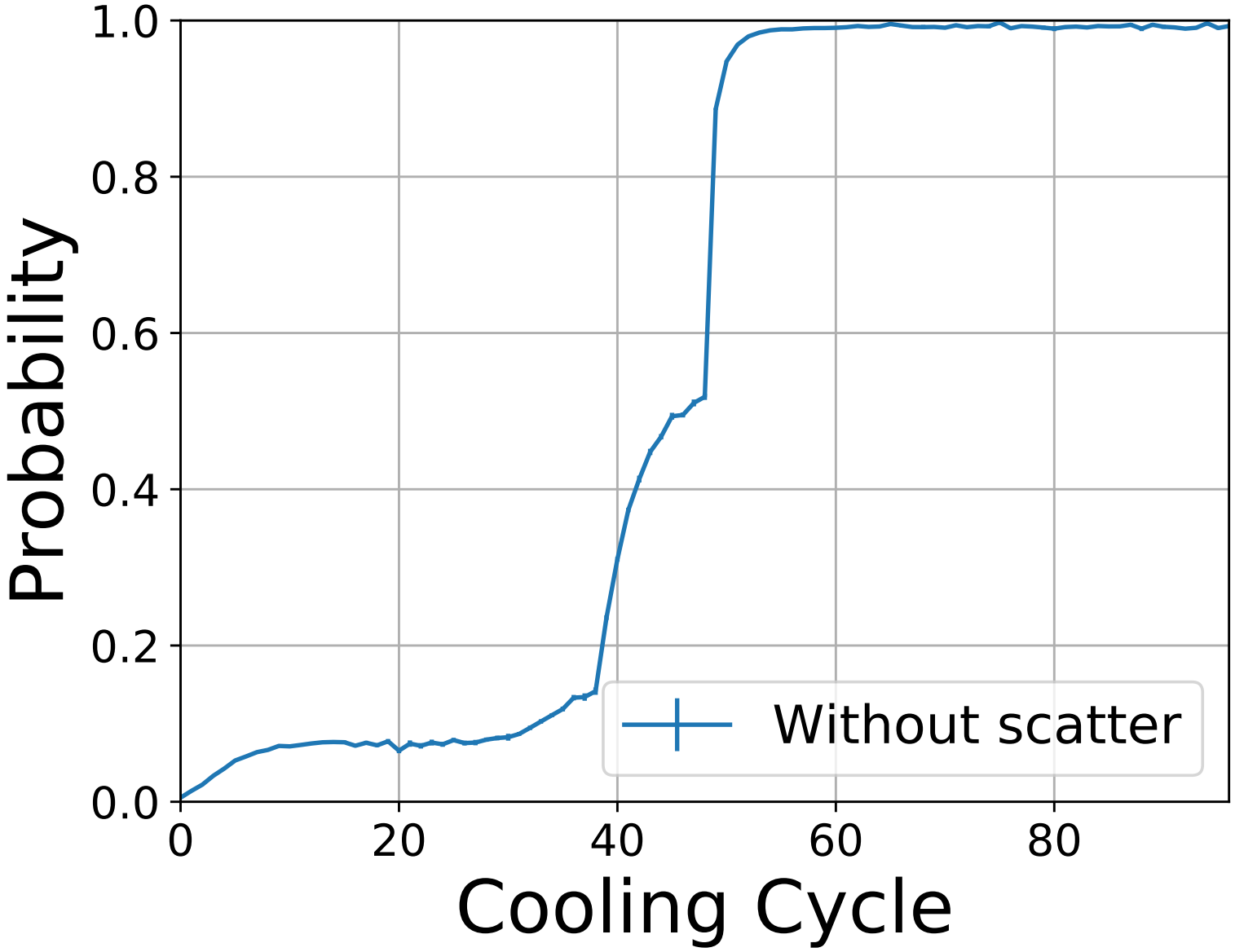
Sequence and simulation



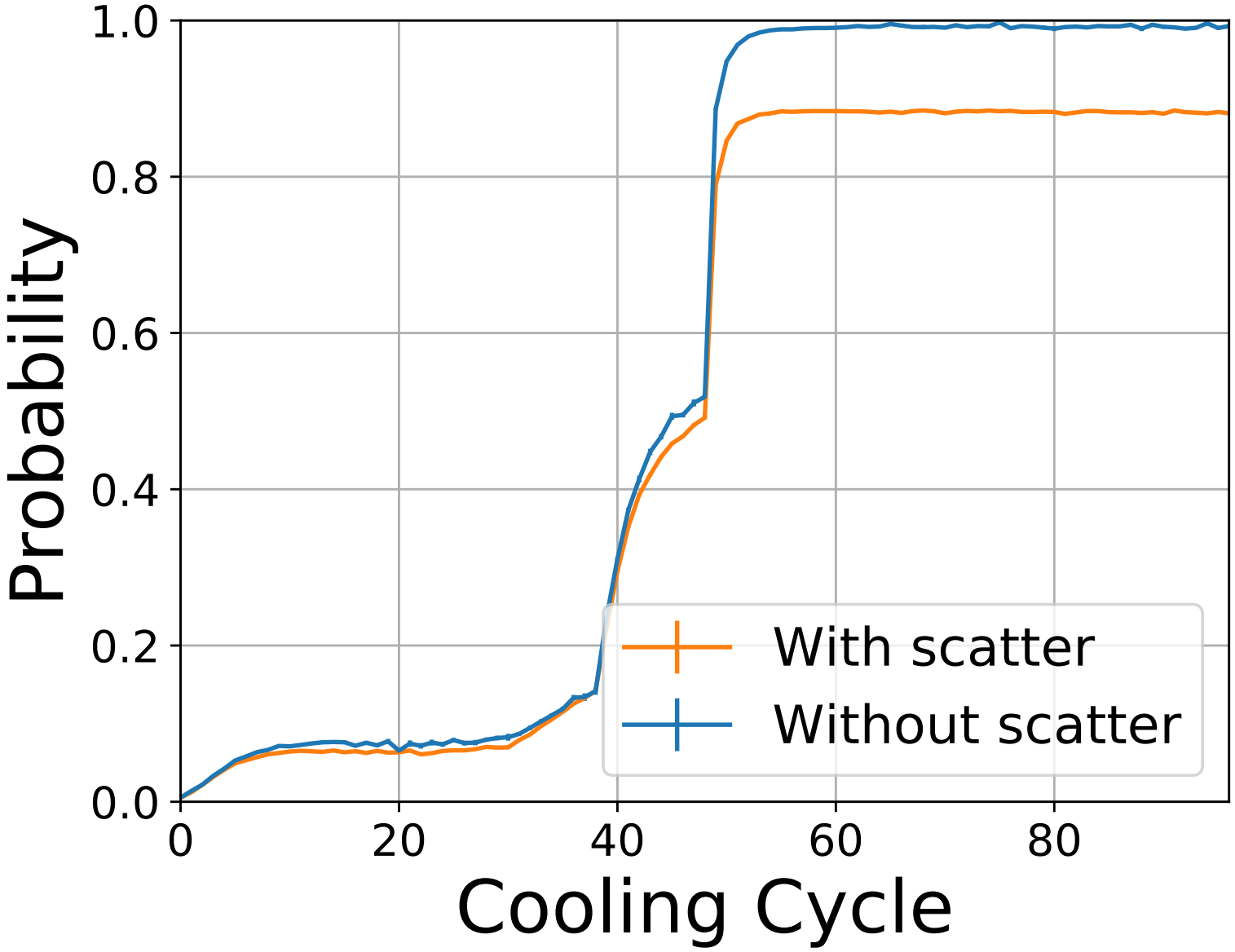
Sequence and simulation



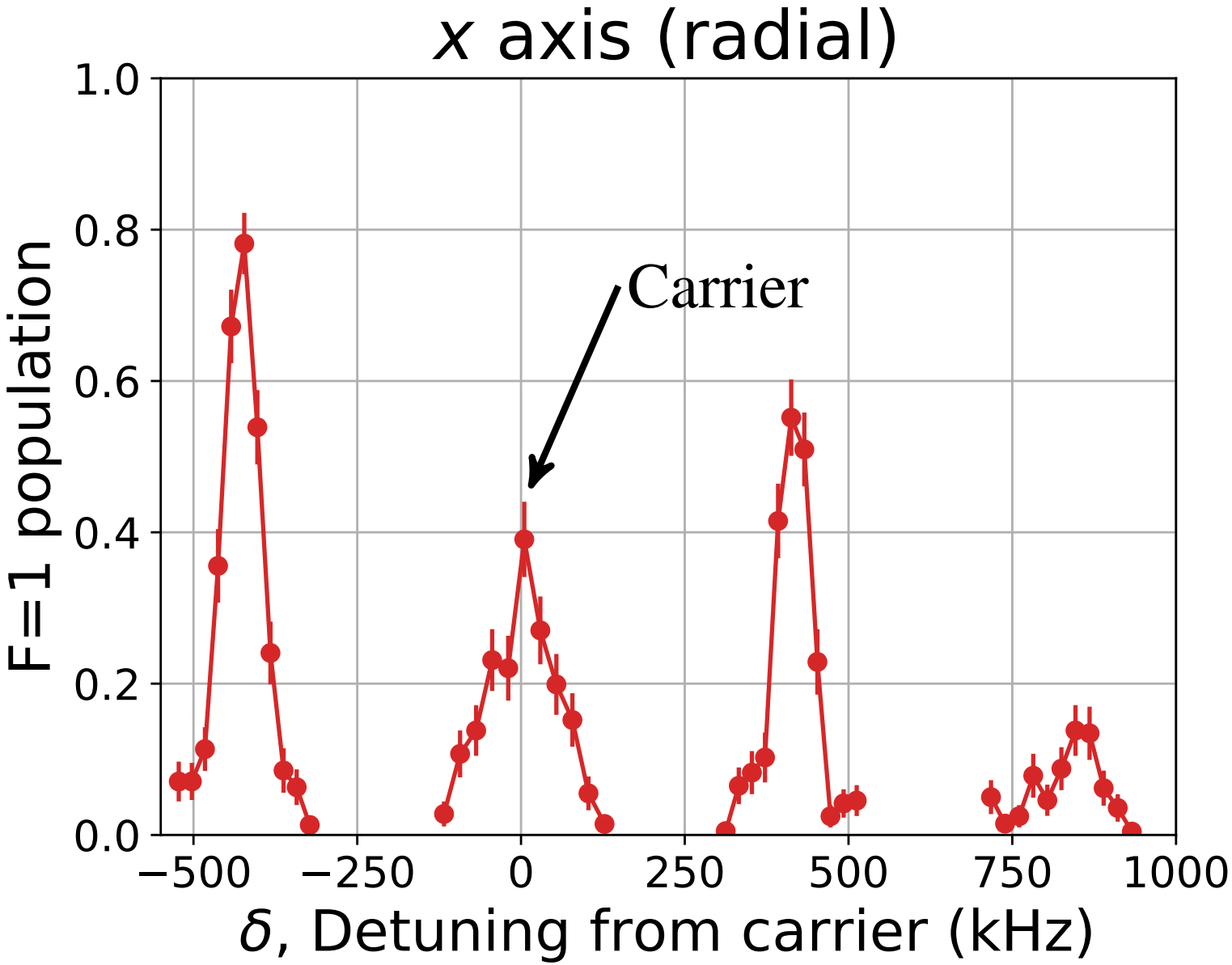
Sequence and simulation



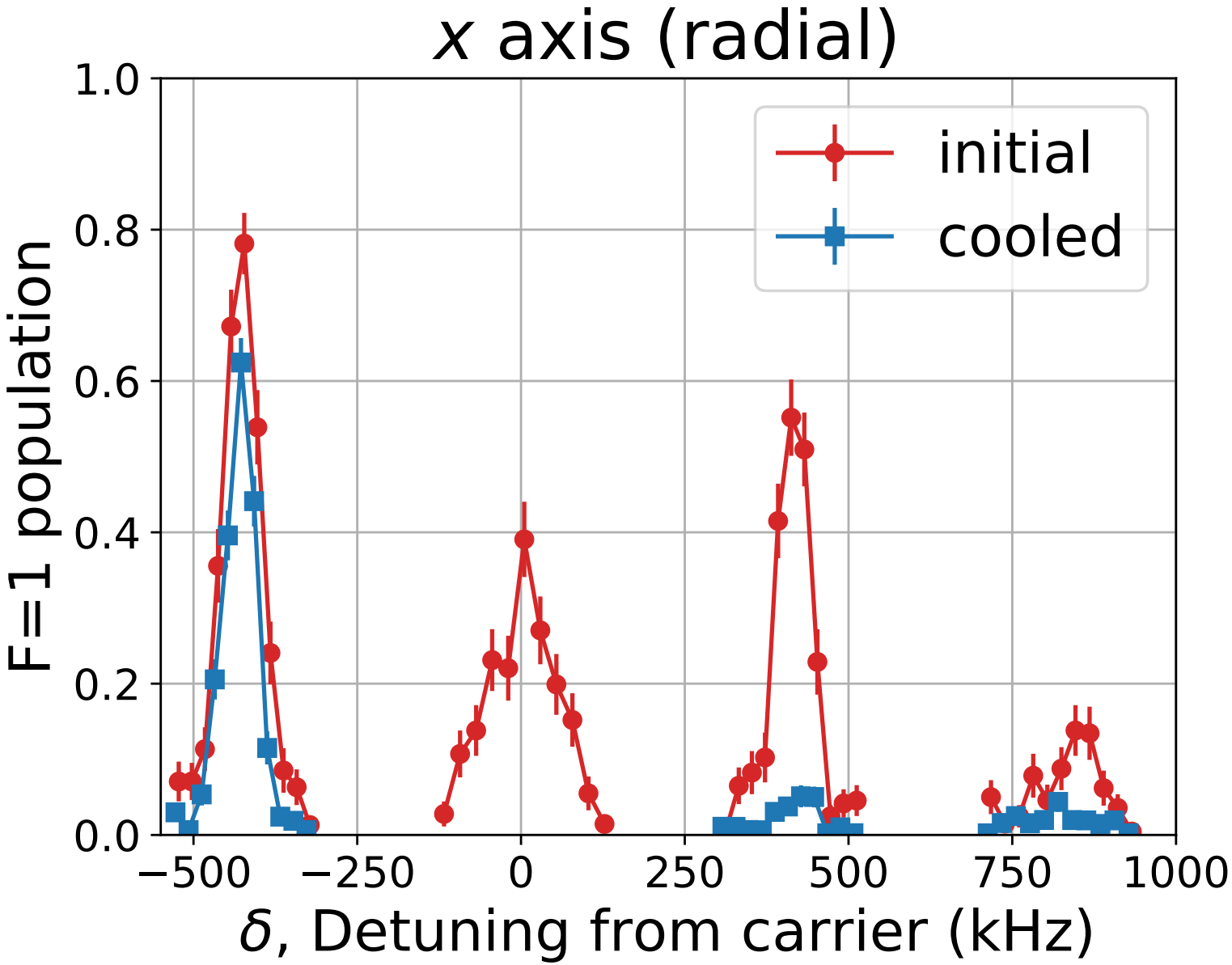
Sequence and simulation



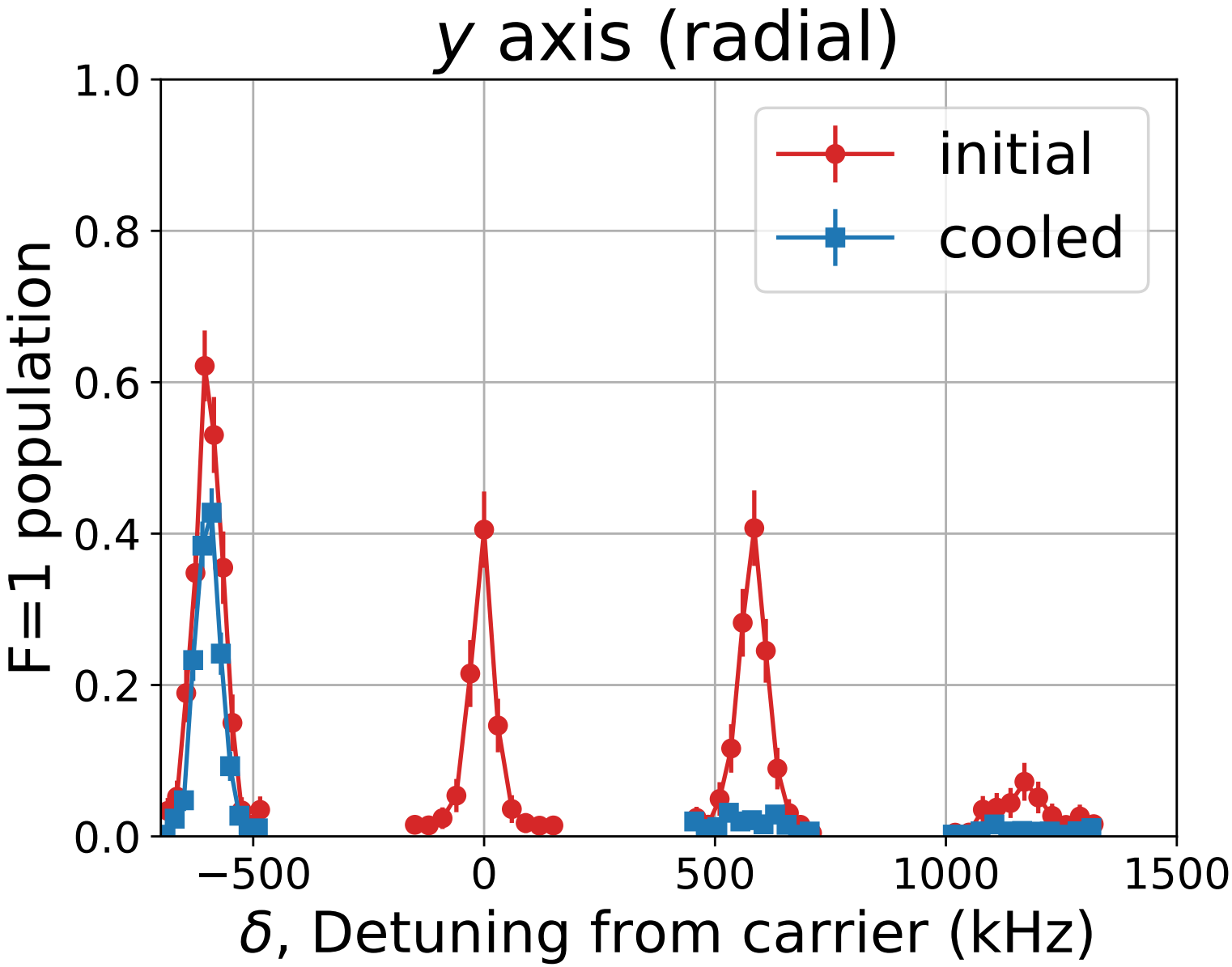
Raman sidebands



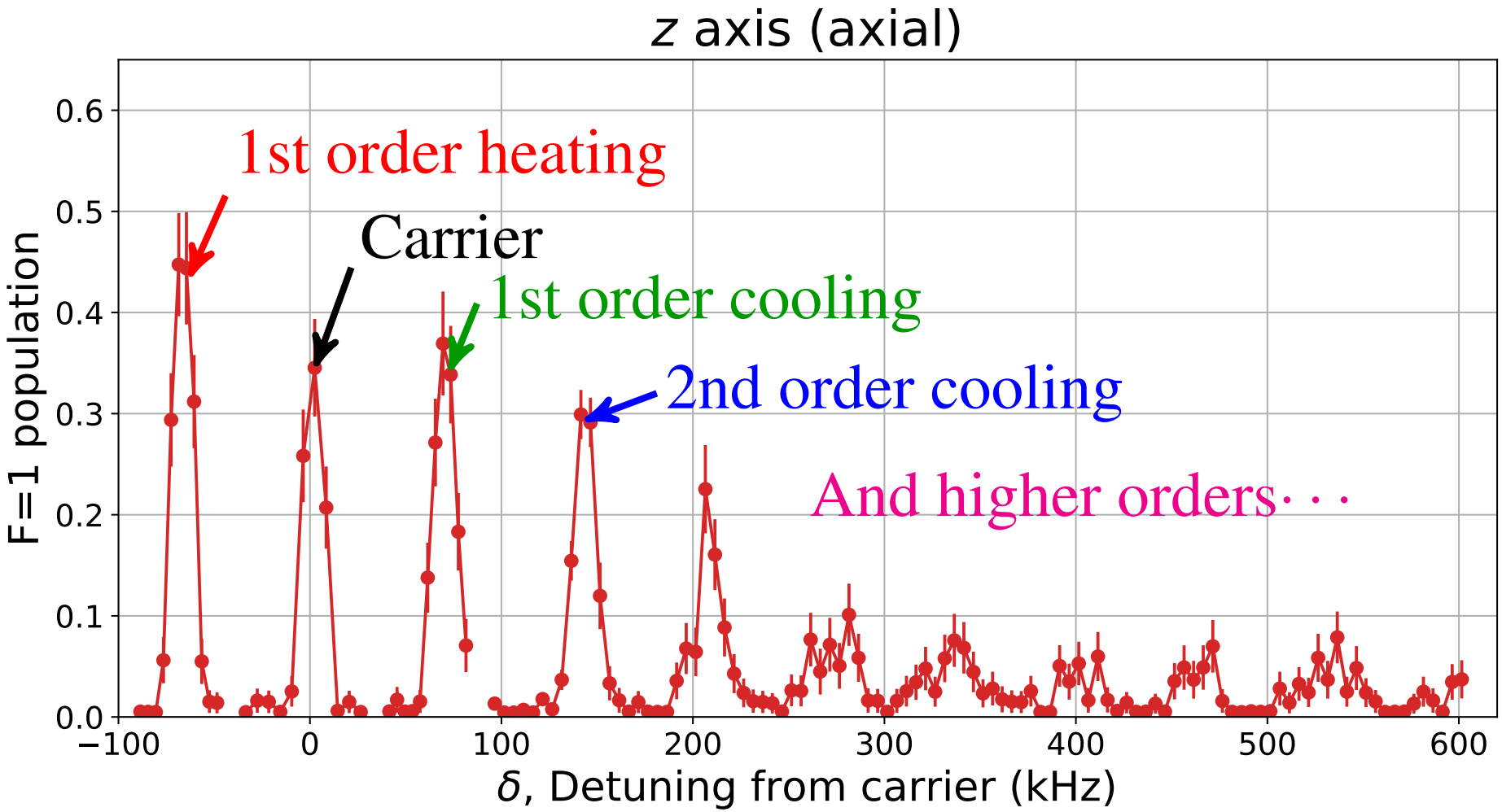
Raman sidebands



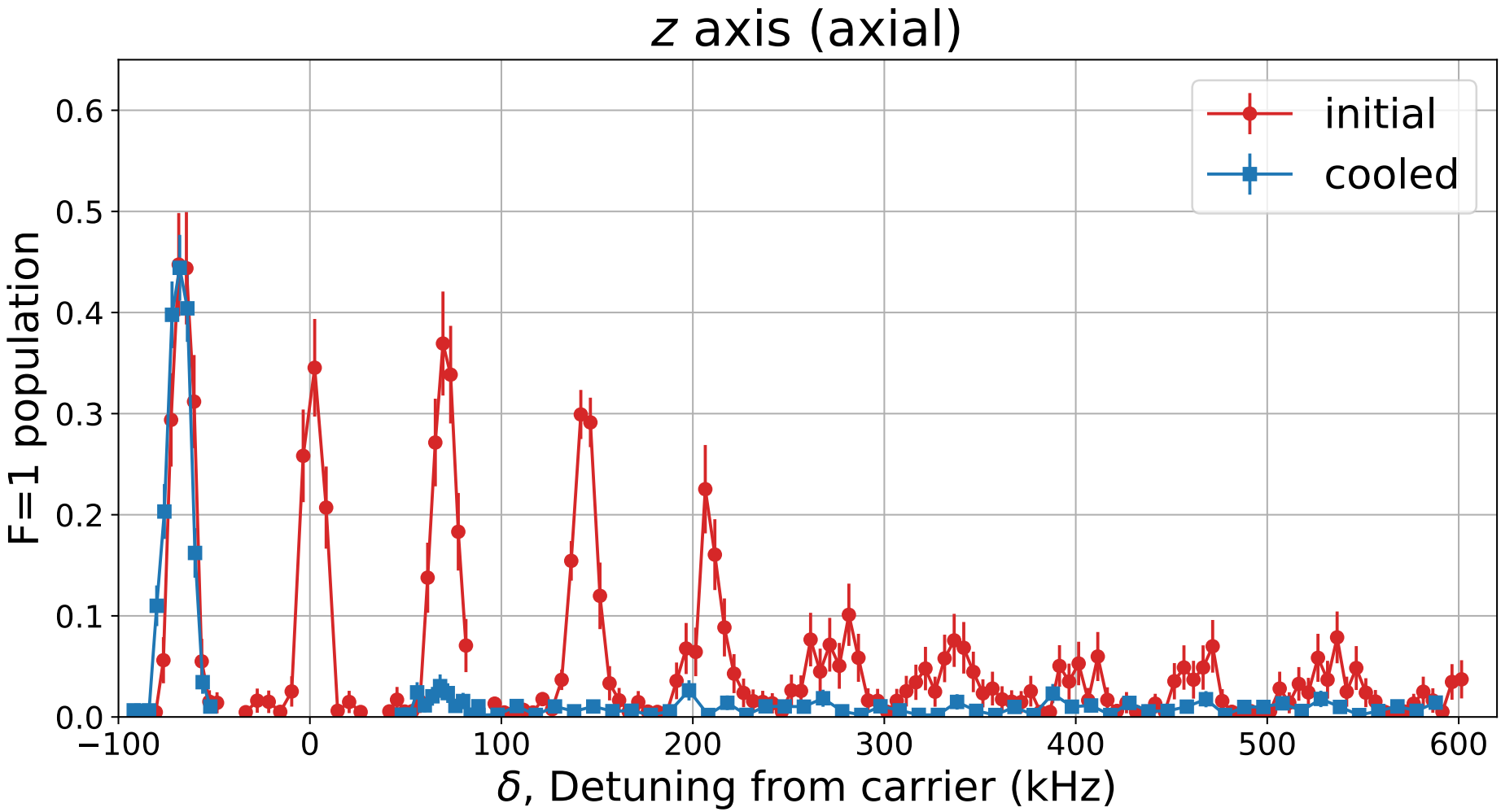
Raman sidebands



Raman sidebands

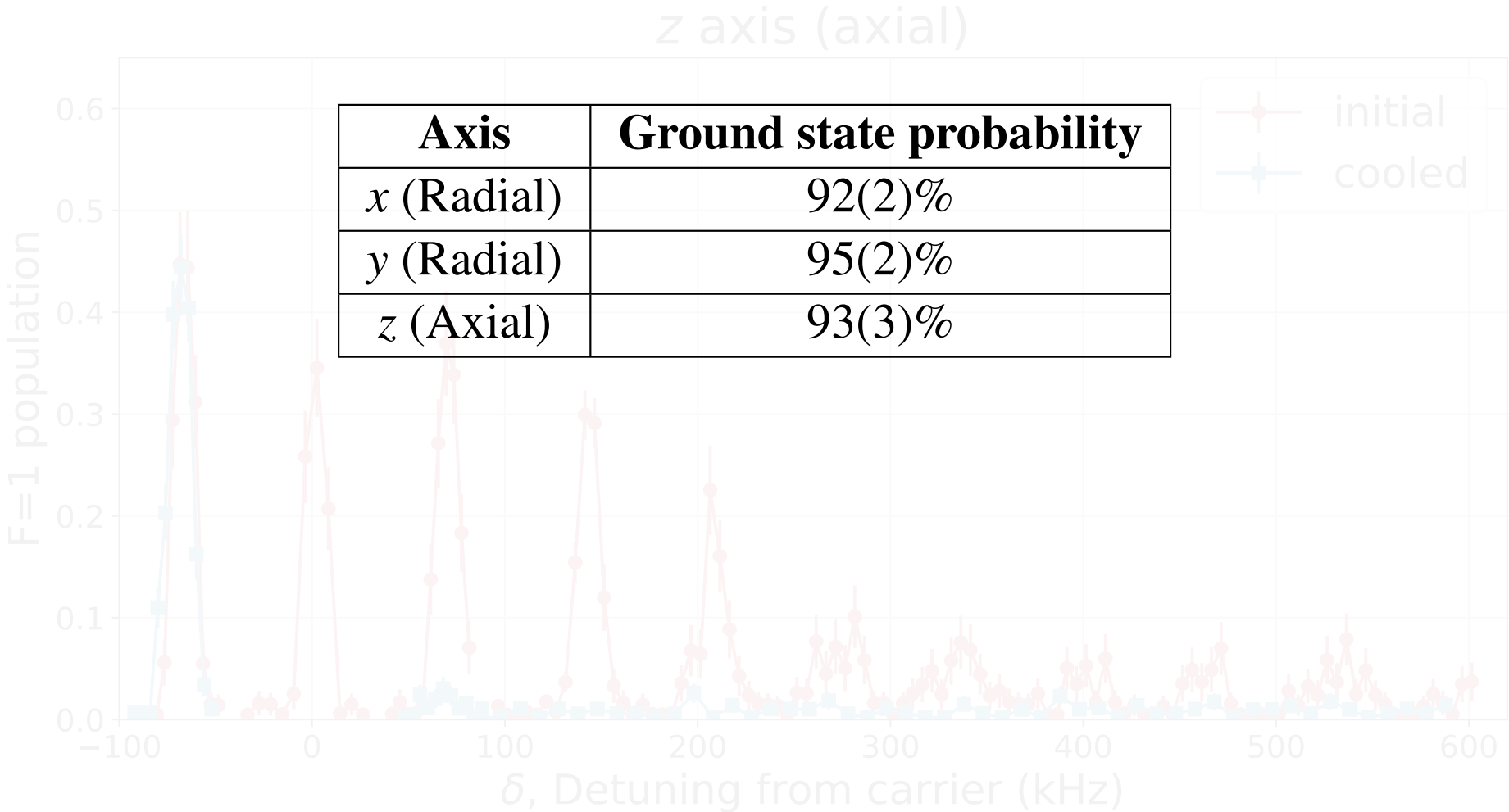


Raman sidebands



Raman sidebands

Axis	Ground state probability
x (Radial)	92(2)%
y (Radial)	95(2)%
z (Axial)	93(3)%



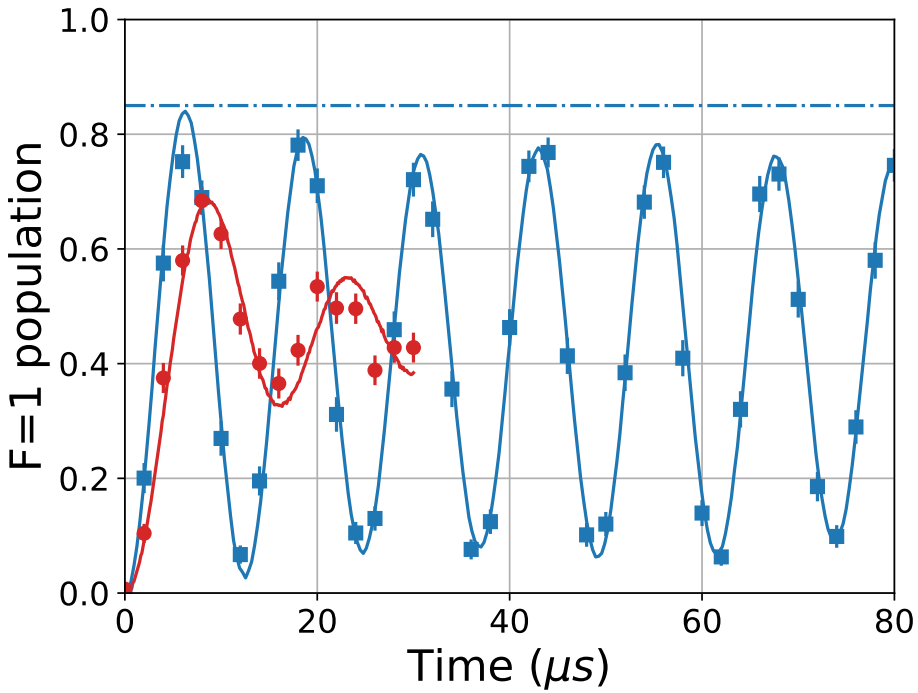
Raman sidebands

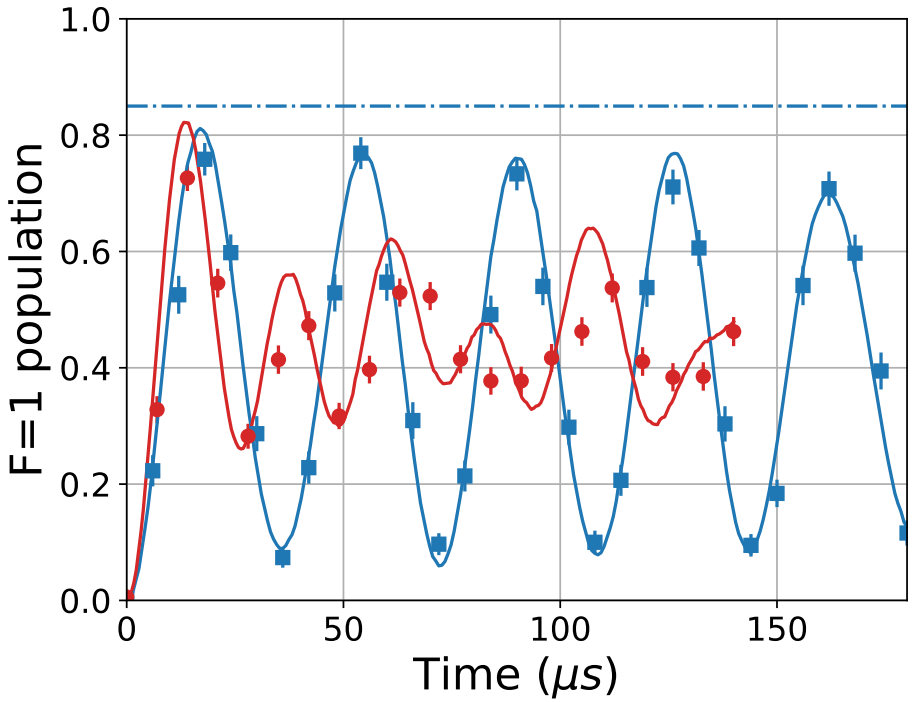
Axis	Ground state probability
x (Radial)	92(2)%
y (Radial)	95(2)%
z (Axial)	93(3)%

3D ground state: 81(4)%
Loss after cooling: 15%

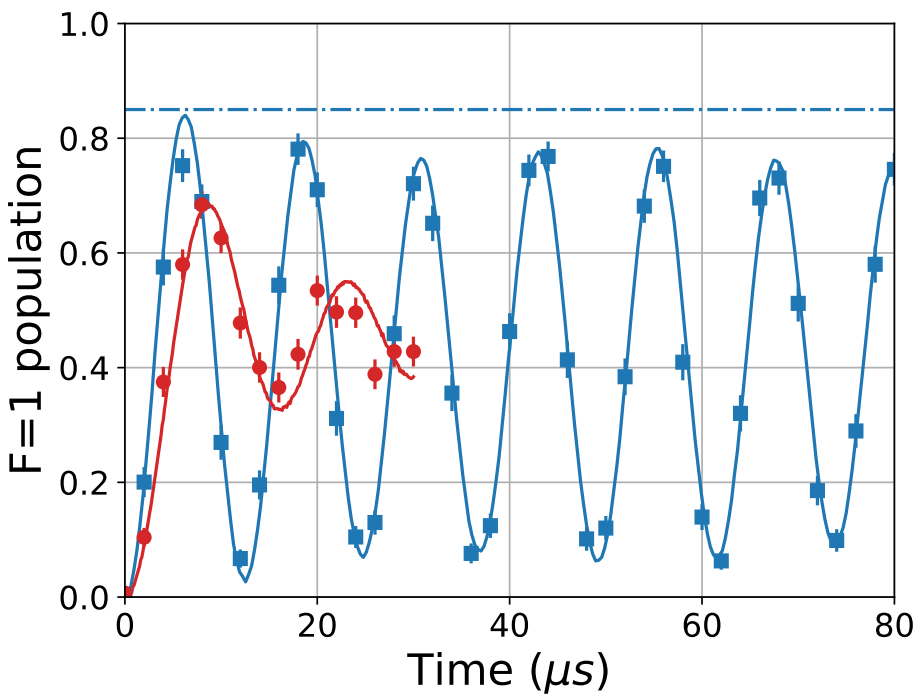
Total 3D ground state preparation fidelity: 69(3)%

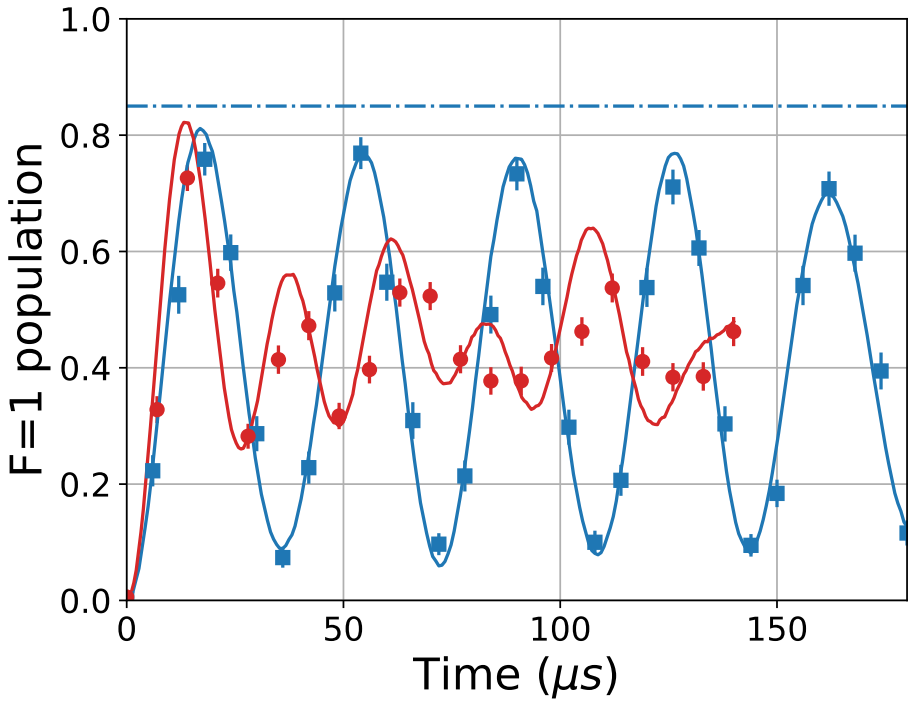
Rabi flopping (radial)





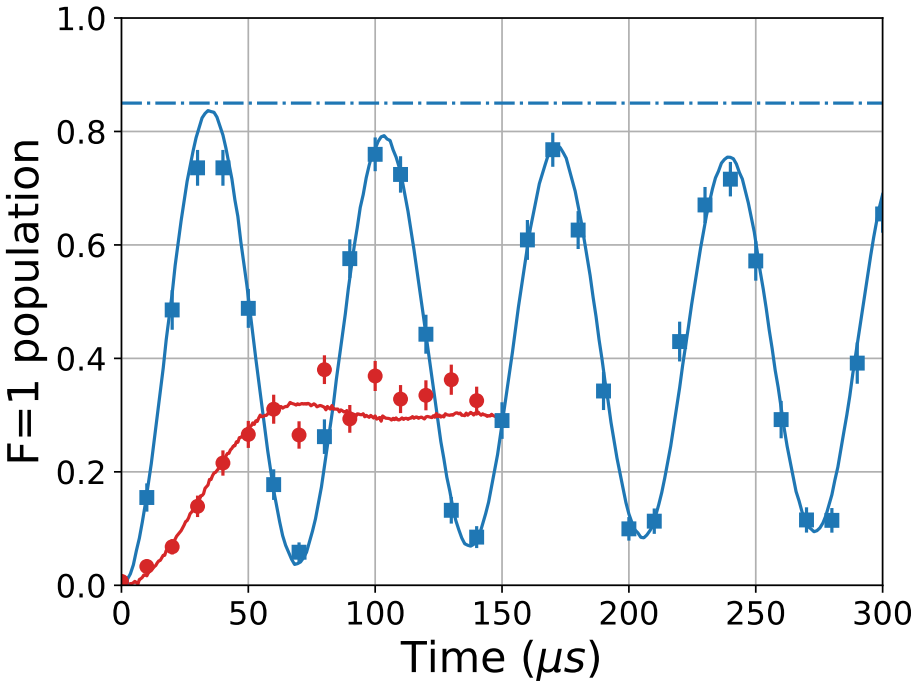
Rabi flopping (radial)

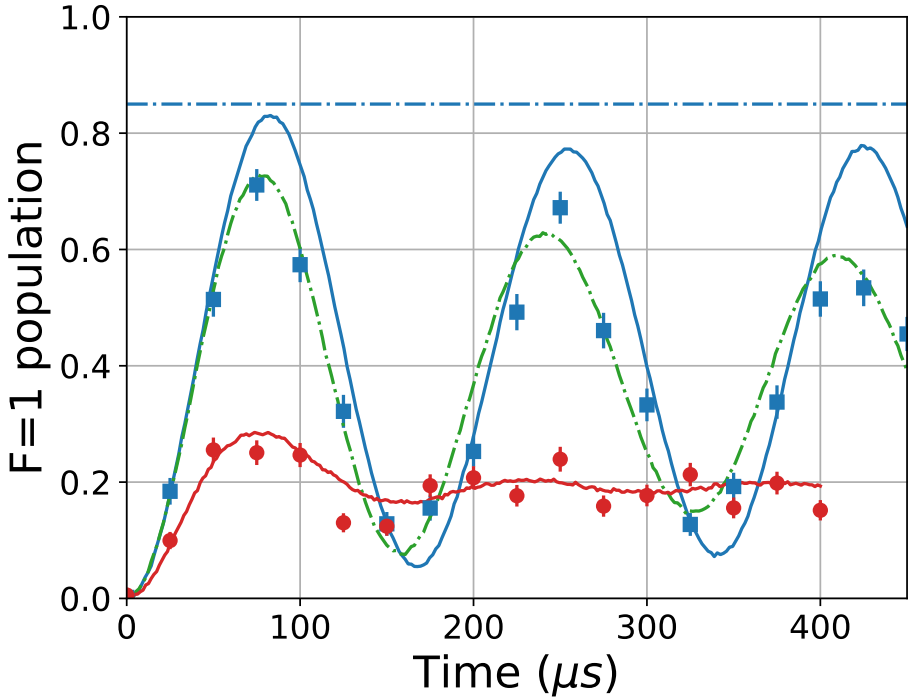




Good agreement in ground state probability between spectrum and Rabi flopping data.

Rabi flopping (axial)





Decoherence caused by technical noise.
E.g. 1.5 mG of magnetic field noise.

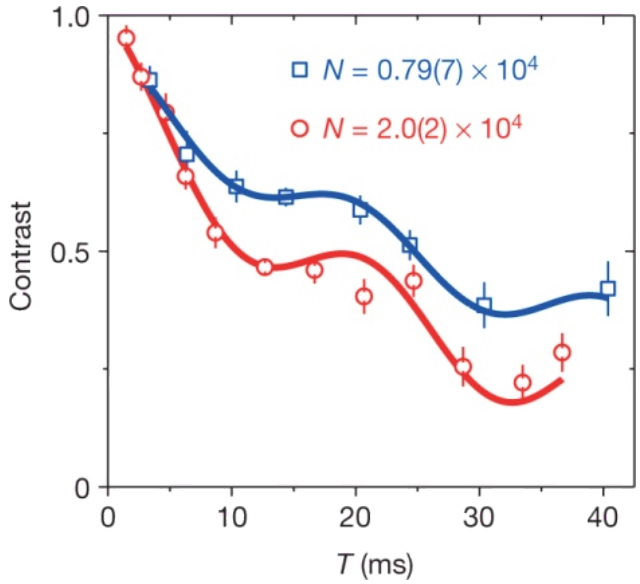
Conclusion

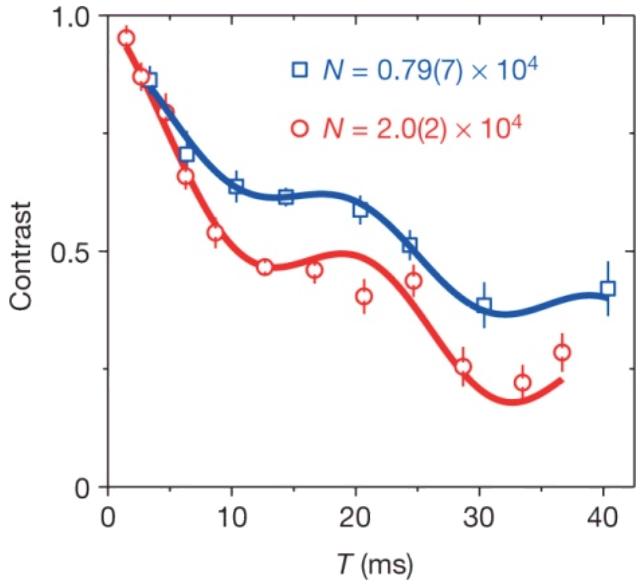
- Trapping of Na and Cs atoms
- Ground state cooling of Na[3] and Cs

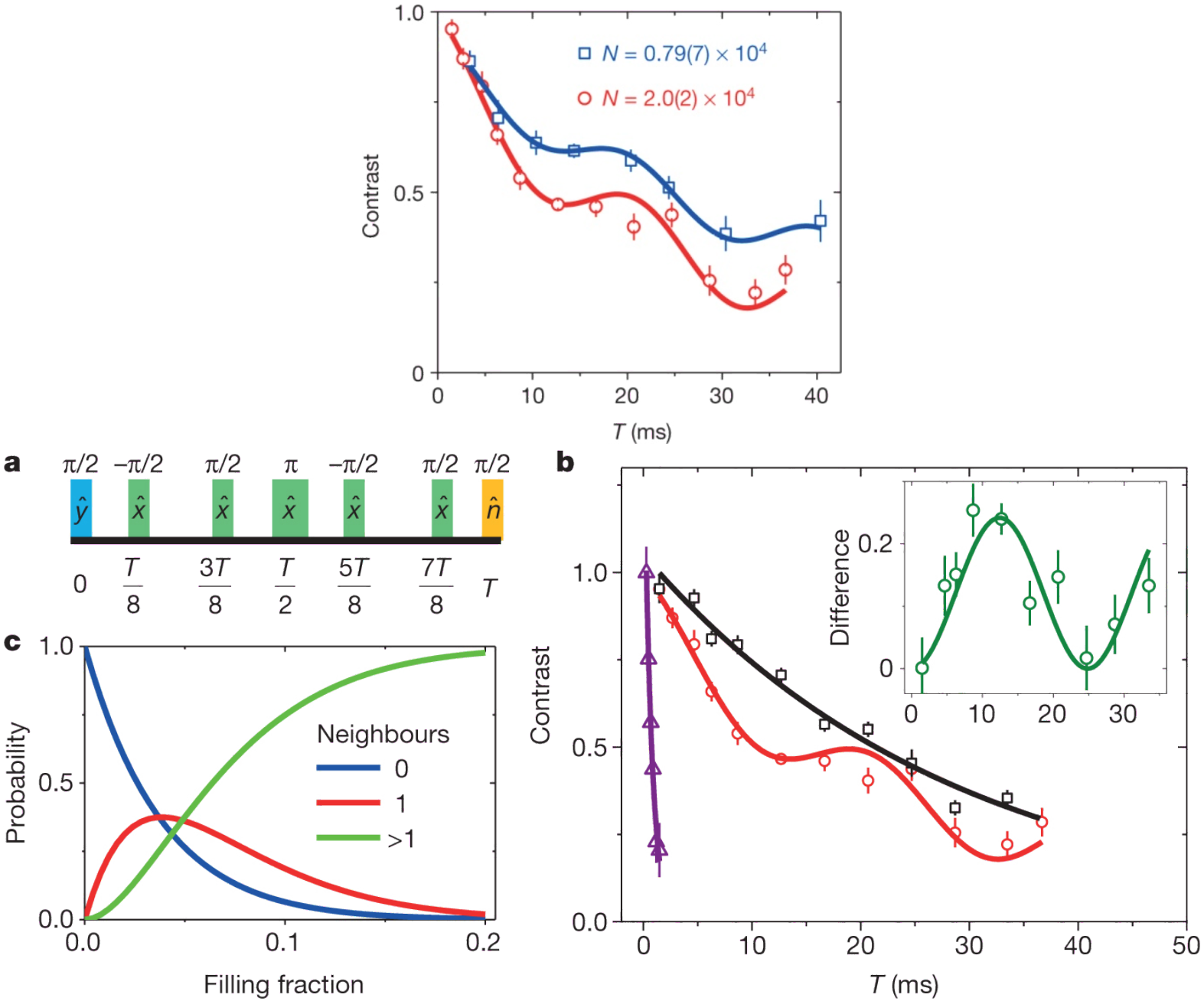
In progress

- Merge trap
- Photoassociation spectroscopy
- Make molecules

[3] Y. Yu et al., "Motional ground state cooling outside the lamb-dicke regime", arXiv 1708.03296 (2017).


1.0
0.5
0
Contrast
0
10
20
30
40
T (ms)
N = 0.79(7) × 10^4
N = 2.0(2) × 10^4


1.0
0.5
0
Contrast
0
10
20
30
40
T (ms)
N = 0.79(7) × 10^4
N = 2.0(2) × 10^4

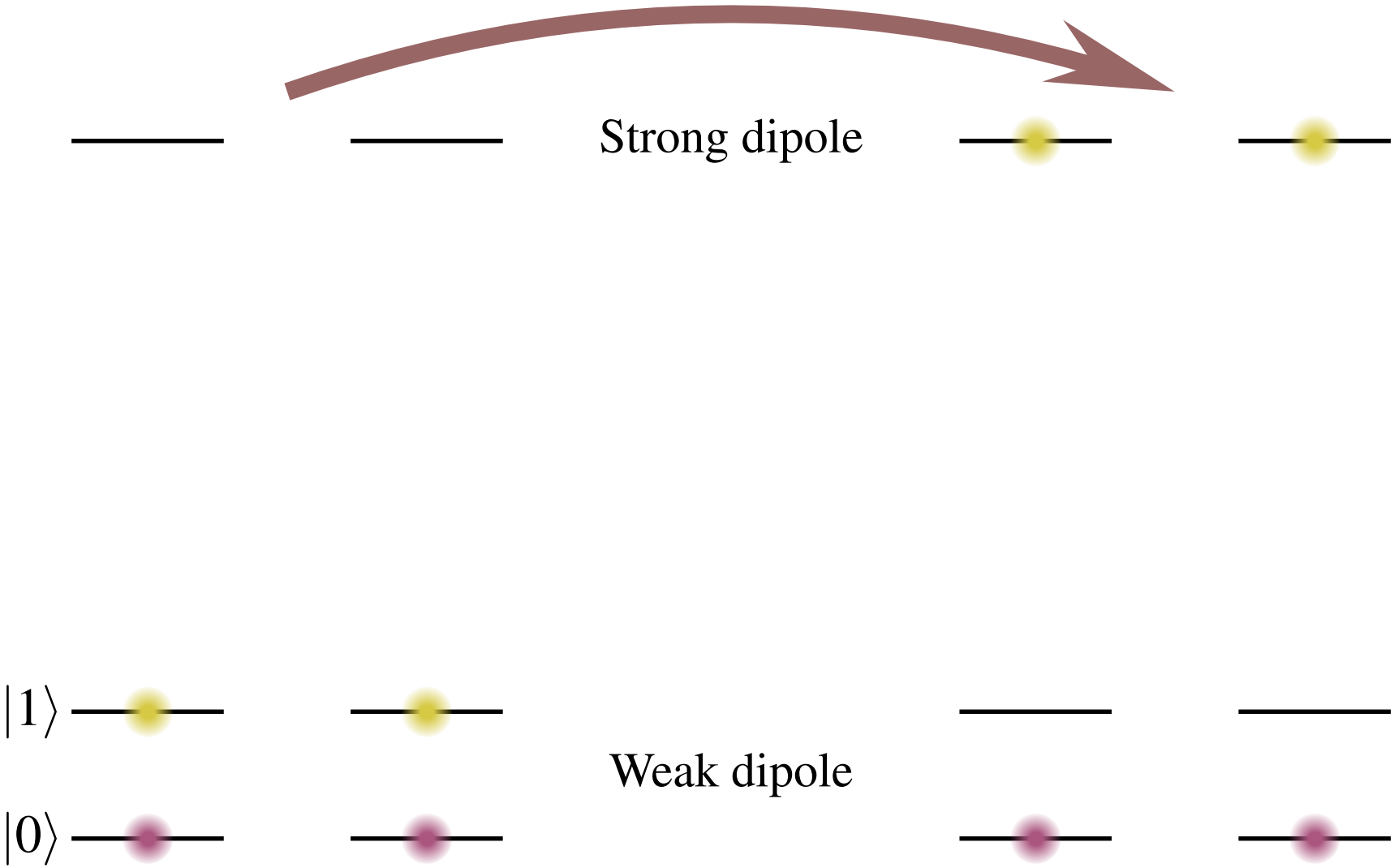

1.0
0.5
0
Contrast
N = 0.79(7) × 10^4
N = 2.0(2) × 10^4
0
10
20
30
40
T (ms)
a
π/2
−π/2
π/2
π
−π/2
π/2
π/2
ŷ
x̂
x̂
x̂
x̂
x̂
n̂
0
T/8
3T/8
T/2
5T/8
7T/8
T
b
Contrast
Difference
0.2
0
T (ms)
c
Probability
Neighbours
0
1
>1
Filling fraction
0.0
0.1
0.2

Quantum computation

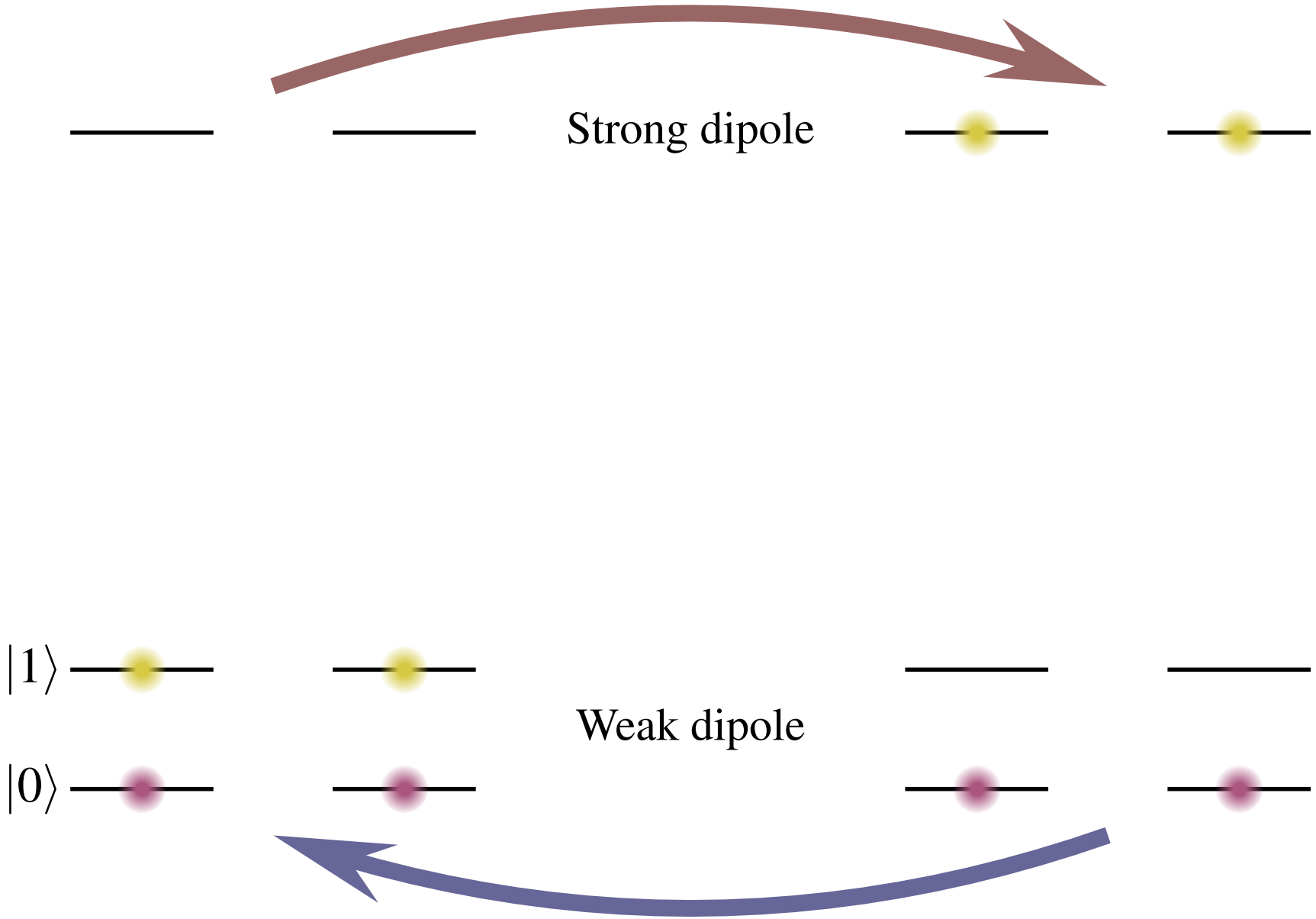
Strong dipole

Weak dipole

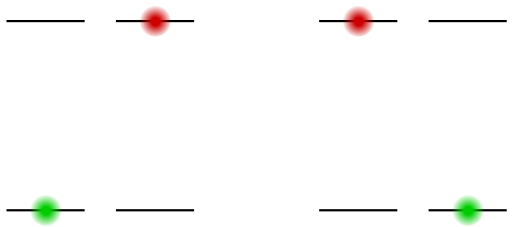
Quantum computation



Quantum computation

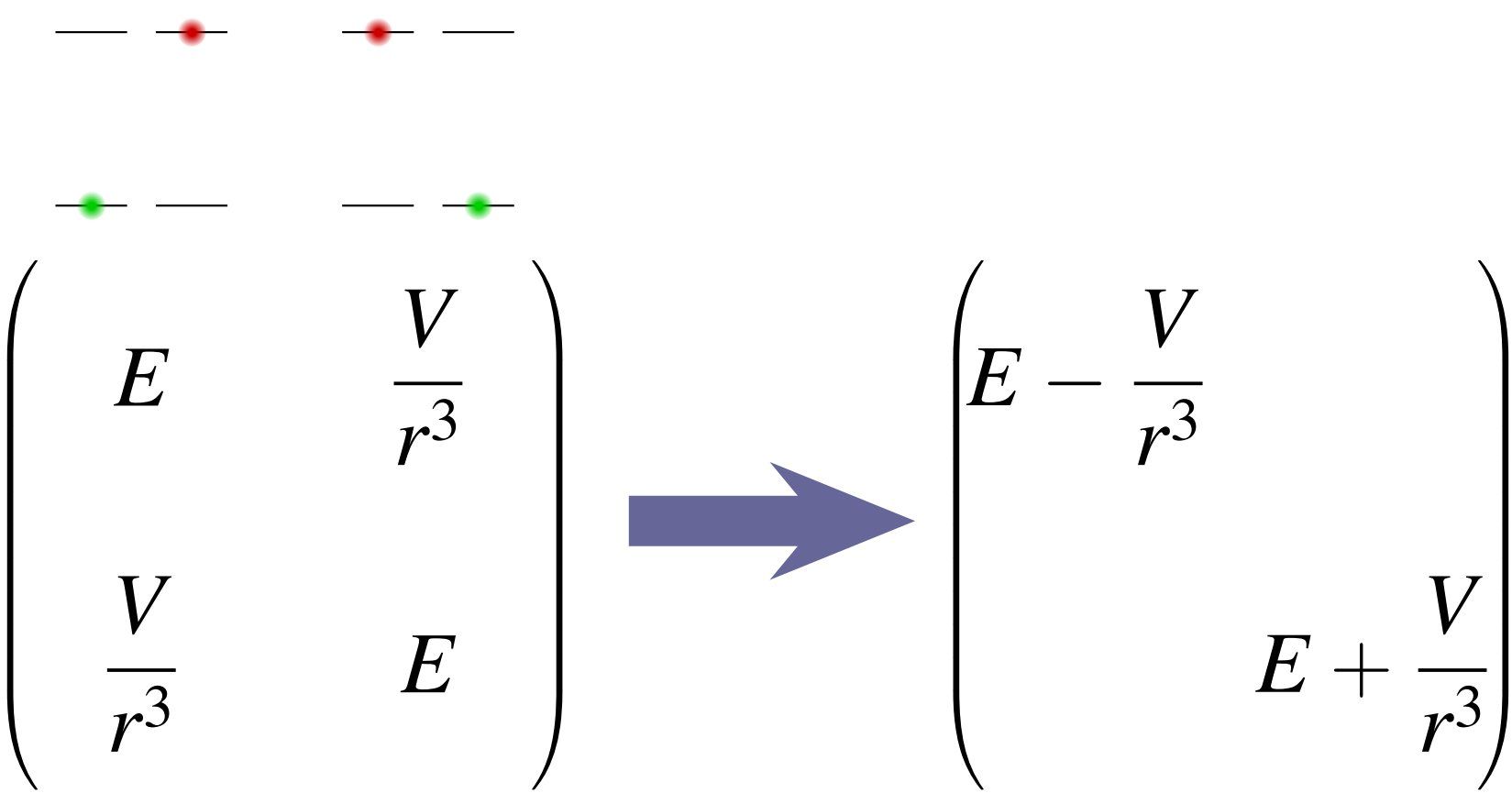


Quantum computation

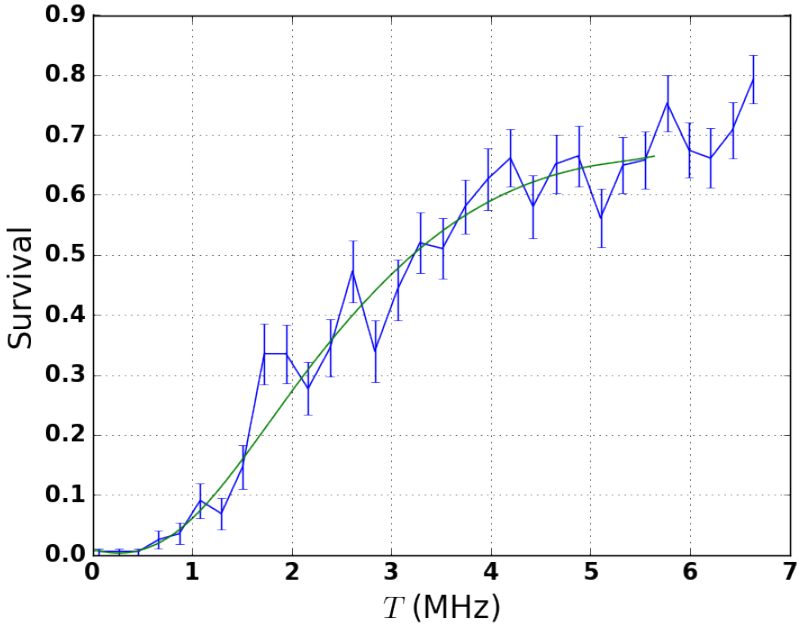


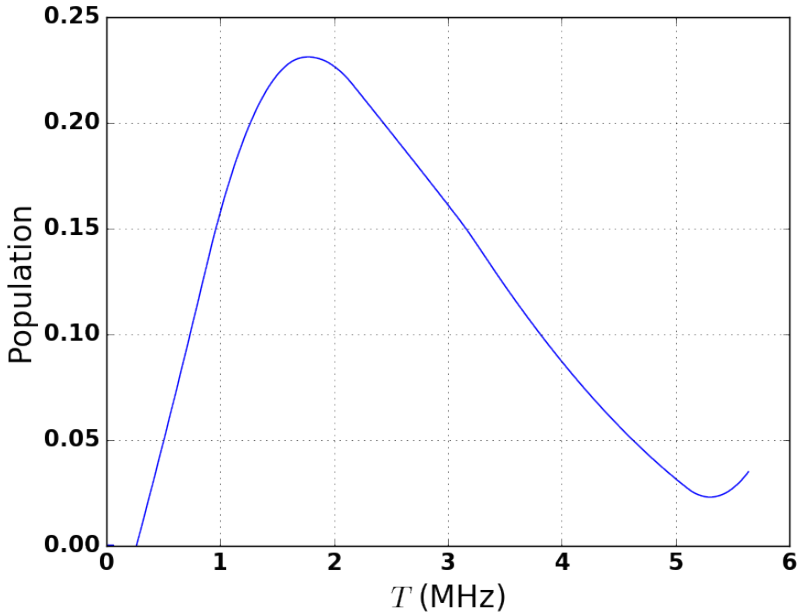
$$\begin{pmatrix} E & \frac{V}{r^3} \\ \frac{V}{r^3} & E \end{pmatrix}$$

Quantum computation

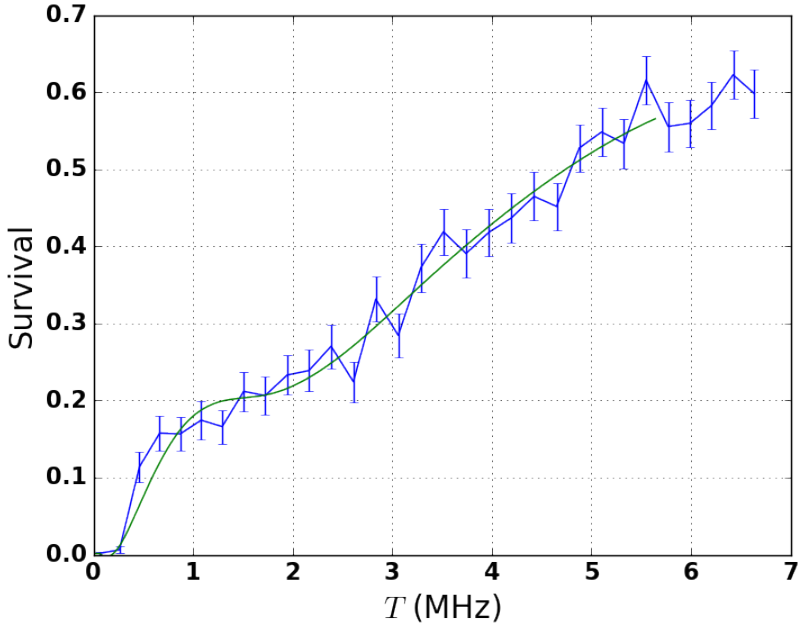


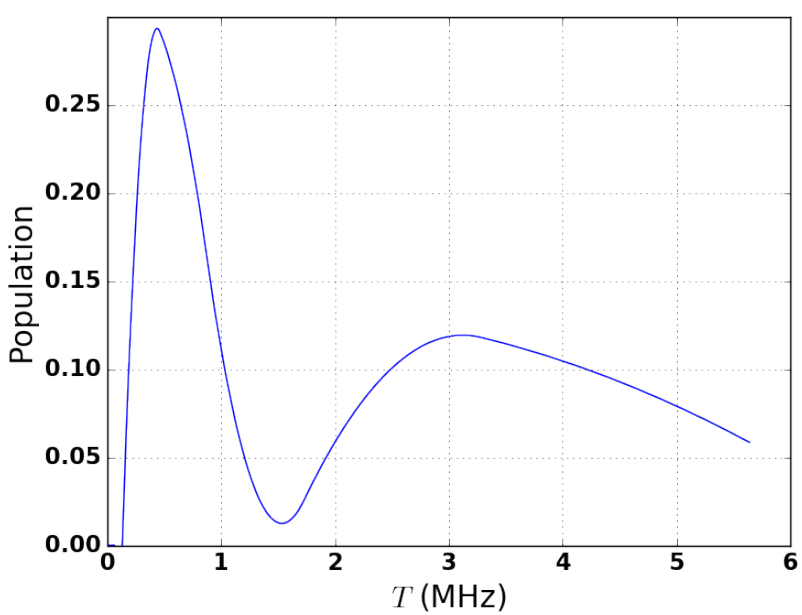
Before cooling



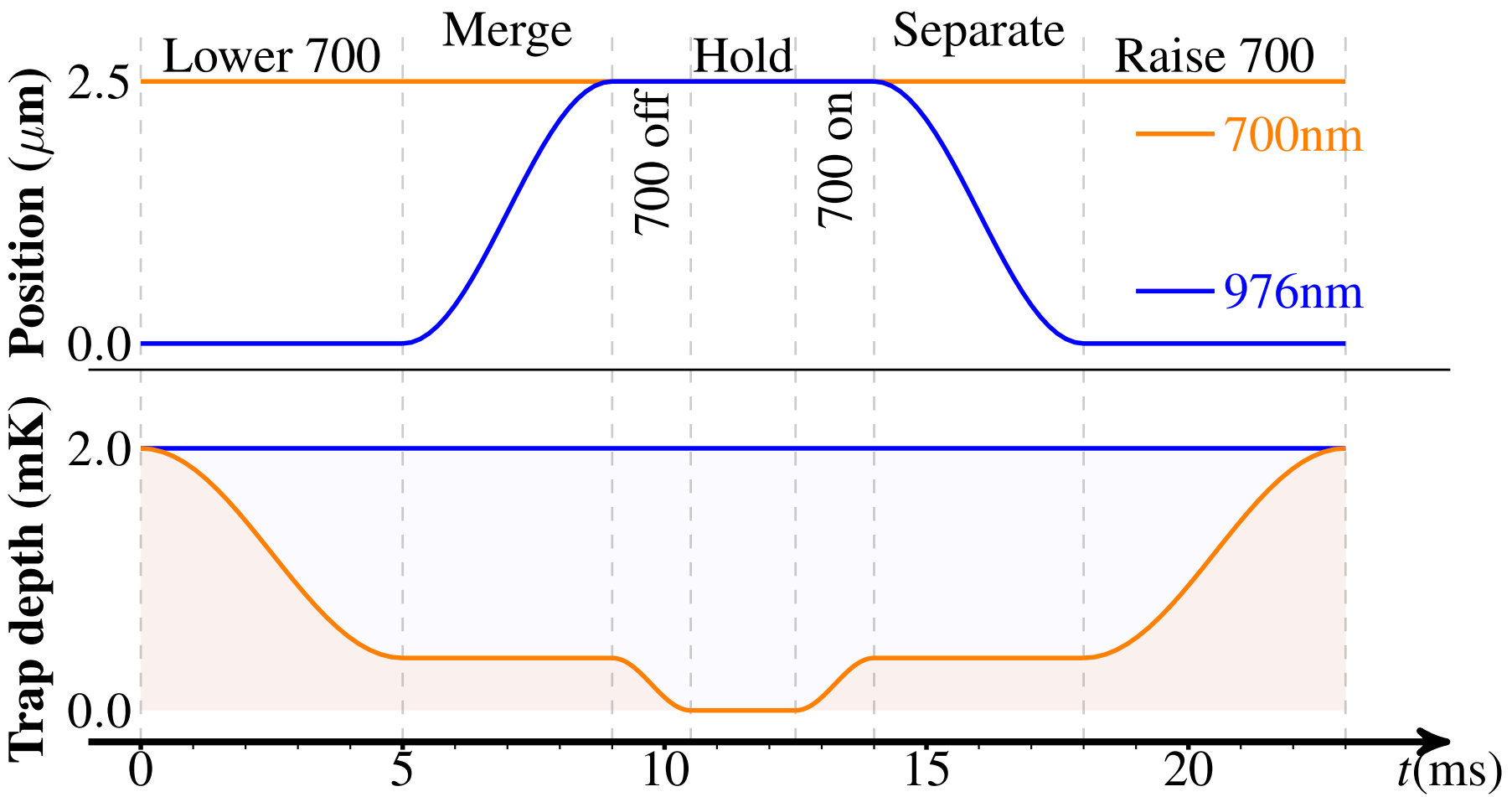


After cooling

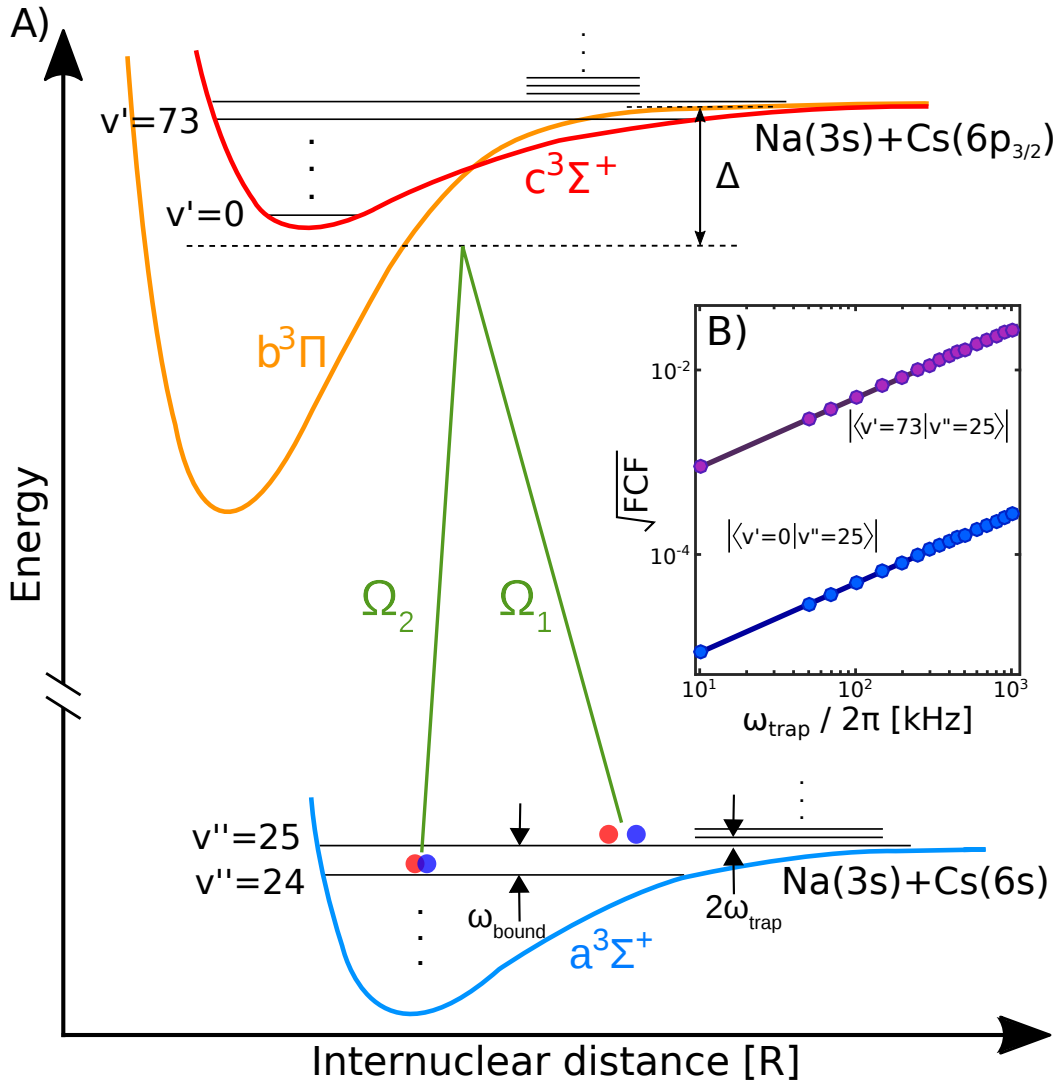




Merge trap


Lower 700
Merge
Hold
Separate
Raise 700
700 off
700 on
700nm
976nm
Position (μm)
2.5
0.0
Trap depth (mK)
2.0
0.0
0
5
10
15
20
t(ms)

Making molecule



Master equation

$$\frac{\mathrm{d}\rho}{\mathrm{d}t} = \frac{1}{\mathrm{i}\hbar}[H,\rho] + \mathcal{L}_{\mathrm{relax}}(\rho)$$

$$\mathcal{L}_{\mathrm{relax}}(\rho) = \sum_m C_m \rho C_m^\dagger - \frac{1}{2}\sum_m \left(C_m C_m^\dagger \rho + \rho C_m C_m^\dagger \right)$$