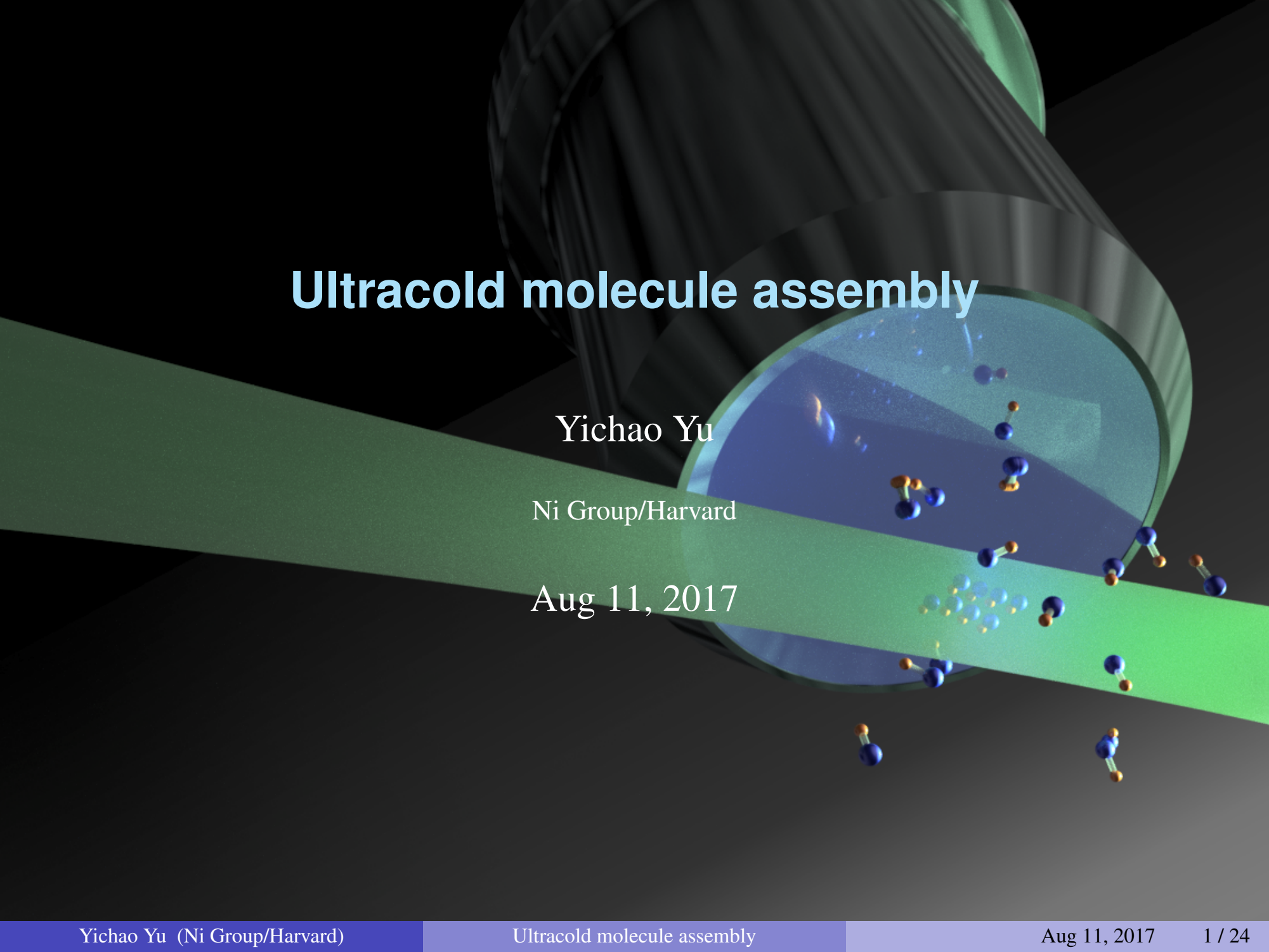


Ultracold molecule assembly

Yichao Yu

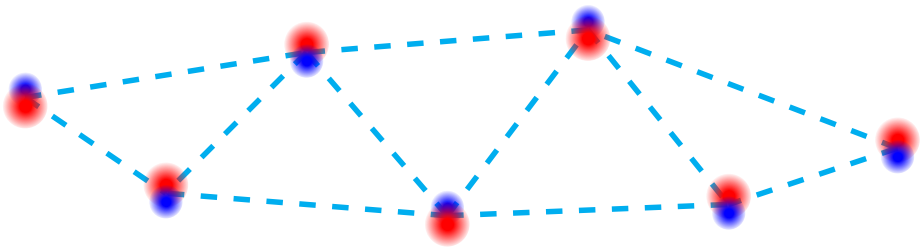
Ni Group/Harvard

Aug 11, 2017

Molecules in optical tweezer

Features

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



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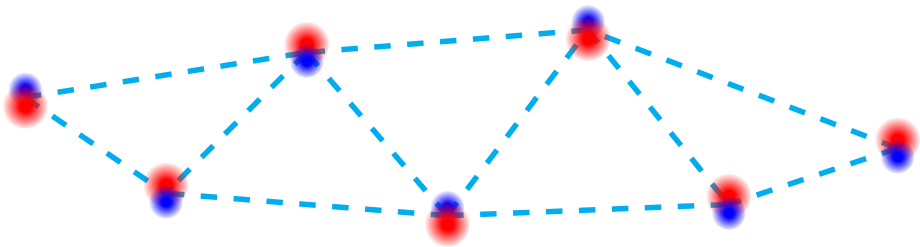

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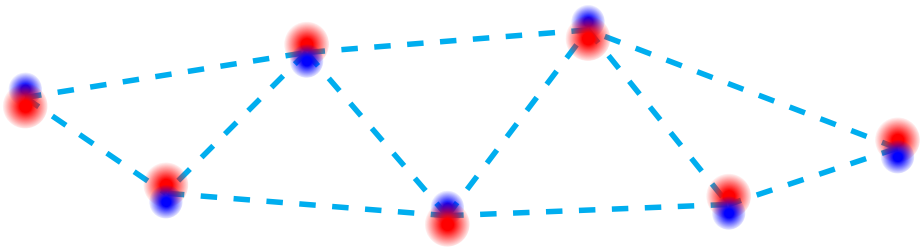

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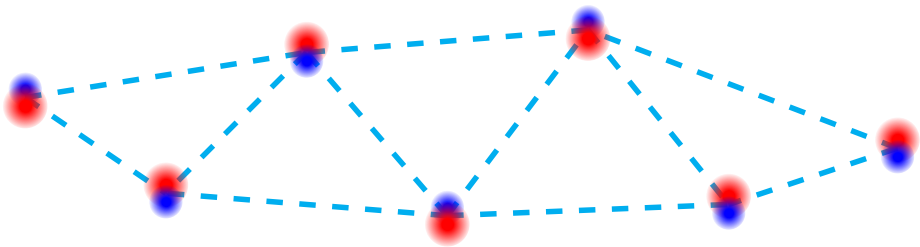

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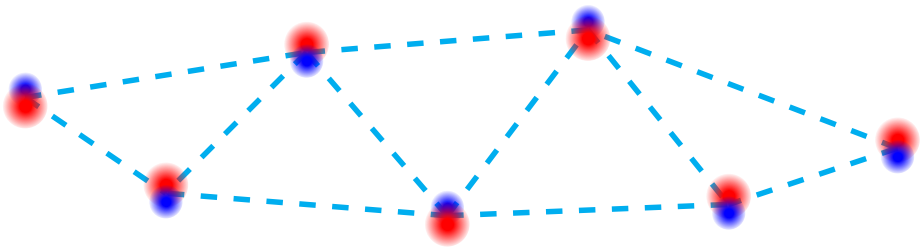
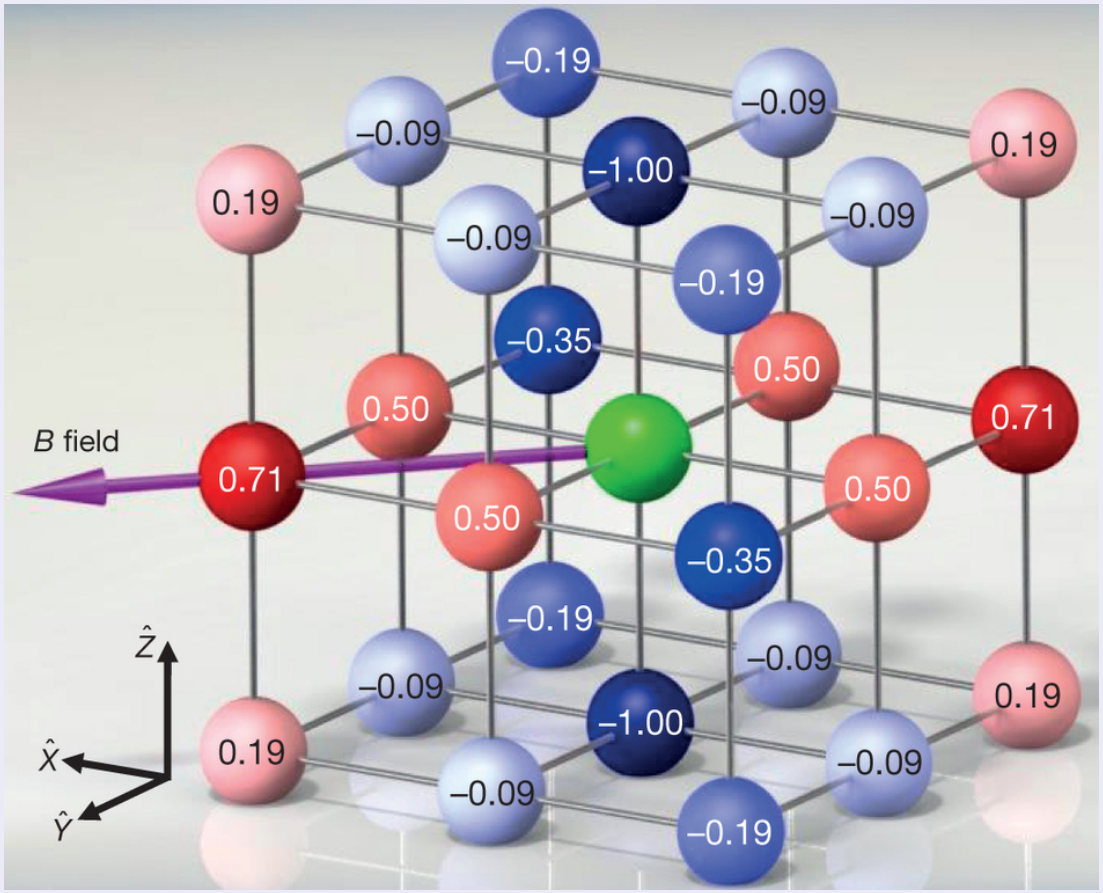


Applications

Simulation of many-body system[1]

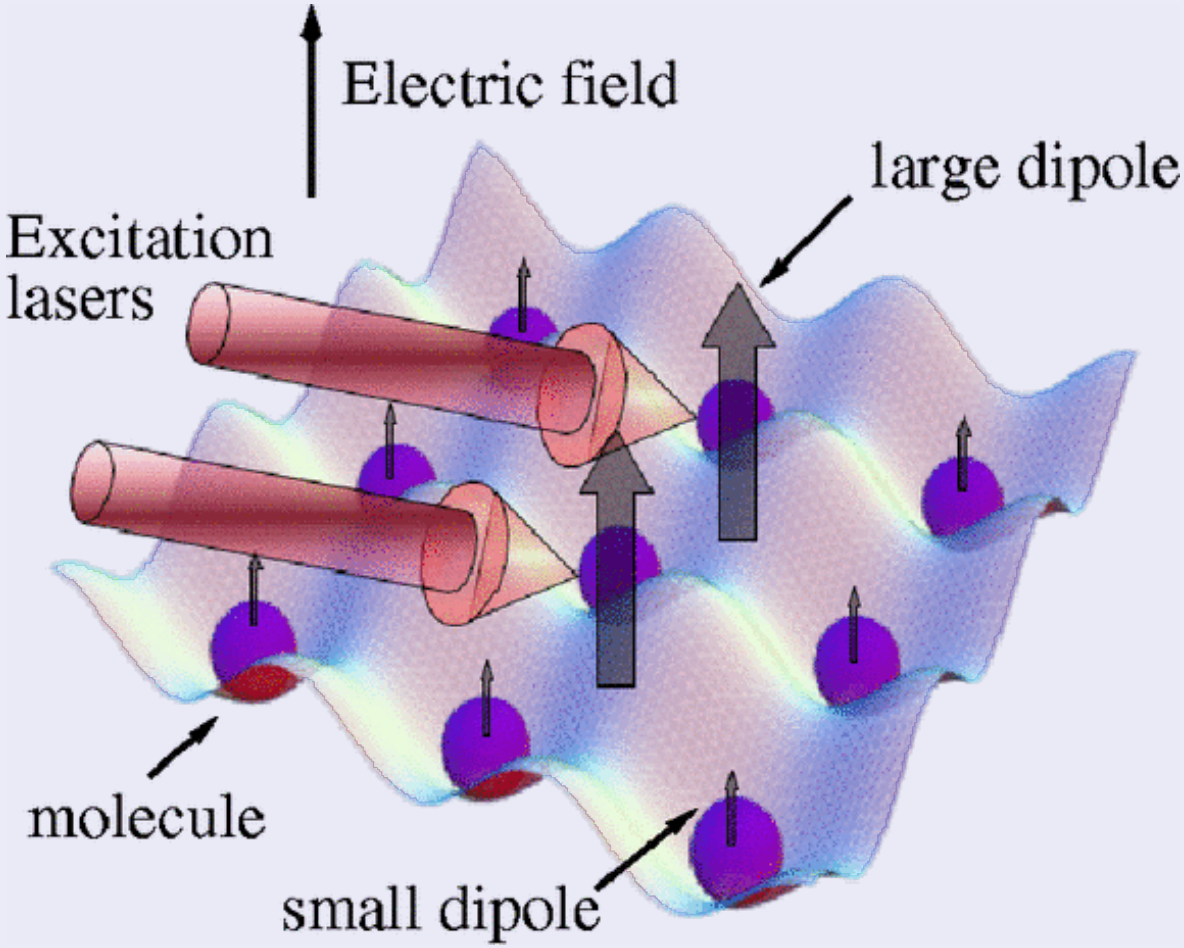


$$H \propto \sum V_{ij}\left(S_i^+ S_j^- + S_i^- S_j^+\right)$$

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

Applications

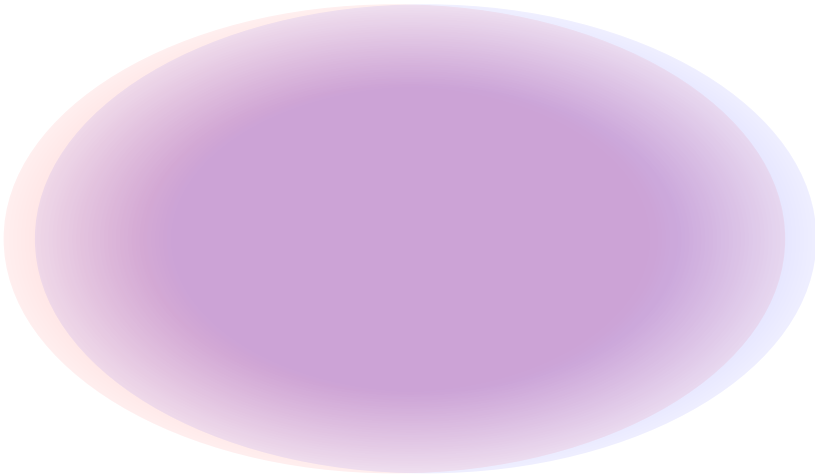
Quantum computation[2]



[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!



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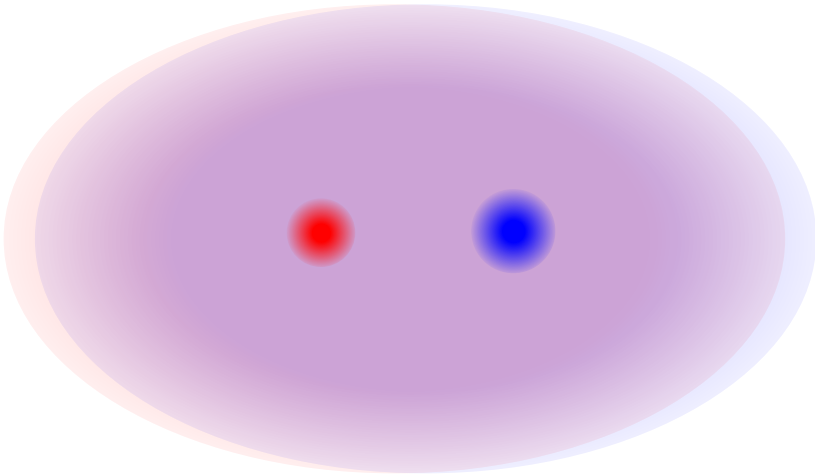

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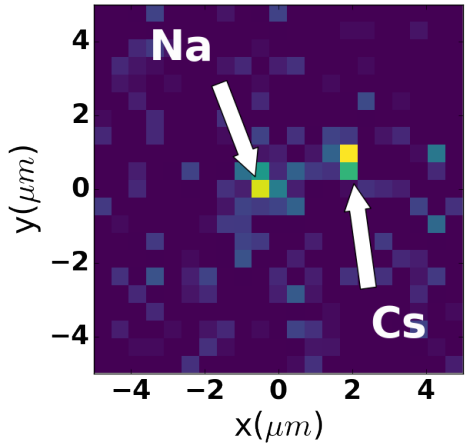
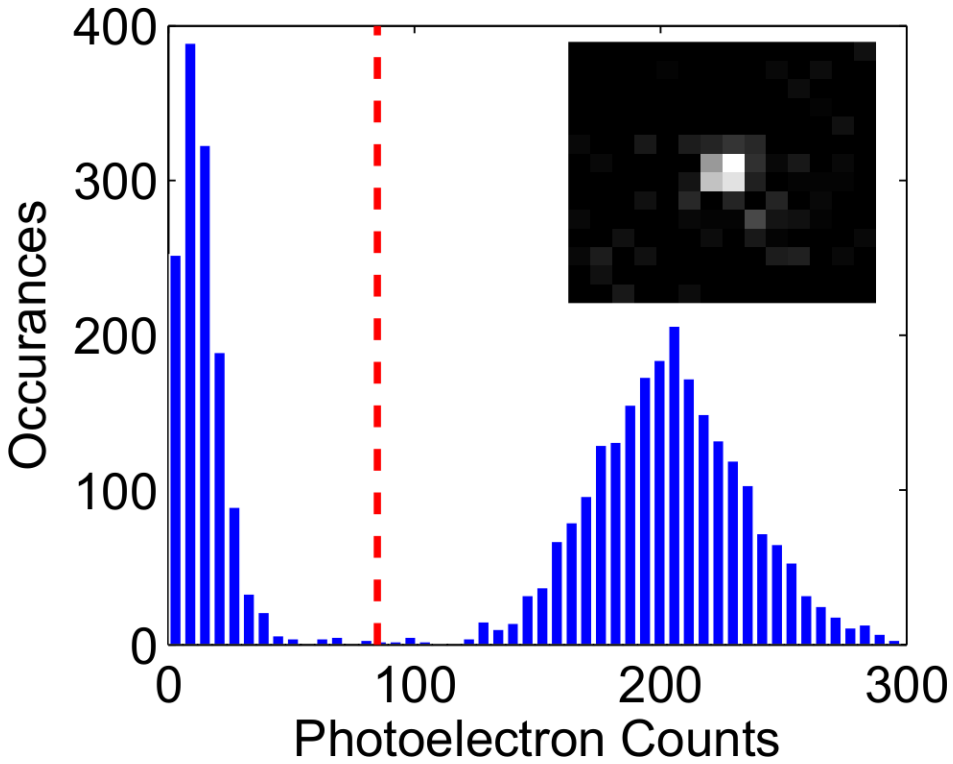
Atom loading and cooling



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



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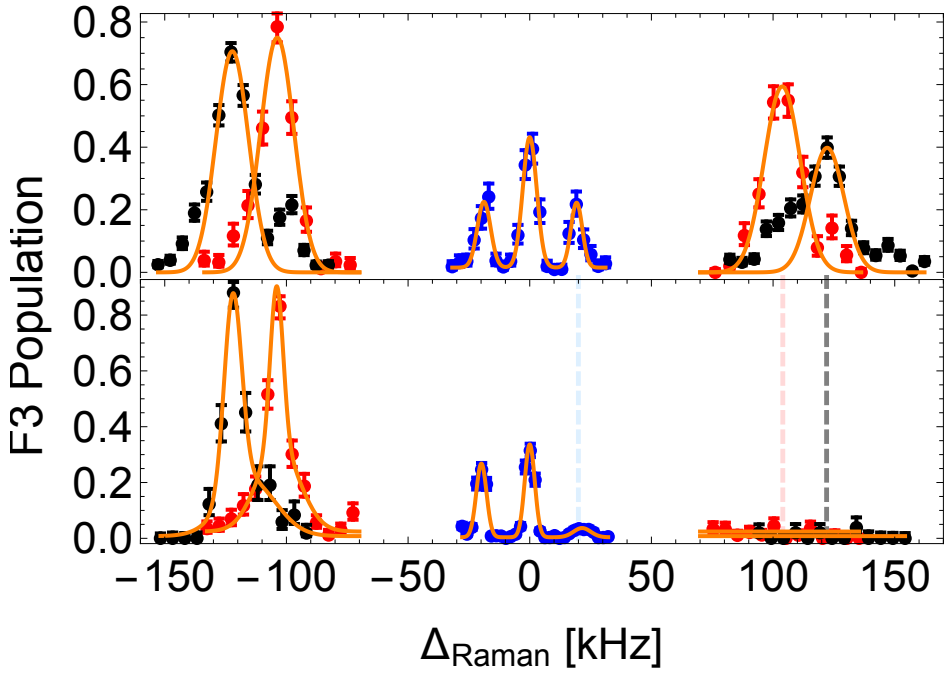
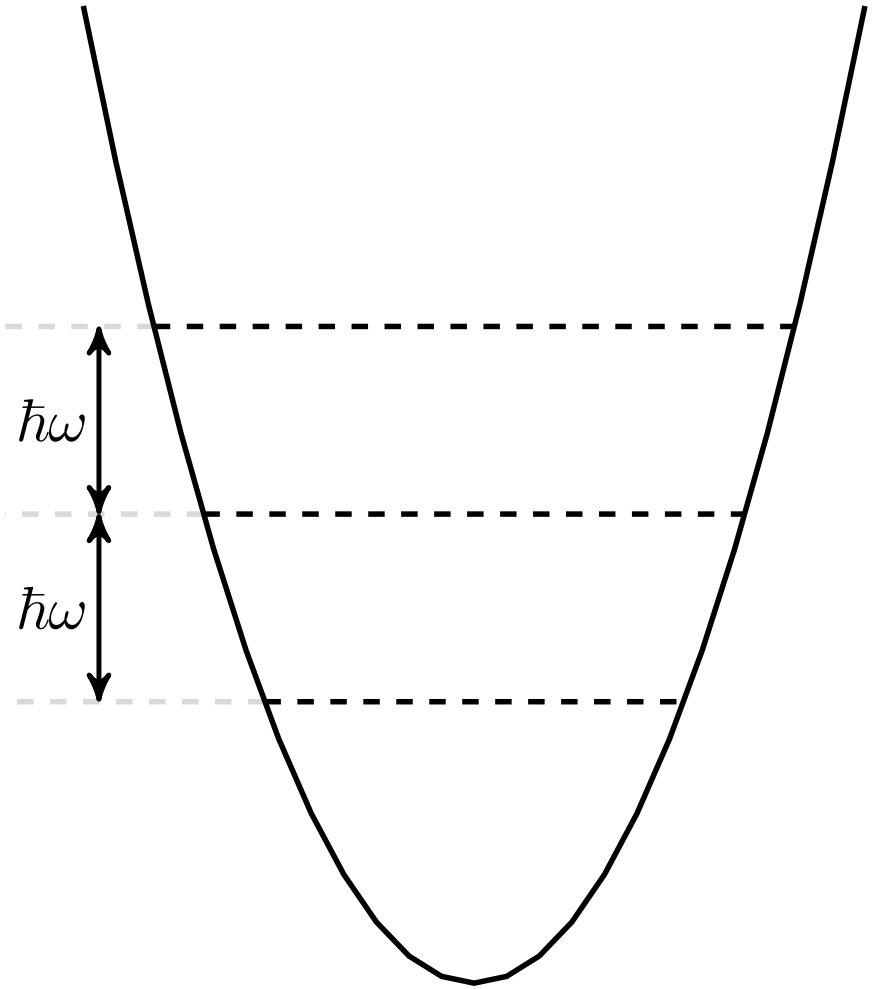


Raman sideband cooling



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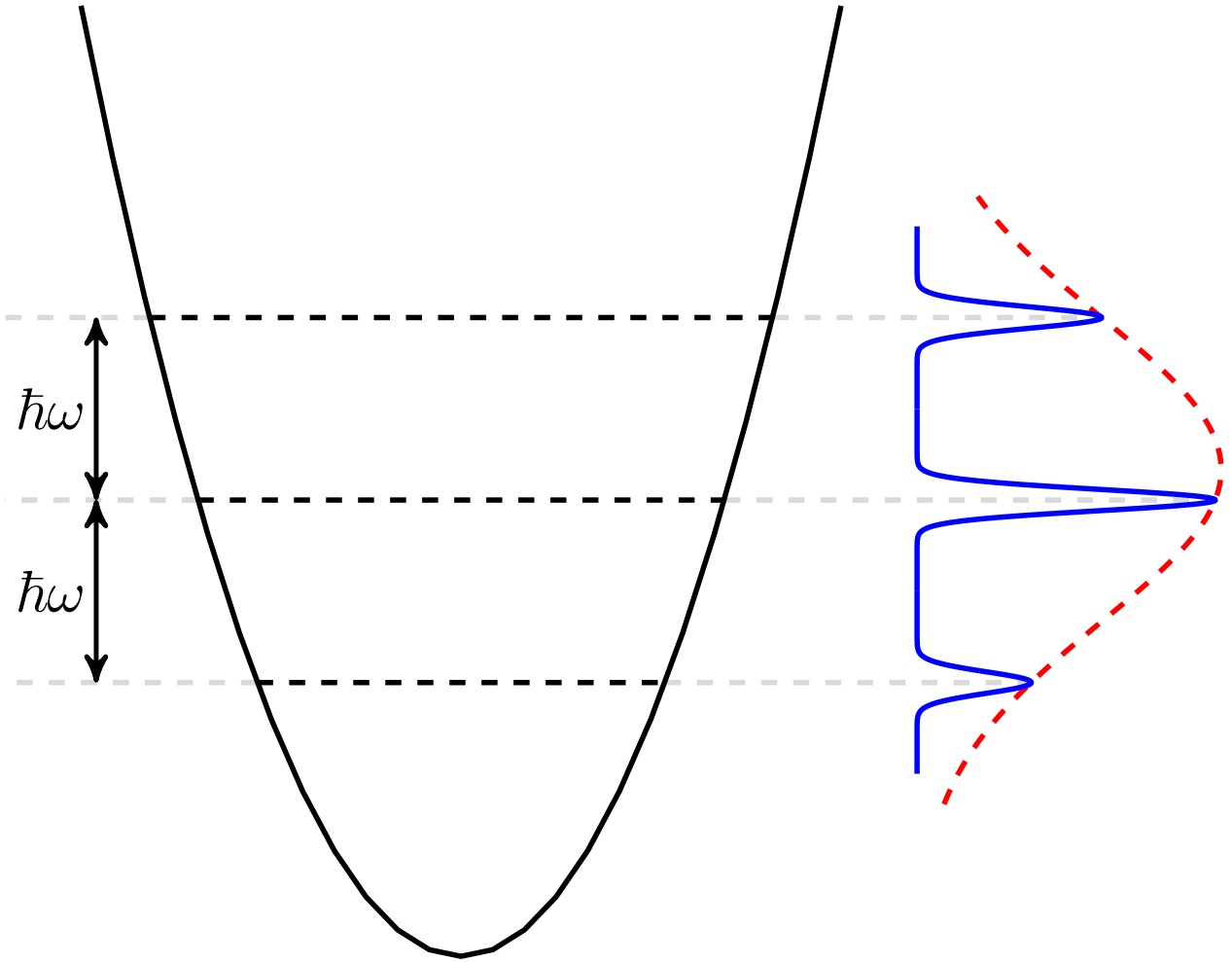

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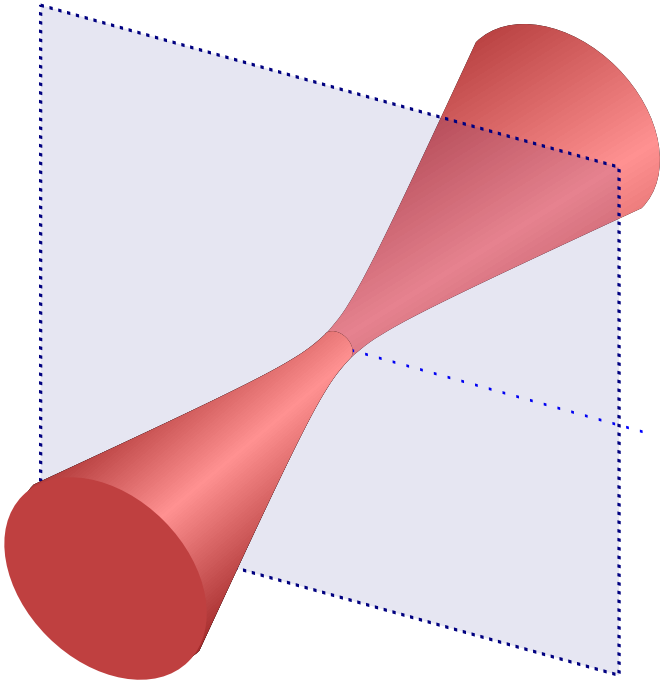

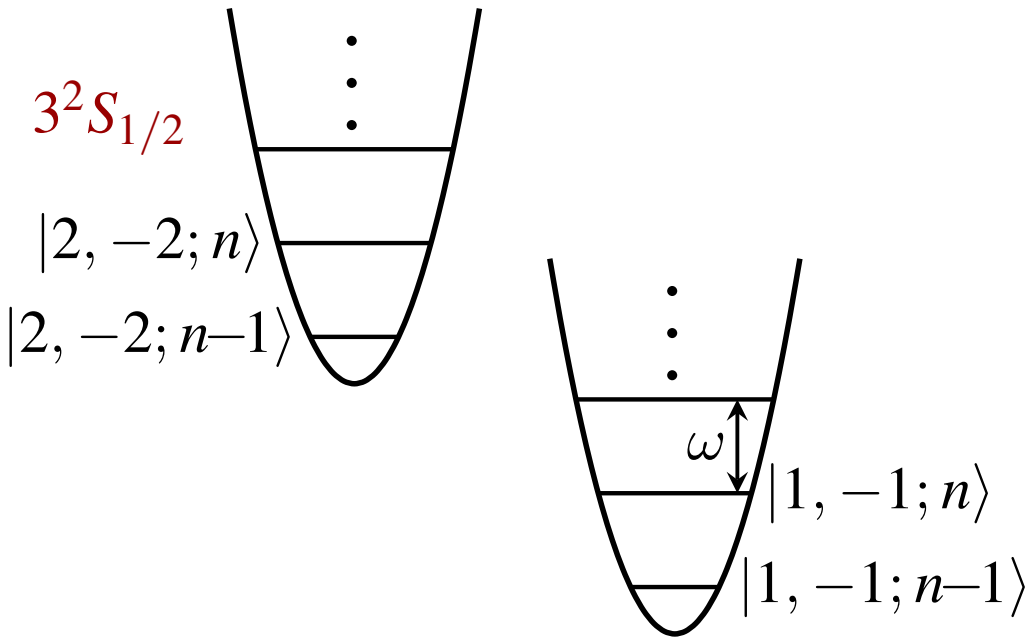

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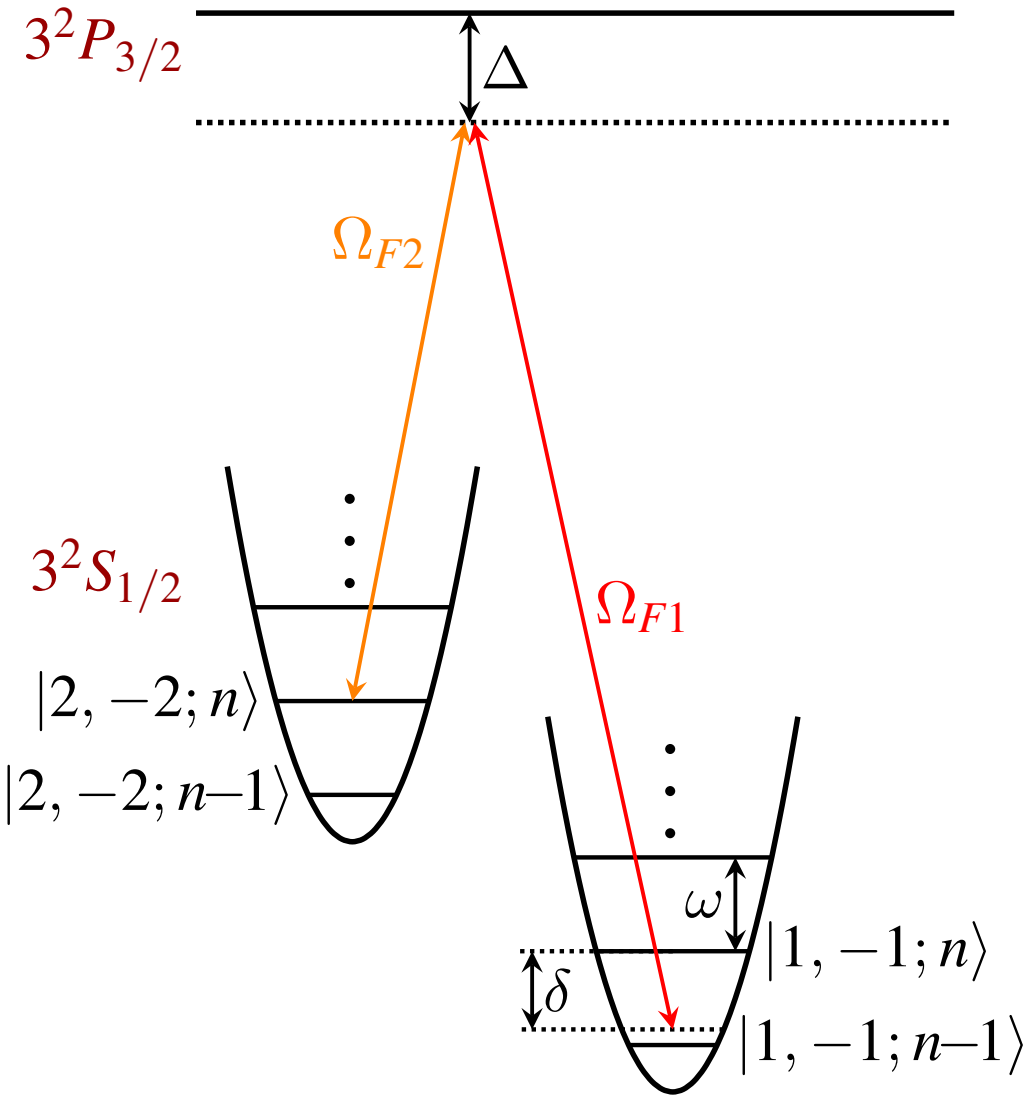

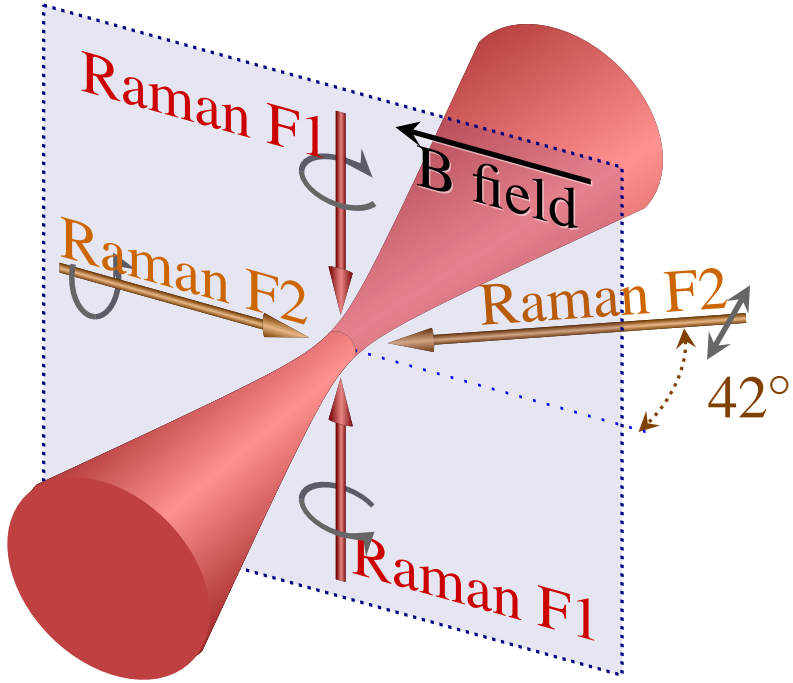

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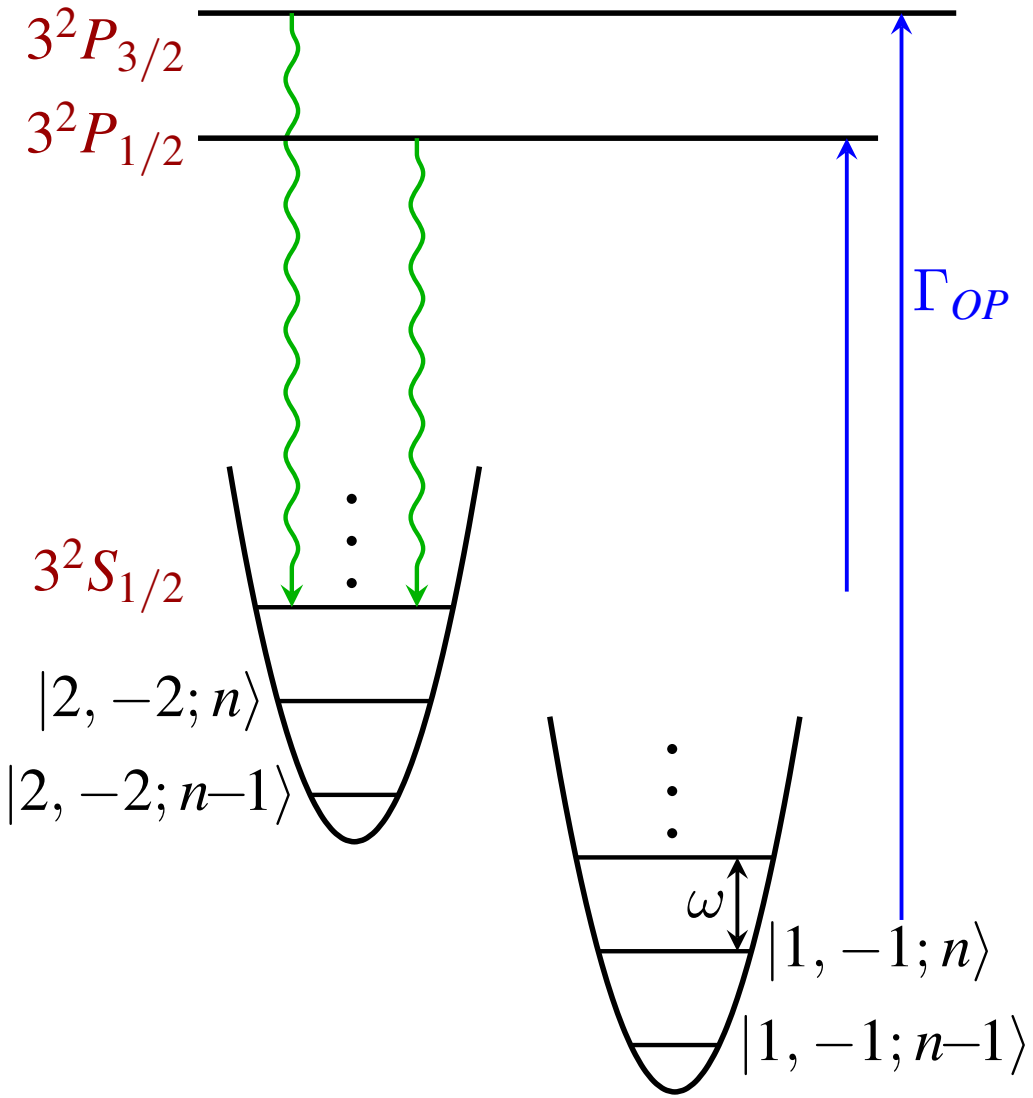

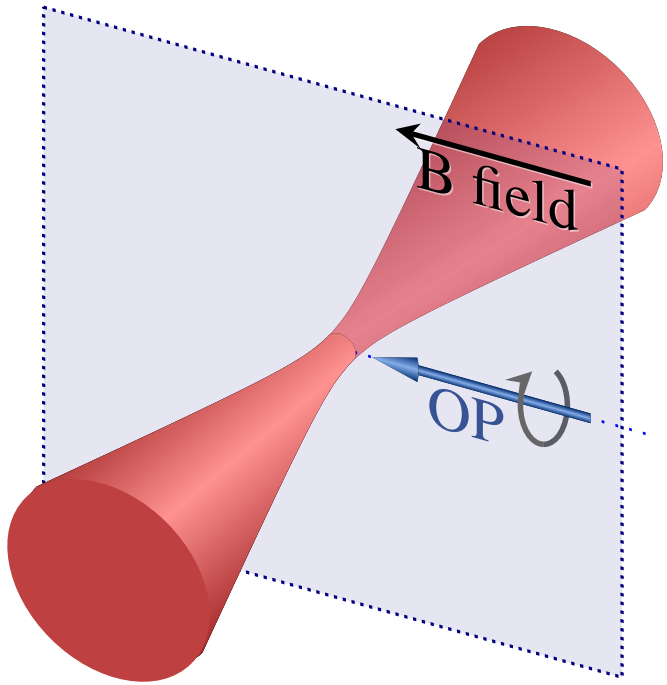

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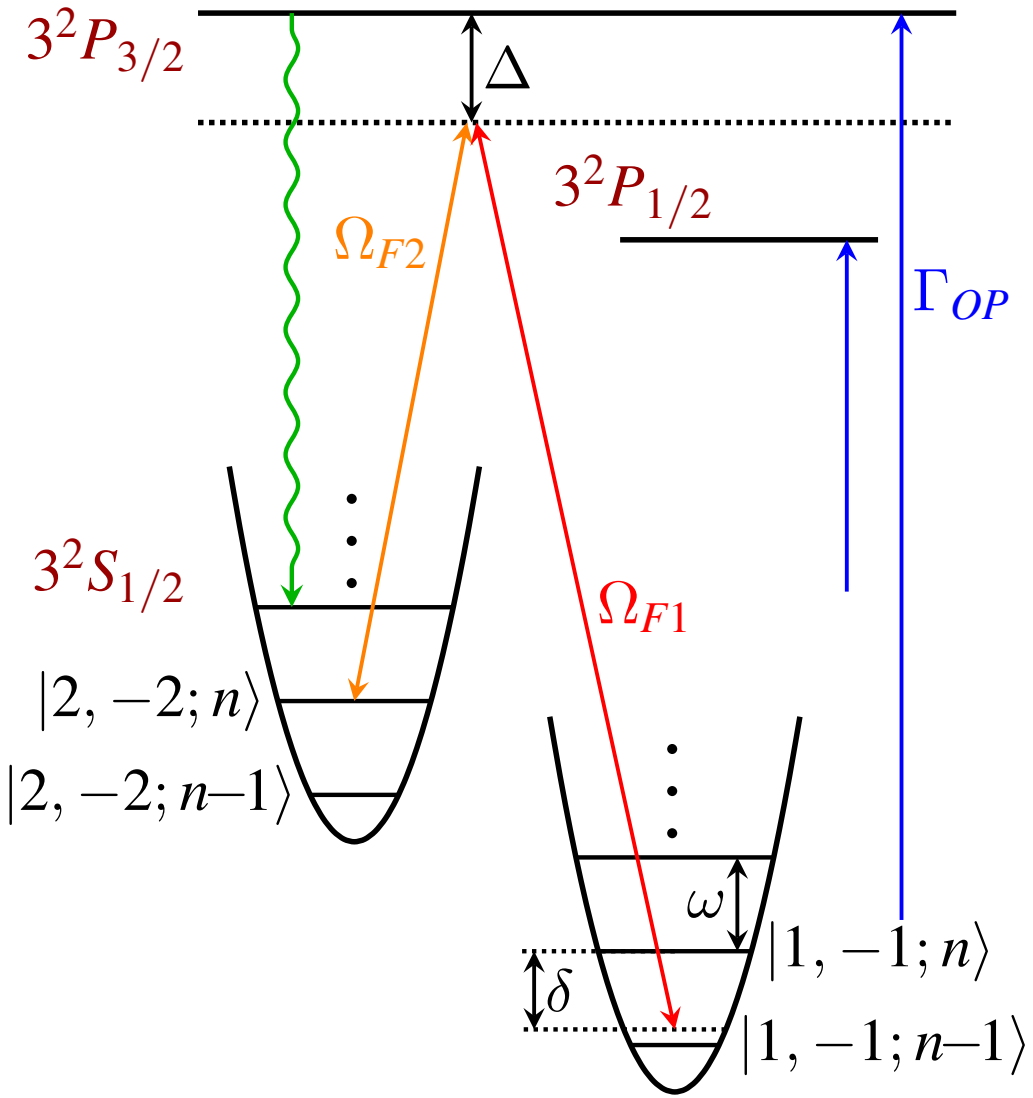
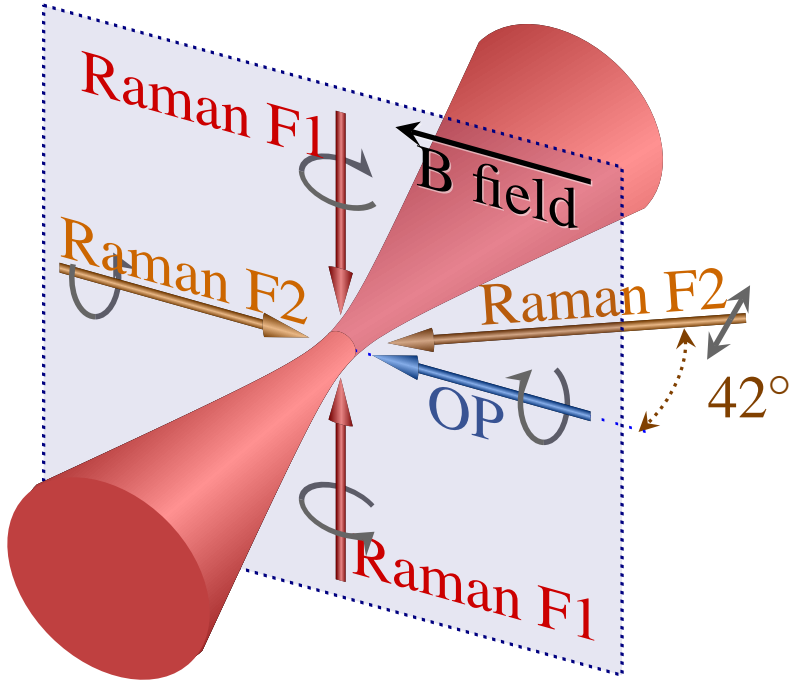
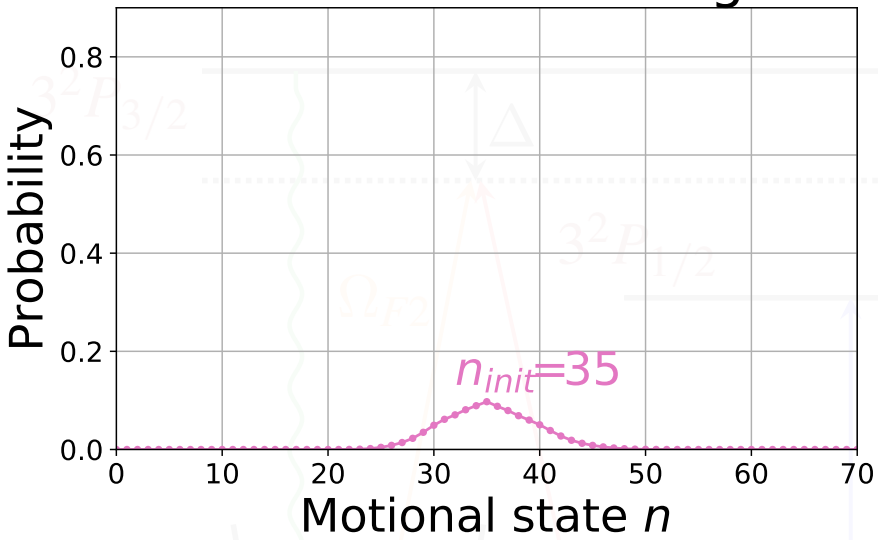




- High initial temperature ($70\mu K$)
- High Lamb Dicke parameter $\eta \equiv kz_0$
- Large light shift
- Trap anharmonicity
- Off resonance scattering $\approx 3 \sim 15$kHz

Motional state branching ratios



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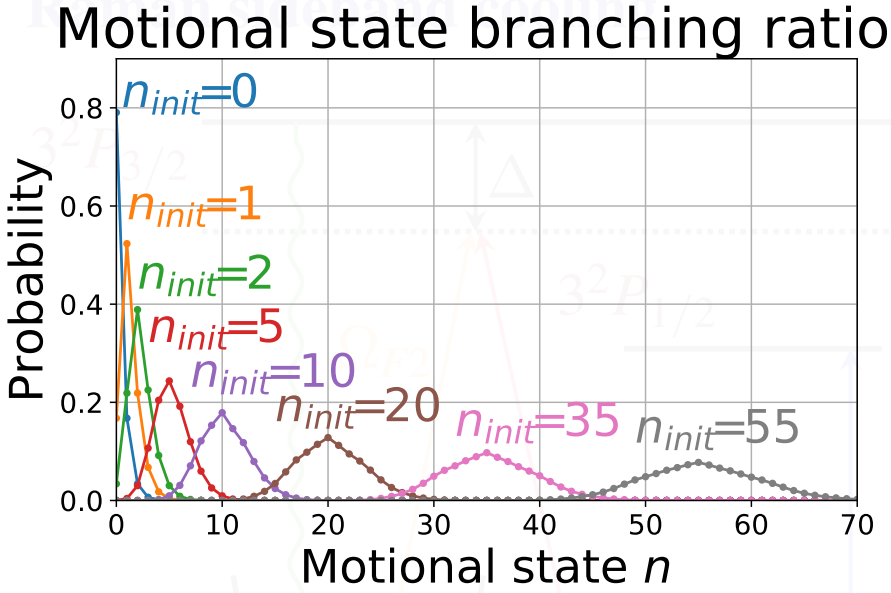

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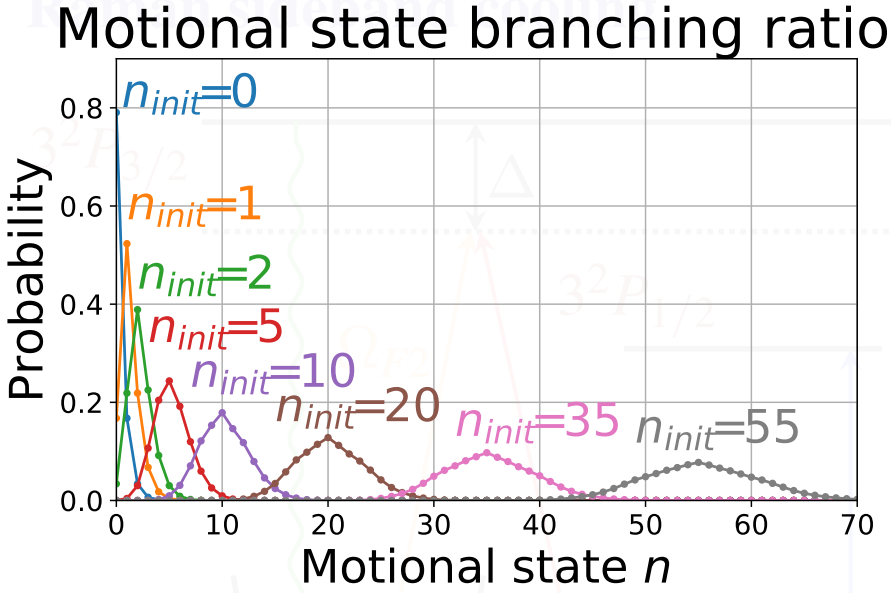

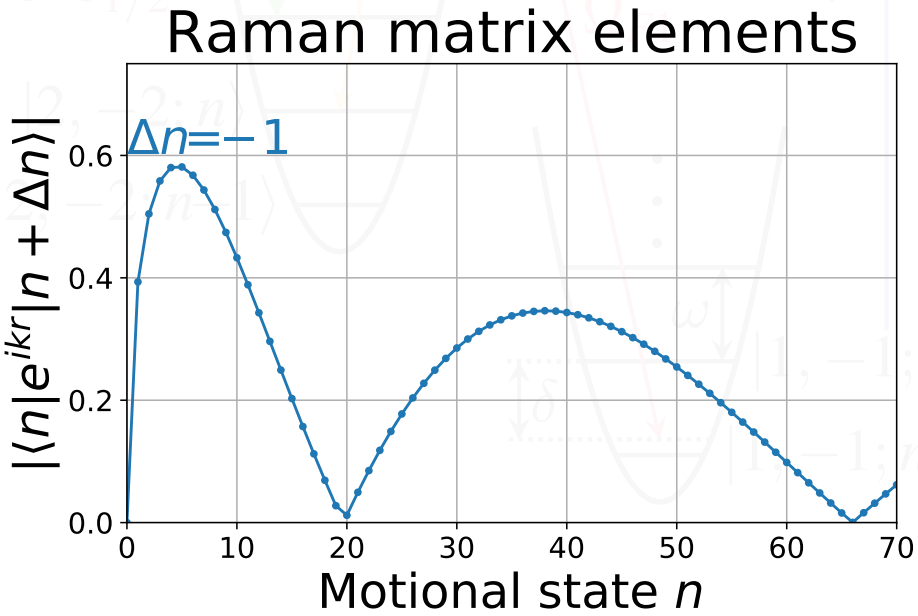

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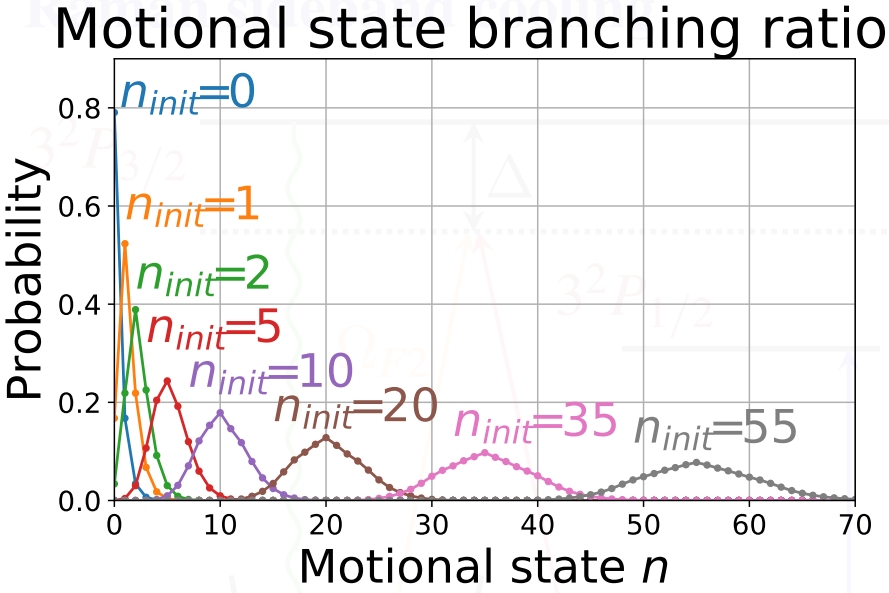

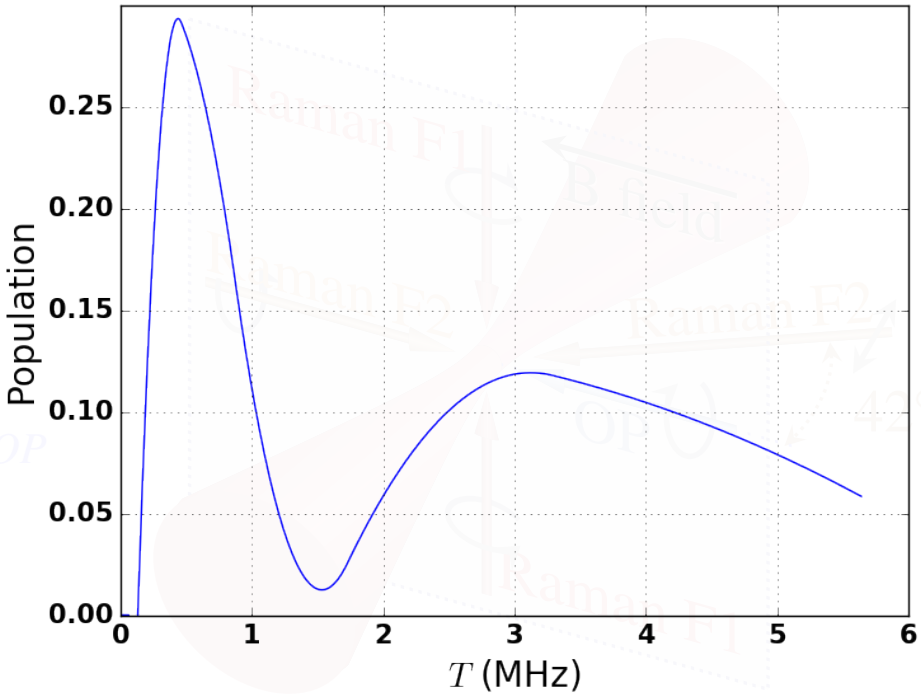

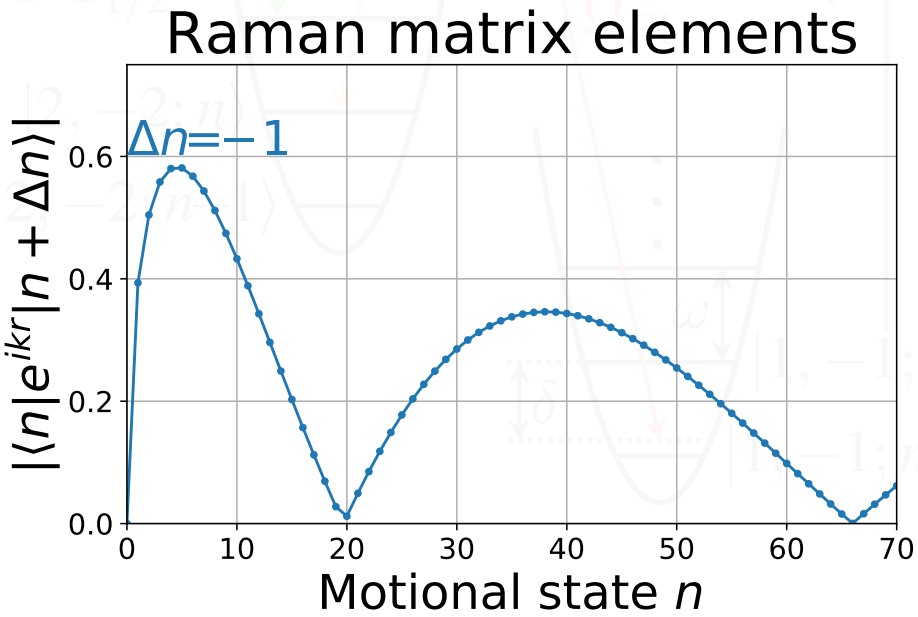

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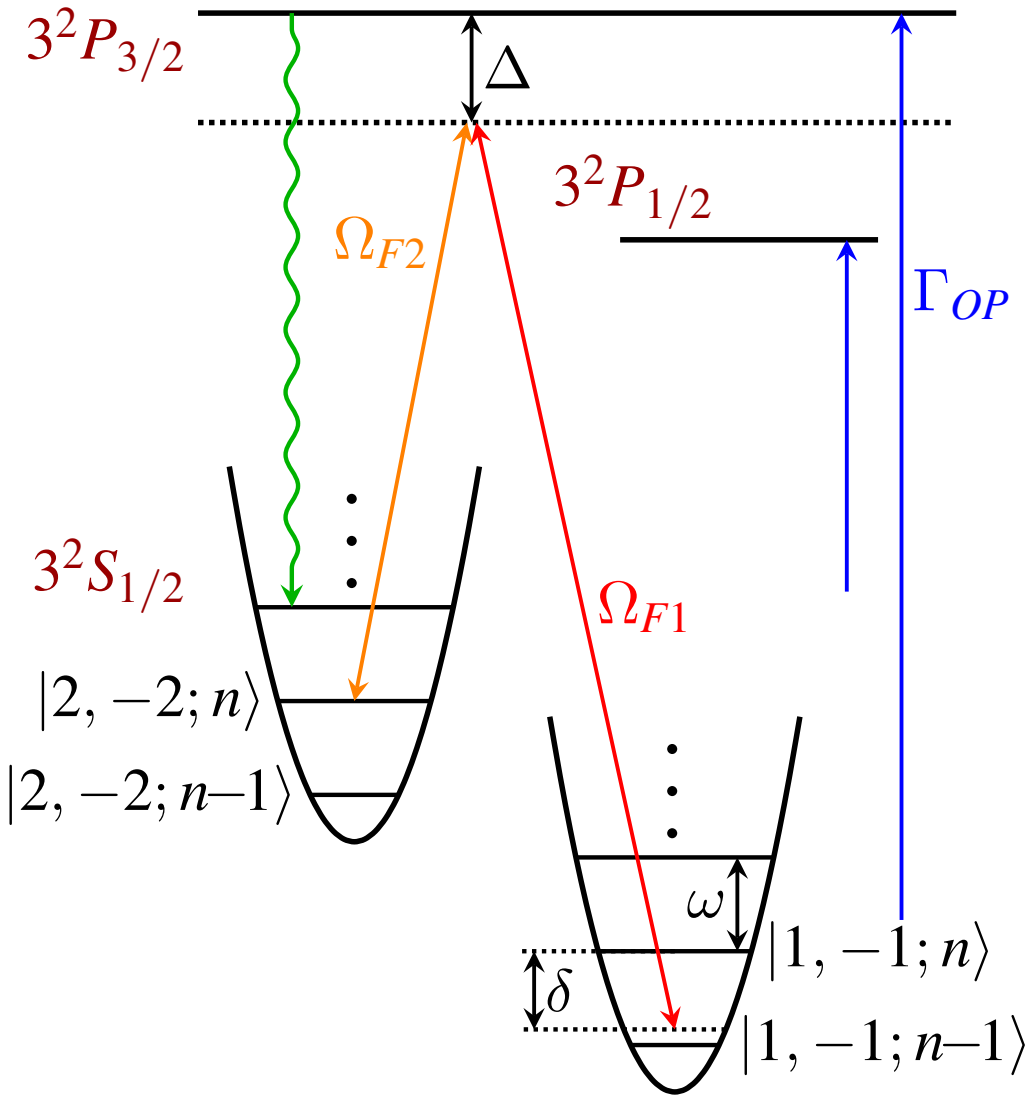

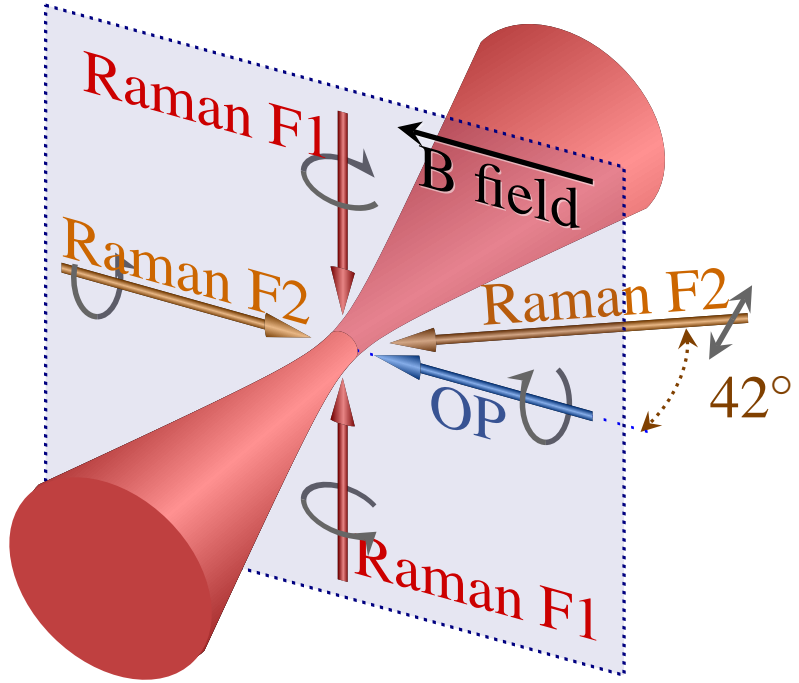

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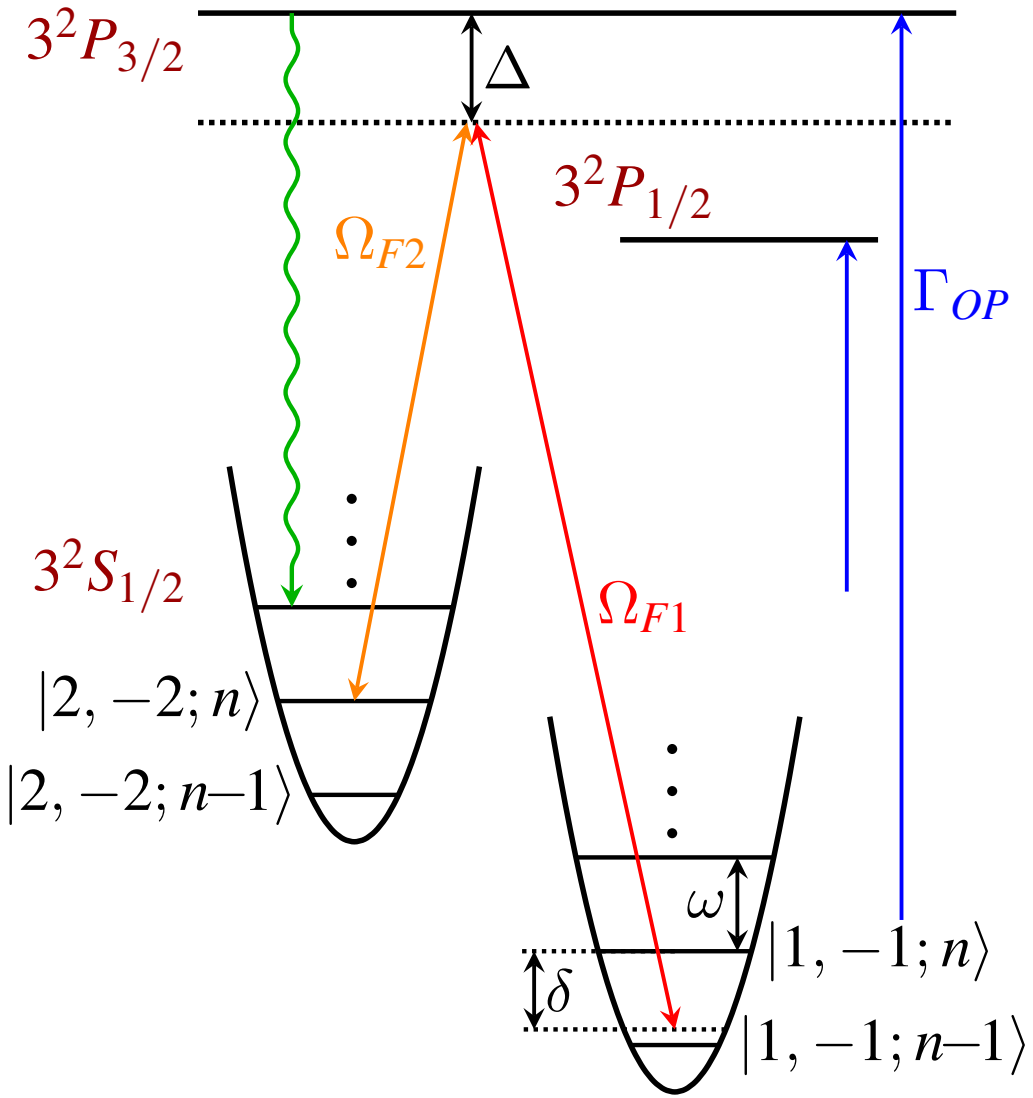

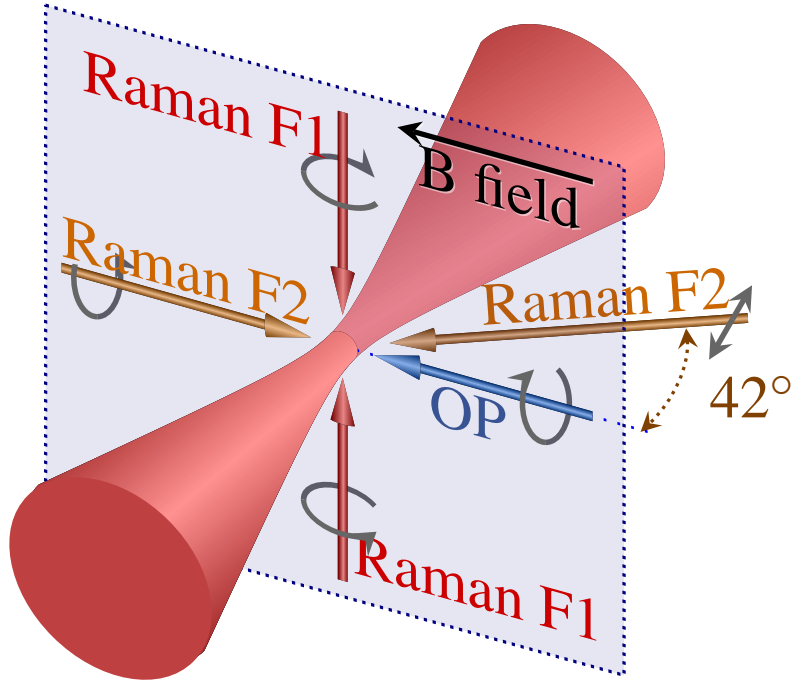

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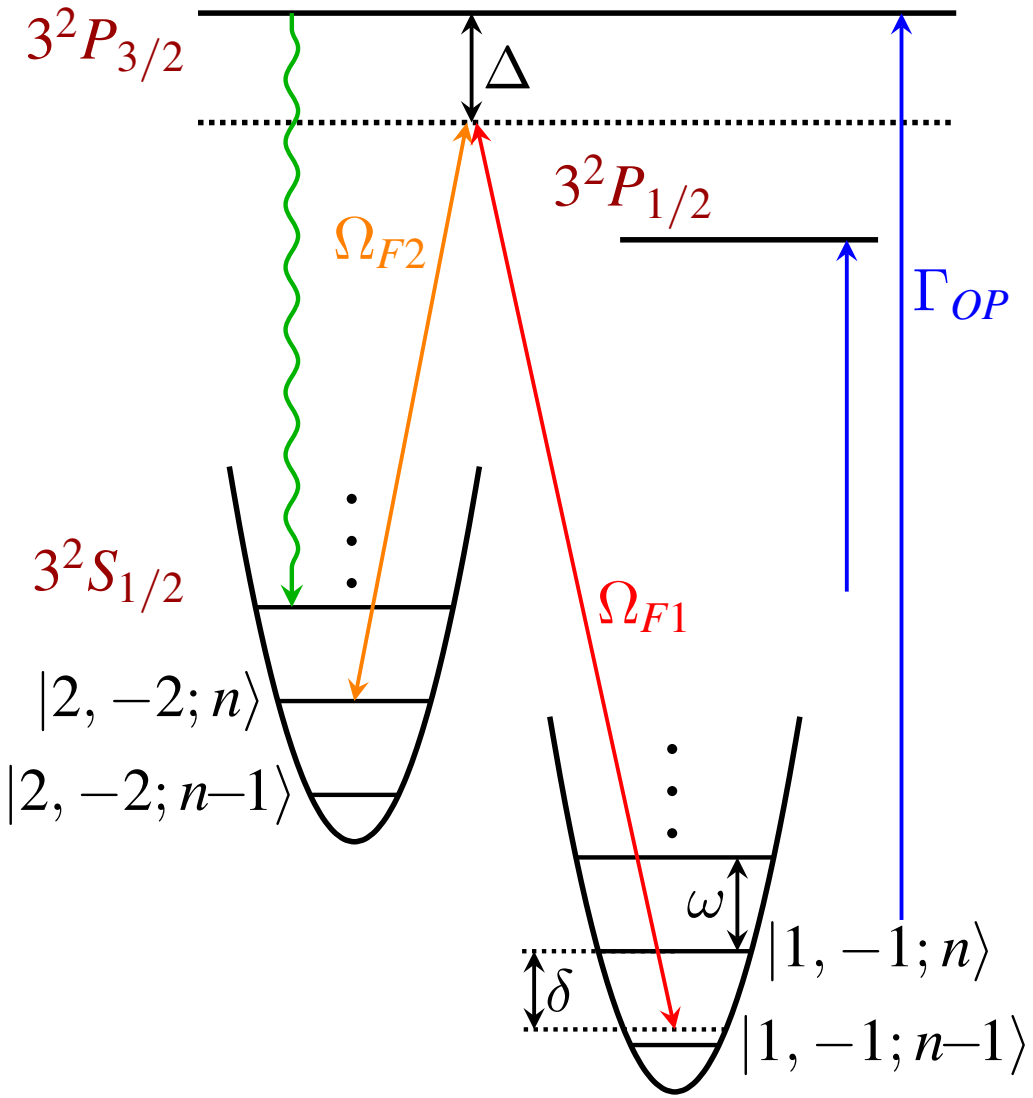

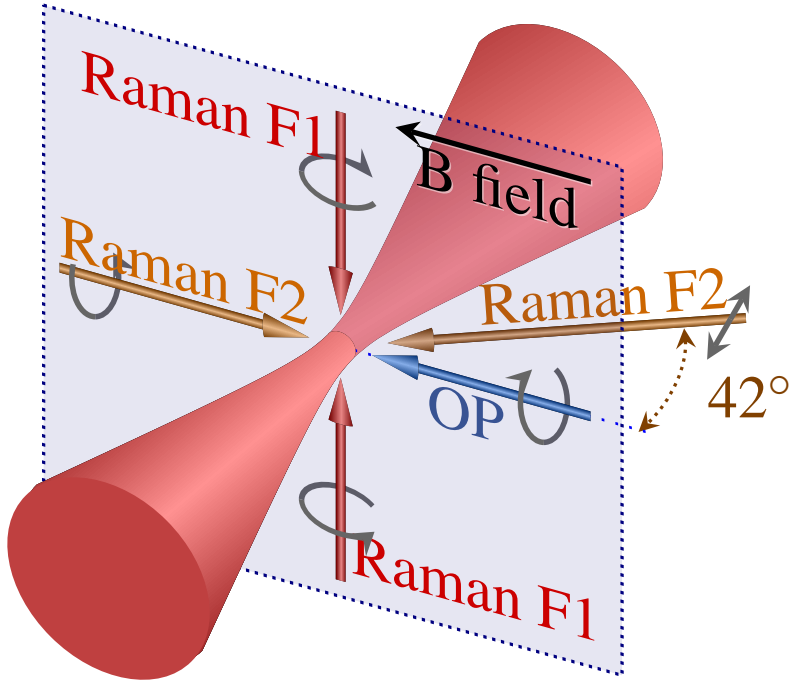

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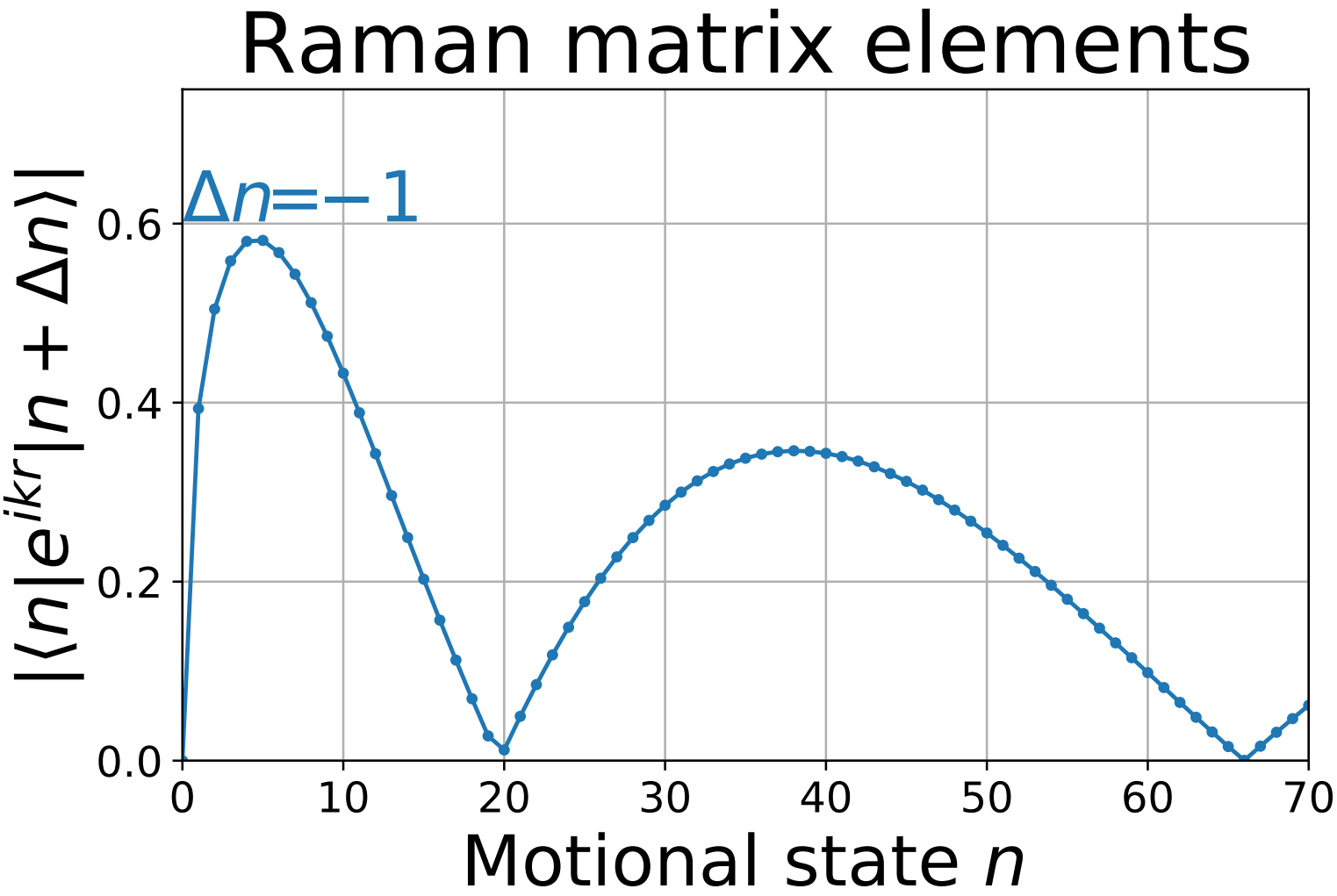
Sequence and simulation



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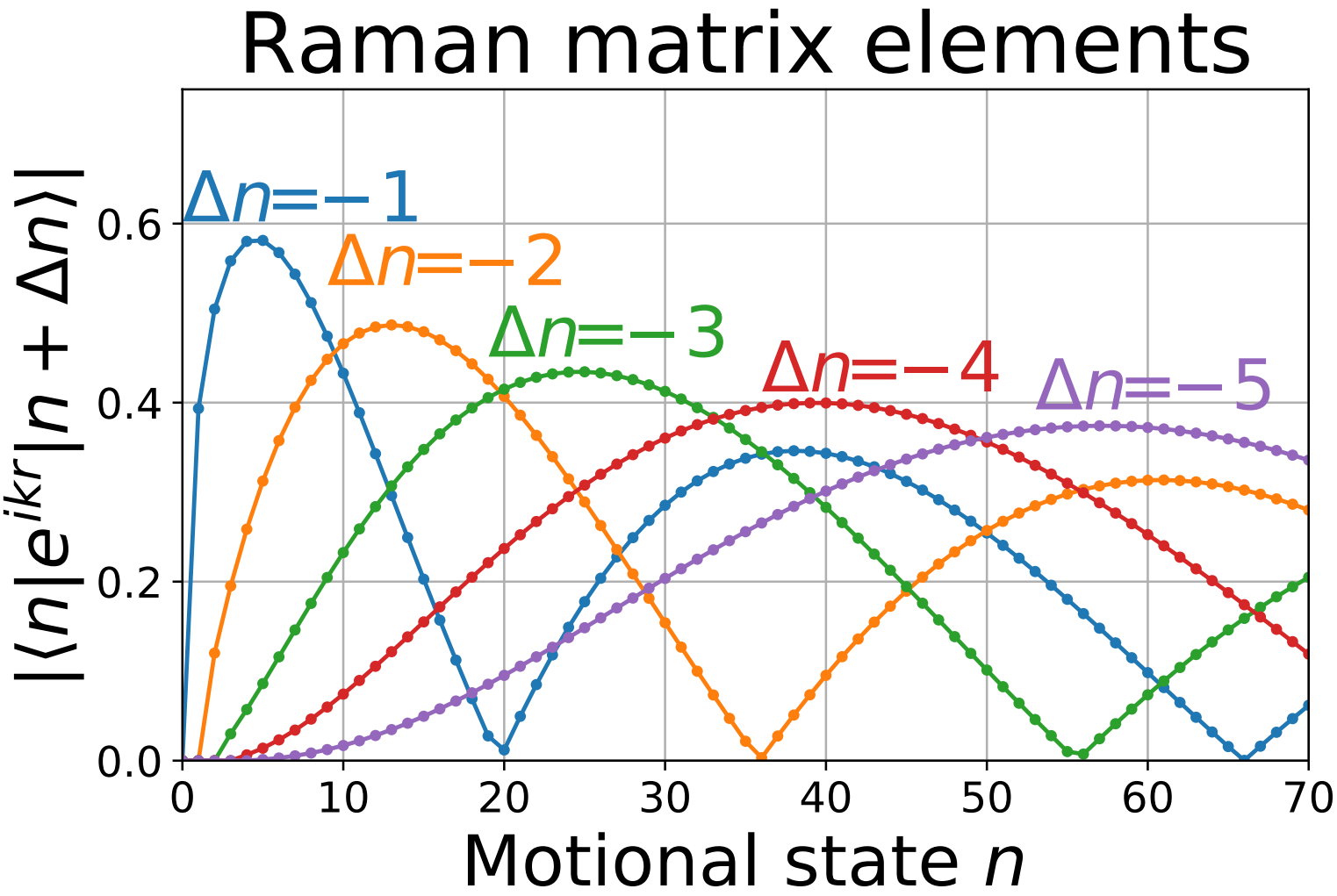

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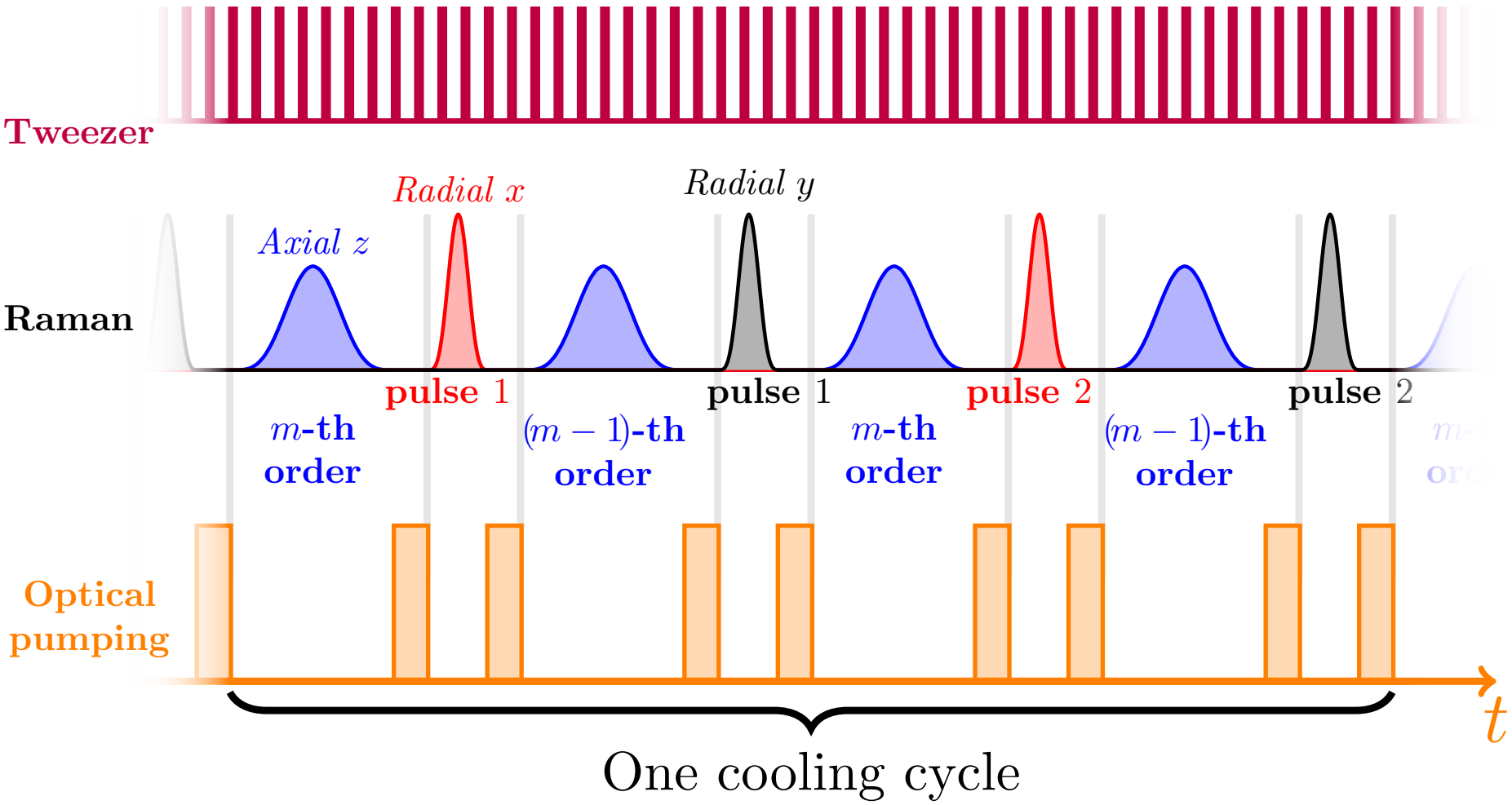

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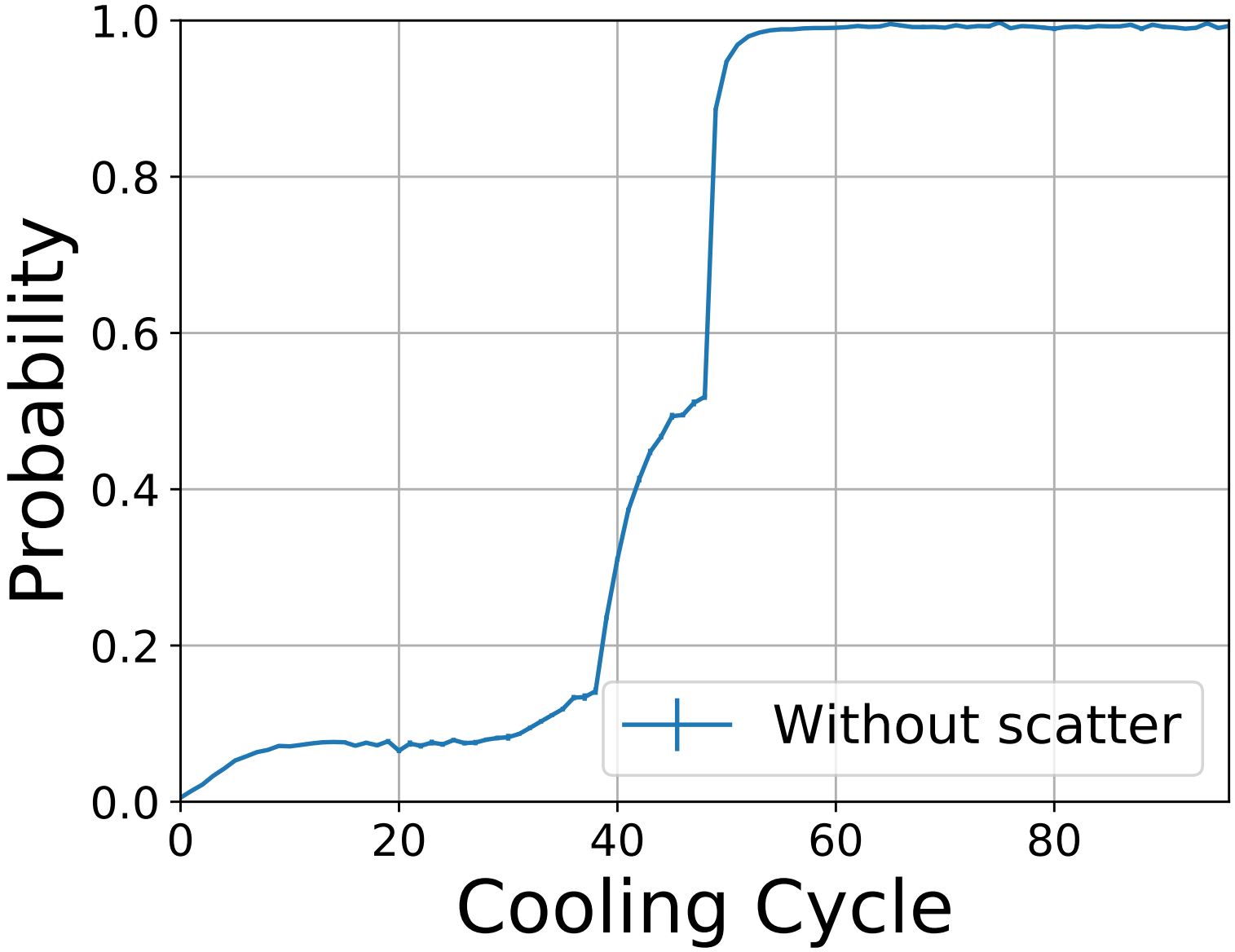

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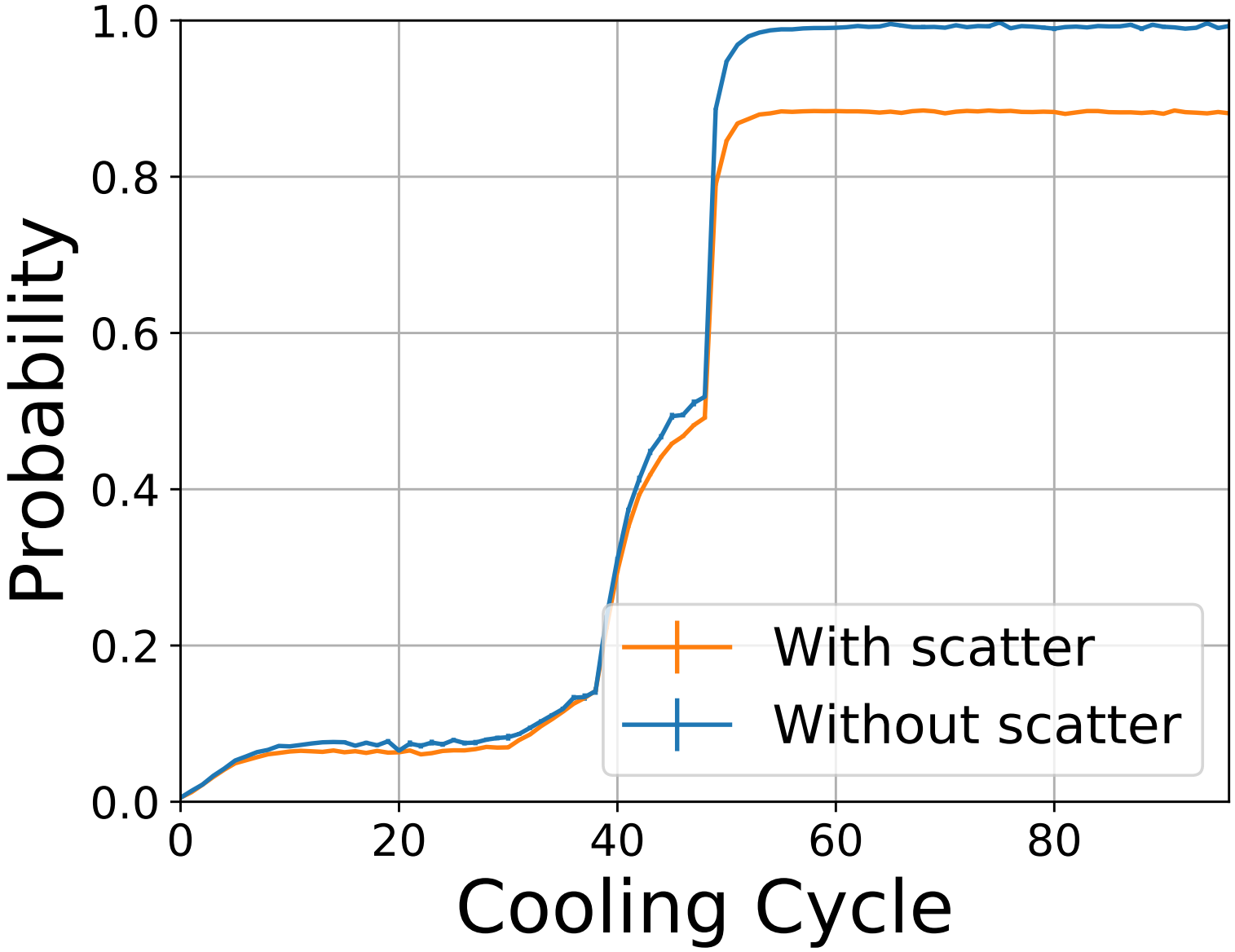
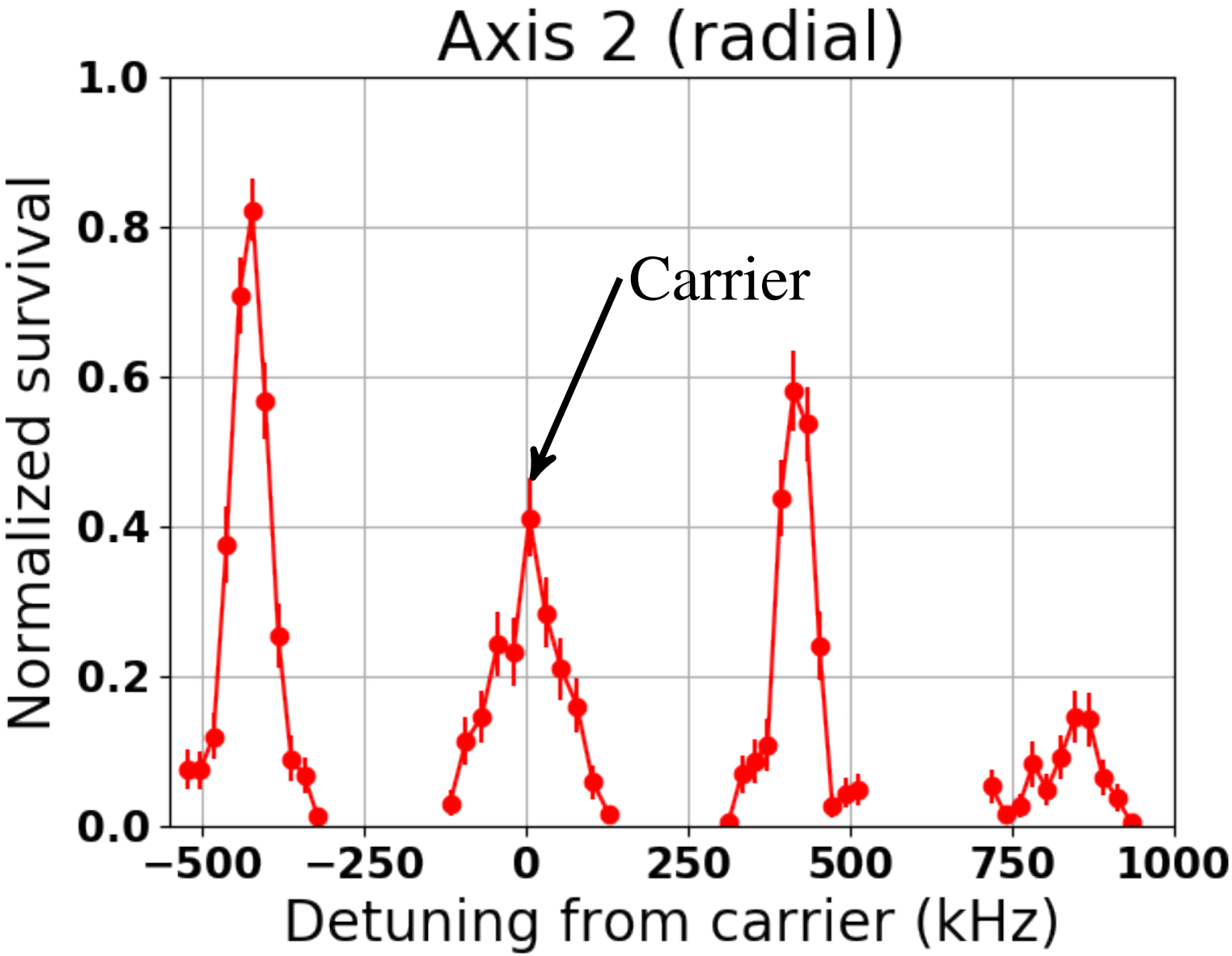


Raman sidebands



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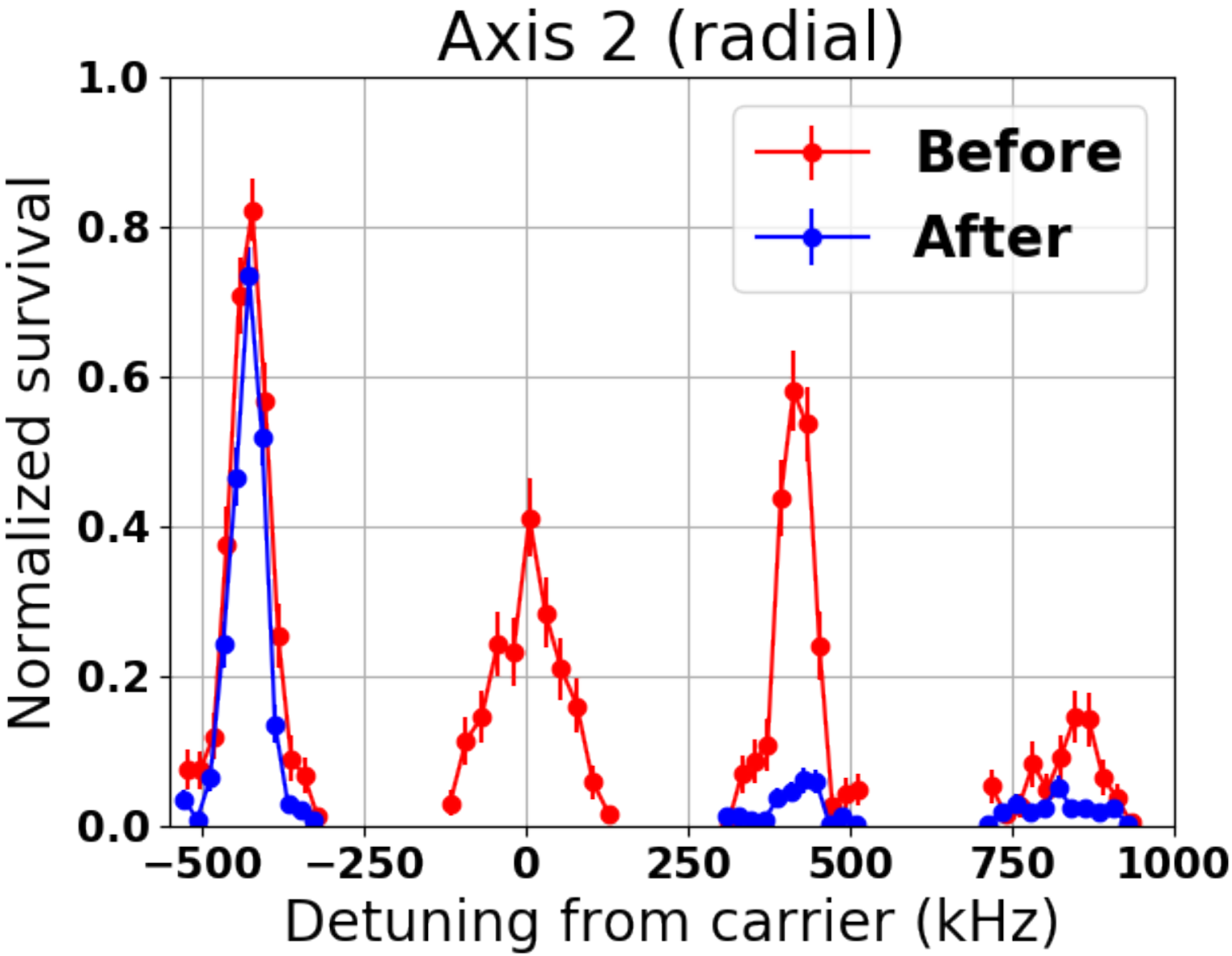

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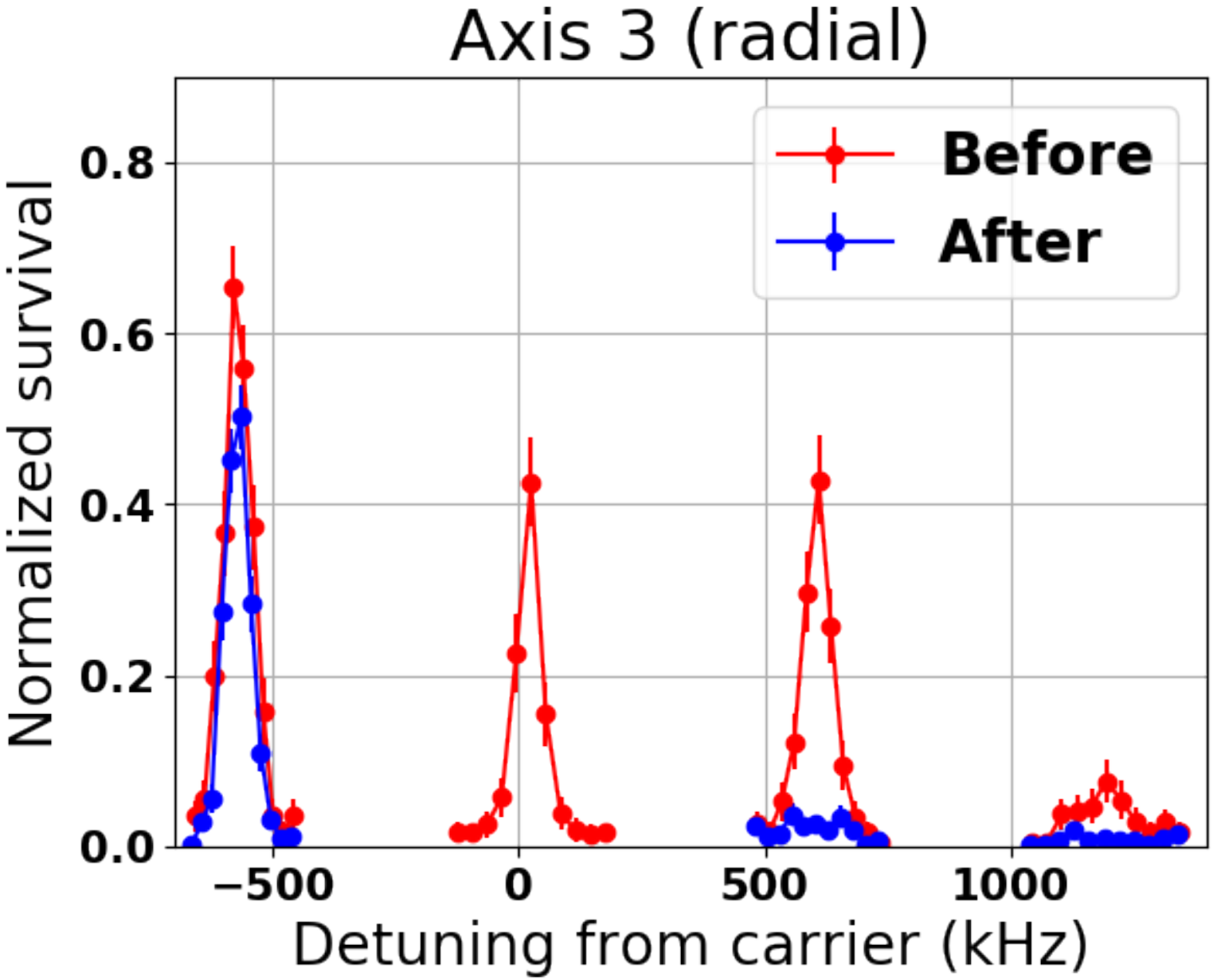

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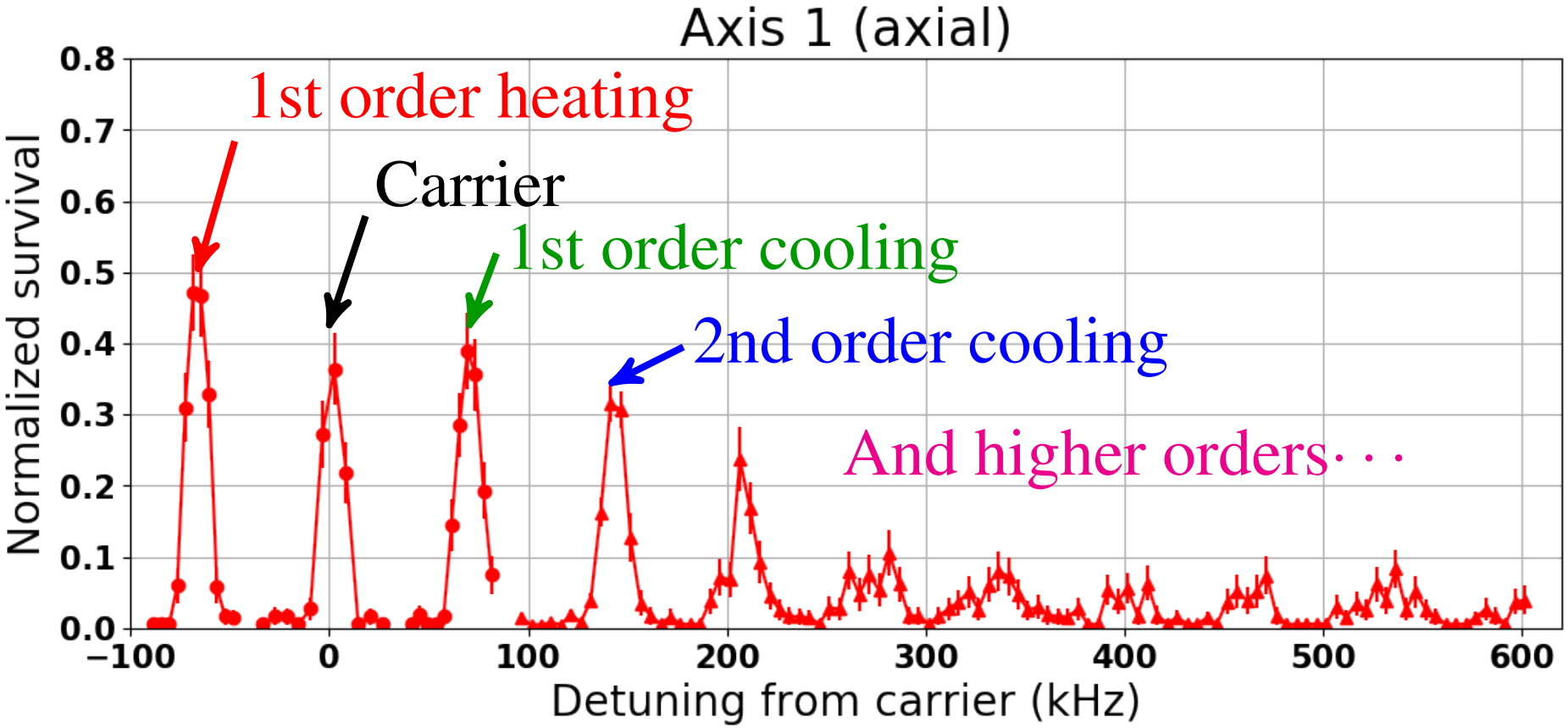

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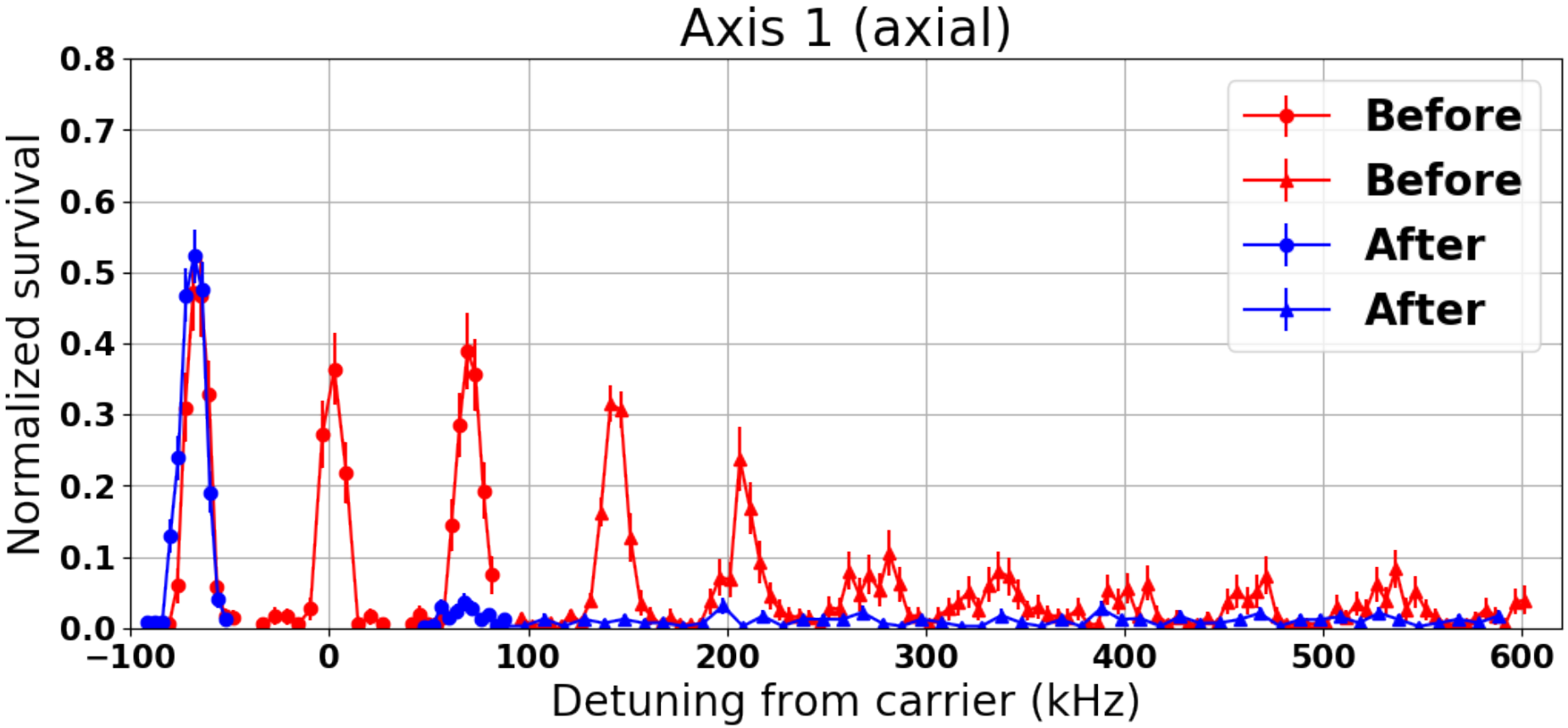
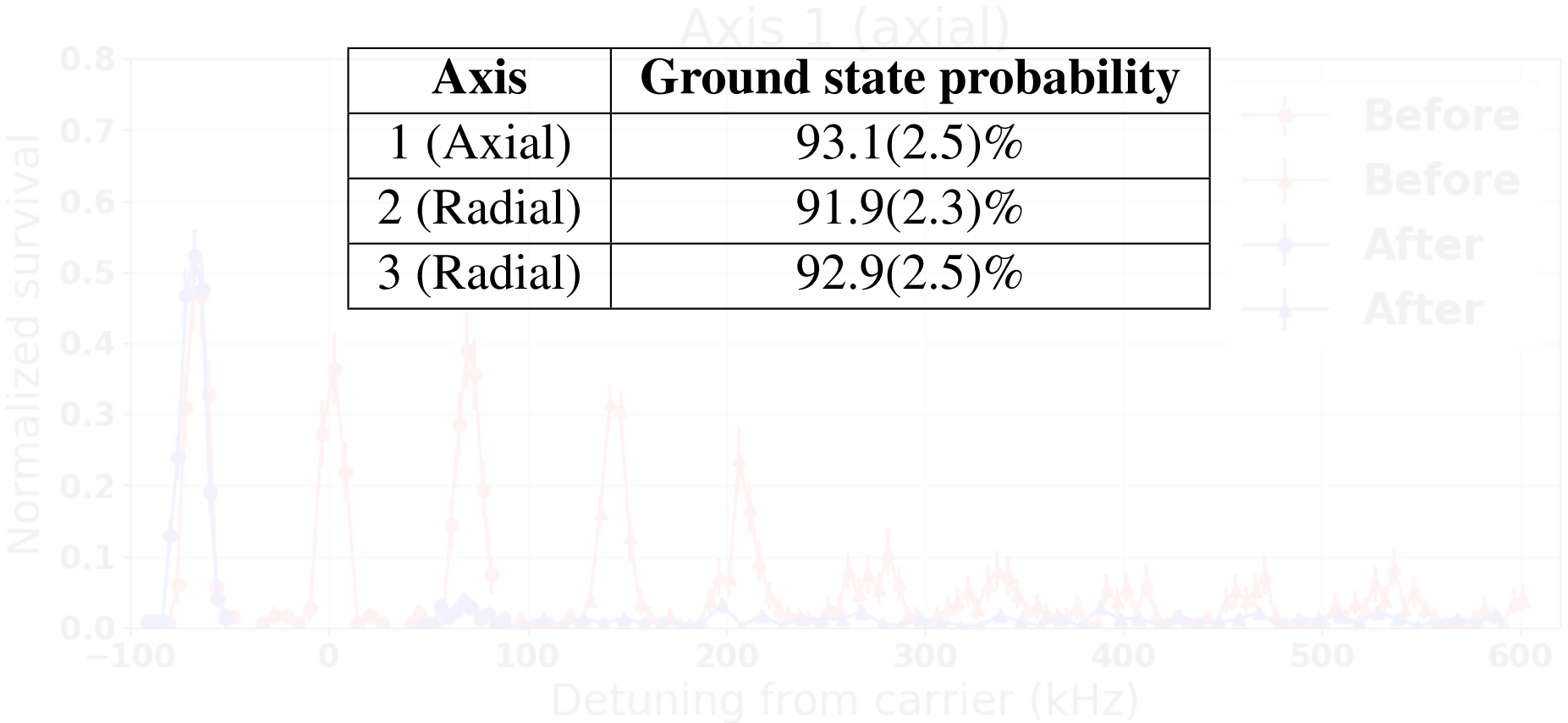


Raman sidebands

Axis	Ground state probability
1 (Axial)	93.1(2.5)%
2 (Radial)	91.9(2.3)%
3 (Radial)	92.9(2.5)%



Raman sidebands

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1 (Axial)	93.1(2.5)%
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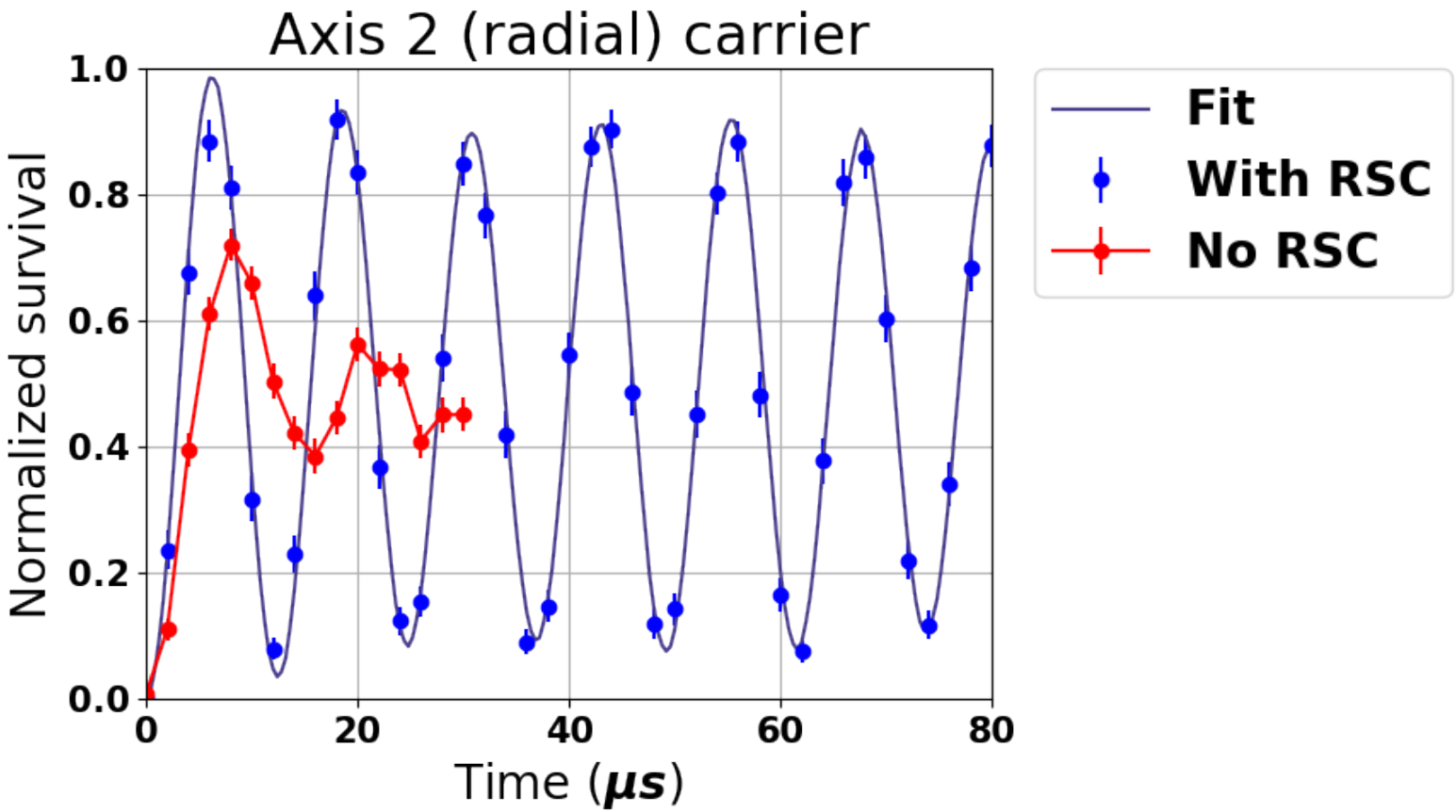
3 (Radial)	92.9(2.5)%

3D ground state: 79.5(3.6)%
Loss after cooling: 15%

Total 3D ground state preparation fidelity: 67.6(3.1)%

Rabi flopping (radial)



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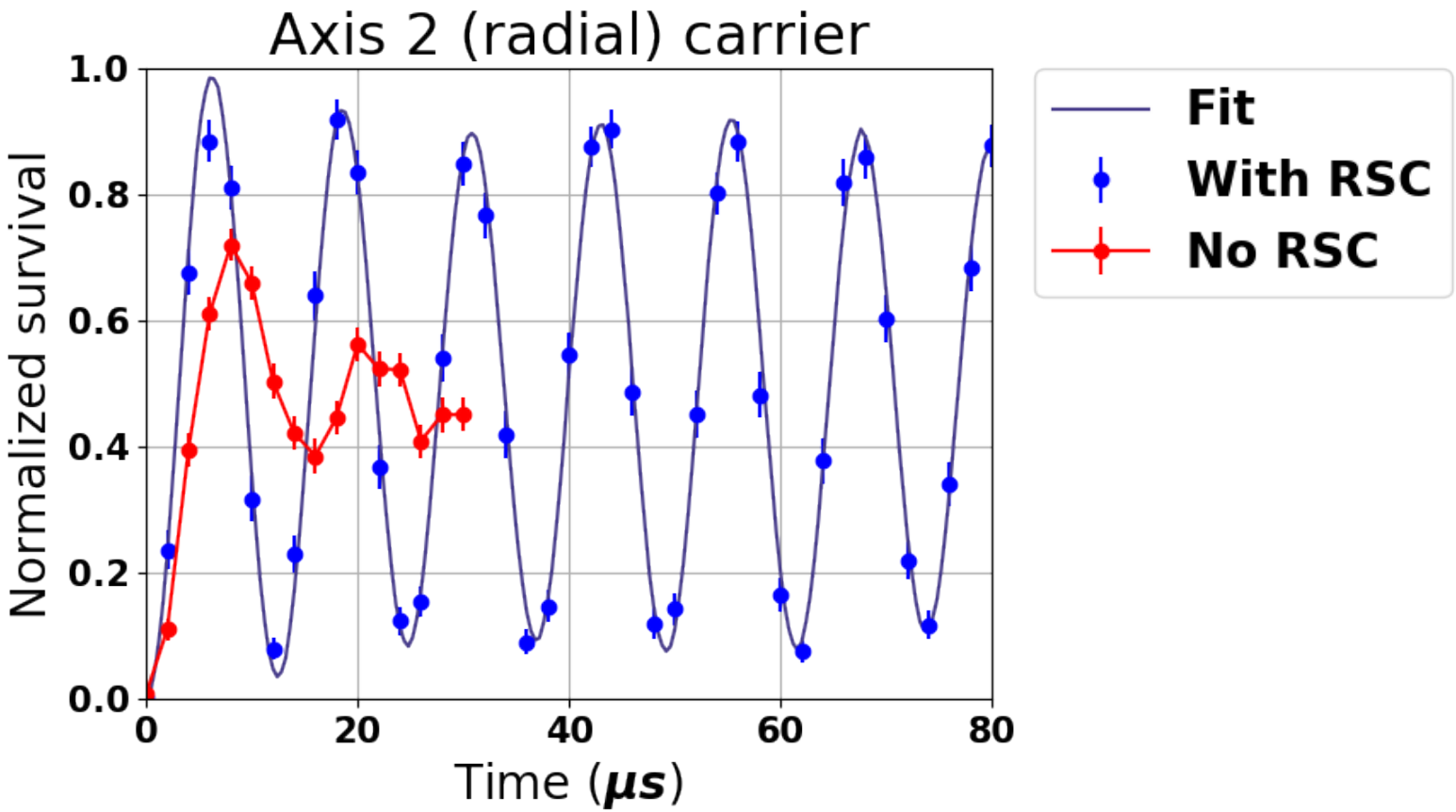
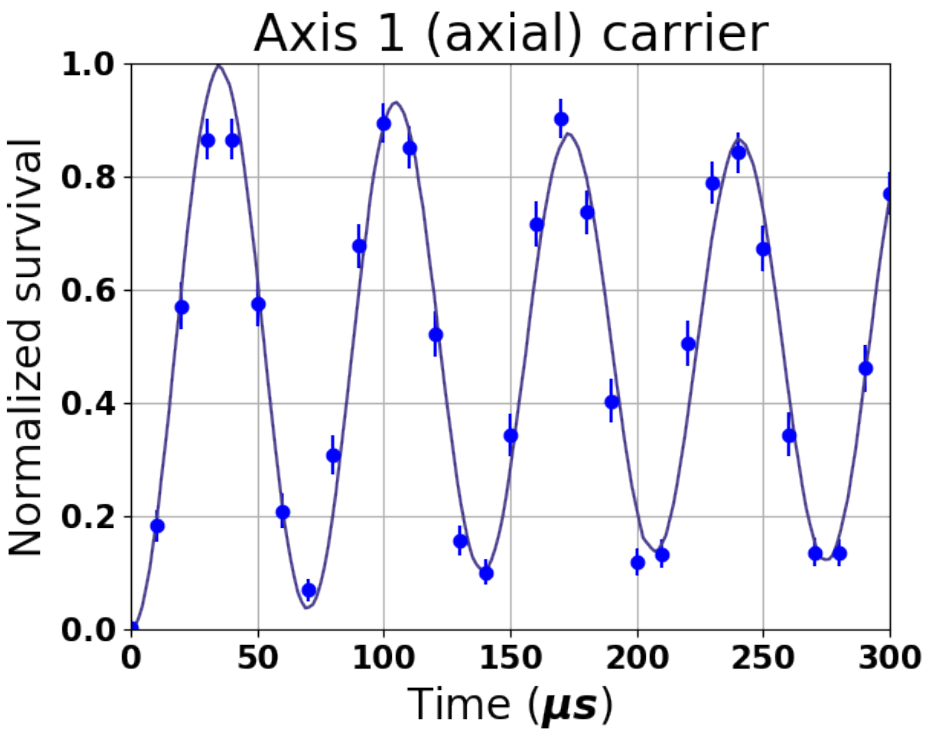
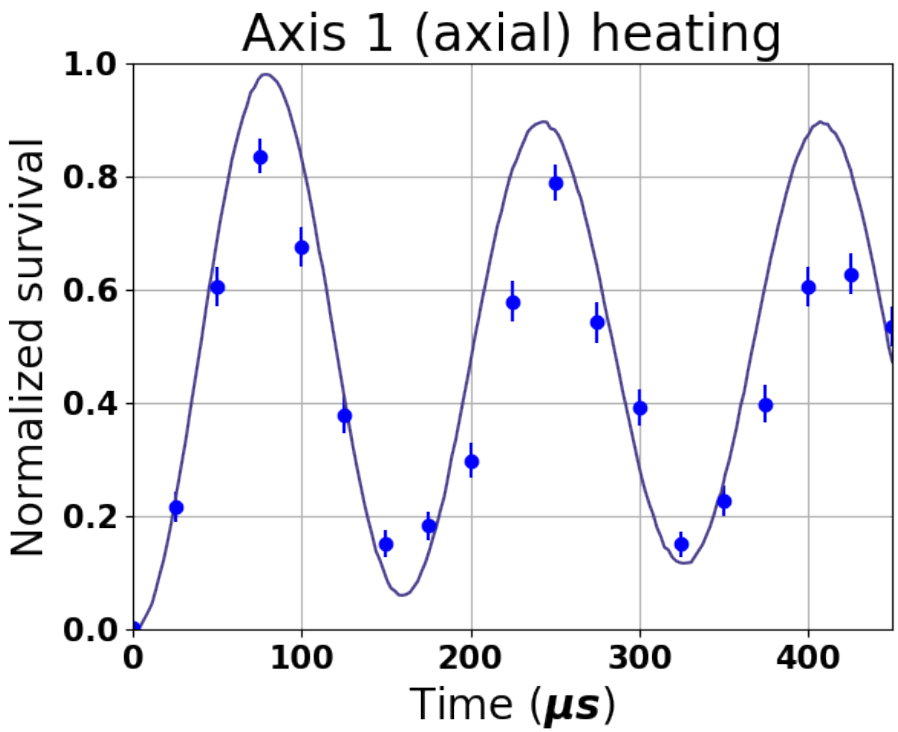


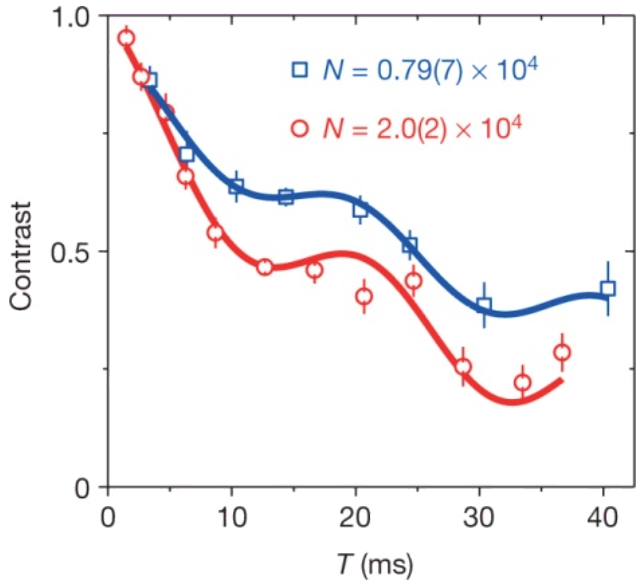
Good agreement in ground state probability between spectrum and Rabi flopping data.

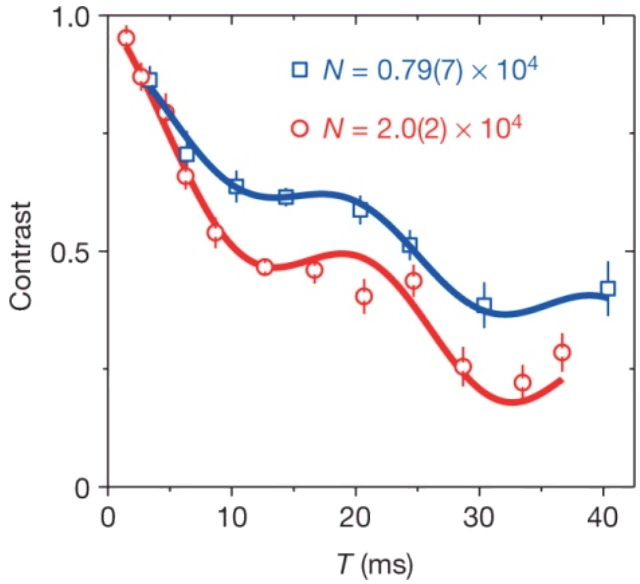
Rabi flopping (axial)

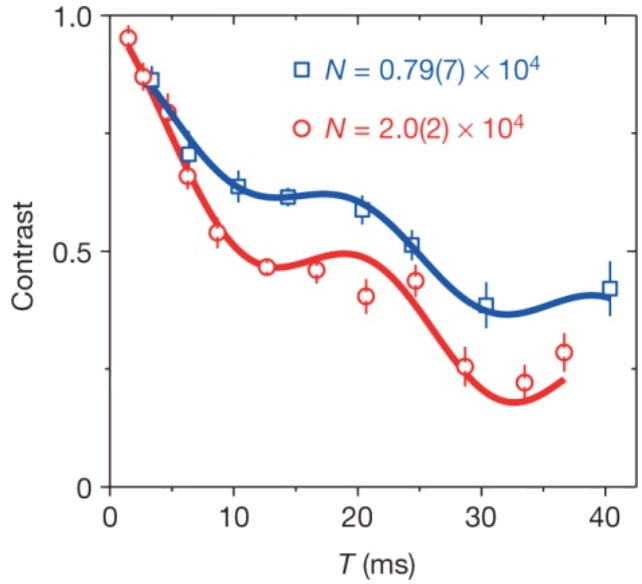


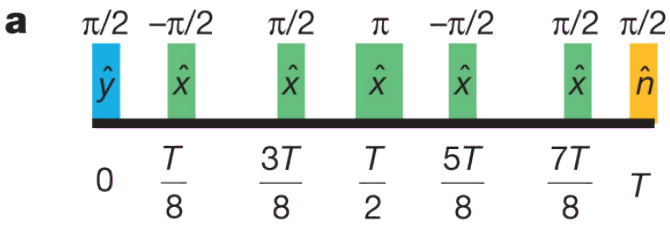


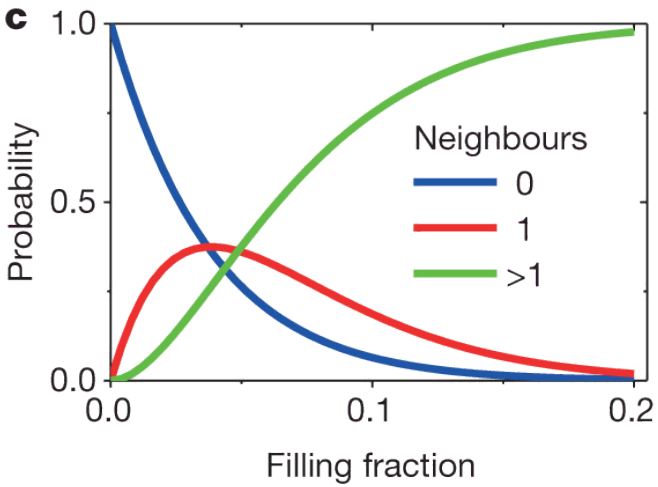
In progress

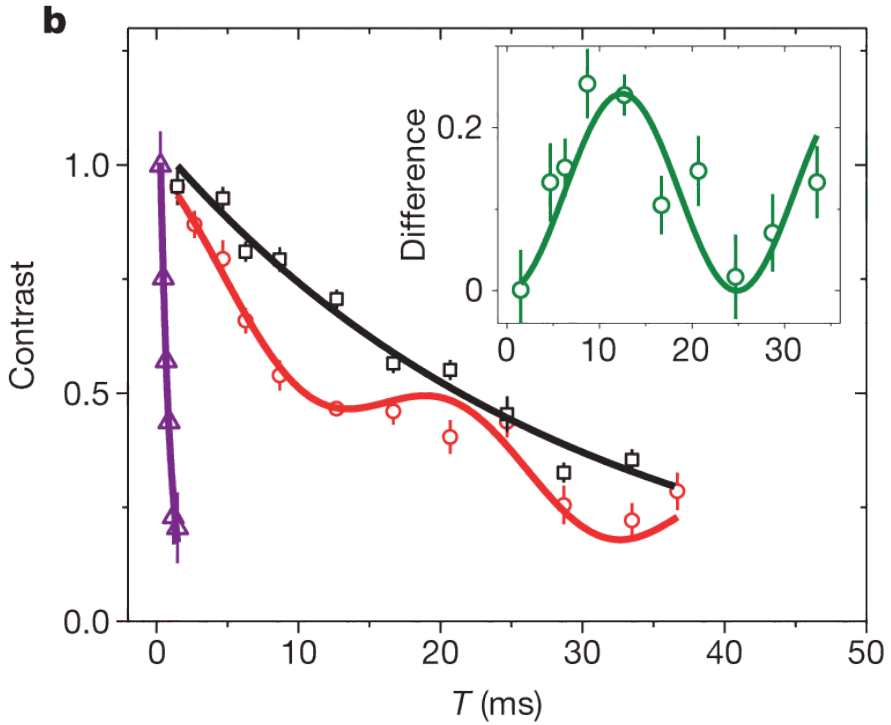

1.0
0.5
0
Contrast
0
10
20
30
40
T (ms)
N = 0.79(7) × 10^4
N = 2.0(2) × 10^4


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
$N = 0.79(7) \times 10^4$
$N = 2.0(2) \times 10^4$
0
10
20
30
40
T (ms)

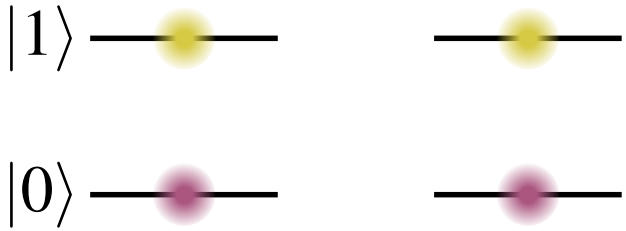

a
π/2
−π/2
π/2
π
−π/2
π/2
π/2
ŷ
x̂
x̂
x̂
x̂
x̂
n̂
0
T/8
3T/8
T/2
5T/8
7T/8
T


c
1.0
0.5
0.0
Probability
Neighbours
0
1
>1
0.0
0.1
0.2
Filling fraction


b
1.0
0.5
0.0
Contrast
Difference
0.2
0
0
10
20
30
40
50
T (ms)

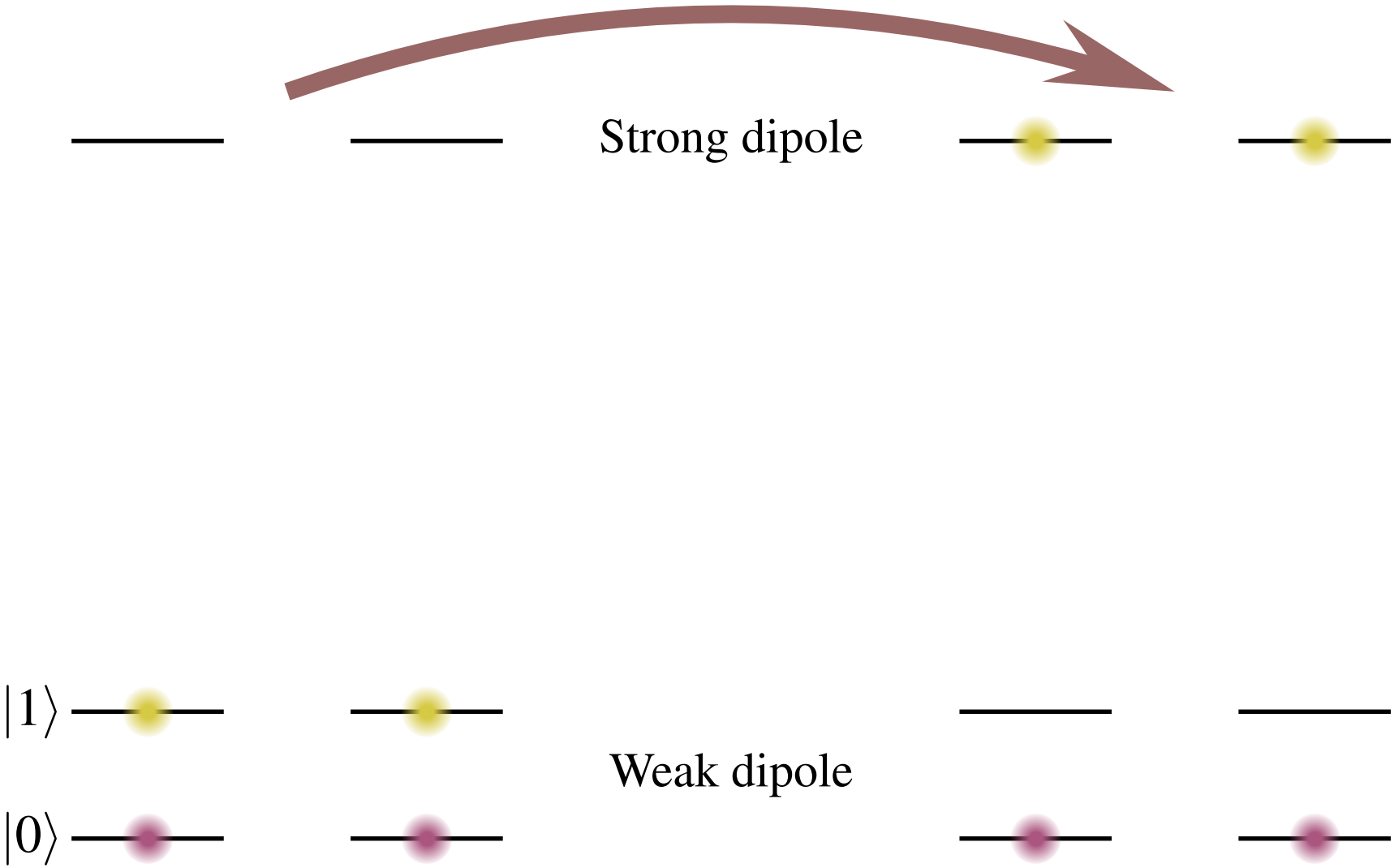
Quantum computation

Strong dipole

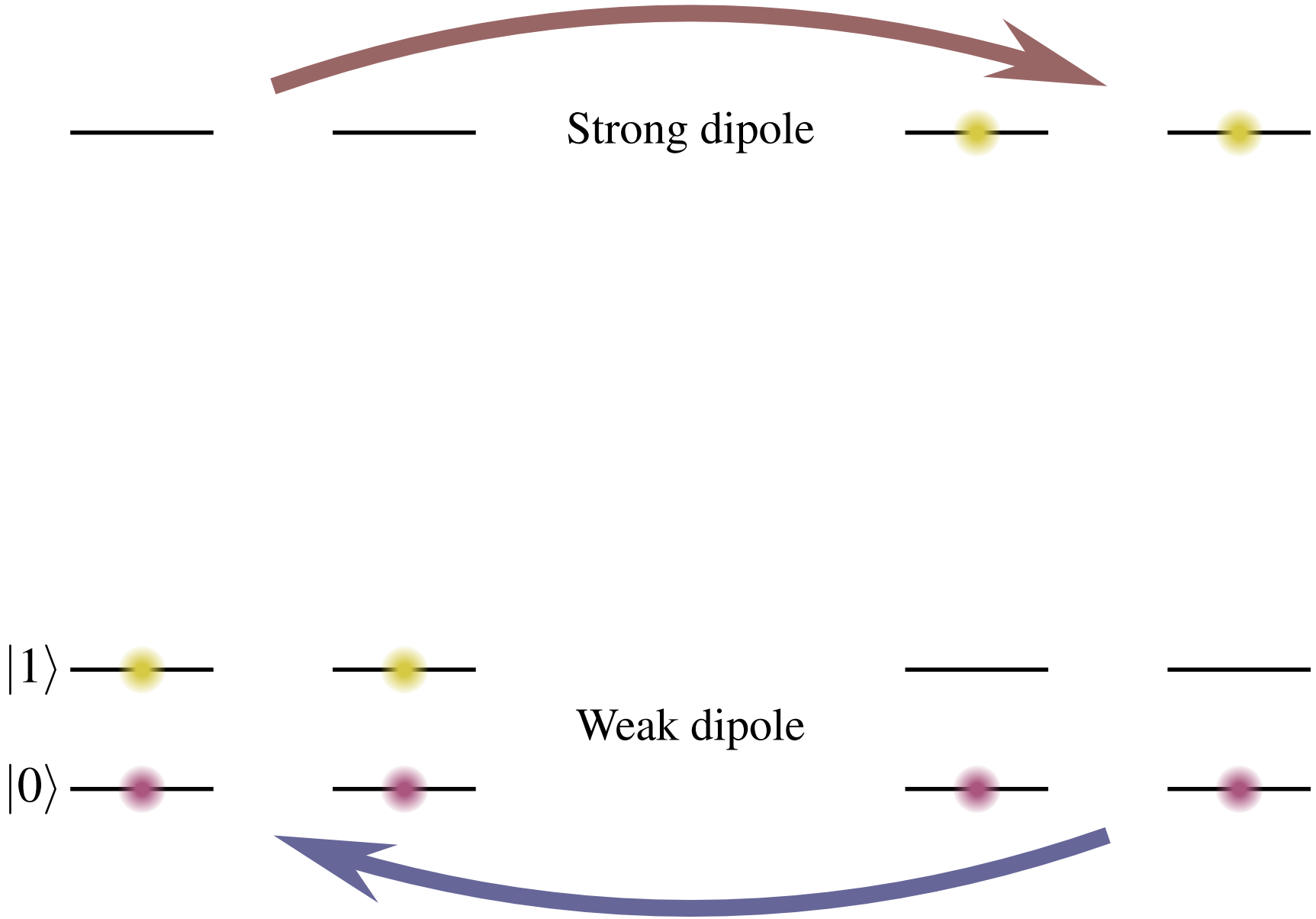


Weak dipole

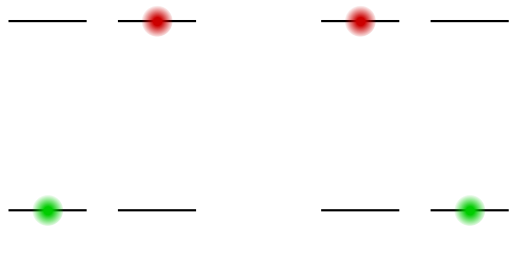
Quantum computation



Quantum computation

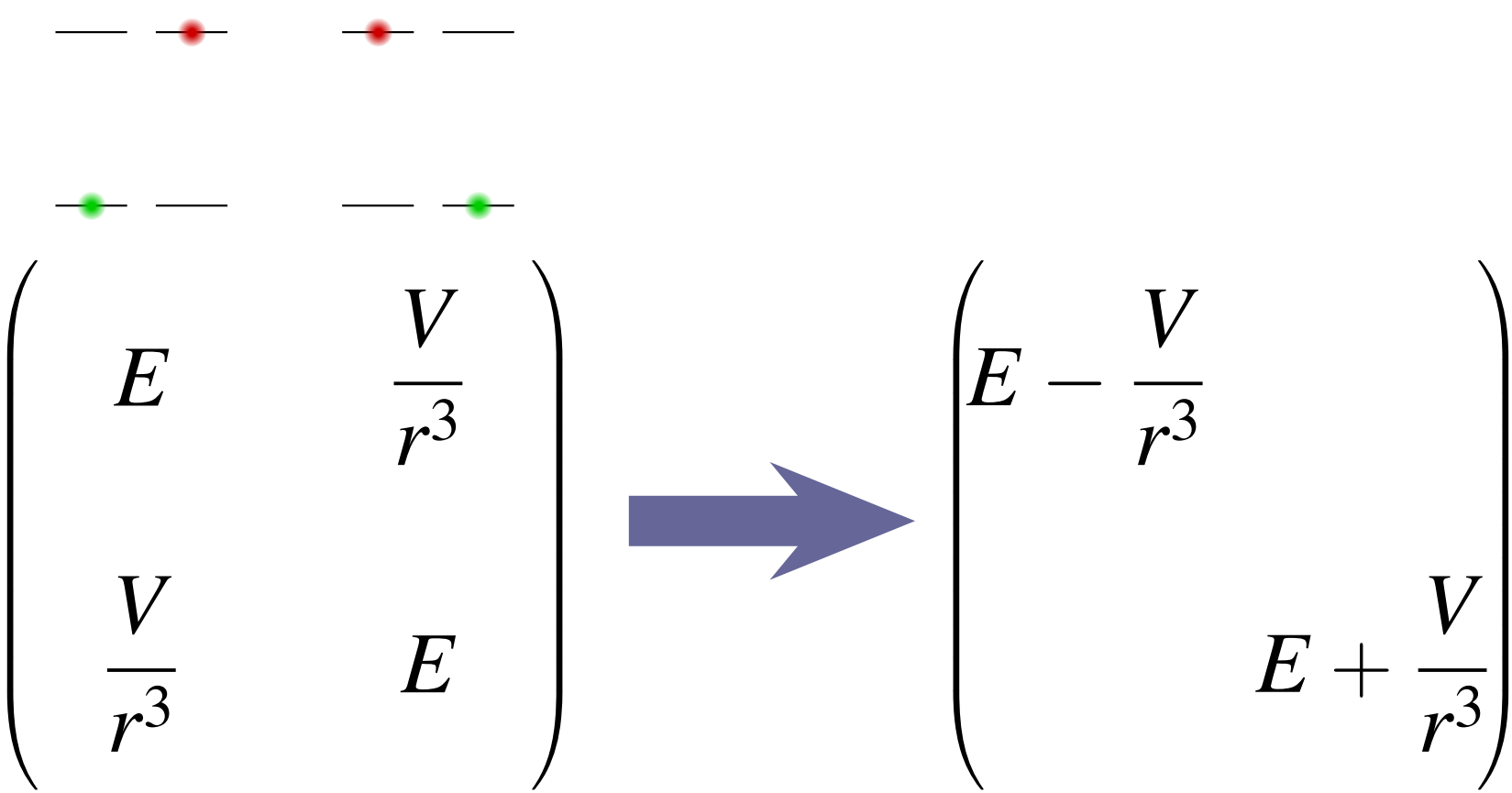


Quantum computation

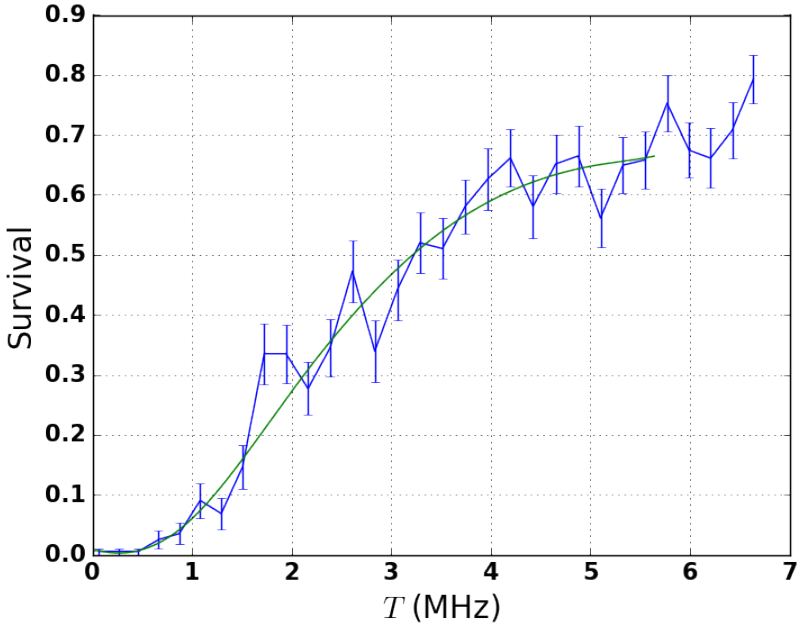


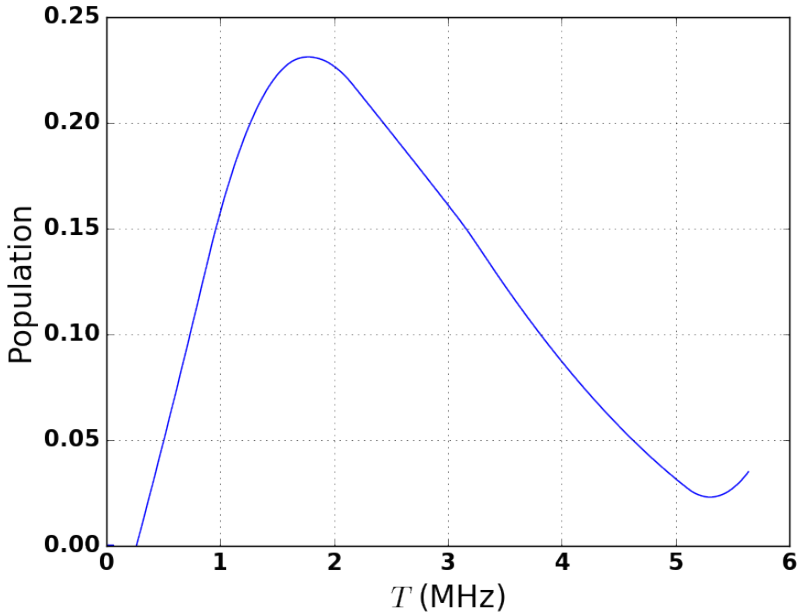
$$\begin{pmatrix} E & \frac{V}{r^3} \\ \frac{V}{r^3} & E \end{pmatrix}$$

Quantum computation

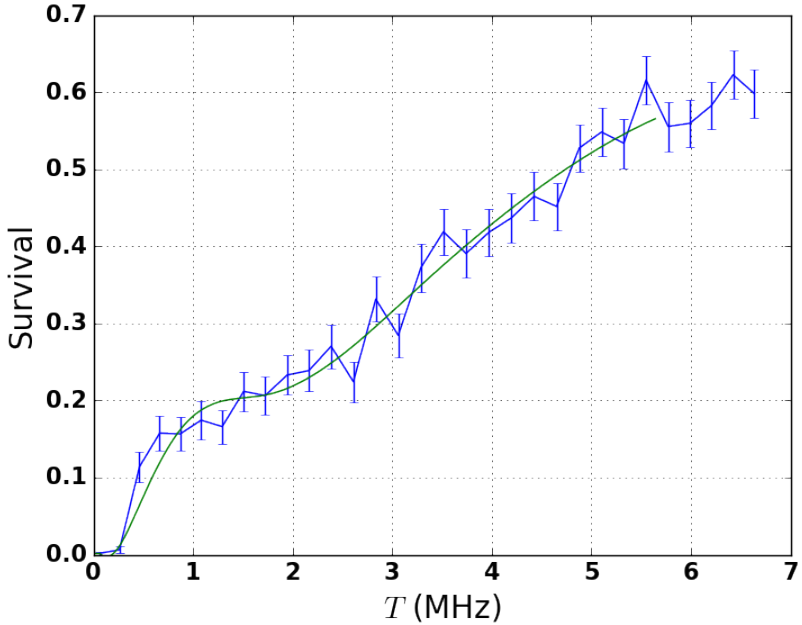


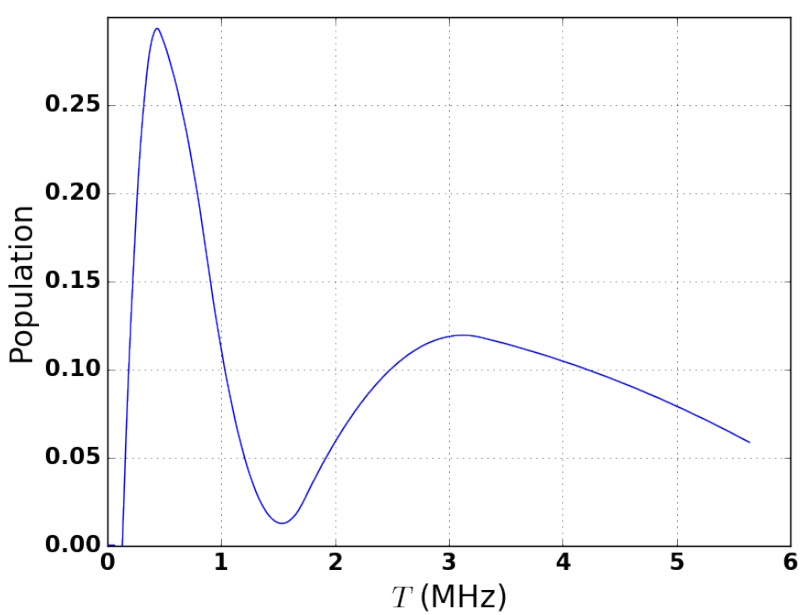
Before cooling



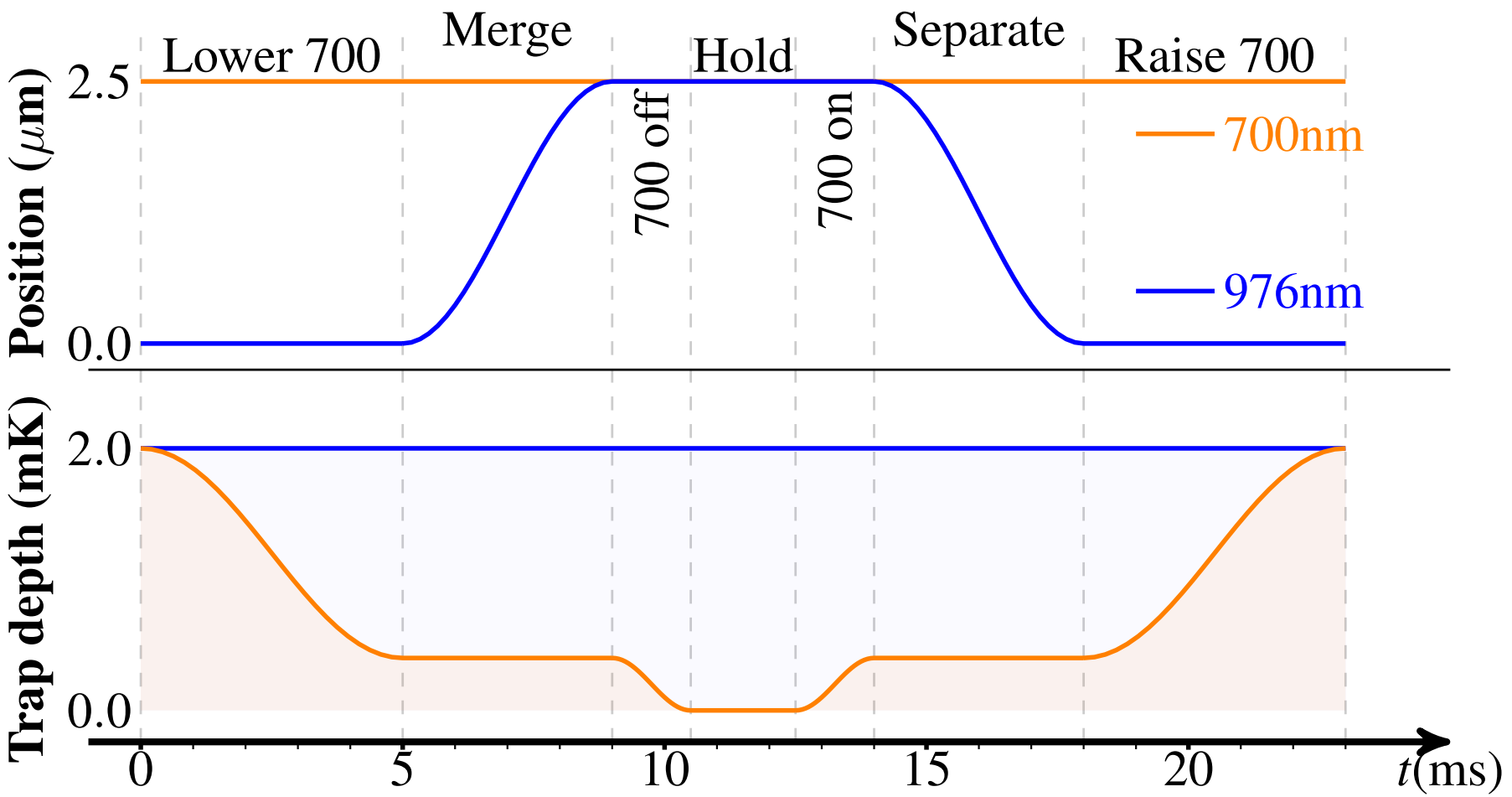


After cooling





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)