Trapped ytterbium ions for scalable quantum technology

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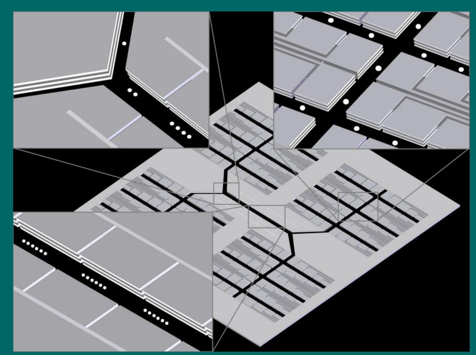
Motivation

Our research is directed towards scalable ion trap quantum technology. Using modern microfabrication techniques we create sophisticated ion trap arrays. We develop techniques to retain and control atoms during shuttling operations inside ion trap arrays.

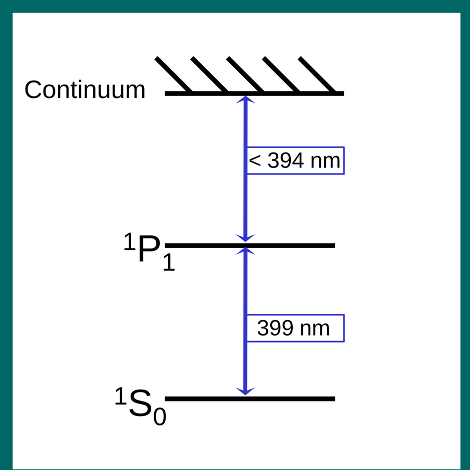


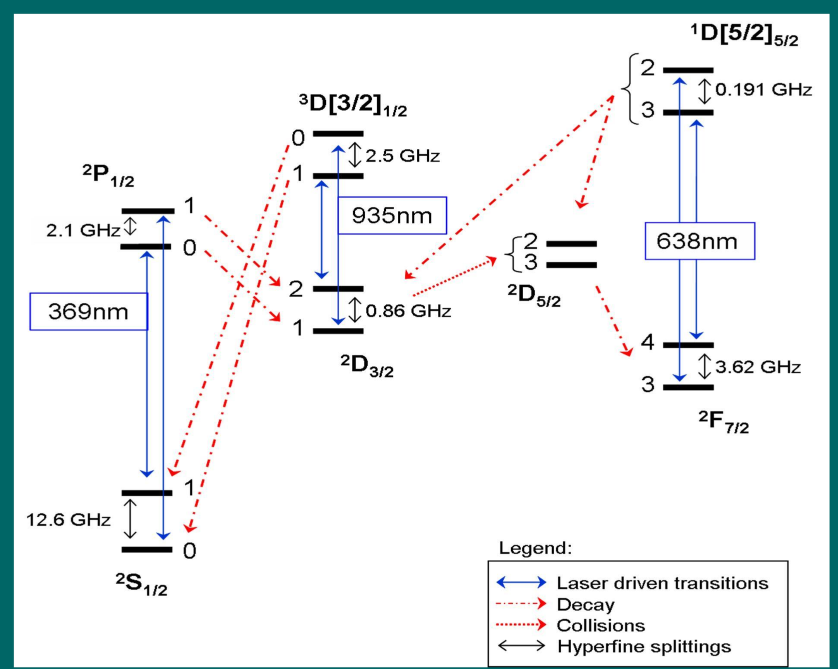
$^{171}Yb^+$

Yb atoms ionised via two-photon ionistation with 399 nm exciting $^1S_0$-$^1P_1$ transition and <394 nm.

$^{171}Yb^+$ has a hyperfine doublet for each fine level, ideal for representing quantum information. All transitions occur at easily accessible wavelengths.

Doppler cooling achieved using 369nm $^2S_{1/2}(F=1)$ - $^2P_{1/2}(F=0)$ dipole transition. Re-pumping lasers at 935nm and 638nm.



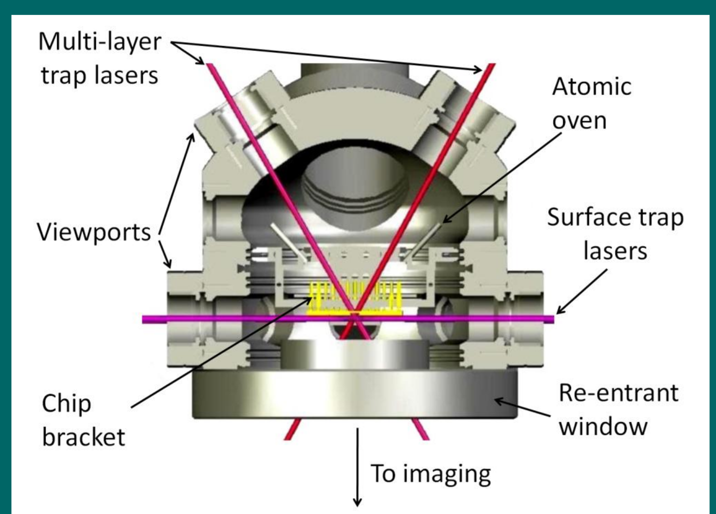


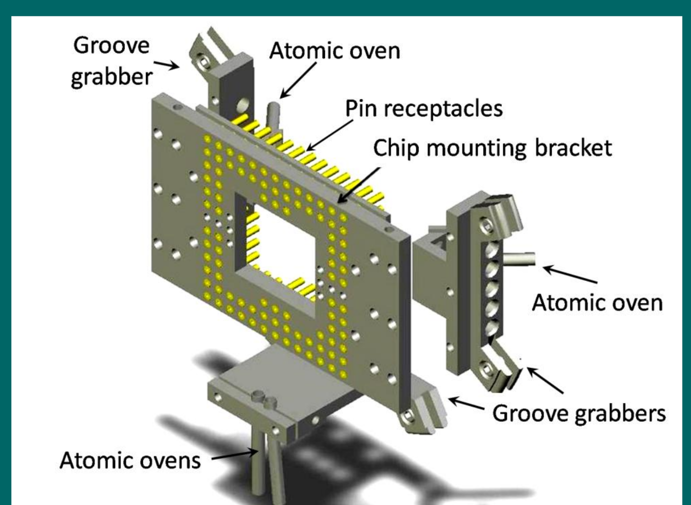
Vacuum system

Vacuum chamber consists of hemisphere and octagon, with 10 AR coated UV grade quartz fused silica viewports.

CF mounted re-entrant window allows ion detection with an intensified CCD camera or PMT.

4 atomic ovens cater for both symmetric and asymmetric traps.





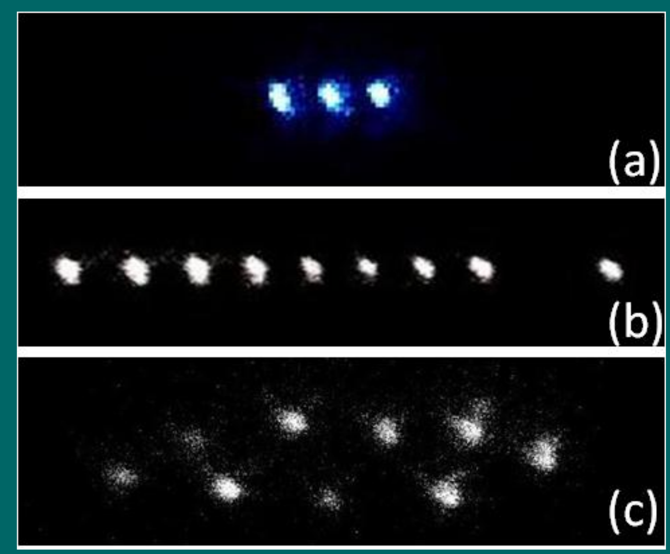
Chamber contains a mounting bracket, with 90 electrical connects to provide control of complex trap geometries.

Receptacles arranged to be compatible with chip carriers, upon which traps will be microfabricated.

Constructing traps onto chips allows for fast turn around times, while the.

Trapped Yb ions

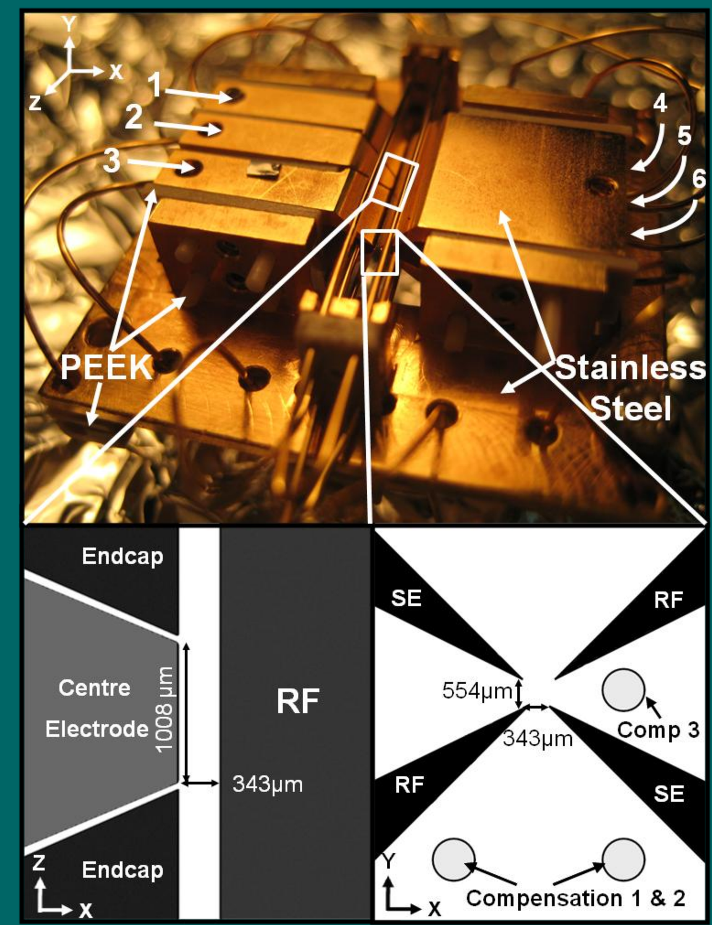
Our ion trap is a two layer linear Paul trap
- Two rf electrodes
- Segmented dc electrodes for end cap potentials and rotating principle axes.
- Compatible with our chip mounting system.



Ion crystals a) Three ions b) 10 ions of different isotopes c) Zig-zag of 9 ions.

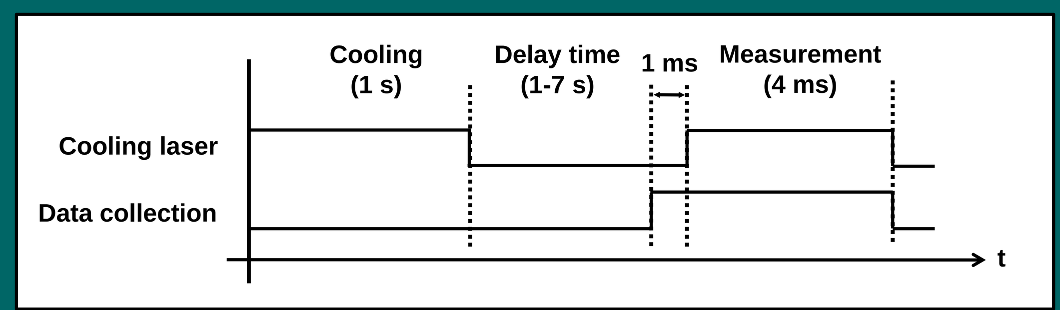
Ion electrode distance
d = 310(10) μm

Secular frequencies:
$\omega_x / 2\pi$ = 2.069(1) MHz
$\omega_y / 2\pi$ = 2.110(1) MHz
$\omega_z / 2\pi$ = 1.030(1) MHz



V_{rf} = 680(10) V
$\Omega_{rf} / 2\pi$ = 21.48 MHz
Trap depth 4.9(2) eV
Static voltages ranging from 7 V to 170 V for axial confinement.

Motional Heating Rate Using $^{174}Yb^+$



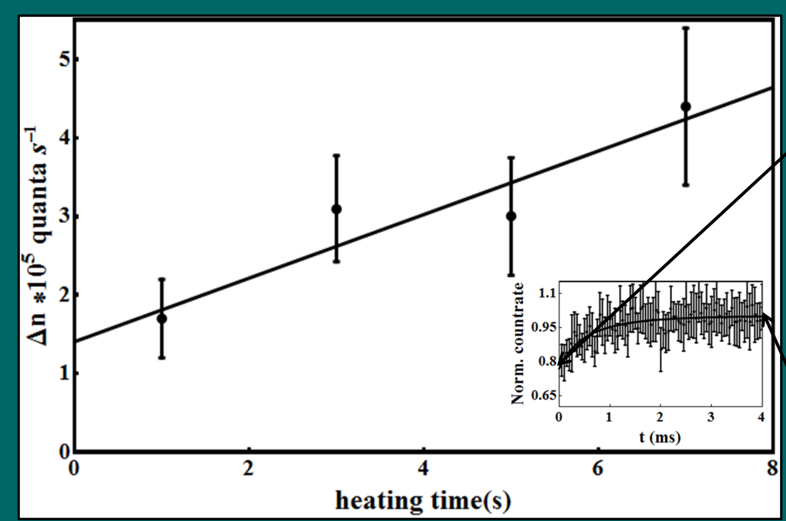
Method proposed by J. H. Wesenberg *et al.* [1]

Using secular frequencies
$\omega_x / 2\pi$ = 2.069(1) MHz
$\omega_y / 2\pi$ = 2.110(1) MHz
$\omega_z / 2\pi$ = 0.178(1) MHz
We assume heating dominant in z-axis

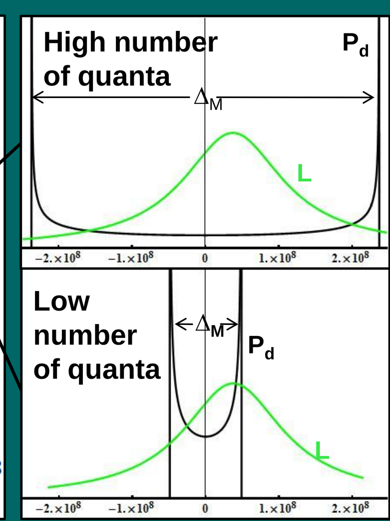
Block 369.5 nm laser to allow ion to heat. Reapply laser and measure fluorescence with photomultiplier tube (Hamamatsu: H8259-01), where the fluorescence depends upon energy of ion.

At the start of re-cooling the motion of the hot ion shifts the transition resonance beyond the broadened linewidth, L. Which results in a low scatter rate. As the ion is cooled the overlap between transition resonance and linewidth improves, increasing scatter rate.

Using the measured change in fluorescence, can determine energy at start of re-cooling. Repeating for different delay times provides heating rate [1].

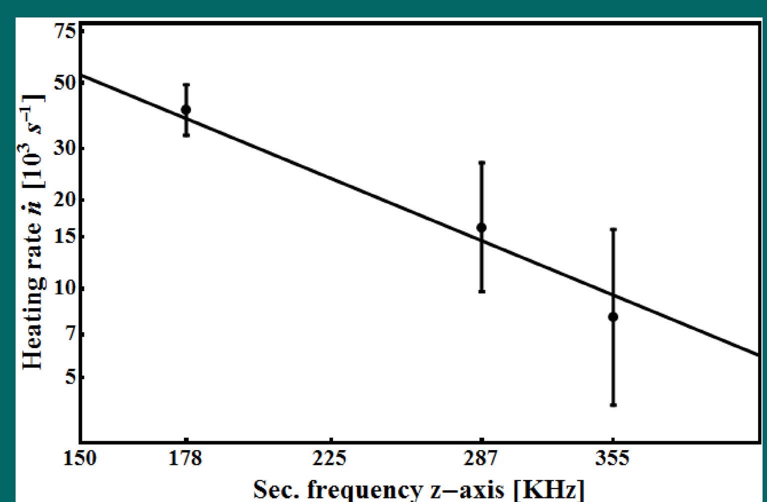


Change of the motional quanta after different heating times

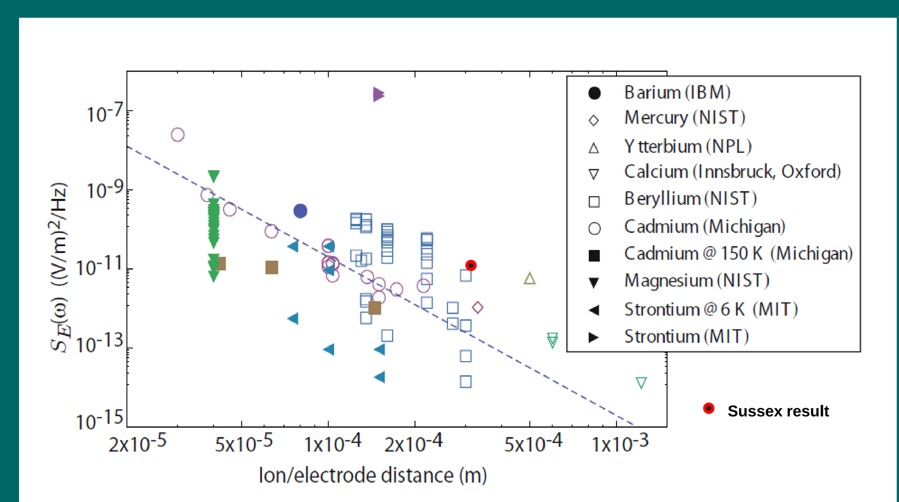


effective detuning (arb. units)

Extrapolated data to determine electric field noise density: S_E(1MHz) = 3.6(9) x 10^{-11} $(V/m)^2$/Hz



Heating rates at secular frequencies
$\omega_z = 2\pi$ = (178, 287, 355) ±1 KHz.



S_E (ω) consistent with measurements of other ion traps of similar dimensions [2].

[1] J. H Wesenberg , R. J. Epstein, D. Leibfried, R. B. Blakestad, J. Britton, J. P. Home, W. M. Itano, J. D. Jost, E. Knill, C. Langer, R. Ozeri, S. Seidelin, and D. J. Wineland Phys. Rev. A **76** 053416 (2007)
[2] J. M. Amini, J. Britton, D. Leibfried, and D. J. Wineland, arXiv:0812.3907v1 (2008)

Frequency Measurements of Cooling and Repumping Wavelengths

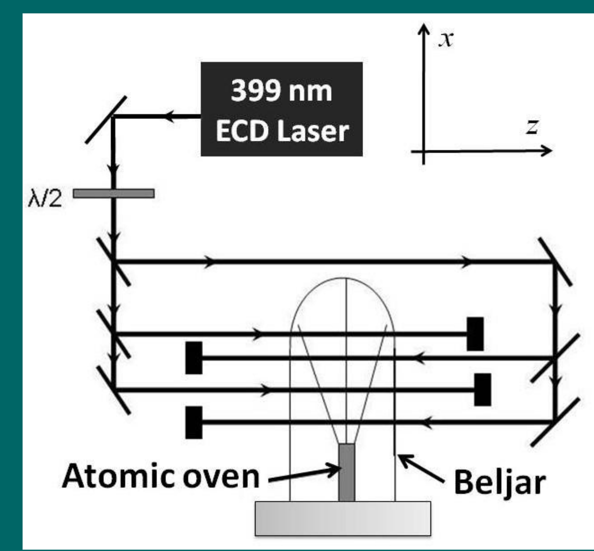
Using fluorescence of trapped ion performed accurate measurements of $^2S_{1/2} \leftrightarrow {}^2P_{1/2}$ and $^2D_{3/2} \leftrightarrow {}^3D[3/2]_{1/2}$ transitions for Yb^+ isotopes.

Yb-Isotope	Wavelength 369 [nm]	Wavelength 935 [nm]
170	369.52364(6)	935.19751(19)
171	369.52604(6)	935.18768(19)
172	369.52435(6)	935.18736(19)
174	369.52494(6)	935.17976(19)
176	369.52550(6)	935.17252(19)

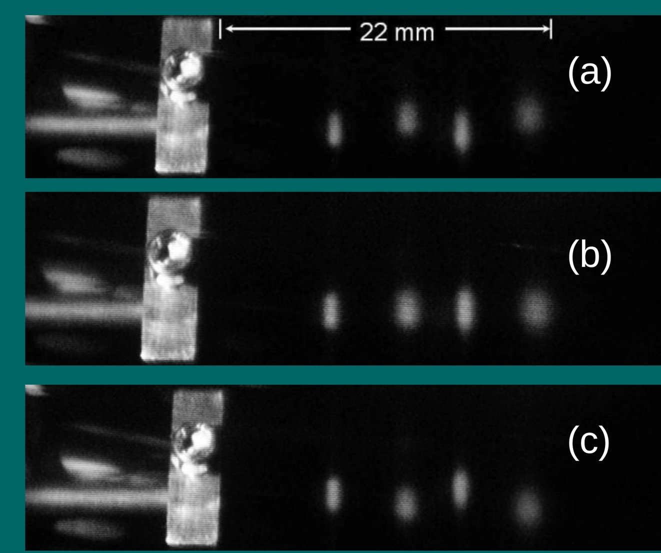
[3] *James J. McLoughlin, Altaf H. Nizamani, James D. Siverns, Robin C. Sterling, Marcus D. Hughes, Bjoern Lekitsch, Björn Stein, Seb Weidt, and Winfried K. Hensinger, Ytterbium ion trap experiment towards scalable quantum technology, arXiv:1007.4010v1*

Doppler-Free Yb Spectroscopy of $^1S_0$ - $^1P_1$ Transition with Fluorescence Spot Technique

Simple method to measure the 398.91nm resonance wavelengths to ±60 MHz by observing fluorescence from neutral Yb excitations.



Two pairs of counter propagating laser beams interact with Yb atomic streams coming out from resistively heated oven tube.



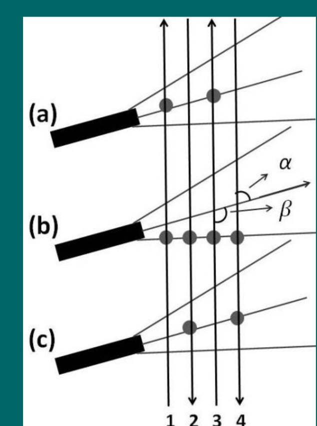
(a) ± 20 MHz from resonance
(b) Resonance
(c) ± 20 MHz from resonance

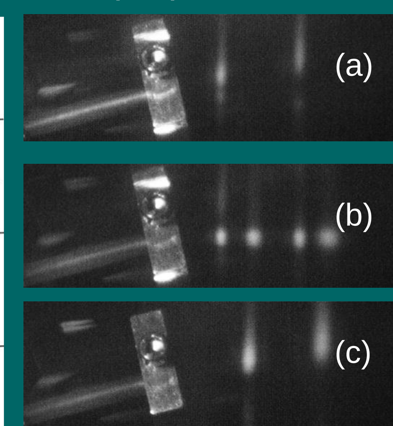
^{174}Yb transition measured to be 751.52665(6) THz [4]

Yb-Isotope	Transition Frequency [THz]	Isotope Shift		
		This work [MHz]	Ref. [4] [MHz]	Ref [5] [MHz]
^{168}Yb	751.52854	1883.0 (30)	1887.400 (50)	
^{170}Yb,^{171}Yb (1/2)	751.52781	1149.0 (60)	1153.696 (61)	1151.4 (56)
^{171}Yb (3/2)	751.52749	829.0 (30)	833.24 (75)	832.5 (56)
^{172}Yb, ^{173}Yb (3/2,7/2)	751.52720	546.0 (60)	533.90 (70)	527.8 (28)
^{174}Yb	751.52665	-	-	-
^{173}Yb(5/2)	751.52639	-264.0 (30)	-254.67 (63)	
^{176}Yb	751.52615	-509.0 (30)	-509.98 (75)	-507.2 (25)

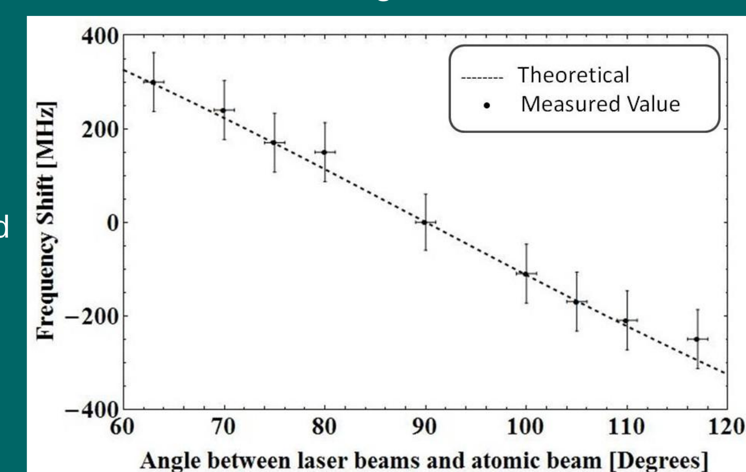
Non-perpendicular atomic beam – laser configuration

By rotating atomic oven can determine Doppler shifted resonance wavelengths when atomic motion is not perpendicular to laser beams.





(a) Laser beams intersect atomic motion at 70º
(b) Laser beams and atomic motion perpendicular
(c) Laser beams intersect atomic motion at 110º



[4] *D. Das, S. Bhatwal, A. Banerjee and V. Natarjan, Phys. Rev. A* ***72*** *032506 (2005*
[5] *T. Loftuss, R. Bochinsky and T.W.Mossberg, Phys.Rev. A* ***63*** *023402 (2001)*
[6] Altaf H. Nizamani, James J. McLoughlin and Winfried K. Hensinger, Doppler-free Yb Spectroscopy with Fluorescence Spot Technique, arXiv:1006.3750v2, to appear in Phys. Rev. A