Laser Cooling of nuclear spin I=0 Alkali atoms

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Motivation:

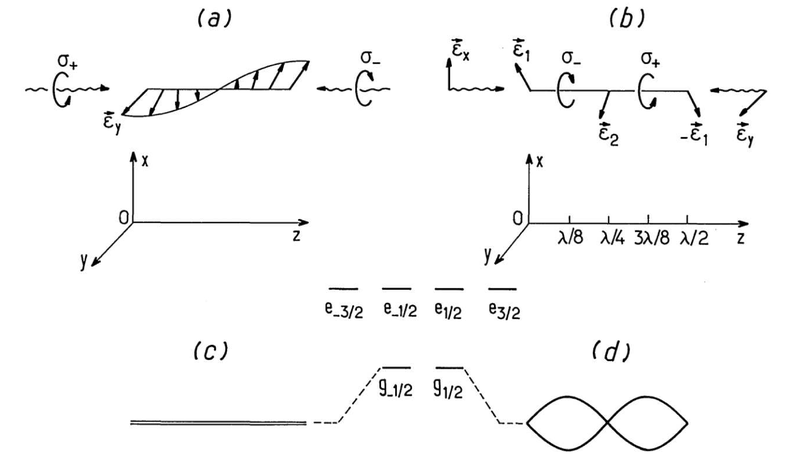
- Nuclear β decay experiments to test the standard model
- Goal: nuclear-spin I=0 ^{38m}K atoms in a MOT.

Measure momentum of decay products β and final nucleus to determine ν momentum

Cloud size is critical: determines angle resolution of outgoing decay product

Sub-Doppler cooling of I=0 alkali: history

J=1/2 → 3/2 (i.e., alkali I=0) does not produce AC stark shifts for Sisyphus cooling in MOT σ^+ σ^-, only for lin⊥lin



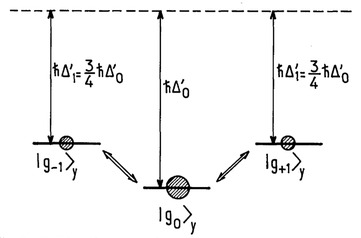


Fig. 6. Light-shifted ground-state sublevels of a $J_g = 1 \leftrightarrow J_e = 2$ transition in the σ^+–σ^- configuration. The quantization axis Oy is chosen along the resulting linear laser polarization. The steady-state populations of these states (4/17, 9/17, 4/17) are represented by the filled circles. The double arrows represent couplings between Zeeman sublevels owing to the transformation to the moving rotating frame.

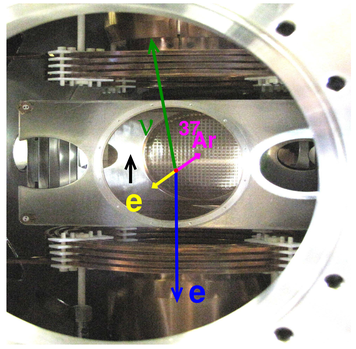
Instead, for I > 0, 'motion-induced orientation' of linear polarization does produce dependence on M_J^2

'Motion-induced orientation' should not work for the I=0 alkali we need

We used Doppler-limited cooling for I=0 ^{38m}K before (Gorelov 2005 PRL), achieving poor temperatures but tight 0.7 mm cloud with high power close to resonance → BUT molecular dimer production was known to perturb ^{21}Na β-ν correlation (Vetter et al. PRC 77 035502 (2008)) by 7%.

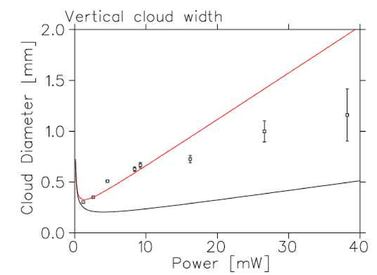
- Plan: Limit dimer production by using less intensity

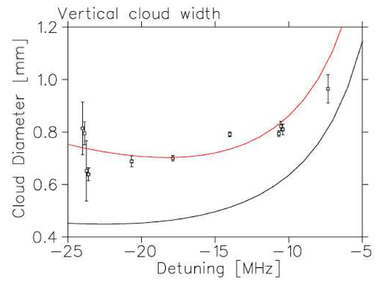
Standard 6-beam MOT for β decay

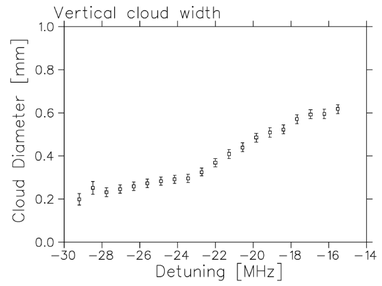


- Position-sensitive ion MCP
- Ar^+ – β^+ coincidences
- β^+ – atomic 'shakeoff' e^- coincidences
- Relieve stress-induced birefringence from conflat viewports with PCTFE gaskets (C.L. Warner, Behr, Gorelov, RSI 85 103106 (2014))

We achieve typical ^{85}Rb cloud size:







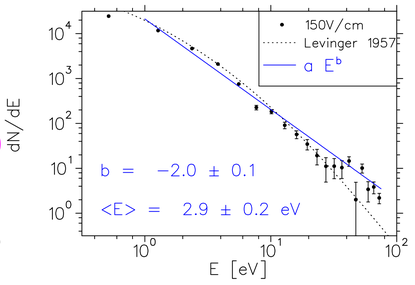
- Cloud size smaller with power
- at relatively high power ↑ (40 mW/beam), detuning still makes cloud smaller

← Smallest size when detune to red with 1 mW/beam

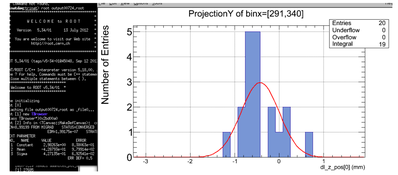
Aside: energy of shakeoff e^- from ^{37}K β^+ decay:

- e^- MCP distribution in uniform $|\vec{E}|$ field → Spectrum fit by sudden approximation calculations with hydrogenic wavefunctions (Levinger PR 90 11 1953).

< 1% have > 25 eV, threshold for double DNA strand breaks– no change in RBE



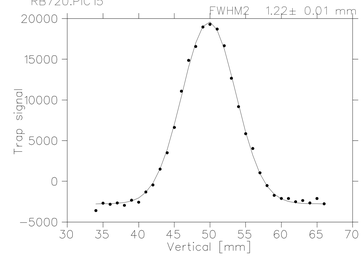
I=0 ^{78}Rb: diagnostics



Photoionized atoms detected by position-sensitive MCP, but statistics limited (10^4 atoms trapped)

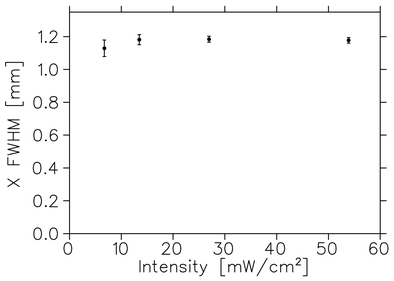
We were unable to get temperature from cloud expansion with MOT off/on

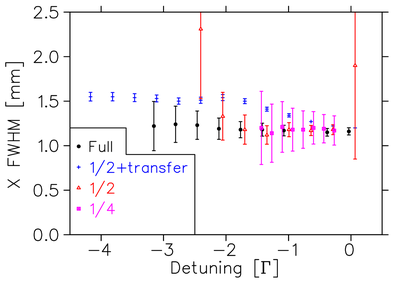
CCD camera → size



So settled for our main goal, minimizing the cloud size in a simple CCD camera with 200 millsec exposures:

I=0 ^{78}Rb cloud size data





Cloud is not expanding with less intensity. This will maintain angular resolution of products while suppressing dimer formation.

Cloud expands with detuning. No signs of sub-Doppler cooling. Sad, but expected

Next: explore more intensity/detuning space with more atoms

- Could use calculations/estimates of molecular dimer production in I=0 alkalis