# Magneto-optical Atom Trapping and Measuring Temperatures of Atoms Below 200 μK

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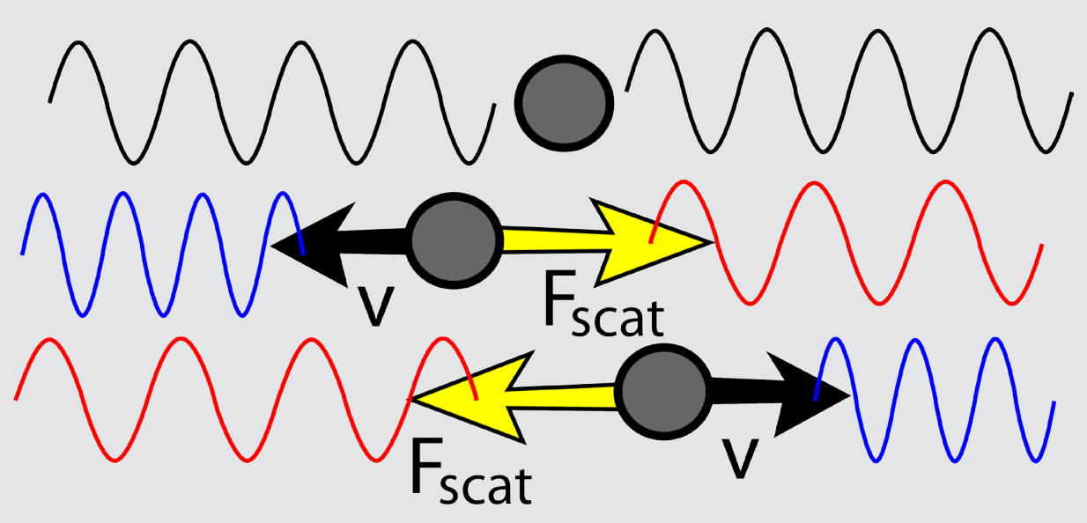
## Introduction

TRIUMF's Neutral Atom Trap (TRINAT) is a magneto-optical trap that traps atoms in a cubic millimeter volume. It is used to examine fundamental asymmetries in nature by studying neutrinos from beta decay of atomic nuclei, searching for physics beyond the Standard Model of particle physics.

To calculate accurate neutrino momenta, the atom cloud must be held at lowest possible temperature and size. We present the design and implementation of an atom trap real-time control system, which we use to optimize these properties.

## Background

### Laser Cooling

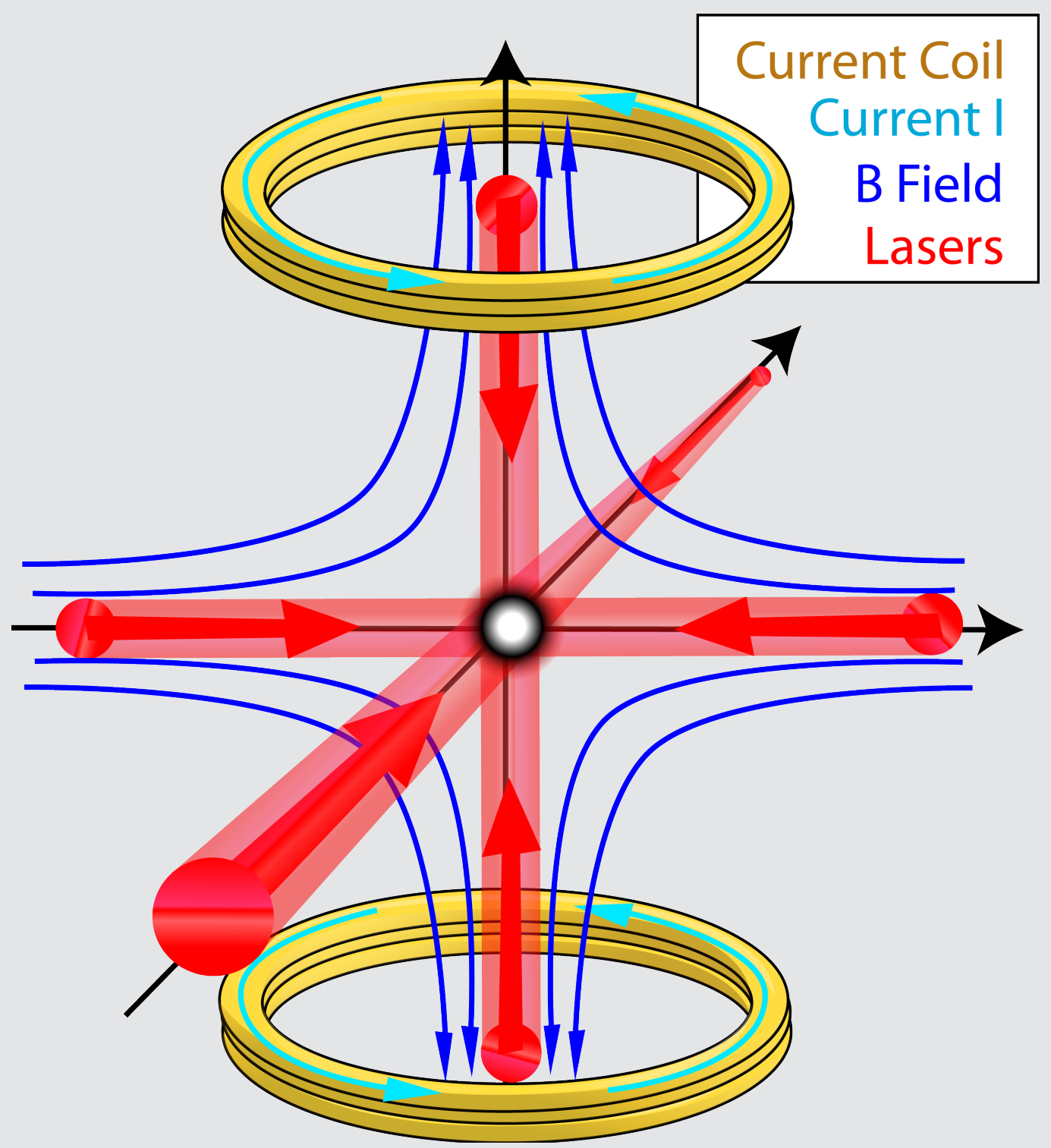


Shining a laser at an atom at the resonant frequency for a specific energy transition causes a photon to be absorbed. This gives a momentum kick to the atom in the direction of photon travel. Atoms absorb more photons closer to the resonant frequency.

### Doppler Cooling

- Laser frequency detuned below the atomic resonance
- If atom moves towards one beam, that light will be Doppler shifted closer to the resonance causing more photons to be absorbed, creating a slowing scattering force $F_{scat}$

### Magneto-optical Trap

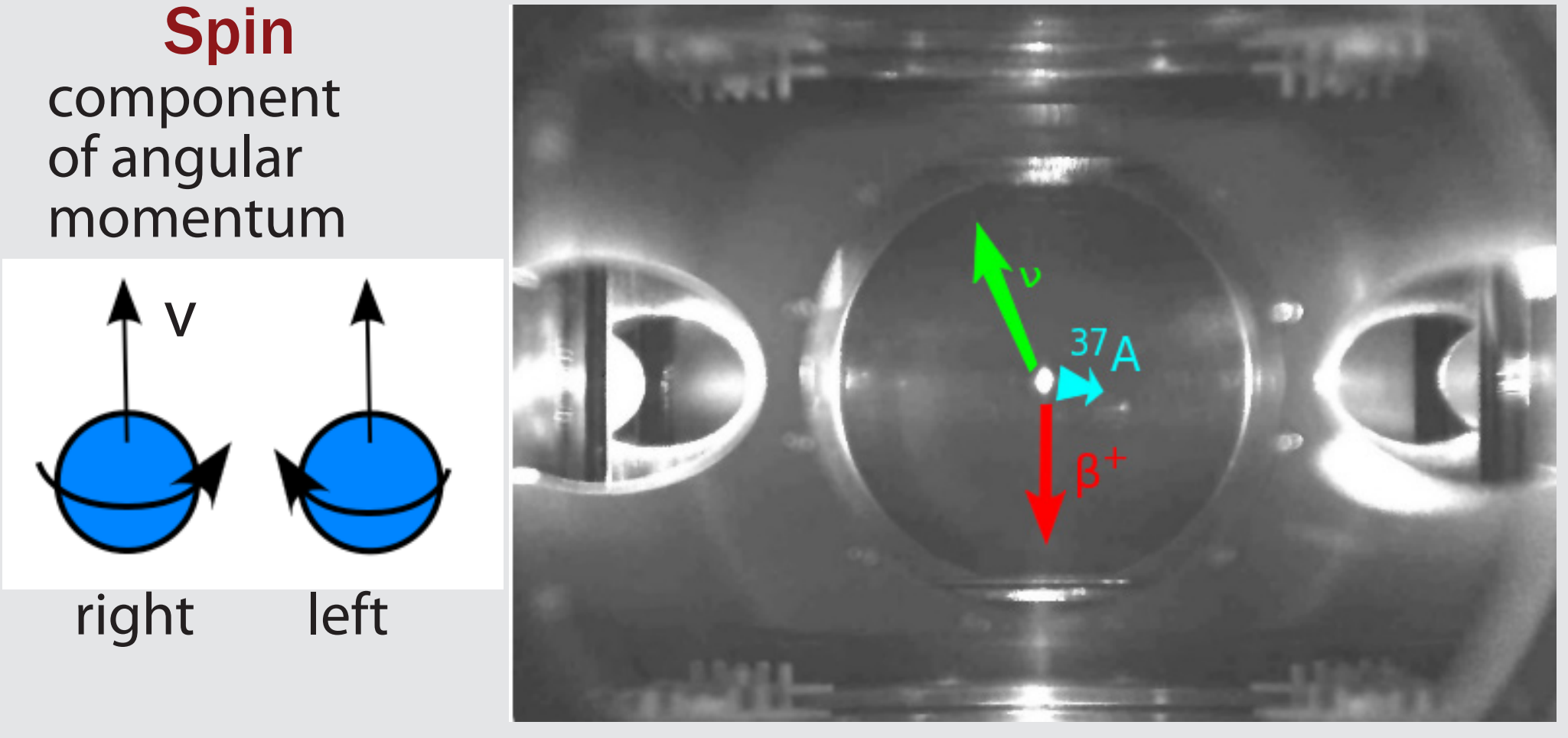


- 3 pairs opposing laser beams point towards atoms
- Quadrupole magnetic B field , 0 at origin
- If atom moves away, nonzero B field causes Zeeman shift in energy levels that increases photon absorption, kicking the atom back to center.

### Beta Decay

- Searching for forbidden right-handed spin neutrinos from beta decay
- Would provide evidence for physics beyond Standard Model

$$^{37}K \rightarrow {}^{37}Ar + \beta^{+} + \nu$$



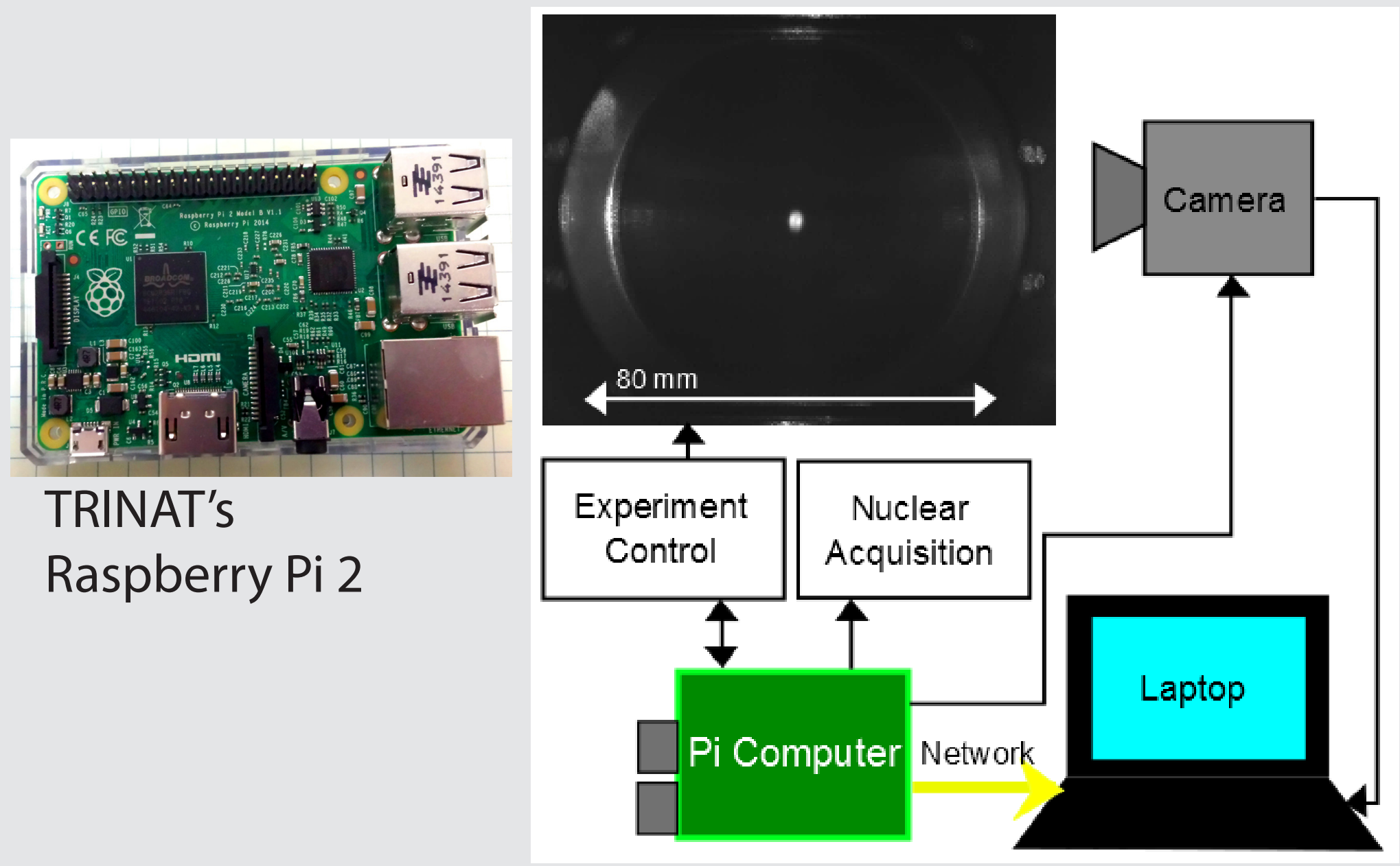
- Momenta of neutrinos cannot be found directly
- Deduced from other particles using momentum conservation
- Important to know initial particle positions and momenta accurately - low temperature and small cloud size

## Purpose

- Design replacement atom trap control system with accurate timing capability
- Use system to determine lowest achievable temperature and trap size to improve accuracy of calculations of neutrino momenta from beta decay

## Methods

### Control System Design



TRINAT's Raspberry Pi 2

- Main control computer is a Raspberry Pi
- Interfaces with control and data acquisition systems
- Runs real-time Linux, timing to 15 μs precision
- Runs custom-written C++ programs for control
- Externally triggers camera

### Temperature Measurements

- Temperature determined from the atom cloud expansion rate
- Used stable isotope Potassium 41

Laser intensity varied from 0.2x to 10x saturation intensity, where the upper and lower energy levels are equally populated

Laser frequency varied from 136MHz to 148 MHz (resonant frequency is 149.29 MHz)

Number of atoms varied between ~100K and ~30K atoms

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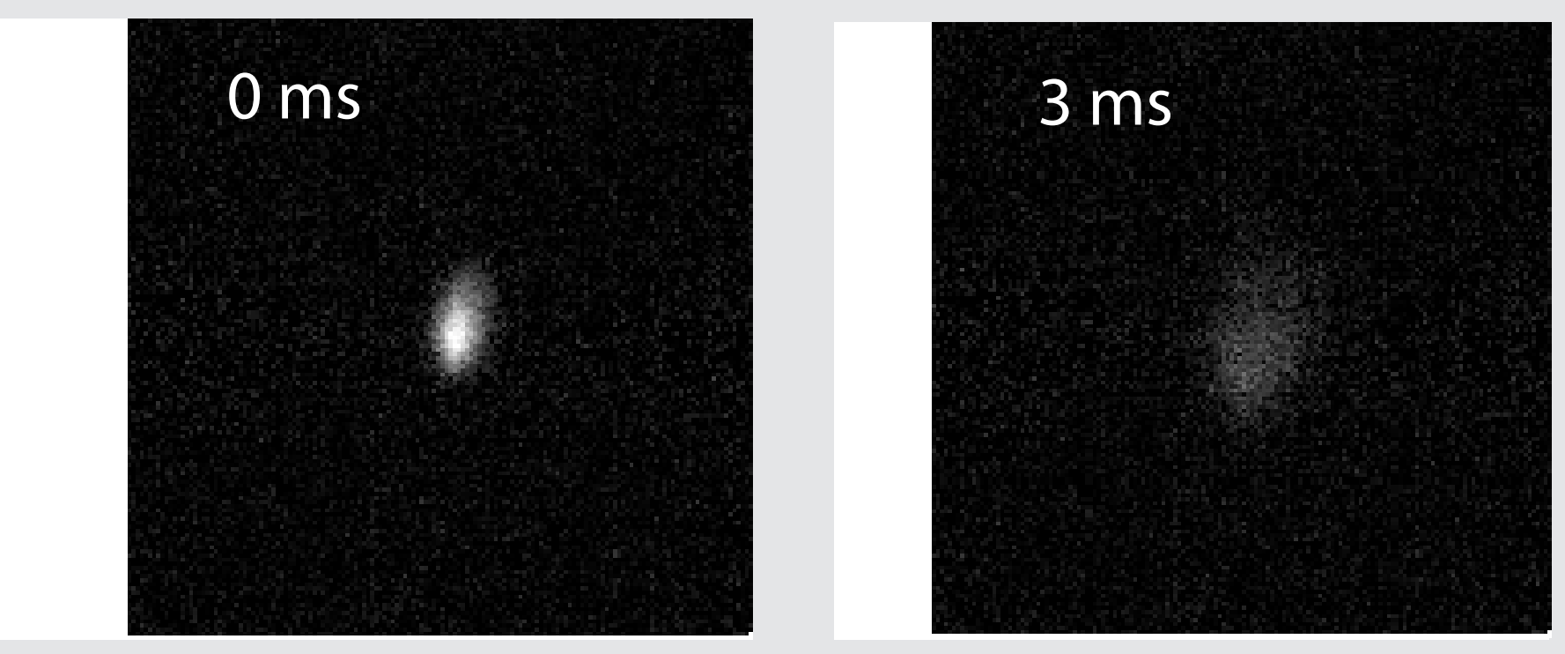
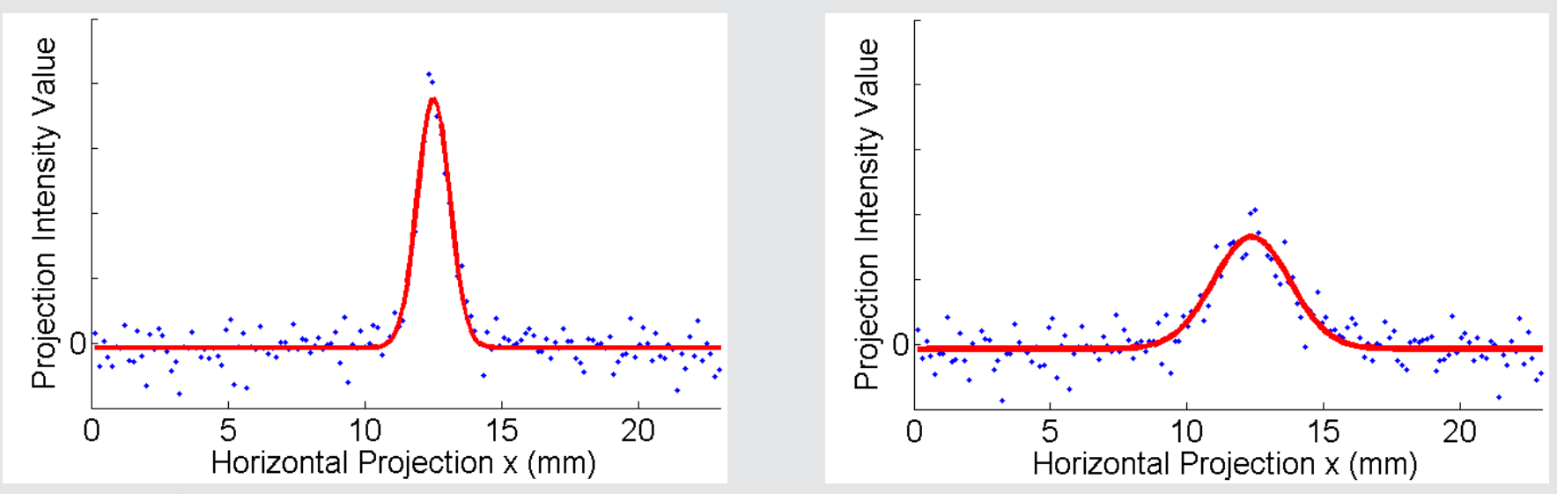


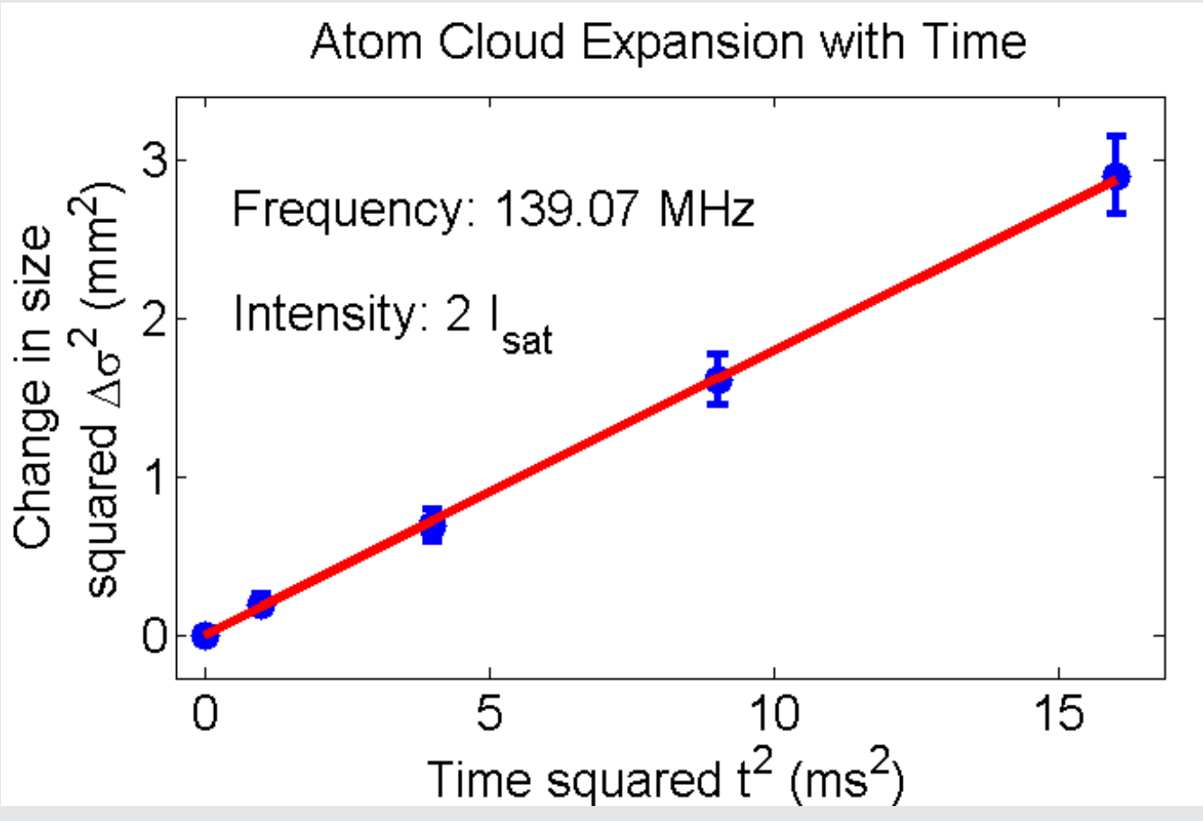
Captured images after letting cloud expand for 0-4 ms

2



Fit cloud profile at each step to Gaussian

3



Fit cloud growth according to theory of ballistic trap expansion

4

$$T = \frac{M}{k_B}\frac{d(\sigma^2)}{d(t^2)}$$

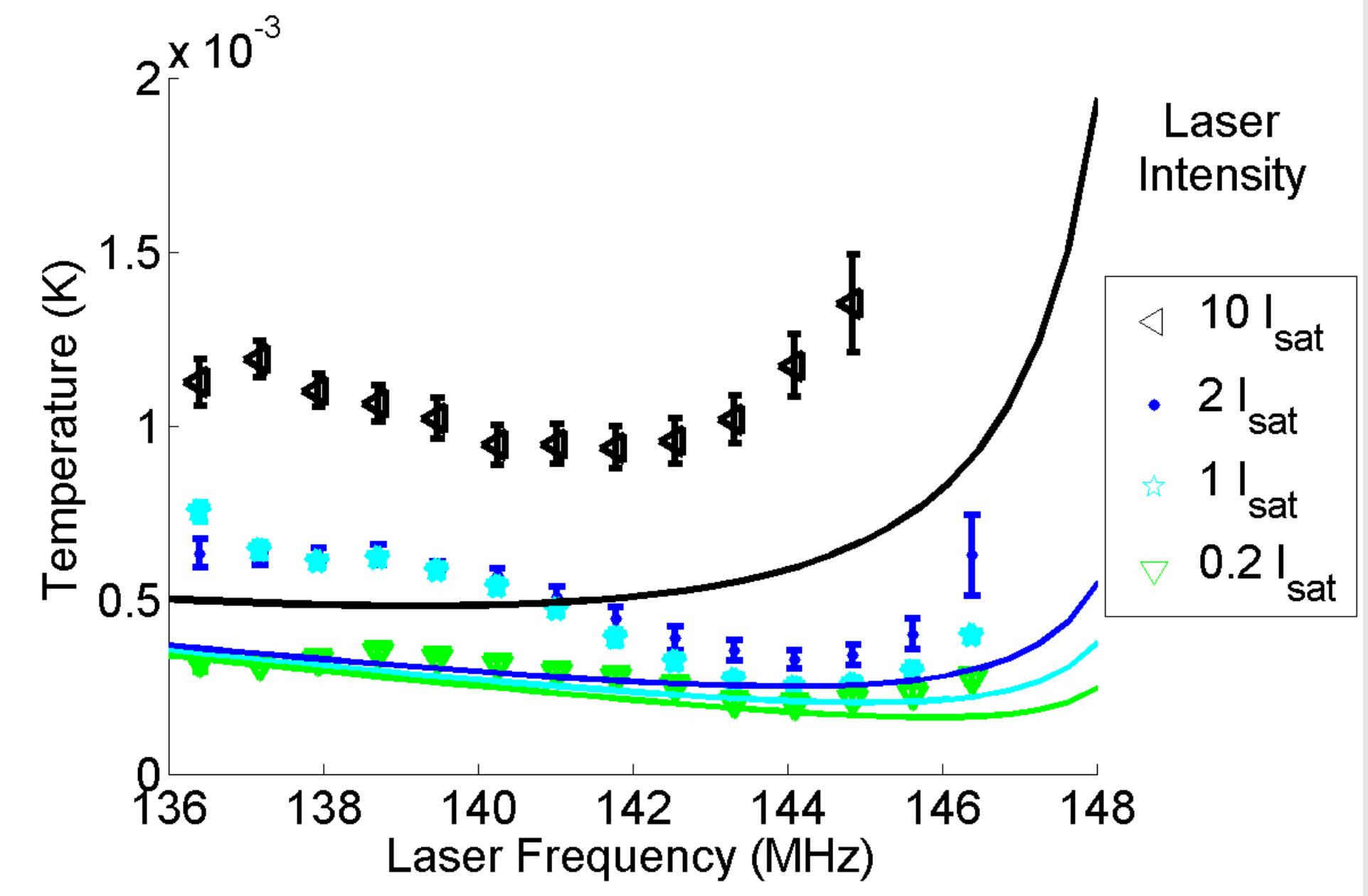
Used cloud expansion rate to calculate temperature

## Results

- Lowest temperature and size 141±12 μK, $\sigma = 0.34 \pm 0.03$mm
- In range of theoretical Doppler cooling limit of 145 μK
- 144.7 MHz frequency, 1x saturation intensity, 30K atoms

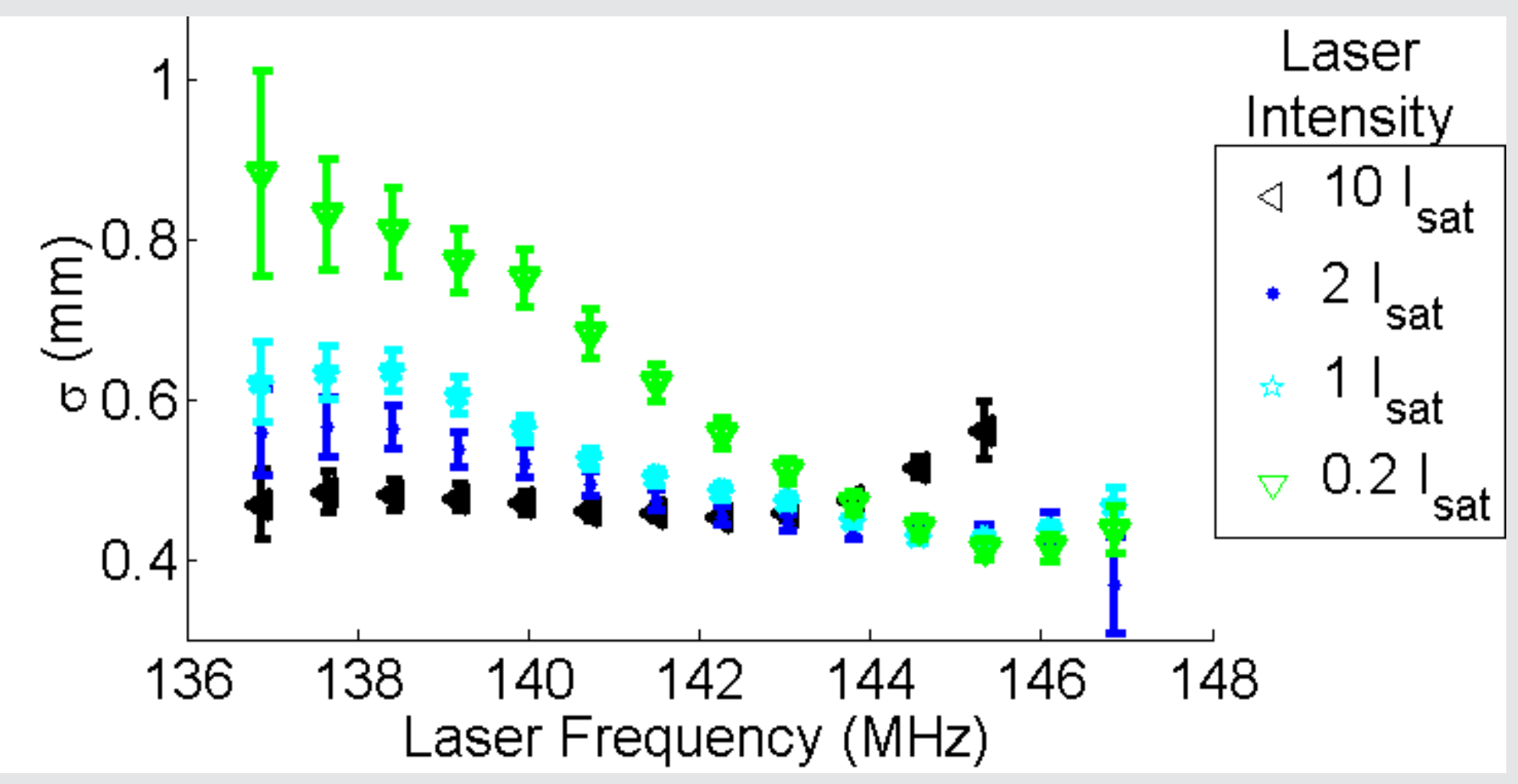
### Temperature dependence on frequency and intensity

~100K atoms, solid curves Doppler cooling predictions



### Size dependece on frequency and intensity

~100K atoms



### Laser Frequency

- Size and temperature small close to the frequency of minimum temperature prediction
- Uncertainty in our frequency of up to 1.7 MHz, so it is possible the data points should all be shifted to higher frequency

### Laser Intensity

- Lowest laser intensities produced best cooling effect
- Extra photons could be producing excess heating due to re-scattering of photons
- Lower laser intensity creates a larger trap far from the prediction minimum frequency, but small close to it

### Number of Atoms

- Temperatures lower for fewer (~30K) atoms, closer to number radioactives trapped in beta decay experiments
- Could be also attributed to re-scattering of photons when atoms are more numerous causing excess heating

## Conclusions

In design, implementation and usage of a replacement atom trap control system we were able to determine laser intensity, frequency and number of atoms settings to optimize the low temperature and small size of the atom trap for beta decay.

With this new knowledge, the next beta decay experiments will be able to conclude more accurate results in calculation of the neutrino momenta.

## Acknowledgements

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### References

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