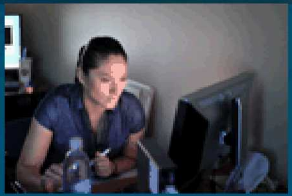
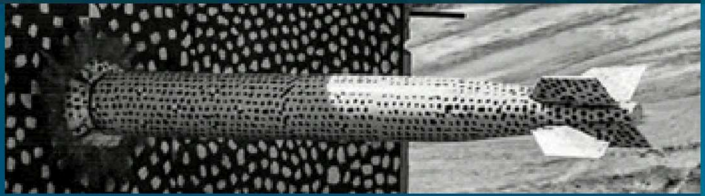
SAND2019-13433PE

# Nanofiber Based Guided Atom Interferometry





*Presented By*

Adrian Orozco

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# Outline

- Nanofiber design and production
- Dual color nanofiber atom trap
- Trapping results
- Atom interferometry
- Future goals

## Project Goal:

Perform atom interferometry with atoms trapped in the evanescent field of a nanofiber

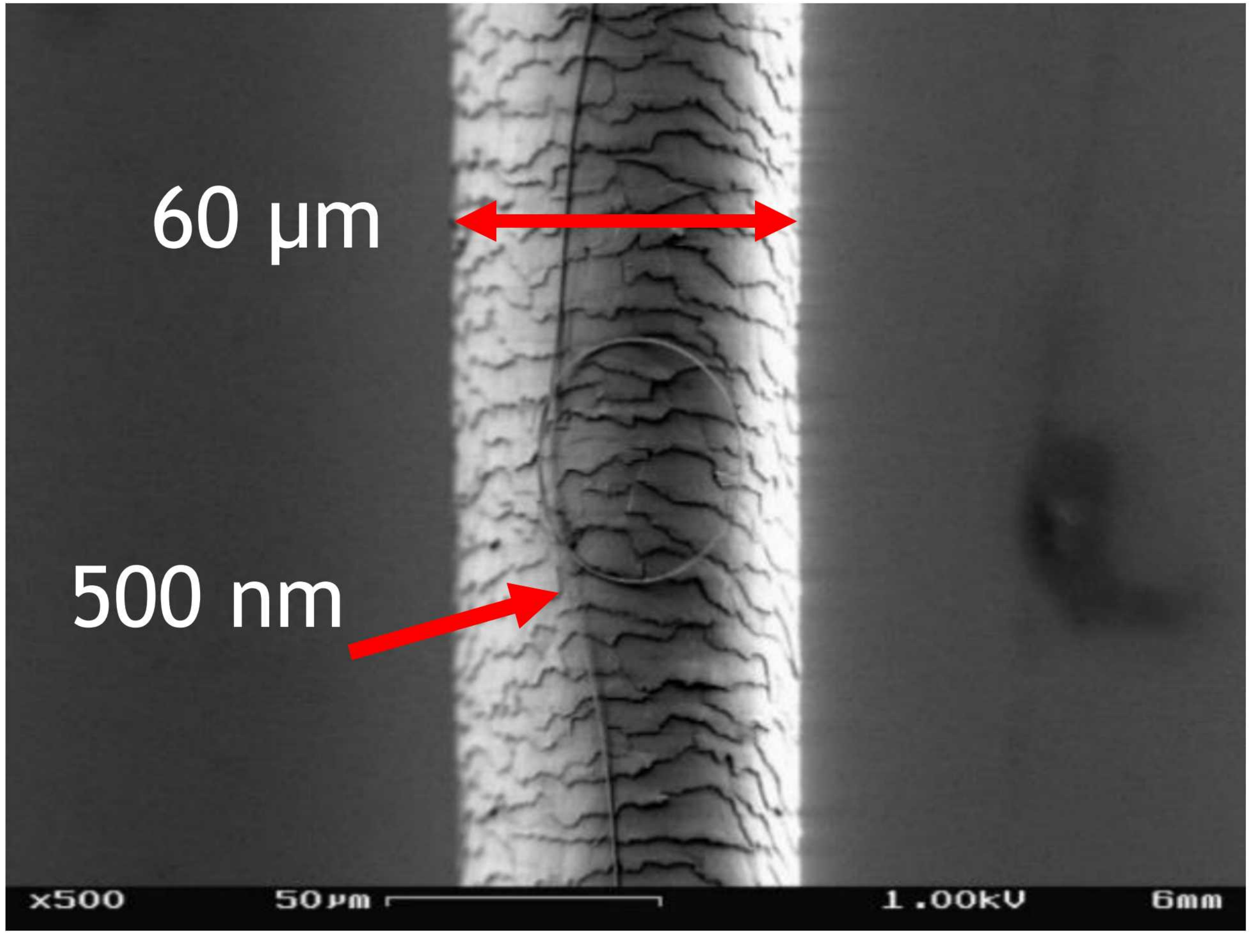
## Motivation:

Fundamental Physics: Probe surface interactions

- Casimir-Polder forces
- inverse square law violations
- fundamental constants measurements

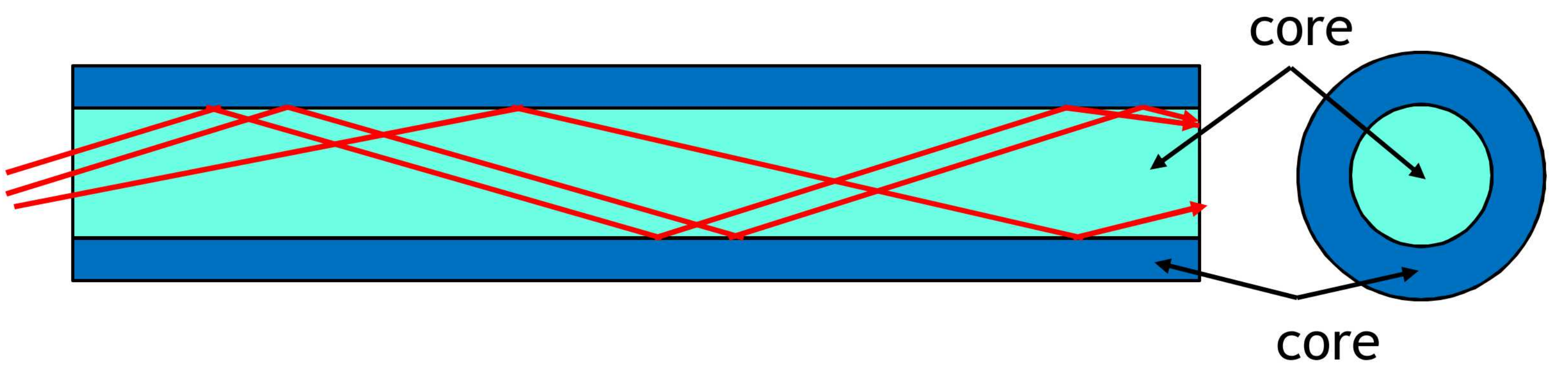
Inertial navigation without GPS

# What is a nanofiber?

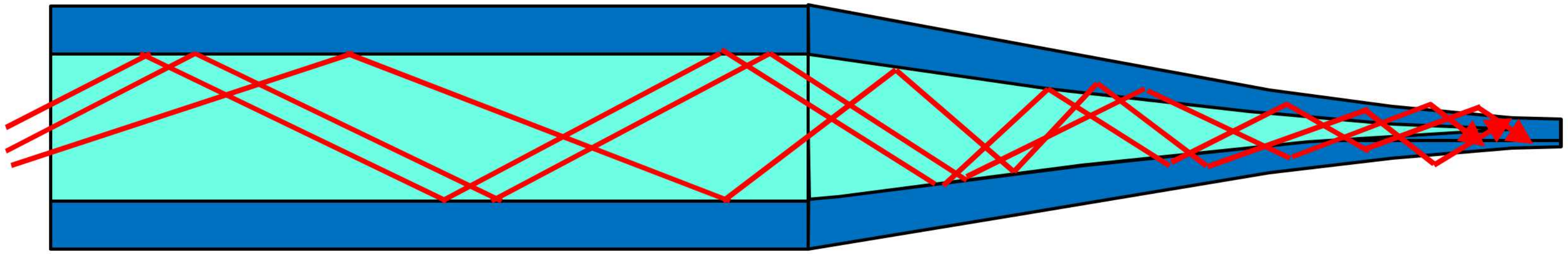


# Tapered Fibers

- Typical step in fibers guide light using total internal reflection

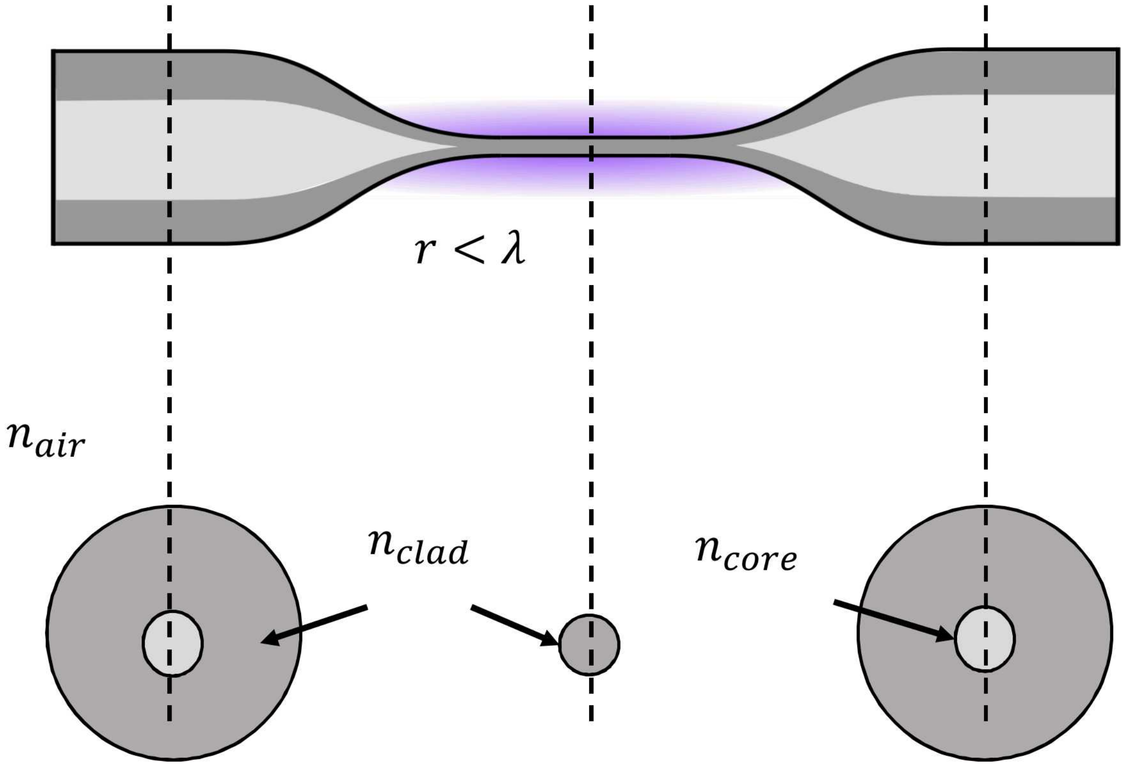



- Reducing the diameter allows the light to get to the surface

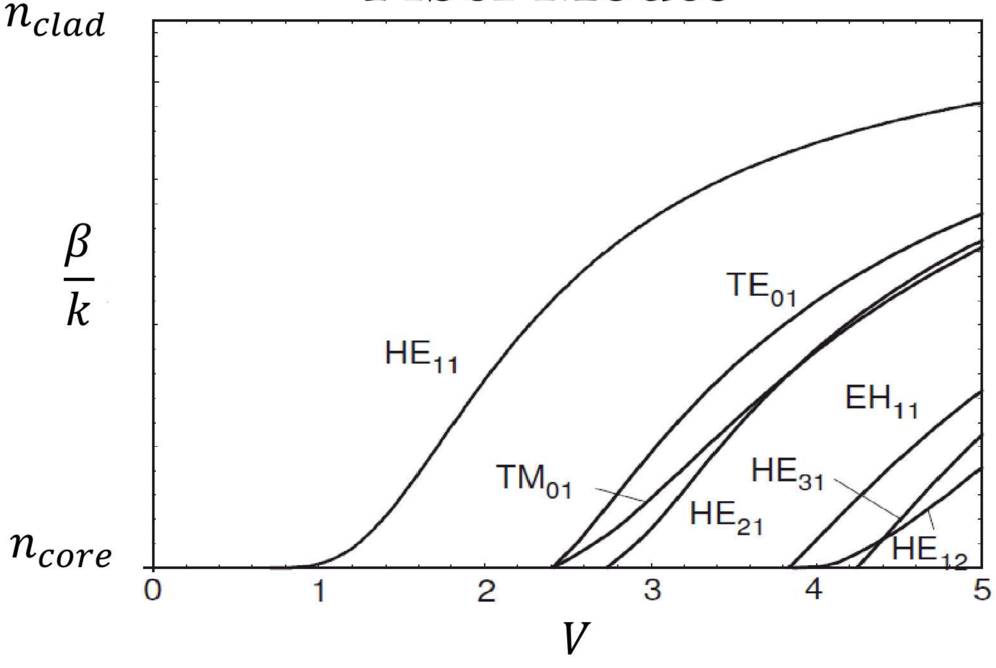


# Tapered Nanofiber Characteristics

## Index of Refraction Profile




## Fiber Modes



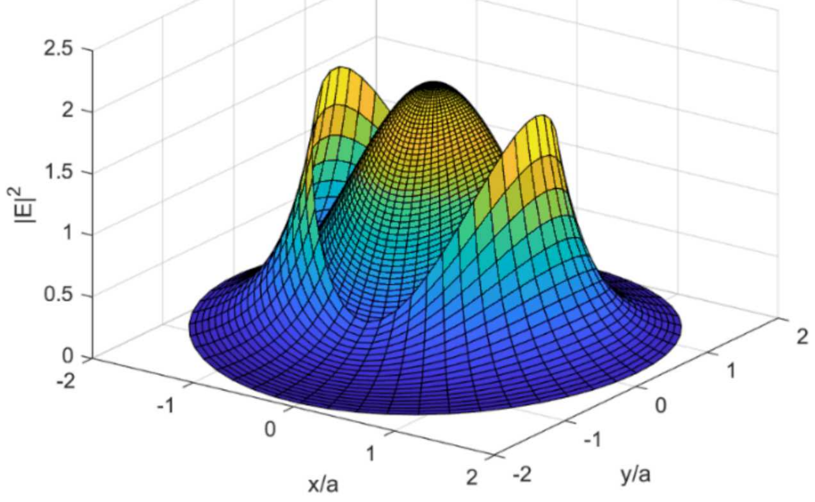

$$V = \frac{2\pi r}{\lambda}\sqrt{n_{core} - n_{clad}}$$

$$n_{clad} < \beta < n_{core}$$

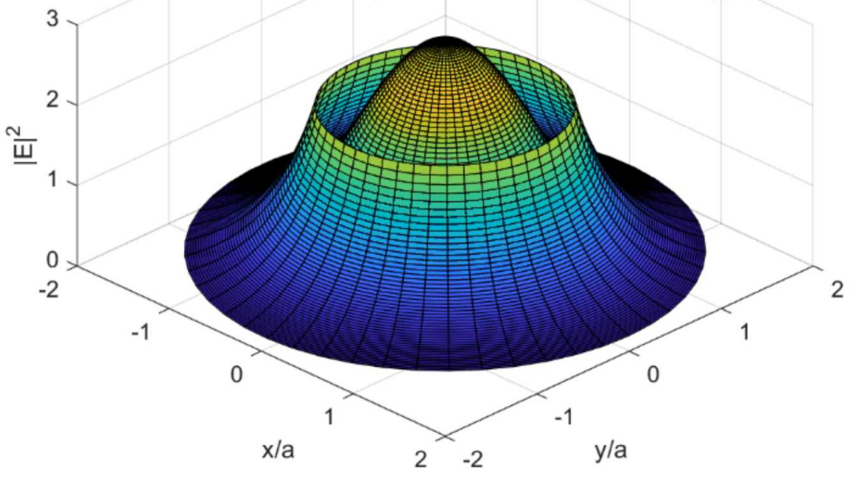
Graph borrowed from Vetsch PhD Thesis (2010)

# Fundamental $HE_{11}$ mode of a nanofiber

Linearly Polarized Input

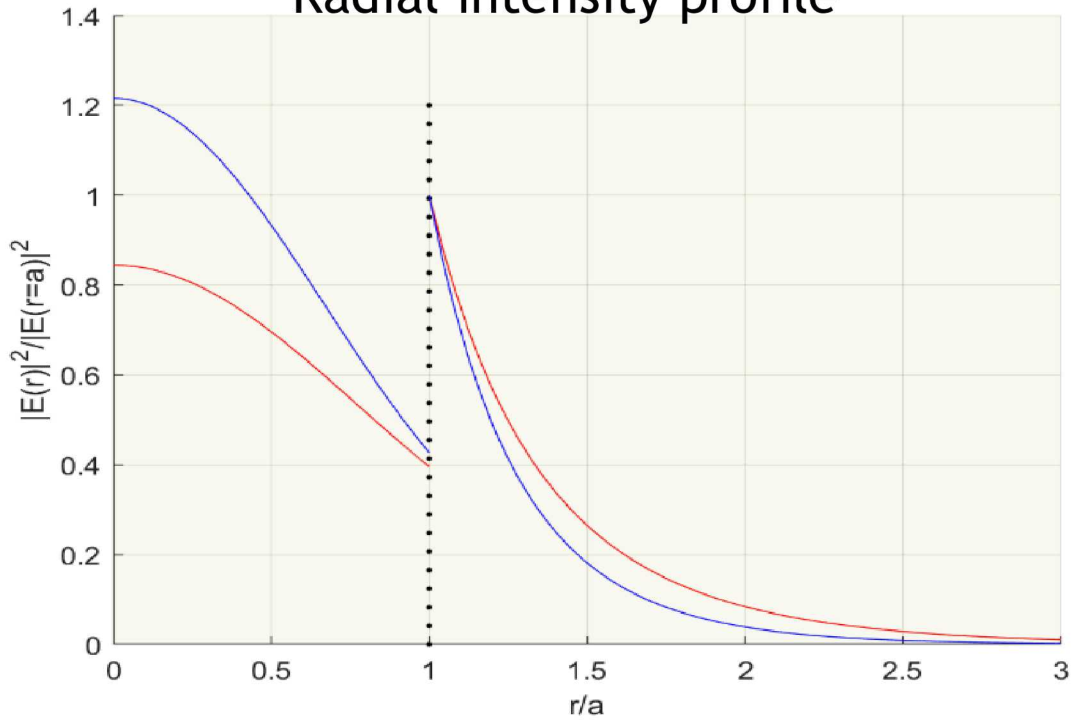



Circularly Polarized Input



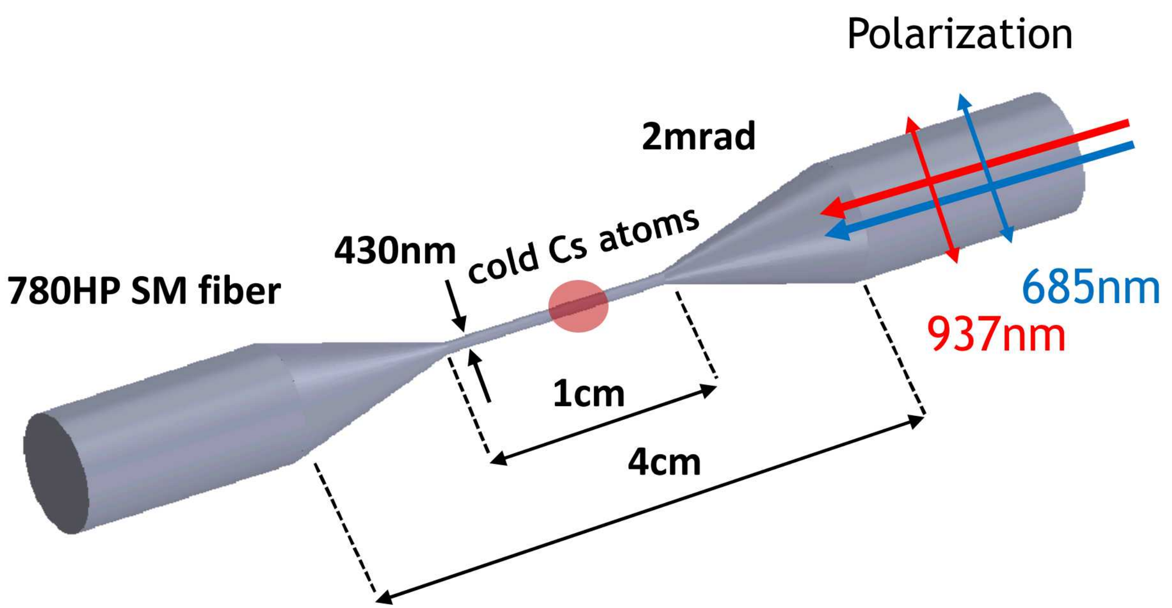

- Radial intensity decays away from the nanofiber surface
- Azimuthally symmetry is dependent on field polarization

Radial intensity profile

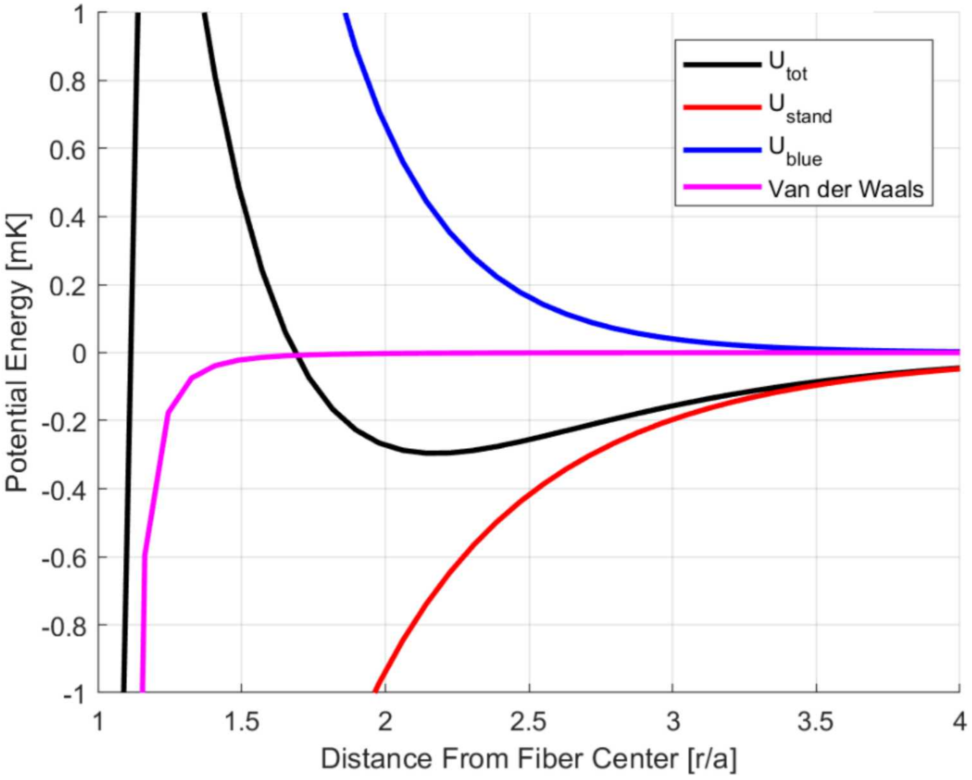


# Nanofiber Trap Potential

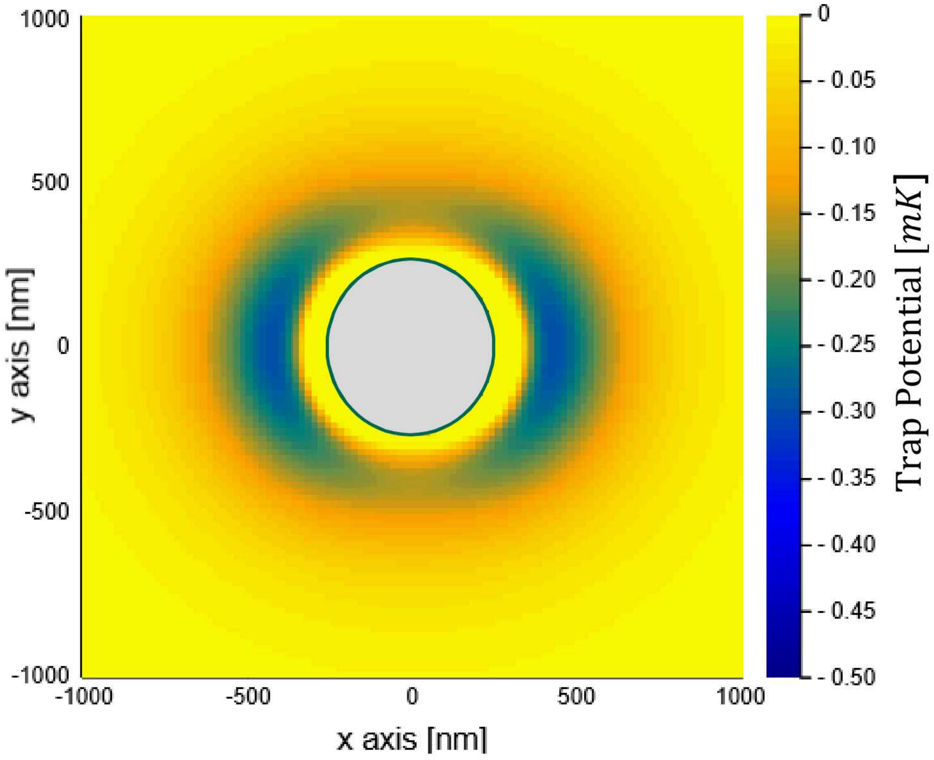
## Trap geometry and configuration

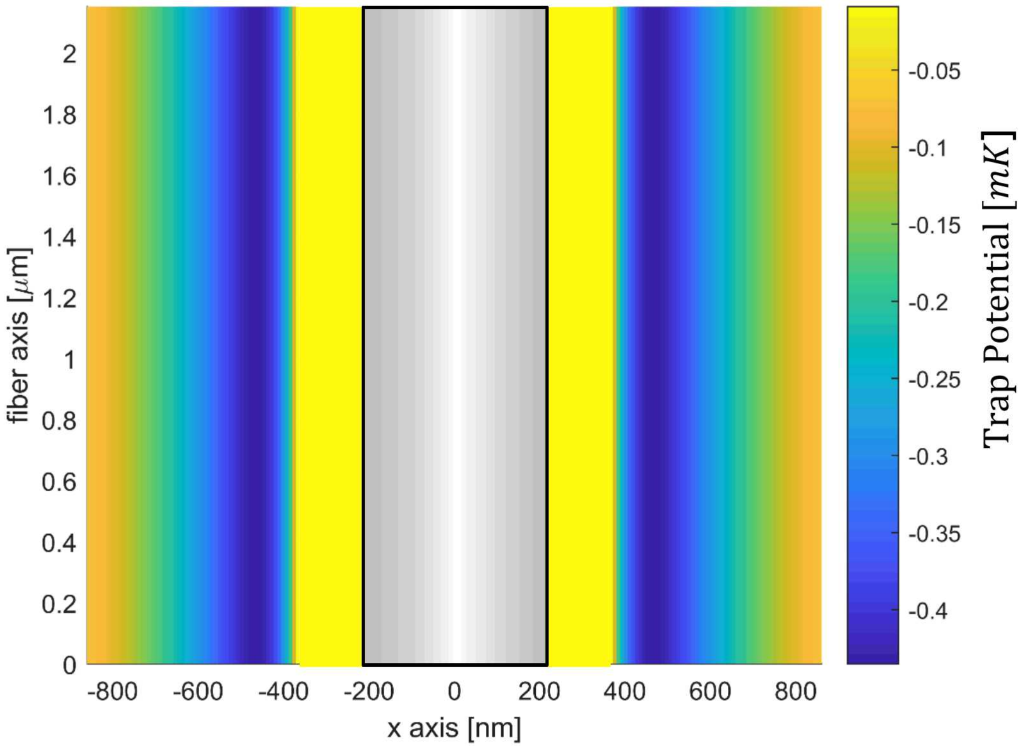



## Radial Trap Potential



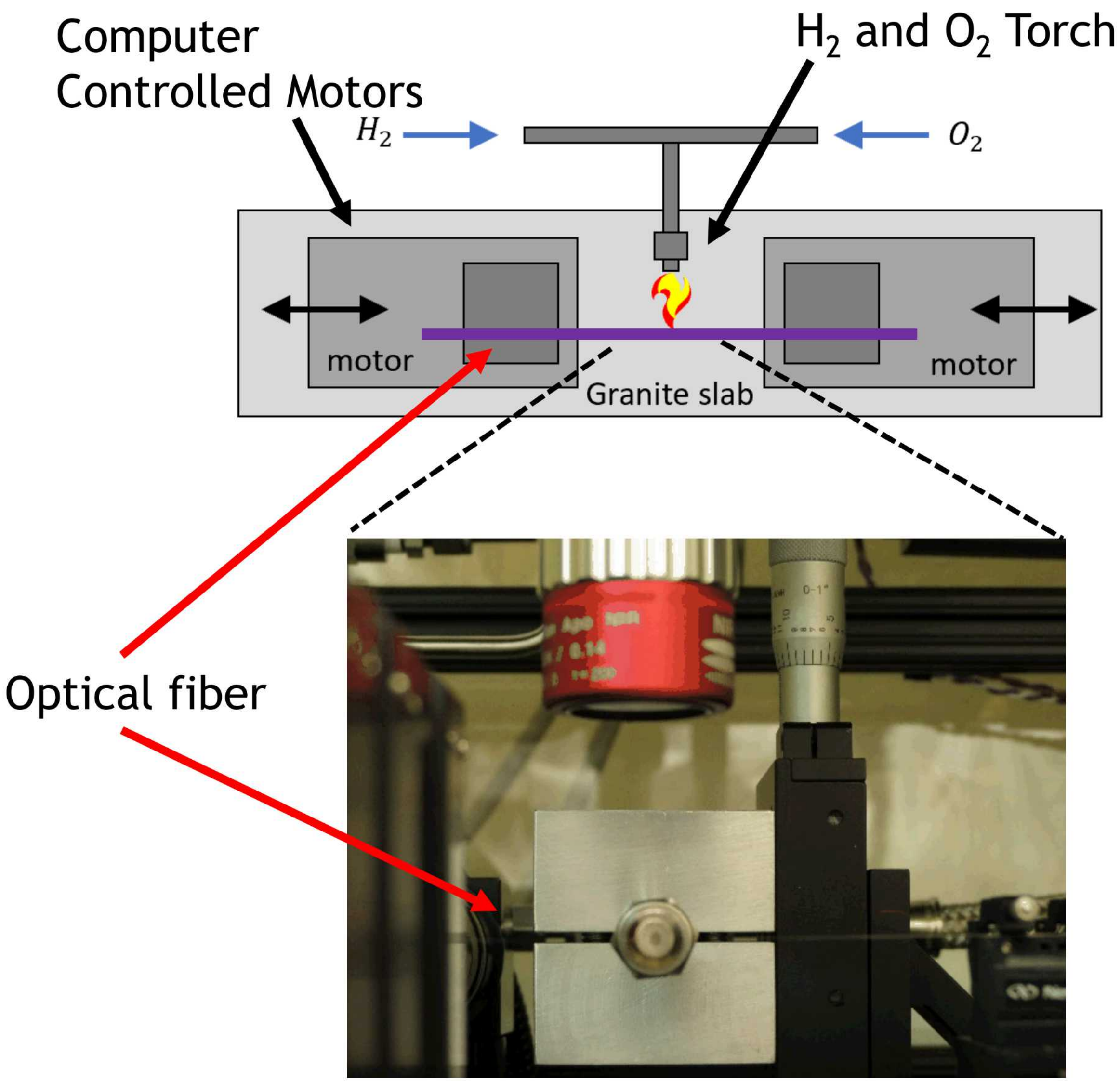
# Dual-color evanescent field nanofiber atom trap: 2-D configuration

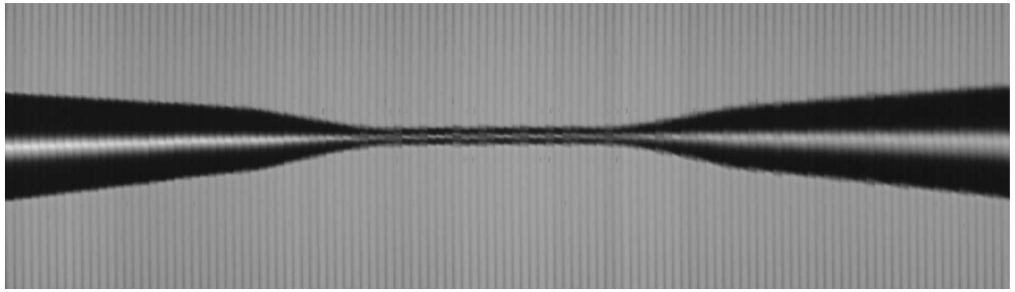


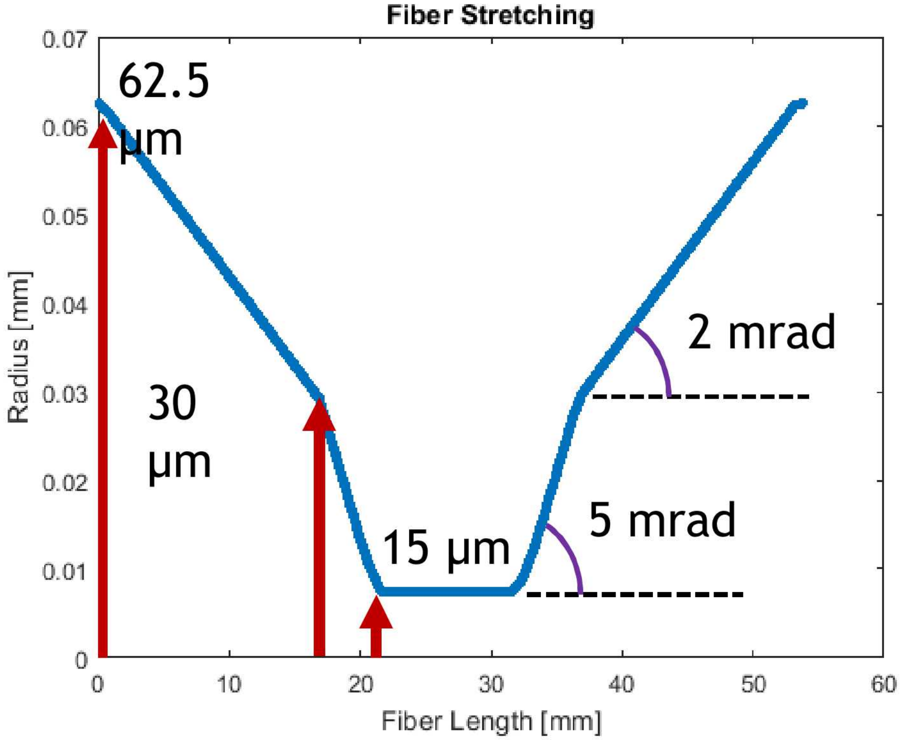




- dipole trap configuration with the magic-wavelength trap of Cs atoms
- Atoms confined in 2-D: azimuthal and radial confinement
- Free axis is along fiber axis
- $P_{938nm}$ = 2.5mW, $P_{685nm}$ = 25mW, $U_{trap}$ = -435μK

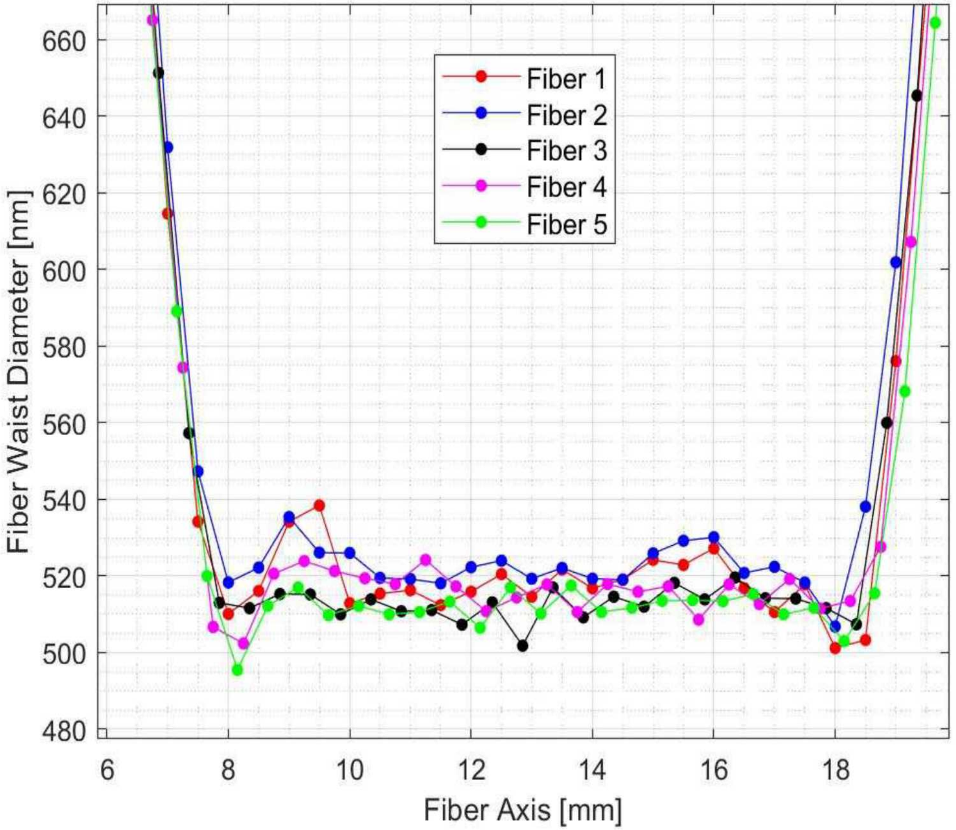
# Nanofiber Manufacturing at Sandia

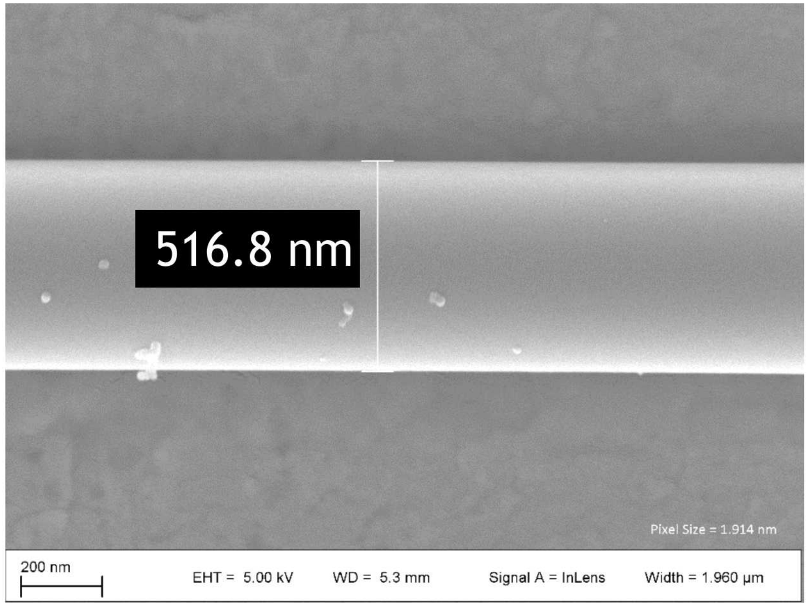




# Nanofiber Manufacturing at Sandia



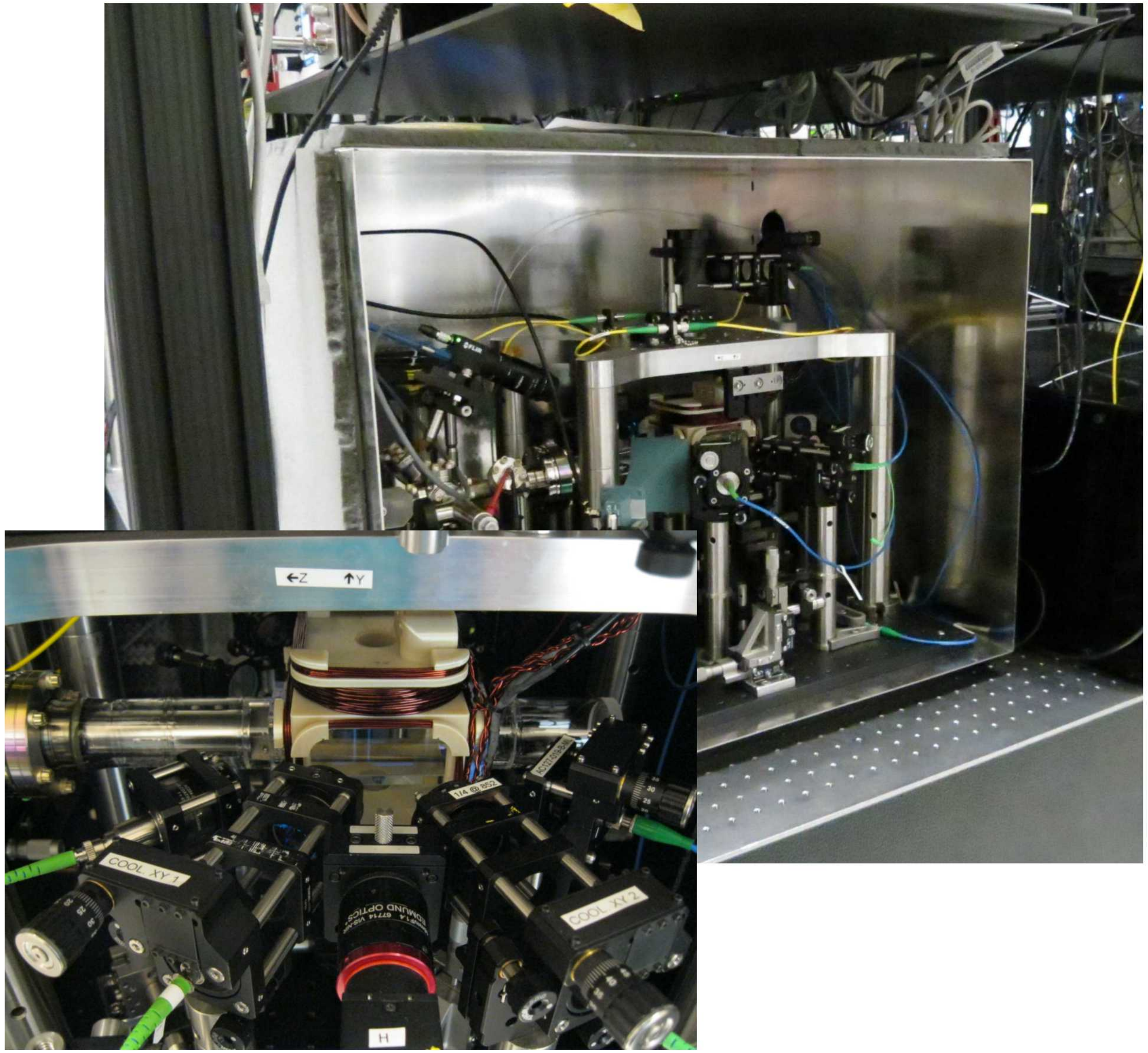




| Fiber | Mean [nm] | STD [nm] |
|---|---|---|
| 1 | 518 | 9 |
| 2 | 522 | 6 |
| 3 | 512 | 4 |
| 4 | 516 | 6 |
| 5 | 512 | 5 |

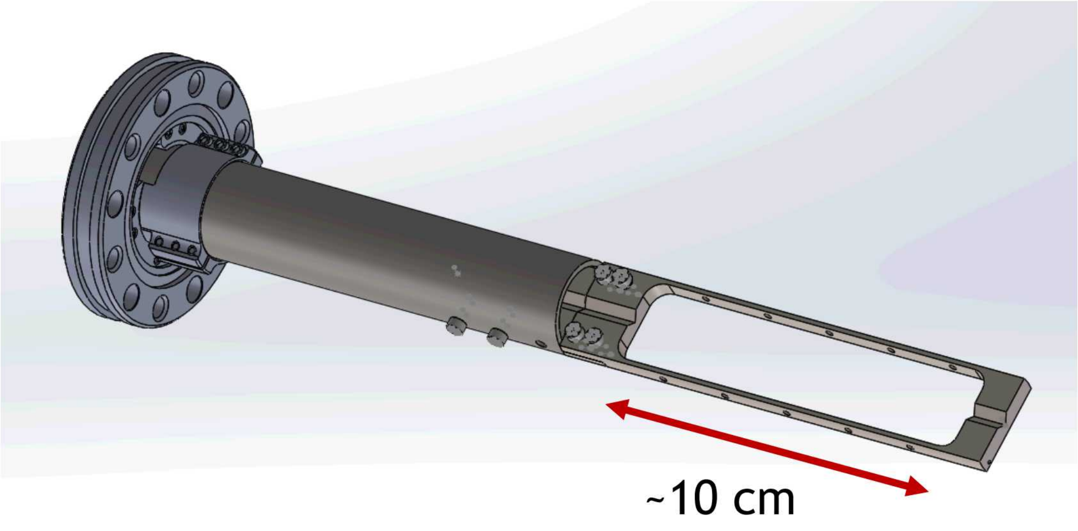
- Target diameter: 500 nm
- Five samples show the repeatability of fiber production

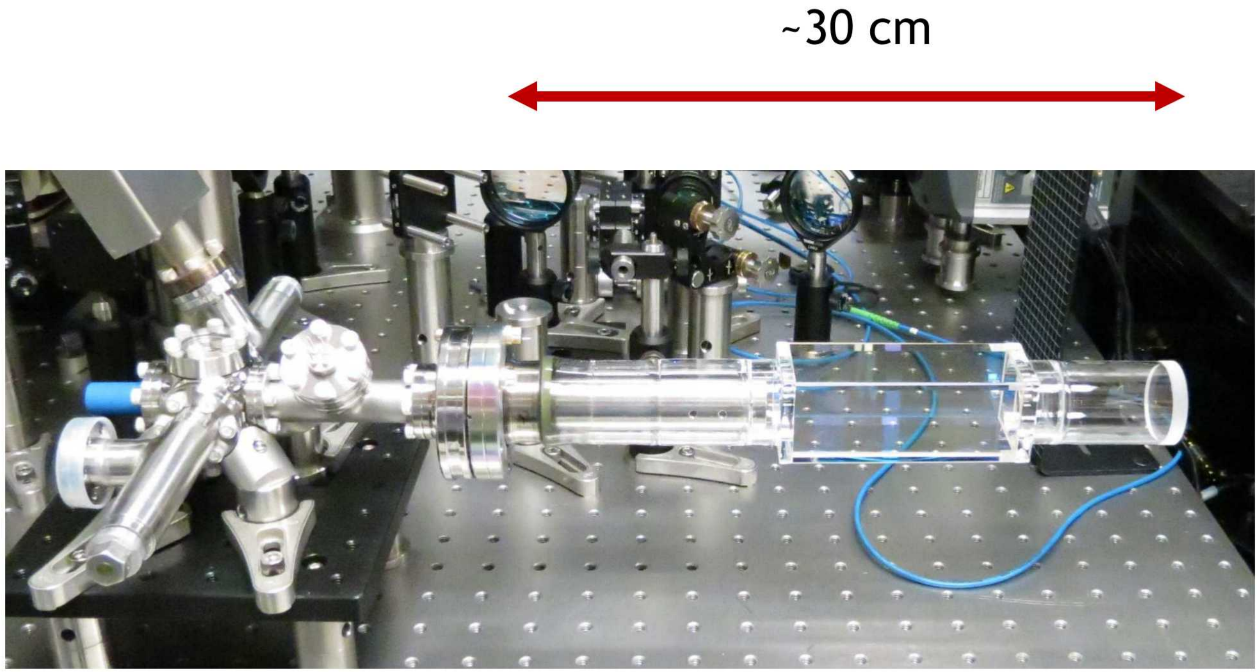
# Experimental Apparatus

- Retroreflected MOT beams reduces complexity
- Enclosed in mu-metal magnetic shield
- Enclosure is about 2' cubed
- Orthogonal cameras used for setting trap beam polarization
- 5 L/s ion pump maintains ultra-high vacuum pressure (~$10^{-9}$ Torr)



# Modifications in the past year: Extended Cell and custom fiber mount

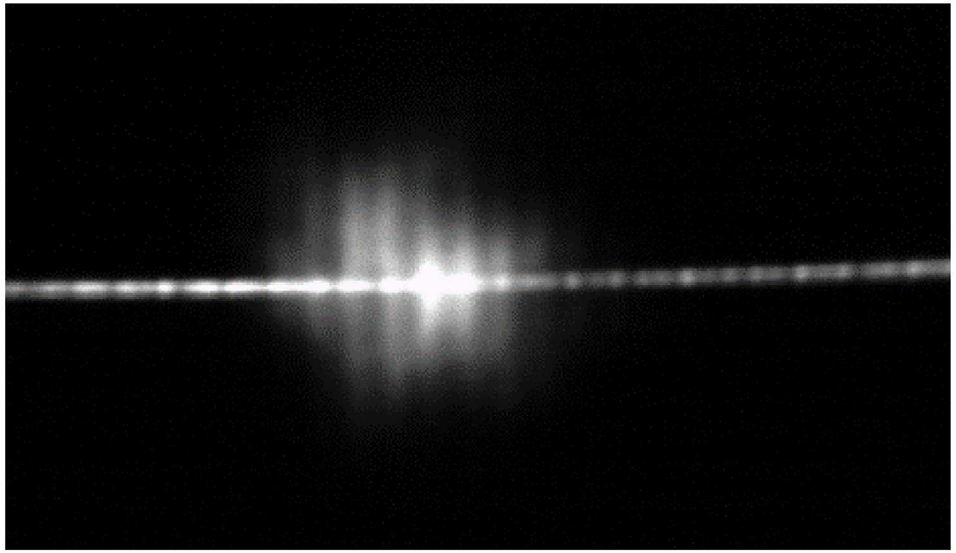


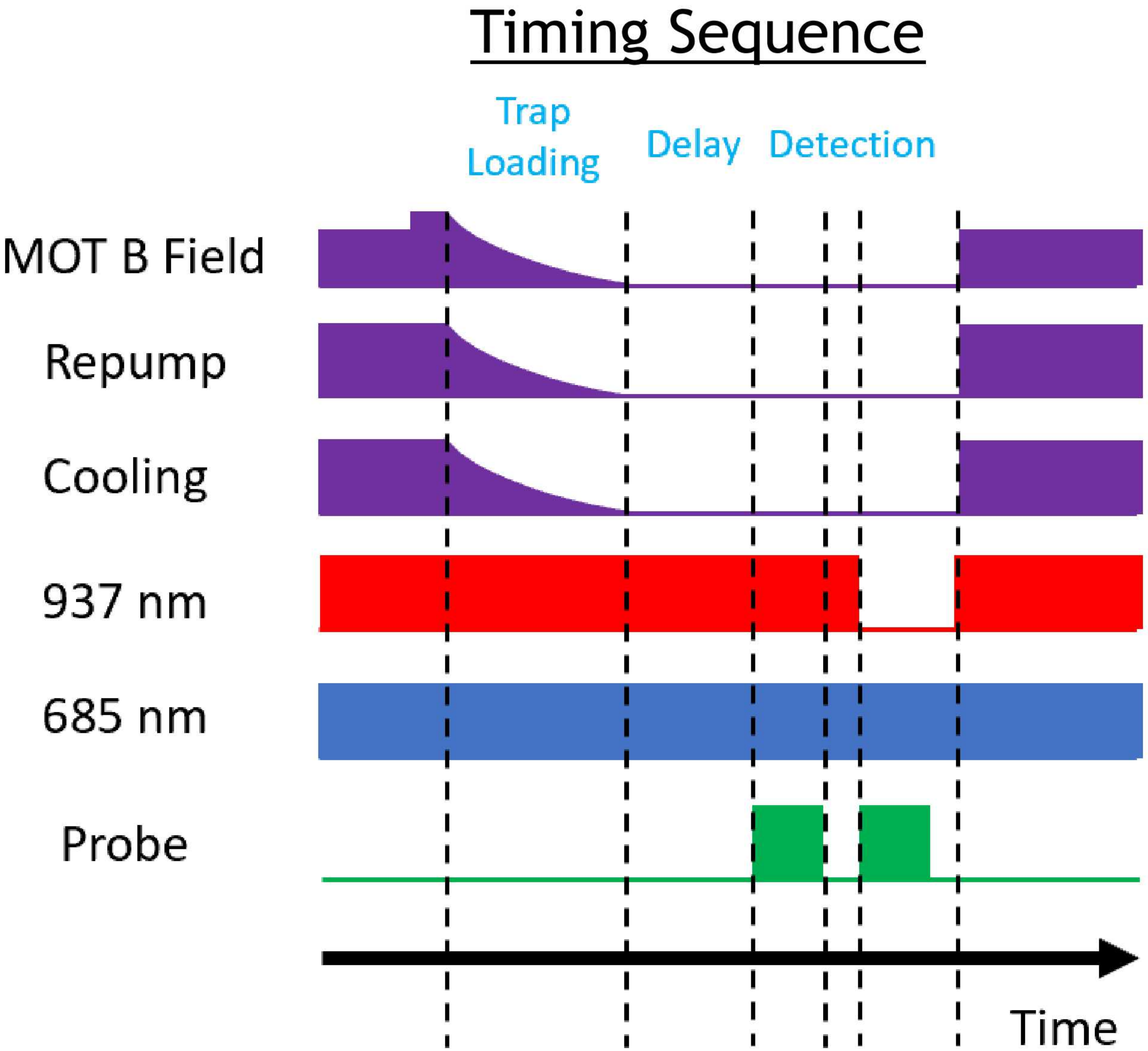




- 3d printed titanium alloy
  - Sturdy rigid design reduces vibrations
  - High resistivity → quickly dissipates eddy currents
- Longer mount → adiabatic mode transfer increases transmission efficiency
- Allows greater fiber bend radius reducing radiative loss and extending fiber lifetime

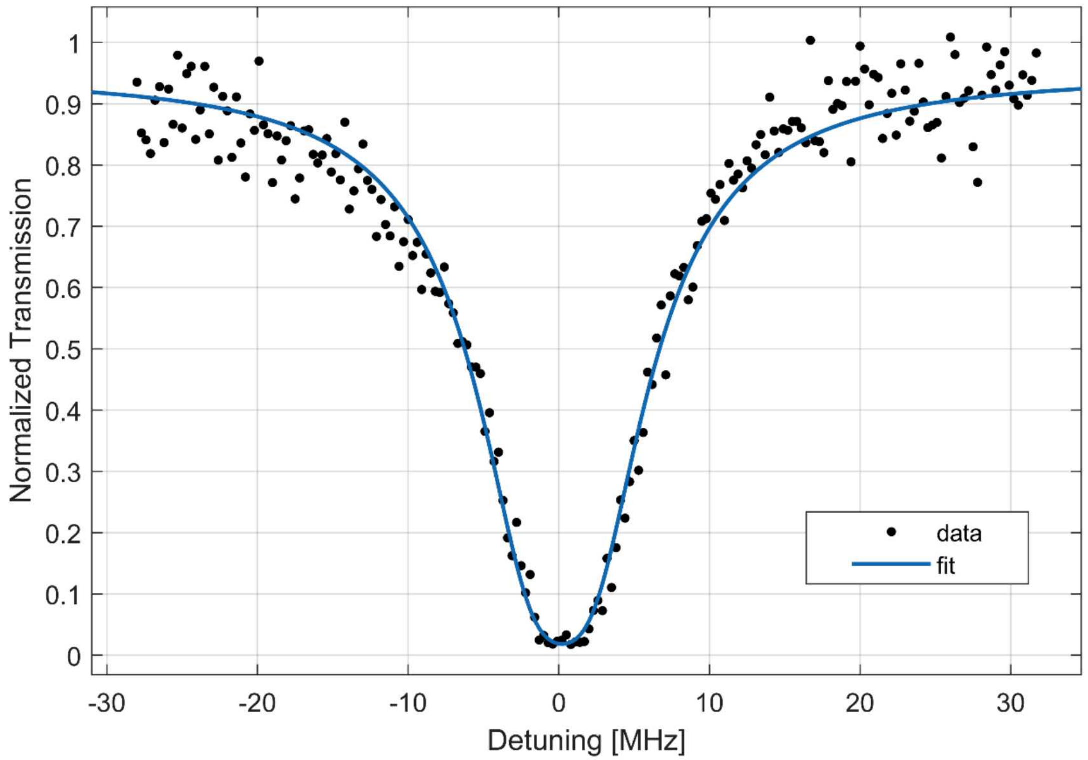
# Trap Sequence

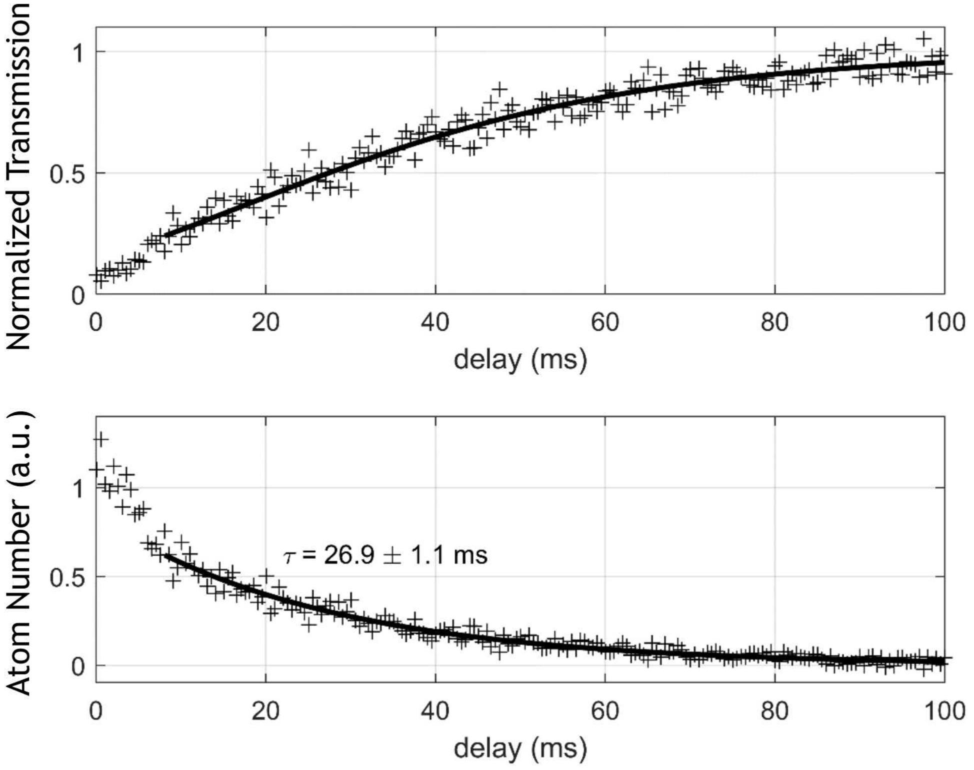
- Overlap MOT (~10^6 atoms) with nanofiber and optimize position using absorption measurement
- Perform timing sequence using LabVIEW control software





# Transmission Signal




- $OD_N = 3.95$, $OD_1 = 0.078$
- Trapped atom number = 50
- Trap depth = -435uK, $P_{Probe; 852nm}$ = 30pW (Cs atoms)
- Estimated MOT atom number ~ $5 \times 10^6$ and its temperature = 28μK

# Light Pulse Atom Interferometry

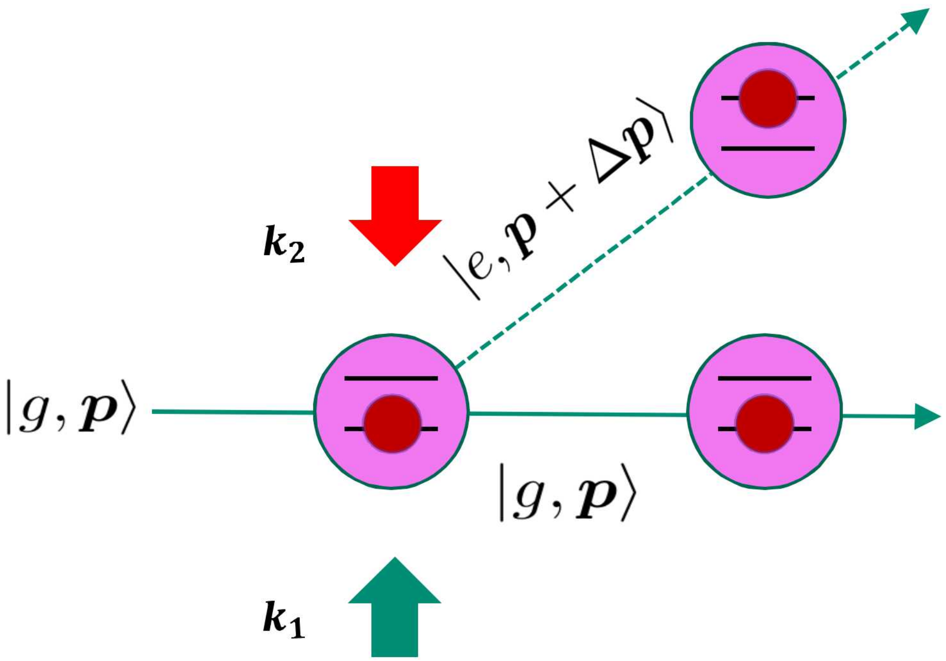
# Optical Trap design for atom interferometry

- Requirements
  - Long nanofiber section for measurement axis
  - 1 cm allows ~45 ms of freefall
- Optical guide complications
  - Time-dependent potential due to atom thermal motion leads to dephasing

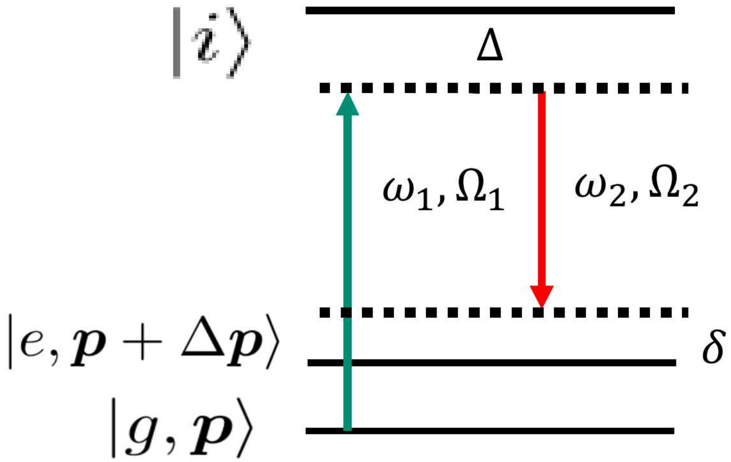
- Magic wavelengths for the D2|F = 4,m=0> to F' manifold ($\lambda = 937\ nm$) and $\lambda = 685\ nm$)

# Controlling Atomic trajectories with Raman pulses

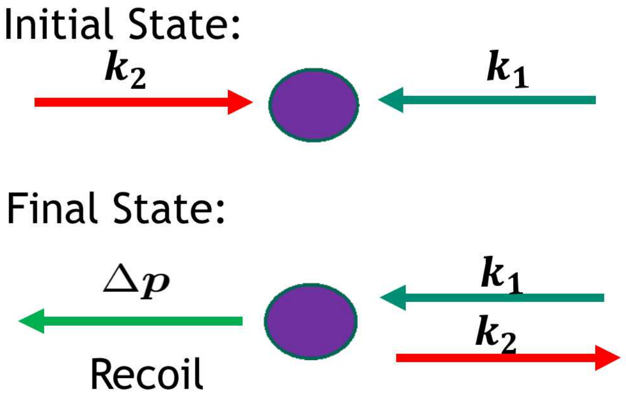
Atom Beam Splitter: $\frac{\pi}{2}$ Pulse




Stimulated Raman Transition



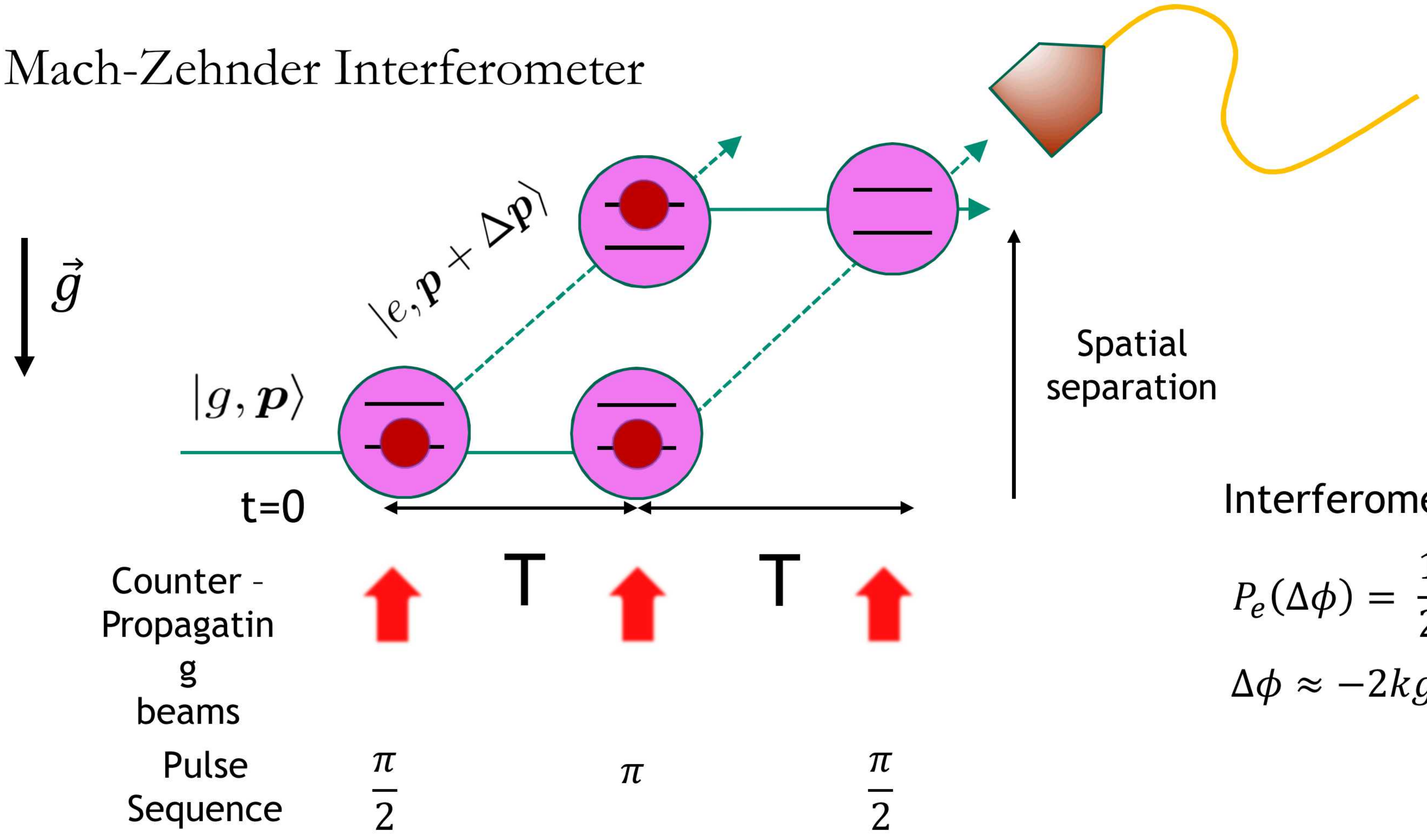

Momentum Conservation




$v_{rec} \sim \frac{mm}{s}$

# Detecting Gravitational Acceleration with Light Pulse Atom Interferometry

## Atomic Mach-Zehnder Interferometer



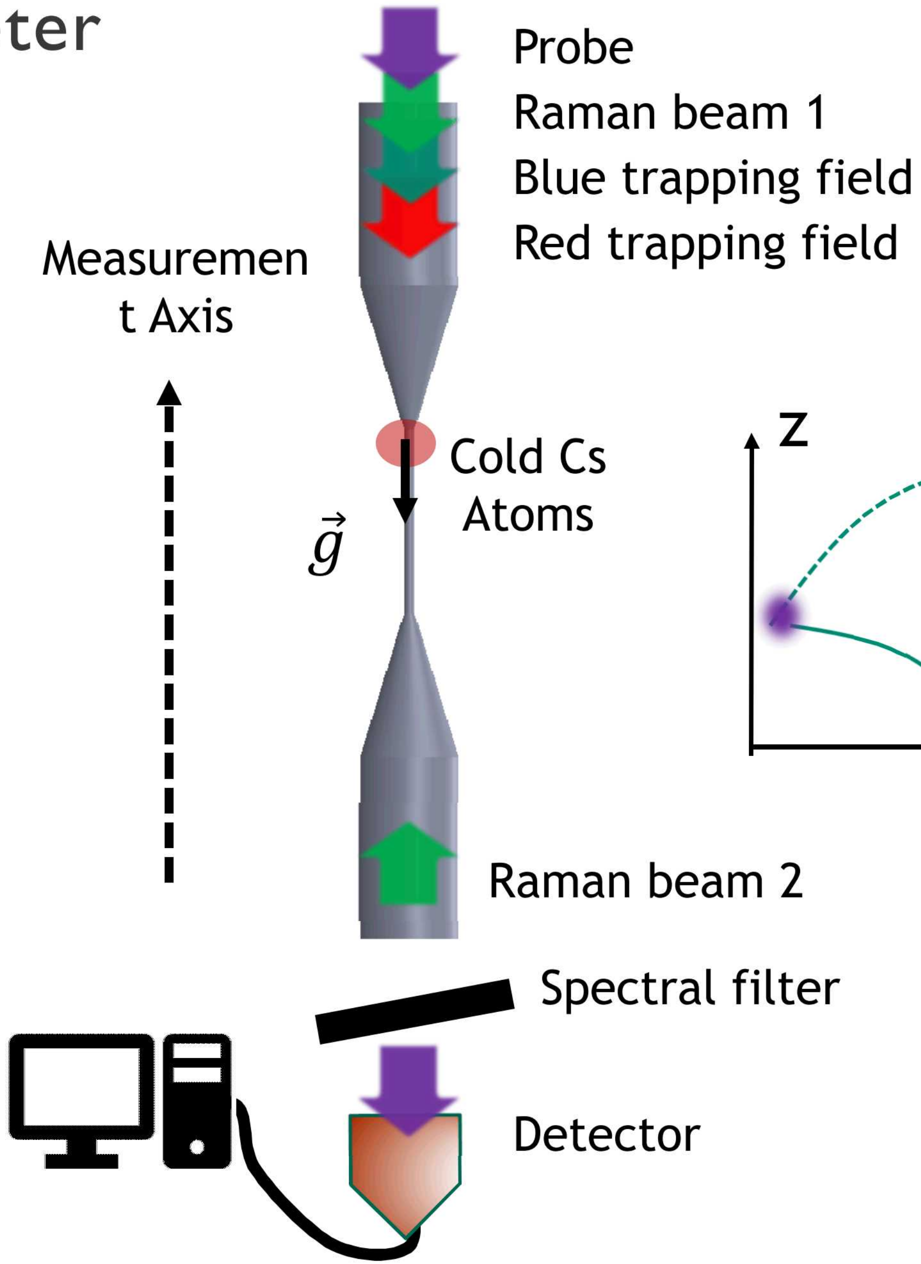

Interferometer Phase Shift

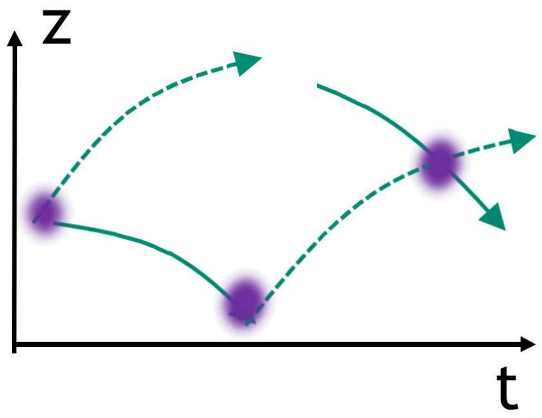
$$P_e(\Delta\phi) = \frac{1}{2}(1 - \cos(\Delta\phi))$$

$$\Delta\phi \approx -2kgT^2$$

# Nanofiber Atom Interferometer

- All fields are coupled into the nanofiber: trap, probe, and Raman
- Use transmission for readout
- Measurement axis is along fiber axis



## Slide 20

**OA7** Try to make it more clear how the atom inteferometer will work

Orozco, Adrian, 10/23/2019

# Not so future goals

- Drive microwave Rabi oscillations using trapped atoms
  - Measure decoherence time
  - Identify decoherence mechanisms
- Drive Raman transitions
  - Doppler free (co-propagating fields)
  - Doppler sensitive (counterpropagating fields)
- Apply nanofiber based atom cooling
  - Degenerate Raman cooling
  - Raman cooling