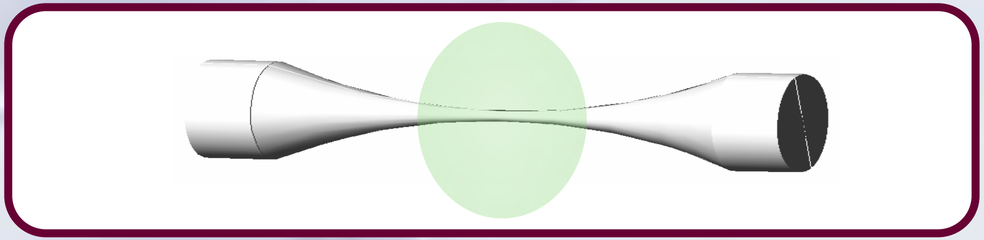
Atomic absorption from the evanescent field of a sub-micron fibre taper



M. Morrissey[1,2], K. Deasy[1,2], T. Bandi[1,2], J. Ward[1,2], B. Shortt[1,2], S. Nic Chormaic[2,3]

1. Cork Institute of Technology,
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3. University College Cork

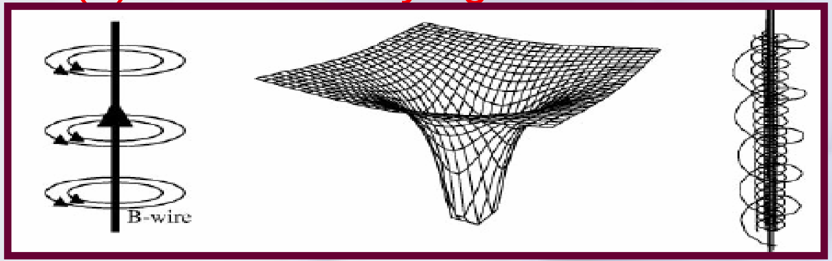
Outline

- Motivation.
- Our aim: two methods.
- State-of-the-art.
- Cold atom experiment.
- Analysis of tapered fibres and their properties.
- Nano-positioning system.
- Future experiments.
- Conclusion.

Motivation: trapping and guiding atoms

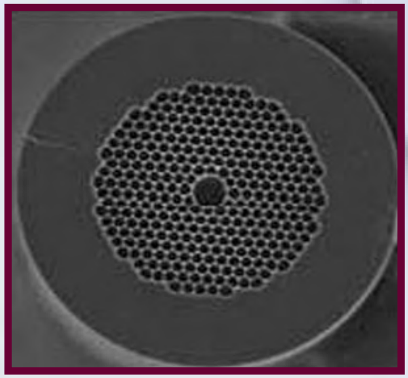
Simplest configuration for trapping and guiding

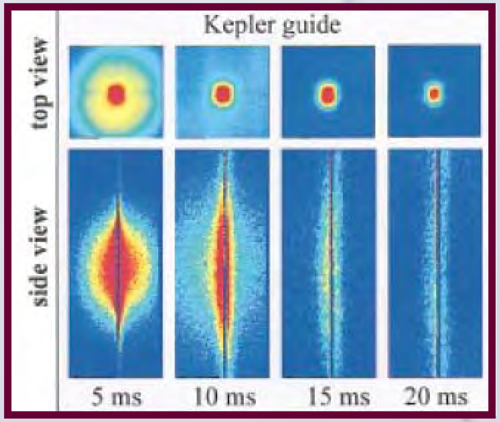
(1) Current carrying metallic wire

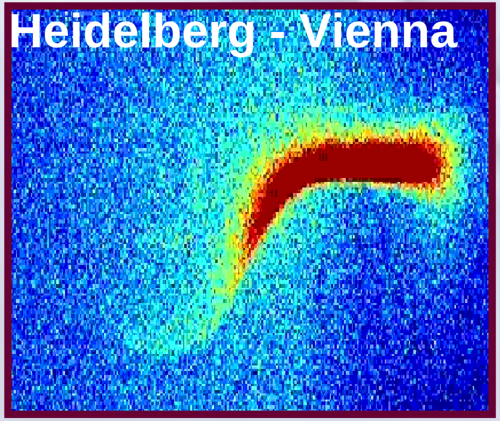


Current carrying wire creates a potential for the atoms to be guided around and along the fibre.

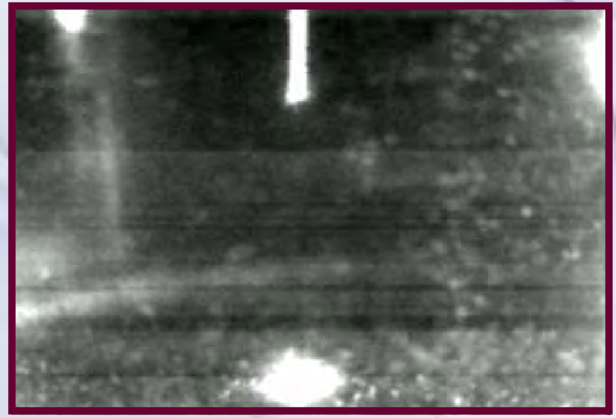
(2) Photonic crystal wire







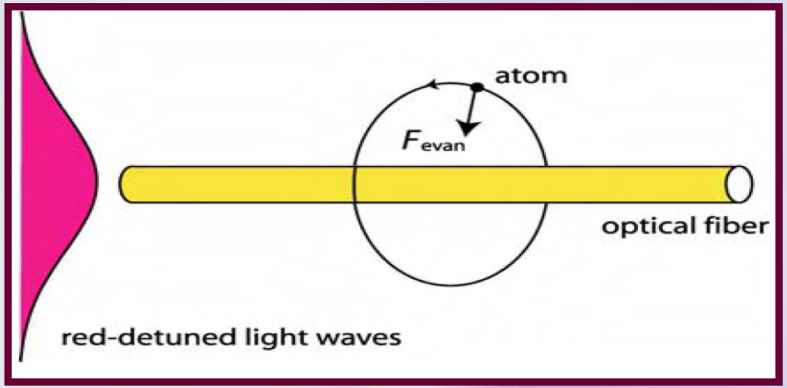
(movie)



(movie)

J. Schmiedmayer

Our aim I: single colour trapping



Attractive force: red detuned light.

Repulsive force: rotational.

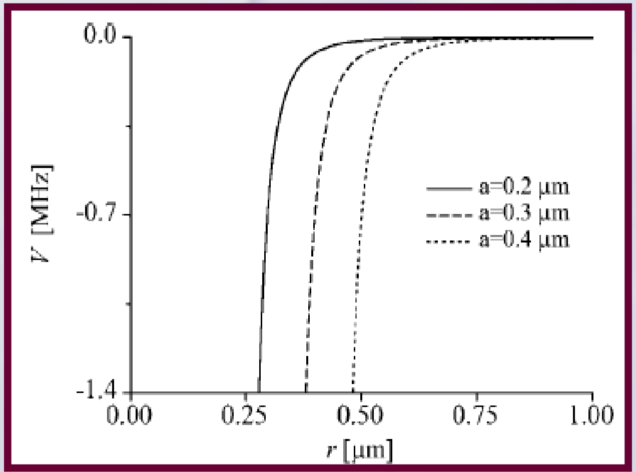
Optical potential: $$U_{red} = -\frac{\hbar \cdot \Omega_0^2}{|\Delta|} K_0^2(qr)$$

Centrifugal barrier: $$U_{ef} = -\frac{\hbar \cdot (m - 1/4)}{2 \cdot M \cdot r^2}$$

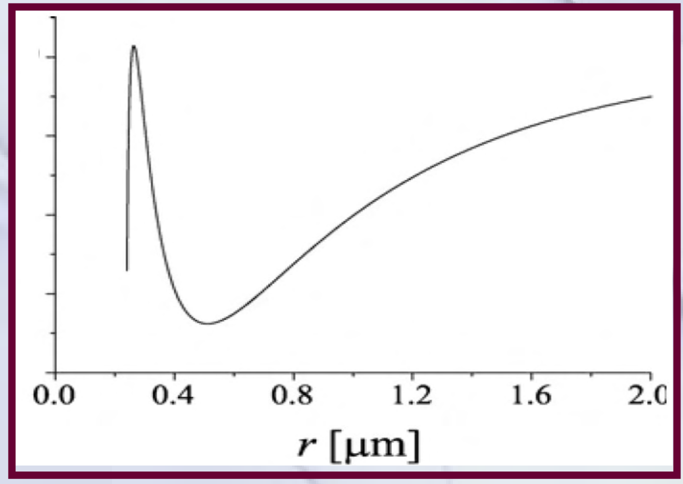
Van der Waals Potential : $$V = -\frac{C_3}{r^3}$$

Total potential: $U_{TOT} = U_{red} + U_{ef} + V$

Van der Waals Force

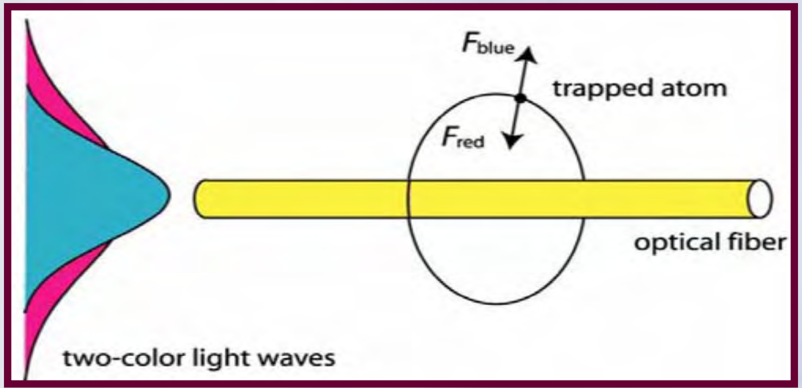


Total Potential



V.I. Balykin, F. Le Kien, Phys. Rev. A 70, 011401 (2004)

Our aim II: two colour trapping



Attractive force: red detuned light.

Repulsive force: blue detuned light.

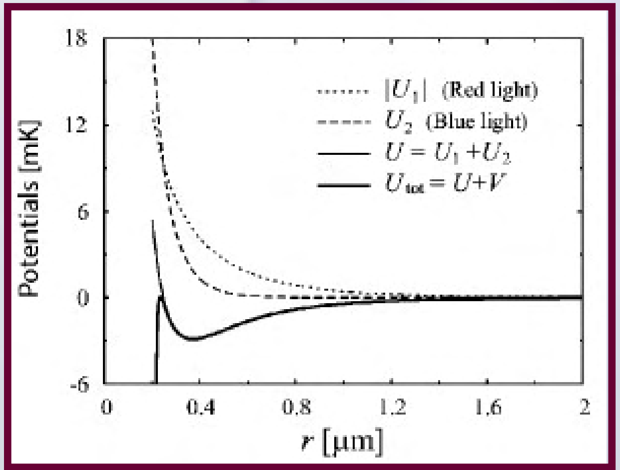
Red detuned light: $U_{red} = -\frac{\hbar \cdot \Omega_r^2}{|\Delta_r|} K_0^2(q_r r)$

Blue detuned light: $U_{blue} = -\frac{\hbar \cdot \Omega_b^2}{\Delta_b} \cdot K_0^2(q_b r)$

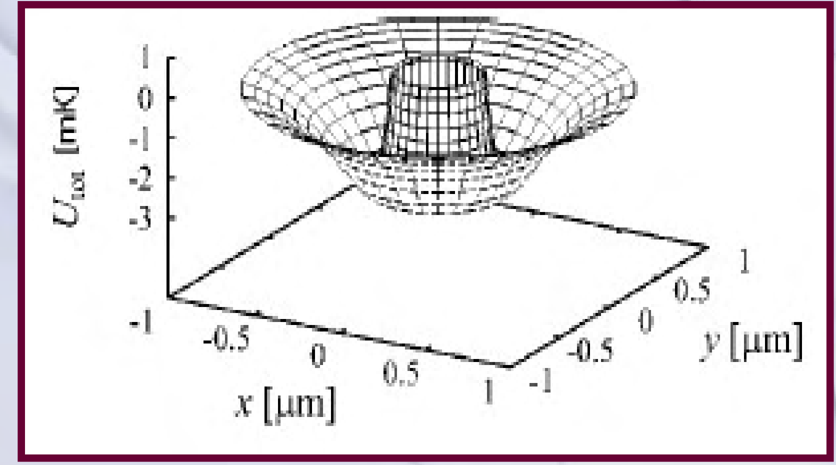
Van der Waals Potential : $V = -\frac{C_3}{r^3}$

Total potential: $U_{TOT} = U_{red} + U_{ef} + V$

Potentials



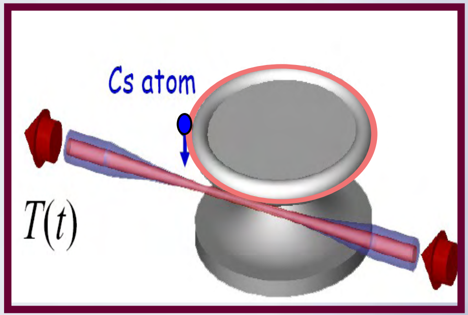
Potential around the fibre



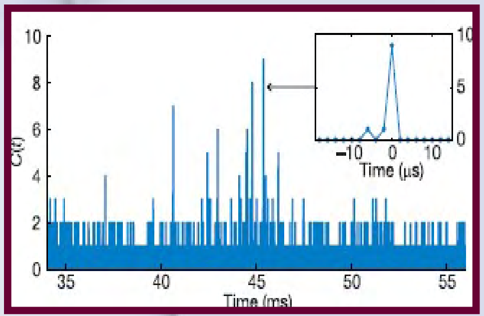
V.I. Balykin & F. Le Kien, Phys. Rev. A 70, 06340 (2004)

State-of-the-art

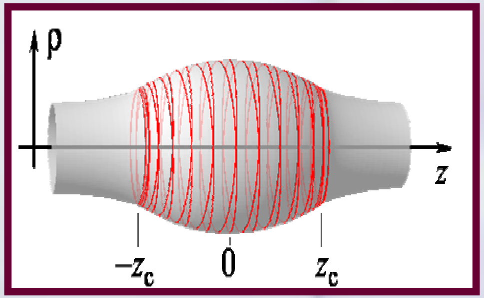
J. Kimble & K. Vahala - Caltech



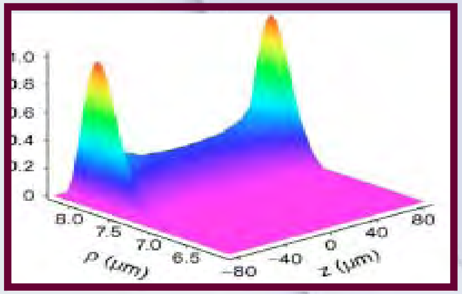
Strong coupling between individual atoms and WGM of microtoroids. Interactions near the surface of the resonator are determined by observing transit events for single atoms falling through evanescent field.



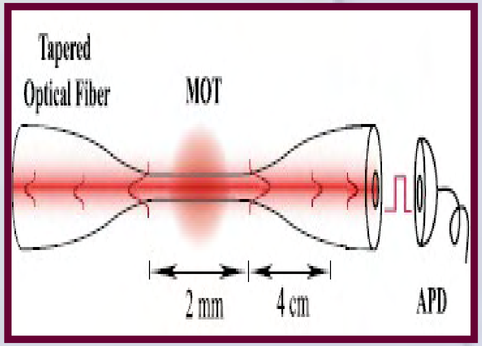
A. Rauschenbeutel & D. Meschede – Bonn/Mainz



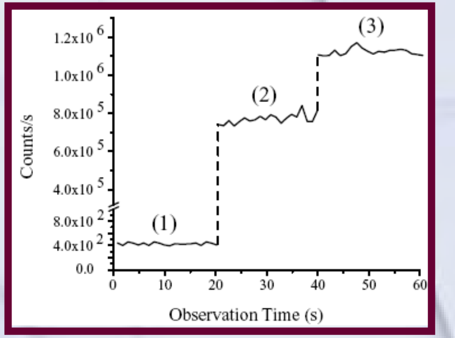
WGM in highly prolate dielectric resonators with a cylindrical symmetry. Such modes exhibit two spatially separate caustics with an enhanced field strength.



F. Le Kien & V. I. Balykin – Tokyo/Moscow



They show that fluorescence photons from atoms around the fibre are measured by observing photons through the fibere guided mode.



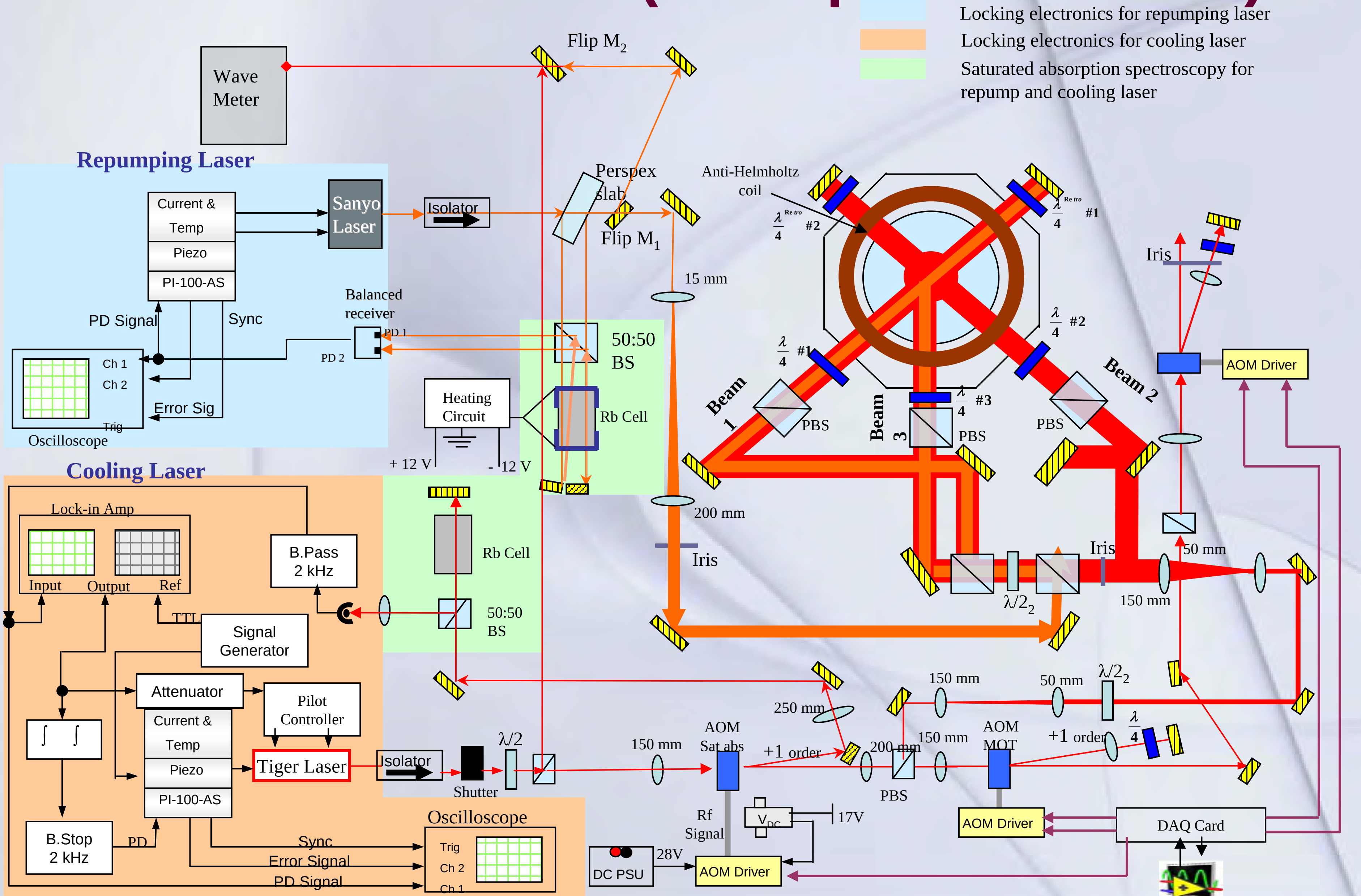
What do we need?

- Cold atom source.
- Tapered fibre with evanescent field.
- Positioning system:
    - Move atoms to fibre (magnetic fields)

      or

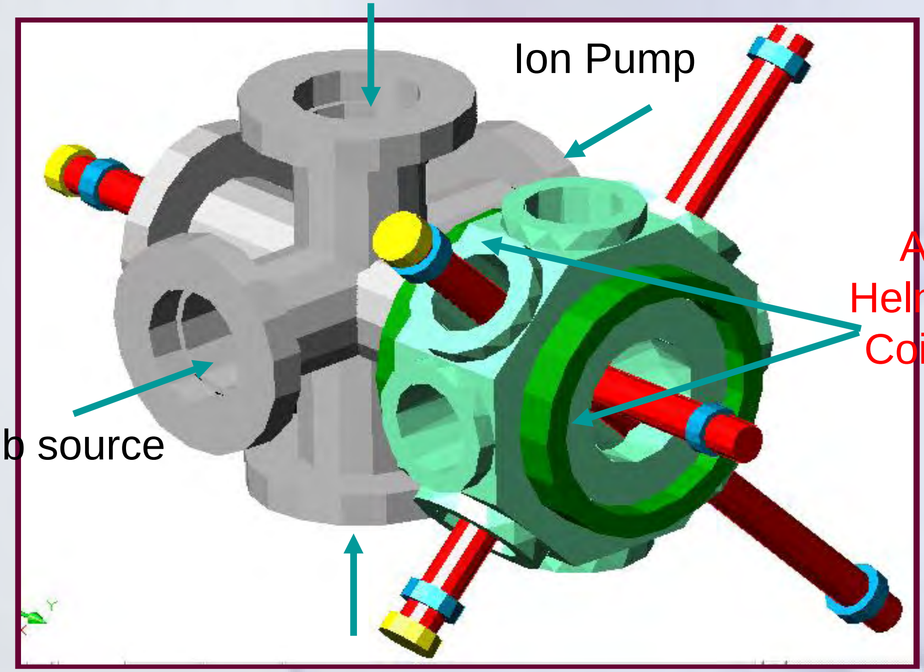
    - Move fibre to atoms (motor).
- Study interaction between evanescent field and atom.

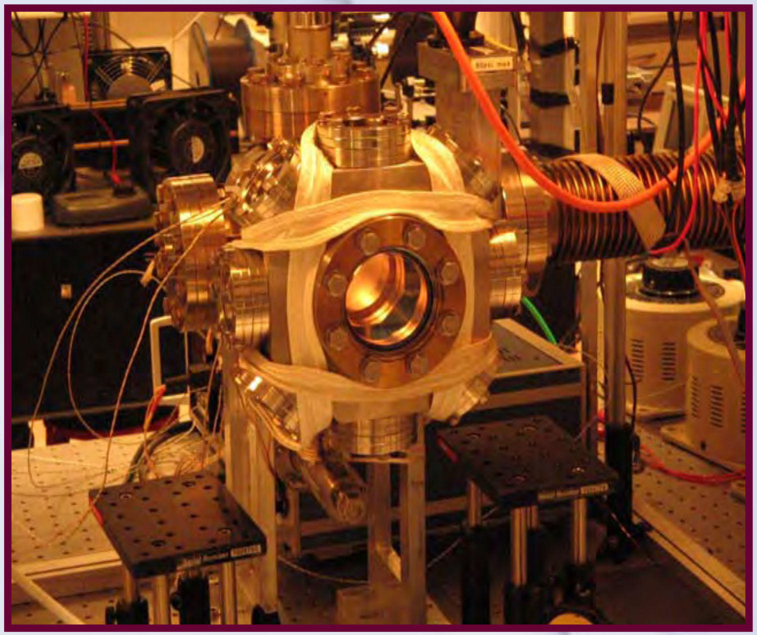
Cold atom source (for experimentalists)



Cold atom source (for theoreticians)

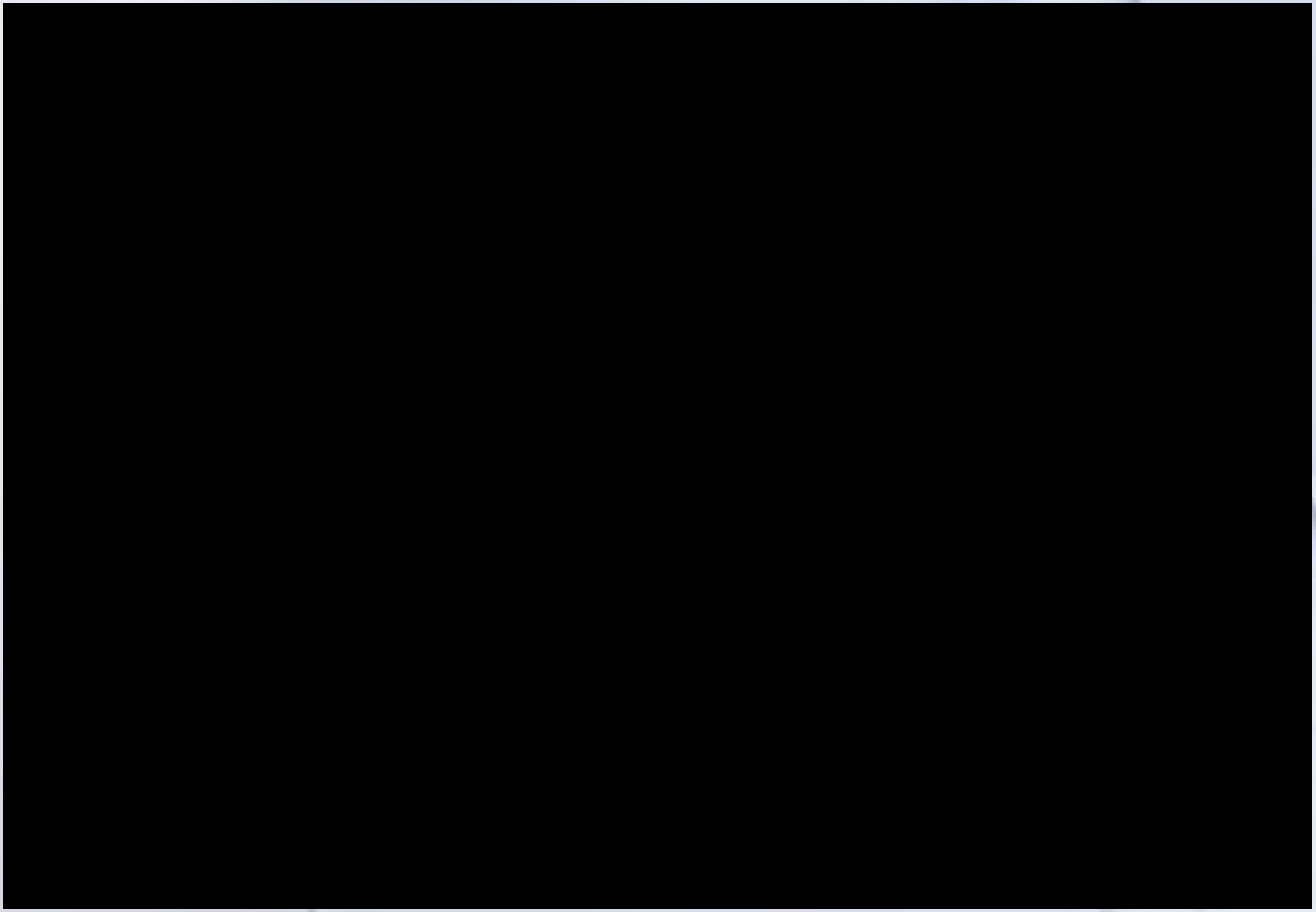
Cold atom source





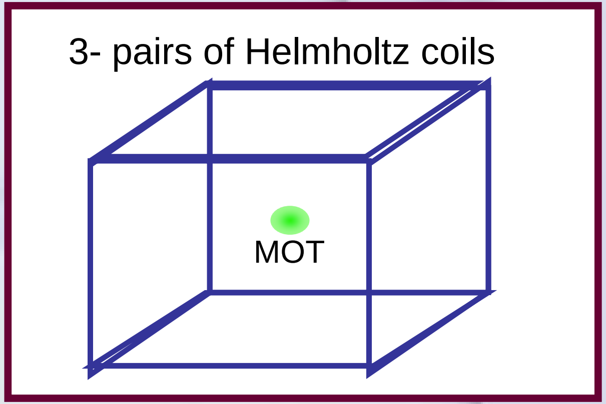
The chamber was flushed with rubidium. The atoms absorb and re-emit the photons from the cooling laser beams

Cold atom movie



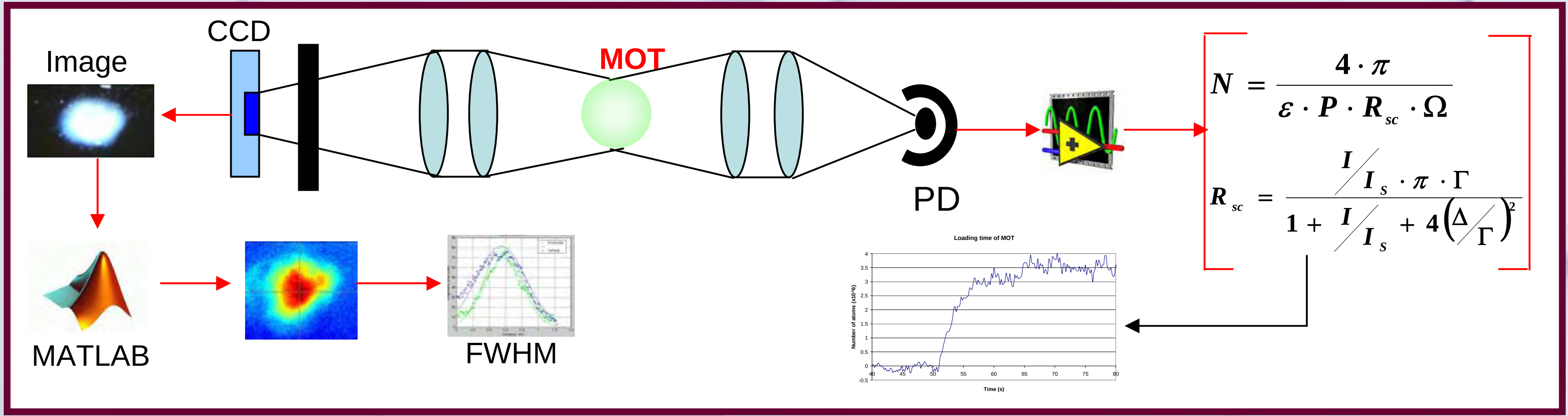
Characterise the MOT

Shape & position: the shape of the atomic cloud is determined by the beam alignment and their overlap with the zero magnetic field. Slight missalignment can be compensated using 3 pairs of Helmholtz coils.



Diameter: the diameter of the MOT is determined from an image focus onto a ccd camera. The FWHM diameter of the intensity cross section is determined.

Number of atoms: the fluorescence from the MOT is measured using a photodiode. From this the number of atoms is calculated.



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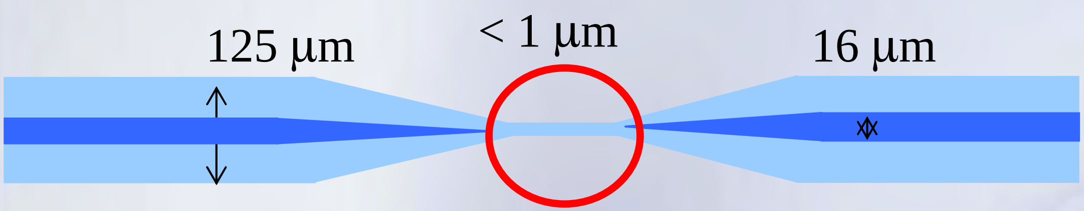
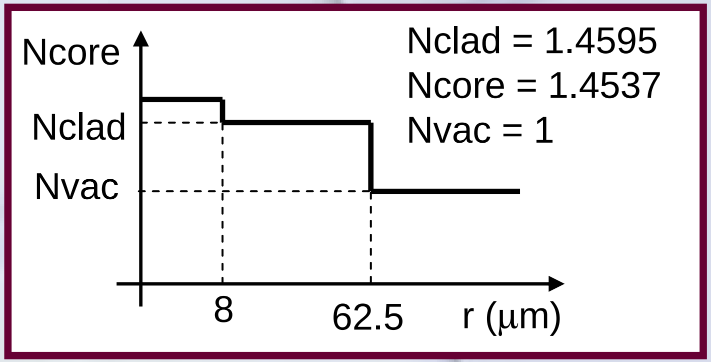
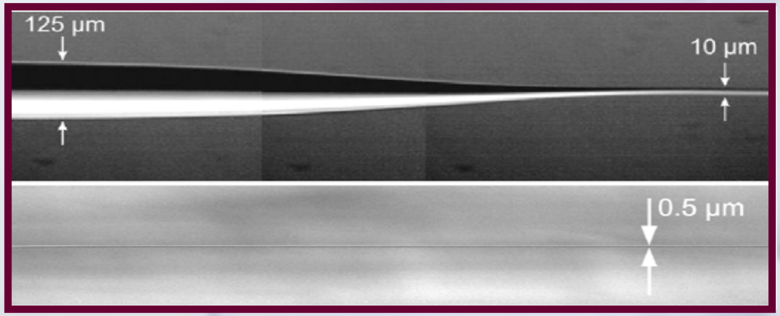
Basic model of a tapered fibre

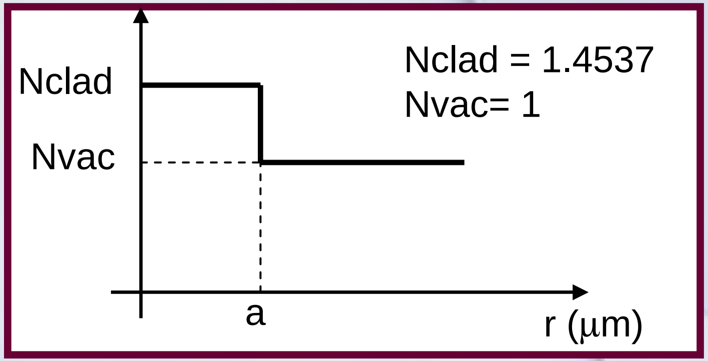


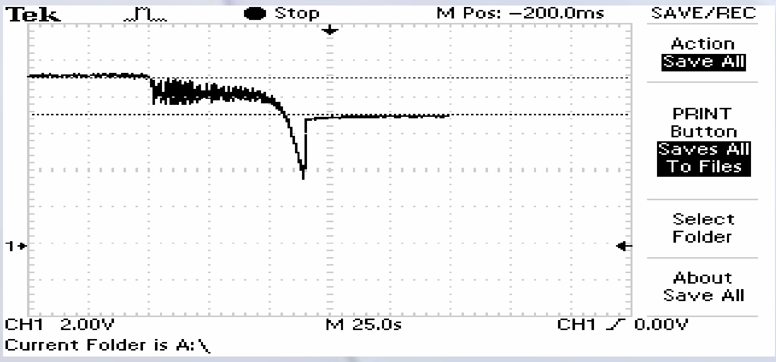
Cladding becomes core,

vacum becomes cladding





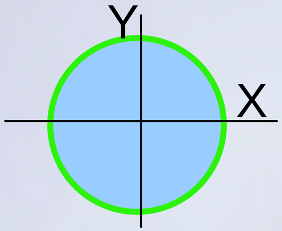


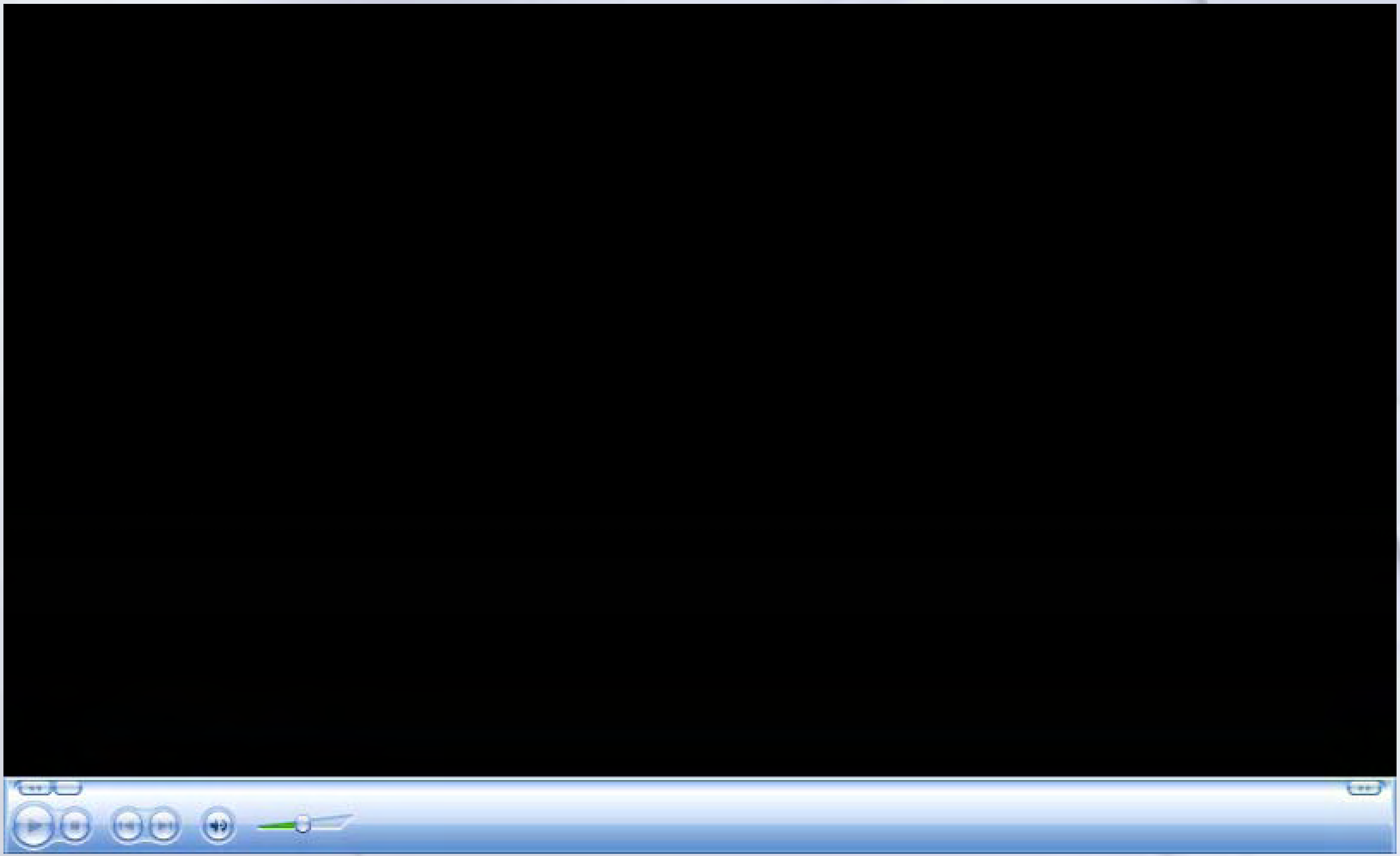


Transmission efficiency:

- Heat source (uniform).
- Tapering angle – pull length.
- Improved by clean air flow.

Intensity profile as a function of radius

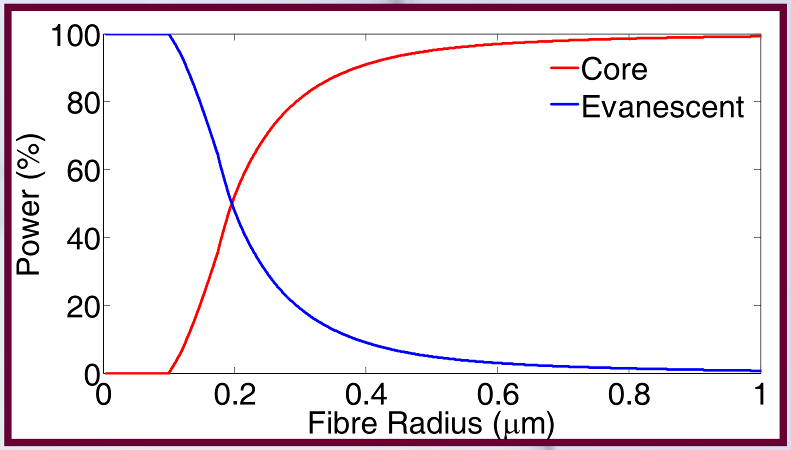


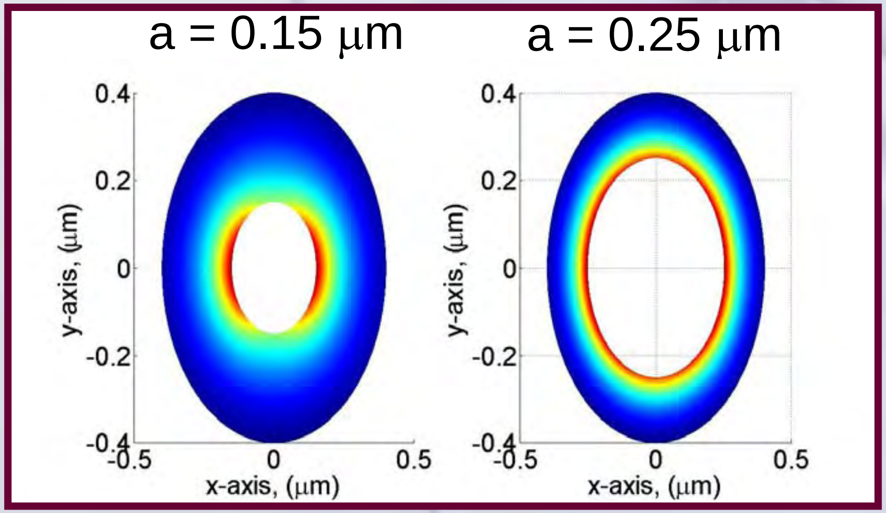


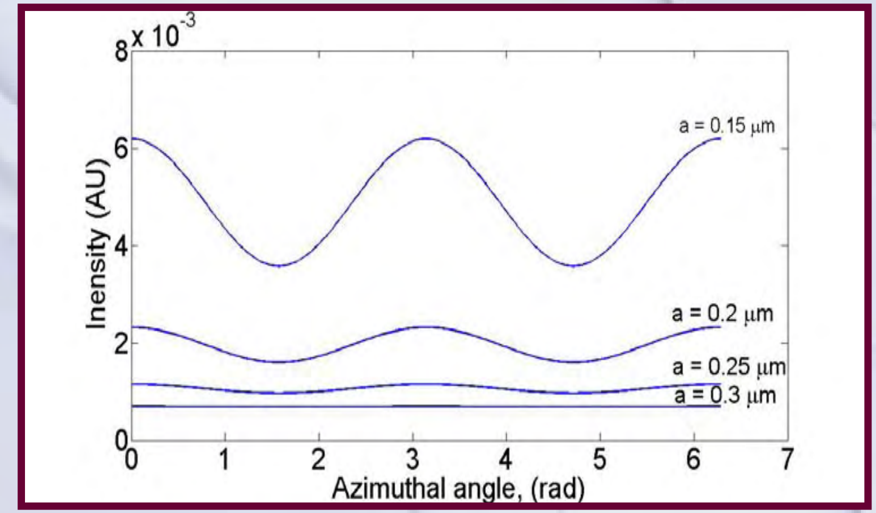
Evanescent field power

It is important to know the amount of power that resides in the core and the evanescent field.

a = 0.5 μm, Ev =5%
a = 0.3 μm, Ev = 20%
a = 0.1 μm, Ev = 100%







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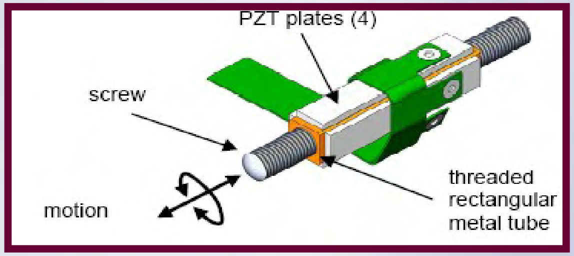
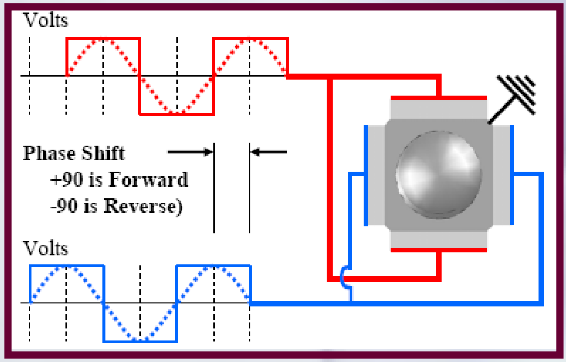
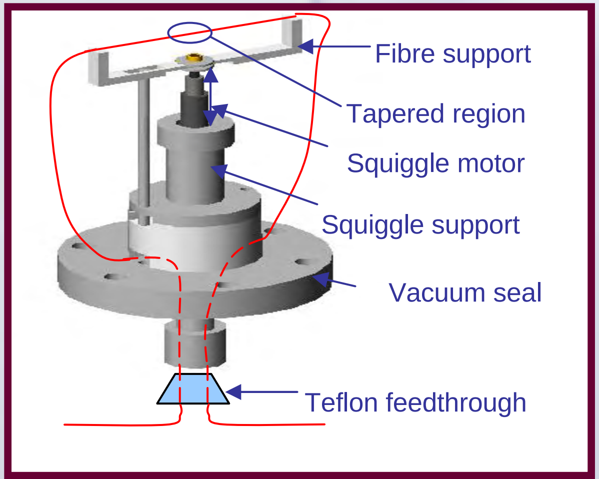
Nano-position fibre control

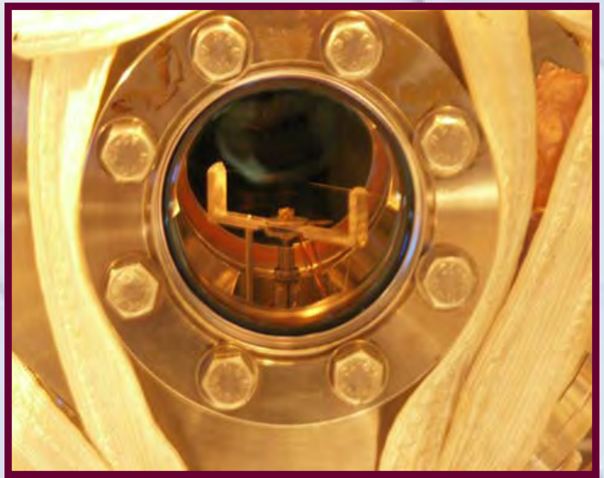




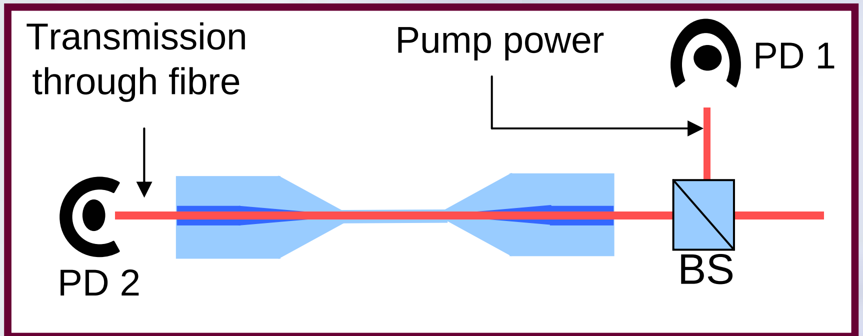
- The squiggle motor uses ultrasonic standing wave vibration in a thread nut to directly rotate a screw.
- The piezoelectric plates are bonded to flat surfaces on the outside of the metal tubing at 90 ° spacing.
- The PZT plates are activated to achieve two phase electric drive with a fixed frequency out of phase by 90°.
- +90° is forward motion, and -90 ° is reverse.

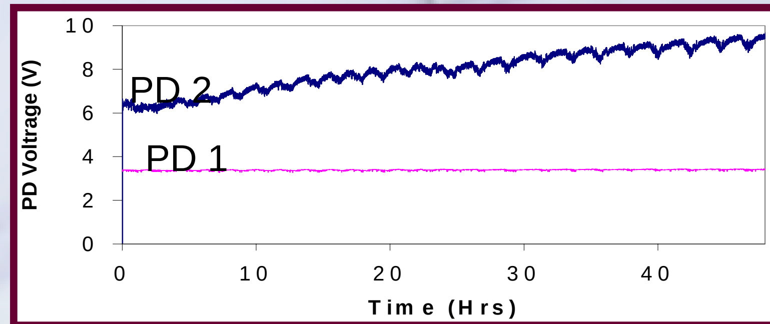


- large travel range.
- miniature.
- nano-scale resolution.
- programmable.
- vacuum compatible



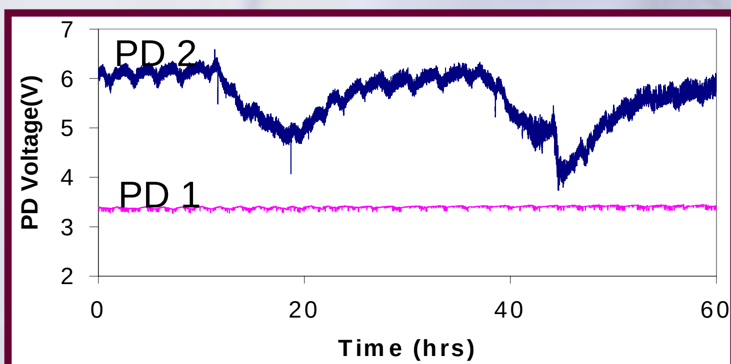
Fibre positioning system in vacuum

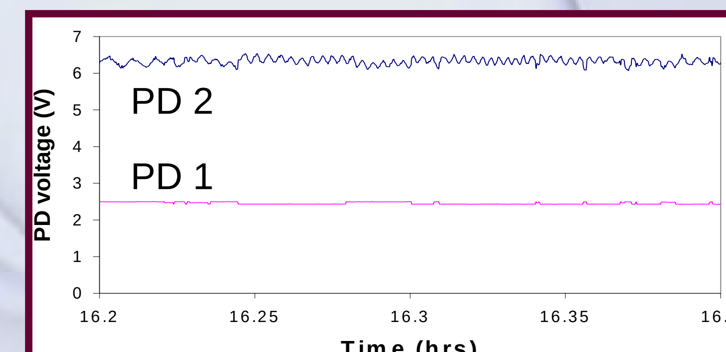




Transmission through the fibre is monitored as a function of pump down and bake-out.

Transmission increases as a function of pump down due to impurities being removed.



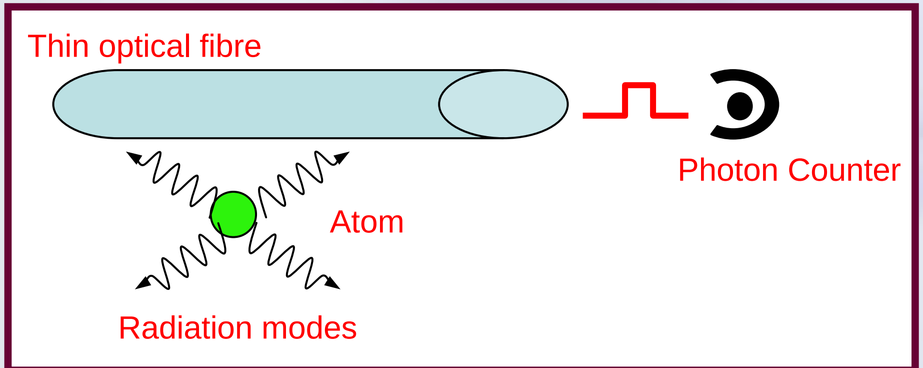


Transmission decreases as a function of bake-out due to out-gassing but recovers once cooled down.

Sustained oscillation in transmission observed when the squiggle motor was operated.

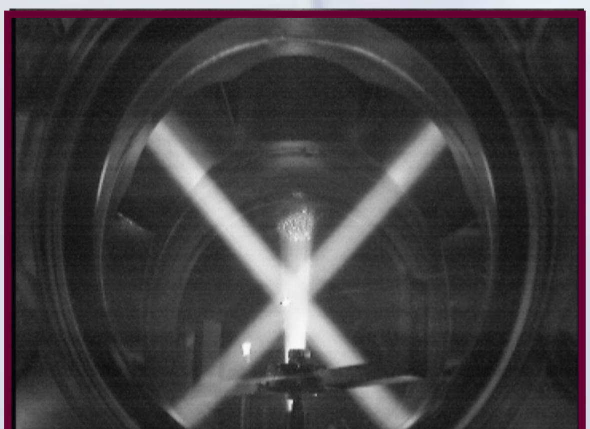
Testing the squiggle motor

Publication: "**Ultrahigh vacuum compatible nanopositing system based on an ultrasonic piezoelectric motor**"



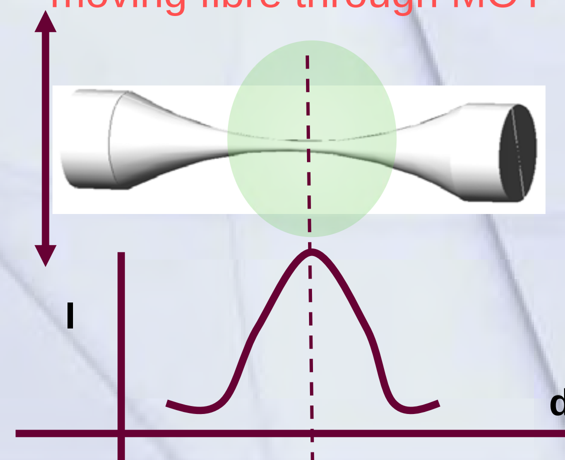
Fluorescence photons emitted into the guided mode are measured through the optical fibre using a photon counting module. Photons are also coupled from the cooling and repump lasers, as well as atomic scattered photons.

$$P_{SCATTERED} = P_{DETECT} - P_{COOLING} - P_{REPUMP} - P_{DARK}$$



The fibre is geometrically overlapped with the atomic cloud by moving the fibre and monitoring its position with two CCD cameras.

Radius measurement by moving fibre through MOT



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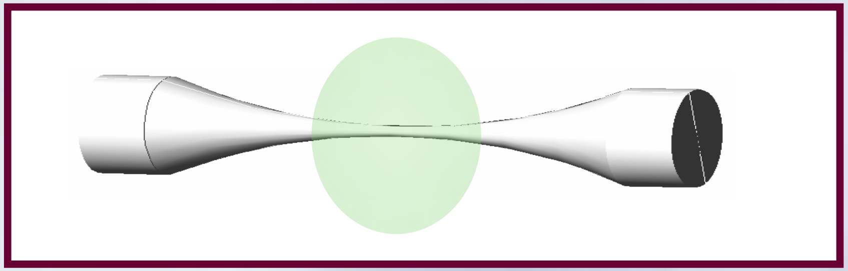
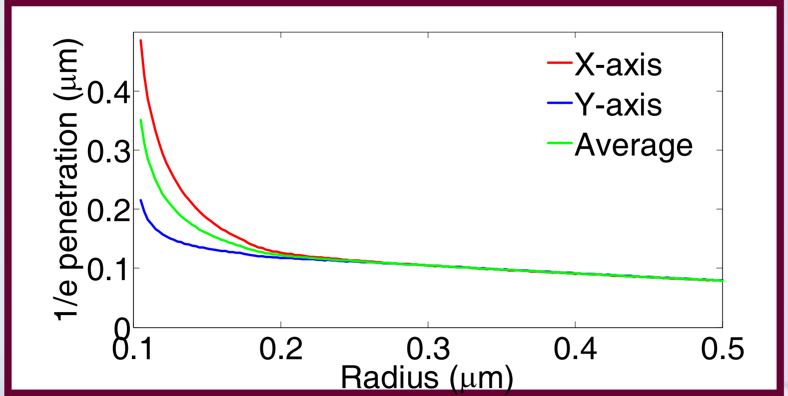
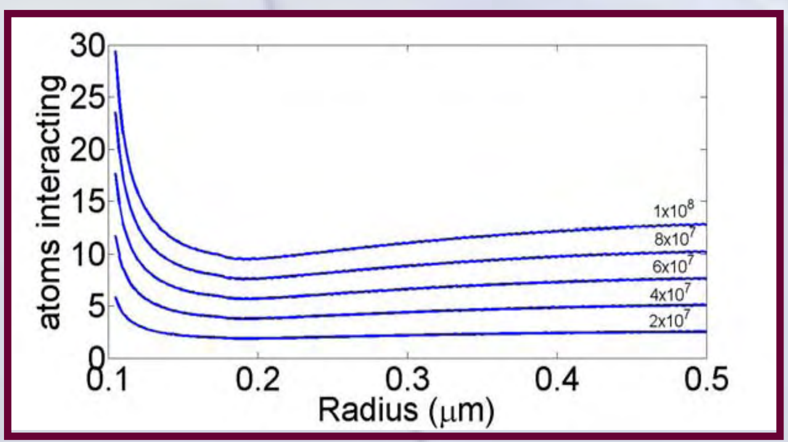
Atoms interacting with evanescent fields



The number of atoms that interact with the evanescent field can be determined by comparing the MOT density with the interaction area.

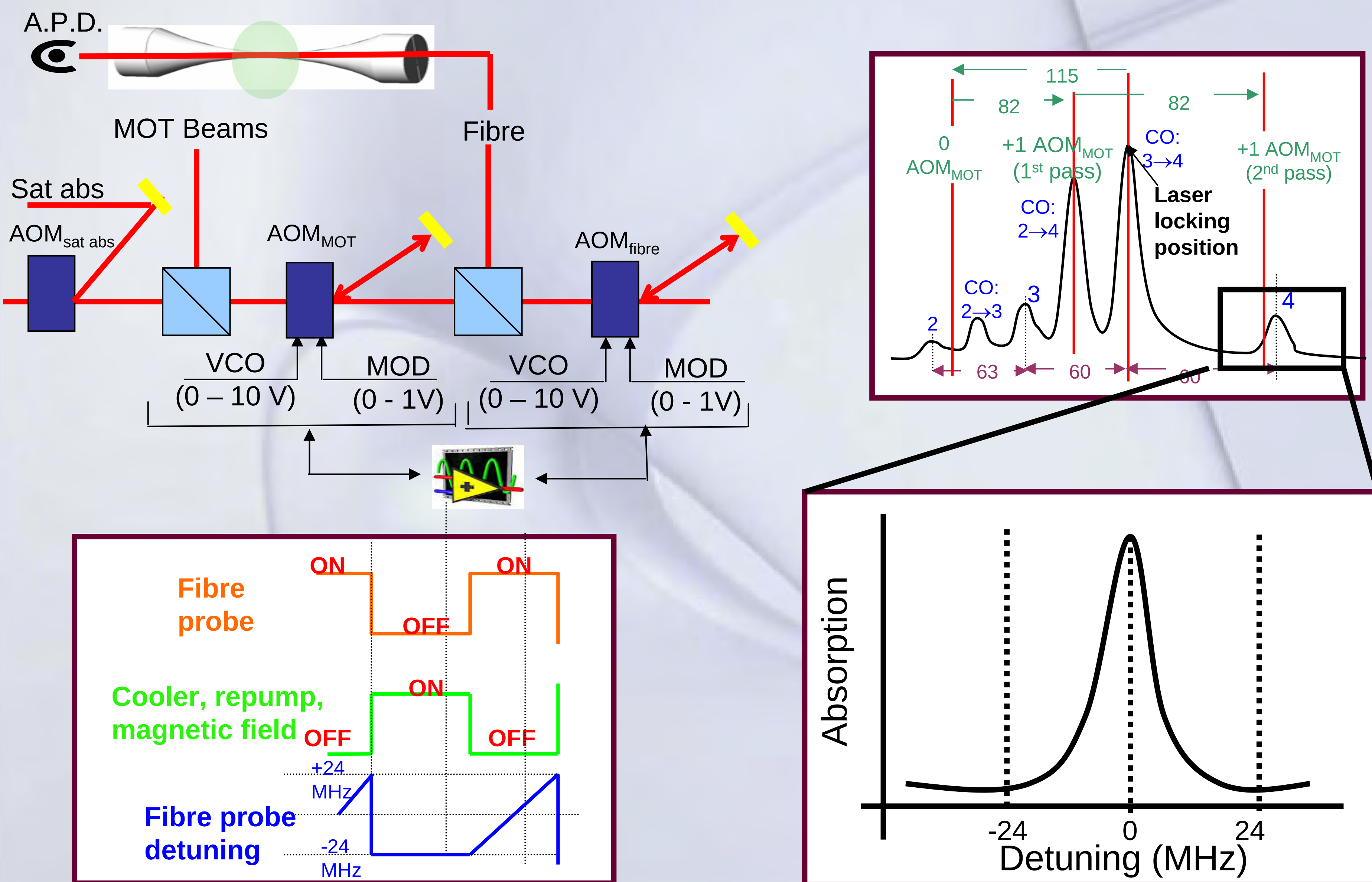
As seen before, the power varies azimuthally around the fibre. This can lead to a variation in the penetration length of the evanescent field. There is no substantial increase in the evanescent field for radii > 0.2 μm





The number of atoms interacting with the evanescent field depends mainly on the density of the atomic cloud rather than the radius of the fibre.

Absorption Experiment



Conclusion

- Outlined long term objective.
- Showed what other groups in the same area are doing.
- Introduced our cold atom experiment.
- Modelled tapered fibres and evanescent field.
- UHV nano-positioning system.
- Future experiments.

Thanks for your attention

Acknowledgements

- This work is supported by Science Foundation Ireland (project number 02/IN1/I28).
- KD acknowledges support from IRCSET (Irish Research Council for Science, Engineering and Technology) through the Embark Initiative.