SWINBURNE

CENTRE FOR ATOM OPTICS AND ULTRAFAST SPECTROSCOPY

AUSTRALIAN RESEARCH COUNCIL CENTRE OF EXCELLENCE FOR QUANTUM-ATOM OPTICS

Magnetic field topology with ultra-cold atoms

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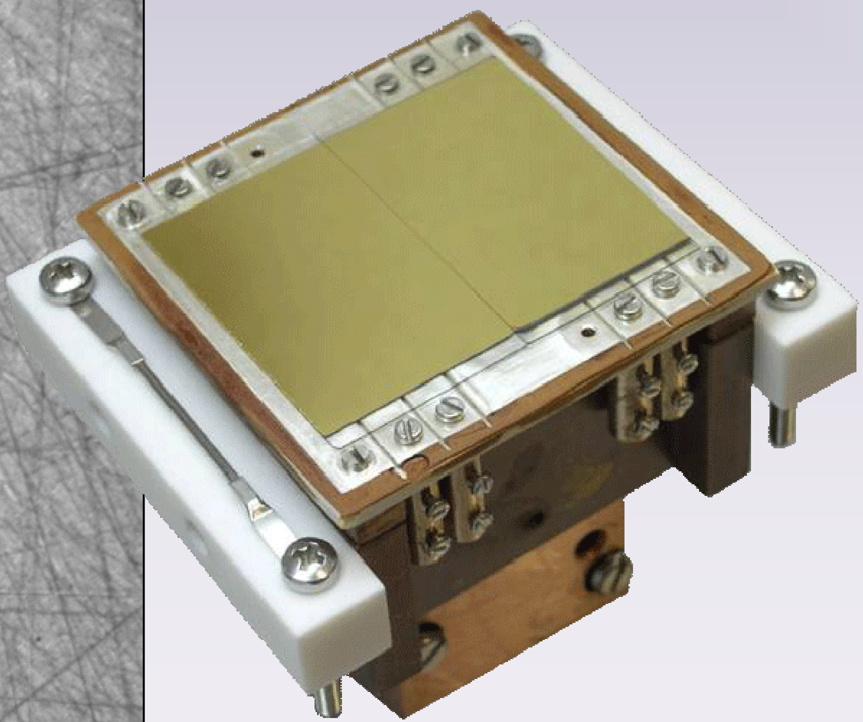


» Atom chips and BEC » »

Advantages of using atom chips

Tight, stable and small trapping potentials.

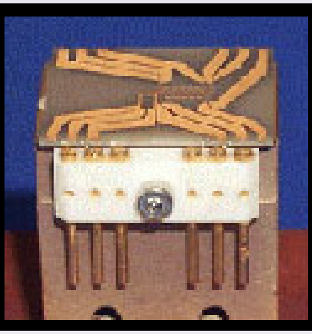
- High elastic collision rates for evaporative cooling.
- 1 dimensional physics, (*Lamb-Dicke regime, Tonks-Giradeau regime)*
- Small structures of order λ_{DB},(*tunnelling, quantum reflection, Josephson oscillation, Anderson localisation, etc)*

Interactions with surfaces.

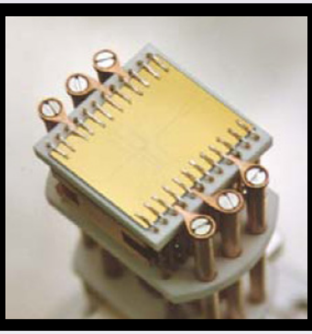
- Precise control over cloud position, *surface tomography, magnetometry.*
- Casmir Polder interactions.
- Mechanisms for decoherence, *coupling to environment, atom loss, heating, etc…*

Integrated atom optics. *Waveguides, beam splitters, interferometers, atom sources, detection*

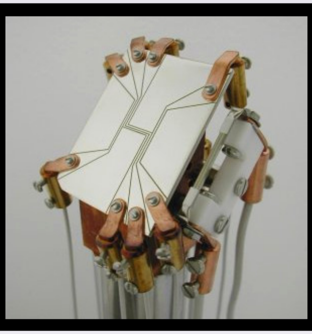
Active BEC on a chip experiments currently include: *Munich, Tubingen, Heidelberg, London, Stanford, Boston, Paris/Orsay, Boulder, Brisbane, Swinburne, Tokyo, Toronto ….*



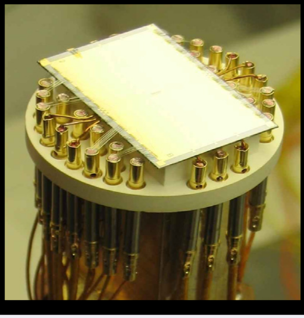
MPQ (1999)



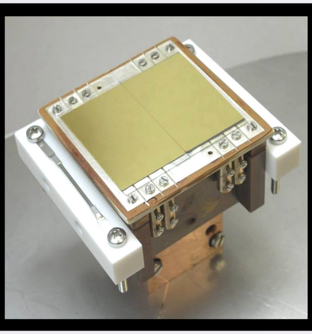
Universität Heidelberg (2002)



University of Queensland (2004)



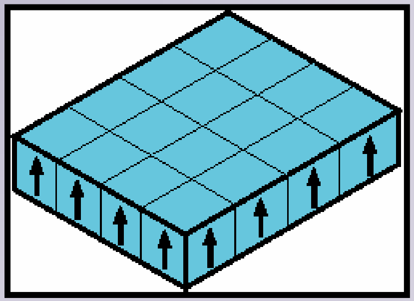
Universiteit van Amsterdam (2005)

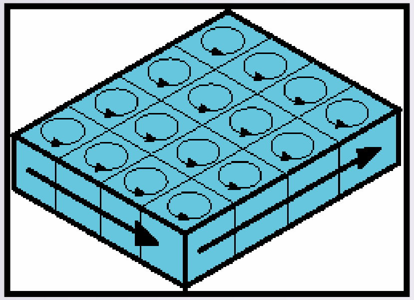


Swinburne University (2005)

» The Swinburne atom chip » »

How to trap using permanent magnetic films ?

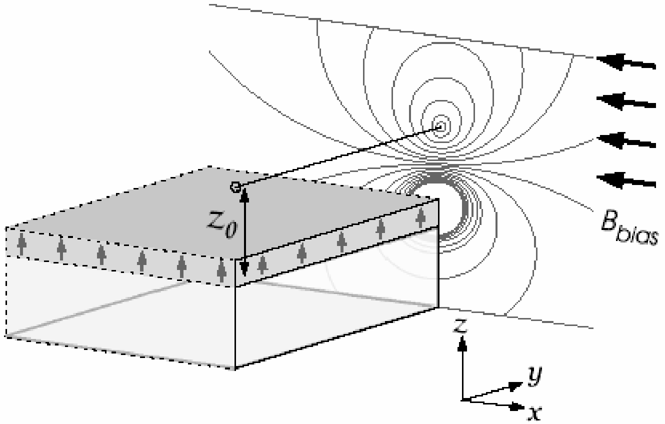




Remanent magnetisation M

Perimeter current I_{eff}

$M \times h$ is an "effective current" I_{eff}



Our films $I_{eff} = 0.2$ A

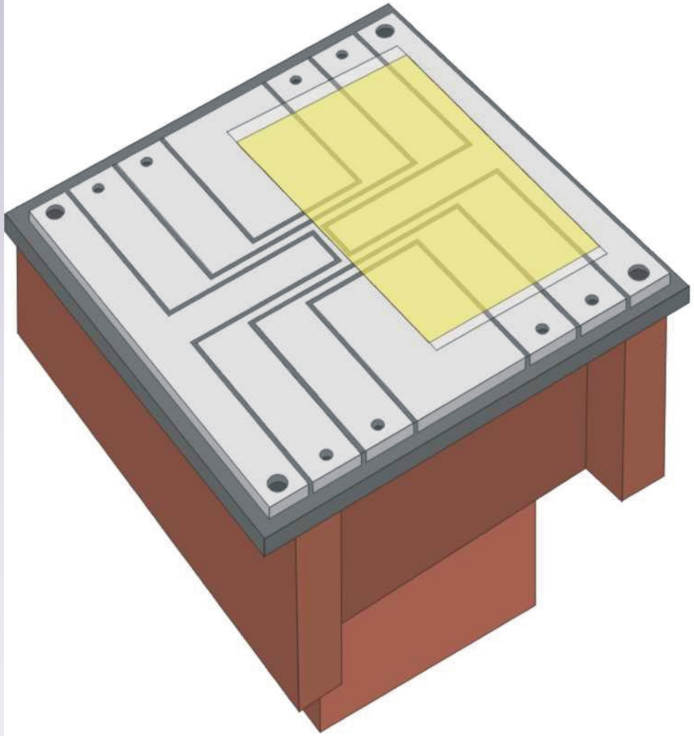
$$B_{film} = \frac{\mu_0}{2\pi}\frac{hM}{z}$$

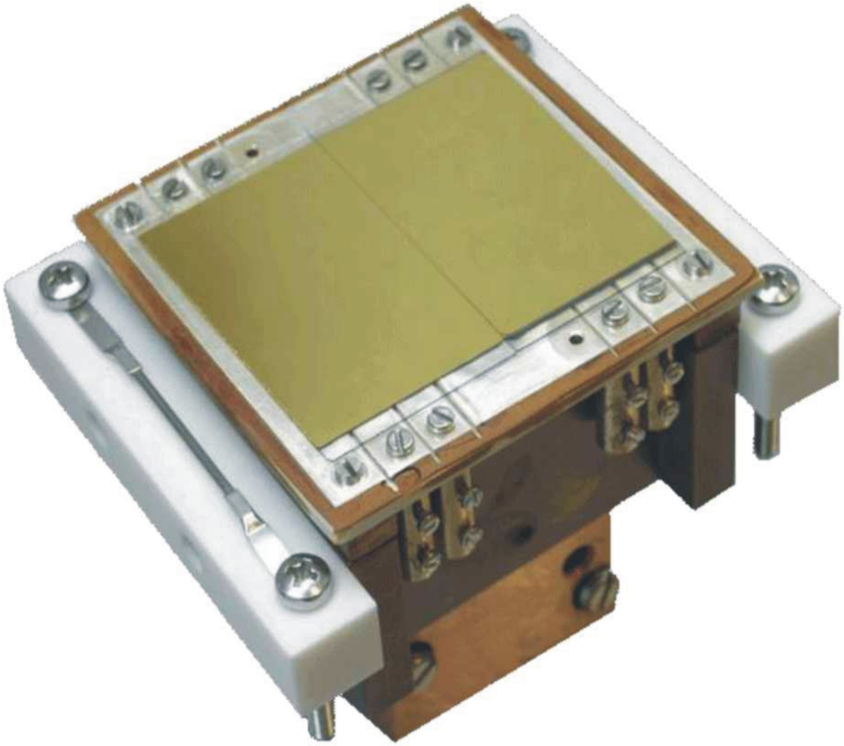
$$2\pi f_{radial} = \frac{\mu_0}{2\pi}\frac{hM}{{z_0}^2}\sqrt{\frac{\mu_B g_F m_F}{m B_y}},$$

» The Swinburne atom chip » »

Atom chip concept

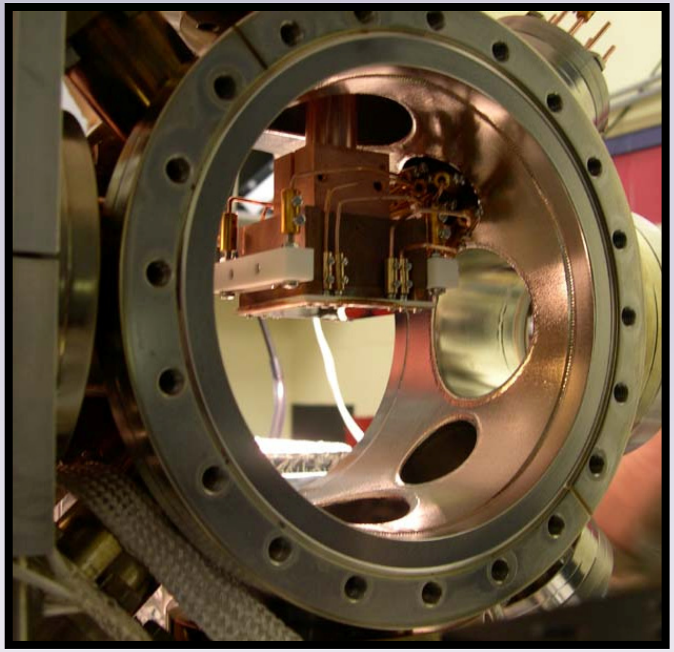
A <u>hybrid</u> design atom chip incorporating a permanent magnetic film (GdTbFeCo) and a current carrying 'H' wire structure.

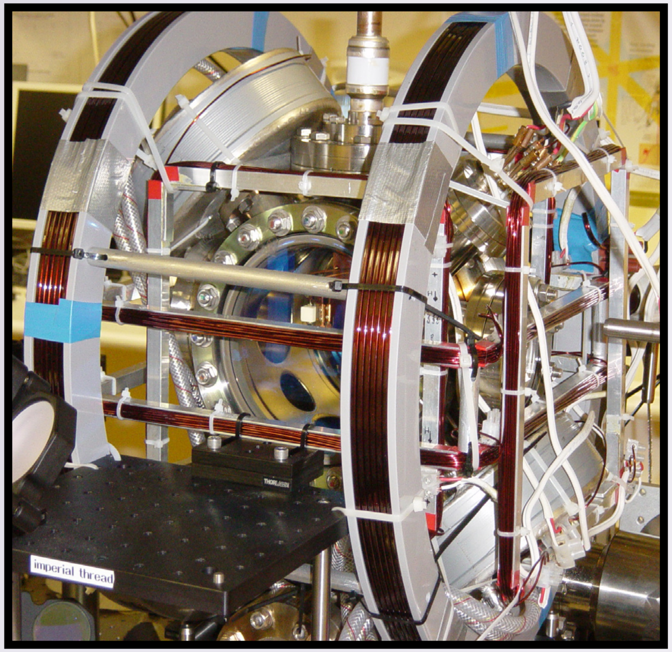




» The Swinburne atom chip » »

Single chamber vacuum system

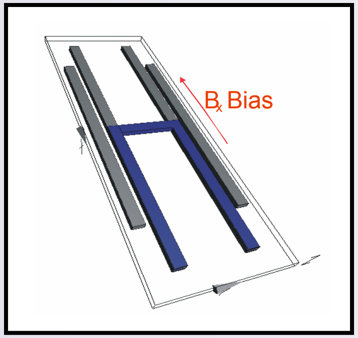


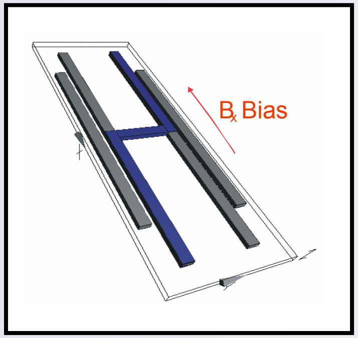


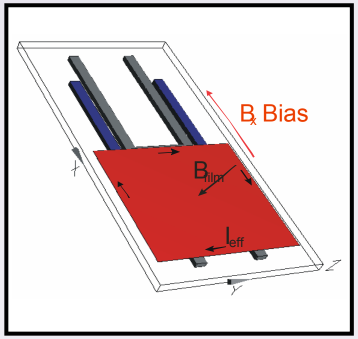
» The Swinburne atom chip » »

Sequence of events

100 ms	Destroy MOT / start clean cycle
9000 ms	Pulse Rb dispenser at 6.5A
15000 ms	Rb vapour decays
20 ms	Transfer to U-MOT
2 ms	Polarisation gradient cooling
1 ms	Transfer to magnetic Z trap
100 ms	Adiabatic compression of Z trap
8800 ms	Initial RF evaporation
150 ms	Transfer to magnetic film
1000 ms	Final RF evaporation
100 ms	Imaging







» The Swinburne atom chip » »

Crossing the BEC critical temperature

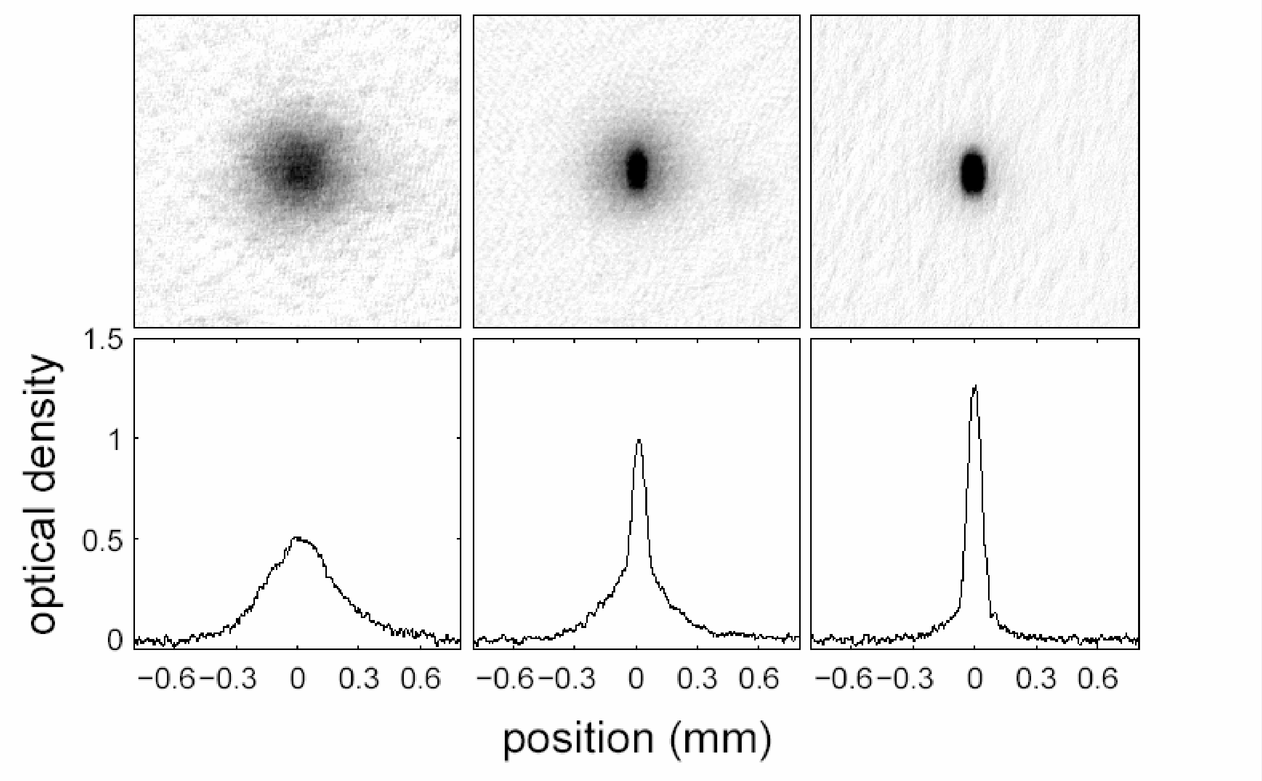
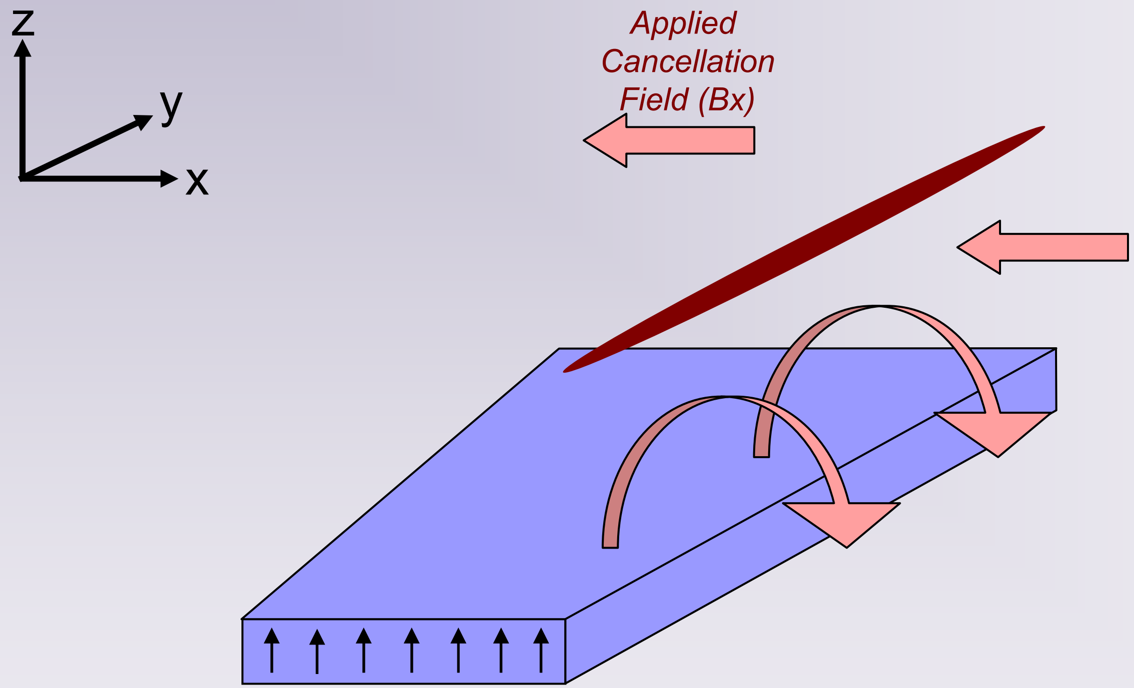


Figure 5. Typical absorption images and optical density profiles of a ballistically expanded atom cloud. Each image is a single realization of the experiment where evaporation is performed in the permanent magnetic film potential. After truncating the evaporation ramp, atoms are held for 150 ms and ballistically expanded for 30 ms before imaging. (a) RF_{final}=804 kHz - thermal cloud, (b) RF_{final}=788 kHz - partially condensed cloud, (c) RF_{final}=760 kHz - an almost pure condensate.

Hall B V, Whitlock S W, Scharnberg F, Hannaford P and Sidorov A, *J. Phys. B: At. Mol. Opt. Phys.* **39**, 27 (2006)

» BEC Experiments

Characterization of the magnetic film potential



Permanent magnetic film 'side-guide'

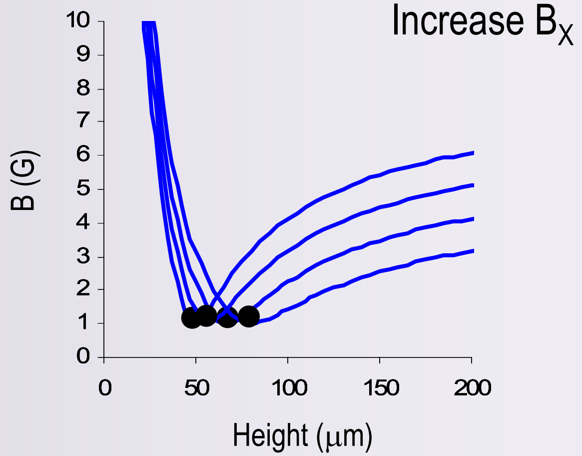
» BEC Experiments

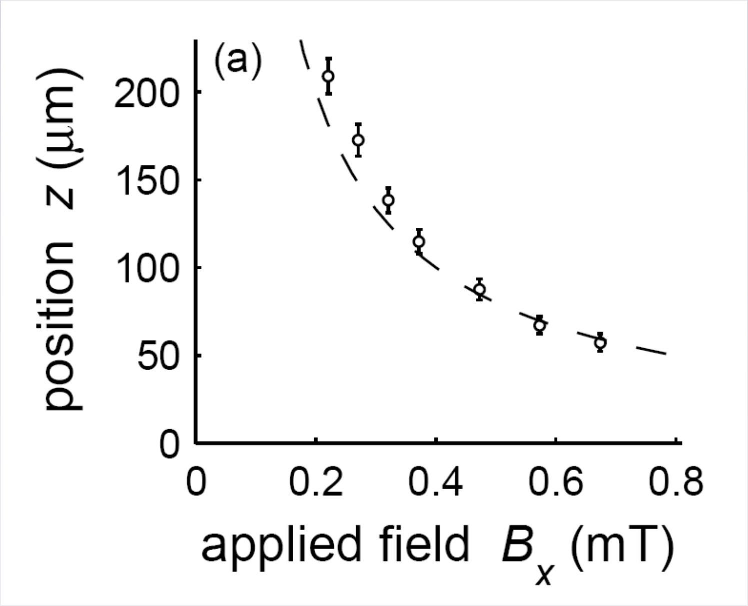
Characterization of the magnetic film potential

Measure the magnetic field of the film versus height.
Trap is formed when:

$$B_{film} = \frac{\mu_0}{2\pi}\frac{hM_R}{z} = -B_X$$

Can measure position accurately (CCD image)





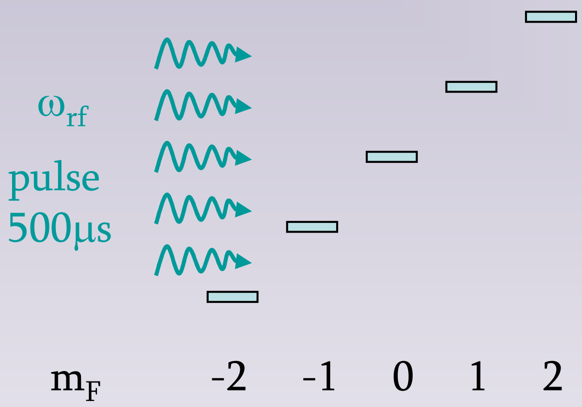
However: need to have accurate knowledge of B_X

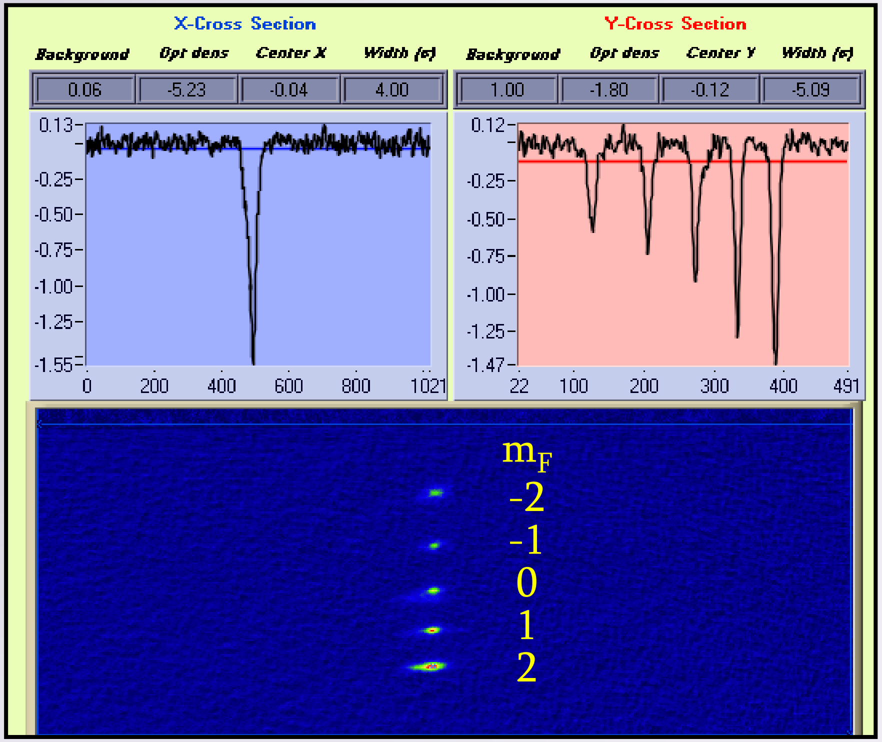
» BEC Experiments » »

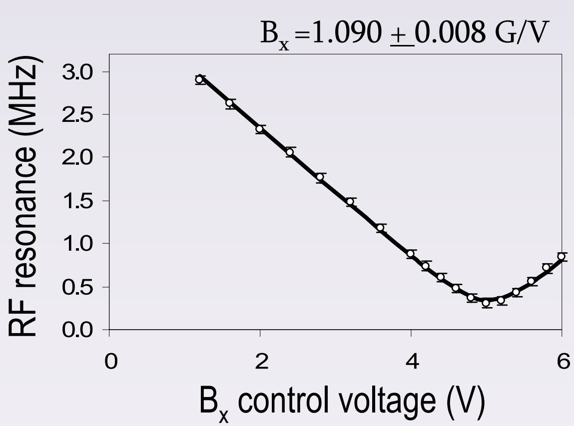
BEC, RF transitions and an in-situ Stern Gerlach magnetometer

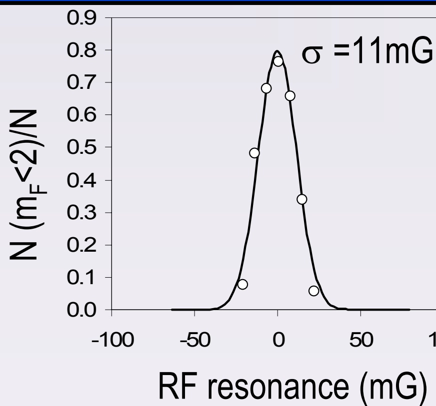
Zeeman splitting of hyperfine substates

$$h\,\omega_{rf} = \Delta m_F\, g_F\, \mu_b\, B_X$$









» BEC Experiments

BEC as a high Q resonator

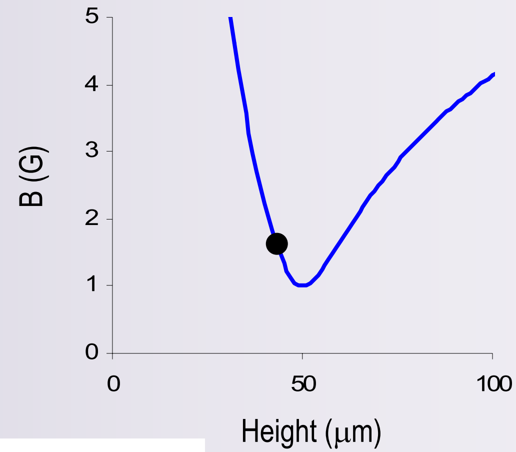
» »

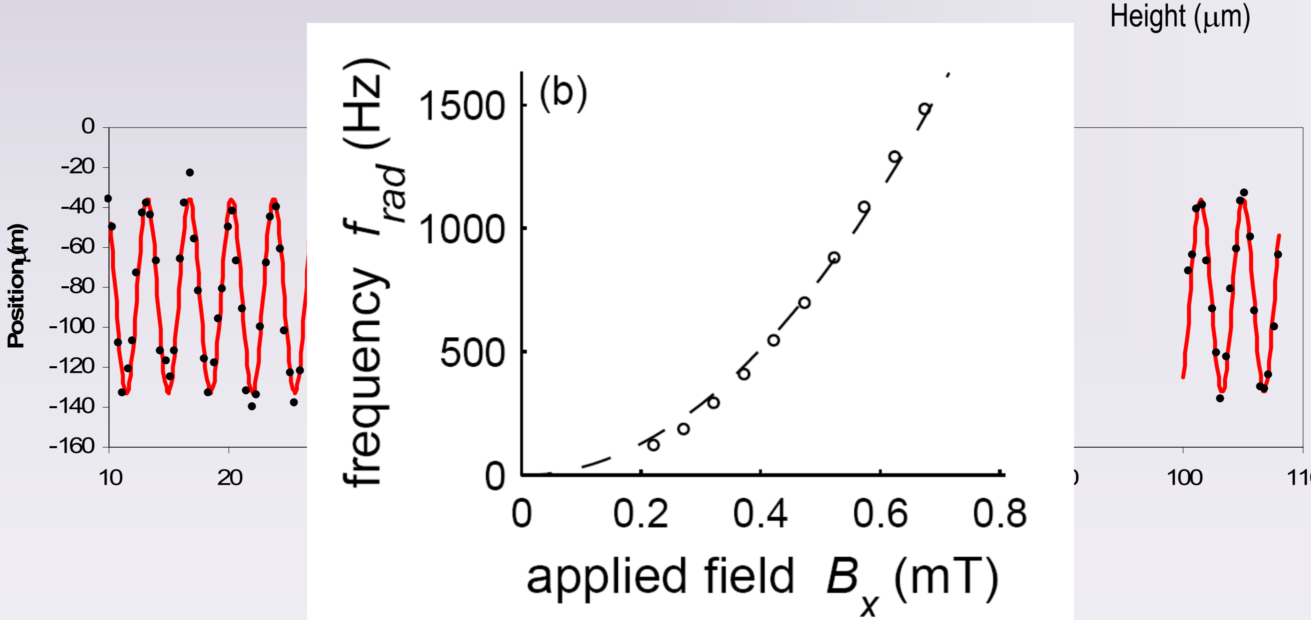
For small amplitude oscillations, have a harmonic trap

$$2\pi f_{rad} = \frac{\mu_0}{2\pi}\frac{hM_R}{{z_0}^2}\sqrt{\frac{\mu_B g_F m_F}{m B_y}},$$

Can measure B_y (to 1mG or <0.07%) via RF output coupling

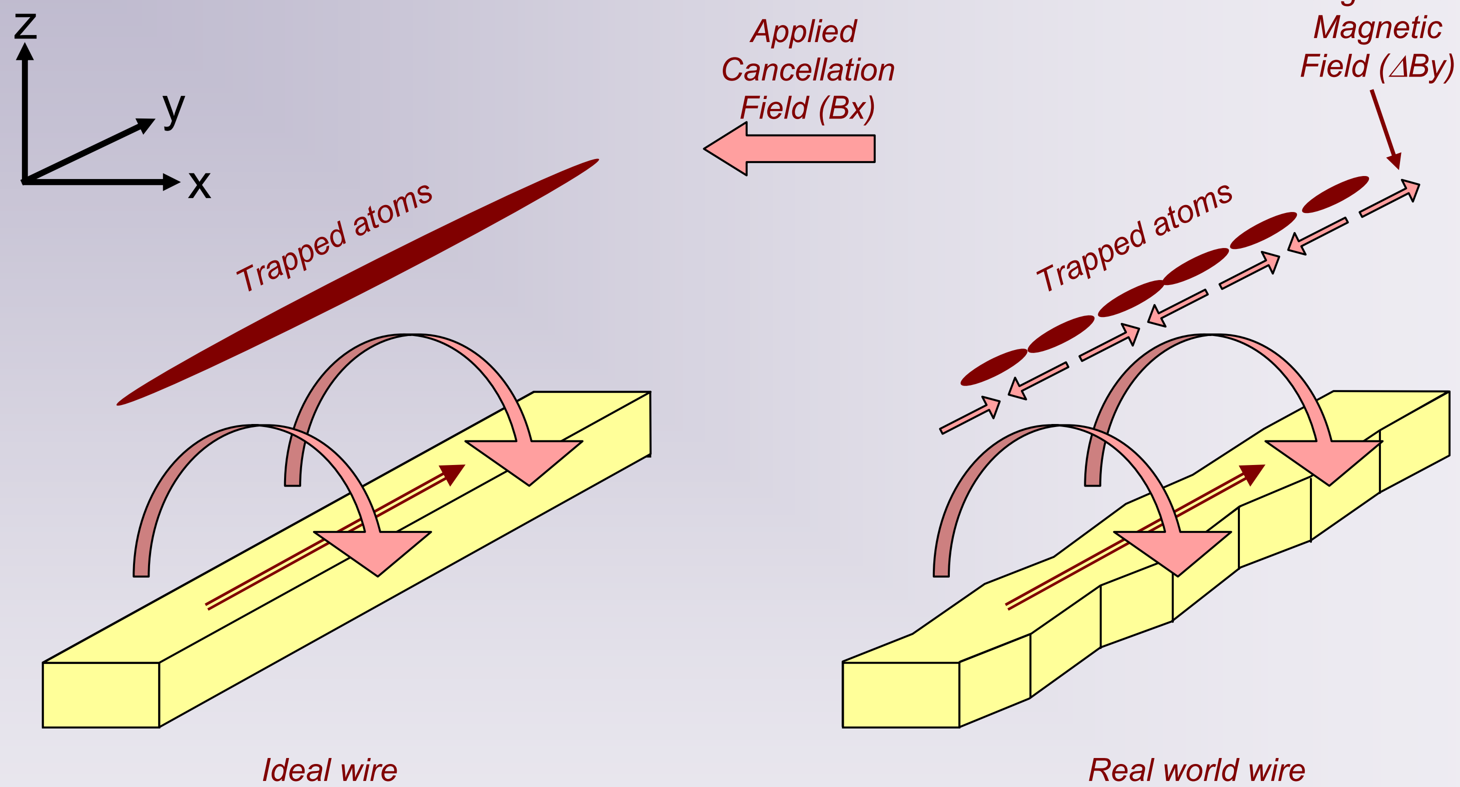
Can measure f_{rad} to < 0.3% accuracy





» BEC Experiments »»

Fragmentation from conducting wires



Observed with ultracold atoms (1 μK = 1.5 μT)

Fortagh *et al* Phys.Rev.A **66** 041604 (2002): Jones *et al* J.Phys.B:At.Mol.Opt.Phys. **37**, L15–L20 (2004)

Attributed to edge roughness from manufacturing process.

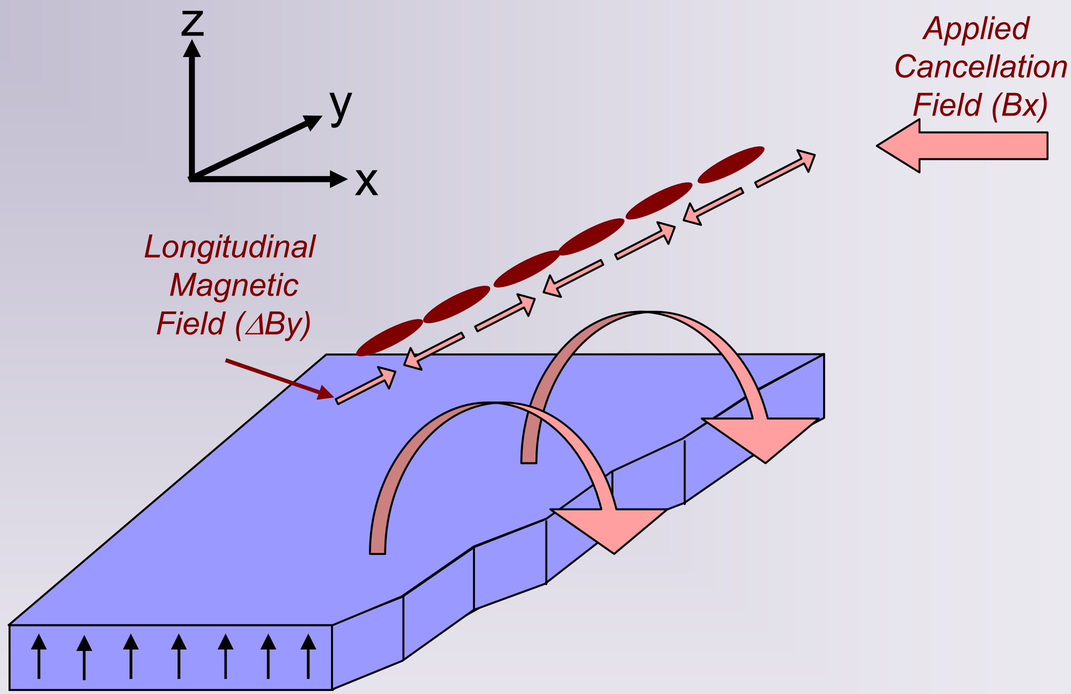
Esteve *et al* Phys Rev A **70** 043629 (2004): Wang *et al* Phys.Rev.Lett. **92** 076802-1 (2004)

Best process to date: electron beam mask/gold evaporation lift-off technique < 100nm roughness

Kruger et al arXiv:cond-mat/0504686 (2005)

» BEC Experiments

Fragmentation from magnetic films



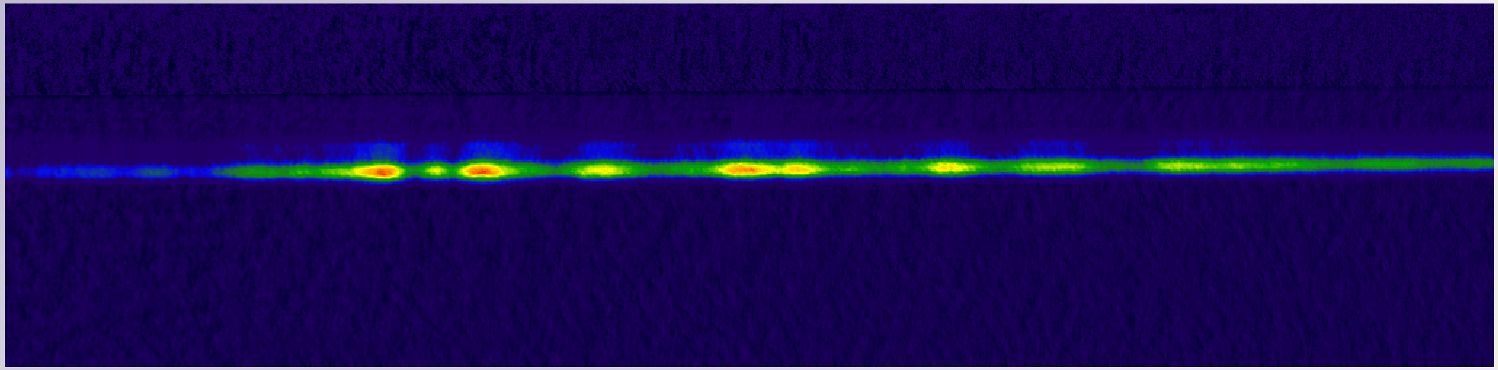
Fragmentation due to edge roughness

Magnetic film follows substrate edge topology

Glass slide was polished prior to deposition.

» BEC experiments » »

Standard method for measuring fragmentation



Assume thermal equilibrium and use Boltzmann law

$V(y) = -k_b T \ln [n(y)]$

n(y) density distribution of thermal cloud of temperature T.

<u>Disadvantages</u>

Not very well suited to measuring over large region of the surface

Depends on accurate calibration of cloud temperature

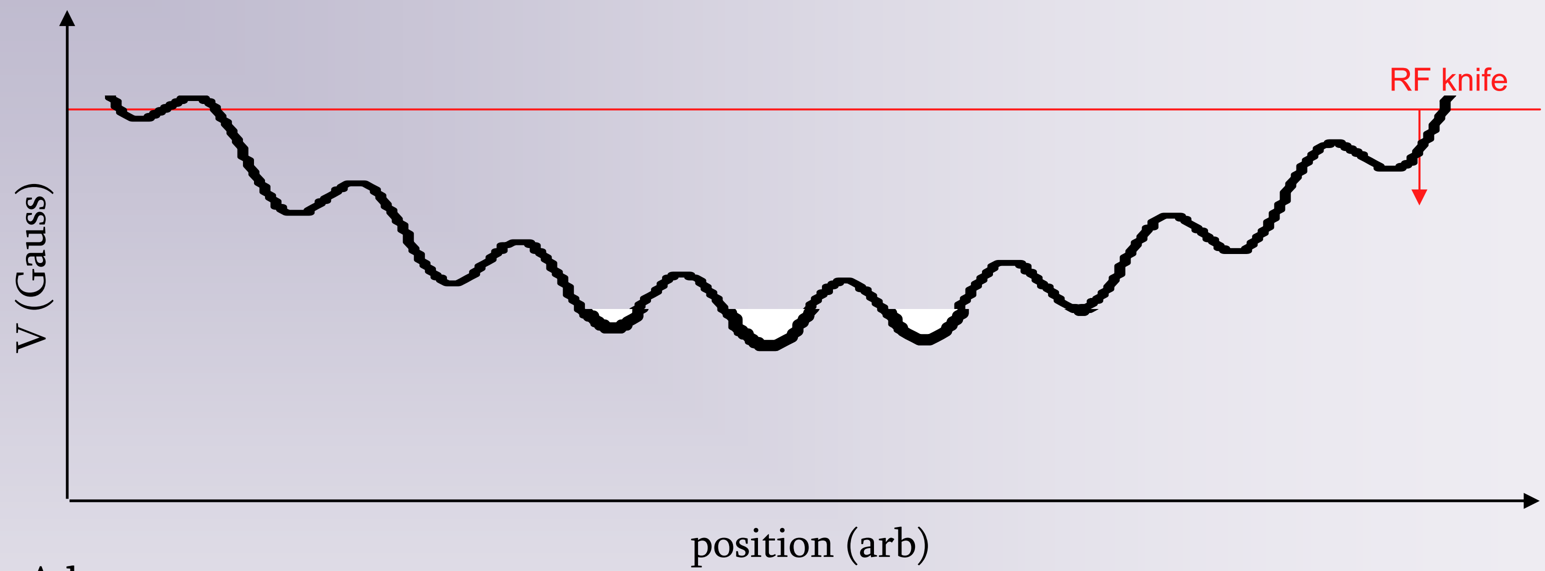
Cannot ensure thermal equilibrium when fragmentation is large

Does not discriminate between magnetic, gravitational and optical potentials

Jones *et al* J.Phys.B:At.Mol.Opt.Phys. **37**, L15–L20 (2004)
Esteve *et al* Phys Rev A **70** 043629 (2004):

» BEC experiments »»

Determine absolute magnetic field using RF output coupling



<u>Advantages</u>

Sensitivity (~ T) increases when measuring near bottom of the trap because of continuous evaporative cooling.

Provides an absolute measurement of magnetic field (can discriminate against gravity)

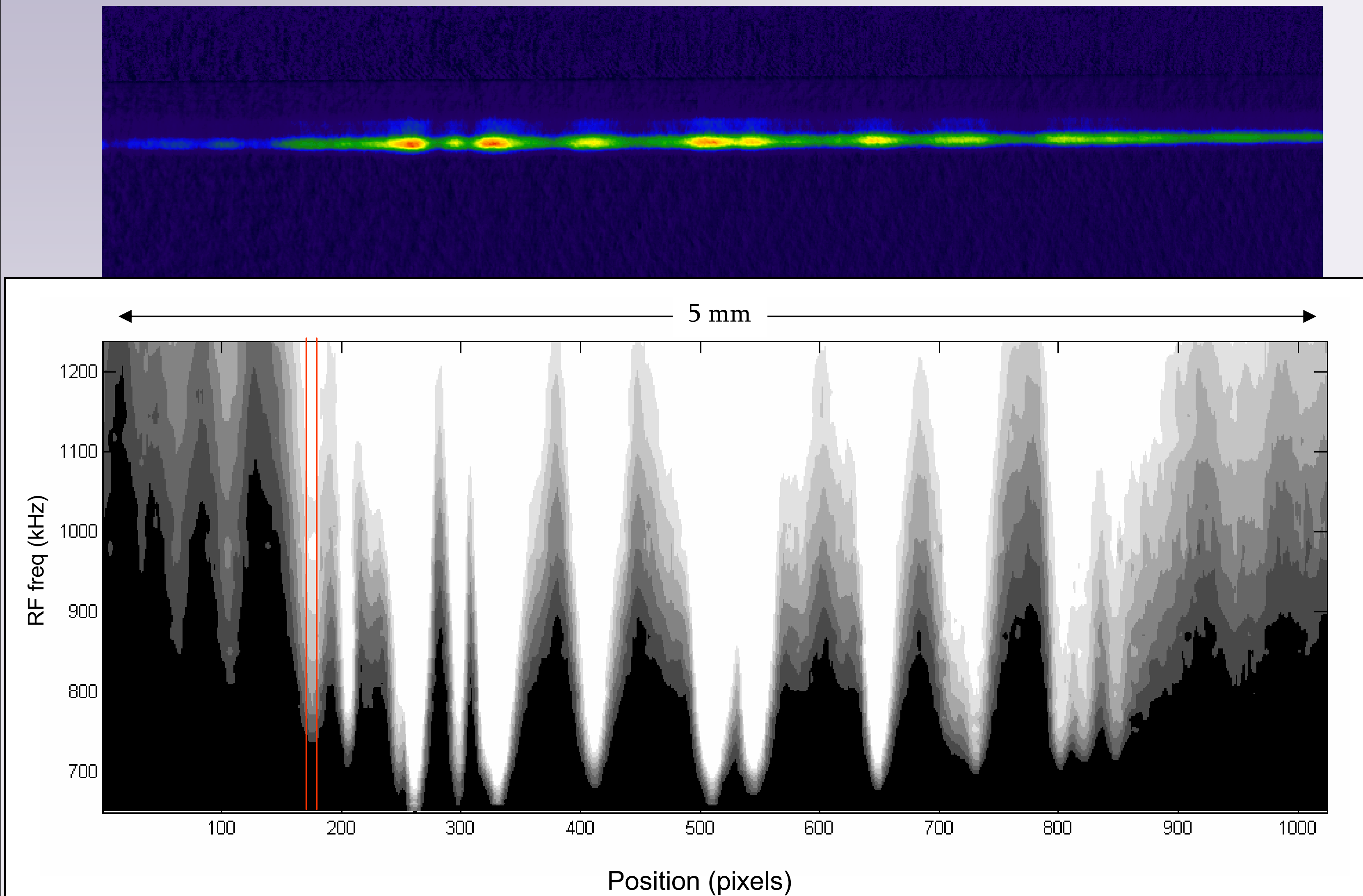
Independent of temperature or thermal equilibrium

Works best with weak confinement (decouple confining potential to fragmentation)

» BEC experiments —————— » »

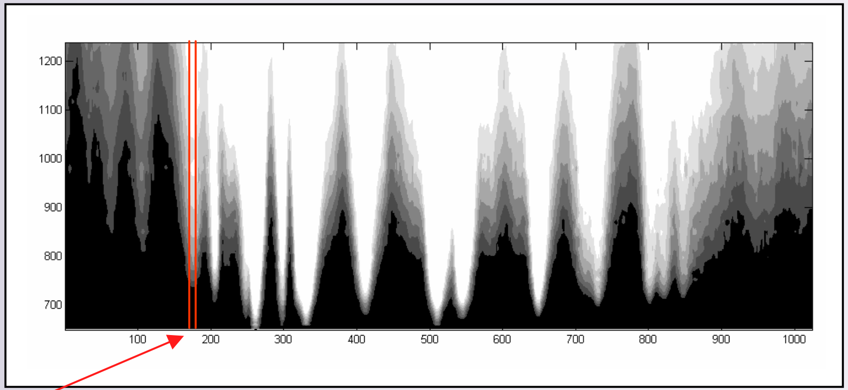
Example measurement

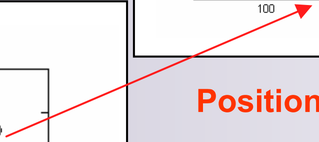
RF frequency logarithmic sweep from 1240 kHz to 650 kHz $z = 65\ \mu m$



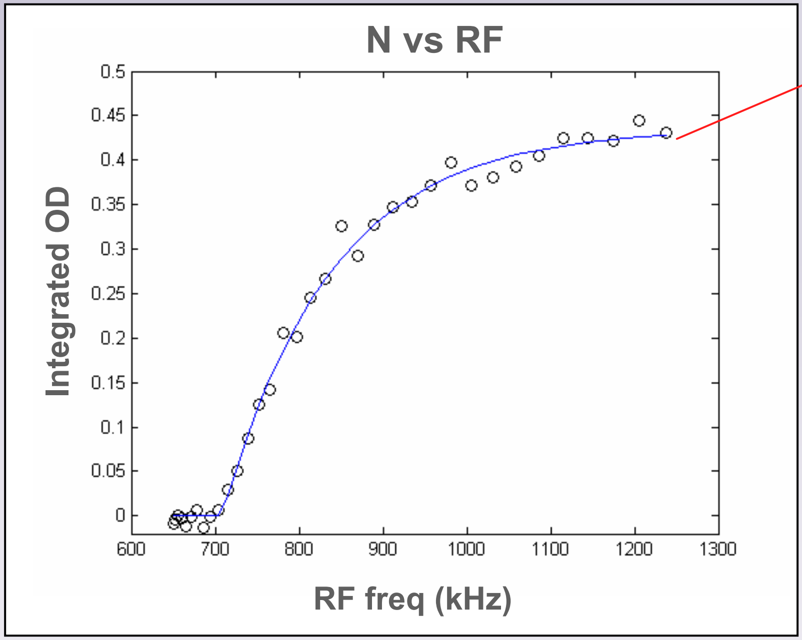
» BEC experiments

Extracting absolute field





Position = 180 px

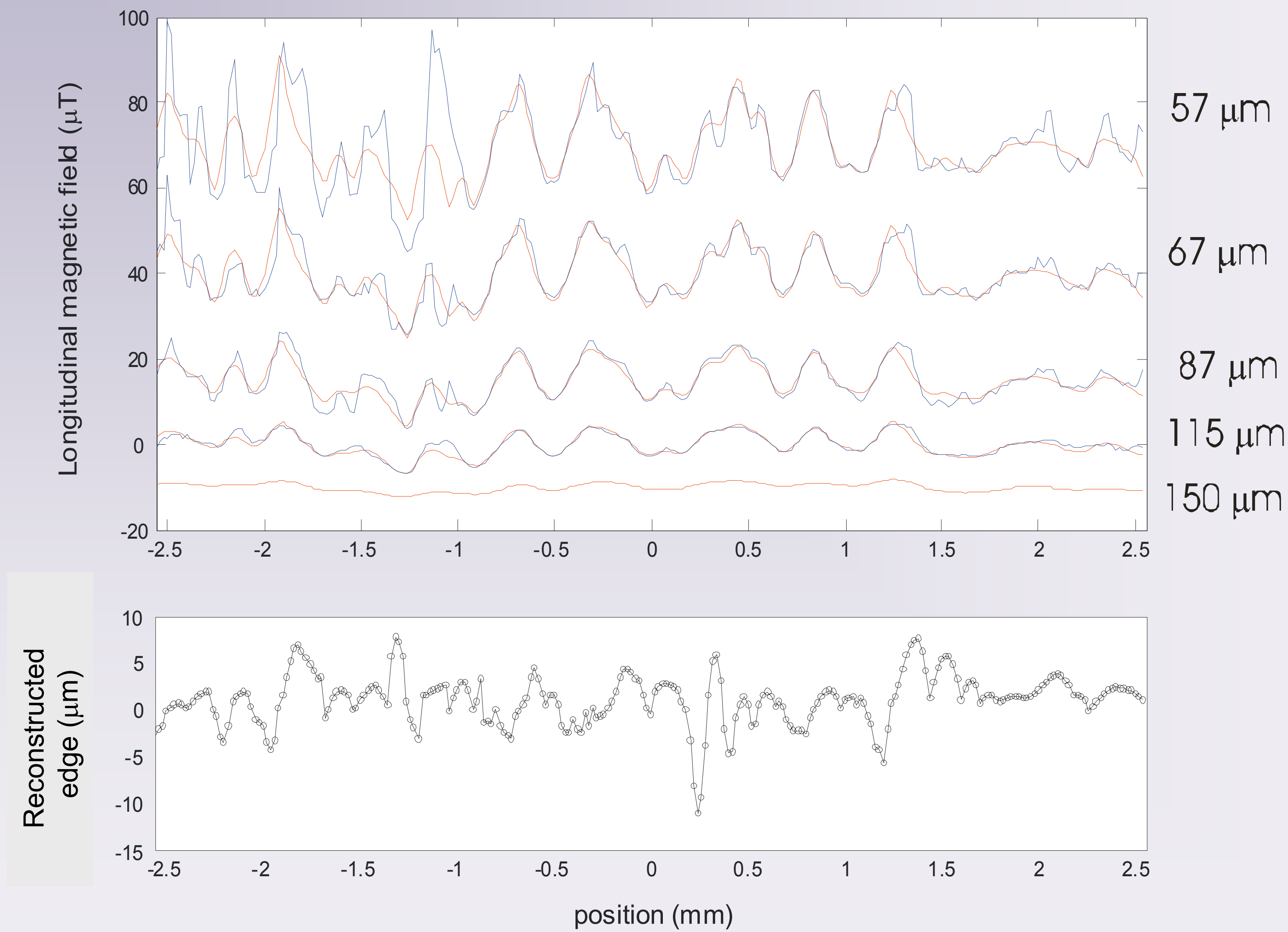


Fit form (for OD > 0) : $$OD = A0\left(1 - e^{-A1(Rf - A2)}\right) + A3(Rf - A2)$$

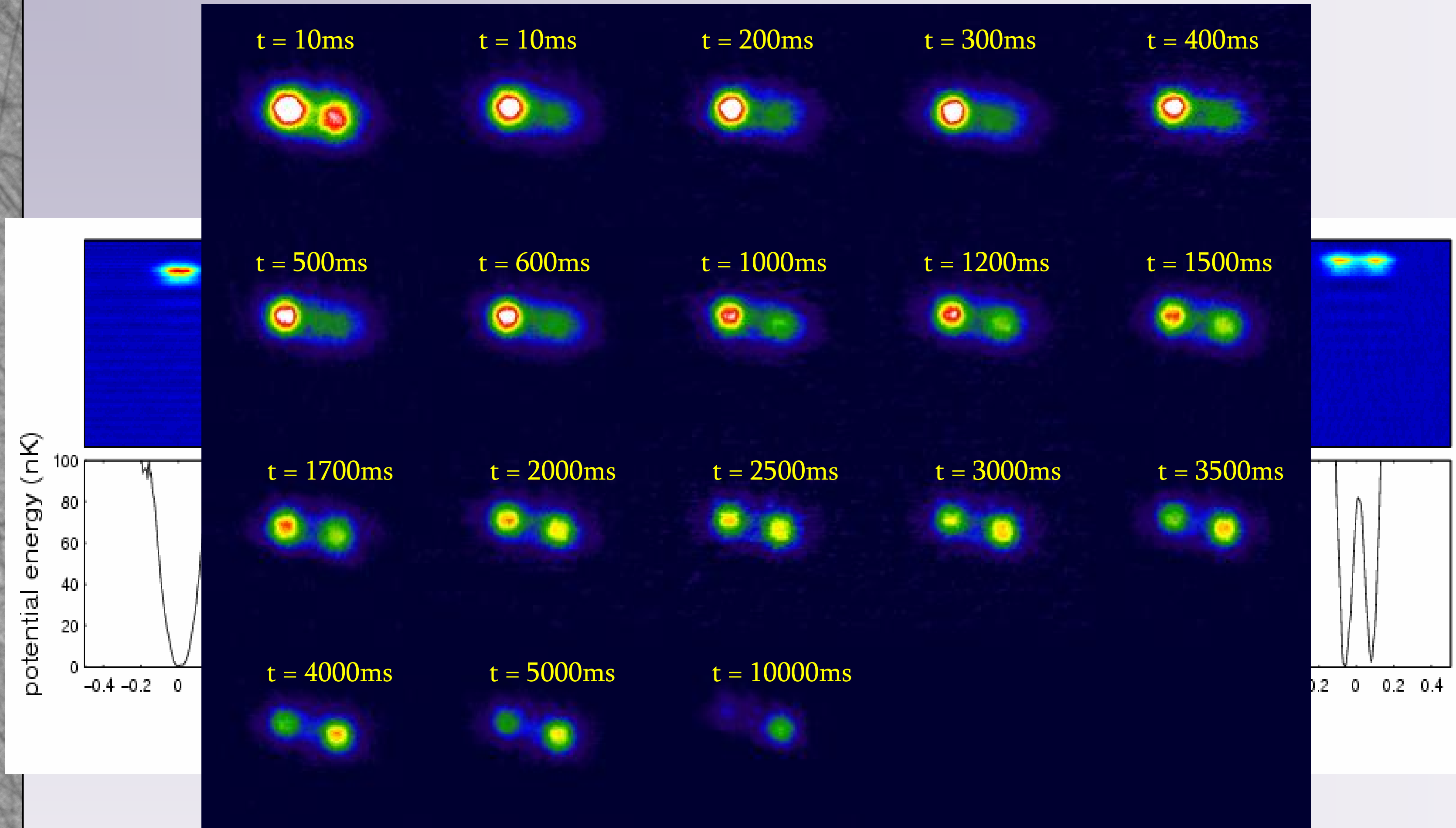
Where A2 = RF frequency for OD → 0.

» BEC experiments

Measurement (blue) and theory (red) of corrugated potential

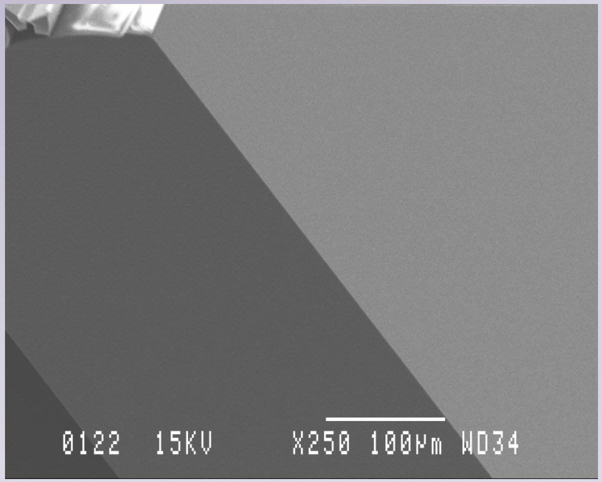


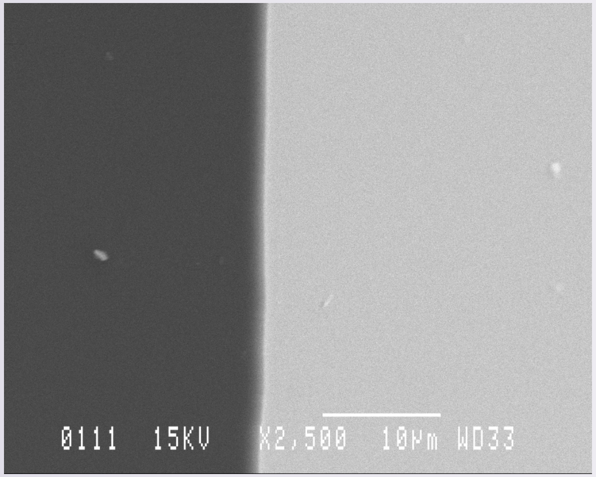
» BEC experiments

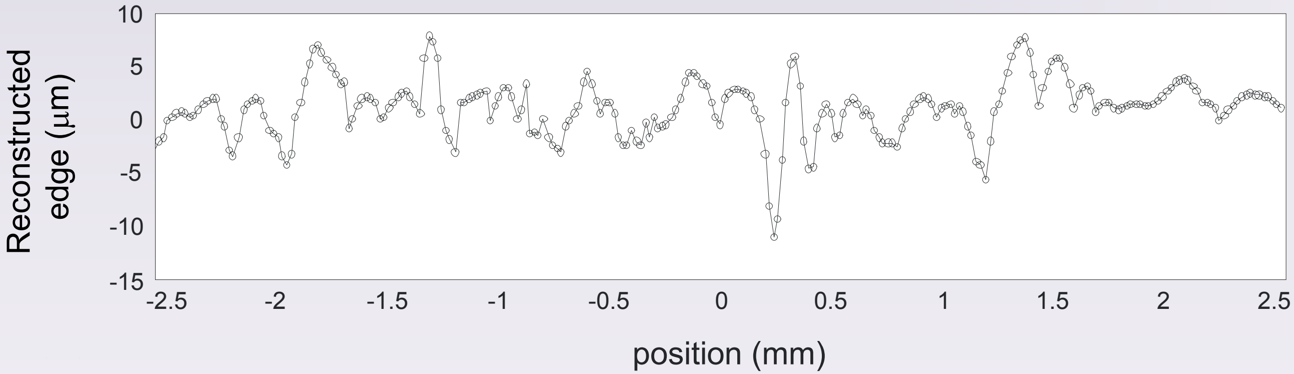


» BEC experiments »»

SEM images of similarly prepared edge

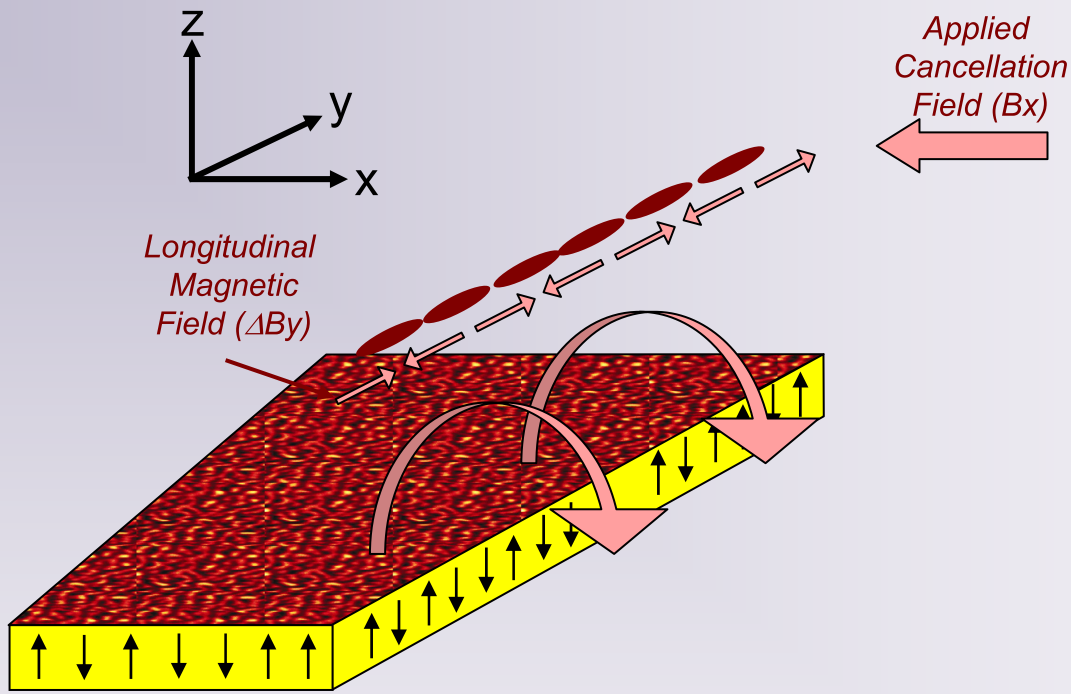






» BEC experiments » »

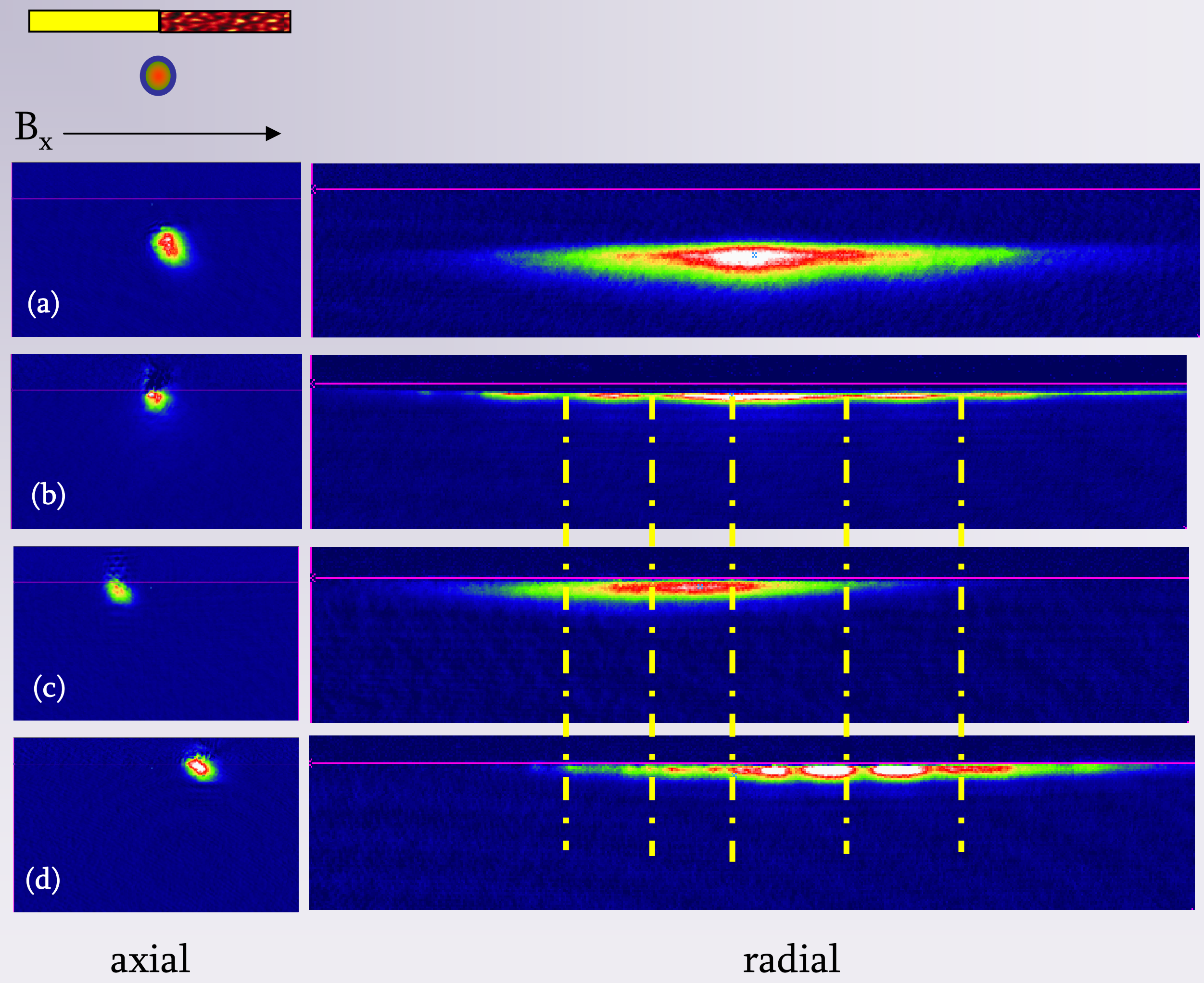
Another source of fragmentation – demagnetization of film



Fragmentation due to magnetic field inhomogeneity

» BEC experiments »»

Probe either side of 'edge' at a radius where fragmentation is small



» In the Future

Current objectives

TbGdFeCo - magnetic field inhomogeneity

- Quantify amount
- Investigate likely source
- Identify likely fundamental limits over material specific limits
- Other materials/compositions of interest (RE-FeCo, multilayer PtCo, FePt)

Permanent magnetic material traps.

- Investigate heating mechanisms, condensate lifetime, heating rates….
  (Russell Anderson Poster)
- Double well experiments: condensate distillation, role of adiabaticity in splitting...

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SWINBURNE UNIVERSITY OF TECHNOLOGY

» People to thank

CAOUS

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Coherence of BEC on a Chip

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PhD: Shannon Whitlock, Falk Scharnberg, Holger Wolf, Russell Anderson.

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