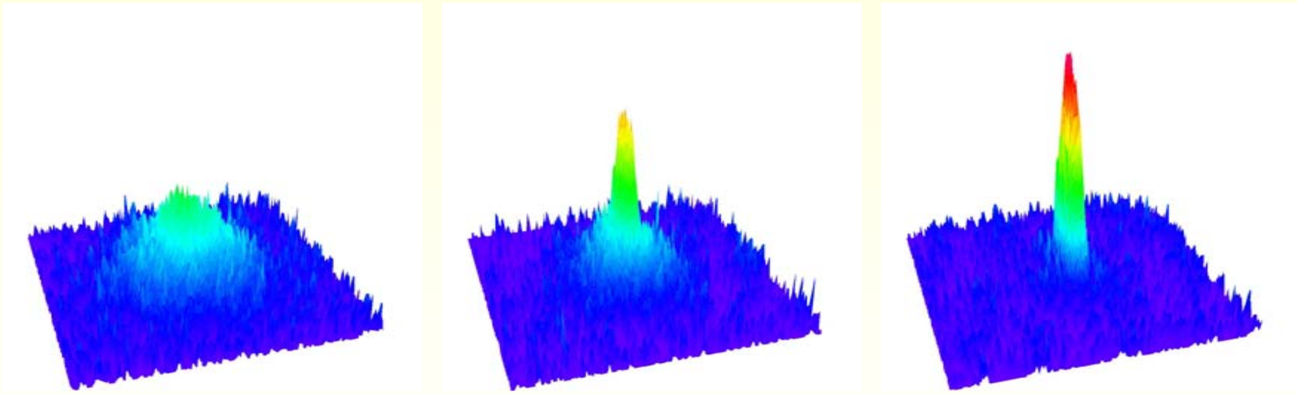
Atom Chips and Bose-Einstein Condensates

Chris Vale



THE UNIVERSITY OF QUEENSLAND

UQ BEC Team

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  A/Prof N. Heckenberg
  Prof G. Milburn
  Dr. C. Holmes
  Dr. M. Davis
  CJV
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  Sean Drake
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- **Research Associate**
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- **Former Members/Visitors**
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  Martin Lenz
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Outline

- BEC on a foil based atom chip
- Fragmentation
- High temperatures…
- Accurate atom number detection
- Conclusions

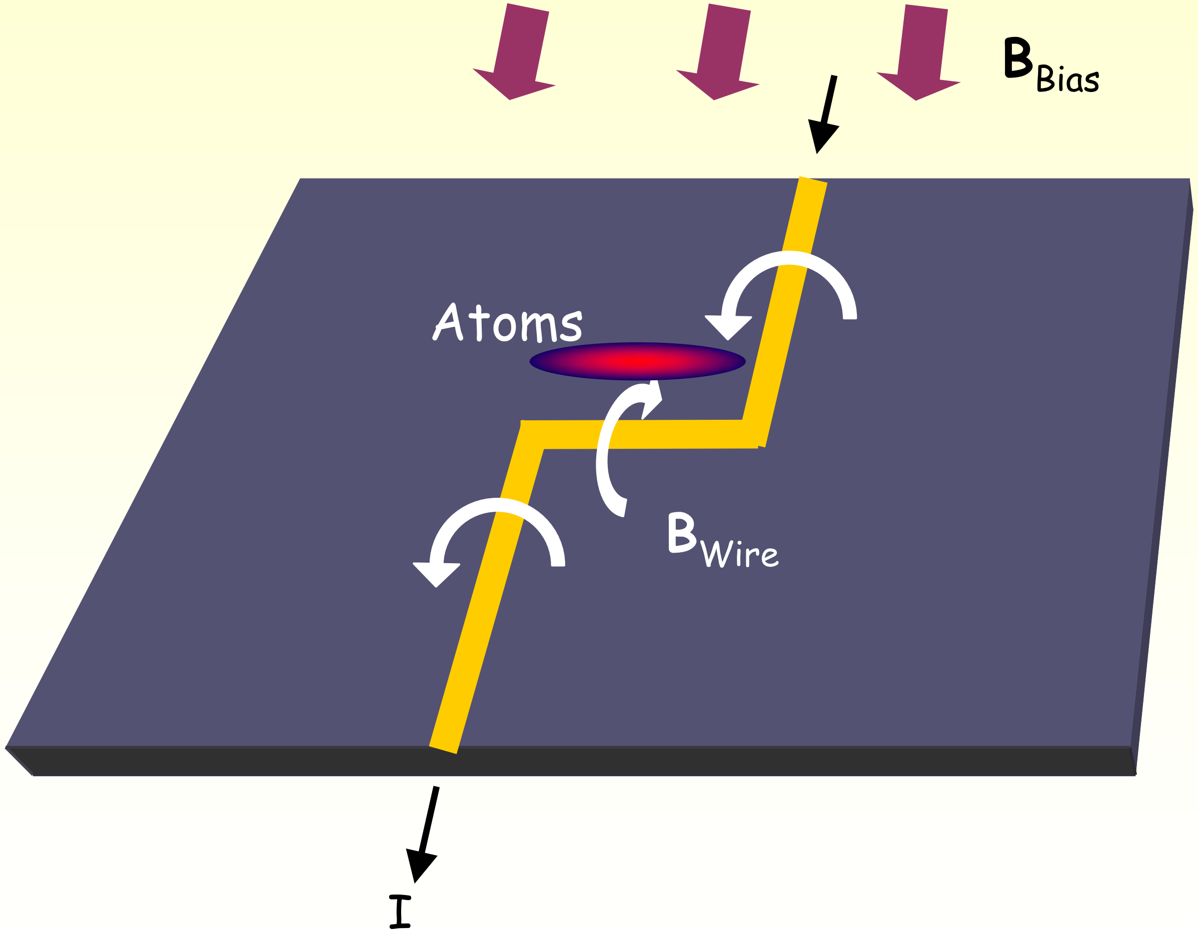
UQ Atom Chip / BEC

Atom Chips

- Atom optics - Control and manipulation of atomic deBroglie waves
- **Atom Chips**: Allow us to place atom optical elements very close to a BEC.
- Two main advantages:
  - o "Easy" to produce BECs (lower currents)
  - o Tight and complex trapping potentials

Atom Chips

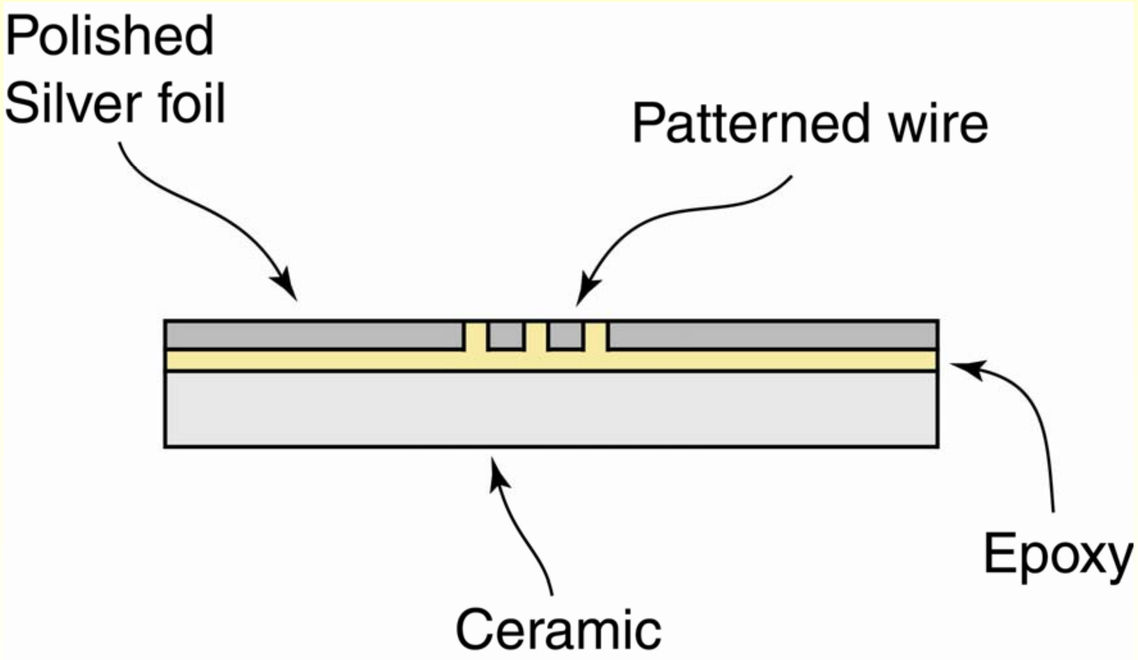
- Z-wire + bias field = mini Ioffe-Pritchard trap



- Produces a magnetic trap with 3D confinement

UQ Atom Chip

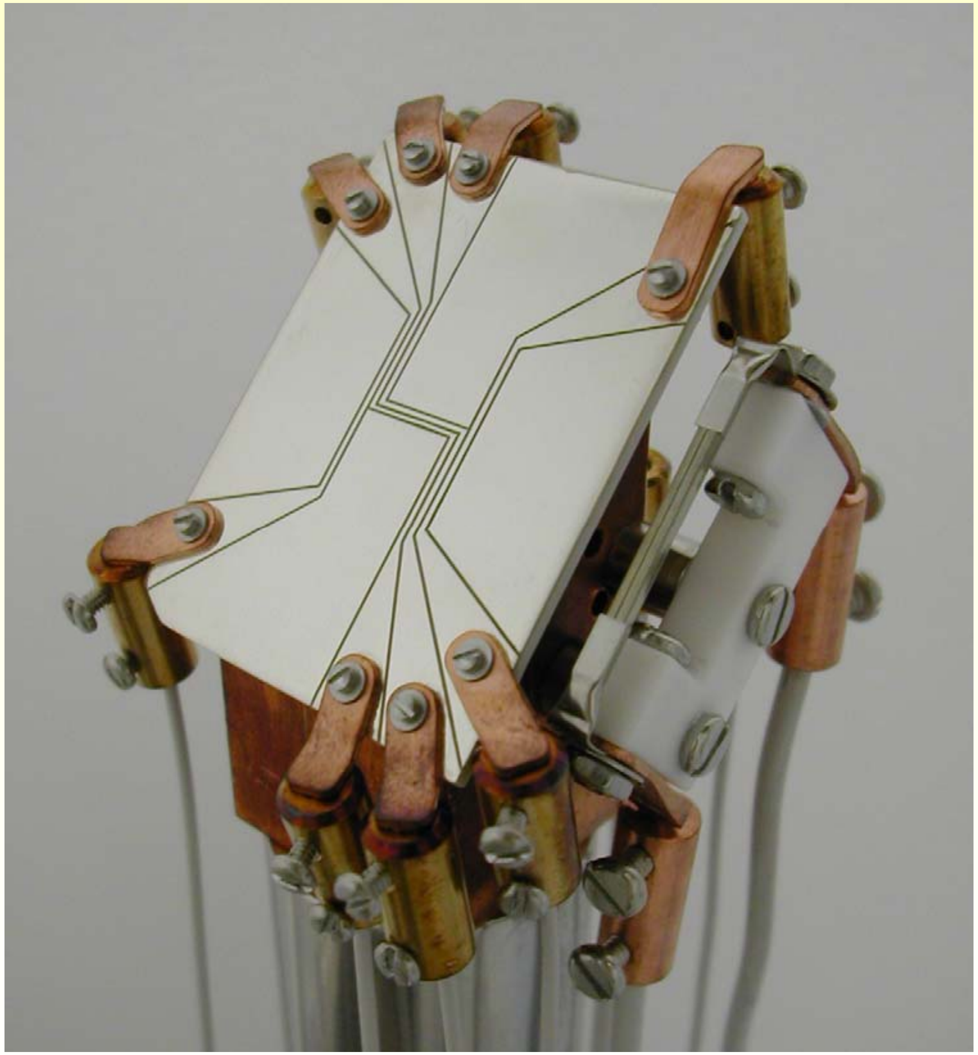
- A silver foil (125 μm) glued to a ceramic substrate.



- Silver polished to mirror finish (thickness ≈ 90 μm).
- All materials UHV compatible.

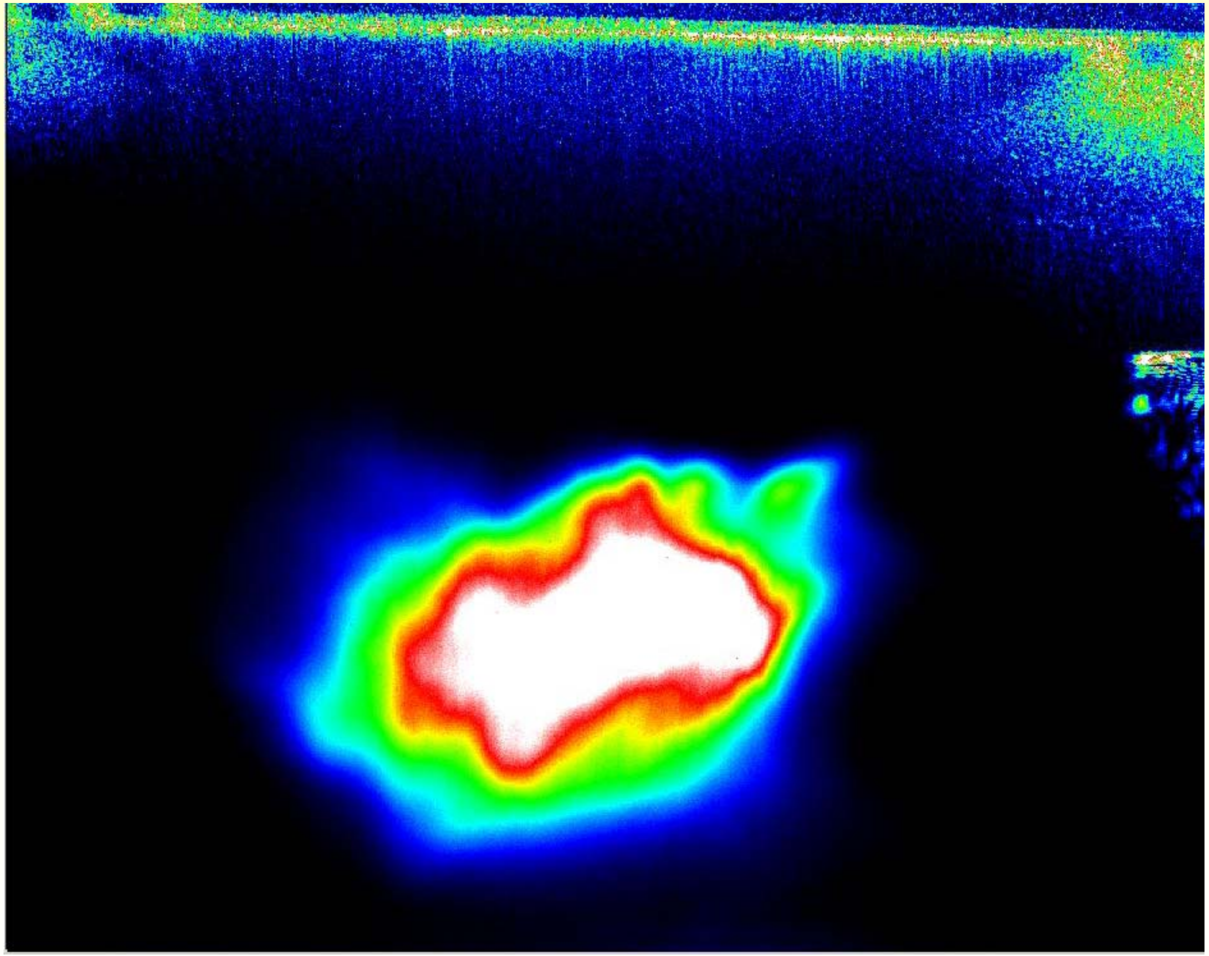
UQ Atom Chip

- Wires patterned with a micro-cutter (150 μm diameter).
- Electrical connections made with copper tabs screwed onto chip.
- Mirror surface for MOT.
- Wires for magnetic trap.



CJV *et al.*, J. Phys B **37**, 2959 (2004)

Magneto-Optical Trap



- Fluorescence image
- ~ 10^8 ^{87}Rb atoms
- $T = 100\ \mu K$

Magnetic Trap

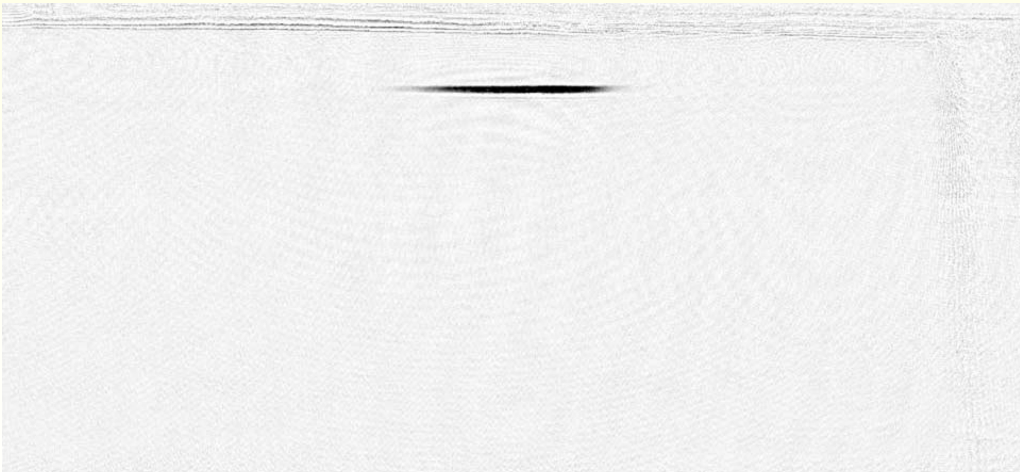
- Atoms trapped in magnetic fields produce by currents through wires on chip.

- Absorption image
- Compressed trap
- ~ 2 X 10^7 atoms
- T = 300 μK

Evaporative Cooling

Final RF = 3MHz

- 3×10^6 atoms
- T = 50 μK

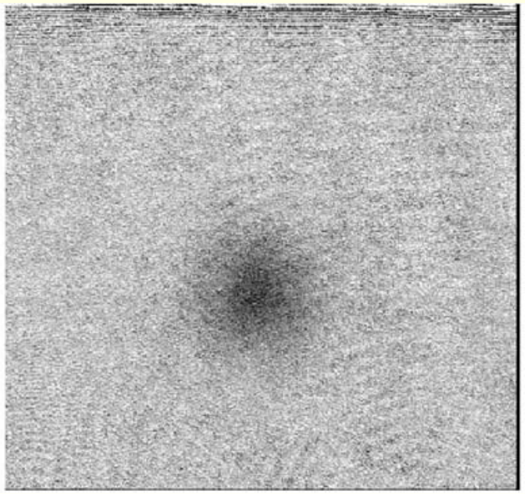


Final RF = 1MHz

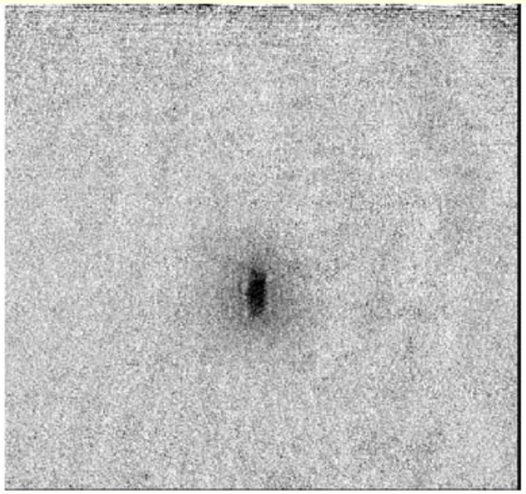
- 5×10^5 atoms
- T = 6 μK

BEC!!

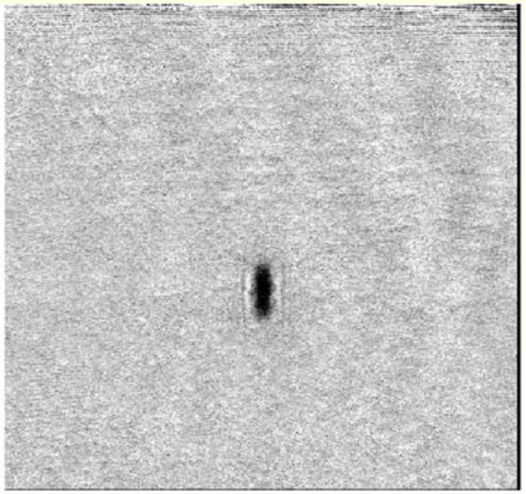
- ~ 4 X 10^4 atoms
- T = 200 nanoK
- View after expansion



N = 2 X 10^5
T = 700nK
Thermal Cloud



N = 8 X 10^4
T = 450 nK
Partial BEC



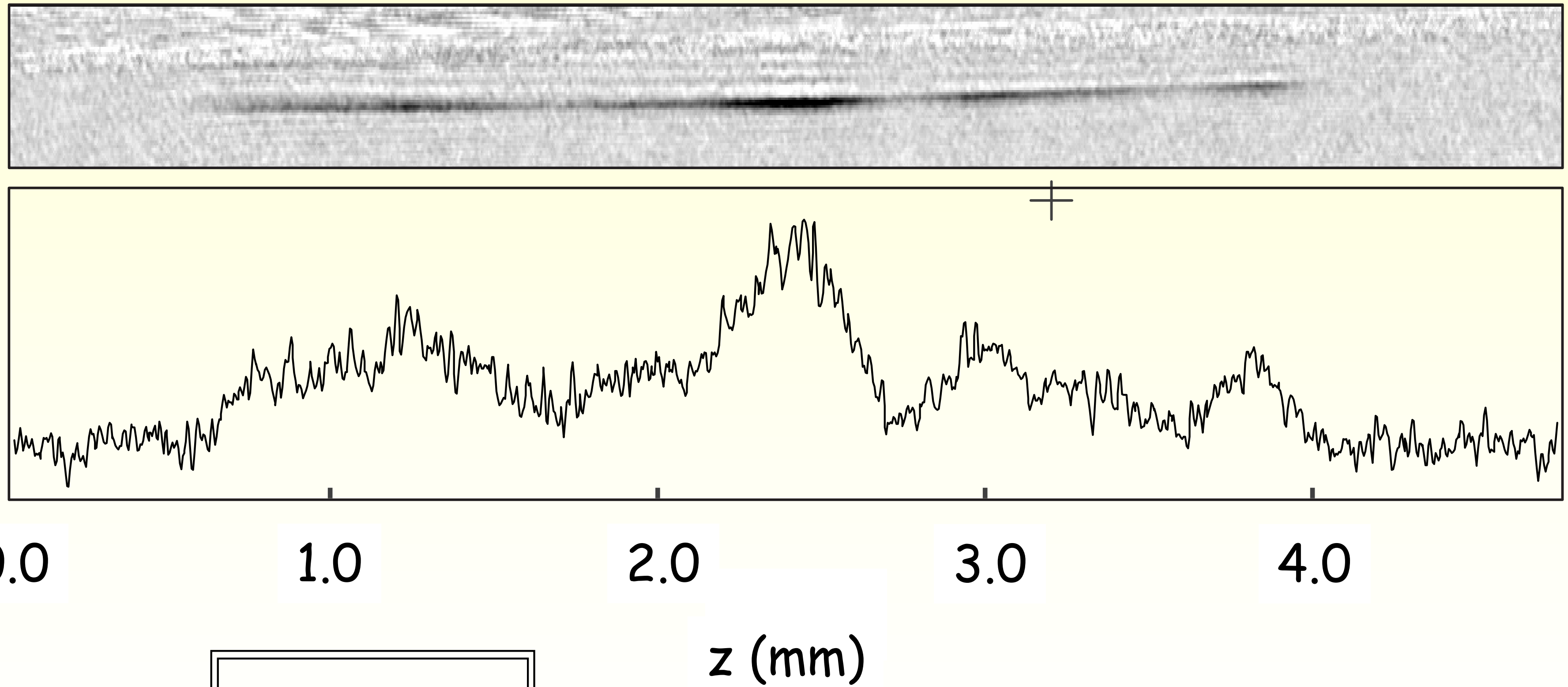
N_0 = 4 X 10^4
T = 200 nK
Almost Pure BEC

CJV *et al.*, J. Phys B **37**, 2959 (2004)

Fragmentation

Fragmentation

- When very cold atom clouds are brought very close to a conducting wire the cloud fragments into lumps.



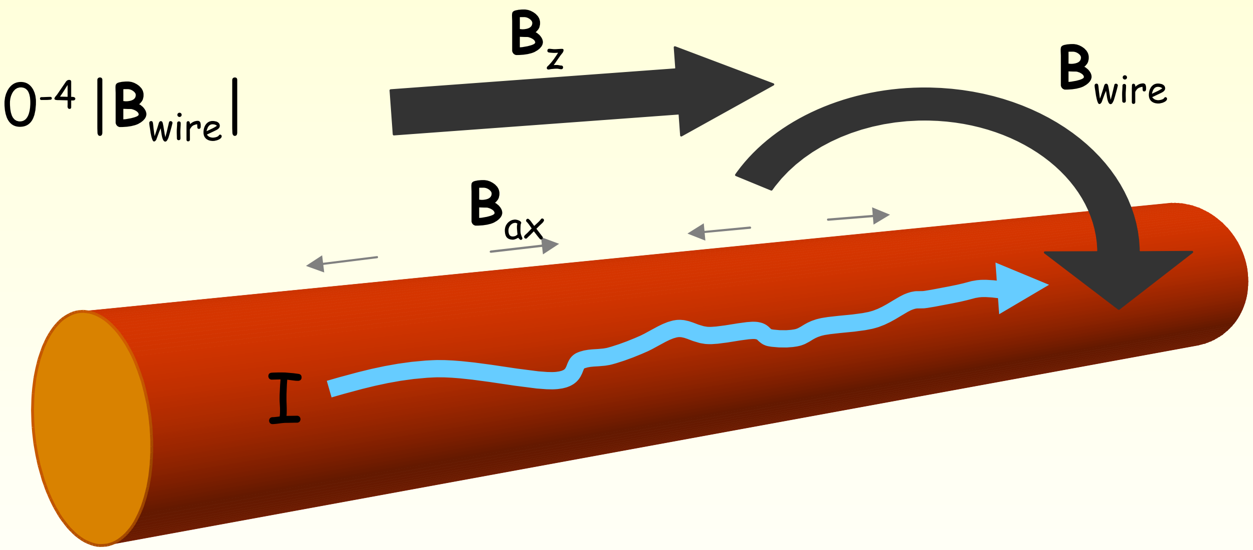
$T = 4\ \mu K$,

$y = 45\ \mu m$.

Fragmentation

• Small axial fields, $\mathbf{B}_{ax}$, are produced by the guide current which can add to/subtract from the total axial field creating potential barriers/wells.

$|\mathbf{B}_{ax}| \sim 10^{-3} - 10^{-4}\,|\mathbf{B}_{wire}|$



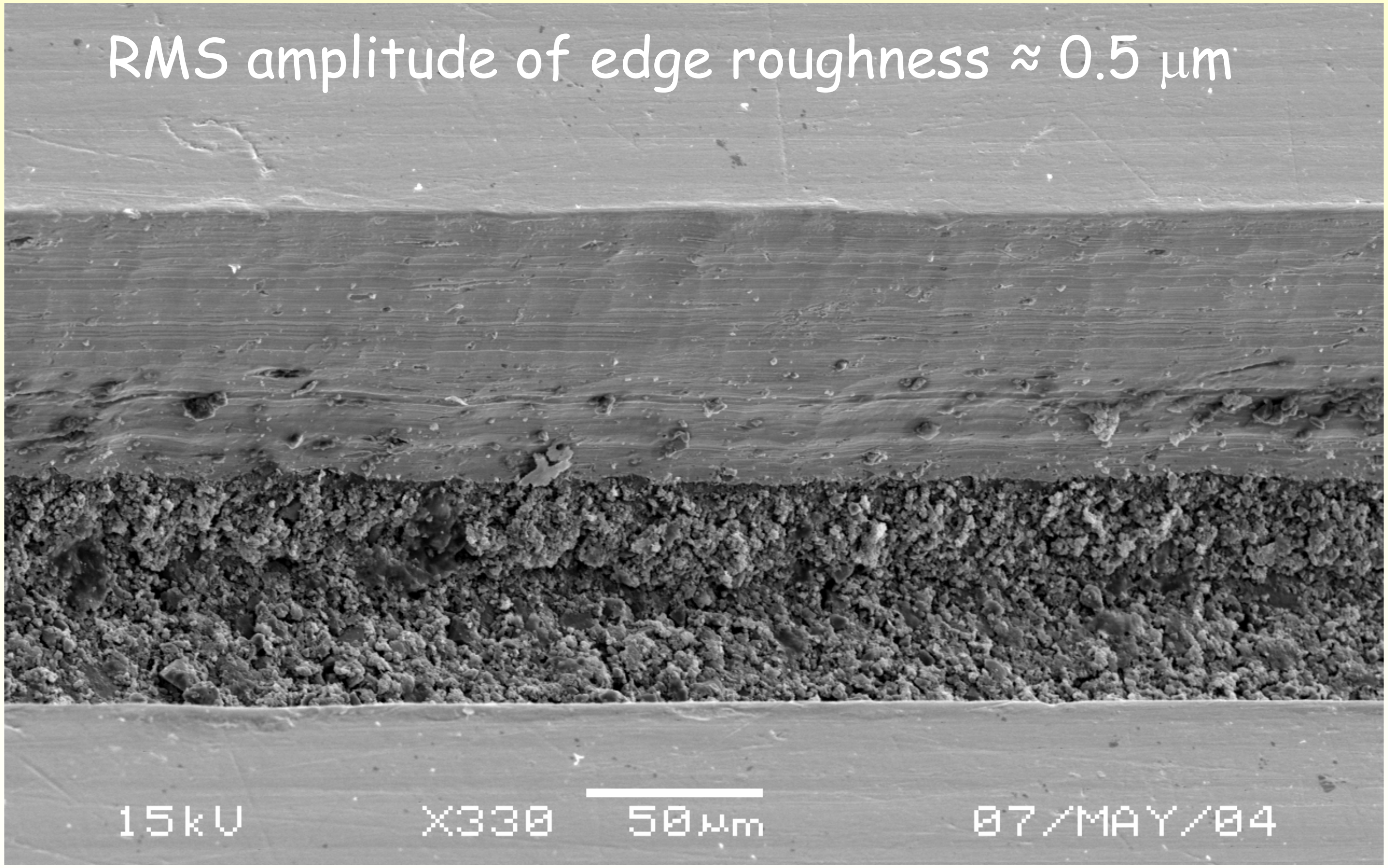
• A meandering current produces these small $\mathbf{B}_{ax}$ components...

Kraft, *et al.*, J Phys B **35**, L469 (2002),

Estéve *et al.*, physics/0403020 (2004).

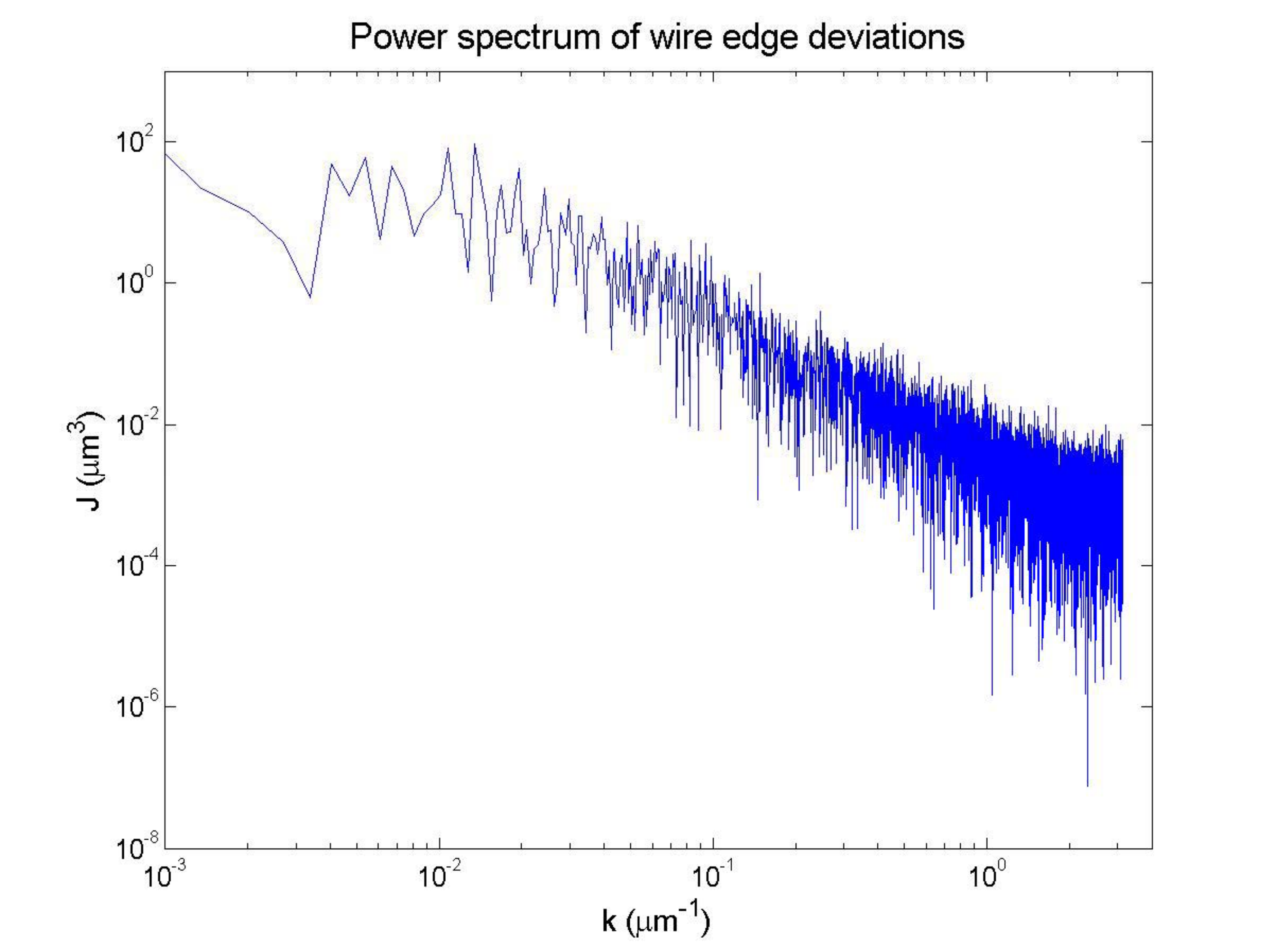
Fragmentation

- If the conductor is not perfectly straight…



- Our fragmentation appears to be due to edge roughness.

Fragmentation



- The amplitude of the fragmenting potential scales as:

$$K_1(ky) \approx \frac{e^{-ky}}{\sqrt{ky}}$$

Jones *et al.*, J. Phys B **37**, L15 (2004)

- When $y > L_{BEC}$ fragmentation becomes negligible

From nanoK to kiloK…

Fire in an a/c duct…

- Experiment not burnt, but covered in soot

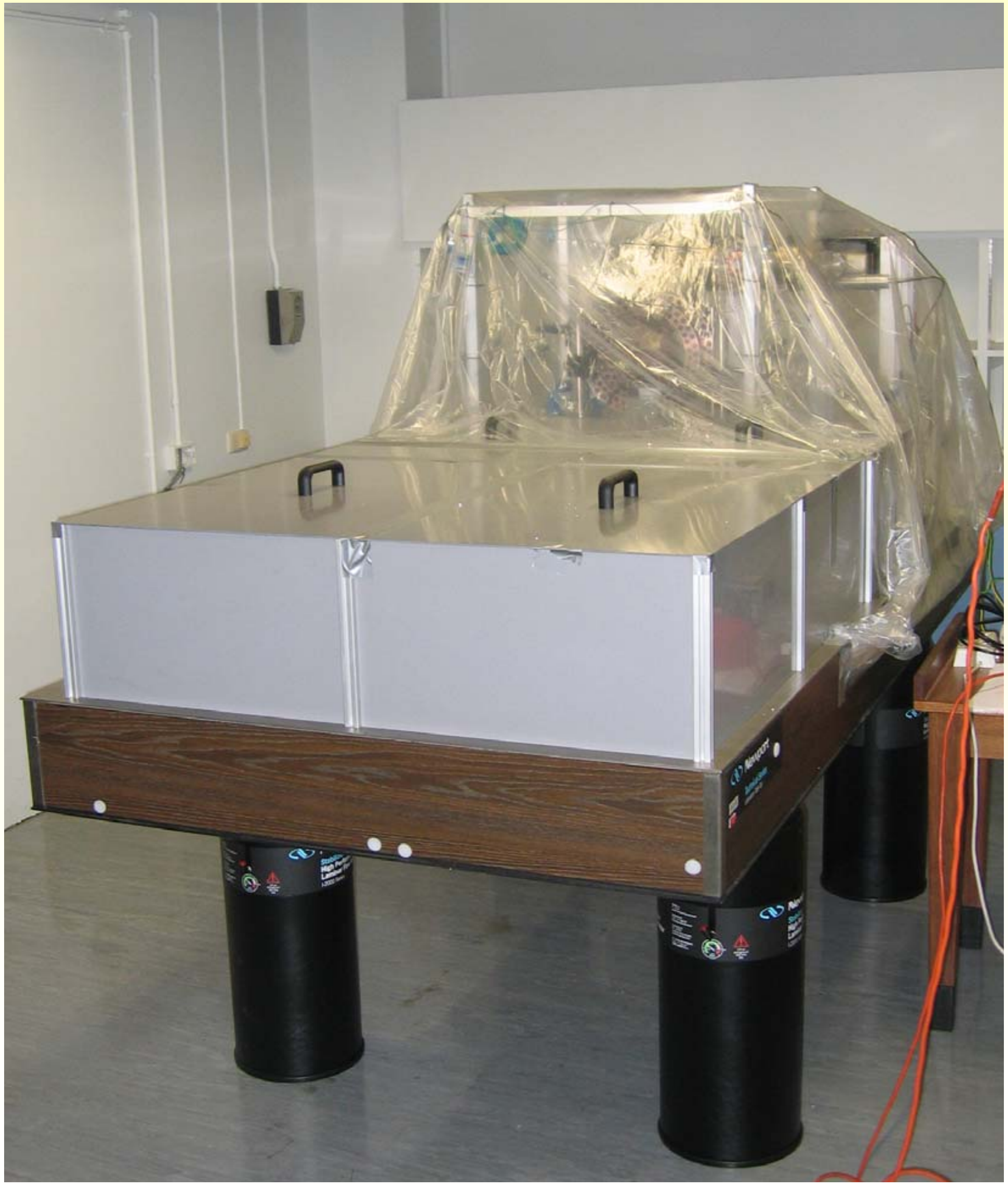
Following the fire…

- Packed up experiment
- New lab space was prepared

Call in the strong men…

Shifted to a new building...

A new home for the BEC



- The experiment is now ready to be reconnected and brought back to life in the new lab.

Accurate Atom Number Detection

What sort of detector??

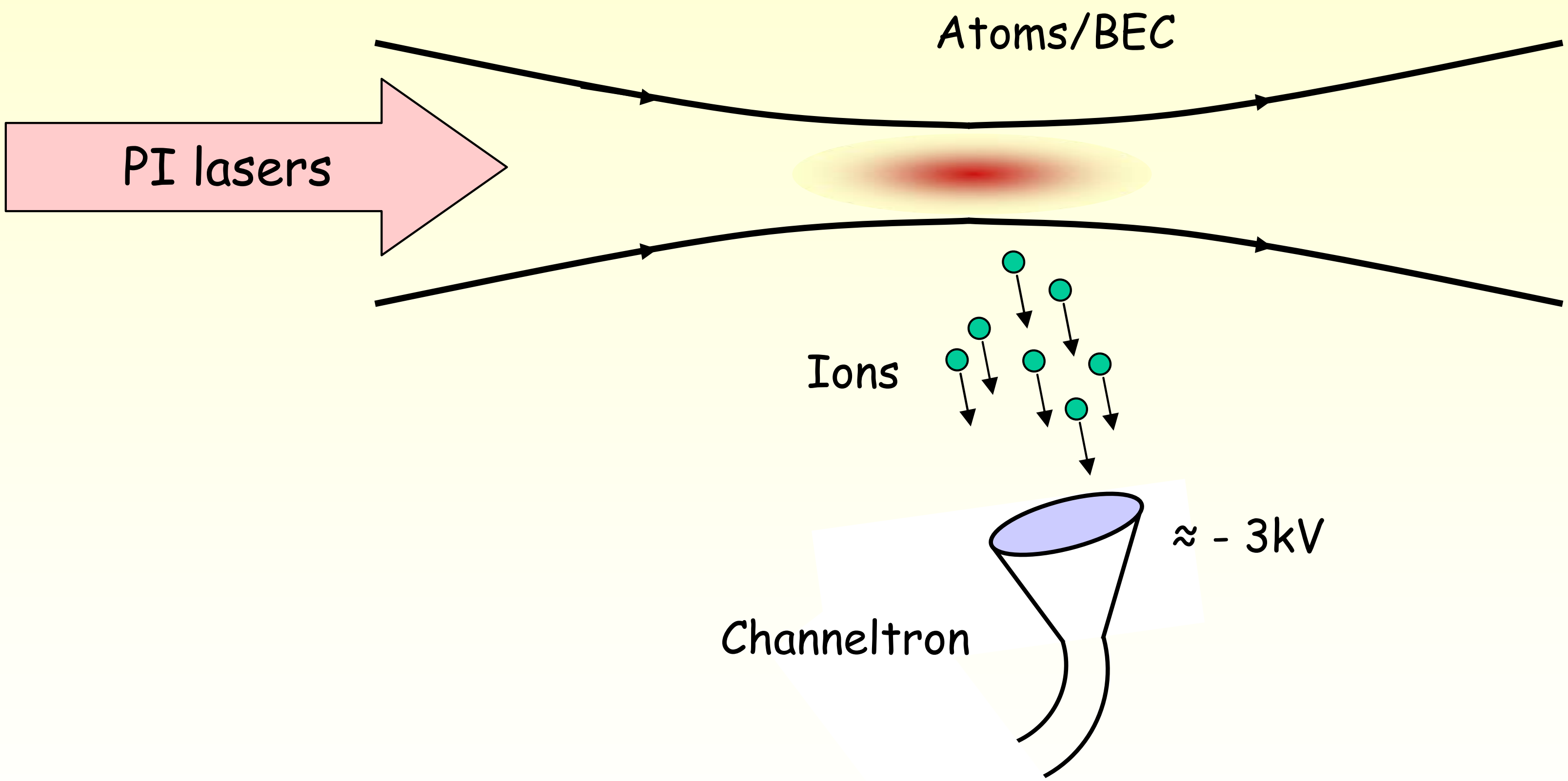
- To study quantum statistics of atom numbers in condensates we would like a detector with accuracy better than 1/√N, typically:

$$\frac{\Delta N}{N} < \frac{1}{\sqrt{N}} \approx 10^{-3}$$

- Absorption imaging doesn't really offer this kind of accuracy (usually a few %).
- **Possible solution: Photoionisation**

Proposed scheme

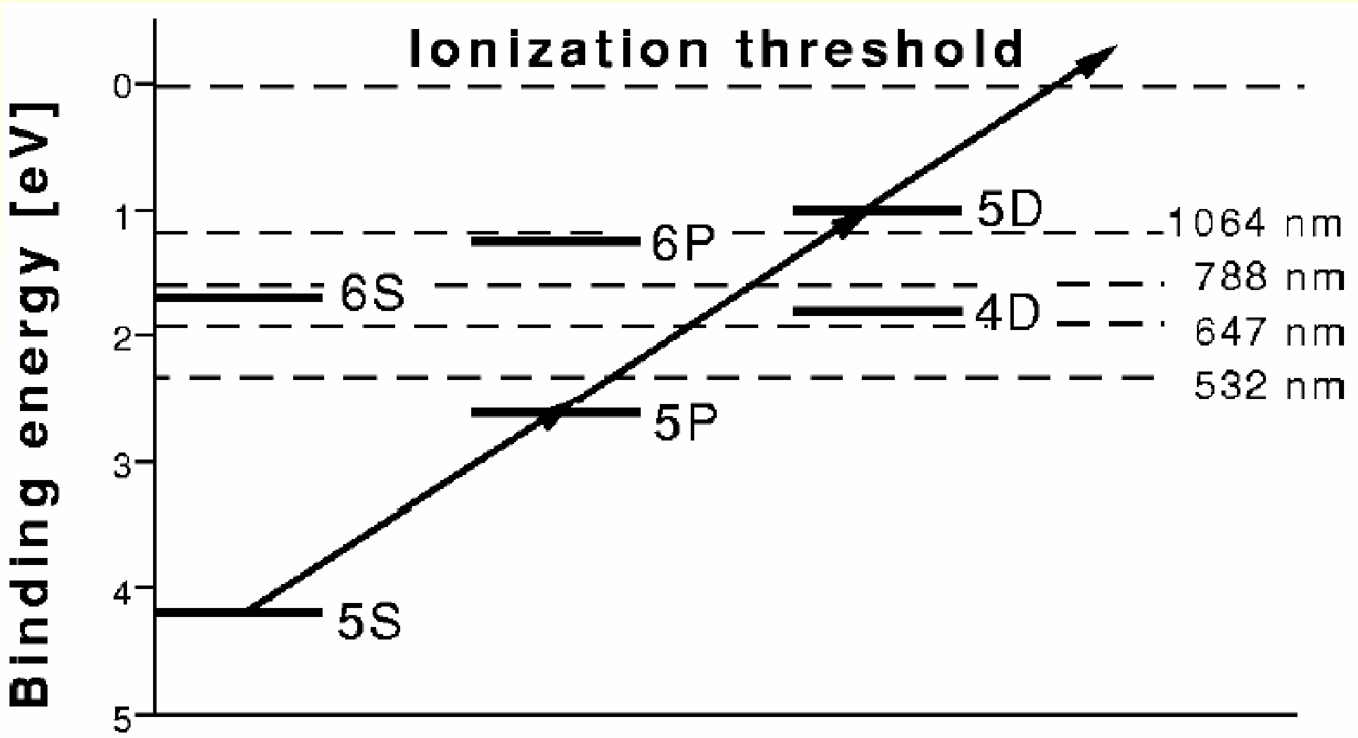
- Our proposed scheme is shown below



- Ions are accelerated towards channeltron and detected there

Efficient Photoionisation

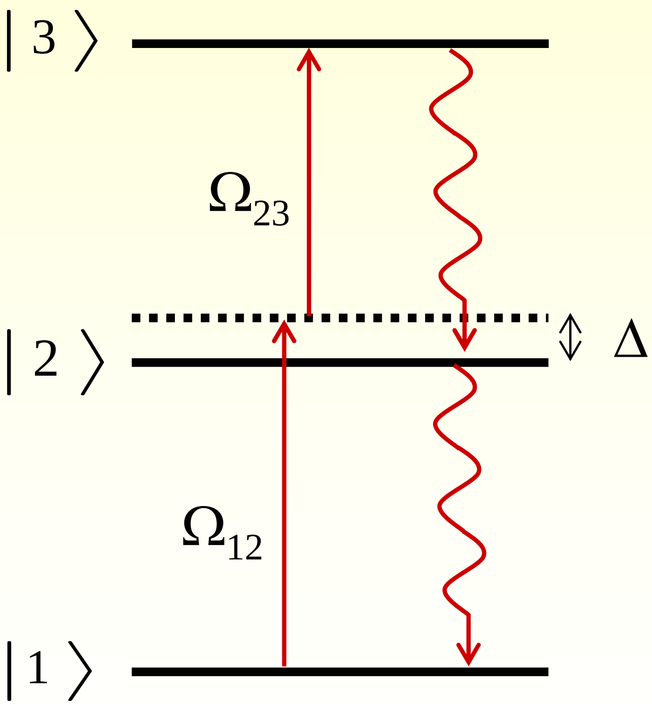
- Use STImulated Raman Adiabatic Passage (STIRAP) to transfer from 5S to 5D state.
- Ionise with pulsed Nd:YAG laser.



Duncan *et al.*, PRA **63** 043411, (2001).

STIRAP (Theory)

- Coherently transfer population from $|1\rangle$ to $|3\rangle$
- Use counter-intuitive pulse order



$$\hat{H} = \frac{\hbar}{2}\begin{bmatrix} 0 & \Omega_{12}(t) & 0 \\ \Omega_{12}(t) & 2\Delta & \Omega_{23}(t) \\ 0 & \Omega_{23}(t) & 0 \end{bmatrix}$$

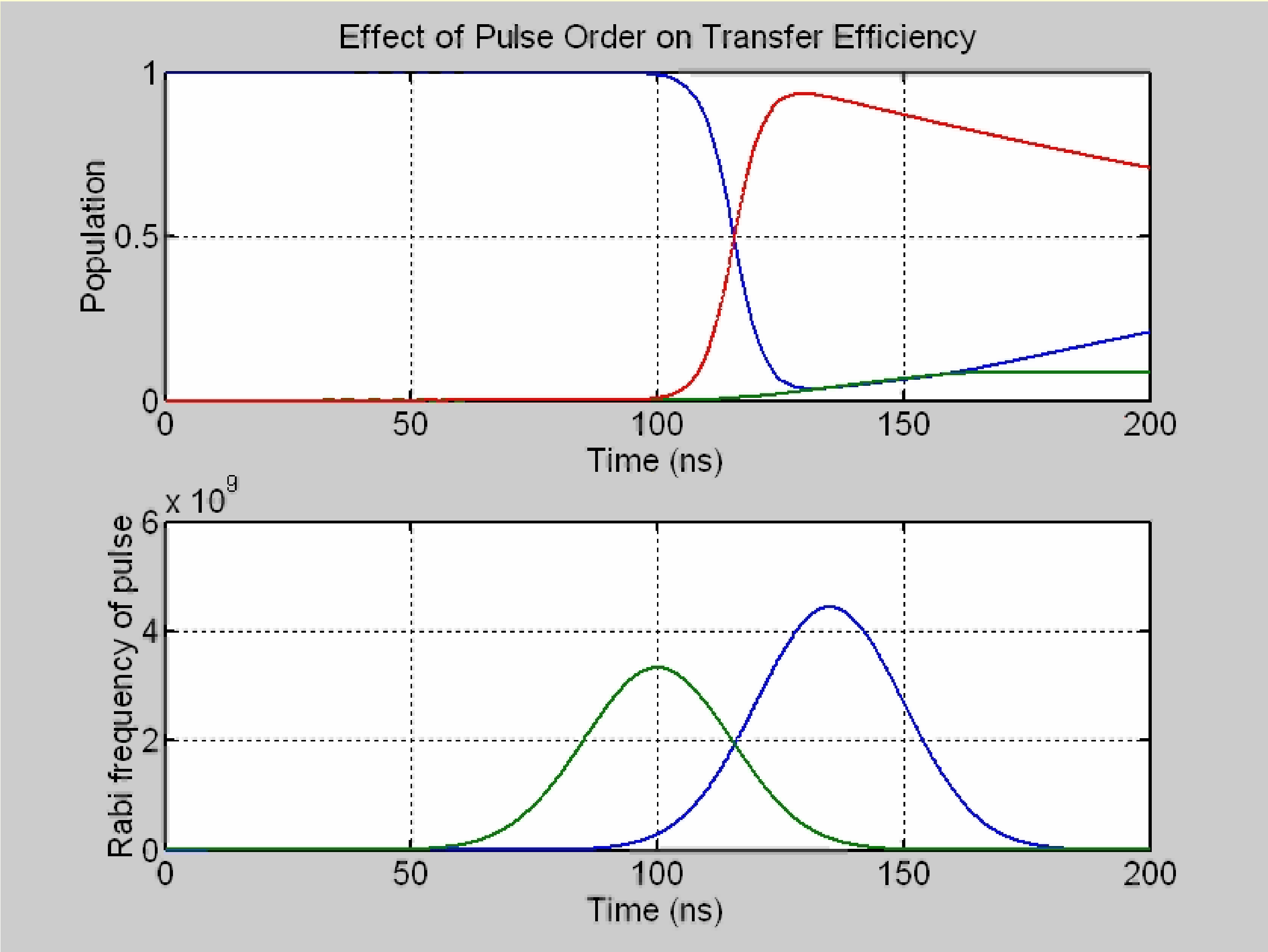
One eigenstate of $\hat{H}$ is:

$$|\psi_0(t)\rangle = \cos(\theta(t))|1\rangle - \sin(\theta(t))|3\rangle$$

where, $\tan(\theta(t)) = \Omega_{12}(t)/\Omega_{23}(t)$

STIRAP (Theory)

- Population transfer vs. pulse timing



— $5D_{5/2}$ population

— $5P_{3/2}$ population

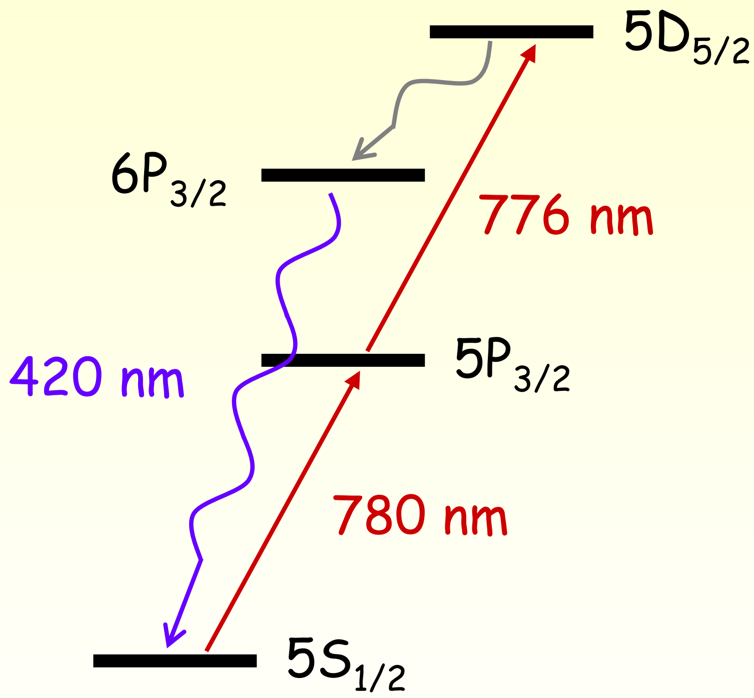
— $5S_{1/2}$ population

— Ω_{23} Rabi freq

— Ω_{12} Rabi freq

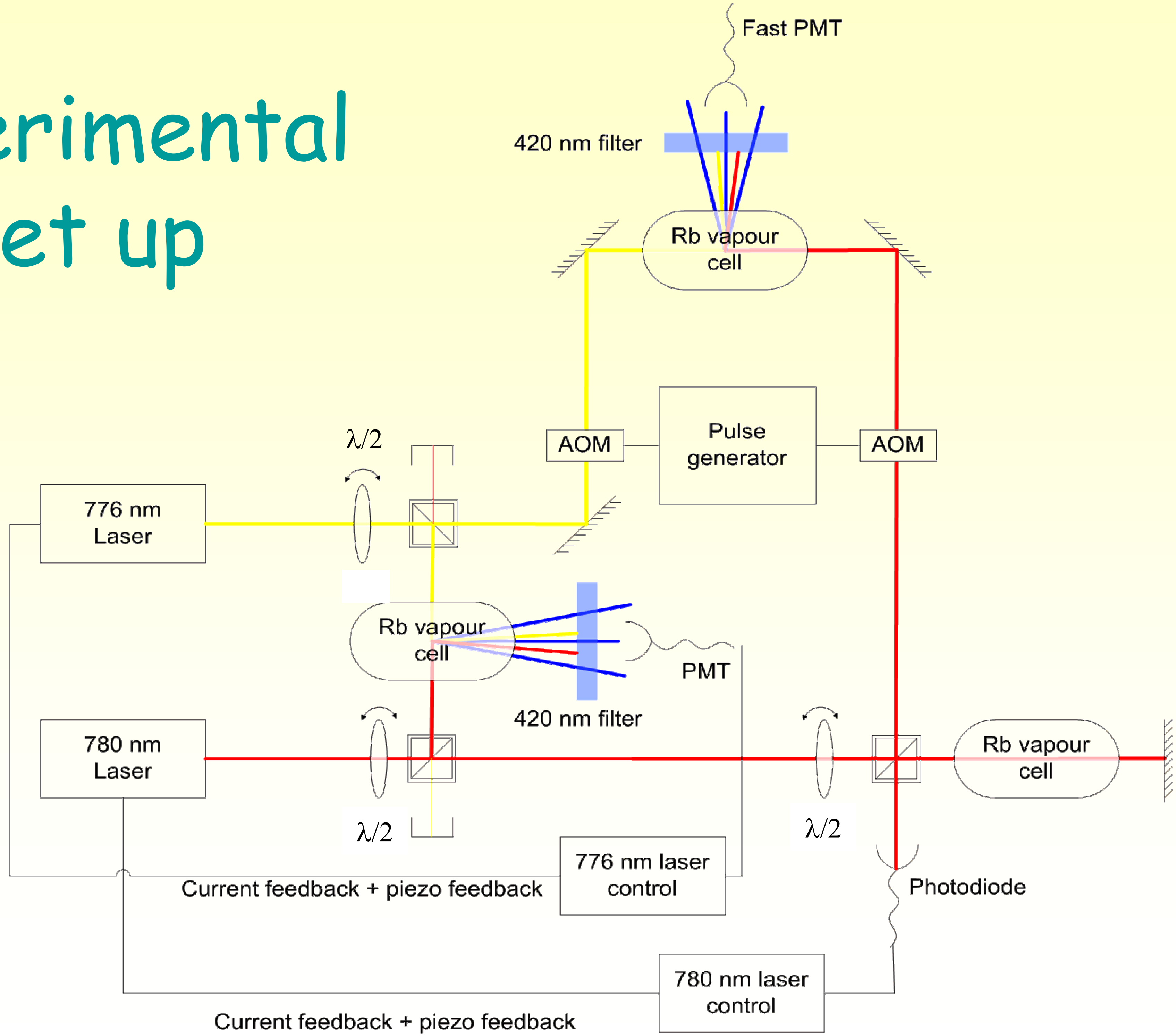
STIRAP (Experiment)

- A signature of the 5D state population is 420nm fluorescence



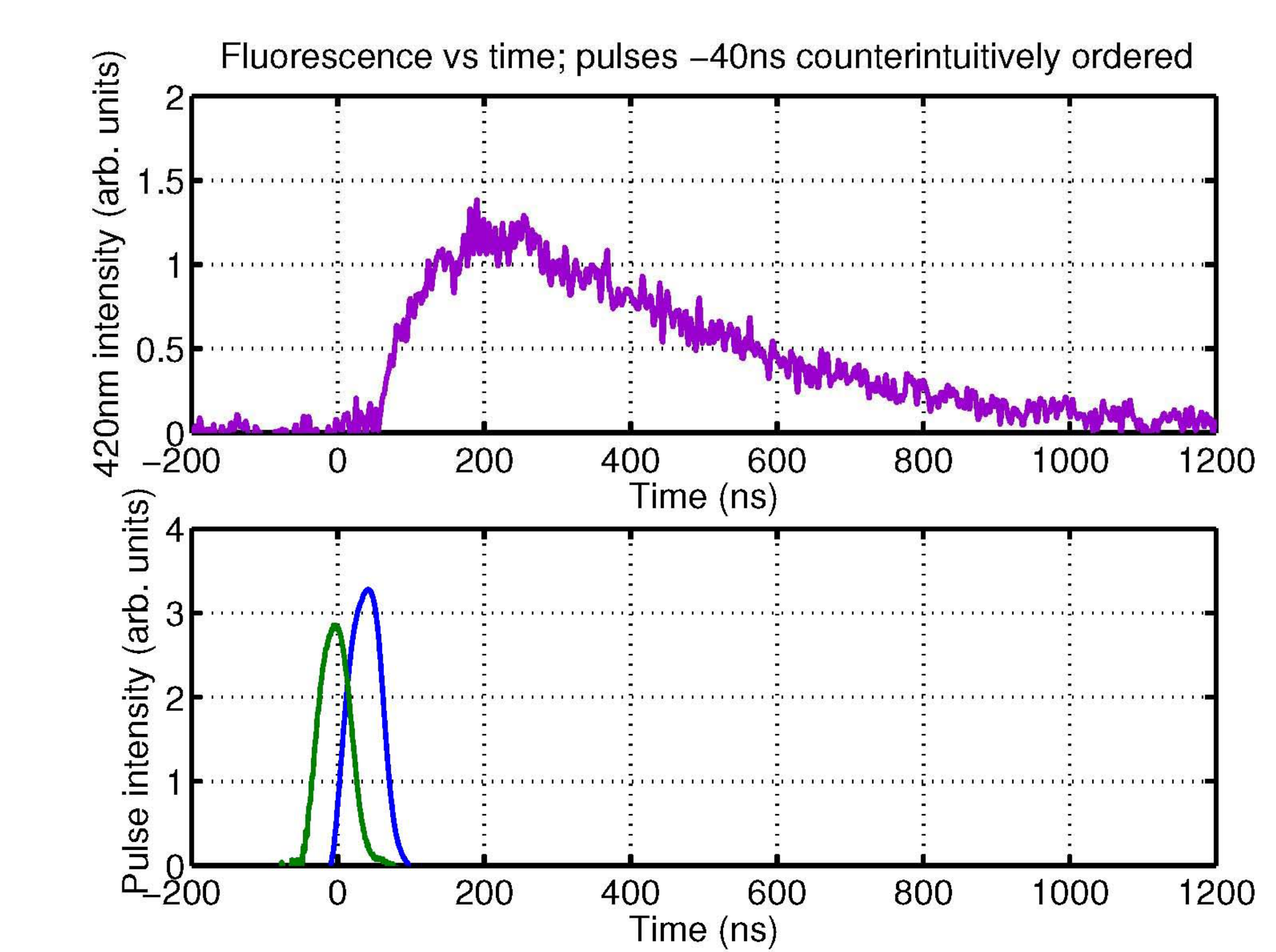
- Measure blue fluorescence to obtain STIRAP efficiencies

Experimental set up

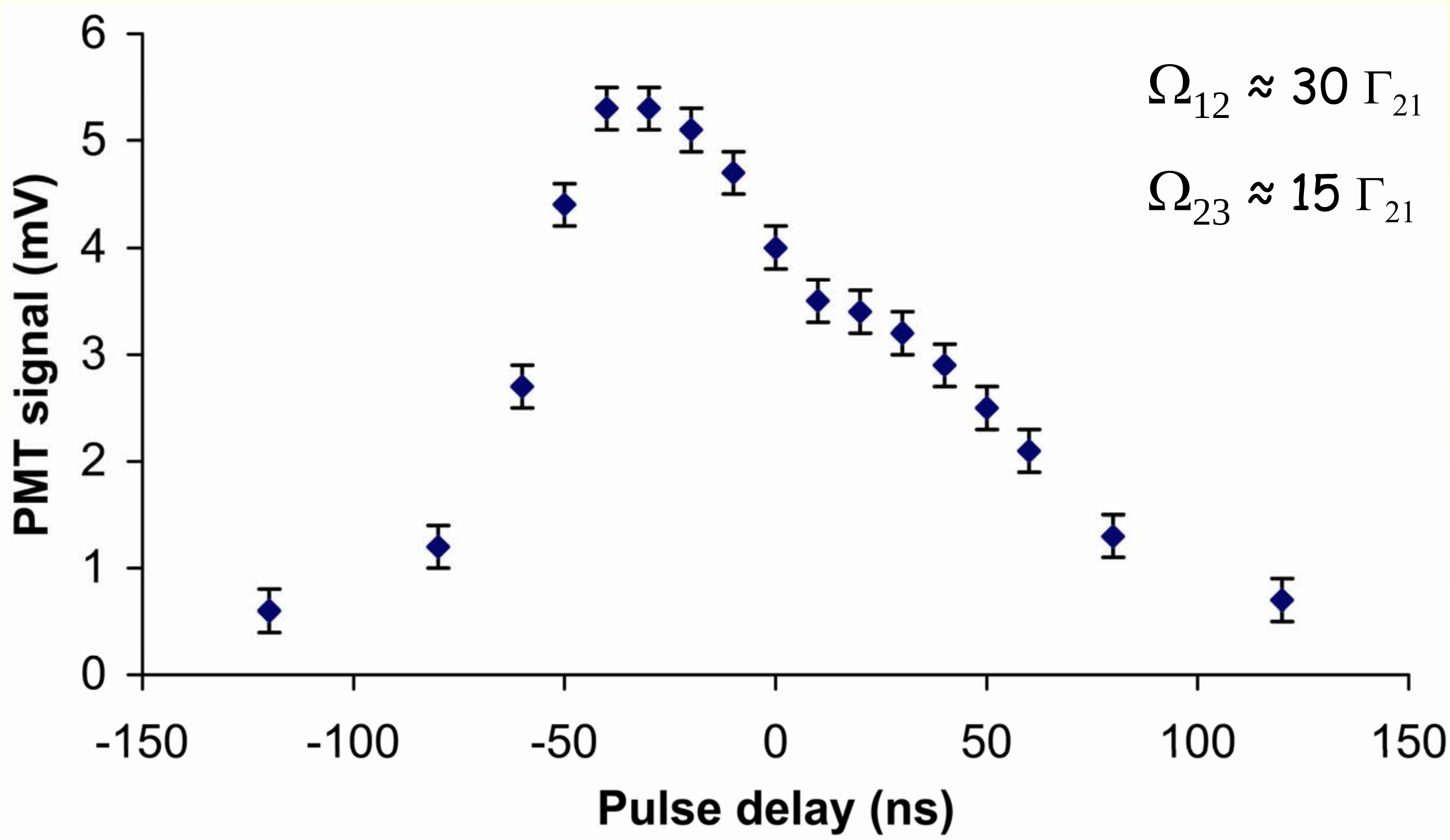


STIRAP Experiment

- The lasers are pulsed on and the blue fluorescence is monitored on a scope



STIRAP Results



- Counter-intuitive ordering works better!!

Summary and Outlook

- Produced BECs on an atom chip
- Saw fragmentation similar to electroplated wires
- Started STIRAP experiments
- New laser locking (see poster by A. Ratnapala)

- Get BEC working in new lab
- Photoionise with a pulsed Nd:YAG laser
- Try to photoionise a condensate
  - Investigate Pauli blockade