Transverse Excitation of ^{87}Rb BEC in an optical Trap

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Abstract

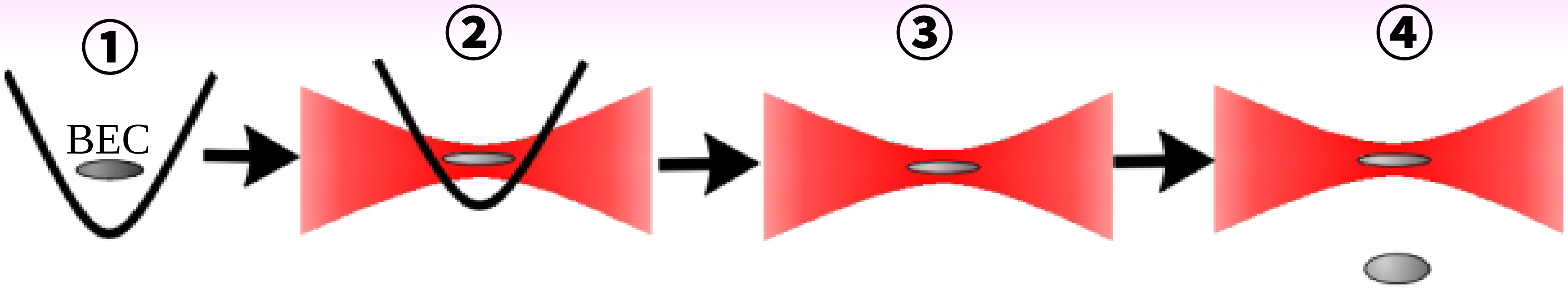
We have observed transverse excitation of BEC in an optical trap generated by a single red-detuned Gaussian laser beam.

The BEC was created in a magnetic trap, and was transferred into optical trap.

Some possible mechanisms for the excitation are discussed.

^{87}Rb state is F=2, mF=2

Experimental procedure 1

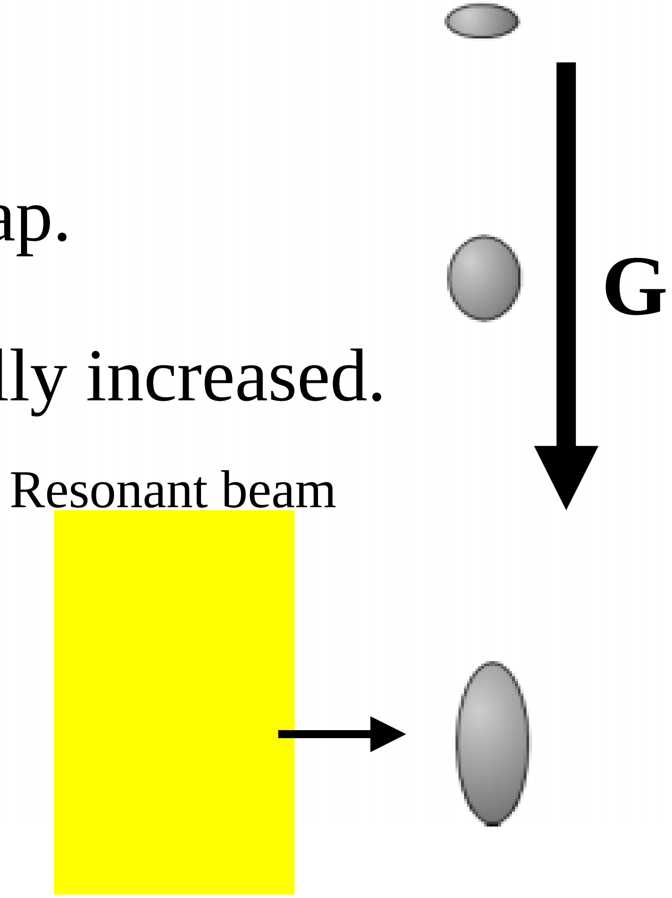


① BEC was created in a Magnetic Trap.

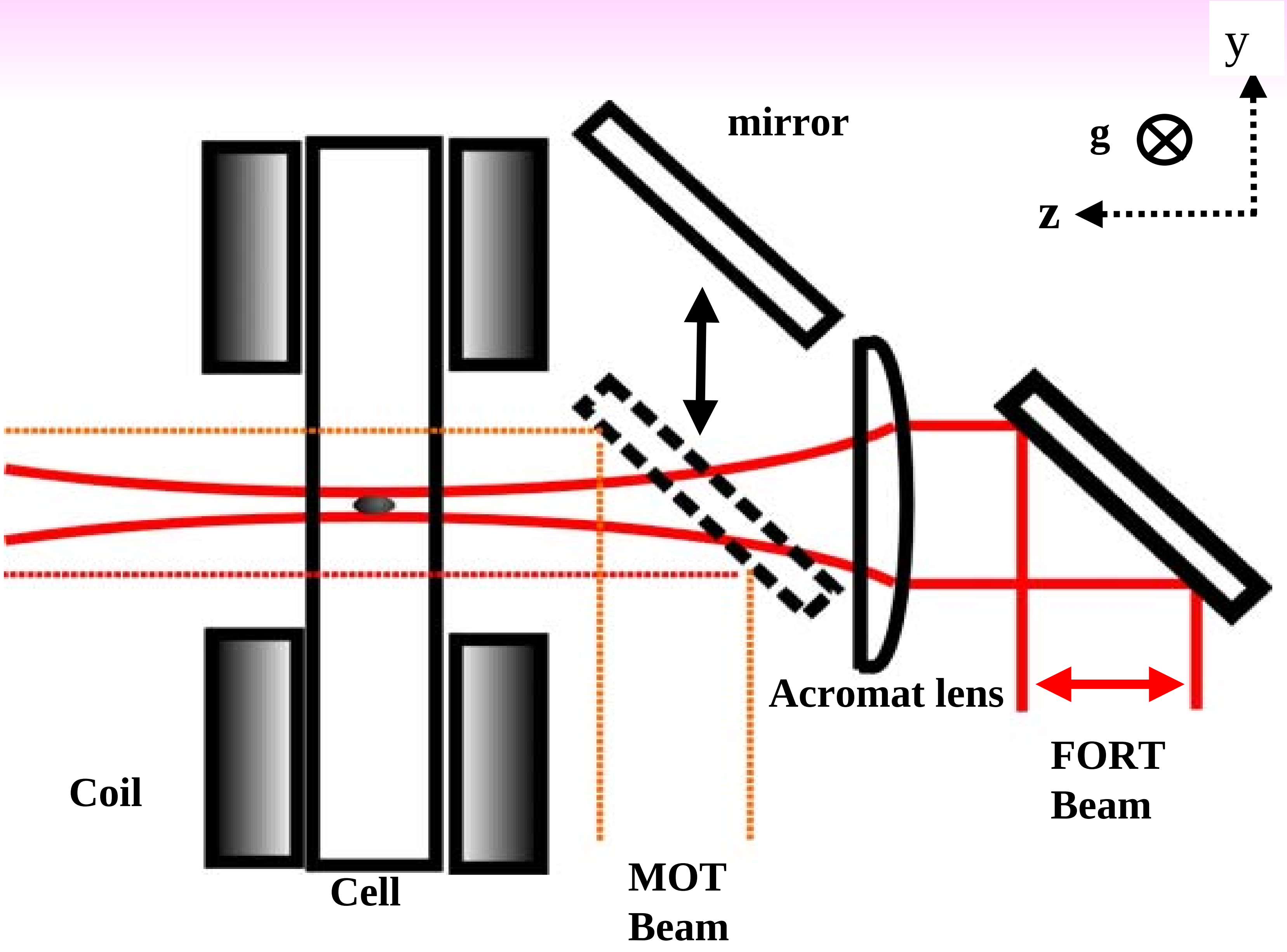
② Intensity of laser beam was gradually increased.

③ Pure optical trapping.

④ Time of Flight, and absorption imaging.



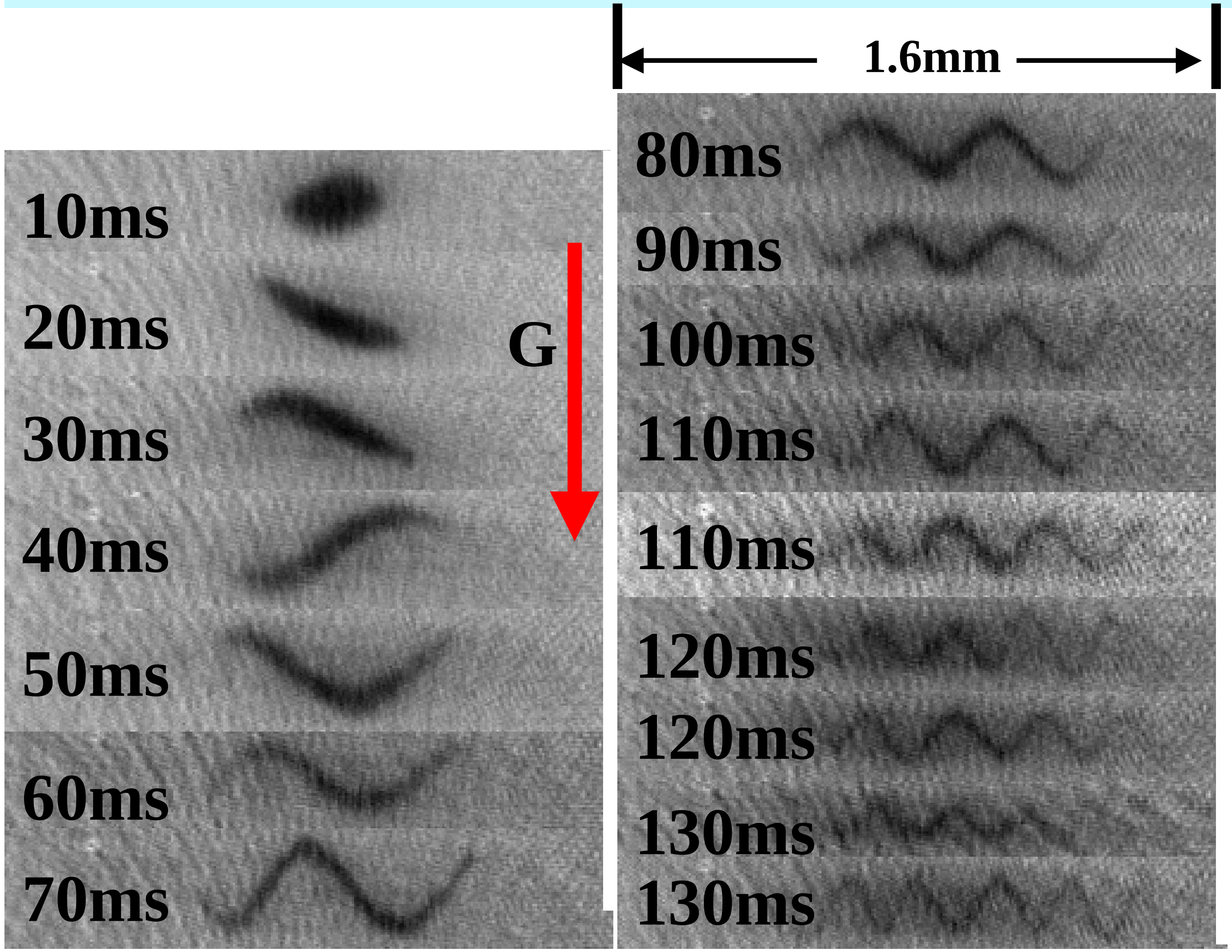
Optical Trap Setup



Experimental data ~ Time evolution in trap 1

Parameter

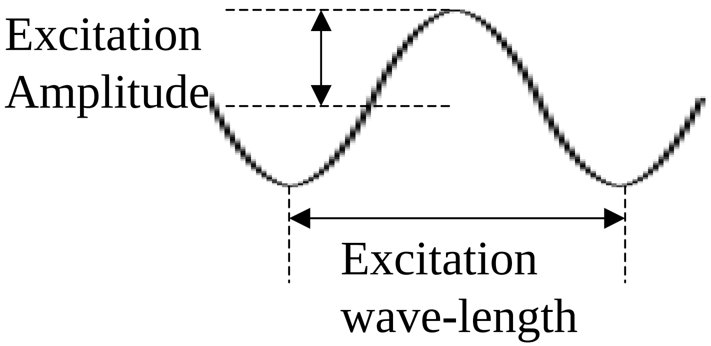
Time of Fright 17ms , Laser Power ~11mW, beam waist 10.5 μm, Ramp up time 300ms

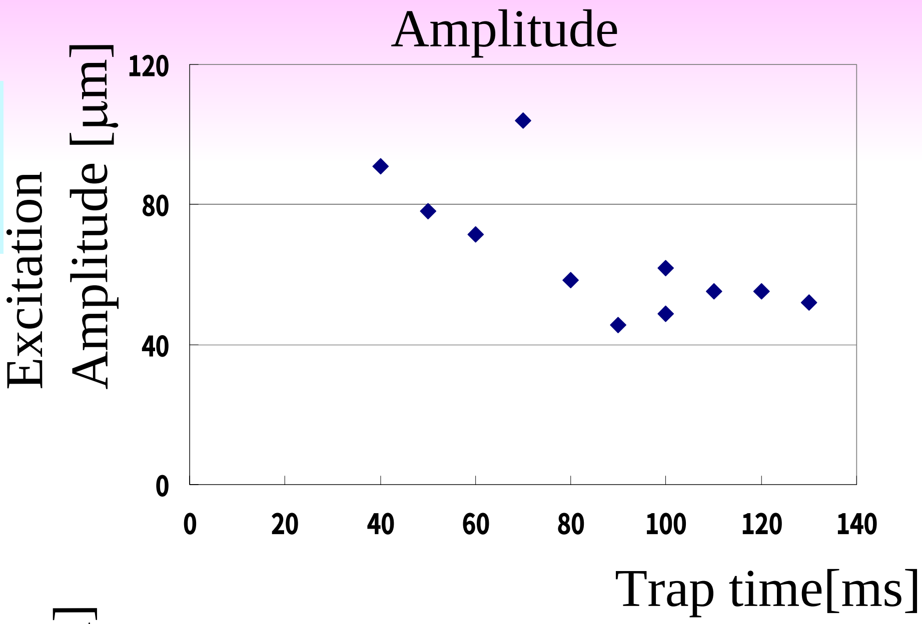


Pure optical trap resulted in this transverse excitation, without any additional perturbation.

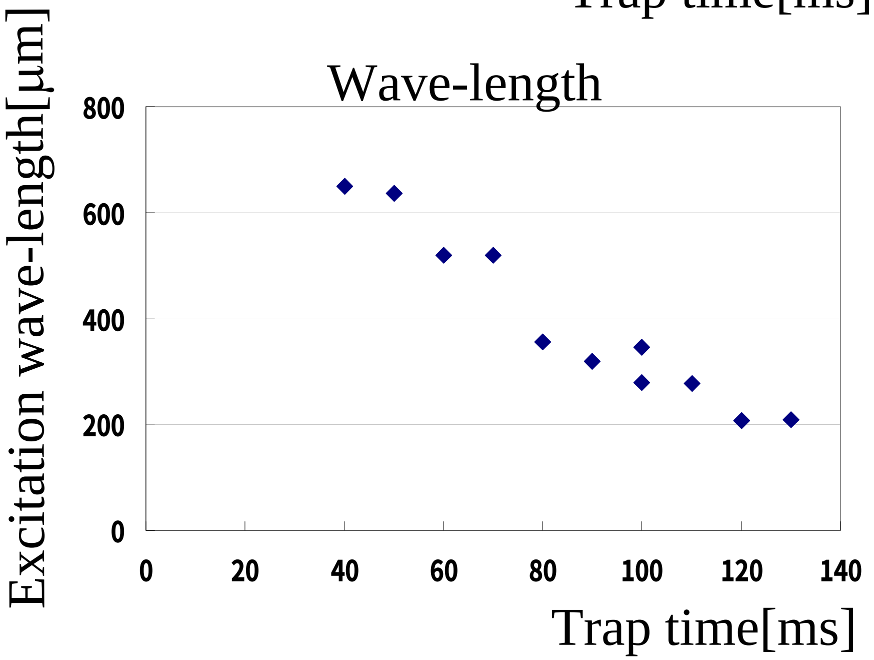
Experimental data ~ Time evolution in trap **2**

Definition of excitation amplitude and excitation wave-length





As the trap time increased, both the excitation amplitude and wave-length become shorter.



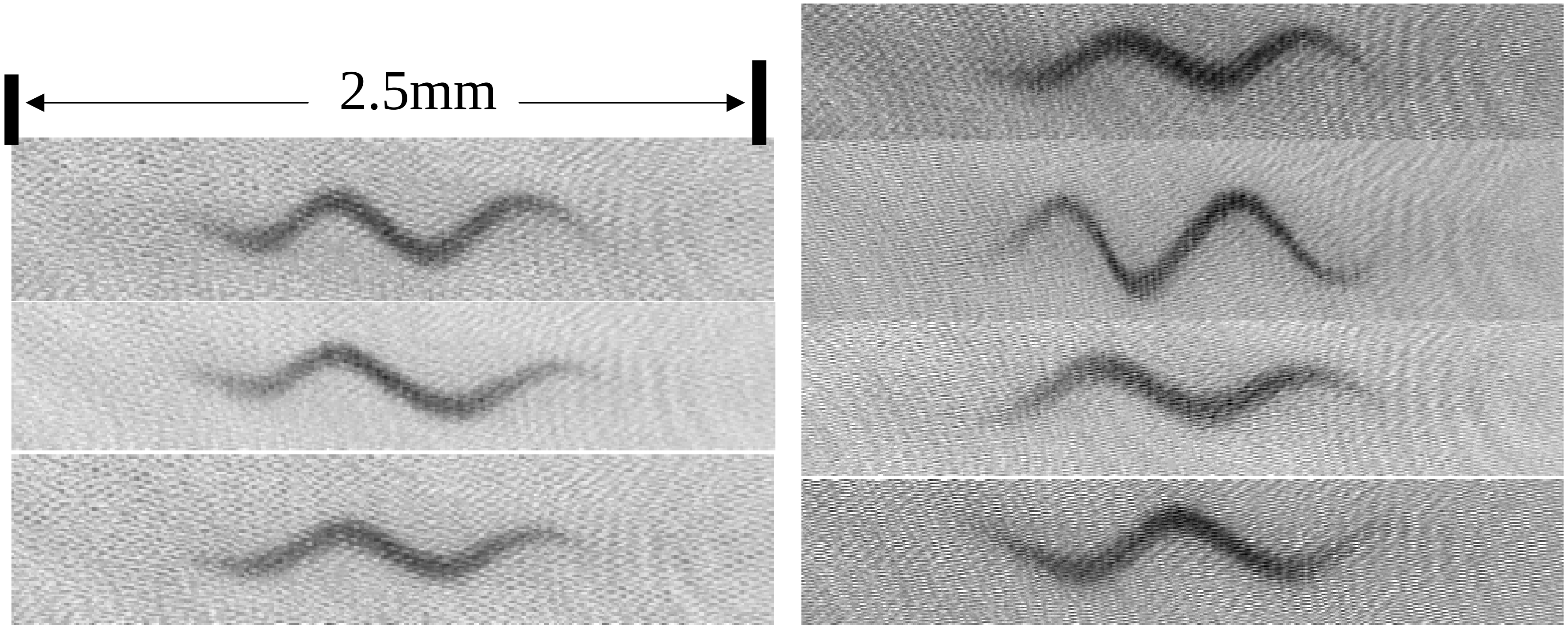
Excitation amplitude: 50μm
TOF time: 17ms
Axial trap frequency : 2π✕250Hz

➡ Initial oscillation amplitude : 1.9μm

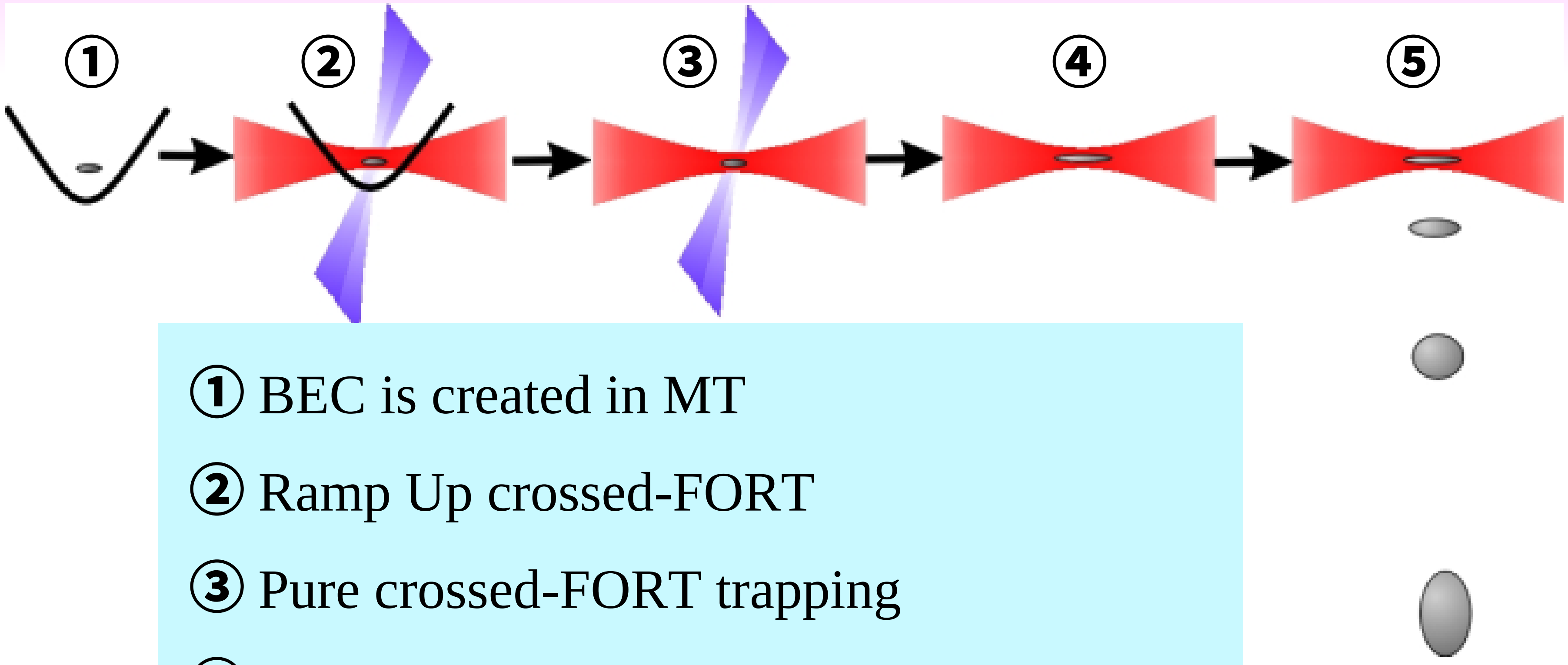
Reproducibility

Trap time 80ms, TOF 22ms, Ramp up time 100ms,
Beam waist 24μm Laser power ~7mw

These data are same condition



Experimental procedure 2



① BEC is created in MT

② Ramp Up crossed-FORT

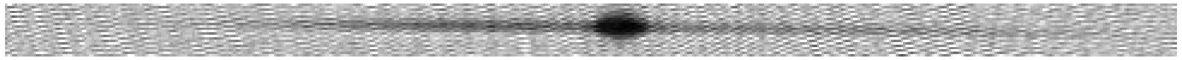
③ Pure crossed-FORT trapping

④ Pure single-FORT trapping

⑤ Time of Flight and absorption imaging

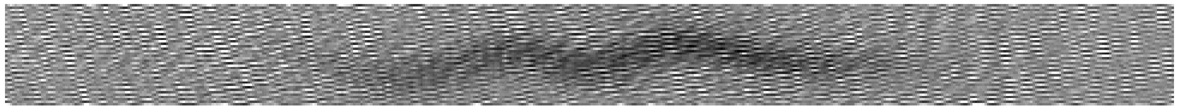
Experimental data2

Trapping by crossed-FORT Crossed trap-time 300ms

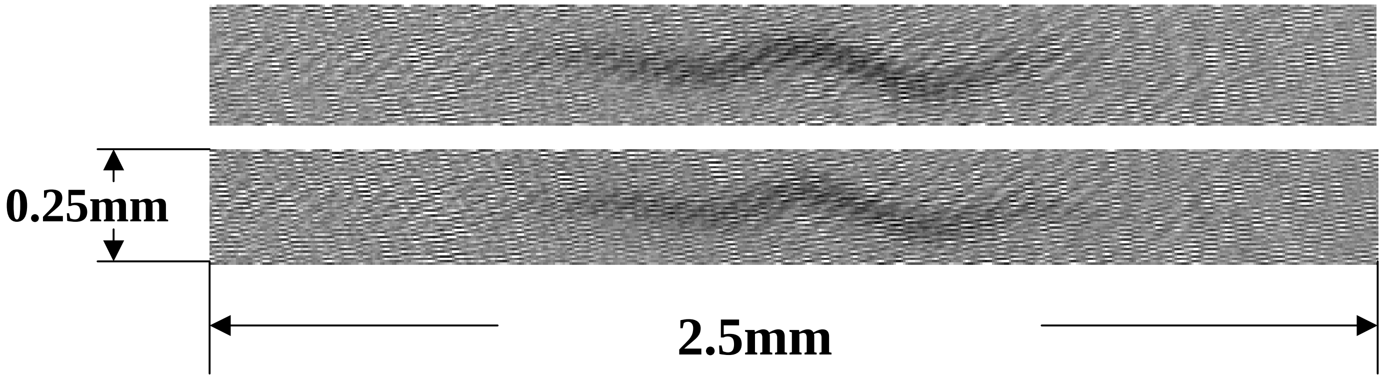


Axial power 7mW

Single-FORT trap time100ms

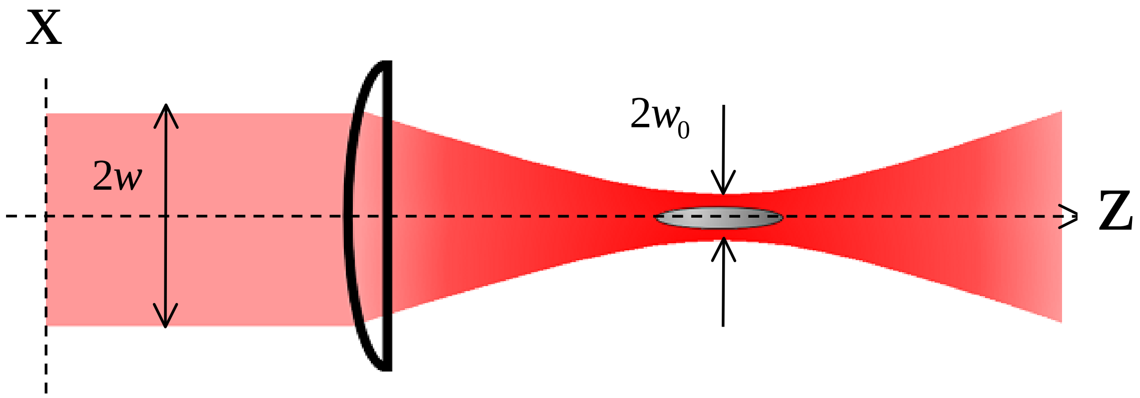


Single-FORT trap time 100ms Crossed trap time 1000ms



Far Off Resonance optical dipole force Trap (FORT)

For red-detuning the focus point is the potential minimum (without gravity).



$$U(x,z) = \frac{U_o}{1+\left(z/z_{ray}\right)^2}\exp\left[-\frac{2x^2}{w_0^{\,2}\left\{1+\left(z/z_{ray}\right)^2\right\}}\right]$$

$$z_{ray} = \frac{kw_0^{\,2}}{2} \qquad U_o = \frac{\eta\Gamma^2}{8\delta}\frac{2P}{I_s \pi w_0^{\,2}}$$

Parameter

P laser power ~ 10mw

$\lambda = \frac{2\pi}{k} = 850\ nm$

w_0 *Laser waist ~24 μm*

U_o ~ 5 μK

δ *Detuning ~ (780 − 850) nm*

Γ Natural line width

I_s saturation intensity

The feature of optical potential with gravity

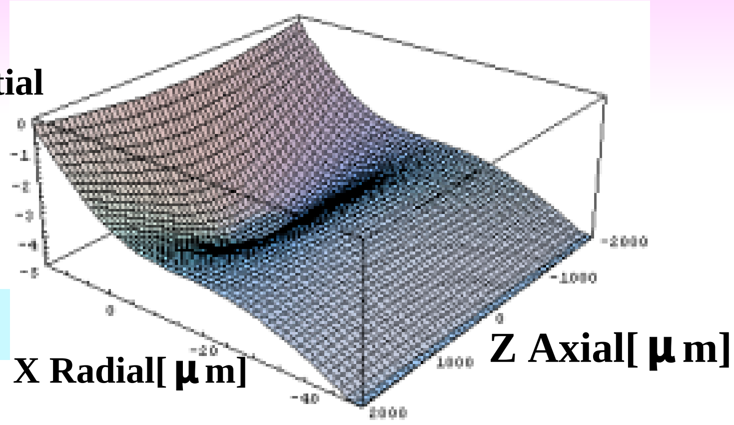


Fig1

Cross section at Z=0 Z=1000μm

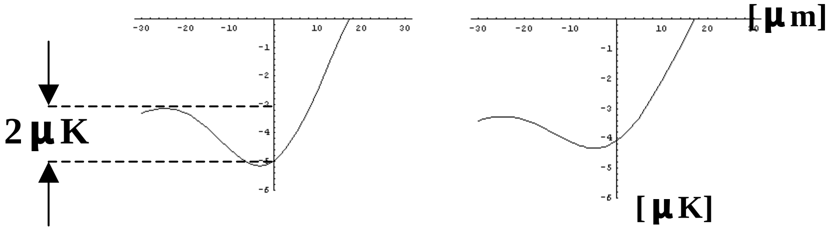


Fig2

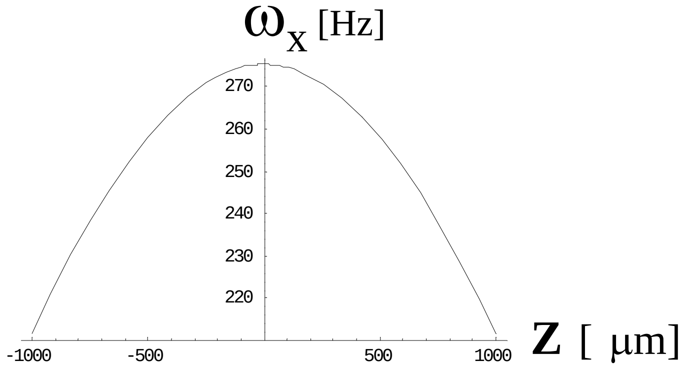


Fig3

Magnetic Trap(MT)	Optical Trap (OT)
$\omega_x = 2\pi \times 155$ Hz	$\omega_y = 2\pi \times 289$ Hz
	$\omega_x = 2\pi \times 275$ Hz
$\omega_z = 2\pi \times 15$ Hz	$\omega_z = 2\pi \times 2.30$ Hz

List1 Trap frequency

Fig1 Potential profile of the optical trap including gravity interaction.

Fig2 Cross section at Z=0 and 1000μm.

Fig3 For focused Gaussian beam, radial trap frequency depends on z position.

List1 Axial trap frequency of MT is larger than OT. After BEC is transferred into optical trap, BEC spreads in the axial direction.

Model 0

1 When MT is switched off, BEC is perturbed by magnetic field

→ In the experimental procedure2, crossed-FORT trap time is taken long enough. However we observed transverse excitation.

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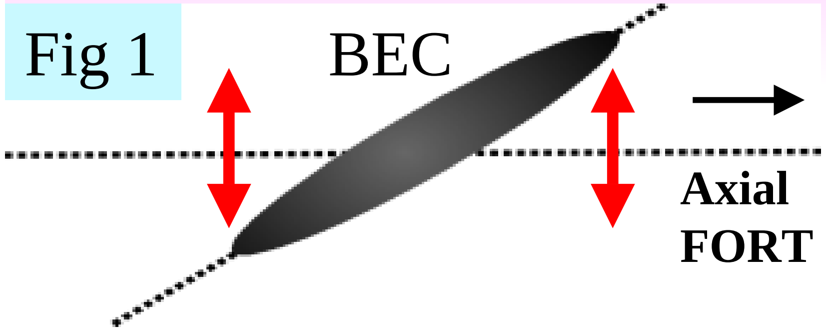
2 FORT beam oscillates when BEC is trapped, therefore BEC is oscillated.

→ FORT beam may oscillate. However in this model, it seems difficult to explain why sinusoidal transverse excitation is observed.

Model 1

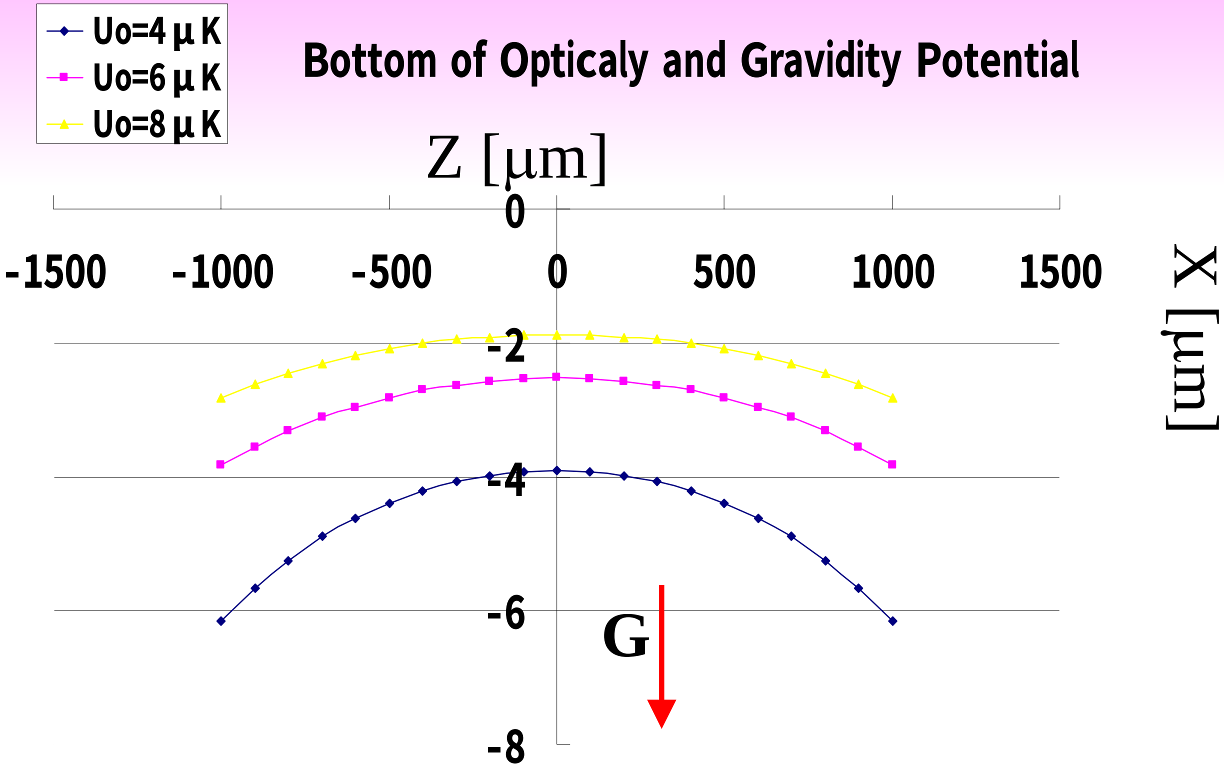


If MT and OT axis are not parallel, BEC may start to oscillate when MT is off. Because the radial trap-frequency depends on the z-position, the oscillation phase may also depend on the position.

Experimental procedure 2. When the crossed-FORT trap time is taken long enough, we can assume that the direction of BEC and single-FORT axis are parallel. Therefore according to model 1, transverse excitation does not occur in this case. However, we have observed transverse excitation even for crossed-FORT case.

This result indicates that the potential profile of single-FORT is important for transverse excitation.

Model 2



This figure shows the minimum point of the potential in x direction as a function of z-position. For a focused beam, the minimum line of potential is not parallel to z-axis.

Does this effect cause transverse excitation when BEC propagates along the minimum line?

cf. A.E.Leanhardt, *et al*.PRL 89. 0404 01 (2002).

Model 3 ~ part 1

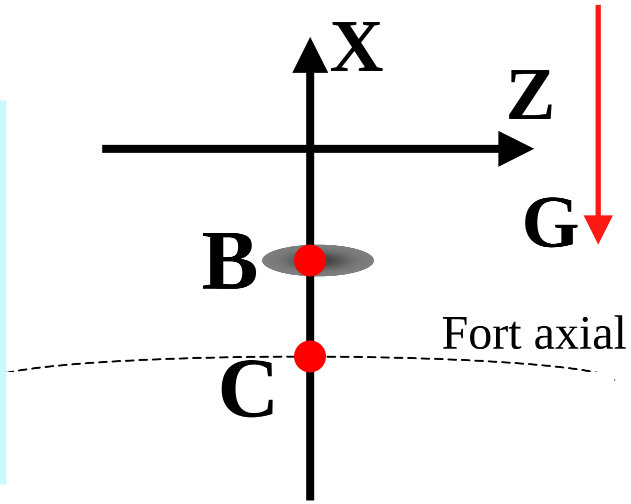
Let's consider change of the potential in the experimental process

minimum point of potential at Z=0

☆Please refer to Experimental procedure 1

② $\mathbf{U} \propto [(\omega_{MT} + \omega_{OT})X]^2 + gX \propto (X-\mathbf{B})^2$

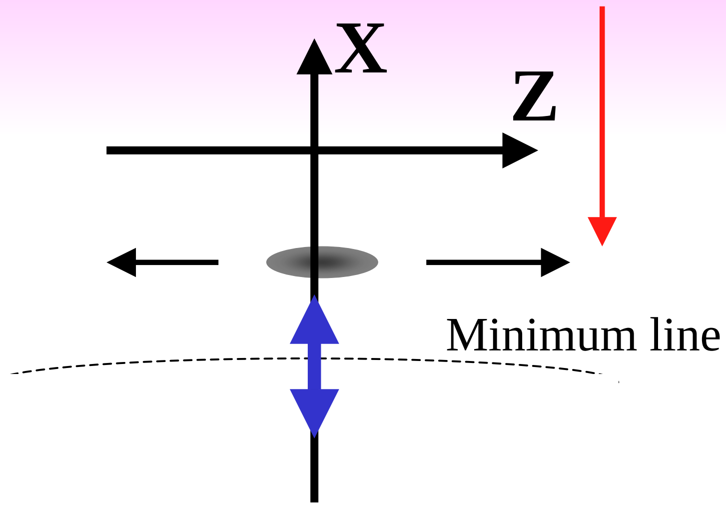
③ $\mathbf{U} \propto (\omega_{OT}X)^2 + gX\ c \propto (X-\mathbf{C})^2$



After ramp up, MT was suddenly switched off. At this time, minimum point is shifted from **B** to **C**. This means BEC may have potential energy and oscillate in OT.

This shift was estimated to be 2~4μm and it is consistent with the excitation amplitude.

Model 3 ~ part 2



BEC propagates in z-direction while oscillating in x-direction.

Because the radial trap-frequency depends on the z-position, the oscillation phase may also depend on the position (as in model 1).

In this model, because the potential has line symmetry, the transverse excitation also must have line symmetry. However, observed transverse excitation does not have line symmetry.