Optical Dipole Force Trap of ^{87}Rb Bose-Einstein Condensates

Department of Physics, Gakushuin University

K. Araki, N. Kikuchi, T. Eno,

T. Kuwamoto, T. Hirano

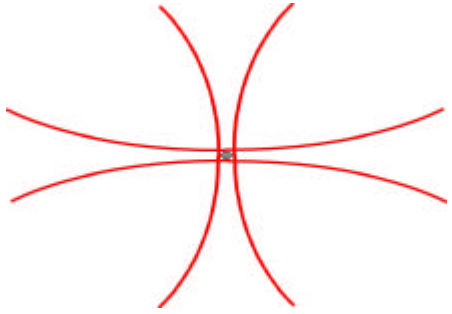
Abstract

- Confinement of BEC in a crossed-FORT

  Control of trap potential, frequency and aspect ratio

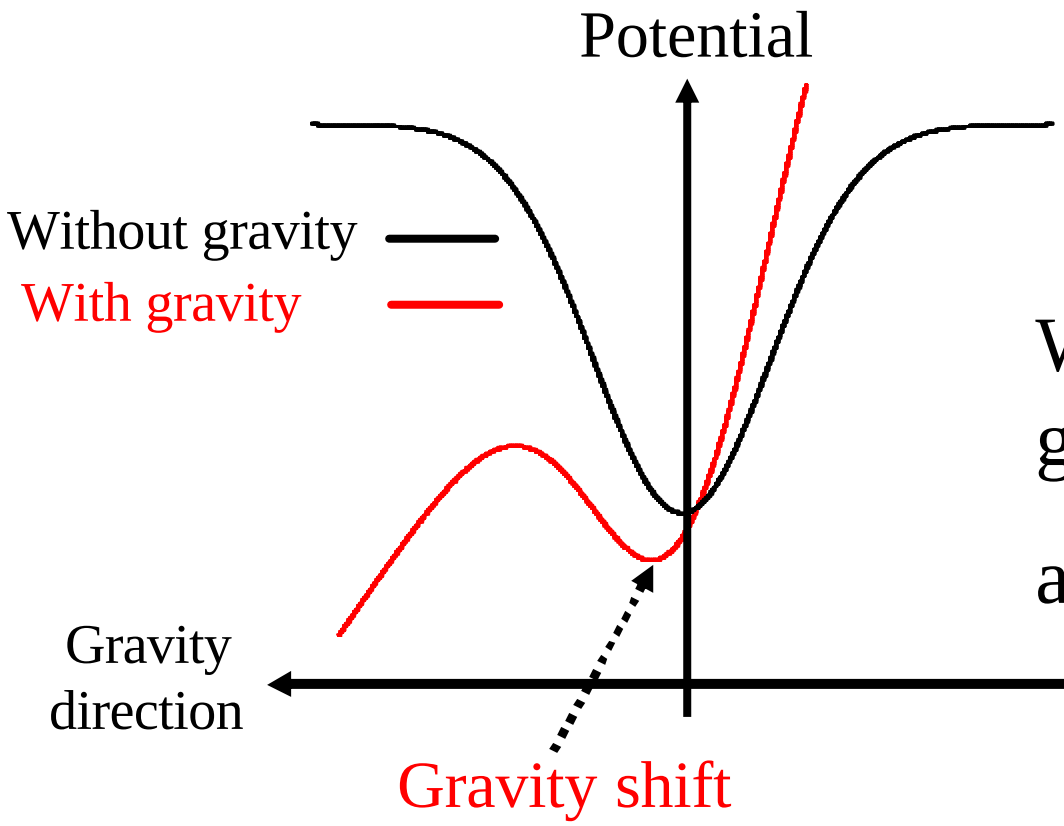
  $\Rightarrow$ We have realized the parameters that are similar to the magnetic trap.

- Life time measurements of BEC in a crossed-FORT



Potential of optical trap

- Shallow potential depth ⇒ Gravity can't be ignored.
- Gaussian beam ⇒ Potential is anharmonic.



We considered the effects of gravity and Gaussian profile,

and calculated as follows ・・・

Calculations of trap depth and frequency (1)

< Trap potential >

$$U(x,y,z) = U_{dip}(x,y,z) + U_g(x)$$

$$\frac{\partial U(x,0,0)}{\partial x} = 0 \quad \Rightarrow \quad x = x_0, x_1 \quad (\,|x_0| < |x_1|\,)$$

$$U_0 = U(x_1,0,0) - U(x_0,0,0)$$

$$U_{dip} = U_{\text{z-axis}} + U_{\text{y-axis}}$$

$$= \frac{U_{\text{z-axis0}}}{1+(z/z_r)^2} \exp\left[\frac{-2(x^2+y^2)}{w_{y0}{}^2(1+(z/z_r)^2)}\right]$$

$$+ \frac{U_{\text{y-axis0}}}{1+(y/y_r)^2} \exp\left[\frac{-2(x^2+z^2)}{w_{z0}{}^2(1+(y/y_r)^2)}\right]$$

< Trap frequency >

$$w_q(x,y,z) = \sqrt{\frac{\partial^2 U(x,y,z)}{\partial q^2} \Big/ m}, \quad (q: x,y,z)$$

$\Rightarrow$**Position dependence**

Trap frequencies are defined at the potential minimum.

$$w_q = w_q(x_0,0,0), \quad (q: x,y,z)$$

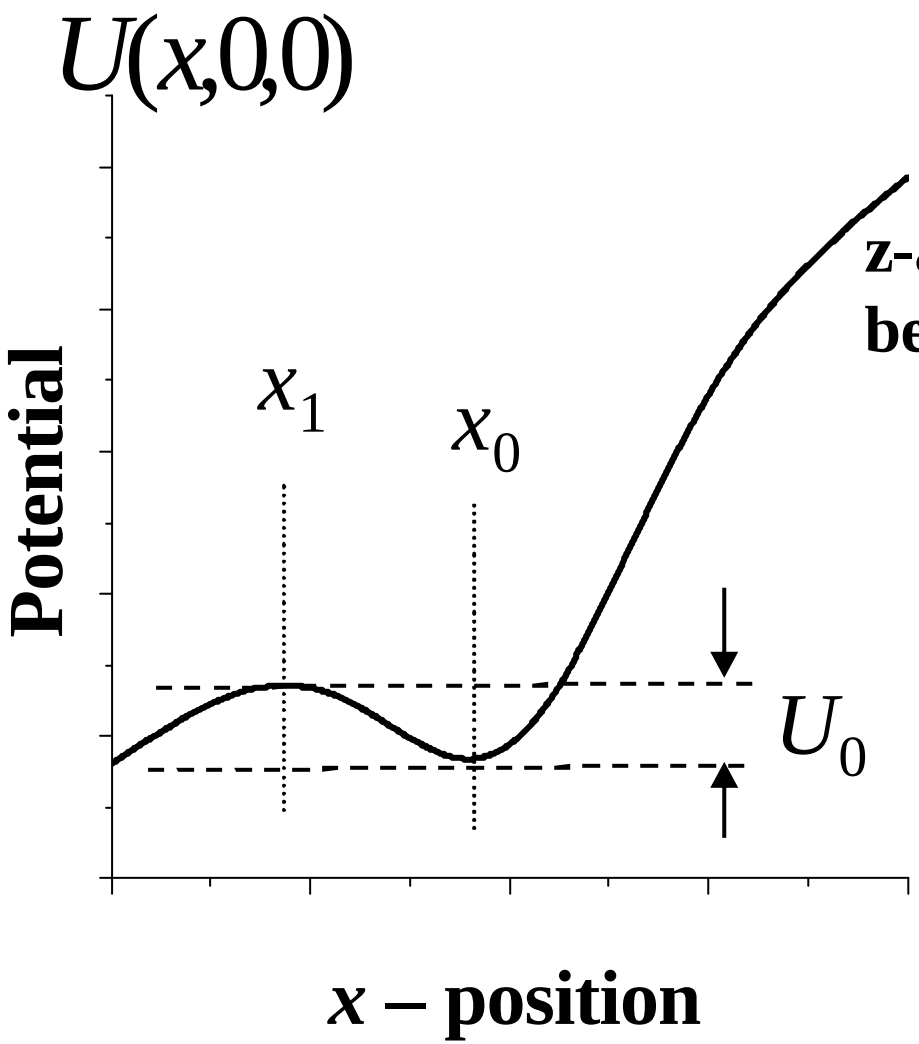
$U_{z-\text{axis}}$: potential of $z-$axis beam

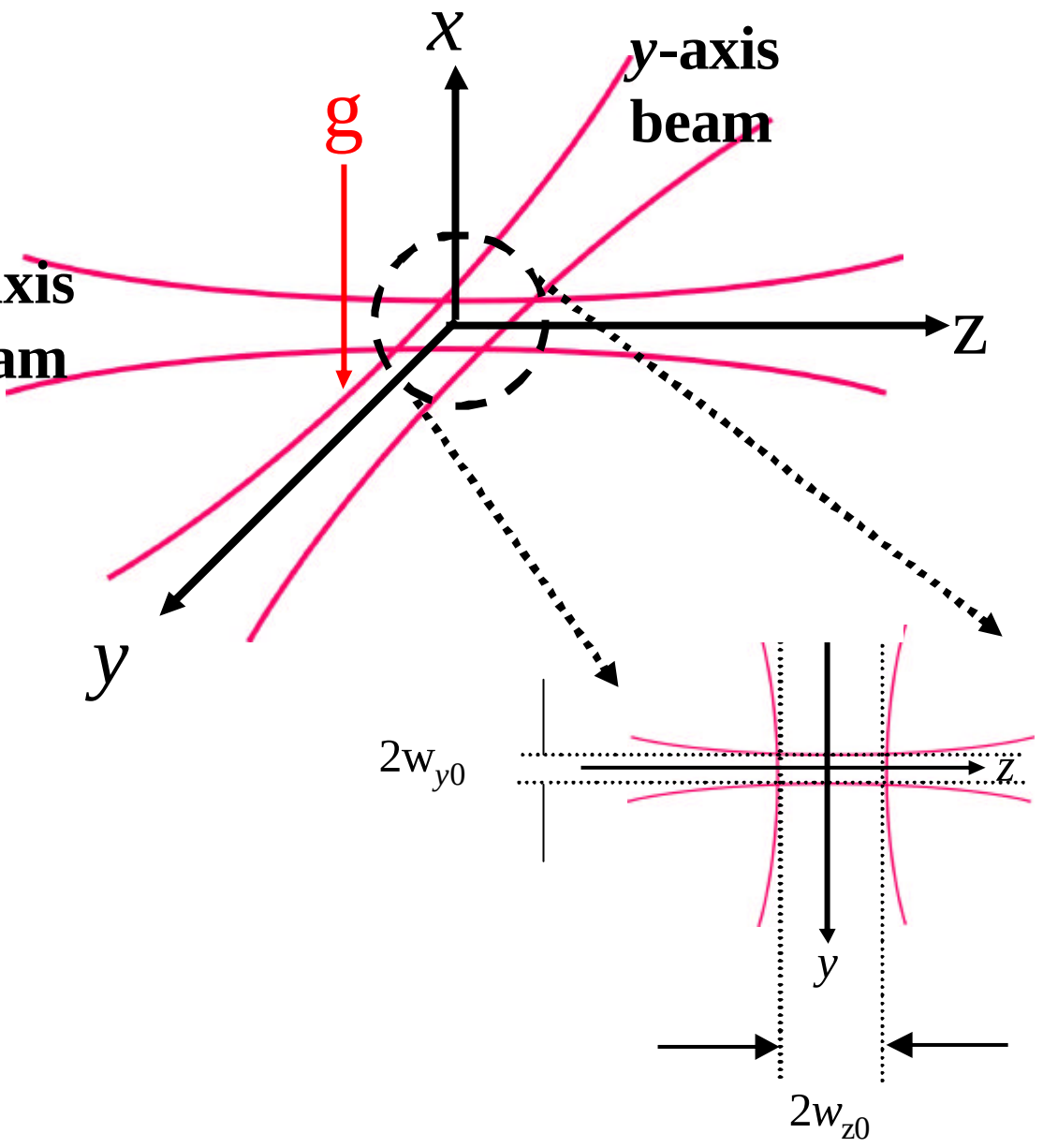
$U_{y-\text{axis}}$: potential of $y-$axis beam

z_r, y_r : Rayleigh length , w_{y0}, w_{z0} : $1/e^2$ radius

$U_{z-\text{axis0}}, U_{y-\text{axis0}}$: maximum potential depth

Calculations of trap depth and frequency (2)





Potential parameters of single-FORT

Adjustment of aspect ratio $1/e$

< Magnetic Trap : MT >

$1/e \sim 10,\ \bar{w} \sim 2p \times 71\ [\mathrm{Hz}],\ U_0 \sim 1.2\ [m\mathrm{K}]$

<Single-FORT>

$l \sim 850\ [\mathrm{nm}]$ (Red tune), $1/e \sim 10$

$\Rightarrow$ beam waist w_0 ($1/e^2$ radius)

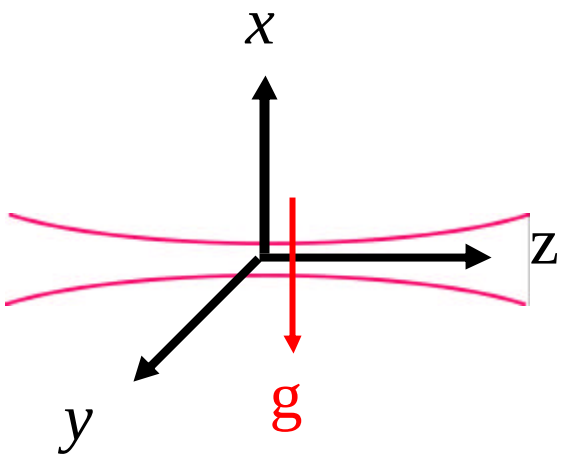
$$w_0 = \frac{l}{pe} \sim 2.8\ [m\mathrm{m}]$$

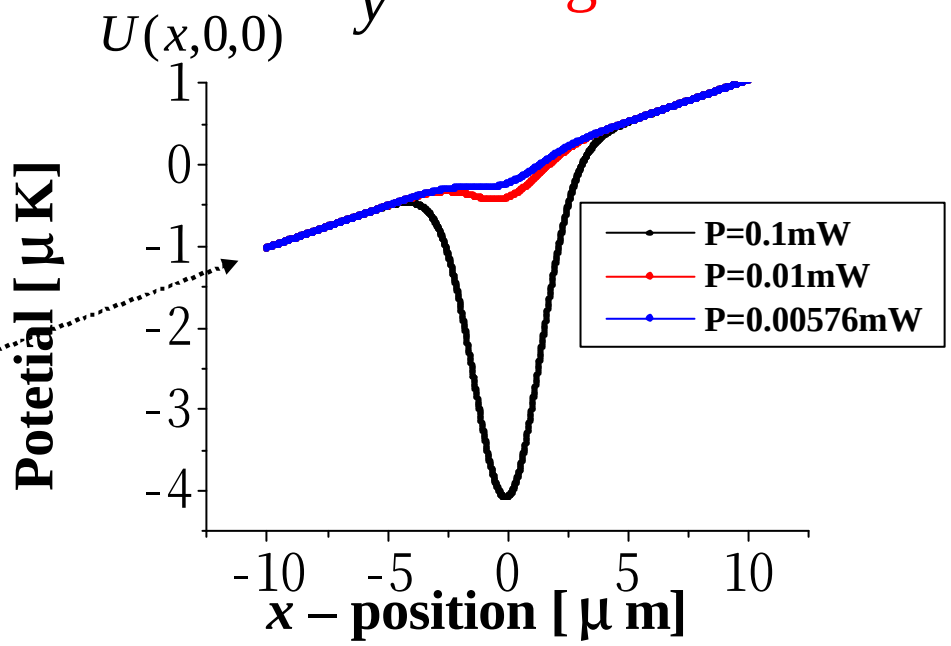
Adjustment of frequency $\bar{w}$

$\bar{w} \sim 2p \times 71\ [\mathrm{Hz}]$

$\Rightarrow$ P ~ 0.00576 [mW]

$U_0 \sim 5.6 \times 10^{-7}\ [m\mathrm{K}]$

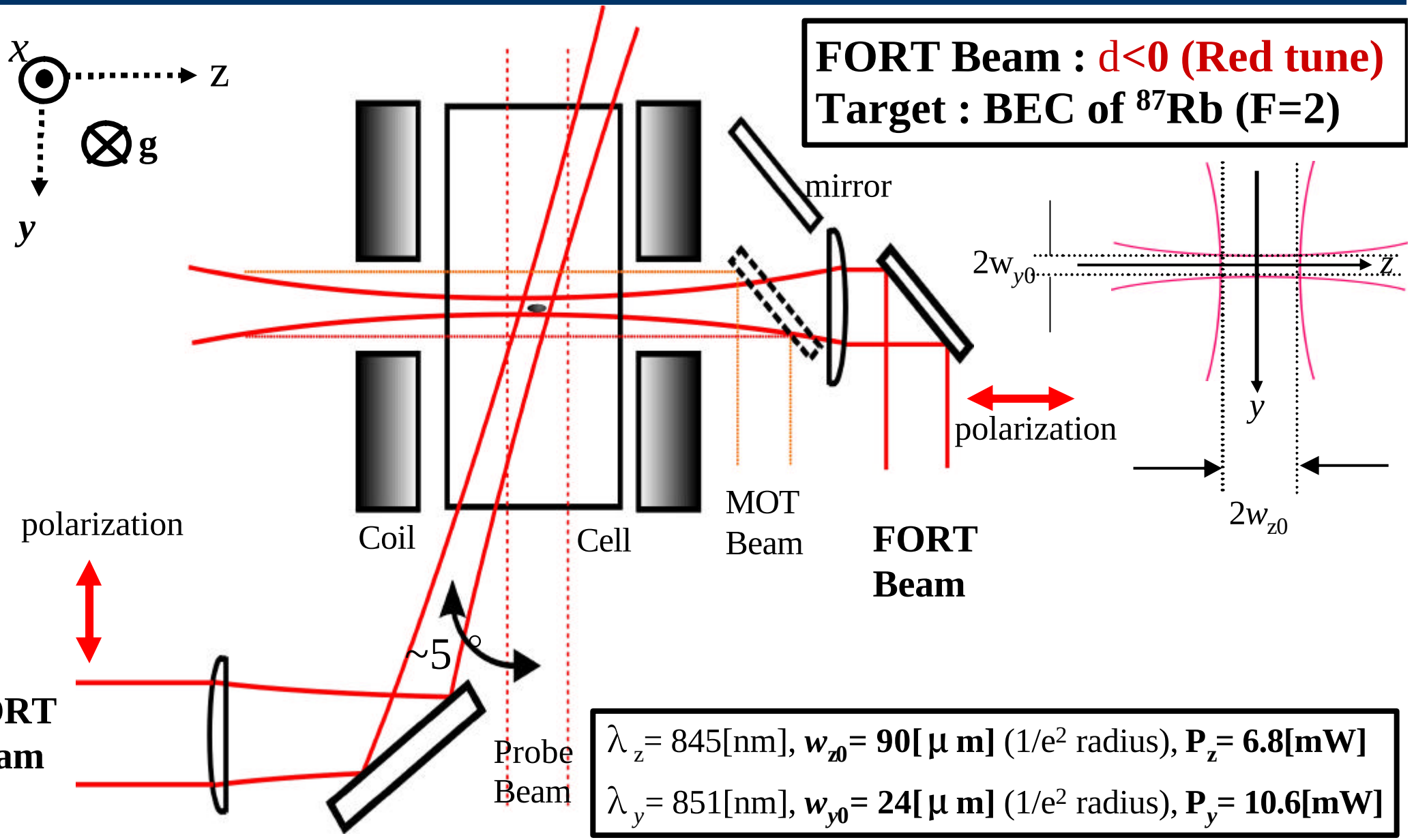




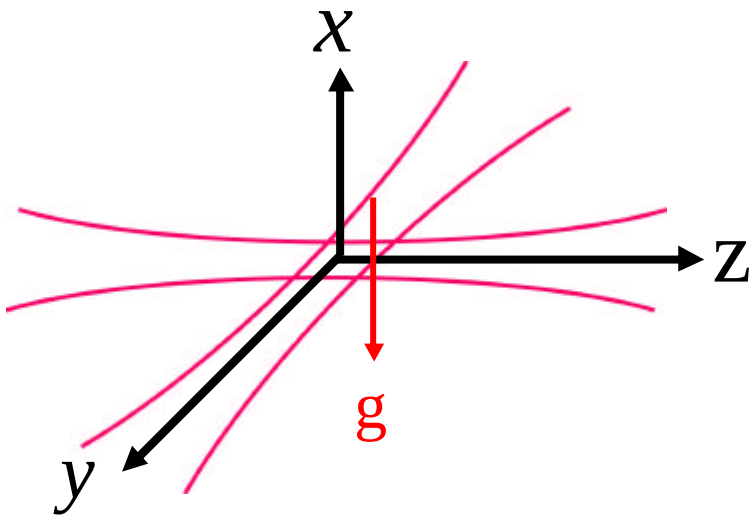
Impossible to adjust single-FORT parameters to the MT's values.

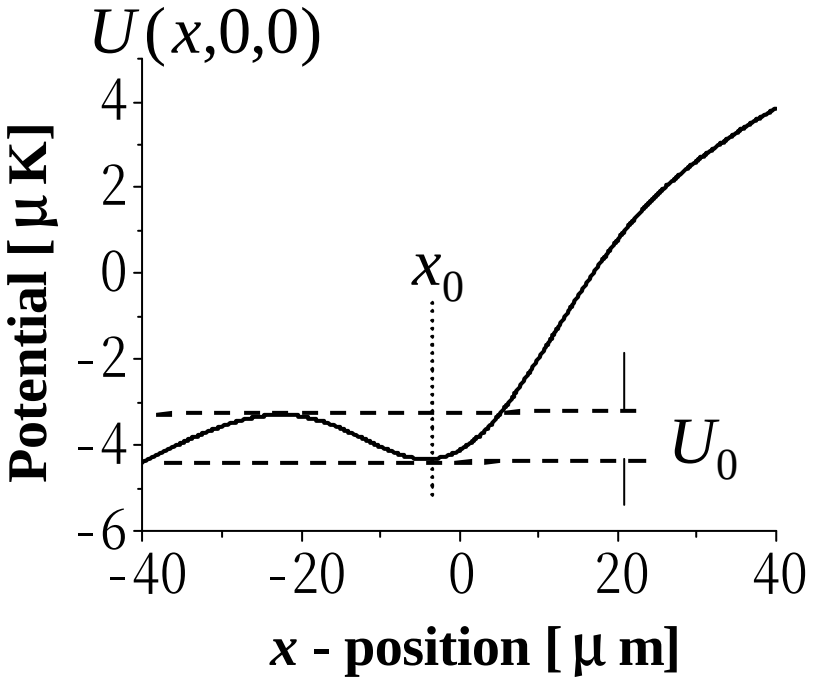
→ **Crossed-FORT**

Experimental setup



Trap potential & frequency (crossed-FORT)





Trap depth : $U_0 \sim 1.0$ [μ K]

Gravity shift : $x_0 \sim -4.2$ [μ m]

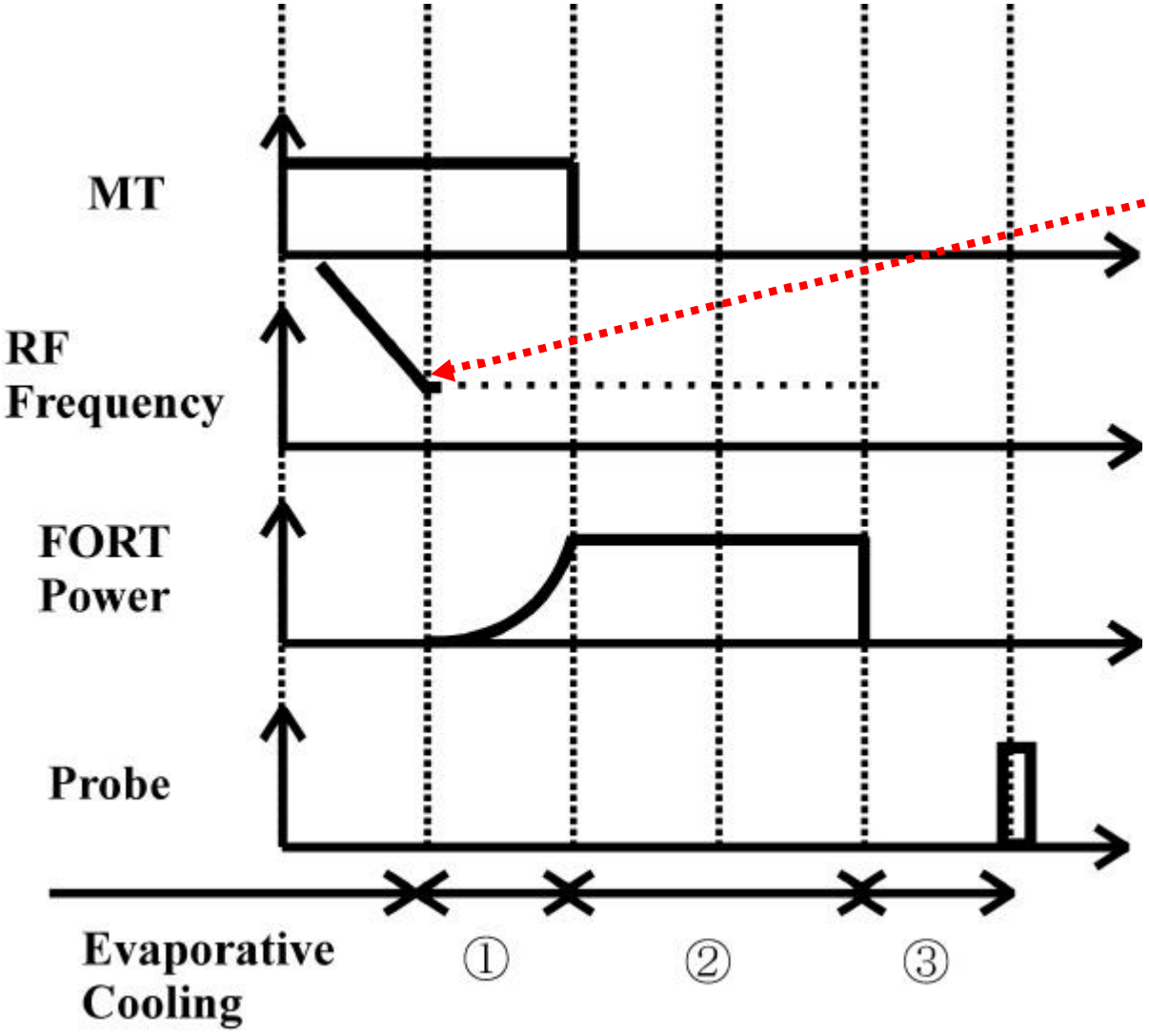
Trap Frequency : $\omega_x \sim 2\pi \times 230$ [Hz]
$\omega_y \sim 2\pi \times 244$ [Hz]
$\omega_z \sim 2\pi \times 21$ [Hz]

Aspect ratio : $(\omega_x\ \omega_y)^{1/2} / \omega_z \sim 11$

c.f. Magnetic Trap:MT $\omega_\rho / \omega_z \sim 10$

FORT's Time Table

MOT→PGC→MT→Evaporative Cooling→



Pure BEC
(F=2 ,m_F=2)

① ramp up time

② FORT trap time

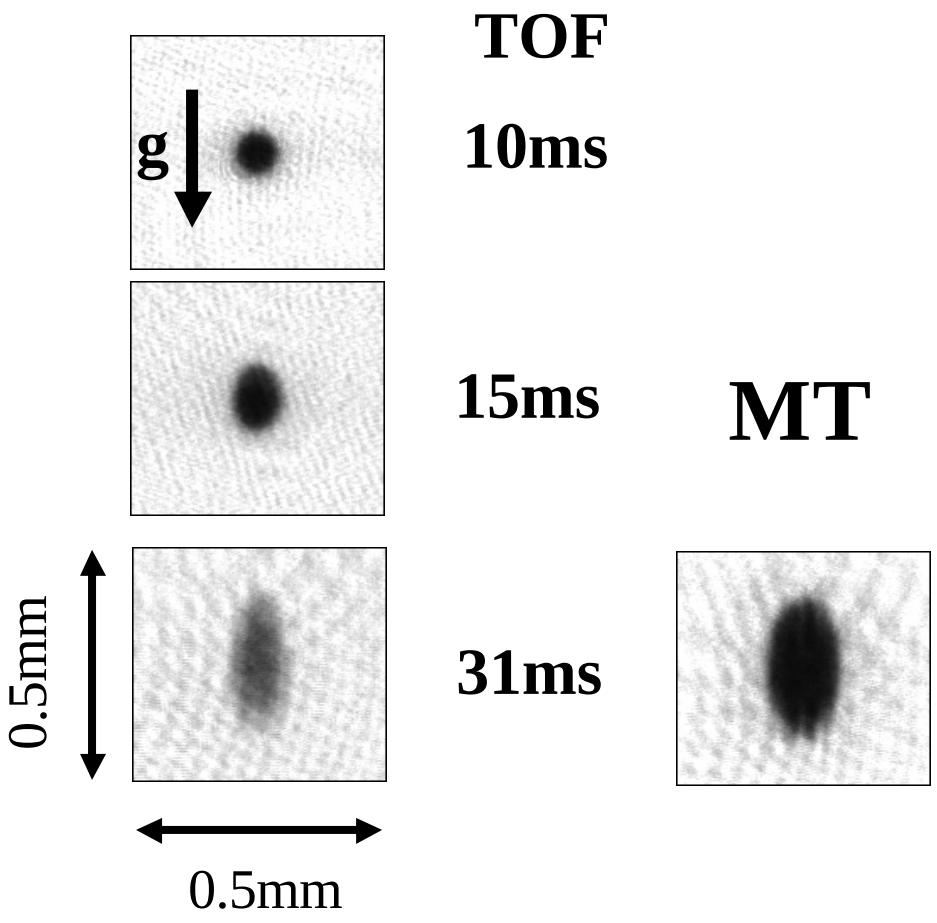
③ Time-Of-Flight (TOF)

① = 50ms

Crossed-FORT TOF imaging (1)

Crossed-FORT

Trap Time : 500ms



Geometric mean trap frequency

Calculation

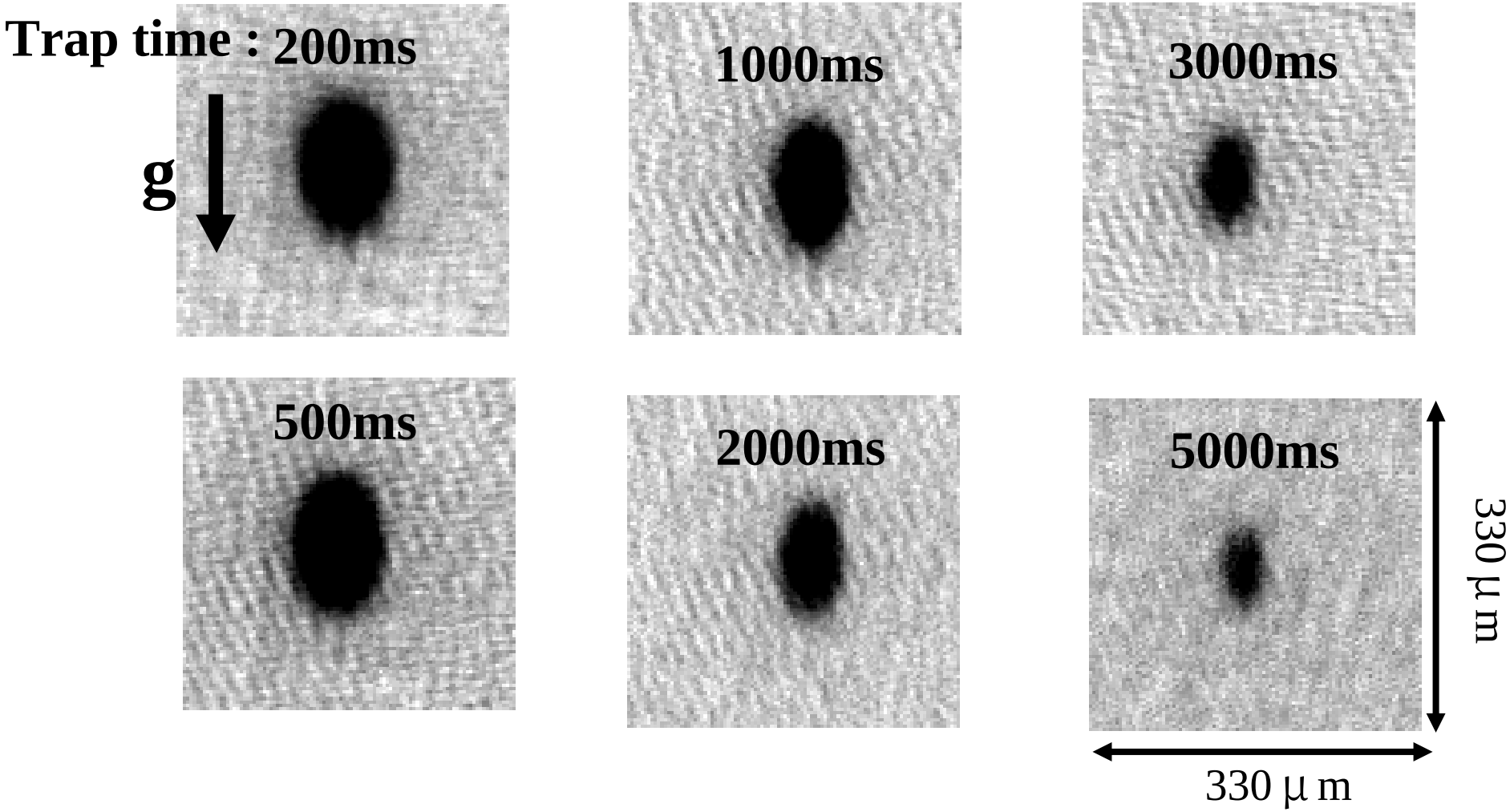
$$\overline{w}_{\mathrm{FORT}} \sim 2p \times 106 \ [\mathrm{Hz}]$$

Experimental value

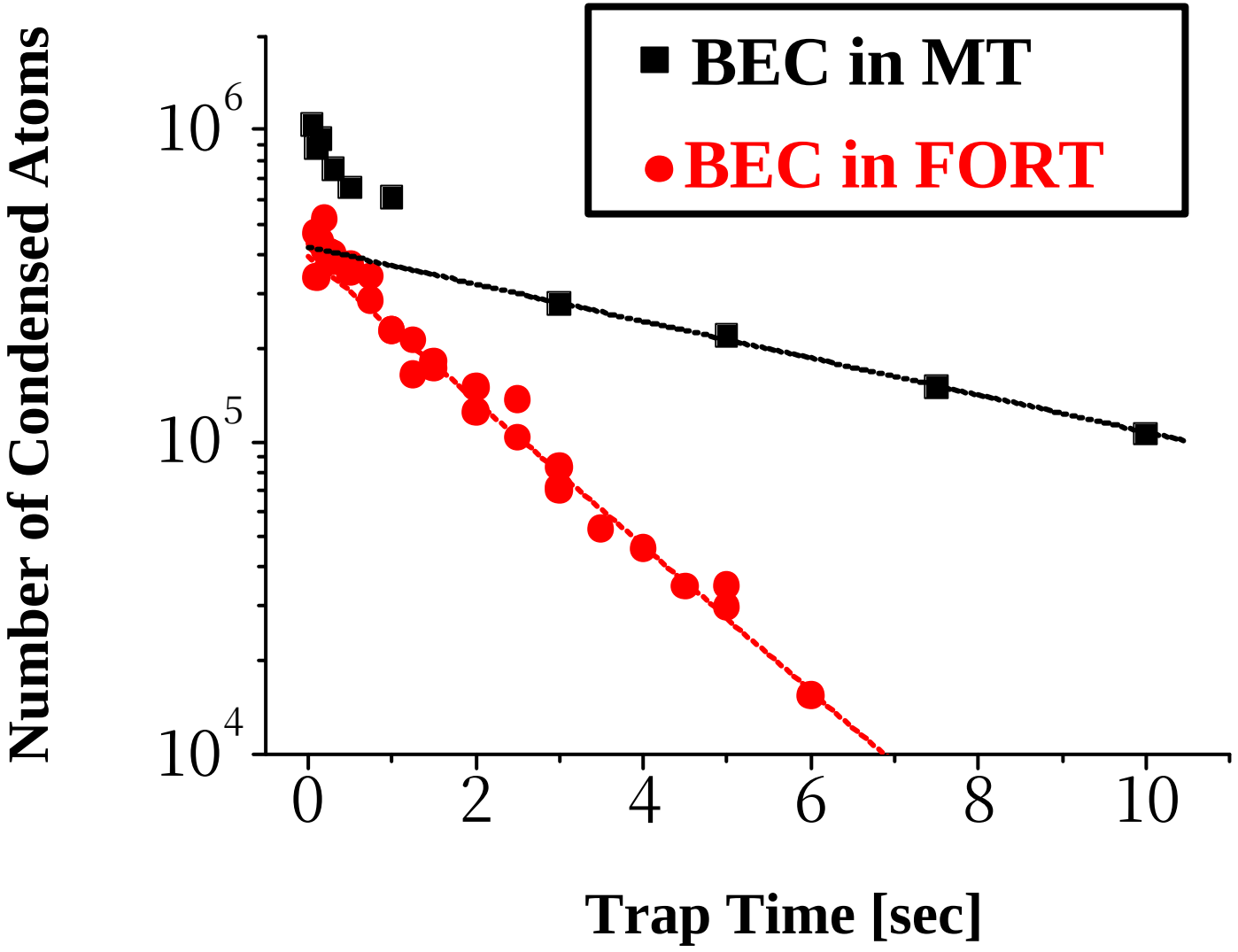
$$\overline{w}_{\mathrm{MT}} \sim 2p \times 71 \ [\mathrm{Hz}]$$

Crossed-FORT TOF imaging (2)

Crossed-FORT (TOF : 17ms)



Life time of BEC (crossed-FORT & MT)



Loss rate for

$N < 3 \times 10^5$ [atoms]

$t_{MT} \sim 7.3$ [sec]

$t_{FORT} \sim 1.9$ [sec]

$$\Rightarrow \frac{t_{MT}}{t_{FORT}} \sim 3.8$$

Possible reasons for short life time in crossed-FORT

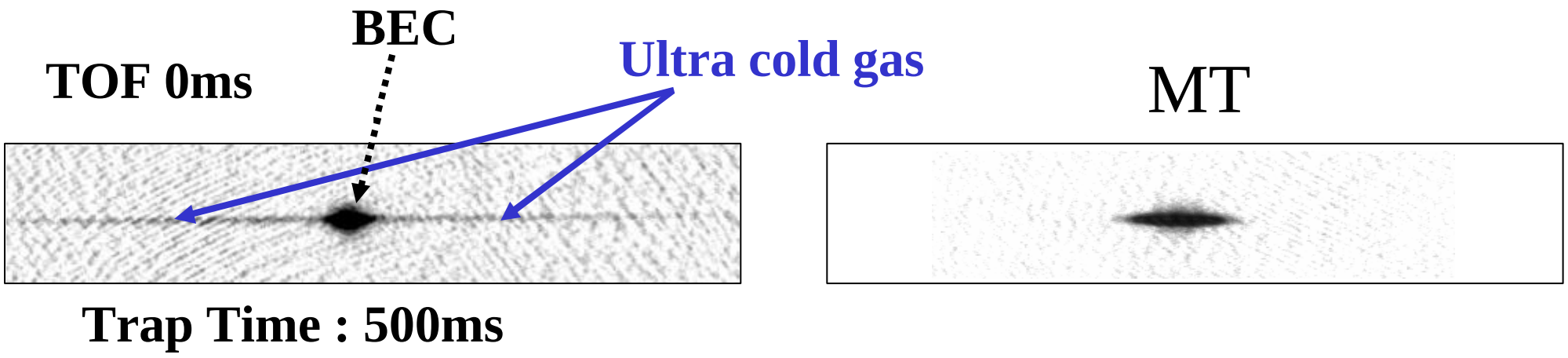
1. Heating ?

① **Absorption of photon ?**

Absorption rate ~ 560 [sec] ⇒ negligible

② **Intensity fluctuation or pointing instability of the beam ?**

2. Thermal cloud ?



Summary

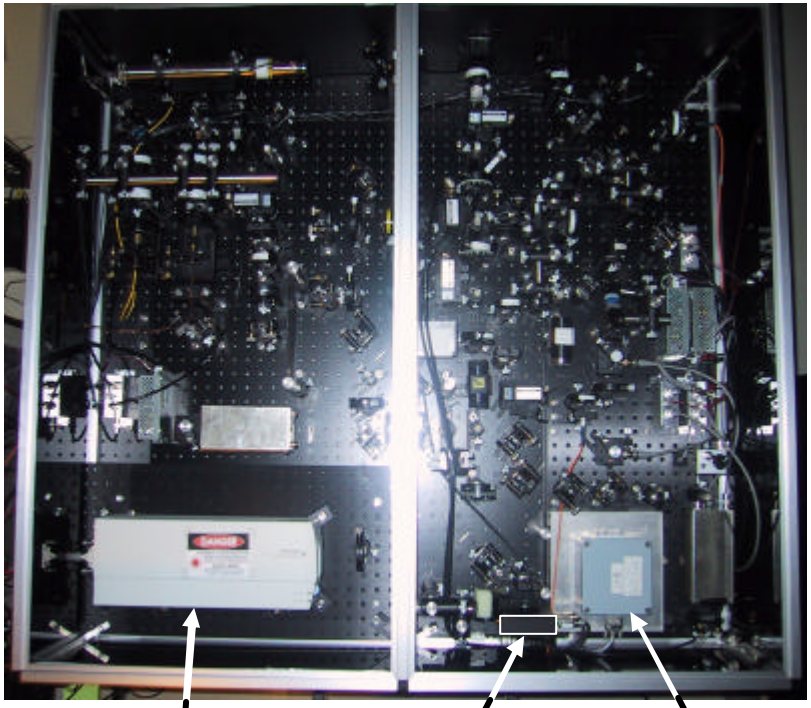
- We could confine rubidium 87 condensates in crossed-FORT.
- Transfer rate of atoms was about 50 % ($\sim 5 \times 10^5$ [atoms]).
- Life time of BEC in the crossed-FORT was about 1.9 [sec].

$\Rightarrow$enough to perform various experiments in an optical trap.

e.g. : dynamics of BEC with spin degrees of freedom.

Experimental apparatus (1)

Optics of laser system

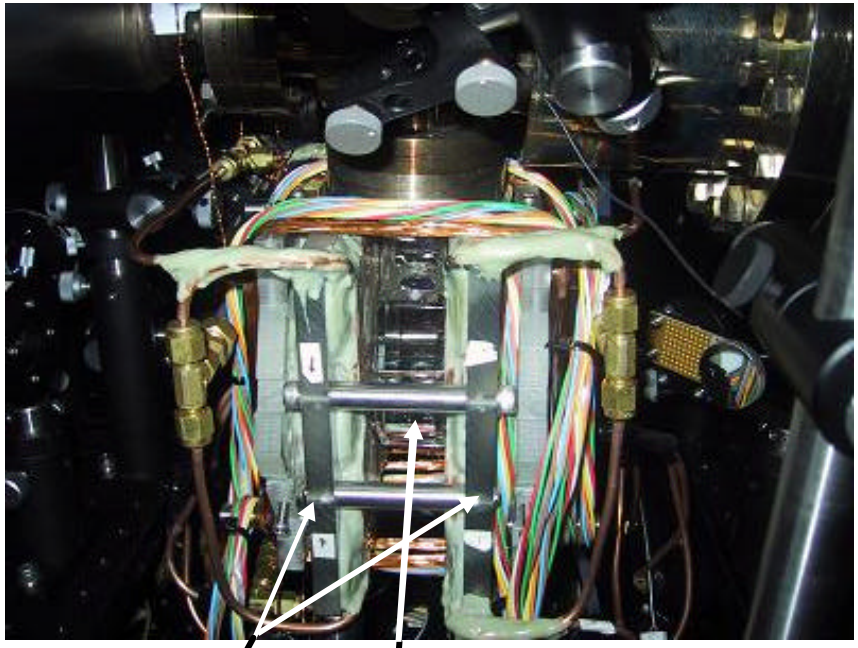


TC-40
(Lower MOT,
probe,pump, push)

slave laser
(Upper MOT)

ECLD
(repump)

Magnetic trap coil

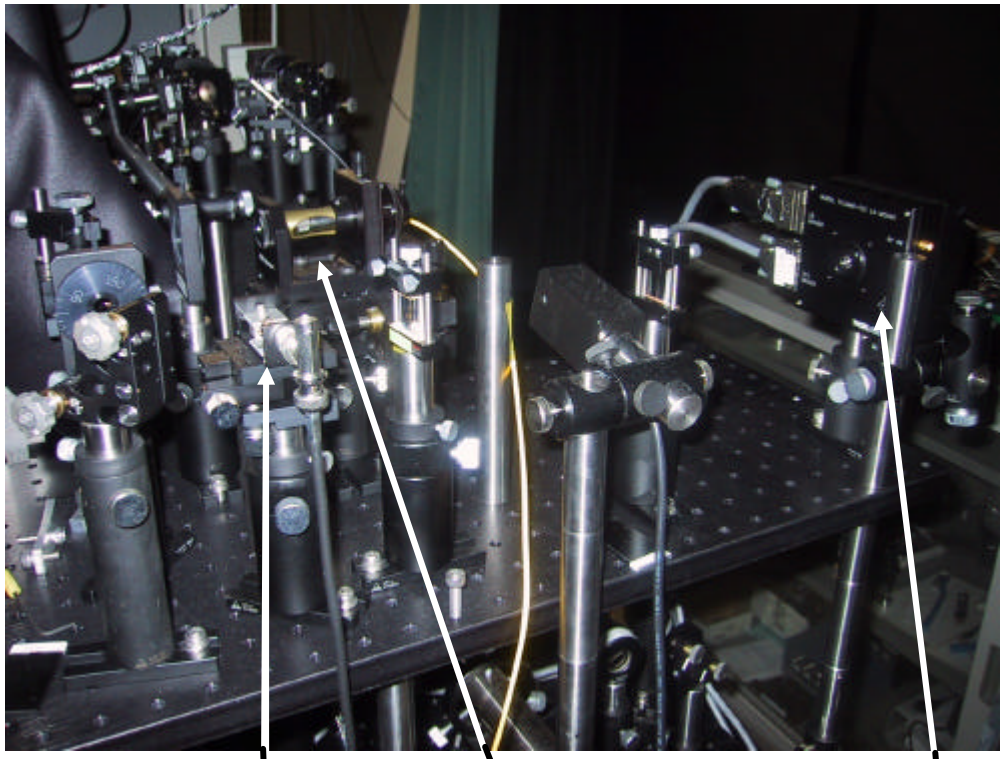


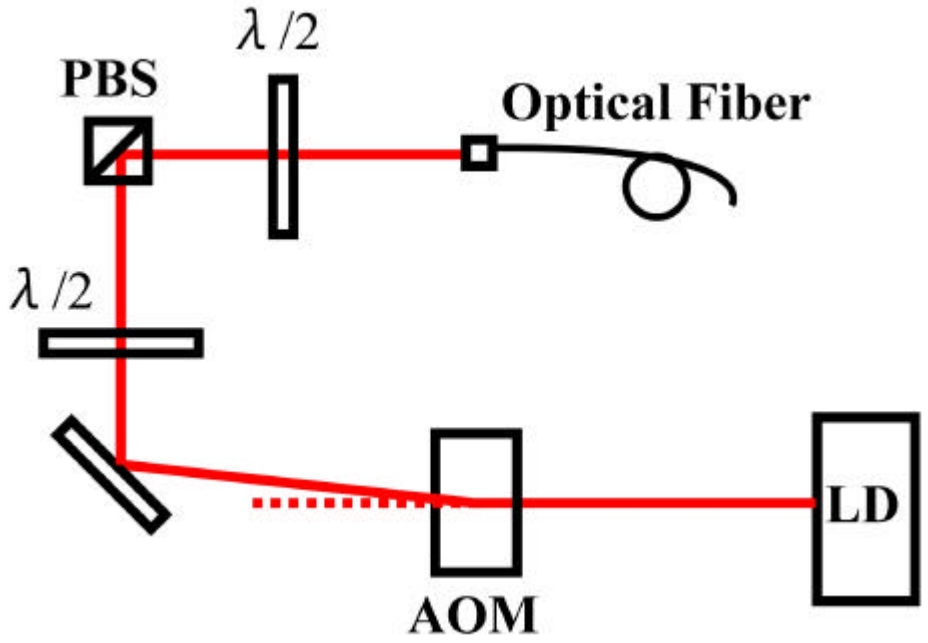
coil

cell

Experimental apparatus (2)

Light source of FORT





< LD >

P_{max} ~ 100 [mW]

λ_z ~ 845 [nm], λ_y ~851 [nm]