Bose Einstein Condensation in the higher band of a time-dependent double well optical lattice

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Motivation

• Simulations of condensed matter systems with atoms in optical lattice.

• The new thing is, we can modify the lattice and the band structure in real time.

• Doesn't even have to be in the lowest band.

• Bose condensation in different dimensionalities. In particular, we are going from a 1D to a 3D system.

• The lattice we are going to study is inspired by a neat experiment in Germany.
[G. Wirth et al., Nature Physics , doi:10.1038/nphys1857(2010)]

2D Lattice Potential with weak harmonic confinement in the 3rd direction

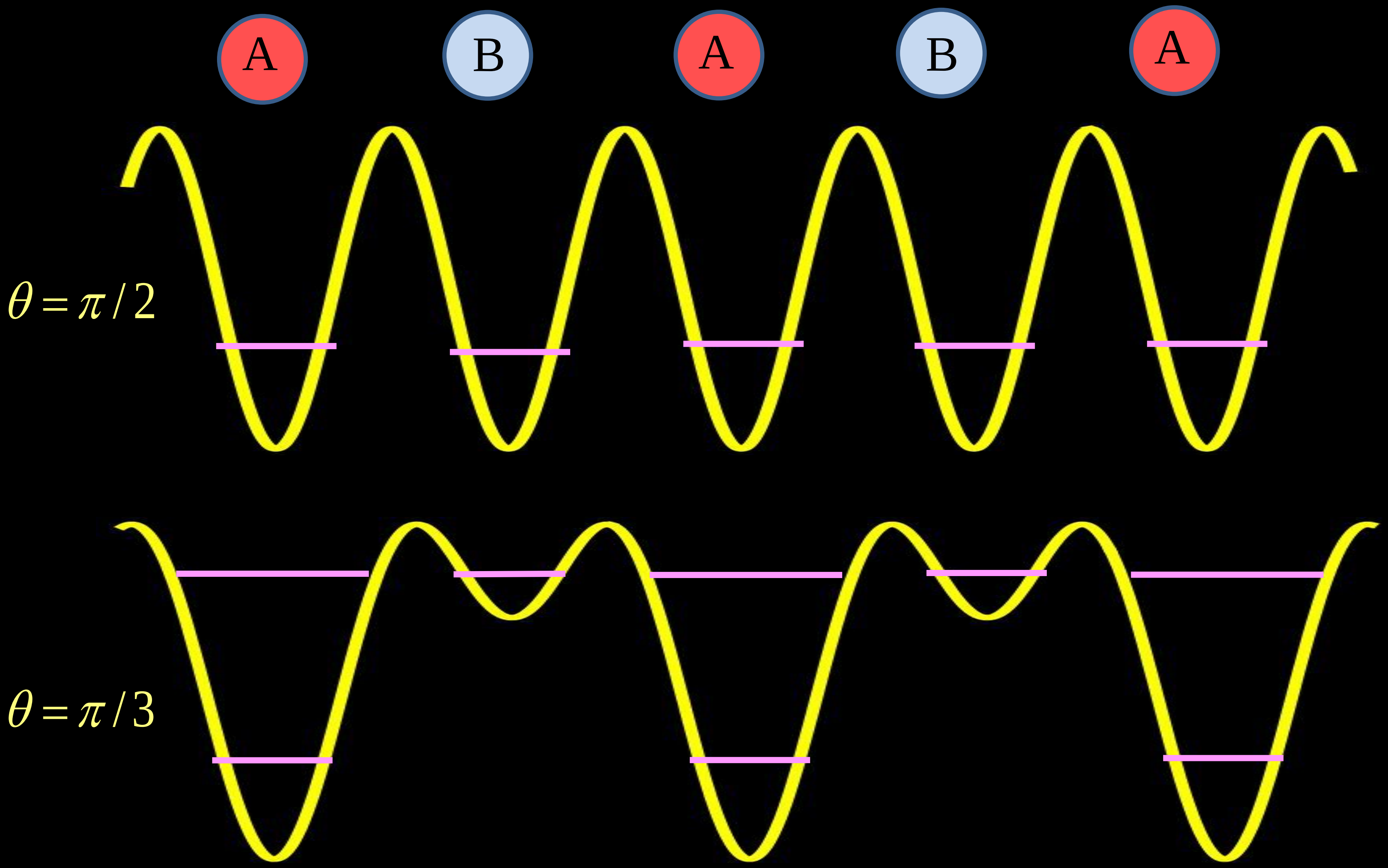
The mathematical form for the trapping potential

$$V(x, y) = -|V_0|\left(\cos^2(kx) + \cos^2(ky) + 2\cos\theta\cos(kx)\cos(ky)\right)$$

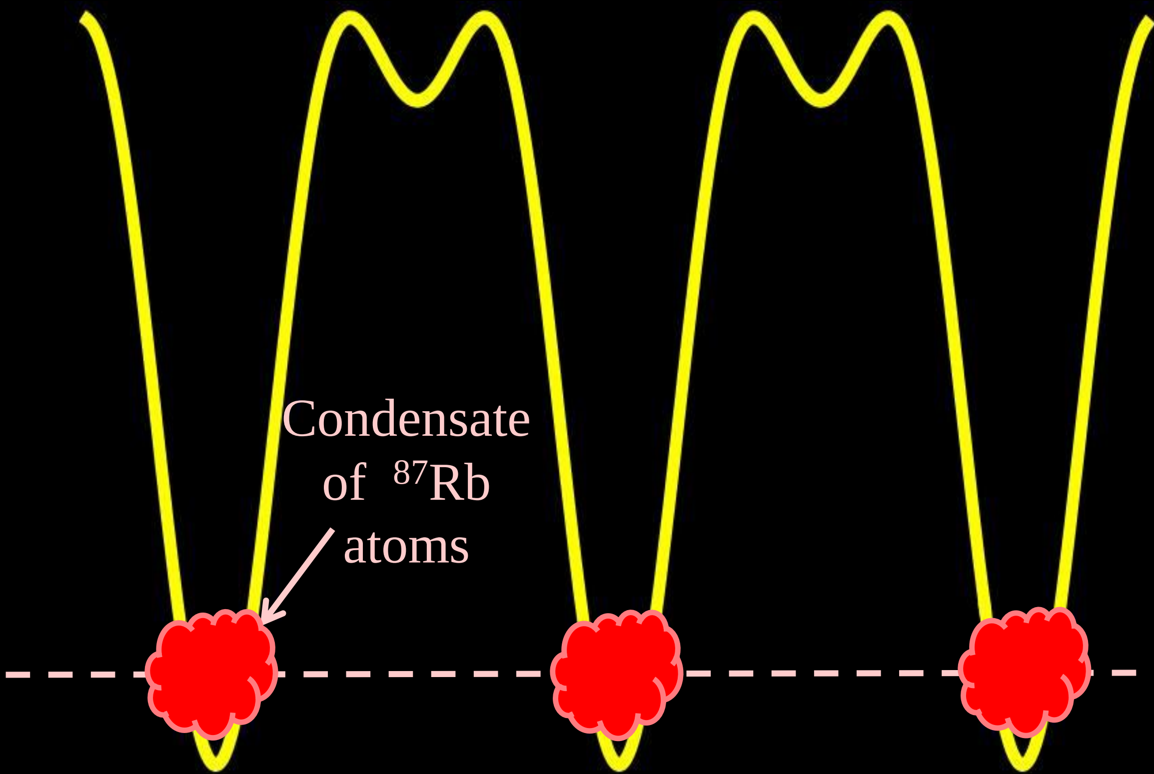
In addition, it is important to note that there is also a weak harmonic trapping potential in the z-direction.

The confinement is much stronger in the x & y direction than the z-direction.

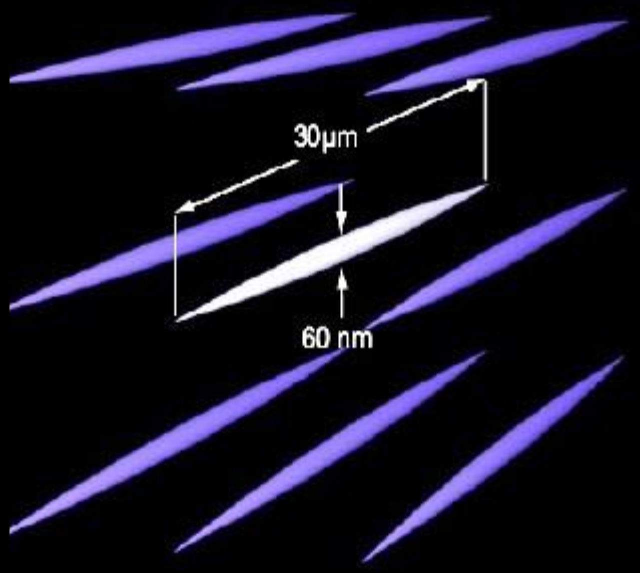
Changing the potential real time



How do they populate the excited bands? Step#1



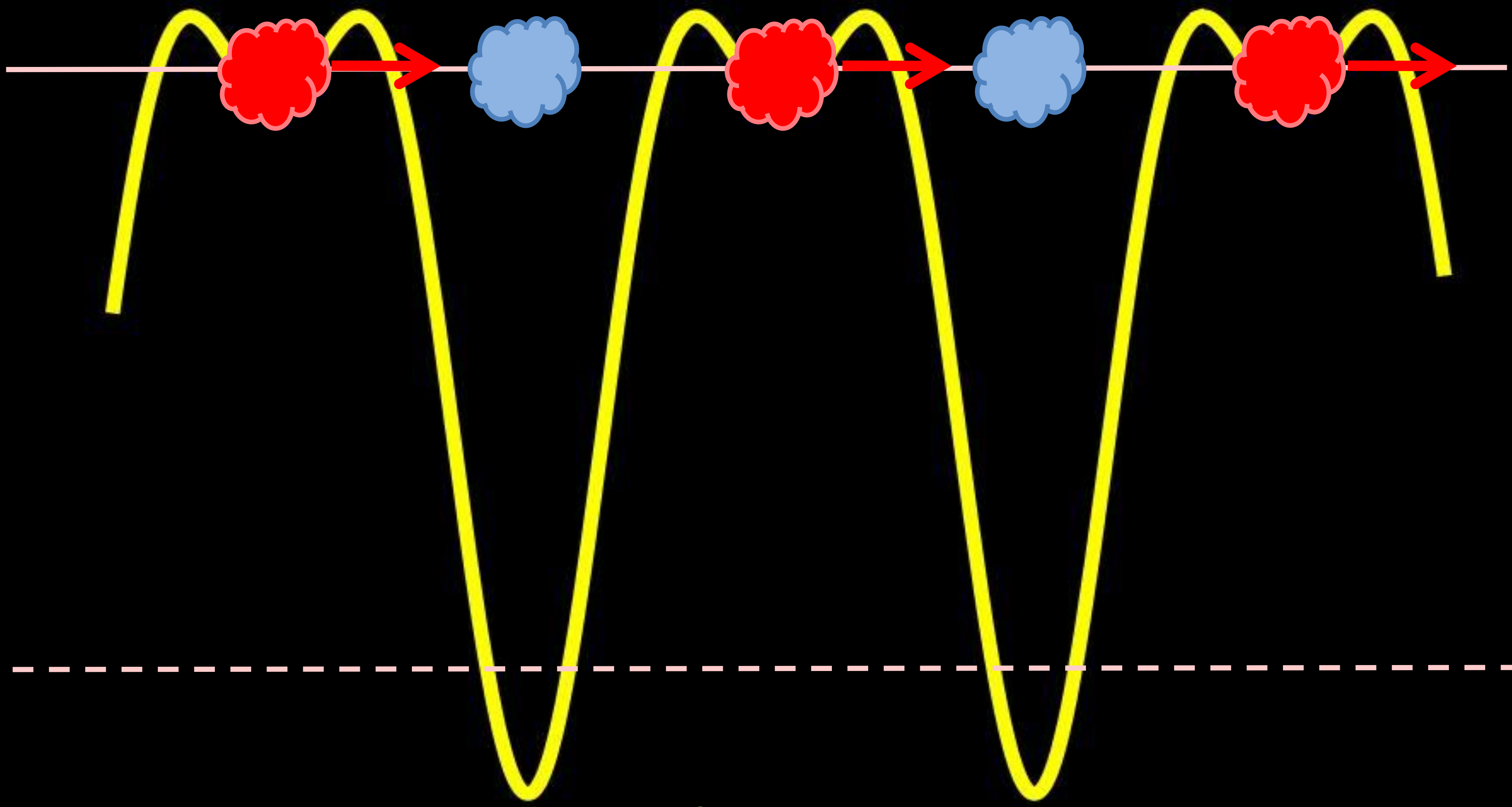
$\theta < \pi / 2$



Collection of 1D systems
with a harmonic confinement
in the z-direction

How do they populate the excited bands? Step#2

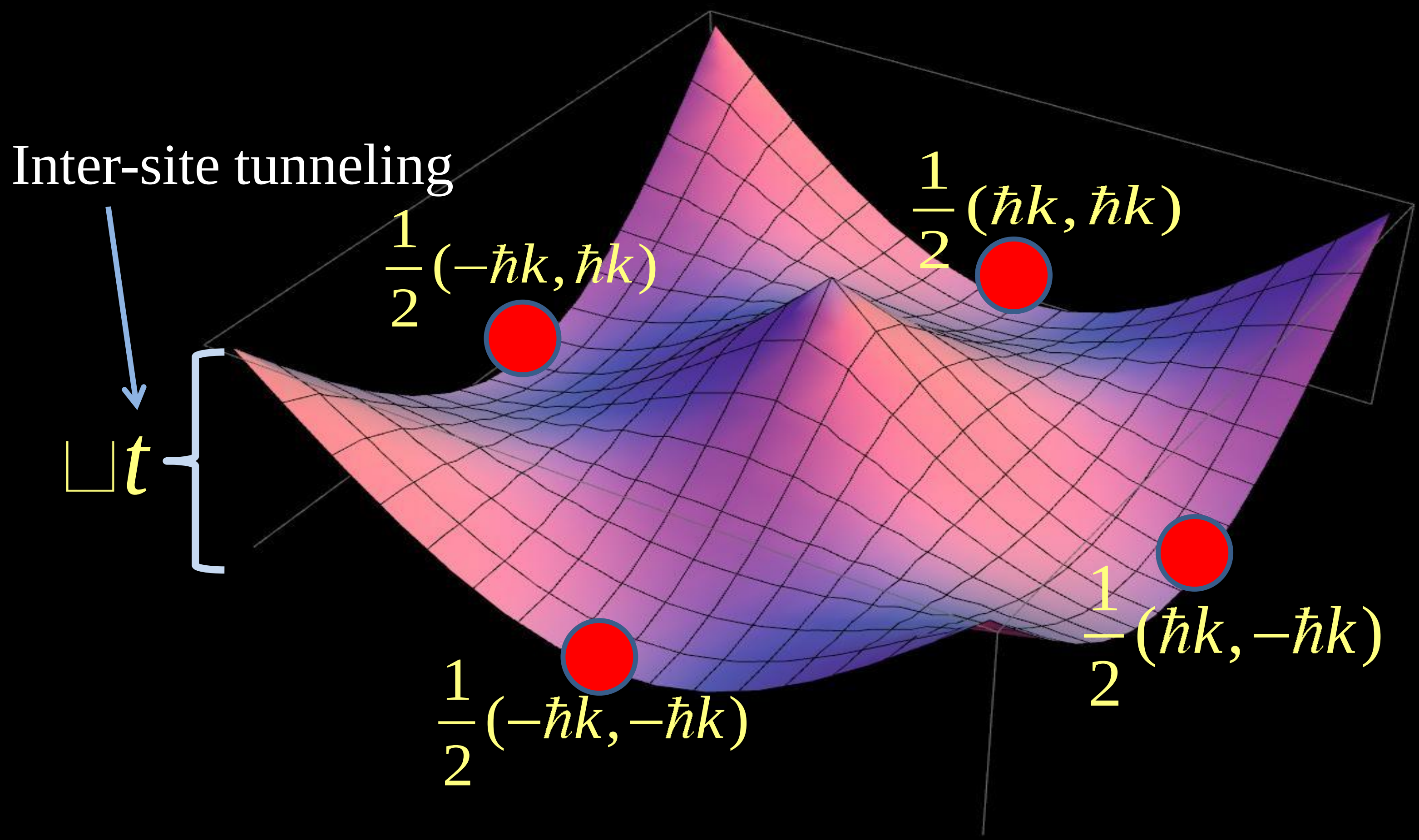
Tunneling and collisions re-distribute the atoms among all sites



$\theta > \pi / 2$

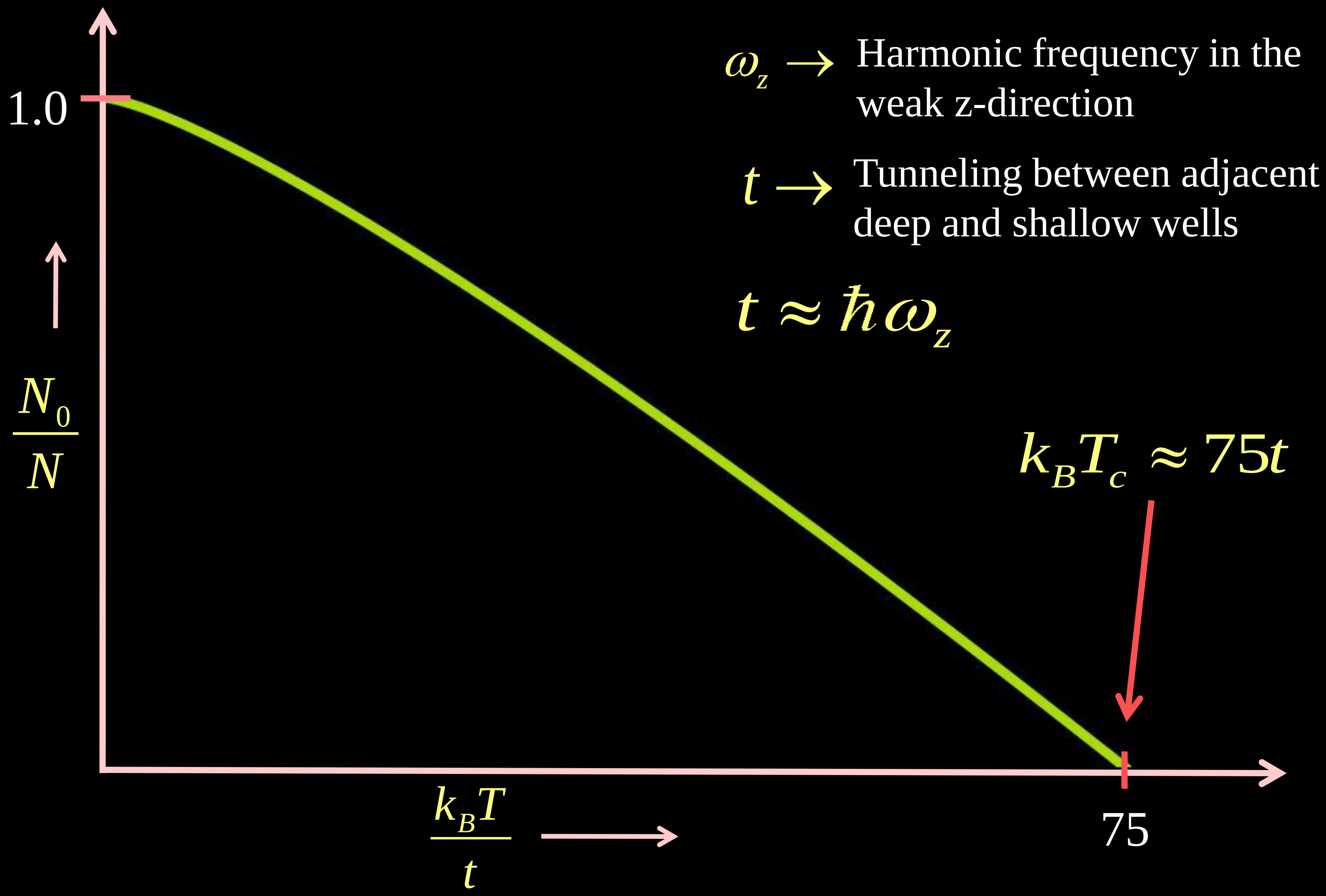
Tight binding calculation of the band structure and formation of a Bose Einstein Condensate

First excited band as a function of 2D quasi momenta in x & y Directions.

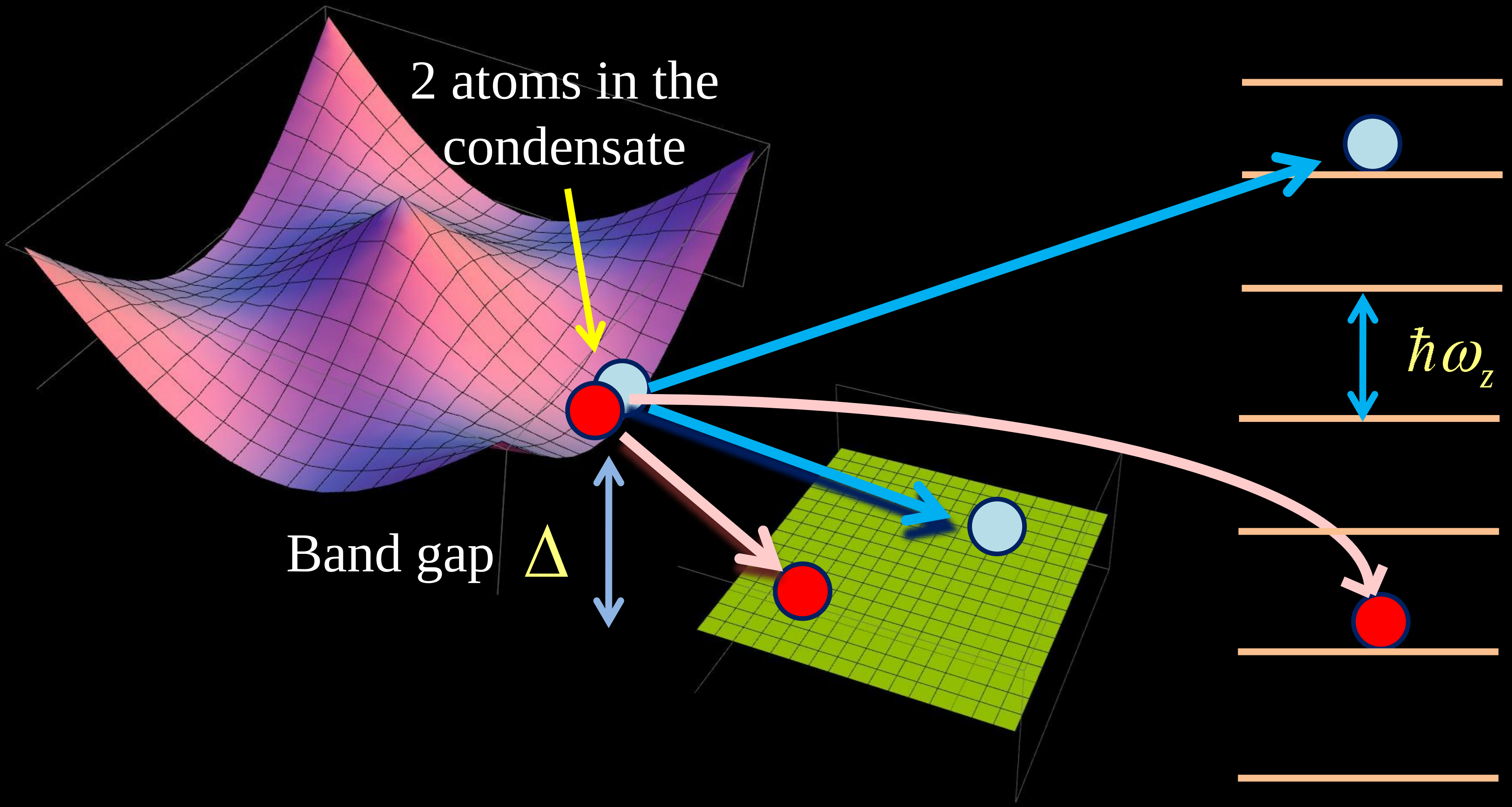


Thermodynamics of the non-interacting gas in the excited band

We determined the fraction of atoms in condensate vs temperature:



Lifetime of the condensate due to collisions to the lowest band



The dominant term

Lifetime of the condensate

Here we present our estimate for the decay rate Γ

Scattering length

# of atoms per lattice site

$$\Gamma = \frac{\pi^{3/2}}{4}\frac{|V_0|}{\hbar}\left(\frac{a_s}{a}\right)^2 n^2 \frac{1}{\sqrt{\Delta/\hbar\omega_z}} \;\Box\; t/\hbar$$

Lattice depth

Lattice constant

Band gap

Harmonic frequency in the weak z-direction

Summary

❖ We have theoretically analyzed the formation of a BEC in the excited state of a double well optical lattice, at the edge of the first and second BZ.

❖ We have shown that the dominant process for decay is collisions between atoms to the lower band. The decay rate is smaller than the intersite hopping rate.

❖ We would like to further understand the transition from the 1D condensate to 3D condensate.