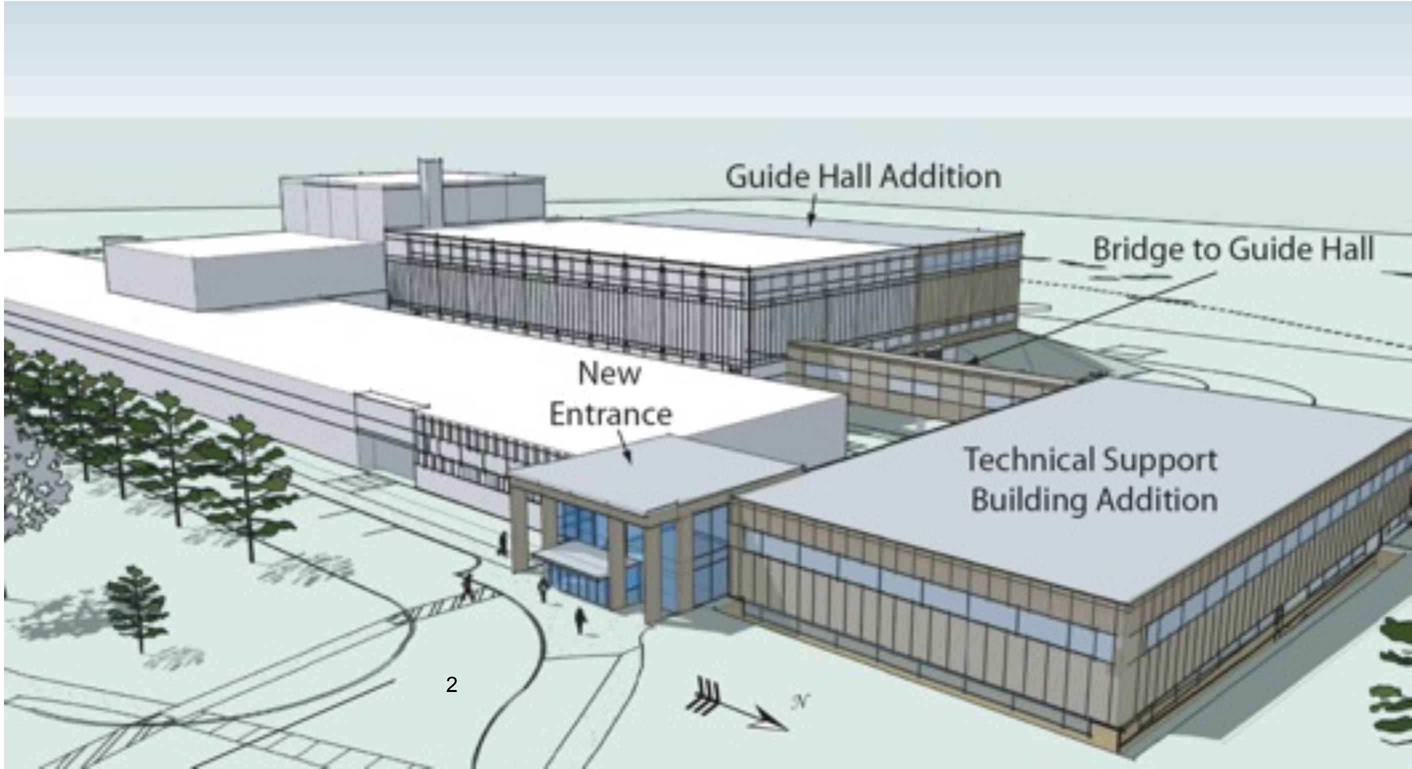
Neutron Interferometry

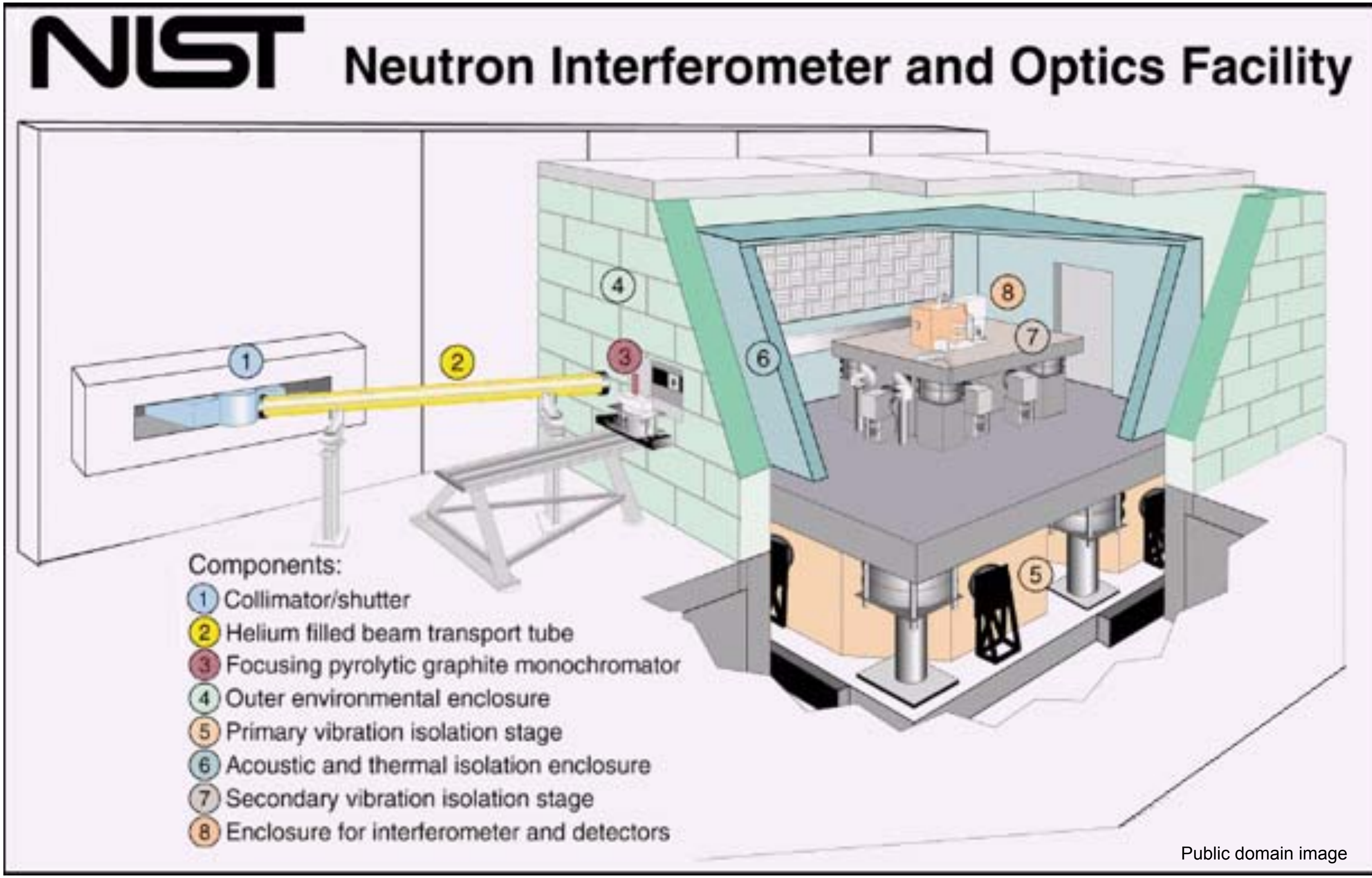
NIST Center for Neutron Research

Home to a 20 MW reactor that provides neutrons for scientific research
Dozens of instruments (most for Solid State applications)
Some instruments for the study of Fundamental Physics

Public domain image

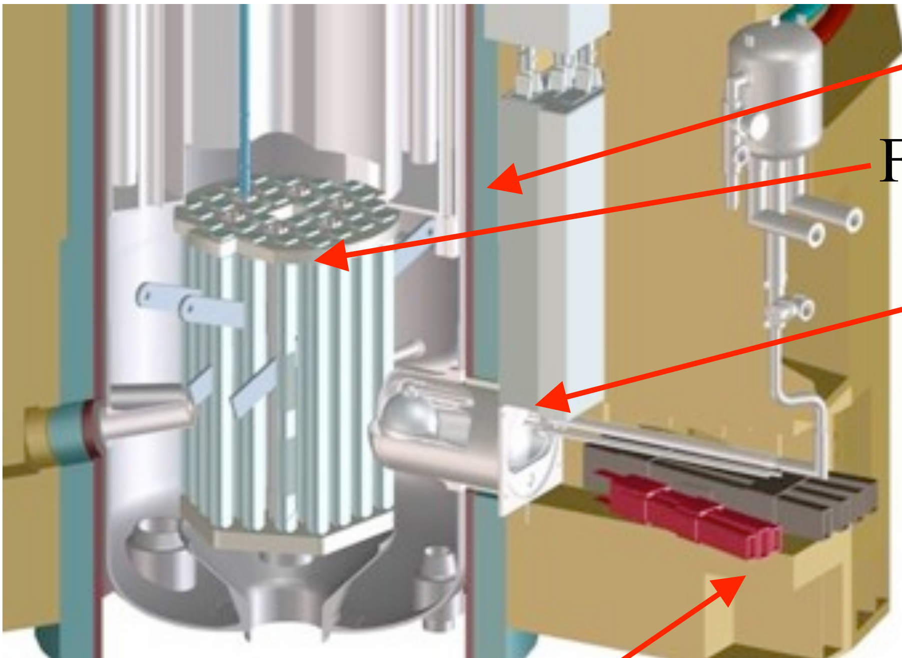


The Neutron Interferometer and Optics Facility



Isolated 40,000 Kg room is supported by six airsprings
Active Vibration Control eliminates vibrations less than 10Hz
Temperature Controlled to +/- 5 mK

Inside the NCNR



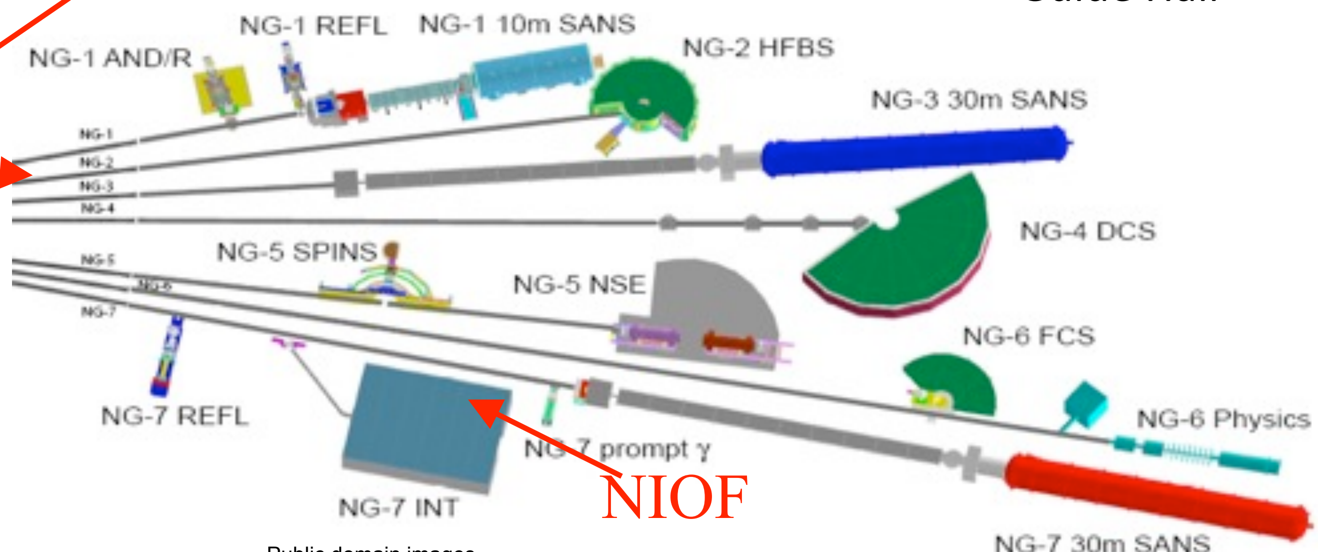
Reactor Core

Fuel Elements

LH_2

7 Neutron Guides

Guide Hall



NIOF

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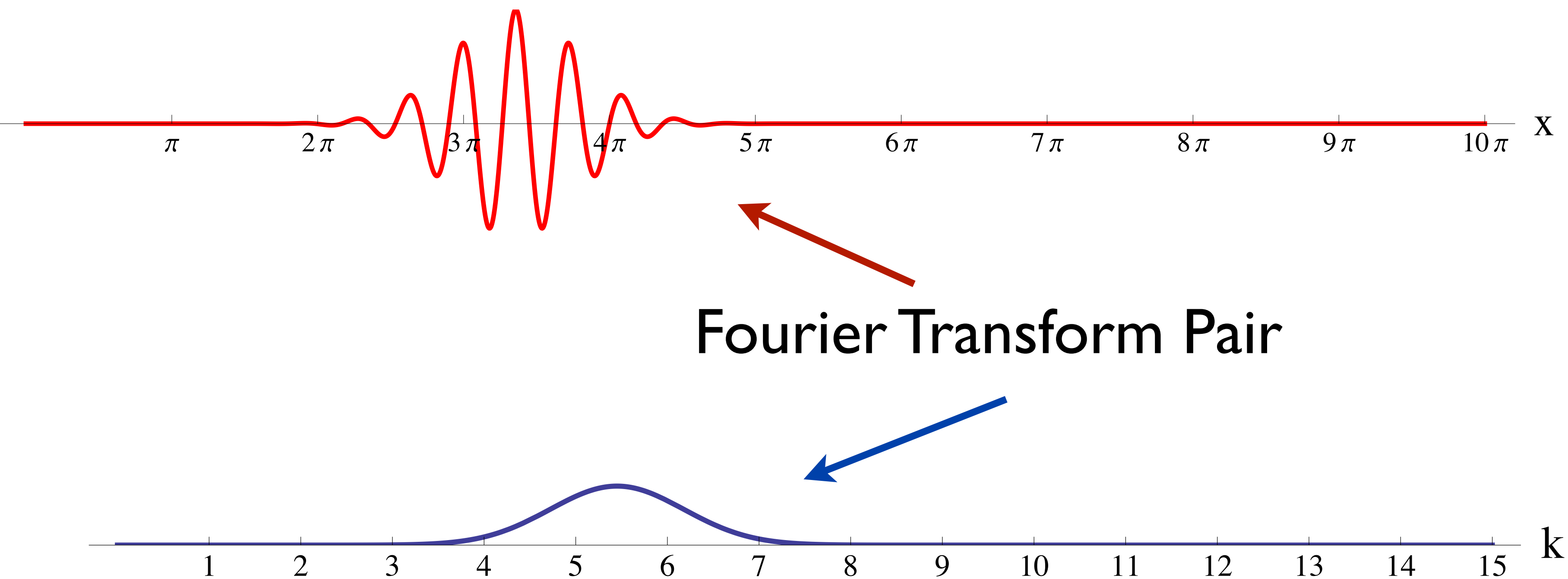
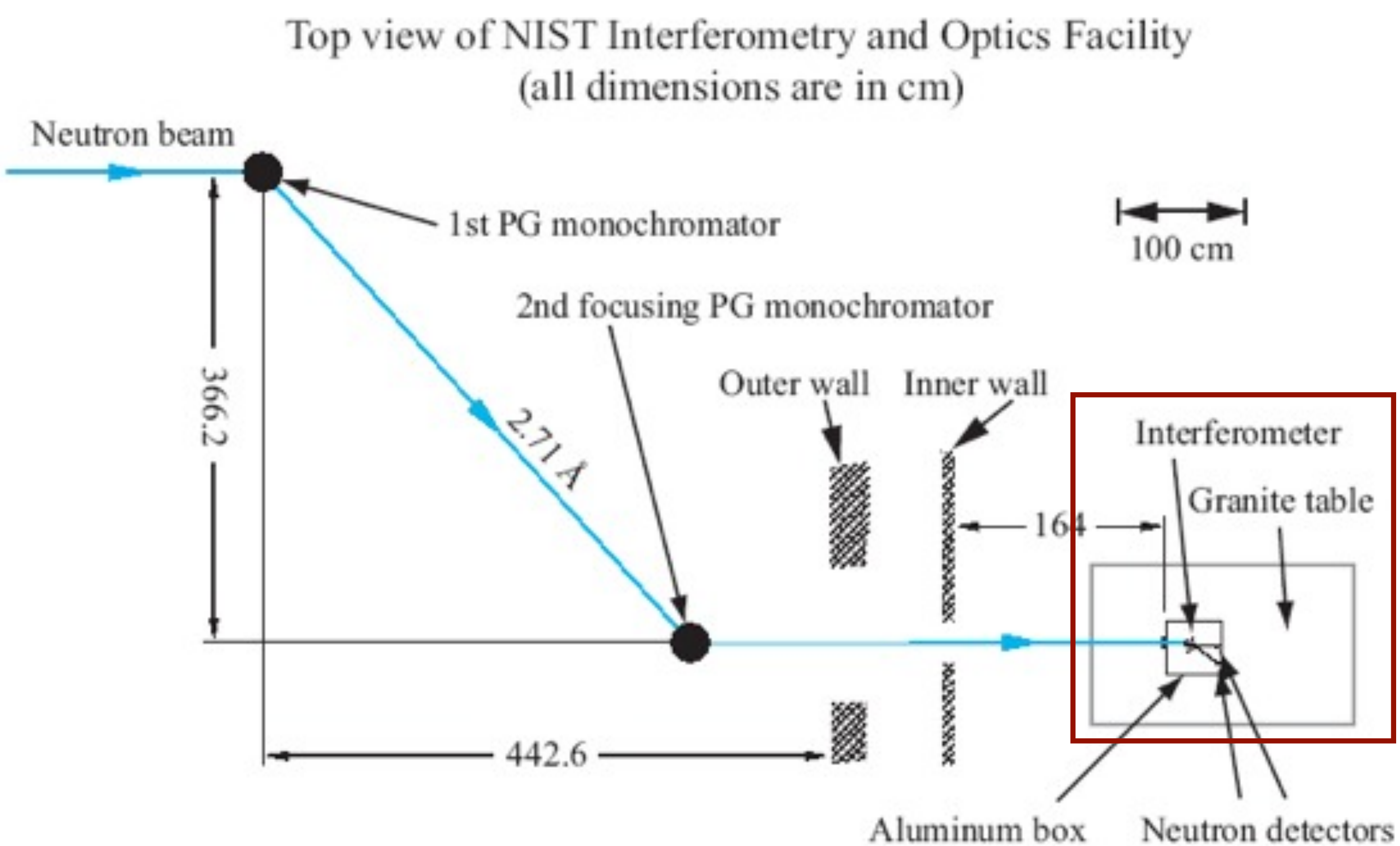
Wavepacket

Neutron coming out of the reactor is a wavepacket:
Sum of many plane waves with different wavenumber k
[not a stationary state: evolves (moves!) in time]



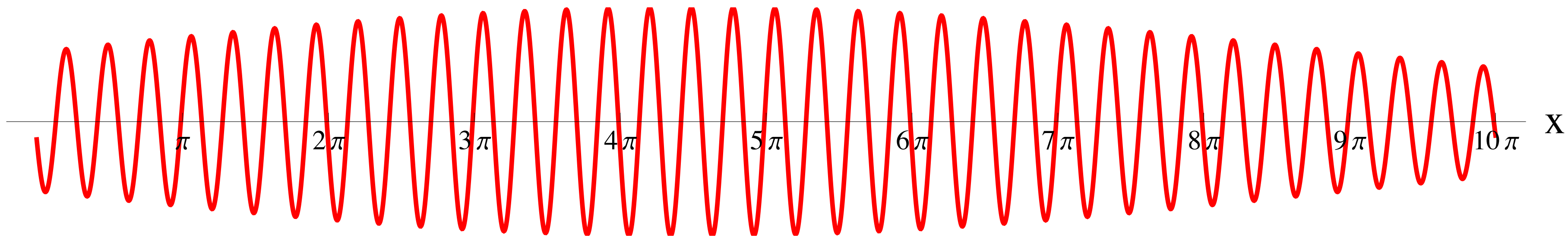
Monochromator

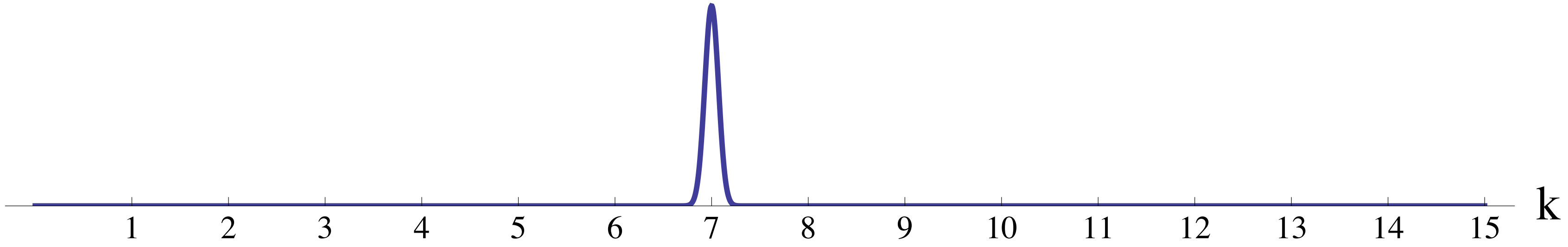


Monochromator selects a small range of momenta

Source: Pushin, Dmitry A. "Coherent Control of Neutron Interferometry." Ph.D. Thesis, MIT, 2006.

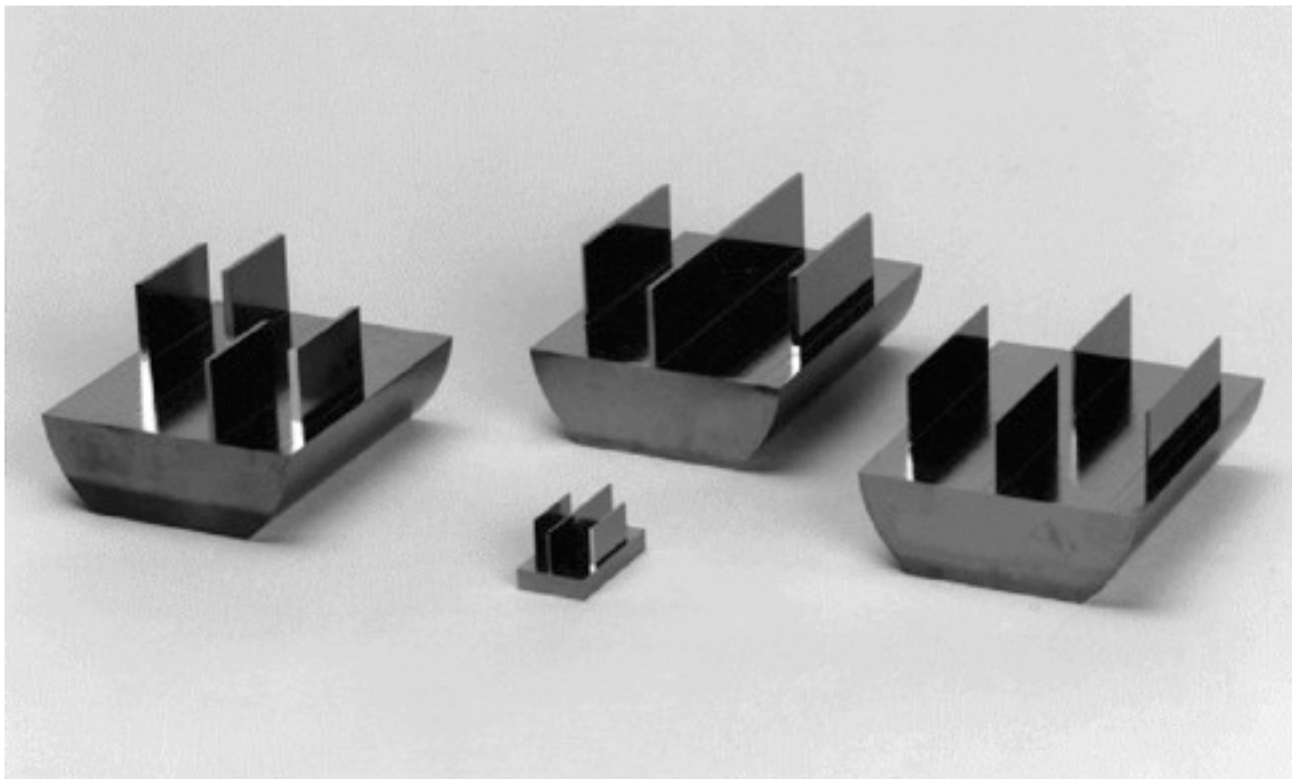
Wavepacket





Neutron Interferometer

3-blade interferometer from single Si crystal



Public domain image (source: NIST).

5-blade interferometer from single Si crystal

Photo courtesy of Dmitry Pushin. Used with permission.

Wavepacket → Plane wave

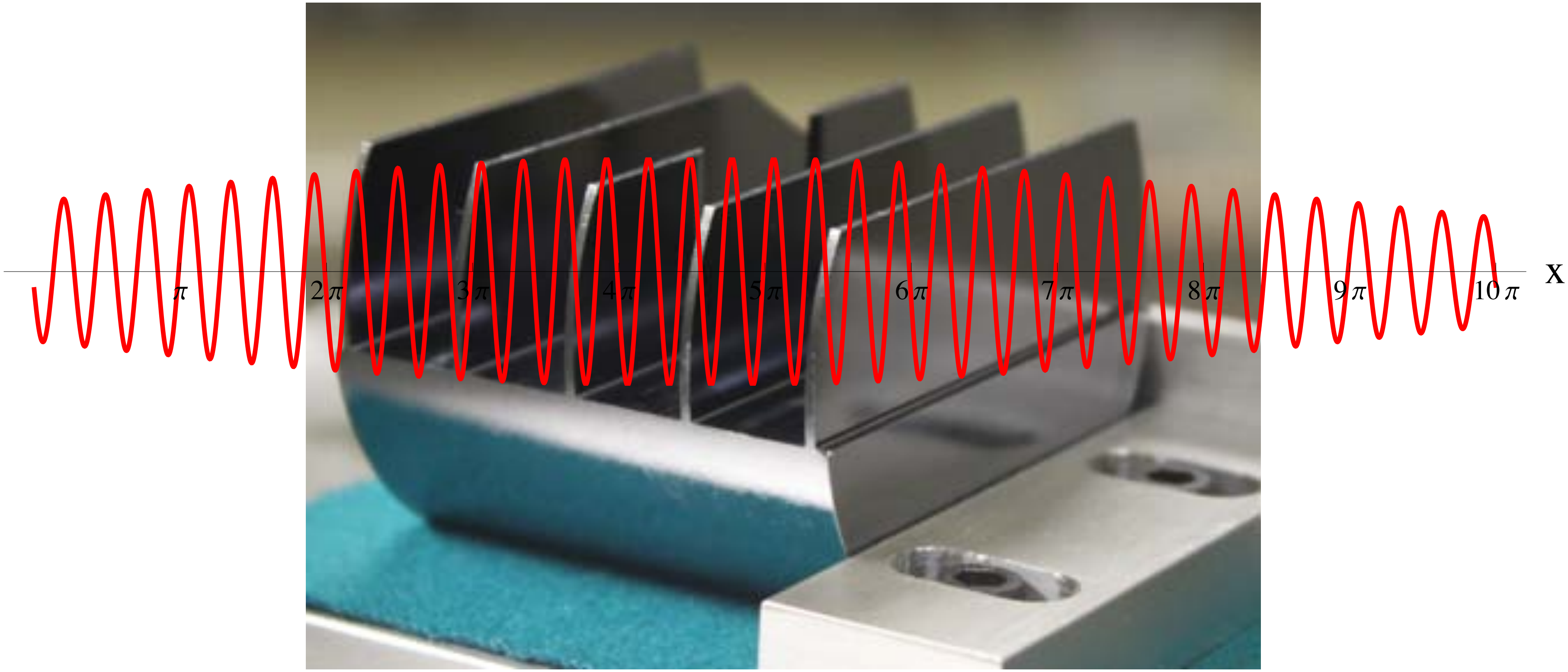
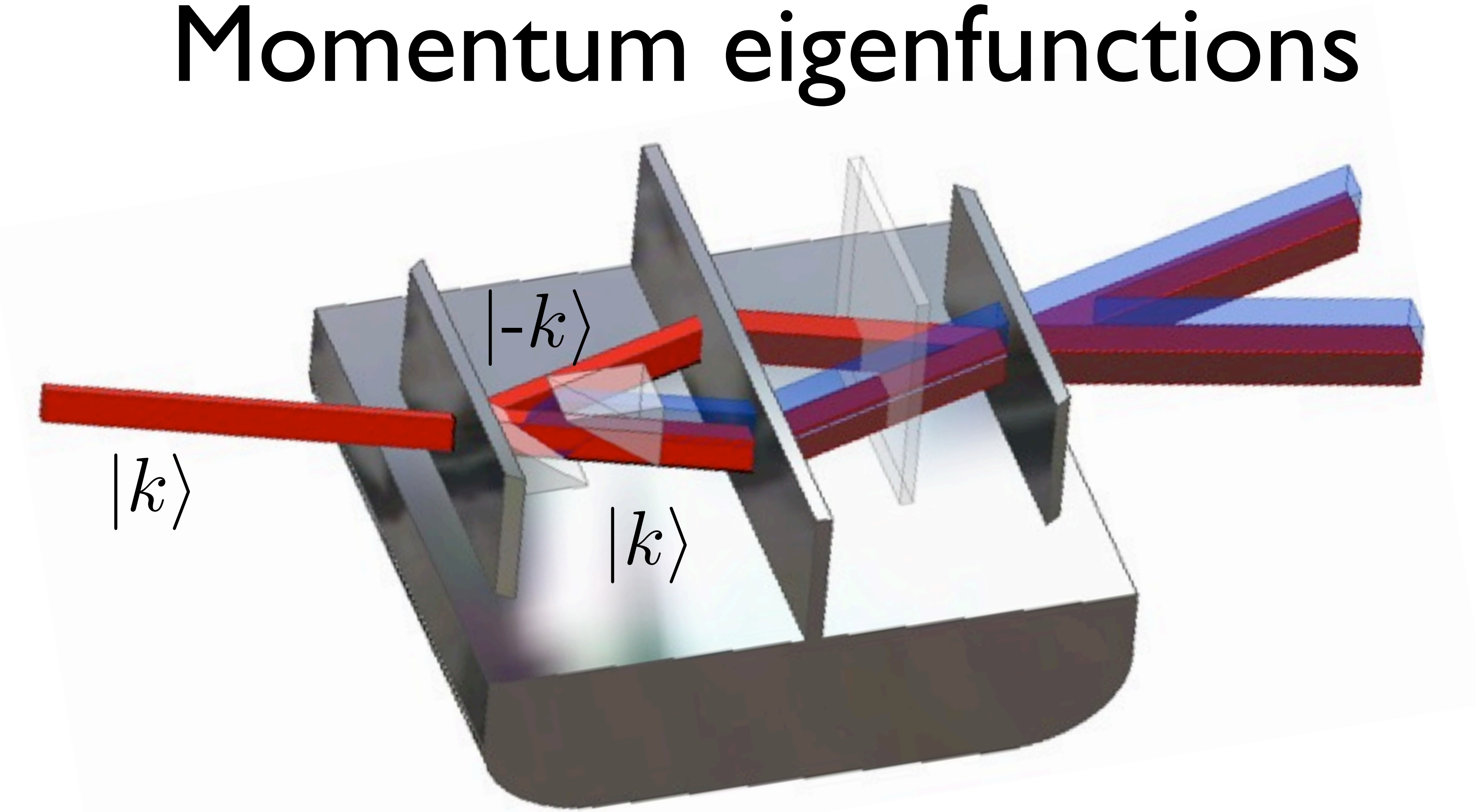


Photo courtesy of Dmitry Pushin. Used with permission.

Wavepacket $\Delta x \gg$ Interferometer → consider $\Delta x = \infty$

or neutron = plane wave $\quad |k\rangle = \varphi_k(x) = \frac{1}{\sqrt{2\pi}} e^{ikx}$

Momentum eigenfunctions

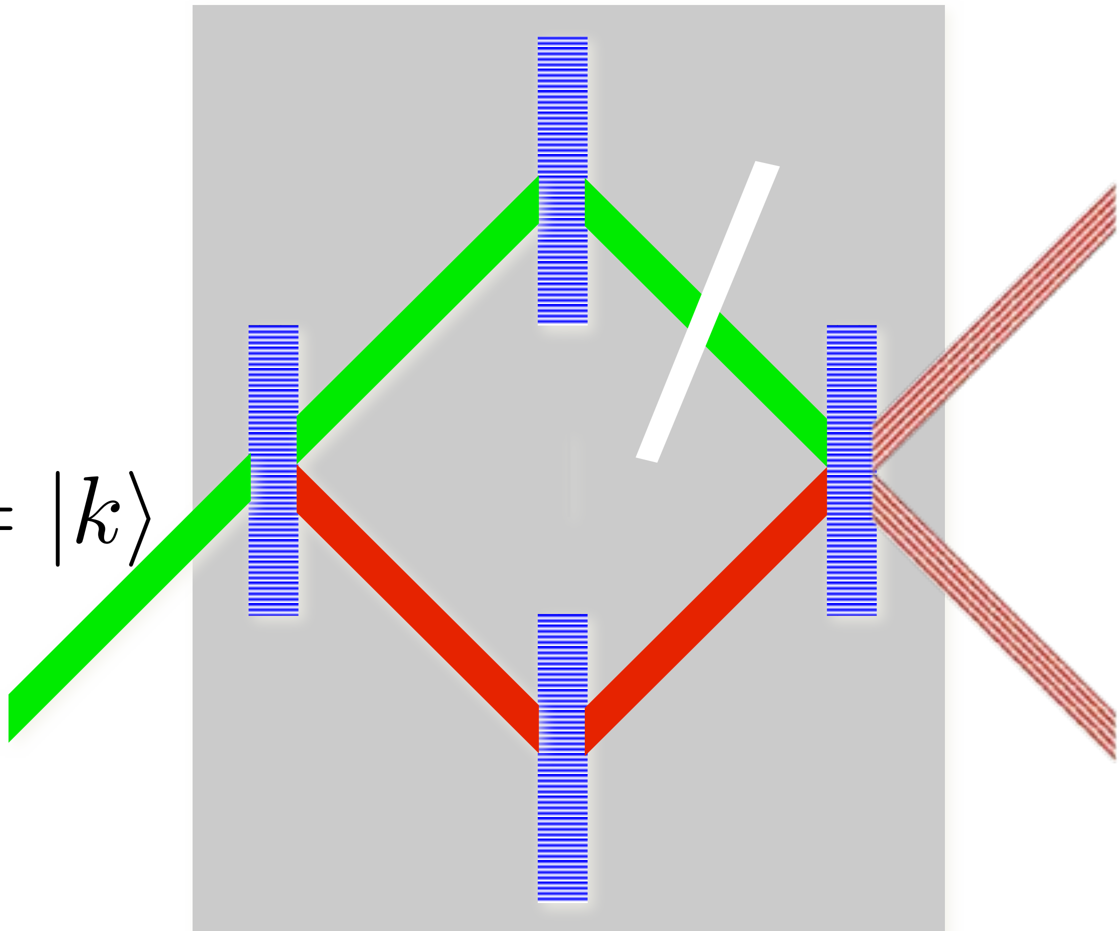


courtesy of Dmitry Pushin. Used with permission.

We can analyze the neutron interferometer looking only at the momentum eigenfunctions: STATIONARY SOLUTION (no time evolution)

Interference

(Calculations: I)



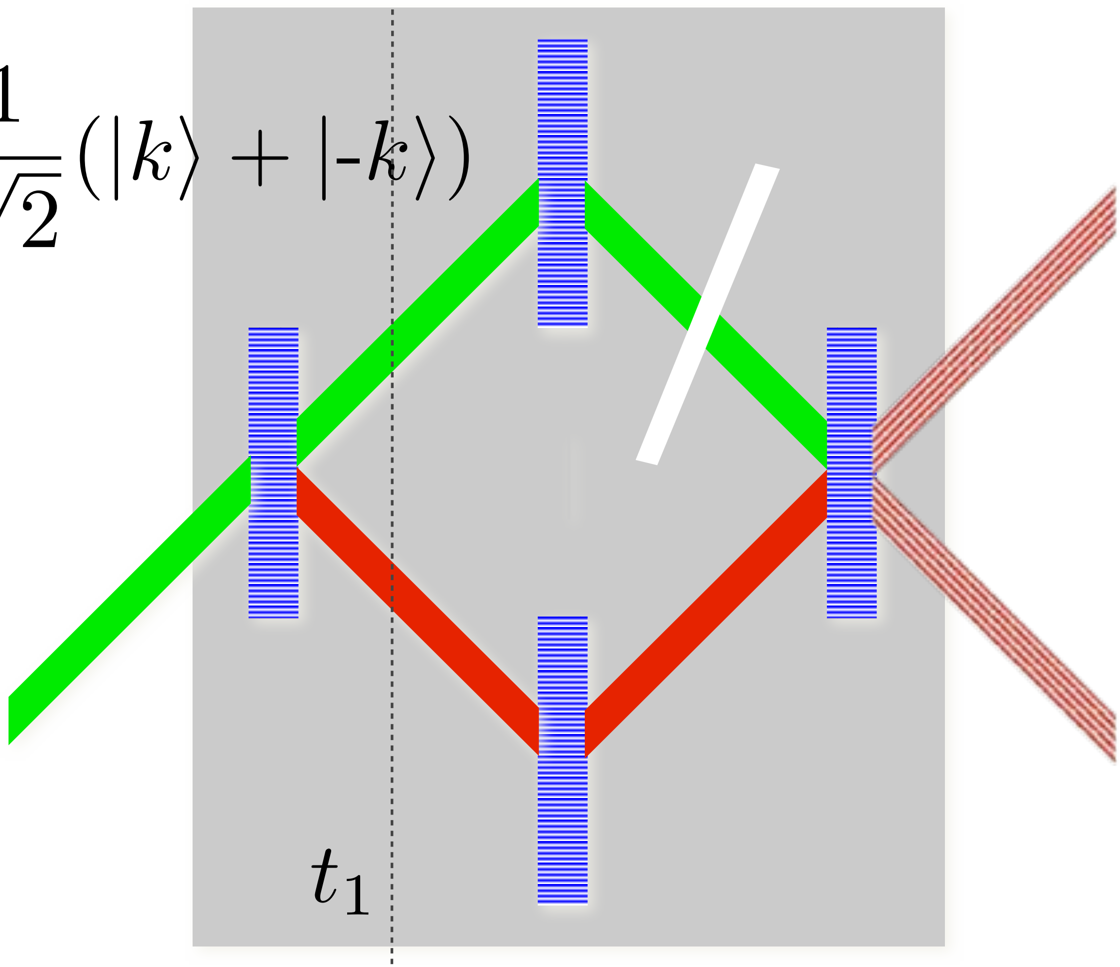
$$|\psi(0)\rangle = |k\rangle$$

The neutron is a plain wave with k>0. The first blade is a beam splitter (50/50% probability of going up or down)

Interference

(Calculations: 2)

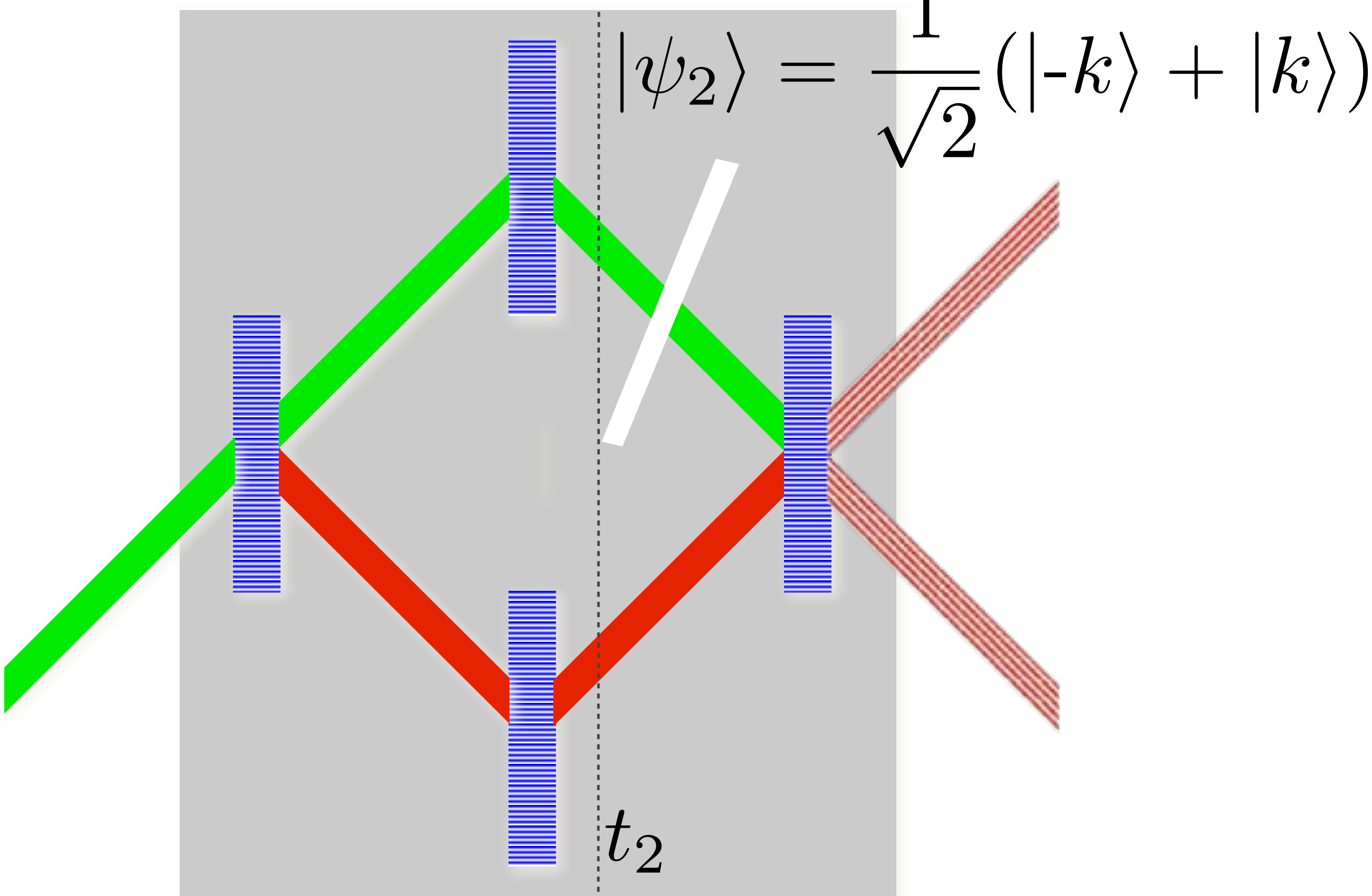
$$|\psi_1\rangle = \frac{1}{\sqrt{2}}(|k\rangle + |\text{-}k\rangle)$$



After the first blade, the state is a superposition.

Interference

(Calculations: 3)

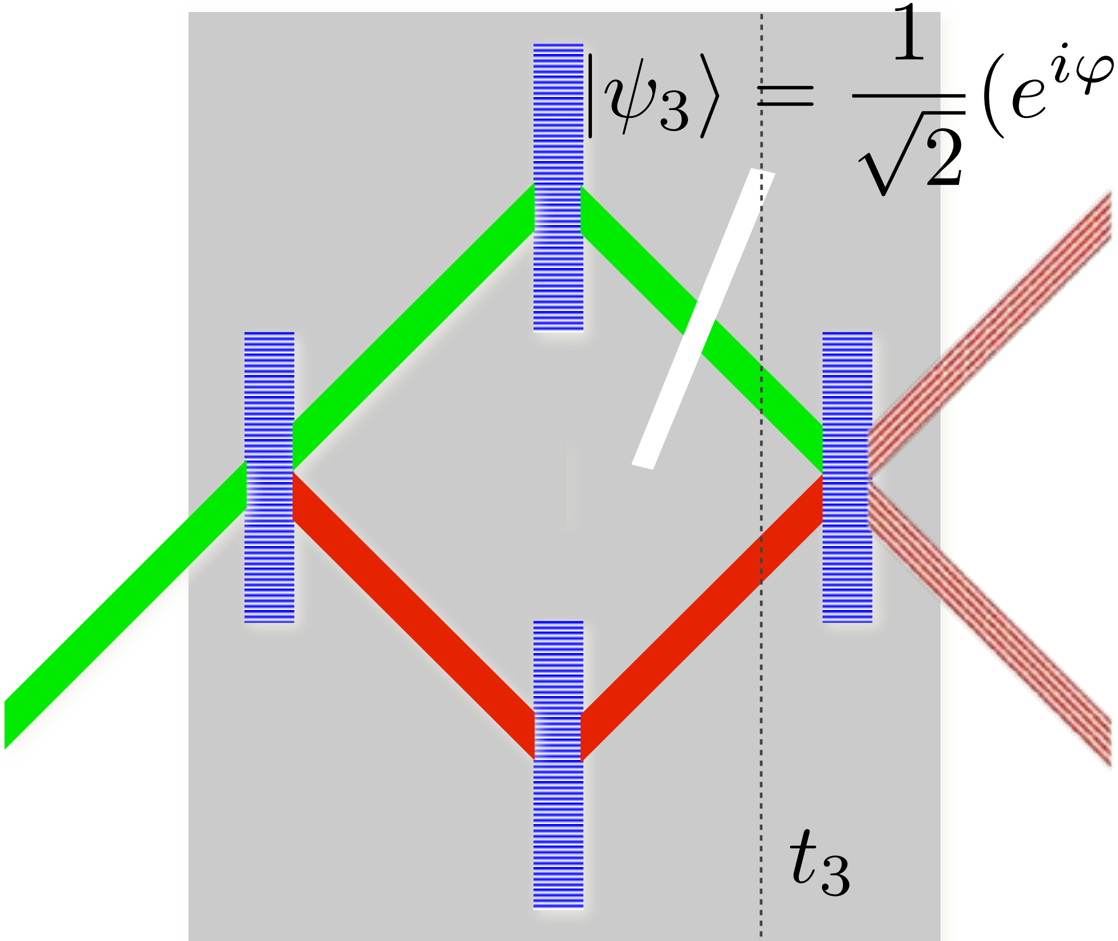


The second blade is a mirror, exchanging neutrons with positive and negative k

Interference

(Calculations: 4)

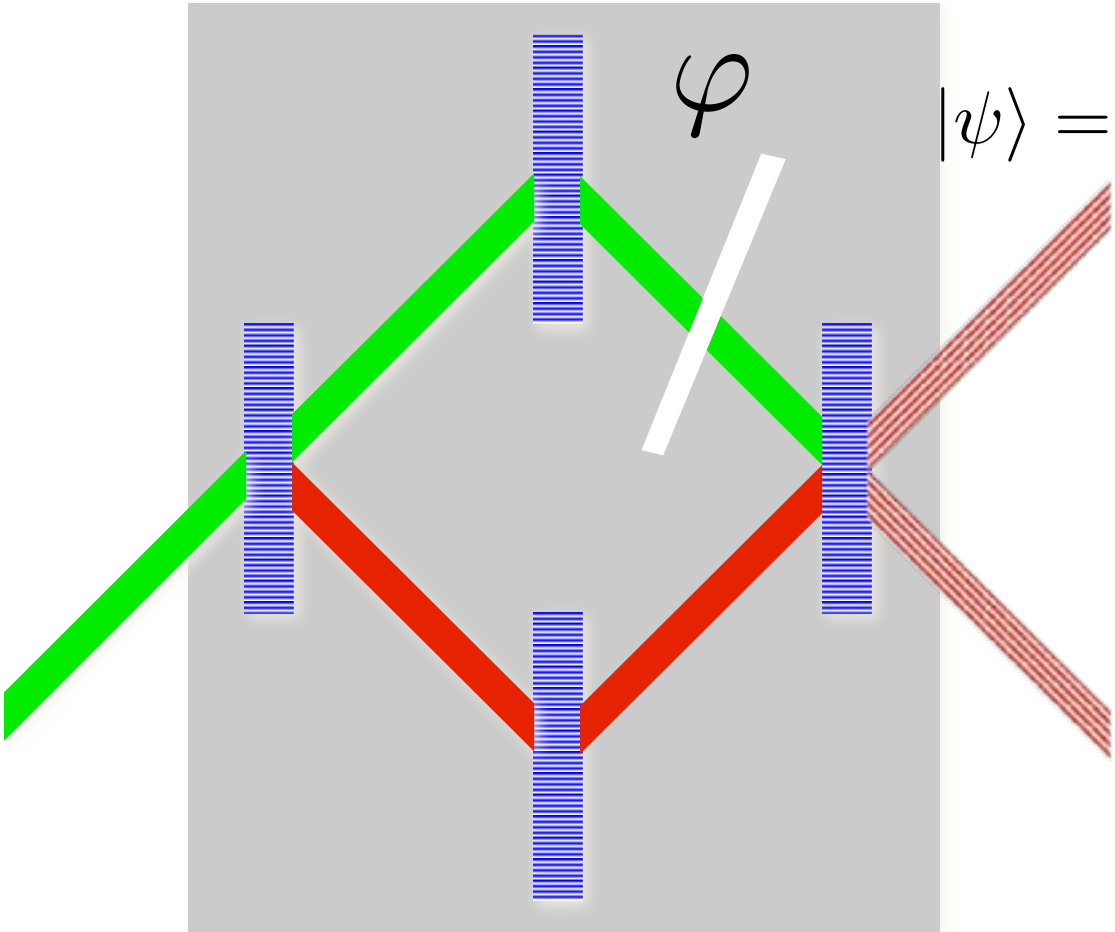
$$|\psi_3\rangle = \frac{1}{\sqrt{2}}(e^{i\varphi}\,|\text{-}k\rangle + |k\rangle)$$



Neutrons in the upper path (with negative momentum) go through the phase flag (an object)

Interference

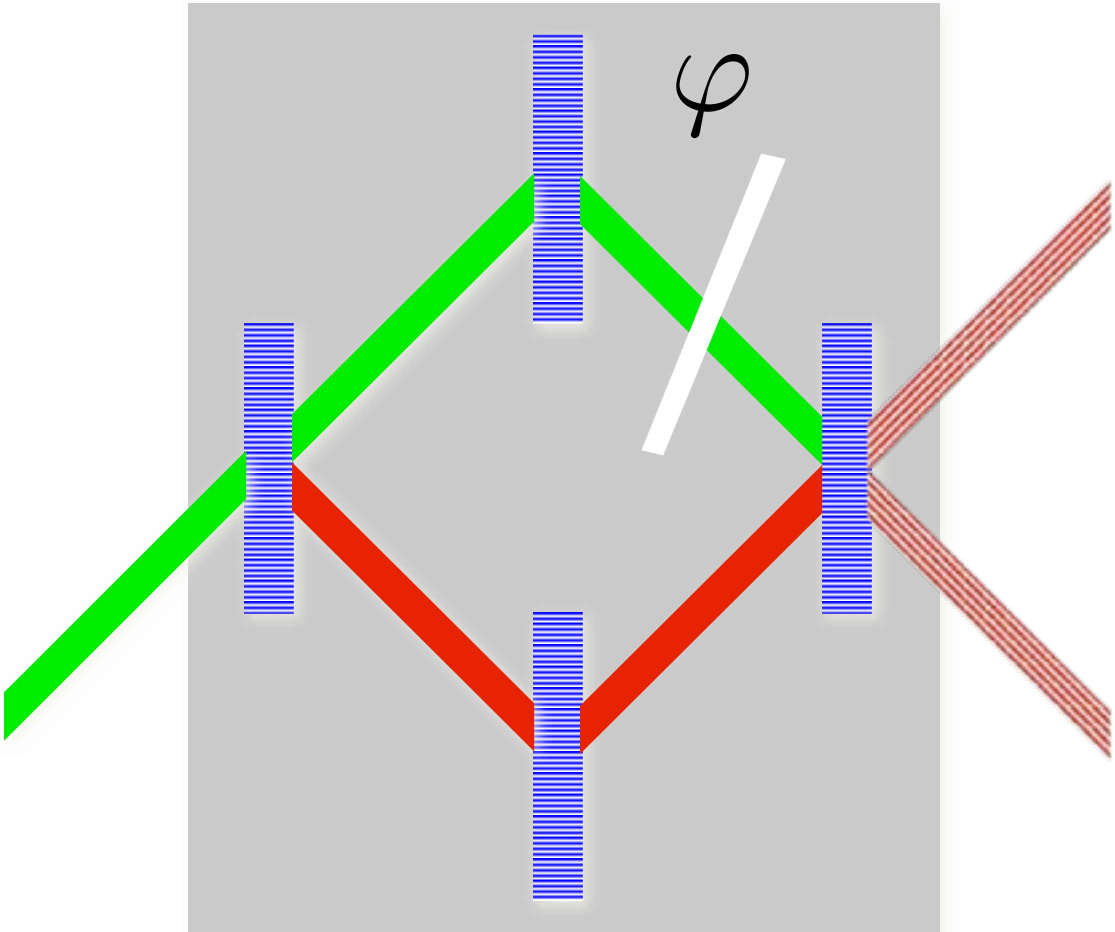
(Calculations: 5)



$$|\psi\rangle = \cos\varphi\,|k\rangle + \sin\varphi\,|\text{-}k\rangle$$

The third blade recombines the beams and allows them to interfere.

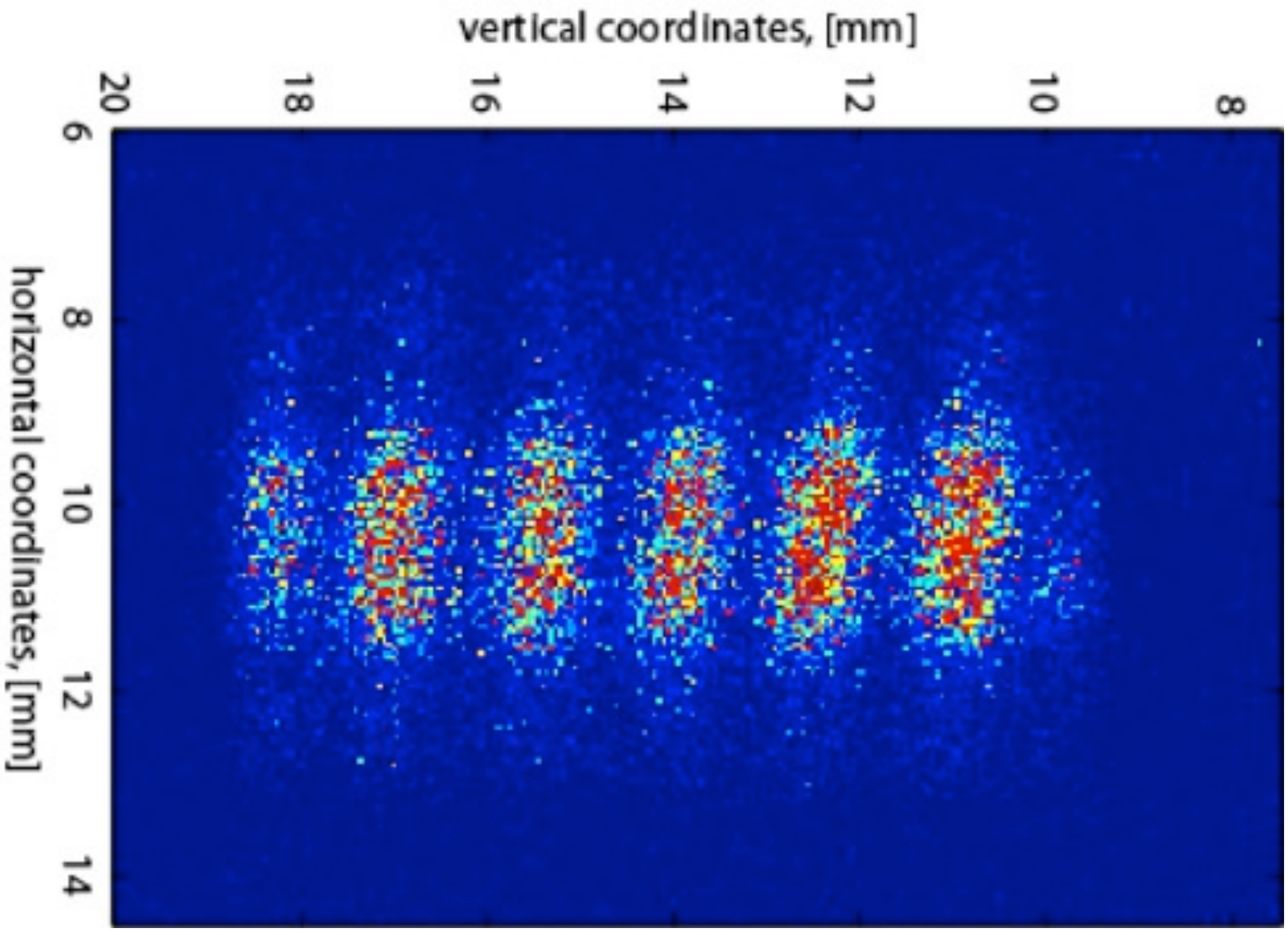
Interference



$$P(+k) = \cos^2(\varphi)$$

The detector measure the neutron flux intensity (number of neutrons per unit time).

Interference



Courtesy of Dmitry Pushin. Used with permission.

Flux of particles

- Plane wave wavefunction $\psi(x) = Ae^{ikx}$ is not properly normalized
- It is difficult to interpret as $|\psi(x)|^2$ as the probability of finding a particle at position x.
- Interpret $v|\psi(x)|^2 = I$ as a flux of particles

set $$A = \sqrt{\frac{mI}{\hbar k}}$$

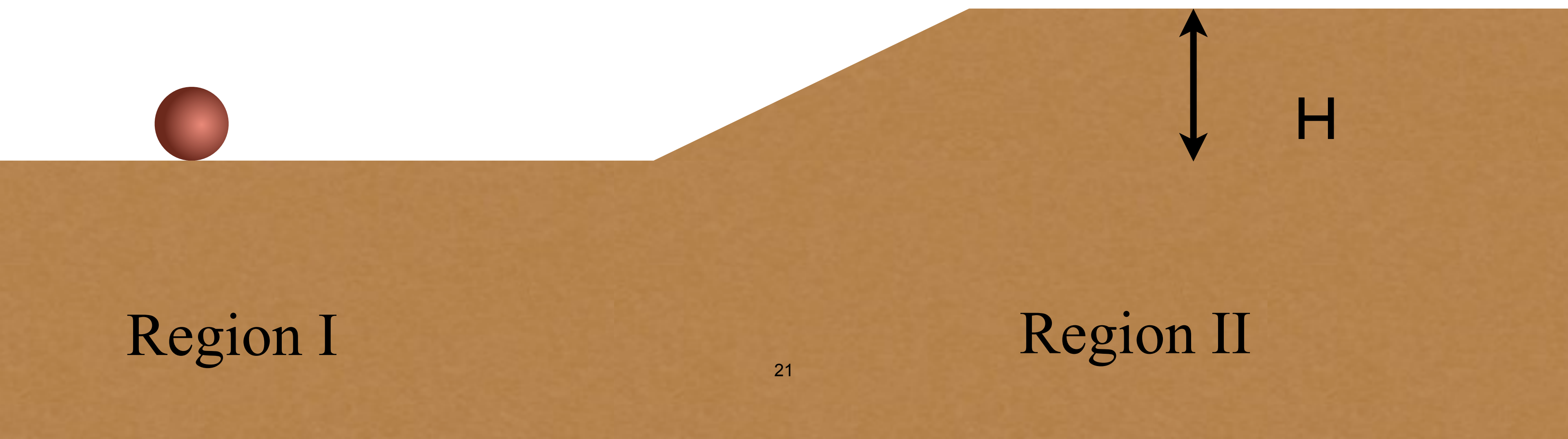
Scattering

of Waves and Particles

Transmission

Energy > Potential Step

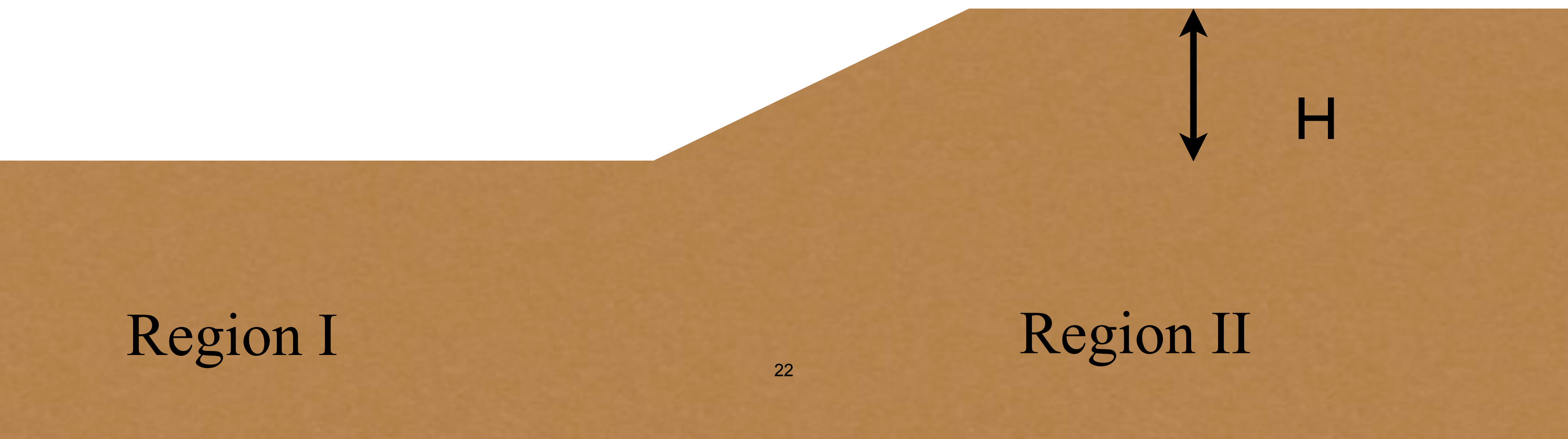
$E=T+V \quad \rightarrow \quad mv_0^2/2 > mgH$



Transmission

Energy > Potential Step

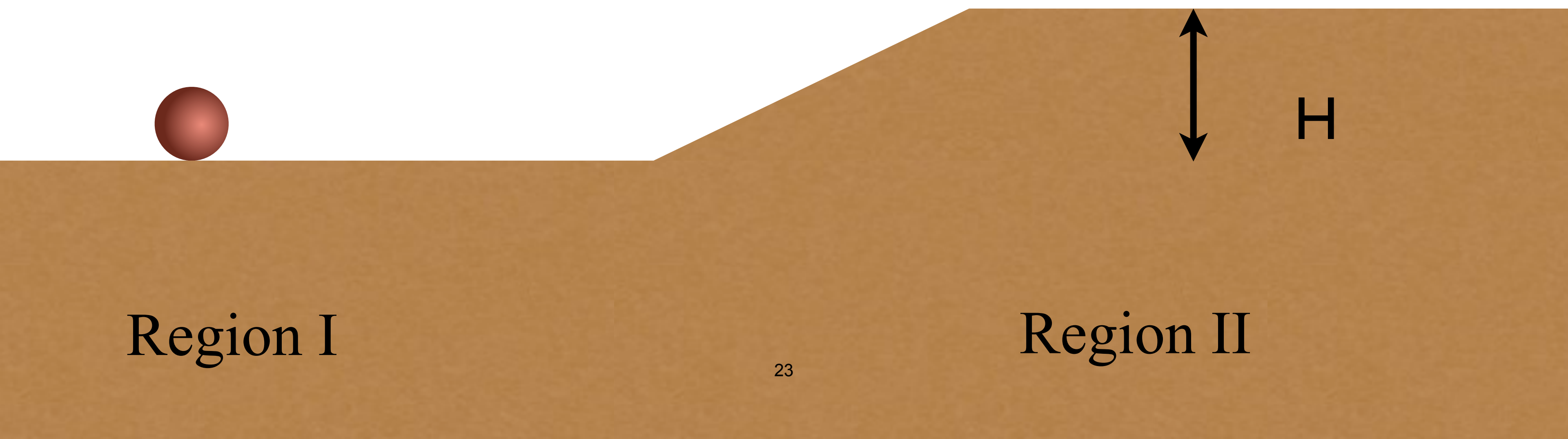
$E=T+V \quad \rightarrow \quad mv_0^2/2 > mgH$



Reflection

Energy < Potential Step

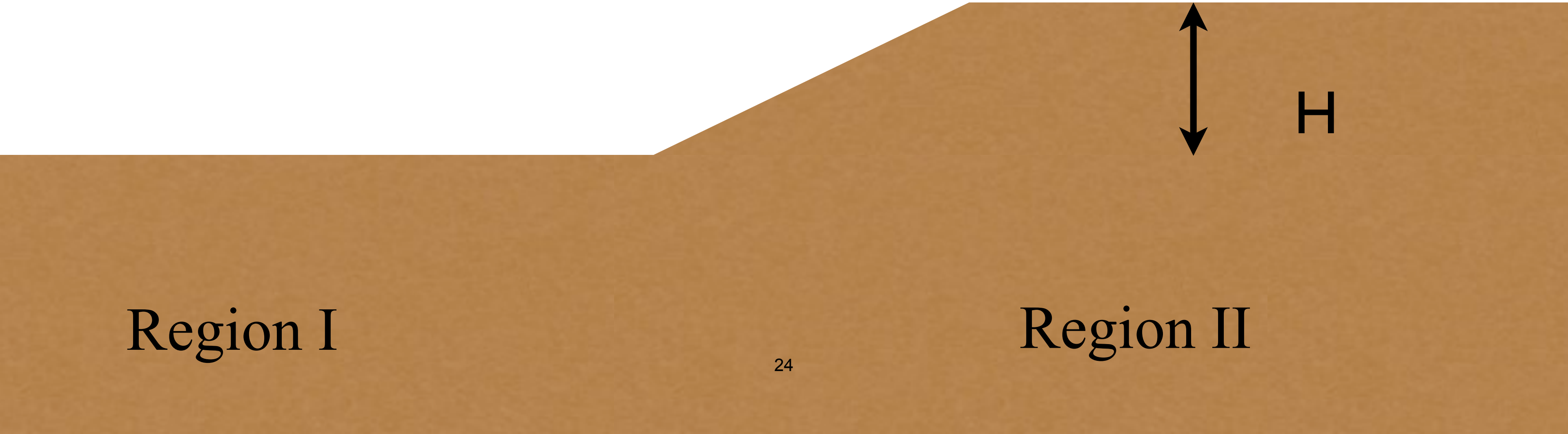
$E=T+V \quad \rightarrow \quad mv_0^2/2 < mgH$



Reflection

Energy < Potential Step

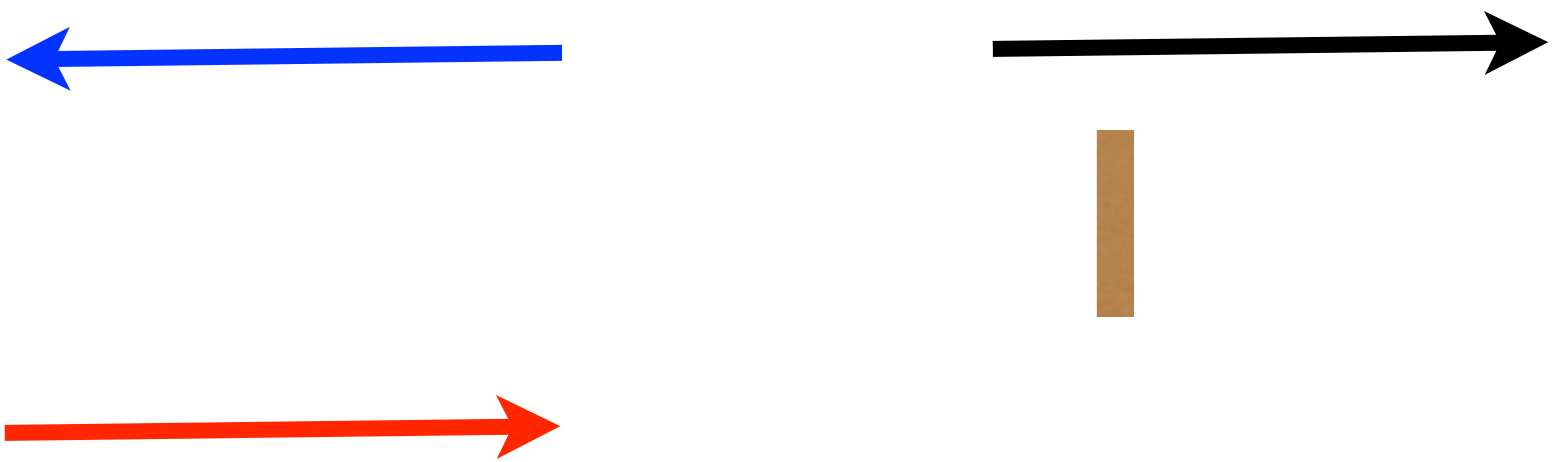
$E = T + V \rightarrow m v_0^2/2 < mgH$



Reflection/Transmission

Reflected wave e^{-ikx}

Transmitted wave e^{ikx}

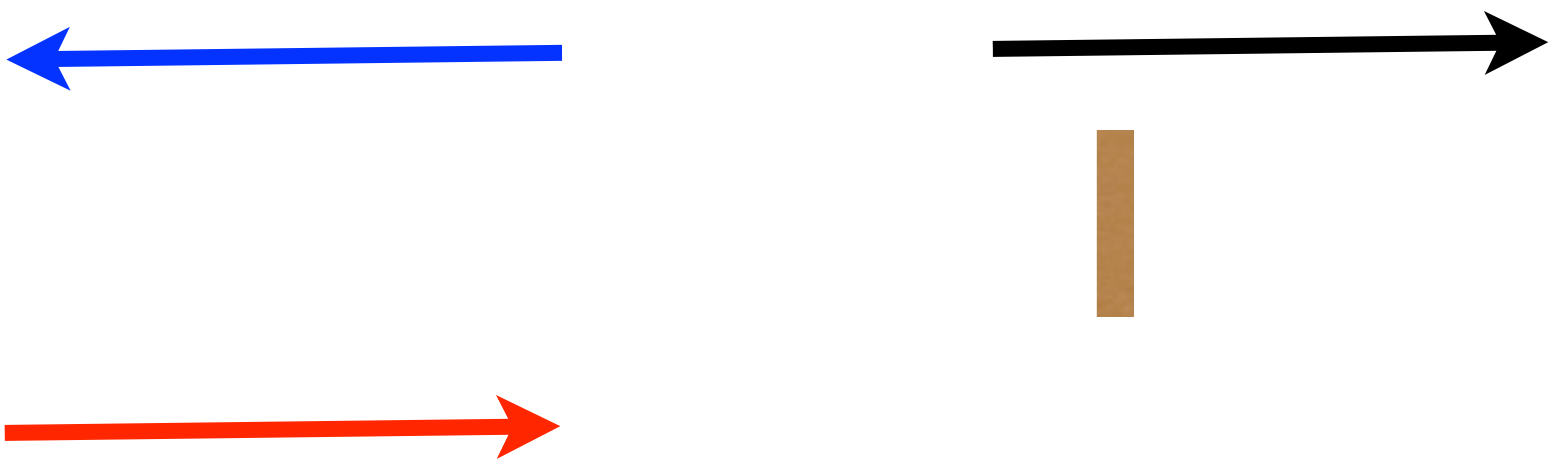


Incoming wave e^{ikx}

Reflection/Transmission

Reflected wave e^{-ikx}

Transmitted wave e^{ikx}



Incoming wave e^{ikx}

22.02 Introduction to Applied Nuclear Physics
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