Photon motion in classically forbidden regions

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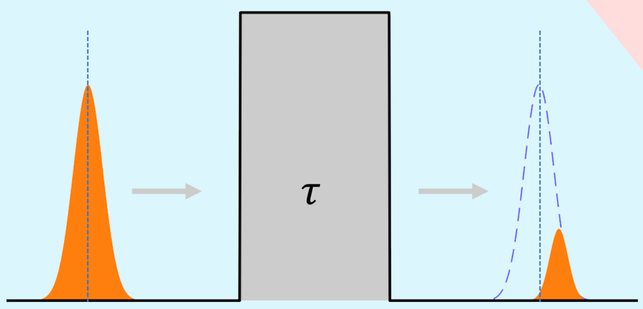
Quantum tunneling

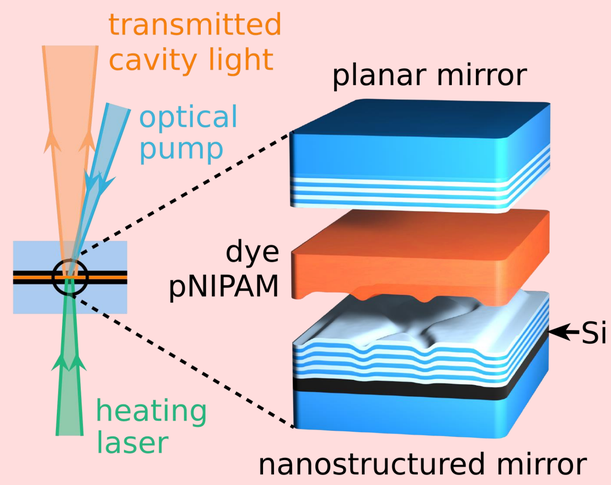
How much time does the particle spend inside the potential barrier?

This issue is still controversial. Some theoretical [1] and experimental [2] works state that the **tunneling time decreases** as one goes deeper into the classically forbidden region. Here we aim to clarify the topic of **velocity of tunneling photons**, based on our recent theoretical proposal [3].



Photon Bose-Einstein Condensation Platform

2D trapped photon gas in microcavity [4]

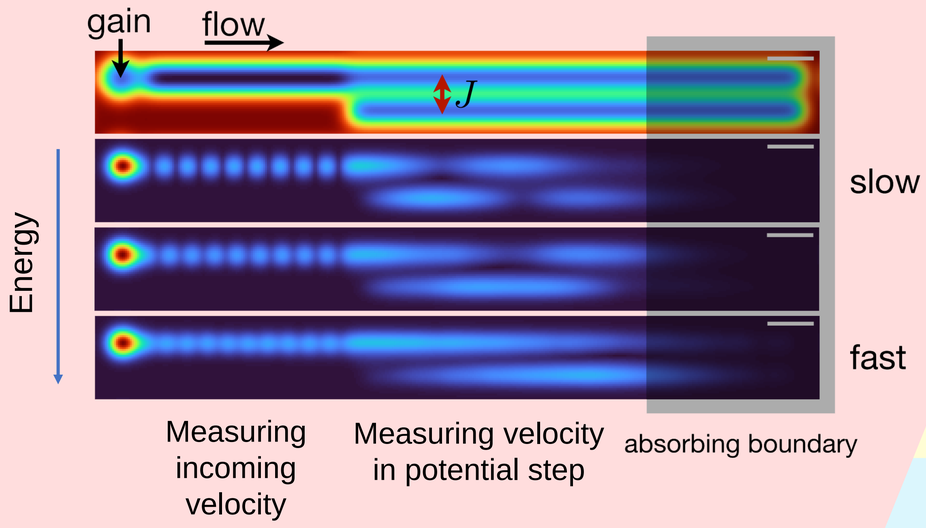


Coupled waveguides

How can we measure velocity of particles inside a potential step?

Experimental ingredients for velocity extraction:

1. Potential step
2. Change & measure incoming velocity
3. Clock



Stationary 1D Schrödinger equations in coupling region:

$$E\psi_1 = \frac{\hbar^2}{2m}\Delta\psi_1 + V_0\psi_1 + \hbar J_0(\psi_2 - \psi_1)$$

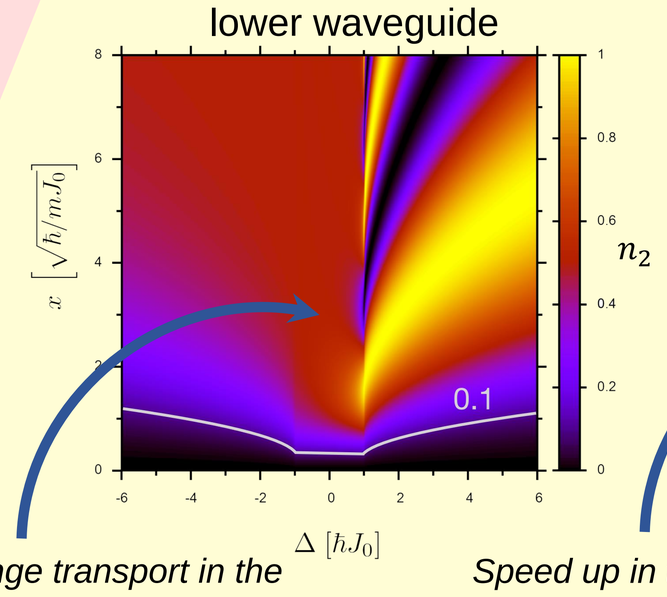
$$E\psi_2 = \frac{\hbar^2}{2m}\Delta\psi_2 + V_0\psi_2 + \hbar J_0(\psi_1 - \psi_2)$$

Analytical Results

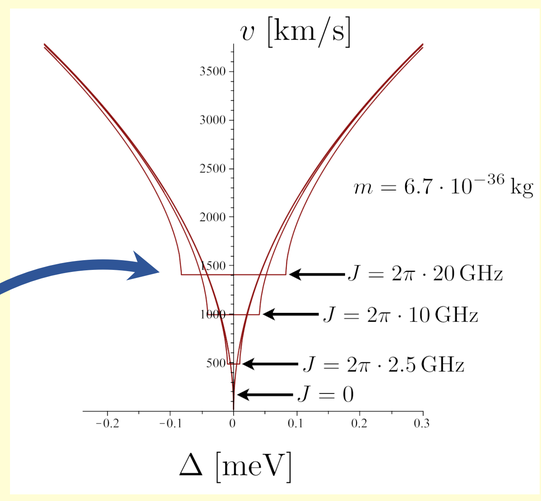
$$n_2 = \frac{|\psi_2|^2}{|\psi_1|^2 + |\psi_2|^2} \approx \left(J_0 \frac{x}{v}\right)^2$$

$$\Delta = E - V_0 + \hbar J_0$$

Relative population in the lower waveguide



Velocity

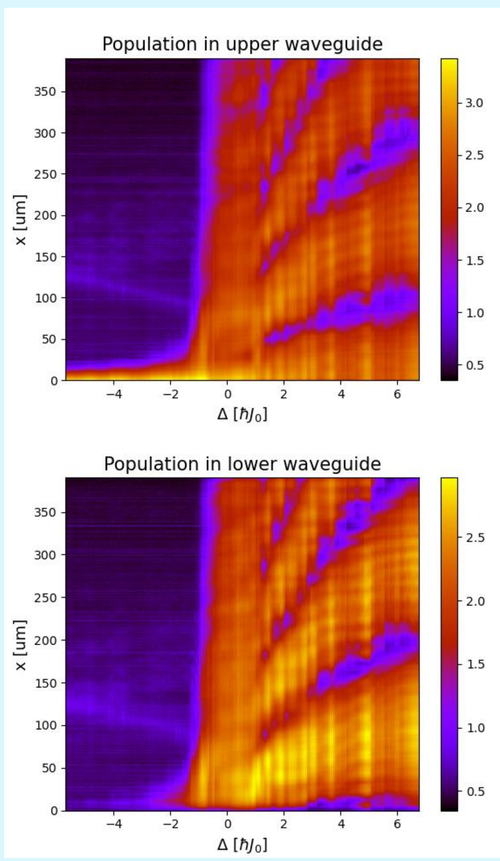


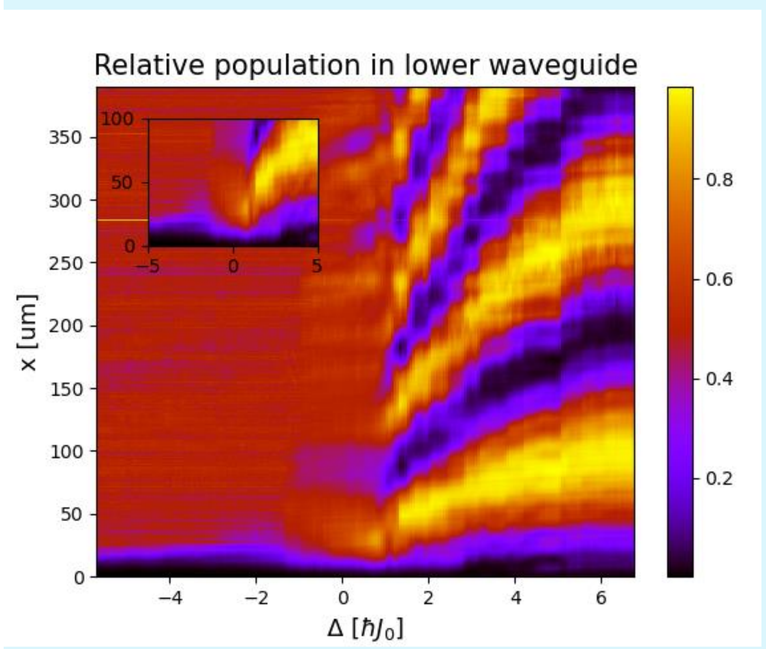
Long-range transport in the classically forbidden region

Speed up in the classically forbidden region

Experimental Results

Work in progress…





Conclusion & Outlook

1. Experiments confirm the presence of long-range transport in classically forbidden region. This mode of transportation effectively acts as a 50/50 beamsplitter.

2. Velocity measurements require getting rid of unnecessary noise and reflections in the cavity. More accurate measurements will be possible with the implementation of active mirror tilt control.

[1] Dumont, R. S., et al. "The relativistic tunneling flight time may be superluminal, but it does not imply superluminal signaling." New Journal of Physics 22.9 (2020).
[2] Ramos, R., et al. Measurement of the time spent by a tunneling atom within the barrier region. Nature 583, 529–532 (2020).
[3] Klaers J., Sharoglazova V., Toebes C. Particle velocities and long-range transport in classically forbidden regions //arXiv preprint arXiv:2212.11575. – 2022.
[4] Vretenar, M., et al. "Controllable Josephson junction for photon Bose-Einstein condensates." Physical Review Research 3.2 (2021)

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