

Non-obvious controls:

- Use the **Save/Load** feature in the **File** menu to save a configuration of barriers and/or detectors for lecture or homework.
- Be sure to try all the different tabs at the top of the simulation.
- Change the **Display** from **Average Intensity** to **Hits** to view the individual particles hitting the screen.
- Use **Copy Screen** to save a copy of the screen so that you can compare the interference patterns for different slit separation, wavelength, type of particle etc.
- In the **Single Particles** tab, check **Auto-Repeat** to get a continuous stream of particles, and **Rapid** to build up the interference pattern more quickly.
- You can **Pause** the sim and then use **Step** to incrementally analyze.
- There is a feature to increase the **Resolution** in the **Options** menu, but this will slow things down. Increasing the **Time Step** will help speed things up by skipping frames.
- Use the **UI** option in the **Options** menu to change the color scheme and fonts.
- If you are doing a lecture demonstration, set your screen resolution to 1024x768 so the simulation will fill the screen and be seen easily.

Important modeling notes / simplifications:

- To illustrate the behavior of waves between the slits and the screen, we focus on a near-field view. The commonly used equation for double slit interference, $d\sin\theta = m\lambda$, is an approximation for the far-field limit, and thus breaks down here.
- This simulation solves the wave equation for light or the 1D Schrodinger equation for particles using the units given on the stopwatch and the ruler, so the behavior is exactly what you would see on this scale.
- In the **Single Particles** tab, the default setting of the detectors is to make periodic measurements in which the wave function collapses to inside the detector if it is detected there, and outside the detector if it is not.¹ Once the particle has been detected inside a detector, the detector is disabled. If you check **Repeat Detect** the detector will not be disabled, and you can trap the particle in the detector by repeated measurements due to the Quantum Zeno Effect. If you uncheck **Autodetect**, the detector will only function when you press **Detect!**
- The purpose of the **Two Lasers** tab is to illustrate that two lasers can interfere if and only if they are the same color.

Insights into student use / thinking:

- Students often have difficulty understanding the meaning of complex wave functions. This can perhaps best be illustrated by the observation that students frequently ask, “What is the physical meaning of the imaginary part of the wave function?” (Students never ask about the physical meaning of the real part!) Using both the real part and the imaginary part with the simulation paused can help students understand how the two are related and see that they are both equally important.
- The simulation includes additional representations of the wave function which show the **magnitude** as a black curve and the **phase** as a color included within the magnitude curve. In interviews, we found that *none* of the students were able to

¹ R. H. Dicke, “Interaction-free quantum measurements: A paradox?” *Am. J. Phys.* **49**, 925 (1981).

make sense of this representation without significant help from the interviewer, including one student who had taken a class where the representation was used extensively. We note that this “phase color” representation is the *only* representation used in most quantum mechanics simulations, both commercial and free. Please use this representation with caution!

- The time and distance scale changes when you switch between particle types. Students often don’t notice this, so if you want them to be aware of it, you will probably need to point it out or incorporate this idea into a homework activity.
- In interviews, we found that even students with no background in quantum mechanics were able to learn a lot from the first two tabs of this simulation.

Suggestions for sim use:

- For tips on using PhET sims with your students see: [Guidelines for Inquiry Contributions](#) and [Using PhET Sims](#)
- The simulations have been used successfully with homework, lectures, in-class activities, or lab activities. Use them for introduction to concepts, learning new concepts, reinforcement of concepts, as visual aids for interactive demonstrations, or with in-class clicker questions. To read more, see [Teaching Physics using PhET Simulations](#)
- For activities and lesson plans written by the PhET team and other teachers, see: [Teacher Ideas & Activities](#)
- We use this simulation in lecture to demonstrate how the double slit experiment shows that light must be both a wave that goes through both slits and a particle that hits the screen at a single location. In our course, this lecture led to an unexpected onslaught of deep, fundamental questions that took up nearly an entire class period. We argue that the visualization provided by the simulation allows students to see the heart of the issue and ask deep questions earlier in the learning process.
- You can illustrate how detecting which slit a particle went through destroys the two slit interference pattern by putting a detector over one or both slits.
- If you are using **Make Quantum Measurement** in a lecture demo, it is much easier for students to follow the measurements if you tell them just before you hit the button.
- You can demonstrate the Quantum Zeno Effect by making quantum measurements in quick succession in **wave packet** mode.