Low-intensity double-slit experiment for physics education and outreach

Application Note

S. Barz, N. Hauser, Institute for Functional Matter and Quantum Technologies, University of Stuttgart, Germany (December 2021)

Introduction

Quantum mechanics is a fascinating and most often a counterintuitive theory. Designing experiments where the laws of quantum mechanics can be observed in a hands-on fashion is a challenging task. In this report we demonstrate an easy experiment that makes the principles of quantum physics easily accessible and provides an introduction into concepts of modern physics.

1. Double-Slit Experiment for Physics Outreach

The double-slit experiment is a famous experiment to demonstrate that photons exhibit characteristics of both particles and waves. If light from a coherent light source like a laser or single-photon source is sent through a double-slit, an interference pattern characteristic to wave-like phenomena can be observed. When the light intensity is reduced such that only very few photons are sent through the double-slit, one can detect the individual photons in a particle-like way. Integrating over many measurements re-establishes the wave-like interference pattern – whereas each single photon detection takes place at a random location, establishing the particle-like nature.

Here, we demonstrate those basic principles of quantum mechanics in a hands-on type experiment. We use an Andor iStar DH334T-18H-13 ICCD-Camera with a temporal resolution of 10 ns, a high spatial resolution with 1024x1024 pixels and a pixel size of 13x13 μm². The experiment can be set up beforehand as a plug-and-play-type experiment or built and aligned by the students themselves due to its simplicity – A picture of the pre-built experiment can be seen in Figure 1.

2. Experimental Setup

The setup of the demonstrator experiment is shown in Figure 2. We use a 632 nm CW laser with an output power of 1 mW, impinging onto the double slit. The laser power is attenuated with an array of neutral density filters that attenuate the intensity by a factor of 10^9, leaving us with an overall power of 1 pW at the detector. The double-slit pattern is then detected with the Andor iStar ICCD-Camera which is set to an exposure time of 10 μs. Assuming no losses, the number of photons from the laser arriving at the camera during the exposure time can be estimated to be $N \approx 30$, meaning there are only a few photons arriving at the detector in the detection window.

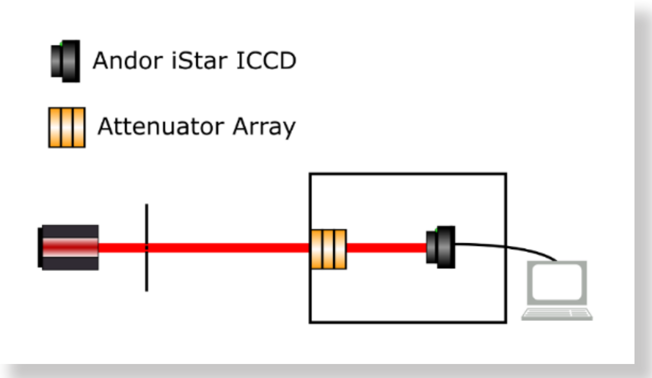

Figure 2: Setup consisting of a 1 mW 632 nm Laser, a double-slit, an attenuator array and the Andor iStar ICCD camera.

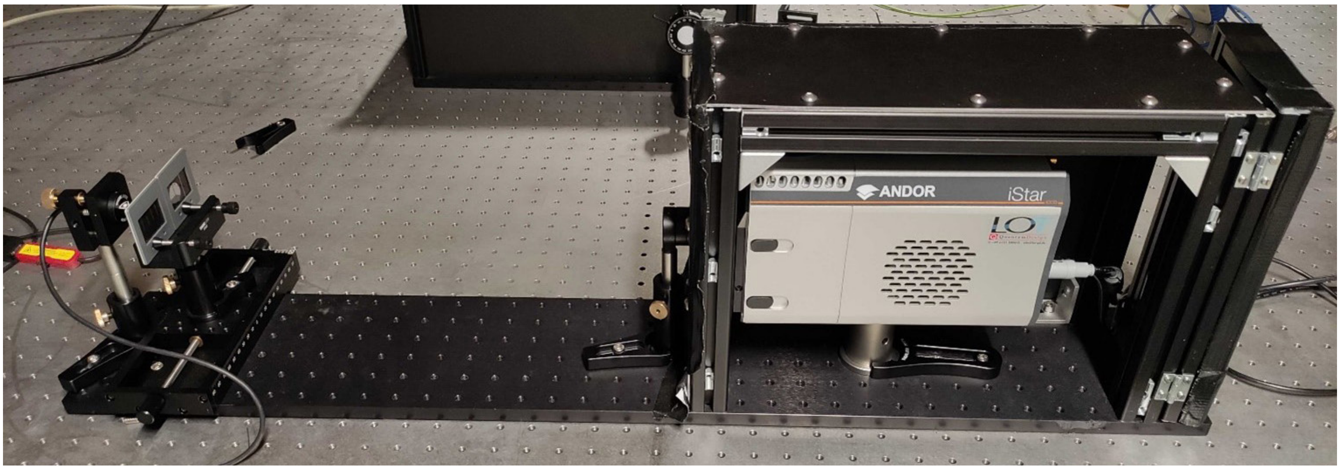

Figure 1: Setup consisting of the 632 nm 1 mW Laser, a double-slit, the attenuator array and the Andor ICCD Camera. The camera is put in a box to minimize background light – The side panel was taken off for the picture.

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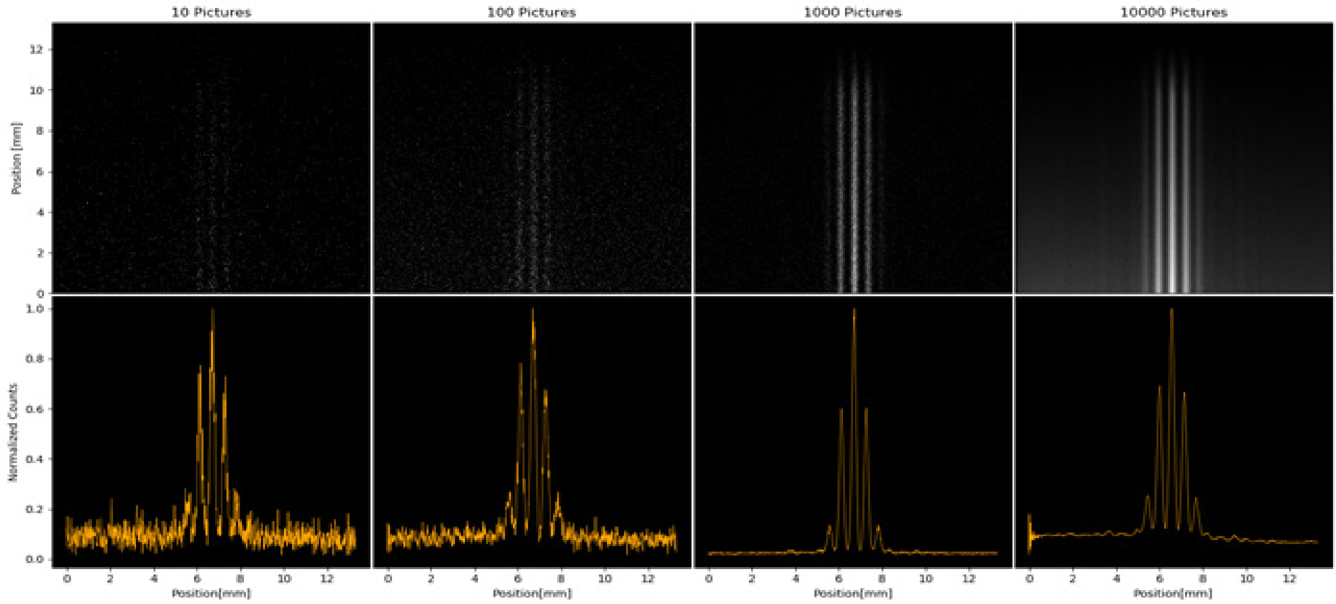

Figure 3: Detection pattern

3. Results

Figure 3 shows the detection pattern, integrated over a certain number of events. We can clearly see the single photon events slowly forming the expected interference pattern characteristic to double-slit experiments. For background correction, two rounds of data acquisition where performed. One with the laser turned on and another one with the laser turned off. The latter data has then been subtracted from the measurement data to reduce the noise in the images. We see that this simple setup clearly visualises the basic principles of quantum mechanics.

4. Conclusion and outlook

The Andor iStar ICCD presents a great tool to be used in education and research alike. With a simple setup we where able to show particle-wave duality in photons – a feat in making quantum mechanical properties observable in a minimalistic setting in order to make the underlying concepts more tangible so students can easily make their first contact with the exciting topics in quantum mechanics.

With the possibility to resolve photons both spatially and temporally, further hands-on experiments could be designed to be performed by students. Such experiments include interesting phenomena like ghost imaging, delayed choice experiments and demonstrations of spatial entanglement.

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