How do we measure the momentum of a quantum particle

James Freericks

Georgetown University, Dept of Physics, 37th and O St, Georgetown University, Washington, USA

In the conventional von Neumann theory of measurement, an experimental device uniquely entangles the eigenstates of the self-adjoint operator with the pointer states of the experimental device. Then, either wavefunction collapse or decoherence due to macroscopic pointer states, selects the measurement value of the experimental device. When von Neumann introduced this theory, which is the cornerstone of both the quantum theory of measurement and of how we teach measurement in quantum mechanics classes, Schroedinger said that the theory was beautiful, but that he did not think it applied to any actual experiment. While there may be some experiments that fit this paradigm (but I am not clear on any myself), most quantum experiments proceed in a different fashion. Most are counting experiments, which then infer the properties of interest from the geometrical set-up of the experiment. Counting experiments lie outside the von Neumann paradigm and do not seem to have any measurement problem associated with them. They simply require a way to amplify the counts, so they can be easily observed, and because they are often destructive, the precise moment of the experiment is also known. In this talk, I will illustrate how many counting experiments really work and how they should be analyzed. For example, most ways to measure momentum use time-of-flight strategies, where we measure position to infer the momentum. While this work is useful for practicing physicists to know, it is most critical that it become part of the pedagogy we teach in the quantum classroom. Especially as we strive to train the next generation of quantum aware scientists for the quantum-enabled workforce and prepare them for work in quantum sensing.