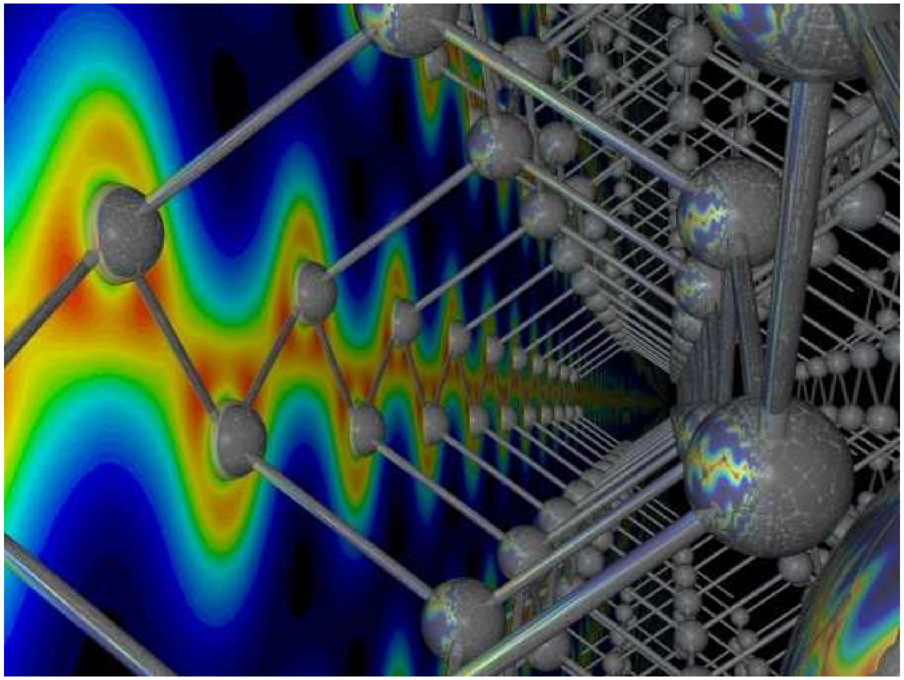
A brief discussion about weak measurements

Electronic Structure Discussion Group, February 2012



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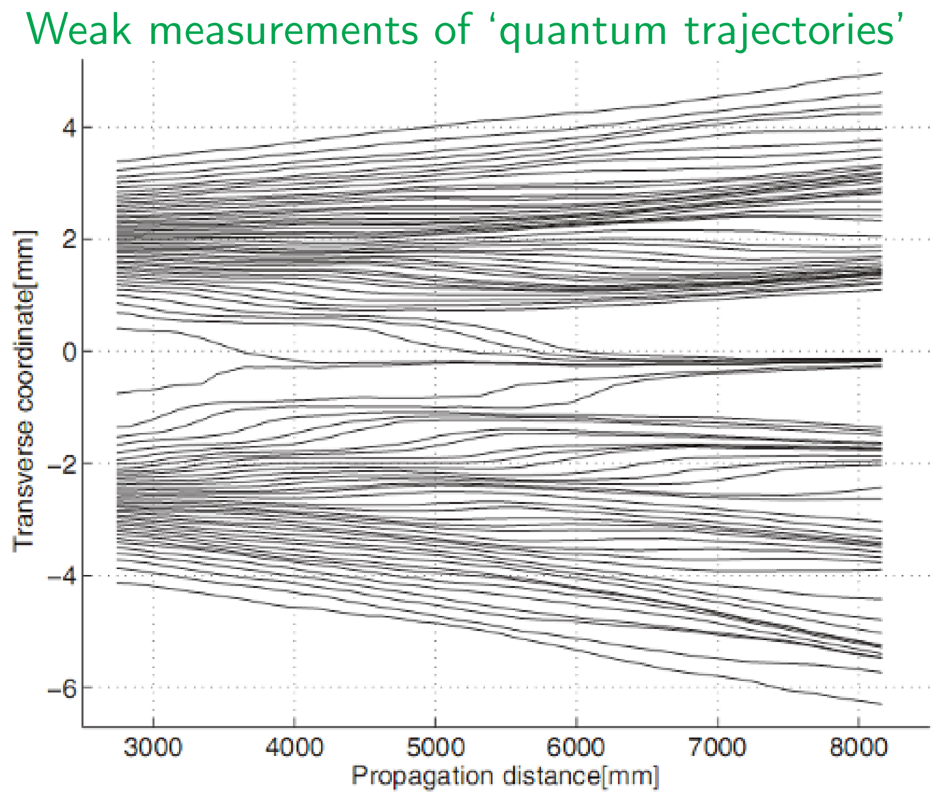
‘Observing the average trajectories of single photons in a two-slit interferometer’

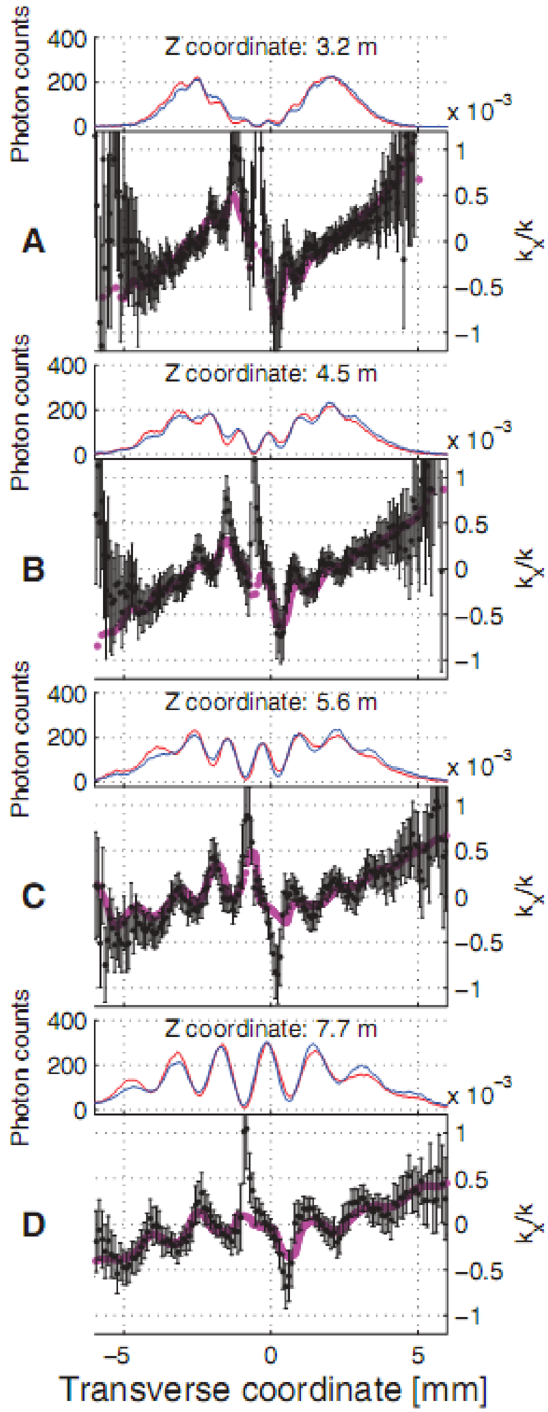


Sacha Kocsis, Boris Braverman, Sylvain Ravets, Martin J. Stevens, Richard P. Mirin, L. Krister Shalm, and Aephraim M. Steinberg, *Science*, **332** (6034), 1179-1173 (2011).

Steinberg’s team won the 2011 Physics World prize for ‘Physics Breakthrough of the Year’ for this exquisite experimental work (see `http://physicsworld.com/cws/article/news/48126`).

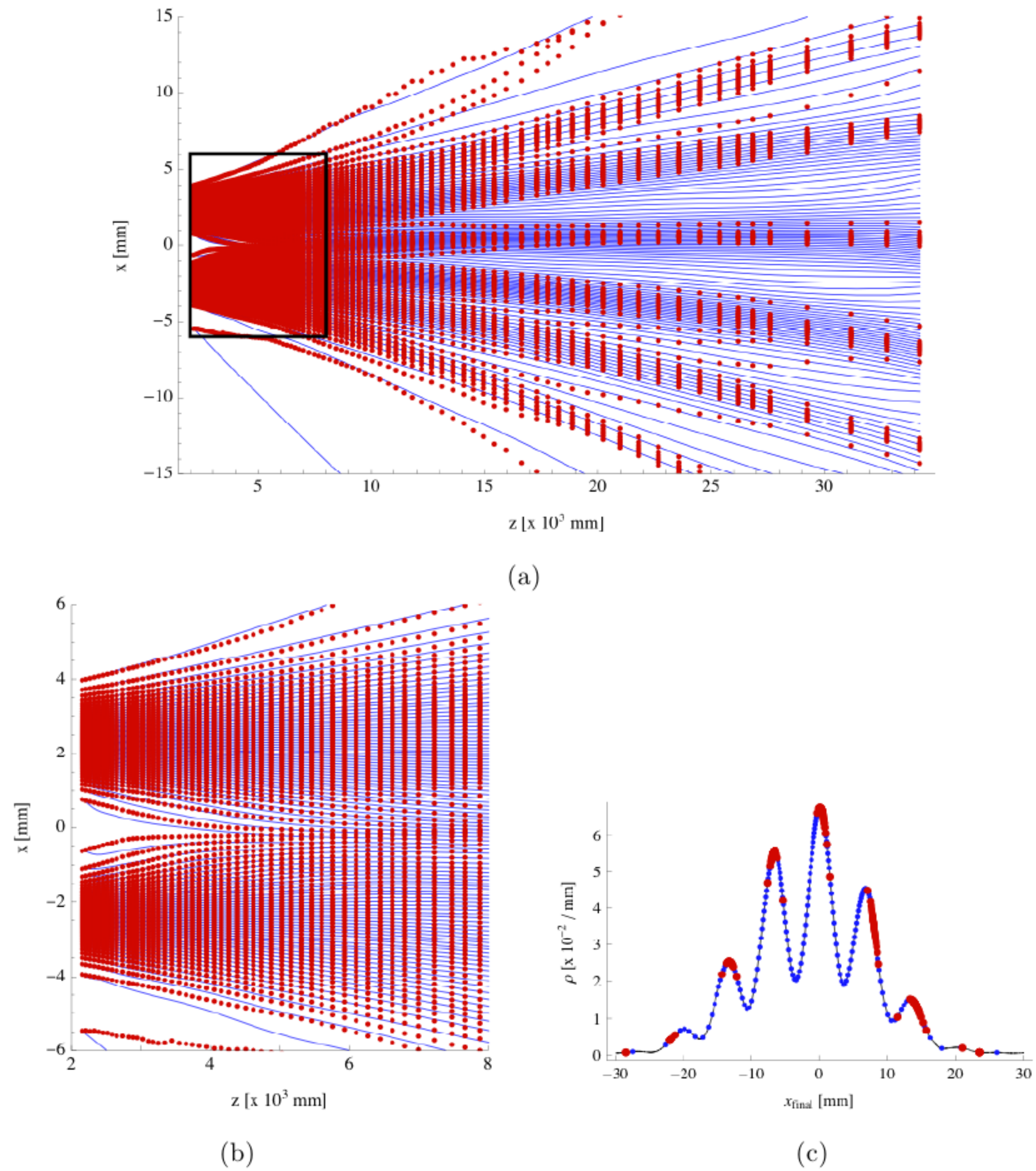
Mentioned by Basil Hiley in his talk here last week.

Where does this come from?



Do these trajectories look like de Broglie-Bohm trajectories?

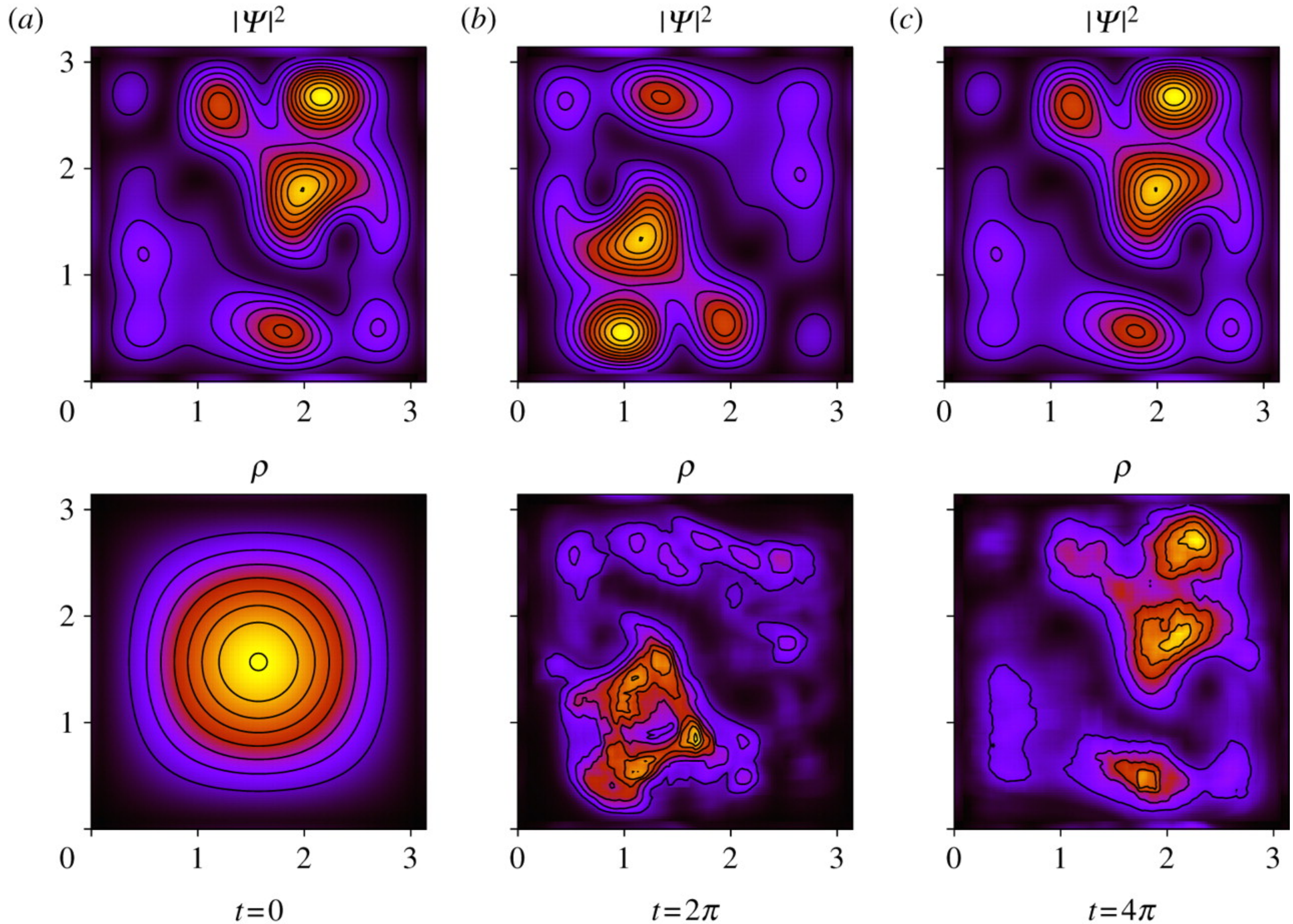
- Kocsis *et al.* say that they do: "*Single-particle trajectories measured in this fashion reproduce those predicted by the de Broglie-Bohm interpretation of quantum mechanics, although the reconstruction is in no way dependent on a choice of interpretation*". No supporting evidence is offered for this statement.
- In a later comment, Coffey and Wyatt (`arXiv:1109.4436`) point out that the trajectories presented in Kocsis *et al.* do **not** in fact converge to high probability regions, a familiar and necessary behaviour of Bohm trajectories.
- However, C+W reanalyze the Kocsis data and computer codes, and show that if you (a) fix minor bugs in the computer code, (b) include all the data, and (c) reanalyze the data using standard density estimation techniques, then the calculated Bohm trajectories and the measured trajectories agree.



So what?

- A *strong* measurement reveals a property of an individual system (though what if anything you are actually 'measuring' is usually not clear - see Lecture 4 of my Bohm graduate course at `www.tcm.phy.cam.ac.uk/~mdt26/pilot_waves.html`). A *weak* measurement only reveals a property of a large statistical ensemble of equally prepared systems. A weak measurement says nothing about an individual system. All 'weirdness' of weak values results from attempts to interpret properties of an ensemble (2.4 children) as properties of an individual system (a family).
- Effectively, the 'De Broglie-Bohm Interpretation of Family Life' asserts that children exist even when nobody watches them, and that the number of children in a family is always an integer. The fact that the average family has 2.4 children does not contradict the deBB interpretation.
- In this sense, the fact that you can measure the *average* velocity vector field in an interferometer and draw tangent curves on it that look like trajectories does not strictly speaking offer evidence for or against the deBB interpretation.
- However, these results shows us that deBB particle trajectories are much more than a part of a controversial interpretation of QM. They are a part of QM itself, irrespective of the interpretation. However, what different interpretations disagree on is what these trajectories really 'are'.
- In this sense, trajectories play a role in QM similar to the role of the wave function. All interpretations involve the wave function, but different interpretations disagree on what this wave function really 'is'.
- Can argue (as who doesn't, e.g. Coffey and Wyatt) that deBB trajectories are just hydrodynamical and kinematically portray the evolution of the probability density (the 'particles' follow the streamlines of the probability current, after all). This is to ignore their *explanatory* role, and anyway is true only in 'quantum equilibrium'; the possibility of 'out-of-equilibrium' non-Born-rule distributions offers potential experimental tests.

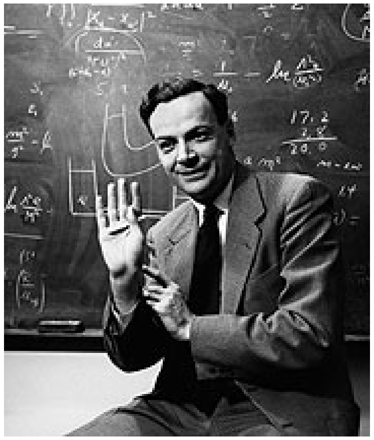
Quantum non-equilibrium



'*Timescales for dynamical relaxation to the Born Rule*' by M.D.Towler, N.J. Russell and A. Valentini
Proc. Roy. Soc. A (2011)

http://rspa.royalsocietypublishing.org/content/early/2011/11/25/rspa.2011.0598.full

Two-slit experiment with electrons



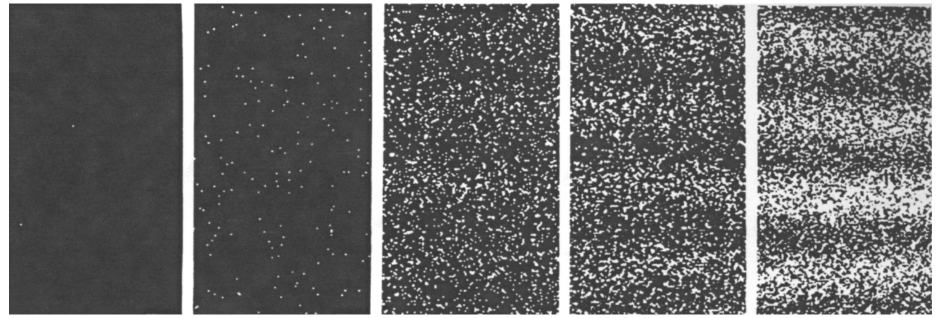
- *"A phenomenon which is impossible, absolutely impossible, to explain in any classical way, and which has in it the heart of quantum mechanics. In reality it contains the only mystery."*

- *"Do not keep saying to yourself, if you can possibly avoid it, 'But how can it be like that?' because you will get 'down the drain,' into a blind alley from which nobody has yet escaped. Nobody knows how it can be like that."*

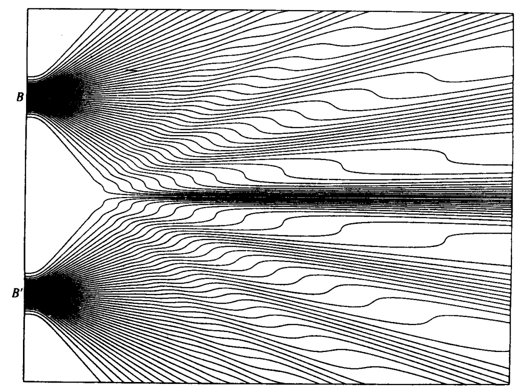
- *"Many ideas have been concocted to try to explain the curve for* P_{12} [that is, the interference pattern] *in terms of individual electrons going around in complicated ways through the holes. None of them has succeeded."*

- This experiment *"has been designed to contain all of the mystery of quantum mechanics, to put you up against the paradoxes and mysteries and peculiarities of nature one hundred per cent."*

- *"How does it really work? What machinery is actually producing this thing? Nobody knows any machinery. Nobody can give you a deeper explanation of this phenomenon than I have given; that is, a description of it."*



Pilot-wave theory: while each particle track passes through just one slit, the wave passes through both; the interference profile that consequently develops in the wave generates similar pattern in the trajectories guided by the wave.



Compare Feynman commentary with that of John Bell:

"Is it not clear from the smallness of the scintillation on the screen that we have to do with a particle? And is it not clear, from the diffraction and interference patterns, that the motion of the particle is directed by a wave? De Broglie showed in detail how the motion of a particle, passing through just one of two holes in the screen, could be influenced by waves propagating through both holes. And so influenced that the particle does not go where the waves cancel out, but is attracted to where they cooperate. This idea seems to me so natural and simple, to resolve the wave-particle dilemma in such a clear and ordinary way, that it is a great mystery to me that it was so generally ignored."

Feynman gives up (he is dead, after all..)

See the latest edition of Feynman and Hibbs's '*Quantum mechanics and path integrals*' edited by D.F. Styer (Dover, 2005).

After a statement suggesting that it is likely that the "*probability interpretation of* Ψ *is the only consistent interpretation of this quantity*" together with some reasons why, the editor has inserted a footnote:

> 'Feynman's hunch was **wrong**: in fact other consistent interpretations *are* possible. One such alternative is the de Broglie-Bohm formulation, described in
>
> David Bohm and B.J. Hiley, *The Undivided Universe: an ontological interpretation of quantum theory* (Routledge, London, 1993).

Which neatly brings us back to last week's speaker..