The Problem of Interpretation

The Quantum Ontological Puzzle

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Three Problems

Historically, there are mainly three orders of evidences that are difficult to integrate in a common building:

1) Dualism between theoretical description (unitary evolution) and experimental observations (reduction).
2) Unification of the behaviour of matter (which in a classical framework is apparently corpuscular) and light (which in a classical framework is apparently undulatory) both in theory and experimental findings.
3) The existence of the different formalisms (apart the Dirac's Picture): Heisenberg's and Schrödinger's ones, which were thought of to be about particle-like and wave-like behaviours, respectively, and in fact turned out to be equivalent (passive and active unitary transformations, respectively, the former related to evolution of observables the latter of the states).

Two Research Lines

There have been two opposite directions in answering to these problems:

1) An Idealistic position, according to which the property and the state of quantum systems depends on operations performed in a given experimental context and even on the mind of the observer,
2) a Realist one, according to which quantum properties and states are independent of any mind and operation.

Idealistic Interpretation

The idealistic position was at least partly embraced by Bohr [1928; 1929], supported in part by von Neumann [1932] and finally articulated by Wigner [1961; 1963; 1964]. With a certain moderation it is become part of the Copenhagen interpretation and can be found commonly in many textbooks. In this form, it consists in pointing out that the theoretical description is a mathematical tool, while it is possible to speak of the properties of a quantum system only in a given experimental context (for instance, for detecting particles or observing wave-like interference).

Here the equivalence of different pictures spread apart from the duality of experimental contexts.

Realist Interpretations

The Realistic position has three main variants [see Auletta/Tarozzi. 2004b]:

(1) Realism of the particles alone [Born 1953],

(2) Realism of the waves alone [Schrödinger 1926; 1927],

(3) Realism of both waves and particles [de Broglie 1927; 1956].

All these are forms of classical realism (locality of the entities and perfect determination of their properties) that differently fails to take the first problem seriously into account. In fact, position (1) has failed to account for typical quantum interdependencies (entanglement), position (2) has assumed that waves are localized wave packets and encountered many difficulties, position (3) has led to assume the existence of an empty wave that has been experimentally falsified.

Compromises?

As a middle line between these two extreme forms of interpretation, we have two further orientations:

1) The statistical interpretation [EPR 1935; Ballentine 1970], which has been shown to be finally wrong: In the latter 30 years experiments with individual quantum systems have become possible [see Auletta 2000]. I do not discuss here the MWI, which is mainly concerned with the measurement problem [see Auletta, Fortunato, Parisi, in press].
2) The later Heisenberg's interpretation [1958], which tried to solve the first problem by introducing the idea that the environment could be somehow responsible for an uncontrolled transformation during measurement and proposed to consider the state quantum systems (before measurement) as a form of weak reality (potential reality).

Potentiality

I would like to pursue this research line and define a property as *potential* if

(1) Is associated to a component of the (superposition) state of the system,

(2) It represents a necessary but not sufficient condition for the (detection) event associated to it,

(3) The associated event is produced only thanks to environmental factors that do not depend on the state of the system.

We can maintain the classical definition of physical state (a combination-but not a collection-of properties) and say that a state is potential independently from specific measurement contexts.

Pursuing a Compromise

Now it is possible to pursue this research line by

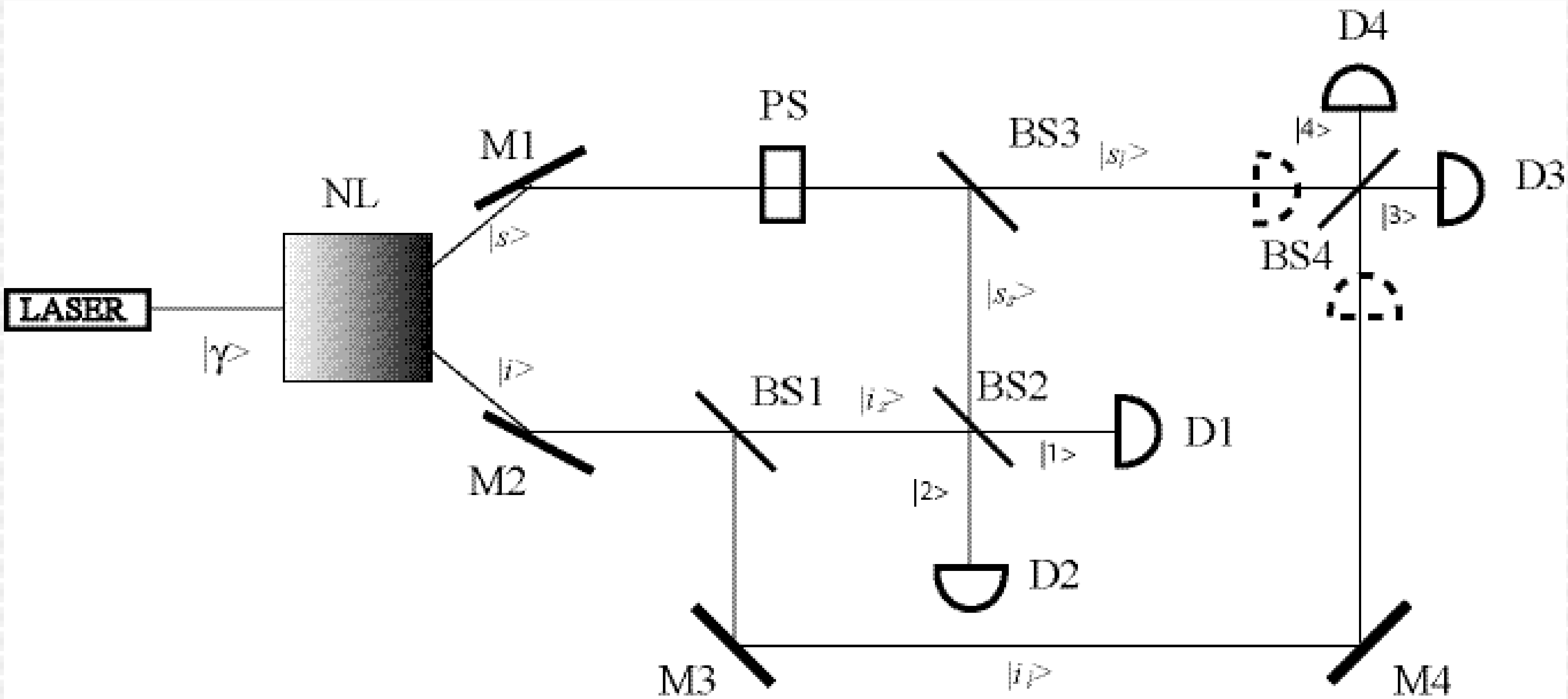
1) Introducing a more objective and smooth (POVM) understanding of complementarity, according to which there are many intermediate states between corpuscular and wave-like behaviours,
2) Taking into account a distinction between global features and local properties (decoherence and theory of quantum open systems), following which measurements appear as a special instance of a wider class of interactions among open systems,
3) Distinguishing between the potential information that the initial state of a system contains and the information that can be acquired [Auletta 2005]. This is evident in a EPR protocol, where we have a negative conditional entropy due the fact that entanglement can represent a reservoir of additional information that may be successively exchanged, i.e. the necessary condition in order to teleport a quantum state [Horodecki *et al*. 2005].

An Asymmetry

All experimental evidences have up to now shown a certain asymmetry when measuring a quantum system: while we can have evidence of a corpuscular behavior each single experimental run, in general the interference profile that reveals the wave-like behavior is reconstructed after many experimental runs, so that it is still possible to avoid to attribute *any* reality (even a potential one) to the quantum state before measuring.

However, I have proposed with Tarozzi [2004a] a complementarity experiment in which we have predictions that can be tested each experimental run in the same context in which no corpuscular behavior can be attributed to the system.

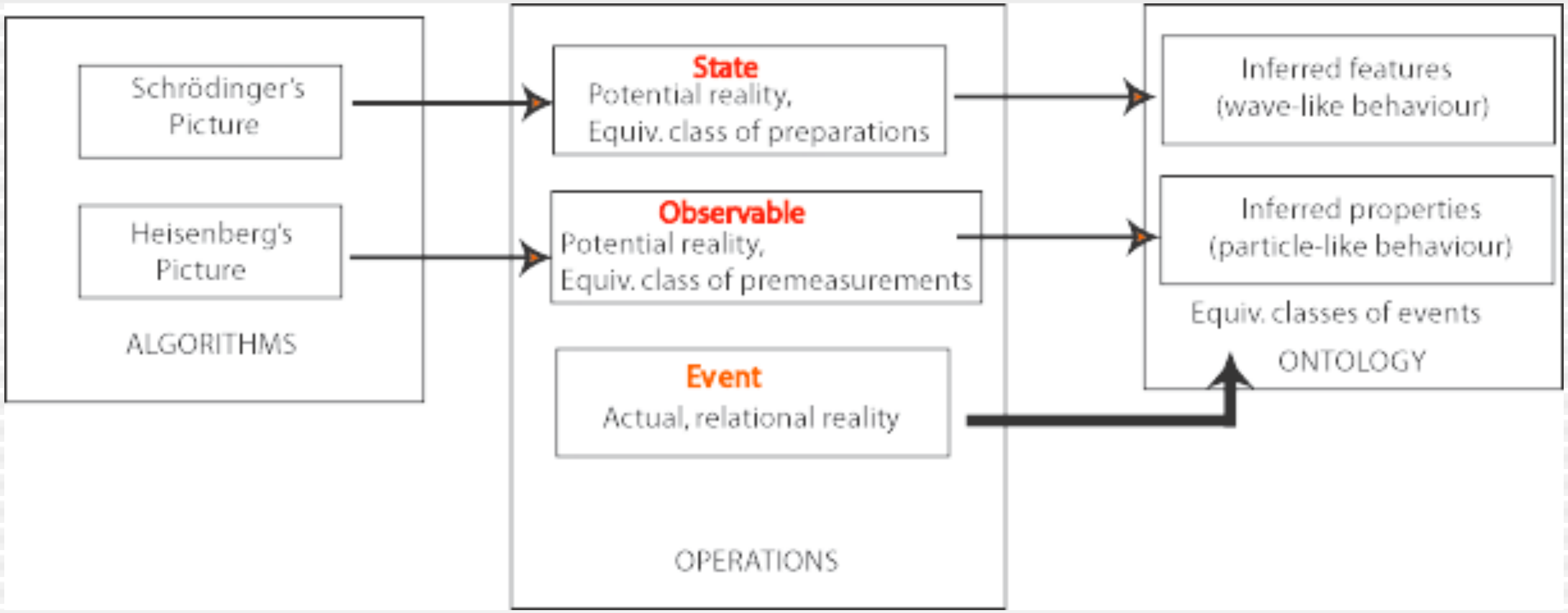
The Proposed Experiment



Overcoming the Above Asymmetry

- In this way both the state and the observables of quantum systems are potential and are described by the equivalent Schrödinger's and Heisenberg's pictures.
- Only the events on the contrary are actual but interactional (they need at least two open systems in mutual interaction for happening), and from them both wave-like features or corpuscular properties may be inferred.
- Properties have a localized nature, have probabilities to occur, and are associated to observables, features do not have a local nature, are described by *a posteriori* statistics that cannot be led to *a priori* probability, and are associated with the state of the quantum system. Non-localized features are a consequence of the fact that the quantum state is not a mere collection of properties.

Schematic Overview



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