Preferred Frame versus Multisimultaneity: meaning and relevance of a forthcoming experiment

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Abstract

It is argued that: 1) Quantum Mechanics implies the preferred frame also because of the collapse delayed at detection, 2) forthcoming experiments with moving beam-splitters will allow us to decide between Preferred Frame and Multisimultaneity, and 3) if Preferred Frame prevails, superluminal communication is in principle possible.

Keywords: multisimultaneity, many-frames experiments, wavefunction collapse, preferred frame, superluminal communication.

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1 Introduction: the conflict between Quantum Mechanics and relativity of simultaneity

Quantum Mechanics predicts the statistical distribution of alternative detection events in experiments according to the superposition principle: in case of a superposition quantum state the probabilities of the possible outcomes of an experiment have to be calculated combining the single quantum amplitudes [1].

It is obviously impossible to determine the statistical distribution of counts an experiment yields other than by counting single detection events. This is why, even if the quantum formalism does not bother on single events but on events distributions, Quantum Mechanics cannot avoid to declare some relationship between the single detection event and the predicted statistical distribution. The theory does this through the so-called “reduction postulate”. A careful analysis shows that this postulate leads to some assumptions about the mechanism of measurement [2, 3, 4, 5, 6]:

1. “Instantaneity of the state-reduction”: a measurement taking place somewhere affects “instantaneously” the whole system everywhere, and this jumps into the measured eigenstate.

2. “Wavefunction collapse at detection”: the outcome of a possible single measurement is not determined till a detection occurs: as far as this is not the case the system has to be considered as a quantum superposition of the possible outcomes, it is at detection when the “collapse of the wavefunction” takes place.

3. “External observer”: the detectors themselves can be considered together with the measured system as a single quantum “system-apparatus state” till the whole becomes collapsed by an external observer.

The relationship between Quantum Mechanics and Relativity has been object of vast analysis since John Bell showed that: a) if one only admits relativistic local causality (causal links with $v \leq c$), the correlations occurring in two-particle experiments should fulfill clear locality conditions (“Bell’s inequalities”), and b) for these experiments the quantum mechanical superposition rule bears predictions violating such locality criteria (“Bell’s theorem”) [7]. Bell experiments conducted in the past two decades, in spite of their loopholes, suggest a violation of local causality: statistical correlations are found in space-like separated detections; violation of Bell’s inequalities ensure that these correlations are not pre-determined by local events [8, 9, 10, 11, 12, 13, 14]. Nature seems to behave non-locally, and Quantum Mechanics predicts well the observed distributions.

Now the question arises: can we use the instantaneous influences involved in Bell’s experiments to built an arbitrarily fast telephone line? From the point of view of Quantum Mechanics the answer is a matter of formalism. According to the standard formalism we cannot use “Bell influences” for faster-than-light communication [15, 16]. Nevertheless it seems that there is no clear reason why Quantum Mechanics, “a specifically nonrelativistic theory”, should prevent superluminal communication
Effectively nonstandard formalisms of Quantum Mechanics have been developed which share the predictions of the standard one for all experiments already done, but lead to superluminal communication in more sophisticated experiments not yet performed [18, 19, 20].

The prevention of faster-than-light communication by the standard formalism led to the celebrated expression of “peaceful coexistence” to characterize the relationship between standard Quantum Mechanics and Special Relativity [2], and is often invoked as demonstration that nonlocality does not conflict with Einstein’s relativistic causality. This way of arguing overlooks somewhat that the principle of Special Relativity effectively implies that nothing in nature goes faster than light, and therefore it is really at odds with the nonlocal behavior of nature revealed by Bell’s experiments. By contrast, the relativity of simultaneity does not exclude any superluminal influence but only those implying backwards causation, as for instance influences leading to superluminal communication between human observers. Hence if one considers that what actually follows from Michelson-Morley’s observations is the relativity of simultaneity, and therefore this principle (and not the postulate of Special Relativity) is the essential of relativity, then it can be appropriately said that there is no conflict between relativity and the nonlocal “Bell influences” so long as these do not lead to superluminal telephone lines or, more in general, backwards causation.

However the way how standard Quantum Mechanics manages nonlocality bear problems because of the assumed timing independence of the nonlocal correlations. Hardy showed that if one considers Bell experiments with moving observers, the quantum mechanical predictions deriving from the superposition principle conflict with the relativity of simultaneity and imply the existence of a preferred frame [26, 25]. In this respect it is interesting to see that Quantum Mechanics has already been consistently developed as absolute space-time scheme in the form of Bohmian Mechanics which keeps instantaneous influences and disposes of the “collapse” [3, 21, 22], or Eberhard’s theory which assumes that the Bell’s correlations originate from signaling at a finite superluminal speed [18], or Rembieliński’s model which remarkably cast preferred-frame Quantum Mechanics into a Lorentz-covariant scheme [20]. As regards other realistic models which incorporate the “collapse” like the GRW theories [23, 24], since they share the quantum mechanical predictions, Hardy’s theorem implies that such descriptions also lead in principle to a preferred-frame.

Concerning the “reduction postulate” Aharonov and Albert did argue that, if one assumes the impossibility of a preferred frame, the assumption of “instantaneity” requires to give up the very concept of state [27]. As regards the collapse of the “system-apparatus state” by the “external observer”, Peres did claim this notion “to have no meaning whatsoever in a relativistic context” [28].

In summary, the “quantum superposition principle”, the “instantaneity of the state-reduction” and the “system-apparatus state” have been considered to be at odds with the relativity of simultaneity. By contrast, to our knowledge, the assumption that the outcome is not determined till detection has never been suspected of conflicting with it. In this article we argue that the assumption of collapse at detection
excludes in principle the relativity of simultaneity, so that Quantum Mechanics has
to be considered a preferred-frame theory because of all its specific features. This
conclusion let appear experiments with moving beam-splitters as particularly relevant
in order to decide whether nature itself really uses a preferred-frame in working out
the phenomena. Would this be the case, then nothing in principle speaks against the
possibility of superluminal signaling, and the lower bound on the “speed of quantum
information” recently set by experiment [29] would acquire practical interest.

2 The unification of nonlocality and relativity into
Multisimultaneity

In light of the predicting success of Quantum Mechanics and Hardy’s theorem, it is
tempting to think that: “although nonlocality does not require a special frame of
reference, it is most naturally incorporated into a theory in which there is a special
frame of reference” [20].

Recent work has proposed a different line of thinking [30, 31, 32]: accepting super-
luminal nonlocality and relativity of simultaneity as experimental facts, one has to
modify to some extent the rule establishing when the probabilities are calculated by
summing of amplitudes. The result is a many frames description called Multisimul-
taneity or Relativistic Nonlocality, which makes predictions contradicting Quantum
Mechanics in the context of experiments not yet performed. The new description
shows that if one assumes Nature itself to use many frames to cause the phenomena
(i.e. real relativity instead of the conventional observer’s one), then superluminal
nonlocality can become most naturally incorporated into a many-frames theory.

Multisimultaneity gives up the key role Quantum Mechanics attributes to detection
and “collapse”, as Bohmian Mechanics also does. What causes a detector to fire,
the “observable particle’s part” (or simply the “particle”), always travels a definite
path, but undetectable information (similarly to the Bohmian “empty” wave) does
travel the alternative paths. One has two kinds of events: The basic event is the
“choice” of the path the “particle” takes at the beam-splitters, which for this reason
are called the “choice devices”. The second event is detection, which simply reveals
the channel by which the “particle” left the preceding “choice device”, but produces
“irreversibility” in the sense that after detection it is no longer possible to arrange
that the “particle” and the unobservable information (traveling the other channel)
meet again.

In the context of two-particle experiments, Multisimultaneity is implemented as fol-
lows: at the instant \((T_{i1})_{i1}\) particle \(i\) meets the beam-splitter \(BS_{i1}\) it is considered
whether in the referential frame of this device particle \(j\) did already meet \(BS_{j1}\) (i.e.
whether \((T_{j1} \leq T_{ik})_{ik}\), and, in case of several alternative paths, whether it is impos-
sible to distinguish by which path pair the particles did enter \(BS_{i1}\) and \(BS_{j1}\) on the
basis of any possible experiment allowing us to monitor the output ports of \(BS_{i1}\) and
\(BS_{j1}\). If these two conditions are met particle \(i\) produces its outcomes taking account
of the phase parameters particle \(j\) meets at the other side of the setup, and if not
particle \( i \) produces its outcomes without taking account of the phase parameters particle \( j \) meets. A particular two-particle experiment is that with before-before timing [30], in which each particle chooses only according to local parameters, and for which Multisimultaneity predicts the absence of nonlocal correlations. Thus, regarding the predictions for new experiments with beam-splitters in motion Multisimultaneity deviates from Quantum Mechanics.

### 3 Quantum collapse at detection excludes relativity of simultaneity

The fact that the detection outcome becomes determined when the particle meets the monitored “choice-device” means, in particular, that to test Multisimultaneity vs Quantum Mechanics in Bell experiments with two referential frames, one has to set the beam-splitters in motion to generate 2-before impacts. Nevertheless, at the beginning of the work to prepare these experimental tests the question arose, whether a version of Multisimultaneity keeping the “collapse at detection” is possible, and one should consider that the detectors are the actual “choice-devices” at which the outcomes become determined. The question was relevant because depending on the answer one has to set the detectors in motion, instead of the beam-splitters. As said above, nothing in principle seemed to speak against the incorporation of “collapse at detection” into a many frames theory. The fact that Bohmian Mechanics, a proper non-relativistic theory, disposes of “collapse at detection” let rather appear as plausible such an incorporation.

However it is possible to show that as far as one keeps to the basic ‘one photon-one count’ principle, the assumption of collapse at detection excludes in principle the relativity of simultaneity, and, therefore, implies the preferred frame [32]. In the following we give a proof that this already holds for single particle experiments, and therefore the incompatibility of collapse and relativity of simultaneity is deep rooted in Quantum Mechanics.

Consider the experiment sketched in Fig. 1 in which single photons emitted from source S impact into a 50-50 beam-splitter BS and get detected thereafter either in detector D(+) or D(−). By means of delay line DL the optical paths are adjusted so that the arrival of the wave at D(−) occurs in the laboratory frame a little bit before the arrival D(+). Suppose the two detectors far away from each other so that a light signal sent at D(−) at the instant of the arrival of the wave at D(−), cannot reach D(+) before the arrival of the wave at D(+).

If detectors are the choice-devices, which detector fires is not determined before the wave reaches the detectors. But if at this instant only one of the detectors can fire, there must be some kind of superluminal influence (“Bell connection”) between the two detectors. According to the basic principle of Multisimultaneity, at the arrival of the wave at each \( D(\sigma) \), \( \sigma \in \{+,−\} \), the choice between “fire” and “not-fire” of \( D(\sigma) \) depends on whether, in this device’s frame, a choice in \( D(−\sigma) \) did already take
Figure 1: Single-particle gedankenexperiment assuming that the arrival of the wave at each $D(\sigma), \sigma \in \{+, -\}$, occurs, in the referential frame of $D(\sigma)$, before the arrival of the wave to $D(-\sigma)$.

place or not. Suppose first both detectors at rest in the laboratory frame: since at the time of arrival at $D(-)$ the wave did not yet reach $D(+)$, then the choice in $D(-)$ takes place at random; by contrast the choice at $D(+)$ takes account of the choice at $D(-)$: if $D(-)$ did fire, then $D(+)$ does not fire, and reversely.

Suppose now the detector $D(+)$ in motion so that the arrival of the wave at each $D(\sigma)$ occurs, in the referential frame of $D(\sigma)$, before the arrival at $D(-\sigma)$. This can be ensured by fulfilling the same condition given in [30] to produce two before impacts at the beam-splitters. Then the fact that each $D(\sigma)$ fires, cannot depend on whether $D(-\sigma)$ fires or not, and therefore it should happen that, even if there is one and only one particle traveling the setup, 25% of the times $D(+) \text{ and } D(-)$ fire jointly, and 25% of the times neither $D(+)$ nor $D(-)$ fires. This means a violation of the basic assumption that one single photon cannot cause two detectors to fire. Therefore, as far as one keeps to the ‘one photon-one count’ principle, the quantum collapse excludes the relativity of simultaneity.

4 An imminent experiment will allow us to decide between Preferred Frame and Multisimultaneity

The proof of the preceding section means that also the collapse delayed at detection makes of Quantum Mechanics a preferred-frame theory. Therefore, as far as one wishes avoid backwards causation [33] and keeps the principles of causality and ‘one photon-one count’, Quantum Mechanics has to be considered a preferred-frame theory because of all its basic ideas. In this sense the real status of the GRW theory [22, 23] seems to be that of a preferred-frame quantum theory with “quantum collapse”.

Regarding superluminal Bell influences (nonlocality), as already noticed in Section 2, they can be incorporated as well into preferred-frame Quantum Mechanics, as many-frames Multisimultaneity.
In light of this analysis the upcoming experiment with moving beam-splitters \[35\] acquires special relevance: it will test two types of nonlocal descriptions against each other and allow us to decide between preferred-frame and many-frames theories, similarly as Bell experiments allow us to decide between nonlocal and local ones.

5 Assumed the preferred frame, nothing in principle speaks against superluminal communication

Vindication of Quantum Mechanics by the experiment with moving beam-splitters referred to would mean that one has to give up the relativity of simultaneity and accept the preferred-frame. A preferred-frame description could be done as well without superluminal signaling in the form of the Bohm’s theory (without collapse) \[21\] or a GRW theory (with collapse) \[23, 22\], as with superluminal signaling in the form for instance of Eberhard’s theory \[18\], Weinberg’s non-linear Quantum Mechanics \[19\], or even Lorentz-covariant schemes \[20\].

Nevertheless we would like to stress that if one accepts the preferred frame the impossibility of superluminal communication can neither originate from special relativity nor from causal requirements related to relativity of simultaneity (to avoid backwards-causation), so that it is not clear in name of which “Relativity” such an impossibility could still be maintained \[34\]: in any case, within the preferred frame faster-than-light propagation of information is consistent with causality \[20\].

And as regards Quantum Mechanics itself, let us say once again, that the whole issue is a pure matter of formalism and not of principle: if “incompatibility with relativity” cannot longer be invoked, “supraluminal communication” cease to be an argument against “non-linear Quantum Mechanics” \[13\], and in the context of an absolute space-time scheme it becomes quite reasonable to explain the correlations appearing in Bell experiments by means of a finite superluminal speed \[18\].

What is more, for reasons of experimental consistency, to exclude a conflict with Michelson-Morley-like observations, preferred-frame schemes have to assume faster-than-light propagation of energy over open paths \[20\]. Consequently it would be only natural that the formalism of preferred-frame Quantum Mechanics exploits such a possibility of superluminal communication.

All this means the following: if the imminent experiment using moving beam-splitters \[35\] uphold the preferred-frame description, then one should seriously take into consideration the possibility of realizing superluminal communication by means of more sophisticated experimental arrangements; maybe corresponding gedankenexperiments already proposed within different nonstandard formalisms \[18, 13, 34\] can be a source of valuable inspiration. In such a context also the Gisin-Zbinden lower bound on the “speed of quantum information” set by experiment \[29\] would acquire the new strong meaning that telephone lines faster than “10 million times the velocity of light” are in principle possible.
Conclusion

Quantum Mechanics appears to be a preferred-frame theory not only because of the predictions deriving from the superposition principle (Hardy’s theorem) [26], but also because of the collapse delayed at detection. Vindication of Quantum Mechanics by experiments with moving beam-splitters would mean that one has to accept the Preferred Frame. Within this context nothing speaks against considering that communication for practical purposes may be possible at velocities of 10 million times the velocity of light. To think that such velocities of communication are “unrealistic”, means in fact to share our conviction that the Preferred Frame is not the correct view, and Quantum Mechanics will fail in the coming experiments with beam-splitters in motion [35]. In conclusion, a unique experimental result is expected within this year: either Multisimultaneity holds and Quantum Mechanical fails, or the Preferred Frame prevails and superluminal communication is in principle possible.

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