On Bell, Suarez-Scarani, and Leggett experiments: 
Reply to a comment, and proposal for a new experiment

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It is shown that the before-before (or Suarez-Scarani) experiment refutes hidden variable models with a deterministic (“realistic”) nonlocal part, and the experimental violation of Leggett-type inequalities models with a random nonlocal part and a biased random local one. Therefore the claim that Gröblacher et al. present “an experimental test of nonlocal realism” [1] is misleading, and Marek Žukowski’s comment [2] misses the point. A new experiment is proposed.

In a recent comment [2] Marek Žukowski, co-author of Reference [1], claims that I wrongly present in Reference [3] the assumptions behind the Leggett’s inequalities, and their modified form used by Gröblacher et al. [1] for an experimental falsification of a certain class of non-local hidden variable models. Nevertheless, Žukowski’s writes that his comment “is not aimed at a detailed discussion of the arguments given by Suarez” [2].

By omitting details Žukowski’s comment misses the point. What I state is this:

The authors of [1] do not only say that their experiment violates the Leggett’s inequalities, but also claim that it is “an experimental test of nonlocal realism”. More specifically, they claim that their result “excludes for the first time a broad class of non-local hidden-variable theories” [1].

Against this claim I argue:

1) The before-before experiment [4, 5, 6] was first in excluding a class of nonlocal hidden variable theories, and thus ”nonlocal realism”.

2) Gröblacher et al. did not test “nonlocal realism”.

Regarding 1)

Bell type experiments refuted local hidden variable models. However, by adding nonlocal hidden variables it is still possible to save determinism (see, e.g., [7]). This is the case in the Suarez-Scarani model [4, 5, 8]. This model uses moving measuring devices, and thereby different relativistic timings. It assumes time-ordered nonlocal dependencies (nonlocal determinism) for certain timings, and only local hidden variables (local determinism) for the before-before timing. This leads to conflict with the timing independence of quantum mechanics. The before-before experiment falsified the nonlocal deterministic model of Suarez-Scarani, and confirmed the quantum prediction [4, 6].

Thus, the Suarez-Scarani experiment was first in excluding nonlocal hidden variable models. It showed that, to borrow a phrase from [1], “giving up the concept of locality is not sufficient to be consistent with quantum experiments”.

“Realism” as defined in Reference [1] has the meaning of determinism. I do not say that Gröblacher et al. support “gender asymmetry” [2], but nonlocal determinism [1]. They assume that Alice’s outcome is nonlocally predetermined by Bob’s one, or Bob’s outcome by Alice’s one. The “explicit toy non-local model” [2] Gröblacher et al. propose clearly shows that they have nonlocal deterministic models in mind (toys are usually good indicators of cognitive structures).

Thus, the model described in Reference [1] can be considered refuted by the before-before experiment (unless one postulates a single preferred frame what, on the one hand, is not the case in [1], and on the other hand, bears severe oddities [3]).

Regarding 2)

In Leggett models the hidden variables have always a local and a nonlocal part [10, 11], independently of any timing.

As soon as one assumes a deterministic nonlocal part, the Suarez-Scarani experiment becomes obviously relevant for Leggett’s models and refutes them.

Thus, the specific aim of experiments testing Leggett-type inequalities is to test models exhibiting nonlocal randomness, and non-trivial local parts, i.e., outcomes that depend on biased random local variables [10, 11].

This means that Gröblacher et al., in spite of assuming “nonlocal realism”, in fact did not test this assumption. Certainly, their experiment [1] (as far as its implementation is correct) would also rule out a model without determinism in the nonlocal part, and so is useful in addition to the before-before experiment when interpreted correctly [13]. And in any case, has the merit of priority as a proposal to test Leggett inequalities.

Conclusion and proposal for a new experiment

The Suarez-Scarani (before-before) experiment excludes time-order or determinism in the nonlocal part. That is, the quantum correlations come from outside
spacetime through free choices in Nature (God plays dice) \[12\].

Leggett experiments demonstrate that Nature refuses even to mimic certain deterministic (“realistic”) features by means of biased random local variables (God plays fair dice).

Putting together the results of both types of experiments one can conclude that Nature is not less random than predicted by quantum mechanics. [14]

Nevertheless, to date the results supporting this conclusion have been gathered in separated experiments. It would be suitable to refute both determinism and biased randomness by one and the same experiment. I think this may be nicely done by a before-before version of the experiment described by Colbeck and Renner [11]. The new experiment would basically consist in demonstrating firstly, that Nature exhibits correlations originating from pure nonlocal links and secondly, these links are not time-ordered. Work exploring this possibility is in progress. Such an experiment would definitely contribute to a better understanding of the quantum.

\textbf{Request:} Though the Suarez-Scarani experiment was first in testing nonlocal determinism and excluding nonlocal hidden variable models, the experiment was not quoted in Reference [3]. Thereby Gröblacher et al. overlooked relevant work and advanced a misleading interpretation of their own results. I think Nature’s general audience deserves to be informed about this state of affairs, and kindly request Anton Zeilinger and the Editor to agree in publishing a clarifying comment.

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\begin{itemize}
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  \item [3] Suarez A., Nonlocal “realistic” Leggett models can be considered refuted by the before-before experiment. \textit{Found. Phys.} \textbf{38}, 583-589 (2008).
  \item [4] Suarez A. and Scarani V., Does entanglement depend on the timing of the impacts at the beam-splitters? \textit{Phys. Lett. A}, \textbf{232}, 9 (1997).
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  \item [8] Scarani V. and Gisin N., Superluminal influences, hidden variables, and signaling. \textit{Phys. Lett. A}, \textbf{295}, 167 (2002).
  \item [9] The very concept of “nonlocal hidden variable” was introduced in the context of Bohmian mechanics to express deterministic nonlocal dependence. One should better avoid it to refer to models without time-ordered nonlocal dependencies.
  \item [10] Branciard C., Brunner N., Gisin N., Kurtsiefer Ch., Lamas-Linares A., Ling A., and Scarani V., Testing quantum correlations versus single-particle properties within Leggett’s model and beyond. \textit{Nature Physics}, published online: 6 July 2008; doi:10.1038/nphys1020(2008).
  \item [11] Colbeck, R. and Renner, R., Hidden variable models for quantum theory cannot have any local part. \textit{Phys. Rev. Lett.} \textbf{101}, 050403 (2008).
  \item [12] In this sense, the Suarez-Scarani experiment also supports Anton Zeilinger’s belief in the two freedoms: the experimenter’s one and in Nature (see Interview, \textit{Die Weltwoche}, Ausgabe 48/05, English at: http://www.signandsight.com/features/614.html).
  \item [13] Roger Colbeck, personal communication.
  \item [14] By contrast, it is still an open question whether Nature is more nonlocal than predicted by quantum physics. See: Brassard G., Buhrman H., Linden N., Methot A. A., Tapp A., Unger F., A limit on nonlocality in any world in which communication complexity is not trivial. \textit{Phys. Rev. Lett.} \textbf{96}: 250401 (2006).  
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