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**Comment on 'White, T., Mutus, J., Dressel, J. et al., "Preserving entanglement during weak measurement demonstrated with a violation of the Bell-Leggett-Garg inequality", npj Quantum Information 2, 15022 (2016).'**

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In the cited paper [1] experimental results were presented that clearly prove that the quantum entanglement between two qubits is preserved after weak enough measurements are performed on them. The theoretical interpretation of the reported results, however, requires further consideration.

In the experiment reported in [1, 2] sequences of pairs of entangled superconducting qubits prepared in an entangled Bell's state were weakly coupled to pairs of ancilla qubits, before the tetrads were projected through strong measurements along predetermined orientations. This innovative experimental setting purportedly allows to measure for each tetrad the four outcomes that are required to build the CHSH correlator and, thus, it supposedly allows to bypass the so-called 'disjoint sampling loophole' [3] and the 'clumsiness loophole' [4] of the standard setting of Bell's experiment, in which only two of the four required outcomes are measured in every single realization.

The collected experimental data reported in [1] clearly demonstrates that the correlator violates the CHSH inequality and, thus, it proves that the entanglement between the two original qubits - or Bell qubits, as they are referred to in [1, 2] - is preserved in spite of their weak interaction with the ancilla qubits. Thus, it supposedly buries all hopes to build a successful local model of hidden variables for the entangled Bell's states exploiting the loopholes associated to the fact that only two of the four outcomes involved in the CHSH correlator are measured in every single realization of a Bell experiment [5]. However, as we shall now show, this last conclusion cannot be properly justified.

First, it must be noticed that in the experiment reported in [1] only the outcomes obtained by strongly measuring the polarizations of the two Bell qubits are indeed binary,  $\beta_{1,2} = \pm 1$ ,

while the outcomes obtained by projecting the two ancilla qubits are not,  $\alpha_{1,2} = \pm 1/V$ : they get normalized by the strength  $V \rightarrow 0^+$  of their coupling to the two original qubits and, moreover, are supposedly contaminated by noise produced by the detectors [2]. Therefore, the analysis presented in [1] of their collected experimental data relies on the assumption that this noise is unbiased [2], so that over a long enough sequence of repetitions of the experiment the effect of noise gets averaged out and the measured correlations, after proper normalization, are indeed associated to underlying binary signals. This assumption is the main interest of this note, because as we shall now show it is straightforward to prove that it cannot be correct.

The assumption seems to be trivially justified, since the noise that affects the outcomes of the measurements performed on each one of the ancilla qubits should not be correlated if the measurements are causally disconnected. However, as we have noticed above the collected data shows a very clear violation of the CHSH inequality and it is straightforward to prove, see [6] and also the straightforward theorem below, that there cannot exist a sequence of four binary outcomes  $\{\alpha_{1,2}(n), \beta_{1,2}(n)\}_{n \in N}$  whose correlations violate the CHSH inequality. In other words, the violation of the CHSH inequality reported in [1] is necessarily associated to the apparent *noise* in the collected data for outcomes  $\alpha_{1,2}$ , which strongly suggest that some component of that *noise* is not actually noise. In fact, the experimental results reported in [1] can be reproduced within the framework of a model of local hidden variables [7, 8].

Furthermore, the experimental results reported in [1] suggest also that it might be possible to predict with high probability the binary outcomes of the strong measurements that shall be later performed on every single pair of Bell qubits by previously weakly coupling them to two ancilla qubits and performing on the ancilla qubits a long sequence of very weak measurements according to the protocol discussed in [9] along the same directions that will be later tested on the Bell qubits. That is, it might be possible to predict with high probability the outcomes of the strong measurements that shall be performed on the two original Bell qubits when they are still entangled. Such a protocol could have serious practical implications regarding quantum communication protocols [10] and also in the study of the theoretical foundations of quantum mechanics [11].

**Theorem:** For any sequence of 4-tuples  $\{(a_1(n), a_2(n), b_1(n), b_2(n))\}_{n \in \{1,2,\dots,N\}}$  of binary numbers  $a_1(n), a_2(n), b_1(n), b_2(n) \in \{-1, +1\}$ ,  $\forall n \in \{1, 2, \dots, N\}$ , the following inequality

holds:

$$\frac{1}{N} \left| \sum_n a_1(n) \cdot b_1(n) + \sum_n a_1(n) \cdot b_2(n) + \sum_n a_2(n) \cdot b_1(n) - \sum_n a_2(n) \cdot b_2(n) \right| \leq 2. \quad (1)$$

Proof:

$$\begin{aligned} & a_1(n) \cdot b_1(n) + a_1(n) \cdot b_2(n) + a_2(n) \cdot b_1(n) - a_2(n) \cdot b_2(n) = \\ & = a_1(n) \cdot (b_1(n) + b_2(n)) + a_2(n) \cdot (b_1(n) - b_2(n)) = \pm 2. \end{aligned}$$


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