Towards Quantum Experiments with Human Eyes Detectors Based on Cloning via Stimulated Emission?

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We believe that a recent theoretical work published in Physical Review Letters (103, 113601, 2009) by Sekatsky, Brunner, Branciard, Gisin, Simon, albeit appealing at first sight, is highly questionable. Furthermore, the criticism raised by these Authors against a real experiment on Micro - Macro entanglement recently published in Physical Review Letters (100, 253601, 2008) is found misleading and misses its target.

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made on a micro-macro photon system by the violation of a Bell inequality. We may describe the proposed experiment on the basis of their Figure 3, as follows. A standard laser system generates by Spontaneous Parametric Down Conversion (SPDC) a polarization singlet couple of photons that are sent to two spacelike distant stations, Alice and Bob. The single photon received by Alice is measured by a standard Optical Stern-Gerlach apparatus (OSGA) consisting of a couple of single-photon detectors coupled to the two output modes of a Polarizing Beam Splitter PBS$_A$. As usual in these experiments, the OSGA is ”rotated” of an angle $\Phi_A$ (All generalized ”rotations” considered in the present letter could possibly imply changes of the state of photon polarization, e.g. from ”linear” to ”circular” etc.) Likewise, the single photon send towards Bob, is amplified by some unspecified device. The $N$ photons generated by the amplifier are then measured by another Optical Stern-Gerlach system (OSGB) consisting of a PBS$_B$ ”rotated” by an angle $\Phi_B$. Needless to say, the (OSGB) is completed by two naked human eyes, accurately drawn in the Figures 1 and 3 of [1], each one staring in one of the output modes of the PBS$_B$. This proposed gedanken experiment reproduces almost exactly the real experiment previously carried out by [12] where the amplifier is a Quantum Injected Optical Parametric Amplifier (QI-OPA) generating $N \approx 10^5$ output photons [11] and the human eyes are replaced, perhaps more reasonably, by two detection apparatus $D_B^1$, $D_B^2$ each involving a linear photomultiplier .

The experimental layout of our real experiment is shown in Figure 1, above.

The gedanken experiment planned by Sebatsky et al. raises further obvious questions. For instance, the two naked eyes, in order to be able to measure different signals, cannot belong to the same person because of the physiological fusion of the related perceptions due to the inextricable and incontrollable interconnections between the optical nerves reaching the left and right sectors of the same brain. The eyes must then belong to two different persons (two students ?). At that point, since the Bell inequality experiments with many photons cannot imply simple yes/no responses but require the registering of the actual level of the synaptic signals, we are again confronted with slippery unanswerable questions about mental pointers, mental signal processing, saturation, linearity, neural connections, betacarotene and alcohol, mutual calibration and stability, consciousness etc.

At last, let’s stop pondering on the bizarre naked eye detection idea and do consider the detailed micro-macro Bell inequality theory also reported in [1]. There a measurement loophole is devised in physical situations implying the calculation of the joint correlation parameters between apparata (OSGA) and (OSGB) tuned on different measurement bases, i.e. when the relative angular settings of the corresponding measurement apparatus differ from zero: $\Delta \Phi \equiv |\Phi_A - \Phi_B| \neq 0$. Indeed, this is a typical situation realized in all Bell inequality experiments. We don’t disagree on several results of the theoretical analysis by [1] but we also want to stress that these ones are quite incorrectly applied to the real experiment reported in [12]. In other words, the criticism to our work by Sebatsky et al, presumably the true motivation of work [1], is misleading as it misses completely the point. For the following reasons:

(A) The work [12] is not a Bell inequality experiment and then no correlations between different measurement bases are measured or calculated within the same experiment. The work [12] merely consists of two totally independent and uncorrelated experiments aimed at the evaluation of two different and uncorrelated quantities, i.e. the ”visibilities" $V_2$ and $V_3$ of the two different and uncorrelated fringing patterns shown in Figure 1, above. (The other ”visibility" was found: $V_3 \approx 0$). These patterns, drawn as function of $\Phi_B$, represent the jointly correlated detection probabilities when a fixed measurement basis of (OSGA) is chosen to be either $\{ R, L \}$ or $\{+, -\}$, respectively. Consider for instance the measurement of $V_2$, i.e. the visibility of the fringe pattern determined by the fixed basis $\{ R, L \}$ set at the Alice’s site. As it is well known $V_2$ is determined by only two points, the maximum and the minimum of the pattern, i.e. exactly the points corresponding to the conditions: $\Phi_A = \Phi_B$, or: $\Delta \Phi = 0$. In other words, the two data used to evaluate $V_2$ are obtained by measuring the joint detection probabili-
ties in the conditions in which the micro-qubit at Alice’s site and the macro-qubit at Bob’s site are mutually par-

tially or anti-parallel spin vectors, i.e., both belonging to the same \( \{R, L\} \) basis on the corresponding, equally oriented Poincaré spheres. The same condition: \( \Phi_A = \Phi_B \) or: \( \Delta \Phi = 0 \) is realized within the measurement of \( V_3 \) where again the common measurement basis \( \{+, -\} \) is realized for both the Alice’s and Bob’s apparata. Then, because of the common condition: \( \Delta \Phi = 0 \) affecting both measurements of \( V_2 \) and \( V_3 \), the ”loophole” devised by Sekatsky et al. is not applicable to our experiment.

(B) Symmetry considerations based on the rotational invariance of the overall micro-macro singlet photon pair expressed by Equation 1 in [12], and of the phase-covariant and information preserving properties of the of the adopted QI-OPA, lead to conclude that the two \( V_2 \) and \( V_3 \) experiments are really identical, in the sense that the micro and macro states adopted in both cases, albeit formally different, are in fact obtained by relabelling for different polarizations the Fock state components of these micro and macro-states. In facts, the experimental outcomes \( V_2, V_3 \) of the two corresponding experiments have been found equal by [12], within the statistical errors.

(C) As presumed by Sekatsky et al. photon losses are indeed present in the multi-photon (Bob) side of experiment [12], mostly due to the reduced quantum efficiency \( QE < 1 \) of the photomultipliers. In any case the effect of losses is a ”local” one and may be modelled, as shown above in Figure 1, by a Beam Splitter (BS) with a transmission \( T = (1 - R) \) placed right at the output of the QI-OPA apparatus. The result of a complete computer simulation of the experiment [12] by adopting the real experimental parameters and by assuming the fixed measurement basis \( \{R, L\} \), is shown in Figure 2. There the ”visibility” \( V_2 \), reported as function of \( R \) is found to be a decreasing function of the amount of photon losses. This result is expected since, being the micro-macro entanglement distributed between all photons emitted by QI-OPA, any photon loss entails a reduction of the amount of entanglement detected on the remaining photons. Furthermore, this behavior agrees with a nice ”entanglement criterion” expressed in a paper by Eisenberg et al. [13] that can be expressed as follows: ”any local transformation cannot enhance the level of entanglement”. A photon loss is indeed a local transformation, by definition. The work by Eisenberg et al. [13] also dealt with experimental multiphoton entanglement detection with \( QE < 1 \).\[17\].

In spite of the entanglement reduction due to the measurement losses, the ”visibility inequality” \( |V_1 + V_2 + V_3| \leq 1 \) was violated in the experiment [12]. This a fortiori demonstrates the nonseparability of our Micro - Macro system.

In summary, all previous considerations fully support our claim asserting that the work [12], taken together with previous works by our Laboratory [11][14] indeed consists of the first exact realization of the Macroscopic Quantum Superposition, i.e. complying exactly with the original definition given by Schrödinger in 1935 [17]. The value of this discovery is further enhanced by the large resilience to decoherence shown by our system, which involves as many as \( N \approx 10^5 \) particles [16]. The robustness against any kind of noise makes our system apt to the investigation on several so far inaccessible fundamental issues of quantum mechanics close to the elusive ”quantum - classical boundary”.

We conclude by stressing our deep appreciation for the continuous interest in our work by P.Sekatsky, N.Brunner, C.Branciard, N. Gisin and C. Simon.

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[16] F. De Martini, F. Sciarrino and N. Spagnolo, Phys. Rev. Lett. 103, 100501 (2009).
[17] Since Christoph Simon co-authored both papers 13 and 1, he may perhaps explain why the "loophole" problems should be applicable to work 12 and not to 13 and why the "visibility inequality" and the "entanglement criterion" should be applicable to work 13 and not to 12.