Single-Pair Measurement of the Bell Parameter

F Piacentini[1], S Virzì[1], E Rebufello[1], F Atzori[1,2], A Avella[1], R Lussana[3], I Cusini[3], F Madonini[3], F Villa[3], M Gramegna[1], E Cohen[4], I P Degiovanni[1,5], and M Genovese[1,5]

[1] *Quantum metrology and nano technologies, Istituto Nazionale di Ricerca Metrologica, Strada delle Cacce 91, 10135, Turin, Italy*

[2] *Politecnico di Torino, Corso Duca degli Abruzzi 24, 10129, Turin, Italy*

[3] *Dipartimento di Elettronica, Informazione e Bioingegneria, Politecnico di Milano, Piazza Leonardo da Vinci 32, 20133, Milan, Italy*

[4] *Faculty of Engineering, Bar-Ilan University, Ramat Gan, Israel*

[5] *Istituto Nazionale di Fisica Nucleare, via P. Giuria 1, 10125, Turin, Italy*

Contact Email: f.piacentini@inrim.it

Since their very formulation [1], Bell inequalities [2–4] have been one of the hot topics of quantum foundations investigation, as well as a fundamental tool for quantum technologies [5]. In the last decades, and especially in the recent years, the scientific community worldwide has put a lot of effort towards exploring them [2, 3, 6–8], but none of the experiments so far was able to extract information on the full inequality from each entangled pair. This is due to the fact that the wave function collapse forbids performing, on the same quantum state, all the measurements needed for evaluating the entire Bell parameter.

Here we present, instead, the first single-pair Bell inequality test, able to estimate a Bell parameter value from each entangled pair. This is achieved by exploiting weak measurements [9–12] in sequence, allowing to measure non-commuting observables on the same quantum state without collapsing it.

Such an approach, on the one hand, provides new insights into understanding the foundations of quantum mechanics, like the concept of counterfactual definiteness [13]. On the other hand, it grants unprecedented measurement capability because, after the Bell parameter measurement certifying the entanglement within the state, such entanglement remains almost unaltered and therefore exploitable for other practical purposes like, *e.g.*, quantum technology protocols [5].

References

[1] J S Bell, Physics **1**, 195 (1965)

[2] M Genovese, Phys. Rep. **413**, 319 (2005)

[3] N Brunner, D Cavalcanti, S Pironio, V Scarani and S Wehner, Rev. Mod. Phys. **86**, 419 (2013)

[4] W Myrvold, M Genovese and A Shimony, The Stanford Encyclopedia of Philosophy, Metaphysics Research Lab, Stanford University. Ed.: Edward N. Zalta, Fall 2021

[5] I Georgescu, Nat. Rev. Phys. **3**, 674 (2021)

[6] B Hensen, H Bernien, A E Dréau *et al.*, Nature **526**, 682 (2015)

[7] M Giustina, M A M Versteegh, S Wengerowsky *et al.*, Phys. Rev. Lett. **115**, 250401 (2015)

[8] L K Shalm, E Meyer-Scott, B G Christensen, *et al.*, Phys. Rev. Lett. **115**, 250402 (2015)

[9] Y Aharonov, D Z Albert and L Vaidman, Phys. Rev. Lett. **60**, 1351 (1988)

[10] A G Kofman, S Ashhab and F Nori, Phys. Rep. **520**, 43 (2012)

[11] B Tamir and E Cohen, Quanta **3**, 7 (2013)

[12] J Dressel, M Malik, F M Miatto, A N Jordan and R W Boyd, Rev. Mod. Phys. **86**, 307 (2014)

[13] Y Aharonov, A Botero, S Popescu, B Reznik and J Tollaksen, Phys. Lett. A **301**, 130 (2002)