# The Einstein-Podolski-Rosen argument revisited (again)

http://tph.tuwien.ac.at/~svozil/publ/2022-Cordoba-pres.pdf

based on

arXiv:2209.09590, DOI: 10.48550/arXiv.2209.09590 and
Entropy 2022, 24(12), 1724, DOI: 10.3390/e24121724

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Tuesday, November 29, 2022, XI Conference on Quantum Foundations, Córdoba, Argentina

# What is is what this year's Nobel Prize in physics is about? (my guess)

- Einstein, Podolsky, Rosen (EPR) according to Einstein (letter to Schrödinger, 1935): for entangled (non-factorizable states), the measurement outcome "here" affects state of the particle constituent (and its measurement outcome) "there".
- Boole, ..., Bell, Specker, Wigner, ..., Clauser, Horne, Shimony & Holt (CHSH), ..., Froissart, Pitowsky, ...: experimentally testable violations of classical probabilities and expectations in certain configurations of quantum observables due to the Born Rule, Gleason's theorem.
- ... under strict Einstein locality conditions (aka space-like separations).

# What can still be realized classically (potential misrepresentations of this year's Nobel prize): Relational encoding

- Peres' bomb example(cf DOI: 10.1119/1.11393): a bomb with initial angular momentum zero explodes into two fragments, both carrying opposite angular momenta (due to conservation). In such a case, the fragments represent shares that are relationally encoded.
- Since quantum mechanics is vector based, quantum shares (eg entangled singlet states) perform differently except for three singular relative orientations of measuremts: there are regions with stronger-than-classical correlations: either more $++/--$ or $+-/-+$ outcomes. (This is responsible for the violations of the aforementioned (in)equalities.)
- Unlike quantum entanlement, and although relationally encoded, the individual bomb fragments/constituents still maintain a (supposedly unknown thus epistemic uncertain) value definiteness.

# "Derivation" of classical conditions of possible experience

$2^4 = 16$ possible valuation cases for four binary variables; assuming independence and non-contextuality:

| valuation # | $A$ | $A'$ | $B$ | $B'$ | $AB$ | $AB'$ | $A'B$ | $A'B'$ | $CHSH = AB + AB' + A'B - A'B'$ |
|---|---|---|---|---|---|---|---|---|---|
| 1 | $+1$ | $+1$ | $+1$ | $+1$ | $+1$ | $+1$ | $+1$ | $+1$ | 2 |
| 2 | $+1$ | $+1$ | $+1$ | $-1$ | $+1$ | $-1$ | $+1$ | $-1$ | 2 |
| 3 | $+1$ | $+1$ | $-1$ | $+1$ | $-1$ | $+1$ | $-1$ | $+1$ | -2 |
| 4 | $+1$ | $+1$ | $-1$ | $-1$ | $-1$ | $-1$ | $-1$ | $-1$ | -2 |
| 5 | $+1$ | $-1$ | $+1$ | $+1$ | $+1$ | $+1$ | $-1$ | $-1$ | 2 |
| 6 | $+1$ | $-1$ | $+1$ | $-1$ | $+1$ | $-1$ | $-1$ | $+1$ | -2 |
| 7 | $+1$ | $-1$ | $-1$ | $+1$ | $-1$ | $+1$ | $+1$ | $-1$ | 2 |
| 8 | $+1$ | $-1$ | $-1$ | $-1$ | $-1$ | $-1$ | $+1$ | $+1$ | -2 |
| 9 | $-1$ | $+1$ | $+1$ | $+1$ | $-1$ | $-1$ | $+1$ | $+1$ | -2 |
| 10 | $-1$ | $+1$ | $+1$ | $-1$ | $-1$ | $+1$ | $+1$ | $-1$ | 2 |
| 11 | $-1$ | $+1$ | $-1$ | $+1$ | $+1$ | $-1$ | $-1$ | $+1$ | -2 |
| 12 | $-1$ | $+1$ | $-1$ | $-1$ | $+1$ | $+1$ | $-1$ | $-1$ | 2 |
| 13 | $-1$ | $-1$ | $+1$ | $+1$ | $-1$ | $-1$ | $-1$ | $-1$ | -2 |
| 14 | $-1$ | $-1$ | $+1$ | $-1$ | $-1$ | $+1$ | $-1$ | $+1$ | -2 |
| 15 | $-1$ | $-1$ | $-1$ | $+1$ | $+1$ | $-1$ | $+1$ | $-1$ | 2 |
| 16 | $-1$ | $-1$ | $-1$ | $-1$ | $+1$ | $+1$ | $+1$ | $+1$ | 2 |

All classical expectations are convex combinations of these "extreme cases", so $\left|\langle AB + AB' + A'B - A'B' \rangle\right| \leq 2$. However, the quantum bound is $2\sqrt{2} > 2$, so violations may occur.

# What do these violations mean? Possible "evasion" strategies (something has to be given up ...)

- evocation of a bit exchange, either signifying/communicating one outcome, or one bit of nonlocality, or the context;
- denying the co-existence of complementary counterfactual observables/shares; but then: how come the outcomes are correlated at all?
- Abandonment of space-time frameworks like kantian Einstein relativity.

# Possible "evasion" strategies to keep a classical framework

- In such "patched" relativities "locality" is defined in terms of entanglement: two events are "close" if they share entangled quantum states.
- There is no absolute notion of "proximity" and "space-time frames".
- Effectively, space-time emerges from quantum theory; it is an epiphenomenon, a secondary concept.

# Speculative summarizing questions and outlook

(i) When can two outcomes be considered independent and separated? I suggest to interpret "spatial separation"—two distinct points in space-time—by decomposability of the quantum state; that is, whether the states of the constituents factorize.

(ii) Can it occur that, for two (or more) of the same constituents, some of their observables factorize (aka separable, not entangled) and are therefore categorized as "spatially separate or apart", and other observables are inseparable (aka not factorable, entangled)?

(iii) Can it happen that all observables of two quanta are disentangled?

(iv) Is it possible to generate emerging space-time categories such as frames or coordinatizations, by purely quantum mechanical means?

Thank you for your attention!