Minimum Detection Efficiencies for Genuine Nonlocality Tests

ICQIST- 2025

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From Hilbert space to laboratory:

- Bell's theorem says Quantum theory is nonlocal.
- Is nature nonlocal?

From Hilbert space to laboratory:

What Schrödinger found problematic—indeed, objectionable—about entanglement was this possibility of remote steering (Ref. 43, p. 556):

> It is rather discomforting that the theory should allow a system to be steered or piloted into one or the other type of state at the experimenter's mercy in spite of his having no access to it.

R. Clifton et al. Foundations of Physics 33, 1561–1591 (2003)

From Hilbert space to laboratory:

He conjectured that an entangled state of a composite system would almost instantaneously decay to a mixture as the component systems separated. (A similar possibility was raised and rejected by Furry[26].) There would still be correlations between the states of the component systems, but remote steering would no longer be possible (Ref. 44, p. 451):

> It seems worth noticing that the [EPR] paradox could be avoided by a very simple assumption, namely if the situation after separating were described by the expansion (12), but with the additional statement that the knowledge of the *phase relations* between the complex constants a_k has been entirely lost in consequence of the process of separation. This would mean that not only the parts, but the whole system, would be in the situation of a mixture, not of a pure state. It would not preclude the possibility of determining the state of the first system by *suitable* measurements in the second one or *vice versa*. But it would utterly eliminate the experimenters influence on the state of that system which he does not touch.

R. Clifton et al. Foundations of Physics 33, 1561–1591 (2003)

From Hilbert space to laboratory:

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- Locality loophole
- Detection loophole
- Free will loophole

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- Locality loophole
- **Detection loophole**
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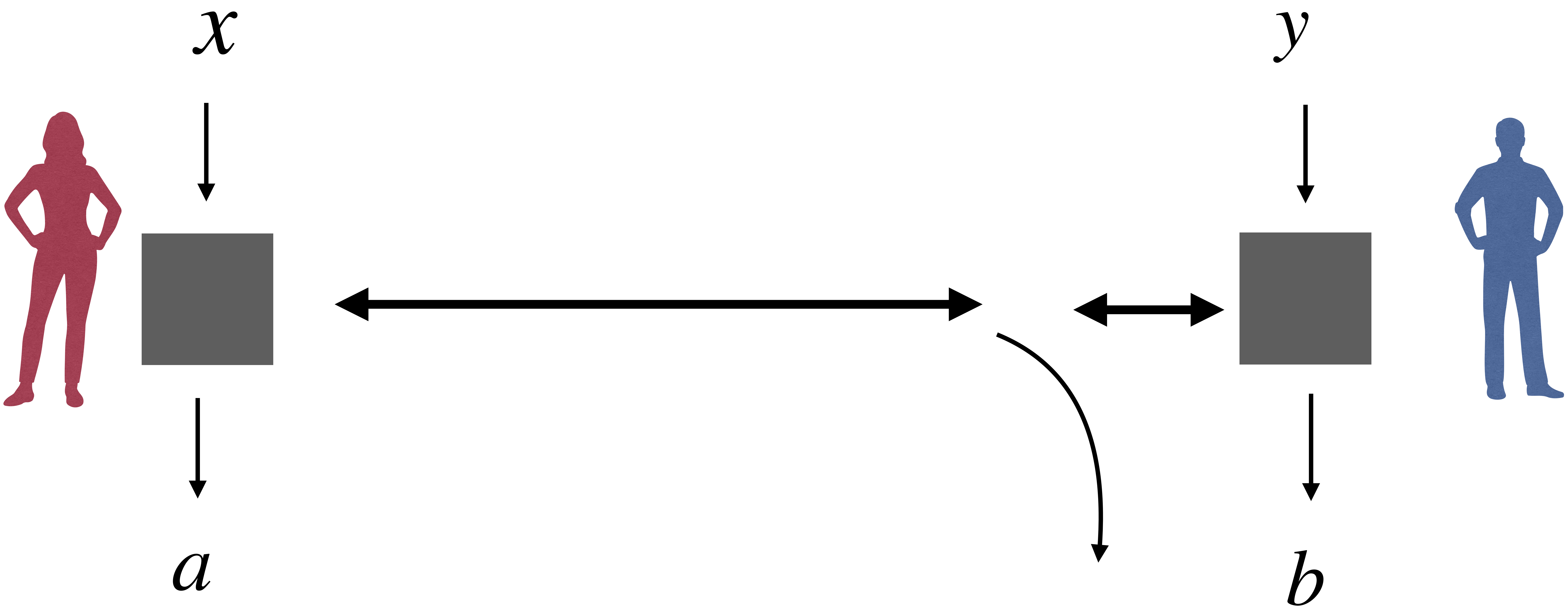
Detection loophole



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- We ask the question for genuine nonlocality.

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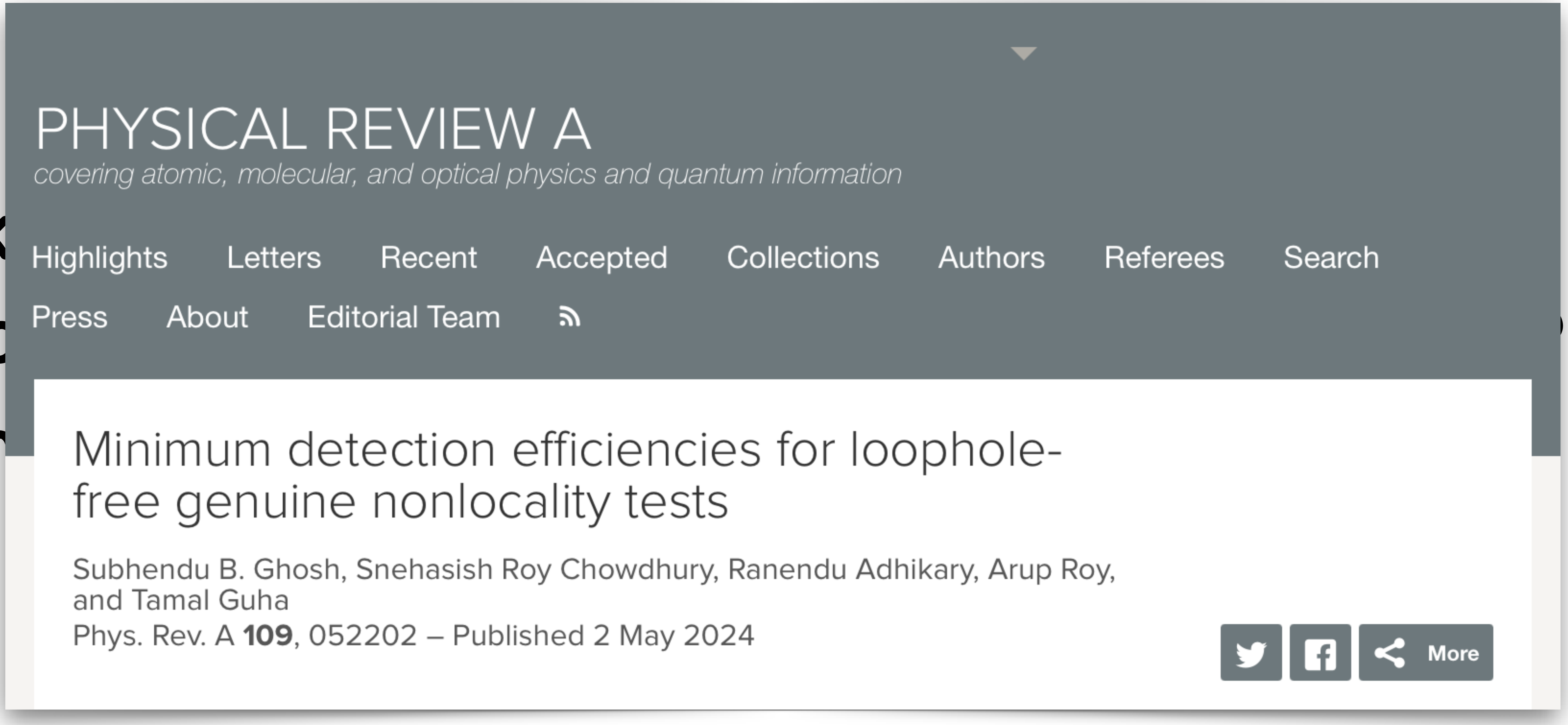
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Minimum detection efficiencies for loophole-free genuine nonlocality tests

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Phys. Rev. A **109**, 052202 – Published 2 May 2024

More

T_2 nonlocality

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T_2 nonlocality

First we consider a operationally motivated class of genuine nonlocality, T_2 nonlocality. (Phys. Rev. A 88, 014102 (2013))

A tripartite correlation $P(abc|xyz)$ will be T_2 nonlocal if it violates the following inequality.

$$\mathscr{B}_{T_2} = -2\{P(00|A_1B_1) + P(00|B_1C_1) + P(00|C_1A_1)\}$$
$$-P(000|A_0B_0C_1) - P(000|A_0B_1C_0) - P(000|A_1B_0C_0)$$
$$+2\{P(000|A_0B_1C_1) + P(000|A_1B_0C_1) + P(000|A_1B_1C_0) + P(000|A_1B_1C_1\} \leq 0$$

Results

- We assign no click events as '1'.
- Three parties with detectors of efficiencies η_A, η_B and η_C.

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Lemma 1: The spatially separated parties would be able to certify genuine three-way nonlocality in terms of the inequality $\mathscr{B}_{T_2}$, when the following condition holds

$$(4\eta_A\eta_B\eta_C - \eta_A\eta_B - \eta_A\eta_C - \eta_B\eta_C) > 0$$

This necessary condition holds for any no-signaling theory.

Results

Lemma 2: There exists a quantum settings with a single parameter θ, which violates the inequality $\mathscr{B}_{T_2}$, whenever $(4\eta_A\eta_B\eta_C - \eta_A\eta_B - \eta_A\eta_C - \eta_B\eta_C) > 0.$

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$\mathscr{B}_{T_2}$, whenever $(4\eta_A\eta_B\eta_C - \eta_A\eta_B - \eta_A\eta_C - \eta_B\eta_C) > 0$.

$$|\psi_{ABC}(\theta) > = k(\theta)[(|011 > + |101 > + |110 >) + \frac{(1 - 3cos\theta)}{sin\theta}|111 >]$$

$$X_0 \equiv \{|0 > , |1 > \}$$

$$X_1 \equiv \{cos\theta|0 > + sin\theta|1 > , sin\theta|0 > - cos\theta|1 > \}$$

Results

Theorem 1: The minimum detection efficiencies for $\mathscr{B}_{T_2}$ for each party must satisfy the following relation

$$(4\eta_A\eta_B\eta_C - \eta_A\eta_B - \eta_A\eta_C - \eta_B\eta_C) > 0$$

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In the case of $\eta_A = \eta_B = \eta_C = \eta$, the $\mathscr{B}_{T_2}$ will be violated iff $\eta > \frac{3}{4}$

Results

- Previous result: MDE for Svetlitchny nonlocality is more than 97%. (V. Gebhart, PRA 106, 062202 (2022)).
- Our result shows 88.1% is sufficient.

Collaborators

- Snehasish, ISI
- Tamalda, Slovak Academy of Sciences
- Arupda, Hooghly Mohsin College
- Ranendu, ISI

Thank you

Table 1.2 *A strategy exploiting the detection loophole for the CHSH test. In each round, Alice and Bob choose one of the eight quadruples of pre-established values that would give $s = +2$ (c.f., Table 1.1). Alice answers always, while Bob declines to answer to the input indicated by brackets, in such a way that the problematic output (boldface) is never produced.*

$\boldsymbol{a_0, a_1; b_0, b_1}$	$\boldsymbol{a_0 b_0}$	$\boldsymbol{a_0 b_1}$	$\boldsymbol{a_1 b_0}$	$\boldsymbol{a_1 b_1}$
$+1, +1;\ +1, [+1]$	$+1$	N	$+1$	**N**
$-1, -1; -1, [-1]$	$+1$	N	$+1$	**N**
$+1, +1; +1, [-1]$	$+1$	**N**	$+1$	N
$-1, -1; -1, [+1]$	$+1$	**N**	$+1$	N
$+1, -1; [+1], +1$	N	$+1$	**N**	-1
$-1, +1; [-1], -1$	N	$+1$	**N**	-1
$+1, -1; [-1], +1$	**N**	$+1$	N	-1
$-1, +1; [+1], -1$	**N**	$+1$	N	-1

Bell nonlocality, V. Scarani