Title: Single-copy activation of Bell nonlocality and entanglement certification via broadcasting of quantum states

Speakers: Emanuel-Cristian Boghiu

Series: Quantum Foundations

Date: September 11, 2023 - 2:00 PM

URL: https://pirsa.org/23090056

Abstract: Activation of Bell nonlocality refers to the phenomenon where some entangled mixed states that admit a local hidden variable model in the standard Bell scenario nevertheless reveal their nonlocal nature in more exotic measurement scenarios. It has recently been shown that by broadcasting the subsystems of a bipartite quantum state, one can activate Bell nonlocality and significantly improve noise tolerance bounds for device-independent and semi-device-independent entanglement certification, with a single copy of the state and local measurements. In this talk I will review the state of the art on activation of nonlocality and existence of local hidden variable models, introduce the broadcasting technique and outline several interesting results and research directions.

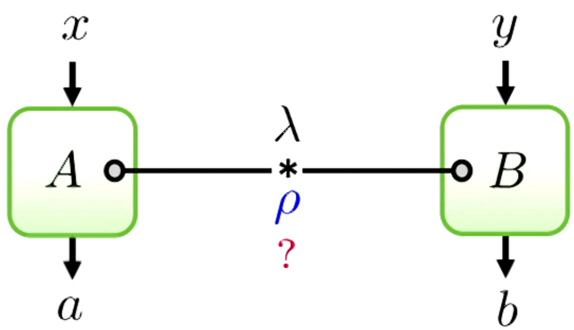
Zoom link https://pitp.zoom.us/j/91214624839?pwd=dXNUOERLMldScjczemlaSUhFbFNWQT09

Activation of nonlocality and DI (+semi-DI) entanglement certification in broadcast Bell scenarios

SciPost Phys. Core 6, 028 (2023)

Emanuel-Cristian Boghiu

Standard Bell scenario



$$\mathcal{L} \ni p(ab|xy) = \int p(a|x\lambda)\; p(b|y\lambda)\; q(\lambda)\, \mathrm{d}\lambda$$

$$\mathcal{Q} \ni p(ab|xy) = \mathrm{tr}\, \rho\; \Pi_a^x \otimes \Pi_b^y$$

$$\mathcal{NS} \ni p(ab|xy) \text{ iff } p(a|xy) = p(a|x)\ \forall y$$
$$p(b|xy) = p(b|y)\ \ \forall x$$

ρ entangled $\iff \exists\, \Pi_a^x, \Pi_b^y$ s.t. $p(ab|xy)$ is nonlocal

~~ρ entangled $\Longleftrightarrow \exists\, \Pi_a^x, \Pi_b^y$ s.t. $p(ab|xy)$ is nonlocal~~ No!

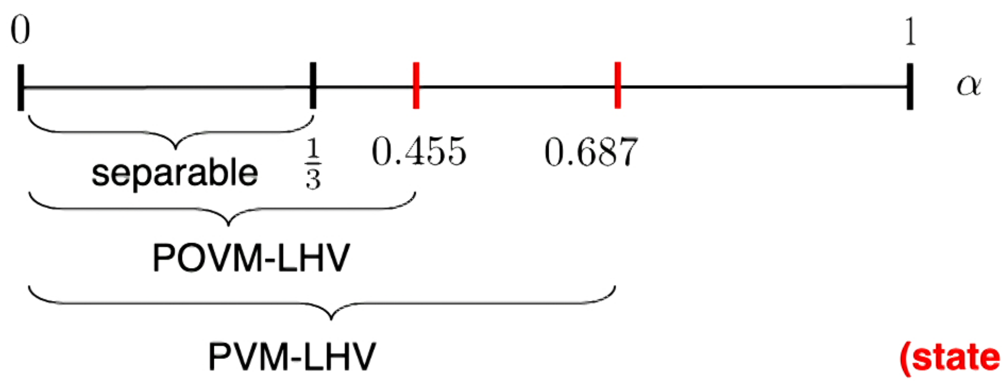
$\Downarrow$

LHV models for quantum states

$$\left(\forall\, \Pi_a^x, \Pi_b^y,\ \mathrm{tr}\, \rho_{\mathrm{LHV}} \Pi_a^x \otimes \Pi_b^y = \int_\lambda p(a|x\lambda) p(b|y\lambda) q(\lambda) d\lambda \right)$$

Local hidden variable models

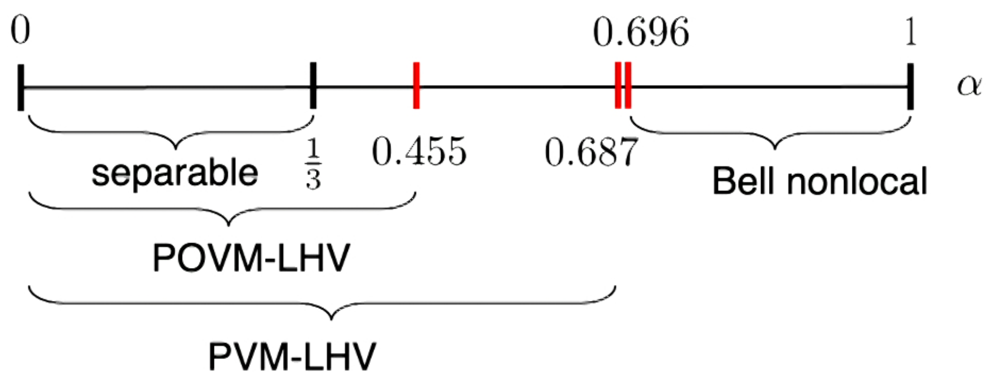
- Isotropic state: $\rho_\alpha = \alpha \left|\Phi^+\right\rangle \left\langle\Phi^+\right| + (1-\alpha)\frac{1}{4}$
- Separability threshold: from PPT criterion.
- (1989 Werner) Locals models for projective measurements.
- (2002 Barrett) Extended result to POVMs.
- Many more results and papers (Designolle 2023, Hirsch 2017).



(state of the art)

Bell nonlocality

- Standard-Bell-nonlocal: CHSH gives $1/\sqrt{2}$.
- Grothendieck's constant: down to 0.696 approximately (Designolle 2023, Hirsch 2017).



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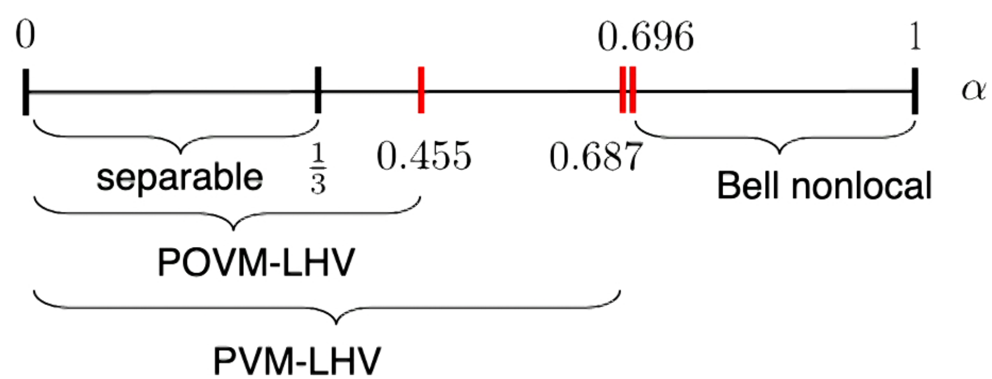

LHV-entangled states $\Longleftrightarrow$ classical shared randomness

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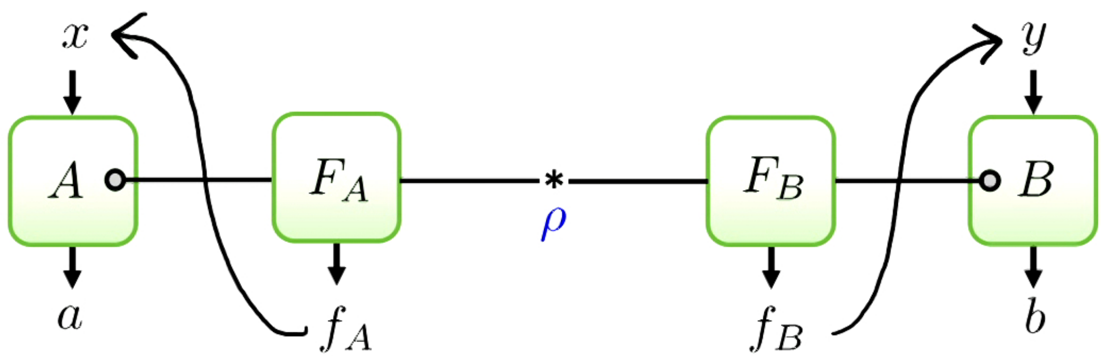
Activation of Bell nonlocality

Activation: hidden nonlocality

- (1995 Popescu) Violation of a Bell inequality after post-selecting on a previous measurement/filter.



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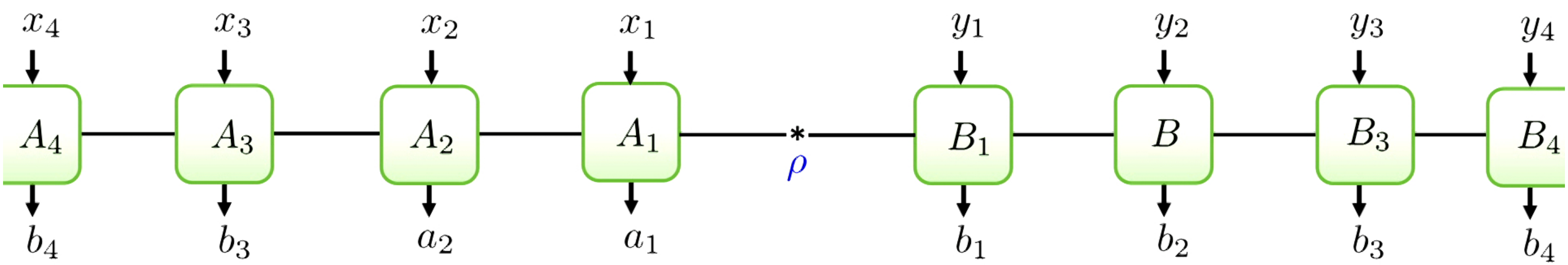
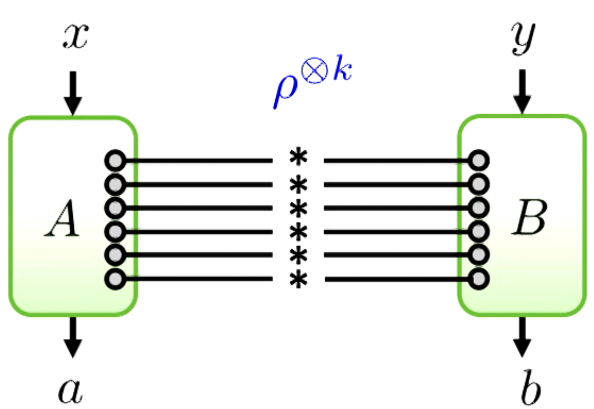


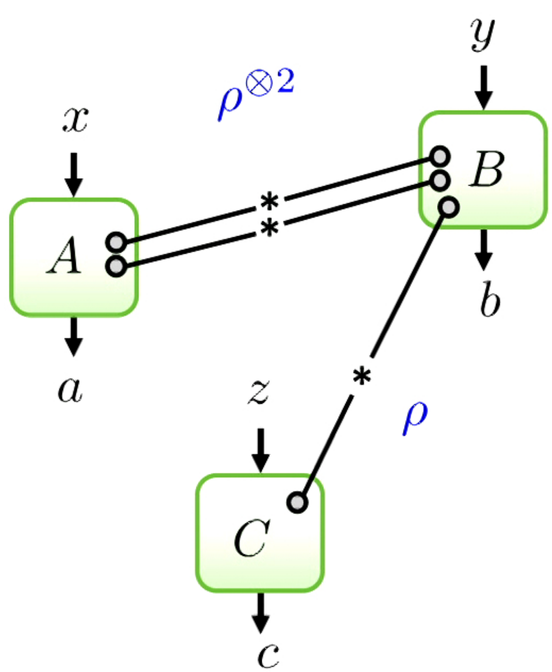
- Generalisation to sequential scenarios. No example of advantage w.r.t. activation over hidden nonlocality.

Activation: multiple-copy scenarios

- (2002 Sen(De) et al, 2011 Cavalcanti et al, 2012 Palazuelos, etc.) Multiple-copies of local states can violate Bell inequalities.



superactivation



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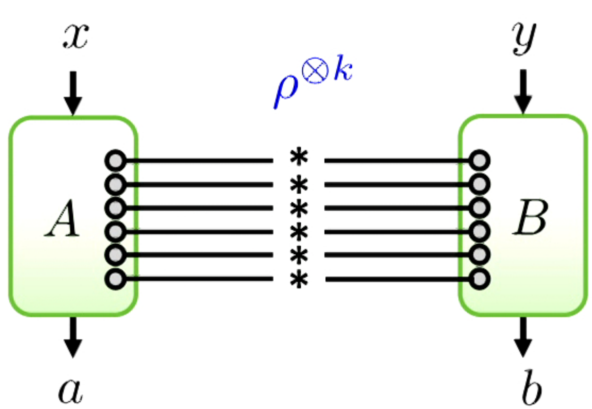

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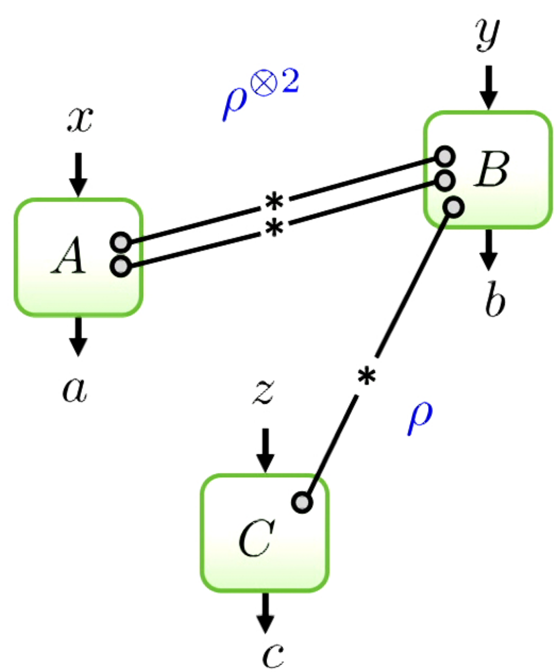


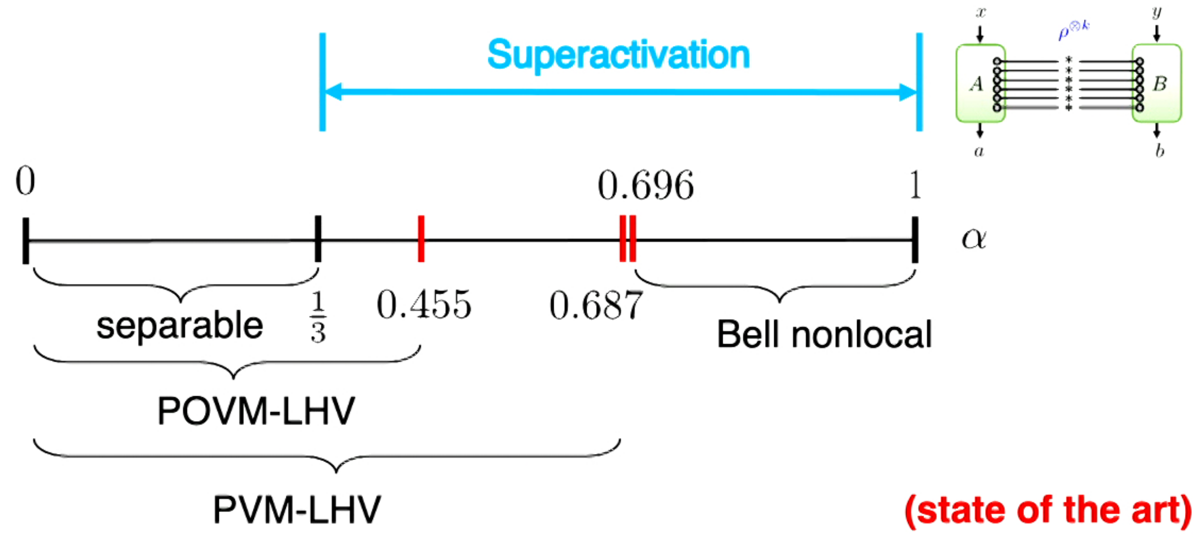
Activation: multiple-copy scenarios

No activation with sequential scenarios for the isotropic state.

**Ducuara et al "On the activation of quantum nonlocality." Universitas Scientiarum …*

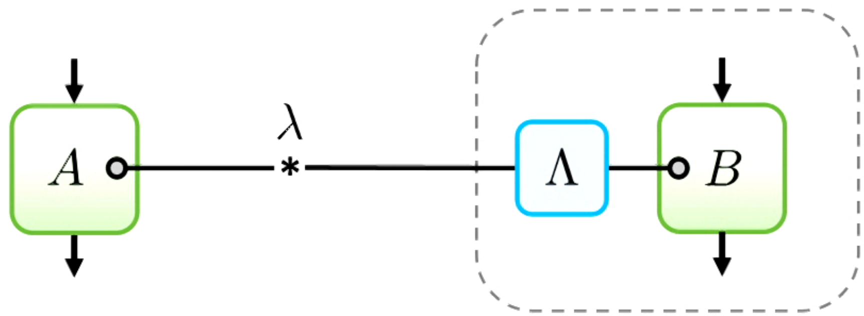
21 copies* ≤ 0.65
42 copies* $\leq 0.50^{+}$
594 copies* ≤ 0.35

entangling measurements



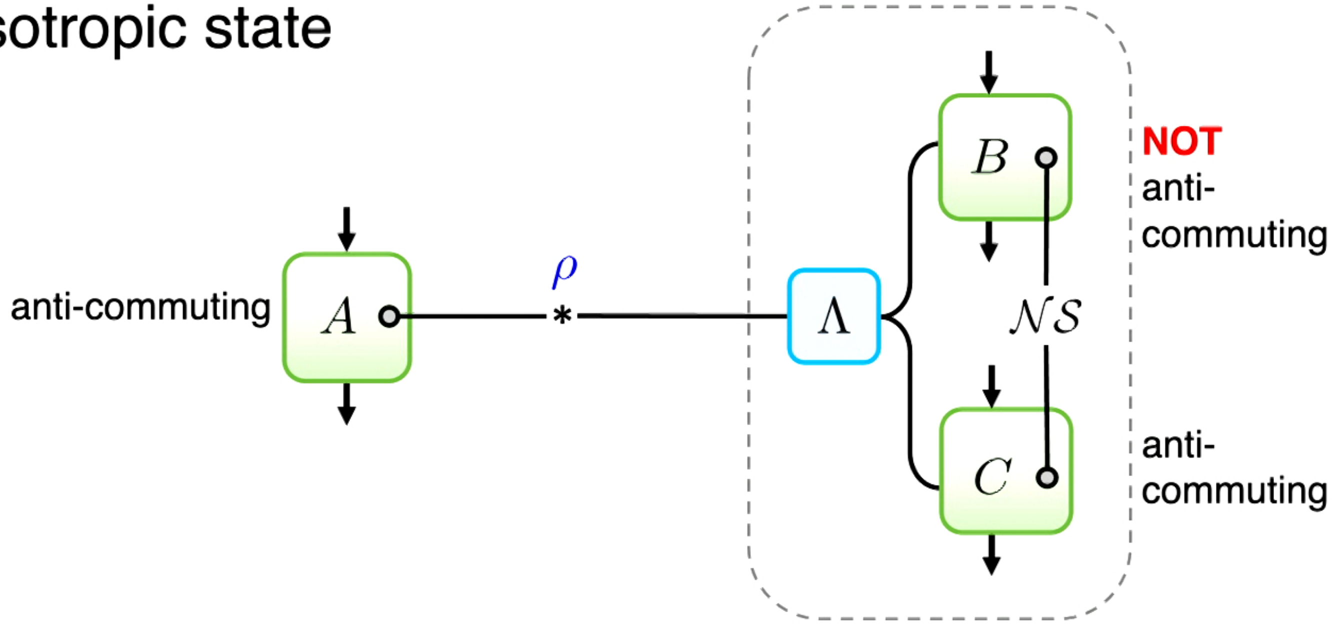
(state of the art)

Activation: broadcast Bell scenarios



Activation: broadcast quantum strategy

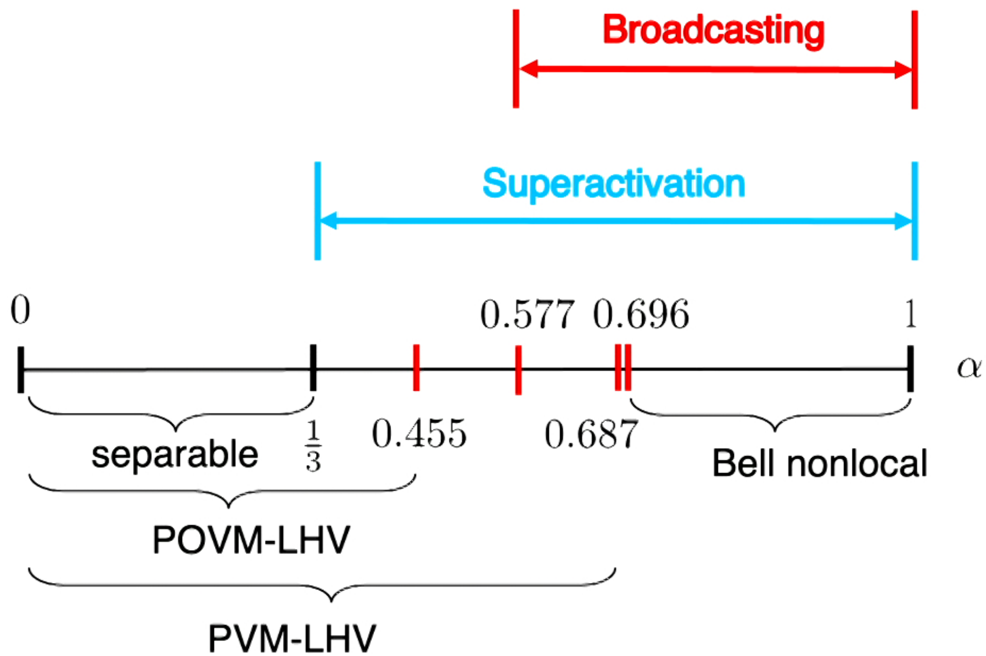
- Isotropic state



$$\Lambda(\rho) = V\rho V^\dagger$$

$$V = |00\rangle\langle 0| + |11\rangle\langle 1|$$

Activation: broadcast activation



New results

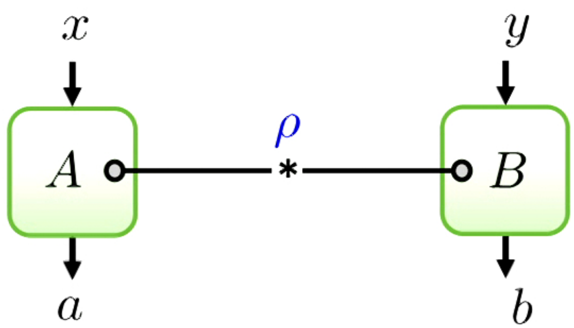
Activation

- Define a family of broadcast Bell inequalities

$$\mathcal{I} = \langle \mathcal{I}[A_0, \ldots, A_m, C_0, \ldots, C_k] \, (B_0 + B_1) \rangle + \mathrm{L}_{\mathcal{I}} \, \langle A_2 \, (B_1 - B_0) \rangle \leq 2\mathrm{L}_{\mathcal{I}}$$

- Example of activation of non-signaling genuine network nonlocality
- Improvements in robustness to detection inefficiencies
- Examples of activation of POVM-LHV states

DI entanglement certification



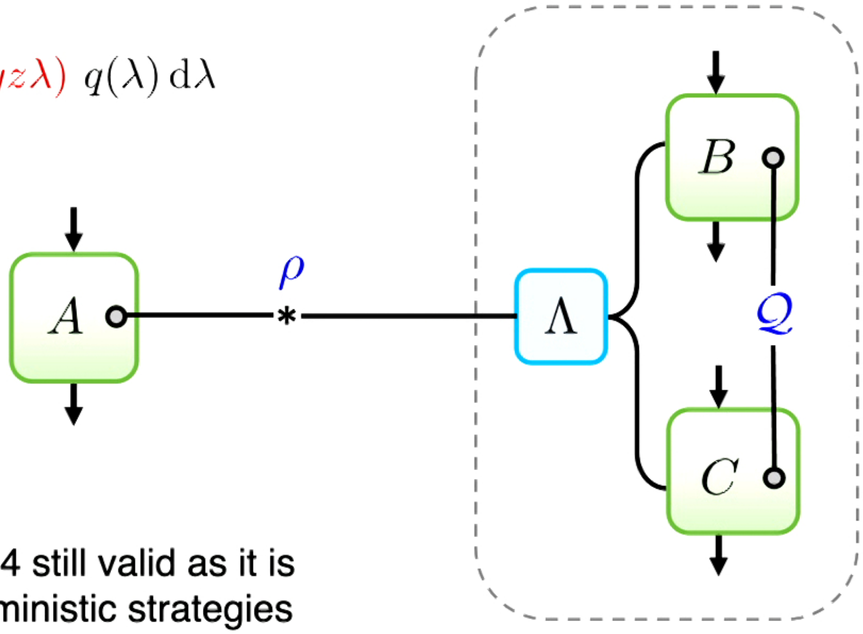
$$\rho_{\mathrm{SEP}} = \int \sigma_\lambda^A \otimes \sigma_\lambda^B \, q(\lambda) \, \mathrm{d}\lambda$$

$$\Downarrow$$

$$p(ab|xy) = \int \mathrm{tr}\left(A_a^x \sigma_\lambda^A\right) \mathrm{tr}\left(B_b^y \sigma_\lambda^B\right) \, q(\lambda) \, \mathrm{d}\lambda$$

DI entanglement certification

$$p(abc|xyz) = \int p(a|x\lambda)\ p^{Q}(bc|yz\lambda)\ q(\lambda)\,\mathrm{d}\lambda$$

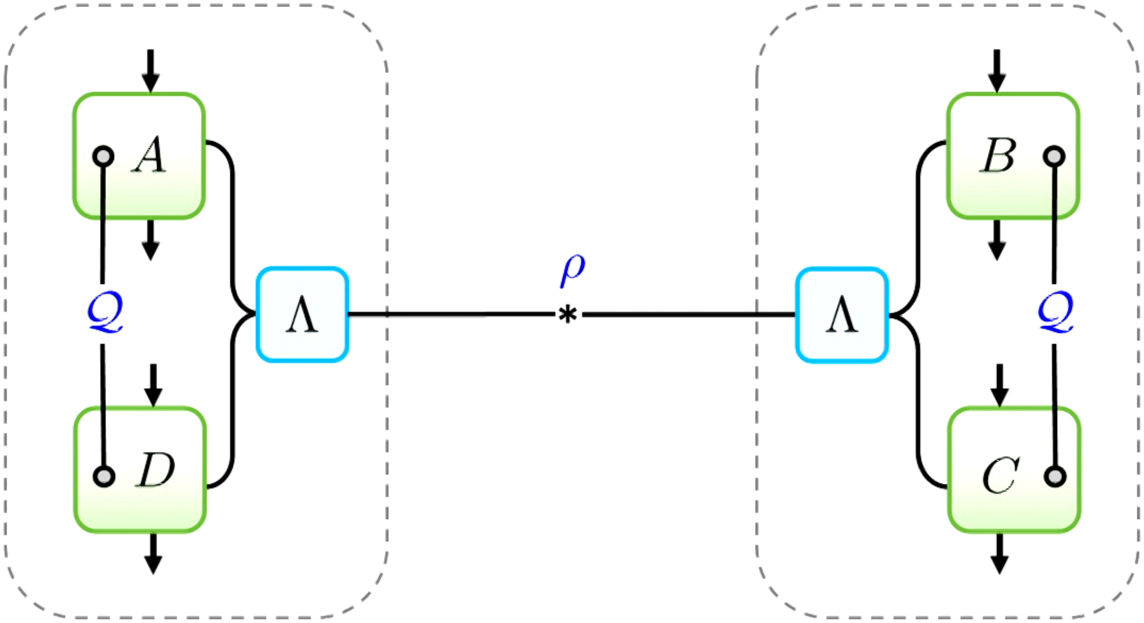


Previous bound of 4 still valid as it is saturated by deterministic strategies between Bob and Charlie.

$$\alpha = 1/\sqrt{3} \approx 0.577$$

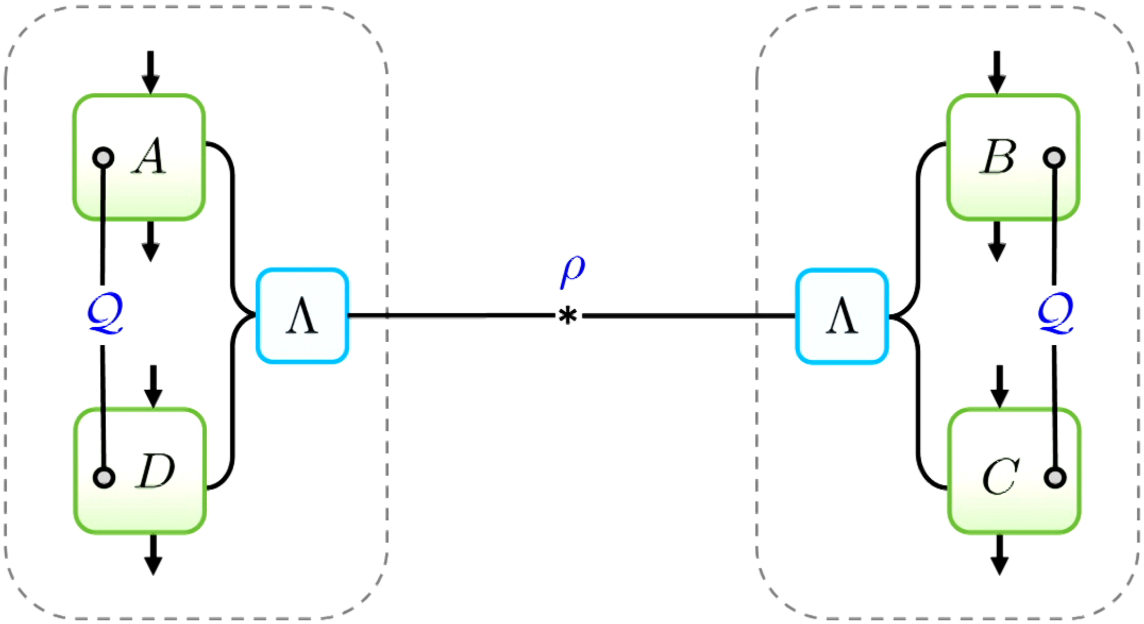
Can we do better?

DI entanglement certification



ρ is sep. $\not\Rightarrow$ $p(adbc|xwyz) = \int p^{\mathcal{Q}}_{AD}(ad|xw\lambda)\, p^{\mathcal{Q}}_{BC}(bc|yz\lambda)\, q(\lambda)\, \mathrm{d}\lambda$ Relax!

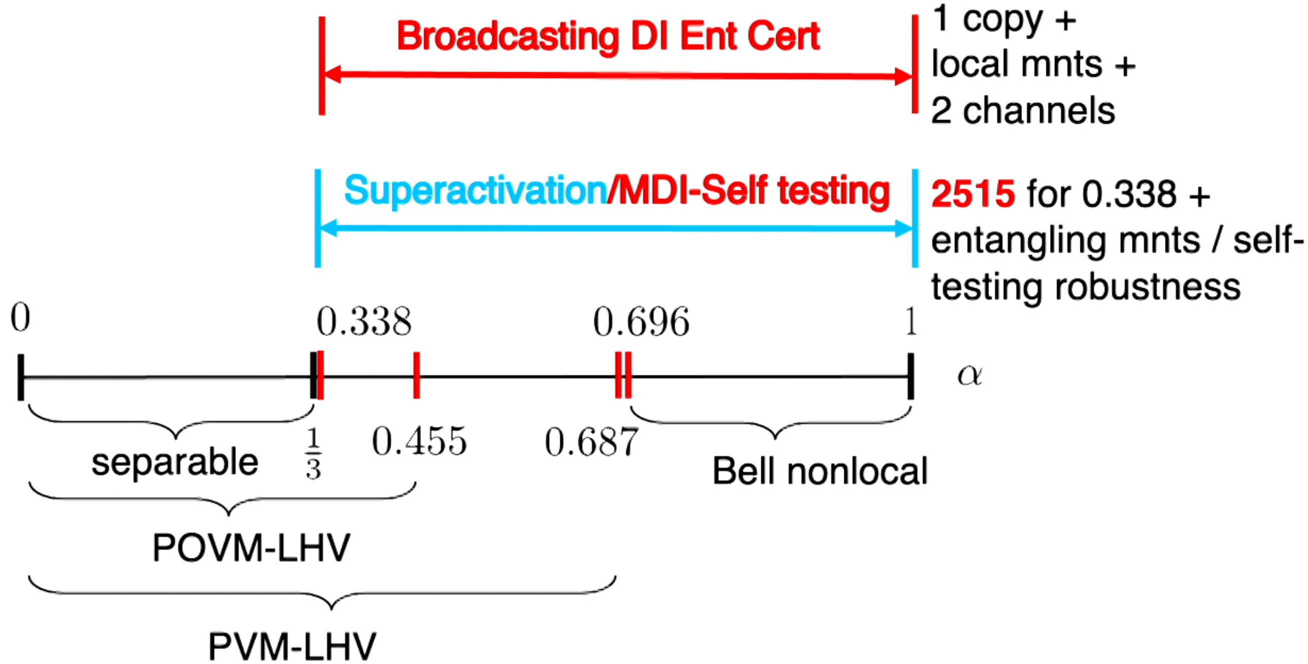
DI entanglement certification



ρ is sep. $\not\approx$ $p \in \mathcal{Q}^{\mathrm{PPT}}_{AD|BC}$ $\not\approx$ SDP relax.[1] $\not\Rightarrow$ $\alpha = 0.338 \approx 1/3$

[1] *Moroder et al, Physical Review Letters, 111(3), Jul 2013*

DI entanglement certification



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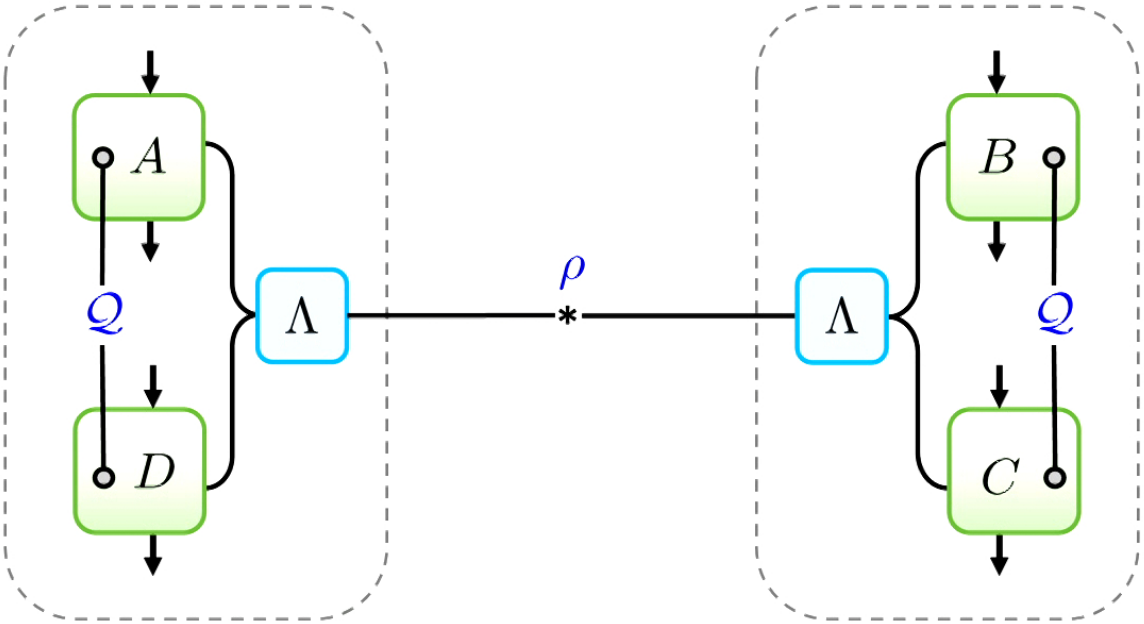

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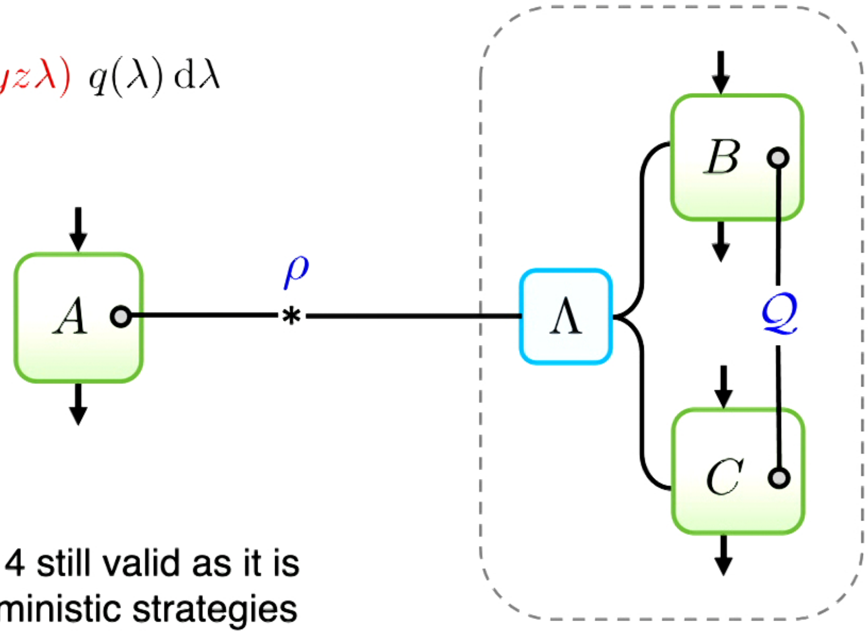

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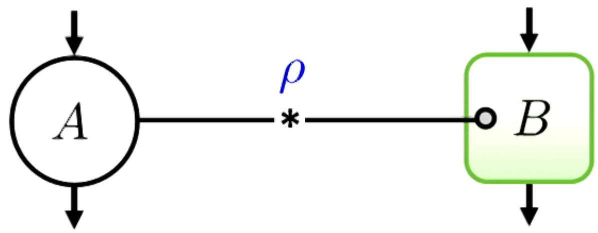
Steering

Alice has trusted measurements



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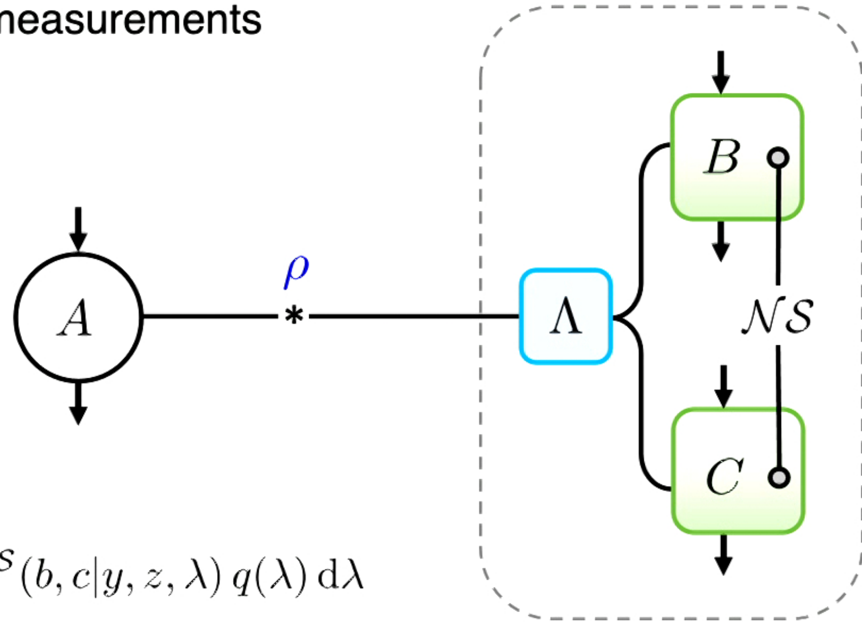
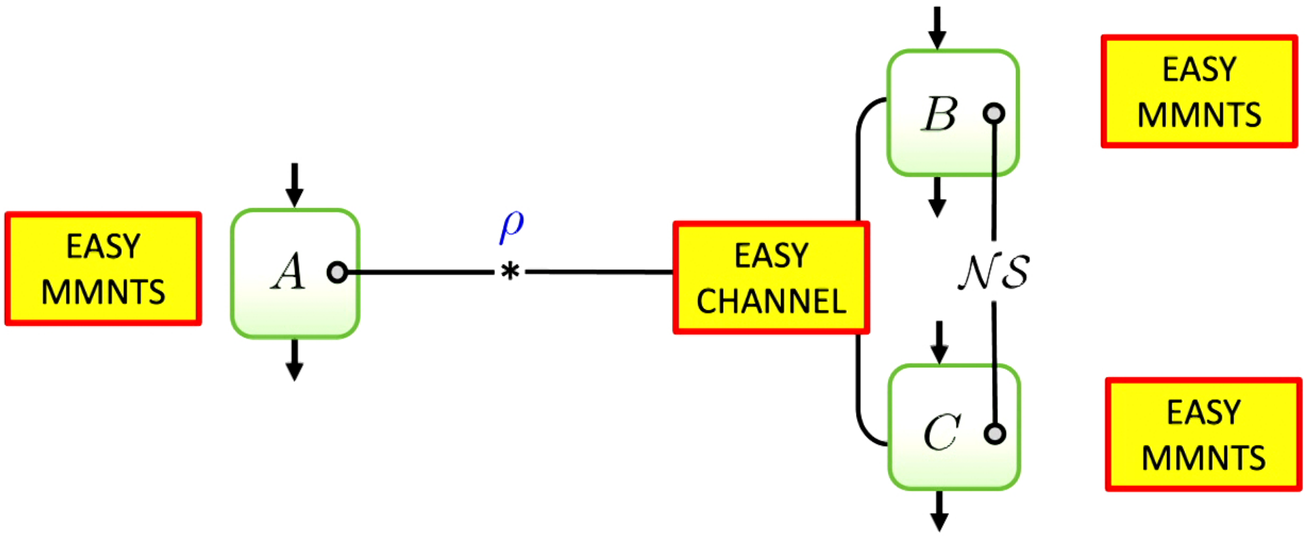


$$\sigma_{bc|yz} = \int \sigma_\lambda \, p^{\mathcal{NS}}(b,c|y,z,\lambda) \, q(\lambda) \, \mathrm{d}\lambda$$

Isotropic state: LHS for $\alpha \leq \frac{1}{2}$ Broadcast steering (A I BCD): $\alpha \geq 0.4678$

Open questions

- Better intuition for both the minimal scenario, and the limit of many broadcasted parties, go down to 1/3 visibility with broadcast nonlocality
- More practical questions: is the scenario useful if we restrict to “easy” channels and measurements?



Open questions

Thank you!

- Better intuition for both the minimal scenario, and the limit of many broadcasted parties, go down to 1/3 visibility with broadcast nonlocality
- More practical questions: is the scenario useful if we restrict to "easy" channels and measurements?
- Ongoing research: how accurate is it to think of the broadcasting protocol as an effective no-signaling POVM implementation?

$$
\begin{aligned}
p(abc|xyz) &= \operatorname{tr} \mathbb{1}_A \otimes \Lambda_{B_0 \to B_1 B_2}(\rho_{AB_0})\, A^{x,a} \otimes B_1^{y_1,b_1} \otimes B_2^{y_2,b_2} \\
&= \operatorname{tr} \rho_{AB_0}\, A^{x,a} \otimes \Lambda^*_{B_0 \to B_1 B_2}(B_1^{y_1,b_1} \otimes B_2^{y_2,b_2}) \\
&= \operatorname{tr} \rho_{AB_0}\, A^{x,a} \otimes B_0^{y_1 y_2, b_1 b_2}
\end{aligned}
$$