Title: Escaping the Shadow of Bellâ€™s Theorem in Network Nonlocality

Speakers: Maria Ciudad AlaÃ±Ã³n

Series: Quantum Foundations, Quantum Information

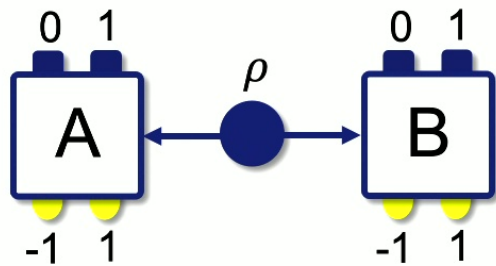Date: September 19, 2024 - 4:10 PM

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ESCAPING THE SHADOW OF BELL'S THEOREM IN NETWORK NONLOCALITY

Authors: Maria Ciudad-Alañón, Emanuel-Cristian Boghiu, Paolo Abiuso and Elie Wolfe

BELL NONCLASSICALITY

Standard Bell scenario
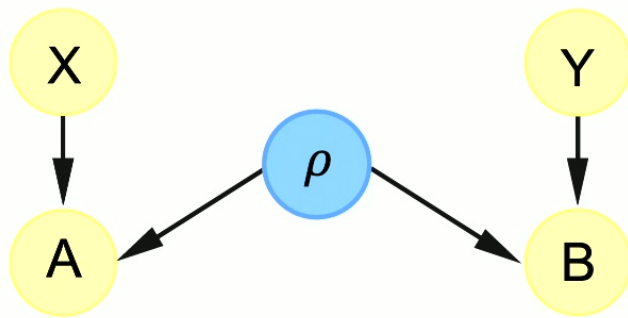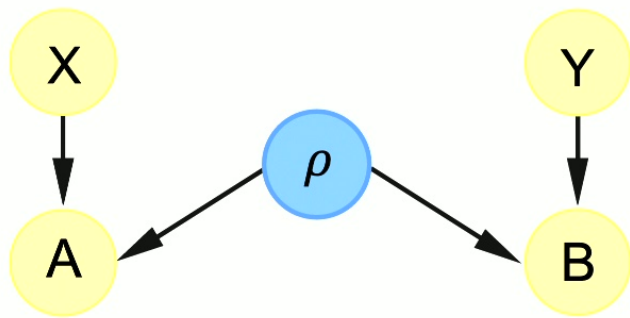

$x, y \in \{0,1\}$
$a, b \in \{1, -1\}$

Correlations $p(a, b|x, y)$

NO-SIGNALLING
PRINCIPLE:

$p(a|x, y) = p(a|x) \quad \forall\, a, x, y$
$p(b|x, y) = p(b|y) \quad \forall\, b, x, y$

BELL NONCLASSICALITY

Standard Bell scenario

$x, y \in \{0,1\}$
$a, b \in \{1, -1\}$

Correlations $p(a, b | x, y)$

NO-SIGNALLING PRINCIPLE:

$p(a | x, y) = p(a | x) \quad \forall\, a, x, y$
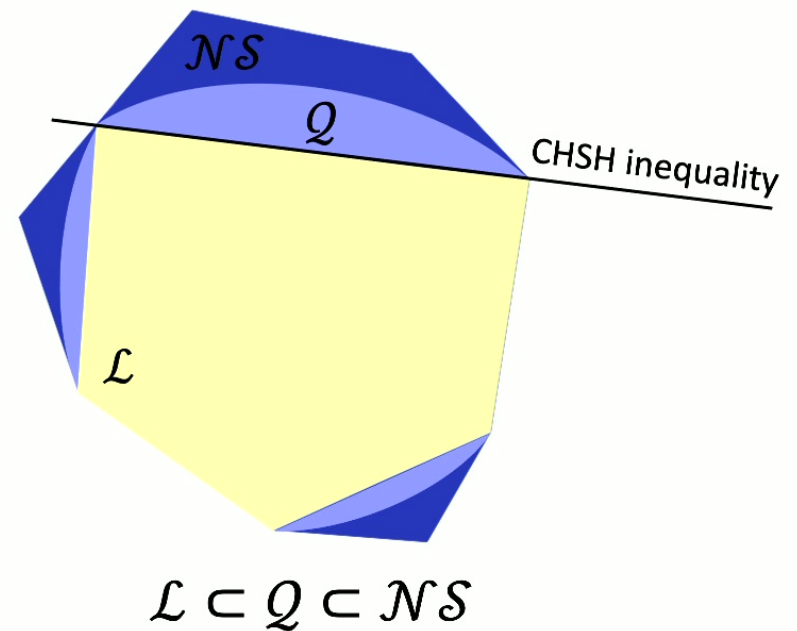$p(b | x, y) = p(b | y) \quad \forall\, b, x, y$

BELL NONCLASSICALITY

Standard Bell scenario

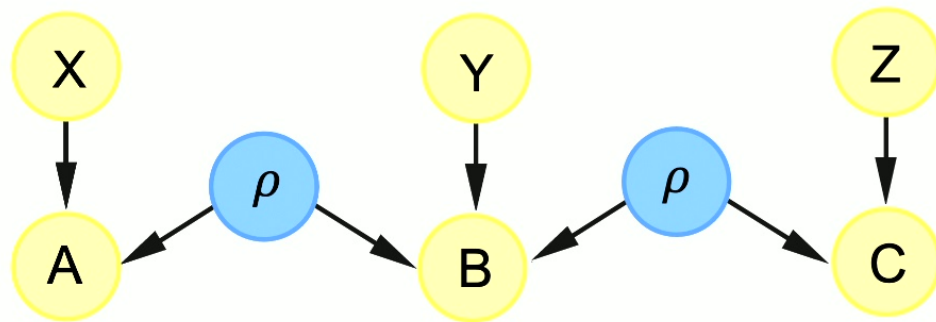$$S_{CHSH} = \langle A_0 B_0 \rangle + \langle A_0 B_1 \rangle + \langle A_1 B_0 \rangle - \langle A_1 B_1 \rangle$$

$$|S_{CHSH}| \underset{\mathcal{L}}{\leq 2} \underset{\mathcal{Q}}{\leq 2\sqrt{2}} \underset{\mathcal{NS}}{\leq 4}$$
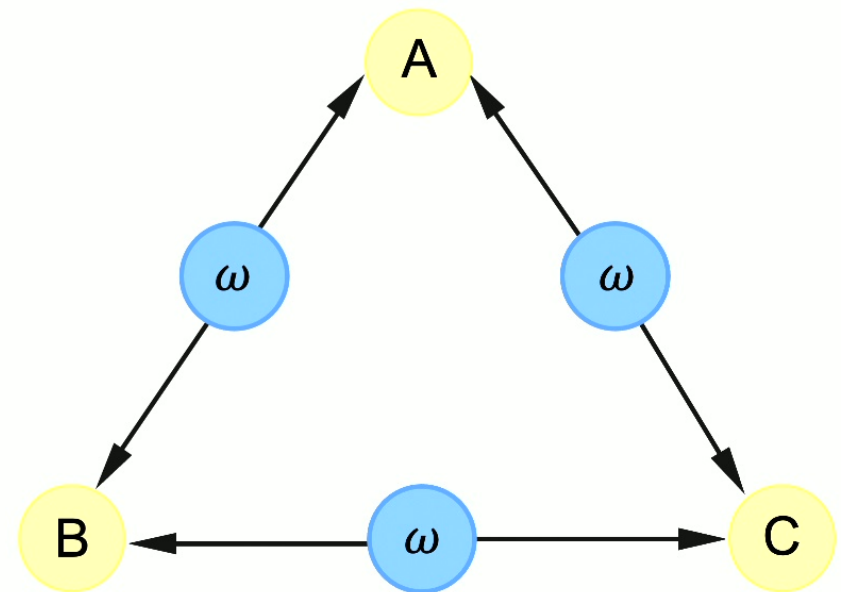

$$\mathcal{L} \subset \mathcal{Q} \subset \mathcal{NS}$$

BEYOND BELL NONCLASSICALITY

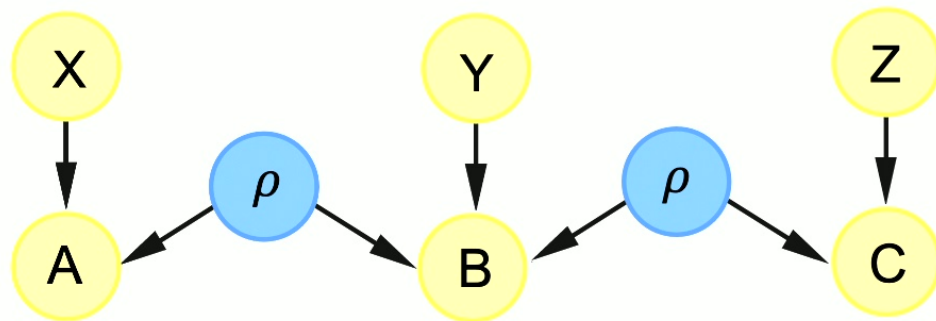## Network nonclassicality:

Triangle scenario

3-chain (bilocality) scenario

BEYOND BELL NONCLASSICALITY

Network nonclassicality:

3-chain (bilocality) scenario

- Independence of the sources.
- Non-convex set.

BEYOND BELL NONCLASSICALITY

Network nonclassicality:

→ What are the simplest network where nonclassical correlations can be produced?

→ When is it posible to guarantee that a network nonclassical behaviour is nontrivial?
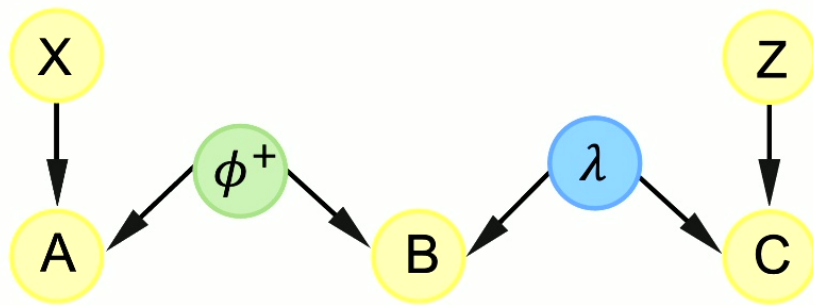
"NONGENUINE" NONCLASSICALITY

Being in the Shadow of Bell's Theorem (Shadowed):

A network nonclassical correlation is said to "live in the shadow of Bell's Theorem" whenever it can be somehow traced back to Bell's theorem as applied in the standard Bell scenario.

[Intentionally vague!]

"NONGENUINE" NONCLASSICALITY

Being in the Shadow of Bell's Theorem (Shadowed):

Nonclassical $p(a,b,c|x,z)$

$\updownarrow$

$p_z(a,b|x,c)$ violating CHSH

[T. Fritz, "Beyond Bell's theorem: correlation scenarios," New J. Phys. **14**, 103001 (2012).]

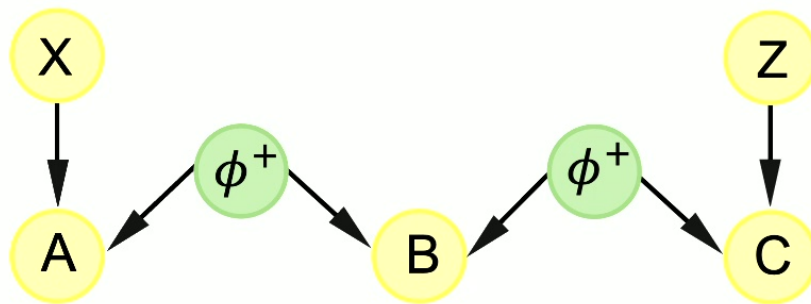# "NONGENUINE" NONCLASSICALITY

[I. Šupić, JD. Bancal, Y. Cai, N. Brunner, "Genuine network quantum nonlocality and self-testing," PRA **105**, 022206 (2022).]

Local measurements on the sources they receive

+

Local wirings of their local measurement settings and outcomes

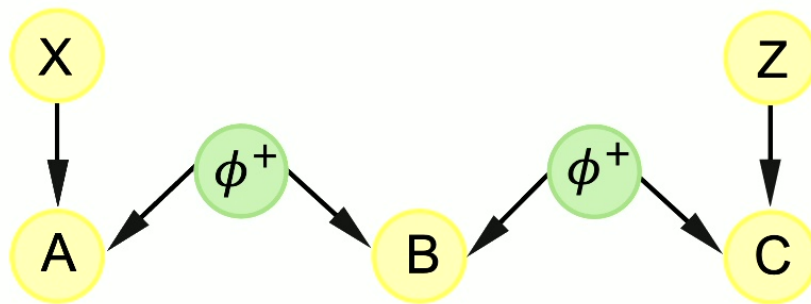Nonclassical p(a,b,c|x,z)

$\updownarrow$

p(a,c|x,z,b=0) violating CHSH

Entanglement-swapping

"GENUINE" NONCLASSICALITY

[A. Pozas-Kerstjens, N. Gisin, A. Tavakoli, "Full Network Nonlocality," PRL. **128**, 010403 (2022).]

All sources in the network
must be nonclassical

Entanglement-swapping

Nonclassical $p(a,b,c|x,z)$

$\updownarrow$

$p(a,c|x,z,b=0)$ violating CHSH

"NONGENUINE" NONCLASSICALITY

Subset Unavoidable Nonclassicality (SUN):

A network nonclassical correlation is said to be **SUN** if all the explanations rely on some **fixed** subset of parties exploiting the nonclassicality of a common cause, either originally present as a source or induced via post-selection.

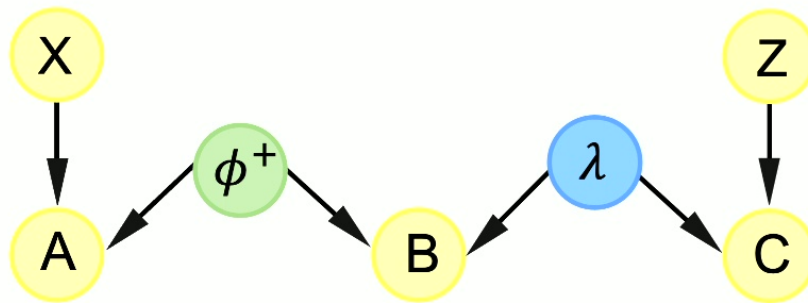Nonclassical $p(a,b,c|x,z)$

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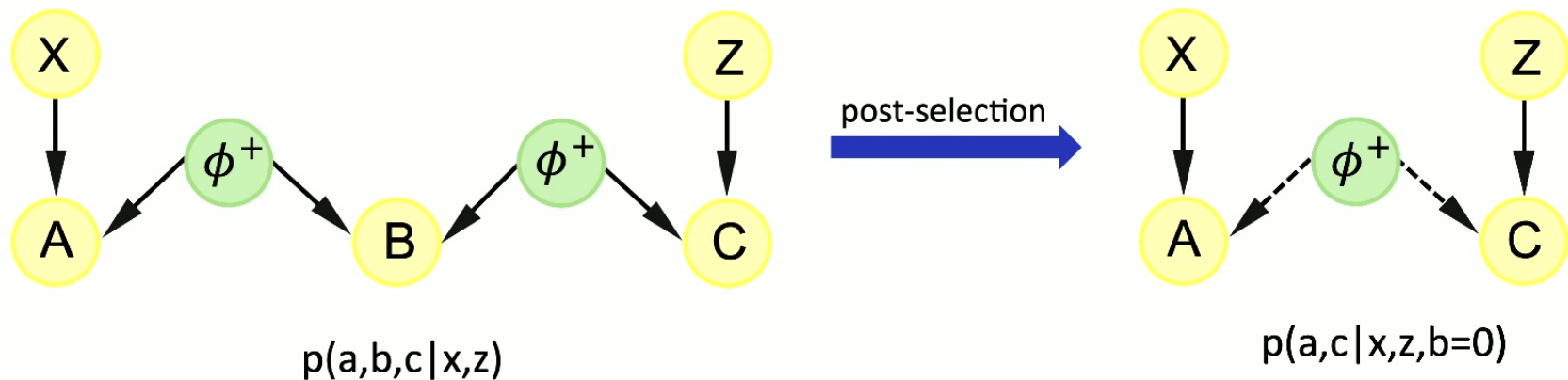

$$p(a,b,c|x,z)$$

post-selection

$$p(a,c|x,z,b=0)$$

"NONGENUINE" NONCLASSICALITY

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A network nonclassical correlation is said to be **SUN** if all the explanations rely on some **fixed** subset of parties exploiting the nonclassicality of a common cause, either originally present as a source or induced via post-selection.

Shadowed $\Rightarrow$ SUN

To be in the Shadow, the Sun must be present

"GENUINE" NONCLASSICALITY

Minimal Network Nonlocality (MNN):
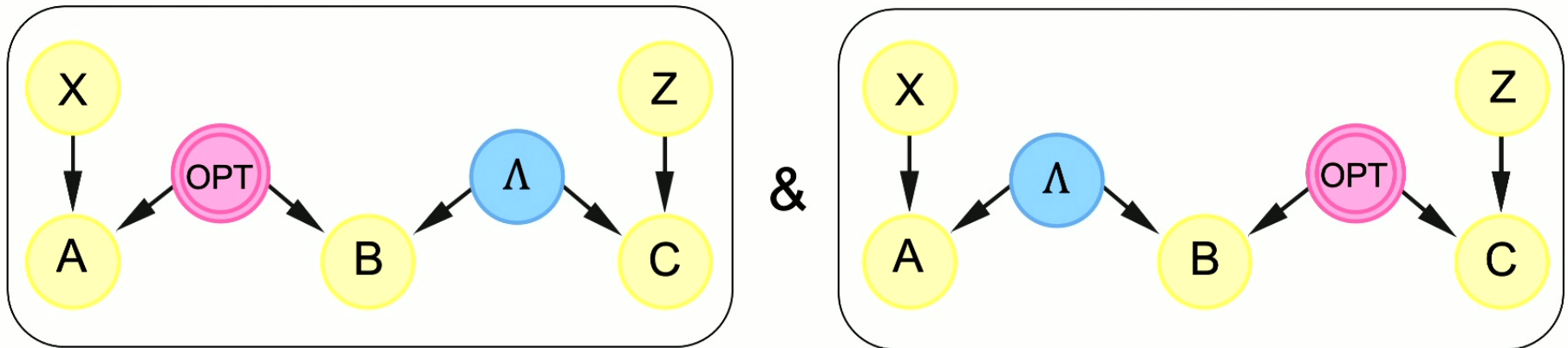

- This nonclassicality is NOT tied to any of the sources $\Rightarrow \neg$SUN $\Rightarrow \neg$Shadowed.
- It comes from the structure of the network and it is theory-independent.
- There is not violation of the CHSH between any pair of parties.
- Cheap in terms of sources (opposite to full network nonlocality).

"GENUINE" NONCLASSICALITY

Minimal Network Nonlocality (MNN):

A correlation p is MNN iff it is not compatible by allowing all the sources to be classical while it is compatible every possibility where one of the sources is OPT and the rest, classical.
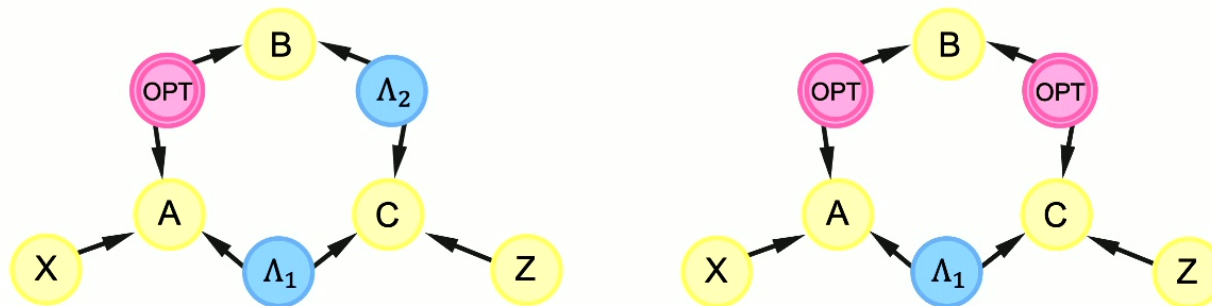
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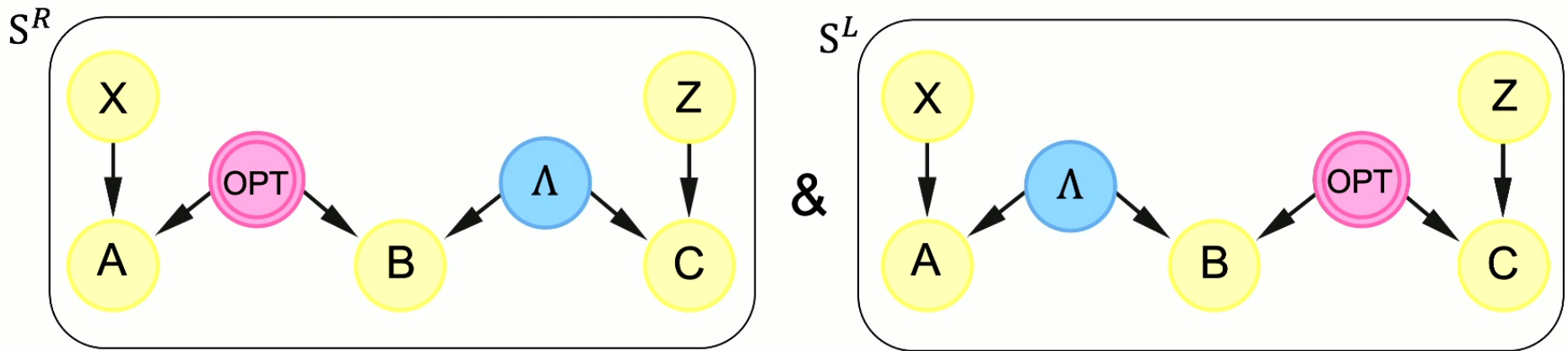
$$\text{MNN} \Rightarrow \neg\text{SUN} \Rightarrow \neg\text{Shadowed}$$

Seeing the M(oo)NN requires an absence of SUN.
In M(oo)Nnlight there are no Shadows.

"GENUINE" NONCLASSICALITY

Minimal Network Nonlocality (MNN):

We found examples of both quantum and OPT compatible correlations of MNN with one of the simplest scenario (binary for all).

[N. Gisin, "The Elegant Joint Quantum Measurement and some conjectures about N-locality in the Triangle and other Configurations," (2017), arXiv:1708.05556 [quant-ph].]

[P. Lauand, D. Poderini, R. Rabelo, R. Chaves, "Quantum non-classicality in the simplest causal network," (2024), arXiv:2404.12790 [quant-ph].]

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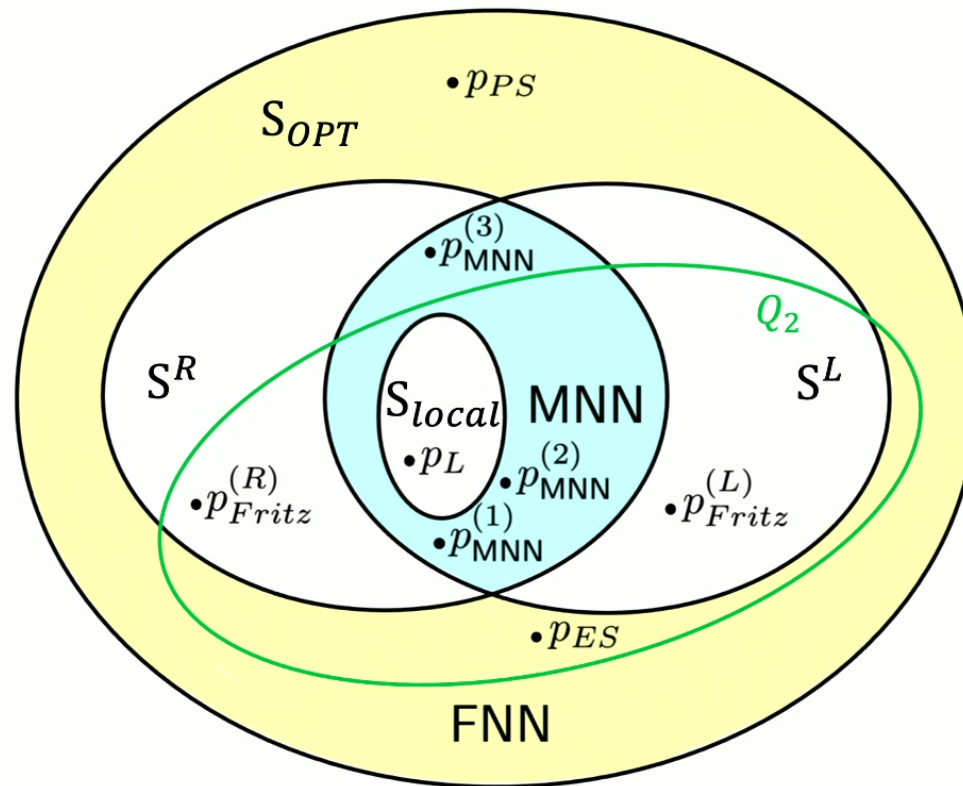# "GENUINE" NONCLASSICALITY

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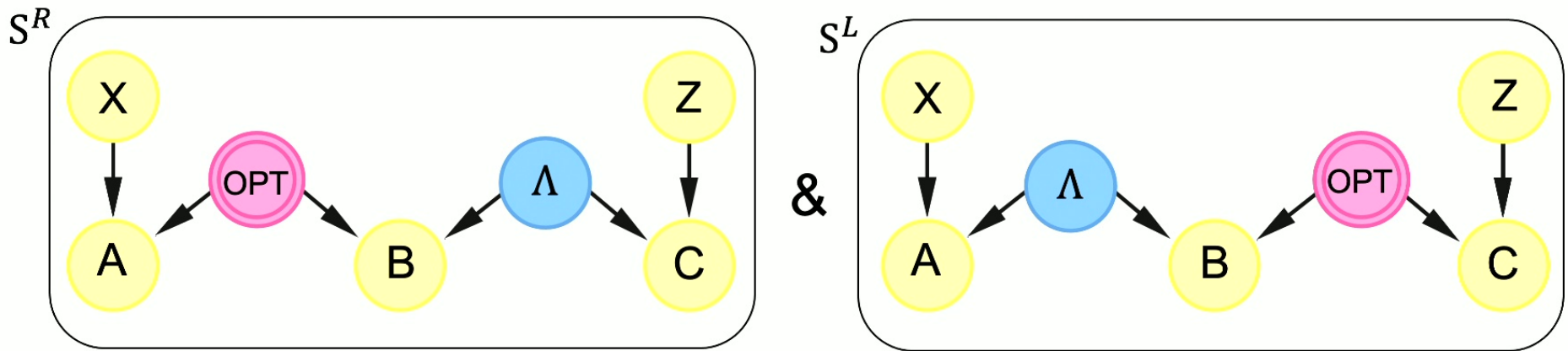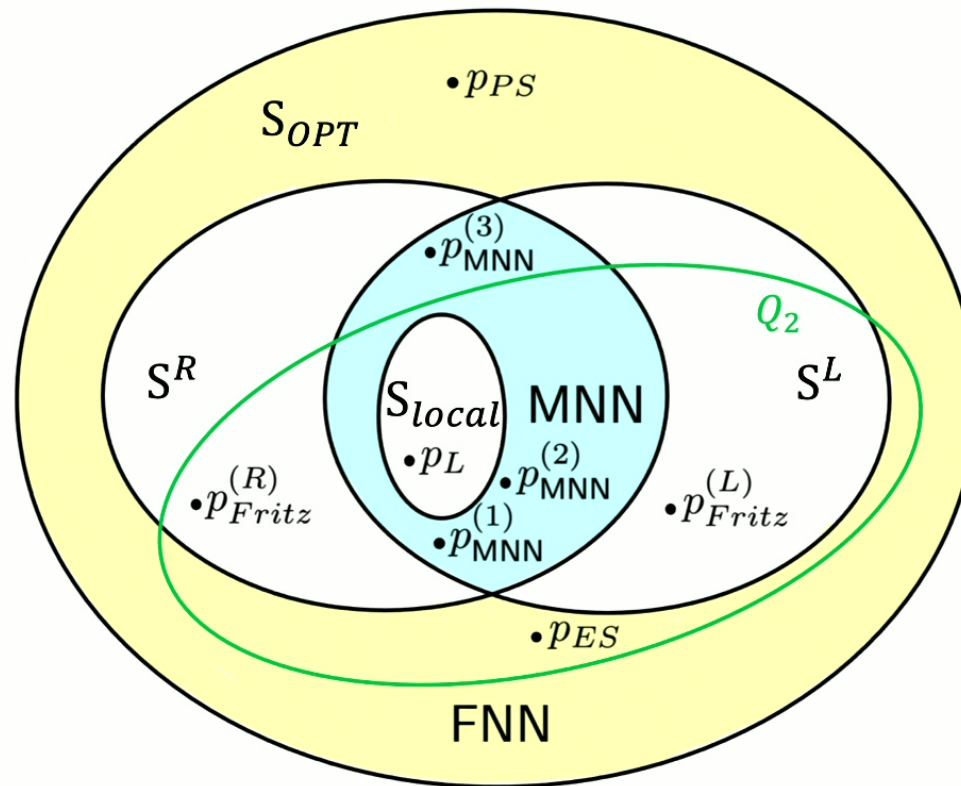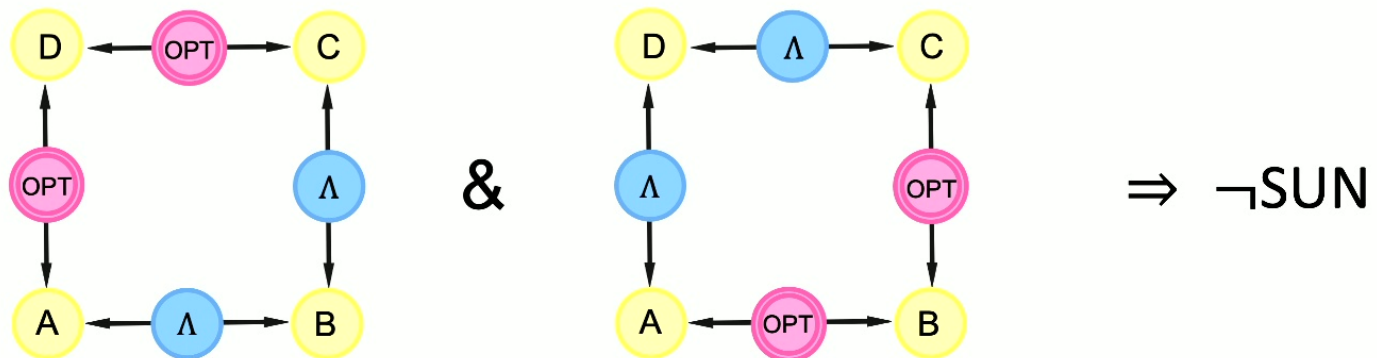
"GENUINE" NONCLASSICALITY

Minimal Network Nonlocality (MNN):

"GENUINE" NONCLASSICALITY

Minimal Network Nonlocality (MNN):

- MNN $\Rightarrow$ ¬SUN $\Rightarrow$ ¬Shadowed.

  ?
  $\Longleftarrow$

- MNN as a witness for genuine nonclassicality but potentially too restrictive.

$\Rightarrow$ ¬SUN

SUMMARY AND OUTLOOK

- We revisited the previous notions for "genuine" nonclassicality.

- New definitions to better understand the notion of "living outside the shadow of Bell".

- New definition as a witness for genuine nonclassicality but potentially too restrictive.

- (Quantum) examples of the new notions of nonclassicality in one of the simplest scenario.

❓ Examples of MNN in other networks.

❓ Is there any genuine nonclassical correlations that are not MNN?

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Thank you!