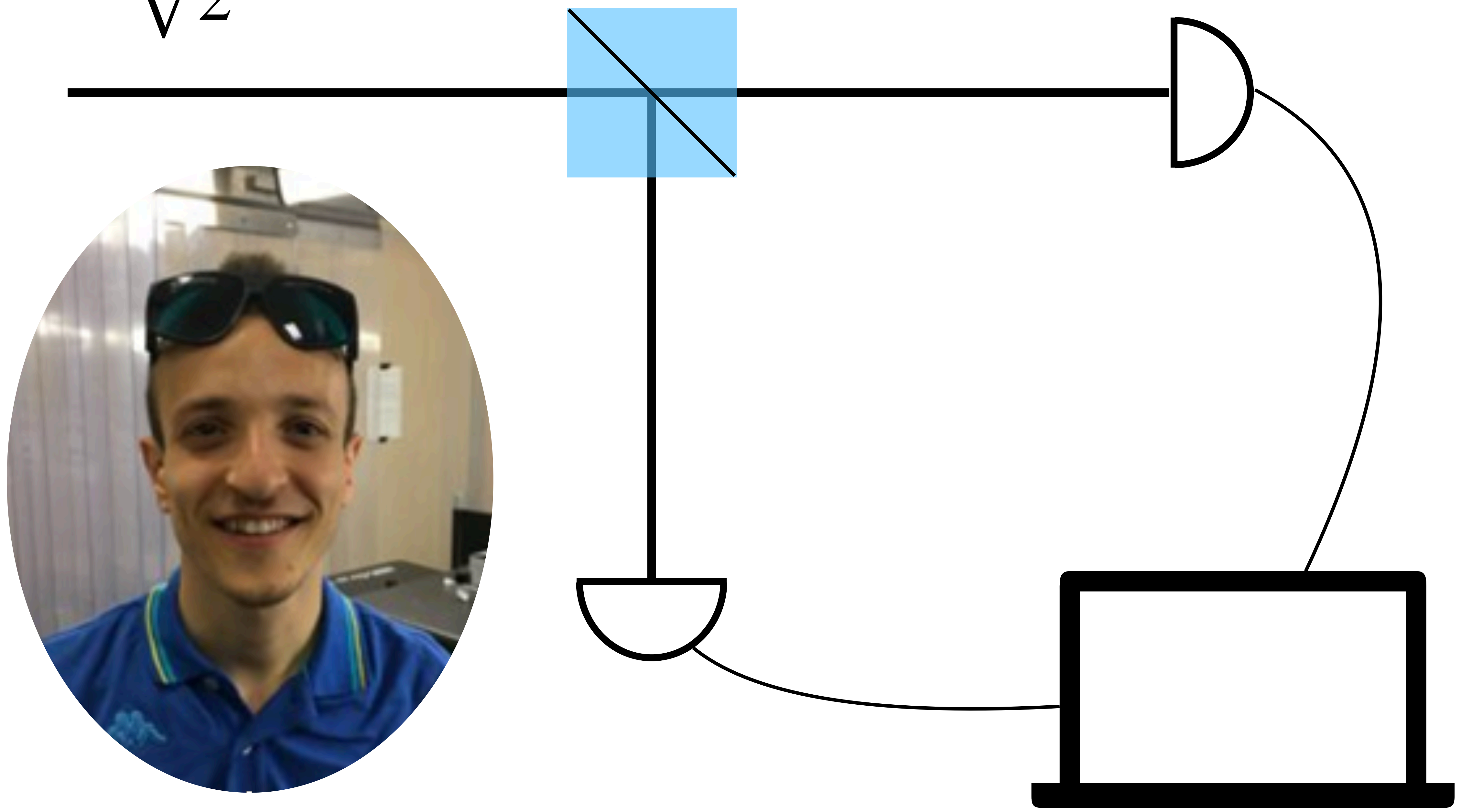
Relative Facts, Relational Quantum Mechanics

Andrea Di Biagio
Ateliers du LKB 2023-10-05

Relative Facts

Friends

$$\frac{1}{\sqrt{2}}|0\rangle + \frac{1}{\sqrt{2}}|1\rangle$$



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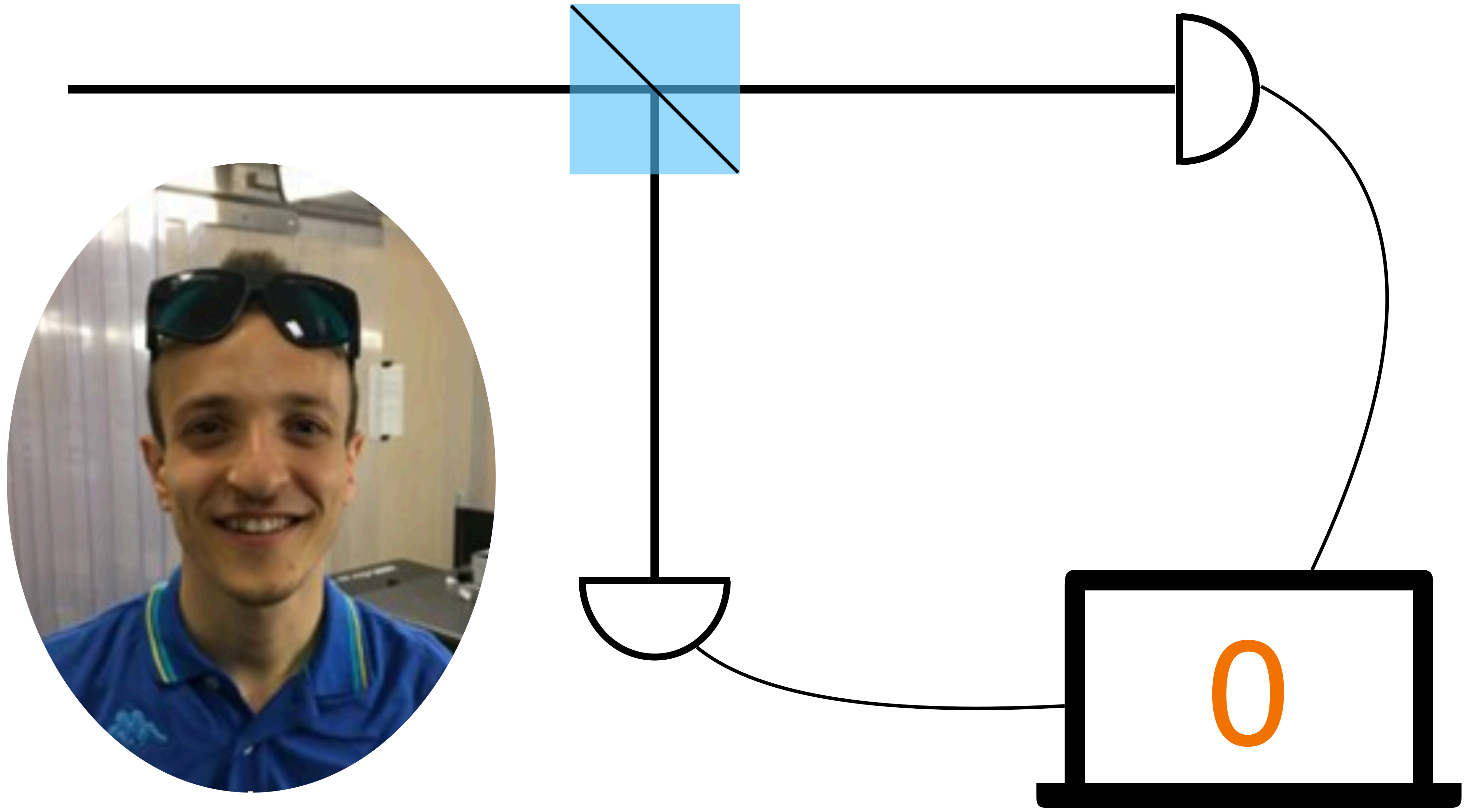

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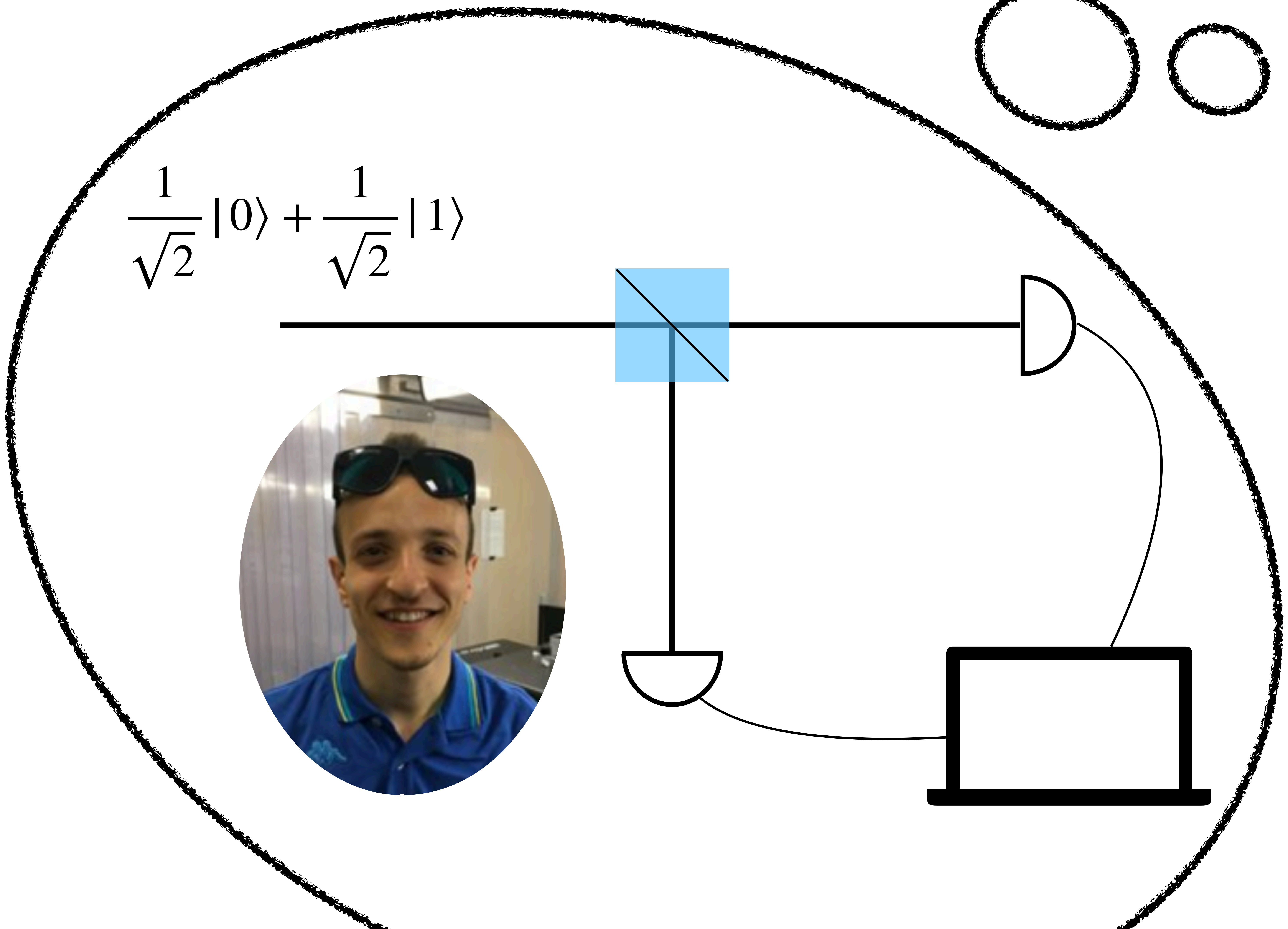
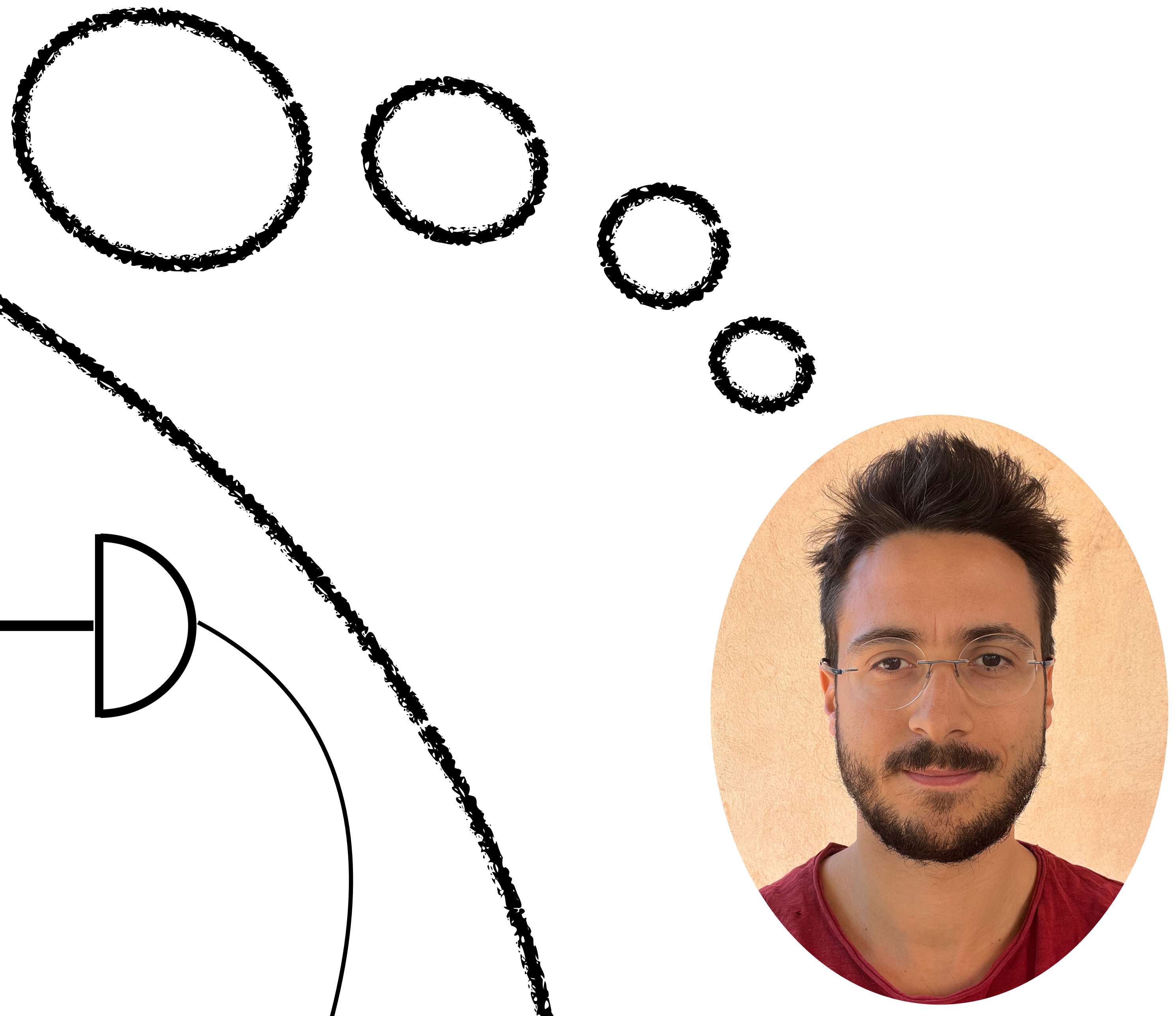
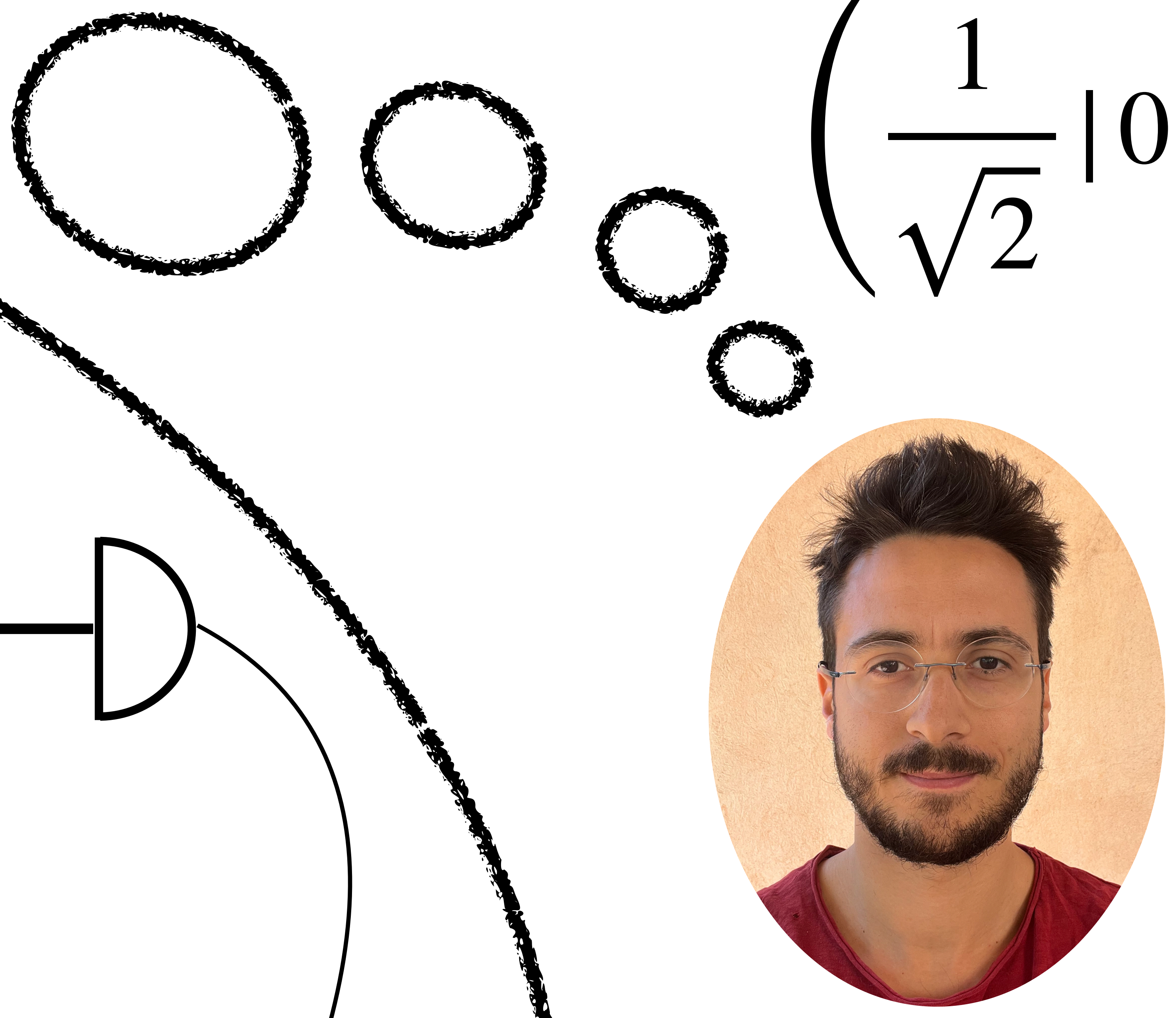




Friends

$$\left(\frac{1}{\sqrt{2}}|0\rangle + \frac{1}{\sqrt{2}}|1\rangle\right) \otimes |\psi\rangle_{\text{lab}}$$



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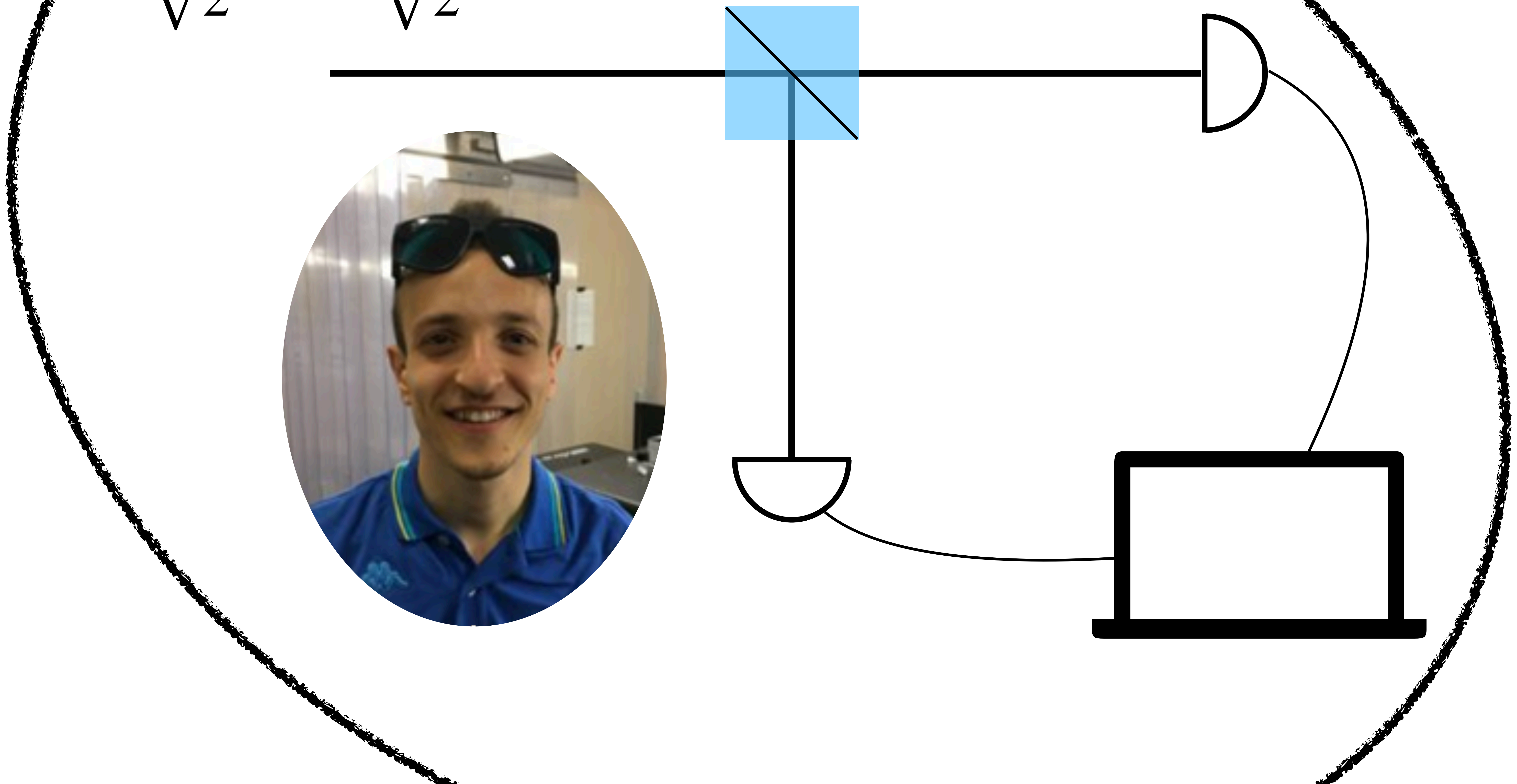

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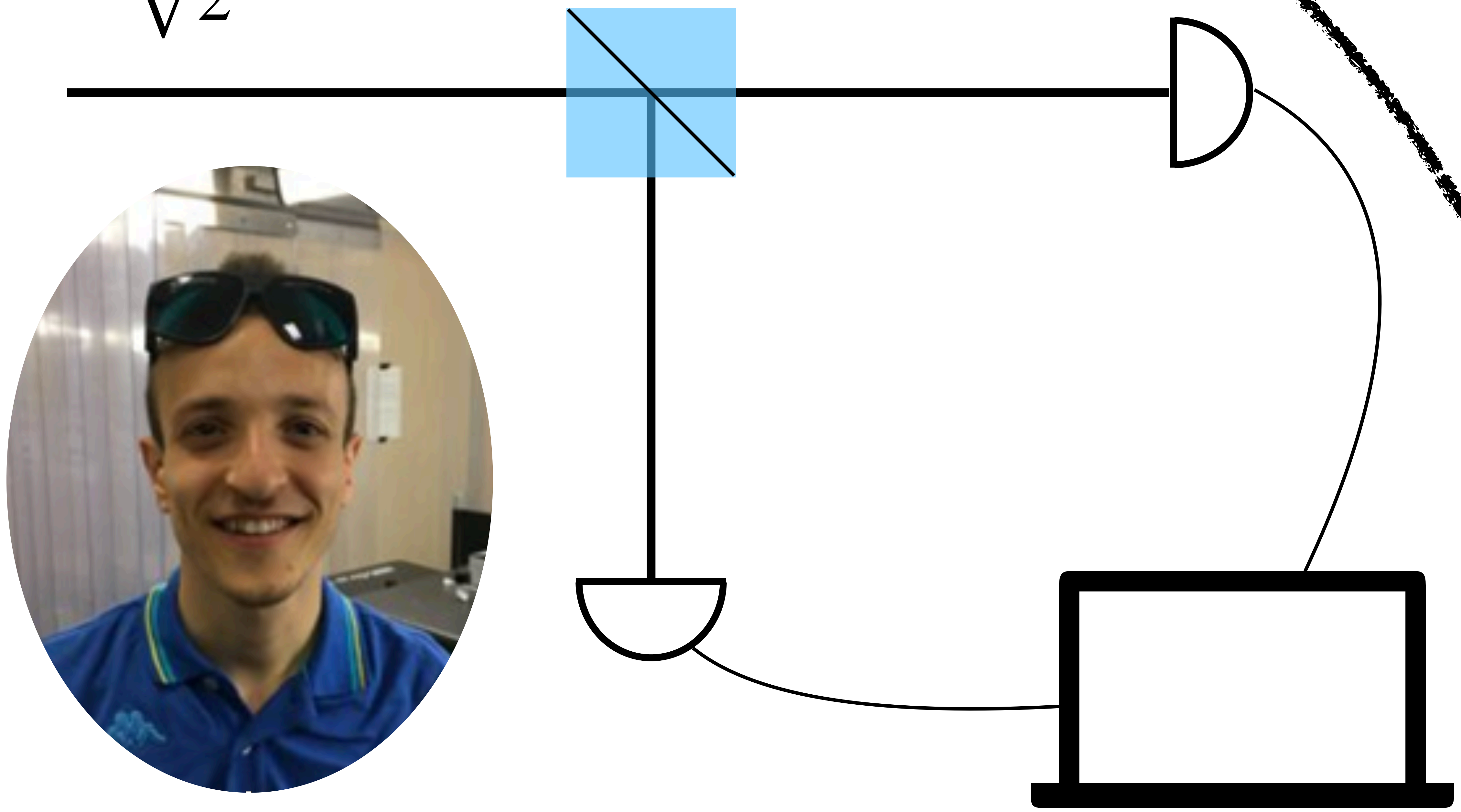

$$\frac{1}{\sqrt{2}}|0\rangle|\psi_0\rangle_{\text{lab}} + \frac{1}{\sqrt{2}}|1\rangle|\psi_1\rangle_{\text{lab}}$$

Relative Facts

Friends

Relative Facts

Wigner's Friend Scenario

Wigner's Friend Scenario

is Emanuele in a superposition?

Relative Facts

Wigner's Friend Scenario

is Emanuele in a superposition?

what does it feel like to be in a superposition?

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Wigner's Friend Scenario

is Emanuele in a superposition?

what does it feel like to be in a superposition?

but whenever I look in the lab, I see him in a definite state

Wigner's Friend Scenario

is Emanuele in a superposition?

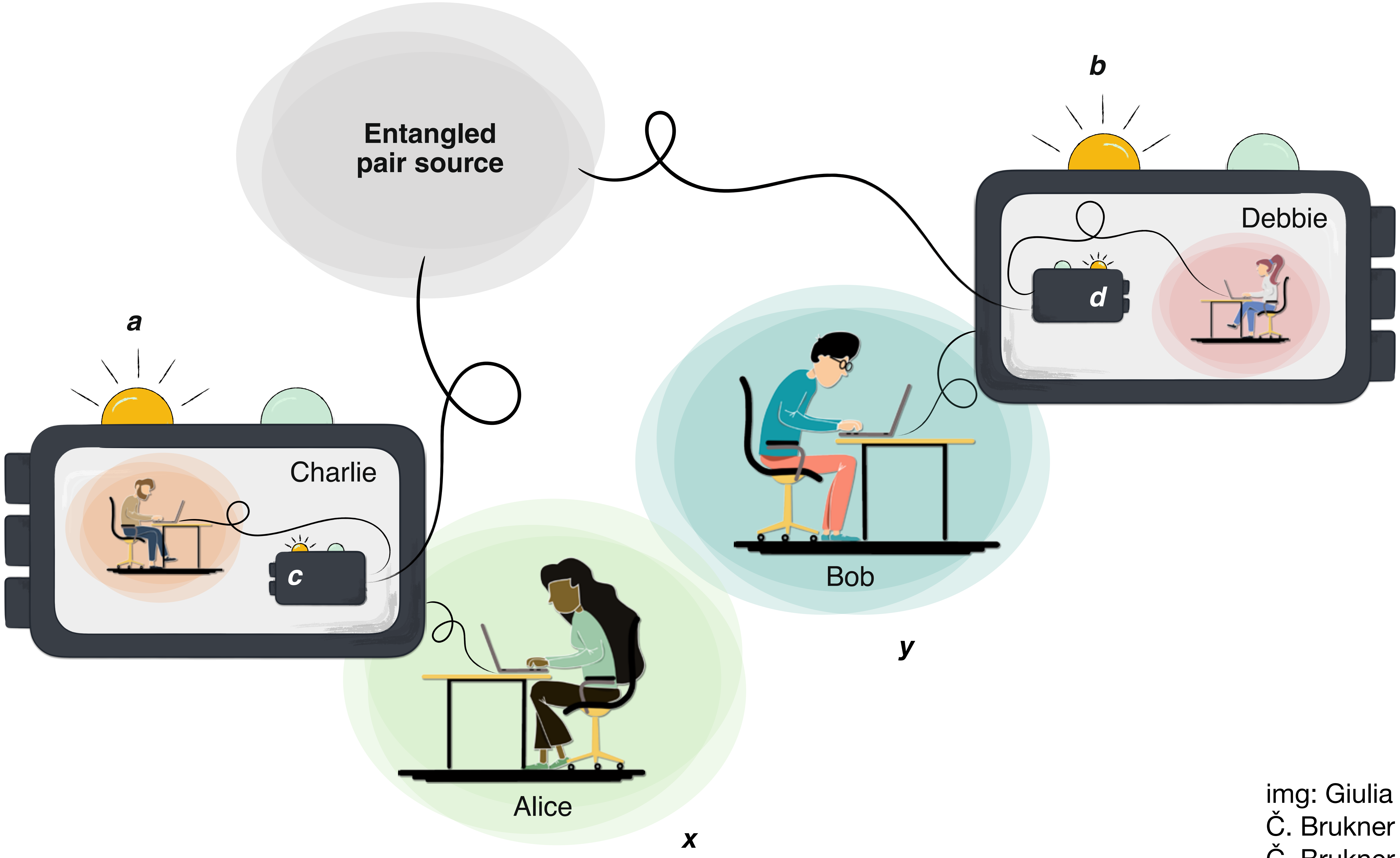
what does it feel like to be in a superposition?

but whenever I look in the lab, I see him in a definite state

it *must* just be a matter of lacking information, not a real superposition... ***right***?

Relative Facts

Extended Wigner's Friend Scenario



img: Giulia Rubino
Č. Brukner DOI:10/gdq8td arXiv:1804.00749
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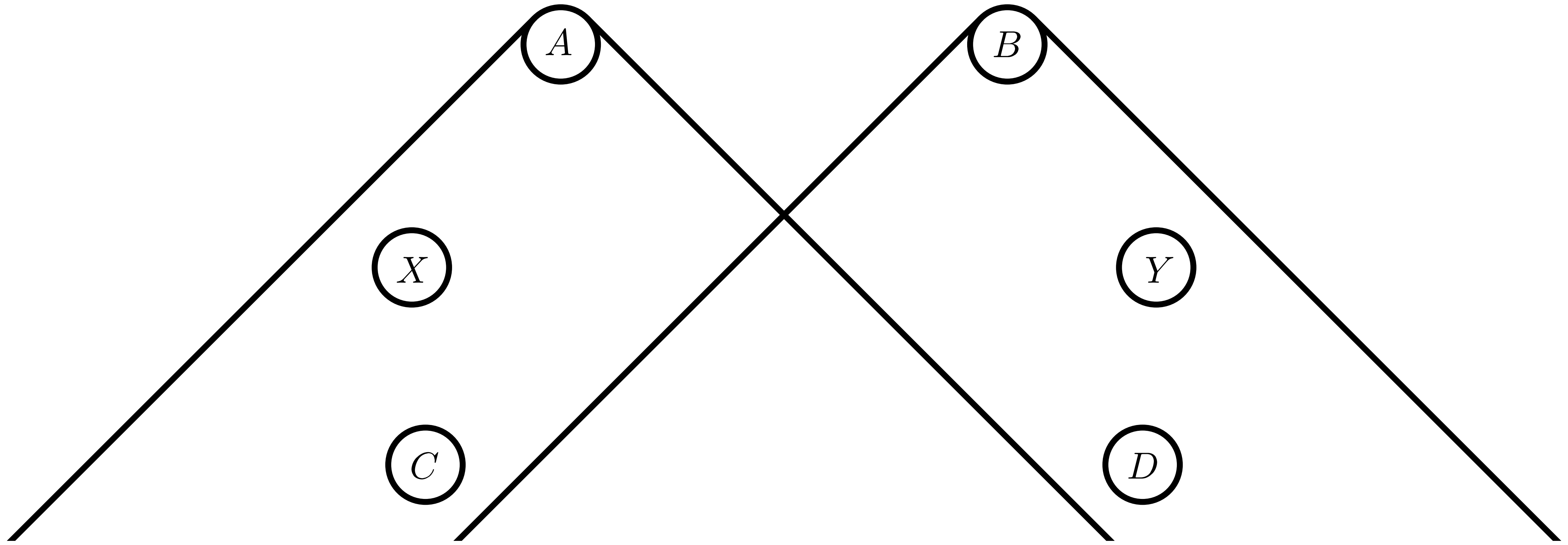
Relative Facts

A no-go theorem

Observed frequencies

$$f(ab\,|\,xy)$$



Article | Published: 17 August 2020

A strong no-go theorem on the Wigner's friend paradox

Kok-Wei Bong, Aníbal Utreras-Alarcón, Farzad Ghafari, Yeong-Cherng Liang, Nora Tischler, Eric G. Cavalcanti, Geoff J. Pryde & Howard M. Wiseman

Nature Physics **16**, 1199–1205 (2020) | Cite this article

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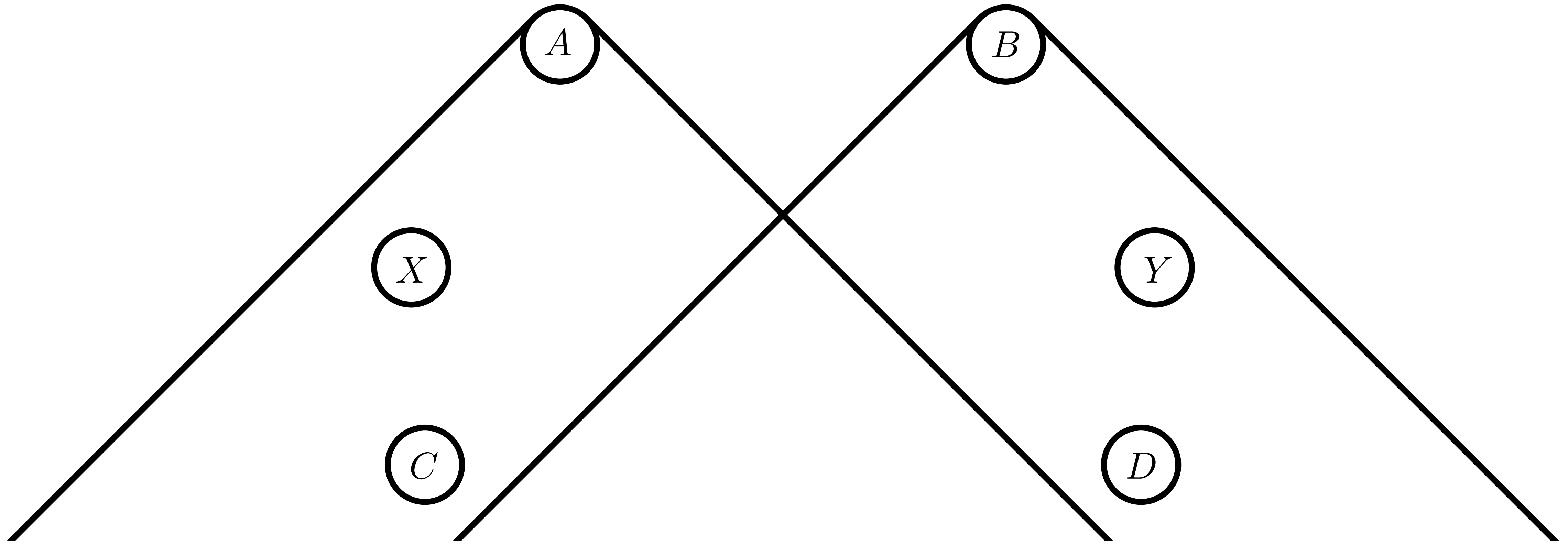

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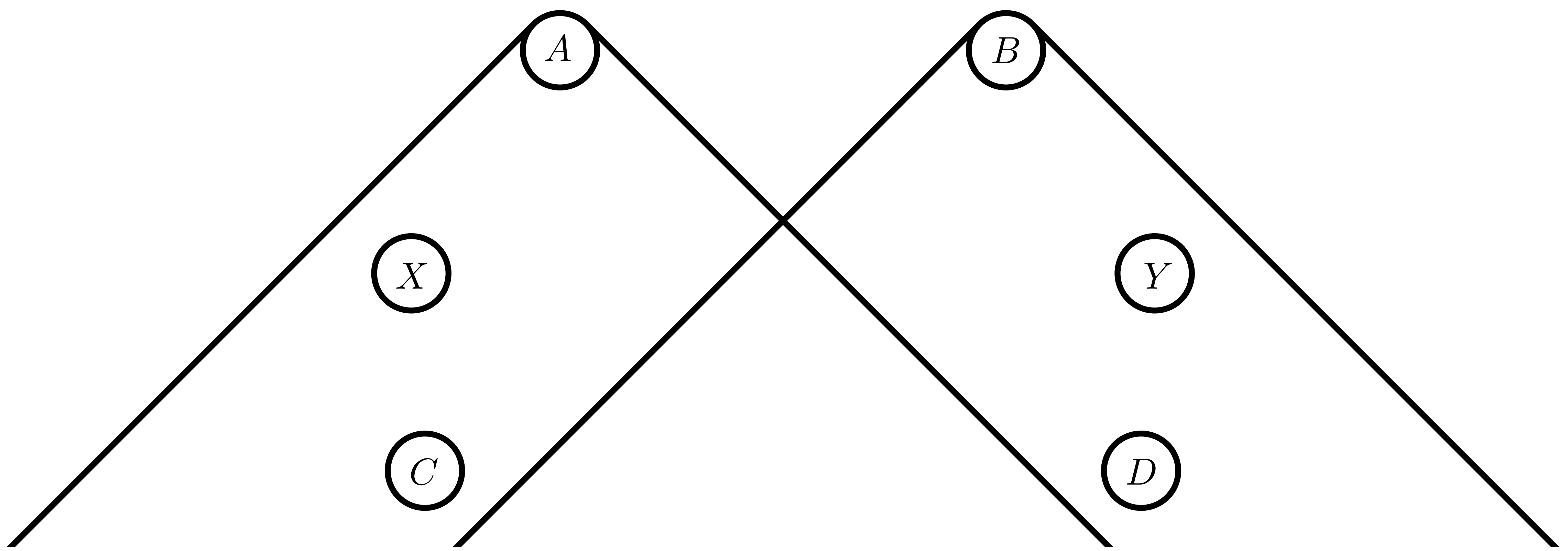

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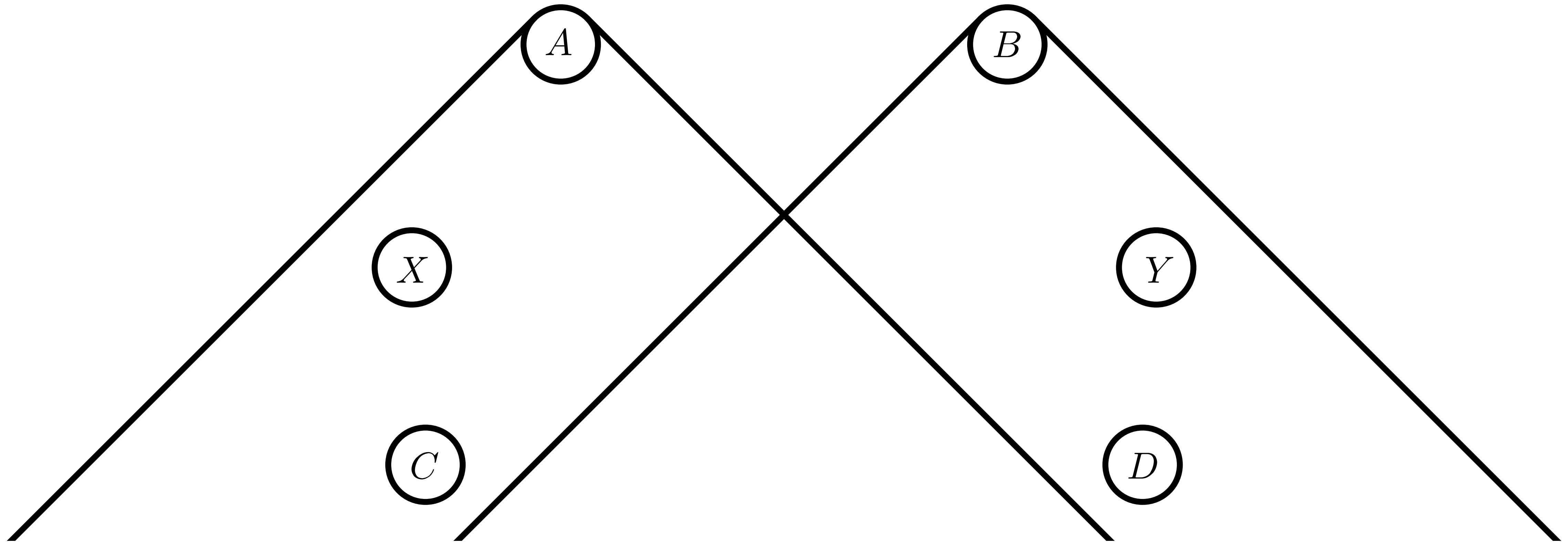

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Locality

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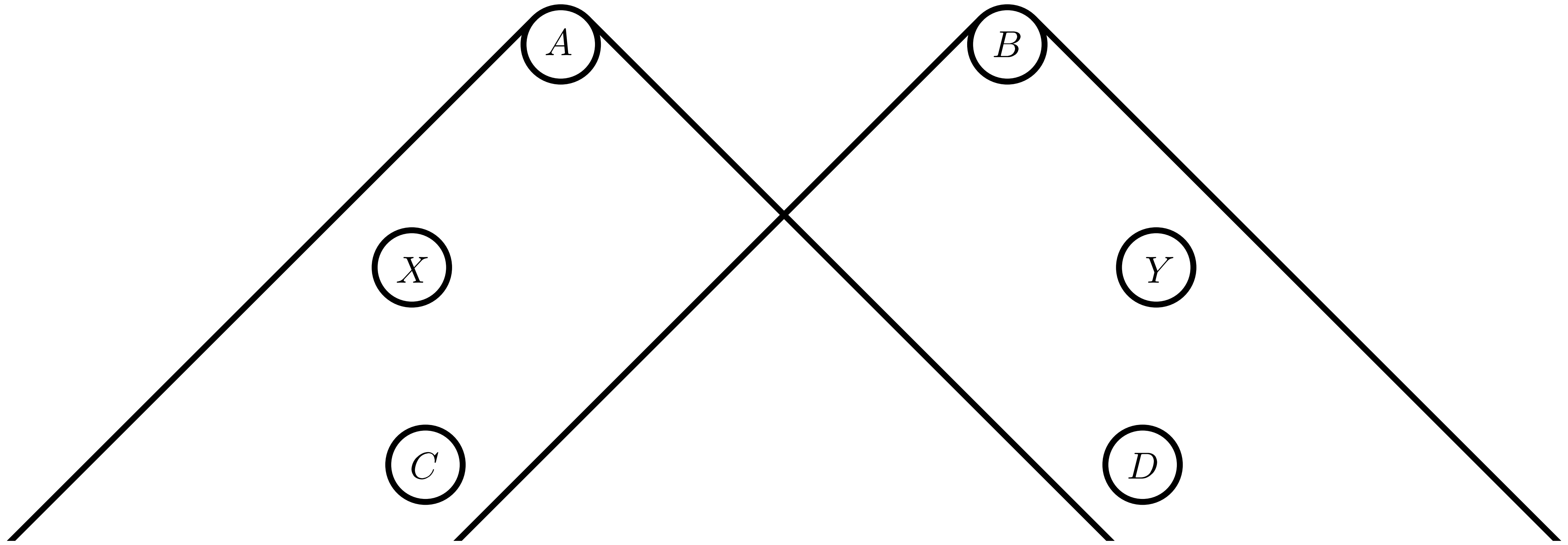

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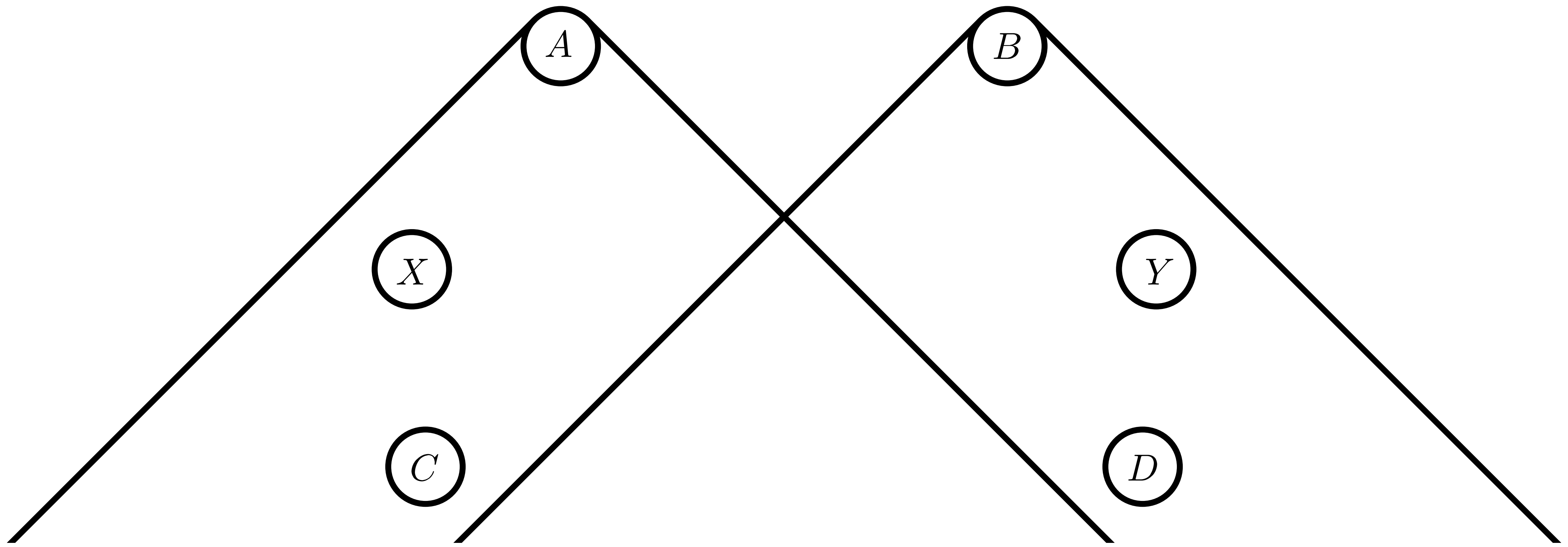

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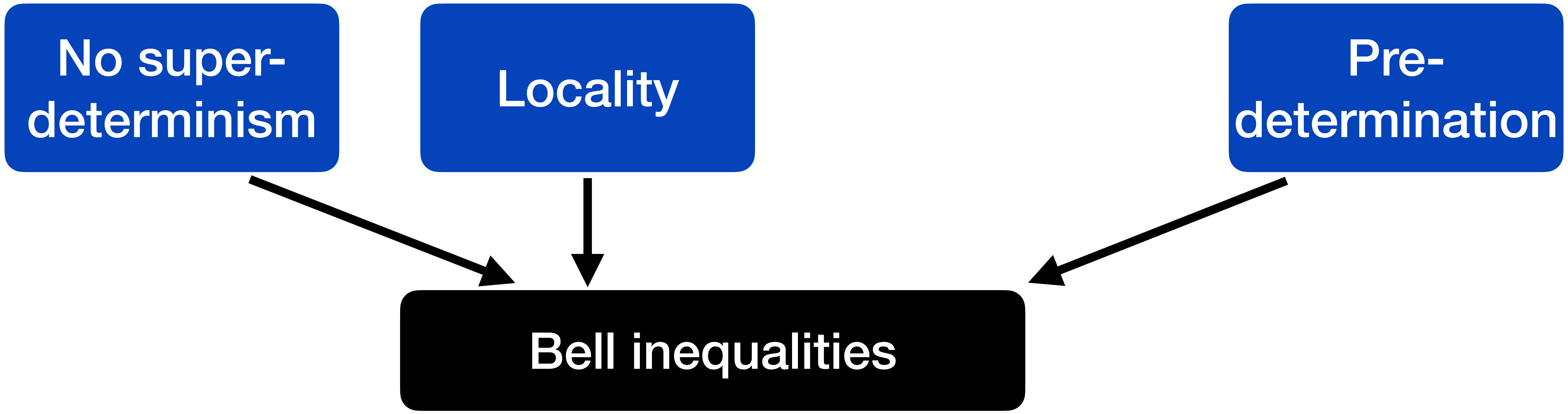
Locality

LF inequalities

Incompatible with QM!

Comparison with Bell

Bell 1964



Wiseman, Cavalcanti arXiv:1503.06413
Cavalcanti, Wiseman DOI:10/gm7w6p arXiv:2106.04065

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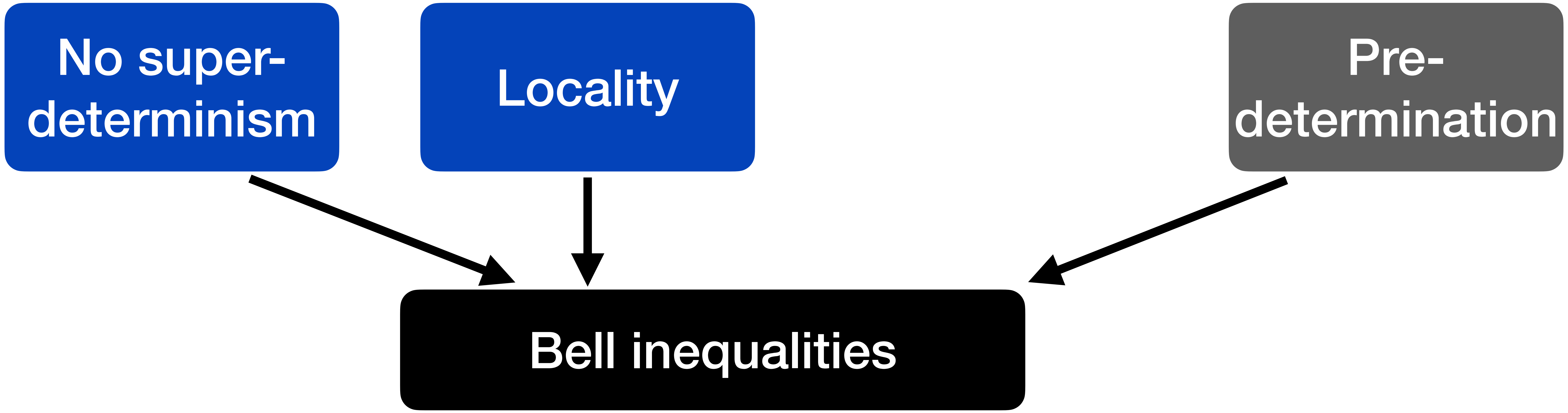

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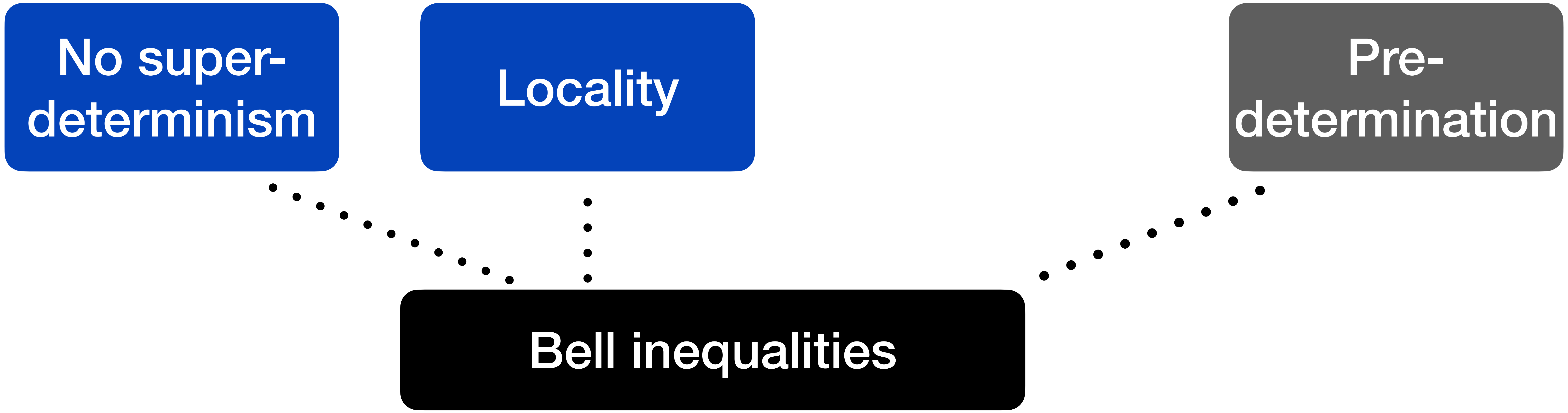

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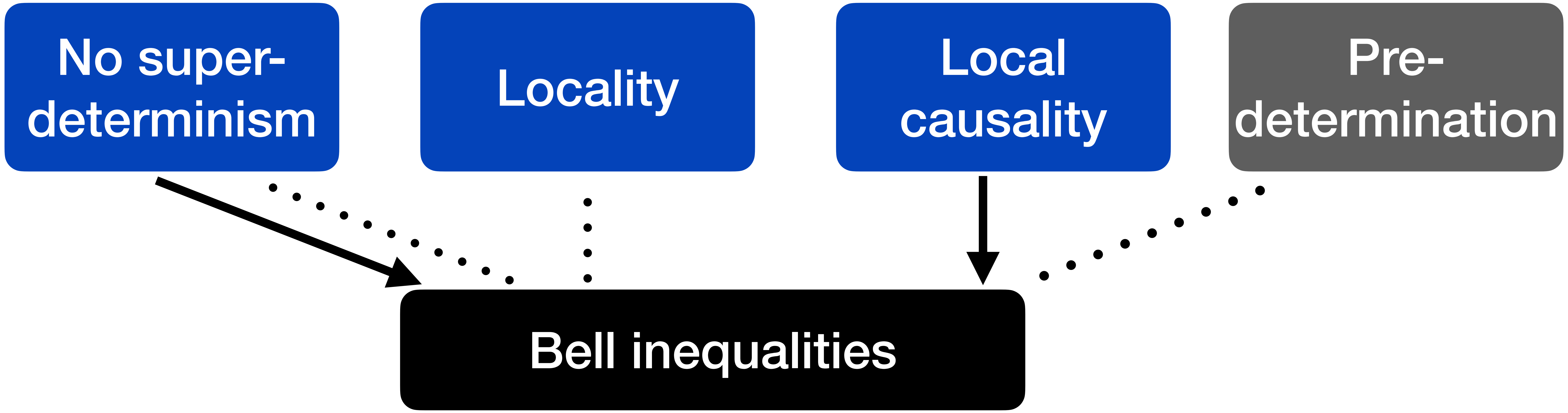

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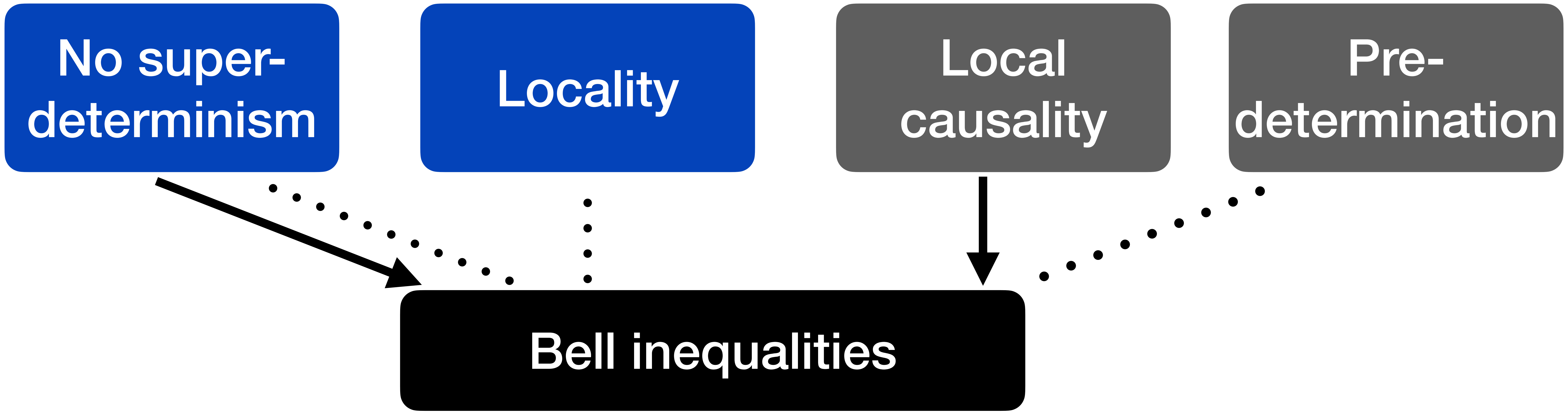

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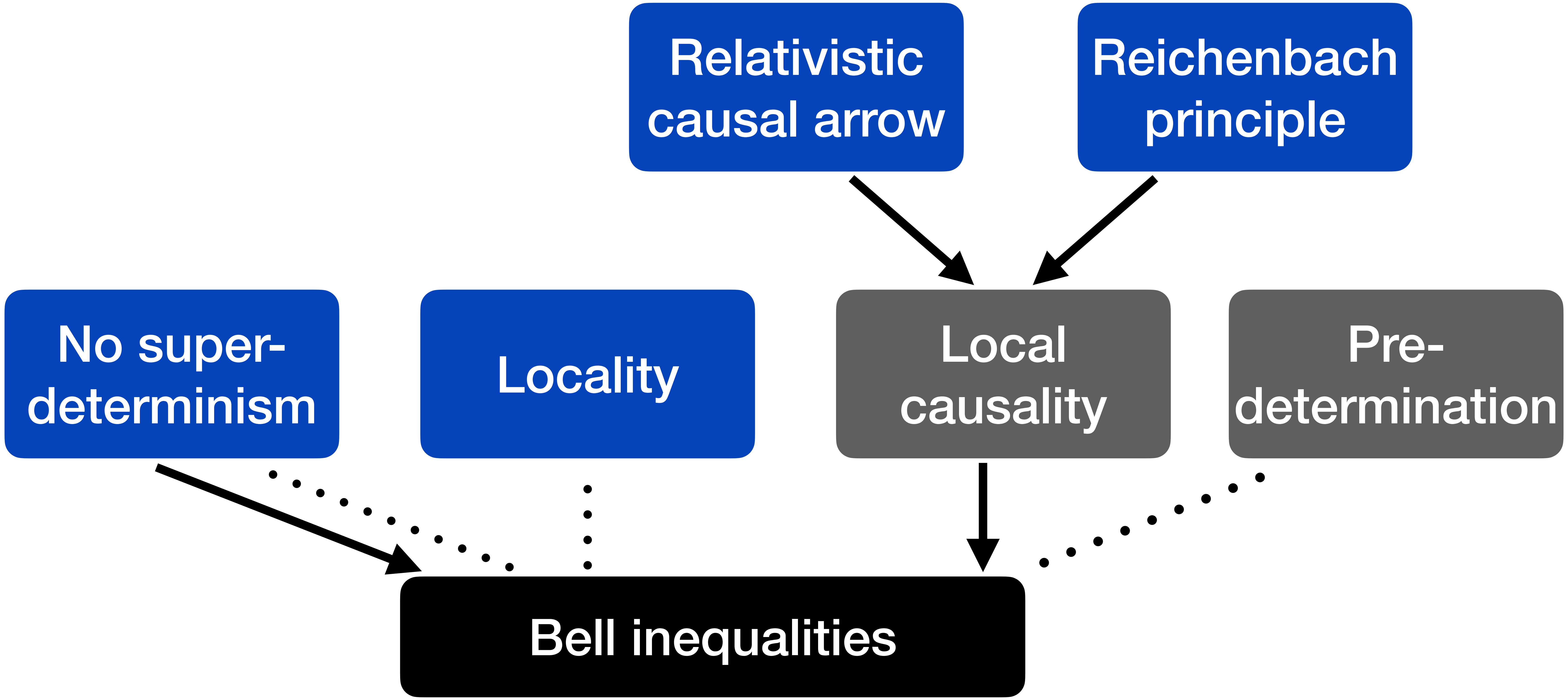

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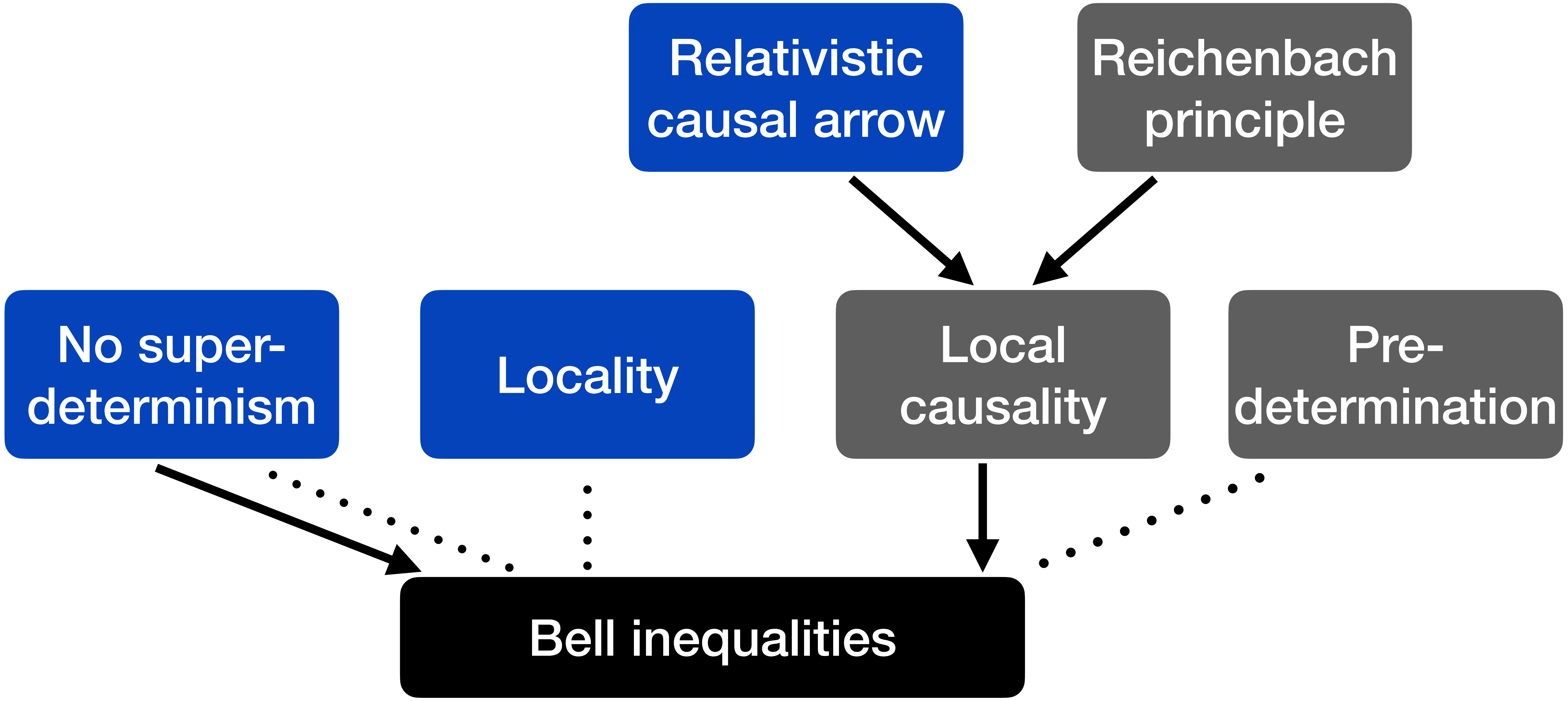

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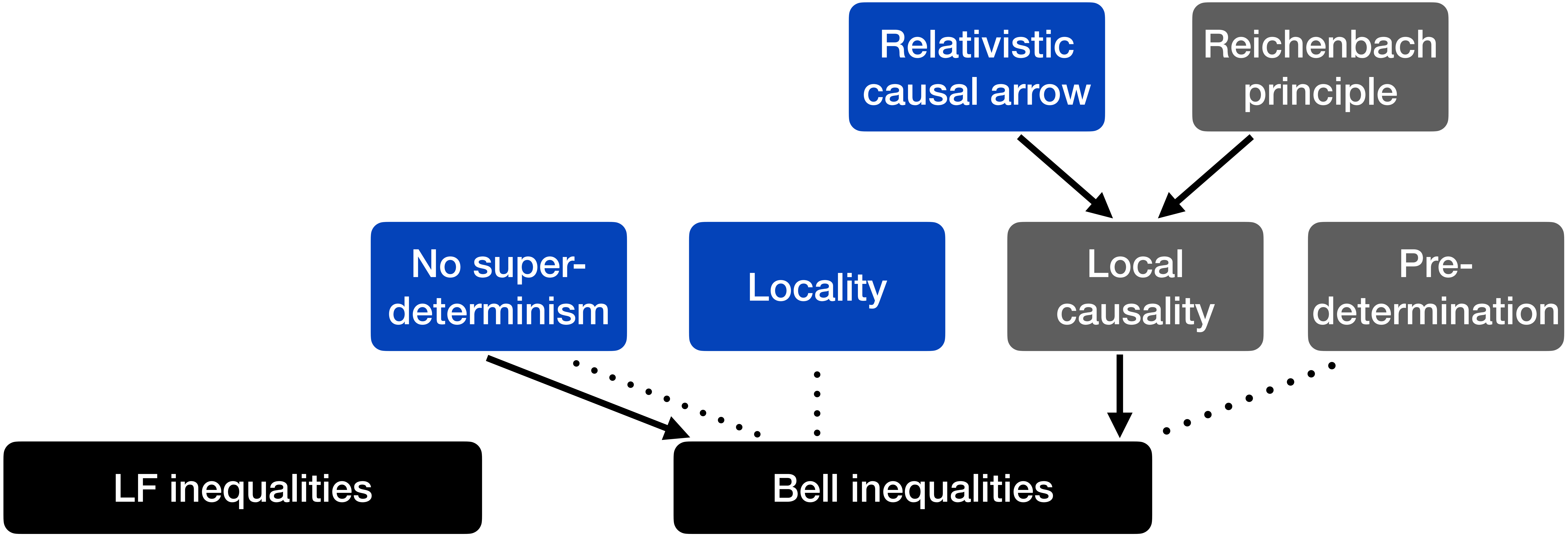

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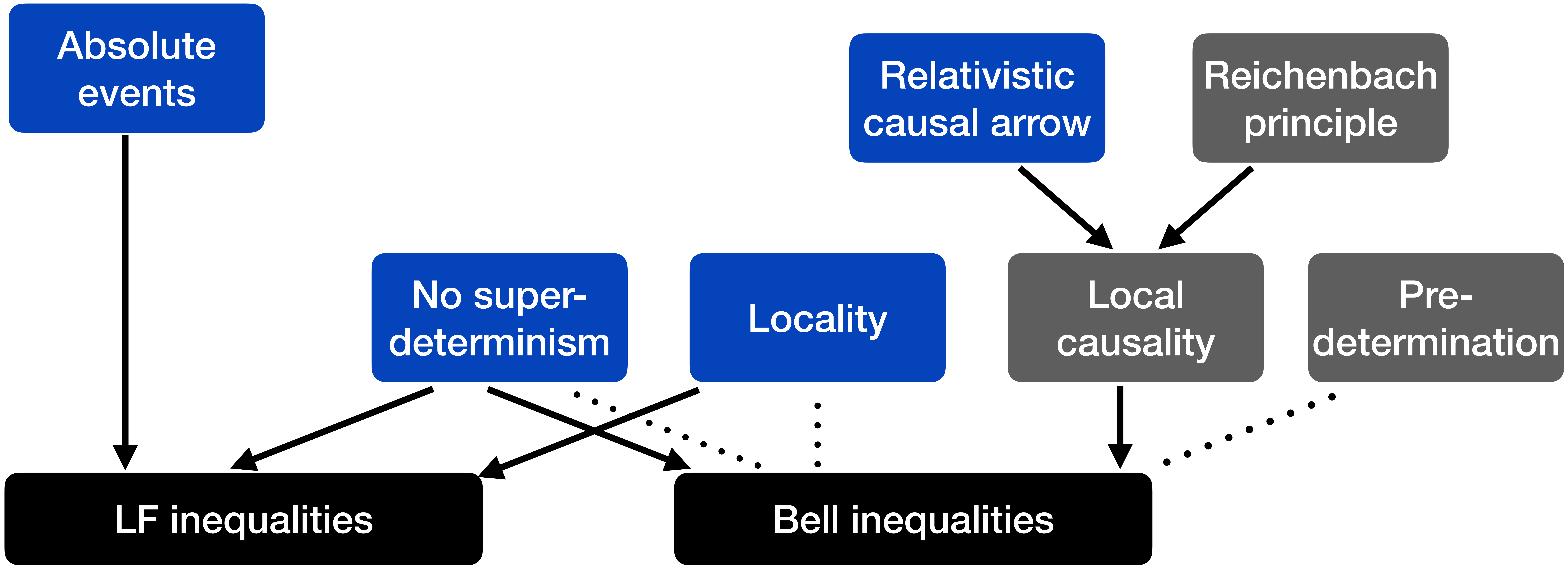

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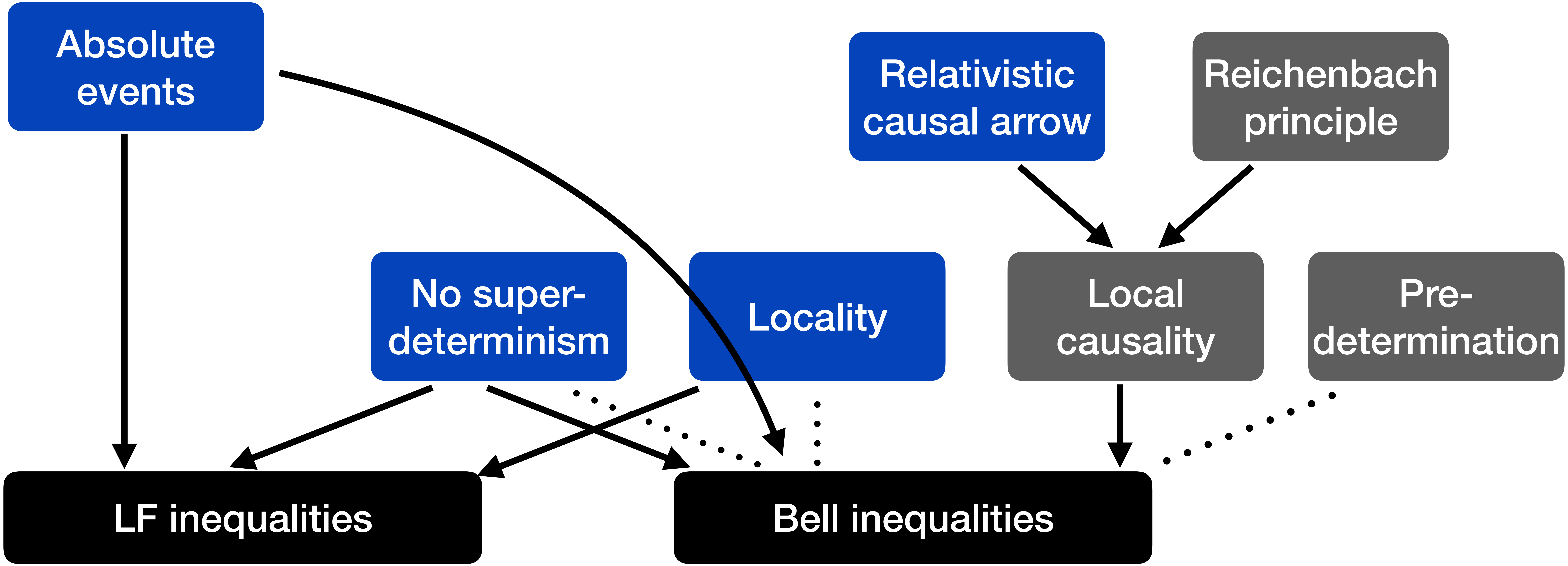

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Causal models

arXiv:2309.12987 (quant-ph)

[Submitted on 22 Sep 2023]

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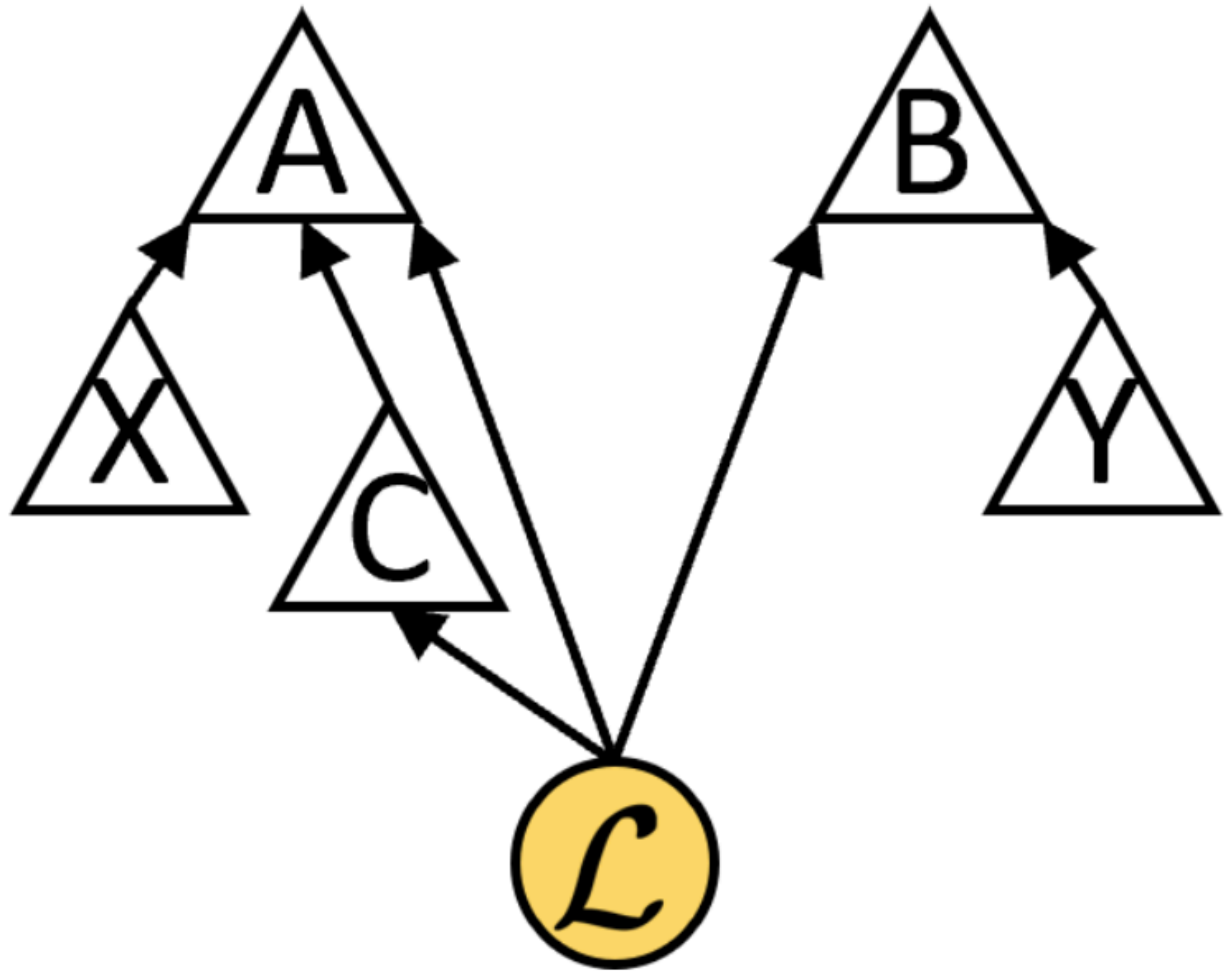

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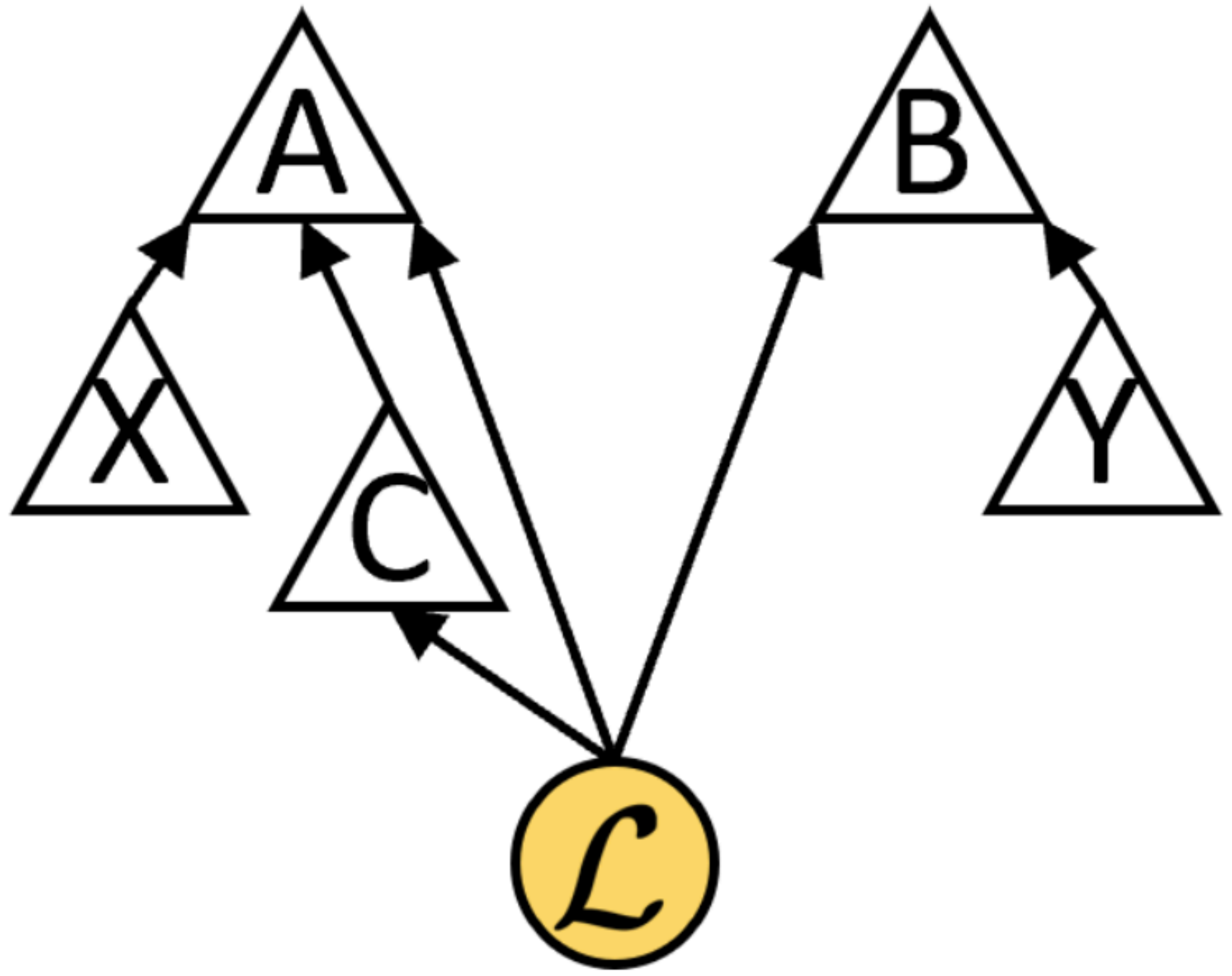

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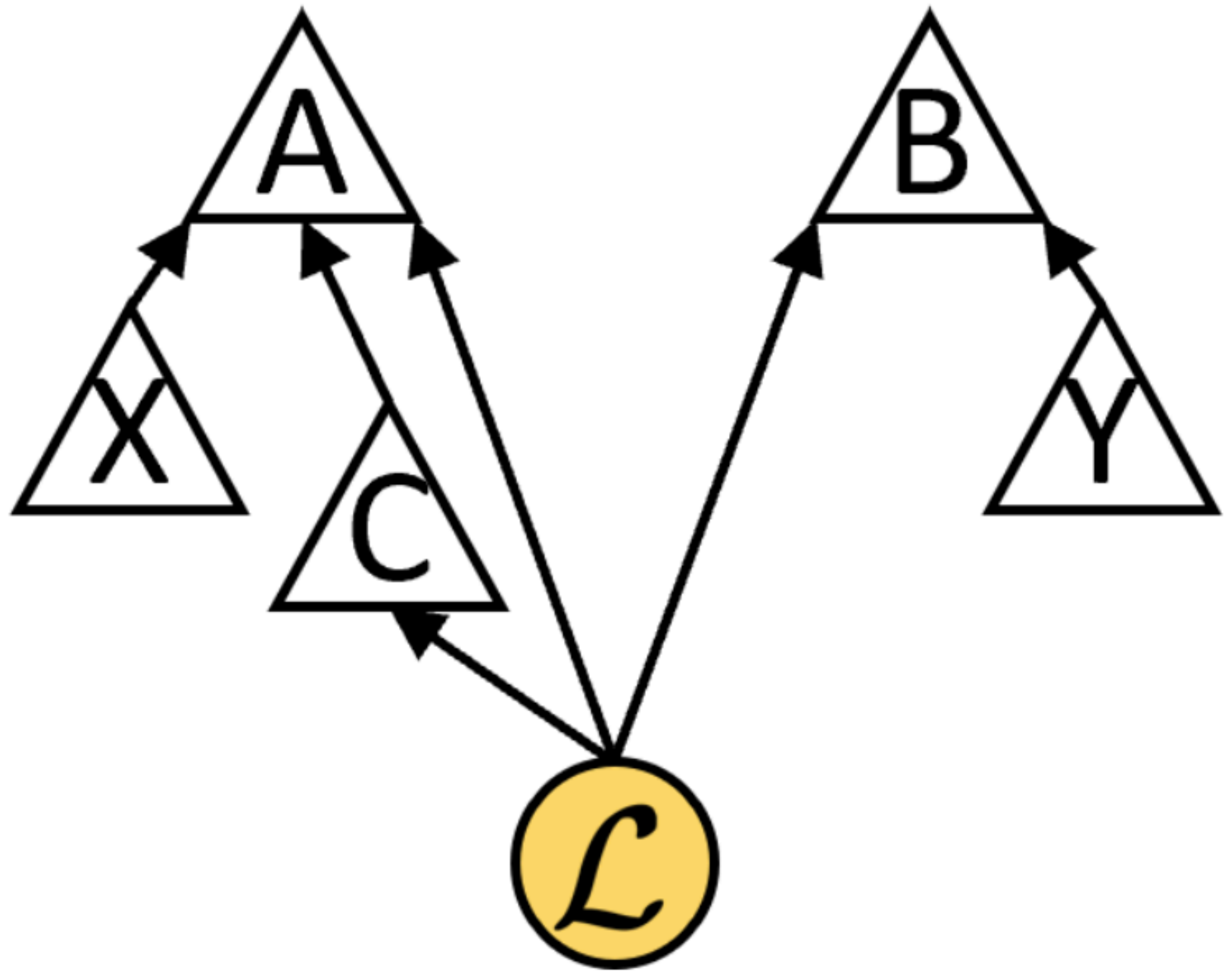

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Essentially the only DAG compatible with the assumptions in the LF no-go theorem.

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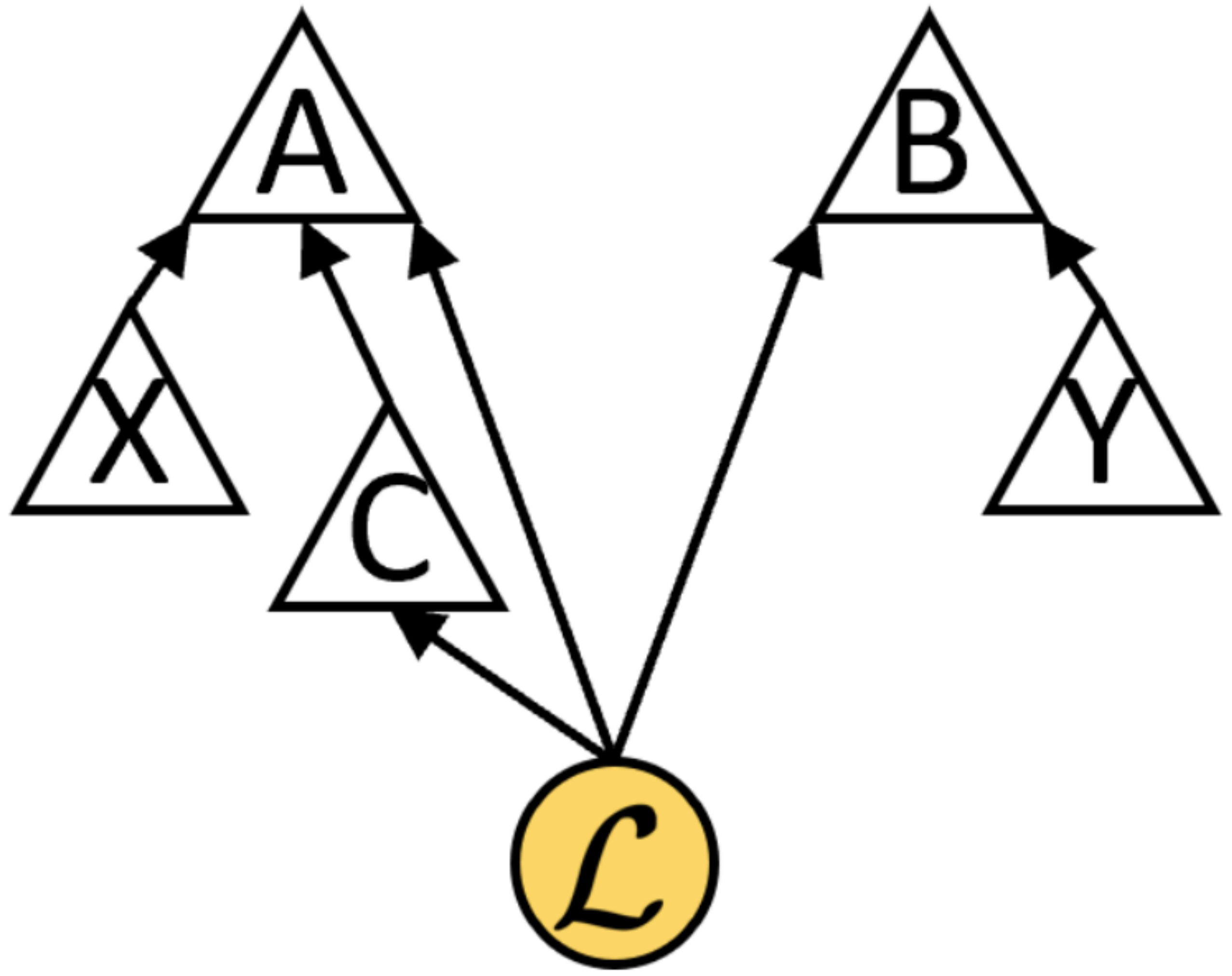

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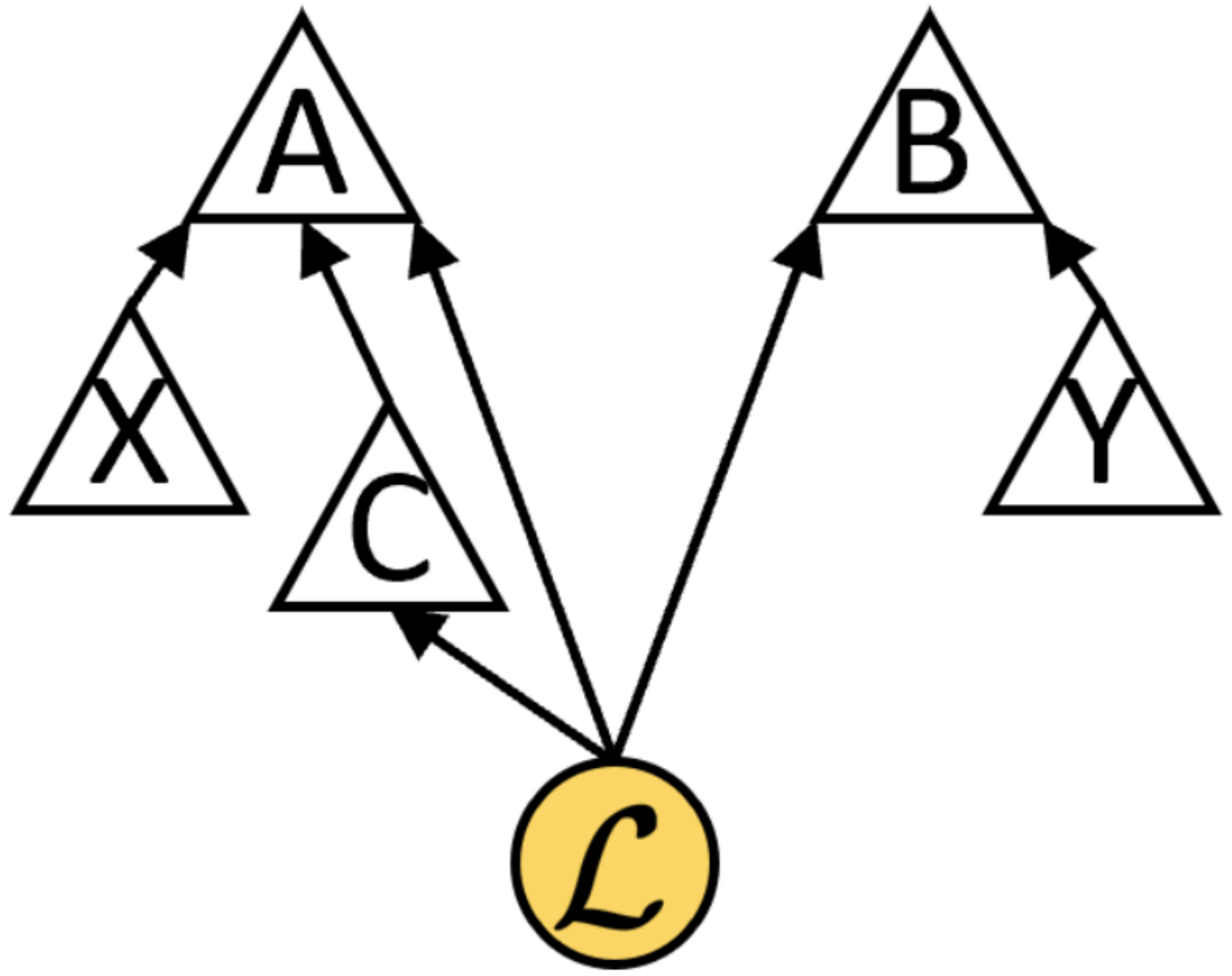

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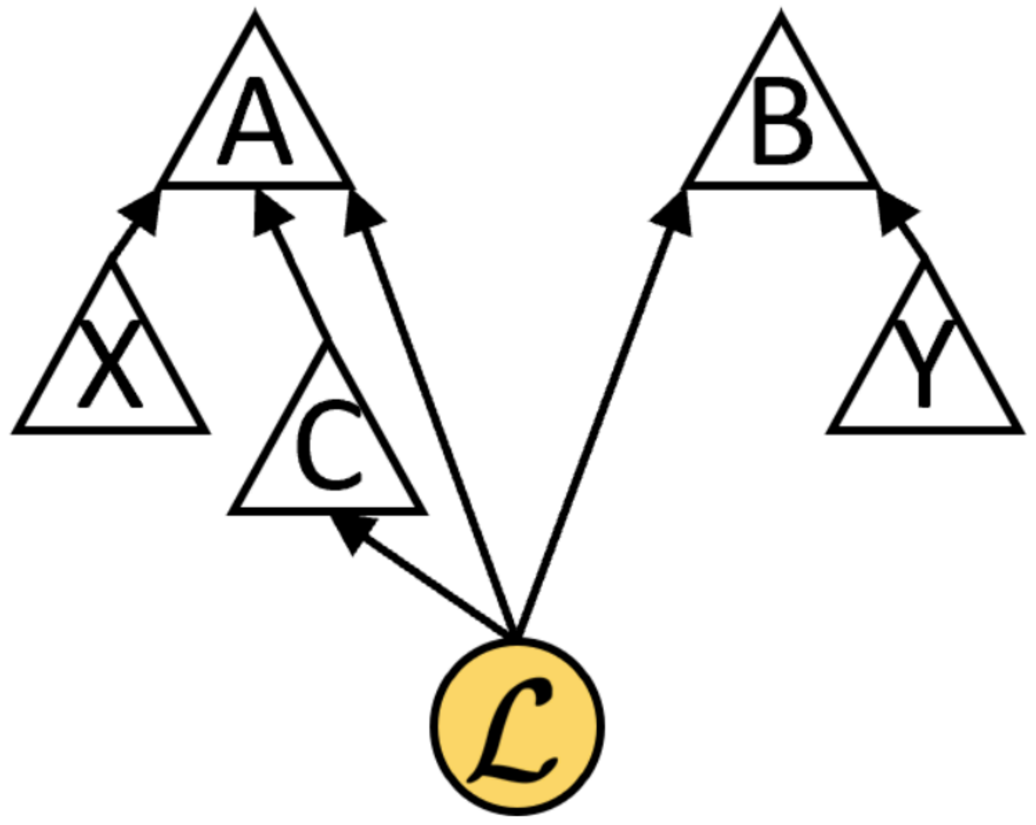
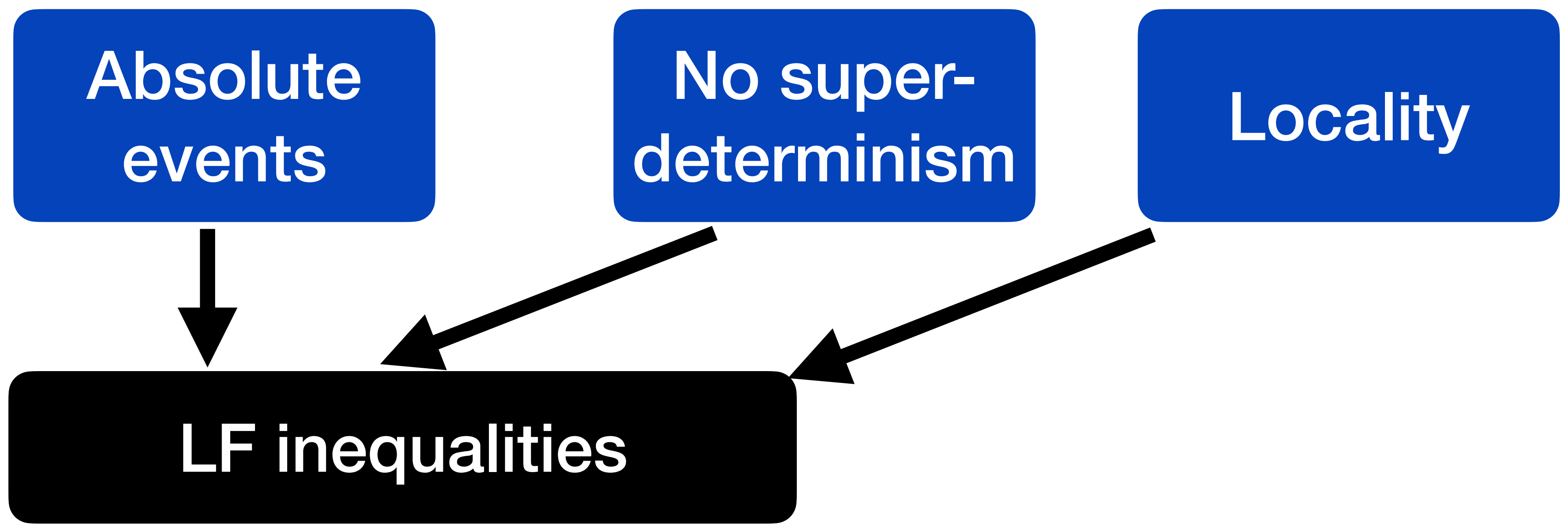
Essentially the only DAG compatible with the assumptions in the LF no-go theorem.

Every DAG that allows the violation of the LF inequalities is *fine-tuned* (even cyclic ones).

$\Longrightarrow$ (post-)GPT causal modelling *cannot explain* LF inequality violations.

How to cope





No-interpretation interpretation not good anymore

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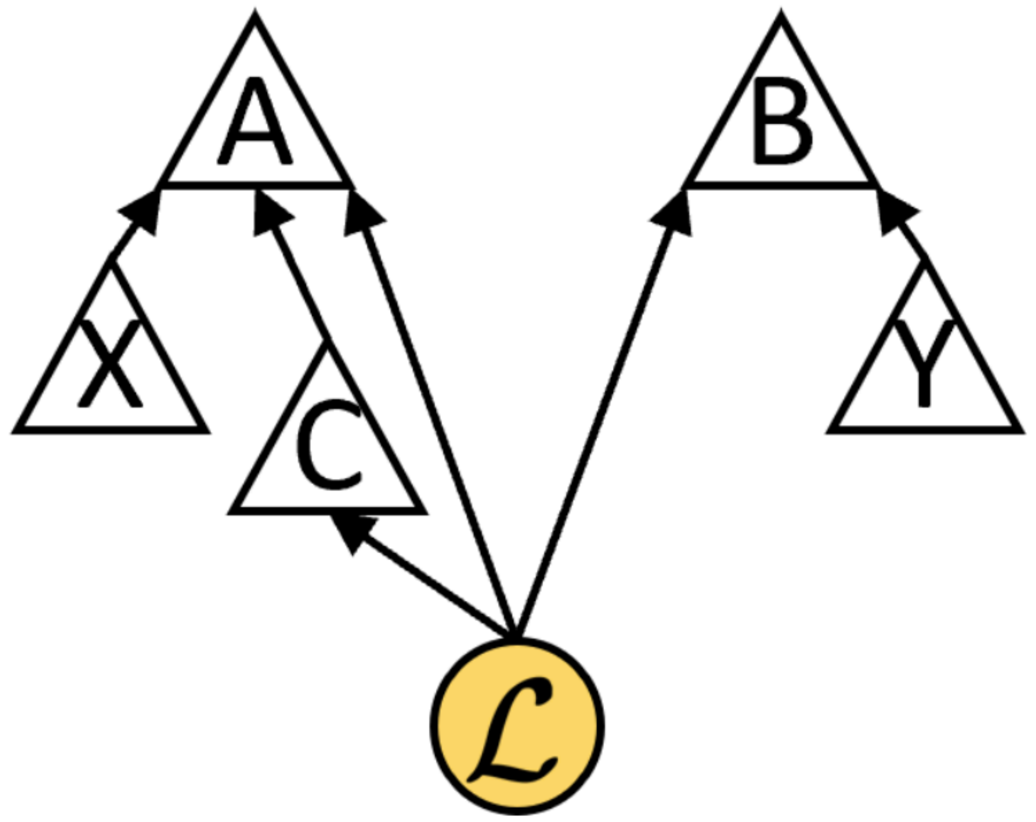

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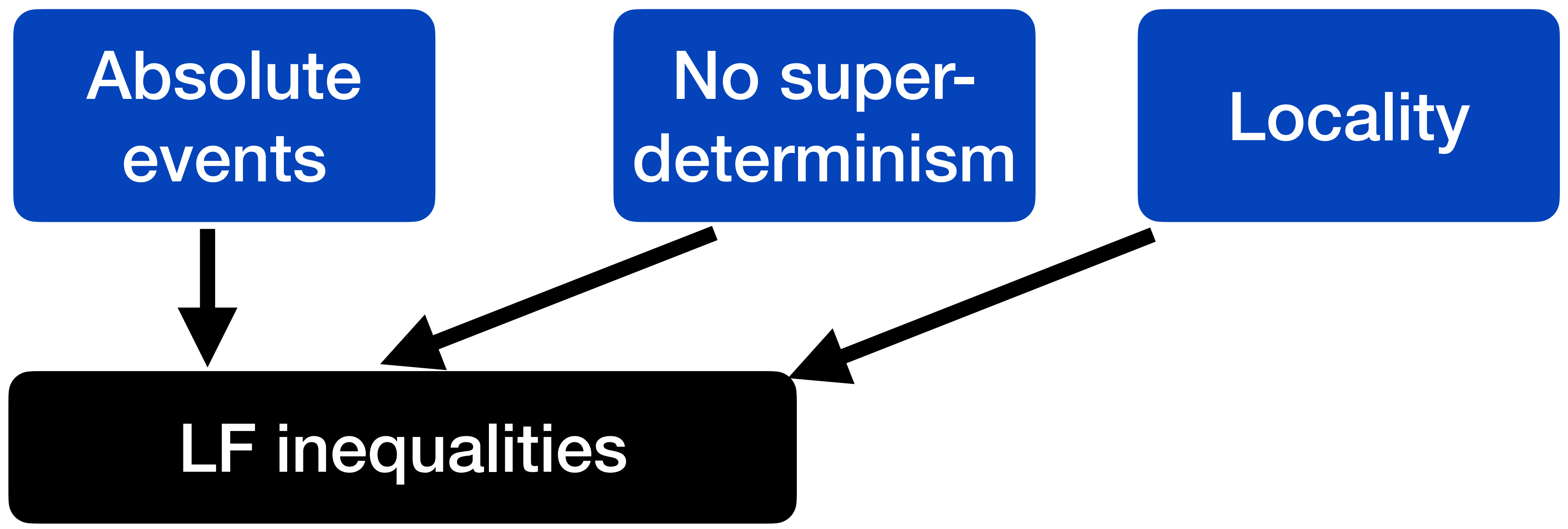
Modify QM: Spontaneous collapse, fundamental observers



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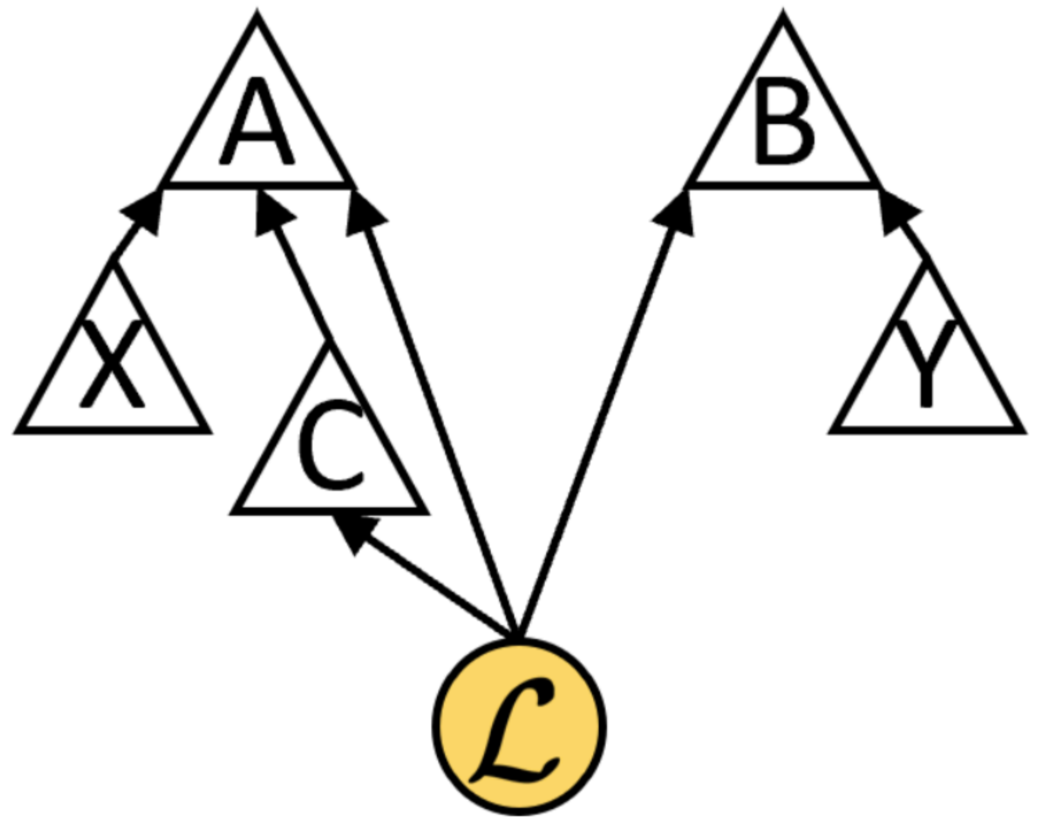

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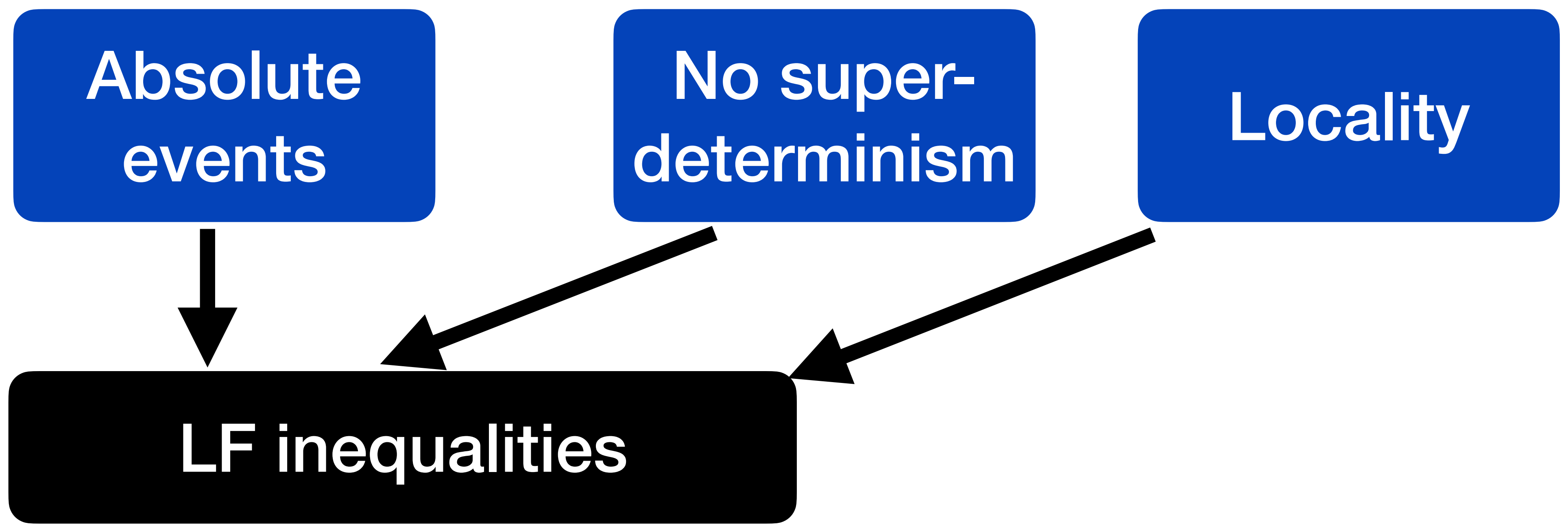
Bohmian mechanics solves this and Bell the same way



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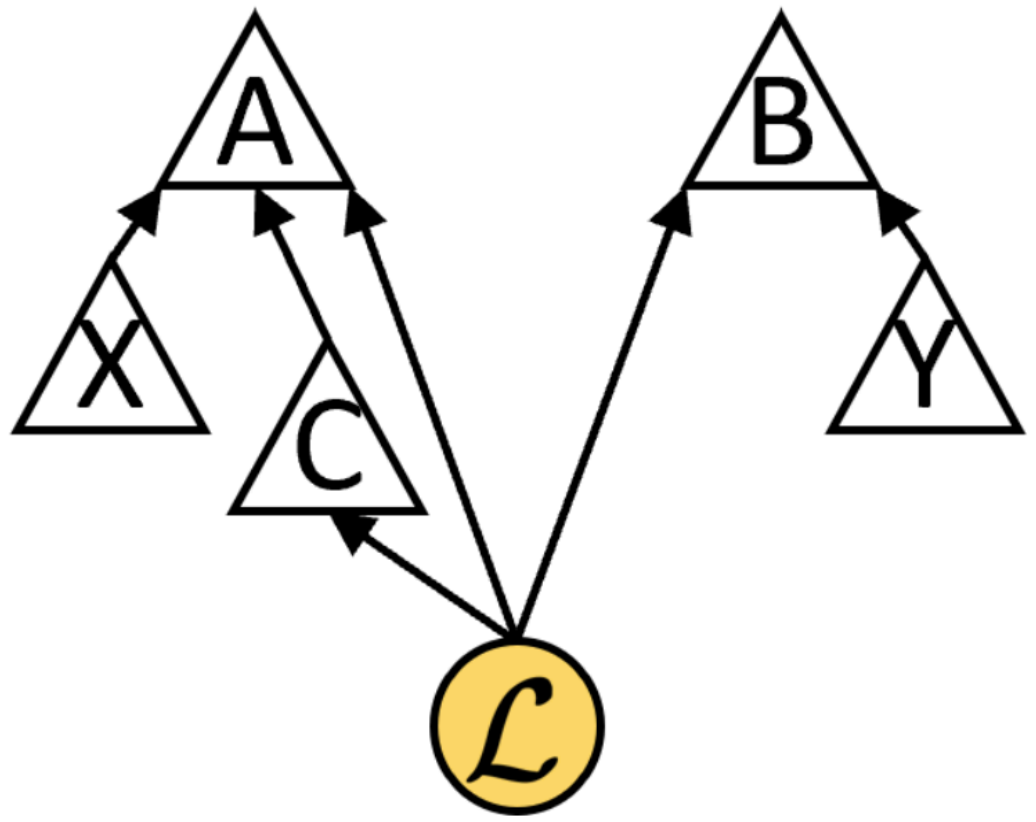

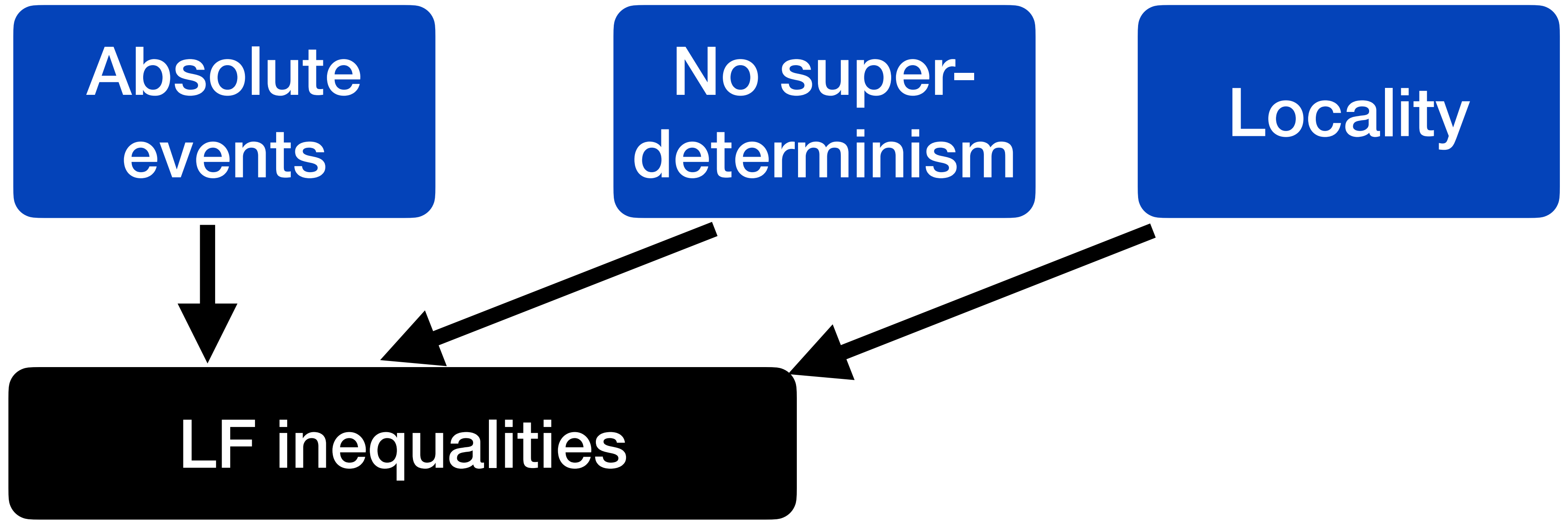

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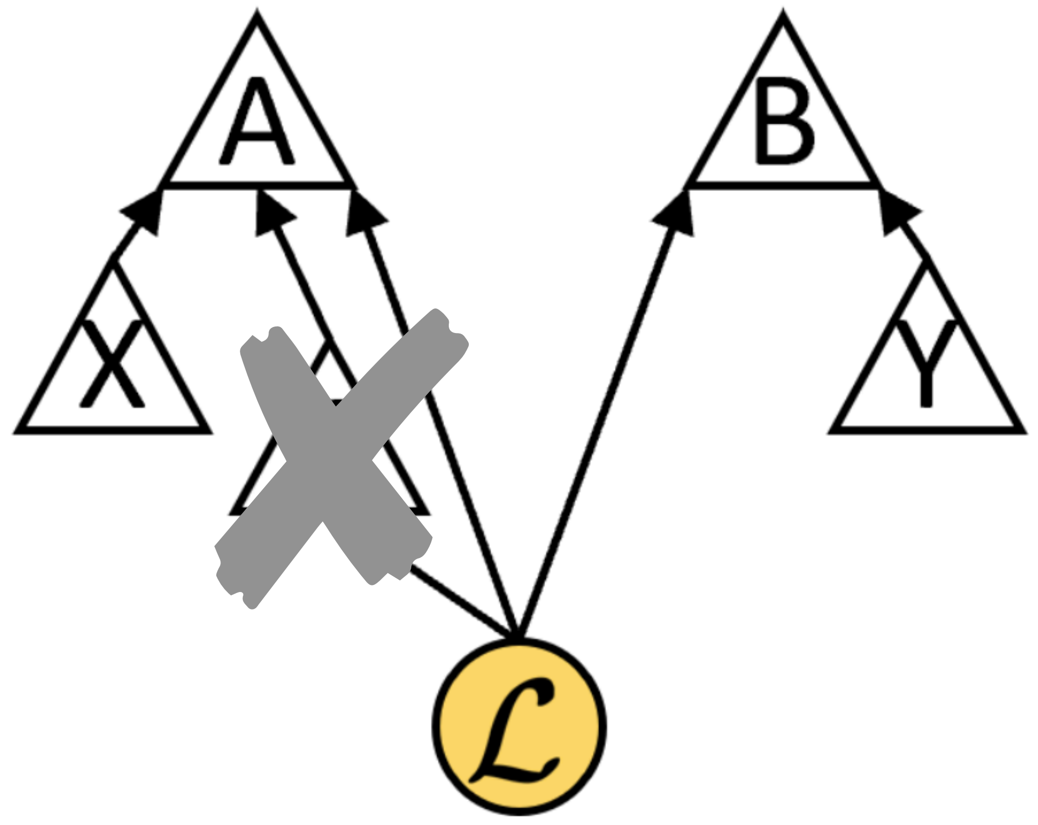

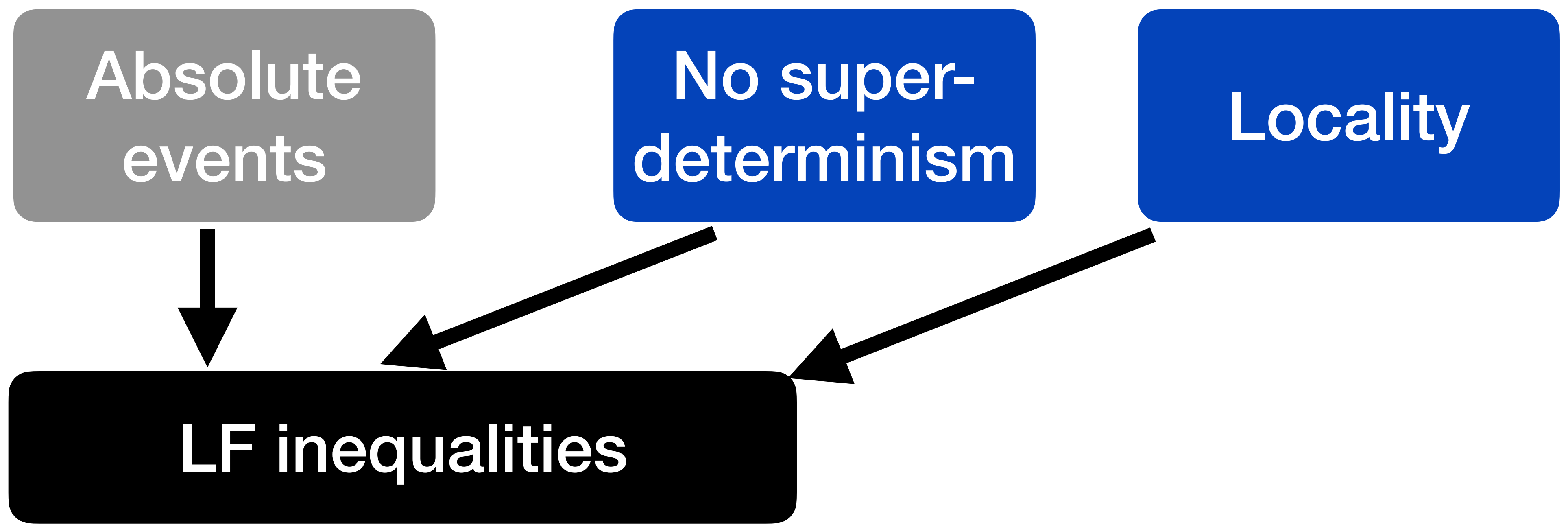

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Embrace relative facts!

Experimental realisations?

Relative Facts

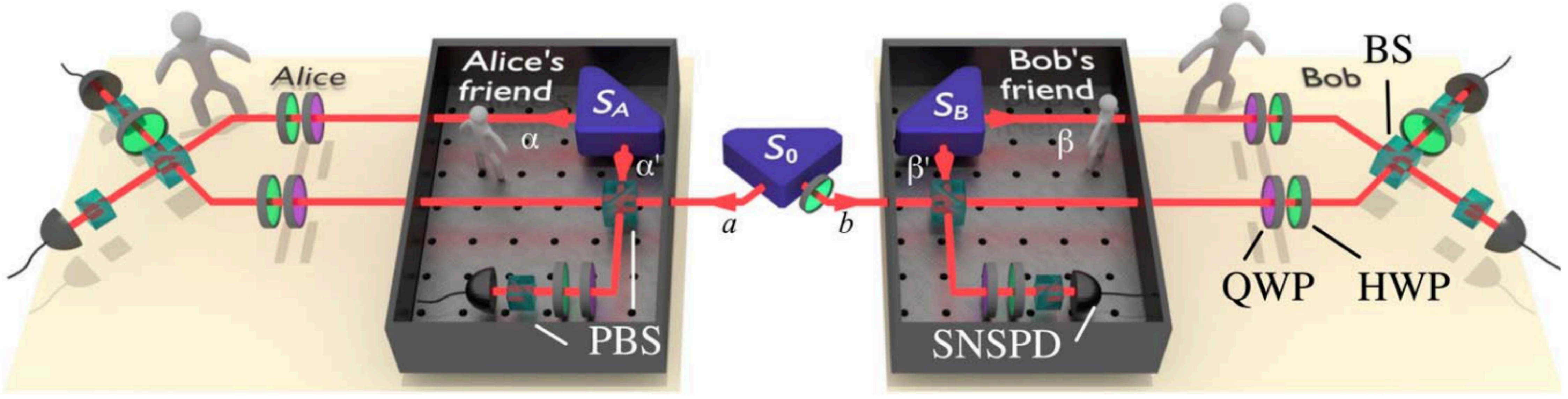
Experimental realisations?

SCIENCE ADVANCES | RESEARCH ARTICLE

PHYSICS

Experimental test of local observer independence

Massimiliano Proietti[1], Alexander Pickston[1], Francesco Graffitti[1], Peter Barrow[1], Dmytro Kundys[1], Cyril Branciard[2], Martin Ringbauer[1,3], Alessandro Fedrizzi[1]*



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ARTICLES

https://doi.org/10.1038/s41567-020-0990-x

Check for updates

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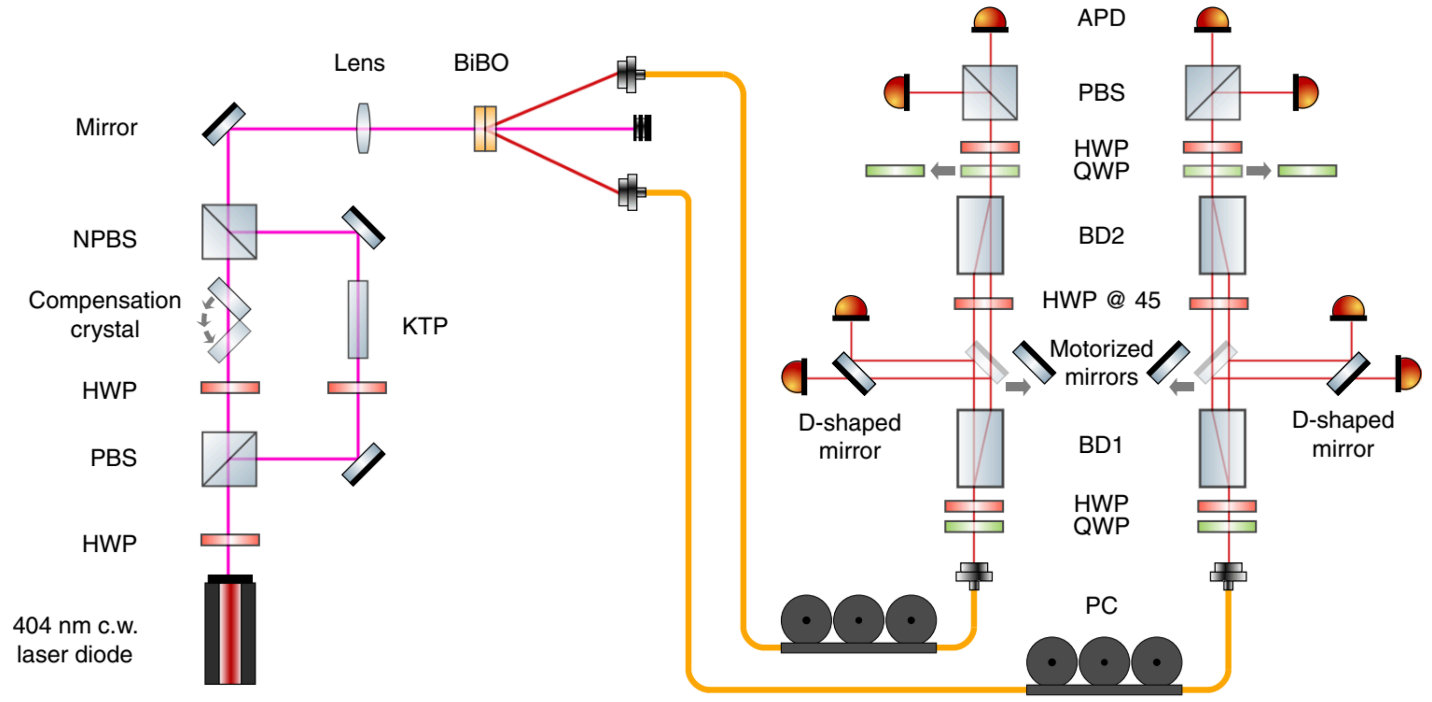

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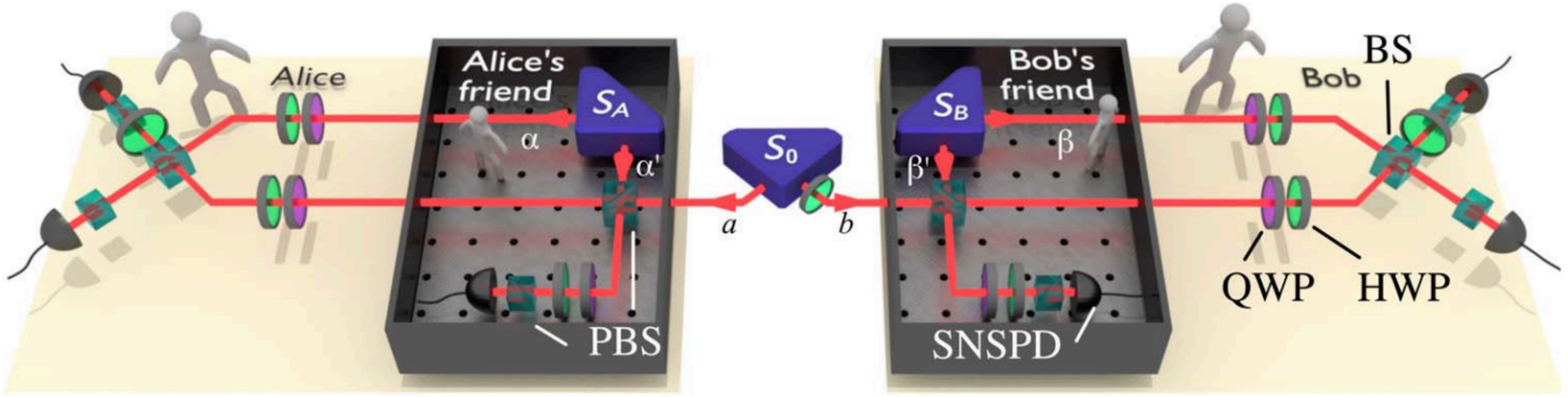

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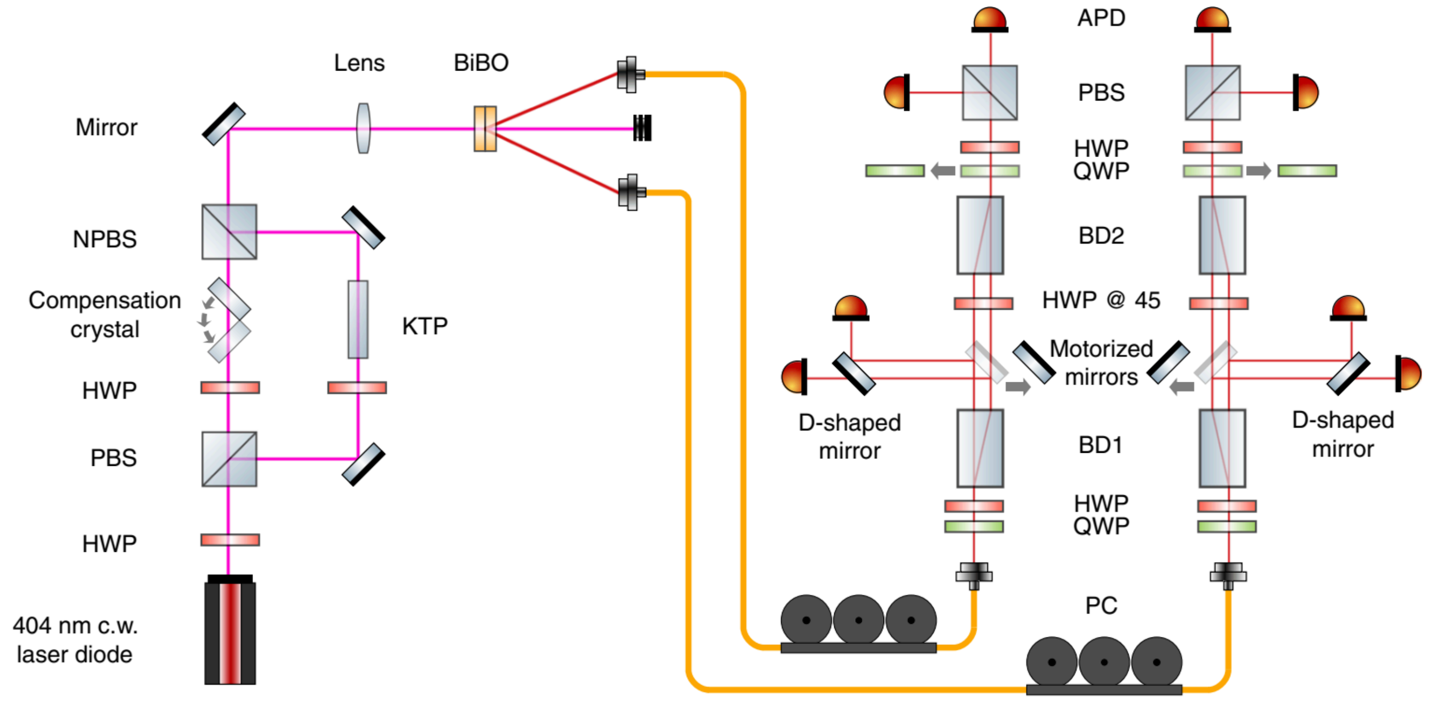

but... are photons friends?

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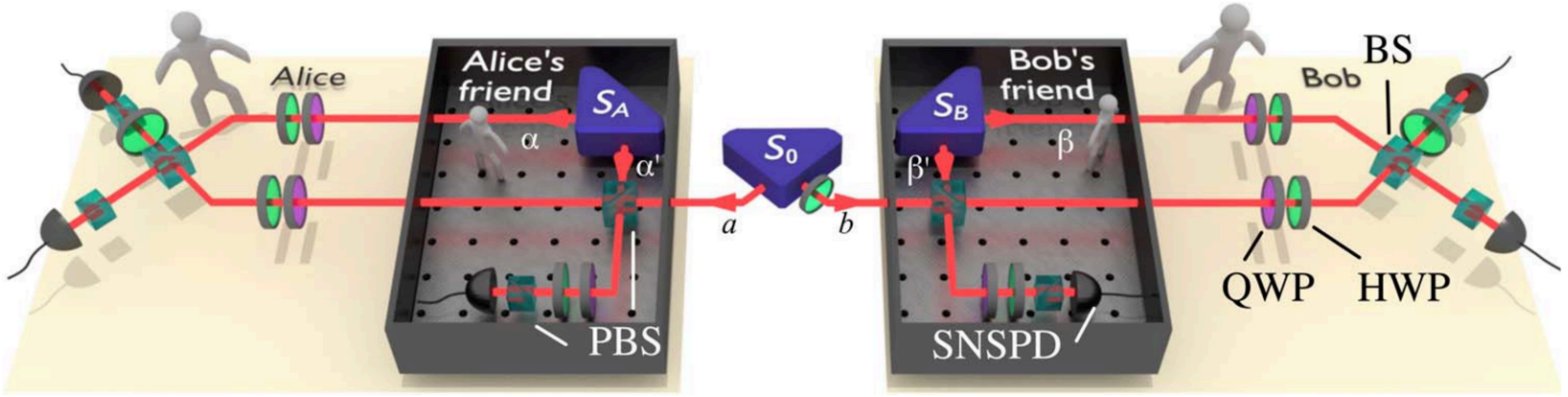
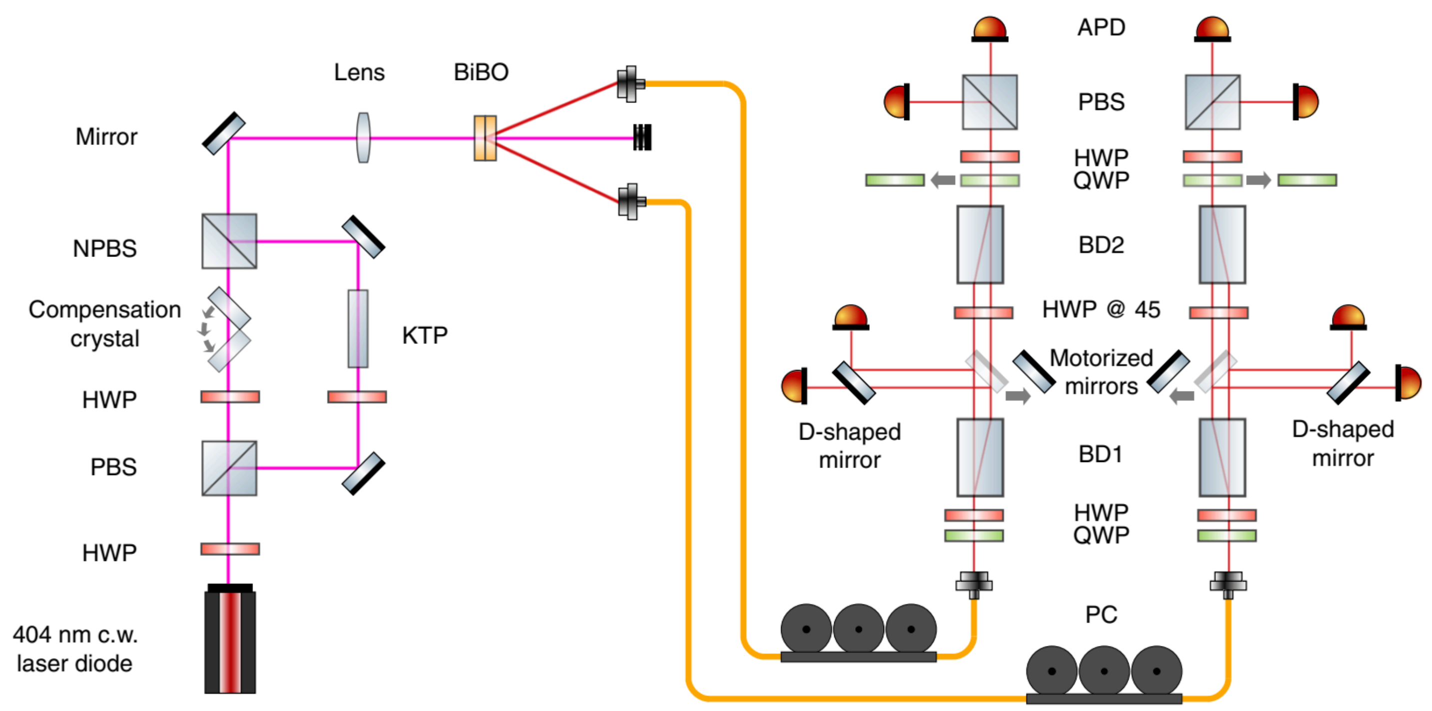
https://doi.org/10.1038/s41567-020-0990-x
Check for updates

A strong no-go theorem on the Wigner's friend paradox

Kok-Wei Bong[1,4], Aníbal Utreras-Alarcón[1,4], Farzad Ghafari[1], Yeong-Cherng Liang[2], Nora Tischler[1]✉, Eric G. Cavalcanti[3]✉, Geoff J. Pryde[1] and Howard M. Wiseman[1]





but... are photons friends?

yes for RQM!
what is a better friend?

Relative Facts

Other theorems

arXiv:2205.12223 (quant-ph)

[Submitted on 24 May 2022 (v1), last revised 15 Jul 2022 (this version, v2)]

A possibilistic no-go theorem on the Wigner's friend paradox

Marwan Haddara, Eric G. Cavalcanti

Implications of Local Friendliness Violation for Quantum Causality

by Eric G. Cavalcanti [1,*] and Howard M. Wiseman [2]

Entropy **2021**, *23*(8), 925; https://doi.org/10.3390/e23080925

Received: 4 June 2021 / Revised: 1 July 2021 / Accepted: 2 July 2021 / Published: 21 July 2021

A "thoughtful" Local Friendliness no-go theorem: a prospective experiment with new assumptions to suit

Howard M. Wiseman[1,2], Eric G. Cavalcanti[3], and Eleanor G. Rieffel[4]

Published:	2023-09-14, volume 7, page 1112
Eprint:	arXiv:2209.08491v4
Doi:	https://doi.org/10.22331/q-2023-09-14-1112
Citation:	Quantum 7, 1112 (2023).

arXiv:1811.02442 (quant-ph)

[Submitted on 6 Nov 2018 (v1), last revised 7 Nov 2018 (this version, v2)]

When Greenberger, Horne and Zeilinger meet Wigner's Friend

Gijs Leegwater

arXiv:2308.16220 (quant-ph)

[Submitted on 30 Aug 2023]

A review and analysis of six extended Wigner's friend arguments

David Schmid, Yìlè Yīng, Matthew Leifer

Relational Quantum Mechanics

Motivations

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- **No need to modify QM:** unitary evolution and Born rule are *both* correct

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- **No inaccessible realities:** no hidden variables, or parallel worlds
- **Relativity and time-symmetry:** wavefunction only used for inference

Origins

Relational quantum mechanics

Carlo Rovelli

International Journal of Theoretical Physics **35**, 1637–1678 (1996)

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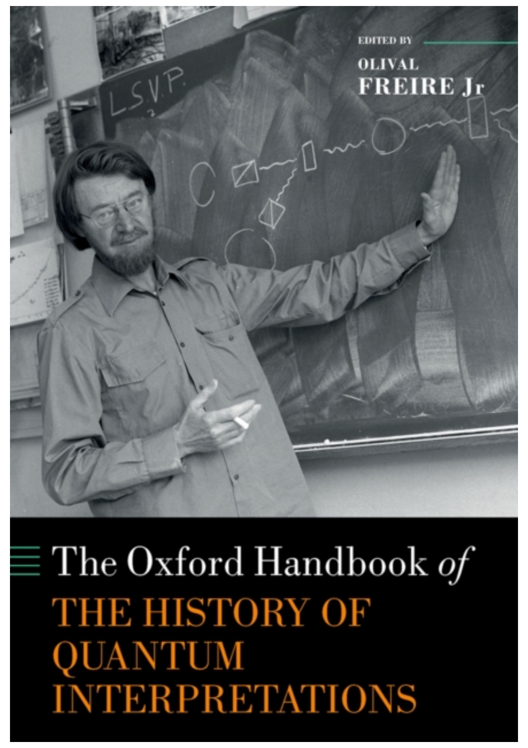
incorrect notion: “observer-independent values of physical quantities.”

Relational Quantum Mechanics

New formulations



CHAPTER

43 The Relational Interpretation

Carlo Rovelli

https://doi.org/10.1093/oxfordhb/9780198844495.013.0044
Published: 19 May 2022

Foundations of Physics (2022) 52:62
https://doi.org/10.1007/s10701-022-00579-5

Relational Quantum Mechanics is About Facts, Not States: A Reply to Pienaar and Brukner

Andrea Di Biagio[1] · Carlo Rovelli[2,3,4]

arXiv:2203.13342 (quant-ph)

[Submitted on 24 Mar 2022 (v1), last revised 14 Apr 2022 (this version, v2)]

Information is Physical: Cross-Perspective Links in Relational Quantum Mechanics

Emily Adlam, Carlo Rovelli

Relative facts

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Key Claims

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6. "Shared" facts

Relative facts

$$P(a) = \sum_i P(a \mid b_i) P(b_i)$$

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$$P\left(a^{(W)}\right) = \sum_i P(a\,|\,b_i)P\left(b_i^{(W)}\right)$$

$$P(a\,|\,b_i) = |\langle a\,|\,b_i\rangle|^2$$

Relative facts

$$P\left(a^{(W)}\right) \neq \sum_{i} P(a \mid b_i) P\left(b_i^{(F)}\right)$$

Interference effects are a sign of the relativity of facts

Stable facts

$$|\psi\rangle = \sum_i \alpha_i |i\rangle_S \otimes |F_i\rangle_F \otimes |\psi_i\rangle_E$$

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$$\longrightarrow \rho = \mathrm{tr}_E |\psi\rangle\langle\psi| = \sum_i |\alpha_i|^2 |i\, F_i\rangle\langle i\, F_i| + O(\epsilon)$$

$$\epsilon = \max_{i \neq j} |\langle\psi_i|\psi_j\rangle|^2$$

Stable facts

$$\rho \approx \sum_i |\alpha_i|^2 \, | i \, F_i \rangle\langle i \, F_i |$$

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$$P\left(a^{(W)}\right) \approx \sum_i P(a\,|\,b_i)P\left(b_i^{(F)}\right)$$

$$P(b_i^{(F)}) := |\alpha_i|^2$$

Sharing facts?

Do we see the same facts?

$$\sum_i |\alpha_i|^2 | i F_i \rangle\langle i F_i |$$

Sharing facts?

Do we see the same facts?

If Friend measures a system S and Wigner measures the system on the same basis, do they see the same outcome?

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Sharing facts?

Do we see the same facts?

If Friend measures a system S and Wigner measures the system on the same basis, do they see the same outcome?

QM predicts that the outcome of Wigner's measurement is compatible with what he sees that Friend saw.

$$\sum_i |\alpha_i|^2 |i\, F_i\rangle\langle i\, F_i| \longrightarrow |2\rangle |F_2\rangle$$

Sharing facts?

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Relational Quantum Mechanics is About Facts, Not States: A Reply to Pienaar and Brukner

Andrea Di Biagio[1] · Carlo Rovelli[2,3,4]

nothing more to say:

describe physics from one perspective only

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cross-perspective link:

measuring "reveals" the value of the relative fact

Emergence of objectivity

Decoherence makes it *look as if* we share facts.

Decoherence is never complete.

Decoherence is *relational*: it depends on the couplings.

Systems can be in different *stability classes*.

Relational Quantum Mechanics

Facts, not states

Published: 04 October 2021

A Quintet of Quandaries: Five No-Go Theorems for Relational Quantum Mechanics

Jacques Pienaar

Foundations of Physics **51**, Article number: 97 (2021) | Cite this article

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Not necessarily.

When F is macroscopic, we know what variable has been measured, but when F is microscopic, how do we decide?

Relational Quantum Mechanics

Consistency of relative facts

Relative Facts of Relational Quantum Mechanics are Incompatible with Quantum Mechanics

Jay Lawrence[1], Marcin Markiewicz[2], and Marek Żukowski[2]

Doi: https://doi.org/10.22331/q-2023-05-23-1015

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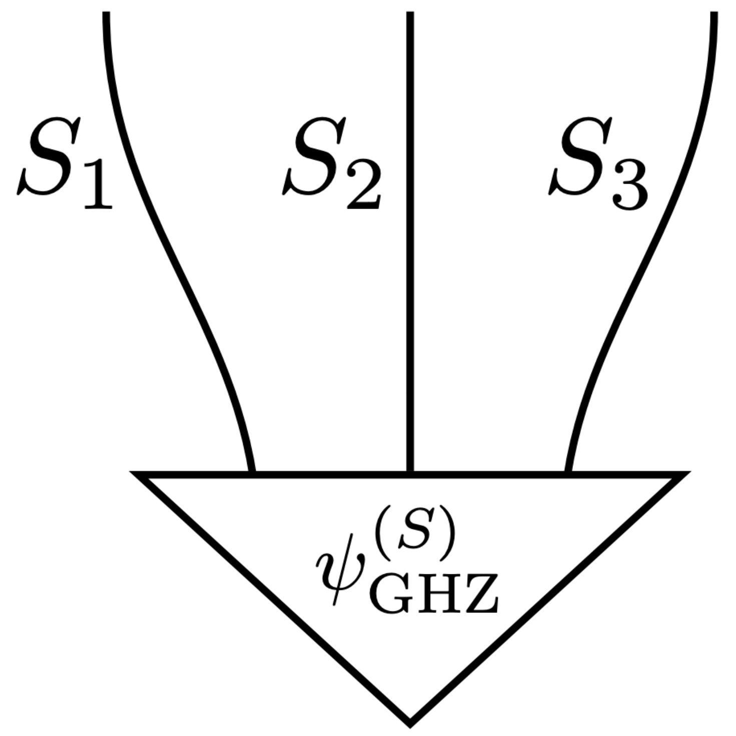

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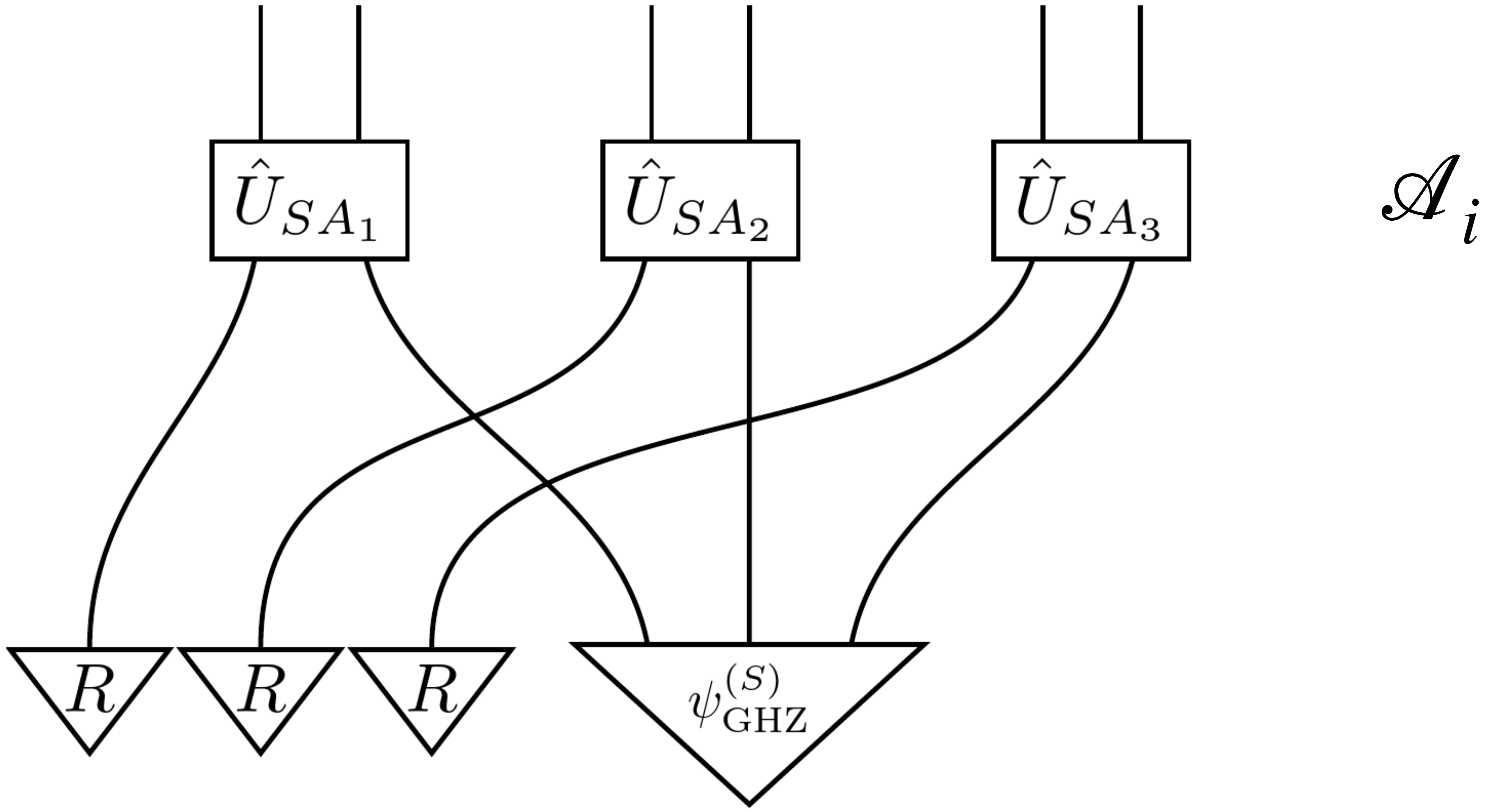

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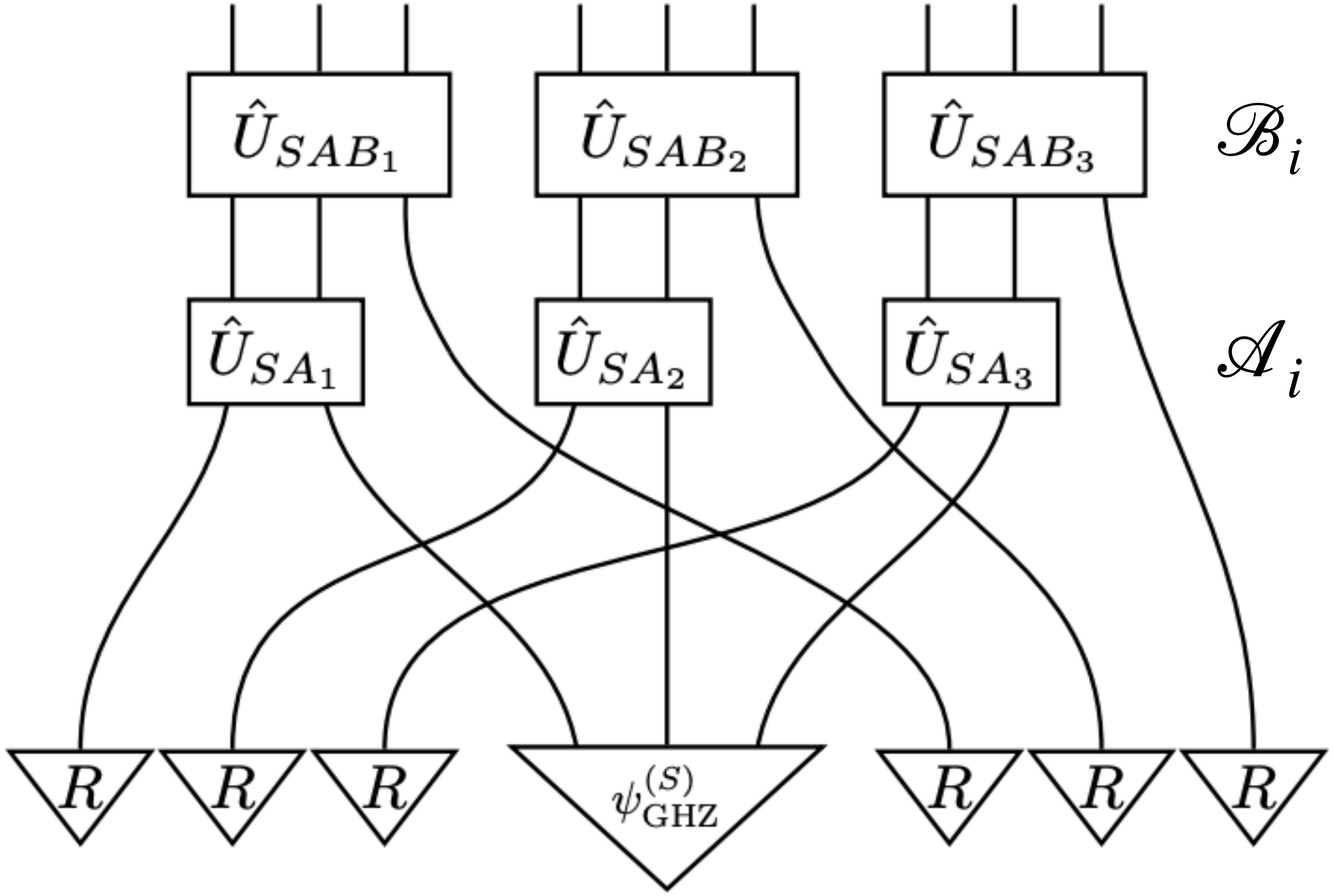
Three qubits are prepared in the GHZ state.

Alice measures them on the z basis. Get outcomes $\mathscr{A}_i$.

Bob measures the spins *and Alice* on the y basis. Gets outcomes $\mathscr{B}_i$.



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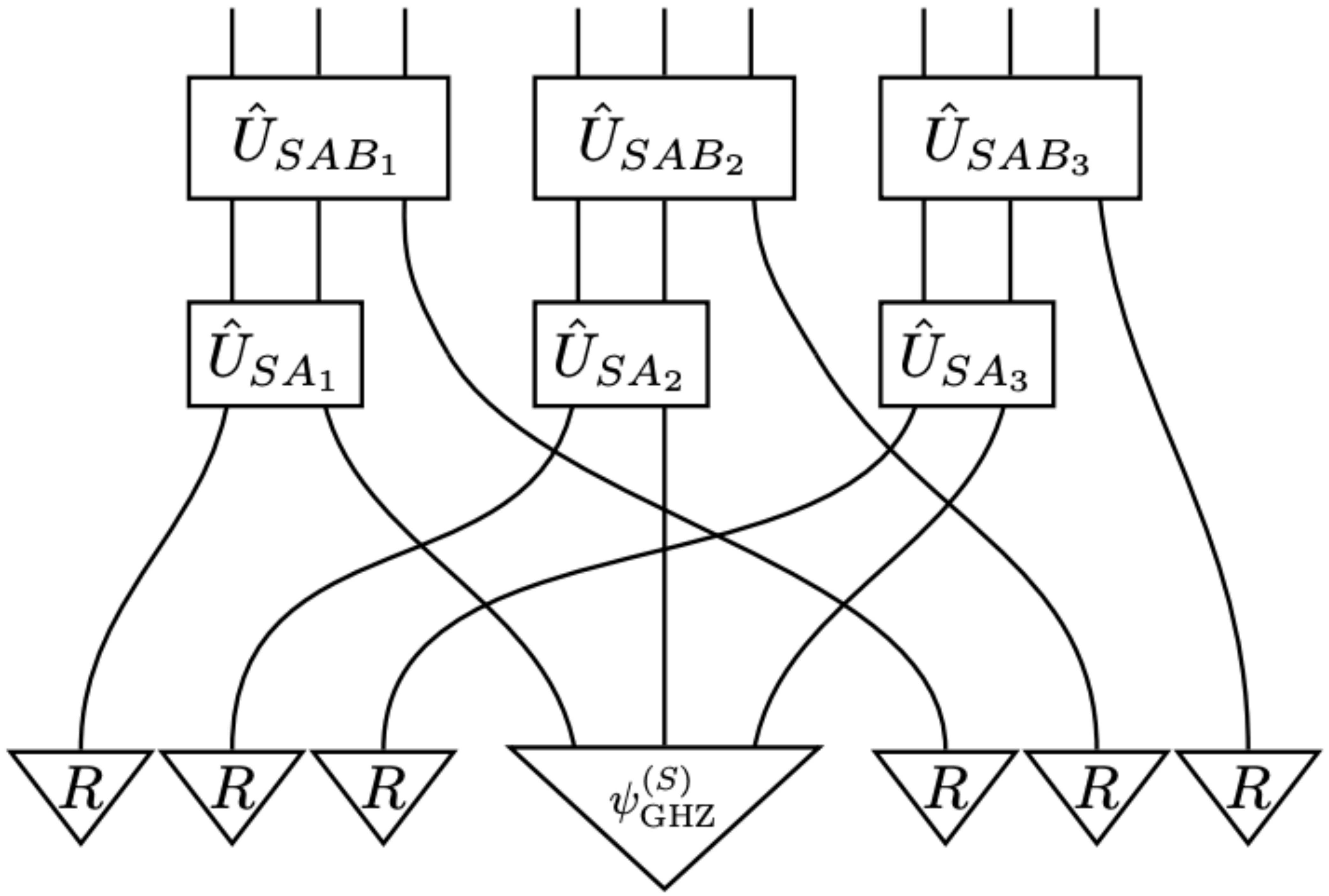

$$\mathscr{B}_1\mathscr{B}_2\mathscr{B}_3 = +1$$

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$$\Downarrow$$

$$(\mathscr{A}_1)^2(\mathscr{A}_2)^2(\mathscr{A}_3)^2(\mathscr{B}_1)^2(\mathscr{B}_2)^2(\mathscr{B}_3)^2 = -1$$

The consistency of relative facts

No observer has access to all these facts.

An observer can compute at most one of these formulas

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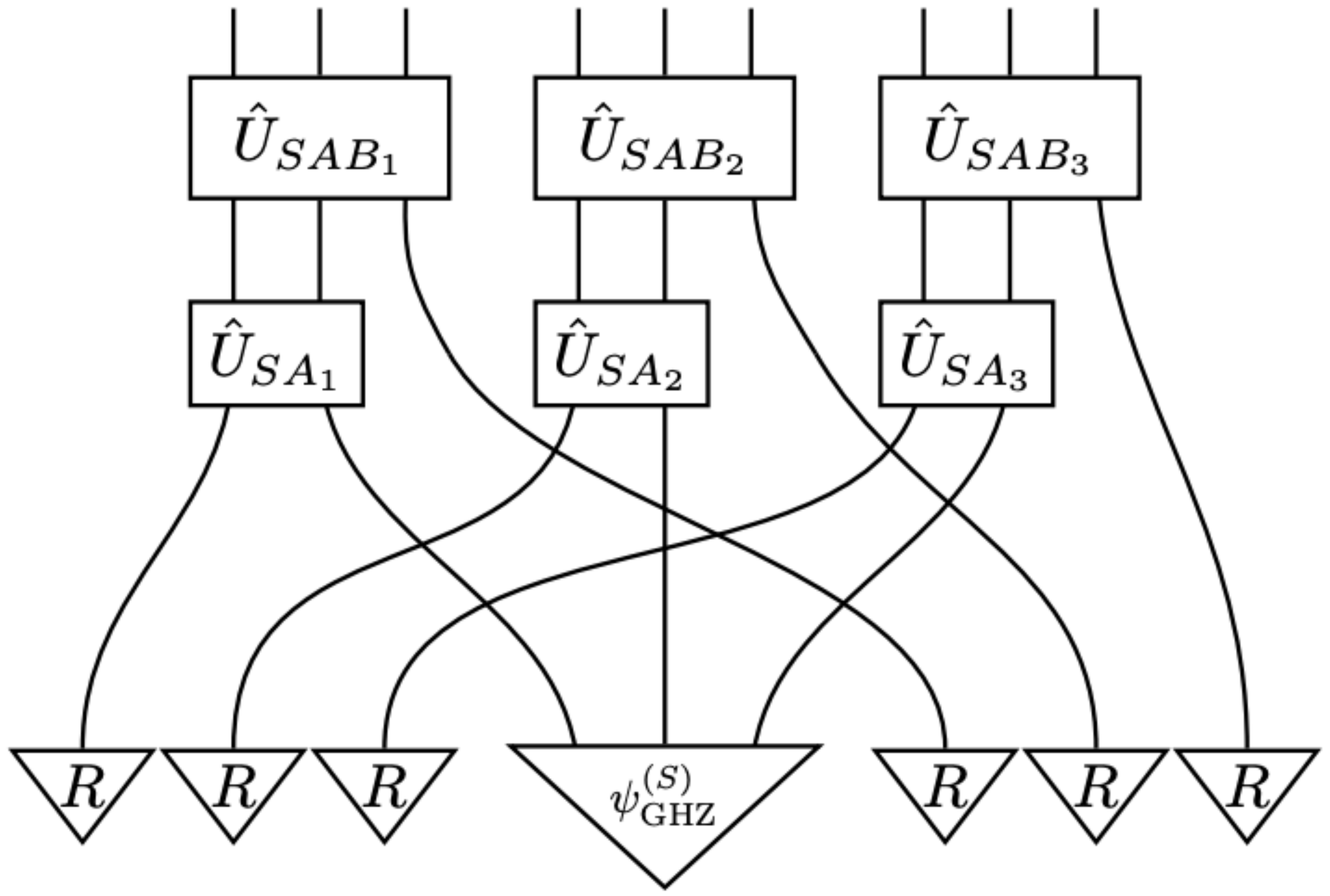

Predictions about single observers are consistent.

But the "list of all relative facts" is odd.

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- Experimentally underway.
- Relational Quantum Mechanics embraces relative facts.
- Decoherence hides the relationality.
- Story not completely worked out.

Some open questions

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6. What is a credible "Friend" for EWFS experiments?

thank you!