Extended Wigner's Friend (EWF) arguments

Yìlè Yīng

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Schmid, Yīng and Leifer, arXiv:2308.16220

Extended Wigner's Friend (EWF) arguments

EWF Argument	Type	Key assumption
Brukner [3]	Parallel	Local Causality (essentially)
Local Friendliness [12]	Parallel	Local Agency
Pusey-Masanes [7, 8]	Parallel	Born Inaccessible Correlations
Frauchiger-Renner [4]	Parallel	Born Inaccessible Correlations Consistency
Gao [17]	Mixed	unclear
Gueren et. al. [18]	Sequential	(a kind of) Linearity

D. Schmid, Y. Yīng, and M. Leifer,
A review and analysis of six extended Wigner's friend arguments (2023),
arXiv:2308.16220

Extended Wigner's Friend (EWF) arguments

- Why are they interesting?
- What are the common assumptions?
- The differences between them

Brukner (2015)

Frauchiger-Renner (2016)

Pusey-Masanes (2017)

Local Friendliness (2019)

Gao (2019)

Gueren et. al. (2021)

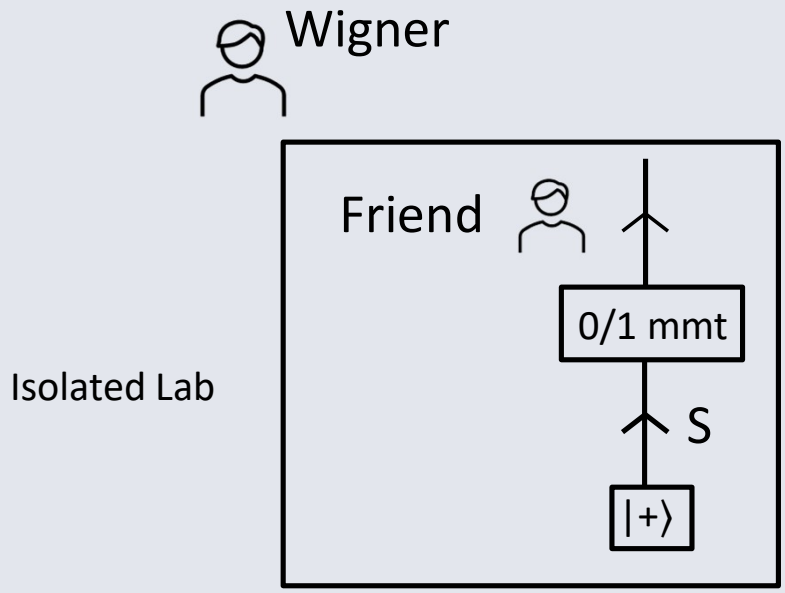
...

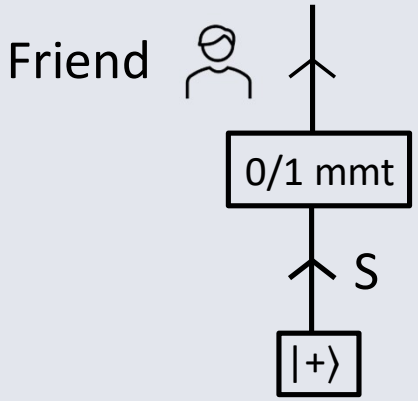
arXiv:2308.16220

Extended Wigner’s Friend (EWF) arguments

- Why are they interesting?
- What are the common assumptions?
- The differences between them

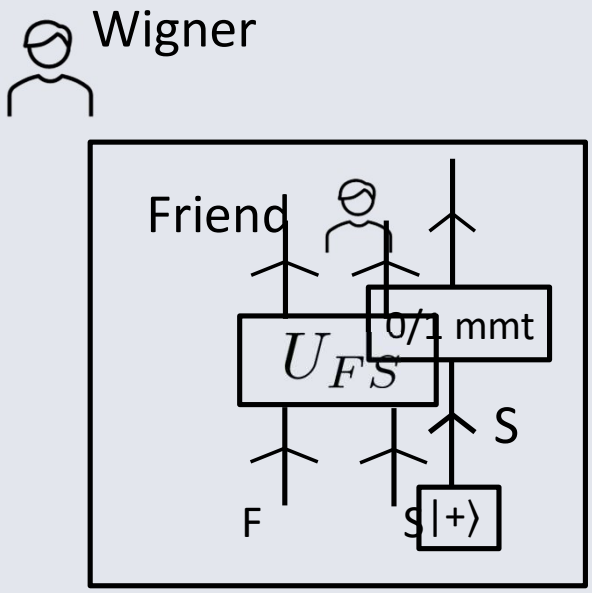
Wigner's friend (1961)





p=50%: outcome 0 is observed; state → $|0\rangle$
p=50%: outcome 1 is observed; state → $|1\rangle$

From Wigner's perspective, the Friend is just another quantum system



$|\text{“ready to do mmt”}\rangle_F|+\rangle_S \quad \rightarrow \quad \frac{1}{\sqrt{2}}|\text{“observed 0”}\rangle_F|0\rangle_S \; + \frac{1}{\sqrt{2}}|\text{“observed 1”}\rangle_F|1\rangle_S$

In the textbook/orthodox interpretation,
these two perspectives are **inconsistent**.

No contradiction if ~~*Ψ-Completeness (eigenstate-eigenvalue link)*~~

Perspective 1

$|+\rangle_S \rightarrow |0\rangle_S$ or $|1\rangle_S$

By the collapse postulate
(Lüders's state update rule)

Indeterministic and discontinuous evolution

Perspective 2

$|\text{“ready”}\rangle_F|+\rangle_S \rightarrow \frac{1}{\sqrt{2}}|\text{“observed 0”}\rangle_F|0\rangle_S + \frac{1}{\sqrt{2}}|\text{“observed 1”}\rangle_F|1\rangle_S$

By the unitary evolution postulate

Deterministic and continuous evolution

Extended Wigner's friend (EWF) arguments

Absoluteness of Observed Events (AOE)

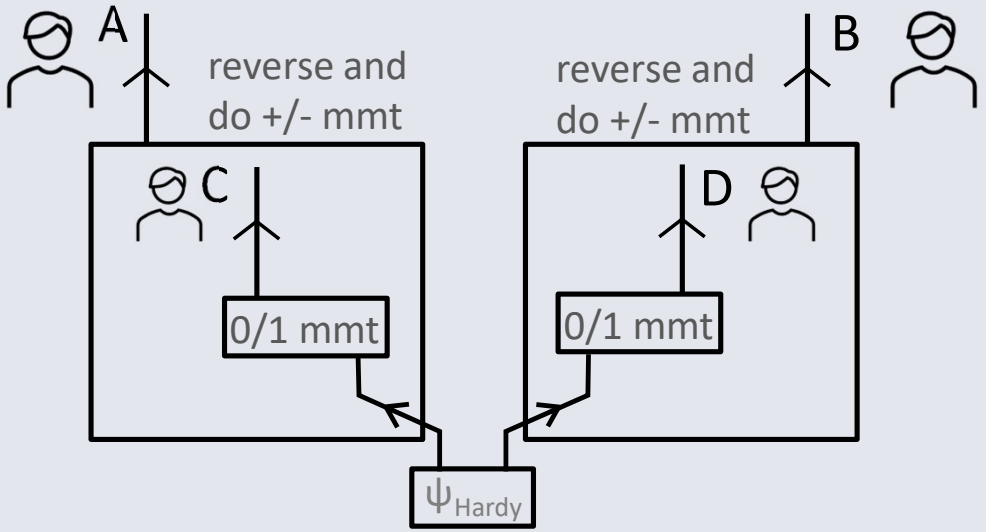
~~the collapse postulate~~

~~the Born rule~~

the unitary evolution postulate

The Pusey-Masanes no-go theorem

$$\frac{1}{\sqrt{3}}(|00\rangle + |01\rangle + |10\rangle)$$



Universality of unitary dynamics, the Born rule

AOE:
a,b,c,d all exists
and are absolute

p(c=1,d=1) = 0
p(c=0,b=−) = 0
p(a=−,d=0) = 0
p(a=−,b=−) ≠ 0

$\Rightarrow$

d=1 $\Rightarrow$ c=0
c=0 $\Rightarrow$ b=+
a=− $\Rightarrow$ d=1

a=− $\Rightarrow$ d=1 $\Rightarrow$ c=0 $\Rightarrow$ b=+

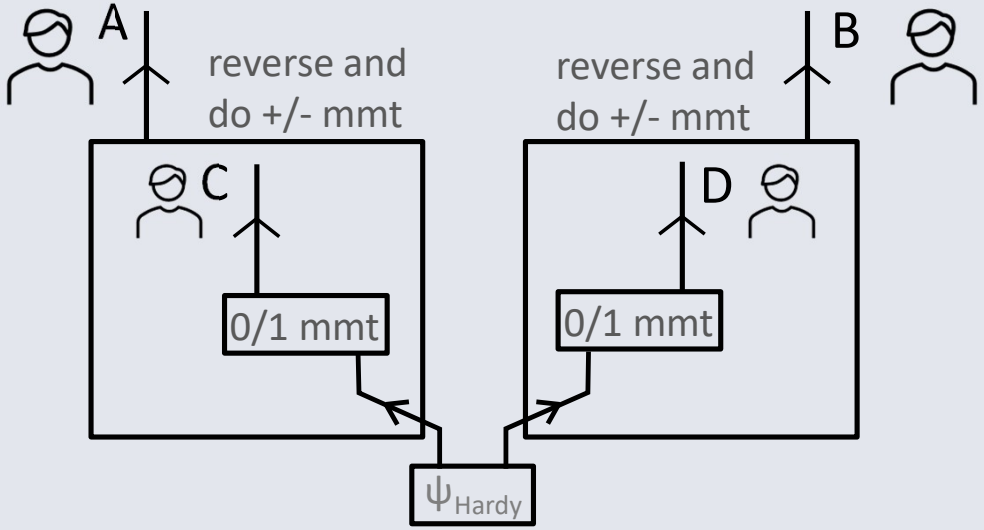
↓

CONTRADICTION

No need for the collapse postulate

Related:
R. Healey, [arXiv:1807.00421]; G. Leegwater, [arXiv:1811.02442]; N. Ormrod and J. Barrett, [arXiv:2209.03940].

The Pusey-Masanes no-go theorem



All measurements can be performed in a single run!

Related:
R. Healey, [arXiv:1807.00421]; G. Leegwater, [arXiv:1811.02442]; N. Ormrod and J. Barrett, [arXiv:2209.03940].

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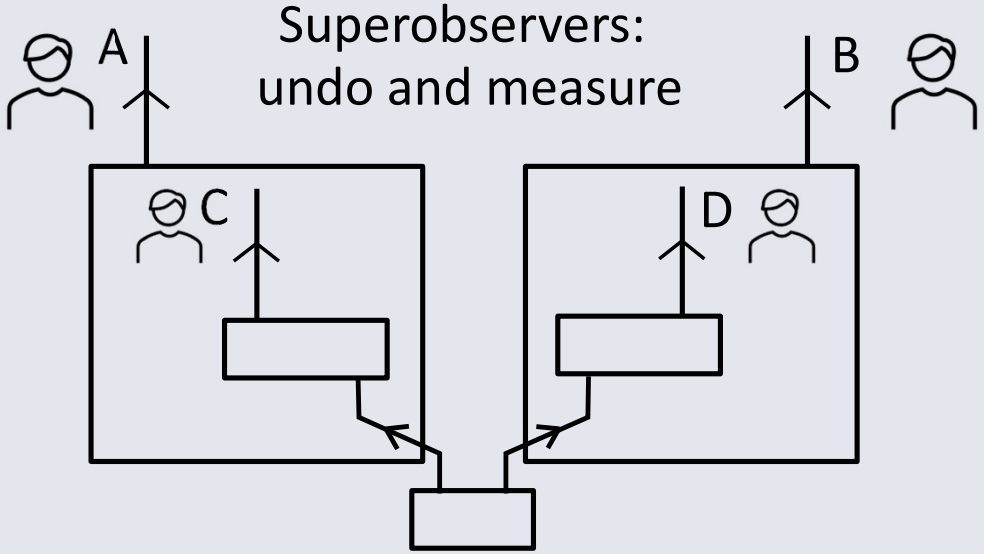

Absoluteness of Observed Events (*AOE*) → P(ABCD)
→ CHSH inequalities on P(AB), P(AD), P(CB) and P(CD)

Universality of unitary dynamics, the Born rule
→ violations of CHSH inequalities

No need for the collapse postulate

Related:
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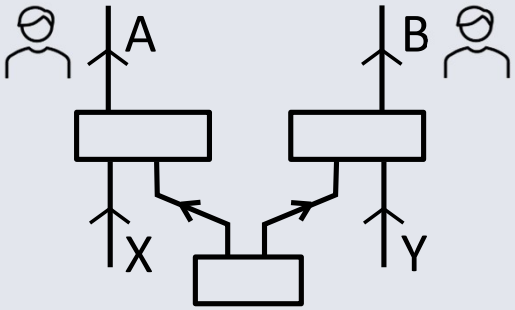
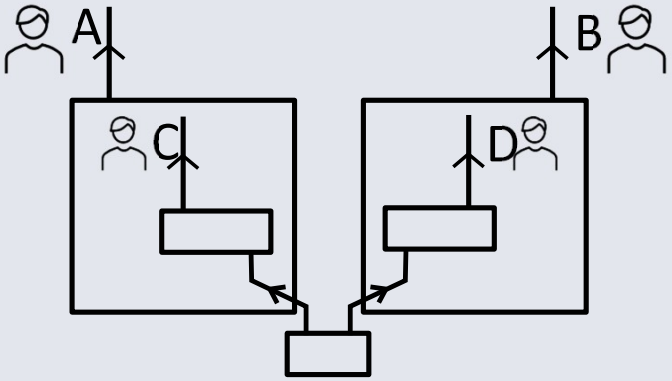
Bell



Pusey-Masanes



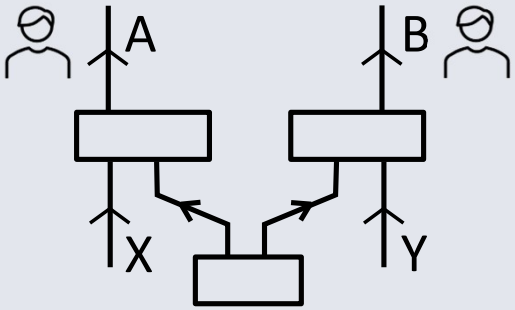
P(A,B|X=0,Y=0)
P(A,B|X=1,Y=0)
P(A,B|X=0,Y=1)
P(A,B|X=1,Y=1)

P(A,B)
P(A,D)
P(C,B)
P(C,D)

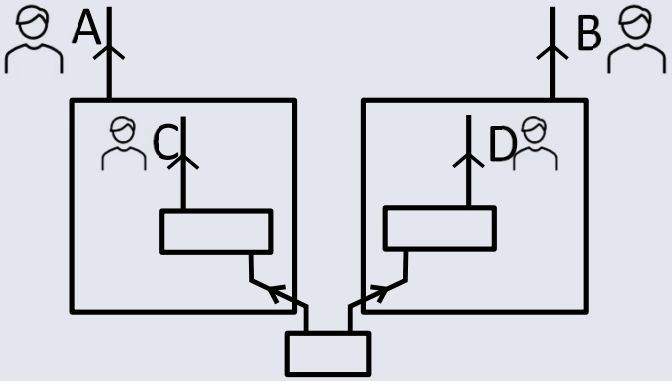
~~Peres: "Unperformed experiments have no results."~~

All measurements can be performed in a single run!

Bell



Pusey-Masanes



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P(A,B)
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P(C,B)
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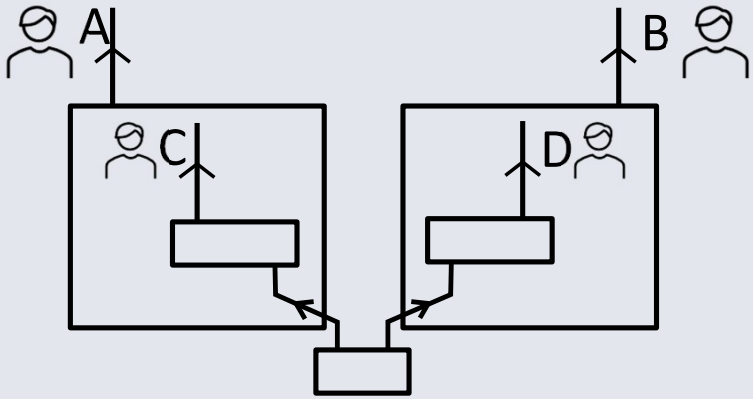
~~Peres: "Unperformed experiments have no results."~~

No need for hidden variables!
(classical realism)



-> The challenge to quantum/nonclassical causal modeling

arXiv:2309.12987

No need for the collapse postulate

- cf. Wigner(1961)

No need for hidden variables

- cf. Bell's and noncontextuality theorems

All measurements can be performed in a single run

- cf. Bell's and noncontextuality theorems

EWF arguments challenge our understanding of physical reality even further than previous theorems did, since they can have weaker or different assumptions.

No need for the collapse state update rule

- cf. Wigner(1961)

No need for hidden variables

- cf. Bell's and noncontextuality theorems

All measurements can be performed in a single run

- cf. Bell's and noncontextuality theorems

All these are true for the Pusey-Masanes theorem
And they are mostly true for other EWF arguments

Exceptions:

No need for the collapse state update rule

The original Frauchiger-Renner theorem
[arXiv:1604.07422]

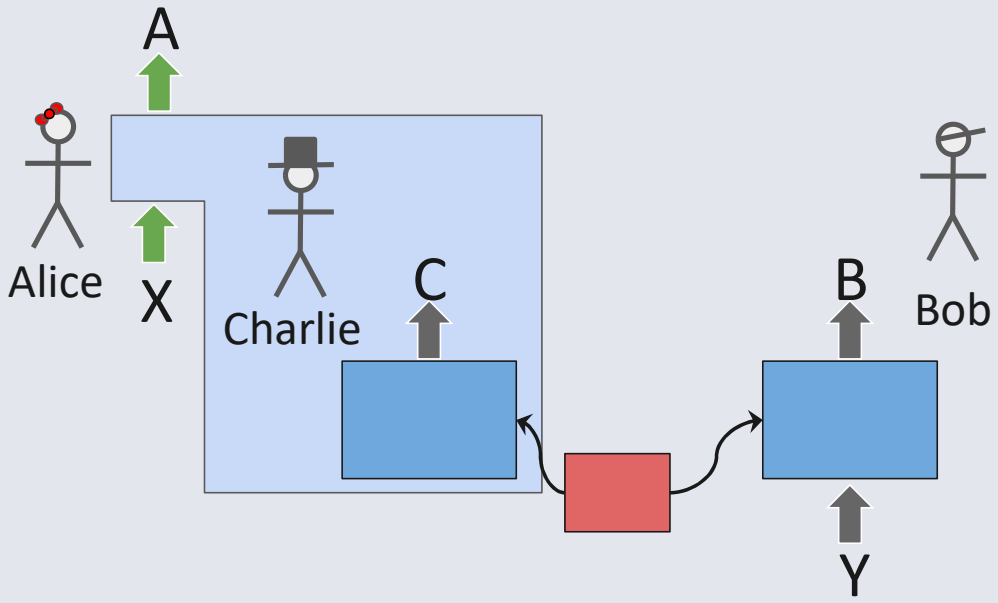
No need for hidden variables

The first-ever EWF theorem: Brukner's theorem
[arXiv:1507.05255, arXiv:1804.00749]

All measurements can be performed in a single run

The minimal version of the Local Friendliness experiment
[arXiv:2209.08491, arXiv:2309.12987]

The Local Friendliness theorem (the minimal version)



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All measurements can be performed in a single run

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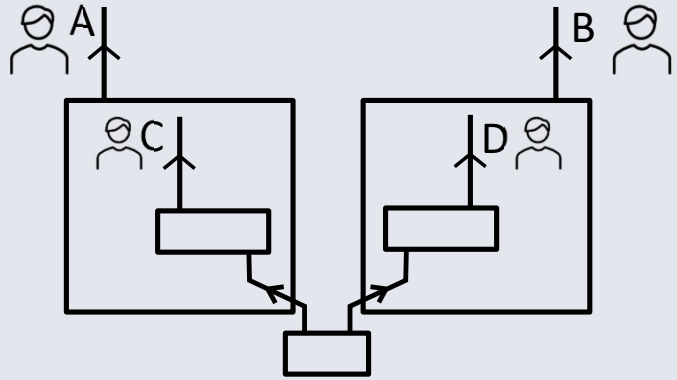
The assumptions



1. Universality of unitary dynamics

2. Absoluteness of observed events

3. The Born rule

These or their variants are present in almost all EWF arguments.

The assumptions:

1. Universality of unitary dynamics

   - rejected by objective collapse interpretations

Variant:

Violations of inequalities:
Theory-independent formulation of the Local Friendliness theorem

EWF theorems in GPTs: arXiv:1904.06247, arXiv:2303.03353, arXiv:2309.12987 and arXiv:2502.03874

The assumptions:

2. Absoluteness of observed events (AOE)

- rejected by Many-worlds, QBism, Relational quantum mechanics, etc,
- arguably implicitly assumed in Bell's and other theorems in all areas of science
- AOE can coexist with the assumption of unitary quantum dynamics

  Unlike the collapse postulate, AOE is **not** about dynamics

  e.g., Bohmian mechanics *https://pirsa.org/13010081*
- AOE applies even when the measurement process is unitary and the record of the outcome may be erased afterward

Variant:

the Consistency axiom in the Frauchiger-Renner no-go theorem

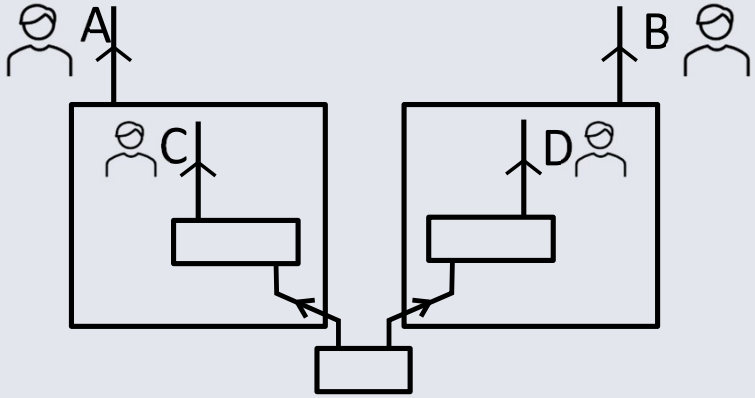
about agent reasonings

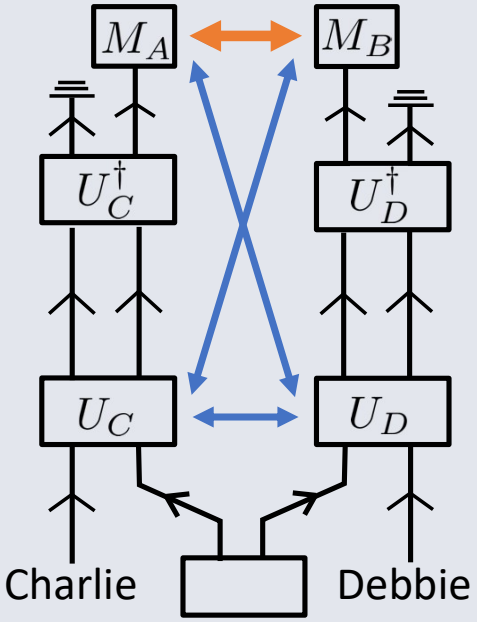
The assumptions:

3. The Born rule for accessible correlations

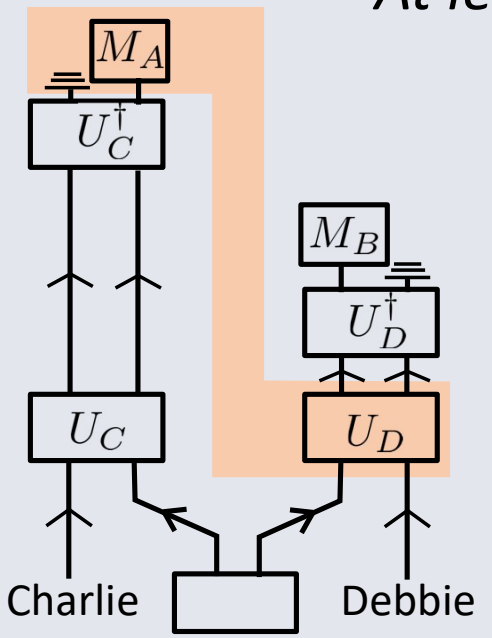
for inaccessible correlations

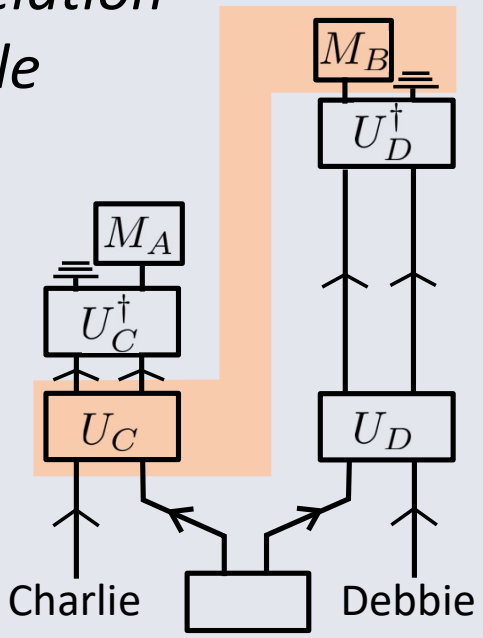
Born Inaccessible Correlations





At least one correlation is inaccessible





p(A,D) is not accessible to anyone, even in principle

(the record for D is erased before A exists)

p(C,B) is not accessible to anyone, even in principle

(similarly)

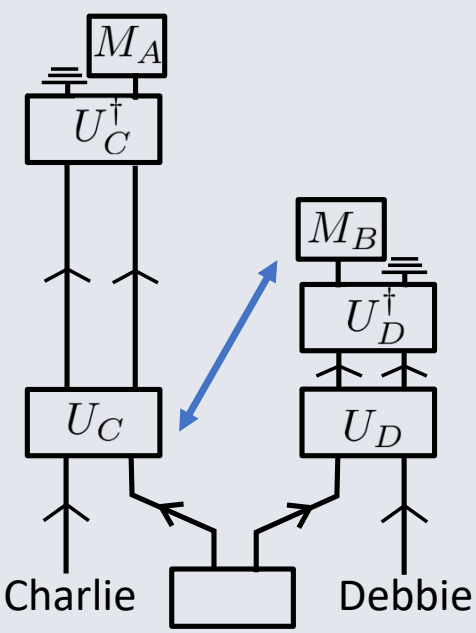
The assumptions:

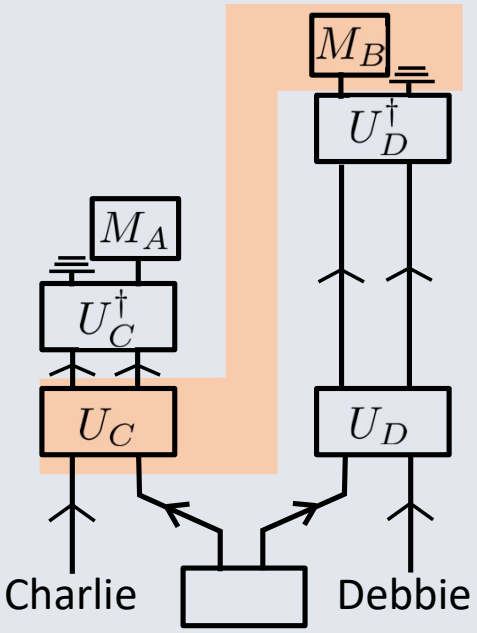
3. Born inaccessible correlations

On what grounds **must** these inaccessible correlations be consistent with the Born rule?

It’s normal, in fact, necessary to have assumptions about inaccessible things in a no-go theorem.

A no-go theorem is interesting only if its assumptions are well-motivated





The Timing Irrelevance assumption:

The length of a trivial Hamiltonian, i.e., an identity channel, is irrelevant for the outcome statistics.

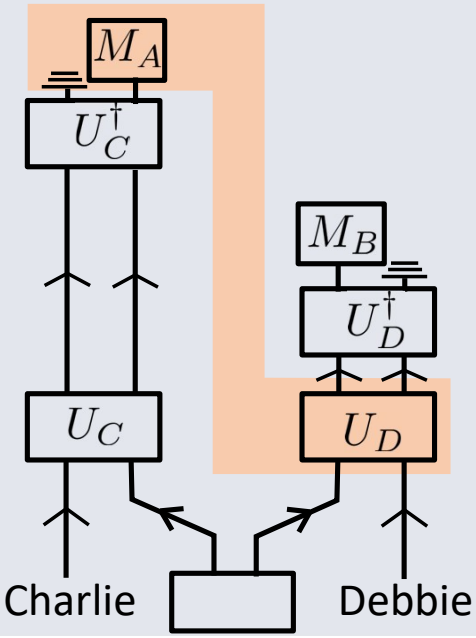
Then p(A,D) and p(C,B) *are* constrained by Born rule in both cases!

The assumptions:

3. Born inaccessible correlations

- can be derived from Timing Irrelevance (+ the Born rule for accessible correlations)
- rejected by nonlocal/contextual interpretation

  e.g., Bohmian Mechanics



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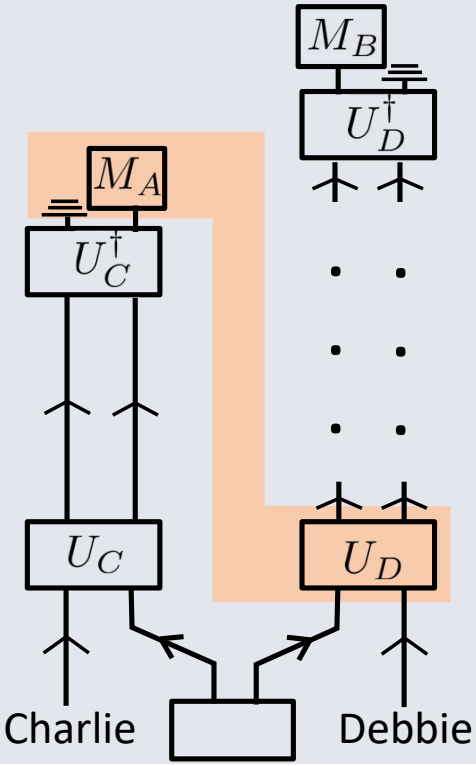

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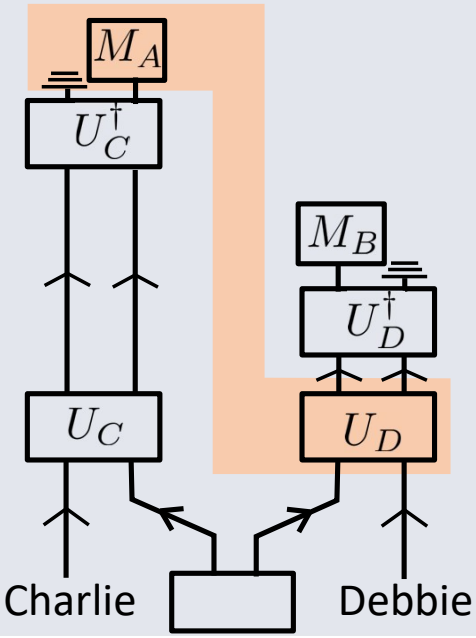


The assumptions:

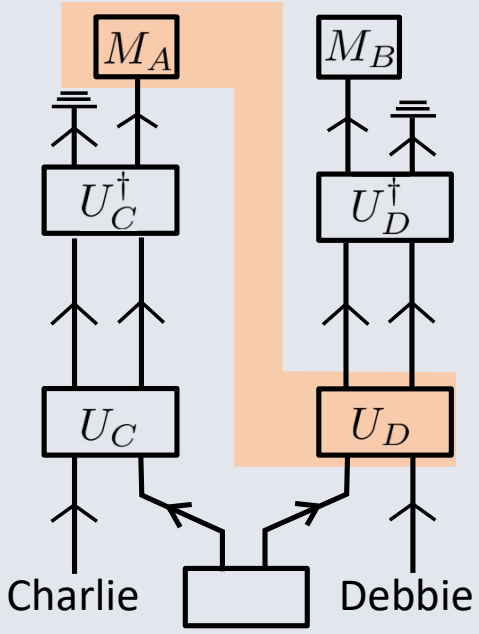
3. Born inaccessible correlations

- implicitly assumed in Frauchiger-Renner

Variants:

Local Agency, No Fine-Tuning
Local Friendliness theorems [arXiv:2106.04065]

Spacelike separation -> e.g., P(A,D) inaccessible
P(A,D) is independent of Bob's measurement choice



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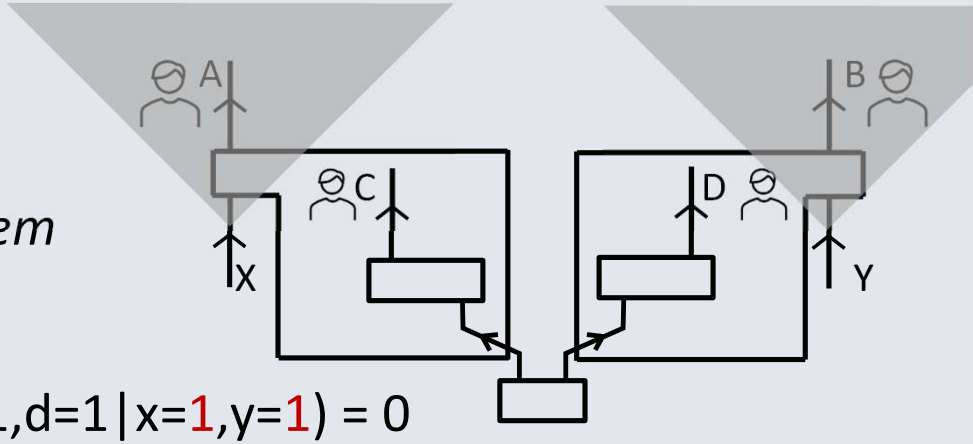
Variants:

Local Agency in the Local Friendliness theorem [arXiv:2106.04065]



$p(c=1,d=1|x=0,y=0) = 0$
$p(c=0,b=-|x=0,y=1) = 0$
$p(a=-,d=0|x=1,y=0) = 0$
$p(a=-,b=-|x=1,y=1) \neq 0$

Local Agency $\Longrightarrow$

$p(c=1,d=1|x=1,y=1) = 0$
$p(c=0,b=-|x=1,y=1) = 0$
$p(a=-,d=0|x=1,y=1) = 0$
$p(a=-,b=-|x=1,y=1) \neq 0$

The assumptions:

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  e.g., Bohmian Mechanics
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Variants:

Local Agency in the Local Friendliness theorem
[arXiv:2106.04065]

The three assumptions

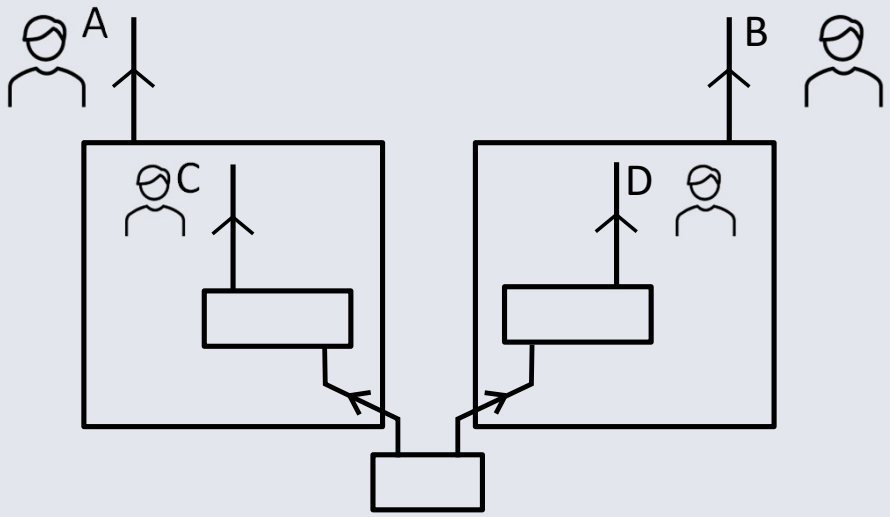
1. Universality of unitary dynamics

2. Absoluteness of observed events

3. Born inaccessible correlations

Most EWF arguments use the Bell-WF mash up

Parallel measurements on a bipartite system

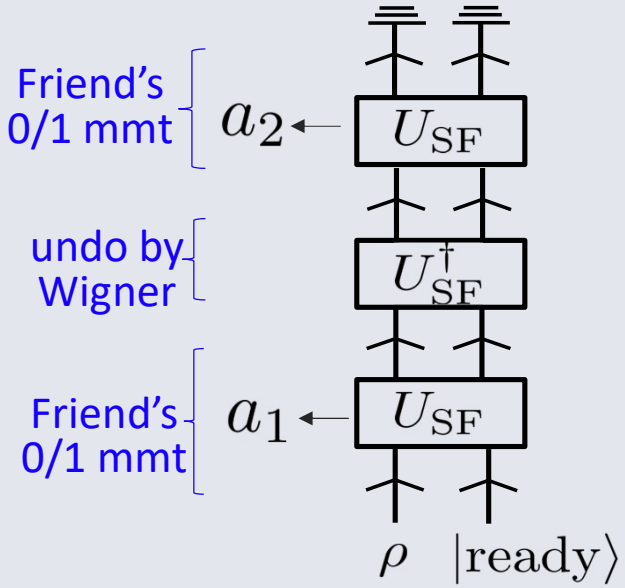


How about sequential EWF scenario?

S. Gao, “Quantum theory is incompatible with relativity: A new proof beyond bell’s theorem and a test of unitary quantum theories,” (2019)

P. Allard Guérin, V. Baumann, F. Del Santo, and Č. Brukner, “A no-go theorem for the persistent reality of Wigner’s friend’s perception,” (2021)

Should $a_1 = a_2$?



Consider preparing the maximally mixed state ϱ

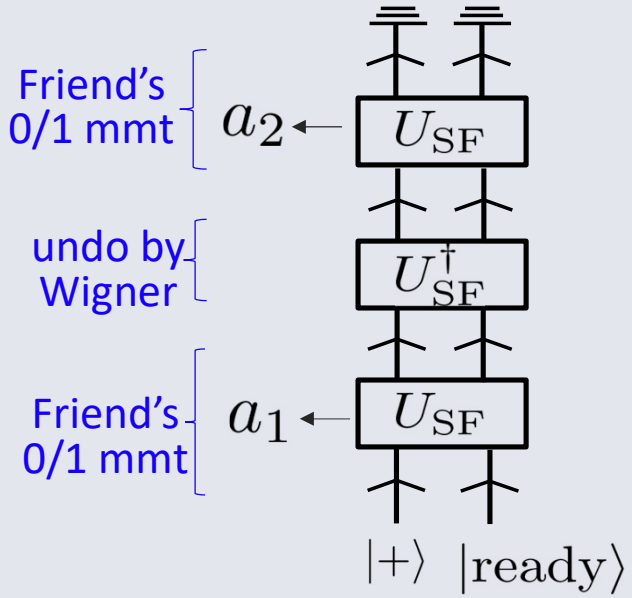
$$\tfrac{1}{2}|0\rangle\langle 0| + \tfrac{1}{2}|1\rangle\langle 1|$$

$$\tfrac{1}{2}|+\rangle\langle +| + \tfrac{1}{2}|-\rangle\langle -|$$

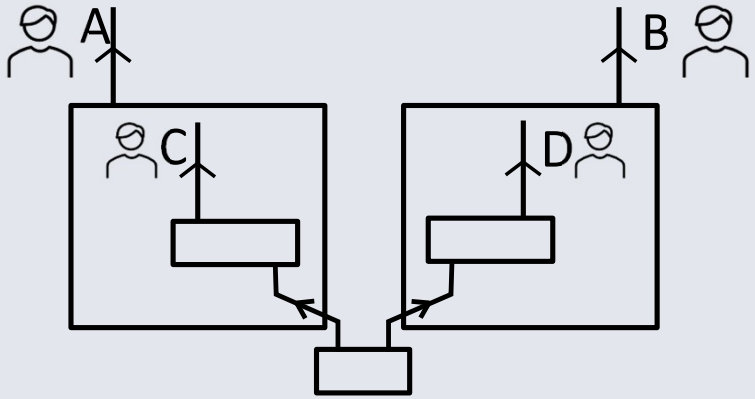
-In the first case, all the outcomes *must* be the same
-In the second case, it's conceivable that the outcomes are random.

So the correlations in such sequential processes can be *different* for the two preparation procedures described by the *same* density operator.

Should $a_1 = a_2$?



$$\mathrm{Tr}[(E_A \otimes E_D)\rho]$$



Without hidden variables, how to constrain *sequential inaccessible* correlations*?*

Extended Wigner's friend paradoxes do not require nonlocal correlations

Laurens Walleghem, Rafael Wagner, Yìlè Yīng, David Schmid

arXiv:2310.06976

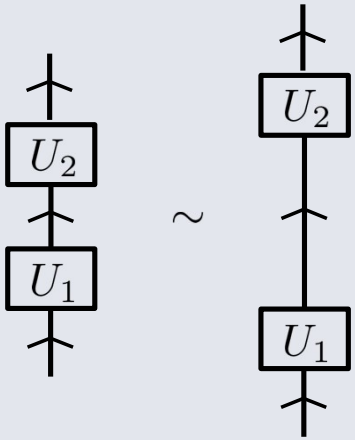
Instead of a Bell-WF mash up, we made a Noncontextuality-WF mash up

All measurements are done sequentially on a unipartite system

Related: Nurgalieva and Vilasini, arXiv:2502.03874

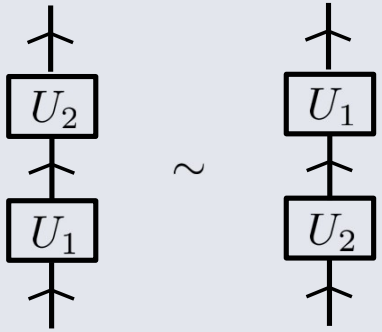
Constrain sequential inaccessible correlations without hidden variables

Timing Irrelevance



Commutation Irrelevance

If $[U_1, U_2] = 0$



arXiv:2310.06976

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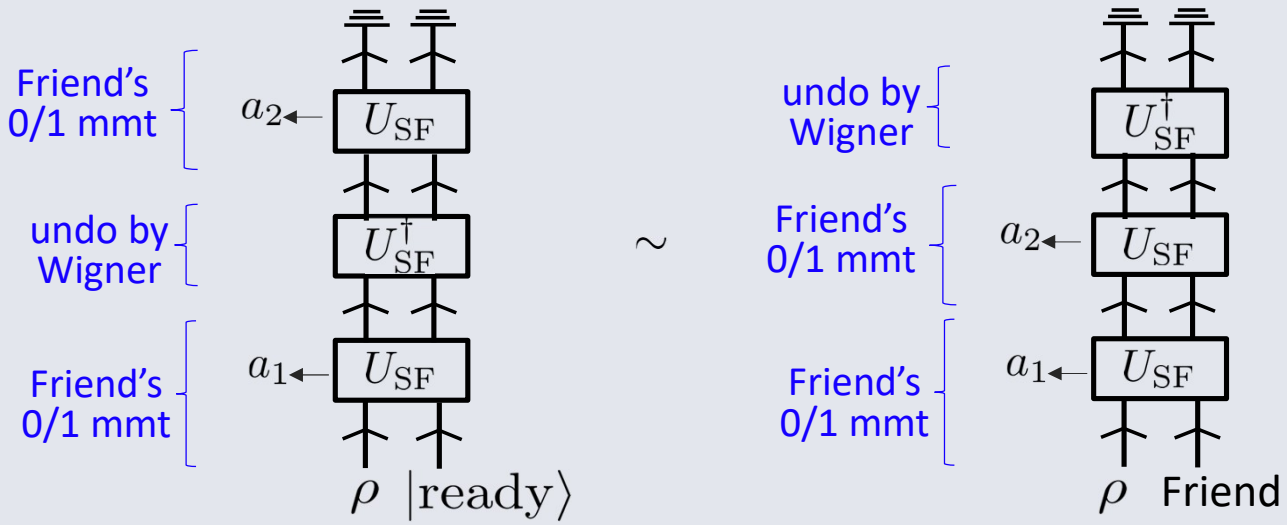

$$a_1 = a_2 \ !$$

arXiv:2310.06976

Advantages

1. No need for the collapse postulate
2. No need for hidden variables
3. All measurements can be performed in a single run of the experiment
4. *No need for assumptions about locality (cf. Bell)*

Assumptions (Pusey-Masanes theorem)

1. Universality of unitary dynamics
2. Absoluteness of observed events
3. Born inaccessible correlations

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Walleghem et. al.	Sequential	Commutation Irrelevance

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Thanks :-)

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