Title: A no-go theorem for observer-independent facts

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Abstract: In his famous thought experiment, Wigner assigns an entangled state to the composite quantum system made up of Wigner's friend and her observed system. While the two of them have different accounts of the process, each Wigner and his friend can in principle verify his/her respective state assignments by performing an appropriate measurement. As manifested through a click in a detector or a specific position of the pointer, the outcomes of these measurements can be regarded as reflecting directly observable "facts". Reviewing arXiv:1507.05255, I will derive a no-go theorem for observer-independent facts, which would be common both for Wigner and the friend. I will then analyze this result in the context of a newly derived theorem in arXiv:1604.07422, where Frauchiger and Renner prove that "single-world interpretations of quantum theory cannot be self-consistent". It is argued that "self-consistency" has the same implications as the assumption that observational statements of different observers can be compared in a single (and hence an observer-independent) theoretical framework. The latter, however, may not be possible, if the statements are to be understood as relational in the sense that their determinacy is relative to an observer.

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A no-go theorem for observer-independent facts

Časlav Brukner

arXiv:1507.05255, 1804.00749

Algorithmic Information, Induction and Observers in Physics,
Perimeter Institute, Waterloo, April 2018

Outlook

- Part 1:

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  - Wigner‘s friend thought experiment

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- Part 2: Remark on Frauchiger-Renner paper

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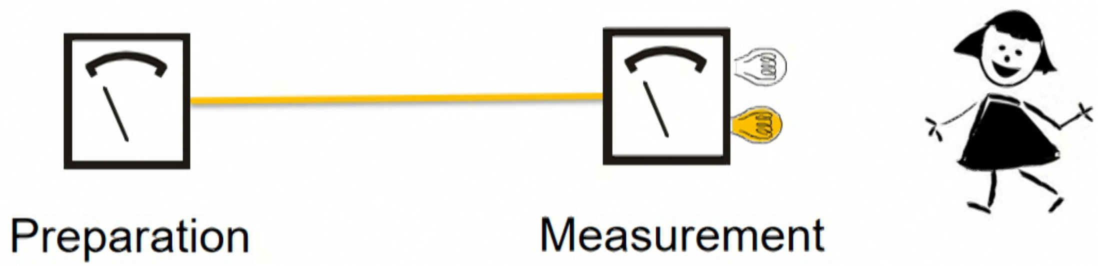
- Part 2: Remark on Frauchiger-Renner paper
- Part 3: Friend can find out that she is in a superposition state („failure of the standard quantum formalism“)

Typical experimental situation



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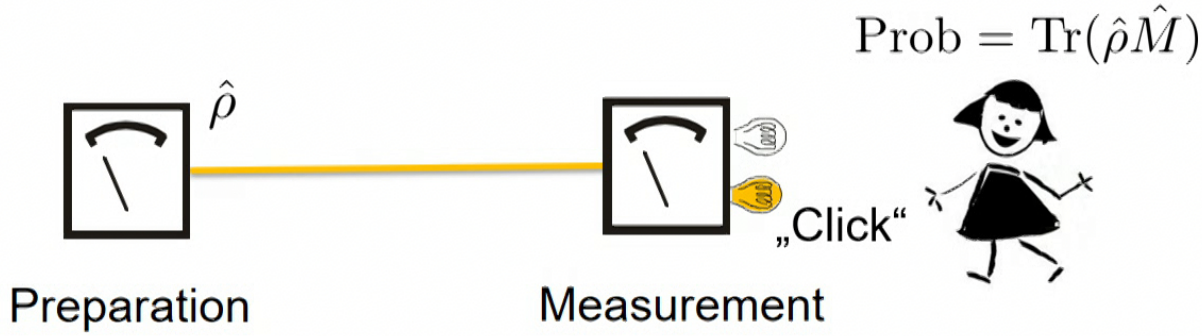

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$$\mathrm{Prob}(X = \pm 1, Z = \pm 1)$$

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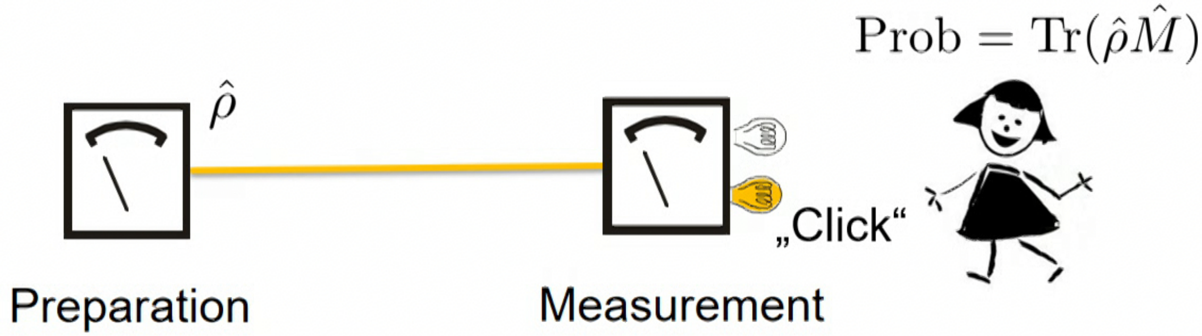

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- Nonetheless, measurement results, e.g. clicks of the detectors, are considered to be “real”. They are “facts”.

„Minimal“ interpretation

“... the state vector is only a shorthand expression of that part of our information concerning the past of the system which is relevant for predicting (as far as possible) the future behaviour thereof.”

E. Wigner, Symmetries and Reflections
(Indiana University Press, 1967), p. 164

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Operational requirement: Observer is able to verify her/his state assignment by performing a suitable measurement on the system.

The "cut"

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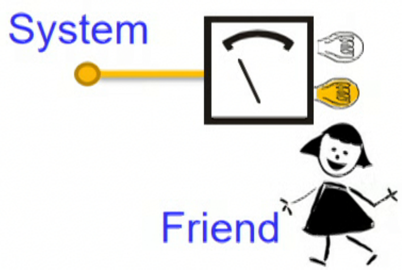
The „cut“ as a functional distinction between object and subject, not a physical one.

The “cut”



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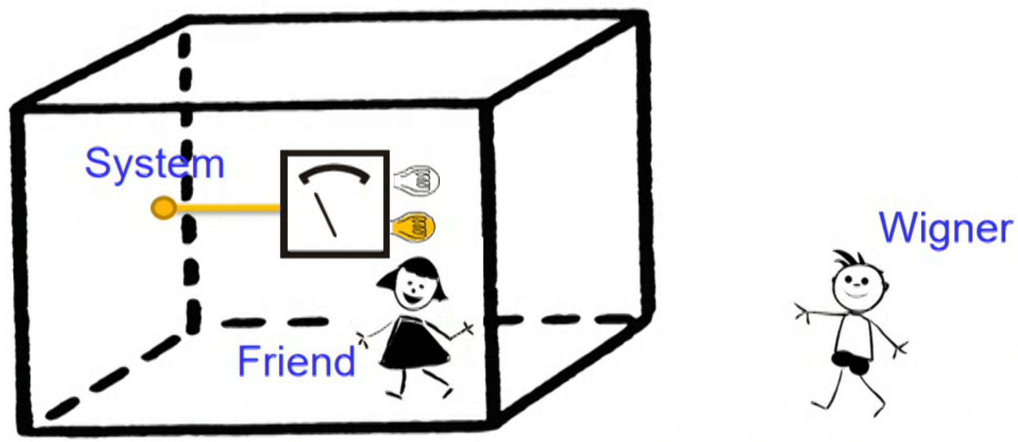

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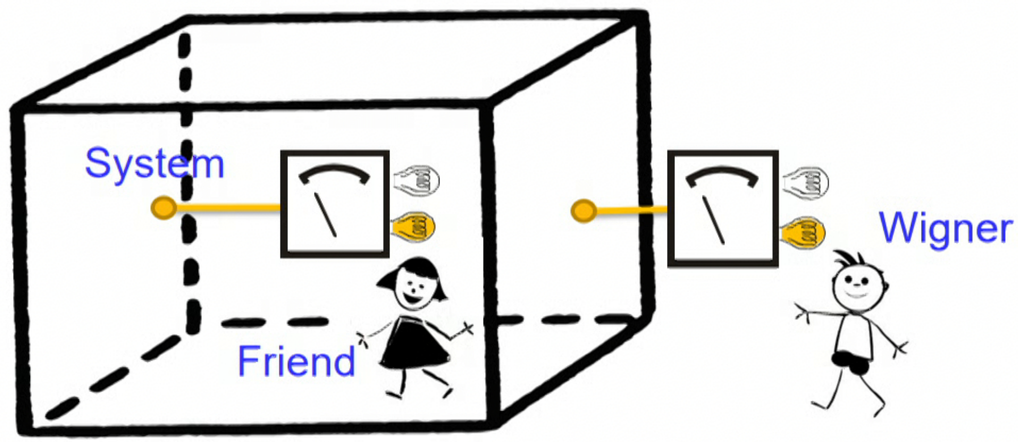

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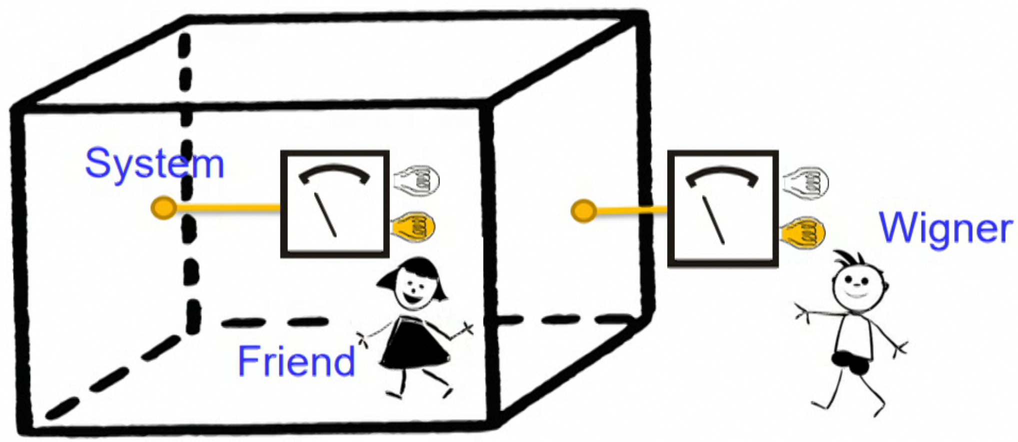
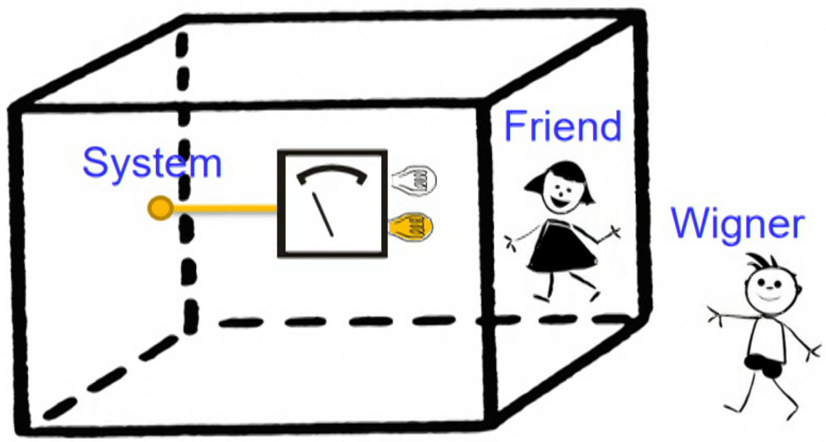


In moving the “cut”, the F’s measurement instrument loses its function and becomes itself a quantum system – an object that can be observed by a further set of W’s measurement instruments.

Wigner's friend thought experiment



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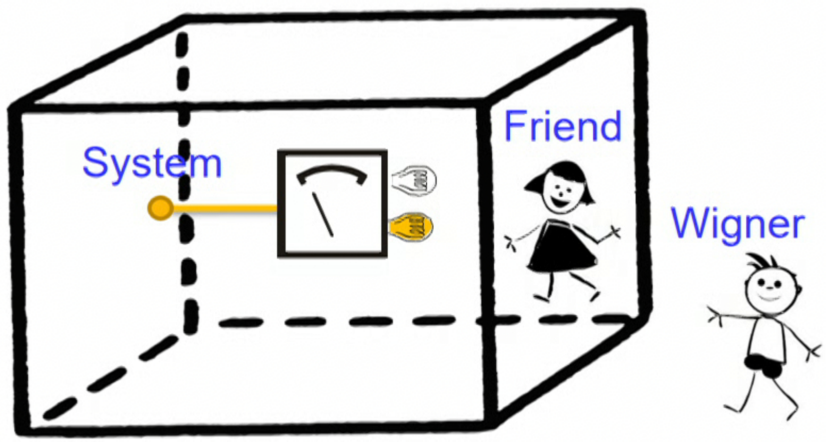

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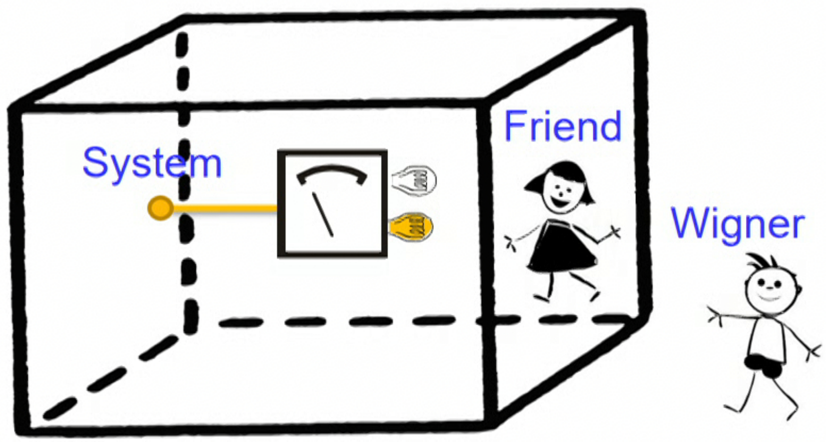

W can verify his state assignment by performing a measurement with outcomes:

$$|\psi_t\rangle^W \langle\psi_t|, \mathbb{1} - |\psi_t\rangle^W \langle\psi_t|$$

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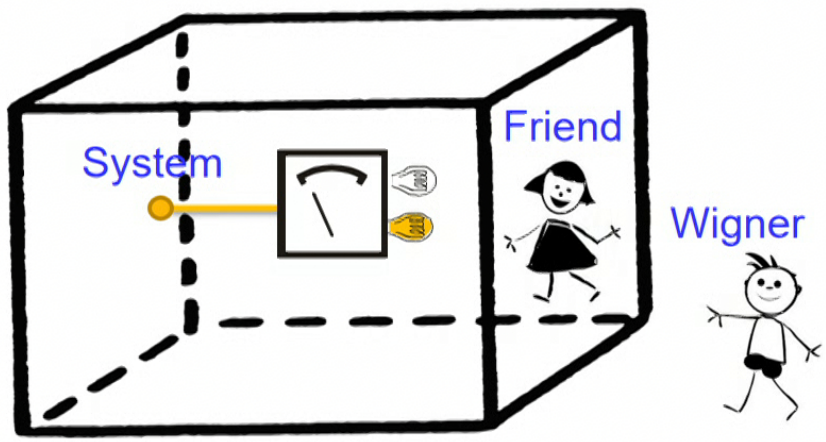

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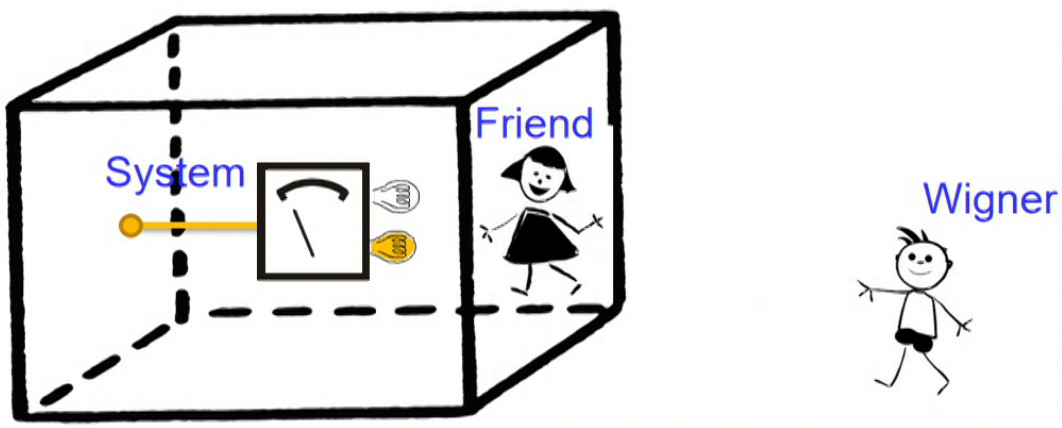
$$\text{Friend: Either } |z+\rangle_S|see\text{ “}up\text{”}\rangle_F \text{ or } |z-\rangle_S|see\text{ “}down\text{”}\rangle_F$$

Deutsch's version of the experiment



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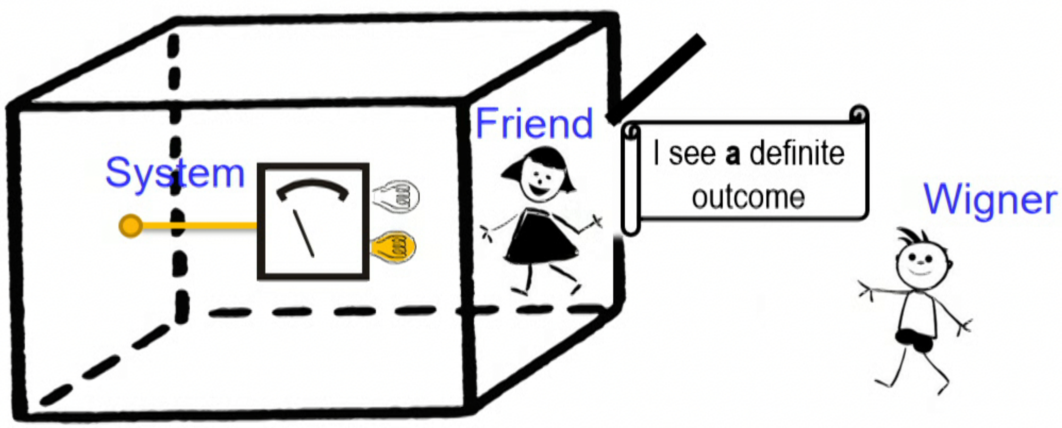

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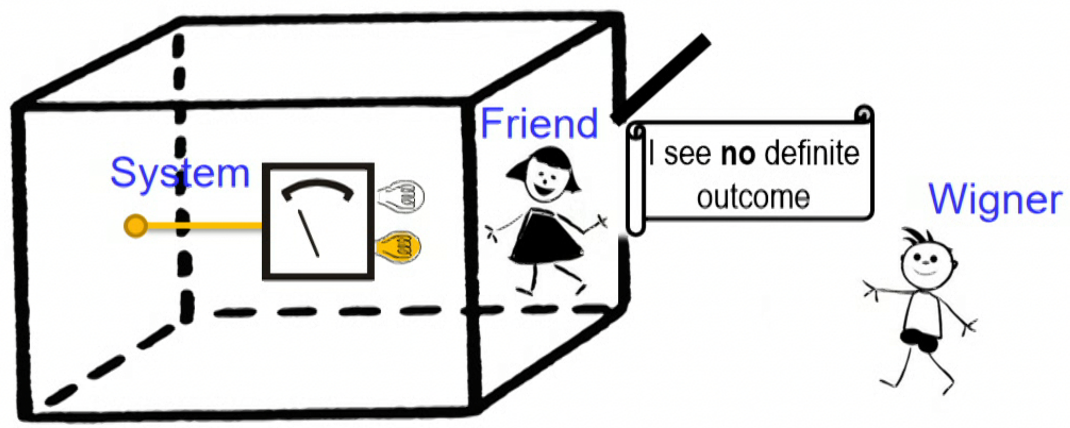

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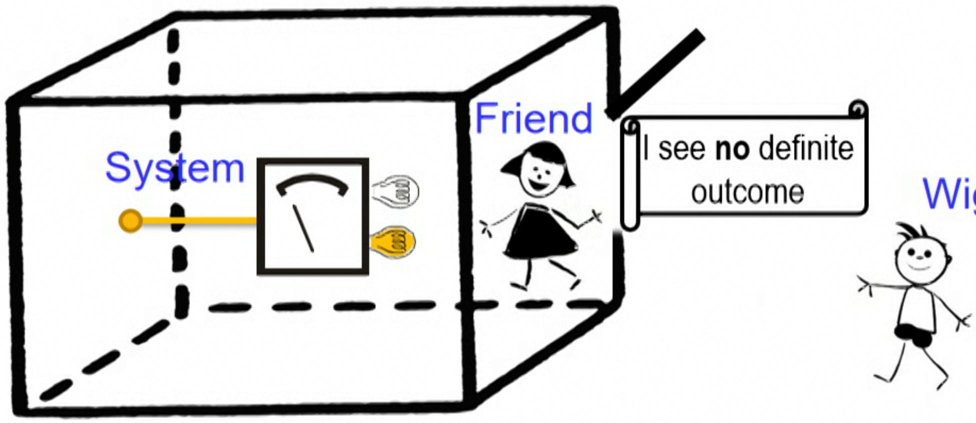

$$|\psi_t\rangle_W = \frac{1}{\sqrt{2}}(|z+\rangle_S|see \text{ "}up\text{"}\rangle_F + |z-\rangle_1|see \text{ "}down\text{"}\rangle_F) \otimes |I\ see \ldots\rangle$$

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2. W confirms the state, and yet F observes a definite outcome.

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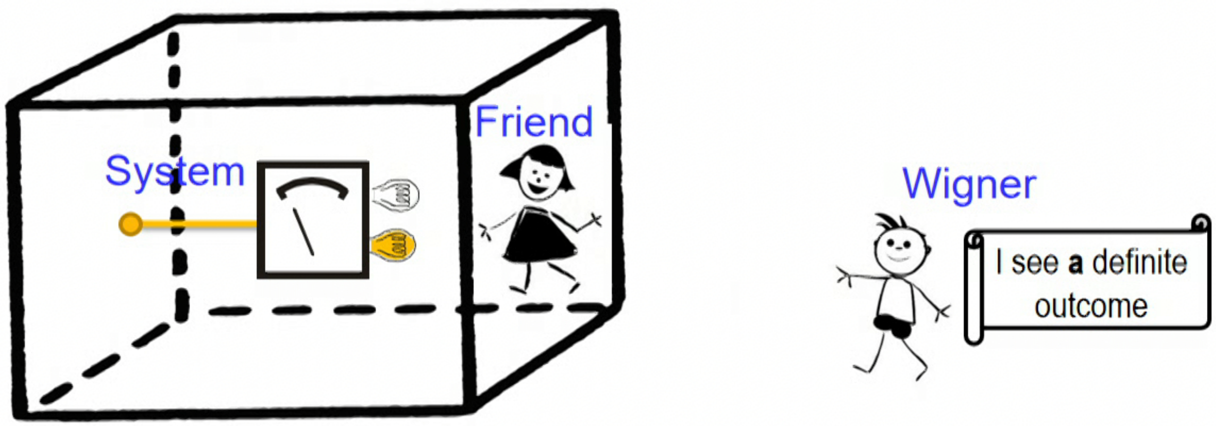

- W has a direct evidence that F has observed a definite outcome,

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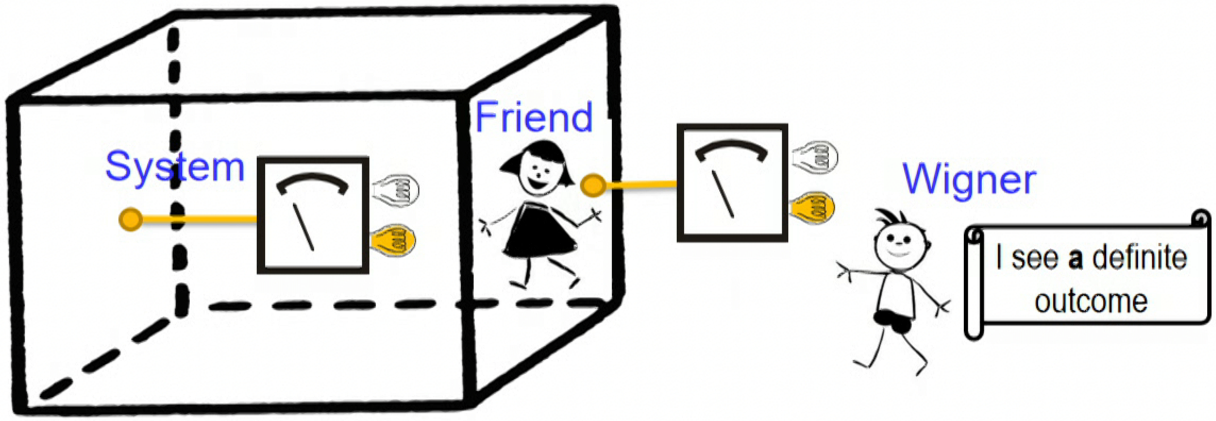

- W has a direct evidence that F has observed a definite outcome, and can observe a definite outcome in his measurement.

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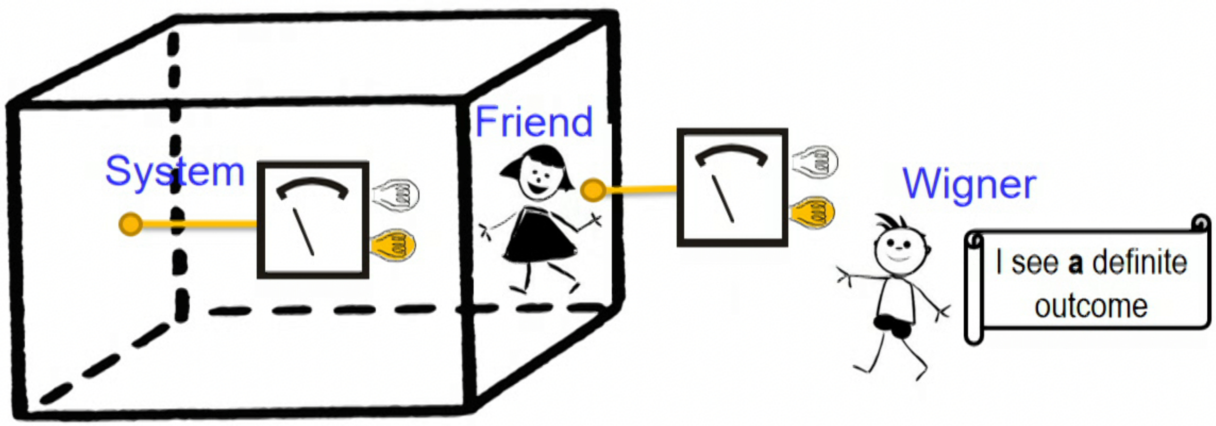

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- Do W's facts and F's facts **coexist?** (Do truth values of the observational statements build a **Boolean algebra?**)

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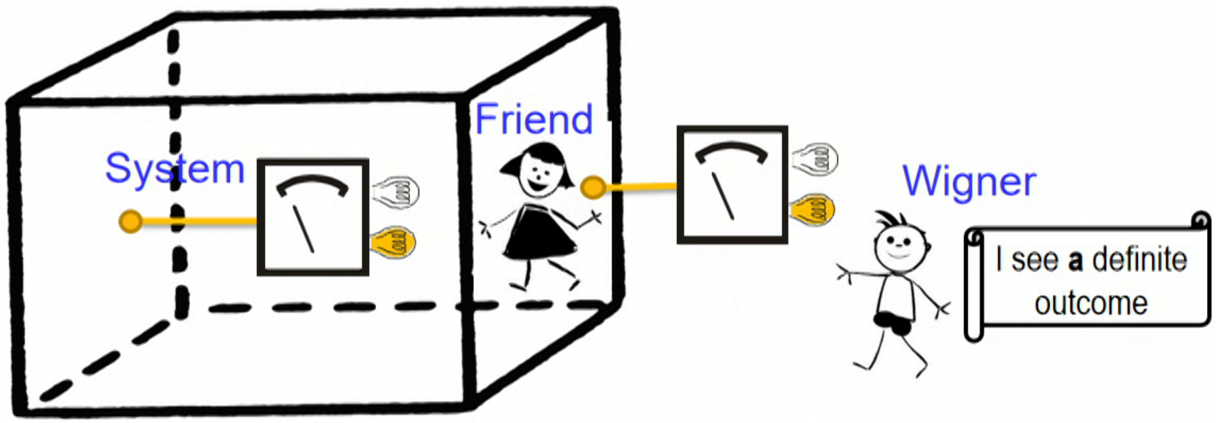

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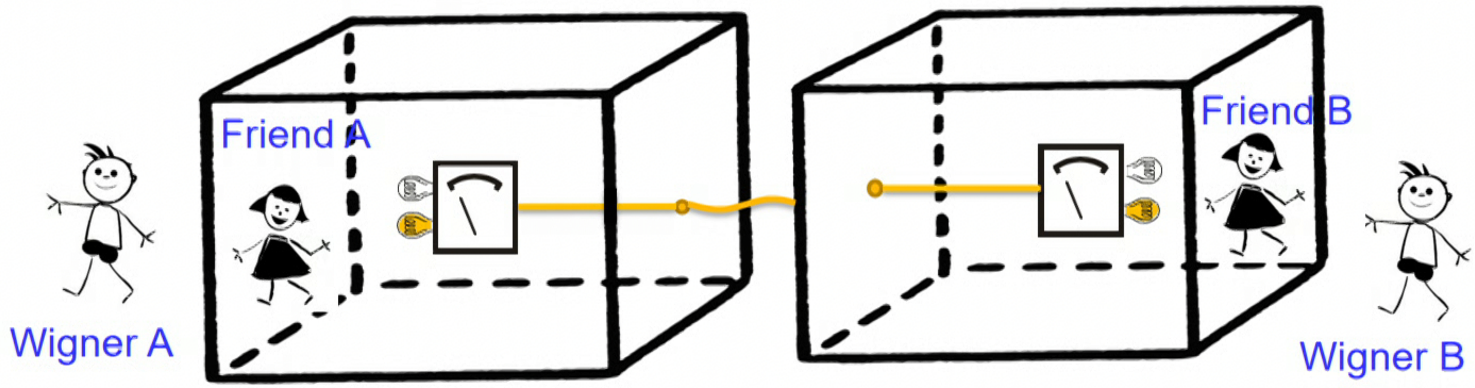
3. **“Locality”**: The choice of measurement setting of one observer does not alter the measurement outcome of the other observer.
4. **“Freedom of Choice”**: The choices of measurements are statistically independent of the rest of the experiment.

Bell's test for Wigners & Friends



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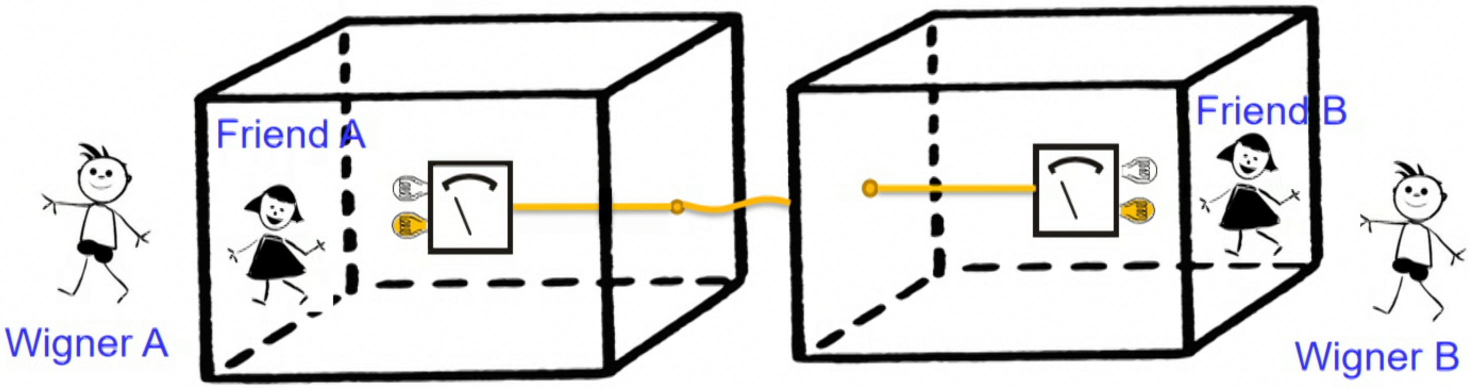

$$|\psi\rangle^{W_A W_B} = [(\mathbb{1} \otimes e^{-\frac{i}{2}\theta\hat{\sigma}_y})|\psi^-\rangle_{S_A S_B}]|0\rangle_{F_A}|0\rangle_{F_B}$$
$$= (-\sin\frac{\theta}{2}|\phi^+\rangle_{S_A S_B} + \cos\frac{\theta}{2}|\psi^-\rangle_{S_A S_B})|0\rangle_{F_A}|0\rangle_{F_B}$$

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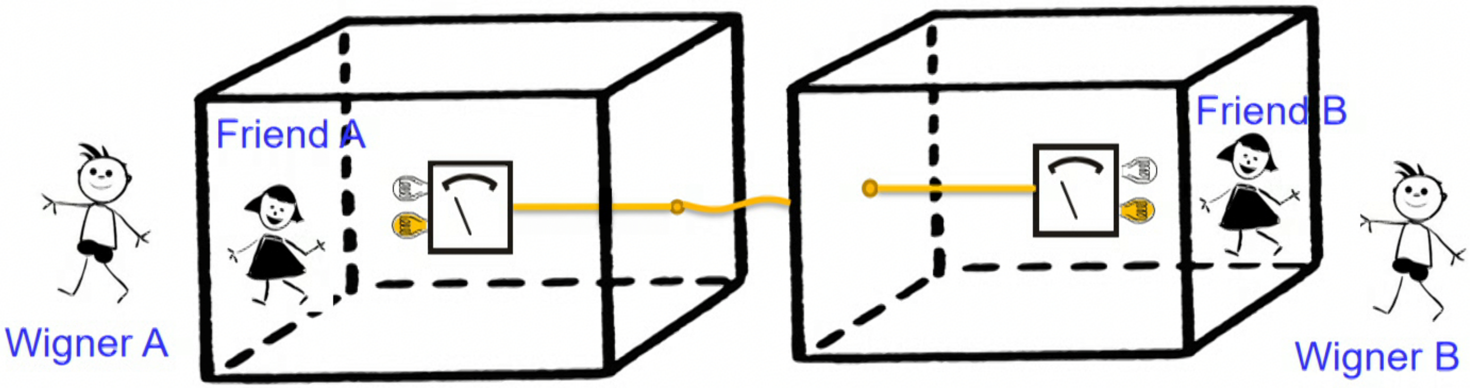

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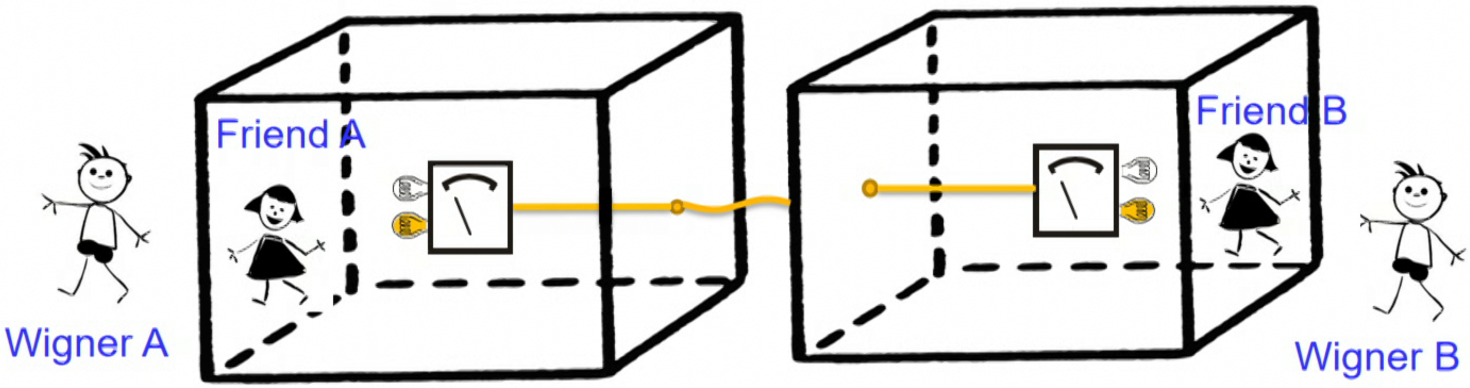

F_A and F_B perform measurements of the spins along z.

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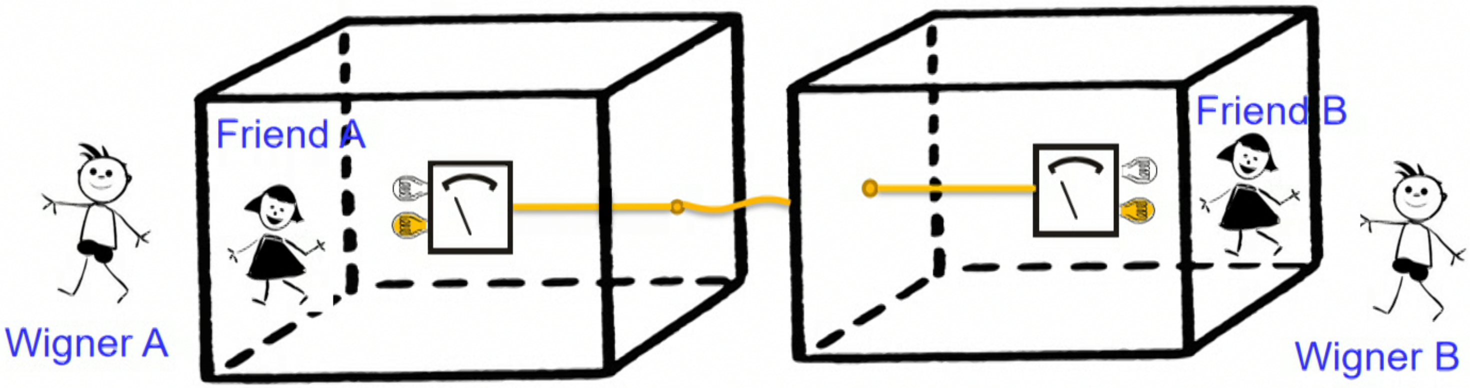

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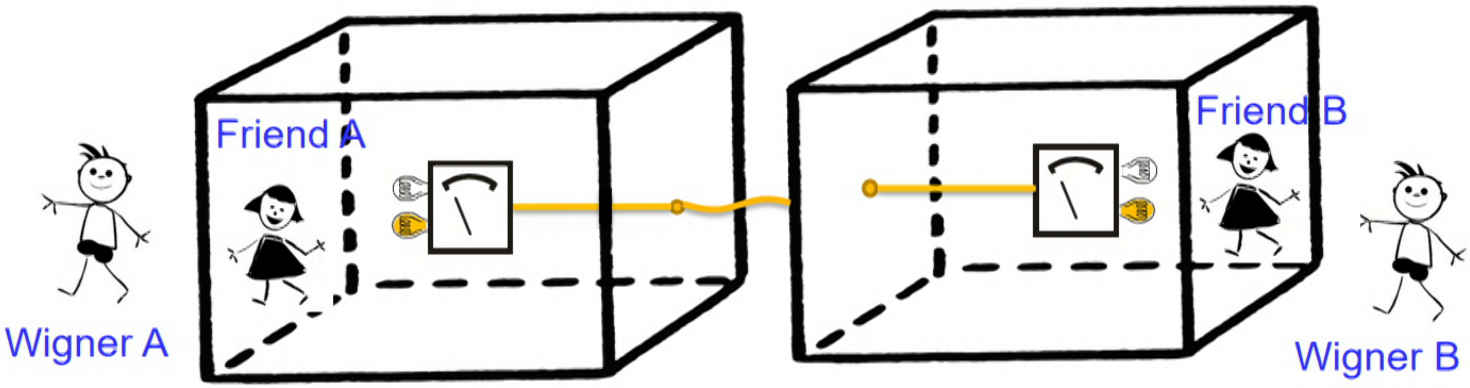

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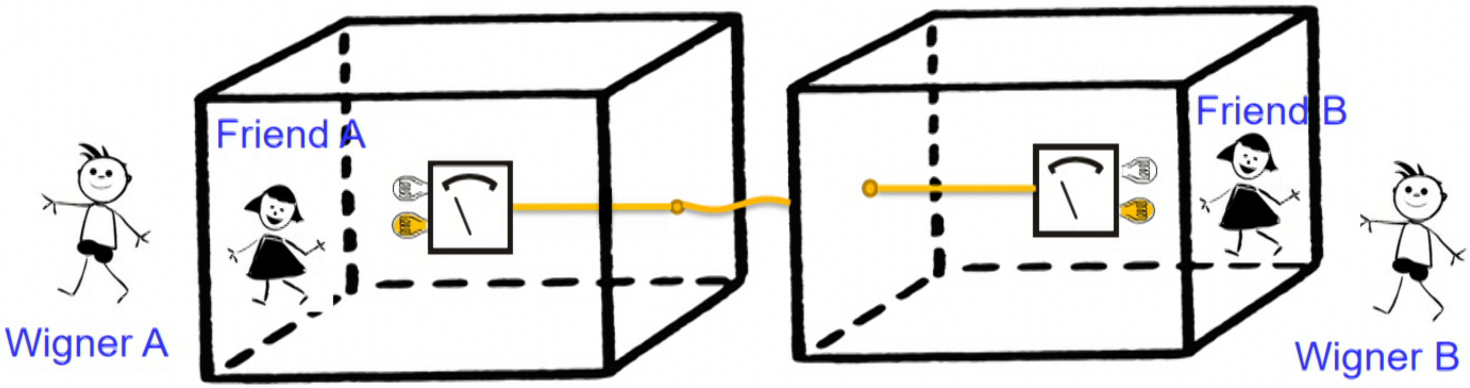

F_A and F_B perform measurements of the spins along z.

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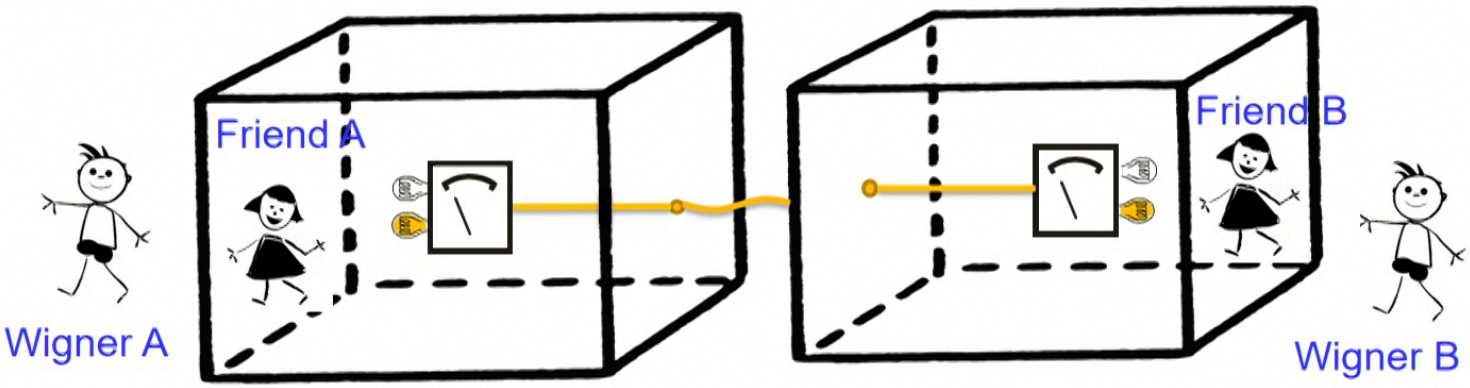

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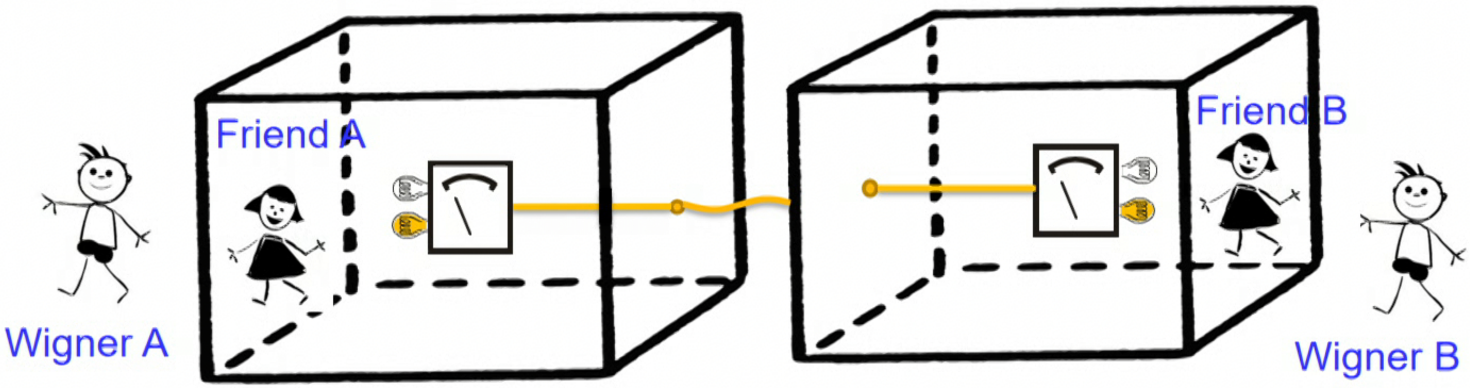

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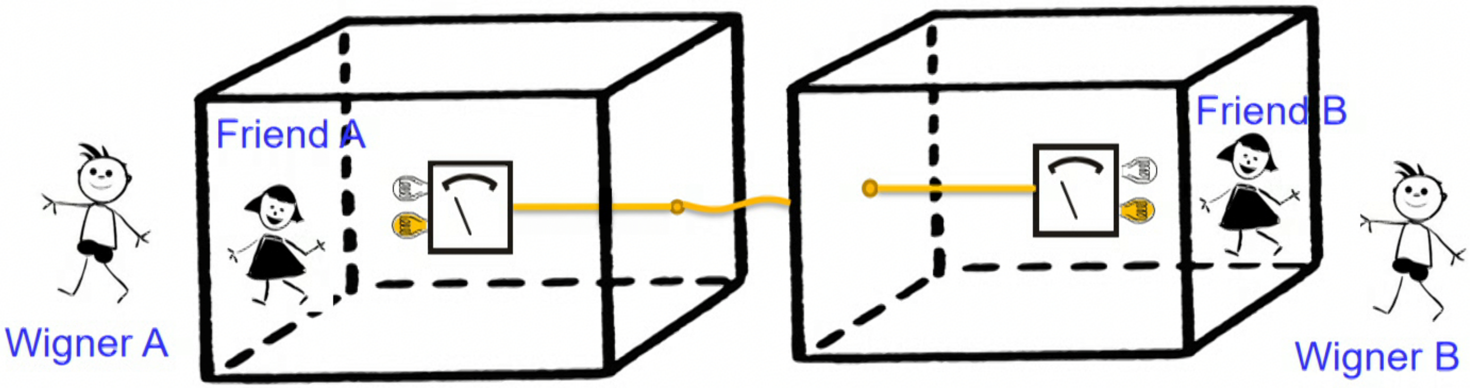

„Observation of the z-spin": F's fact

$$A_1 = A_z = |A \text{ “}up\text{”}\rangle\langle A \text{ “}up\text{”}| - |A \text{ “}down\text{”}\rangle\langle A \text{ “}down\text{”}|$$

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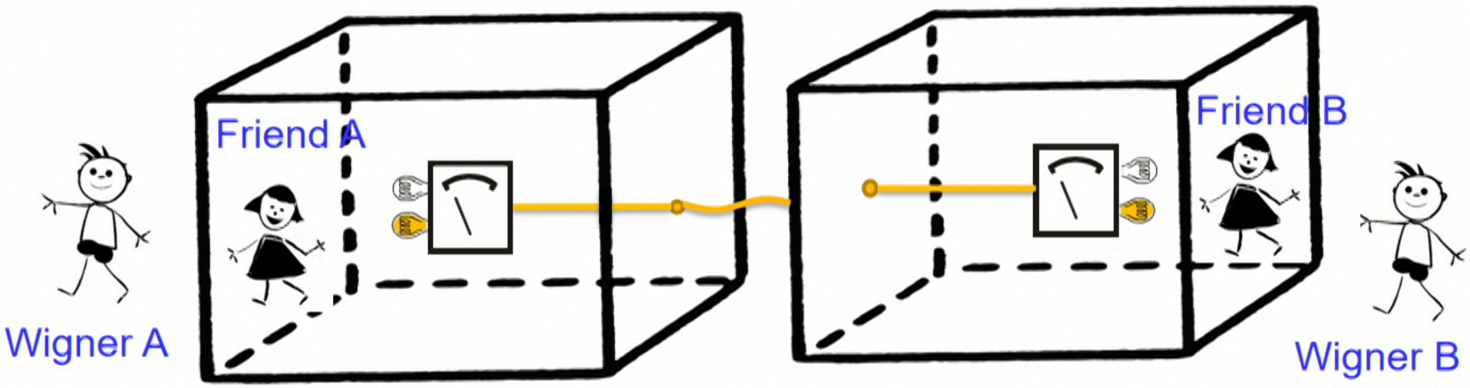

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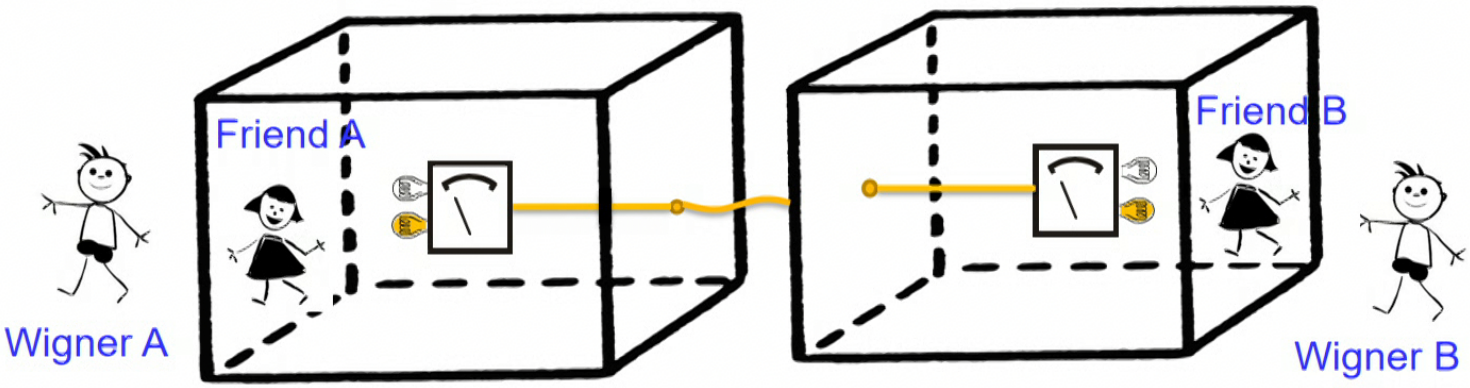
„Observation of the x-spin“: W‘s fact

$$A_2 = A_x = |A \text{ ``}up\text{''}\rangle\langle A \text{ ``}down\text{''}| + |A \text{ ``}down\text{''}\rangle\langle A \text{ ``}up\text{''}|$$

Bell's test for Wigners & Friends



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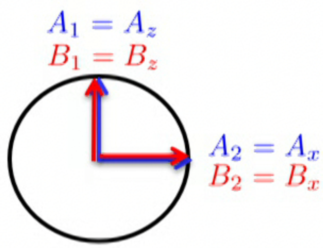

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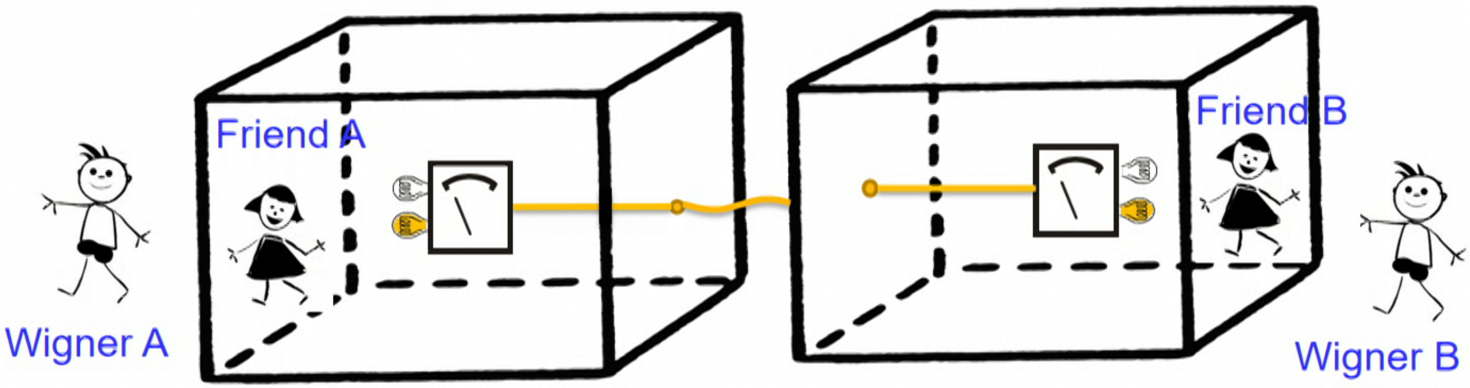

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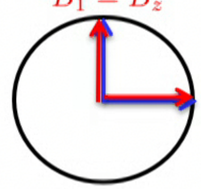

$$|\langle A_1 B_1\rangle + \langle A_1 B_2\rangle + \langle A_2 B_1\rangle - \langle A_2 B_2\rangle \leq 2 \quad \textbf{LHV}$$

$$2\sqrt{2} \quad \textbf{QM}$$

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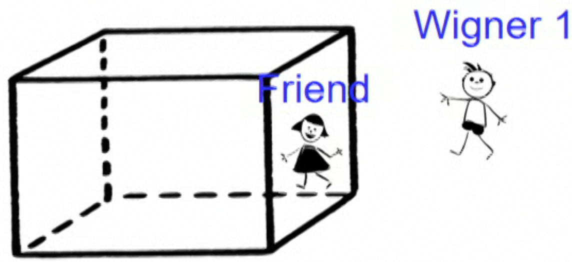

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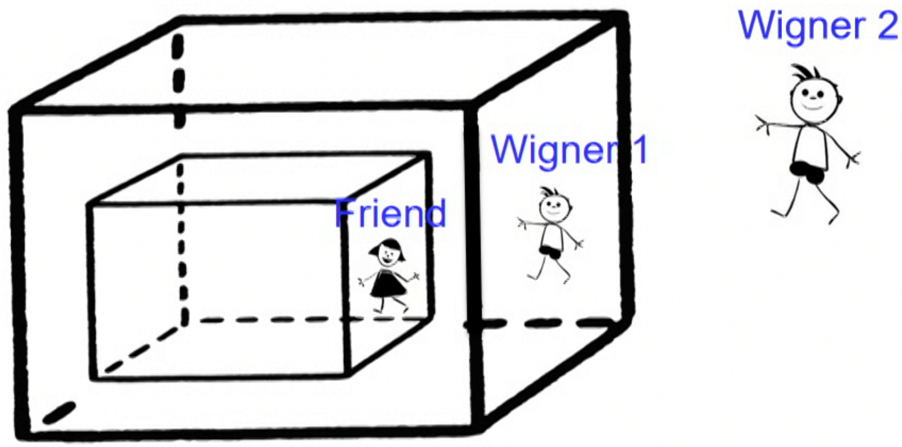

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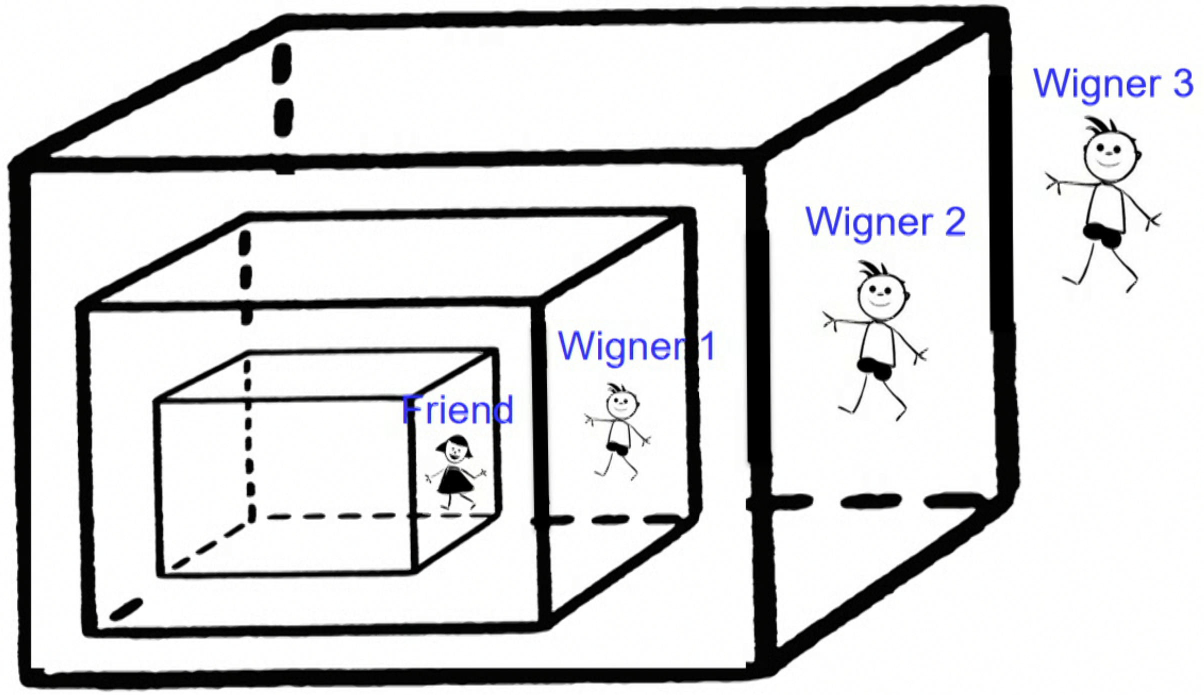

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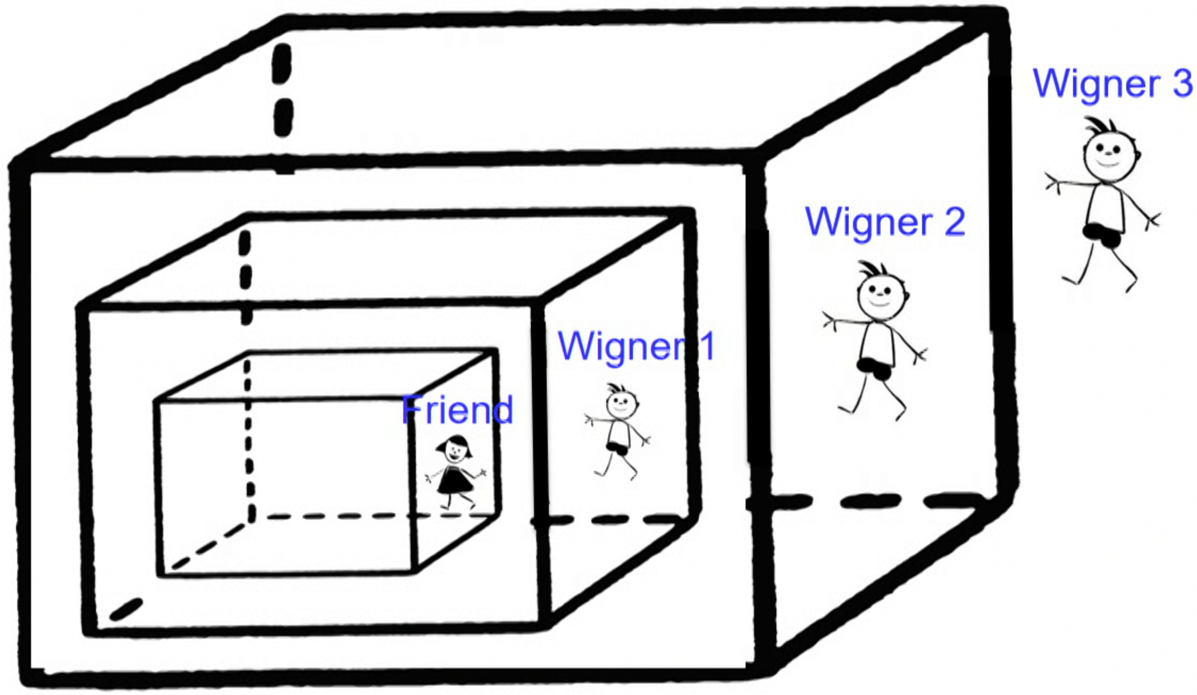

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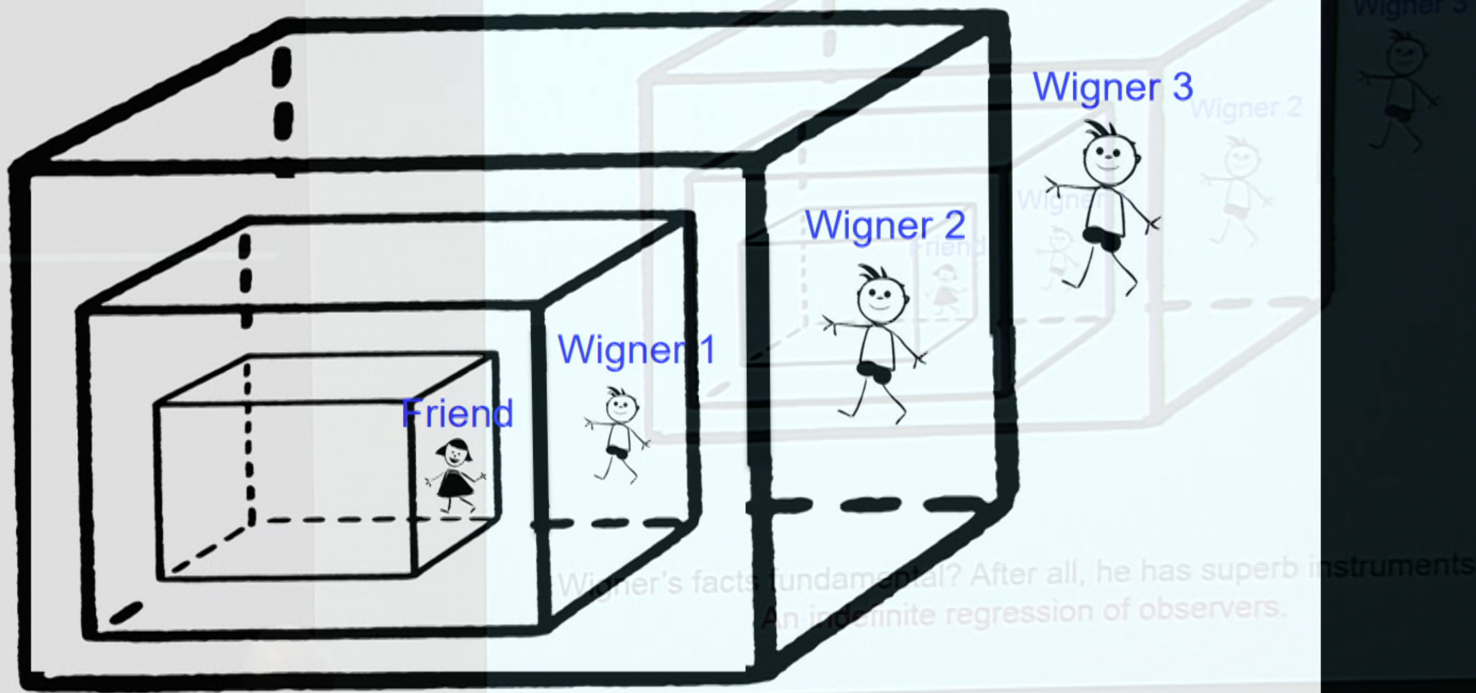

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An indefinite regression of observers.

A way out?: „*The wave function of the universe*“

Č.B., arXiv:1507.05255, arXiv: 1804.xxxxx

A way out?: „*The wave function of the universe*“

Another way out: *There are no “facts of the world” per se, but only relative to observers*.

Copenhagen (a version of it) , QBism, Relational int.

Č.B., arXiv:1507.05255, arXiv: 1804.xxxxx

Part 2

Frauchiger & Renner paper

arXiv:1604.07422

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- **(QT) Compliance with quantum theory:** T forbids all measurement results that are forbidden by standard quantum theory (and this condition holds even if the measured system is large enough to contain itself an experimenter).

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$\Rightarrow$ "Single-world interpretations of quantum theory cannot be self-consistent."

Frauchiger & Renner paper

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The argument combines a set of statements S_1, S_2, S_3 and S_4 that involve different observers F_1, F_2, A and W and can be drawn on the basis of theory T:

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The argument combines a set of statements S_1, S_2, S_3 and S_4 that involve different observers F_1, F_2, A and W and can be drawn on the basis of theory T:

S_1: If F_1 sees $r = t$, then W sees $w \neq ok$.

S_2: If F_2 sees $z = +$, then F_1 sees $r = t$.

S_3: If A sees $x = ok$, then F_2 sees $z = +$.

S_4: W sees $w = ok$ and is told by A that $x = ok$.

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SC enables a "collapse others' knowledge into one's own"*:

"W knows that A knows that F_2 knows that F_1 knows that $w \neq ok$"

$\Rightarrow$ *"W knows that $w \neq ok$"*

*R. Renner, private communication

Frauchiger & Renner paper

arXiv:1604.07422

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$\mathbf{S_1}$: $R \Rightarrow S$

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$[P \wedge (P \Rightarrow Q) \wedge (Q \Rightarrow R) \wedge (R \Rightarrow S)] \Rightarrow$ S, which is in a contradiction with the directly observed: $\neg$S: "W sees $w = ok$"

Frauchiger & Renner paper

arXiv:1604.07422

SC is also not satisfied in the theory of relativity: Every inertial observer claims that her/his clock ticks slower than that of a moving partner.

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The statements **have only meaning with respect to the specific, observer-dependent, measurement procedure** defining “simultaneity”.

Similarly, the quantum states referring to outcomes of different observers in a Wigner-friend type of experiment have only meaning with respect to observers’ specific experimental arrangements, in agreement with Bohr's idea of contextuality.

Frauchiger & Renner paper

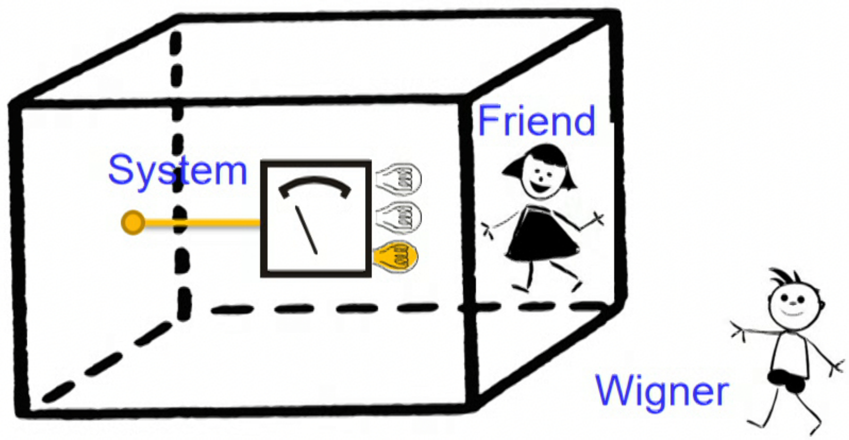
arXiv:1604.07422

Conceptual value: The result points to the necessity to differentiate between ones' knowledge about direct observations and ones' knowledge about others' knowledge that is compatible with physical theories.

Important for **development of Bayesian inference** in situations as in the Wigner-friend experiment.

Part 3

F can find out if she is in a superposition



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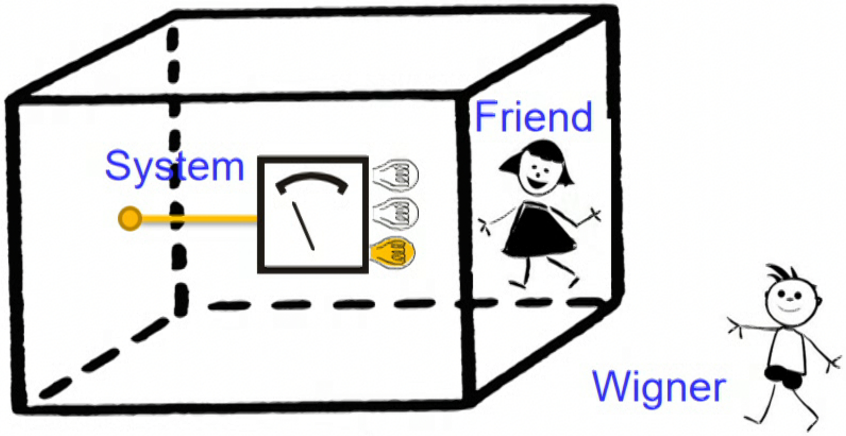

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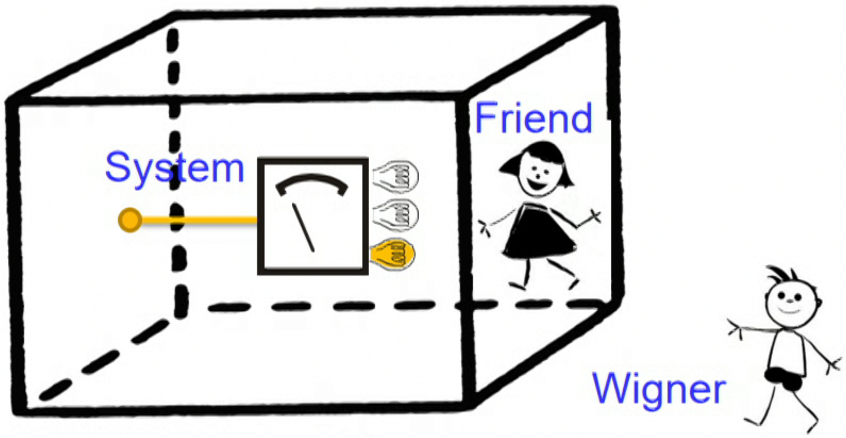

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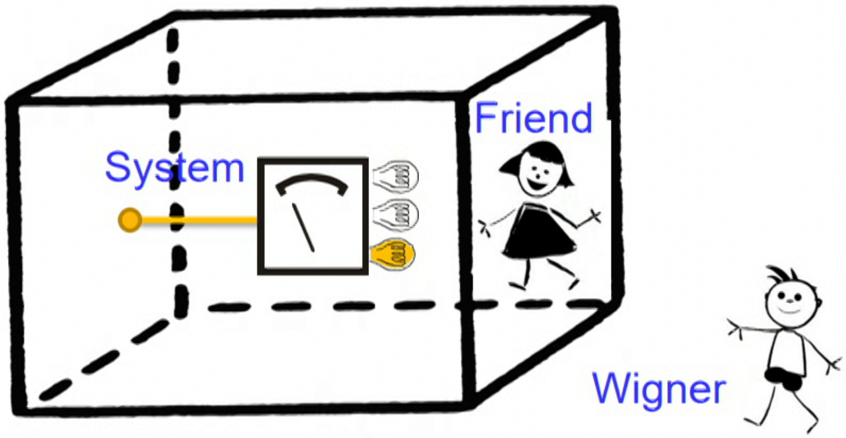

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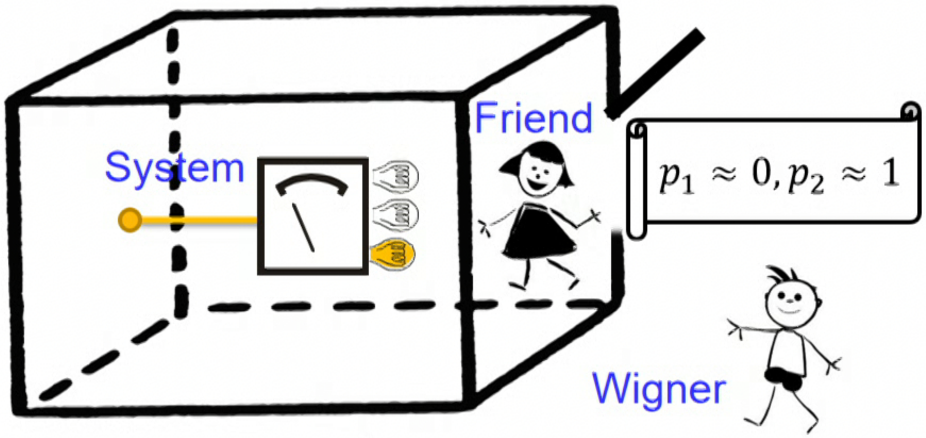

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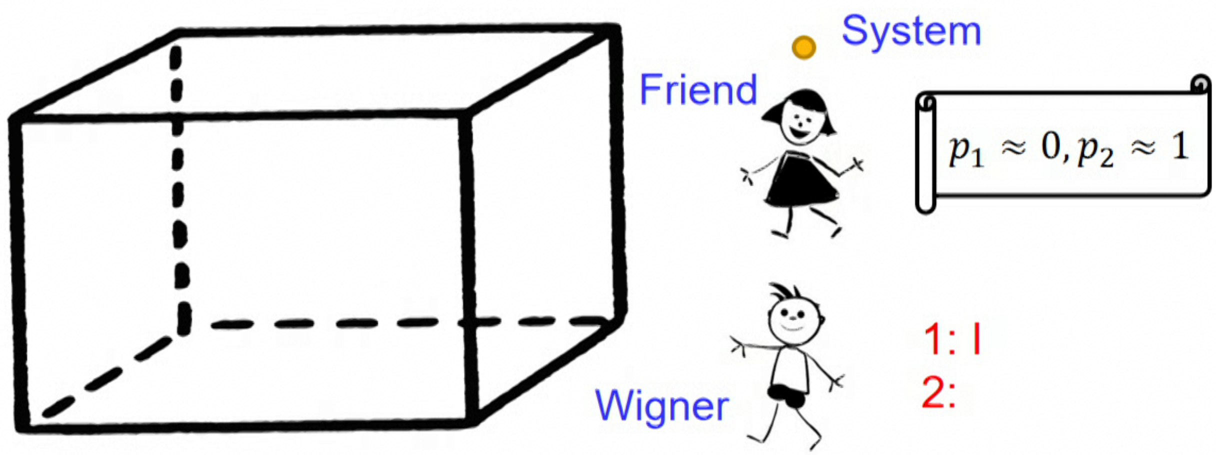

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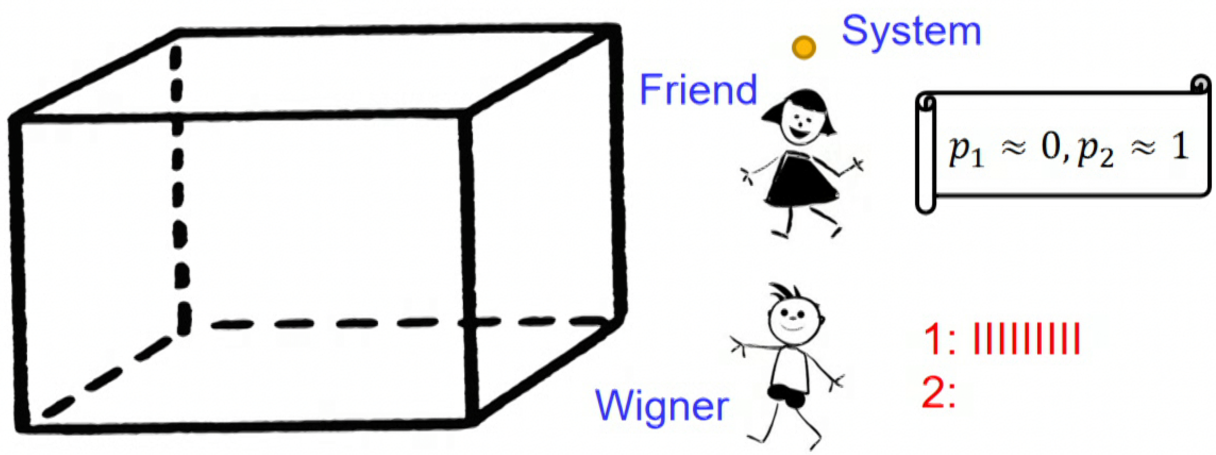

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In both cases there is an element of dissatisfaction as regarding to how an observer should practice QT.

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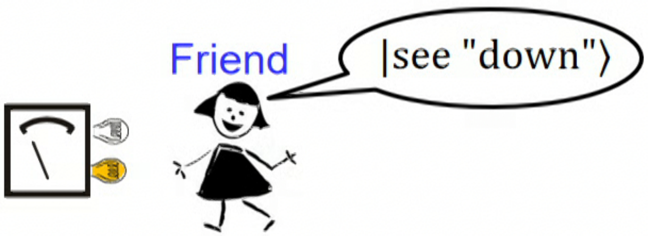

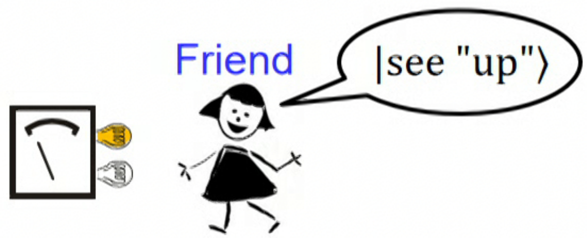

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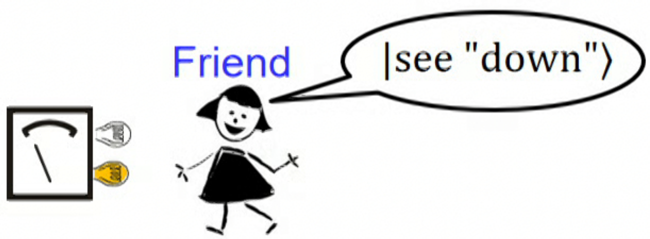
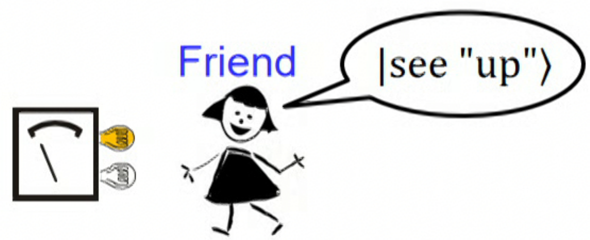
„Problems" arise if the predictions are about outcomes involving the "Schrödinger-cat states",

$$\frac{1}{\sqrt{2}}(|see\ \text{"}up\text{"}\rangle_F + e^{i\Phi}|see\ \text{"}down\text{"}\rangle_F)$$





Conclusions

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Č.B., arXiv:1507.05255, arXiv:1804.00749

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- **„Self-consistency“** of Rauchiger-Renner might be too restrictive requirement on a physical theory.
- „Standard“ (textbook) quantum theory seems not to be appropriate for making predictions involving observers‘ memories (see V. Baumann, S. Worf, arXiv:1710.07212)

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