

Title: Foundations of Quantum Mechanics - Lecture 8

Date: Jan 11, 2012 11:30 AM

URL: <http://pirsa.org/12010047>

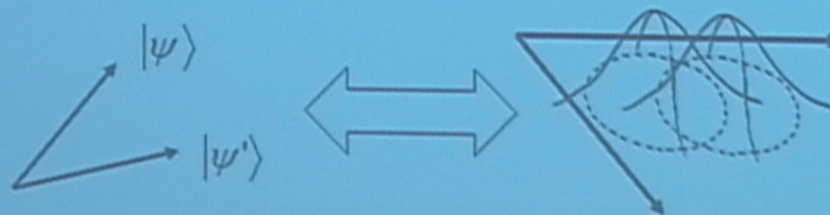
Abstract:



Classical statistical theory
+
fundamental restriction on statistical distributions
↓
A large part of quantum theory

In the sense of reproducing the operational predictions

In the resulting model
quantum states are states of incomplete knowledge



Categorizing quantum phenomena

Those arising in a restricted
statistical classical theory

Noncommutativity
Entanglement
Ambiguity of mixtures
EPR Steering
Collapse
Coherent superposition
Teleportation
No cloning

Others...

Type 1 Nonclassicality

Those not arising in a restricted
statistical classical theory

Bell inequality violations
Contextuality
Computational speed-up
Certain aspects of items on the left
Others...

Type 2 Nonclassicality

Categorizing quantum phenomena

Those arising in a restricted
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Others...

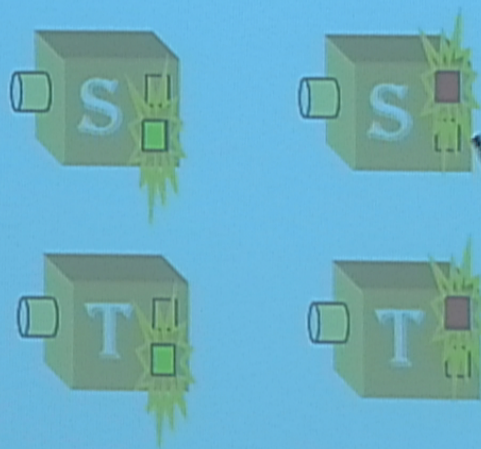
Type 1 Nonclassicality

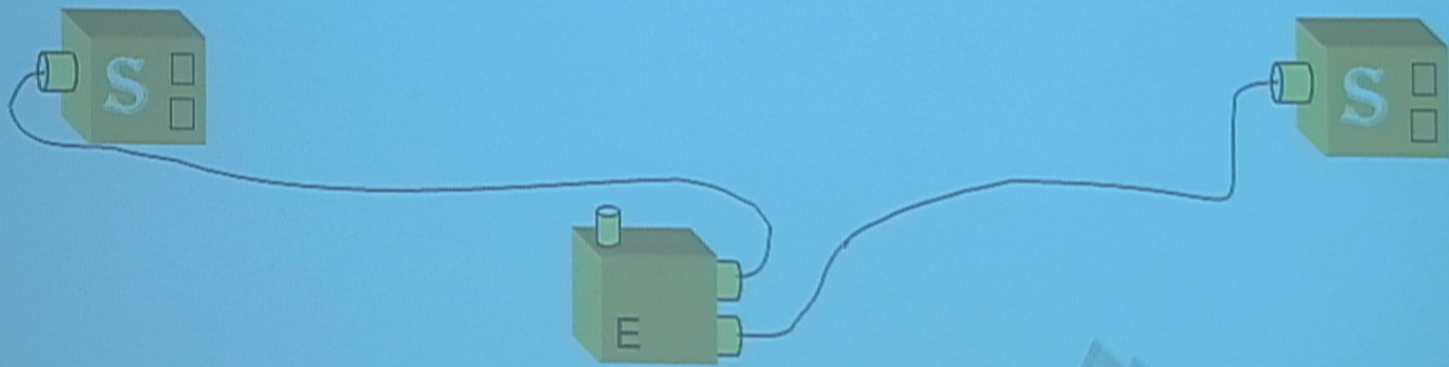
Those not arising in a restricted
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Bell inequality violations
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Type 2 Nonclassicality

A pair of two-outcome measurements

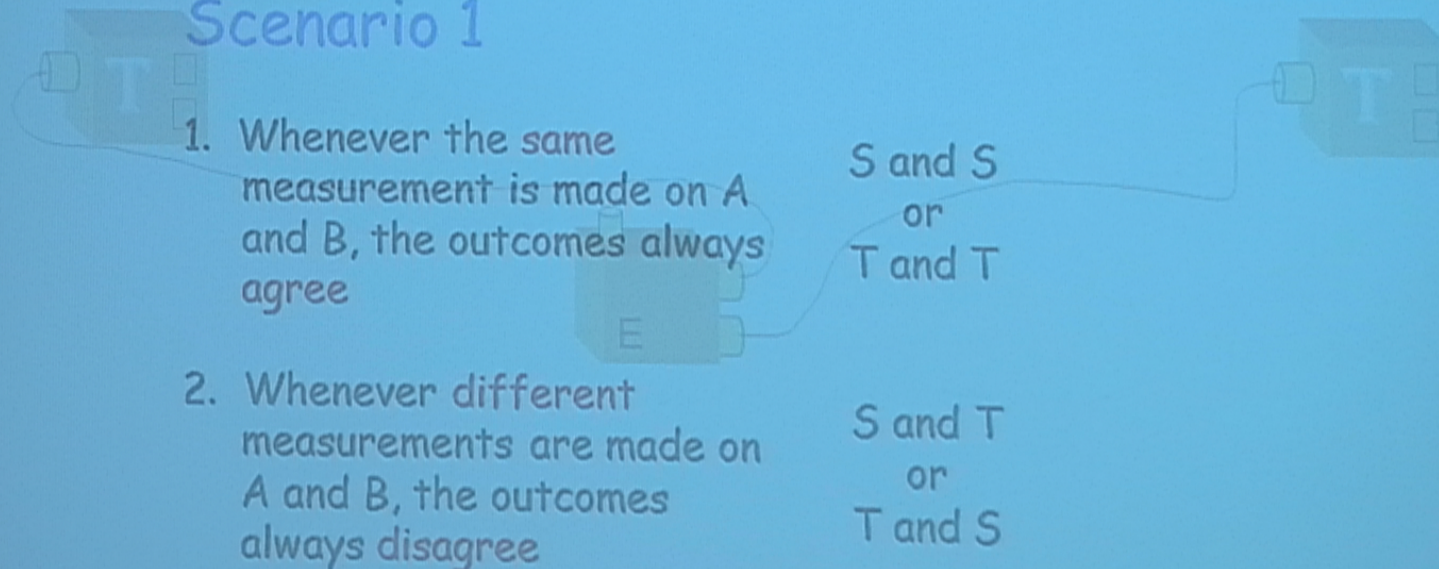


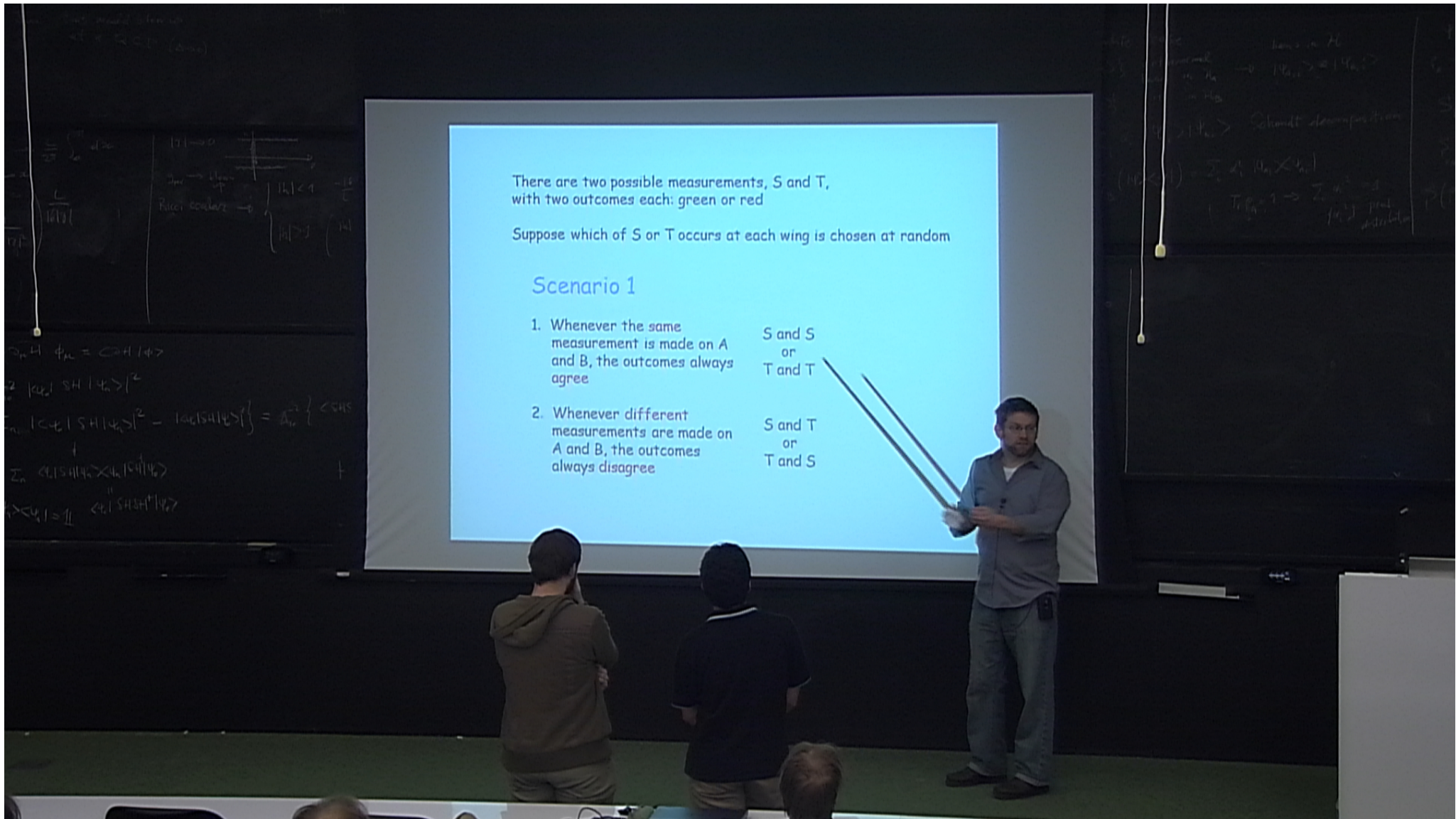


There are two possible measurements, S and T,
with two outcomes each: green or red

Suppose which of S or T occurs at each wing is chosen at random

Scenario 1





There are two possible measurements, S and T,
with two outcomes each: green or red

Suppose which of S or T occurs at each wing is chosen at random

Scenario 1

1. Whenever the same measurement is made on A and B, the outcomes always agree
2. Whenever different measurements are made on A and B, the outcomes always disagree

S and S
or
T and T

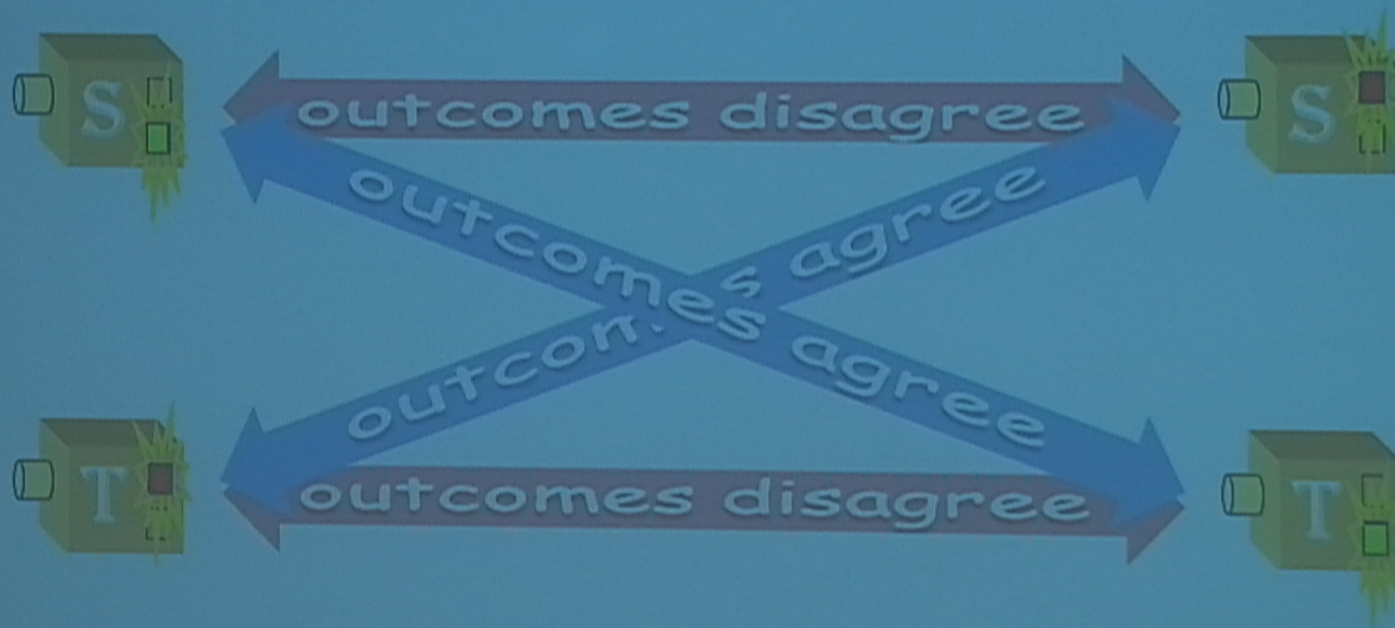
S and T
or
T and S

There are two possible measurements, S and T,
with two outcomes each: green or red

Suppose which of S or T occurs at each wing is chosen at random

Scenario 2

1. Whenever the **same** measurement is made on A and B, the outcomes always **disagree**
S and S
or
T and T
2. Whenever different measurements are made on A and B, the outcomes always **agree**
S and T
or
T and S



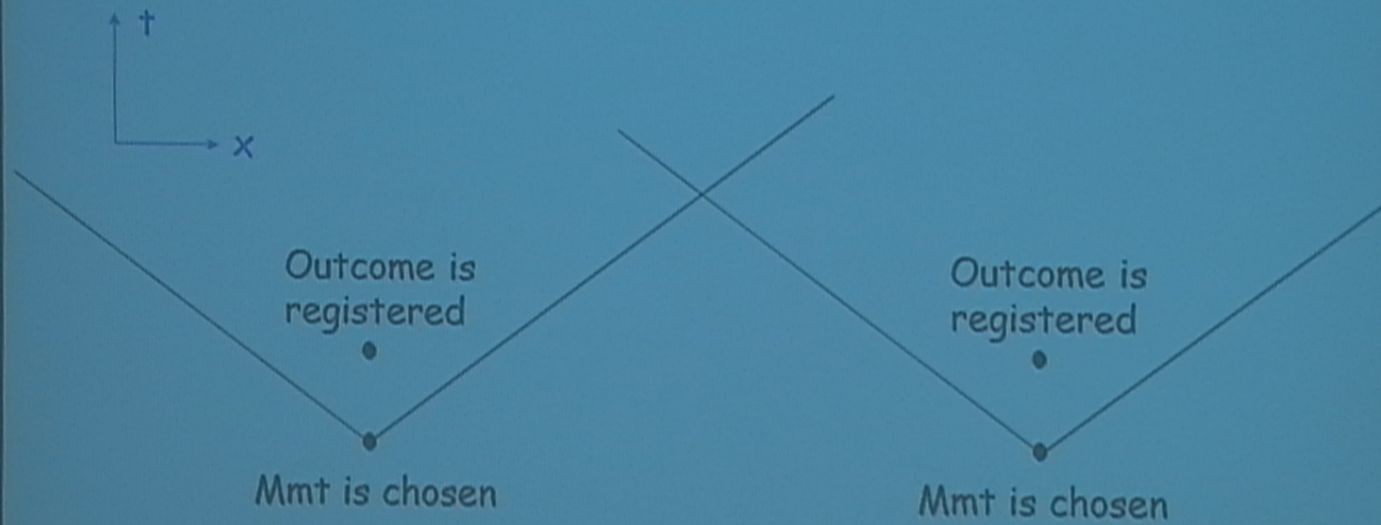
There are two possible "measurements", S and T,
with two outcomes each: green or red

Suppose which of S or T occurs at each wing is chosen at random

Scenario 3

- | | |
|--|---|
| 1. Whenever the measurement
T is made on both A and B,
the outcomes always
disagree | T and T |
| 2. Otherwise, the outcomes
always agree | S and S
or
S and T
or
T and S |

Tension with the theory of relativity



Experiment can distinguish:

- 1) the quantum predictions
- 2) the predictions of any locally causal theory

If the particles have access to randomness when deciding on their strategy, can it help them to generate the correlations?

No. The degree of correlation can only be the same or less.

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If the particles have access to *local* randomness (i.e. independent randomness at the two wings), can it help them to generate the correlations?

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If the detector inefficiencies are sufficiently high (sometimes there is no outcome), can particles obeying local causality simulate the correlations on the detected pairs?

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Yes. This is the detector loophole.

Is there a problem if the choice of measurement is made too early?

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Is there a problem if the choice of measurement is made too early?

Yes. This is the locality loophole.

When seeking a realist explanation of these experiments, the mystery is the tension between:

- 1) No superluminal signalling (independence of statistics at one wing on choice of measurement at the other)
- 2) The necessity of superluminal influences (dependence of particular outcomes at one wing on choice of measurement at the other)

When seeking a realist explanation of these experiments, the mystery is the tension between:

- 1) No superluminal signalling (independence of statistics at one wing on choice of measurement at the other)
- 2) The necessity of superluminal influences (dependence of particular outcomes at one wing on choice of measurement at the other)

$$p(\text{success}) = \frac{1}{4} [p(\text{agree}|SS) + p(\text{agree}|ST) \\ + p(\text{agree}|TS) + p(\text{disagree}|TT)]$$

Realist theories that are locally causal predict

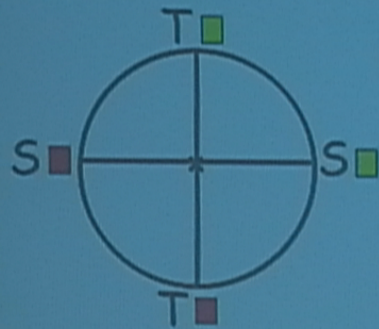
$$p(\text{success}) \leq 0.75$$

A Bell Inequality

Quantum theory predicts that one can achieve

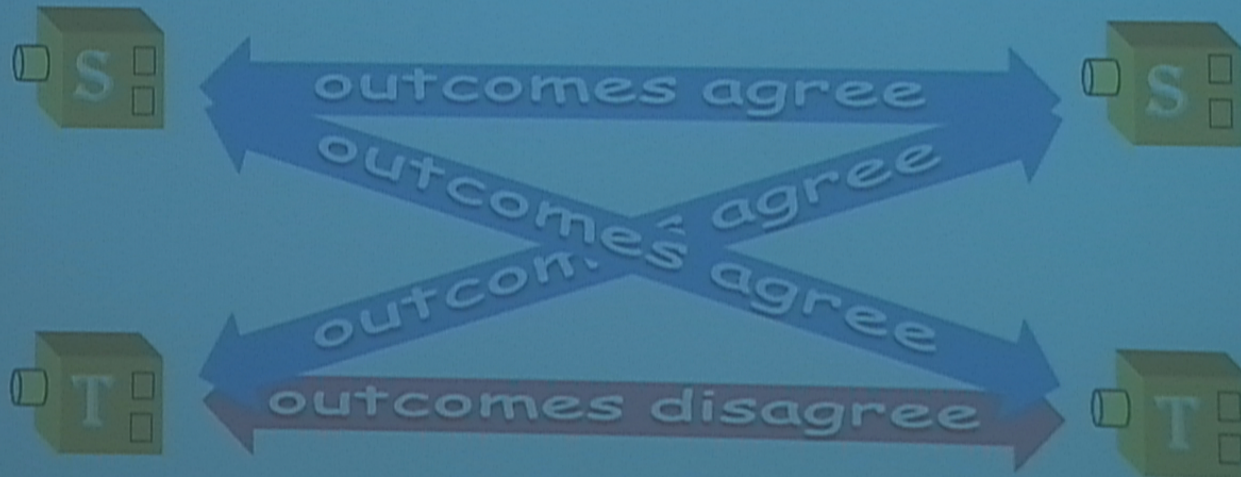
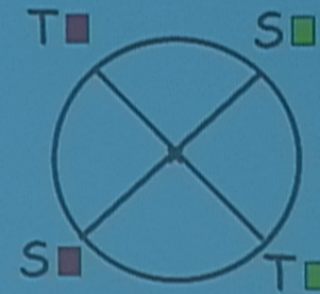
$$p(\text{success}) \simeq 0.85$$

The Bell-inequality violation in quantum theory

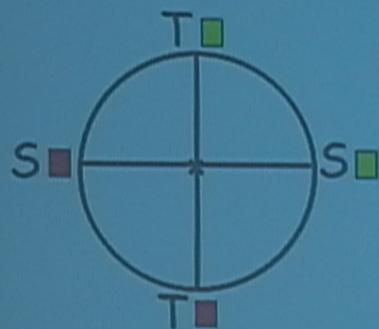


$$|\psi\rangle_{AB} = \frac{1}{\sqrt{2}}(|0\rangle_A|0\rangle_B + |1\rangle_A|1\rangle_B)$$

$$p(\text{success}) = \frac{1}{2} + \frac{1}{2\sqrt{2}} \approx 0.85$$

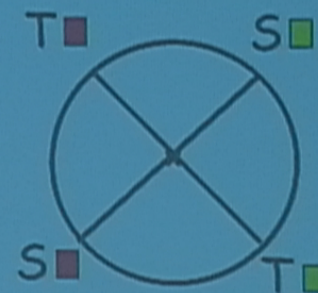


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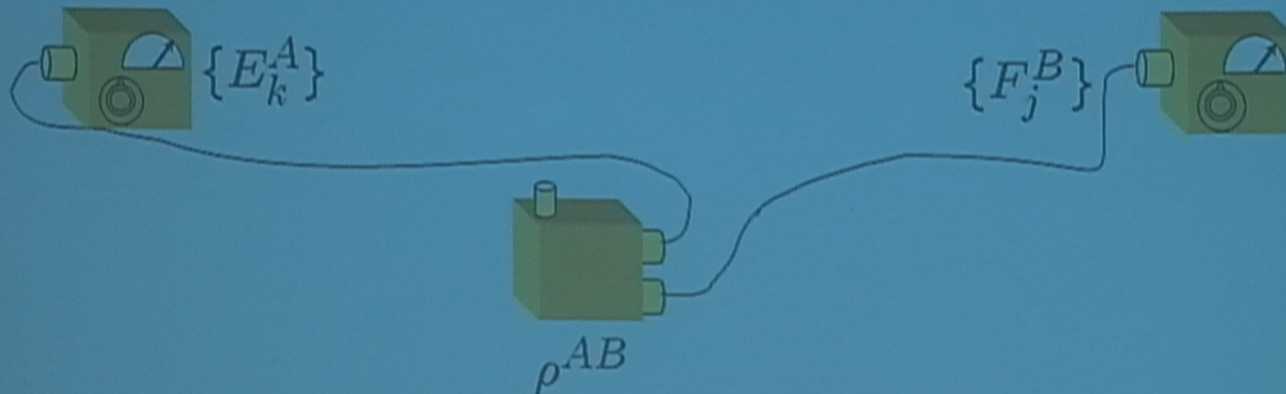


$$\begin{aligned} {}_A\langle +\hat{n}|\psi\rangle_{AB} &= [\cos(\theta/2){}_A\langle 0| + \sin(\theta/2){}_A\langle 1|] \frac{1}{\sqrt{2}}(|0\rangle_A|0\rangle_B + |1\rangle_A|1\rangle_B) \\ &= \cos(\theta/2)|0\rangle_B + \sin(\theta/2)|1\rangle_B \\ &= |+\hat{n}\rangle_B \end{aligned}$$

$$|\langle +\hat{n}|_A \langle +\hat{m}|_B |\psi\rangle_{AB}|^2 = |\langle +\hat{m}| + \hat{n}\rangle|^2 = \cos^2(\theta/2)$$

$$\begin{aligned} p(\text{agree}|SS) &= p(\text{agree}|ST) = p(\text{agree}|TS) = p(\text{disagree}|TT) \\ &= \cos^2(\pi/8) = \frac{1}{2} + \frac{1}{2\sqrt{2}} \end{aligned}$$

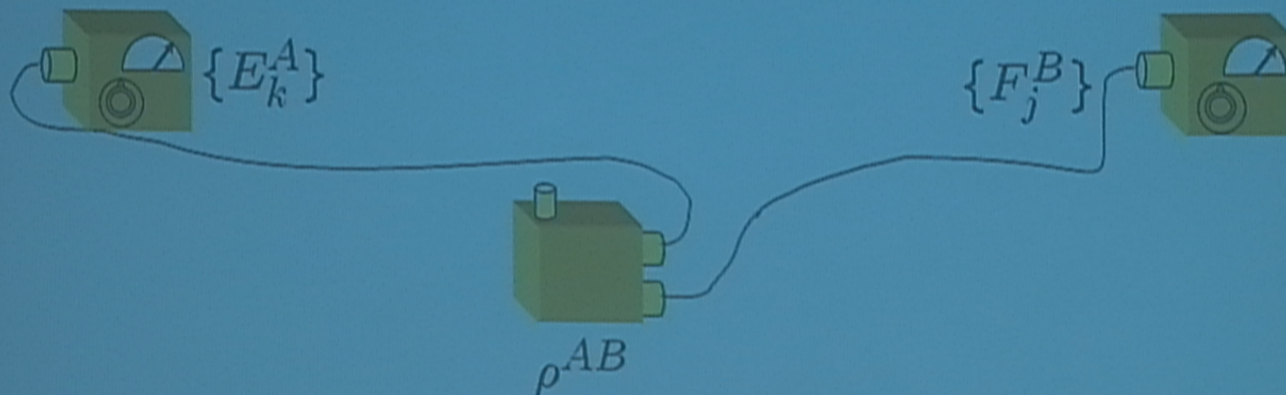
No signalling in quantum theory



$$\begin{aligned} p(j) &= \sum_k p(k, j) \\ &= \sum_k \text{Tr}_{AB} [(E_k^A \otimes F_j^B) \rho^{AB}] \\ &= \text{Tr}_{AB} [(I^A \otimes F_j^B) \rho^{AB}] \quad \text{Independent of choice of} \\ &\quad \text{measurement at A} \end{aligned}$$

Note $[E_k^A \otimes I^B, I^A \otimes F_j^B] = 0$ for A and B space-like separated

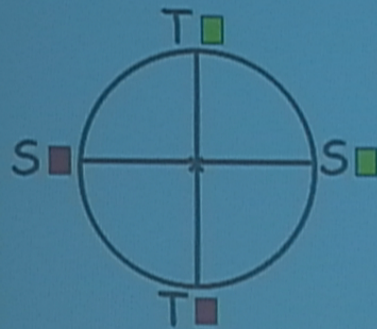
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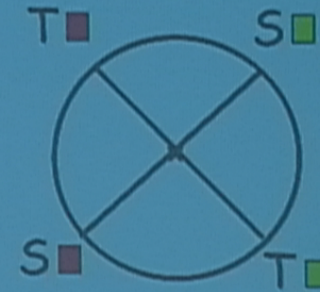
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The Bell-inequality violation in quantum theory



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$$p(\text{success}) = \frac{1}{2} + \frac{1}{2\sqrt{2}} \simeq 0.85$$



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