Can a Future Choice Affect a Past Measurement's Outcome?

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ABL

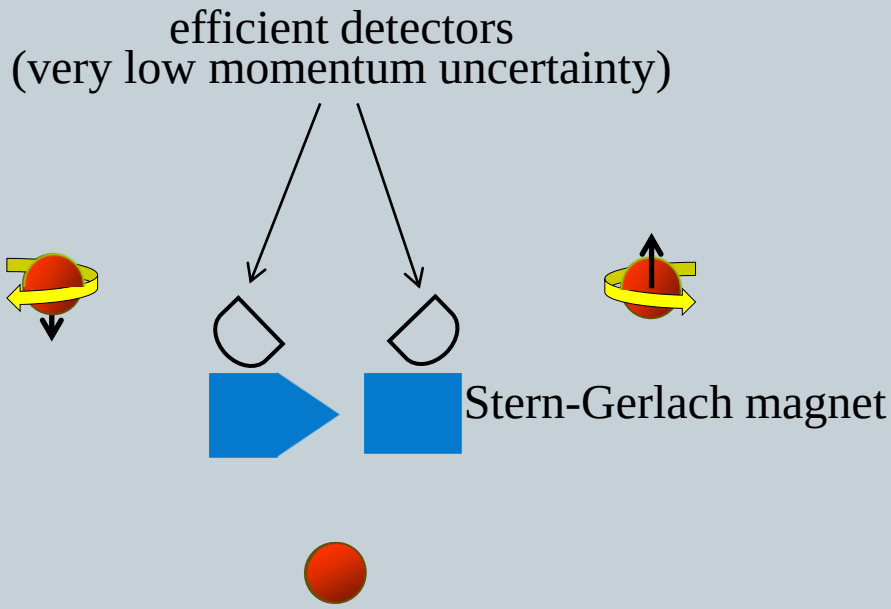
- In their 1964 paper Aharonov, Bergmann and Lebowitz introduced a time symmetric quantum theory.
- By performing both pre- and postselection ($|\psi(t')\rangle$ and $\langle\Phi(t'')|$ respectively) they were able to form a symmetric formula for the probability of measuring the eigenvalue c_j of the observable c:

$$P(c_j) = \frac{\langle\Phi(t'')|c_j\rangle\langle c_j|\psi(t')\rangle}{\sum_i \langle\Phi(t'')|c_i\rangle\langle c_i|\psi(t')\rangle}$$

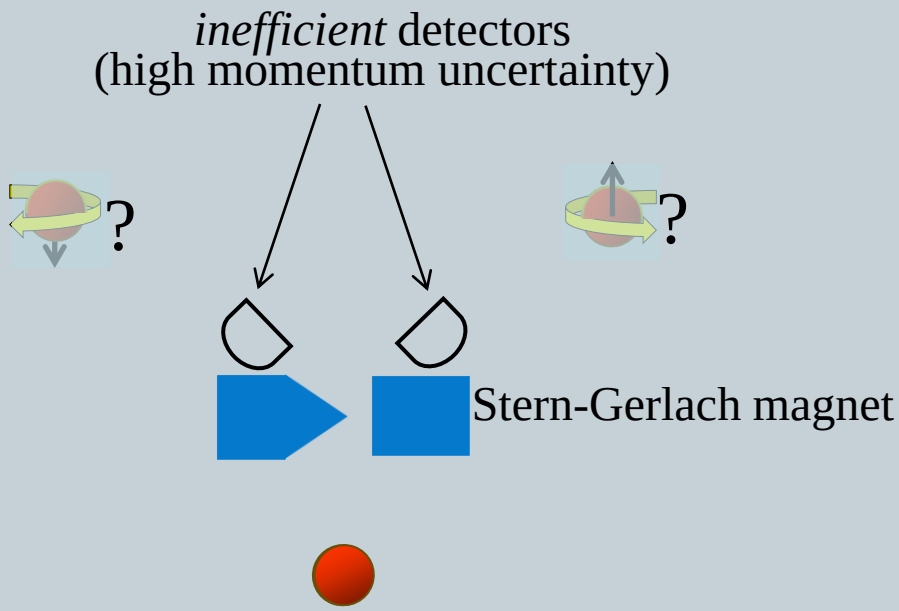
TSVF

- This idea was later widened to a new formalism of quantum mechanics: the Two-State-Vector Formalism (TSVF).
- The TSVF suggests that in every moment, probabilities are determined by two state vectors which evolved (one from the past and one from the future) towards the present.
- This is a hidden variables theory, in that it completes quantum mechanics, but a very subtle one as we shall see.

Strong Measurement

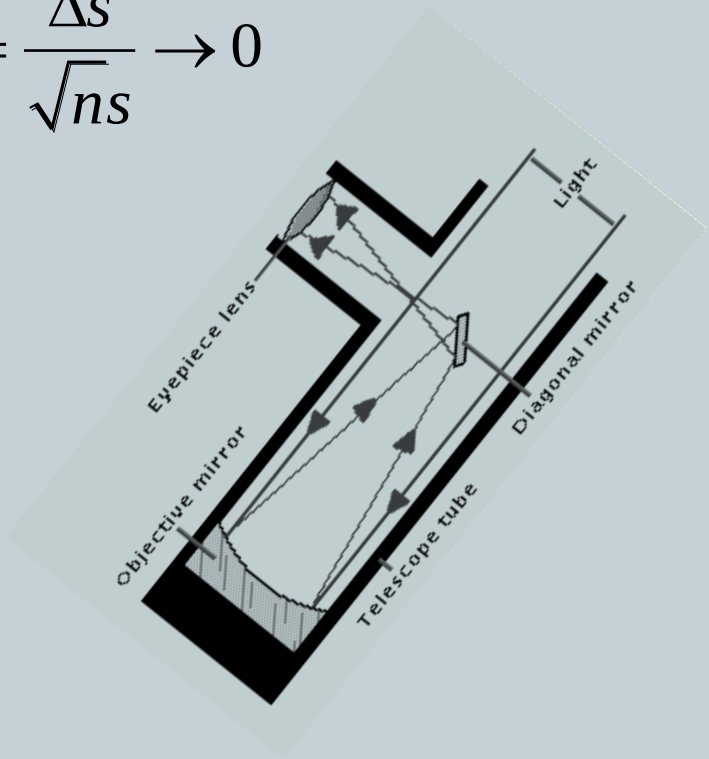


Weak Measurement - I

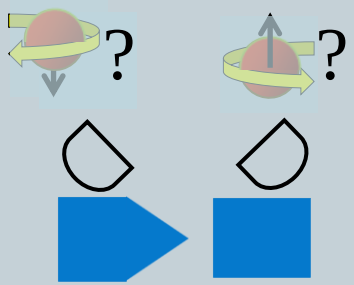


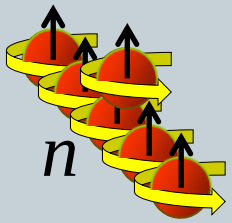
Why Weak Measurement?

$$\frac{\Delta s}{s} \Rightarrow \frac{\sqrt{n}\Delta s}{ns} = \frac{\Delta s}{\sqrt{n}s} \to 0$$



$$[\sigma_i, \sigma_j] = 2i\varepsilon_{ijk}\sigma_k$$





Weak Measurement - II

- The Weak Measurement can be described by the Hamiltonian:

$$H(t) = \frac{\lambda}{\sqrt{N}} g(t) A_s P_d$$

- In order to get blurred results we choose a pointer with zero expectation and $\delta >> \frac{\lambda}{\sqrt{N}}$ standard deviation.
- In that way, when measuring a single spin we get most results within the wide range $\frac{\lambda}{\sqrt{N}} \pm \delta$, but when summing up the $N/2\uparrow$ results, most of them appear in the narrow range $\lambda\sqrt{N}/2 \pm \delta\sqrt{N}/\sqrt{2}$ agreeing with the strong results when choosing $\lambda >> \delta$.

A Classical Experiment with Causality: Coins

Weighing results on evening:
highly accurate, sliced into *I/II*

N/2 = 500,000

I

1=t 2=h 3=h 4=t 5=h 6=t 7=h 8=h 9=h …*n*=t

II

N/2 = 500,000

"head"
or
"tail"?

N/2 = 500,000

1=h 2=t 3=h 4=t 5=t 6=t 7=h 8=h 9=t …*n*=h

Flipping results on morning:
inaccurate but **engraved in stone**

N = 1,000,000

N/2 = 500,000

$P($  $) = P($  $)$

A Quantum Experiment With Causality - Spins

498,688

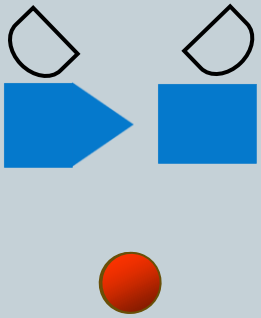
I

1=↑ 2=↓ 3=↓ 4=↑ 5=↓ 6=↑ 7=↓ 8=↓ 9=↓ …*n*=↑

II

501,312

Strong measurements' results on evening: highly accurate, sliced into *I/II*



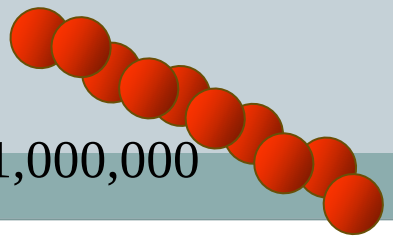
498,688

1=↑ 2=↓ 3=↓ 4=↑ 5=↓ 6=↓ 7=↑ 8=↓ 9=↓ …*n*=↑

Weak measurements' results on morning: inaccurate but **engraved in stone**

501,312

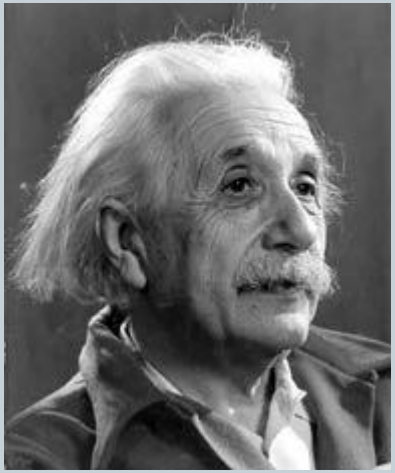
~ *N*/2 =~ *N*/2



N = 1,000,000

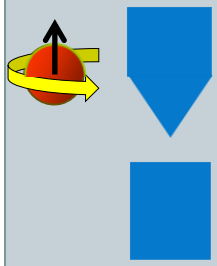
"up" or "down"?

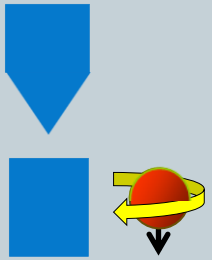
Hidden Variables?



Yes, but of a very subtle kind

The EPR Experiment





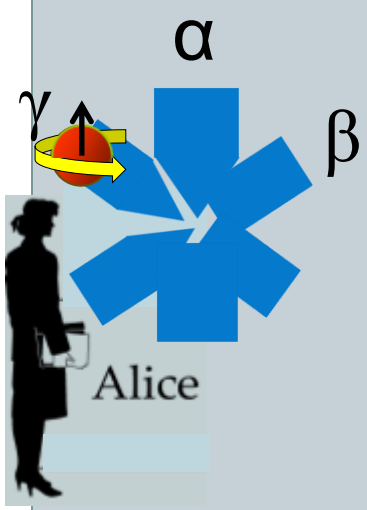
A pre-existing spin, only to be passively *detected*?

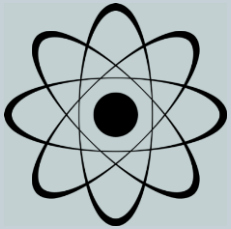
or

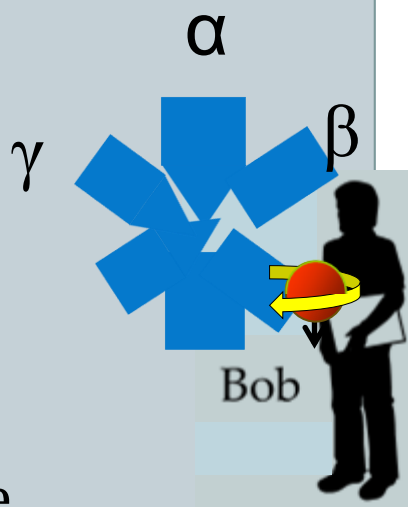
A superposed state,
to *become definite* upon measurement?

J.S Bell's Proof

Alice and Bob can freely choose *at the last moment* the spin orientation to be measured.





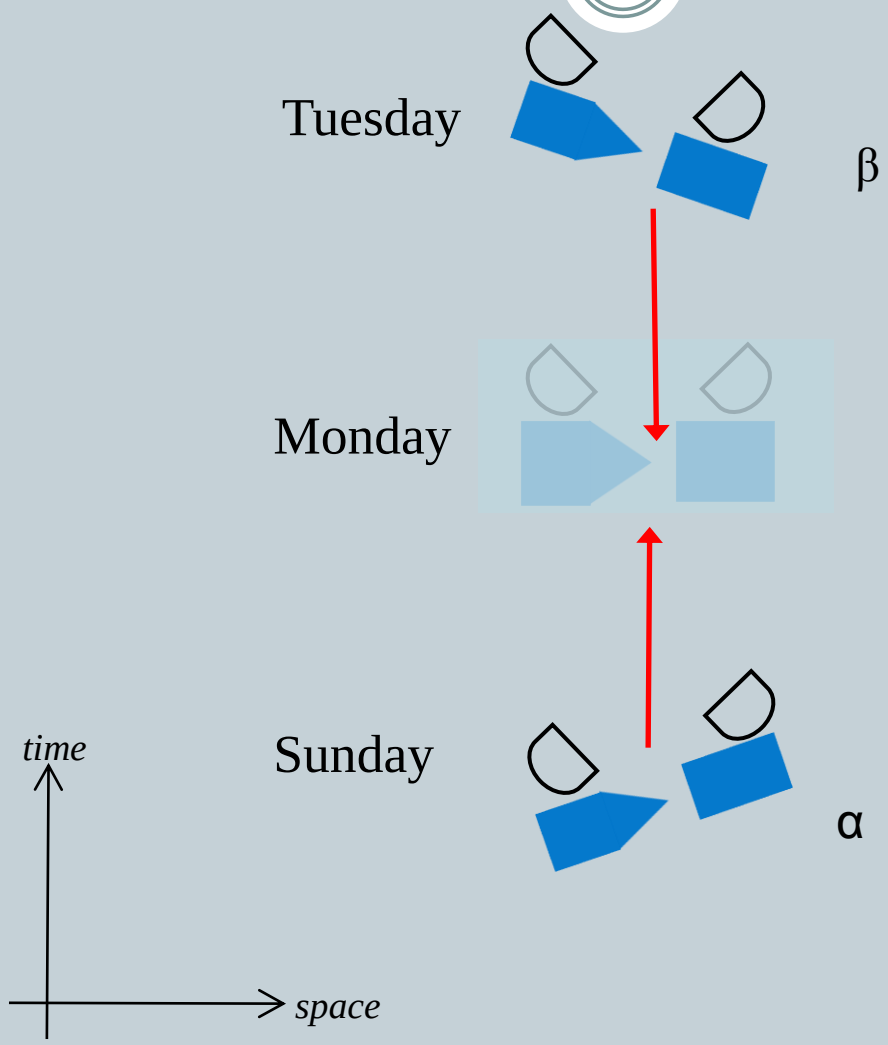


Correlations or anti-correlations will emerge depending on the *relative angle* between magnets

Conclusion:

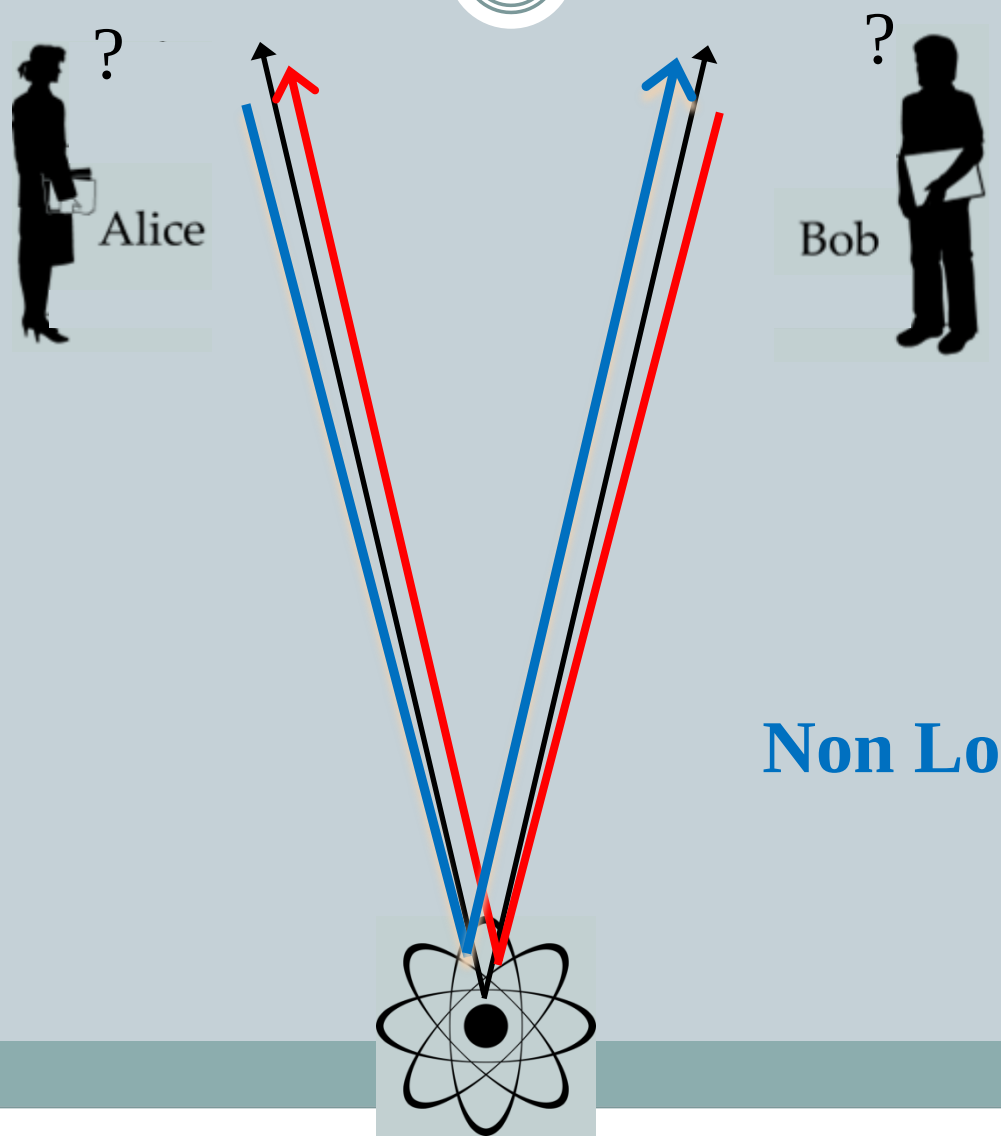
No pre-established spins can exist for every possible pair of choices

The TSVF – New Account Of Time



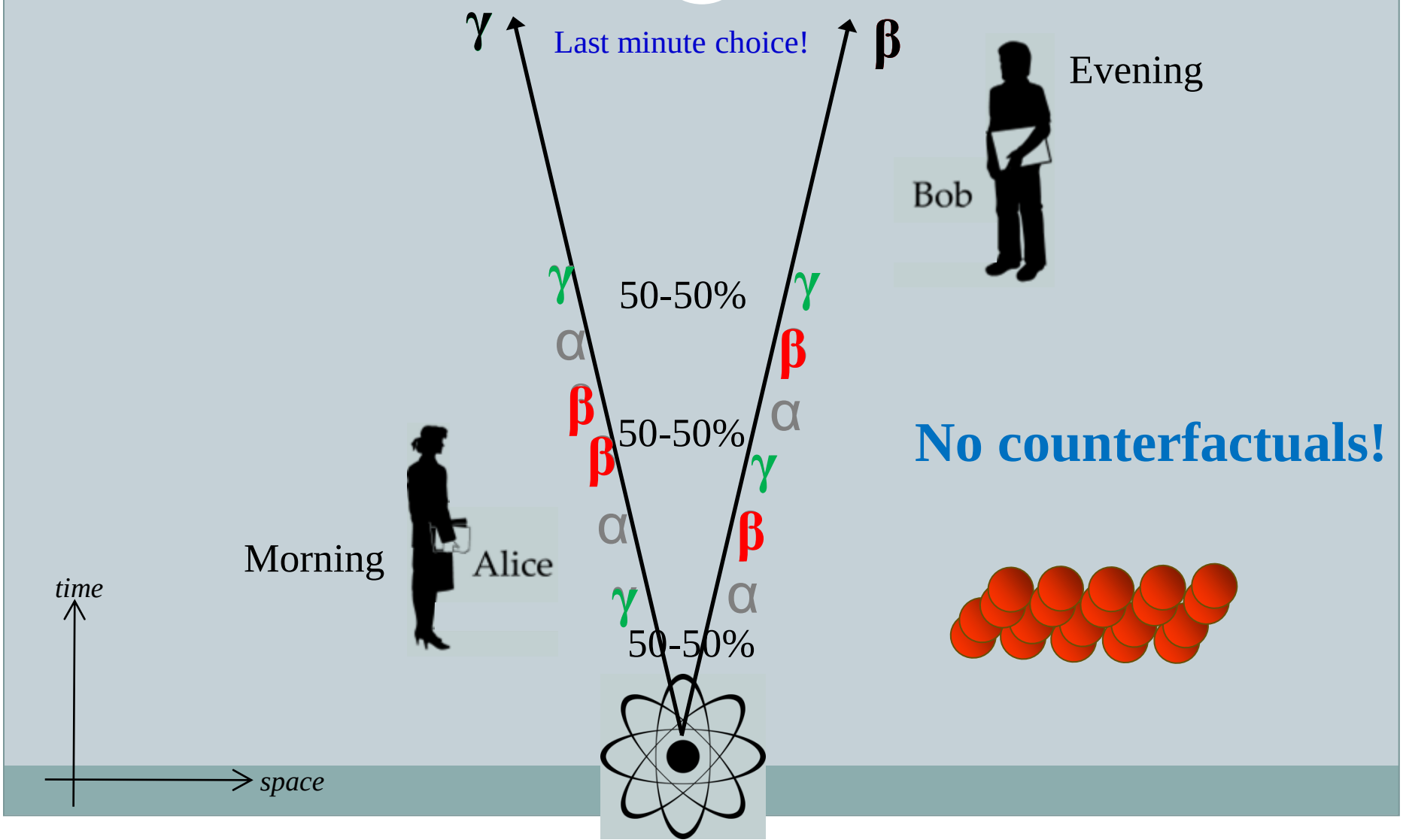
$$[\sigma_i, \sigma_j] = 2i\varepsilon_{ijk}\sigma_k$$

Quantum Experiment with Causality: EPR Pairs

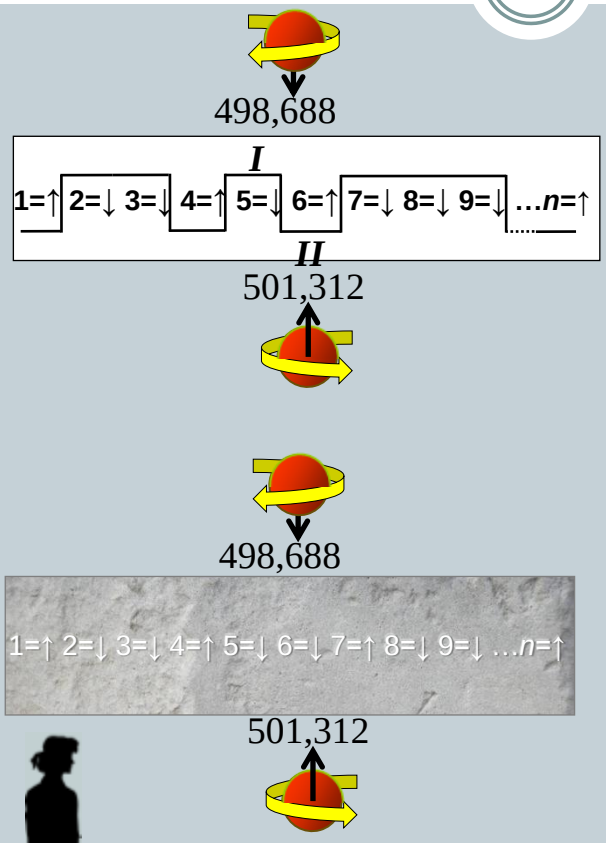


Non Locality?

A Quantum Experiment with Causality



A Quantum Experiment with Causality



The spins "knew" Bob's **specific** choices and their results but couldn't tell us!

Control Experiments

- Time reversing the measurement's order.
- Bob tries to cheat Alice.
- Alice tries to predict Bob's results using her data.
- GHZ experiment.

Interpretation

- Collapse???
- λ^2 Collapse??
- Subtle Collapse?
- 1-Vector?
- Superdeterminism?
- **TSVF!**

Free-Will


Thank You!

Acknowledgements

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