

Novel Temporal Paradoxes in QM

Offering Insights to the Nature of Time







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Outline

1. I hate the Block Universe 
2. EPR: it's about time to revisit time
3. EPR time-reversed => Becoming 
4. EPR + weak measurement => Block Universe 
5. Eppur si muove! 

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1. I hate the Block Universe 🙄

Time: The Common View

Events Become and Go, One by One

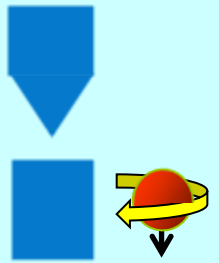
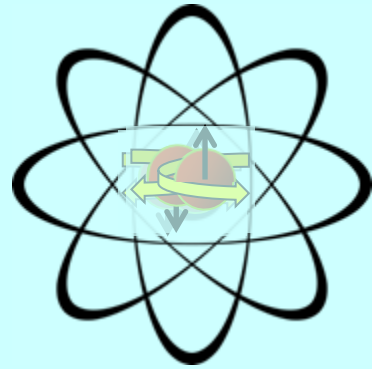
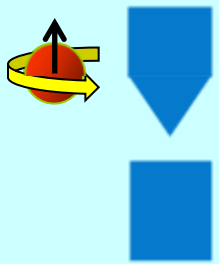


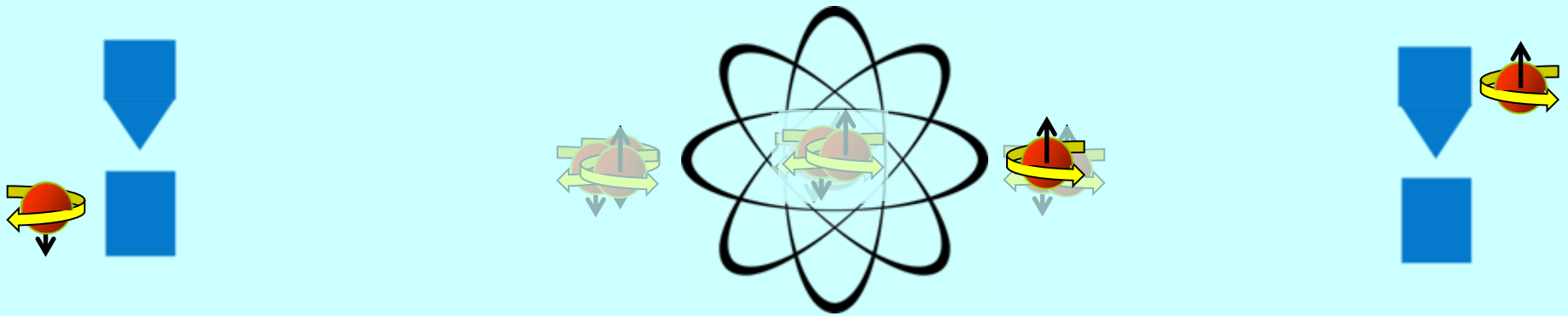
Time: The Relativistic View

All Events Coexist along Time



2. EPR: it's about time to revisit time

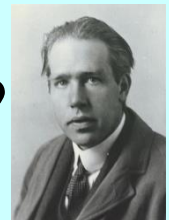
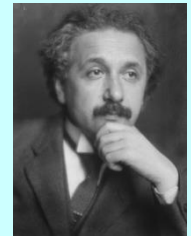




?

A pre-existing spin, to be just *detected*
or

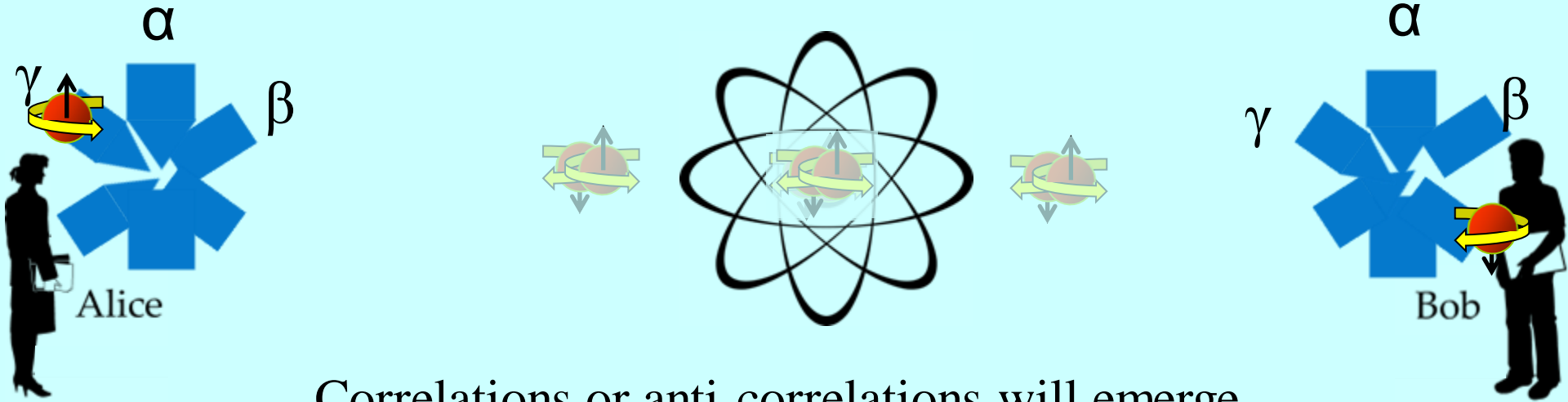
A superposed state,
to *become definite* upon measurement?



Bell's Proof (1964)



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

3. EPR time-reversed \Rightarrow Becoming



The EPR-Bohm Experiment for Particle Pairs Paradox: 3 Repeating Bell's Third Question Answers



1. Is your spin “up” in the α direction?

50% “Yes” , 50% “No”

2. Is your spin “up” in the β direction?

3. ~~Are you entangled with the other?~~ **Are you entangled with the other?** particle?

50% “Yes” , 50% “No”

The Elitzur-Dolev Quantum Liar Paradox

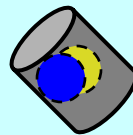
Remember: Quantum Ignorance is Power!



$$\frac{1}{\sqrt{2}} \left(|1\rangle_A |0\rangle_B - |0\rangle_A |1\rangle_B \right)$$



excited state



ground state

- Two excited atoms A1 and A2 reside in cavities facing a beam-splitter
- One detector clicks, source of the photon uncertain
- Thereby entangling the two atoms
- An orthogonal measurement to excited/ground is introduced
- EPR
- Bell's-proof holds
- The Quantum Liar Paradox

The Quantum Liar Paradox

- One atom is found to be excited, which seems to indicate that it has emitted no photon.
- Hence, it could not interact with the other atom and should not be entangled with it.
- But, by violating Bell's inequality, its “having preserved its photon” is due to entanglement with the other atom!

Большая Советская Энциклопедия



History, The Soviet Encyclopedia's Version

When the “hero of the people” former KGB head is shot as a traitor, you take back old volumes of the encyclopedia, take out the pages of the entry “Beria” and replace them with “Bering.”

Our Relativistic Quantum Model

Could Nature be similarly reiterating a process's evolution at the quantum level?

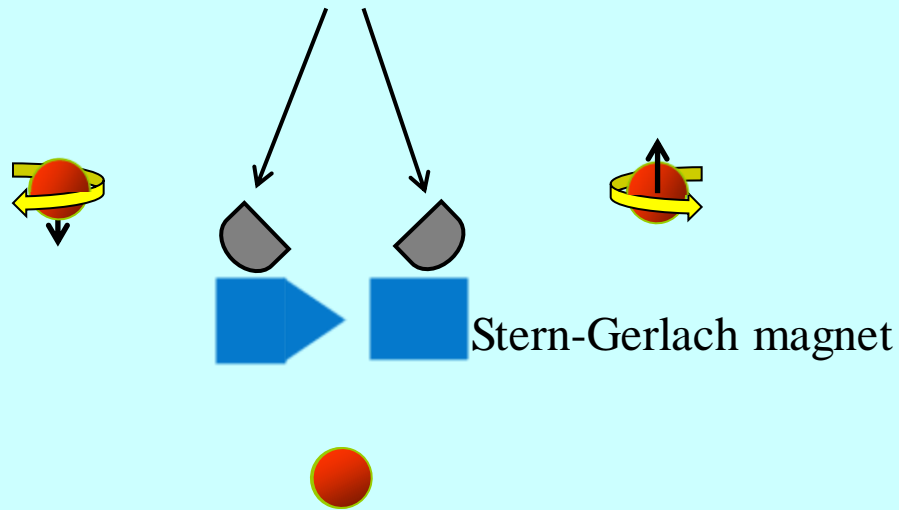
4. EPR + weak measurement \Rightarrow Block Universe



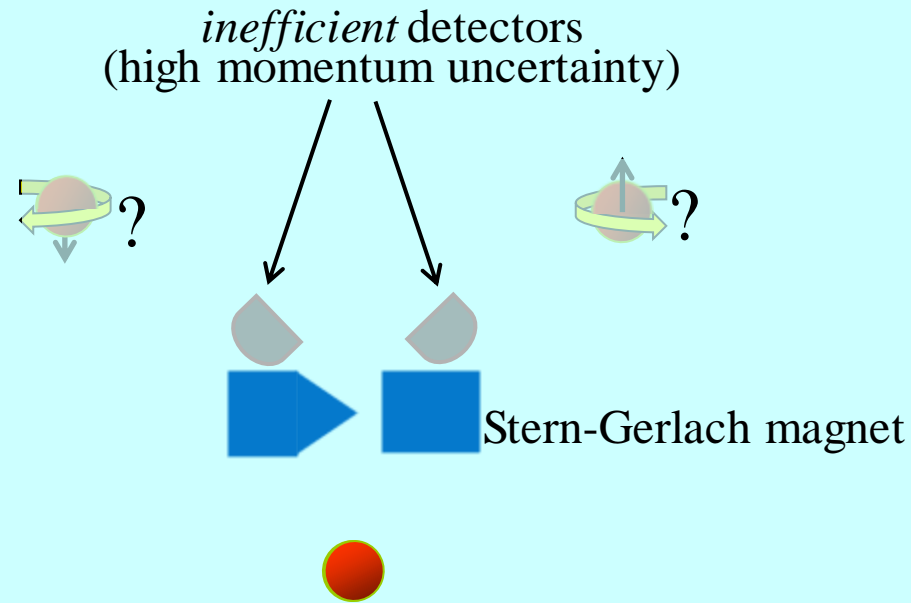
Standard Quantum Measurement of a Particle's Spin



efficient detectors
(very low momentum uncertainty)



Weak Quantum Measurement of a Particle's Spin



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 $\delta \gg \frac{\lambda}{\sqrt{N}}$ standard deviation.
- ❖ This way, when measuring a single spin, we get most results within the wide range of signal and noise $\frac{\lambda}{\sqrt{N}} \pm \delta$, but when summing up the results, most of them appear in the narrow range $\frac{\lambda\sqrt{N}}{2} \pm \frac{\delta\sqrt{N}}{\sqrt{2}}$, agreeing with the strong results when $\lambda \gg \delta$.

feeble Signal
(always at center)

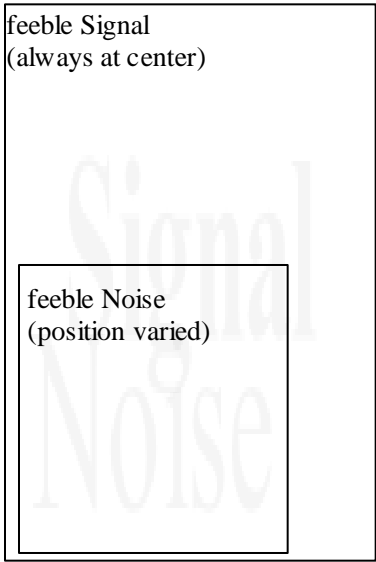
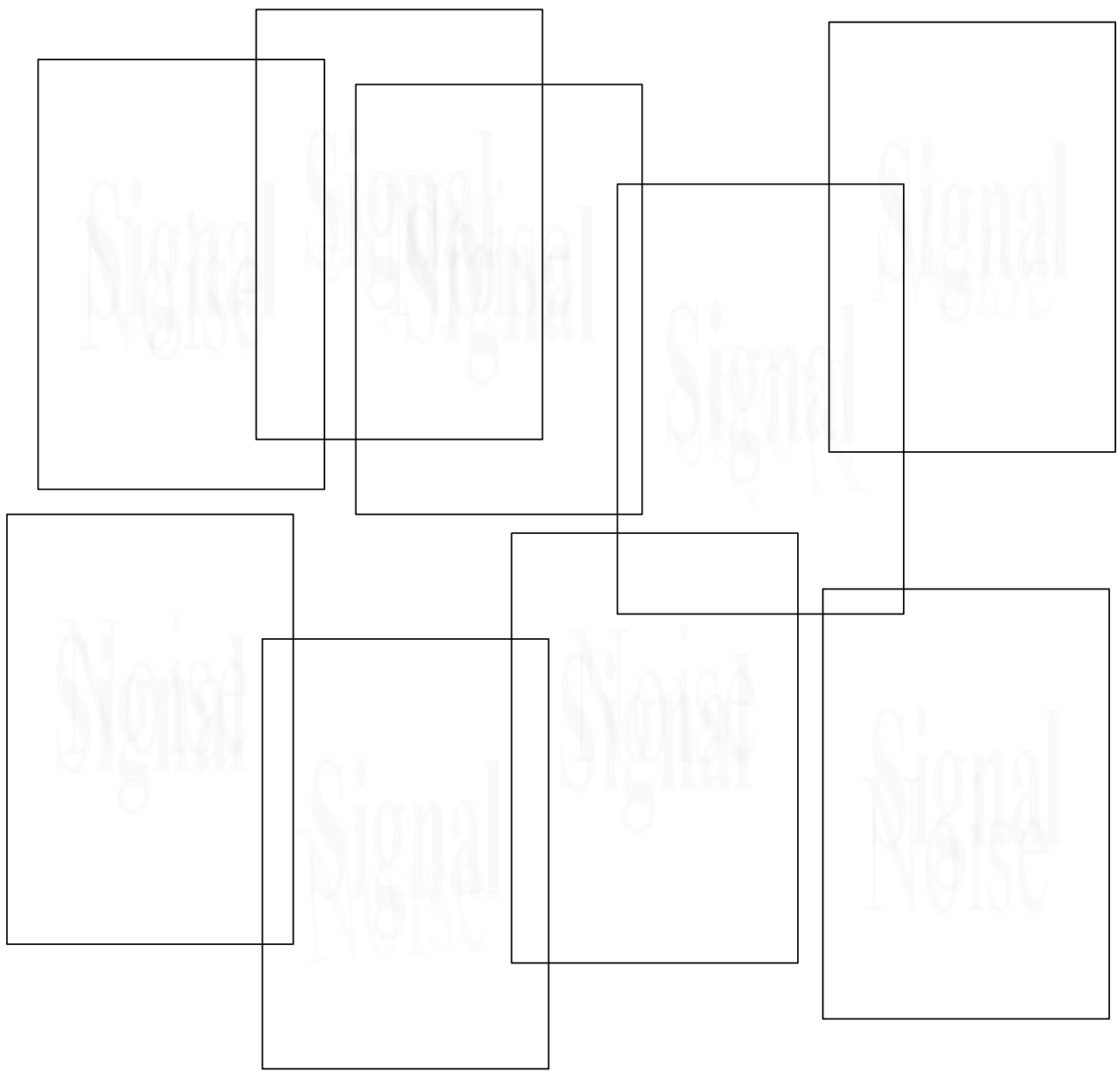
feeble Noise
(position varied)

Signal
Noise

feeble Signal
(always at center)

feeble Noise
(position varied)

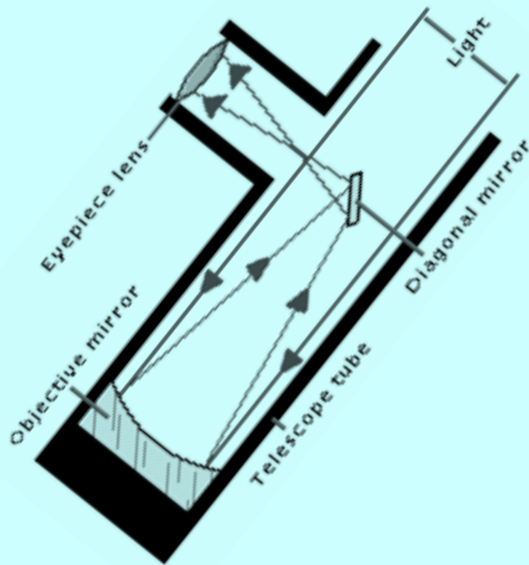
Signal
Noise

A large rectangular box with a thin black border. Inside, the text "feeble Signal (always at center)" is positioned at the top left. Below it, a smaller rectangular box with a thin black border contains the text "feeble Noise (position varied)". At the bottom of the large box, the words "Signal" and "Noise" are written in a large, light gray, serif font, with "Signal" above "Noise".A collection of ten overlapping rectangular boxes arranged in a grid-like pattern. Each box contains the words "Signal" and "Noise" in a large, light gray, serif font. The boxes are positioned such that they overlap horizontally and vertically, creating a complex, layered visual effect. The text "Signal" is consistently placed above "Noise" within each box. The boxes vary slightly in their vertical and horizontal alignment, contributing to the overall sense of depth and movement.

Why “Weak Measurement”?

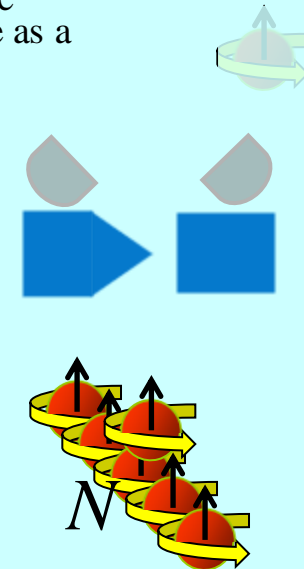
Signal overcomes noise.

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



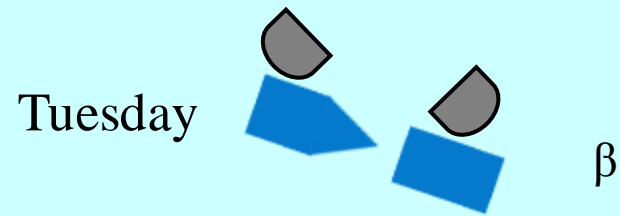
$$[\sigma_i, \sigma_j] = 2i\varepsilon_{ijk} \sigma_k$$

But when carried out on many particles, it becomes as accurate as a strong measurement.



A metaphysical question gets an empirical twist:

What is a particle's state between two measurements?



Monday

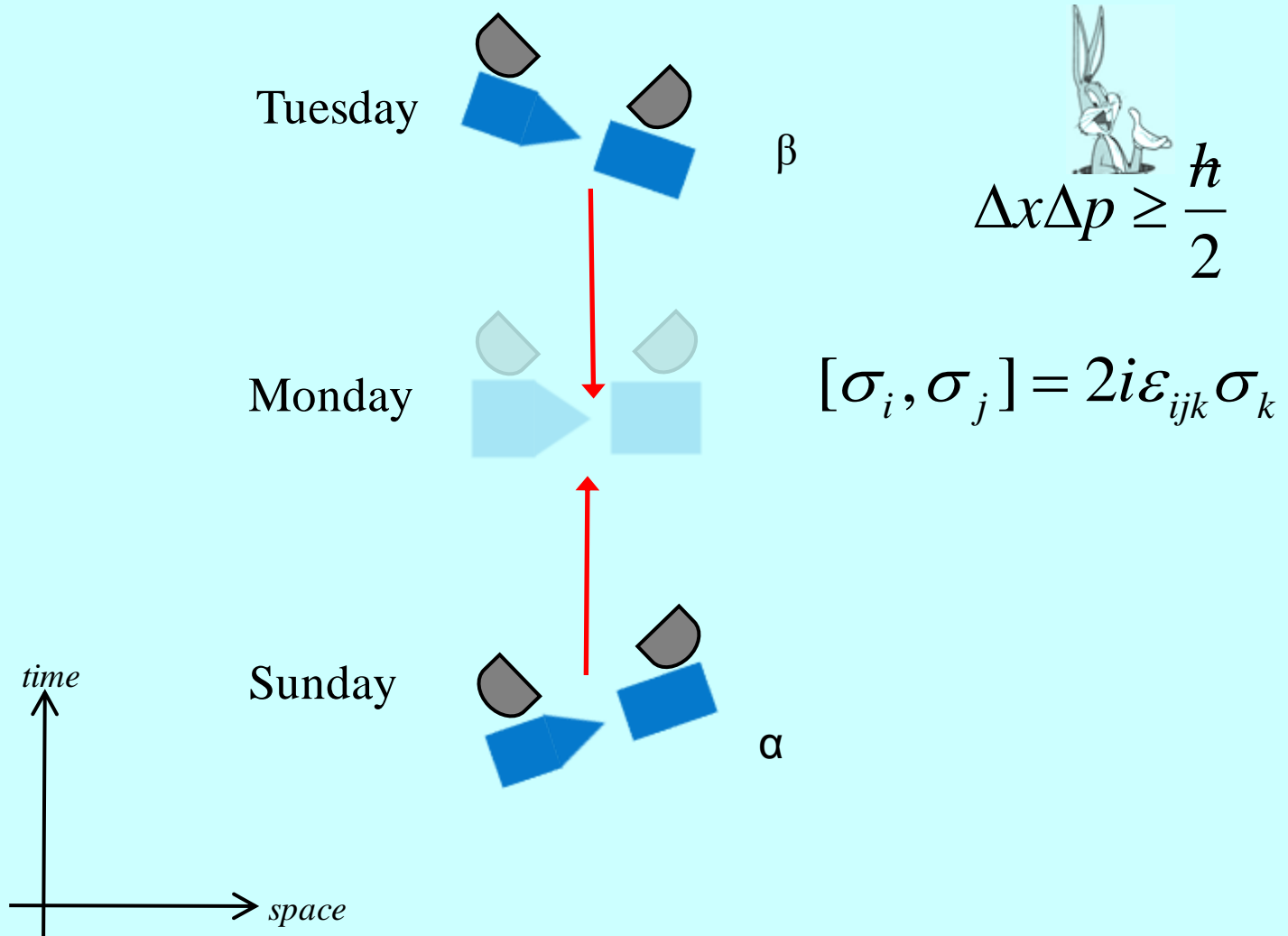


A large red question mark is centered between the Tuesday and Sunday diagrams, representing the unknown state of the particle during the intervening day.



The Two State-Vector Formalism:

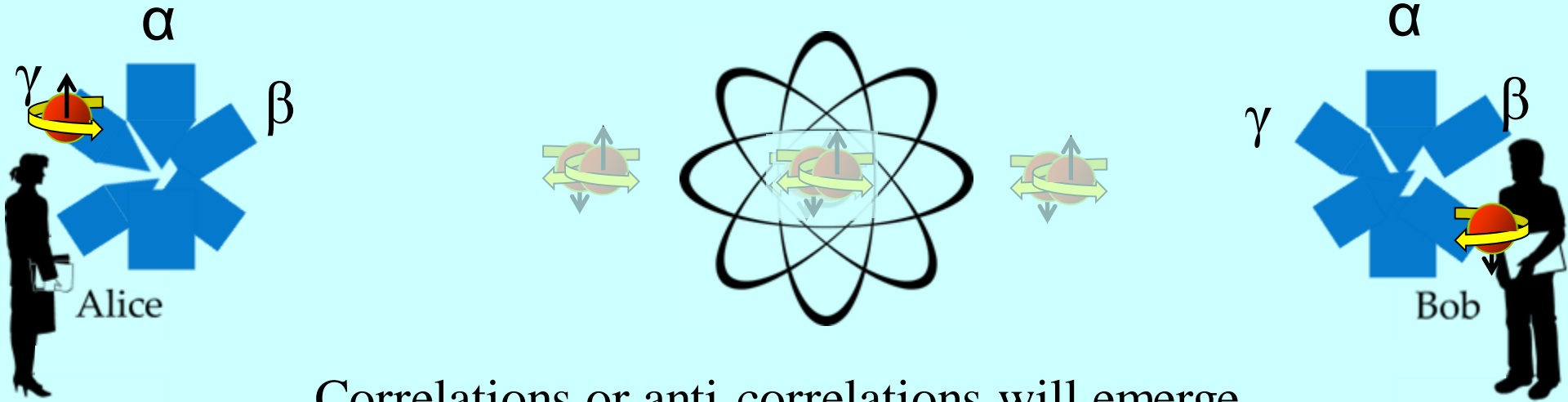
Weak Measurement gives a New Account of Time



J. S. Bell's Proof (1964)



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



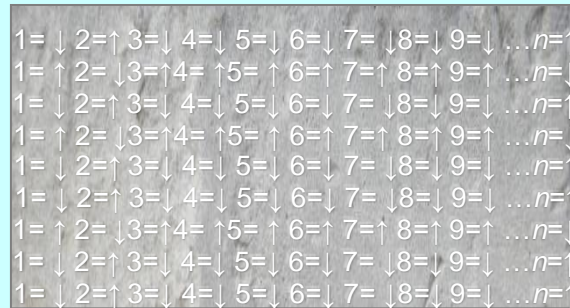
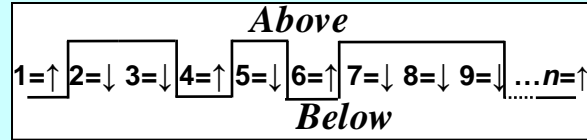
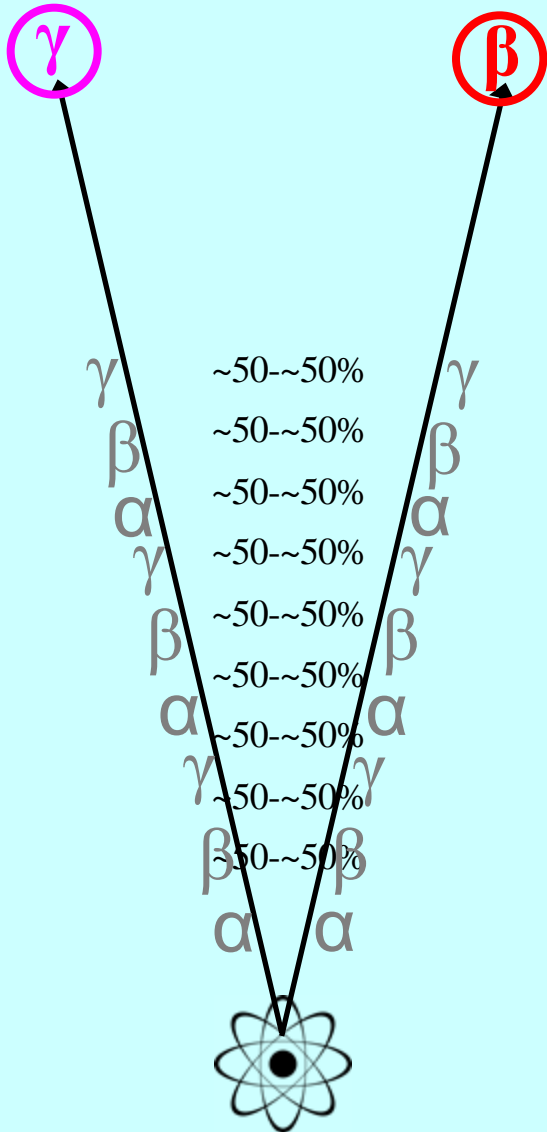
Correlations or anti-correlations will emerge depending on the *relative angle* between magnets

Conclusion:

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

A Quantum Experiment with Causality: EPR Pairs

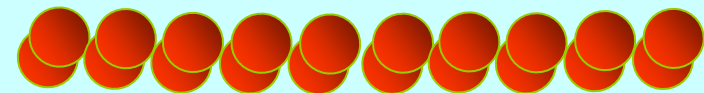
Last minute choice!



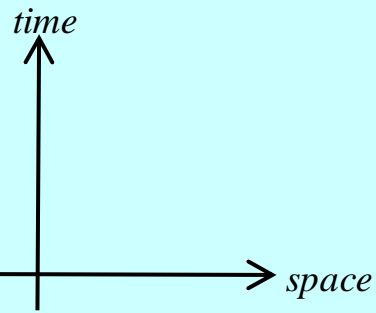
Evening: Bob



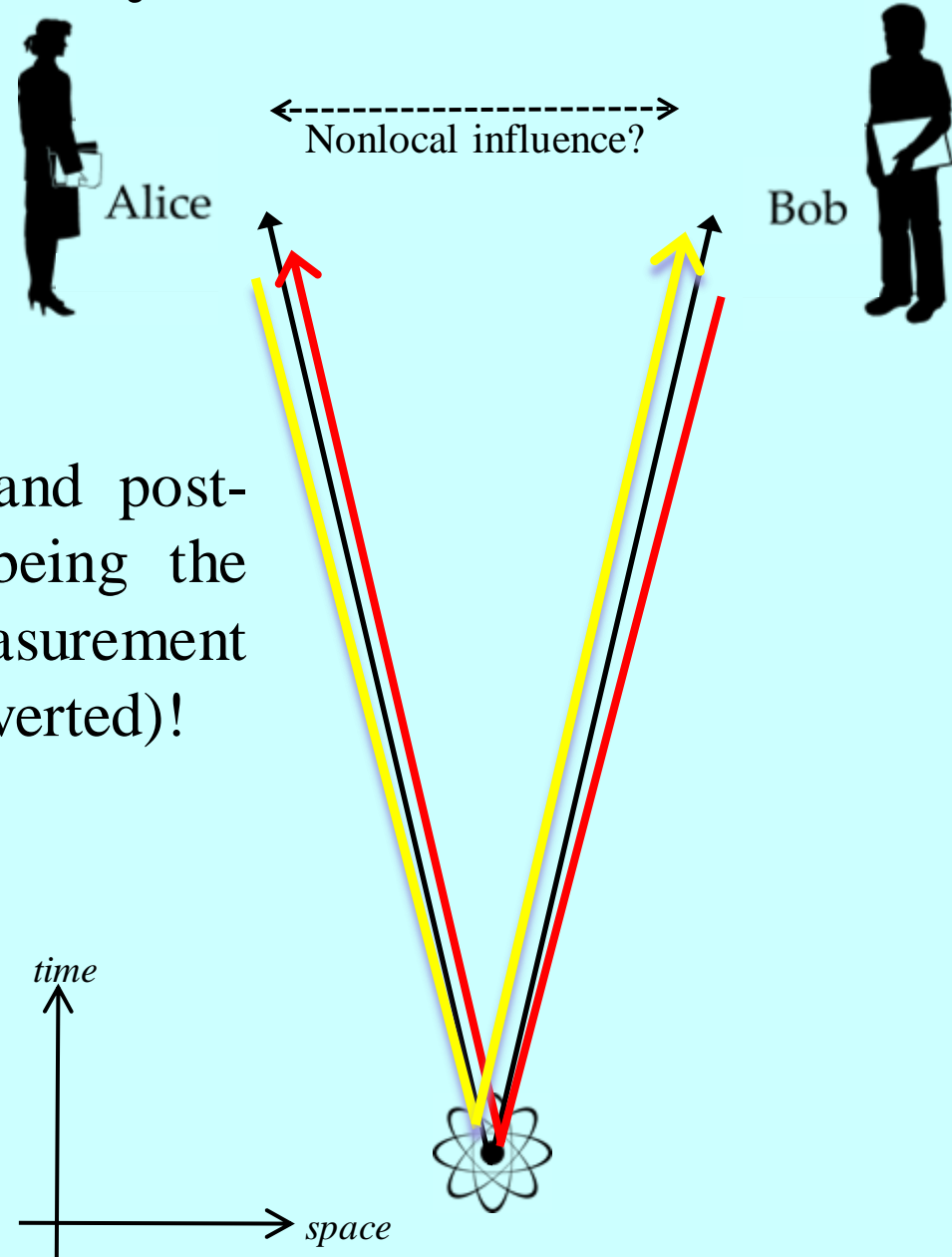
Morning: Alice



N EPR pairs



Quantum Nonlocality Naturalized



Each EPR particle is again pre-and post-selected, its own measurement being the post-selection while the other's measurement is its pre-selection (with the sign inverted)!

Chronology is Protected

The fact that the future choice has been somehow encrypted within past measurement results is revealed only after the choice is actually made.

References

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2. Aharonov Y., Rohrlich D. (2005), *Quantum paradoxes: Quantum theory for the perplexed*, ch. 7-8, Wiley, Weinheim.
3. Elitzur A. C., Cohen E. (2011), The retrocausal nature of quantum measurement revealed by partial and weak measurements. In Sheehan, D. [Ed.] *Quantum Retrocausation: Theory and Experiment. AIP Conference Proceedings* 1408: 120-131.
4. Aharonov Y., Cohen E., Elitzur A.C. (2012), Strength in Weakness: Broadening the Scope of Weak Quantum Measurement. Submitted to *Phys. Rev. A*. <http://arxiv.org/abs/1207.0655> .
5. Aharonov Y., Cohen E., Elitzur A.C. (2012), Coexistence of past and future measurements' effects, predicted by the Two-State-Vector-Formalism and revealed by weak measurement. Submitted to *Phys. Rev. A*. <http://arxiv.org/abs/1207.0667> .
6. Aharonov Y., Cohen E., Grossman D., Elitzur A.C. (2012), Can a future choice affect a past measurement's outcome? <http://arxiv.org/abs/1206.6224> .

5. Eppure si muove!

