Title: Quantum Information Lecture

Speakers: Eduardo Martin-Martinez

Collection: Quantum Information 2023/24

Date: March 18, 2024 - 9:00 AM

URL: https://pirsa.org/24030058

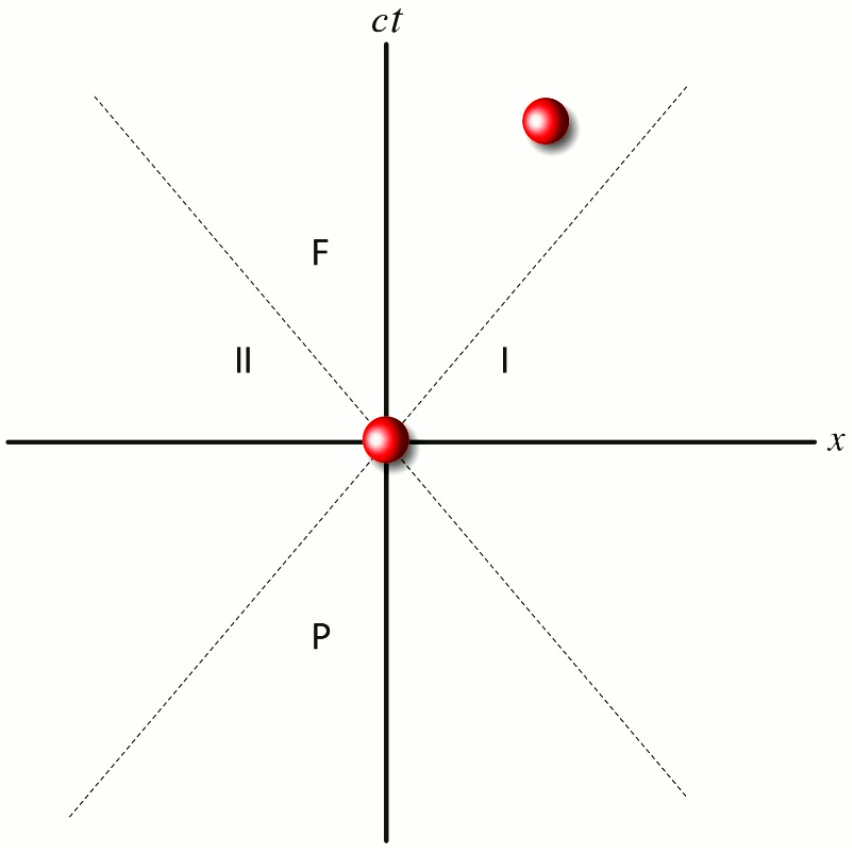
$$|\psi\rangle = \frac{1}{\sqrt{2}}\left(|0\rangle + |1\rangle\right)$$

$$\hat{\rho} = \frac{1}{2}\begin{pmatrix} 1 & 1 \\ 1 & 1 \end{pmatrix} \rightarrow \frac{1}{2}\left(\right.$$

$$|\psi\rangle = \frac{1}{\sqrt{2}}\left(|0\rangle + |1\rangle\right)$$

$$\hat{\rho} = \frac{1}{2}\begin{pmatrix} 1 & \cancel{0} \\ \cancel{0} & 1 \end{pmatrix} \rightarrow \frac{1}{2}\begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}$$

What does it mean to place a qubit on spacetime?



What entanglement is not

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The Race To Prove 'Spooky' Quantum Connection May Have a Winner

Entanglement breakthrough could lead to unhackable Internet

By **Devin Powell** August 29, 2015

Particles don't obey the same rules as people. Poke a particle, and another one far away can instantly respond the touch -- without any messages passing through the space between, as if the two particles were one. "Entanglement" is what quantum physics calls the intimate connection.

Einstein called it "spooky." To his dying day, he refused to believe that nature could be so unreasonable.

From http://www.popsci.com

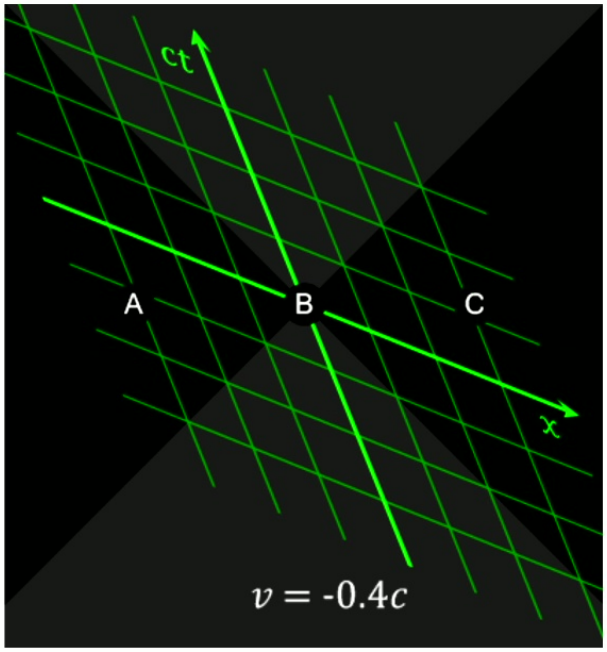
Quantum Entanglement

Alice: I grab one set of dice at random…
I roll it and it gives 8!

I know what Bob's roll's gonna be! (or was)

Getting Familiar with Spacetime

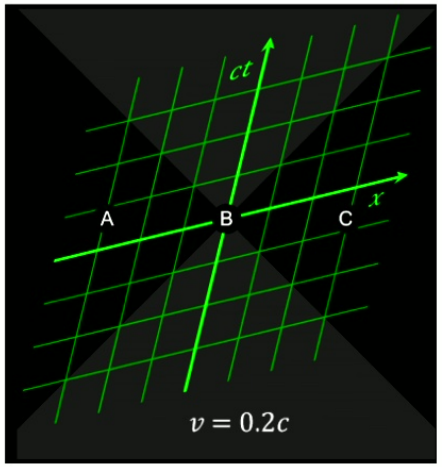
Simultaneity is Relative!



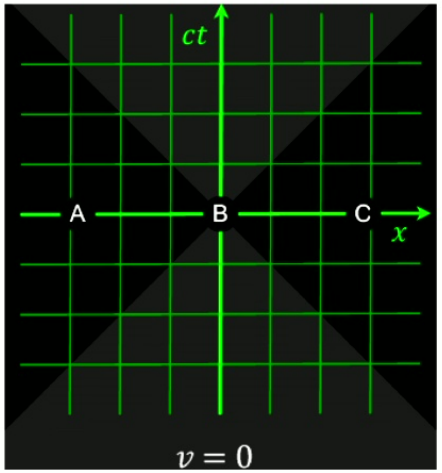
Two observers in different states of motion would not agree about what happens first

Getting Familiar with Spacetime

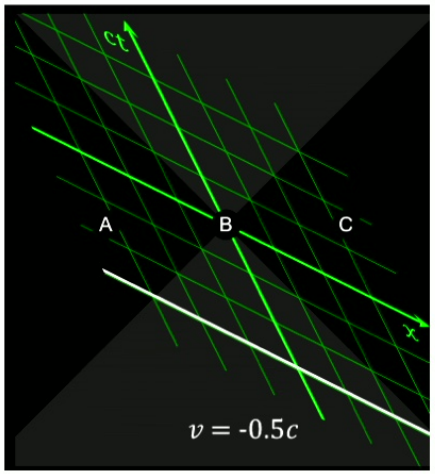
Simultaneity is Relative!
Who collapses what??
Who pokes what??



A happens after C



A and C are simultaneous



A happens before C

Quantum Entanglement

Beware of Collapse!!

Instantaneous action is incompatible with relativity

Measurements in Quantum Theory

Still an open problem!

Proposal: At least some Measurements can give values (e.g., 42) that we can write on a notepad

In QM, we model that with idealized measurements

Idealized measurements of non-degenerate observables update states through a rank-1 projector on the spectrum of the measured observables

But Quantum to Classical transition? Interpretation?

You could "not care"! And still get rich and famous

Measurements in Quantum Theory

How about QFT?

Maybe we want to measure localized observables of the field
(e.g., the electric field in my room during the duration of my talk)

If you measure it, it is not unthinkable you get a definite reading
(e.g., 42 V/m)

Can you become rich and famous with idealized measurements in QFT?

No idealized measurements?

Rafael Sorkin (1992):

No idealized measurements in QFT?

Impossible Measurements on Quantum Fields*

RAFAEL D. SORKIN

Department of Physics, Syracuse University, Syracuse NY 13244-1130

Abstract

It is shown that the attempt to extend the notion of ideal measurement to quantum field theory leads to a conflict with locality, because (for most observables) the state vector reduction associated with an ideal measurement acts to transmit information faster than light. Two examples of such information-transfer are given, first in the quantum mechanics of a pair of coupled subsystems, and then for the free scalar field in flat spacetime. It is argued that this problem leaves the Hilbert space formulation of quantum field theory with no definite measurement theory, removing whatever advantages it may have seemed to possess vis a vis the sum-over-histories approach, and reinforcing the view that a sum-over-histories framework is the most promising one for quantum gravity.

No idealized measurements?

Rafael Sorkin (1992):

No idealized measurements in QFT?

Argues that idealized measurements are incompatible with causality

Two examples:

Example 1: Two-Qubit system

Consider a state: $|0_A 0_B\rangle$

1-Perform local Unitary on A

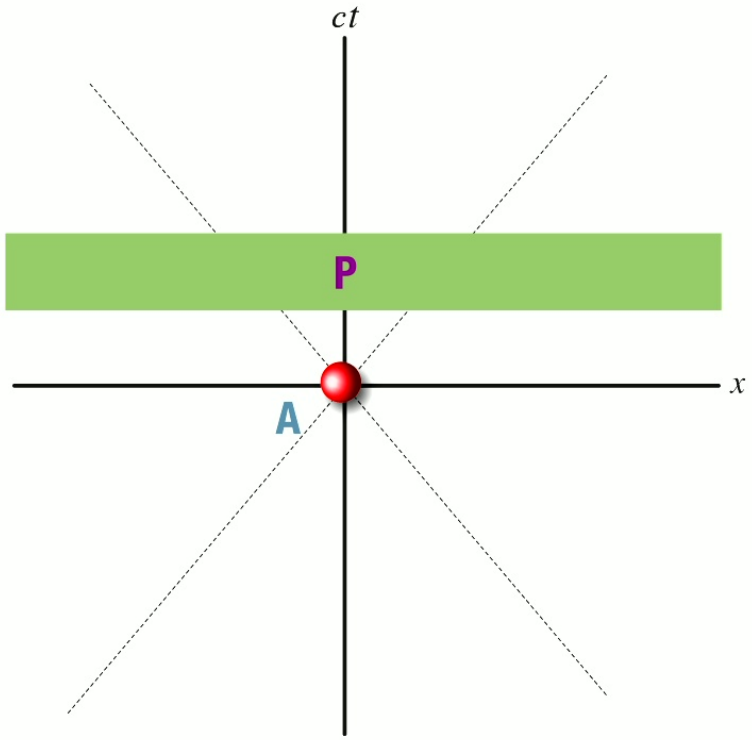
2-Make an idealized Bell measurement projecting on to $\frac{1}{\sqrt{2}}(|0_A 0_B\rangle + |1_A 1_B\rangle)$

3-Expectation of observable on B gains information about the unitary on A

Surprised?

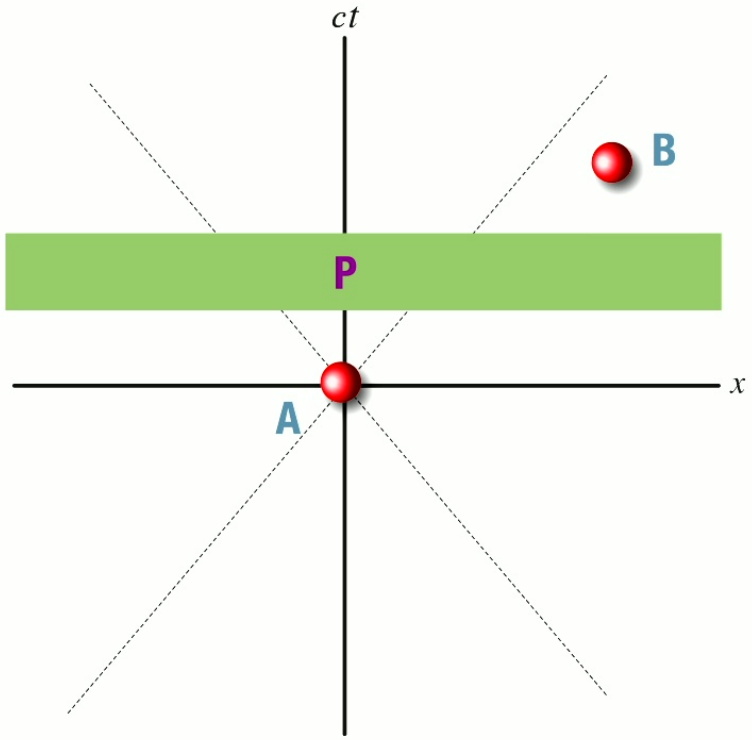
No idealized measurements?

2-Make an idealized measurement (Non-local) on a spacetime "horizontal" slice



No idealized measurements?

3-Expectation of local observables on B gains information about the unitary on A



No idealized measurements?

People kept using such idealized measurements (actively and by assumption)

Useless Qubits in "Relativistic Quantum Information"

Fay Dowker

Blackett Laboratory, Imperial College, London, SW7 2AZ, U.K.
and
Perimeter Institute, 39 Caroline St. N., Waterloo, ON N2L 2Y5, Canada

Abstract

I draw attention to previous work that shows that the observables corresponding to relativistic quantum field modes commonly employed in papers on "relativistic quantum information" cannot be measured by ideal measurements.

So what's the plan?

People kept using such idealized measurements (actively and by assumption)

People in RQI followed two paths:

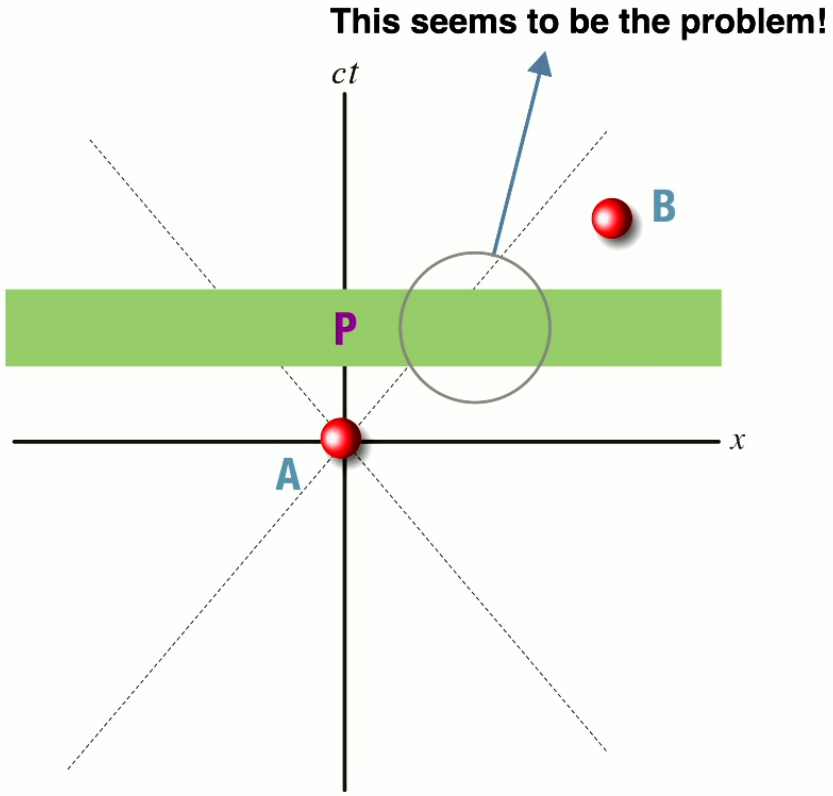
Particle detectors

More on this later!

Localized idealized measurements

Is this okay?

Localized idealized measurements

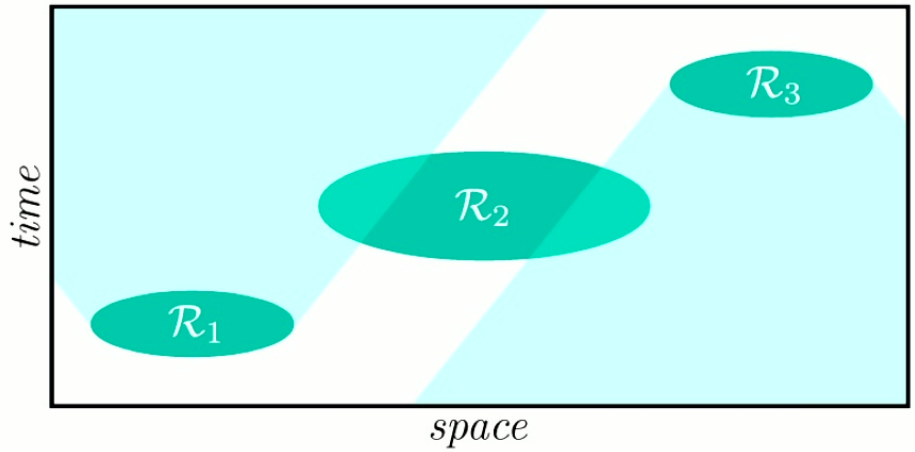


Can we solve the issue by disallowing 'too non-local' kinds of measurement?

Localized idealized measurements

Impossible measurements revisited

L. Borsten,* I. Jubb,† and G. Kells‡
School of Theoretical Physics, Dublin Institute for Advanced Studies, 10 Burlington Road, Dublin 4, Ireland
(Dated: December 16, 2019)



What if take the physicist road (only measure in regimes where there's no signalling)

Localized idealized measurements?

Foundations of Physics, Vol. 25, No. 1, 1995

Theorem 1. If $P \in R(O)$, then P is an infinite-dimensional projector.

Proof. This follows directly from the result of Driessler[7] which states that the quasi-local algebra associated with an unbounded wedge of space-time is a type III factor. Now any bounded region is internal to some wedge, so by isotony $R(O)$ is a subalgebra of some wedge algebra. So the projectors in $R(O)$ are identified with some of the projectors in the wedge algebra. But in a type III factor *all* the projectors are infinite-dimensional. So all the projectors in $R(O)$ are infinite-dimensional.

Localized idealized measurements?

Foundations of Physics, Vol. 25, No. 1, 1995

More Ado about Nothing

Michael Redhead[1]

Received February 9, 1994

In this paper questions about vacuum fluctuations in local measurements, and the correlations between such fluctuations, are discussed. It is shown that maximal correlations always exist between suitably chosen local projection operators associated with spacelike separated regions of space-time, however far apart these regions may be. The connection of this result with the well-known Fregenhagen bound showing exponential decay of correlations with distance is explained, and the relevance of the discussion to the question "What do particle detectors detect?" is addressed.

No localized idealized measurements

So… Now what?

Measurements in Quantum Theory

What do I want from a measurement theory in QFT?

1-Capable of producing definite values

2-Provides an update rule

3-Consistent with the theory
(e.g., respect causality in a relativistic theory)

4-Reproduces experiments!!!

Is there an alternative to idealized measurements?

Does the particle detector approach work?

Getting that 42!

Extracting definite values:

1-Couple the detector to the field

2-Idealized measurement on the detector (remember, non-Rel)

Update rule:

3-Update the field state with the consistent POVM compatible with the outcome

A detector-based measurement theory for quantum field theory
J. Polo-Gómez, L. J. Garay, E. M-M. arXiv:2108.02793
Phys. Rev. D 105, 065003 (2022)