The problem in quantizing gravity

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Universita' di Pavia

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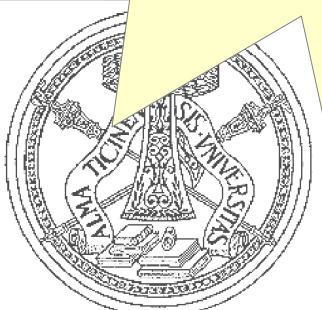
FQXi Foundation,
"The physics of what happens"

The ro ar zing

WORK IN PROGRESS!



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A problem in the formulation of the two main theories in physics

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GR ⟶ events

QM ⟶ systems

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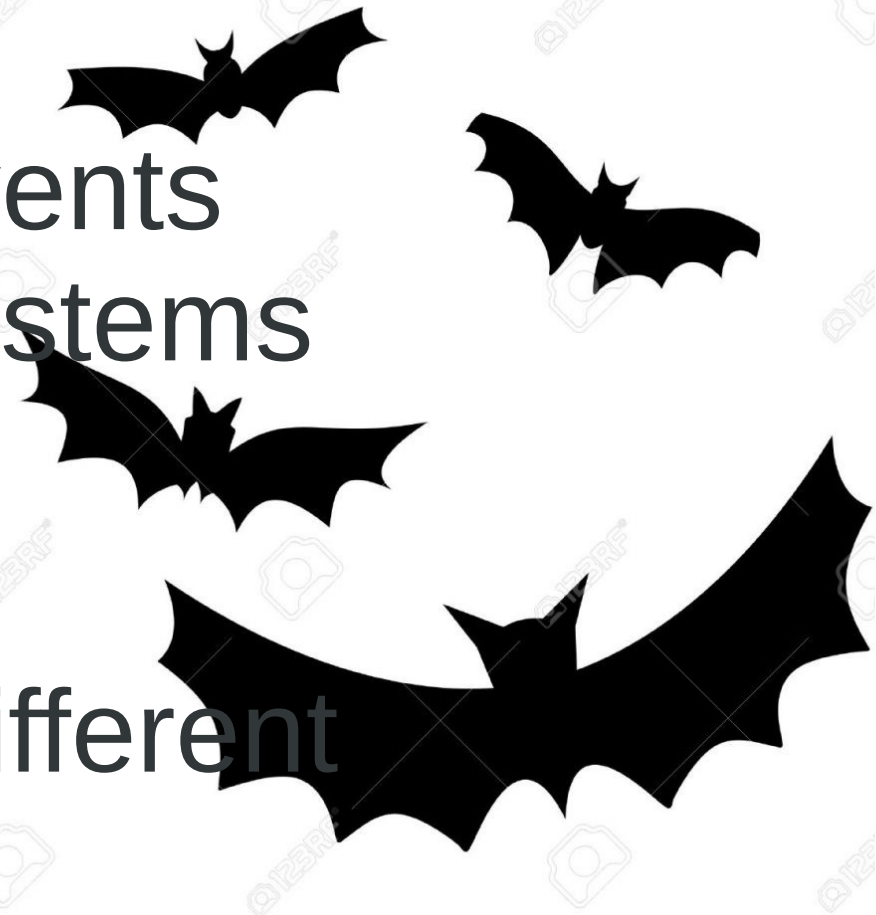
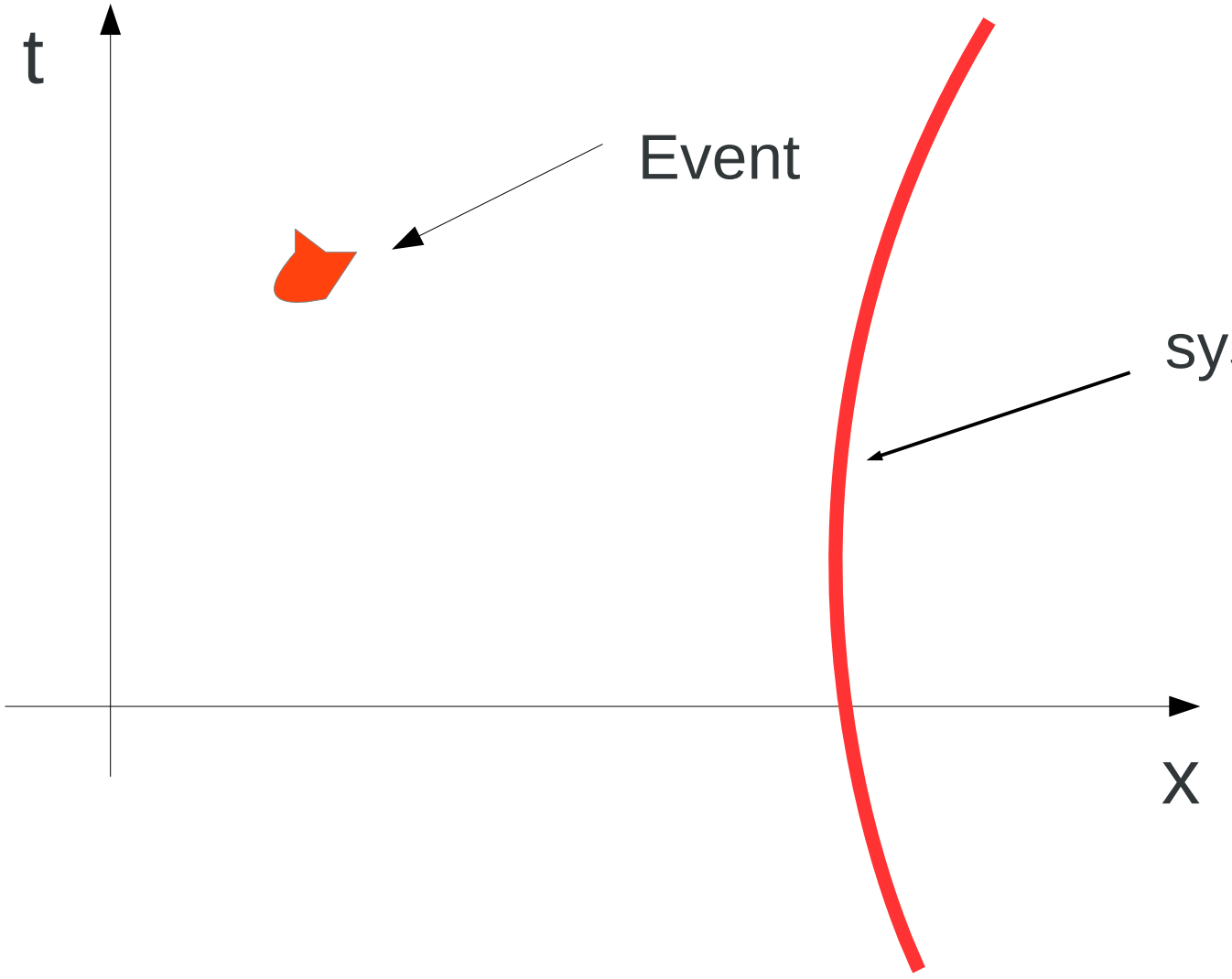


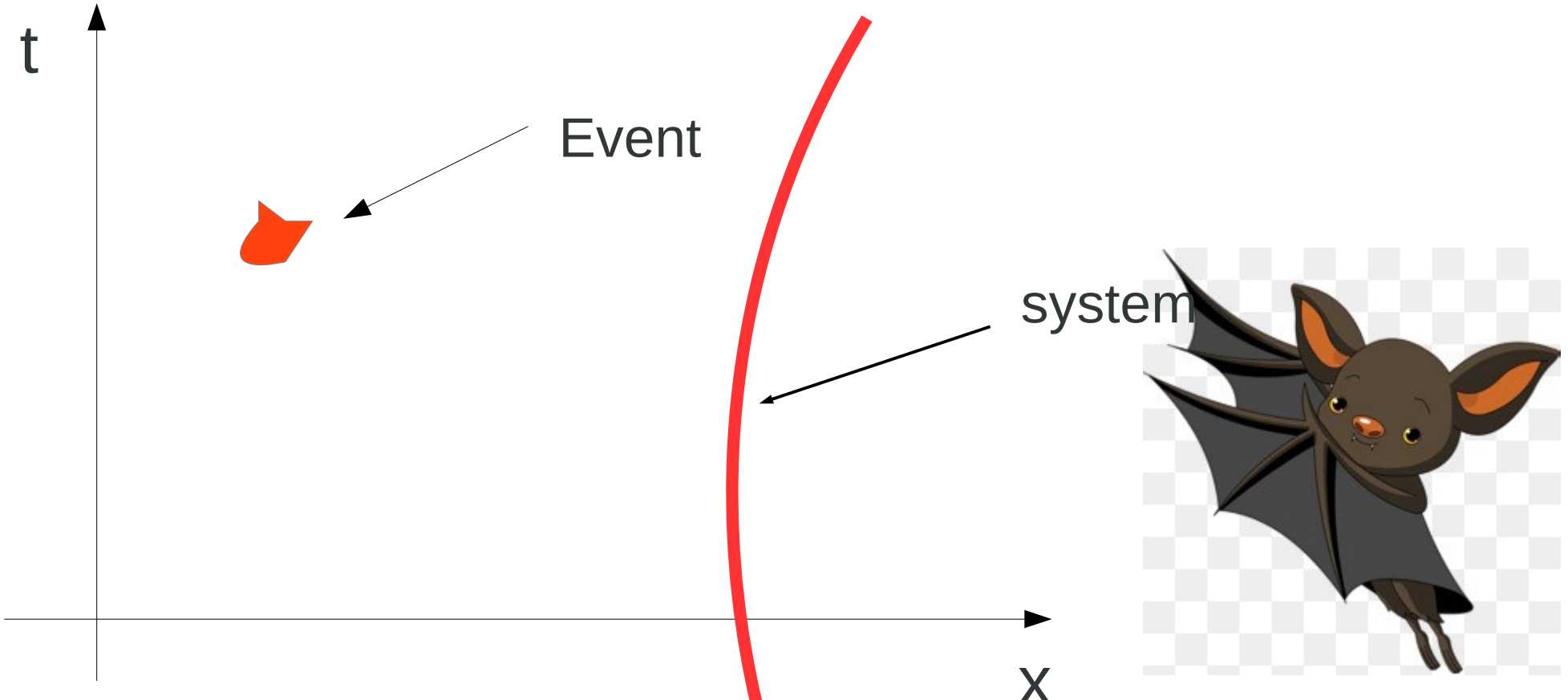
They talk about different objects!

Event: a limited region in spacetime

system: limited in space (usually)
but infinite in time



Both theories include both concepts



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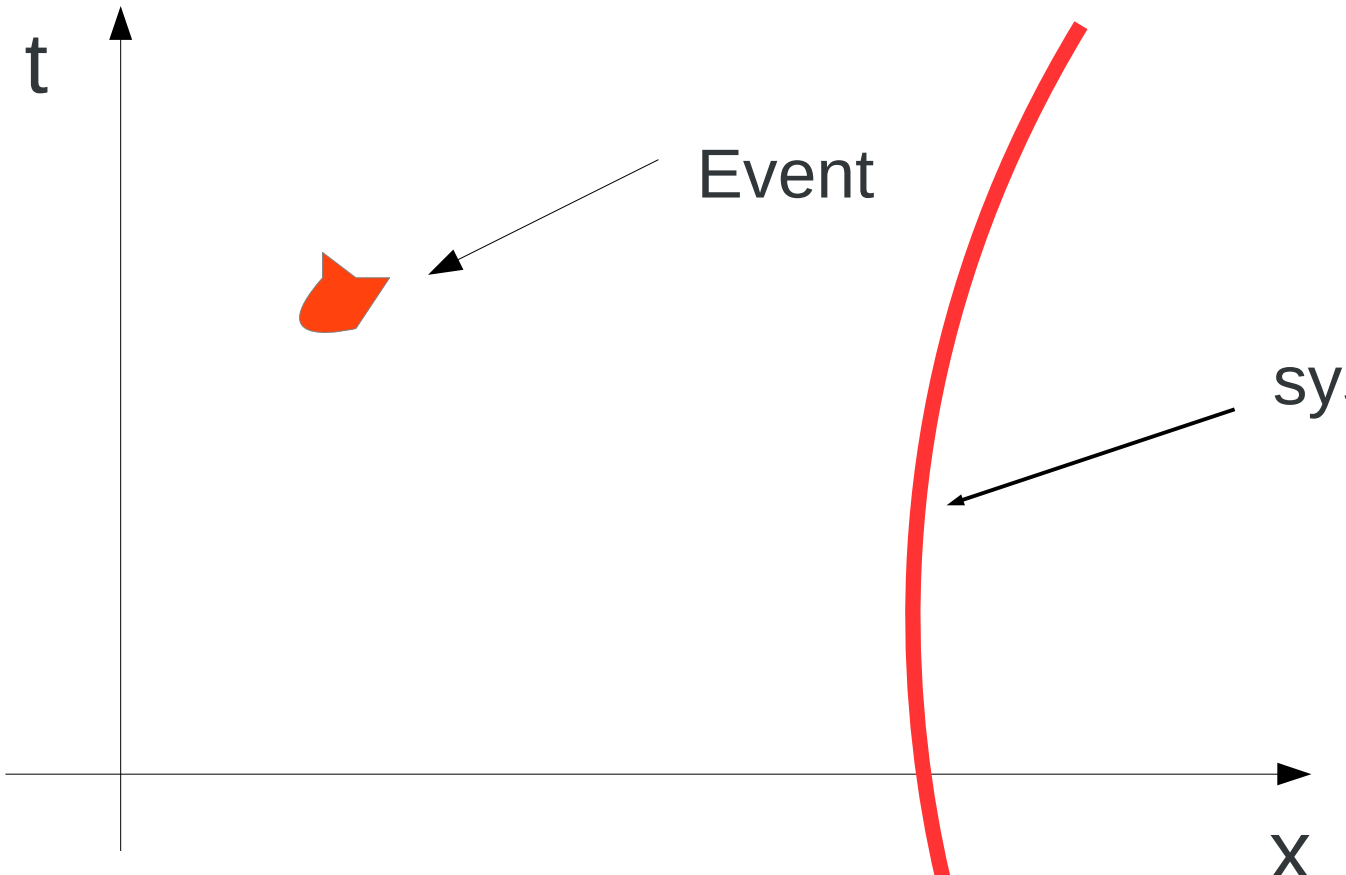
GR: event is fundamental
system=succession of events



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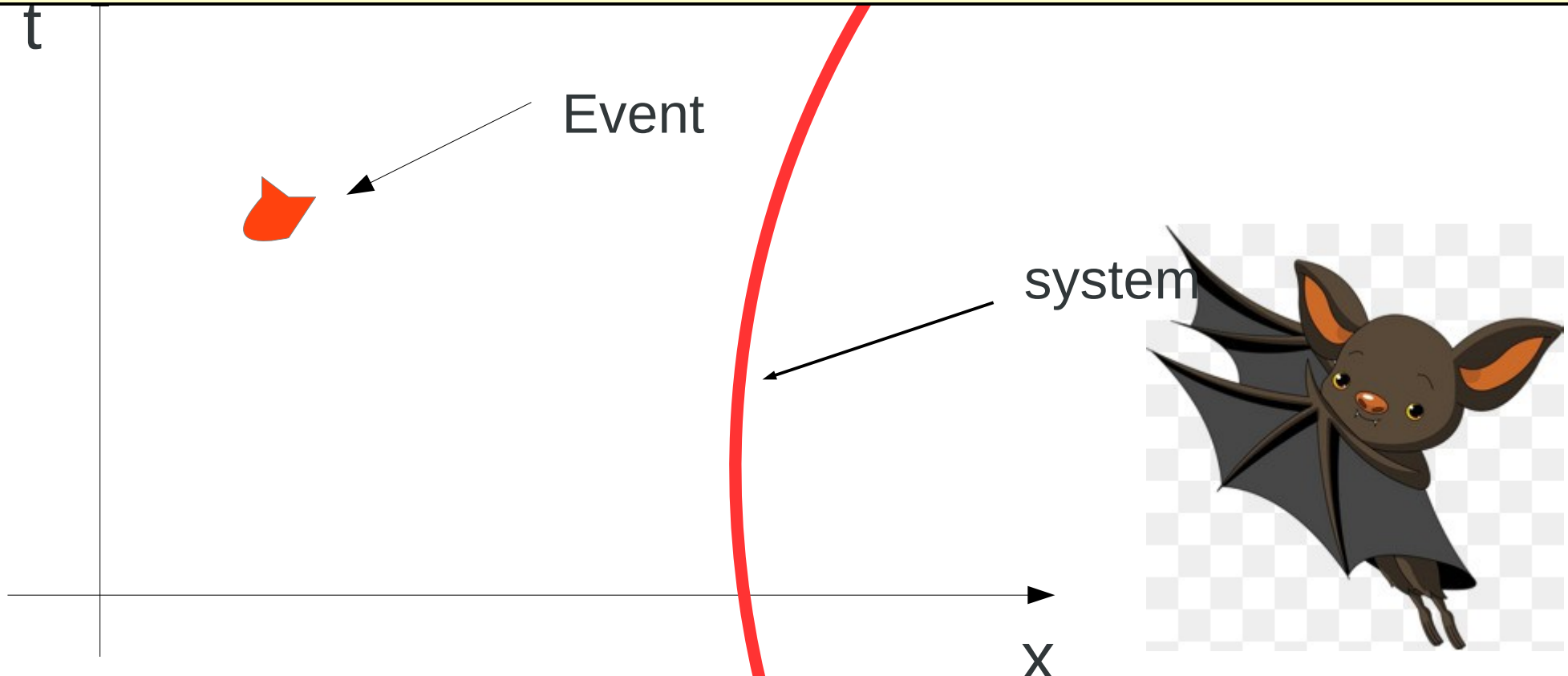
system=succession of events

QM: event=something that happens to a system
system is fundamental



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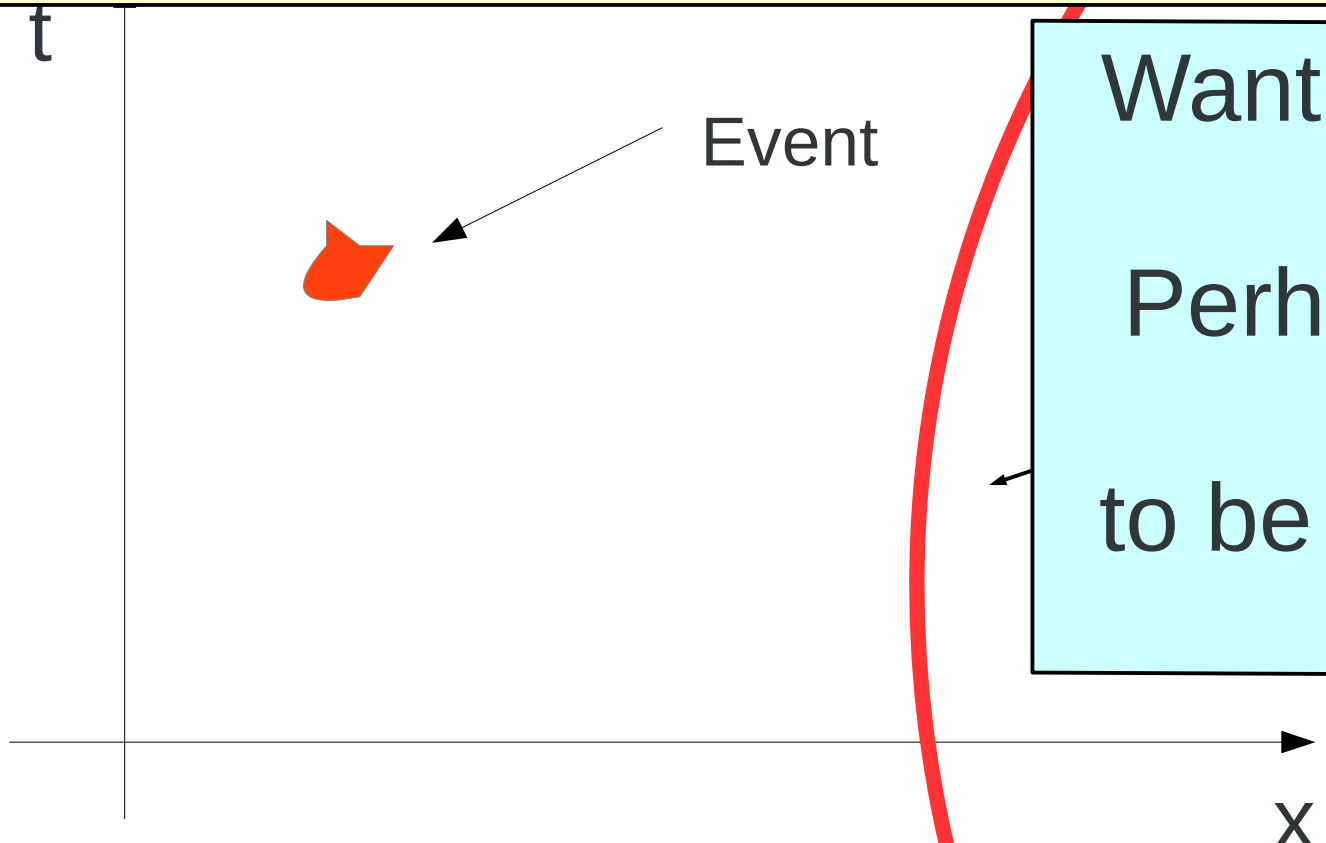

Want covariance?!

Perhaps we need
events
to be fundamental!

GR: relates **spacetime** geometry to its energy-momentum content

it's a theory of **events**
(what GR talks about)

This talk: what does it take to create a quantum theory for events?

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Just a (possible) roadmap.
We don't have it (yet)

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(and maybe it can't be done)

Textbook axiomatic formulation of QM:

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$$p(a) = \langle\psi|\Pi_a|\psi\rangle$$

Textbook axiomatic formulation of QM:

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in a c
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The whole QM can be derived from these axioms

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Time evolution of the state,
not of the system
(Hilbert spaces don't evolve)
Systems are eternal

Two types of spacetime asymmetries in QM

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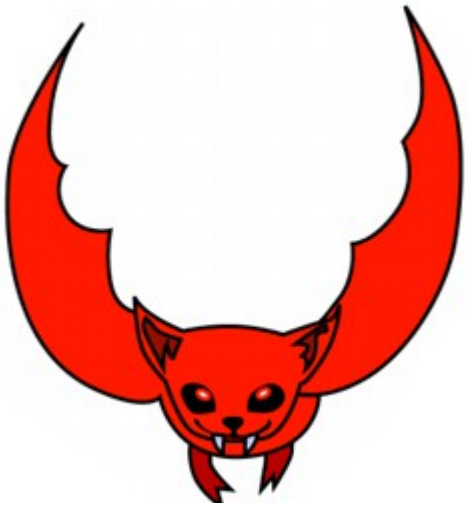
QFT only PARTIALLY resolves the asymmetry



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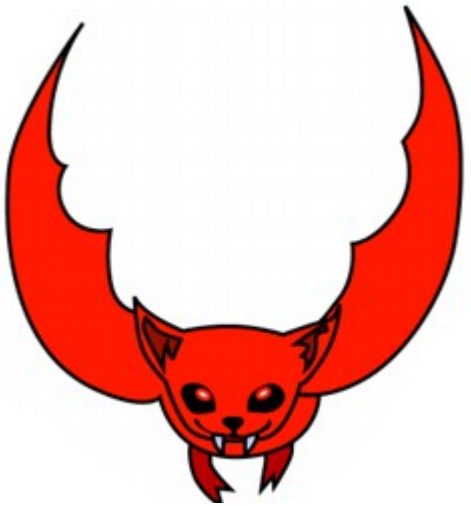

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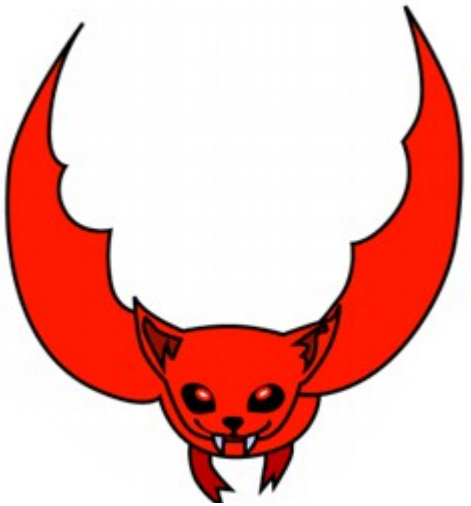

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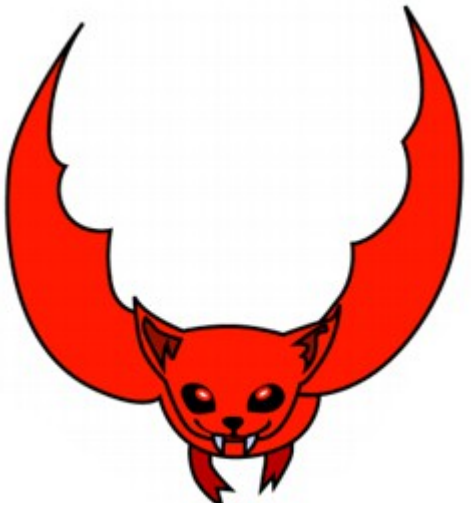

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BUT.....

QFT cannot be used to quantize gravity as is.

(Uses a global time and properties of infinite systems are undefined)

Operators (in the Schroedinger picture)
or states (in the Heisenberg picture)
are evaluated at t=0

WHY?!?

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Conditional probabilities!!

$|\langle x|\psi(t)\rangle|^2$ =p(x|t)

because of the ***conditioned*** nature of QM,
QM is not well suited for general relativity

(where coordinate time has no physical meaning
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A quantum theory of events....

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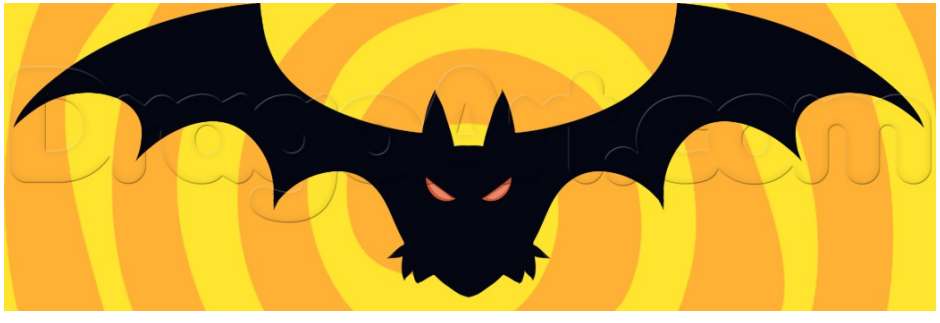
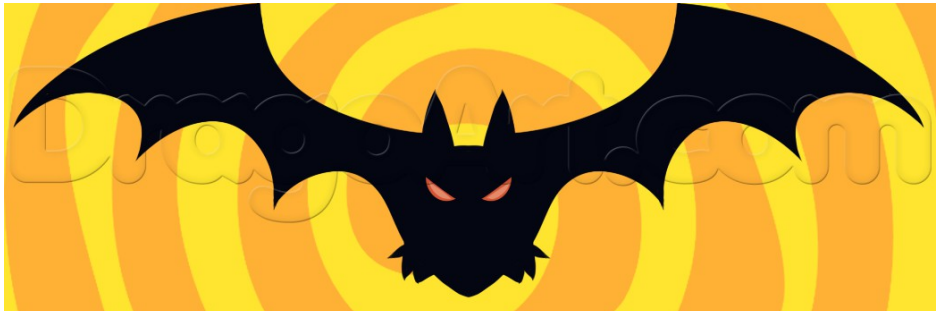


A quantum theory of events....

... that still **retains** the axiomatic formulation we all know and **love**!!

(It has been tested to incredible accuracy)



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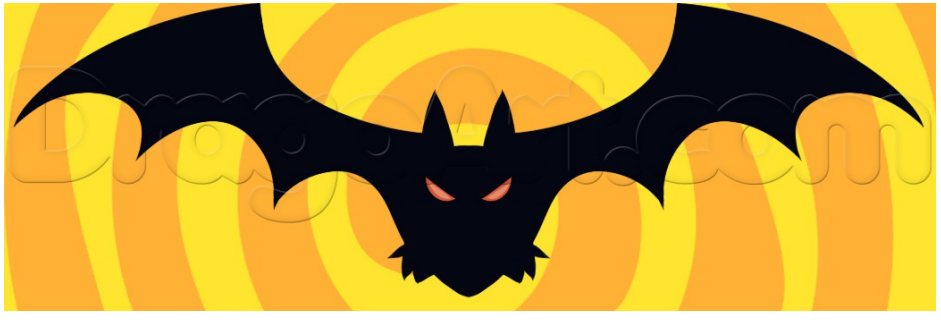

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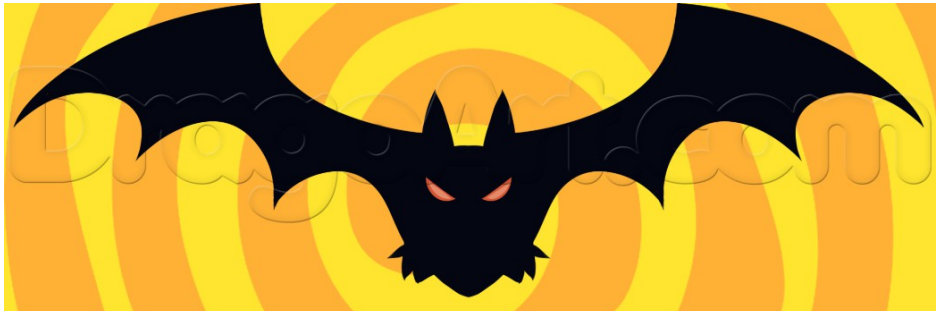

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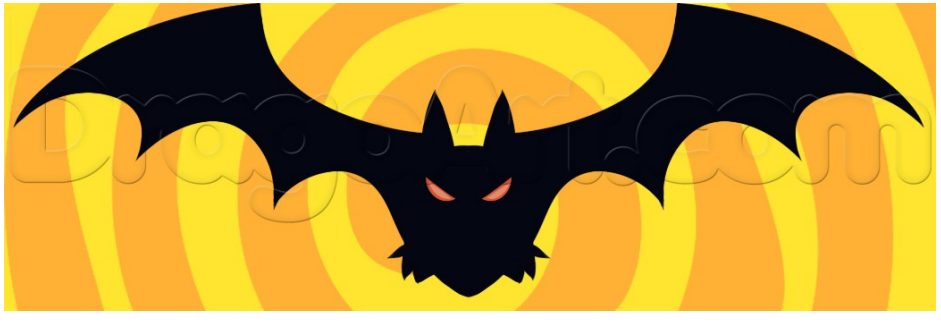
e.g. time can be promoted to a q-number using constrained QM [quantum time: PRD 92, 045033]



(a first step in this program)

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NOT GOOD: world lines (trajectories) don't exist in QM

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(good for QM, but still based on systems? classical limit unclear)

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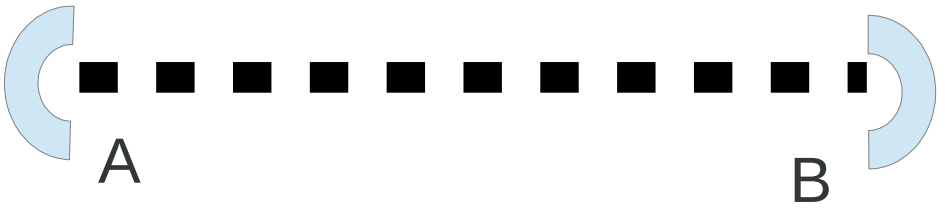

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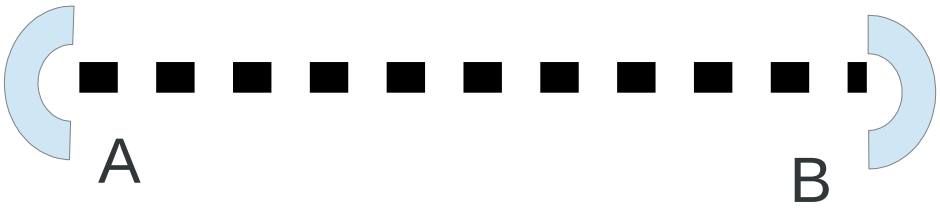

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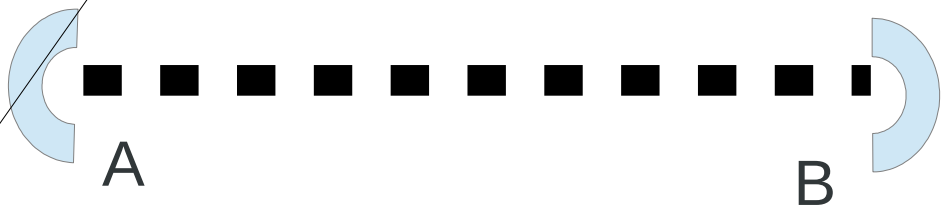

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The particle crosses all intermediate times:

$$\int dx |\langle x|\psi(t)\rangle|^2 = 1 \; \forall t$$

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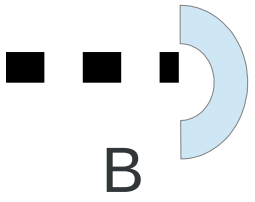

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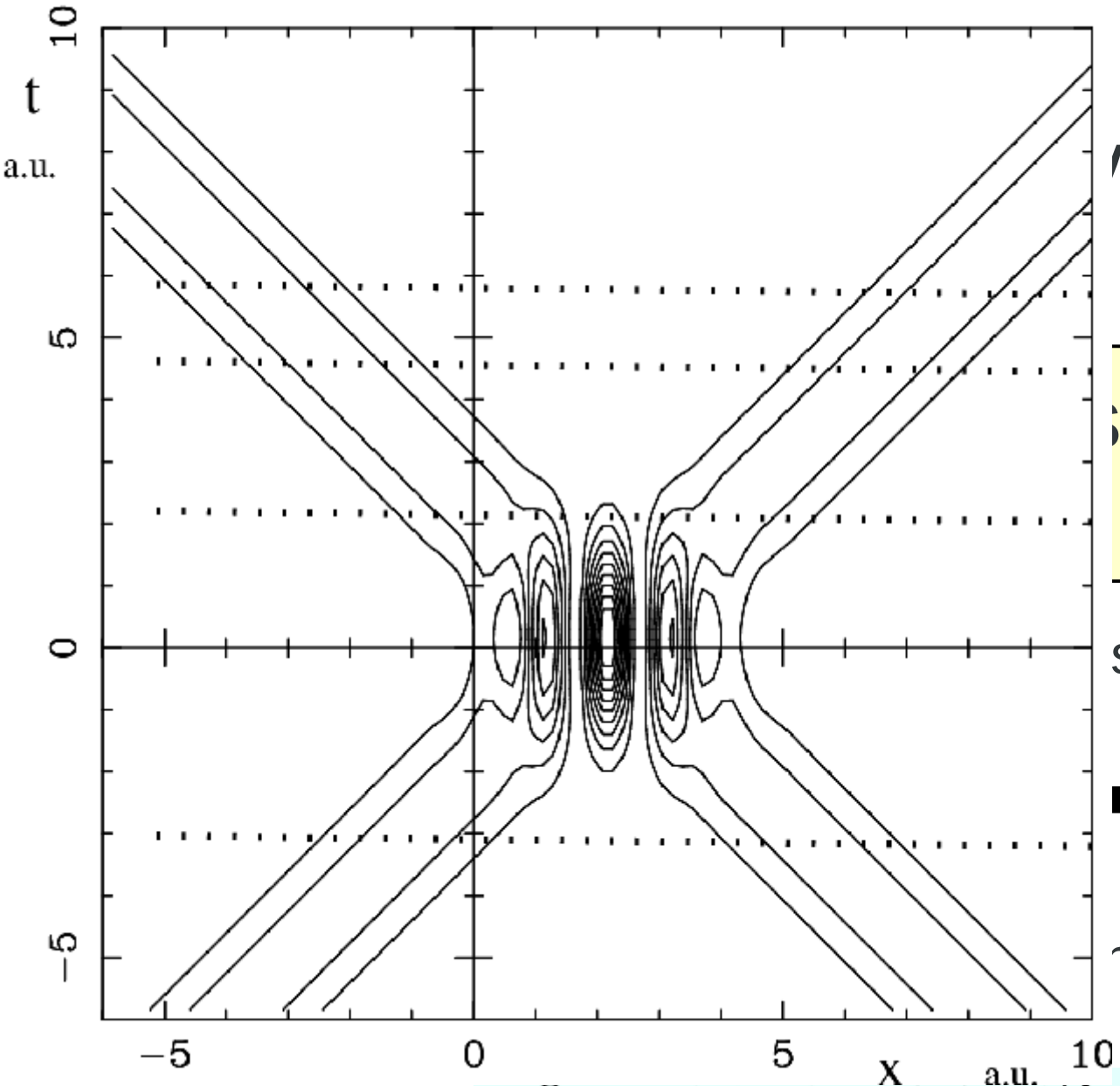

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From -∞ to +∞ !!!!

Is this ***reasonable***?!?! In GR?

The big bang was a finite number of seconds ago.....

Part

B

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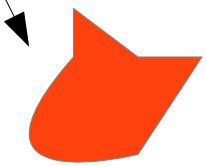

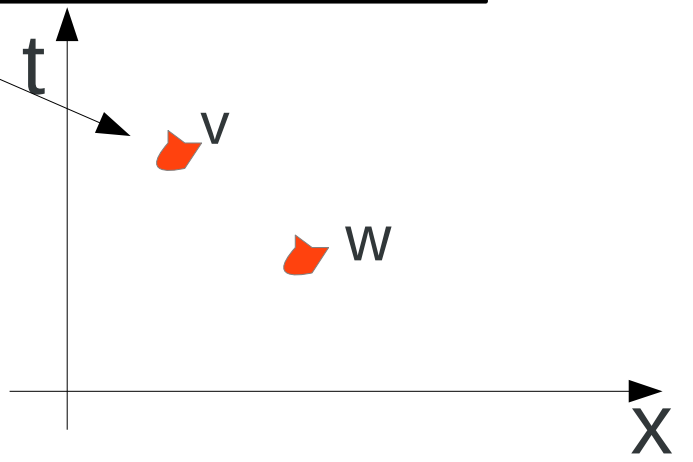

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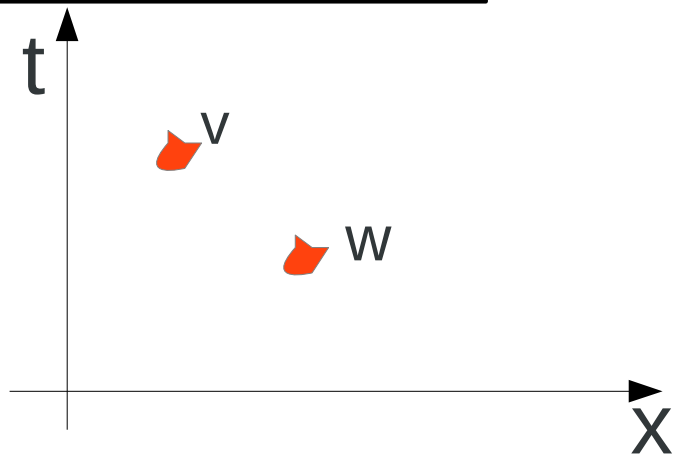

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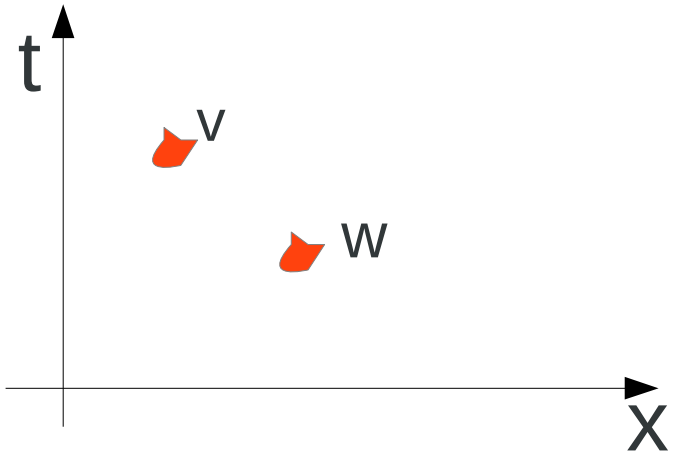

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Superpositions imply complementarity "spacetime energy-momentum"?!?
(complementary to spt position).

Classical limit for Ehrenfest theorem

Ok, we don't have a good definition of event for now....

... but can we say something about a

q theory of events?

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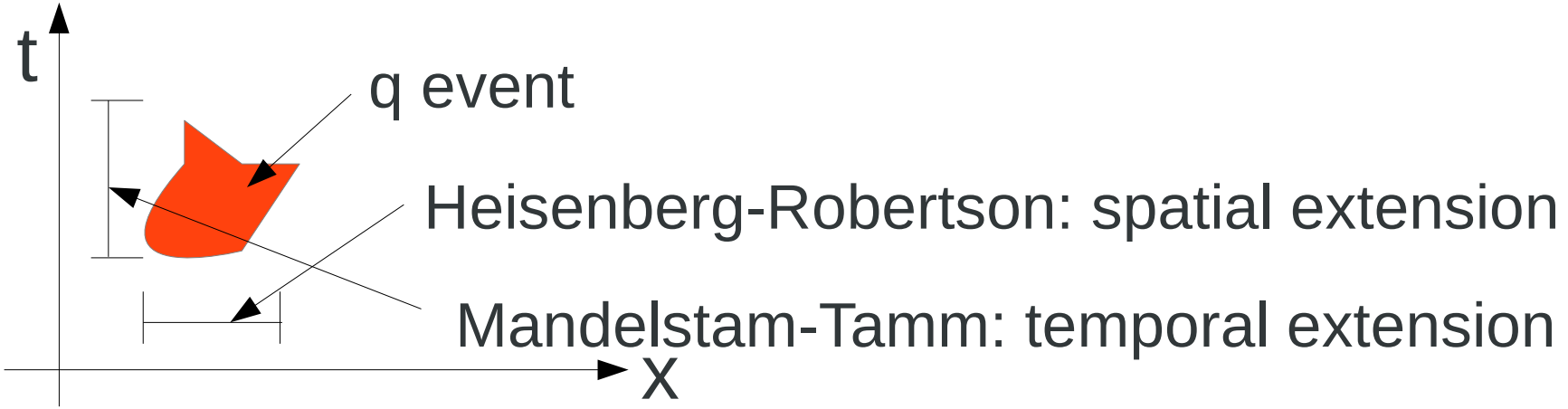
- uncertainty: connects events' spacetime extension with their energy-momentum



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Dependent events are necessary if one wants to define system="a succession of events".

$$|\psi(t_1)\rangle|\psi(t_2)\rangle|\psi(t_3)\rangle\cdots$$

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1. Initial state
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[Smolin] [Wharton]

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} QM
GR's Hamiltonian formulation
(geometrodynamics)

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} GR's covariant formulation
Fermat's princ.

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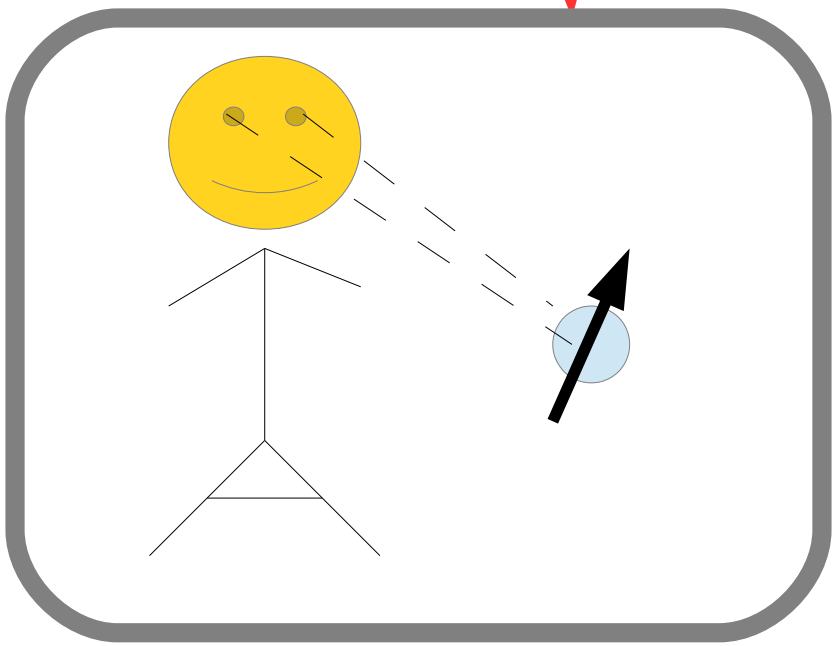
Probably not!

Describe a measurement as an interaction with the apparatus (von Neumann's prescription) and the Born rule gives the correct statistics (even for multiple measurements)

[quantum time: PRD 92, 045033]

Use von Neumann's quantum mechanics! (Born's rule and all that)

While we do admit that a unitary description of a measurement apparatus must exist, we still work in the conventional quantum framework.



Alice's lab

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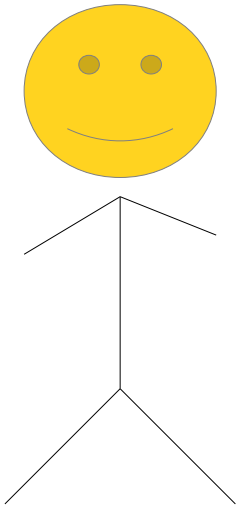
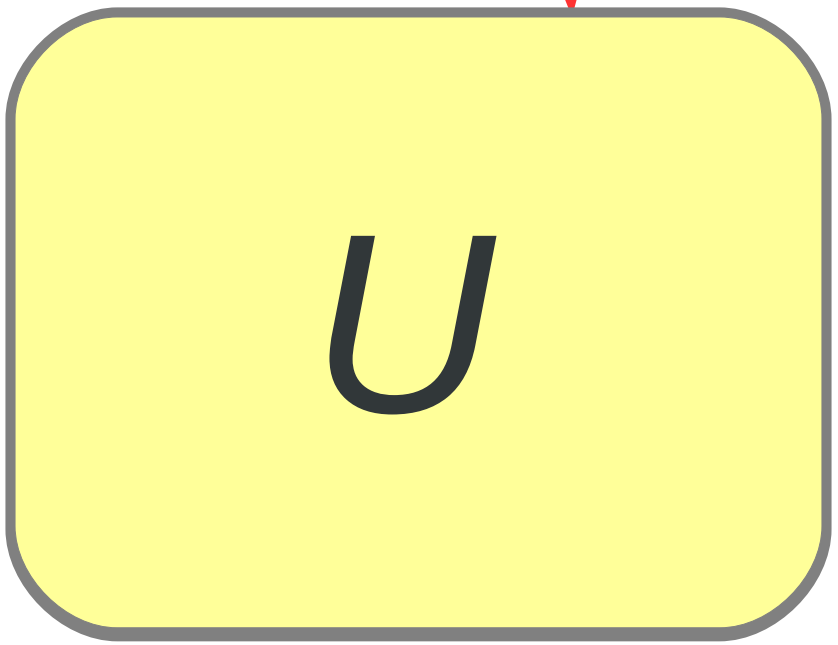


Bob's point of view



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A successful theory for q events would satisfy these and give rise to the usual axiomatic formulation of QM (in the appropriate limits)

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(like everyone else does!!!)

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"A **larger** number of events happen to the **same** number of systems"

(technically: continuous nature and infinities of QFT)

We should be able to do better than that...

A good testbed for a q GR?

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Goedel universe!

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we know that QM cannot deal with CTCs

[Deutsch] [PRL. **106**, 040403]

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[Deutsch] [PRL. **106**, 040403]

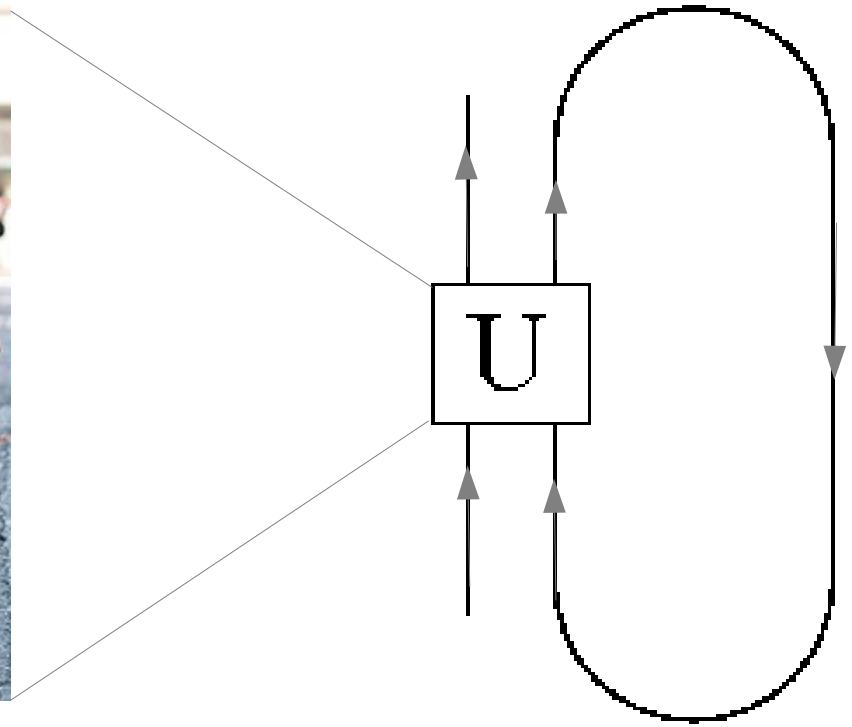
we know that GR *has* CTCs

they won't go away in a quantum GR

(they appear in macroscopic scenarios where q corrections are certainly negligible)

What is a CTC?

CTC=Closed Timelike Curve is a closed trajectory in space-time ⇒ Following a CTC an object can interact with its own past



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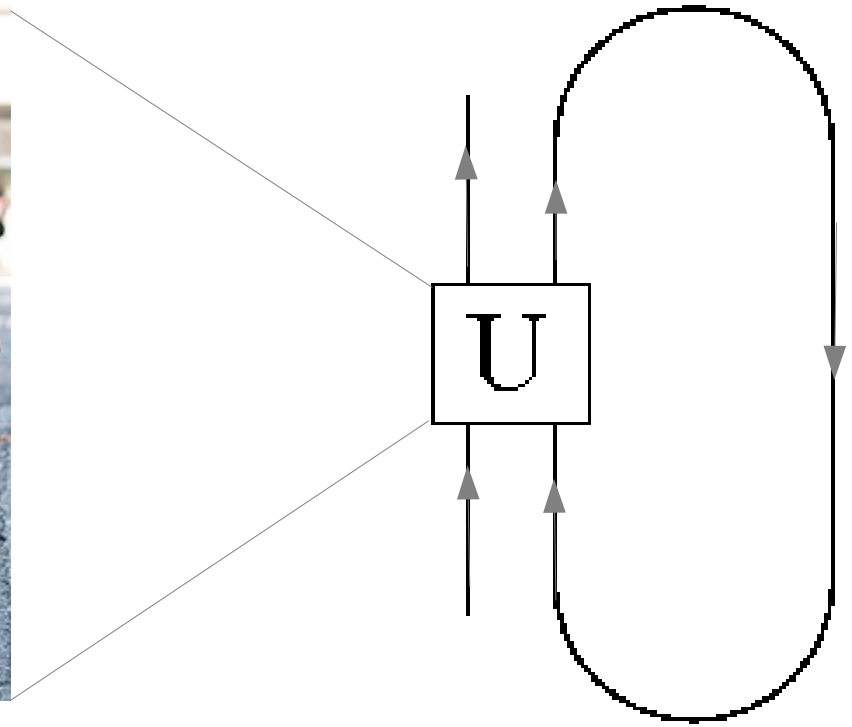

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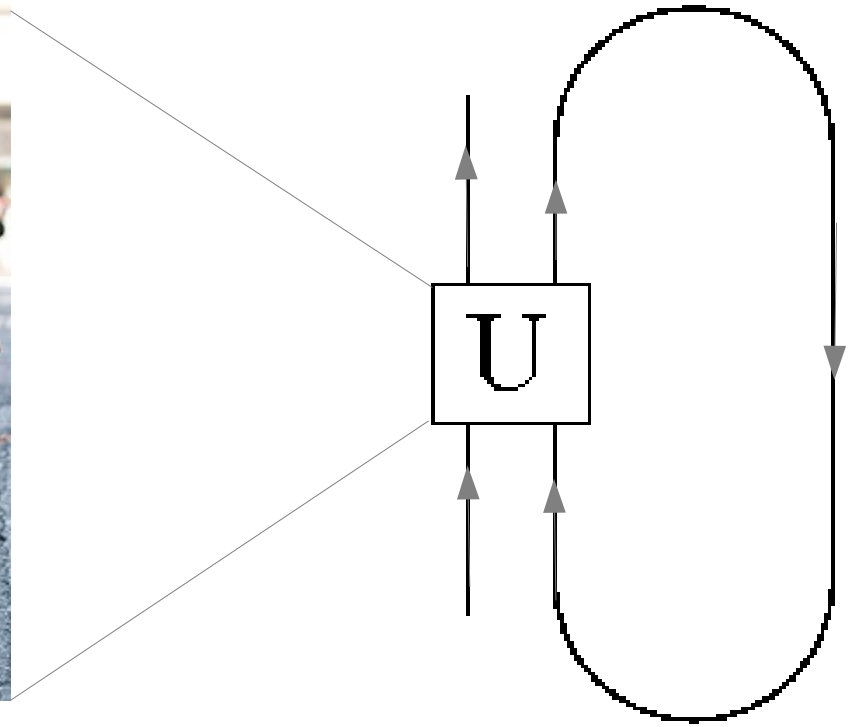

CTCs typically form around massive rotating objects: frame dragging bends the null cones.

We currently don't know whether our universe contains any such object

... but in any case, they are quite typical in GR

Conclusions: What did I say?

- GR → Events
- QM → Systems

} talk of different objects

- What is a quantum event? Can we base QM on events instead of systems?
- What does a q theory of events look like? Three desiderata
- What do we gain?

Take home message

To join QM and GR maybe we need a **quantum theory of events**

Lorenzo Maccone
maccone@unipv.it

q events: work in progress
quantum time:
PRD **92**, 045033
Pauli objection:
Found. Phys. **47**, 1597


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