Tachyons

Abhilash Sengupta

“Anything that is not forbidden is compulsory.”

-Murray Gell-Mann

What is a tachyon?

- Tachyons are hypothetical superluminal particles.
- The particle number of tachyons is not Lorentz invariant (will be explored a bit later)

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- Tachyons are hypothetical superluminal particles.
- The particle number of tachyons is not Lorentz invariant (will be explored a bit later)

- No! We have not yet detected/created tachyons.

Glossary

- **Tardyons**: Particles with subluminal ($\beta < 1$) velocity which can be observed at rest and have a non-zero rest mass.
- **Luxons**: Massless particles with velocity of light ($\beta = 1$).

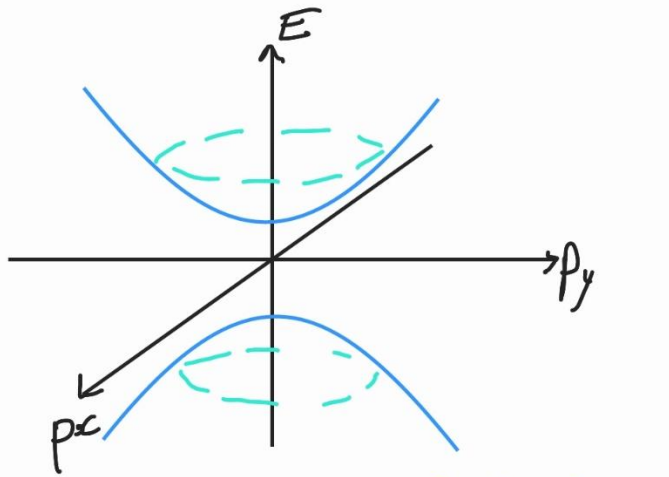
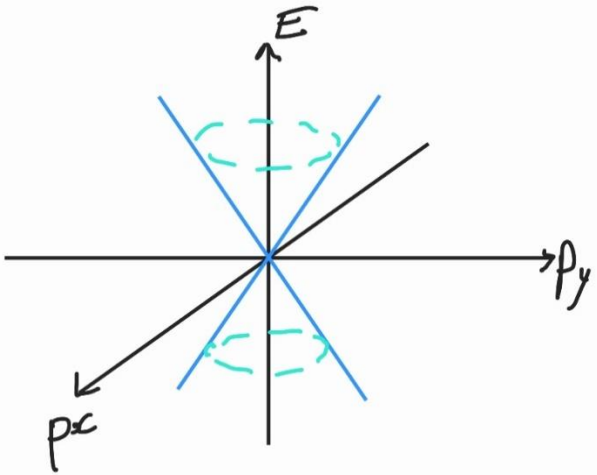


FIG: TARDYONS
(class I)



$E^2 - p^2 = m^2 = 0$

FIG: LUXONS (CLASS II)

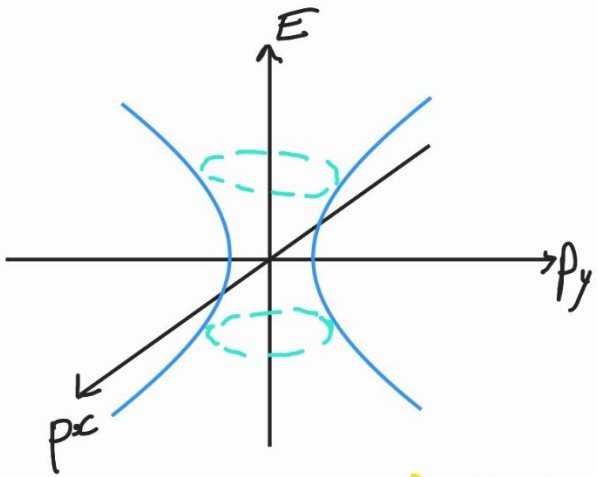


FIG: TACHYONS
(class III)

$$m = im_*$$

Tachyons (sort of) break causality

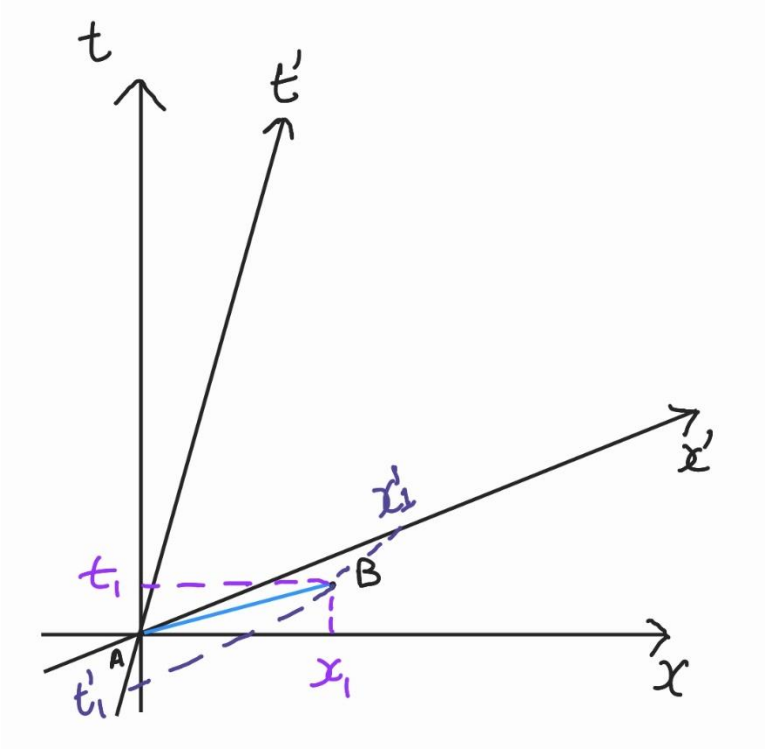


FIG: Tachyon emission as observed from 2 different frames

Frame O’ is moving with velocity β wrt O

But this does not just happen for Tachyons!

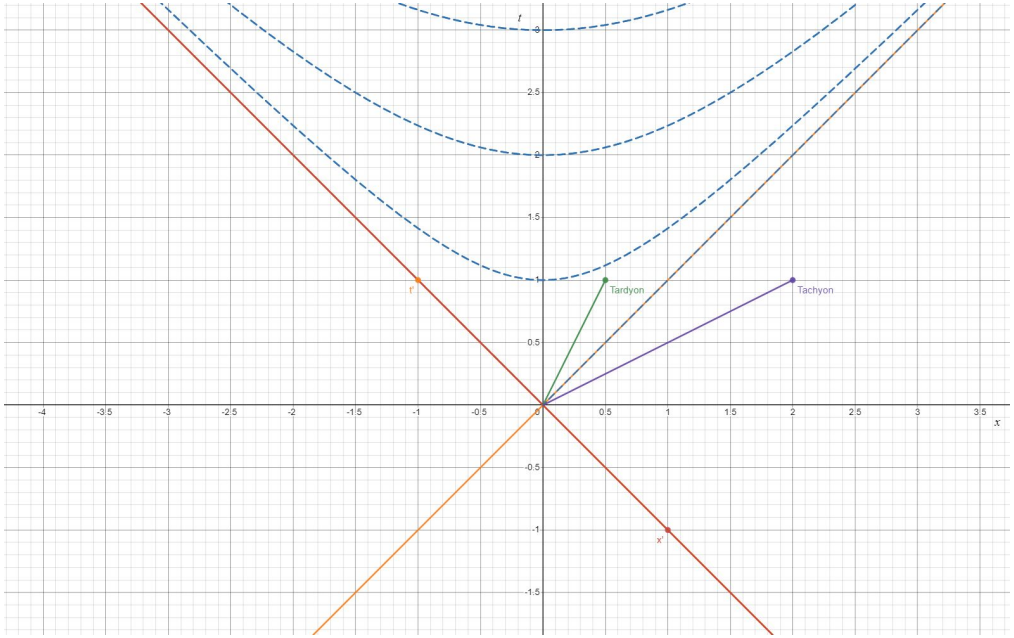


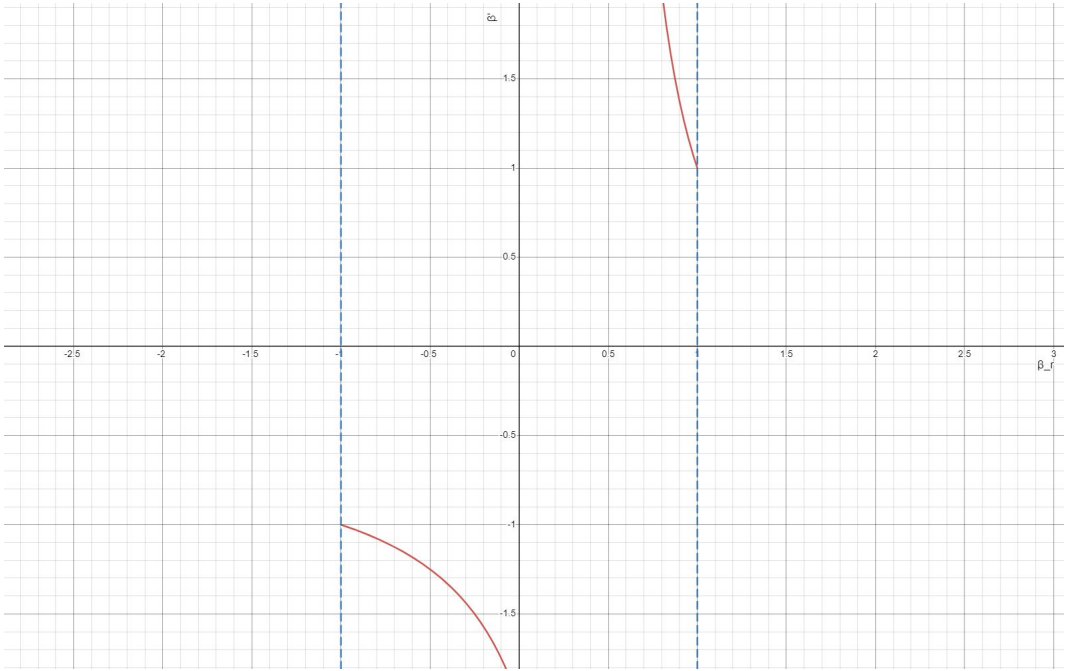
Fig: Space-time from the frame of an observer with $-1<\beta<1$

Temporal ordering

- Temporal order may reverse if $\beta < \beta_r^{-1}$. This is, however, only a problem when this situation prevails with change in β.
- From the velocity addition formula,

$$\beta' = \frac{\beta + \beta_r}{1 + \beta\beta_r}$$

where, β' is the velocity of the particle observed from frame O'.



β oscillates from -2 to 2

Reinterpretation Principle

Negative-energy tachyons propagating backward in time are interpreted as Positive-energy tachyons propagating forward in time.

Imaginary Mass?

- For Tardyons, when β = 0,

$$E_{rest} = m_{rest}$$

- But for Tachyons, β>1. Rest mass is not an observable quantity and thus it being imaginary is not an issue.
- Accordingly, “rest” energy will also never be imaginary.

$$E = \frac{m}{\sqrt{1-\beta^2}} = \frac{\pm m_*}{\sqrt{\beta^2-1}}\epsilon\mathbb{R}$$

$$p = \frac{m\beta}{\sqrt{1-\beta^2}} = \frac{\pm m_*\beta}{\sqrt{\beta^2-1}}\epsilon\mathbb{R}$$

Proper length and time need to be imaginary?

$$l = \lambda\sqrt{1-\beta^2} = i\lambda\sqrt{\beta^2-1}$$

$$t = \frac{\tau}{\sqrt{1-\beta^2}} = i\frac{\tau}{\sqrt{\beta^2-1}}$$

Here, l and t are the length and time. λ and τ are the proper length and time.

The Observer

- All observers have real mass and are Tardyonic, so β between 2 such co-ordinate systems can never exceed 1.
- But from the “rest” frame of reference of a Tachyon, no observer is ever at rest.
- λ and τ are unobservable for a Tachyon, and thus they need not be real.

Tachyon-Tardyon interactions

- Consider a tachyon (imaginary mass $m = im_*$) with the initial 4-momenta $(\overrightarrow{p_0}, E_0)$.
- Also consider a tardyon (real mass m') with the initial 4-momenta $(\overrightarrow{p_0'}, E_0')$.

- After collision, let their final 4-momenta be

$$(\vec{p}, E) \ \& \ (\overrightarrow{p'}, E')$$

  respectively.
- From the laws of Energy and Momentum Conservation we obtain,

$$E_0 + E_0' = E + E'$$

$$\overrightarrow{p_0} + \overrightarrow{p_0'} = \vec{p} + \overrightarrow{p'}$$

$$E_0^2 - p_0^2 = E^2 - p^2 = m^2 < 0$$

$$E_0'^2 - p_0'^2 = E'^2 - p'^2 = m'^2 < 0$$

Viewed from a reference frame where all the energies are positive, we observe an ordinary elastic 2-particle collision.
However, viewed from a frame where the Tachyon has –ve energy, the Reinterpretation Principle has to be employed again.

Reinterpretation Principle in action!

Initial condition:

Tardyon with 4-momentum $(\overrightarrow{p_0'}, E_0')$ colliding with
2 Tachyons with 4-momenta $(\overrightarrow{p_0}, E_0)$ and $(-\vec{p}, -E)$ respectively

After collision,

$$\overrightarrow{p_0} + \overrightarrow{p_0'} + (-\vec{p}) = \overrightarrow{p'}$$
$$E_0 + E_0' + (-E) = E'$$

$$E_0^2 - p_0^2 = (-E)^2 - (-p)^2 = m^2 < 0$$
$$E_0'^2 - p_0'^2 = E'^2 - p'^2 = m'^2 > 0$$

So What?

Alvarez Criterion

$$\mu = P \times \sigma$$

μ = Merit of an experiment,
P = Probability of its success,
σ = Significance of result

Alvarez Criterion

$$\mu = P \times \sigma$$

μ = Merit of an experiment,
P = Probability of its success,
σ = Significance of result

For Tachyon detection, $P = 0; \sigma = \infty$

Most notable attempts to detect Tachyons

- During 1963-65 Torsten Alväger and Peter Erman, at the Stockholm Nobel Institute, attempted to observe emission of charged Tachyons from a strong beta-ray source and attempted to look for meta-electrons.

- A subsequent experimental search for tachyons by means of their Cherenkov Radiation effect was carried out by Torsten Alväger and M.N. Kreisler at the Penn-Princeton Accelerator. They bombarded lead with gamma rays from a 5-mCi Cesium-134 source and assumed the creation of charged tachyon pairs in the surrounding lead shield.

Probably why we didn't detect any Tachyons yet

- Tachyons might just be neutral.
- If charged Tachyons do, in fact, exist their detection can be shown to be extremely difficult. Mathematically, we begin from the energy loss per unit length,

$$\frac{dE}{ds} = -4\pi^2 Z^2 e^2 \int (1 - \frac{1}{\beta^2 n^2}) \upsilon d\upsilon = \frac{-Z^2 e^2 m_*^2 E^2}{2p^2}$$

Where, Ze = tachyon's charge; β = tachyon's velocity;
n = Refractive index; υ = Frequency of emitted radiation

Letting, E_i = initial energy of the Tachyon and
E_f = final energy of the Tachyon. The distance travelled during this radiation is,

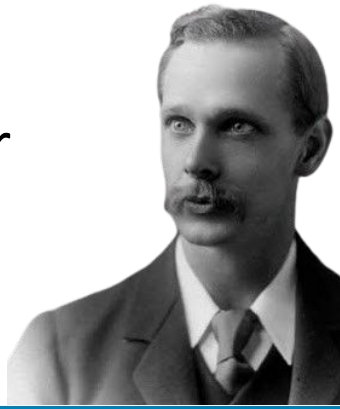
$$s = \frac{2}{Z^2 e^2 m_*^2}[E_i - E_f + m_*^2({}^1/_{E_f} - {}^1/_{E_i})]$$

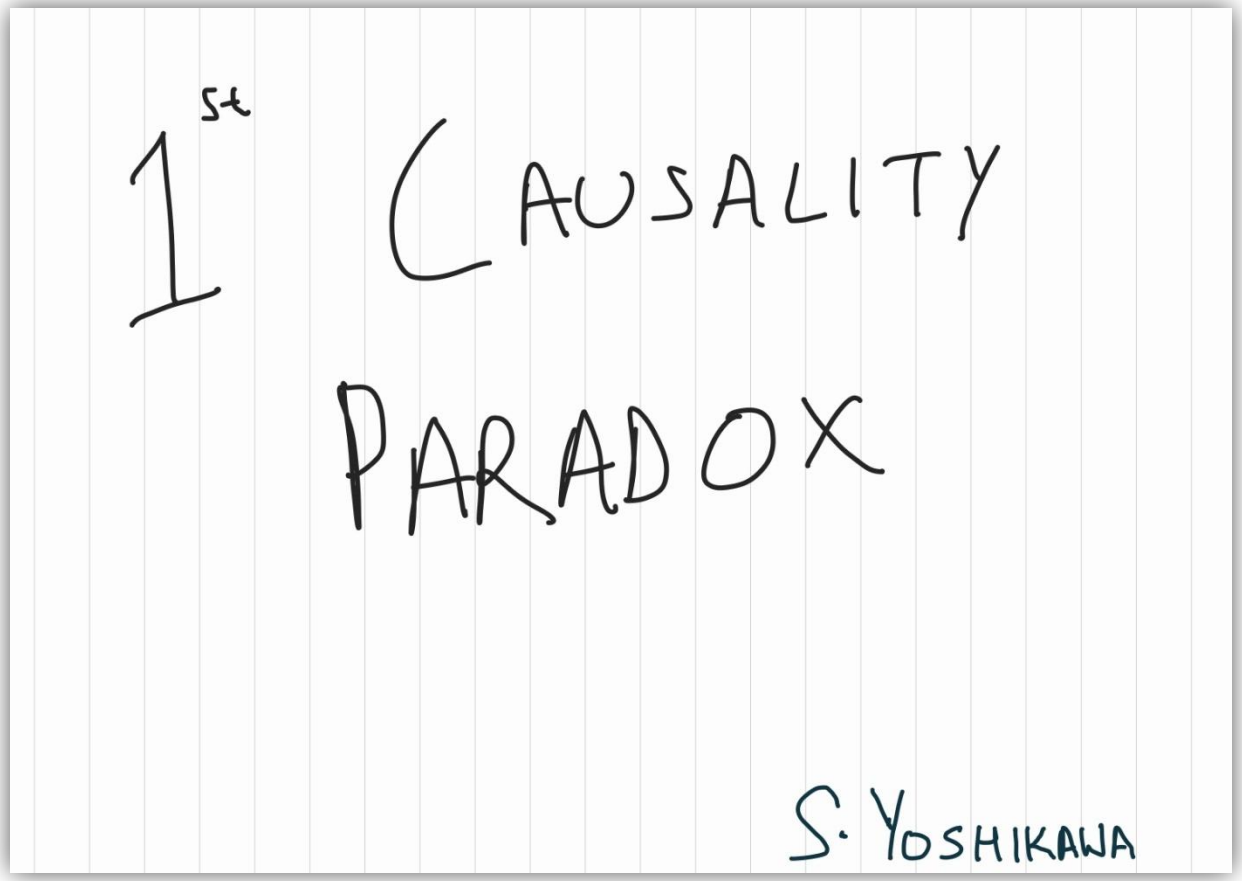
If $E_i \approx m_*$ and $E_i \gg E_f$, then we can approximate

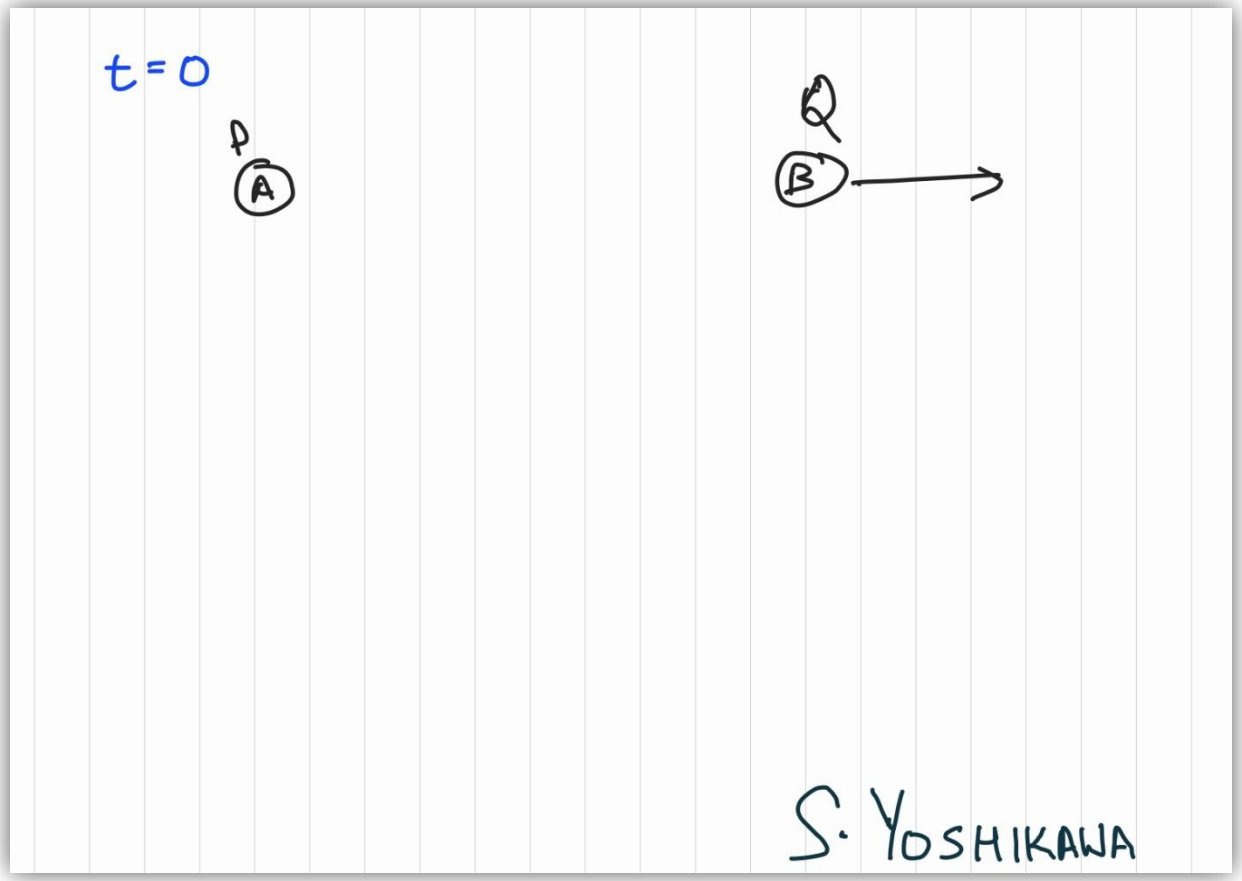
$$s \approx \frac{2}{Z^2 e^2 E_f}$$

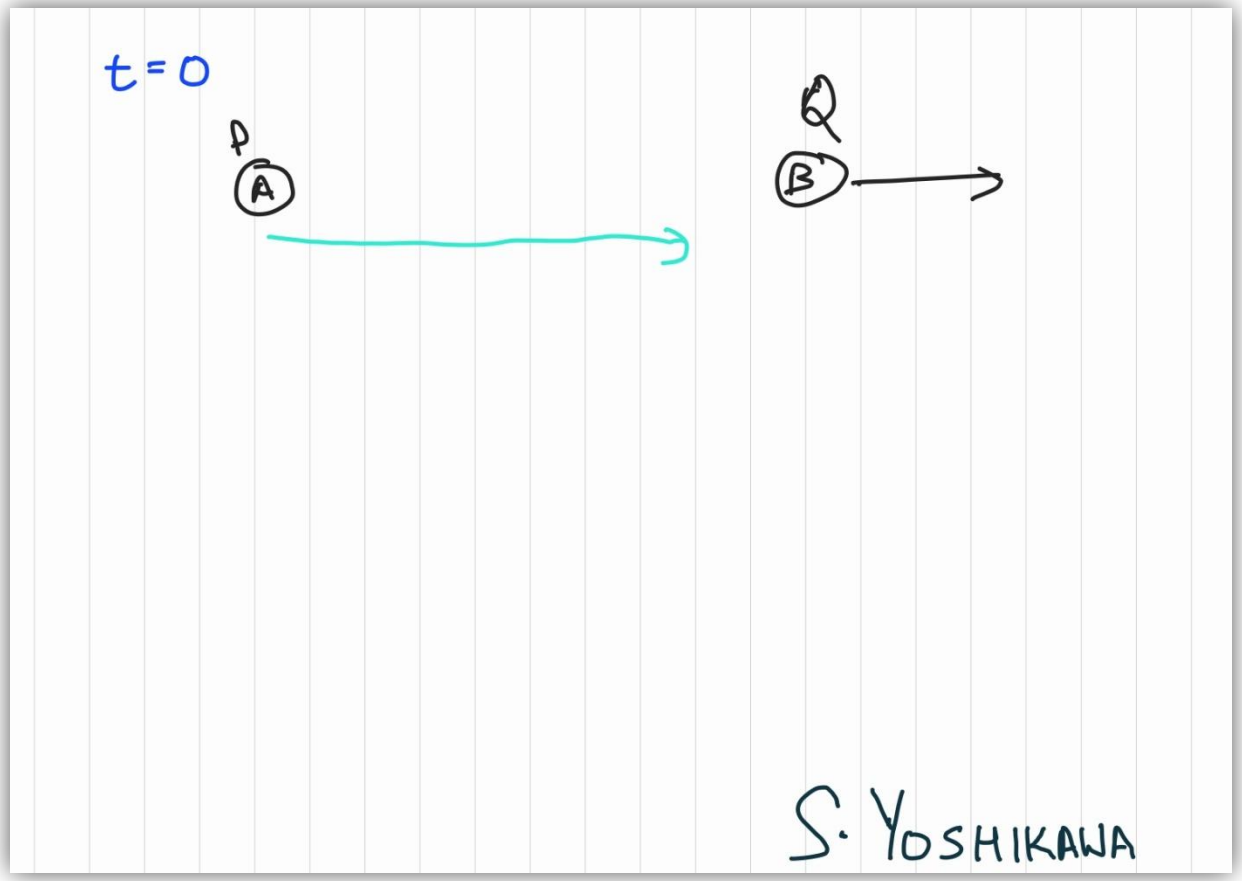
There was a young lady named Bright
Whose speed was far faster than light.
She went out one day
In a relative way
And returned the previous night.

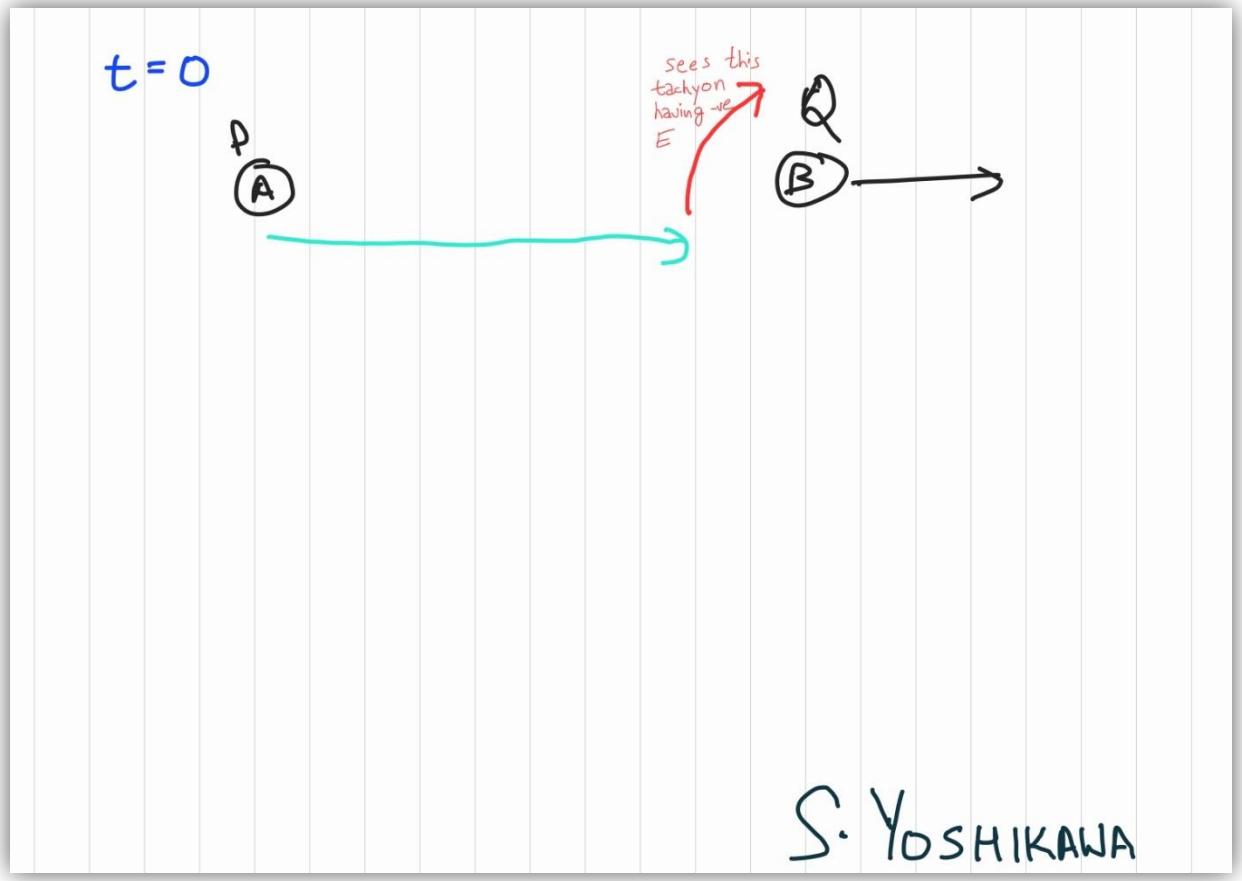
-Arthur Henry Reginald Buller

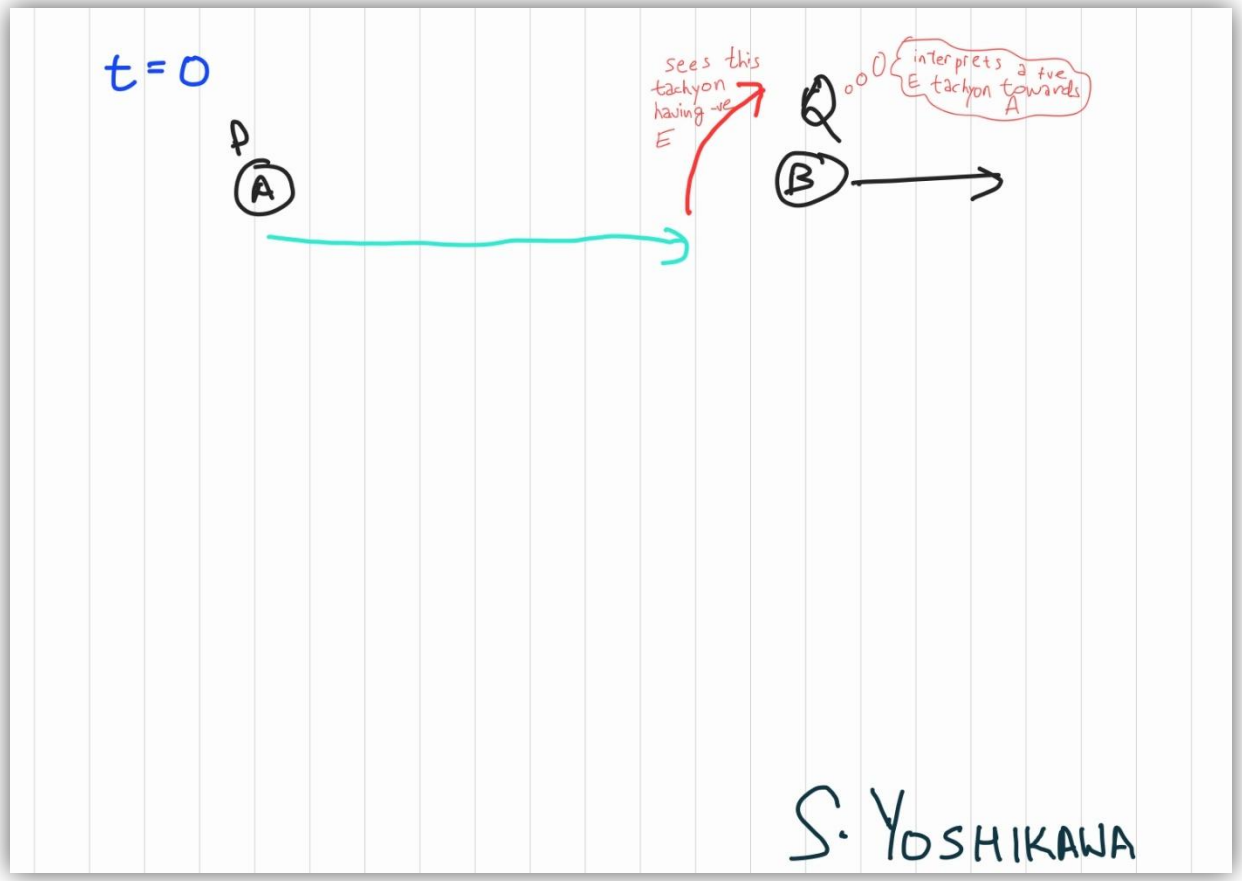


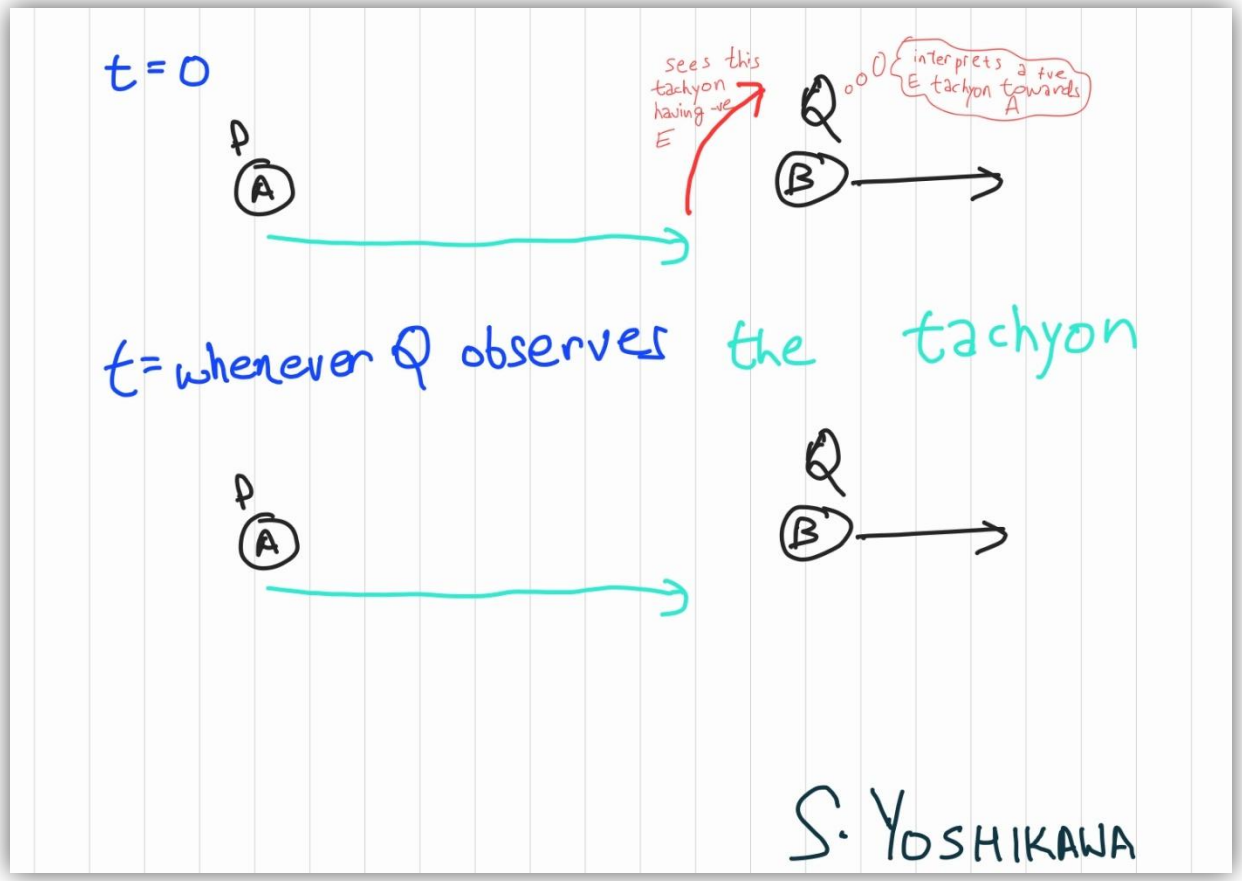

1st CAUSALITY
PARADOX
S. YOSHIKAWA

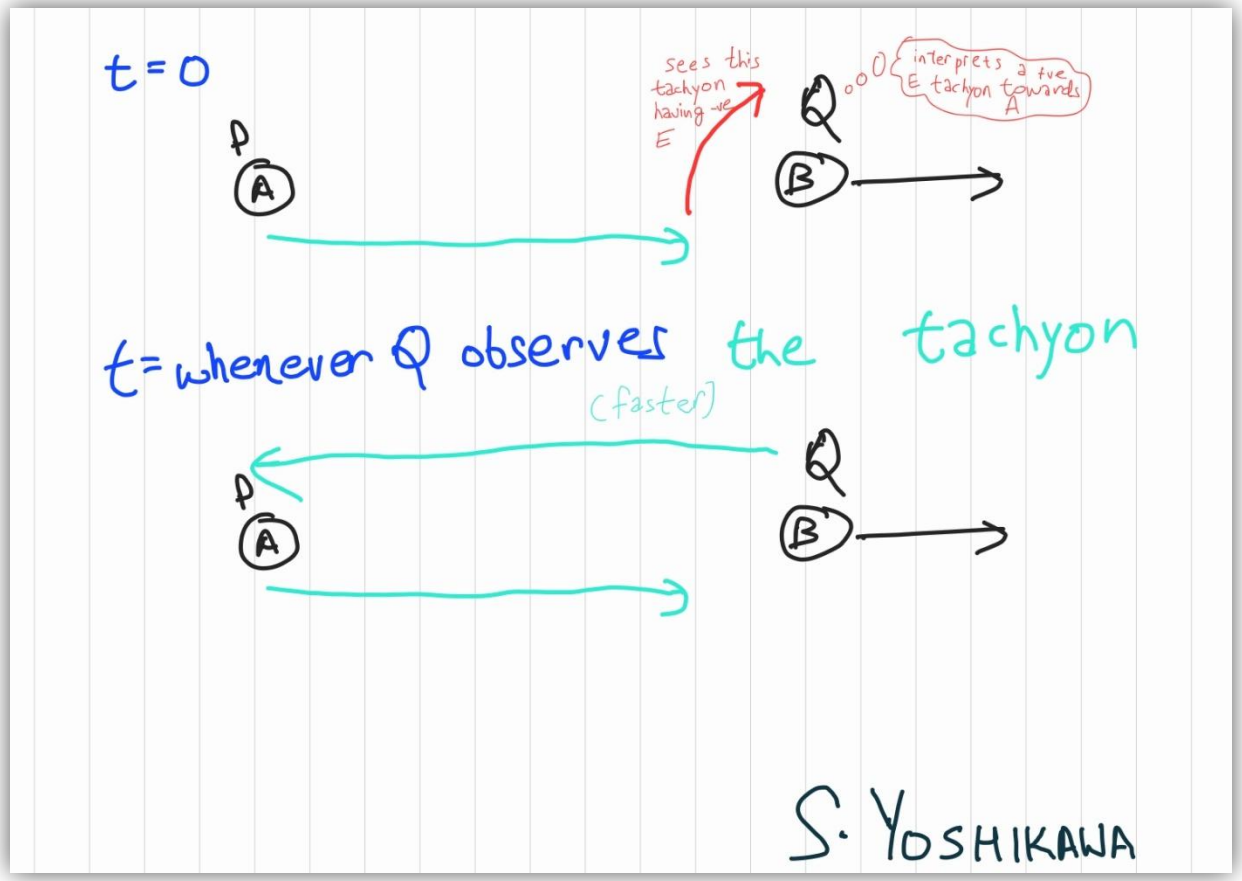

t=0
P
A
Q
B
S. YOSHIKAWA

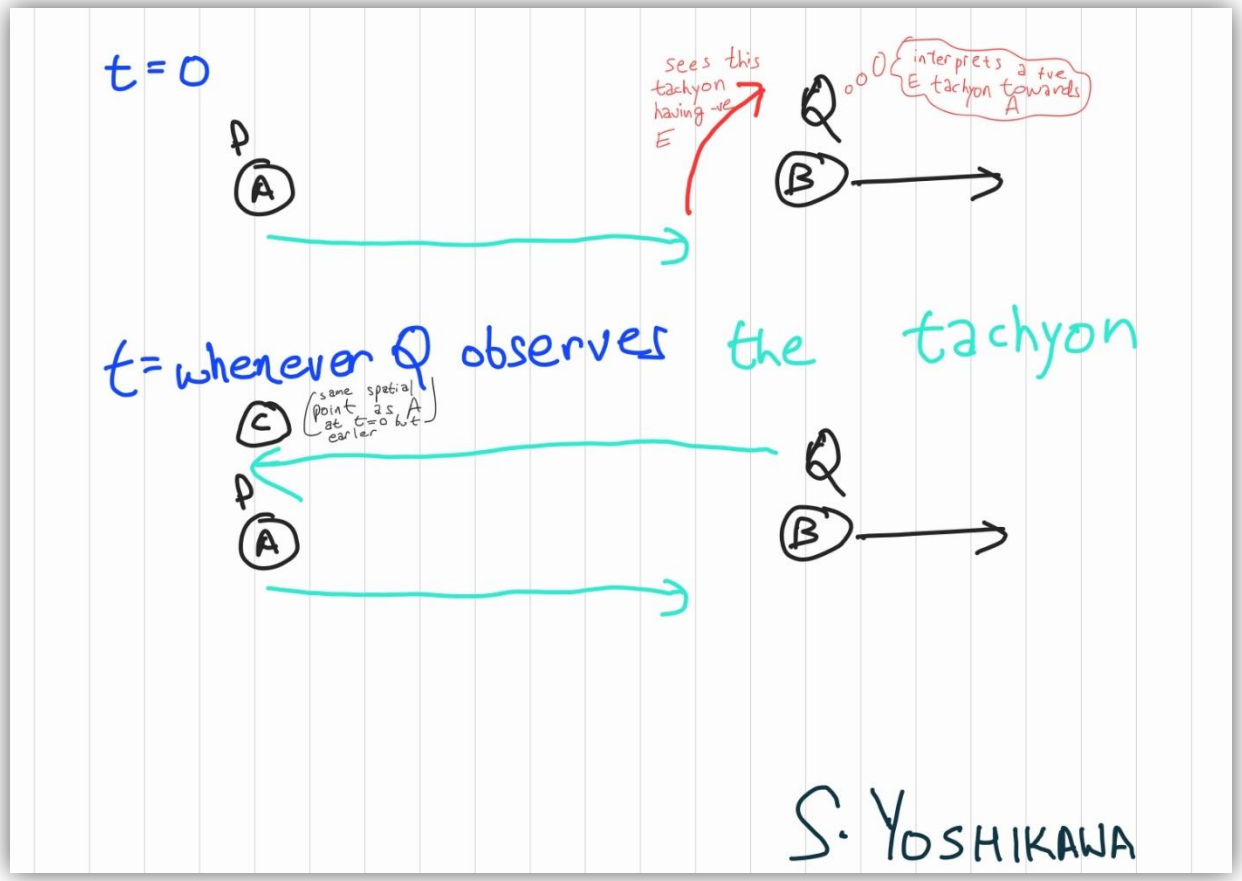

t=0
P
A
Q
B
S. YOSHIKAWA

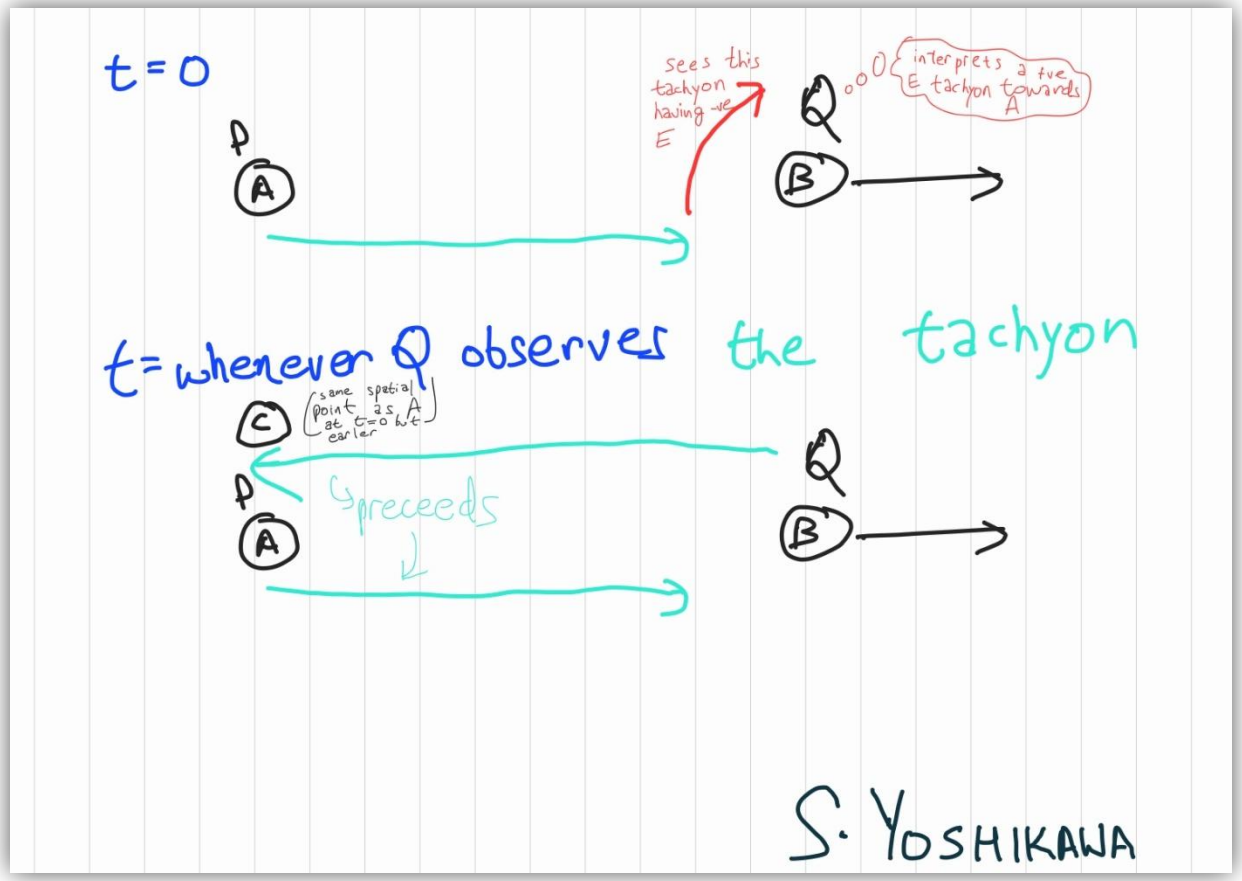

t = 0
P
A
sees this tachyon having -ve E
Q
B
S. YOSHIKAWA

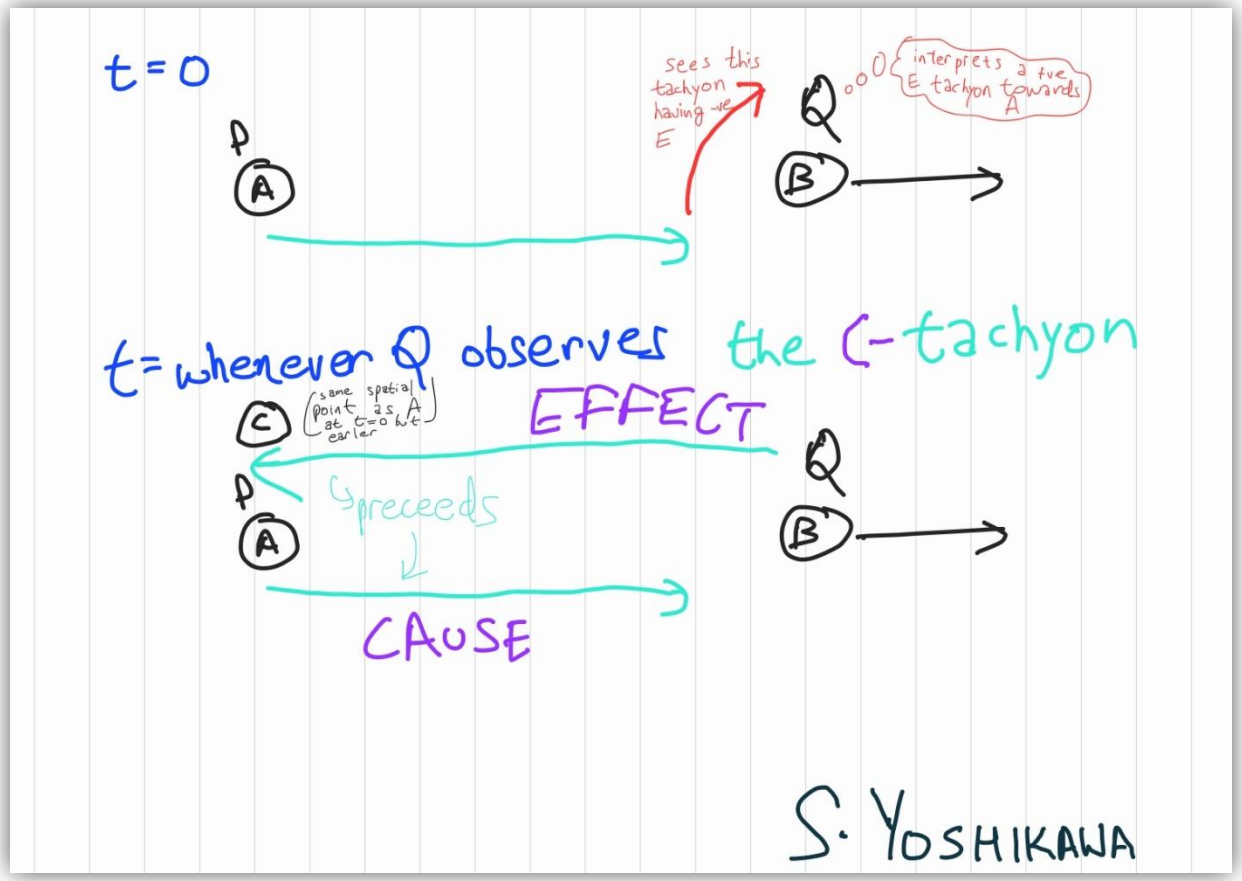

t = 0
p
A
sees this tachyon having -ve E
Q
B
interprets a tve E tachyon towards A
S. YOSHIKAWA

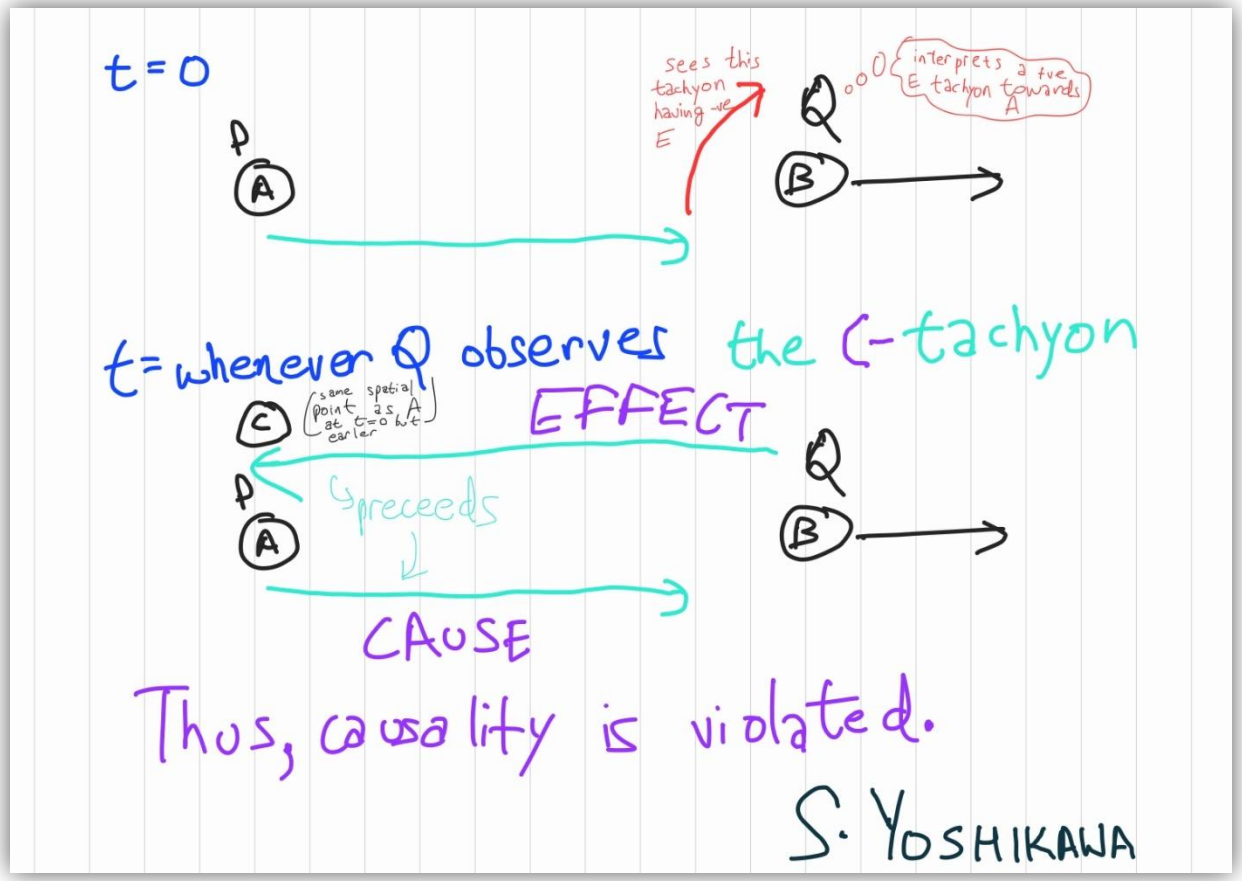

t = 0
P
A
sees this tachyon having -ve E
Q
B
interprets a tve E tachyon towards A
t = whenever Q observes the tachyon
P
A
Q
B
S. YOSHIKAWA

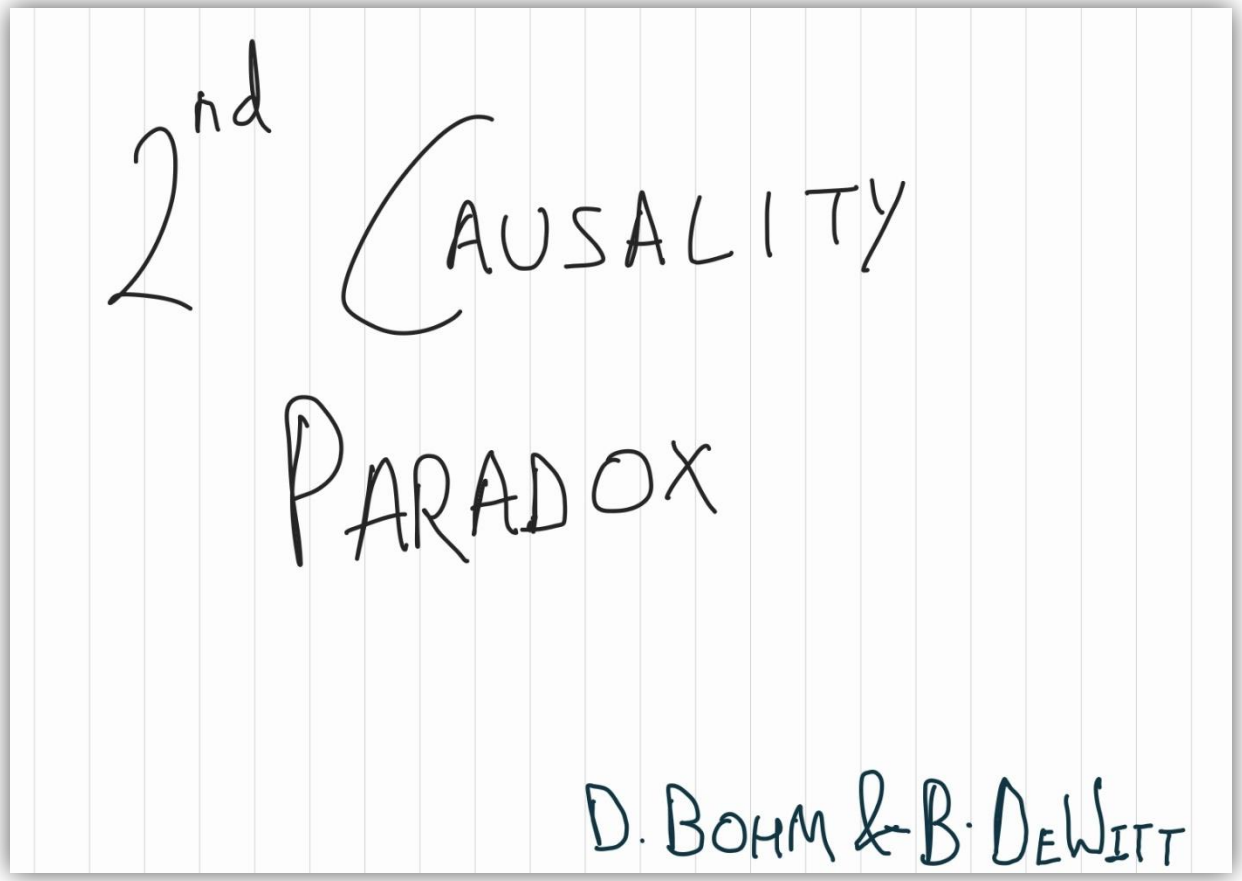

t = 0
P
A
sees this tachyon having -ve E
Q
B
interprets a +ve E tachyon towards A
t = whenever Q observes the tachyon
(faster)
P
A
Q
B
S. YOSHIKAWA

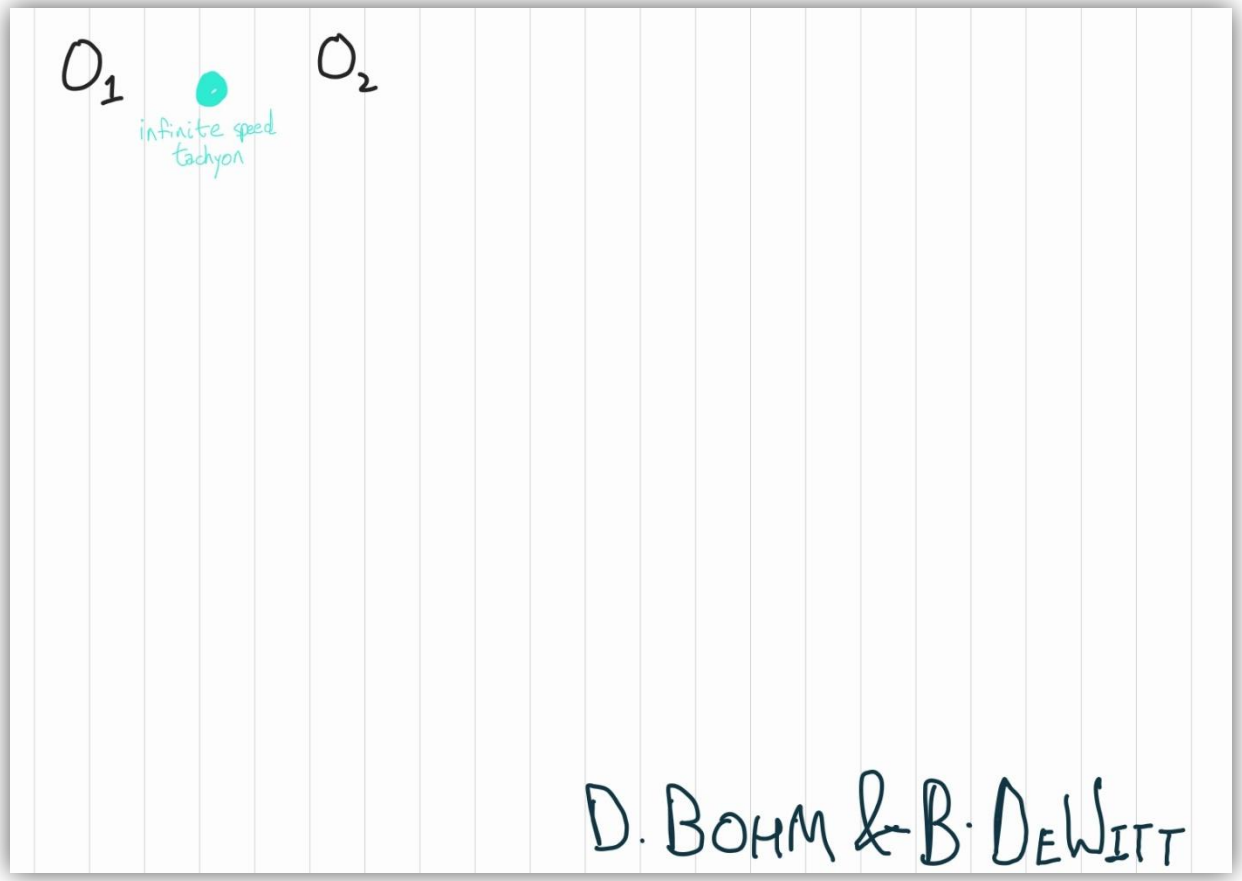

t = 0
P
A
sees this tachyon having -ve E
Q
B
interprets a tve E tachyon towards A
t = whenever Q observes the tachyon
C
(same spatial point as A at t=0 but earlier
P
A
Q
B
S. YOSHIKAWA

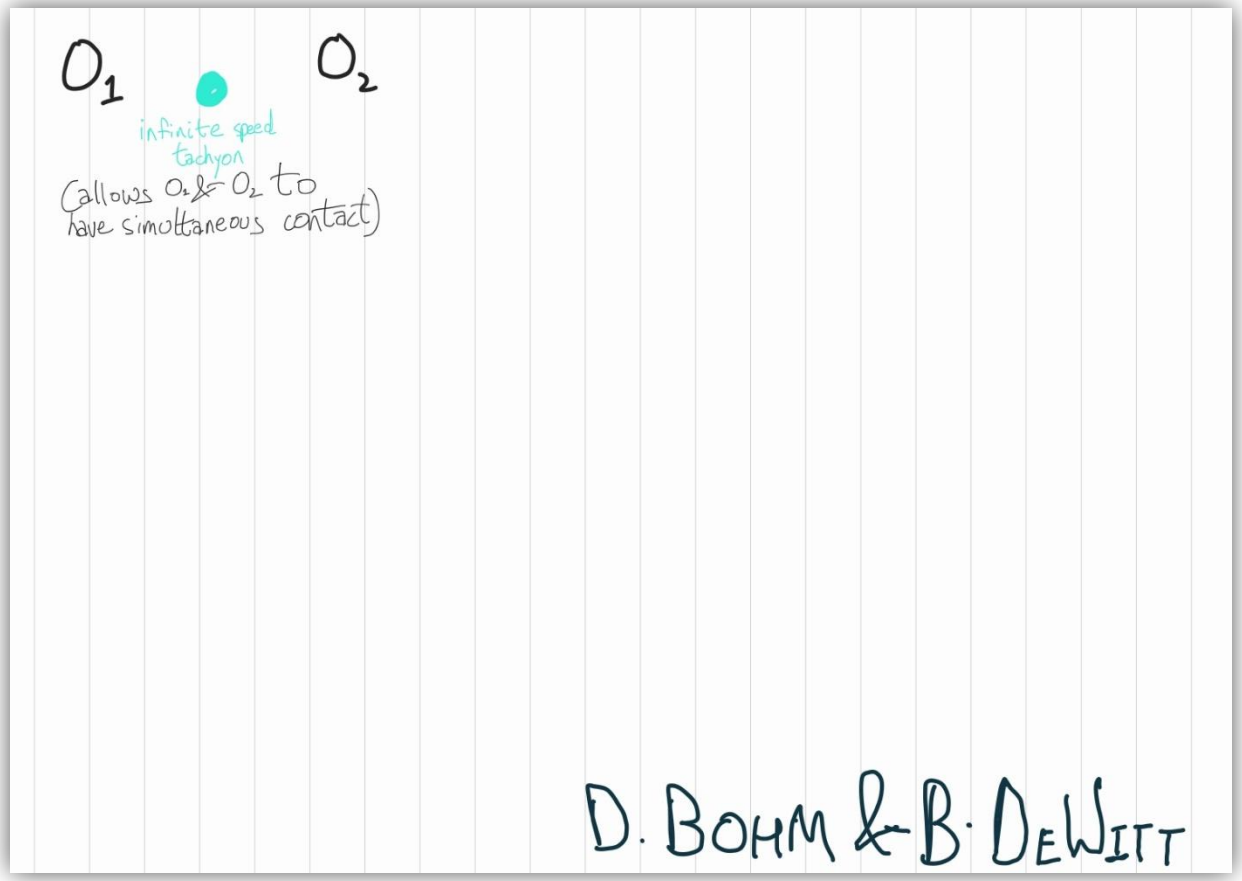

t = 0
P
A
sees this tachyon having -ve E
Q
B
interprets a tve E tachyon towards A
t = whenever Q observes the tachyon
C
(same spatial point as A at t=0 but earlier)
P
A
proceeds
Q
B
S. YOSHIKAWA

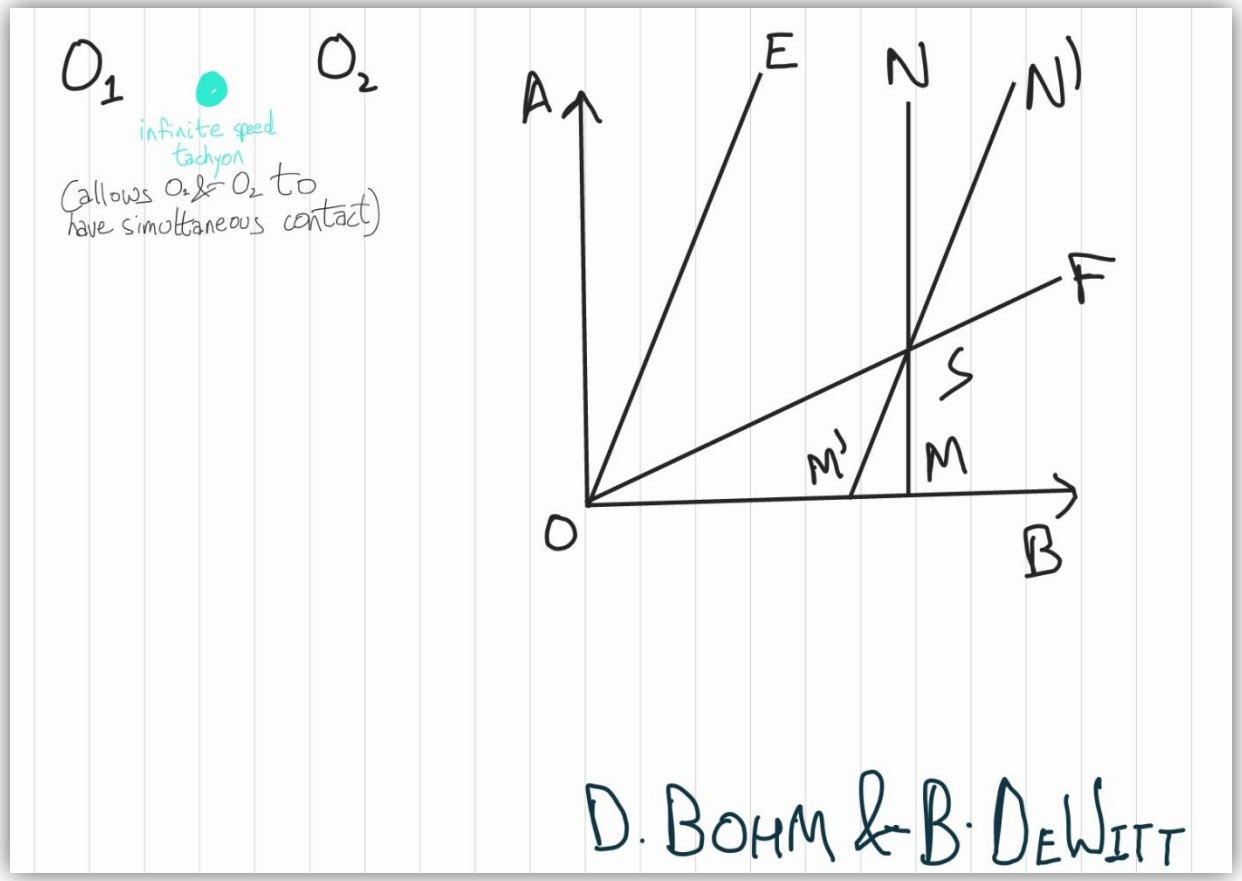

t = 0
P
A
sees this tachyon having -ve E
Q
B
interprets a tve E tachyon towards A
t = whenever Q observes the C-tachyon
C
same spatial point as A at t=0 but earlier
EFFECT
P
A
Q
B
proceeds
CAUSE
S. YOSHIKAWA

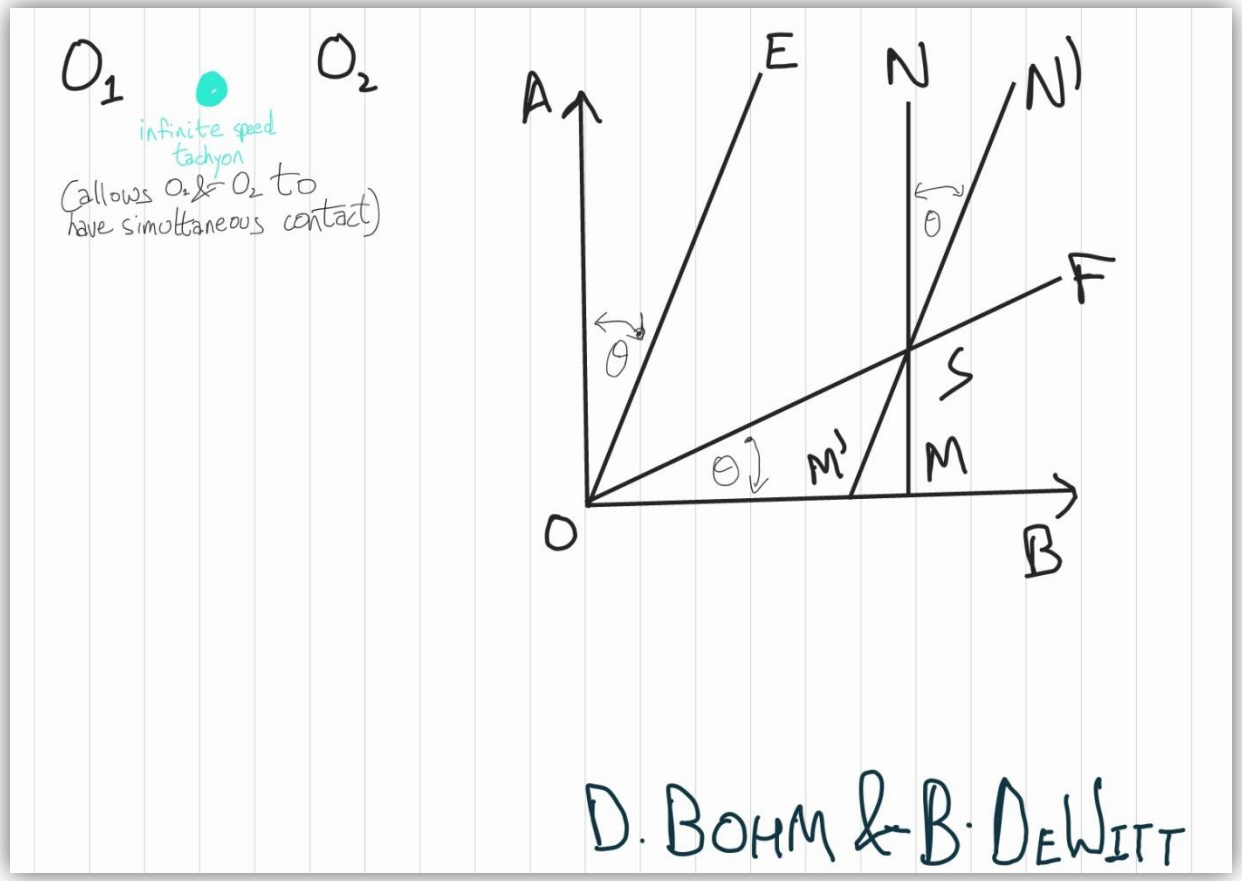

t = 0
P
A
sees this tachyon having -ve E
Q
B
interprets a tve E tachyon towards A
t = whenever Q observes the C-tachyon
C
(same spatial point as A at t=0 but earlier)
EFFECT
P
A
Q
B
proceeds
CAUSE
Thus, causality is violated.
S. YOSHIKAWA

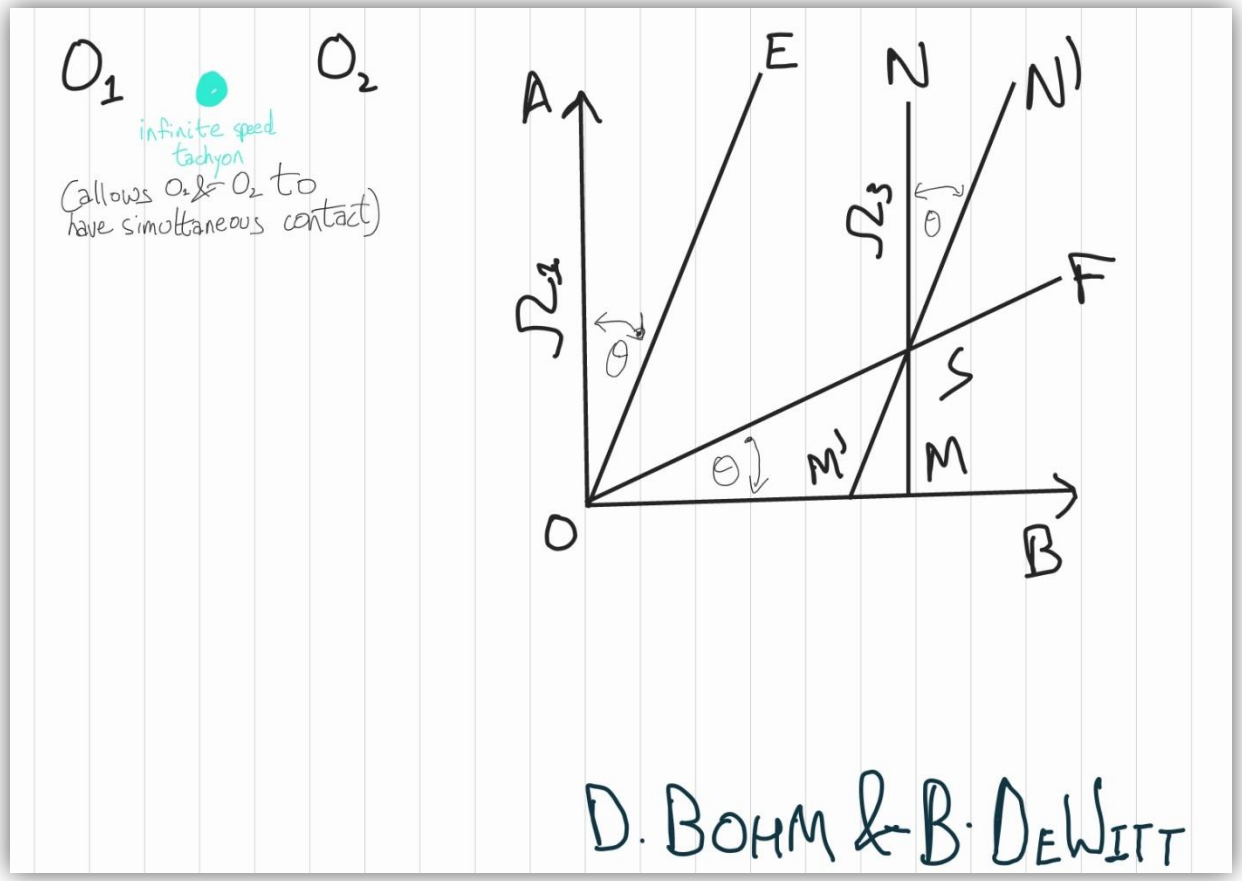

2nd
CAUSALITY
PARADOX
D. BOHM & B. DEWITT

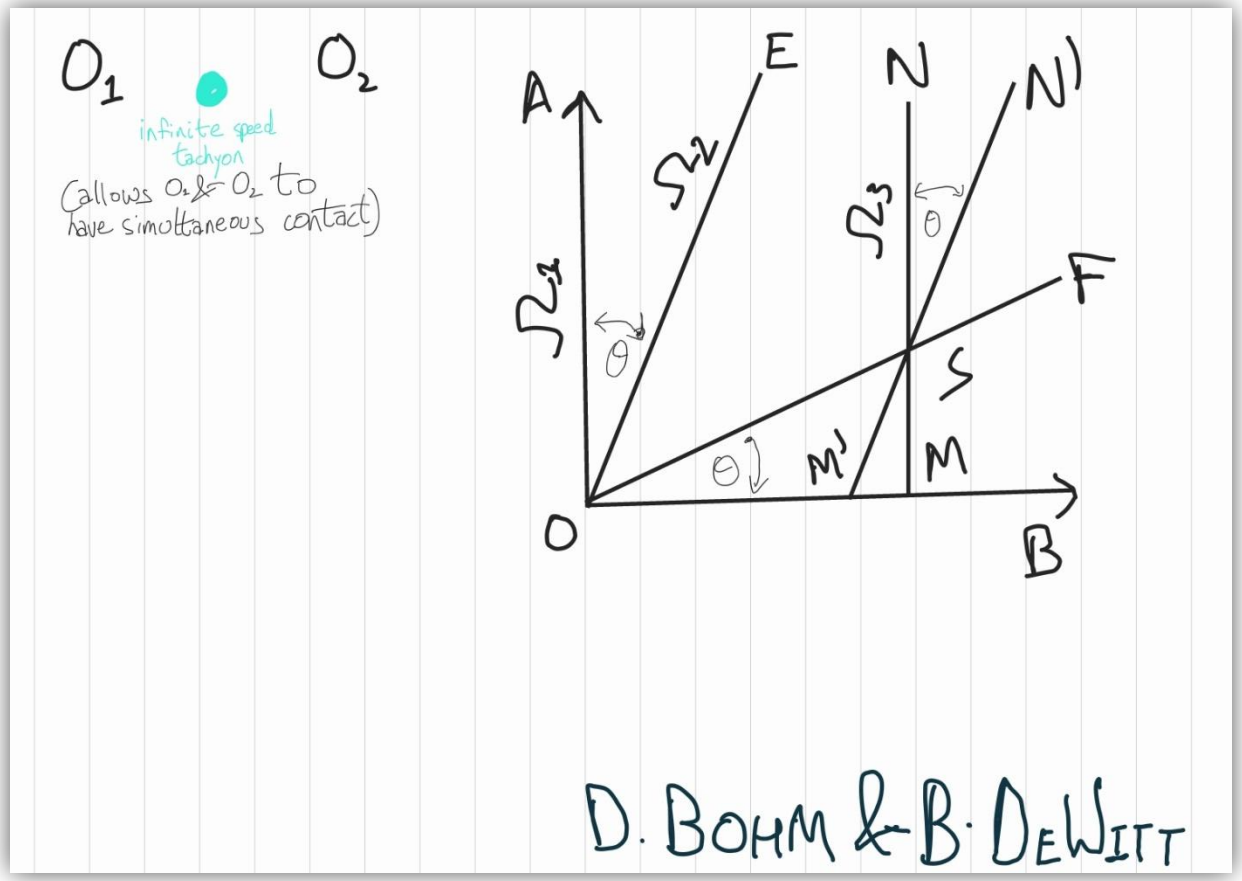

O_1
O_2
infinite speed tachyon
D. BOHM & B. DEWITT

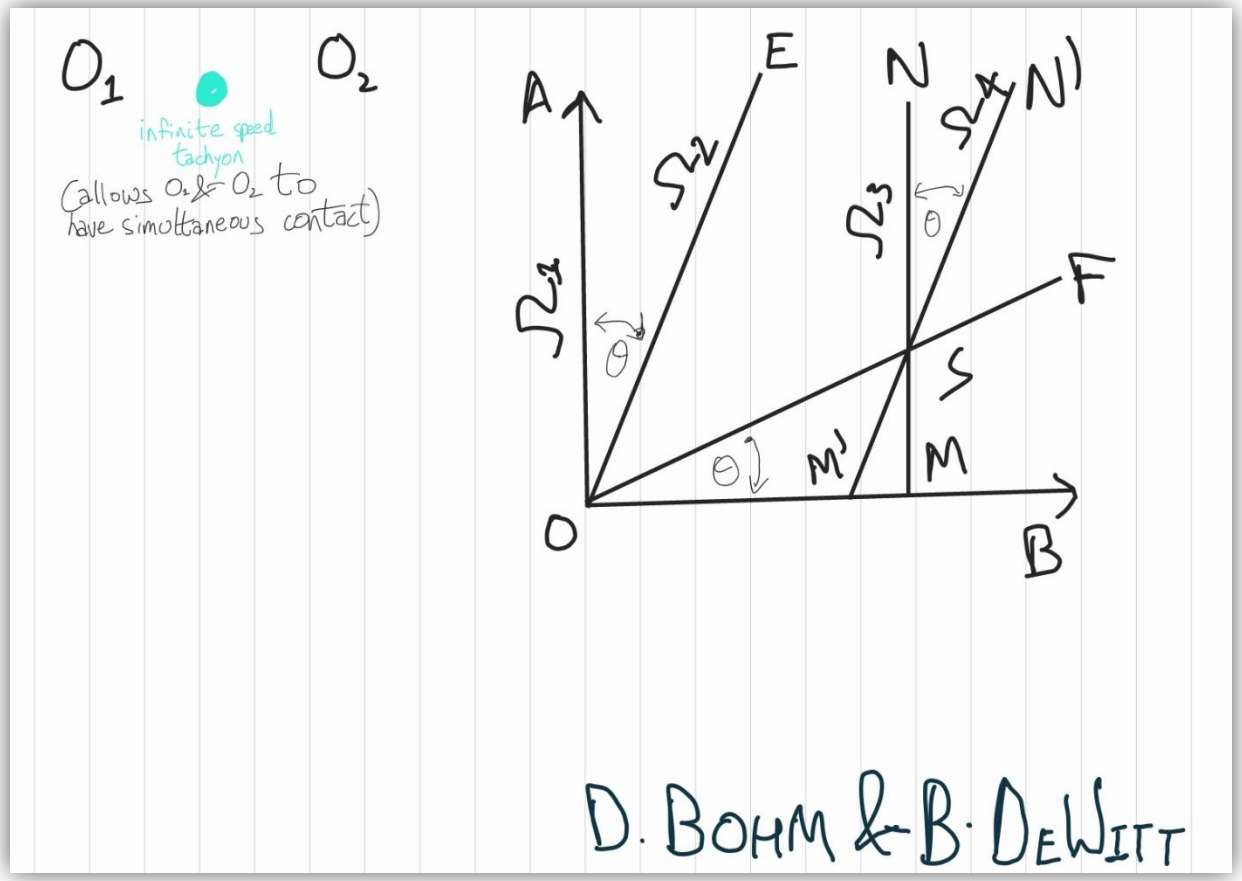

O_1
O_2
infinite speed tachyon
(allows O_1 & O_2 to have simultaneous contact)
D. BOHM & B. DEWITT

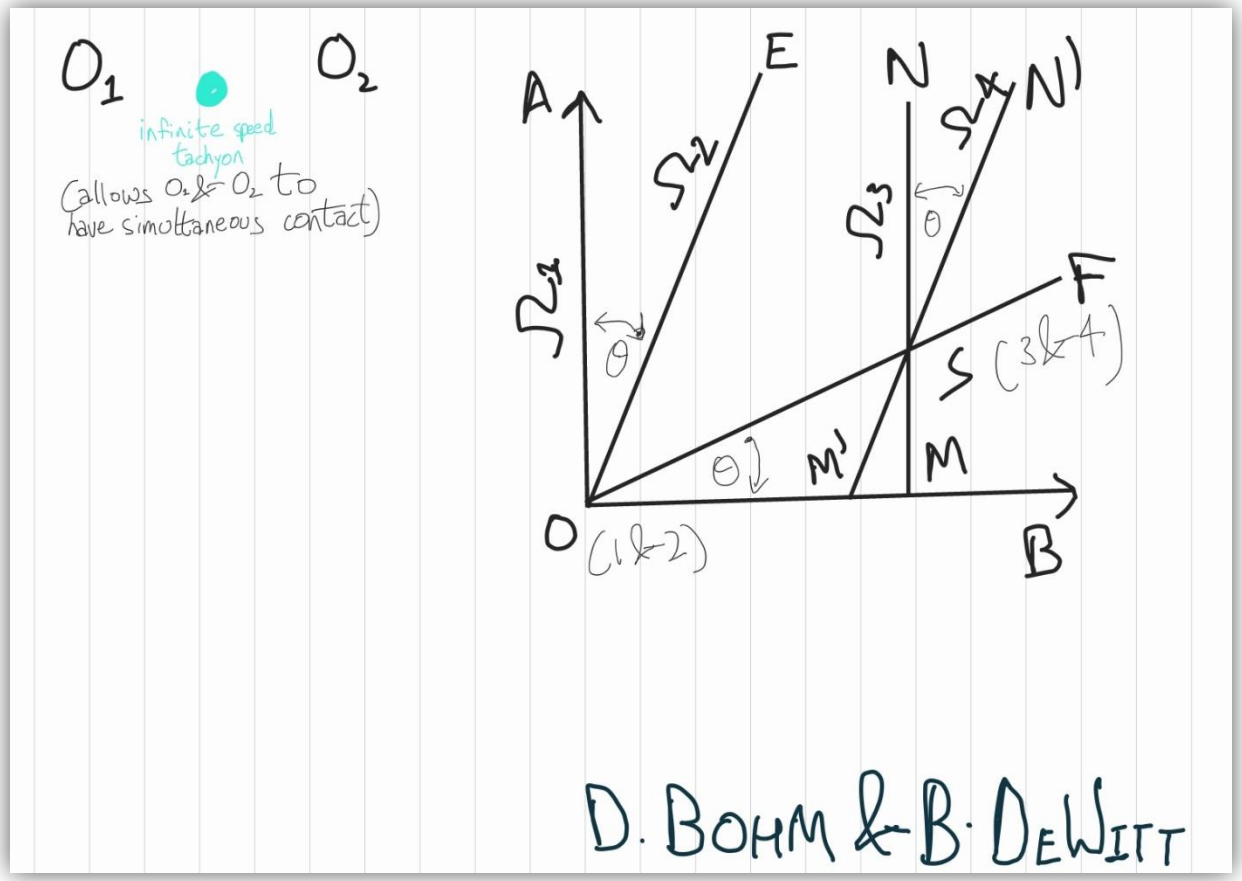

O_1
O_2
infinite speed tachyon
(allows O_1 & O_2 to have simultaneous contact)
A
E
N
N'
F
S
M'
M
O
B
D. BOHM & B. DEWITT

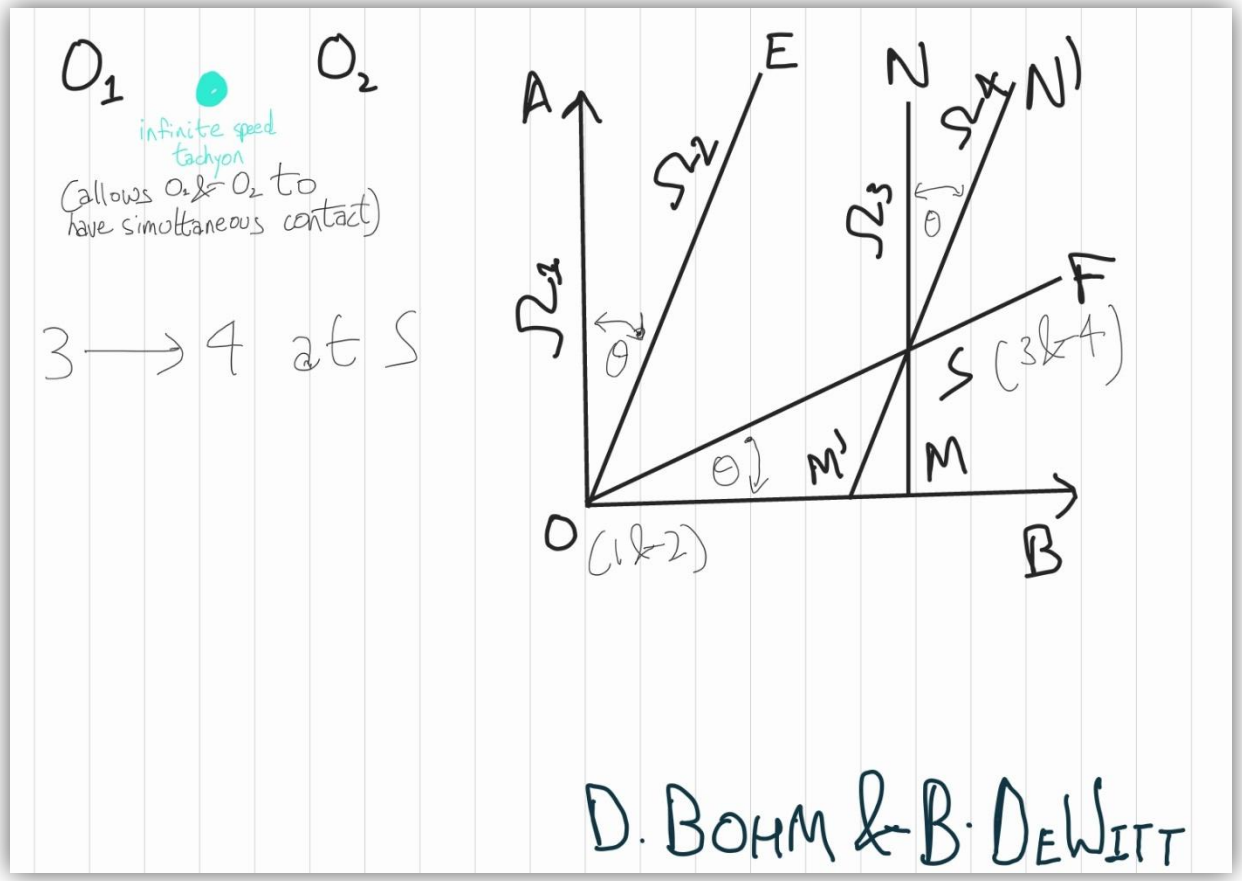

O_1
O_2
infinite speed tachyon
(allows O_1 & O_2 to have simultaneous contact)
A
E
N
N'
F
S
M'
M
O
B
θ
θ
θ
D. BOHM & B. DEWITT


O1
O2
infinite speed tachyon
(allows O1 & O2 to have simultaneous contact)
A
E
N
N'
F
S
M'
M
O
B
θ
θ
θ
Ω1
Ω3
D. BOHM & B. DEWITT

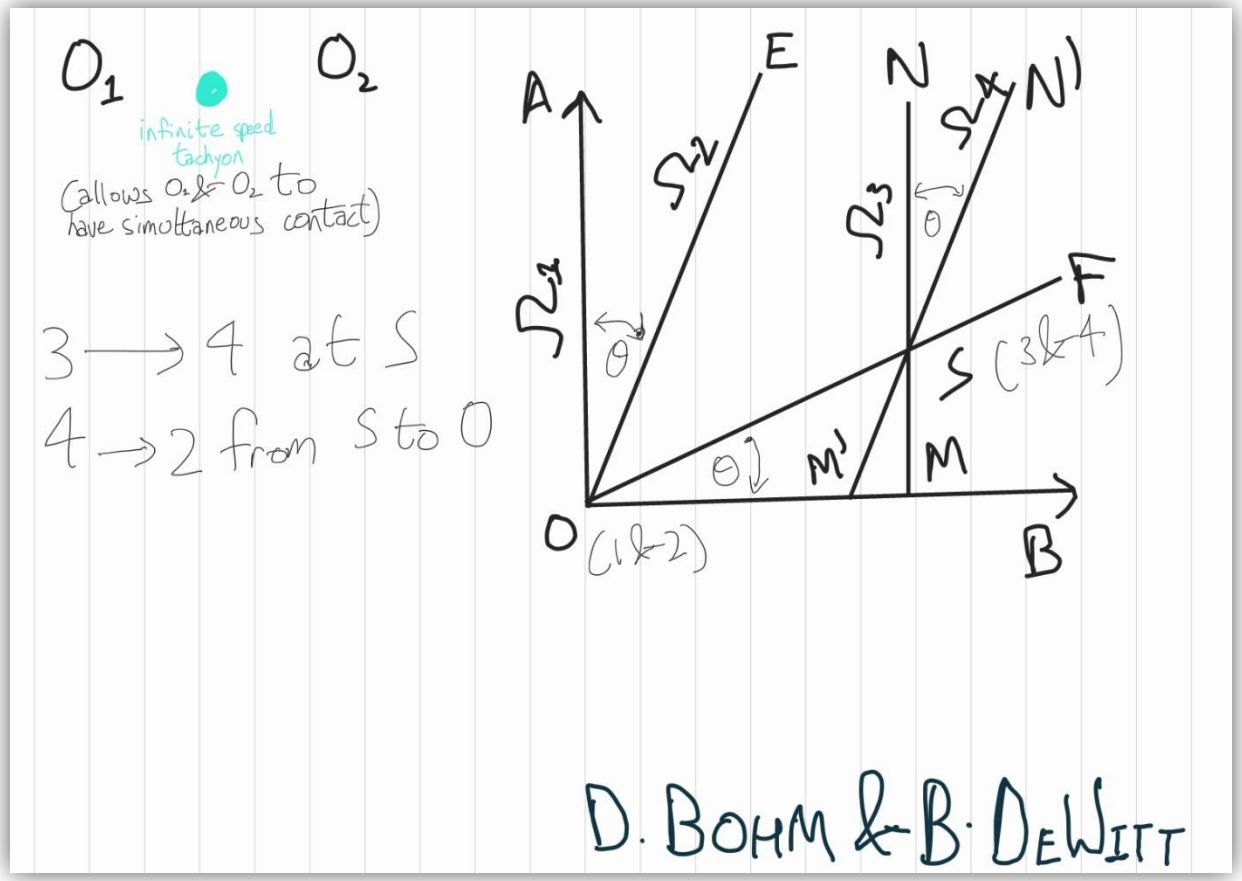

O1
O2
infinite speed tachyon
(allows O1 & O2 to have simultaneous contact)
A
E
N
N'
F
S
M'
M
O
B
θ
θ
θ
Ω1
Ω2
Ω3
D. BOHM & B. DEWITT


O1
O2
infinite speed tachyon
(allows O1 & O2 to have simultaneous contact)
A
E
N
N'
F
S
M'
M
O
B
θ
θ
θ
Ω1
Ω2
Ω3
Ω4
D. BOHM & B. DEWITT

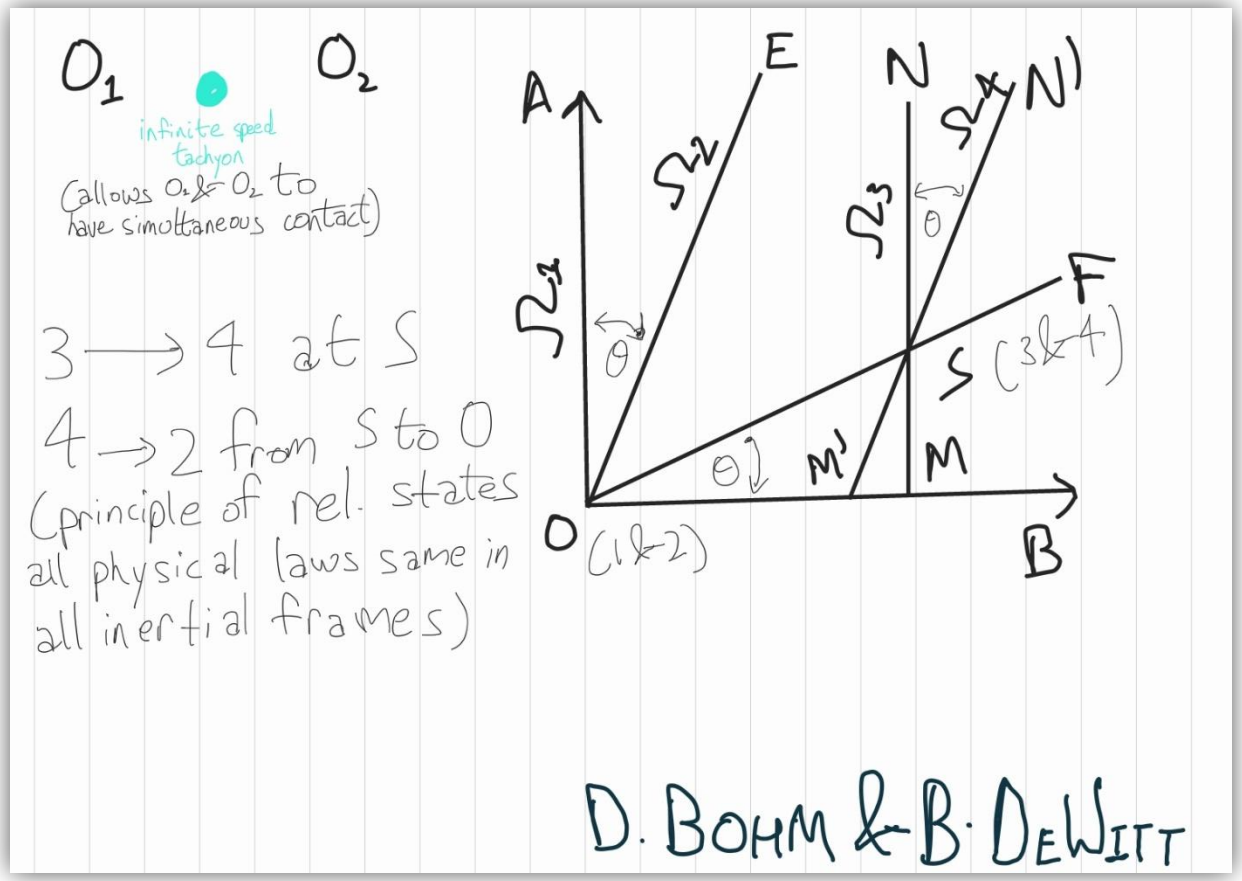

O1
O2
infinite speed tachyon
(allows O1 & O2 to have simultaneous contact)
A
E
N
N'
F
S (3k-4)
M'
M
O (1k-2)
B
θ
θ
D. BOHM & B. DEWITT

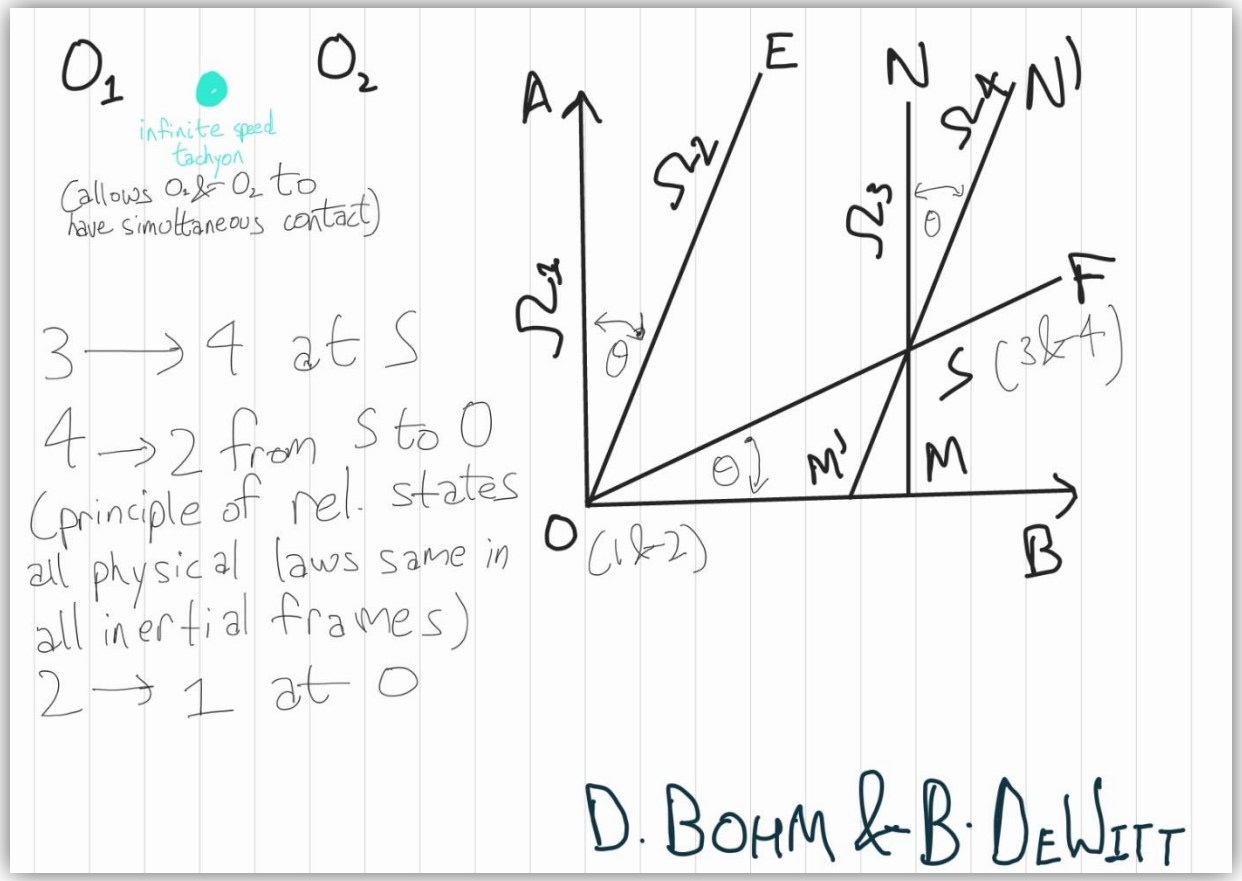


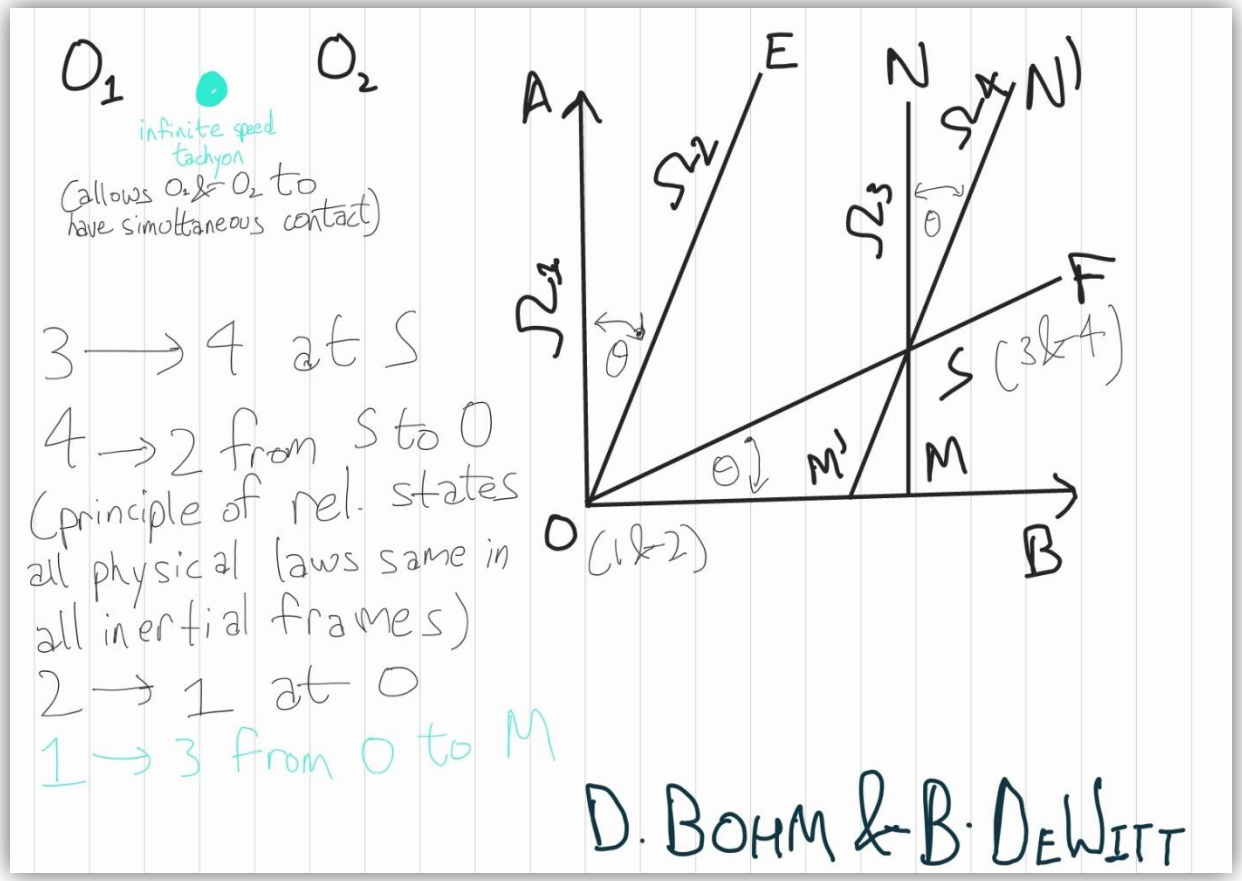
O_1
O_2
infinite speed tachyon
(allows O_1 & O_2 to have simultaneous contact)
3 ⟶ 4 at S
A
E
N
N'
F
S (3&4)
M'
M
O (1&2)
B
Ω_1
Ω_2
Ω_3
Ω_4
θ
D. BOHM & B. DEWITT

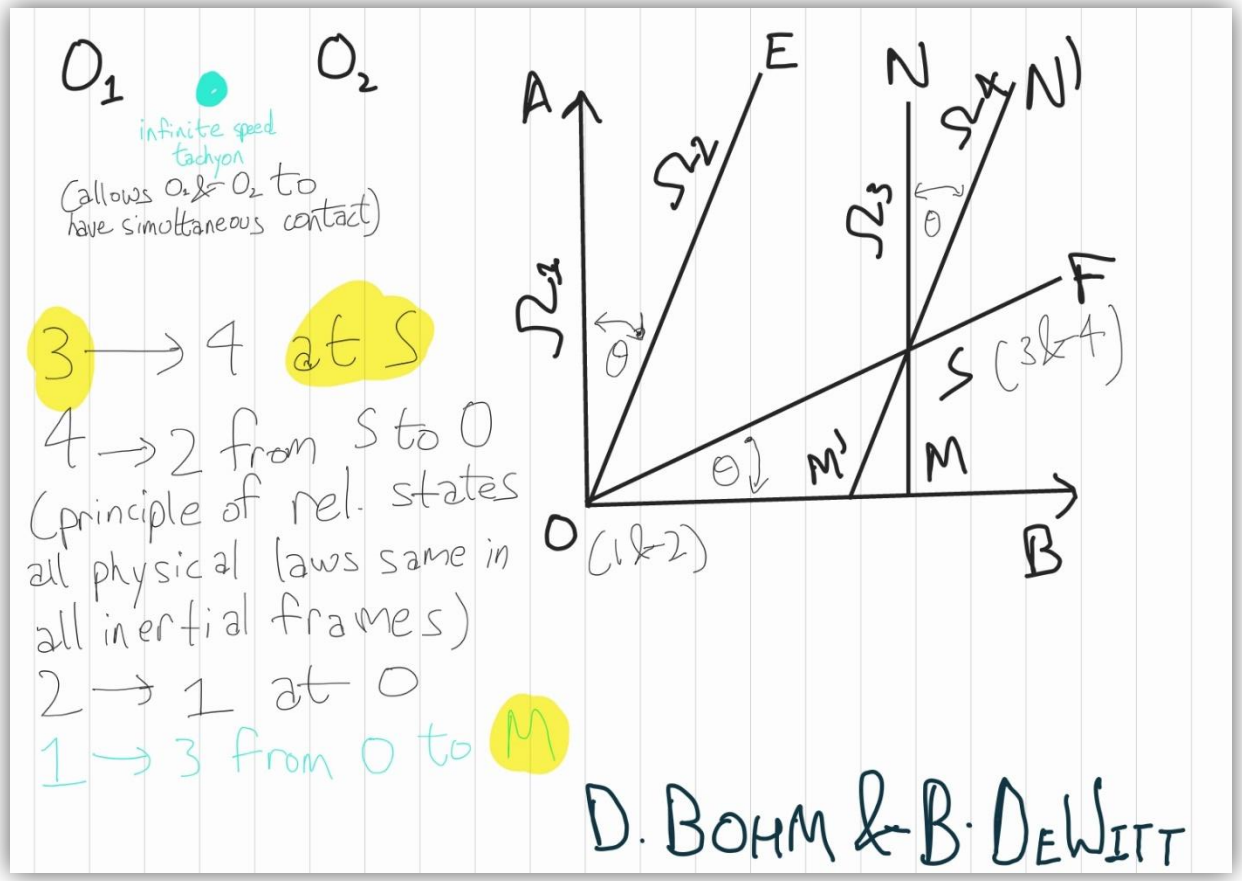


O_1
O_2
infinite speed tachyon
(allows O_1 & O_2 to have simultaneous contact)
3 → 4 at S
4 → 2 from S to O
A
E
N
N'
F
S (3&4)
M'
M
O (1&2)
B
Ω_1
Ω_2
Ω_3
Ω_4
θ
D. BOHM & B. DEWITT


O1
O2
infinite speed tachyon
(allows O1 & O2 to have simultaneous contact)
3 → 4 at S
4 → 2 from S to O
(principle of rel. states all physical laws same in all inertial frames)
A
E
N
N'
F
S (3&4)
M'
M
O (1&2)
B
D. BOHM & B. DEWITT


O_1
O_2
infinite speed tachyon
(allows O_1 & O_2 to have simultaneous contact)
3 → 4 at S
4 → 2 from S to O
(principle of rel. states
all physical laws same in
all inertial frames)
2 → 1 at O
A
E
N
N'
F
S
O
M'
M
B
Ω_1
Ω_2
Ω_3
Ω_4
θ
θ
(3&4)
(1&2)
D. BOHM & B. DEWITT


O_1
O_2
infinite speed tachyon
(allows O_1 & O_2 to have simultaneous contact)
3 → 4 at S
4 → 2 from S to O
(principle of rel. states all physical laws same in all inertial frames)
2 → 1 at O
1 → 3 from O to M
A
E
N
N'
F
B
O
M
M'
S
Ω_1
Ω_2
Ω_3
Ω_4
θ
θ
(1 & 2)
(3 & 4)
D. BOHM & B. DEWITT



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Ω_2
Ω_3
Ω_4
θ
D. BOHM & B. DEWITT

Possible solutions?

1. Tachyons only exists as virtual particles
2. By some as-yet-not-understood “quantum” effect information sent into the past is removed to avoid paradoxes.
3. There exists some **PREFERRED INERTIAL FRAME**.

Preferred Inertial Frame

- E.C. George Sudarshan and O.M. Bilaniuk settle on the existence of such an inertial frame.
- They postulate that the number of tachyons is finite in this preferred frame.

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- **Only those signals which carry both information and energy in the same direction as seen in the standard frame are possible.**

Other (almost as radical, if not more) solutions

- Roger Newton asks why we cannot have an effect which precedes its cause in time. After all, it is not a contradictory situation in the sense of mathematical logic.

- Paul L. Csonka had undertaken to discredit the principle of causality by devising an ingenious time-symmetric theory of elementary interactions.

- Ya. P. Terletskii considers causality principle to be only a macroscopic law which need not necessarily be followed at microscopic scales. He defines **“signal”** to be any propagating localised disturbance which carries energy and negative entropy. Similarly, he describes an **“antisignal”** to be a localised disturbance which upon emission decreases the entropy of the receiver during absorption.

The Thermodynamic Reinterpretation Principle

- Consider a reversible superluminal signal, and then by a Lorentz transformation, reverse the emitter and receiver's position, in turn making the signal an anti-signal.
- Of course, this problem can be circumvented by considering all Tachyons to be zero-signals but the transference of entropy is much more consistent with our understanding of Information theory.

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- Of course, this problem can be circumvented by considering all Tachyons to be zero-signals but the transference of entropy is much more consistent with out understanding of Information theory.
- To allow superluminal signals to be more than reversible microprocesses, we introduce a **Thermodynamic Reinterpretation Principle**. Which simply perceives antisignals travelling back in time as signals propagating forward in time!

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Phew, just made it in time.

If you have any questions, ask away, I’ll look it up later and get the answer to you right away!