Tachyons from a Laboratory Perspective

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Abstract

Since the first part of the twentieth century, it has been maintained that faster-than-light motion could produce time travel into the past with its accompanying causality-violating paradoxes. However, there are two different approaches to tachyon communication around a loop, one employs a "hand-off" between momentarily-adjacent observers in relative motion passing each other, while the other applies direct tachyon communication between moving observers who are not adjacent. Tachyon physics in the latter method clearly precludes causality violation, but it is more subtle in the former approach. An analysis of what would be observed in a physics laboratory, rather than what is inferred from a Minkowski diagram, attests that causality violation does not occure in the hand-off method, either. Thus it is demonstrated that tachyons do *not* violate causality.

1 Introduction

In 1907 A. Einstein considered it to be "sufficiently proven" that any velocity greater than that of light is an impossibility[1] by analysis of the Lorentz transformation equation for time. Given an inertial frame moving at velocity v with respect to a "stationary" frame, the time differential in the moving frame over a distance Δx in the stationary frame is

$$\Delta t' = \gamma(\Delta t - \frac{v\Delta x}{c^2}) \qquad (1)$$

where Δt refers to the time differential in the "stationary" frame and where $\gamma = 1/\sqrt{1 - v^2/c^2}$. He concluded that for Δt less than $v\Delta x/c^2$, $\Delta t'$ would be negative, implying that any such speedy object would arrive at its destination before it departed from its origination point, according to a moving observer. Similarly, R. C. Tolman pointed out in 1917 that velocities greater than the speed of light presented the possibility that effect could precede cause.[2]

The assertion that causality can be violated by faster-than-light travel is also mainstream thought in this century. N. D. Mermin[3] wrote, "In the [moving] frame the object is in two different places at the same time! This is such a bizarre situation that one's suspicion is strengthened that the difficulty we have already encountered in producing an object moving faster than light must be a reflection of the impossibility of such motion."

Figure 1 is a Minkowski diagram depicting the conventional view that faster-than-light communication results in causality violation.[4] The vertical axis is the time axis in the "stationary" frame (labeled t), and the axes in the moving frame are labeled x' and t'. What is considered "stationary" and what is considered "moving" are, of course, arbitrary. A and D are observers that have the hypothetical capability of sending signals to each other instantaneously. The word "observer" means a conscious entity or a device that can indicate position and local time

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[1] A. Einstein, "Uber das Relativitatsprinzip ...," Jahrb. Radioakt. Elektron. 4, 411 (1907)

[2] R. C. Tolman, The Theory of Relativity of Motion, (Berkeley, California, 1917), p. 54

[3] N. D. Mermin, It's About Time, (2005), pp. 53-54.

[4] *e.g.,* P. A. Tipler and R. A. Llewellyn, Modern Physics, (2008), p. 55.

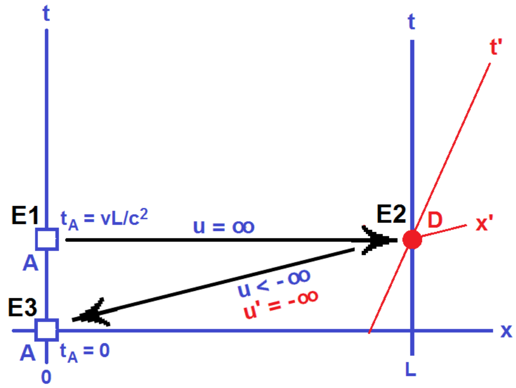

Figure 1: Typical Minkowski diagram showing purported causality violation. A and D are assumed to have some technology that allows superluminal communication.

and relay that data to an observer. Observer D is moving at some positive velocity, v, with respect to A, where v is less than c. According to the Lorentz transform, the axes of the moving frame, x′and t′, are tilted with respect to the stationary frame, the t′axis of the moving frame being defined by $t = x/v$ and the x′axis being defined by $t = vx/c^2$, where t and x are coordinates of the stationary frame. D is at x = L when the tachyon signal is received, and its time is $t_D{}' = 0$.

According to this view, A originates a signal at event E1, at time $t = vL/c^2$, and transmits it instantaneously to D (horizontal black arrow) at time $t_D{}' = 0$, at event E2, then D transmits the signal instantaneously back to A at time $t_A = 0$, at event E3. The downward-sloping, leftward-going black arrow follows the x' axis, indicating that the signal is infinitely-fast in the moving frame ($\Delta t' = 0$). Thus A receives the signal at event E3 before he sends it at event E1. This means that A at $t = vL/c^2$ could not have originated the signal in the first place since he can be influenced by the signal received by his earlier self; hence, a causality violation.

O. M. P. Bilaniuk, V. K. Deshpande and E. C. G. Sudarshan were the first to consider faster-than-light particles in the context of special relativity.[5] G. Feinberg later coined the name “tachyon”[6] for a particle that always travels faster than light, satisfies the principle of relativity and is Lorentz-invariant. The limiting value is c, but, as Feinberg points out, a limit has two sides.

The possibility of “backward in time” phenomena with tachyons is akin to Wheeler’s concept of antimatter particles being matter particles moving backward in time.[7] Alternatively, a “reinterpretation principle” has been proposed wherein such tachyons would have “negative energy.”[5] Others call this the “switching procedure.”

The properties of tachyons were addressed in a previous paper,[8] which demonstrated that direct tachyon communication as well as one leg of the “hand-off” method does *not* create causality problems, and would seem to militate against the other “hand-off” scenario doing so either. This paper demonstrates that superluminal communication by the “hand-off” method, which is widely believed to allow communication with the past, does *not* present the bizarre absurdities of going backward in time which mainstream thought purports to occur with superluminal motion.

2 Tachyon Dynamics

As discussed previously,[8] the Lorentz transform and the Minkowski diagram are kinematic representations of reality, concerned with geometrically possible motion, but does not address dynamics, which considers the effects of energy and forces. The hypothetical existence of tachyons which obey the relativistic energy equation,[9] has

[5]O. M. P. Bilaniuk, V. K. Deshpande E. C. G. Sudarshan, “‘Meta’ Relativity,” American Journal of Physics, 30, (10): 718-723 (1962)

[6]G.Feinberg, “Possibility of Faster-Than-Light Particles,” Physical Review, 159, (5): 1089-1105 (1967)

[7]R. P. Feynman, “The Theory of Positrons, Physical Review, 76 (6), pp. 749-759

[8]G. L. Harnagel, “Causality Between Events with Space-Like Separation,” viXra 1908.0306

[9]http://hyperphysics.phy-astr.gsu.edu/hbase/Relativ/releng.html

been proposed

$$E^2 = p^2c^2 + m^2c^4 \tag{2}$$

where m is imaginary for tachyons, $p = \gamma mu$ and u is the velocity of the tachyon. Rewriting Equation (2) with m replaced with im,

$$E^2 = \frac{m^2u^2c^2}{u^2/c^2 - 1} - m^2c^4 \tag{3}$$

The m in Equation (3) is the absolute value of the tachyon mass. This shows that E, the energy of a tachyon, approaches zero as the tachyon velocity, u, approaches infinity. As a practical matter, any signal transmission requires at least *some* expenditure of energy, hence it is not physically possible to send a tachyon signal at infinite speed. Infinite speed represents a barrier which cannot be breached, even by a tachyon. Furthermore, infinite speed would mean that the tachyon would be everywhere at once, which would present an analytical and philosophical conundrum. When this paper refers to infinite speed it is to be understood as an idealization with the awareness that it will signify some speed that approaches but does not attain infinity.

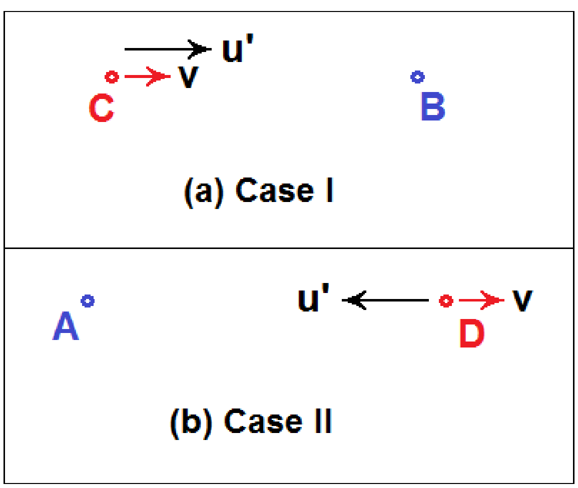

Figure 2: The two cases of direct superluminal communication.

Figure 2 presents the two situations that can occur with direct tachyon communication. The signal moves in the same direction as the source (Figure 2a), referred to as Case I, or it moves in the opposite direction (Figure 2b), which is called Case II. In Figure 2a, observer C is moving toward stationary observer B at velocity, v, and C sends an (almost) infinitely-fast signal (u') directly to B. The signal has almost no energy relative to C, but it is observed by B as having significantly more energy since the energy of C's motion is added (relativistically) to the signal's energy. Consequently, the signal travels *slower* relative to B according to Equation (3). When an observer moving at velocity v with respect to a stationary observer sends out a signal or object at velocity u' (with respect to the moving observer), the velocity of said signal or object with respect to the stationary observere, according to the kinematics of the Lorentz transformation, is[10]

$$u = \lim_{u' \to \infty} \frac{u' + v}{(1 + \frac{u'v}{c^2})} = \frac{c^2}{v} \tag{4}$$

This equation, valid for v and u' having the same sign, shows that when the signal velocity relative to the moving frame, u', is (nearly) infinite, the velocity relative to the stationary frame is $u = c^2/v$. This kinematic result is in agreement with energy considerations and is clearly a consequence of the Relativity of Simultaneity.

In Figure 2b, observer D moves away from observer A and sends an infinitely-fast signal back to A. The signal has almost no energy relative to D, but its energy relative to A must be *subtracted* from its energy relative to D. Unfortunately, it cannot have negative energy so A cannot detect the signal from D. D must give the signal more energy so it will have positive energy when it reaches A, which means that the signal velocity relative to D is slower. The maximum velocity can be determined from the relativistic velocity composition equation for the signal moving in the opposite direction from Equation (4):

$$u = \frac{-u' + v}{1 - u'v/c^2} \tag{5}$$

[10] J. D. Jackson, Classical Electrodynamics, (1965), p.361

where u' is positive for propagation in the negative x' direction for illustration purposes. Equation (5) shows that for leftward-going u', it is limited to c^2/v, at which point u becomes infinite. This is exactly the limit needed for D to send a signal to A successfully.

With this understanding of the dynamics of tachyons, one can immediately see that an infinitely-fast signal cannot be sent from A to D as depicted in Figure 1. Rather, A must send it no faster tha $u = c^2/v$, which means it will arrive at D no sooner than $t = vL/c^2$, where L is the distance between A and D when the tachyon signal arrives at D. Furthermore, D must send it back to A at $u' = -c^2/v$ but A will observe it moving at $u = -\infty$. Thus it will arrive back at A no sooner than $t = vL/c^2$, the round-trip time being $\Delta t = vL/c^2$, and there is no causality violation. Thus tachyons cannot create a loop involving negative time as presumed in Figure 1.

Direct tachyon communication between observers in relative motion is very simple, straightforward and does not violate causality; however, it is asserted that an additional stationary observer, B, can be located at E2 in Figure 1 who can receive an infinitely-fast tachyon signal from A and then pass it to D by a radio signal (or some sublight method) with infinitesmal delay since B and D are in very close momentary proximity. In addition, a moving observer, C, is supplied adjacent to A (at an appropriate time) to receive infinitely fast tachyons from D. It is asserted that such an arrangement *does* violate causality. This technique will be referred to as the "Hand-off" method in this paper.

3 The "Hand-off" Method in a Laboratory Environment and Presentation in a Minkowski Diagram

Direct communication with moving transmitters and receivers was shown to preserve causality, but it has been claimed that "handing off" the message to a momentarily adjacent observer in relative motion *can* violate causality; that is, a message can be received before it is sent. There are many different "hand-off" arrangements that purport to do this, but the one presented in Figure 3 distills them all down to the basics.

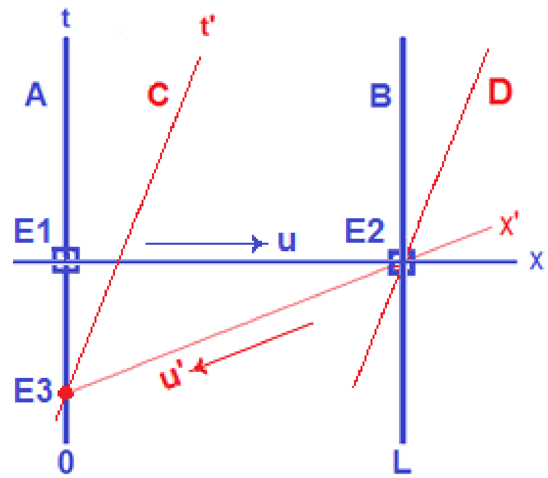

Figure 3: A "hand-off" arrangement that purportedly violates causality.

This is similar to Figure 1 except that events E1 and E2 represent tachyon transmission solely between A and B which are at relative rest. At event E2, B passes the information received from A to observer D which is momentarily adjacent, then D transmits a tachyon signal to C, which arrives at event E3. C is momentarily adjacent to A and can pass it to A *before* A will initiate it at event E1, thus creating a causality violation. The only limit to tachyon speed between transmitters and receivers at relative rest is that the tachyons must arrive with *some* energy to allow detection. The speeds of u and u' in Figure 3 are idealized to infinity. It is extremely easy to fall into the block universe concept when manipulating the Lorentz transform and the Minkowski diagram, but it seems to be much more difficult to do so when dealing with events as observed in a laboratory.

Figure 4 presents the same scenario as Figure 3, but from the perspective of an observer in a laboratory environment. The positions of

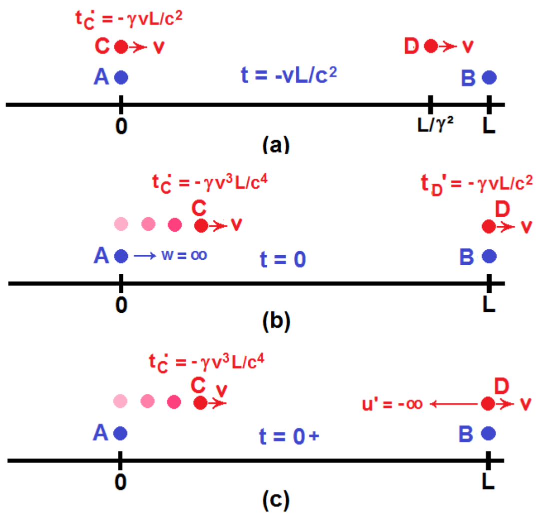

Figure 4: The "hand-off" arrangement from the perspective of an observer in a laboratory.

objects in the laboratory are illustrated at three different "snapshots" of time, and is consistent with the concept of the Minkowski diagram as instantaneous layers of constant time:[11] "We build a spacetime by taking instantaneous snapshots of space at successive instants of time and stacking them up."

The scenario starts when C is adjacent to A, at laboratory time $t = -vL/c^2$ (Figure 4a). The time according to C's clock is $t'_C = -\gamma vL/c^2$.

As time passes in the laboratory, it also progresses for C and D. Figure 4b depicts laboratory time $t = 0$. C's clock is at $t'_C = \gamma v^3 L/c^4$, but D's clock is at $t'_D = -\gamma vL/c^2$ due to the relativity of simultaneity. When B (whose clock reads $t = 0$) passes the message to D, D's clock reads $t'_D = -\gamma vL/c^2$.

If D were to transmit a tachyon signal to C infinitely fast, C would (apparently) receive it at $t'_C = -\gamma vL/c^2$ also; however, the laboratory observer claims C is at $x = v^2 L/c^2$ (the bright red spot in Figure 4c), not at $x = 0$ (the lightest pink spot). So which C receives the tachyon signal?

If D were to send a light signal (or a tennis ball or a bullet) to C, there would be no question as to which C would receive it. Would tachyons be any different? Tachyons *appear* to have the ability to go backward in time. This means that they could arrive at a destination before they are sent, which is absurd on the face of it for that would mean they could be in two places at once; however, *being* in two places at once isn't the same as *appearing to be* in two places at once. When A receives a message from a doppelganger, *that* makes it real, so the laboratory physicist is faced with an absurdity. Figure 5 demonstrates this irrationality as a laboratory sequence of the tachyon signal propagating backward in time.

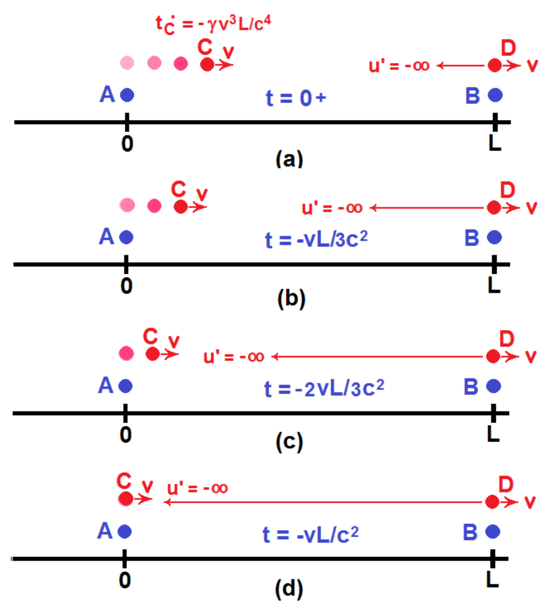

Figure 5: Can time in a laboratory be reversed by a tachyonic signal between moving observers?

How can anything happening completely within a moving frame have any effect on what happens in the laboratory? Can time go backwards in the laboratory in *any* case? If time *can* go backward in the lab, can it go backward *only* in the lab? Wouldn't it extend outside the lab also? How far outside? Fortunately, these absurd questions need not be addressed since entropy and the arrow of time forbid the possibility of time

[11] *pitt.edu/ jdnorton/teaching/*HPS_0*410/chapters/spacetime/*

reversing in the laboratory.

The physicist is compelled to either declare faster-than-light phenomena impossible, or to treat tachyons as normal objects, in this specific case, and concede that C at laboratory time $t = 0$ (the C that exists at $x = v^2L/c^2$ when the tachyons arrive in Figure 4c) *must* receive them. Even *if* the past C existed at $x = 0$, C at $x = v^2L/c^2$, the path from D to past C is obsured by the most recent C and prevents past C from receiving the signal, but the absurdity of time going backward in the laboratory is sufficient to forbid past C from receiving the signal in any case.

Thus the tachyon signal is initiated at $t'_D = -\gamma vL/c^2$, $xD' = \gamma L$ and is received by C at $t'_C = \gamma v^3L/c^4$, $x'_C = 0$, so $u' = -c^2/v$. As measured by A and B (who are at rest in the laboratory), however, this velocity is $-\infty$. Of course, most recent C isn't adjacent to A, so the message cannot be passed to A, and this arrangement fails. This failure can be corrected by the arrangement in Figure 6.

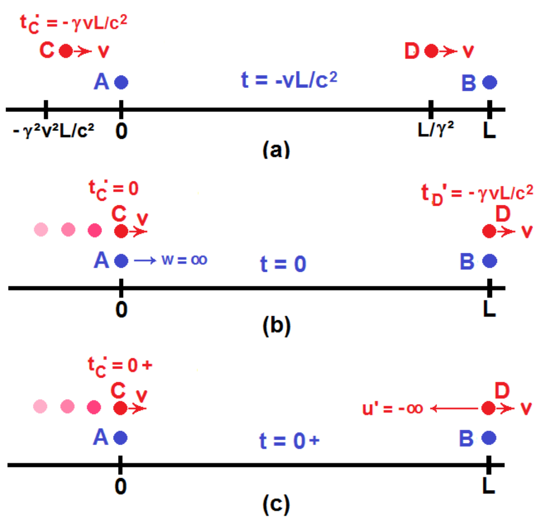

Figure 6: Correcting the "hand-off" failure in Figure 4 in accordance with legitimate tachyon reception

By a similar argument, the velocity of the tachyon signal launched by A is limited to c^2/v. From the perspective of C and D, B is moving to the left, thus the most recent position of B receives the tachyon signal, not any past position. Therefore, the correct laboratory arrangement is depicted in Figure 7. A sends the tachyon signal to B at $w = c^2/v$ due to the logistics of the arrangement at $t = 0$ and D sends the signal to C at $u' = -c^2/v$; however, the signal is observed in the laboratory to travel at $u = -\infty$.

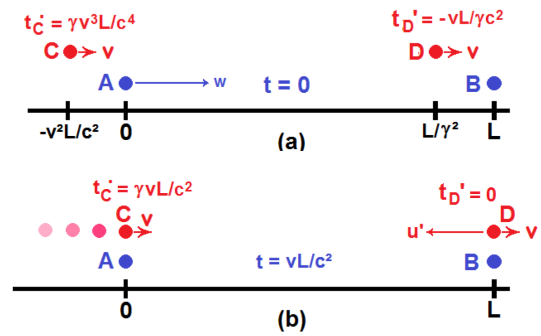

Figure 7: The appropriate "hand-off" arrangement from the perspective of an observer in a laboratory.

Of all the possible "hand-off" arrangements, why is this one correct? First of all, Figure 7 is consistent with direct tachyon communication between moving observers in that the round-trip message time is $\Delta t = vL/c^2$. Other arrangements have different time delays, one such (Figure 6) even has $\Delta t = 0$; however, this one doesn't address the "obscuration effect" from the perspective of C and D, so it fails on that account. It seems strange that introducing extra participants in the communication process could reduce the time to send a message around a loop, and it doesn't.

It may seem unsatisfactory that the unrestrained speed of tachyons can be $c < u < \infty$ within any given inertial frame, yet in the "hand-off" scenario it's limited to $c < u < c^2/v$. Observer A *could* transmit the signal to B at $u = \infty$, but B would have to wait until D is adjacent, so sending it at $u = c^2/v$ doesn't change the time when D receives it. Interestingly, from the perspective of C and D, D *could* send the tachyon signal infinitely fast (to past C), but past C would have to wait until A was adjacent, so sending it at $u' = -\infty$ doesn't change the time that A receives it. The switching of the "obscuration effect" from C (from the perspective of A and B) to B (from the perspective of C and D) is simply due to the relativity of motion, as required by the Principle of Relativity, yet perspective and "most recent position" of a moving object is no less real in the laboratory. Furthermore, it makes no difference whether viewed from the laboratory of A and B or from the equally-valid laboratory of C and D.

4 Conclusion

It has been demonstrated definitively that direct tachyon communication in a loop between transmitters and receivers in relative motion always obeys causality. It has also been shown that adding additional participants can't violate causality either, provided that tachyons aren't imbued with unreasonable properties. The limitations of rationality and logistics apply particularly to the "hand-off" approach, infringement of which has been responsible for assertions of causality violation. Thus tachyon signals can be sent at near-infinite speed between transmitters and receivers at rest in a laboratory, the speed being governed only by the sensitivity of the receivers. Detection of the laboratory signals by moving observers will obey causality, even though events with space-like separation in the laboratory may appear to have effect before cause. The mere observation of such, however, doesn't produce a message being sent backward in time.

The fact that *one* arrangement of a message loop, employing the "hand-off" method (Figure 7), is fully consistent with causality and with tachyon dynamics in the direct method (Section 2), while all others fail in one way or another, is sufficient to affirm that tachyons never violate causality. Consequently, causality violation as a disproof of faster-than-light speeds is a canard.

Although there is no solid experimental evidence at present for faster-than-light physical phenomena, it has been hypothesized that the electron antineutrino may be tachyonic.[12] [13]. This line of thought is still very much active,[14] [15] and the initial results from the KATRIN experiment do not refute this since the expected value for the neutrino mass is imaginary,[16] so interesting times are ahead. In any case, if and when the existence of tachyons is confirmed, we need not worry that our past histories can be altered or erased.

5 Acknowledgments

The author thanks R.T. Longo for helpful discussions and members of the Google sci.physics.relativity discussion group for ardently presenting the mainstream view.

[12] A. Chodos, A. I. Hauser and V. A. Kostelecky, "The Neutrino as a Tachyon," Physics Letters B 150, 431 (1985)

[13] J Ciborowski and J. Rembielinski, "Tritium Decay and the Hypothesis of Tachyonic Neutrinos," arXiv 9810355 (1998)

[14] C. Schwartz, "Tachyon Dynamics - for Neutrinos?" Int. J. Mod. Phys A 33, 1850056 (2018) https://arxiv.org/abs/1710.09904v2

[15] R. Ehrlich, "Review of the Empirical Evidence for Superluminal Particles and the 3 + 3 Model of the Neutrino Masses," Advances in Astronomy, 2019, Article ID 2820492

[16] M. Aker et al., "An improved upper limit on the neutrino mass from a direct kinematic method by KATRIN," Phys. Rev. Lett. 81, 1562 (2019), arXiv 1909.06048