The Results of Recent Neutrino Velocity Experiments Disprove Special Relativity Theory

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Abstract

The time dilation predicted by Special Relativity Theory is completely determined by the Lorentz Factor. The Invariance Principle, expressed in γ, puts two categorical constraints on the velocity β: 1. $\beta < 1$, and 2. $\gamma(\beta) = \gamma(-\beta)$. The findings of recent neutrino velocity experiments, which tested the first constraint, reveal that the velocity of neutrinos is not statistically different from the velocity of light. Surprisingly, in all these experiments, the second constraint, $\gamma(\beta) = \gamma(-\beta)$, which constitutes the essence of the Lorentz Invariance, was not tested. Here I explain why the design of the neutrino velocity experiments qualifies them as "severe" tests of the Lorentz invariance. I further show that Special Relativity fails colossally in predicting all the reported (v-c)/c values. I also show that for all the discussed experiments, abandoning the Lorentz Invariance yields accurate predictions.

Keywords: Special Relativity, Lorentz Invariance, Neutrino velocity, OPERA, Falsification test.

1. Introduction

Over the past century, Special Relativity has become a cornerstone of modern physics, and its Lorentz invariance is a foundation of every current fundamental theory of physics. So it is crucial that it be thoroughly tested. In a paper published in *Nature* in 1962, Herbert Dingle argued, based on theoretical grounds, that the theory of Special Relativity leads to inconsistency, which justifies its refutation [1]. Dingle's view was countered by many, in *Nature* and elsewhere, and was eventually ignored [2-5]. Since then the theory has been confirmed by many experiments [6-13]. Today, almost all physicists believe that Special Relativity has been tested extremely well and stands unrefuted, although current thoughts about quantum gravity suggest that it might not truly be a symmetry of nature [1, 14-18]. In examining the experimental status of Special and General Relativity, a recent study [7] concludes that "all of the available constraints on the validity of the founding principles of SR and GR have so far failed to crack any faults in these centuryold theories, which thus remains the standard against all competitors so far". Such firm belief in the correctness of Special Relativity and its Lorentz Invariance has not been much affected by a growing number of cosmological observations and experimental results attesting to the breakdown of Lorentz invariance [e.g., 19-26], and by recent quantum gravity theories which require Lorentz Invariance violation [17-18]. Given the great importance of Special Relativity, a cornerstone of all theoretical physics, continual effort to subject its predictions to increasingly stringent tests is called for. It is argued here that not enough efforts have been invested in this direction and that the over-confidence in the correctness of Special Relativity has hampered the ingenuity and efforts needed for subjecting Special Relativity to stringent tests, i.e. to what Carl Popper has termed a "risky" or "severe" falsification test [27, see also 28-29]. According to Popper, a theory which is not refutable by any conceivable event is non-scientific. Popper argued that "all a scientist can do … is to test his theories, and to eliminate all those that do not stand up to the most severe tests he can design. But he can never be quite sure whether new tests (or even a new theoretical discussion) may not lead him to modify, or to discard, his theory. In this sense all theories are, and remain hypotheses: they are conjecture (doxa) as opposed to indubitable knowledge (episteme)" [30].

Albert Einstein expressed identical ideas to Popper's falsification principle, by noting that: "A theory can, thus be recognized as erroneous [*unrichtig*], if there is a logical error in its deductions, or as incorrect [*unzutreffend*] if a fact is not in agreement with its consequences. But the truth of a theory can never be proven. For one never knows that even in the future no experience will be encountered which contradicts its consequences; and still other systems of thought are always conceivable which are capable of joining together the same given facts" [31].

2. A Severe Test of Special Relativity

Special Relativity postulates that: 1. there is no preferred frame of reference (The *Relativity Principle*) 2. The velocity of light measured by an observer is independent from the motion of the light source relative to the observer's internal frame (*The invariance of c principle*). Of the several results of the theory, the following are the most well- known, as rules of how nature behaves: 1. *Time dilation*: The time interval of an event, measured by an observer in frame F, is longer than the time interval measured by an observer in frame F', which moves with constant velocity v relative to F. 2. *Distance contraction*: The distance measured by an observer in frame F, is shorter than the distance measured by an observer in frame F' which

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moves parallel to the measured distance with constant velocity *v* relative to *F*. 3. Mass-energy equivalence: E= mc^2.

I tested Special Relativity using six neutrino velocity experiments conducted by the MINOS, OPERA, ICARUS, LVD and Borexino collaborations [32-37]. CNGS neutrinos travel about 730 km in matter with one of the highest relativistic *γ* factors ever artificially produced. The neutrino mass is at most 2 eV/c^2, while the CNGS average beam energy is 17 GeV, so *γ* is always > 10^{11}, much bigger than that obtained in any charged particle beam. A test of Special Relativity with these particles is therefore meaningful.

I focus on the theory's *time transformation* $t = \gamma\, t' = \frac{t'}{\sqrt[2]{\mathbf{1}-\beta^{2}}}$, which is completely determined by the Lorentz Invariance. The invariance principle, expressed in γ, puts two categorical constraints on the velocity *β*:

1. *β< 1*,
2. γ(*β*) = γ(-*β*).

The first constraint is challenged by the above mentioned neutrino velocity experiments, which show that the velocity of neutrinos is not different from the velocity of light. A less conservative interpretation of the results of these experiments is that the probability that the velocity of neutrinos is equal to or larger than the velocity of light is strictly higher than the probability that the velocity of neutrinos is smaller than the velocity of light, or Prob(*β*≥1) > Prob(*β*<1).

Strikingly, the second constraint, namely that the same *time dilation*s will be observed, ***regardless of whether F' is approaching F or departing from it***, has never been tested. The simplest test of the above prediction could be one in which the time interval Δt_1 which it takes the external frame $\boldsymbol{F'}$ to travel with constant velocity *v*, from *x* = 0, the point of origin in *F*, to *x* = *d*, is compared with the time interval Δt_2 which it takes the external frame to travel from distance *d* to the point of origin in *F* from the same distance *d* with equal velocity *v*. Such test qualifies as being a "risky" or "severe" falsification test. A result showing $\Delta t_1 \approx \Delta t_2$ (within error limits) will confirm the above invariance proposition, while a noticeable difference which confirms $\Delta t_1 \neq \Delta t_2$ will disprove it. Surprisingly, no such experiment has been conducted.

Notwithstanding, the above cited neutrino velocity experiments qualify, due to their design, as "severe" tests of the second constraint. It is shown here that despite the failure to detect faster than light neutrinos, all the existing neutrino velocity experiments, without exception, provide strong evidence for the refutation of the second constraint, and as a result, of Special Relativity. Since Special Relativity is indifferent to the direction of travel and since the source laboratory and the detector laboratory are at rest with respect to each other, it follows that according to Special Relativity, the source and detector laboratories are stationed in the same frame of reference. On the other hand, if, contrary to the assumption of Special Relativity, the direction of movement matters, then, since the neutrino *departs from the source* laboratory and *approaches the detector* laboratory, the two laboratories constitute two different frames of reference. Thus, the design of the neutrino velocity experiments qualifies them as "severe" falsification tests of Special Relativity, since their data enables us to test an essential proposition of the theory, namely the Lorentz invariance principle. Interestingly, not a single attempt has been taken so far to put Special Relativity to such test.

3. Prediction of Special Relativity

To calculate the prediction of Special Relativity for the neutrino velocity, consider a prototypical neutrino velocity experiment depicted in Figure 1. Denote the laboratories of the neutrinos source and neutrinos detector by *S* and *D*, respectively, and the distance between the two by *d*. According to Special Relativity, the two laboratories are at rest in one frame of reference (F), and the neutrino at rest in another frame of reference (F').

Denote the times measured at F and F' by t and t', respectively, and assume that at t_1= t_1'= 0 the neutrino starts moving from the source towards the detector with constant velocity v. Special Relativity predicts that:

$$\Delta t = \frac{\Delta t'}{\sqrt[2]{1-(\frac{v}{c})^2}} \qquad \text{...... (1)}$$

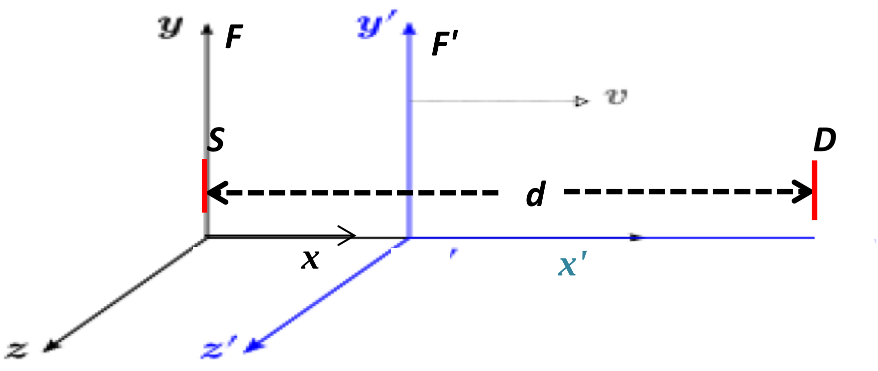

Figure1. A schematic design of a neutrino velocity experiment

Where $\Delta\boldsymbol{t}$ is the time interval in F between the start and end points of a neutrino event, $\Delta\boldsymbol{t'}$ is the same event's time interval in the neutrino rest frame F', v is the neutrino velocity relative to earth, and c is the velocity of light in vacuum (c = 299792.458 $km/_{sec}$). For a (fictitious) observer at the neutrino rest frame, the detector stationed in frame F approaches F' with constant velocity v. Thus we can write:

$$\Delta\boldsymbol{t'} = \frac{\boldsymbol{d}}{\boldsymbol{v}} \qquad \text{...... (2)}$$

Where d is the distance at $t'=0$ between the source S and the detector D. Substituting the value of $\Delta\boldsymbol{t'}$ from Eq. 2 in Eq. 1, we obtain:

$$\Delta t = \frac{\frac{d}{v}}{\sqrt[2]{1-(\frac{v}{c})^2}} \qquad \text{...... (3)}$$

For an *early neutrino arrival time* (δt) with respect to the velocity of light c, we obtain:

$$\frac{d}{c} - \delta t = \frac{\frac{d}{v}}{\sqrt[2]{1-(\frac{v}{c})^2}} \qquad \text{...... (4)}$$

Solving for $\frac{v}{c}$, we get:

$$\frac{v}{c} = \pm \sqrt[2]{\frac{1}{2}\ (1 \pm \sqrt[2]{1-\frac{4}{(1-\frac{c\delta t}{d})^2}}} \qquad \text{...... (5)}$$

And,

$$\frac{v-c}{c} = \pm \sqrt[2]{\frac{1}{2}\ (1 \pm \sqrt[2]{1-\frac{4}{(1-\frac{c\delta t}{d})^2}}}\ -1 \qquad \text{...... (6)}$$

Table 1 depicts a comparison of Special Relativity predictions with the experimental results reported in six recent neutrino velocity experiments.

Table 1

Special Relativity Predictions for six neutrino velocity experiments

Experiment	**Neutrino Early Arrival Time (δt) in ns.**	$\frac{v-c}{c}$ **Experimental**	**Predicted**
MINOS 2007 [32] *d* =734298.6 m	126 ± 32 (stat.) ± 6 (sys.)	(5.1±2.9) (stat) $\times 10^{-5}$	±0.1339597±0.5000257 *i*
OPERA 2012 (corrected result [33]) *d* = 730085 m	6.5 ± 7.4 (stat.)+ $^{+9.2}_{-6.8}$ (sys.)	$(2.7 \pm 3.1$ (stat.)$^{+3.8}_{-2.8}$ (sys.)) $\times 10^{-6}$	±0.1339738±0.5000013 *i*
OPERA 2013 [34]	-1.6 ± 1.1 (stat.)$^{+6.1}_{-3.7}$ (sys.)	(- 0.7 ± 0.5 (stat.)$^{+2.5}_{-1.5}$ (sys.)) $\times 10^{-6}$	±0.1339748±0.4999997 *i*
ICARUS 2012 [35] *d*=730478.56 m	0.10± 0.67 (stat.) ± 2.39(sys.)	(0.4 ± 2.8(stat.) ± 9.8 (sys.)) $\times 10^{-7}$	±0.1339746±0.5 *i*
LVD 2012 [36] *d*=731291.87 m	0.9± 0.6 (stat). ± 3.2 (sys.)	(1.2 ± 2.5(stat.) ± 13.2 (sys.)) $\times 10^{-7}$	±0.133976±0.5 *i*
Borexino 2012 [37] *d*=730472.082 m	0.8± 0. 7 (stat.) ± 2.9(sys.)	(3.3 ± 2.9(stat.) ± 11.9 (sys.)) $\times 10^{-7}$	±0.1339737±0.5000017 *i*

The table speaks for itself. The predictions of Special Relativity for all the reported results are similar and incorrect imaginary values, *including for negative δt values*, which does not contradict with the first constraint ($\beta<1$). Moreover, calculation of Special Relativity predictions for all velocities corresponding to reported negative lower bounds of *δt* (δt_L = *δt- stat. – sys.* < 0), yielded grossly incorrect results. For example, the lower bound reported by OPERA 2012 (corrected result) equals δt_L = 6.5 – 7.4 – 6.8 = - 7.7 ns. Substituting this value in Eq. 1 yields: $\frac{v-c}{c}$ = -0.1339737±0.5000016*i*, an imaginary value almost equal to the result calculated for the reported δt average. Similar incorrect predictions were obtained for the lower bounds δt_L of the above discussed experiments.

4. Possible Objections

The first objection, which I raise here rhetorically, is the widely used claim by Special Relativity proponents in the context of the Twin Paradox. The claimed solution of the paradox in Special Relativity prescribes that the "staying" twin grows older that the "traveling" twin. To justify the asymmetrical preference of the Earth's frame of reference, Special Relativity theorists often "solve" the paradox by invoking the theory's prediction of distance contraction. The problem with such an argument lies in its circular nature. The distance contraction expression is derived on the assumption that the time dilation expression is correct. Hence it cannot be used to prove it. Had the distance contraction been proven experimentally, the state of affaire would obviously be different, but the review of the literature shows that the predicted distance contraction has never been tested [38].

To demonstrate the circular nature of invoking the distance contraction in the present context, let as assume, for the sake of the argument, that Eq. 2 should be modified such that $\Delta \boldsymbol{t}' = \frac{\boldsymbol{d'}}{\boldsymbol{v}}$, where $\boldsymbol{d'} = \frac{\boldsymbol{d}}{\boldsymbol{\gamma}}$ and γ is the Lorentz Factor. In this case substitution in Eq. 1 yields:

$$\Delta t = \gamma\, \Delta \boldsymbol{t'} = \gamma\, \frac{\frac{\boldsymbol{d}}{\boldsymbol{\gamma}}}{\boldsymbol{v}} = \frac{d}{v} \qquad \text{….. (7)}$$

But this is a simple, non-relativistic, result of the calculation: time equals distance divided by velocity. It has no mentioning whatsoever of the Lorentz factor, which was introducing through the front door, and removed, instantly, through a back door. In fact,any theory prescribing $\Delta t = \Delta \boldsymbol{t'}.F(..)$ and $\boldsymbol{d} = \boldsymbol{d'} \cdot \frac{\mathbf{1}}{\boldsymbol{F}(..)}$, with any $\boldsymbol{F}(..)$ and any independent variables can do the trick**.**

In the following section I demonstrate that the elimination of the Lorentz Invariance results in a theory which predicts the results of all the neutrino velocity experiments discussed above with impressive accuracy. But before doing that, three additional rhetorical objections to the falsification of Special Relativity are raised and replied, each in turn.

Objection A Even if the above results contradict Special Relativity, they are few, compared to numerous results that support it.

This claim is false, since its stands against the very bases of what constitutes a scientific, as opposed to pseudo-scientific, theory. In reflecting about Carl Popper's falsification principle, Albert Einstein pointed out that: “If an experiment agrees with a theory it means ‘perhaps’ for the latter,” he wrote. “If it does not agree, it means ‘no.’ Almost any theory will experience a ‘no’ at one point in time - most theories very soon after they have been developed” (quoted in ref. 39, p. 203).

Objection B The results above, even if correct, might be explained as another spontaneous breaking of the Lorentz Invariance.

This objection is easily shown to be false, unless we expand the term "breaking" to mean total breakdown, which is synonymous to simply being wrong.

Objection C The option of holding on to Special Relativity is justified on theoretical grounds, since the alternative of receding to Newtonian Mechanics has been proven to be non-proportionally worse.

This argument is common among proponents of Special Relativity, although there is no logical or theoretical basis for the claim that the only alternative to Special Relativity must be Newton's mechanics and its related absoluteness of time. In fact, an alternative for inertial motion has been proposed by the author, and its predictions for the neutrino experiments discussed above will be detailed hereafter.

5. Prediction of Relativity without Lorentz

An alternative to Special Relativity, termed Complete Relativity [40-42], is based on the following propositions: 1.The laws of physics are the same in all inertial frames of reference. 2. The magnitudes of *all* physical entities, as measured by an observer, depend on the relative motion of the observer with respect to the rest frame of the measured entities. 3. The transformations of all physical entities, from one frame of reference to another, may depend on the methods used for their measurement. 4. All translations of information from one frame of reference to another are carried by light or electromagnetic waves of equal velocity.

What is of interest here is that Complete Relativity abandons the Lorentz Invariance (and the corresponding constancy of the velocity of light). To derive the time transformation without the Lorentz Invariance, consider the two frames of reference F and F'shown in Figure 2. Assume that at $t_1 = t_1' = 0$, F and F' start departing from each other with relative constant velocity *v*. Also assume that simultaneously, an event starts at time t_1' in F' and terminates at t_1', and that two observers in F and F' are informed about the termination of the event by means of light, or another signal with equal velocity

The termination time t, measured in F, equals the termination time t' measured in F' plus the time δt which it takes the light beam, signaling the termination of the event, to arrive at F, or: $t = t' + \delta t$. But $\delta t = \frac{x}{c}$, where *x* is the distance (measured in *F*) that is traveled by F' relative to F, and c is the velocity of light measured in $\boldsymbol{F}$. But $x = v\,t$, thus we can write:

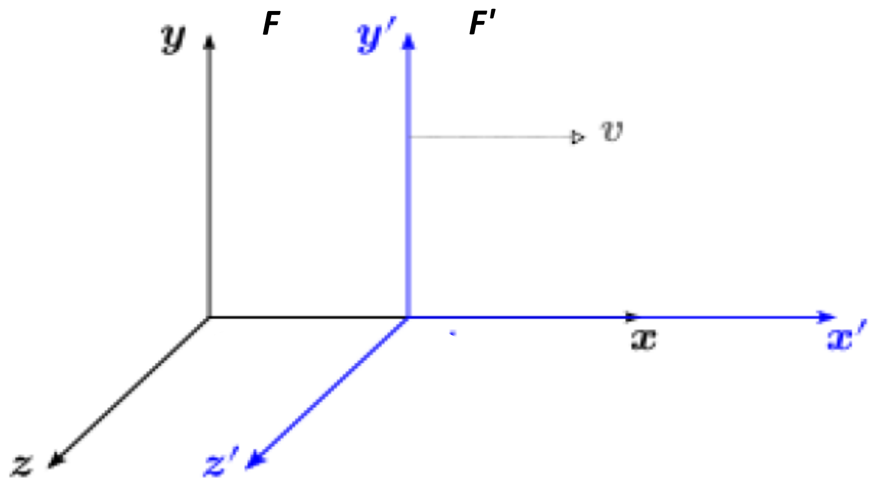

Figure 2. Observers in two reference frames moving with velocity *v* with respect to each other

$$t = t' + \frac{x}{c} = t' + \frac{v\,t}{c} = t' + \frac{v}{c}\,t \qquad \text{...... (8)}$$

Or:

$$\frac{t}{t'} = \frac{1}{1 - \frac{v}{c}} = \frac{1}{1 - \beta} \qquad \text{...... (9)}$$

Where $\beta = \frac{v}{c}$

Note that Eq. (9) is similar to the Doppler Formula, except that the Doppler Effect describes red- and blue-shifts of waves propagating from a departing or approaching wave source, whereas the result above describes the time transformation of moving objects.

It is important to note that $\frac{1}{1-\beta}$ is *positive* if F and F' *depart* from each other, and *negative* if they *approach* each other. Thus viewed in the framework of Complete Relativity, the experimental setup depicted in Fig. 1 includes *three* frames of reference: *The source frame F, the neutrino frame F', and the detector frame F''.* F is *departing* from F' with velocity v and *approaching* F'' with velocity – v. F and F'' are at rest relative to each other. Using Eq. 9 we can write:

$$\Delta t_S = \frac{\Delta t'}{1 - \frac{v}{c}} \qquad \text{...... (10)}$$

And

$$\Delta t_D = \frac{\Delta t'}{1 - \frac{-v}{c}} = \frac{\Delta t'}{1 + \frac{v}{c}} \qquad \text{...... (11)}$$

Where Δt_S is the flight time relative to the neutrino source in frame F, Δt_D is the flight time relative to the neutrino detector in frame F'' and in F, $\Delta t'$ is the flight time interval in the neutrino rest frame F', *v* is the neutrino velocity and c is the velocity of light as measured on Earth.

The neutrino time of flight tof_v is equal to difference in time between the detector and the source, or:

$$tof_v = \frac{\Delta t'}{1+\frac{v}{c}} - \frac{\Delta t'}{1-\frac{v}{c}} = -\frac{2\frac{v}{c}}{1-(\frac{v}{c})^2}\Delta t' \quad \text{…. (12)}$$

Substituting the neutrino rest time $\Delta \boldsymbol{t}'$ from Eq. 2, we have:

$$tof_v = -\frac{2\frac{v}{c}}{1-(\frac{v}{c})^2}\ \frac{\boldsymbol{d}}{\boldsymbol{v}} \quad \text{….. (13)}$$

For an early neutrino arrival time with respect to the velocity of light of *δt*, we can write:

$$\frac{d}{c} - \delta t = tof_v = -\ \frac{2\frac{v}{c}}{1-(\frac{v}{c})^2}\ \frac{d}{v} = \quad \text{….. (14)}$$

Solving for $\frac{v}{c}$ yields:

$$\frac{v}{c} = (\frac{2}{1-\frac{c\,\delta t}{d}} - 1)^{\frac{1}{2}} \quad \text{…. (15)}$$

Or:

$$\frac{v-c}{c} = \sqrt[2]{\frac{2}{1-\frac{c\ \delta t}{d}} - 1} - 1 \quad \text{…. (16)}$$

For the *corrected* result of the OPERA 2011 experiment [33], *d* = 730.085 km. and δt = (6.5 ± 7.4 (stat.) $\pm^{+9.2}_{-6.8}$ $(sys.)$) ns. Substituting in Eq. 16, we get:

$$\frac{v-c}{c} = (\frac{2}{1-\frac{299792.458\ x\ 6.5\ x\ 10^{-9}}{730.085}} - 1)^{\frac{1}{2}} - 1 \approx -2.67 \text{ x } 10^{-6} \quad \text{…. (17)}$$

Which is identical to the reported result of $\frac{v_n-c}{c}$ $(Exp.)$= (2.7 ± 3.1 $(stat.)$ $\pm^{+3.8}_{-2.8}$ (sys.)) $\times 10^{-6}$. Applying Eq. 16 to all the discussed experiments yields the results summarized in Table 2.

Table 2

Predictions of Complete Relativity (without the Lorentz Invariance)

Experiment	**Experimental** $\frac{v-c}{c}$	**Theoretical** $\frac{v-c}{c}$
MINOS 2007	(5.1±2.9))(stat) $\times 10^{-5}$	5.14 10^{-5}
OPERA 2012 (corrected result)	$(2.7 \pm 3.1\ (\text{stat.}) + ^{+3.8}_{-2.8}\ (\text{sys.})) \times 10^{-6}$	2.67 x 10^{-6}
OPERA 2013	$(-0.7 \pm 0.5\ (\text{stat.}) + ^{+2.5}_{-1.5}\ (\text{sys.})) \times 10^{-6}$	- 0.66 x 10^{-6}
ICARUS 2012	$(0.4 \pm 2.8(\text{stat.}) \pm 9.8\ (\text{sys.})) \times 10^{-7}$	0.41 x 10^{-7}
LVD	$(1.2 \pm 2.5(\text{stat.}) \pm 13.2\ (\text{sys.})) \times 10^{-7}$	1.23 x 10^{-7}
Borexino	$(3.3 \pm 2.9(\text{stat.}) \pm 11.9\ (\text{sys.})) \times 10^{-7}$	3.28 x 10^{-7}

6. Conclusions

More than half a decade ago, Herbert Dingle argued, based on theoretical grounds, that Special Relativity Theory leads to contradictory results, and that its inner inconsistency qualifies its refutation. His criticism was countered by many physicists, and in the final analysis it was ignored. The challenge advanced here is far more serious. I have shown that Special Relativity fails completely in predicting the results of six significant neutrino velocity experiments. This holds true not only for positive neutrino arrival time (δt) values, but also for negative δt values, and for negative lower bounds (δt – stat. error – sys error).

As detailed in Section 2, the neutrino velocity experiments, by virtue of their design, qualify as "severe" falsification tests of the Lorentz Invariance. Thus, the failure of Special Relativity to account for their results is attributed to the Lorentz Invariance. Strong support for this conclusion is provided by the fact that the abandonment of the Invariance Principle yielded accurate predictions for all the discussed experiments.

What is real will most probably never be revealed to us in its profoundness. Science can only infer about reality from empirical data. When theory and robust experimental findings conflict, the true scientist should question the theory.

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