# Are neutrinos superluminal?

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## Contents



**Abstract**

OPERA collaboration in CERN has reported that the neutrinos travelling from CERN to Gran Sasso in Italy move with a super-luminal speed. There exists also earlier evidence for the super-luminality of neutrinos: for instance, the neutrinos from SN1987A arrived for few hours earlier than photons. The standard model based on tachyonic neutrinos is formally possible but breaks causality and is unable to explain all results. TGD based explanation relies on sub-manifold geometry replacing abstract manifold geometry as the space-time geometry. The notion of many-sheeted space-time predicts this kind of effects plus many other effects for which evidence exists as various anomalies which have not taken seriously by the main stream theorists. In this article the TGD based model is discussed in some detail.

# 1 Introduction

The newest particle physics rumour has been that the CERN OPERA team working in Gran Sasso, Italy has reported 6.1 sigma evidence that neutrinos move with a super-luminal speed. The total travel time is measured in milliseconds and the deviation from the speed of the light is nanoseconds meaning $\Delta c/c \simeq 10^{-6}$ which is roughly $10^3$ times larger than the uncertainty $4.5 \times 10^{-9}$ in the measured value of the speed of light. If the result is true it means a revolution in the fundamental physics. There is now an article by OPERA collaboration [7] in arXiv so that superluminal neutrinos are not a rumour anymore. Even the finnish tabloid "Iltalehti" reacted to the news and this is really something unheard! Maybe the finding could even stimulate colloquium in physics department of Helsinki University!

The superluminal speed of neutrino has stimulated intense email debates and blog discussions. The reactions to the potential discovery depend on whether the person can imagine some explanation for the finding or not. In the latter case the reaction is denial: most physics bloggers have chosen this option for understandable reasons. What else could they do? Personally I cannot take tachyonic neutrinos seriously but I would not however choose the easy option and argue that the result is due to a bad experimentation as Lubos and Jester do. The six sigma statistics does not leave much room for objections but there could of course be some very delicate systematical error involved. Lubos wrote quite an interesting piece about possible errors of this kind and classified the possible errors to timing errors either at CERN or Italy or to errors in distance measurement.

## 2 Basic data

The neutrinos used are highly relativistic having average energy 17 GeV much larger than the mass scale of neutrinos of order .1 eV. The distance between CERN and Gran Sasso is roughly 750 km, which corresponds to the time of travel equal to $T = 2.4$ milliseconds. The nasty neutrinos arrived to Gran Sasso $\Delta T = 60.7 \pm 6.9$ (statistical) $\pm 7.4$ (systematic) ns before they should have done so. This time corresponds to a distance $\Delta L = 18$ m. From this is is clear that the distance and timing measurements must be extremely accurate. The claimed distance precision is 20 cm [7].

Experimentalists tell that they have searched for al possible systematic errors that they are able to imagine. The relative deviation of neutrino speed from the speed of light is

$$\frac{c-v)}{v} = (5.1 \pm 2.9) \times 10^{-5} \ ,$$

which is much larger than the uncertainty related to the value of the speed of light. The effect does not depend on neutrino energy. 6.1 sigma result is in question so that it can be a statistical fluctuation with probability of $10^{-9}$ in the case that there is no systematic error.

The result is not the first of this kind and the often proposed interpretation is that neutrinos behave like tachyons. The following is the abstract [8] of the article giving a summary about the earlier evidence that neutrinos can move faster than the speed of light.

*From a mathematical point of view velocities can be larger than c. It has been shown that Lorentz transformations are easily extended in Minkowski space to address velocities beyond the speed of light. Energy and momentum conservation fixes the relation between masses and velocities larger than c, leading to the possible observation of negative mass squared particles from a standard reference frame. Current data on neutrino mass squared yield negative values, making neutrinos as possible candidates for having speed larger than c. In this paper, an original analysis of the SN1987A supernova data is proposed. It is shown that all the data measured in '87 by all the experiments are consistent with the quantistic description of neutrinos as combination of superluminal mass eigenstates. The well known enigma on the arrival times of the neutrino bursts detected at LSD, several hours earlier than at IMB, K2 and Baksan, is explained naturally. It is concluded that experimental evidence for superluminal neutrinos was recorded since the SN1987A explosion, and that data are quantitatively consistent with the introduction of tachyons in Einstein's equation.*

## 3 TGD inspired model

This kind of effect is actually one of the basic predictions of TGD reflecting the differences between kinematics of relativities based on a view about space-time as abstract manifold and TGD in which one has sub-manifold gravitation. and emerged for more than 20 years ago. Also several Hubble constants are predicted and explanation for why the distance between Earth and Moon seems to increasing as an apparent phenomenon emerges. There are many other strange phenomena which find an explanation [5, 4, 3].

It is sub-manifold geometry which allows to fuse the good aspects of both special relativity (the existence of well-defined conserved quantities due to the isometries of imbedding space) and general relativity (geometrization of gravitation in terms of the induced metric). As an additional bonus one obtains a geometrization of the electro-weak and color interactions and of standard model quantum numbers. The choice of the imbedding space is unique. The new element is the generalization of the notion of space-time: space-time identified as a four-surface has shape as seen from the perspective of the imbedding space $M^4 \times CP_2$. The study of field equations leads among other things to the notion of many-sheeted space-time.

For many-sheeted space-time light velocity is assigned to light-like geodesic of space-time sheet rather than light-like geodesics of imbedding space $M^4 \times CP_2$. The effective velocity determined from time to travel from point A to B along different space time sheets is different and therefore also the signal velocity determined in this manner. The light-like geodesics of space-time sheet corresponds in the generic case time-like curves of the imbedding space so that the light-velocity is reduced from the maximal signal velocity. Space-time sheet is bumpy and wiggled so that the path is longer. Each space-time sheet corresponds to different light velocity as determined from the travel time. The maximal signal velocity is reached only in an ideal situation when the space-time geodesics are geodesics of Minkowski space.

### 3.1 Estimate fro the light velocity from Robertson-Walker cosmology

Robertson-Walker cosmology imbedded as 4-surface (this is crucial!) in $M^4 \times CP_2$ [4] gives a good estimate for the light velocity in cosmological scales.

1. One can use the relationship

$$\frac{da}{dt} = g_{aa}^{-1/2}$$

   relating the curvature radius a of RW cosmology space (equal to $M^4$ light-cone proper time, the light-like boundary of the cone corresponds to the moment of Big Bang) and cosmic time t appearing in Robertson-Walker line element

$$ds^2 = dt^2 - a^2 d\sigma_3^2 \ .$$

2. If one believes that Einstein's equations in long scales, one obtains

$$\frac{8\pi G}{3} \times \rho = \frac{(g_{aa}^{-1} - 1)}{a^2} \ .$$

   One can solve from this equation $g_{aa}$ and therefore get an estimate the cosmological speed of light -call it $c_\#$ as

$$c_\# = (g_{aa})^{1/2} \ .$$

3. By plugging in the estimates

$$a \simeq t \simeq 13.8 \times Gy \ \ \text{(the actual value is around 10 Gy)} \ ,$$

$$\rho \simeq \frac{5m_p}{m^3} \ \ \text{(5 protons per cubic meter)} \ ,$$

$$G = 6.7 \times 10^{-11} m^3 kg^{-1} s^{-2} \ ,$$

   one obtains the estimate

$$c_\# = (g_{aa})^{1/2} \simeq .73 \ ,$$

What can one conclude from the estimate?

1. The result leaves a lot of room to explain various anomalies (problems with determination of Hubble constant, apparent growth of the Moon-Earth distance indicated by the measurement of distance by laser signal,....). The effective velocity can depend on the scale of space-time sheet along which the relativistic particles arrive (and thus on distance distinguishing between OPERA experiment and SN1987A), it can depend on the character of ultra relativistic particle (photon, neutrino, electron,...), etc. The effect is testable by using other relativistic particles -say electrons.

2. The energy independence of the results fits perfectly with the predictions of the model since the neutrinos are relativistic. There can be dependence on length scale: in other words distance scale and this is needed to explain SN1987A -CERN difference in $\Delta c/c$. For SN1987A neutrinos were also relativistic and travelled a distance is L=cT=168,000 light years and the neutrinos arrived about $\Delta T = 2-3$ hours earlier than photons (see this). This gives $\Delta c/c = \Delta T/T \simeq .8-1.2\times 10^{-6}$ which is considerably smaller than for the recent experiment. Hence the tachyonic model fails but scale and particle dependent maximal signal velocity can explain the findings easily.

3. The space-time sheet along which particles propagate would most naturally correspond to a small deformation of a "massless extremal" ("topological light ray" [1]) assignable to the particle in question. Many-sheeted space-time could act like a spectroscope forcing each (free) particle type at its own kind of "massless extremal". The effect is predicted to be present for *any* relativistic particle. A more detailed model requires a model for the propagation of the particles having as basic building bricks wormhole throats at which the induced metric changes its signature from Minkowskian to Euclidian: the Euclidian regions have interpretation in terms of lines of generalized Feynman graphs. The presence of wormhole contact between two space-time sheets implies the presence of two wormhole throats carrying fermionic quantum numbers and the massless extremal is deformed in the regions surrounding the wormhole throat. At this stage I am not able to construct detailed model for deformed MEs carrying photons, neutrinos or some other relativistic particles.

## 3.2 Can one understand SN1987A-OPERA difference in TGD framework?

The challenge for sub-manifold gravity approach is to understand the SN1987A-OPERA difference qualitatively. Why neutrino (and any relativistic particle) travels faster in short length scales?

1. Suppose that this space-time sheet is massless extremal topologically condensed on a magnetic flux tube thickened from a string like object $X^2 \times ; Y^2$ subset $M^4 \times CP_2$ to a tube of finite thickness. Suppose that this means that the properties of the magnetic flux tube determine the maximal signal velocity. The longer and less straight the tube, the slower the maximal signal velocity since the light-like geodesic along it is longer in the induced metric (time-like curve in $M^4 \times CP_2$). There is also rotation around the flux lines increasing the path length: see below.

2. For a planar cosmic string ($X^2$ is just plane of $M^4$) the maximal signal velocity would be as large as it can be but is expected to be reduced as the flux tube develops 4-D $M^4$ projection. In thickening process flux is conserved so that $B$ scales as $1/S$, $S$ the transversal area of the flux tube. Magnetic energy per unit length scales as 1/S and energy conservation requires that the length of the flux tube scales up like $S$ during cosmic expansion. Flux tubes become longer and thicker as time passes.

3. The particle -even neutrino!- can rotate along the flux lines of electroweak fields inside the flux tube and this makes the path longer. The thicker/longer the flux tube,- the longer the path- the lower the maximal signal velocity. I emphasize that classical $Z^0$ and $W$ fields (and also gluon fields!) are the basic prediction of TGD distinguishing it from standard model: again the notion of induced gauge field pops up!

4. Classically the cyclotron radius is proportional to the cyclotron energy. For a straight flux tube there is free relativistic motion in longitudinal degrees of freedom and cyclotron motion in transversal degrees of freedom and one obtains essentially harmonic oscillator like states with degeneracy due to the presence of rotation giving rise to angular momentum as an additional quantum number. If the transversal motion is non-relativistic, the radii of cyclotron orbits are proportional to a square root of integer. In Bohr orbitology one has quantization of the neutrino speeds: wave mechanically the same result is obtained in average sense. Fermi statistics implies that the states are filled up to Fermi energy so that several discrete effective light velocities are obtained. In the case of a relativistic electron the velocity spectrum would be of form

$$c_{eff} = \frac{L}{T} = \frac{c_{\#}}{\sqrt{1 + n\hbar\frac{eB}{m}}} \quad .$$

Here $L$ denotes the length of the flux tube and $T$ the time taken by a motion along a helical orbit when the longitudinal motion is relativistic and transversal motion non-relativistic. In this case the spectrum for $c_{eff}$ is quasi-continuous. Note that for large values of $\hbar = n\hbar_0$ (in TGD Universe) quasicontinuity is lost and in principle the spectrum might allow to the determination of the value of $\hbar$.

5. Neutrino is a mixture of right-handed and left handed components and right-handed neutrino feels only gravitation where left-handed neutrino feels long range classical $Z^0$ field. In any case, neutrino as a particle having weakest interactions should travel faster than photon and relativistic electron should move slower than photon. One must be however very cautious here. Also the energy of the relativistic particle matters.

This would be the qualitative mechanism explaining why the neutrinos (and relativistic particles in general) travel faster in short scales. The model can be also made quantitative since the cyclotron motion can be understood quantitatively once the field strength is known.

Here brane-theorists trying to reproduce TGD predictions are in difficulties since the notion of induced gauge field is required besides that of induced metric. Also the geometrization of classical electro-weak gauge fields in terms of the spinor structure of imbedding space is needed. It is almost impossible to avoid $M^4 \times CP_2$ and TGD.

## 3.3 What about electrons and photons?

If I were a boss at CERN, I would suggest that the experiment should be carried out for relativistic electrons whose detection would be much easier and for which one could use much shorter scale.

1. Could one use both photon and electron signal simultaneously to eliminate the need to measure precisely the distance between points A and B.

2. Can one imagine using mirrors for photons and relativistic electrons and comparing the times for $A \rightarrow B \rightarrow A$?

As a matter fact, there is an old result by electric engineer Obolensky [6] that I have mentioned earlier [2], and which states that in circuits signals seem to travel at superluminal speed. The study continues the tradition initiated by Tesla who started the study of what happens when relays are switched on or off in circuits.

1. The experimental arrangement of Obolensky suggest that that part of circuit - the base of the so called Obolensky triangle- behaves as a single coherent quantum unit in the sense that the interaction between the relays defining the ends of the base is instantaneous: the switching of the relay induces simultaneously a signal from both ends of the base.

2. There are electromagnetic signals propagating with velocities $c_0$ (with values $271 \pm 1.8 \times 10^6$ m/s and $278 \pm 2.2 \times 10^6$ m/s) and $c_1(200.110 \times 10^6$ m/s): these velocities are referred to as Maxwellian velocities and they are below light velocity in vacuum equal to $c = 3 \times 10^8$ m/s. $c_0$ and $c_1$ would naturally correspond to light velocities affected by the interaction of light with the charges of the circuit.

3. There is also a signal propagating with a velocity $c_2$ ($(620 \pm 2.7) \times 10^6$ m/s), which is slightly more than twice the light velocity in vacuum. Does the identification $c_2 = c_{max}$, where $c_{max}$ is the maximal signal velocity in $M^4 \times CP_2$, make sense? Could the light velocity c in vacuum correspond to light velocity, which has been reduced from the light velocity $c_\# = .73c_{max}$ in cosmic length scales due to the presence of matter to $c_\# = .48c_{max}$. Note that this interpretation does not require that electrons propagate with a super-luminal speed.

4. If Obolensky's findings are true and interpreted correctly, simple electric circuits might allow the study of many-sheeted space-time in garage!

If these findings survive they will provide an additional powerful empirical support for the notion of many-sheeted space-time and could be for TGD what Mickelson-Morley was for Special Relativity. It is sad that TGD predictions must still be verified via accidental experimental findings. It would be much easier to do the verification of TGD systematically. In any case, Laws of Nature do not care about science policy, and I dare hope that the mighty powerholders of particle physics are sooner or later forced to accept TGD as the most respectable known candidate for a theory unifying standard model and General Relativity.

### 3.4 Additional support for TGD view from ICARUS experiment

Tommaso Dorigo [10] managed to write the hype of his life about super-luminal neutrinos. This kind of accidents are unavoidable and any blogger sooner or later becomes a victim of such an accident. To my great surprise Tommaso described in a completely uncritical and hypeish manner a study by ICARUS group [12] in Gran Sasso and concluded that it definitely refutes OPERA result. This if of course a wrong conclusion and based on the assumption that special and general relativity hold true as such and neutrinos are genuinely superluminal.

Also Sascha Vongehr [9] wrote about ICARUS as a reaction to Tommaso's surprising posting but this was purposely written half-joking hype claiming that ICARUS proves that neutrinos travel the first 18 meters with a velocity at least 10 times higher than c. Sascha also wrote a strong criticism of the recent science establishment. The continual uncritical hyping is leading to the loss of the respectability of science and I cannot but share his views. Also I have written several times about the ethical and moral decline of the science community down to what resembles the feudal system of middle ages in which Big Boys have first night privilege to new ideas: something which I have myself had to experience many times.

What ICARUS did was to measure the energy distribution of muons detected in Gran Sasso. This result is used to claim that OPERA result is wrong. The measured energy distribution is compared with the distribution predicted assuming that Cohen-Glashow interpretation [11] is correct. This is an extremely important ad hoc assumption without which the ICARUS demonstration fails completely.

1. Cohen and Glashow assume a genuine super-luminality and argue that this leads to the analog of Cherenkov radiation leading to a loss of neutrino energy: 28.2 GeV at CERN is reduced to averge of 12.1 GeV at Gran Sasso. From this model one can predict the energy distribution of muons in Gran Sasso.

2. The figure 2 in Icarus preprint demonstrates that the distribution assuming now energy loss fits rather well the measured energy distribution of muons. The figure does not show the predicted distribution but the figure text tells that the super-luminal distribution would be much "leaner", which one can interpret as a poor fit.

3. From this ICARUS concludes that neutrinos cannot have exceeded light velocity. The experimental result of course tells only that neutrinos did not lose energy: about the neutrino velocity it says nothing without additional assumptions.

At the risk of boring the reader I repeat: the fatal assumption is that a genuine super-luminality is in question. The probably correct conclusion from this indeed is that neutrinos would lose their energy during their travel by Cherenkov radiation.

In TGD framework situation is different (see this, this, this, and alsothis article). Neutrinos move in excellent approximation velocity which is equal to the maximal signal velocity but slightly below it and without any energy loss. The maximal signal velocity is however higher for a neutrino carrying space-time sheets than those carrying photons- a basic implication sub-manifold gravity. I have explained this in detail in previous postings and in this article.

The conclusion is that ICARUS experiment supports the TGD based explanation of OPERA result. Note however that at this stage TGD does not predict effective superluminality but only allows and even slightly suggests it and provides also a possible explanation for its energy independence and dependences on length scale and particle. TGD suggests also new tests using relativistic electrons instead of neutrinos.

It is also important to realize that the the apparent neutrino super-luminality -if true- provides only single isolated piece evidence for sub-manifold gravity. The view about space-time as 4-surface permeates the whole physics from Planck scale to cosmology predicting correctly particle spectrum and providing unification of fundamental interactions, it is also in a key role in TGD inspired quantum biology and also in quantum consciousness theory inspired by TGD.

### 3.5 OPERA confirms super-luminal velocity of neutrinos

OPERA collaboration has published an eprint Measurement of the neutrino velocity with the OPERA detector in the CNGS beam [13] providing further support for the claim that neutrinos move faster than photons. Tommaso Dorigo describes the improved measurements in this blog. The abstract of the preprint is following.

*The OPERA neutrino experiment at the underground Gran Sasso Laboratory has measured the velocity of neutrinos from the CERN CNGS beam over a baseline of about 730 km with much higher accuracy than previous studies conducted with accelerator neutrinos. The measurement is based on high-statistics data taken by OPERA in the years 2009, 2010 and 2011. Dedicated upgrades of the CNGS timing system and of the OPERA detector, as well as a high precision geodesy campaign for the measurement of the neutrino baseline, allowed reaching comparable systematic and statistical accuracies. An early arrival time of CNGS muon neutrinos with respect to the one computed assuming the speed of light in vacuum of (57.8 ± 7.8 (stat.)+8.3-5.9 (sys.)) ns was measured. This anomaly corresponds to a relative difference of the muon neutrino velocity with respect to the speed of light* $(v-c)/c = (2.37 \pm 0.32$ *(stat.) (sys.))* $\times 10^{-5}$*. The above result, obtained by comparing the time distributions of neutrino interactions and of protons hitting the CNGS target in 10.5 μs long extractions, was confirmed by a test performed using a beam with a short-bunch time-structure allowing to measure the neutrino time of flight at the single interaction level.*

In the new experiment the spacing between pulses was only 3 ns. This implies that pulse shape and duration cannot explain the earlier OPERA result as a measurement error. Effectively one studies individual neutrinos. Pulse shape and size has provided for the main stream theorist a cheap and fast way to explain the observation out from his mindscape. Certainly this finding also kills a large class of explanations for neutrino super-luminality. Of course, one must still keep mind open for some delicate measurement error. Lubos suggests that there is a systematic error in GPS system, other colleagues have not taken this option seriously.

Second new finding is that there is a "jitter" in travel times: the arrival times vary within 50 ms range which corresponds to a distance about 15 m. The shortening of travel times is not however not less than 40 ns from that when neutrinos move with light velocity as the figure that can be found from the posting of Phil Gibbs demonstrates [14]. Is the determination of the arrival time inaccurate? Or does the neutrino velocity have values above minimum velocity larger than c?

1. In TGD framework this could mean that the space-time sheet along which neutrino arrives would vary from neutrino to neutrino. The simplest possibility is that its length varies and velocity is constant: this does not look totally implausible.

2. Also the state of neutrino inside space-time sheet could vary from neutrino to neutrino. Classical long ranged $Z^0$ fields are one of the basic predictions of TGD and in the earlier posting I proposed that neutrino feels classical $Z^0$ magnetic field and arrives along cyclotron orbit. This would give a discrete spectrum of arrival velocities as

$$v = \frac{c_{\#}}{[1 + n \times \hbar \times \frac{Q_Z(\nu) g_Z B_Z}{m_\nu}]^{1/2}}$$

   with $n = 0, 1, 2, ....$ For some value of $n$ the velocity would become sub-luminal. If $\hbar$ is large enough, the discrete spectrum could be seen in the arrival times. This spectrum does not however look an attractive explanation for the jitter for which spectrum seems to be above minimum value rather than below maximum value.

### 3.6 Answers to questions by Eugen Stefanovich

Eugen Stefanovich made in my blog some questions allowing to bring additional details to the overall picture. The answers should reveal what the questions where.

1. There is no energy dependence. There is particle and scale dependence. There is an argument suggesting that the velocity is higher for neutrinos than for photon and for photon higher than for relativistic electron. The difference between neutrino families is expected to be small if the proposed mechanism based on electroweak interactions is correct: this because of the universality/flavor independence of electroweak interactions.

2. The dependence on the length scale of the orbit should be via p-adic length scale and therefore piecewise constant. This kind of jump would come at half octaves of basic length scale and might

be therefore observable. Increasing or decreasing the distance between CERN and receiver by a factor of $\sqrt{2}$ could reveal this effect.

3. The distance between CERN and Gran Sasso is 750 km. If I understood correctly, the distance travelled by neutrinos in MINOS experiment is 734 km) [15]. 734 km is slightly above p-adic length scale $L(151 + 2 \times 46) = 2^{46} \times L(151) = 2^{46} \times 10^{-8}$ meters= $L(243)$=703 km. If I take p-adic length scale hypothesis seriously then the result should be the same.

4. In cosmic scales one can estimate maximal signal velocity for photon: a very rough estimate using imbedding of Roberston-Walker cosmology as Lorentz invariant 4-surface is 73 per cent from absolute maximum (for light-like geodesic of $M^4$). For SN1987A neutrinos and photons the velocity difference would be much smaller than in shorter scales suggesting that the deviation from absolute maximum approaches to zero at very long distance scales.

   (a) One possibility is

   $$\Delta[\frac{v}{c}(p] \propto L_p^{-n} \propto p^{-n/2} \quad ,$$

   where $L_p \propto p^{1/2}$ is the p-adic length scale. By p-adic length scale hypothesis the p-adic prime $p$ satisfies $p \simeq 2^k$. $n$ is an exponent which need not be an integer.

   (b) Second suggestive possibility is logarithmic dependence on $L_p$ and therefore on $p$.

## 3.7 Superluminal neutrinos cannot be tachyons

New Scientist reported about the sad fate of the tachyonic explanation of neutrino superluminality. The argument is extremely simple.

1. One can start by assuming that a tachyon having negative mass squared: $m(\nu)^2 < 0$ and assume that super-luminal velocity is in question. The point is that one knows the value of the superluminal velocity $v(1+\epsilon)c$, $\epsilon \simeq 10^{-5}$. One can calculate the energy of the neutrino as

   $$E = |m(\nu)|[-1 + v^2/(v^2-1)]^{1/2} \quad ,$$

   $|m(\nu)| = (-m(\nu)^2)^{1/2}$ is the absolute value of formally imaginary neutrino mass.

2. In good approximation one can write

   $$E = |m(\nu)|[-1 + (2\epsilon^{-1/2}]^{1/2} \simeq |m(\nu)|(2\epsilon)^{-1/2} \quad .$$

   The order of magnitude of $|m(\nu)|$ is not far from one eV - this irrespective of whether neutrino is tachyonic or not. Therefore the energy of neutrino is very small: not larger than keV. This is in a grave contradiction whith what is known: the energy is measured using GeV as a natural unit so that there is discrepancy of 6 orders of magnitude at least. One can also apply energy conservation to the decay of pion to muon and neutrino and this implies that muon has gigantic energy: another contradiction.

What is amusing that this simple kinematic fact was not noticed from beginning. In any case, this finding kills all tachyonic models of neutrino super-luminality assuming energy conservation, and gives additional support for the TGD based explanation in terms of maximal signal velocity, which depends on pair of points of space-time sheet connected by signal and space-time sheet itself characterizing also particular kind of particle.

Even better, one can understand also the jitter [13] in the spectrum of the arrival times which has width of about 50 ns in terms of an effect caused fluctuations in gravitational fields to the maximal signal velocity expressible in terms of the induced metric [5]. The jitter could have interpretation in terms of gravitational waves inducing fluctuation of the maximal signal velocity $c_\#$, which in static approximation equals to $c_\# = c(1+\Phi_{gr})^{1/2}$, where $\Phi_{gr}$ is gravitational potential.

Suprisingly, effectively super-luminal neutrinos would make possible gravitational wave detector [5]! The gravitational waves would be however gravitational waves in TGD sense having fractal structure since they would correspond to bursts of gravitons resulting from the decays of large $\hbar$ gravitons emitted primarily rather than to a continuous flow [?]qastro. The ordinary detection criteria very probably exclude this kind of bursts as noise. The measurements of Witte [16] attempting to detect absolute motion indeed observed this kind of motion identifiable as a motion of Earth with respect to the rest frame of galaxy but superposed with fractal fluctuations proposed to have interpretation in terms of gravitational turbulence - gravitational waves.

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