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Tiny Neutrinos May Have Broken Cosmic Speed Limit

By DENNIS OVERBYE
Published: September 22, 2011

Roll over, Einstein?

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Scientists: Particles appear to travel faster than light

By **Laura Smith-Spark**, CNN
updated 12:32 AM EDT, Sat September 24, 2011

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NEUTRINO-FORSCHUNG

Wankt Einsteins Relativitätstheorie?

Messungen zeigen: Neutrinos übertreffen die Lichtgeschwindigkeit. Unmöglich, wenn Einsteins berühmte Formel stimmt. Fehler oder Sensation?

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By Ned Potter
@NedPotterABC

Sep 23, 2011 9:08am

Neutrino Faster Than Light ... Maybe. Revising Relativity?

theguardian

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Faster than light particles found, claim scientists

Particle physicists detect neutrinos travelling faster than light, a feat forbidden by Einstein's theory of special relativity

Ian Sample, science correspondent
The Guardian, Thursday 22 September 2011 18.32 EDT
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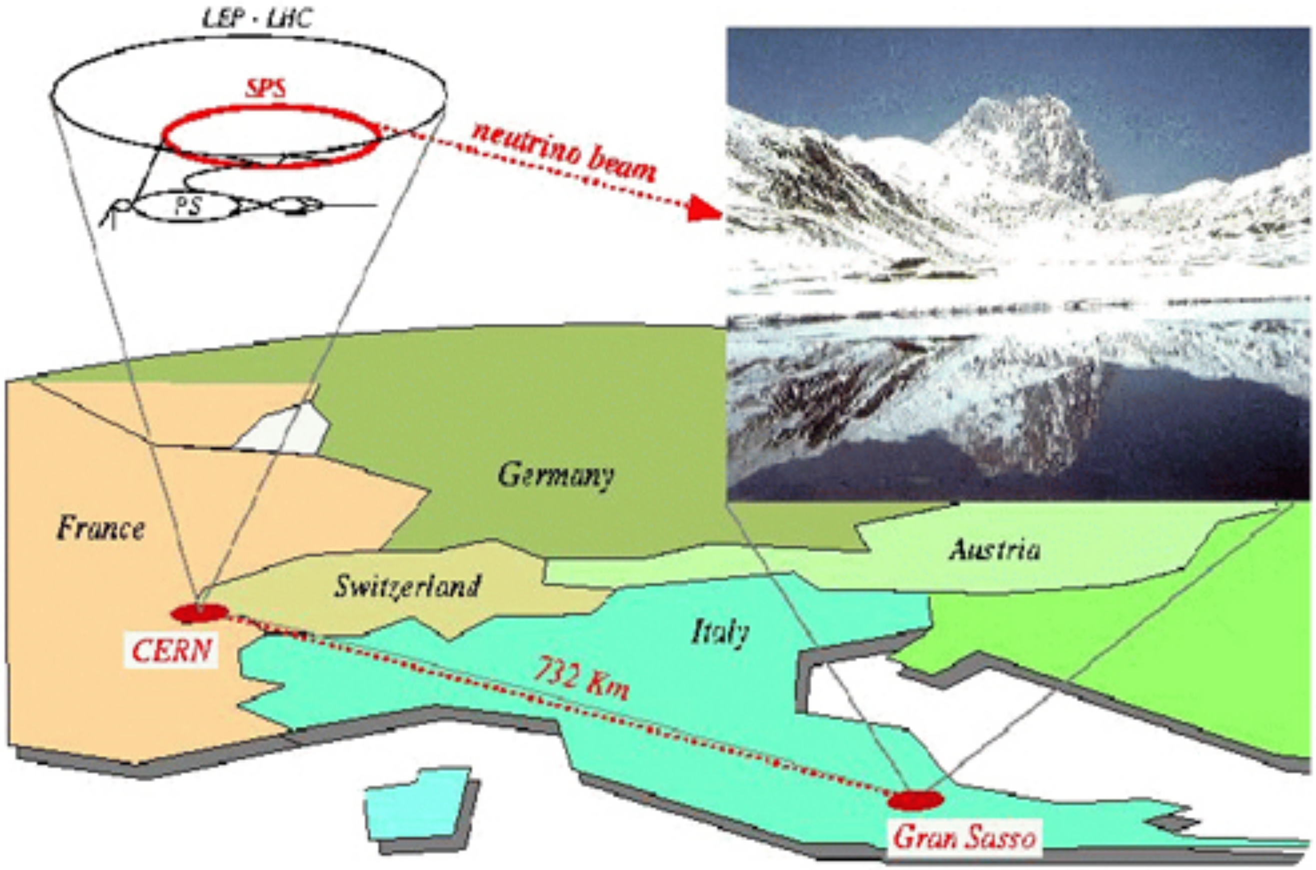
What are neutrinos (ν)?

- Elementary particles
- Charge = 0
- Almost mass = 0
  - mass(ν) < 10^{-6} mass(electron)
  - They travel very very close to the speed of light
- They interact very weakly with matter
  - The probability that a single neutrino crossing the earth will interact is ~ 10^{-11}

Where do neutrinos come from?

- **From the sun**
  - Radioactive decays or nuclear interactions
  - On earth, flux of neutrinos from sun ~ 10^{11} per cm^2 per second
- **From natural radioactivity**
  - eg, decays of ^{40}K (half life of $1.2\ 10^9$ years)
- **From cosmic rays**
  - Protons hitting nuclei at the top of the atmosphere can make "pions", pions decay into "muons" and neutrinos, muons themselves decay into electrons and neutrinos
- **From nuclear power station**
- **From particle accelerators**
  - Same process as for cosmic rays, but now in a controlled environment. Start with a beam of protons, end up with a beam of neutrinos

CERN to Gran Sasso Neutrino Beam

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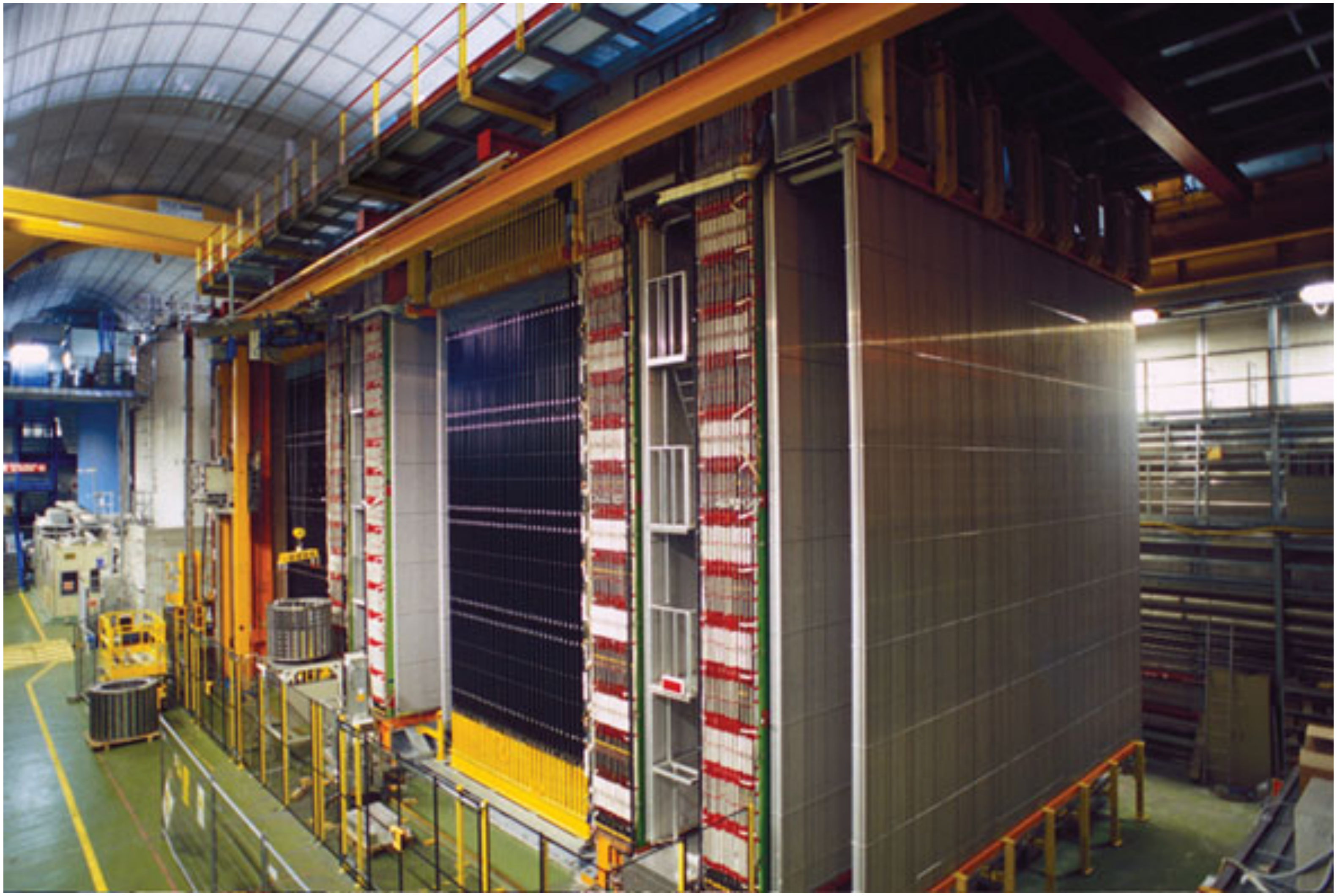


Velocity of neutrinos in this experiment

Typical energy of neutrinos from CERN: **$E = 17$ GeV $= 1.7\ 10^{10}$ eV**

Take neutrino mass as **$m_\nu c^2 \sim 0.1$ eV**

(Compare with electron: **$m_e c^2 = 511$ KeV $= 5.11\ 10^5$ eV**)

$E = \gamma m_\nu c^2 \rightarrow$ **$\gamma = 1.7\ 10^{11} \rightarrow V = (1 - 3\ 10^{-12})\ c$**

Transit time CERN $\rightarrow$ Gran Sasso for object traveling at speed of light

$t = L/c =$ 732 km/ $3\ 10^8$ m/sec = **2.44 msec**

Time correction due to finite neutrino mass (ie $v \neq c$)

$\Delta t = 3\ 10^{-12} \times 2.44$ msec **$= 7.3\ 10^{-15}$ sec**

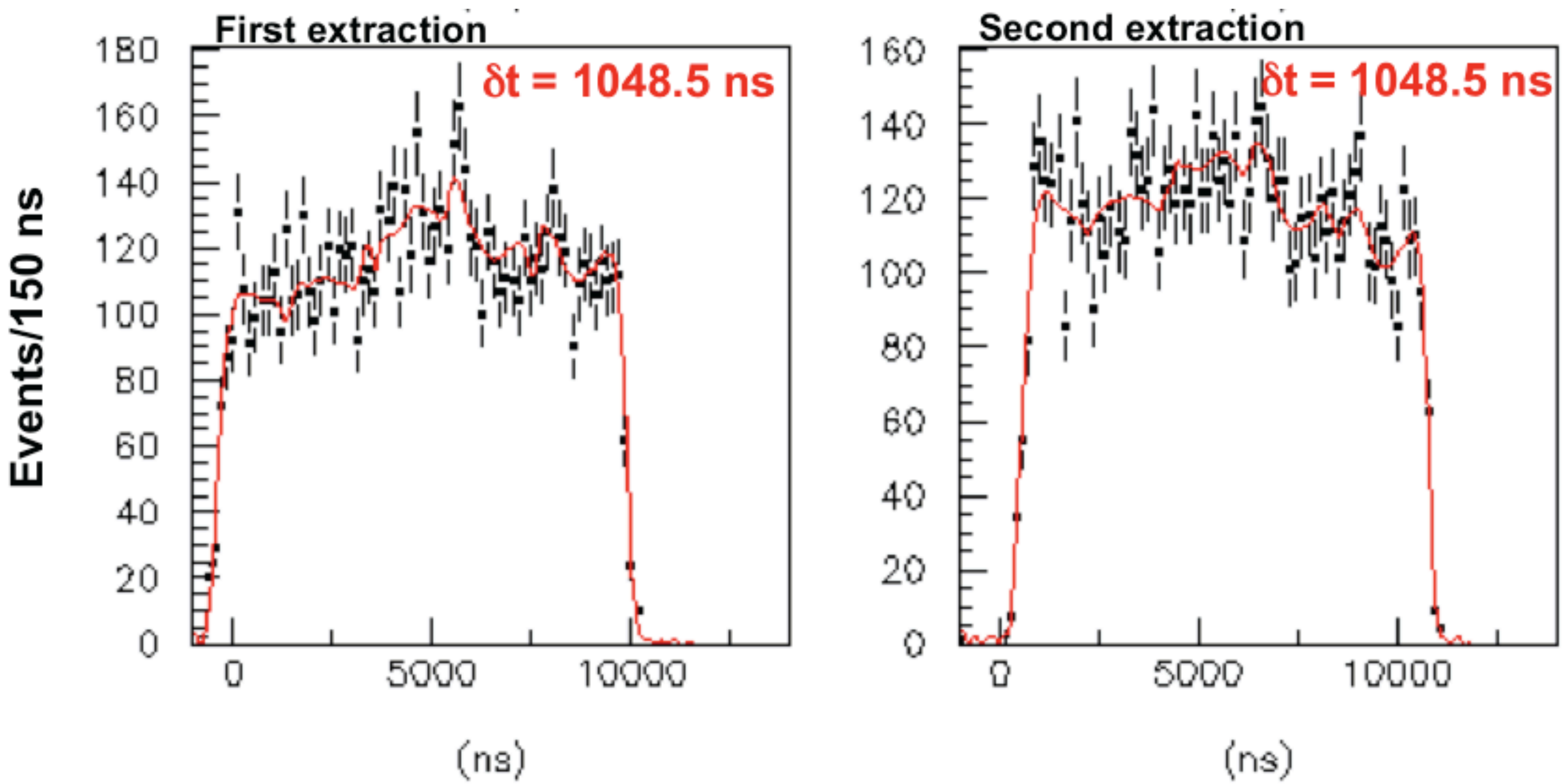
This is unobservable. Expect to measure v consistent with c

Measurement of the neutrino velocity with the OPERA detector in the CNGS beam

Abstract

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 (60.7 ± 6.9 (stat.) ± 7.4 (sys.)) ns was measured. This anomaly corresponds to a relative difference of the muon neutrino velocity with respect to the speed of light $(v-c)/c = (2.48 \pm 0.28\ (\text{stat.}) \pm 0.30\ (\text{sys.})) \times 10^{-5}$.

Note: c ~ 1 ft/nsec → 61 nsec is equivalent to 61 ft


First extraction
Second extraction
δt = 1048.5 ns
δt = 1048.5 ns
Events/150 ns
(ns)
(ns)
0
5000
10000
0
20
40
60
80
100
120
140
160
180

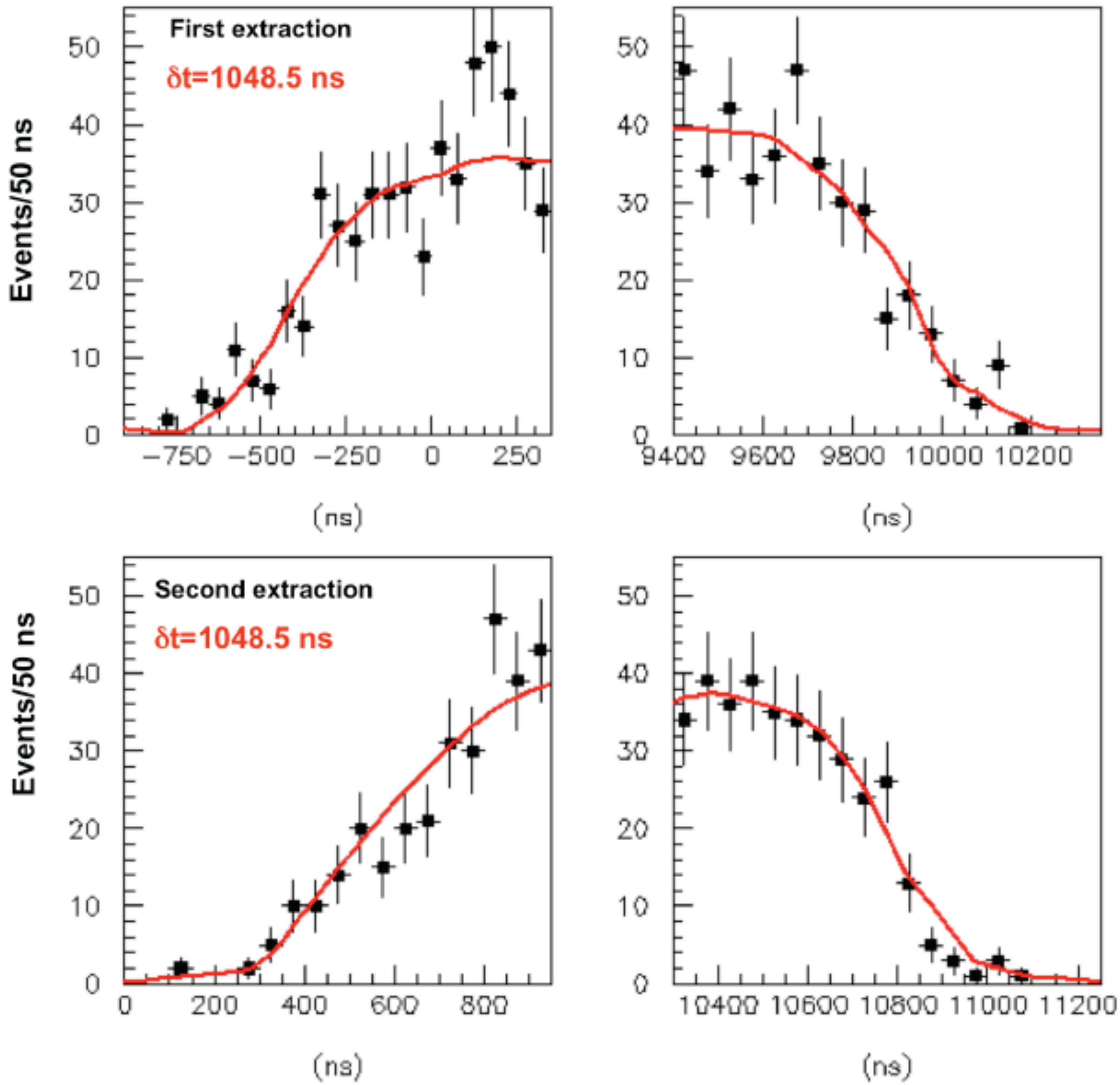

First extraction
δt=1048.5 ns
Second extraction
δt=1048.5 ns
Events/50 ns
Events/50 ns
(ns)
(ns)
(ns)
(ns)

Table 2: Contribution to the overall systematic uncertainty on the measurement of δt.

Systematic uncertainties	**ns**
Baseline (20 cm)	0.67
Decay point	0.2
Interaction point	2.0
UTC delay	2.0
LNGS fibres	1.0
DAQ clock transmission	1.0
FPGA calibration	1.0
FWD trigger delay	1
CNGS-OPERA GPS synchronisation	1.7
MC simulation for TT timing	3.0
TT time response	2.3
BCT calibration	5.0
Total sys. uncertainty (in quadrature)	**7.4**

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Flaws found in faster-than-light neutrino measurement

Two possible sources of error uncovered.

Eugenie Samuel Reich

22 February 2012

But according to a statement OPERA began circulating today, two possible problems have now been found with its set-up. As many physicists had speculated might be the case, both are related to the experiment's pioneering use of Global Positioning System (GPS) signals to synchronize atomic clocks at each end of its neutrino beam. First, the passage of time on the clocks between the arrival of the synchronizing signal has to be interpolated and OPERA now says this may not have been done correctly. Second, there was a possible faulty connection between the GPS signal and the OPERA master clock.

A possible faulty connection in the OPERA experiment may account for neutrinos appearing to travel faster than light.

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