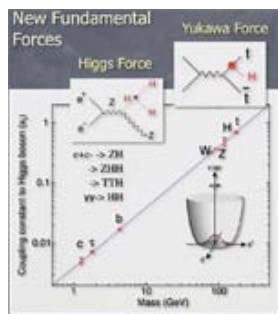


FEATURE



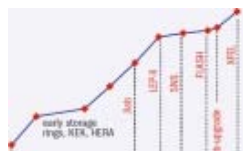
Is the Higgs enough?

by Rika Takahashi

Few particles get as much attention today as the theorised Higgs boson, which so far has eluded detection. Whatever the outcome of the Large Hadron Collider's search for it - whether it finds a Higgs particle or not - there is still compelling physics that a future collider should explore.

FEATURE

From CERN Courier: Advances in acceleration: the superconducting way



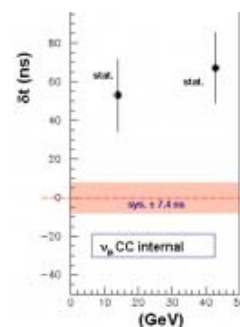
The most ambitious future application under study is for the International Linear Collider (ILC), a 500 GeV superconducting linear accelerator. It will require 16 km of superconducting cavities operating

at gradients of 31.5 MV/m. Intense research is underway to reach a high yield for high gradients: 30–40 MV/m. New vendors for niobium, for cavities and for associated components are being developed around the world.

DIRECTOR'S CORNER

Breaking the speed limit of the universe?

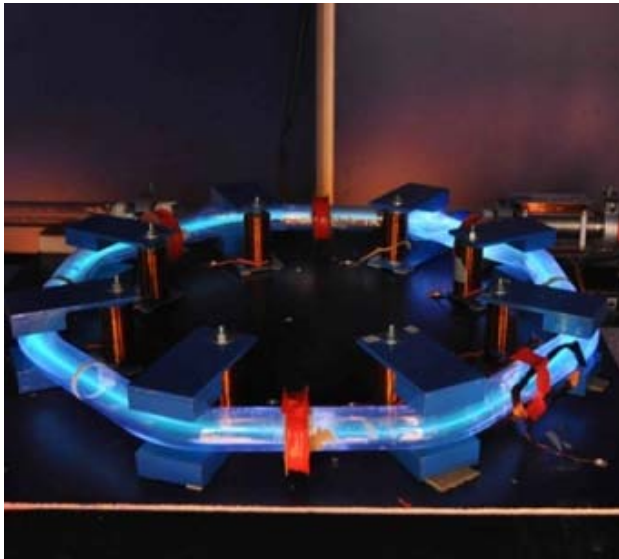
by Barry Barish



An experiment at the Gran Sasso Laboratory in Italy, designed to study the oscillation properties of neutrinos in travelling 732 kilometres from CERN to the Gran Sasso National Laboratory in Italy, reported evidence that these neutrinos arrive sooner than expected for particles travelling at the speed of light. Although the reported deviation is quite small, if correct, it would violate Einstein's

theory of relativity. The physics community now has to check whether the evidence is correct.

IMAGE OF THE WEEK



Electrons dance in Paris

Image: Sciences-ACO

Last month, a true tabletop electron accelerator was shown to the public for the first time during the CNRS exhibition *Entrée en matière* in Trocadéro's gardens in Paris, France. This model was built to serve as a general introduction to the understanding of the principles underlying accelerator operations in general and more specifically colliders. The public can actually see and manipulate the controls and therefore easily grasp what is happening. The model is a small replica of the Orsay storage ring (Anneau de Collision d'Orsay, ACO) at LAL. ACO was in service as a collider from 1965 to 1980 with an energy of 500 MeV for each beam. The real accelerator is now a museum, listed on the French heritage register.

Learn more (in French) about the model called "Electrons' dance".

IN THE NEWS

from **WIRED (Japanese edition)**

9 November 2011

[Can ILC be an accelerator for recovery from the earthquake disaster?](#)

震災復興の「加速器」となるか 宇宙誕生の謎を解くILC計画

from **Interactions**

9 November 2011

[First result from a new generation of reactor neutrino experiments](#)

Physicists of the Double Chooz experiment detected a short-range disappearance of electron antineutrinos. They presented this result on Wednesday 9 November 2011 at the LowNu conference in Seoul, Korea.

from **Physics World**

3 November 2011

[Undulator brings ILC closer to reality](#)

A full-scale undulator module that could produce the intense positron beams needed for next-generation particle colliders has been unveiled by an international team of physicists.

CALENDAR

UPCOMING EVENTS

[WHIZARD - Event Generation for LHC, ILC, CLIC](#)

DESY, Hamburg

21- 23 November 2011

[TESLA Technology Collaboration \(TTC\) Meeting](#)

IHEP, Beijing, China

05- 08 December 2011

[5th Annual Workshop of the Helmholtz Alliance "Physics at the Terascale"](#)

Bonn, Germany

07- 09 December 2011

2nd International Workshop on Accelerator-Driven Sub-Critical Systems & Thorium Utilization
Bhabha Atomic Research Centre, Mumbai, India
11- 14 December 2011

SiD Workshop
SLAC
14- 16 December 2011

UPCOMING SCHOOLS

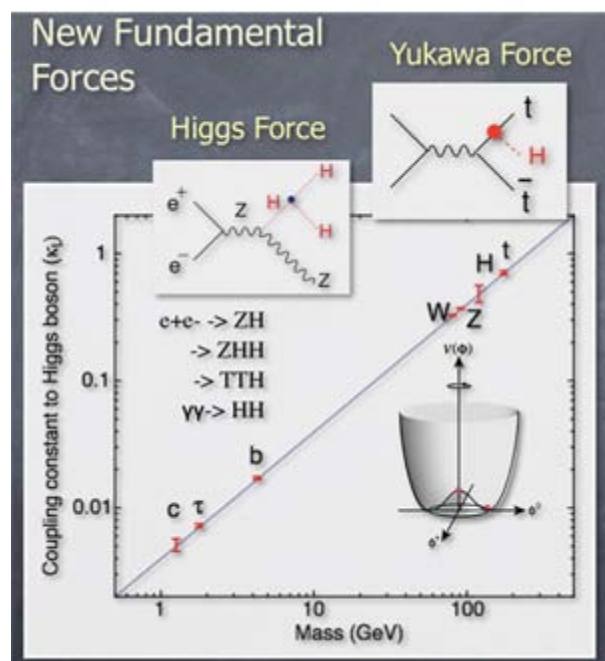
Sixth International Accelerator School for Linear Colliders
Pacific Grove, California, USA
06- 17 November 2011

[View complete calendar](#)

FEATURE

Is the Higgs enough?

Rika Takahashi | 10 November 2011



The ILC will help scientists observe the force that makes the Higgs boson condense in the vacuum. Image: Keisuke Fujii

The Large Hadron Collider at CERN is running extremely well and its two general-purpose detectors ATLAS and CMS are collecting data at a much faster pace than expected. The LHC successfully concluded its 2011 proton run at the end of last month.

The ILC physics community is preparing for the results expected to emerge from the LHC, and there were many discussions about LHC results at the [linear collider workshop](#) held in Granada in September. In the ILC physics session on the first day of the workshop, Keisuke Fujii, associate professor at KEK, made a presentation entitled “Is Higgs enough? Or do we need something clearly beyond the Standard Model?”

“My answer to the question is: it is surely enough and we definitely need the ILC,” said Fujii.

Why would it be enough?

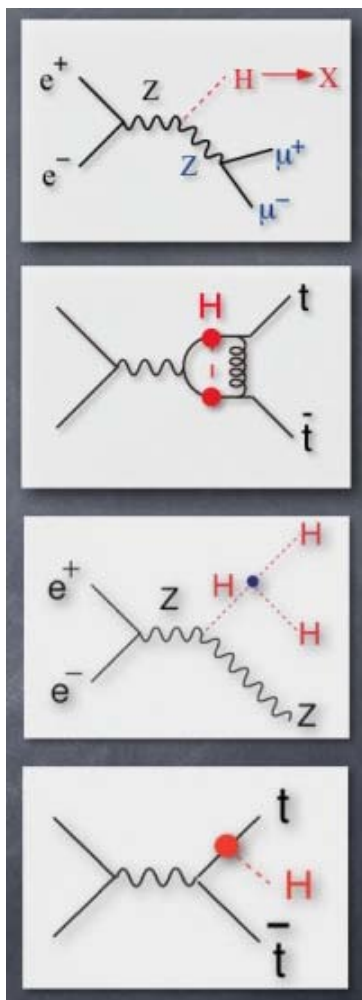
It is generally accepted among the world's scientists that exciting new discoveries from the LHC are vital to justify the ILC project.

“The question here is what discovery would justify the ILC,” he said.

As is stated in a recent [CERN press release](#), proving or disproving the existence of the Higgs boson, which was postulated in the 1960s as part of a mechanism that gives mass to fundamental particles, is among the main goals of the LHC scientific programme.

Many scientists believe that, based on the past experiments and the Standard Model of particle physics, it is highly likely that the Higgs particle is hiding in a low-energy region. “The LHC has not yet discovered any hint of new physics that goes beyond the Standard Model. To put it the other way around, you can say that the probability of finding the Higgs particle in the energy region around 120 gigaelectronvolts (GeV) predicted by the Standard Model is getting higher,” said Fujii.

There are other new particles that scientists are seriously looking for: particles predicted by supersymmetry (often shortened to SUSY). So far, there is no indication of supersymmetric particles in the LHC data. “It is, however, still possible that so-called color-singlet supersymmetric particles such as the chargino and neutralino are in the reach of the 500-GeV ILC, since the currently available LHC data are not yet enough to exclude this possibility. You can also interpret that supersymmetric partners of the Standard Model particles are all rather heavy, and exist in the energy region beyond the reach of the current sensitivity of the LHC,” said Fujii.



Measurements can be taken for a number of interactions at 500 GeV.
Image: Keisuke Fujii

If supersymmetric particles are all heavy, the lightest SUSY Higgs would look very much like the Standard Model Higgs, having similar properties including its mass. "You will need to measure the discovered Higgs ultra-precisely to see whether it is a SUSY Higgs or the Standard model one. This is where the ILC comes in," argues Fujii.

Such a precision measurement can be started at an energy as low as between 230 and 250 GeV, which is enough to produce the Standard Model-like Higgs. "There are many important measurements to be made in this energy range," Fujii says.

One outstanding example is the absolute measurement of an interaction called ZZH coupling. This can be made by counting the associate productions of the Higgs with the Z boson through the annihilation of a collided electron and positron into a virtual Z particle that subsequently splits into the Higgs and Z. "The observation of the associate production of the Higgs with Z is clear evidence that the produced Higgs is indeed condensed in the vacuum," Fujii explains.

Under the assumption of the Standard Model, a single Higgs field is responsible for the whole mass of the Z boson. The ILC can check whether the mass of the Z is really entirely coming from the single Higgs field to about 1 percent precision. "If the Higgs here is the only Higgs that gives mass to the Z particle, this mass has to be equal to the known mass of the Z particle. If it is not the case, that means there must be something else condensing in the vacuum, presenting evidence of something beyond the Standard Model."

With the value of the ZZH coupling determined, the rate of the associate production of the Higgs with the Z boson can be calculated and hence the total number of the produced Higgs bosons can be unambiguously estimated. It is then possible to determine absolute couplings of the Higgs to various matter particles by measuring the branching ratios for the corresponding H decays. "The ILC allows an absolute measurement of the ZZH coupling, even when the Higgs decays into invisible dark matter, which is possible only at the ILC," Fujii emphasised.

There are many more rich physics opportunities scientists can explore in the reach of the baseline design of the 500-GeV ILC. "The next milestone is the energy region of 350 GeV, where we can produce the top quark," Fujii said.

The top quark is the heaviest member of the quark family. Since the Higgs is thought to be the process that gives elementary particles their masses, measuring the interaction between those two particles is particularly important.

Another area of physics scientists can explore with the 500-GeV ILC is the ultimate check on the Higgs properties, the measurement of the Higgs self-coupling. "Once we reach 500 GeV, we will be able to produce two Higgs particles, and there we can measure the interaction of the Higgs with itself (self-coupling), which is none other than the force that makes the Higgs field condense in the vacuum".

Fujii says that he would go so far as to say that we need the ILC even if nothing new, including a Higgs-like object, will be found at the LHC. "If there would be absolutely no hint of a Higgs-like particle or other new particles, that would be a complete contradiction with the success of the Standard Model, which has explained the mechanisms, particles and forces of the universe so well so far. We will need to extend our investigation on what went wrong in every detail by scrutinising the Standard Model particles such as W, Z, and top. The ILC will work very well on this, too." One major scenario in which there is the case of finding no light Higgs boson is called the strong-interaction mechanism of electroweak symmetry breaking, where the properties of the W, Z and the top quark will look different from those in the Standard Model. These systems will have potential for discovery, one that is not very well appreciated today, Fujii says.

In Granada, the ILC physics community agreed that the 500-GeV ILC will have enough of a physics case to explore whatever finding comes out of the LHC. It also presents the possibility of starting experiments with a shorter, less expensive accelerator.

"But we have not reached consensus on how much energy we should aim for or which direction we should follow for the no-Higgs scenario at the LHC," said Fujii. There is enough scientific justification for the baseline machine. However, building the next-generation machine involves factors other than science.

The ILC physics community will have a [dedicated meeting in February](#) at DESY, Germany, to continue the discussion started in Granada.

500 GEV | HIGGS BOSON

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Advances in acceleration: the superconducting way

2011 marks the 50th anniversary of the launch of RF superconductivity, which is now the key technology for accelerators at the high-energy and luminosity frontiers. Hasan Padamsee describes some of the key developments in the field and surveys its widespread use today.

Résumé

Améliorer l'accélération par la supraconductivité

Un article pionnier publié en 1961 proposait l'utilisation de la supraconductivité pour les cavités radiofréquence (RF) pour permettre le fonctionnement en continu d'un accélérateur de protons linéaire. Il a fallu près de 40 ans pour que ce rêve devienne réalité, mais, pendant ce temps, le recours à la supraconductivité pour les cavités RF dans les accélérateurs de particules s'est développé progressivement. Cette technologie est maintenant très utilisée, non seulement en physique des particules, mais aussi pour d'autres applications s'appuyant sur des linacs de protons de haute intensité, ainsi que pour les sources de lumière synchrotron et les lasers à électrons libres. C'est à présent la technologie essentielle pour les accélérateurs aux limites des hautes énergies et des hautes luminosités, comme l'explique Hasan Padamsee.



[First proposal](#)

In a seminal paper published in June 1961 A P Banford and G H Stafford described how a future superconducting proton linear accelerator could run continuously, instead of at the 1% duty cycle of the 50 MeV proton accelerator that was operating at the time at the Rutherford High Energy Laboratory in the UK. The basic argument was that, because ohmic losses in the accelerating cavity walls increase as the square of the accelerating voltage, copper cavities become uneconomical when the demand for high continuous-wave (CW) voltage grows with particle energy. It is here that superconductivity comes to the rescue.

The RF surface resistance of a superconductor is five orders of magnitude less than that of copper. The quality factor (Q_0) of a superconducting resonator is typically in the billions (i.e., a billion oscillations before the resonator energy dissipates). After accounting for the refrigerator power needed, the net gain in the overall cooling power remains a factor of several hundred. It became clear that the higher-voltage, shorter superconducting structures can also reduce the disruptive effect that accelerating cavities have on the beam, resulting in better beam quality, higher maximum current and less beam halo (less activation). By virtue of low losses in the walls, a superconducting RF (SRF) cavity design can also afford a large beam aperture, which further reduces beam disruption and beam halo.

It took nearly 40 years for the early dream of that high duty-factor, high-intensity proton linear accelerator to be fulfilled. Today, the Spallation Neutron Source (SNS) at Oak Ridge National Laboratory runs at 6% duty cycle with 88 m of

superconducting cavities providing 1 MW of beam power with a 1 GeV, 10 mA beam. The success of the SNS has stimulated the construction of the European Spallation Source (ESS), with 5 MW of beam power, to be completed in 2016.

Pioneering work

In the early 1960s, Stanford University, under the leadership of William Fairbank, pioneered the development of superconducting cavities for electron accelerators. By 1968 they achieved a Q value of more than 10^{10} at 1.7 K for an 8.5 GHz TM₀₁₀-mode single-cell pill-box resonator built of solid niobium. The first niobium cavity also demonstrated the exciting prospect of gradients of more than 30 MV/m.

However, with the more practical, lower frequency (1.3 GHz) accelerator structures that were built in the 1970s, the performance level fell to 2–4 MV/m. The primary roadblock was multipacting – the spontaneous resonant production of electrons. By the mid-1980s, the physics of multipacting was understood. It turned out that the limiting field-levels scale with the RF frequency, so the high-frequency cavities of the 1960s had been fortuitously exempt.



[Early 1.3 GHz HEPL structure](#)

The next three decades saw several layers of gradient problems being uncovered, the underlying physics understood and solutions developed. Cavity performance then ratcheted up at a steady pace, as did accelerator applications. The development of the anti-multipacting, spherical (and elliptical) cavities was a breakthrough moment. With multipacting overcome, thermal breakdown of superconductivity became the next limiting mechanism, at 4–6 MV/m. Local heating at surface imperfections led to thermal runaway and a quench of superconductivity. The cure was to switch to niobium of high-purity – high residual-resistance ratio (RRR) niobium. With the co-operation of industry, RRR improved by an order of magnitude and cavity gradients rose on average by a factor of three. Another cure for thermal breakdown was to sputter a micron-thin film of niobium onto a copper cavity-substrate, which also had the benefit of reduced material costs – especially for the cavernous, low-frequency (0.35 GHz) cavities.

With the corresponding rise in surface electric fields, electron emission became the next limit to gradients, at 10–15 MV/m. Global R&D revealed microparticle contamination to be the dominant source of field emission, so the solution demanded better preparation techniques, such as powerful surface scrubbing with high-pressure (100 atm) water and assembly in Class 100 clean rooms. With these advances, cavity gradients climbed to 20 MV/m.



[High-intensity proton linac](#)

Above 20 MV/m, however, RF losses began mysteriously to rise exponentially with the field. The physics of such losses is still under investigation but pragmatic countermeasures are already in place. Electro-polishing has replaced the standard chemical etching to obtain a smoother surface, followed by mild baking at 120 °C for two days. There is now excellent prognosis for reaching 35–40 MV/m. Many nine-cell, 1 m-long niobium structures have demonstrated performance above 40 MV/m in qualification tests, while basic research continues to push towards the theoretical limit of 55 MV/m.

SRF takes off

As gradients improved steadily from the mid-1980s, RF superconductivity grew into a key technology for accelerators at

the energy and luminosity frontiers, as well as at the cutting edge of low- and medium-energy nuclear physics, nuclear astrophysics and basic materials science. SRF cavities are now routinely accelerating electron, proton and heavy-ion beams in a variety of frontier accelerators.



[Cavities run CEBAF](#)

It was in the early 1990s that SRF took off to push the energy frontier in storage rings, with TRISTAN at KEK and HERA at DESY. In the late 1990s the energy of the Large Electron-Positron collider at CERN doubled, with 500 m of superconducting cavities built by sputtering niobium on copper. Nb-Cu superconducting cavities now meet the voltage and high current demands of the LHC at CERN. At the luminosity frontier, high-current, high-luminosity electron-positron storage rings have operated and continue to operate with SRF cavities for copious production of c and b quarks at the Cornell Electron Storage Ring in the US, the KEKB facility in Japan and the Beijing Electron Positron Collider in China.

At the cutting edge of nuclear physics, Jefferson Lab has installed a 1 GeV superconducting linac to achieve 6.5 GeV beam by re-circulation. The laboratory's Continuous Electron Beam Accelerator Facility (CEBAF) has been operating for 15 years with more than 150 m of SRF cavities, the largest number in operation at one facility. Looking ahead, Jefferson Lab has also developed 20 MV/m cavities to upgrade CEBAF's energy from 6.5 GeV to 12 GeV.

For heavy ions, the CW superconducting accelerator provides an optimized array of independently phased resonators, to accelerate a variety of ion species with different velocities and charge states. The Argonne Tandem Linac Accelerator System at Argonne National Laboratory and the ALPI machine at the Legnaro National Laboratory have been operating for several decades. TRIUMF has expanded its radioactive-beam facility ISAC by adding a superconducting heavy-ion linac to supply more than 40 MV. Heavy-ion linacs in New Delhi and Mumbai have also come online. More than 250 superconducting resonators are currently operating around the world. New radioisotope beam (RIB) facilities are under construction with the SPIRAL2 project at the GANIL laboratory, HIE-ISOLDE at CERN and the ReA3 re-accelerator at Michigan State University (MSU).

Electron storage rings working as light sources are having an enormous impact on materials and biological science. SRF accelerating systems have been used in upgrading storage-ring light sources, such as the Cornell High Energy Synchrotron Source and the Taiwan Light Source. The Canadian Light Source, DIAMOND in the UK, the Shanghai Light Source in China and SOLEIL in France also operate with SRF; the National Synchrotron Light Source II at Brookhaven and the Pohang Light Source in Korea are planning to use SRF cavities. The Swiss Light Source at PSI and ELETTRA in Trieste have both installed third-harmonic superconducting cavities to improve beam lifetime and stability.



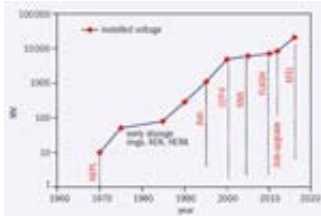
[XFEL cavities](#)

Free-electron lasers (FELs) based on SRF linacs provide tunable, coherent radiation over a wide range of wavelengths. The Jefferson Lab FEL generates 14 kW of CW laser power in the infrared, with energy recovery by recirculating nearly 1 MW of beam power. This is an important milestone toward the use of energy-recovery linacs (ERLs) for future light sources and electron-cooling applications. SRF-based FELs have operated at the Japan Atomic Energy Research Institute and at the ELBE project in Germany. FLASH at DESY is a short-wavelength FEL based on the self-amplified stimulated emission (SASE) principle, delivering 6 nm wavelength light. Its SRF linac uses more than 60 cavities, each 1 m long to accelerate a 1 GeV electron beam. A variety of innovative linac-based light sources are also under study for FELs and ERLs to deliver orders of magnitude higher brightness and optical beam quality. High-intensity beams for ERLs have spurred explorations for electron-cooling applications and for electron-ion colliders, for example to upgrade the

Relativistic Heavy Ion Collider at Brookhaven.

With many exciting prospects on the horizon, the world SRF community has expanded to include many new laboratories where extensive SRF facilities have been installed. In all, more than 1 km of superconducting cavities have been installed worldwide to provide more than 7 GeV of acceleration. The next big jump of 16 GeV is already under construction, with the largest SRF application underway on a superconducting linac for the European XFEL at DESY. It will be based on nearly 700 niobium cavities operating at a gradient of more than 22 MV/m. When completed in 2016 it will provide X-ray beams of unprecedented brilliance at sub-nanometre (Ångström) wavelengths.

A new Facility for Rare Isotope Beams (FRIB) is underway at MSU to allow the study of exotic isotopes related to stellar evolution and the formation of elements in the cosmos. FRIB will be based on more than 330 low-velocity resonators, doubling the number currently in operation.



[On the path to increase](#)

The most ambitious future application under study is for the International Linear Collider (ILC), a 500 GeV superconducting linear accelerator. It will require 16 km of superconducting cavities operating at gradients of 31.5 MV/m. Intense research is underway to reach a high yield for high gradients: 30-40 MV/m. New vendors for niobium, for cavities and for associated components are being developed around the world. Improved techniques for performance reliability and cost reduction are emerging. New assembly and test facilities are coming together at DESY, Saclay, KEK and Fermilab; the experience of the DESY XFEL will be a key stepping stone. Future ILC energy upgrades toward 1 TeV would benefit from even higher gradients that would push niobium towards its ultimate potential of 55 MV/m and thus open the door for new materials with gradients of 100 MV/m. Nb₃Sn is the most promising candidate offering the prospect of 100 MV/m gradients, but substantial research is needed to verify this potential and guide the development necessary to harness it.

With the success of the SNS and the upcoming ESS, high-intensity proton linacs are likely to fulfil future needs in a variety of arenas: upgrading injector chains of proton accelerators at Fermilab's Tevatron (Project X) and CERN's LHC (the SPL), transmutation applications for treatment of radioactive nuclear waste, nuclear-energy production using thorium fuel, high-intensity neutrino beamlines, high-intensity muon sources for neutrino factories based on muon storage rings and eventually a muon collider at the multi-tera-electron-volt energy scale. All of these far future prospects will of course depend on the success of on-going efforts.

The 2011 International SRF conference in Chicago hosted more than 350 SRF enthusiasts. We can remain confident that the RF superconductivity community has both the creativity and determination to face the upcoming challenges and successfully bring these exciting prospects to fruition.

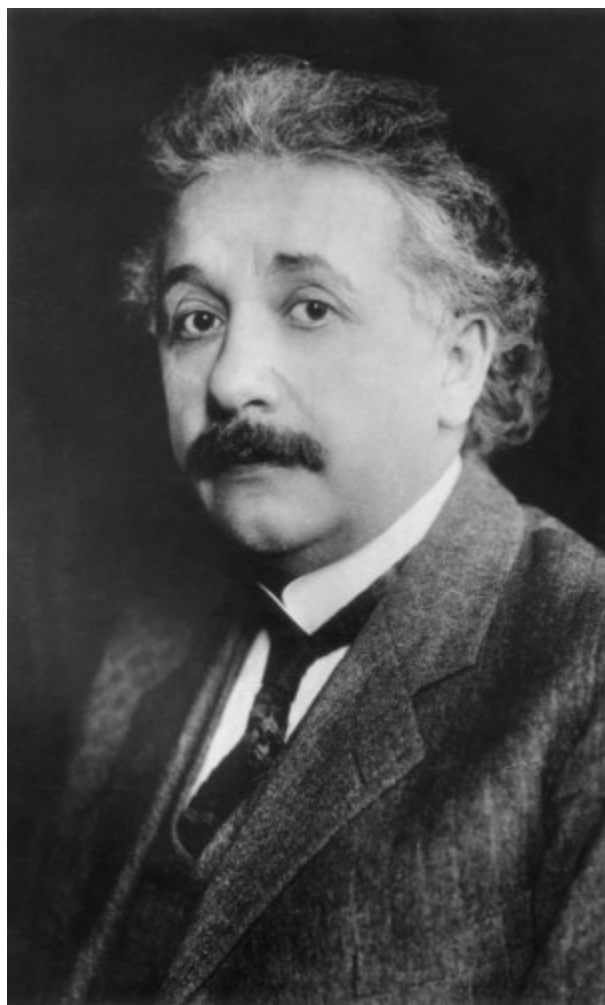
About the author

Hasan Padamsee, Cornell.

DIRECTOR'S CORNER

Breaking the speed limit of the universe?

Barry Barish | 10 November 2011



The speed limit was set by Einstein's theory of relativity in 1905. Image: German Federal Archive

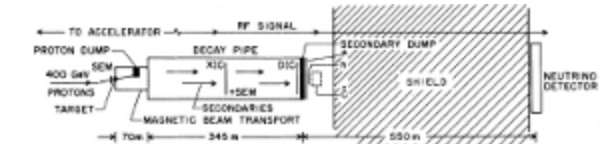
Experimental physics plays many roles in advancing science. We make lots of measurements that help enable us to describe the physical world. We test theories and sometimes it leads to surprising discoveries that change our understanding of the physical world. Part of doing and advancing science is experimentally checking the correctness of our description of nature, even if we expect to only validate what is theoretically expected. That is a duty of experimental physics, and every once in a while we are surprised, finding that even long-held beliefs are wrong.

For more than 100 years, we have had very good reason to believe that based on Einstein's theory of relativity, no particles travel faster than the speed of light. Nevertheless, as physicists we have the responsibility to check such a 'law' as precisely as we are experimentally able. An experiment has just performed such a measurement and has presented evidence that neutrinos originating at CERN and detected in the OPERA experiment at Gran Sasso Laboratory travelled faster than the speed of light. Astonishingly, they claim that the arrival time from CERN for neutrino is 60 nanoseconds earlier than expected for particles travelling at the speed of light. Wow! But is this result correct?

In 1976, Frank Sciulli of Columbia University and I were co-spokesmen for a neutrino experiment at Fermilab designed to study high-energy neutrino interactions using a special beam having two bands of neutrinos, one from pion and one from kaon decay. One day, Professor George Kalbfleisch, a physicist at the University of Oklahoma, approached us and suggested that we use our experiment to check the velocity of neutrinos. Intrigued, we

joined together to measure the neutrino velocity in 1976; George and collaborators followed up with a higher statistics analysis in 1979. Our technique was to make a straightforward comparison of the arrival times of neutrinos and antineutrinos interacting in our detector with those of high-energy muons that penetrated the shield. The two resulting papers are quoted as reference 5 (Phys. Rev. Lett. 43, 1361 (1979) and Phys. Rev. Lett. 36, 837 (1976)) in the OPERA experiment paper, and they report no measurable deviation from the speed of light with a limit of $|v-c|/c < 0.4 \times 10^{-4}$.

The long-baseline experiments that have recently been developed to measure neutrino oscillations give us an opportunity to significantly improve these measurements because of the very long path length traversed by the neutrinos (about 732 kilometres in the case of the CERN-to-Gran Sasso beam). However, to exploit this long baseline, new techniques are required to accurately measure the distance from the accelerator to the detector, to determine the start time of the neutrino beam and to determine the interaction time and position of neutrinos interactions in the detector.



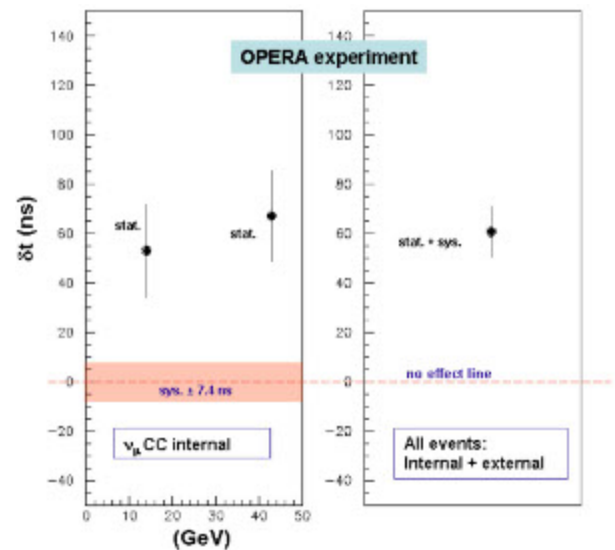
Fermilab setup in 1976 for direct measurement of neutrino velocity by comparing neutrino interactions with high-energy muons penetrating the shield

The MINOS experiment had already made such a long-baseline measurement for neutrinos, yielding a [result for about-3-GeV neutrinos](#) published in 2007. They compared detection times of neutrino events in their near detector at Fermilab near Chicago, US and their far detector at the Soudan mine in Minnesota, coincidentally also some 734 kilometres away. MINOS recorded a total of 473 far-detector neutrino events and used them to measure for neutrinos $|v - c|/c = 5.1 \pm 2.9 \times 10^{-5}$ (at 68% confidence level), consistent with the speed of light to within 1.8σ .

The OPERA experiment at Gran Sasso, like MINOS, was built to study long-baseline neutrino oscillations. Their new measurement of neutrino velocity has much larger statistics and also, they claim, improved systematics. They have made a concerted effort to reduce the systematic errors by improving the timing systems and making accurate measurements of the neutrino baseline through accurate GPS measurements transferred deep underground to the detector. As a result, they find an apparent early arrival for neutrinos relative to that expected for particles moving at the speed of light in vacuum of 60.7 ± 6.9 (statistical), ± 7.4 (systematic) nanoseconds. This early arrival corresponds to an improved measurement of neutrino velocity relative to the speed of light of $|v - c|/c = 2.48 \pm 0.28$ (statistical), ± 0.30 (systematic) $\times 10^{-5}$.

The OPERA result is more precise and therefore not inconsistent with the earlier accelerator limits I discuss above. However, the most sensitive limit comes from neutrinos from a supernova, where the arrival times of neutrinos in the Kamioka detector in Japan and the Irvine-Michigan-Brookhaven detector in the US were compared with photons originating from SN1987a. This analysis yielded a limit of $|v - c|/c < 2 \times 10^{-9}$, four orders of magnitude better than the terrestrial accelerator measurements. There is one caveat, however: The supernova neutrinos are much lower-energy neutrinos (about 30 MeV).

Where does all of this leave us? Can we conclude that neutrinos travel faster than the speed of light?? Of course not! This result must now be followed up by rigorous analysis of their experiment. The OPERA analysis is now undergoing just such scrutiny by the scientific community. Already, valid questions have been posed. One is whether there are corrections due to the motion of the satellite in using GPS. Another is drawn up in a [theoretical paper by Cohen and Glashow](#). The authors show that such superluminal neutrinos would lose energy by radiating electron-positron pairs on the way to the Gran Sasso. They claim the result is therefore not possible and they also point out that it is inconsistent with other experiments.



The OPERA result showing the measured early arrival time for neutrino events. Image: OPERA

Finally, the experimental observation must be checked by another experiment, MINOS, which is expected to make a renewed effort to confirm or refute this result. This is one of the real beauties of being a physicist. We can generally check claims like OPERA's by critiques such as those by Cohen and Glashow and by checking it experimentally.

If this astounding result actually does turn out to be correct, it will change our fundamental understanding of physics. But, before we get too excited, we need to let this play out. Ultimately experiment will decide.

As a final thought, one might wonder why this result so quickly captured the imagination of the public. My colleague Nick Walker relayed to me a conversation he had with his son, Patrick. When the OPERA result hit the news, the 14-year-old asked Nick with curiosity: "Does the neutrino weigh anything?" His dad (Nick) said that it was an interesting question, and in fact by recent experiments we know the answer is YES. Patrick then displayed his joy and replied, "*GOOD! That means there is hope for us (to go faster than the speed of light)!*"

[MINOS](#) | [NEUTRINOS](#) | [OPERA](#) | [SCIENTIFIC METHOD](#) | [SPEED OF LIGHT](#)

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