WHAT'S a Neutrino?

WHERE DO NEUTRINOS COME FROM?

HOW many are going through this poster every second?

FLAVORS? CAN YOU SEE A NEUTRINO?

Neutrinos have flavors? Is chocolate a neutrino flavor?

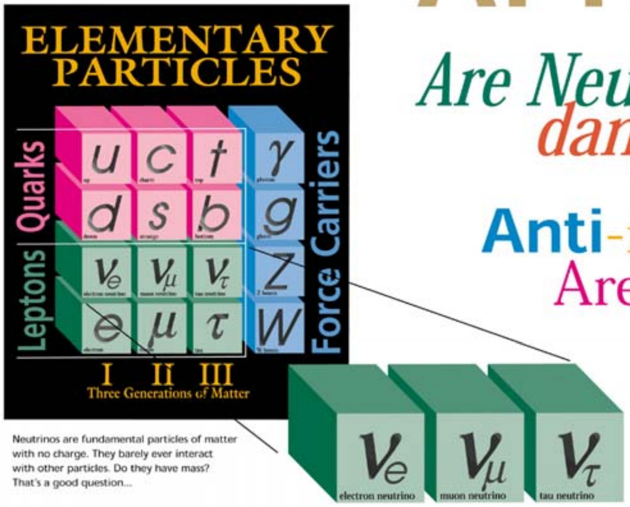
A particle without mass?

IS THAT POSSIBLE?

How big is a **NEUTRINO?**

Do Neutrinos Have MASS**?** ? **Do We Care?**

Can you make neutrinos AT HOME?



Neutrinos are fundamental particles of matter with no charge. They barely ever interact with other particles. Do they have mass? That's a good question...

Are Neutrinos dangerous?

Anti-neutrinos**?**
Are you
kidding**?**

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The STORY of the Neutrino

1930

In a letter to the attendees of a physics conference in Tübingen, Germany, Wolfgang Pauli proposes as a "desperate remedy" the existence of a new neutral particle to explain the apparent energy nonconservation in radioactive decays. During the next few years, scientists elaborate Pauli's theory and conclude that the new particle must be very weakly interacting and extremely light.

1933

Enrico Fermi proposes "neutrino" as the name for Pauli's postulated particle. He formulates a quantitative theory of weak particle interactions in which the neutrino plays an integral part.

1956

Two American scientists, Frederick Reines and Clyde Cowan, report the first evidence for neutrinos. They use a fission reactor as a source of neutrinos and a well-shielded scintillator detector nearby to detect them.

1957

An Italian physicist, Bruno Pontecorvo, living in the USSR, formulates a theory of neutrino "oscillations." He shows that if different species of neutrinos exist, they might be able to oscillate back and forth between different species.

1958

Maurice Goldhaber, Lee Grodzins, and Andrew Sunyar at Brookhaven National Laboratory demonstrate that the new neutrino has lefthanded helicity, meaning that it spins along the direction of its motion in the sense of a lefthanded screw. The experiment helps to distinguish among different forms of weak interactions.

1962

A group of scientists from Columbia University and Brookhaven National Laboratory perform the first accelerator neutrino experiment and demonstrate the existence of two species of neutrinos, the electron neutrino, ν_e, and the muon neutrino, ν_μ. In 1987, Jack Steinberger, Leon Lederman, and Mel Schwartz win the Nobel Prize for this discovery.

1968

An experiment deep underground in the Homestake mine in South Dakota makes the first observation of neutrinos from the sun. But experimenters see far fewer neutrinos than solar models had predicted.

1973

An international team working at CERN, the European Laboratory for Particle Physics, in Geneva, Switzerland, uses a bubble chamber to observe the first example of a "neutral current" event. Observation of this new interaction lends strong support to a unified theory of weak and electromagnetic interactions proposed a few years earlier by Sheldon Glashow, Abdus Salam, and Steven Weinberg. Shortly afterward, scientists at Fermilab confirm the discovery.

1975

A new lepton, tau, is discovered by a group led by physicist Martin Perl at the Stanford Linear Accelerator Center. Experiments performed shortly afterward provide strong evidence that there also exists a third species of neutrino, the tau neutrino, ν_τ. In 1995, Perl and Reines win the Nobel Prize for their discoveries.

1987

Large underground water detectors in the Kamioka mine in Japan and in the Morton salt mine in the U.S. detect the first neutrinos from a supernova, SN1987A.

1989

Experiments at CERN and at Stanford show that there exist only three species of light (or massless) neutrinos. Thus ν_e, ν_μ, and ν_τ must complete this class of particles. This direct measurement verifies strong suggestions previously deduced from the cosmological measurements.

1990

Two experiments, SAGE in the USSR and GALLEX in Italy, are set up to look at neutrinos from the sun. The detection of these neutrinos in subsequent years is the first proof of energy production by fusion of hydrogen in the sun—but still, far fewer neutrinos are detected than expected.

1998

At the Neutrino '98 conference in Japan, physicists from the Super-Kamiokande experiment present significant new data on the deficit in muon neutrinos produced in the Earth's atmosphere. The data suggest that the deficit varies depending on the distance the neutrinos travel—an indication that neutrinos oscillate and have mass.

1999

The Main Injector at Fermilab begins operation. The combination of its high-intensity particle beam and an energy of 120 GeV allows a new generation of neutrino experiments that will continue to probe some of nature's most fundamental questions.

2000

DONUT collaboration reports the first direct evidence for the tau neutrino (July 21, 2000)

2001

MiniBooNE, will begin a search for neutrino oscillations using protons from the Fermilab Booster. It seeks to confirm puzzling results from an earlier experiment at Los Alamos.

2003

NuMI/MINOS will begin the search for neutrino mass. Using 120 GeV protons from the Main Injector as its source, MINOS will send a beam of muon neutrinos through the earth to the Soudan mine in Minnesota, where experimenters will seek signals for neutrino oscillations.


Wolfgang Pauli


Frederick Reines


J. Steinberger, K. Goulianos, J. Gaillard, N. Mistry, G. Danby, W. Hayes, L. Lederman, M. Schwartz


Enrico Fermi


December 4, 1930

Dear Radioactive Ladies and Gentlemen,

As the bearer of these lines, to whom I graciously ask you to listen, will explain to you in more detail, how because of the "wrong" statistics of the N and Li6 nuclei and the continuous beta spectrum, I have hit upon a desperate remedy to save the "exchange theorem" of statistics and the law of conservation of energy. Namely, the possibility that there could exist in the nuclei electrically neutral particles, that I wish to call neutrons*, which have spin 1/2 and obey the exclusion principle and which further differ from light quanta in that they do not travel with the velocity of light. The mass of the neutrons should be of the same order of magnitude as the electron mass and in any event not larger than 0.01 proton masses. The continuous beta spectrum would then become understandable by the assumption that in beta decay a neutron is emitted along with the electron such that the sum of energies of neutron and electron is constant.

I admit that my remedy could seem improbable because one should have seen those neutrons much earlier if they really exist. But only the one who dares can win and the difficult situation, due to the continuous structure of the beta spectrum, is lighted by a remark of my honored predecessor, Mr. Debye, who told me recently in Bruxelles: "Oh, it's best therefore, not to think about this at all, like new taxes". Therefore, every solution to the issue must be discussed seriously. Thus, dear radioactive people, examine and judge. Unfortunately, I cannot appear in Tübingen personally since I am indispensable here in Zurich because of a ball on the night from 6 to 7 of December. With my best regards to you, and also to Mr. Back.

Your humble servant,

W. Pauli

* Pauli originally called the new particle the neutron. Later, Fermi renamed it the neutrino.

A 1930 letter from Wolfgang Pauli to colleagues in Tübingen, Germany described a "desperate remedy" –the neutrino.


A neutral current event observed in the Gargamelle bubble chamber at CERN


Stanford Linear Accelerator Center


GALLEX


Super Kamiokande experiment


Vittorio Paolone of DONUT


MiniBooNE detector


MINOS collaboration

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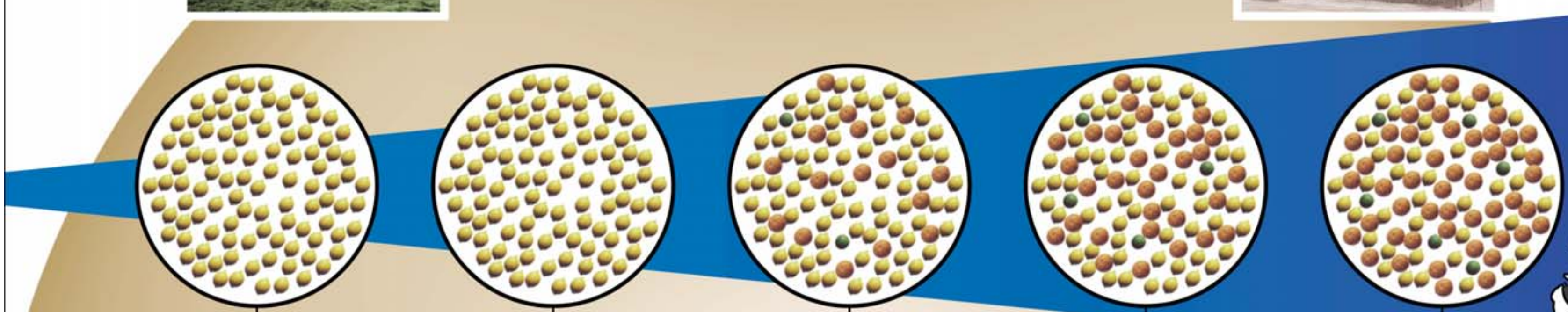
Can Neutrinos CHANGE Flavor?

If we can detect neutrinos changing from one flavor to another, then we know that they have mass.

Neutrinos start at Fermilab…

…and, *two* milliseconds later, arrive at the Soudan Mine.



1. A beam of protons strikes a target, creating a beam of pions and kaons, which decay into a beam of muon neutrinos (ν_μ). The fruits in the circle represent the proportion of muon neutrinos (lemon) that oscillate into tau (orange) and electron (lime) neutrinos.

2. The MINOS "near" detector measures the rate, energy spectrum and flavor composition of the NuMI neutrino beam immediately after the neutrinos are produced and before any oscillations can take place.

3. Assuming that the neutrino oscillation length is great, muon neutrinos will not oscillate significantly until they travel well beyond the Fermilab site. In this example, a fraction of the muon neutrino beam has transformed into tau neutrinos (orange). If the oscillation potential is great, this fraction will be significant. Note that very few muon neutrinos have oscillated into electron neutrinos (lime), because the oscillation potential is small, or the oscillation length is very great.

Distances not to scale.

4. The MINOS "far" detector is located 735 kilometers from Fermilab, in Soudan, Minnesota. The neutrino beam diverges and becomes less intense as it travels away from the source. However, the long distance from the source allows the muon neutrinos more length to transform into tau neutrinos, though not enough distance to transform into a significant number of electron neutrinos.

Neutrinos come in three flavors: electron, muon and tau. Each one has a charged partner particle, an electron, a muon or a tau lepton. Here, a muon neutrino is a lemon, an electron neutrino is a lime and a tau neutrino is an orange.

muon neutrino (ν_μ)

electron neutrino (ν_e)

tau neutrino (ν_τ)

About 10,000 billion neutrinos from the sun pass through this square every second.

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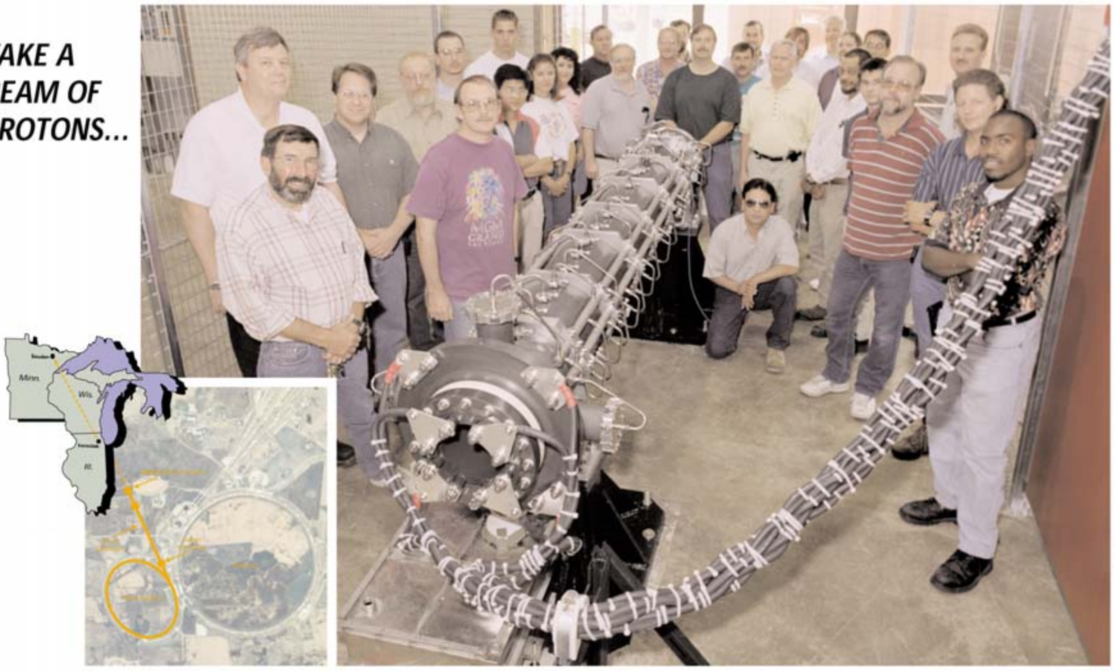
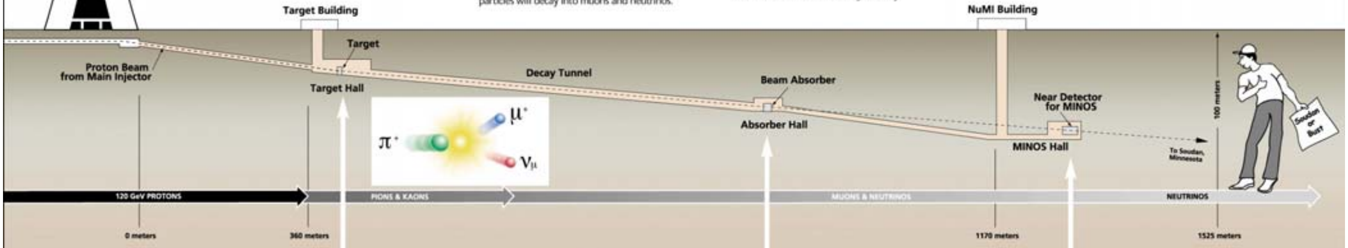
How to MAKE a Neutrino Beam

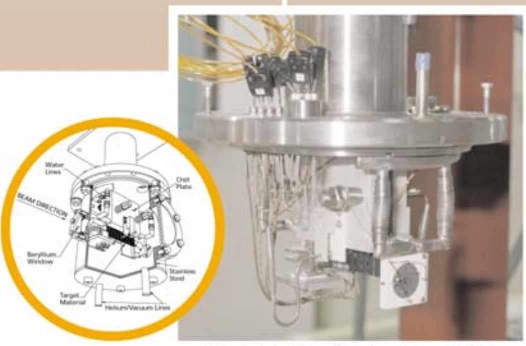
TAKE A BEAM OF PROTONS...



The first of two horns (magnetic filters) that align the positively charged particles produced in the target, posed with the team that built it. Current pulses of 200,000 amps are applied to the horn for a thousandth of a second at the same time as the proton beam strikes the target.

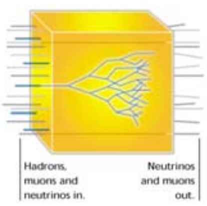
1. Take a beam of protons, accelerated to 120 GeV.
2. Smash protons into a target. (Beryllium, graphite or aluminum will do.) NOTE: Expect many different particles to come out of the target, in all directions.
3. Filter particles. Use a magnetic filter, or "horn" (above), to retain most of the positive particles. NOTE: Discard negative particles.
4. Allow the positive particles to travel down a long empty space. Most of the pion and kaon particles will decay into muons and neutrinos.
5. At the end of the empty space, position a specialized particle sponge to absorb all remaining particles. This sponge will mop up the pions, kaons and protons, but have little effect on the muons—and no effect on the neutrinos. A few tons of aluminum, steel and concrete will do the job nicely.
6. Allow the remaining muons and neutrinos to pass through a few meters of rock. NOTE: Most of the muons will slow down and stop.
7. Result: Billions of fresh neutrinos, northward bound. Minnesota, here we come!





A prototype of the MINOS target. 4×10^{13} protons, accelerated to 120 GeV, will strike the black graphite fins of the target every 1.9 seconds. Water cooling keeps the target from melting.

Particle Beam Absorber



The near detector, located at Fermilab, is a smaller version of the main MINOS detector at Soudan, Minnesota. The near detector is used to verify the flavor of the neutrino beam at the source. The detector is smaller because the neutrino beam hasn't yet spread out very much.

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