FermiNews

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INSIDE

Good ν's

News from studies of solar neutrinos and neutrinos in cosmic rays points to a strong suggestion—some may even say a conclusion—that neutrinos oscillate from one flavor to another and thus have mass. Would such a discovery bring the study of fundamental properties of neutrinos to a close? On the contrary, much as Watson and Crick's deciphering of the DNA molecule closed a chapter in genetic coding but opened a book in molecular biology, this discovery could mark the beginning of the golden age of neutrino physics.

Photo by Bob Palmer

In a story on page 10, physicist Stanley Wojcicki, spokesman for the MINOS experiment, surveys the field of neutrino physics and the role of MINOS in the context of worldwide neutrino experiments.

Booster Digs In For Another Workhorse Role In Run II

By Mike Perricone, Office of Public Affairs

Preparing for the worst on his inspection tour, Dixon Bogert laced up his workboots. Over them, he pulled on mud-crusted rubber boots that buckled up to near his knees.

"There's mud, and then there's *mud*," he said, setting off past thick rolls of blueprints rubber-banded into close formation near the door of his office.

All those precise drawings translate into digging in the mud below one of the two Booster towers. Wearing one of his many Beams Division hard-hats, Bogert directs this intricate project to slip 1,450 tons of steel underneath a building whose support has been transferred to a series of piles that have been sunk nearly 70 feet beneath the surface to reach bedrock.

The tower (incongruously, just two stories high) follows the curve above a segment of the Booster, the 475-meter ring that accelerates or "boosts" the energy of protons from 400 million electron volts (400 MeV) to eight billion electron volts (8 GeV).

CRITICAL PATH

In the old days, protons were extracted from the east side of Booster (as it's called by those closest to it) and transferred by an 8 GeV line to the now-defunct Main Ring. For Run II, protons will be extracted from a new point in Booster's northwest quadrant and transferred by a newly-constructed 8 GeV line to the Main Injector.

At the extraction point, protons get a jolt of energy from a kicker magnet, and jump across a metal gateway called a septum, into the 8 GeV line. Even the most accurate and efficient transfer will produce low-level radiation losses.

The old extraction point was under the shielding of an earthen berm. The new point is directly beneath a corner of the continually-occupied tower. With increased demands from the Tevatron and Main Injector, Booster will be sending more pulses through the 8 GeV line, meaning more total losses even with the rate of loss remaining constant.

Below the building, 1,450 tons of steel will be inserted as shielding.

"Laboratory rules in general try to keep radiation exposures well below Department of Energy and legal standards," Bogert said. "The Lab set its goal as not exceeding 100 millirems per year based on continual loss. If you divide that by the number of working-hours in a year, we should not be exceeding 50 microrems per hour—that's fifty one-millionths of a rem. Last spring, when we began to extract beam from Booster and run it to the temporary abort in the middle of the new 8 GeV line...we discovered that, indeed, we exceeded 50 microrems."

An average person who never goes near an accelerator can expect to absorb approximately 360 millirems a year (3.6 times the Lab's self-imposed limit) from the sun, soil, buildings, dental x-rays, smoke detectors and other facets of 20th-century life.

If the towers hadn't been added in the 1980s, the original earthen berms probably would have offered sufficient shielding. But the buildings are there to stay. And the top of the Booster tunnel is only 12-14 feet below the surface, compared to 22 feet for the Tevatron tunnel and 24.5 feet for the Main Injector tunnel (the 2.5-foot increase is a consequence of the greater expectation for beam intensity in the Main Injector than from the Main Ring). The clearance between the tunnel and the Booster tower is akin to that of a crawl space in construction terms.

Inserting the shielding also means some connections to Booster must be rerouted around the steel, forming an s-shape instead of a

Photos by Reidar Hahn

Not your ordinary construction site, the two-story tower sits above the Booster Ring, which will take on a new profile as part of Run II.

straight line. Offices have been closed in areas above the construction site. Two electrical transformers were removed and their precisely-aligned concrete pads ripped out; electrical service to the building was maintained through a temporary parallel system. A restraining, or secant, wall had to be added to keep the building from sliding into the excavation.

"This is not just a simple project," Bogert said.

Nor is it a cheap one, beginning with a $1.25 million construction contract. Including design work, electrical work, and the cost of steel, Bogert estimates the price as more than $2 million.

Whitaker Excavating of Earlville, Ill., is handling the digging, concurrently with projects at CZero and FZero. TCDI of Lincolnshire, Ill., brings the expertise for the project's signature component: drilling down to bedrock, sinking 14 steel piles, building bridges between the piles, and permanently transferring the load of the building onto those bridges and piles. The piles are three concentric tubes, from 7.5 to 10 inches in diameter, designed to prevent shallow groundwater from leaking into the subterranean aquifer. Among TCDI's credentials is constructing a new roof over the old roof during renovations to Chicago's renowned Orchestra Hall.

With the Booster tower supported permanently on its stilts, the earth will be excavated between the building and tunnel; the tunnel also is being reinforced to carry extra shielding. Steel slabs are being collected in a parking lot near the Meson Assembly Building, some reclaimed from old experiments, and about 650 tons of what Bogert calls "boat-anchor steel" purchased at bargain prices from US Steel in Gary, Indiana. The slabs will have to be trimmed, numbered and fitted together in shapes conforming to Booster's configuration. A run-of-the-mill slab is nine inches thick and weighs 18-20 tons.

The schedule calls for the first steel slabs to be slid into place early in July. The earth will then be filled in and brought back up to grade. The concrete transformer pads will be poured and cured, then the transformers will be replaced and full power restored so Booster can be turned on—the primary milestone.

All this by mid-August, when the schedule calls for Booster to begin "off-hours" operation, with full-time running slated for mid-September. This is the critical path for circulating beam in the Main Injector, which can't be commissioned unless Booster provides beam. The old workhorse of Lab accelerators will have to meet new demands.

"And this old workhorse has gotten older in the past 30 years," said Bob Webber of Beams Division.

For Run II of the Tevatron, Booster will produce slightly less than one pulse of protons per second; for NuMI (Neutrinos at the Main Injector), it will produce three pulses per second. The MiniBooNE (Mini Booster Neutrino Experiment) proposal has requested seven to eight pulses per second. The number of protons per pulse expected from Booster will rise by 20 to 25 percent, from about 4.2×10^{12} protons per pulse, to 5×10^{12} protons per pulse. A longer term goal will be to raise that number even higher.

"Historically, Linac (the linear accelerator) and Booster have had a fairly low profile in the Lab as a whole," said Webber. "They did what they needed to do and people kept them running smoothly. Now they're being asked to do new things, and that's going to raise the profile of these machines in the Lab's landscape."

Booster's new profile will brandish its mud stains as a badge of honor. ■

Workers deal with mud at every stage of the Booster shielding project. The building's beam supports will be carried on "stilts" that are sunk down to bedrock.

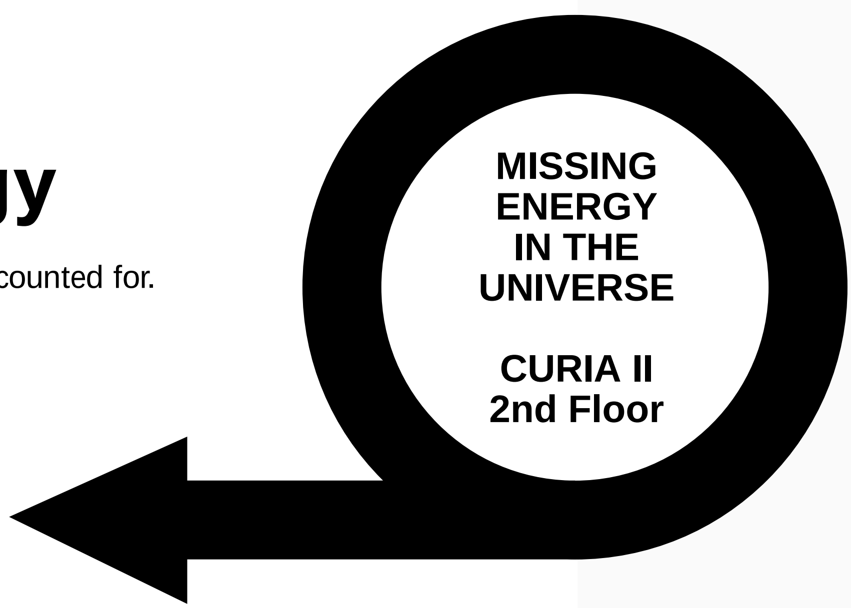
Information on the Booster is available at http://www—bd.fnal.gov/proton/booster/booster.html

ACCELERATOR SCHEDULE 1998

CRITICAL PATH	May 1998	June 1998	July 1998	August 1998	September 1998	October 1998	November 1998	December 1998
Booster	← Civil Construction →			← Start-Up & Beam to Main Injector →				
Main Injector	Ready For Beam (7/31) →			→	Intermittent Commissioning	← Commissioning →		Shut Down
Recycler	Ready For Beam (8/22) →				Intermittent Commissioning	← Proton Commissioning →		Vacuum Bakeout
Accumulator	Ready For Beam (10/15) →					← Intermittent Commissioning →		Install Debuncher Cooling
Tevatron	← Shut Down →							

Department of (Missing) Energy

Much of the energy of the universe is unaccounted for. It must be around here somewhere, cosmologists say.



By Judy Jackson, Office of Public Affairs

For the universe, density is destiny. The very shape the universe takes depends on the amount of "stuff" it contains, in the form of matter and energy. A universe containing more than a certain critical energy density would curve positively, like the surface of a baseball. A universe with less than the critical amount would curve negatively, like the seat of a saddle. But a universe with neither more nor less than the critical density of matter and energy would be geometrically flat.

Many cosmologists, including several at Fermilab, are not shy about predicting which of these shapes will prove correct.

"We live in a flat universe," said University of Chicago / Fermilab cosmologist Michael Turner, during a recent workshop organized by Fermilab's Theoretical Astrophysics Group on "The Missing Energy of the Universe," held at Fermilab May 1-3. Turner was among several dozen cosmologists gathered to try to make sense of an influx of astrophysical data suggesting that something funny is going on in the universe.

In particular, the cosmological books don't balance. Adding up all the matter, both luminous and dark, in the universe yields only about a third of the critical density required to flatten the universe. If the universe is indeed flat — it might not be, but persuasive theoretical models and some experimental evidence suggest that it is—then something must be making up the other two-thirds of the critical density. That "something" is the so-called missing energy that drew cosmologists, astrophysicists, particle physicists and science journalists to Fermilab, if not to find it, at least to explore the most likely places to look.

Among workshop participants were members of two research teams that recently presented startling evidence that the expansion of the universe is not only not slowing down, as everyone thought it should, but in fact appears to be speeding up. If they prove right and the universe really is accelerating, the effect on the critical density problem will be profound. The missing component of the critical density will have to exhibit a property called "negative pressure" that tends to push the universe apart, rather than pulling it together.

In his opening talk, Turner summed up the state of the field at the moment.

"Current observations tell us that most of the universe is funny energy whose pressure is negative, and little more."

Candidates for Turner's "funny energy," the missing two thirds of the critical energy density, include the cosmological constant, a background energy density, first proposed by Einstein, that remains the same over space and time. Or it could come from something more dynamical that changes and interacts with matter as it evolves.

"Matter is the stuff in the universe that clumps," explained University of Chicago / Fermilab astrophysicist Josh Frieman to a group of science journalists over lunch. "To distinguish the missing energy from the clumpy stuff, we talk about a smooth component. The smooth stuff could be the cosmological constant, that is an energy that remains the same. Or there could be something else that is not constant but changes over space and time. It could have a negative pressure that would cause the universe to accelerate. Evidence is building for a smooth component with negative pressure. An accelerating universe is a smoking gun for a smooth component."

And why, asked a reporter, do we care?

After a rare moment of stunned silence among the assembled experts, University of Pennsylvania cosmologist Paul Steinhardt gave a response to gladden a physicist's heart.

"This is a monumental issue," Steinhardt said. "Understanding it is important for understanding the fundamental laws of physics, whatever form it takes." ■

Information on Missing Energy is available at http://www.physics.upenn.edu/~www/astro-cosmo/caldwell/workshop/index.html

Photo by Jenny Mullins

Cosmologist Scott Dodelson of the Fermilab Theoretical Astrophysics Group, which organized the missing Energy Workshop. "The nature of the missing energy in the universe has profound implications for particle physics," Dodelson said.

How does a Fermilab physicist spend the day?

The Shadow Knows

Eighth-grader Kurt Fenner, an aspiring physicist, describes the day he spent shadowing Peter Mazur, a physicist in Fermilab's Technical Division

By Kurt Fenner, Batavia Middle School

My day at Fermilab was very exciting, but also rather exhausting. I had to get up at 6:30 a.m. to get there by 8:30. Just getting there was exciting. The first thing that happened was that I saw a group of geese; but when we drove by, one bent the antenna on my mom's car.

Well, we finally got to the Public Affairs Office, where I met the scientist I would shadow, Peter Mazur. From there, we went to Dr. Mazur's office. We had nothing to do until 9:00. It was 8:30, so he explained many things to me. First, he explained what our basic schedule would be for the day. Then he told me how all the gadgets in his office worked and why he got them. They were all really neat.

Then, finally it was 9:00, and it was time for the first experiment. We had to test some water that they deionized. This distilled water was more distilled than the distilled water that you buy in the store. What they did was take some of the water and placed it in different nutrients to see if any bacteria grew. We finished that, and then went back to the office and Dr. Mazur made some phone calls.

By 10:00 we went into the accelerator tunnel and looked at the stainless steel pipes. See, most people think that if you have stainless steel pipes no bacteria will do any harm, but they are wrong. The bacteria that grew actually ate through the pipes and there were leaks. So they rewelded the pipes, and cleaned them out with a new invention. It was a bunch of sandpaper attached to a spinning device to clean the pipes. This was so that, hopefully, no more bacteria would grow.

When we finished that we went into the industrial area and looked at all the different magnets they had. One even weighed 50 tons! We saw how they looked and then saw the liquid helium tester they were building. Then at 11:30, we went back to the office. There was really nothing to do until 12:15 when we started to walk to lunch. (That is how we got our exercise.) We met up with other physicists and an engineer and ate lunch. It was provided by Fermilab. Then at about 1:15, after lunch, we started to walk to a meeting. When we got there, they talked about how their water tanks were working. I didn't really understand, and after lunch I was tired, so I almost fell asleep, but I didn't.

Finally, the meeting was over and we looked at the water tanks. By then it was 3:30, and the day was almost over, so we took a tour of the main building. We went to the top floor and could actually see the top of the Sears Tower and John Hancock building. When it was 4:30, we went to the administration office and met my mom. We said our good-byes and left. I couldn't believe it was over so soon. Someday I hope to go back and actually have a good understanding of what they are talking about. ■

Photo by Fred Ullrich

Fermilab physicist Peter Mazur and eighth-grader Kurt Fenner discuss installation of components of Fermilab's new Main Injector accelerator.

Polar Expedition

DZero experimenters explore their data for evidence of a lone magnetic pole.

By Greg Landsberg, DZero

People have known about electricity and magnetism for centuries. The ancient Greeks noted that pieces of amber, when rubbed, would attract light objects. The word ‘electricity’ comes from the Greek word for amber: “elektron.”

In time, observers found that there are two types of electric charge, (Benjamin Franklin named them positive and negative) and that opposite charges attract. In the twentieth century Robert Millikan showed that the electric charge is quantized: all electric charges are multiples of the elementary electric charge found on the electron.

The ancient Greeks also knew about magnetism. They saw that certain minerals attracted iron and other pieces of the same mineral. About a thousand years ago, the Chinese noticed that a magnetized needle always points in the same direction and thus could be used for navigation. However, unlike electric charges, which can be isolated, magnetic materials always have two “poles,” called north and south for the directions they point to on Earth. Break a compass needle in two, and each will again have both north and south poles. It appears impossible to isolate a single magnetic pole; only the combination of north and south poles (a “dipole”) seems to exist. This absence of a single magnetic charge, or monopole, makes the laws of electricity and magnetism different, and this difference has bothered symmetry-loving physicists for years.

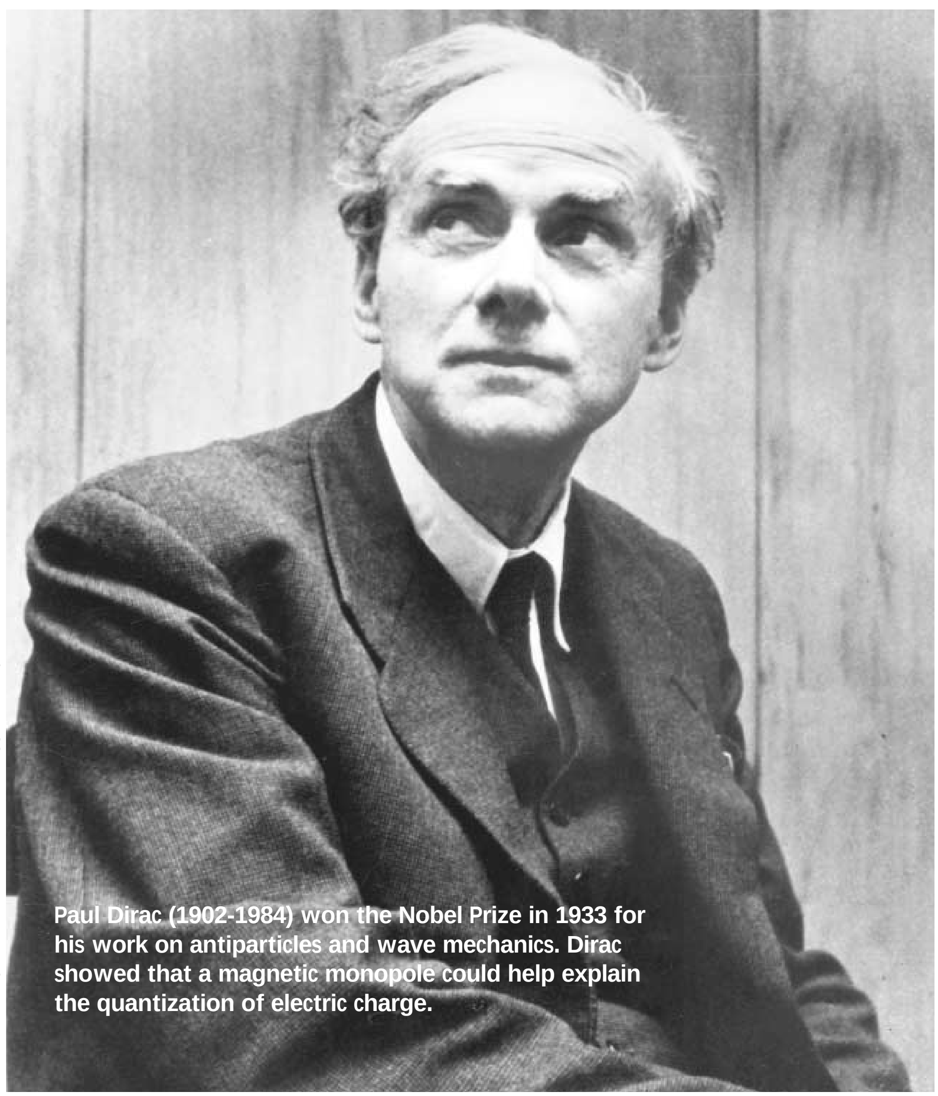
In 1931 one of the founders of quantum mechanics, Paul Dirac, showed that if a magnetic monopole existed, it could help to explain the puzzling fact that electric charge is quantized. The existence of a magnetic monopole is one of the few theoretical ways to explain the quantization of electric charge. In fact, the existence of only one magnetic monopole in the entire universe would do the trick! Naturally, physicists would like to find one.

Dirac found that the product of the electric charge (e) and a magnetic monopole charge (g) is necessarily an integer multiple of the fundamental constant in quantum mechanics, $2\hbar c$ (where $\hbar$ is Planck’s constant, which relates the energy and the frequency of a photon, and c is the speed of light). Given the values of $\hbar$, c, and e, the minimum monopole charge g must be at least a few thousand times larger than e. This implies that light would scatter off the monopoles like billiard balls struck by a cue ball—much more strongly, in fact, than off ordinary electrically charged particles. The monopole could exist with intrinsic angular momentum (spin) of 0, 1/2, or 1. For comparison, the spin of the electron is 1/2.

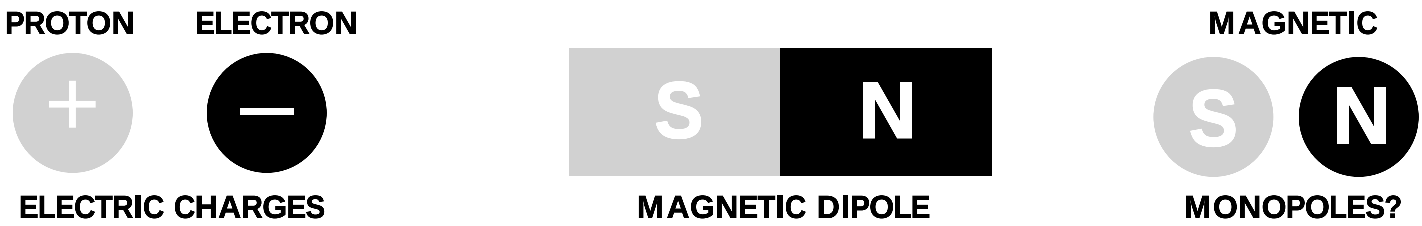
Recently, I. Ginzburg and A. Schiller completed theoretical calculations of the scattering of photons at the Fermilab Tevatron for heavy pointlike magnetic monopoles. (A pointlike particle, such as a quark or an electron, has no discernible size.) The calculation gave a large scattering probability for photons from monopoles of masses of up to about 1000 GeV/c^2, a thousand times the mass of the proton. (However, we should note that it is still unknown if pointlike monopoles are fully consistent with current theory at these masses.)

The absence of a single magnetic charge, or monopole, makes the laws of electricity and magnetism different, and this difference has bothered symmetry-loving physicists for years.

Photo by AIP NIELS BOHR LIBRARY Meggers Gallery of Nobel Laureates



Paul Dirac (1902-1984) won the Nobel Prize in 1933 for his work on antiparticles and wave mechanics. Dirac showed that a magnetic monopole could help explain the quantization of electric charge.



Theory in hand, a group of DZero collaborators performed a search for evidence of these signature scattered photons using data accumulated in the 1994-1995 Tevatron run. We did find evidence for the production of two or more photons, but the scattering we found can be fully accounted for by a sum of two backgrounds involving ordinary interactions of quarks on the one hand, or detector misidentification of parton jets or electrons as photons on the other. We found no excess of photon scattering beyond these backgrounds that would point to the presence of a monopole.

Converting our measurement into limits on monopole mass, we can say that pointlike magnetic monopoles do not exist with masses below about 600, 900, and 1600 GeV / c^2 for monopole spins of 0, 1 / 2, and 1, respectively. These are the most restrictive limits on the monopole mass to date. The sensitivity of our experiment in the low monopole mass region is limited by the requirement on the minimum photon energy and by theoretical assumptions used in the calculations. We are sensitive to a monopole mass as low as a few hundred GeV / c^2. Combined with the previous measurement by the L3 experiment at the Large Electron-Positron Collider at CERN, which explored a lower monopole mass range, our measurement excludes the existence of pointlike magnetic monopoles in a broad mass range from few dozen GeV / c^2 to our new experimental limit. ■

Information on the Dirac Monopole is available at http://d0server1.fnal.gov/www/gll/Monopole_PE.htm

“450 Physicists Fail to Find....”


The New York Times

315 Physicists Report Failure In Search for Supersymmetry

The negative result illustrates

DZero collaborators set out to look for the hypothetical creature called the Dirac Magnetic Monopole, combing through the data from Run I for signs of this theoretical particle. They didn’t find it. Does that mean their search was a failure? Most physicists would say no, for a number of reasons.

First, from their search, the experimenters learned more about what kind of creature the monopole will be if it does exist. They learned more than anyone had known before about its mass and cross section. This new information will give the next group of searchers a better idea of where to look and what to look for. It will also kick the ball back to the theorists, to incorporate the new information into their theoretical picture of the monopole.

Second, the scientific search process itself often produces new and unexpected results. Consider the famous example of the centuries-long attempt to prove Fermat’s Last Theorem, inspired by the notorious marginal note that Fermat scribbled in his father’s copy of Diophantus’s *Arithmetica* around 1630. For more than 350 years, mathematicians tried, and failed, to prove the FLT. In the process, a number of great mathematicians significantly advanced the knowledge of number theory. In fact, in quite early stages, it became apparent that the mathematics of the FLT is closely connected to other fields, such as complex number theory, and is related to fundamental properties of space. When the mathematician Andrew Wiles first announced the proof of FLT in 1993, and completed it in 1995 with the help of Richard Taylor, the proof required the entire mathematical apparatus accumulated over three and a half centuries since Fermat’s margin-scribbling: number theory, complex analysis, Galois groups, Riemann’s hypothesis, elliptic functions and more.

In the same way, the 18-year search for the top quark produced countless advances in accelerator and detector technology, data storage and analysis, networking and particle theory.

Just because you don’t find what you’re looking for doesn’t mean the search wasn’t worthwhile.

On the other hand, as Fermilab theorist Chris Quigg has pointed out, for years physicists failed to find the top quark at Fermilab—but we didn’t have a party until they found it.

Judy Jackson and Greg Landsberg

Time and Fate:

The Past and Future of Fermilab's Wetlands

Main Ring wetlands show a healthy mix of vegetation with good perching.

By Sharon Butler, Office of Public Affairs

Time is supposed to heal all wounds, but scientist are beginning to doubt whether newly created wetlands can ever compensate for the loss of those destroyed by road and building construction. Restored wetlands, they say, may never equal the real ones.

The Fermilab site was once virtually all wetlands, according to resident ecologist Rod Walton. But in the middle of the 1800s, as pioneers eyed the fertile land for grain, they dug an efficient drainage system composed of clay field tiles that ran the water off their properties to the nearby Ferry and Indian creeks.

The land dried up, enabling farmers to plant corn and wheat crops, creating acres of rich farmland. In the process, though, they lost a valuable resource. Once dismissed as fetid, insect-ridden swamps, wetlands are now recognized as vital ecosystems. They process nutrients, store floodwaters and shelter an amazing variety of plants and animals.

When Fermilab took over, the landscape reverted in part to its former self. The laboratory broke the field tiles that the farmers had laid, creating a ring of cooling water for the heat exchange system needed for the accelerator. Without maintenance, the drainage system was deteriorating anyway, helped by the construction of roads and facilities that broke the underground tiles.

As a result, Fermilab now has 225 acres of wetlands stretching across the southern and eastern sections of the site. According to Walton, the property now is closer to its natural state than it has been in years.

The best wetlands are located at the center of the Main Ring, where Fermilab once tried to create lakes in the shape of the laboratory's

logo. This time of year, the great cottonwoods turn into a heron rookery, with nesting great blue herons, great egrets and sometimes even cormorants.

The youngest wetlands lie on a 10-acre plot in the center of the Main Injector ring. They were created to compensate for the loss of 6.5 acres of forested wetlands bordering Indian Creek when the tunnel for the new accelerator was constructed. Under the Clean Water Act, Section 404, the federal government requires that "compensatory" wetlands be created, in the same floodplain and preferably resembling the original. Since 1982, according to *Science* magazine, about a million acres of fresh- and saltwater wetlands have been restored or created

But the fate of these kinds of reconstructed wetlands, and whether they can ever resemble the wetlands they were meant to replace, is now in question.

A recent study of a reconstructed marsh in the Sweetwater National Wildlife Refuge in California found that the marsh had failed to attract light-footed clapper rails, as it was supposed to. The problem was, the transplanted *Spartina* cordgrass didn't grow to the height the birds require. To make it grow, the researchers added nitrogen fertilizer to the sandy soil. But then pickleweed overtook the cordgrass.

The researchers also found that the marsh accumulated fewer nutrients and produced less organic matter than comparable natural wetlands.

Mike Becker, of the Roads and Grounds Department, expects that it will take at least a century to bring Fermilab's reconstructed wetlands in the Main Injector area to a natural state. Certain plants typical of wet prairies are doing well: rattlesnake master and some of the tall grasses like big blue stem, switchgrass and species of sedges. The Roads and Grounds crew routinely seeds the area, using seeds of native plants obtained from the state's forest preserves. But woody vegetation, as expected, is a constant problem. Box elders and cottonwoods, while native to the area and hence desirable, nevertheless claim ground before other vegetation has had a chance to root. Regular burns each year check these unwanted plants, but until there is enough plant material for fuel, the fires don't get hot enough to destroy the tougher woody species. Deer have also been a problem, damaging the young oak trees planted to recreate a forested swath of wetlands.

Eventually, this restored wetland may turn around. But it will take time, and the magic hand of chance. ■

A World Wide Web search under "wetlands" turns up many interesting sites.

Newly created wetlands in the Main Injector area are far from resembling the real thing.

An egret gracefully surveys wetlands created inside the Main Ring nearly 30 years ago.

Preserved wetlands in the Nelson Lake Road area of Batavia illustrate the ideal.

Photos by Fred Ullrich

Good ν's

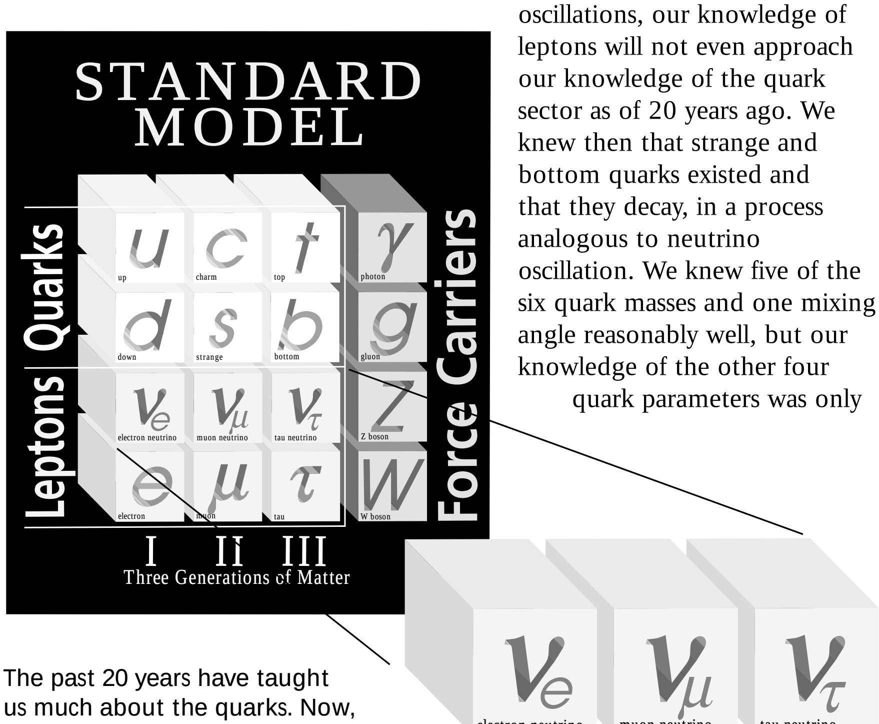
The good news:
Neutrino physics is entering a new era in experiments around the world —and at Fermilab.

By Stanley Wojcicki, Stanford University

The fundamental particles of matter, the quarks and the leptons, are cousins. Each group contains six of the 12 fundamental fermions that are the building blocks of our universe. The three flavors of neutrinos, together with their charged partners, electron, muon, and tau, are the six leptons. Many parallels exist between quarks and leptons; by looking at what we have learned about quarks, we can anticipate some of the lepton characteristics.

We can describe both the quark and lepton families by 10 fundamental parameters, or numbers. Currently, we have no idea where these numbers come from; we rely on experiments to measure them. In the future, an as-yet-unformulated theory may explain their values. These 10 numbers are the six masses of the quarks (or leptons) and four more parameters that describe how different quarks (or leptons) "mix," or transform from one to another.

If the solar and atmospheric neutrino data demonstrate the existence of neutrino oscillations, our knowledge of leptons will not even approach our knowledge of the quark sector as of 20 years ago. We knew then that strange and bottom quarks existed and that they decay, in a process analogous to neutrino oscillation. We knew five of the six quark masses and one mixing angle reasonably well, but our knowledge of the other four quark parameters was only rudimentary. Neutrino oscillation results would give us the first inkling about neutrino mass structure and the first crude equivalent information about neutrinos. The last 20 years have witnessed an intense and largely successful effort to complete the knowledge of the 10 quark parameters. Neutrino physics has a long way to go to catch up with the quarks.



The past 20 years have taught us much about the quarks. Now, the leptons are beginning to catch up.

In another telling historical analogy, our initial information about the quark sector came from cosmic rays. Particles like pions, kaons, lambdas and charged sigmas and xis were discovered in cosmic rays. But systematic study of these particles required accelerator experiments with experimental conditions controlled and optimized for specific goals. There are no knobs to turn off cosmic rays or the sun, to change the energy or nature of the beam. Clear understanding of the neutrinos will also require controlled accelerator experiments. We are now entering that phase.

There are other reasons to understand neutrinos besides their fundamental nature. Neutrinos played an important part in the evolution of the universe immediately after the Big Bang. They are still all around us, the relics of that distant past, with 300 neutrinos per cubic centimeter everywhere in the universe. We are also constantly bombarded by neutrinos from outside the Earth: from the sun, from cosmic ray interactions in the atmosphere, from distant supernovae, from every violent astrophysical event. Neutrinos, because of their extremely weak interaction, may offer us a new window on the outer edges of the universe. And finally, neutrinos may contribute to the unseen dark mass in the universe.

Changing flavors

Consider next the oscillation situation. Oscillation is a phenomenon that causes neutrinos of one flavor to change into neutrinos of another flavor as a neutrino beam propagates through space. A most general neutrino beam can be described as a superposition of the three neutrino flavors: ν_e, ν_μ, ν_τ. From studies of Z^0 decays, at SLAC and at CERN, we have reason to believe that there are only these three neutrino flavors. It is a quantum mechanical property of neutrinos that if they have mass, then one flavor can change into another flavor. An initially pure ν_μ beam can acquire a ν_e or ν_τ component.

An analogy with light might illustrate this phenomenon. A beam of light of any color can be thought of as composed of the three primary colors: red, green and blue. Imagine a beam that starts out as pure red slowly acquiring a green or bluish tinge as it shines through space.

There are two general kinds of experiments to look for neutrino oscillation: appearance and disappearance. In appearance experiments, we directly detect the presence of an initially absent neutrino flavor, at a distance from the source. In disappearance experiments, we measure the number of neutrinos of the initial flavor to see if they are fewer than expected. In the light-beam analogy, an appearance experiment would use a filter that blocks the red light (if the initial beam was red) and transmits perfectly one of the other primary colors, such as green. A disappearance experiment would use a filter that transmits only red light, and we would measure whether the light intensity diminished at some distance from the source. Appearance experiments are more sensitive and are ideal to look for small effects. But sometimes circumstances do not allow us to perform such experiments.

The Mass Squared Difference

Studying neutrino oscillations is a powerful method to learn about the 10 fundamental lepton constants. We already know three of them well: the masses of the electron, muon and tau. Oscillations can teach us about the other seven, the three neutrino masses and the four mixing parameters. Specifically, the wavelength associated with the oscillations (how far a neutrino of a given energy has to go before it changes from one flavor to another and back again) is inversely related to the difference of mass squared of two neutrino mass states. More precisely, the wavelength is proportional to $E_\nu/\Delta m^2$. Thus if the mass squared difference is small, we must go far away from a neutrino source to observe the oscillations. The amplitude of the oscillation (what fraction of one flavor converts into another flavor at the optimum location) teaches us about the four mixing parameters.

Hints

Currently, there are three classes of experimental hints for the existence of neutrino oscillations. The oldest comes from the measurement of the number of solar neutrinos striking the Earth. From the standard solar model and the measured intensity of the solar electromagnetic radiation striking the Earth we can predict the number of expected neutrino interactions in a detector. Experiments see fewer than predicted. The theoretical interpretation of these disappearance experiments is difficult. The sun emits electron neutrinos; if they oscillate into ν_μ's or ν_τ's, the number of detected ν_e's would be lower than expected. Unfortunately, the energy of solar neutrinos is so low that the generated ν_μ's or ν_τ's are below the threshold for creating muons or taus and cannot be detected. An appearance experiment is hence impossible; we cannot directly identify a new neutrino flavor.

Solar neutrino experiments are truly heroic ventures, because the interaction rate of solar neutrinos is very low. They require massive detectors and ingenious techniques. The

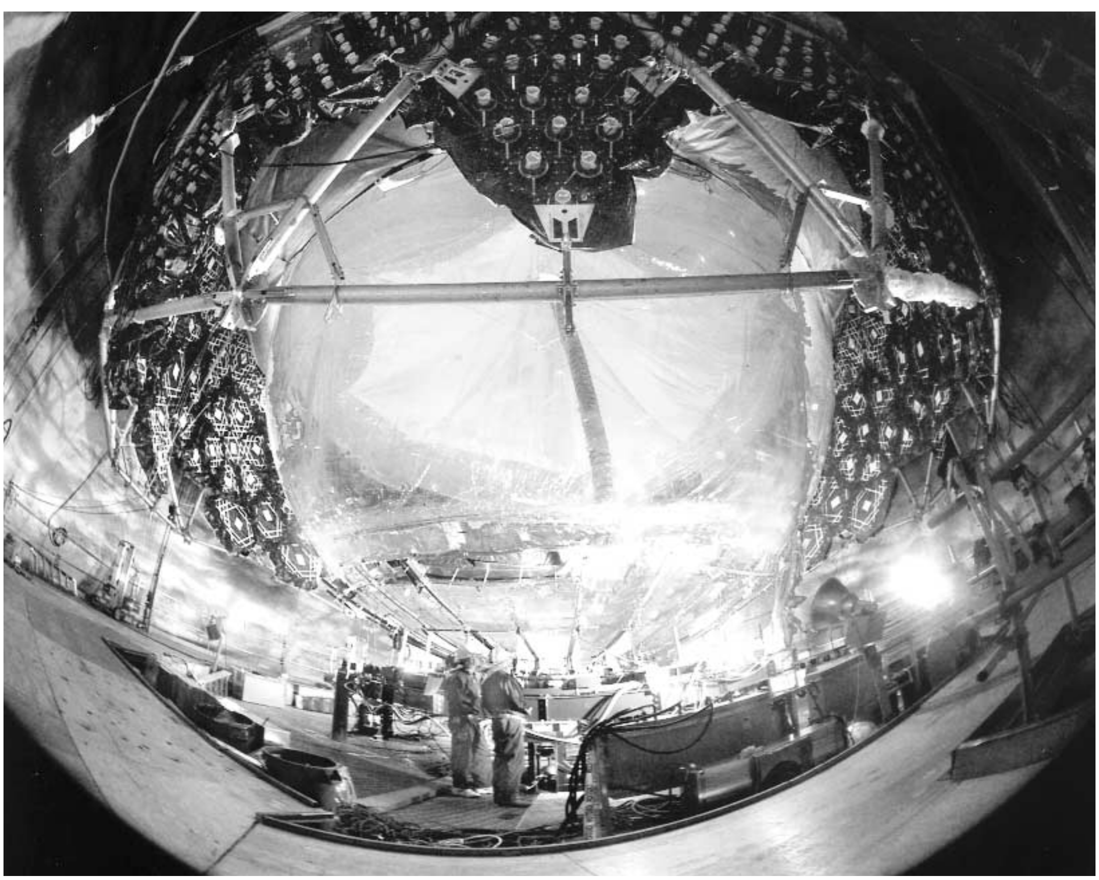


Photo courtesy of Lawrence Berkeley National Laboratory

Solar neutrino experiments, like the Sudbury Neutrino Observatory in Canada, are heroic ventures. U.S. physicists, supported by DOE, are collaborators in SNO.

Neutrinos

GALLEX experiment, for example, on the average observes one gallium->germanium nuclear transformation per day, in a tank of 30 tons of gallium, due to solar neutrino interaction. Experimenters have the challenge of identifying the one germanium atom in a batch of 2.5×10^{29} other gallium atoms. Now results from four different solar neutrino experiments all show a deficiency of observed ν_e's but cannot detect the postulated neutrinos of different flavors.

The second hint is the "atmospheric neutrino anomaly." The Earth is constantly bombarded by energetic cosmic rays, mainly protons and heavier nuclei. As they enter the atmosphere, they interact with oxygen or nitrogen nuclei, typically some 20 km above the Earth's surface. These interactions produce secondary particles, which in turn also interact or decay, and so on. The resulting cosmic ray shower contains both electron and muon neutrinos resulting from pion and muon decays. We can calculate their ratio from our knowledge of how these particles decay and from the knowledge of muon and pion lifetimes. Thus the cosmic ray neutrino "beam" striking the earth is a well-defined mixture of ν_e's and ν_μ's. In the light analogy, we can predict exactly what the color should be. The goal of the experiments is to measure that color — the ν_μ / ν_e ratio — to see if it agrees with the prediction.

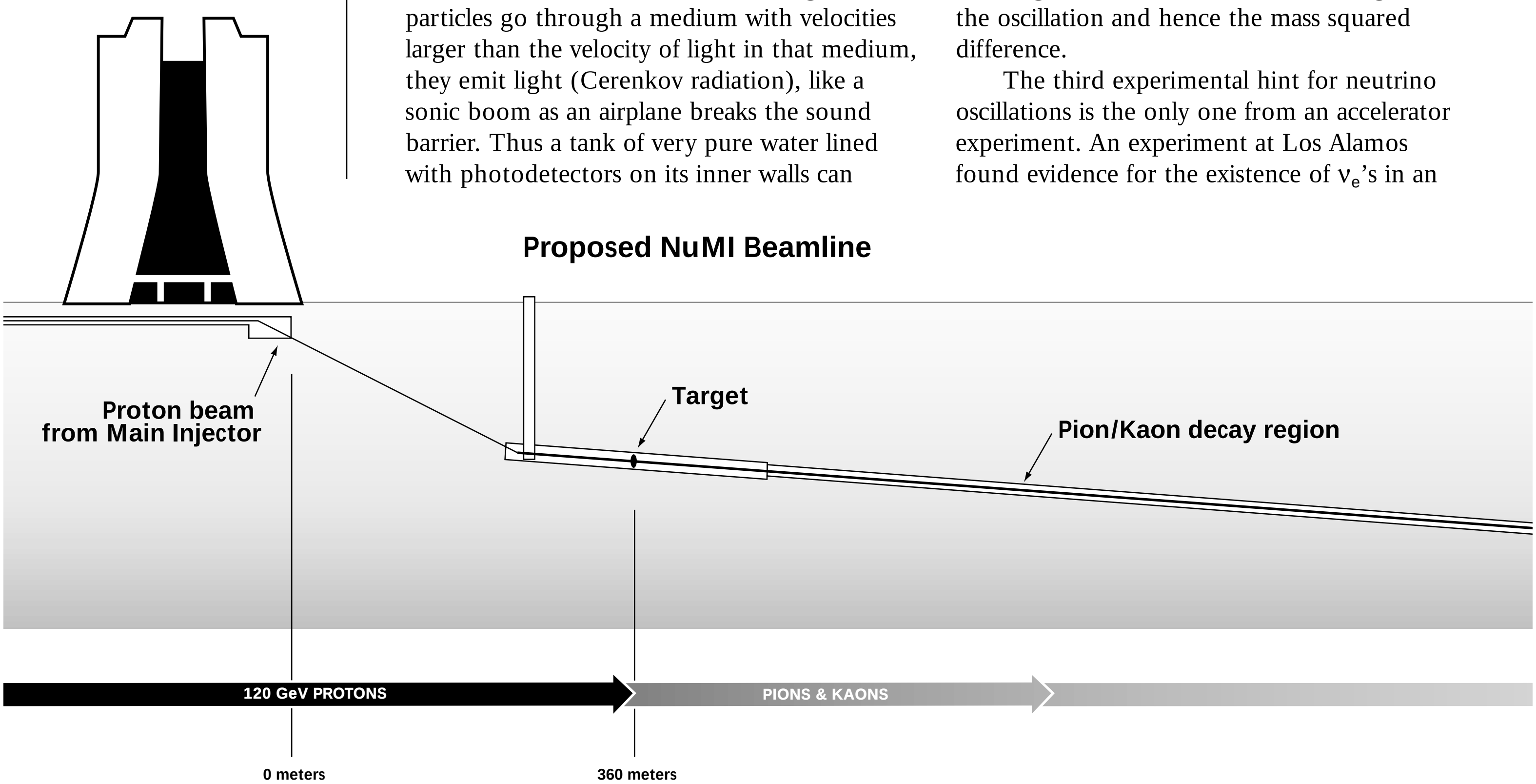
The pioneering and currently most precise data in this area come from large underground water Cerenkov counters. When charged particles go through a medium with velocities larger than the velocity of light in that medium, they emit light (Cerenkov radiation), like a sonic boom as an airplane breaks the sound barrier. Thus a tank of very pure water lined with photodetectors on its inner walls can identify charged particles resulting from neutrino interactions in the water and, from the pattern of the Cerenkov light, determine the flavor of the interacting neutrino. The most ambitious of these detectors, now taking data for two years, is the Super-Kamiokande in Japan. It is a cylindrical underground cavern, 42 m high and 39 m in diameter, filled with water, its inner surfaces lined with 11,200 20" photomultiplier tubes, deep underground to shield it from the non-neutrino cosmic ray particles.

The Super-Kamiokande results, as well as the results of other large experiments studying this problem, detect fewer ν_μ's than expected. The most likely interpretation of the data is $\nu_\mu \rightarrow \nu_\tau$ oscillations; as in the solar neutrino case, appearance experiments for this mode are not possible here. Most of the atmospheric neutrinos have too little energy to produce taus directly.

However, these experiments can teach us about the mass squared difference of oscillating neutrinos. Neutrinos arriving at different zenith angles have traveled different distances from their creation in the atmosphere to their detection points. For example, a typical path length for downward-going neutrinos will be about 20 km or less; for upward-going neutrinos, those from cosmic rays interacting on the other side of the Earth, the path length will be about 12,000 km, the Earth's diameter. Evidence suggests that the muon neutrino deficit varies with different zenith angles, allowing deductions about the wavelength of the oscillation and hence the mass squared difference.

The third experimental hint for neutrino oscillations is the only one from an accelerator experiment. An experiment at Los Alamos found evidence for the existence of ν_e's in an

The MINOS experiment will send a beam of muon neutrinos to Minnesota. Will they change flavor on the trip?

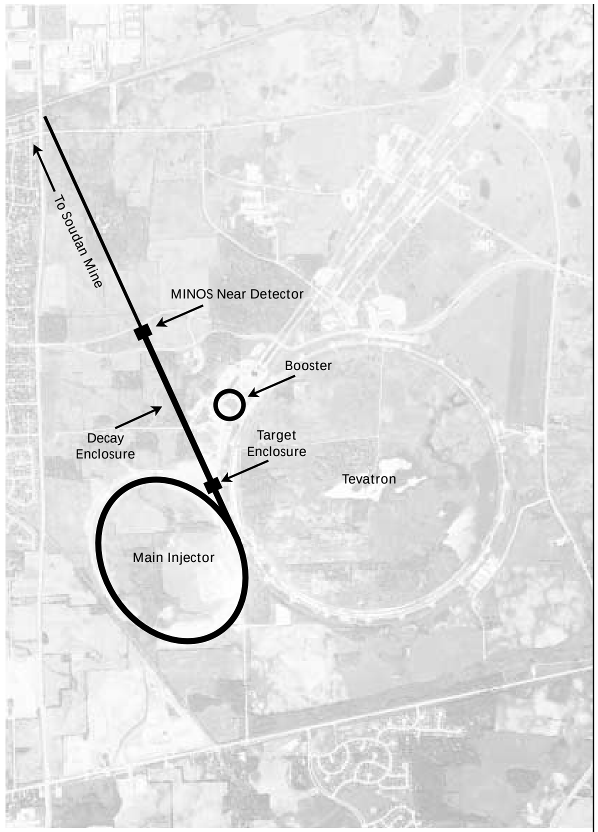


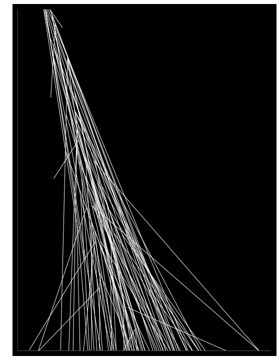
initially pure ν_μ beam. This evidence is still somewhat controversial, because other experiments that might also have been able to see this effect have reported null results. However, the Los Alamos experiment is the only one that covers a certain small region of neutrino parameter space, so the other experiments do not absolutely contradict the Los Alamos results.

The jury is out

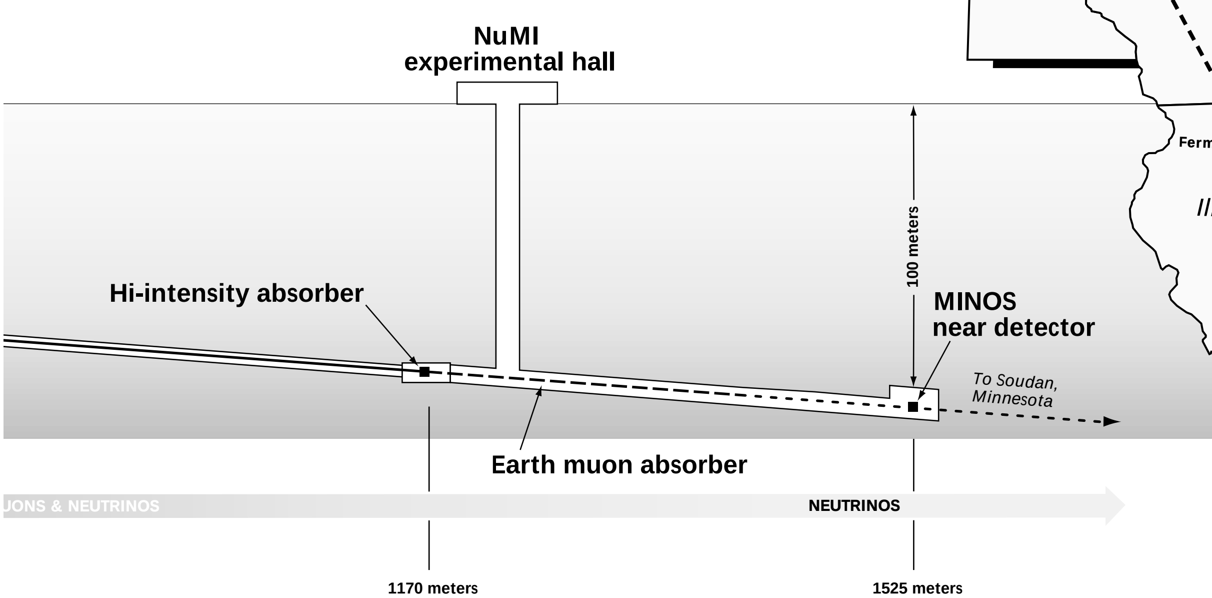
When we look at these three sets of results, a difficulty emerges. The mass squared difference indicated by the three experiments — about 10^{-5} for solar neutrinos, 10^{-3} - 10^{-2} for atmospheric neutrinos, and about 1 for Los Alamos (all in units of eV^2) are not compatible with originating from only three different masses, which could give only two independent mass squared values. At least one of the experiments is wrong, or the observed effect is not neutrino oscillations, or there is some exotic theoretical possibility. For example, a fourth, sterile neutrino could exist that does not interact with the matter in our universe at all and thus would not be seen in the Z^0 decays. In other words, the jury is still out on neutrino oscillations. New, more powerful experiments will have to resolve the controversy.

What are the most productive ways to pursue these issues? More refined solar neutrino experiments are planned, and more data will come from the existing solar and atmospheric neutrino detectors. But if history is any guide, we will need accelerator experiments to resolve the possibilities put forth by the nonaccelerator experiments. The mass scales, and hence oscillation wavelengths, suggested by the solar data are such that they cannot be probed with terrestrial accelerator experiments; the Earth is simply too small. MiniBooNE, a proposed Fermilab experiment, would use the Fermilab Booster to improve the sensitivity of the Los Alamos experiment and verify or contradict its results. And an experiment with neutrinos from the Fermilab Main Injector, to be detected in the Soudan mine in northern Minnesota some 730 km away, is being designed to study and understand the atmospheric anomaly question. This article concludes with a discussion of that effort.





Cosmic rays (above) have given inklings of new neutrino physics, but it will require accelerator experiments like the NuMI project at Fermilab to resolve the questions raised.



Neutrinos

MINOS far detector layout, showing the vertical mine shaft and the detector caverns.

International Collaboration

The MINOS (Main Injector Neutrino Oscillation Search) experiment is an international collaboration of scientists from 23 institutions, 13 of them from the U.S. and the rest from China, Great Britain, and Russia. It will use the Fermilab Main Injector to provide an unprecedented flux of neutrinos in the energy range suitable for general investigation of neutrino oscillations. Its initial goals were to explore as large a domain of neutrino parameters as possible; as the atmospheric results become more reliable and definite, the collaboration will optimize the beam and the detector for studying neutrino parameters in the region of the atmospheric neutrino anomaly. The source-to-detector distance, coupled with the GeV range of the Main Injector neutrinos, is well suited to explore the 10^{-3} to 10^{-2} eV^2 mass squared difference region.

MINOS will measure the neutrino beam and its properties at two widely separated locations, using the same beam, and detectors as similar as possible, so that uncertainties will cancel and even small differences will show up in the event characteristics at the two locations. In our light analogy, we are measuring the color of our beam both at Fermilab and at Soudan to see if the color has changed. Experimenters will perform a variety of different and redundant measurements, with different potential systematic errors, to help experimenters draw accurate conclusions from the data.

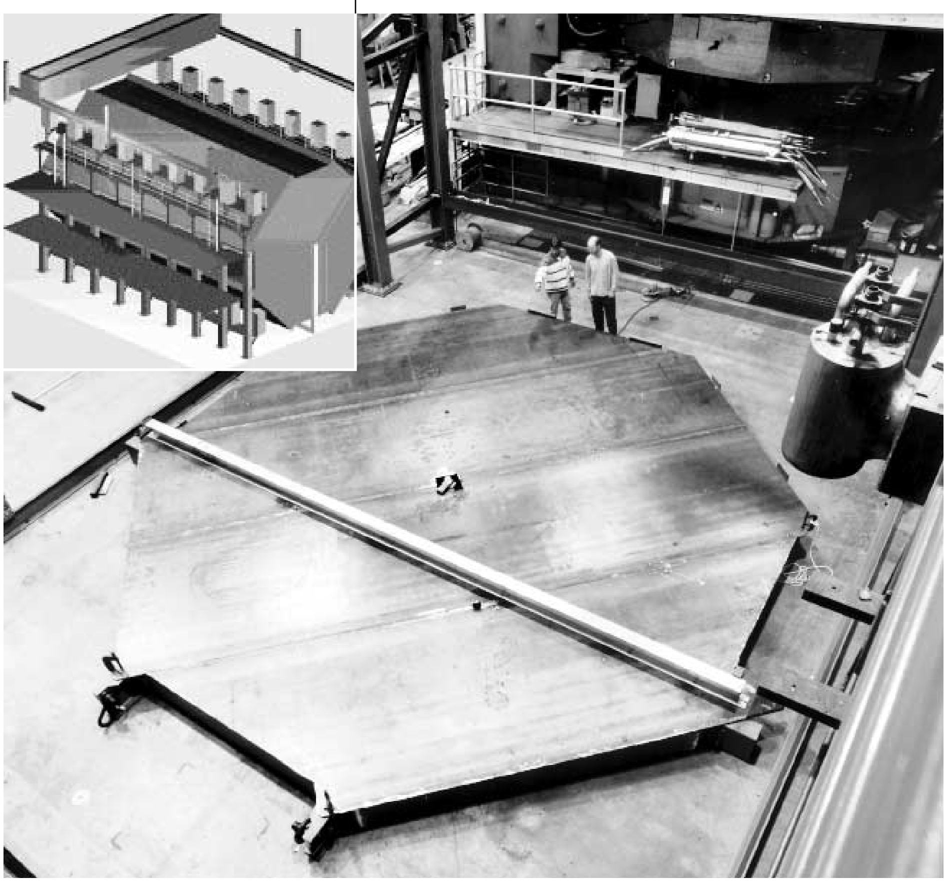


Photo by Reidar Hahn

Octagonal steel plates, like slices in a loaf of bread, will alternate with scintillator in the MINOS far detector (inset).

How MINOS works

To produce the neutrino beam, experimenters will extract the 120 GeV proton beam from the Main Injector and direct it to a carbon target downstream. The pions and kaons produced in the resulting interactions are then focused with pulsed current devices called magnetic horns. They act like lenses for a beam of light and make the resulting particle beam parallel, like a light beam from a flashlight. These secondary particles will then travel in an 800 m long evacuated decay pipe; their decays produce the neutrinos of interest, predominantly ν_μ's. The beam is aimed at the Soudan mine; because of the Earth's curvature, it must be directed downward at about a three-degree angle. The first detector is located about 350 m downstream of the end of the decay pipe. Neutrinos interact so weakly (at these energies, if 10,000 neutrinos strike the earth, only one will interact) that they can travel to Soudan through the Earth without any significant loss of intensity. But the flip side of this low interaction rate is that the detector in the Soudan cavern must be massive, to detect a significant number of interactions.

The current design of the MINOS far detector is an 8-kiloton magnetized iron spectrometer, consisting of 730 octagonal steel plates, 8 m in diameter and an inch thick. Interleaved between the steel plates are planes of scintillator bars, 4 cm wide. When a neutrino interacts in a steel plate, the resulting secondary particles will travel through a number of downstream iron and scintillator layers. The charged particles traversing the scintillator will produce visible light, which will be trapped by wavelength-shifting fibers embedded in the scintillator and transported to photodetectors at the edges of the steel plates. The different flavors of neutrinos produce characteristic patterns of light from their interactions. Muon neutrinos produce muons, which lose energy slowly and light up many consecutive scintillators. The patterns of light for electron and tau neutrinos typically extend a far shorter distance. By separating events into "short" and "long," we can distinguish on average the ν_μ's from the ν_e's and ν_τ's. MINOS works by measuring the neutrino flavor content in two places, Fermilab and Soudan, and looking for a change—proof of oscillation. The experimenters expect to see and measure about 30,000 neutrino events per year. Furthermore, unlike the case in the atmospheric neutrino beam, the energy of MINOS neutrinos will be high enough so that tau leptons can be produced if $\nu_\mu \rightarrow \nu_\tau$ oscillations occur.

The MINOS far detector will be constructed in three supermodules so that data-taking can start before the full detector is complete, using the first supermodule. This approach allows experimenters to reexamine how to proceed as more information becomes available. One possibility is to substitute for part of the MINOS main detector thin layers of lead and emulsion sheets to allow identification of taus (and hence tau neutrinos) one by one, by observing their characteristic decay kinks.

For FY1998, Congress has appropriated the first funds for the design and study of the neutrino beamline for MINOS. For the next fiscal year, FY1999, the President's budget requests $14.3 million for the start of construction. If Congress appropriates these funds, construction of the experiment can start in the fall, with the first neutrino interactions in the year 2002.

Plans around the world

The question of neutrino oscillations is important enough that other laboratories have plans (definite or tentative) to pursue this topic. In Japan, KEK is building a neutrino beamline from the accelerator to the Super-Kamiokande detector about 230 km away. The properties of that accelerator, however, cannot guarantee exploration of the full suggested region of parameter space. Nature could choose parameters that allow this experiment to see a significant effect, but the statistical power of the experiment is insufficient for the detailed studies that MINOS can perform. There is also interest in Europe to build a beam at CERN to the Gran Sasso Laboratory. The European community has not yet decided whether they should pursue that ambitious undertaking.

The subject of neutrino oscillation has been the main topic of a number of international conferences and workshops during the past few years, including the one at Fermilab in the spring of 1997. These studies focused on physics goals of these experiments with a view toward maximizing international collaboration. The MINOS collaboration continues to explore possibilities for expanded international participation in MINOS.

The study of fundamental properties of neutrinos is coming of age. Our knowledge of the leptons lags far behind our understanding of the quarks, but there are ample hints that the physics of the leptons is just as rich. In the coming years, the leptons may provide important clues essential to understanding the physical laws of the universe. ■

Information on the MINOS experiment
is available at http://www.hep.anl.gov/NDK/Hypertext/numi.html

CALENDAR

MAY 20

Wellness Works presents: Health & Fitness Day!

MAY 22

Potluck Supper at Kuhn (Village) Barn. Drinks and appetizers at 6 p.m. Dinner at 6:30 sharp. Everybody either brings a main dish serving 6-8; or a dessert for 12; or contribute $3. Soft drinks provided, pizza for the kids and wine for adults. Babysitting is available. Questions? Call Angela Jöstlein (630) 355–8279.

Fermilab International Film Society presents: *Microcosmos*. Dir: Claude Nuridsany & Marie Perennou, FRANCE (1996). Admission $4, in Ramsey Auditorium, Wilson Hall at 8 p.m. For more information (630) 840-8000 or http://www.fnal.gov/culture/film_society.html.

JUNE 27

Fermilab Art Series presents: *Tommy Makem with John Forster*, $16. Performance begins at 8 p.m., Ramsey Auditorium, Wilson Hall. For reservations or more information call (630) 840-ARTS.

ONGOING

NALWO coffee mornings, Thursdays, 10 a.m. in the Users' Center, call Selitha Raja, (630) 305–7769. In the Village Barn, international folk dancing, Thursdays, 7:30–10 p.m., call Mady, (630) 584–0825; Scottish country dancing Tuesdays, 7–9:30 p.m., call Doug, x8194.

Conversational English classes, 9–11:30 a.m., Thursdays, in the Users' Center.

http://www.fnal.gov/faw/events.html

Chez Léon

MENU

Lunch served from
11:30 a.m. to 1 p.m.
$8/person
Dinner served at 7 p.m.
$20/person

For reservations, call x4512
Cakes for Special Occasions
Dietary Restrictions
Contact Tita, x3524

Lunch
Wednesday
May 20

Closed

Dinner
Thursday
May 21

Closed

Lunch
Wednesday
May 27

Booked

Dinner
Thursday
May 28

Antipasto
Grilled Stuffed Veal Chops
Oven-Roasted Vegetables
with Herbs
Lemon Cake
with Blackberry Sauce

CLASSIFIEDS

FOR SALE

■ Chrome BMX bike GT Mach One, 1410 chromalloy frame, 20" alum. wheels. Includes U-lock, exc. cond., for kids 9-14 years old; $189 obo. Call x8492.

■ Baby Cockatiels, hand-raised, very tame. Beautiful birds! $50-$60. Call x3230.

■ West Suburban Caged Bird Club's annual Bird Fair, Sat. May 30, DuPage County Fairgrounds, 10am-4pm, admission $2. For more information, contact Mary J., x3721.

■ House - Batavia, 1.5 story, 2 bdrms, 1 bath. Well maintained updated charming farmhouse, large lot w / many trees, newer furnace, water heater, central air, 3 season sun porch & 15X16 deck. $134,900. Call Lynn Amore (630) 232-1581 or (630) 377-1855 for an appointment.

■ House - 3 bdrms, 2 baths, screened porch, 2 fireplaces, large country kitchen, 2 car garage, cathedral ceiling in living room, cedar siding & shake roof, St. Charles school district. On 2.5 acres in mature dense oak forest, private pond, cul-de-sac. $260,000. (847) 741–7539.

RENT

■ NE Geneva location, lower 3-BR, spacious living / dining area opening to yard with patio, garage & laundry. Near bike trail & river. June 1. $950. (630) 584–1204.

■ Looking for a room to rent from mid May till mid August as a summer intern in Fermilab. If you have a room near Fermilab for sublease for this period, please contact Echo Qiu. (815) 753–1247 (9am-11pm) or e-mail: e2159@ceet.niu.edu

FRENCH LESSONS

■ Je suis française. J'enseigne le français. Peggy-Henriette Ploquin. (630) 682-9048.

LAB NOTES

Attention Fermilab Artists and Artisans:

Now is the time to show us your artistic side! The biannual Employee's Arts & Crafts Show will take place on the 2nd Floor Gallery of Wilson Hall, July 1— July 31. All Fermilab employees, visiting scientists, retired employees, contractors and their immediate families are encouraged to enter the exhibit. The last exhibit featured, among other things, a wonderful mixture of photographs, prints, paintings, sculptures, weavings, quilts, and jewelry. Application forms for participating are available at the Wilson Hall Atrium desk. Application deadline is June 22, and exhibit drop-off is Monday, June 29.

Summer Recreation

For information on Fermi Coed Summer Volleyball, Basketball, Softball, and Soccer Leagues or Children's Swimming Lessons and Pool information, consult the Recreation web page:

http: / / fnalpubs.fnal.gov / benedept / recreation / recreation.html

MILESTONES

BORN

■ Riley Garret to Bob (BD / OPS) and Tammie Carrier on April 23rd, at Central DuPage hospital.

■ Jillian Marie, to Thom (TD / Machine Shop) and Sheila Nurczyk on April 28 at St. Joseph's Hospital in Joliet.

AWARDED

■ Paula Lambertz, a Sr. Drafter with BD / CD / Cryogenics Systems group, received an award and a $100 gift certificate for an image she created for the ICCON (I-DEAS Customer Cooperative Network) Image Contest. Lambertz placed 5th among 26 entries at the 1998 ICCON Users Conference in Dallas, Texas. Her computer-generated solid model and image of a connecting box for the Anti-Proton Debuncher cryogenic upgrade is viewable on the web at http: / / www-adcryo.fnal.gov / .

■ Muzzafer Atac received a patent on his photo-avalanche imaging detector. This detector can have revolutionary impact on medical x-ray imaging, nuclear research, airport security, and many other areas.

CONNECTED

■ The Fermilab Amateur Radio Club, station WB9IKJ, with station IY5PIS in Coltano, Italy, on Saturday, April 25, at 11:50 AM CDT, marking International Marconi Day. The station in Coltano was set up by Luciano Ristori, a CDF collaborator from INFN Pisa, on the site where Guglielmo Marconi operated one of the first intercontinental wireless stations. For a 24-hour period on International Marconi Day, 40 amateur radio special event stations operated around the world, some located on the original sites of Marconi's international radiotelegraph stations. For more information about the club check the web site, http: / / www.fnal.gov / orgs / radioclub / farca.htm.

Photo by Rob Atkinson

Fermilab Amateur Radio Club members Rob Atkinson, Lester Wahl and Kermit Carlson after exchanging greetings with the Marconi Day event station at Coltano, Italy.

SI NON VIS IMPRIMI NOLI PATI FIERI
FERMINEWS MCMLXXVII

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Due to the Memorial Day holiday, *FermiNews* will be published on a revised schedule. The next issue will appear on Friday, June 5, 1998. The deadline for this issue is Tuesday, May 26, 1998

Please send your article submissions, classified advertisements and ideas to the Public Affairs Office, MS 206, or e-mail ferminews@fnal.gov.

FermiNews welcomes letters from readers. Please include your name and daytime phone number.

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