The Village Crier

fermi national accelerator laboratory

Operated by Universities Research Association Inc.
Under Contract with the Energy Research & Development Administration

Vol. 9 No. 3 January 20, 1977

THE ELUSIVE, WONDER-FUL NEUTRINO

Of all the objects in the universe, neutrinos are the smallest, the weakest, the most abundant, and the most elusive. Silently, invisibly, they stream down from space, flowing through your body by the trillions every second, passing onwards through the walls around you, through the bedrock of the continents, through the core of the Earth, and out the other side, as if nothing were there. They come from all directions: even at midnight, a ghostly "neutrino-shine" from the sun wells up beneath your feet just as brightly as it rains down at noon.

...University of Wisconsin physicists William Fry (L) and Juergen von Krogh examine an enlargement of film exposed at the Fermilab 15-ft. Bubble Chamber during a run studying neutrino interactions...

Neutrinos are so unconcerned with our ordinary world that only the most sophisticated experiments can detect them. In fact, physicists have a tough time just describing them. They tell us that a neutrino is a type of subatomic particle, a tiny grain of matter less than a billionth of an inch across. But they also tell us that the neutrino's subatomic world is a stark and eerie place, where ordinary words like color, shape and texture have no meaning.

Instead, physicists define neutrinos by what the particles do (or don't do): a neutrino is an object that carries energy, but no mass and no electric charge. It moves at the speed of light and can never stand still. It spins like a top, and can never slow down. It responds to just one kind of force, the "weak" force, which no one understands.

But as bizarre and elusive as neutrinos may be, they are not magic, and they do exist. They are emitted naturally by certain radioactive elements, and by thermonuclear fusion in the core of the sun and the stars. They are also emitted from nuclear reactors as a byproduct of uranium fission. And they can be created artificially in giant particle accelerators such as the one at Fermilab.

But knowing where a particle comes from -- and even being able to create it at will -- is not the same thing as understanding it. Why does the neutrino exist?, physicists are asking. What role does it play in its subatomic world, which it shares with dozens of other types of particles? And why does the neutrino do what it does? What is this thing called the weak force?

In the next few years we may begin to see some answers to these questions. For the first time since the neutrino was discovered, 40 years ago, giant machines like the Fermilab accelerator are producing enough neutrinos, at high enough energy, for physicists to study them in detail. But even at Fermilab the experiments are difficult, painstaking, and often inconclusive. And in the early days it was worse: it took 25 years after the neutrino was "discovered" before anybody was able to find one.

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WONDER-FUL NEUTRINO (Continued)

In the beginning the neutrino was a figment of the imagination, a wild guess at explaining a baffling phenomenon: radioactivity. In 1896 the French physicist Henri Becquerel had found that certain chemical elements, such as uranium, constantly radiated high-speed particles in all directions. These elements were thus "radioactive". Research during the next several decades had convinced physicists that these particles were coming from the central core of the atom, a tiny, dense kernel of matter they called the atomic nucleus.

Their research had also convinced them that radioactivity was complicated; in fact they had identified three different types. The type we are concerned with involved objects called neutrons (NEW-trons. Don't confuse them with neutrinos; neutrons are the heavy, electrically neutral particles that make up about half the mass of the atomic nucleus. The other half is made up of protons, which have positive electric charge.) The physicists had discovered that neutrons in certain radioactive elements would slowly tear themselves apart, for no apparent reason. One fragment, a proton, would stay within the nucleus. Another fragment, a much lighter particle called an electron, would fly off as radiation.

Clearly, some unknown force was at work. But that wasn't all. Careful measurements of the neutrons' rupture had shown that energy was disappearing. Now if there's anything dear to a physicist's heart, it is the law that says "Energy does not disappear, it is conserved." Rather than give up this law, the German physicist Wolfgang Pauli suggested in 1931 that the missing energy was being carried off by an invisible particle. Scientists are rarely inclined to believe in things they can't see. But Enrico Fermi (the Italian physicist for whom Fermilab is named) took Pauli's idea seriously, and in 1934 christened the new object with the delightful name "neutrino", which means "little neutral one" in Italian.

Fermi had realized that Pauli's new particle must be deeply involved in the mysterious forces within the neutron. None of the familiar, everyday forces -- gravity, electricity or magnetism -- seemed capable of tearing the neutron apart. Neither did the less familiar "strong", or "nuclear" force, which binds protons and neutrons together in the nucleus.

Fermi called the unknown quantity the "weak" force, because it worked so slowly, and he wrote down a mathematical equation that described in an approximate way how neutrons, neutrinos, electrons and other particles behave when the force is acting. With some changes, this equation is a useful guide for neutrino physicists today.

Thus, the neutrino was "discovered" in the 1930's. But nobody had ever really seen one, and until somebody did, not even Fermi could be sure that neutrinos were real. The problem was, and is, the weak force itself. It's so very weak, and so very slow, that a neutrino tends to fly right through ordinary matter before the force has a chance to do anything to stop it. And if the weak force doesn't catch it then nothing will, because a neutrino ignores everything else.

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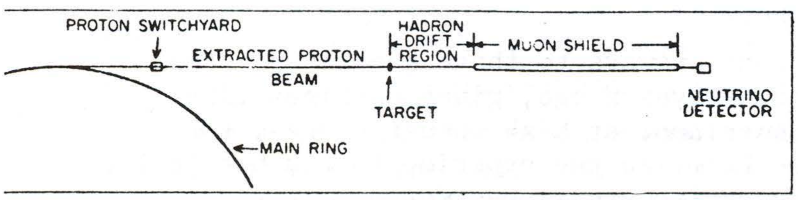
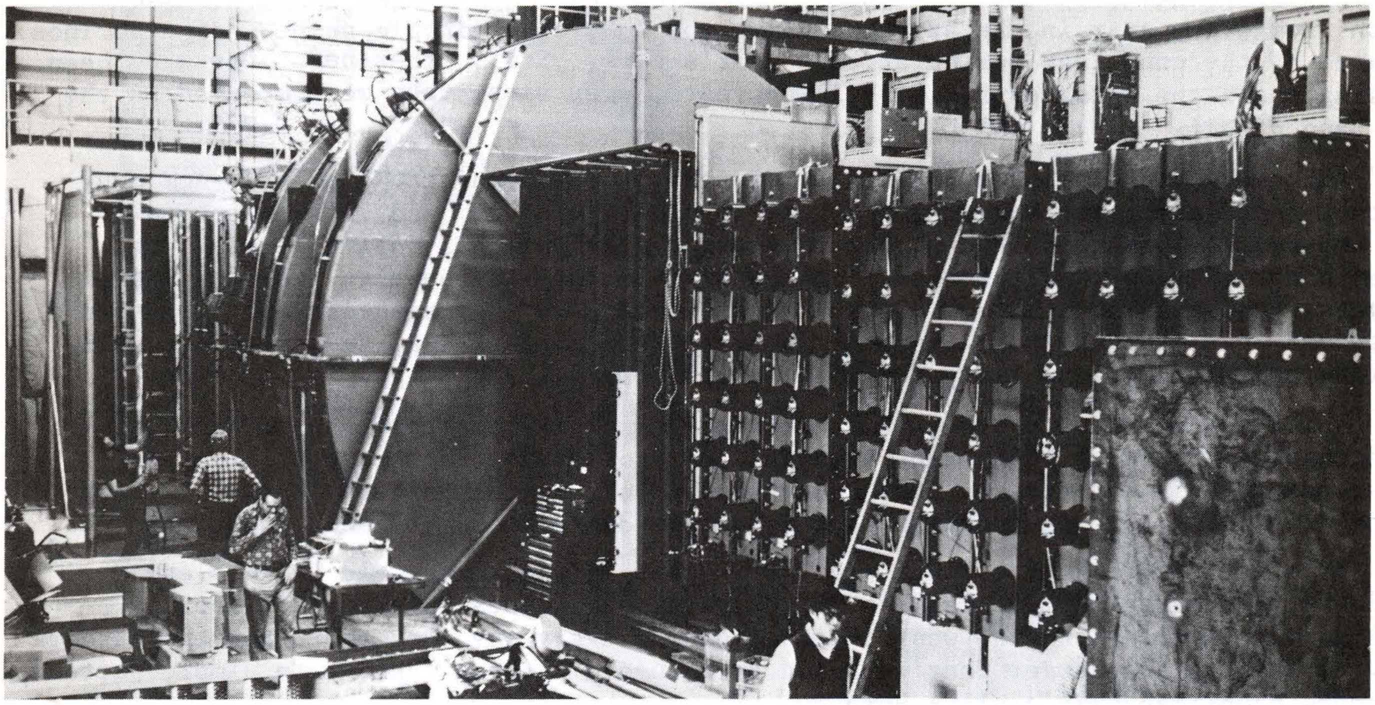


...A schematic of the Neutrino Line at Fermilab where neutrinos are generated indirectly from protons. Protons from the accelerator strike a metal target, generating pions and kaons which they decay mainly into muons, neutrinos and anti-neutrinos. Muons and any remaining hadrons are filtered out as they pass through the mound of earth (muon shield); At the end of this process only neutrinos and anti-neutrinos remain. Detectors such as the 15-ft. Bubble Chamber and the equipment of other neutrino experiments are placed at this point to record neutrino activity in its purest form...



...The experimental apparatus of Experiment #310 in Lab C of the Fermilab Neutrino Area. Neutrino beam enters from the right. Interactions are detected in the large scintillator tanks at right and in the circular magnets at left.

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So try to catch one. Try to put it in a box. How? The thing will sail right out of the box, right through the Earth itself, and never even notice.

Or...almost never. Suppose you take a big enough mass -- say a huge tank of water -- put it where a lot of neutrinos will pass through, and wait. If you wait long enough, there's a tiny chance that the weak forces in one or two of the water molecules might be able to catch a neutrino before it quite gets away.

Two very patient physicists did just this experiment in 1956. Fredrick Reines and Clyde L. Cowan placed their tank outside a nuclear reactor at the Atomic Energy Commission's Savannah River Plant, near Augusta, Georgia. Using Fermi's equation they had estimated that the uranium fission inside the reactor should be emitting about a quadrillion neutrinos per second. And they were right: once or twice an hour a water molecule would in fact catch a neutrino -- and the jolt of energy would blow it apart. The submicroscopic fragments of that collision would then fly off through the water, triggering automatic detectors and giving Reines and Cowan proof -- indirect, but undeniable -- that neutrinos were real.

But there's always a question about this kind of abstract science: "so what?" In this case, so what if neutrinos are real? We can't see them, or hear them, or touch them, and they ignore us so thoroughly that it doesn't seem to make much difference to us if they exist or not. Well, it's true that neutrinos aren't particularly relevant to our everyday affairs. But take a larger view. For example how might neutrinos affect the ultimate fate of the universe?

Right now, the universe is expanding: astronomers believe that all the stars and galaxies are fragments of a single vast explosion -- the "Big Bang" -- which created the universe some 20 billion years ago. Many astronomers also believe that the universe will keep on expanding forever, until all the galaxies have receeded to infinity and the night sky is empty.

But what about neutrinos? The universe is awash with neutrinos. They gush

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forth from every star in the sky, including the sun, unimaginable numbers of neutrinos created by thermonuclear fusion at each star's core. Still other neutrinos have been sailing among the galaxies for 20 billion years, ever since they were created in the Big Bang itself.

All these neutrinos are invisible, of course, so no one knows exactly how many of them there are. But invisible or not, they have energy. And Prof. Einstein has assured us that this causes them to exert a gravitational pull on everything else in the universe. If there are enough of them, say astronomers, then billions of years from now their combined gravitation could slow the expanding universe to a halt, and pull it back in on itself -- stars, planets, galaxies, and neutrinos, all collapsing together in a fiery reversal of the original Big Bang.

This is pretty heady stuff, but neutrinos also play a vital role in slightly less cosmic matters -- the birth, life and death of stars, for example. In fact, they seem to be a key for our full understanding of how the universe works -- which makes it all the more frustrating that we really don't know very much about them.

It's not for lack of trying. In the 20 years since Reines and Cowan's experiment, and especially in the last five years, physicists have been collecting data about neutrinos and the weak interactions in every way they can. But the harder they've looked, the harder they've tried to reduce all these facts to a simple pattern, the more complicated it's all become.

In 1962, for example, a second type of neutrino was discovered, identical to the first in every way but one. That one way shows up only on those rare occasions that the neutrinos interact with another particle. Ever since Fermi wrote down his equation, physicists have known that the (original) neutrino interacts by grabbing off some negative electric charge with the weak force -- and turning itself into a negatively charged electron.

In the same situation, the second type of neutrino grabs some negative charge and turns itself into a muon (MEW-on), a particle that's exactly like the electron except that it's heavier.

Now what kind of pattern is this? Nobody understands the first neutrino/electron pair, yet here is this second set that's just the same, but different! What's the second set for? Is nature just being redundant? Or are there even more sets we haven't discovered yet, with more neutrinos and even heavier versions of the electron and muon?

And what's this business of "grabbing charge", and turning into something else? When a cue ball hits an 8-ball it just bounces off; it doesn't change into a watermelon. Don't either of the neutrinos ever just bounce off other particles?

On the other hand, maybe nature is trying to tell us something here. There is clearly a connection between the weak force and electric charge. Does this mean that electricity and the weak force are really just two faces of the same force? (For mathematical reasons, such a force would also have to include a third face: magnetism.) There are also connections between the weak force and the strong forces within the nucleus. Could this mean that all four -- electricity, magnetism, strong force and weak force are parts of a single, underlying unity?

The physicists who designed Fermilab in the 1960's had these questions very much in mind. Their basic idea was much the same as that of the Savannah River experiment: fire an intense beam of high-energy neutrinos through a massive target and watch for the rare neutrino interactions. If the physicists were lucky enough, and clever enough, they might be able to learn something from the collision fragments about the weak force, the neutrino, and -- as a bonus -- about how the target particles themselves are put together.

Crude? Yes. One physicist says the process is like trying to learn how a wristwatch works by hanging it from a tree, shooting BB's at it, and watching how they bounce off. But crude as the process is, it works. Physicists have been firing protons

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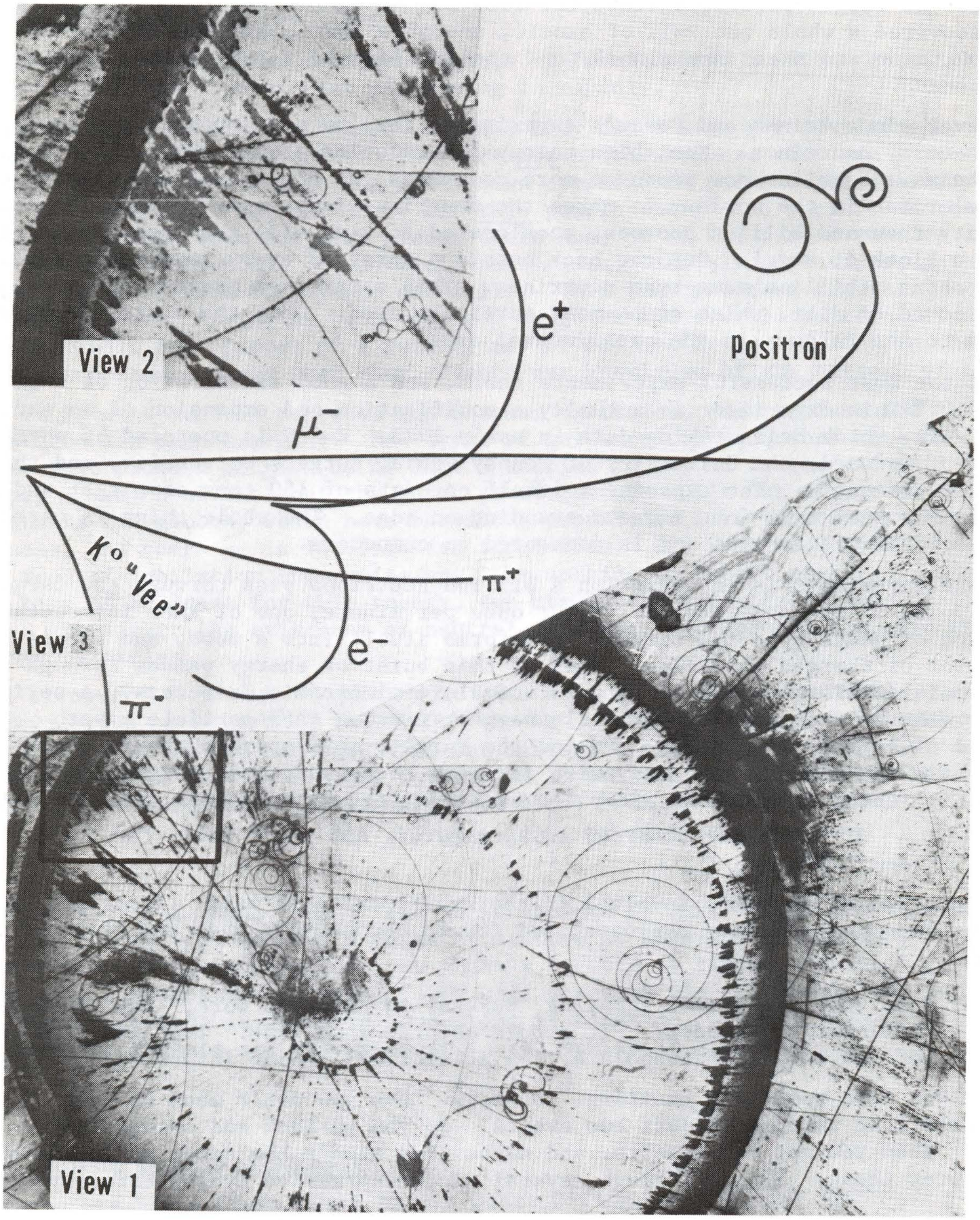

How do scientists learn about the elusive neutrino? This is a composite photograph showing one of the events found in the Fermilab 15-ft. Bubble Chamber during a run in which the Chamber was filled with neon and hydrogen, exposed to a beam of neutrinos, and recorded by Experiment #28A. A neutrino interaction is indicated at the vertex of the event.

View 1 above is a photograph of the entire event. View 2 is a close-up of the vertex of the event shown in the rectangle outlined in View 1. View 3 is a schematic explanation of the event.

These events are interpreted by the experimenters as involving the production of a new particle in the neutrino interaction, a particle which then decays into a neutral K meson, a positron and an invisible neutrino. The original neutrino turns into a muon.

and electrons at target particles since the 1930's. Among the collision fragments they've discovered a whole zoo full of exotic, unstable particles (in addition to the electron, muon and their neutrinos), and they've learned a lot about how these particles behave.

And ever since Reines and Cowan's experiment, they've also been trying to develop a useful beam of neutrinos. Most high energy laboratories around the world now have neutrino beams. Fermilab now produces more neutrinos, at higher energies, than any other accelerator in the world. It makes the neutrinos indirectly. Every 10 seconds about twenty thousand billion protons, accelerated to virtually the speed of light, slam into a block of steel. Out the back bursts a spray of every imaginable particle -- including about a billion muon-type neutrinos. This spray then passes into a one-half mile mound of dirt, which stops most particles dead. Only the neutrinos make it through to the targets in the experimental area.

One of the most successful experiments there, and a good illustration of them all, is E-310.* This experiment is actually a modification and expansion of an earlier experiment, E1A, which began taking data in early 1973. E-310 is operated by physicists from Fermilab, Harvard, the University of Pennsylvania, Rutgers University, and the University of Wisconsin. The experiment itself consists of 150 tons of target and a line of four circular 24-foot magnets standing on edge. The whole thing is wired with sophisticated electronics and is connected to computers.

When the experiment is in operation a billion neutrinos pass through the target with every pulse of the accelerator. About once per minute, one of them interacts with a proton or neutron in the target, transforms itself into a muon, and blasts loose a shower of charged particles. Some of this burst of energy passes through the liquid scintillator causing it to glow and alert electronic detectors. A series of "spark chambers" then automatically discharges, tracing each particle's path with a trail of bright pink sparks. Behind the target, more spark chambers track the muon, while the magnets bend and twist its path to measure its energy. In the end, a few billionths of a second after its creation, the muon is lost into the walls of the building. The data are recorded in a computer, and E-310 waits for the next burst of neutrinos.

Meanwhile, the physicists involved in the experiment also wait. Their job will come later, when they evaluate the data, and try to reconstruct what has happened in each event.

"Nobody runs down the street shouting 'Eureka' in neutrino work," says University of Wisconsin physicist Don Reeder. "It's more painful than that. The data come in very slowly, and you have to extrapolate from statistically poor information."

"Maybe you find something exciting," he says, "but you don't want to base something startling and new on just two events. So you go back and change the experiment. Then you get new results, and maybe they aren't the same, so you have to re-interpret those. You go through several manic-depressive cycles before you're sure."

However arduous the physicists' job may be, they've managed to compile over 10,000 neutrino events since E-310 began operation as E1A. (Less than 100 total had ever been seen before Fermilab.) This mass of data has led to two major discoveries.

First, neutrinos can indeed bounce off other particles without grabbing away their charge. (Or, in physicist's jargon, "neutral currents" exist.) This discovery was announced at Fermilab in the summer of 1973.

Second, new types of particles exist with the property known as charm. In recent years, charmed particles have been found in many different experiments. But E1A's evidence, while indirect (in about 100 cases the magnets found two neutrinos

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*Spokesmen for E-310 described this experiment and experimental results in an article in *Scientific American Magazine*, January, 1976, p.44, "The Search for New Families of Elementary Particles."

instead of just one), was the first.

Meanwhile, in other neutrino experiments at Fermilab and at other institutions around the world, new discoveries are coming in rapidly.

What do these discoveries mean? Perhaps they don't seem very exciting by themselves. But that's the point: they are not by themselves, they are part of a pattern. Scientific research has often been compared to putting together a puzzle. That's a good analogy. But remember, for this puzzle there's no picture on the box-top. No one is even sure how many pieces there are, or if the pieces they've already got are assembled correctly. So particle physicists, like all scientists, gather their new pieces of data slowly and carefully. Then they put them together in different combinations, trying as best they can to guess the overall pattern. Individual facts, like individual pieces of a puzzle, may or may not be interesting in themselves; their real importance comes when they advance our knowledge of the pattern of nature.

So it is with neutral currents and charmed particles. In the last few years a new pattern has been emerging. New types of mathematical equations have been developed that promise to give us at last a unified theory of forces and particles. The theory -- which claims that the known particles are built out of unseen objects called quarks and gluons, which have marvelous properties like isospin, hypercharge, strangeness, and charm -- is far from its final form. But even so, physicists today share a mood of jubilation and excitement like nothing in recent memory, because two crucial bits of evidence for this theory, two absolutely essential pieces of the puzzle -- are first, the existence of neutral currents, and second, the existence of charmed particles.

The discovery of these two phenomena has fired in particle physicists the feeling that a revolution in scientific understanding may be very close. The new science of particles is still dim and hazy, but the mists are clearing very rapidly. And when the scientific history of this revolution is written, it will surely show that Fermilab and the Fermilab neutrinos played a vital role.

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NOTE: Professor A.K. Mann, one of the collaborators on Experiment #310 mentioned in the article above, will deliver a Sigma Xi lecture at Fermilab on Tuesday, January 25, 1976, at 8 p.m. in the Auditorium. Dr. Mann's lecture is titled, "Exploring the Universe with a Neutrino Microscope." He will describe the universal implications of the research which his group is conducting at Fermilab. There is no charge for the lecture and tickets are not necessary. The public is invited.

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BOULDING LECTURE TICKETS AVAILABLE

Tickets are being distributed by the Guest Office, CL 1-W, for the Kenneth Boulding lecture at Fermilab on Friday, February 4, at 8:30 p.m.

Prof. Boulding's lecture is titled, "Pandora's Box: The Dilemmas of Energy Policy." He speaks from the unique vantage point of being both an authoritative economist and a social scientist. Because of his broad background, his views on major policy issues are highly regarded.

Prof. Boulding is on the staff of the University of Colorado. He has also been a visiting professor at universities all over the world.

The Fermilab Bicentennial Lecture Series is supported in part by the Illinois Humanities Council and the National Endowment for the Humanities. There is no charge for the lectures, but tickets are necessary.

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URA SCHOLARSHIPS OPEN

Children of Fermilab employees who will begin a four-year college program in the fall of 1977 can apply for a scholarship for up to $1,200 per year for four years, sponsored by Universities Research Association, Inc., the parent body of Fermilab.

Students selected for the URA scholarships are selected on the basis of their Scholastic Aptitude Test (SAT) scores -- both verbal and math. A copy of the student's official notification of scores must accompany the scholarship application. The score range of scholarship recipients varies from year to year. Winners are chosen by the staff of URA's Washington office.

Applications for the URA scholarship are now available from Vivian Butler or Ruth Thorson, Personnel Office, CL-6E. They must be returned by March 1, 1977.

EXHIBIT OF MODERN JAPANESE PRINTS

In addition to the exhibit of Ukiyo-e prints by Hiroshige, a new exhibit of modern Japanese prints has been hung in the west end of the 2nd floor lounge in the Central Laboratory. These prints form a unique collection in that they represent the work of some of the best-known modern Japanese print makers. Some show a strong western influence, while in others the combination of east and west is most effective. Both shows will be up through the first week of February.

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H E L P !!!!!

Eric Jarzab, Food Services Manager, is once again requesting that all tableware from the cafeteria be returned. "Fermilab employes responded well to the last request several months ago," said Eric, "and I feel confident that they will respond well this time. We are fast reaching a critical shortage of trays, plates and silverware. We will assist anyone with a large amount to return." Call extension 3646 for assistance.

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The Fermilab Co-operative Playgroup, an activity of NALWO, has openings for the current session in the older group (ages 3-5). These sessions are currently held on Tuesday and Thursday mornings and Friday afternoon for 3 hours. For further information, please contact Nan Bunce 879-2182 or Dottie Mantsch 231-4786.

Possibilities also exist for establishing new groups of all ages from 18 months to 5 years.

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CLASSIFIED ADS

FOR SALE - Scope (triggered) - Exc. cond. - $200. Call Phil, Ext. 3690.

SCUBA COURSE - George Williams College starting Feb. 3. Contact Strauss, Ext. 3671 for details.

FOR SALE - Women's skiis, ski boots, size 6, bindings, poles, never used. 879-2478.

FOR SALE - 1975 Opel Manta 1900 coupe, rallye gold. NADA retail price, $2800. Sell or take over payments plus $200. Stick shift, low mileage. Ernie, Ext. 3210.

FOR SALE - 1975 LUV pickup, 16,000 miles, no dents, no rust, ziebarted, insulated cap. Dick Ahlman, Ext. 3355 or 897-0928.

FOR SALE - Set of snowtires on wheels, size C78 x 14, $40. C. Plezbert, Ext. 3205.

FOR SALE - 1974 Olds Cutlass, 350 V-8, ps/pb/air/radio/vinyl roof/35,000 miles, mint condition, $3,500. Ext. 3190, Leo Pooley.

FOR SALE - 1976 Pinto wagon, many options included, exc. cond., asking $3,200. Call 377-1965.