DOWNLOAD PDF NEUTRINO ASTROPHYSICS

Chapter 1 : Neutrino Physics | Neutrino Physics at Fermilab

Neutrino astronomy is the branch of astronomy that observes astronomical objects with neutrino detectors in special observatories. Neutrinos are created as a result of certain types of radioactive decay, or nuclear reactions such as those that take place in the Sun, in nuclear reactors, or when cosmic rays hit atoms.

The neutron can be detected by its capture on an appropriate nucleus, releasing a gamma ray. The coincidence of both events â€" positron annihilation and neutron capture â€" gives a unique signature of an antineutrino interaction. The experiment was performed in a specially prepared chamber at a depth of 3 km in the ERPM mine near Boksburg. A plaque in the main building commemorates the discovery. The experiments also implemented a primitive neutrino astronomy and looked at issues of neutrino physics and weak interactions [24]. Neutrino flavor[edit] The antineutrino discovered by Cowan and Reines is the antiparticle of the electron neutrino. In , Leon M. Lederman , Melvin Schwartz and Jack Steinberger showed that more than one type of neutrino exists by first detecting interactions of the muon neutrino already hypothesised with the name neutretto , [25] which earned them the Nobel Prize in Physics. When the third type of lepton , the tau , was discovered in at the Stanford Linear Accelerator Center , it too was expected to have an associated neutrino the tau neutrino. First evidence for this third neutrino type came from the observation of missing energy and momentum in tau decays analogous to the beta decay leading to the discovery of the electron neutrino. The first detection of tau neutrino interactions was announced in by the DONUT collaboration at Fermilab ; its existence had already been inferred by both theoretical consistency and experimental data from the Large Electronâ€"Positron Collider. Solar neutrino problem In the s, the now-famous Homestake experiment made the first measurement of the flux of electron neutrinos arriving from the core of the Sun and found a value that was between one third and one half the number predicted by the Standard Solar Model. This discrepancy, which became known as the solar neutrino problem , remained unresolved for some thirty years, while possible problems with both the experiment and the solar model were investigated, but none could be found. Eventually it was realized that both were correct, but rather it was the neutrinos themselves that were far more interesting than expected. It was postulated that the three neutrinos had nonzero and slightly but indistinguishably different masses, and could therefore oscillate into undetectable flavors on their flight to the Earth. This hypothesis was investigated by a new series of experiments, thereby opening a new major field of research that still continues. Eventual confirmation of the phenomenon of neutrino oscillation led to two Nobel prizes, to Raymond Davis, Jr. Neutrino oscillation A practical method for investigating neutrino oscillations was first suggested by Bruno Pontecorvo in using an analogy with kaon oscillations ; over the subsequent 10 years he developed the mathematical formalism and the modern formulation of vacuum oscillations. In Stanislav Mikheyev and Alexei Smirnov expanding on work by Lincoln Wolfenstein noted that flavor oscillations can be modified when neutrinos propagate through matter. This so-called Mikheyevâ€"Smirnovâ€"Wolfenstein effect MSW effect is important to understand because many neutrinos emitted by fusion in the Sun pass through the dense matter in the solar core where essentially all solar fusion takes place on their way to detectors on Earth. Starting in , experiments began to show that solar and atmospheric neutrinos change flavors see Super-Kamiokande and Sudbury Neutrino Observatory. This resolved the solar neutrino problem: Although individual experiments, such as the set of solar neutrino experiments, are consistent with non-oscillatory mechanisms of neutrino flavor conversion, taken altogether, neutrino experiments imply the existence of neutrino oscillations. The KamLAND experiment has indeed identified oscillations as the neutrino flavor conversion mechanism involved in the solar electron neutrinos. Similarly MINOS confirms the oscillation of atmospheric neutrinos and gives a better determination of the mass squared splitting. McDonald of Canada received the Nobel Prize for Physics for their landmark finding, theoretical and experimental, that neutrinos can change flavors. Cosmic neutrinos[edit] Raymond Davis, Jr. These efforts marked the beginning of neutrino astronomy. Also being leptons, neutrinos have been observed to interact through only the weak force , although it is assumed that they also interact gravitationally. Flavor, mass, and their mixing[edit] Weak interactions create neutrinos in one of three leptonic flavors:

Chapter 2 : Neutrino Physics | University of Washington

The experiments also implemented a primitive neutrino astronomy and looked at issues of neutrino physics and weak interactions. Neutrino flavor [edit] The antineutrino discovered by Cowan and Reines is the antiparticle of the electron neutrino.

Tzanov The high-energy physics group focuses on two areas of research, neutrino physics and the highest energy cosmic rays. Our research is addressing very exciting puzzles that nature has to offer. Despite the fact that neutrinos are some of the most abundant particles in the Universe they are difficult to detect. We require very large and sophisticated detectors to observe and study them. Our detectors are located in underground laboratories to shield against cosmic rays and related particles which could create undesirable signals inside the detector. They are also generated in nuclear reactors and we use particle accelerators to create intense beams of neutrinos. The highest energy cosmic rays are particles arriving on Earth with energies many orders of magnitude larger than what could be accomplished with man-made particle accelerators. The composition of these highest energy cosmic particles and their origins are an active area of our studies. We are involved in a number of experimental projects to collect data on neutrinos and the highest energy cosmic rays in order to solve the mysteries associated with these particles. Neutrino Physics Neutrinos are a source of surprises and many of their fundamental properties and characteristics remain to be explored. It is a challenge to study neutrinos because they rarely interact with matter and hence are difficult to detect. Experiments have provided evidence for the existence of three types of neutrinos. This mixing of neutrino types is very different from what has been observed in the quark sector where mixing between quark types is comparatively small. We are working on experiments to accurately measure the parameters that describe neutrino mixing. One of these experiments is the neutrino long baseline experiment T2K Tokai to Kamiokande which measures several of the neutrino oscillation parameters. We are actively involved in the T2K experiment which is located in Japan and directs a muon-neutrino beam through a near detector complex and towards the km distant Super-Kamiokande water Cherenkov detector. A comparison of measurements at the near detector, which samples the un-oscillated neutrino beam, with observations made by the far detector allows to study neutrino oscillation characteristics. At T2K we also study the properties of anti-neutrinos and we are particularly interested to learn whether they behave differently from neutrinos. Our recent results give a first hint that neutrinos and anti-neutrinos may indeed behave differently. We are merely at the beginning of what promises to be an exciting exploration of uncharted physics terrain. DUNE is an international collaboration amongst many scientists at numerous institutions. Together we are optimizing the layout, performing research and development of components and we are preparing construction of the experiment. Previously we studied neutrinos from the Sun and also searched for additional types of neutrinos: Neutrinos are produced in the fusion reactions that fuel stars. Hence, our Sun is a powerful source of neutrinos. As the neutrinos travel from Sun to Earth they change their type. Earlier experiments had only been sensitive to one type of neutrino and therefore they were only able to detect a fraction of the expected solar neutrinos. The SNO experiment which consisted of 1 kton of heavy water, which was viewed by nearly 10, light sensitive photo-sensors was able to distinguish between different types of neutrinos and was able to observe all three types. We observed the solar neutrino flux of all three types of neutrinos to agree very well with predictions. The experiment studied neutrinos coming from a man-made neutrino beam but was not able to unequivocally refute or confirm the existence of sterile neutrinos. Follow-up experiments are in preparation. The Highest Energy Cosmic Rays The highest energy cosmic rays are particles that have been observed on Earth with energies in excess of eV. One of the largest mysteries associated with the highest energy cosmic rays is their origin: Where do they come from? What astrophysical objects and mechanisms can accelerate particles to energies of eV and above? What exactly are these particles? The Pierre Auger Observatory is a project which is currently taking data to answer the above questions. The observatory is located in Mendoza Province, Argentina. It consists of an array of regularly spaced water Cherenkov detectors spread out over an area the size of Rhode Island and a series of fluorescence telescopes which monitor the atmosphere above the detector array. The strengths of both of these detection techniques complement each other and allow collection of complementary information on the highest energy cosmic rays.

Chapter 3 : Neutrino Physics - CRC Press Book

Neutrino Astronomy/Astrophysics Measuring the flux is the goal but it is useful to make a rough estimate of what the diffuse and point source flux might be. The figure below show such an estimate.

MINOS Site Index Neutrino Physics Every second, hundreds of billions of these neutrinos pass through each square inch of our bodies, coming from above during the day and from below at night, when the sun is shining on the other side of the earth! They have no charge and have no mass And do not interact at all. The earth is just a silly ball To them, through which they simply pass, Like dustmaids down a drafty hall Or photons through a sheet of glass. They snub the most exquisite gas, Ignore the most substantial wall, Cold shoulder steel and sounding brass, Insult the stallion in his stall, And, scorning barriers of class, Infiltrate you and me. Like tall And painless guillotines they fall Down through our heads into the grass. At night, they enter at Nepal And pierce the lover and his lass From underneath the bed - you call It wonderful; I call it crass. Originally in The New Yorker. The Story of the Neutrino In the continuing quest to understand the fundamental structure of matter and the nature of the universe, physicists have designed a project to explore the ghostly subatomic particles called neutrinos. The MINOS Main Injector Neutrino Oscillation Search experiment will try to solve a mystery that has intrigued scientists for many years by answering the question whether neutrinos have mass. According to the current model that gives us our best explanation of the behavior of fundamental particles and forces, neutrinos are massless. But if experiments show that neutrinos do have mass, however tiny, that discovery will profoundly change our view of the universe. He invented the neutrino in response to a dilemma: The sum of energy and momentum after the decay event did not add up to the initial total energy and momentum. Pauli was confronted with a mystery. To solve it, he proposed a new particle, the neutrino. If he factored the neutrino into the picture, it would carry the missing energy and momentum. A careful accounting of the energy and momentum before and after the decay showed that if a particle was indeed slipping away undetected, it must be uncharged, or neutral, and must have practically no mass and almost no interactions with matter. In other words, Pauli had invented a particle that would be almost impossible to observe. He himself thought that experimenters might never find proof of the existence of neutrinos. Pauli was almost right - but not quite. As often happens, developing technology led indirectly to a breakthrough in basic science. Calculations showed that newly developed nuclear reactors should produce huge numbers of neutrinos - a large "neutrino flux" - as a byproduct. Inspired by the challenge of finding a particle that was considered impossible to detect, Frederick Reines and his colleague Clyde Cowan set about trying to detect neutrinos from the nuclear reactor at Savannah River, South Carolina. Today, neutrinos are an integral part of the theory of the fundamental particles and forces of nature. The first neutrino experiments at a particle accelerator demonstrated that there are at least two "flavors" of neutrinos: The tau neutrino would complete the third pair of the triad: Many experiments have verified that the tau neutrino does exist, but so far no one has observed it directly. The Mystery of the Vanishing Neutrinos Neutrinos permeate the world around us. Every cubic centimeter of space contains more than a hundred neutrinos. Yet we know very little of these elusive particles beyond their angular momentum and the fact that their mass, if any, must be very small. We do not know if they have magnetic moment, or what the lifetime of neutrinos may be. In contrast, we know the properties of other leptons, such as the electron, very precisely. Physicist Mel Schwartz and the Brookhaven detector that showed experimenters in that the muon has its own neutrino, different from the electron neutrino. About 30 years ago, as improving technology made possible better and better detection of neutrinos, physicists came upon another neutrino mystery. Deep in the Homestake mine in South Dakota, they discovered the first of several "smoking guns" in the mystery of the vanishing neutrinos. Calculations of solar nuclear activity had predicted how many electron neutrinos should arrive on earth from the sun. But when experimenters in the Homestake Mine counted the electron neutrinos that actually showed up, they found only about half the number predicted. More recently, other experiments also observed a deficit of muon neutrinos from the interactions of cosmic rays with atoms in the upper atmosphere - a second smoking gun. Where were the missing neutrinos? Finally came the great puzzle of the "dark matter" that makes up 90 percent of the universe, but which we cannot see. Could dark matter be yet a third smoking gun in the neutrino mystery? All of these clues seem to hint at a possible solution to the mystery. If experiments can show that neutrinos do indeed have mass, then some of them could change from one type into another, accounting for the missing neutrinos arriving on earth: And if neutrinos turn out to have mass, they may account for some fraction of the dark matter of the universe. In , a group of scientists working at Los Alamos National Laboratory reported results that provide another hint of the existence of neutrino oscillations. In a study of neutrino interactions in an essentially pure beam of muon neutrinos, they observed events whose most likely explanation would be interactions of the electron neutrino. If this interpretation is correct, a possible explanation would be the oscillation of muon neutrinos into electron neutrinos. Three years later, the Super-Kamiokande experiment in Japan turned in significant new results. The international group of scientists confirmed previous results showing that the number of atmospheric neutrinos is far less than the laws of physics would predict. But the scientists also found an asymmetry between the number of neutrinos that entered their detector from overhead and the number that entered from underneath, having traveled an extra 13, kilometers through the earth. These results highly suggest that neutrinos do indeed oscillate. Solving the mystery of the vanishing energy in gave us the neutrino. As we solve the new mysteries surrounding these elusive particles, we will learn more about the fundamental nature of matter and the universe. Basics for the Public.

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Chapter 4 : Neutrino Astrophysics

The high-energy physics group focuses on two areas of research, neutrino physics and the highest energy cosmic rays. Our research is addressing very exciting puzzles that nature has to offer.

Page ii Share Cite Suggested Citation: The National Academies Press. The project that is the subject of this report was approved by the Governing Board of the National Research Council, whose members are drawn from the councils of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine. The members of the committee responsible for the report were chosen for their special competences and with regard for appropriate balance. This report has been reviewed by a group other than the authors according to procedures approved by a Report Review Committee consisting of members of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine. The National Academy of Sciences is a private, nonprofit, self-perpetuating society of distinguished scholars engaged in scientific and engineering research, dedicated to the furtherance of science and technology and to their use for the general welfare. Upon the authority of the charter granted to it by Congress in , the Academy has a mandate that requires it to advise the federal government on scientific and technical matters. Bruce Alberts is president of the National Academy of Sciences. The National Academy of Engineering was established in , under the charter of the National Academy of Sciences, as a parallel organization of outstanding engineers. It is autonomous in its administration and in the selection of its members, sharing with the National Academy of Sciences the responsibility for advising the federal government. The National Academy of Engineering also sponsors engineering programs aimed at meeting national needs, encourages education and research, and recognizes the superior achievements of engineers. White is president of the National Academy of Engineering. The Institute of Medicine was established in by the National Academy of Sciences to secure the services of eminent members of appropriate professions in the examination of policy matters pertaining to the health of the public. The Institute acts under the responsibility given to the National Academy of Sciences by its congressional charter to be an advisor to the federal government and, upon its own initiative, to identify issues of medical care, research, and education. Shine is president of the Institute of Medicine. Functioning in accordance with general policies determined by the Academy, the Council has become the principal operating agency of both the National Academy of Sciences and the National Academy of Engineering in providing services to the government, the public, and the scientific and engineering communities. The Council is administered jointly by both Academies and the Institute of Medicine. Bruce Alberts and Dr. White are chairman and vice chairman, respectively, of the National Research Council. This project was supported by the Department of Energy under Grant No. Additional copies of this report are available from: Board on Physics and Astronomy HA

Chapter 5 : Neutrino Physics

The neutrino physics groups at Unversity of Washington have been involved in many of the exciting results regarding neutrinos in the last 15 years. In the SuperK collaboration discovered neutrino oscillations, where neutrinos change flavor as they propagate.

History[edit] Neutrinos were first recorded in by Clyde Cowan and Frederick Reines in an experiment employing a nearby nuclear reactor as a neutrino source. Bahcall successfully detected the first solar neutrinos in the Homestake experiment. The project began in and although it was eventually cancelled in , it acted as a precursor to many of the following telescopes in the following decades. The detector is located at a depth of 1. In , it was the first to deploy three strings to reconstruct the muon trajectories as well as the first to record atmospheric neutrinos underwater. The depth proved to be insufficient to be able to reconstruct the trajectory due to the scattering of light on air bubbles. The AMANDA array was subsequently upgraded until January when it consisted of 19 strings with a total of optical modules at a depth range between m and m. It consists of 12 strings, each carrying 25 "storeys" equipped with three optical modules, an electronic container, and calibration devices down to a maximum depth of m. A suitable site at a depth of 3. The second phase as well as plans to deploy the full-size prototype tower will be pursued in the KM3NeT framework. The proof of concept will be implemented in the KM3Net framework. It currently consists of digital optical modules installed on 86 strings at depths of to m in the Antarctic ice. KM3NeT is planned to cover several km3. This is the first time that a neutrino detector has been used to locate an object in space and that a source of cosmic rays has been identified. Neutrino detector Since neutrinos interact only very rarely with matter, the enormous flux of solar neutrinos racing through the Earth is sufficient to produce only 1 interaction for target atoms, and each interaction produces only a few photons or one transmuted atom. The observation of neutrino interactions requires a large detector mass, along with a sensitive amplification system. Given the very weak signal, sources of background noise must be reduced as much as possible. The detectors must be shielded by a large shield mass, and so are constructed deep underground, or underwater. They record upward going muons in charged current muon neutrino interactions. Upward because no other known particle can traverse the entire Earth. This background also provides a standard calibration source. Sources of radioactive isotopes must also be controlled as they produce energetic particles when they decay. The detectors consist of an array of photomultiplier tubes PMTs housed in transparent pressure spheres which are suspended in a large volume of water or ice. The PMTs record the arrival time and amplitude of the Cherenkov light emitted by muons or particle cascades. The trajectory can then usually be reconstructed by triangulation if at least three "strings" are used to detect the events. Applications[edit] When astronomical bodies, such as the Sun , are studied using light, only the surface of the object can be directly observed. Any light produced in the core of a star will interact with gas particles in the outer layers of the star, taking hundreds of thousands of years to make it to the surface, making it impossible to observe the core directly. Since neutrinos are also created in the cores of stars as a result of stellar fusion , the core can be observed using neutrino astronomy. There are currently goals to detect neutrinos from other sources, such as Active Galactic Nuclei AGN , as well as Gamma-ray bursts and Starburst galaxies. Neutrino astronomy may also indirectly detect dark matter.

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Chapter 6 : IceCube Upgrade for precision neutrino physics and astrophysics kicks off

Theoretical work in astrophysics and in particle physics in increasing rapidly. The subject of solar neutrinos has many seemingly independent aspects, both in its theor This authoritative text provides a lively, thought-provoking and informative summary of neutrino astrophysics.

The basic properties of the electron-neutrino â€”no electric charge and little massâ€”were predicted in by the Austrian physicist Wolfgang Pauli to explain the apparent loss of energy in the process of radioactive beta decay. An electron-neutrino is emitted along with a positron in positive beta decay, while an electron-antineutrino is emitted with an electron in negative beta decay. Despite such predictions, neutrinos were not detected experimentally for 20 years, owing to the weakness of their interactions with matter. Because they are not electrically charged, neutrinos do not experience the electromagnetic force and thus do not cause ionization of matter. Furthermore, they react with matter only through the very weak interaction of the weak force. Neutrinos are therefore the most penetrating of subatomic particles, capable of passing through an enormous number of atoms without causing any reaction. Finally, in a team of American physicists led by Frederick Reines reported the discovery of the electron-antineutrino. In their experiments antineutrinos emitted in a nuclear reactor were allowed to react with protons to produce neutrons and positrons. The unique and rare energy signatures of the fates of these latter by-products provided the evidence for the existence of the electron-antineutrino. The discovery of the second type of charged lepton , the muon , became the starting point for the eventual identification of a second type of neutrino, the muon-neutrino. Identification of the muon-neutrino as distinct from the electron-neutrino was accomplished in on the basis of the results of a particle-accelerator experiment. High-energy muon-neutrinos were produced by decay of pi-mesons and were directed to a detector so that their reactions with matter could be studied. Although they are as unreactive as the other neutrinos, muon-neutrinos were found to produce muons but never electrons on the rare occasions when they reacted with protons or neutrons. In the mids particle physicists discovered yet another variety of charged lepton, the tau. A tau-neutrino and tau-antineutrino are associated with this third charged lepton as well. In physicists at the Fermi National Accelerator Laboratory reported the first experimental evidence for the existence of the tau-neutrino. All types of neutrino have masses much smaller than those of their charged partners. For example, experiments show that the mass of the electron-neutrino must be less than 0. Then in the Sudbury Neutrino Observatory SNO , in Ontario, Canada, found the first direct evidence that electron-neutrinos emitted by nuclear reactions in the core of the Sun change type as they travel through the Sun. Learn More in these related Britannica articles:

Chapter 7 : Neutrino Astrophysics by John N. Bahcall

Astronomy - Astrophysics - Space Science/High Energy Astrophysics - Neutrino Physics This area of research exploration, encompasses about one-third of the faculty members of the department.

Chapter 8 : Neutrino - Wikipedia

Abstract: In the present lectures the following topics are considered: general properties of neutrinos, neutrino mass phenomenology (Dirac and Majorana masses), neutrino masses in the simplest extensions of the standard model (including the seesaw mechanism), neutrino oscillations in vacuum, neutrino oscillations in matter (the MSW effect) in 2- and 3-flavour schemes, implications of CP, T and.

Chapter 9 : [] Neutrino Physics

NOTICE: The project that is the subject of this report was approved by the Governing Board of the National Research Council, whose members are drawn from the councils of the National Academy of Sciences, the National Academy of

Engineering, and the Institute of Medicine. The members of the committee.