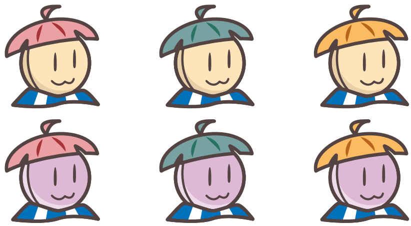
NEUTRINO!

Exploration of Particle Physics and Cosmology with Neutrinos

Unification and Development of the Neutrino Science Frontier

What are the neutrinos?



Neutrino means
“Neutral = no electric charge” and “-ino = small (in Italian).”
They are one of the elementary particles.

“Neutral” and “ino” → “neutrino”!

Then, what are elementary particles?

Elementary particles are **the smallest elements that make up matter**! Well that doesn't explain much about them so here we go!

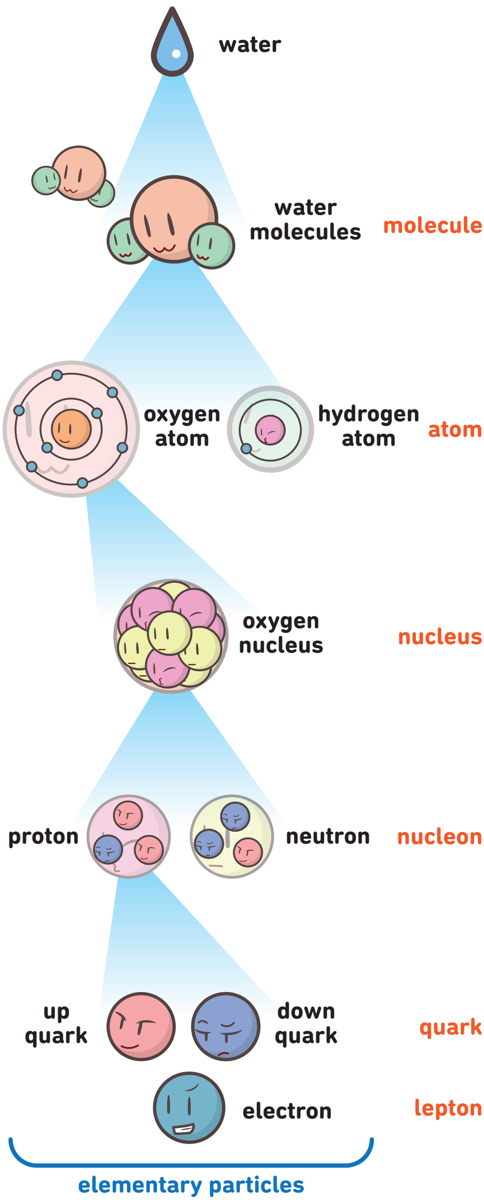
For example, water is a bunch of water molecules, and each water molecule is made with two hydrogen atoms and one oxygen atom.

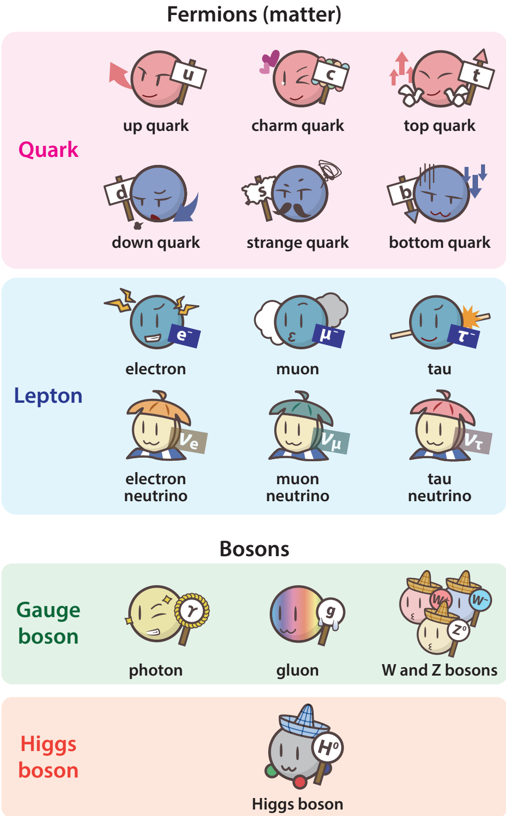
Inside of an atom, **electrons** are orbiting around a **nucleus** sitting in the middle.

Further inside of a nucleus, there are **protons** and **neutrons**. These two types of particles are called **nucleons** (A hydrogen nucleus is made up of one proton only).

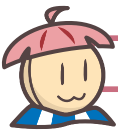
Then, what about the inside of nucleons? Nucleons are made with three **quarks**.

There are no smaller particles than these quarks and electrons, the **elementary particles**. At this moment, we think we cannot further break down these particles.





The elementary particles include; six types of **quarks**, six types of **leptons** (including electrons), **gauge bosons** which carry forces between particles, and **Higgs bosons** which give a mass (weight) to other particles. Furthermore, all these particles have partners called anti-particles which have opposite electric charges. Quarks bind to other quarks strongly and they make up nucleons. On the other hand, leptons bind weakly and they stay alone. Water, flowers, the universe, and even ourselves, everything around us is made by these elementary particles. Neutrinos are a type of lepton.



Discovery of Neutrinos!

In 1930, a scientist named Dr **Pauli** found a problem while he was studying neutrons. Pauli thought the problem could be solved by the existence of very light particles without electric charges. However, such a small light particle can pass through any object and Pauli thought it would be impossible to find such a ghost particle. Three years later, Dr **Fermi**, who had studied these ghost particles, named these particles **neutrinos**.

In 1956, two more scientists, Dr Reines and Dr Cowan, finally succeeded the first saw neutrinos with an experiment that used a nuclear reactor. Dr. Reines won the Nobel Prize in Physics for this achievement.

What are the properties of neutrinos?

These are so many!

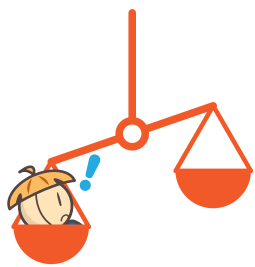
There are so many neutrinos around us. Lots of neutrinos are produced by the Sun during the production of heat, by the supernova explosion at the end of the life of a star, and by nuclear reactors. About 100 trillion neutrinos are passing through our bodies every second, but we cannot feel them and they can't hurt us.

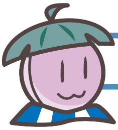
Invisible ghost particle.

Neutrinos are neutral particles without either a positive or negative electric charge. This means neutrinos do not attract, repel, or affect any materials. Furthermore, they are extremely small and they can pass through any atoms. Neutrinos can pass through our bodies and the Earth. Scientists have a hard time to see them because these particles are like ghosts - they even pass through detectors!

They have mass!

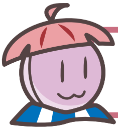
For a long time, people believed neutrinos do not have mass. However, the Super-Kamiokande experiment led by Dr Kajita and the SNO experiment led by Dr McDonald overturned this myth. These experiments confirm neutrinos have mass by measuring neutrino oscillations, the phenomena through which 1 type of neutrino can change to another type. The laws of elementary particles, the "Standard Model", say that neutrinos are massless, but they are not! This discovery was a breakthrough in particle physics!





What can we learn?

Neutrinos are the second most abundant particles in the universe only after light. By studying their properties scientists think it may be possible **to understand the mystery of the beginning of the universe and the origin of matter**. Although neutrinos are extremely important to understand the universe, **neutrinos have many mysterious features**.



What are the projects of "Unification and development of the Neutrino Science Frontier" and "Exploration of Particle Physics and Cosmology with Neutrinos"?

Scientists from different fields of science are collaborating to study neutrinos, including the world's first study using neutrinos to understand the "**difference between matter and antimatter**", and observation of neutrinos from the universe to **uncover the mystery of the origin of the universe**, such as "**why do we exist?**"

We perform a high-precision measurement of neutrino oscillations using a neutrino beam produced by the world-class accelerator J-PARC at Tokai-village, Ibaraki prefecture and the Super-Kamiokande detector located at Hida-city, Gifu prefecture, Japan. (T2K experiment)

Neutrino oscillations can be studied by measuring neutrinos from nuclear reactors (Double-Chooz experiment). Furthermore, we aim to establish the technology to monitor nuclear reactors by applying this technology.

We observe neutrinos from the atmosphere. On top of measurements by the Super-Kamiokande experiment, we are developing the next generation neutrino detector "Hyper-Kamiokande".

We observe neutrinos from the universe. These neutrinos carry information from the deep-universe nobody has ever seen (IceCube Neutrino Observatory).

We are developing state-of-the-art particle detectors. They improve the nuclear reactor safeguard system, nuclear-imaging technology, and new various other applications.

Theoretical studies of neutrinos across particle physics, nuclear physics, and cosmology are important to answer fundamental questions such as "what is space-time?".

Accelerator Neutrino
T2K Experiment

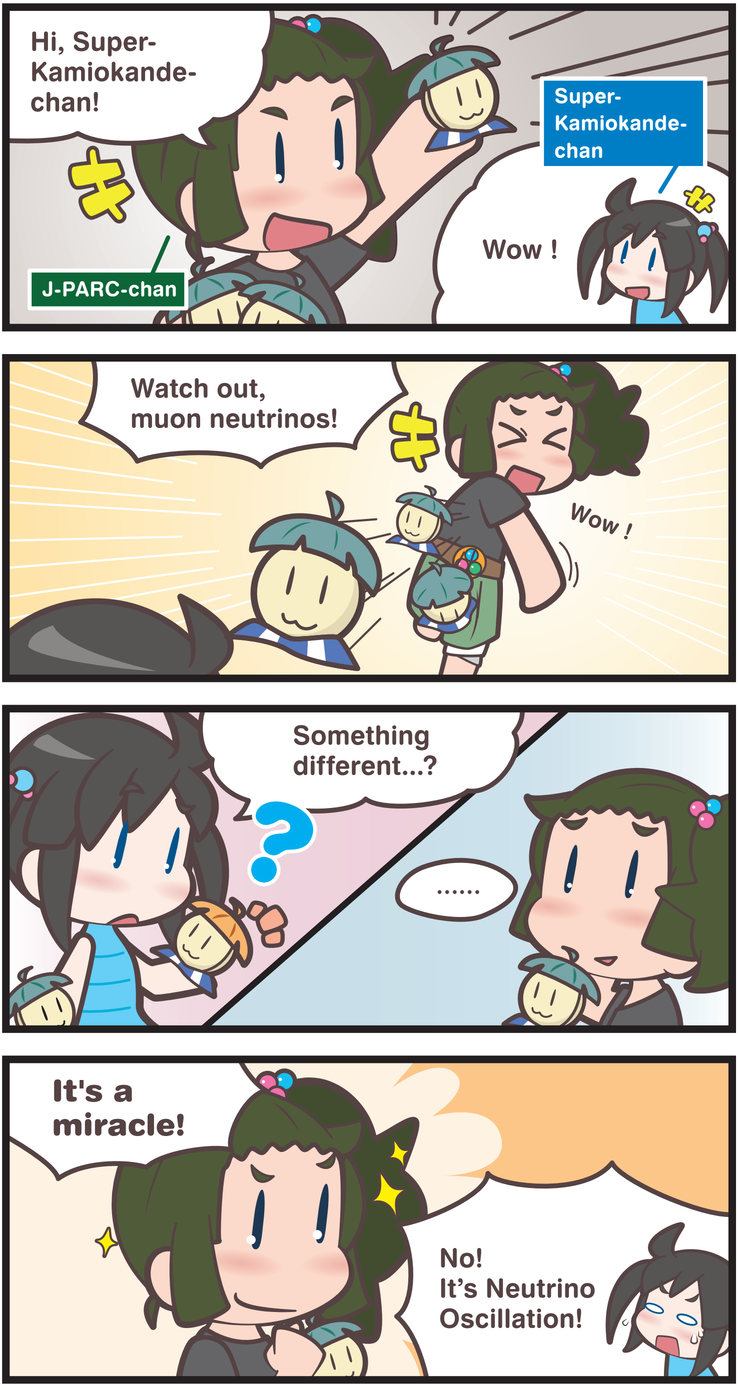
Neutrino oscillation is a fascinating phenomenon in which a neutrino changes its identity. In order to study neutrino oscillations, a neutrino beam is shot from the large accelerator facility J-PARC in Tokai village and the neutrinos are observed at the Super-Kamiokande detector in Kamioka town, 295 km away. The experiment is named T2K (Tokai-to[2]-Kamioka). In the T2K experiment, a new type of oscillation from a muon neutrino to an electron neutrino was discovered. Recently, we produced a beam of anti-neutrinos, the neutrino's anti-particle, and studied the violation of symmetry between a particle and its anti-particle, called CP symmetry violation. T2K has the interesting result that CP symmetry may really be violated in neutrinos. This might be a big hint that neutrinos help explain the mystery of our universe, where anti-matter is rare compared to matter.

View of the T2K experiment
A neutrino beam is shot from the J-PARC accelerator in Tokai village to the Super-Kamiokande detector in Kamioka town.

Particle Physics elucidates the mystery of invisible tiny elements constituting our universe. In Particle Physics research, we have a dream and passion challenging the mystery with large-scale experiments, such as using a kilometer-scale accelerator or a gigantic detector located 1000 m underground. Let's discover together how our universe is created.

Dr. Tsuyoshi Nakaya
Professor in Physics, Faculty of Science, Kyoto University

T2K!

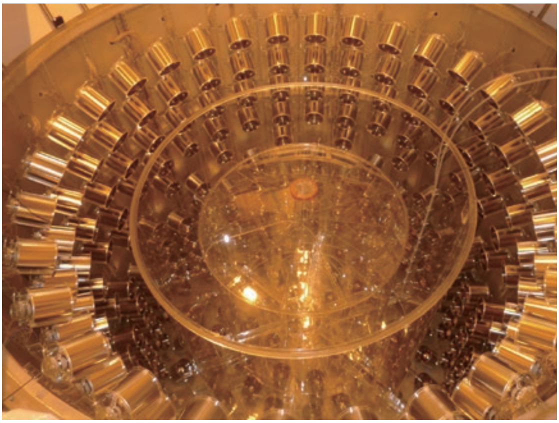


J-PARC-chan: lives in Tokai-mura, Naka-gun, Ibaraki, Japan.

Super-Kamiokande-chan: lives in Kamioka-cho, Hida-city, Gifu, Japan.

Reactor Neutrino
Double Chooz Experiment

Nuclear power plants produce electric power from the thermal energy obtained from Uranium nuclear fission. Did you know that a huge amount of neutrinos are produced at the same time? Those neutrinos escape to outer space without being used. The Double Chooz experiment at the Chooz nuclear power plant in France investigated such reactor neutrinos precisely and measured the θ_{13} mixing angle, an important parameter for the study of neutrino oscillation phenomena. It is an international collaboration with seven countries, and the Japanese group is playing a central role in it. Furthermore, we are conducting R&D application studies for new measures of nuclear non-proliferation by placing a small neutrino detector outside of the reactor building.

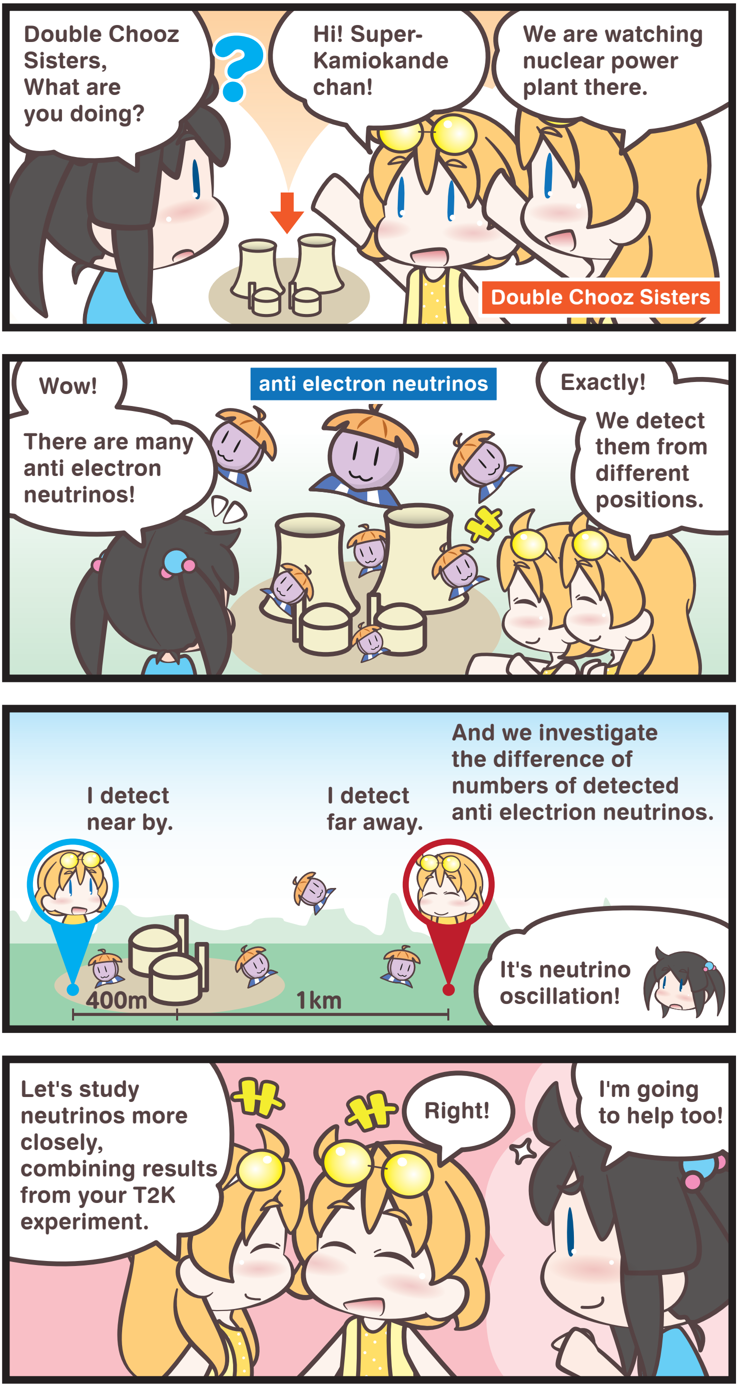


The Double Chooz detector during its construction, which has a double-acrylic vessel for liquid scintillators and 390 photo-multiplier tubes contained in magnetic shields.

In elementary particle experiments such as neutrino experiments, young graduate students and researchers work in large international collaborations together with others from all over the world, with an ambition to "see for the first time what mankind has never seen". Why don't you come and join us?

Dr. Masahiro Kuze
Professor at Tokyo Institute of Technology

Near and Far



Double Chooz Sisters:
Twins living near Chooz nuclear power plant in France. They measure together the neutrinos from the reactors.

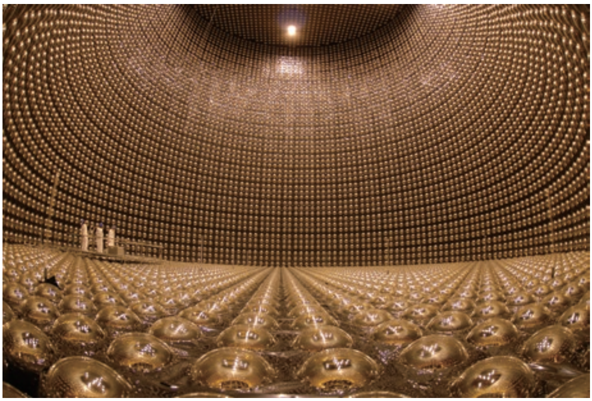
Observe from Near and Far:
By detecting anti electron neutrinos from the reactors at two distances, neutrino oscillation parameters are investigated in detail.

Atmospheric Neutrino

Super-Kamiokande and Hyper-Kamiokande Experiments

We observe neutrinos born in the Earth's atmosphere (atmospheric neutrinos) using the Super-Kamiokande detector to determine the order which type of neutrino is heaviest and which is lightest (called the "Mass ordering"). The mass ordering can cause a small enhancement of neutrino oscillations when the atmospheric neutrinos pass through the high density core of the Earth. We examined a lot of data in detail and found that the hypothesis that the third generation neutrino has a heavier mass than the first and second generation neutrinos matches the data better. However, further study is needed to conclude the order of the masses. The Hyper-Kamiokande detector will provide major new capabilities to make new discoveries in particle and astroparticle physics. It is a priority project listed in the Roadmap2017 of the Japanese Ministry of Education, Culture, Sports, Science and Technology, and we are preparing to start the detector construction.

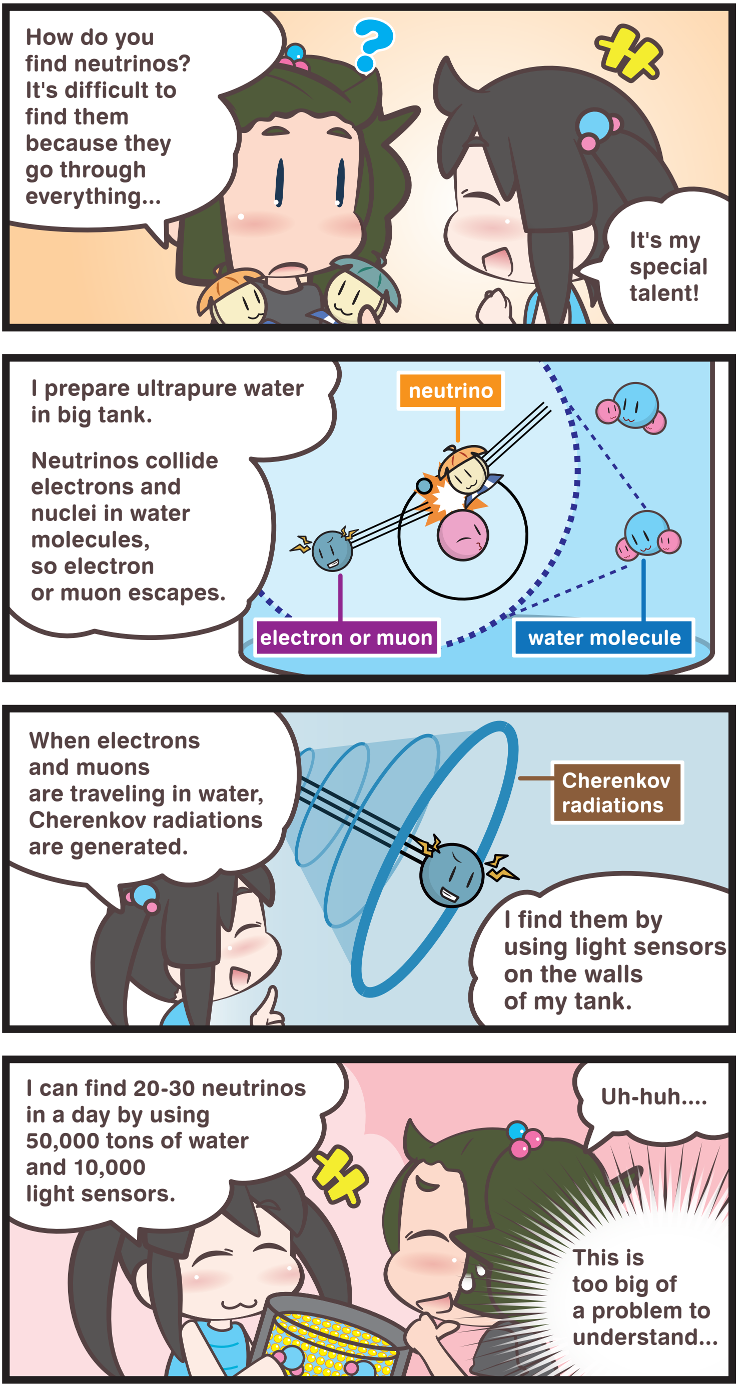
By operating the Super-Kamiokande detector, we observe natural neutrinos from the Sun, atmosphere, and Supernova explosions, and artificial neutrinos from the J-PARC accelerator to study elementary particles and celestial bodies. We also look for not-yet-discovered proton decay phenomena in the tank water.

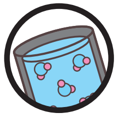


Detailed measurements of properties of neutrinos and spontaneous proton decays have the potential to make great progress in understanding the laws of nature. I would like to construct the Hyper-Kamiokande detector with sensitivity exceeding Super-Kamiokande and advance this research.

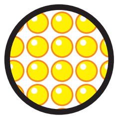
Dr. Masato Shiozawa
Professor at Institute for Cosmic Ray Research, the University of Tokyo

How to find Neutrino





Gigantic tank:
It is filled with 50,000 tons of ultra-pure water.
The bigger it is, the more neutrinos can be detected.



A lot of light sensors:
Light sensors called photomultiplier tubes (PMTs).
There are 11,129 sensors inside the tank.

High Energy Cosmic Neutrino

IceCube Experiment

Large amounts of highly energetic matter travels through the cosmos at nearly the speed of light. This matter is called 'cosmic rays', and mostly consist of protons, the very basic building blocks of matter in our universe. Some of these cosmic rays have energies thousands of thousands of billion times higher than visible light. How are all these products of the extreme Universe generated? In fact astronomical objects radiating cosmic rays are also expected to yield neutrinos. Neutrinos, chargeless elementary particles only sensitive to the "weak force", are traveling straight over huge distances, unattenuated. Hunting of these neutrinos can indeed reveal the new image of the high energy universe we would never see otherwise. We "watch" our cosmos by the world's largest neutrino telescope, IceCube, built at the South Pole.

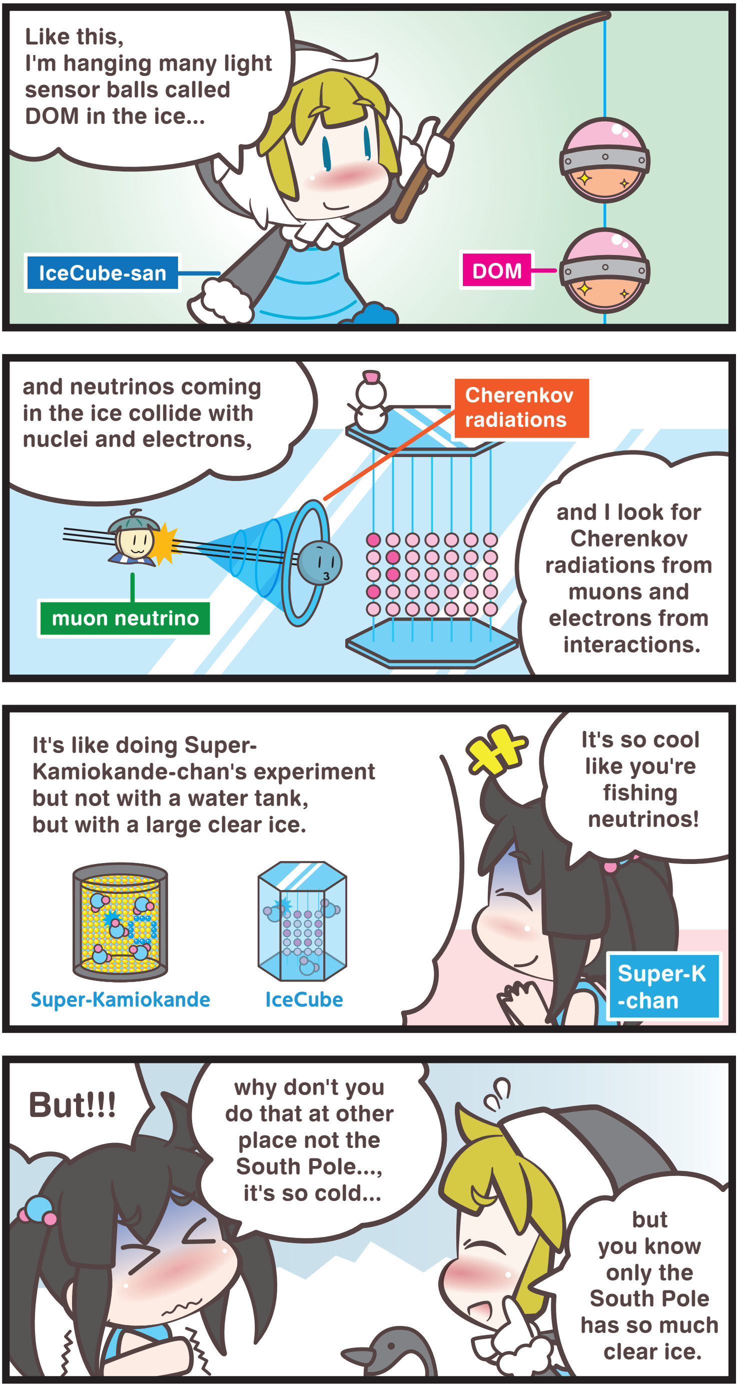
IceCube Neutrino Observatory built at the South Pole. The 5165 photo-detectors are deployed in the deep glacier ice. Signals from the in-ice detectors are transmitted via cables to the observatory, where the primary data processing to select neutrino signals takes place.

Your life is one time. Let's challenge whatever stimulates your enthusiasm. Action first, then you have a plenty of time later to worry if your challenge is successful or not.

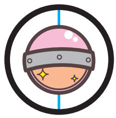
Dr. Shigeru Yoshida

Professor at Graduate school of Science, Chiba University

Neutrino Hunter!



IceCube-san: is observing neutrinos using Antarctic glacier ice. These experimentalists are incredible as they go to such remote places to hunt for neutrinos.

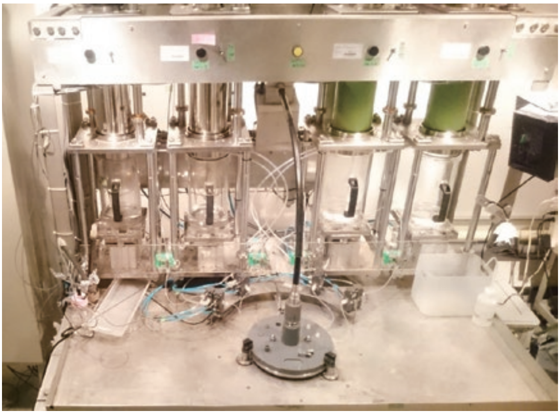


DOM: It stands for Digital Optical Module. About 5,000 pcs of them have been deployed in the deep ice, waiting for a signal from a cosmic neutrino.

Novel Neutrino detector:
Nuclear Emulsion

Nuclear emulsion has been contributing to fundamental particle physics for a long time, especially for charm particles and tau neutrinos so far. To apply a nuclear emulsion detector for the next step of neutrino physics, neutrino CP violation or physics beyond the standard model probed by neutrinos, we are developing and improving the technology of nuclear emulsion.

In the era of digital photography, the commercial photo film market has shrunk. We installed a nuclear emulsion production machine in Nagoya University and have been producing nuclear emulsion films with the help of retired technicians from a photographic company. The development and production of optimized nuclear emulsion for a variety of observations is resulting in fruitful output for not only neutrino physics, but also observations such as a dark matter search, balloon-borne gamma ray telescope, and cosmic-ray muon radiography.



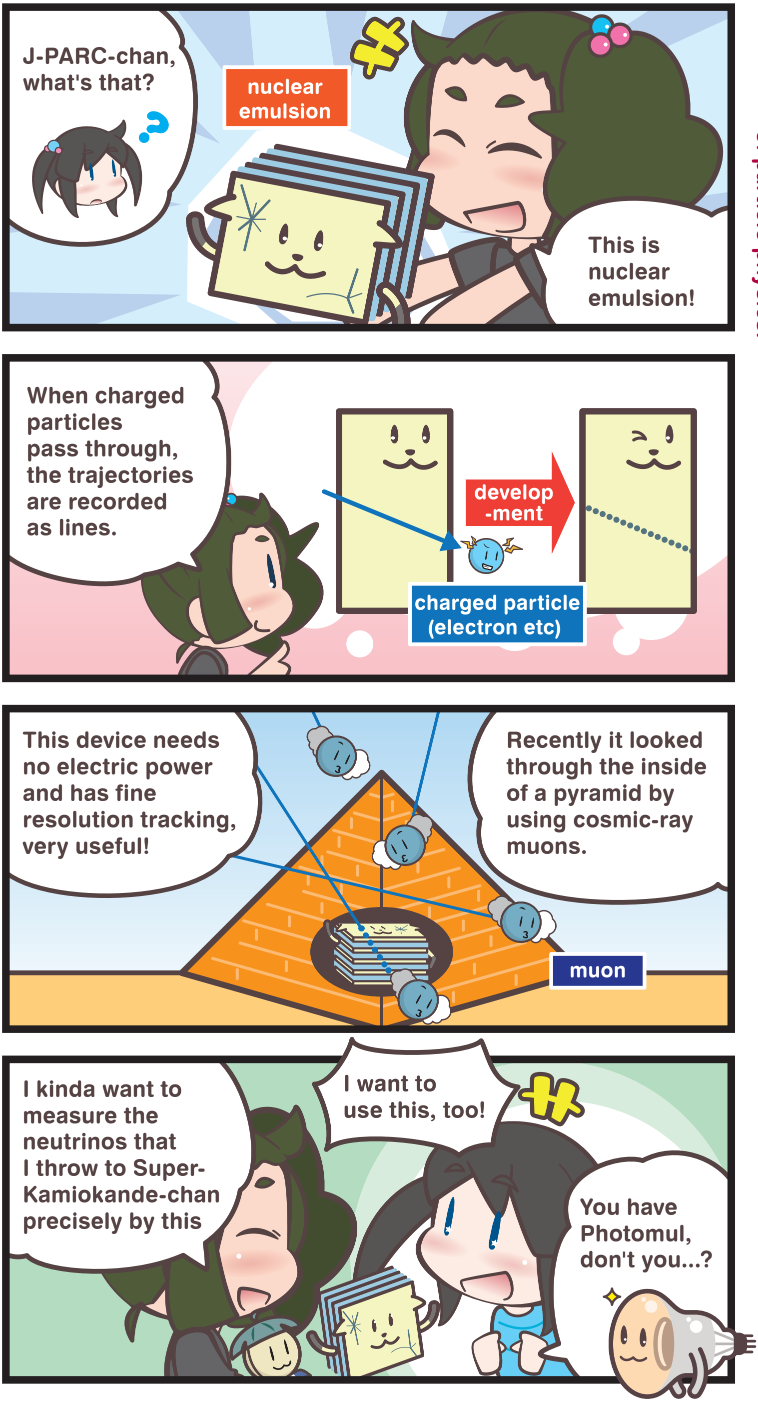
Production machine for nuclear emulsion gel

This system makes nuclear emulsion gel by carefully controlling the temperature and mixing of a solution of silver nitrate and sodium bromide. The nuclear emulsion gels provided by this machine hava been used in the neutrino experiment at J-PARC, gamma-ray telescopes and muon radiography.

Two dimensional photographic films have largely been replaced by digital photographic techniques. However nuclear emulsion, as three dimensional photographic films, still continues to grow. Since an infrastructure to make nuclear emulsion gel was installed at our laboratory in this research field, we can try to test easily new methods as soon as we think up a new idea. This has quickened young scientists drafting and performing new experimental projects with nuclear emulsion.

Dr. Mitsuhiro Nakamura
Professor at Institute of Materials and System for Sustainability, Nagoya University

Emulsion as popular trend device

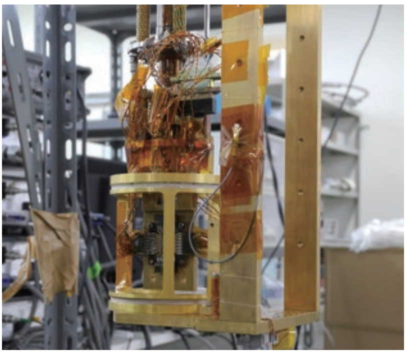


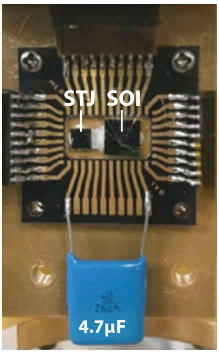
Nuclear emulsion: A kind of particle detector, same principle as photographic films, has been used for fundamental particle observations from the dawn of particle physics.

J-PARC-chan and emulsion: NINJA experiment is planned to precisely measure neutrinos produced by J-PARC-chan.

Search for Neutrino Decay:
COBAND Experiment

Cosmic background neutrinos are predicted to exist uniformly in space. To perform the COBAND rocket experiment to search for the cosmic neutrino background, we are developing the Superconducting Tunnel Junction (STJ) detector which measures the energy of far-infrared photons from neutrino decays with an accuracy of 2%. We have developed a cryogenic amplifier which is a key component of the cryogenic far-infrared photon detector, consisting of the Nb/Al-STJ detector and a diffraction grating, and succeeded in amplifying the Nb/Al-STJ signal for the visible laser pulse light. We have developed the Hf-STJ detector using Hf as a superconductor with a very narrow energy gap for the future satellite experiment, and succeeded in observing the Hf-STJ signal for the visible laser pulse light. We are preparing the whole equipment including the optical system and the 0.4K refrigerator for the rocket experiment.



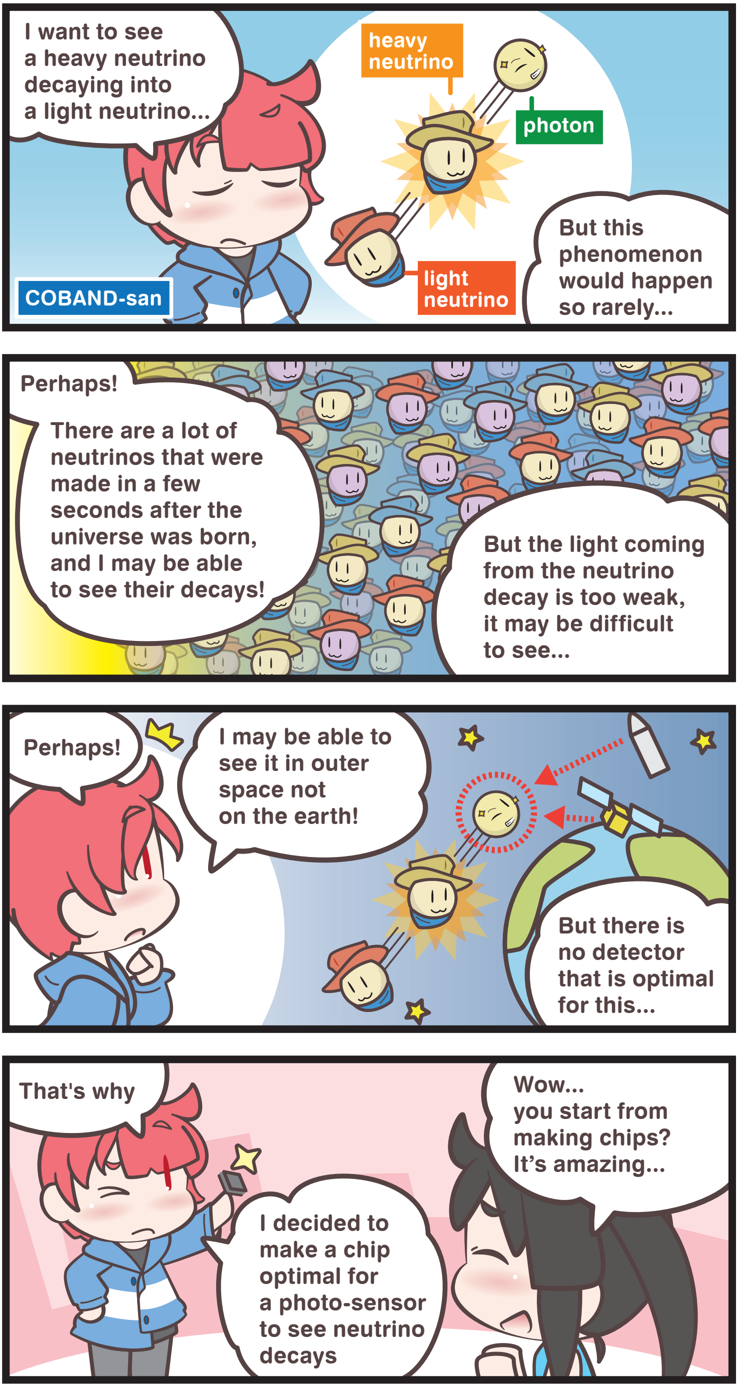


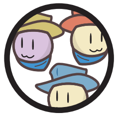
The Nb/Al-STJ detector is connected to the SOI cryogenic amplifier on the same chip carrier as the Nb/Al-STJ at 0.4K refrigerator.

To perform the COBAND experiment which searches for the cosmic background neutrino decay, we have developed the Superconducting Tunnel Junction (STJ) detector which measures the energy of the far-infrared photon from the neutrino decay. This technology of superconducting particle detectors is expected to be used for the dark matter search, the coherent neutrino scattering experiment and so on in the future.

Dr. Shinhong Kim
University of Tsukuba, Faculty of Pure and Applied Science, Professor

For Neutrino Watching





Cosmic Background Neutrino: The universe is thought to be filled with Cosmic Background Neutrinos which became free a few seconds after the Big-Bang.

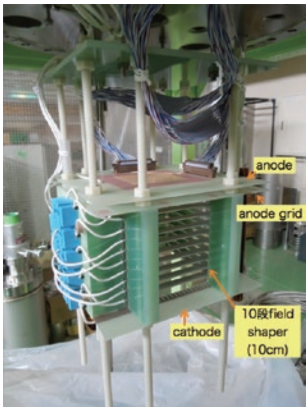
COBAND-san: Try to determine the neutrino masses by observing neutrino decay.

Novel Neutrino detector:
Liquid Ar Time Projection Chamber

The liquid argon 3D imaging detector provides the 3D image of elementary particles visually with online. It is a kind of the modern updated version of "the bubble chamber", Due to its high capability of the detector, it is an ideal and ultimate candidate of the future neutrino or nucleon decay experiments.

The largest size of the liquid argon 3D imaging detector so far is the ICARUS detector which has 600 tons, however the enlarged size of the detector is necessary for the future experiments. For those experiments, R&D of the detector, especially R&D for the technology with reasonable costs is highly desired. Also the test-beam of the detector using well defined charged particles such as energy, momentum, angles and identification is quite important to understand the response of the detector to the elementary particles.

For this purpose, this research program has large amount of R&D for the key device with the reasonable costs for the future experiments, and the test-beams.

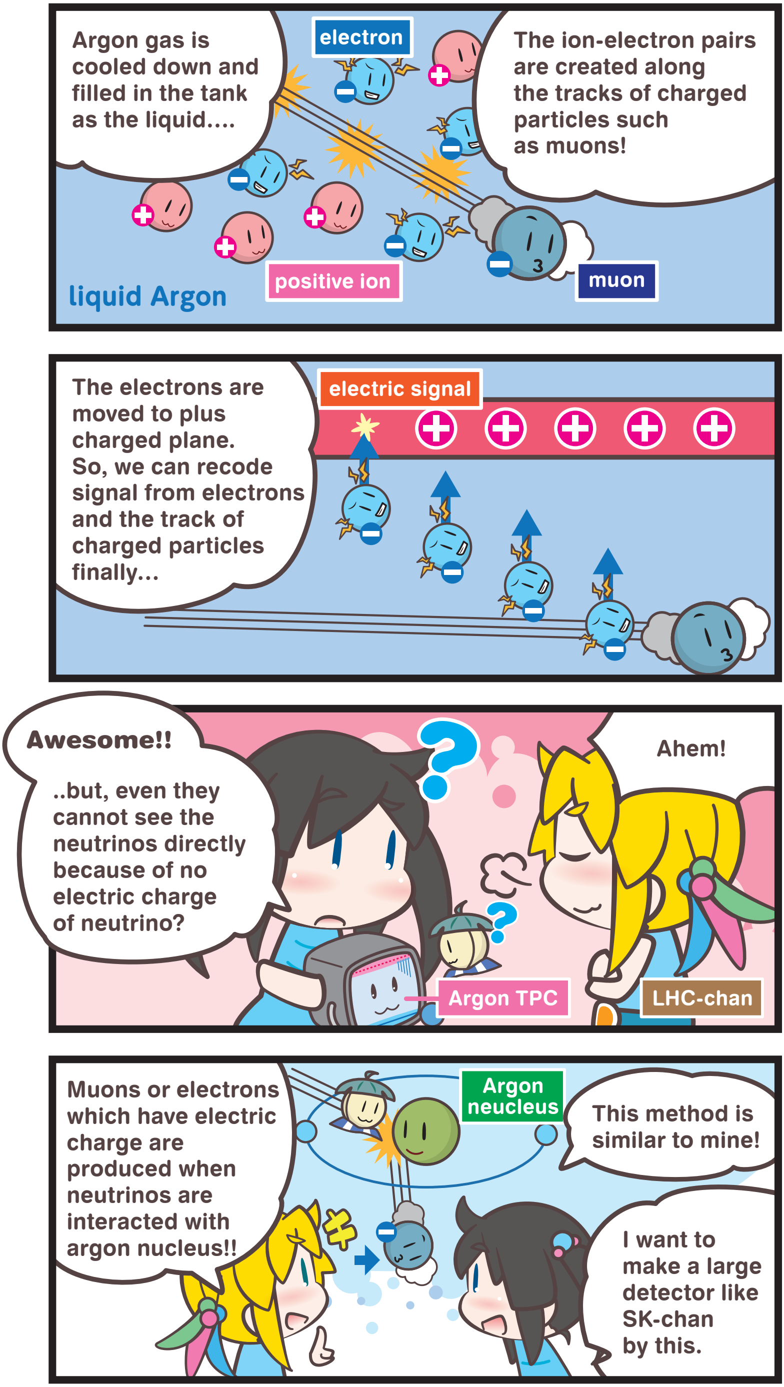


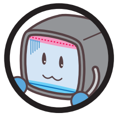
KEK 30L liquid argon 3D imaging detector.

The liquid argon 3D imaging detector is one of ultimate detectors for the neutrino and nucleon decay physics, therefore there are a lot of R&D activities around the world. There are also some on-going experiments which have order of 100 tons level. In this research program, we have done a lot of R&D of the detector key devices and the test-beam for the future experiments.

Dr. Takasumi Maruyama
Associate Professor at KEK, Institute of Particle and Nuclear Studies

Even neutrinos are seen?



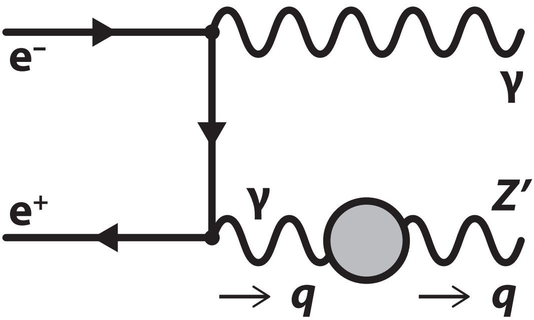


The Argon TPC:
This detector has the track signals when charged particles pass the argon volume. TPC is an abbreviation of "Time Projection Chamber"

Neutrinos and TPC:
Neutrinos do not have electric charge, but we can see the charged particles' tracks which were produced by the neutrino-argon interactions.

Neutrino Phenomenology

A theory called the Standard Model of particle physics explains most of all the phenomena of elementary particles, but neutrino mass is one of the mysteries which cannot be explained by the Standard Model. One important subject in particle physics is to search for new physics beyond the Standard Model, and research on neutrinos is believed to bring a breakthrough along that direction. Various experimental results have been announced since the Superkamiokande experiment in 1998, and research on neutrinos is now entering a new stage. In our group we are doing researches, such as phenomenology of experiments to determine precisely the parameters of neutrino mixing, phenomenology of new physics which can be probed by neutrinos, constraints on new physics which can be obtained through charged leptons at large accelerator experiments, etc.

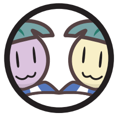


A process which was proposed to experimentally check a model which was invented to explain mysterious phenomena.

Research on particle physics, including that on neutrinos, does not have any direct application to our daily life. Because of such nature, however, we do not have conflict of interest and we have quite active international collaboration. We are carrying on research to find out the ultimate law of the universe.

Dr. Osamu Yasuda
Professor at Faculty of Science, Tokyo Metropolitan University

Exactly like...?



Electrically neutral neutrino and anti neutrino:
We can tell that they are a particle and anti-particle because of the electric charges of the particles produced by the reactions.

Anti muon neutrino-chan with a hat moved:
From the T2K experiment we are beginning to see a tiny difference between the properties of anti muon neutrino and muon neutrino.

Neutrino-Nucleus reactions

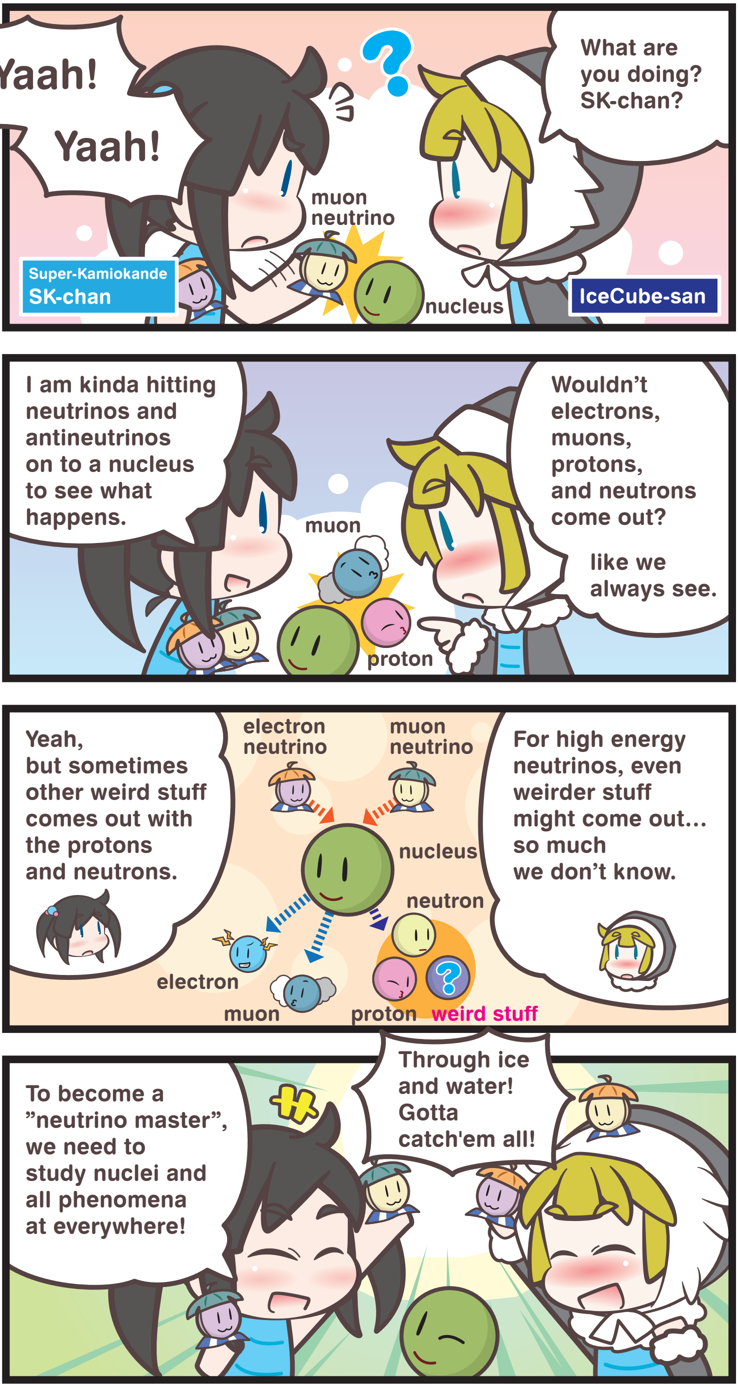
Precise description of neutrino-nucleus reaction is crucial to extract neutrino properties from current and next-generation neutrino oscillation experiments. We are working to understand how particles such as muon, electron, nucleon and pion are produced from the neutrino-nucleus reactions in wide neutrino energy region. One of our main efforts is meson production in the nucleon resonances region. A model of lepton-nucleon reactions for both electromagnetic and weak meson production reactions in the resonance region is developed. The other is neutrino reactions in the deep inelastic region. Nuclear effects in charged lepton reactions and neutrino reactions are investigated.

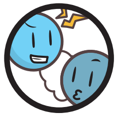
Workshop on 'Neutrino-Nucleus Interaction in the Few-GeV Region' held at Osaka in 2015 (NuInt2015).

Theoretical description of the neutrino-nucleus reactions is a challenging subject. Collaboration among researchers in nuclear structure, nuclear reaction, hadron physics and particle physics are important. We hope that young researchers join the field, enjoy working with people from various field, and develop new ideas.

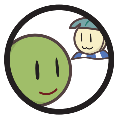
Dr. Toru Sato
Guest Professor at RCNP, Osaka University

Nucleus and Neutrino





Production of electron and muon:
An electron is produced by electron-neutrino reaction with nucleus, while a muon is produced by muon-neutrino reaction.

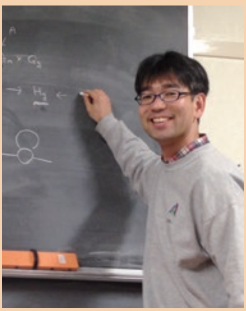


Understanding neutrino-nucleus reaction:
While unified description the neutrino-nucleus reactions in the whole energy region not yet available, we are improving our descriptions step by step.

Neutrino physics and the origin of the Universe

How did the Universe started and how has it evolved into the current form of structures made of galaxies and clusters of galaxies? The properties of elementary particles are quite important to answer these fundamental questions of our world. Our group has been studying the properties of neutrinos in the early Universe. Recently, we found that the neutrino oscillation phenomena during the Big Bang can explain why there are no anti-particles around us. We are now studying how this hypothesis can be tested. We have also proposed various new possibilities of particle/cosmology phenomena, such as explaining the origin of the high-energy neutrinos discovered in the IceCube experiment as the decay products of dark matter particles, the hypothesis of dark matter made of the Higgs particles, supersymmetry to explain the mysteries of the Universe, and the relation between the vacuum structure of string theory and the history of the Universe.

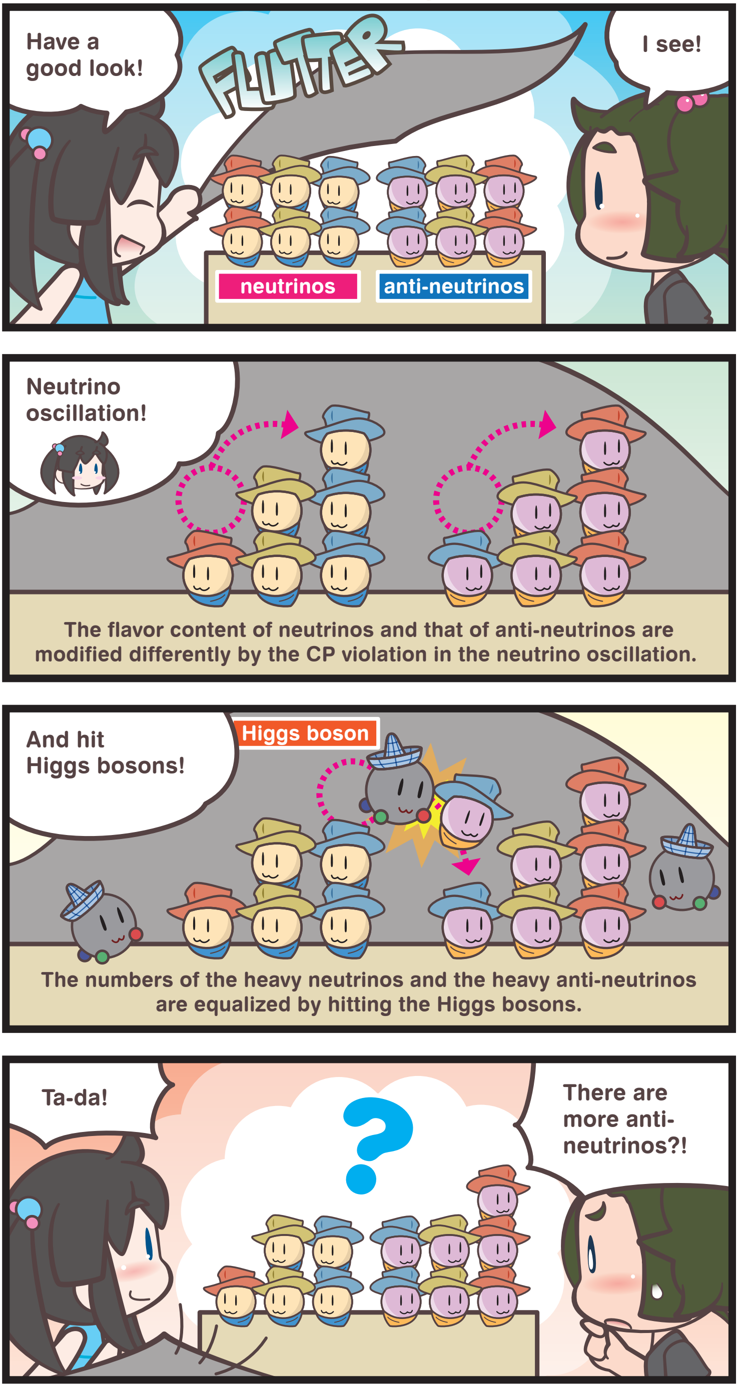
The theory/experiment joint regular meetings, "New Physics Forum," have been held in Tokyo area. "New Physics Forum" offers good opportunities to form new collaborations among physicists.



Our theory team works on particle physics and cosmology such as the origin of baryonic matter in the Universe, nature of dark matter, and also physics beyond the Standard Model through the studies of neutrinos. We build up new hypothesis to attack unsolved questions in particle physics and cosmology aiming at finding new facts of our Universe.

Dr. Ryuichiro Kitano
Professor at KEK, Institute of Particle and Nuclear Studies.

Neutrino Magic!

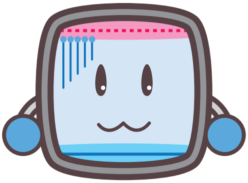


More anti-neutrinos than neutrinos?:
Starting with the same numbers of neutrinos and anti-neutrinos, some magic under the cloth created an imbalance between them. This CP violating phenomenon, if it has really happened in the early Universe, give the reason for the Universe being made of matter rather than anti-matter.

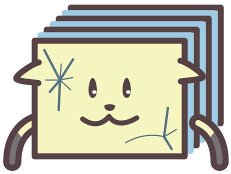

electron neutrino

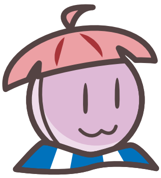

muon neutrino

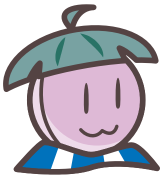

tau neutrino

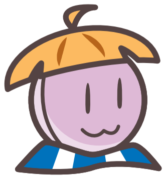

time projection chamber


photomultiplier tube


nuclear emulsion


anti electron neutrino


anti muon neutrino


anti tau neutrino

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