and the advanced detectors makes the experiment a leading project.

The CONUS experiment uses high-purity germanium semiconductor detectors sensitive to ionizing radiation. Several layers of ultrapure lead and boron-doped polyethylene shielding with a total mass of 11 tons protect the detectors against external radioactivity (see cover picture). Furthermore, concrete and a water pool at the reactor site provide an extra shield reducing cosmic muon radiation. The remaining fraction of this background radiation is rejected using an extra cosmic-ray detector. The shielding design is based on the world-leading expertise established at MPIK over many decades.

Early April 2018, data collection with the CONUS setup started. First the reactor was turned off for about one month and then restarted. A comparison of the reactor ON and the reactor OFF data yielded a hint for the rare neutrino interaction process already after two months of data acquisition only. With the additional statistics of more data and refined analyses methods, the CONUS collaboration will be able to scrutinize the coherent neutrino-nucleus scattering with reactor neutrinos in the upcoming years. After the foreseen shutdown of the reactor end of 2021, CONUS plans to continue data collection for one more year to study, characterize and discriminate background events for an improved signal to background ratio.

Applications

Detection and precise measurement of coherent neutrino-nucleus scattering are of fundamental importance for basic research, since they give insights in various microscopic processes. Moreover, neutrinos play a crucial role in several eminent astrophysical and cosmological events in the Universe. This includes star collapses (supernovae) emitting inconceivable amounts of neutrinos undergoing coherent scattering processes with nuclei during their propagation through the imploding star layers. The CONUS experiment at the nuclear power plant in Brokdorf offers the unique opportunity to measure for the first time coherent neutrino-nucleus scattering in the energy range of reactor neutrinos applying most up-to-date germanium detector technology. A precise measurement of the neutrino flux at nuclear reactors could in principle be used in the context of reactor monitoring, safeguard applications or for thermal power determination.

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CONUS

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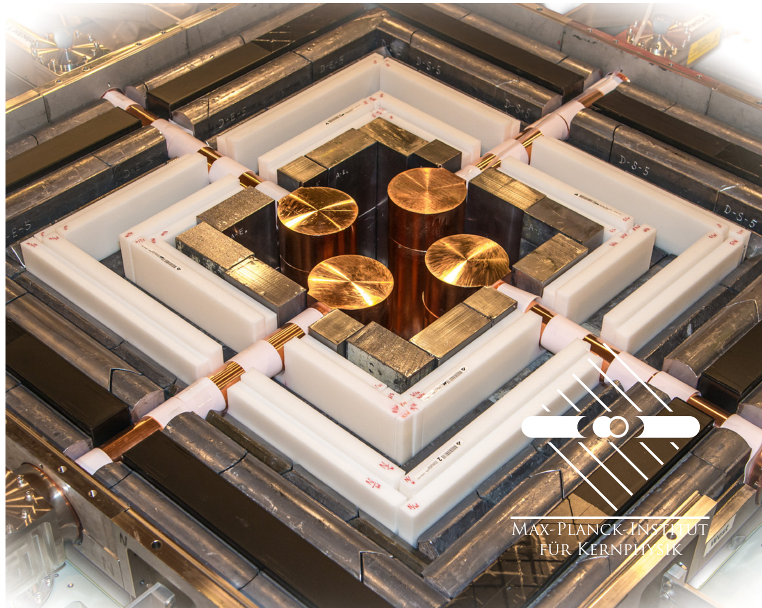
CONUS

Detecting coherent neutrino-nucleus scattering



CONUS
Detecting coherent neutrino-nucleus scattering

The coherent scattering of neutrinos on atomic nuclei is an interaction predicted from theory and is of major relevance for fundamental research. The CONUS experiment at the nuclear power plant in Brokdorf operated by PreussenElektra GmbH aims to characterize this interaction channel. Neutrinos, which are created in large amounts by nuclear fission products and not usable for power generation, are studied in this experiment on a novel way.

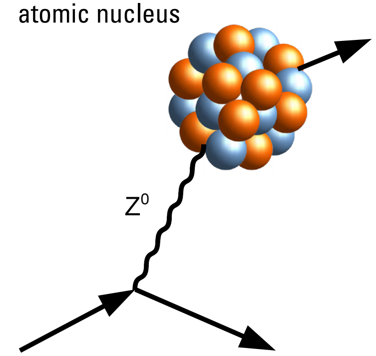
Neutrinos – mysterious particles

Neutrinos are elementary particles with amazing properties. As indicated by the name, they are electrically neutral and very tiny. They only interact weakly with matter and are therefore sometimes entitled as 'ghost particles'. A neutrino could pass a dense barrier with a thickness of about 10 quadrillion kilometers before being stopped with high probability. The neutrino was first postulated by Wolfgang Pauli in 1930 to explain an apparent violation of energy conservation in the radioactive beta decay. The detection of the shy elementary particle appeared to be extraordinarily difficult and was achieved for the first time at the Savannah River nuclear power plant in 1956 (Nobel Prize 1995). The radioactive decay of fission products generated in the nuclear reactor produces antineutrinos carrying away 4% of the released energy without notice. Therefore nuclear reactors are strong, well localized neutrino sources allowing for experiments under controlled conditions. Several neutrino properties were measured for the first time or with higher precision at nuclear reactors.

Besides these man-made neutrino sources there are also sources of natural origin. The omnipresent relic neutrino density in the Universe from the Big Bang is 300 per cubic centimeter. Another important natural neutrino source is the Sun. In its center neutrinos are produced from nuclear fusion processes. The solar neutrino flux on Earth corresponds to 65 billions per second passing through the surface of a thumb nail. The first observation of these elusive particles from the Sun was awarded with the Nobel Prize in 2002. There are more sources emitting a considerable amount of neutrinos such as the Earth interior (geo-neutrinos from the decay of long-lived radionuclides) or the atmosphere (secondary products from interactions between cosmic radiation and air molecules).

Nowadays, the Standard Model of sub-atomic particles distinguishes between three types of neutrinos, which are related to their electrically charged companions electron, muon and tauon. One of the most amazing properties of neutrinos is that they can change into each other. The detection of these 'neutrino oscillation' was rewarded with the Nobel Prize in 2015. Other intriguing neutrino properties predicted by theories with far reaching consequences up to astrophysical and cosmological scale, might be just right behind the corner, but still need to be unraveled.

Interaction with matter



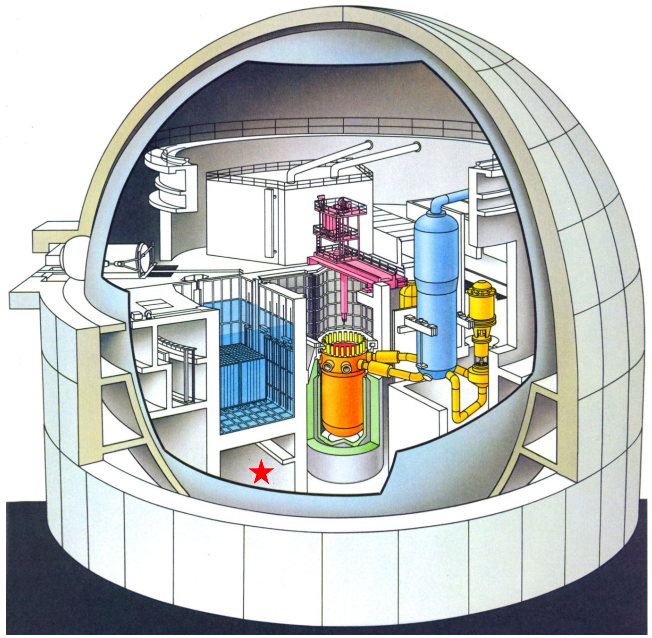
Coherent scattering of a neutrino on an atomic nucleus.

Since neutrinos only interact weakly with matter, the devices for neutrino detection are typically very large up to masses of hundreds of tons material with a still increasing trend. In principle, neutrinos can interact with matter in two ways: either on electrons in the atomic shell or on protons/neutrons in the nucleus. In the latter case, there is the possibility for the neutrino to 'coherently' scatter on the nucleus as a whole increasing substantially the probability for the scattering process. On the other hand, the energy transfer on the nucleus is tiny for the coherent scattering, similar to the situation of a table tennis ball hitting a basketball. It is quite simple to strike, but hard to move the target.

Therefore, dedicated detectors with very low energy threshold are needed for this detection, but only few kilograms of material might be sufficient to meet the goal! The challenges of such an experiment made the experimental confirmation of the theoretical predictions in the 1970ies impossible for more than 40 years. In 2017 the coherent scattering of neutrinos on nuclei was detected for the first by the COHERENT experiment. The higher-energy neutrinos in this experiment were produced using a neutron beam. Complementary measurements with lower-energy neutrinos at nuclear reactors are still pending and will further improve the understanding of models in particle physics.

The CONUS experiment

The detection and characterization of the coherent neutrino-nucleus scattering require an experimental setup very close to a strong and well controlled neutrino source. In competition to other international efforts, this idea is realized in the CONUS (COherent Neutrino nUcleus Scattering) experiment, which is operated in collaboration with PreussenElektra GmbH in Brokdorf. The measurement of the reactor neutrinos does not influence the reactor or make any demands on the operation of the power plant. The distance of the experimental setup to the reactor core is 17 meters only. Therefore, from one of the worldwide strongest reactors, an extremely high flux of 24 trillions of neutrinos per second and square centimeter is available for measurements. The combination with the purpose-built shielding



Inner view of the safety containment of the nuclear power plant in Brokdorf. The location of the CONUS setup is marked with a red star and is only 17 m distant from the center of the reactor core (orange).