The Double Chooz experiment

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Introduction

The goal of the Double Chooz experiment is the precise determination of the neutrino mixing angle θ_{13}. Two identical detectors measure the electron antineutrinos emitted from two nuclear reactors at the Chooz nuclear power station in France. The far detector in 1 km distance from the reactor cores started data taking in April 2011. A second near detector at a distance of about 400 m from the reactors is currently under construction and will start data taking in 2014. The near detector will monitor the unoscillated neutrino flux whereas the far detector is searching for a disappearance effect due to neutrino oscillations. If the electron antineutrinos change their flavor (for a nonzero value of θ_{13}), a reduced electron antineutrino flux is observed at the far detector.

Detector Setup

The target of the Double Chooz detector consists of about 8 tons of a newly developed Gadolinium-loaded liquid scintillator. The detection reaction is the inverse beta decay: $\bar{\nu}_e + p \rightarrow n + e^+$. The positron created in this reaction provides a prompt scintillation light signal and carries the energy information of the neutrino. The neutron is captured with high probability on the Gd dissolved in the target scintillator with a typical delay time of $\sim 30\mu$s releasing gamma radiation with a total energy of about 8 MeV. This coincidence allows an efficient neutrino detection and background reduction. The target scintillator is contained in a transparent acrylic vessel which is surrounded by the gamma catcher scintillator with 18 tons total mass, also contained in an acrylic vessel. Its main purpose is the conversion of the full energy of the gamma radiation produced by the Gd into scintillation light. The gamma catcher is surrounded by a non-scintillating buffer liquid with a total mass of about 80 tons. It reduces accidental background events created by natural radioactivity coming from the outer detector parts and the surrounding rock. 390 PMTs mounted on the inner surface of a cylindrical stainless steel vessel detect the scintillation light. This vessel is surrounded by the inner veto, consisting of 80 tons of organic scintillator contained in a cylindrical steel vessel. The inner veto is equipped with 80 PMTs to detect cosmic ray muons entering the detector. An additional outer veto consisting of several layers of plastic scintillator sheets is installed on top of the detector. The detector setup is sketched in fig. 1

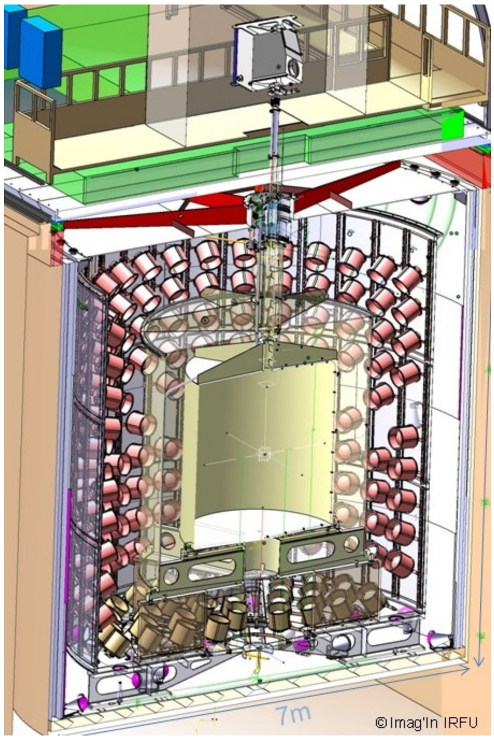

Figure 1: Setup of the Double Chooz detectors.

Status of the Experiment

In 2011 the Double Chooz experiment was the first reactor neutrino experiment presenting a hint for a positive value of the neutrino mixing angleθ_{13} [1]. From the first analysis Double Chooz included the shape information of the neutrino energy spectrum to extract the result. In 2012 the Double Chooz result was confirmed with higher precision by the experiments Daya Bay in China and RENO in Korea [2, 3]. In the same year, the Double Chooz analysis was improved with more data and reduced systematics. In this analysis the no-oscillation hypothesis could already be excluded at 99.8 % CL with the Double Chooz far detector only [4]. Fig. 2 shows the measured prompt energy spectrum together with the best fit and the no-oscillation expectation. In 2013 several cross-check analyses were done demonstrating the robustness of the Double Chooz result. Due to the very low background of the Double Chooz detector, it was also possible to analyse inverse beta decay events with neutron captures on hydrogen atoms (leading to the emission of a single 2.2 MeV gamma with $\sim 200\mu$s delay). In this way the fiducial volume of the detector was more than doubled, since the gamma catcher could be included. On the other hand, the signal-to-noise ratio is worse in the H analysis due to the longer coincidence time and the lower energy of the gamma. The combined Gd and H analysis provided the most sensitive DC analysis so far of $\sin^2(2\theta_{13}) = 0.109 \pm 0.035$ [5]. An independent analysis based on rate-only information was also performed in

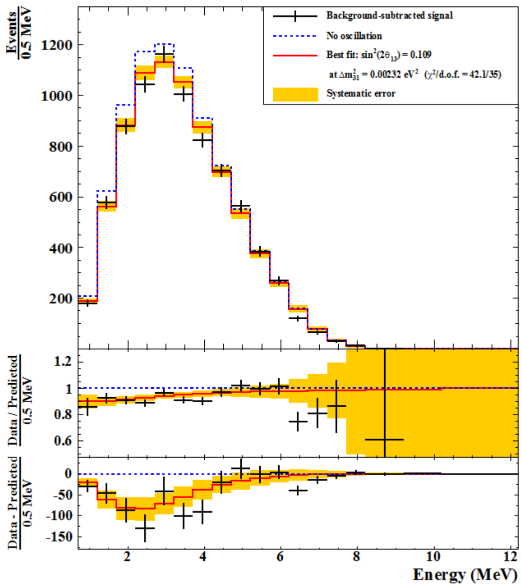

Figure 2: Double Chooz prompt energy spectrum: Background-subtracted data (black points) are superimposed on the spectra expected in the case of no oscillations (dashed blue) and for the best-fit oscillation (solid red).

2013. Here the observed and expected neutrino candidate rates are compared for different reactor power conditions, e. g. with both reactors on, one reactor off, both reactors off or intermediate configurations when the reactors are not running at full power. Plotting the observed candidate rate versus the expected rate for these different reactor power conditions allows to fit the data points with a linear model parametrized by θ_{13}. This approach is independent of specific background models. The background rate was measured directly during two reactor-off periods (total 8 days). The reactor rate modulation analysis was also done for neutron captures on Gd, H and a combined fit. The result is in very good agreement with the rate and shape result [6]. In the final configuration with two detectors, Double Chooz expects to reach a final precision of about 10 % on $\sin^2(2\theta_{13})$.

Activities at TUM

The group at TUM is responsible for the production of the muon veto scintillator and buffer liquid of both detectors (in total about 400 m^3). These liquids have to fulfill demanding requirements concerning their optical properties and radiopurity. Moreover their density has to match exactly that of the target scintillator. For this purpose, the optical and radiochemical properties of several candidate liquid components have been studied at TUM [8]. The radiopurity of many materials used in the detector construction (steel, liquid components, PMTs) has been screened by Ge spectroscopy at the UGL [13]. The measurement of the proton quenching of the Double Chooz liquid scintillators performed at the MLL is described in the article of V. Zimmer in this report.

Together with the group from MPIK Heidelberg, we designed the liquid and gas handling system of the detector, and are responsible for the detector filling [12]. As the detector vessels have been constructed as thin as possible (to introduce as little radioactive background as possible), all four detector volumes have to be kept at the same pressure, and at the same filling level (with a difference < 3 cm) at any time, also during the filling process. For this purpose we developed a level monitoring system, relying on several redundant methods as hydrostatic pressure measurement, laser distance measurement, buoyancy measurement etc., with an overall accuracy better than 2 mm [9, 11]. This system was successfully employed for the far detector filling, and will, with an improved readout-system, also be implemented in the near detector.

In order to improve the predicted neutrino spectra for reactor experiments in general, an experiment was performed at the research reactor FRMII in Garching to determine the cumulative antineutrino spectrum of the fission products of ^{238}U [7, 14].

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