Searching for θ_{13} with the Double Chooz Experiment

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1. Introduction

In the general scenario for mixing of three massive neutrino flavours, mass and flavour eigenstates are related via a unitary 3×3 matrix, characterized by three mixing angles θ_{12}, θ_{23} and θ_{13}. However, only two of these mixing angles have been measured up to now. θ_{12} has been determined in solar neutrino experiments and in KamLAND ($\sin^2 2\theta_{12} = 0.82 \pm 0.07$), θ_{23} in atmospheric neutrino experiments and in K2K ($\sin^2 2\theta_{23} > 0.92$). The CHOOZ experiment has set the best upper limit on the third mixing angle $\sin^2 2\theta_{13} < 0.2$ (90 % C.L.). The goal of the Double Chooz experiment is an improvement of this limit down to $\sin^2 2\theta_{13} < 0.02 - 0.03$.

2. Experiment Design

The Double Chooz experiment consists of two identical neutrino detectors in a distance of $\sim$ 200 m and 1.05 km from the reactor cores of the Chooz nuclear power station (8.4 GW_{th}). The far detector will look for the disappearance of electron antineutrinos, while the near detector will monitor the total antineutrino flux emitted by the reactor cores.

The central part of each of the two Double Chooz detectors will consist of $\sim 10\,m^3$ liquid scintillator, doped with 0.1 % Gadolinium, contained in a cylindrical acrylic vessel, and will be surrounded by a scintillating γ-catcher ($22\,m^3$) and a non-scintillating buffer ($100\,m^3$). 500 photomultiplier tubes (PMTs), mounted on the inner surface of the cylindrical steel vessel containing the buffer volume will collect the scintillation light. A muon veto consisting of another $90\,m^3$ of scintillator and about 80 PMTs cylindrically surrounds the buffer vessel (Fig. 1).

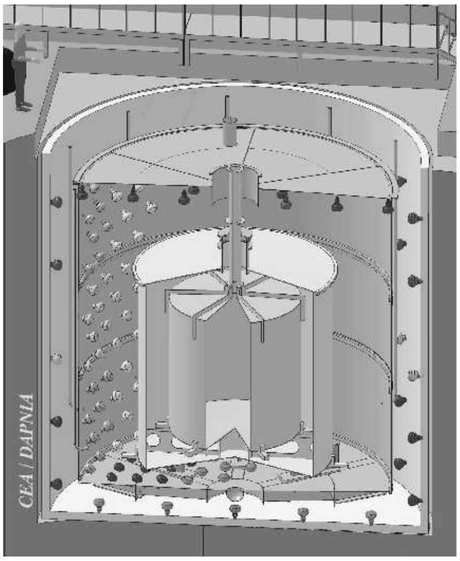

Fig. 1: Sketch of the Double Chooz far detector. The detector is located in the pit used for the old CHOOZ experiment (7 m × 7 m). About $10\,m^3$ of Gd-doped scintillator will be contained in the central transparent acrylic cylinder, surrounded by γ-catcher, buffer and muon veto. The layout of the far and near detector are identical.

3. Signal and Background

The antineutrinos will be detected via their capture on protons (inverse beta decay) $\bar{\nu_e} + p \rightarrow n + e^+$. The positron takes most of the neutrino energy and immediately annihilates with an electron, leading to a prompt signal between 1 and 10 MeV. The neutron is captured by Gd with a mean life of 30 μs leading to the emission of $\sim$ 8 MeV γ's . The coincidence of the prompt positron event and the delayed neutron event gives a neutrino event. We expect about 70 events per day in the far detector and about 2000 events per day in the near detector.

Background can be classified in two categories: accidental and correlated background. While careful selection of detector materials and shielding design can lower the accidental background, the most serious correlated background is induced by cosmic ray muons in or near the detector. These muons can create fast neutrons which are able to pass the muon veto without making a signal there, and subsequently deposit some of their energy in the scintillator (prompt signal) before being captured by Gd. Or they can create relatively long-lived β- delayed neutron emitters (^{8}He, ^{9}Li) whose decay also mimicks a neutrino signal. The goal is to keep the signal to background ratio above 100 in order to keep the associated systematic uncertainty below 0.2 %.

The expected sensitivity of Double Chooz is shown in fig.2.

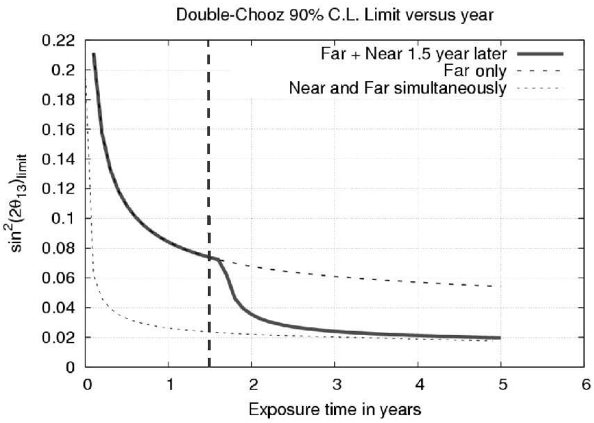

Fig. 2: Expected $\sin^2(2\theta_{13})$ sensitivity limit of Double Chooz versus time assuming the true value of θ_{13} is zero. The near detector will come online about 1.5 years after the far detector.

4. Status

During 2005, a prototype of the experiment at the scale 1:5 has been constructed and filled with $\sim$ 110 l of Gd-loaded scintillator in the target and $\sim$ 200 l of unloaded scintillator as gamma-catcher. The optical monitoring of all liquids will assess the long-term stability of the Double Chooz scintillators under experimental conditions that are as close as possible to the full-scale experiment. The TUM group has provided the liquids for the gamma-catcher and has been involved in the filling of the prototype detector. At TUM, we are studying the light yield and time response of different scintillator mixtures for Double Chooz. Together with University Tübingen, the TUM group is responsible for the muon veto of both detectors.