Double Chooz

G. Horton-Smith, for the Double Chooz collaboration[1]

Kansas State University, Manhattan, KS 66503, USA

Abstract. The Double Chooz collaboration proposes to measure the value of the neutrino mixing angle θ_{13}. The experiment will measure the flux of electron antineutrinos at two detectors placed $\simeq$150 m and $\simeq$1 km from the reactor cores at the Chooz nuclear power station. With 3 years of data and a relative detector normalization uncertainty of 0.6%, the error on the quantity $\sin^2 2\theta_{13}$ will be ± 0.02; if θ_{13} is small, then an upper limit of 0.03 (90% CL) will be established on $\sin^2 2\theta_{13}$. This experiment, which could start as early as the spring of 2007, will rapidly and substantially improve on the current best limit established by CHOOZ, and will guide future experiments.

Keywords: neutrino, neutrino mixing, reactor antineutrino
PACS: 14.60.Pq, 23.40.Bw

INTRODUCTION

In the general scenario for mixing of three neutrino flavors, three modes of neutrino oscillation may be present, with amplitudes characterized by the mixing angles θ_{12}, θ_{23}, and θ_{13} [3]. However, only two of these oscillation modes have been observed: global fits to the observations of solar neutrino experiments plus KamLAND[4] imply $\sin^2 2\theta_{12} = 0.82 \pm 0.07$, while the most recent Super-Kamiokande and K2K measurements yield $\sin^2 2\theta_{23} > 0.92$ [5]. The CHOOZ experiment has set the best upper limit on the amplitude of the third oscillation: $\sin^2 2\theta_{13} < 0.2$ (90% C.L.) [6, 7].

We of the Double Chooz collaboration propose [1, 2] to re-use existing facilities at the site of the successfully concluded CHOOZ experiment to obtain a relatively quick measurement (or limit) on the neutrino mixing parameter θ_{13}. The experiment will look for the “disappearance” of electron antineutrinos, emitted by reactor cores at the CHOOZ nuclear power station, when they travel $\simeq$ 1 km from source to detector. The new experiment will consist of two new, nearly identical detectors, referred to as the “far” and “near” detectors. The far detector will be housed in the existing CHOOZ experimental hall, $\simeq$ 1 km from the reactor cores, and the near detector will be placed in a new experimental hall to be constructed 100 $\sim$ 200 m from the cores.

THE SITE

CHOOZ nuclear power station. The CHOOZ nuclear power station, near the town of Chooz in northern France, is the site of both the completed CHOOZ experiment and the new Double Chooz experiment. Two 4200 MWth (megawatt thermal power) capacity reactor cores operate at this site, with an average 80% load factor.

Existing CHOOZ experimental hall. The original CHOOZ detector was located in an underground tunnel approximately 1000 m from the reactor cores. The underground location is covered by 300 meters-water-equivalent (m.w.e.) of rock overburden. Although the original detector has been removed, the detector pit and utility infrastructure still exist. This facility will be used for the far detector of the new Double Chooz experiment.

New Double Chooz near detector site. A parking lot approximately 150 m from the cores will become the site of the Double Chooz near detector. A “bury and cover” method will be used to construct an overburden of 60 m.w.e. Internally supported mounds of this height are well within standard civil construction capabilities.

EXPERIMENT DESIGN

Central detector. The same design will be used for the central detectors at the near and far site. (See Fig. 1.) In this design, a central target volume containing about 12 m^3 of Gd-loaded dodecane+PXE scintillator is contained within a transparent acrylic vessel. Surrounding the target volume is a layer of unloaded dodecane+PXE scintillator, used to “catch” gammas from n-Gd capture events inside the target region, thus reducing edge effects. Surrounding the “gamma catcher” acrylic tank is a non-scintillating dodecane buffer, contained within a stainless tank. Photomultiplier tubes on the inside of the

---

[1] For a list of collaborators, see the author lists of references [1] and [2].

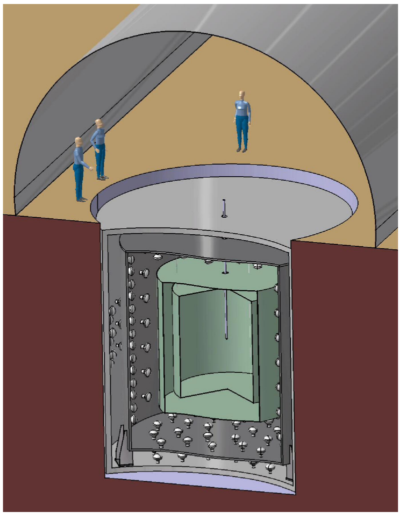

FIGURE 1. Cutaway rendering of the Double Chooz detector, copied from the proposal[1, 2], shown as it would appear at the far detector site.

TABLE 1. Summary of relative normalization uncertainties at Double Chooz

	Goal
Solid Angle	0.2%
Volume	0.2%
Density	0.1%
Fraction H Atoms	0.1%
Neutron Efficiency	0.2%
Neutron Energy Cut	0.2%
Time Cut	0.1%
Dead Time	0.2%
Acquisition	0.1%
Background	0.2%
Total	0.6%

stainless tank collect light from the target volume and gamma catcher.

Inner veto. A 60 cm thick cylindrical “veto” region filled with liquid scintillator will surround the central detector at the far site. A slightly thicker inner veto (100 cm) will be used at the near site to reduce the number of untagged muons close to the detector. Note that neither the inner nor outer “veto detectors” will be used to veto any triggers at the hardware or DAQ level, but rather the data from these detectors will be acquired and stored along with inner detector data, to be used for removing muon-related backgrounds in downstream analysis.

Outer veto. An active outer veto system consisting of four layers of proportional tubes will provide additional data to be used to remove muon-induced backgrounds. It will provide a cross-check for inner veto efficiency, track muons more accurately than possible with the inner veto, and detect muons passing through the shielding just outside the inner veto. At the near site, the outer veto will cover the top and sides of the central detector and inner veto; and the far site, the outer veto will cover only the top of the detector, due to space constraints. Note that at the far site, there is less need for the outer veto due to the significantly greater overburden, but we desire to have an outer veto at both sites for comparison. We aim for a muon detection efficiency exceeding 98%.

Signal. The reactor antineutrinos are detected through the inverse beta decay $\overline{\nu}_e + p \rightarrow e^+ + n$. An easy number to remember for the rate of such reactions in a reactor experiment is 1 event per day per ton of liquid organic scintillator target at 1 km from a 1 GWth reactor core, or “1 per GWth-ton-day at 1 km” for short. With 10 tons of scintillator in our target volume, located 1 km (150 m) from two 4.2 GWth cores operating at 80% load factor, we expect to average about 70 events/day (3000 events/day) in the far (near) detector, not accounting for detector deadtime.

Backgrounds. The most serious backgrounds for the experiment come from correlated event pairs produced by β-delayed neutron emitters (mostly ^{9}Li) and fast external neutrons, both of which are produced by cosmic rays in or near the detector. Fast neutrons events are numerous, but can be removed with a short time cut following each passing muon. While background from ^{9}Li is much lower, it cannot be removed by such a cut, but may be measured. We estimate the total untagged background rate at the far detector to be between 1/day and 2/day, provided we attain an efficiency of the veto detectors exceeding 98%. At the near detector, we project a total background rate between 9/day and 23/day, under the same assumptions. By tagging a large sample of muon-induced fast neutron and ^{9}Li events using veto detectors of known efficiency, we will reduce the uncertainty in the untagged background to sufficiently low levels.

Systematic errors. Many systematic uncertainties that affected CHOOZ and all previous single-baseline reactor neutrino experiments are greatly reduced by having both a near and far detector. We are limited primarily by how closely we can approach the ideal of “identical” construction and operation of the two detectors. Table 1 summarizes the relative normalization uncertainties expected.

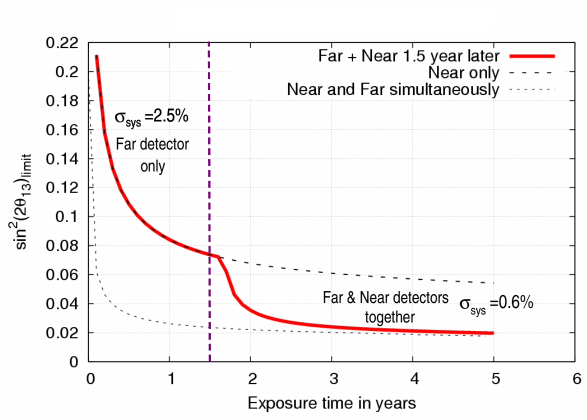

FIGURE 2. The $\sin^2(2\theta_{13})$ sensitivity limit of Double Chooz assuming the real value of θ_{13} is zero and the near detector is built 1.5 years after the far detector.

SENSITIVITY AND SCHEDULE

Because of the existing infrastructure at the far lab, it is possible that the far detector could be built as early as the end of spring, 2007. The near lab and detector could come as early as one and a half years later. The sensitivity as a function of time under this scenario is shown in Fig. 2. The old CHOOZ limit would be surpassed before the near detector is even built. After three years of data-taking with both detectors operational, the sensitivity will be $\sin^2 2\theta \simeq 0.03$, almost an order of magnitude improvement on the current limit, giving Double Chooz excellent discovery potential.

CONCLUSION

The Double Chooz collaboration is moving forward rapidly with the detailed technical design of this experiment. It is the best chance of substantially improving on the CHOOZ limit prior to the start of more ambitious (and expensive) long baseline accelerator and reactor experiments, which are generally anticipated to turn on no earlier than 2009. Furthermore, Double Chooz will employ many of the same techniques and technologies proposed for a reactor experiment at the more challenging $\sin^2 2\theta \sim 0.01$ level. Both the results and experience of Double Chooz will be valuable to later experiments.

REFERENCES

1. F. Adellier, *et al.* (European Double Chooz group), “Letter of Intent for Double-CHOOZ: a Search for the Mixing Angle θ_{13},” arXiV:hep-ex/0405032, May, 2004.
2. S. Berridge, *et al.* (U.S. Double Chooz group), “Proposal for U.S. participation in Double-CHOOZ: A New theta-13 Experiment at the Chooz Reactor,” arXiV:hep-ex/0410081, October, 2004.
3. B. Kayser, “Neutrino mixing”, chapter 13 of **Review of Particle Physics**, S. Eidelman *et al.*, Phys. Lett. **B592** (2004) 145.
4. T. Araki, *et al.* (KamLAND Collaboration), Phys.Rev.Lett. 94 (2005) 081801.
5. Super-Kamiokande Collaboration, Phys.Rev. D71 (2005) 112005.
6. M. Apollonio, *et al.* (CHOOZ collaboration), Eur. Phys. J. C27 (2003) 331.
7. Note the limit on θ_{13} is actually a function of the value assumed for Δm^2_{13}. The quoted limit $\sin^2 2\theta_{13} < 0.2$ assumes $\Delta m^2_{13} = 2 \times 10^{-3}\mathrm{eV}^2$.