Double Chooz: Optimizing CHOOZ for a possible $\theta_{13}$ measurement

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The proposed Double Chooz $\theta_{13}$ experiment is described. Double Chooz will be an optimized reactor disappearance experiment similar to the original CHOOZ. The optimization includes an increase in the signal to noise by increasing the target volume to twice the original CHOOZ, reducing singles background with a non-scintillating oil buffer region around the target and carefully controlling systematic uncertainties by measuring the $\bar{\nu}_e$ flux of the source with a near detector. The Double Chooz far detector will be situated in the same cavern as CHOOZ but will detect $\sim 50000 \bar{\nu}_e$s in three years of operation. We estimate a systematic uncertainty of 0.6%, and a reduction of the upper limit on $\sin^2(2\theta_{13})$ to 0.03.

1. INTRODUCTION

In recent years, Super-Kamiokande, SNO and KamLAND have shown that the three known types of neutrino ($\nu_e$, $\nu_\mu$, $\nu_\tau$) have mass and undergo flavor oscillation. In particular, $\nu_e \rightarrow \nu_\mu$ or $\nu_e \rightarrow \nu_\tau$ oscillations were proven by SNO [1]. KamLAND [2] measured the oscillation parameters $\Delta m^2_{12} = 7.9^{+0.6}_{-0.5} \times 10^{-5}$eV$^2$ and $\sin^2 2\theta_{12} = 0.82 \pm 0.07$, and Super-Kamiokande measured the $\nu_\mu \rightarrow \nu_\tau$ oscillation parameters ($1.5 \times 10^{-3} < \Delta m^2_{23} < 3.4 \times 10^{-3}$eV$^2$ and $\sin^2 2\theta_{23} > 0.92$ [3]). Other interesting issues remain. Strangely, both $\theta_{12}$ and $\theta_{23}$ are close to maximal but $\theta_{13}$ is constrained to be small by CHOOZ. Additionally, neutrinos may violate CP conservation. In experiments that search for $\nu_e$ appearance in a $\nu_\mu$ beam the CP violating term and $\theta_{13}$ are degenerate. Disappearance experiments that measure the $\bar{\nu}_e$ remaining in a $\bar{\nu}_e$ source are sensitive only to $\theta_{13}$, allowing a clean measurement. In the following, “CHOOZ” will refer to the original experiment [4], “Double Chooz” to the new proposal.

2. IMPROVEMENTS TO CHOOZ

The most important improvement to CHOOZ will be a near detector situated $\sim 150$ meters from the reactor cores. Its inner detector will be identical to that of the far detector enabling a precise measurement of the unoscillated $\bar{\nu}_e$ signal. Its outer detector will incorporate an extra veto covering the top and sides to account for the higher muon flux at its shallow depth ($\sim 65$ meters water equivalent).

CHOOZ has the best upper limit on $\theta_{13}$ of $\sin^2 2\theta_{13} < 0.2$ at $\Delta m^2_{13} = 2 \times 10^{-3}$eV$^2$. The $\bar{\nu}_e$s were detected via the inverse beta decay reaction $\nu_e + p \rightarrow e^+ + n$, giving a prompt signal due to the $e^+$ and a delayed signal $\sim 30\mu s$ later from neutron capture on Gadolinium (Gd). Gd doped scintillator has a short capture time and increased neutron capture detection efficiency due to the large amount of energy released ($\sim 8$ MeV). Unfortunately, nitrates used to dissolve the Gd caused a reaction with the scintillator that colored it, limiting the lifetime of the experiment. Since the CHOOZ result, R&D work for LENS at the Max Plank Institute has developed two classes of Gd loaded scintillator suitable for a new generation of reactor neutrino experiment.

The signal to noise ratio of Double Chooz will be $\sim 100$, four times better than CHOOZ. This results from doubling the target volume and providing a non-scintillating buffer zone between the target and the PMTs to reduce background.
3. SYSTEMATIC UNCERTAINTIES AND BACKGROUNDS

Table 1 shows the systematic uncertainties expected. The differences between the near and far detectors must be small in order to achieve our goal of 0.6% total relative systematic uncertainty. Particular care must be taken to ensure that both detectors have the same number of target protons. Therefore both target vessels will be made to the same specifications by the same vendor at the same time. They will then be installed, fully assembled, into their respective detectors and filled from the same batch of scintillator. The scintillator will be carefully weighed during the filling process.

The improved detector design and lower background rate will enable a simplification of the analysis relative to CHOOZ. The Double Chooz analysis will require only energy and time cuts.

A singles event rate at the level of 1Hz will be achieved with U, Th and K concentrations of $\sim 10^{-12}$, $\sim 10^{-12}$ and $\sim 10^{-10}$ grams/gram respectively in the scintillator and $\sim 10^{-10}$, $\sim 10^{-10}$ and $\sim 10^{-8}$ grams/gram respectively in the acrylic vessels. Background estimates from the rock were scaled from the CHOOZ experiment while those of the PMTs were obtained from simulations which included Hamamatsu estimates.

The correlated backgrounds can also be estimated by scaling from the CHOOZ experiment using reactor off data. The $^9$Li and $^8$He rate measured in CHOOZ was $\sim 0.2$/day. Doubling the target volume gives $\sim 0.4$/day in Double Chooz.

4. SENSITIVITY LIMIT

The sensitivity limit of Double Chooz is shown in Figure 1 assuming an achievable systematic uncertainty of 0.6% and a $\bar{\nu}_e$ signal rate of $\sim 50,000$ events over three years. The old CHOOZ limit is surpassed within a few months, even before the near detector is built. The sensitivity after three years with the near detector will be $\sin^2 2\theta_{13} \sim 0.03$, giving an $\sim 85%$ reduction in the CHOOZ limit and excellent discovery potential.

![DoubleChooz 90% C.L. versus year](image)

Figure 1. The $\sin^2(2\theta_{13})$ sensitivity limit of Double Chooz assuming the real value of $\theta_{13}$ is zero.

REFERENCES

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