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The Palo Verde Neutrino Oscillation Experiment

Presented by Giorgio Gratta on behalf of the Palo Verde Collaboration

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We are building a long baseline neutrino oscillation experiment utilizing ν_e from the large Palo Verde Nuclear Generating Station near Phoenix, Arizona. Once completed this experiment should reach sensitivities of $\Delta m^2 \simeq 1.5 \times 10^{-3}$ eV^2 and $\sin^2 2\theta \simeq 0.1$ exploring masses about one order of magnitude smaller that the current limits. Our range of sensitivity will allow us to conclusively ascertain whether the atmospheric neutrino anomaly is caused by $\nu_e - \nu_X$ oscillations. We report on the status of the construction describing the main experimental challenges of the project.

1 Introduction

Neutrino oscillations, if discovered, would shed light on some of the most essential issues of modern particle physics ranging from a better understanding of lepton masses to the exploration of new physics beyond the Standard Model. In addition the phenomenon of oscillations would have important consequences in astrophysics and cosmology. Experiments performed using both particle accelerators and nuclear reactors have been carried on extensively in the last 20 years finding no firm evidence for neutrino oscillations. However, in the last few years, evidence has been collected on two effects that could point to oscillations: the solar neutrino puzzle and the anomaly observed in atmospheric neutrinos. While in the first case an interpretation in terms of neutrino oscillations would lead to a Δm^2 too small to be directly observable in a ground

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based experiment, the atmospheric neutrino anomaly points to a region in parameter space, $\Delta m^2 \sim 1.5 \times 10^{-2}$ eV^2, $\sin^2 2\theta > 0.1$, that is accessible using MeV-energy neutrinos and a baseline of about a kilometer. In general terms a detector of adequate size located at such a distance from the core of a reactor would allow to reach $\Delta m^2 = 1 \times 10^{-3}$ eV^2 exploring a region of Δm an order of magnitude below the present experimental limits for $\bar{\nu}_e - \bar{\nu}_\mu$ and $\bar{\nu}_e - \bar{\nu}_\tau$ oscillations. Figure 1 shows the current limits in the oscillation parameter space together with the projected limits for future experiments.

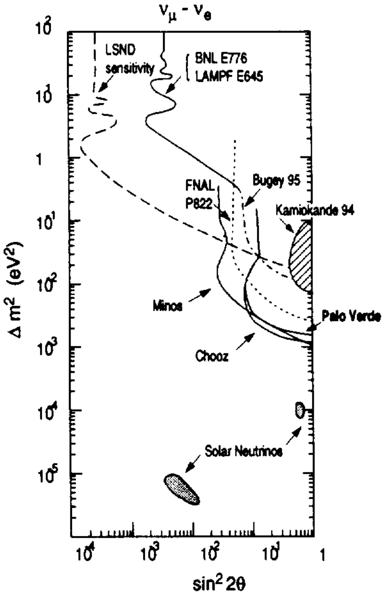

Figure 1: Phasespace for $\nu_e - \nu_X$ oscillations. The existing limits are compared with future experiment and the region obtained by interpreting the atmospheric neutrino anomaly as due to oscillations.

Two reactor long baseline experiments are presently in preparation: Chooz and Palo Verde. While the first is presented in[1] this paper will concentrate on the second[2].

2 Neutrino Source

The Palo Verde Nuclear Generating Station, located about 70 km west of Phoenix, Arizona, consists of three identical Pressurized Water Reactors producing a total thermal power of $\simeq$11 GW corresponding to $\simeq 2.3 \times 10^{31}\nu/\mathrm{s}$. A view of the complex is shown in Figure 2.

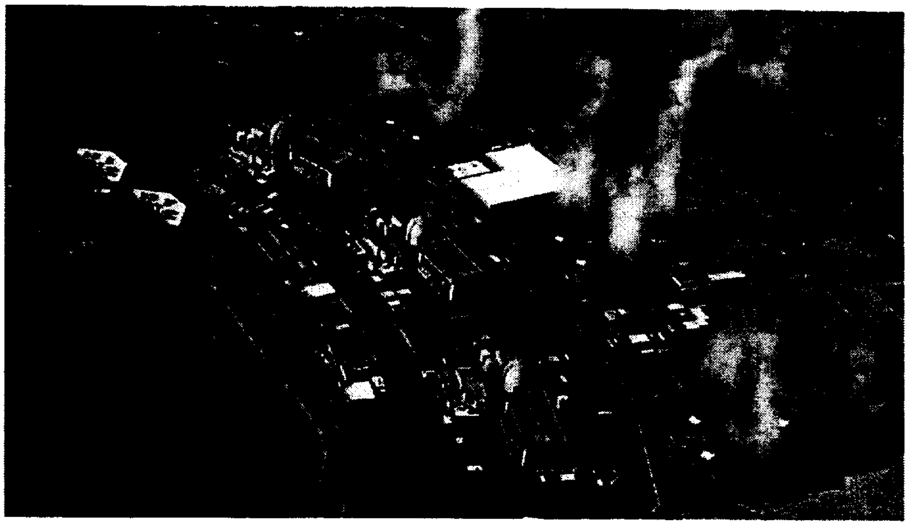

Figure 2: Aerial view of the Palo Verde Nuclear Generating Station. The neutrino oscillation laboratory is located 750 m from the reactors, past the cooling towers.

The refueling schedule of the plant consists of two periods of about 40 days each during which one reactor is down. We will use those periods at 2/3 power to measure the cosmic ray induced background.

The detector is located at 750 m distance from the reactors, in an underground laboratory with 46 mwe earth overburden that eliminates the hadronic component of cosmic radiation and reduces the muon component.

Compared with the San Onofre site near San Diego, California, where our experiment was originally supposed to be installed, the Palo Verde site has the advantage of larger power (by a factor 1.7) and heavier overburden (by a factor 1.6). Those advantages are compensated by the fact that the background subtraction will be less accurate at Palo Verde, since it will be measured at 2/3 power instead of 1/2 power. The conclusion of the Monte Carlo studies performed on the two sites is that there is no significant difference in the sensitivity achievable at the two sites using the same detector. In addition, although the extra statistics (51 events/day at Palo Verde versus 30 events/day at San Onofre for no oscillations) does not directely improve the accuracy that is dominated by the background subtraction, it will certainly help us in understanding and reducing systematics.

At the time of writing the underground laboratory is under advanced construction as shown in Figure 3, we expect to complete civil construction in october 1996.

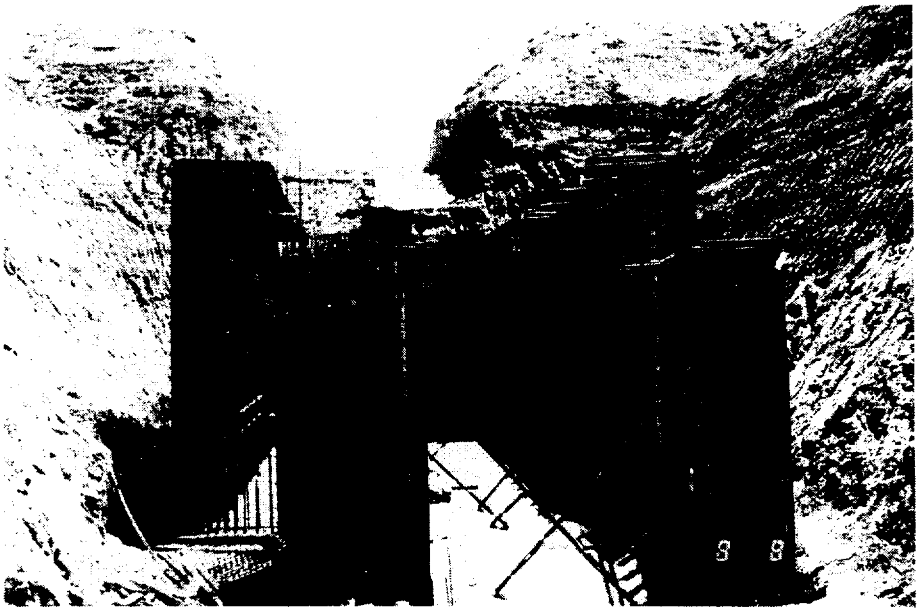

Figure 3: Underground construction as of early august 1996.

Our move from San Onofre to Palo Verde has been forced on us by the extreme difficulties of operating under unreasonably strict environmental regulations in Southern California. The baseline for the oscillation measurements has remained unchanged.

3 Detector Description

In order to have the best possible background identification we have designed a liquid scintillator segmented detector where the neutrino induced inverse-β decay reaction is identified by a four-fold coincidence. A neutrino event consists of a prompt triple coincidence produced by the e^+ and its two annihilation photons, followed by a delayed signal from the neutron capture. The time window for the delayed coincidence is kept as short as $100\mu s$ by doping the scintillator with 0.1% Gd, hence greatly reducing the n-capture time. At the same time the Gd loading benefits greatly the γ-ray background, as the 8 MeV Gd γ cascade is well above the energies produced by natural radioactivity. A detector end-view is shown in Figure 4. The active fiducial mass consists of 12 ton scintillator contained in 66 independent acrilic tanks. Each tank is 9 m long and can be fitted with two 5-inch photomultipliers on each end. Acrilic partitions form 80 cm long pure mineral oil buffers shielding active shintillator from external background in the end regions. Each acrilic tank from the central detector is supported by rollers and can be extracted for calibration purposes. A special 5-inch photomultiplier (D691) has been developped by Electron Tubes Inc.[3] to satisfy our requirements of low activity, single photoelectron separation, fast risetime and high gain.

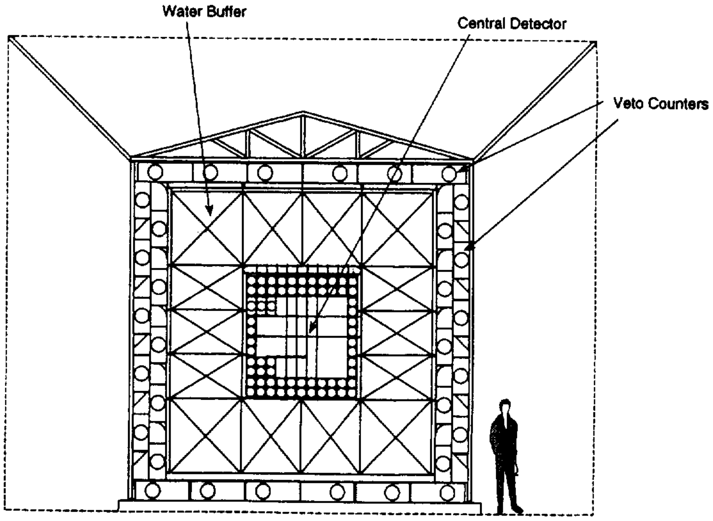

Figure 4: End view of the Palo Verde detector.

The neutrino detection efficiency has to be calibrated to about 3% in order to reach the sesitivity shown in Figure 1. Since this efficiency is a strong function of the energy detection threshold for the two γs from the positron annihilation we plan to perform real efficiency calibrations only few times (probably twice) in the experiment's life, using frequent energy calibrations to "interpolate" between them. The efficiency for e^+ triple coincidence detection is calibrated by using β^+ with $E < 1.9$MeV from Ga decay in

$$^{68}\mathrm{Ge}\xrightarrow{\mathrm{EC}}{}^{68}\mathrm{Ga}\xrightarrow{\beta^+,89\%}{}^{68}\mathrm{Zn}.$$

The radioactive Ge is diluted in a special acrilic tank that replaces, in turn, several tanks in geometrically representative positions. Monte Carlo simulation is used to transport the efficiency to other cells and to correct for different positron energies. Tests with a solution of tetra-n-butylgermane in hexane have shown that a very uniform source can be obtained, yielding the required calibration accuracy in a setup with shorter cells. Energy calibrations will be performed every few weeks using Compton-edge positions from several miniaturized γ-sources fed at various positions in the detector by a system of thin plastic pipes. Daily monitoring of the liquid scintillator attenuation length and of the photomultipliers gain will be provided by LEDs illuminating the scintillator through teflon diffusers and optical fibers carrying short pulses of laser light.

The 66 acrilic tanks are surrounded by a 1 m thick water wall contained in large steel tanks. The water serves the double function of γ-ray shield and neutron moderator.

A set of 32 large liquid scintillator counters surrounds the water buffer and it is used as cosmic ray veto. These 12 m long counters are leftovers from the MACRO detector [4]. Endcap veto coverage is provided by two $\simeq 4 \times 4\mathrm{m}^2$ walls, each formed by a stack of four liquid scintillator tanks. A system of rails allows walls to be retracted for access to the central detector.

4 Background

Background in the detector has been simulated using two different Monte Carlo programs. We call "uncorrelated" the background originated from γ-rays produced by radioactive decays around and inside the detector and from energy deposition from thermal neutrons. Four-fold coincidences can be produced if the space-time requirements for good events are accidentally met. This kind of background can be measured with negligeable statistical uncertainty by altering the coincidence structure in such a way as not to retain events with signal-like signature.

On the other hand "correlated" background consists mainly of fast neutrons depositing energy three times in quick succession, then thermalizing and being captured. These events have a signature that is practically undistinguisheable from signal events. Hence this kind of background can only be measured by observing the rate during the refueling periods when the power plant runs at 2/3 power. The great majority of fast neutrons is produced by cosmic-ray-muon spallation in the concrete of the laboratory structure (muons entering the detector region are rejected by the veto detector). Although we can reliably simulate the neutron energy depositions, moderation and capture, data on the neutron spectrum for the spallation process is not entirely consistent in the literature [6]. Using the recent measurement from Karmen[5] we predict a correlated background of 34 events/day, while this rate goes from 9 to 79 events/day using the most and least favorable spectra available.

All materials used for the detector, mechanical structure and underground laboratory are selected for low γ-ray emission in order to keep the uncorrelated background low. The aggregate (gravel and sand) used for the concrete is either a Marble available in Arizona (100-200 ppb Th concentration) or Olivine from Bellingham, Washington (10-20 ppb Th concentration). The central detector photomultipliers are built using low activity glass (respectively 50 ppb ^{40}K, 140 ppb U, 270 ppb Th concentrations), while a special ventilation system and nitrogen flushing of the central detector will be used to reduce the effect of ^{222}Rn. We expect a rate of uncorrelated background of 15 events/day using the Karmen results for the thermal neutron contribution, while the above best and worst case scenarios give 5 to 24 events/day.

In addition to these "forseen" backgrounds one has in general to try to be prepared for "unforseen" ones, we believe that the segmentation of our detector and the tight signature required are of substantial help in this respect. For instance backgrounds involving e^- - n (like ^{9}Li$\rightarrow^5$He $\beta^- + 2\alpha$+n) are easy to identify for us.

5 Conclusions

The Palo Verde neutrino oscillation experiment is now in the stage of advanced construction. We are planning to assemble the detector with water buffer, veto counters and 9 central detector elements in the fall and have a technical run by the end of 1996. The rest of the detector should be ready to take data in the spring 1997.

Acknowledgments

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