SCINTILLATION CRYSTAL DETECTOR FOR LOW ENERGY NEUTRINO PHYSICS

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A research collaboration among scientists from Taiwan, Mainland China and the United States has been built up since 1997 to initiate and pursue an experimental program in Neutrino and Astroparticle Physics. The theme of our efforts is the use of scintillating crystal detector for low-energy low-background experiments. The flagship experiment is based on CsI(Tl) crystals placed near the core of the Kuo-Sheng Nuclear Power Station in Taiwan to study low energy neutrino interactions. Various R&D projects are being pursued. A summary of our efforts and program is presented.

1 Overview

Since 1997, the TEXONO[a] Collaboration has been built up to initiate and pursue an experimental program in Neutrino and Astroparticle Physics [1]. By summer 2000, the Collaboration comprises more than 40 research scientists from major institutes/universities in Taiwan (Academia Sinica†, Institute of Nuclear Energy Research, National Taiwan University, National Tsing Hua University, and Kuo-Sheng Nuclear Power Station), Mainland China (Institute of High Energy Physics†, Institute of Atomic Energy†, Institute of Radiation Protection, Tsing Hua University, Nanjing University, Shandong University) and the United States (University of Maryland), with AS, IHEP and IAE (with †) being the leading groups. It is the first research collaboration of this size and magnitude. among Taiwanese and Mainland Chinese scientists

The research program is based on the the unexplored and unexploited theme of adopting the scintillating crystal detector techniques for low-energy low-background experiments in Neutrino and Astroparticle Physics [2]. The "Flagship" experiment [3] is based on CsI(Tl) crystals placed near the core of the Kuo-Sheng Nuclear Power Station (KSNPS) at the northern shore of Taiwan to study low energy neutrino interactions. It is the first particle physics experiment performed in Taiwan where local scientists are taking up major roles and responsibilities in all aspects of its operation: conception, formulation, design, prototype studies, construction, commissioning, as well as data taking and analysis.

In parallel to the flagship experiment, various R&D efforts coherent with the theme are initiated and pursued or being discussed and prepared.

[a] **T**aiwan **EX**periment **O**n **N**eutrin**O**

2 Scintillating Crystal Detector for Low-Energy Experiments

One of the major directions and experimental challenges in neutrino physics [4] is to extend the measurement capabilities to the sub-MeV range for the detection of the p-p and ^{7}Be solar neutrinos, Dark Matter searches and other topics. For instance, while high energy (GeV) neutrino beams from accelerators have been very productive in the investigations of electroweak, QCD and structure function physics, the use of low energy (MeV) neutrino as a probe to study particle and nuclear physics has not been well explored. Nuclear power reactors are abundant source of electron anti-neutrinos ($\bar{\nu_e}$) at the MeV range and therefore provide a convenient laboratory for these studies.

On the detector technology fronts, large water Cerenkov and liquid scintillator detectors have been successfully used in neutrino and astro-particle physics experiments. New detector technology must be explored to open new windows of opportunities. Crystal scintillators may be well-suited to be adopted for low background experiments at the keV-MeV range [2]. They have been widely used as electromagnetic calorimeters in high energy physics, as well as in medical and security imaging and in the oil-extraction industry. They offer many potentials merits for low-energy low-background experiments. In particular, they are usually made of high-Z materials which provide strong attenuation for γ's of energy less than 500 keV. Consequently, it is possible to realize a compact detector design with minimal passive materials equipped with efficient active veto and passive shielding. Externally originated photons in this energy range from ambient radioactivity or from surrounding equipment cannot penetrate into the fiducial volume. Therefore, the dominating contribution to the experi-

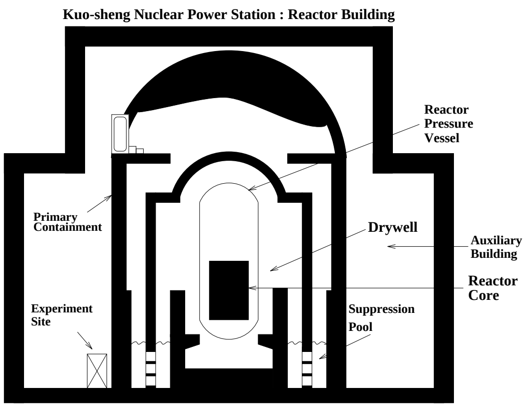

Figure 1: Schematic side view, not drawn to scale, of the Kuo-sheng Nuclear Power Station Reactor Building, indicating the experimental site. The reactor core-detector distance is about 28 m.

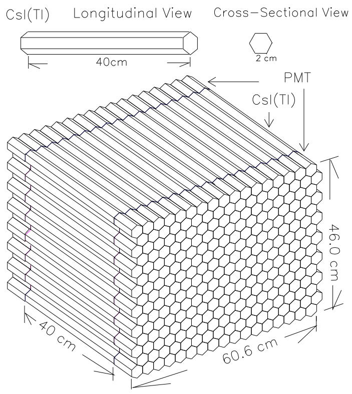

Figure 2: Schematic drawings of the CsI(Tl) target configuration.

mental sensitivities is expected to be from the internal background in the crystal itself, either due to intrinsic radioactivity or cosmic-induced long-lived isotopes, both of which can be identified and measured such that the associated background can be subtracted off accordingly. The experimental challenges are focussed on the understanding and control of the *internal background*. Pioneering efforts have already been made with NaI(Tl) crystals for Dark Matter searches,

3 Flagship Experiment

An experiment towards a 500 kg CsI(Tl) scintillating crystal detector to be placed at a distance of 28 m from a core in KSNPS is under construction to study various neutrino interactions at the keV-MeV range [3], and to establish and explore the general techniques for other low-energy low-background applications. The layout of the experimental site is shown in Figure 1

The physics objectives of the experiment are to improve on or to explore the subjects of: (1) Neutrino-electron scatterings, which is a fundamental interaction providing information on the electro-weak parameters (g_V, g_A, and $\sin^2\theta_W$), and are sensitive to small neutrino magnetic moments ($\mu\nu$) and the mean square charge radius, as well as the W-Z interference effects. (2) Neutrino interactions on nuclei such as ^{133}Cs and ^{127}I, and in particular the neutral current excitation (NCEX) channels where the signatures are gamma-lines at the characteristic energies. Their cross-sections are related to the physics of nucleon structure, and are essential to explore the scenario of applying these interaction channels in the detection of low energy solar and supernova neutrinos. (3) Matter effects on neutrinos, since this is the first big high-Z detector built for reactor neutrino studies.

To fully exploit the advantageous features of the scintillating crystal approach in low-energy low-background experiments, the experimental configuration should enable the definition of a fiducial volume with a surrounding active 4π-veto, and minimal passive materials. This is realized by a design shown schematically in Figure 2. One CsI(Tl) crystal unit consists of a hexagonal-shaped cross-section with 2 cm side and a length 20 cm, giving a mass of 0.94 kg. Two such units are glued optically at one end to form a module. The modules will be installed in stages towards an eventual 17×15 matrix configuration. The light output are read out at both ends by custom-designed 29 mm diameter photo-multipliers (PMTs) with low-activity glass, whose signals will pass through amplifiers and shapers to be digitized by 20 MHz FADCs [5]. The sum and difference of the PMT signals gives information on the energy and the longitudinal position of the events, respectively. The passive shieldings consist of, from inside out, 5 cm of copper, 25 cm of boron-loaded polyethylene, 5 cm of steel, 15 cm of lead and finally plastic scintillators as cosmic-ray veto. The target is housed in a nitrogen environment to prevent background events due to the diffusion of the radioactive radon gas.

Extensive measurements on the crystal prototype modules have been performed. The response is depicted in Figure 3, showing the variation of collected light for Q_1, Q_2 and Q_{tot} as a function of position within one crystal module. The error bars denote the FWHM width of the ^{137}Cs photo-peaks. The discontinuity at L=20 cm is due to the optical mis-match between the glue (n=1.5) and the CsI(Tl) crystal (n=1.8). It can be seen that Q_{tot} is independent of the position and a 10% resolution is achieved. The detection threshold (where signals are measured at both PMTs) is <20 keV. The longitudinal position can be obtained by considering the variation of the ratio $R = (Q_1 - Q_2)/(Q_1 + Q_2)$ along the crystal. Resolutions of 2 cm and 3.5 cm at 660 keV and 200 keV, respectively, have been demonstrated.

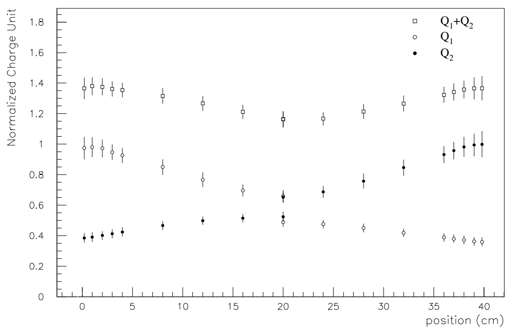

Figure 3: The measured variations of Q_1, Q_2 and $Q_{tot} = Q_1 + Q_2$ along the longitudinal position of the crystal module. The charge unit is normalized to unity for both Q_1 and Q_2 at their respective ends.

In addition, CsI(Tl) provides powerful pulse shape discrimination capabilities to differentiate γ/e from α events, with an excellent separation of >99% above 500 keV [6]. The absence of multiple α-peaks above 3 MeV in the prototype measurements suggests that a ^{238}U and ^{232}Th concentration (assuming equilibrium) of $< 10^{-12}$ g/g can be achieved.

By Fall 2000, all the components and shieldings are constructed and tested such that the detector assembly is taking place on site at KSNPS. A pilot data taking with a high purity germanium detector is underway, with focus on the understanding of background as well as for conducting a search of radiative decay of neutrinos. A 100 kg system will be installed on site after this program, while more target mass will be added in stages.

4 R&D Projects

Various smaller-scale projects with stronger R&D flavors are proceeding in parallel to the flagship experiment. A feasibility study of using boron-loaded liquid scintillator for the detection of $\bar{\nu_e}$ has completed [7,8]. The cases of using of GSO [9] and LiI(Eu) [10] scintillating crystals for low energy solar neutrinos are explored. The adaptations of CsI(Tl) crystal scintillator for Dark Matter WIMP searches are studied, which involves a neutron test beam measurement scheduled to be performed at the TANDEM accelerator at IAE.

Complementary to these physics-oriented program are detector R&D efforts. Techniques to grow CsI(Tl) mono-crystal of length 40 cm, the longest in the world, have been developed and are deployed in the production for future batches. Adaptations of other new technical development such as readout scheme and crystal wrappings are being planned. Measurements of intrinsic radiopurities of samples with the accelerator mass spectroscopy techniques have been scheduled. Links with the related theorist communities are being established.

5 Outlook

Neutrino physics and astrophysics will remain a central topics in experimental particle physics in the coming decade and beyond. There are room for ground-breaking technical innovations - as well as potentials for surprises in the scientific results.

A Taiwan, Mainland China and U.S.A. collaboration has been built up with the goal of playing a major role in this field. It is the first generation collaborative efforts in large-scale basic research between scientists from Taiwan and Mainland China. The technical strength and scientific connections of the Collaboration are expanding and consolidating. The flagship experiment is to perform the first-ever particle physics experiment in Taiwan.

The importance of the implications and outcomes of the experiment and experience will lie besides, if not beyond, neutrino physics.

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