The Starting Up of a Neutrino Project in Taiwan

C.Y. Chang *, S.C. Lee, and H.T. Wong †

Institute of Physics, Academia Sinica, Taiwan R.O.C.

There may be a unique opportunity to perform a long baseline reactor neutrino oscillation experiment in Taiwan, profiting from the power reactors which provide an abundant supply of neutrinos and the local mountainous geography where an underground laboratory can be built. A Taiwan-based Collaboration has been built up to intensely pursue a detector R&D program in preparation for a pilot experiment at the power reactors, the first step towards this goal. Our current efforts and future plans are presented.

1. INTRODUCTION

Phenomenal growth in basic and applied research has been taking place in the Asia Pacific region in the past decade [1]. As the economy of the region further strengthens, many projects in different fields have been initiated, and resources and positions were made available. Research directions and traditions are now being explored and defined. A wide spectrum of future particle physics projects in the Far East have been planned or discussed, and an overview is presented in [2].

Activities in experimental particle physics started in Taiwan in the early 90's. By now, there are more than 10 faculty-level physicists participating in a number of international experiments (L3, CDF, Fermilab E871, Belle, AMS, RHIC-PHOBOS), working on various hardware, online software and data analysis projects. A neutrino group was started in 1996, looking into the possibilities and opportunities in reactor neutrino experiments.

2. TAIWAN NEUTRINO GROUP

The principal objectives of the neutrino group are to initiate a program in experimental neutrino physics and astro-particle physics, as well as to build up a qualified experimental team for future projects.

The eventual goal is to conduct a world-class experiment in Taiwan. A good local research program is complementary to the participation of international projects, and is essential to the solid foundation of international collaborative basic research in the country. As the field grows and matures, the community has to acquire the experience of conceiving, formulating, fighting for, and then implementing and coordinating a big project. A local program also serves as a base for training young students and scientists, as well as promoting the subject to the general public.

Given the above implications and considerations, the field of choice is reactor neutrino. There are operational power reactors in Taiwan with parameters shown in Table 1. The mountainous landscape dotted with mines and tunnels makes the construction of an underground laboratory conceivable. The proximity of the reactor locations and the possible underground sites (Nuclear Power Plants I, II and IV are all about 20-30 km from Taipei city) to the city infrastructures and comfort provides an additional advantage. Since the project is started afresh, there are more flexibilities to optimize the various parameters like the reactor-detector distance and the detector target mass.

Starting 1996, a collaboration‡ has been built up to investigate the feasibility of performing a long baseline reactor neutrino oscillation experiment in Taiwan. At present, the Collaboration comprises more than 40 scientists with diversified expertise from Taiwan (Academia Sinica, Institute of Nuclear Energy Research, National Taiwan University, National Tsing Hua University and Taiwan Power Company), China (Institute of

*Also at University of Maryland, U.S.A.

†Contact Person : htwong@phys.sinica.edu.tw

Table 1
Power Reactor Plants in Taiwan and their Parameters

Plant	Type	#Cores	Power/core (GW)	Location	Status
I	Boiling Water	2	1.78	Northern Shore	Operational
II	Boiling Water	2	2.90	Northern Shore	Operational
III	Pressurized Water	2	2.78	Southern Shore	Operational
IV	Advanced Boiling Water	2	4.1	Northern Shore	Completed 2004

High Energy Physics at Beijing, Nanjing University, Shandong University, University of Science and Technology at Hefei) and the United States (University of Maryland).

The Collaboration has been intensely pursuing efforts in two fronts : 1) an R&D program on liquid scintillator, and 2) the preparation of a pilot experiment using a detector with 1-ton target mass to be put inside the Nuclear Power Plant II at about 40 m from the core. These projects are funded and will serve as important learning exercise and team-building efforts for our new Collaboration. It is expected that this experience will equip us with the necessary experimental techniques in this field and will help us to build up a qualified team to make major contributions in future projects. The scientific aspects of these efforts are discussed in further details in the next section.

First investigations will soon be carried out towards the conception and formulation of the "next" project. This "next" project will have to be coupled to the world agenda and will probably be international. There are a few alternatives :

- an O(1 km) + O(10 tons) detector probing the atmospheric neutrino anomaly region (down to $\Delta m^2 \sim 10^{-3}$ eV^2 in the $\bar{\nu_e} \rightarrow \bar{\nu_x}$ channel) - whether a second generation experiment in this region is justified and of interest will depend critically on the forthcoming results [3] from the Chooz [4] and Palo Verde [5] experiments.

- an O(10 km) + O(1 kilo-ton) detector probing the large mixing solution of the solar neutrino puzzle (down to $\Delta m^2 \sim 10^{-5}$ eV^2 in the $\bar{\nu_e} \rightarrow \bar{\nu_x}$ channel) - this is very ambitious and will require several years of internationally-coordinated R&D efforts to define the scientific program and the practical detector design. A proposal (KamLAND [2]) already exists along this line, utilizing the existing underground site of the Kamiokande detector.

- being a new group, we are also leaving our options open to other interesting avenues.

3. CURRENT ACTIVITIES

The principal objective of the current R&D program is to develop large scale (> 1 m in the initial phase) detector system of liquid scintillator loaded with ^{10}B, and with pulse-shape discrimination (PSD) (α/γ separation) capabilities.

Electron anti-neutrinos from the reactor interact with proton from the liquid scintillator via the standard reaction :

$$\bar{\nu_e} + p \rightarrow e^+ + n \quad . \tag{1}$$

The emitted neutron will be thermalized and captured by ^{10}B with a typical delay of less than a few μs :

$$n + {}^{10}B \rightarrow {}^{7}Li^* + \alpha \quad (Q = 2.3 \text{ MeV}) \tag{2}$$

$$^{7}Li^* \rightarrow {}^{7}Li + \gamma \quad (E_\gamma = 480 \text{ keV}). \tag{3}$$

The large cross section ($\sigma \sim 4000$ barn) and high isotopic abundance (20%) makes ^{10}B an interesting isotope to provide thermal neutron capture. In particular, liquid scintillator can be produced with a concentration up to the range of 1% ^{10}B by weight (or up to 5% ^{10}B if the isotopic abundance is further enriched). Indeed, though expensive, commercial liquid scintillator with enriched-^{10}B loading [10] does exist. This leads to a much shorter capture time (a few μs) with >99% capture efficiency compared to other good isotopes adopted in previous and current reactor neutrino experiments where the capture time is of the range of 30-100 μs: ^{3}He in Goesgen (inhomogeneous detector) [6], ^{6}Li in Bugey (0.1% by weight) [7], and ^{157}Gd in Chooz [4] and Palo Verde [5] (0.1% by weight). The capture time in unloaded liquid scintillation is typically 180 μs. The capture time distribution for neutrons with an initial energy of 0.5 keV in a liquid scintillation with different amount of ^{10}B by weight, based on a full MCNP simulation [11], is depicted in Figure 1, showing a mean capture time of 2.3 μs for a ^{10}B concentration of 1%.

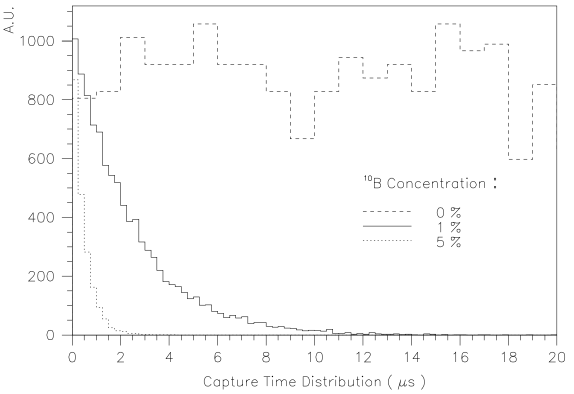

Figure 1. Full simulation of the capture time distribution of neutron with 0.5 keV initial energy in a liquid scintillator medium with 0%, 1% and 5% ^{10}B by weight. The mean capture time is 2.3 μs for a ^{10}B concentration of 1%..

Besides reactor neutrinos, large-scale boron-loaded liquid scintillator may find potential applications in other neutrino experiments. ^{11}B (isotopic abundance 80%) has been identified as an attractive candidate for solar neutrino detection (both charged- and neutral-currents) [8], while the measurements of the neutral-current excitation cross sections of ^{11}B may shed lights on the axial isoscalar neutral-current couplings [9].

Modest success have been achieved and the liquid scintillator developed (a pseudocumene + trimethyl-borate based solution) has similar performance in terms of light yield, attenuation length and PSD capabilities as the commercial product [10], whereas the cost is much reduced. Their comparisons are shown in Table 2, while Figure 2 displays their measured attenuation length as a function of wavelength.

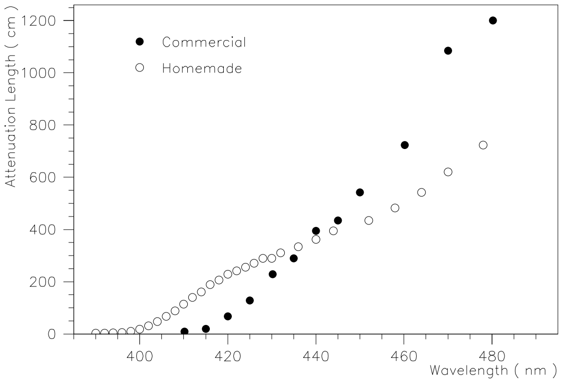

Figure 2. Measured attenuation length of the homemade liquid scintillator as compared to the commercial one.

PSD capabilities are powerful means for identifying the $e^+ - \alpha$ signatures. The measured "PSD spectrum" (partial to total charge collected) of the homemade liquid scintillator at 1.0% ^{10}B concentration is depicted in Figure 3, demonstrating good α/γ separation. The data are based on measurements of the $\alpha +^7$ Li signatures from the thermal neutron capture of ^{10}B with an electron-equivalence light output of only 50 keV, as compared to the γ pulses from a 60 keV ^{241}Am X-ray source.

Parallel to the R&D program, intense efforts are being made in the preparation of a pilot experiment at the reactor, a necessary technique-learning and team-building exercise. The detector will be located at Nuclear Power Plant II, at a distance of about 43 m from one core and 80 m from the second one. It will be modular in design, with a 10×10 cells array each having a dimension of $8 \times 8 \times 150$ cm^3. The target will be boron-loaded liquid scintillator, having a total mass of about 820 kg. The reactor $\bar{\nu}_e$ spectrum will be measured and compared with calculations.

Table 2
Comparison between the Commercial and Homemade Liquid Scintillator

	Commercial [10]	Homemade
Mean attenuation length	4 m	3.2 m
Relative light yield	1.00	1.06
PSD (relative figure of merit) ¶	0.9	1.0
% ^{10}B by weight	4.4% (90% enriched)	0.4% (natural)
Cost	USD 4600 /l	USD 60 /l

¶ On α's from ^{241}Am.

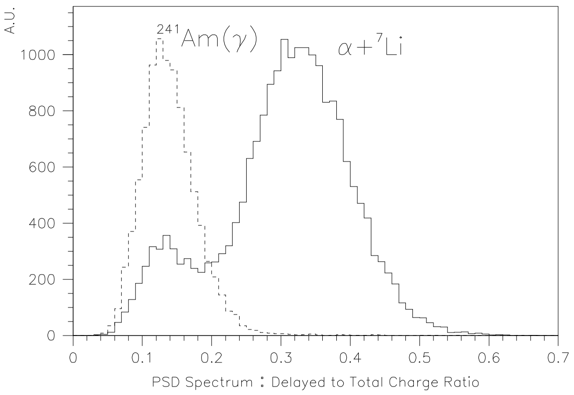

Figure 3. Measured PSD spectrum of the home-made liquid scintillator loaded with 1.0% ^{10}B by weight : γ from ^{241}Am (60 keV) and $\alpha +^{7}$ Li from the neutron capture of ^{10}B (50 keV).

4. OUTLOOK

The Asia Pacific region, with its rising economic prosperity and solid basic education, is now matured to move into the arena of international collaborative basic research (the “Big Science”). This is a new “parameter space” of experience which the region will have to explore. A Taiwan and mainland China collaboration has been built up to intensely study the feasibility of performing a long baseline reactor neutrino experiment in Taiwan.

This is a pioneering “foundation” effort for Taiwan, and the importance of its outcome lies besides, if not beyond, neutrino physics. The Collaboration will make a rigorous attempt towards the realization of this goal.

‡ Taiwan Neutrino Project Collaboration : C.P.Chen, G.C.Jon, G.C. Kiang, W.P. Lai, S.C. Lee, R.W.S. Leung, I.C. Shih, P.K. Teng, C.W. Wang, S.C. Wang, H.T.K. Wong (Academia Sinica); K.C. Cheung, T.S. Guung, D.L. Lin (INER); T.I. Ho, C.C. Hsu, H.B. Li, S.L. Wang (NTU); J.H. Chao, K.P. Chen, H.M. Liu, C.H. Jiang, J.J. Kai, L.J. Yuan (NTHU); R.F. Su (TPC); J. Li, Z.P. Mao, Z.Q. Yu, D.X. Zhao, Z.P. Zheng (IHEP Beijing); X.Q. Yu (Hefei); T.Y. Chen, Q.G. Xu, Z.W. Zhang (Nanjing); Y. Fu, M. He, J.Y. Li, N.J. Zhang, X.Y. Zhang (Shandong); G.C.C. Chang, C.Y. Chang (Maryland).

REFERENCES

1. For further details, see Nature **383**, 11 (1996).
2. K. Nakamura, these Proceedings (1997).
3. Y. Declais, these Proceedings (1997).
4. H. de Kerret et al., Chooz Proposal (1993); A. Baldini, these Proceedings (1997).
5. F. Boehm et al., Palo Verde Proposal (1993); P. Vogel, these Proceedings (1997).
6. G. Zacek et al., Goesgen Collaboration, Phys. Rev. **D 34**, 2612 (1986).
7. B. Achkar et al., Bugey Collaboration, Nucl. Phys. **B 434**, 503 (1995).
8. R.S. Raghavan, S. Pakvasa, and B.A. Brown, Phys. Rev. Lett. **57** 1801 (1986).
9. J. Bernabéu et al., Nucl. Phys. **B 378**, 131 (1992).
10. Liquid Scintillator BC523A, Bicron, U.S.A.
11. J. F. Briesmeister ed., "MCNP - A General Monte Carlo N-particle Transport Code, Version 4A", LA-12625-M (1993).