AS-TEXONO/00-02
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NSC Research Proposal (2000-2001)
on
Low-Energy Neutrino Physics
and
Scintillating Crystal Detectors

Henry Tsz-king Wong [α], Jin Li [β], and George Chia-Cheh Chang [γ]

[α] Institute of Physics, Academia Sinica, Taiwan
[β] Institute of High Energy Physics, Chinese Academy of Science, China
[γ] Department of Physics, University of Maryland, U.S.A.

on behalf of
The TEXONO Collaboration

Abstract

A Collaboration comprising scientists from Taiwan, Mainland China and the U.S.A has been built up since 1996 to initiate and pursue an experimental program in neutrino and astro-particle physics. A pilot experiment to be performed at the Nuclear Power Plant II in northern Taiwan is now under intense preparation, while various R&D projects towards future experiments are being pursued. This article presents an overview of our efforts and serves as part of the supporting materials submitted for the funding request from the National Science Council in the period August 2000 till July 2001. We request funding to enhance and upgrade the operation of the pilot experiment, and for the procurement of equipment and materials to support part of the R&D program.

1 Overview

Since 1996, under the initiation and leadership of the High Energy Physics group from the Institute of Physics of the Academia Sinica, a Collaboration comprising scientists from Taiwan, Mainland China and the U.S.A was built up to initiate and pursue an experimental program in neutrino and astro-particle physics [1]. By 1999, the TEXONO[1] Collaboration consists of more than 50 collaborators with diversified and inter-disciplinary background and expertise that cover a wide spectrum of experimental techniques. The collaborator list is shown in Table 1. Strong connections have also been established with the industries and other major research institutes world-wide.

After an initial R&D effort on loaded liquid scintillator [4], the activities of the Collaboration since 1997 have been related to the general theme of adopting "Scintillating Crystal Detectors for Low-Energy Low-Background Experiments" [5]. The focus in 1997-1999 has been on the conception, formulation, prototype design studies and the construction of a "pilot" experiment [2,6,TR1] to be performed near the reactor core of the Nuclear Power Plant II (NP2) [I] at northern Taiwan. It is based on a CsI(Tl) crystal scintillator to be placed 30 m from a reactor core to study various low energy interactions between neutrinos (electron-antineutrinos $\bar{\nu}_{\rm e}$ to be exact) and matter (electrons and nuclei). Various future directions are also discussed and explored [TR2]. Funding for the construction of the pilot experiment has been provided by the National Science Council (Taiwan), the National Science Foundation (Mainland China) and the National Science Foundation (U.S.A.) [I].

In the 2000-2001 time frame, the focus will be on the execution of the pilot experiment, as well as on launching the various R&D efforts paving the way for future experiments which the Collaboration may evolve into. We request continuing support from NSC to consolidate and substantiate these efforts.

2 Research Projects

The details of our research efforts are thoroughly discussed in the enclosed documents [III,IV], and the technical reports [TR1,TR2]. In this section, we present our the status of the pilot experiment, and elaborate on the new development.

[1] **T**aiwan **EX**periment **O**n Neutrin**O**

2.1 Pilot Experiment

The experimental details are described in our Technical Design Report [TR1]. The major new development is the choice of photo-multiplier (PMT) with a newly developed low-activity glass envelope instead of the original option of "photo-diode plus pre-amplifier". This gives much better detector performance in terms of energy and position resolution, as well as the detection threshold [8], giving a sensitivity down to 20 keV - important for the magnetic moment studies, and for the full exploitation of the merits of the crystal scintillator technique.

At present (December 1999), design studies and prototyping work are completed [6]. The first 100 kg of CsI(Tl) were grown while the second 100 kg batch are under preparation. The complete electronics and trigger system (41 electronic boards with 13 different design, all developed by the Collaboration) [9] for 200 channels are being mass produced and tested. Online data acquisition, monitoring and "slow control" software, as well as the offline simulation and data analysis packages, are being developed. A 16-channel system has been in stable operation at the AS laboratory. Detector performance parameters are measured while the calibration procedures are worked out. The engineering design of the 50-ton shielding complex has successfully passed the NP2 safety review, and is being constructed, first at the contractor's home base. The shielding is scheduled to be moved to the NP2 site in April 2000, after which a 100-channel system will be installed there to start data taking and on-site background studies.

The digital camera images of (a) a crystal module (2 kg), (b) the FADC board, (c) part of the electronics circuits developed for this experiment, (d) part of the 16-channel prototype system operation at AS, and (e) the shielding under construction at the contractor's base are enclosed with this document [V].

We will start data taking on-site by summer 2000, first with a 100-channel system and will evolve in phase to the 200-channel system in 2001. Further increase of target mass or other detector upgrades will necessarily depend on the first results.

2.2 R&D Directions

The possible future directions of the Collaboration and our options and strategies to proceed are discussed in a technical report [TR2]. While the pilot experiment is getting to the implementation and execution phase, we plan to launch several R&D projects towards these ends. The topics and the respective leading institutes are listed below.

1. **Further Development on the Crystal Scintillator Technique:**
   There are various fronts relating to the further development of this detector technique.

   - Production of CsI(Tl) crystal scintillators are typically limited in length to about 30 cm. Efforts are underway to explore the techniques of producing longer crystals (first goal 40 cm) either as single-crystal or in poly-crystalline form. **(IHEP, industrial partner)**
   - A new coating material called "sol-gel" was developed recently for the LHC-CMS lead tungstate electromagnetic calorimeter. It can be as thin as a few microns and promises to greatly reduce the inactive volume and materials within the fiducial volume of the detector. This may further enhance the merits of the crystal scintillator approach in low-background experiments, since radioactivity is proportional to the mass. We plan to study this material, in connections with its effects on CsI(Tl) performance and its intrinsic radiopurity. **(AS, UMD, IHEP)**
   - Recently, Hamamatsu Photonics announced the availability of a new "Flat Panel PMT" in April 2000, which has potentials of revolutionizing PMTs' applications. We plan to study the adaptation of this device in low-background experimentation. **(AS)**

   Though our goals are on low-energy low-background applications, these R&D efforts may well find applications in other areas.

2. **Radiopurity Measurements with Accelerator Mass Spectroscopy (CIAE, AS):**
   Measuring the radiopurity of detector target materials as well as other laboratory components are crucial to the success of low-background experiments. The typical methods are direct photon counting with high-purity germanium detectors, or the neutron activation techniques. We plan to enhance the capabilities of radiopurity measurements further with the new Accelerator Mass Spectroscopy (AMS) techniques. This technique may be complementary to existing methods since it is sensitive to radioactive isotopes that do not emit γ-rays (like single beta-decays from ^{87}Ru and ^{129}I) or where γ emissions are suppressed (for instance, measuring ^{39}K provides a gain of 10^5 in sensitivity relative to detecting γ's from ^{40}K). Beam time is scheduled at the CIAE Tandem accelerator in 2000 for a pilot run. The approval statement is enclosed [I].

3. **Development of New Crystal Scintillators (NTU, AS, industrial partner):** Crystals based on zirconium oxide are industrially produced in large-scale (tons per day) in Taiwan for the jewelry industry. Production rate is at least 10 times faster than scintillating crystals while the price is at least 10 times cheaper. It has good transmission for optical light. Studies are being made with the goal of making the crystal scintillate by doping with appropriate chemicals. If the scheme is successful, it can be an attractive new detector technology. Possibilities of producing indium- and ytterbium-based crystals using similar techniques are also considered. Both ^{115}In and ^{176}Yb are good candidates for solar neutrino detection, by providing spatial and temporal correlations to the signatures.

4. **Development of GSO Crystals (CIAE, AS, industrial partner):** It is recognized recently that ^{160}Gd is a good candidate target in the detection of solar neutrino by providing a flavor-specific time-delayed tag. The scintillating crystal GSO (Gd_2SiO_5(Ce)) may be an optimal way to realize a detector. We are in close contact with groups from Grenoble and Tokyo within the LENS[2] proto-collaboration in exploring the feasibilities of this idea. Besides solar neutrino detection, ^{160}Gd is also a double beta decay candidate isotope. In addition, GSO offers superior performance in every aspect than the commonly used crystal BGO. If the price can be driven down, it has the potentials of replacing BGO as electro-magnetic calorimeters and in medical imaging.
   Up to now, the crystal is commercially available only from Hitachi Co., Japan. The Collaboration succeeded already in growing the crystal, and the immediate next steps are on the systematic studies and optimizations. Our industrial partner plans to market the product eventually at a similar price range to BGO. Meanwhile a 1.7 kg crystal grown by Hitachi (worth 1M Yen) is on loan to us from Osaka University. Performance, background and sensitivities studies are under way [10].

5. **Development of LiI(Eu) Crystals (UMD, industrial partner):** The University of Maryland group first proposed the use of LiI(Eu) detector for solar neutrino detection in 1994, because of the relatively large charged and neutral current cross-sections. Based on the experience built up by the pilot experiment, the idea will be pursued further.

6. **Feasibility Studies for Dark Matter Searches (AS, NTU):** Experiments based on the mass range of 100 kg of NaI(Tl) are producing some of

[2]**Low Energy Neutrino Spectroscopy**

the most sensitive results in Dark Matter "WIMP" searches. We are studying the feasibilities and technical details of adapting CsI(Tl) or other good candidate crystal like CaF_2(Eu) for these experiments.

Experience and results from the pilot experiment will shed much light on the feasibilities and sensitivities of this detector approach. For the nuclear recoil signatures due to WIMP-nuclei elastic scattering, the crucial issue is the detector performance and background at the 1-10 keV range Another signature based on WIMP-nuclei inelastic scattering are gamma-lines at the characteristic energies. This will be studied based on data from the pilot experiment.

Further details and a complete list of reference for items 4,5,6 discussed above can be found in the enclosed documents [5] and Technical Report [TR2].

3 Collaboration Organization and Tasks Sharing

The overall research efforts of the TEXONO Collaboration are co-ordinated by the AS group. Co-ordination of tasks as well as the funding request and management within the three regions are under the responsibilities of their respective principal investigators: H.T.K. Wong for Taiwan, J. Li for Mainland China, and G.C.C. Chang for the U.S.A. Collaboration meetings are held once every three to four months, while regular electronic mails, telephone meetings and video conferences provide the necessary communications in between.

Prototyping studies, design work and the construction of the different detector components for the pilot experiment are distributed among the collaborating institutes. The task sharing is summarized in Table 2. The assembly, installation and operation of the experiment, as well as the co-ordination of subsequent analysis, are under the responsibility of the AS group.

Collaborating institutes generate the various research projects mentioned in Section 2.2. The infra-structures and working relationships, as well as the efficient channels of communications and sharing of resources (equipment and expertise), already established in the past three years provide a solid base to carry out these projects.

The list of collaborating institutes and collaborators are expanding with time, as more contacts are established and as our efforts and idea are gaining further attention. For instance, the AMS and GSO teams from CIAE were not on the initial NSC Proposal for the pilot experiment. They recently joined the Collaboration to explore new areas of applications to their expertise. In a similar spirit, the NTU-HEP group (having experience with BGO crystals for electromagnetic calorimetry) participates in the R&D efforts for Dark Matter Search.

4 Schedules and Expected Results

The expected status and results for the various research efforts of the TEXONO Collaboration in the 2000-2001 time frame would be :

1. **Pilot Experiment.**
   As discussed in Section 2.1, the shielding complex is scheduled to move to NP2 in April 2000. The first 100 channels of detector and full electronics will be installed by July 2000, after which detector commissioning and data taking will start. The system will evolve in stages to 200 channels by 2001. On-site background conditions, as well as their understanding and control, will be the major experimental challenge at this stage. Data analysis on neutrino-electron scatterings as well as neutrino neutral current excitations on nuclei (^{127}I and ^{133}Cs) will be the primary physics focus with the first data.
   Future upgrades and directions of the pilot experiment, as well as the potentials of this approach in the world-scene, will depend on the operational experience and detector performance results. Interested colleagues elsewhere are eager to know how far and how well we can proceed with this idea.

2. **R&D Projects.**
   The various R&D projects discussed in Section 2.2 will be pursued. Items 4,5,6 have already started, while a pilot run for exploring the AMS technique in radiopurity measurement is scheduled with the CIAE Tandem in the second half of 2000. Further beam times are expected. Preparations are under way to launch the crystal detector development projects while the development of new scintillators is in the discussion phase.
   By 2001, we expect to complete the various crystal detector development projects (Item 1), paving the way for the upgrades of the pilot experiment and contributing to the conceptual design of future experiments along this direction. The AMS adaptations (Item 2) to radiopurity measurements would be explored. It would be a solid contribution to the field. The GSO crystal (Item 4) would become a matured

product from our industrial partner, adequate for applications as calorimeters and medical imaging. Its feasibilities for solar neutrino experiments would be clear.

3. **Formulation of Future Experiments.**
   All along, the Collaboration will keep an open eye on other interesting R&D projects which can be incorporated into our operation framework. Contact will be maintained and enhanced with the international community towards the goal of the conception and formulation of the next generation low-energy solar neutrino experiment.

It should be noted and stressed that our efforts represent the one of the first large-scale collaborative research efforts in basic science among leading research institutes in Taiwan and Mainland China. During the course of our work in the past three years, many difficulties were identified and solved. Many unexplored channels relating to the mutual flow of manpower, equipment and funding were studied and opened up. Extensive contacts have been established with the research communities and with the industries in Mainland China. An official Memorandum of Understanding [II] has been signed between Academia Sinica and the Institute of High Energy Physics. These experience and contacts will provide valuable reference to similar collaborative efforts in the future.

5 Publications

The published articles in SCI-journals as well as those scheduled to be submitted in 2000 are listed below.

1. "The Starting-Up of a Neutrino Project in Taiwan", C.Y. Chang, S.C. Lee and H.T. Wong, Nucl. Phys. **B** (Procs. Suppl.) **66**, 419 (1998).

2. "A Pilot Experiment with Reactor Neutrinos in Taiwan", H.T. Wong and J. Li, hep-ex/9805024, Nucl. Phys. **B** (Procs. Suppl.) **77**, 177 (1999).

3. "Charge Comparison Method to Discriminate Photons and Neutrons in Liquid Scintillators" (in Chinese), Y. Chen et al., High Energy Physics and Nuclear Physics **23**, 616 (1999).

4. "A Feasibility Study of Boron-Loaded Liquid Scintillator for the Detection of Electron Anti-neutrinos", S.C. Wang et al., Nucl. Instrum. Methods **A 432**, 111 (1999).

5. "Prospects of Scintillating Crystal Detector in Low-Energy Low-Background Experiments", H.T. Wong et al., hep-ex/9910002, submitted to Astropart. Phys. (1999).

6. "A CsI(Tl) Crystal Scintillator for the Studies of Low Energy Neutrino-Electron Scatterings", H.B. Li et al., hep-ex/0001001, submitted to Nucl. Instrum. Methods (2000).

7. "A CsI(Tl) Crystal Detector for Low Energy Neutrino Physics", H.T. Wong, J. Li and C.C. Chang, to appear in Nucl. Phys. **B** (Procs. Suppl.) (2000).

8. "Studies of Prototype CsI(Tl) Crystals for Low-Energy Neutrino Experiments", C.P. Chen et al., in preparation for Nucl. Instrum. Methods (2000).

9. "The Electronics and Data Acquisition Systems for a Multi-Channel CsI(Tl) Scintillating Crystal Detector for Low Energy Neutrino Physics", W.P. Lai et al., in preparation for Nucl. Instrum. Methods (2000).

10. "Background Measurements and Subtraction Methods for GSO Crystal", S.C. Wang et al., in preparation for Nucl. Instrum. Methods (2000).

11. "A Compact Low-Noise Pre-amplifier for Photo-diode Readout in Scintillating Crystal Detector", Z.S. Liu et al., in preparation for High Energy Physics and Nuclear Physics (2000).

6 Request of This Proposal

In this Proposal to the NSC Research Grant (2000-2001), we focus on several specific items during this period.

1. **Operation of the Pilot Experiment**
   The Collaboration has secured funding adequate for the construction of 200 kg of CsI(Tl) crystals, 120 photo-multipliers and their base, 250 channels of Ver. 1.0. electronics plus data acquisition systems, and the entire 50-ton shielding complex. In the 2000-01 time frame, we request 50% funding for:
   - an additional 100 kg of CsI(Tl) crystals, for spares, upgrades and tests, and
   - the next 120 photo-multipliers and base.

   The remaining 50% will be provided by the Academia Sinica operation fund. In addition, we request funding for the components of electronics upgrades, connectors and cables, data storage disks, as well as for the budget for installing operating the experiment at NP2. Furthermore, the support of a postdoc position for Dr. Wen-ping Lai, the software co-ordinator of the Collaboration, will be very crucial.

2. **R&D Efforts**
   Most of the resources necessary to launch the various R&D initiatives will be based on the operation funds from AS, IHEP, CIAE and UMD, and from the infrastructures the Collaboration built up in the past year. In this NSC proposal, we only request funding support for:
   - the new Hamamatsu Flat-Panel PMTs,
   - materials cost for the Accelerator Mass Spectrometry efforts at CIAE.

7 Documents and Articles Included

Several articles prepared by the Collaboration are included to this Proposal. They provide many experimental details to substantiate the global framework described in the article. A comprehensive list of references are cited therein. A list of all our public-domain articles can be refered to and down-loaded from our Web-page **http://www-hep.phys.sinica.edu.tw/EXONO/index.html/TEXT/TEXONO/**.

I. Copies showing (a) the available funding from the National Science Foundation (Mainland China) and (b) the National Science Foundation (U.S.A.) for the construction of the pilot experiment, as well as (c) the official approval letters for working at Nuclear Power Plant II from Taiwan Power Company, and (d) for beam time at the Tandem acceleration at Mainland China's Institute of Atomic Energy for doing Accelerator Mass Spectroscopy measurements.

II. The official Memorandum of Understanding signed between the PIs from the Academia Sinica and the Institute of High Energy Physics.

III. "Prospects of Scintillating Crystal Detector in Low-Energy Low-Background Experiments", H.T. Wong et al., hep-ex/9910002, AS-TEXONO/99-02, submitted to Astropart. Phys. (1999).
(Ref. 5 in publication list)

IV. "A CsI(Tl) Scintillating Crystal Detector for the Studies of Low Energy Neutrino Interactions", H.B. Li et al., hep-ex/0001001, AS-TEXONO/00-01, submitted to

Nucl. Instrum. Methods (2000).
(Ref. 6 in publication list)

V. Digital camera images of (a) a crystal module (2 kg), (b) the FADC module, (c) part of the electronics circuits developed for this experiment, (d) part of the 16-channel prototype system operation at AS, and (e) the shielding under construction at the contractor's base.

In addition, we note in particular two Technical Reports which are available on request or download-able from our Web-page. They have been submitted as supporting documents in our NSC-Proposal (1999-2000). We do not include them in this package for economy and simplicity reasons.

TR1. "A Pilot Experiment with Reactor Neutrinos in Taiwan : A Technical Status Report", C.P. Chen et al., TEXONO Collaboration, AS-TEXONO/98-07 (1998).
(120 pages, the "Blue Book" : description of experimental details of the pilot experiment)

TR2. "Experimental Neutrino Research in Taiwan: Directions and Prospects", H.T. Wong, AS-TEXONO/98-08 (1998).
(40 pages, the "Brown Book" : discussions of directions and strategies and approaches)

The TEXONO Collaboration

C.P. Chen, Y.P. Chen, G.C. Jon, G.C. Kiang, W.P. Lai, S.C. Lee,
C.S. Luo, P.K. Teng, C.W. Wang, S.C. Wang, H.T.K. Wong †
Academia Sinica, Taipei, Taiwan

D.I. Lee, T.R. Yeh
Institute of Nuclear Energy Research, Lungtan, Taiwan

Y.C. Tan
National Chiayi Teachers College, Chiayi, Taiwan

T.F. Lin
National Taitung Teachers College, Taitung, Taiwan

P.T. Chang, T.I. Ho, W.S. Hou, H.B. Li, M.Z. Wang, K. Ueno
National Taiwan University, Taipei, Taiwan

J.H. Chao, C.Y. Liang, H.M. Liu
National Tsing Hua University, Hsinchu, Taiwan

R.F. Su
Nuclear Power Plant II, Kuosheng, Taiwan

S. Jiang, L. Hou, H.C. Sun, H.Q. Tang, Z.Y. Zhou
Institute of Atomic Energy, Beijing, China

Y.F. Lai, J. Li †, Y. Liu, J.G. Lu, Z.P. Mao, J.F. Qiu, H.Y. Sheng, F. Shi, L.S. Wang,
P.L. Wang, X.M. Xia, C.X. Yu, D.X. Zhao, J.W. Zhao, P.P. Zhao, S.Q. Zhao, B.A. Zhuang
Institute of High Energy Physics, Beijing, China

Z.S. Liu, Z.Y. Zhang
Institute for Radiation Protection, Taiyuan, China

T.Y. Chen
Nanjing University, Nanjing, China

M. He, X.Y. Zhang
Shandong University, Jinan, China

C.Y. Chang, G.C.C. Chang †
University of Maryland, Maryland, U.S.A.

† **Co-Principal Investigators:**

Taiwan - Henry T.K. Wong, Academia Sinica (htwong@sinica.edu.tw)
Mainland China - Jin Li, Institute of High Energy Physics (lijin@bepc5.ihep.ac.cn)
U.S.A. - George C.C. Chang, University of Maryland (chang@enp.umd.edu).

Table 1: The institutes and collaborators list of the TEXONO Collaboration, for both the pilot experiment and various R&D projects.

Institutes	**Tasks and Responsibilities**
AS	Overall coordination, physics, electronics design and construction, data acquistion and on-line control systems, simulations, offline software coordination, experiment installation and operation. **R&D projects : coordination,** **Dark Matter searches.**
INER	Shielding design and construction, mechanics and workshop facilities, radiopurity (neutron activation).
NCTC	Student participation.
NTTC	Student participation.
NTU	Student participation, data acquisition, physics and chemistry of scintillation. **R&D projects : new crystal detectors,** **Dark Matter searches.**
NTHU	Nuclear engineering, neutron transport calculation, radiopurity (germanium detectors), electronics design.
NP2	Site provision and logistic support, safety.
CIAE	Physics, neutron transport simulation, reactor neutrino spectrum calculation, crystal prototype measurements. **R&D projects : GSO,** **radiopurity with accelerator mass spectroscopy.**
IHEP	Physics, CsI(Tl) production and quality control, tests and measurements of prototypes, inner detector engineering design, electronics design and construction, simulations. **R&D projects : crystal scintillator techniques.**
IRP	Electronics design and production.
NU	Analysis and simulations.
SU	Analysis and simulations.
UMD	Plastic scintillators and PMTs for veto, simulations. **R&D projects : LiI(Eu).**

Table 2: Major items in the tasks and responsibilities sharing among the collaborating institutes. The R&D projects are denoted in **bold**.