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Research Proposal on Low-Energy Neutrino Physics and Scintillating Crystal Detectors

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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 request of the Academia Sinica Research Grant, addressing in particular **Section 7** of the application. We request funding to enhance the operation of the pilot experiment, and for the procurement of equipment and materials to support part of the R&D program.

1 History

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. By 1999, the TEXONO[1] Collaboration consists of more than 40 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.

The focus in 1997-1999 has been on the conception, formulation, prototype design studies and the construction of a "pilot" experiment to be performed near the reactor core of the Nuclear Power Plant II (NP2) at northern Taiwan [3,4]. Various future directions are also discussed and explored [5]. 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.) [1].

The pilot experiment will represent the first high-energy-physics-style experiment performed in Taiwan, where local scientists are completely responsible for all aspects of the experiments, that is, to "generate an experiment and make it work" in its totality. It is also a first-generation large-scale scientific collaborative efforts among Taiwanese and Mainland Chinese scientists. Tremendous pioneering spirits are involved.

In the 2000-2002 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 funding and positions from the AS Research Grant to support and enhance these efforts.

2 Aim and Focus

After an initial R&D effort on loaded liquid scintillator [6], 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" [2].

A pilot experiment has been successfully conceived and formulated and are being constructed under intense efforts [3,4]. It is based on a CsI(Tl) crystal scintillator to

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

be placed 30 m from a reactor core to study various low energy interactions between neutrinos (electron-antineutrinos $\bar{\nu}_e$ to be exact) and matter (electrons and nuclei). The $\bar{\nu}_e$-e scatterings are related to electro-weak physics (where there are not much data at the MeV range) and the neutrino magnetic moments, while $\bar{\nu}_e$-N neutral current excitations may be sensitive to the axial isoscalar component of NC interactions and the strange quark content of the nucleon. Both processes - and the experience and results of our efforts as well as the detector performance parameters we can achieve - are related to the discussions of the feasibility and design studies of future big neutrino experiments. Neutrinos in low energy (for example, the keV-MeV range solar neutrinos) can be detected via neutrino-electron scattering and the neutrino-nuclei charged or neutral current interactions.

The pilot experiment provides an indispensible "launch-pad" for realizing more ambitious future projects. Close working relationships and protocols are built up among the collaborating institutes and collaborators. Technical know-hows, as well as equipment and laboratory infrastructures, are accumulated. Connections are established with related industries and the major research groups around the world. Numerous presentations have been made at important international meetings.

The Collaboration has been exploring various future directions [5], around the theme of the application and development of the scintillating crystal detector technology for low-energy low-background experiment [2]. Workshops on Solar Neutrinos experiments and Dark Matter searches were organized. We have also participated in the discussions of the international LENS (Low Energy Neutrino Spectroscopy) proto-collaboration whose aim is to develop a low energy solar neutrino experiment capable of measuring real-time the actual solar neutrino pp and ^{7}Be spectra. Our approach and efforts are well-received and colleagues in our field are eager to learn about the experience and results from our pilot experiment, which may serve as important benchmark to assess whether the idea can be further expanded and extended.

3 Research Projects

The details of our research efforts are thoroughly discussed in the enclosed documents. In this section, we present a summary and elaborate on the new development.

3.1 Pilot Experiment

The experimental details are described in our Technical Design Report [4]. 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 [2], 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 (October 1999), design studies and prototyping work are completed. The first 100 kg of CsI(Tl) were grown while the second 100 kg batch are under preparation. The complete electronics system 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 Collaboration has secured funding for the construction of the pilot experiment for the first 200-channels of CsI(Tl) crystals, photo-multipliers, and associated electronics. We will start data taking on-site 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. We request the availability of positions for the operation and execution of the experiment in this proposal.

3.2 R&D Directions

The possible future directions of the Collaboration and our options and strategies to proceed are discussed in an enclosed report [5]. 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 tech-

nique.

- 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 "Plat 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.

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 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.

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 the most sensitive results in Dark Matter searches. We are studying the feasibilities and technical details of adapting CsI(Tl) or another good candidate crystal CaF_2(Eu) for these experiments. The crucial issue is the detector performance and background at the 1-10 keV range. Experience and results from the pilot experiment will shed much light on the feasibilities and sensitivities of this detector approach.

Further details and a complete list of reference for items 4,5,6 discussed above can be found in the enclosed documents No. [2] and [5].

4 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 3.2. 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.

5 Schedules and Expected Results

The expected status and results for the various research efforts of the TEXONO Collaboration in the 2000-2002 time frame would be :

1. **Pilot Experiment.**
   As discussed in Section 3.1, 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 3.2 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 2002, 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 besides the potential contributions to our own fields (neutrino physics, new detector development), the efforts of the Collaboration may have further implications and impact. 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 problems 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. These experience and contacts will provide valuable reference to similar collaborative efforts in the future, which may not necessarily be restricted to our specific fields.

6 Request of This Proposal

In this Proposal to the Academia Sinica Research Grant, we focus on several specific items during the 2001-2003 periods.

1. **Operation of the Pilot Experiment**
   While the Collaboration has secured funding adequate for the construction of 200 channels of the pilot experiment, the existing funding structures do not provide sufficient available positions to actually run the experiment. We hope the AS Grant can provide this complementary but necessary support. We request, for each of the three years:
   - a one-year visiting professor level position, and
   - three times four-month visiting scientist position,

   in addition to a regular post-doctoral fellowship.

2. **R&D Efforts**
   We focus in this Proposal on the funding support for crystal scintillator detector development [Item 1] (for raw materials and crystal growth, new PMTs, associated equipment) and the adaption of AMS techniques in radiopurity measurement [Item 2] (for beam time, material cost, equipment). The Collaboration as a whole are pursuing the other projects as well, based on support from other sources. We request 2 MNT for these two R&D projects in the first year, and 1 MNT for each of the two subsequent years.

The Co-PIs, Henry Wong(AS), Jin Li(IHEP) and George Chang(Maryland), are listed as responsible persons for this Proposal. In actual operation, all the research efforts involve expertise from many groups, and individual projects are not confined to a certain PI's

group or region. As an illustration, in the development of crystal detector, new crystals are grown by our industrial partner in Mainland China or elsewhere, then taken to IHEP, Beijing for a first performance characterization. Then it will be shipped to AS for detailed performance parameters studies. The NTHU and/or INER groups will subsequently do the first measurement on its intrinsic radiopurity, If necessary, a smaller sample will be shipped to a high-sensitivity germanium facility operated by the University of Neuchâtel, Switzerland, for a sensitive measurement. Another sample may be measured with the AMS technique at CIAE after the methods are established.

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/**.

1. Copies showing the available funding from the National Science Council (Taiwan), the National Science Foundation (Mainland China) and the National Science Foundation (U.S.A.) for the construction of the pilot experiment.

2. "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).

3. "A Pilot Experiment with Reactor Neutrinos in Taiwan", H.T. Wong and J. Li, hep-ex/9805024, AS-TEXONO/98-04, Nucl. Phys. **B** (Procs. Suppl.) **77**, 177 (1999); also in *Procs. of OCPA Conf. on "Recent Advances and Cross-Century Outlooks in Physics", Atlanta, 1999,* ed. C.Y. Wong, to be published by World Scientific (2000).

4. "A Pilot Experiment with Reactor Neutrinos in Taiwan : A Technical Status Report", C.P. Chen et al., TEXONO Collaboration, AS-TEXONO/98-07 (1998).

5. "Experimental Neutrino Research in Taiwan: Directions and Prospects", H.T. Wong, AS-TEXONO/98-08 (1998).

6. "A Feasibility Study of Boron-Loaded Liquid Scintillator for the Detection of Electron Anti-neutrinos", S.C. Wang et al., AS-TEXONO/98-05, Nucl. Instrum. Methods **A 432**, 111 (1999).

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Table 1: The institutes and collaborators list of the TEXONO Collaboration.

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.
NTU	Student participation, data acquisition,
	physics and chemistry of scintillation.
	R&D projects : new crystal detectors.
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**.