RESEARCH PROGRAM OF THE TEXONO COLLABORATION: STATUS AND HIGHLIGHTS

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This article reviews the research program and efforts for the TEXONO Collaboration among scientists from Taiwan and China. These include reactor-based neutrino physics at the Kuo-Sheng Power Plant in Taiwan as well as various R&D efforts related to the experimental techniques in neutrino and astro-particle physics.

1 Introduction and History

The TEXONO[a] Collaboration[1] has been built up since 1997 to initiate and pursue an experimental program in Neutrino and Astroparticle Physics[2]. By the end of 2001, the Collaboration comprises more than 40 research scientists from major institutes/universities in Taiwan (Academia Sinica[†], Chung-Kuo Institute of Technology, Institute of Nuclear Energy Research, National Taiwan University, National Tsing Hua University, and Kuo-Sheng Nuclear Power Station), China (Institute of High Energy Physics[†], Institute of Atomic Energy[†], Institute of Radiation Protection, Nanjing University, Tsing Hua 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 Chinese scientists from major research institutes.

The research program[3] is based on the the unexplored and unexploited theme of adopting detectors with high-Z nuclei, such as solid state device and scintillating crystals, for low-energy low-background experiments in Neutrino and Astroparticle Physics[4]. The "Flagship" program[5] is a reactor neutrino experiment to study low energy neutrino properties and 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.

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

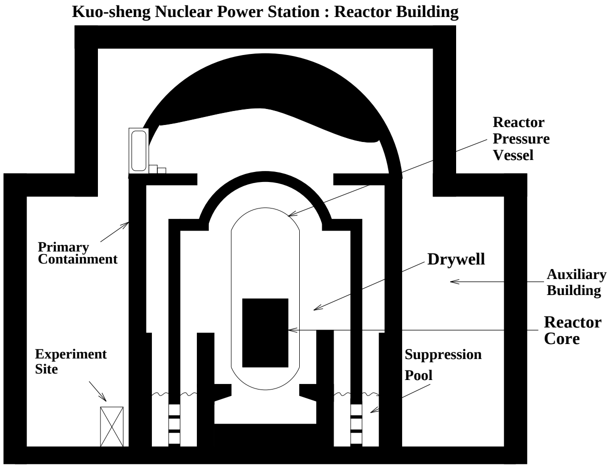

Figure 1. Schematic side view, not drawn to scale, of the Kuo-sheng Nuclear Power Station Reactor Building, indicating the experimental site. The reactor core-detector distance is about 28 m.

In parallel to the reactor experiment, various R&D efforts coherent with the theme are initiated and pursued. Subsequent sections give the details and status of the program.

2 Kuo-Sheng Neutrino Laboratory

The "Kuo-Sheng Neutrino Laboratory" is located at a distance of 28 m from the core #1 of the Kuo-Sheng Nuclear Power Station (KSNPS) at the northern shore of Taiwan[5]. A schematic view is depicted in Figure 1.

A multi-purpose "inner target" detector space of 100 cm$\times$80 cm$\times$75 cm is enclosed by 4π passive shielding materials cosmic-ray veto scintillator panels, the schematic layout of which is shown in Figure 2 The shieldings provide attenuation to the ambient neutron and gamma background, and are made up of, inside out, 5 cm of OFHC copper, 25 cm of boron-loaded polyethylene, 5 cm of steel and 15 cm of lead.

Different detectors can be placed in the inner space for the different scientific goals. The detectors will be read out by a versatile electronics and data acquisition systems[6] based on a 16-channel, 20 MHz, 8-bit Flash Analog-to-Digital-Convertor (FADC) module. The readout allows full recording of all the relevant pulse shape and timing information for as long as several ms af-

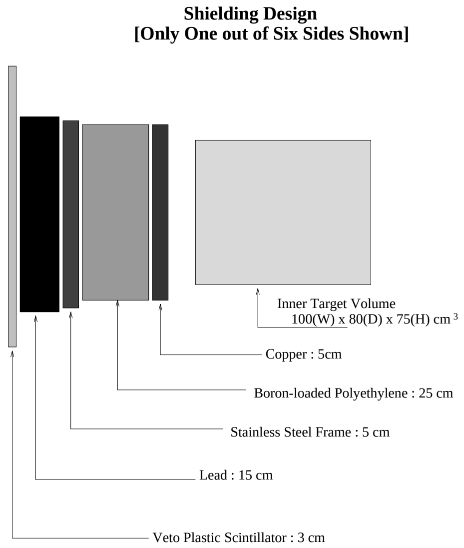

Figure 2. Schematic layout of the inner target space, passive shieldings and cosmic-ray veto panels. The coverage is 4π but only one face is shown.

ter the initial trigger. The reactor laboratory is connected via telephone line to the home-base laboratory at AS, where remote access and monitoring are performed regularly. Data are stored and accessed in a multi-disks array with a total of 600 Gbyte memory via IDE-bus in PCs.

It is recognized recently[8] that due to the uncertainties in the modeling of the low energy part of the reactor neutrino spectra, experiments to measure Standard Model neutrino-electron cross sections with reactor neutrinos should focus on higher electron recoil energies (T>1.5 MeV), as with (b), while neutrino magnetic moment searches should base on measurements with T<100 keV.

Accordingly, data taking for Period I Reactor ON/OFF has started in July 2001 and will continue till March 2002. Two detector systems are running in parallel using the same data acquisition system but independent triggers: (a) an Ultra Low Background High Purity Germanium (ULB-HPGe), with a fiducial mass of 1.06 kg, and (b) 46 kg of CsI(Tl) crystal scintillators. The target detectors are housed in a nitrogen environment to prevent background events due to the diffusion of the radioactive radon gas.

Kuo-Sheng Experiment : HPGe Detector

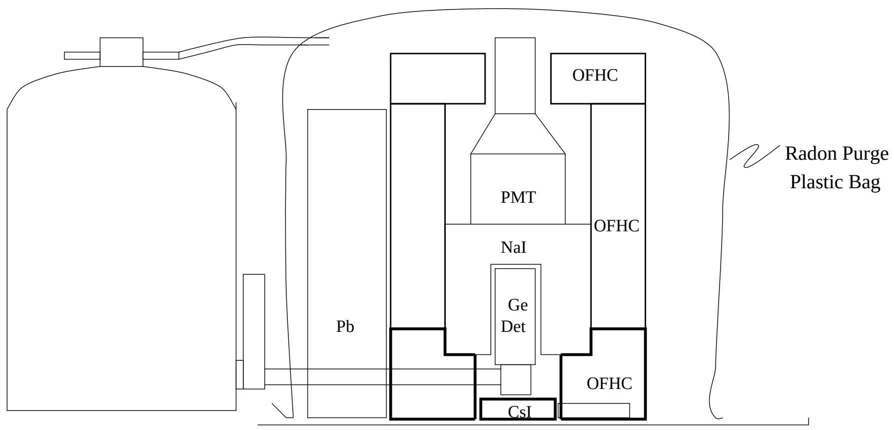

Figure 3. Schematic drawings of the ULB-HPGe detector with its anti-Compton scintillators and passive shieldings.

2.1 Germanium Detector

As depicted in Figure 3, the ULB-HPGe is surrounded by NaI(Tl) and CsI(Tl) crystal scintillators as anti-Compton detectors, and the whole set-up is further enclosed by another 3.5 cm of OFHC copper and lead blocks.

The measured spectrum, after cuts of cosmic and anti-Compton vetos, during 12.2 days of reactor ON data taking is displayed in Figure 4. Background (order of 1 $\mathrm{keV^{-1}kg^{-1}day^{-1}}$) and threshold (5 keV) levels comparable to underground Dark Matter experiment has been achieved on site. Additional cuts based on pulse shape and timing information are expected to further reduce the background level at low energy. It is expected the data taken in Period I would allow us to achieve world level sensitivities in $\bar{\nu_e}$ magnetic moments (μ_ν)[9], and therefore indirectly, radiative lifetimes (Γ_ν)[10]. These are the lowest threshold data so far for reactor neutrino experiments, and therefore allow the studies of more speculative topics, like μ_ν and Γ_ν for ν_e from reactors, possible nuclear cross-sections, as well as anomalous neutrino interactions.

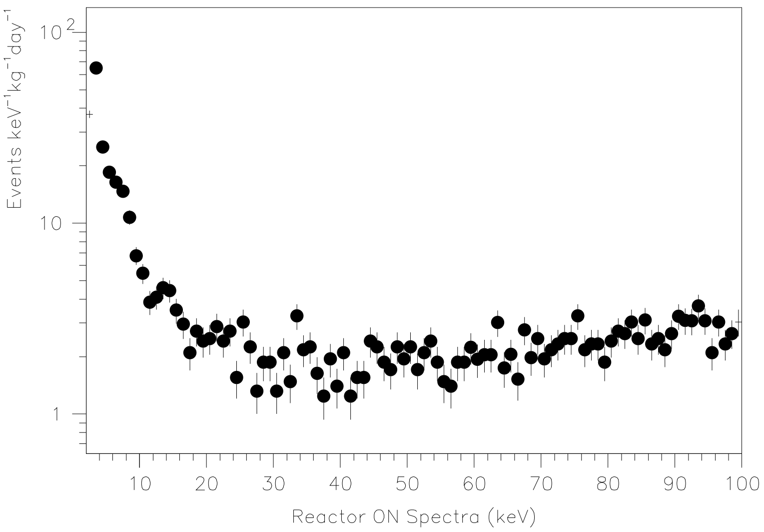

Figure 4. The measured spectrum from the ULB-HPGe, after cuts of cosmic and anti-Compton vetos, during 12.2 days of reactor ON data taking.

2.2 Scintillating CsI(Tl) Crystals

The potential merits of crystal scintillators for low-background low-energy experiments were recently discussed[4].

The CsI(Tl) detector system is displayed in Figure 5. Each crystal module is 2 kg in mass and consists of a hexagonal-shaped cross-section with 2 cm side and a length 40 cm. The first sample is with two 20 cm crystals glued optically at one end to form a module (L20+20). Techniques to grow CsI(Tl) mono-crystal of length 40 cm (L40), the longest in the world for commercial production, have been developed and are deployed in the production for subsequent batches. The light output are read out at both ends by custom-designed 29 mm diameter photo-multipliers (PMTs) with low-activity glass. The sum and difference of the PMT signals gives information on the energy and the longitudinal position of the events, respectively.

Extensive measurements on the crystal prototype modules have been performed[11]. The energy and spatial resolutions as functions of energy are depicted in Figure 6. The energy is defined by the total light collection $Q_1 + Q_2$. It can be seen that a ∼10% FWHM energy resolution is achieved at 660 keV. The detection threshold (where signals are measured at both

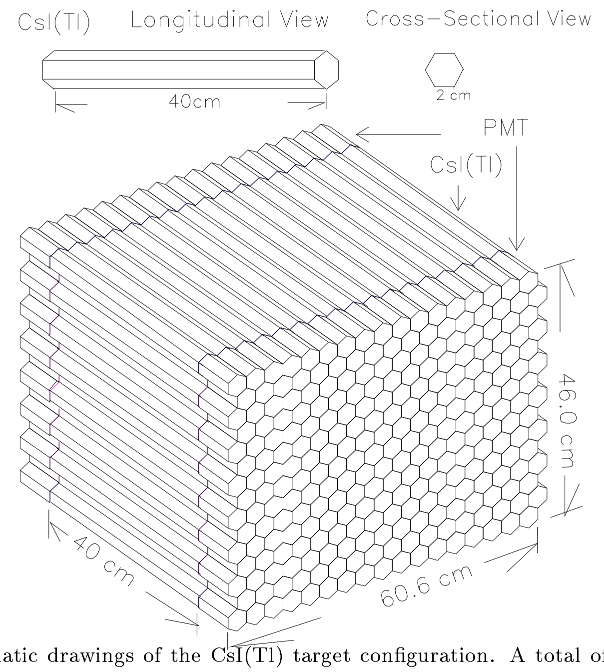

Figure 5. Schematic drawings of the CsI(Tl) target configuration. A total of 23 modules (46 kg) is installed for Period I.

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.

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. The light output for α's in CsI(Tl) is quenched less than that in liquid scintillators. The absence of multiple α-peaks above 3 MeV [12] in the prototype measurements suggests that a ^{238}U and ^{232}Th concentration (assuming equilibrium) of $< 10^{-12}$ g/g can be achieved.

The data taken from the CsI(Tl) detector for Period I would be used for further optimization of the operation parameters as well as for studying the background. A cosmic muon event is shown in Figure 7. A >150 kg system will be installed for Period II. The physics goals include studies of neutrino-electron and neutrino-nuclei scattering cross sections.

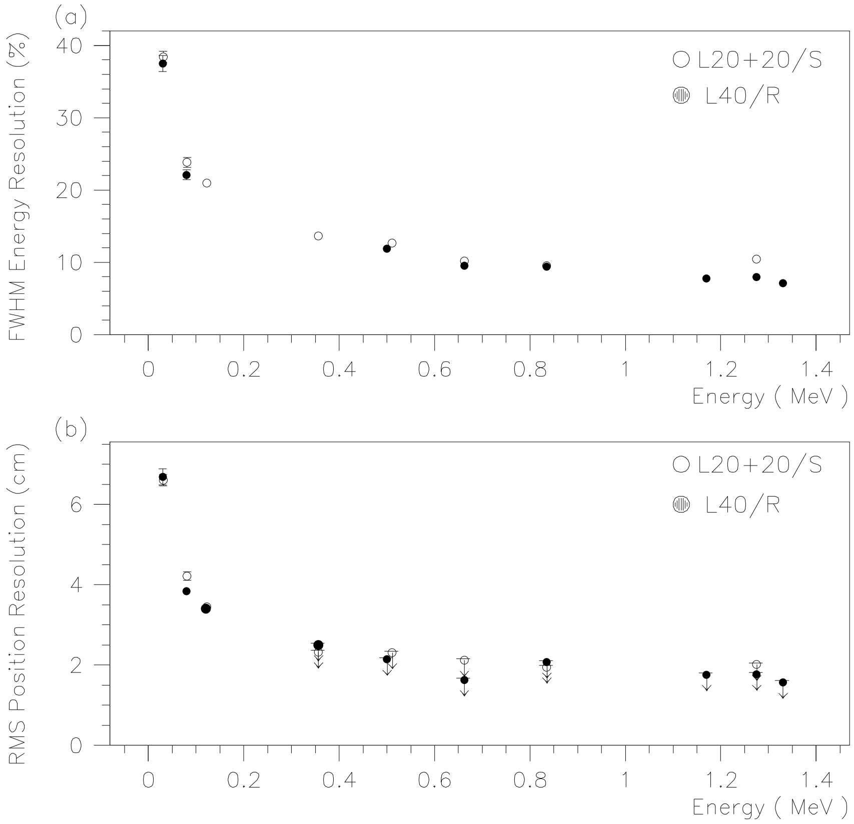

Figure 6. The variation of (a) FWHM energy resolution and (b) RMS position resolution with energy for the CsI(Tl) crystal modules. Only upper limits are shown for the higher energy points in (b) since the events are not localized.

3 R&D Program

Various projects with stronger R&D flavors are proceeding in parallel to the reactor experiment. The highlights are :

3.1 Low Energy Neutrino Detection

It is recognized recently that ^{176}Yb and ^{160}Gd are good candidate targets in the detection of solar neutrino (ν_e) by providing a flavor-specific time-delayed

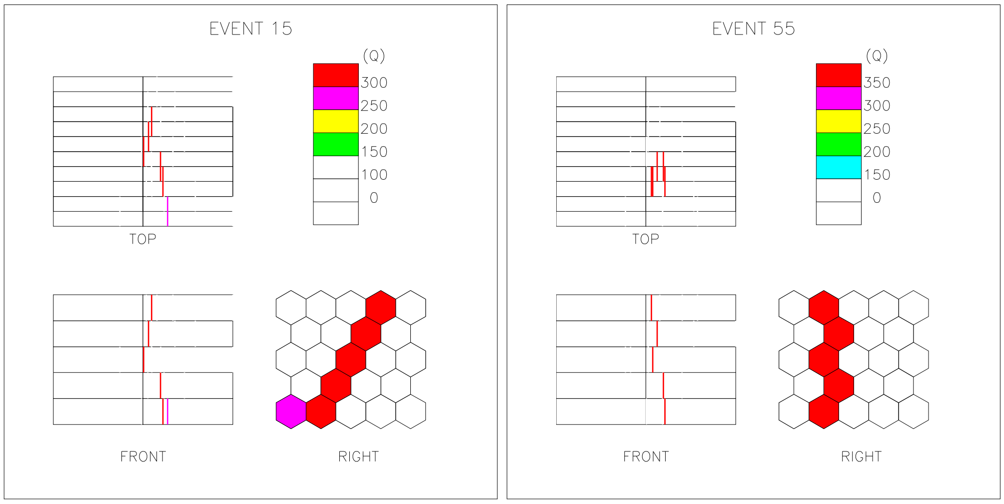

Figure 7. Two typical cosmic ray events taken on site at KS Lab with the CsI(Tl) detector system.

tag[13]. Our work on the Gd-loaded scintillating crystal GSO[14] indicated major background issues to be addressed. We are exploring the possibilities of developing Yb-based scintillating crystals, like doping the known crystals $YbAl_{l5}O_{12}$(YbAG) and $YbAlO_3$(YbAP) with scintillators.

In addition, we have completed a feasibility study on boron-loaded liquid scintillator for the detector of $\bar{\nu}_e$[15]. The case of "Ultra Low-Energy" HPGe detectors, with the potential applications of Dark Matter searches neutrino-nuclei coherent scatterings, are now being investigated.

3.2 Dark Matter Searches with CsI(Tl)

Experiments based on the mass range of 100 kg of NaI(Tl) are producing some of the most sensitive results in Dark Matter "WIMP" searches[16]. The feasibilities and technical details of adapting CsI(Tl) or other good candidate crystal like CaF_2(Eu) for WIMP Searches have been studied. A neutron test beam measurement was successfully performed at IAE 13 MV Tandem accelerator[17]. We have collected the world-lowest threshold data for nuclear recoils in CsI, enabling us to derive the quenching factors, displayed in Figure 8, as well as to study the pulse shape discrimination techniques at the

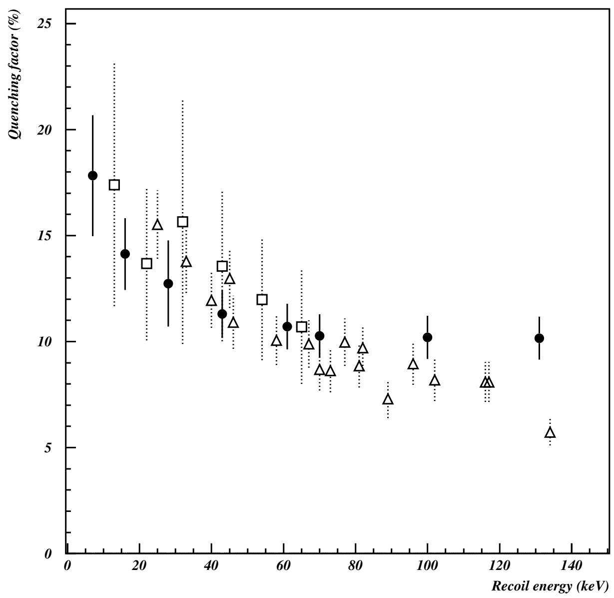

Figure 8. The quenching factors, shown as black circles, measured at IAE Tandem, as compared to Open triangles and open squares from previous work.

realistically low light output regime. The KIMS Collaboration will pursue such an experiment in South Korea[18].

3.3 Radio-purity Measurements with Accelerator Mass Spectrometry

Measuring the radio-purity 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, α-counting with silicon detectors or the neutron activation techniques. We are exploring the capabilities of radio-purity measurements further with the new Accelerator Mass Spectroscopy (AMS) techniques[19]. This approach may be complementary to existing methods since it is in principle a superior and more versatile method as demonstrated in the ^{13}C system, and it is sensitive to radioactive isotopes that do not emit γ-rays (like single betadecays from ^{87}Rb 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). A pilot measurement of the ^{129}I/^{127}I ratio ($< 10^{-12}$) in CsI was successfully performed demonstrating the capabilities of the Collaboration. Further beam time is scheduled at the IAE AMS facilities[20] to devise measuring schemes for the other other candidate isotopes like ^{238}U, ^{232}Th, ^{87}Rb, ^{40}K in liquid and crystal scintillators beyond the present capabilities by the other techniques.

3.4 Upgrade of FADC for LEPS Experiment

Following the success in the design and operation of the FADCs at the KS Lab, we will develop new FADCs for the Time Projection Chamber (TPC) constructed as a sub-detector for the LEPS experiment at the SPring-8 Synchrotron Facilities in Japan[21]. The current FADCs are being used to provide readout to test the prototype TPC, an event of which is depicted in Figure 9. The upgraded FADCs will have 40 MHz sampling rate, 10-bit dynamic range and be equipped with Field Programmable Gate Array (FPGA) capabilities for real time data processing. This new system is expected to be commissioned in Fall 2002.

In addition, the Collaboration is participating in the discussions on the scientific program and technical feasibilities of (a) the "H2B" project[22]: a 2000 km Very Long Baseline High Energy Neutrino Experiment at Beijing to receive a neutrino beam from the HIPA Facilities in Tokyo due to be commissioned by 2006 in Japan, and (b) the detection scheme of very high energy tau-neutrinos using mountain ranges as target and air as the subsequent showering volume[23].

4 Outlook

With the strong evidence d neutrino oscillations from atmospheric and solar neutrino experiments[7], there are intense world-wide efforts to pursue the next-generation of neutrino projects. Neutrino physics and astrophysics will remain a central subject 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, China and U.S.A. collaboration has been built up with the goal of establishing a qualified experimental program in neutrino and astroparticle physics. It is the first generation collaborative efforts in large-scale basic research between scientists from Taiwan and Mainland China. The tech-

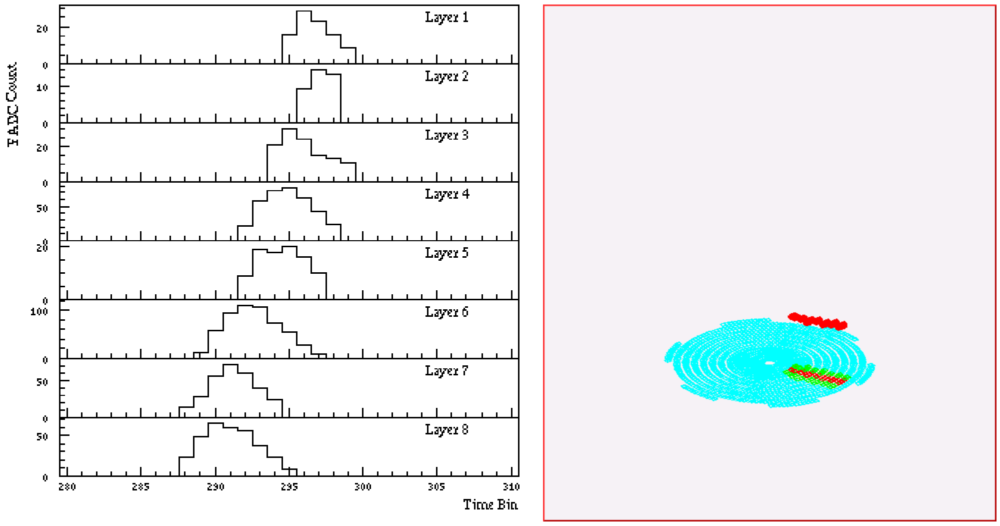

Figure 9. Measurements from the prototype TPC for LEPS Experiment, with the TEXONO FADC system. Only one sector of of the TPC is equipped with readout electronics.

nical 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 at the Kuo-Sheng Reactor Plant. From the Period I data taking, we expect to achieve world-level sensitivities and neutrino magnetic moments and radiative lifetime studies. A wide spectrum of R&D projects are being pursued. New ideas are being explored within a bigger framework.

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

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