From the TEXONO Neutrino Program to the China Jinping Underground Laboratory

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Neutrinos provide a platform of history making. We recall the events of how the studies of neutrinos would bring forth the first particle physics experiment in Taiwan – the TEXONO program, through which the first basic research collaboration between scientists from Taiwan and Mainland China was realized. The acquired technical expertise and working relationships set the stage for the construction of the largest and deepest underground research facility in the world – the China Jinping Underground Laboratory. Future prospects are outlined. Scientific details and full bibliography can be referred to recent reviews [1,2].

1 Foundation – Experimental Neutrino Physics *in* Taiwan

Phenomenal growth in basic and applied research took place in the Asia Pacific region in the decades of 1980's and 1990's [3]. Activities in experimental particle physics started in Taiwan in the early 90's, through participation in international experiments, with contributions on various detector hardware, data acquisition software and data analysis projects.

Attempts to "perform an experiment at home" became inevitable. Chang Chung-Yun (University of Maryland, while on a sabbatical year at the Academia Sinica (AS)) and Lee Shih-Chang (AS) initiated a research program towards such goals in 1996. This ambition soon found a resonating chord with senior physicist Wang Gan-Chang from the China Institute of Atomic Energy (CIAE) in China. Zheng Zhi-Peng (then Director of the Institute of High Energy Physics (IHEP), Beijing, China) mobilized his Institute to participate. The project would therefore carry with it an additional pioneering spirit of being the first collaboration in basic research among scientists from Taiwan and China, standing on a decade of mutual visits and academic exchanges. Many scientific, technical, administrative and logistic issues have to be ironed out to make advances on these virgin grounds.

The author (H.T. Wong) was recruited by AS in 1997 to realize such visions – with Li Jin (senior physicist at IHEP) as the leader of the Chinese groups. The TEXONO (Taiwan EX-

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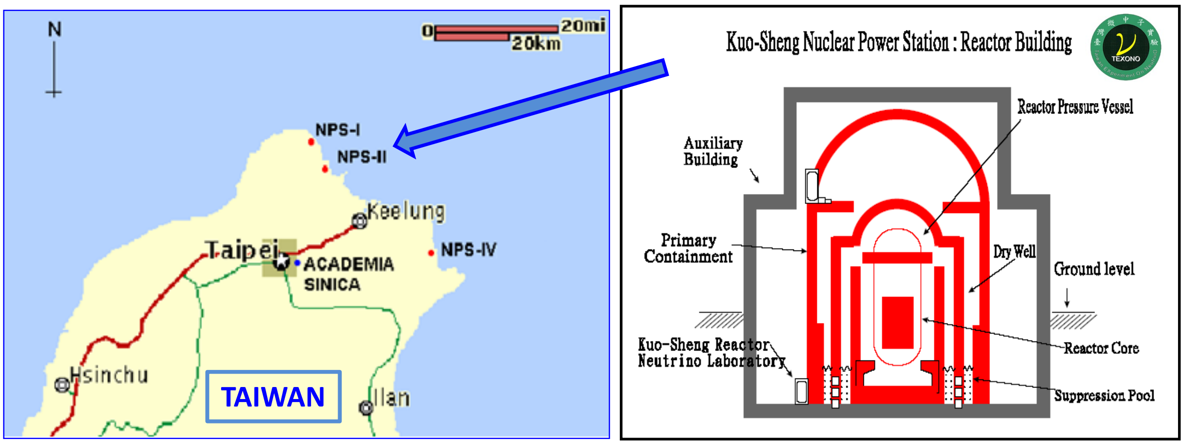

Figure 1 – Schematic view, not drawn to scale, of the Kuo-Sheng Nuclear Power Station Reactor Building, indicating the site for the neutrino laboratory KSNL. The reactor core-detector distance is about 28 m. The power station is located at the northern coast of Taiwan.

periment On NeutrinO) Collaboration was established, where the founding partners comprised institutes from Taiwan (AS, Institute of Nuclear Energy Research, Taiwan Power Company Nuclear Station II, National Taiwan University and National Tsing-Hua University), China (IHEP, CIAE, Nanjing University) and the USA (University of Maryland). The AS-group has been leading and coordinating the efforts in Taiwan. International partners from India (Banaras Hindu University) and Turkey (Middle East Technical University, Dokuz Eylül University) joined the Collaboration in its first decade. An international graduate student training scheme was set up as part of the operation. Numerous graduate students from China, India and Turkey have stationed long-term at AS to pursue research within of the TEXONO program and produced research theses from the efforts.

Anomalous results from solar and atmospheric neutrino measurements [5,6] were gathering momentum in the 1990's, cumulating in the presentation of evidence of neutrino oscillation by the Super-Kamiokande experiment in 1998. The case of having missing energy density in the Universe in form of Dark Matter [6] was also getting increasingly compelling. Non-accelerator based particle physics was at its early stage and constituted a good opportunity for the young research group to move into.

Reactor neutrino was identified in the foundation days as a realistic platform for the TEXONO program. The Kuo-Sheng Reactor Neutrino Laboratory (KSNL) [1], the site selected for its comfortable commuting distance from AS, was established. A schematic layout is given in Figure 1. The aspired goal was that the first experiment should on its own be able to produce valid scientific results. The natural choice of long baseline oscillation projects was recognized to be unfeasible to be a serious contender. The science subjects evolved to the complementary studies of neutrino interactions and properties, which benefit from a location close to the reactor core having an intense neutrino flux. The selected detector techniques are scintillating crystal detectors for studying Standard Model (SM) $\bar{\nu}_e$-electron scattering and germanium (Ge) ionization detectors for probing exotic neutrino electromagnetic effects. In particular, previous reactor neutrino experiments were all based on measurements of events at MeV or above. Using low threshold Ge detectors, the TEXONO program would open the previously-unexplored detector window in the low energy regime with sub-keV measureable energy.

The TEXONO experiment at KSNL has produced world-level limits in the search of neutrino magnetic moments and milli-charge as well as the best experimental sensitivities on $\bar{\nu}_e$-e scattering cross-section, which led to measurements of SM electroweak parameters at MeV-scale and the verification of destructive interference between the SM charged- and neutral-current interactions. The theory program made advances on the derivations of neutrino and dark matter detection cross-sections at low energy with state-of-the-art atomic physics techniques, as well as on identifying new and smoking-gun signatures for their exotic properties.

2 China Jinping Underground Laboratory

The TEXONO program pursued development of Ge-detectors with sub-keV sensitivities towards the goals of studying neutrino-nucleus coherent scattering at KSNL. The potentials for dark matter WIMP (weakly interacting massive particles) searches were immediately realized with such detectors. Dark matter searches were conducted as by-product with the KSNL reactor data, while the TEXONO-Tsinghua University (THU) group explored the means to turn it into dedicated experiments. An underground site is therefore mandatory. The THU group spearheaded a pilot project of installing a prototype Ge-detector at the Yangyang Underground Laboratory in Korea in 2004, supported by the KIMS group as host of that Facility.

A construction road tunnel was completed in 2008 under the Jinping mountains in Sichuan province in China to facilitate the construction of the numerous hydro-electric power facilities in that region. The THU group immediately recognized the opportunities and potentials. By 2010, agreement was made between the site owner Yalong River Hydropower Development Company and THU to jointly develop and operate an underground laboratory facility − the China Jinping Underground Laboratory (CJPL) [2] which, at a rock overburden of 2400 meter, is the world's deepest underground research facility. The drive-in tunnel access and existing infrastructures are also crucial merits. The completed CJPL Phase-I laboratory hall was inaugurated in December 2012.

The THU group evolved to form and lead a new CDEX (China Dark matter EXperiment) Collaboration focusing on, in its first-generation phase, dark matter experiments at CJPL. The CDEX program is led by Kang Ke-Jun (a former Vice President of THU), while the TEXONO Collaboration is a founding partner of this endeavour. Competitive constraints were achieved in the searches of Light WIMPs and axion-like-particles by the CDEX-1 experiments at CJPL-I.

3 Prospects

Additional laboratory space for CJPL Phase-II[2] is currently under construction. It will consist of four experiment halls each with dimension 14 m(W)×14 m(H)×130 m(L), connected by an array of access tunnels. Upon completion, CJPL will be the world's largest underground laboratory.

The current generation of neutrinoless double beta decay ($0\nu\beta\beta$) experiments with ^{76}Ge [6] are among those with leading sensitivities. The objective of next generation experiment will be to completely cover the inverted neutrino mass hierarchy [6] and to demonstrate sufficient margins to advance further towards the normal hierarchy. The recently established LEGEND collaboration [7] has the goal of meeting this challenge.

The CDEX groups, as participating institutes within the LEGEND program, are exploring the option of CJPL-II as a candidate site to host such a "world" experiment with ton-scale germanium target. A pit of diameter 18 m and height 18 m, as depicted in Figure 2, is being built at one of the halls of CJPL-II to house such an experiment. The conceptual design is a central region for germanium detector arrays, surrounded by cryogenic liquid and/or water shielding.

Such visions stand on several important merits and deserve serious considerations. The overburden at CJPL is among the deepest in the world, essential for the unprecedented background control requirements. Being a new laboratory, there are ample space for possible Ge-crystal growth and detector fabrication and passive shielding production, in addition to the already available pit for the main detector and shielding. Furthermore, the crucial aspect of this project is the necessity of delivering industrial standard practices and control during the mass production of detector hardware. This requirement matches well to the profile of the CDEX-THU group,

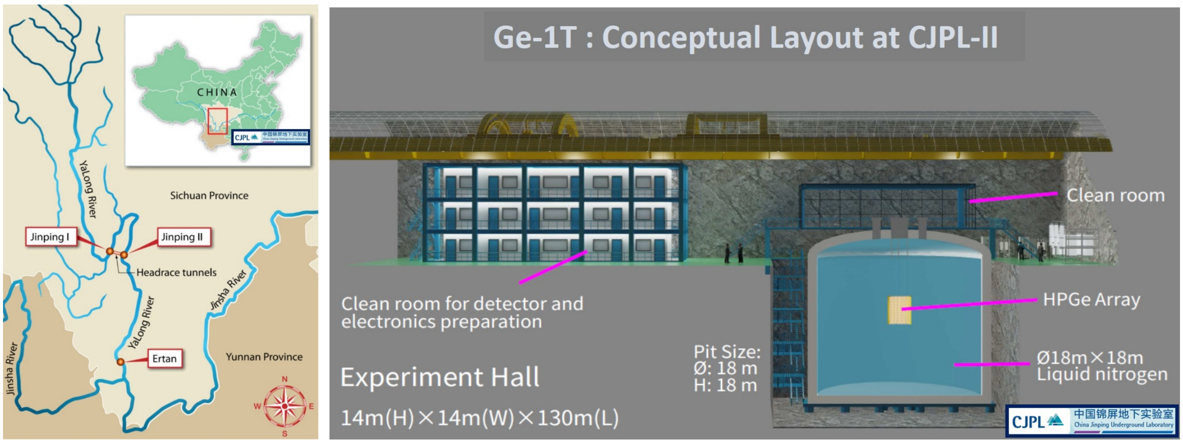

Figure 2 – Conceptual configuration of a possible future ton-scale germanium experiment at CJPL-II, showing the pit in which the detector, cryogenic liquid and water shielding can be placed. This is a candidate option for the LEGEND-1T $0\nu\beta\beta$ program. The location of CJPL in Sichuan province, China, is shown. The diagram displays half of the four experimental halls at CJPL-II, each with the dimensions listed.

being closely associated with an industry [8] which has strong experience in the construction and deployment of large radiation detector systems for international clients.

Acknowledgments

The studies of neutrinos – the particles that hardly interact – provide the backdrop and set the stage of realizing one piece of history in the development of science in Asia. The author is whole-heartedly grateful to the various invaluable contributions from all our colleagues and collaborators, technical and administrative staff, as well as funding agencies who have "made these happen". There are grounds to anticipate that the future evolution of this story will be as exciting and rewarding.

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