Jinping Neutrino Experiment: a Status Report

Benda Xu

Department of Engineering Physics, Tsinghua University, Beijing, 100084, China

E-mail: orv@tsinghua.edu.cn

Abstract. A large liquid scintillator detector is being discussed and actively developed in China JinPing underground Laboratory. We envision a 5 kt detector at 7000-water-meter-equivalent overburden to target terrestrial, solar and supernovae neutrinos. A 1t prototype detector has been installed on-site in 2017. Liquid scintillator performance, radioactive and cosmogenic backgrounds, simulation and analysis pipelines have been carefully investigated. We report the status of the Jinping Neutrino Experiment project and milestones of R&D studies.

1. Introduction

China **J**in**P**ing underground **L**aboratory (CJPL) is among the deepest underground laboratories in the world and has the largest vertical rock overburden of 2.4 km [1]. Located in the middle of the traffic tunnel of Jinping hydropower plants, the laboratory is accessible by large vehicles. That is a convenient factor to construct large experiments underground. The site is in the southwest of China and is more than 1000 km from the commercial nuclear power plants along the coast, giving it the lowest reactor neutrino flux among all the underground laboratories in the world [2]. It is an ideal place for neutrino observation.

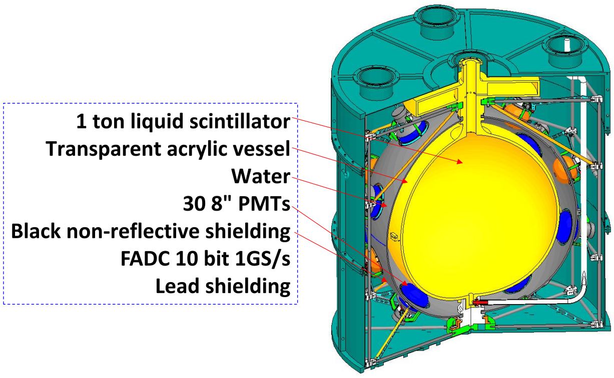
The Jinping Neutrino Experiment is a program to ultimately construct a kiloton scale liquid scintillator (LS) detector deep underground to unleash the full potential of neutrino astronomy of CJPL [2]. The program aims at CNO solar neutrinos [3], Himalaya terrestrial neutrinos [4, 5] and supernova neutrinos [6]. The program has commissioned a 1 t prototype from 2017 [7] and is designing and scheduling a 100 t-scaled detector as the next step. In this report, we scratch the preliminary results from the 1 t detector and the development of key technologies for the 100 t detector.

2. Progress of Jinping Neutrino Experiment

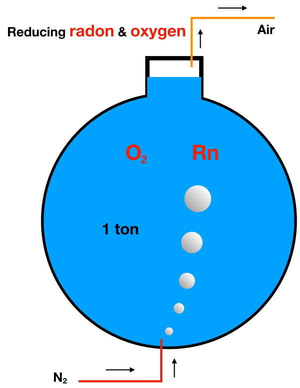
The 1 t liquid scintillator detector [7] is installed in CJPL-I, next to the PandaX [8] and CDEX [9] direct dark matter search experiments.

The liquid scintillator is composed of *linear alkylbenzene* (LAB), *diphenyloxazole* (PPO) and *1,4-bis(2-methylstyryl)benzene* (bis-MSB) tuned for balancing energy resolution and Cherenkov photon separation from scintillation [11], and is filled into an acrylic container of $\sim$1.3 m diameter. Outside the acrylic container, a stainless steel supporting shell is equipped with 30 inward-facing 20 cm (8 inch) photomultipliers (PMTs). The whole structure is fitted into a cylinder stainless steel tank filled with pure water. All the PMTs are readout by FADC and frontend electronics at 1 Gs/s. A schematic view of the detector is in Figure 1a.

Starting from 2017, after several iterations of commissioning, the detector is running stable.



(a) Schematics of 1 t detector.



(b) Positive pressure for Rn tightness.

Figure 1: 1 t prototype detector for background measurement, purification development, and slow liquid scintillator performance assessment.

2.1. *Background Measurement*

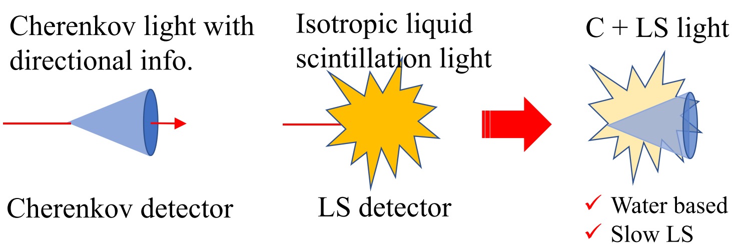
To guard against leakage of Rn into the liquid scintillator from the environment, a positive pressure system is installed on-site with pure N_2 gas as shown in Figure 1b. After Rn decaying out, the concentration of ^{238}U in LAB is measured by ^{214}Bi-^{214}Po decay pairs to be $(2.2 \pm 0.3) \times 10^{-13}$ g/g assuming secular equilibrium. ^{212}Bi-^{212}Po coincidence pair is used for estimating ^{232}Th to be $< 1.8 \times 10^{-14}$ g/g (90% C.L.).

It is encouraging to remark that the LAB is used right after production. An onsite liquid scintillator distillation system is being designed so as to further reduce radioactivity in LAB.

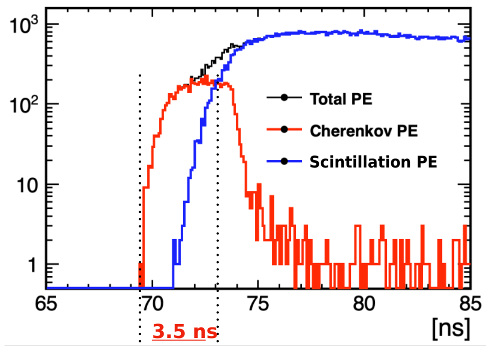
At GeV scale, cosmic muons are observed, and the angular distribution is being measured. As of 2019, the 1 t liquid scintillator is the biggest target in CJPL and thus can serve as the most sensitive screening facility.

2.2. *Slow Liquid Scintillator*

In the context of radiation detection, Cherenkov light can reveal particle momentum, while scintillation has a higher light yield. Until recently, Cherenkov and liquid scintillation detectors fit into different energy windows and physics targets. The advances have made possible dual readout of Cherenkov and scintillation light signals, as shown in Figure 2a.



(a) Principle of dual photon readout.



(b) Ideal 2 MeV e$^-$ time profile.

Figure 2: Cherenkov scintillation dual photon readout. Under ideal assumptions, 2 MeV electron can give a 3.5 ns Cherenkov time window.

The dual signals will boost the particle identification performance of both the traditional Cherenkov and LS detectors. Viable candidates are water-based liquid scintillator [10] and slow liquid scintillator [11].

A slow LS prescription is used in the 1 t prototype for assessment. Under the ideal assumptions, there is roughly a 3.5 ns time window for the Cherenkov photons, as plotted in Figure 2b. Cherenkov photons are subject to absorption, especially by bis-MSB, and to dispersion, scattering, etc., which makes observing Cherenkov photons more challenging.

Cherenkov photons are not isotropic. A test statistic is constructed accordingly,

$$\chi^2 = \sum_{i=0}^{29} \frac{(q_i - \bar{q})^2}{\bar{q}},$$

where q_i is the charge of i-th PMT in a certain time window and $\bar{q} = \sum_{i=0}^{29} q_i/30$, with 30 denoting the number of PMTs.

Table 1: Light emission sphericity of the BiPo pair.

	First 10 hits	Next 10 hits
α	spherical	spherical
β	non-spherical	spherical

For ^{214}Bi-^{214}Po decay pair, prompt $\sim$2 MeV β emits Cherenkov light but delayed $\sim$8 MeV α does not. Selecting signals from the detector center $R < 0.2$ m, the evidence of Cherenkov photon is established statistically. In Table 1, the first 10 photoelectrons (PEs) of a β event in the BiPo pair will give a larger χ^2 than others. In Figure 3 it is evident that the distribution of first 10 PEs of electrons is skewed towards higher χ^2, and the other three cases have similar χ^2 distribution skewed to lower values as predicted by Table 1.

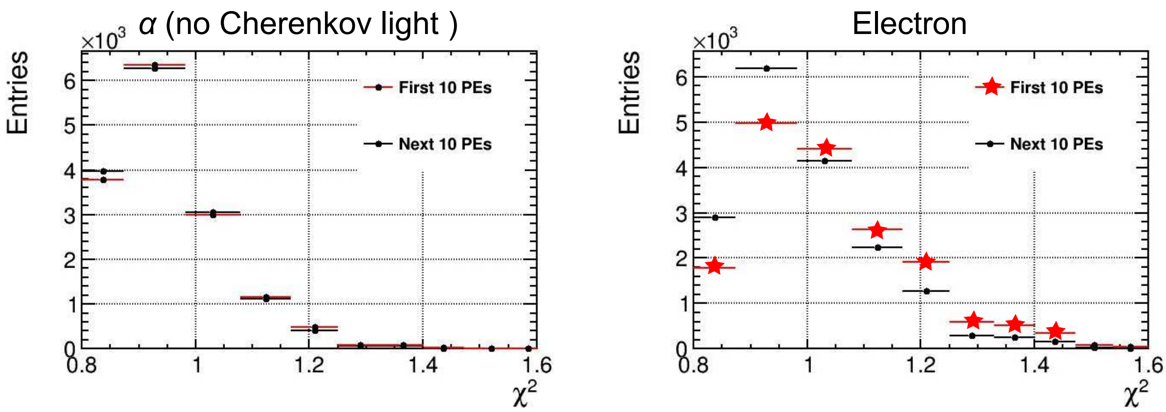


Figure 3: Distribution of sphericity statistic χ^2 for the first and second 10 PEs of α and β events.

A likelihood-based fitter is developed to extract Cherenkov photons on an event-by-event basis. Preliminary results show that for 2 MeV the angular bias is $\sim$30°. The waveform analysis success ratio is 93%, calling for further improvements.

2.3. Waveform Analysis

PE timing is the most effective information for extracting Cherenkov photons. The limiting factors are PMT transit time spread, frontend electronics timing resolution, and waveform analysis.

Waveform analysis is by nature a deconvolution challenge. Each PE produces a voltage pulse at the PMT readout, and pileups of these pulses severely affect timing resolution of later PEs. Consequently, traditionally only the first PE of a PMT is used for timing, abandoning information from the following PEs.

With the advancement of readout electronics and signal processing, it is valuable to revisit the waveform analysis problem to expand state-of-the-art. A competition has been held online [12] to host a waveform analysis challenge. More than 60 participants competed on an auto-grading and ranking platform. Each score is calculated by Wasserstein distances [13] from the PE truth timing to the submitted answers. Deep learning methods began to dominate the leader board, with fitting methods coming close. A post-competition summary is being prepared and included into Jinping Neutrino Experiment offline framework.

2.4. 100 t *Detector Design*

In July 2019, China Jinping Laboratory started as "national magnificent scientific and technological infrastructure". One of the experimental halls of CJPL-II is selected as the candidate to hold a neutrino experiment, suitable for the next 100 t detector of Jinping Neutrino Experiment. Detector design and development are being actively pursued.

3. Conclusion

Neutrino experiment at Jinping aims at terrestrial, solar and supernova neutrinos. 1 t prototype detector is running in CJPL. It has measured the backgrounds and verified the slow LS potential of separating Cherenkov and scintillation photons. More improvements such as waveform analysis on 1 t detector data are being developed. A pre-collaboration for Jinping Neutrino Experiment has been established during several dedicated workshops. The group is going to realize a 100 t in CJPL as the next step towards the ultimate goal of the project.

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