Introductory remark on the First International Workshop towards the Giant Liquid Argon Charge Imaging Experiment (GLA2010)

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Abstract. Based on the strong scientific demand to realize Giant Liquid Argon Time Projection Chamber, which makes widely spread scientific exploration possible, the First International Workshop towards the Giant Liquid Argon Charge Imaging Experiment (GLA2010) is held on March 29-31 2010, in Tsukuba Japan. Here, introductory remark on the workshop which includes the motivation and the skeleton of the workshop is described.

1. Introduction

Giant Liquid Argon Time Projection Chamber with 100 kton size will open a fascinating opportunity to explore wide spread scientific subjects. It would be ideal for the next generation accelerator based neutrino research approaching the lepton sector CP symmetry breaking, would extend the search for the proton decay via modes favored by the supersymmetric grand unified models (e.g. $p\rightarrow\nu K^+$) up to $10^{35}$ years. Moreover, it would cover wide range of neutrino physics with astrophysical and terrestrial sources (e.g. solar and atmospheric neutrinos, neutrinos from stellar collapse and the neutrinos from Dark Matter annihilation.).

2. New generation accelerator based neutrino experiment and proton decay experiment

One of the primary motivation of neutrino physics research recently in the world is to improve the sensitivity to the $\nu_\mu \rightarrow \nu_e$ conversion phenomenon in the atmospheric regime. In Japan, as the first experiment utilizes KEK/J-PARC (Japan Proton Accelerator Research Complex) neutrino facility, T2K (Tokai to Kamioka Long Baseline Neutrino Experiment) starts operation to explore above subject. The similar project, NOvA is under preparation in USA.

The final goal for T2K is to accumulate an integrated proton power on target of $0.75\ \text{MW} \times 5 \times 10^7 \text{ seconds}$. As is shown in Figure 1, within a few years of run, critical information, which will guide the future direction of the neutrino physics, will be obtained based on the data corresponding to about 1 to 2 $\text{MW} \times 10^7 \text{ seconds}$ integrated proton power on target (roughly corresponding to a $3\sigma$ discovery at $\sin^2 2\theta_{13} > 0.05$ and 0.03, respectively).

If a significant $\nu_\mu \rightarrow \nu_e$ conversion signal were to be observed at T2K, an immediate step forward to a next generation experiment aimed at the discovery of CP violation in the lepton sector would be recommended with high priority. Compared with presently available experimental conditions, lepton sector CP violation discovery requires...
Figure 1. T2K discovery potential on $\nu_\mu \rightarrow \nu_e$ as a function of integrated proton power on target.

- improved neutrino beam intensity;
- an improved main far neutrino detector.

Detector improvements include

- detector technology;
- its volume;
- its baseline and off-axis angle with respect to the neutrino source.

Naturally, next generation far neutrino detectors for lepton sector CP violation discovery will be very massive and huge. As a consequence, the same detector will give us the rare and important opportunity to discover proton decay. A total research subject would be, to address a long standing puzzle of our physical world, the “Quest for the Origin of Matter Dominated Universe” (see e.g. [1]), with exploration of

- the lepton sector CP violation by precise testing of the neutrino oscillation processes;
  - measure precisely the CP phase in lepton sector ($\delta_{CP}$) and the mixing angle $\theta_{13}$;
  - examine matter effect in neutrino oscillation process and possibly conclude the mass hierarchy of neutrinos.

- proton decay:
  - Search for $p \rightarrow \nu K^+$ and $p \rightarrow e^+\pi^0$ in the life time range $10^{34}$ to $10^{35}$ years,
with assuming non-equilibrium environment in the evolution of universe. Even in case that $\sin^2 2\theta_{13}$ is below T2K sensitivity, it is still worth while trying to improve neutrino beam intensity and far detector performance to open the way to explore $\nu_\mu \rightarrow \nu_e$ conversion phenomenon with by an order of magnitude better sensitivity.

3. Far detector options: How to approach lepton sector CP violation

The effects of lepton sector CP phase $\delta_{CP}$ appear either

- in the energy spectrum shape of the appearance oscillated $\nu_e$ charged current events (sensitive to all the non-vanishing $\delta_{CP}$ values including 180°);
- as a difference between $\nu$ and $\bar{\nu}$ behaviors (this is sensitive to the $CP$-odd term which vanishes for $\delta_{CP} = 0$ or 180°).

It should be noted that if one precisely measures the $\nu_e$ appearance energy spectrum shape (peak position and height for 1st and 2nd oscillation maximum and minimum) with high resolution, CP effect could be investigated with neutrino run only. One more aspect which should be noted is that antineutrino beam conditions are known to be more difficult than those for neutrinos (lower beam flux due to leading charge effect in proton collisions on target, small antineutrinos cross-section at low energy, etc.). Moreover, the systematic uncertainty for the neutrino mode experiment and antineutrino mode experiment is different each other and not much cancellation is foreseen.

![Figure 2. Neutrino flux for various off-axis angle (left) and probability for $\nu_\mu \rightarrow \nu_e$ oscillations as a function of the $E(\text{GeV})/L(\text{km})$ for various $\delta_{CP}$ (right).](image)

Figure 2 (left) shows neutrino flux for various off-axis angles. If one selects on-axis setting, 1) wide energy coverage is foreseen which is necessary to cover the 1st and 2nd maximum simultaneously, and 2) measurement suffers from severe $\pi^0$ background originated from high energy neutrino which requires the detector with high performance discrimination ability between $\pi^0$ and electron. On the other hand, if one selects off-axis setting, 1) requirement for $\pi^0$ background discrimination is soft, and 2) measurement is essentially counting experiment at the 1st oscillation maximum.

Figure 2 (right) shows the oscillation probability as a function of the $E(\text{GeV})/L(\text{km})$. If the distance between source and detector is fixed, the curves can be easily translated to that for the expected neutrino energy spectrum of the oscillated events. As can be seen, if the neutrino energy spectrum of the oscillated events could be reconstructed with sufficiently good resolution.
in order to distinguish first and second maximum, useful information to extract the CP phase would be available even only with a neutrino run. If baseline is set to be long, 1) energy of 2nd oscillation maximum gets measurable. 2) statistical significance may get worse, and 3) measurement is affected by large matter effect. On the other hand, if baseline is set to be short, 1) it is impossible to extract 2nd oscillation maximum information, 2) statistical significance may get better, and 3) measurement is less affected by matter effect.

In addition to above consideration on the measurement of lepton sector CP phase $\delta_{CP}$, discovery potential for proton decay and reality to realize huge detector are also the essential issues to be taken into account, to define far detector option.

4. Optimal configuration for the investigation of lepton sector CP Phase $\delta_{CP}$ with Liquid Argon Time Projection Chamber

Optimal experimental set up such as, the length of the baseline, the angle with respect to the neutrino beam axis and the detector technology, highly depends on the way to extract the effects of CP phase as discussed in the previous section. Since the Liquid Argon TPC has an excellent energy resolution for the neutrino energy measurement and event reconstruction capability from sub GeV to a few GeV and from single prong to high multiplicity configuration, it is suitable for spectrum measurement with wide energy coverage. Moreover, since the Liquid Argon TPC has an excellent discrimination capability of $\pi^0$ and electron, wide band on-axis beam is tolerable. It should be seriously taken into account the fact that there is an inevitable boundary condition from available accelerator facility, namely, the finite neutrino intensity and the energy range of the neutrino beam (30 GeV 1.66MW KEK/J-PARC MR for Japanese case). Also it is important to obtain experimental result within reasonable time scale of about five years. Thus, the optimal choice for the Liquid Argon TPC for the investigation of lepton sector CP symmetry breaking is the "Measurement of the energy spectrum shape of the appearance oscillated $\nu_e$ charged current events (emphasis on the 1st and 2nd oscillation maximum) with on-axis beam with 5 years neutrino beam running". After this first phase measurement, next experimental configuration (e.g. antineutrino mode running) will be decided.

5. Possible scenarios in Europe

The FP7 Design Study of a pan-European Infrastructure for Large Apparatus studying Grand Unification and Neutrino Astrophysics (LAGUNA) [2] is a collaborative project involving 21 beneficiaries, composed of academic institutions from Denmark, Finland, France, Germany, Poland, Spain, Switzerland, the United Kingdom as well as industrial beneficiaries specialized in civil and mechanical engineering and rock mechanics. LAGUNA brings together on one hand the scientific community interested in this kind of research, and on the other hand the industrial and technical experts able to help assess the feasibility of this infrastructure.

The principal goal of LAGUNA is to assess the feasibility of a new international research infrastructure in Europe able to host the next generation, very large mass, deep-underground neutrino observatory, with a volume in the range of 100,000 to 1,000,000 m$^3$. Europe currently hosts four world-class national deep underground laboratories –with high-levels of technical expertise– that are located in Boulby (UK), Canfranc (Spain), Gran Sasso (Italy), and Modane (France). However, none of these is large enough for the detector envisioned by LAGUNA. Therefore, in addition to the possible extensions of the existing underground laboratories, the LAGUNA consortium has been studying the creation of new laboratories in the region of Umbria (Italy), Pyhäsalmi (Finland), Sierozsowice (Poland) and Slanic (Romania).

The LAGUNA design study considers three different underground neutrino detector technologies located at the several potential underground sites cited above, in order to identify the scientifically and technically most appropriate and cost-effective strategy for future large-scale underground detectors in Europe. The first detector option (MEMPHYS [3]) is based
on the well-established Water Cerenkov Imaging technology developed by IMB in USA and Kamiokande/SuperKamiokande in Japan. The second option (LENA [4]) considers a very large non-segmented liquid scintillator detector. The third is based on the next generation liquid argon time projection chamber technique (GLACIER [5]). At this stage, the three gLiquid detectors are studied in parallel, exploiting synergies and common issues.

After three years of detailed studies that led among others to the publication of seven reports describing the feasibility of the LAGUNA infrastructure in each of the pre-selected site the Pyhäsalmi site has been identified by the LAGUNA consortium as a high-priority potential site together with the Fréjus site. Both sites will be further investigated in the context of the recently approved LAGUNA-LBNO study (2011-2014) [6].

LAGUNA is high priority project of the Roadmap of Astroparticle Physics (ASPERA) which states gWe recommend that a new large European infrastructure is put forward as a future international multi-purpose purpose on the 100-1000 ktons scale for improved studies of proton decay...h and gThe three detection techniques being studied for such large detectors in Europe, Water Cherenkov, Liquid Scintillator and Liquid Argon, should be evaluated in the context of a common design study which should also address the underground infrastructure and the possibility of an eventual detection of future accelerator neutrino beams.h. At the same time, the possibility to couple the far detector to a high intensity neutrino beam from CERN clearly places the LAGUNA project at the interface with the CERN European Strategy Update to be delivered by the end of 2012. As such the LAGUNA project constitutes a high astro-particle physics priority to be discussed within the CERN strategy update process.

6. Possible scenario in USA
There is a proposal named the Long-Baseline Neutrino Experiment (LBNE) [7] which utilize a high intensity neutrino source at Fermi National Accelerator Laboratory (Fermilab) aiming at 20 kt Liquid Argon TPC located at the proposed Deep Underground Science and Engineering Laboratory (DUSEL) 1300km away from Fermilab.

7. Possible scenario in Japan: J-PARC to Okinoshima long baseline neutrino experiment
The study of possible new generation discovery experiments with KEK/J-PARC neutrino beam was initiated at the 4th International Workshop on Nuclear and Particle Physics at J-PARC (NP08) [8]. With the same configuration as T2K (2.5° off-axis angle), the center of the neutrino beam will go through underground beneath SK (295 km baseline), and will automatically reach the Okinoshima island region (658 km baseline) with an off-axis angle 0.76° (almost on-axis).

7.1. KEK/J-PARC and Main Ring Synchrotron
KEK/J-PARC (Figure 3) is a KEK-JAEA joint facility for MW-class high intensity proton accelerator. It provides unprecedented high flux of various secondary particles, such as neutrons, muons, pions, kaons, and neutrinos, which are utilized for elementary particle physics and material and life science.

In the accelerator complex, H^- ions are accelerated to 181 MeV with LINAC, fed into Rapid Cycling Synchrotron (RCS) with stripping out electrons and are accelerated to 3 GeV. At final stage, proton beam goes into Main Ring Synchrotron (MR) and accelerated to 30 GeV. For the neutrino experiment, accelerated protons are kicked inward to neutrino beam facility by single turn with fast extraction devices. Main characteristics of MR is described in Figure 4.

7.2. KEK/J-PARC neutrino beam facility
The proton beam from MR run through KEK/J-PARC neutrino beam facility and producing intense muon neutrinos toward the west direction. KEK/J-PARC neutrino beam facility is
Figure 3. KEK/J-PARC accelerator and experimental facility.

Figure 4. The overview of the KEK/J-PARC MR.

composed of following parts with their functionalities (Figure 5).

- Preparation section: Match the beam optics to the arc section.
- Arc section: Bend the beam ∼90° toward the west direction with superconducting combined function magnet.
• Final focus section: Match the beam optics to target both in position and in profile. Level of mm control is necessary which corresponds to 1 mrad $\nu$ direction difference, also not to destroy target.

• Graphite target and horn magnet: Produce intense secondary $\pi$’s and focus them to the west direction. (3 horns system with 320 kA pulse operation)

• Muon monitor: Monitor $\mu$ direction ($=\nu$ direction), pulse to pulse, with measuring center of muon profile.

• On-axis neutrino monitor (INGRID): Monitor $\nu$ direction and intensity.

This facility is designed so that up to $\sim$2 MW beam power is tolerable. The limitation is due to temperature rise and thermal shock for the components such as Al horn, graphite target, and Ti vacuum window. Since everywhere suffers from high radiation, careful treatment of radioactive water and air ($\sim$10 GBq/3weeks) is required. Moreover, maintenance scenario of radioactive components has to be seriously planned.

7.3. KEK/J-PARC neutrino beam upgrade plan

As for the neutrino beam intensity improvement, MR power improvement scenario toward MW-class power frontier machine, KEK Roadmap plan, is analyzed and proposed by the KEK/J-PARC accelerator team as shown in Table 1.

The plan will be realized with the combination of high repetition cycle and high beam density. Items to be modified from start up toward high intensity are listed as following.

• Number of bunches in MR should be increased from 6 to 8. For this purpose, fast rise time extraction kicker magnet have to be prepared. Its installation is foreseen in 2010 summer.

• Repetition cycle of MR has to be improved from 3.5 seconds to $<1.92$ seconds. For this purpose RF and magnet power supply improvement is necessary.

• RCS operation with harmonic number 1 has to be conducted. This is to make the beam bunch to be longer in time domain to decrease space charge effect. For this purpose RF improvement is necessary. When RCS is operated with harmonic number 2, beam is injected...
Table 1. MR power improvement scenario toward MW-class power frontier machine (KEK Roadmap).

|                | Achieved (March 2011) | Next Step | KEK Roadmap |
|----------------|-----------------------|-----------|-------------|
| **Power (MW)** | 0.145                 | 0.45      | > 1.66      |
| **Energy (GeV)** | 30                    | 30        | 30          |
| **Rep. Cycle (sec.)** | 3.04          | 2.2       | 1.92 ~ 0.5  |
| **No. of Bunches** | 8                      | 8         | 8           |
| **Particles/Bunch** | 1.2 × 10^{13}     | 2.5 × 10^{13} | (4.1 ~ 8.3) × 10^{13} |
| **Particles/Ring** | 9.2 × 10^{13}        | 2.0 × 10^{14} | (3.3 ~ 6.7) × 10^{14} |
| **LINAC (MeV)** | 181                   | 181       | 400         |
| **RCS^a**      | h = 2                 | h = 2     | h = 2 or 1  |

^a Harmonic number of RCS

... to MR with 2 bunches × 4 cycles. On the other hand, when RCS is operated with harmonic number 1, beam is injected to MR with single bunch with doubled number of protons × 8 cycles.

- LINAC 400 MeV operation is required to avoid severe space charge effect at RCS injection. Construction of necessary component is already approved and started.

7.4. J-PARC to Okinoshima long baseline neutrino experiment

The scenario is depicted in Figure 6 [9][10]. In order to cover a wider energy range, detector...
has to be located at an energy larger than about 400 MeV, the baseline should be longer than about 600 km. In addition, in order to collect enough statistics, baseline should not be too much longer than above stated. Taking into account all of the above mentioned conditions, the Okinoshima region (658 km baseline and almost on-axis (0.76° off-axis) configuration) turns out to be ideal.

Analysis here based on the assumption using a neutrino run only during five years to be reasonable time duration for the single experiment (10^7 seconds running period/year is assumed), under the best KEK/J-PARC beam assumption. An anti-neutrino beam (opposite horn polarity) might be considered in a second stage in order to cross-check the results obtained with the neutrino run (in particular for mass hierarchy problem). Detector is assumed to be a 100 kton Liquid Argon Time Projection Chamber. This type of detector is supposed to provide higher precision than other huge detectors to separate the two peaks in energy spectrum. In addition, the π^0 background is expected to be highly suppressed thanks to the fine granularity of the readout, hence the main irreducible background will be the intrinsic ν_e component of the beam.

The right hand side plot in Fig. 6 shows the energy spectra of electron neutrino at the cases of δ_{CP} equal 0°, 90°, 180°, 270°, respectively. Shaded region is common for all plots and it shows the background from beam ν_e. Here perfect resolution is assumed. As shown, the value of δ_{CP} varies the energy spectrum, especially the first and the second oscillation peaks (heights and positions), therefore comparison of the peaks determine the value δ_{CP}, while the value of sin^2 2θ_{13} changes number of events predominantly. Allowed regions in the perfect resolution case are shown in left hand side of Fig. 6. Twelve allowed regions are overlaid for twelve true values, sin^2 2θ_{13}=0.1, 0.05, 0.02, and δ_{CP}=0°, 90°, 180°, 270°, respectively. The δ_{CP} sensitivity is 20~30° depending on the true δ_{CP} value [9][10].

8. World wide consensus and the motivation of the workshop
There is no question about importance of 100 kt Liquid Argon Time Projection Chamber. The question is how to realize it. The first International Workshop towards the Giant Liquid Argon Charge Imaging Experiment (GLA2010) is the place to discuss how to realize 100 kt Liquid Argon Time Projection Chamber.

9. The aim of the GLA2010
The aim of the GLA2010 is to bring together researchers having common interest in realizing a giant neutrino observatory based on the liquid Argon time projection chamber technology combining next-generation searches for proton decay and neutrino physics with natural and artificial sources. The workshop will review the current worldwide efforts towards large liquid Argon detectors and aims at fostering collaborations on the medium and long time scales.

10. The skeleton of the GLA2010
The skeleton of the GLA2010 program is as follows.

- Learn experiences thoroughly, and integrate presently available knowledge
  - Special session the ICARUS Liquid Argon TPC
  - Lessons on Liquid Argon Charge Imaging technology from ongoing developments
  - Lessons from Xe based Liquids Imaging detectors
  - Studies on physics performance
- Push present efforts forward coherently
  - Ways to improve the Liquid Argon Charge Imaging technology
- Toward realization of Giant Liquid Argon TPC
  - Localization studies
Future steps towards the realization of Giant Liquid Argon Charge Imaging detectors

Needless to say, based on physics argument

Main goals of Giant Liquid Argon Charge Imaging Experiments

The workshop starts with the talk on the pioneering and world leading experiences and efforts by the ICARUS Liquid Argon project presented by Professor Carlo Rubbia.

References

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