Responses to the NuSAG committee from the T2K 2KM group

Q1: What is the assumed systematic error on the background in your sensitivity projections? What measurements, yours and other experiment's, are required to reach this assumed error? How are these measurements to be performed?

A1: For the T2K sensitivity projection using the 2KM alone, **we assume a total systematic error on the background of 7.5%**, which we believe is conservative and could be improved. The estimate is based on detailed MC simulations of both the 2KM water Cherenkov detector and SK, with simple scaling of event rates by $1/r^2$. Please see section 11.1.4 of the 2KM proposal for more details. For those errors which needed to be estimated with real calibration sources or data we have taken the values already obtained using the K2K 1kt water Cherenkov detector. **Because the flux, target and detector technology match between 2KM and SK, we do not rely strongly on measurements from other experiments; uncertainties in these quantities naturally cancel. We do rely on the beam profile monitor at 280m to demonstrate that the beam is left-right symmetric.**

To improve the systematic error, we would address the uncertainty in selection efficiency. In our current work, the ratio of efficiencies $\frac{\epsilon_{SK}}{\epsilon_{2km}}$ is assumed to be unity (see Equation 11, section 11.1.4 of the 2KM proposal). In order to obtain a conservative result, we currently take the full difference in efficiency for each cut $\epsilon_{2km} - \epsilon_{SK}$ as the systematic error. The total systematic error of 7.5% is found by adding all the errors in quadrature. In Table 1, the efficiency differences between SK and 2KM are listed. In a full analysis the efficiency differences would be corrected for and the systematic uncertainty on the differences would be separately estimated and likely be smaller. **The measurements needed to improve the estimate would come from tuning the 2KM Monte Carlo to best match the 2KM data set. Efficiencies at SK are studied using various calibration sources as well as atmospheric neutrinos.**

Cut	NC	beam ν_e	CC-ν_μ
1)1 ring	6.3%	4.6%	-2.7%
2)e-like	-2.3%	2.1%	1.2%
3)no decay e-	-1.5%	2.5%	0.05%
4)$\cos\theta < 0.9$	-2.3%	1.5%	0.03%
5)$M_{\gamma\gamma} < 95$ MeV	-0.3%	0.4%	0.06%
6)$\Delta \log L < 150$	1.5%	1.7%	0.04%

Table 1: $\epsilon_{2km} - \epsilon_{SK}$ for each cut.

Of special concern, as they do not fully cancel, are errors on the fiducial volume and the energy scale at 2KM versus SK. These must be based on calibrations; we have conservatively set them to 4% and 3% respectively (based on our experience from K2K 1kton detector and our current understanding of SK). The systematic error on the volume is the same for all three background categories; therefore it is added in quadrature in the total systematic estimate to avoid over-counting.

We are investigating calibration systems to determine the energy scale and reduce the fiducial volume uncertainty. For example, this summer we are using the K2K 1kton to investigate adding a smaller set of internal PMTs to more clearly define the fiducial volume. In addition, an external manipulator arm has been tested in the K2K 1kton tank. The arm would give us the ability to move sources at will inside the detector and further refine our understanding of our reconstruction algorithms. Finally we have also recently tested a light cone generator for producing artificial π^0 light patterns in the Cherenkov detector.

The above discussion emphasized the search for ν_e appearance. **For ν_μ disappearance we have shown that with no corrections whatsoever to the ν_μ flux as measured at the 2KM, we can predict the un-oscillated ν_μ flux at Super-K to better than than 5%.** The backgrounds in this measurement are misreconstructed non-quasielastic interactions, typically feeding down from higher neutrino energies than the oscillation minimum energy of 0.6 GeV. **The 2KM will help address this background by detailed comparisons of data and neutrino Monte Carlo in the water Cherenkov detector as well as the liquid argon detector with water target. Measurements from experiments such as MINERνA are also welcome to help tune the neutrino Monte Carlo.**

Q2: What is your sensitivity (to ν_e appearance and to $\sin^2(\theta_{13})$) vs. calendar time for 20%, 10%, and 5% systematic errors?

A2: Figure 1 shows the sensitivity as a function of exposure for Super-K with 20%, 10% and 5% uncertainties in the background normalization in the 40GeV JPARC beam. This figure assumes that the J-PARC accelerator delivers 1.0×10^{21} protons per year of operation from the beginning of the experiment with a 40 GeV beam energy and a beam power of 0.67 MW. As can be seen, if the total background uncertainty is allowed to approach 20% the result becomes systematics-limited. Our goal is to control the total uncertainty at about 10% with the ND280 detector alone and below 10% with the ND280 and 2KM detectors combined.

The expected beam power of the J-PARC accelerator is shown in Figure 2, which shows various JPARC beam intensity options. There are 4 solid curves with different colors. (Please ignore the dotted curve.), each of which corresponds to a different beam power. The option previously presented publicly is shown by the line with black squares (the lowest beam power option) and corresponds to .67 MW. The orange curve with triangles shows the case for a factor of 2 increase in the beam power. A factor of 2 improvement can be achieved by doubling the number of proton bunches while the beam intensity is relatively low. When the beam intensity approaches the original design value, we can instead double the beam intensity by increasing the repetition rate (instead of increasing the number of proton bunches), thereby keeping the instantaneous energy deposit to the target and beam window

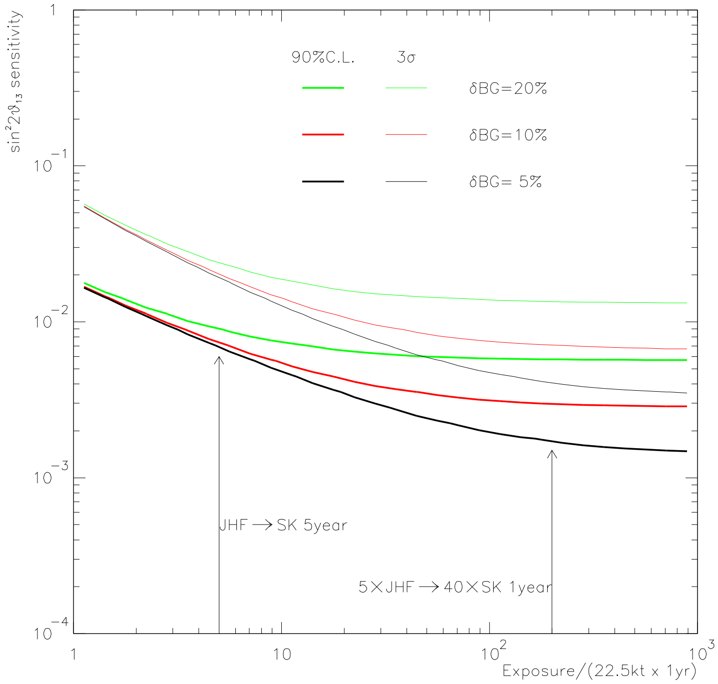

Figure 1: Sensitivity to $\sin^2 2\theta_{13}$ as a function of exposure for three uncertainties in the background prediction. This figure assumes that the J-PARC accelerator delivers 1.0×10^{21} protons per year of operation from the beginning of the experiment with a 40 GeV beam energy.

within the current design of the neutrino beam line. In this case, a beam power of 1.34 MW at full intensity would be achievable. There are several other accelerator running options currently being studied in KEK.

Using these beam-turn-on profiles we have calculated the $\sin^2 2\theta_{13}$ sensitivity as a function of time. As an example, choosing the option currently considered most likely by the JPARC accelerator staff, we assume that the beam intensity upgrade curve is the one shown by the orange triangles in Figure 2. With this configuration, which corresponds to a doubling of the previously presented beam power, the sensitivity as a function of Japanese fiscal year (April 1 to March 31) is shown in Figure 3. Also shown in this figure, for comparison, is the sensitivity as a function of year for the previous option as shown by the black line in Figure 2. These plots explicitly take into account the beam-turn-on profile, and for that reason, the limit improves at different rate than that shown in Fig. 1.

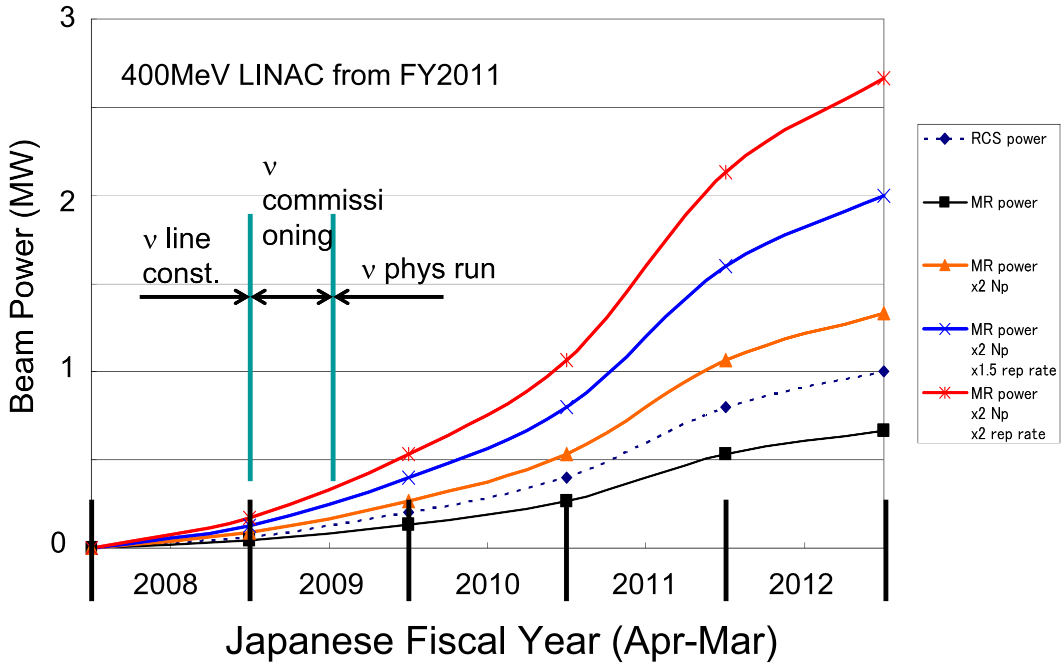

Figure 2: Expected J-PARC beam power upgrade for various accelerator options.

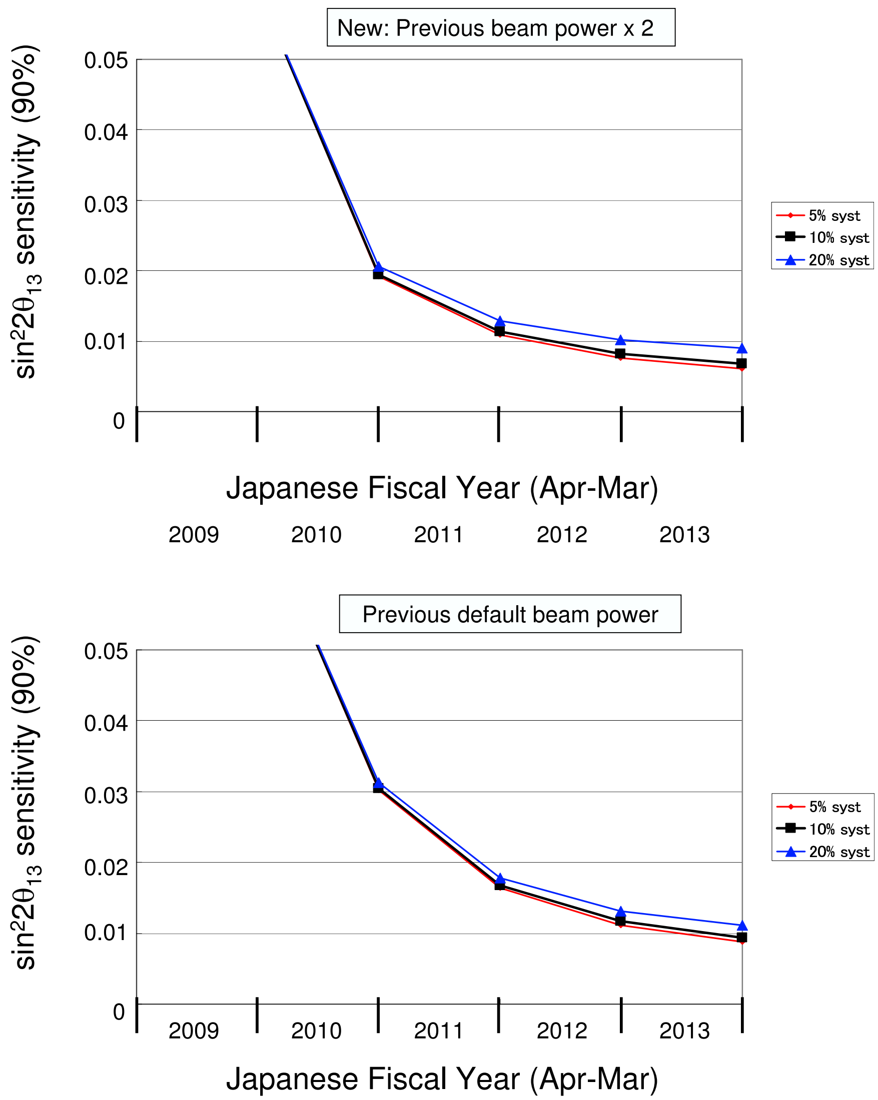

Figure 3: Sensitivity to $\sin^2 2\theta_{13}$ as a function of year considering the beam power profile. The top plot(corresponding to the orange line on Figure 2) is for for the case where the beam power is doubled with respect to the previous default option shown as the bottom plot (corresponding to the black line on Figure 2).

Q3: In the absence of a reactor θ_{13} measurement, how well and unambiguously can you determine θ_{13} and θ_{23}?

A3: Currently, we are still doing full calculations to answer this question. However, we present our rough estimate. Regarding the θ_{13} determination, if we only run with neutrinos and we know θ_{23} perfectly, we expect that the uncertainty in $\sin^2 2\theta_{13}$ due to uncertainties in δ is approximately a factor of two or more. This can be seen in the following plot taken from hep-ph/0310023 by Minakata, Nunokawa and Parke.

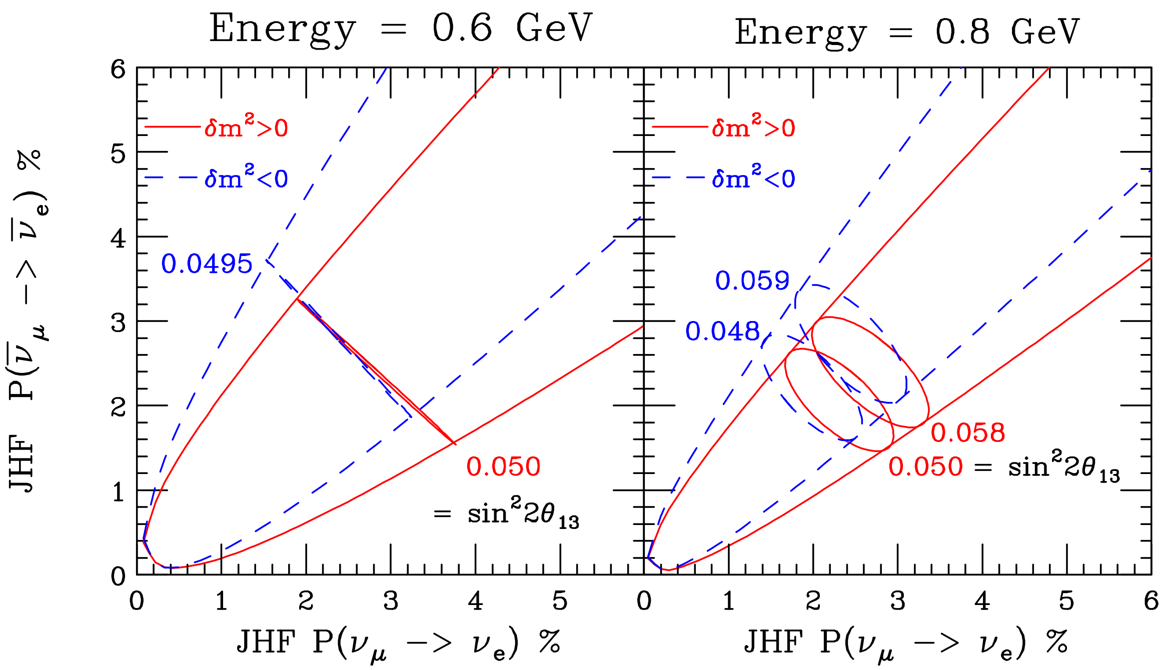

Figure 4: $P(\nu_\mu \to \nu_e)$ and $P(\overline{\nu}_\mu \to \overline{\nu}_e)$ are plotted as a function of the CP phase and the mass hierarchy. (Plot from hep-ph/0310023 by Minakata, Nunokawa and Parke.)

The left hand panel shows the relationship between neutrino and anti-neutrino oscillation as δ is varied between 0 and 2π with a beam whose spectrum has the peak flux at the maximum oscillation energy. The red and blue lines reflect the different hierarchies. The distance between the origin and the collapsed ellipse represents $\sin^2\theta_{23}\sin^2 2\theta_{13}$. Here we assume that $\sin^2\theta_{23}$ =0.5. For example, if P($\nu_\mu \to \nu_e$)=2.5%, P($\bar{\nu}_\mu \to \bar{\nu}_e$) could be between 1% and 5%, and the range of $\sin^2 2\theta_{13}$ could be between 0.035 and 0.075. **In conclusion, the uncertainty in $\sin^2 2\theta_{13}$ is slightly larger than a factor of two even if we know θ_{23} perfectly, at this value of θ_{13}.** Another example may be seen in Figure 5, at the limit of our sensitivity. Here, the limit on $\sin^2 2\theta_{13}$ varies by about a factor of six as delta changes.

Initially our focus is to make the first observation of ν_e appearance. However, in order to reduce the intrinsic uncertainty in our θ_{13} measurement, the T2K collaboration is seriously considering the possibility of carrying out an anti-neutrino run after the nominal 5-year period of neutrino running. By combining the ν_e and anti-ν_e appearance data, we expect that the uncertainty due to the CP phase and mass hierarchy can be reduced dramatically since the distance between the origin and the collapsed ellipse in Figure 4 can be determined almost independently of the CP phase and the mass hierarchy.

Finally, we discuss the $\sin^2 2\theta_{23}$ determination. As discussed in the LoI, in the case of pure $\nu_\mu \to \nu_\mu$ oscillations with full mixing and Δm^2 around $2.5\times10^{-3}\text{eV}^2$, the expected accuracy in the measurement of $\sin^2 2\theta_{23}$ is 1%. It gets slightly worse for smaller $\sin^2 2\theta_{23}$. For non-zero θ_{13}, the effect of θ_{13} on the $\sin^2 2\theta_{23}$ measurement must be taken into account. The leading and the next leading terms of $P(\nu_\mu \to \nu_\mu)$ are expressed (see for example hep-ph/0411402 by Donini et al.) as:

$$P(\nu_\mu \to \nu_\mu) = 1 - (\sin^2 2\theta_{23} - \sin^2 \theta_{23} \sin^2 2\theta_{13} \cos 2\theta_{23}) \sin^2(1.27\Delta m^2 L/E). \quad (1)$$

The size of the sub-leading term $(\sin^2 \theta_{23} \sin^2 2\theta_{13} \cos 2\theta_{23})$ within the currently allowed parameter regions is approximately; $0.64(0.55)\times0.1\times0.28(0.1) = 0.018(0.0055)$, where we assumed that $\sin^2 2\theta_{23} = 0.92(0.99)$, $\theta_{23} > \pi/4$ and $\sin^2 2\theta_{13} = 0.1$. These numbers show the size of the corrections that must be applied in order to determine $\sin^2 2\theta_{23}$. Therefore, if there is a factor 2 uncertainty in $\sin^2 2\theta_{13}$, we have about 1(0.3)% uncertainty in the magnitude of the correction for the case of the small(large) $\sin^2 2\theta_{23}$ and large $\sin^2 2\theta_{13}$. The uncertainty coming from a factor of 2 uncertainty in $\sin^2 2\theta_{13}$ is still smaller than the expected accuracy of the $\sin^2 2\theta_{23}$ measurement. Reactor experiments or the anti-neutrino run in T2K will help reduce the uncertainty in the $\sin^2 2\theta_{23}$ measurement, if $\sin^2 2\theta_{13}$ is as large as the present limit. However, we point out that unless we know if θ_{23} is larger or smaller than $\pi/4$, we do not know the sign of the sub-leading term, and therefore the ambiguity in the measurement of θ_{23} due to θ_{13} remains.

Q4: What is the effect of Δm^2_{23} on your sensitivity?

A4: This question is answered best with the following figures: (Figs. 5 and 6). The first figure shows the 90% C.L. $\sin^2 2\theta_{13}$ sensitivity dependence on Δm^2_{13} ($\approx \Delta m^2_{23}$), and the second figure shows the dependence on the sign of Δm^2_{13}.

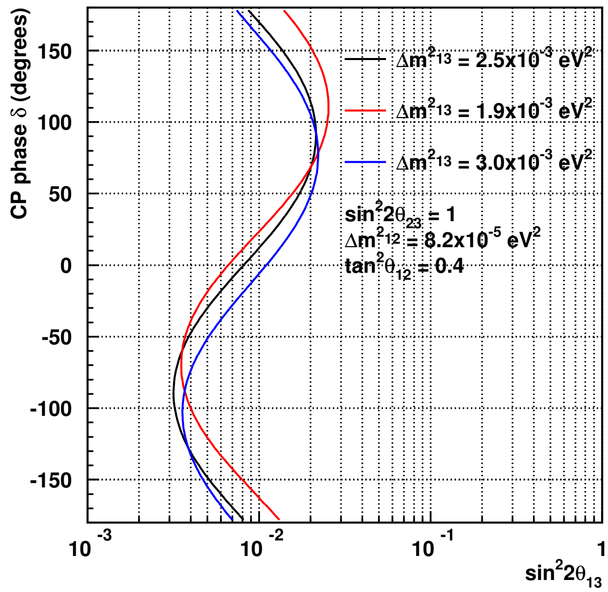

Figure 5: Sensitivity to $\sin^2 2\theta_{13}$ as a function of δ for different values of the atmospheric Δm^2.

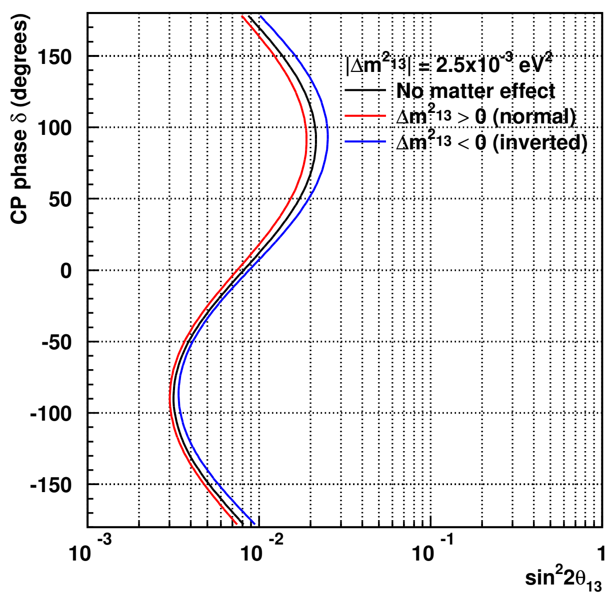

Figure 6: Sensitivity to $\sin^2 2\theta_{13}$ as a function of δ for the two different mass hiearchies.

Q5: How much would improved neutrino cross section measurements, using appropriate targets for your experiment, allow you to reduce the systematic uncertainty on your background estimate? In particular, please evaluate the potential that the Minerva experiment has to improve your result, and whether or not you are counting on having these measurements.

A5: For the ν_e appearance measurement we are fairly insensitive to cross section uncertainties since we will measure the background and extrapolate to Super-Kamiokande. In the 2KM we measure the flux times the cross section on a water target with the same beam spectrum as at Super-K. Actually, the ν_μ spectrum is different at SK due to neutrino oscillations; however the fraction of background coming from mis-identified CC-ν_μ events in the signal region is the smallest of all of the contributions to the total background. Using the shape of the measured background spectra in the water Cherenkov detector plus exclusive reconstruction in the LAr detector, we hope to separately estimate the fraction of NC and intrinsic ν_e background. Good control and cross-checks on the background estimation will greatly contribute to the believability of the background subtracted spectrum at SK.

The leading uncertainty in the background at SK which drives the systematic error and determines the sensitivity is the rate of NC single-π^0 interactions on water which fake a single-ring electron. The 2KM water Cherenkov detector will provide a direct measurement of these interactions using a detector with nearly identical response. Approximately 700 NC-π^0 will be misidentified as ν_e background in the 2KM, contributing to a prediction of the background rate at Super-Kamiokande. Another 20000 NC-π^0 will be successfully reconstructed, allowing us to explore the way in which π^0 events become misidentified as well as to develop improved reconstruction algorithms that can be applied in the far detector.

For the ν_μ disappearance search all information on cross sections that helps us understand the non-quasi elastic contribution will be useful since those events can have mis-reconstructed energy at Super-Kamiokande. The MINERνA experiment will study quasi-elastic, resonant pion, and coherent pion events at energies that contribute to this background. The target will be composed of CH, Fe and Pb. As far as we know, there are no plans to measure cross-sections on water, but such would be useful to us. These measurements from MINERνA should significantly improve neutrino Monte Carlos, which we greatly rely upon.

We will undertake studies of neutrino interactions with our own detectors. At 2KM, the low energy threshold of the LAr detector and bubble chamber like reconstruction ability will allow us to make detailed measurements in the same beam as seen in Super-Kamiokande. We will study the nuclear target difference between the argon and the water using a frozen water target [see question 9]. In addition, the events measured in the LAr detector, owing to the low detection thresholds, may be used as "data simulators", a technique successfully used in the NOMAD experiment. The idea is to use the actually measured events in the LAr detector to predict the events in the near and far WC detectors, thus alleviating the use of neutrino Monte-Carlos. More detailed studies of this possibility are on-going.

Q6: Please discuss as succinctly as possible the added value of the 2 km detector for T2K, given the existence of the 280 m detectors. Comment on the sensitivity to both θ_{13} and θ_{23}, and distinguish between the contributions of the water Cherenkov and liquid argon detectors.

A6: There are two types of answer to this question. The first, a quantitative comparison of the θ_{13} sensitivity with and without the 2km detector is difficult at this time since the detailed performance of the 280 meter detector is still under study. **If the 280 meter detector can achieve a 10% total systematic error then the numerical improvement in the sensitivity in the early stages of the experiment due to the addition of the 2km detector will be modest. However, as the luminosity increases our best sensitivity will be achieved with the 2km detector.** Refer to Figure 1.

The second answer to your question deals with the believability of the result. Let's assume that we can see a small signal due to electron neutrino appearance. This requires background rejection at better than one part in a thousand. We now have to prove that the large extrapolations that were made in going from a detector in a different beam, with a different target material, and a different detector technology were correct. **The strength of the 2KM detector is in providing a believable, direct estimate of the background to be subtracted using a large sample of measured background events.** Few assumptions or model dependencies are necessary with the 2km WC detector, as it measures the same flux times cross section for NC and beam ν_e events. In addition, if we can use the 280 meter detector to correctly predict what we should see in the 2KM detector, then we can extrapolate to Super-K using information from both and have confidence in the appearance result. Finally, the 2KM water Cherenkov detector will allow us to make studies of the dominant background with approximately 20000 NC-π^0 events. These studies may lead to improved reconstruction algorithms that can be applied at SK, improving the overall experiment. **Only at the 2KM can we record a large sample of events that are useable to directly study water Cherenkov reconstruction algorithms.**

To attempt to provide a quantitative answer of the first type, we provide a preliminary result from a different analysis framework than that used for the 2KM proposal. In this framework, a simultaneous fit to 2KM and SK data (simulated by repeated toy experiments) is used. This is more sophisticated than the simple scaling arguments referred to in A1 above, as it takes into account correlations; it is still largely dominated by the cancellations in flux and cross section, however.

Regarding the ν_e appearance experiment: Fig. 7 shows that inclusion of the 2KM detector improves the limit on $\sin^2 2\theta_{13}$ by anywhere from a factor of 15% to 30%. If the 280M detector can achieve 10% total uncertainty, we assume the curve using the 280M detector alone would be somewhat worse than the SK+2KM curve in Figure 7. The use of both together would exceed the SK+2KM limit, approaching, but not reaching, the lowest curve with no systematic uncertainty.

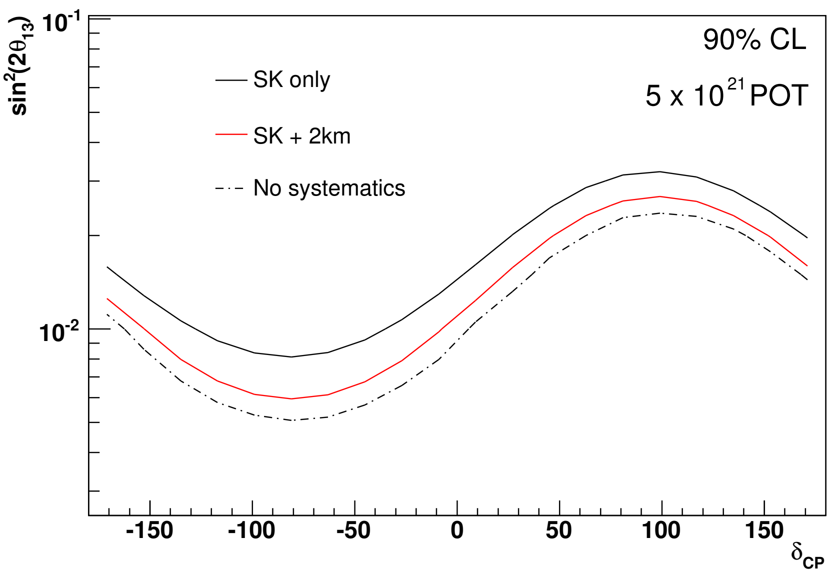

Figure 7: The sensitivity to θ_{13} of the T2K experiment using a simultaneous fit of simulated 2KM plus SK data sets of 5×10^{21} pot, as a function of δ. A curve is provided for the result using no 2KM to cancel flux and cross section uncertainties, the 2KM detector, and the best possible result where all systematic uncertainties are set to zero.

Regarding the ν_μ disappearance experiment, we use the same framework to calculate preliminary confidence intervals (Figure 8 for a test point distinct from maximal mixing, but still allowed by SK atmospheric results. At least for this test point, the 2KM detector helps distinguish the result from maximal mixing. As argued above, a configuration of 2KM+280M would improve only slightly and a configuration of only 280M will be somewhat worse. In this preliminary study, canonical values on neutrino cross section uncertainty were propagated. This is important, as the background which limits the θ_{23} sensitivity feeds down from higher neutrino energies. The 2KM detector would make unique contributions to improving these results: (1) the high energy tail can be monitored using energetic muons which exit the water Cherenkov detector and range out in the MRD, and (2) the LAr detector will constrain exclusive neutrino interaction final states at the relevant energies. Furthermore, the over-constrained reconstruction of quasi-elastic events with visible recoil protons (using the LAr) gives an independent and direct determination of the neutrino energy spectrum.

Q7: The 2 km detector is 1.5 deg south of line connecting the target with Super-K. Why was this location chosen, given that it will not directly sample the beam as it

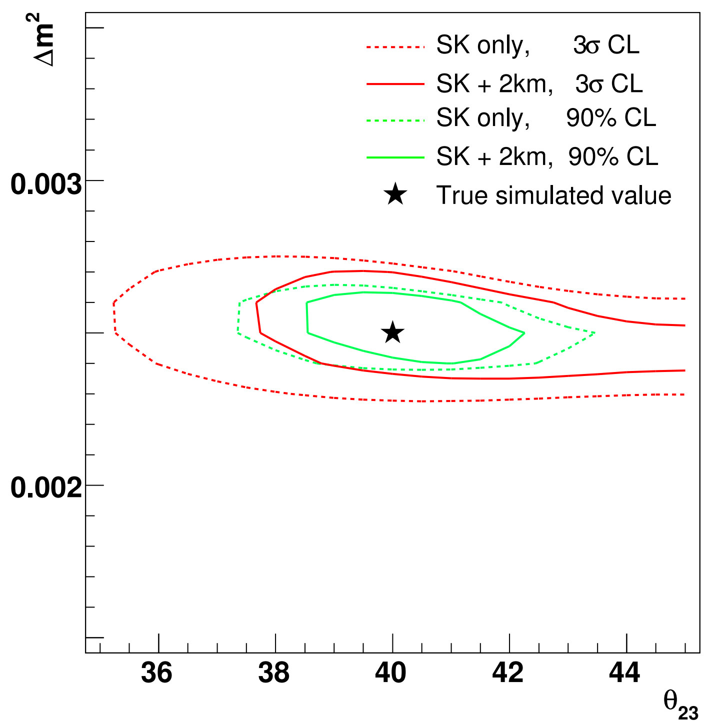

Figure 8: The allowed contours for the ν_μ disappearance experiment at a test point of $\Delta m^2 = 2.5 \times 10^{-3}$ eV^2 and $\sin^2 2\theta = 0.97$ simultaneous fit of simulated 2KM plus SK data sets of 5×10^{21} pot.

travels to Super-K? Because of its location, 2 km must rely on the 280 m detector to monitor the left-right symmetry of the beam in order correct for any asymmetry in the intensity vs. energy. How well can this be monitored by the 280 m detector, and what systematic error is introduced in the background estimate from the 2 km detector due to the resulting uncertainty on the symmetry of the neutrino beam?

A7: The T2K beam is 2.5 degrees below both the Super-Kamiokande and future Hyper-Kamiokande sites. **The 2KM detector is on the beam path to Hyper-K mainly for reasons of cost.** There is no easily available site on the Super-K side between 1.5 and 2.4 km. There is a potential candidate site at 2.5 km at the Super-K side on a hill. The extra civil construction cost of making a deeper hole would have increased the budget by a large amount. At the symmetric location on the Hyper-K side, we found a good site on municipal land, for which we have already negotiated rent-free use. And since the overall T2K program will potentially extend to using the Hyper-K direction, for very sensitive measurements where control of systematics is even more important than in the first phase, this site is optimum for the long range plans of the experiment.

The beam symmetry will be monitored by:

- The on axis neutrino beam monitor. This system which is located in the 280 m hall but distinct from the 280 m off-axis detector will monitor the profile of the beam. The current design does not extend to 2.5 degree off-axis. Therefore we would probably add two more beam monitor neutrino detectors at the Super-K and the 2KM side.
- The muon monitors at the end of the beam dump also monitor the beam shape. It does not extend to 2.5° in the 2KM direction so we will need to rely on extrapolation.
- Comparisons with extrapolation from the off axis detector at 280m to the 2KM can also by used as a check that all of the beam systematics are understood.

We have not yet carried out detailed studies on the effect of this systematic error.

Q8: Is there an Oxygen Deficiency Hazard for the LAr detector in the confined underground space? If so, how will DOE ES&H regulations be enforced at the 2 km site?

A8: We have not considered the specific DOE ES&H regulations since operation is foreseen in Japan. However, safety issues when handling liquid argon are well known and are handled according to international standards. Satisfying the Japanese regulations should go a long way to answer most DOE ES&H regulations.

The liquid argon (or “refrigerated argon”) hazards are the following: (a) contact may cause cold burns; (b) high concentration may cause asphyxiation (victims may not be aware because argon is odorless). It is important to take some precautionary fire measures. indeed, external fire may cause containers to rupture/explode. Argon itself is however non-flammable and all known extinguishers may be used. It is therefore important to ensure a minimum distance between the liquid argon cryostat and other potentially flammable devices.

When using large quantities of cryogens, another concern is the accidental release of gas in large quantities due to liquid evaporation. In this case, safety measures require the evacuation of the area and adequate air ventilation. Personnel should not enter the area unless the breathing conditions are shown to be safe. If possible, one should immediately stop flow of the product. Argon gas, being heavier than air, will not evacuate from the underground hall without forced ventilation.

The basic concept for the liquid argon cryostat has been developed and engineered as shown in our proposal. We followed the internationally recognized codes for the design of conventional cryogenic-fluid pressure storage-vessels as covered in the ASME (American Standards of Mechanical Engineers) Boiler & Pressure Vessel Code, Sect. VIII (www.asme.org). Design and construction according to these standards should already bring us a long way towards ensuring a reliable and safe operation.

We have had preliminary industrial contacts with the Linde firm in Germany. Linde has broad knowledge in cryogenic devices and process, and already has contacts and experience in Japan. In addition, we have contacted a Japanese company which has experience in underground safety regulations. The preliminary information from this company indicates that an independent forced ventilation is recommended, but not much more. The company suggested that more details must be discussed with the local government and the local fire brigade office. We will do so before the actual construction starts. The civil engineering contractor has already been contacted to estimate the cost of an additional vertical shaft dedicated to a suitable forced ventilation system, and it was found to be negligible compared to the rest of the work. Hence, as shown in our proposal, we already included the additional shaft and the accompanying surface equipment for the forced ventilation.

We note that the scale of our problem is similar to that of other large scale HEP experiments, like for example ATLAS at LHC, which must handle 50 ton of LAr in a 150 m underground hall.

It is important to identify and understand the specific safety issues related to the different phases of operation of T2K-LAr:

1. Initial cooling: this is a transitory phase which will last roughly a week in which the detector frame will be cooled down. The mass of the inner-detector and and of the dewar is about 40 ton. These will be cooled with argon. The amount of argon needed for cooling is about 20 m^3 of LAr. Hence, we expect a gaseous Ar venting of about 15000 m^3 which is about three times the size of the underground hall. Surface venting will be provided via piping and additionally the hall ventilation will be operated during this phase.

2. Thermal insulation: a closed circuit of liquid argon with compressors on surface will be controlled by the temperature/pressure of inner vessel. The heat losses under normal conditions yield a consumption of about 100 LAr l/day. This corresponds to a power of approximately 500 W (cold) or 10 kW electric. Including liquid argon purification, this number increases to 600 LAr l/day (estimated) or approximately 30 kW electric. In the case of an accidental loss of vacuum insulation, the consumption should raise to 2000 LAr l/day or about 1 m^3gas Ar/minute. In this case, gas will be evacuated to the surface through venting via dedicated piping and the hall ventilation.
3. Transfer lines, piping or external components failure: safety will be ensured by redundant pumps, valves, etc. Thermal stress of transfer lines resulting potentially in loss vacuum insulation of pipes will be taken into account.
4. Catastrophic failure of cryostat (unlikely): possible causes are (a) fire in the hall, (b) external impact, (c) earthquake. Shock absorbers will damp the effect of earthquakes. In case of rupture, one expects a "flash" production of gaseous argon due to the equilibration of the pressures. If the detector is operated at an overpressure lower than 0.2 bar (this will be controlled by the external refrigerator), less than 600 m^3 will be produced, to be compared to the size of the hall of 4830 m^3. Forced ventilation will deal with the flash. Unfortunately a catastrophic failure could cause major spill of liquid argon. By design, our liquid argon is within a double containment since both inner and outer vessel must break for argon to spill in the hall. However, this would represent a major hazard. A containment pool could provide a triple containment for maximal safety.

Overall, underground installation and operation is a relevant issues for LAr TPC detectors, and already at this early stage of our project these issues are being properly handled. This is in contrast to other initiatives based on a large scale LAr TPCs where these issues where considered in series (construction of cryostat and then installation) rather than in a parallel fashion, where design and installation are considered together in a unique project.

More work has to be performed to understand the potential safety hazards due to interference between simultaneously occurring incidents in the MRD, WC and LAr detectors.

Q9: The frozen water target volume in the LAr detector is 1 - 5 tons, or 0.1 - 0.5% of the 2 km water Cherenkov volume, and will have a correspondingly reduced event rate. How many ν_e and NC background events do you expect to observe from the water target in the LAr detector per year?

A9: Many of the required numbers are already mentioned in the proposal. Here we repeat and complete these figures, as shown in Table 2. At this stage we consider the option of the parallelepiped shaped inner target with a thickness between 12.5 and 50 cm. The fiducial volume of the water Cherenkov detector is 100 tons so the frozen water target within the LAr detector (1 - 5 tons) represents 1 - 5% of the 2km water Cherenkov volume. We expect to observe between 119 and 476 ν_e interactions and between 705 and 2820 NC background events (includes only inelastic interactions), depending on the final choice of thickness of the water target for each 1.0×10^{21} protons on target.

Target Width	12.5 cm	25 cm	50 cm
Target Mass (tons)	2.69	5.37	10.74
Total number of QE interaction per 10^{21}pot	3278	6556	13112
QE protons (%)	50	30	19
QE full reconstruction (%)	36	22	14
QE full reconstruction (number per 10^{21}pot)	1178	1440	1832
total number of nonQE interaction per 10^{21}pot	1853	3706	7412
nonQE protons (%)	32	22	16
nonQE π^+ (%)	94	85	71
nonQE π^0 (%)	95	85	76
nonQE full reconstruction (%)	27	17	9
nonQE full reconstruction (number per 10^{21}pot)	500	630	670
total number of ν_e interaction per 10^{21}pot	119	238	476
total number of NC interaction per 10^{21}pot	705	1410	2820

Table 2: The number of neutrino interactions in the water target of the LAr detector. The expected rates for three possible target thicknesses are shown.

Q10: The maximum drift time in the LAr detector is 1 ms, and the area of LAr tank is roughly 1/2 the area of the Cherenkov water tank, so a simple scaling suggests that the cosmic rate in the LAr detector will be 500 Hz , leading to a dead time of 500Hz * 1ms = 50% from cosmic ray triggers. Is this naive estimate correct?

A10: When studying how cosmic rays affect the LAr detector performance the critical parameter is "dead volume" rather than "dead time".

Neutrino interactions taking place while a muon is going through the detector have been simulated. In $\sim$ 80% of these events the tracks coming from the neutrino interaction and the muon track are well separated in the drift coordinate and the cosmic ray does not affect the reconstruction at all. (Figure 9 and Figure 10). When two 2D views are matched to have a 3D reconstruction the major complication comes from hits on different wires at the same time; since both the direction of the neutrino beam and the main direction of cosmic rays are orthogonal to the drift direction, it is possible to have a good 3D reconstruction most of the time.

Given the efficiency on the reconstruction when a cosmic ray passes through, it is crucial to know how many muons cross the detector in 1 ms. If we consider that the detector is sited 50m underground, we find that there are only 0.06 muons per ms crossing the LAr detector; however we must take into account that there is the open shaft.

A detailed simulation with the proper shaft geometry has therefore been carried out using the following parameters:

- 170 μ m^{-2} s^{-1}
- angular distribution $\propto cos^2\theta$
- cut off 1 GeV/c

and the result is that 1.1% of the generated muons enter the LAr active volume and 1.1% enter only the non-active LAr volume. The number of muons that enter the shaft in 1 ms is ∼11 which means that the average number of muons crossing the LAr detector in 1 ms is ∼0.1. **Our conclusion is that less than 2% of the events will be affected in the analysis because of overlapping cosmic rays.**

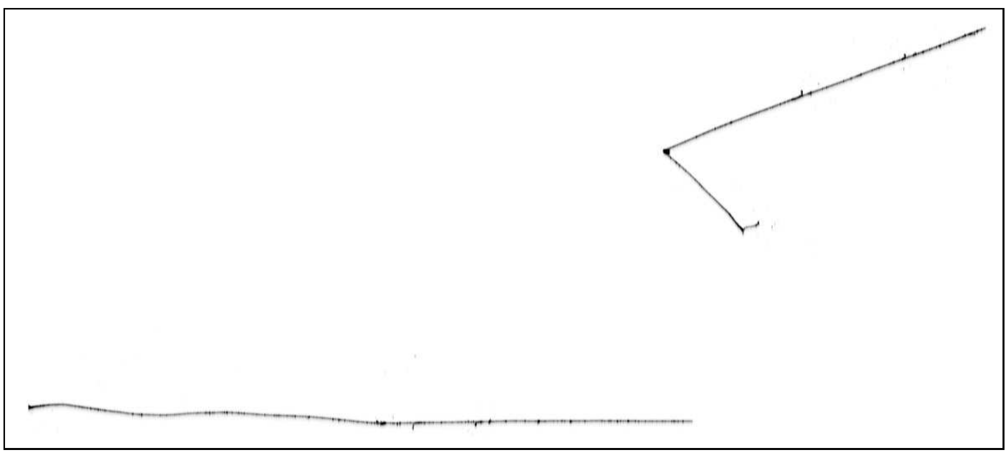

Figure 9: Zoomed view of the simulated raw collection view of a beam-induced neutrino interaction with an overlapping out-of-time crossing cosmic ray muon.

Q11: The systematic error calculated on the number of background events in the proposal is 7.5% after 5 years running, for fully contained events in Super-K, with Evis between 100 MeV and 1 GeV. Does the 7.5% include the systematic uncertainties on the relative fiducial volume, energy scale, and energy resolution?

A11: **Yes**. The errors on volume and energy scale are taken into account explicitly. The error on energy resolution is included in the difference in reconstruction efficiencies used to calculate the systematic error. Please see the answers to question one for more details.

Q12: The proposed budget has US contributions of 50% of the water Cherenkov detector, 15% of the LAr detector, and 50% of civil construction. What specific components of the water Cherenkov and LAr will be contributed by US groups? Why is US

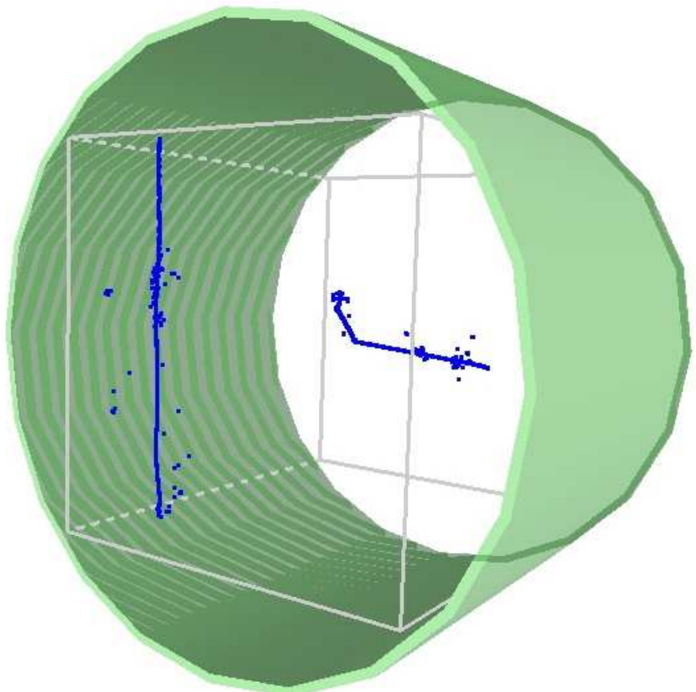

Figure 10: 3D visualization of neutrino interaction and cosmic muon.

proposing to contribute such a large percentage of cash for civil construction in Japan, and such a small fraction to the LAr detector, which would involve US universities and train students and postdocs?

A12: We consider the 2KM project as a clearly identifiable way to add value to the T2K experiment. We view the 2KM project as joint between Japan/U.S./Europe, with roughly equal contributions to the costs. **The exact contributions will be fine-tuned as participation is clarified and responsibilities are assigned.**

The water Cherenkov detector is the most essential item, and as the Japan/U.S. Super-K groups both bring equal expertise for this component, we propose to share the costs and credit equally. We extended this to include civil construction, mainly to address a particular need for the 2KM project related to funding paths in Japan. The civil construction for the 2KM hall in Japan must be funded through the KEK laboratory since it is an accelerator-based project. The money for detectors can come from other sources. All of the money for civil construction at KEK is completely committed through the construction of the beam line and 280 meter detectors. If the US pays for 1/2 of the civil construction (as part of its 1/3 of the total cost of the project), and assuming the U.S. funding can be made available during the period when Japanese funding is locked up with J-PARC construction, we have the opportunity to begin the civil construction and accelerate the project. This will make more than a one year difference in when we can start collecting data.

At this time we suggest that the project be largely viewed in terms of percentage contribution rather than contribution by detector element. Nevertheless, there are certain items which the U.S. expects to provide such as the water purification system (already developed for K2K). We have not yet decided how to divide responsibilities with respect to PMTs, HV, cables, electronics and so on. But both the U.S. Super-K group and the Japan group have extensive experience with all aspects of building water Cherenkov detectors and dividing responsibilities should be straightforward.

The European group proposed to contribute uniquely by the liquid argon detector, therefore they bear most of that cost. The LAr detector was initially proposed as a turnkey contribution, but recently we identified potential U.S. participation. The U.S. fraction of the LAr contribution was estimated by the fraction of U.S. participation (approximately 15-20% of personnel).

There is a growing interest in the noble liquid imaging detector technology for some of the most compelling non-accelerator physics programs. Large volume detectors based on liquid argon and xenon are being developed for experiments ranging from neutrinoless double beta decay to dark matter direct detection to solar neutrino physics. From cryogenics to signal readout, from electronics to data acquisition, these experiments share many technological challenges and solutions. Preliminary discussions about sharing of responsibilities foresees well-identifiable items for US groups like the high-voltage system for the drift field, the field shaping electrodes and the scintillation light readout. If the number of US groups in T2K-LAr were to increase, or if a national lab would endorse the project, e.g. to provide logistic infrastructure for US groups, then a larger US total contribution could be envisaged while still keeping the WC and civil construction budget fixed. In this case, a US contribution including design and fabrication of large components of the system, such as the entire inner detector, could be realistically envisaged.

Indeed, a larger US participation in the new and promising LAr TPC technology would provide added-value and positive feed-back to US universities, and provide a natural way to give first hand training in this technology to the physicists involved. Building a strong base of expertise in LAr technology in the US with participation in T2K will be beneficial for future programs in neutrino physics and particle astrophysics. A more visible US role in this international effort will guarantee early significant physics results for university-based scientists and graduate students, while providing the opportunity for training and forming the next generation of experimentalists for neutrino physics worldwide.

Q13: 2 km requests approval to begin construction in 2008, and with an aggressive 3-year construction will be ready to take date in 2011. T2K's schedule shows data taking starting in 2009 for 5 years, until 2013. How much contingency is there in the 2 km schedule?

A13: Before answering this question, we would like to clarify the period of the T2K experiment. We wrote the proposal assuming 5 years of full intensity running (1.0×10^{21}

protons on target per year with a 40 GeV beam). However, this does not mean that T2K will turn off at the end of its nominal 5-year run. As long as T2K is producing meaningful physics results, we will request KEK and J-PARC to keep the experiment running.

We believe the 3-year construction schedule is realistic for the purposes of the water Cherenkov and MRD detectors, with which we have extensive experience. It does not have any schedule contingency specifically identified. We did make a specific design choice for the civil construction to allow the LAr detector to go in last. It has the greatest schedule risk, and 2KM results will not be greatly diminished if this one component begins later.

The running period for the first phase of T2K includes five years of high intensity running. The first year or two so should have lower intensity. Therefore, the 2KM can be taking data for most of the delivered protons on target. Prompt approval of the 2KM project will allow us to take the greatest advantage of the the beam, and essentially inserts an enormous contingency. As we have already shown in Figure 3, it is very important to have the 2KM detector in 2011, when the θ_{13} sensitivity begins to be strongly dependent on the experimental systematic error, to make sure that the best physics results can be obtained from the T2K experiment.