Measuring electron neutrino appearance BG using the T2K 2KM detector

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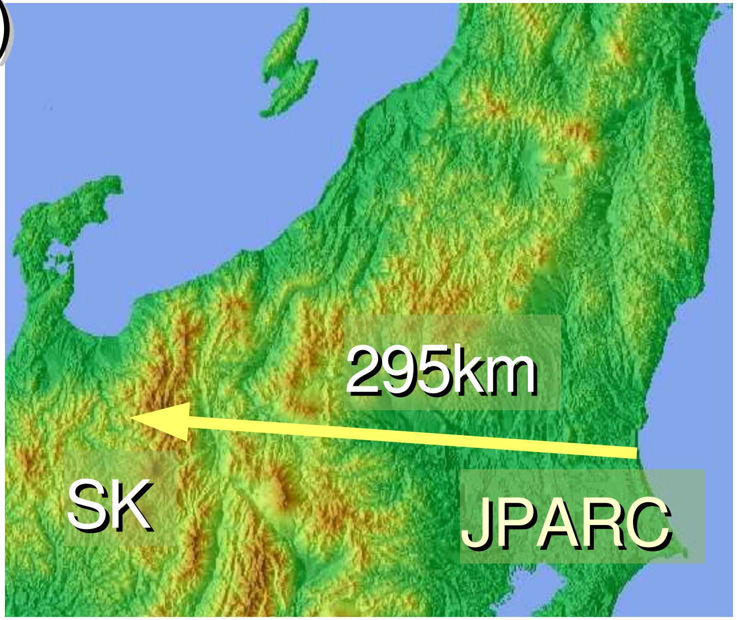
Outline

- T2K and Intermediate detector project
- Neutrino spectra at 280m/2KM/SK
- Motivation and performance of 2KM detector
- ν_e appearance analysis

T2K experiment

T2K (Tokai-to-Kamioka experiment)

- JPARC (40GeV PS)
  - New accelerator
  - 0.75 MW $\rightarrow$ 4 MW
  - Peak ν_μ energy at 0.7 GeV

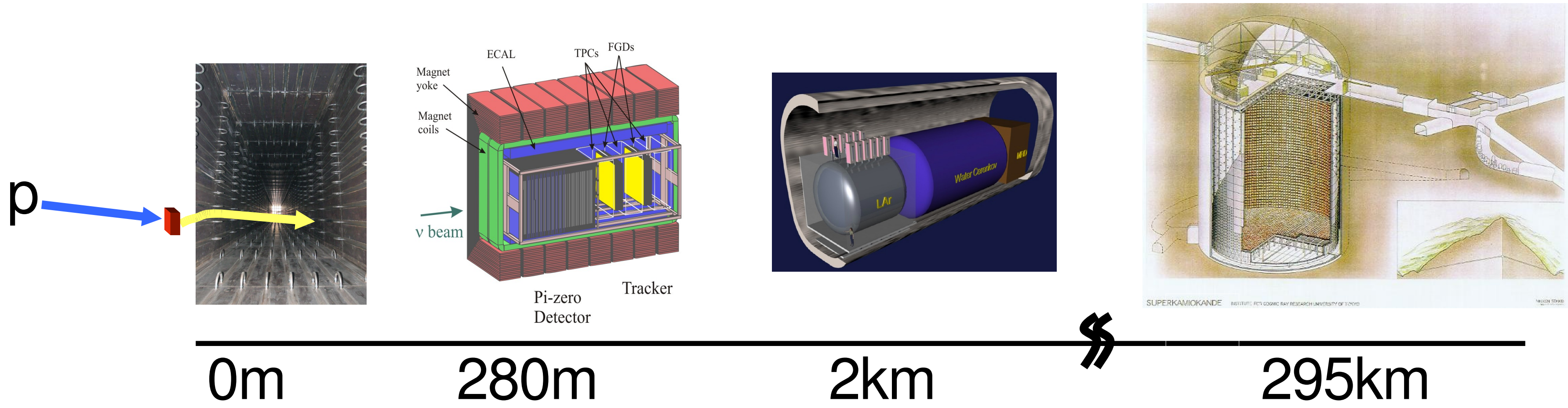


- 2.5° off-axis at Super-Kamiokande
  - To obtain low energy narrow band neutrino energy, we use the off-axis technique
  - Beam center doesn't point to SK, but reduces the beam-originated background
  - This will maximize the signature for the disappearance of ν_μ and the appearance of ν_e

Goal of T2K experiment

- The major physics goals of the T2K experiment are :
  - Searching for non zero θ_{13} by looking for electron neutrino appearance in mostly pure ν_μ beam
  - Precise measurement of Δm_{23}^2 and $\sin^2 2\theta_{23}$ with a few % and 1% accuracy by observing ν_μ disappearance
- The key to the T2K experiment is to cancel systematic uncertainties as much as possible and to understand the backgrounds in the beam before the neutrino oscillations have taken place $\rightarrow$ Near detectors

T2K detectors

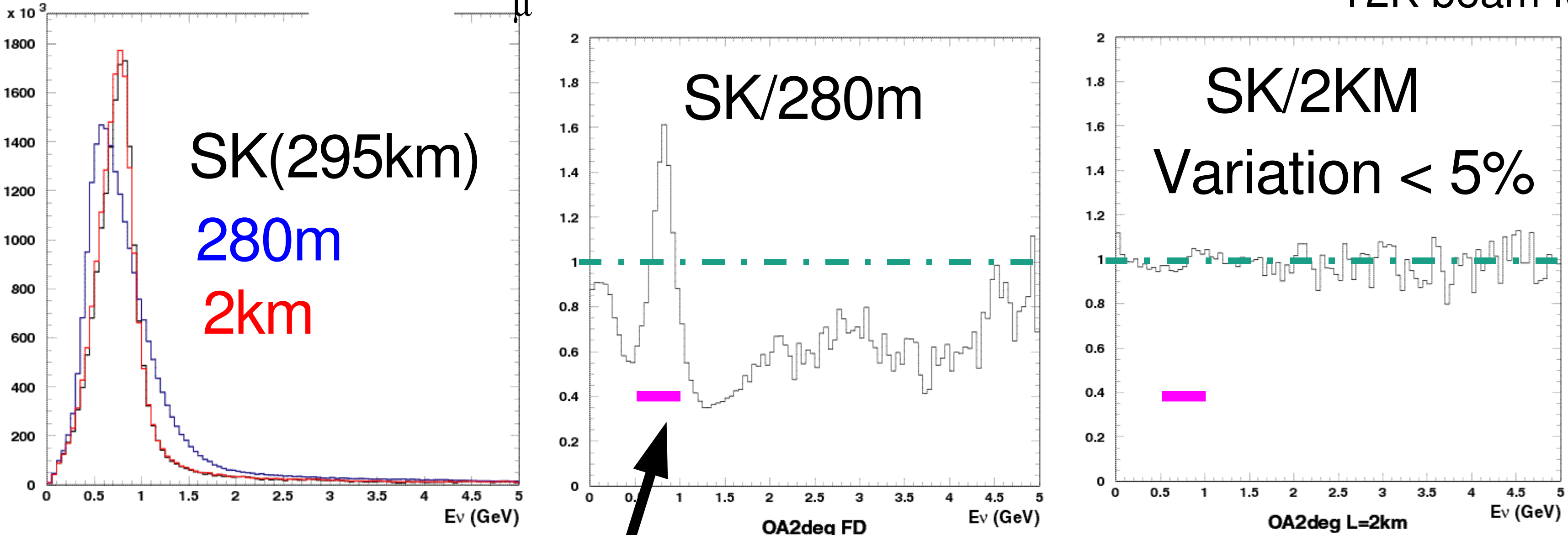


- Near detectors : one detector at 280m, and the 2KM detector, 2km away from the ν_μ beam source
- Far target : Super-Kamiokande
- Source of neutrinos looks like a point at 2KM

Neutrino spectra at the different locations

Non-oscillated ν_μ

T2K beam MC

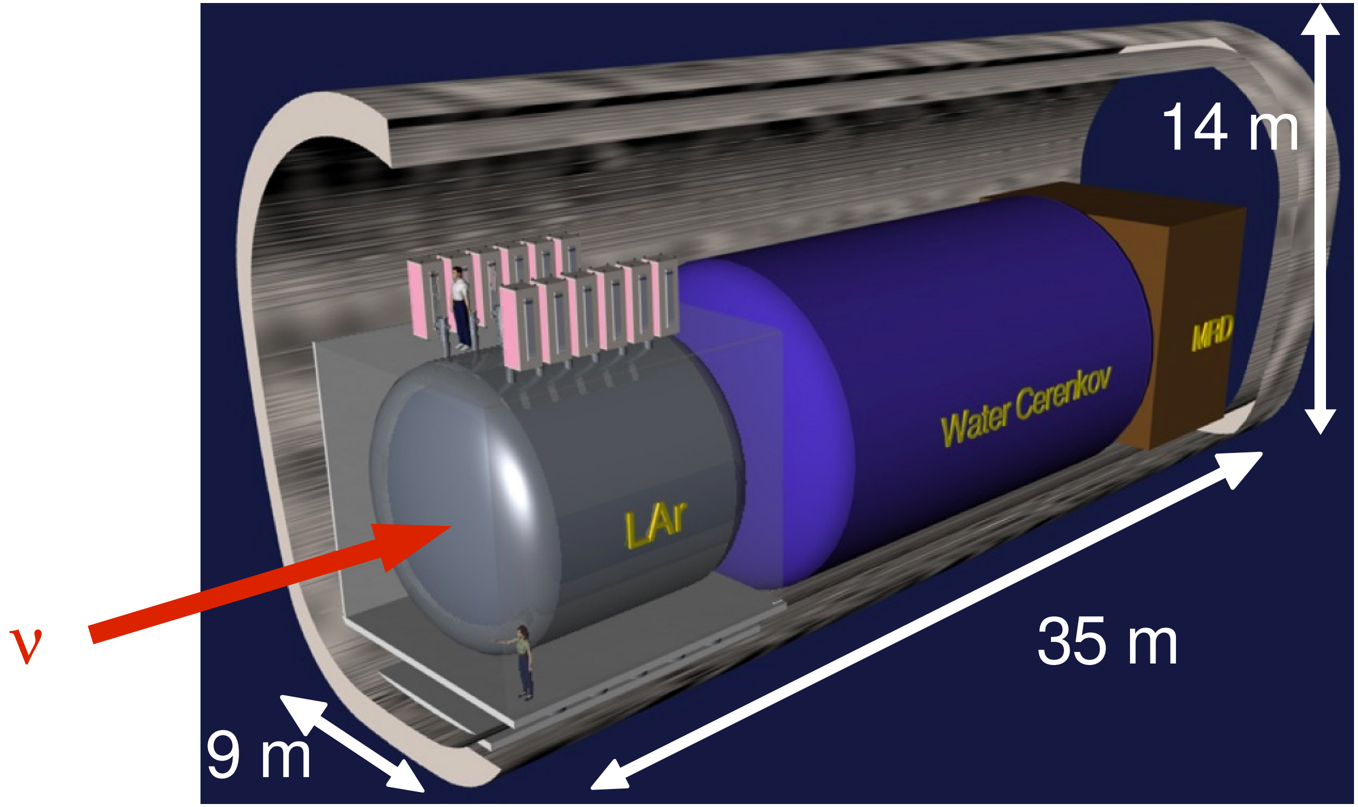


Largest differences at peak where the ν_μ disappearance and ν_e appearance signals are located

- At 280m, neutrino source is not point like, significant spectrum difference
- Almost the same neutrino spectrum at SK and 2KM even without correction

2KM detector configuration

- The candidate site is located 2km down stream
- 2KM detector consists of three sub-systems :



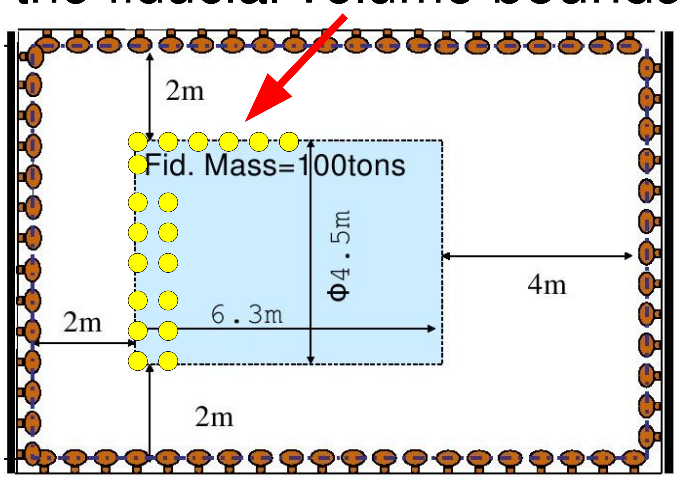
<u>Muon Ranger :</u>
Measure high energy tail of neutrino

<u>Liquid Argon detector :</u>
exclusive final states
frozen water target

<u>Water Cherenkov detector :</u>
Same detector technology as SK
~ 1 interaction/spill/1kton

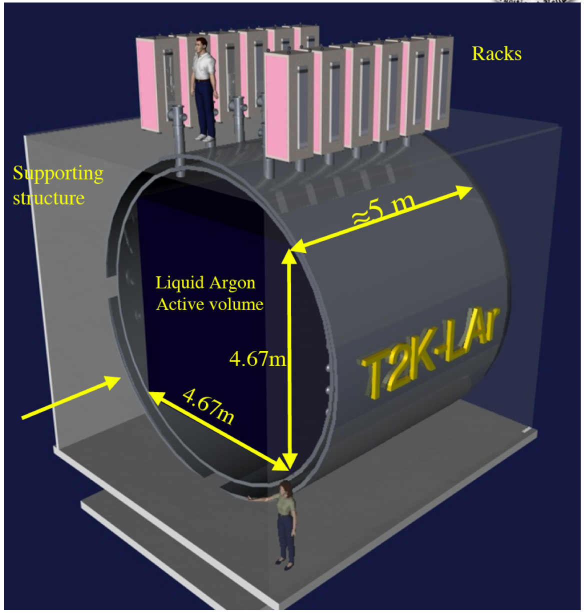
Water Cherenkov detector

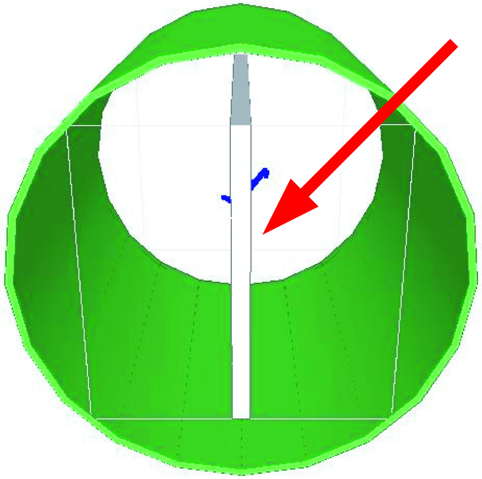
- 1 kton water Cherenkov detector, fiducial mass : 100t
- 5660 8-inch PMTs (11164 20-inch PMTs in SK)
- The same technique, the same target as SK. Also, we can use the same techniques to calibrate the PMTs that have been developed for SK.
- Fiducial volume determination
  - We will extrapolate the measurement of BG at 2KM to SK
  - One of the biggest error comes from the mass of water
  - Install grid of small(2”) PMTs along the fiducial volume boundary to measure syst. uncertainty
  - 0.7% error on FV identification error is expected by MC study → smaller than originally planned



Liquid Argon detector

- Fine grained time projection chamber, total LAr mass : 315t, fiducial mass : 100t
- Particles below Cherenkov threshold are visible, especially protons.
- Independent measurement of off-axis flux and non-QE/QE event ratio
- Exclusive measurement of NC and intrinsic electron neutrino BG. Excellent PID will allow these to be separately measured.
- Since SK is made of water, which is different than Ar, we will install water in the inner target. Measure the neutrino interaction with water with tracking information.

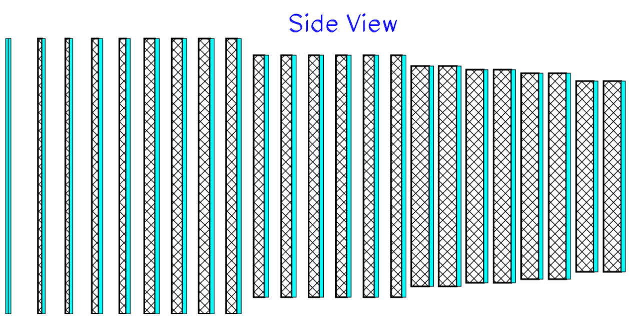


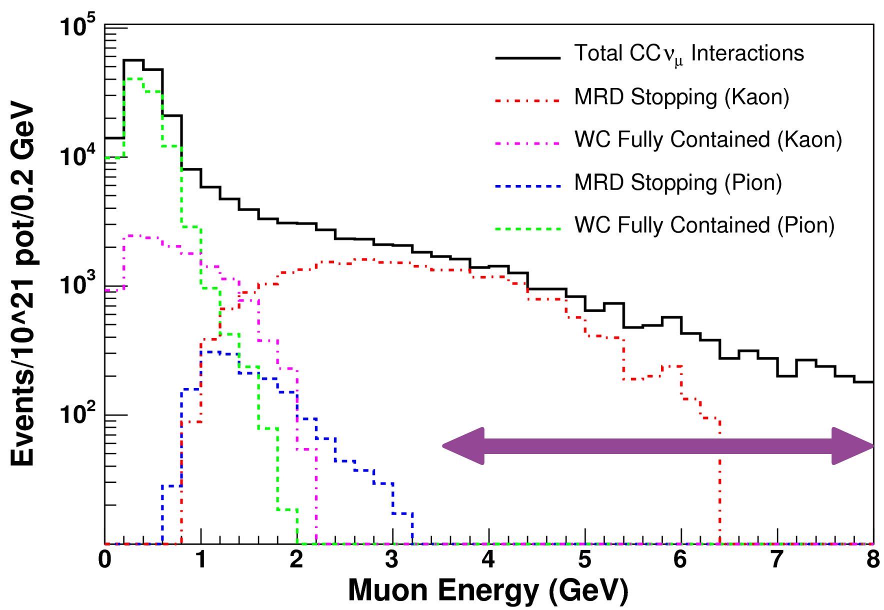


Muon range detector

- The MRD consists of 22 octagonal steel planes, each followed by an octagonal scintillator plane
- Measure high tail of the neutrino spectrum which causes electron neutrino BG

Sideview

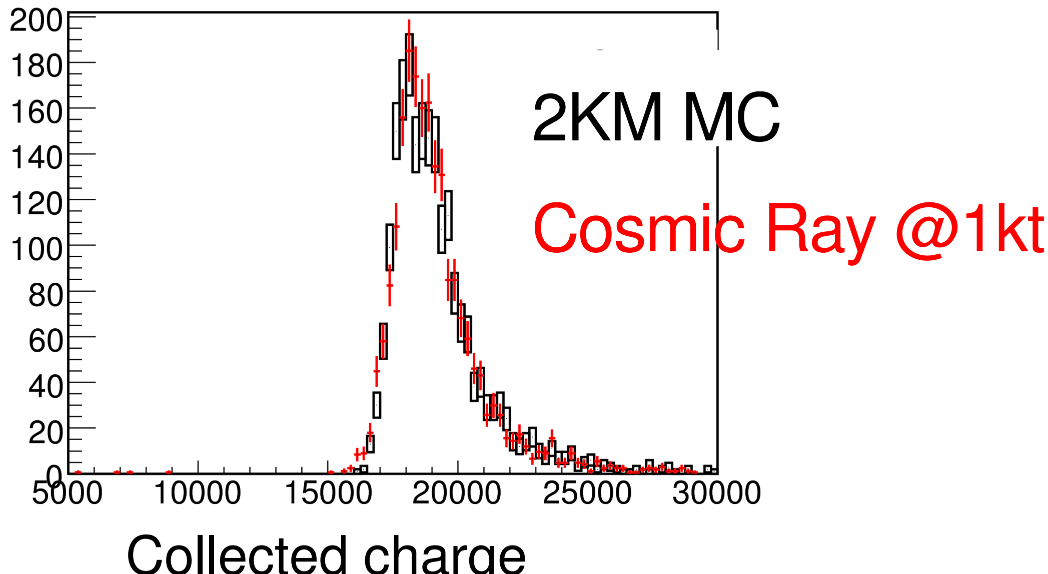




High energy μ come from K which also produce electron

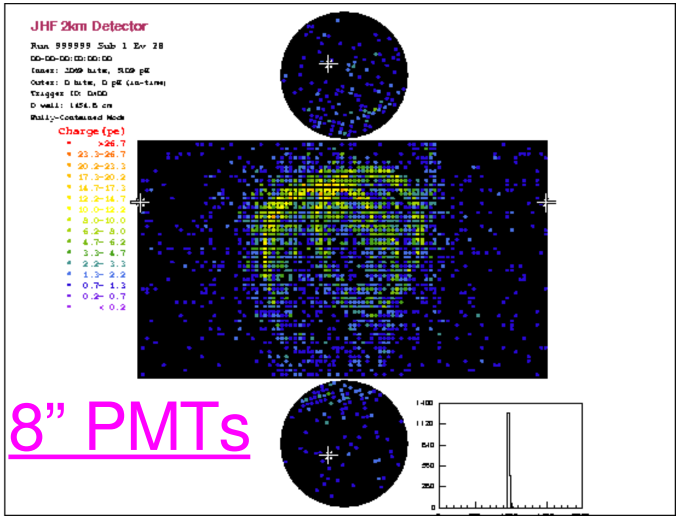
2KM detector simulation & performance

- Design concept : the same technique as SK, but should match <u>the physics quantitative response</u> between the 2km and SK
- We made a detector simulation program based on SK & K2K 1-kton experience with Geant4 and tuned it using 1-kton data from K2K
  - Flexibility → Can switch 1kt ↔ 2KM detector configuration easily



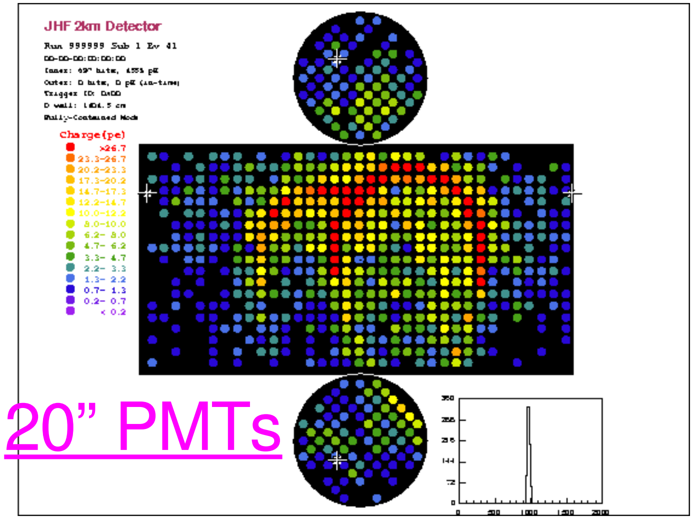
WC detector performance

2km 5660 PMTs



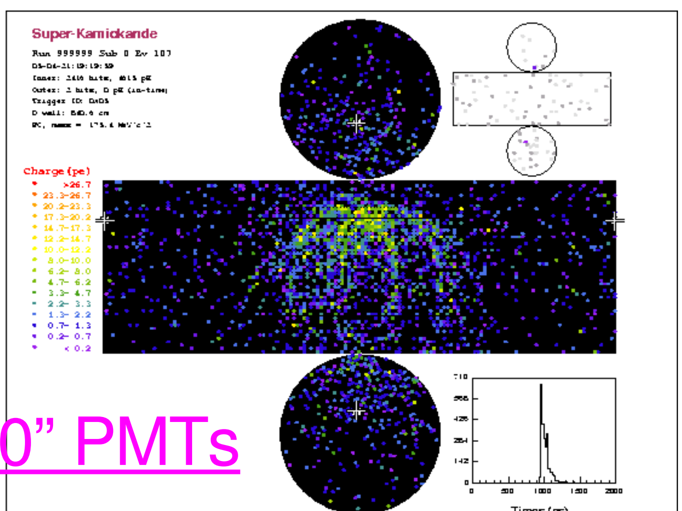
8” PMTs

2km 841 PMTs



20” PMTs

SK 11164 PMTs



20” PMTs

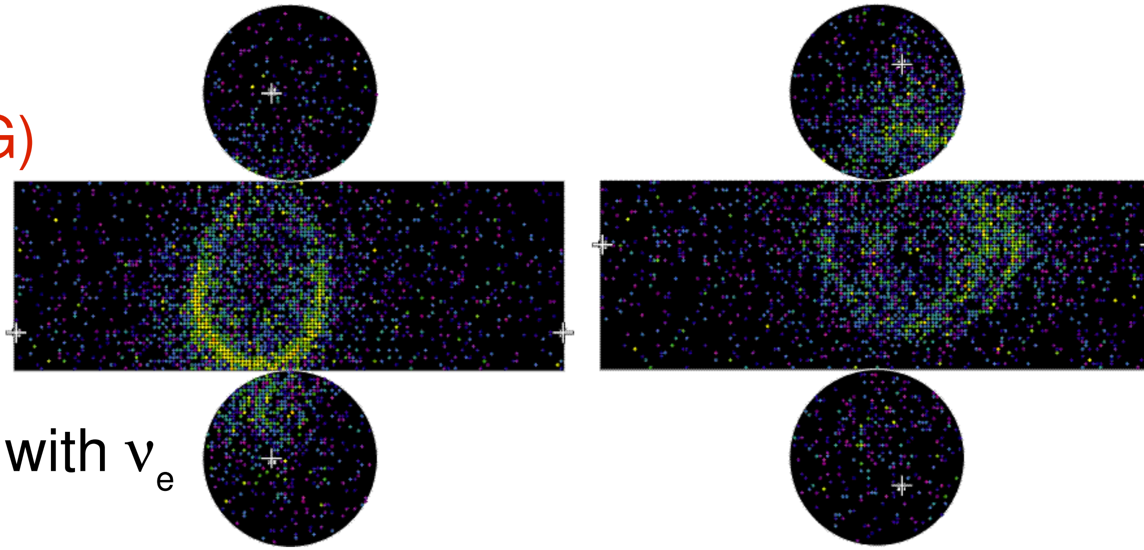
- A simulated NC π^0 event in the 2km/SK WC detector with different size of diameter of PMTs
- 8-inch PMT shows the best match SK performance

ν_e appearance analysis signal and background

- Signal : CCQE electron-like, 1-ring, non-π^0 events
- Main sources of background for ν_e appearance at T2K
  - NC π^0 production

    (Most serious BG)

    Confuse $\pi^0 \rightarrow \gamma\gamma$ with ν_e



  - Intrinsic beam ν_e

$\pi^+ \rightarrow \mu^+ \nu_\mu$, $\mu^+ \rightarrow e^+ \bar{\nu}_\mu \nu_e$ $\quad K^+ \rightarrow \pi^0 e^+ \nu_e$ $\quad K^0_L \rightarrow \pi^+ e^- \nu_e$

DECAY PIPE

  - CC ν_μ mis-ID

The same selection criteria are used at SK and 2km

e/π^0 separation variables

Special variables to reduce NC-π^0 BG

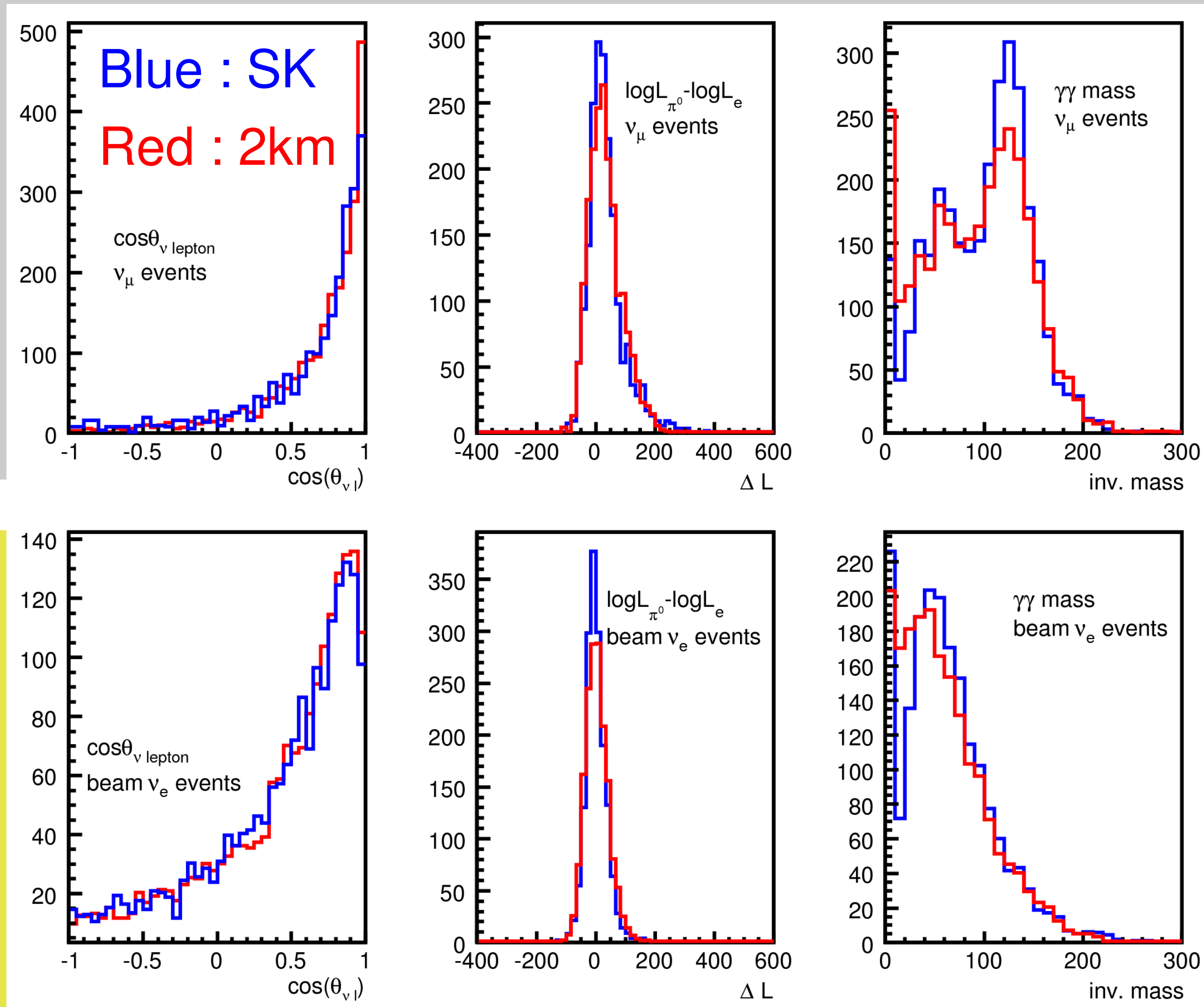
All analysis cuts other than the one plotted have been applied

Beam $\nu_\mu \rightarrow$ NC

Background

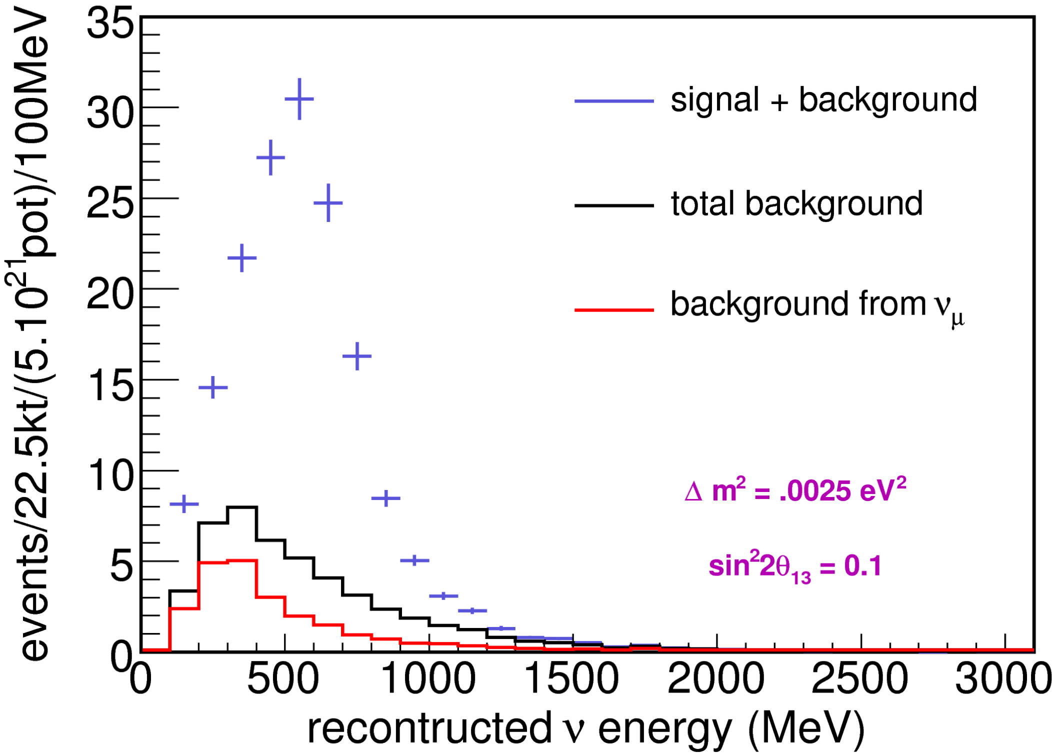
Beam $\nu_e \rightarrow$ CC ν_e

The response of the 2KM & SK agree well



Expected ν_e signal in SK

- An example : if we have an oscillation point at Chooz limit, ν_e signal is found

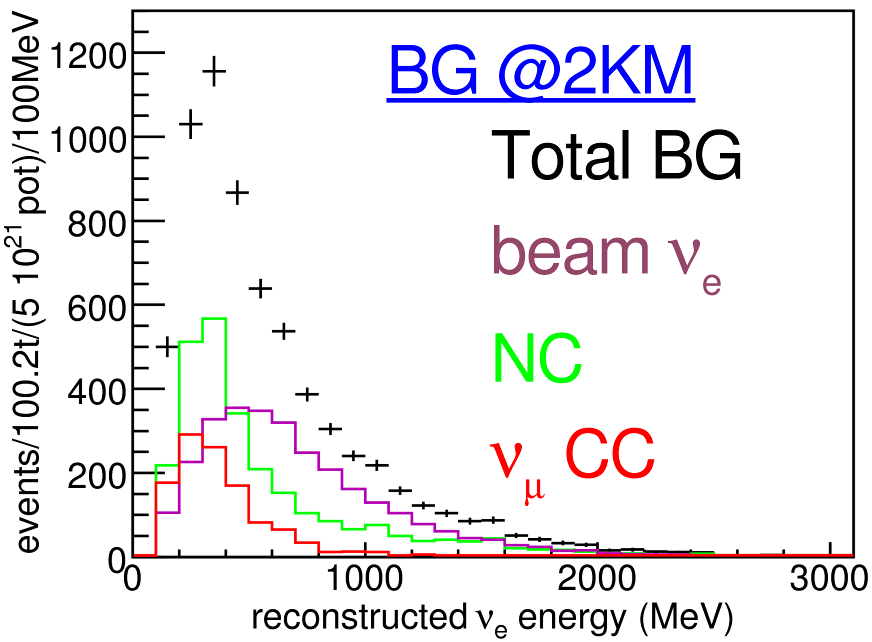


- But if there is no observed signal, or the signal is quite small, the error or sensitivity will be dominated by how well we can determine the background to the search.

Background for ν_e appearance

- Simulate 5yr 2KM MC and apply the same analysis cuts as at SK, ~3000 events in 100t fiducial volume

	NC	beam ν_e	CC-ν_μ
1) FCFV, E_{vis} >100 MeV	93805	20250	564229
2) 1-ring e-like	20971	10113	12264
3) no decay-e	17241	8045	3284
4) 0.35 GeV < $E^{rec}_{\nu e}$ <0.85 GeV	6939	2430	1223
5) e/π^0separation	1122	1551	469

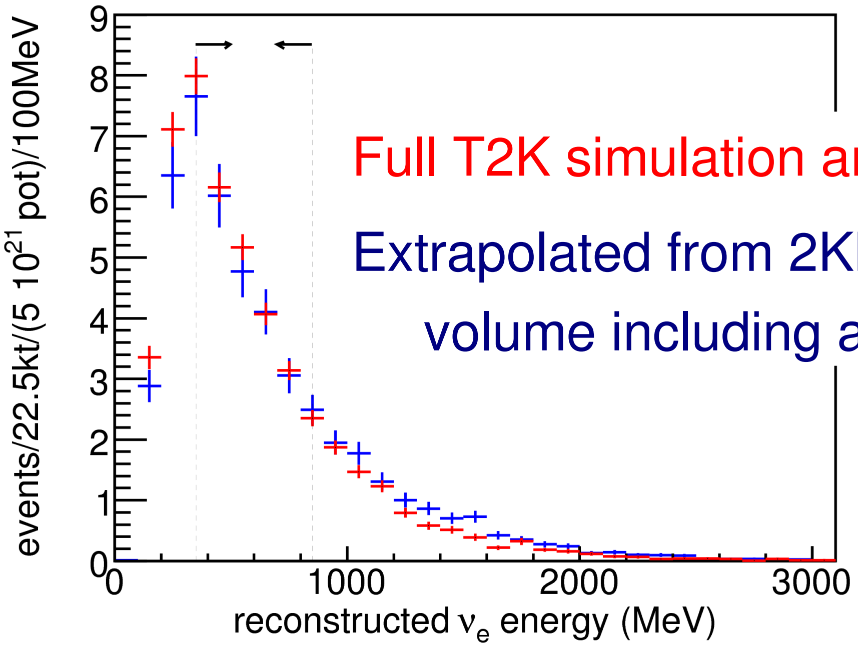


Prediction of BG for ν_e appearance at SK using 2km

- Simple scaling :

$$N^i_{SK} = N^i_{2km} \times (M_{SK}/M_{2km}) \times (L_{SK}/L_{2km})^2 \times (\varepsilon_{SK}/\varepsilon_{2km})$$

No beam MC correction, assume $(\varepsilon_{SK}/\varepsilon_{2km})=1$



Full T2K simulation and reconstruction at SK

Extrapolated from 2KM by simple scaling by volume including all known errors

Shape and normalization are well predicted by this method even with only simple scaling

Total background for ν_e appearance

- Preliminary, simple & conservative estimate of systematics
  - Errors due to : fiducial volume 4%, analysis + energy systematics 6.7% (conservative)
- Expected BG at SK from MC=23.80 ± 4.76(stat)
- Extrapolated BG from 2KM=23.01 ± 0.41(stat) ± 1.79(syst)
  = 23.01± 8%(total error)
- In order not to be dominated by systematic error at phase I, <10% is required
- We believe we already know how to bring this down to 5%
- 2KM detector can predict the event seen at SK with very little correction

Full spectral analysis of ν_e appearance

Full spectral analysis with complete systematic errors are also being done. We have extensive analysis experience from the Super-K and K2K experiments.

Neutrino Interaction (common)

- M_A in quasi-elastic and single π
- Quasi-elastic scattering (model dependence)
- Quasi-elastic scattering (cross section)
- Single π production (cross section)
- Multi π production (model dependence)
- Multi π production (cross section)
- Coherent π production (cross section)
- NC/CC ratio
- Nuclear effect in ^{16}O (not included)

19 out of 20 systematic errors has been included

Event Reconstruction

- 1-ring/multi-ring separation (common between SK & 2KM)
- 1-ring/multi-ring separation (difference between SK & 2KM)
- Particle ID (common between SK & 2KM)
- Particle ID (difference between SK & 2KM)

T2K related Errors

- Fiducial volume (SK)
- Fiducial volume (2KM)
- Energy scale (SK)
- Energy scale (2KM)
- Electron/π^0 separation (Polfit) (common between SK & 2KM)
- Electron/π^0 separation (Polfit) (difference between SK & 2KM)
- Beam related ν_e intrinsic BG

Conclusion

- 2KM detector can measure accurately the background of ν_e appearance measurement at SK before oscillation
  - Systematic errors due to the neutrino flux and target are canceled
- 2KM detector is essential for ultimate sensitivity for ν_e appearance search
  - It can predict the events seen at SK with very little correction