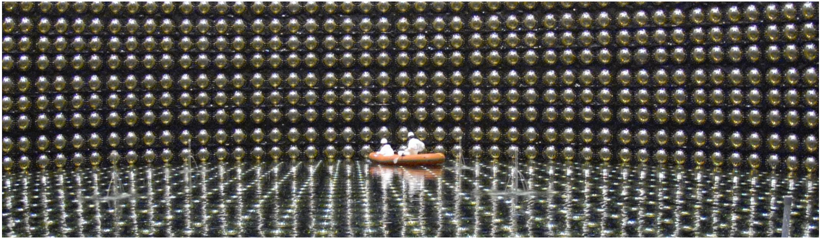
Imperial College
London

The T2K Experiment - Super-Kamiokande, Analysis and Results



Pip A. Hamilton

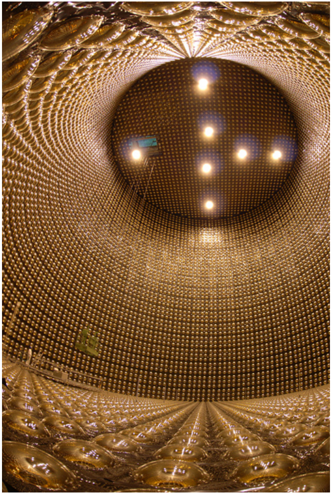
Contents

Super-Kamiokande

'Super-K' – water-based Cherenkov detector under Mt. Ikeno, Japan.

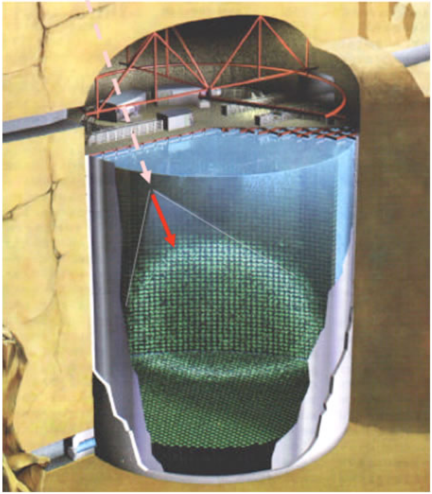
- 50,000 tonnes of ultra-pure water
- 11,129 inward-facing PMTs
- Inner volume of $>$ 8 CMS detectors

Successor to the first KamiokaNDE detector – designed originally to look for proton decays.



Imperial College London

- Inner volume surrounded by outer detector
  - Provides passive shielding (2m of water) against background from cavern walls
  - Instrumented to veto cosmic rays
- ν_e/ν_μ strike nuclei in H_2O, produce e^-/μ^- via weak charged-current (CC) interactions.
- Passage of leptons through detector produces Cherenkov light, picked up by the PMTs.



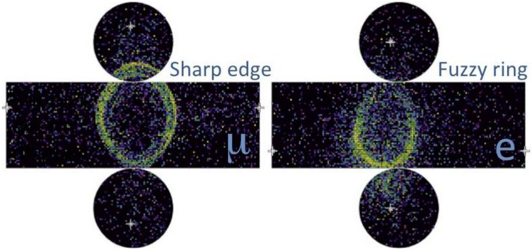
Analysis Method

Large overlap in methodology between ν_μ disappearance and ν_e appearance studies: I will focus on ν_e appearance.

- Counting experiment: looking for ν_e excess predicted from oscillation
- Must be able to distinguish ν_e from ν_μ
- Expect a *small* excess: important to understand all backgrounds contributing to the ν_e signal

Particle Identification (PID)

- Muons travel cleanly through the detector
  $\Rightarrow$ produce a single Cherenkov cone and a sharp ring of PMT hits on the detector wall.
- Electrons (being much lighter) scatter and shower
  $\Rightarrow$ produce multiple overlapping cones and a fuzzy ring of hits.



PID success rate $\sim$ 99%

Imperial College London

Backgrounds

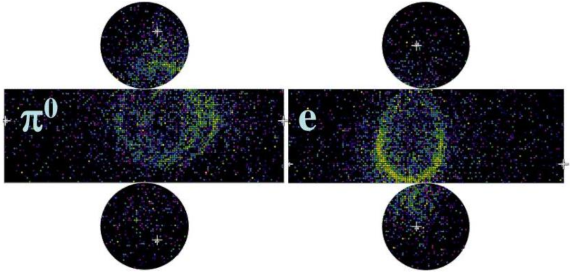
Backgrounds come in two categories: beam-related (dominant) and outside the beam. A series of selection cuts are applied to reduce both kinds (non-beam backgrounds reduced to estimated 0.003 events).

There remain two **main backgrounds** from within the beam itself:

- **Particle mis-ID**
  → π^0s from weak neutral-current (NC) interactions are primary culprits
- ν_e **contamination of the beam**
  (NB: not as significant a background for ν_μ disappearance, for obvious reasons)

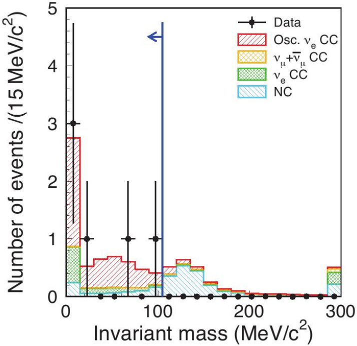
NC π^0 background

- π^0s produced through $\nu + N \rightarrow \nu + \Delta$, $\Delta \rightarrow \pi^0 + N$
- π^0s decay via $\pi^0 \rightarrow \gamma\gamma$ (BR 98.8%).
- Photons shower like electrons, producing similar Cherenkov rings. Analysis cuts on there being only one ring, but the γs can still fake an electron signal if only one ring is seen, i.e.
  - Energy of the photons is highly asymmetric
  - Small opening angle, rings overlap
  - One photon escapes without showering



Imperial College London

Solution: Force reconstruction of two rings, cut on invariant mass.



Coloured histograms are of MC predictions; blue line shows position of invariant mass cut (105 MeV).

ν_e contamination

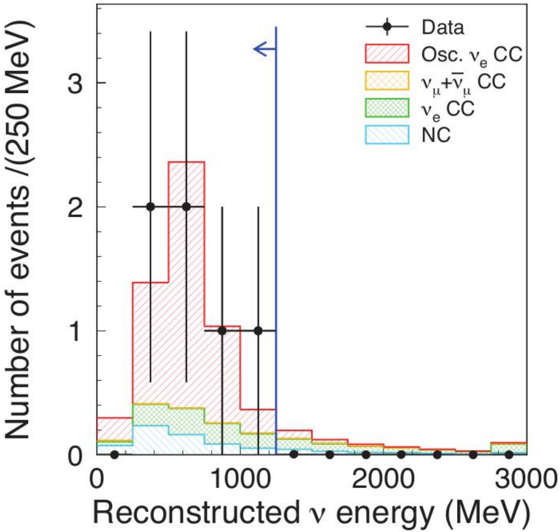
ν_μ beam contaminated from outset with small proportion of ν_es via two processes:

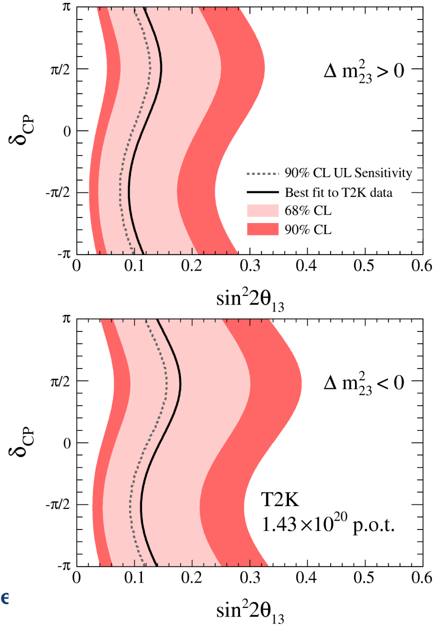
- $\mu^+ \longrightarrow e^+ \nu_e \bar{\nu}_\mu$, from the muons produced in the pion decays
- $K^+ \longrightarrow \pi^0 e^+ \nu_e$ (BR $\sim$ 5%), from kaons produced alongside the pions

Background from kaon decays can be reduced by a cut on the maximum energy (have wider energy spectrum).

Results

	Data	ν_μCC	ν_eCC	NC	$\nu_\mu \rightarrow \nu_e$CC
(0) interaction in FV	n/a	67.2	3.1	71.0	6.2
(1) fully-contained FV	88	52.4	2.9	18.3	6.0
(2) single ring	41	30.8	1.8	5.7	5.2
(3) e-like	8	1.0	1.8	3.7	5.2
(4) $E_{vis} > 100$ MeV	7	0.7	1.8	3.2	5.1
(5) no delayed electron	6	0.1	1.5	2.8	4.6
(6) non-π^0-like	6	0.04	1.1	0.8	4.2
(7) $E_\nu^{rec} < 1250$ MeV	6	0.03	0.7	0.6	4.1


Number of events /(250 MeV)
0
1
2
3
0
1000
2000
3000
Reconstructed ν energy (MeV)
Data
Osc. ν_e CC
$\nu_\mu+\bar{\nu}_\mu$ CC
ν_e CC
NC



$\theta_{13} \neq 0$

Summary

1. Described Super-K detector
2. Identified main backgrounds
    - External
    - Intrinsic to beam
3. Shown how these backgrounds are controlled
4. Shown first physics results!
    - Strong indication that $\theta_{13} \neq 0$

Data taking should resume from March.

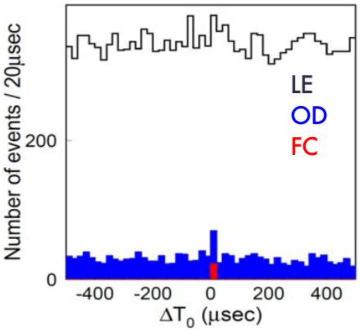
Backup Slide: Background Cuts

Non-beam:

- No activity in the outer detector
- 100μs acceptance window before/after arrival time

Beam:

- Interaction vertex must lie in the fiducial volume (2m in from detector wall)
- Minimum reconstructed neutrino energy of 100 MeV
- No delayed electron from muon decay (for ν_e study)



Imperial College London