Status of K2K experiment

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Motivation

Atmospheric neutrinos in Super-Kamiokande

The first evidence of $\nu_\mu - \nu_x$ with $\Delta m^2 \approx (1\sim5) \times 10^{-3} \text{ eV}^2$

atmospheric
Large L/E
Intense $\nu_\mu + \nu_e$

accelerator
Known L/E
Pure $\nu_\mu$
Before Super-K / After Super-K

Existence of $\nu_\mu \leftrightarrow \nu_x$ oscillations

- Discovery ➔ Precision measurement
- Non-zero $\nu$ mass ➔ Lepton flavor physics
- $\Delta m^2$ ➔ $\sin^2 2\theta$
- 2-generation ➔ 3-generation

Solar $n$ mass scale ?
LMA or SMA ?
LSND ?
Absolute mass ?
Majorana mass ?
Overview of K2K

- $E_\nu = \sim 1.3\text{GeV}$, $L=250\ \text{km}$
- 99% pure $\nu_\mu$ beam
The K2K collaboration

- Over 100 physicists
- Japan-Korea-US collaboration (in alphabetic)
- 2/3 is overlapped with Super-Kamiokande collaboration
K2K neutrino beam-line

- 13 GeV/c proton
- 1.1 μsec spill/2.2 sec (9 bunch)
- 6x10^{12} protons/spill
1kt water Cherenkov
- Miniature of Super-K
- Direct comparison to SK
- Flux normalization

MRD
- drift tubes + Fe
- Huge mass, Large area
- profile, spectrum
- good to check stability

SCFI
- SCFI tracker + water
- Fine vertex tracking
- $\nu_\mu$ spectrum

Front Detector
Neutrino event in 1kt $\text{H}_2\text{O}$ target (same as SK)

- Same detection principle as SK
- $\rightarrow$ expect least syst. err. for SK exp’ed
- Fid. mass 25ton
- Event selection: $\text{Q}_{\text{tot}} > 1000\text{p.e.}$
  - $\sim 2\text{events/100spill}$

680 20-inch PMT
With 20% coverage
(same as SK)
Neutrino event in SCFI

Neutrino interaction in SCFI $\text{H}_2\text{O}$ target (+Al 20%)

- Pos. resolution $\approx 1\text{mm}$
  - well defined fid. vol.
  - multi track resolution
- Fid. mass = 5.8 ton
- Event selection: matching SFT & MUC track
- 1 event/1000 spill
Neutrino events in MRD

Neutrino int. in MRD iron plates

- CC inclusive (no NC)
- Large area coverage (8m) → profile (vtx dist.)
- Large mass → high rate (~5/100spill)
Far detector
Super-Kamiokande

- 41.4m(H) x 39.3m (D) (tank)
- ID : 36.2m(H) x 33.8m(D)
- OD: ~ 2m thick
- 11146 20"PMT (ID)
- 1885 8"PMT (OD)
- 2700m w.eq. underground
Beam Monitors & Front Detectors

- **Direction to Super-K?**
  - MUMON, MRD

- **Absolute flux?**
  - 1kt (SCFI, MRD)

- **Stability?**
  - MRD

- **How to extrapolate to Super-K?**
  - PIMON

- **Ev spectrum?**
  - PIMON, SCFI, 1kt, MRD

- **Neutrino interaction model?**
Beam Spread at 250km

Beam-line construction
- GPS 0.01 mrad
- Civil 0.1 mrad

Requirement 3 mrad
Neutrino Profile by MRD

Vertex distribution of Fe events (Nov99)

Fitted center:
- $x: 1 \pm 5\text{cm (stat)}$
- $y: -10 \pm 4\text{cm from SK dir.}$

Centered within sys. err. of 20cm (0.7mrad)
Profile at 1kt water Cherenkov

2000/Jan-Mar

Also Agree with MC
Stability of profile center (MRD)

Neutrino profile stability (99June - 00June)

Stable within ±1mrad.
Stability of MUMON center

Fast (spill-by-spill) but indirect monitor

Stable within $\pm 1\text{mrad}$

Jun '99

Jun '00

Nov '99

Jan '00

Feb '00

Mar '00

Apr '00

May '00

Stability of MUMON center
Stability of energy spectrum

Muon Energy of Fe events

Stable within stat. error.
Stability of event rate at MRD

Stable.
$N(p_\pi, \theta_\pi) \rightarrow$ Neutrino flux $\Phi(E_\nu)$ at any distance using only decay kinematics
Far/Near ratio checked by PIMON

$$R(E_\nu) = \frac{\Phi_{SK}(E_\nu)}{\Phi_{FD}(E_\nu)}$$

$E_\nu$ spectrum

Far/Near ratio
Delivered proton on target

➤ SK Live = $2.29 \times 10^{19}$ POT(Jun99-Jun00)
Event selection at Super-K by GPS

\[ -0.2 \leq \Delta T = T_{SK} - T_{Spill} - \text{TOF} \leq 1.3 \mu \text{sec} \]

\( T_{Spill}, T_{SK} \): Abs. time of spill start, SK event measured with GPS

\( \text{TOF} \): 0.83 ms (Time of flight from KEK to Kamioka)
Observed beam events at SK

-5µs

Selection window

+5µs

$\Delta T (\mu s)$

28 observed.

Exp'ed Atm-ν BG $< 10^{-3}$ in 1.5µs win.

no pre.act

>200p.e
### Summary of observed events

<table>
<thead>
<tr>
<th>Type</th>
<th>Obs.</th>
<th>No Ocsi.</th>
</tr>
</thead>
<tbody>
<tr>
<td>FC 22.5kt</td>
<td>28</td>
<td>37.8 $^{+3.5}_{-3.8}$</td>
</tr>
<tr>
<td>1-ring</td>
<td>15</td>
<td>22.7±3.2</td>
</tr>
<tr>
<td>$\mu$-like</td>
<td>14</td>
<td>20.8±3.2</td>
</tr>
<tr>
<td>e-like</td>
<td>1</td>
<td>1.9±0.4</td>
</tr>
<tr>
<td>multi ring</td>
<td>13</td>
<td>15.1±2.5</td>
</tr>
</tbody>
</table>
## Summary of systematic errors

\[ N_{SK}^{\text{exp}} = 37.8 \pm 0.2(\text{stat.})^{+3.5}_{-3.8}(\text{syst.}) \]

<table>
<thead>
<tr>
<th>Source</th>
<th>Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>Near/Far Ratio</td>
<td>±6%</td>
</tr>
<tr>
<td>1kt ΔV/V</td>
<td>±4%</td>
</tr>
<tr>
<td>Multi Event</td>
<td>±3%</td>
</tr>
<tr>
<td>Spectrum (eff.)</td>
<td>±2%</td>
</tr>
<tr>
<td>SK (mainly ΔV/V)</td>
<td>±3%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>+9%</td>
</tr>
<tr>
<td></td>
<td>−10%</td>
</tr>
</tbody>
</table>
Visible energy of FC events

$E_{\text{vis}}$, F.C. 22.5kt

Preliminary!
Reconstructed $E_\nu$ of 1 ring FC

Reconstructed Momentum F.C. 22.5kt 1-ring

Preliminary!
Event rate stability at far detector

Preliminary! (ICHEP version)
Gap distribution of FC event rate

Preliminary! (ICHEP version)

- Simple average: $1.18/10^{18}\text{POT}$
- Exponential Fitted: $1.19\pm 0.42/10^{18}\text{POT}$
- Expected for No-osc: $1.76\pm 0.20/10^{18}\text{POT}$
Spectrum at $10^{20}$POT

Reconstructed Neutrino Energy (MC)

MC 1ring μ-like

- null
- $\sin^22\theta=1$
- $\Delta m^2=0.01$

$E_\nu$ (GeV)

MC 1ring μ-like

- null
- $\sin^22\theta=1$
- $\Delta m^2=0.005$

$E_\nu$ (GeV)

MC 1ring μ-like

- null
- $\sin^22\theta=1$
- $\Delta m^2=0.0028$

$E_\nu$ (GeV)

MC 1ring μ-like

- null
- $\sin^22\theta=1$
- $\Delta m^2=0.0015$

$E_\nu$ (GeV)
Sensitivity at $10^{20}$POT

K2K $\nu_\mu \rightarrow \nu_\tau$ oscillation sensitivity

- 22.5kton FC 1 ring
- $\mu$-like $E_{\nu}^{\text{rec}} = 500\text{MeV}$
- $\sin^2 2\theta$
- $\Delta m^2 (\text{eV}^2)$
Accuracy of parameter measurement at $10^{20}$POT

$\nu_\mu \leftrightarrow \nu_\tau$ oscillation allowed region (MC)

$\Delta m^2$ (eV$^2$) vs. $\sin^22\theta$

- $\Delta m^2 = 0.01$ with $\sin^22\theta = 1$
- $\Delta m^2 = 0.005$ with $\sin^22\theta = 1$
- $\Delta m^2 = 0.0028$ with $\sin^22\theta = 1$
- $\Delta m^2 = 0.0015$ with $\sin^22\theta = 1$
Summary

Method of LBL exp is established for this time

- K2K is the 1st LBL ν osc exp of L=O(100km)
  - Will see the 1st positive signal in accelerator exp
- 28 FC events is observed in 22.5kt FV of SK
  - Jun,1999 ~ Jun, 2000 data, 2.29E19 POT
- 37.8 FC events is expected w/ 10% sys error
  - Near Flux is measured by 1kt water Chrenkov
  - Extrapolation is validated by PIMON measurement
- Continue data taking for 1020POT in 3 more year
  - Continue until end of Jun for this year