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@JHF-SK ν workshop

Strategy of the JHF-Kamioka neutrino experiment
- 2nd Generation LBL Neurino experiment -

- Physics of neutrino oscillation
- Narrow band beam at the oscillation maximum
- Neutrino energy reconstruction
- Low energy neutrino beam

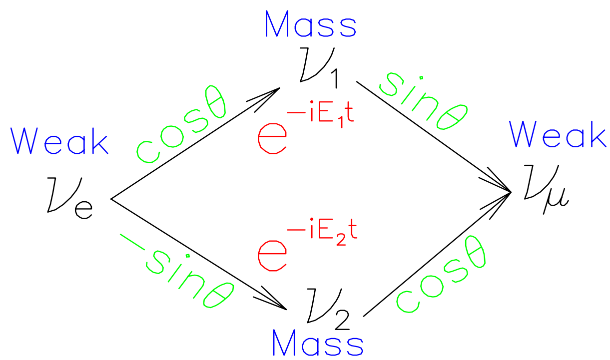
Discovery of Z^0 (SPS)
$\Rightarrow$ Precision measurements of Electroweak int. at Z^0 pole (LEP)

Discovery of ν oscillation (Super-Kamiokande)
$\Rightarrow$ Precision measurements of ν oscil. at oscil. max. (JHF-Kamioka)

Physics of neutrino oscillations

- Neutrino oscillation in 2 generations

$$\begin{pmatrix} U_{e1} & U_{e2} \\ U_{\mu 1} & U_{\mu 2} \end{pmatrix} = \begin{pmatrix} cos\theta & -sin\theta \\ sin\theta & cos\theta \end{pmatrix}$$



$$\begin{aligned} P(\nu_e \to \nu_\mu) &= |sin\theta cos\theta(e^{-iE_1 t} - e^{-iE_2 t})|^2 \\ &= sin^2 2\theta sin^2 \frac{1.27\Delta m^2 L(km)}{E(GeV)} \end{aligned}$$

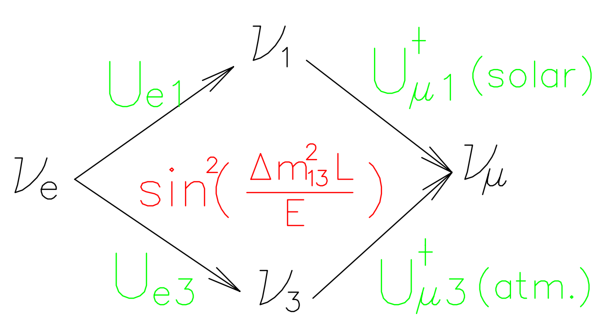
- 3 generation effect

$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} = \begin{pmatrix} U_{e1} & U_{e2} & U_{e3} \\ U_{\mu 1} & U_{\mu 2} & U_{\mu 3} \\ U_{\tau 1} & U_{\tau 2} & U_{\tau 3} \end{pmatrix} \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{pmatrix}$$

Leptonic CKM
(MNS matrix)

$$\begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos\theta_{23} & \sin\theta_{23} \\ 0 & -\sin\theta_{23} & \cos\theta_{23} \end{pmatrix} \begin{pmatrix} \cos\theta_{13} & 0 & \sin\theta_{13} \\ 0 & 1 & 0 \\ -e^{i\delta_{CP}}\sin\theta_{13} & 0 & e^{i\delta_{CP}}\cos\theta_{13} \end{pmatrix} \begin{pmatrix} \cos\theta_{12} & \sin\theta_{12} & 0 \\ -\sin\theta_{12} & \cos\theta_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

$\nu_e \leftrightarrow \nu_\mu$ is suppressed
due to small Δm^2_{12}
$\Delta m^2_{13}(\theta_{13})$ term dominates
Large CP contribution



- Common oscillation maximum

Two independent mass square differences:

$\Delta m^2_{13} = \Delta m^2_{12} + \Delta m^2_{23}$, $\Delta m^2_{23} >> \Delta m^2_{12} \quad \Rightarrow \quad \Delta m^2_{13} \simeq \Delta m^2_{23}$

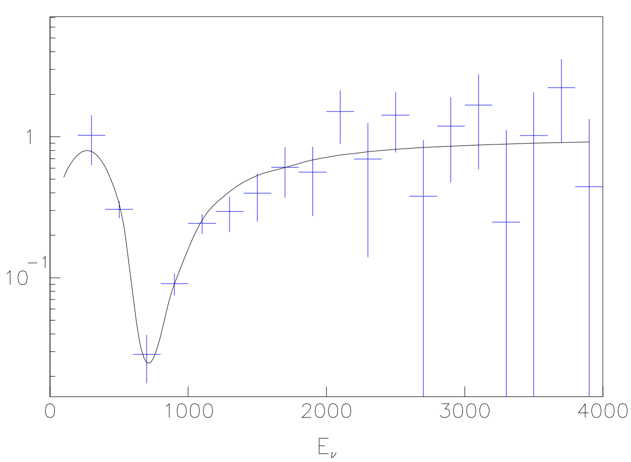
ν_μ oscillations have common oscillation maximums

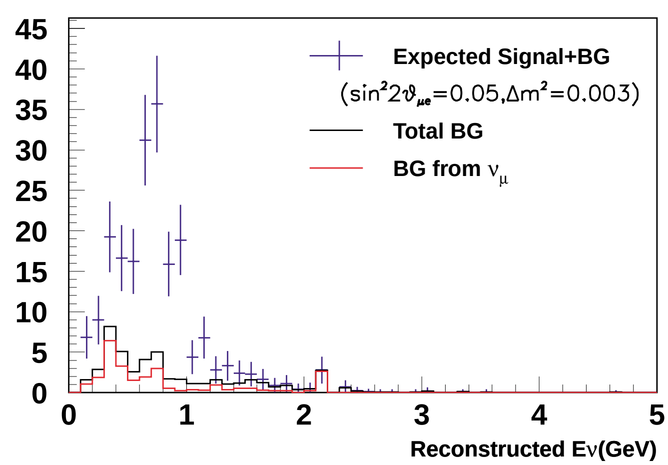
$$P(\nu_\mu \to \nu_\tau) \sim \sin^2 2\theta_{23} \sin^2 \frac{1.27 \Delta m^2_{atm} L}{E}$$

$$P(\nu_\mu \to \nu_e) \sim \cos^2 \theta_{23} \sin^2 2\theta_{13} \sin^2 \frac{1.27 \Delta m^2_{atm} L}{E}$$

$$P(\nu_\mu \to \nu_e)_{CPV} \sim \sin 2\theta_{13} \sin 2\theta_{23} \sin 2\theta_{12} \frac{1.27 \Delta m^2_{sol} L}{E} \sin^2 \frac{1.27 \Delta m^2_{atm} L}{E}$$

$$\Delta m^2_{12} \simeq \Delta m^2_{sol} = 10^{-10} - 10^{-4}$$
$$\Delta m^2_{13} \simeq \Delta m^2_{23} \simeq \Delta m^2_{atm} = (1.6 - 4.0) \times 10^{-3} eV^2$$





Difference in notations:

$\sin^2 2\theta_{\mu\tau} \simeq \sin^2 2\theta_{23}$

$\sin^2 2\theta_{\mu e} \simeq \frac{1}{2} \sin^2 2\theta_{13} \simeq 2 |U_{e3}|^2$

Narrow band beam at the oscillation max.

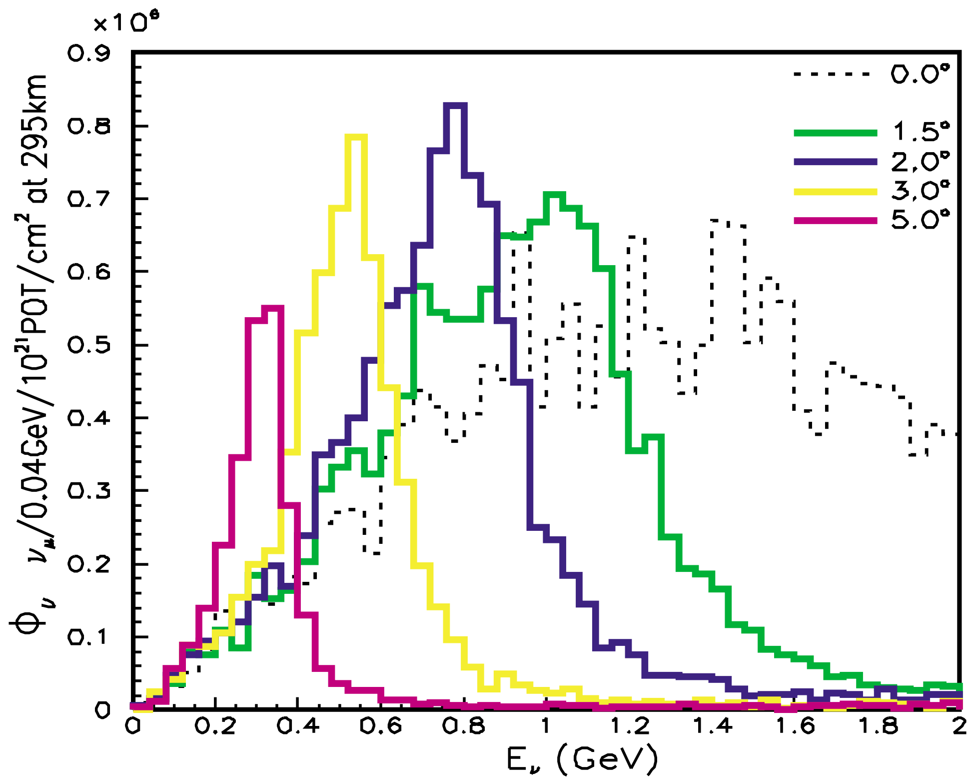
- Maximum oscillation ⇒ maximum signal enhancement

- Neutrnio energy at the oscillation maximum for JHF-Kamioka:
$$\frac{1.27\Delta m^2_{atm}L}{E} = \frac{\pi}{2} \quad \Rightarrow \quad E_\nu\text{=0.4-1.0GeV for L=295km}$$

- Tuning the narrow band beam energy

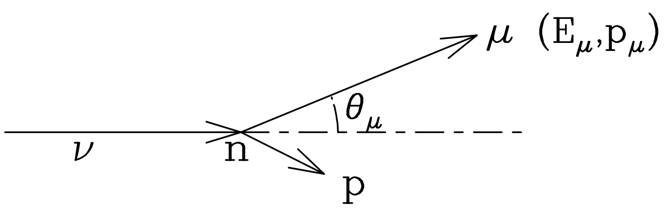
  Narrow band beam (NBB): Dipole current

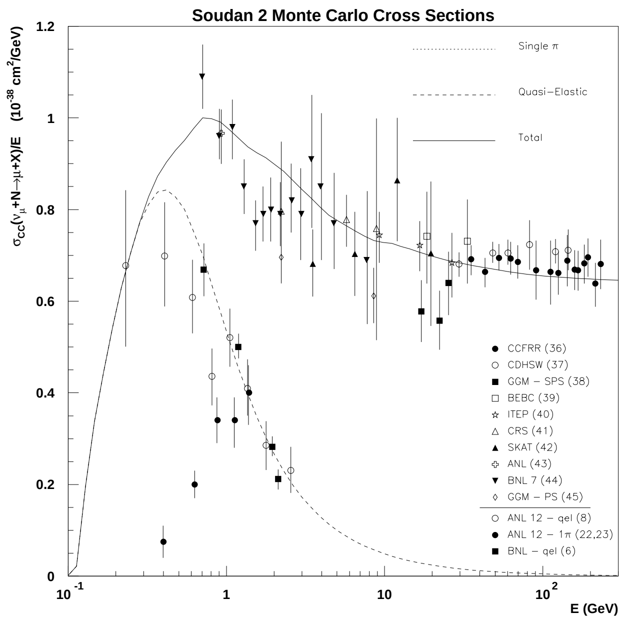
  Off axis beam (OAB): Offset angle



Neutrino energy reconstruction

- Tow body Quasi-elastic (QE) reaction for E_ν reconstruct.

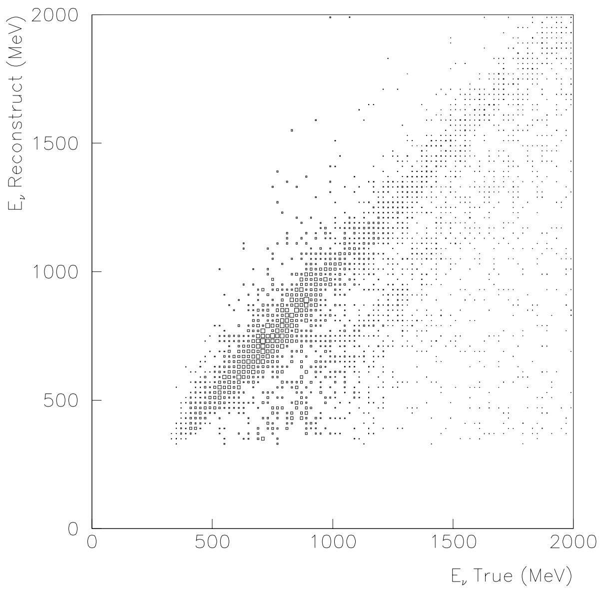


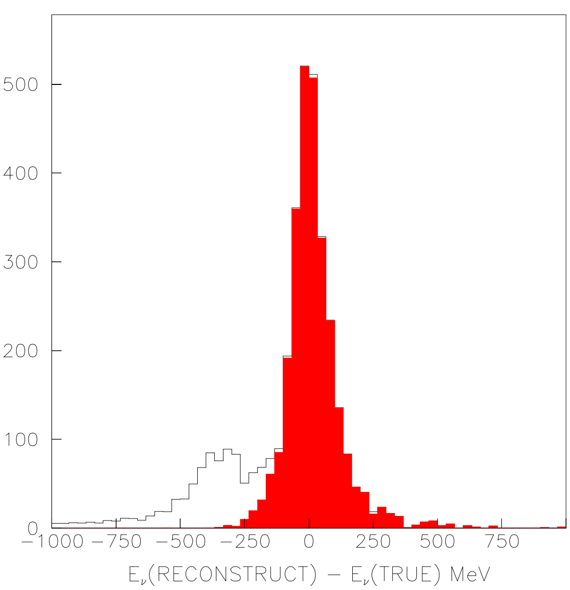


$$E_\nu = \frac{m_N E_l - m_l^2/2}{m_N - E_l + p_l cos\theta_l}$$

QE dominates in E_ν=0.4-1.0GeV region.
QE cross sections for ν_μ and $\bar{\nu}_\mu$ are reasonably high.

- Resolution of the reconstructed energy
ΔE_ν=80MeV ($\Delta E_\nu/E_\nu$=10%): limited by Fermi motion

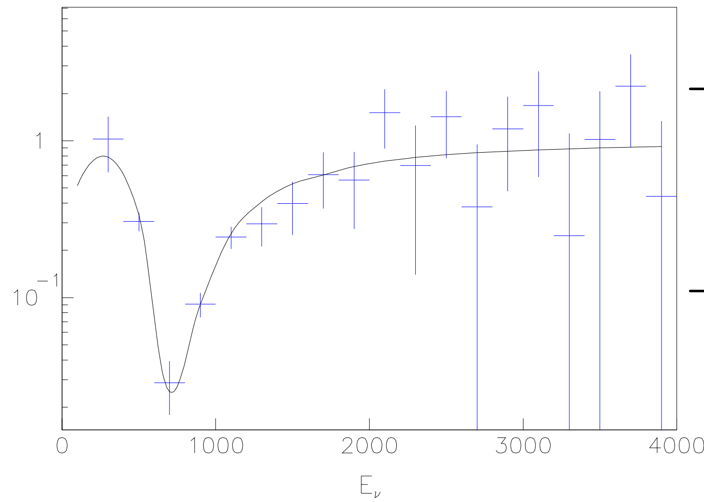




$\Rightarrow$ Precise oscillation pattern measuement

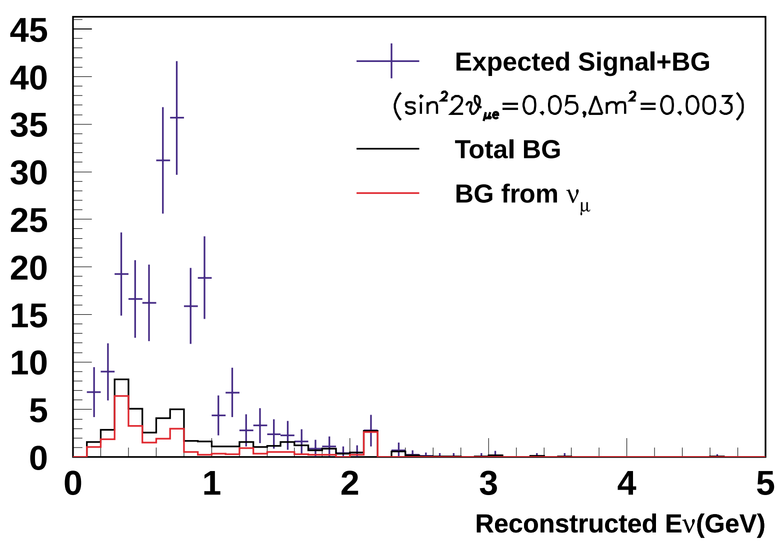
Oscillation pattern measurement at the oscil. max.

- Signal enhancement



+ Depth of the dip $= 1 - \sin^2 2\theta_{23}$:
  10% measurement of the dip
  $\Rightarrow$ 0.03·10%=0.3% in $\sin^2 2\theta_{23}$
+ Position of the dip:
  $\Rightarrow \Delta m^2 = \frac{\pi}{2} \cdot \frac{1}{1.27} \cdot \frac{E_\nu}{L}$

- Background suppression
  - Energy window around the oscillation maximum



- Suppression of the systematic uncertainties
  - Enhancement of signals and suppression of backgrounds
  - Positive ID of the signal by the oscillation pattern
  - Events outside the energy window to monitor backgrounds.

Low energy neutrino beam

- Baseline length of 295km $\Rightarrow$ Oscil. max. at 0.4-1.0GeV
- Quasi-elastic reaction dominates
  - Neutrino energy reconstruction
  - Flux measurement (Q^2 dependence of the cross section)
- Water Čerenkov detector is available
  - Large fiducial mass is possible
  - Good energy and angular resolutions
    $\Delta E/E \sim 3\%$, $\Delta\theta \sim 3^\circ$ for 1GeV μ
  - Excellent particle identification
    R(e/μ)$\sim$500, R($NC-\pi^0/e$)$\sim$100
- Intense narrow band neutrino beams are available
- Advantages in CP measurements
  - Enhancement of CP asymmetry at low energy
  - Suppression of the fake matter asymmetry