JHF to SuperK Neutrino Experiment (JHFnu)

- Overview of the project and the status
- Systamatic uncertainty in background measurements
- Resolving the degeneracy
Principle of the JHF-Kamioka project

- The highest intensity proton beam J-PARC
- The largest water Čerenkov Super-K
  Excellent for $E_\nu < 1\text{GeV}$
- Narrow band beam at oscillation max Off-axis
  $L=300\text{km} \Rightarrow E_\nu=(0.4-1.0)\text{GeV}$
- Reconstruction of the neutrino energy QE
  Works best for $0.5\text{GeV} < E_\nu < 1\text{GeV}$

\[
E_\nu = \frac{m_N E_l - m_l^2/2}{m_N - E_l + p_l \cos \theta_l}
\]
\( \nu_\mu \) disappearance

Physics goal: **Test of the oscillation framework**

- **Precise oscillation pattern study**

![Graph](graph.png)

- Does \( \nu_\mu \) disappearance follow the oscillation curve? Sterile? Extra dimension? New interactions?
- Precision measurement of \( \theta_{23} \) and \( \Delta m_{23}^2 \)
  \( \sin^2 2\theta_{23} < 1 \), \( \sin^2 2\theta_{23} = 1 \), or \( \sin^2 2\theta_{23} > 1 \)?
- Comparison of \( \theta_{23} \) and \( \Delta m_{23}^2 \) between \( \nu_\mu \) and \( \bar{\nu}_\mu \) (CPT)
- NC/CC ratio: Admixture of sterile neutrinos?

Neutrino oscillation has been presenting surprises
An excellent place to hunt for new physics
\( \nu_\mu \rightarrow \nu_e \) appearance \( (\theta_{13}) \)

- **Signal**: \( \nu_e \) (far)/\( \nu_\mu \) (near)
  Expected to appear at the \( \nu_\mu \) disappearance dip.

- Sensitive to \( \sin^2 2\theta_{\mu e} > 0.003 \) \( (\sin^2 2\theta_{13} > 0.006) \)
Future of JHF-Kamioka

- **Hyper-Kamiokande detector**
  - Water Čerenkov technology allows 1Mton detector
  - Extend $\sin^2 2\theta_{13}$ down to $10^{-3}$
  - CP violation measurement for $\delta_{CP} > 20^\circ$
  - $\times$10 better sensitivity in proton decay
  - Detector site identified and PMT R&D on going

- **JHF to Korea?**
  - The beam emerges in Korea, 1200km away.
  - Resolve degeneracies:
    - Matter effect $\text{sign}[\Delta m^2_{13}]$
    - Second oscillation maximum $\delta_{CP}$ vs. $\theta_{13}$
Systematic uncertainty in BG estimations

1. Background understanding is essential for the discovery
   - “Rare” $\nu_\mu \rightarrow \nu_e$ appearance signal
   - “Weak” signature of the neutrino signal:
     $\text{Observable} = (\text{Flux}) \times (\text{Cross section}) \times (\text{det.eff})$
   - Challenges
     - $E_\nu$ reconstruction for NC events is impossible
     - Far/near ratio (solid angle, decay position effect)
     - $E_\nu$ spectrum changes between near and far for CC
     - Neutrinos from K’s
     - Pion absorption in the final state

2. Strategies: sub-GeV neutrino beam
   - Off-axis near detectors
     Realistic detector depth due to shorter decay pipe and shorter baseline at low energy
   - Clean signatures of the signal and backgrounds:
     - QE-signal: recoil proton provides extra constraints
       $\Rightarrow$ non-QE/QE ratio
     - Two main background processes:
       NC-single $\pi^0$ production and beam $\nu_e$ contamination
       CC contribution is small
3. Redundant measurements of the backgrounds

- Near detector (e.g. fine grained calorimeter)
  - non-QE/QE ratio from recoil proton measurement
  \( \nu_\mu \) signal flux and beam \( \nu_e \) contamination

- Similar \( E_\nu \) spectrum in the off-axis detector
  NC background measurement without \( E_\nu \) reconst.
  - CC background is smaller and can be identified.

- Far detector (Super-K)
  - Single \( \pi^0 \) detection for NC-\( \pi^0 \)
    \( \Rightarrow \) Simulate asymmetric \( \pi^0 \) decay kinematics
  - Sideband in \( E_\nu \) distrib. to monitor \( \nu_e \) contam.
  - CC background further suppressed by oscillation.
Resolving the degeneracies

The next step after $\theta_{13}$: CP and matter effect

- Similar sizes of CP and $\theta_{13}$ contributions
- Reactor or anti-neutrino data could resolve it
- Matter effect is small for JHFnu:
  Longer baseline, preferably 2000-3000km needed for sign[$\Delta m_{13}^2$].

Experimental parameter for the next step experiments will be known better after $\nu_\mu \rightarrow \nu_e$ discovery
Status of the JHF-SK project

1. Initial LOI, June. 2001 (hep-ex/0106019)

   155 people from 12 countries; Japan(45) and Canada(20).

3. Pre-collaboration meeting in May 2003

4. International advisory committee, Mar. 2003
   • Statement by Yoji Totsuka, the new KEK DG:
     “1st Priority for KEK’s FY2004 budget proposal for J-PARC will be the neutrino oscillation experiment”
     – JHEPC (Japanese high energy physics committee) recommends.
     – Recommendation from the Research Plan Committee of IPNS
     – Priority set within KEK, repeatedly stated by the KEK-DG.
   • “The IAC strongly recommends that the neutrino oscillation experiment be brought into Phase I”

   • recommend early realization of JHFν experiment

6. Grant request submitted to MEXT in June 2003
   MEXT: ministry of education, science and technology

7. MEXT to ministry of finance in August 2003
   (Yomiuri newspaper report.)

8. Funding decision expected in December 2003

9. The first collaboration meeting in January 2004