Status of the T2K experiment

Ken Sakashita (KEK) for the T2K collaboration
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1. Introduction of T2K experiment
   - Motivation, Features and Sensitivity
2. Beam Commissioning in Apr-May ’09
   - T2K ν beam-line operation started
3. Status of preparation toward physics run
4. Future prospects
5. Summary
Next step of neutrino oscillation experiment

- discover a finite $\theta_{13}$
- determine $|U_{e3}|$
  $\rightarrow$ important role for future neutrino experiments
- CPV in lepton sector
  $\rightarrow$ hint on Baryon# asymmetry of Universe
- mass hierarchy
- precise measurement
  - Is $\theta_{23}$ maximal?
- Dirac or Majorana
- absolute mass scale

$U_{e3} = s_{13}e^{-i\delta}$

\[
\begin{pmatrix}
0.8 & 0.5 & ?
0.4 & 0.6 & 0.7
0.4 & 0.6 & 0.7
\end{pmatrix}
\]
Next step of $\nu$ oscillation experiment

- discover a finite $\theta_{13}$
- determine $|U_{e3}|$
- important role for future neutrino experiments
  - CPV in lepton sector
    - hint on Baryon# asymmetry of Universe
  - mass hierarchy
- precise measurement
  - $T2K: \nu_\mu$ disappearance
  - Is $\theta_{23}$ maximal?
- Dirac or Majorana
- absolute mass scale

$U_{e3} = s_{13}e^{-i\delta}$

$U_{MNS} \approx \begin{pmatrix} 0.8 & 0.5 & ? \\ 0.4 & 0.6 & 0.7 \\ 0.4 & 0.6 & 0.7 \end{pmatrix}$
T2K Experiment

Long base-line ν oscillation experiment in Japan

T2K features to enhance the sensitivity

- **Super-K(SK) as main neutrino detector**:
  - 22.5kton(fiducial) water cherenkov detector & good PID (e/μ) performance

- **Off-axis beam** (intense & narrow-band low energy neutrino beam)

- **Neutrino energy reconstruction**:
  - CCQE interactions dominate at T2K beam energy
Off-axis beam: intense & narrow-band beam

- ~1.2k CC int./year for SK
- small high $E_{\nu}$ tail (narrow-band)

$\rightarrow$ small # of bkg. for CCQE

Important to keep the beam direction stable
(monitoring & controlling the beam)

The beam energy depends on the off-axis angle (beam direction)

Set off-axis angle to 2.5°
$\rightarrow$ beam energy at oscillation max.
(current $\Delta m^2_{23}$ & L=295km)

- ~1.2k CC int./year for SK
- small high $E_{\nu}$ tail (narrow-band)
$\rightarrow$ small # of bkg. for CCQE
Sensitivity

$\nu_e$ appearance

$> x10$ improvement from CHOOZ limit

$90\% \text{ CL } \theta_{13}$ Sensitivity

$\sin^2 2\theta_{23} = 0.87$

$\sin^2 2\theta_{23} = 1.0$

$\Delta m^2_{23} = 2.4 \times 10^{-3} \text{ eV}^2$

$\Delta m^2_{12} = 7.6 \times 10^{-5} \text{ eV}^2$

$\nu_\mu$ disappearance

$\delta(\sin^2 2\theta_{23}) \sim 1\%$

$\delta(\Delta m^2_{23}) < 1 \times 10^{-4} \text{ eV}^2$

@ $8 \times 10^{21}$ protons(30GeV) on target

CHOOZ excluded

Stat. only (OA2.5°)
Beam commissioning
and
status of preparation toward physics run
J–PARC
(Japan Proton Accelerator Research Complex)

Linac
25Hz, 330m
H- 181MeV

3GeV Synchrotron (RCS)
25Hz, 350m,
0.6 ~ 1MW

30GeV MR
0.3Hz, 1.6km,
0.75MW

Material/Life Science Facility

Hadron Experimental Facility

Neutrino Facility
Neutrino to Super-Kamiokande

Joint Project between KEK and JAEA
Construction completed & Operation was started
* MR
  - successfully accelerate the beam up to 30GeV (Dec.2008)
  - successfully operate with 6-bunches (so far 3.5kW beam power) (Jun.2009)
T2K Neutrino Beam-line

- Completed the beam-line construction [2004~2009, 5 years]
  (Horn-2,3 to be installed in this summer)

start beam commissioning in April ’09 as scheduled
with low intensity (typically $4 \times 10^{11}$ p/pulse) beam to reduce
radio-activation of target area for Horn-2,3 installation in summer ’09
T2K neutrino beam-line starts operation

(First beam in Apr/23/2009)

Muon monitor signal at 1st shot after SC turned on

proton profile just in front of the target after 9 shots beam tuning (fluorescence plate)

We successfully started to produce neutrino beam
Achievements in the beam commissioning

9 days, 705 shots in total (Apr-May ’09)

- transfer the proton beam without any significant beam loss
- SC combined function magnets work as expected
- Muon yield is increased by Horn On
- control beam position on the target
- beam dir. was stable (\(\Delta \theta_\mu < 1\) mrad) during 0.5 hour operation
- Successfully pass the government inspection of radiation
- operate with several beam condition (e.g. 2-bunches operation)

T2Kν beam-line works with expected performance
Status of preparation toward physics run

- Horn 2,3 installation and construction, installation of Near Detector (ND) are going on

commissioning of ND will be started from Dec. ‘09
Prospects & Schedule

We aim for better sensitivity than the current limit by CHOOZ in 2010 as a first step

- T2K beam commissioning in fall-winter 2009
  - with full setup (3 Horns, NearDetector)
  - with high intensity beam
- physics run starts in Dec. 2009

Next : We hope to discover $\nu_e$ appearance with $1-2 \times 10^7$ MW*sec in a few years

- $\sin^2 2\theta_{13} = 0.05$ (3$\sigma$ discovery @ 1MW*sec)
- 0.03 (3$\sigma$ discovery @ 2MW*sec)

Final results with $3.75 \times 10^7$ MW*sec
  
  (8$\times 10^2$ i p.o.t.)
Summary

- T2K neutrino oscillation experiment, our goals are
  - discover $\nu_\mu \rightarrow \nu_e$ appearance (a finite $\theta_{13}$)
    one order of magnitude sensitivity improvement from the current limit
  - $\nu_\mu$ disappearance for precise measurement of $\sin^2 2\theta_{23}$, $\Delta m^2_{23}$
- First beam commissioning was successfully completed
  - neutrino production was confirmed with observing muon signal
  - confirmed basic functionality of the T2K beam-line
- Installation & construction works are going on toward physics run
- Aim for better sensitivity than the current limit by CHOOZ in 2010
backup
1. J-PARC outline, parameters and beam commissioning status

2. Issues to be solved: RFQ, RCS RF cavity and MR magnet power supply

3. Plan: (1) Neutrinos (Fast Extraction)  
(2) Hadrons (Slow Extraction)  
(short term, middle term and long term)

M.Yoshioka’s talk, “J-PARC Status and Plan”  
@ CERN Workshop on New Opportunities in the Physics Landscape at CERN
(1) T2K and beyond:  
3-step Power Upgrade Scenario  
Based on the assumption that three machine issues will be solved in a few years

- **Short term plan (2009~2010)**  
  - FY2009 → Establish 30 kW run and 100kW trial  
  - FY2010 → Establish 100kW (10^7 sec) and 300kW trial

- **Middle term plan (2011~in a few years??)**  
  - Achieve design beam power (750kW)  
    - Understanding/solving space charge effect and collimator scenario/aperture  
    - Improvement of MR magnet power supply to increase repetition rate  
    - Linac 400 MeV energy recovery and upgrade of the RCS injection system

- **Long-term plan toward power frontier (>MW)**  
  - KEK roadmap
ν Energy Reconstruction

- ν’s Energy reconstruction is possible for CC Quasi-Elastic interaction (CCQE: ν_{μ(e)} + n → μ(e) + p)

\[ E_{ν}^{rec} = \frac{m_n E_μ - m_μ^2/2 - (m_n^2 - m_p^2)/2}{m_n - E_μ + p_μ \cos θ_μ} \]

T2K’s beam energy
θ_{13} measurement by ν_e appearance

\[ P(ν_μ \rightarrow ν_e) = 4C_{13}^2 S_{13}^2 S_{23}^2 \sin^2 Φ_{31} \]

\[ + 8C_{13}^2 S_{12} S_{13} S_{23} (C_{12} C_{23} \cos δ - S_{12} S_{13} S_{23}) \cos Φ_{32} \sin Φ_{31} \sin Φ_{21} \]

\[ - 8C_{13}^2 C_{12} C_{23} S_{12} S_{13} S_{23} \sin δ \sin Φ_{32} \sin Φ_{31} \sin Φ_{21} \]

\[ + 4S_{12}^2 C_{13}^2 (C_{12}^2 C_{23}^2 + S_{12}^2 S_{23}^2 S_{13}^2 - 2C_{12} C_{23} S_{12} S_{23} S_{13} \cos δ) \sin^2 Φ_{21} \]

\[ - 8C_{13}^2 S_{13}^2 S_{23}^2 (1 - 2S_{13}^2) \frac{aL}{4E} \cos Φ_{32} \sin Φ_{31} \]

\[ L = 295 \text{ km}, \ \langle E_ν \rangle \sim 0.6\text{GeV} \]

\[ \sin Φ_{21} \sim 0.05 \]

δ → −δ, a → −a for \( P(\bar{ν}_μ \rightarrow \bar{ν}_e) \)

\[ \frac{aL}{4E} = 7.6 \times 10^{-5}[\text{eV}^2] \left( \frac{ρ}{[\text{g/cm}^3]} \right) \left( \frac{E}{[\text{GeV}]} \right) \frac{L}{4E} \propto L \]

- \( P(ν_μ \rightarrow ν_e) \rightarrow \sin^2(2θ_{13}) \) : some ambiguity due to unknown params.
- It is possible to measure CPV by comparing ν and ν̅.
$\nu_e$ appearance search

- Signal: $e^-$ from $\nu_e$ CCQE int.
- Background
  - intrinsic $\nu_e$ in the $\nu_\mu$ beam (0.4% of $\nu_\mu$ at peak energy)
  - NC $1\pi^0$ interaction
    - $\pi^0$ misidentified as $e$
  - further $e/\pi^0$ separation cut & understanding efficiency
ν beam direction monitor

- first look in agreement with simulation

- 1 month data w/ 1% beam

- Tracking plane efficiency 99.5 ± 0.6 %
Off-axis detectors

construction/installation/hardware test is going on