

T2K status





Tokai → Kamioka



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IFIC, Valencia (on behalf of the T2K collaboration)

6th Low Energy Neutrino Physics Workshop 11/11/11 Seoul, Korea





- 12 countries
- **59** institutes
- ~ **500** authors

. . .

- ~ **22500** tons water (FD)
- ~ 70000 el. channels (ND)

- **1.43x10**²⁰ protons on target



Neutrino Oscillations T2K

in one slide...

"Strange" experimental results from the 70's to the 90's: \rightarrow Neutrino mass, interaction eigenstates do not coincide!

Can be connected through a "rotation matrix"

Usual phenomenological representation: PMNS Matrix: $s_{ii} = \sin \theta_{ii}, c_{ii} = \cos \theta_{ii}$

 $U = \begin{pmatrix} 1 & 0 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{22} & c_{22} \end{pmatrix} \times \begin{pmatrix} c_{13} & 0 & s_{13}e^{-i\sigma} \\ 0 & 1 & 0 \\ -s_{12}e^{i\delta} & 0 & c_{12} \end{pmatrix} \times \begin{pmatrix} c_{12} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix} \times \begin{pmatrix} e^{i\alpha_1/2} & 0 & 0 \\ 0 & e^{i\alpha_2/2} & 0 \\ 0 & 0 & 1 \end{pmatrix}$

"Atmospheric" "Interference"

"Solar"

"Majorana"

Experimental signature:

$$P(\nu_{\mu} \rightarrow \nu_{e}) = \overline{\sin^{2} 2\theta_{13}} \sin^{2} \theta_{23} \sin^{2} \left(1.27 \Delta m_{\text{atm}}^{2} (\text{eV}^{2}) \frac{L(\text{km})}{E(\text{GeV})} \right)$$

$$P(\nu_{\mu} \rightarrow \nu_{\mu}) = 1 - \overline{\sin^{2} 2\theta_{23}} \sin^{2} \left(1.27 \Delta m_{\text{atm}}^{2} (\text{eV}^{2}) \frac{L(\text{km})}{E(\text{GeV})} \right) \text{ (Mass)}^{2}$$



The T2K experiment T2

overview

Long Baseline Neutrino Oscillation Experiment

• A (*mainly*) muon-neutrino beam with mean energy 600MeV, propagates ~295 km through Japan and is measured at near and far sites

Aims :

- Discover/Measure the remaining mixing angle, $\theta_{\rm 13}$
- Improve measurement of the "atmospheric" mass splitting Δm^2_{23}





The Beam

Muon neutrino production





- 30 GeV protons on carbon target
- 3 focussing horns for secondary pions
- Pions decay producing neutrinos



The Beam



The Off-Axis principle

 $E_{\rm V}$ (GeV)

1.2

B.0

0.6

0.4

D.2

0.8 £ 06

> 0.4 02

3500

3000 2500

0°

30

2°

2.50

DAB 2.5 degree

Oscillation Prob.

v energy spectrum

(Δm²=2.5x10⁻³)

(Flux × x-section)

 p_{π} (GeV/c)

[BNL889 proposal]

• Pion Decay:

- At non-zero angles, neutrino energy weakly changes with pion momentum
- 2.5° off-axis angle gives narrow band beam:
- -Peak at oscillation maximum → more statistics
- Less background from NC interactions at high energy





The Beam



Beam Production history



- Started physics data taking in January 2010
- Total Dataset 1.43x10²⁰ POT
- All data analyzed



The Near Detectors



On-Axis: INGRID

- Designed to measure beam profile (intensity, direction, stability)
- 7+7 modules (iron/scintillator plane) in cross shape
- Measured stability of neutrino beam direction within 1 mrad:



• Measured event rate stability (neutrino beam intensity):



integrated day(1 data point / 1day)







The Near Detectors **T2**



Off-Axis: ND280



"Tracker": 3 TPC/2 FGD

- FGD: scintillator tracker with 1cm² bars
- TPC: New MicroMEGAS technology for tracking and PID

POD: (π⁰ detector)

- Scintillator/Brass/Pb tracker and calorimeter.
- Water target

ECAL (surrounds inside detectors):

• Pb/scintillator tracking calorimeter

Magnet/SMRD:

- Refurbished UA1 magnet
- Scintillator inside magnet yoke (muon tracking/ID)

V



ND280 event album



Measurements at ND280



p (MeV/c)



The Far Detector

principle of operation





Water Cherenkov detector With 22.5kton fiducial volume

Inner Detector (ID): ~11,000 20- inch PMT Outer Detector (OD): ~1900 8-inch PMT

New DAQ system from 2008









- Neutrino ($\nu_{\!_{\rm \mu}}$ and $\nu_{\!_{\rm e}})$ spectrum in the Far Detector is based on MC
- MC is modified based on results of the p+C interaction experiment NA61
- Prediction is checked (normalization only) in ND280



Cut Sequence for CCQE numu:

Cut	Data
Single ring mu-like	33
Muon momentum, $p_{\mu} > 200 MeV$	33
Less than 2 decay electrons	31

For **no-oscillation** : **103.6** events expected

For oscillation with $\sin^2\theta_{23}=1$, $\Delta m^2=2.4 \times 10^{-3} eV^2$: 28.3 events expected



- Oscillation pattern visible in spectrum
- No-oscillation excluded at 4.5σ

- 2 independent analyses, consistent results
- In full agreement with MINOS, SK



v_e appearance



selection

1.5



Expected backgrounds: 1.5 + -0.3

Cut Sequence for CCQE v_e :

	Cut		Data	Data	
Single-ring e- like			8		
E _{vis}	, > 100	MeV	7		
No decay electron			6		
Invariant mass < 100MeV/c		nass eV/c	6		
Neutrino energy in oscillation region		nergy tion	6		
Background breakdown:					
otal	v_{μ} CC	$v_e {\sf CC}$	NC	$v_{\mu} \rightarrow$	
1.5	0.03	0.8	0.6	0.0	

0.09



v_e appearance



 $\Delta m_{23}^2 > 0$

0.5

 $\Delta m_{23}^2 < 0$

0.6



KS test of R2 gives 11% probability

Pvalue of *null* hypothesis: 0.7%

0.5

0.6



The Earthquake

• Big **earthquake and tsunami** occurred near the pacific coast of Japan on 11/3/2011.

• Combined with the Fukushima plant destruction and pollution, it is a *grave national disaster* for Japan.

• J-PARC was not affected directly by the tsunami (although on the coast)

• Structural damage to infrastructure quickly repaired over summer.

• More detailed tests and controls (e.g. alignment) underway





Neutrino velocity

Official Statement:

- 1) Based on our initial assessment of our capability, at the moment T2K cannot make any definitive statement to verify the Opera measurement of the speed of neutrino (Opera Anomaly).
- 2) We will assess a possibility to improve our experimental sensitivity for a measurement to cross-check the OPERA anomaly in the future. Such a measurement with an improved system, however, could take a while to achieve.



Future Plans



Near Detector:

- Include spectrum measurement
- Improve v_{e} measurements

Far Detector:

- Improve calibrations to reduce systematics
- Improve reconstruction, event selection

Neutrino Flux prediction:

• Incorporate new NA61 results

• Incorporate new neutrino interactions measurements (SciBOONE, MiniBOONE)

• Use ND280 measurements

• Restart data taking early 2012

• Main goal: discovery of non-zero θ_{13}



Conclusions



- \bullet T2K has given the first indication for non-zero $\theta^{}_{13}$
 - 6 v_e candidate events (1.5 expected background)
 - First hint of v_e appearance! (2.5 sigma)

T2K results published in *Phys. Rev. Lett.* **107**, 041801 (2011)

+ T2K measures $\nu_{\!\mu}$ oscillation parameters in agreement with MINOS, SK

• T2K has collected 2% of the goal protons on target by March 2011

• Starting in early 2012, much more results are expected soon!

BACKUPS

The six nue candidate events



Large acceptance spectrometer and time-of-flight detectors





30 GeV proton beam to match T2K

Two target types:

1) 0.04 λ "thin target"

2) T2K replica "long target"

Pion production from thin target used in this analysis

Good TOF and dE/dx performance allows for particle separation



Schematic of beam production

