The T2K Experiment

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NuInt
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On behalf of

504 people, From 59 institutes, In 12 countries
The T2K Experiment

- Long-baseline neutrino oscillation experiment
- J-PARC produces off-axis neutrino beam
- Near Detectors for flux and cross-sections
- Far Detector at Super-Kamiokande
- Precision measurements of $\theta_{23}$, $\theta_{13}$, $\Delta m^2_{32}$ and neutrino interaction cross-sections
Beam Content

Flux (/cm²/50MeV/10²¹POT)

- $\nu_\mu$ at ND280
- $\overline{\nu}_\mu$ at ND280
- $\nu_e$ at ND280
- $\overline{\nu}_e$ at ND280

E$_{\nu}$ (GeV)

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Off-Axis Beam

The diagram shows the $\nu_\mu$ flux (au) as a function of $E_\nu$ (GeV). The curves labeled OA2.0°, OA2.5°, and OA3.0° represent different off-axis angles compared to the main beam direction (0°). The flux peaks at different energies for each curve, indicating the effect of off-axis beams on neutrino flux measurements.
Beam Performance

Total Delivered: $3 \times 10^{20}$ POT
Near Detectors

- 280m downstream
- On-axis detector: INGRID
  - Flux normalisation
  - Beam direction
- Off-axis detector: ND280
  - Flux composition
  - Flux energy spectrum
  - Interaction cross-sections
INGRID

- 16 Modules
  - 7 Horizontal
  - 7 Vertical
  - 2 off-axis
- Plastic scintillator & steel
- 1 additional module with scintillator only
INGRID

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INGRID – Profile

Horizontal

Vertical

Run32

χ² / ndf 10.4 / 4
Constant 1.03e+04 ± 61.16
Mean -2.817 ± 2.918
Sigma 439.2 ± 4.815

Run32

χ² / ndf 8.148 / 4
Constant 1.064e+04 ± 61.76
Mean -7.991 ± 3.117
Sigma 461.4 ± 5.393

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1 mrad shift gives ~2% energy shift at peak
ND280

- Off-axis detector
- Central target region:
  - $\pi^0$ Detector (P0D)
  - Tracker (FGDs + TPCs)
- Surrounding EM Calorimeters
- UA1/NOMAD 0.2T Magnet
- Scintillator planes inside magnet:
  - Side Muon Ranging Detector (SMRD)
\[ \pi^0 \] Detector – The P0D

- NC \( \pi^0 \) is a serious \( \nu_e \) appearance background
- Central Target:
  - Water
  - Triangular scintillator bars
  - Brass foils
- Up and Downstream ECals
  - Triangular scintillator bars
  - Lead sheets
- Can be run with water in/out
Tracker

- 2 Fine Grained Detectors
  - Square plastic scintillator bars
  - FGD1 is pure scintillator
  - FGD2 has water targets interspersed
  - Provide interaction target
- 3 Time Projection Chambers
  - Predominantly Argon gas
  - Provide momentum (from curvature)
  - Provide Particle ID (from dE/dx)
Tracker

- 2 Fine Grained Detectors
  - Square plastic scintillator bars
  - FGD1 is pure scintillator
  - FGD2 also has water targets
  - Provide interaction target
- 3 Time Projection Chambers
  - Predominantly Argon gas
  - Provide momentum (from curvature)
  - Provide Particle ID (from dE/dx)
Tracker Particle ID

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ECals

- 7 modules surround tracker:
  - Particle ID
  - EM Energy measurement
  - Photon conversion

- 6 modules surround the P0D:
  - Catch high-angle particles escaping P0D
  - Veto incoming backgrounds
  - Constructed at Warwick

- Rectangular plastic scintillator and lead
ECals

- 7 modules surround tracker:
  - Photon conversion
  - EM Energy measurement
  - Particle ID
- 6 modules surround the P0D:
  - Catch high-angle photons
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- Rectangular plastic scintillator and lead
ECal Particle ID

Electron – Proton
Muon - Electron
Muon – Pion

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ND280

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Super-Kamiokande
Super-Kamiokande

- 50kT water Cherenkov detector
- 22.5kT fiducial volume
- 295km from beam
- Can distinguish $\nu_e$ and $\nu_\mu$
- Can measure momentum and angle
- Good timing
T2K at Super-K

Number of events/40nsec

$\Delta T_0$ (nsec)

Number of events

$\cos \theta_{beam}$

RUN1-3 data
(3.010$x10^{26}$ POT)

$\nu_e$ candidates:
All FC events
$\nu_e$ candidates:
- RUN1+2
- RUN3

$\nu_\mu + \bar{\nu}_\mu$ CC QE
- $\nu_\mu + \bar{\nu}_\mu$ CC non-QE
- $\nu_e + \bar{\nu}_e$ CC
- NC
(MC w/ 2-flavor osc.)

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T2K at Super-K

$\nu_e$ Candidate
The T2K Experiment

Physics
$\nu_e$ Appearance

11 candidate $\nu_e$ events selected
3.2 expected if $\theta_{13} = 0$
$\theta_{13} > 0$ at 3.2$\sigma$

$\Delta m^2_{23} = 2.4 \times 10^{-3}$ eV$^2$
$\sin^2 2\theta_{23} = 1.0$

$\Delta m^2_{31} = -2.4 \times 10^{-3}$ eV$^2$
$\sin^2 2\theta_{13} = 1.0$

T2K Run 1+2+3
3.01 $\times$ 10$^{20}$ p.o.t.

3.01 $\times$ 10$^{20}$ POT

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νμ Disappearance

31 candidate νμ events selected
103 expected with no oscillations

1.4 x 10^{20} POT
From Summer 2011
New Result Soon!

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Cross-Sections

$\nu_\mu$: Inclusive (Monday)
Quasi-Elastic (Thursday)
Single $\pi$ (Thursday), Multi $\pi$, etc.

$\nu_e$: Inclusive

$\bar{\nu}_\mu$: Inclusive
Quasi-Elastic

NC: Inclusive
Elastic
Single $\pi^0$ (Thursday)
Cross-Sections

- Multiple Target Materials:
  - Plastic scintillator: P0D, FGDs, ECals
  - Water: P0D, FGD2
  - Lead: P0D, ECals
  - Steel: INGRID
  - Brass: P0D

- Sometimes exclusive, sometimes in combination
Conclusions

- T2K: neutrino oscillations with an off-axis beam
- Making precision measurements of $\theta_{13}$, $\theta_{23}$, $\Delta m^2_{32}$
- Near Detectors:
  - Will make a broad range of interaction measurements
  - Capable of multiple event topologies
  - Containing many target materials
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