The Status of the T2K Near Detectors

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for the T2K Collaboration
## The T2K Collaboration

<table>
<thead>
<tr>
<th>Country</th>
<th>Institutes</th>
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<tbody>
<tr>
<td><strong>France</strong></td>
<td>CEA Saclay, IPN Lyon, LLR E. Poly., LPNHE Paris</td>
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<tr>
<td><strong>Germany</strong></td>
<td>U. Aachen</td>
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<tr>
<td><strong>Japan</strong></td>
<td>ICRR Kamioka, ICRR RCCN, KEK, Kyoto U., U. Kobe, U. Miyagi, U. Osaka City, U. Tokyo</td>
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<tr>
<td><strong>S. Korea</strong></td>
<td>N. U. Chonnam, U. Dongshin, N. U. Seoul</td>
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<td><strong>Spain</strong></td>
<td>IFIC, Valencia, U. A. Barcelona</td>
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<td><strong>Switzerland</strong></td>
<td>ETH Zurich, IFIC, Valencia, U. A. Barcelona</td>
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<tr>
<td><strong>USA</strong></td>
<td>Boston U., B.N.L., Colorado S. U., Duke U., Louisiana S. U., Stony Brook U.</td>
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<tr>
<td><strong>Russia</strong></td>
<td>U. Rochester, U. Washington</td>
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The T2K Experiment

- Long baseline neutrino experiment
  - Baseline 295km
  - First off axis neutrino experiment
- Search for/measure neutrino oscillations:
  - $\nu_\mu \rightarrow \nu_e$
  - $\nu_\mu \rightarrow \nu_\tau$
- Improve measurement of $\theta_{23}$, $\Delta m^2_{23}$
  - Is $\theta_{23}$ maximal?
- First measurement of $\theta_{13}$
  - How small is $\theta_{13}$?
The Near Detector Complex

- **INGRID**
  - On Axis Detector
  - Beam Monitoring
    - Rate
    - Direction
    - Stability
- **ND280**
  - Off Axis Detector
  - Neutrino Flux and Spectra
  - Inputs into oscillation analyses
  - Neutrino Cross Section
Technologies in ND280

- **Scintillator Detectors**
  - Plastic scintillator bars
  - Wavelength shifting fibres
    - Kuraray Y11, 1 mm diameter
  - MPPCs
    - Multi-Pixel Photon Counters
    - 1.3x1.3mm
    - 667 pixels
    - First large scale deployment of MPPCs.
    - Readout via 2 electronics types
      - TRIPT (Ingrid, P0D, ECAL, SMRD)
      - AFTER (FGD)

- **TPC**
  - Readout via micromegas
    - 72 modules 34.2x35.9 cm²
    - Pads: 7x9.8 mm²
On Axis : INGRID

- Iron - Scintillator Detector
  - 16 Modules across the beam profile
- Monitor the beam intensity and direction
  - Use the interaction of the forward muon neutrinos.
Analysis at Ingrid

- Select Events via:
  - Reconstructed Tracks.
  - Beam Timing
  - Fiducial Volume
    - Avoid entering events (sand muons)

Reconstructed Track Angles

Angular Resolution

Selection Efficiency
Beam Direction

• A change in the beam direction of 1 mrad corresponds to a variation of $E_{\text{peak}}$ at SK of $\pm 2\%$

• The beam profile and steering are measured across INGRID.

• Horizontal
  • $-0.014 \pm 0.025(\text{stat}) \pm 0.33(\text{sys})$ mrad

• Vertical
  • $-0.107 \pm 0.025(\text{stat}) \pm 0.37(\text{sys})$ mrad
Beam Stability

Beam Power Check:

Rate: Data/MC = 1.057 ±0.001(stat)±0.040(sys)
The ND280 Off-Axis Detector

Understanding the beam
- $\nu_\mu$ Flux and Spectrum
- $\nu_e$ Beam Contamination
- Neutrino Cross-Sections
Off-Axis Detector Design

- Refurbished UA1 Magnet 0.2T field
- Fine Grained Detectors (FGDs)
  - Neutrino target region for the tracker.
- TPCs
  - Particle Tracking
    - $\nu_\mu$, $\nu_e$ measurements
- P0D
  - Measure NC $\pi^0$ rate
- ECAL
  - Surrounds tracker and P0D.
  - Capture and measure EM energy
  - Only the DS ECAL in Run 1
- SMRD
  - Muon ranging instrumentation in the magnet yoke
Key Features of the Off-Axis detector

- **Tracker Region**
  - High precision tracking with a magnetic field.
    - Provides excellent momentum resolution for charged particles.
  - Excellent particle identification
    - $dE/dx$ in the TPC
    - Further particle ID in the ECAL and FGD
  - ECAL surrounding the tracker
    - Capture all the energy leaving the vertex.

- **P0D**
  - Specialised for the measurement of NC $\pi^0$s, a key T2K background.
  - Water and Carbon targets for determination of cross sections on multiple materials.
    - Key point for T2K as SK target is water.
The FGDs

- Fine-Grained detectors
  - Alternating x-y planes of scintillator bars.
  - 9.6x9.6x1844 mm
  - 8448 channels
    - 0.24% bad channels
- Acts as the neutrino target for the tracker.
  - Good vertexing
  - Identification of short primary tracks.
- FGD1
  - Upstream
  - Scintillator Only
- FGD2
  - Downstream
  - Includes water target
- Extract rate on water by comparing both FGDs.
FGD Vertices

The FGD contains the primary vertex for tracker events.
FGD Particle Identification

- PID in the FGD is crucial for identification of short tracks from the vertex.
- Use DE/DX information for PID.
  - Separate protons and muons.
  - Examine tracks that stop in the FGD
- Michel Electrons

\[
\chi^2 / \text{ndf} = 86.97 / 72
\]

\[
p_0 = -0.7034 \pm 1.8208
\]

\[
p_1 = 319.9 \pm 9.0
\]

\[
p_2 = 2.23 \pm 0.09
\]
The TPC

- 3 TPCs interleaved with the 2 FGDs
- Readout via micromegas
  - 1726 pads per module
  - 124416 readout channels
  - 0.13% bad channels
- Provide detailed tracking information
  - 700 μm point resolution at full drift distance.
  - Momentum resolution 7% at 1GeV

Cathode ~ 25 kV

Micromesh ~ ~350V

Pad pitch 7.0mmx9.8mm

~1 electron/ion pair per 0.3 mm

Drift ~1m

128 μm
dE/dx in the TPC

- dE/dx information in the TPC provides a very powerful PID tool.
- Can separate muons/pions from electrons and protons with high precision.
  - Crucial for $\nu_e$ analysis due to high muon rate from beam composition.
The ECAL

- Surrounds the tracker (FGD/TPC) and the P0D
  - Collects particles leaving those regions.
- Lead scintillator sandwich
  - 1x4 cm bar cross section
- Readout via wavelength shifting fibres and MPPCs.
- 22326 Channels on 336 TFBs in 13 modules
  - 35 (0.16%) bad channels.
- Downstream ECAL installed in 2009
  - Present in all data
  - Calibrated in testbeam at CERN
- Barrel ECAL and P0D ECAL installed in summer 2010.
  - Present only in run 2 data.
ECAL Energy

- Determine photon and electron energy.
  - Needed to reconstruct all the energy leaving the neutrino interaction.
- Detector response calibrated via muons.
  - Normalise to minimum ionising particle at normal incidence.
  - Correcting for attenuation in the fibre.
- EM Energy proportional to total charge collected.
  \[
  \frac{\sigma_E}{E} = 9.8\% \quad \frac{\sqrt{E}}{E} (\text{GeV})
  \]
Particle Identification in the ECAL

- Provides an independent PID to DE/DX in the TPC.
  - Improved purity
  - Further reduction to muon backgrounds.
  - Cross checks.
- Use a neural net based on the shape and charge distribution of a cluster.
- Verified with:
  - Testbeam data
  - Cosmic events
  - Beam induced muons

![Graphs showing particle identification results](image-url)
The P0D

- Optimised to detect neutral current $\pi^0$s.
  - 33.5(B)x17.25(H) mm triangular bars
  - Lead and brass radiators
  - 10400 channels
    - 0.07% bad channels
- Water target designed for operation with water in/water out.
  - Determine rate on $^{16}\text{O}$
  - Water in: all run 1 and $6.98 \times 10^{19}$ pot in run 2
  - Water out: $3.03 \times 10^{19}$ pot in run 2.
Events in the P0D

- Event Yield
- Event Timing
- Vertex Distribution

Integral of 3D Vertices vs Protons@CT5

Time Distribution of Vertices

Beam Centre
The SMRD

- Scintillator panels instrumenting the magnet
  - Measure the muon from neutrino interactions
  - Provide cosmic trigger
- Panels are:
  - 870x167x7 mm horizontal
  - 870x175x7 mm vertical
  - Unique wiggled groove for fibre.
- 4016 channels
  - 0.07% bad channels.
Events in the SMRD

Beam Timing in the SMRD

SMRD Beam Event Hits

Time Distribution in Integration window
Impact of the Earthquake on ND280

- The Near Detector was running when the Earthquake struck in March
- The UPS maintained power and systems shut down as UPS power was used up.
  - UPS batteries have been replaced.
- Since the earthquake all near detector subsystems have been powered up and cosmic data has started to be collected.
  - Damage to the subsystems is minor.
  - Work will be carried out over the summer to recommission the detector.
- The near detector will be ready to start collecting data with the beam in December.
Physics Analysis at ND280

- Currently only available from T2K run 1 data.
  - Analysis of run 2 data is ongoing.

- First ND280 Analyses:
  - Inclusive $\nu_\mu$ rate
    - Input to oscillation analysis via beam normalisation
    - FGD+TPC
  - Inclusive $\nu_e$ rate
    - Verification of beam prediction.
    - FGD+TPC

- ND280 has a rich physics program to come.

- For more details talk by D. Brook-Roberge on Thursday.
\( \nu_\mu \) CC Event Selection at ND280

- Inclusive Analysis, just uses the muon.
  - CCQE analysis is more complex, will be used in the future.
- Require
  - No track in TPC1
  - Vertex in FGD1 and at least 1 track \( p > 50 \text{MeV} \) in TPC 2
  - Select highest momentum track
  - TPC \( dE/dx \) consistent with muon.
  - If no tracks in TPC2, repeat with FGD2/TPC3 combo
$\nu_\mu$ CC Inclusive measurement

Data/MC = $1.036 \pm 0.028^{+0.044}_{-0.037}$ (stat) +0.038 (phys model)

- Systematics include
  - TPC Tracking efficiency, Detector matching
  - dE/dx distribution
  - Backgrounds

T2K Run 1 = $2.88 \times 10^{19}$ pot
Measurement of the Beam $\nu_e$ component.

- Unlike $\nu_\mu$ analysis there are significant backgrounds:
  - Muons
    - Need very good PID
  - Electrons
    - Interactions from $\nu_e$ are not the only source of electrons.
  - External Backgrounds
    - Beam induced gammas that shower in the FGD

- Run 1 analysis
  - Uses FGD+TPC combination
  - Require
    - Vertex in FDG fiducial volume
    - No track in upstream TPC
    - Most energetic track is negative and electron like
      - TPC PID is crucial
    - $M_{\text{inv}} < 100$ MeV if 2 tracks
      - Photon rejection
    - $0 < p < 2000$ MeV
\( \nu_e \) Inclusive Measurement

- We carry out a maximum likelihood fit to signal and background
- Background dominated by real electrons

- Fit gives 8 beam \( \nu_e \) events.

\[
\frac{N_{\nu_e}}{N_{\nu_\mu}} = 0.010 \pm 0.007 \text{(stat)} \pm 0.003 \text{(sys)}
\]

\[
\frac{(N_{\nu_\mu}/N_{\nu_e})_{\text{Data}}}{(N_{\nu_\mu}/N_{\nu_e})_{\text{MC}}} = 0.6 \pm 0.4 \text{(stat)} \pm 0.2 \text{(sys)}
\]

T2K Run 1 = 2.88\times10^{19} \text{ pot}
Conclusions

• The T2K near detector suite is working well

• The near detector survived the earthquake and will be ready for data taking when JPARC resumes operations in December

• First results from the near detector are available and are used in T2K oscillations analyses
  • In the future additional near detector information will be added to the oscillation analyses.
  • Neutrino cross section measurements will be produced.
Events at ND280