T2K 280m detector

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Representing the ND280 group of the T2K collaboration
Outline

● Brief reminder of the physics goals of the T2K long baseline neutrino oscillation experiment
  ● requirements for the near detectors

● Baseline design of the off axis ND280m detector
  ● selected technologies
  ● expected capabilities

● Timescales for construction and initial operation
T2K physics program

- The proton beam from the 50 GeV synchrotron under construction at JPARC will be used to produce an intense neutrino beam directed to the Super Kamiokande detector (295 km away)
  - measurement of $\nu_\mu$ disappearance to improve accuracy for:
    \[
    \sin^2 2\theta_{23} \rightarrow \approx 1\% \quad \Delta m^2_{23} \rightarrow \approx 2\%
    \]
  - measurement of $\nu_e$ appearance to improve sensitivity to $\sin^2 2\theta_{13}$ by an order of magnitude
JPARC facility
T2K neutrino beamline

- Use off-axis principle
- select angle corresponding to oscillation maximum

![Flux graph](image)

![Beamline diagram](image)
T2K near detectors: muon monitor

- A muon monitor system is directly downstream of the beam dump:
  - a real time status monitor – sensitive to
    - proton intensity
    - proton beam position on target
    - horn performance

- Combination of detector technologies:
  - He gas ion chambers
  - semiconductor detectors – possibly diamond
T2K near detectors: on axis $\nu$ monitor

- Located 280 m downstream of the proton target

- monitor $\nu$ beam properties on a day-by-day basis
  - centre
  - profile

- iron-scintillator stacks
T2K near detectors: off axis $\nu$ detector

- Located 280 m downstream of the proton target
- measure neutrino beam properties and neutrino interaction cross sections and kinematics
  - $\nu_\mu$ disappearance:
    - flux and spectrum of $\nu_\mu$ prior to oscillation
    - study processes that SK will misinterpret and assign an incorrect $\nu_\mu$ energy
  - $\nu_e$ appearance:
    - flux and spectrum of $\nu_e$ in beam
    - study processes that SK will misinterpret as coming from $\nu_e$
- requires a large, highly segmented detector
  - charged, neutral energy measurements, particle ID
ND280 group

- Canada
  - UBC, Regina, Toronto, Victoria, TRIUMF, York
- France
  - CEA/Saclay
- Italy
  - Bari, Napoli, Padova, Rome
- Japan
  - Hiroshima, KEK, Kobe, Kyoto, ICRR, Tokyo
- Korea
  - Chonnam, Dongshin, Kangwon, Kyungpook, Gyeongsang, Sejong, Seoul, SungKyunKwan
- Russia
  - INR Moscow
- Spain
  - Barcelona, Valencia
- Switzerland
  - Geneva
- United Kingdom
  - Imperial, Lancaster, Liverpool, Queen Mary, CCLRC, Sheffield, Warwick
- United States
  - Louisiana State, Stony Brook, Rochester, Washington
ND280 off axis detector: overview

- UA1 magnet provides 0.2 T B field
- inner volume: $3.5 \times 3.6 \times 7.0 \text{ m}^3$
- front optimized for $\pi^0$ from NC
- rear optimized for CC studies
- surrounded by ECAL and muon detector
Pi-zero detector

• designed to make high statistics measurements of $\nu$ interactions with electromagnetically showering particles
  • scintillating bar tracking planes
  • front section interleaved with passive water layers (blue)
  • statistical subtraction of events in rear from front used to determine oxygen cross sections
Pi-zero detector

- schematic view of one layer:
  - co-extruded triangular polystyrene bars with TiO$_2$ reflective layer and central hole with WLS fiber
  - thin (0.6 mm) lead sheets (red) to promote photon conversion
Pi-zero detector

- Typical NC single $\pi^0$ production events:
  - $0.5 \text{ GeV/c } \pi^0 + 1 \text{ GeV/c proton}$
  - $0.5 \text{ GeV/c } \pi^0 + \text{ undetected neutron}$
Pi-zero detector

- With a fiducial mass of 1.7 tons of water, expect \( \sim 17 \times 10^3 \) NC single \( \pi^0 \) events in the water target for \( 10^{21} \) protons on target (one nominal year)
  - must determine water cross sections by statistical subtraction (from total of \( \sim 60 \times 10^3 \) such events)
  - eff. for \( \pi^0 \) reconstruction, \( p > 200 \) MeV/c: 50-60%
  - \( \pi^0 \) fake rate \( \sim 20\% \)

- Ample statistics to help improve MC simulations
Tracker

- The tracker is optimized to study neutrino interactions that produce charged particles:
  - $\nu_\mu$ CC quasi-elastic (CCQE) interactions to measure the $\nu_\mu$ flux and spectrum prior to oscillation
  - $\nu_\mu$ CC in-elastic interactions that can be misinterpreted by SK to be CCQE, and thus assigning an incorrect $\nu_\mu$ energy
  - $\nu_\mu$ NC in-elastic interactions that produce $\pi^+$ and $\pi^-$ that can be misinterpreted by SK to be CCQE
  - $\nu_e$ CCQE interactions, to determine the $\nu_e$ flux and spectrum, an important background to $\nu_e$ appearance at SK
Tracker

- consists of solid active target modules (FGD) and gas time projection chamber modules (TPC)
Tracker - FGD

- each FGD: $2 \times 2 \times 0.3 \, \text{m}^3$ target volume
- scintillator bars: $1 \times 1 \times 200 \, \text{cm}^3$ arranged in alternating x-y planes
  - fine segmentation needed to track low energy protons, in order to distinguish CCQE and non-elastic
- the back FGD will contain water layers
  - initially 3~cm passive water layers between each x-y scintillator plane
  - active program to produce water-based scintillator for a future upgrade
- plan to use “SiPM” devices for readout
Tracker - TPC

- use a low diffusion gas to achieve p resolution goal:
  - 10% for $p < 1$ GeV/c
- double wall with field cage as inner wall
- micropattern gas detector readout
- custom ASIC readout electronics
Tracker - TPC

- readout segmented into $8 \times 8 \text{ mm}^2$ pads
- width of active volume: 600 mm per module
  - detailed full simulation:
    - full reconstruction: $\delta p/p < 10\%$ for $p < 1 \text{ GeV/c}$
    - $dE/dx$ resolution: $\sim 7\%$
      - sufficient for $\mu$ / $e$ separation
Tracker – $\nu_\mu$ CC event

Event No.: 24  Reaction code: 1  Position in File: 24
Primary Vertex [mm]: (-423, 53, 808)
Located in
Basket_0/TRK_0/Active_1/ScintX1_136/bar_37278

Informational particles

<table>
<thead>
<tr>
<th>Particle</th>
<th>KE (MeV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\nu_\mu$ (14)</td>
<td>1340 MeV</td>
</tr>
<tr>
<td>n (2112)</td>
<td>0 MeV</td>
</tr>
</tbody>
</table>

Primary particles

<table>
<thead>
<tr>
<th>Particle</th>
<th>KE (MeV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\mu^-$ (13)</td>
<td>938 MeV</td>
</tr>
<tr>
<td>p (2212)</td>
<td>170 MeV</td>
</tr>
<tr>
<td>n (2112)</td>
<td>72 MeV</td>
</tr>
<tr>
<td>p (2212)</td>
<td>12 MeV</td>
</tr>
<tr>
<td>p (2212)</td>
<td>3 MeV</td>
</tr>
<tr>
<td>p (2212)</td>
<td>3 MeV</td>
</tr>
<tr>
<td>$\gamma$ (22)</td>
<td>6 MeV</td>
</tr>
</tbody>
</table>
Tracker – $\nu_e$ CC event

Top view

Side view

Event No.: 13  Reaction code: 1  Position in File:  13
Primary Vertex [mm]: (423, 543, 985)
Located in
Basket_0/TRK_0/Active_1/ScintX1_145/bar_39527

Informational particles
$$\nu_e \ (12) \quad \text{Trk} \ -1, \quad \text{KE} = 2893 \text{ MeV}$$
$$n \ (2112) \quad \text{Trk} \ -1, \quad \text{KE} = 0 \text{ MeV}$$

Primary particles
$$e^- \ (11) \quad \text{Trk} \ 1, \quad \text{KE} = 2578 \text{ MeV}$$
$$n \ (2112) \quad \text{Trk} \ 2, \quad \text{KE} = 46 \text{ MeV}$$
$$p \ (2212) \quad \text{Trk} \ 3, \quad \text{KE} = 15 \text{ MeV}$$
$$p \ (2212) \quad \text{Trk} \ 4, \quad \text{KE} = 117 \text{ MeV}$$
$$p \ (2212) \quad \text{Trk} \ 5, \quad \text{KE} = 86 \text{ MeV}$$
$$p \ (2212) \quad \text{Trk} \ 6, \quad \text{KE} = 14 \text{ MeV}$$
$$\gamma \ (22) \quad \text{Trk} \ 7, \quad \text{KE} = 4 \text{ MeV}$$
Tracker

- With ~ 1.2 ton total mass in each FGD module, expect ~ $4 \times 10^5$ neutrino interactions in the tracker in a nominal year ($10^{21}$ POT)
  - fiducial cuts, efficiency reduce this, but ample statistics for tuning MC simulations

- Note that combined, the TPC inner volumes hold ~ 16 kg gas, resulting in ~ $2 \times 10^3$ neutrino interactions in a nominal year
  - an interesting sample – all charged particles tracked
ECAL

- An electromagnetic calorimeter surrounds the Pi-zero detector and the Tracker:
  - to measure photons, primarily from $\pi^0$ production
  - to distinguish $e$ and $\mu$

- Conceptual design not complete
  - lead/scintillator stack
  - reasonable lateral and longitudinal segmentation appears to provide sufficient pointing accuracy for reconstructing $\pi^0$'s from neutrino interactions in the Tracker
    - $\pi^0$ mass cut helps purity and to identify which FGD plane was involved
ECAL

- segmentation schemes under study
Side muon range detector (SMRD)

- The yoke of the UA1 magnet was made with 1.7 cm gaps between iron plates
- SMRD will consist of 6-7 layers of the gaps instrumented with scintillator slabs
  - muons produced in the FGD at an angle near 90° or those produced at large angles in the Pi-zero detector cannot be measured by the TPCs – the SMRD can provide muon energy measurement to < 10%
  - in addition SMRD will be useful to veto activity from neutrino interactions in magnet or walls, and will form the basis for a cosmic trigger for calibrations if the inner detectors
Schedule

- Neutrino beamline commissioning: April 2009
- ND280 groups now seeking construction funding

- Apr 2007: ND280 hall construction start
- May 2008: Install magnet
- Aug-Dec 2008: complete ND280 building
- Jan 2009: begin installation of ND280 detectors
  - on axis detector
  - off axis Tracker
- Summer/Fall 2009: install remaining detectors
Summary

- T2K experiment is an exciting opportunity to extend our understanding of neutrino oscillations
- A number of detectors near the proton target are necessary to achieve the physics goals
- The off axis near detector is expected to provide a wealth of information on low energy neutrino interactions
- A lot of work ahead of us – a real challenge to be ready in time!
Extra slides
neutrino spectra

\[ \nu_\mu \quad \text{on axis} \quad \text{off axis} \]

\[ \nu_e \quad \text{on axis} \quad \text{off axis} \]
muon disappearance

![Graph showing muon disappearance](image)
sensitivity to $\theta_{13}$

![Graph showing sensitivity to $\theta_{13}$]
neutrino spectra across off axis detector

![Graph showing neutrino spectra across off axis detector. The x-axis represents energy (E\text{\nu} in GeV), and the y-axis represents entries (arbitrary units). Four curves are shown, each corresponding to different angular intervals: 0.0285 < \theta < 0.0319 rad, 0.0319 < \theta < 0.0353 rad, 0.0353 < \theta < 0.0386 rad, and 0.0386 < \theta < 0.0420 rad. Each curve represents the distribution of neutrino interactions within the given angular range.]
muon properties in ND280

- Histogram 1: 
  - x-axis: $p_\mu$ (GeV/c)
  - y-axis: Entries
  - Data points in red and gray
  - CCQE region

- Histogram 2: 
  - x-axis: $\theta_\mu$ (degrees)
  - y-axis: Entries
  - Data points in red and gray
  - CCQE region
proton momenta at ND280
pi-zero distribution in ND280

![Histogram of pi-zero momentum distribution in ND280 with entries, mean, and RMS values shown.](image)
Silicon Photomultiplier
Beam power at JPARC

400MeV LINAC from FY2011

Beam Power (MW)

Japanese Fiscal Year (Apr-Mar)