T2K ND280 Upgrade

Thorsten Lux
On behalf of the T2K Collaboration
The Tokai-to-Kamioka (T2K) experiment

Far detector
Super Kamiokande

Near detector
complex

J-Parc
Neutrino Beam

@SK
Measure oscillated beam

@ND280
Characterize beam and $\nu$ interactions

@J-PARC
Create Neutrino’s off-axis beam $\nu_\mu$ or $\bar{\nu}_\mu$

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Measure oscillated beam

@SK

@ND280

@J-PARC
T2K-II (2022-2026)

- New subdetectors for ND280
- Beam power upgrade: 0.5 MW → 1.1 MW (→ 1.3 MW HyperK)
- Statistics: 3E21 POT (2018) → 12E21 POT (2026)
- Aim: systematics from 5-6% to 4%
- Aim for CPV observation in optimal scenario at 3σ
The current ND280 detector

Current ND280 sketch

Event display of basket elements

Current limitations

✦ Tracks w/o TPCs (high angle).
✦ Tracks w/o TPCs (low momentum).
✦ Limited timing information => no direction information
✦ No neutron info
✦ Poor electron/photon separation
✦ High detection threshold

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The upgraded ND280 detector

Replace P0D by new subdetectors

2 High Angle TPCs

Drift volume
MicroMegas
8 ERAM
Module Frame

90cm
180cm
80cm

New read-out concept

1 SuperFGD

182 cm
192 cm
56 cm

Novel detector concept

6 ToF panels

150 ps time resolution resolution

Milestones

✦ 2018 → TDR arXiv:1901.03750
✦ 2021/22 final modules
✦ 2022 installation

NIM A 957 163286 (2020)

JINST 13, P02006 (2018)
JINST 15 P12003 (2020)

JPS Conf. Proc. 27, 011005 (2019)
A new scintillator tracker concept (SuperFGD)

To improve the granularity the new active target will be a novel 3D tracking technology.
Scintillator cubes and Box design

- Production of all cubes (~2.1 millions) finished.
- All cubes and holes underwent quality control
- 56 layers + 1 spare (182x192 cubes) assembled
- Design of the box finished and validated with prototypes
- Box: 120k precise holes, has to withstand weight of 2 tonnes and earthquakes
- Production to be started soon
• Approx. 60k MPPC will readout the fibers
• Design of electronics based on the CITIROC chip is being finished
• Excellent timing information: 2.5 ns binning
• Integrated calibration system will allow to calibrate all MPPCs regularly
SuperFGD Testbeam and MC Performance

- Various prototypes were exposed to testbeams at CERN (charged particles) and Los Alamos (neutrons)
- Charged particle analysis indicates good dE/dx and timing (published Dec. 2020, 2020 JINST 15 P12003)
- Neutron data analysis ongoing
- Used to tune MC
- Promising results for stopping particles
High Angle-TPCs

- 2 new TPCs being produced
- Dimensions: 1865x2000x820 mm³
- Composite materials for field cage
- Readout by 8 resistive Micromegas (ERAM) per side (novel technology)
- 1152 readout channels with 10.09x11.18 mm² pads per ERAM
- T2K gas (95 Ar, 3 CF₄, 2 iC₄H₁₀)
- Providing tracking and particle identification
HA-TPC Field Cage

- TPC consists of 2 halves and separate cathode
- Production based on layers wrapped around mould
- 2 full length prototypes for 1 MM + several mock-ups were produced and tested
- Successfully tested:
  - Metrology
  - HV stability in air and argon up to 35 kV
  - Gas tightness
HA-TPC ERAM Modules

- Novel resistive MM readout
- Charge over several pads => better point resolution
- 32 ERAM modules needed + 8 spares
- Various prototypes with different RC parameters produced and tested
- Pre-production of 8 modules ongoing at CERN MPGD workshop
HA-TPC ERAM Results

- Prototypes tested in testbeams (DESY/CERN) and with cosmics (Saclay)
- Excellent understanding of performance of this new technology
- New reconstruction algorithms developed based on testbeam data
HA-TPC ERAM Results

- Very good dE/dx and point resolution performance
- For all angles better than 600 um (using different reconstruction algorithms)
- For first 15 cm values below 300 um
- dE/dx resolution below 10% for final detector
TOF

- 6 modules (2.3x2.5 m²) mounted each with 20 bars
- Double sided readout with 12 SiPMs per side
- Tested in several testbeams
- Excellent time resolution of 150 ps achieved
- Currently quality control of all modules using cosmics
- Important to determine direction of particles
Physics Impact

• Ugraded ND280 covering similar phase space coverage as SuperKamiokande
• Significant lower energy threshold
• Neutron detection capability

Much better constraint on beam and better cross section measurements!
Summary

• Upgrade of ND280 will be crucial to reduce systematic uncertainties
• Important not only for T2K but also HK/DUNE
• Novel technologies will be used
• All new detector technologies were tested in intensive testbeam campaigns
• Construction of new subdetectors progressing
• T2K collaboration looking forward for the data from the upgraded ND280 in 2023
Related Talks and Posters

• Talk:
  • "Scintillator cubes for 3D neutrino detector SuperFGD" by Sergei Fedotov
• Posters:
  • "The SuperFGD prototype PID beam tests"
  • “Development of the in-situ Calibration System using LEDs and Light Guide Plates for the SuperFGD”
Backup Slides
Physics Processes vs Event Topologies

Interaction Modes

CCQE

\[ \nu_e \rightarrow \mu^- \]

CCRES

\[ \nu_\mu \rightarrow \pi^- \]

2p2h

Nuclear Effects

Interaction Topologies

CC0\(\pi\)

(CCQE-like)

\[ \nu_e \rightarrow \mu^- \]

CC1\(\pi\)

(CCRES-like)

\[ \nu_\mu \rightarrow \pi^- \]

CC0\(\pi\)+Np

(N>0)

\[ \nu_\mu \rightarrow p + \pi^- \]
Several Near Detectors

INGRID:
• On-axis
• Monitoring beam direction and flux

ND280:
• Off-axis
• Magnetized
• Cross-sections

Others:
• WAGASCI
• NINJA