The upgrade project of the T2K near detector

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University of Geneva,
EPS-HEP conference (Venice 8/7/17)
The T2K experiment

- Long-baseline neutrino oscillation experiment in Japan
- Precise measurement of neutrino oscillation parameters ($\sin^2\theta_{23}$, $\Delta m^2_{32}$, $\sin^2\theta_{13}$) and search for CP violation

**NIM A 659 (2011) 106–135**

**T2K-II phase**: $20 \times 10^{21}$ Protons On Target (POT) by 2025: $\sim x3$ T2K approved
- exclude CP conservation hypothesis at more than 3$\sigma$ if $\delta_{CP} \sim -\pi/2$ and NH
- Need to reduce the systematic error and the cross-section model dependence

**arXiv:1609.04111**
The T2K off-axis near detector: ND280

• 2.5° off the neutrino beam axis:
  - narrow beam at oscillation maximum
• 0.2 T dipole magnet
• 2 Fine-Grain-Detectors (FGD) as active target (XY):
  - FGD1: plastic scintillator
  - FGD2: water + plastic scintillator
• 3 vertical TPCs

Good acceptance only for forward tracks
ND280 upgrade detector configurations

- Keep the current tracker (2 FGDs + 3 vertical TPCs)
- Build new tracking detectors upstream
  - horizontal plastic scint. detector (1.8x0.6x2 m³)
  - 2 horizontal TPCs

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<td>2.2</td>
<td>4.3</td>
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The New horizontal TPCs

<table>
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<tr>
<th>Parameter</th>
<th>Value for 1 TPC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dimension</td>
<td>1.8(x) x 0.8(y) x 2.0(z) m³</td>
</tr>
<tr>
<td>Volume</td>
<td>2.9 m³</td>
</tr>
<tr>
<td>Drift Length</td>
<td>90 cm</td>
</tr>
<tr>
<td>Pad area</td>
<td>~1 cm²</td>
</tr>
<tr>
<td></td>
<td>(~2 cm² resistive MM)</td>
</tr>
<tr>
<td>Sensitive area</td>
<td>3.2 m⁴</td>
</tr>
<tr>
<td># MM</td>
<td>16</td>
</tr>
<tr>
<td># channels</td>
<td>3.2x10⁴</td>
</tr>
</tbody>
</table>

- Plan to build a thin (few cm) field cage (Aleph / ILC scheme)

Resistive Bulk MicroMegas (charge spread, intrinsic spark protection)
The new scintillator-based target detector

- We are considering several options
  - simulation studies are ongoing to choose the technology with best performance

1) FGD-like detector: well known technology

- FGD XY rotated by 90°
- Extruded plastic scintillator bars coated with TiO$_2$
- MPPC (S10362-13-050C) 1.3x1.3 mm$^2$
  (PDE@525nm 26-30%)
- ~30 photoelectrons per MIP crossing a bar
- FGD1 (scint. layers), FGD2 (scint.+water layers)
The new scintillator-based target detector

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1) FGD-like detector: well known technology
• FGD XY rotated by 90°
• FGD3D: bars along XYZ directions
  - 3 views with 3 hits
  - 25% of volume is air
  - no water cross section measurement
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2) Scintillator fiber detector (XY fibers)
- Kuraray 2mm single-clad
- 23.7±0.1 p.e./mm @15cm (MIP)
- Expect very good performance but many channel (>300k)

- R&D by Neutrino group of Kyoto University at Research Center for ELectron PHoton Science (ELPH), Tohoku University
The new scintillator-based target detector

3) WAGASCI-like detector
- T59 experiment will run at J-PARC (JPS Conf. Proc. 8, 023003 (2015))
- prototype running in front of the T2K On-Axis detector

- Empty or filled with water: measurement of neutrino interactions in water
- Efficiency to select muons $\geq 90\%$ over the full solid angle
- Empty module drastically reduces the momentum threshold ($\sim 300$ MeV/c for protons) but 3 times less target mass
The new scintillator-based target detector

4) SuperFGD
   - plastic scint. 1x1x1 cm$^3$ cubes coated
   - all the volume is fully active
   - 3 views per hit

- Simulation studies and hardware R&D are ongoing
- 230 cubes manufactured by Uniplast chemical company (Russia)
  - light yield (cosmics): ~150 pe/MIP in total
  - prototype and test beam in Autumn

arXiv:1707.01785
Time of Flight detector

• Determine the sense of the tracks
• Improve particle identification, $e^+$ / protons and electrons / muons
  • Extruded plastic scintillator
    - 2 extruded plastic scintillators bars
    - 4 WLS Kuraray 1mm fibers (glued), single connector, 3x3mm$^2$ MPPC, double-end
    - Time resolution is 630-650 ps
    - R&D studies at INR (Moscow)
  • Cast plastic scintillator
    - about 4m attenuation length
    - 8 sensors of 6x6 mm$^2$
    - Time resolution is 120-140 ps
    - R&D at University of Geneva (SHiP)

See A.Korzenew’s poster
Simulation studies

- Simulated with GEANT4 both ND280 upgrade and current-like detectors
- Select $\nu_\mu$ ($\bar{\nu}_\mu$) Charged-Current (CC) events:
  - muon track reconstructed in either TPC or ECal
- Use ToF informations for track reconstruction

<table>
<thead>
<tr>
<th>Expected # of selected events</th>
<th>10^{21} POT</th>
<th>Current-like</th>
<th>Upgrade</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\nu_\mu$</td>
<td>95860</td>
<td>199775</td>
<td></td>
</tr>
<tr>
<td>$\bar{\nu}_\mu$</td>
<td>27443</td>
<td>54249</td>
<td></td>
</tr>
</tbody>
</table>

- Reduce systematic uncertainties by 20-40% more than ND280 current
- Work is ongoing on $\nu_e$ ($\bar{\nu}_e$) interaction studies
Conclusions

• T2K Near Detector upgrade launched as official T2K project
  - improvement of Near Detector toward T2K-II (and Hyper-K)
  - Expression of Interest in January 2017: CERN SPSC-EOI-015
    - signed by ~190 physicists (aims to be part of the CERN neutrino platform)
• Plan for the T2K near detector upgrade
  - end of 2017: technical design and submit the proposal to SPSC
  - 2017-2018: prototypes of TPCs, scint. detectors in testbeam
  - 2019-2020: production, integration at CERN, system test
  - 2021: shipment to Japan, installation, commissioning
• R&D of a High Pressure TPC as a detector to explore the details of neutrino interactions
• Already 3 open workshops since November 2016
• Next open workshop at CERN Aug. 1-2: https://indico.cern.ch/event/644360/
  New members are already joining and more are welcome
BACKUP
Prospects for the future: T2K-II

- Expect to reach the approved T2K statistics ($7.8 \times 10^{21}$ POT) around 2021
- **T2K-II phase**: proposed to extend T2K run to $20 \times 10^{21}$ POT by 2025 (Stage-I status at summer 2016 JPARC PAC)
- Plan to gradually increase the beam intensity up to $\sim 1$ MW in 2021
- Demonstrated $3.41 \times 10^{13}$ protons per beam operation $\rightarrow$ 1MW equivalent

**Excluding CP conservation hypothesis** at more than $3\sigma$ if $\delta_{CP} \sim -\pi/2$ and NH

We need to reduce the systematic uncertainties
- 30 GeV proton beam on 90 cm long graphite target
- $\nu_\mu$ and $\bar{\nu}_\mu$ produced by pion and kaon decay:
  - $\pi^+ \rightarrow \mu^+ + \nu_\mu$
  - $\pi^- \rightarrow \mu^- + \bar{\nu}_\mu$
- Invert magnet polarity to produce a $\bar{\nu}_\mu$ beam
- First off-axis neutrino beam experiment (2.5°)
  - narrow spectrum peaked at 0.6 GeV, on the expected oscillation maximum
Prospects for the future: T2K-II

• Expect to reach the approved T2K statistics (7.8x10^{21} POT) around 2021

• **T2K-II phase**: proposed to extend T2K run to 20x10^{21} POT by 2025 (Stage-I status at summer JPARC PAC)

• Plan to gradually increase the beam intensity up to ~1 MW in 2021

• Aiming for >1 MW intensity for 2021 and 1.3 MW in ~2026: accelerator and beam-line upgrade is needed

• Demonstrated 3.41x10^{13} protons per beam operation → 1MW equivalent

**arXiv:1609.04111**
The ND280 TPCs

- Gas mixture is Ar:CF$_4$:iC$_4$H$_{10}$ (95:3:2)
- Two gas volumes: CO$_2$ as insulator
- 12 Micromegas modules:
  - 9m$^2$ surface covered
  - 70mm$^2$ pad segmentation

- Performances:
  - 0.7mm space resolution
  - 9% momentum resolution @1GeV
  - 7.8% resolution in dEdx (MIP)

- Key role in the study of the neutrino interactions: charge, momentum, PID
The ND280 Fine Grain Detector (FGD)

- XY extruded plastic scintillator bars coated with TiO$_2$ (0.25mm thickness)
- MPPC (S10362-13-050C) 1.3x1.3 mm$^2$ (PDE@525nm 26-30%)
- About 30 photoelectrons per MIP crossing a bar
- FGD1 (15 XY scintillator layers) - FGD2 (7 XY scintillator + 6 water layers)
  - measure neutrino interactions both in water and plastic (~1.1 ton each)
- Limit: bad acceptance high-angle tracks

Kuraray Y11 double-clad fiber

NIM A 696 (2012) 1–31
The neutrino target detector

- Plastic scintillator structure: $4\pi$ acceptance

- Empty module drastically reduces the momentum threshold but $\sim 30\%$ mass
- Protons threshold down to $\sim 300$ MeV/c (close to Fermi momentum)
- Efficiency $>90\%$ over the full solid angle
Time of Flight detector

- Provide timing for good track reconstruction
- Improve particle Identification, e.g. separate $e^+$ from $\sim$1GeV protons

**Extruded plastic scintillator**

- 2 extruded plastic scintillators (20x0.7x270 cm$^3$)
- 4 WLS Kurakay 1mm fibers glued in each slab
- 8 WLS fibers connected to the connector at each side
- Connector mounted directly on the scintillator
- Single 3x3mm$^2$ MPPC at each end
- Expected time resolution is $\sim$630-650 ps

Several tests made at INR
Time of Flight detector

- Provide timing for good track reconstruction
- Improve particle Identification, e.g. separate $e^+$ from $\sim1$GeV protons

Cast plastic scintillator

Bar size: $6\times1\times270\text{ cm}^3$

- Same as proposed for SHiP experiment
- Plastic material: EJ200(BC408) or EJ208(BC412)
  - Attenuation length $\sim4$ m
  - $1.42\text{ kg/bar}$
- 8 sensors of $6\times6\text{ mm}^2$
- $\sigma_t$ at $50\text{ cm}$ is $\sim140\text{ ps}$. With $1\text{ m}$ long and double-end readout $\sigma_t\sim100\text{ ps}$
- Better time resolution but more expensive than extruded plastic scintillator
R&D for a High Pressure TPC

- High pressure gas filled with time projection chamber:
  - use the gas as neutrino interaction target
- Complementary to plastic scintillator detectors:
  - much less target mass but detect most of the particles

- Beam test: prototype of 1 m³ at 5 bar (CF4, Ar, Ne, CH4)
- Target is 2018 at CERN
- Measure proton-nucleus and pion-nucleus cross section
Preliminary EOI-15 Work Packages and Contact persons

Management: MZ and Masashi Yokoyama,
Contact with CERN: Alain Blondel

• WP1 Mechanical design and integration (Marcela Batkiewicz, Davide Sgalaberna)
• WP2 TPC field cage and gas vessel (Gabriella Catanesi, Emilio Radicioni)
• WP3 TPC Readout technology (Alain Delbart, CERN)
• WP4 TPC electronics and DAQ (Denis Calvet, Andrzej Rychter)
• WP5 Scintillator-based trackers (Japan+LLR)
• WP6 TOF system (Yury Kudenko)
• WP7 Gas system and calibration (Blair Jamieson, CERN)
• WP8 Test beam measurements (Federico Sanchez, Stefania Bordoni)
• WP9 High Pressure TPC (Asher Kaboth, Morgan Wascko)
• WP9 Simulation and optimization studies (Davide Sgalaberna)
• WP10 Physics studies (Sara Bolognesi, Claudio Giganti)
• WP11 DAQ (Giles Barr)
• WP12 Software (Yoshi Uchida)