Ageing of the scintillator detectors of the T2K off-axis and on-axis detectors, ND280 and INGRID

Maria Antonova on behalf of the T2K collaboration
Instituto de Fisica Corpuscular (UV and CSIC), Valencia, Spain

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Motivation

- Plastic scintillators coupled with wavelength shifting (WLS) fibres and silicon photomultiplier readouts are widely used in various applications
  - Neutrino physics, LHC experiments, medical use detectors etc.
- Long-term operation study is beneficial for understanding detector performance
- The T2K neutrino experiment
  - Collecting data for over 10 years
  - Near detector complex with multiple scintillator bar designs
  - Great source of data for such study!
Leading results for $\nu(\bar{\nu})$ oscillations in appearance/disappearance channels

**T2K experiment**
Tokai-to-Kamioka long-baseline neutrino experiment

- **Near Detector**
  - "Off-axis" concept: 0.6 GeV peak beam tuned for 1st osc. maximum at SK point

- **Off-axis detector**
  - Constrains flux and cross-section uncertainties in the oscillation analysis
  - ~36,000 scintillator bars
  - Overall ~64,000 SiPMs in ND280 and INGRID

- **On-axis detector**
  - Beam direction and rate stability monitor
  - Day-by-day measurements
  - ~ 9,500 scintillator bars

**More on T2K analysis results and performance in talks by J.Walsh, S.Kasetti, M.Guigue etc.**
Analysis method

- Light yield (LY) corrected for
  - Attenuation in fibre
  - Detector specific calibration
  - Track angle correction
- Used minimum ionising particle (MIP) like tracks from cosmic rays (ECal, INGRID) or $\nu$ interactions (PØD, FGD, SMRD)
- Fitted with Landau-Gauss convolution to get most probable value (MPV)
- MPV distribution over time fitted with linear function
- Due to detector construction current study doesn’t separate between a counter, WLS fibre and SiPM
Ageing analysis results

**Linear fit function**

\[
\text{Light Yield (Year)} = A - B \times \text{Year}
\]

Exclude first two years data for ND280 detectors due to different calibration

**Ageing constants**

<table>
<thead>
<tr>
<th>Sub detector</th>
<th>Annual Light Yield Reduction (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PØD</td>
<td>1.8 ± 0.2</td>
</tr>
<tr>
<td>FGD</td>
<td>1.2 ± 0.2</td>
</tr>
<tr>
<td>ECal</td>
<td>(1.9 − 2.2) ± 0.1</td>
</tr>
<tr>
<td>SMRD</td>
<td>0.9 ± 0.4</td>
</tr>
<tr>
<td>INGRID</td>
<td>1.6 ± 0.1</td>
</tr>
</tbody>
</table>

- **Typical ageing about 1-2% per year**
- **Good agreement for PØD, ECal, FGD and INGRID (same composition)**
Projected response

- ECal bars with double end readout record lowest MPV
- ECal can be used to project the “worse” future response of ND280 scintillators
- This study uses exponential fit
  - Better describes data on longer time scale

\[ \text{Light Yield (Year)} = A \exp \left( -\frac{\text{Year}}{a} \right) \]

- Projection of the light yield up to 2040

- ND280 and INGRID to be used for T2K-II, T2HK

- Response drops by ~50% over 30 years this still remains above corrected charge threshold (5.5PEU)

M.Antonova for T2K collaboration
Separate fibre and scintillator ageing study

- Without attenuation correction
  MIP MPV can be extracted at different point from MPPC
- Fitting this data as a function of time allows to calculate MIP MPV at 0cm from the sensor
  - Removes fibre effect
- Degradation rates (with and without fibre effect) are consistent ~1σ

<table>
<thead>
<tr>
<th>ECal Bar Type</th>
<th>Readout Type</th>
<th>A (PEU)</th>
<th>B (PEU/yr)</th>
<th>Annual Light Yield Reduction (Reference (%))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barrel X</td>
<td>Single-ended (mirrored)</td>
<td>38.22 ± 0.49</td>
<td>0.76 ± 0.09</td>
<td>2.07 ± 0.25 (1.98 ± 0.04)</td>
</tr>
<tr>
<td>Barrel Y</td>
<td>Single-ended (mirrored)</td>
<td>37.10 ± 0.46</td>
<td>0.75 ± 0.08</td>
<td>2.11 ± 0.23 (2.02 ± 0.05)</td>
</tr>
<tr>
<td>Barrel Z</td>
<td>Double-ended</td>
<td>27.66 ± 0.18</td>
<td>0.51 ± 0.03</td>
<td>1.91 ± 0.11 (2.15 ± 0.07)</td>
</tr>
<tr>
<td>Downstream</td>
<td>Double-ended</td>
<td>27.84 ± 0.32</td>
<td>0.48 ± 0.05</td>
<td>1.79 ± 0.18 (1.87 ± 0.07)</td>
</tr>
</tbody>
</table>

Double exponential fit to MIP MPV with respect to the distance from sensor

Linear fit for MIP MPV at 0 cm from sensor over 10 years
Summary

- Studied the rate of ageing for the T2K near detector complex scintillators with ~10 years of data collection.

- Observed annual light yield degradation:
  - ECAL, PØD, and INGRID (identical material, all produced at Fermilab) 1.6%-2.2%
  - FGD (Canada) and SMRD (Russia) 1.2% and 0.9% respectively.

- Results are comparable with similar studies by MINOS experiment - 1.2 % per year.

- Inconsistent with MINERvA study (was performed on a smaller time scale) 7.5% per year.

- Results of the study will be used to:
  - Predict long term performance of the detector.
  - Parts of current T2K detector setup will be used for T2K-II/T2HK.
  - Correct signal reconstruction methods.
  - Already applied in reconstruction for INGRID and ND280 detectors.
  - Take into account for new generation of the detectors.
    - SuperFGD, WAGASCI, Baby-MIND in T2K/T2K-II /T2HK.
Thank you!

(Official T2K publication in preparation, stay tuned)
Backup
Scintillator detectors in T2K

- Plastic scintillator bars of various profiles and sizes*
  - ~ 9,500 in INGRID and ~ 36,000 in ND280
- All using 1mm Kuraray Y11(200) WLS fibre
  - Glued into the bar or coupled through an air gap
- Read-out via customised Hamamatsu MPPC (SiPM) (S10362-13-050C)
  - First time used 64,500 SiPMs
  - Overall failure rate is 0.5%

667 APD pixels (each pixel 50x50 \(\mu m^2\))

Enlarged sensitive area 1.3x1.3 mm\(^2\)
INGRID

- 16 Iron/scintillator modules
- 11 tracking scintillator planes per module (placed perpendicular to beam direction)
- 24 horizontal and 24 vertical bars per plane
  - Bars in a plane are glued to each other
- Each bar is 1203 mm long with a 50x10 mm$^2$ cross section
- On one end readout. Other end is mirrored
- Fibre coupled to scintillator through air gap

- On-axis detector
- Beam direction and rate stability monitor
- Day-by-day measurements
ND280 complex

- Sub-detectors in 0.2T magnetic field:
  - Tracker:
    - Fine grained detectors (FGD)
    - Time-projection chambers (TPC)
  - Electromagnetic calorimeter (ECal)
  - Side muon range detector (SMRD)
  - Neutral pion detector (PØD)

- Off-axis detector

- Constrains flux and cross-section uncertainties in the oscillation analysis
ND280: ECAL

- Counters with 40x10 mm² cross section
- Three big modules with different lengths of the bars:
  - Barrel, Downstream (1700 bars of length 2000 mm) and PØD (latter is not used in this study)
  - Barrel divided into sub modules: X(6144 bars of length 1520 mm), Y(3072 bars of length 2280 mm), Z(3990 bars of length 3840 mm)
- Bars parallel (Z Barrel) or perpendicular (X, Y Barrel, Downstream) to the beam direction
- Readout from one end of the bar (both ends for Z Barrel and Downstream)
- Air gap coupling between WLS fibre and scintillator
**ND280:PØD**

- Triangular cross section (17 mm height and 33 mm width)
- Horizontal bars are 2133 mm long (134 bars in total)
- Vertical bars are 2272 mm long (127 bars in total)

- Bars grouped into 40 modules (PØDules)
- All bars are placed perpendicular to the beam
- PØDules compose 4 SuperPØDules
- One end signal readout
- Another end is mirrored with vacuum deposition of aluminium
- Same MPPC/fibre coupling design as ECAL and INGRID

Design and composition is identical to MINERvA bars.
ND280: FGD

- Grouped in horizontal (vertical) layers of 192 bar each, perpendicular beam direction
- Two layers make a module (in two FGDs 22 modules in total)
- Within each layer alternate bars read from alternate ends
- Signal readout from one end only, the other end is mirrored
- Square profile scintillator bars (9.6 mm side, 1864 mm length)
- Air gap coupling between fibre and bar
ND280: SMRD

- Vertical (7x175x185 mm$^2$) (horizontal (7x167x185 mm$^2$)) bars
- Bars grouped by 4(5) in modules located in the magnetic flux return yokes
- In total SMRD consist of 404 modules
- S-shaped WLS fibre for better light collection
- Fibre is glued into the bar with optical glue
- Readout from the both sides of the counter
- Custom endcap at the end of the bar for better coupling between MPPC and fibre
Scintillator bars

- FGD, ECal, PØD and INGRID counters:
  - Polystyrene co-extruded with TiO$_2$
  - Doped with 1%PPO and 0.003% POPOP

- SMRD counters:
  - Extruded polystyrene
  - Outer surface etched by chemical reagent to provide reflective layer
  - Doped with 1.5% PTP and 0.01% POPOP

- PØD, ECal and INGRID bars produced at FNAL (2007-2009)
- SMRD slabs produced by Uniplast, Vladimir, Russia (2007-2008)
- PØD, FGD, ECal, INGRID scintillators composition and production method are identical to ones of the MINOS experiment
- PØD bars are totally identical to bars used for MINERvA experiment