T2K Near Detector Tracker

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On behalf of T2K collaboration

ICHEP 2010
July 24th 2010, Paris, France
T2K collaboration

~500 members, 61 Institutes, 12 countries

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TRIUMF*  
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U. Regina*  
U. Toronto  
U. Victoria*  
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* TPC and FGD groups
Outline

- The T2K experiment
- Off-axis near detector ND280
- Tracker
  - Fine Grained Detectors
  - Time Projection Chambers
- Conclusion
**Goals**

- $\nu_\mu \rightarrow \nu_e$: Measure or improve limit on $\theta_{13}$ by at least an order of magnitude;
- $\nu_\mu$ disappearance: Precise measurement of $\Delta m^2_{23}$ and $\theta_{23}$.

**Neutrino oscillation long baseline experiment (Japan)**

- $\nu_\mu$ beam (~600 MeV) produced at J-PARC (Tokai) by a 30 GeV proton beam;
- Beam monitor OTR before target and Muon monitor at 120 m from proton target;
- Near detector: ND280 at 280 m;
- Far detector: Super Kamiokande at 295 km.

- 1st beam in April 2009 → data taking started in January 2010.
• Located at **280m** from the proton target, off-axis angle of **2.5°**.

**Goals:**

• **characterize** neutrino beam before oscillation → flux, spectra, beam composition and direction, cross-section measurements.

• Uses **UA1 magnet: 0.2 T** magnetic field.

**Different detector types:**

• **P0D** ($\pi^0$ detector);

• **Tracker:** 3 Time Projection Chambers (TPCs) + 2 Fine Grained Detectors (FGDs);

• **Ecal** (Electromagnetic calorimeter);

• **SMRD** (Side Muon Range Detector) embedded in the magnet yoke.
• **Status**
  - Magnet operational, field mapped.
  - All detectors except barrel Ecal installed in the pit.
  - Barrel Ecal installed this summer.

  • All installed detectors have been commissioned and are taking data!

• **Event display:**
  - Sand muon crossing P0D and part of the tracker
  - Neutrino interaction in FGD1 (deep inelastic scattering).
Tracker event display

Cosmic ray event
(entering through the P0D)

Neutrino CC event candidate
(in FGD1)
Goals:

- Provide **target mass** for neutrino interactions (~1 ton per FGD).
- Measure **neutrino cross sections** in carbon and water (oxygen).
- Track and vertex **reconstruction, particle identification**.

Design:

- **Thin scintillator bars** (9.61 x 9.61 x 1864 mm³) organized in X-Y layers to allow tracking.
  → 5760 bars in FGD1, 2688 in FGD2
- Additional **passive water panels** in FGD2.
- Scintillation light collected by a **WaveLength Shifting (WLS) fiber**, mirrored on one tip (1mm Ø).
- Fibers transport the light into **Multi Pixel Photon Counters** (MPPCs).
- **AFTER ASIC** based electronics.
- LED based **light injection system** for calibration.

1st large scintillator based detectors using MPPCs!
- Bars yield ~30 pe / MIP
- High quantum efficiency MPPCs (667 pixels)
  (by Hamamatsu Japan and Kyoto U.)

- Hit efficiencies measured with through going cosmics.
- Looking at the middle layer every three hit layers.
- First and last layer of each orientation is omitted.
- Hit efficiency = # of hits / total layers crossed.

- Efficiency for all layers better than 99%

- Difference between vertical and horizontal layers is due to a geometrical effect → cosmics are mainly downward going.

Efficiency for all layers better than 99% so better than required
- Cross-talk and afterpulsing are included.
- Modeling of fiber attenuation well understood. → Light leaking out of the scintillator bar can be taken into account in 2 different ways (blue and red curve).
- Good agreement with previous measurements.

- Beam is delivered in 6 bunches separated by 581 ns, and bunch trains are separated by 3.52 s.
- Bunch structure is clearly visible in the FGDs.
Time Projection Chambers (TPCs)

- **Goals:**
  - Reconstruct charged particle's tracks
  - **Particle identification** (dE/dX resolution < 10%) → distinguish muons/electrons and protons/pions.
  - **Momentum measurement** (resolution < 10% @1 GeV, momentum scale precision < 2%).

- **Design:**
  - **Double wall** structure (construction @TRIUMF).
  - Read-out plane instrumented with **bulk MICROMEGAS** detectors.
  - Front-end electronics equipped with **AFTER ASIC**.
  - Gas mixture: Ar (95%) / CF$_4$ (3%) / iC$_4$H$_{10}$ (2%)
  - **Laser system** provides real time calibration.
• **All-in-one detector** (anode + mesh)  
  → cf. Jochen Kaminski’s talk

• Saclay design and production by CERN/TS-DEM-PMT, with a dedicated test bench at CERN.

• 12 MICROMEGAS detectors per readout plane  
  → **72 MM modules** for all 3 TPCs ;

• Each module is 35x36 cm² and has a **pad pitch** of 7.0 mm x 9.8 mm:
  
  → **1726 active pads** per module  
  → **Total active surface of ~ 9 m²**

• **Gain ~10³** (128 µm amplification gap, -350V) ;

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**First large size TPCs based on MPGD !**  
(Micro Pattern Gaseous Detector)

→ cf. S. Anvar et al. NIM A **602**: 415-520 (2009)
• **124 272 channels to read out**
• **AFTER ASIC** based electronics (developed at Saclay)
  • Low electronic noise (noise ~ 600 e⁻)
  • Sampling frequency up to 50 MHz
  • Adjustable gain
  • Programmable peaking time

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**T2K TPCs' Electronics**

- **Low Voltage input**
- **Optical fiber readout**
- **Front-End Card (FEC)**
- **MM Module**
- **AFTER chip**

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**WaveForm for all single hit event**

- **55Fe event**
- **200 ns peaking time**

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**T2K AFTER SAclay 08 10817_018**
Quality control check
- Faulty pads ~ 10 out of ~120,000 pads → < 0.01%
- Edge effects

Characterization and calibration pad per pad
- Energy resolution measurement @ 5.9 keV
- Gain and resolution uniformity @ nominal gain

Response uniformity of 2%
Beam tests in the M11 area at TRIUMF to study FGD and TPC performances (energy and spatial resolution).

- Beam provides $e$, $\mu$, $\pi$ (momentum < 400 MeV/c).
- $e$, $\mu$, $\pi$ tagging done by a Time Of Flight system.
- Each track crosses 2 MicroMegas modules.

**TPC spatial resolution results**

Spacial resolution is measured by the residual distribution:

$\rightarrow$ resolution is better if more than one pad per column is illuminated.

**Spatial resolution is 650 µm @ 75cm drift**

$\rightarrow$ good enough to have a momentum resolution < 10% @ 1 GeV.
Particle Identification (PID) is based on the deposited energy ($dE/dx$) by the charged particles.

- A truncated mean method is used.
- Resolution on $dE/dx$ is $7.8 \pm 0.2\%$ (goal was 10\%).
- Negative particles: mainly muons, some low energy $e^-$. Positive particles: mainly pions and protons, some low energy $e^+$. 

**Energy loss distribution for negative particles with $400 < p < 500$ MeV/c**

**dE/dx for negative particles**

**dE/dx for positive particles**
• Beam line and detectors constructed and commissioned → 1st physics run January → June 2010. Next run will start in November 2010.

• ND280 (INGRID, P0D, FGDs, Ecal and SMRD) is the 1st large scintillator based detector instrumented with MPPCs → ~35 000 MPPCs installed and working!

• FGDs have a hit efficiency higher than 99% and cross-section measurements on carbon and water will be important for Super Kamiokande measurements since it's a water Cerenkov detector.

• T2K TPCs, 1st large TPCs instrumented with MPGDs have met the requirements set by T2K.

• dE/dx resolution is 7.8% → achieved the resolution goal.

Tracker performances' requirements have been reached. More refined studies are under way and physics analyses have started!
Thank you for your attention!
Back up
Neutrino: neutral lepton, 3 families ($\nu_e$, $\nu_\mu$, $\nu_\tau$), small cross-section

- Flavour (interaction) eigenstates ≠ Mass (propagation) eigenstates
  → oscillation given by PMNS matrix:

$$U = \begin{pmatrix} 1 & 0 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{23} & c_{23} \end{pmatrix} \begin{pmatrix} c_{13} & 0 & s_{13}e^{-i\delta} \\ 0 & 1 & 0 \\ -s_{13}e^{i\delta} & 0 & c_{13} \end{pmatrix} \begin{pmatrix} c_{12} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

$c_{ij} = \cos \theta_{ij}$, $s_{ij} = \sin \theta_{ij}$, $\delta = $ CP violation phase

- All parameters have been measured except $\theta_{13}$ and $\delta$.

- If $\theta_{13}$ and $\delta \neq 0$, there is CP violation in the leptonic sector, which could explain the matter-antimatter asymmetry observed in the Universe (leptogenesis theory).
T2K $\sin^2 2\theta_{13}$ sensitivity

100 kW for $10^7$ s (1 nominal year)

0.008 @ $\Delta m_{23}^2 = 2.4 \times 10^{-3} \text{ eV}^2$, $\delta_{CP} = 0$
and normal hierarchy 20% sys. error
Why off-axis?

- Quasi-monochromatic beam
- Tuned at expected oscillation maximum
Located at 280m from the proton target, on-axis.

Goals:
- High-precision beam direction monitoring \( \sin^2\theta_{23} \sim 1\% \Rightarrow 1\text{mrad} \)
- Measure beam profile and intensity.

Design: 7 vertical modules and 7 horizontal modules, layed out in a cross-shape, centered at the neutrino beam center + 2 off-axis modules.
MPPC, solid-state Multi-Pixel Photon Counter:

- Developed and produced by Hamamatsu Japan and Kyoto University.
- 1.3 x 1.3 mm² modules, specifically designed for T2K
- Suited for 1 mm diameter fiber
- 667 pixels: 26x26 50 µm pixels (-9 in the corner for lead)
- Dark noise: < 1.2 MHz at nominal voltage
- Gain: 7.5 x 10^5 at 25°C.
- Photon detection efficiency: ~30% at nominal voltage
- Dead channels in FGDs: ~30 out of ~ 8500 (< 0.4%)
The effective fiber attenuation curve derived from cosmics for these (mirrored) fibers agrees well with ex-situ measurements.

- Major effect in the middle of the fiber described by:

\[ I = Af(x) \]

\[ f(x) = e^{-x/L} + (B/A)e^{-x/S} \]

→ \( x \) = distance, \( S \) (short) and \( L \) (long) attenuation coefficients.

- Light leaking out of the scintillator bar can be taken into account in 2 different ways (blue and red curve).

\[ I = Af(x)g(x) \]

\[ g(x) = 1 - \frac{1}{2} \left( e^{m(D-x)} + e^{-mx} \right) \]

or

\[ g(x) = 1 - \frac{1}{2} \left( e^{-m\sqrt{(D-x)}} + e^{-m\sqrt{x}} \right) \]
$B = 0.2 \, T$

$E \sim -200 \, V/cm$

- Gap = 128 \, \mu m
Laser calibration system

- Targets on the central cathode
- Illuminated by **UV laser light** to measure:
  - Field distortion calibration (in situ)
  - Electron drift velocity