

# Operation of the T2K time projection chambers

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**Georges Vasseur \***

*CEA, IRFU, SPP, Centre de Saclay,  
F-91191 Gif-sur-Yvette, France  
E-mail: georges.vasseur@cea.fr*

**ABSTRACT:** The three time projection chambers of the T2K near detector are micro pattern gaseous detectors based on bulk micromegas technology. They have been operated successfully during the first two physics runs of the experiment. Their design, operation, and performance are presented.

**KEYWORDS:** Time projection chambers; Micropattern gaseous detectors; Particle tracking detectors (Gaseous detectors); dE/dx detectors.

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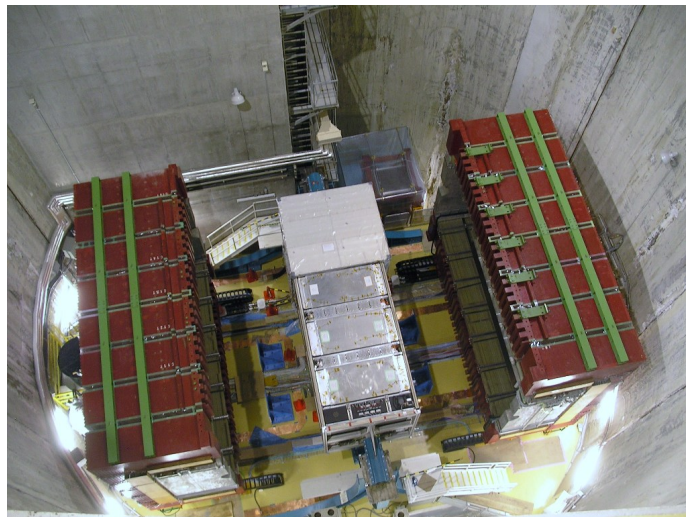
## Contents

1. The T2K experiment and ND280 near detector	1
2. The time projection chamber design	2
3. The time projection chamber performance	5
4. Conclusion	8

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### 1. The T2K experiment and ND280 near detector

The Tokai to Kamioka (T2K) experiment [1] is a long baseline neutrino oscillation experiment taking place in Japan. A 30 GeV proton accelerator at the J-PARC facility in Tokai is used to produce a high intensity  $\nu_\mu$  beam with a peak energy around 0.7 GeV that is sent to a near detector in Tokai and to the SuperKamiokande water Cerenkov far detector, 295 km away. The main two goals of the experiment are to get a first measurement of the mixing angle  $\theta_{13}$  through  $\nu_e$  appearance and to measure precisely the atmospheric parameters  $\theta_{23}$  and  $\Delta m_{32}^2$  through  $\nu_\mu$  disappearance.



**Figure 1.** View of ND280 from the top of the pit with the magnet open. The three TPCs can be seen sandwiching the two FGDs between the POD (top) and the downstream ECAL (bottom).

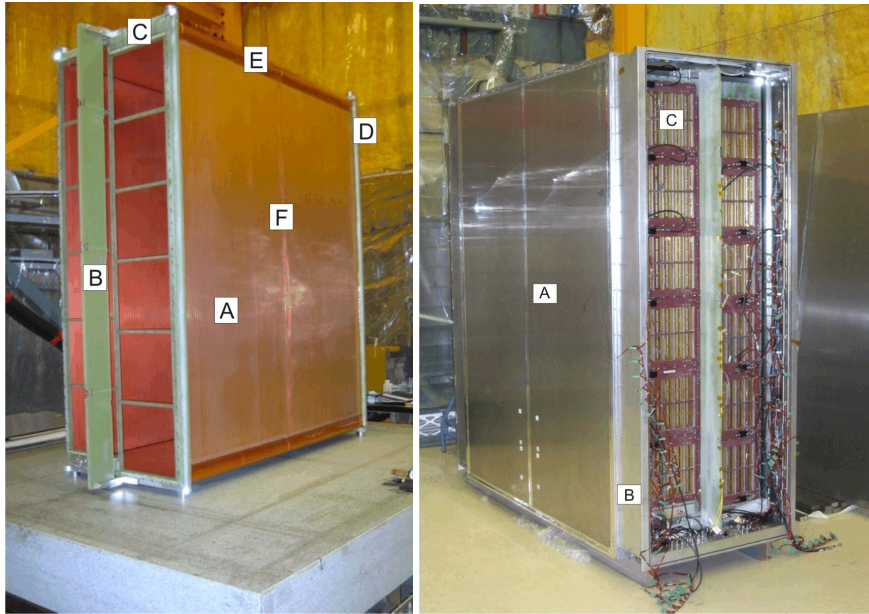
The off-axis near detector ND280, shown in figure 1, is located 280 m downstream of the production target. It consists of several detectors inside the UA1 magnet, producing a horizontal magnetic field of 0.188 T. The tracker is composed of two scintillator-based fine grained detectors

(FGD) acting as active neutrino target interleaved with three time projection chambers (TPC). Upstream is a  $\pi^0$  detector (POD), all around are electromagnetic calorimeters (ECAL) and inserted in the magnet yoke are muon range detectors. The goal of the near detector is to characterize the neutrino beam before oscillation: in particular to measure the  $\nu_\mu$  energy spectrum, to determine the  $\nu_e$  intrinsic contamination in the beam, and to study other background processes.

## 2. The time projection chamber design

The TPCs [2] are used for tracking and particle identification. A relatively modest resolution of 10% on the transverse momentum measurement at 1 GeV is enough as the neutrino energy estimation is limited by the Fermi motion of the struck nucleon at the level of about 10%. The overall momentum scale however needs to be known at better than 2% for  $\Delta m_{32}^2$  measurement. Finally, to be able to separate electrons from muons and measure the  $\nu_e$  contamination in the beam, a resolution on the energy loss  $dE/dx$  better than 10% is needed.

A TPC has a rectangular shape, as shown in figure 2. Its tracking length along the beam direction is 72 cm and its active height is about 200 cm. The electrons drift along the electric field direction from the central cathode to both endplates of the TPC, each of which is instrumented with twelve micromegas (MM) modules, in two columns of six. This gives a maximum drift distance of 90 cm on each side and a total active area for the three TPCs of 9 m<sup>2</sup>. T2K TPCs were indeed the first large size TPCs using micro pattern gaseous detectors.



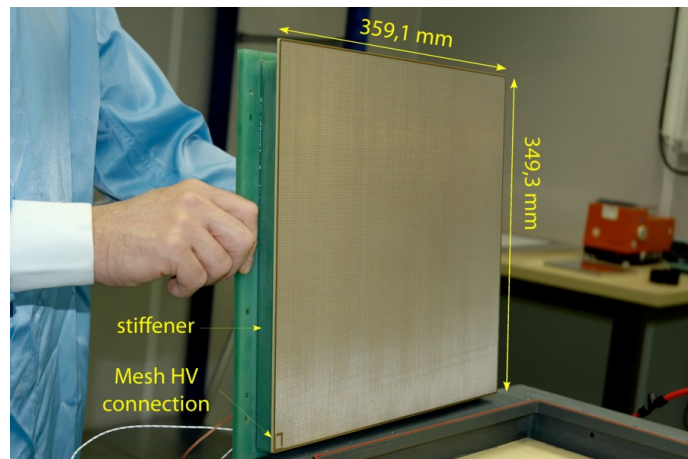
**Figure 2.** Left: TPC inner box with (A) box wall, (B) module frame stiffening plate, (C) module frame, (D) endplate, (E) field-reducing corner, and (F) central cathode. Right: outer box with (A) box wall, (B) service spacer, and (C) a micromegas module.

Mechanically, a TPC consists of two gastight boxes, one inside the other. The inner box, made of copper clad G10 laminated panels, is divided by the central cathode and has one module

frame at each end to support the MM modules. The electric field is shaped by copper strips. Requirements are set on the cathode flatness and module plane planarity at the 0.1 and 0.2 mm level to minimize electric field distortions. The outer box is made of aluminum/rohacell laminated panels. Spacers behind the detectors are used for services: cooling, readout electronics, voltage connection, temperature probes, and calibration system.

Both of the boxes are filled with gas. The gas mixture in the inner drift volume is based on argon at 95% and contains also 3% of freon and 2% of isobutane. This gives a sufficiently high gain, a large drift velocity of  $7.5 \text{ cm}/\mu\text{s}$ , and a low transverse diffusion coefficient of about  $250 \mu\text{m}/\sqrt{\text{cm}}$  with the magnetic field on. The gas is circulating and two small TPCs are used to monitor the supply and return gas, in particular to measure the gain and drift velocity. As for the outer volume it is filled with CO<sub>2</sub> for electrical insulation.

The T2K TPCs are based on bulk micromegas technology [3]. In the drift region between the cathode set at -25 kV and the mesh set at -350 V, with an electric field of 280 V/cm, the electrons created by the ionization of the gas when a charged particle goes through the TPC drift to the mesh. Then they enter the  $128 \mu\text{m}$  thick amplification region between the mesh and the grounded pads, where the electric field is about 100 times higher, resulting in an avalanche. For a high voltage of 350 V between the mesh and the pads, the TPC has a gain of 1500.

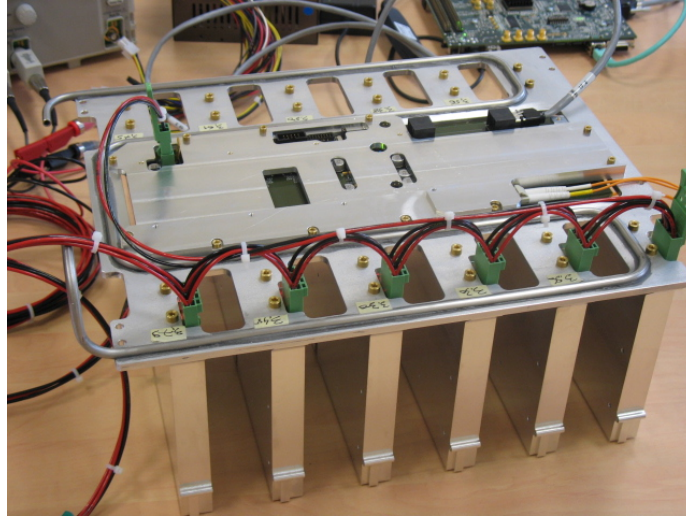


**Figure 3.** View of a micromegas module.

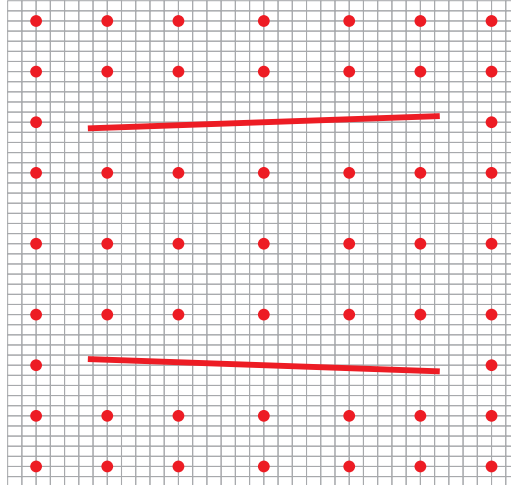
Figure 3 shows one MM module. It is  $36 \times 35 \text{ cm}^2$  and has 1726 active pads,  $6.9 \times 9.7 \text{ mm}^2$ . As there are 12 modules on each TPC endplate, we have in total 72 modules for the 3 TPCs and about 120,000 channels overall. MM modules were produced and tested on a test bench at CERN by a complete scan of all the active area with a  $^{55}\text{Fe}$  source emitting 5.9 keV photons. The energy resolution obtained is 8% and the uniformity over a module is good: 3% in gain and 6% in energy resolution.

The front-end electronics is based on the asic AFTER. This is a chip with 72 channels where the maximum charge, the peaking time, and the sampling frequency are programmable. They are set to 120 fC, 200 ns, and 25 MHz respectively in T2K data taking. There are four asics per front-end card (FEC), which reads out one sixth of a module. The front-end mezzanine (FEM), one per

module, does the data collection from six FECs and applies the zero suppression. A FEM and its associated six FECs are shown on figure 4. The data are then sent by optic fibers outside the TPC to 18 data concentrator cards (DCC) and then to the data acquisition system.



**Figure 4.** View of the readout electronics for one module.



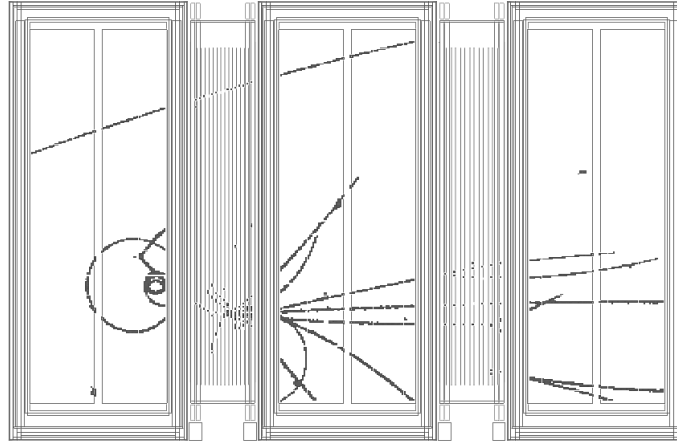
**Figure 5.** Laser target pattern

For calibration purpose, the TPCs have a laser system. It emits 266 nm UV light, brought through a set of optical fibers. The target pattern, illustrated in figure 5, is made of aluminum discs and strips glued on the cathode, which emit photoelectrons when flashed with UV light. The laser is used to study electric and magnetic field distortions, drift velocity and gain variations.

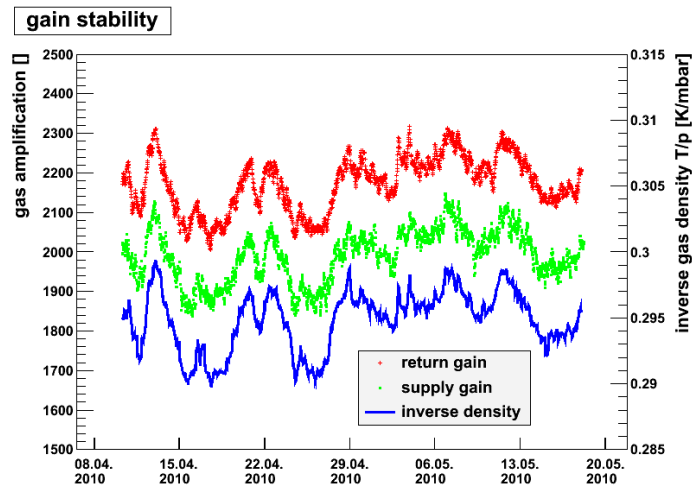


### 3. The time projection chamber performance

The production and construction phase took place from 2007 to 2009. All three TPCS were assembled and tested with beam at TRIUMF as soon as 2008 for the first one and in 2009 for the last two. Then they were installed at J-PARC and commissioned at the end of 2009. They were operational during the first T2K physics run from January to June 2010 and the second one from November 2010 to March 2011. Figure 6 shows the display of one beam event.



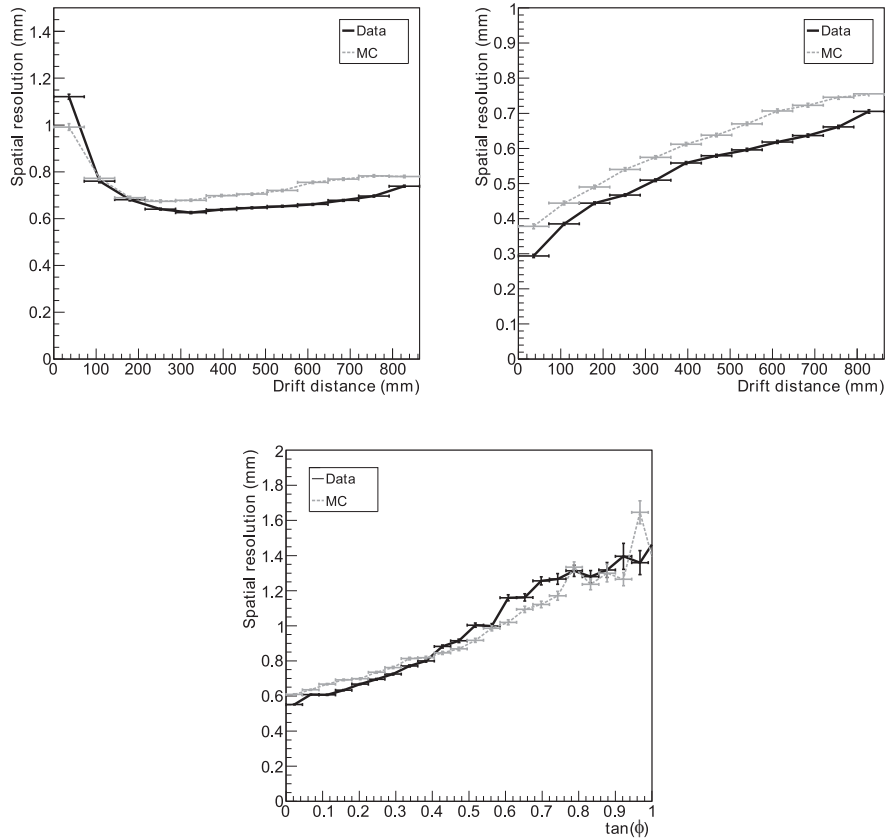
**Figure 6.** Event display showing a deep inelastic scattering neutrino interaction in the first FGD (left) with many tracks in the three TPCs. There is an additional through going track (top left) coming from an upstream neutrino interaction.



**Figure 7.** Evolution with time of the gain measured in the supply line (green curve) and return line (red curve) and of the inverse gas density (blue curve).

The TPC life fraction during beam time is nearly 100%. MM modules have a spark rate of about 0.1 per hour at 350 V, inducing negligible dead time. The front-end electronics electric

consumption is 2.8 kW. The rate of TPC data to DAQ is less than 2MB/s with a trigger rate at 20 Hz. During data taking, many quantities are monitored including gain, gas density, gas quality, drift velocity, temperatures, voltages and currents. For the gain for example, the two monitoring chambers show large variations of the gain overtime, shown in figure 7. But these variations are pretty much correlated with the variation of the inverse gas density, which is mainly due to changes in temperature and pressure. As these quantities are also monitored, T and P corrections can be applied to the gain. After that, the gain is stable within 1%.



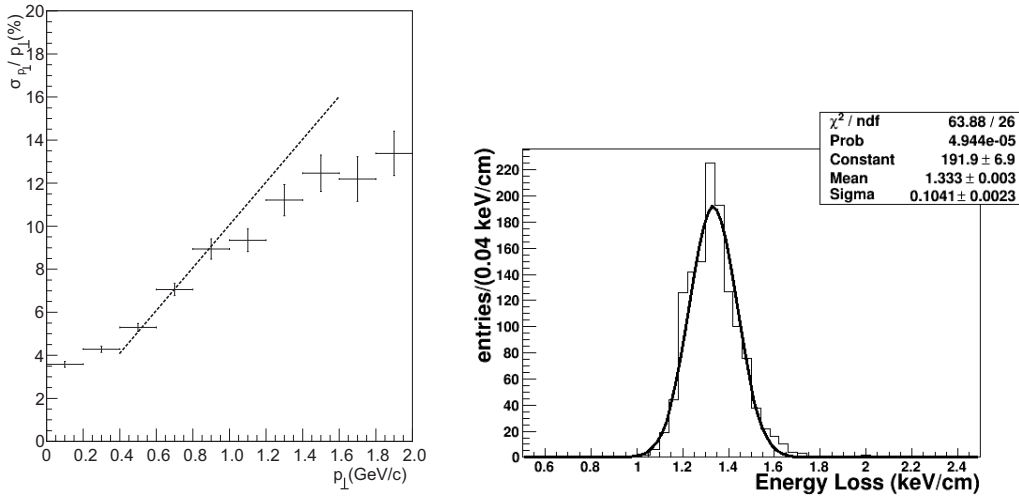
**Figure 8.** Spatial resolution (top) as a function of drift distance for (left) all clusters and (right) two-pad clusters, and (bottom) as a function of the tangent of the angle in the vertical plane. Data are shown by the black points and solid lines, while simulations are given by the gray points and dashed lines.

In the reconstruction, clusters are formed from neighboring pads either within a column for horizontal tracks or within a line for vertical tracks. A track is a set of such clusters. For each TPC, the spatial resolution is estimated by comparing the transverse coordinate resulting from the global track fit to the one obtained with a single cluster fit. As shown in figure 8 (top left), it is smaller than  $800 \mu\text{m}$  for drift length above 150 mm. The degraded resolution at short drift distance is due to the larger fraction of single pad clusters. For two-pad clusters, the increase of the resolution with drift distance seen in figure 8 (top right) shows the effect of the diffusion. Finally the strong dependence of the spatial resolution upon the angle in the vertical plane, illustrated in figure 8

(bottom), is due the ionization fluctuation along the track. We get a spatial resolution of  $600 \mu\text{m}$  for horizontal tracks. There is generally a good agreement between the simulated and the measured spatial resolution.

The relative resolution on the track transverse momentum with respect to the B-field direction for a single TPC is estimated with a Monte Carlo sample of muons obtained from simulated neutrinos interactions. The result illustrated in figure 9 (left) shows that for transverse momenta above  $0.4 \text{ GeV}/c$  the required relative momentum resolution of 10% is achieved.

Particle identification uses an energy loss truncated mean. Figure 9 (right) shows that a relative resolution on the energy loss of 7.8% is obtained, so here again better than the design goal of 10%.



**Figure 9.** Left: relative transverse momentum resolution for a single TPC as a function of transverse momentum. The dashed line shows the required resolution. Right: distribution of the energy loss for negatively charged particles with momenta between  $0.4$  and  $0.5 \text{ GeV}/c$ .

The distortions of electric or magnetic field, which affect the reconstructed track parameters, are studied using laser calibration data. Electric field distortions are obtained with the magnet off from the observed offsets of the aluminum discs on the cathode with respect to the geometrical survey. The rms values obtained in both directions are smaller than the space point resolution. As for the magnetic field distortion, they are investigated by comparing the measurements done with and without magnetic field. The offsets are typically less than 1mm, but reaching 5 mm in some regions of the downstream TPC at maximum.

As a consequence of the earthquake on March 11, 2011, T2K data taking was stopped. The status of ND280 could be checked in details in May 2011. In particular, for TPC, the gas system, cooling, the front-end electronics, the back-end electronics, the high voltages for cathodes and micromegas modules were all powered up successfully. So the TPCs were brought back to full operation and should be ready to resume data taking when the beam is back. The current plan is to restart beam operations in December 2011 and start a new T2K physics run in the beginning of 2012.



## 4. Conclusion

In summary, the three T2K ND280 TPCs have been operating successfully during the first two physics run from January 2010 to March 2011. They will be ready for the next T2K physics run foreseen for the beginning of 2012. They are contributing in an essential way to T2K physics results [4].

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