Time Projection Chambers for the T2K experiment

TIPP09, Tsukuba, Japan
March 13, 2009

D. Karlen / U. Victoria & TRIUMF representing the T2K ND280 TPC group
The T2K Experiment

Super-Kamiokande (ICRR, Univ. Tokyo)

J-PARC Main Ring (KEK-JAEA, Tokai)

295 km

ND280 off axis detector

ND280 tracker: FGDs and TPCs

March 13, 2009
Detector objectives

- The ND280 tracker is designed to
  - measure the $\nu_\mu$ and $\nu_e$ spectra and interaction rates prior to oscillation
  - measure neutrino interaction kinematics to better understand backgrounds in the far detector

- The TPC modules are designed to
  - provide excellent pattern recognition to select high purity event samples for different types of neutrino interactions in the Fine Grained Detectors
  - measure momenta and charge of charged particles
  - distinguish electrons, muons/pions, and protons
TPC Design considerations

- Neutrino energy estimate is limited by Fermi motion of the nucleons. This sets the $p$ resolution requirement to be $< 10\%$ for $p_t = 1$ GeV/c

- $dE/dx$ for electrons is $\sim 45\%$ greater than for muons over the momentum range of interest. This sets the $dE/dx$ resolution requirement to be $< 10\%$

- These goals can be achieved with $B = 0.2$ T for
  - sampling length $\sim 60$-70 cm
  - pad size $\sim 70$ mm$^2$

- Micromegas technology was selected to provide the gas amplification for readout
Mechanical design

- Three TPCs measure charged particles exiting and entering the two FGD modules.
- Each TPC has a double box structure:
  - Inner box walls make up the field cage.
  - Outer box walls at ground.
  - Gas insulator between them.
  - All walls are composite with ~1 cm rohacell cores.
TPC design

- The full size TPC design was based on the concepts validated by prototypes
Full size TPC module construction

- A large bed router at TRIUMF was used to machine the TPC panels
Inner box panel

Field strips cut on copper clad G10 skin
Field cage preparations

- Jumpers, checking resistances
Inner box assembly

- Ensuring cathode is parallel to endplates
Rounded corners

- connects strips on adjacent panels
- reduces electric fields at the corners
Aluminum dots and strips on cathode

- For calibration purposes, a set of aluminum targets are placed & surveyed on the cathode
  - We illuminate the cathode with pulses of UV light to produce controlled patterns of photoelectrons
Closing the inner box

- Module frame holds 12 micromegas modules
Completed inner box
Close up of readout plane
Readout electronics

- 1726 pads readout per module by 6 FECs
  - FECs based on custom ASIC with SCA (72 x 511)

Technology:
- AMS CMOS 0.35 μm
- Area: 7546 μm x 7139 μm
- Submission: 24 April 2006
- Delivery: end of July
- Package: LQFP 160 pins; Plastic
- Dimensions: 30mm x 30mm
- Thickness: 1.4mm
- Pitch: 0.65mm
- # of transistors: 400,000

March 13, 2009
TPCs for the T2K experiment
Installation of electronics and services
Beam test of FGD & TPC in M11 (July-December 2008):
Mixed beam of $p, \pi, \mu, e$ tunable from 100-400 MeV/c
TPC and FGD in testbeam area
Event gallery – multiple tracks

3.5 modules instrumented

Side view

Top view

YZ Projection

TPC

FGD

beam direction

Uninstrumented

ZT Projection

March 13, 2009
Event gallery – multiple tracks

Side view

Top view

YZ Projection

ZT Projection

Run:7532 Event:54

March 13, 2009

TPCs for the T2K experiment
Event gallery – multiple tracks

Side view

Top view

YZ Projection

ZT Projection

Run: 7532 Event: 432
Track reconstruction – match to FGD

TPC+FGD: XZ Projection

XZ Projection

TPC Data

Fit to TPC Data

FGD Data
Track resolution

- Residuals from single column of pads
  - sufficient to meet momentum resolution goals

\[ \sigma \sim 0.68 \text{ mm} \]
dE/dx resolution

- Initial analyses show very good resolution
  - Note: dE/dx (electrons) $1.4 - 1.5 \times$ dE/dx (muons)

Run 3879 $\rightarrow$ $p = 150$ MeV  Selected muons with TOF

- 1st MM Resolution 9.0%
- 2nd MM Resolution 8.0%
- All TPC Resolution 6.1%
Arrival time distribution

Only Channels near the lines are used: 96 Channels

Since the Max ADC time distribution is very narrow it gives us a nice opportunity to determine drift velocity with high precision.

March 13, 2009 TPCs for the T2K experiment
1) Signals Produced due to UV light on a test pattern of Aluminum on the Central Cathodes have a Poisson distribution.

2) Variance of the Poisson distribution is equal to Mean value of the distribution

Let \( ADC = \alpha \times N \)
Where \( \alpha \) is a gain and \( N \) is equal to the number of photoelectrons. Then

\[
V(ADC) = V(\alpha \times N) = \alpha^2 \times N
\]

So, \( V[ADC] \) versus \( ADC \) should be a linear function, where \textit{slope will be a gain.}

\[
V[ADC] = \alpha^2 \times N
\]

\textit{Lets have a look on a real data ...}
Results – Gain (ADC/photoelectron)
Problems with laser events

- When large amount of charge arrives at micromegas at once, the sudden current across the micromegas gap temporarily reduces the mesh potential – inducing small opposite polarity signals of equal amplitude on all pads in module.
  - Problem is reduced by modifying the HV filter.

- Only a few dim dots are seen.
  - Strips are bright.
  - A more rigorous cleaning of the dots was found to be necessary.
Gas system

- Gas system is designed to
  - mix and circulate inner volume gas through filters
    - baseline choice: Ar : CF₄ : iC₄H₁₀ (95:3:2)
  - flow CO₂ gas through outer volume
  - flow rates: up to 1 volume change per 5 hours
    - 30 l/min inner, 20 l/min outer (all 3 TPCs)
  - maintain ΔP between outer volume and atmosphere at less than ~5 mbar
  - maintain ΔP between inner and outer volumes at about 0.1 mbar

- Gas system is controlled by Programmable Logic Control (PLC) system
Gas system schematic

PROPOSED T2K TPC GAS HANDLING SYSTEM

Gas system schematic
Mixing system (surface)
Example: mixing rack

- One of 7 racks that make up the gas system
T2K TPC schedule

- First TPC module now returning to test beam area – now fully instrumented
  - send to Japan end of May
- Second TPC module under construction
  - plan to test in May and ship at end of June
- Third TPC module to be completed late this year
  - hopefully installed before end of year

- Commissioning the ND280 detector starts in September 2009
- First beam with detectors: December 2009
Summary

- The T2K TPCs are the first large TPCs to be used in an experiment with MPGD readout
- Initial tests completed – performance goals met
- All components are on track to complete the 3 TPCs this year
- Much work ahead for our group to bring the TPCs into full operation in Japan by the end of the year

  - T2K ND280 TPC group:
    - Canada (TRIUMF, UBC, U. Victoria)
    - France (CEA-IRFU/Saclay, Paris LPNHE)
    - Germany (RWTH Aachen)
    - Italy (INFN/Bari)
    - Spain (IFAE Barcelona, U. Valencia)
    - Switzerland (U Geneva)
Additional material
Module-0 gas system

- Only one chamber is operated, so flow rate, pump capacity, etc. are downscaled by 1/3
- Three component gas mixing
- Pressure controlled pump loop for recirculation
- Input and recycling flow control
- Filtering for O₂ and H₂O
  - O₂ level < 5 ppm
- Bubblers for pressure relief
\( \Delta P \) system performance

- Inner box follows atmospheric variations (+/- 10 mbar) to better than 0.01 mbar

March 13, 2009
Proton event – negative pulses

Run 5154, event 3 HV=320

proton direction
Proton event – negative pulses

Run 5154, event 3 HV=320
Figure 3.1: Transverse diffusion coefficient (left) and drift velocity as function of the applied drift field for fractions of CF$_4$ between 0% (blue) and 3% (yellow).