T2K ND280
Time Projection Chambers

NSERC Review
December 16, 2007

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

- Physics requirements and mechanical design
- Prototype studies: update
- Full size module construction status
- Gas system status
- TPC integration issues
- Micromegas modules
- Readout electronics
- Summary
Physics requirements

- The ND280 tracker is designed to
  - measure the $\nu_\mu$ and $\nu_e$ spectra and fluxes prior to oscillation
  - measure neutrino interaction cross sections and kinematics

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

- The 3D tracking capability of TPCs provide excellent pattern recognition
- Neutrino energy estimate is affected by Fermi motion. This sets the scale for $p$ precision needed by the TPC to be $< 10\%$ at $1\, \text{GeV}/c$
- $dE/dx$ for electrons is $\sim 50\%$ greater than for muons over the momentum range of interest. This sets the scale for $dE/dx$ precision needed by the TPC to be $< 10\%$
- These goals can be achieved with $B=0.2\, \text{T}$ for
  - sampling length $\sim 60-70\, \text{cm}$
  - the pad size $\sim 70\, \text{mm}^2$
- Micromegas technology was selected to provide the gas amplification for readout
TPC Workpackages, contributors, WP leaders

- Oversight by TPC convenors (D. Karlen and M. Zito)

1. TPC mechanical – Canada (Chris Hearty)
2. gas system – Canada (Issei Kato)
3. ND280 integration – Canada (Roy Langstaff)
4. micromegas modules – Europe (Alain Delbart)
5. micromegas mechanical – Europe (Eric Perrin)
6. readout electronics – Europe (Denis Calvet)
7. online – Europe (Jacques Dumarchez)
8. offline software – Europe & Canada (Federico Sanchez)
9. calibration – Europe & Canada (Anselmo Cervera)
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
Mechanical design

- The tracker is supported by a basket within the UA1 magnet:
Prototype studies: update

- A prototype with 2 readout modules, full drift distance was completed in Jan 2006
  - proved concept was sound
  - resolution goals achieved
Prototype: Example cosmic event

coloured according to arrival time

coloured according to amplitude
Prototype update: attenuation

- saw reduction of signal with drift distance
  - interpreted this to be due to electron attachment, electron lifetime of about 200 μs lifetime—using relatively slow gas (Ar CO2 90:10, 100 μs drift time)
  - recently we realized that an apparent attenuation is a result of the short shaping time of the ALTRO electronics, c.f. the width of the arrival time distribution of electrons (depends on dip angle and drift distance)
    - difficult to model and to correct
    - not a problem for final electronics
Prototype update: new baseline gas

- As requested by review committee we operated prototype with new baseline gas (Ar CF$_4$ isobutane – 95:3:2)
  - no “attachment” observed – faster gas, so that the arrival time distribution of electrons shorter than shaping time
  - allows for amplification systems to operate at lower voltages for the same gain
Prototype: photoelectron calibration

- A UV pulsed laser was finally acquired in May 2007 – used to flash the central cathode with diffuse light: producing photoelectrons from aluminum strips
  - worked very well
  - drift velocity to 0.01% in few minutes
photoelectron calibration - distortions

Distortion measurements:
- compare reconstructed locations with designed locations of strips
  - small displacements, but an apparent rotation
Photoelectron calibration plans

- For full size TPCs, use dots to determine actual displacements – and correct for them.

  projection of pattern and observed electrons on single readout module

  observed displacements – magnified by factor of 10
Full size prototype module

- As a test of the TPC design and construction, a full size prototype was planned (module 0)
Module-0 construction

- A new large bed router at TRIUMF was acquired through CFI – primary use is for TPC and FGD machining
Module-0 construction

At the time of the last review, we had hoped to have completed module-0 by this time.

In 2007 we suffered many setbacks due to:

- router startup problems (installation)
- continuing router calibration/firmware problems
  - was challenging to operate at specified tolerances (0.1 mm over distances of ~2 m)
- delays in bringing up two shifts on router
  - now we are back to one shift – job ad out for TRIUMF machinist replacement
Router issues

- moving work off router, to reduce bottleneck
  - using external company to make rough cuts of G10 materials (oversized) using water jet cutters

- performance of router has improved
  - compensation tables successfully incorporated
  - backlash reduced by tightening rack and pinion
  - optical survey determined bow in gantry (0.25 mm)
Status of module-0 construction

- outer panels: complete
- inner panels: under construction
- outer endplates: completed
- module frame: just started
- central cathode: under construction
- service spacer: under construction
- service covers: completed
Module-0 parts

outer box panels (now complete)

inner box panels (under construction)

test of groove cuts for inner panel
Module-0 parts

inner box upper panel – strips cut
Module-0 parts

inner box module frame – rough cut
Module-0 parts

Outer box endplates (now complete)
Module-0 parts

- Service spacer – welding completed
Module-0 parts

- Outer box – dry assembly
Schedule for construction

- Times required for machining parts on the router are much longer than original estimates (factor 2 or more)
  - serious problem: not only is production schedule longer, but the start of production modules has been delayed

- We cannot have an accurate estimate of the total time needed for router, until module-0 parts are complete
  - expect that subsequent modules will be produced more quickly
Schedule for construction

- Given the progress so far, we believe that module-0 will have machining complete in April 2008 and ready for cosmic+beam tests in May.

- Over the next several months we will evaluate the production module schedule:
  - a likely strategy:
    - produce production modules in series rather than parallel
    - complete module-1 by spring 2009
    - install module-0 and module-1 in ND280 in summer 2009
    - install module-2 in 2010
  - will explore ways to have 3 TPCs completed in time for 2009 installation – but we must ensure that we have 2.
Gas system

- Gas system is designed to
  - mix and circulate inner volume gas through filters
    - baseline choice: Ar CF$_4$ iC$_4$H$_{10}$ (95:3:2)
  - flow CO$_2$ 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 $\Delta P$ between outer volume and atmosphere at less than ~5 mbar
  - maintain $\Delta P$ between inner and outer volumes at about 0.1 mbar
Complete gas system drawing
Mixing system (surface)
Module-0 gas system test

- Only one chamber is operated, so flow rate, pump capacity, etc. are downscaled by 1/3
- Pressure controlled pump loop for recirculation
- Input and recycling flow control
- Pressure protection by pressure switches and automatic air valves
- Bubblers for pressure relief
- Did not incorporate mixing system for this test
Module-0 gas system test

2000 litres (Steel Tank)

T2K TPC Test GHS
R.Openshaw 07/11/29
Module-0 gas system test

- Successful achievements:
  - Input and recycling flow control
  - Pressure control in the chamber as required
    - Achieved $\Delta P = 0.1 \pm 0.01$ mbar
  - Response time for system measured
  - Automatic flow shutoff when over/under-pressure occurs

- Some problems identified during the testing:
  - Bubbler blows out and the air is sucked into the system when valve is opened to switch the system into operation mode.
    - A solution identified and was demonstrated by manual operation
    - Next: show that the solution works in automatic operation
Tests of final gas system concepts

- design goals appears to be achievable
Surface gas building

- Issei Kato has prepared specification
  - safety review at TRIUMF and KEK
Integration issues

- Service routing planning underway
## Integration issues

- Installation planning starting

<table>
<thead>
<tr>
<th>ID</th>
<th>Task Name</th>
<th>Duration</th>
<th>Start</th>
<th>Finish</th>
<th>predecessors</th>
<th>Resource Names</th>
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<td>Tracker Manpower Requirements</td>
<td>163 days</td>
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<td>Fri 10/5/05</td>
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<td>2</td>
<td>Uplift Tracker container - LNCC area</td>
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<td>Mon 6/9/05</td>
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<td>Person O Electrician</td>
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</table>

**Project: Tracker Manpower Requirement**

**Task Progress:**
- **Rollup Progress:**
- **Project Summary:**
Micromegas modules (Europe)

• Bulk micromegas technology used for gas amplification
• 12 modules (34 cm x 36 cm) on each TPC endplate

Micromegas production to start in early 2008 – 8 per month. Complete 84 by March 2009.

December 16, 2007
Micromegas modules (Europe)

- Stiffener frame is bonded to the micromegas PCB to
  - provide extra strength
  - attach the module to the TPC endplate
  - form a gas tight seal with the endplate
Readout electronics (Europe)

- 1726 pads readout per module by 6 FECs
  - FECs based on custom ASIC with SCA (72 x 511)
  - ASIC completed PRR – going into production

![Diagram of readout electronics]

- 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
Micromegas inserted into HARP field cage. Readout by T2K TPC front end cards.
Summary

- The TPC modules are a critical part of the ND280 off axis detector
- ND280 TPC Group is a large collaboration involving Canada and Europe
- Progress made:
  - full size module under construction (late)
  - gas system designed and tests successful
  - Micromegas & electronics readout systems verified
- Commission ND280 off-axis in fall 2009
  - must work hard to ensure 2 (or 3) TPCs available
ND280 TPC group

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Attenuation of signals

\[ \chi^2 / \text{ndf} = 1032 / 46 \]
Constant: \[ 9.415 \pm 0.007472 \]
Slope: \[ -0.0004622 \pm 1.412e-05 \]

\[ \chi^2 / \text{ndf} = 1439 / 92 \]
Constant: \[ 9.55 \pm 0.001684 \]
Slope: \[ -0.0003103 \pm 2.719e-06 \]
Shaping time issue

- Amplitude vs. dip angle for constant drift distance
Gas properties

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).
Gas properties

Figure 3.2: Transverse diffusion coefficient (left) and drift velocity as function of the applied drift field for fractions of CO₂ between 0% (blue) and 6% (black).
Bulk micromegas production

Base Material

Lamination of Vacrel

Positioning of Mesh

Encapsulation of Mesh

Development of Contacts and Spacers

Copper Plane

FR4

Vacrel

Mesh

Contact to anode plane

Spacers

Contact to Mesh