T2K TPC Conceptual Design

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(representing the T2K ND280m TPC group)

T2K collaboration meeting at KEK
March 11, 2005
Overview

- At the previous T2K collaboration meeting (August 2004) the Time Projection Chamber concept was presented to the collaboration for the first time
  - since then, much progress has been made

- This presentation:
  - Summary of the TPC concept as it appears in the current CDR draft
    - includes updates from presentations at the March 7 TPC meeting from Fabrice Retiere, Issei Kato, Marco Zito, Alain Delbar, Denis Calvet, Anselmo Cervera, D.K.
Primary purpose: to provide the most accurate estimate of the $\nu_\mu$ spectrum by measuring $\mu$ momenta from CCQE interactions in the other ND280m detectors

- at the peak of the $\nu_\mu$ spectrum, the energy resolution is limited by Fermi motion to about 10%

The TPC momentum resolution goal is therefore: $\delta p/p < 10\%$ for momenta below $\sim 1$ GeV/c
Introduction to the TPC system

Other purposes:

- provide valuable information for other neutrino interaction events in the FGD planes
  - determine charges, measure momenta
  - distinguish electrons / protons / muons+pions
- distinguish the products of interactions within the FGD fiducial volume from other particles
  - eg. neutrino interactions in magnet iron or ECAL will produce many particles entering the fiducial volume
- provide samples of a few thousand neutrino-gas events/year that can be used to study low energy hadron production
TPC geometry

- To fit the geometry of the UA1 magnet, the TPC must be rectangular
- To surround the FGD planes, several TPC modules need to be constructed
- To achieve the momentum resolution, ~60 cm track length required

- Outer dimensions of the current concept: 2.5 m × 2.5 m × 0.9 m (ν direction)
Gas choice

- With the relatively low magnetic field, best momentum resolution will be achieved with a gas of intrinsically low diffusion
- Some gases under consideration:
Gas choice

- A gas mixture with very high CO₂ concentration is disfavoured because it enhances the attachment of electrons by O₂:

<table>
<thead>
<tr>
<th>CO₂ (%)</th>
<th>E (V/cm)</th>
<th>O₂ ppm (20 % loss)</th>
<th>O₂ ppm (40 % loss)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>200</td>
<td>13</td>
<td>29</td>
</tr>
<tr>
<td>10</td>
<td>400</td>
<td>31</td>
<td>71</td>
</tr>
<tr>
<td>20</td>
<td>400</td>
<td>7</td>
<td>16</td>
</tr>
<tr>
<td>30</td>
<td>400</td>
<td>3</td>
<td>7</td>
</tr>
<tr>
<td>100</td>
<td>400</td>
<td>0.2</td>
<td>0.5</td>
</tr>
</tbody>
</table>
Field cage and gas containment

- Design goals:
  - Drift field: 100 V/cm – 400 V/cm
    - uniform at level of $10^{-4}$
    - all surface fields < 20 kV/cm
  - Central cathode at 10 – 40 kV, outer surface at ground
    - strong, reliable electrical isolation
  - Good gas seal
    - limit O$_2$ contamination to < 10 ppm
  - Simple, repeatable construction methods
    - several modules (plus spare) needed
Field cage concept

- Double wall design – a box within a box

- gas envelope: helps gas purity, field uniformity, thermal insulation, allows relatively simple wall construction method, avoids the risk of HV breakdown of a solid insulator
Very good field uniformity
$399.98 < |E_x| \text{ (V/cm)} < 400.02$

E field calculations by Juergen Wendland using FEMLAB

From presentation by Fabrice Retiere, TRIUMF
Wall properties

- One wall for gas containment
- One wall carrying field defining strips
- Material: rohacell with copper clad G10 skins

<table>
<thead>
<tr>
<th></th>
<th>width</th>
<th>Rad length</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>4 G10 sheets</td>
<td>4 mm</td>
<td>2%</td>
<td>12.2 kg</td>
</tr>
<tr>
<td>4 Cu planes or strips</td>
<td>80 μm</td>
<td>0.5%</td>
<td>1.3 kg</td>
</tr>
<tr>
<td>2 Rohacell sheets</td>
<td>2 cm</td>
<td>0.3%</td>
<td>1.9 kg</td>
</tr>
<tr>
<td>Flash gap</td>
<td>75 mm</td>
<td>0.04%</td>
<td>0.26 kg</td>
</tr>
<tr>
<td>Total</td>
<td>~ 10 cm</td>
<td>2.84%</td>
<td>15.66 kg</td>
</tr>
</tbody>
</table>

Not to scale
Draw copper strip pattern with a router.

- Drill groove through the copper/G10
- Precision ~50 microns
- To be tested for reproducibility
- Router will be purchased by TRIUMF
Field at the corners. Zoom

Best compromise
4-6 cm radius
STAR

Flashing the central cathode

Pros
- simple

Cons
- Full drift length: integrate all distortions
Prototyping this concept
## Field cage material cost estimate

<table>
<thead>
<tr>
<th>Material</th>
<th>Unit cost</th>
<th>Number for 3 TPCs</th>
<th>Total for 3 TPCs</th>
</tr>
</thead>
<tbody>
<tr>
<td>4x8ft Copper clad G10</td>
<td>200 C$</td>
<td>120 (102)</td>
<td>24 kC$</td>
</tr>
<tr>
<td>4x8ft Rohacell 51IG</td>
<td>300 C$</td>
<td>60 (51)</td>
<td>18 kC$</td>
</tr>
<tr>
<td>Aluminum lids</td>
<td>1300 C$</td>
<td>6</td>
<td>7.8 kC$</td>
</tr>
<tr>
<td>Glue</td>
<td>500 C$/gal</td>
<td>3?</td>
<td>1.5 kC$</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td><strong>51.3 kC$</strong></td>
</tr>
</tbody>
</table>
Gas system concept

- Gas envelope: flushed with CO$_2$
- Drift volume: A recirculating system with filters to maintain low O$_2$ levels
- Designed to follow atmospheric pressure
  - to avoid distortion of field cage structures
Ar/CO₂ gas mixture is assumed.

This is described on CDR.

- Ar/CO₂ tanks
- Buffer tank
- Purifiers/Filters
- Mass flow meters/controllers
- Exhaust manifolds
- Differential pressure control
- Gas recycling

By R. Openshaw (TRIUMF)

From presentation by Issei Kato, TRIUMF
Preliminary Design of Gas System (simplified)

- CO2 in liquid
- Ar
- 30 litter/min
- 1 bar
- 0.4–0.7 bar
- Buffer Tank
- Purifiers / Filters
- 60 litter/min
- O2 monitor
- Drift volume gas
- Flush gap gas
- Chamber Exhaust Manifold
- Flush Gap Exhaust Manifold

I. Kato: T2K TPC Conceptual Design on March 11, 2005
## Rough Cost Estimations

<table>
<thead>
<tr>
<th>Item</th>
<th>Unit Price</th>
<th># Units</th>
<th>Total Costs</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass Flow Controller/Meter</td>
<td>$3,000</td>
<td>15</td>
<td>$45,000</td>
<td></td>
</tr>
<tr>
<td>Purifier/Filter</td>
<td>$15,000*1</td>
<td>1</td>
<td>$15,000</td>
<td></td>
</tr>
<tr>
<td>Pressure Xducer</td>
<td>$2,000*2</td>
<td>2</td>
<td>$4,000</td>
<td>for exhaust manifold pressure</td>
</tr>
<tr>
<td>Pressure Xducer (cheap)</td>
<td>$500</td>
<td>6</td>
<td>$3,000</td>
<td>for pump and other line pressure</td>
</tr>
<tr>
<td>Pump</td>
<td>$5,000</td>
<td>2</td>
<td>$10,000</td>
<td></td>
</tr>
<tr>
<td>Misc.</td>
<td>$10,000</td>
<td></td>
<td>$10,000</td>
<td></td>
</tr>
<tr>
<td>O$_2$ Analyzer</td>
<td>$10,000</td>
<td>1</td>
<td>$10,000</td>
<td></td>
</tr>
<tr>
<td>H$_2$O Analyzer</td>
<td>$10,000</td>
<td>1</td>
<td>$10,000</td>
<td></td>
</tr>
<tr>
<td><strong>Subtotal</strong>$^3$</td>
<td>$107k ±20k</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*1: Depends dramatically on purity requirement  
*2: Assume medium accuracy  
*3: Tubing, manifolds, buffer tanks, power supplies, fittings, hardware, racks, valves, slow control readout, pressure relief bubblers, etc., are not included. The cost of the purifier/filter unit(s) is at this point uncertain.
Both concepts have been built and proven to work (COMPASS)
Minor advantages/drawbacks each:
Both need to tackle the large surface, multidetectors problem (dead zones, mechanics, etc)!
Decision to be taken at the end of 2005 (performance, cost, robustness, flexibility, …)
Common micropattern issue

- For the two techniques, large scale active area has to be proven:
  - segmentation and dead zones
  - dead zones impact on Electric field uniformity on edges
  - gain uniformity on large surfaces
  - gain cross calibration (gain cross-calibration between different detectors)
A possible TPC readout plane

X/X₀ radiation length estimation and minimization in progress
Mechanical dead zones

Dimensions in mm

Vertical Dead zones
Horizontal misalignment to prevent high energy tracks from being lost

Horizontal Dead zones

Fixing holes

Total dead zone = Mechanics + vacrel frame (10 mm) + local E distortions

Micromes h
Micromegas « Bulk » at SACLAY

1. Vacrel laminator
2. Vacrel Insulator
3. Vacrel development
4. Vacrel heating
Exploded view of a 27x26 cm² Micromegas module

Ref: J-Ph Mols

FEC

Woven mesh

Support

FR4

Pads PCB

Vacrel

« Bulk » Micromegas

Vacrel

Seal
4 Micromegas modules prototype

Cover with drift electrode
For dust protection
And gain calibration
### 6 readout planes funding estimate

#### Investment cost estimate for 6 readout planes of 2x7 Micromegas modules

<table>
<thead>
<tr>
<th>Estimated Unit cost</th>
<th>Qty</th>
<th>Total Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mechanical support plane (+1 spare)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Matter (aluminum) (7x200 kg)</td>
<td>0,01 k€</td>
<td>1400</td>
</tr>
<tr>
<td>Manufacturing (20h/plane)</td>
<td>0,05 k€</td>
<td>140</td>
</tr>
<tr>
<td>without seals, screws . . . For mounting</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Readout plane support SUBTOTAL</strong></td>
<td>21,0 k€</td>
<td>(10%)</td>
</tr>
<tr>
<td>Mechanical support (+16 spares)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Matter (aluminum) (100x7 kg)</td>
<td>0,01 k€</td>
<td>700</td>
</tr>
<tr>
<td>Manufacturing (20h/module)</td>
<td>0,05 k€</td>
<td>1000</td>
</tr>
<tr>
<td>Seals</td>
<td>0,03 k€</td>
<td>100</td>
</tr>
<tr>
<td>Cover (with drift electrodes)</td>
<td>0,10 k€</td>
<td>100</td>
</tr>
<tr>
<td>Screws, gas connectors . . .</td>
<td>3,0 k€</td>
<td></td>
</tr>
<tr>
<td><strong>Micromegas support modules SUBTOTAL</strong></td>
<td>130,0 k€</td>
<td>(61%)</td>
</tr>
<tr>
<td>Anode PCBs (+16 spares)</td>
<td>0,50 k€</td>
<td>100</td>
</tr>
<tr>
<td>Woven meshes (2x0,5 m²/4 modules)</td>
<td>0,27 k€</td>
<td>25</td>
</tr>
<tr>
<td>HV connectors, photoresist, . . .</td>
<td>5,0 k€</td>
<td></td>
</tr>
<tr>
<td><strong>Micromegas structure SUBTOTAL</strong></td>
<td>61,7 k€</td>
<td>(29%)</td>
</tr>
<tr>
<td><strong>Micromegas readout plane TOTAL cost</strong></td>
<td>213 k€</td>
<td></td>
</tr>
</tbody>
</table>

With 20% safety margin 255 k€

→ And HV power supply to estimate . . .

+ **Manpower (Eng.year)**

5x3x150k€ = 2,25 M€
HARP Field cage

- Stesalit cylinder of 80/82 cm inner/outer diameter and 201 cm length
- Maximum drift length 154 cm
- Field shaping integrated on gas envelope: a structure of electrodes, each kept at a precise degrading potential

From presentation by Anselmo Cervera, Geneva
We have to attack the problem of mounting two modules side-by-side.

- Reduce the dead space to <1 cm (~0.6 cm, Saclay)
- Study how to bring services inside
Electronics and data acquisition

- Front end ASIC design underway at Saclay
- Features of system:
  - selectable pre-amp gain
  - selectable shaping time and sampling frequency
    - accommodates many gas options
  - analog buffer (SCA)
  - 10 bit digitization
  - digital buffer
  - communication through optical links
  - low noise
  - low power consumption
The electronic front end for the T2K experiment

ARCHITECTURE OF THE ASIC

From presentation by Denis Calvet, Saclay
**ASIC SPECIFICATION**

Estimated dimension = 60mm²
Expected rms noise level < \(\sim\) ENC = \(200\) e- +\(10\) e- /pF (ts=1\(\mu\)s)
Expected Power = 3 mW / Channel (3.3V)

**Planning:**

- Conceptual design of the Front end: Schematic & layout in the end of 2005 (9 months)
- Reception ASIC: April or June 2006 (duration of process: 3 months)
- Test of the ASIC: 2 or 3 months (in laboratory; with detector ???)

1. If o.k: Production in beginning of 2007
2. If redesign: 2 months & reception in beginning of 2007

Test of the production: 3 months ???
Logical Read-Out Flow

**Architecture principles**

- Front-end ASIC with analog memory (Switch Capacitor Array)
- ADC + digital buffer stage on-detector
- Multiple optical fibers send data to off-detector concentrators
- Interface to common DAQ via standard network

1-4 Tbaud*/s peak

*1 baud = 10 bit

~2 ms retention max.

20 Gbaud/s peak

200 Gbit/s peak

~1 Gbit/s averaged

0.1-1 Gbit/s

Detector Pads

Front-end ASICs

On-detector electronics

Optical fibers

Standard LAN connection(s)

Pre-amp and shapers

Samplers and analog memory buffers

Analog to digital conversion

Digital buffer

Data concentration

Shared DAQ system

1-4 Tbaud*/s peak

~2 ms retention max.

20 Gbaud/s peak

200 Gbit/s peak

~1 Gbit/s averaged

0.1-1 Gbit/s
## Resources and Manpower

<table>
<thead>
<tr>
<th>Component Type</th>
<th>Manufacturing Cost (k€)</th>
<th>Laboratory Manpower (FTE x year)</th>
<th>Total Cost (1 FTE= 150 k€)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electronics for TPCs</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ASIC design, test and production</td>
<td>170</td>
<td>2 x 3</td>
<td>1220</td>
</tr>
<tr>
<td>(3 runs; 2000 chips)</td>
<td></td>
<td>+1 (testbench)</td>
<td></td>
</tr>
<tr>
<td>Analog Front-End Cards</td>
<td>130</td>
<td>2 x 3</td>
<td>1100</td>
</tr>
<tr>
<td>(370 cards)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Digital Front-End Cards</td>
<td>20</td>
<td>2 x 3</td>
<td>990</td>
</tr>
<tr>
<td>(100 cards)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Off-detector Concentrator Cards</td>
<td>15</td>
<td>2 x 3</td>
<td>985</td>
</tr>
<tr>
<td>(10 cards)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Crates, Low voltage power</td>
<td>40</td>
<td>-</td>
<td>40</td>
</tr>
<tr>
<td>supplies, Cables, etc</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Integration</td>
<td>-</td>
<td>2 x 1</td>
<td>300</td>
</tr>
<tr>
<td>Total</td>
<td>375 k€</td>
<td>27 FTE</td>
<td>~4.7 M€</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>~6.5 oku-yen</td>
</tr>
</tbody>
</table>

- Estimate for 86,000 channels
- Not included: detectors and mechanics, HV power supplies, travel expenses, etc.
Expected performance

- Study of muon momentum resolution has been performed using full simulation and reconstruction programs:
  - adapted from Linear Collider TPC R&D project - reproduces results from prototype GEM-TPCs
  - NEUT events used as input, GEANT3 propagates particles across gas in uniform magnetic field, energy loss converted to electrons, transport to endplate, generates digitized signals
  - reconstruction program: track fitter using digitized signals on pads
Simulation geometry

Example events:

\[ \delta \] rays included:

interactions occur at edge of TPC
Muon sample

- only forward muons considered
- forward peak – high pt muons
Resolution: 8 mm × 8 mm pads

\[
(p_t^{\text{fit}} - p_t^{\text{true}}) / p_t^{\text{true}}
\]

- shown below for 4 ranges of \(p_t\)
- Tails are predominantly due to large \(\tan(\lambda)\)

---

0 – 0.2 GeV/c

- 0 – 0.2 GeV/c
- 0.4 – 0.6 GeV/c
- 0.2 – 0.4 GeV/c
- 0.6 – 0.8 GeV/c

March 11, 2005

T2K TPC Conceptual Design
Comparison of pad geometries

- (a) 6 mm × 6 mm
- (b) 8 mm × 8 mm
- (c) 10 mm × 10 mm
- (d) 12 mm × 12 mm
- (e) 6 mm × 10 mm
- (f) 4 mm × 15 mm
Square pad resolution

better for smaller pads

\[ \sigma \left[ \left( p_i^{\text{fit}} - p_i^{\text{true}} \right) / p_i^{\text{true}} \right] \text{ vs. } p_t^{\text{true}} \text{ (GeV/c)} \]
Square pad resolution

- azimuthal dependence: track length

\[ p_t < 0.8 \text{ GeV} \rightarrow p_t \text{ and } \phi \text{ independent} \]

\[ \sigma \left( \frac{p_t^{\text{fit}} - p_t^{\text{true}}}{p_t^{\text{true}}} \right) \text{ vs. } \phi \text{ (degrees)} \]
Performance summary

- Design goal resolution achieved at $B = 0.2 \, T$ with relatively large pads ($8 \, mm \times 8 \, mm$)
  - resolution improves with smaller pads
- resolution is achieved for:
  - a wide range of diffusion values
  - different neutrino interaction points
  - a wide range of pre-amp gain levels
  - large channel to channel gain differences
  - large electronics noise
Construction plans:

- **Now:**
  - complete designs of prototypes, begin construction
  - begin ASIC design

- **Fall 2005:**
  - complete prototype construction, begin tests

- **Spring 2006:**
  - design review
  - begin production of full scale modules

- **Fall 2008:**
  - complete construction
Summary

- TPC project is progressing well
- Several prototype efforts are planned to test all components
- Design of the DAQ system (incl. ASIC) is underway
- Full simulation & reconstruction indicates that the design concept can achieve the performance goals
- Need to keep the momentum!
T2K TPC Feasibility Report
December 6, 2004

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