The T2K TPC

Dean Karlen
TPC Applications Workshop
April 7, 2006
LBNL
Outline

● Introduction:
  ● T2K experiment – physics goals
  ● Purpose of the near detector (ND280)
  ● TPC performance requirements

● T2K TPC concept

● Canadian T2K TPC prototype
  ● design, construction, first results

● T2K TPC endplate R&D in Europe

● Summary and outlook
T2K physics program

- The proton beam from the 50 GeV synchrotron under construction at JPARC will be used to produce an intense neutrino beam directed to the Super Kamiokande detector (295 km away)
  - measurement of $\nu_\mu$ disappearance to improve accuracy for:
    \[
    \sin^2 2\theta_{23} \rightarrow \approx 1\% \quad \Delta m^2_{23} \rightarrow \approx 2\%
    \]
  - measurement of $\nu_e$ appearance to improve sensitivity to $\sin^2 2\theta_{13}$ by an order of magnitude
T2K neutrino beamline

- Uses off-axis principle
  - select angle corresponding to oscillation maximum

![Graph showing neutrino flux](image)

![Map of T2K neutrino beamline](image)
Purpose of the near detector

- $\nu_\mu$ disappearance:
  - flux and spectrum of $\nu_\mu$ prior to oscillation
    - measure momenta of muons from CCQE
  - study processes that SK will misinterpret and assign an incorrect $\nu_\mu$ energy
    - reconstruct events in much greater detail than SK

- $\nu_e$ appearance:
  - flux and spectrum of $\nu_e$ in beam
    - identify electrons from CCQE
ND280 group (www.nd280.org)

- Canada
  - UBC, Regina, Toronto, Victoria, TRIUMF, York
- France
  - CEA/Saclay
- Italy
  - Bari, Napoli, Padova, Rome
- Japan
  - Hiroshima, KEK, Kobe, Kyoto, ICRR, Tokyo
- Korea
  - Chonnam, Dongshin, Kangwon, Kyungpook, Gyeongsang, Sejong, Seoul, SungKyunKwan
- Russia
  - INR Moscow
- Spain
  - Barcelona, Valencia
- Switzerland
  - Geneva
- United Kingdom
  - Imperial, Lancaster, Liverpool, Queen Mary, CCLRC, Sheffield, Warwick
- United States
  - Louisiana State, Stony Brook, Rochester, Washington
ND280 off axis detector: overview

- UA1 magnet provides 0.2 T B field
- inner volume: $3.5 \times 3.6 \times 7.0$ m$^3$
- front optimized for $\pi^0$ from NC
- rear optimized for CC studies
- surrounded by ECAL and muon detector
Tracker - TPC

- use MPGD amplification with $8 \times 8$ mm$^2$ pads
- width of active volume: $\sim$600 mm per module
  - detailed full simulation:
    - full reconstruction: $\delta p/p < 10\%$ for $p < 1$ GeV/c
      - corresponds to roughly 0.7 mm resolution per row of pads
    - $dE/dx$ resolution: $\sim 7\%$
      - sufficient for $\mu$ / e separation
Pad geometry studies

- use non-staggered 8 mm square pads:

  8 mm w/ stagger

  8 mm no stagger

  6 mm w/ stagger

10% pt resolution achievable

$\phi$ (degrees)

$p_t$ (GeV/c)

$p_t < 0.8$ GeV/c
Tracker – $\nu_\mu$ CC event

Event No.: 24  Reaction code: 1  Position in File: 24

Primary Vertex [mm]: (-423, 53, 808)

Located in
Basket_0/TRK_0/Active_1/ScintX1_136/bar_37278

Informational particles
$\nu_\mu$ $\times 14$  Trk -1,  KE= 1340 MeV
$\bar{n}$ $\times 2112$  Trk -1,  KE= 0 MeV

Primary particles
$\mu^-$ $\times 13$  Trk 1,  KE= 938 MeV
$p$ $\times 2212$  Trk 2,  KE= 170 MeV
$n$ $\times 2112$  Trk 3,  KE= 72 MeV
$p$ $\times 2212$  Trk 4,  KE= 12 MeV
$p$ $\times 2212$  Trk 5,  KE= 3 MeV
$p$ $\times 2212$  Trk 6,  KE= 3 MeV
$\gamma$ $\times 22$  Trk 7,  KE= 6 MeV
Tracker – $\nu_e$ CC event

Event No.: 13  Reaction code: 1  Position in File: 13
Primary Vertex [mm]: (423, 543, 985)
Located in
Basket_0/TRK_0/Active_1/ScintX1_145/bar_39527

Informational particles
- $\nu_e$ (12)  Trk -1,  KE= 2893 MeV
- n (2112)  Trk -1,  KE= 0 MeV

Primary particles
- $e^-$ (11)  Trk 1,  KE= 2578 MeV
- n (2112)  Trk 2,  KE= 46 MeV
- p (2212)  Trk 3,  KE= 15 MeV
- p (2212)  Trk 4,  KE= 117 MeV
- p (2212)  Trk 5,  KE= 86 MeV
- p (2212)  Trk 6,  KE= 14 MeV
- $\gamma$ (22)  Trk 7,  KE= 4 MeV
TPC concept – Gas choice

- A low diffusion gas would be used, since the magnetic field is relatively weak (0.2 T)
  - Initial choice: Ar CO₂ (90:10), with a drift field of about 200 V/cm
  - Higher concentrations of CO₂ reduce the diffusion, but require higher drift fields and lower O₂ concentration
    - Concept designed to work at 400 V/cm
  - Other gas mixtures also under consideration
TPC concept – Field cage

- Field cage needs to be robust to survive the transport to Japan
  - ruled out suspended strip design of ALICE, NA49
  - use field strips on wall, like STAR or ALEPH
  - simplified construction using light-weight composite laminate
    - Cu/G10-rohacell-Cu/G10
    - use router to accurately machine strips on the inner box walls from the copper clad G10 surface.

- Follow the box within a box approach of ALICE, STAR
  - reduces O₂ contamination, provides thermal insulation
  - safe electrical insulator – cannot be permanently broken
  - FEA field calculations show that inner box should have aligned strips on both sides of the walls
Field cage concept

- Gas Envelope
- Inner Wall
- Central Cathode
- Drift Volume
- Fieldforming Strips
Full scale tracker concept

THREE TPC MODULES WITH TWO FGD UNITS FOR THE ND280 EXPERIMENT
Full scale TPC module concept
Full scale TPC module concept
T2K TPC Electronics

- The readout electronics are being designed and constructed by the SACLAY group
  - funding approved
  - custom ASIC – 0.35 um technology (60 mm²)
  - each chip: 72 SCA pipelines with 512 buckets
  - commercial ADC (off chip)
  - fully adjustable: polarity, preamp gain, shaping time, sampling frequency
  - 3 mW/channel (3.3 V)
  - 200 e + 10 e/pF (at 1 us)
- first run chips available Spring/Summer 2006
Prototype TPC

- To test the T2K TPC concept, a prototype was designed and constructed in 2005 in Canada.
Prototype construction

- Composite walls (outer walls) – gluing technique
Prototype construction

● Outer box glued in a heated tent in clean room
Prototype construction

- Inner box walls with field strips and matched surface mount resistors
- Jumpers through the wall
Prototype construction

- Rounded corners for inner box being installed
Prototype construction

● Central cathode connection
Prototype construction

- Completed TPC field cage/gas containment
Prototype construction

- A look inside:
  - Al strip pattern for laser calibration
Prototype construction

- GEM module preparation
Prototype construction

- Alignment and gluing
Prototype construction

- GEM stack
Prototype construction

- attaching the wire grid
Prototype construction

• inserting in test box
Prototype construction

- GEM modules inserted into TPC
Prototype construction

- connections/telescope
Prototype construction

- ALICE FECs
  - signal inverters
DAQ for prototype

The table shows the status of the MIDAS experiment "tpcexpt" on April 7, 2006.

<table>
<thead>
<tr>
<th>Equipment</th>
<th>FE Node</th>
<th>Events</th>
<th>Event rate[s]</th>
<th>Data rate[kB/s]</th>
<th>Analyzed</th>
</tr>
</thead>
<tbody>
<tr>
<td>EVB</td>
<td><a href="mailto:mevb@ladd01.triumf.ca">mevb@ladd01.triumf.ca</a></td>
<td>1851</td>
<td>0.0</td>
<td>0.0</td>
<td>100.0%</td>
</tr>
<tr>
<td>TPC01</td>
<td><a href="mailto:fetcpc01@ladd01.triumf.ca">fetcpc01@ladd01.triumf.ca</a></td>
<td>1851</td>
<td>0.2</td>
<td>424.9</td>
<td>0.0%</td>
</tr>
<tr>
<td>TPC02</td>
<td><a href="mailto:fetcpc02@ladd01.triumf.ca">fetcpc02@ladd01.triumf.ca</a></td>
<td>1851</td>
<td>0.2</td>
<td>425.7</td>
<td>0.0%</td>
</tr>
<tr>
<td>TPCcheck01</td>
<td><a href="mailto:fetcpc01@ladd01.triumf.ca">fetcpc01@ladd01.triumf.ca</a></td>
<td>0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0%</td>
</tr>
<tr>
<td>TPCcheck02</td>
<td><a href="mailto:fetcpc02@ladd01.triumf.ca">fetcpc02@ladd01.triumf.ca</a></td>
<td>0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0%</td>
</tr>
</tbody>
</table>

- **Channel**: 0 run00515.mid
  - **Active**: Disabled
  - **Events**: 0
  - **MB written**: 0.000
  - **GB total**: 338.404

**21:00:37 [mhttpd] Run #522 started**

- mhttpd [ladd01.triumf.ca] - Logger [ladd01.triumf.ca] - fetcpc01 [ladd01.triumf.ca]
- mevb [ladd01.triumf.ca] - fetcpc02 [ladd01.triumf.ca] - Analyzer [ladd01.triumf.ca]
Prototype HV system

- inexpensive DCC controls gain of each GEM separately (DCCs outside TPC)
- identical potential for upper surfaces of GEMs – better field uniformity
- no resistor dividers – nominally no currents, voltages can be specified
Prototype HV system

DCC on a custom board

HV box with voltage and current displays
Prototype gas system

- Gas mix maintained by mass flow controllers
- $O_2$ filter for inner volume gas - monitored at inlet and outlet
Example event from prototype

coloured according to amplitude

coloured according to arrival time

Example event from prototype.

Run 475, event 21.
A movie of all cosmic triggers (no selection applied)

pads coloured according to arrival time
Track Fit

- Likelihood analysis
- estimate includes sigma: the width of the signal distribution on the pads
Gas properties

- Diffusion measured from width of ionization – and its dependence on drift distance

<table>
<thead>
<tr>
<th>sample</th>
<th>offset</th>
<th>slope</th>
<th>defoc.</th>
<th>diffusion</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>mm²</td>
<td>mm²/tb</td>
<td>mm</td>
<td>um/sqrt(cm)</td>
</tr>
<tr>
<td>9s2a</td>
<td>0.32</td>
<td>4.26E-03</td>
<td>0.57</td>
<td>182.4</td>
</tr>
<tr>
<td>11s2a</td>
<td>0.51</td>
<td>4.44E-03</td>
<td>0.71</td>
<td>186.2</td>
</tr>
<tr>
<td>9mc</td>
<td>0.13</td>
<td>4.72E-03</td>
<td>0.36</td>
<td>190.5</td>
</tr>
<tr>
<td>11mc</td>
<td>0.15</td>
<td>5.14E-03</td>
<td>0.39</td>
<td>198.8</td>
</tr>
</tbody>
</table>
Attachment

Use truncated mean of dE/dx vs drift time
  • reproduces attachment inserted into MC simulation
  • e lifetime is only 200 us with negligible O₂
  • starting “canary chamber” study to identify culprit

<table>
<thead>
<tr>
<th>sample</th>
<th>e lifetime</th>
<th>equiv O₂</th>
<th>meas O₂</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>us</td>
<td>ppm</td>
<td>ppm</td>
</tr>
<tr>
<td>set 3a</td>
<td>61</td>
<td>84</td>
<td>60-80</td>
</tr>
<tr>
<td>set 2b</td>
<td>142</td>
<td>36</td>
<td>10-15</td>
</tr>
<tr>
<td>set 2a</td>
<td>190</td>
<td>27</td>
<td>&lt;5</td>
</tr>
<tr>
<td>set 3e</td>
<td>200</td>
<td>26</td>
<td>&lt;1</td>
</tr>
<tr>
<td>set 1</td>
<td>190</td>
<td>54</td>
<td>?</td>
</tr>
</tbody>
</table>
Spatial resolution

- Resolution depends on number of pads hit in a row
  - 1 hit rows occur most often when track passes over the centre of a pad:
Spatial resolution

Resolution for different numbers of pads hit:

- \( n = 1 \)
- \( n = 2 \)
- \( n = 3 \)
Spatial resolution

Comparison with MC:

<table>
<thead>
<tr>
<th>data set</th>
<th>trans field</th>
<th>frac n=1</th>
<th>frac n=2</th>
<th>res n=1 (mm)</th>
<th>res n=2 (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MC</td>
<td>V/cm</td>
<td>36%</td>
<td>63%</td>
<td>1.44</td>
<td>0.55</td>
</tr>
<tr>
<td>2a</td>
<td>800</td>
<td>21%</td>
<td>74%</td>
<td>1.13</td>
<td>0.64</td>
</tr>
<tr>
<td>3b</td>
<td>600</td>
<td>27%</td>
<td>71%</td>
<td>1.28</td>
<td>0.65</td>
</tr>
<tr>
<td>3e</td>
<td>800</td>
<td>18%</td>
<td>78%</td>
<td>1.09</td>
<td>0.64</td>
</tr>
<tr>
<td>3d</td>
<td>1000</td>
<td>11%</td>
<td>79%</td>
<td>1.22</td>
<td>0.60</td>
</tr>
</tbody>
</table>

1 pad fraction depends strongly on transfer fields

bigger effect than expected from the diffusion differences alone – still to be investigated
Spatial resolution

- Comparison with MC looks favourable
  - resolution (mm) vs azimuthal angle (rad)

Monte Carlo

- data: 2a
- data: 3d
Large Area GEM suppliers

- CERN GEMs used for prototype – a year ago it was not clear whether they could produce enough GEMs for the T2K TPC modules
  - Two US companies, TechEtch and 3M, have made GEMs for us similar to the CERN GEMs
European T2K TPC endplate R&D
(from summary talk by T. Lux)

SACLAY/INFN/Barcelona/Geneva

Field cage:
- used in the HARP experiment
- ca. 150 cm long
- ca. 80 cm diameter

Magnet: 0-0.7 T (part time available)
European T2K TPC endplate R&D
European T2K TPC endplate R&D

design of a micromegas module

- design of the endplate with two micromegas modules
Micromegas Endplate

from inside

from outside
GEM Endplate

- Sandwich type mounting
- 3 GEM+frame and guard frame screwed on pad plane from inside the chamber
- Guiding pins through frames of all 3 GEM planes
- Dimensions determined by availability of a batch of LHCb GEMs → 24x20 cm sensitive area
GEM Endplate
Measurements with Micromegas

- Data taken from Nov 8 to Nov 30
- 2 Gases: Ar-CF4(3%)-C4H10(2%) and Ar-CO2(10%)
- ≈250k triggers registered
- B=0, 0.2, 0.3 and 0.4 T (Ar-CF4(3%)-C4H10(2%) only)
- 48 rows instrumented (=12 Alice FEC, 1536 ch), track length 40cm
Measurements with Micromegas
Attachment (MM)

Ar-CF4-C4H10

Attenuation length > 33m

Ar-CO2

Attenuation length: 3.4m
Resolution Studies (MM)

Little information in clusters with one pad hit.
Distribution integrated over z. Need to study residuals vs z

Res 1 pad
σ 1800 μm

Res 2 pad
σ 610 μm

Res 3 pad
σ 856 μm
Measurements with GEMs

- data taking with two different gases: P5 (only 2 days) and ArCO₂ (10/5 days)
- 48 rows, 31 rows instrumented (12 Alice FECs), part time only 24 rows read out
- no magnetic field measurements
Loss of one Sector (GEM)

- shortly after the first tracks a spark occurred during ramping up the system (no voltage was applied across the GEMs)
- one GEM in the top GEM sector not operable afterwards
- operation of bottom GEM tower was still possible (and there was no spark at all afterwards)

⇒ data taking with only one GEM tower during the first data taking period
Broken GEM

- afterwards dismantling of the GEM module
- but no obvious reason for the short was detected
- after inspecting the short disappeared and the GEM could be ramped up again to 500 V (but was replaced)

⇒ Most probably tiny particle between GEM and pad plane

Quality test procedure has to be reviewed
Measurements (GEM)

- wonderful straight tracks over both sectors
- whole procedure was done within 2 days by 2 persons
- and the best: no sparks at all afterwards!
- data will be analysed soon (data taking ended last Friday!)}
Attachment (GEM)

<table>
<thead>
<tr>
<th>$\chi^2$/ndf</th>
<th>46.90 / 15</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>7.320 ± 0.8651E-02</td>
</tr>
<tr>
<td>Slope</td>
<td>-0.4946E-03 ± 0.9028E-05</td>
</tr>
</tbody>
</table>

2 runs with and without delay directly taken one after the other

2 runs with 3 days and 2 gas bottle changes in between
Cuts:
1. Only 2 and 3 hit clusters
2. $\varphi_{\text{track}} < 0.1$ rad

Clusters included in the fit
Refitting of the track

RMS

$\approx 420 \, \mu m$
Summary and outlook

- Successful T2K TPC prototype tests
  - spatial resolution goal achieved
  - need to understand attachment – further studies underway
  - collaboration to decide on GEM vs MM soon…

- Funding coming in place
  - Canada and SACLAY groups have secured funding
  - Geneva and Spanish groups

- Next steps:
  - Full size module 0 in 2006
  - Three production modules in 2007-2008
  - Installation in Japan early 2009