The T2K TPCs

Claudio Giganti
IRFU-CEA Saclay

On behalf of the T2K TPCs working group:

Canada  
University of British Columbia
University of Victoria
TRIUMF

France  
IRFU-CEA Saclay
LPNHE Paris-VI-VII universities

Germany  
RWTH Aachen

Italy  
INFN

Spain  
UAB/IFAE University of Barcelona
University of Valencia

Switzerland  
University of Geneva
The T2K experiment

- Long Baseline Neutrino oscillation experiment
  - The neutrino beam started in April 2009
  - The data taking with all the ND280 facility installed will start in December 2009
- 30 GeV proton accelerator will be used to produce a $\nu_\mu$ beam that will be sent from Tokai to SuperKamiokande
  - $L = 295$ Km
  - Mean neutrino energy $E_\nu = 0.7$ GeV (where the maximum of the oscillation is expected)
- Search for $\nu_e$ appearance $\Rightarrow$ Improve the actual limit on $\theta_{13}$ by 1 order of magnitude
- $\nu_\mu$ disappearance $\Rightarrow$ Precise measurement of $\theta_{23}$ and $\Delta m^2_{23}$
The Near Detector and the TPC

- Near Detector complex at 280 meters from the proton target
- Several detectors inside the UA1 magnet (with a field of 0.2 T)
  - Characterize neutrino beam (before the oscillations)
  - Measure $\nu_e$ contamination in the beam
  - Study background process to oscillation signal

- Tracker system (TPC + FGD):
  - $\nu_\mu$ and $\nu_e$ fluxes and spectra
  - Measure neutrino cross section
- 3 large TPCs
  - Excellent pattern recognition to distinguish the different interactions
  - Measure the charge and the momenta of the charged particles
  - Particle Identification: distinguishing electrons/muons and pions/protons
TPCs design

- Double wall structure:
  - Inner volume walls create the drift field
  - Outer volume for gas/HV insulation
  - Sensitive volume: 180 x 200 x 70 cm
  - Total active area of ~9 m²
- Gas mixture: Ar/CF₄/iC₄H₁₀ (95/3/2)
  - Fast gas:
    - \( v_d \sim 7.9 \text{ cm/μs} @ 280 \text{ V/cm} \)
  - Low transverse diffusion:
    - \( D_t \sim 270 \text{ μm/√cm} @ 280 \text{ V/cm} \) → good spatial resolution
- Electron amplification provided by MicroMegas
- A Laser system is installed to provide real time calibration during the operations

- TPC physics requirements:
  - \( δp/p < 10\% @ 1\text{GeV} \) to reconstruct neutrino energy spectrum
  - dE/dx resolution better than 10\% to perform electron/muon separation
  - Energy scale to be controlled at the 2%
Readout plane: Bulk MicroMegas

- **Signal Amplification:**
  - 12 large (35x36 cm²) bulk-MicroMegas on each endplate → **72 modules** in 3 TPCs
  - Each module has 1726 active pads (6.9x9.7 mm)
  - Pads arranged in 36 columns and 48 rows
  - Total of ~**120 000 channels**
  - Produced @ CERN/TS-DEM-PMT, tested and validated in a test bench at CERN

- **Readout electronic:**
  - ASIC AFTER (72 channels) with programmable gain, sampling time…
  - 6 FEC + 1 FEM on each module
Construction status

- Assembling and integration undergoing at TRIUMF
  - **Module 0:**
    - Construction completed
    - Fully equipped
    - Beam test completed
    - Shipped to Tokai
  - **Module 1:**
    - Construction completed
    - Fully equipped
    - Beam test currently undergoing
    - Will be shipped to Tokai in August
  - **Module 2:**
    - Under construction
    - Sent to Tokai by the end of the year
Beam test with TPCs

- The TPC Mod0 and Mod1 underwent beam tests in the M11 area at TRIUMF
- The beam provides e, μ, π with a momentum up to 400 MeV/c
- A Time Of Flight system provides e, μ, π tagging
- Each track crosses 2 MicroMegas modules
Tracks in the TPC Module 0

- Beam track on 2 MM modules (with a $\delta$ ray)

- Cosmic on the full endplate

We used these data to study the TPC performances in terms of:

- Energy resolution $\rightarrow$ Particle Identification
- Spatial resolution $\rightarrow$ Momentum resolution
M11 results: Energy loss

- One of the main purposes of the TPCs is the Particle Identification
- The PID is based on the deposited energy by the charged particles
- This distribution is broad due to the Landau tails

- A truncated mean method is used to exclude the tails:
  - Order the charge per column $C_C$ as a function of increasing charge

\[
C_T = \frac{1}{\alpha N} \sum_{i} C_C(i)
\]

- $C_T$ has a Gaussian distribution with a resolution $< 8\%$

\[
\alpha = 0.7
\]

<table>
<thead>
<tr>
<th>Charge per column data</th>
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Electrons

<table>
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<tr>
<th>Muons</th>
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Energy resolution

- Good agreement between data and MC
- ~40% separation between electrons and muons \( \rightarrow \) We need a resolution better than 10% to distinguish them
- Energy resolution better than 9% for all the momenta
- Electron/Muon separation better than 5\( \sigma \) if the momentum is larger than 200 MeV
Spatial resolution

- The spatial resolution is defined by the residual distribution:
  - Distance column by column between the center of mass of the charge and the track’s fit position
  - The resolution is better if more than one pad are illuminated

- Spatial resolution in M11 data:
  - 650 μm @ 75 cm of drift dist
  - Good agreement with previous results with MicroMegas prototypes (NIM 602(2): 415-420)
  - Will allow to meet the requirements for the momentum resolution
    - (δp/p < 10% @ 1 GeV)
Conclusions

- The 3 TPCs are one of the key elements of the T2K Near Detector
  - The Module 0 is ready, fully equipped and has already been received in Japan
  - The Module1 is ready, fully equipped and is under beam test at TRIUMF
  - The Module 2 is under construction and will be sent to Tokai by the end of the 2009
  - T2K will start the data taking in December 2009

- The beam tests performed at TRIUMF showed that the TPCs meet the requirements:
  - Energy resolution better than 8% for a MIP
  - Electron/Muon separation better than $5\sigma$ @ $p>200$ MeV
  - Spatial resolution of $650 \, \mu m$ @ 75 cm $\rightarrow \delta p/p < 10\%$ @ 1 GeV
Back up slides
Neutrino mixing

\[
\begin{pmatrix}
\nu_e \\
\nu_\mu \\
\nu_\tau
\end{pmatrix} =
\begin{pmatrix}
1 & 0 & 0 \\
0 & \cos \theta_{23} & \sin \theta_{23} \\
0 & -\sin \theta_{23} & \cos \theta_{23}
\end{pmatrix}
\begin{pmatrix}
\cos \theta_{13} & 0 & \sin \theta_{13} e^{-i\delta} \\
0 & 1 & 0 \\
-\sin \theta_{13} e^{-i\delta} & 0 & \cos \theta_{13}
\end{pmatrix}
\begin{pmatrix}
\cos \theta_{12} & \sin \theta_{12} & 0 \\
-\sin \theta_{12} & \cos \theta_{12} & 0 \\
0 & 0 & 1
\end{pmatrix}
\begin{pmatrix}
\nu_1 \\
\nu_2 \\
\nu_3
\end{pmatrix}
\]

\[
P(\nu_\mu \rightarrow \nu_\mu) \approx 1 - \cos^4 \theta_{13} \sin^2 2\theta_{23} \sin^2 (1.27 \Delta m^2_{23} L/E_\nu)
\]

\[
P(\nu_\mu \rightarrow \nu_e) \approx \sin^2 2\theta_{13} \sin^2 (1.27 \Delta m^2_{13} L/E_\nu)
\]
The Bulk MicroMegas

- The Bulk MicroMegas is a technology developed at CERN/Saclay
- Sandwich of:
  - 3 photo-imageable insulator layer (Pyralux) of 64 μm each
  - 1 steel mesh with a width of 2.4 mm and 2 layers (x,y) of 19 μm wires
- The sandwich is laminated on the PCB, exposed to UV, cleaned-heat-dried 2-3 times and then after a global QC test it’s cut to the final dimensions
- Total thickness 19.5 mm
- Advantages:
  - Steel mesh → Robustness
  - Large area can be produced
  - Less dead zones on the edge
  - Better gain uniformity in the corners
TPC Module 0 @ TRIUMF

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18th July 2009
Installation of the electronic on the TPC

Module 0 is now fully equipped with 24 MicroMegas and all the Front-End electronic
Energy resolution in the MicroMegas

- Muons, $p = 150$ MeV/c, energy resolution in the 2 MM modules

Res $1^{st}$ MM = 10.0%
Res $2^{nd}$ MM = 9.4%
Res all TPC = 6.9%
Resolution for different particles

- With the TOF system we selected samples of electrons, muons and pions for a given momentum
- TPC horizontal, $p = 150$ MeV/c

At 150 MeV/c we can clearly see 3 different peaks

- **e⁻ res = 5.6%**
  - Entries: 179
  - Mean: 4995
  - RMS: 30.0
  - $\chi^2$/ndf: 13.03 / 20
  - Prob: 0.4798
  - Constant: 15.96 ± 1.73
  - Mean: 4975 ± 23.9
  - Sigma: 244 ± 11.2

- **μ res = 6.9%**
  - Entries: 154
  - Mean: 4995
  - RMS: 346.4
  - $\chi^2$/ndf: 26.29 / 25
  - Prob: 1.0697
  - Constant: 4577 ± 2.50
  - Mean: 4567 ± 14.1
  - Sigma: 310 ± 15.4

- **π res = 6.7%**
  - Entries: 165
  - Mean: 4229
  - RMS: 634.0
  - $\chi^2$/ndf: 32.88 / 24
  - Prob: 6.1086
  - Constant: 28.8 ± 2.6
  - Mean: 2200 ± 37.2
  - Sigma: 422.8 ± 34.3
M11 data pressure dependence

- The gain of the MicroMegas depends on the external pressure
- This dependence can be seen analyzing runs taken at the same conditions and with different external pressure
- Useful runs in the night of 22nd November, $P = 300$ MeV/c
  - Pressure variation from $\sim 1001$ mbar to $\sim 1007$ mbar

- $\Delta g = 3.3 \pm 0.6 \%$ for $\Delta p = 1\%$
- During previous MicroMegas test, with a $^{55}$Fe source, we found $\Delta g = 3.1 \pm 0.3 \%$ for $\Delta p = 1\%$
Laser calibration system

- In situ field distortion calibration
- Targets placed on the central cathode, positions surveyed by router (accuracy better than 100 $\mu$m)
- The targets, illuminated with UV laser light, emit photoelectrons that are then collected on the MicroMegas plane
MicroMegas tests in the HARP field cage

Residual width vs drift distance

- $B = 0 \, T$
- $B = 0.2 \, T$

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18th July 2009
**History of tests**

- **Oct. 2007**
  - TPC 0 construction

- **Sep. 2008**
  - Test CERN 2007 with a MM prototype in the HARP field cage

- **Nov-Dec. 2008**
  - Beam test TPC 0 with 2 MM modules with their FE

- **March 2009**
  - Beam test TPC 0 (TRIUMF) with 12 MM modules with 3.5 equipped with FE

- **April 2009**
  - TPC 1 construction

- **July 2009**
  - TPC 2 construction

- **July 2009**
  - Cosmic test TPC 0 (TRIUMF) with 24 MM modules with their FE

- **March 2009**
  - Beam and cosmic tests TPC 1 with 24 MM

- **Start of the T2K experiment Dec. 2009**

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