The particle identification in the T2K TPC

Claudio Giganti
IRFU-CEA Saclay

T2K TPC group: CERN/TS-DEM-PMT, INFN, IRFU-CEA Saclay, LPNHE University of Paris VI-VII, RWTH Aachen University, TRIUMF, University of British Columbia, UAB/IFAE Barcelona University, University of Geneva, University of Victoria, and Valencia University
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)
- $\nu_e$ appearance $\rightarrow$ First measure of $\theta_{13}$
- $\nu_\mu$ disappearance $\rightarrow$ Precise measurement of $\theta_{23}$ and $\Delta m^2_{23}$
First T2K neutrino beam

- The T2K neutrino beam is in the commissioning phase
- On April 23rd the proton beam has been extracted and sent to the target → The first T2K neutrinos has been produced!

\[ p + N \rightarrow \pi^{+} \rightarrow \mu^{+} + \nu_{\mu} \]

- Muons produced with neutrinos have been detected in the Muon Monitor
- Many neutrinos to detect in the next months/years!
- Many physics to do…
The Near Detector and the TPC

- Near Detector complex at **280 meters** from the neutrino beam production point
- 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

- **3 large TPCs**
- Long drift distance (**90 cm**)
- Total active area ~**9m²**

Requirements:
- $\delta p/p < 10\% @ 1\text{GeV}$ to reconstruct neutrino energy spectrum
- **dE/dx resolution better than 10%** to perform electron/muon separation
Readout plane

**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 are arranged in 36 columns and 48 rows
- Total of ~120 000 channels
- MM are produced **CERN/TS-DEM-PMT** and are 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
The MicroMegas principles

- Charged particles crossing the TPC ionize gas molecules
- The produced electrons drift to the MicroMegas mesh
- Once on the mesh the \( \text{e}^- \) enter in the amplification region where avalanches are generated
  - Gain \( \sim 10^3 - 10^4 \)
  - \( \sim 100\% \) collection efficiency (if drift/amplification field is high enough)
  - Small gap \( \rightarrow \) short rise time
- Ions flow back to the mesh
  - Only few ions permil go back to the drift space
  - Avoids space charge effects
Particle Identification in the TPC
The Particle Identification in the TPC

- The TPCs are able to recognize different particles using measurements of the energy loss in the gas
  - The main purpose of this measurement is to distinguish electrons from muons → Measure the $\nu_e$ contamination in the beam, one of the main backgrounds to the measurement of $\theta_{13}$ via $\nu_e$ appearance
- We developed a method to perform the PID using MC simulation
- We tested this method using the beam test of the TPC Module 0
- The PID is based on the measurement of the truncated mean of the track crossing the TPC
The track is reconstructed fitting along the TPC the charge contained in each MM column. This charge is usually distributed on 1, 2 or 3 pads. The charge distribution in each column is large and not gaussian.
For each reconstructed track that crosses all the TPC we have 72 measurements of energy (36 in each MM module)

We measure the truncated mean of the charge for each track, selecting the 70% of the clusters with less charge (to reject Landau tails)

$$C_T = \frac{1}{\alpha N} \sum_i C_C(i)$$

We also need to parameterize corrections for the track angle and for the number of samples

- Gaussian distribution
- Resolution ($\sigma$/Mean) $\sim$6.6%
Parameterization of the expected energy loss curve

- The energy loss in the gas is a function of only $\beta\gamma$
- Producing samples of different particles (electrons, muons, protons) we parameterized the expected curve of the energy loss

Knowing the parameterization for each track:
- Measure the momentum $P$
- Measure the trun mean $C_T$
- Compare $C_T$ with $C_E$ for a particle of momentum $P$ and mass $M_i$ (i.e., $e$, $\mu$, $\pi$, $p$, $K$)
Corrections for number of samples and gap

- The energy loss depends also from the number of samples that we used to perform the measurement and from the path of the particle into each pad.
- To check the effect of the sample number we used the same horizontal muons and we computed the energy loss using only different numbers of columns (from 24 to 72).
- To check the effect of the different sample length we produced muons with different angles into the TPC and we analyzed their energy loss.
Sample number correction

- Important correction for tracks that exit from the TPC

**Truncated mean**

\[ \Delta C_T = 1 + p_0 \cdot (72 - N) + p_1 \cdot (72 - N)^2 \]

**Sigma**

\[ \sigma = e^{(C + A \cdot N_{row})} \]
Sample length

- In the case of bented tracks is not sufficient to simply correct for the angle of the track

\[
dE / dx_{\text{true}} = dE / dx_{\text{meas}} \cdot \sqrt{\frac{1}{1 + \tan^2(\vartheta_{xz}) + \tan^2(\vartheta_{yz})}}
\]

- With the truncated mean method we basically perform a measurement of the peak of the distribution of the energy lose that doesn’t scale linearly with the angle

- To study this effect we produced some samples of muons with different gap and we studied the energy release
Sample length corrections

With these bent muons we confirmed that the truncated means and the sigma depends by the gap and we parameterized this dependence

$$\Delta C_T = 1 + p_0 \cdot (d - d_0) + p_1 \cdot (d - d_0)^{-}$$

$$\sigma = p_0 + p_1 \cdot d$$
Simulation of neutrino interactions

- To quantify the PID we define a pull variable

\[ P^j(i) = \frac{C_T(i) - C_E^j(i)}{\sigma_E^j(i)} \quad j = e, \mu, \pi, p, K \]

- The distribution of the pull for a given particle in the right hypothesis is a gaussian centered in 0 with width 1

Looking at the pull in the electron hypothesis we can distinguish \( \nu_e/\nu_\mu \) interactions.
Results of the Beam Test
TPC Module 0 @ TRIUMF

Dead zones between 2 modules

Δy = 7.7 mm

Δz = 21 mm

Internal face

Cathode

Module frame

Dead zones between 2 modules
Installation of the electronic on the TPC

Module 0 is now fully equipped with 24 MicroMegas and all the Front-End electronic
Beam test with Module 0

- Starting from September the Mod 0 has been installed in the M11 beam line 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 module
Some tracks from module 0 tests

- Beam track on 2 MM modules (with a $\delta$ ray)
- Cosmic on the full endplate
Purpose of these studies

- The beam test have been used to check the capabilities of the T2K TPC

- In particular we used the beam test data to:
  - Study the energy resolution of the TPC
  - Test the PID method

- We took data with different momenta (from 100 MeV/c to 350 MeV/c)

- For each reconstructed track we measured the truncated mean

- The TOF allowed to select samples of different particles independently from the TPC response
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, $p = 150 \text{ MeV/c}$

At 150 MeV/c we can clearly see 3 different peaks
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, \( P = 300 \text{ MeV/c} \)
  - Pressure variation from \( \sim 1001 \text{ mbar} \) to \( \sim 1007 \text{ mbar} \)

\[ \Delta g = 3.3 \pm 0.6 \% \text{ for } \Delta p = 1\% \]

During previous MicroMegas test, with a \(^{55}\text{Fe}\) source, we found
\[ \Delta g = 3.1 \pm 0.3 \% \text{ for } \Delta p = 1\% \]
Energy loss vs momentum

- Selecting particle with the TOF we computed the $C_T$
- Compared the obtained curve for $\mu$, $\pi$ and $e$ with the expected one from the MC studies $\rightarrow$ good agreement
e/μ separation

Resolution for muons better than 8%
Separation larger than 5σ if the momentum is larger than 200 MeV

The TOF cannot distinguish muons from pions

Resolution for muons better than 8%
Separation larger than 5σ if the momentum is larger than 200 MeV
Conclusions

- We developed methods to perform the PID in the TPC and we tested them with the data taken in the beam test
  - The method is based on measuring the truncated mean for each track
  - It allows to recognize different particles according to their energy loss
  - Energy resolution for muons better than 8% in both, data and MC
  - $e/\mu$ separation better than $5\sigma$ if the momentum is larger than 200 MeV
  - This will allow to measure the $\nu_e$ contamination in the T2K beam
- The T2K TPCs are under construction at TRIUMF
  - The Module 0 is ready, fully equipped and is taking data in a beam test, the others 2 modules will come soon
  - With the data taken in the Module 0 beam test we successfully tested the PID method
  - The TPCs will be installed in the summer/fall 2009 T2K will start the data taking in December 2009
Back up slides
History of tests

Oct. 2007

TPC 0 construction

Test CERN 2007 with a MM prototype in the HARP field cage

Beam test TPC 0 (TRIUMF)
2 MM modules with their FE

Sep. 2008

Beam test TPC 0 (TRIUMF)
12 MM modules with 3.5 equipped with FE

Nov-Dec. 2008

TPC 1 et 2 construction

Cosmic test TPC 0 (TRIUMF)
24 MM modules with their FE

March 2009

TPC 1 et 2 construction

Start of the T2K experience Dec. 2009

March 2009

Beam test TPC 0 with 24 MM
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