

The test beams of the T2K TPC

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Abstract. T2K is a long baseline neutrino experiment that will search for $\nu_\mu \rightarrow \nu_e$ oscillation. A near detector complex (ND280) will be installed at 280 meters from the neutrino production point and will be used to measure the neutrino energy spectrum, flavor content and neutrino cross-sections of the unoscillated neutrino beam. ND280 includes three large TPCs based on bulk-MicroMegas technology as readout device. Performances of bulk-MicroMegas modules with an $Ar/iC_4H_{10}/CF_4$ (95/2/3) gas mixture are presented. First results of beam tests performed with the first T2K/TPC are also discussed and in particular measurements of the deposited energy resolution and particle identification capability of the TPC will be presented.

1. The T2K experiment

The T2K (Tokai to Kamioka) experiment is a long baseline neutrino oscillation experiment mainly designed to search for $\nu_\mu \rightarrow \nu_e$ oscillation[1]. The Japan Proton Accelerator Research Complex (JPARC) at Tokai (Japan) will provide an high intensity proton beam, accelerating protons up to 30 GeV. These protons interacting with a graphite target will produce mesons that will then decay into neutrino in a decay volume. In this way a ν_μ beam is produced. The neutrino will travel to SuperKamiokande[2], a water Cerenkov detector at a distance of 295 km from the neutrino production point. The main physics goals of the T2K experiment are the precise measurement of the parameters Δm_{23}^2 and θ_{23} and the first measurement of θ_{13} , the only angle not yet measured in the neutrino mixing matrix. The existing upper limit for this angle comes from the CHOOZ reactor experiment[3] that performed the measurement in the ν_e disappearance channel. The T2K experiment instead open the possibility to measure this angle in an appearance experiment. The main background to this measurement comes from neutral current π^0 production and from the intrinsic ν_e contamination in the beam.

For the T2K physics goals it is not sufficient to measure neutrinos only in the far detector, but a second detector, near the neutrino production point is required. For this reason a near detector complex (ND280), at 280 meters from the beam production point, will be installed. In ND280 there will be several detectors inside the ex-UA1 magnet (see figure 1), that will provide a magnetic field of 0.2 T. The main purpose of ND280 is to measure the unoscillated neutrino spectrum and flux, the ν_e contamination and the interaction cross sections.

2. The T2K TPCs

In ND280 three large TPCs (see figure 2) together with 2 FGDs (Fine Grained Detectors), will provide a clean sample of charged current quasi elastic (CCQE) events. The momentum

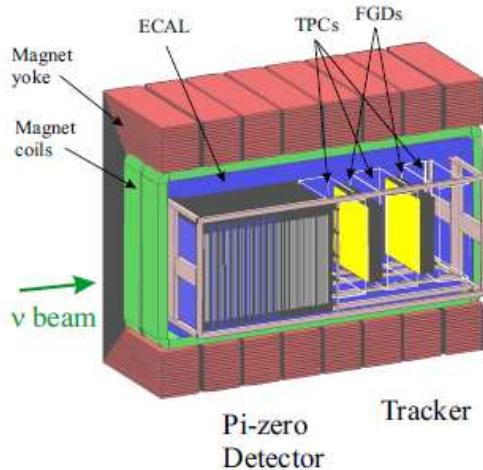


Figure 1. The ND280 complex

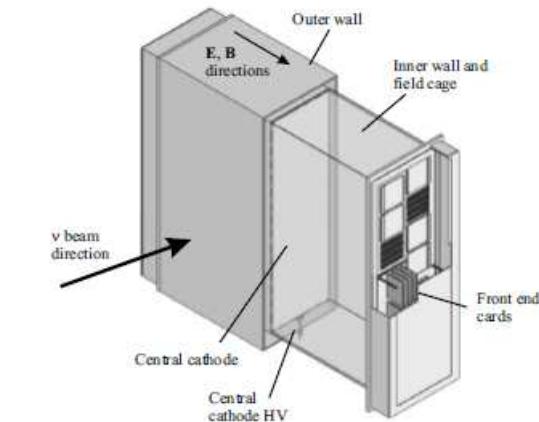


Figure 2. One TPC of the ND280 complex

of the muons produced in the interactions will be measured in the TPCs and will be used to determine the energy spectrum of the neutrino beam. Moreover in the TPCs it will be possible to distinguish electrons from muons measuring the energy released by the crossing particle in the gas. This will allow to measure the electron neutrino contamination in the beam.

The requirements for the T2K TPC can be summarized as follows:

- The momentum resolution must be better than 10% for 1 GeV muons. This requires a good point resolution due to the very low magnetic field.
- The energy scale has to be known at the 2% level. This can be achieved by an excellent control of magnetic and electric field distortions
- The dE/dx resolution has to be better than 10% to allow a 3σ separation of electrons and muons in the T2K energy region.

3. The TPC design

The ND280 tracker includes three identical rectangular TPCs consisting of an outer volume with a dimension of $2.5 \times 2.5 \text{ m}^2$ in the plane perpendicular to the neutrino beam direction, and 0.9 m along the beam direction. The active volume, equal to $1.8 \times 2.2 \times 0.7 \text{ m}^3$ is defined by the inner box divided into two halves by a central cathode to limit the maximum drift distance to 0.9 m. It will be filled with a gas mixture of $Ar/iC_4H_{10}/CF_4$ (95/2/3). A simplified layout of the TPC showing inner and outer boxes is presented in figure 2.

The central cathode is set at very high potential (close to 25 kV) and primary ionization electrons are drifted under an electric field of about 200 V/cm. The cathode will be loaded with aluminum strips for the laser calibration system. The outer box is separated from the inner box by a gap of 6.8 cm on the sides and top and 11.8 cm on the bottom. The surfaces of the outer box are aluminum at nominal ground potential. To guarantee the HV stability of up to 40 kV the gap between the inner and the outer box is filled with CO_2 .

To amplify the signals and read out the TPCs, micro-pattern devices based on the Bulk-MicroMegas technology are used. This solution, developed by a CERN/TS-DEM and CEA Saclay Collaboration offers a good gas gain uniformity and allows to minimize the dead zones on the edges of the modules. The manufacturing process is described in detail in [4].

4. The Bulk MicroMegas

The Bulk-MICROMEGAS module designed for the T2K experiment consists of a segmented Printed Circuit Board used as anode covered by a photo-imageable polyimide film and a 430 LPI (lines per inch) woven micromesh, 30 μm thick. These three components are laminated together and undergo UV exposure with an appropriate mask. After a chemical development, the 20736 pillars with 400 μm diameter define the 128 μm amplification gap thickness. A 3.2 mm wide border at the edge made of a copper strip called BFM (border frame mesh) and a polyimide overlay is also produced during the process (see figure 3). It allows to hold the stretched mesh without using an external additional frame. In this way, large surfaces can be instrumented with a compact, thin and robust low mass detector.

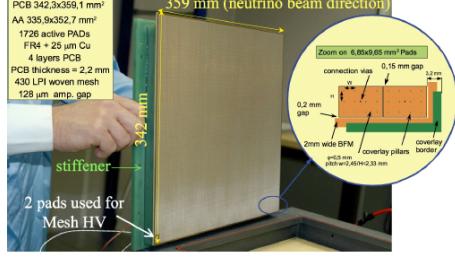


Figure 3. A $34 \times 36 \text{ cm}^2$ Bulk-MicroMegas module glued on his stiffener

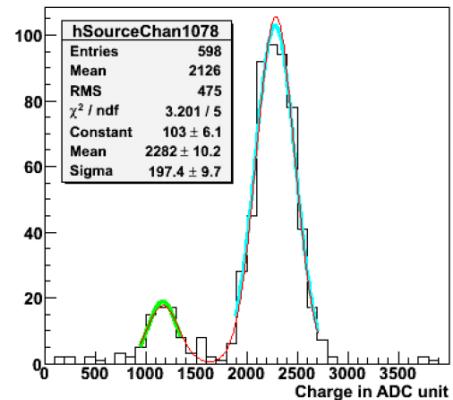


Figure 4. Charge spectrum in ADC unit reconstructed from the ^{55}Fe source in one pad

The detector is then glued on a FR5 mechanical frame with a ± 0.1 mm mechanical tolerance to stiffen the detection surface and to ensure good positioning, thereby ensuring a uniform drift electric field near the detection plane. The active area of a Bulk-MicroMegas module is $34 \times 36 \text{ cm}^2$ and the anode is segmented into 1728 pads of $6.9 \times 9.7 \text{ mm}^2$, arranged in 48 rows and 36 columns. Two pads located in one corner are used for the mesh high voltage connection from the backside of the PCB. A total of 72 modules are needed to instrument the three TPCs for a total effective surface of 9 m^2 .

Each module is readout by six Front-End Cards (FECs) based on the low noise AFTER chip. This new ASIC has been designed specifically for TPC applications and its main characteristics are described in details in [5]. The AFTER ASIC consists of 72 multiplexed channels including for each channel a 12-bit amplifier/filter stage with 4 different charge ranges (120 fC to 600 fC) with various tunable peaking times (100 ns to 2 μ s) and a Switch Capacitor Array (SCA) to sample and store the analog signal in 511 memory cells with a sampling frequency up to 100 MHz. The analog multiplexed output of the chip is read back and converted by an external ADC. A digital Front-End Mezzanine (FEM) card plugged directly on the six FECs is responsible for the slow control of the FECs, collection of digitized data, pedestals subtraction and zero suppression.

5. The test bench at CERN

Each Bulk-MicroMegas module is tested and validated with a dedicated test-bench located at CERN. The module is mounted on a gas box with an uniform electric field in a drift space of 4 cm. A 370 MBq ^{55}Fe source is placed on a motorized holder for a pad-per-pad scan over the whole active area.

The main purposes of the test bench are to find faulty pad, to provide absolute energy calibration and energy resolution measurement for each pad and to obtain the curve of the gain as a function of the applied voltage. These information are obtained by reconstruction of the 5.9 keV photoelectric peak spectrum of the ^{55}Fe source.

The scans are performed with the T2K/TPC front-end electronics and a drift electric field of about 200 V/cm is applied. The gas mixture used is $\text{Ar}/i\text{C}_4\text{H}_{10}/\text{CF}_4$ (95/2/3).

Up to now 12 modules have been tested in the test bench and only one faulty pad (over 21000) has been found. The energy resolution at 5.9 keV is of the order of 9% (see figure 4) with a dispersion of 6%. The pads have a good gain uniformity with a dispersion of 3% and the results obtained for the different modules show a good reproducibility in terms of gain uniformity and energy resolution.

6. Test with cosmic rays in the HARP TPC

In September 2007 one prototype of the MicroMegas detector for the T2K TPC was installed in the field cage of the HARP experiment [6]. During this test cosmic rays were taken with different magnetic fields (from 0 to 0.4 T) and different MicroMegas High Voltage and electronic settings.

The purpose of these tests was to study the performance of the MicroMegas prototype in terms of spatial and energy resolution. To study the energy resolution a truncated mean method is used.

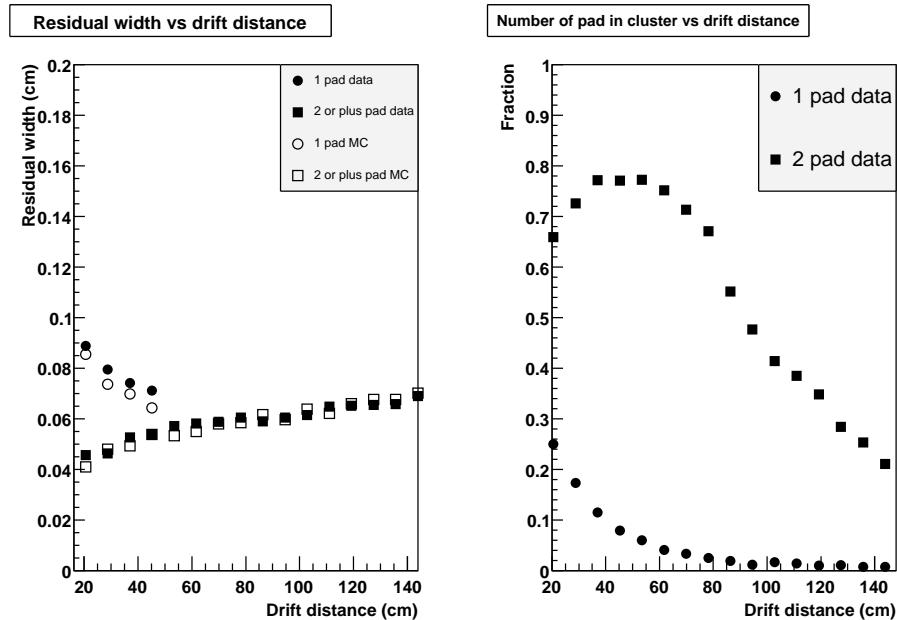


Figure 5. The measured spatial resolution (left) and number of pad fraction (right) for the test with cosmic rays in the HARP field cage (from [6])

With a gas mixture of $Ar/iC_4H_{10}/CF_4$ (95/2/3), with a magnetic field of 0.2 T and an electric drift field of 160 V/cm, a spatial resolution of 600 μm at 100 cm was measured (see figure 5), while the energy resolution, measured for cosmics with a momentum between 0.7 and 1 GeV, was $(12 \pm 1)\%$ for a track length of 36 cm.

7. Test Beam at TRIUMF

Between october and december 2008, beam tests with a mixed e^- , π and μ beam and the first T2K/TPC module have been performed. The TPC was equipped with 12 Bulk-MicroMegas modules and 4 of these modules were equipped with the front-end electronic. Data have been taken, without magnetic field, for various particle momenta, between 100 and 350 MeV/c. With a Time Of Flight system was possible to select samples of each particle, independently from the TPC response.

The MicroMegas modules and the electronic operated smoothly, without particular problems. The measured sparking rate was of 1 spark per hour per module at 360 V.

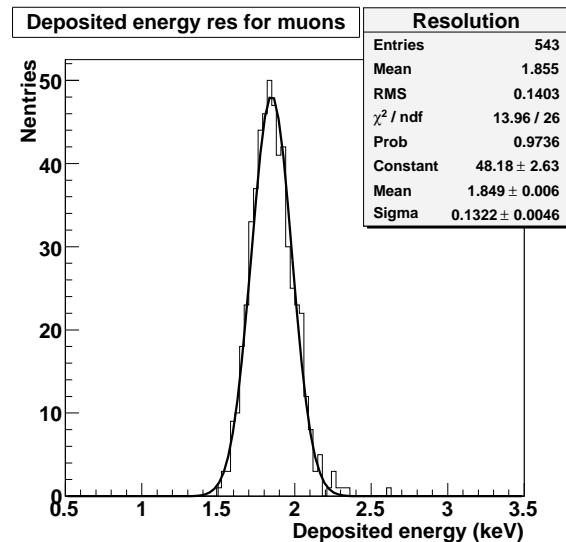


Figure 6. Deposited energy resolution for muons with a momentum of 150 MeV/c

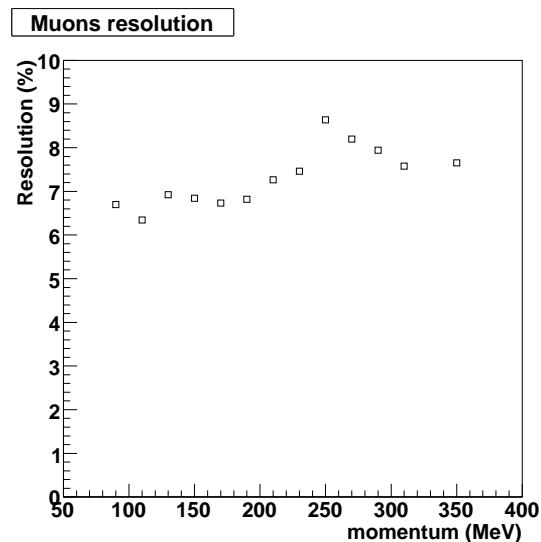


Figure 7. Deposited energy resolution as a function of particle momentum

One of the main goal of these tests was to study the particles identification capability of the TPC. In the TPC the particle identification is performed measuring the energy loss of the particle crossing the detector. To measure the energy loss a truncated mean method is used. For an horizontal track crossing the TPC, 72 deposited energy measurement will be provided, one for each MicroMegas column. The truncated mean method consists in the exclusion of a fixed fraction of clusters where the energy deposition is larger due to the Landau tails and, then, in the measurement of the mean energy deposited in the remaining clusters. The method was initially developed with a Monte Carlo simulation and it was found that, using the 70% of the columns with less charge, the resolution in the measurement of the energy loss was optimized. Using the test beam data it was possible to measure the energy resolution of the TPC for the different samples of particles. In figure 6 it is shown the typical resolution for a sample of monochromatic muons, with a momentum of 150 MeV/c, that cross all the TPC. In this case the energy resolution was measured to be 6.9%. In figure 7 it is shown the energy resolution for muons as a function of the momentum of the particle. As it can be seen the energy resolution

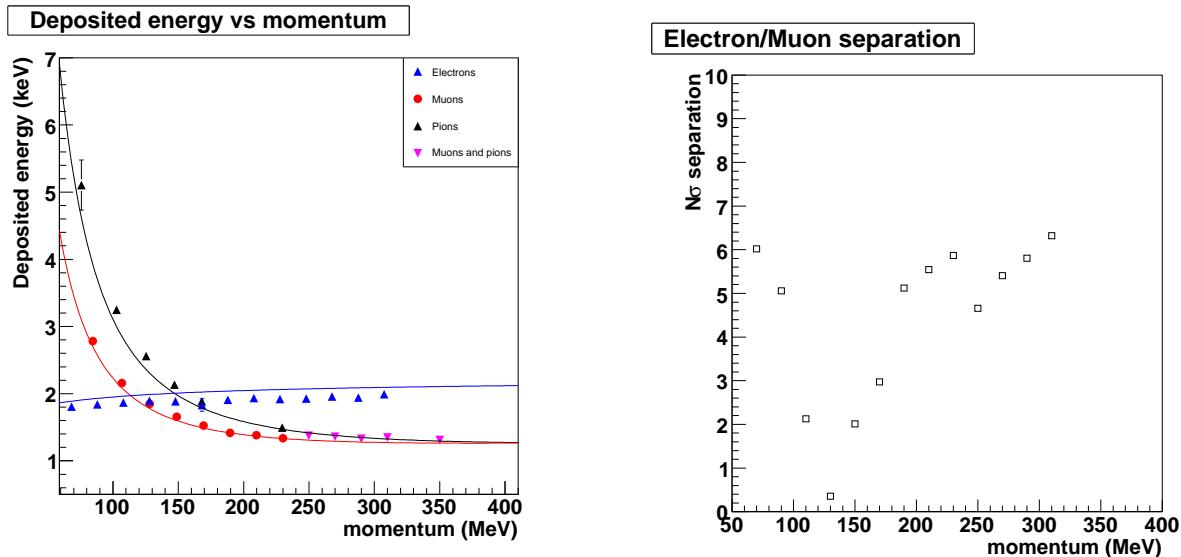


Figure 8. Measured deposited energy loss as a function of momentum for muons, electrons and pions, compared with a Monte Carlo simulation

Figure 9. Measured separation between electrons and muons as a function of momentum

is better than 8% for each analyzed momentum.

The energy loss measured for the different particle samples, as a function of the momentum, is shown in figure 8 and it is compared with a Monte Carlo simulation of the energy loss curve. Finally also the electron/muon separation has been measured (see figure 9). A separation better than 5σ was observed if the particle momentum is larger than 200 MeV/c.

8. Conclusions

The T2K experiment will use three large TPCs based on large size Bulk-MicroMegas detectors as amplification devices. The production of the first TPC is completed and has been equipped with 12 Bulk-MicroMegas modules.

Calibration of the first 12 modules shows a good reliability of manufacturing process and good performance in terms of energy resolution and gain uniformity over the whole active surface. Both, cosmic and beam tests, have demonstrated that the Bulk-MicroMegas technology is suitable to meet T2K requirements. In particular a spatial resolution of $100\ \mu\text{m}$ at a drift distance of 100 cm and an energy resolution below the 8% for muons have been measured at momenta larger than 200 MeV/c.

The installation of the fully instrumented TPCs at JPARC will start in August 2009 while the T2K experiment will start the data taking in December 2009.

References

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