Development of resistive Micromegas TPCs for the T2K experiment

D. Attié
on behalf of the ND280/HA-TPC collaboration

CEA-Saclay/DRF-IRFU, Univ. Paris – Saclay
**The T2K Experiment**

**The ND280 Near Detector**

- **T2K**: long baseline neutrino experiment between $\nu_\mu$ beam (J-Parc) in Tokai and Kamioka
- **Goal of ND280**:
  - measure flux & spectrum of neutrinos
  - measure $\nu_e$ contamination

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### Super-Kamiokande (SK)

- 22.5 kt → ~200 kt (Hyper-K)

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### ND280

- Development of resistive Micromegas TPCs for T2K experiment

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K. Abe et al., NIMA 659 (2011), p.106
• **Current ND280**

Good acceptance only for forward tracks

- Reconstructed momentum and angle

  - \( \mu \) selected at ND280

- **Proposed ND280 upgrade**

  - 2 High-Angle TPCs
  - + a new highly granular scintillator detector (Super-FGD)
  - + 6 TOF planes surrounding the new tracker

ND280 upgrade TDR: arXiv:1901.03750v1

• **Reconstructed momentum and angle**

  - \( e^- \) selected at SK

**V-TPC spatial resolution**

HA-TPC should be as performant as v-TPC

Development of resistive Micromegas TPCs for T2K experiment
HIGH-ANGLE TPCs FOR T2K-II PHASE

• T2K-II phase:
  - Installation in 2022
  - Data taking after main ring upgrade
  - Goal: measure $\delta_{CP}$ at $3\sigma$
    by decreasing of systematic errors
    in ND280 from 6% to 4%

<table>
<thead>
<tr>
<th>Parameter</th>
<th>HA-TPC</th>
<th>v-TPC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall $x \times y \times z$ (m)</td>
<td>$2.0 \times 0.8 \times 1.8$</td>
<td>$0.85 \times 2.2 \times 1.8$</td>
</tr>
<tr>
<td>Drift distance (cm)</td>
<td>90</td>
<td></td>
</tr>
<tr>
<td>Magnetic Field (T)</td>
<td>0.2</td>
<td></td>
</tr>
<tr>
<td>Electric field (V/cm)</td>
<td>275</td>
<td></td>
</tr>
<tr>
<td>Gas Ar-CF$_4$-iC$<em>4$H$</em>{10}$ (%)</td>
<td>95 - 3 - 2</td>
<td></td>
</tr>
<tr>
<td>Drift Velocity cm/µs</td>
<td>7.8</td>
<td></td>
</tr>
<tr>
<td>Transverse diffusion ($\mu m/\sqrt{cm}$)</td>
<td>265</td>
<td></td>
</tr>
<tr>
<td>Micromegas gain</td>
<td>1000</td>
<td></td>
</tr>
<tr>
<td>Micromegas dim. $z \times y$ (mm)</td>
<td>340x420</td>
<td>340x360</td>
</tr>
<tr>
<td>Pad $z \times y$ (mm)</td>
<td>10 $\times$ 11</td>
<td>7$\times$10</td>
</tr>
<tr>
<td>N pads</td>
<td>36864</td>
<td>124272</td>
</tr>
<tr>
<td>el. noise (ENC)</td>
<td>800</td>
<td></td>
</tr>
<tr>
<td>S/N</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>Sampling frequency (MHz)</td>
<td>25</td>
<td></td>
</tr>
<tr>
<td>N time samples</td>
<td>511</td>
<td></td>
</tr>
</tbody>
</table>
• To keep $\frac{\Delta E_{\perp}}{E_{||}} \leq 10^{-4}$ confined at $<1.5$ cm from FC walls, the TPC cage requirements are:
  - Cathode flatness better than 0.1 mm,
  - Micromegas detector flatness better than 0.2 mm,
  - Cathode/Anode planes parallel to within 0.2 mm,
  - Field Cage walls flatness better than 0.3 mm,
  - Voltage divider resistors matched within $\text{rms} \sim 0.1\%$

G. Collazuol (INFN Padova)
Module Test Bench for Production

- Test bench to measure, verify and calibrate:
  - Quality: find dead pads, inhomogeneity, etc.
  - Mapping for all MM modules of:
    1. Signal amplitude/gain
    2. Energy resolution
    3. Charge signal spreading–verify spatial resolution

- Need to scan the active surface with a strong radioactive source or small X-ray lamp.

Development of resistive Micromegas TPCs for T2K experiment
Two identical chambers for supply and return gas
Sequential measurement of drift velocity and gain

Detected charge from defined deposition

Time difference between ionization tracks of defined distance
FIELD CAGE DESIGN

- Thin & low Z composite materials of the wall

<table>
<thead>
<tr>
<th>Layer of the wall</th>
<th>Material</th>
<th>thickness d (d) (mm)</th>
<th>average (X_0) (mm)</th>
<th>(d/X_0) (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 (inner layer)</td>
<td>Double layer strip foil (+glue)</td>
<td>0.05</td>
<td>14.3 (Cu)</td>
<td>~0.07</td>
</tr>
<tr>
<td></td>
<td>(\rightarrow) Copper strips</td>
<td>~0.005</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Aramil Fiber Fabric (Twaron)</td>
<td>2.0</td>
<td>~240</td>
<td>0.70</td>
</tr>
<tr>
<td>3</td>
<td>Aramil honeycomb panel (Nomex)</td>
<td>25</td>
<td>14300</td>
<td>0.17</td>
</tr>
<tr>
<td>4</td>
<td>Aramil Fiber Fabric (Twaron)</td>
<td>2.0</td>
<td>(~240)</td>
<td>0.70</td>
</tr>
<tr>
<td>5</td>
<td>Kapton tape (+glue)</td>
<td>0.125</td>
<td>285</td>
<td>0.04</td>
</tr>
<tr>
<td>6 (outer layer)</td>
<td>Aluminized Mylar (+glue)</td>
<td>0.05</td>
<td>89 (Al)</td>
<td>~0.02</td>
</tr>
<tr>
<td></td>
<td>(\rightarrow) Aluminum layer</td>
<td>0.01</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>(~30)</td>
<td>(~1.6)</td>
<td></td>
</tr>
</tbody>
</table>

- 220 strips on both sides of a Kapton foil shifted by half the pitch

First MM1 pad will be placed @ 12 mm from the wall

G. Collazuol (INFN Padova)
HA-TPC READOUT ELECTRONICS
A NEW AFTER-BASED ARCHITECTURE

- AFTER chip designed for T2K (511 bucket SCA, 120fC-600 fC, 100ns-2µs peaking time)
- ~700 chip left from the initial dice funding already tested
- New FEC with 8 AFTER chips to digitize pad signal with an 8 ch. ADC (dead time of 3.3 ms)
- FEM for control (&trigger), synchronization, data aggregation, data buffering & zero suppression
- The TDCM is a generic clock and trigger distributor and data aggregator (FPGA+2 xilinx CPU+1 GB DDR3)

Inside magnet
Front-End Card
FPGA
Front-End Mezzanine Card

Outside magnet
Slave Clock Module

RJ45 cable

Optical fiber

(Private) Ethernet

nd280 network

Global Event Builder,
Run Control, Condition Database,
Event Display, Mass Storage

D. Calvet: arXiv 1806.07618

36.864 detector pads
512 AFTER (72 channels) 64 FECs (8 ASICs each)
32 FEMs (1 drives 2 FECs)

2 TDCMs (1 controls 16 FEMs, i.e. 1 TPC)
1 PC (controls 2 TDCMs)
Development of resistive Micromegas TPCs for T2K experiment
**Resistive Bulk Micromegas (MM) with Diamond-Like Carbon Layer**

- **Standard Bulk-MM**
  - Mesh @ ~ -400V
  - Amplification gap: ~128μm
  - E
  - FR4 PCB

- **Resistive Bulk-MM**
  - Mesh @ GND
  - ~128μm
  - E
  - DLC@ ~ +400V
  - Insulator: ~50μm
  - glue: ~75μm
  - FR4 PCB

### Charge dispersion in 2-D RC network

\[
\rho(r, t) = \frac{RC}{2t} e^{\left[-\frac{r^2 RC}{4t}\right]}
\]

### Gaussian spreading as a function of time

\[
\sigma_r = \sqrt{\frac{2t}{RC}}
\]

\[
t \approx \text{shaping time (few 100 ns)}
\]

\[
RC_{\text{[ns/mm}^2\text{]}} = \frac{180 \ R_{\text{[MΩ/□]}}}{d_{\text{[μm]}}} / 175
\]

- Signals expected over contiguous strips

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- Development of resistive Micromegas TPCs for T2K experiment


ILC-TPC R&D: P. Colas *et al*.

R: surface resistivity
C: capacitance/unit area
## Resistive Bulk Micromegas (MM) with Diamond-Like Carbon Layer

### Development of resistive Micromegas TPCs for T2K experiment

#### Name

<table>
<thead>
<tr>
<th>Name</th>
<th>MM0-DLC#</th>
<th>MM1-DLC#</th>
</tr>
</thead>
<tbody>
<tr>
<td>Readout PCB</td>
<td>Original T2K-TPC</td>
<td>HA-TPC</td>
</tr>
<tr>
<td>Size</td>
<td>34 × 36 cm²</td>
<td>34 × 42 cm²</td>
</tr>
<tr>
<td>Pads</td>
<td>48 × 36 cm²</td>
<td>32 × 36 cm²</td>
</tr>
<tr>
<td>Pad size</td>
<td>6,85 × 9,65 mm²</td>
<td>10,09 × 11,18 mm²</td>
</tr>
<tr>
<td>Pad number</td>
<td>1728</td>
<td>1152</td>
</tr>
<tr>
<td>Isolation layers</td>
<td>75-200 μm glue + 50 μm APICAL</td>
<td>75 m glue + 50 μm APICAL</td>
</tr>
</tbody>
</table>

- **MM0-DLC1 (2,5 MΩ/sq):**
  \[\sigma \approx 1,6 \text{ mm for } t=400 \text{ ns}\]

- **MM0-DLC3 (~0,5 MΩ/sq) with MM1 stack design:**
  \[\sigma \approx 2,5 \text{ mm for } t=400 \text{ ns} \]
  \[\sigma \approx 1,75 \text{ mm for } t=200 \text{ ns}\]

- **MM1-DLC1 (~0,25 MΩ/sq):**
  \[\sigma \approx 2,5 \text{ mm for } t=200 \text{ ns}\]
  \[\sigma \approx 3,5 \text{ mm for } t=400 \text{ ns}\]
• Epoxy (~0.02 mm) is used to fill the gap between copper pads of 10.09 × 11.18 mm²
• 75 µm thick glue layer is used for the 50 µm Kapton +0.4 MΩ/□ DLC

PCB design thickness: 2.21 mm

B. Mehl, R. de Oliveira, O. Pizzirusso (CERN-EP-DT-EF)
DLC BULK MICROMEGAS DESIGN

- 7 x DLC foils (1x0.6 m²) at CERN
- Resistivity dispersion: 0.3-0.7 MΩ/□
- Provided by Be-sputter (Japan) with help from A. Ochi
- Micromegas mesh grounded in 4 points (PCB corners)
- DLC polarised using a continuous connection

Grounded mesh encapsulated in bulk-micromegas @ ~0.253 mm from pad plane

Mesh connection

DLC connection via HV filter

1 mm DLC free border

Resistive layer protection

Silver paste strip (1 mm width) connected to 2 mm width PCB

Copper strip

<1 µm DLC resistive layer (~0.4 Mohm after DLC pressing)

128 µm (Pyralux pillars)
50 µm (resistive Kapton)

75 µm (Glue)
35 µm (copper pad)

With epoxy filling inbetween

PCB with 36x32 pads 10.09 x 11.18 mm²

DLC HV ~+400 V (2 contacts in corners)

Aluminum stiffener
**MM0-DLC Resistivity Control**

- **DLC Foil #2/7**

  • **MM0-DLC3 #1**
    - Resistivity dropped down to ~half its original 290-407 kΩ/□ value after DLC pressing
    - A ~20% increase is observed after connector wave-soldering
    - Final resistivity 220 kΩ/□ measured in active area

  • **MM0-DLC3 #2**
    - Resistivity dropped from 400-660 kΩ/□ down to ~320-400 kΩ/□ after DLC pressing
    - Final resistivity 400-640 kΩ/□ measured outside the active area borders (to be checked again)

**Variations of DLC resistivity under investigation**

- Tests on small samples + investigations on the measurement protocol & reproductibility
- Need to assess the spatial resolution & dE/dx sensitivity to resistivity non-uniformities
Development of resistive Micromegas TPCs for T2K experiment
• Gas volume: HARP TPC
  - 1.5 m drift distance
  - 25 kV (166 V/cm)
  - 25 L/h Argon(95%)/CF4(3%)/isobutane(2%)

• Detector: module MM0-DLC1
  - Micromegas module with 2.5 MΩ/□ DLC
  - horiz. x vert. = 36 x 48 pads
  - each pad 0.97 x 0.69 cm
  - nominal MM voltage 340 V (up to 380 V)
  - ν-TPC FEE: sampling time 80 ns (12.5 MHz)

• Data taking
  - Cosmic trigger with 2 plastic scintillators +MPPC
  - Fe55 source for 5.9 kEv X-rays
  - Beam: 0.5,± 0.8, 1, 2 GeV/c momentum

+ $^{55}\text{Fe}$ X-ray source in the middle of the cathode
PRELIMINARY RESULTS
CHARGE SPREADING, SPATIAL RESOLUTION

• Still margin for going from MM0 [6.9 × 9.7 mm²] to MM1 [10.09 × 11.18 mm²] pads by decreasing the resistivity to ~0.4 MΩ/□ (trade-off btw charge spreading & spark protection)

~ 2 times better (~320 µm @ 30 cm) than non-resistive ν-TPC modules
Development of resistive Micromegas TPCs for T2K experiment

Micromegas gain uniformity
\( Q_{\text{pad}} / Q_{\text{pad\ average}} \geq 0.93 \)

- Known problematic pads (noise)
- Border pads partially covered by insulator

\( ^{55}\text{Fe} \) x-ray source

\( dE/dx \) resolution using truncated mean method with 36 clusters

Gain Vs DLC layer HV

Cluster charge
- Entries: 12913
- Mean: 9530 ± 21.25
- Std Dev: 2414 ± 15.03

Energy [a.u.]

Gain
READOUT ELECTRONICS FOR TEST PROTOTYPE OF MM1

- Front-end: 4 x 288-channel ARCv2-AFTER (minor corrections compared to ARCv1)
- Back-end: TDCM + PC running MIDAS for configuration and DAQ

MM1-DLC1 Glued on stiffener

2 FEC-interfARC (Lpnhe)

Optical link

4 ARCv2 (Irfu)

TDCM (Irfu)

ARCv1

TDCM mechanics for insertion in a 6U crate

Development of resistive Micromegas TPCs for T2K experiment
Readout Electronics
First Signals from MM1-DLC1

- Cosmic data taking started 02 May
- Software for hit display being finalized
- Only one FEC adapter V2 available
- RC can be evaluated by fitting the signal pulses

15.3 cm drift

With 2 ARC cards

External HV filter
CONCLUSIONS & PERSPECTIVES

• The tests of a resistive bulk-Micromegas module on CERN/PS-T9 beam showed a 2 times better spatial resolution while keeping the dE/dX capabilities in control (9-10% with only one module track length)

• Analysis is on-going to understand, measure the DLC resistivity non-uniformity

• A small prototype of a HA-TPC field cage equipped with a full-size resistive bulk Micromegas module MM1 will be tested with beam at DESY in June 2019

• The T2K / ND280 near detector upgrade development is on-going (FEC, FC, test bench

• The 2 new HA-TPCs design will be soon fixed and production should start in October 2019 for a completion scheduled for march 2021
THANK YOU
**THE T2K-II PHASE**

- **2019 HA-TPC prototype**
  - Under production at INFN Lagnaro workshop

- **Saclay mini-TPC**
  - New parts to be produced

Development of resistive Micromegas TPCs for T2K experiment
Preliminary Results
Micromegas Gain, dE/dx Resolution

Part of DLC foil #7/7 used for MM1-DLC1

Development of resistive Micromegas TPCs for T2K experiment
MM1-DLC1: RESISTIVITY MEASUREMENT @ CERN WITH “OCHI” PROBE

- MM1-DLC1 resistivity – active area side (CERN “ochi” probe, k=6,79)

<table>
<thead>
<tr>
<th>1/ 197 kΩ</th>
<th>2/ 197 kΩ</th>
<th>3/ 265 kΩ</th>
<th>4/ 265 kΩ</th>
</tr>
</thead>
<tbody>
<tr>
<td>166 kΩ</td>
<td>25 k</td>
<td>53 k</td>
<td>53 k</td>
</tr>
<tr>
<td>170 kΩ</td>
<td>25 k</td>
<td>53 k</td>
<td>53 k</td>
</tr>
<tr>
<td>173 kΩ</td>
<td>25 k</td>
<td>53 k</td>
<td>53 k</td>
</tr>
<tr>
<td>203 kΩ</td>
<td>29.9 k</td>
<td>29 k</td>
<td>29 k</td>
</tr>
<tr>
<td>222 kΩ</td>
<td>210 k</td>
<td>210 k</td>
<td>210 k</td>
</tr>
<tr>
<td>221 kΩ</td>
<td>29.9 k</td>
<td>29 k</td>
<td>29 k</td>
</tr>
</tbody>
</table>

Saclay Probe (front)  Saclay Probe (back)

Rx9.78 → not consistent with CERN

MM1-DLC1 resistivity (CERN “ochi” probe, k=6,79)

Active area side

Development of resistive Micromegas TPCs for T2K experiment