PROCEEDINGS OF SCIENCE

MPPC for T2K Fine-Grained Detector

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The FGDs (Fine-Grained Detectors) are a part of the T2K near detector which will detect particle tracks from neutrino interactions to measure the initial neutrino beam flux, flavour and energy prior to neutrino oscillation effects. It is constructed as an array of scintillator bars which are read out by MPPCs via wavelength-shifting fibers. We have integrated all 8448 channels of MPPCs and tested the read out electronics in the beam test at TRIUMF. Finally, it will be installed this autumn to start data-taking in the winter. I will briefly talk about MPPC integration on the FGD, the readout electronics, and the MPPC performance in the beam test.

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1. Introduction of Fine-Grained Detector

The Fine-Grained Detectors(FGDs) are a part of T2K near detector, designed to measure initial neutrino beam flux, flavour and energy spectrum prior to neutrino oscillation effects. Three Time Projection Chambers(TPCs) and two FGDs detects the particle tracks from neutrino interaction for these measurements.

The FGDs will act as a target of neutrino interaction while detecting particle tracks around interaction vertex. The main signal for neutrino flux measurement is $\nu + n \rightarrow l + p$ (Figure 1) and the background for this main signal is $\nu + n \rightarrow l + p + \pi$. The FGDs must be capable of detecting all charged particles produced at the interaction vertex with good effciency, in order to determine the type of these interactions.

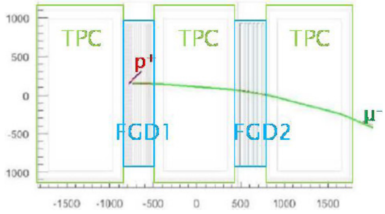

Figure 1: Simulated neutrino event

It is constructed as an array of fine-segmented scintillator bars (Figure 2) which are read out by MPPCs(Multi-Pixel Photon Counters) via wavelength-shifting fibers. FGD1 consists of 15 X,Y layers of those scintillator bars, FGD2 consists of 7 X,Y scintillator layers and 6 water panels to measure neutrino interaction in water target, since we use water chelenkov detector Super-Kamiokande for the far detector. The physics requirements for FGDs are listed below.

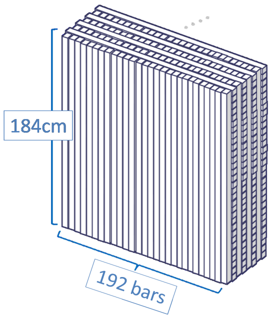

Figure 2: FGD1 architecture

- Particle detecting efficiency > 99% → MPPC's PDE should be high enough
- Particle ID capability
  - By dE/dx, particle range → Good energy resolution required. Need enough gain, linearity.
  - By detecting Michel positrons from π → Electronics should be alive long enough.
- Timing resolution → ∼3ns per neutrino interaction for matching with photons in the downstream calorimeter.

The MPPCs and electronics must satisfy the requirements below to fulfill these physics requrements:

- Gain>5×10^4 for energy resolution
- PDE should be better than PMT for 100% efficiency for MIP
- Noise rate<500kHz for timing and energy resolution
- Dynamic range>400pixels for more than 50MIP dynamic range
- Crosstalk+Afterpulse<20% for energy resolution
- Electronics dynamic range>5μs + few muon lifetimes to identify muons

2. MPPC mass test in Kyoto before installation

The MPPCs which we use for T2K experiment contain 667 pixels in 1.3 × 1.3mm^2 area. We have tested ∼18000 MPPCs in Kyoto before installation to check the quality and to understand their performance. The measured quantities are listed below. Figure 3 shows the test setup.

-Gain
-Breakdown Voltage
-Noise Rate
-Crosstalk + Afterpulse Rate
-Photon Detection Efficiency compared to reference PMT

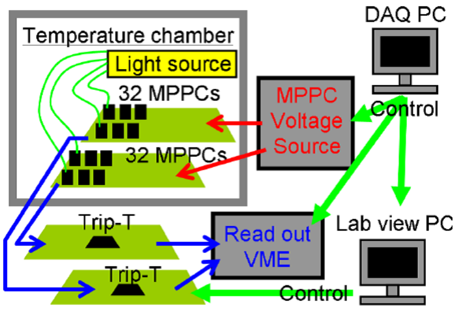

Figure 3: Mass test setup

Each set of measurement was taken at 15 ℃, 20 ℃ and 25 ℃ by using a temperature chamber. We took voltage scan in 0.1V steps for over voltage=0.7 V to 1.8V.

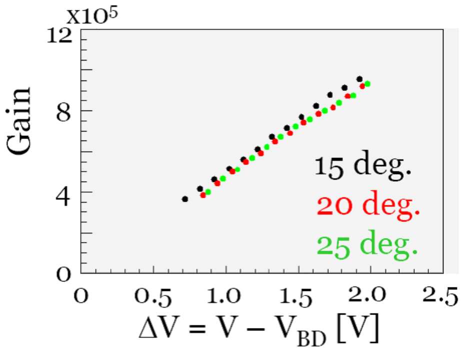

Figure 4: Gain for one MPPC

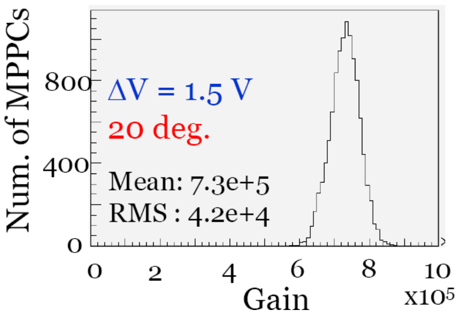

Figure 5: Gain for 12064ch

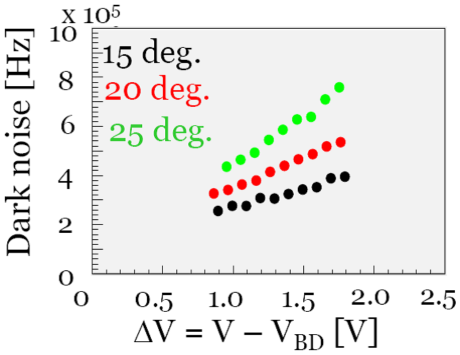

Figure 6: Noise for one MPPC

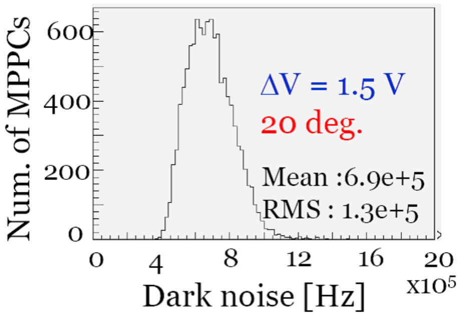

Figure 7: Noise for 12064ch

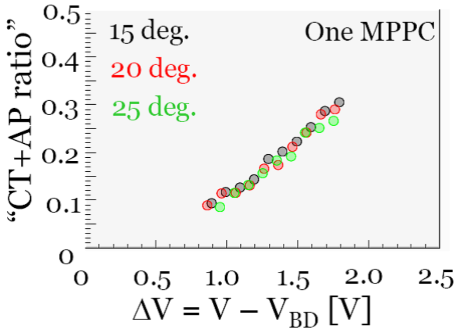

Figure 8: Crosstalk+Afterpulsing ratio

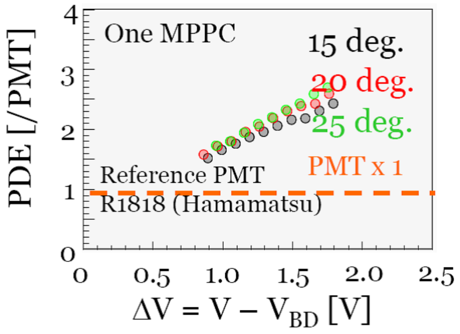

Figure 9: PDE

Parameter	Mean	RMS
Gain	4.85×10^5	2.59×10^4(5.3%)
Breakdown voltage[V]	68.29	0.73(1.1%)
Noise rate[Hz]	4.47×10^5	1.02×10^5(23%)
Crosstalk+Afterpulse rate	0.070	0.036(51%)
PDE	1.53	0.33(22%)

Table 1: Measured mean and RMS at T=20 ℃, over voltage=1.0V

Figures 4 ~ 9 show the result. The gain, crosstalk+afterpulsing ratio and PDE increased as the overvoltage (bias voltage - breakdown voltage) increased, not depending on the temperature (Figures 4, 8, 9). The deviation of the gain for 12064 channels was small (Figure 5). On the other hand, the dark noise rate was affected by both overvoltage and the temperature (Figure 6). Higher temperature corresponded to higher noise rate. It seemed to have big dispersion depending on the channels (Figure 7). Table 1 shows the measured mean and RMS of MPPC parameters at 20 ℃, and over voltage 1.0V. The gain and the breakdown voltage seemed to have small deviation, while the noise rate, crosstallk+afterpulse rate and PDE have big dispersion. We have tested ~400 channels/day, and 9 broken channels were found in total. Broken rate was very low. All the MPPC parameters measured fulfill T2K near detector requirements.

3. FGD readout electronics

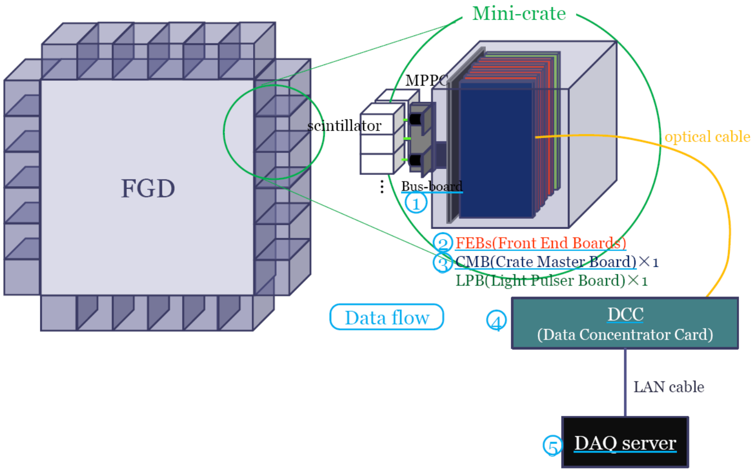

Figure 10: Electronics overview

FGD's electronics overview is shown in Figure 10. Every 16 MPPCs are mounted on the bus boards. The signal from the bus board is read out by the minicrates on the four sides of the FGD. The minicrate contains 4(2) Front-End Boards and 1 Crate Master Board for FGD1(2). In the minicrate, Front-End Boards(FEBs) record the data and send it to a Crate Master Board(CMB). The Data Concentrator Cards(DCCs) will collect the data from CMBs and send it to the backend PC. In this system, heat producing elements are separated from the MPPCs to avoid temperature effect for MPPCs.

- MPPC connection
  We use a special optical connector for fiber-MPPC coupling. The bus board carries 16 MPPCs (Figure 11). It also contains LEDs, and temperature sensors for calibration of MPPCs.

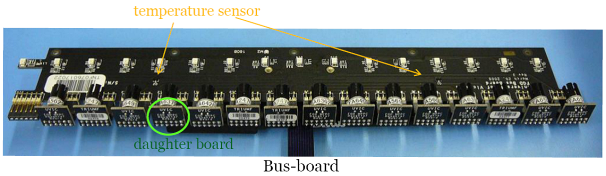

Figure 11: Bus board

- Front-End Board(FEB)
  The FEBs perform data readout and supply bias voltage for individual MPPCs. We use a special chip called AFTER ASIC chip for waveform digitization. The Switched Capacitor Array in this chip records the waveform in 50MHz, for 10μs. This chip also contains preamp-shaper to achieve timing resolution. High/Low attenuation channel are implemented to read out the signal in wide dynamic range.

- Crate Master Board(CMB)
  The CMB controls the FEBs. It can also compress the data by using pulse finder to find a pulse and selecting the waveform only around the pulse (Figure 12).

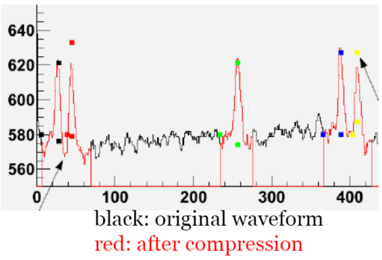

Figure 12: Example of waveform

4. Beam test at TRIUMF

We have tested the read out electronics and FGD's physics performance in the beam test at TRIUMF, Canada. Secondary beam of e, μ, π, p in the momentum range of 100∼400MeV are used for this test to check the response for various particles.

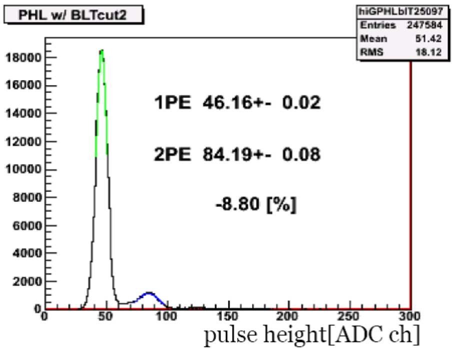

Figure 13: Noise histogram

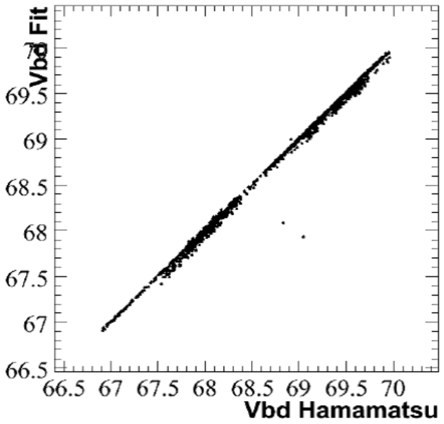

Figure 14: Breakdown voltage (measured vs Hamamatsu spec sheet)

- Gain calibration by noise
  We have performed calibration by using noise histogram. Photo electron can be derived by fitting 1p.e. peak at the noise waveform and dividing the signal pulse height by 1p.e. pulse height. The example of noise histogram is shown in Figure 13.

- Breakdown voltage measurement
  We have measured the breakdown voltage of MPPCs by taking voltage scan data. The result was well matched with the spec sheet from Hamamatsu Photonics (Figure 14).

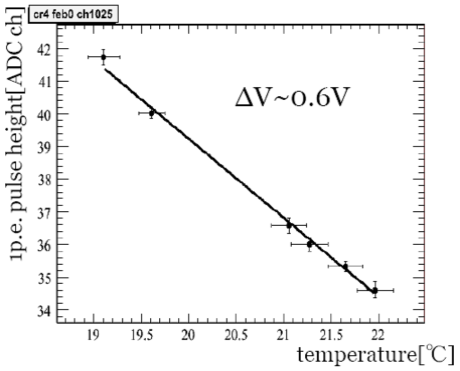

Figure 15: Temperature dependency of gain

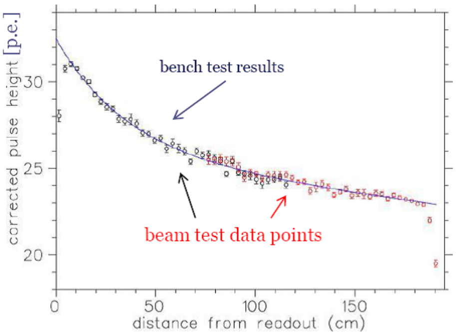

Figure 16: Light attenuation test

- Gain temperature dependence check
  We have checked temperature dependency of the gain by measuring the gain of MPPC in different temperature (Figure 15). The result was well matched with what we measured in Kyoto mass test.

- Light attenuation test
  We have checked light attenuation of fiber and compared the result with the result from bench test in Regina (Figure 16). Beam test result was consistent with the bench test.

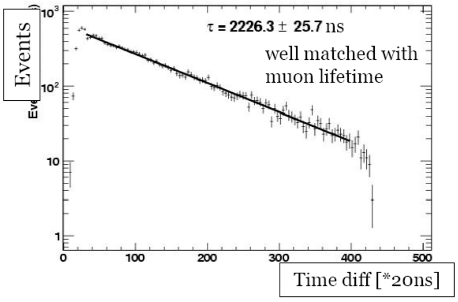

Figure 17: Time difference between incident µ and second hit in the bar

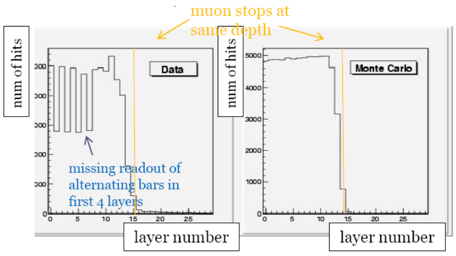

Figure 18: Number of hits in the layers for 150MeV/c muon

- Muon lifetime check
  We have confirmed that we can identify muons by deriving muon lifetime from the time difference of first hit and second hit in the bar (Figure 17). This makes us possible to distinguish protons and pions by checking delayed hit in the bar.

- Muon range check
  We have checked the range of muon by looking at the number of hits vs scintillator layer depth (Figure 18). The depth of layer where muon stops was consistent with Monte Calro simulation.

5. Current status and future

FGD1 and FGD2 have been shipped from Canada to Tokai in June and July. They will be installed in October after electronics commissioning at Tokai. Data taking will start from December 2009.