Fine Grained Detector (FGD) Preparation for T2K

Caio Licciardi

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On behalf of the T2K FGD group
UBC, Kyoto University, University of Regina,
TRIUMF, University of Victoria

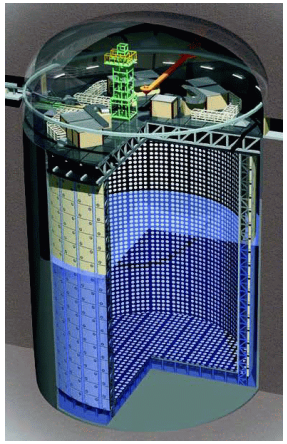
Outline

- T2K Experiment
  - T2K Near Detectors
  - Fine Grained Detectors in T2K
- Reception and installation in Tokai
- Calibration
  - Fiber attenuation
- Studies on Data
  - Cosmics
  - Neutrino
- Conclusion

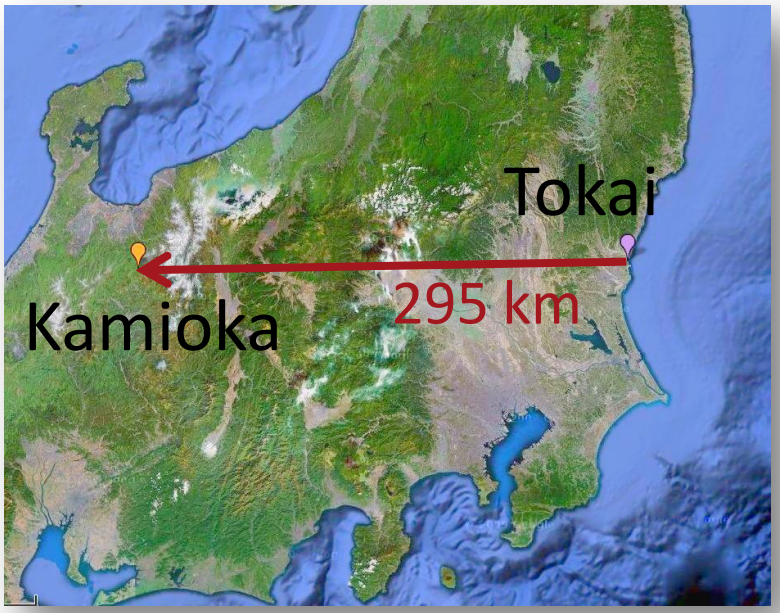
Tokai-to-Kamioka (T2K) Experiment

- Next generation neutrino oscillation experiment
- Intense neutrino beam
- Long-baseline (295 km)

50-kt water cherenkov



Super-Kamiokande (ICRR, Univ. Tokyo)



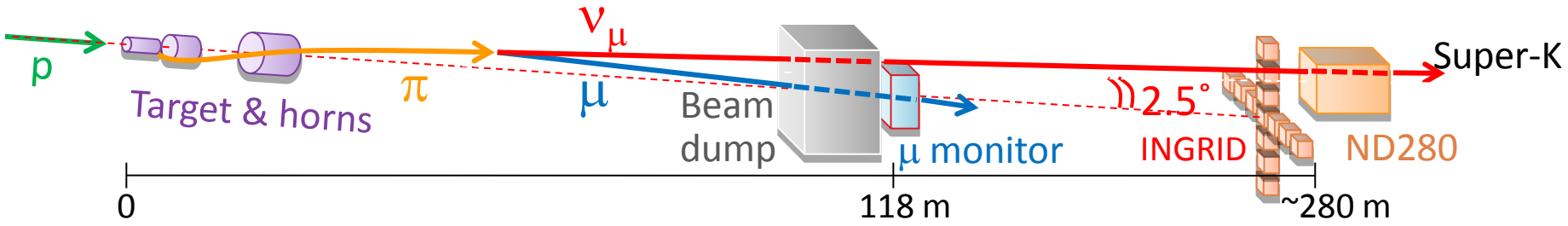
30-GeV proton beam

J-PARC Main Ring (KEK-JAEA, Tokai)

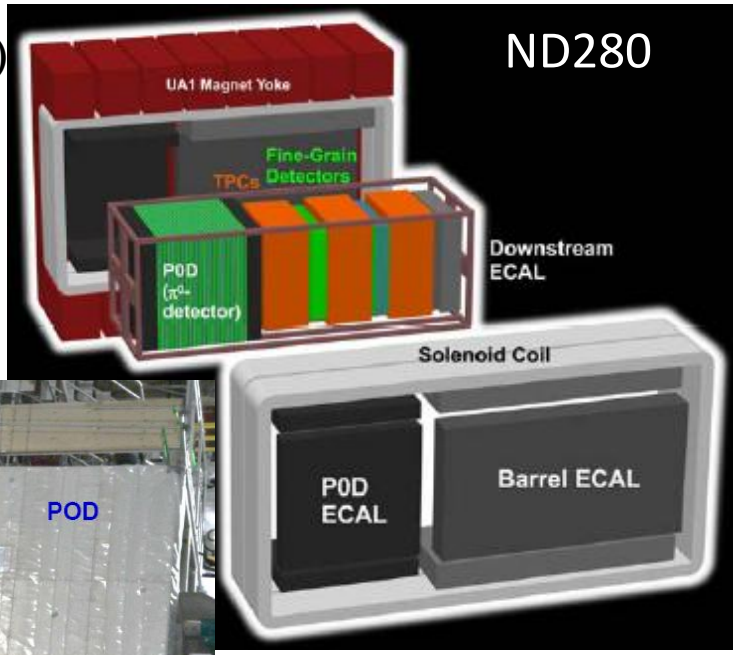
Main goals:

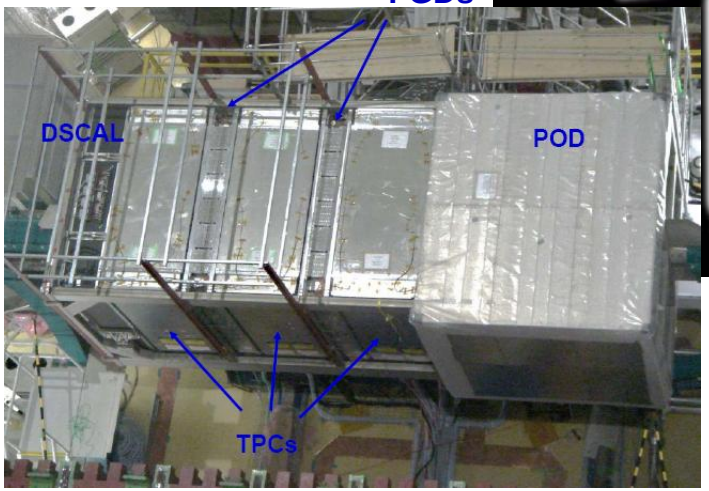
- to precisely measure ν_μ disappearance (θ_{23}, Δm^2_{23})
- to intensively search for $\nu_\mu \rightarrow \nu_e$ appearance (non zero θ_{13})

T2K Near Detectors

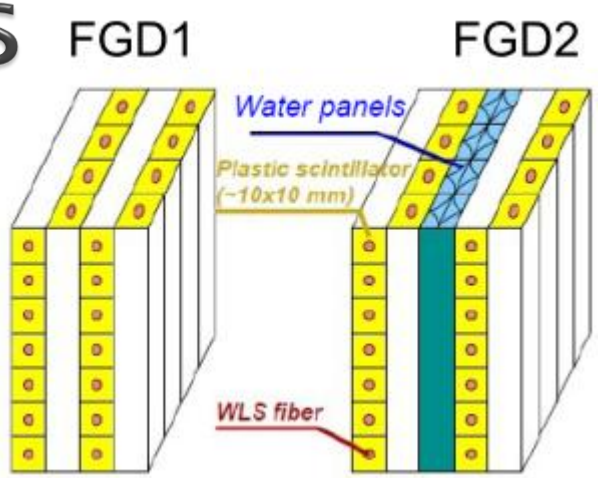


- Produce ν_μ beam and observe effects of oscillation at far detector (Super-Kamiokande)
- Near detector located 280m from hadron production target to characterize neutrino beam before oscillation
- ND280 is off-axis detector (2.5°)
- Tracker is composed of:
  - 3 TPCs
  - 2 FGDs
- Tracker designed to study CC and NC final states





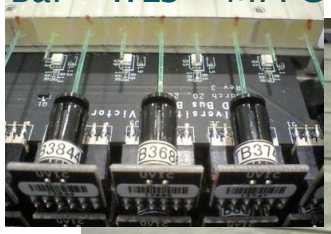
Fine Grained Detectors

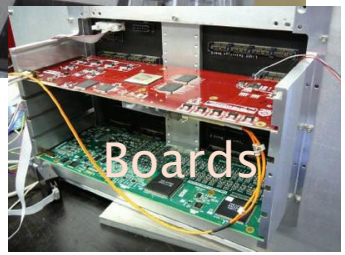


Requirements

- Provide target mass for neutrino interaction
- Reconstruction and particle ID for short tracks

Bar – WLS – MPPC





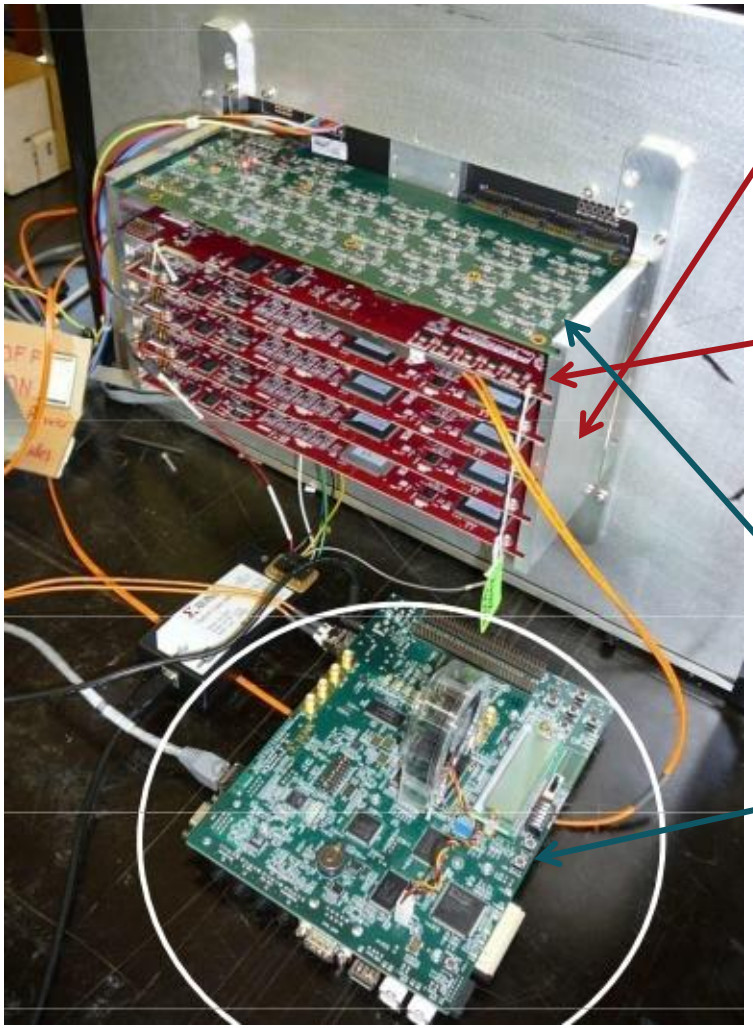
Composition

- Thin scintillator bars organized into XY-modules
- FGD1 contains 15 modules (30 layers)
- FGD2 contains 7 modules interleaved with 6 water panels
- Total of 8448 channels

Technique

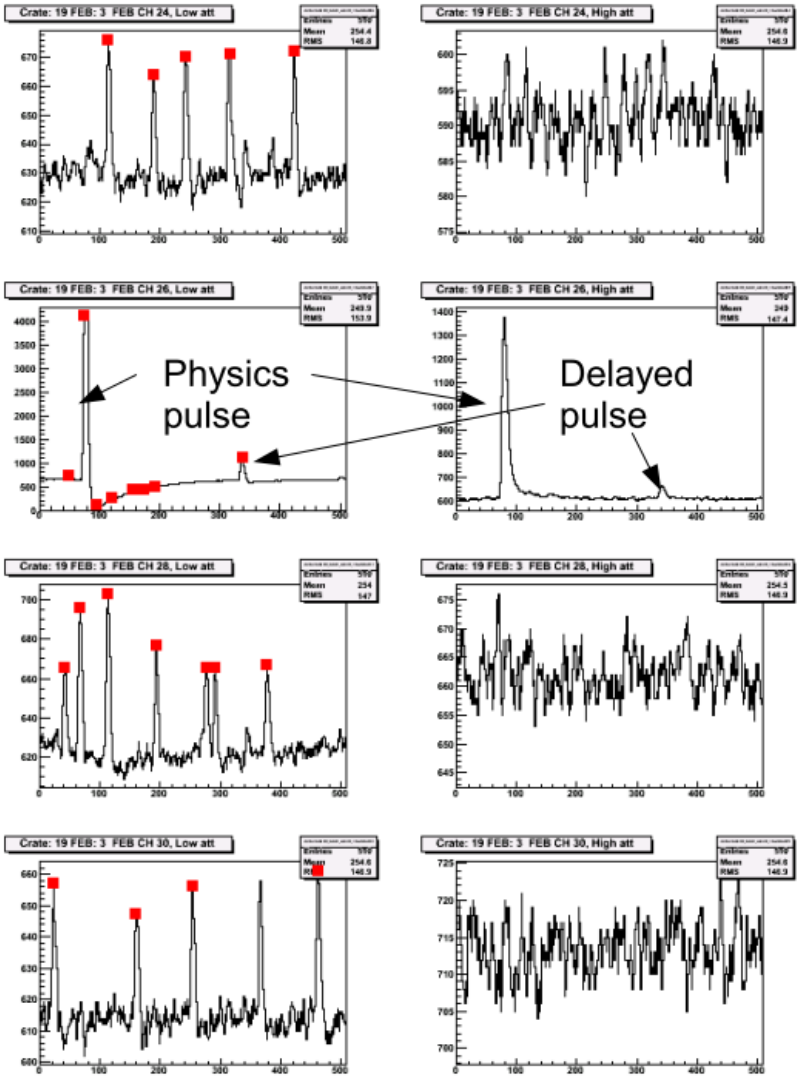
- Light produced in scintillator bar is collected by WaveLength Shifting (WLS) fibers
- WLS fibers transport light to Multi Pixel Photon Counters (MPPCs)

FGD Electronics



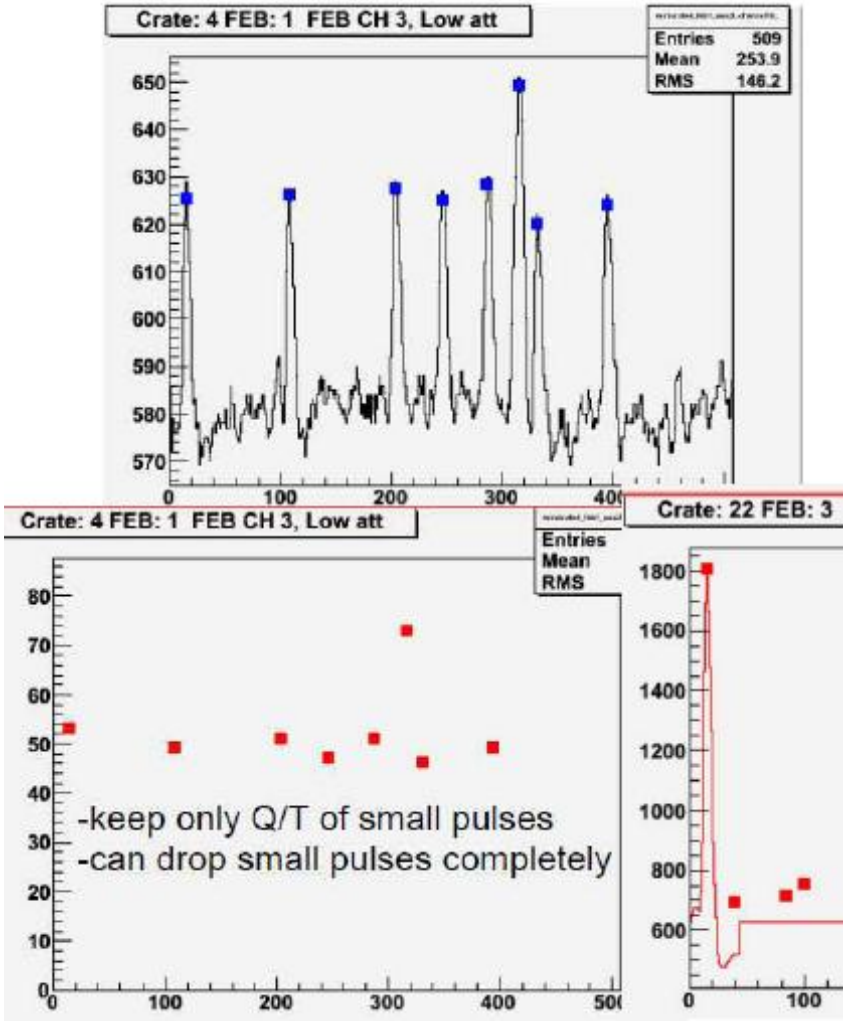
- Front End Boards (FEB)
  - Waveform digitalization at 50 MHz in a loop of 512 cells
  - Split MPPC signal to high/low attenuation
- Crate Master Board (CMB)
  - Read data from 4 FEBs
  - Transmission of data to DCC
  - Distribution of incoming trigger/data request
  - LPB management
- Light Pulser Board (LPB)
  - Flash LEDs inside dark box
  - Test integrity of signal path
  - Calibration of MPPC non-linearity
- Data Concentrator Board (DCC)
  - Gather and process data before shipping them to the backend computer for data logging
- Slow Control
  - Circuitry located in all FGD boards
  - Monitoring of hardware (temperature, ...)

FGD Data



Low attenuation channels

High attenuation channels



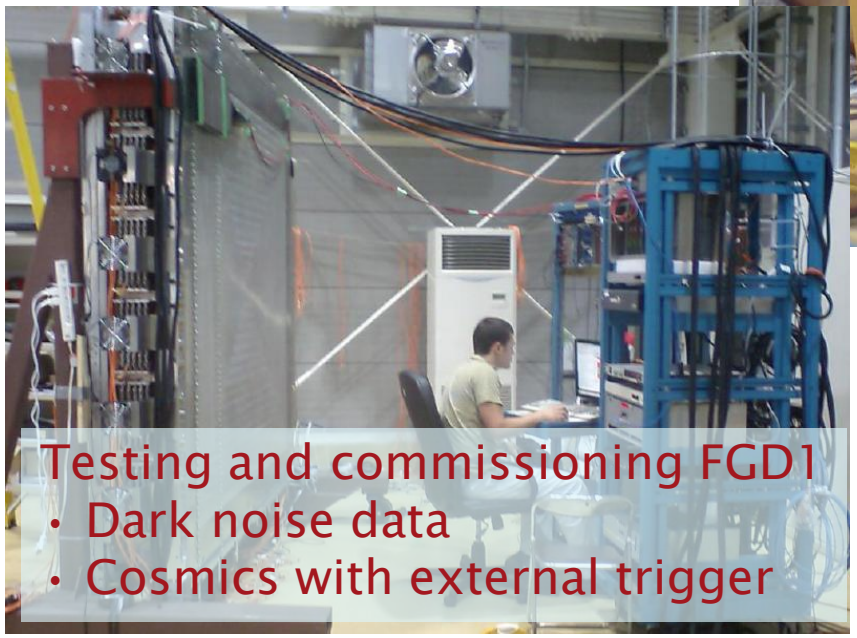
Reception and installation in Tokai


Lifting FGD2 off the truck


Tilting FGD2 to vertical

Reception done during Summer 2009

Installation performed in Fall 2009


Testing and commissioning FGD1
- Dark noise data
- Cosmics with external trigger


Lowering FGD2 into the basket in the pit

Calibration

- Steps completed for first data processing
  - Timing calibration
  - ADC-to-PE conversion
  - High gain to low gain conversion
  - Second order (PDE, crosstalk and afterpulsing)
  - MPPC saturation
  - Fiber coupling correction
  - Fiber attenuation
  - Internal alignment
- Work done with in situ and ex situ data
- I will only have time to comment on one of these calibrations

Fiber Attenuation

- Light yield per path for cosmic rays passing through the FGD

- The major effect in the middle of the fiber is well described by the empirical function:

$$I = Af(x)$$

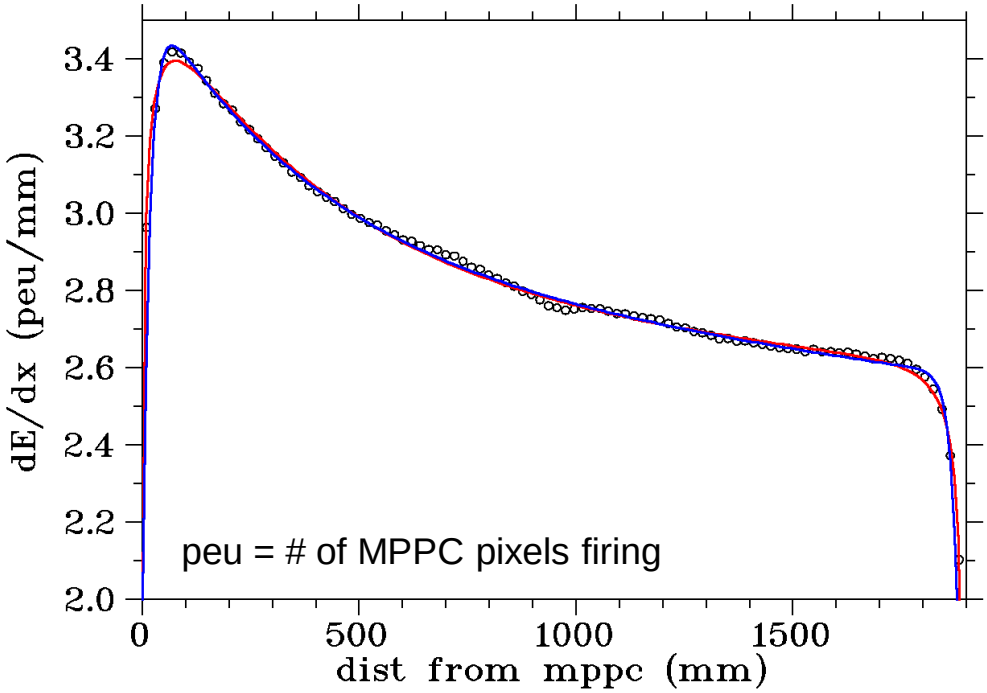
$$f(x) = e^{-x/L} + (B/A)e^{-x/S}$$

x is the distance, S and L the short and long attenuation coefficients.

- The falloff at both ends is from light leaking out of the scintillaton bar, not making it in to the WLS fibers. Laboratory bench tests have shown that this effect can be included in the empirical function with one additional parameter:

$$I = Af(x)g(x)$$

$$g(x) = 1 - \frac{1}{2}\left(e^{m(D-x)} + e^{-mx}\right) \quad \text{or} \quad g(x) = 1 - \frac{1}{2}\left(e^{-m\sqrt{(D-x)}} + e^{-m\sqrt{x}}\right)$$



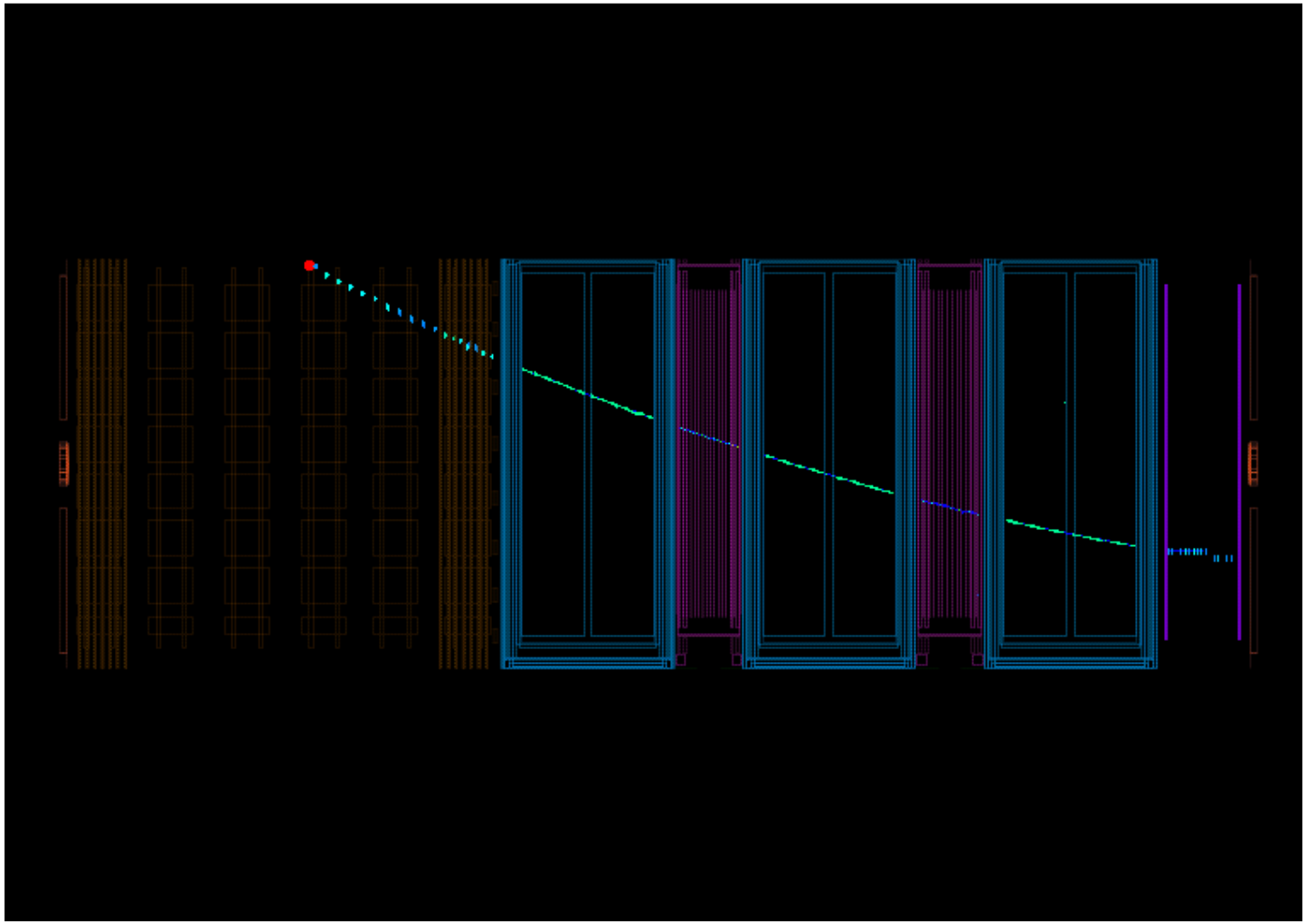
- The blue and red lines are first and second g(x) formulas respectively. D is the length of a bar and m an additional coefficient.

The effective fiber attenuation curve derived from cosmics for these (mirrored) fibers agrees well with ex situ measurements

First Studies on Data

- Collected good amount of cosmics data
  - Hit efficiency
  - Time difference between FGDs
  - Angular distribution
  - Energy deposited per path length
  - Comparison with monte carlo
- Neutrino data
  - Event rate
  - Spatial distribution
  - Timing distribution
- I will only have time to highlight some of these results

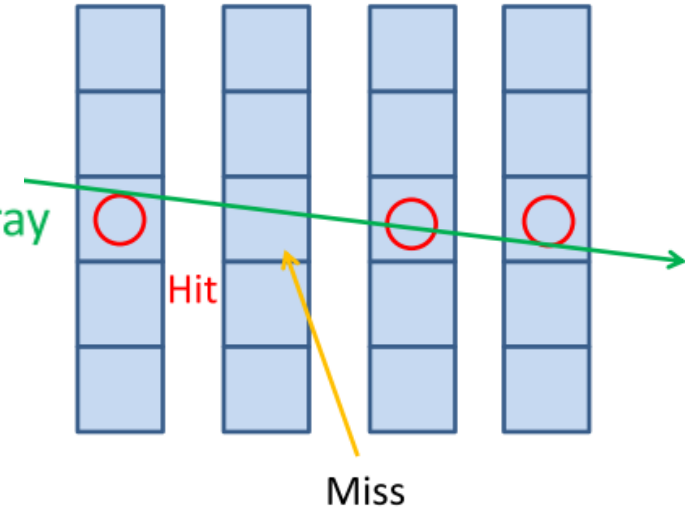
Cosmic Ray in Event Display

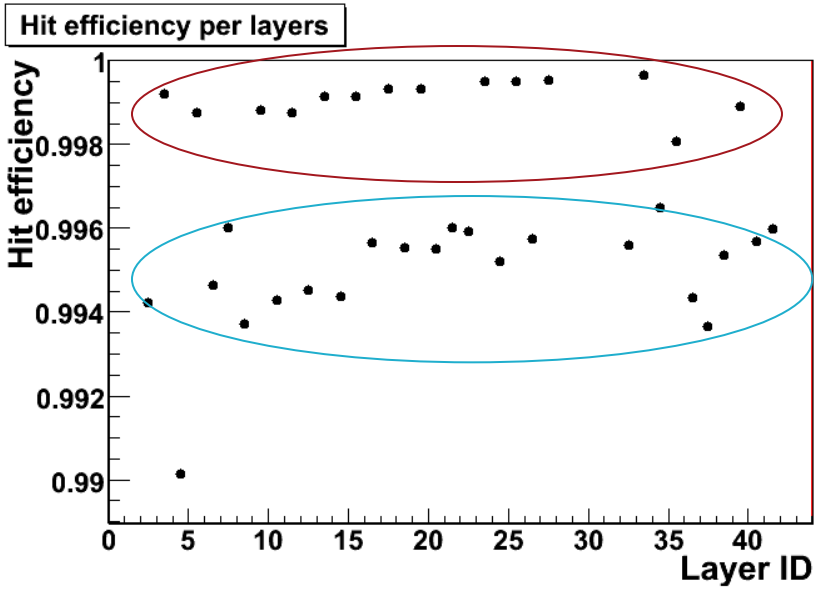


Cosmics I

Hit efficiencies for most of XZ and YZ layers as measured with through going cosmics

- Looking at the middle layer for layers of three that were hit
- First and last layer of each orientation is omitted
- Hit efficiency = # of hits / total layers crossed



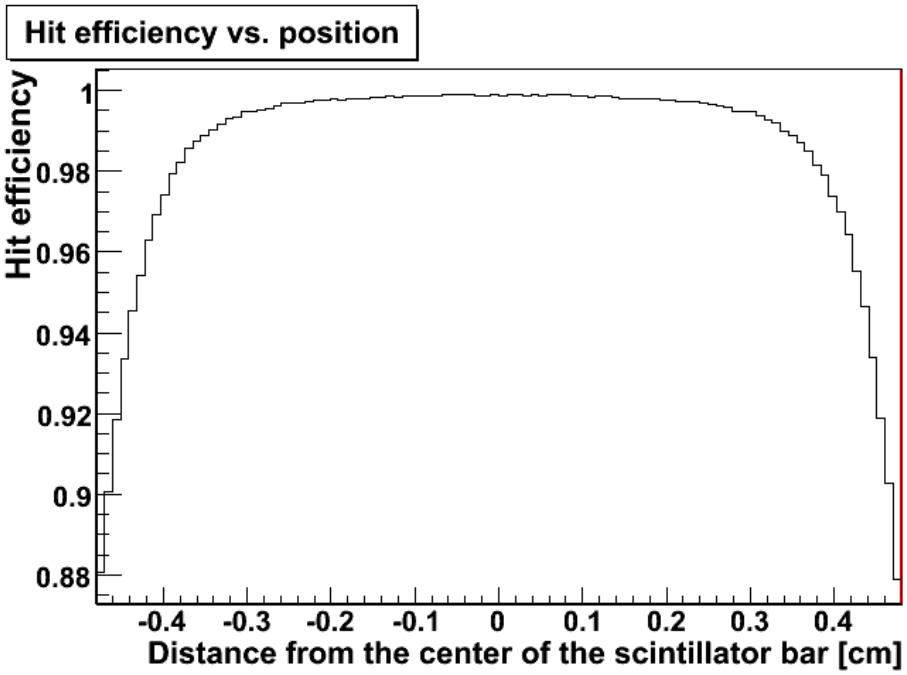


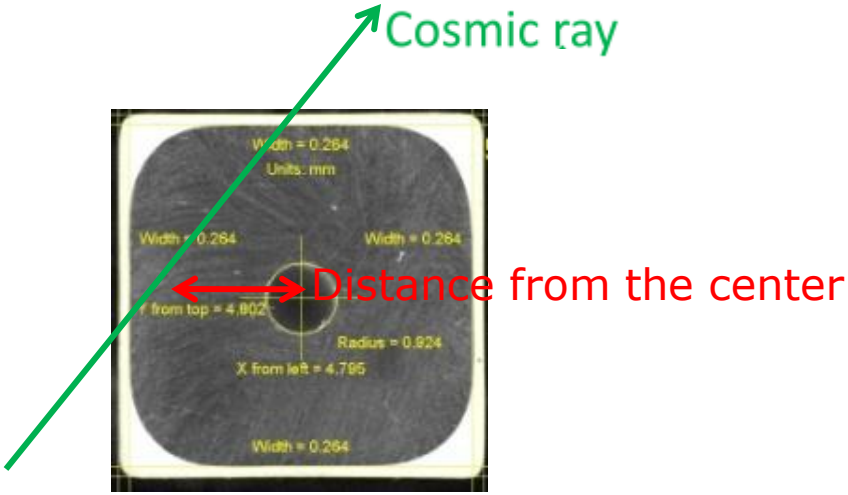
- The hit efficiency is higher for horizontal layers than for vertical layers, since cosmic rays are predominantly downward going
- Layer 4 is an unexplained outlier
- All layers have better than 99% efficiency

Cosmics II

Average hit efficiency of FGD bars as a function of where the cosmic ray hits the bar

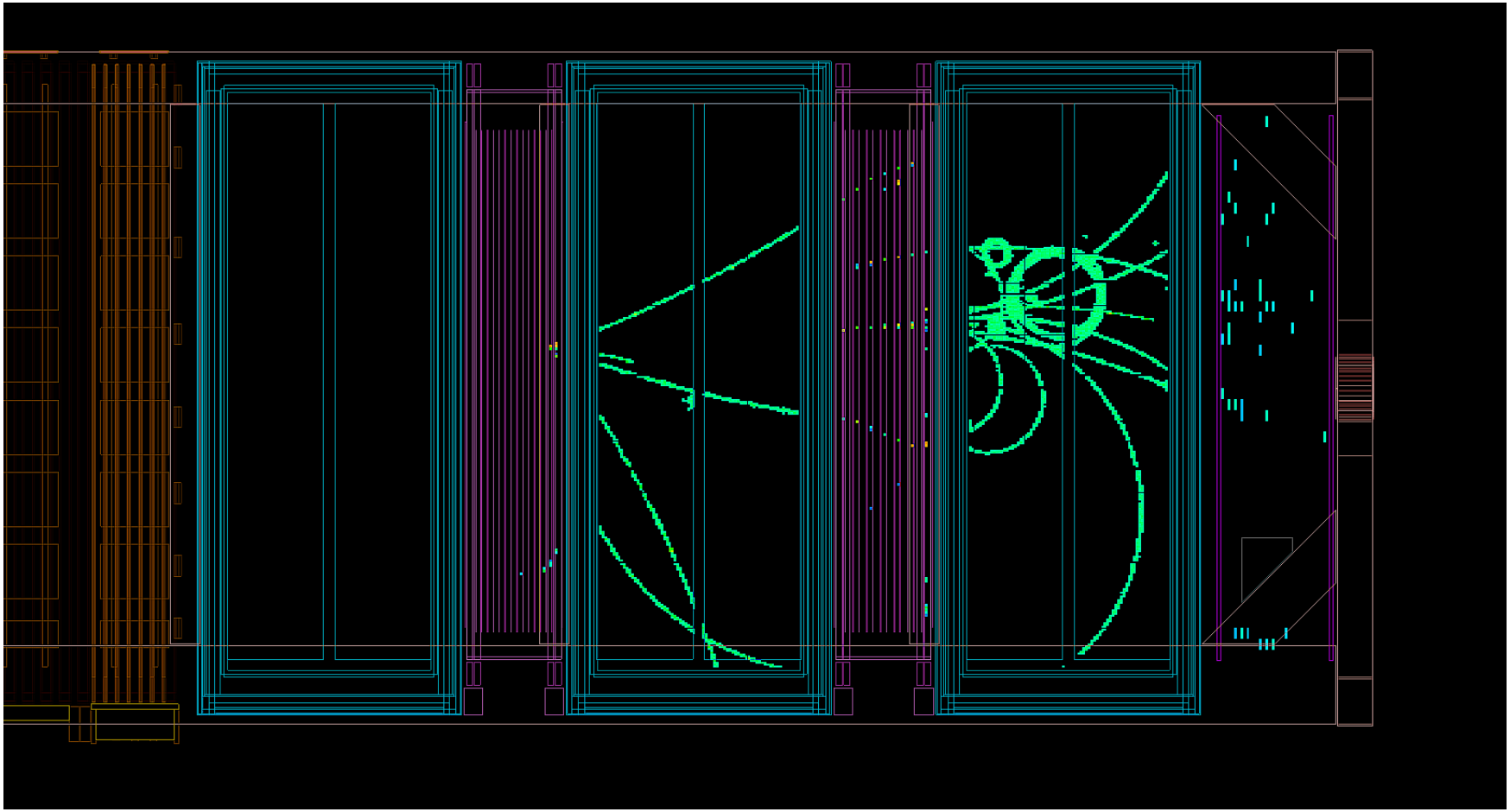
- Looking at calculated distance from the center of the scintillator bar after fiting the track



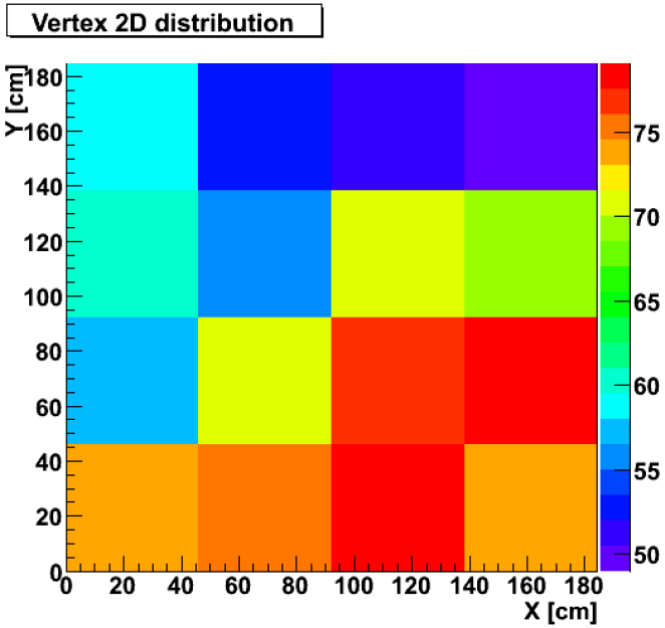


- Cosmics passing close to the edge have much lower efficiencies due to inactive coating
- FGD-only reconstruction can resolve sub mm-level features of the bar

Neutrino in Event Display



Neutrino



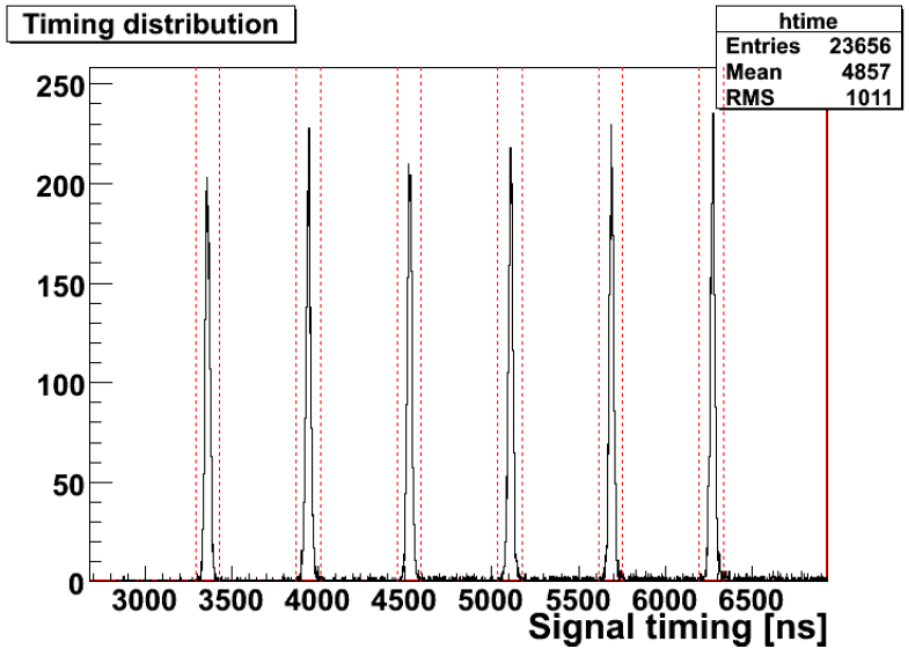
Beam Center

Spatial distribution of hits using beam trigger

- Higher number of hits closer to beam center

Best time of neutrino spills measured in FGD

- Red lines indicate expected region for each of six bunches



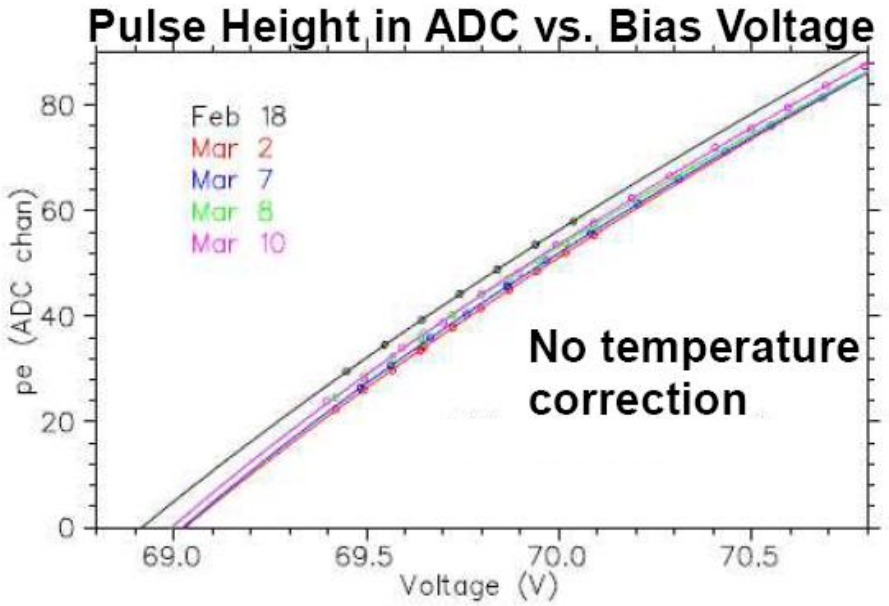
Conclusion

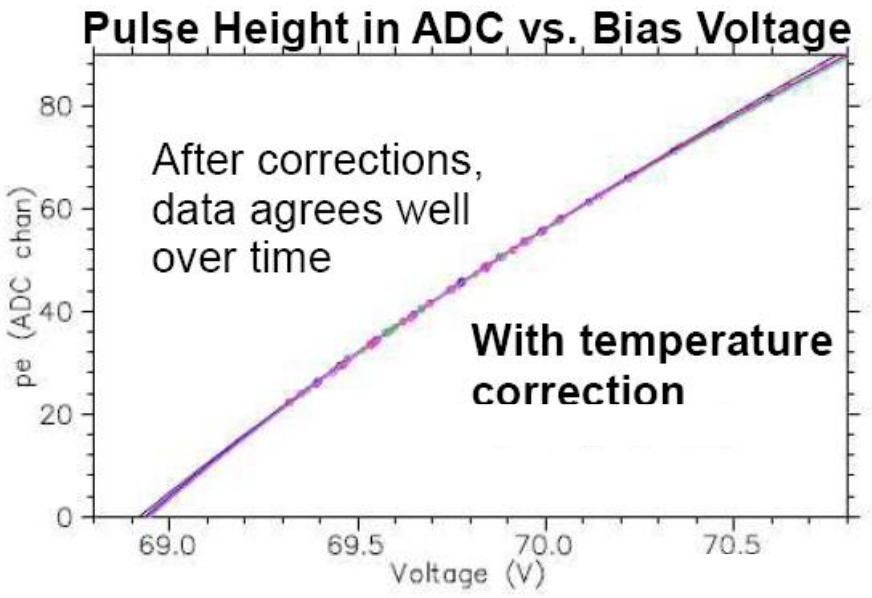
- FGD provides significant portion of target mass for neutrino interactions in T2K
- Installation completed
- Commissioning finished
- Calibration is well underway
- Initial data process has begun

- Tremendous progress in one year!

Extra Slides

ADC-to-PE Conversion





- Measure of single PE height as function of MPPC bias voltage
- Adjust MPPC bias voltages to achieve uniform pulse heights
  - Voltage scan data used to derive optimum bias voltages
- Expected linear dependence $pe = g(V - V_0 - k\Delta T)$

where g is the gain, V_0 is the breakdown voltage, ΔT is the temperature difference and k is the temperature correction coefficient.

- Observed some non-linearity in conversion, possibly due to voltage drop across a protection resistor. Added quadratic term:

$$pe + c\,pe^2 = g(V - V_0 - k\Delta T)$$

Calibration – Birk's Constant