Characterization of Multi-Pixel Photon Counters for the T2K Near Detector Upgrade

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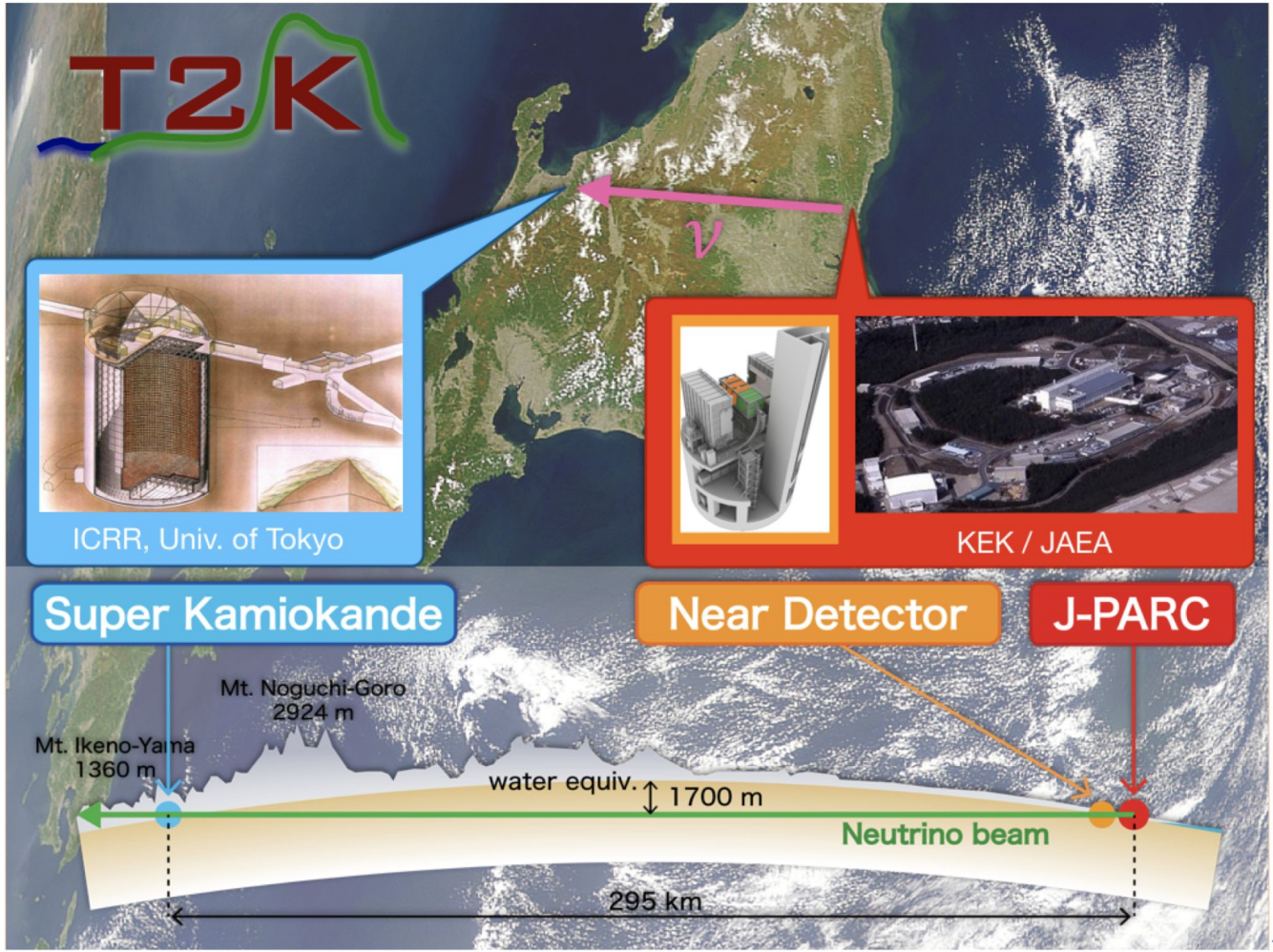
credit

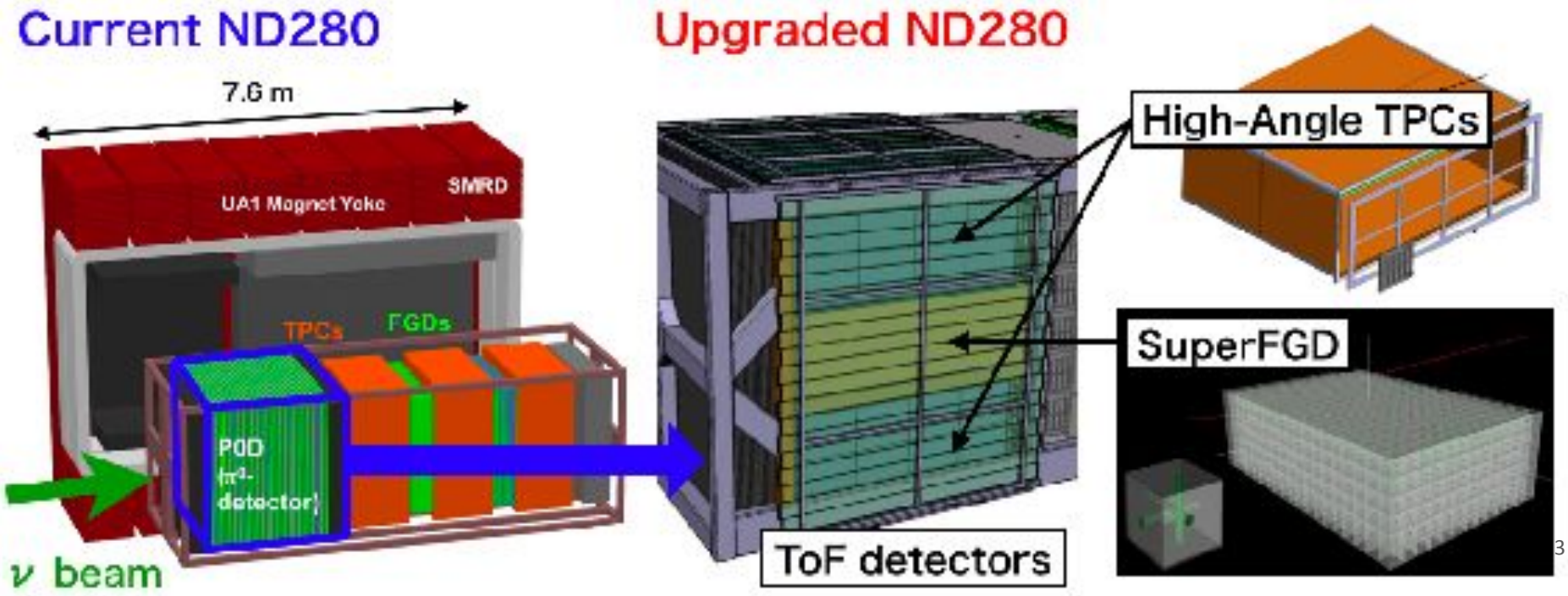


Overview of the T2K Experiment

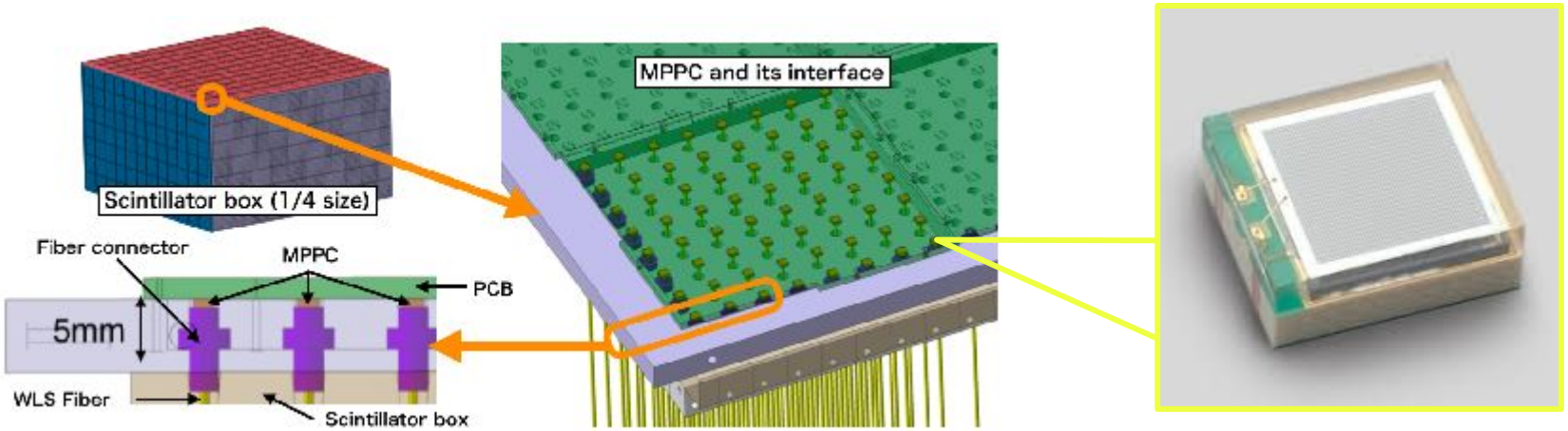
- The Tokai-to-Kamioka Neutrino Oscillation Experiment
  - The INGRID on-axis near detector
  - The ND280 off-axis near detector
  - SuperKamiokande
- $\nu_\mu / \bar{\nu}_\mu$ beam peaking at 600 MeV
- Physics goals
  - CP violation in the neutrino sector
  - oscillation parameters in ν_μ disappearance
  - θ_{13}, sterile, ...

ND280 Upgrade

- Novel active target detector (~2 tons) and two TPCs to cover high-angle escaping particles surrounded by a Time-of-Flight detector
- Coupled with the Main Ring power supply upgrade at J-PARC in 2021 —> beam power from 0.5 to 1.3 MW

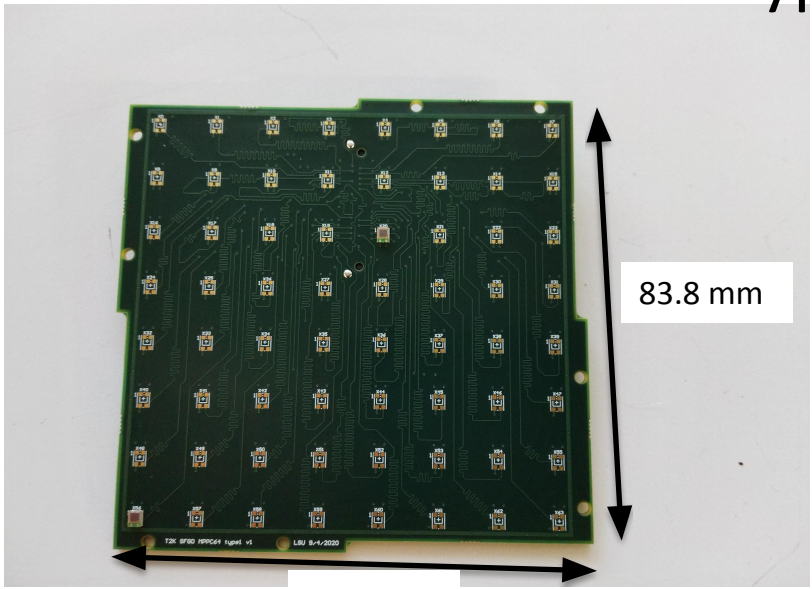


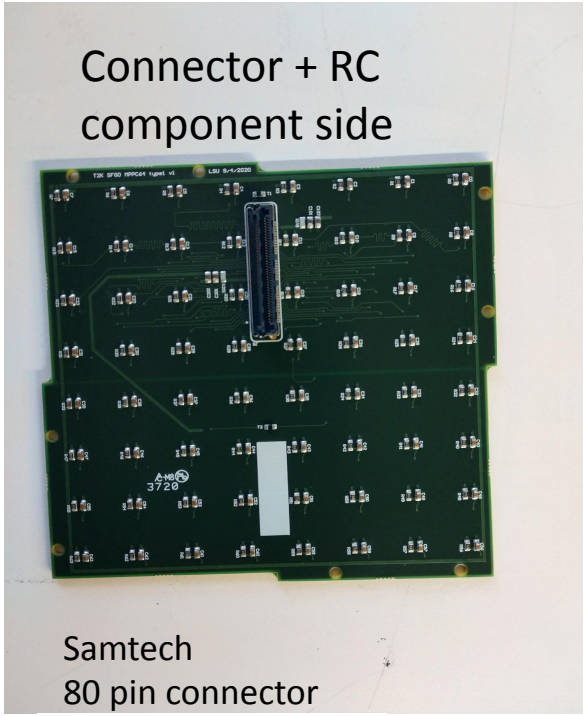
Multi-Pixel Photon Counters (MPPCs) for SuperFGD



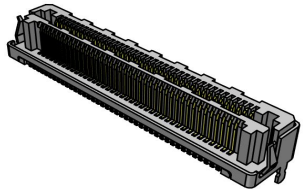
- About 60000 readout WLS/MPPC channels
- Solid-state single-photon-sensitive devices based on Single-photon avalanche diode
- Biased well above its reverse-bias breakdown voltage, operated in Geiger-mode
- Typical gain of about 10^6
- Breakdown voltage, MPPC gain, and dark count rate are important parameters for operation

64-Channel MPPC PCB Prototype



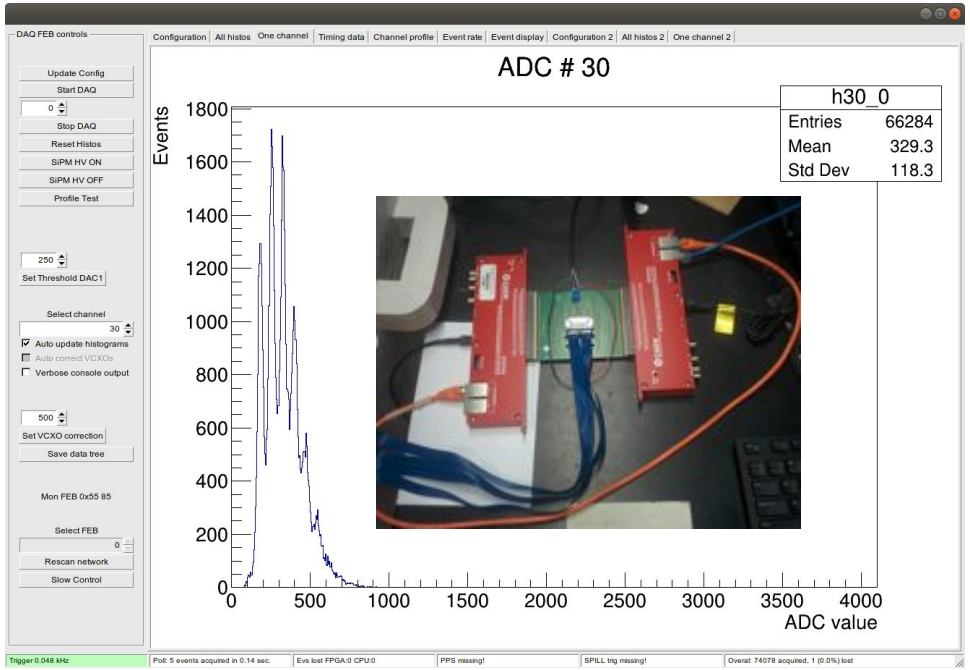


- 4 layer board (1.7 mm thick)
- rotationally symmetric
- 2 separate HV inputs (32 channels each)
- 64 Hamamatsu MPPC S13360-1325PE



System Setup for Large-Quantity Automated Characterization

Test Stand at LSU -- DAQ



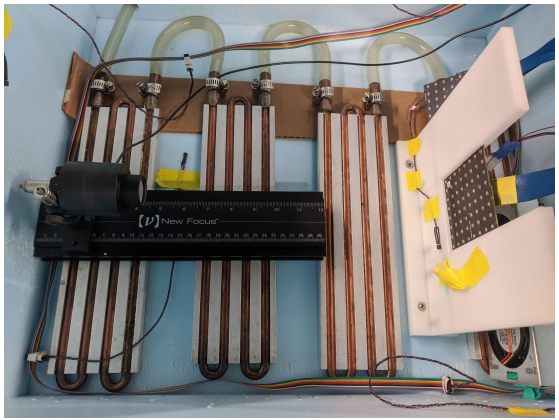
- Setup has 64 channels
- Use with internal and external (LED) trigger
- DAQ is setup to allow for automated operation of measurement sequence

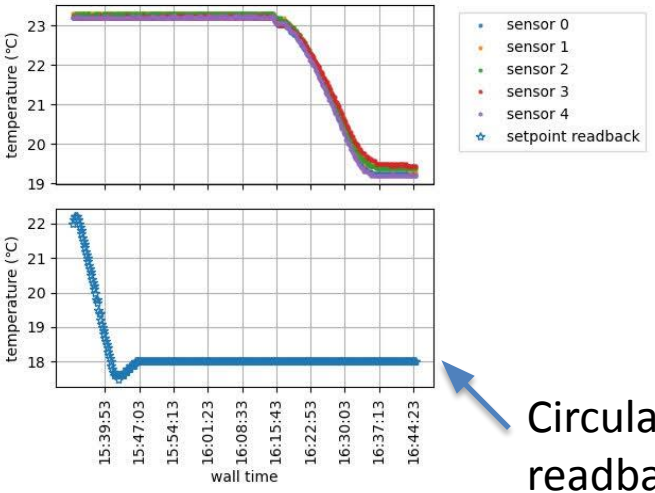
Typical measurement sequence:
Flash and trigger on LED and

1. Take spectra at a fixed bias voltage and scan bias voltages
2. Measure dark rate and scan thresholds

Experience so far < 20 minutes/board can be achieved for items 1&2.

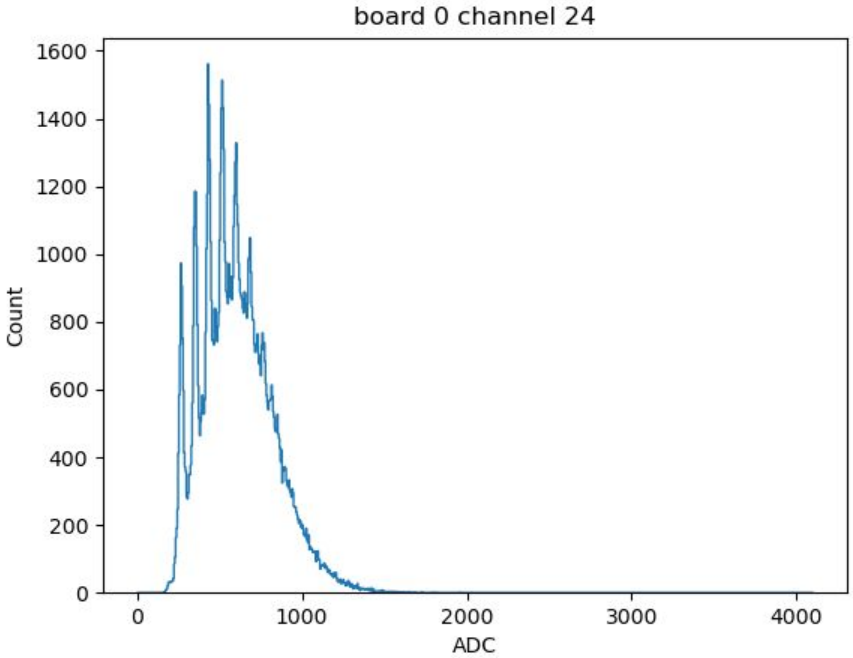
Temperature Controlled Environment

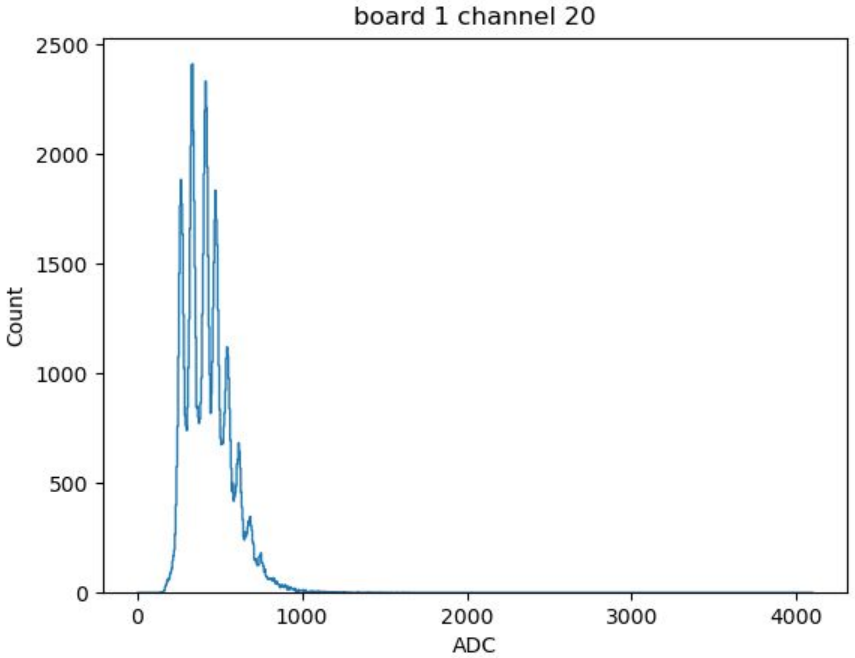




- Can achieve desired temperature in 15 - 20 min
- Setup allows stable operation
- Measurement done at 20 °C (T2K operation) and 25 °C (Hamamatsu datasheet)

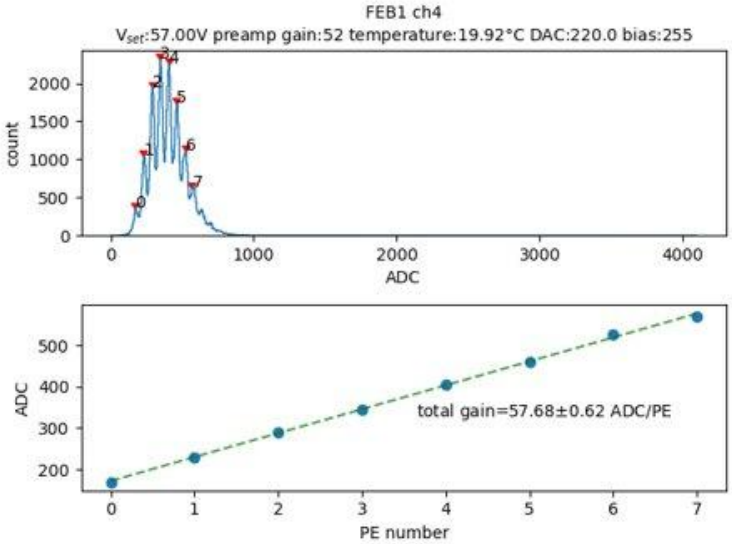
Example Data

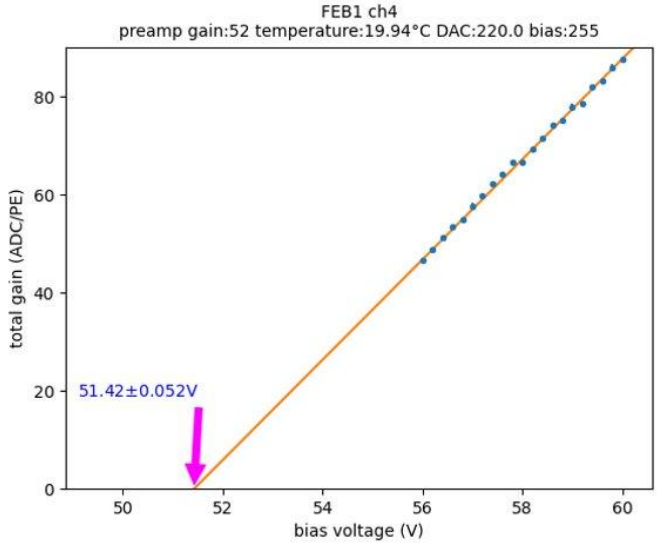




LED run, showing one channel from each FEB.

Breakdown Voltage Measurement

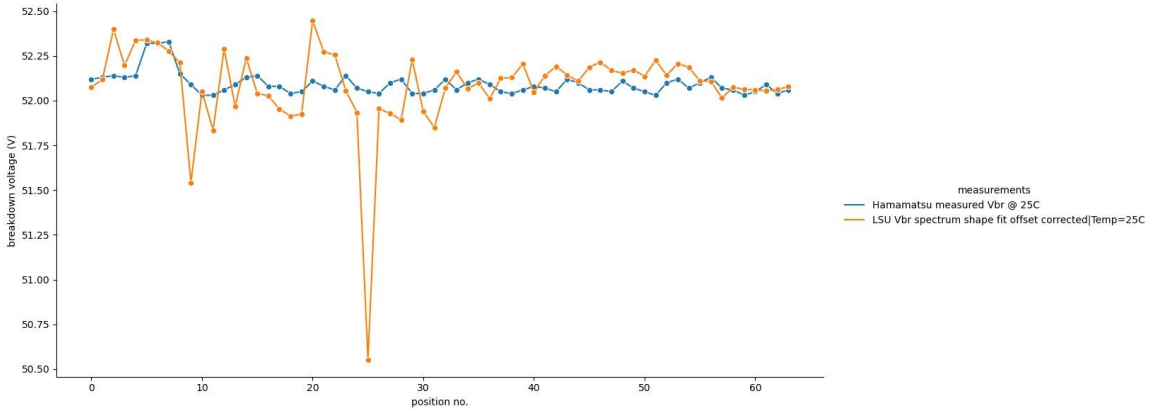


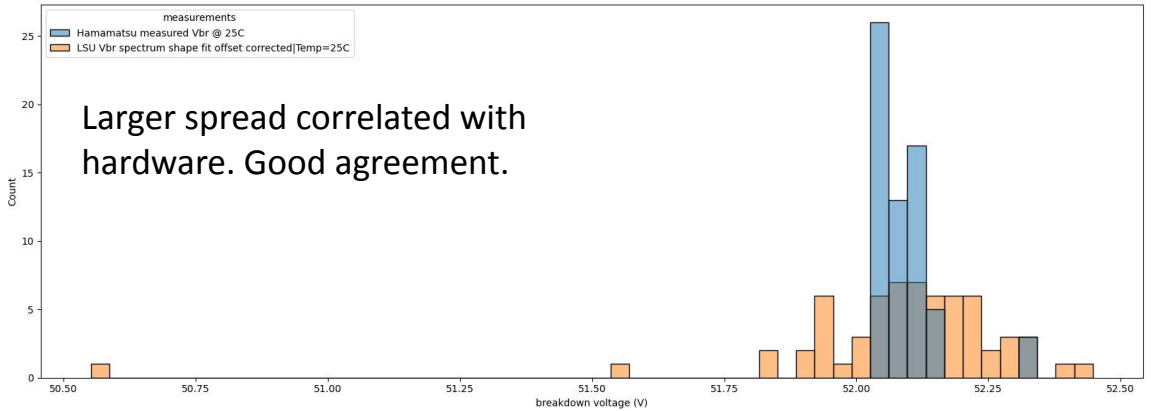


1. Fix a bias voltage
2. Measure the ADC spectrum
3. Determine the uncalibrated gain by fitting a line to ADC peak position vs photoelectron (PE) number

4. Vary the bias voltage and repeat steps 1. to 3. to form this plot.
5. Fit a line, and the x-intercept is the breakdown voltage.

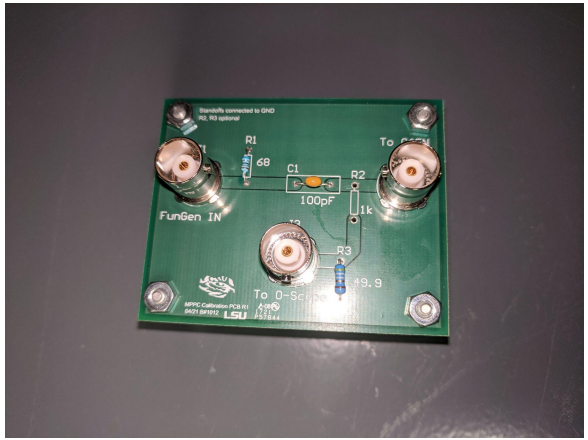
Breakdown Voltage Measurement - 64-channel PCB comparison with Hamamatsu

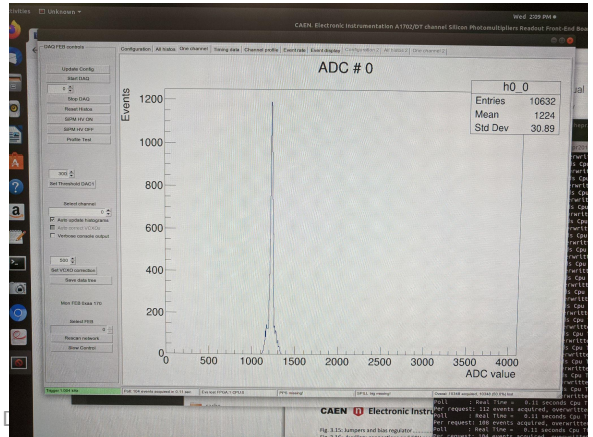




Larger spread correlated with hardware. Good agreement.

Charge Injection for MPPC Gain Measurement





A known charge is injected to the circuit. By measuring the ADC response, the conversion factor, #electrons/ADC is determined.

Injected charge seen on a scope

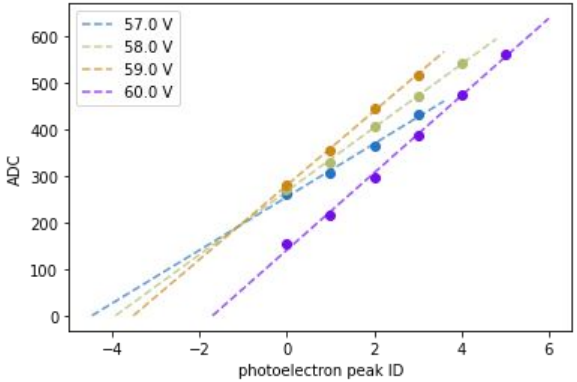
PE number Determination

slope

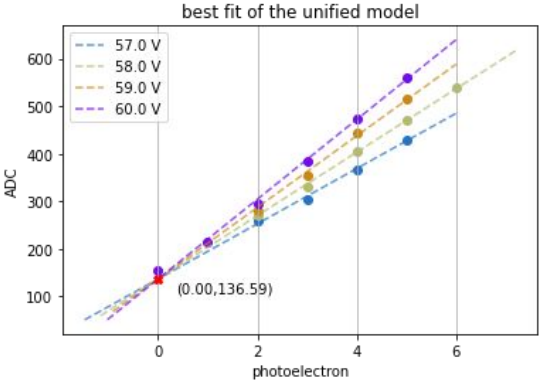
Breakdown voltage

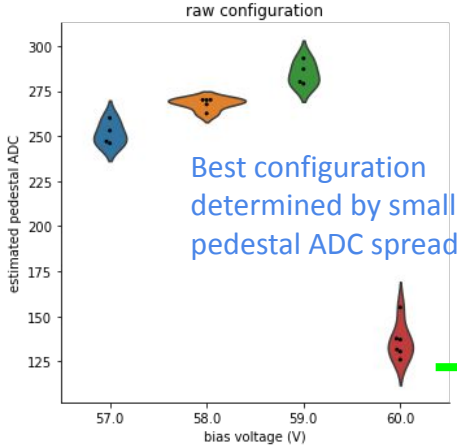
$$ADC = \beta(V - V_{bd})PE + \gamma$$

pedestal ADC

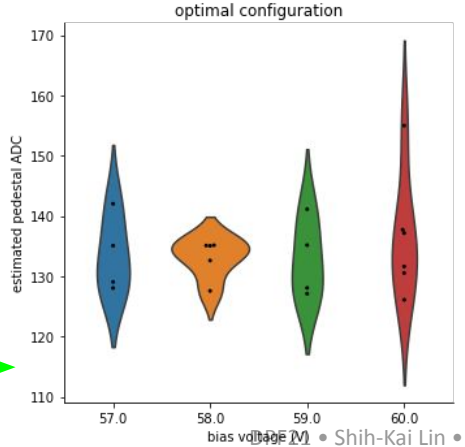


After best configuration found



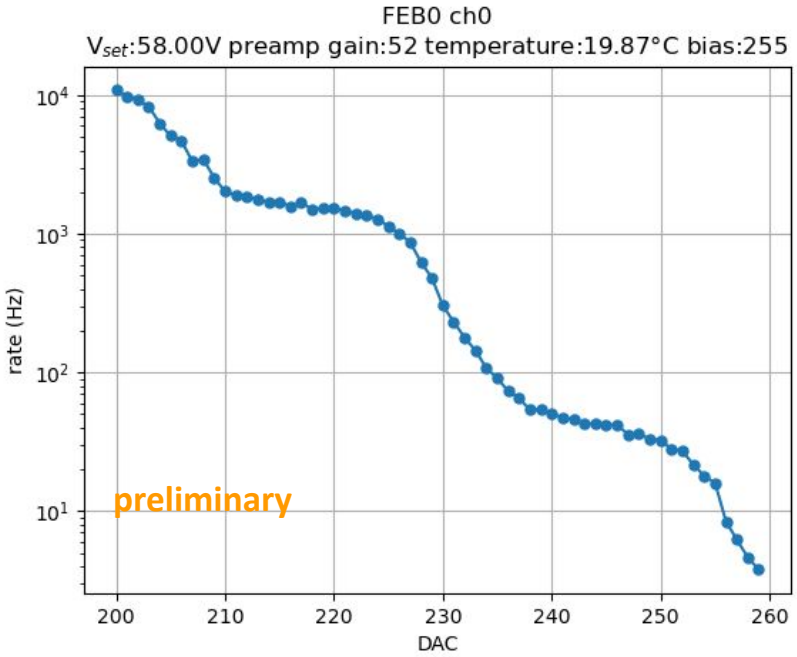


Best configuration determined by smallest pedestal ADC spread



- Due to fixed trigger threshold setting, the first peak number is undetermined.
- By measuring the slopes and breakdown voltages, we get groups of pedestal ADC values.
- Scan through the configuration space (relative unit shift in x for each line) to minimize the spread of pedestal ADC.

Dark Count Rate Measurement



By scanning through trigger thresholds, the rate vs. threshold curve can be obtained.

The curve shows step-like features where the sharp decreases in rate indicate crossing a PE peak.

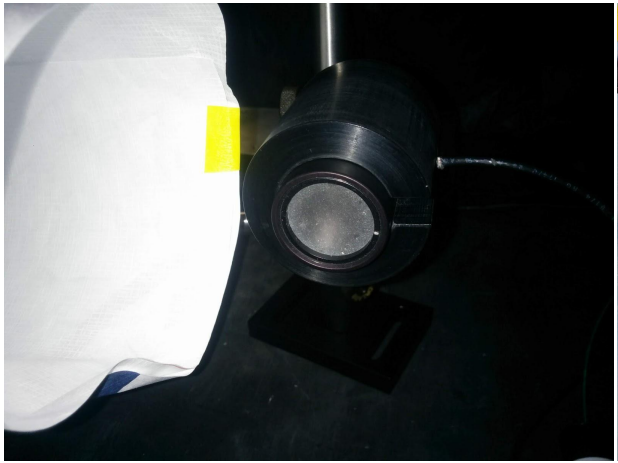
Work in progress: By threshold to PE map, we can measure dark count rate as a function of threshold in PE unit.

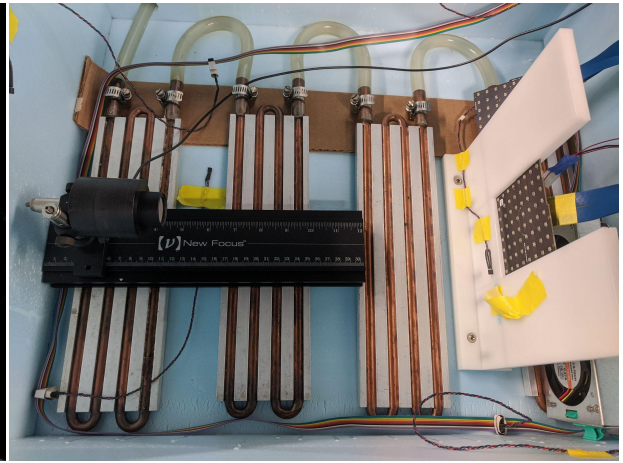
Summary

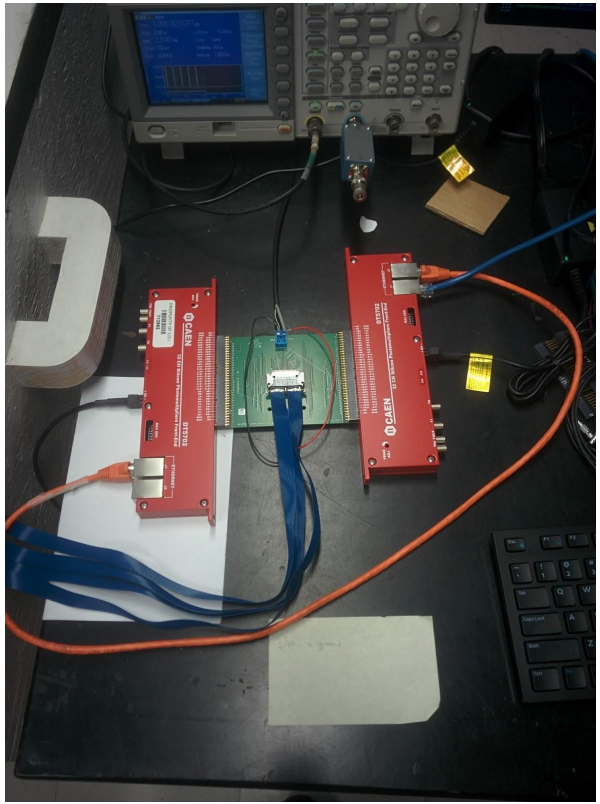
- A test stand at LSU is set up for large-quantity MPPC characterization.
- This set up measures MPPC's
  - Breakdown voltage
  - MPPC gain
  - Dark count rate
- So far good agreement in breakdown voltage with Hamamatsu's reference
- Currently 64 channels at a time. Plan to expand to 128 channels.

Backup

Test Stand at Louisiana State University (LSU)







The test stand includes

- Bias voltage supply
- LED driver & LED + diffuser
- 2 x CAEN DT5702
- Temperature controllable environment
  - Styrofoam box for thermal insulation
  - Thermal sensors
  - Water circulator for cooling