Commissioning and calibration of the Super-FGD in the T2K near detector upgrade

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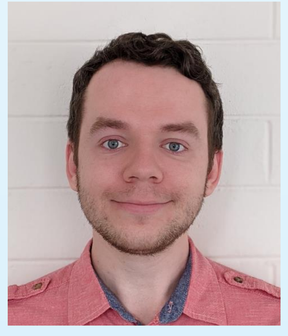

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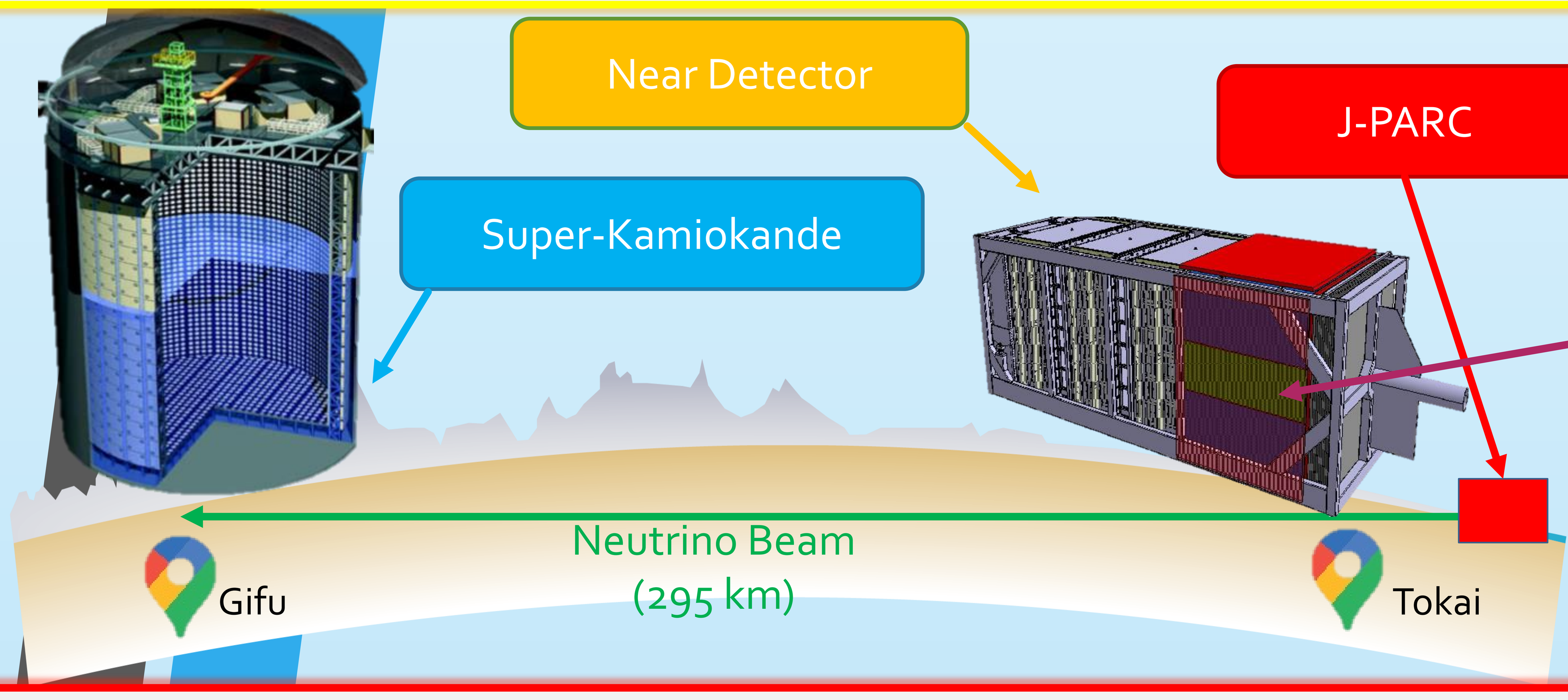
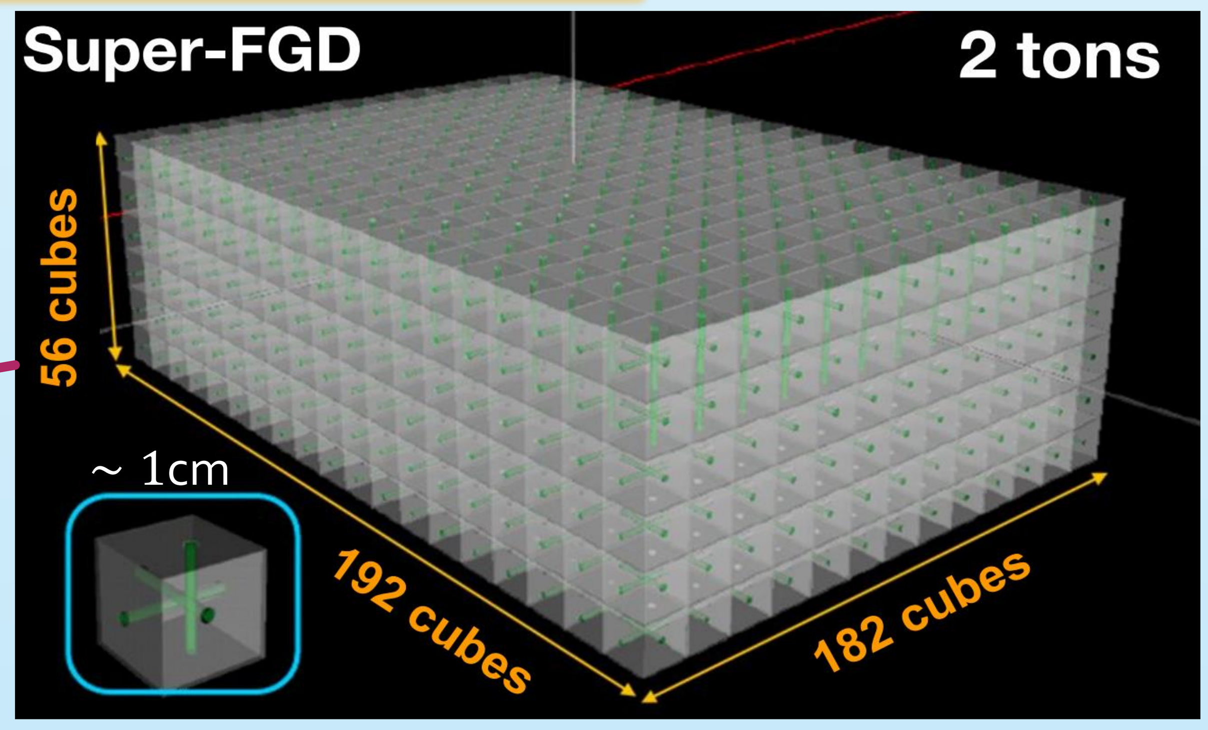
The T2K experiment and SFGD

The T2K (Tokai to Kamioka) experiment measures the fundamental parameters of neutrinos, including their mass hierarchy, oscillation angles and degree of Charge-Parity violation [1].
A beam of ν_μ or $\bar{\nu}_\mu$, is generated in Tokai on the east coast of Japan, directed at Super-Kamiokande, in Gifu.
Many $\nu_\mu \rightarrow \nu_e$ oscillations occur, which can be detected from Cherenkov radiation in SK. To reduce the systematic uncertainty related to the number of ν_μ particles in the beam, accurate measurements of the beam before neutrino oscillation are needed, so a detector is placed 280m downstream of the beam origin.

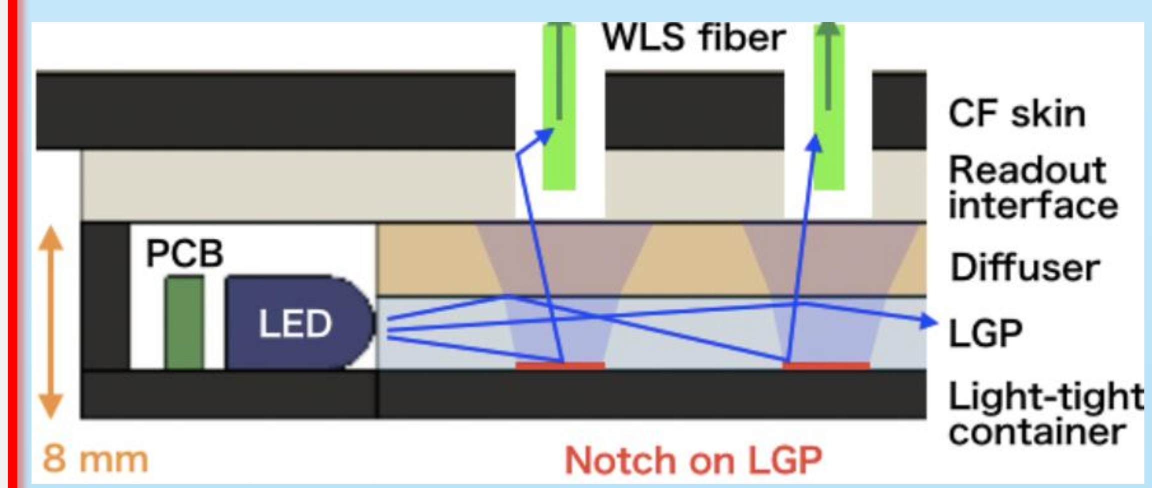
The Super Fine Grain detector was fully installed in April 2024 as part of a significant upgrade [2] to reduce systematic uncertainties from 6% to ~3% [3]. These uncertainties are associated with solid angle acceptance, the threshold for detecting low-energy pions and protons, and electron/photon separation. With approximately 2 million polystyrene cubes threaded with wavelength-shifting fibres in the SFGD, there are 55,888 channels to read – and calibrate. See more on the physics capabilities in posters by Liz Kneale, Katharina Lachner and Weijun Li.

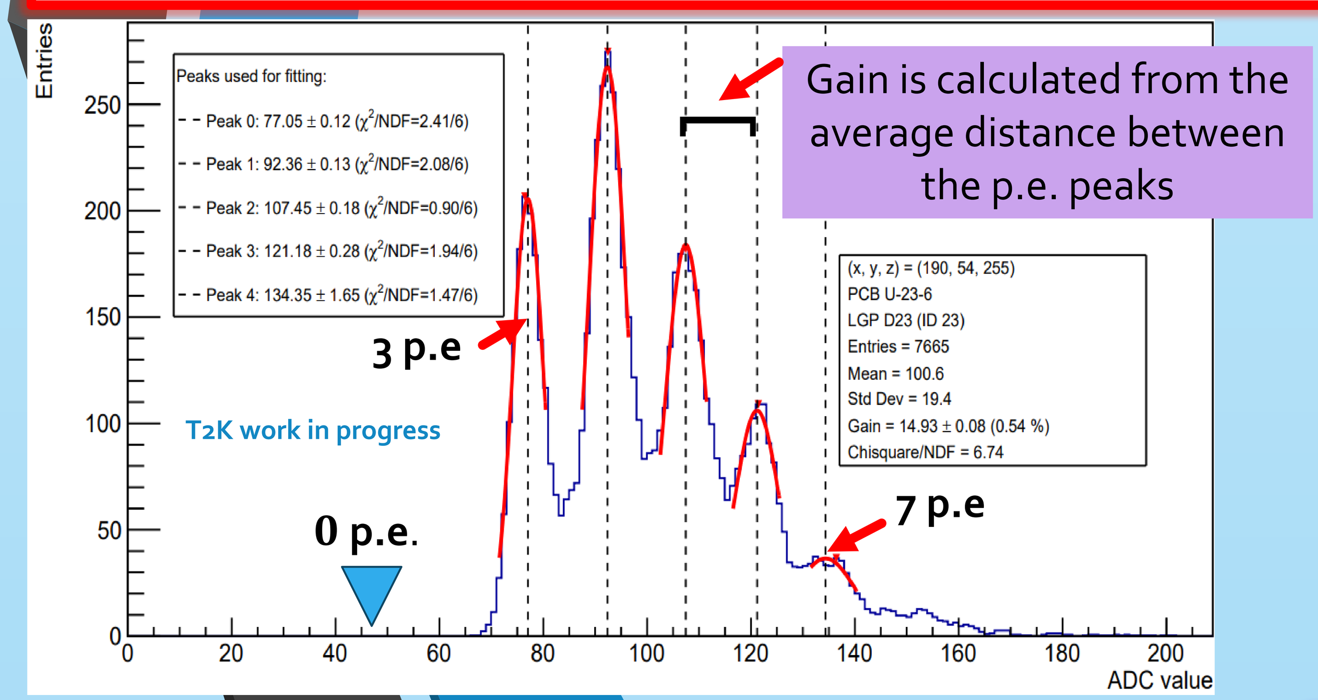


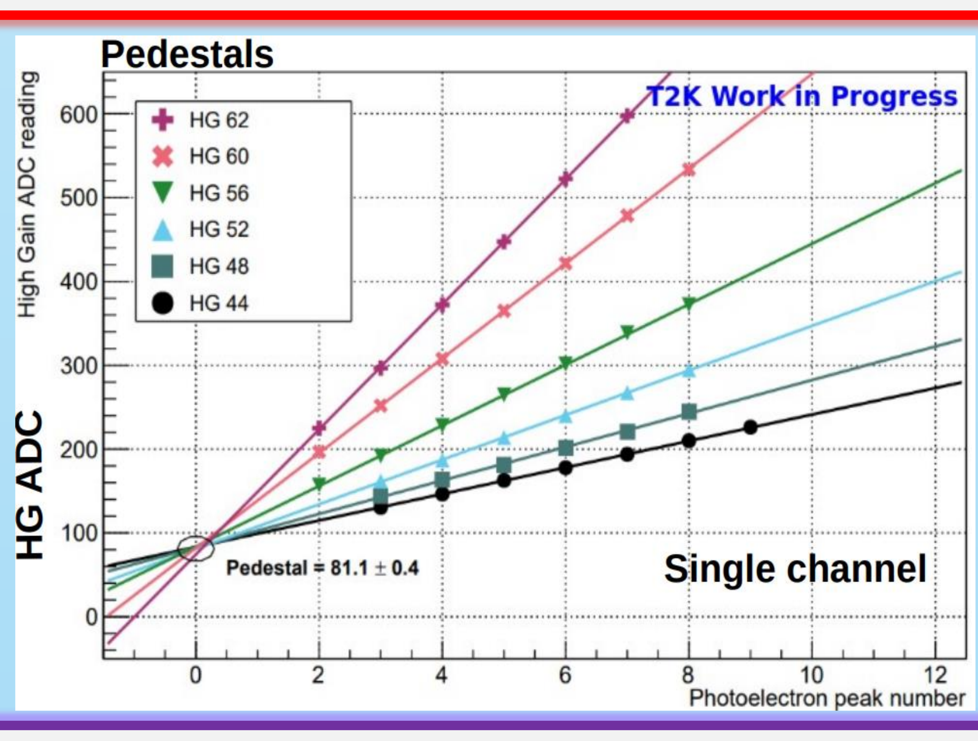


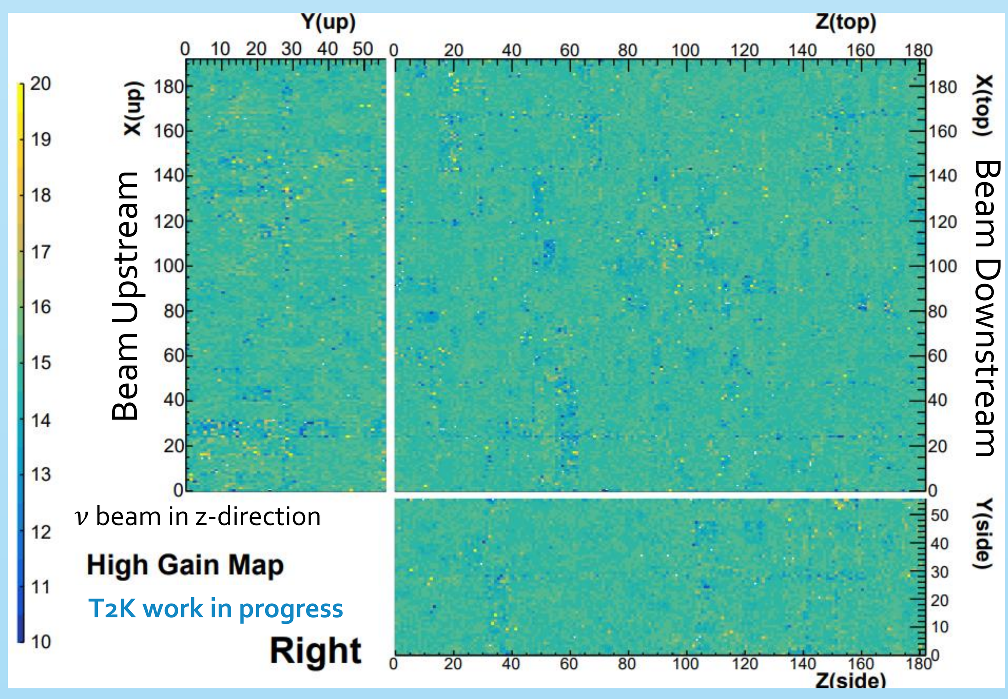
SFGD LED Calibration system

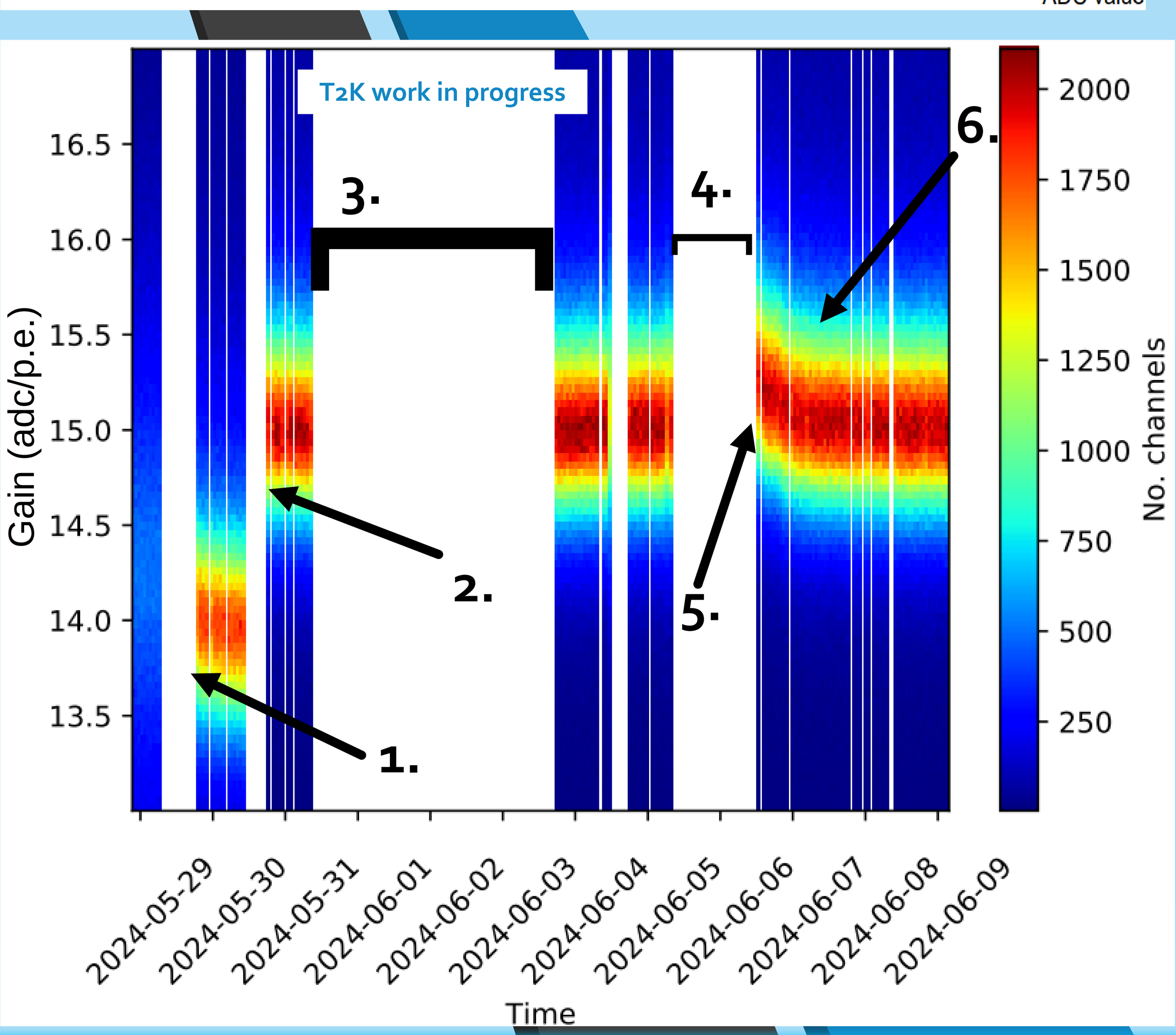
- LED panels surround the detector (see right plot), and flash at different intensities.
- Finger plots show electronics readout from LED flashes, peaks correspond to a different photoelectron peaks.
- Gaussian fits for the position of peaks used to determine gain (below left).
- 0p.e. point (pedestal, below middle) is determined by extrapolating peak positions from different gain voltage settings.
- An analysis pipeline system, b2luigi [4], is used to process and measure the gain in all channels, adapted from Spotify's Luigi pipelines.











1. **Histogram data taking optimised**
2. **SFGD high gain voltages re-calibrated**
3. **Cosmic data taking for low gain calibration**
4. **Magnet off (temperature dropped)**
5. **Magnet on, ND280 temperature restabilising**
6. **Beam run with fully upgraded ND280 started!**

Commissioning program

- The CITIROCs in the SFGD electronics will allow for the readout of both low and high gain signal amplification, along with the Time Over Threshold for coverage between 3 and ~2000 p.e. See Viet Nguyen's poster for more details.
- High gain covers up to around 200 p.e. and is calibrated with the LED system, low gain is calibrated using cosmic events.
- Fine-tuning of the high gain for a partial detector installation took place in January 2024, with new calibration data taken each week during beam time. Fine tuning of the full detector was finalised in May 2024, aiming for a high gain value of around 15 adc/p.e.
- The high gain tuning resulted in the final map of the high gain before beam started (above right), which shows a high level of uniformity.

Gain monitoring

- LED panels are triggered to flash between beam spills. Electronics readout is saved into histogram data banks, allowing for the gain to be measured and monitored during beam time. This was tested during beam time with the partial detector in February 2024 and has since been optimised to be able to measure the gain of the whole detector every hour.
- As the gain fluctuates with time and temperature, we can re-calibrate voltage settings as necessary. The plot on the left demonstrates the gain response to different conditions. Gain values observed from two days of near continuous beam operation show a mean gain fluctuation of less than 1%.
- See Tristan Doyle's poster for more information about performance.

References:
[1] K. Abe et al. (T2K), *The T2K experiment*, Nucl. Instrum. Meth. A 659, 106 (2011)
[2] K. Abe et al. (T2K), *T2K ND280 Upgrade - Technical Design Report*, (2019), arXiv:1901.03750
[3] A. Dergacheva, et al., *3D SuperFGD detector for the T2K experiment*, NIM A 1041, 167219 (2022)
[4] https://b2luigi.belle2.org