Component Quality Assurance for the T2K Project

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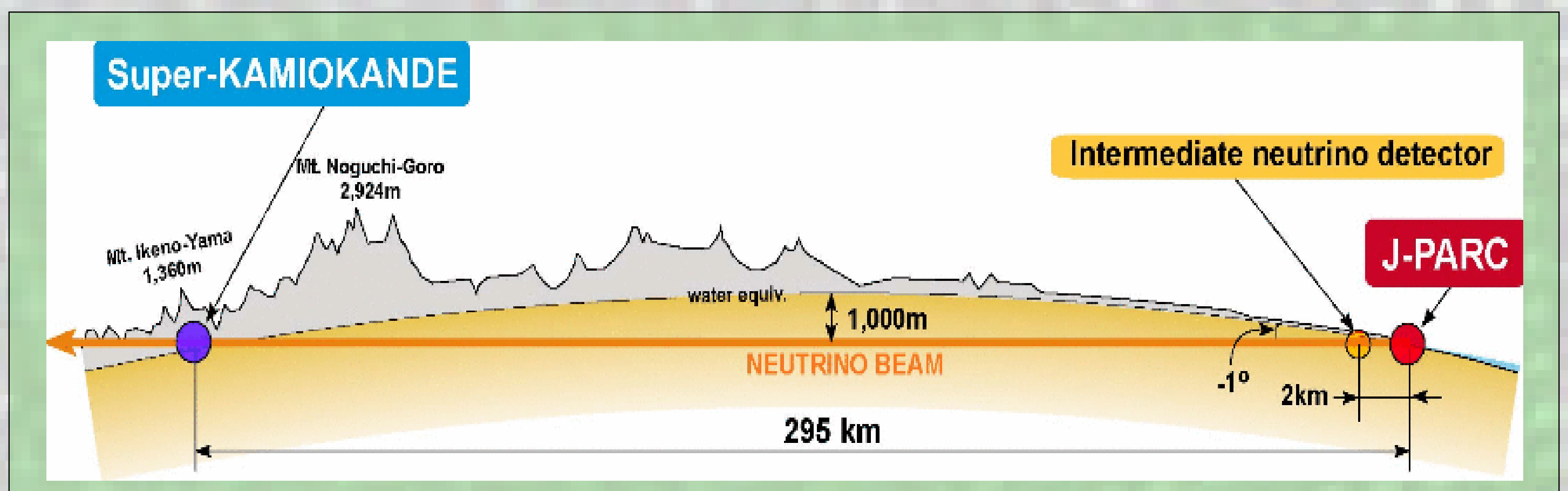


Figure 2: A diagram of the experimental setup for T2K. The beam is produced at J-PARC, passes through the intermediate ND280 detector, before passing underneath Japan and arriving at the Super-KAMIOKANDE detector nearly 300km away.

The T2K Experiment

What is T2K?

The Tokai-to-Kamioka (T2K) experiment, due to start in 2009, will seek to observe muon neutrinos oscillating into electron neutrinos, hopefully measuring some of the neutrino oscillation parameters. This work can then be used to gain a better understanding of physics, taking us beyond the Standard Model.

How will it work?

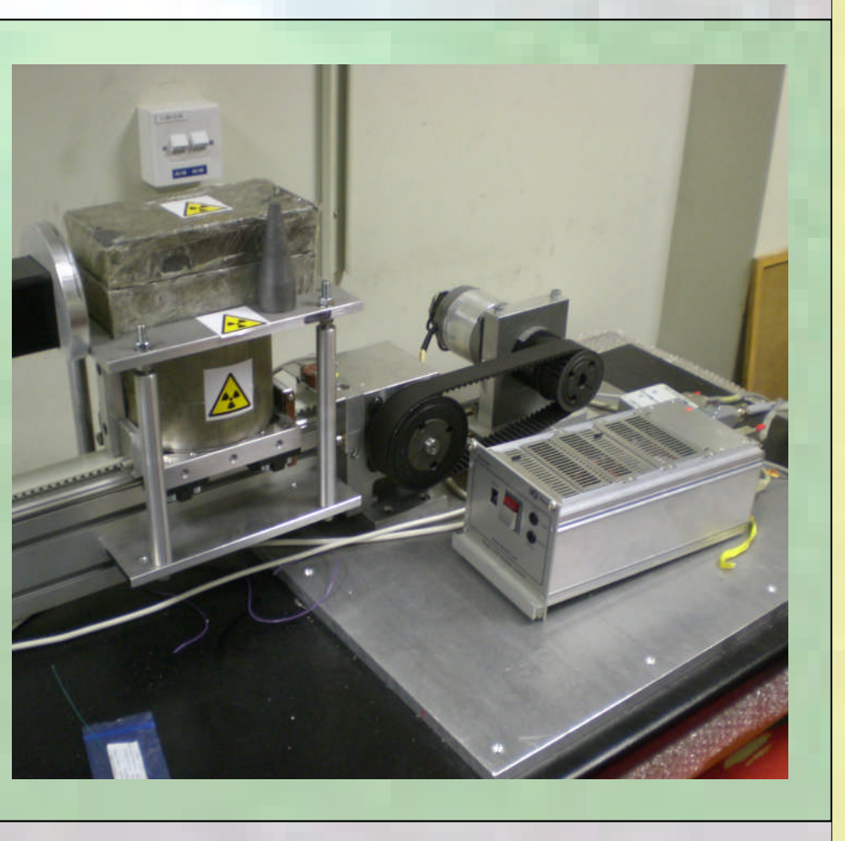
- The neutrino beam will be generated at J-PARC in Tokai, Japan, with a proton beam and graphite target. The pions produced by this collision will be focussed, and will decay into muons and muon neutrinos by the reaction in (1).
- To determine the initial properties of the neutrinos, an intermediate ND280 detector will intercept the beam after it is produced.
- The neutrinos will then travel 295km across Japan, oscillating and changing flavour.
- The beam will then be detected with the 50 kiloton Super-KAMIOKANDE underground water detector at Kamioka, and the properties of the beam measured again.

What is the UK doing?

The T2KUK collaboration is currently working on the detection instruments for the ND280 detector, with the work spread across many institutions in the UK. Warwick's job is the quality assurance and testing of the optical fibres and light sensors, and this is what I was helping with for the six weeks of my project.

Figure 5: A photograph of the MPPCs used to measure the amount of light travelling down the optical fibres. Produced by Hamamatsu Photonics of Japan, they are photon counting devices made up of multiple avalanche photo-diode (APD) pixels, which detect very low levels of light (each APD pixel of the MPPC outputs a pulse signal when one photon is detected).

Figure 3: A photograph of the radioactive source and drive motor mechanism for the fibre scanner. The motion of the carriage on which the source sits is controlled by pre-written computer software.



Testing the Sensors

Data Analysis

The light sensors for T2K are MPPCs (multi-pixel photon counters – see Figure 5), which all need to be tested before installation. However, the analysis code for the data from the tests sometimes analysed it incorrectly, and so needed to be fixed. For example, correct analysis should produce the two graphs in Figure 6, where the code has found the first three peaks and fitted smooth Gaussian curves to them, but sometimes peaks were missed out, or included twice, and sometimes the Gaussian fit was wildly wrong.

Solving the Problem

It was possible to force the program to find 4 peaks rather than 3, then pick the 3 peaks that were needed from those. Also, by changing some of the parameters of the peak-finding section, instances where split peaks were detected could be disregarded. This led to a much improved peak-finder, though the peak-fitter proved more problematic. After finding the peaks, the code fitted separate curves to each peak, and then fitted a sum of those curves to the whole spectrum. The individual fits seemed to be fine, implying that the problem was in the sum peak-fitter, and was probably something to do with the initial fit parameters or the limits that these parameters were allowed to vary between. After extensive testing and modification of individual parameters, this section of the code was improved, but unfortunately I was unable to totally fix the fitter.

Project Extensions

Clearly the peak-fitter still needs work, as does the peak-finder as it still occasionally does not find some of the peaks. Also, the next stage of the experiment at Warwick will involve scanning many times more fibres, which would take far too long on the current setup. The next generation of fibre scanner, the design of which is still to be finalised, must be able to scan multiple fibres at once, drastically cutting down on the time taken for the fibre quality assurance process.

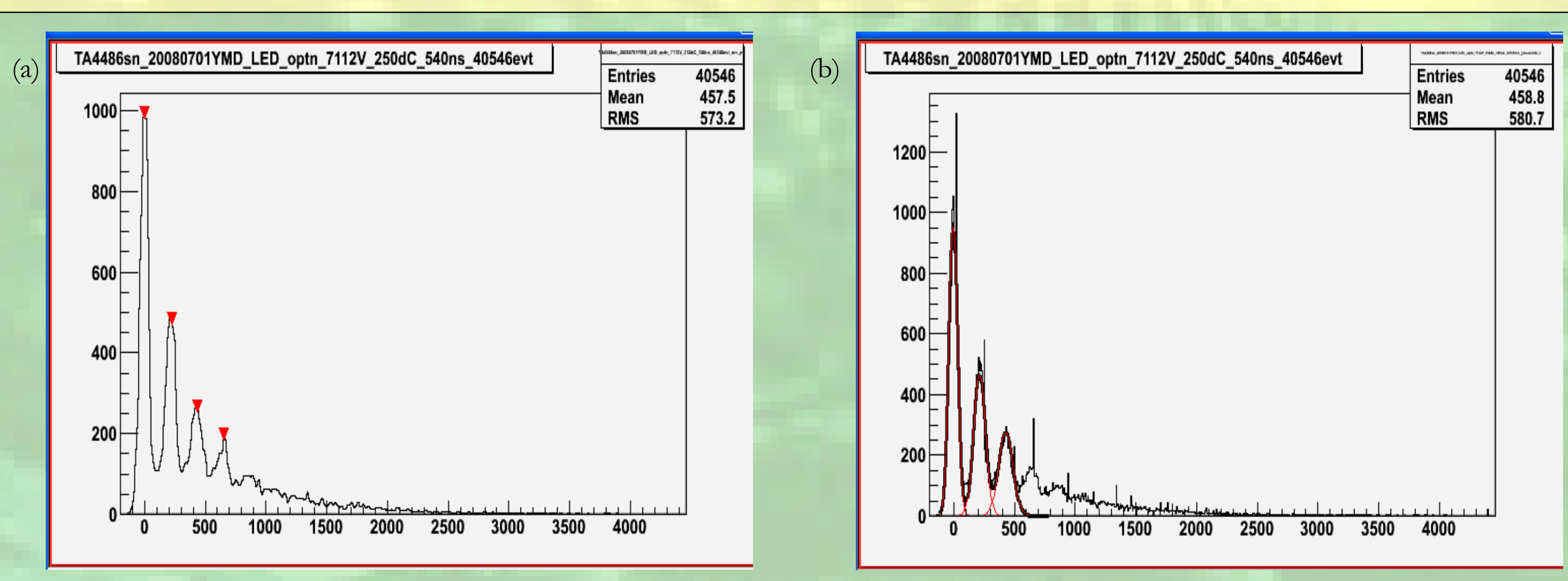


Figure 6: An example of when the peak-finder and Gaussian peak-fitter worked well. The peaks have been marked in (a) and the fitted curves overlaid in (b) on the original smoothed test data spectrum for the sensor TA4486.

Neutrino physics

What are neutrinos?

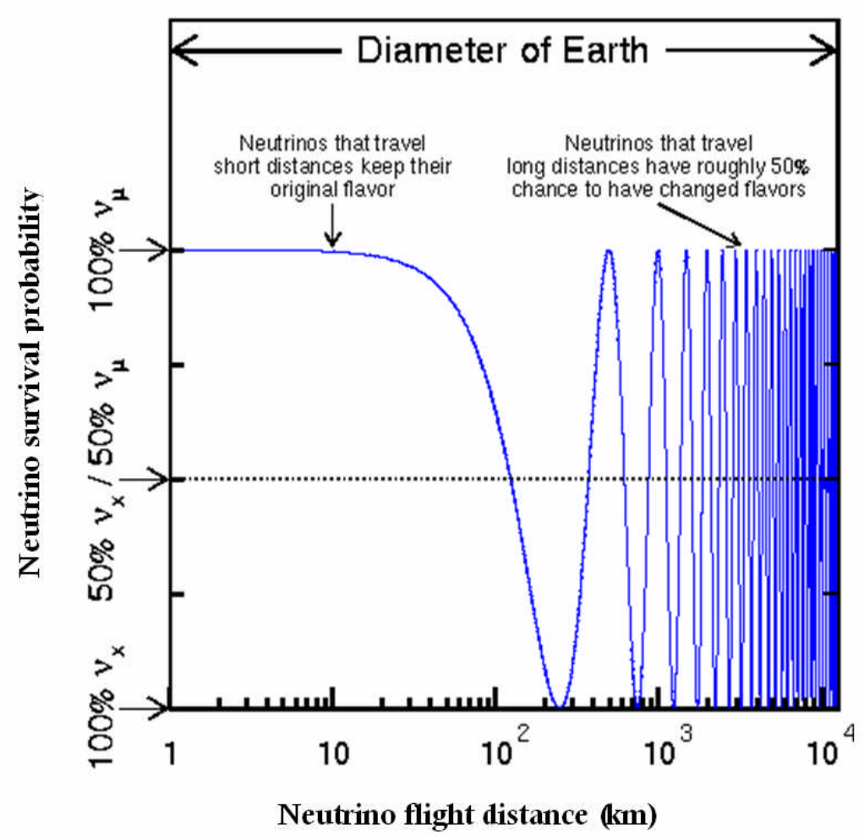
Neutrinos are a type of elementary particle, usually denoted by the Greek letter, ν (nu). They travel very close to the speed of light, are electrically neutral, and only interact with normal matter very rarely, making them extremely difficult to detect. There are three types, called 'flavours', of neutrinos, *electron neutrinos*, *muon neutrinos*, and *tau neutrinos*, which are produced in particle reactions with their associated particle (electrons, muons, or tau particles respectively). For example, a pion (a type of non-elementary particle) could decay into a muon (μ) and a muon neutrino (ν_μ), as shown below.

$$\pi^+ \longrightarrow \mu + \nu_\mu \tag{1}$$

Why study them?

An odd property of neutrinos is that they actually change their flavour over time. For example, the neutrino in (1) is a muon neutrino when created, but after it has travelled a certain distance there is a non-zero probability that it will be observed to be a tau neutrino. This can only happen if the mass of neutrinos is non-zero. However, this is not the prediction of the Standard Model, which describes the particles in our universe and their possible interactions, and is our best theory of particle physics to date. So studying the mass of the neutrino could be the key to developing the next generation of theories, and thereby coming even closer to understanding the true fundamental nature of our universe.

Figure 1: A plot of the oscillations between muon neutrinos and neutrinos of another flavour, x. It shows the survival probability as a function of distance, i.e. the probability a neutrino is a given flavour at any distance (up to the diameter of the Earth) away from the point of origin.



The Fibre Scanner

The Equipment

The optical fibres were tested individually using equipment consisting of a radioactive source (^{137}Cs) sitting on a moveable carriage (shown in Figure 3), which could run underneath a light-tight tube closed by an end-cap containing a working sensor (shown in Figure 4). The tube contained a scintillator bar with a hole drilled along it, through which the fibres could be inserted.

The Process

The optical fibres were loaded by threading them through the scintillator bar and coupling them to the sensor. The tube was sealed, and the computer control program was run. This moved the source along the fibre, stopping at set distances. The source irradiated the scintillator bar (through the tube), causing an electromagnetic (EM) shower, i.e. producing lots of light. This light was collected by the fibre in the centre of the bar, and transmitted to the sensor at the end, which recorded how much light was being picked up by the fibre.

The Analysis

The aim of this process was to show whether there were any cracks or discontinuities in the fibre – if so, there would be a sudden drop in light yield after the distance along the fibre where the problem was. Another aim was to discover which fibres, if any, had abnormally low light yields in general, which could cause problems in the final experiment. This was done by comparing the yield of each fibre to a running average, with fibres being designated as bad if their light yields were greater than 20% lower than the average. 4 fibres out of roughly 2000 failed this test, and these, along with fibres failing other quality assurance criteria, were removed before being sent on to the next stage.

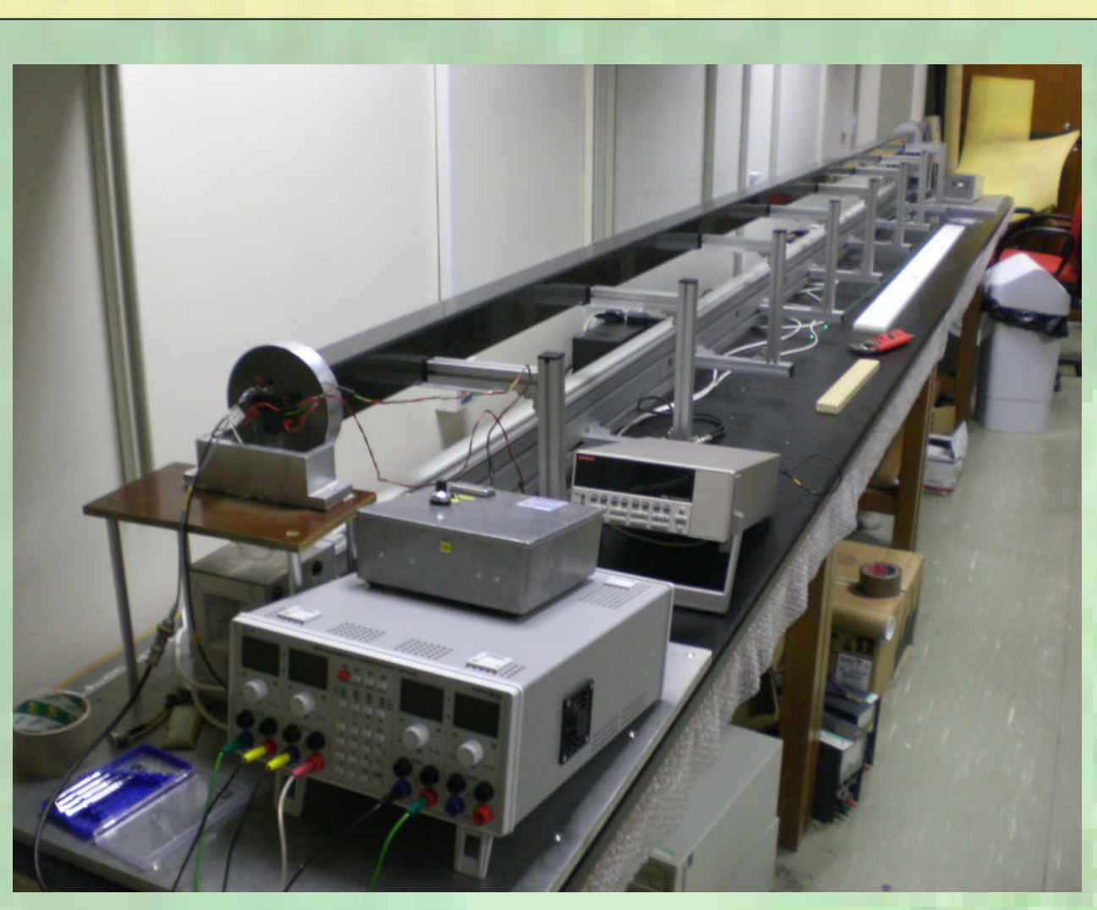


Figure 4: A photograph of the fibre scanner. The sensor and cooling equipment are contained within the circular end-cap, and the fibre is held in place against the sensor with a cushioned screw.

References

- **Background image:** View of the interior of the Super-KAMIOKANDE particle detector at Kamioka, Japan, taken from,

http://www.particlephysics.ac.uk/news/picture-of-the-week/picture-archive/super-kamiokande--9000-neutrino-eyes/980610_sm.jpg

- **Figure 1:** Taken from the Boston University High-Energy Physics website, http://hep.bu.edu/~superk/osc.html
- **Figure 2:** Taken from the University of Warwick EPP group website, http://www2.warwick.ac.uk/fac/sci/physics/research/epp/exp/t2k
- **Figure 5:** Taken from the website of the manufacturer (Hamamatsu Photonics), http://jp.hamamatsu.com/products/sensor-ssd/4010/index_en.html

Acknowledgements

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