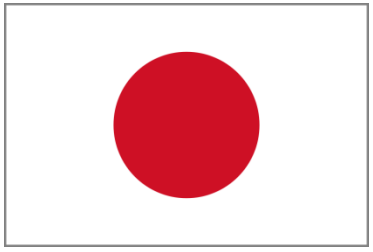
Optical Calibration of Water Cherenkov Detectors

JENNIFER Meeting, QMUL
September 2016



Dr Adrian Pritchard
a.a.pritchard@liverpool.ac.uk
On behalf of Universities of Liverpool, Warwick, Sheffield

About Me

- I am a post-doctoral research associate from the University of Liverpool, and have been working on Hyper-Kamiokande since October 2015, and Super-Kamiokande since April 2016

- I obtained my PhD from Liverpool in 2015, analysing B meson decays with the LHCb detector at CERN

- From jennifer-project.eu: “JENNIFER aims also to cross fertilize different communities: flavour and neutrino physicists…” – hopefully I will fit this model well by the end of this post-doc!

Pulsed LED Calibration System

- Goal: develop an optical calibration system to obtain a good understanding of the PMT response in Hyper-Kamiokande, to enable accurate determination of detector properties and water parameters

- This is crucial to allow HK to achieve the sensitivity required for a number of key physics analyses

- Inject light pulses of known emission time and intensity at several visible wavelengths using fibre coupled LEDs

- Multiple injection points will allow all PMTs to be illuminated and therefore allow a full calibration of both the time response and gain

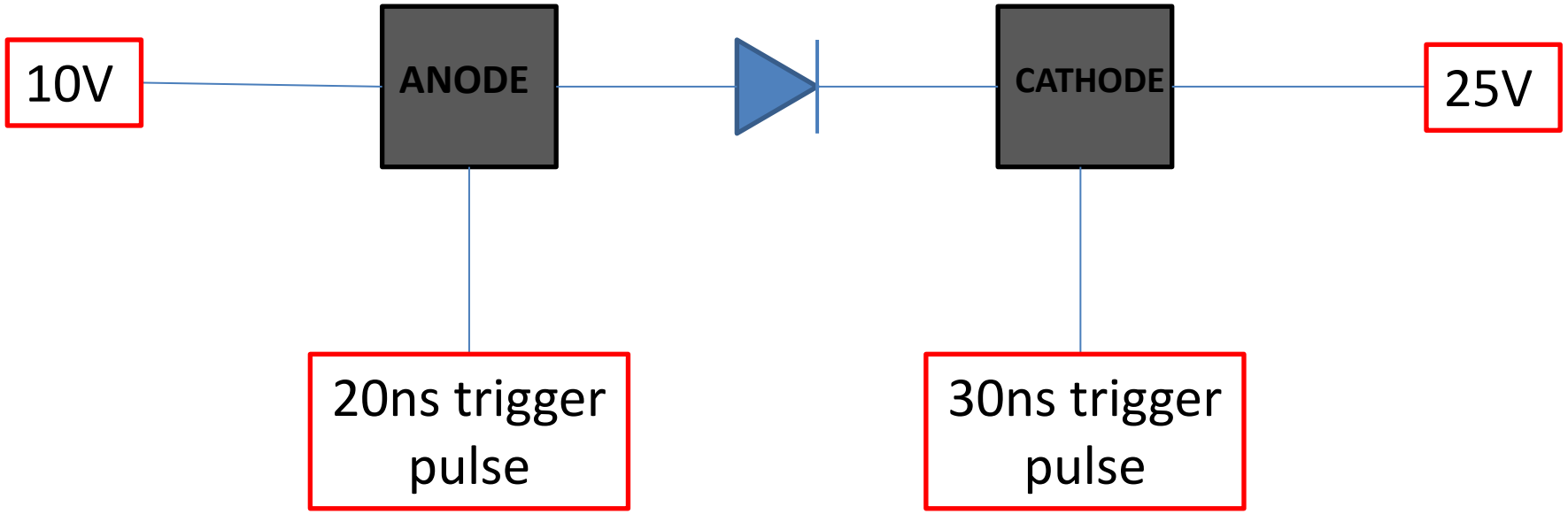
Pulsed LED Calibration System

- Develop light source using fibre-coupled pulsed LED system
- Full calibration and monitoring requires pulses with:
  - Short (order of a few ns) pulse duration
  - Well understood time profile
  - Variable but well controlled intensity
  - Good pulse to pulse stability
  - Various LEDs with different wavelengths

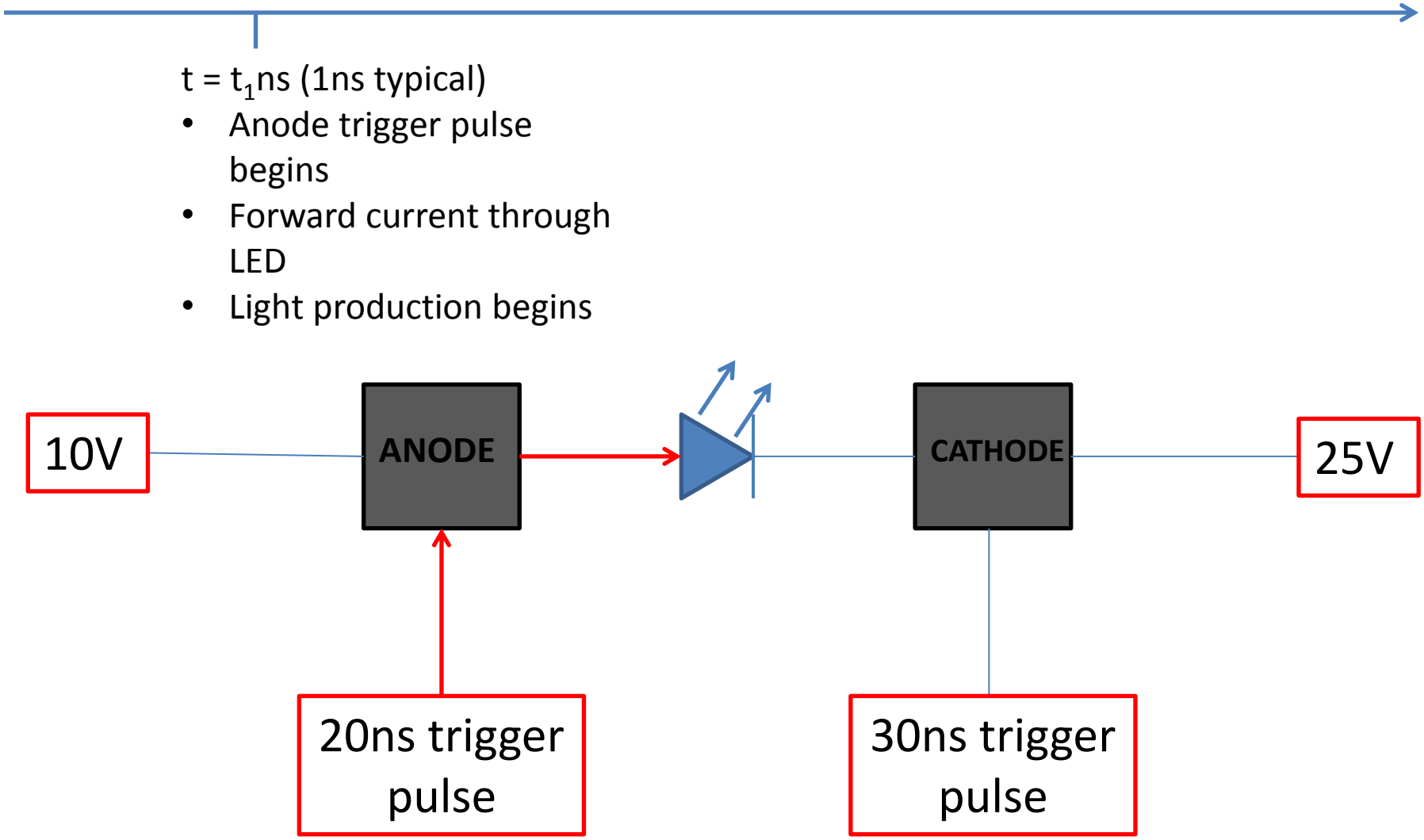
Operating Principle

t = 0ns

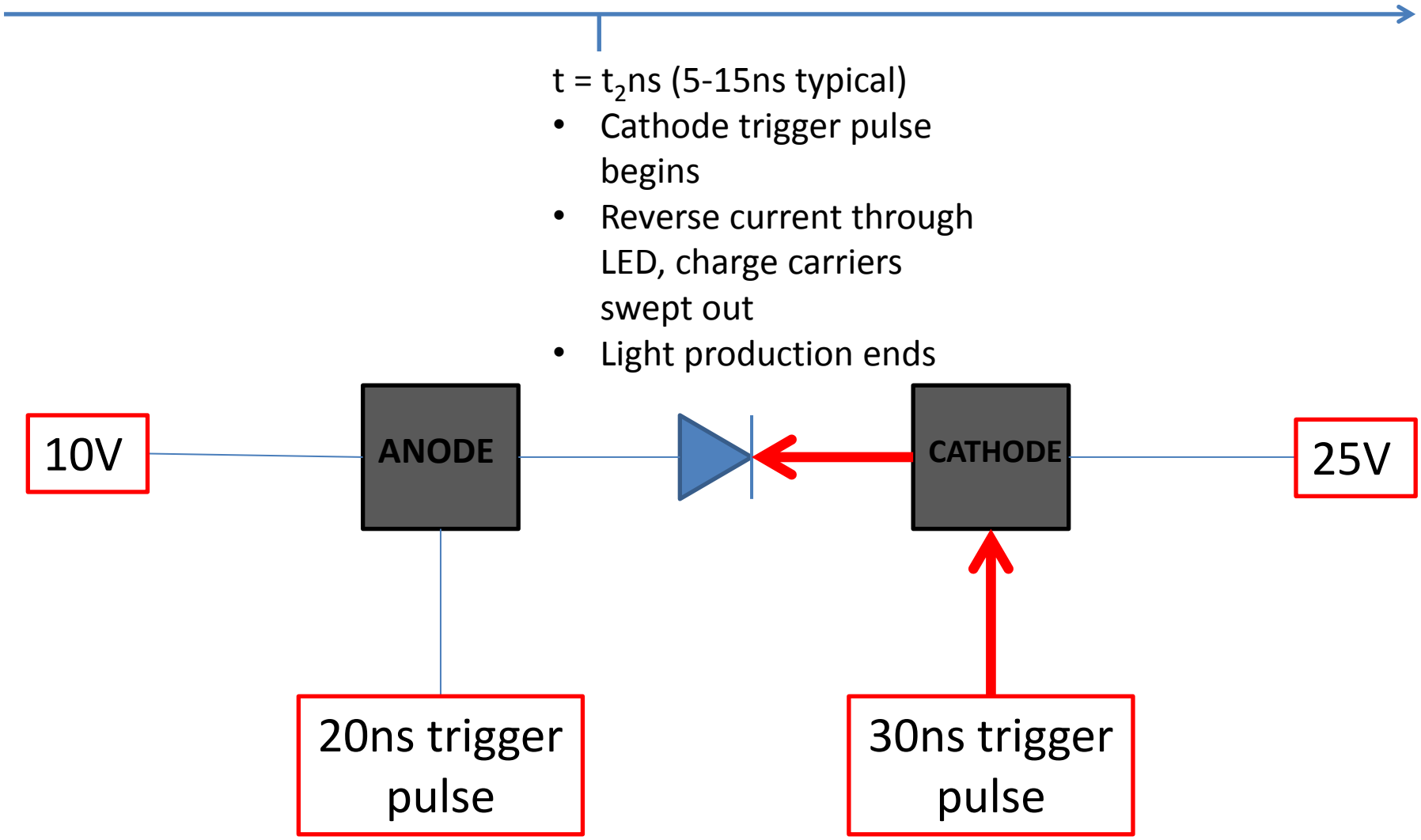
- No pulses
- No current through LED
- No light production



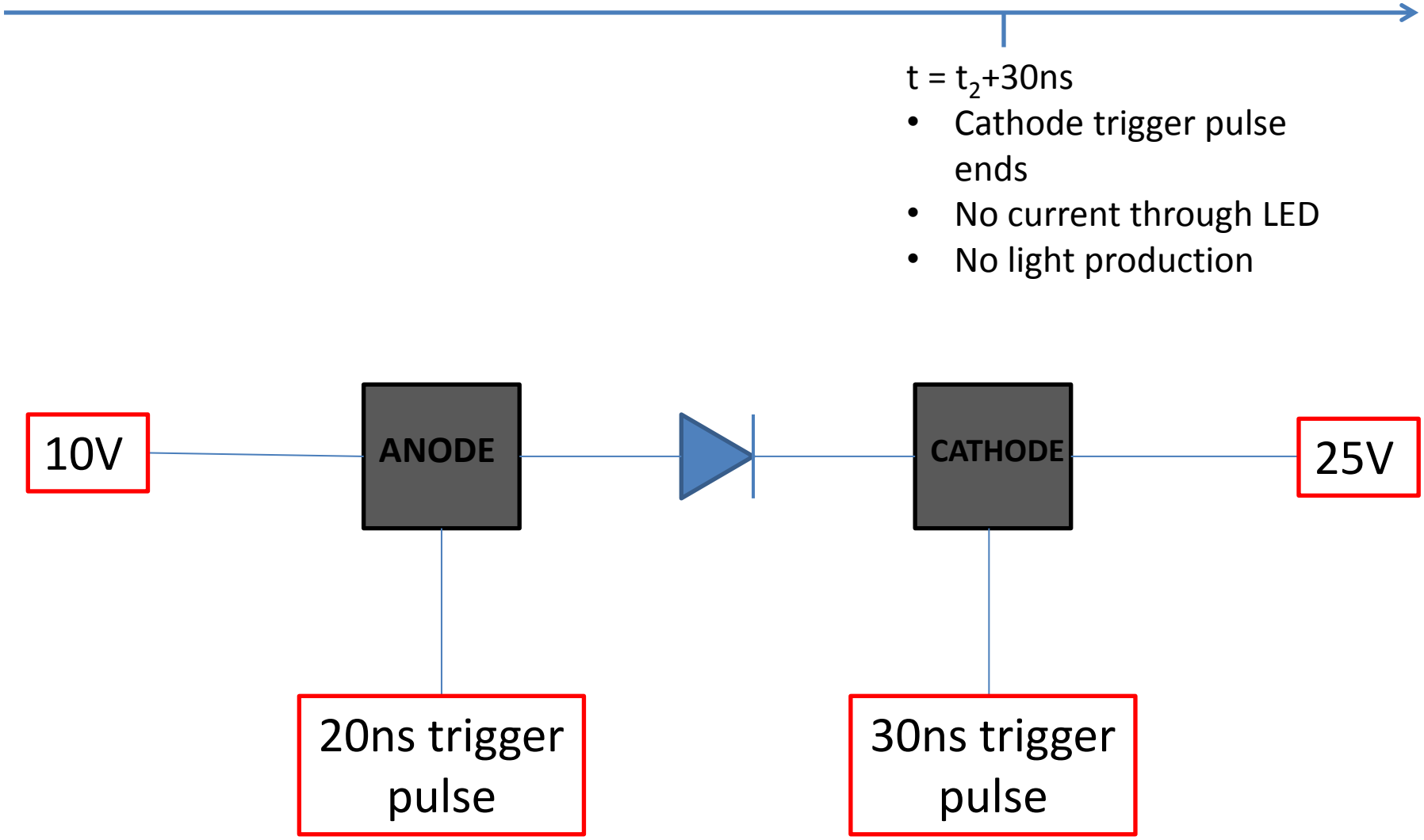
Operating Principle



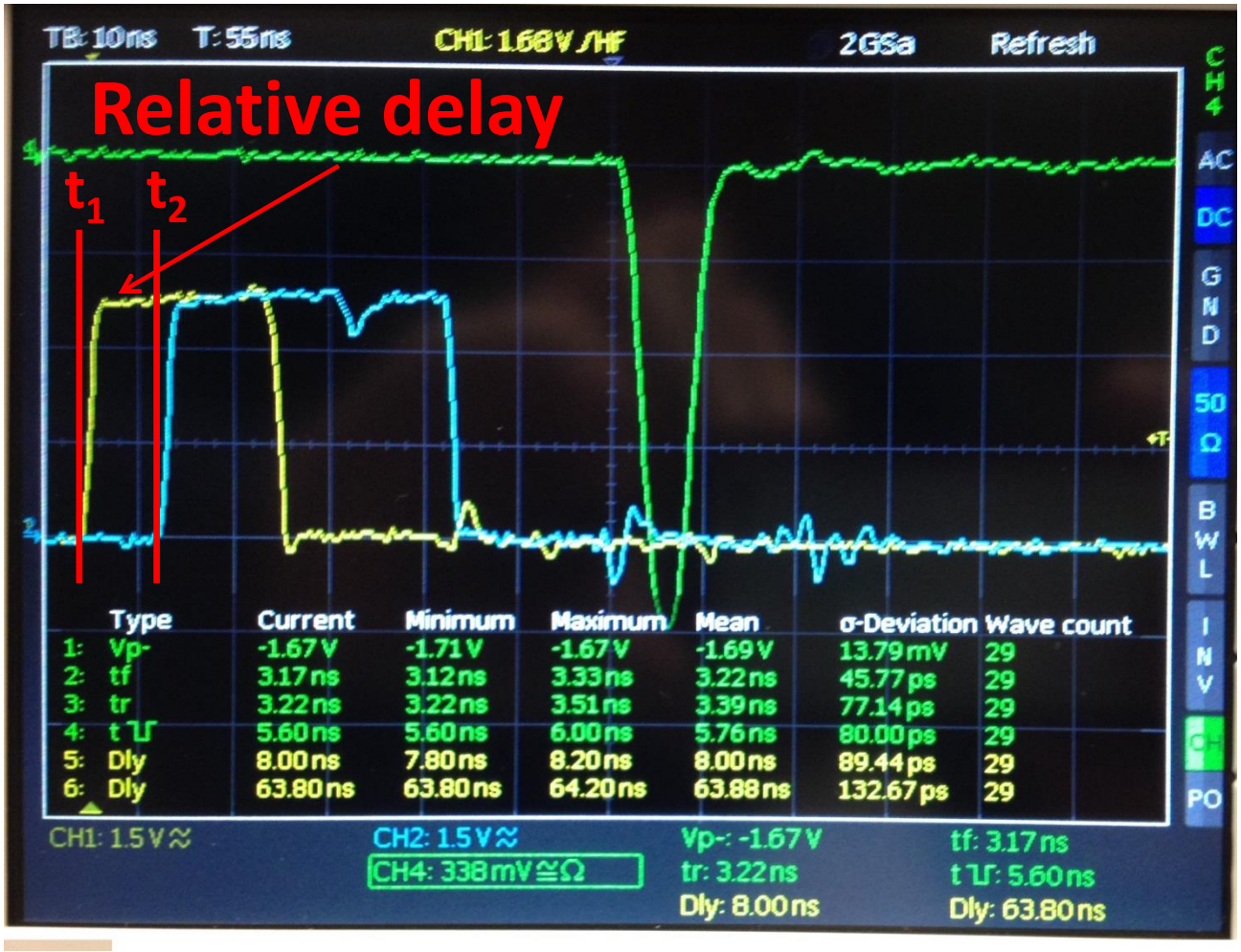
Operating Principle



Operating Principle

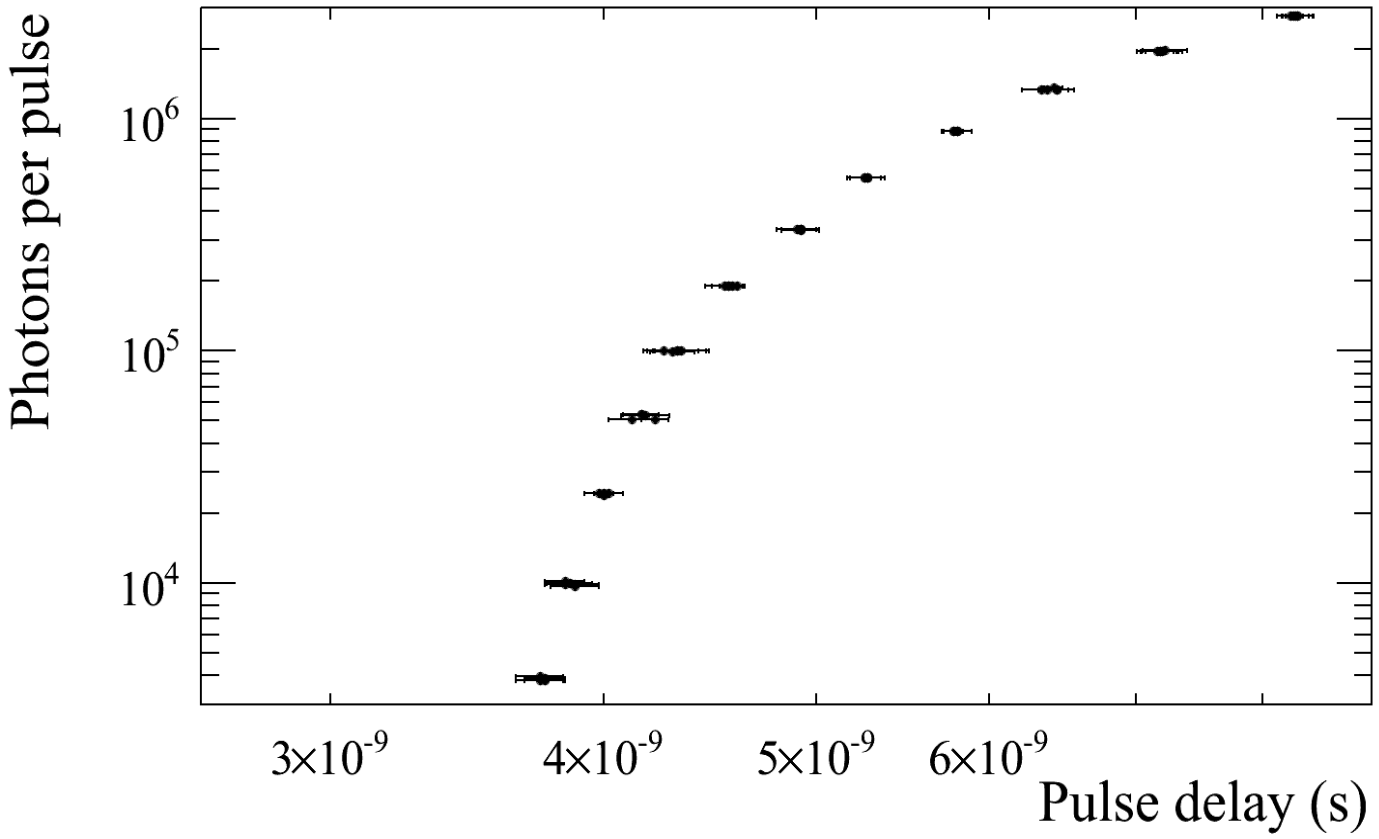


Operating Principle

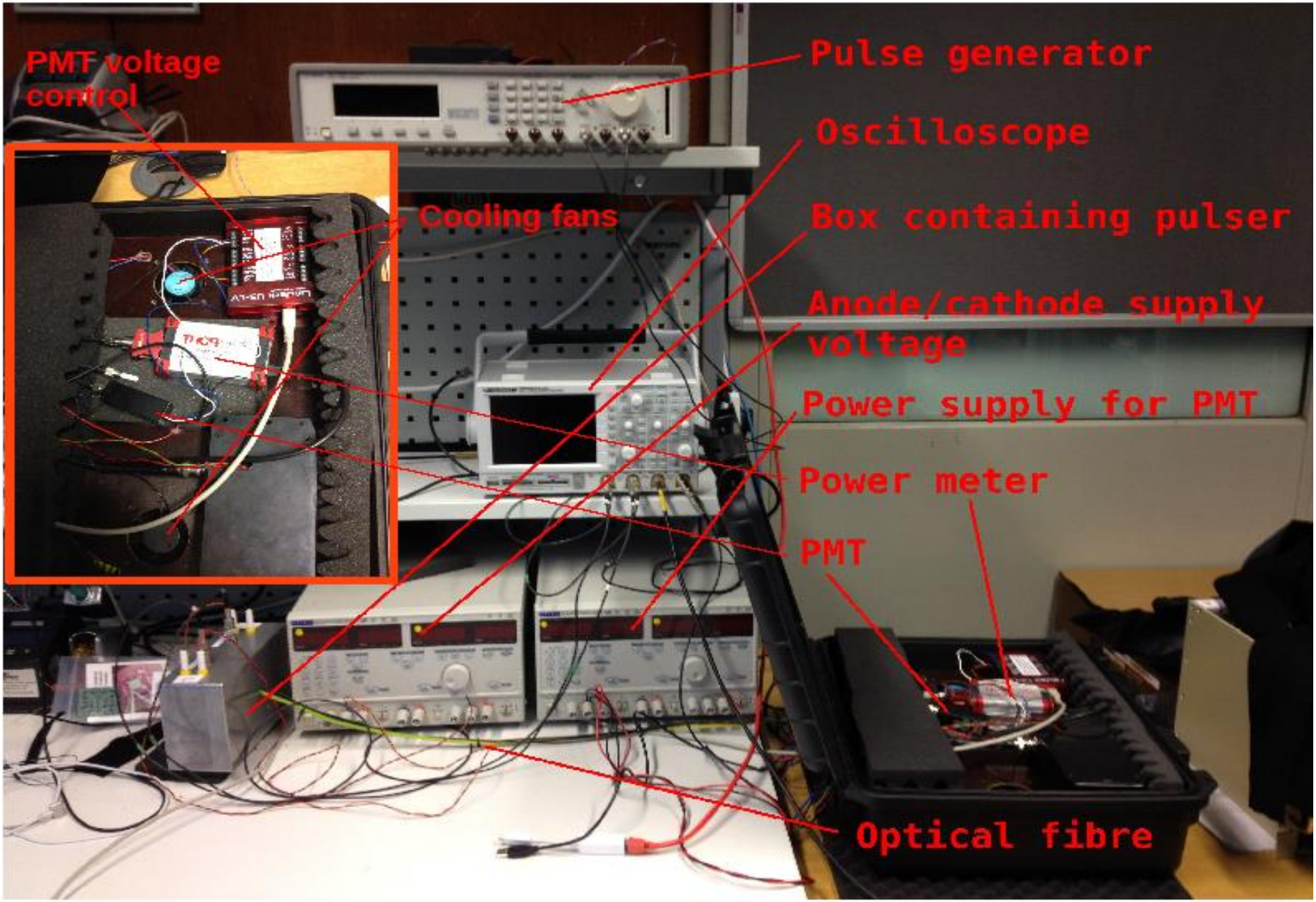


- Number of photons varied by varying the relative delay time, t_1-t_2
- Pulse width controlled by anode/cathode voltages

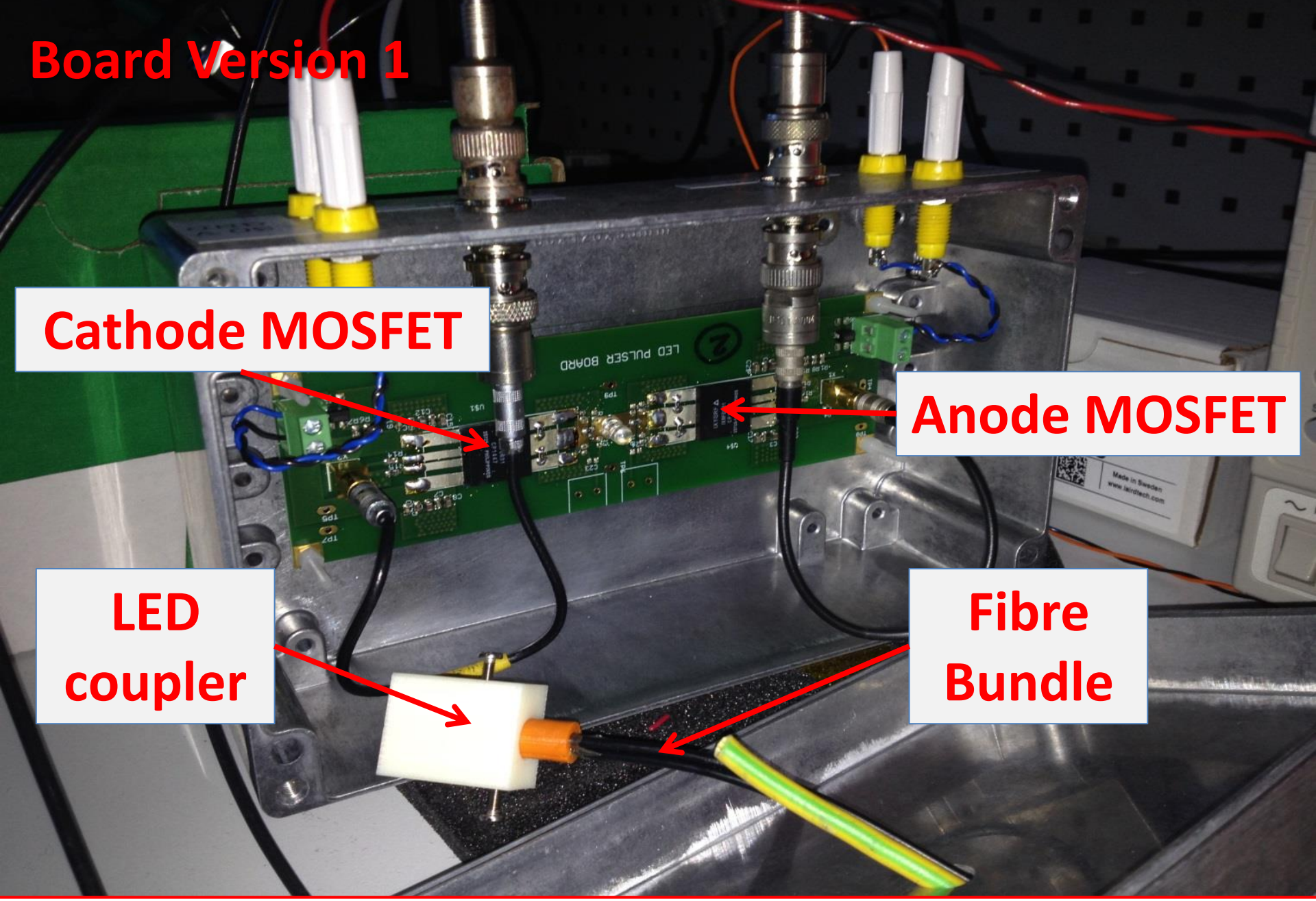
Operating Principle



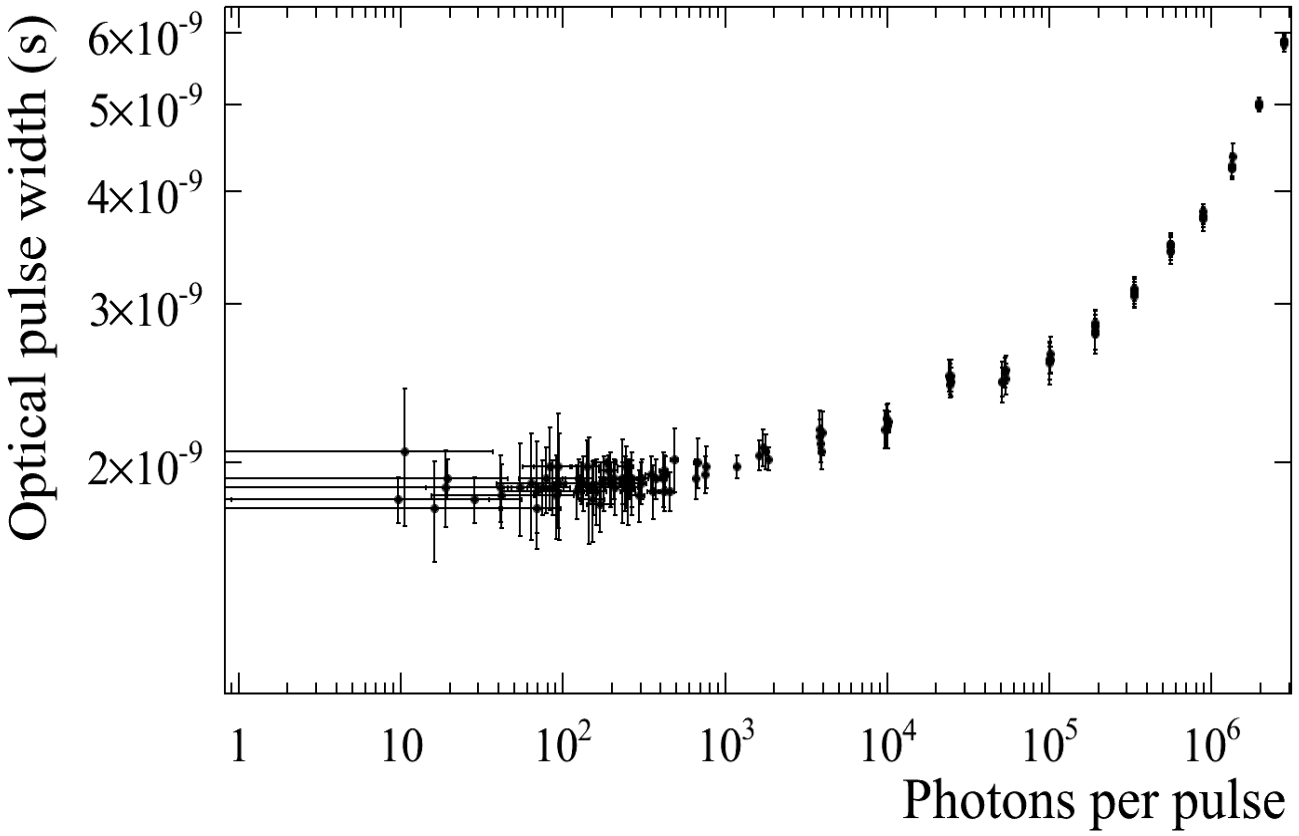
- Photons per pulse controlled by the relative delay between the anode and cathode pulses


PMT voltage control
Pulse generator
Oscilloscope
Cooling fans
Box containing pulser
Anode/cathode supply voltage
Power supply for PMT
Power meter
PMT
Optical fibre

Board Version 1



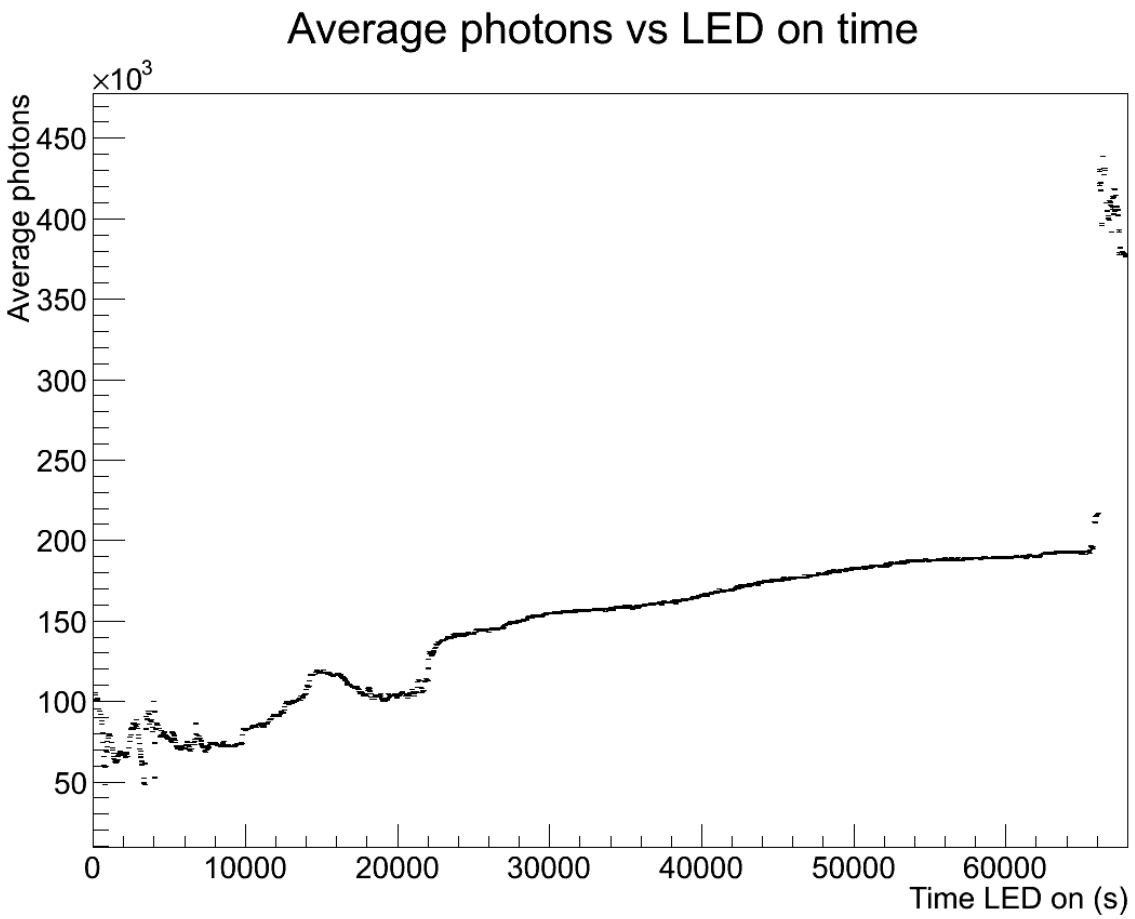
Results From Board Version 1.0



- Generally good performance, pulse widths of <3ns at 100,000 photons/pulse

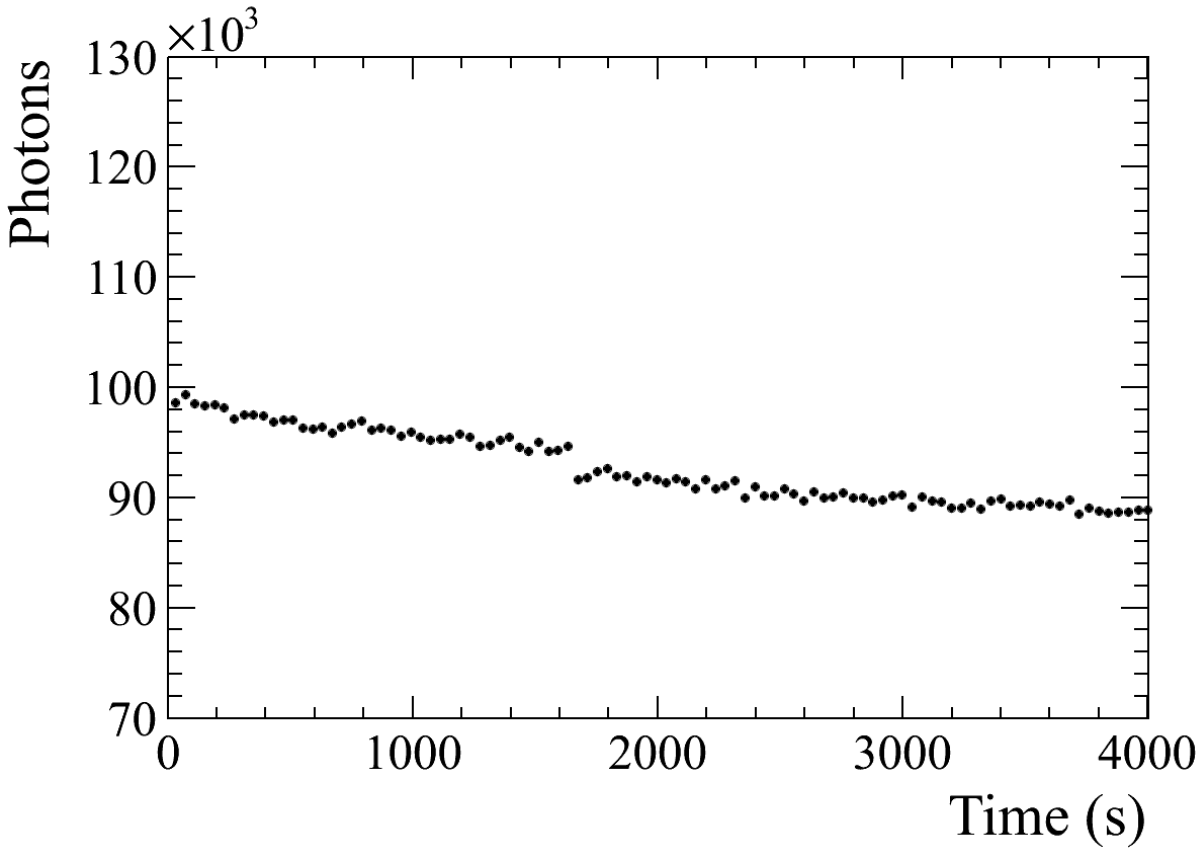
Results From Board Version 1.0

- Number of instabilities observed during board testing
- Long period (~20hr) run showed different instabilities in number of photons



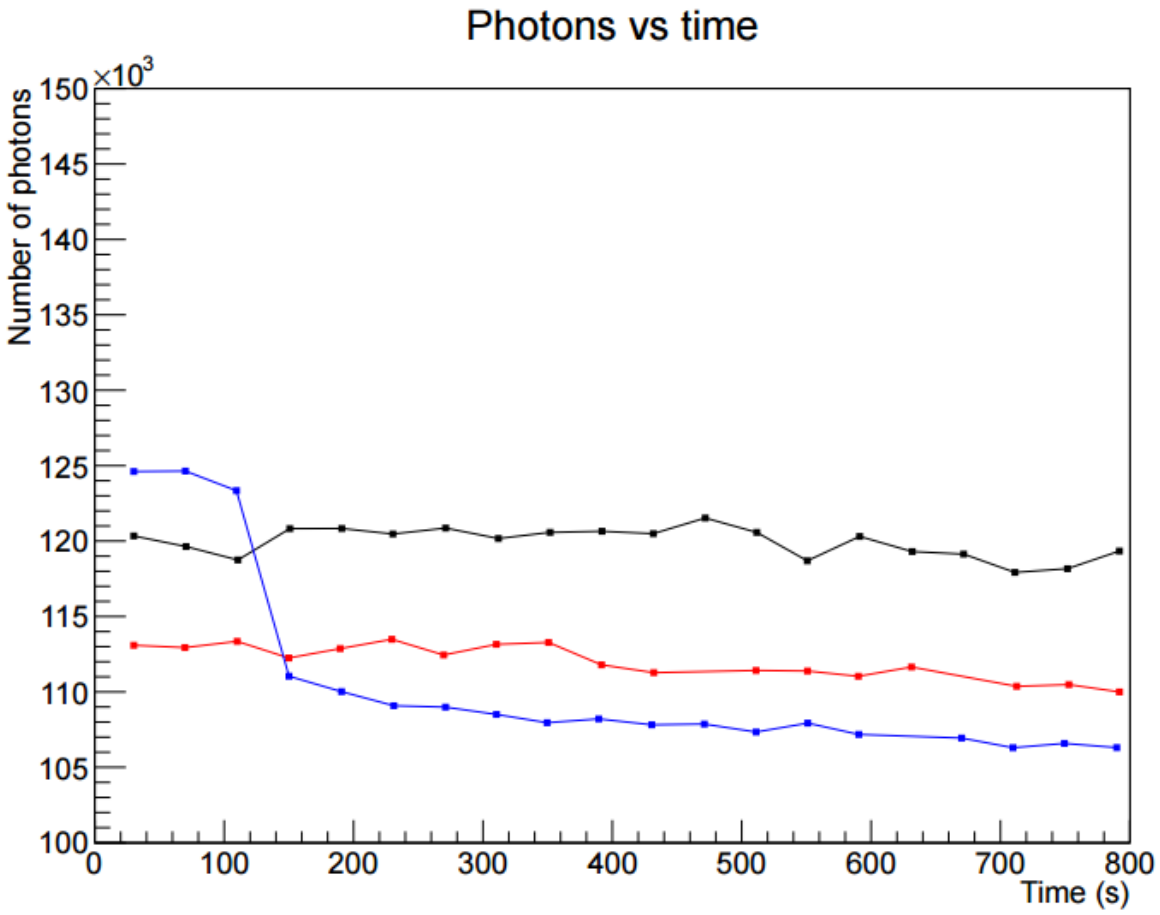
Results From Board Version 1.0

- Observed some drift in the output over time
- We have established some temperature dependence of the LED output, explains this drift



Results From Board Version 1.0

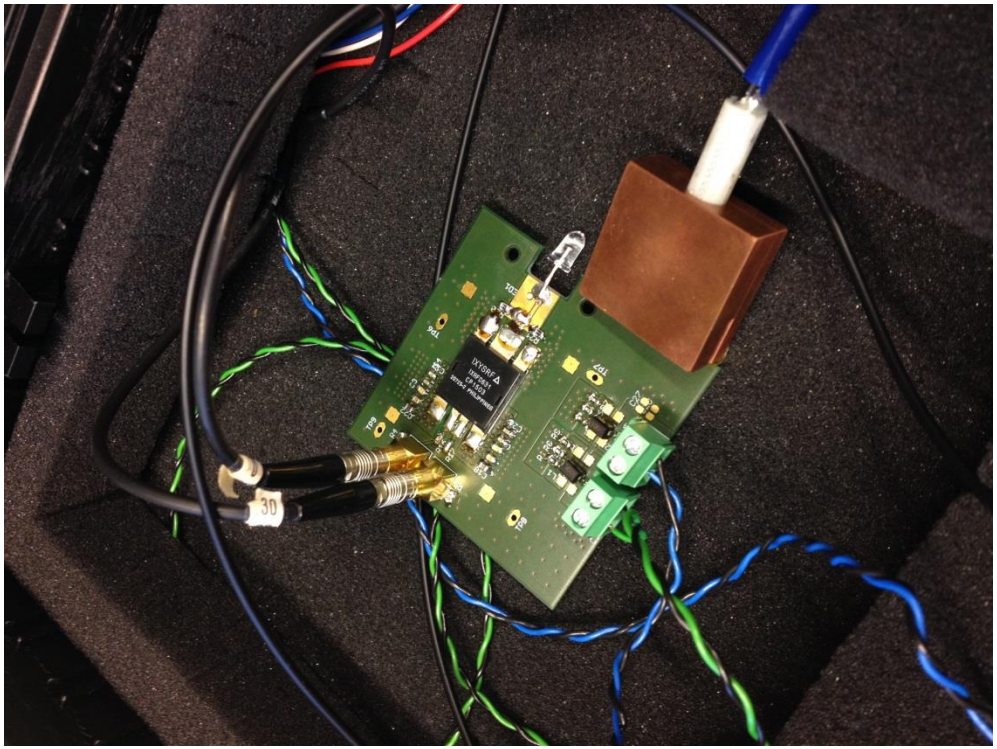
- Also some variation in the photon output when powering off/on all lab kit
- Some of instability potentially due to precision of equipment



Board Version 2.0

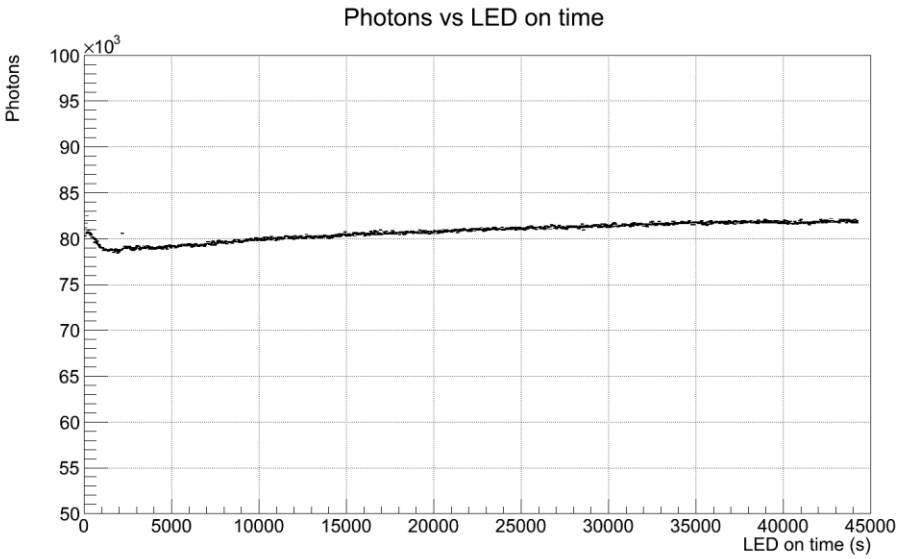
- New board has been produced to try to solve some of the stability issues

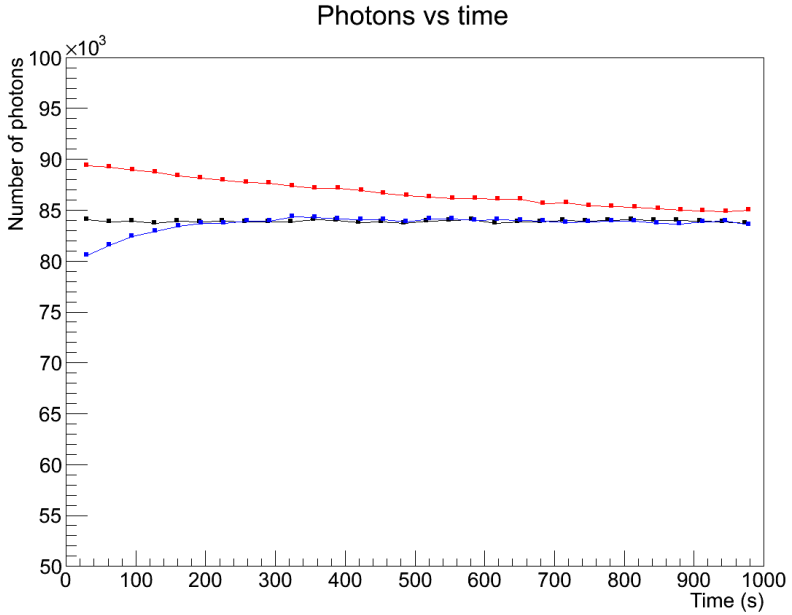
- Principle is unchanged, but some components have been upgraded, and the MOSFETs have been moved closer together and to opposite sides of the board

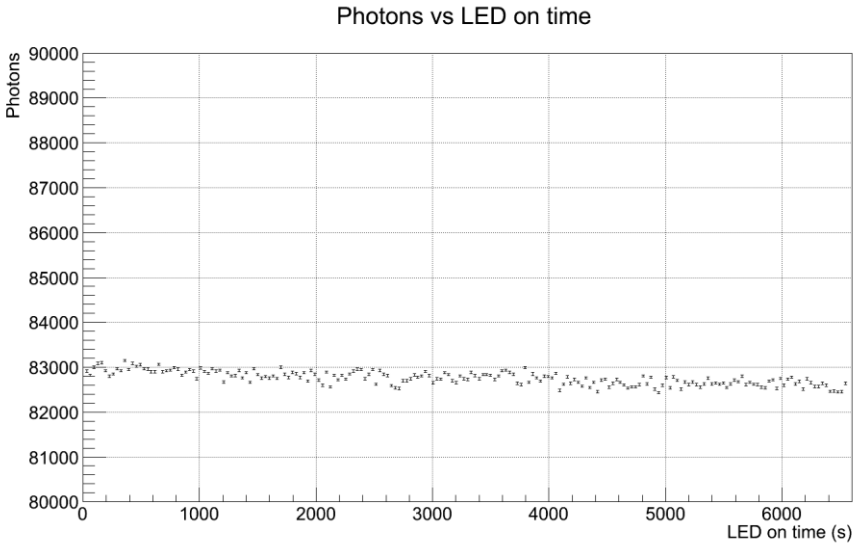


- Preliminary results from first tests are shown on next slide, same tests as shown for previous board

Results From Board Version 2.0







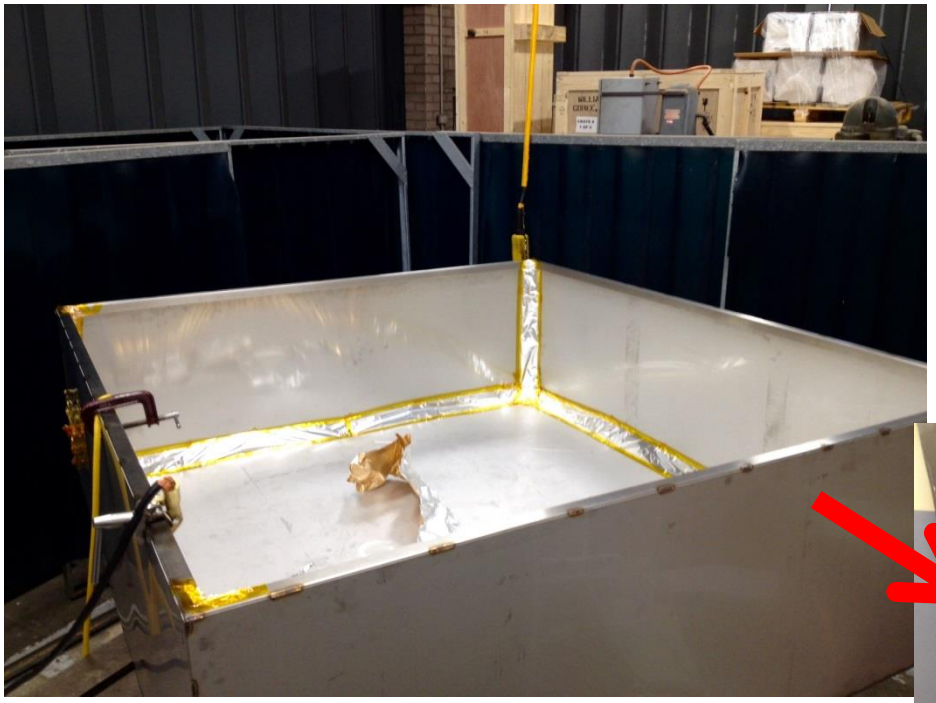
- Initial results are very promising, but will require more testing before any conclusions can be reached

Testing Output Underwater

- We need to measure a number of important optical properties to fully optimise the eventual calibration system:
  - Opening angle of light from bare fibre underwater
  - Intensity profile across the output from the bare fibre
  - The same quantities when using diffusers at the end of the fibre to control the light output

- To measure these properties, we have constructed a water tank in Liverpool to measure the underwater fibre output

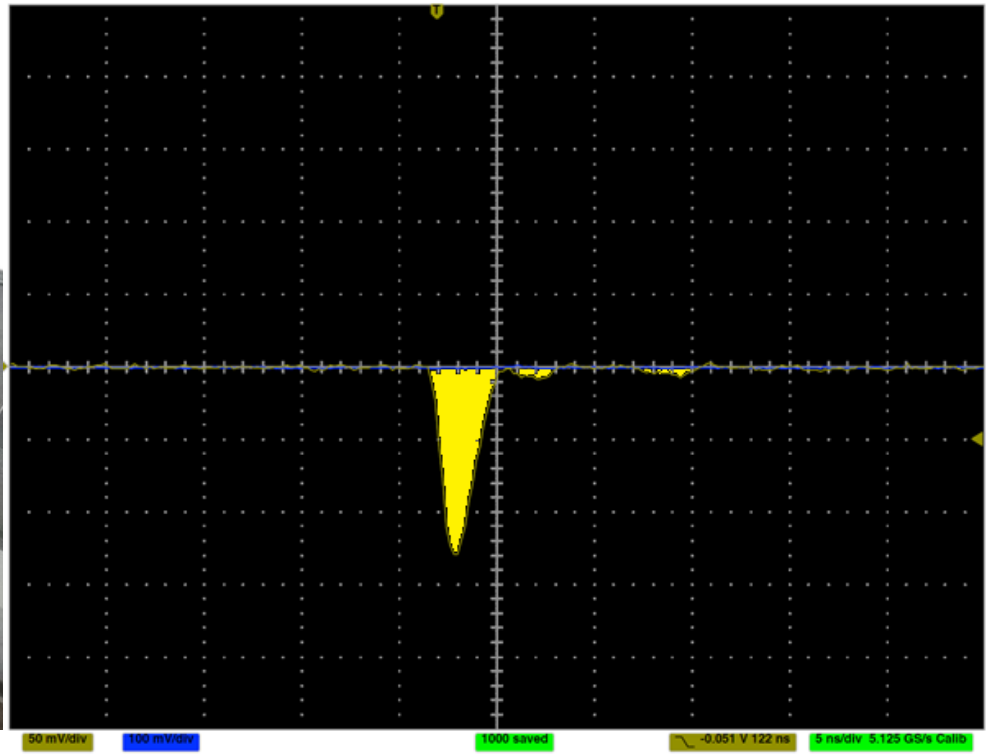
Testing Output Underwater



- Tank construction in workshop in Liverpool (top)

- Tank installation in basement room before first testing

Initial Results From Tank

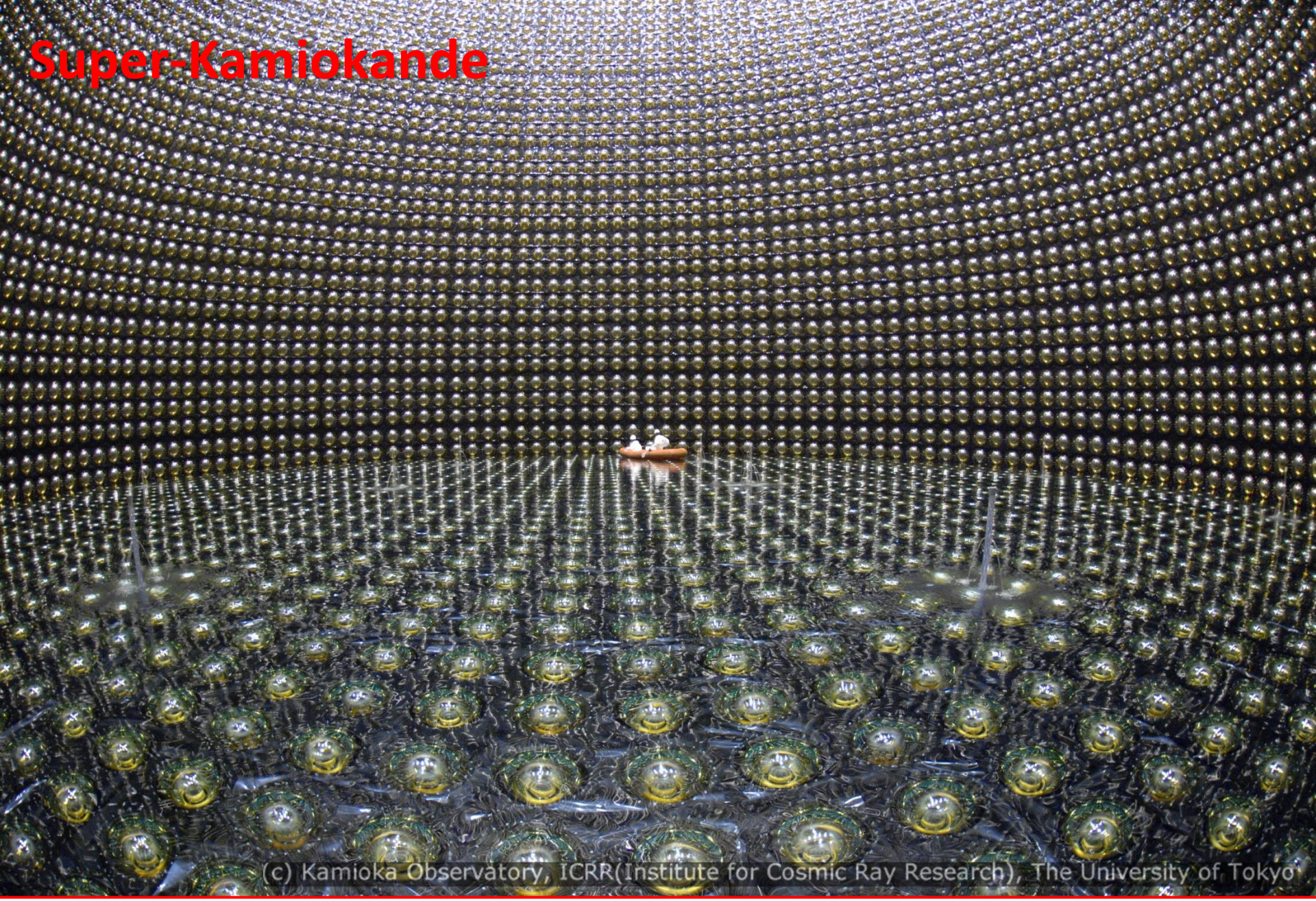


- Tank light tightness was confirmed
- First tests use a fibre output, fibre collection setup. Concept seen to be successful, will switch to a potted PMT for collection in future to improve efficiency

Future Testing

- To properly understand the system and its operation in HK, we ideally need some larger scale test facility
- We aim to produce and deploy a full scale prototype of one injection point to fully calibrate and assess the performance of the pulser system
- If only there were a pre-existing multi-kiloton Water Cherenkov detector where we could install and test the prototype…

Super-Kamiokande



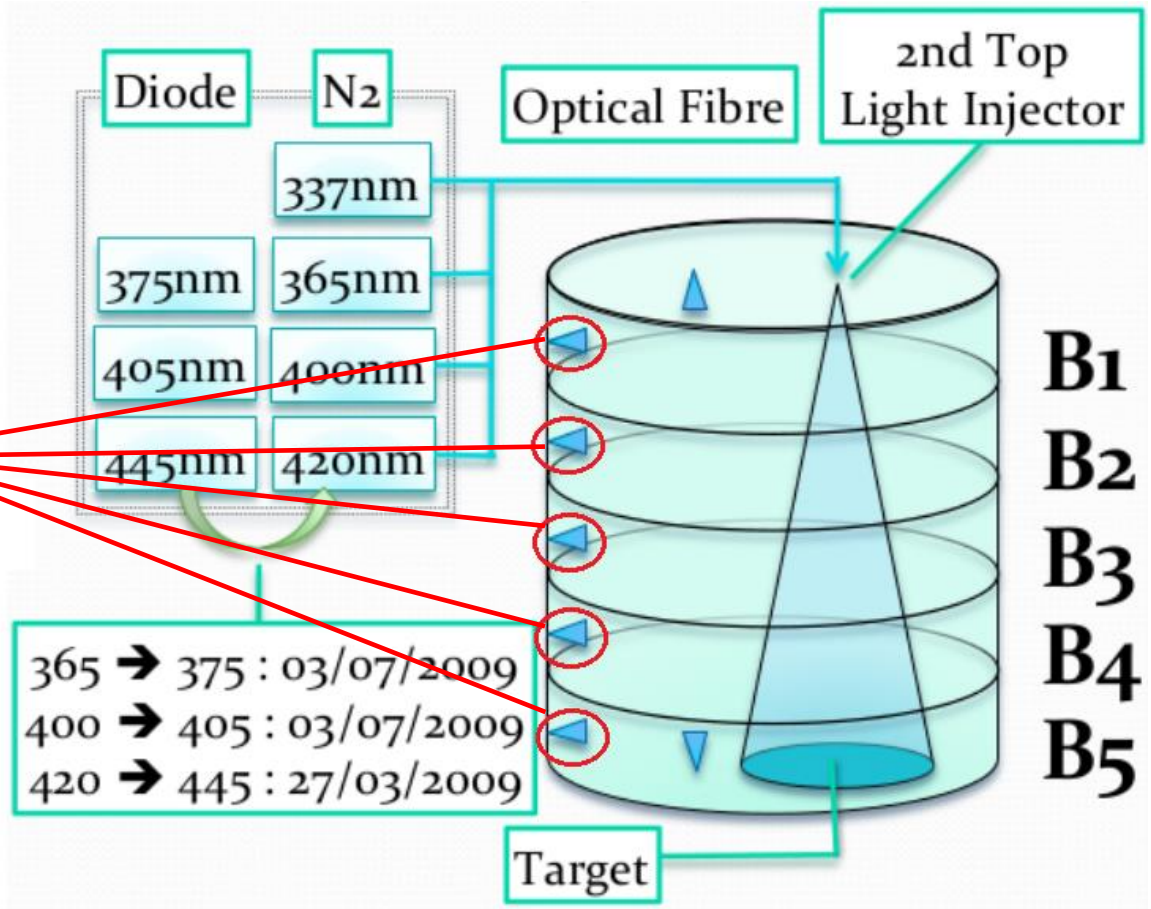
SK Optical Calibration

- Water absorption and scattering coefficients are extracted using a laser calibration system

- Analysis to date has used only one vertical injector point

- There are also 5 horizontal injection points

- Also another top and one bottom injector points, both unused



SK Optical Calibration

- We are aiming to produce a full working prototype and install it in the redundant tank top injector point

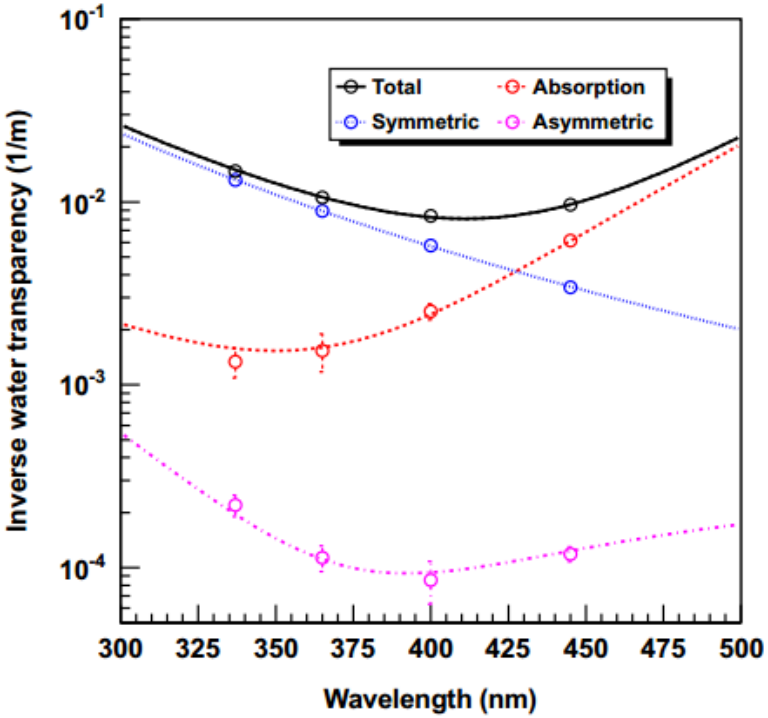
- Opportunity to access the injectors during the SK tank opening ahead of Gd doping in 2018

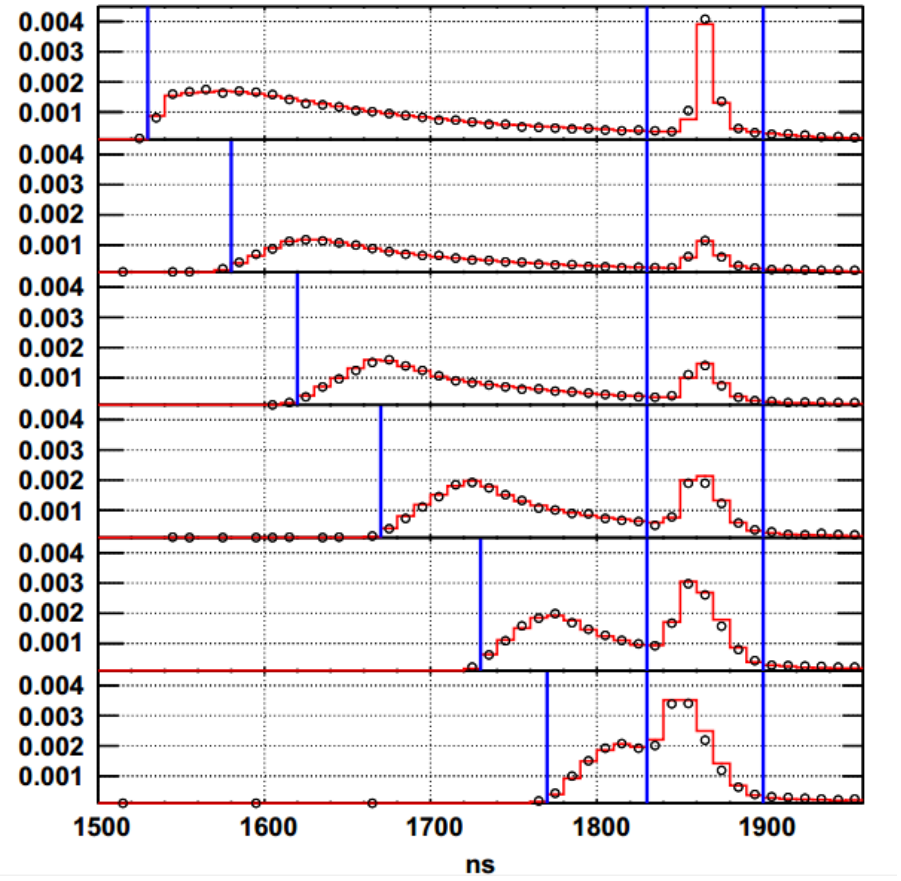
- In the meantime, we are aiming to help out with the SK calibration work
  - Good to establish a working relationship with the group ahead of installation, by performing a helpful analysis
  - Also good from a personal standpoint to gain experience of the analysis required when we begin collecting data

SK Optical Calibration

- Parameters are extracted by producing MC and comparing with TOF corrected PMT charge distributions in 5 areas of the tank

- Initially 4, now 5, different wavelengths used





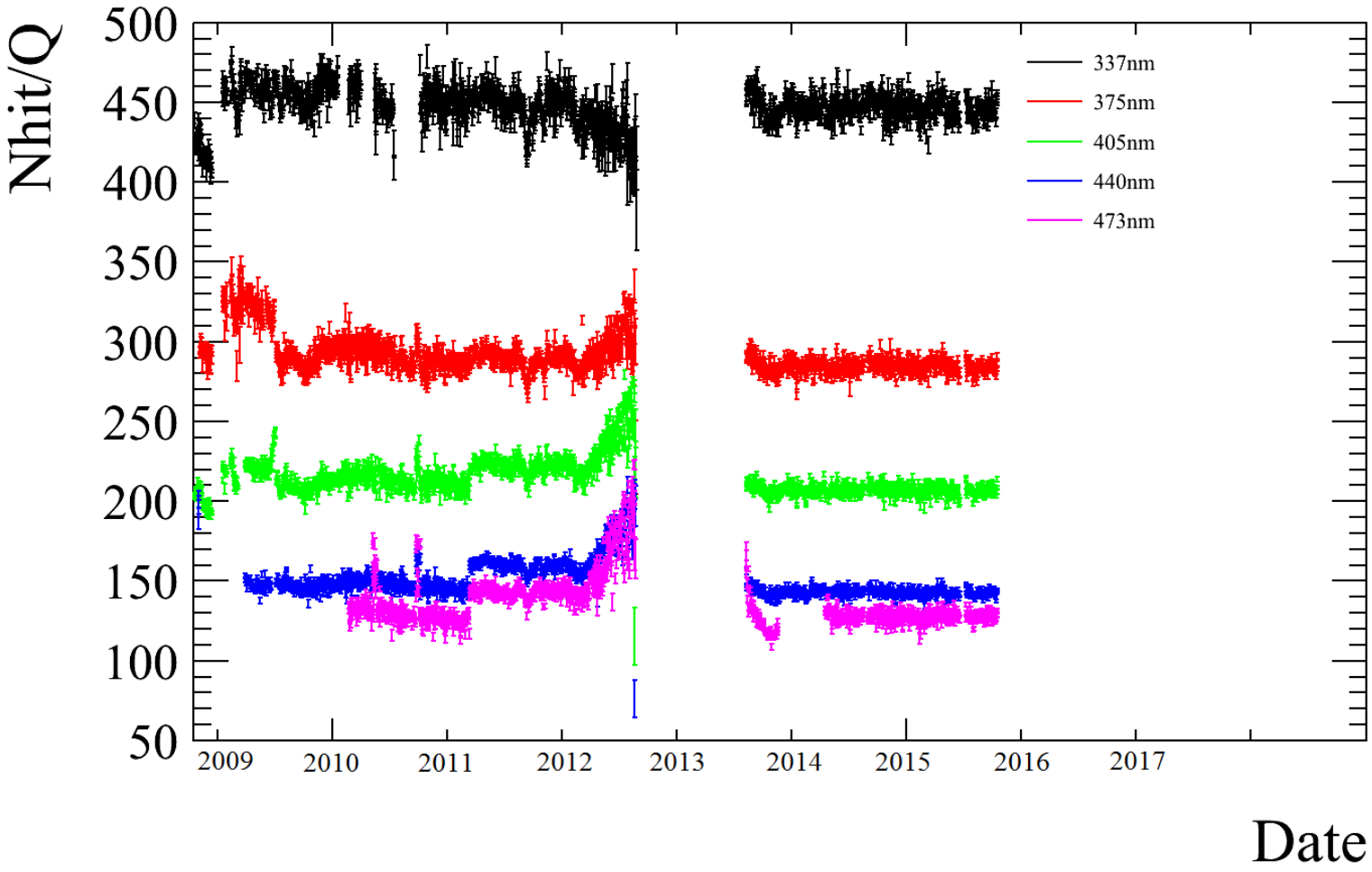
Plots from SK calibration paper: NIM A 737C (2015)

SK Optical Calibration

- Current SK analysis only uses data from an injector on the tank top
- There is a known to be a potential z dependence of water quality, but this is difficult to quantify using only vertical laser
- We are aiming to replicate the existing analysis, but using the 5 horizontal injectors instead
  - This should allow us to probe the depth dependence of the absorption and scattering water parameters
- First step is to check the quality of the data and ensure there are no long time gaps, we examine total PMT hits/total charge to smooth out fluctuations in laser intensity

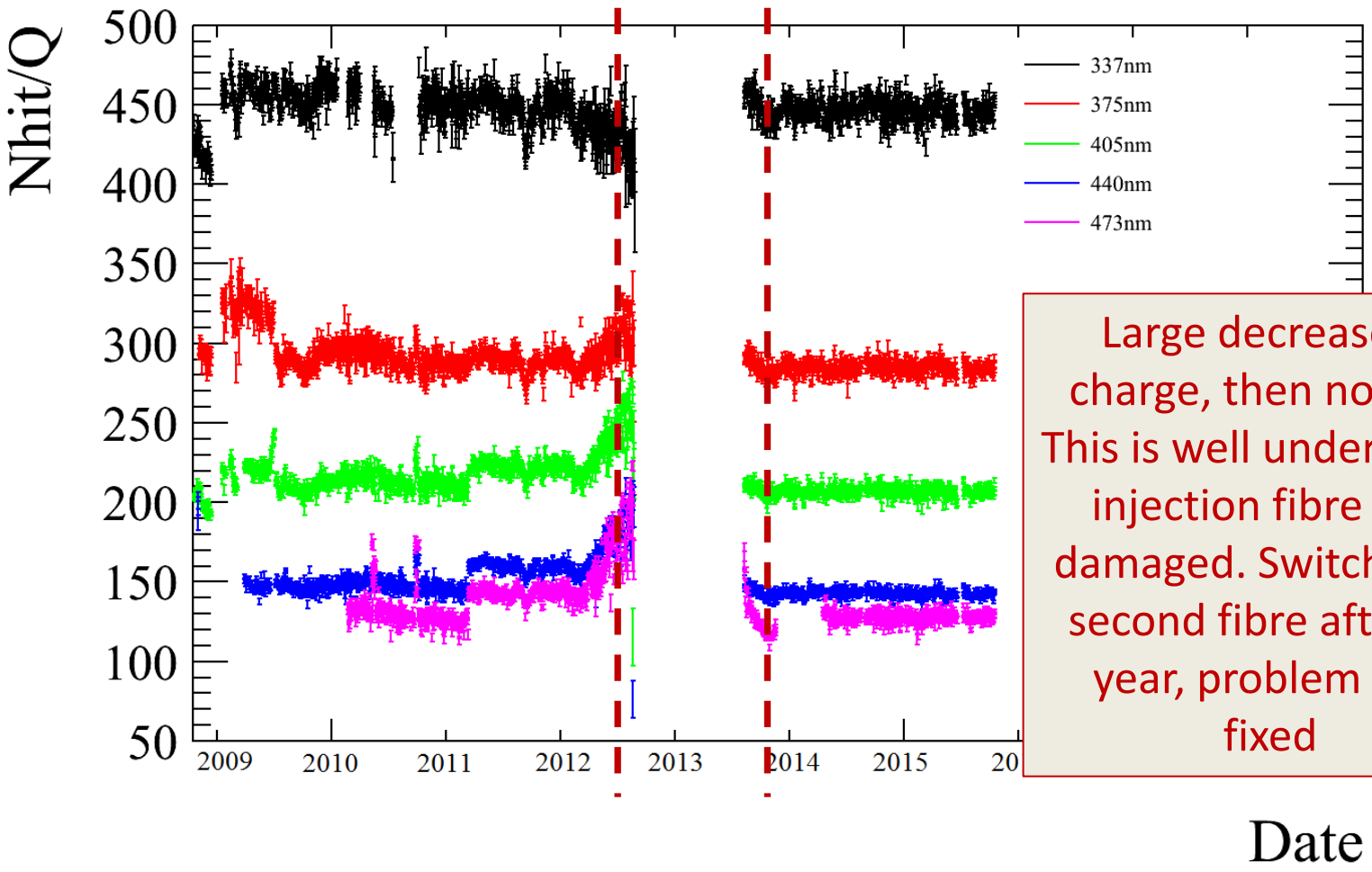
SK Optical Calibration

Position B1 (Top of tank):



SK Optical Calibration

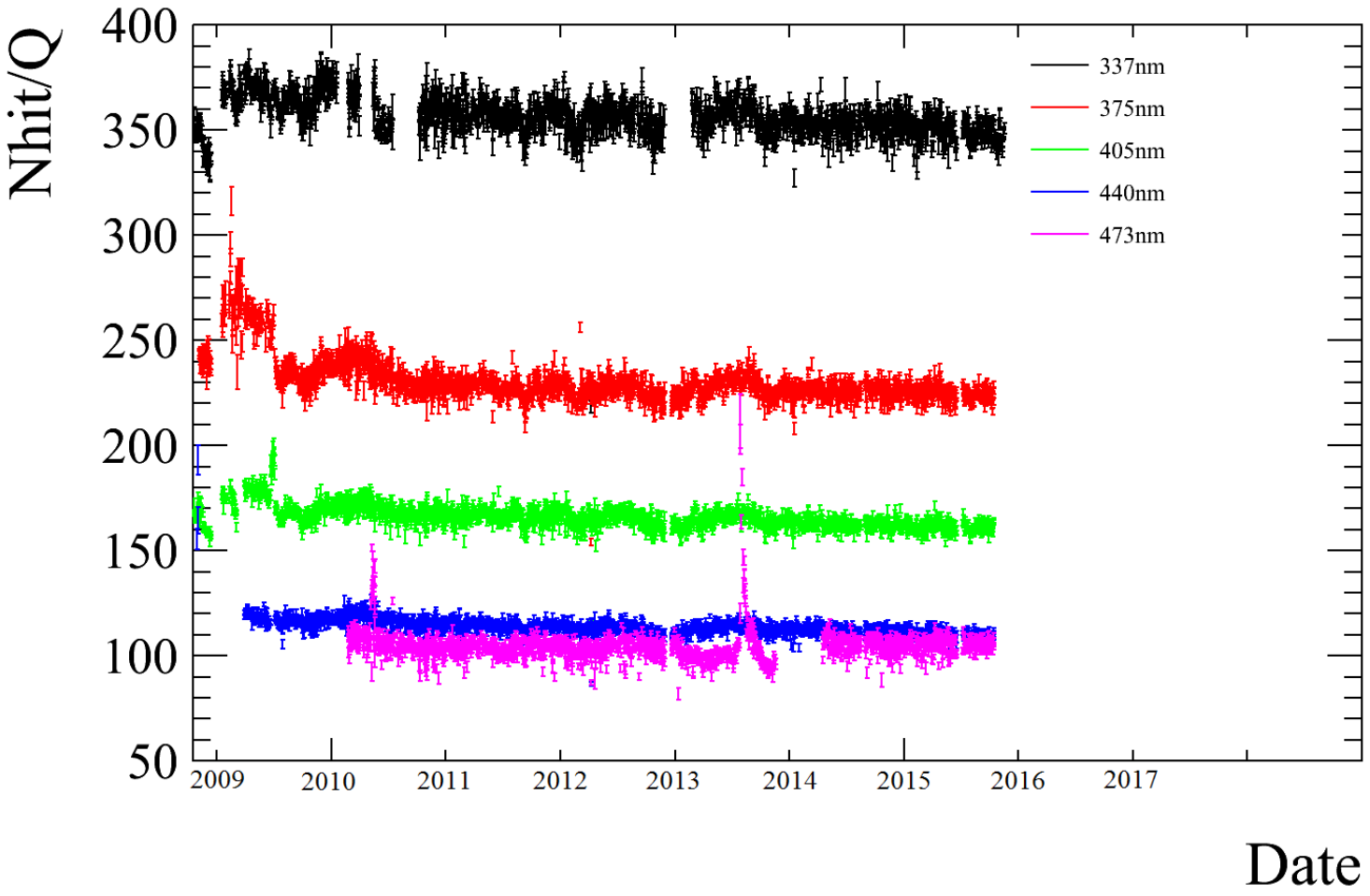
Position B1 (Top of tank):



Large decrease in charge, then no data
This is well understood, injection fibre was damaged. Switched to second fibre after ~1 year, problem was fixed

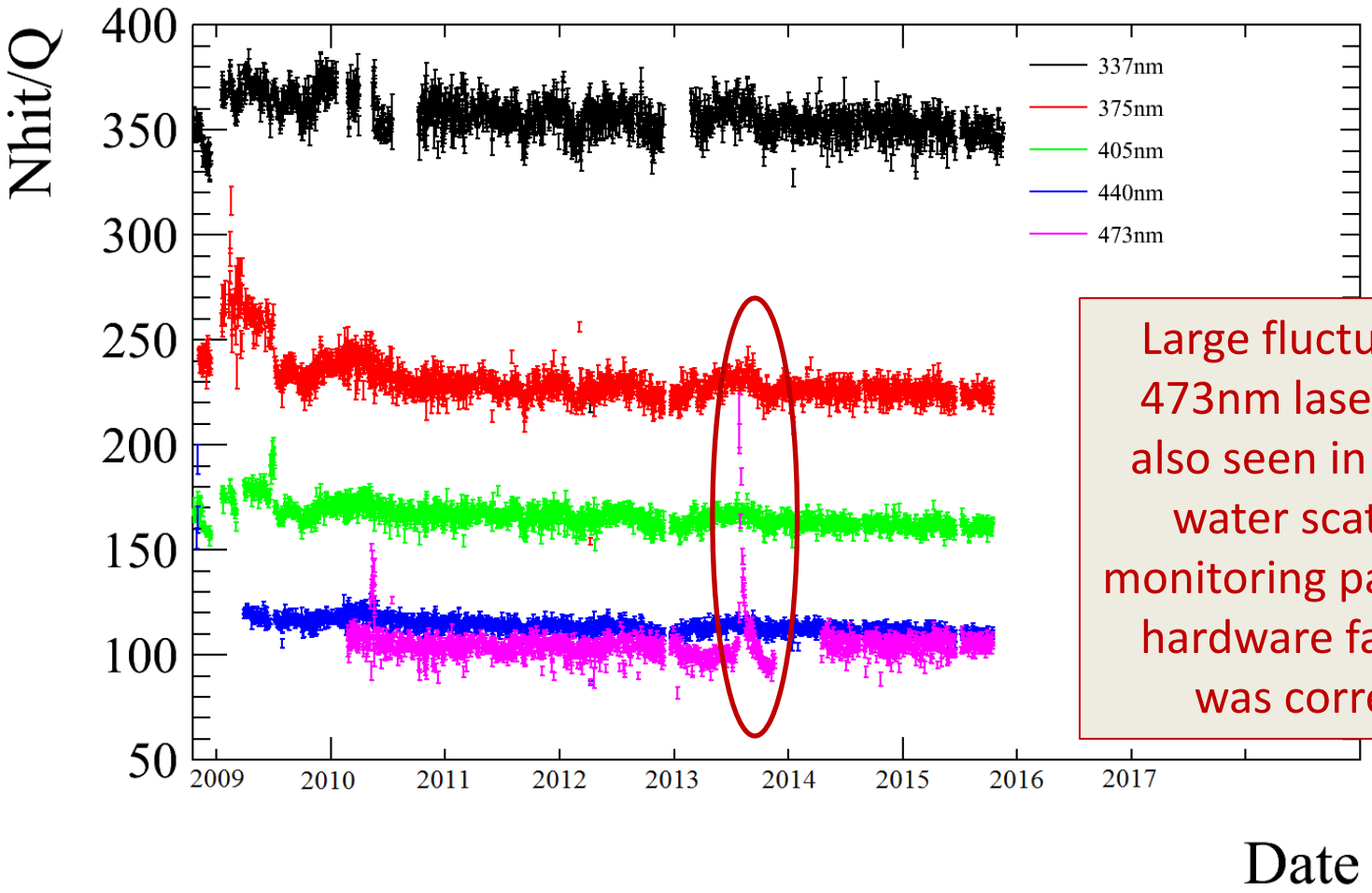
SK Optical Calibration

Position B3 (Centre of tank):



SK Optical Calibration

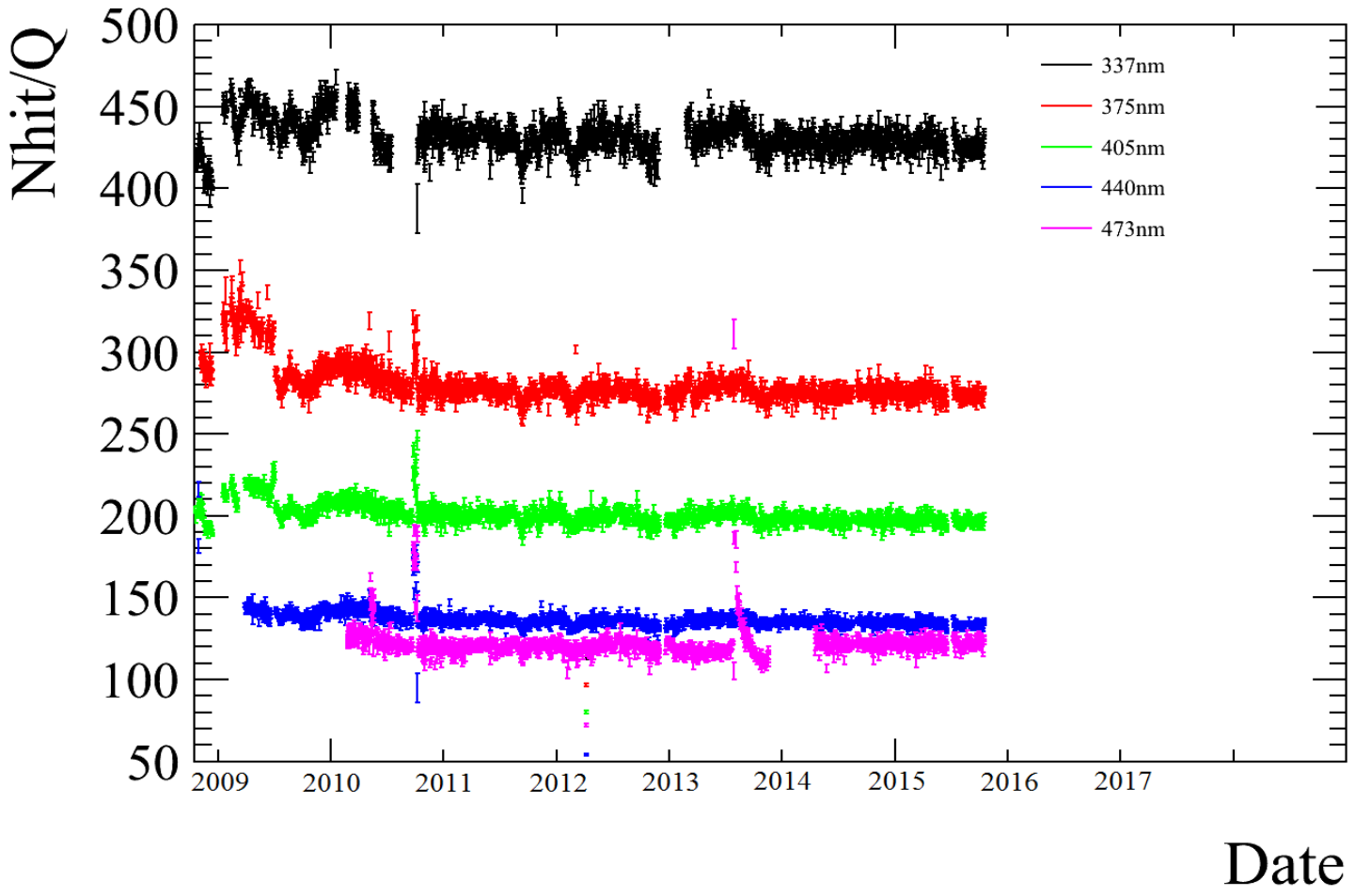
Position B3 (Centre of tank):



Large fluctuation in 473nm laser. This is also seen in plots on water scattering monitoring page, some hardware fault that was corrected

SK Optical Calibration

Position B5 (Bottom of tank):



SK Optical Calibration

- Data seems to exist for all of the SK IV running period, with a couple of exceptions
- Some fluctuations are seen over the course of SK IV, some are understood, others are not
- Will need to try to understand the sources of these fluctuations, possible systematic uncertainties due to water quality, laser stability, etc
- Will then move on to examining scattered hit region of time of flight corrected charge distributions, and extracting water parameters through comparison with MC produced in SKDetSim

SK Optical Calibration

- Thanks to funding from JENNIFER, I have been able to establish a close link with the SK calibration group
- This work has been presented at HK calibration meetings in Kashiwa and London, and an SK meeting in Toyama
- I have also undertaken shifts in the mine at SK
- Will complete a secondment in Kamioka in November, undertaking shifts and attending the next SK collaboration meeting

Thank you!