Optical Calibration of the Hyper-Kamiokande Detector with Test Data in Super-Kamiokande

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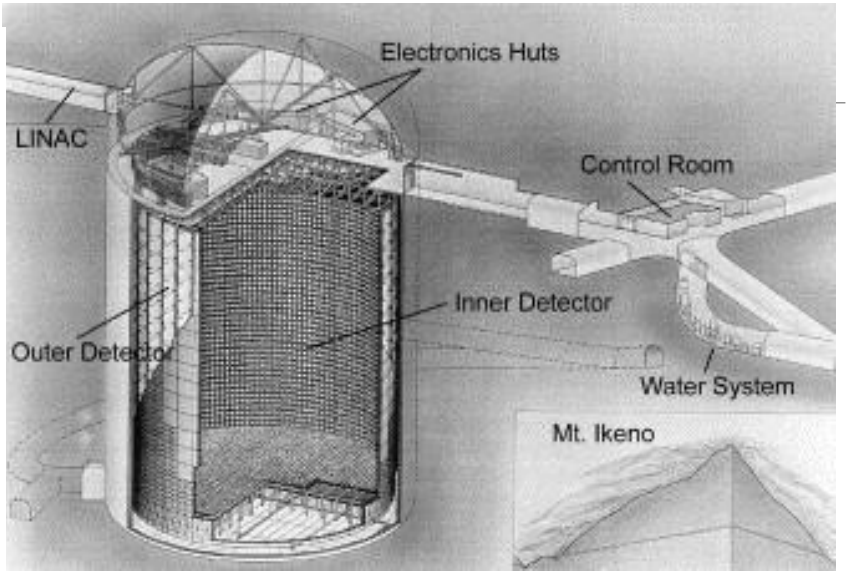
Super-Kamiokande

- Ring imaging Cherenkov detector
- ~11000 PMTs
- 50kton with 22.5kton fiducial volume
- 41.4m height, 39.3m diameter
- Situated in Kamioka, Japan
- Supernova ready

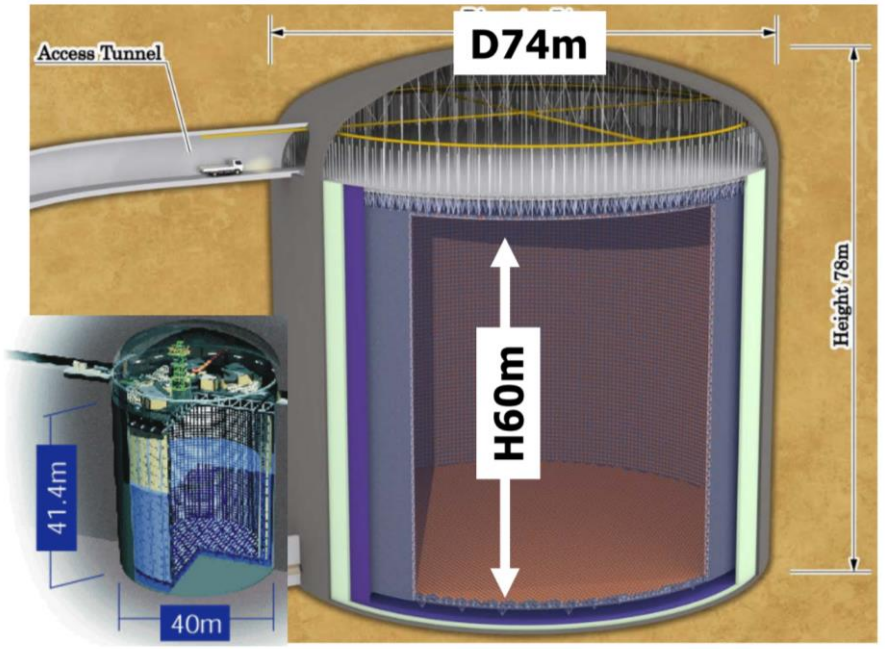


- Officially approved SK-Gd upgrade
  - Super-Kamiokande-Gadolinium
- Tank Open: June 2018

Hyper-Kamiokande

- Will be the next generation of WC detectors
- House ~40000 PMTs
- 60m height, 74m diameter
- 0.26 Mton scale (10x larger than SK)
- Investigate CP violation and search for proton decay
- UK are developing a light injection calibration system to measure water properties

- **260k ton total**
- **220k ton ID for SN observation**

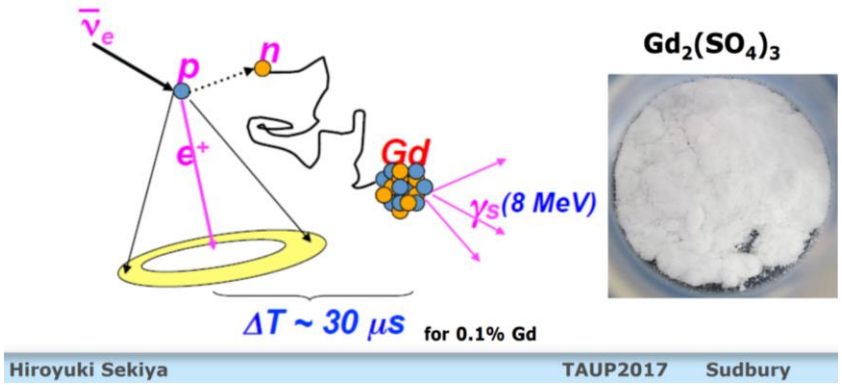


Neutrino Physics

- Super-K studies solar and atmospheric neutrinos as well as beam neutrinos JPARC (Japan Particle Accelerator Research Complex) as part of the T2K experiment.
  - Supernova neutrinos are also of interest
  - Proton decay

- Super-K is being upgraded to SK-Gd, beginning in June 2018

  - SK-Gd (Super-Kamiokande-Gadolinium) will be loaded with 0.2% Gd
  - Such an upgrade allows for Neutron tagging, important for Supernova neutrino detection



- The tank open schedule will begin with draining in June

- Shifts are currently being assigned and the UK group will be taking many shifts over July-August in order to install the calibration systems

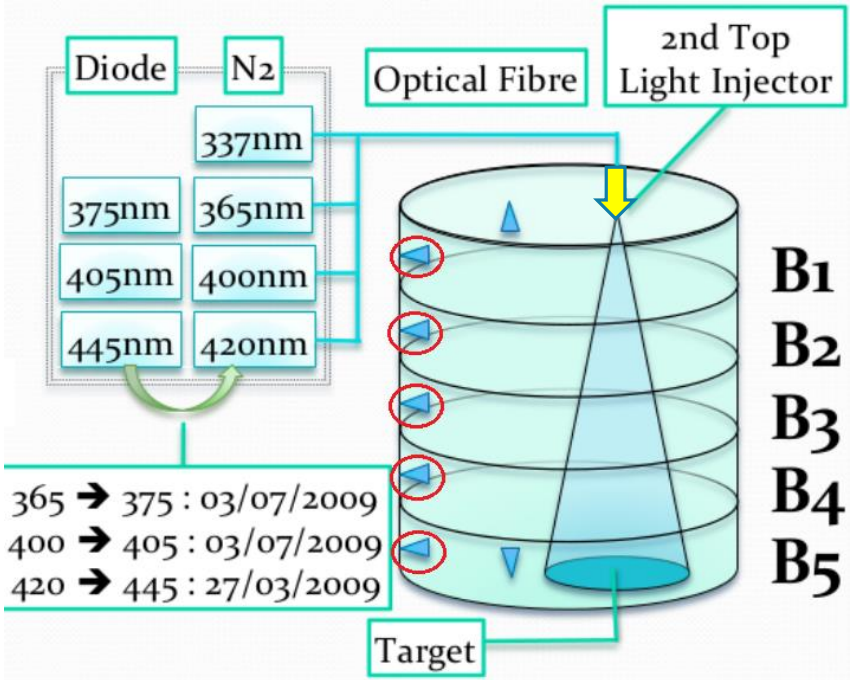
Calibration Goals

- Detector uncertainties are one of the main reducible systematics in physics analysis

- There are several important measurements essential for maximising the sensitivity in physics studies
  - Monitoring of water quality
    - Measurements of water absorption/scattering coefficients
    - Positional water quality dependence
  - PMT response
    - Timing calibration
    - PMT gain measurement
      - Time evolution of gain

- The UK group are developing a multi-optics calibration system that will cover these measurements

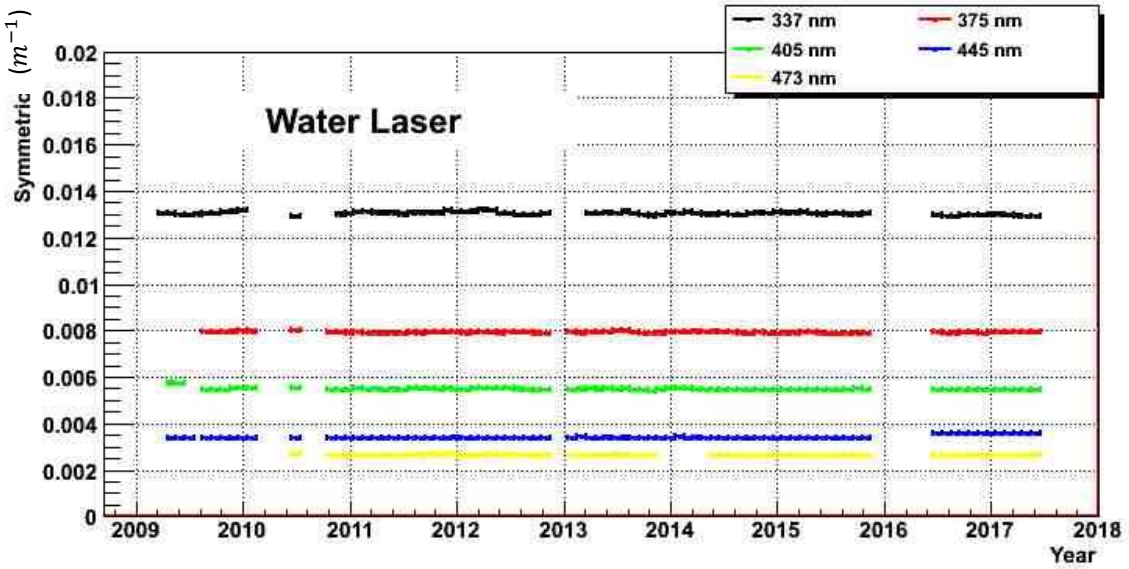
SK Calibration System



- Current optical calibration system uses laser injection at several wavelengths
- There are 8 light injection points in the tank
- The highlighted top position is used to measure absorption and scattering coefficients in the water
- <u>Analysis</u>
- Extract charge and hit information from data histograms
- Calculate Hits/Charge and compare to many MC with combinations of scattering parameters
- Extract best fit χ^2value and calculate water coefficients

Time Variation of Water Parameters in SK

Symmetric scattering coefficient



Wavelength (nm)	RMS/Mean variation
337	0.5%
375	0.4%
405	0.5%
445	1.9%
473	0.6%

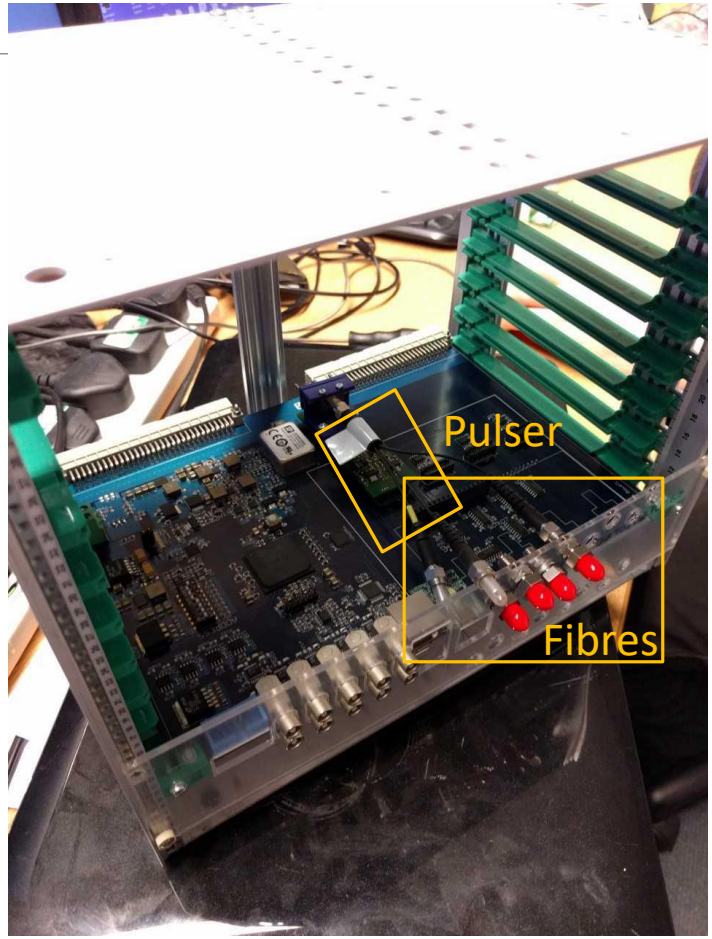
- Example of vertical laser measurements
- Symmetric scattering parameter is stable over current SK period
- Important for PID systematics
  - Need to how much light is scattering from the Cherenkov rings

UK Calibration System

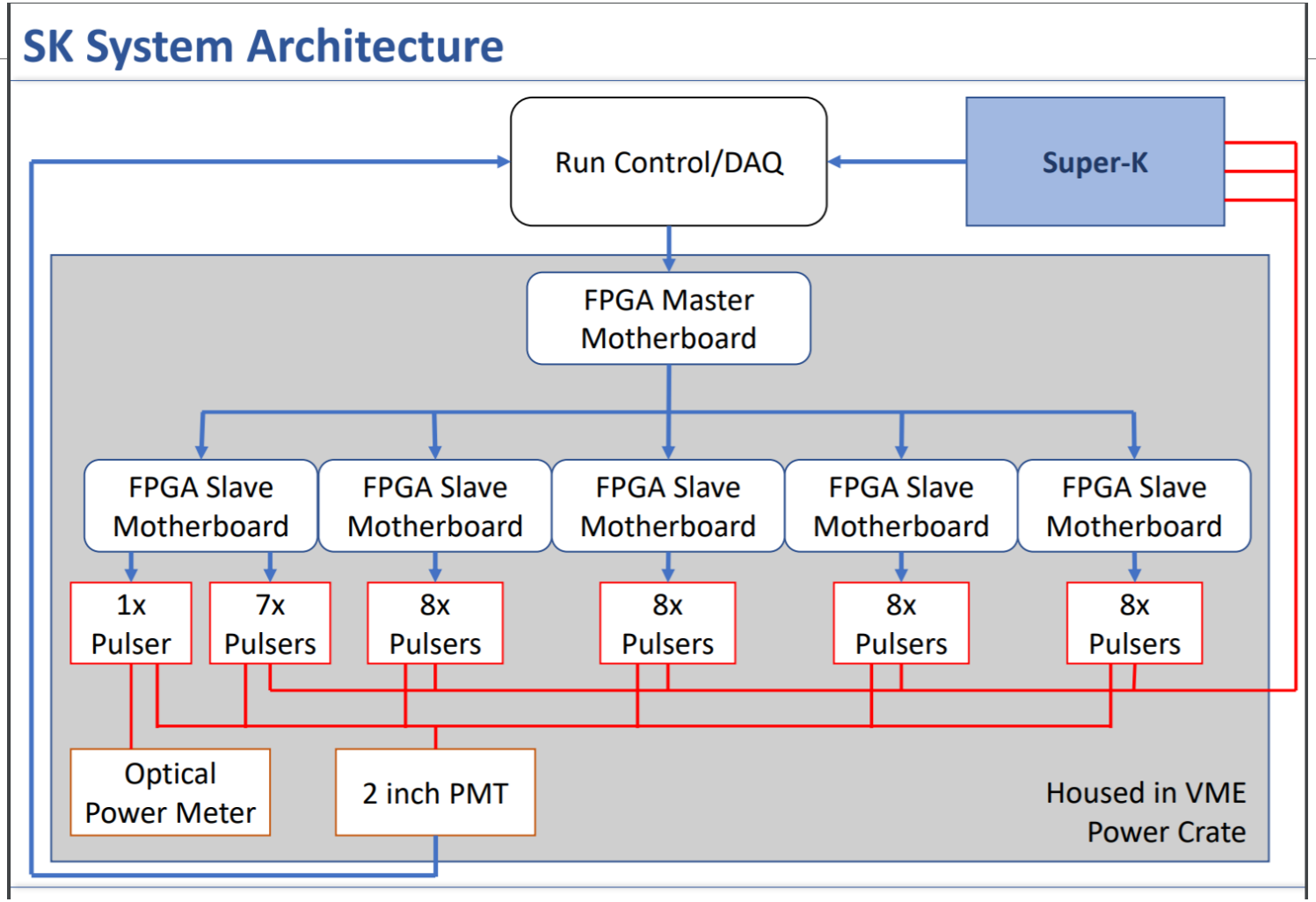
- The system uses three plate mounted components
  - Bare fibre
  - Wide angled diffuser
  - Collimator (narrow angle)
- Controlled light input and the illumination of various sized regions of PMTs
- The light input is an LED pulser board where the light intensity can be tuned by using specially developed software
- The system will use several mother boards providing trigger pulses to a series of daughterboards via FPGA
- The boards can be “self triggered” or can be triggered externally
- For more information on the recent development of the system
  - For hardware development: Sammy Valders poster
  - For MC modelling in Hyper-K: William Vinnings poster

The Electronics

- Motherboard/daughterboard system
  - Motherboard – control
  - Daughterboard – Pulsers
- Has been designed to cooperate with current SK trigger system
- Light is split in 3 ways
  - 1/3 into detector
  - 1/3 into monitoring PMT
  - 1/3 into optical diode – safety monitor
- Dedicated monitoring calibration channel
  - Light into power meter instead of the detector
  - High frequency run for photon calibration



The Electronics

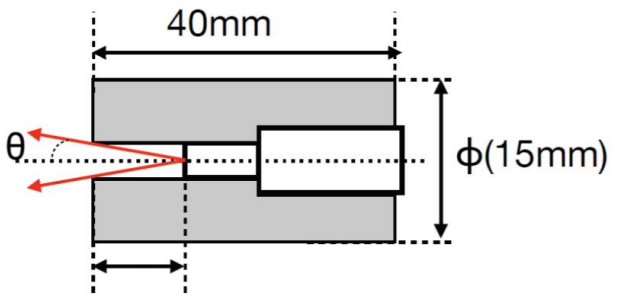


Diffuser (Wide Angle Beam)

- Diffuser allows measurements of:
  - PMT gain evolution over time
  - Water attenuation
  - PMT timing calibration
- Diffuser ball is made from PMMA (Poly(methyl methacrylate)) and housed in a watertight enclosure
- Aim to produce a wide angle beam with uniform intensity and timing
- Goal for HK is: 1% uniformity over a 45° angle

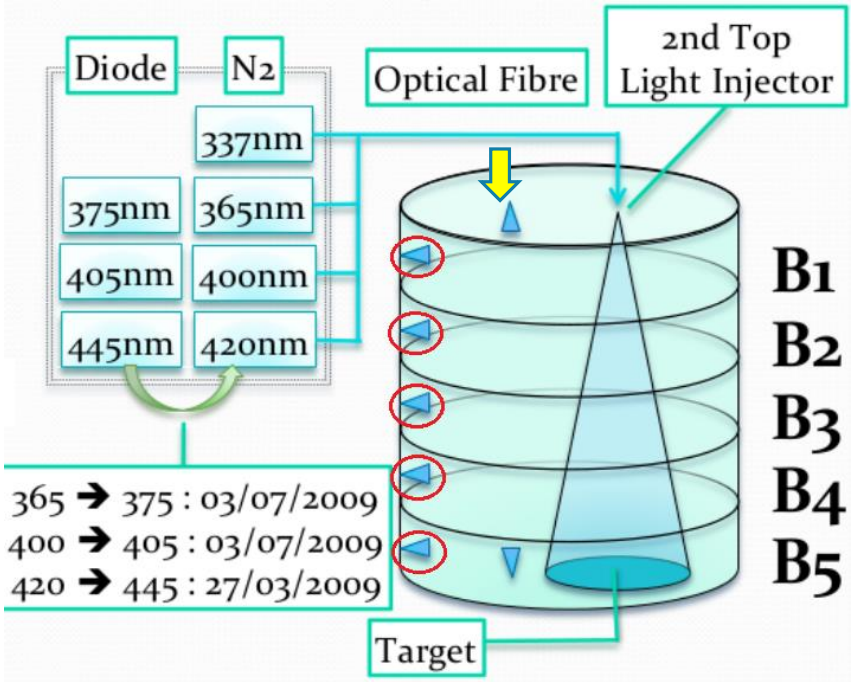
Collimator (Narrow Angle Beam)

- Collimator allows measurements of:
  - Water parameters
  - Depth variation of parameters
- A GRIN (gradient index) lens is inserted inside a stainless steel cylinder
- Aim to produce a well defined, narrow angle beam with a higher intensity
  - The opening angle can be controlled by varying the distance D
  - Required opening angle is ~3.5°
- The collimators are designed to illuminate a patch of 5x5 PMTs on the target wall area
  - With the precise target, less PMTs on the target wall are excluded in the analysis giving a more accurate calculation of the beam spot
  - Better calculation of positional dependence of parameters



D = 15mm

SK Deployment

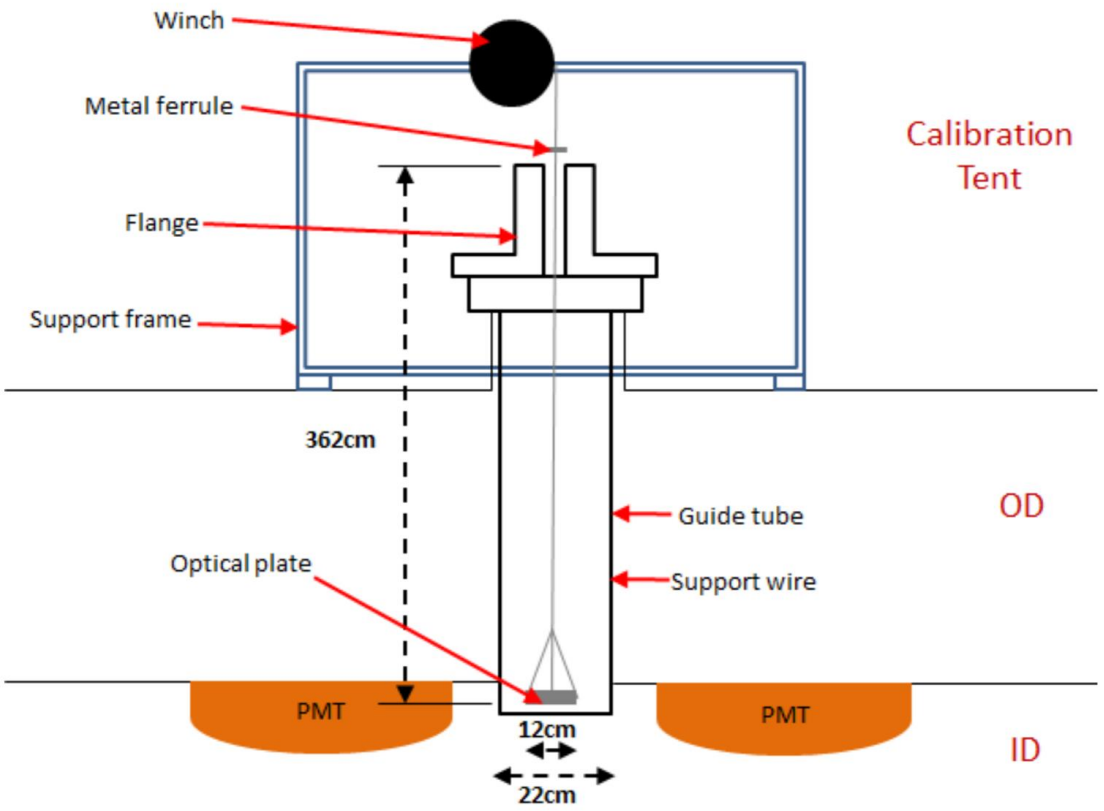


- Deployment of the system in the highlighted position in SK is completed
- In summer, the UK equipment will be deployed at the 5 circled barrel positions and run alongside the current system
- The January deployment allowed us to review the hardware and electronics performance (yellow position)
- We are currently making the necessary improvements for the next step
- Feasibility studies have been completed in Liverpool showing that it is possible to make improved measurements with this system

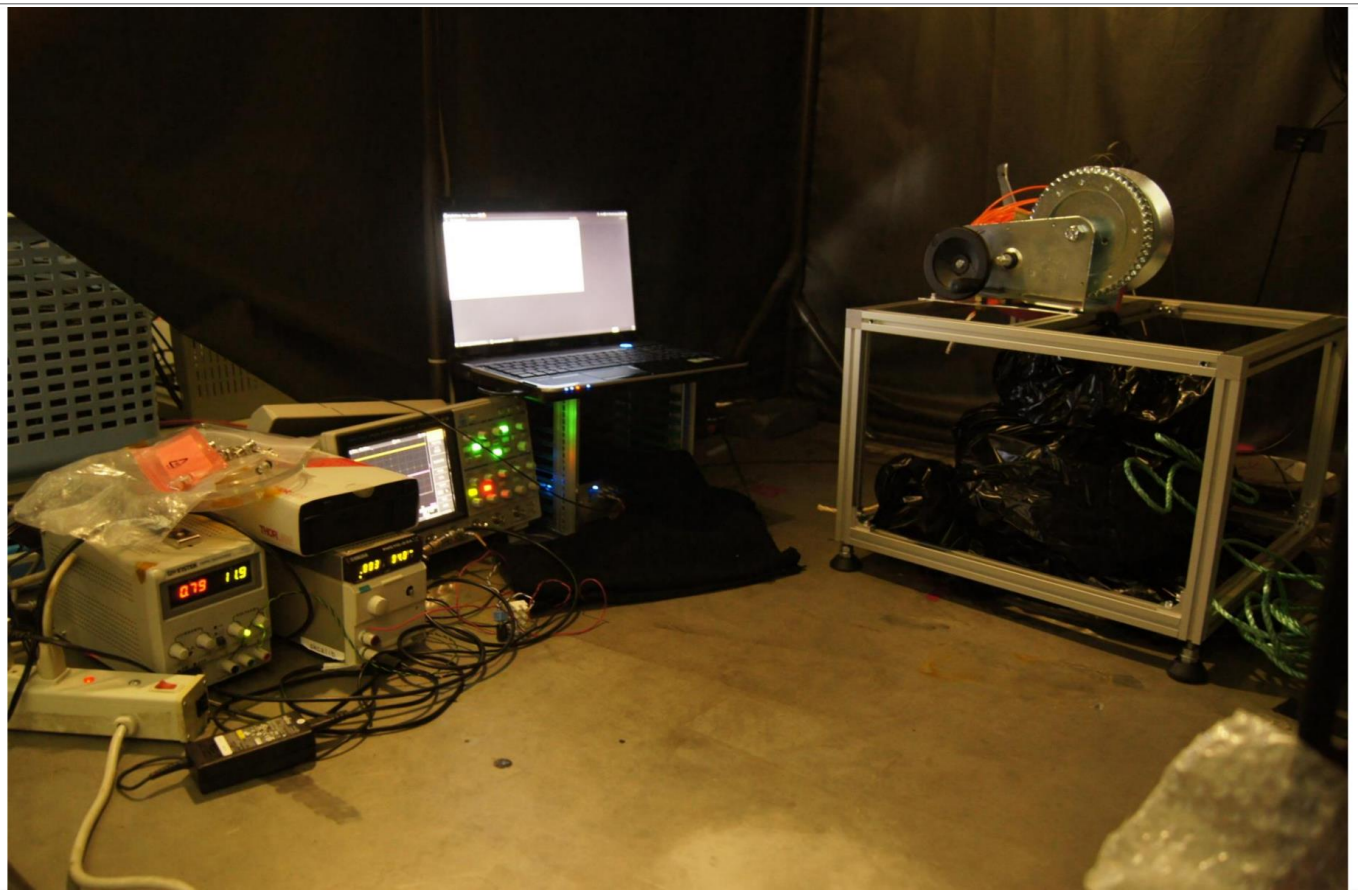
First SK Deployment

- The UK group deployed the system at SK in January 2018 with full testing of the hardware and current electronics system
- The right image shows the current design of the diffuser plate which contains the diffuser, collimator and bare fibre
- Data was collected with each of the optics and various intensities
- Monitoring pmt into SK electronics
- Triggers were taken externally from SK allowing us to collect data through SK data reduction

January SK Deployment



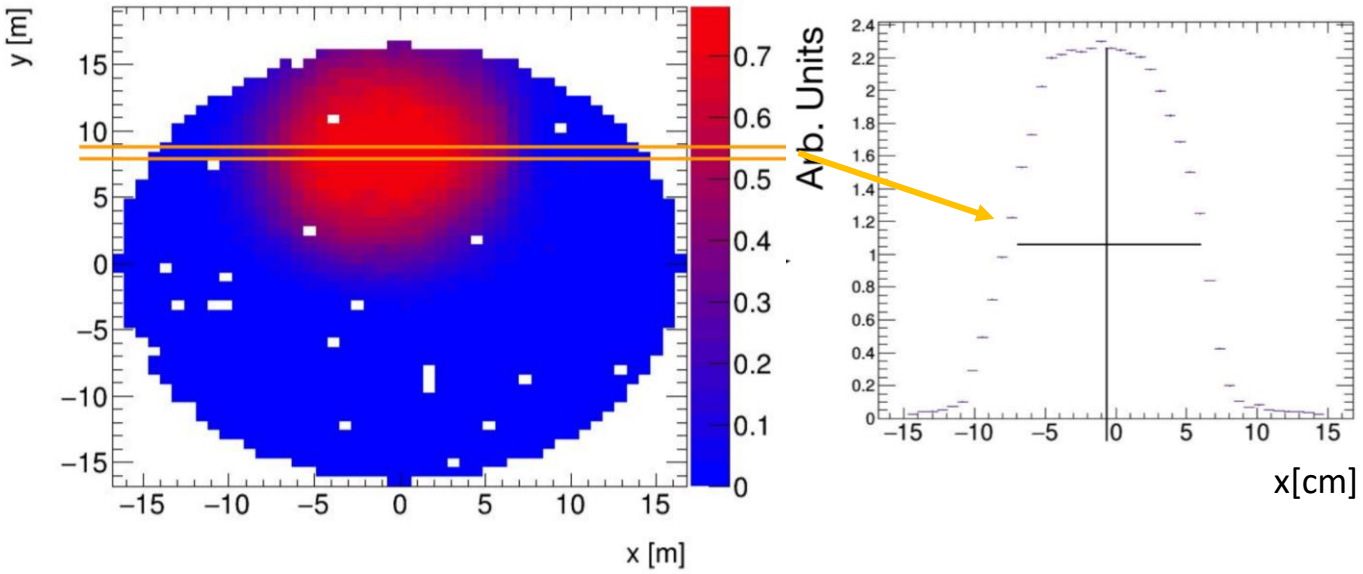
First SK Deployment



First SK Deployment: Data

Bare Fibre

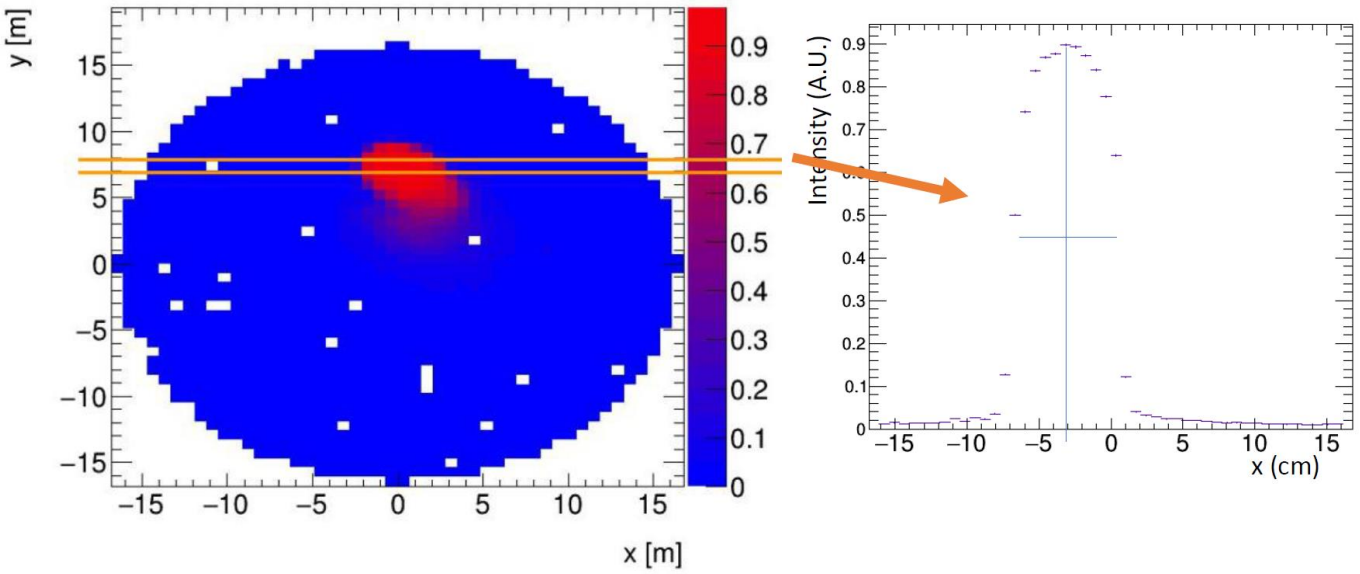
- Colour scale shows run average occupancy for all PMTs on the tank bottom
- FWHM ~ 14m
- Corresponds to a beam opening angle of 10°



First SK Deployment: Data

Collimator

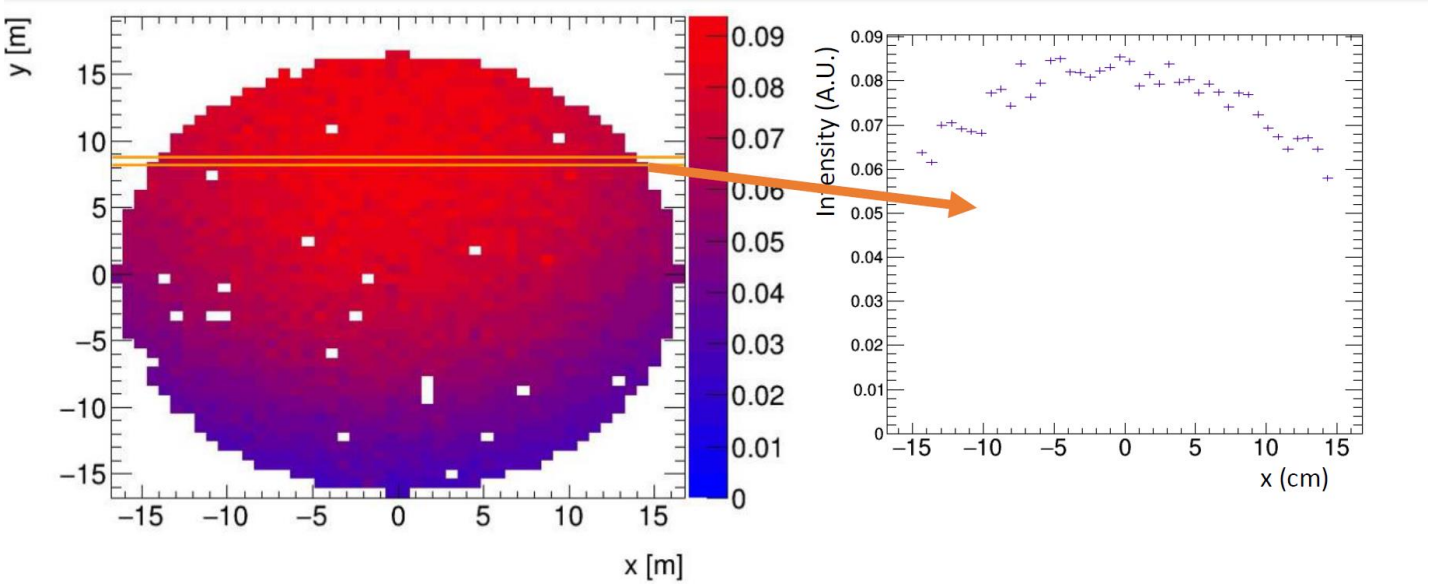
- N.B. Non circular beam shape, possible reasoning is being studied
  - Likely due to misalignment of the fibre with the GRIN lens inside collimator
- FWHM ~ 5m
- Corresponds to a beam opening angle of ~ 3.5°



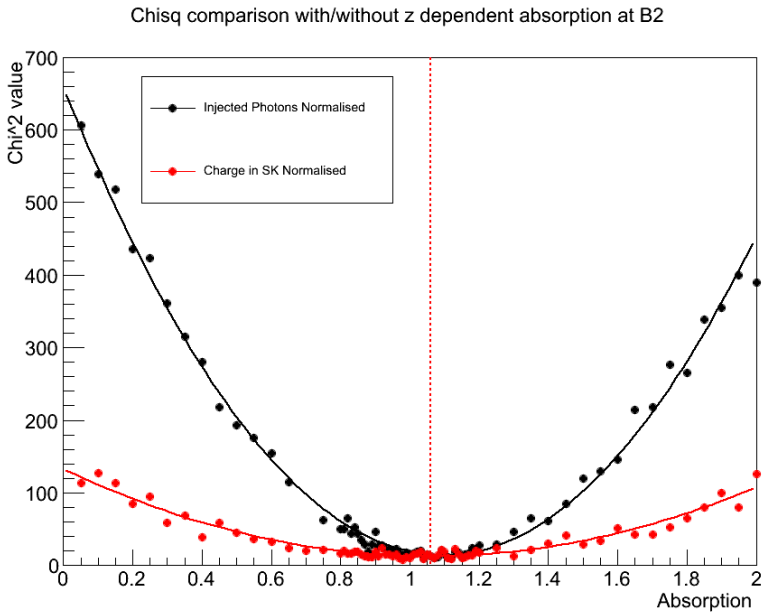
First SK Deployment: Data

Diffuser

- Colour scale shows run average occupancy for all PMTs on the tank bottom
- Need to apply corrections to data before we can determine the beam angle
  - Solid Angle
  - Attenuation



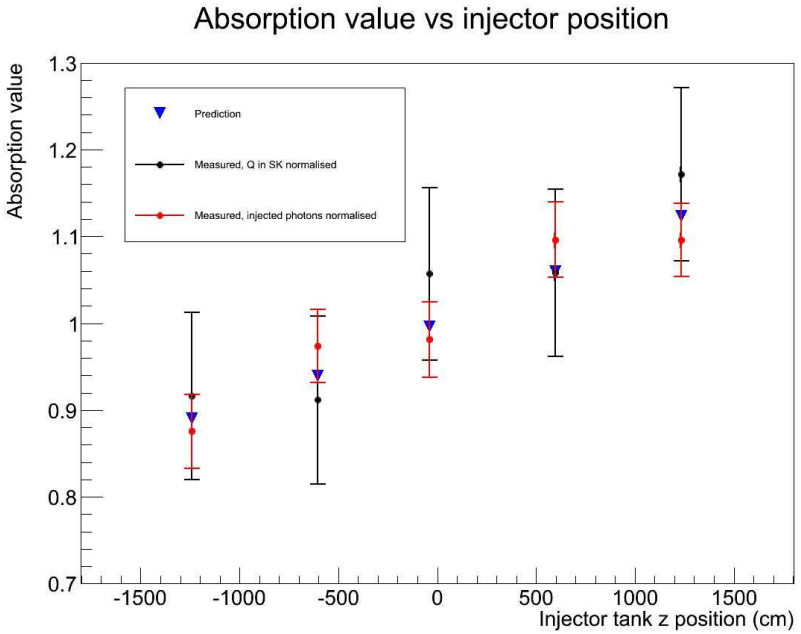
Depth Optical Asymmetry



- Being able to probe the z dependency of the water parameters will be an important new technique that out system can offer over the current SK laser system

- Feasibility studies have been done for the UK system

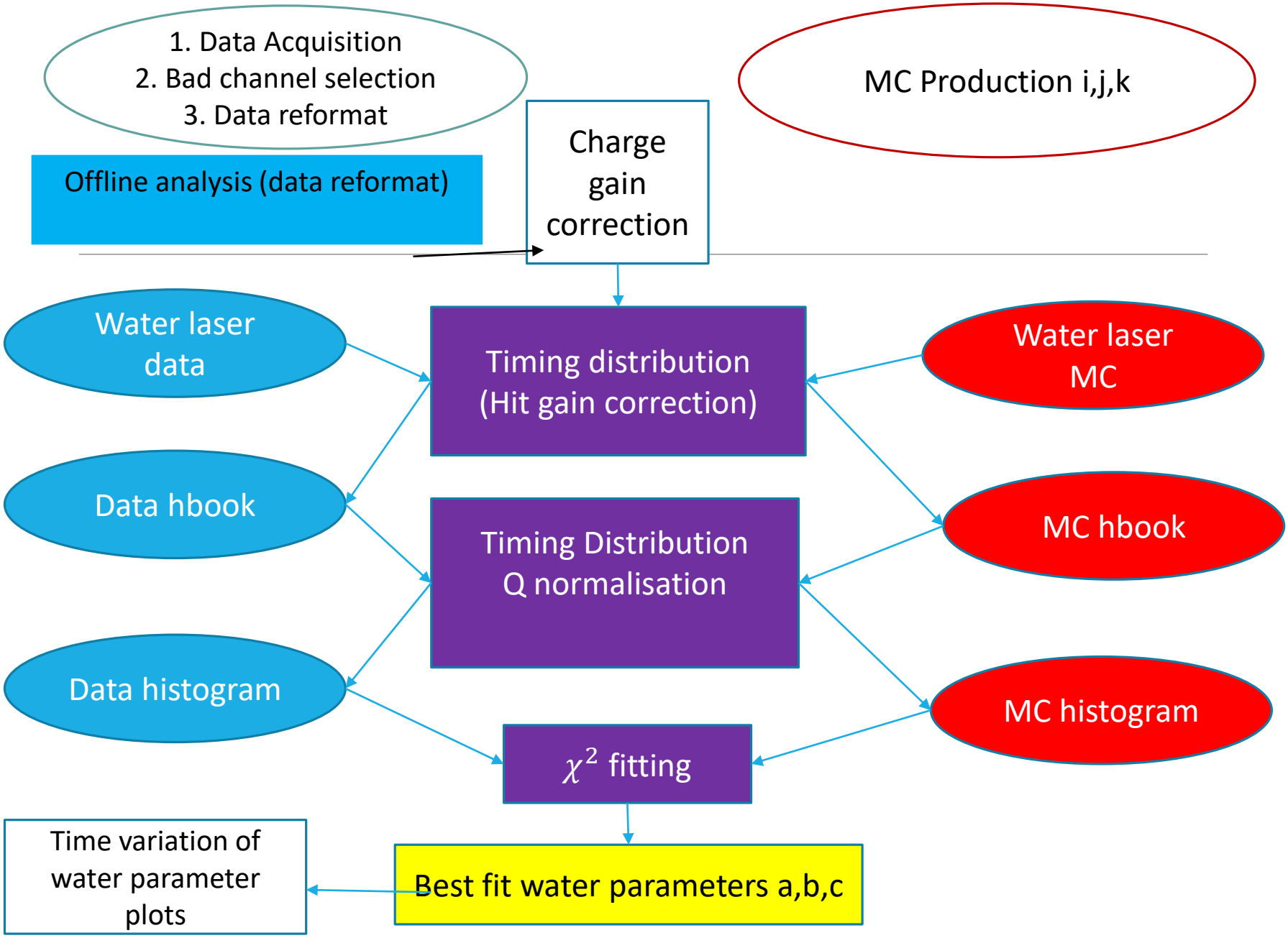
- Show that we can better probe the z dependence of the water compared to the current SK methods



Summary

- The HK-UK calibration group have been developing a new optical calibration system for Hyper-Kamiokade and have adapted it for deployment in Super-Kamiokande and SK-Gd
- The UK injector system has successfully undergone the first stage in long term deployment in SK
- The first look at the data looks promising and is helping us refine the system for summer deployment in SK
- As shown by the feasibility study and recent data from the first deployment, the ability to measure the z dependence of water parameters looks promising
- The UK system will have some key advantages over the current SK system
  - Use of a monitor PMT means hit normalisation is independent from the water parameters themselves – increases sensitivity
  - The collimator allows the system to probe a more defined region in z with less PMT exclusion around the beam spot – better sensitivity

Back Up


1. Data Acquisition
2. Bad channel selection
3. Data reformat
MC Production i,j,k
Offline analysis (data reformat)
Charge gain correction
Water laser data
Timing distribution (Hit gain correction)
Water laser MC
Data hbook
Timing Distribution Q normalisation
MC hbook
Data histogram
MC histogram
χ^2 fitting
Time variation of water parameter plots
Best fit water parameters a,b,c