Overview of HK calibration
&
PMT calibration

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Overview of HK Calibration

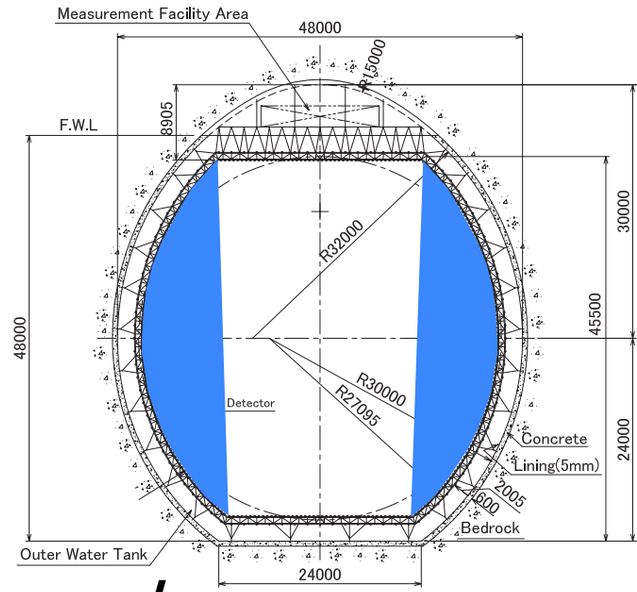
Goal of HK calibration

- Physics sensitivity studies are in progress, and requirements from physics to HK calibration are not clear yet.

- We set our preliminary goal:
  HK detector needs to be calibrated to achieve SK (SK-II) level detector performance.

Baseline idea of HK calib

- SK has been operated successfully over decade, and has established several techniques to calibrate a large water Cherenkov detector.
- HK calibration will be designed based on SK calibration method/system
- However, there are some key differences between HK and SK:
  - Multiple compartments (like 10 SKs)
    → Automated calibration system
  - Asymmetric detector shape
    → 3D scanning (not only Z-positions)
- ➜ Incorporate "new" calibration technique/system of the other existing experiments (ex. SNO, Borexino)



HK calibration
and overview of this session

- HK calibration major components, and talks in this session:
  - PMT calibration and detector monitoring [Hide]
  - Water optical properties [Hiro]
  - Higher level calibration [Koshio-san, Mine-san]
    - ex. Energy calibration (Low and High Energies)
  - Outer detector calibration [Mine-san]
  - Calibration source deployment system [Szymon]

- Prototyping and R&Ds are projected.
- Preparation of "Conceptual Design Document" for HK calib is in progress
  - Trying to write up 1st draft by end of this month.

PMT calibration

Goals of PMT calibration

- HK has ~99,000 of PMTs in the inner detector, and the detector is optically segmented into 10 compartments.
  - One compartment has similar size of volume and number of PMTs to SK

- Goals of the "PMT calibration" are
  - Measure & calibrate the charge and time responses of PMT/electronics and evaluate calibration constants.
  - Monitor the detector stability during the data-taking, and apply correction to the calibration constant time-to-time, as needed.

Strategy of PMT calib

Pre-calibration

A fraction of PMTs calibrated in detail prior to installation (all other PMTs calibrated referencing to them)

Post-installation calibration

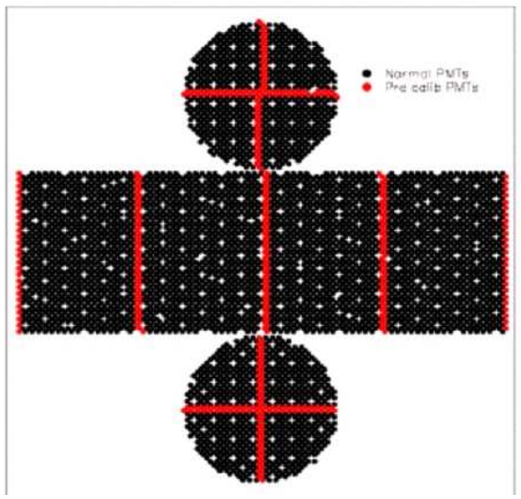
Tune/calibrate all PMTs *in situ* after installed (ex. HV, gain, QE, timing)

Detector monitoring

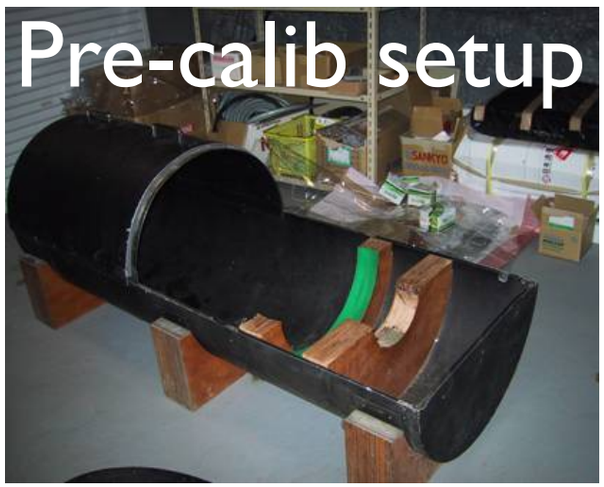
Monitor the stability of the detector during data taking, and apply correction to the calib constants time-to-time, as needed.

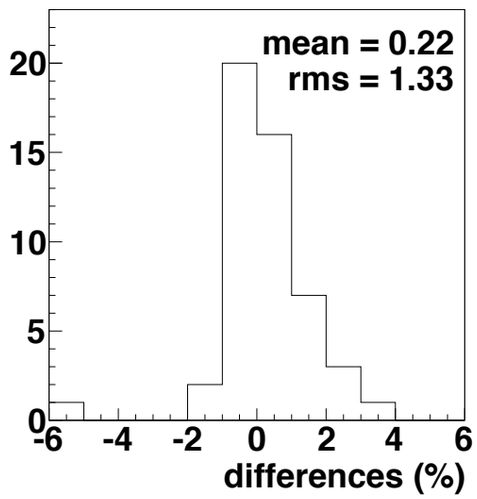
Pre-calibration

- A fraction of PMTs are calibrated prior to installation, called *"standard PMTs"*
  - All other PMTs are calibrated *in situ* after installed with reference to the standard PMTs.
- SK pre-calibration
  - SK have 420 of standard PMTs (~4%)
    - The standard PMTs were installed in the tank geometrically symmetric.
  - Pre-calibration determined HV values of the standard PMTs to obtain the identical charge (30 p.e.) between them.
  - Pre-calibration took ~2 weeks



SK 'standard PMTs' location

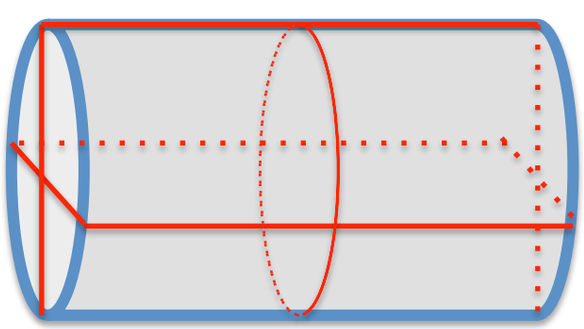




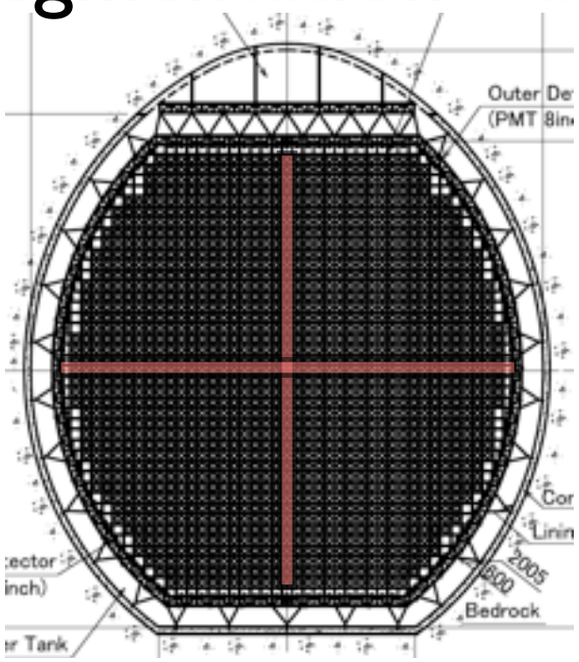
Pre-calib in HK

- Since HK detector is not symmetric shape, unlike SK, expected that the standard PMTs are more important in HK detector calibration.
- Adapt similar idea to SK in HK:
  - ~500 PMTs / compartment
    - see figures for PMT allocation
  - → ~5k standard PMTs in total (~5% of total HK PMTs)

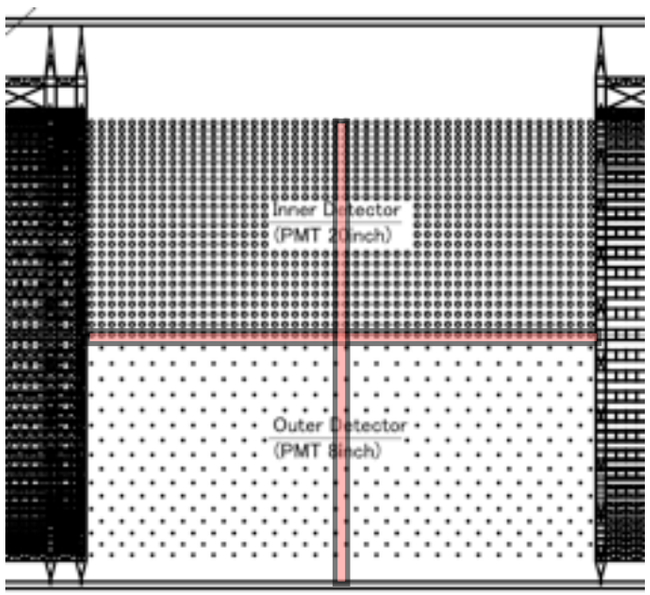
: 'Standard PMTs' location



Segmentation wall



Barrel



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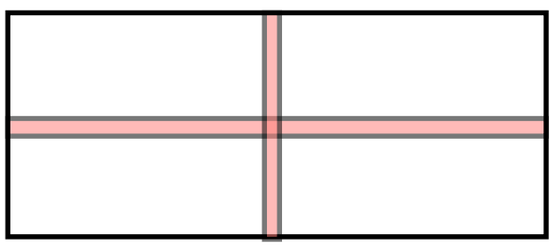

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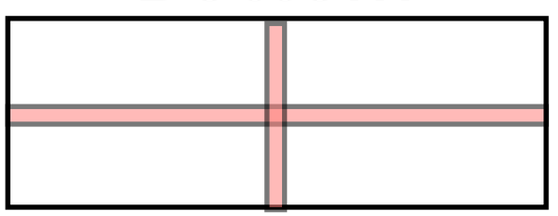


Post-installation calib

HV tuning

Tune HV all PMTs w.r.t the standard PMTs

Charge to p.e.

1 p.e. measurement

Photo-detection efficiency

Hit rate measurement @1p.e.

Timing

Time-work etc.

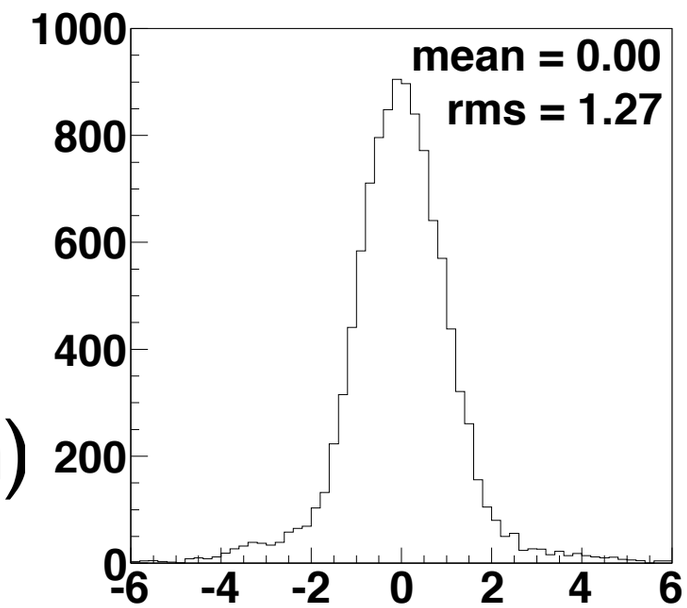
Charge linearity

PMT, elec. linearity

.....

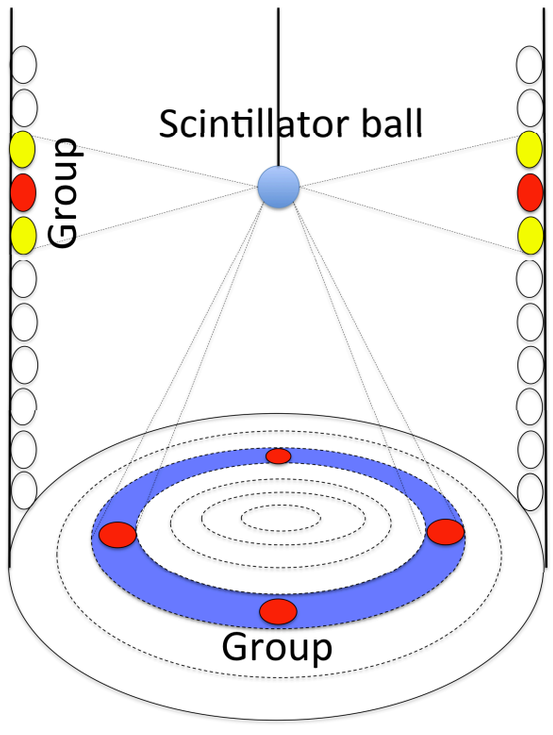
HV tuning

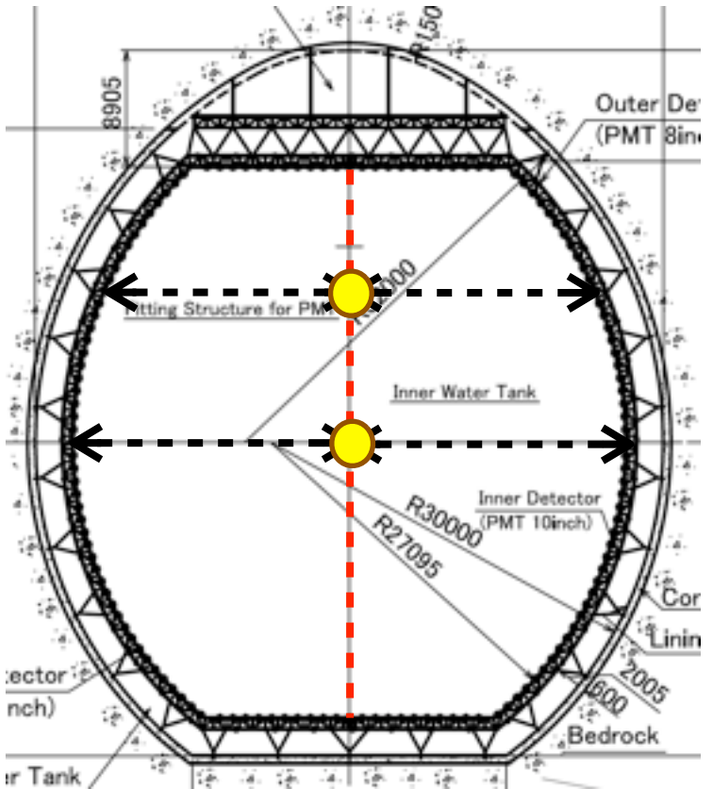
- Tune HV to obtain the same charge (pulse height) for all PMTs with reference to the reference PMTs.
- Deploy Xe lamp + scintillator ball to obtain tens of p.e. level of light
- Move the source along Z-axis (height direction) and tune HV 'group-by-group'

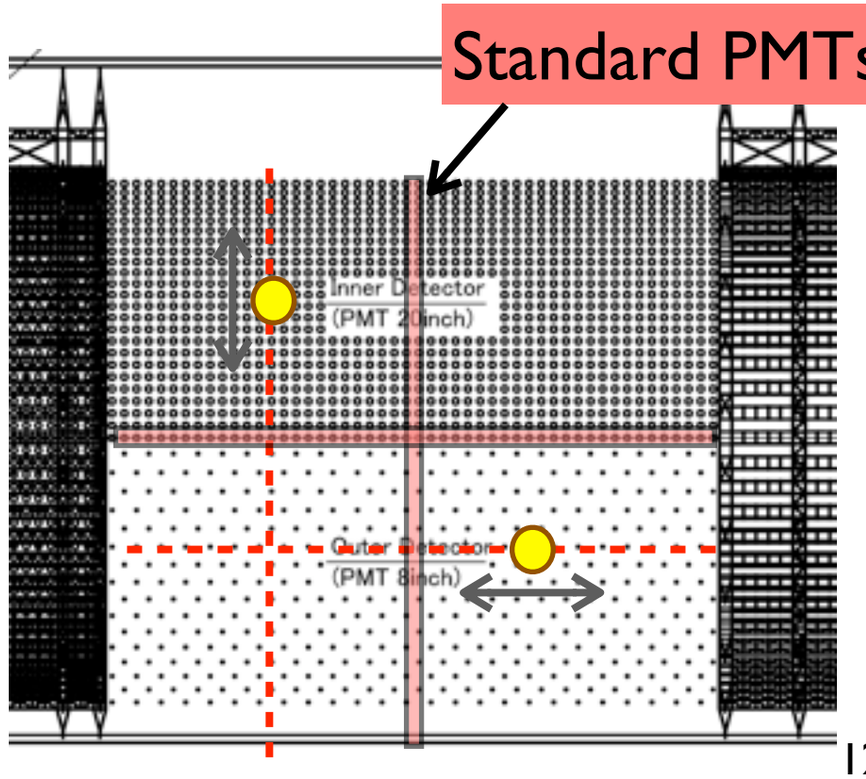


- HK may need a little complicated procedure

SK



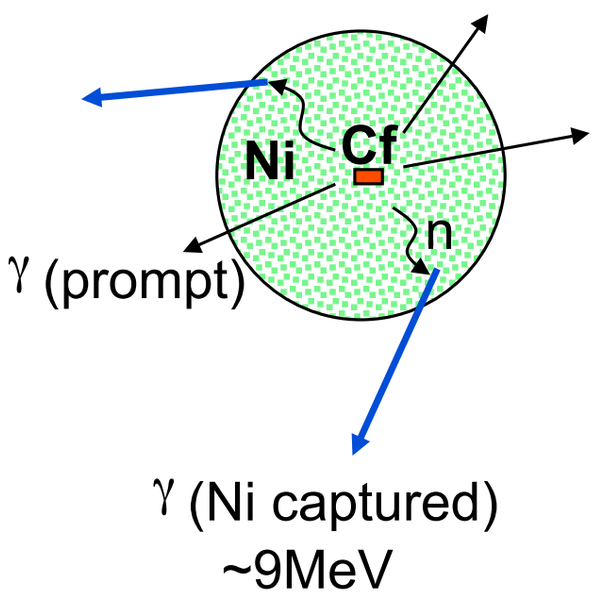




Charge to p.e. conversion

- Conversion factor from charge (pC) to photo-electron (p.e.) can be obtained by measuring 1 p.e. distribution
- Deploy "Nickel source" to obtain 1 p.e. level light
  - Nickel source ≡ nickel-californium source, Ni(n,γ)Ni, E_γ~9MeV

SK Nickel source



SK 1 p.e. distribution

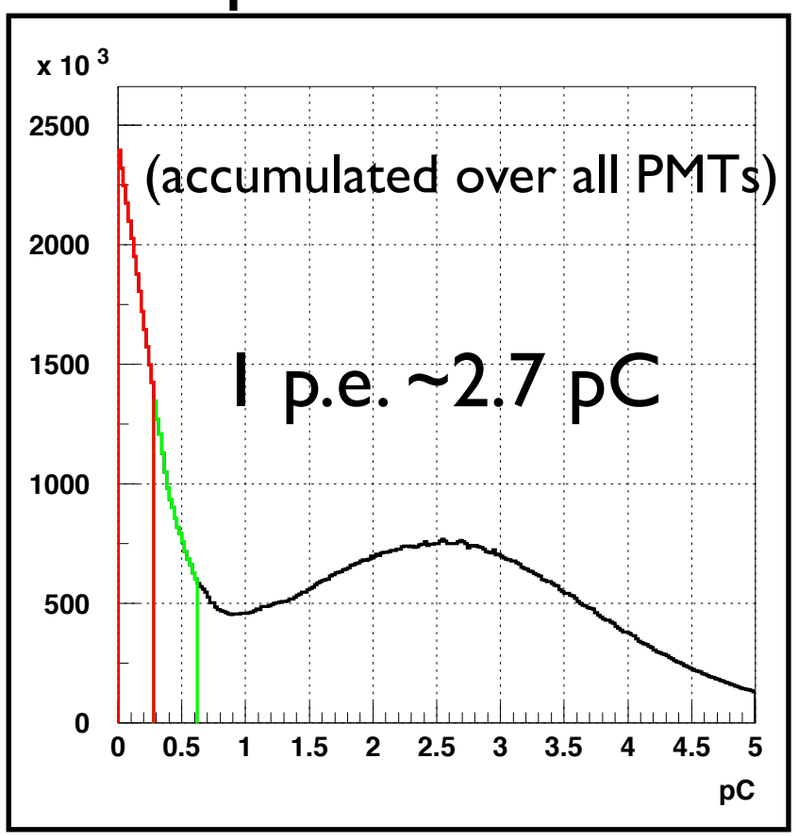


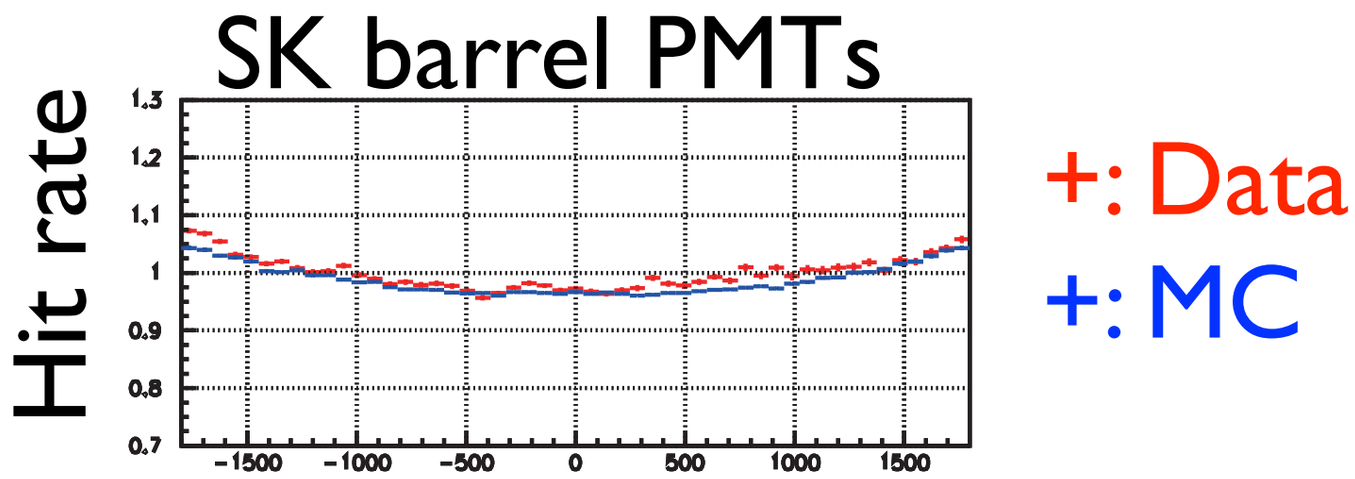
Photo-detection efficiency

- Photo-detection efficiency "ε" is defined by
  - Quantum Efficiency (QE) x Collection Efficiency (CE)
- Hit rate (N_{hit}) for 1 p.e. level of light is proportional to the photo-detection efficiency:

$$N_{hit} \propto N_{photon} \times \varepsilon$$

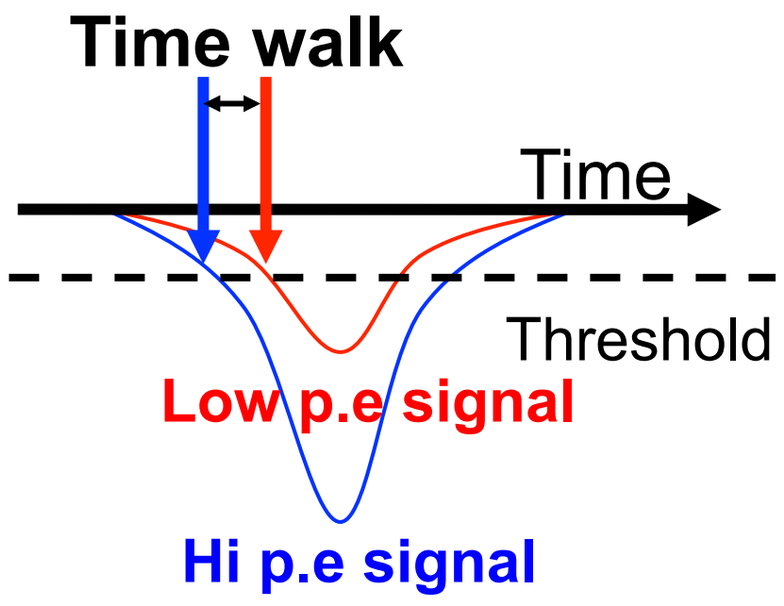
- Deploy Nickel source to evaluate the hit rate, and compare with MC which has 'known' number of photons reached to PMT

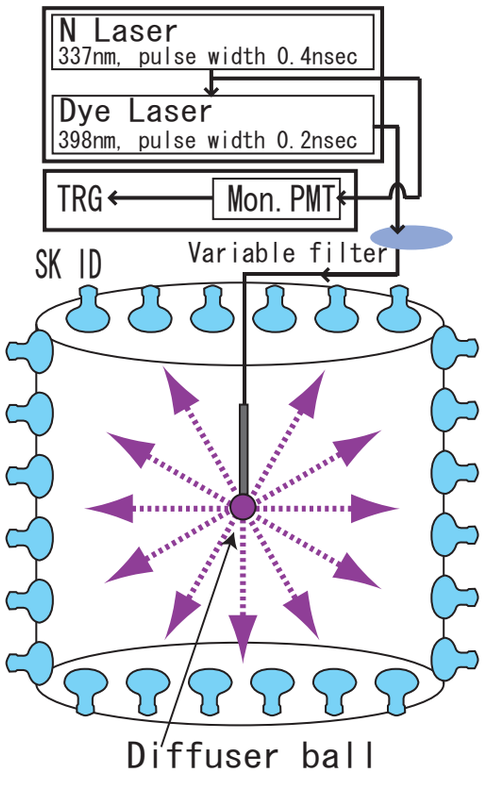
→ Evaluate relative ε for every single PMTs from difference between data and MC



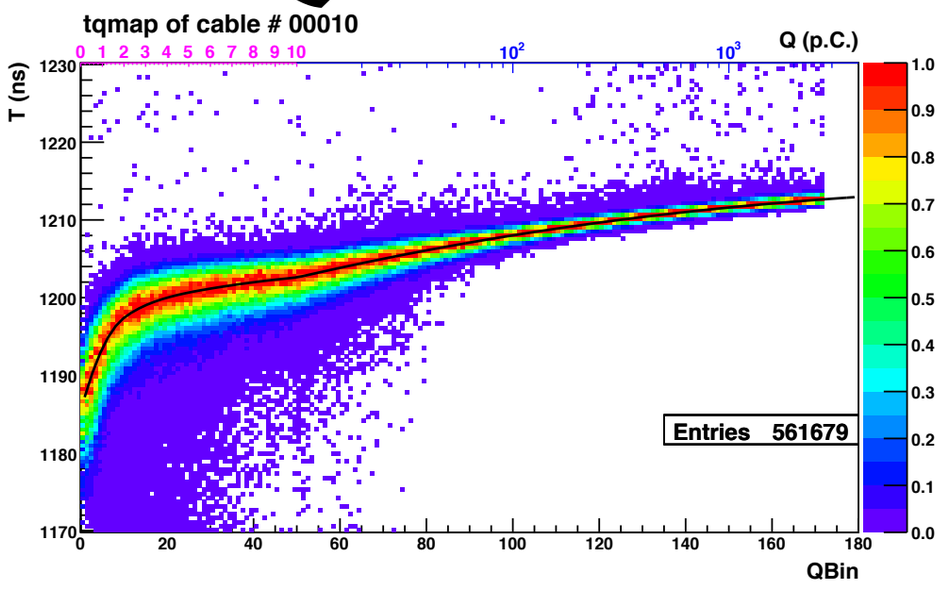
Timing calibration

- Time response of readout channel (PMT+elec) need to be calibrated to correct the *time-walk* effect etc.
- N_2-dye laser + variable optical filter + diffuser ball to obtain fast pulsed light with various intensities covering the entire dynamic range of electronics.





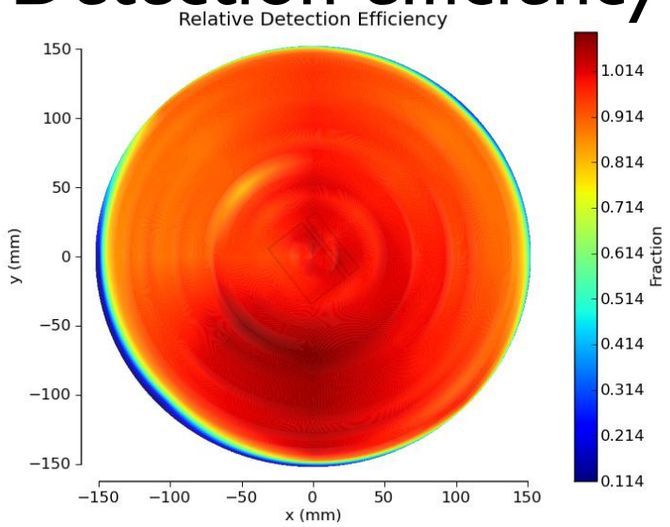
SK TQ-distribution



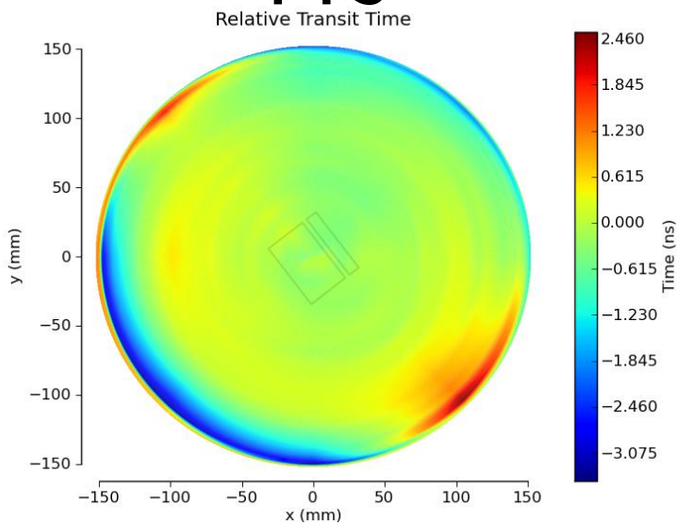
PMT properties *ex-situ* measurement

- PMT has position/angular dependence of the detection efficiency and time response (TTS).

Detection efficiency



TTS

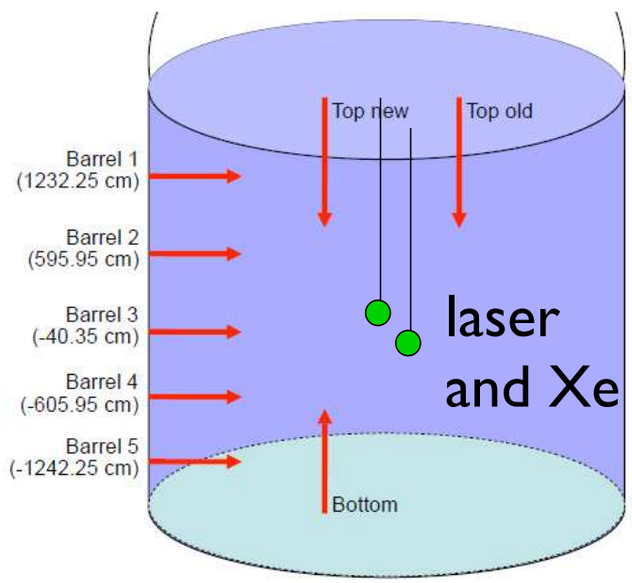


(Figures from LBNE CDR, arXiv:1204.2295)

- Hard to measure such properties of PMT *in situ*, after PMTs installed → need *ex situ* measurement.
- A test stand is being built at TRIUMF to test/measure these properties.

Detector monitoring

- Monitor the stability of the detector during data taking, and apply correction to the calib constants time-to-time, as needed.
- SK uses various light sources to monitor the PMTs, measuring the relative changes/variation as a function of time:
  - Xe lamp + scintillator ball for the charge response
  - N_2 laser + diffuser ball for the time response
  - (Laser diodes w/ various wavelengths for the monitoring of water property)
  - Optical fibers + scintillator/diffuser balls permanently stay inside the detector (near the center of tank)



Summary

- HK Calibration Overview
  - HK calibration method/system are being developed based on SK experience.
  - Trying to incorporate new ideas
  - Preparation of "Conceptual Design Document" for HK calib is in progress

- HK PMT calibration
  - PMT calibration techniques, established in SK, would work in HK too, even HK detector shape is not symmetric unlike SK.
  - Though, further details need to be thought out
  - If HK uses HPDs (instead of PMTs), may need to develop additional calibration items
    → Collaborate with Photodetector WG