Overview of the calibration system in Super-Kamiokande

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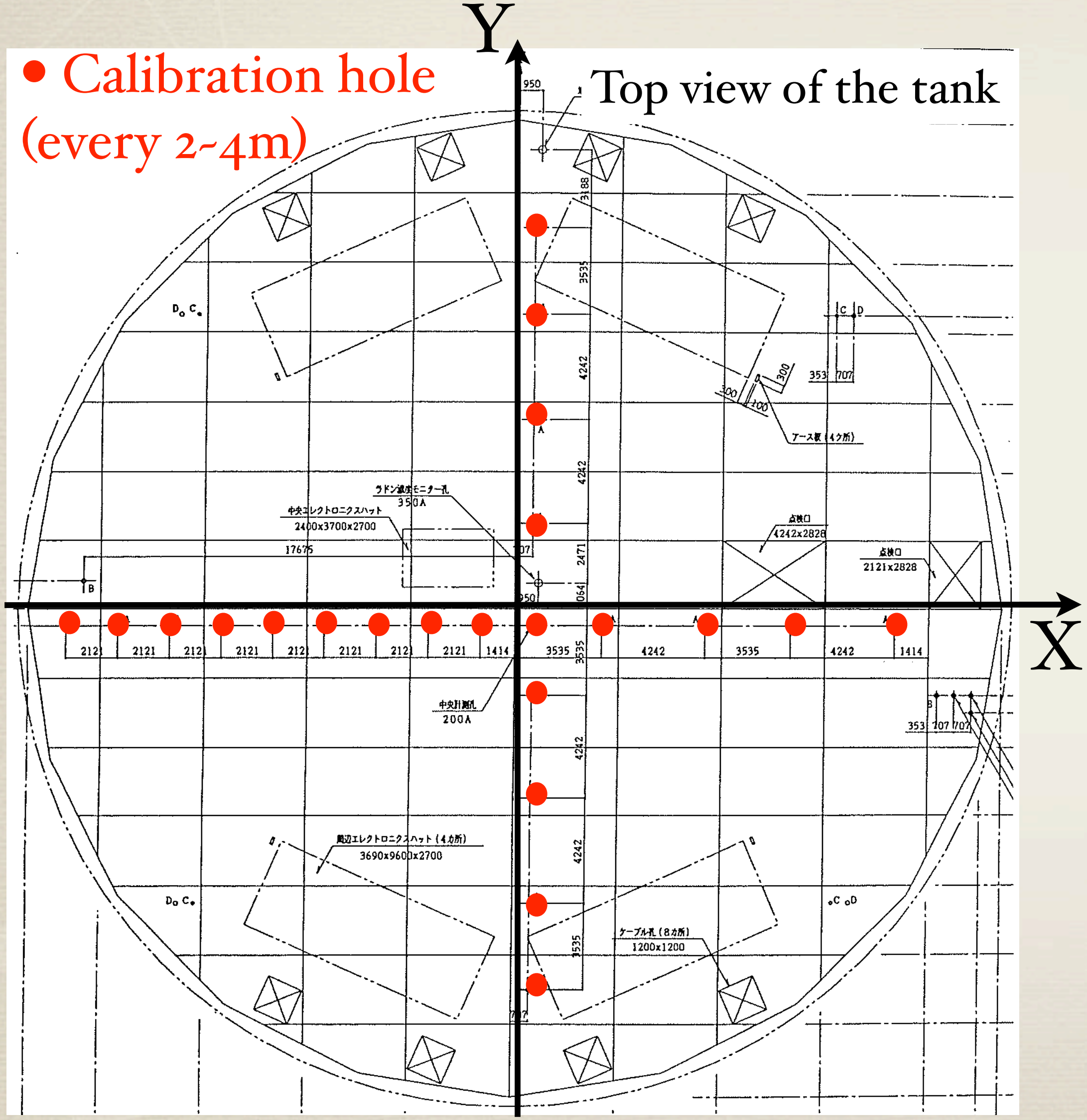
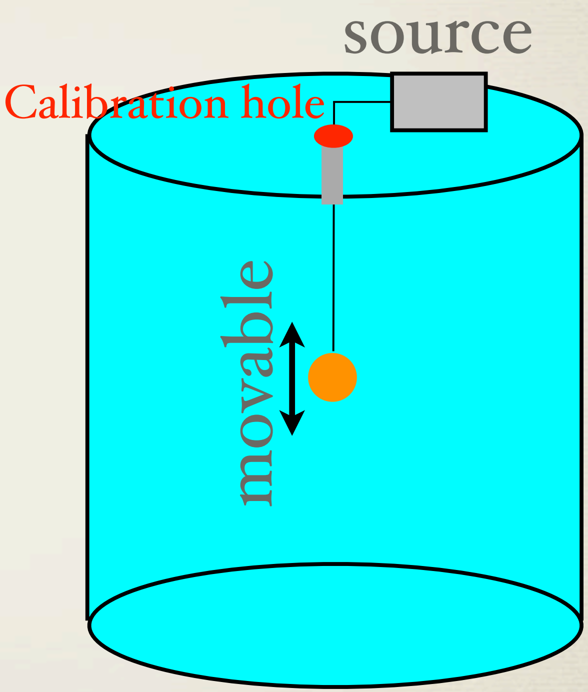
(Thanks for many suggestions from SK calibration group!)

Requirement

- Measurable for number of photo-electrons and arrival timing on each PMT as precise as possible.
- Understanding the water quality in detail.
- Possible to estimate the uncertainty of reconstruction, such as energy, position, direction etc.
- Monitoring a long term stability for PMT gain, Water condition, Energy scale, etc.

Access to inside of the tank





Flow of the calibration

Pre-Calibration

- For gain determination
- Measured 400 PMTs in stand alone

before SK start

after / during SK

Initial Calibration

- For gain, timing adjustment.
- Measured QE in each PMT
- Absorption/Scattering in water

Long term monitoring

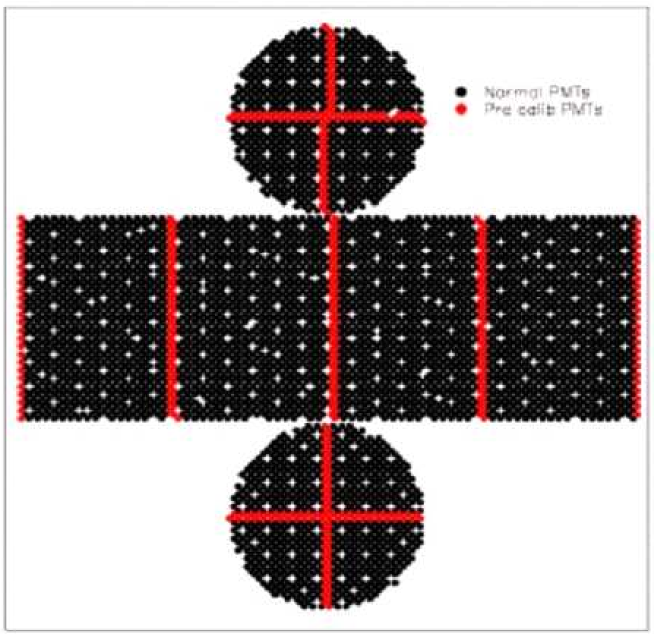
- Check a long term stability
  for gain, timing, water condition,
  energy scale, etc.

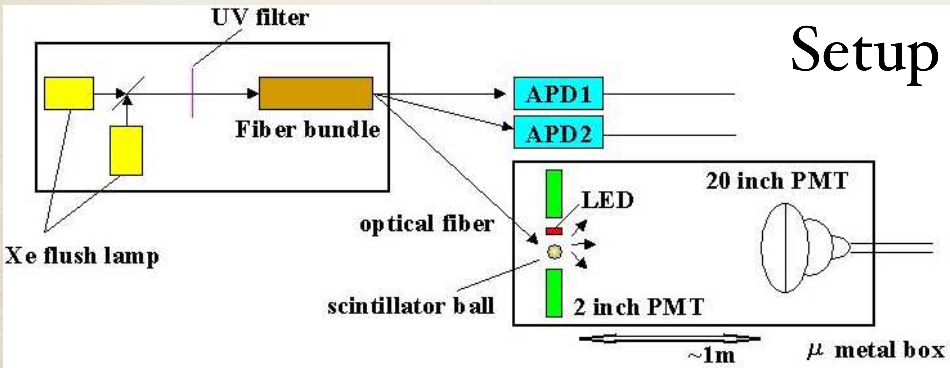
Calibration for estimate systematic errors

- Energy/Vertex/Direction in each analysis
- MC tuning

Pre-Calibration

- Prepare 400 PMTs with precise gain measurement before the SK starts.
- Set them in geometrically uniform to SK.
- Adjust HV for other PMTs to these PMTs.





Initial calibration in SK

Number of photo-electrons

Electronics calibration

- Relation between channel vs pC

HV adjustment

- Used ~30 p.e. light for each PMT
- Adjustment of 'QE x gain'

Gain measurement

- Absolute/Relative PMT gain

Q.E. measurement

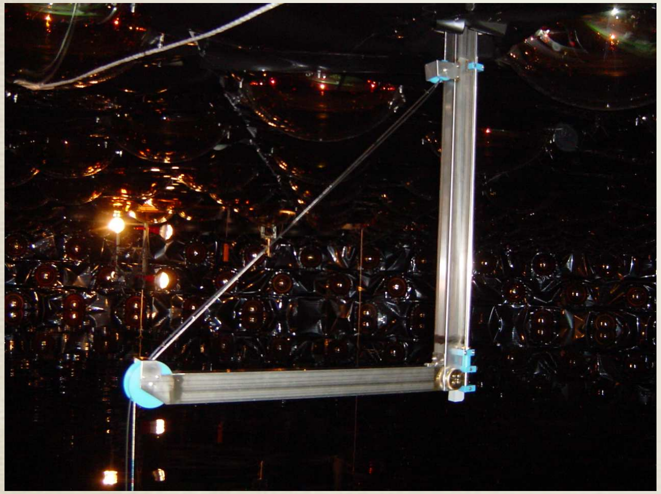
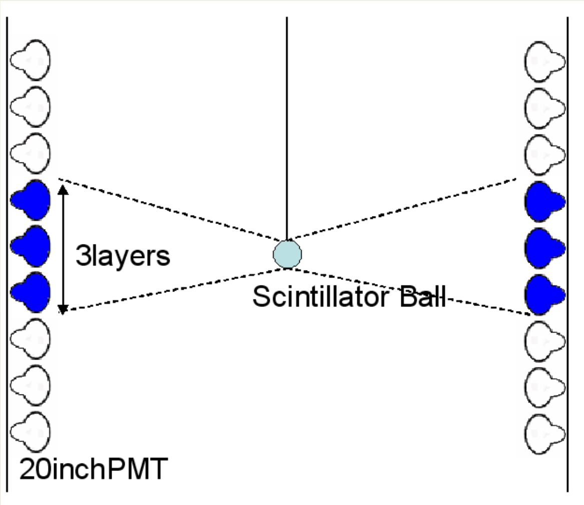
- Hit ratio in each PMT by 1 p.e. level light

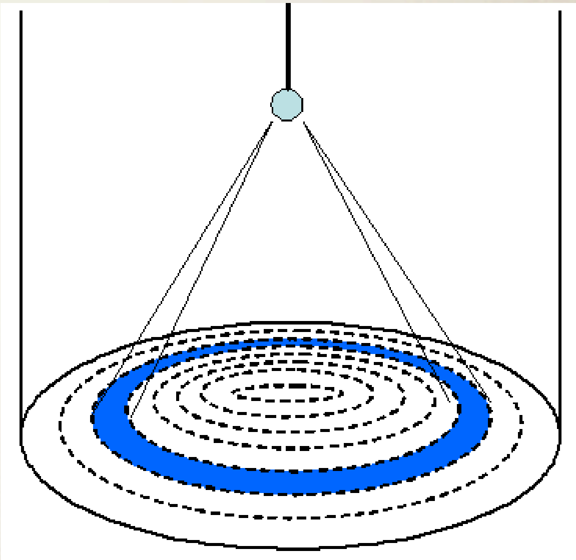
Charge with p.e. for data ⇔ Charge with p.e. for MC

- Fine tuning for PMT correction efficiency

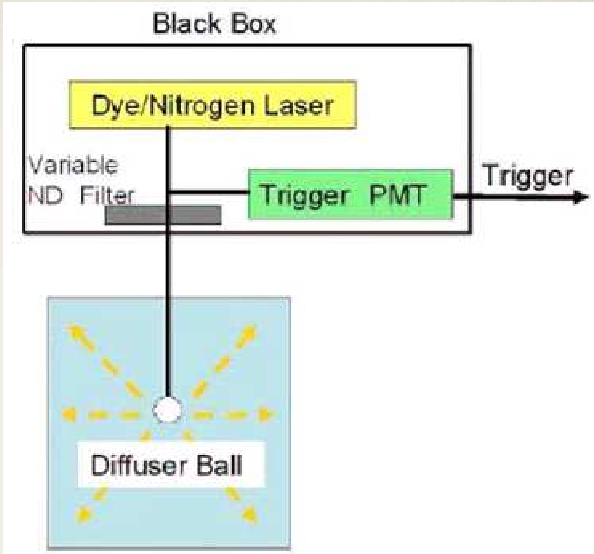
HV adjustment

* Set light source (Xenon lamp + Scintillator ball) at the exact center position by Arm.
* Adjust number of photo-electrons in all PMTs to reference PMT
* The 'QE x gain' for each PMT is adjusted in this calibration.



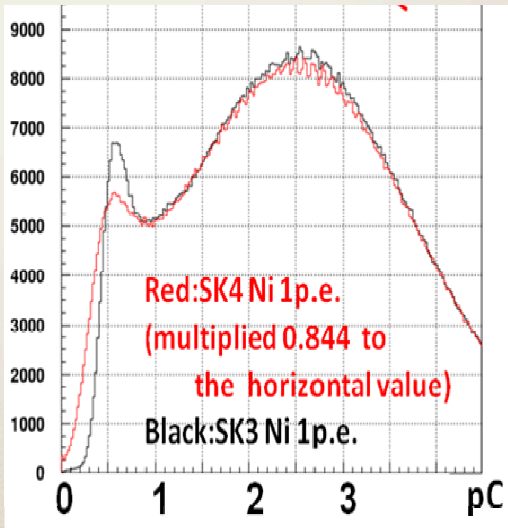
Gain measurement



- Relative gain of each PMT was measured by the ratio of low/high intensity of laser light. It is applied as a correction table of observed photo-electrons for each PMT.

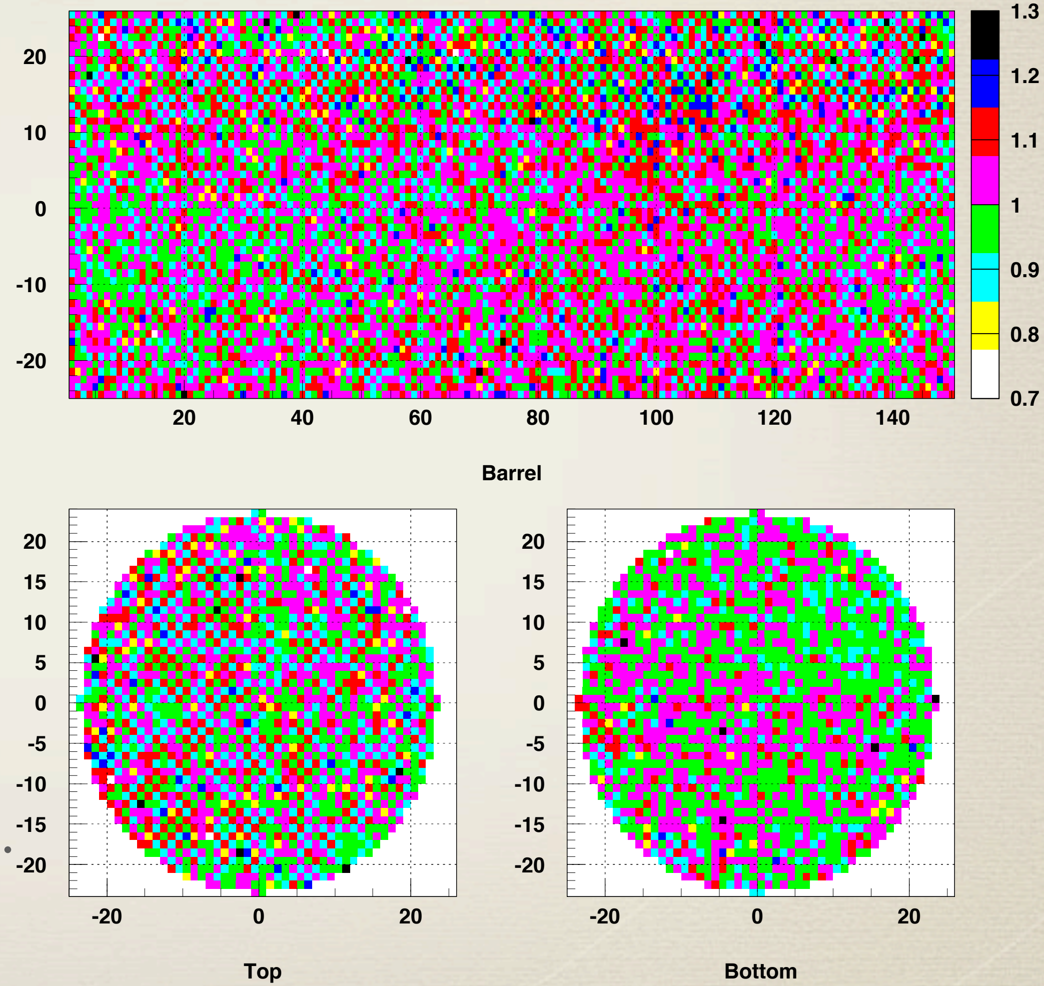
- Absolute gain (averaged) was determined by the 1 p.e. peak by 'Nickel calibration'.

- It was hard to get absolute gain for each PMTs, since the electronics pedestal drift in time.



QE measurement

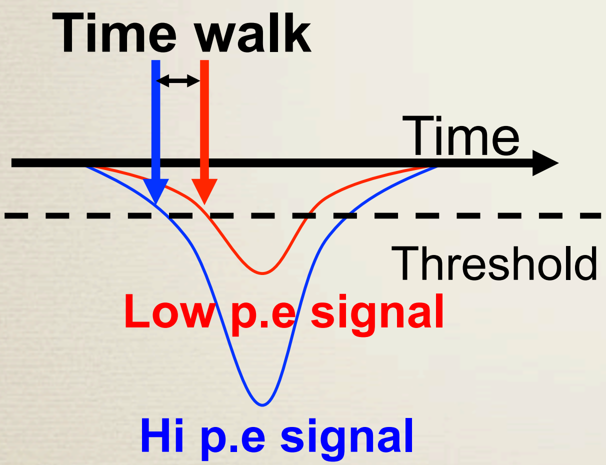
- Relative QE factor of each PMT was measured by the hit ratio from 1 p.e. level light ("Ni source")
- This measurement can be done only when the water quality is uniform all over the detector.
- It is applied to each PMT for MC as a correction table.

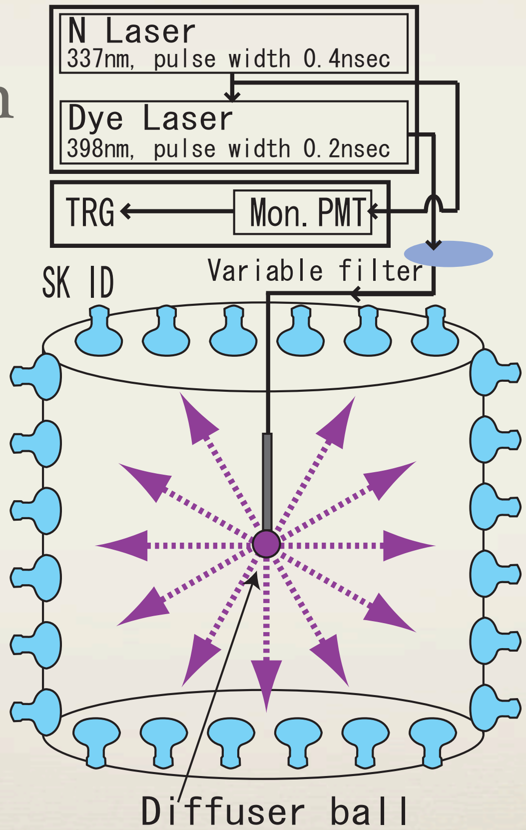


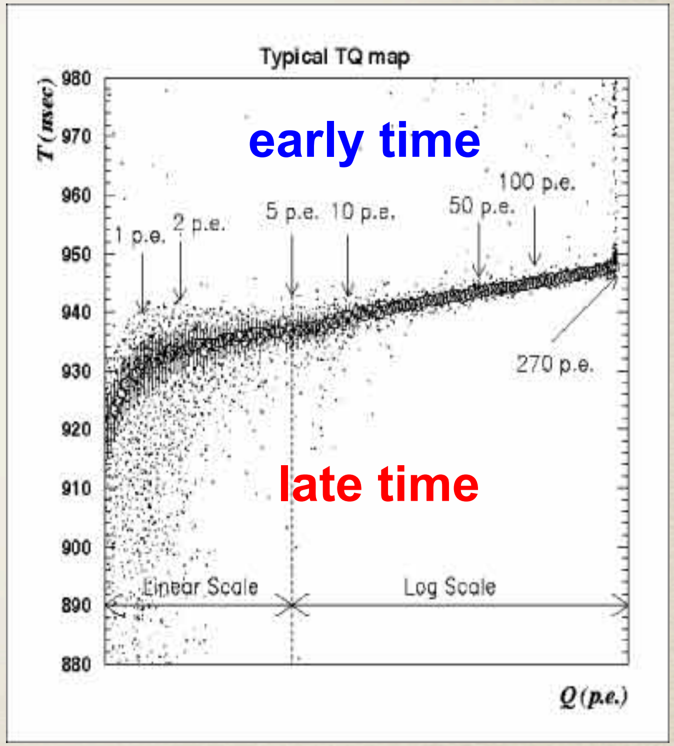
Initial calibration in SK

Arrival Timing

Time walk correction
for each PMT



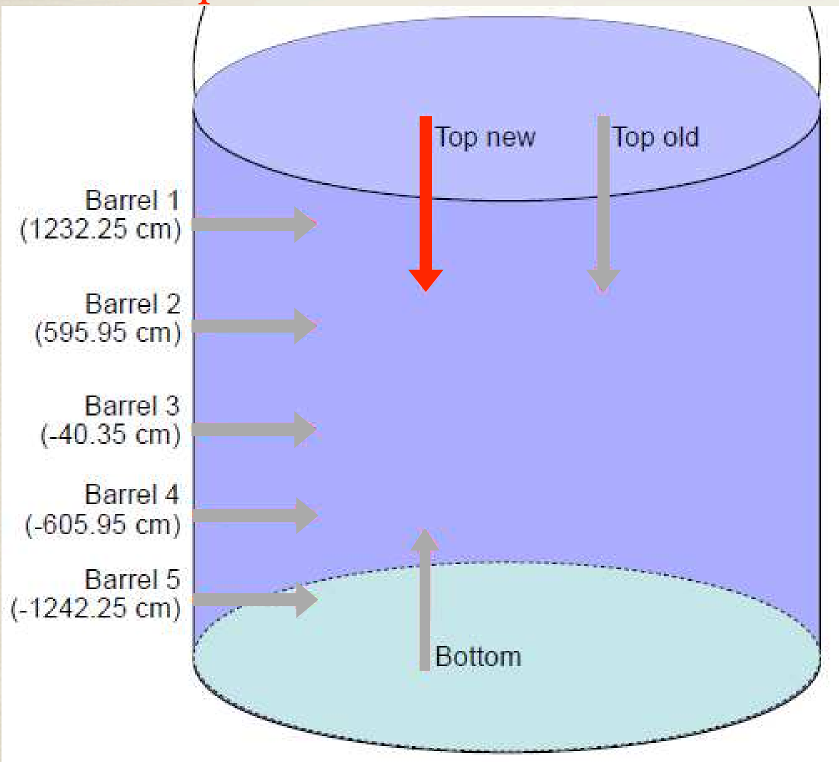




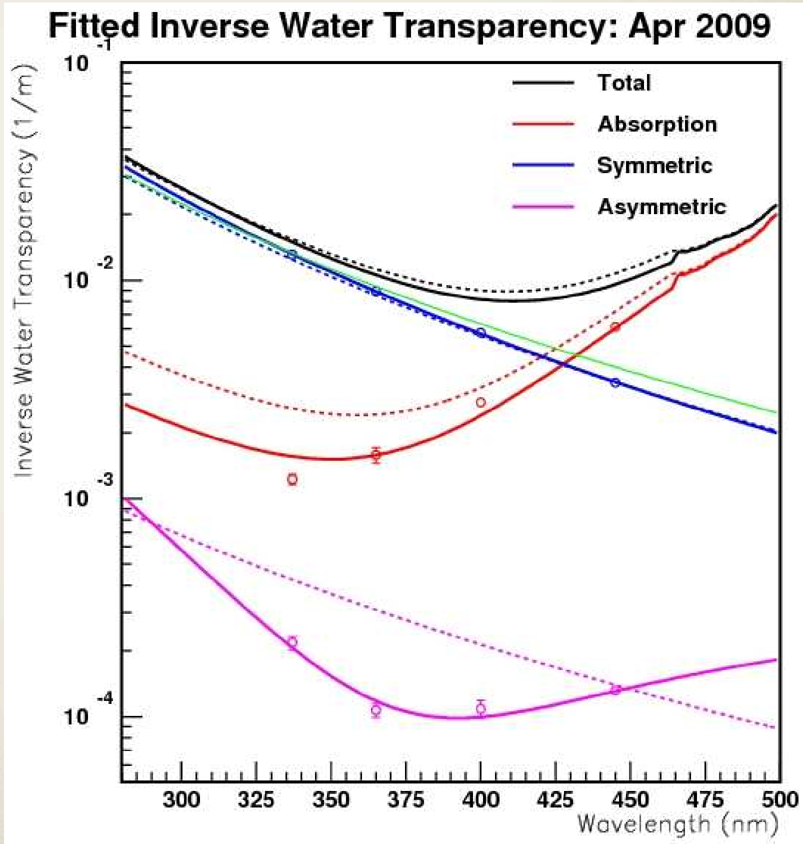
MC tuning

Water quality (scattering/absorption)

Outputs of the light source are set on several positions on the detector wall

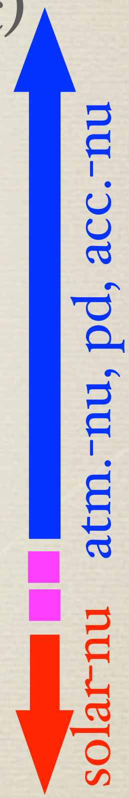


A precise water model is available.



Energy calibration

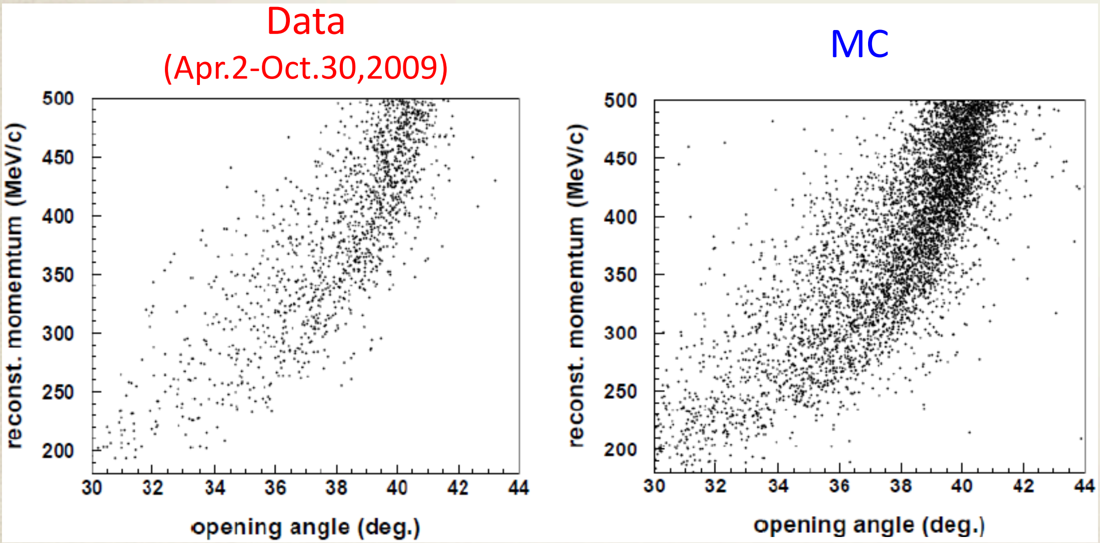
- Track range of high energy stopping muon (10-1 Gev/c)
- Cherenkov angle of low energy stopping muon (500-200MeV/c)
- Invariant mass of π^0's produced by atmospheric neutrino interactions (~130 MeV/c)
- Momentum of decay electron (~50 MeV/c)
- LINAC and DT (4-20MeV)



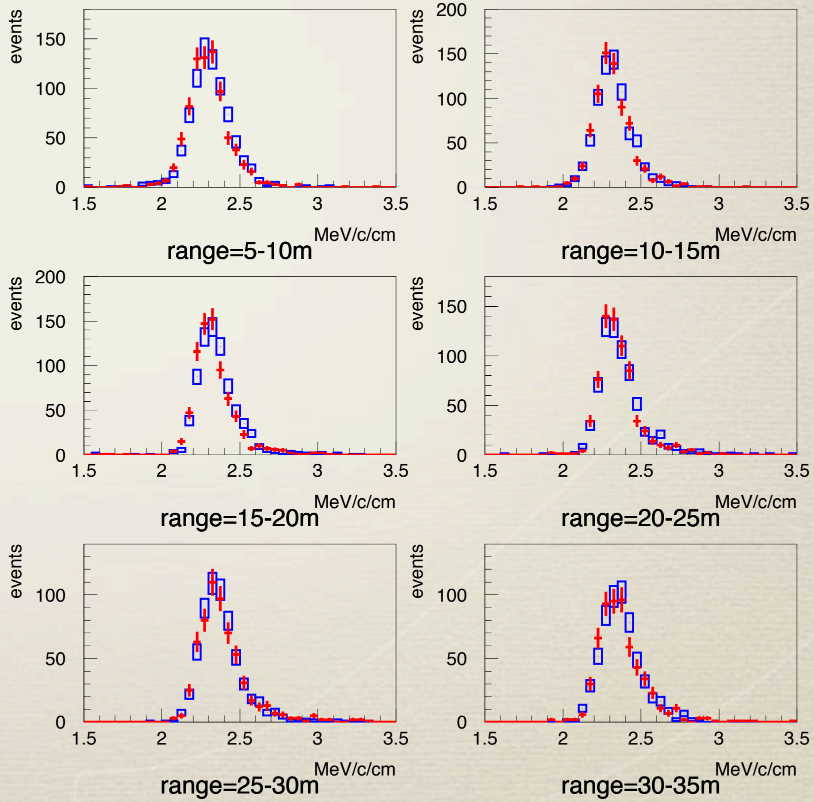
Energy calibration

“natural sources” for higher energy region

(1) Track range of high energy stopping muon



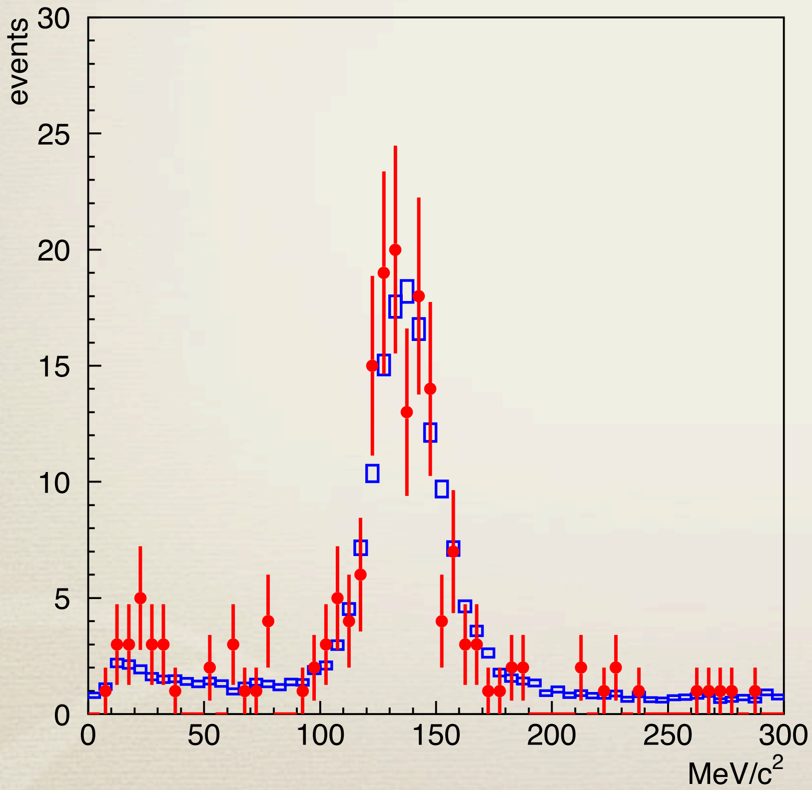
(2) Cherenkov angle of low energy stopping muon



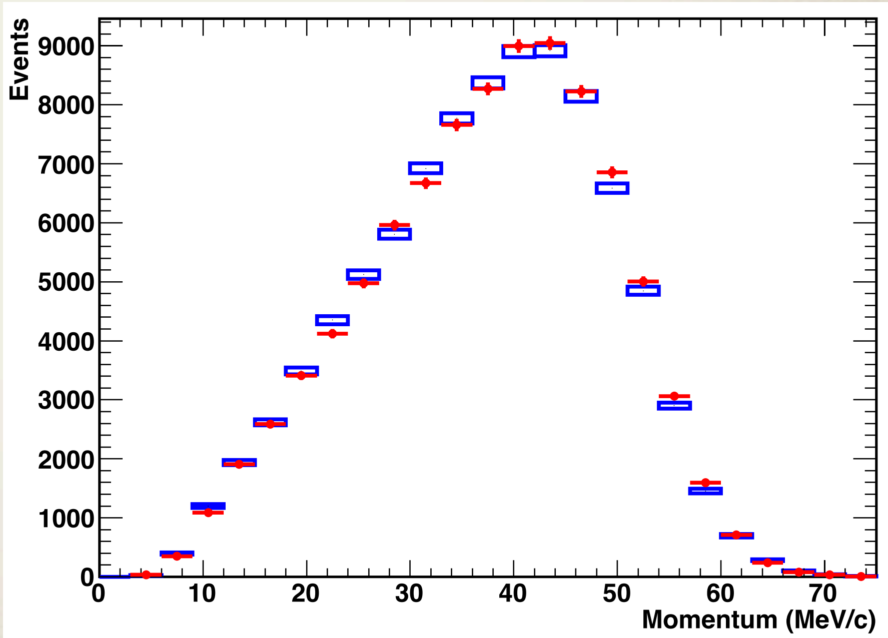
Energy calibration

"natural sources" for higher energy region

(3) Invariant mass of π^0



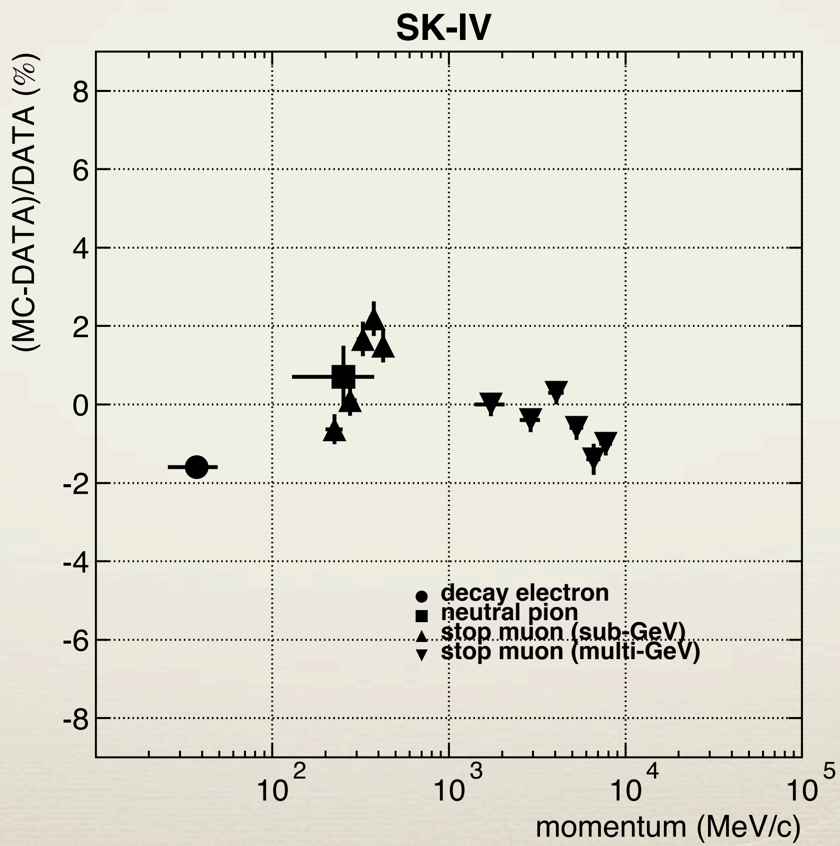
(4) Decay electron momentum



Energy calibration

"natural sources" for higher energy region

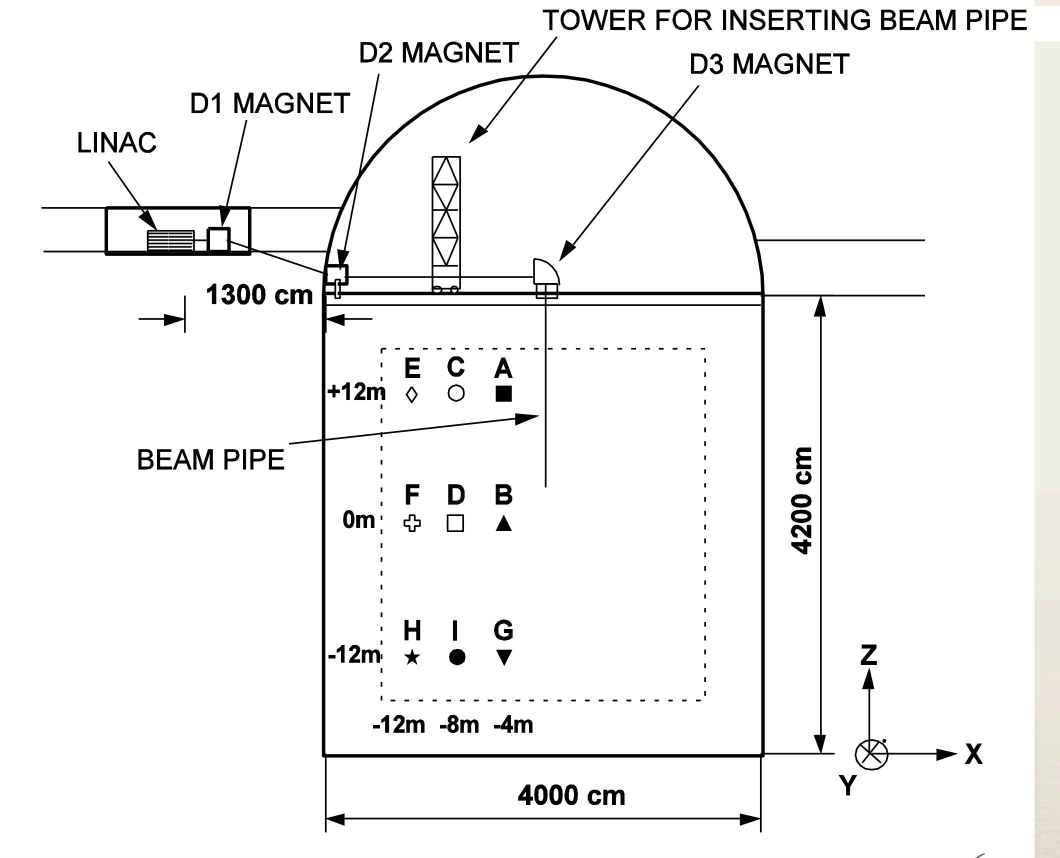
Data and MC is consistent with ±1%



Energy calibration

LINAC/DT for lower energy region

(1) LINAC calibration



pipe insert from calibration hole

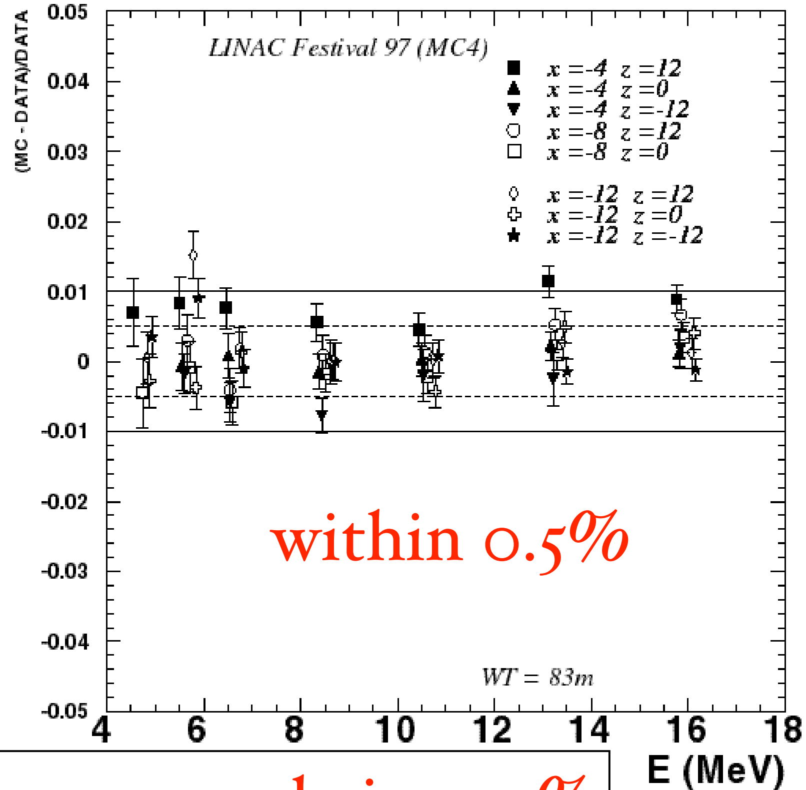
Energy calibration

LINAC/DT for lower energy region

(1) LINAC calibration

- Monochromatic energy (4~20MeV)
- Very precise energy determination (~keV)
- "The LINAC festival" is held once per year, takes ~2weeks.

differences between data and MC

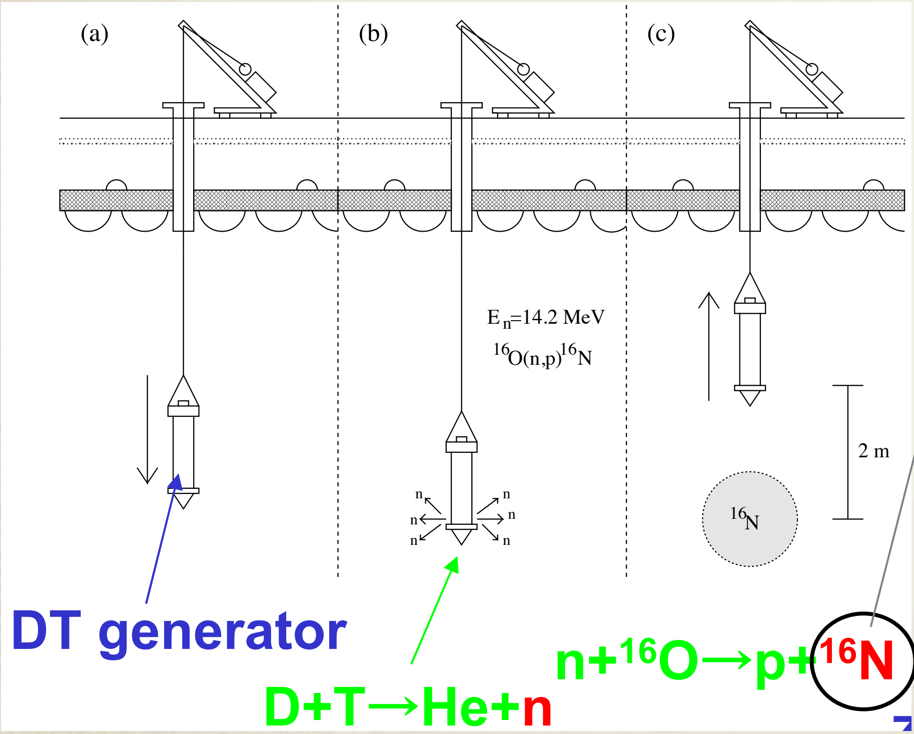


Uncertainty of absolute energy scale is ~0.5%

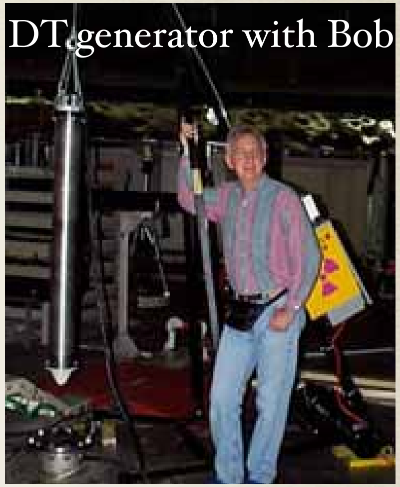
Energy calibration

LINAC/DT for lower energy region

(2) DT calibration



$\tau_{1/2}$=7.13sec
β 4.3 + γ 6.1 (66%)
β 10.4MeV (28%)
uniformly generated



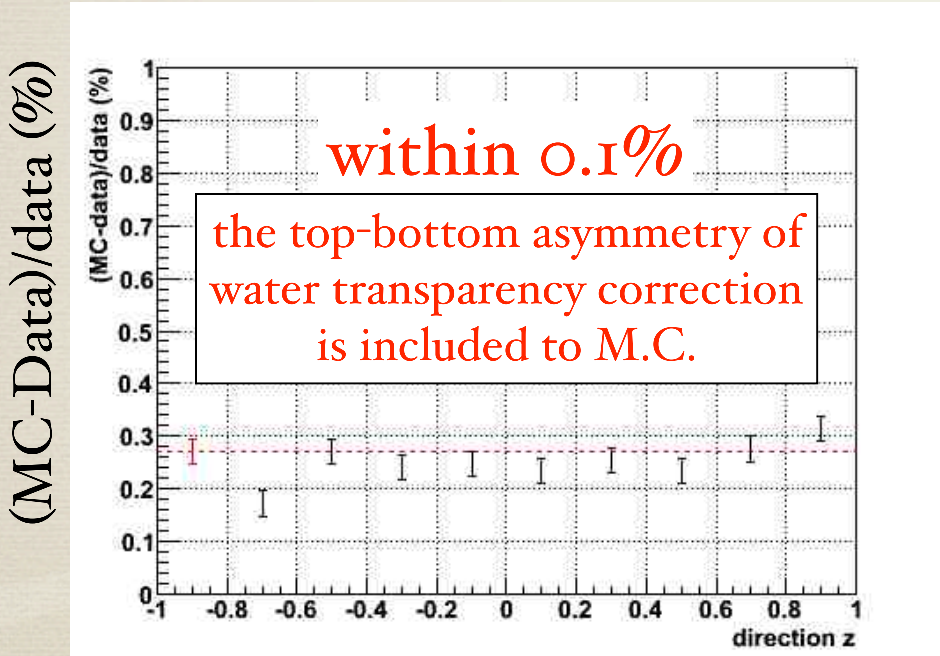
take data every 3 month

Energy calibration

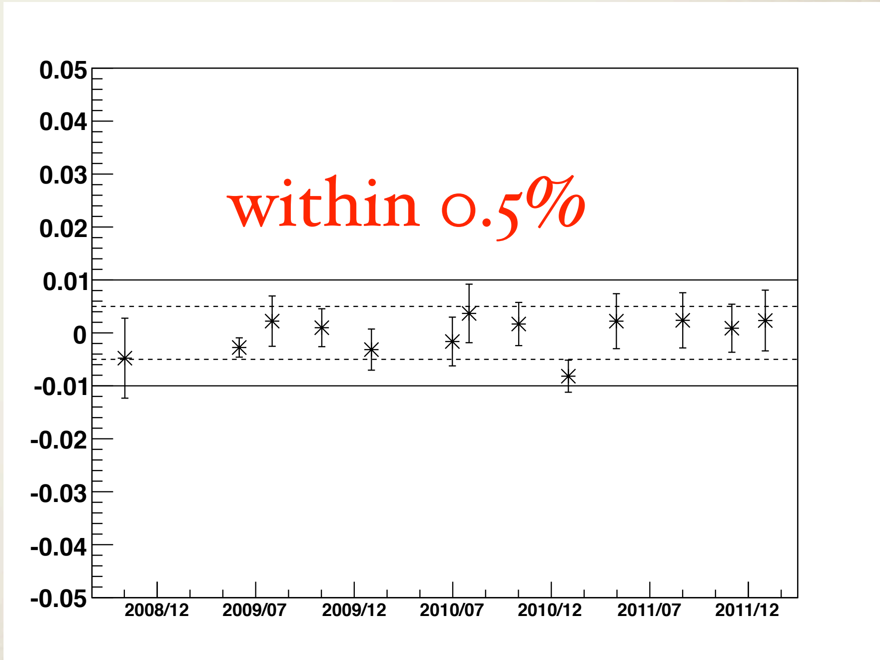
LINAC/DT for lower energy region

(2) DT calibration

Zenith angle dependence

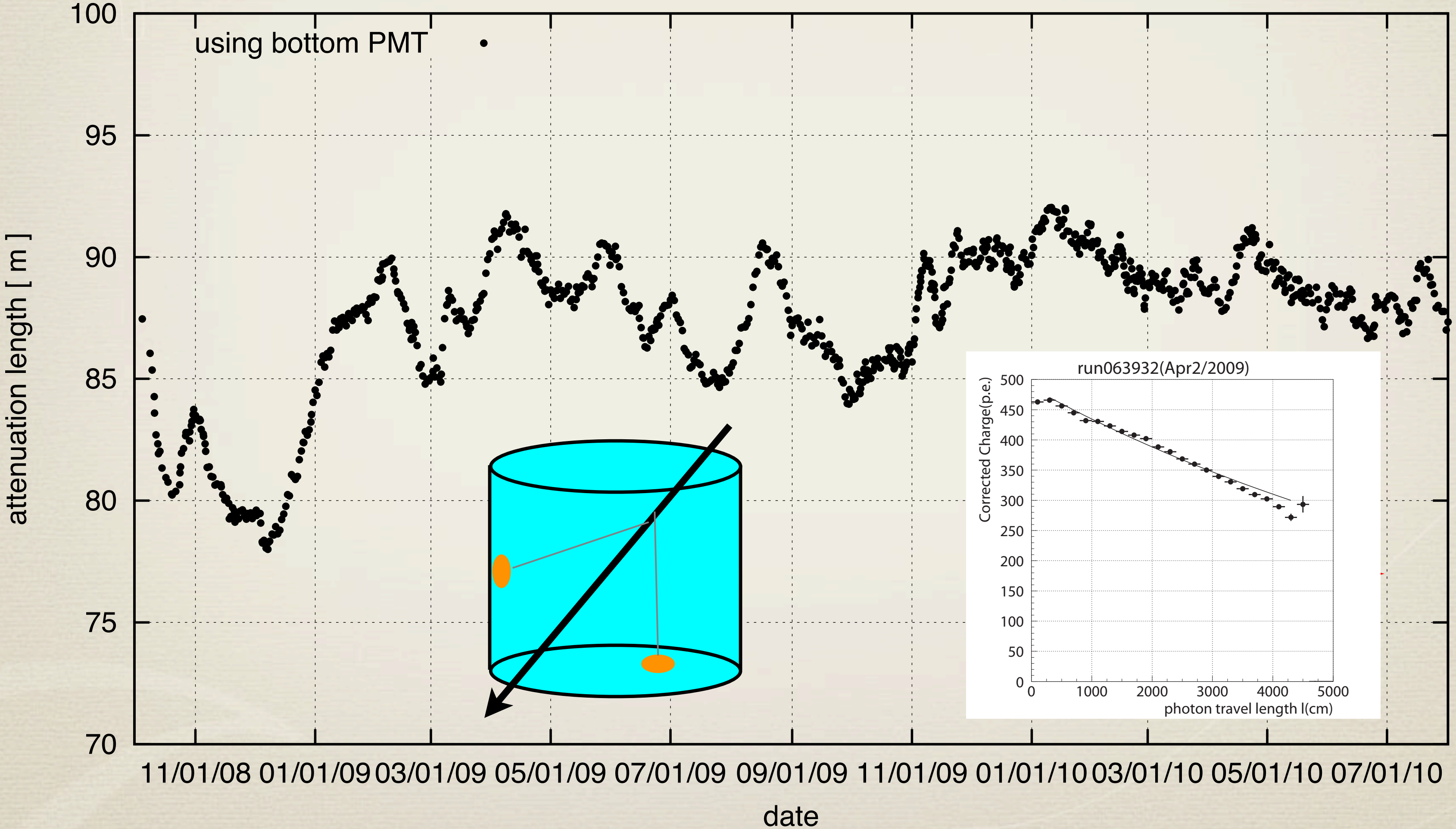


Long term stability



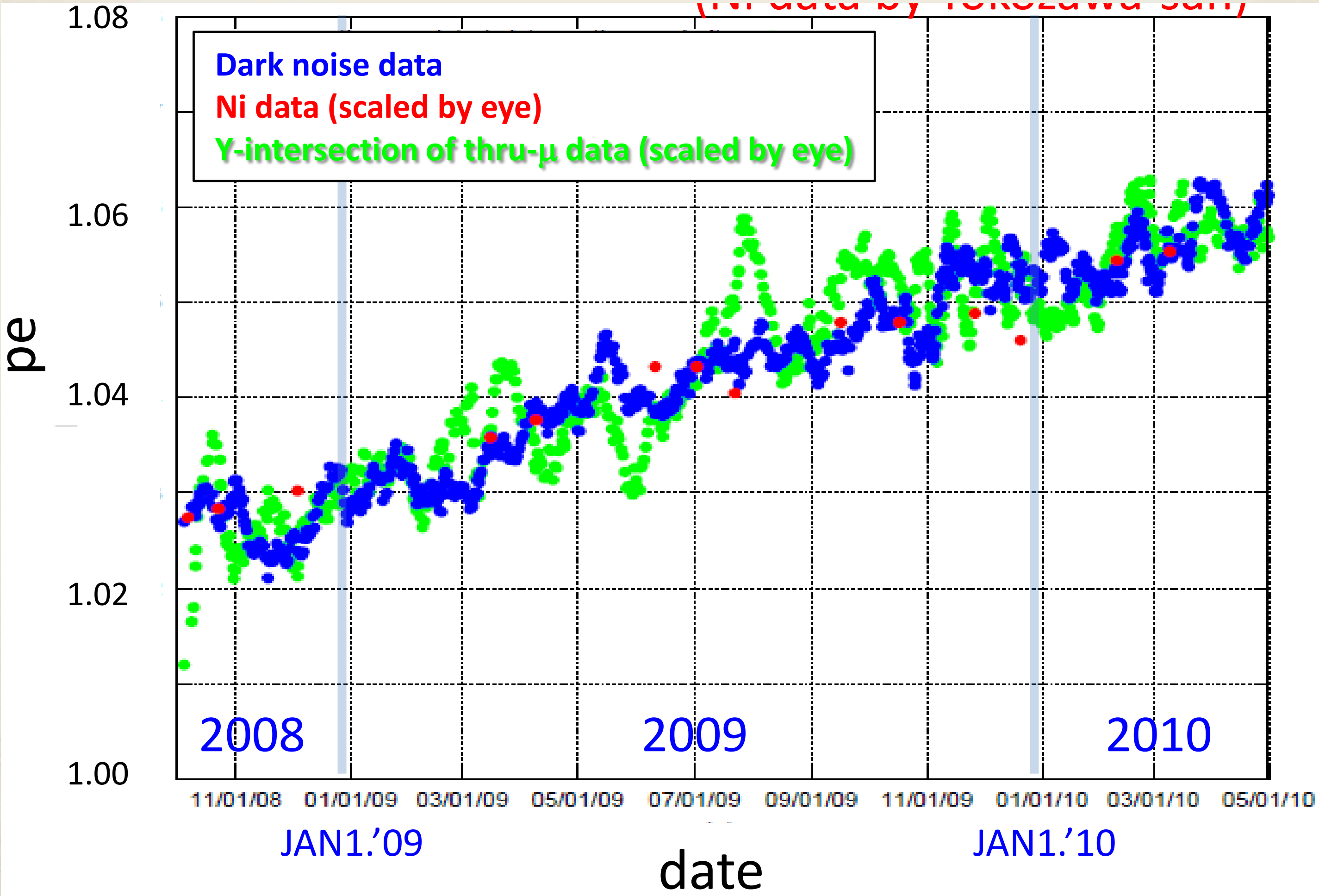
Long term stability

Water transparency measured by penetrating muons



Long term stability

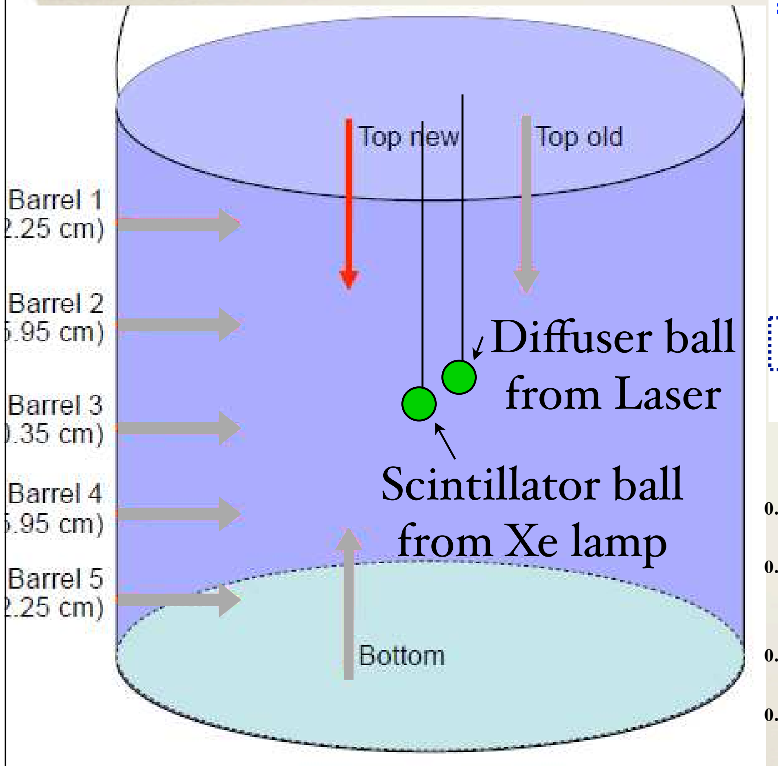
PMT gain measured by charge peak of dark noise

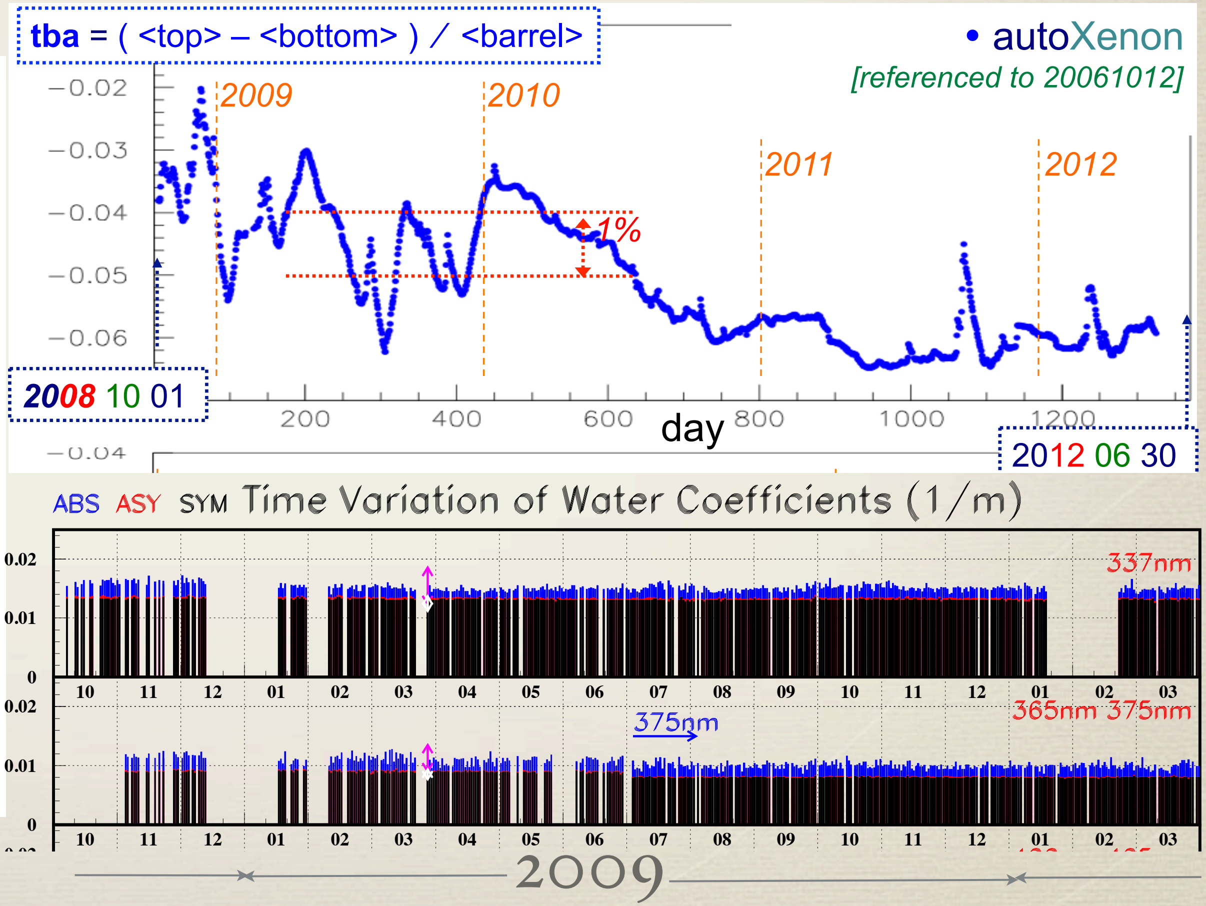


Long term stability

'Auto calibration'

take a data automatically every 1 second during normal data taking. 'water', 'gain' and 'timing'

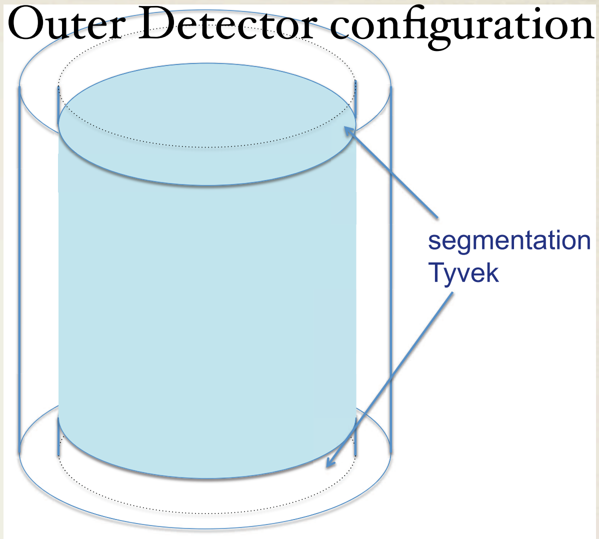


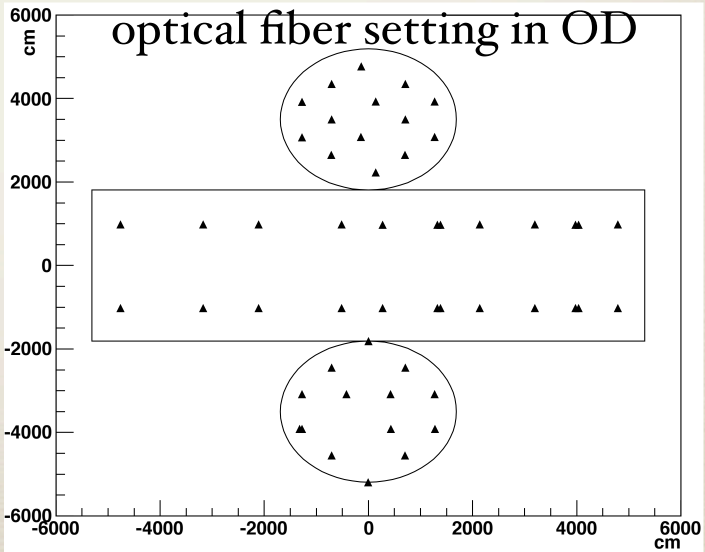


OD calibration

* Essentially same calibration as ID, precise measurement for number of photo-electrons and arrival timing to PMTs.

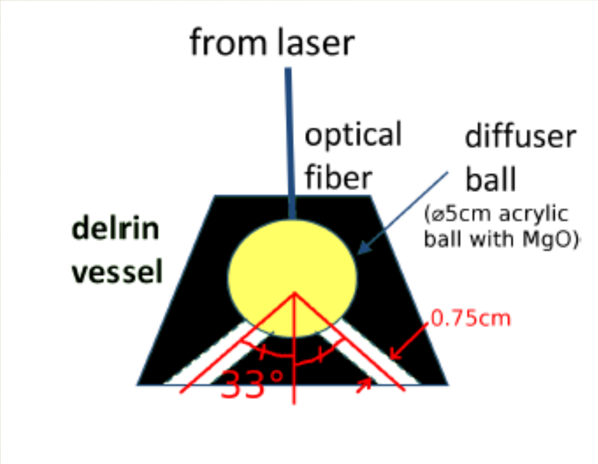
* Done using cosmic ray, dark rate data, and laser light data.

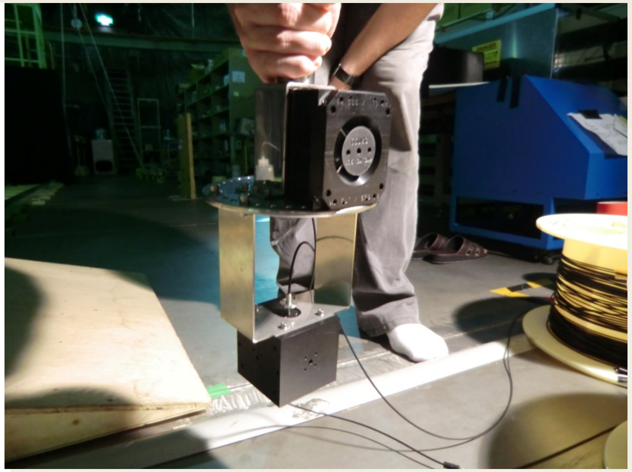


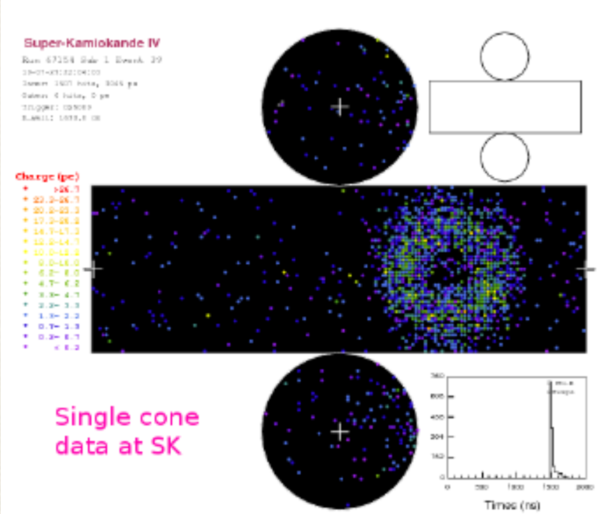


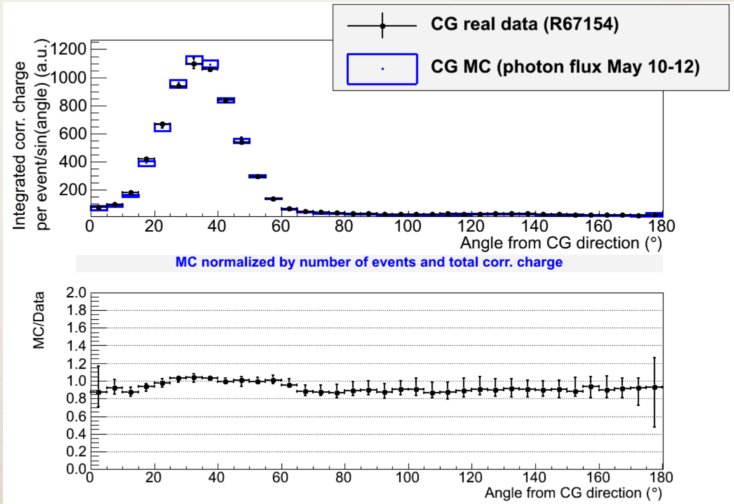
Other calibrations

Cone generator   Check charge profile between data and MC

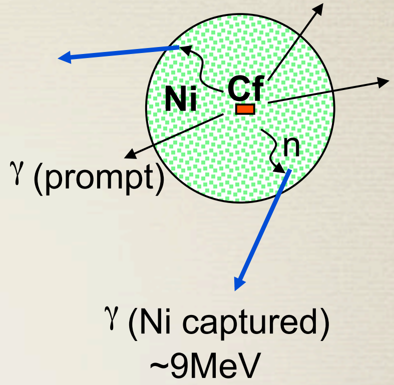






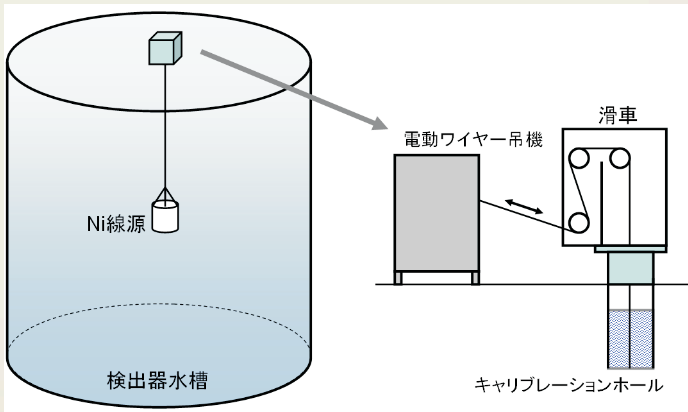


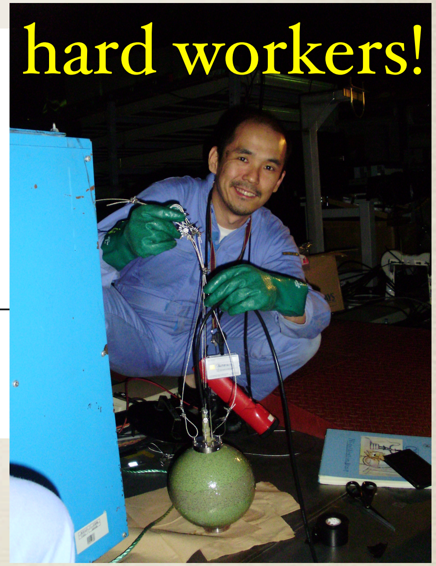
Other calibrations



Nickel calibration

Ideal one photon level source
- Uniformly generated
- Stable
- easy to handle





Used for many purposes:
- 1 p.e. distribution
- QE measurement
- water quality (top-bottom asym.)
- trigger efficiency
- reconstructed vertex calibration
- angular dependence of energy scale
- etc..

Monthly data taking

Summary

* Many calibration in SK can lead precise physics results, we understand the detector from every points of view within 1% level.
* The method for water Cherenkov detector is established, therefore, we can do similar things for Hyper-K in general, but there're several things to be considered.
  - Appropriate for larger detector? What calibrations are really needed? What's demand from each physics analysis group? Anything new idea?
  - The advantage of geometrical symmetry is used at most in SK, but the situation in Hyper-K will become different.
  - Should be reduce dead time as much as possible not to miss a SuperNova.
  - Should be automatic as much as possible, we cannot rely on hard workers...
  - Any others?