Calibration of energy scale uncertainty based on understanding of Super-Kamiokande detector elements

Exploration of Particle Physics and Cosmology with Neutrinos
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Kotaro Shimizu, Katsuki Hiraide, Yuki Nakano, Masato Shiozawa,
Super-Kamiokande Collaboration
(ICRR)

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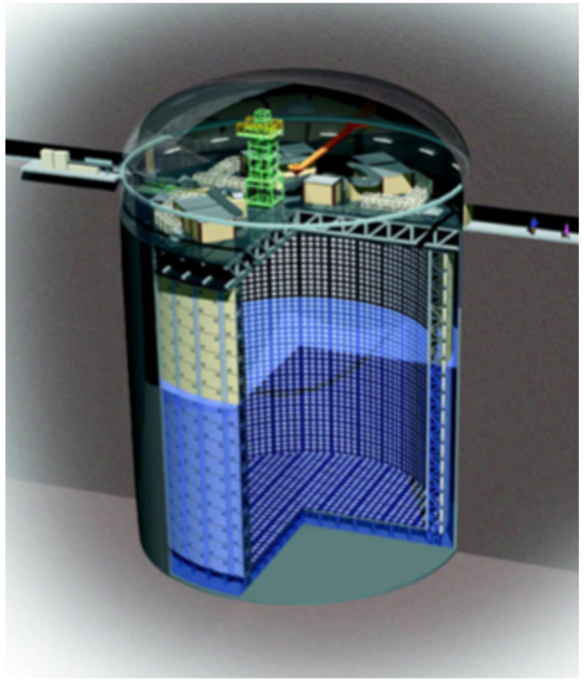
Super-Kamiokande（SK）

Purposes of Super-Kamiokande (SK) experiment

(1) Measure the oscillation parameters of neutrinos (solar ν, atmospheric ν and accelerator ν).

(2) Observe neutrinos from supernova explosions.

(3) Search for nucleon decay and verify the GUT etc.



・diameter : 39.3 m, hight : 41.4 m
cylindrical tank is filled with ultrapure water

・A total of 11,146 Cherenkov photodetectors (PMTs) are installed on the wall

Motivation | Energy scale uncertainty

Energy scale uncertainty

- 2% for O(GeV) energy scale in current SK
- In HK, 0.5% is required for CP phase angle measurement

  → want to demonstrate this goal in SK by bottom-up method

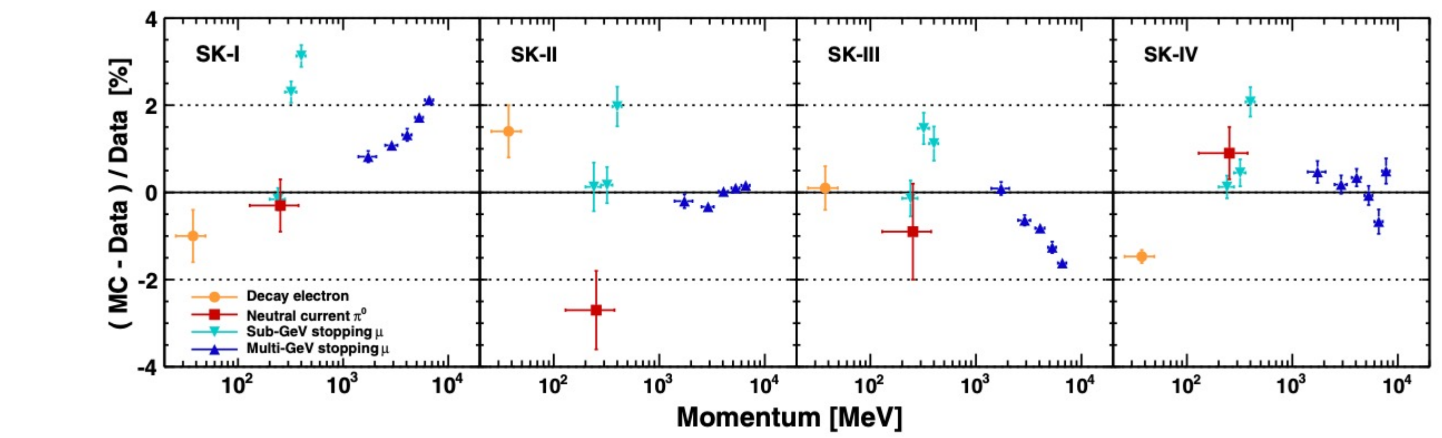


FIG. 3. Absolute energy scale measurements for each SK period. Vertical error bars denote the statistical uncertainty and horizontal error bars the momentum range spanned by each analysis.

[1] K. Abe et al. (Super-Kamiokande Collaboration), Phys. Rev. D 97, 072001 (2018).

Possible causes of the uncertainty

Before the light reaches the PMT

- Absorption
- Reflection
  (PMT glass surface, black sheet on the wall)
- Scattering
  (Rayleigh, Mie)

When the light reaches the PMT

- Angular dependence of incident light
  (reflection, quantum efficiency, collection efficiency, light transmission at photocathode, etc.)

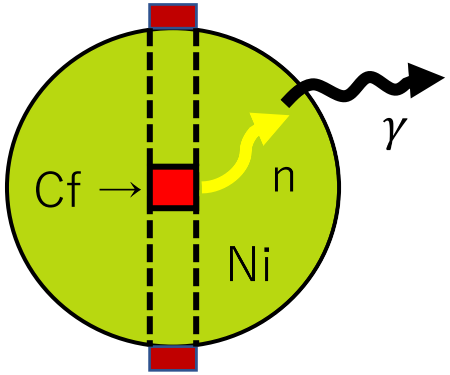
After reaching PMT

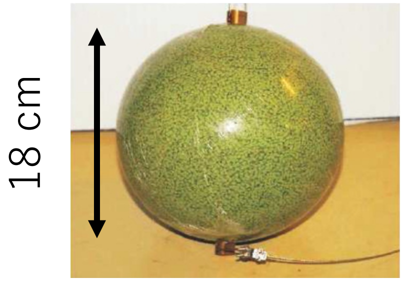
- After-pulse, etc.

Method | Ni/Cf source

<u>Ni/Cf source</u>

- Light can be isotropically emitted.
- The position of the source can be clearly identified.

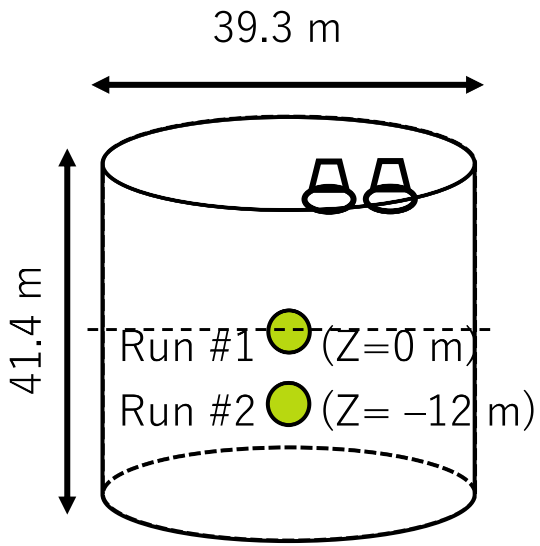




<u>Data</u> (Period when water is convected.)

-Run#1 : source position Z=0 m (center of the tank)

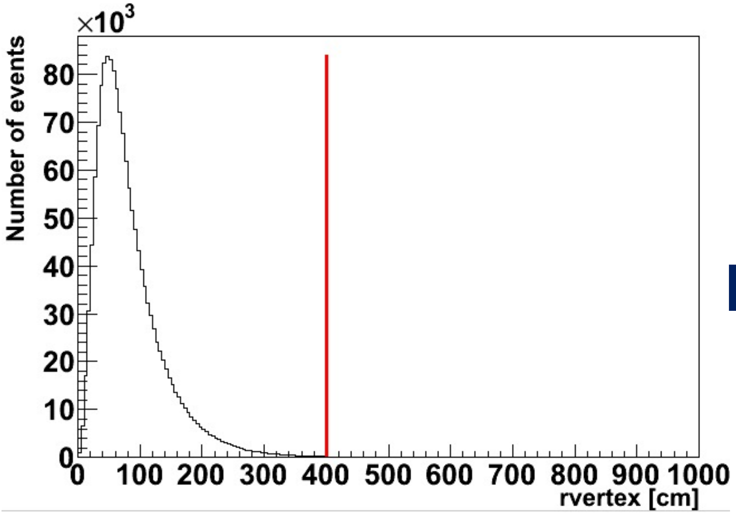
-Run#2 : source position Z=－12 (off-center)



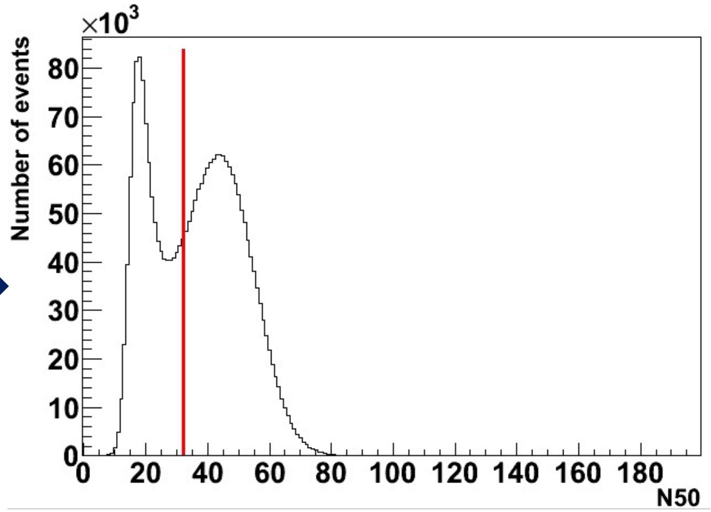
・Match the Relative QE (quantum efficiency) of Data with MC for Run#1.

・Compare Data and MC on each Run.

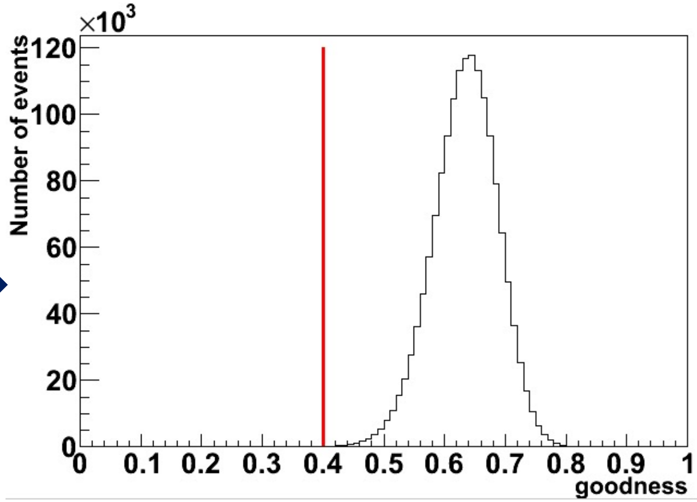
Method | Ni/Cf event selection



rvertex < 400 cm
reconstructed light source position is close to Ni/Cf source position



N50 > 32
gamma ray hits a certain number of PMTs within 50 ns

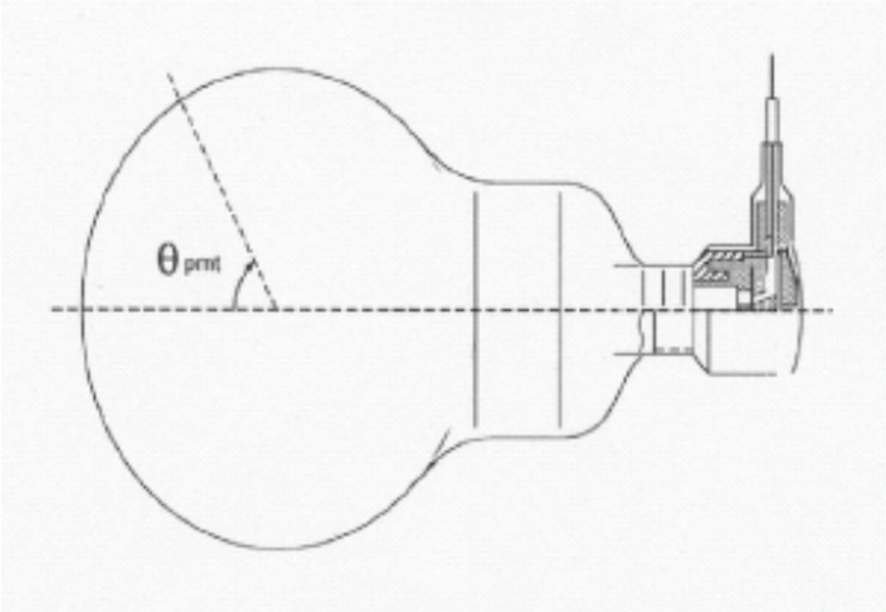


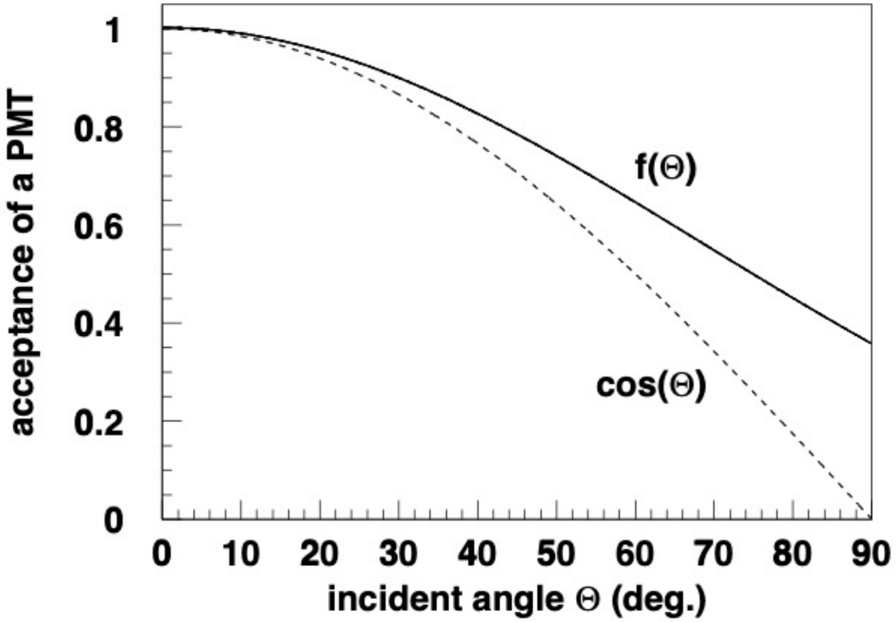
Goodness > 0.4
fitting of the vertex is working well

Method | How to get Hit Rate

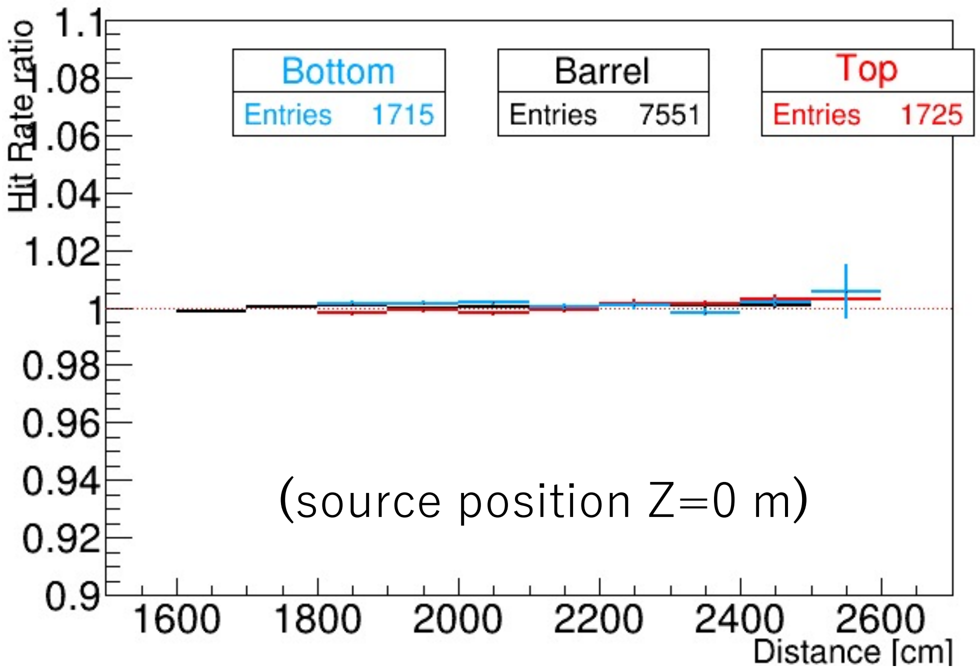
$$\text{Hit Rate}\ (i) = \frac{\text{Number of events with hit}(i) \times r(i)^2 / F(\theta(i))}{\sum[\text{Number of events with hit}(i) \times r(i)^2 / F(\theta(i))]\ /N}$$

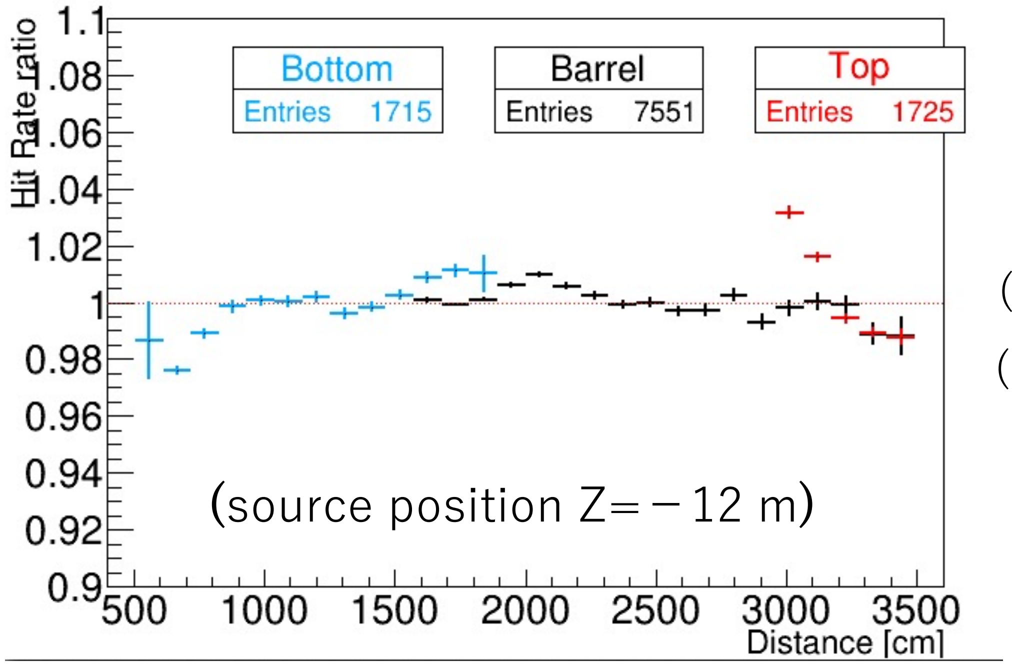
i : PMT cable number (1～11146), $r(i)$: distatnce (source to each PMT)
$F(\theta(i))$: acceptance of a PMT as a function of incident angle, N : Number of PMTs (11146)

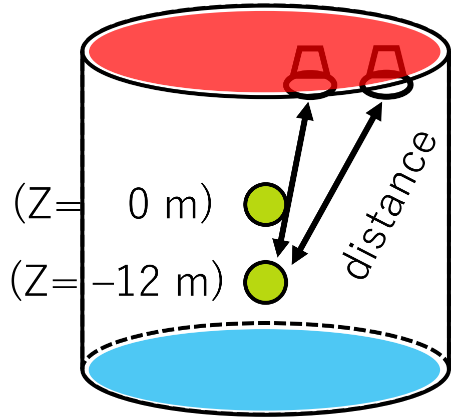




Results | distance distribution of Hit Rate



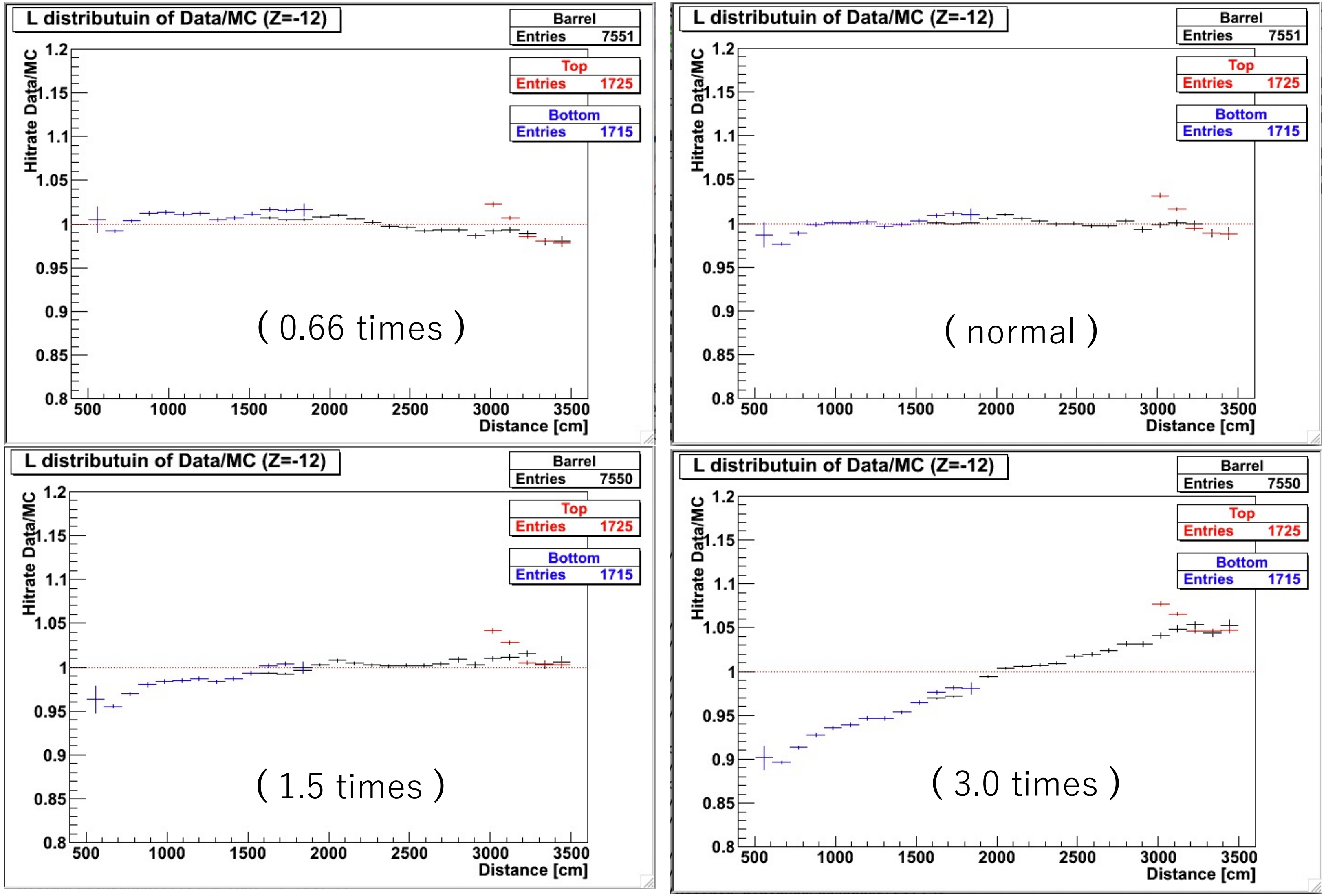




- For Top PMT in right figure, Hit Rate ratio decreases with increasing distance.
- But this tendency is not seen in Barrel PMT.

→ Data/MC disagreement is not caused by water absorption parameter.

Results | Changed absorption parameters



Conclusion and Future Step

- So far, I compared the Data and MC of Hit Rate in off center using MC that was calibrated in center data.
- As a result, I eliminated the possibility that water absorption is the cause of Data/MC disagreement of hit pattern.

- I want to identify the cause of uncertainty from the tendency of Data/MC agreement and change the parameters (reflection, scattering, angle dependence of PMT etc..) and calculation methods of MC in low energy.