# スーパーカミオカンデ有効体積拡張に向けた光センサ性能の位置依存性測定

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# Super-K (SK)

- At Kamioka mine, ~1000m underground.
- By detecting water Cherenkov light with PMTs, Super-K reconstructs the event vertex (using timing information) and momentum (using charge information) etc…

**Fiducial Volume** (= 22.5kton)

Cylindrical volume with surfaces 2 meters inwards from the inner detector wall (2 meters cut).

**Physics Target**

Atmospheric $\nu$ (Murase-san's talk)

Solar $\nu$

Supernova $\nu$ (Mori-kun's talk)

Proton decay

etc…

Diameter:~39m

Height:~42m

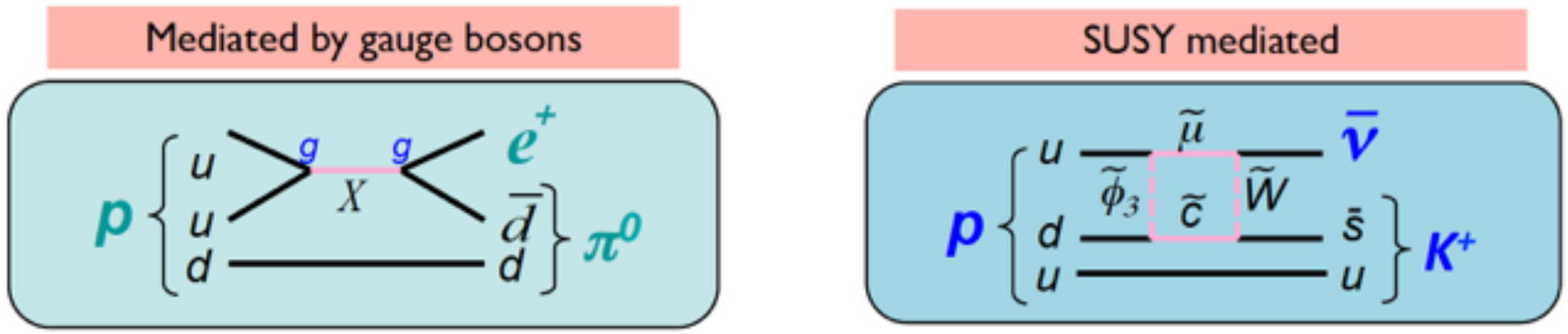
Total Volume:50kton water

PMT: ~10000 in inner detector

~2000 in outer detector

# Proton Decay

- Direct evidence of the Grand Unification Theory (GUT).



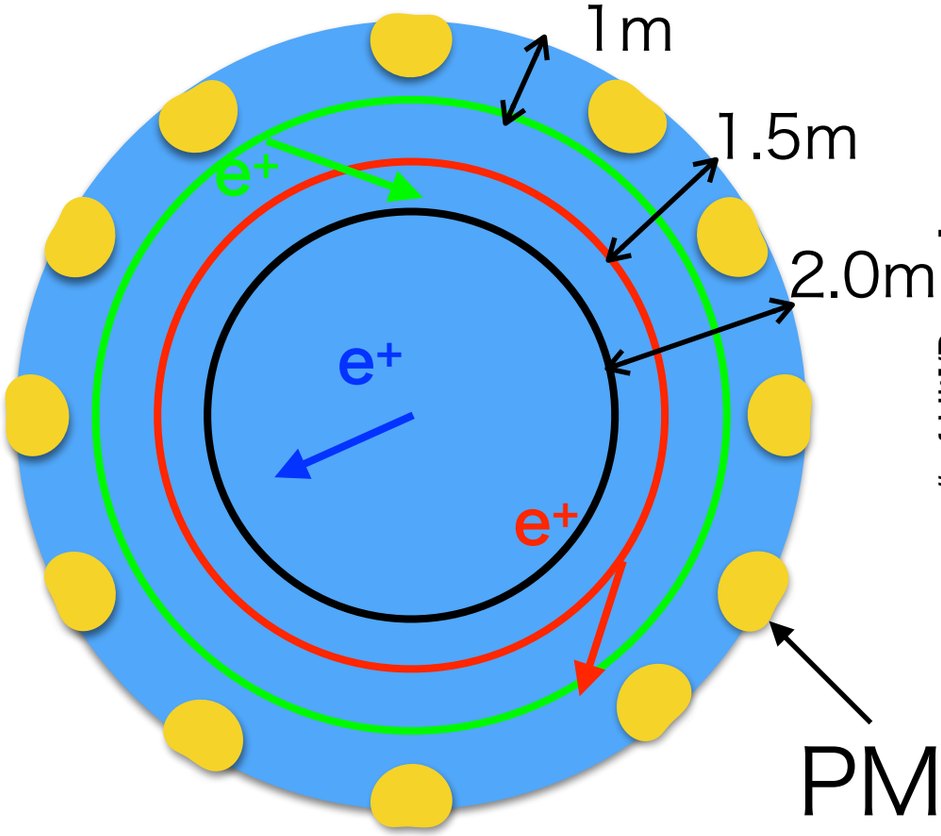

- Super-K has not detected significant signals.
  ($\tau_{p\to e\pi}$>1.6×10$^{34}$ years, $\tau_{p\to \nu K}$>5.9×10$^{33}$ years)

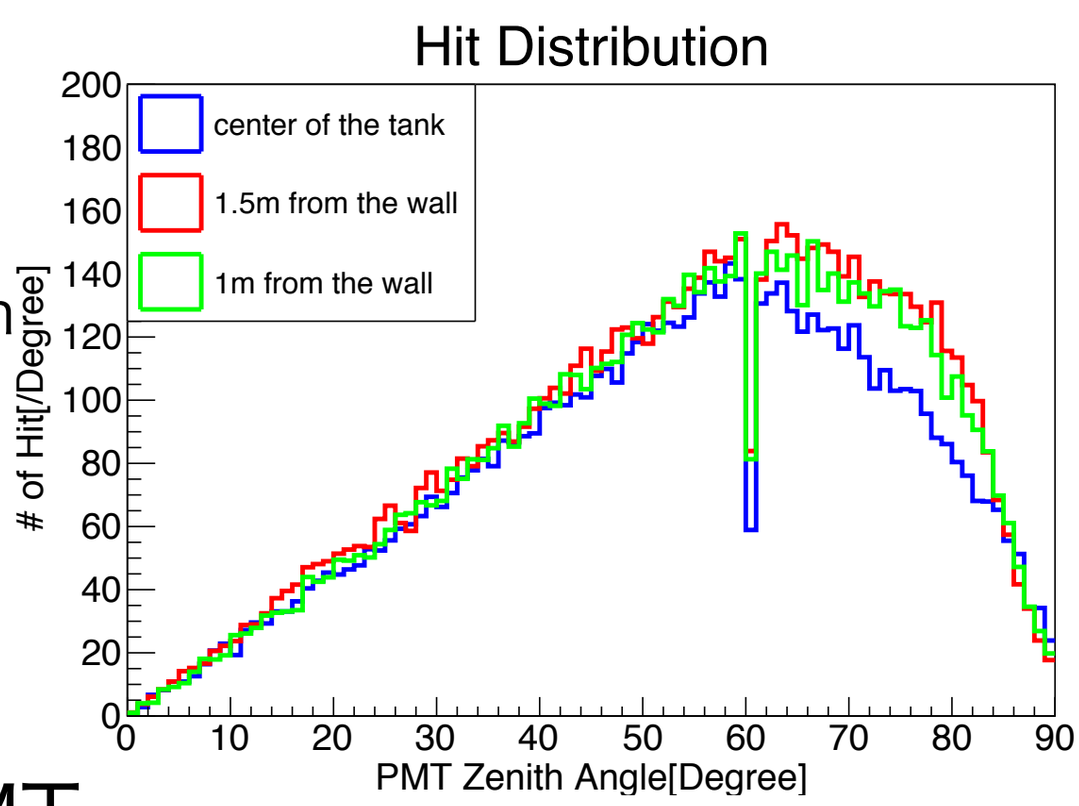
**Need huge number of protons!**

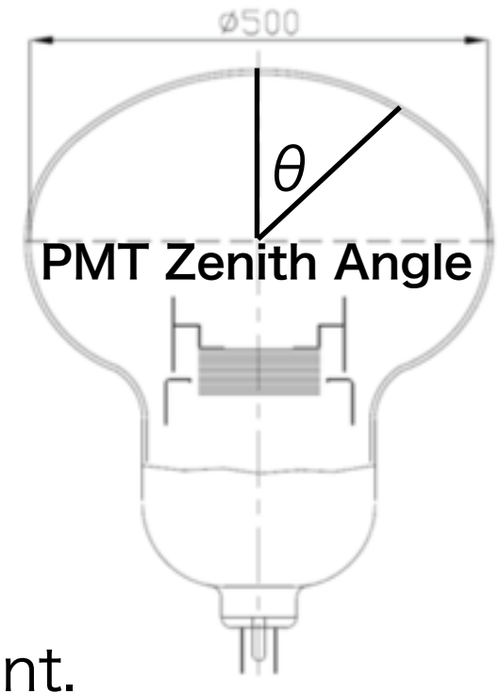
- To observe proton decay, one of the simplest ways is to expand fiducial volume.

# Motivation for Position Dependence Study

- When events happen near the detector wall, Cherenkov photons are more likely to hit the edge side of the PMT. → Need to position dependence of PMT response of charge & timing.
- MC condition: 400MeV positron($e^+$). Direction is random.



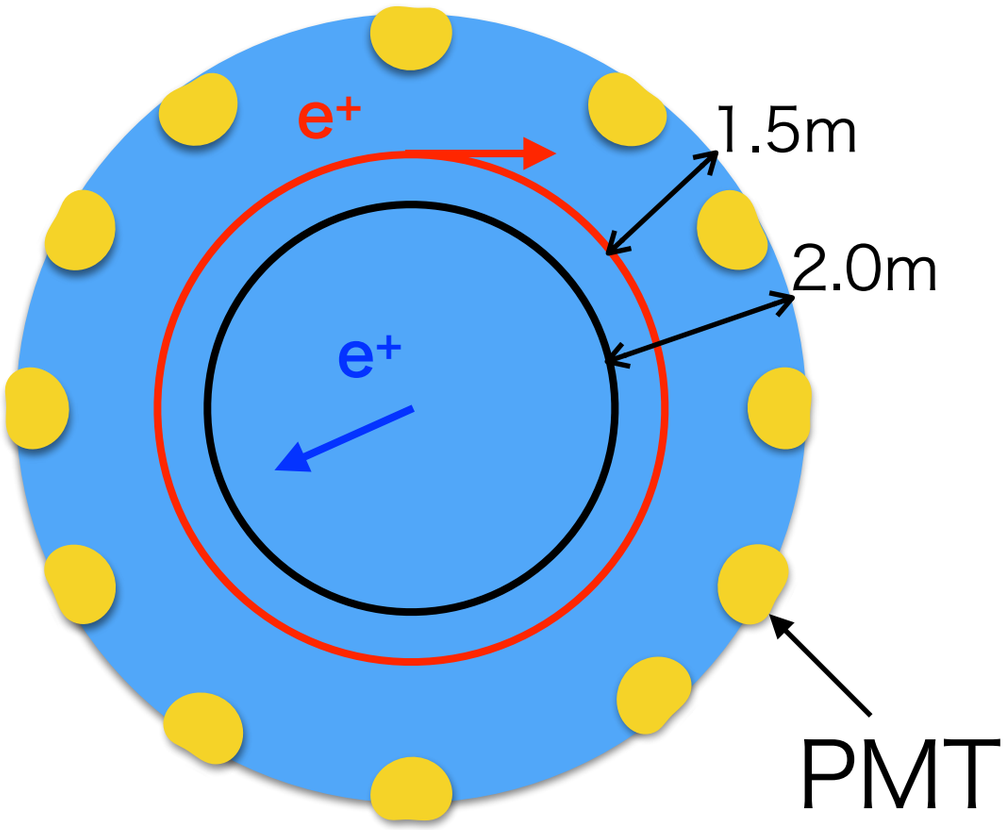



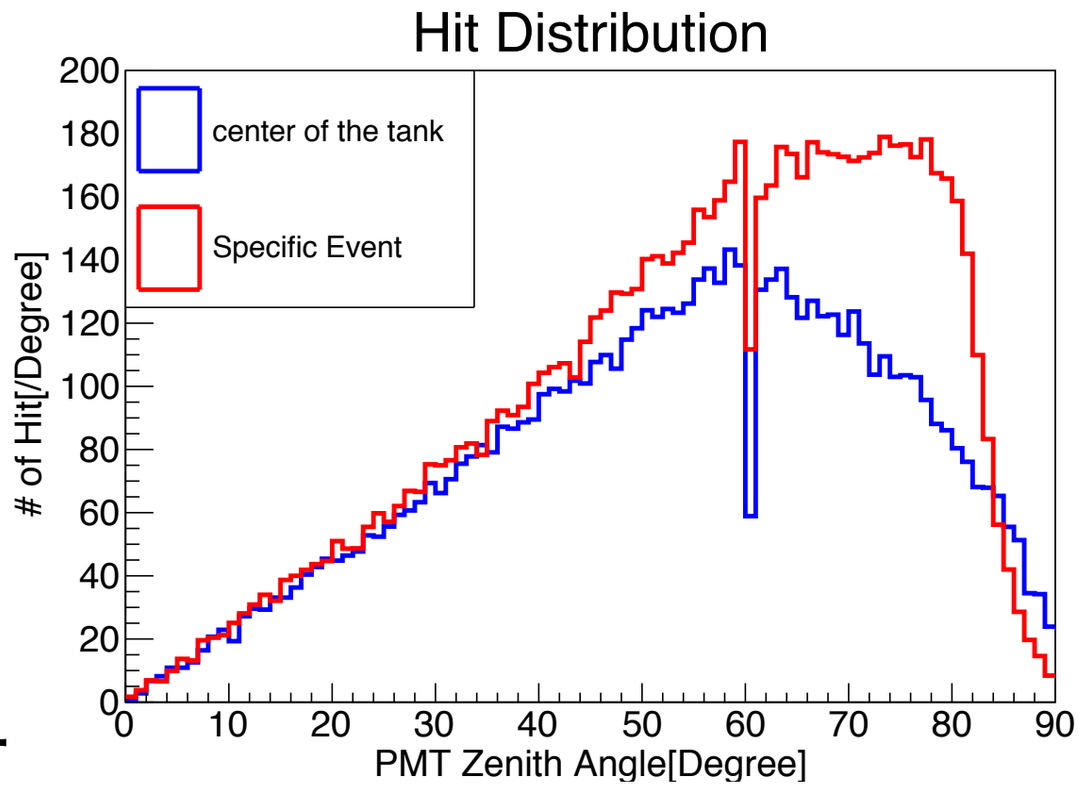

The number is normalized per event.

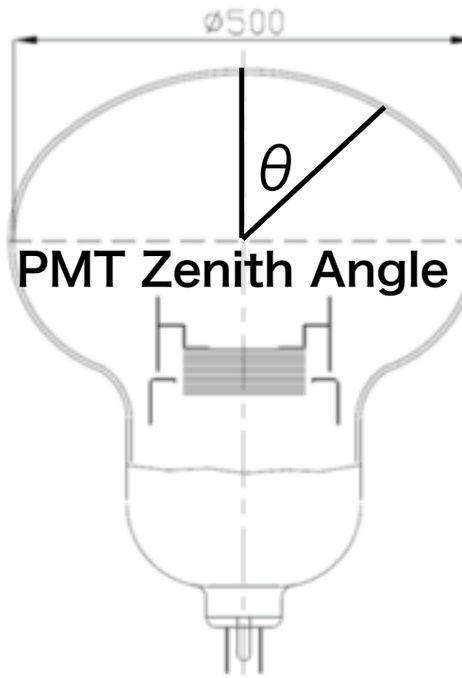
# Motivation for Position Dependence Study

- When events happen near the detector wall, Cherenkov photons are more likely to hit the edge side of the PMT. → Need to position dependence of PMT response of charge & timing.
- MC condition: 400MeV positron($e^+$). Direction is fixed (Red).




**View From Above**



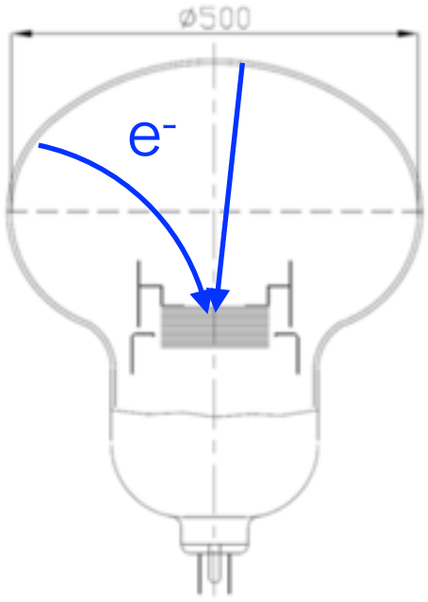



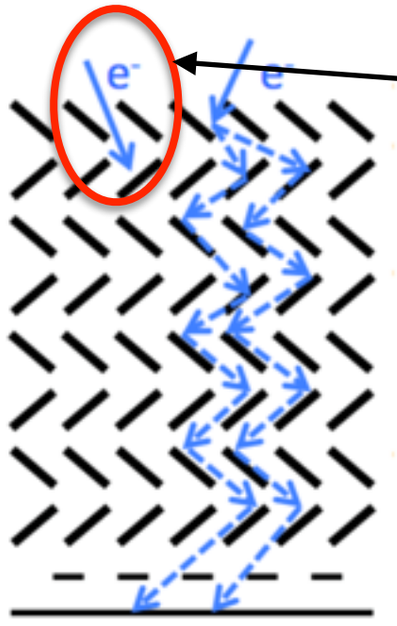

The number is normalized per event.

# Super-K PMT

- 20 inch diameter photomultiplier tube.
- By amplifying photoelectron emitted at photocathode, PMT produces current.
- Photoelectron emitted at photocathode sometimes skips the first dynode and is not amplified successfully. → Lower gain
- There are some position dependent differences about the path length form photo cathode to dynode. → Transit time deferences

Transit Time Deference




Skipping Dynode

# Setup

- At Kamioka mine lab we have Helmholtz coils to compensate geomagnetic field ($|B_{Geo}|$ ~ 450mG). The ambient residual is ~±10mG.
- We injected photon at 13 points ($\theta$ =0°,10°,20°,30°,40°,45°, 50°,55°,60°,65°,70°,75°,80°) for each direction (±X,±Y, ±Diagonal).

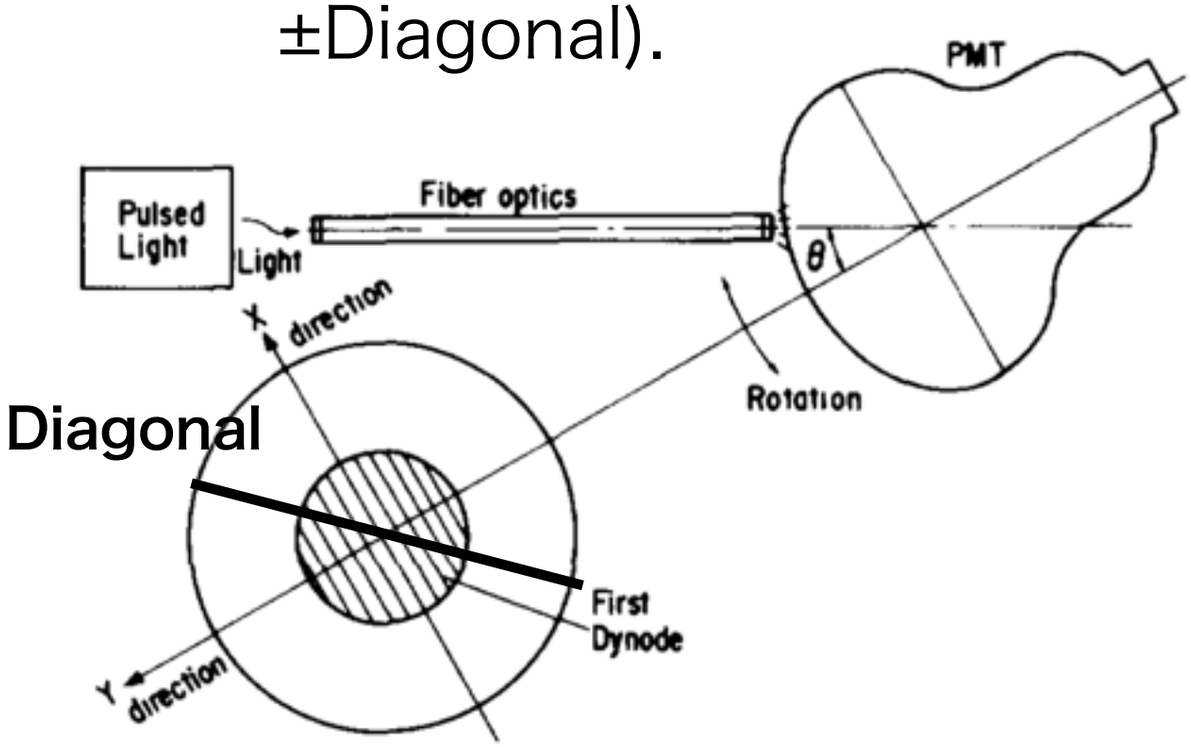
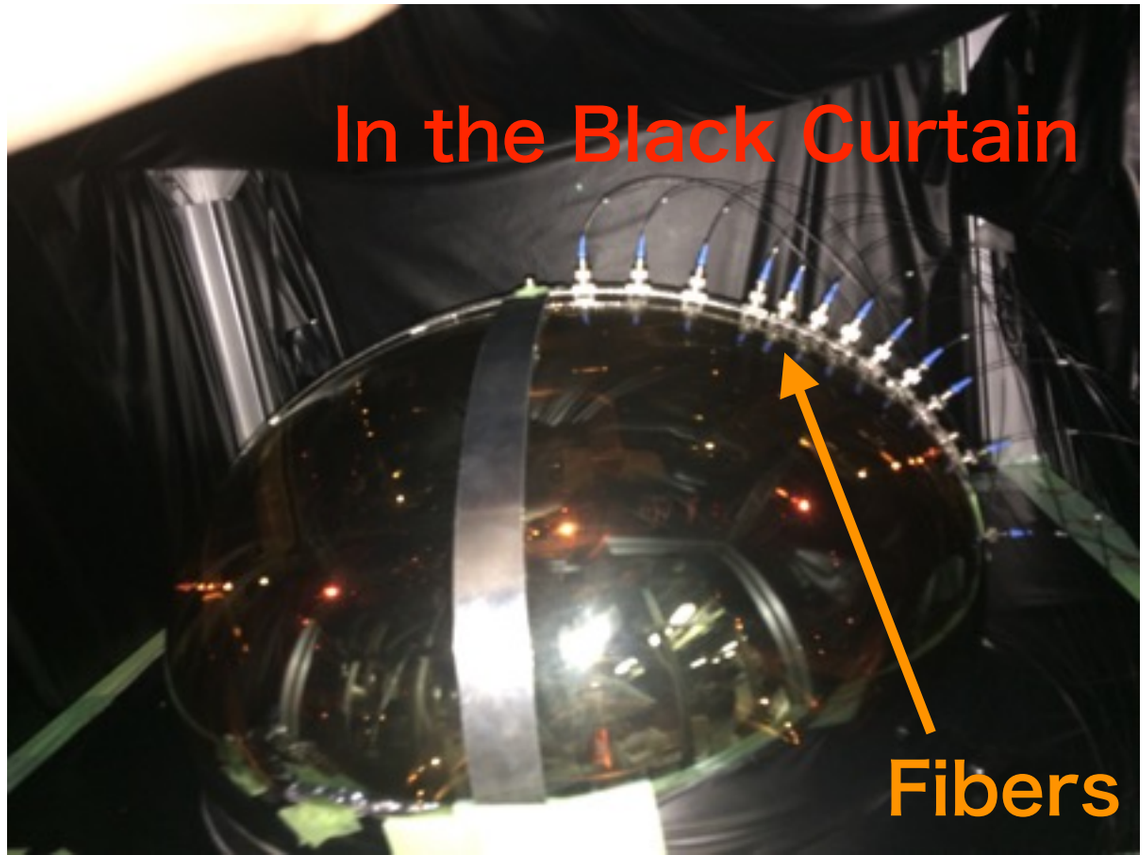
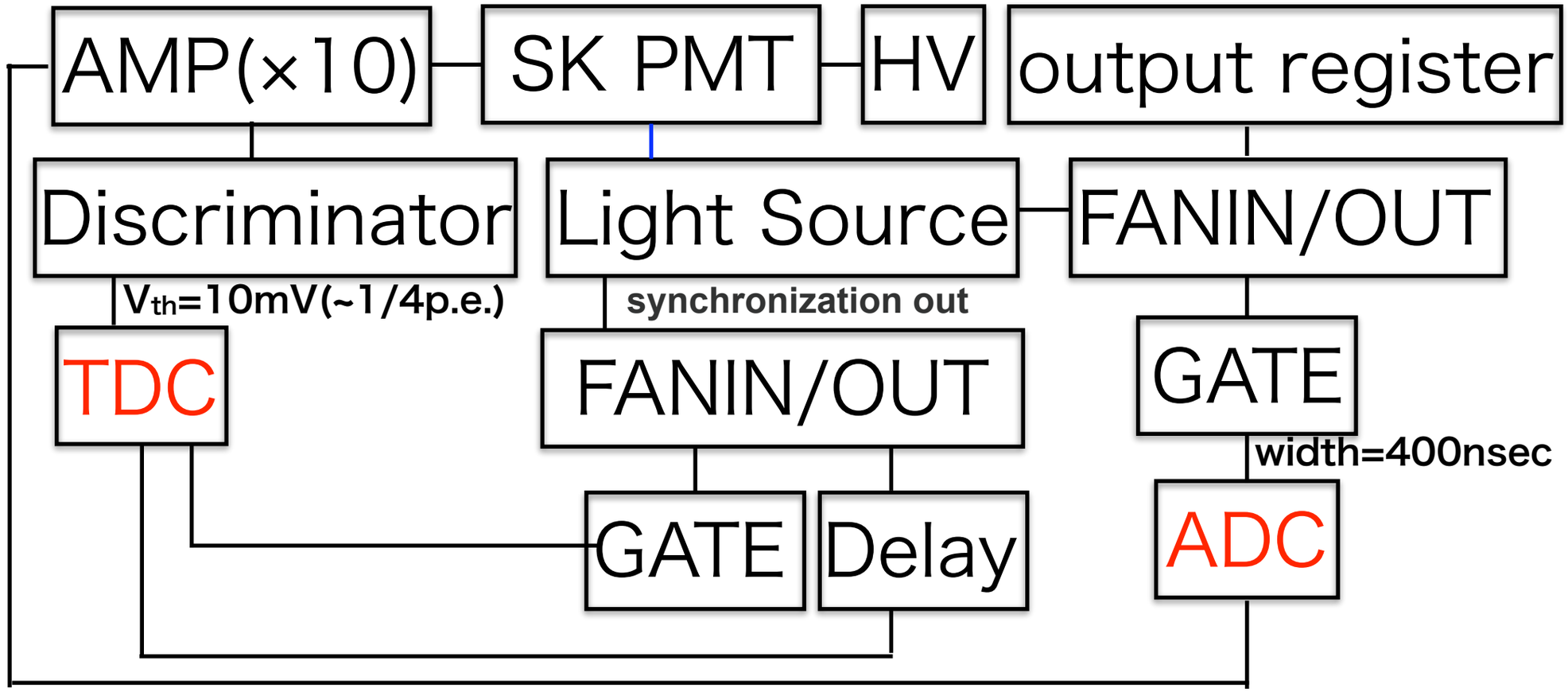



Fig. 22. Layout of a uniformity measurement.



# Setup for Charge/Timing Measurement

- Charge and timing information is measured simultaneously.
- Light intensity is much less than 1p.e. (photoelectron) level ((Number of 1p.e. signals)/(Number of triggers) ~ 1%).

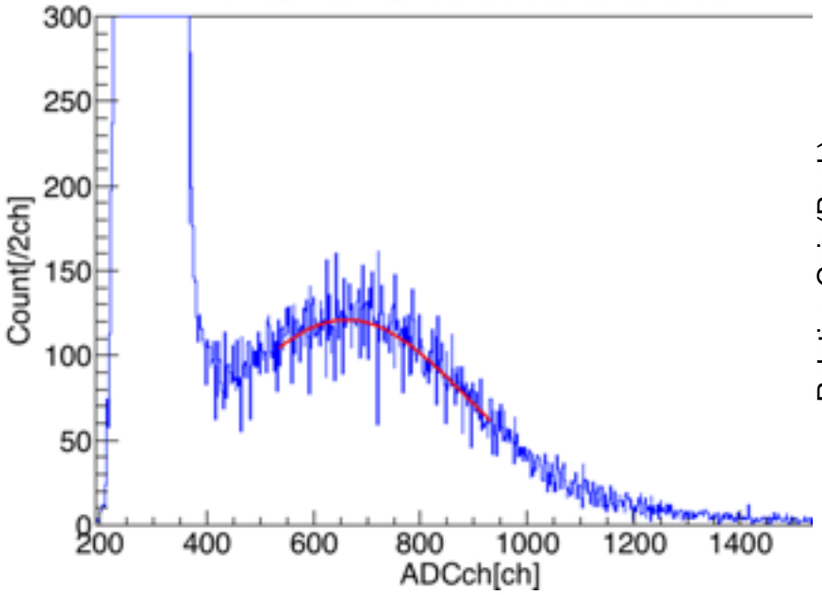


# Gain and Efficiency

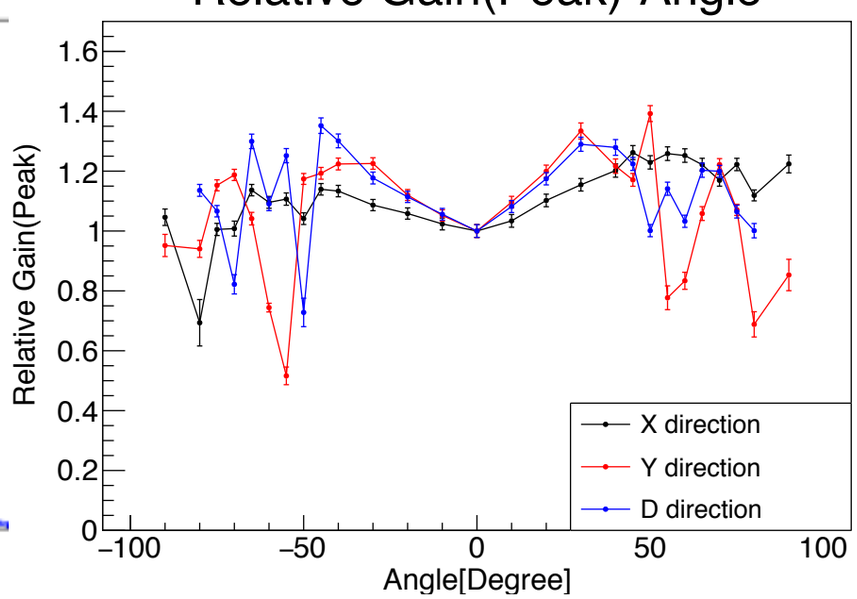
- Gain is calculated from pedestal peak and 1p.e. peak.

- Efficiency (Quantum efficiency × Collection efficiency) is calculated from the number of counts (pulse height > 1mV ~ 1/4p.e.).

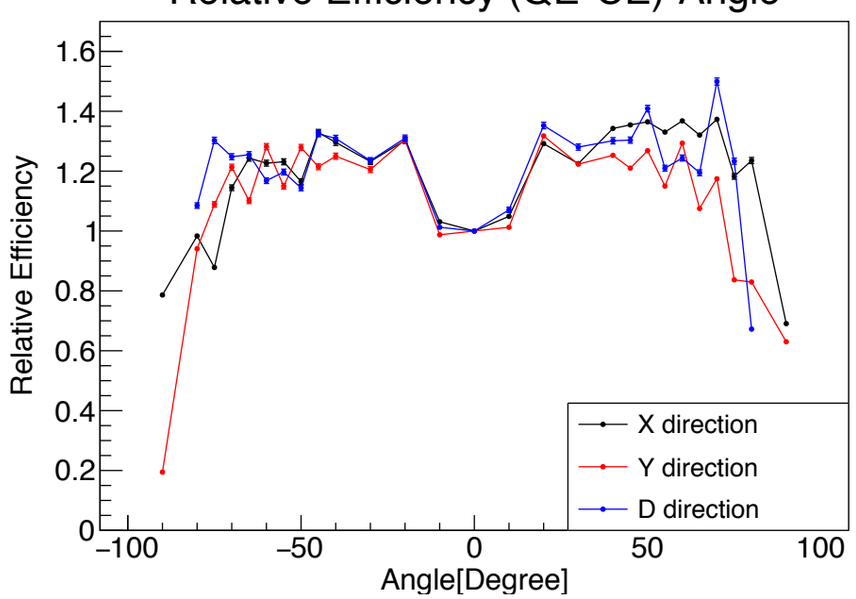
ADC Distribution




Relative Gain(Peak)-Angle




Relative Efficiency (QE*CE)-Angle



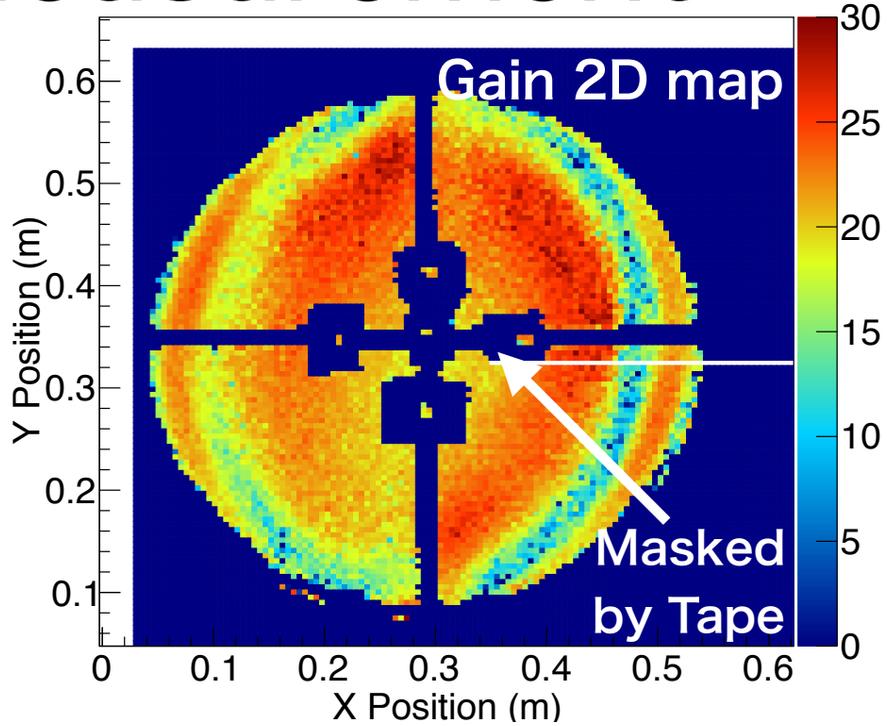

normalized by center position (0°) value

For Y(Diagonal) direction, there are some lower gain points.

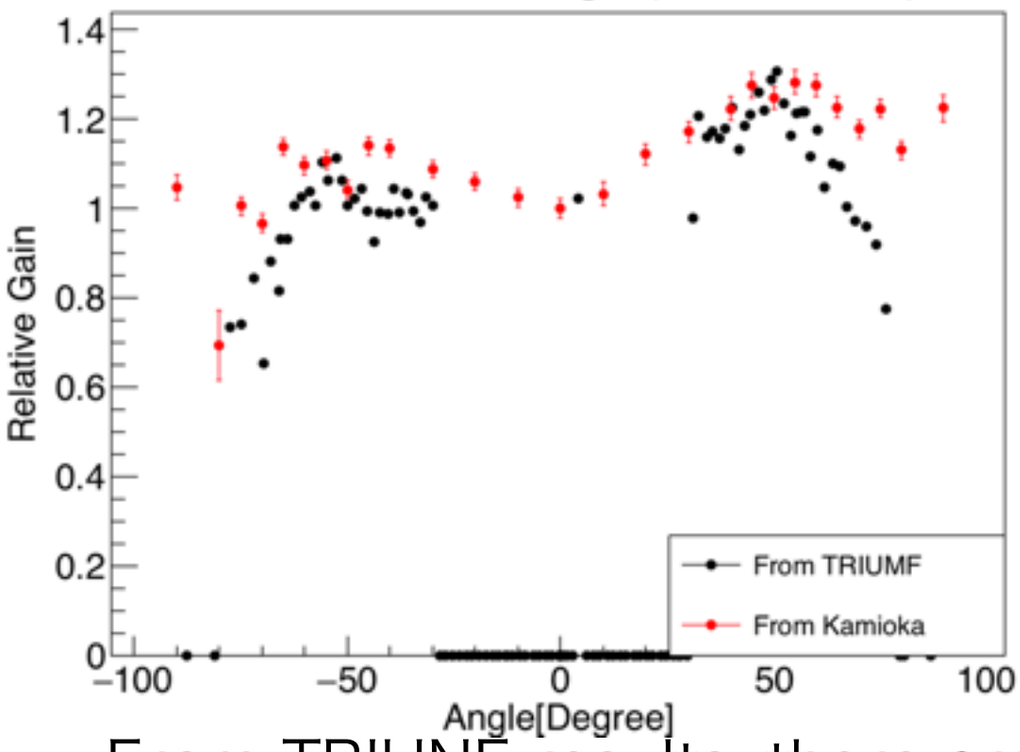
Photoelectron from this position may skip the first dynode.

# Comparison with Other Measurement

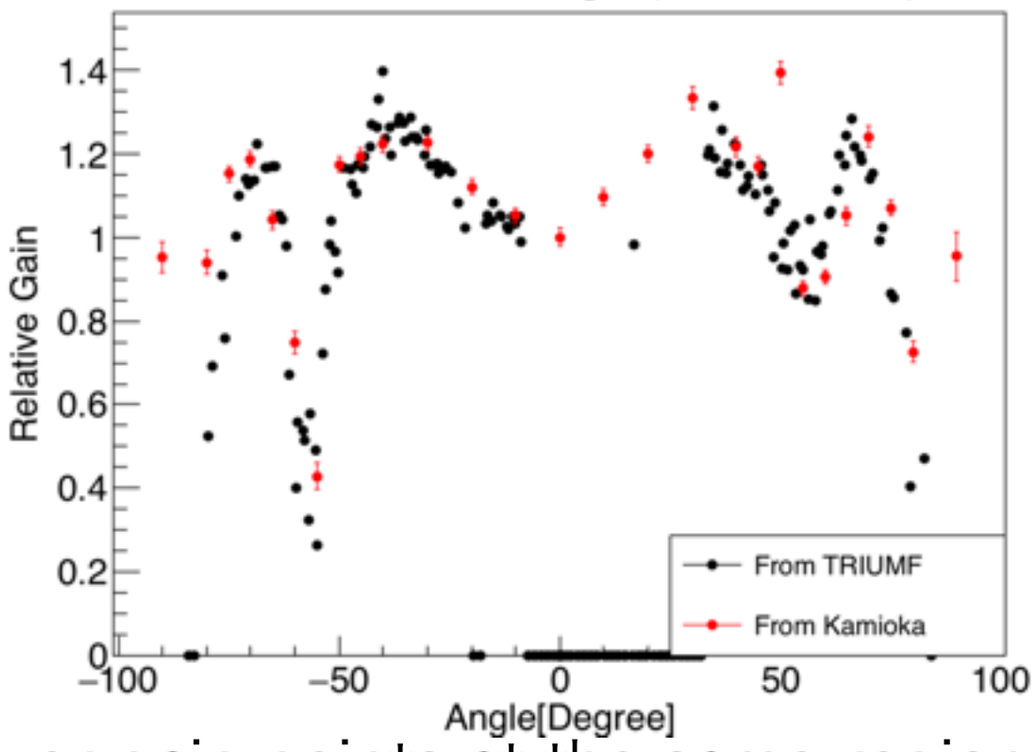
- Photosensor calibration is on going at TRIUMF (@Vancouver) and I did automatic precise measurements (Black Plots).
- Made 1D projection from TRIUMF 2D map for comparison and confirmed consistency with Kamioka measurement (Red Plots).




Relative Gain-Angle(X Direction)




Relative Gain-Angle(Y Direction)




From TRIUNF results, there are lower gain points at the same region.
It may be Super-K PMT general property.

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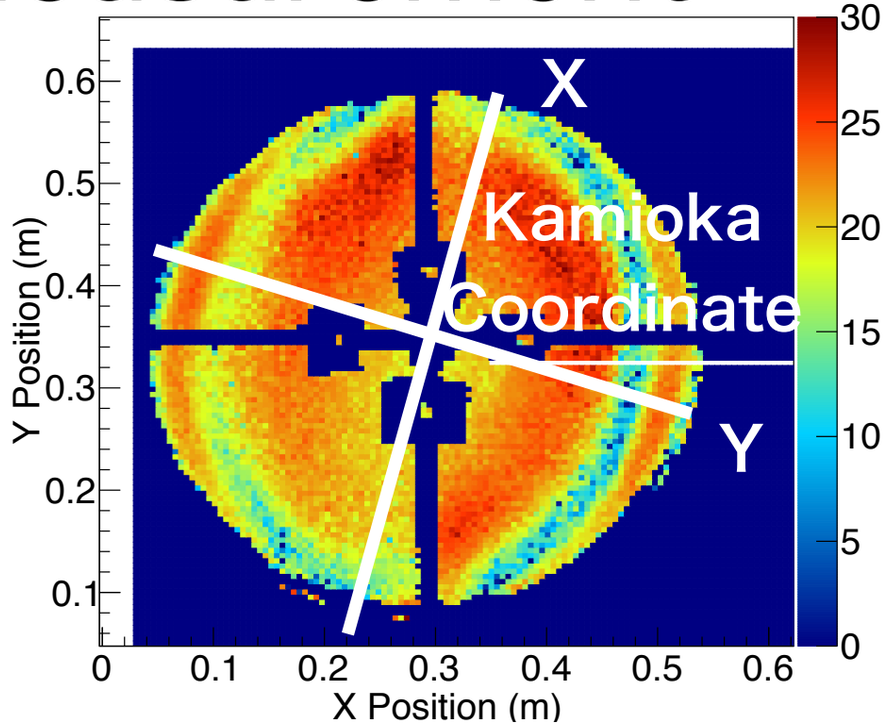
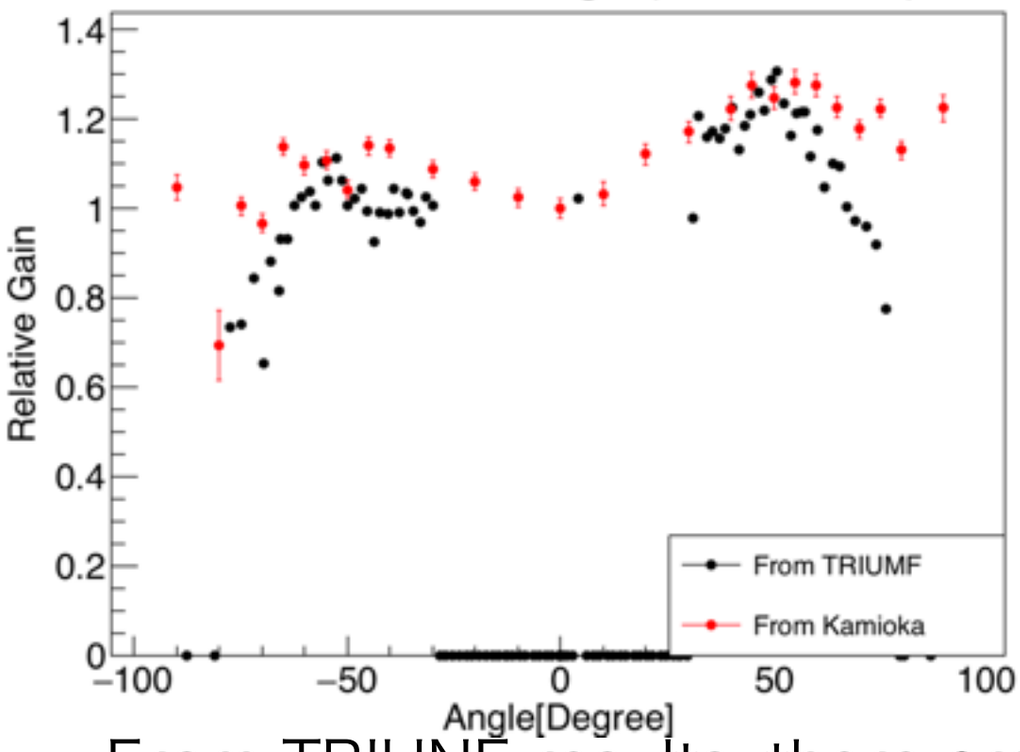
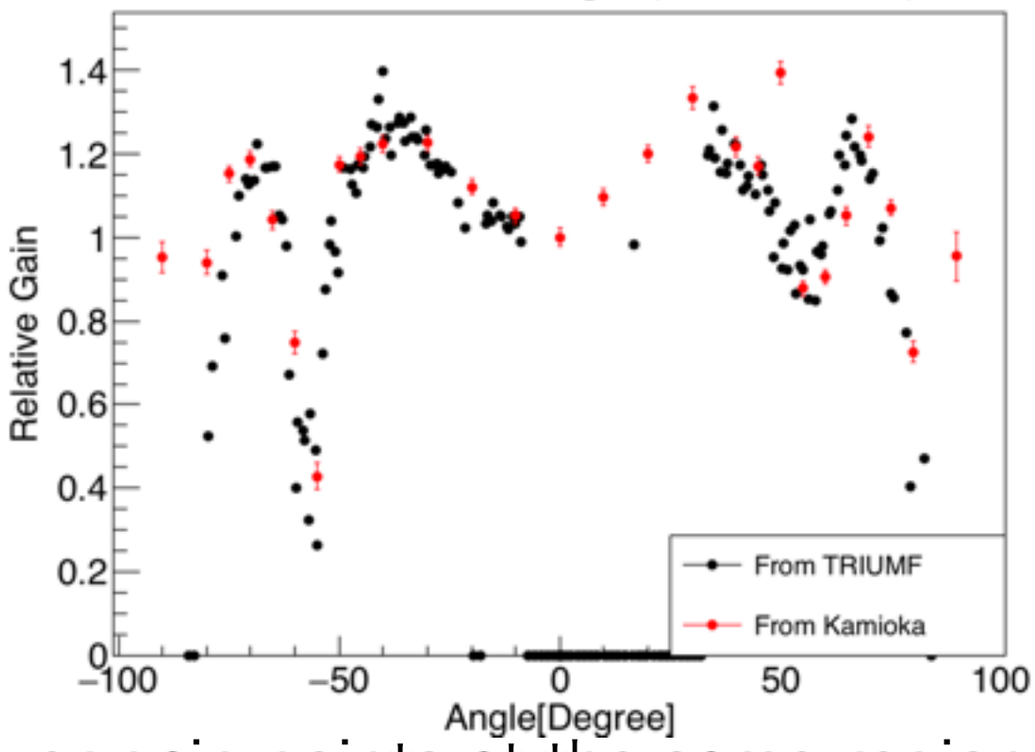



Relative Gain-Angle(X Direction)




Relative Gain-Angle(Y Direction)

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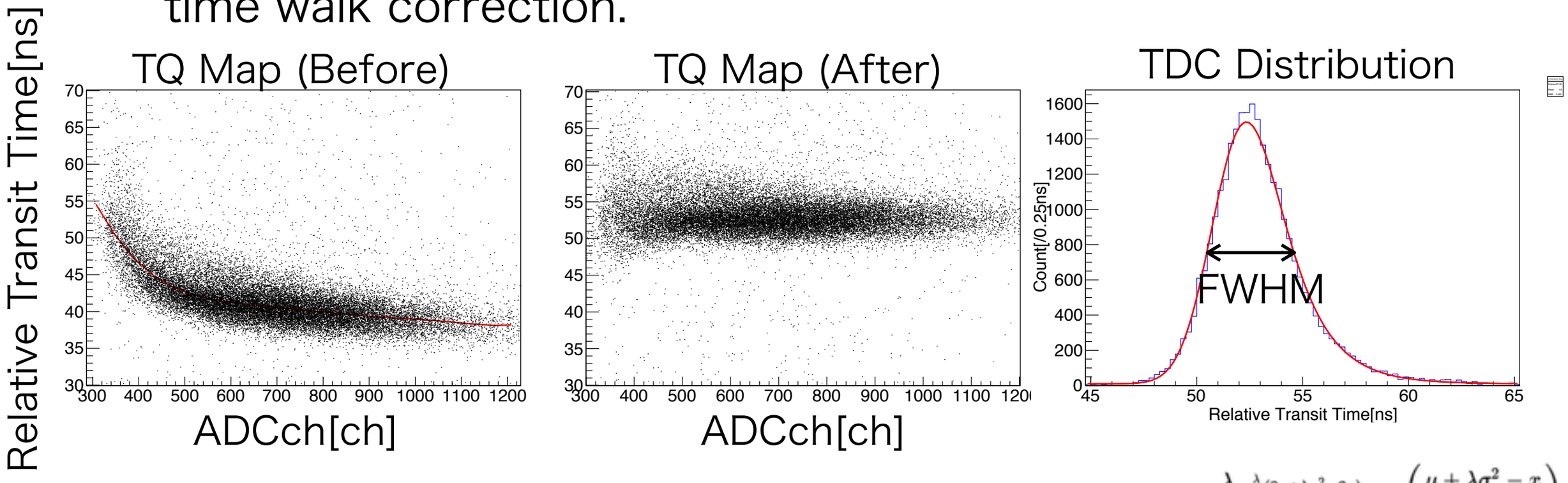
It may be Super-K PMT general property.

# Transit Time and Transit Time Spread

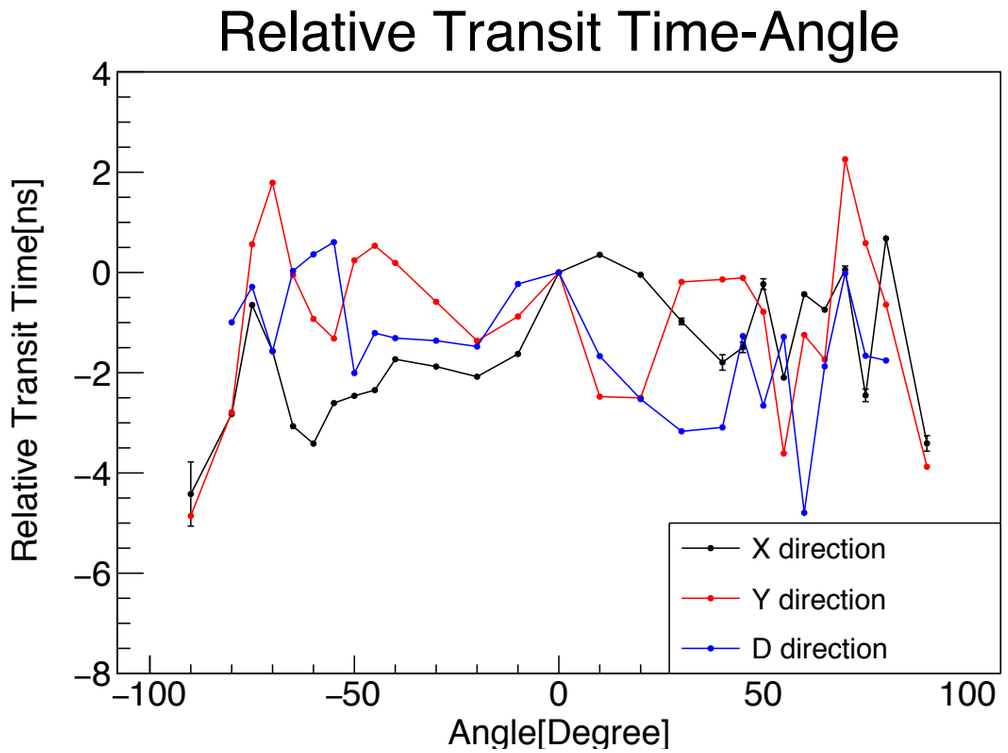
- Transit time is calculated using the timing when pulse height is beyond the threshold (-1mV).
- Transit time and T.T.S (FWHM) is calculated by fitting TDC distribution using Exponentially modified Gaussian after time walk correction.

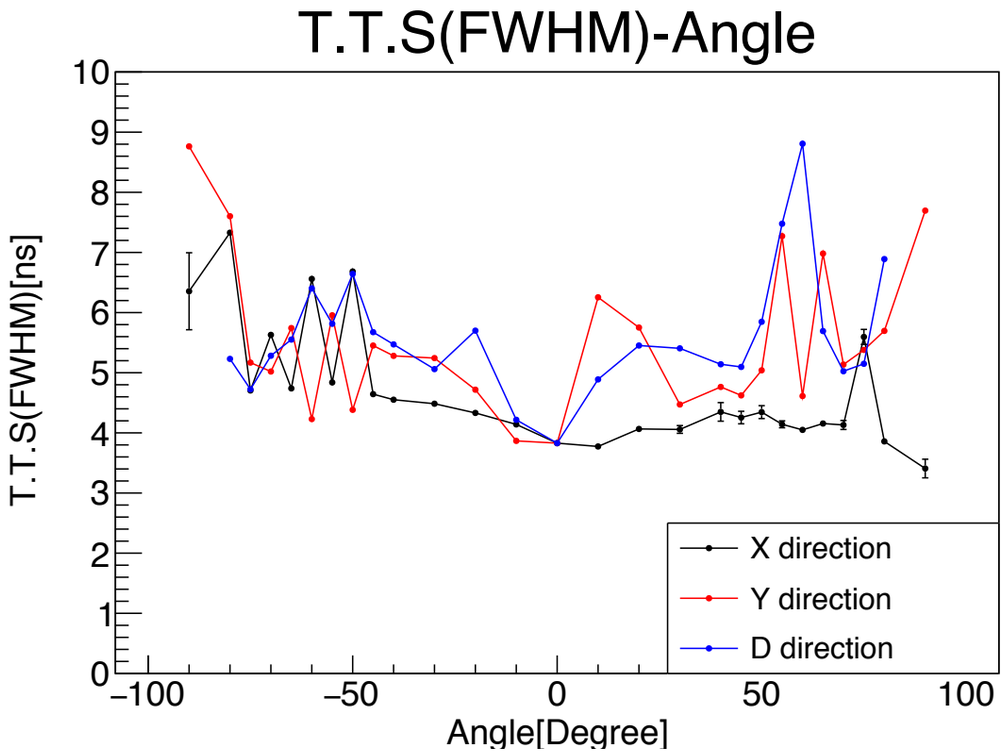



$$f(x;\mu,\sigma,\lambda) = \frac{\lambda}{2} e^{\frac{\lambda}{2}(2\mu+\lambda\sigma^2-2x)} \operatorname{erfc}\left(\frac{\mu+\lambda\sigma^2-x}{\sqrt{2}\sigma}\right),$$

# Transit Time and Transit Time Spread

- Transit time is calculated from the peak of fit function.
- T.T.S is from FWHM of fit function.




Both have clear position dependence.

At the edge side, timing resolution becomes worse.

# Summary and Outlook

- Position dependence of Super-K PMT response of charge & timing is measured. We understand some general properties.

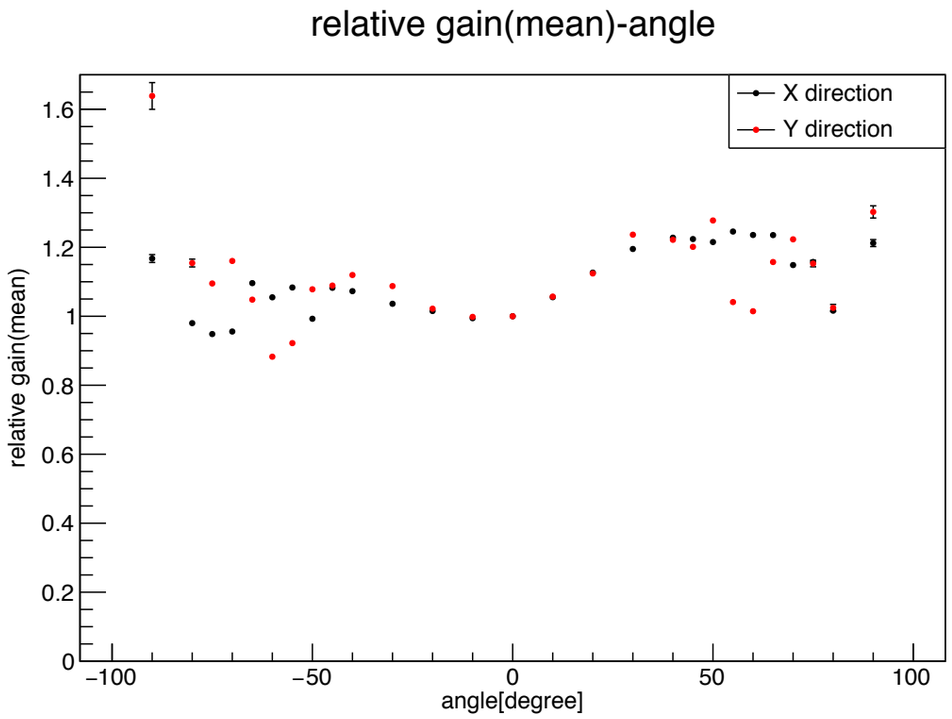
- Magnetic field also affects PMT response and there will be PMT by PMT difference, so we are measuring the magnetic dependence using another Super-K PMT.

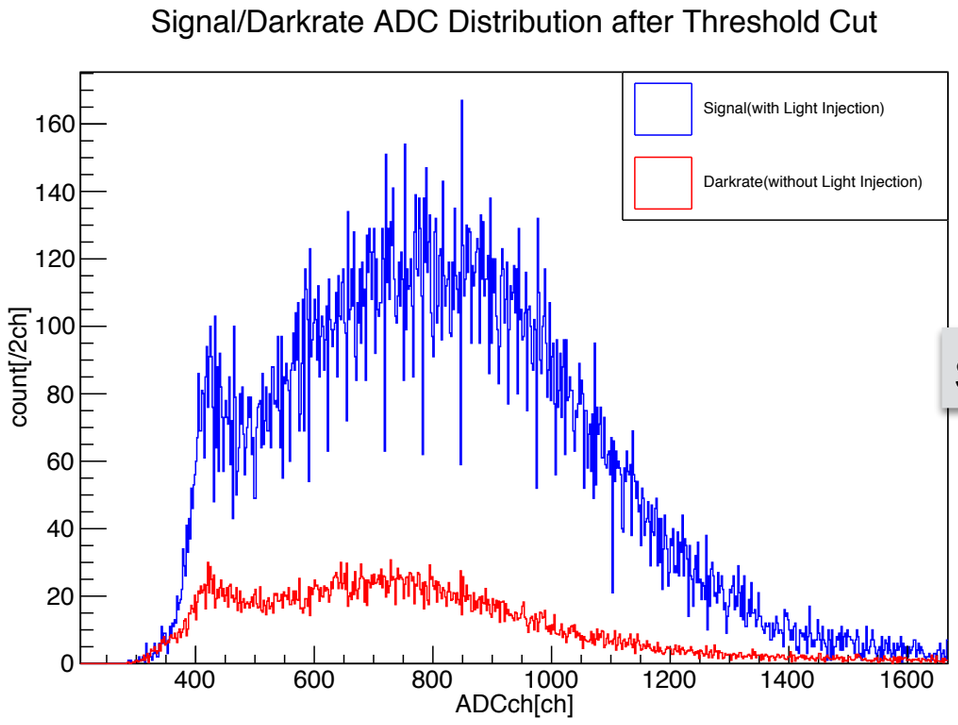
- Implement position dependence to Super-Kamiokande detecter simulation and estimate the influence.

# Back Up

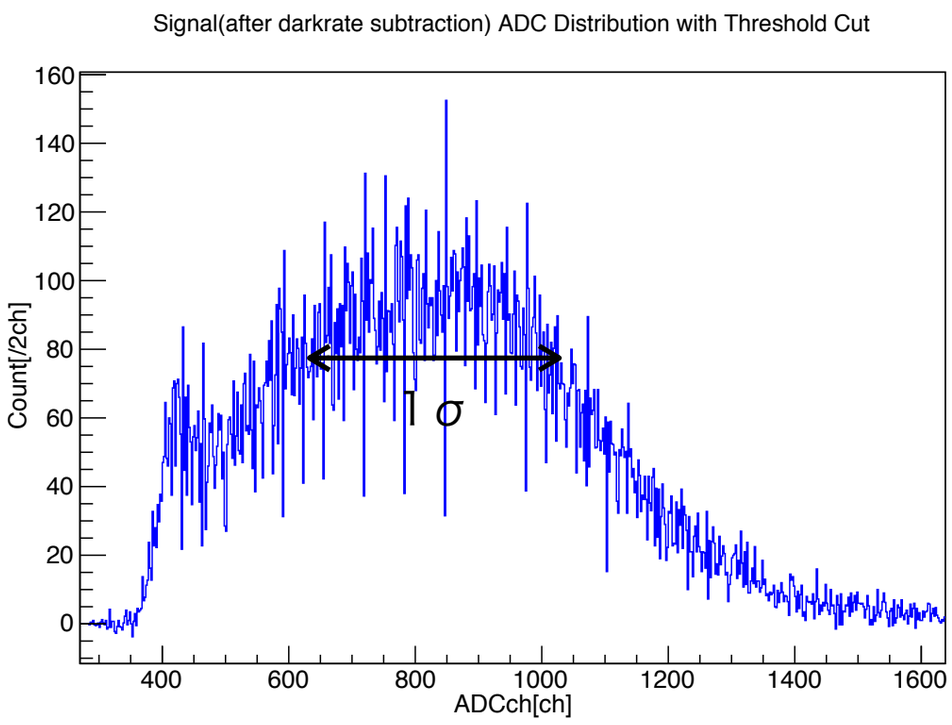
# Gain Result

- Here gain is the mean of the histogram after dark rate subtraction and threshold 1mV cut.

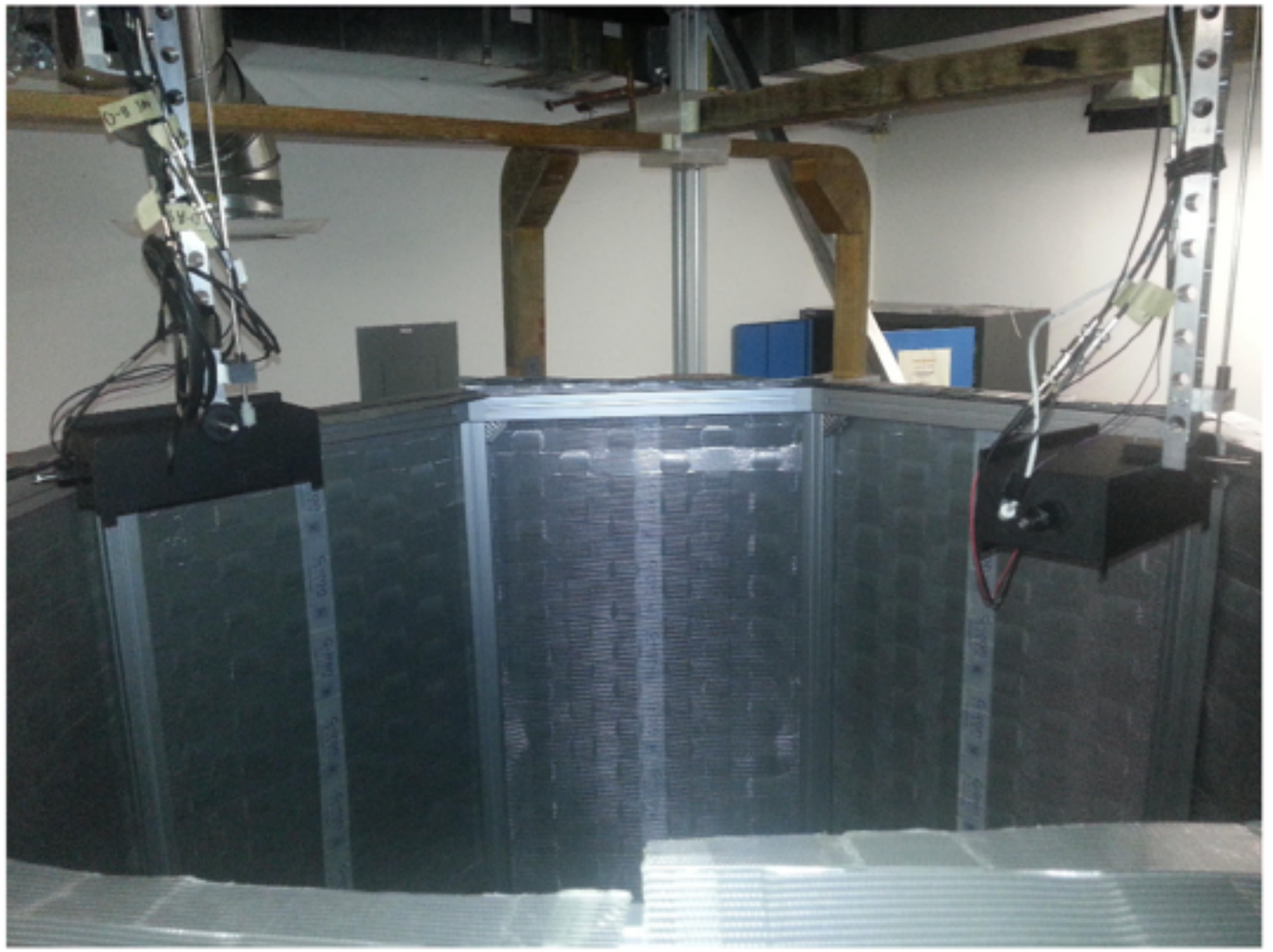



subtraction



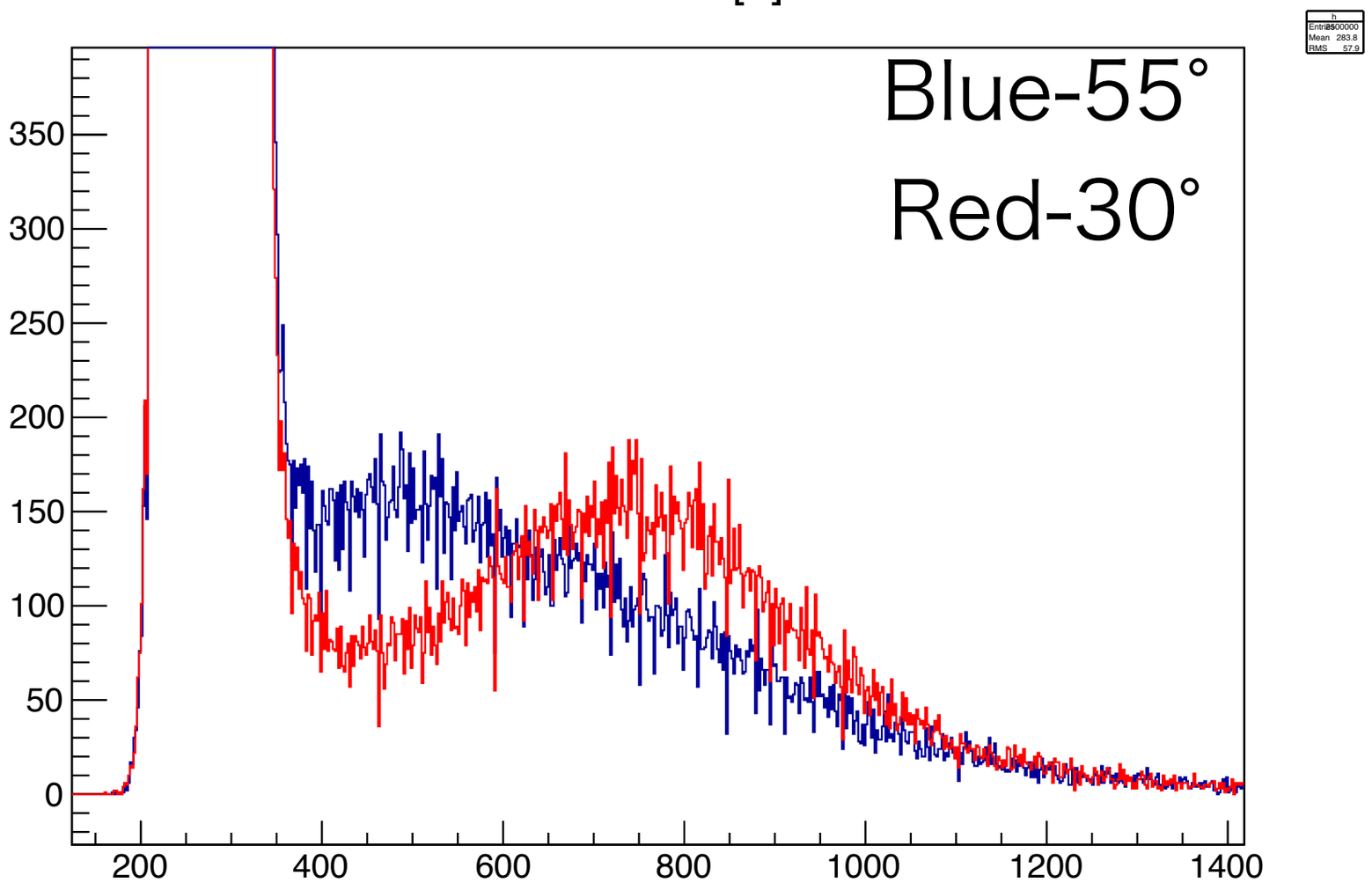
# Mechanical system



- 20" PMT centered inside tank with ultrapure water.
- 5 stepping motors for each of two manipulator arms (gantries) $\Rightarrow$ 5D (x,y,z, rotation, tilt)
- Waterproof optical box with laser, monitor and receiver PMT attached to the head of the gantry arm.
- Active cancellation with Helmholtz coil, passive cancellation with two layers of g-iron.
- Light shielding with dark curtains.
- Position accuracy: $\sim$1 mm (x,y,z) and $\sim 1^\circ$ (rotation and tilt).

# Super-K PMT in water in the PTF

adc.count[0]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Entries 500000
Mean 283.8
RMS 57.9
Blue-55°
Red-30°
350
300
250
200
150
100
50
0
200
400
600
800
1000
1200
1400