5th international workshop on new photon detectors - PD18

Performance of the Hyper-Kamiokande 20” PMT

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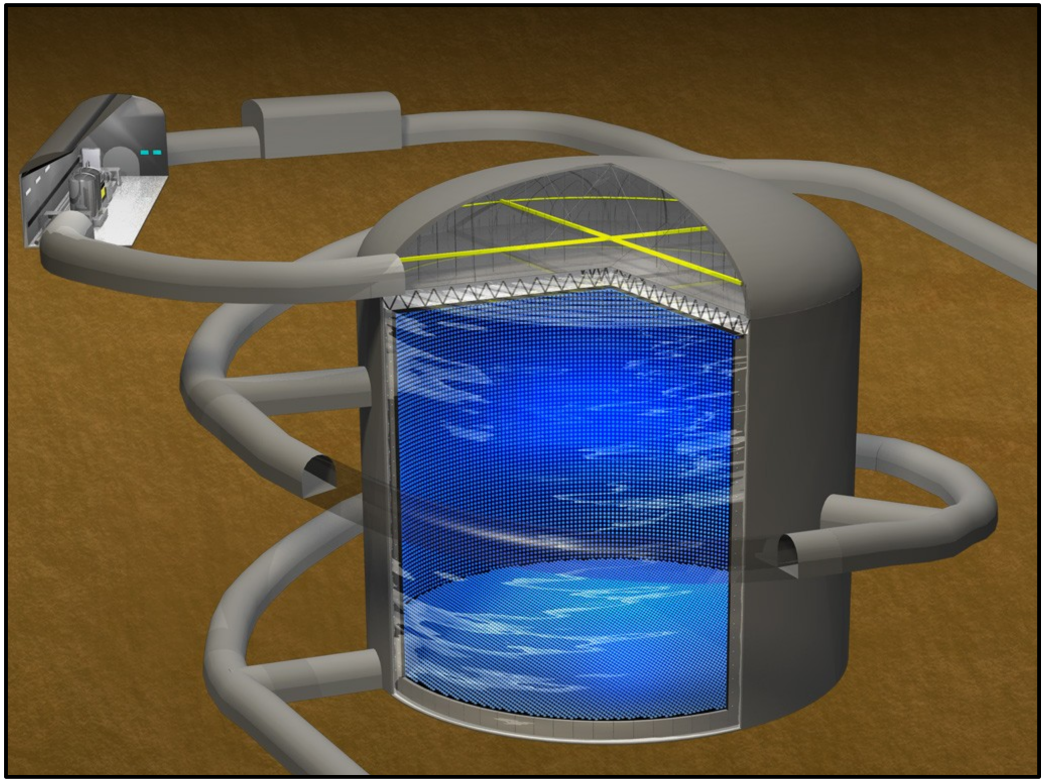
2018-11-29

Hyper-Kamiokande project



Construction start: JFY2020
Beginning of data taking: JFY2026

Wide physics program:
- ✓ Atmospheric neutrinos
- ✓ Accelerator neutrinos
- ✓ Solar neutrinos
- ✓ Supernova neutrinos
- ✓ Proton decay
- ✓ Dark matter indirect detection

Builds on the successful strategies used in Super-Kamiokande (SK), K2K and T2K with:

- Larger detector for increased statistics
  60m height x 74m diameter tank, 190 kton fiducial volume (SK:22.5 kton)
- **Improved photo-sensors for better efficiency**
- Higher intensity beam and updated/new near detector for accelerator neutrino part

Hyper-Kamiokande photo-detectors

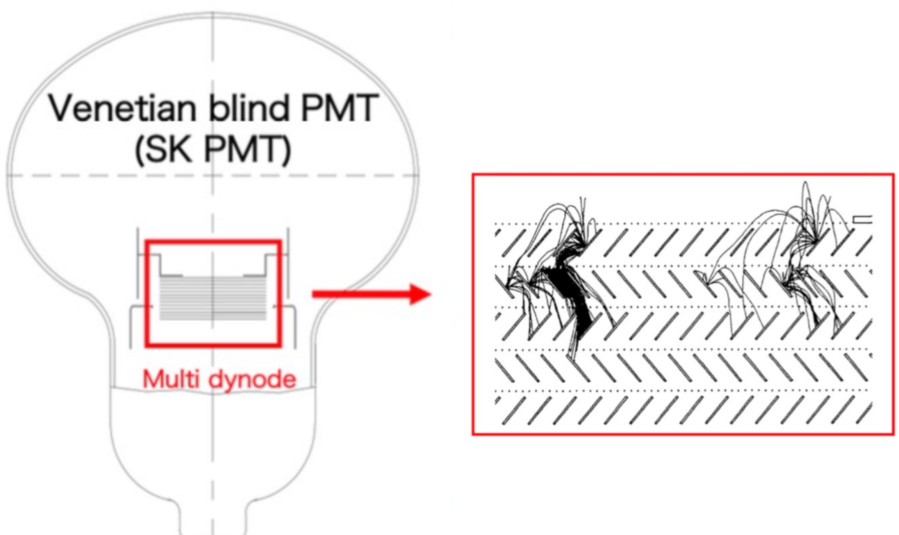
- Baseline configuration: 40k 20” PMTs for Inner Detector
  see presentation by B. Quilain for alternative option using mPMT and presentation by S. Zsoldos for Outer Detector
- Primary candidate: Hamamatsu R12860
  Also considering MCP-based PMTs from NNVT

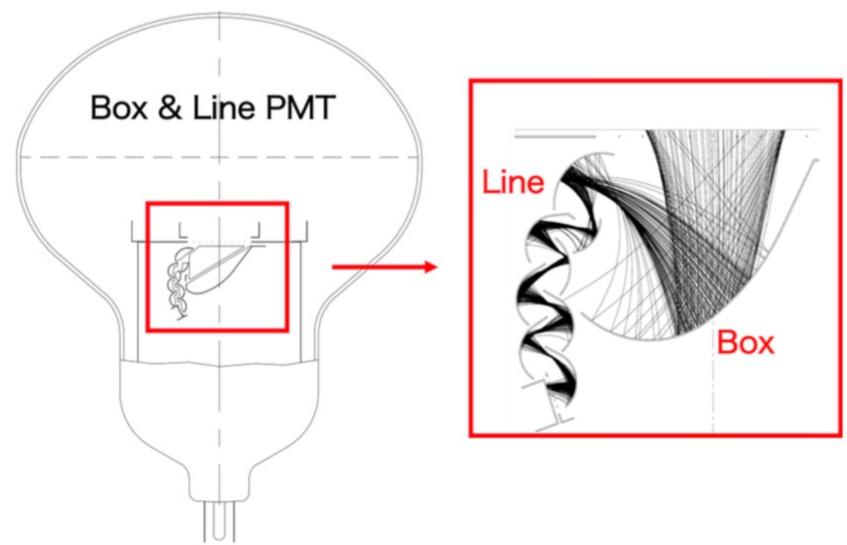
Super-K PMT
Hamamatsu R3600

Venetian blind dynode

Hamamatsu R12860

Box and line dynode
+ high QE

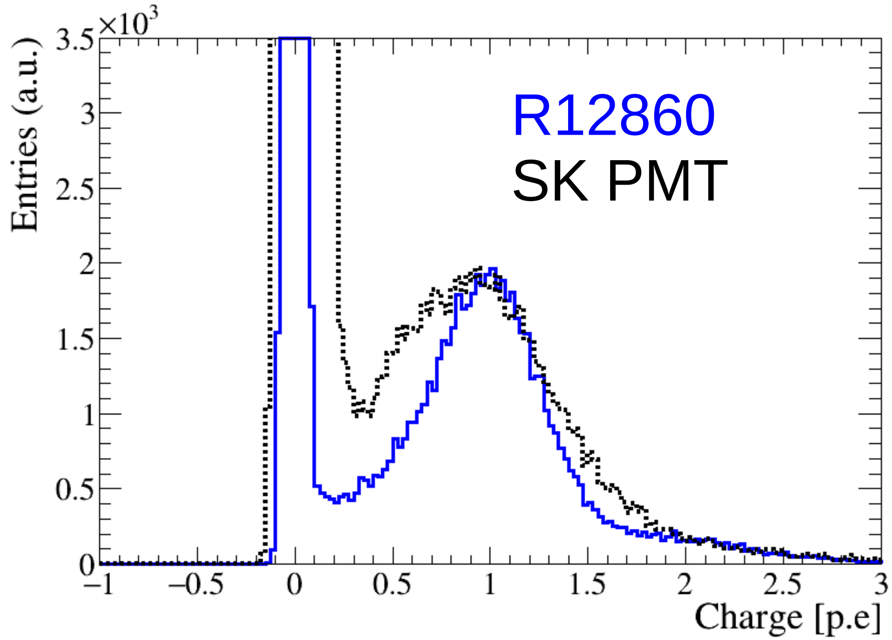


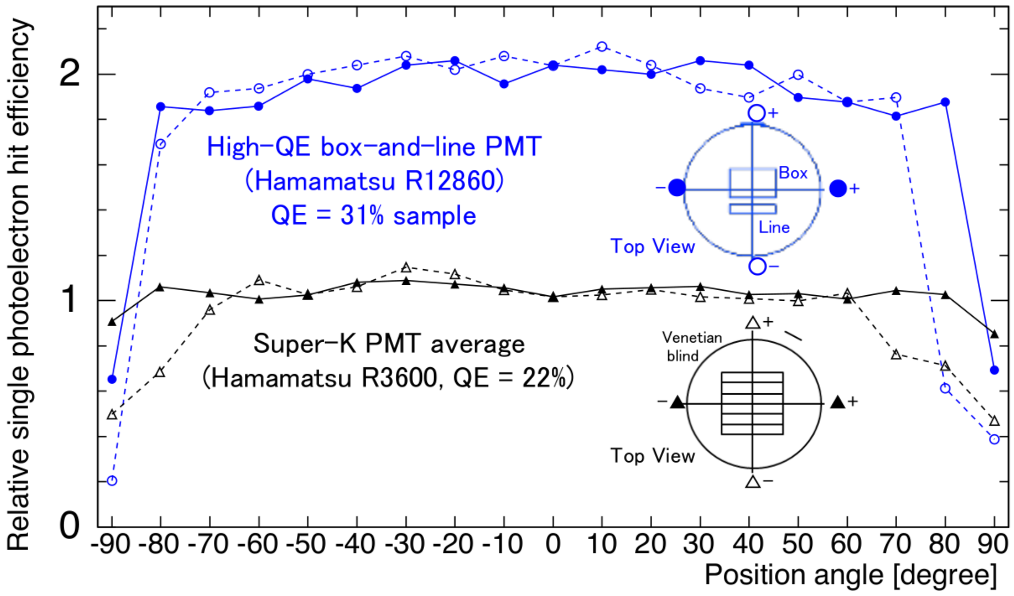


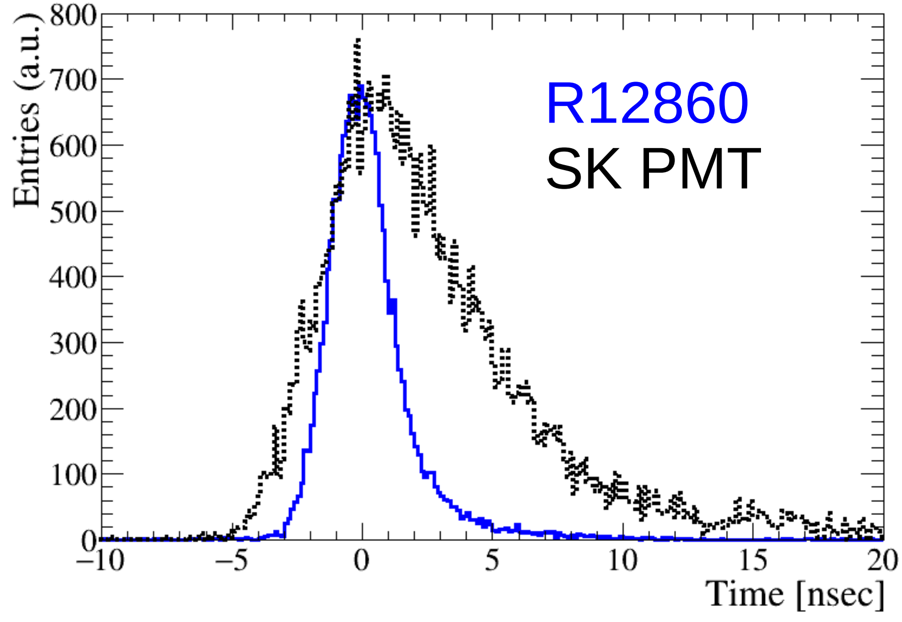
Hamamatsu R12860

Improved performance compared to SK PMT:

- ~2x photo-detection efficiency
- TTS: 6.73 ns → 2.59 ns (FWHM)
- Charge resolution: 60.1% → 30.8%







Hamamatsu R12860
Use in Super-Kamiokande

Refurbishment of the Super-Kamiokande detector last summer
- → 140 Hamamatsu R12860 purchased to replace dead channels
- → 136 were installed in the detector

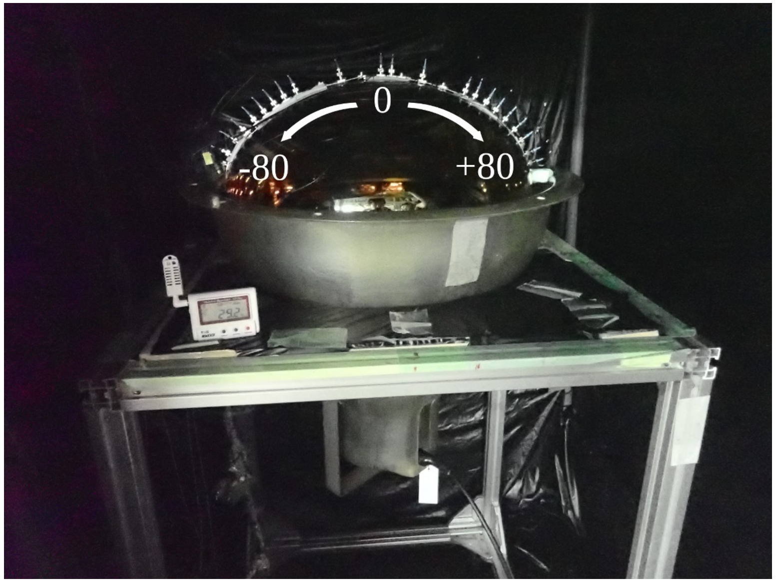
- ✓ High quality PMTs for Super-K, and additional inputs for Hyper-K studies
- ✓ Long term operation of a large number of PMTs: stability and durability
- ✓ Also allows to confirm consistency of production quality

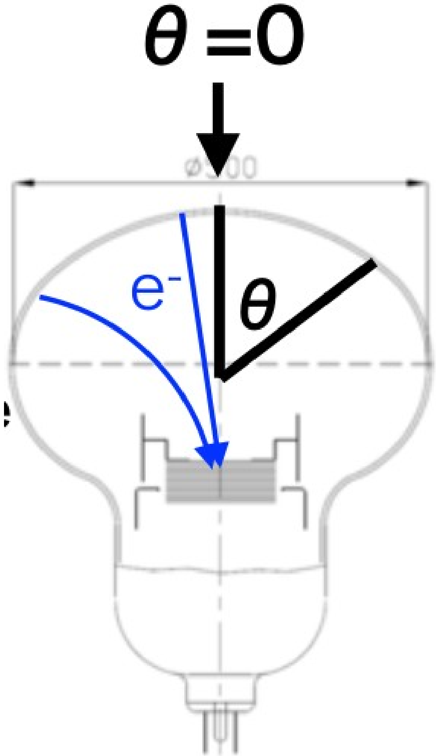
Tests before installation: all 140 PMTs passed the selection criteria

See poster by J. Xia for details

Hamamatsu R12860
Uniformity measurement

For 9 PMTs checked uniformity of PMT response and performance:
- As a function of photon hit position for zero magnetic field
- As a function of magnetic field for photons hitting at a given position



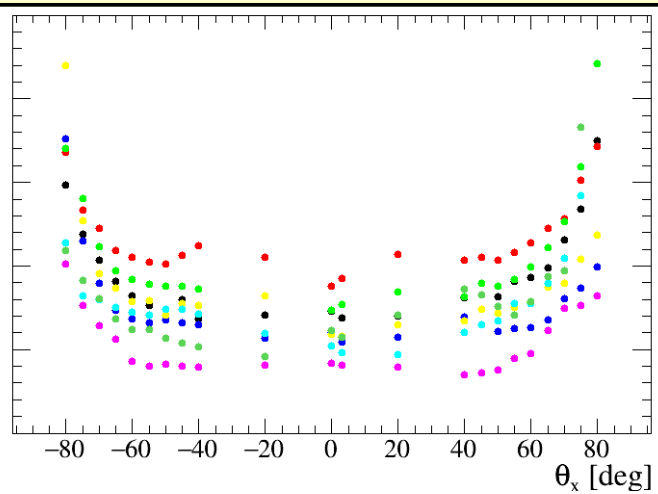


Plot construction

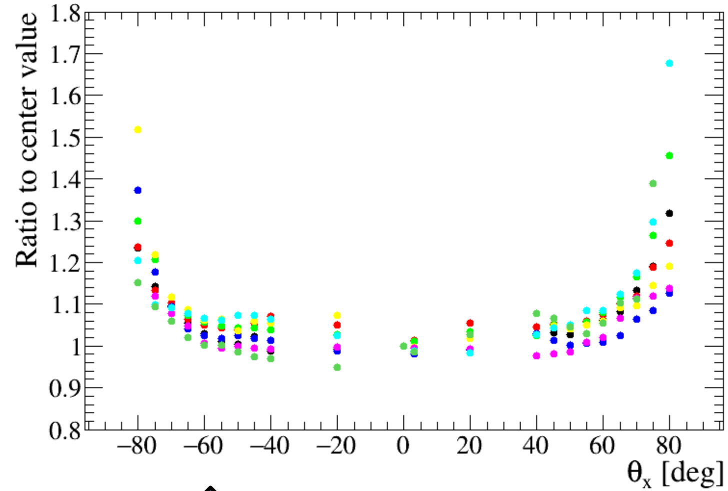
Measurement on 9 different PMTs:

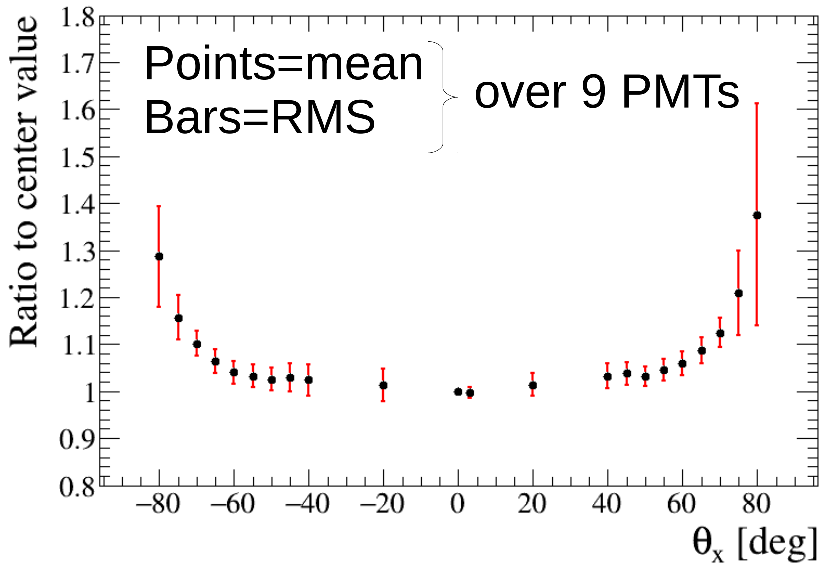
- differentiate real pattern from problem on one PMT or measurement
- variation on the size of the effects seen from one PMT to another

1. Measure in each configuration for each PMT



2. Make ratio to reference value (fiber at center or B=0) for each PMT

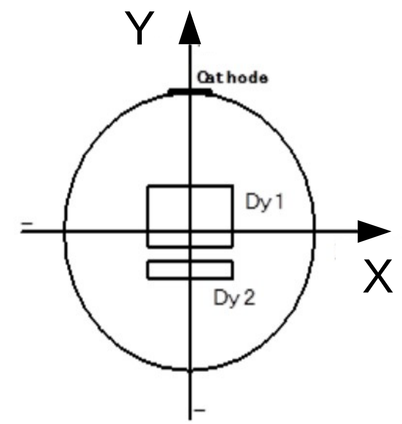




3. Convert to mean and dispersion of the 9 PMTs for each point on the horizontal axis

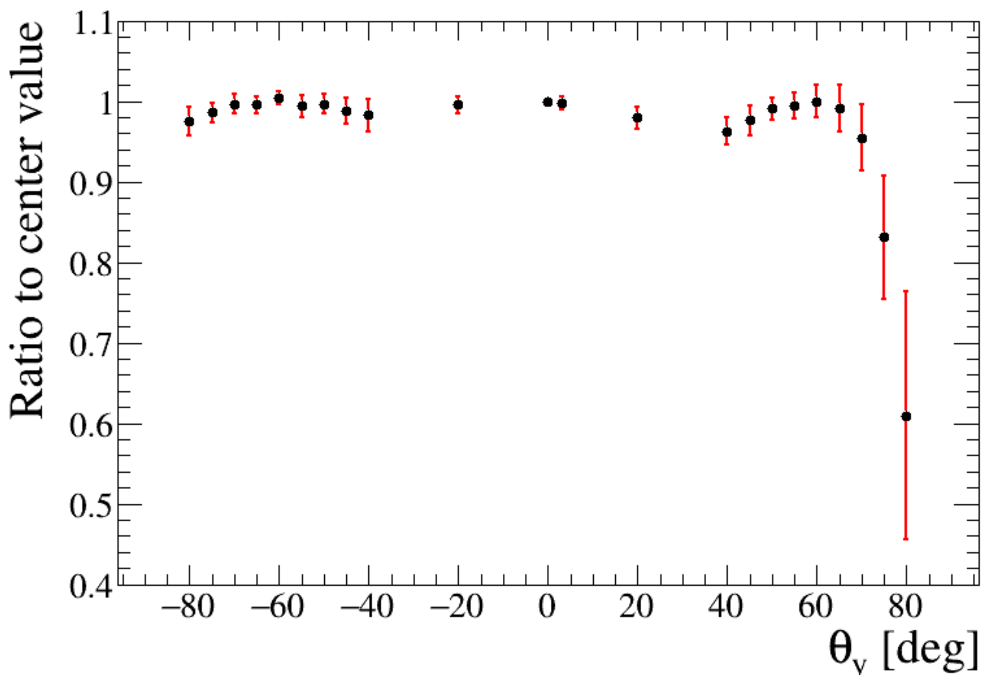
Gain as a function of position

- Gain seen to be stable as a function of the photon hit position, except in the edge regions
- Asymmetry between box and line regions

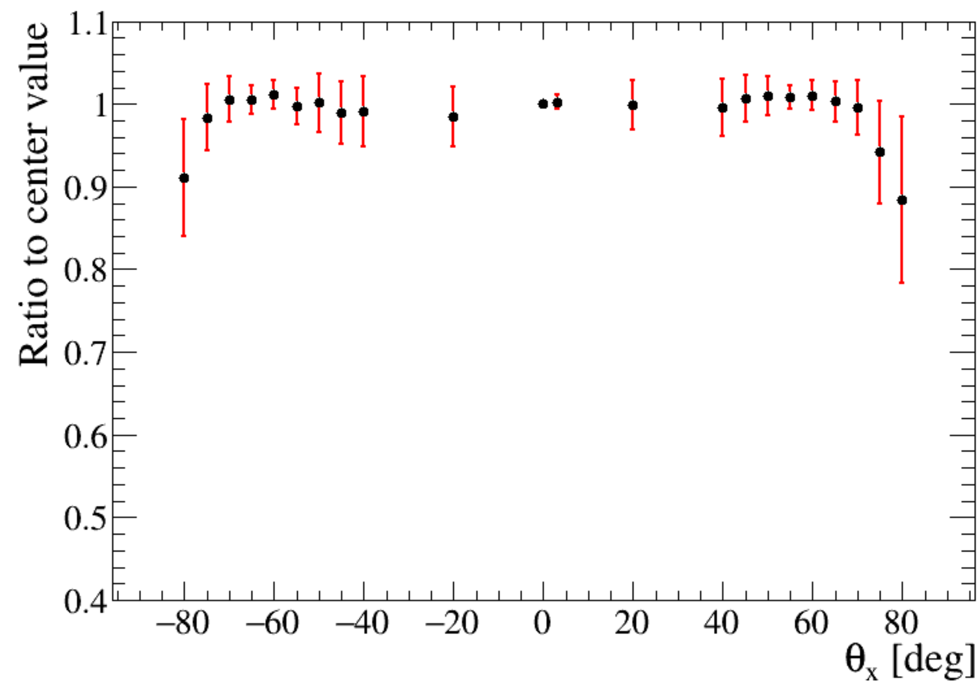


R12860 TOP VIEW

<u>Line to Box direction</u>
(Y axis)

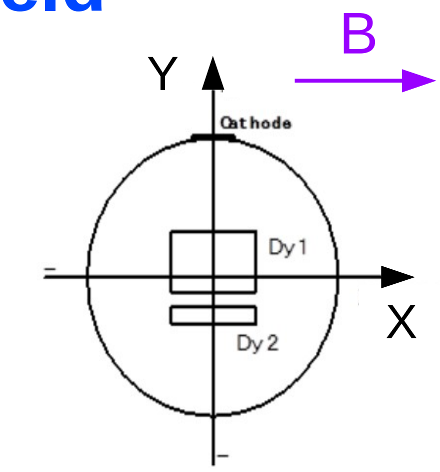


<u>Perpendicular direction</u>
(X axis)



(no magnetic field)

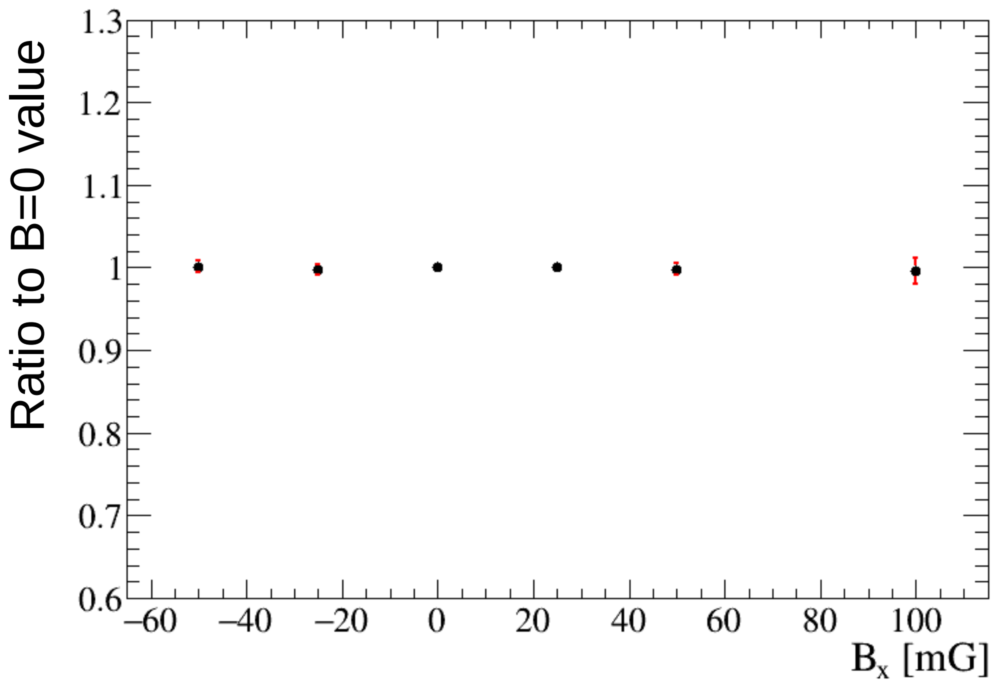
Gain as a function of magnetic field



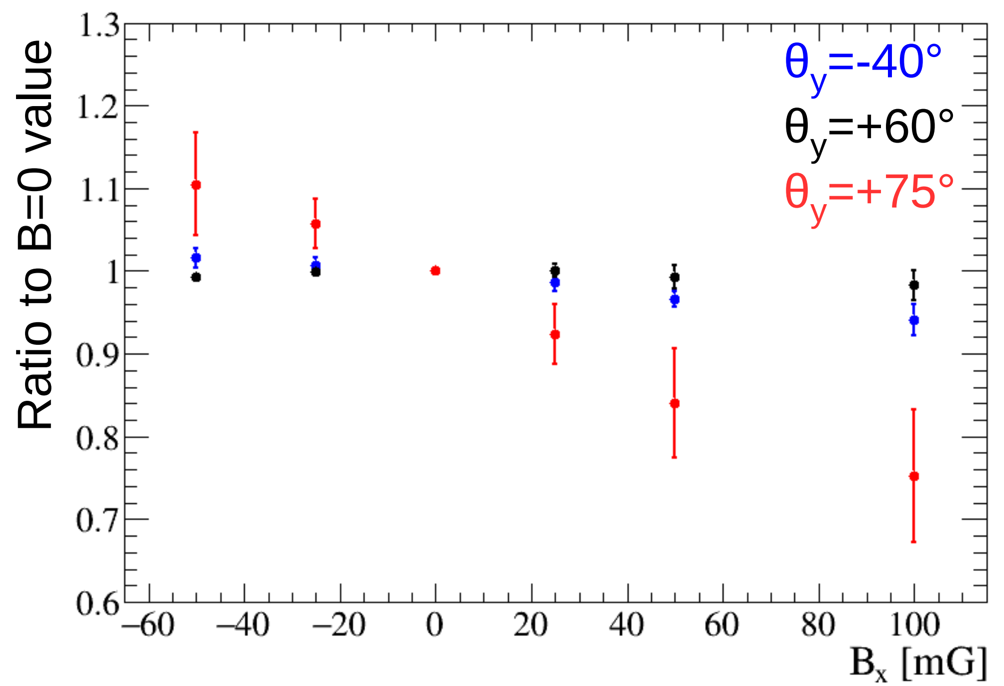
R12860 TOP VIEW

- No effect on gain if photon hits in the central region, or away from center on the axis parallel to the field
- Can see an effect for hits displaced along an axis perpendicular to the field:
  - size of the effect depend strongly on position in that case
  - biggest effect seen on the Y axis behind the box dynode (θ_y>75°)
  - in other places, variations of less than 10% in the expected range of magnetic field in Hyper-K (-100mG to +100mG)

Photon hitting at θ**x**=75°



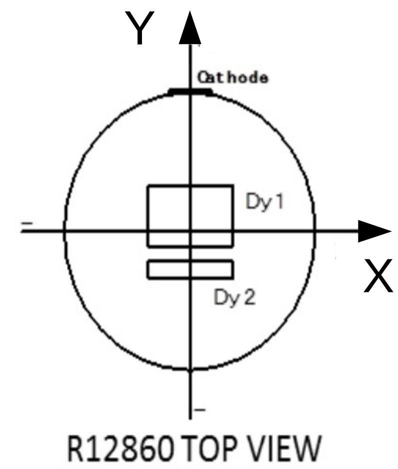
Displacement perpendicular to B field



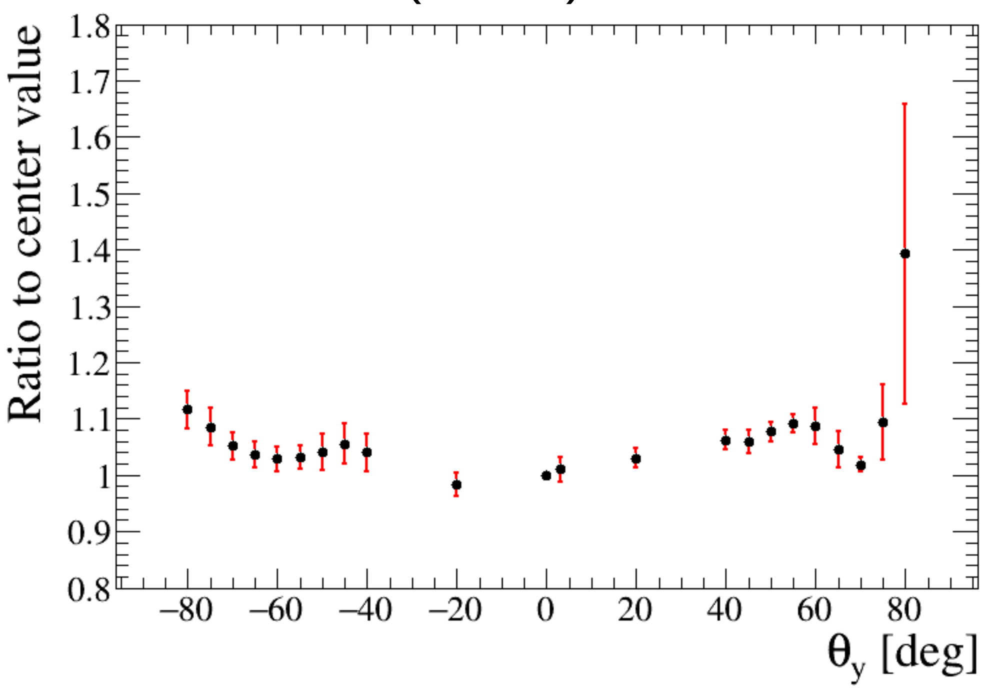
(Magnetic field along the x axis, null along the other axis)

TTS as a function of position

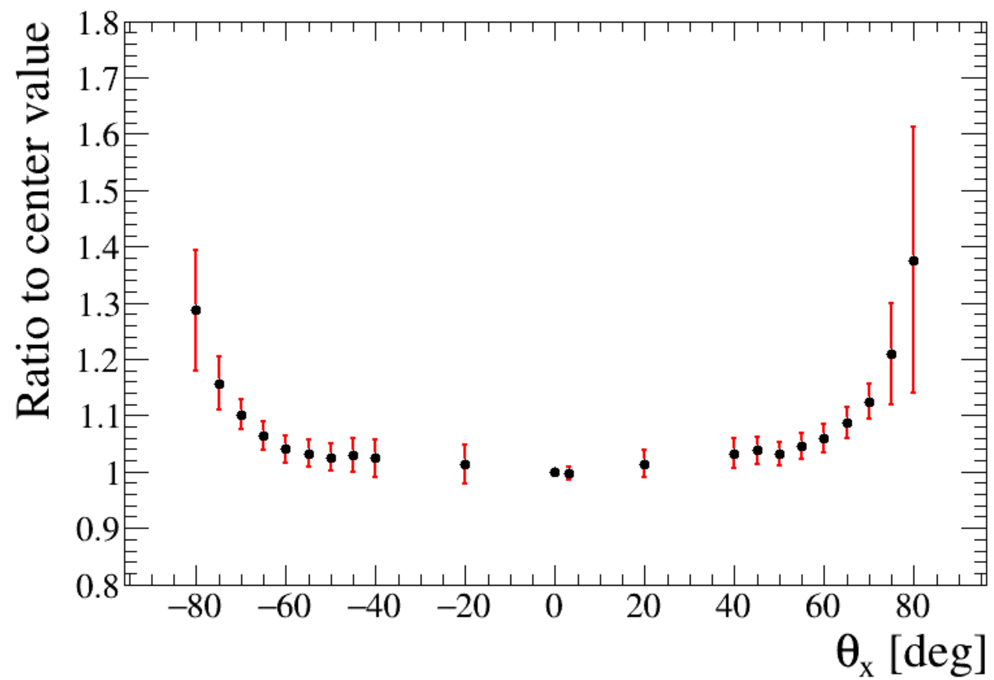
- TTS seen to increase when moving away from the center of the PMT
- Larger effect in the direction perpendicular to the Line to Box axis
- Pattern is a bit more complicated behind the box dynode



Line to Box direction
(Y axis)



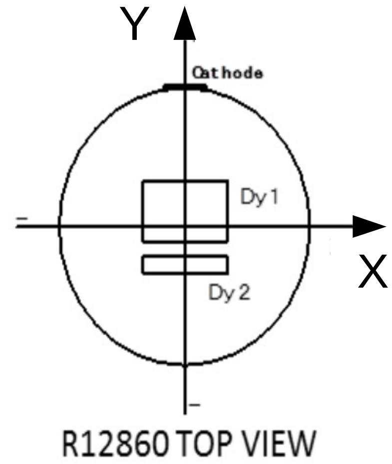
Perpendicular direction
(X axis)



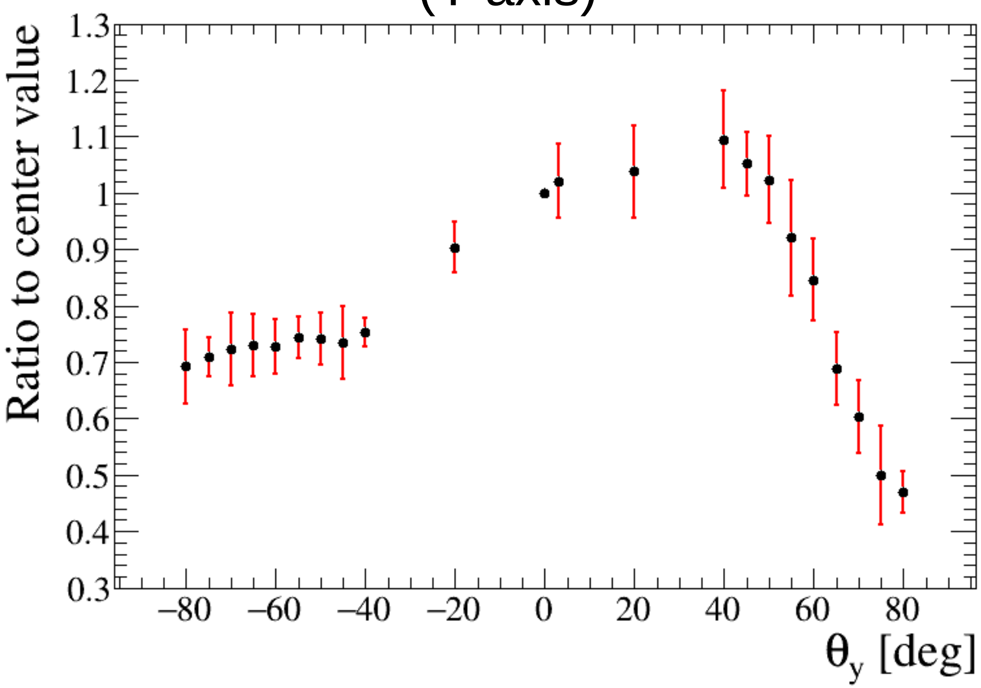
(no magnetic field)

Late pulse as a function of position

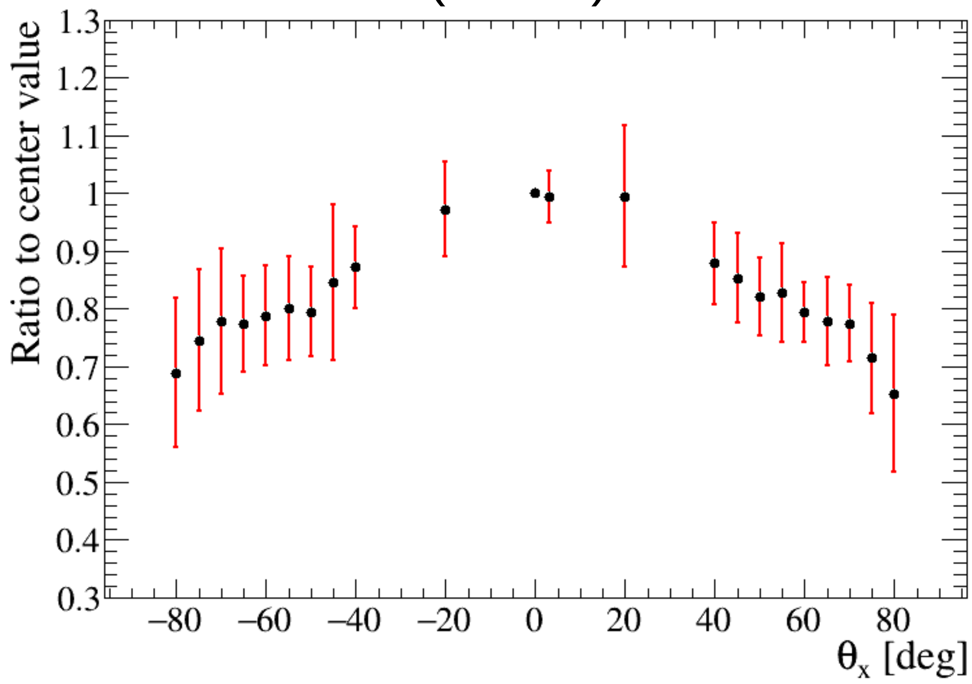
- For R12860, a fraction (2-3%) of the hits arrive ~100ns later than expected
- Believed to be due to electrons back-scattering
- Fraction of those late pulses depend strongly on position



Line to Box direction
(Y axis)

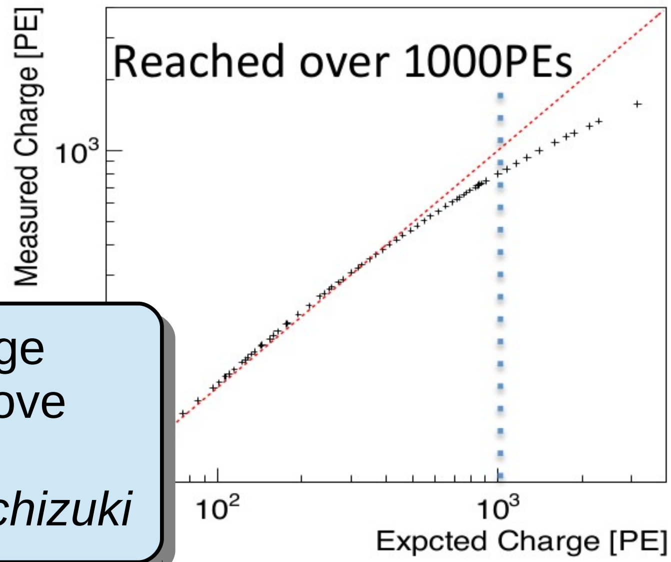


Perpendicular direction
(X axis)



(no magnetic field)

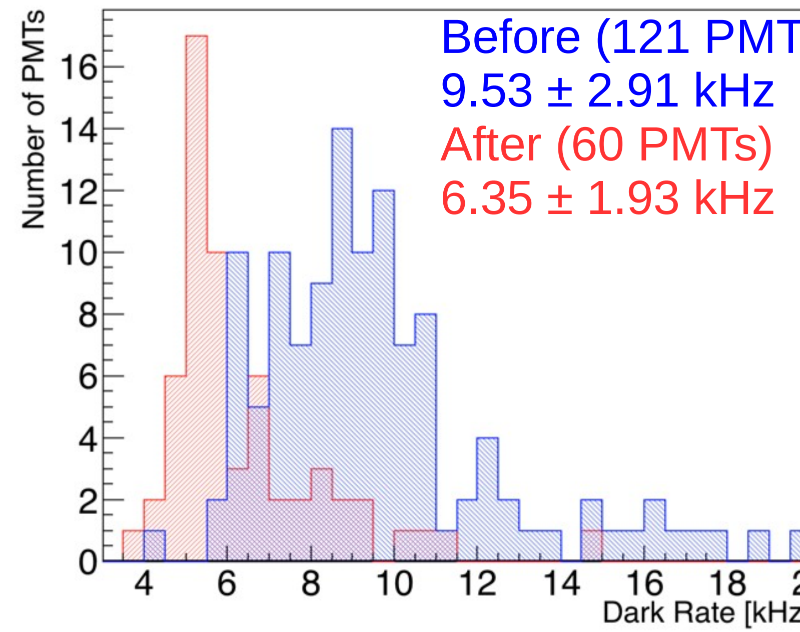
R12860 – Other developments



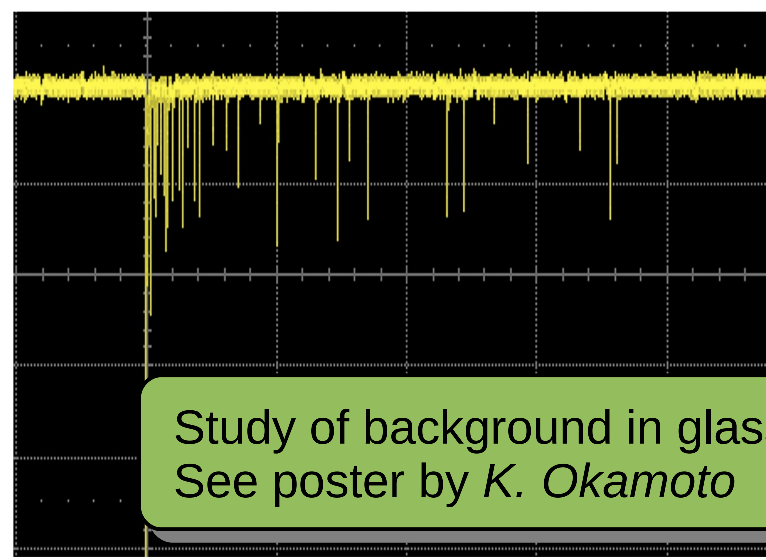
Optimization of voltage divider ratios to improve dynamic range
See poster by T. Mochizuki

Design and test of protective covers

Dark rate reduction
(Hamamatsu)



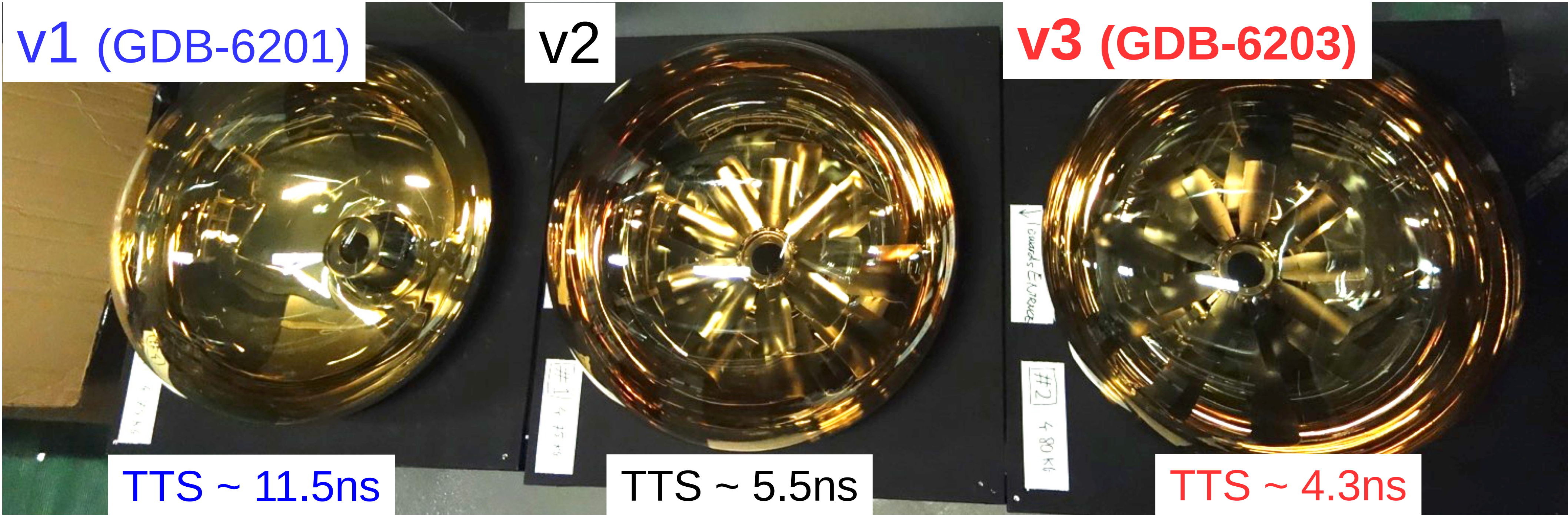
(measured at room temperature)



Study of background in glass
See poster by *K. Okamoto*

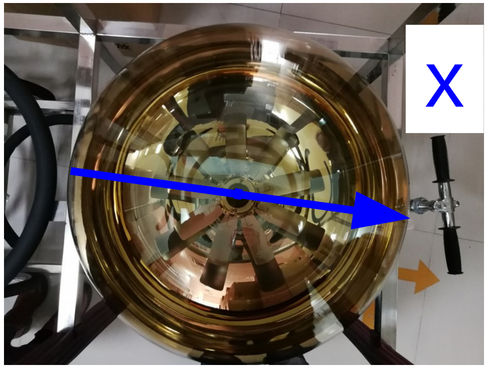
MCP PMT - development

- 20” (and 8”) PMTs produced by NNVT
- Uses Micro-Channel Plates
- Used in JUNO
- Good detection efficiency, pressure tolerance and low RI glass
- Weaker point was timing resolution, but TTS reduced trough successive improvements for Hyper-K
- Latest version has smaller TTS than current SK PMTs (6.73 ns), but larger than Hamamatsu R12860 (2.59 ns)



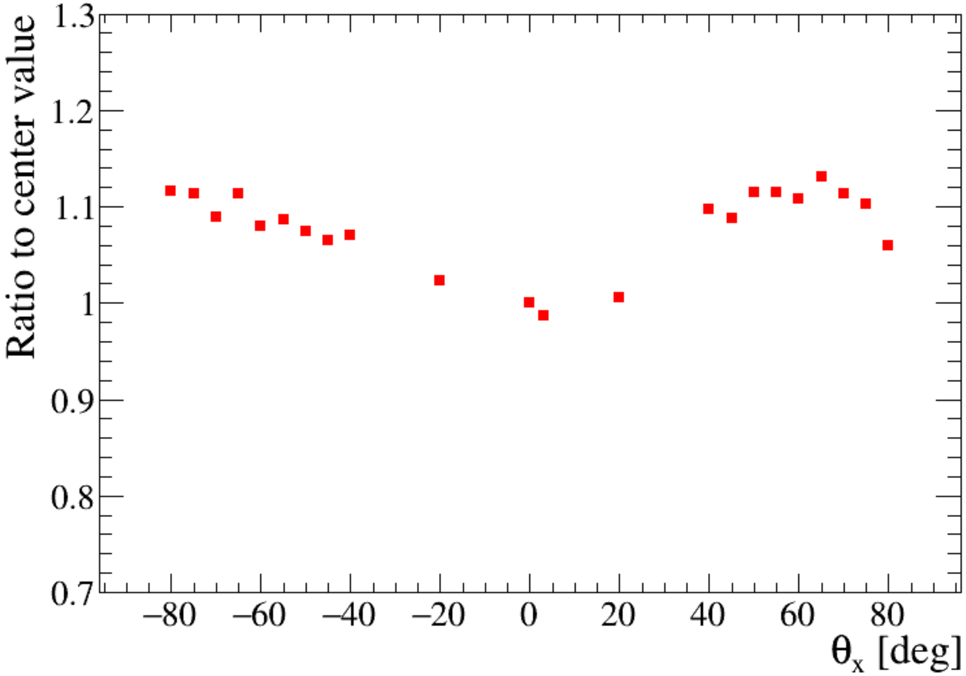
MCP PMT - Uniformity Gain

- Measured one MCP PMT (v3) in the same setup as B&L PMTs
- Gain looks ~10% larger on the edges than center, uniform within 5% in each region
- Magnetic field does not have a strong effect on gain (largest effect seen is 5%)

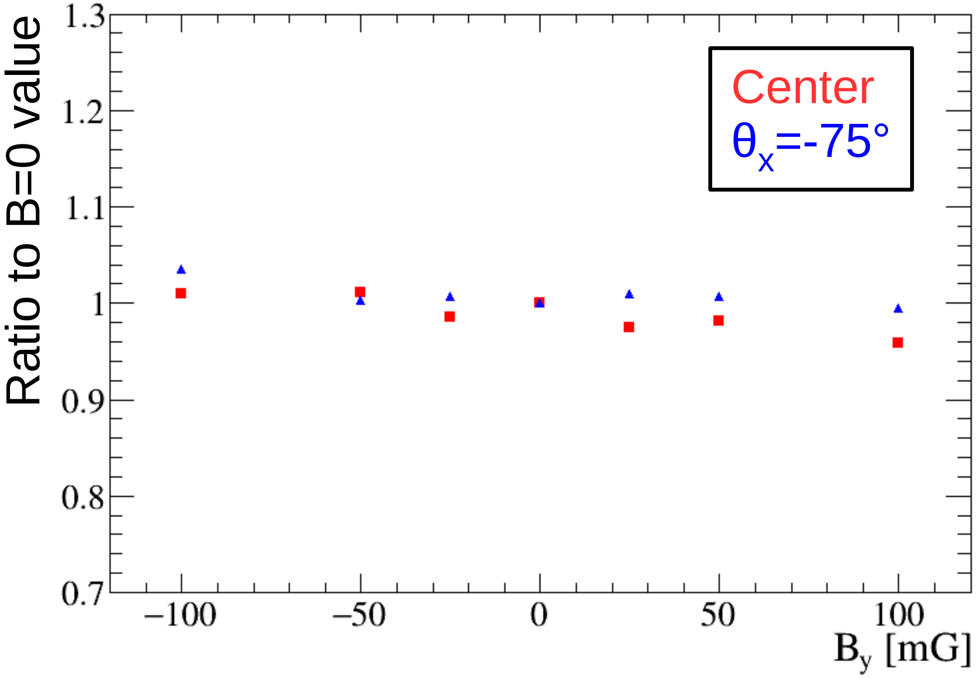


x<0: electrode
x>0: between electrodes

Gain=f(position) B=0

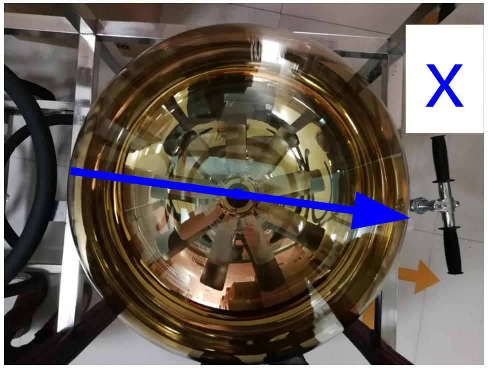


Gain=f(By) Fixed position



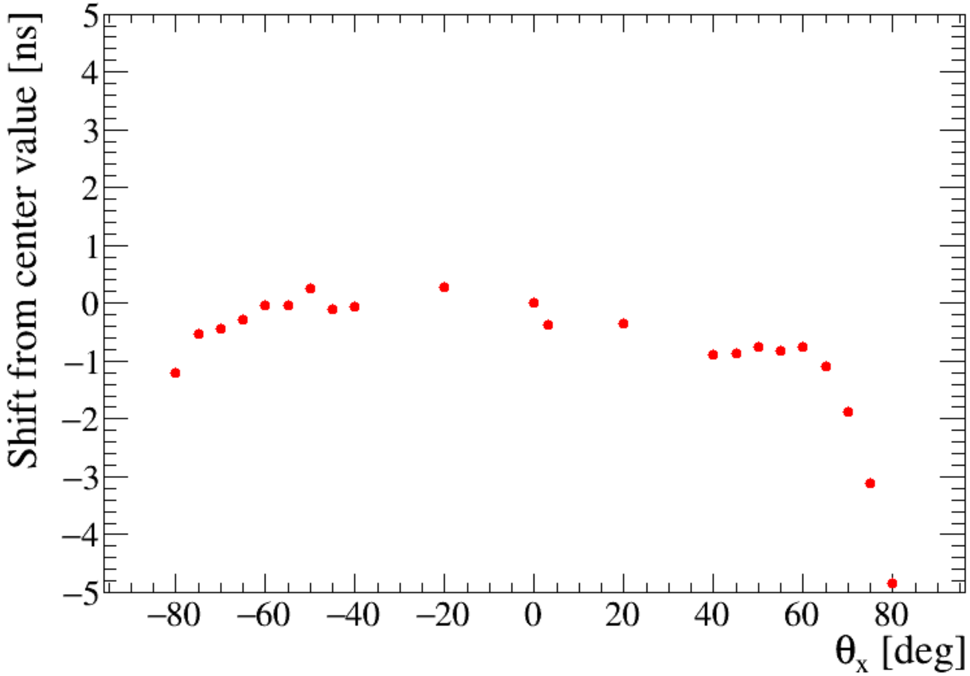
MCP PMT - Uniformity Timing

Comparing timing distributions for different hit positions:
- Peak of the distribution stable within 1ns for most positions. Larger shifts on the very edge region of the side with no electrode
- TTS is ~20% smaller in the region -40°<θ_x<0

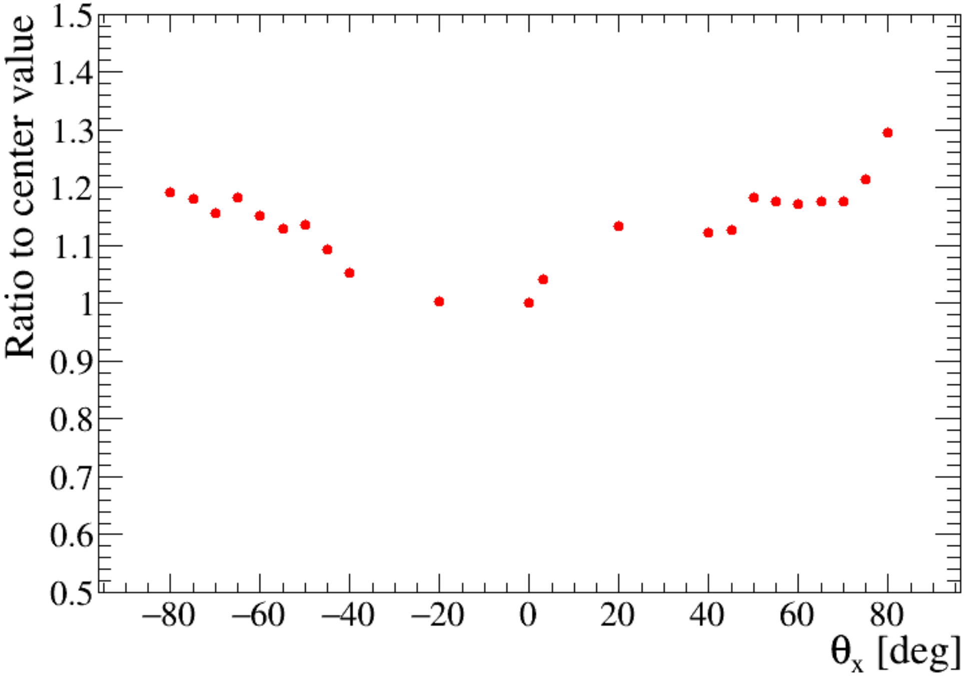


x<0: electrode
x>0: between electrodes

Transit time peak position shift



Transit time spread



Variations as a function of photon hit position, no magnetic field

Summary

- Next generation water Cerenkov experiment Hyper-Kamiokande will be using improved photo-sensors compared to the currently running Super-Kamiokande

- Hamamatsu R12860 have twice the detection efficiency and charge resolution of the PMTs used in SK, and more than twice as good timing resolution

- 136 of those PMTs have been installed in Super-Kamiokande
  All of them passed Hyper-Kamiokande requirements in pre-installation measurements

- MCP based PMTs produced by NNVT studied as an alternative option
  Improved version now has better timing resolution than current Super-Kamiokande PMTs

- Uniformity of the properties as a function of photon hit position and magnetic field value was measured for both types of PMTs

BACKUP

Test of 140 B&L PMT in Super-K
Pre-selection criteria

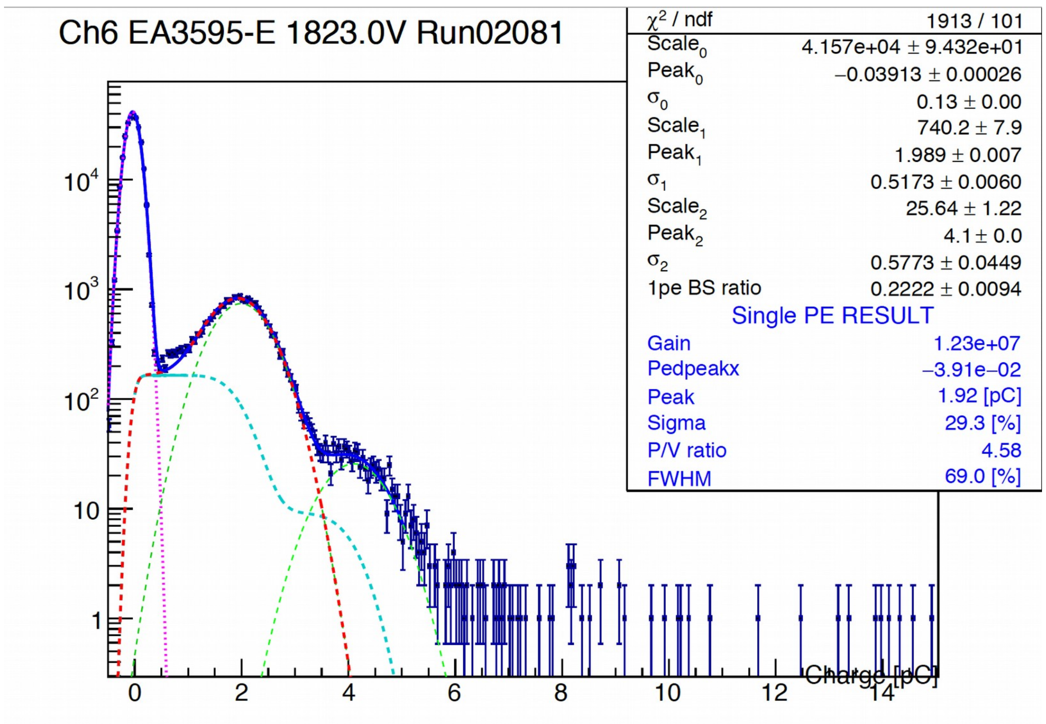
All of the 140 PMTs were tested at Kamioka
- checked PMTs pass requirements to be installed in Super-K
- Measurement with SK gain (1.4e7)

Pre-selection	Min	Max	Unit
Voltage for 1e7 gain	1500	2350	V
Voltage for 1.4e7 gain	1500	2350	V
Dark rate	2	30	kHz
TTS (FWHM)	1	4	nsec
1PE Resolution (sigma)	20	70	%
P/V	2.5	-	
Afterpulse rate (0.5-40us)	0	10	%
Maximum output	3	12	V

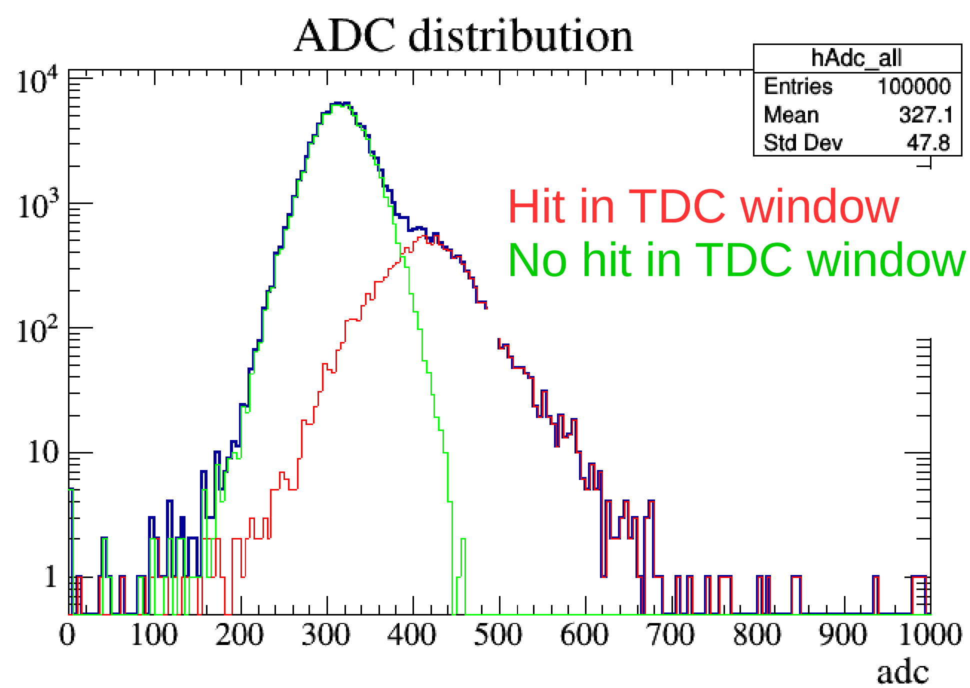
Uniformity measurement details

- Used a particular setup that allows to take adc and tdc measurements at the same time
- However has an impact on the performance: pedestal peak gets broaden, and cannot clearly see 1 pe peak

Calibration setup



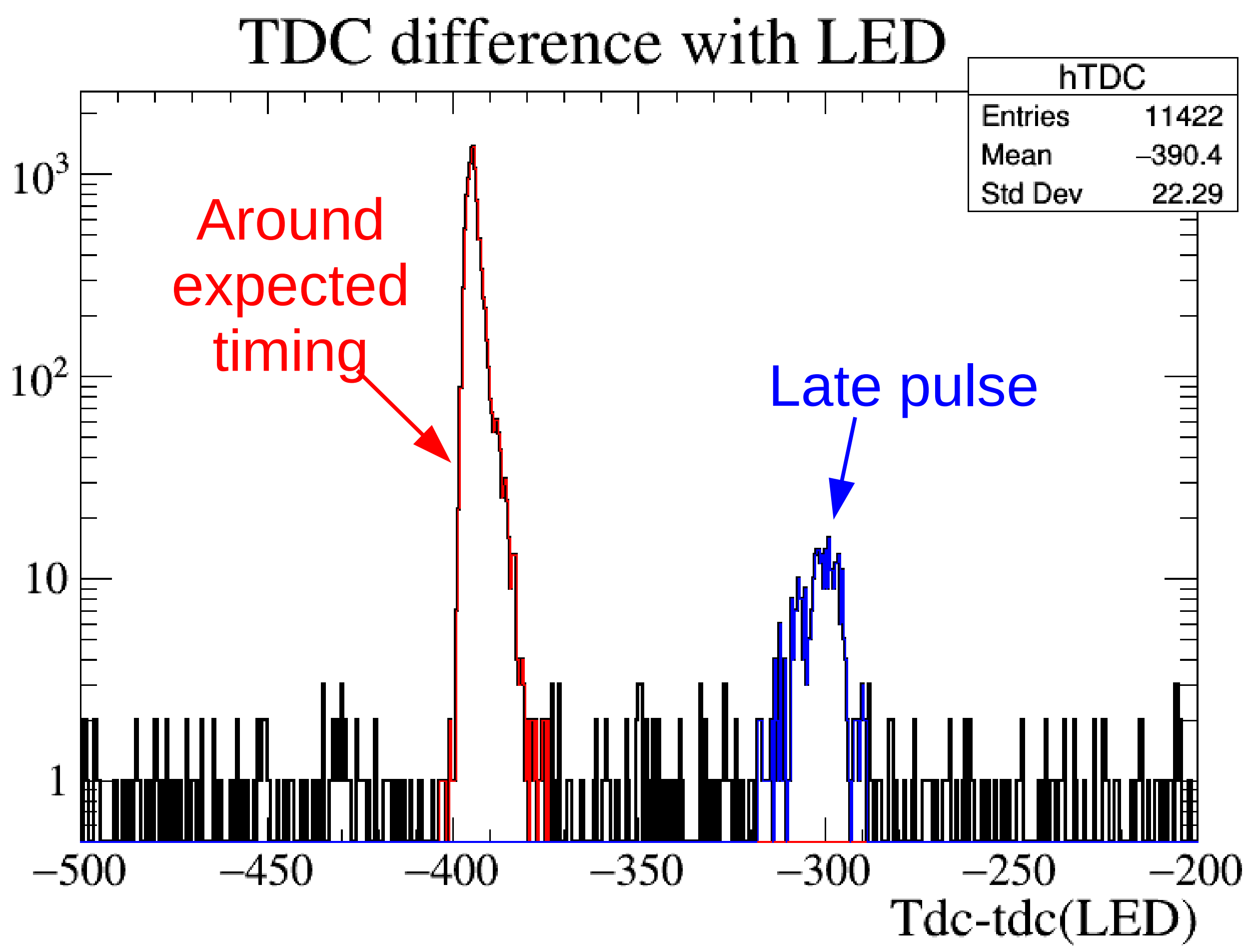
This setup



- Use TDC information to separate hits from pedestal
- Only look at relative variations

Late pulse
Definition

For B&L PMTs, a fraction of the hits arrive ~100ns later



Look at the ratio of those late pulse hits over number of hits around the expected timing