Hyper-Kamiokande

Multi-PMTs at the Water Cherenkov Test Experiment /IWCD at Hyper-K

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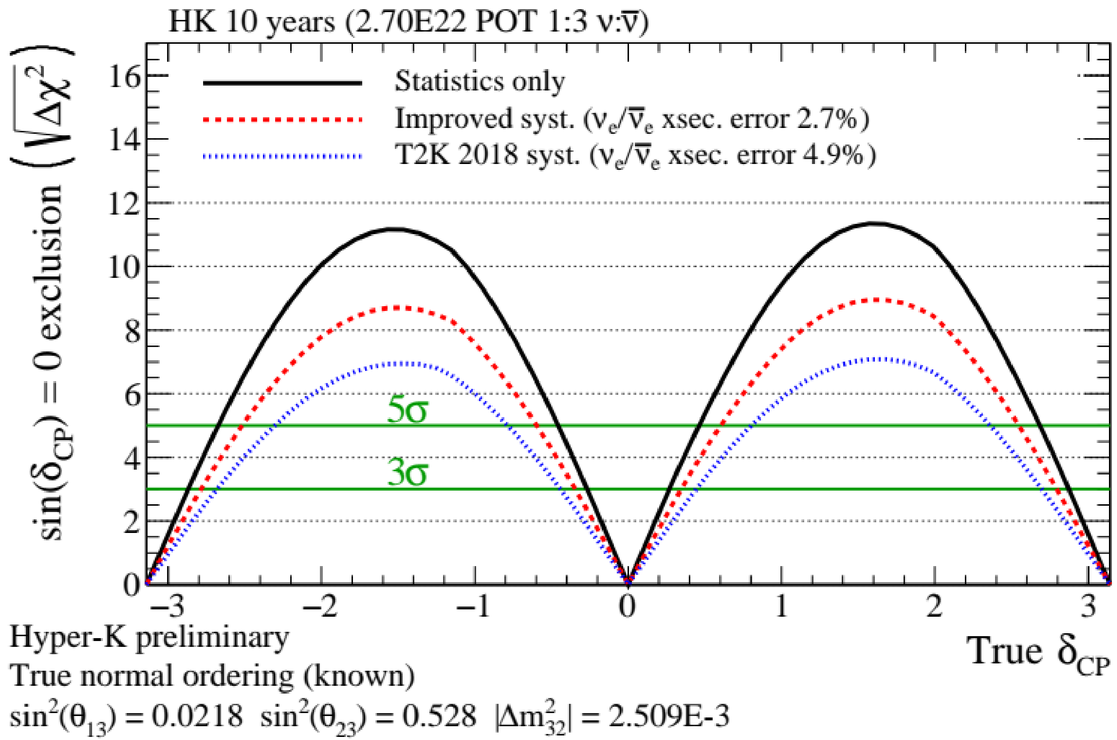
August 2, 2022/WG6, NuFact2022

TRIUMF

The Hyper-Kamiokande Long-Baseline Program

Hyper-K

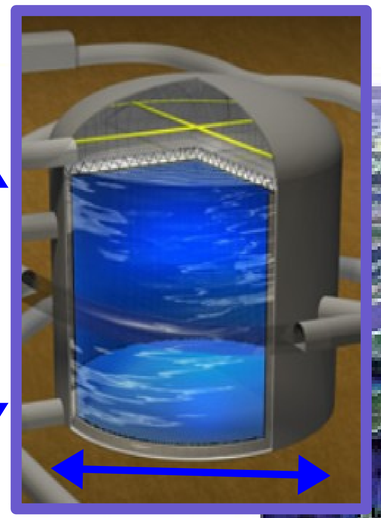
Sensitivity to CPV



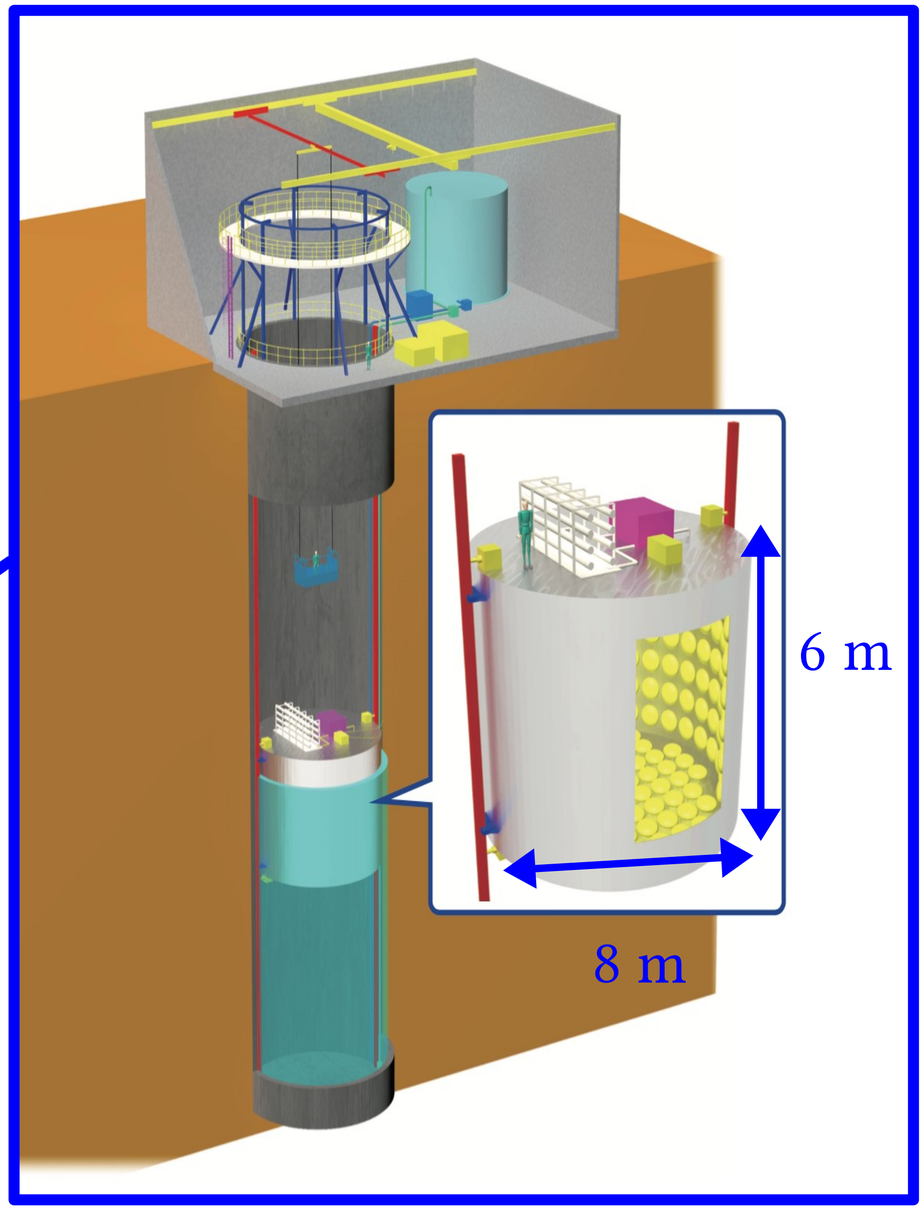
- Will perform the long-baseline program with high purity $\nu_\mu/\bar{\nu}_\mu$ beam, following the successful T2K experiment
- Measurements will be systematically limited due to ~20 times higher interaction rate compared to T2K
- The $\nu_e/\bar{\nu}_e$ cross-section uncertainties will the dominant errors in CP violation studies

Intermediate Water Cherenkov Detector (IWCD)

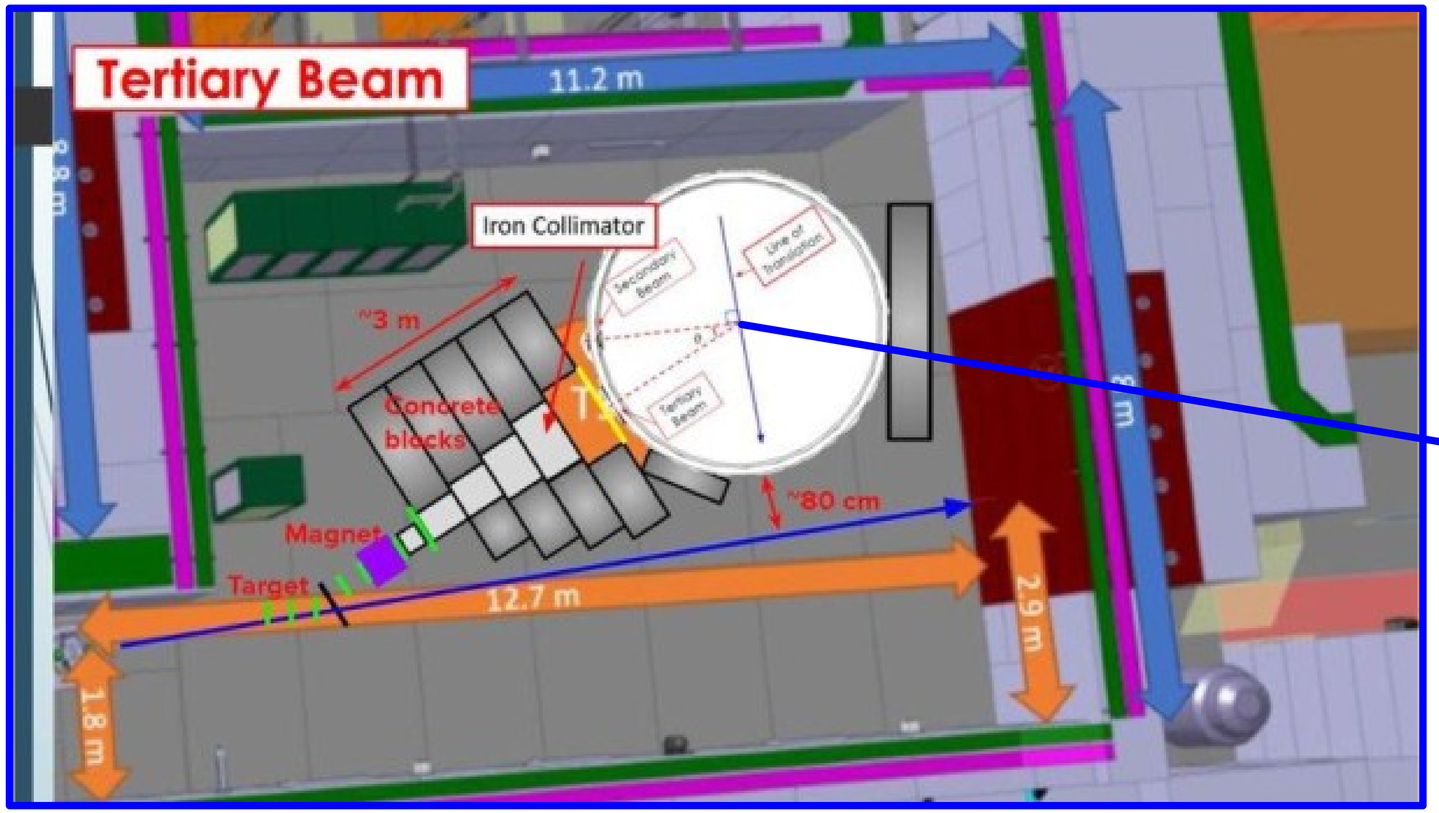
- Sub-kiloton scale water Cherenkov detector (Φ8m x 6m)
  - will be located at ~1 km away from the beam source
  - 480 multi-PMT modules inside the tank
  - 60 tons of fiducial volume for $\nu_e/\bar{\nu}_e$ cross-section measurements

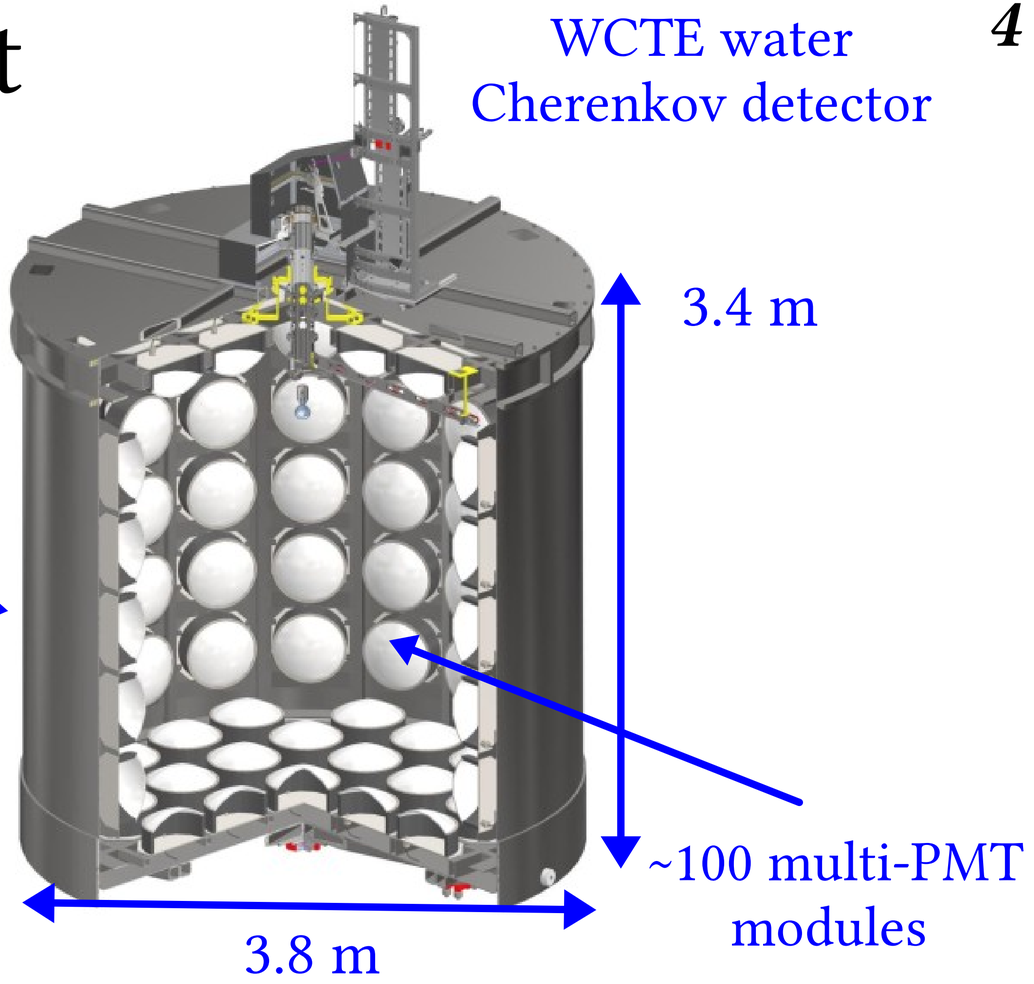


Hyper-K



Water Cherenkov Test Experiment





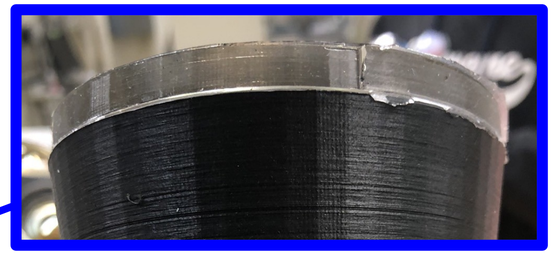
- Will test new technologies in both hardware and software, which will be used in the Hyper-K experiment
- Responses to known particle fluxes (e, μ, π, p, potentially γ) will be studied
- Measurements of Cherenkov light emission profile and secondary neutrons are also planned

Multi-PMT (mPMT) module

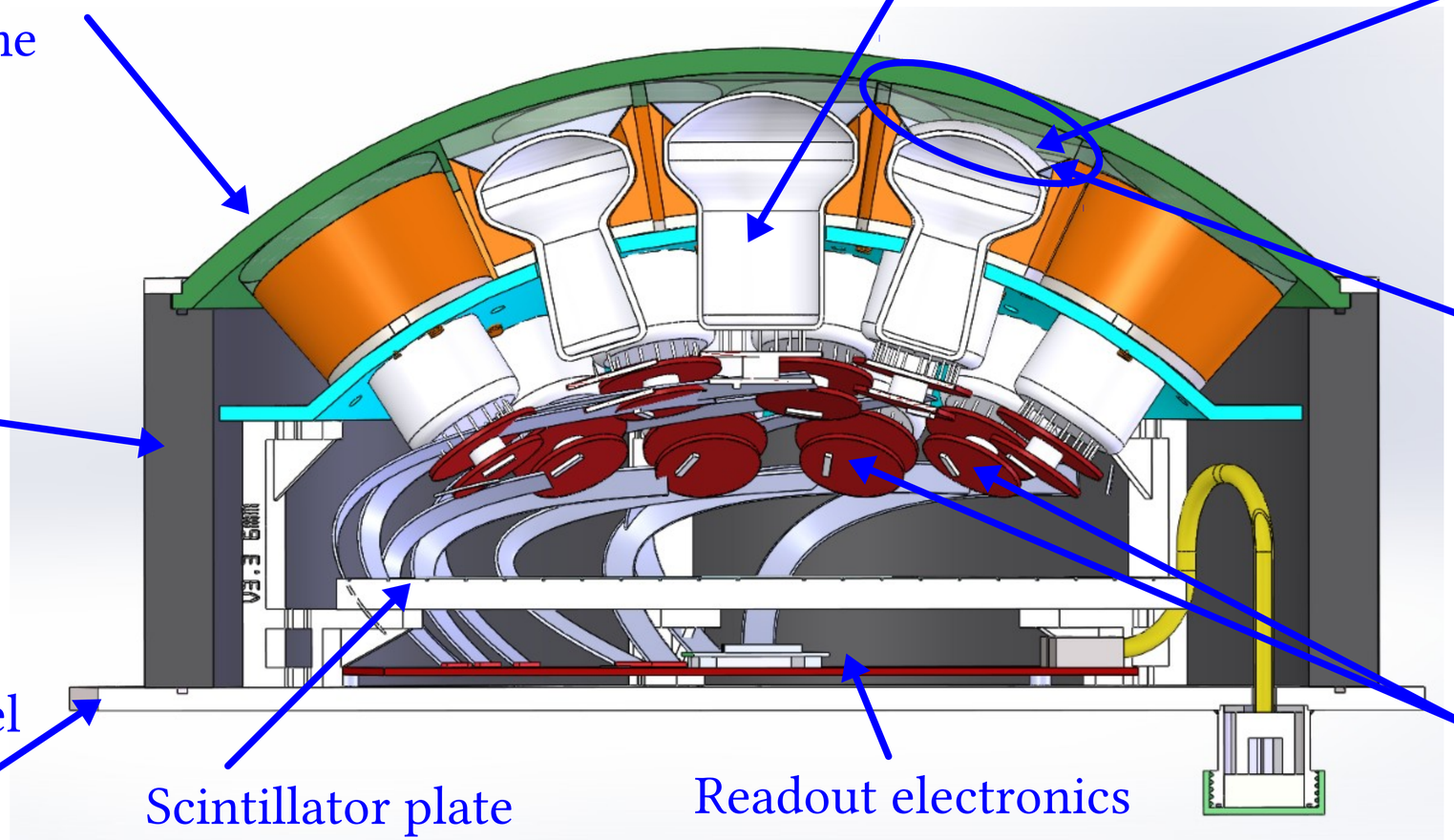
- 19 x 3” diameter photomultiplier tubes (PMTs) are integrated in a water-tight module

Hamamatsu R14374

Optical silicone gel



UV transparent acrylic dome



Reflector

PVC cylinder

Stainless steel backplate

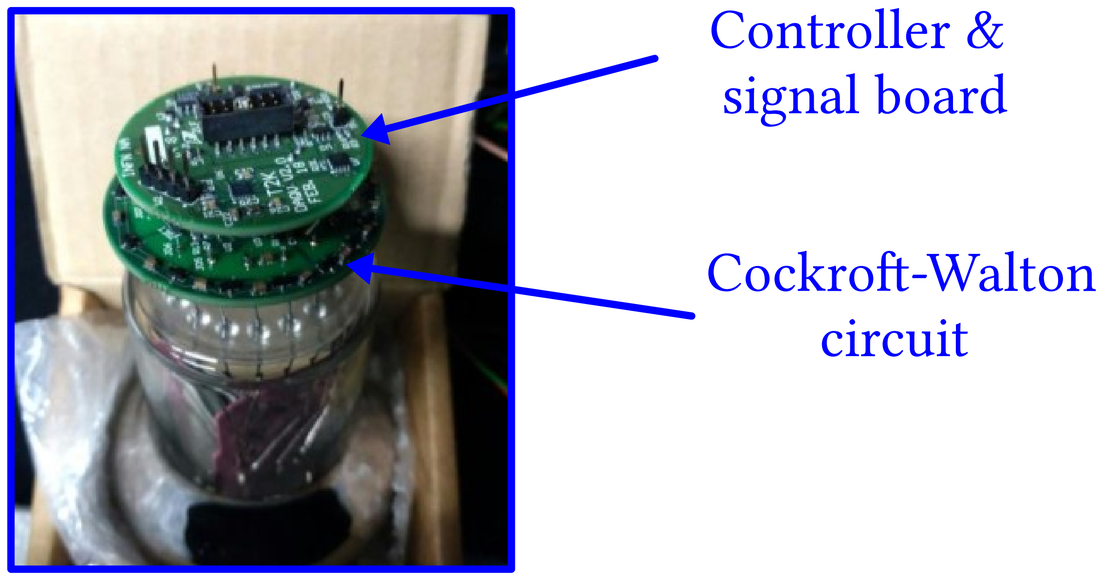
Scintillator plate

Readout electronics

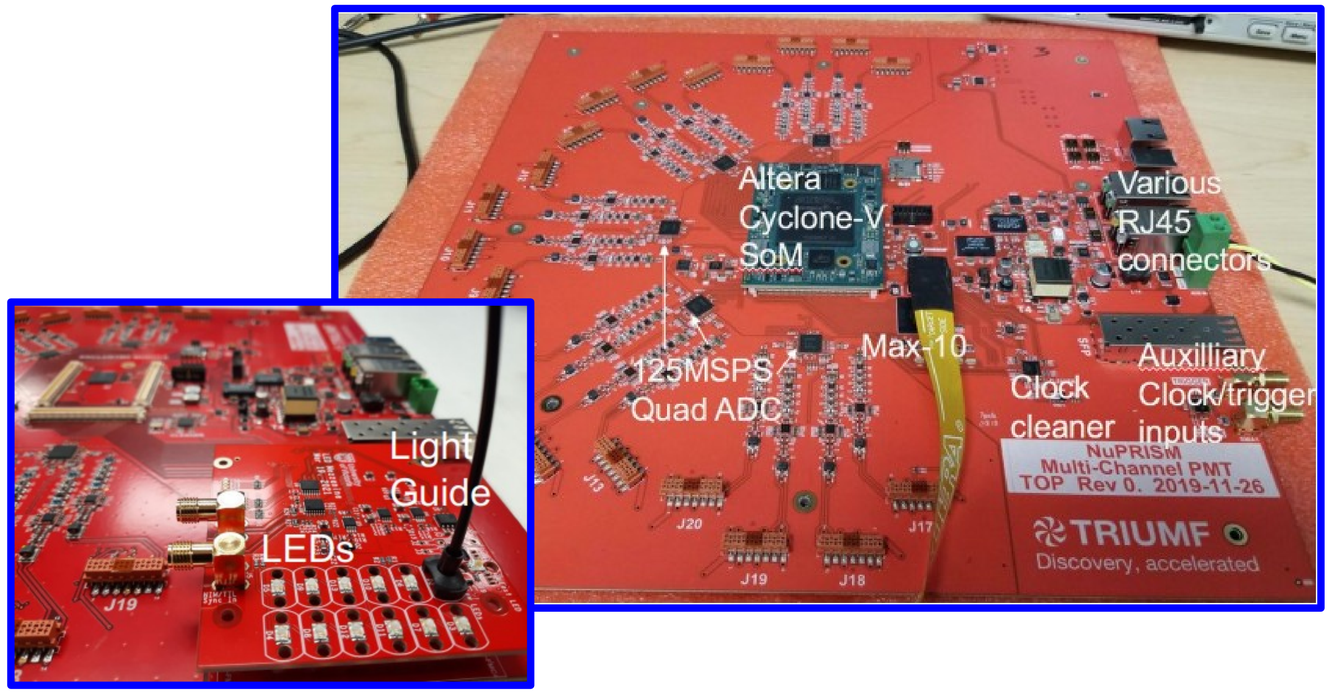
High voltage circuits

High voltage & readout electronics

- High voltage generated with Cockroft-Walton circuit
  - Lower power consumption compared to resistive base



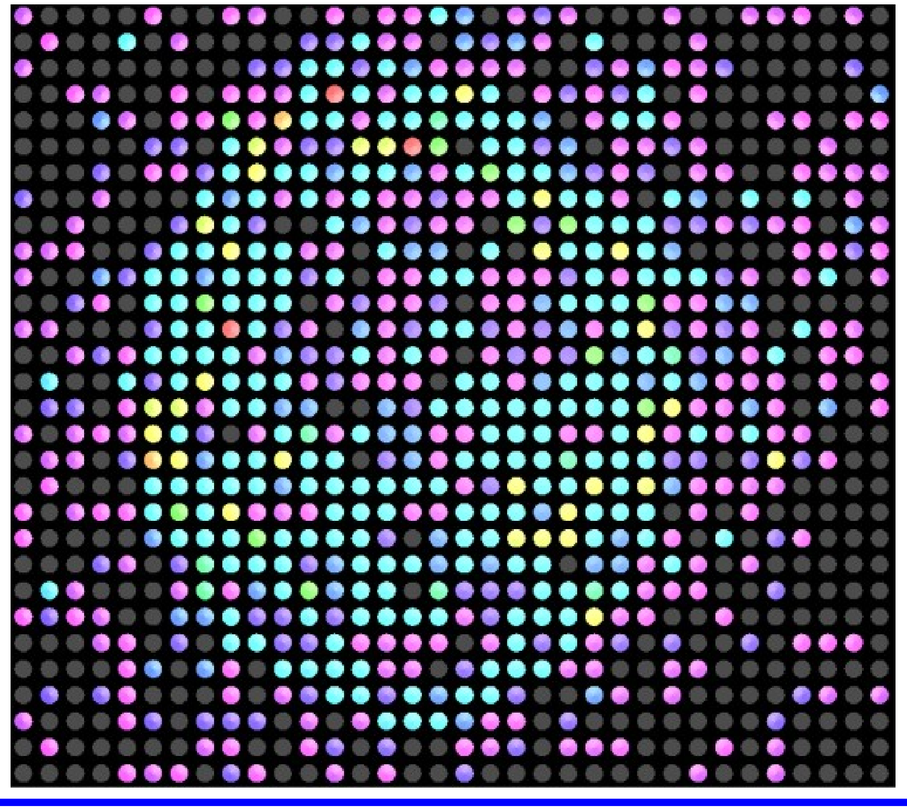
- 20-channel 125 MSPS FADC mainboard
  - Full waveform can be readout, allowing better pile-up event identification
  - Digitization and pulse-finding are done
  - LEDs are mounted for detector calibration



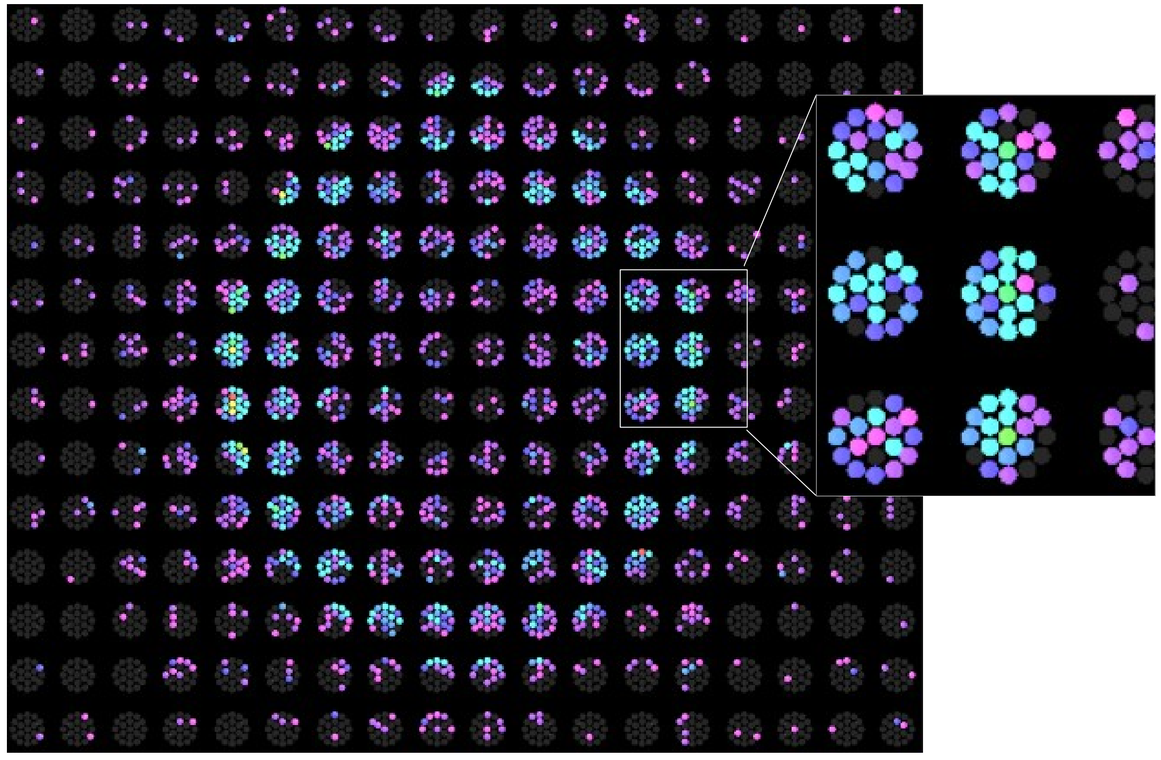
Why mPMT?

Simulated an electron event

8” PMT geometry



mPMT geometry



- IWCD is much smaller than the Hyper-K detector ⟶ distance to the detector wall is shorter
- mPMT provides higher granularity and better timing resolution thanks to 3” PMTs

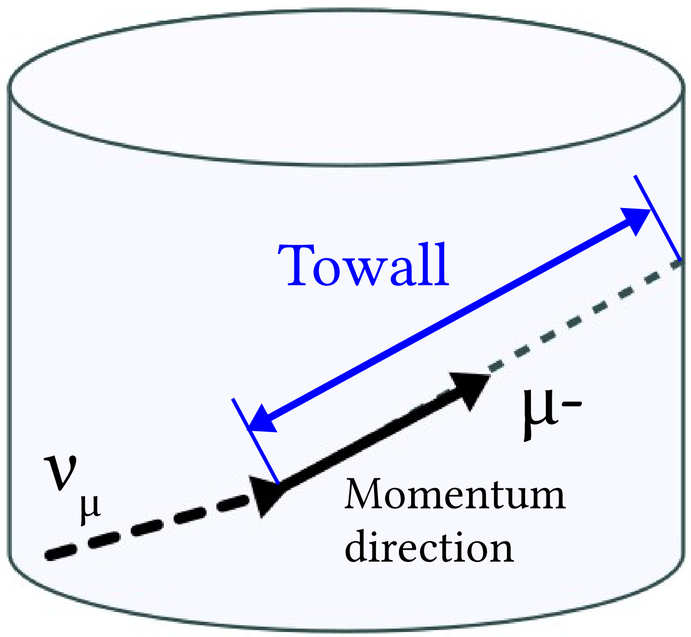
  ⟶ Higher event reconstruction performance near the detector wall

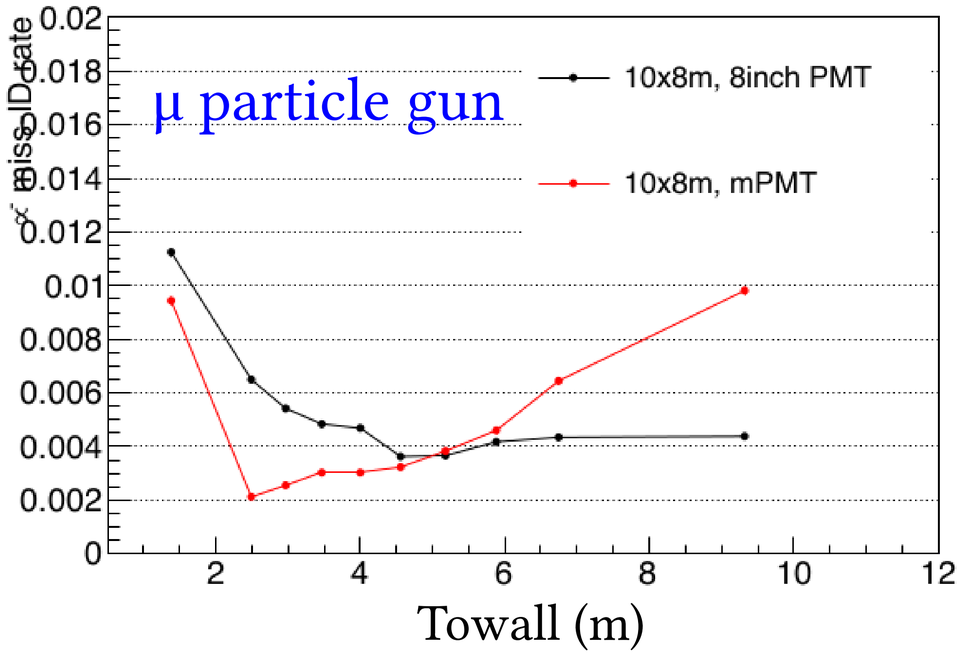
Reconstruction performance

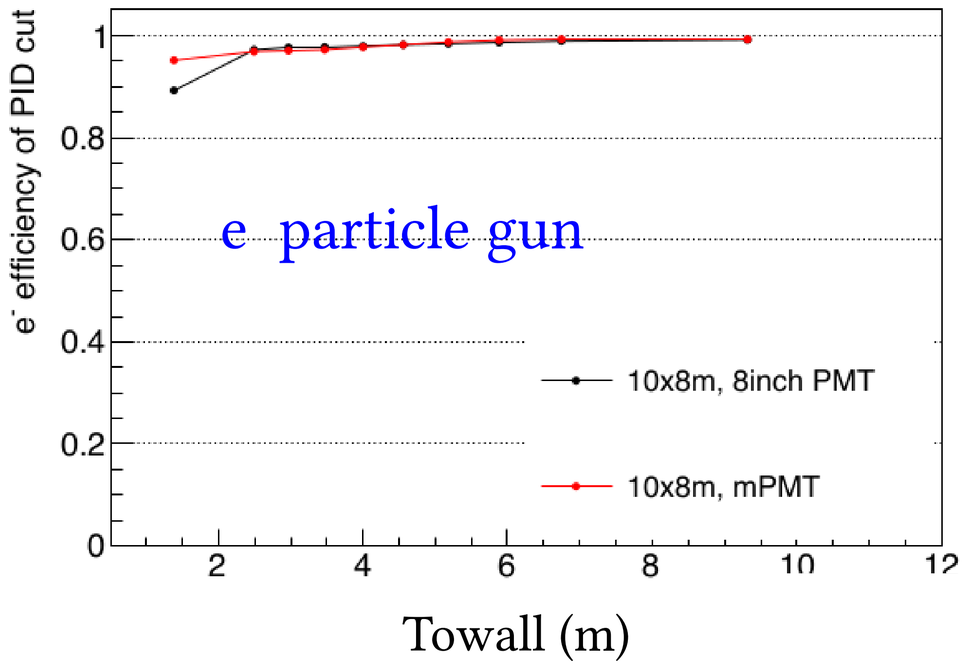
- $\nu_e/\bar{\nu}_e$ fluxes make up only ~1% of the total beam flux

  → e/μ separation is particularly important for $\nu_e/\bar{\nu}_e$ cross-section measurements

- mPMT provides better e/μ separation near the wall







Use of mPMT

◆ 3” PMTs for event reconstruction

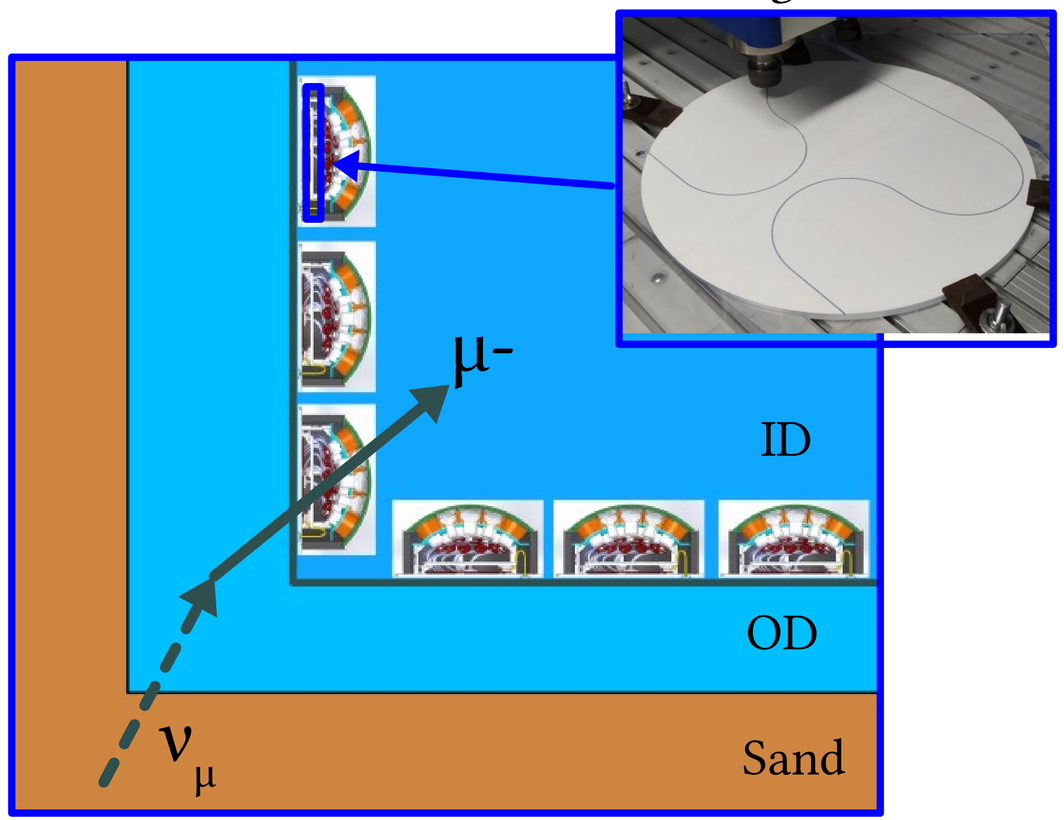
- Granularity for particle identification
- Timing resolution for vertexing
- Gain for momentum estimation

◆ LEDs for detector calibration

- Fast pulsed LED (0.6 ns FWHM) for PMT’s timing offset and light scattering measurements
  - 230 – 700 nm available
- Continuous LEDs for in-situ measurements of mPMT’s positions by photogramatery technique

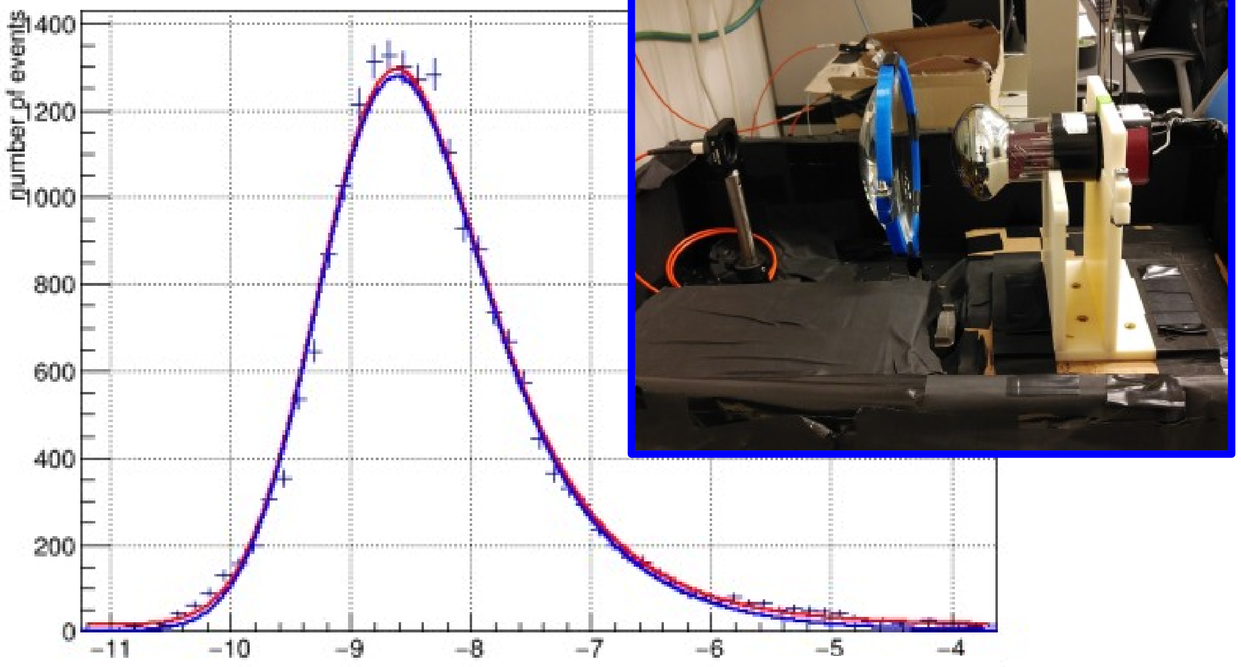
◆ Scintillator plates for OD veto

- Tagging charged particles crossing from the OD to ID regions

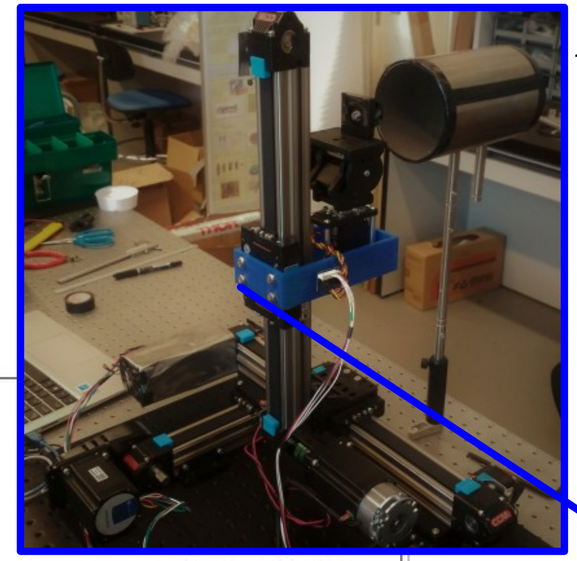


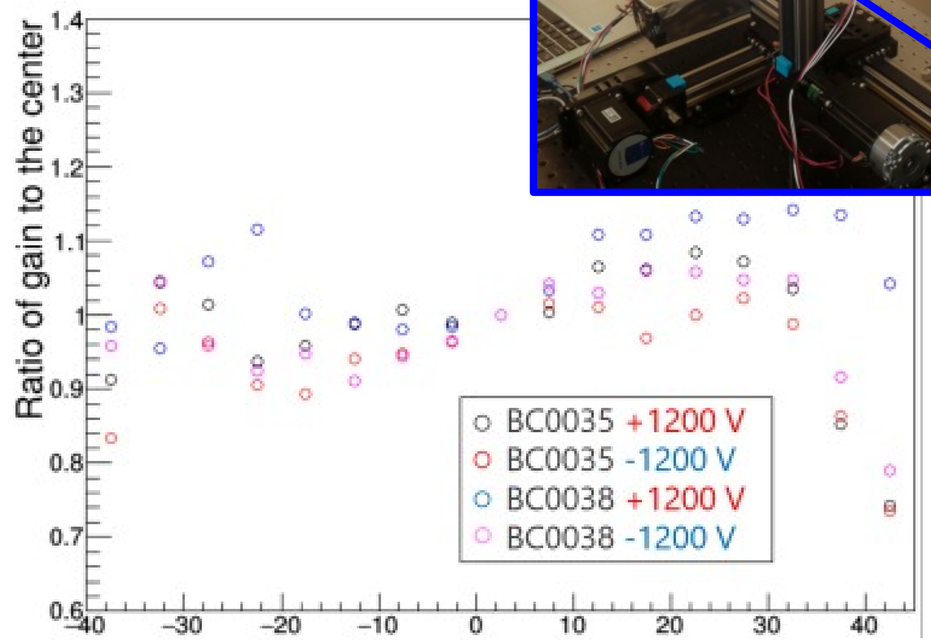
Timing resolution & Relative gain

Timing resolution



Gain vs position

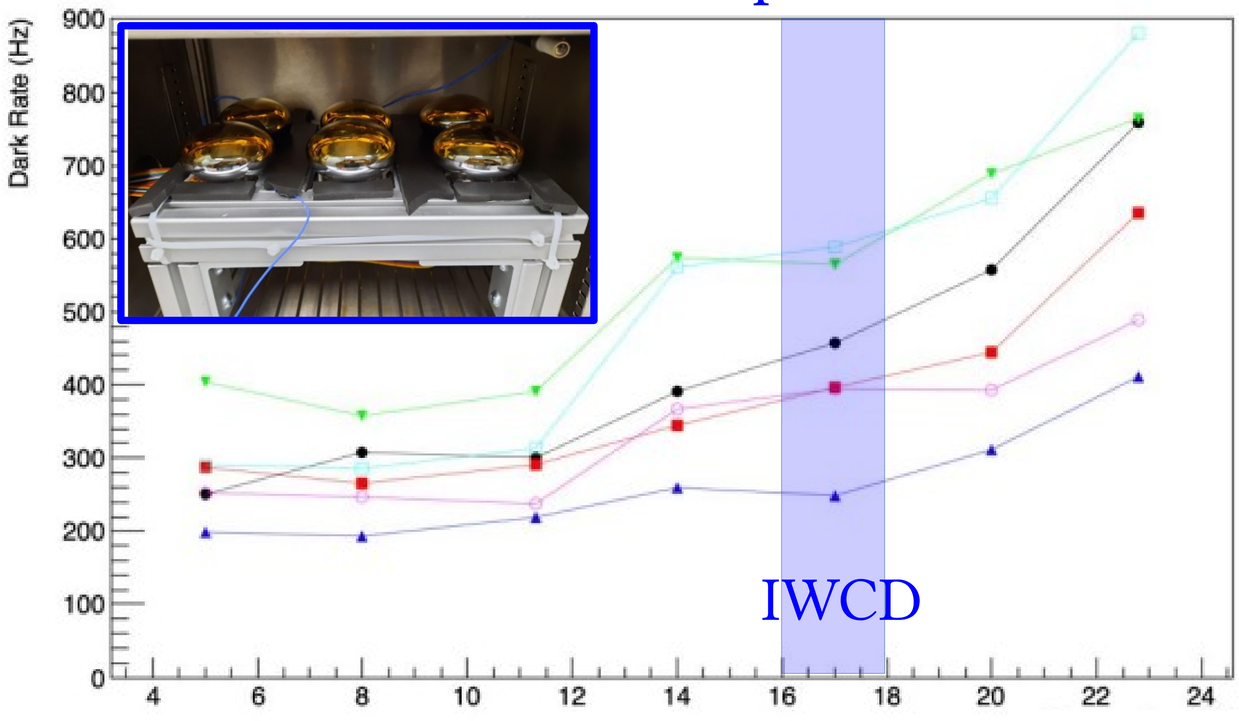




- Measured timing resolution at 1 p.e. level is 1.5 ns (FWHM)
- Measured gain was uniform within ~10%, depending on the dynode orientation

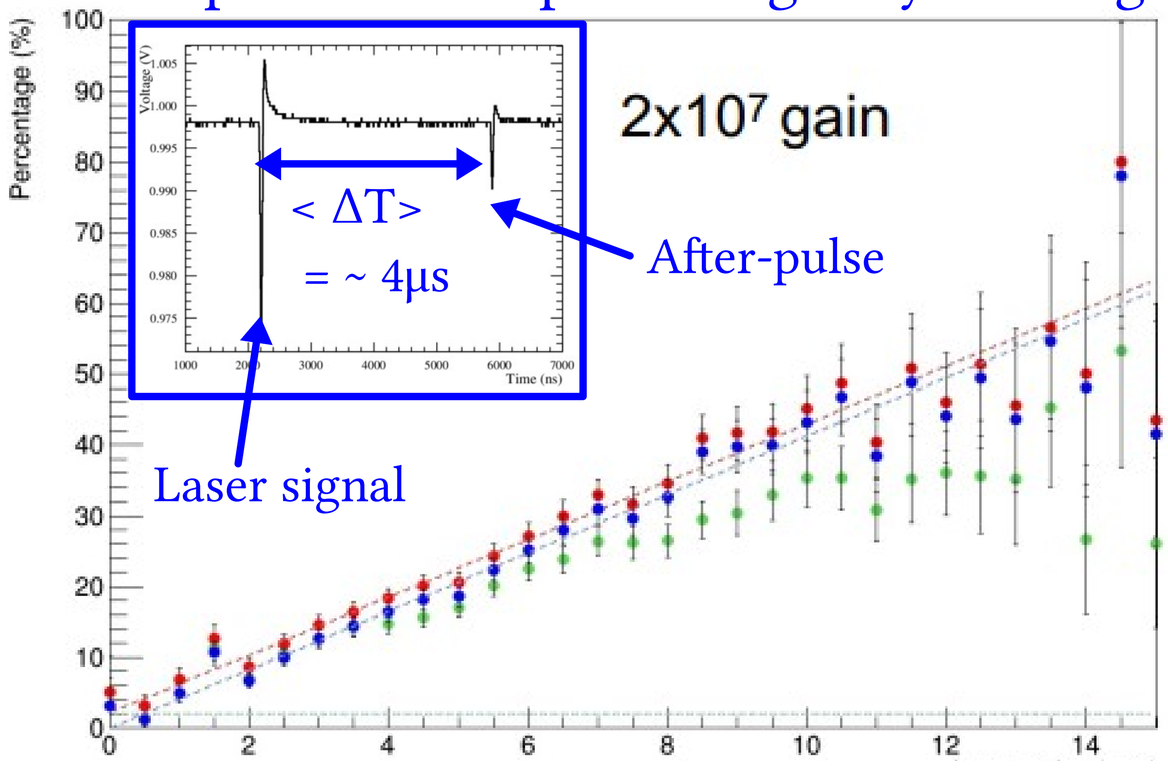
Single PMT measurements: dark rate & after-pulse

Dark rate vs temperature



Temperature (C°)

After-pulse rate vs pulse height by laser light

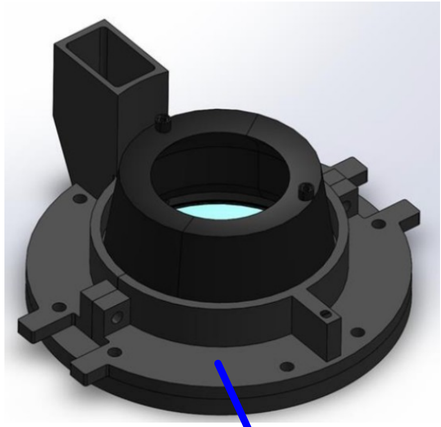


Prompt pulse height (photoelectrons)

- Measured dark rates are lower than 1 kz, which satisfies the requirement
- Measured after-pulse rate is acceptable

Mechanical assembly w/ ex-situ gelling

- 19 x 3” PMTs are individually gelled, using gelling mold
- The gelled PMTs are placed on the support matrix
- Acrylic dome and PVC cylinder are lowered onto matrix and are screwed down to backplate
- Full contacts between the acrylic dome and 19 gelled PMTs have been achieved
- PMT measurements of a fully assembled module is ongoing



Mechanical assembly w/ in-situ gelling

- 19 x bare 3” PMTs are placed on the matrix, and acrylic dome and PVC cylinder are lowered on support matrix

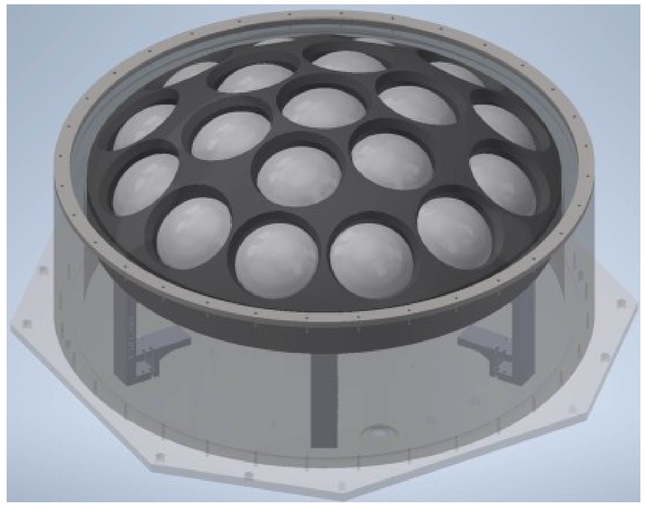
- The semi-assembled module is turned up-side down

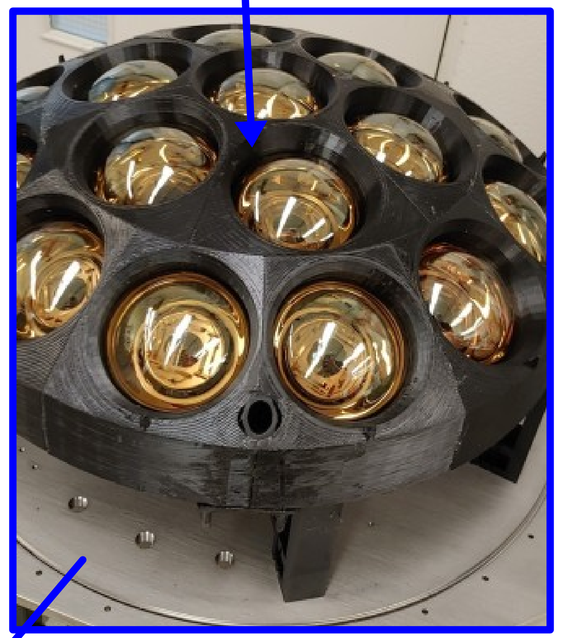
- Mixed gel is pored directly into the module, and backplate is attached to the module

- Results of full assembly test are encouraging

  - Further modifications are being made

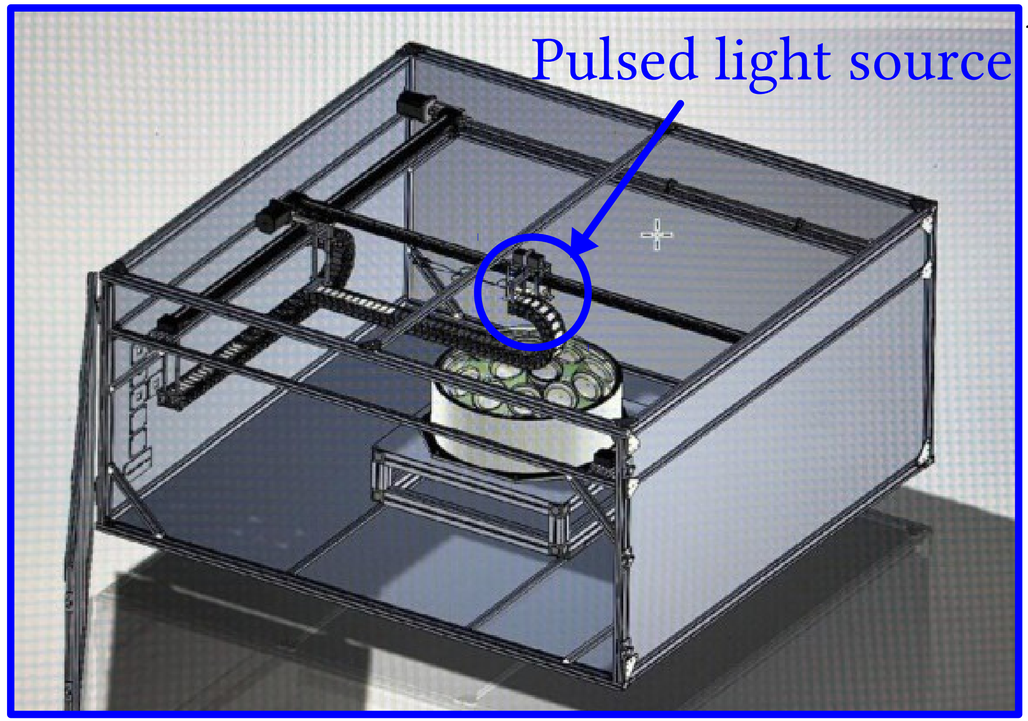
Conceptual design





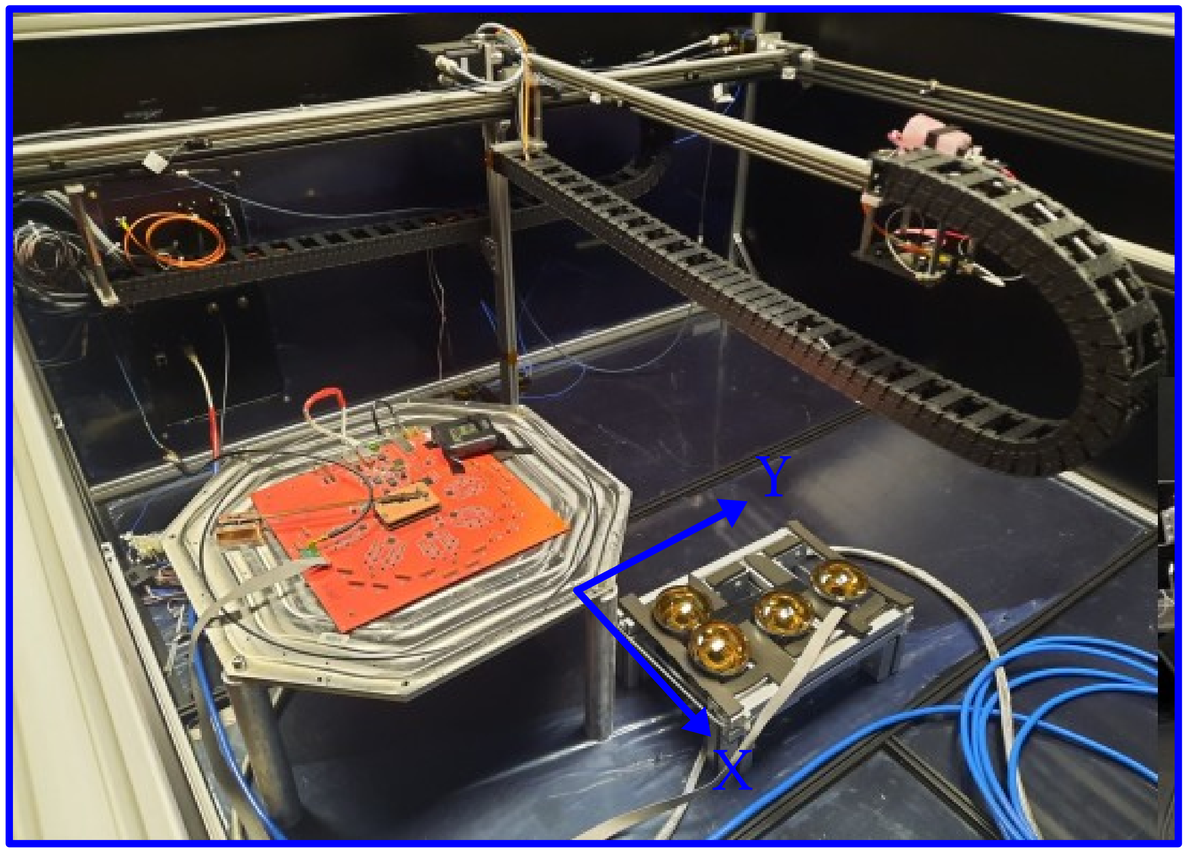
mPMT test stand

- Will calibrate 3” PMTs integrated in module by using a 2D gantry system with pulsed light source
  - High voltage
  - Gain/detection efficiency
  - Timing resolution

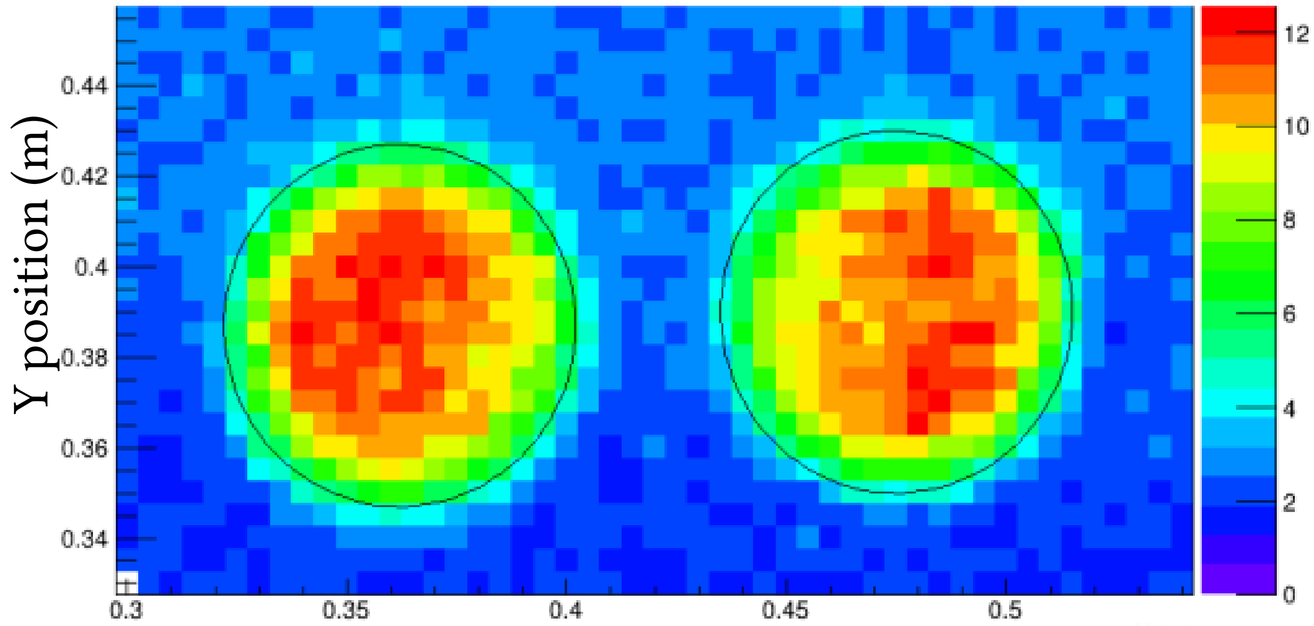


- A test stand being developed
  - Can operate with both uniform and collimated light sources, allowing position dependence measurements
  - Temperature controlled

mPMT test stand



Efficiency
(# pulses/# registered waveforms)



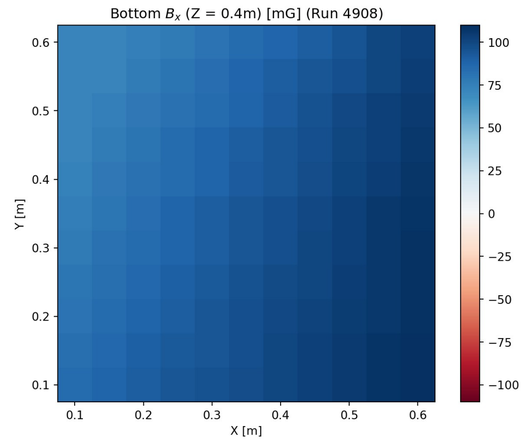
- Commissioning was done with bare 3” PMTs (i.e. no optical gel and no acrylic dome)
- Distinct two circles were observed, indicating that the system is working
- Initial scan for a fully integrated mPMT module is ongoing

Photosensor Test Facility

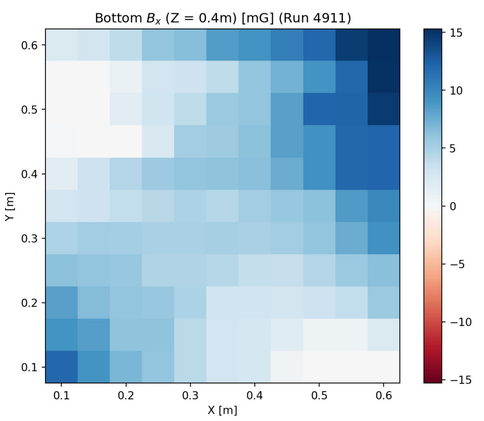
- This facility enables making further detailed measurements in water
  - Can measure magnetic field/polarization dependence
- Currently Super-Kamiokande's 20" PMT is being measured
  → mPMT module will be measured

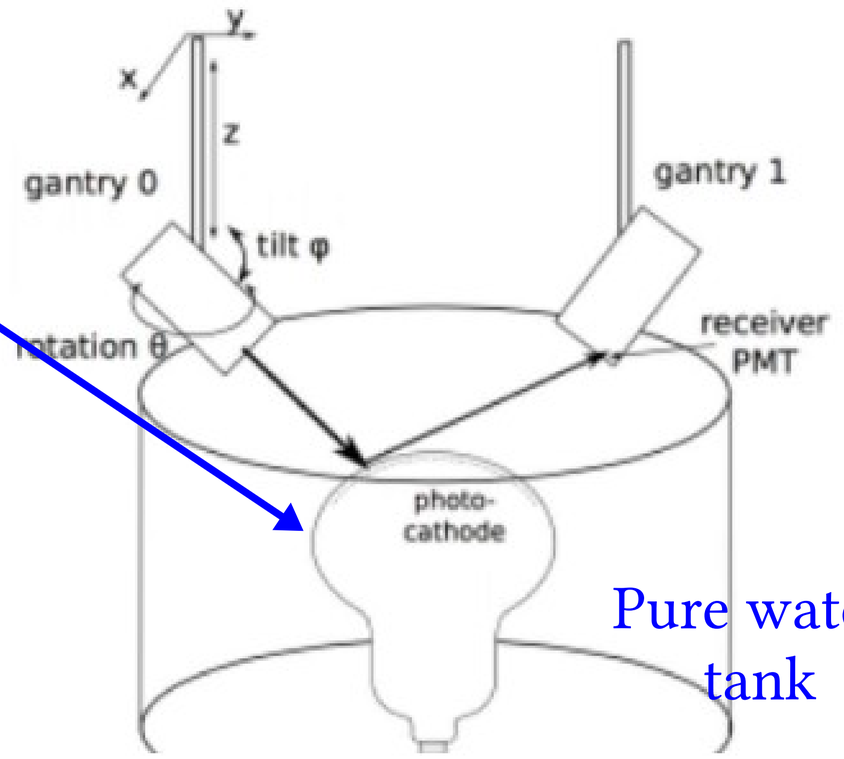
B-filed compensation

w/o



w/





Summary

- The size of the IWCD detector will be much smaller than the Hyper-K detector.
- Thus, IWCD is required to use photosensor that has higher granularity and better timing resolution compared to the 20” PMT used in the Hyper-K detector
- Multi-PMT module consisting of 19 x 3” PMTs has been developed and can be used in many different ways: event reconstruction, detector calibration, and OD veto
- Module assembly methods have been developed and PMT measurements with a fully integrated module is ongoing
- ~100 mPMT modules will be produced and be tested with the WCTE detector in the water Cherenkov test experiment before the IWCD experiment

Backup