

Hyper-Kamiokande: progress and prospects with IWCD

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Rencontres du Vietnam 2025



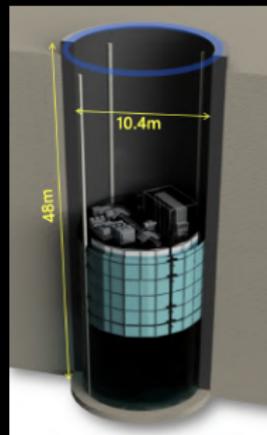
the Hyper-Kamiokande experiment



- ▶ **J-PARC beam:** ν_μ and $\bar{\nu}_\mu$ beam, 600 MeV, power upgraded to reach 1.3 MW
- ▶ **near detectors:** 280 m, measure before oscillations, tune fit, reduce systematics to 3%
- ▶ **IWCD:** 850 m downstream, water Cerenkov like far detector
- ▶ **far detector:** Hyper-Kamiokande, 295 km

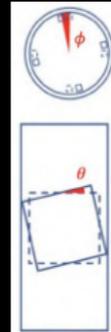
Intermediate Water Cerenkov Detector

- ▶ water Cerenkov cylinder (like FD)
- ▶ 850 m downstream
 - ▶ one more point for matching near/far fluxes
 - ▶ reduce pile-up wrt ND
- ▶ located on surface, in 50 m pit



monitor
position

< 1 mrad



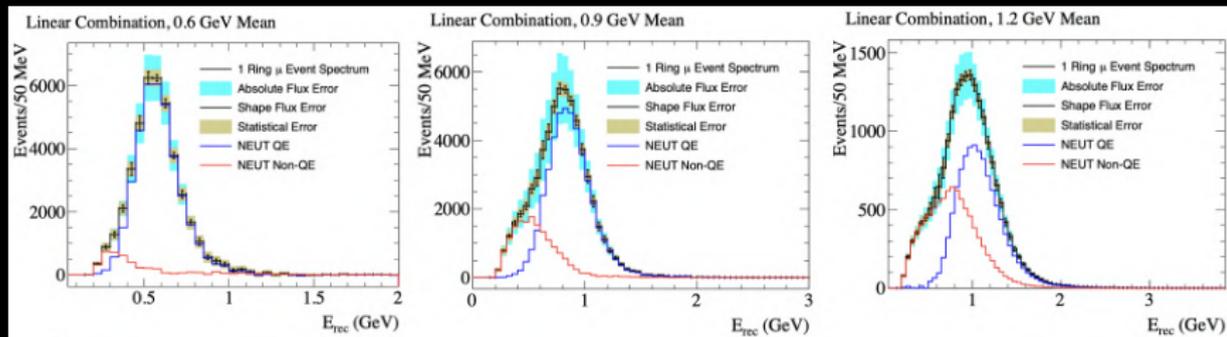
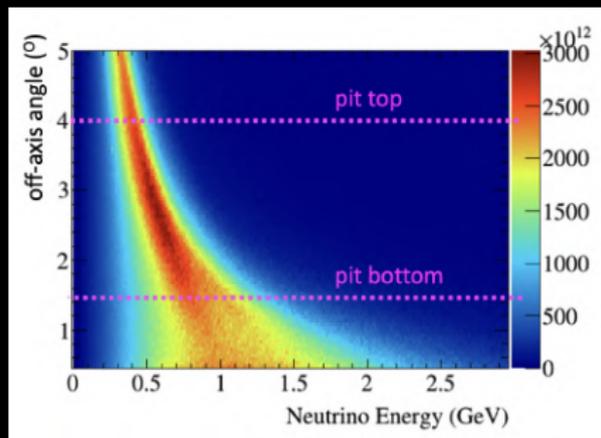
ID diameter	7 m
ID height	8 m
water mass	640 t
ID mPMTs	368
OD PMTs	368

this is a picture of the
half-sized prototype...

more on this later!

concept of spanning off-axis angles

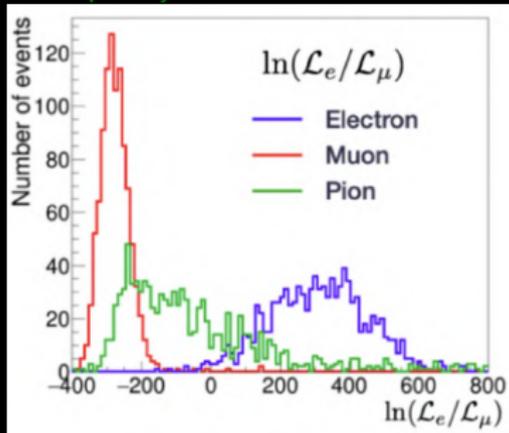
- ▶ IWCD can move to sample ($1^\circ, 4^\circ$) off-axis angles
 - ▶ 2.5° in HK
- ▶ different energy spectrum at different off-axis positions
- ▶ linear combinations result in “mono-energetic” beams
- ▶ also, hard to measure ν_e and $\bar{\nu}_e$ components at peak energy
 - ▶ only 0.5% of beam flux
- ▶ higher off-axis angle \rightarrow larger intrinsic ν_e and $\bar{\nu}_e$ rate



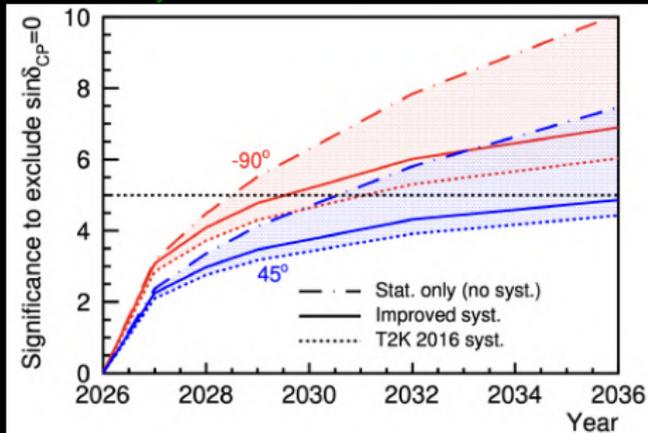
the goal of fighting systematic errors

- ▶ ν_e cross-section is the main systematic error on δ_{CP}
- ▶ IWCD can measure ν_e and ν_μ cross section, as a function of energy
- ▶ identical nuclear target to FD removes need for subtraction analysis
- ▶ measure ratios $R = \sigma(\nu_e)/\sigma(\nu_\mu)$ and $\bar{R} = \sigma(\bar{\nu}_e)/\sigma(\bar{\nu}_\mu)$
- ▶ crucial for HK to know R/\bar{R} to 3-4%
- ▶ also, essential to measure intrinsic ν_e , NC backgrounds

PID capability



HK sensitivity to CP violation

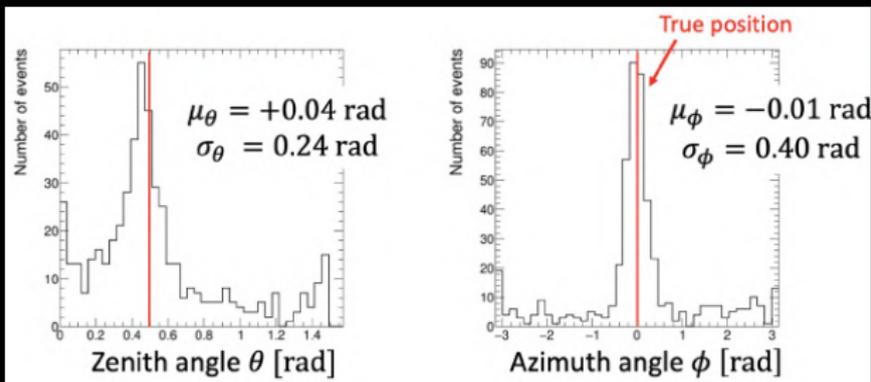
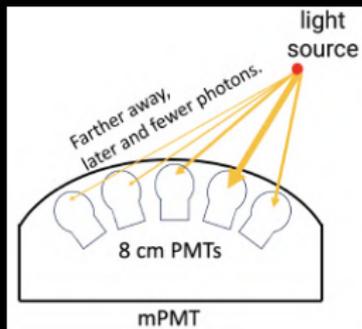


mPMTs

- ▶ 368 ID mPMTs (same as FD)
- ▶ concept from KM3NeT
- ▶ module with 19 8 cm PMTs
- ▶ good spatial resolution and timing (1.8 ns FWHM)
- ▶ economical
- ▶ little magnetic field sensitivity
- ▶ directional sensitivity from variation in detection time and n.p.e



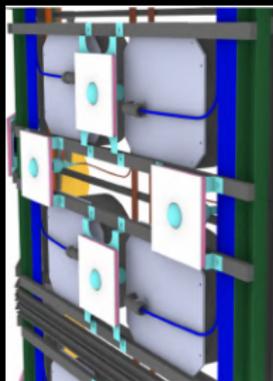
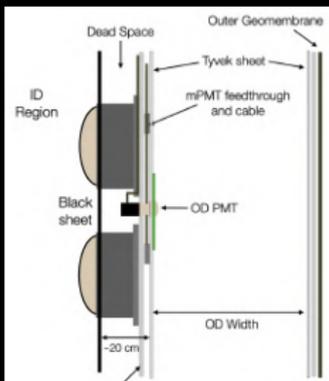
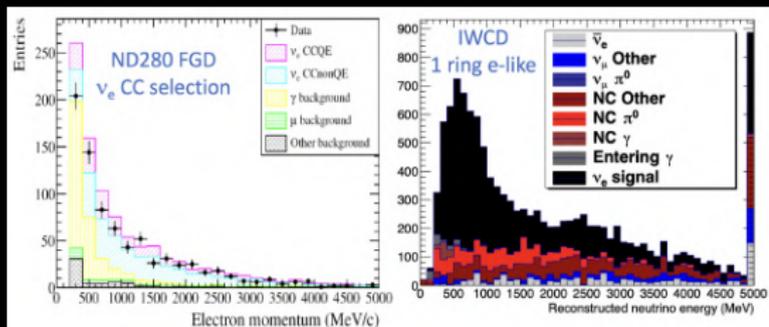
11 degrees pointing from each mPMT module



IWCD OD

OD goals:

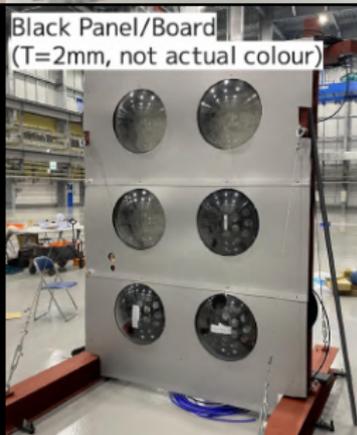
- ▶ veto external bkg
 - ▶ cosmic μ flux: 5 kHz
 - ▶ external γ in ν_e selection
- ▶ determine if ID events is contained
- ▶ identify pile-up events
 - ▶ beam bunch gap: 500 ns



OD structure:

- ▶ OD thickness: 0.7 m
- ▶ 368 PMTs pointing outwards
- ▶ 8 cm PMT embedded in WLS plate
 - ▶ same as FD OD
- ▶ reflective Tyvek on all OD walls
- ▶ electronics and HV outside of water

mock frame @ J-PARC

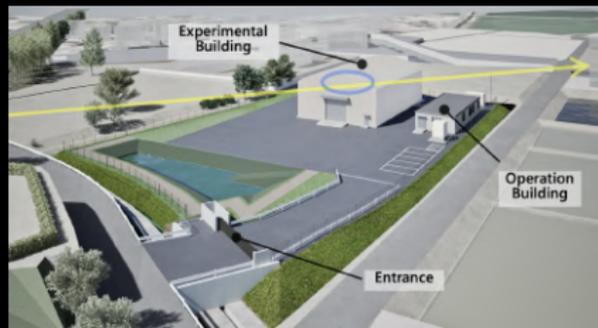


test:

- ▶ design
- ▶ assembly
- ▶ installation
- ▶ materials

status of IWCD facility

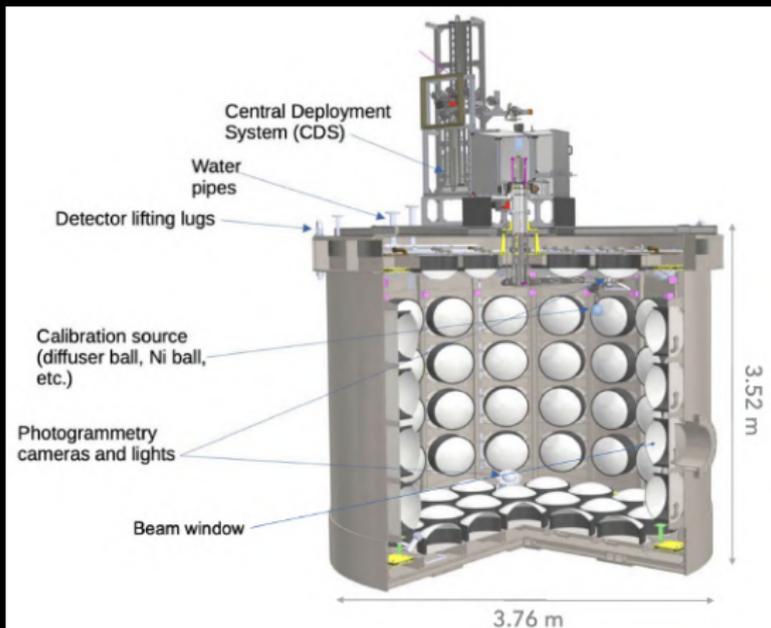
- ▶ newly constructed outside of J-PARC area
- ▶ 50 m pit, 850 m downstream
- ▶ civil construction started in March 2025
- ▶ start pit excavation in current summer
- ▶ completion of civil construction 2027



Water Cerenkov Test Experiment @ CERN

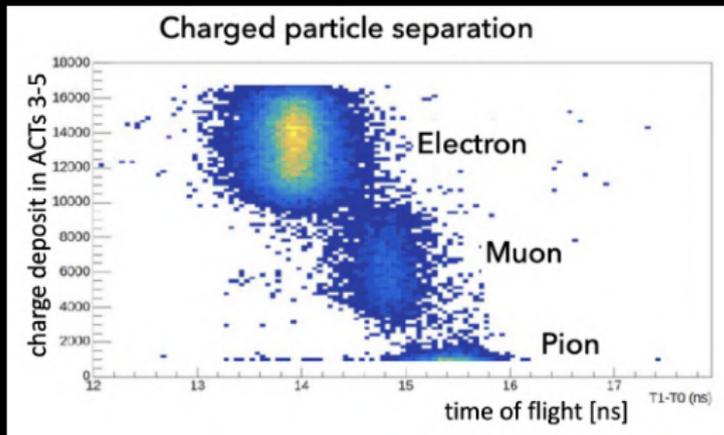
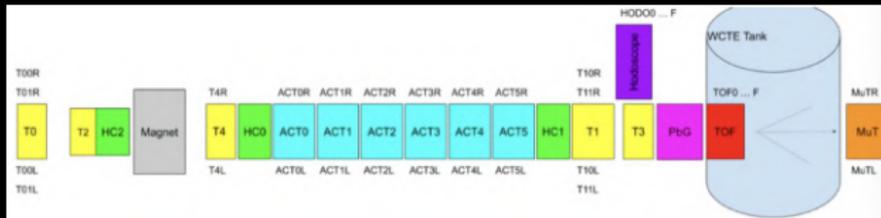
- ▶ a prootype for IWCD
 - ▶ same photonsensors, calibration and water system
- ▶ ID size is half of IWCD
- ▶ operated in CERN T9 (East Hall) beam line
- ▶ data taking 2024-2025

ID diameter	3.8 m
ID height	3.5 m
water mass	30 t
mPMTs	93



WCTE beam

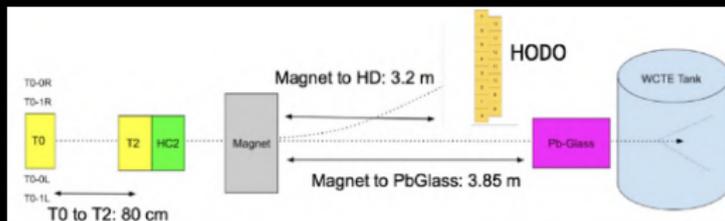
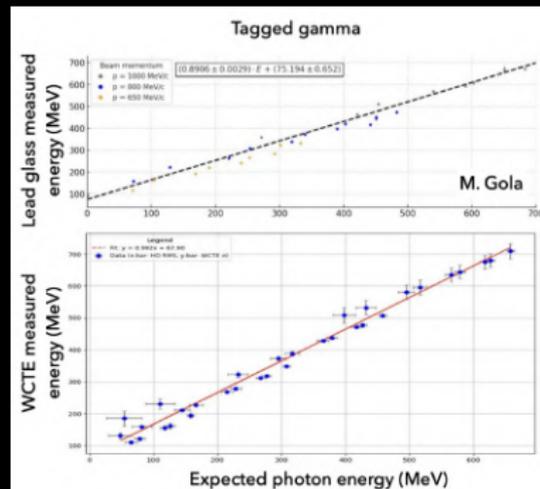
- ▶ particles:
 $e^\pm, \mu^\pm, \pi^\pm, p^+$,
tagged γ
- ▶ momentum:
0.2 – 1.1 GeV/c



- ▶ beam detectors:
 - ▶ scintillators
 - ▶ hole counters
 - ▶ aerogel Cerenkov threshold
 $n = 1.01 - 1.15$
 - ▶ TOF detectors
- ▶ event by event, beam detectors:
 - ▶ identify charged particles
 - ▶ measure momentum
 - ▶ provide WCTE trigger

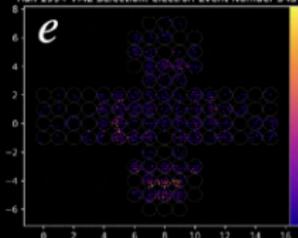
WCTE physics goals

- ▶ measure e/μ scattering on nuclei
 - ▶ constrain nuclear models
 - ▶ needed for ν scattering with nucleon(s)
- ▶ study π interaction in water
 - ▶ absorption, charge exchange, QE
 - ▶ challenging to model
 - ▶ impact on T2K and SK analysis
- ▶ study e/γ separation
 - ▶ γ 's are bkg in ν_e and $\bar{\nu}_e$ candidates
 - ▶ tagged γ from e bremsstrahlung
 - ▶ bent e measured in hodoscope spectrometer
- ▶ γ 's also used to study π photoproduction in water

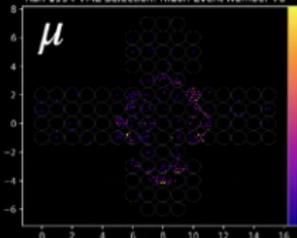


WCTE as a demonstrator

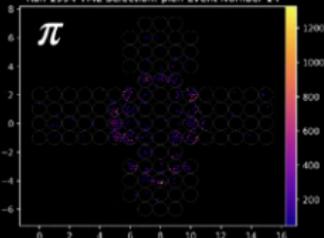
Run 1994 VME Selection: electron Event Number 543



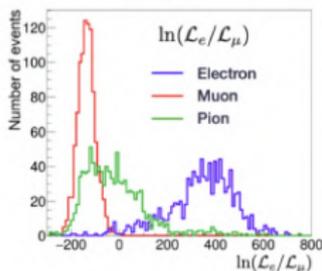
Run 1994 VME Selection: muon Event Number 78



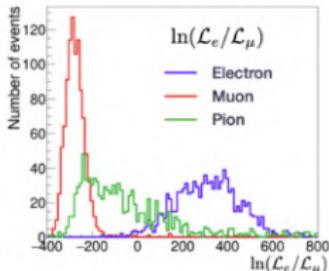
Run 1994 VME Selection: pion Event Number 14



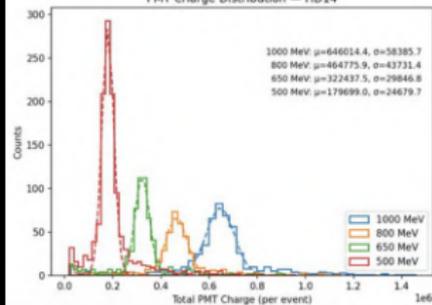
WCTE



IWCD

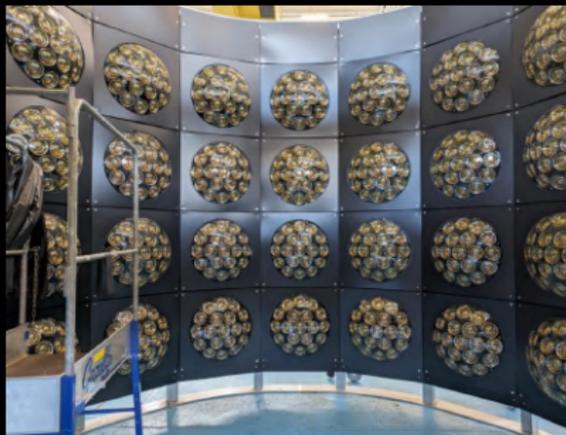
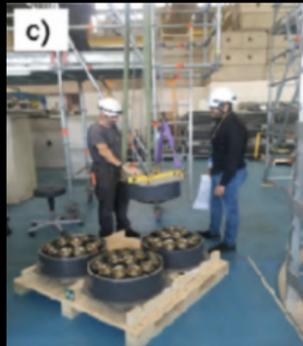


PMT Charge Distribution — HD14



- ▶ demonstrate $e/\mu/\pi$ PID capability
- ▶ study $e/\mu/\pi^0$ energy reconstruction in water Cerenkov detector

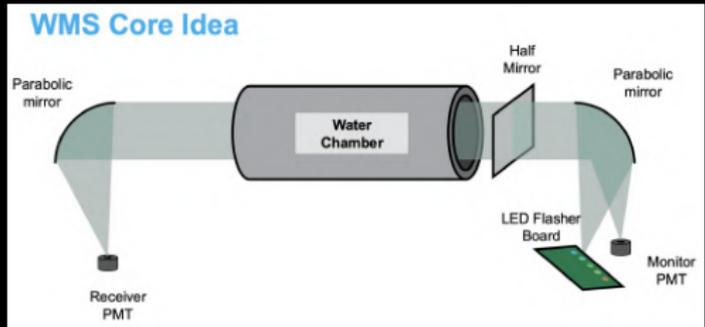
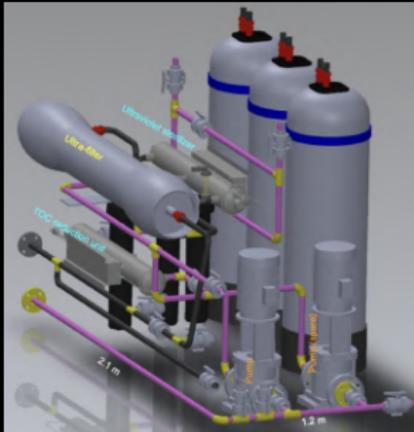
WCTE assembly @ CERN



- ▶ commissioned Oct 2024
- ▶ data taking 2024-25
- ▶ disassembled June 2025

water system and water monitor

- ▶ IWCD water temperature: $16 - 17^\circ$
- ▶ no water resonance if earthquakes
- ▶ water purification: 2 t/hr (WCTE), 6 t/hr (IWCD)

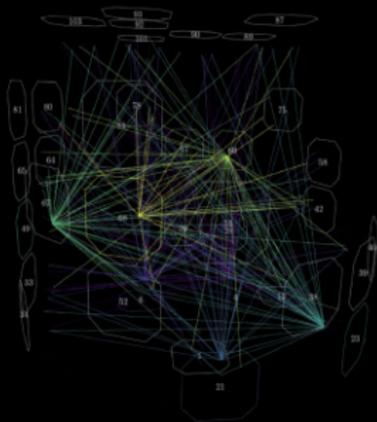


- ▶ monitor transporence within $< 1\%$
- ▶ 8.6 m long water chamber
- ▶ 220-410 nm LED (UV to detect bacteria and organic contaminants)
- ▶ 0.15 p.e. level, ideal for photon counting
- ▶ double ratio between experimental water and reference ultra-pure water

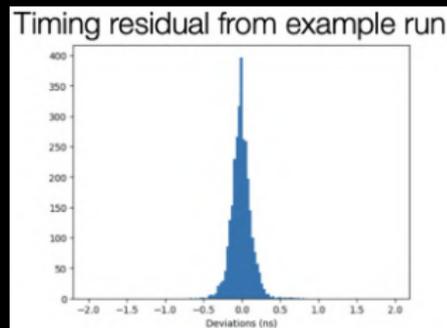
LED calibration



- ▶ each mPMT contains 3 fast-pulsing LEDs (365, 405, 470 nm)
- ▶ one diffuse, two collimated
- ▶ calibrate SPE gain and charge distribution

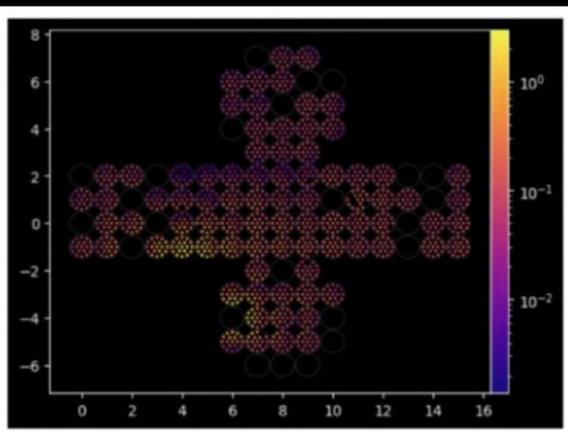
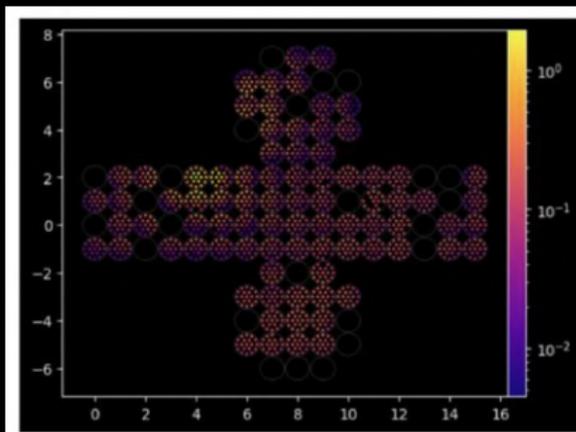
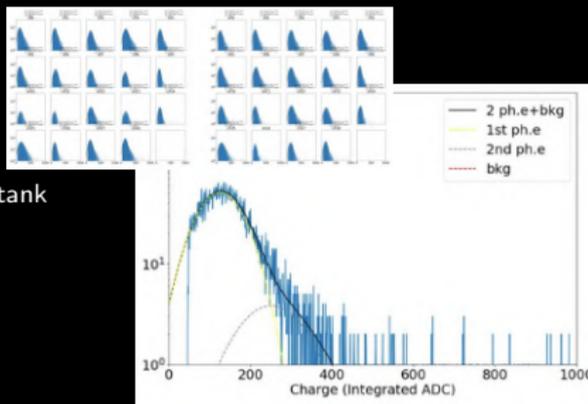


- ▶ pulse LED
- ▶ measure Δt between emission (PMT1) and detection (PMT2)
- ▶ calibrate Δt within < 0.5 ns



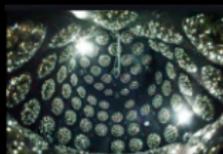
laser light injectors

- ▶ laser ball introduced at 9 different positions in tank
- ▶ measure charge distribution for different PMTs
- ▶ fit bkg, 1 p.e. and 2 p.e. peaks
- ▶ extract gain

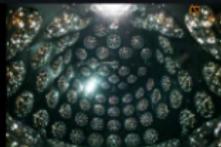


photogrammetry program

- ▶ 8 photogrammetry cameras in WCTE
- ▶ can take video and pictures
- ▶ observe water filling and draining
- ▶ check PMTs positions
- ▶ monitor source deployment
- ▶ discover injection of bubbles from air leak



PCH1



PCH2



PCH3

PCH4



PCH8



PCH7



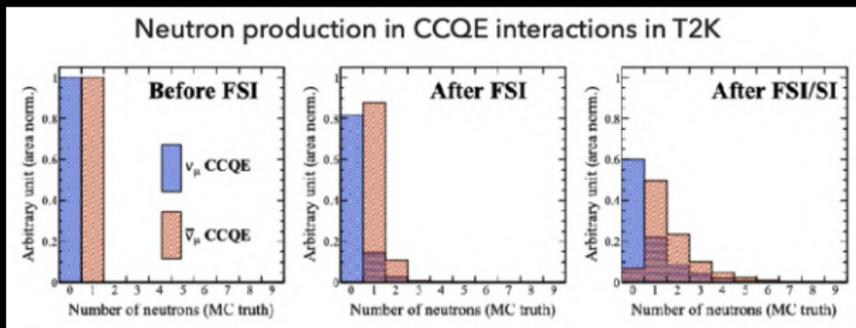
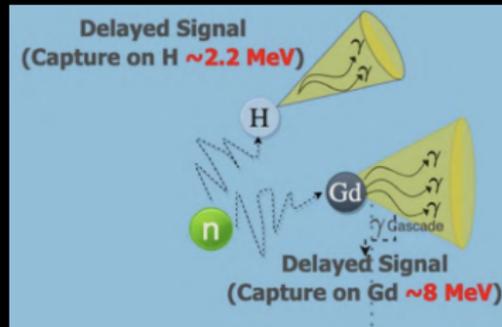
PCH6



PCH5

adding gadolinium

- ▶ Gd enhances neutron capture and makes it visible
 - ▶ loaded in SK since 2020
- ▶ tag neutrons to separate ν from $\bar{\nu}$
 - ▶ mainly ν makes p^+ , $\bar{\nu}$ makes n



constrain nuclear models

- ▶ neutron production from 2p-2h in QE
- ▶ alternative approach to experiments with thin targets

measure secondary neutrons

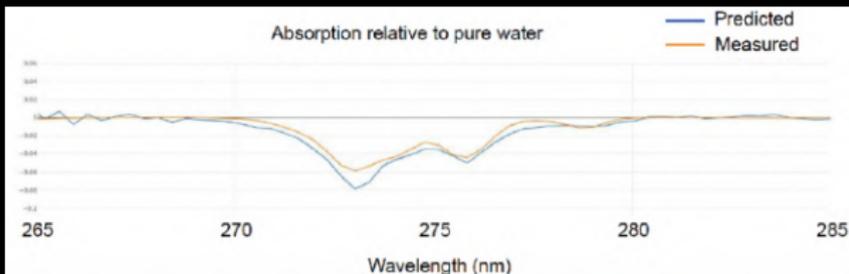
- ▶ produced in water from p^+ , stopped μ^- and π^\pm
- ▶ important for using n to ID $\bar{\nu}$ events in SK

WCTE Gd phase

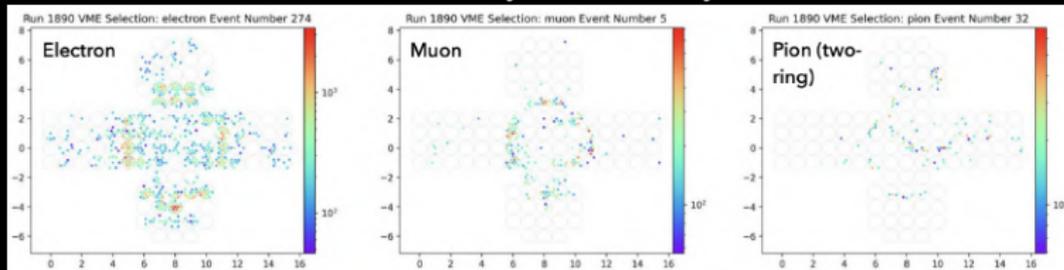
- ▶ 9 days of Gd data (May 2025)
- ▶ Gd 0.03% as $Gd_2(SO_4)_3$
- ▶ 75% n capture on Gd
- ▶ 64 μs n lifetime



Gd is mixed using motorized mixer in Gd-mixing tank



data analysis underway



Summary

- ▶ HyperKamiokande is the next-generation neutrino experiment
 - ▶ 8× larger than SK
 - ▶ improved photo-sensors
 - ▶ upgraded 1.3 MW beam
 - ▶ excavation ongoing
 - ▶ construction 2026-7
 - ▶ turn on 2028



- ▶ IWCD
 - ▶ intermediate between near and far detectors
 - ▶ water Cerenkov like FD
 - ▶ movable to sample different off-axis angles
 - ▶ crucial to reduce systematic errors

Back-up slides