Report from A01

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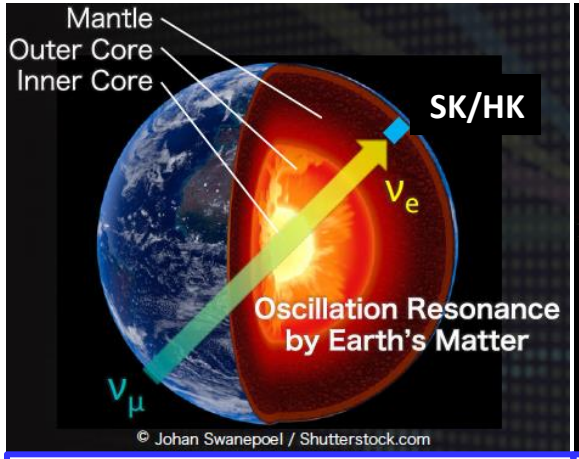
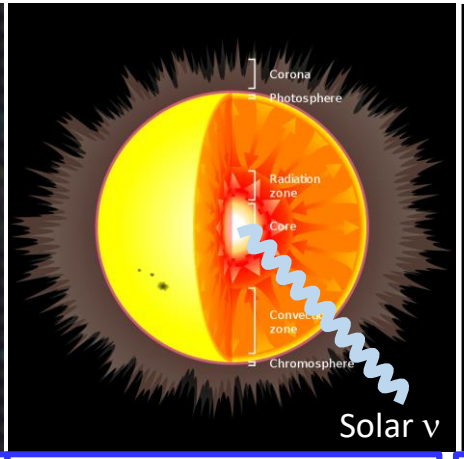
for A01 members

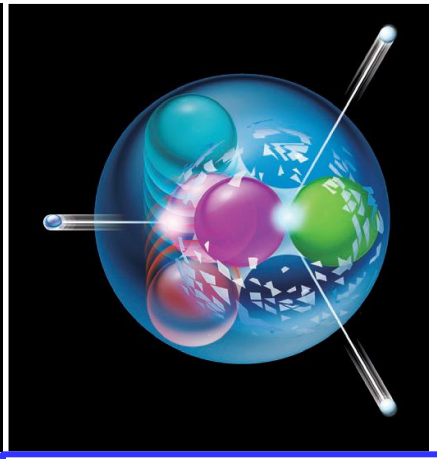
Physics targets of A01

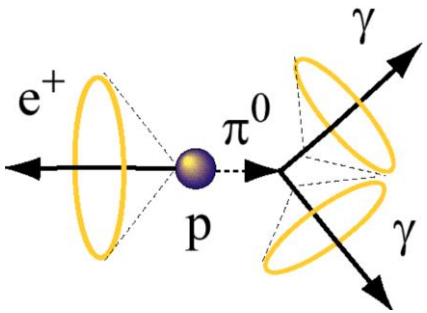
- Neutrino mass hierarchy using the atmospheric neutrino
- CP violation in lepton sector
  using the atmospheric and accelerator neutrinos (with A02)
- Matter effects using the solar neutrino
- Comprehensive search for the proton decay

- R&D to maximize the performance of Hyper-Kamiokande









Atmospheric neutrino Mass hierarchy (CP violation with T2K)	Solar neutrino Matter effects New physics?	Proton decay (Grand Unification Theory)

Neutrino oscillation studies using atmospheric ν

High statistics atmospheric neutrino data

Possibility in observing small distortion in ν_e

Difference in # of electron events:

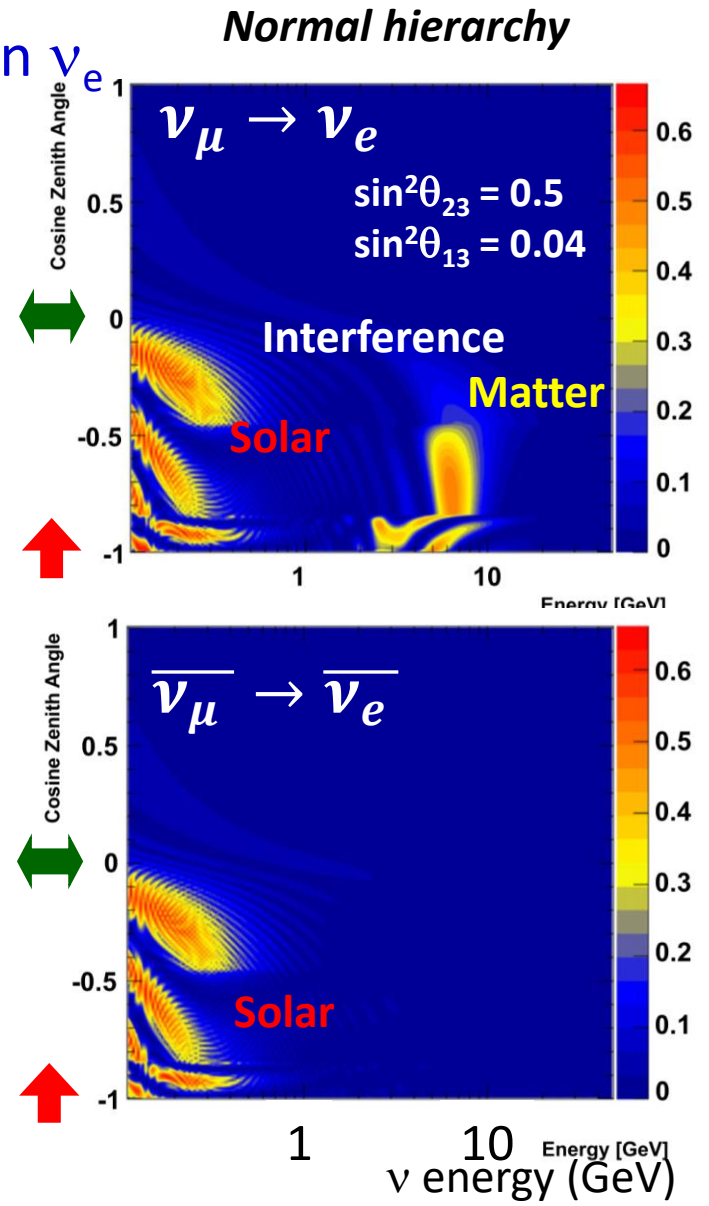
$$\Delta_e \equiv \frac{N_e}{N_e^0} \cong \Delta_1(\theta_{13}) + \Delta_2(\Delta m^2_{12}) + \Delta_3(\theta_{13}, \Delta m^2_{12}, \delta)$$

⬅ Matter effect

⬅ Solar term

⬅ Interference

- Matter effect; mass hierarchy
  Possible enhancement in several GeV passed through the earth core
  One of the flavors (ν_e or $\bar{\nu}_e$) shows this enhancement.
- Solar term; θ_{23} octant degeneracy
  Possible ν_e enhancement in sub-GeV
- Interference: CP phase



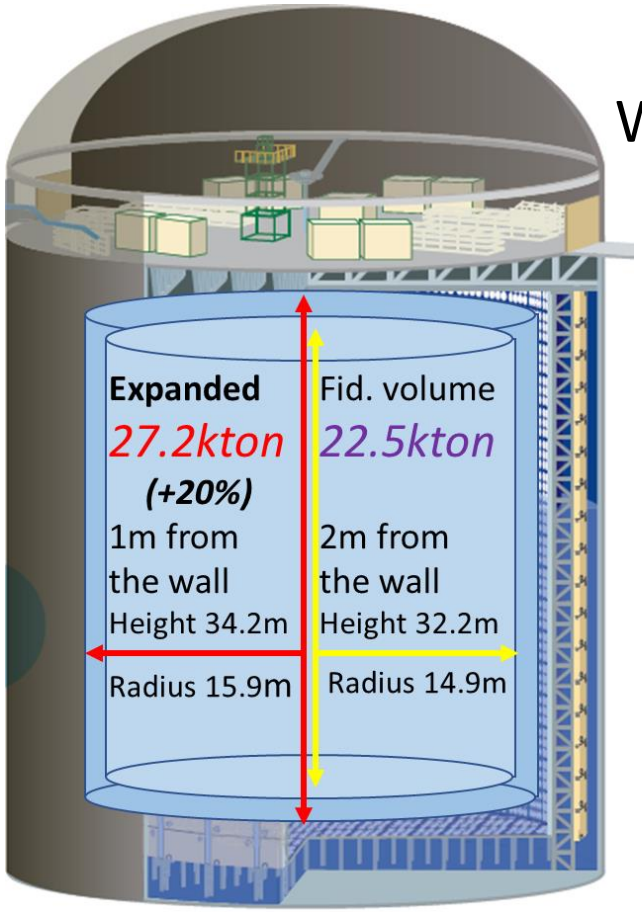
Improvements of analysis ~ event reconstruction

Accumulated data at the end of SK-IV is ~6,000 days.

However, we need more statistics

Neutrino oscillation parameter determination,

Mass hierarchy, nucleon decay…



We didn't use the events whose vertices are less than 2m from the wall. (22.5kton)

T2K analyses have already started to use ***the new reconstruction tool*** and expanded the fiducial volume.

Also, this new reconstruction tool has better particle (ring) finding efficiency and particle ID performances.

Reconstruction tools for atmospheric neutrino and proton decay were also improved and the fiducial volume is now expanded.

Super-Kamiokande; Proton decay searches

$p \to l^- \eta$, (Preliminary)
$(\eta \to 2\gamma \text{ or } \eta \to 3\,\pi^0)$

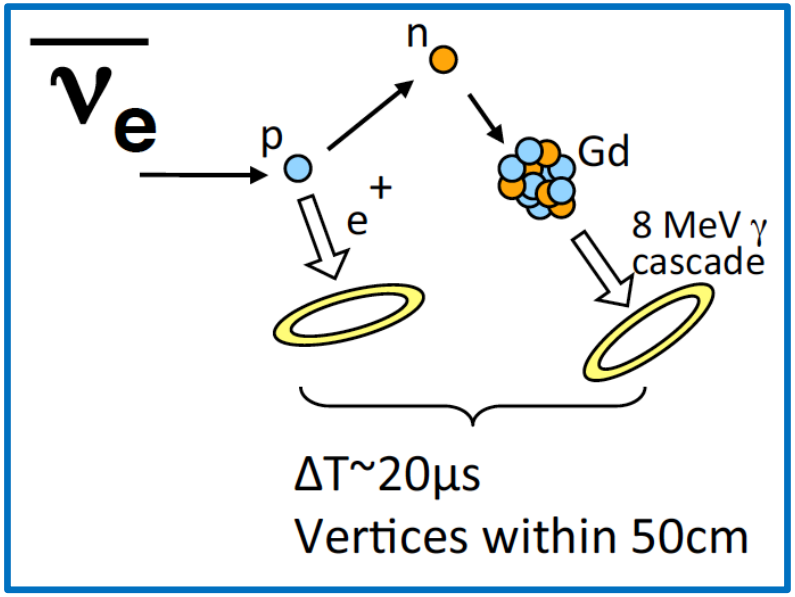
Modes	BG rate	Candidates	Probability	Lifetime (limit, yrs.)
$p \to e^- \eta$	0.42 ± 0.13	0	65.7	14.0×10^{33}
$p \to \mu^- \eta$	0.93 ± 0.25	2	23.9	7.3×10^{33}

$p \to \mu^- K^0$ (Preliminary)
$(K_S^0 \to 2\pi^0\,,\ K^0 \to \pi^+\pi^-, K_L^0 \to \pi^\pm l^\mp \nu, K_L^0 \to 3\pi^0, K_L^0 \to \pi^+\pi^-\pi^0)$

Modes	Candidates	Lifetime (limit, yrs.)
$p \to \mu^- K^0$	0	4.5×10^{33}

New analyses of $p \to \nu K^+$ and $p \to e^+\pi^0\pi^0$ are in progress.

Upgrade of the Super-Kamiokande detector (SK-Gd)

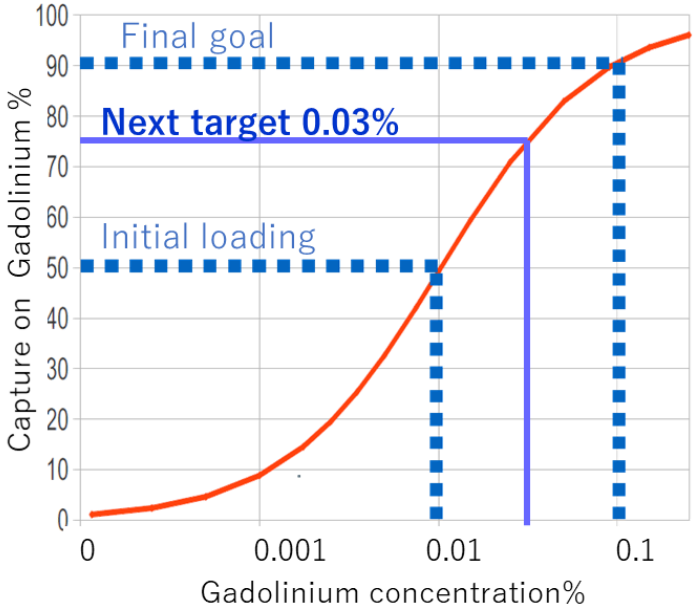


$$\bar{\nu}_e + p \rightarrow e^+ + n$$

Gadolinium captures neutron and emit **~ 8 MeV γ**

Detection efficiency of 8MeV γ ~ 100%

Add Gadolinium (Gd) to the SK water.



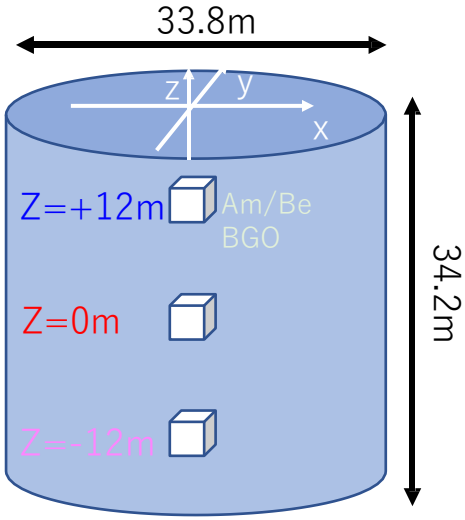
Neutrino / anti-neutrino discrimination

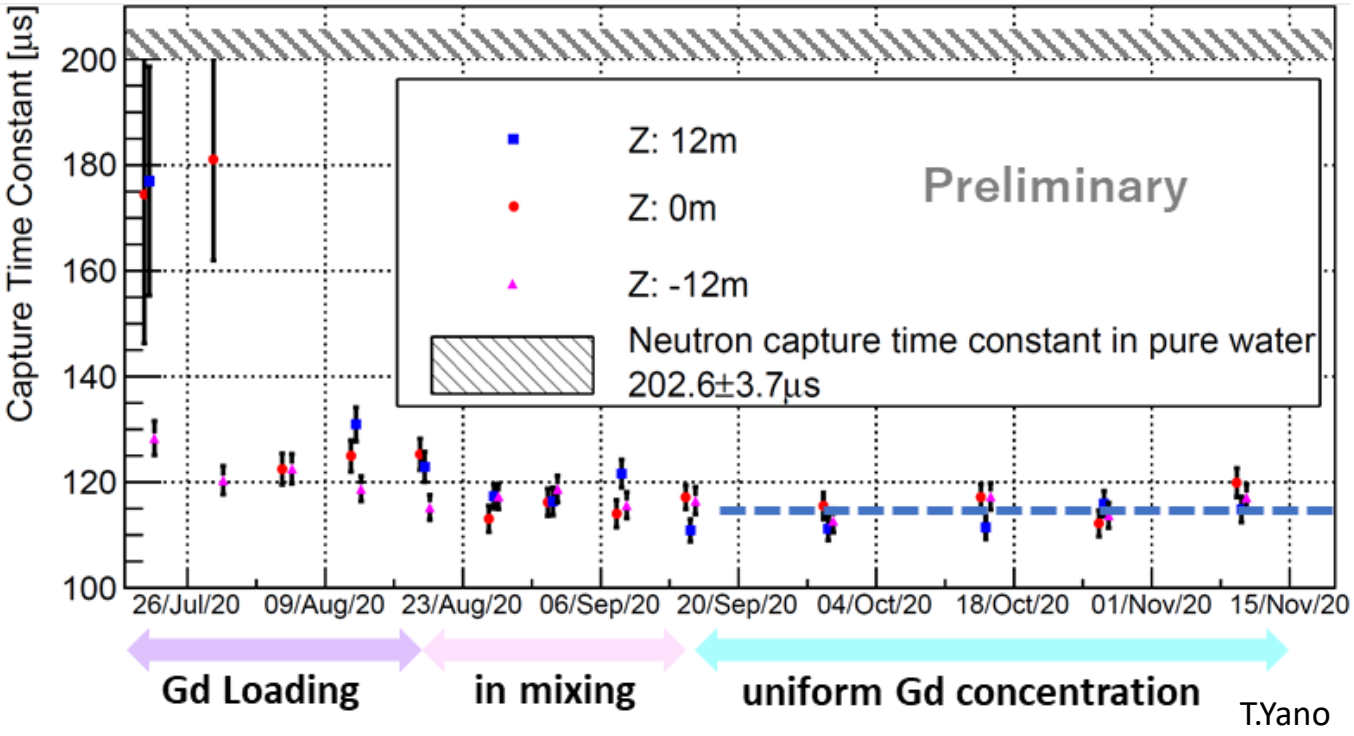
- Discovery of supernova(SN) diffuse ν search and pointing accuracy improvement for SN burst
- Improve Discrimination power of ν and $\bar{\nu}$ in T2K and atmospheric neutrino analyses
- Nucleon decay background rejection

Upgrade of the Super-Kamiokande detector (SK-Gd)

Study of Gd neutron capture using the Am/Be + BGO neutron source

Collect Am/Be data in various heights in SK.





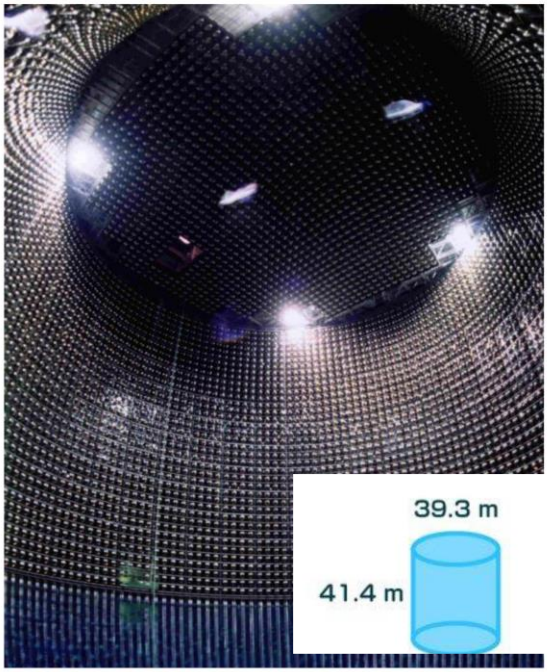
Neutron capture time (average) is found to be 115.6±0.6μs.
Derived Gd concentration using the capture time is 109.1±1.2 ppm,
which is consistent with the dissolved amount of Gadolinium.

Hyper-Kamiokande

Need much higher statistics

- Lepton CP violation (discovery, parameter measurement)
- Neutrino mass hierarchy
- Nucleon decay search (discovery, decay branch, branching ratio)
- Neutrino from astronomical objects (Sun, Supernova)

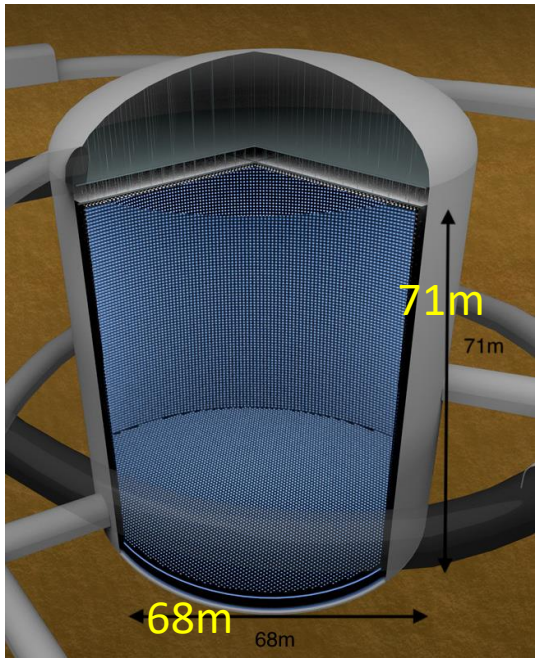
Super-Kamiokande



Fid. Vol. 22,500~27,000 tons

ID Photo sensors 11,146

Hyper-Kamiokande

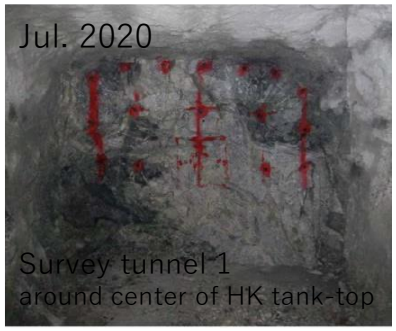


Fid. Vol. 190,000 tons

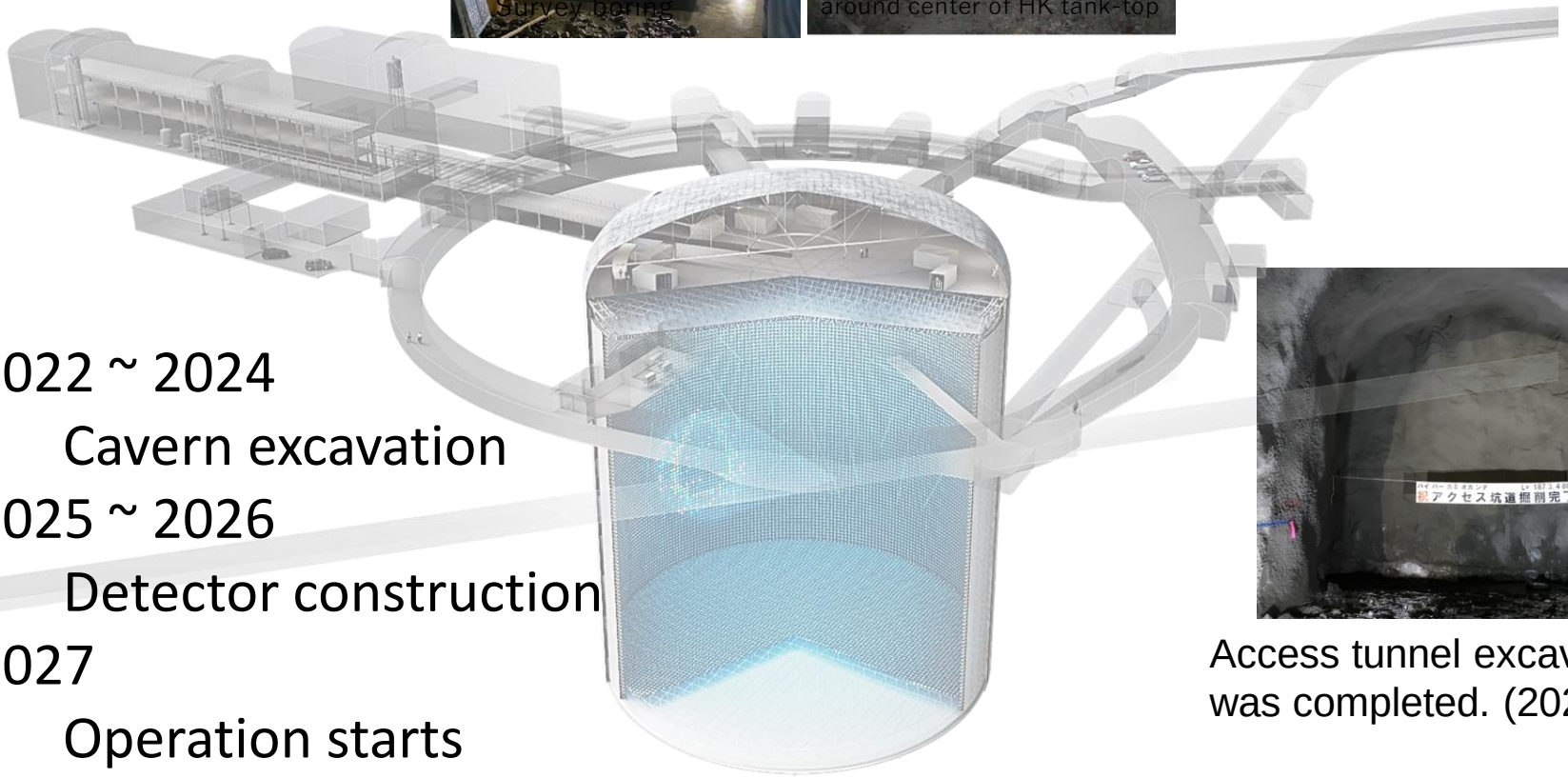
ID Photo sensors 20,000 + mPMT

Hyper-Kamiokande

Construction was started in 2020.



Entrance of the access tunnel



2022 ~ 2024

Cavern excavation

2025 ~ 2026

Detector construction

2027

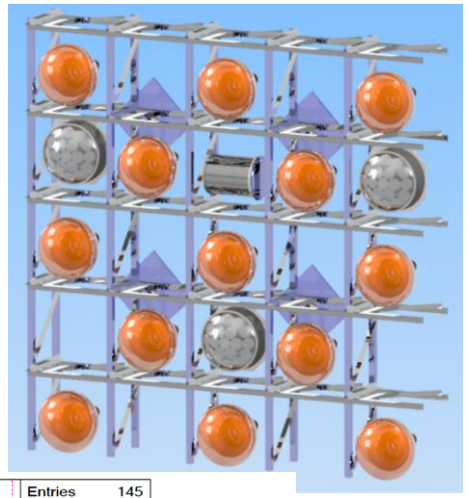
Operation starts

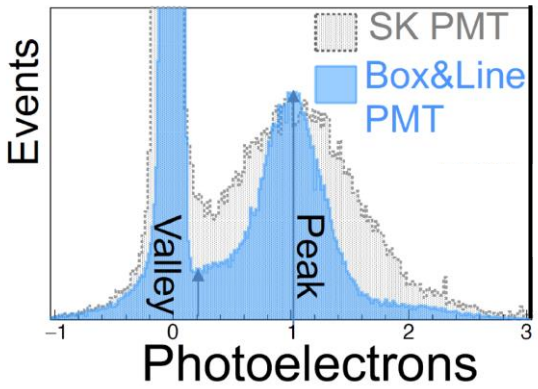
Access tunnel excavation was completed. (2022 Feb.)

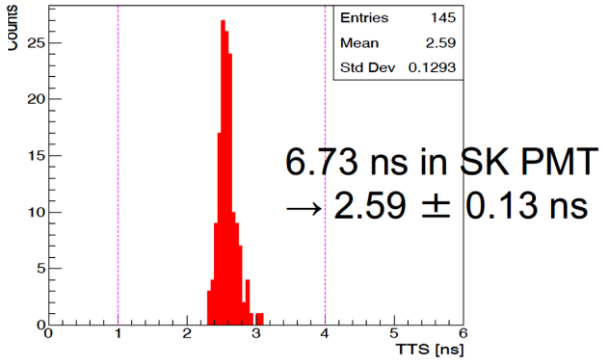
Hyper-Kamiokande

New 50 cm Box & Line PMT (20,000)

- Twice higher photon detection efficiency
- Twice better 1 p.e. resolution
- Twice better timing resolution







multi-PMT

- 3 inch PMTs are enclosed in the pressure vessel.
- Directional sensitivity
- Higher granularity

Hyper-Kamiokande

Maximally utilize the performance of the PMT

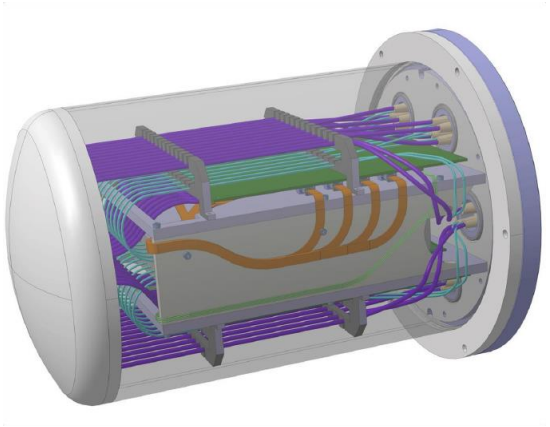
Install the front-end electronics modules in the water.

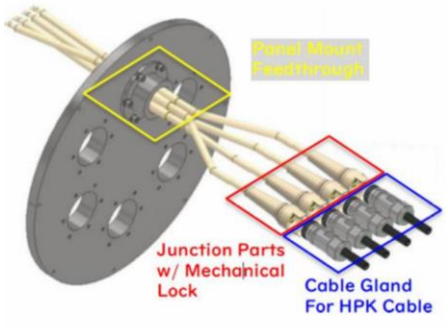
Stable and reliable system without failure

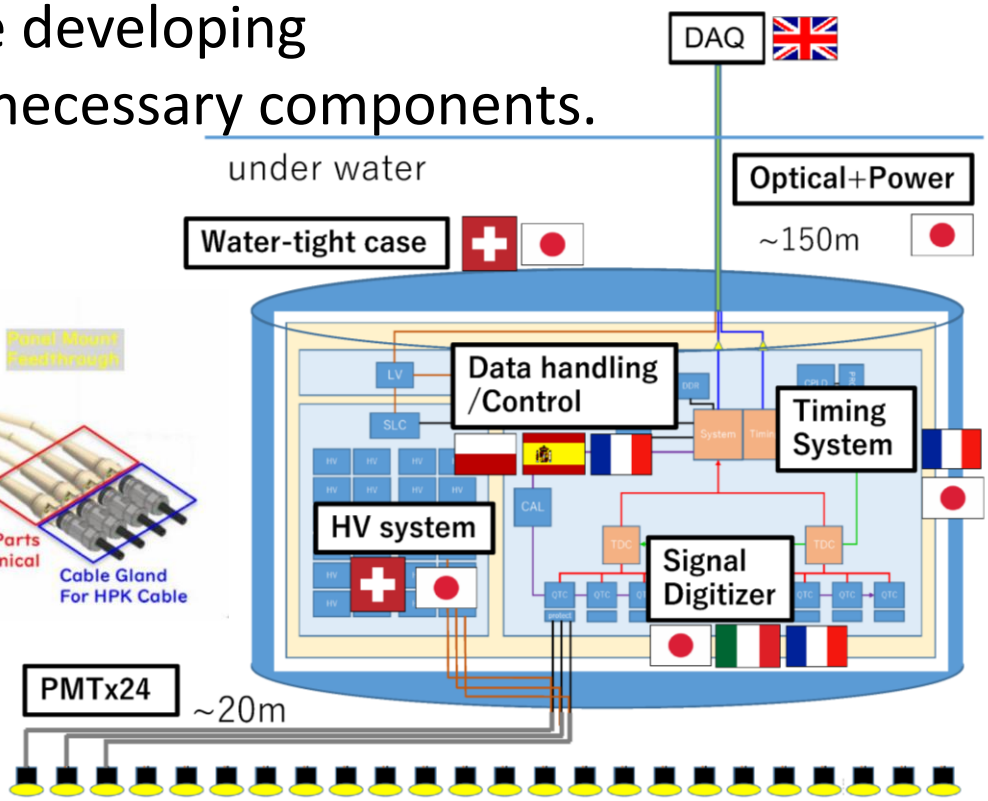
Continuous operation 24hrs/7days/365 days for > 10 years

Difficult to repair during the operation.

International collaborators are developing necessary components.







Summary

Publications in 2021 (Since the last workshop) related to A01

- First gadolinium loading to Super-Kamiokande
  Super-Kamiokande collab.
  Nucl.Instrum.Meth.A 1027 (2022) 166248
- Diffuse supernova neutrino background search at Super-Kamiokande
  Super Kamiokande collab.
  Phys.Rev.D 104 (2021) 12, 122002
- Neutron-antineutron oscillation search using a 0.37 megaton-years exposure of Super-Kamiokande
  Super-Kamiokande collab.
  Phys.Rev.D 103 (2021) 1, 012008
- Supernova Model Discrimination with Hyper-Kamiokande
  Hyper-Kamiokande collab.
  Astrophys.J. 916 (2021) 1, 15

- Two papers related to the neutrino-nucleus interactions