25th International Workshop on Next Generation Nucleon Decay and Neutrino Detectors

Hyper-Kamiokande Status and prospects

C. Bronner

Oct. 30th, 2026

Hyper-Kamiokande

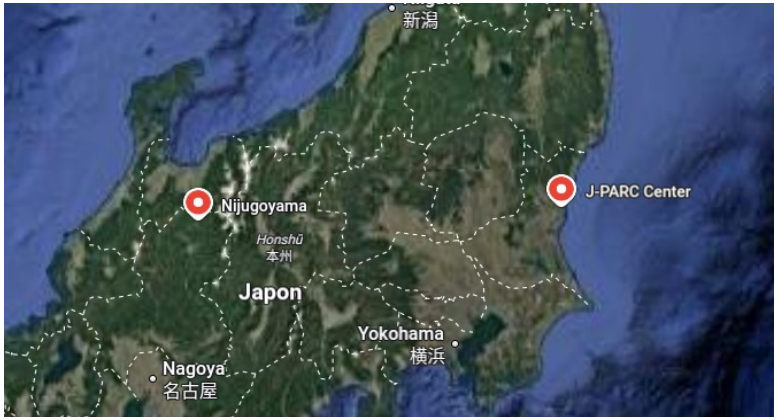
YOKOHAMA National University YNU

Hyper-Kamiokande Project

The Hyper-Kamiokande experiment Overview

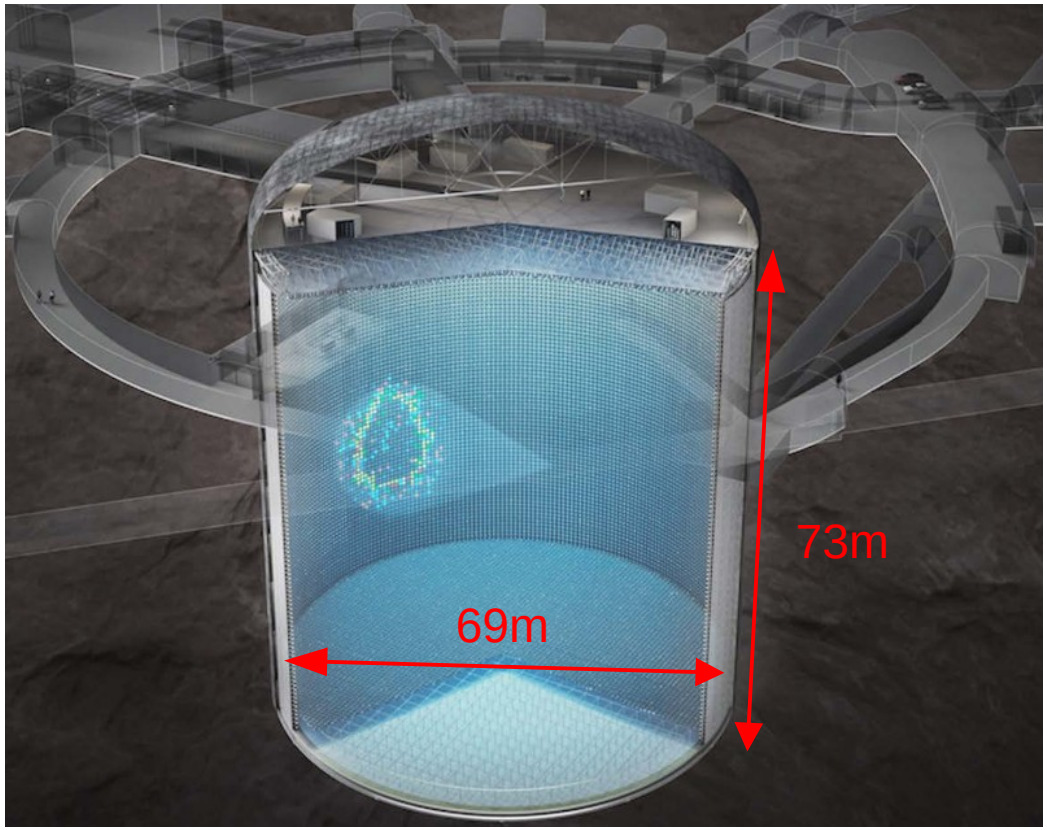
Kamioka

- Massive (258 kton) water Cherenkov detector
- 600m underground below mount Nijugo

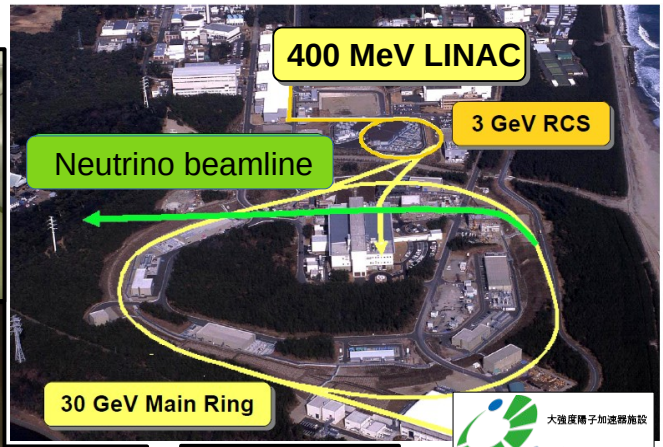


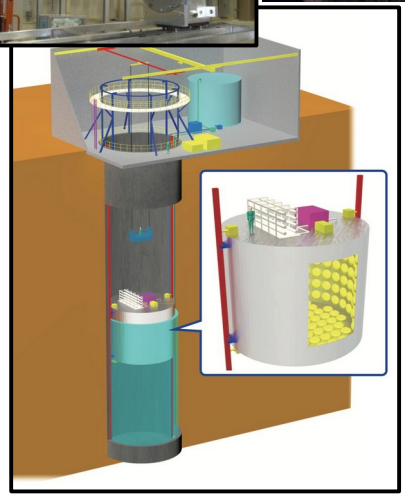
J-PARC (Tokai-mura)

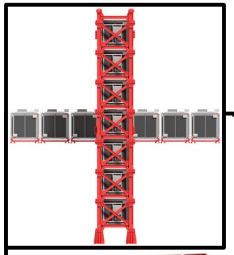
- Beam line for production of neutrino beam from accelerated protons
- Set of (near) detectors to monitor beam and study neutrino interactions



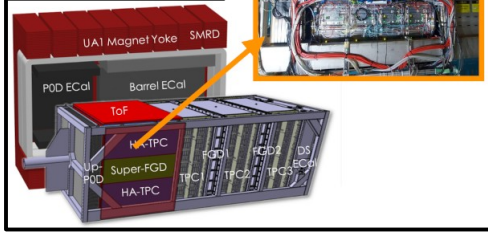




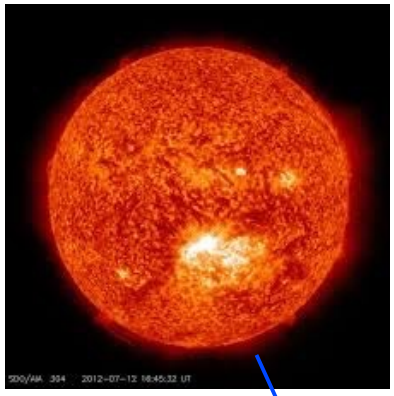


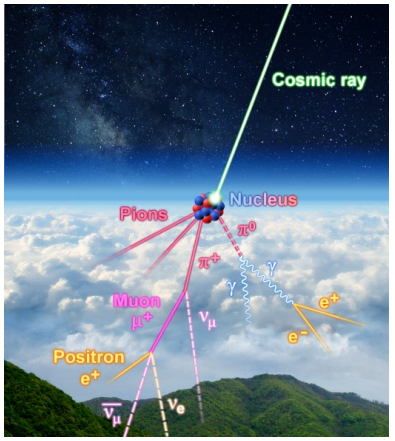






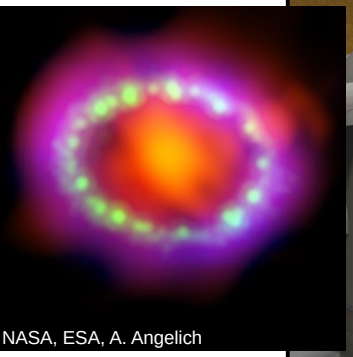
Physics goals

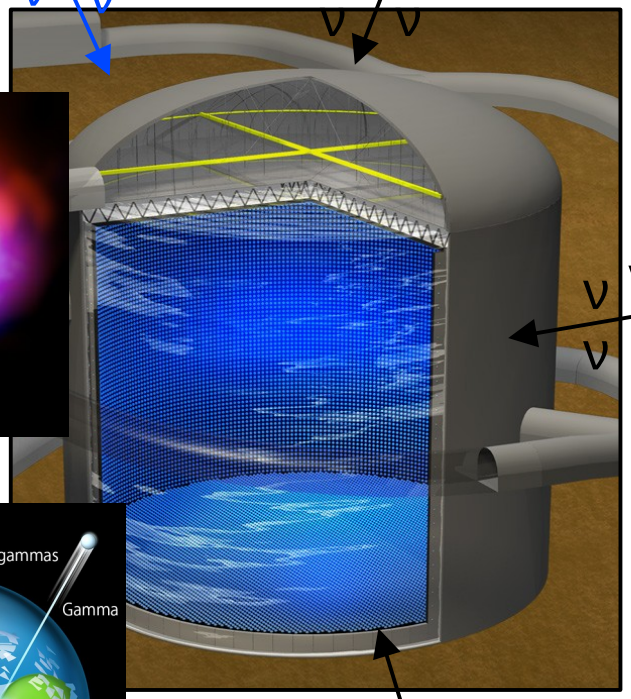


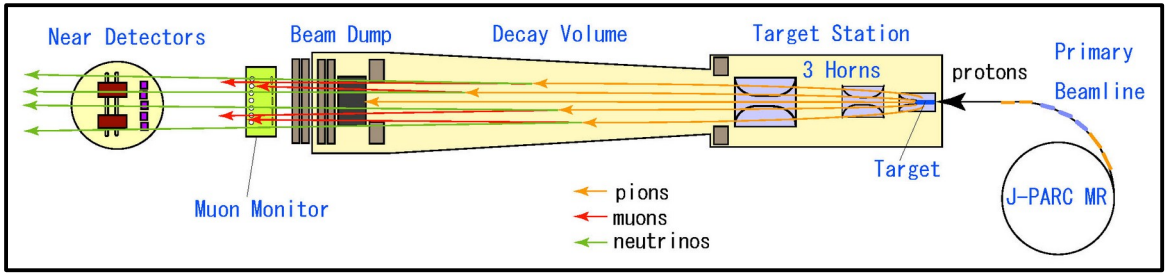


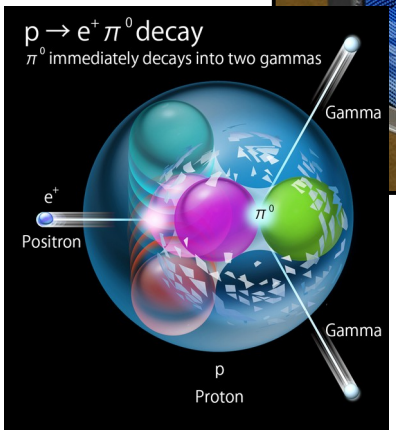
Broad physics program:

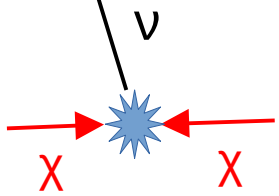
- Oscillations of atmospheric, accelerator and solar neutrinos
- Neutrino astronomy and astrophysics
- Supernova neutrinos
- Search for proton decay
- Dark matter indirect detection
- Other searches for new physics (monopoles, Q-Balls, ...)

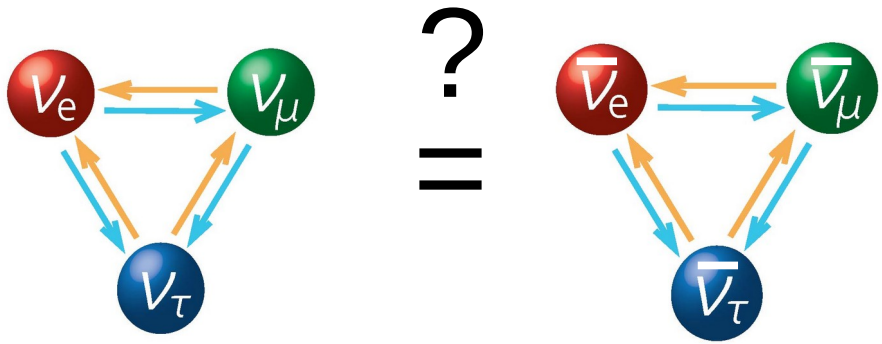








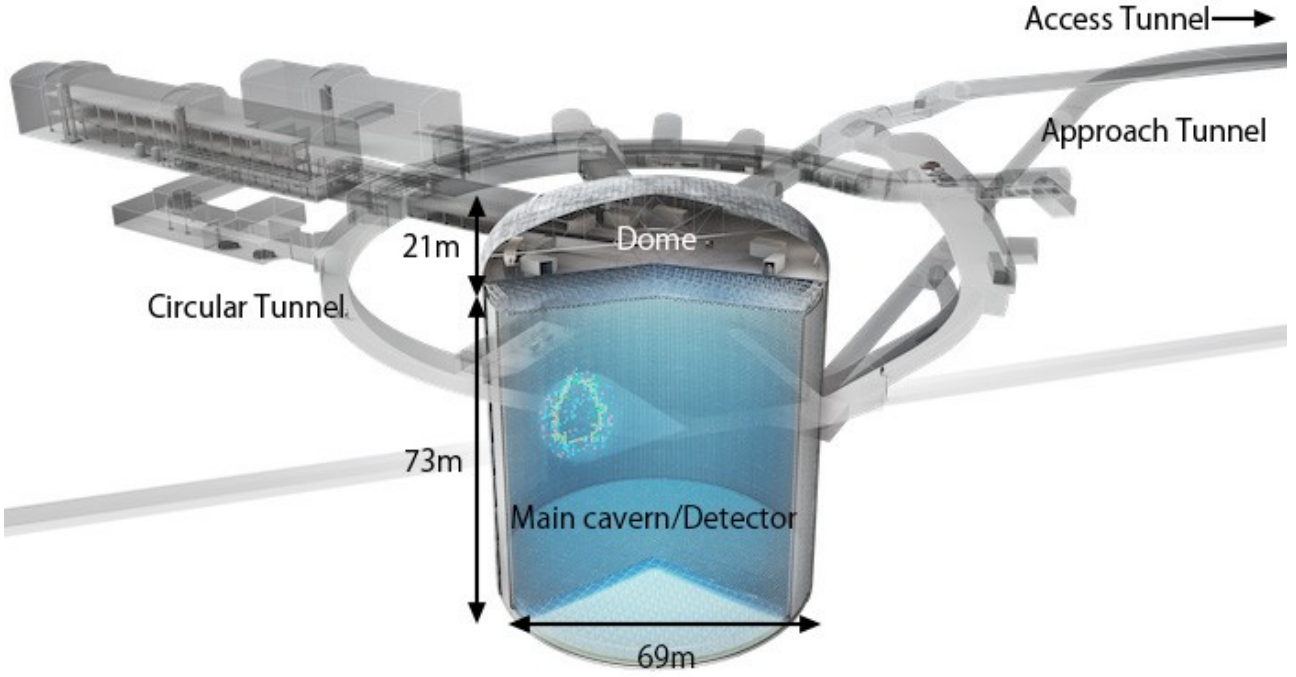


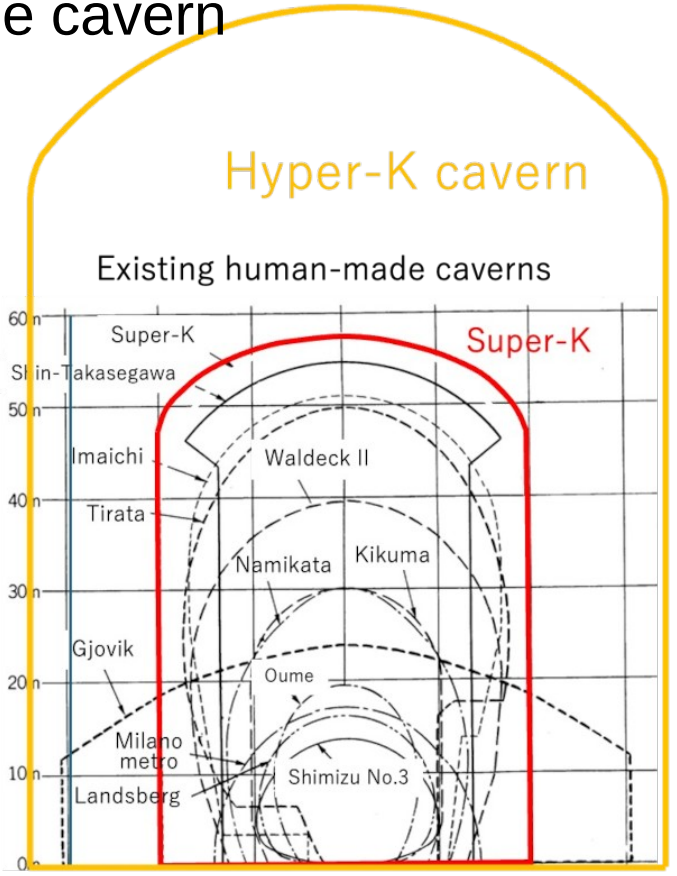


The Hyper-Kamiokande experiment
Far detector

- For most of the physics goals, main limitation in current experiments is statistics: need larger detector to accumulate statistics faster
- Water Cherenkov detector:
  - Well established technology
  - "Easy" to scale up
  - Lot of experience from Super-K and T2K

Building a large new underground complex, including largest ever human-made cavern

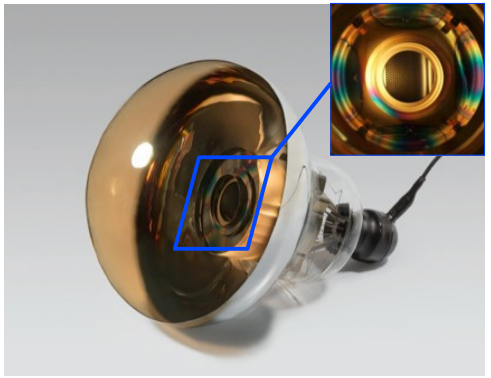


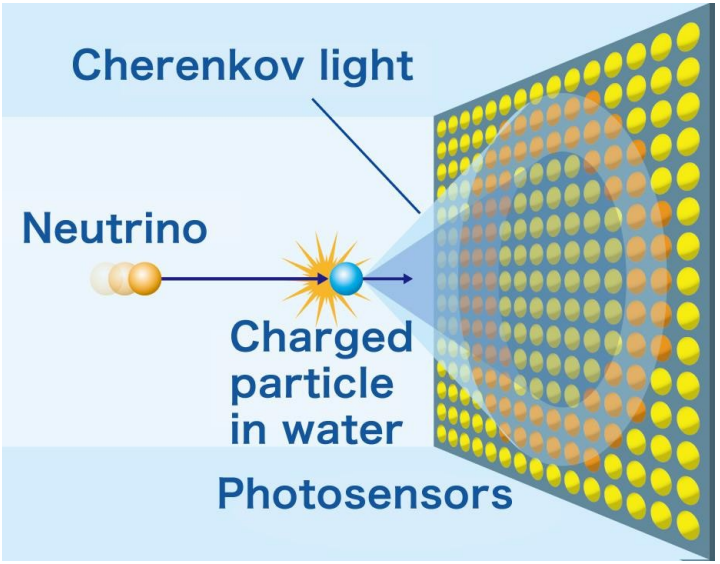


73 m height x 69 m diameter tank
188.4 kton fiducial volume (~8.4x SK)

The Hyper-Kamiokande Far Detector
Improved photo detector system

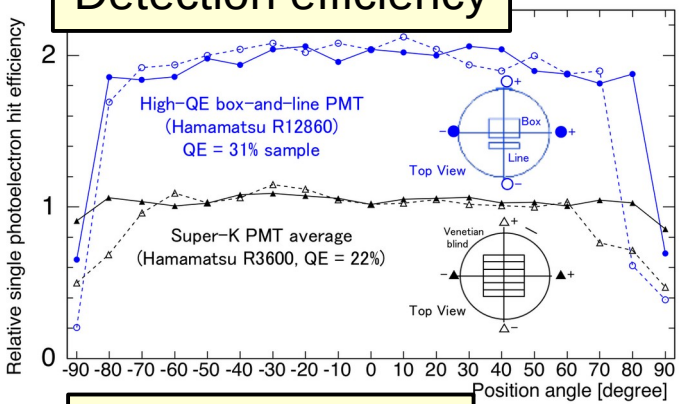
- Performance of Inner Detector (ID) light detectors critical
- HK will use 20k 50cm PMTs to instrument ID
- Improved model compared to SK: R12860 by Hamamatsu Photonics
  - 2x charge resolution and detection efficiencies
  - >2x timing resolution



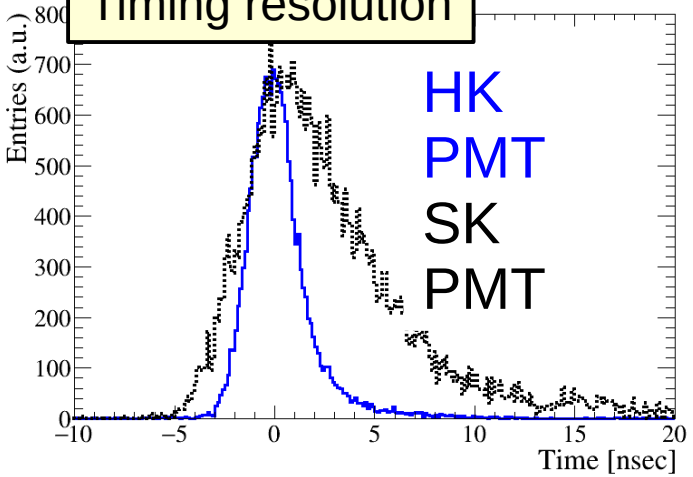


Impact of PMT performance:
- Vertex <-> timing resolution
- Momentum <-> charge resolution, detection eff.

Detection efficiency

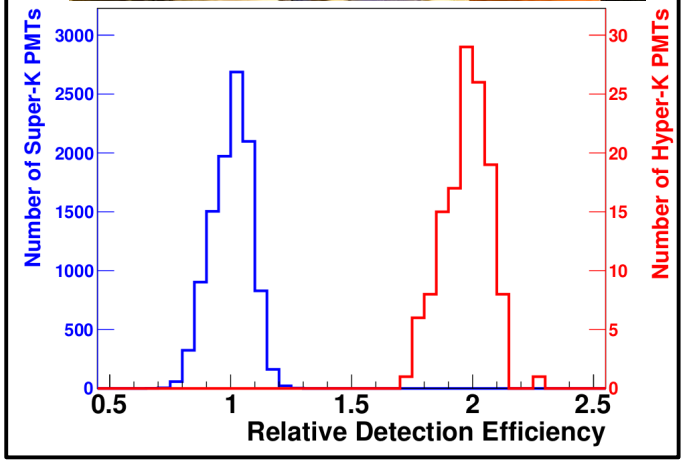


Timing resolution



Improved performance confirmed in SK (136 PMTs)

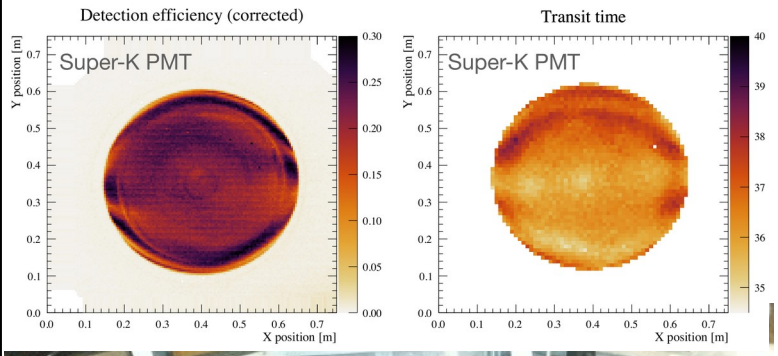




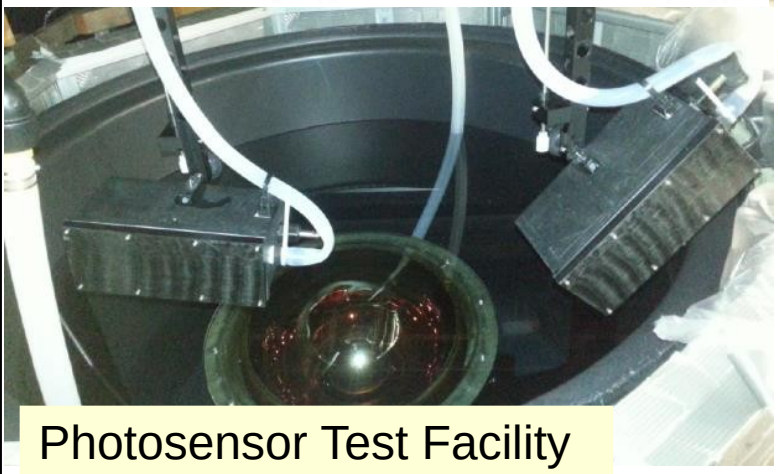
The Hyper-Kamiokande experiment
New calibration methods

- Use of water Cherenkov detector (PID, momentum, ...) well established in SK
- HK: high statistics, need good control of systematics, including detector response
- Detector will need to be understood with higher precision than SK
- A number of new calibration approaches, both in-situ and pre-measurements

Precise characterization of 50 cm PMTs







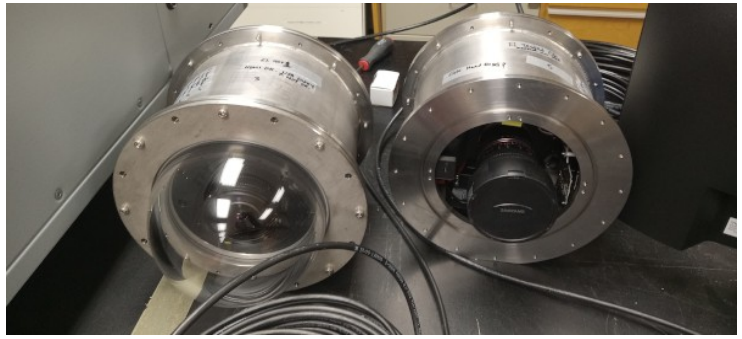
Photosensor Test Facility (TRIUMF)

PMT pre-calibration



Photogrammetry

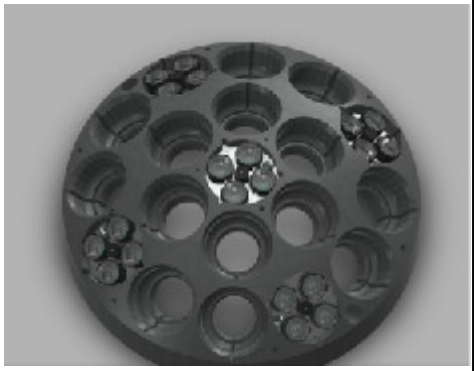
Cameras in walls for precise PMT positions



~800 Multi-PMTs (19 3” PMTs) in FD

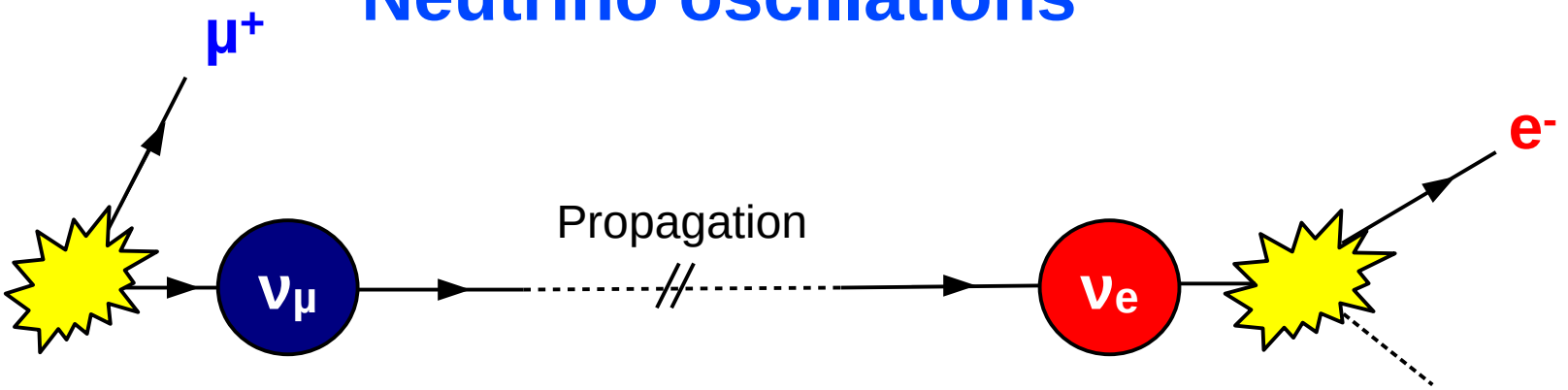
200 equipped with LEDs (including 295 and 305 nm for Raman scattering)





Physics goals and sensitivity

Neutrino oscillations

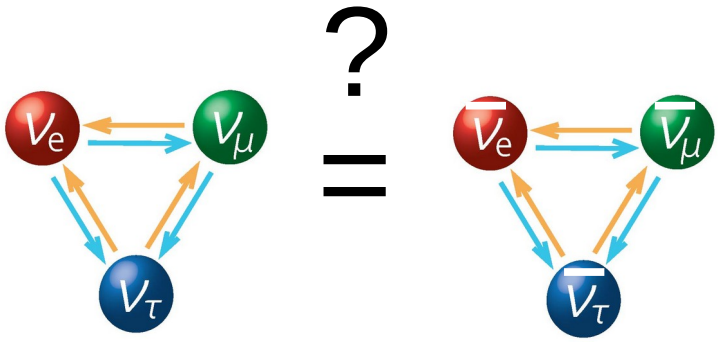


- 3 open questions in standard oscillations
- Precise measurements to test standard framework, in search of physics beyond the standard model

CP symmetry

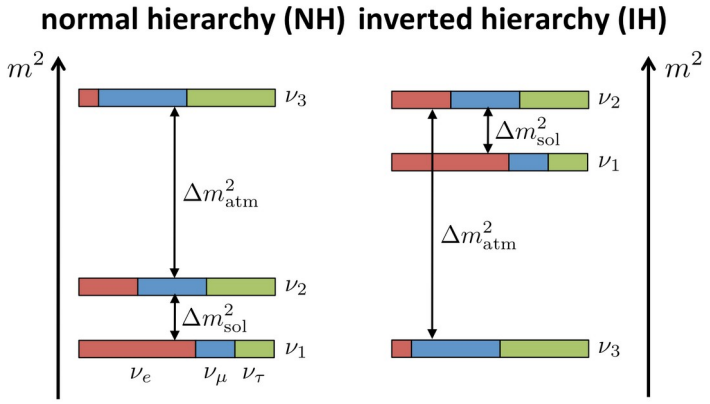
- difference matter/anti-matter

~~CP~~ ⇔ **sin(δ) ≠ 0**



Mass ordering

- Neutrino mass models
- input for other experiments (0νββ, supernova)



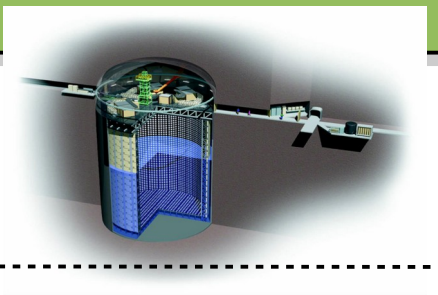
Octant of θ_{23}

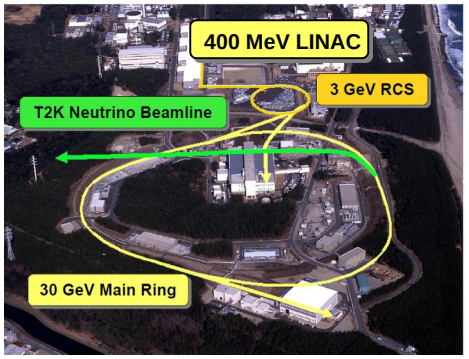
- symmetries in lepton sector

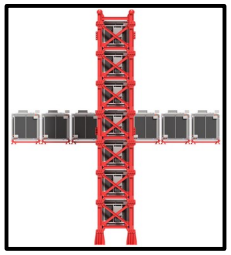
$\theta_{23} > \pi/4$?
$\theta_{23} = \pi/4$?
$\theta_{23} < \pi/4$?

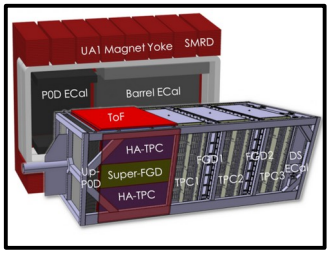
Long Baseline oscillations: T2K

- Accelerator neutrinos allow for precise neutrino oscillation measurements:
  - Good L/E resolution and knowledge of initial neutrino content
  - "Near detectors" to constrain uncertainties
  - either (mostly) neutrino or (mostly) anti-neutrino beam
- Successfully used in T2K since 2009









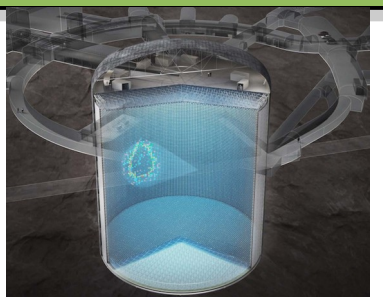
Study neutrino before oscillations

$\nu_\mu \rightarrow \nu_e$ appearance
$\nu_\mu \rightarrow \nu_X$ disappearance

- Baseline: 295 km
- Off-axis beam

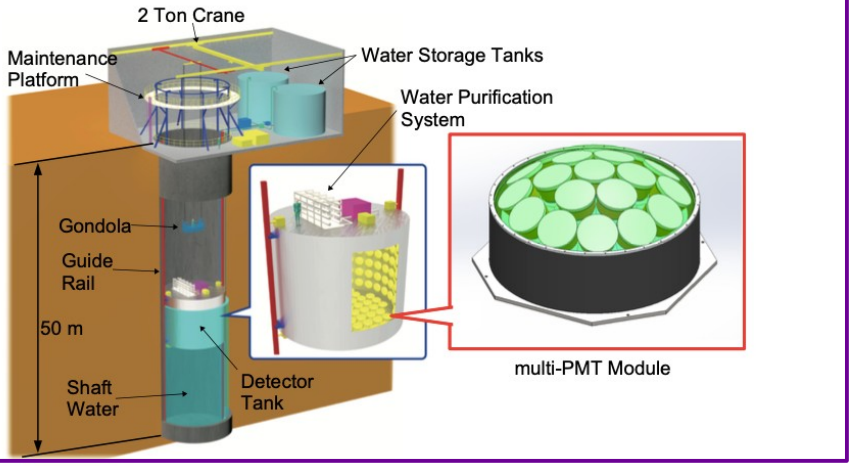
Long Baseline oscillations: Hyper-K

- HK far detector 8 km south of Super-K: looks very similar seen from J-PARC
- Same baseline (295 km) and off-axis angle (2.5°) as T2K
- Main differences: increased beam power (1.3 MW) and intermediate detector



- Inherited from T2K
- Beam intensity will continue to increase to reach 1.3 MW
- Possibility of further upgrade of the off-axis near detector

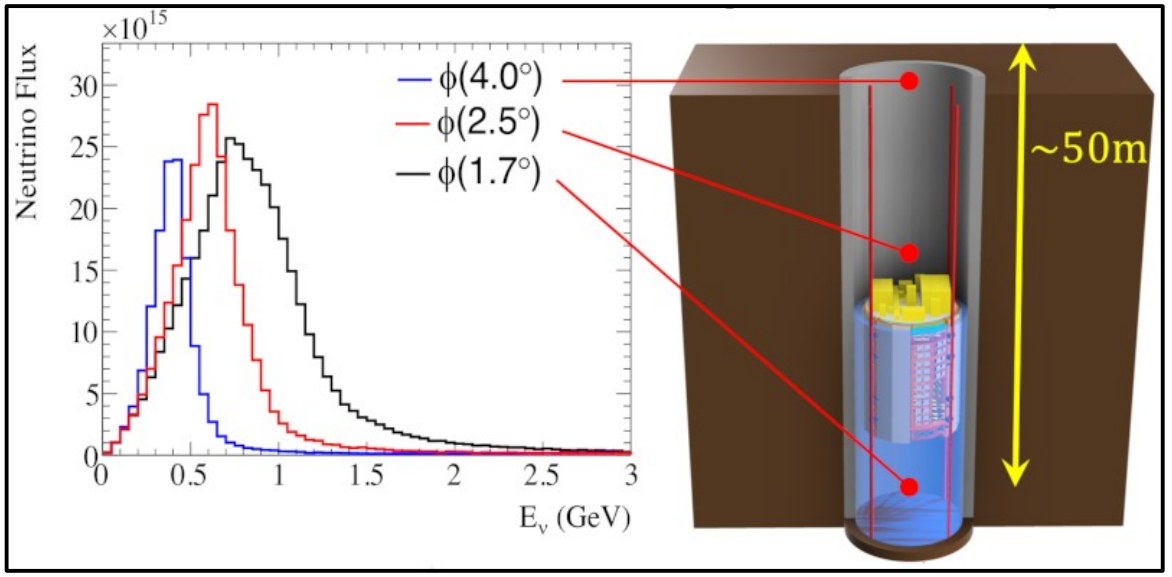
Intermediate Water Cherenkov Detector

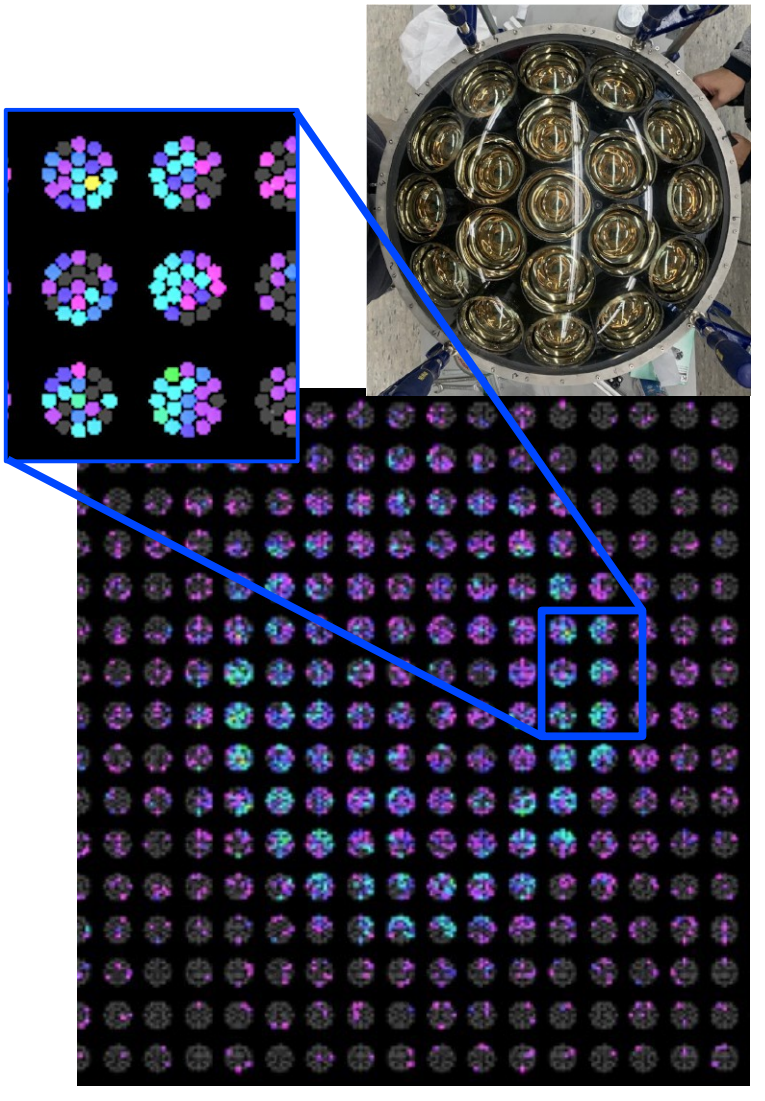


The Hyper-Kamiokande experiment
Intermediate Water Cherenkov Detector

- Additional “near” detector located ~850m from target
- 600 ton Water Cherenkov detector instrumented with mPMTs

Key element to control systematic uncertainties
- Same target material and 4π acceptance as FD
- Measure $\sigma(\nu_e)/\sigma(\nu_\mu)$, NC and beam ν_e bckg
- Movable detector: use of PRISM technique

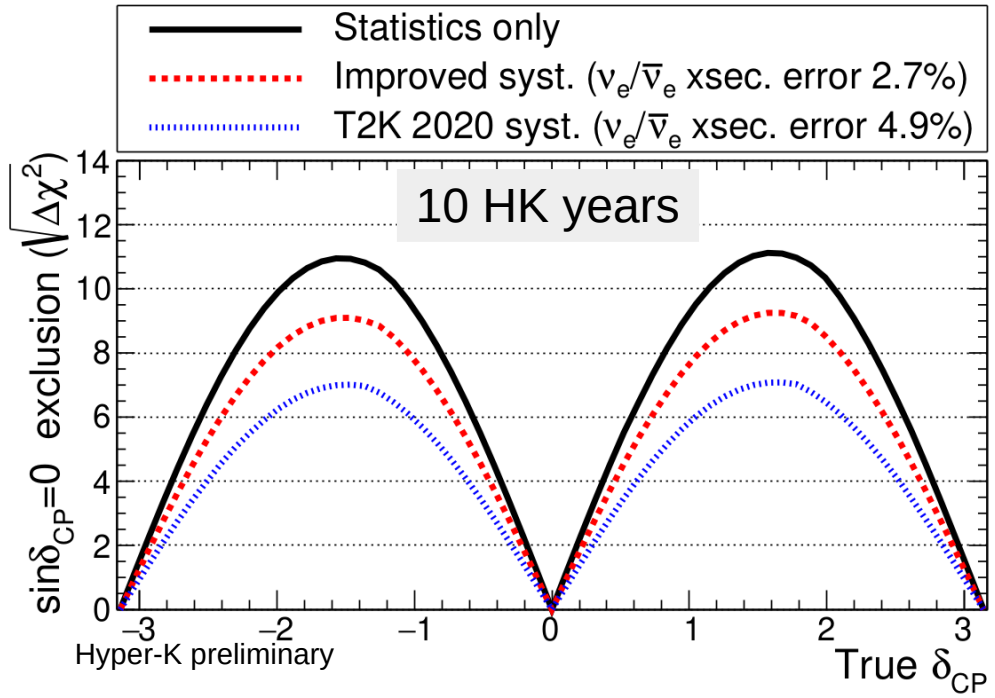


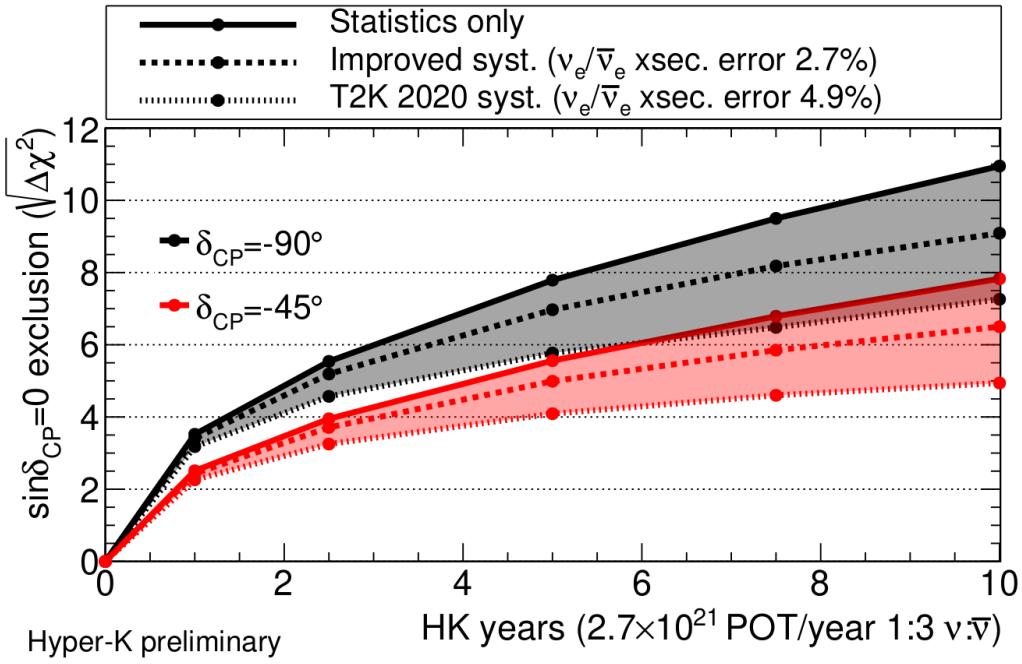


Long Baseline oscillations Sensitivity - CP symmetry

- Based on T2K analysis (Eur. Phys. J. C 83, 782 (2023)) scaled to HK statistics
- "Improved systematics" to represent improved systematics constraints from IWCD and upgraded near detector measurements

- With **known MO** and improved syst., 5σ sensitivity for 62% of true δ_{CP} values in 10 years
- In most favorable case (NO, δ_{CP}=-π/2), can exclude CP conservation in 3-5 years depending on systematics





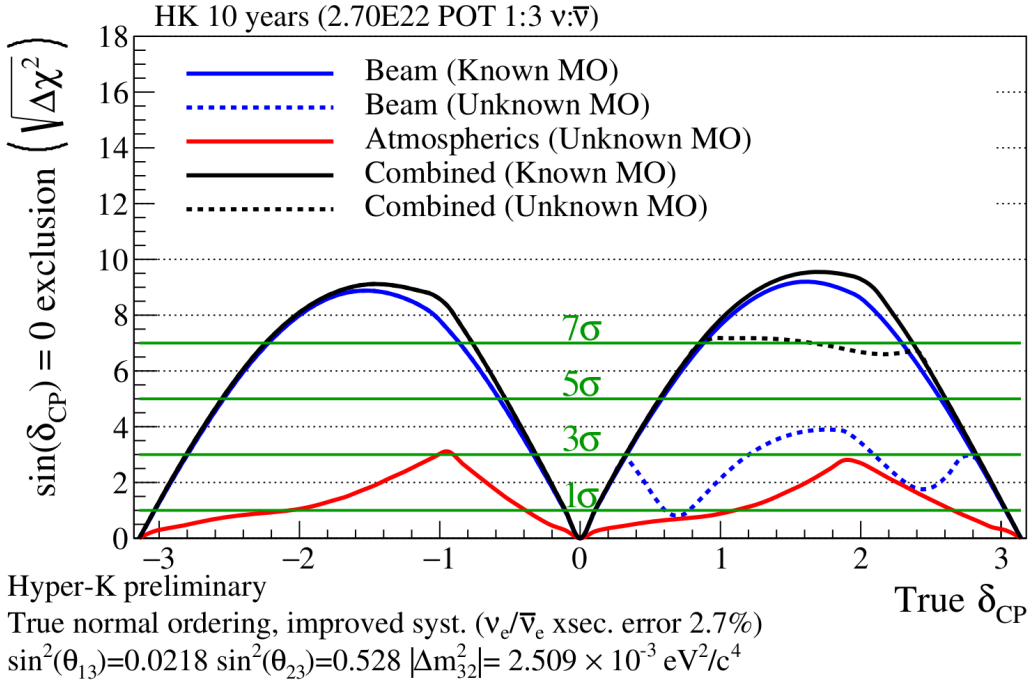
True values of parameters: Normal ordering, $\sin^2\theta_{13}$=0.0218±0.0007, $\sin^2\theta_{23}$=0.528, Δm^2_{32}=2.509×10^{-3}eV^2/c^4

Eur. Phys. J. C 86, 170 (2026)

Long Baseline oscillations
Combination with atmospheric neutrinos

- Previous slides assumed known mass ordering
- If unknown, degeneracies can degrade sensitivity to δ_{CP} and octant
- Combination with atmospheric neutrinos can resolve degeneracies
- Additionally gives improved sensitivity to the mass ordering
- Rigorous combined analysis established by T2K and Super-K (Phys. Rev. Lett. 134, 011801 (2025))

Ability to reject CP conservation



	$\sin^2\theta_{23}$	Atmospheric neutrino	Atm + Beam
Mass ordering	0.40	2.2 σ	→ 3.8 σ
	0.60	4.9 σ	→ 6.2 σ
θ_{23} octant	0.45	2.2 σ	→ 6.2 σ
	0.55	1.6 σ	→ 3.6 σ

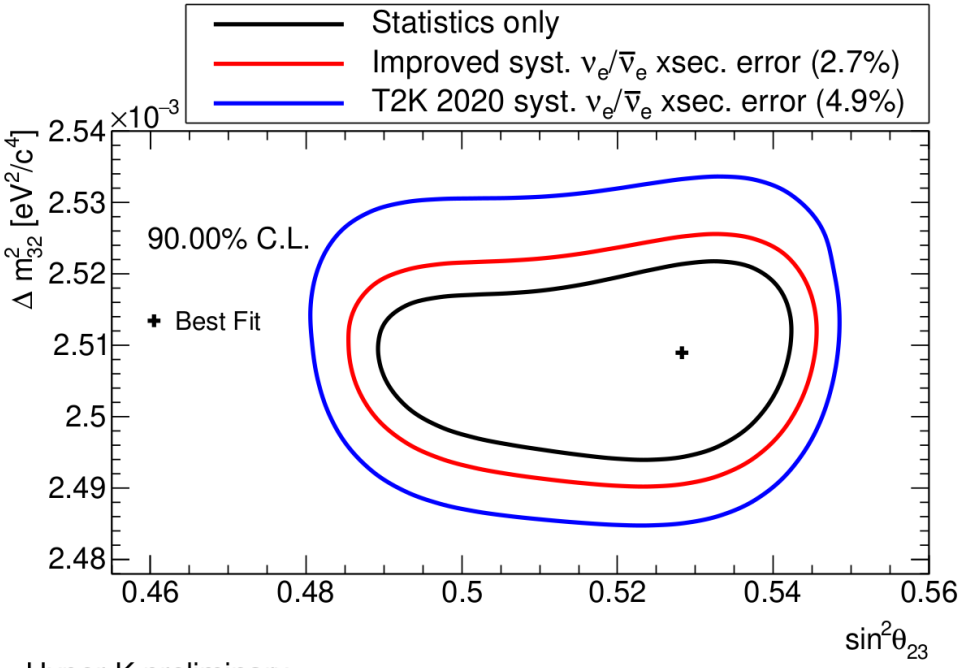
10 years with 1.3MW, normal mass ordering is assumed

Based on older version of T2K analysis. Updates based on T2K+SK joint analysis in preparation

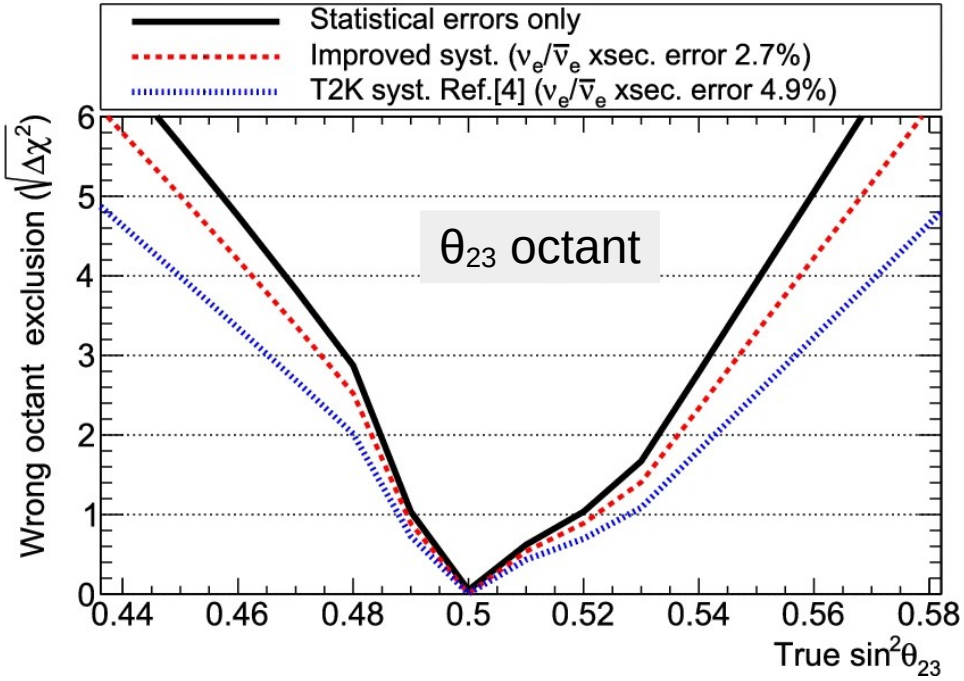
Long Baseline oscillations
Sensitivity – Atmospheric parameters

Using 10 years of HK data and improved systematics:
- Precise measurements of Δm^2_{32} (0.35% error) and $\sin^2\theta_{23}$ (2.47% error)
- Can determine octant if true $\sin^2\theta_{23}<0.45$ or true $\sin^2\theta_{23}>0.57$

Sensitivities for 10 HK-years (2.7×10^{22} POT 1:3 ν:$\bar{\nu}$) with **known MO**



Hyper-K preliminary

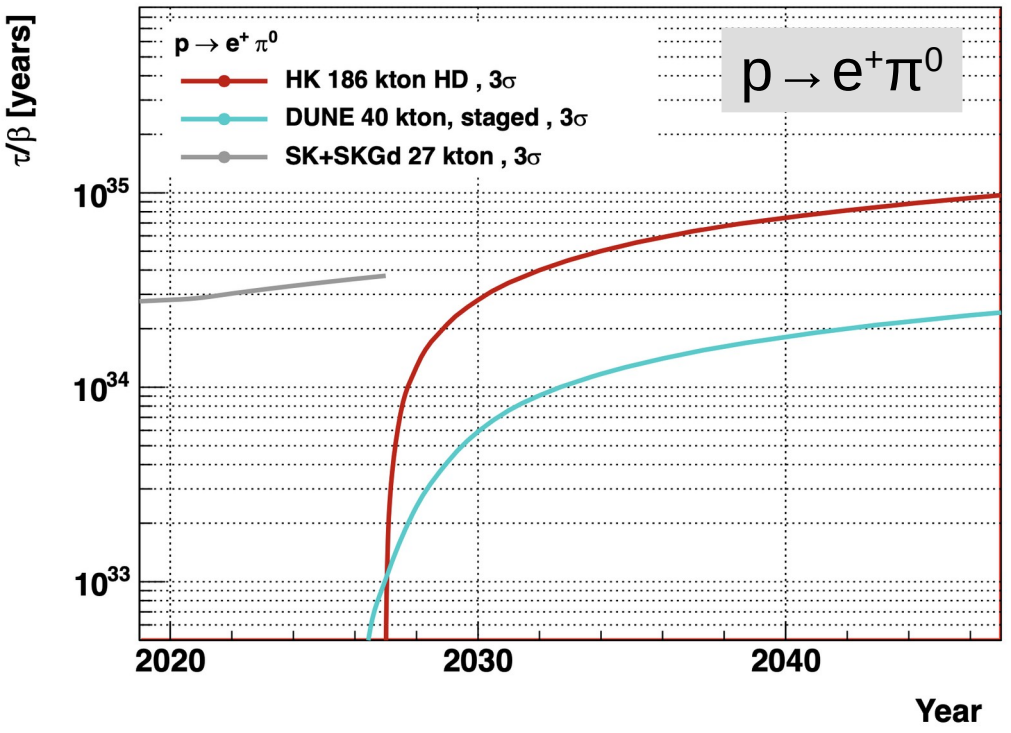


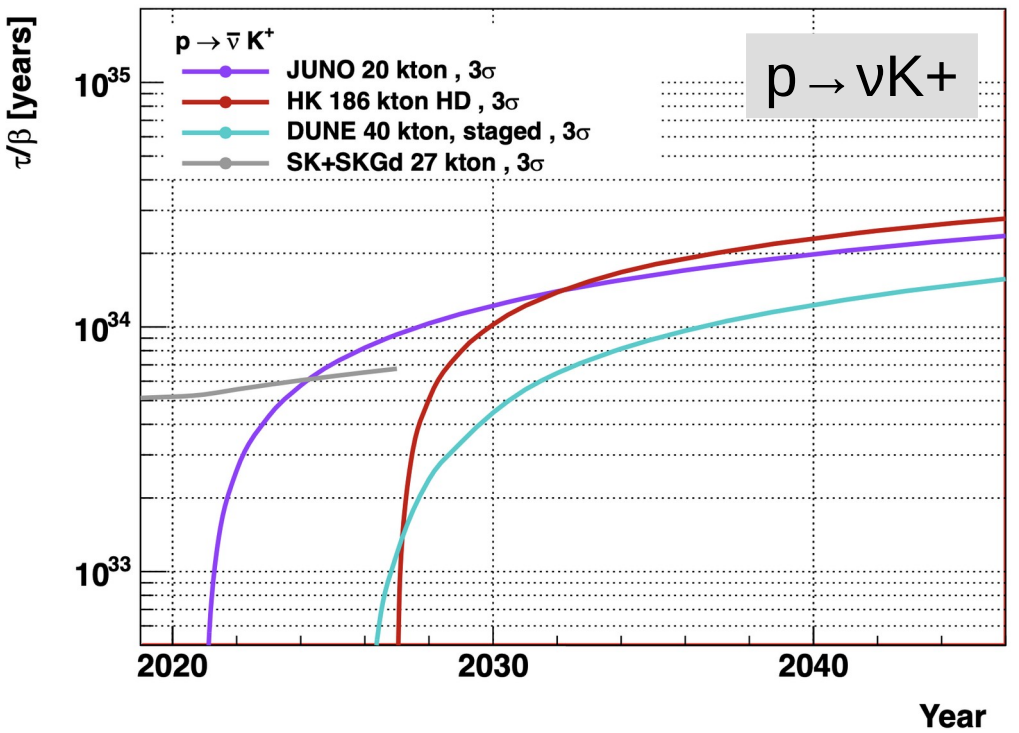
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Search for nucleon decay

- World leading sensitivity for proton decay searches: large mass and can use free protons to avoid problems of nuclear effects
- 3σ discovery potential reaches half-life of 10^{35} years for $p \rightarrow e^+\pi^0$ and $3x10^{34}$ years for $p \rightarrow \nu K^+$ after 20 years

3σ discovery potential as a function of time



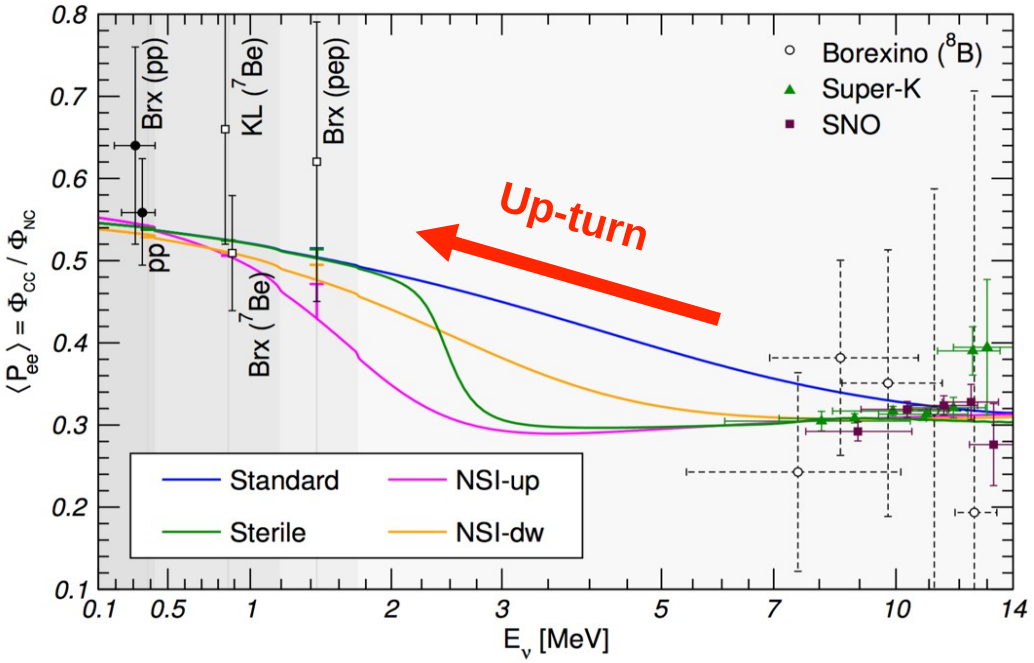


See posters by T.Aoki and T. Yamazumi

Low energy neutrinos oscillations
Solar neutrinos

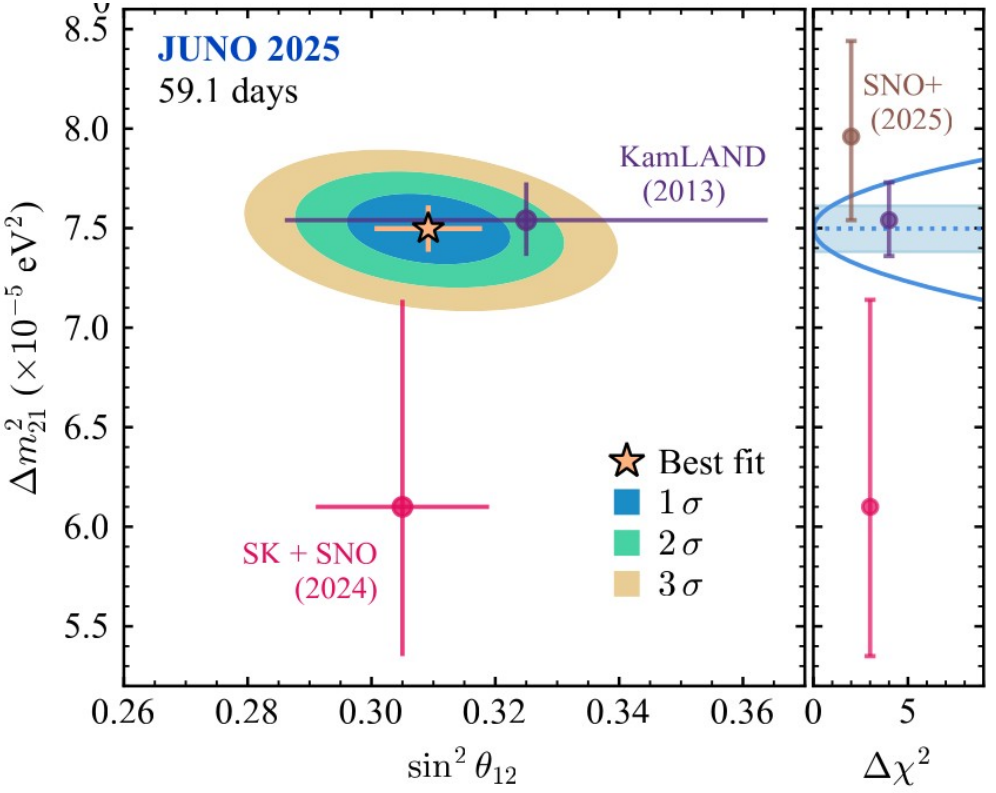
- At low energy, Hyper-K will study remaining questions on solar neutrino oscillations
- ~130 solar neutrino events per day
- > 3σ sensitivity for the spectrum up-turn in 10 yrs (E_{th}=4.5 MeV).
- ~2σ day/night sensitivity expected for the difference in $\nu_e/\bar{\nu}_e$ osc. in 20 yrs.

Upturn from transition from matter dominated to vacuum dominated oscillations in the sun



M. Maltoni et al., Phys. Eur. Phys. J. A52, 87 (2016)

~1.5σ tension between solar and reactor Δm^2_{21} measurements



Nature 654, 343–348 (2026)

Low energy neutrinos
Supernova neutrinos

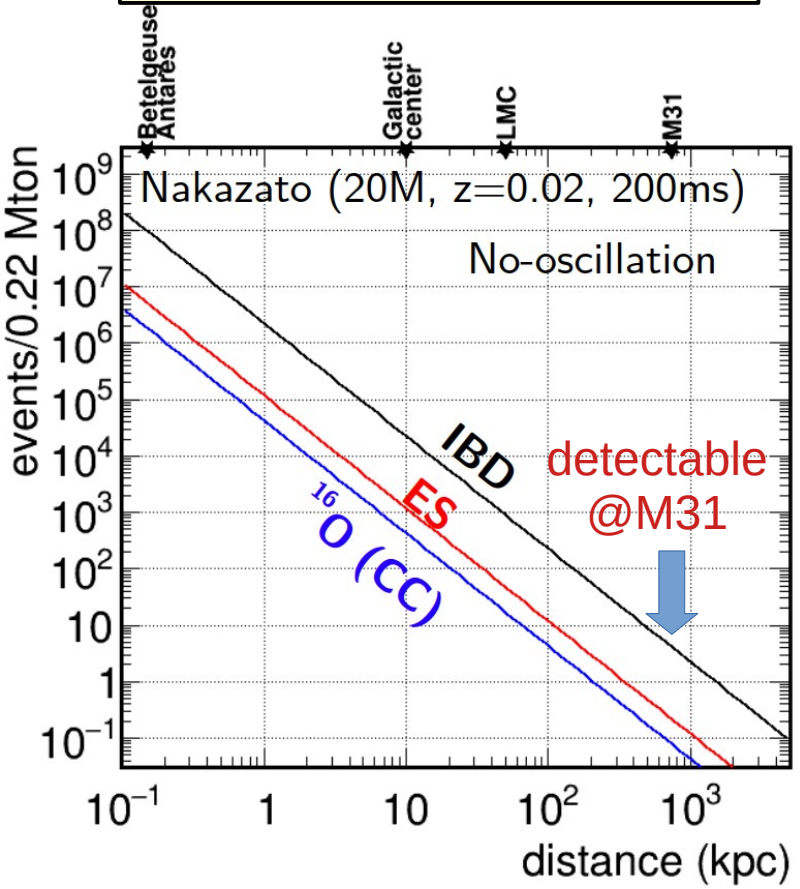
Large size of HK allows it to be sensitive to supernova burst in the Andromeda galaxy, as well as observe more DSNB neutrinos than other experiments

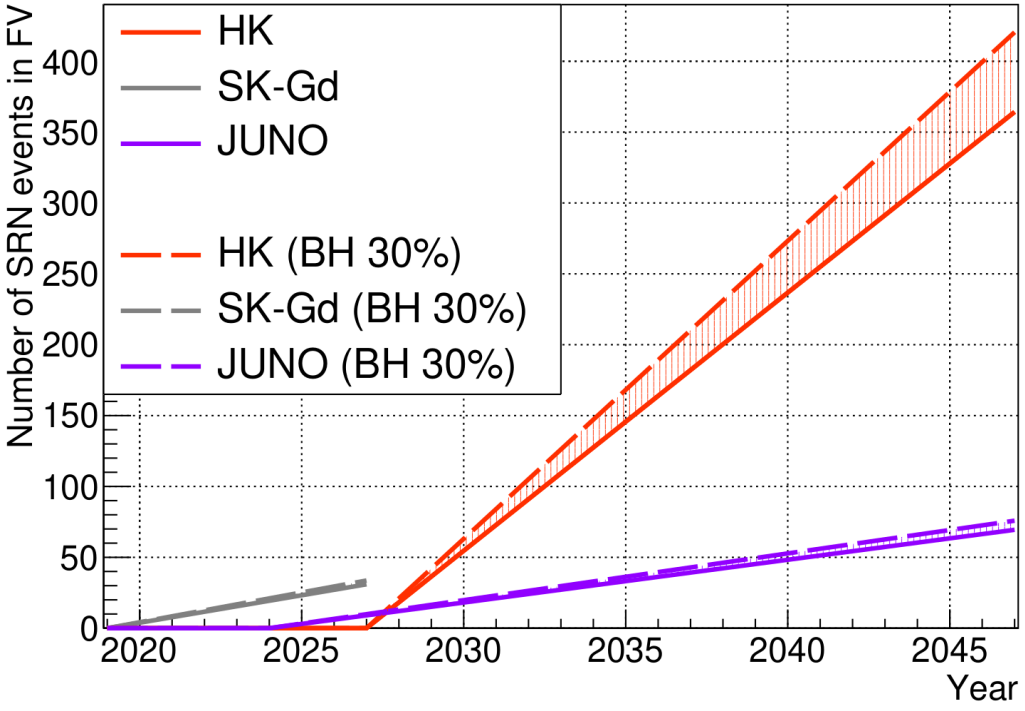
Supernova burst

- explosion mechanism,
- BH/NS formation,
- alert with 1° pointing

Diffuse Supernova Neutrino Background

- Stellar collapse model
- Star formation rate
- Heavy element synthesis





Status

Hyper-Kamiokande status
Collaboration

- Hyper-K officially approved in 2020
- Collaboration has been growing since, and continuing
- 23 countries, 104 institutes, ~660 people as of June 2026


Feb. 2026 collaboration meeting

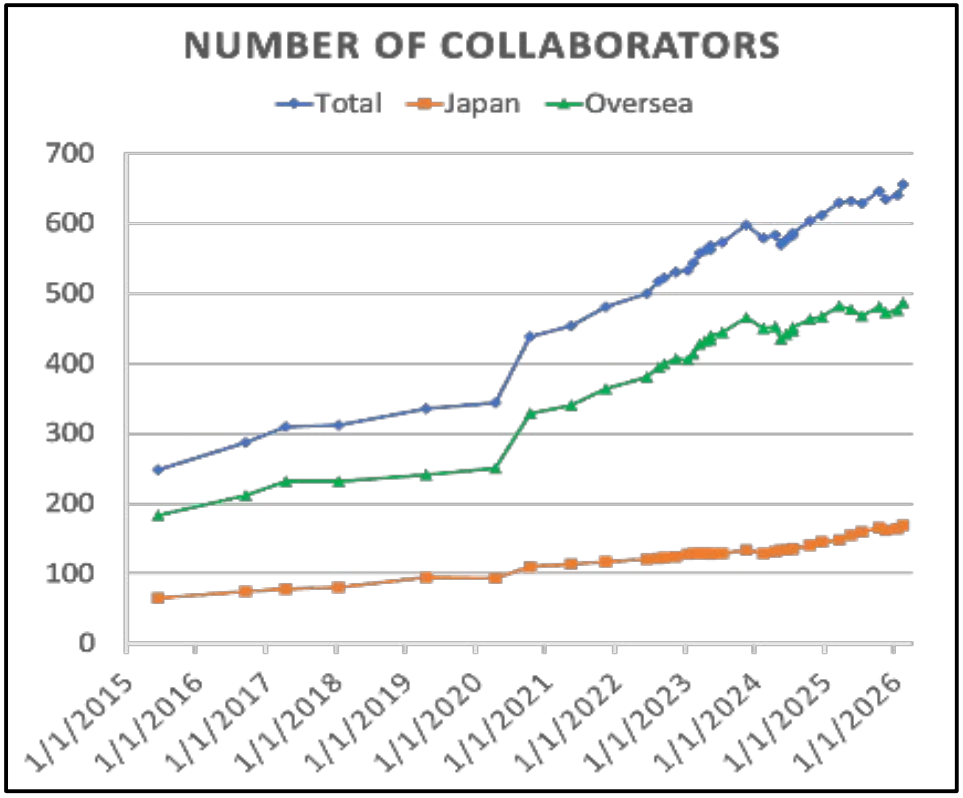
Europe	361 members
Armenia	3
Czech	10
France	54
Germany	1
Greece	3
Italy	62
Poland	55
Russia	27
Spain	45
Sweden	4
Switzerland	10
Ukraine	2
UK	85

Asia	214 members
India	10
Korea	22
Japan	174
Vietnam	8

Oceania	12 members
Australia	12

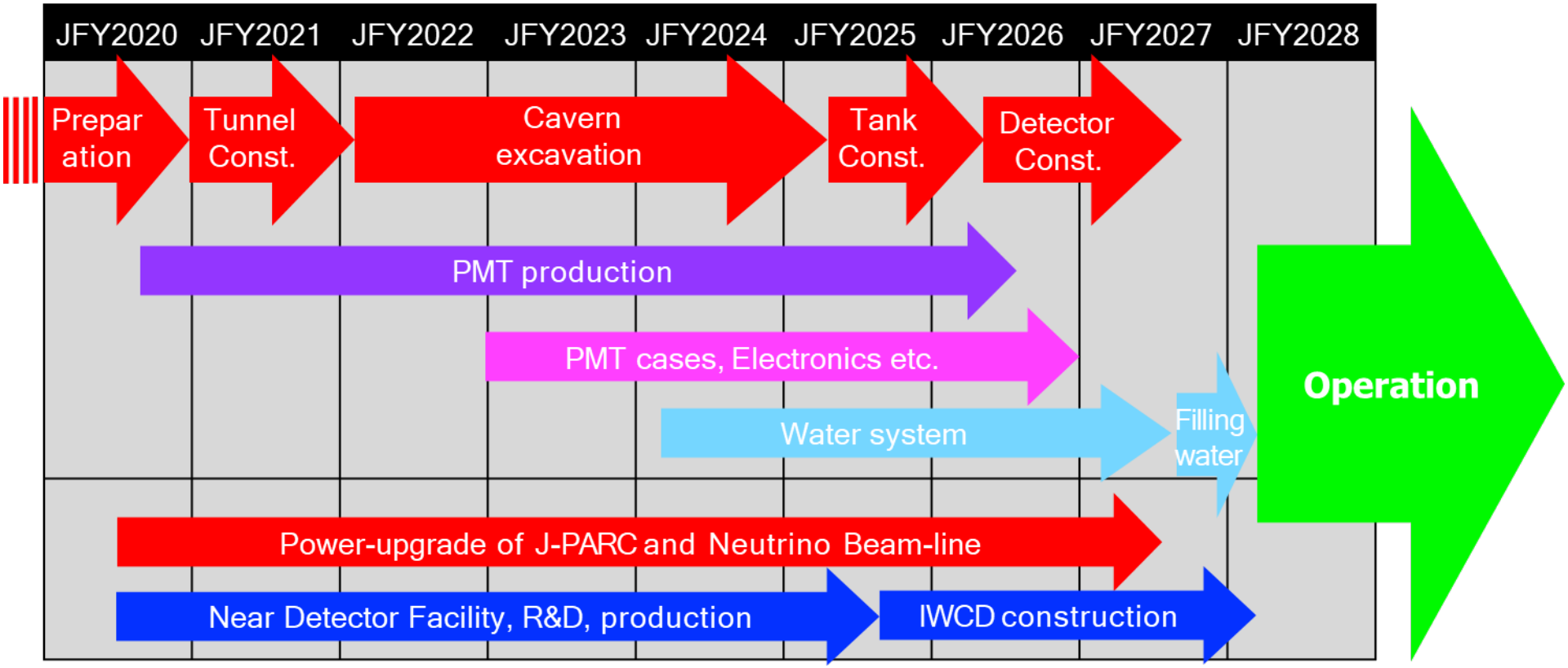
Americas	70 members
Brazil	5
Canada	49
Mexico	6
USA	10

Africa	9 members
Morocco	9



Hyper-Kamiokande status
Schedule

- Significant construction project, spanning several years
- Project started in 2020
- Several major construction milestones completed
- **Start of physics operation in 2028**



Note: Japanese Fiscal Year starts April 1st

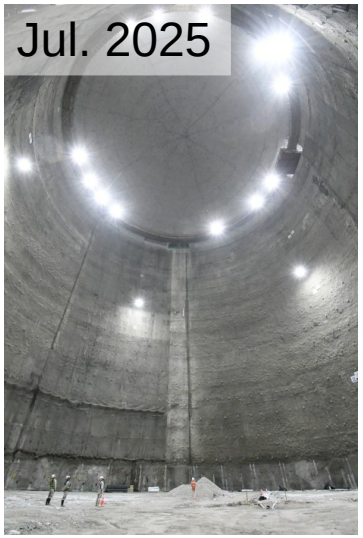
Hyper-Kamiokande status
Excavation

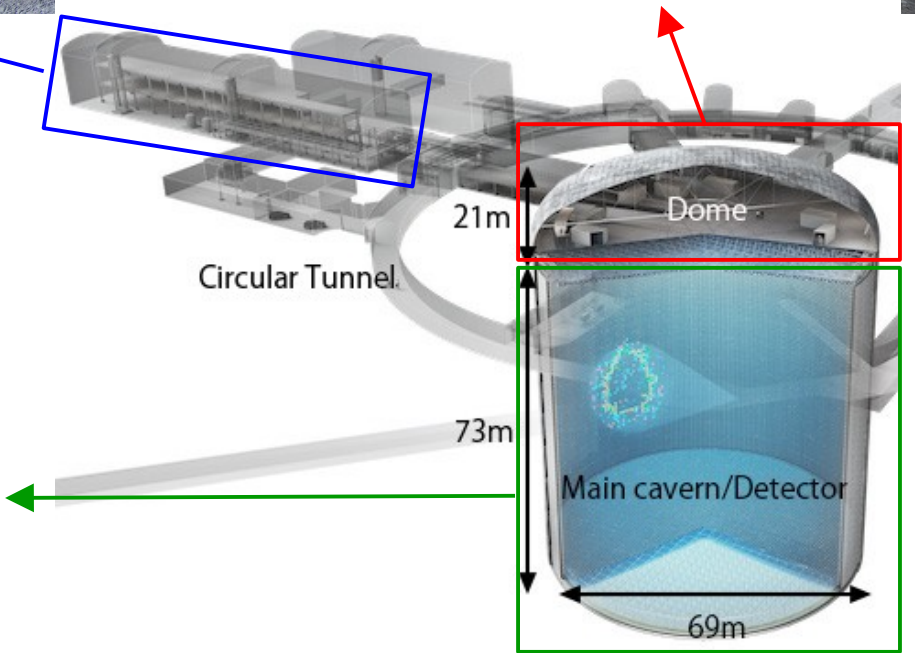
- Excavation of approach tunnels started in May 2021 and completed in 2022
- Excavation of dome part (main technical challenge) and cavity for water system completed in 2023
- Excavation of detector cavern completed in July 2025











Hyper-Kamiokande status
Facility construction

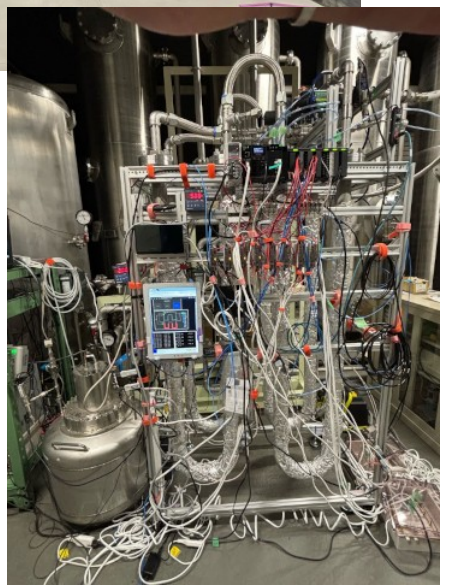
- Construction of tank started end of summer 2025, lining completed July 2026
- Construction of support structure on-going
- Keeping such a large amount of water ultra-pure requires massive water system (will process 155m^3/h). Construction started in July 2025 and in progress
- Additional development on-going for a new radon removal system







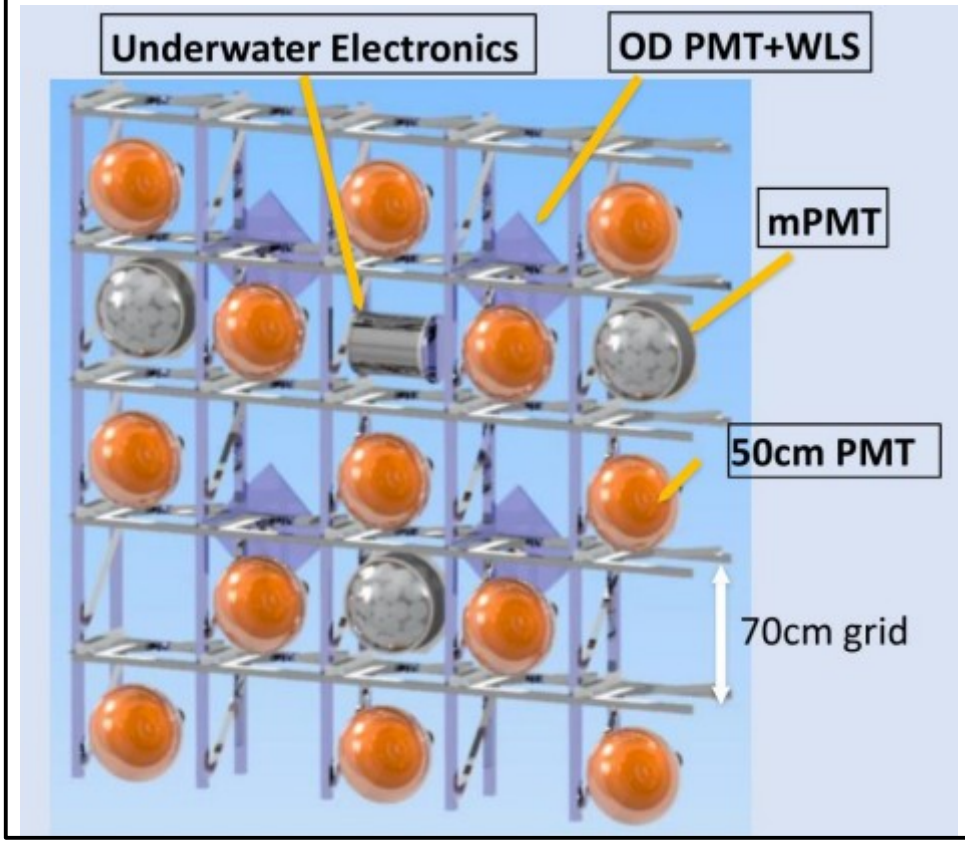


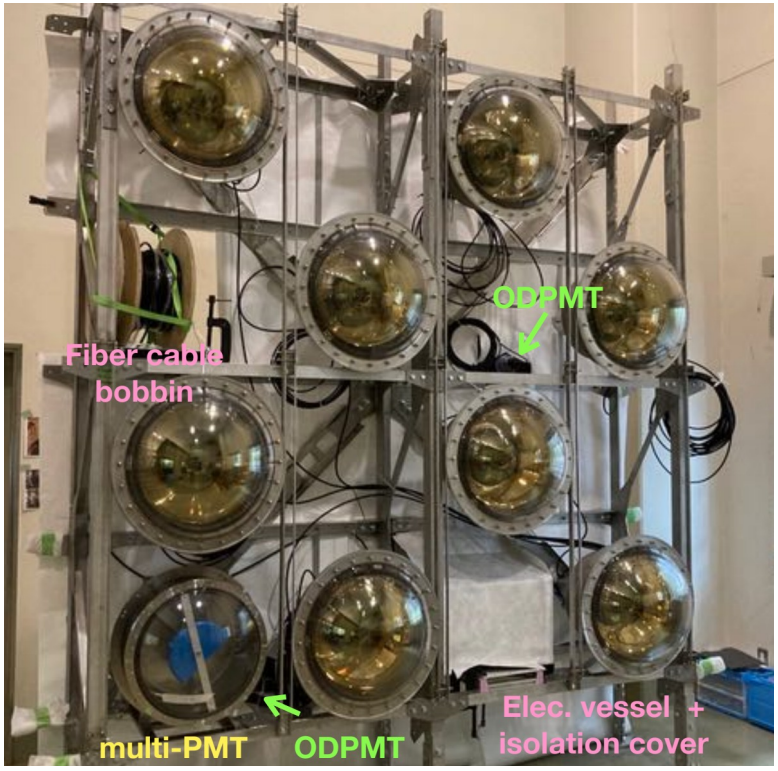


Hyper-Kamiokande status
Underwater components

- PMTs and electronics will be attached to a stainless steel support structure
- Design of the different elements completed, now in mass production
- Detailed plans for installation being finalized, with tests using mockups
- Start of detector installation spring 2027

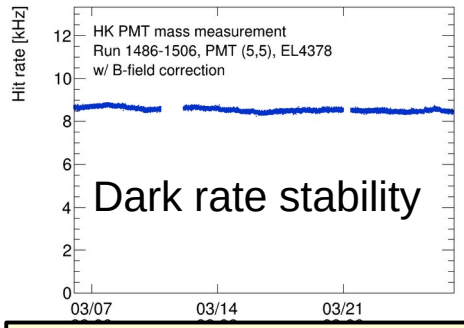
Mock-ups in Japan (ID and OD) and UK (mostly for OD) for tests and validation of the design and installation procedures





Hyper-Kamiokande status
50cm PMTs

- Mass production of 20.5k **50cm PMTs** started in 2020, suspended in 2022 due to higher than expected failure of tests criteria. Restarted 2023, **delivery completed summer 2026**
- 2 test facilities in Kamioka allowed QA test of 3.4k and 750 PMTs respectively
- **Protective covers for 50cm PMTs** to prevent chain implosion
- Developed new covers producing less background than Super-K ones
- Validated using hydrostatic and underwater implosion tests, now **in mass production**



“Mass measurement”
2x 100 PMTs

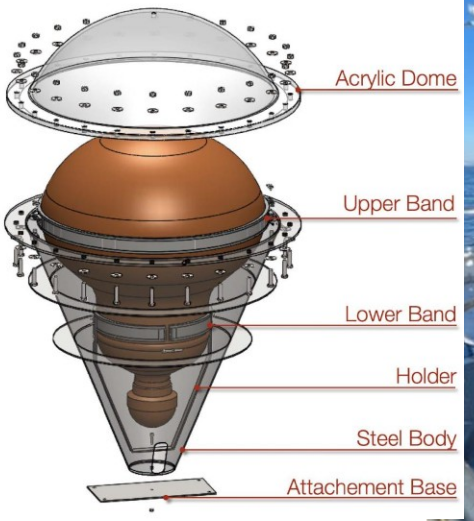


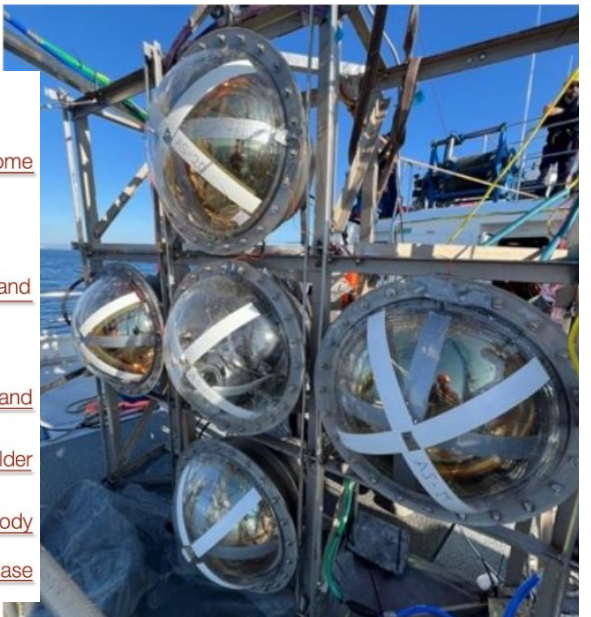
“Precise measurement”
2x 8 PMTs







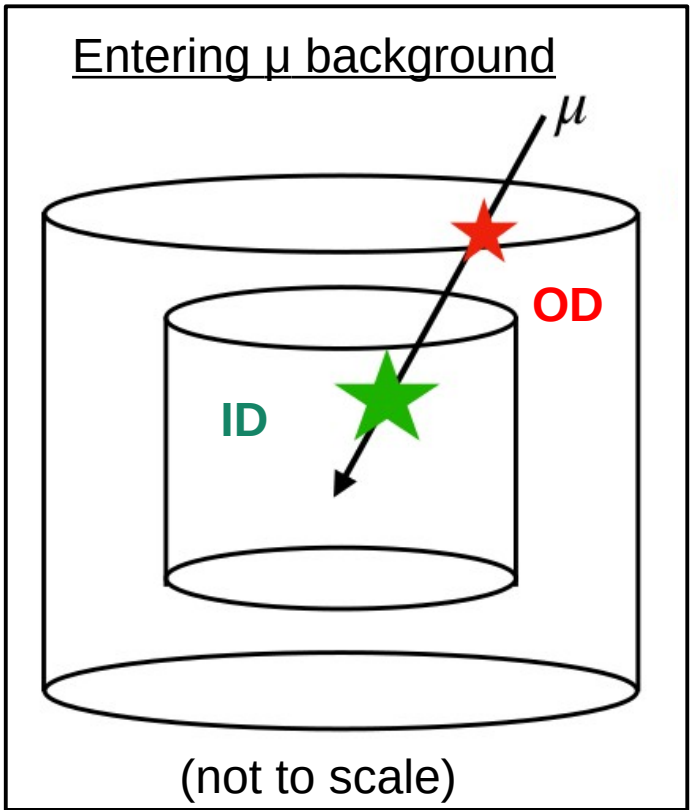


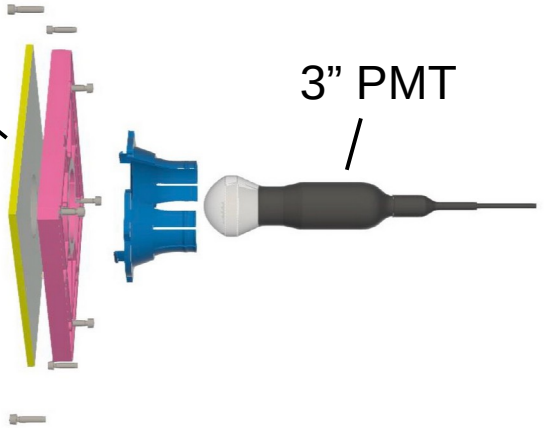


See posters by CB and Zenta Utagawa

Hyper-Kamiokande status
Outer detector

- OD: optically separated region surrounding the Inner Detector (barrel: 1m, top/bottom:2m)
- Main role is to identify entering backgrounds (cosmic μ, gamma, ν interactions in surrounding rock, ...)
- Instrumented with 3.6k “detection units” made of 3” PMT (HPKK R14374) and WLS plates, with reflective Tyvek on walls to enhance amount of light collected
- Mass production of PMTs and WLS plates on-going, delivery started
- Dedicated setup for QA test of all delivered 3” PMTs





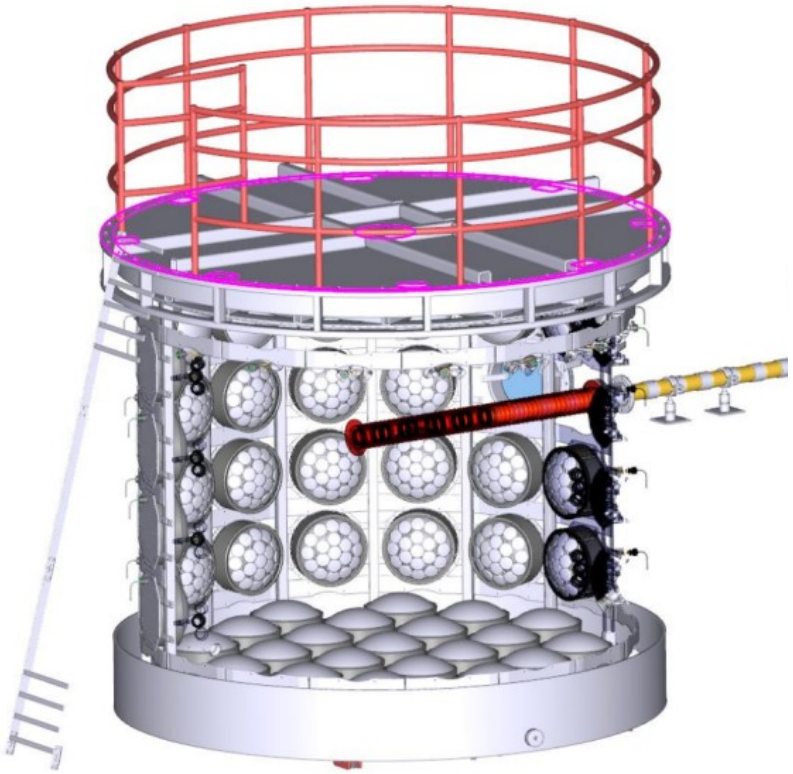




Hyper-Kamiokande status
Multi-PMTs

- Different types: FD, FD with LED and IWCD, with common basis
- Design complete, mass production of parts on-going and assembly started (FD type)
- First test for assembly and operation in real detector conditions with WCTE (mostly IWCD type)

Water Cherenkov Test Experiment



- WCTE measured charged particle scattering at CERN between fall 2024 and summer 2025
- Prototype for IWCD and FD mPMT assembly
- Assembled 100 IWCD style and 5 FD style mPMTs, validating assembly procedure and speed estimates

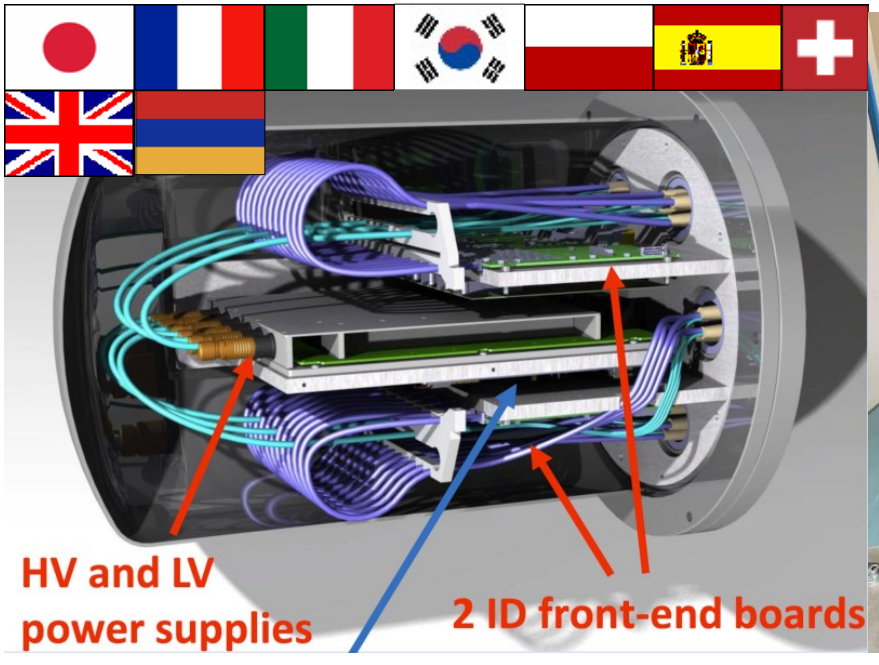




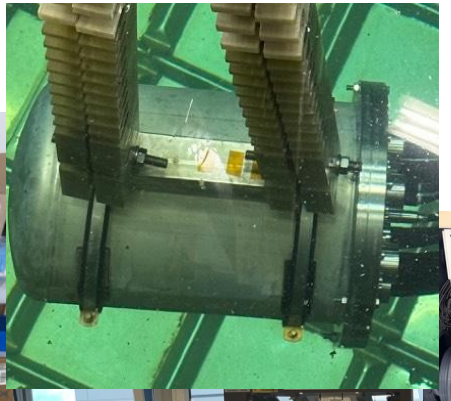
Note: WCTE is an independent collaboration from Hyper-Kamiokande

Hyper-Kamiokande status
Electronics

- Electronics will be underwater, in pressure vessels
- Multiple components with contributions from several countries
- Prototypes and tests of all the components complete, now in mass production.
- Calibration, water-tightness proof and assembly of mass produced components will be carried out at CERN
- Assembled modules then shipped to Japan for installation







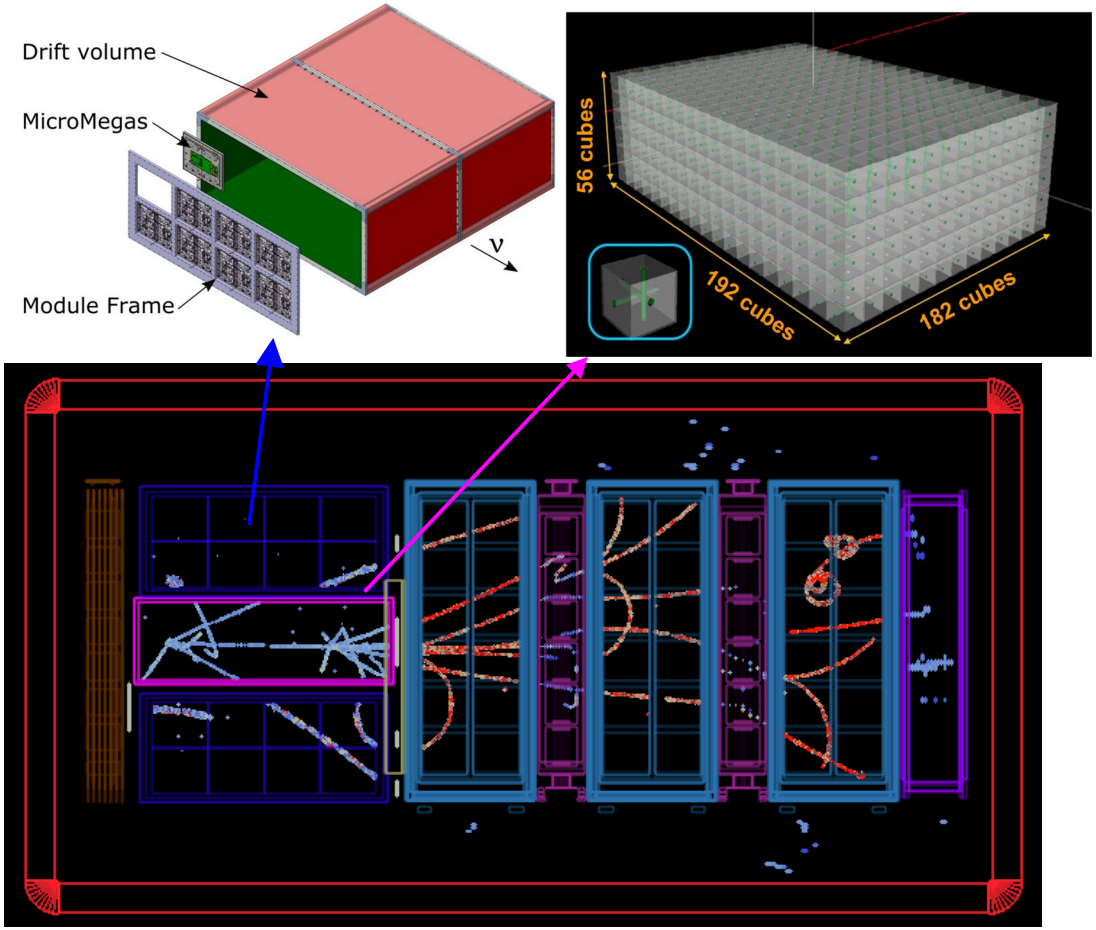




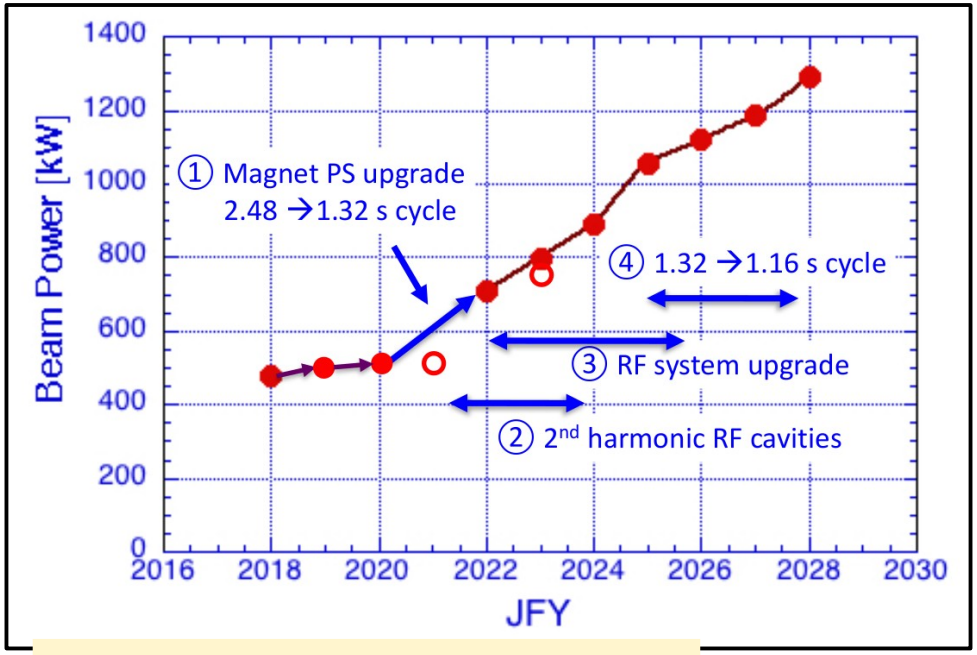
Data processing and timing boards

Hyper-Kamiokande status
J-PARC: beam and near detectors

- J-PARC neutrino beamline and ND being operated as part of T2K since 2009
- Operation at progressively increased beam intensity (reached ~900 kW this year)
- Off-axis near detector ND280 completed significant upgrade in May 2024
- Major upgrade started summer 2026 to prepare for 1.3 MW operation: new target, improved cooling, remote maintenance capability



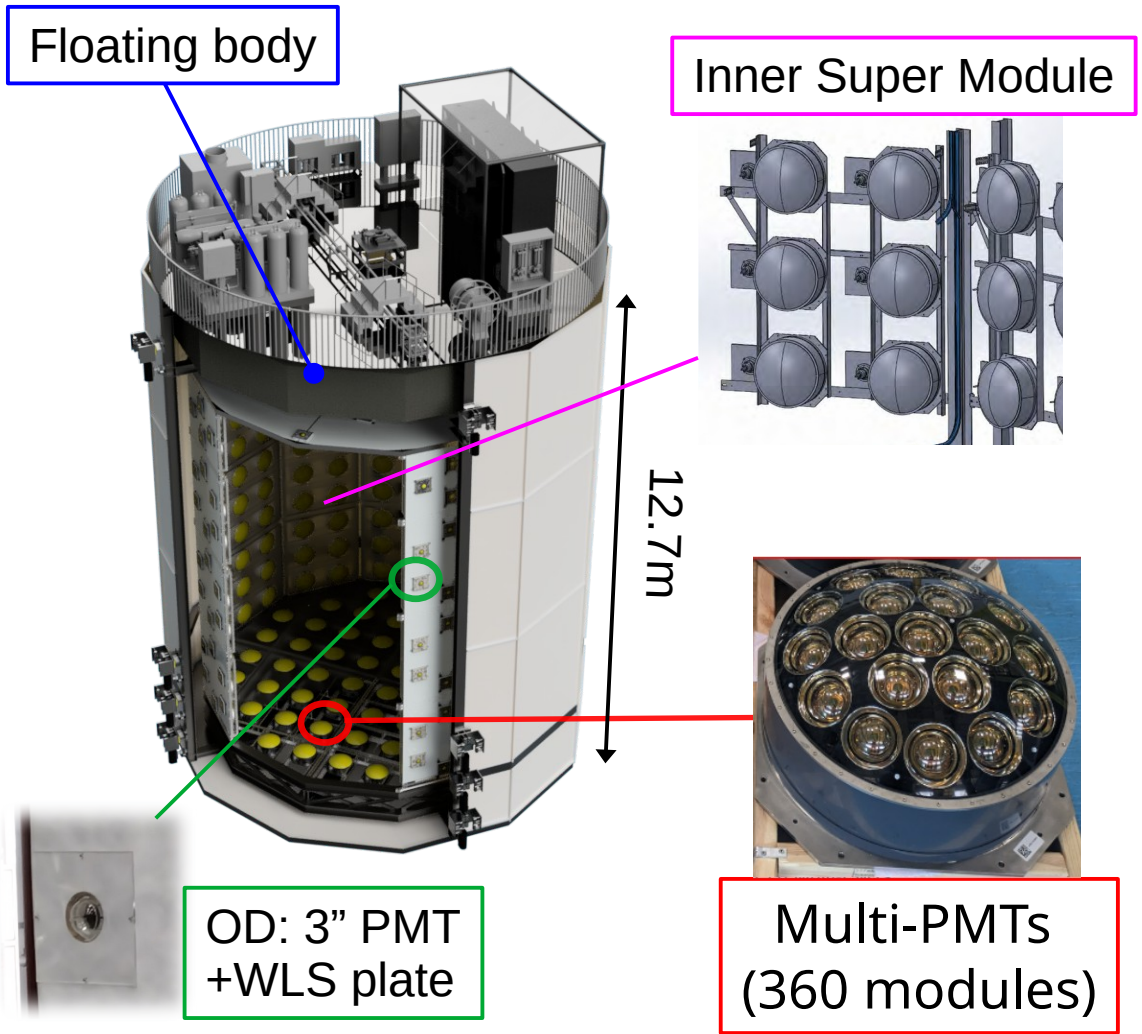
Continuous beam power increase to 1.3MW by the start of HK



From Y. Sato @ J-PARC PAC

Hyper-Kamiokande status
J-PARC: Intermediate Detector

- Detailed design of the detector completed
- Work started with construction of a new facility near J-PARC
- Excavation of a 48m-deep pit started, now 40% complete
- Target completion of detector installation and start of operations in 2028







Summary

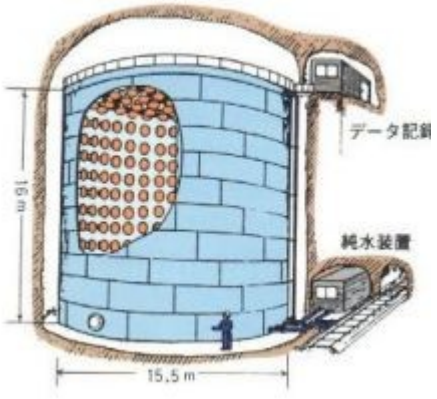
- Hyper-Kamiokande is the next generation Water Cherenkov experiment in Japan.
- Two sites: a 258kt water Cherenkov detector in Kamioka, and a neutrino beamline +near detectors in J-PARC
- Large statistics will allow high precisions studies of the oscillation of atmospheric, accelerator and solar neutrinos, as well as searches for new physics (proton decay in particular)
- Long baseline part will use the J-PARC beamline and near detectors currently used in T2K, together with a new intermediate water Cherenkov detector
- Assuming known Mass Ordering, can exclude conservation of CP symmetry in neutrino oscillation at 5σ for 62% of true δ_{CP} values in 10 years with long baseline part of the analysis
- Construction started in 2020, excavation completed in 2025 and construction of the underground facility (tank, water system) on-going
- Design and validation of the different parts of detector complete, now in mass production phase towards start of installation in 2027
- Start of operation planned for 2028

BACKUP

A new chapter in a successful series

Kamiokande experiment

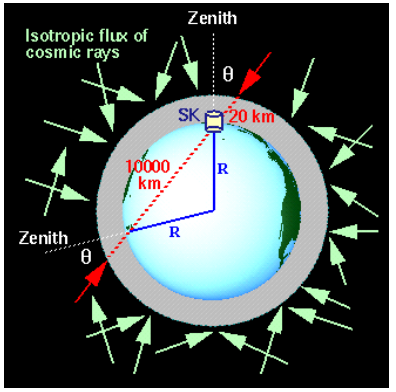
- 1983-1996
- 3kt ultra-pure water
- 1k 20” PMTs

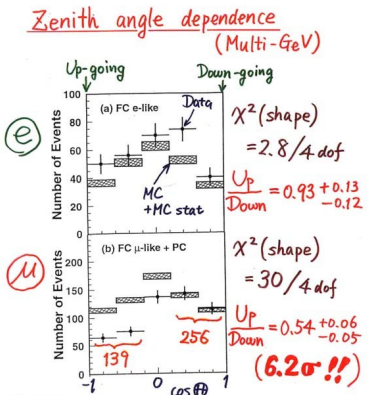




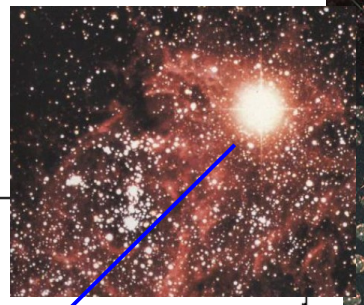
Super-Kamiokande experiment

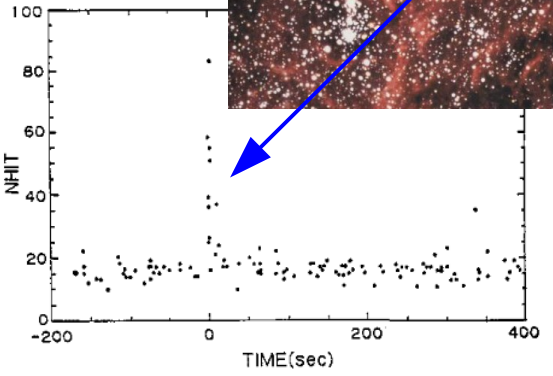
- 1996~
- 50kt ultra-pure water
- 11.1k 20” PMTs

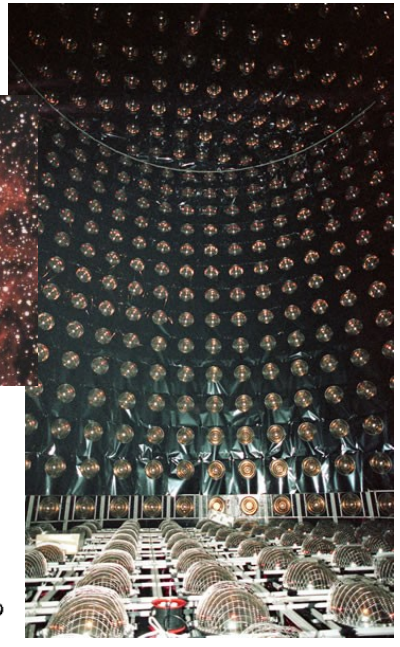


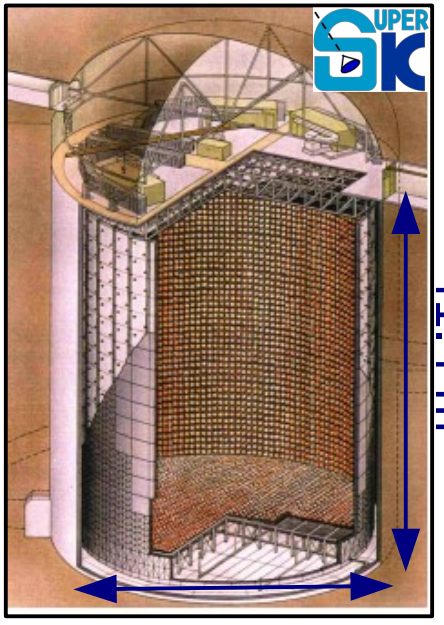


SN1987A







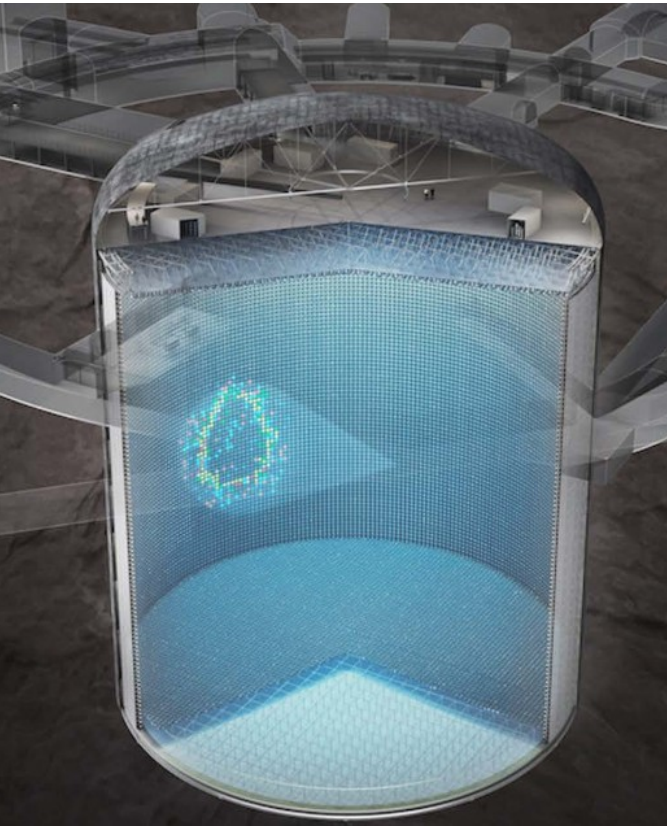




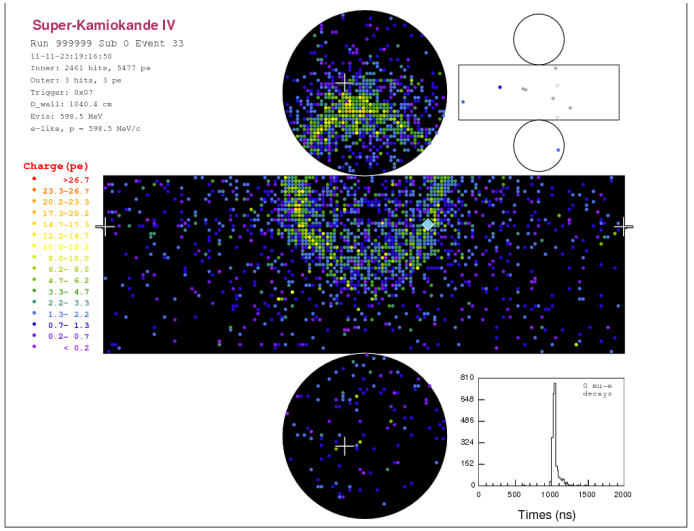


The Hyper-Kamiokande (Far) Detector

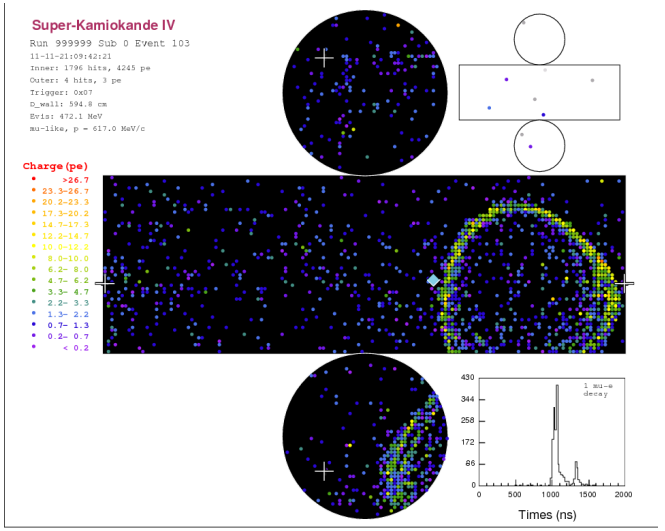
- Optically separated between inner and outer detector
- Charged particles appear as ring patterns on walls of the inner detector
- Instrumented with high performance photon detectors (PMTs)
- Good separation between showering ($e^{\pm}$,γ) and non-showering ($\mu^{\pm}$,$\pi^{\pm}$) particles
- Large water mass allows to study rare phenomena and particles with low interaction probabilities



Showering



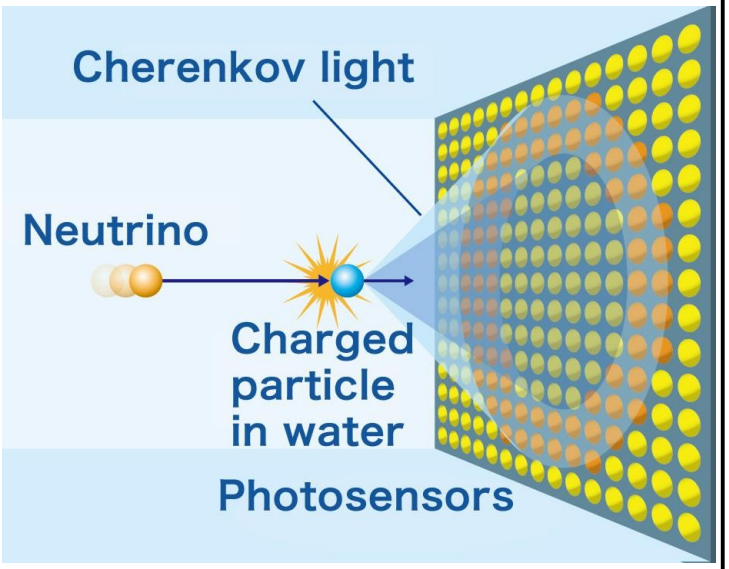
Non-showering



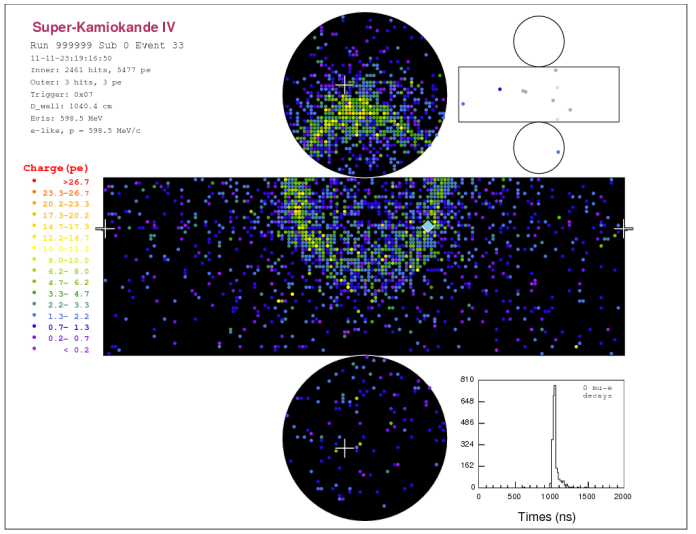
Examples from Super-K simulation

Events in water Cherenkov detector

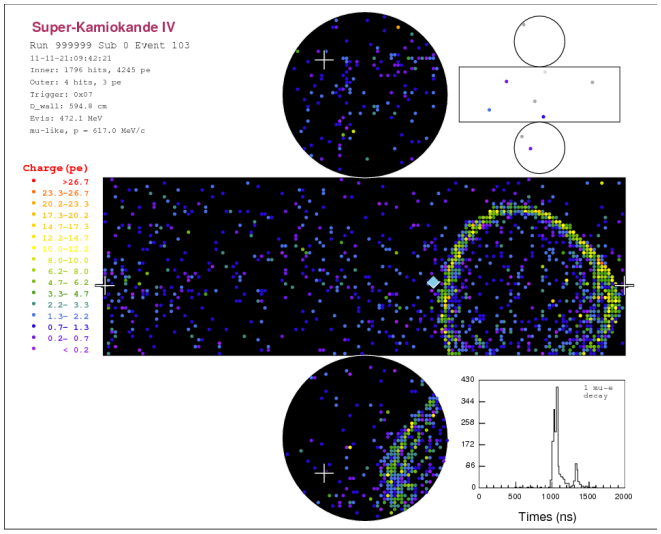
- Charged particles above Cherenkov threshold appear as ring patterns on walls of the inner detector
- PID from sharpness of ring edges, separate between showering ($e^{\pm}$,γ) and non-showering ($\mu^{\pm}$,$\pi^{\pm}$)
- Interaction vertex position by minimizing spread of (photon arrival time)-(time of flight)
- Momentum from charge deposited in a certain region around ring direction
- Reject entering background using outer detector



Showering



Non-showering



Examples from Super-K simulation

PMTs in the far detector

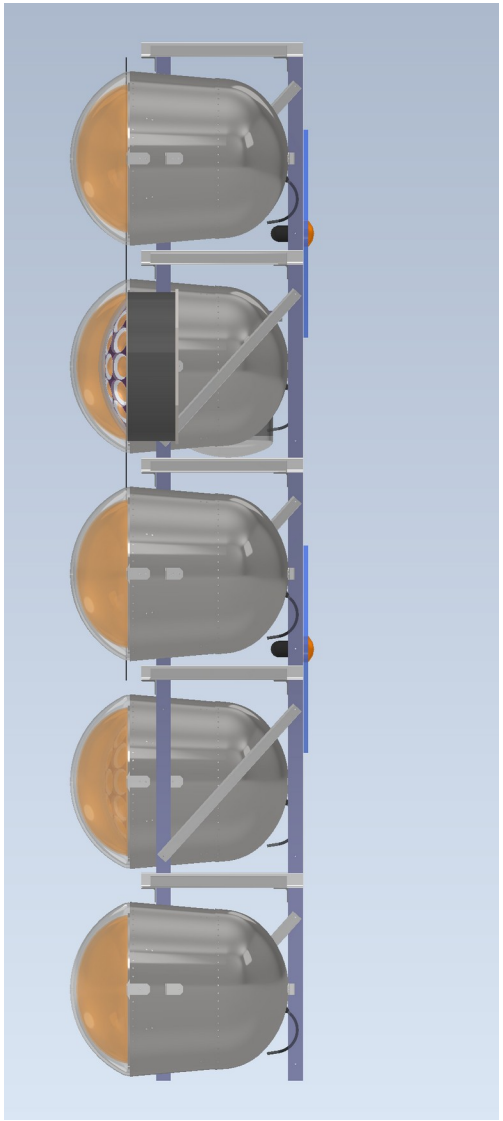
Photo-detection systems have different goals in inner and outer detectors: important characteristics differ

Inner detector

Event reconstruction

- Timing resolution for vertex reconstruction
- Charge resolution, coverage and detection efficiency for momentum
- Granularity for PID
- Photo-coverage and detection efficiency for low energy events
- Low dark rate for neutron tagging from hydrogen capture

Optimized high QE 20” PMTs + multi-PMTs



Outer detector

Reject entering background

Veto based on cluster of hits above threshold:

- Large number of PMTs to increase information entropy of signal
- Good light collection efficiency
- Low dark rate to be able to use low threshold

3” PMTs in WLS plates with high reflectivity Tyvek

Hamamatsu R12860

A number of improvements compared to R3600 used in Super-Kamiokande:

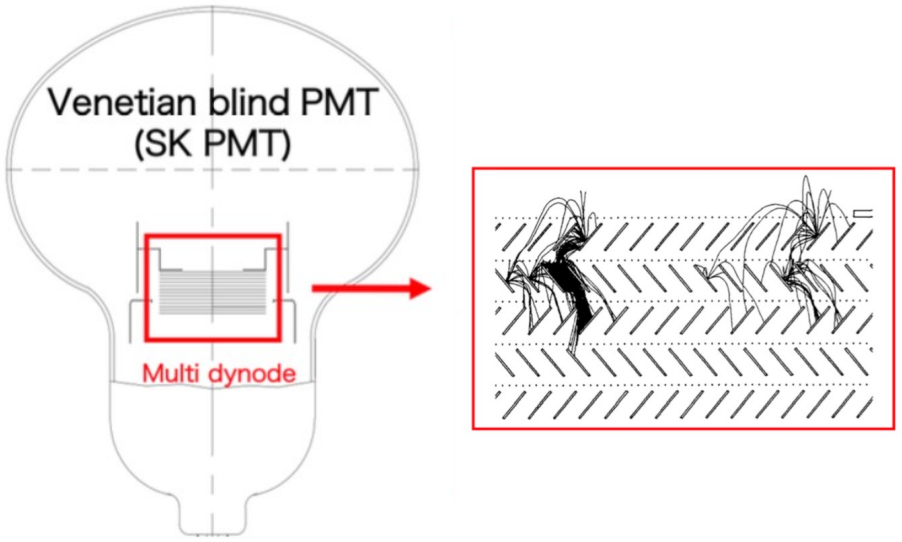
- Higher QE and electrons less likely to miss first dynode => higher detection efficiency
- More uniform electron drift path => better timing and charge resolutions

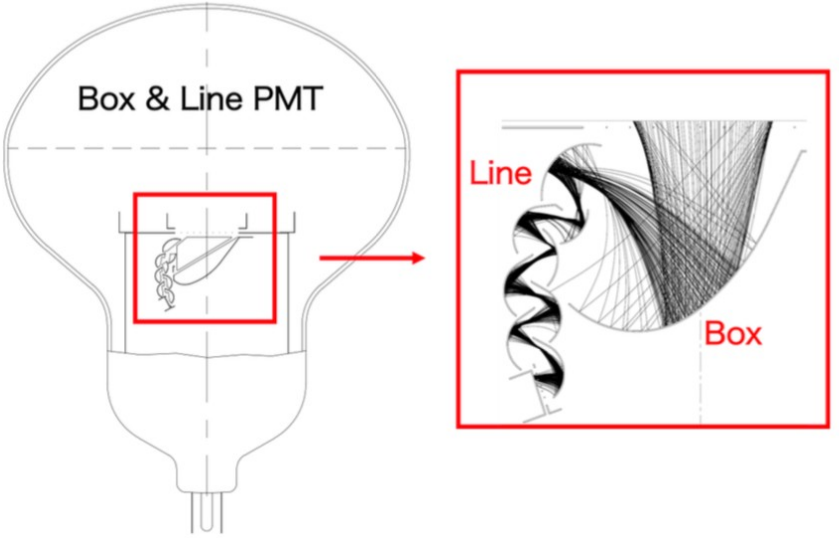
Super-K PMT
Hamamatsu R3600

Venetian blind dynode

Hamamatsu R12860

Box and line dynode
+ high QE

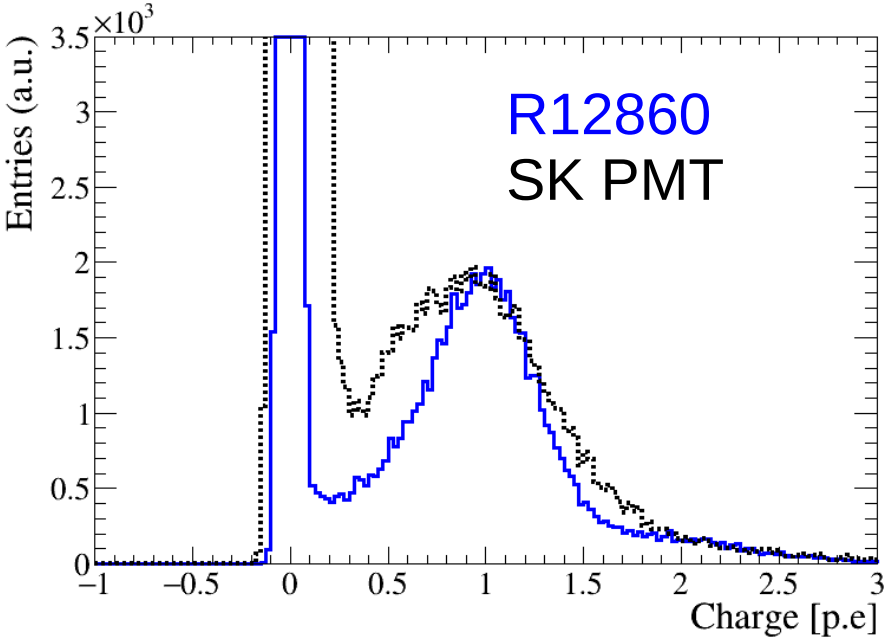


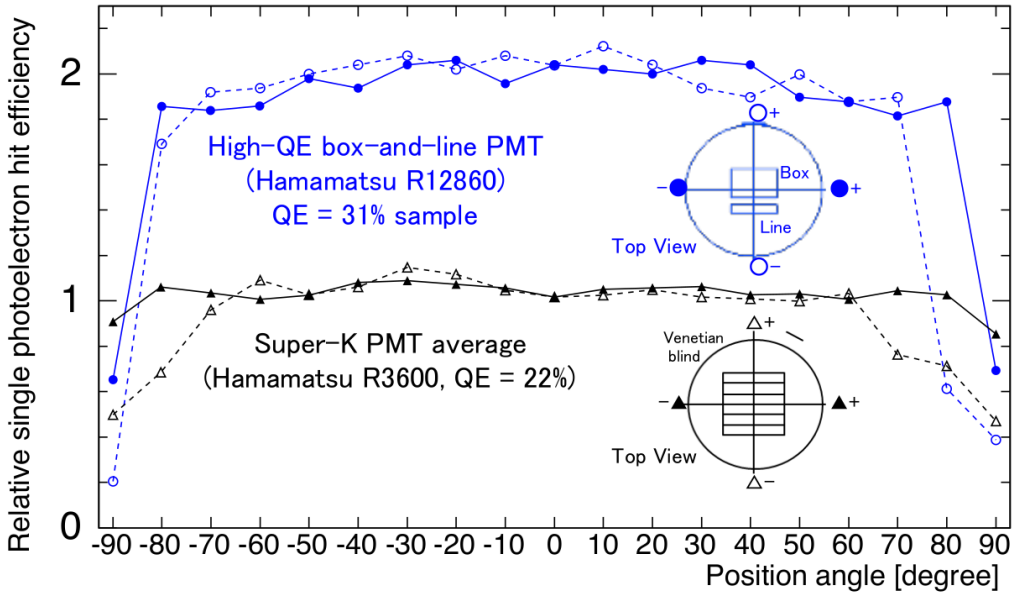


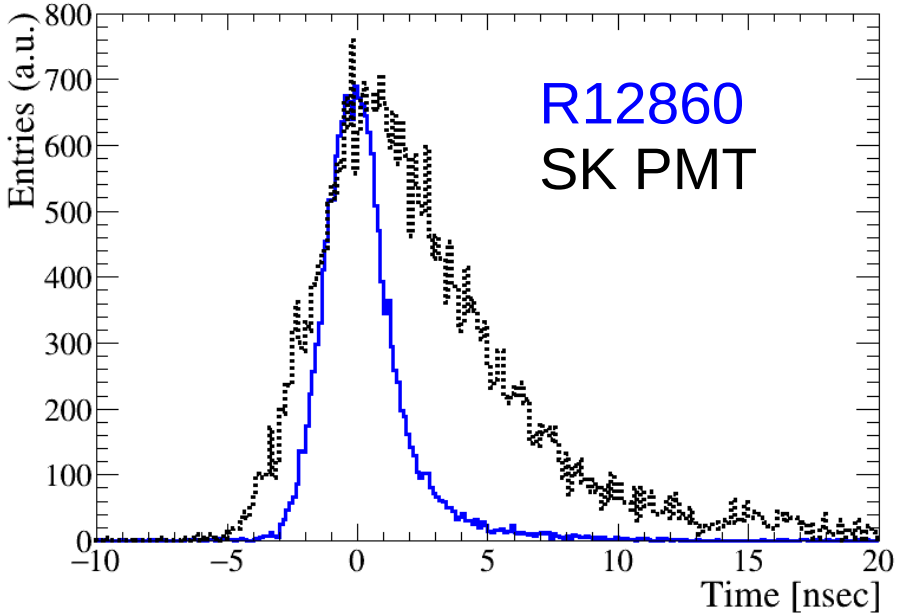
Hamamatsu R12860

Clear improvement seen in tests:

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

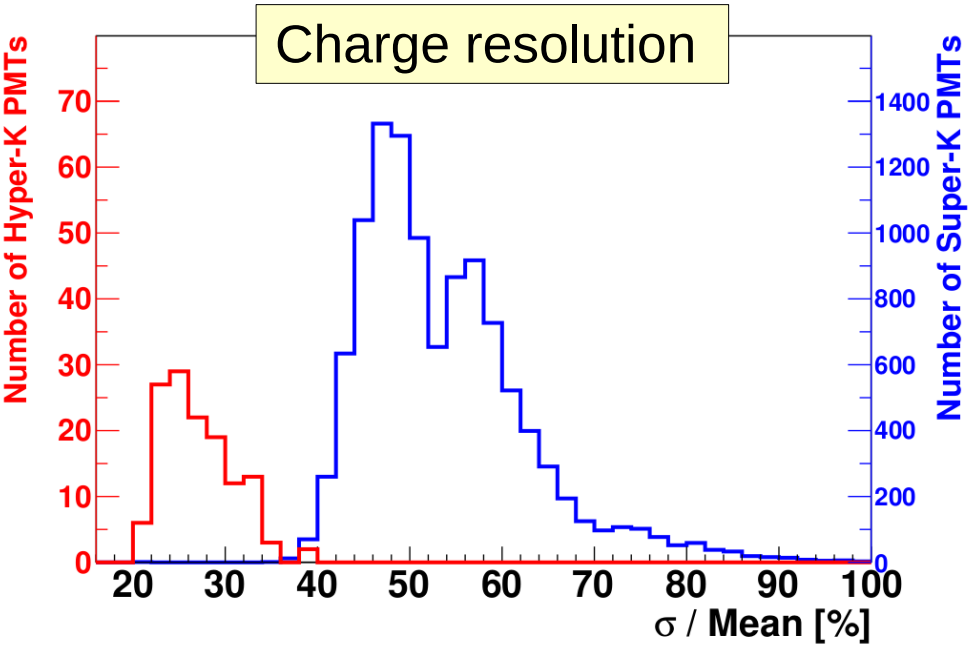


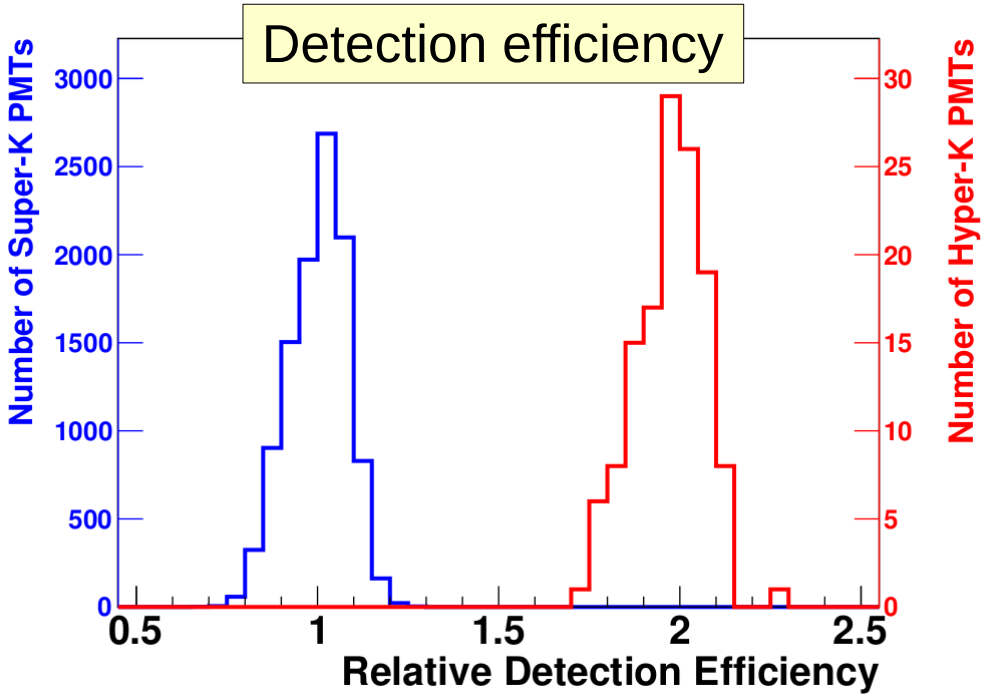


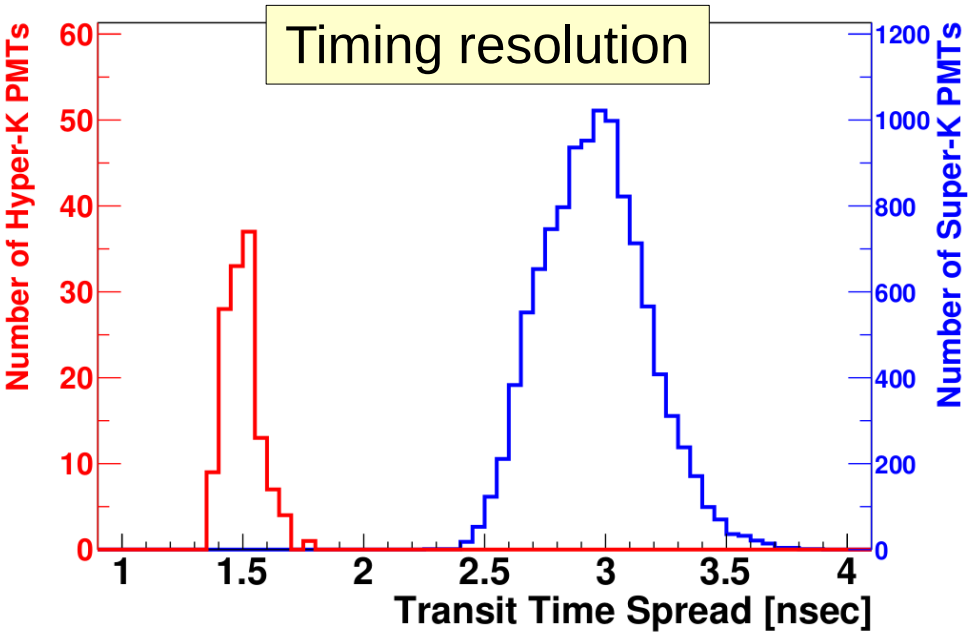


Hamamatsu R12860 Performance in Super-Kamiokande

- Measurement inside Super-K confirmed improved detection efficiency, and charge and timing resolution in real detector conditions
- Measured timing resolution (σ=1.5 ns) worse than pre-installation tests (σ=1.1 ns), believed to be due to unidentified element in Super-K measurement and not change of PMT performance



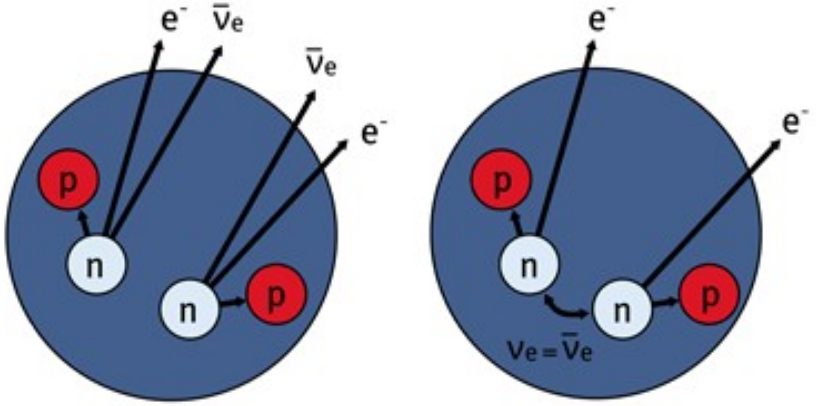


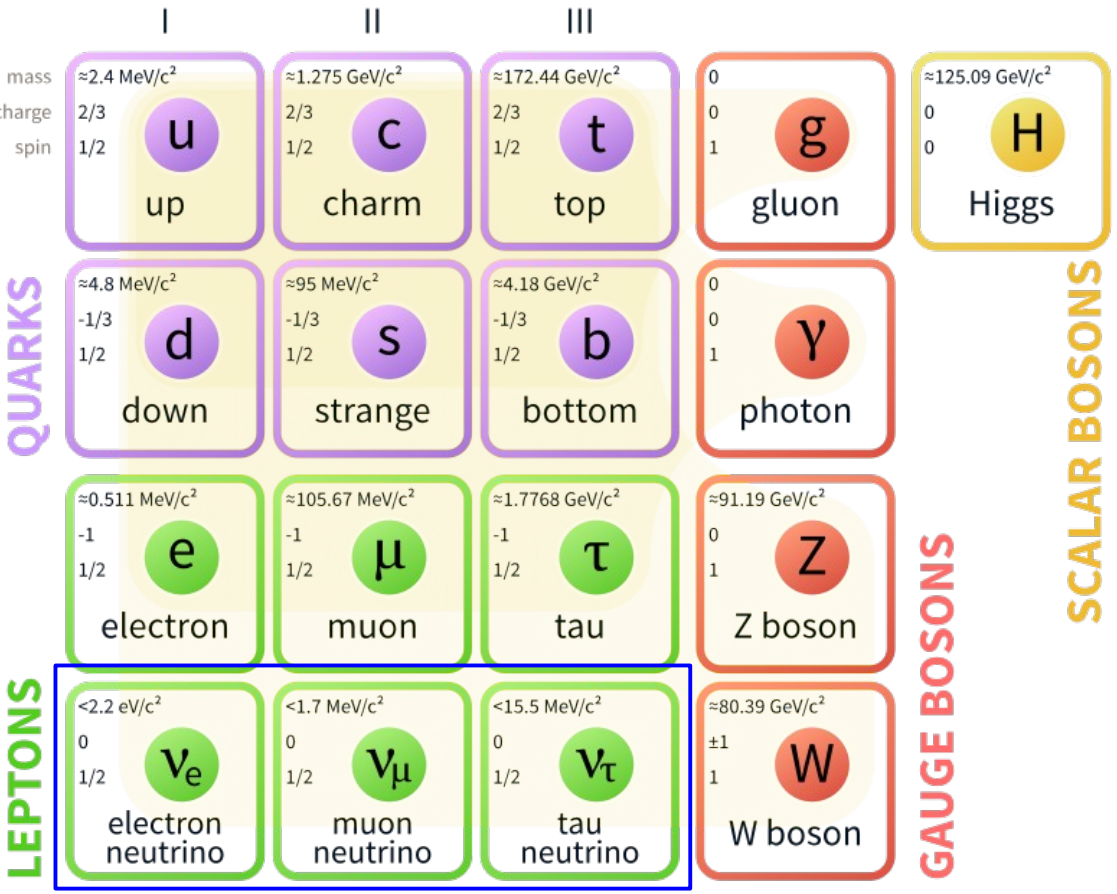


Neutrinos

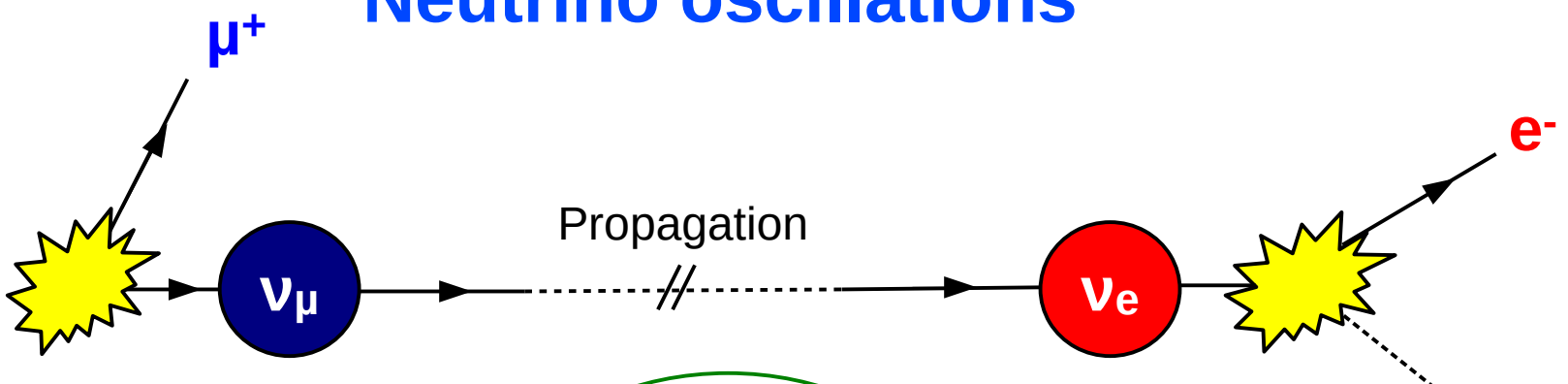
In the standard model, fundamental particle that comes in 3 flavors
- Interact only through weak force: hard to detect
- Not very well known despite its abundance

Many open research topics:
- Low but non-zero mass
  - ➔ Origin of its mass ?
  - ➔ Determination of absolute mass
- Could be its own anti-particle (Majorana particle)
- **Neutrino oscillations**
- **Astrophysical observations through ν**





Neutrino oscillations



Flavor eigenstates
(interaction)

$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} = \begin{pmatrix} U_{e1} & U_{e2} & U_{e3} \\ U_{\mu 1} & U_{\mu 2} & U_{\mu 3} \\ U_{\tau 1} & U_{\tau 2} & U_{\tau 3} \end{pmatrix} \times \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{pmatrix}$$

Mass eigenstates
(propagation)

Mixing (or Pontecorvo-Maki-Nagawa-Sakata) matrix
link between the two sets of eigenstates

$P(\nu_\alpha \rightarrow \nu_\beta)$ oscillates as a function of distance L traveled by the neutrino with periodicity $\mathbf{\Delta m^2_{ij} L/E}$

$(\Delta m^2_{ij} = m^2_i - m^2_j)$

Neutrino oscillations Parameters

$$U = \begin{pmatrix} 1 & 0 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{23} & c_{23} \end{pmatrix} \begin{pmatrix} c_{13} & 0 & s_{13}e^{-i\delta} \\ 0 & 1 & 0 \\ -s_{13}e^{i\delta} & 0 & c_{13} \end{pmatrix} \begin{pmatrix} c_{12} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

($c_{ij} = \cos(\theta_{ij})$, $s_{ij} = \sin(\theta_{ij})$)

$P(\nu_\alpha \rightarrow \nu_\beta)$ depends on 6 parameters:

- 3 **mixing angles** : **θ_{12}, θ_{23}, θ_{13}**
- 2 **mass splittings** : **Δm^2_{ij}**
- 1 (complex) phase : The **CP phase δ**

→ Amplitude

→ Periodicity

→ Difference in oscillations $\nu/\bar{\nu}$

$$P(\nu_\alpha \rightarrow \nu_\beta, U) = P(\bar{\nu}_\alpha \rightarrow \bar{\nu}_\beta, U^*)$$

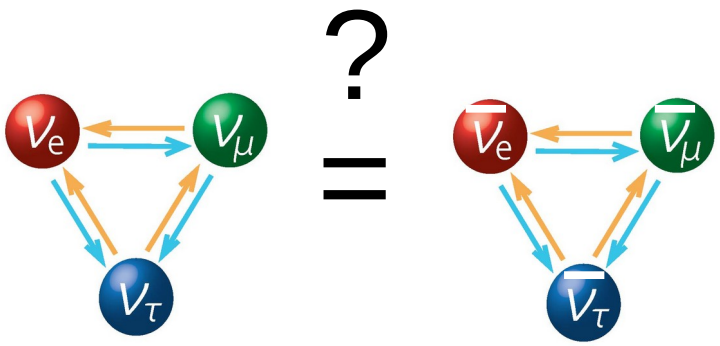
Neutrino oscillations
Current physics goals

- Existence of the phenomenon well established
- Parameters of the 3 flavor oscillation model measured to a certain precision
- 3 open questions in standard oscillations
- Precise measurements to test standard framework, in search of physics beyond the standard model

CP symmetry

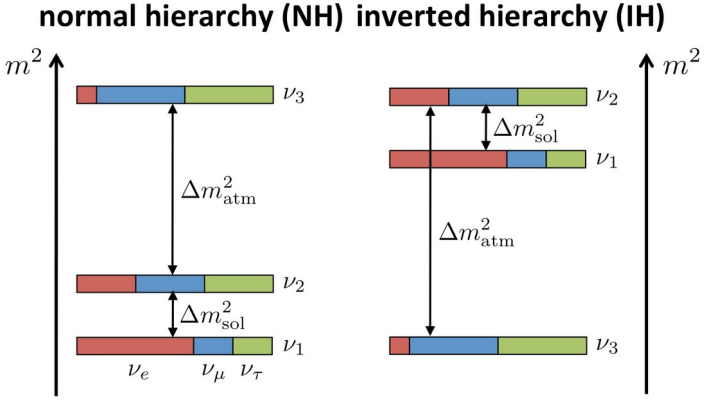
- difference matter/anti-matter

$\not{CP} \Leftrightarrow$ **$\sin(\delta) \neq 0$**



Mass ordering

- Neutrino mass models
- input for other experiments (0νββ, supernova)



Octant of θ_{23}

- symmetries in lepton sector

$\theta_{23} > \pi/4$?
$\theta_{23} = \pi/4$?
$\theta_{23} < \pi/4$?

Sensitivity to open questions

Golden channel: $\nu_\mu \rightarrow \nu_e$ "appearance" channel

- CP phase and mass ordering modify $P(\nu_\mu \rightarrow \nu_e)$ and $P(\bar{\nu}_\mu \rightarrow \bar{\nu}_e)$ differently
- Comparing them allows to measure sin(δ) and the mass ordering
- Also sensitivity to θ_{23} octant if θ_{13} well known:

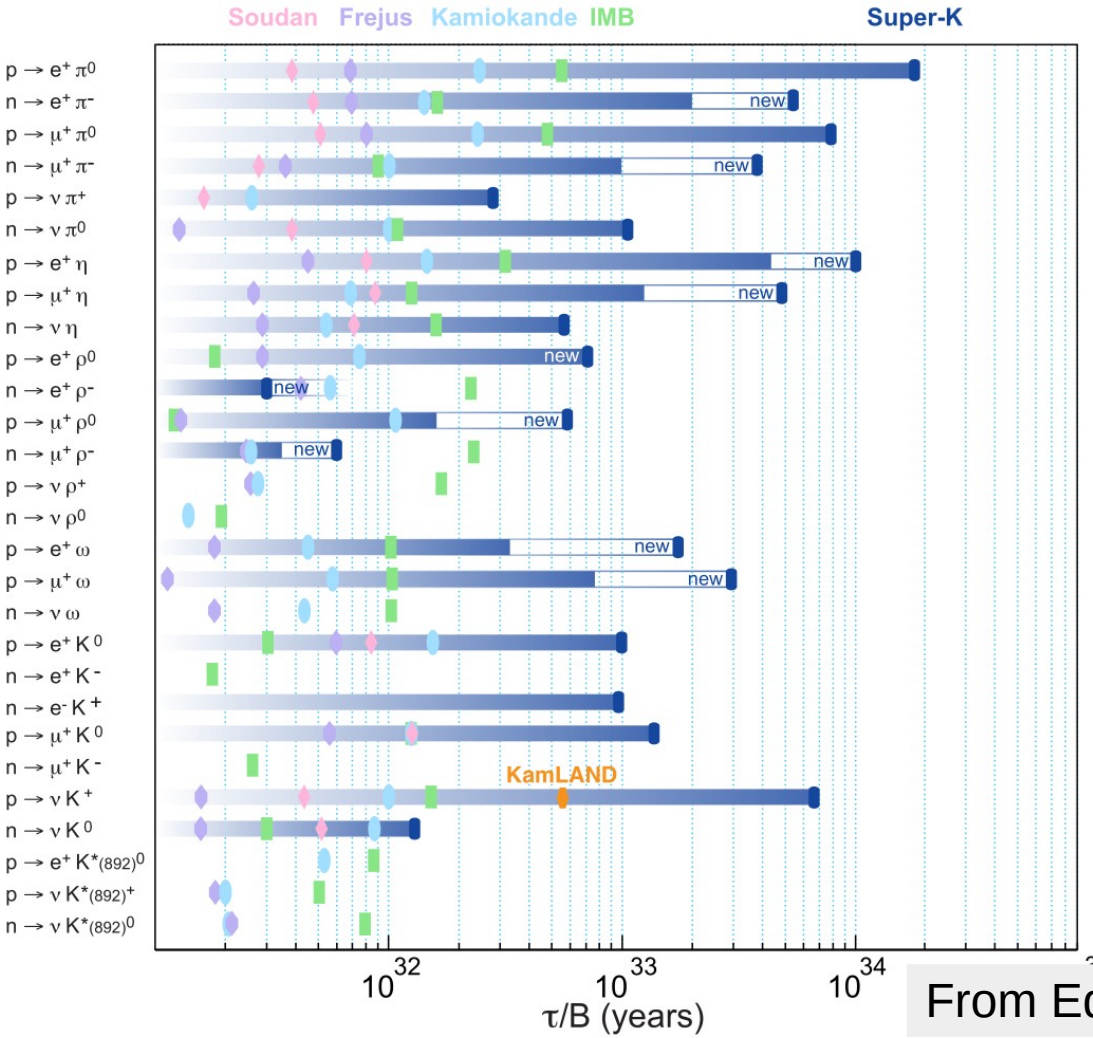
$$P(\nu_\mu \rightarrow \nu_e) \approx \sin^2(\theta_{23}) \sin^2(2\theta_{13}) \sin^2\left(1.27 \frac{\Delta m^2 L}{E}\right)$$

Channel	sin(δ) > 0	sin(δ) < 0	Normal ordering	Inverted ordering
$\nu_\mu \rightarrow \nu_e$	Suppressed	Enhanced	Enhanced	Suppressed
$\bar{\nu}_\mu \rightarrow \bar{\nu}_e$	Enhanced	Suppressed	Suppressed	Enhanced

- Degeneracies between δ and mass ordering
- T2K/HK baseline "not very long": effect of δ dominates (~<27% vs ~10%)

Nucleon decay

- GUTs attempt to unify strong and electroweak interactions
- As a result of proposed unification, baryon number no longer conserved and proton can decay: experimental tests of GUTs
- Predicted lifetimes very large, typically 10^{29}~10^{36} years
- Experimental searches conducted through many channels, no observations so far



From Ed Kearns, BLV2017