Hyper-Kamiokande Project

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Experimental Particle and Astro-Particle Physics Seminar @ UZH

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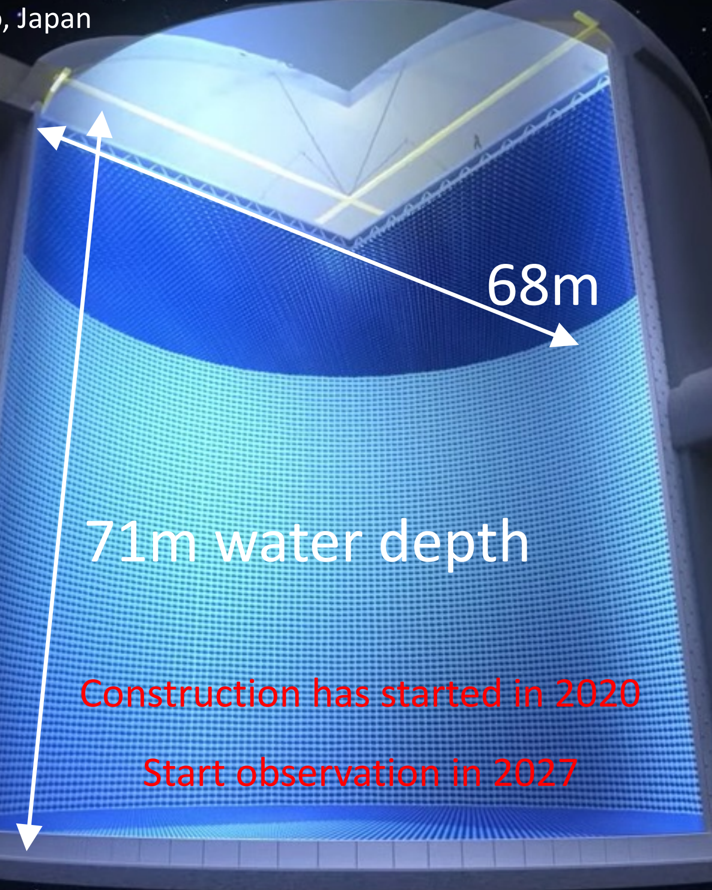
Hyper-Kamiokande Project

The Hyper-Kamiokande Project

= A Larger Water Cherenkov Detector + High-intensity Accelerator and near detectors

Hosted by University of Tokyo, Japan — Hosted by KEK, Japan



Large Cavern Construction

× 8.4 of Super-Kamiokande target water

High-sensitivity Photosensors

×2 performance

\+ **Detector system**

With international contributions

= Far detector at long-baseline ν experiment

KEK 高エネルギー加速器研究機構 J-PARC

1.3MW beam intensity

× 2.6 of current intensity

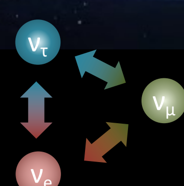
\+ **Systematic suppression**

By improved and new near detectors

For Leptonic CP Violation

Major Physics Targets

Search for Proton Decay



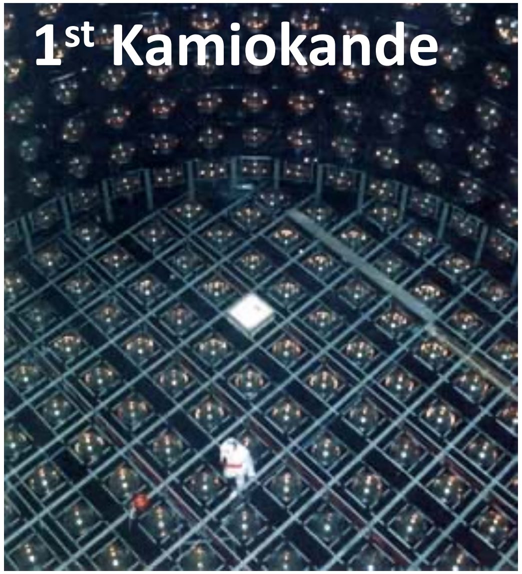
Neutrino Oscillations

Neutrino Astronomy

Kamiokande Series

Kamioka Nucleon **D**ecay **E**xperiment

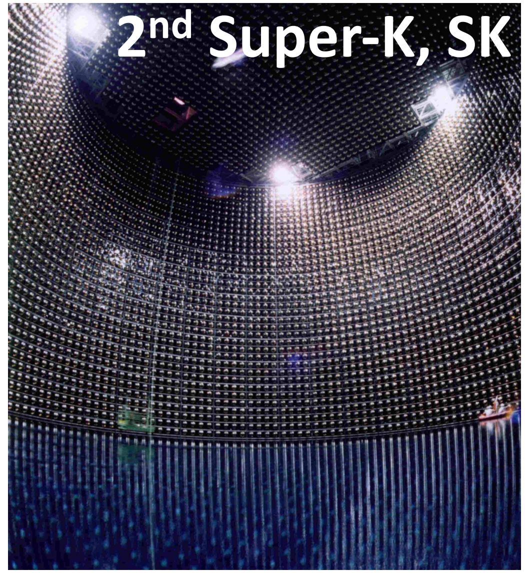
+ **Kamioka N**eutrino **D**etection **E**xperiment



Kamiokande
(1983-1996)

- Atmospheric and solar neutrino "anomaly"
- Supernova 1987A

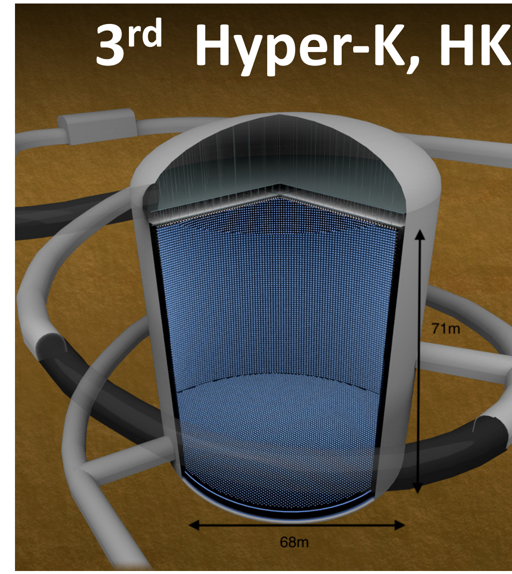
Birth of neutrino astrophysics



Super-Kamiokande
(1996 - ongoing)

- Proton decay: world best-limit
- Neutrino oscillation (atm/solar/LBL)
  - All mixing angles and $\Delta m^2 s$

Discovery of neutrino oscillations



Hyper-Kamiokande
(start operation in 2027)

- Extended search for proton decay
- Precision measurement of neutrino oscillations
  (ν CPV, mass ordering, etc.)
- Neutrino astrophysics

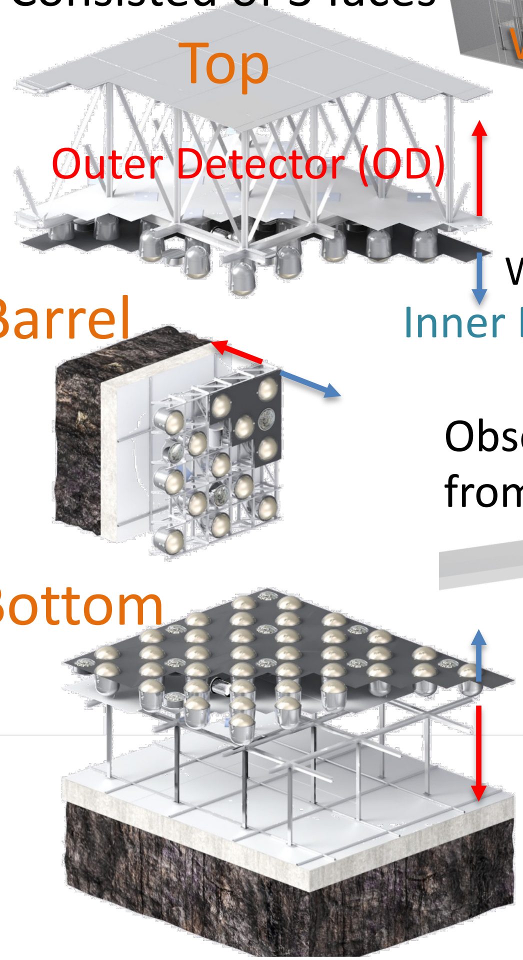
Explore new physics

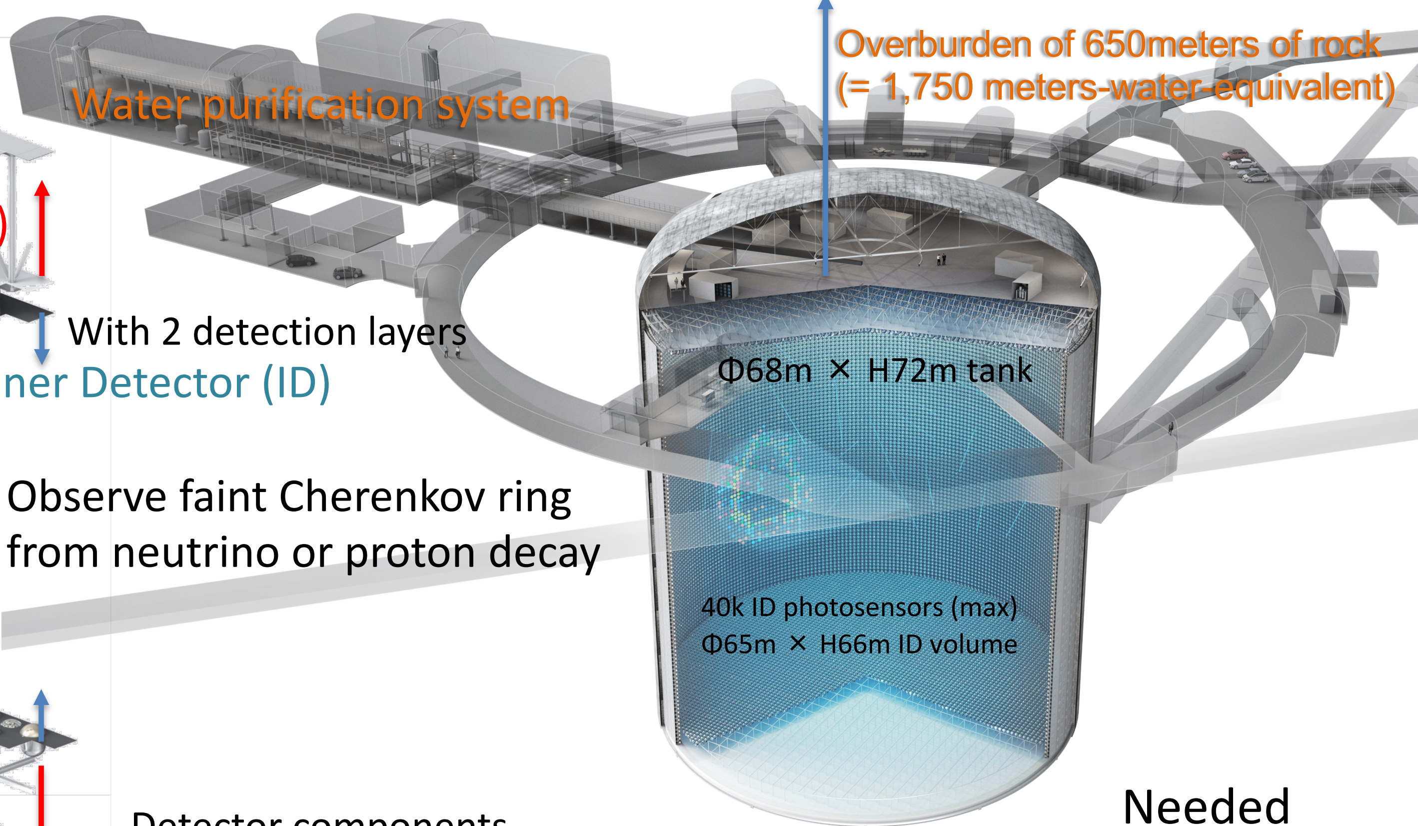
Hyper-Kamiokande Detector

Water Cherenkov detector

Far detector (FD) from J-PARC neutrino source

Consisted of 3 faces





Observe faint Cherenkov ring from neutrino or proton decay

Needed

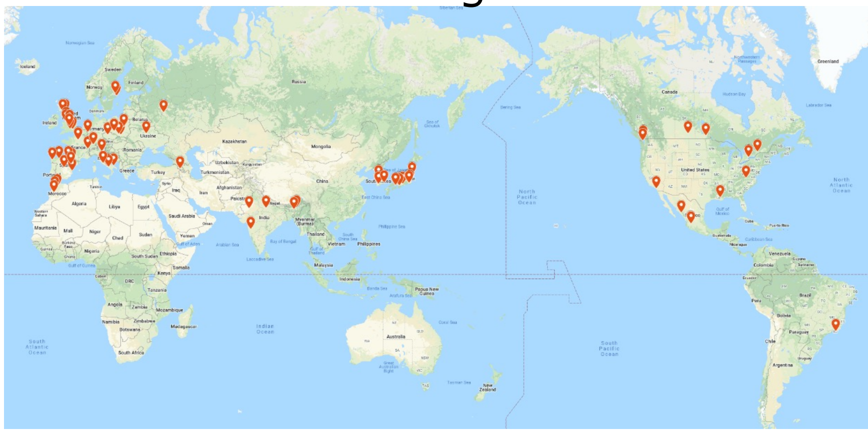
Detector components

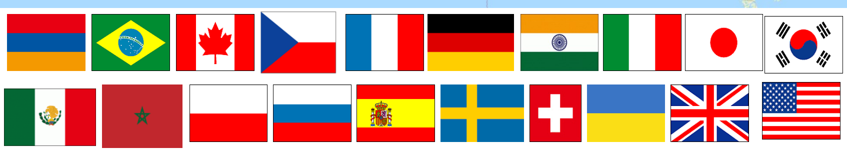
- Tank in deep underground → Low background
- Ultra pure water → Transparent and known optical characteristics
- ID/OD photosensors → High performance
- Electronics in the water → Stable operation with shorter signal cables

Broad international contribution is required to realize the detector.

Hyper-Kamiokande Collaboration

Collaborating Institutes





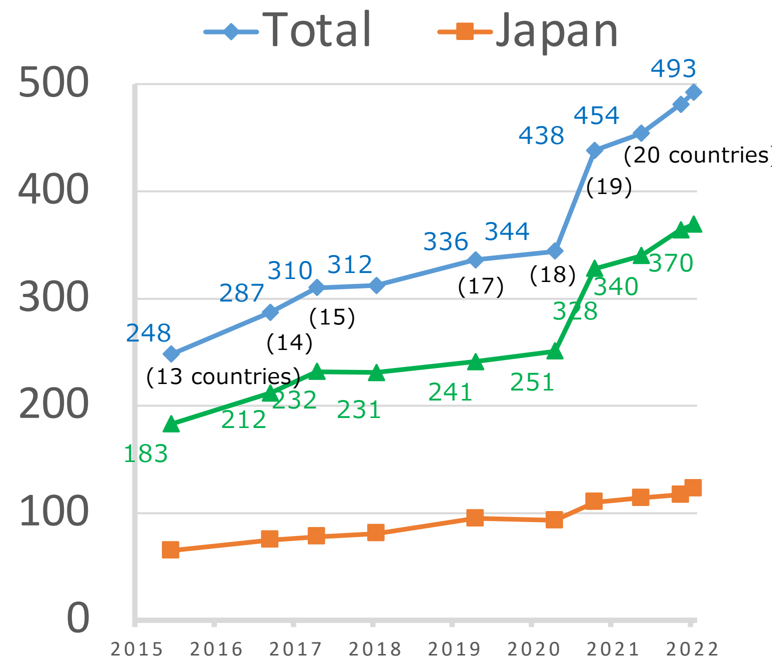
Europe	281 members
Armenia	3
Czech	4
France	27
Germany	1
Italy	55
Poland	38
Russia	22
Spain	35
Sweden	5
Switzerland	13
Ukraine	4
UK	74

Asia	149 members
India	8
Korea	18
Japan	123

Americas	52 members
Brazil	3
Canada	32
Mexico	8
USA	9

Africa	11 members
Morocco	11

Number of Collaborators



20 countries, 99 institutes, ~500 people as of Jan 2022, and growing

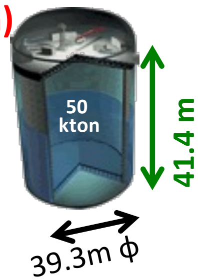
ETH Zurich and Universite de Geneve from Switzerland

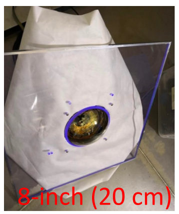
Still looking for more collaborations!

ID / OD at Hyper-Kamiokande

Super-Kamiokande (Super-K, SK)

ID : 11k 20-inch (50 cm) photosensors + OD 2k 8-inch (20 cm) photosnsors





22.5 kton

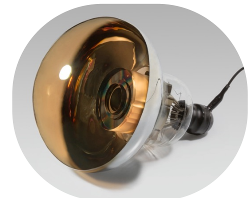
Hyper-Kamiokande (Hyper-K, HK)

ID : 40k max 20-inch (50 cm) photosensors

Fiducial mass

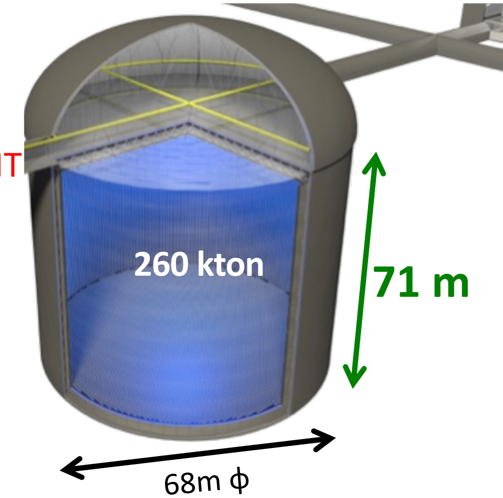
x 8.4

188 kton

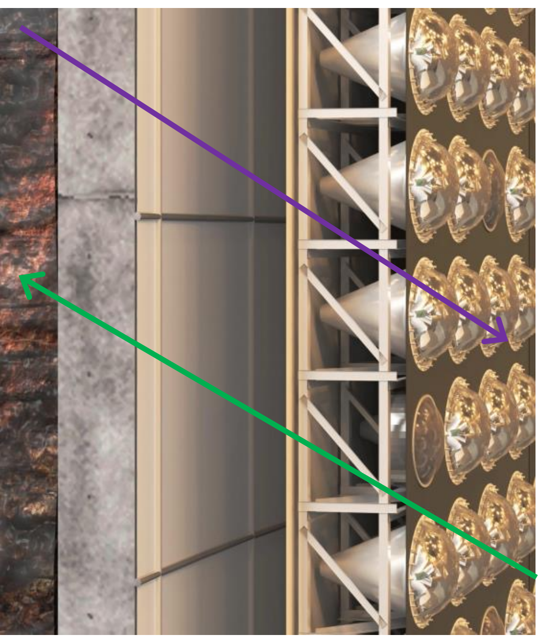


20k 50 cm High-QE Box&Line PMT from Japan

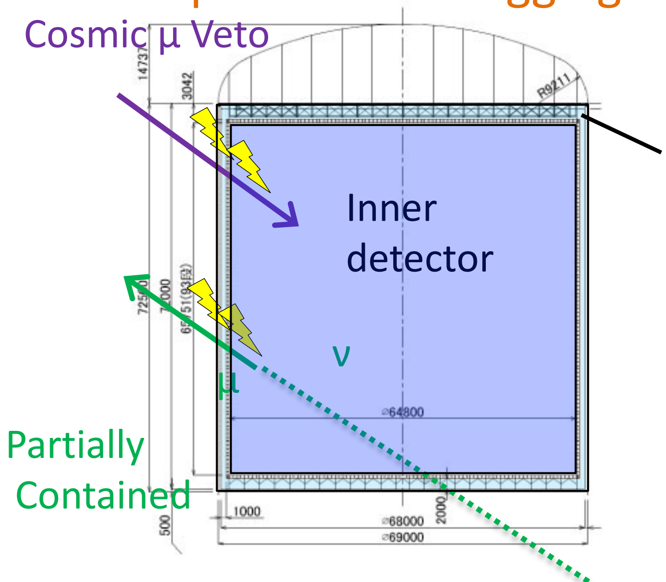
O(1k) 50 cm multi-PMT module



- Scalable to larger mass ⇒ rare process (neutrinos, proton decay)
- Based on well established technology from Super-Kamiokande



4π Acceptance with Tagging inward / outward going particles

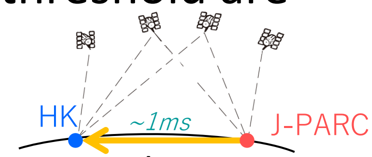


with ~10k 3-inch (8 cm) photosensors

and wavelength shifting plate

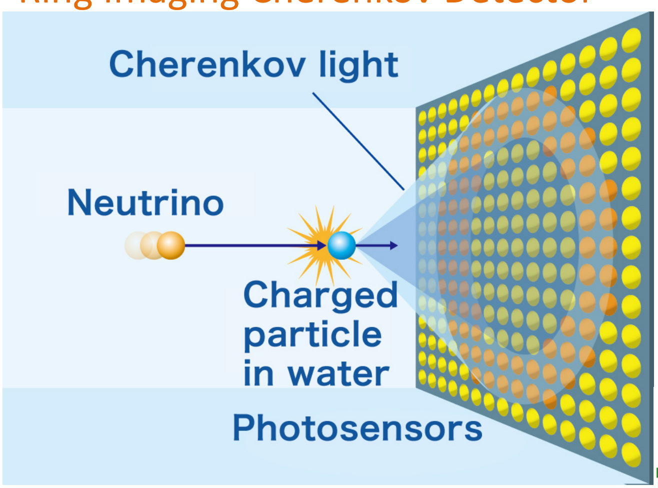
Event Observation

- Time and charge of each photosensor at single-photoelectron hit threshold are always taken for all photosensors as hits.
- Event Trigger by sum of hits in some set of time window



  - Accelerator neutrinos at beam spill timing synchronized with GPS time between HK and J-PARC
- Cherenkov ring gives vertex position, direction, momentum of particles and type.

Ring Imaging Cherenkov Detector

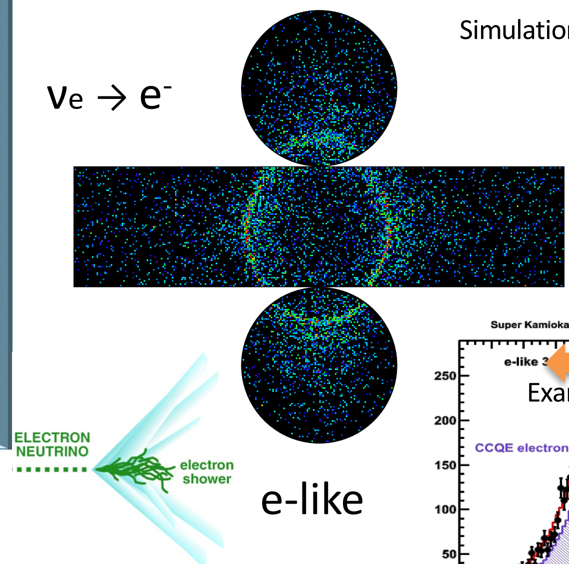


Vertex position by hit timing,
Momentum reconstruction
(energy and direction)

Particle Identification with Ring Pattern

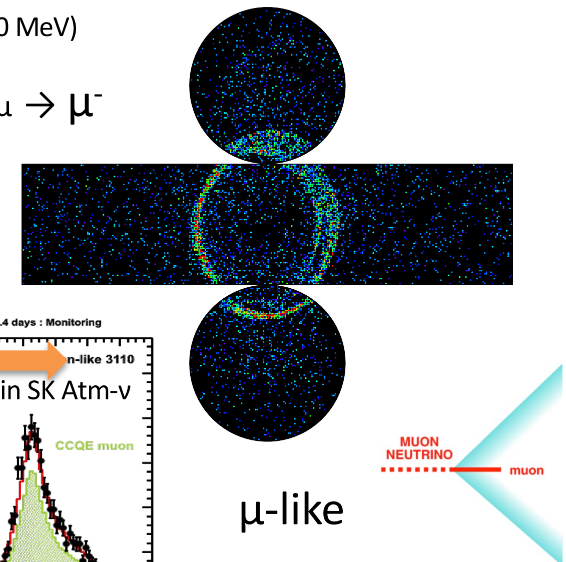
Simulation (600 MeV)

$\nu_e \rightarrow e^-$

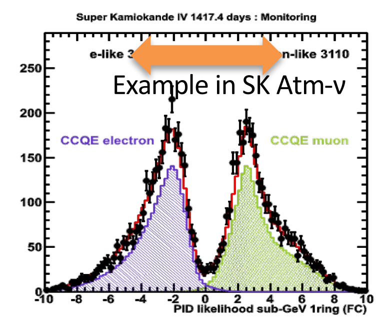


e-like

$\nu_\mu \rightarrow \mu^-$



μ-like

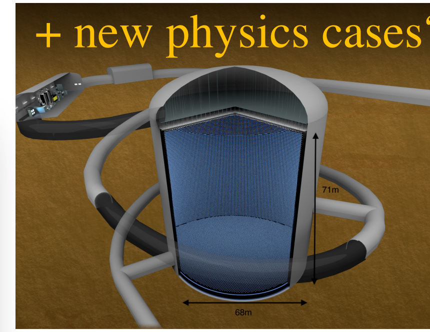


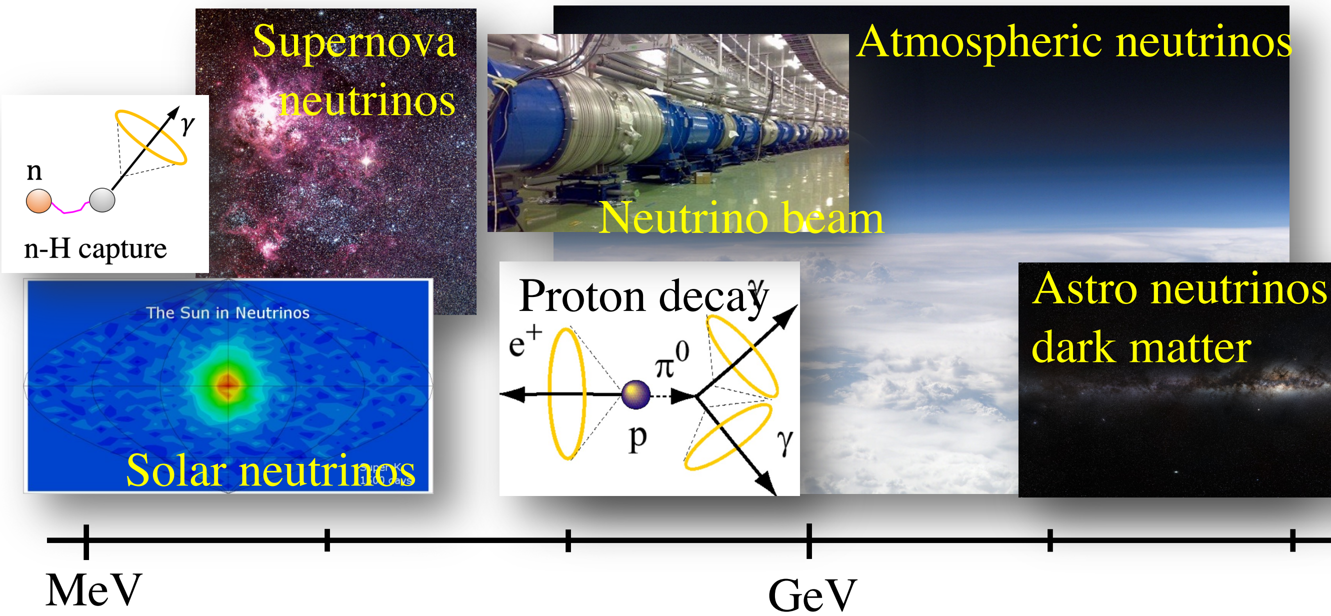
Particle identification (>99% efficiency for μ/e separation)

- Event selection with OD veto, fiducial volume cut by a distance from the wall

Wide Physics Targets

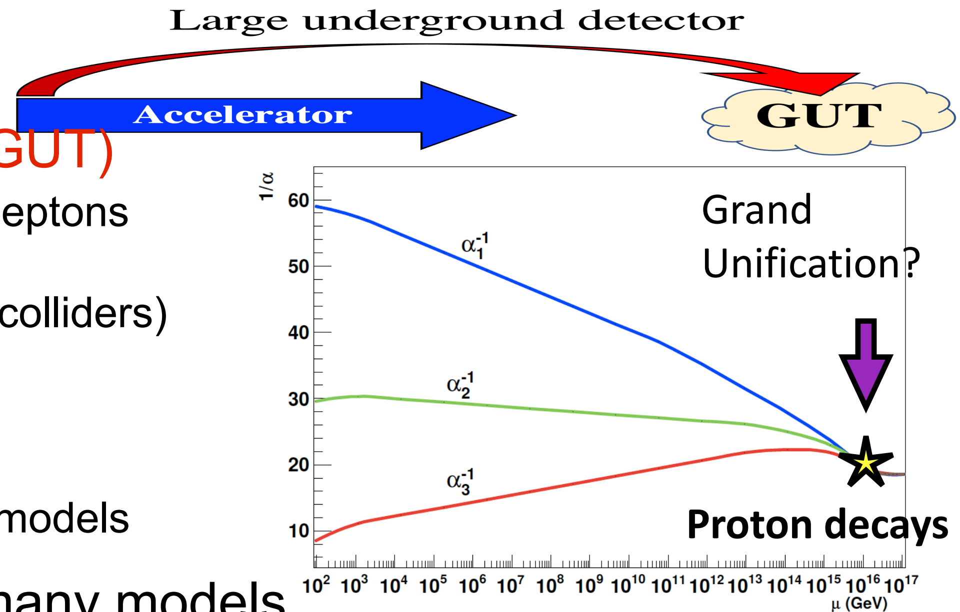
Various neutrino sources are visible at the single detector





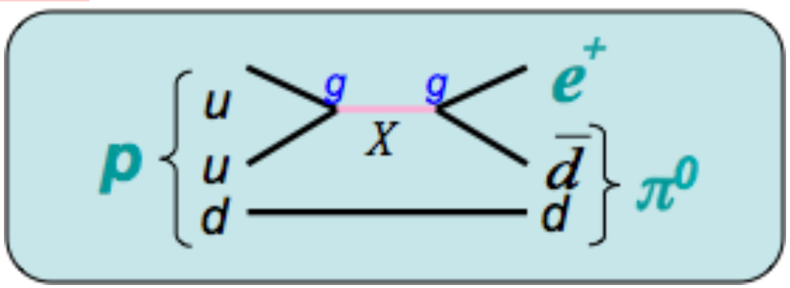
- Hyper-Kamiokande is a multi-purpose detector with the capabilities
  - Real time measurement of vertex, direction, energy and particles types
    - Alert of supernova to astronomical observatories
  - Large fiducial mass with low radioactive background
  - Wide dynamic range to observe neutrinos from MeV to TeV energy scale

Motivation of Nucleon Decay Searches



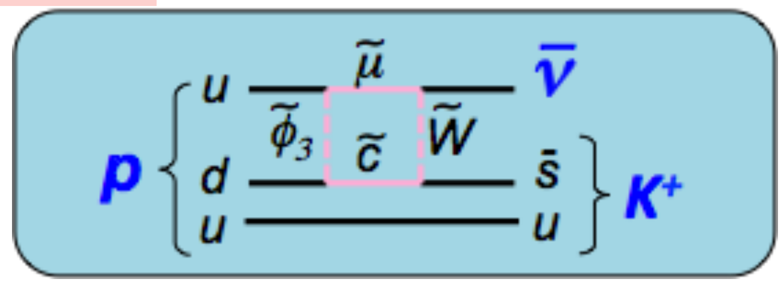
- Test of Grand Unified Theories (GUT)
  - Look for direct transition of quarks to leptons → Direct prove of GUT
  - Unique (Unreachable by high-energy colliders)
- Ambitious physics goals
  - Determination of GUT scale
  - Gauge symmetry group, test of SUSY models
- Two major modes predicted by many models

$p \to e^+\pi^0$ Mediated by gauge bosons



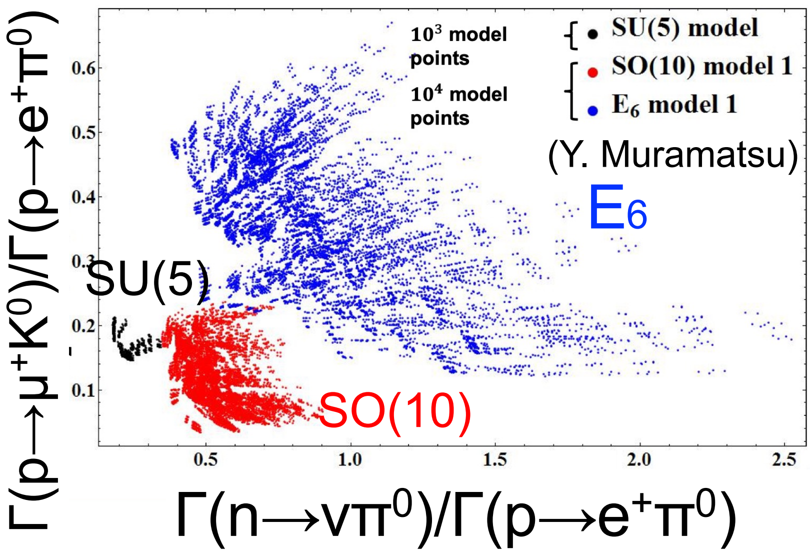
$$\Gamma(p \to e^+\pi^0) \sim \frac{g^4 m_p^5}{M_X^4}$$

$p \to \nu K^+$ SUSY mediated

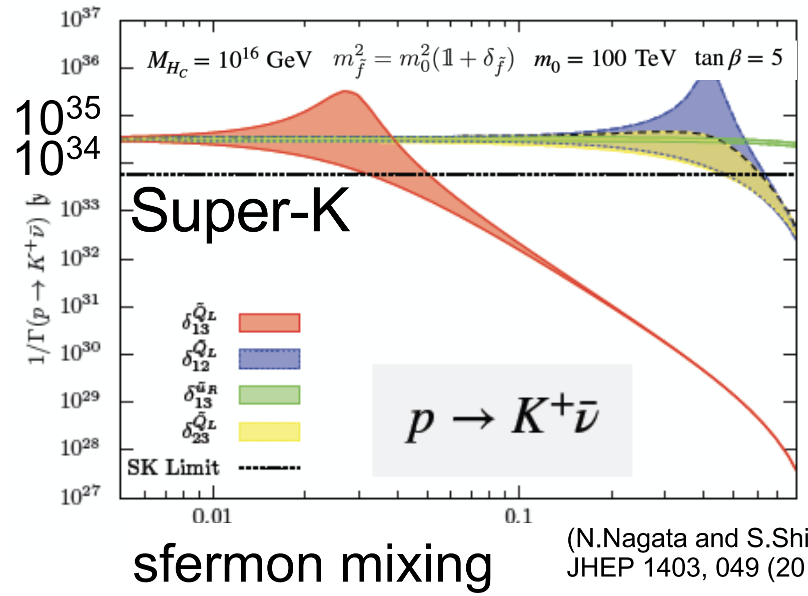


$$\Gamma(p \to \bar{\nu} K^+) \sim \frac{\tan^2\beta \times m_p^5}{M_{\tilde{q}}^2 \times M_3^2}$$

Strong BSM Cases by Models

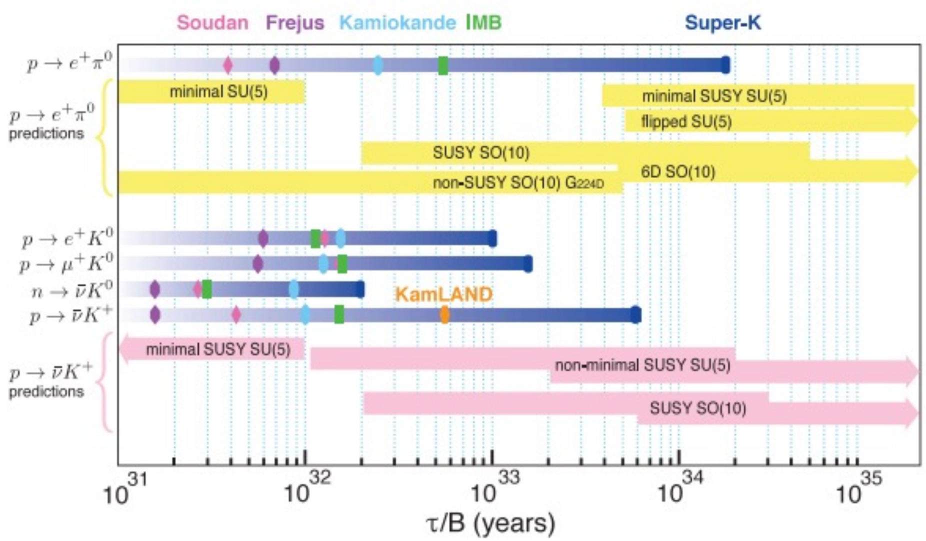


→ Identify details of unification picture with both modes



(N.Nagata and S.Shirai, JHEP 1403, 049 (2014))

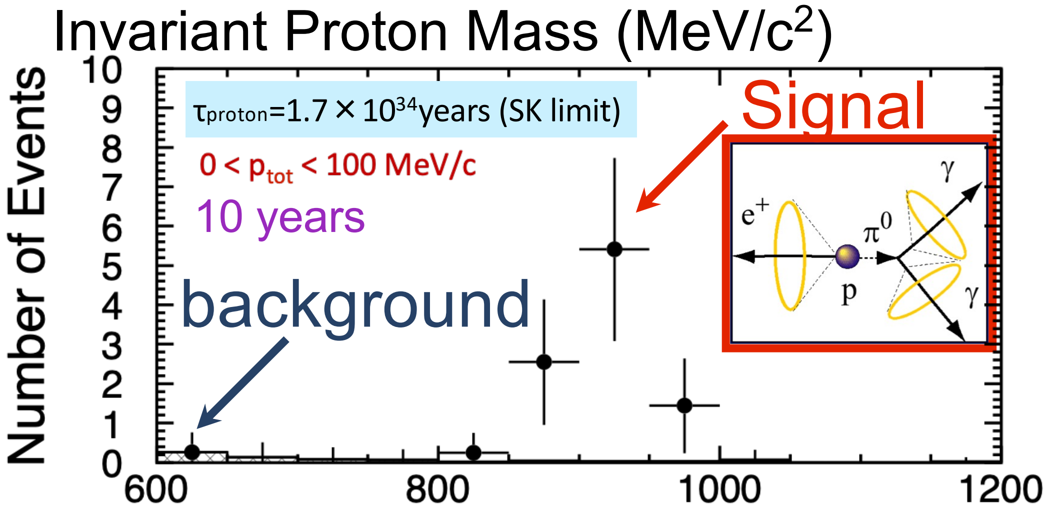
→ Extract flavor structure of SUSY particles

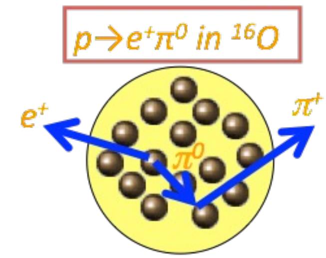


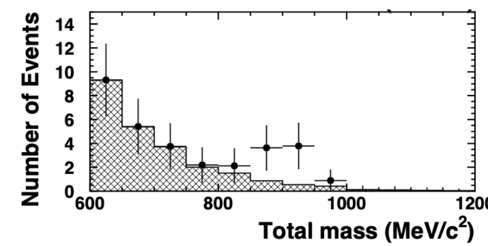
- Many models predict proton decays around current limits.
- Need various modes to test GUT models.
- Hyper-K can search more decay modes.

$p \rightarrow e^+\pi^0$ discovery in Hyper-K

3 coincident rings in signal



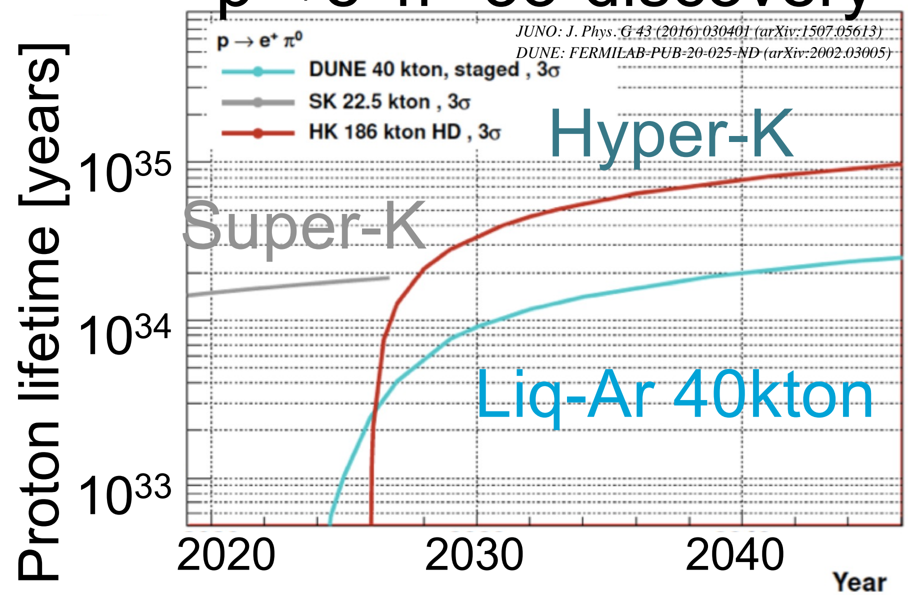




- Invariant proton mass would be a compelling evidence
- Reach to 10^{35} yrs
- BG free search possible: 0.06 BG/Mton・year

	p_{tot}<100MeV/c		100<p_{tot}<250MeV/c	
	Sig. ε(%)	Bkg (/Mtyr)	Sig. ε(%)	Bkg (/Mtyr)
HK	18.7	0.06	19.4	0.62

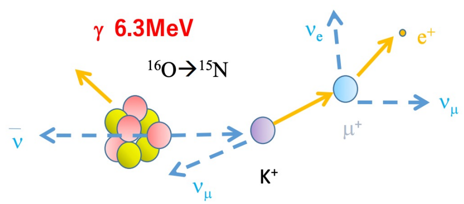
$p \rightarrow e^+\pi^0$ 3σ discovery

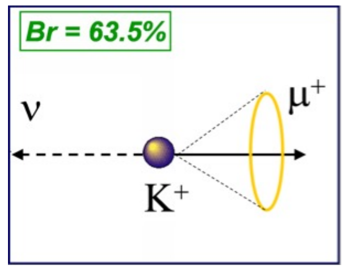


$p \rightarrow \nu K^+$ discovery in Hyper-K

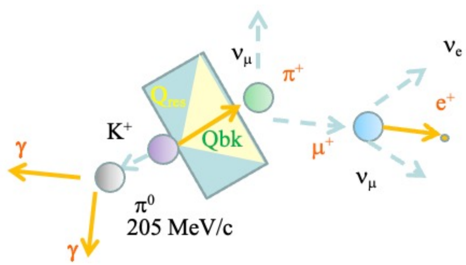
arXiv:1805.04163 Hyper-K DR

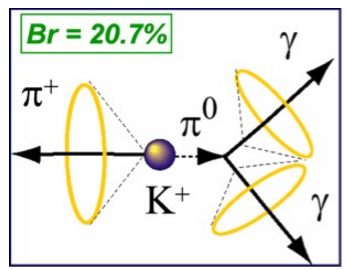
- K^+ is invisible.
  - 236 MeV/c muon





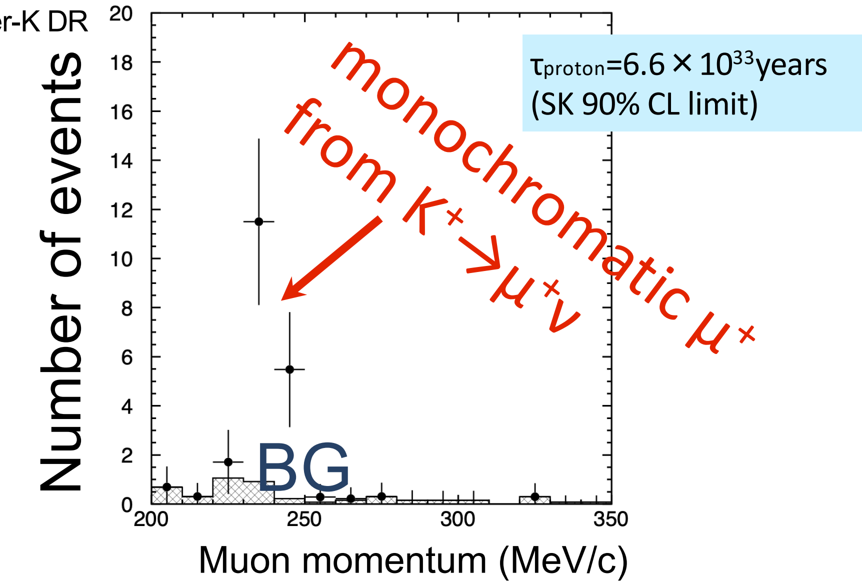
  - $\pi^+\pi^0$

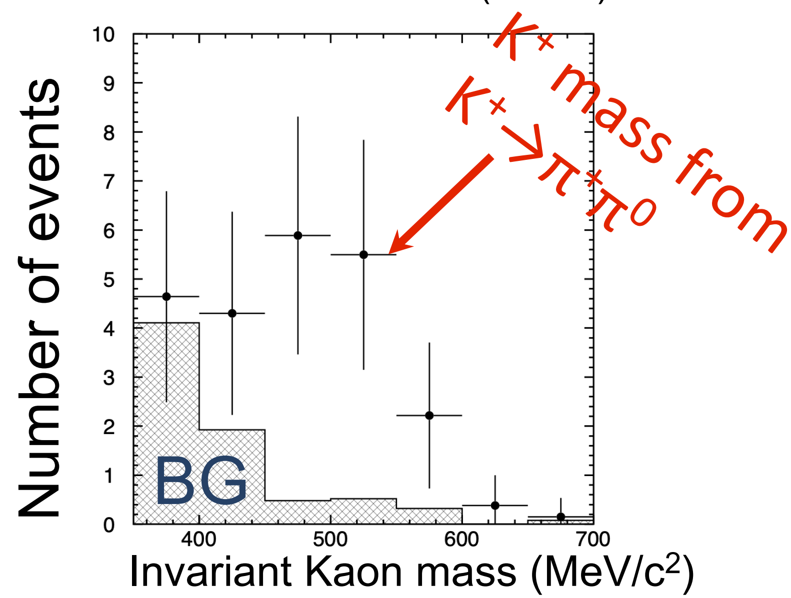




- Discovery reach to 3 $\times 10^{34}$ years

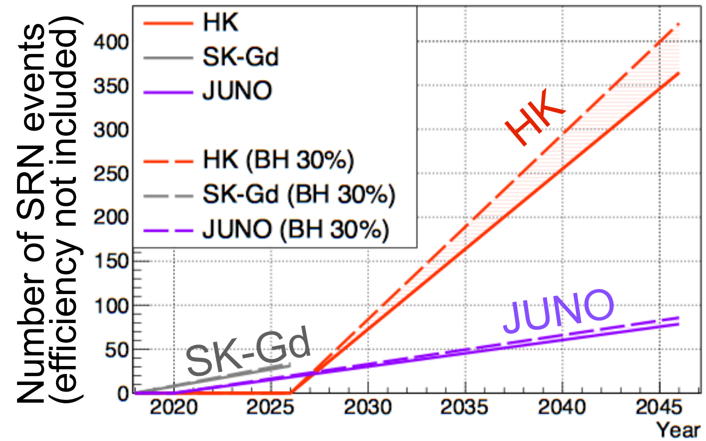
	prompt-γ & $K^+ \rightarrow \mu^+ \nu$		$K^+ \rightarrow \pi^+ \pi^0$	
	Sig. ε(%)	Bkg (/Mtyr)	Sig. ε(%)	Bkg (/Mtyr)
HK	12.7	0.9	10.8	0.7





Neutrino Astrophysics

- Observation of ~10 MeV neutrinos with the time, energy and direction
  - ➢ Unique role in multi-messenger observation
  - ➢ Sensitivities depend on the energy thresholds

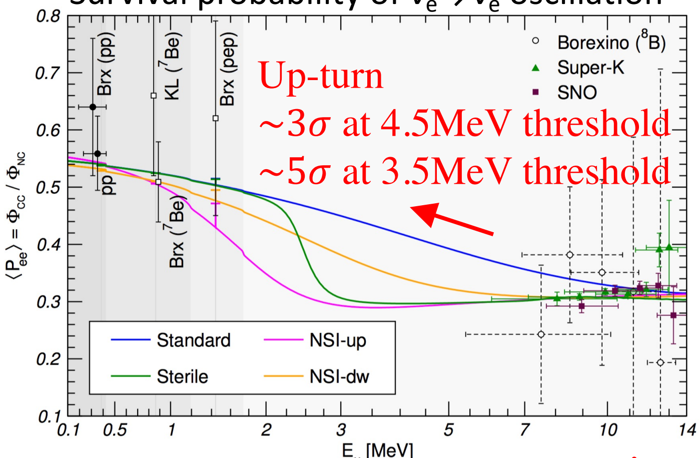


Supernova Relic Neutrino (~10/yr)

stellar collapse, nucleosynthesis and history of the universe

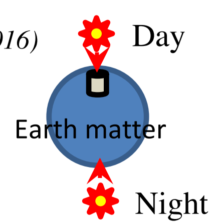
Solar neutrinos (~130/day)

Survival probability of $\nu_e \rightarrow \nu_e$ oscillation

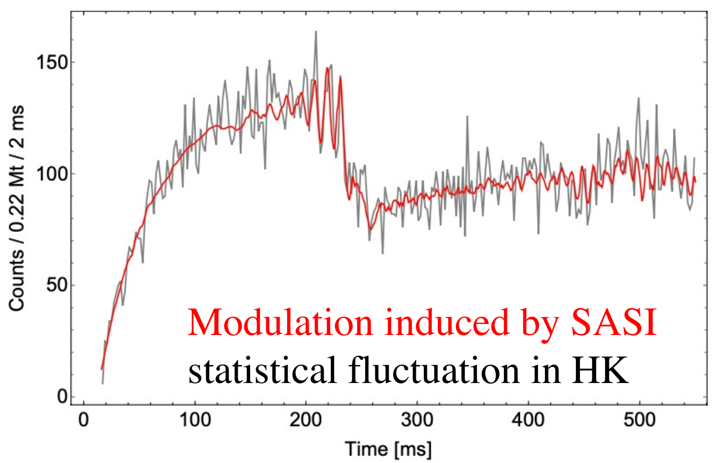


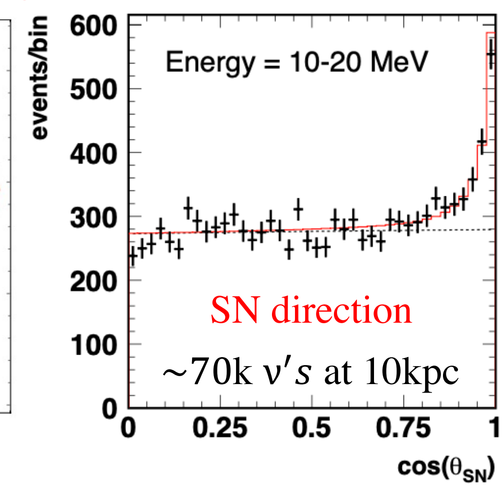
M. Maltoni et al., Phys. Eur. Phys. J. A52, 87 (2016)

Up-turn at vacuum-MSW (Mikheyev–Smirnov–Wolfenstein or matter effect) transition region, Day/Night, hep ν



Supernova burst (~50k/burst)





Some 2D and 3D simulations indicate SASI (Standing Accretion Shock Instability) is important process for the supernova explosion

Explosion mechanism, BlackHole/NeutronStar formation, alert with 1° pointing

Neutrino Oscillations

$$(\nu_e,\nu_\mu,\nu_\tau)^T = U^{MNS}_{\alpha i}(\nu_1,\nu_2,\nu_3)^T$$

U^{MNS}: Maki-Nakagawa-Sakata matrix

$$\begin{pmatrix}\nu_e\\ \nu_\mu\\ \nu_\tau\end{pmatrix}=\begin{pmatrix}\cos\vartheta_{12} & \sin\vartheta_{12} & 0\\ -\sin\vartheta_{12} & \cos\vartheta_{12} & 0\\ 0 & 0 & 1\end{pmatrix}\begin{pmatrix}\cos\vartheta_{13} & 0 & \sin\vartheta_{13}e^{-i\delta}\\ 0 & 1 & 0\\ -\sin\vartheta_{13}e^{i\delta} & 0 & \cos\vartheta_{13}\end{pmatrix}\begin{pmatrix}1 & 0 & 0\\ 0 & \cos\vartheta_{23} & \sin\vartheta_{23}\\ 0 & -\sin\vartheta_{23} & \cos\vartheta_{23}\end{pmatrix}\begin{pmatrix}\nu_1\\ \nu_2\\ \nu_3\end{pmatrix}$$

$$P(\overset{(-)}{\nu}_\alpha \to \overset{(-)}{\nu}_\beta) = \delta_{\alpha\beta} - 4\sum_{i>j}\mathrm{Re}(U^*_{\alpha i}U_{\beta i}U_{\alpha j}U^*_{\beta j})\sin^2\frac{(m_i^2-m_j^2)L}{4E_\nu}$$

$$\overset{(-)}{+}2\sum_{i>j}\mathrm{Im}(U^*_{\alpha i}U_{\beta i}U_{\alpha j}U^*_{\beta j})\sin\frac{(m_i^2-m_j^2)L}{2E_\nu}$$

Matter-effect is omitted here

Neutrino Oscillation Parameters: 6 = 4 matrix elements and 2 mass-squared differences

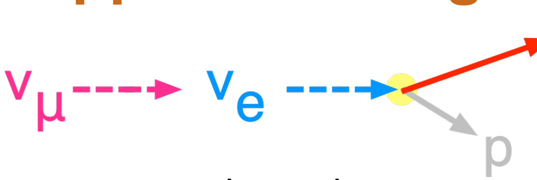
θ_{23}~45±5° $\Delta m^2_{23}=2.4\times10^{-3}eV^2$ Atmospheric, $\pi\to\mu+\nu_\mu$, $\mu\to e+\nu_\mu+\nu_e$ in air Accelerator Neutrinos	θ_{12}~34±3° $\Delta m^2_{21}=7.6\times10^{-5}eV^2$ Solar, $4p\to He+2e^++2\nu_e$ Reactor Neutrinos	θ_{13}~9° Accelerator, $\pi\to\mu+\nu_\mu$ Reactor Neutrinos $n\to p+e^-+\nu_e$	Leptonic CP phase δ=unknown Accelerator, Atmospheric Neutrinos

Mass Hierarchy or Mass Ordering ($\Delta m^2_{32}=m^2_3-m^2_2>0$ or $\Delta m^2_{32}<0$) is unknown

Octant of θ_{23} or $\theta_{23}=\pi/2$ is also interesting question

J-PARC ν_μ ($\bar{\nu}_\mu$) beam (~0.6GeV)

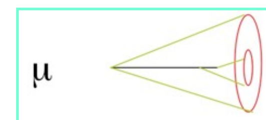
ν_e appearance signal = single e event



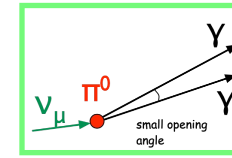
CCQE : $\nu_e + n \rightarrow e + p$

(dominant process at J-PARC beam energy)

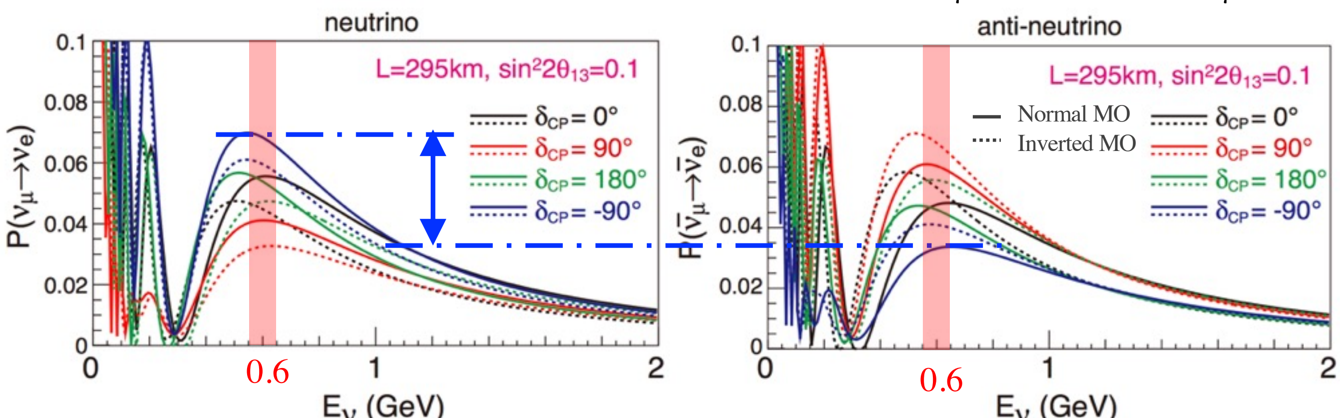
νμCC



NC π^0



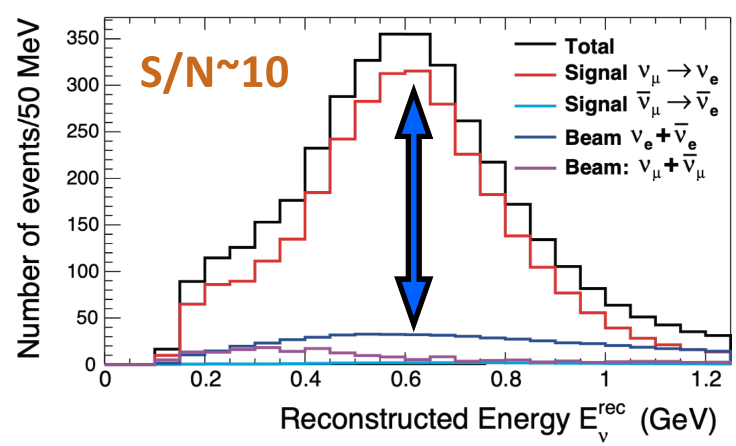
Measures CP violation by precision comparison of $P(\nu_\mu \rightarrow \nu_e)$ and $P(\bar{\nu}_\mu \rightarrow \bar{\nu}_e)$



After 295 km travelling from J-PARC at Hyper-K

- High background rejection
  - >99.9% ν_μCC, 99% NC π^0 rejection
  - keeping 60% ν_e signal efficiency
- **Unique CPV measurement**
  - High statistical, clean (S/N~10)
  - Simple Eν reconstruction by charged lepton kinematics (for CCQE)
  - Less matter effect (fake CPV effect, 295 km)

Appearance ν mode



- A few % statistical uncertainties after 10 years operation with >1000 ν_e and $\bar{\nu}_e$ signals

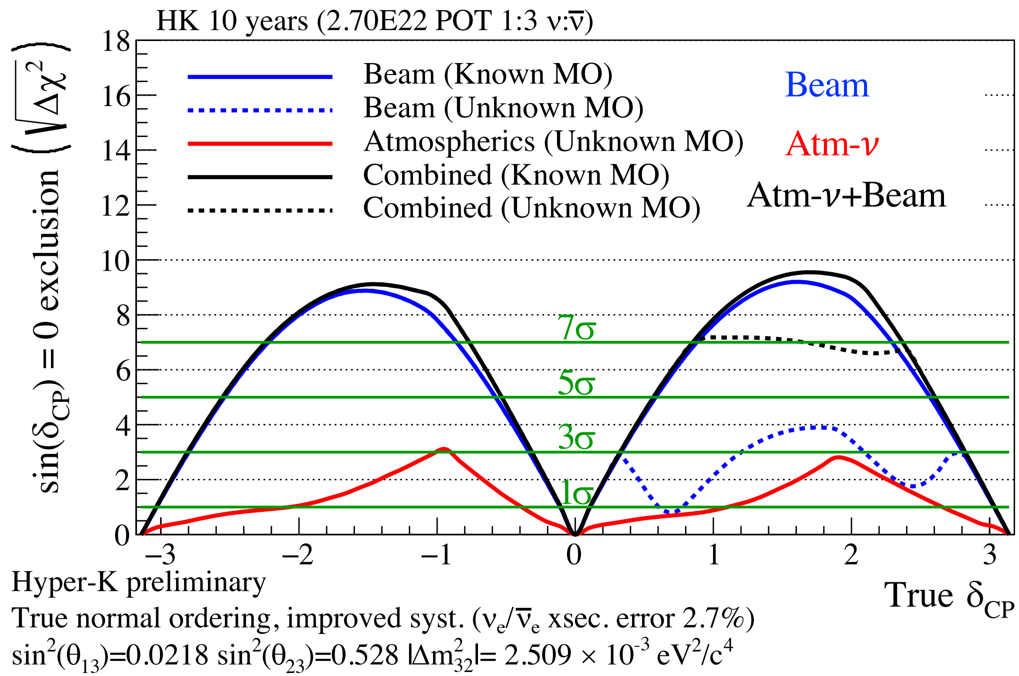
Strategy of Oscillation Measurement

Combination of long-baseline and atmospheric neutrino observations
⇒ Resolve parameters degeneracy

10 years with 1.3MW, normal mass ordering is assumed

	$\sin^2\theta_{23}$	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

CPV discovery potential

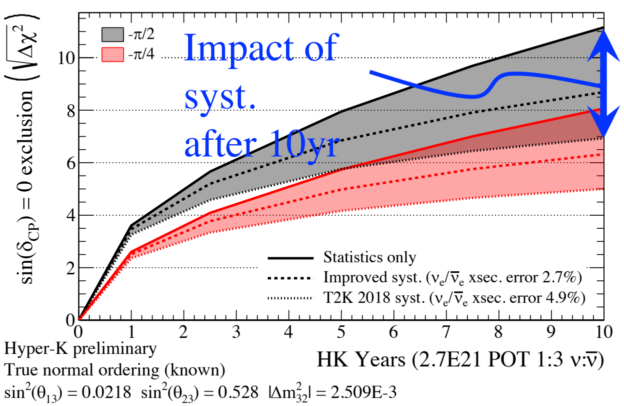


Atmospheric neutrino: sensitive to mass ordering by Earth's matter effects
→ Constraints on mass ordering enhance sensitivity to CP violation by long-baseline

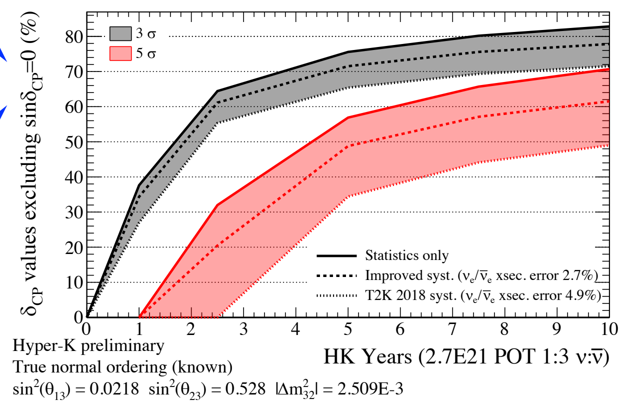
Precision Measurement of Neutrino Oscillations

1.3MW, 10 years

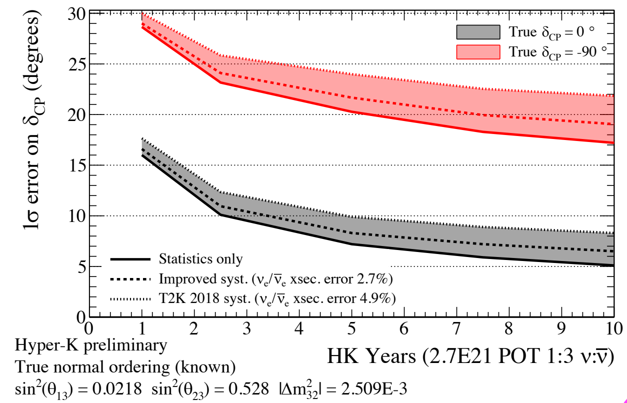
δ_{CP} Projected sensitivity to CPV



Fraction of δ_{CP} to exclude $\sin\delta_{CP} = 0$

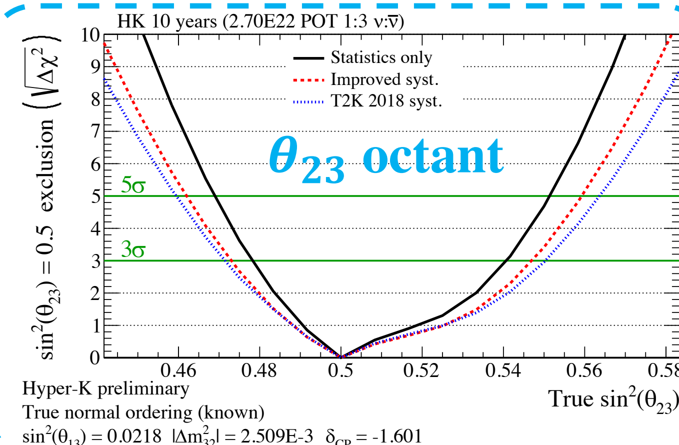


Precision of δ_{CP} measurement



- Good opportunity to make discovery of CP violation at >5 σ
- Measurement of δ_{CP}
  - ~20° for $\delta_{cp} = -90°$ / ~7° for $\delta_{cp} = 0°$

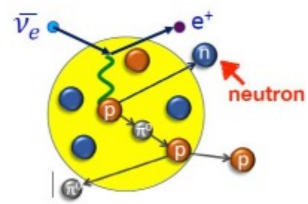
- Reduction of systematic uncertainty has sizable impact
  - Upgrade of ND280 + 1kton scale water Cherenkov (IWCD)
  - Aim to suppress detector error below 1%

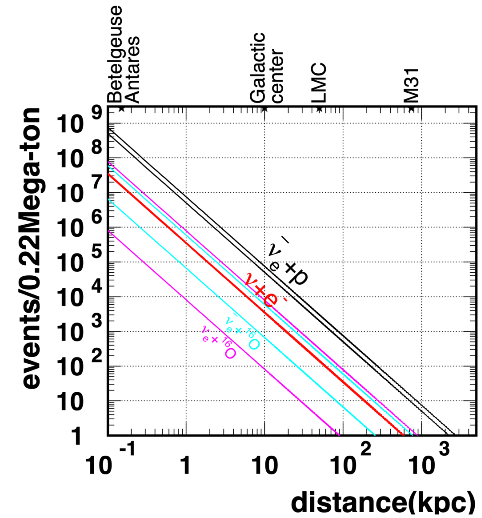


Expect to determine all neutrino oscillation parameters (except for absolute mass).

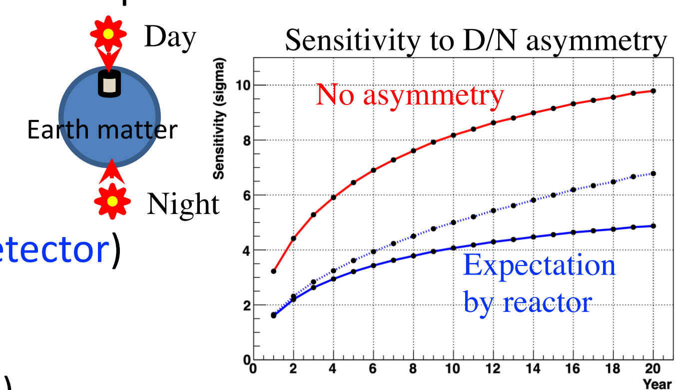
Requirements for the Detector

- Trigger
  - Peak event rate reaches 50kHz for supernova at galactic center
  - Detection of delayed signals
    - Michel electrons $\sim 2\mu s$ after muons
    - Neutron tagging: 2.2 MeV γ-ray $\sim 200\mu s$ after neutrino interactions





- Energy scale
  - Wide dynamic range from single p.e. (a few MeV) to >1000 p.e. (>100 GeV)
  - GeV-scale (atmospheric/accelerator/proton decay):
    - ~2% uncertainty in SK → Aim for < 1% uncertainty at HK to realize precision measurement
  - MeV-scale (solar/supernova)
    - High detection efficiency of Cherenkov photons
    - Low background in the water and photosensors
    - ~0.5% uncertainty in SK with LINAC calibration
    - Major source due to position dependence (uniformity in detector) → Important for Day/Night asymmetry measurement



- Timing
  - ~1ns resolution required for vertex position reconstruction (~20 cm) → BG rejection (spallation, external γ from rock/PMT), control of fiducial volume by vertex position
- Long term stability
  - Stable for >10 years without repair (Less dead channel, stable detector response)

Improvements from Super-K

High QE Box&Line PMT

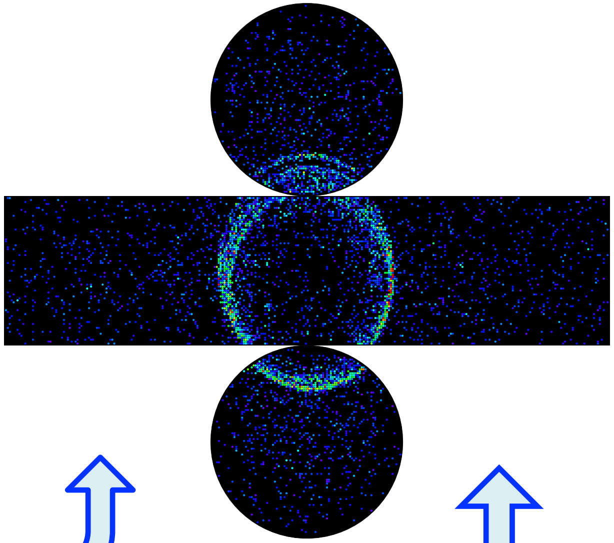
×2 photon detection

×2 timing resolution

- Lower dark rate
  (similar level to SK, better S/N)
- Lower radioactive contamination

×2 pressure tolerance

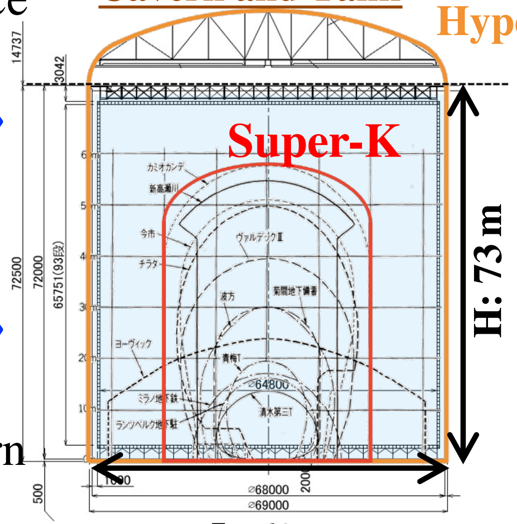
Precision measurement



New detector design (cost reduction)

R&D for large cavern

Cavern and Tank



Φ: 69 m

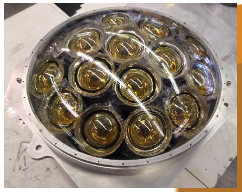
Water depth: 71 m
Fiducial volume: 188 kt

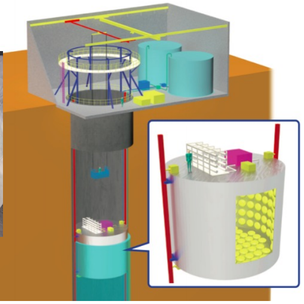
Grossmünster

High statistics neutrino data

Systematic control

High-resolution sensor module, mPMT
New intermediate detector, etc.



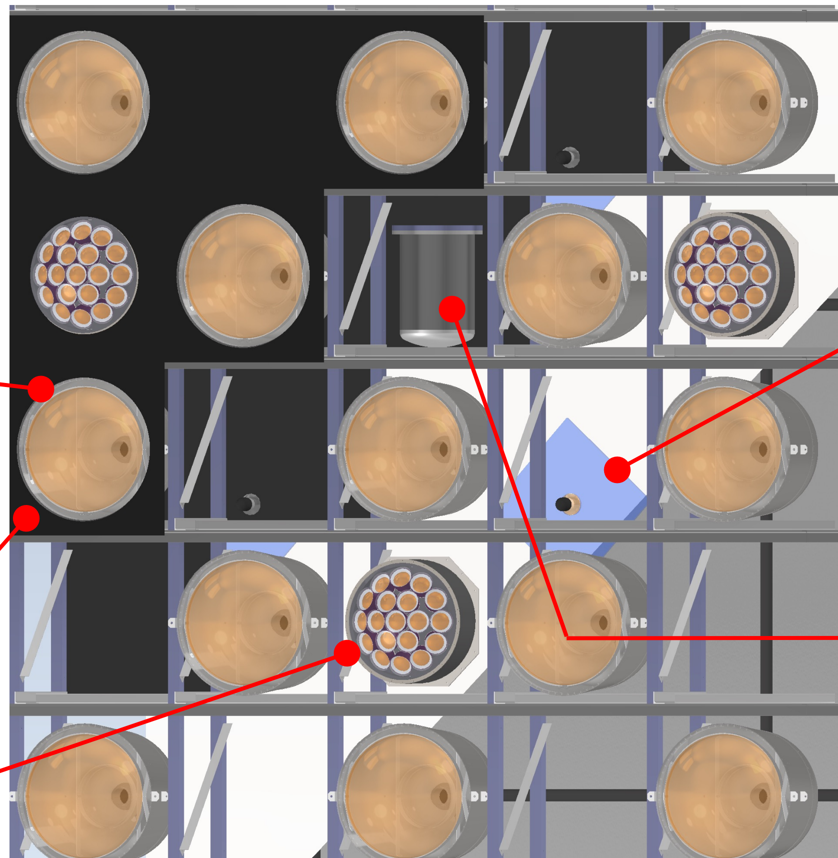


New detector design by synergy of different technologies

Hyper-K Detector Components

Start the detector installation in 3 years

View from inner barrel detector side



3 photosensor types
attached to detector layer
in 0.6 m width

Inner Detector (ID)

50 cm Photosensor in Cover

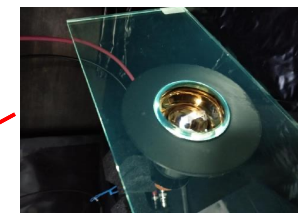
Black sheet wall
made of PET
(Polyethyleneterephthalate)

Multi PMT
High granularity,
directionality
and precise timing

and looking for more photosensors

Outer Detector (OD)

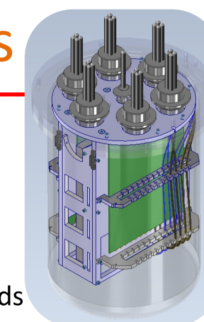
8 cm Photosensor with Wavelength Shifting Plate



+ White reflection sheet
made of Tyvek

Electronics

Watertight cases
for 50 cm and 8 cm
photosensors
and for Multi-PMT
Concentrator Cards



+ Calibration system, electronics, DAQ on top of the tank

50cm (20-inch) Photosensors

The largest photomultiplier tube was developed for Hyper-Kamiokande.

For Kamiokande

Hamamatsu R1449
(Venetian blind dynode)

NIM 205 (1986) 443-449

Performance improved
R1449 → R3600

Design improved

- Focusing mesh
- To half dynode space
- Wide aperture
- Insulator added at dynode
- Waterproofing, etc.

For Super-K

R3600
(Venetian blind dynode, improved)

NIM A329 (1993) 299-313

- Collection efficiency 40-50% → 70%
- Transit Time Spread (σ) 4.4 ns → 2.2 ns
- Rise time 20→10ns, FWHM of signal 30 → 18ns

For KamLAND

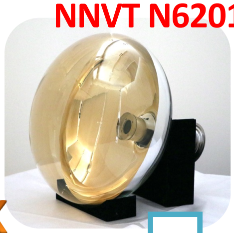
42 cm (17”) aperture Box&Line PMT

R7250
(Box&Line dynode)

with 50 cm bulb of R3600

For JUNO

50 cm MCP PMT
NNVT N6201

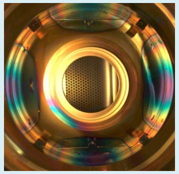


(Micro Channel Plate)

3 types of photosensors developed for Hyper-K

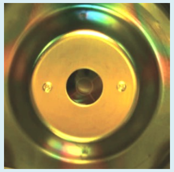
50 cm Box&Line PMT

R12860-HQE (Box&Line dynode)



50 cm Hybrid Photo-Detector (HPD)

R12850-HQE (Avalanche diode × amp)

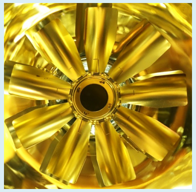


50 cm MCP PMT

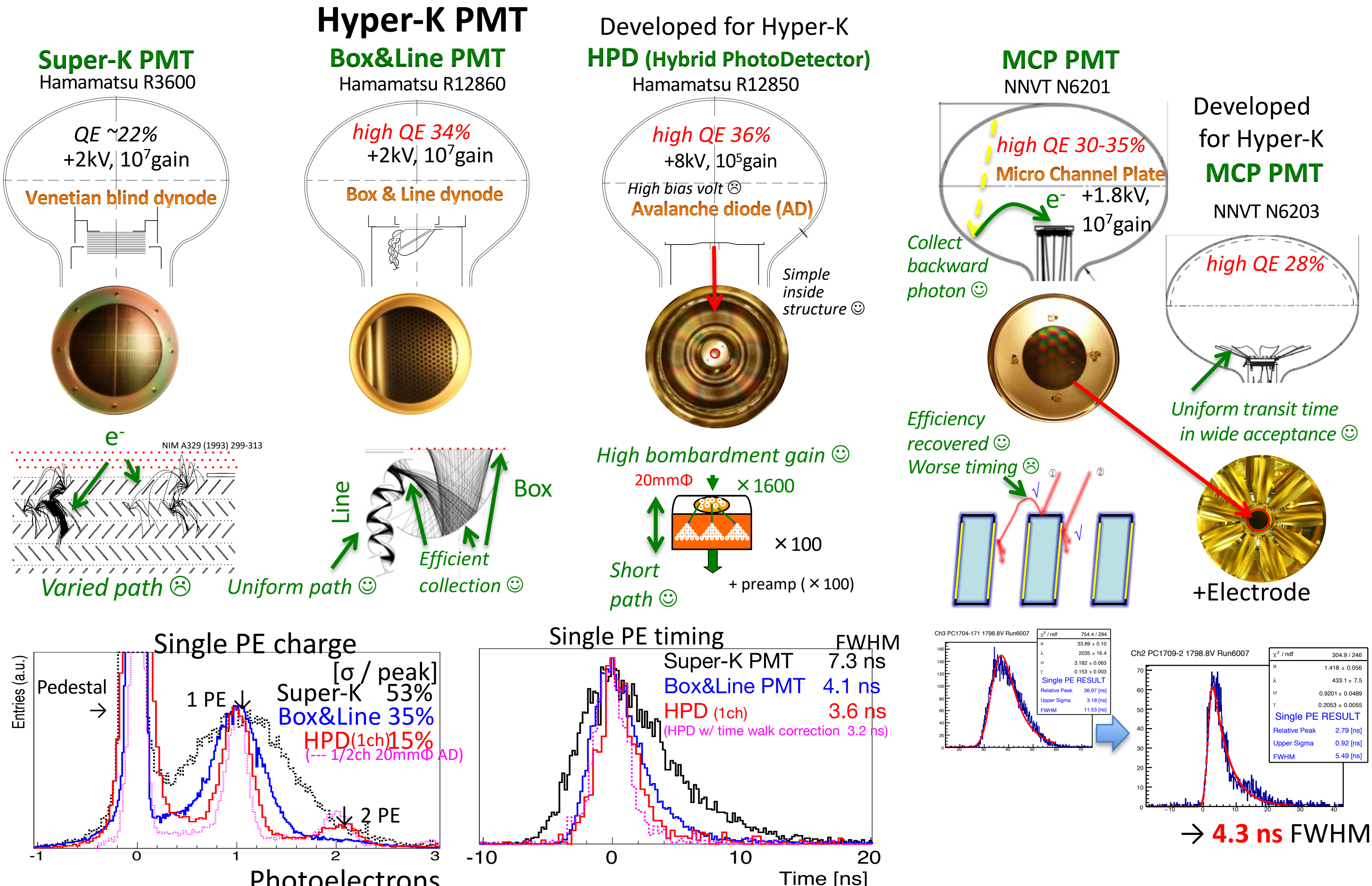
N6203 by NNVT and IHEP

w/ better timing performance

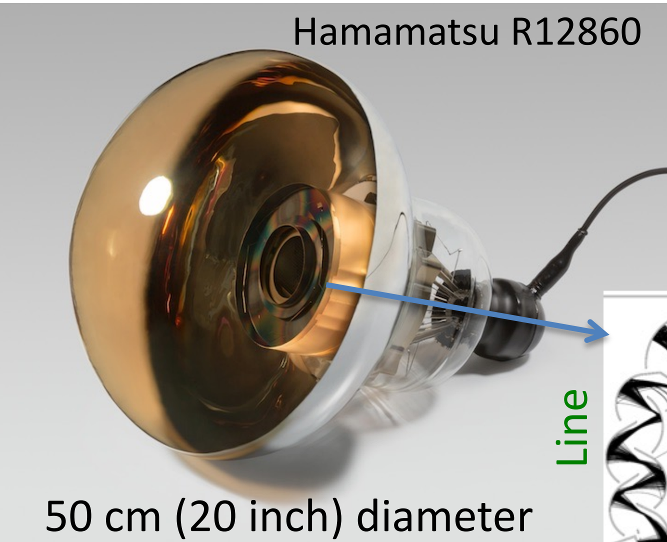
+ electrodes



Amplification of 50 cm Photosensors



50cm Photosensors for Hyper-K



The largest photomultiplier tube for single-photon counting

× 2 high pressure tolerance

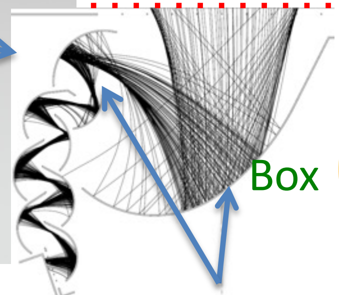
× 2 high detection efficiency

× 1/2 time&charge resolutions

× 1/2 Radioactive contamination for U, Th

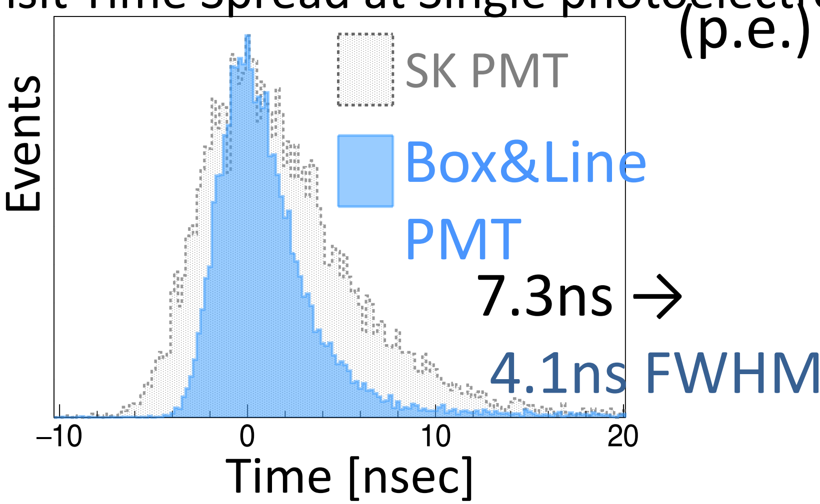
× 1/10 for Rn and K activities

improved from Super-K PMTs

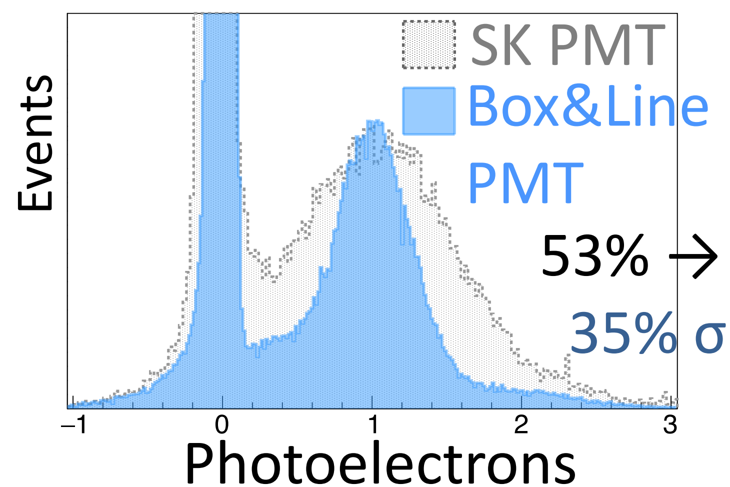


Efficient collection

Transit Time Spread at Single photoelectron (p.e.)



Single p.e. charge



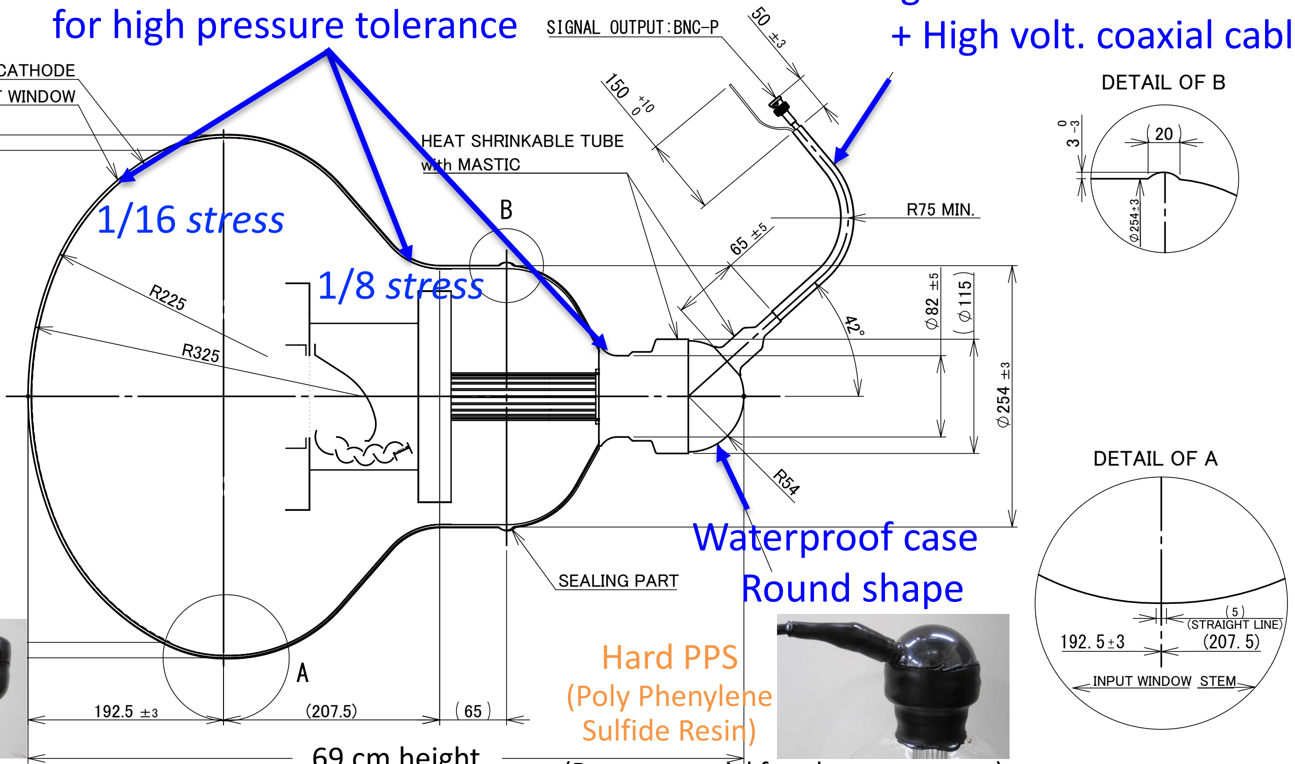
50 cm Box&Line (BL) dynode PMT

R12860 Box&Line (BL) dynode PMT

10^7 gain
at 2000 V typical

Improved glass curvature
for high pressure tolerance

Waterproof cable complex
Signal coaxial
+ High volt. coaxial cables

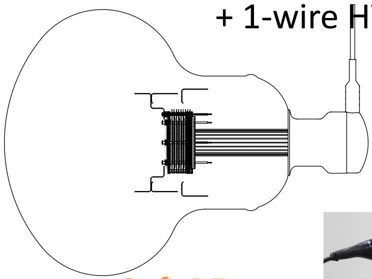


Waterproof case
Round shape

Hard PPS
(Poly Phenylene
Sulfide Resin)
(Better material for ultra pure water)

Super-K PMT R3600

Signal coaxial
+ 1-wire HV.



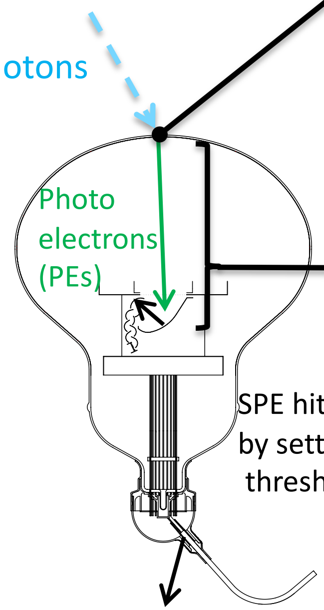
Soft PE
(polyethylene)

For safety operation more than 20 years

- Achieved 1.25 MPa pressure tolerance confirmed with many pressure tests.
- All PMTs will be tested in high pressure water before installation.
- PMT cover to avoid chain implosion was developed for Hyper-K.

Improved Detection Efficiency and Gain stability

Single Photoelectron (PE) detection efficiency = QE x CE x HE



SPE hit is taken by setting threshold.

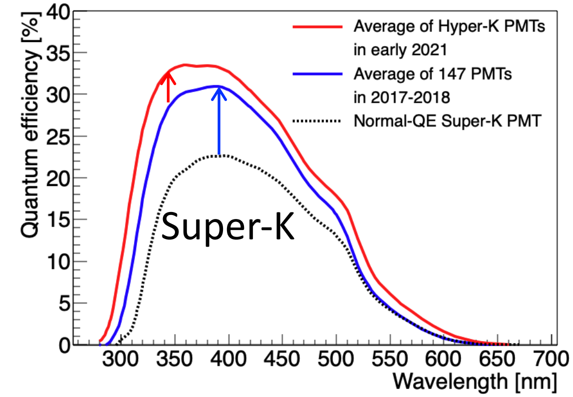
Quantum Efficiency (QE)

Peak QE 21-22% in Super-K → 30.1%

Improved photocathode deposition to decrease loss by reflection, etc.

→ 33.7±1.2% in Hyper-K (2021)

Improved in short wavelength with reducing iron contamination in glass.

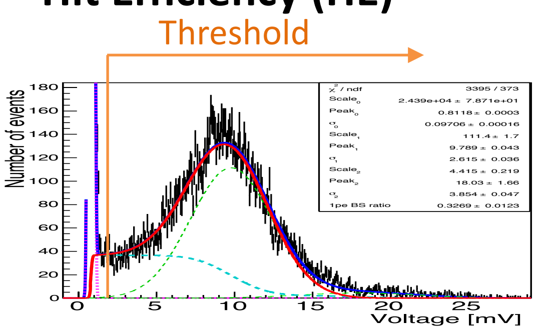


Collection Efficiency (CE)

68% in Super-K (Calculation in 46 cm ϕ)

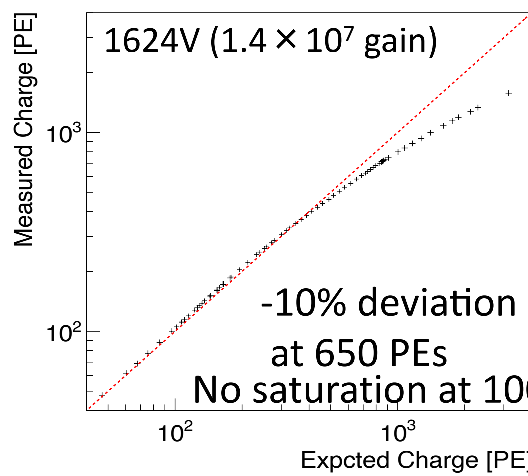
→ 95% in Hyper-K

Hit Efficiency (HE)



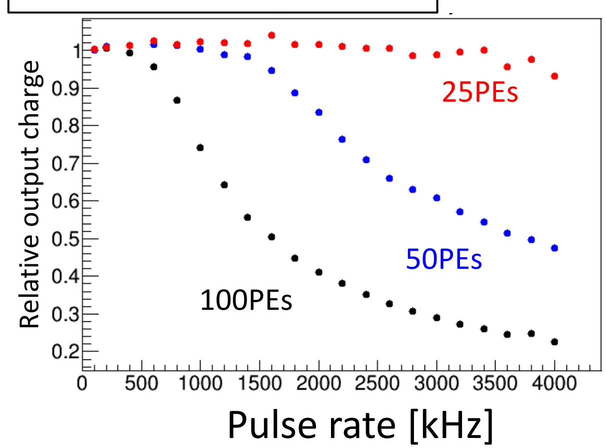
Single PE pulse height

Gain linearity in wide range



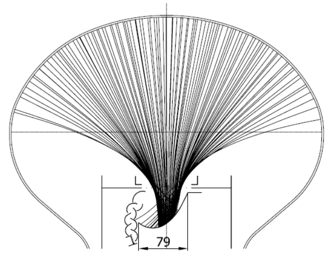
No saturation at 1000 PE

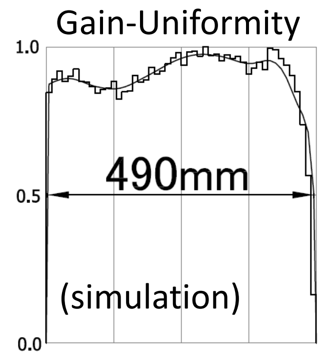
Rate tolerance of gain



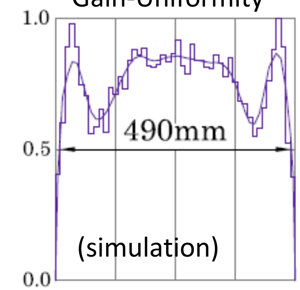
Total Detection Efficiency of Single PE

<u>Improvements of response uniformity by</u>
1. Tuning of photocathode curvature
2. Add focusing accelerator electrode

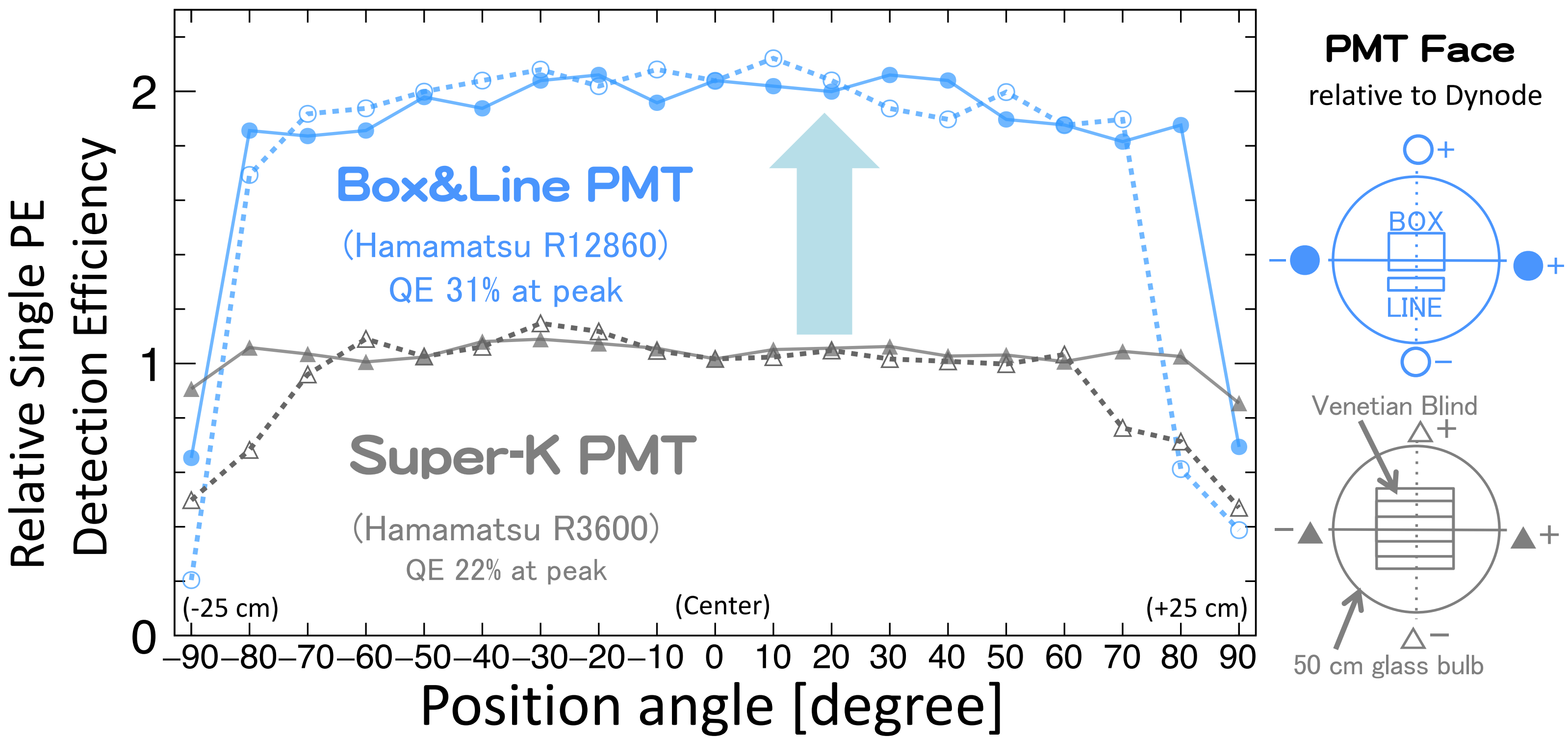




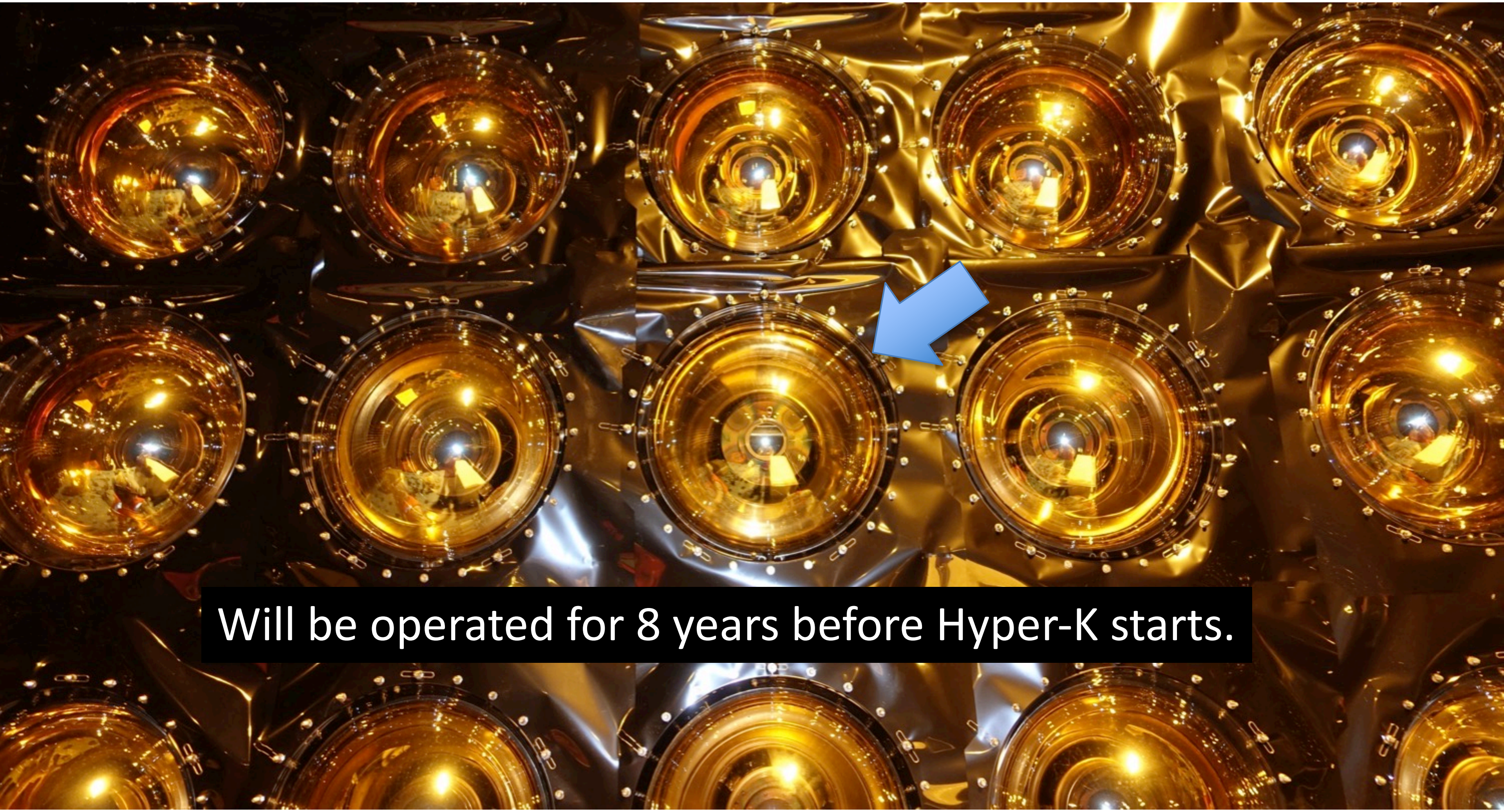
By diameter



- Double improvement and flat response in wide acceptance



Installation of ~140 Box&Line PMTs to Super-Kamiokande in 2018

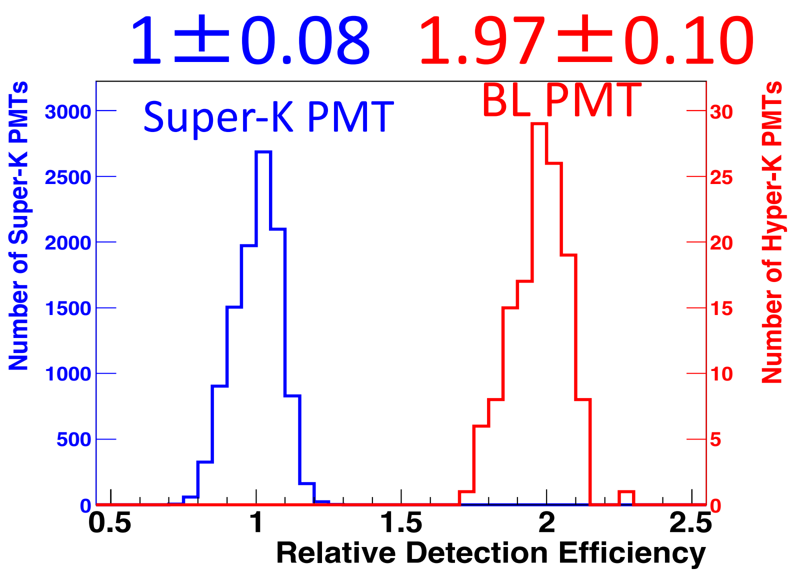


Will be operated for 8 years before Hyper-K starts.

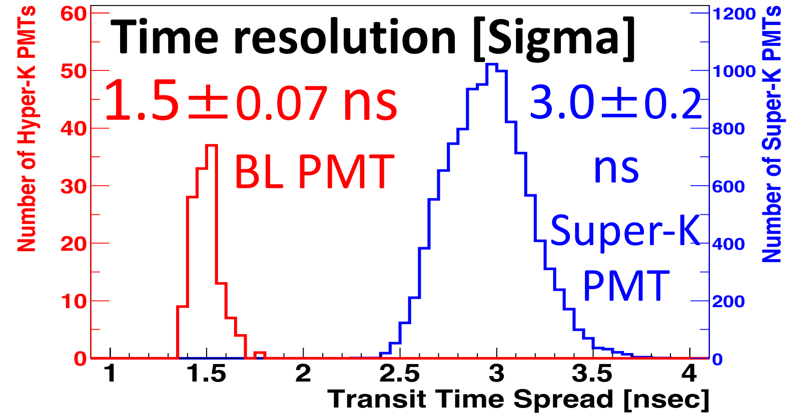
Performance of BL PMT in Super-K

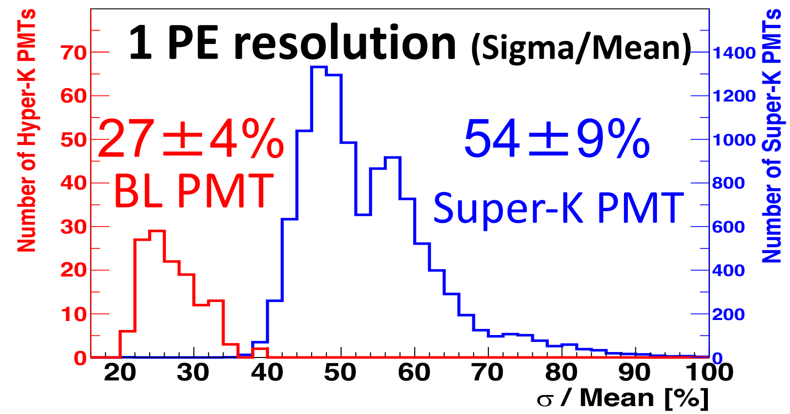
Evaluated performance in Super-K in 2018.

Detection efficiency of single PE was measured relatively by Cherenkov photons



Gain was calibrated to 1.7 × 10^7 for all PMTs.





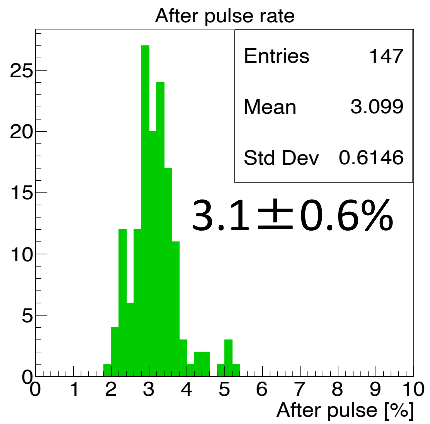
Double detection efficiency and half resolutions were confirmed in Super-K.

Noise Reduction of BL PMT

Noise reduced by R&D (Initial BL PMT → by 2020)

- Noise from PMT
  - Glass : U, Th, ^{40}K Radioactivity (5.5, 1.8, 18.2) → (2.9, 0.95, 2.0) mBq/kg
    - Improved glass raw material and production
  - Cable : Radioactive radon emanation 1.4 → < 0.1 mBq/m
    - Changed material inside cable complex from PVC to PE.
- Noise in PMT
  - After pulse : 30% → 5% / single PE
    - Improved dynode structures, bulb cleaning and voltage ratios
  - Dark count rate : > 20 kHz → **4 kHz** at 1/6 PE
    - Optimized photocathode deposition with maximizing QE

After pulse of 147 BL PMTs for SK in 40us window

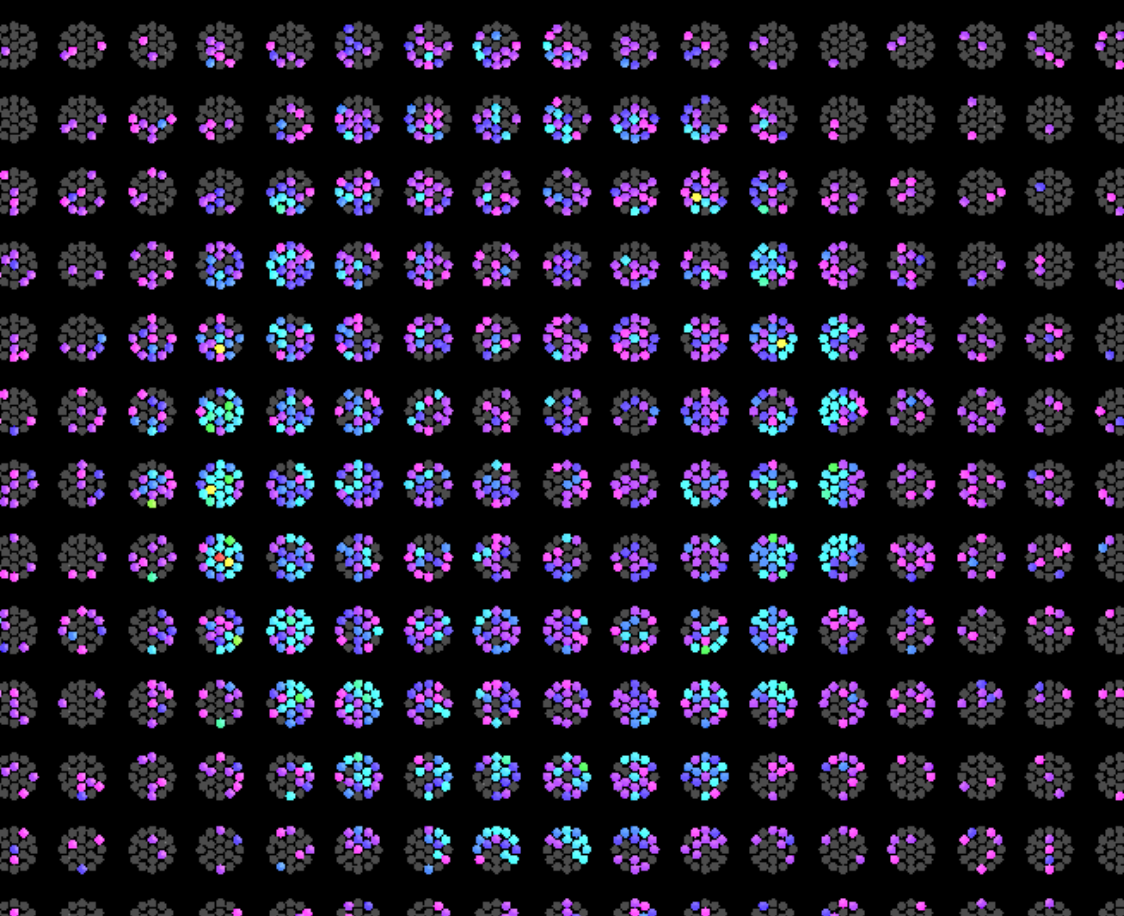


Reached 4 kHz goal of the noise rate in 2020 → satisfied all requirements for Hyper-K.

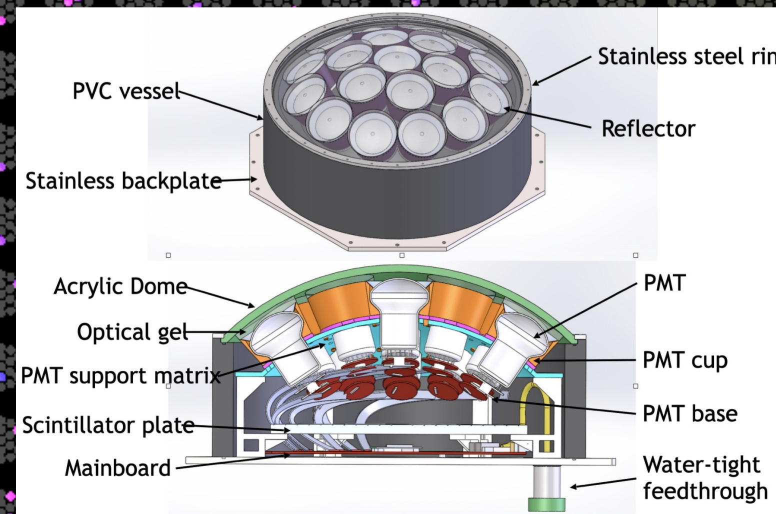
Production of 20k BL PMTs from Japan as half of Hyper-K photosensors started in late 2020.

Multi-PMT for Hyper-K and IWCD

Event display (MC) at Intermediate Water Cherenkov Detector



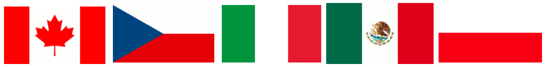
19 of 8 cm PMTs with electronics



For Hyper-K using O(1k) modules with 20k of 50 cm PMTs

- High granularity and better time resolution to improve near-to-wall reconstruction
- Calibration control to suppress systematic uncertainty, etc.

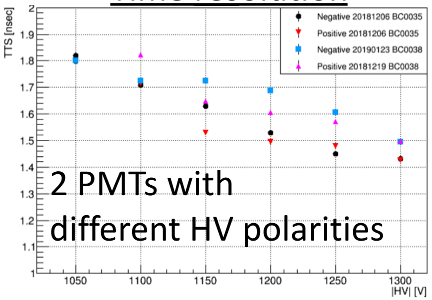
Multi PMT R&D



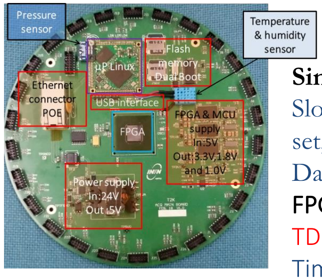
2 vessel designs tested in high pressure water

Active +HV base

Time resolution



2 PMTs with different HV polarities



Main board

Single Board Computer-Linux:

Slow control (HV and Threshold set, I/V)

Data acquisition and transmission

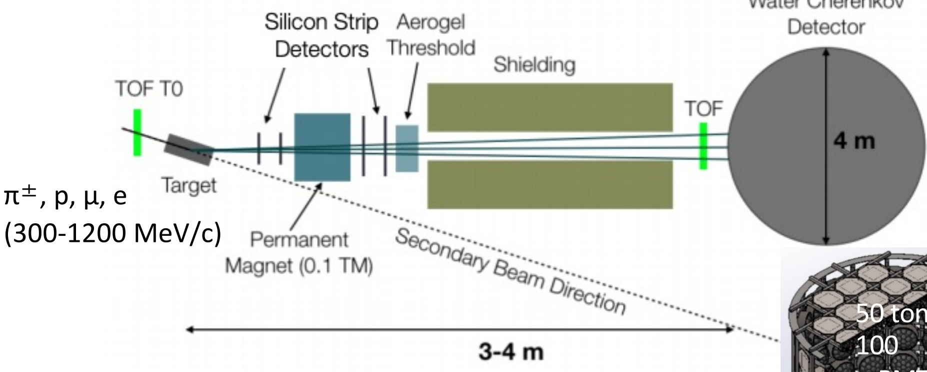
FPGA:

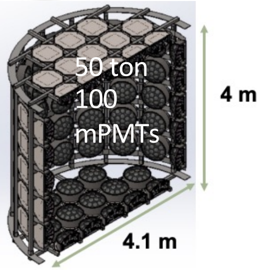
TDC/ADC control

Time stamp

By G. De Rosa at ICHEP2020

Water Cherenkov Test Experiment at CERN (2024-)

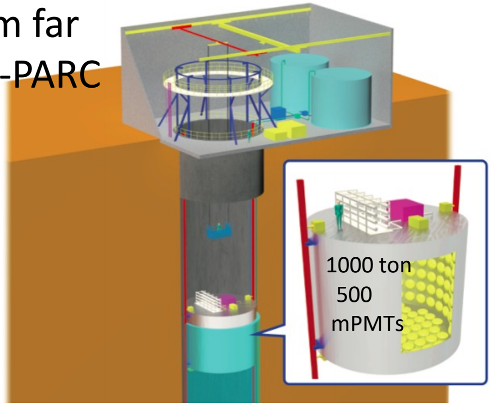




Test started at Memphyno water tank in France

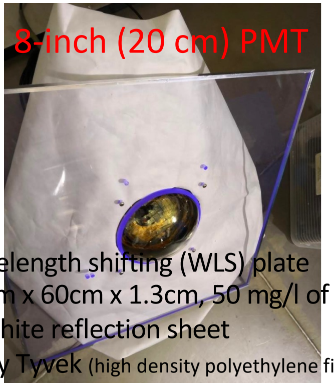
Intermediate Water Cherenkov Detector

~1-2 km far from J-PARC



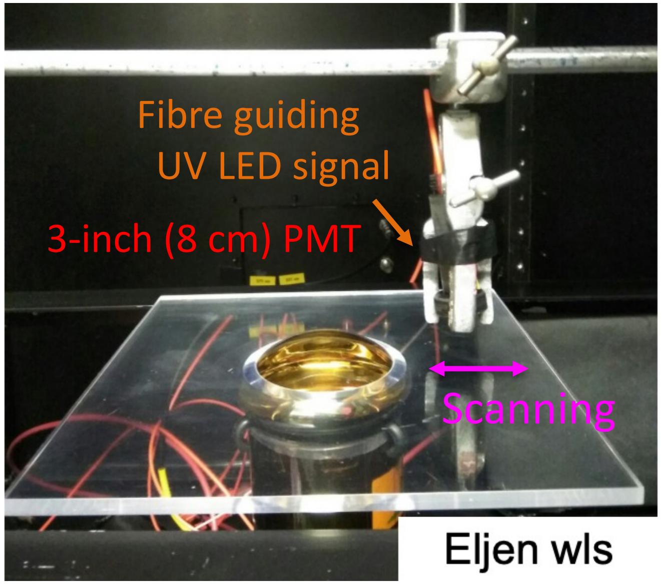
Photosensors for Outer Detector

In Super-K



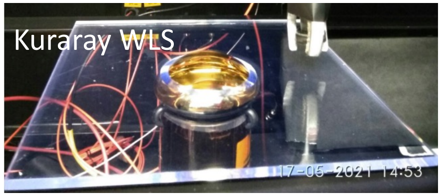
Wavelength shifting (WLS) plate
(60cm x 60cm x 1.3cm, 50 mg/l of bis-MSB)
on white reflection sheet
by Tyvek (high density polyethylene fibres)

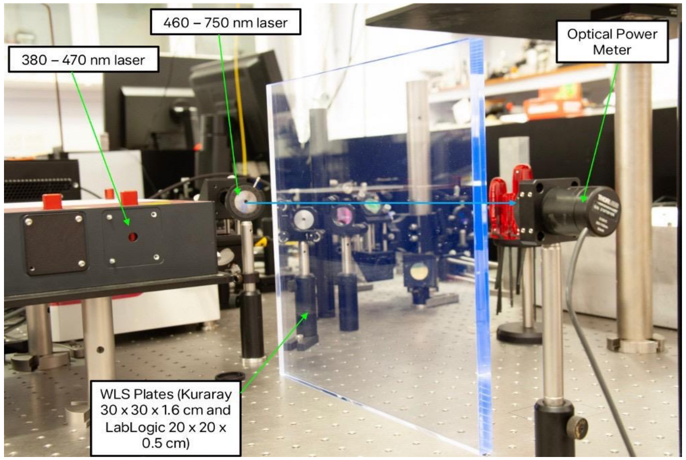
Similar structure with compact size



Eljen wls

Comparing some different WLS plates





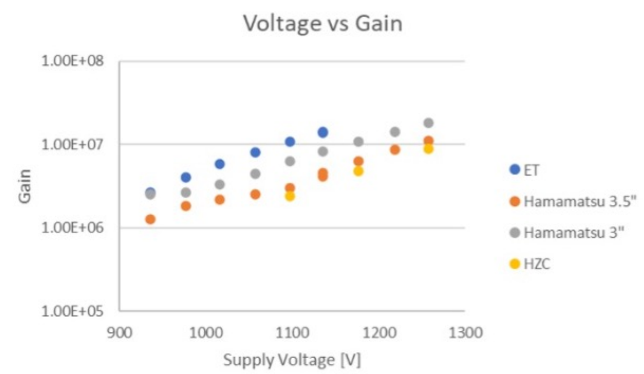
Characterization to select PMT type

HZC XP72B2F 3”

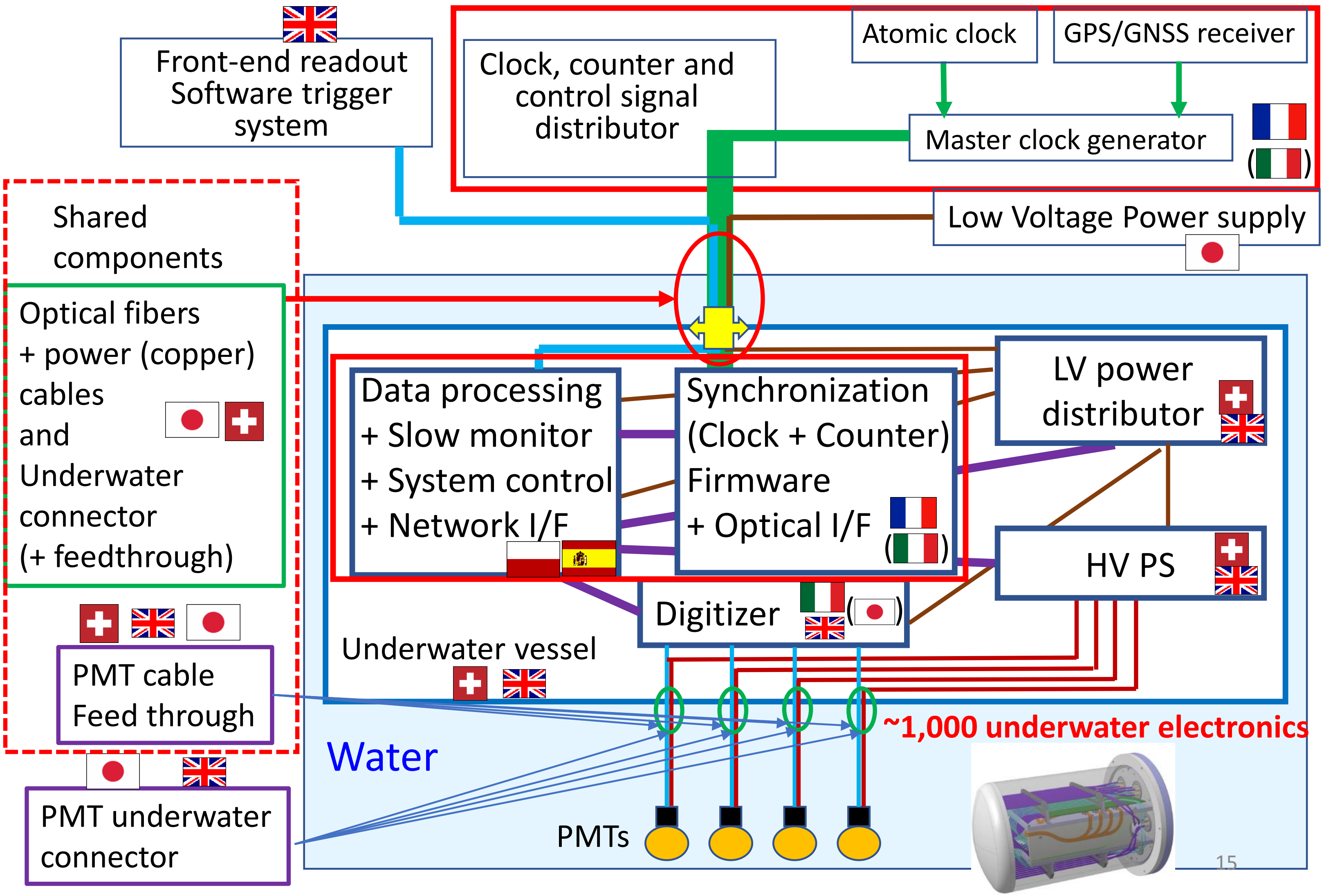
ET Enterprises D459/2KFLB 3”

Hamamatsu R14689 3.5”

Hamamatsu R14374 3”



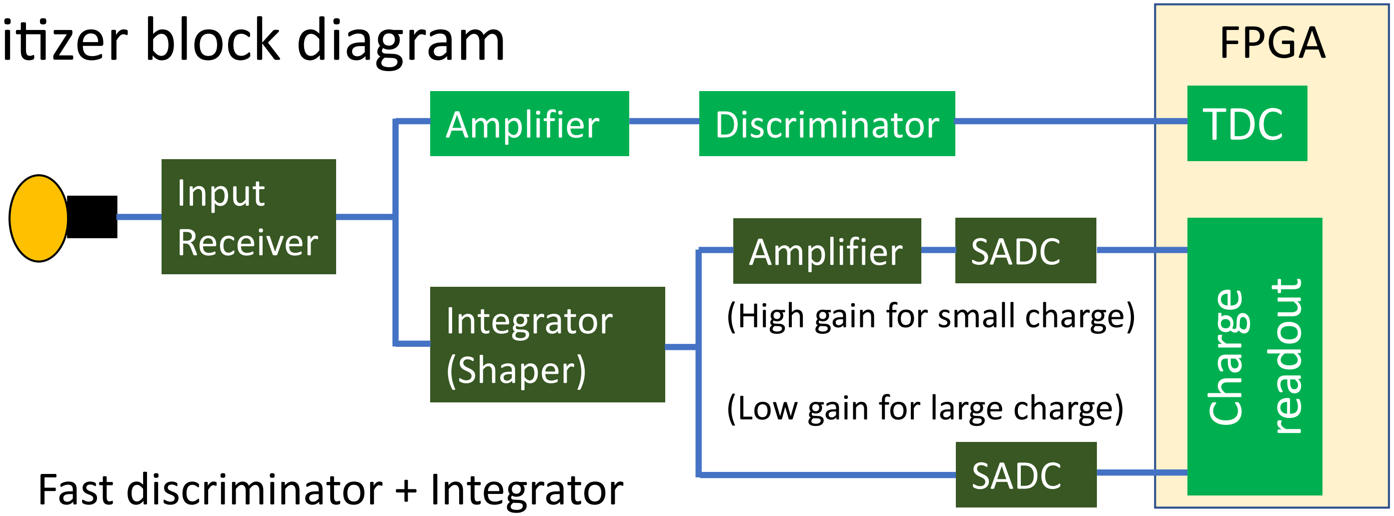
Electronics



Preparing for test with signal, mechanical test, integration/installation planning and test, etc.

Electronics R&D

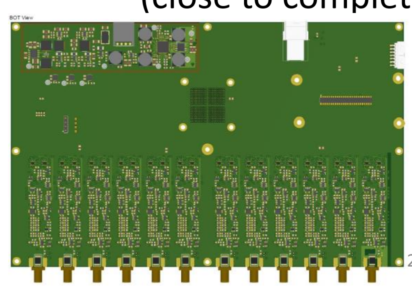
Digitizer block diagram



Fast discriminator + Integrator

Evaluation has been done with 24 channel prototype.

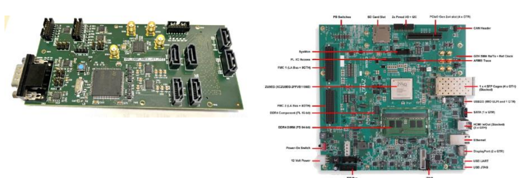
Designing 12 channel ID board (close to complete)



HV Power supply

Timing distributor

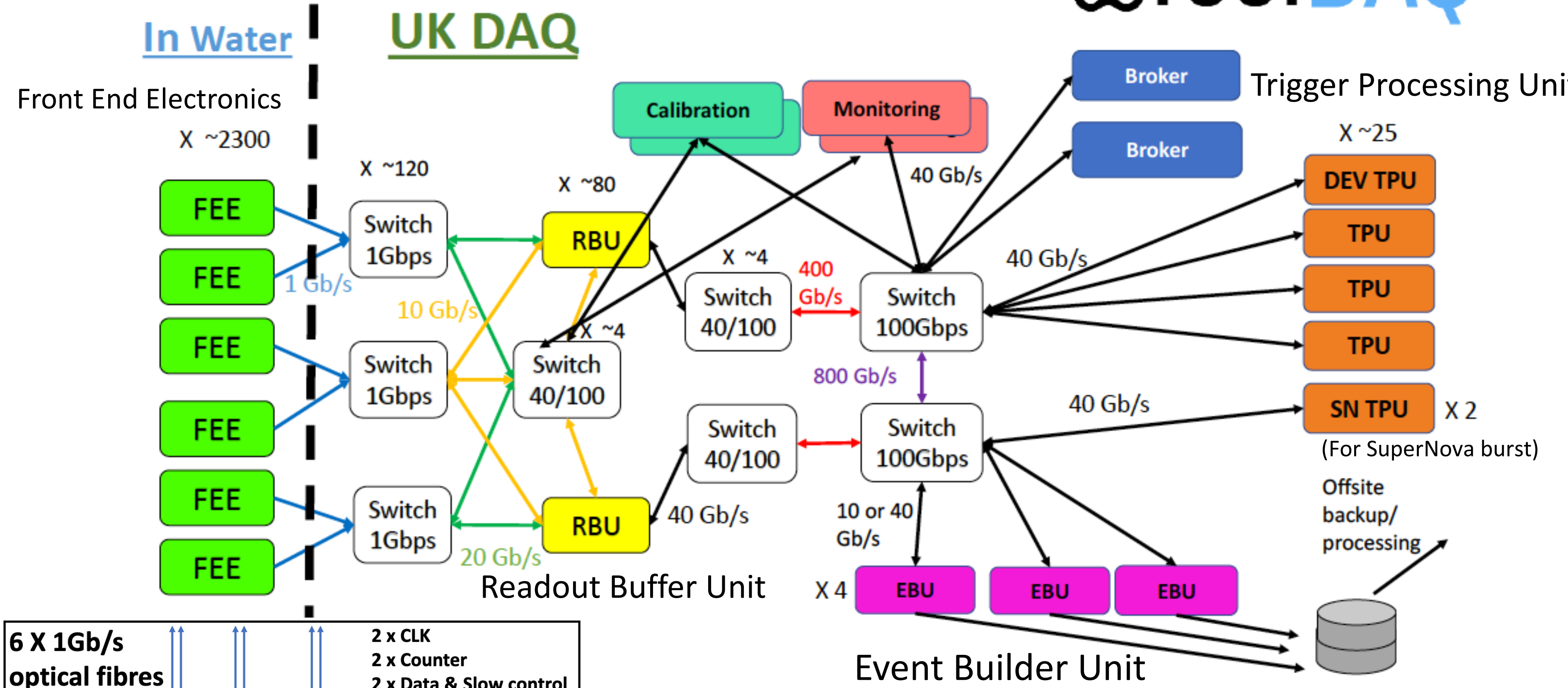
Data processing board
(I/F + evaluation board)

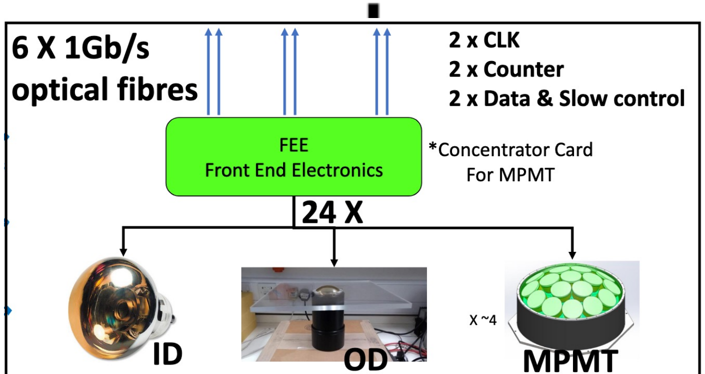


LV Power supply

DAQ Concept

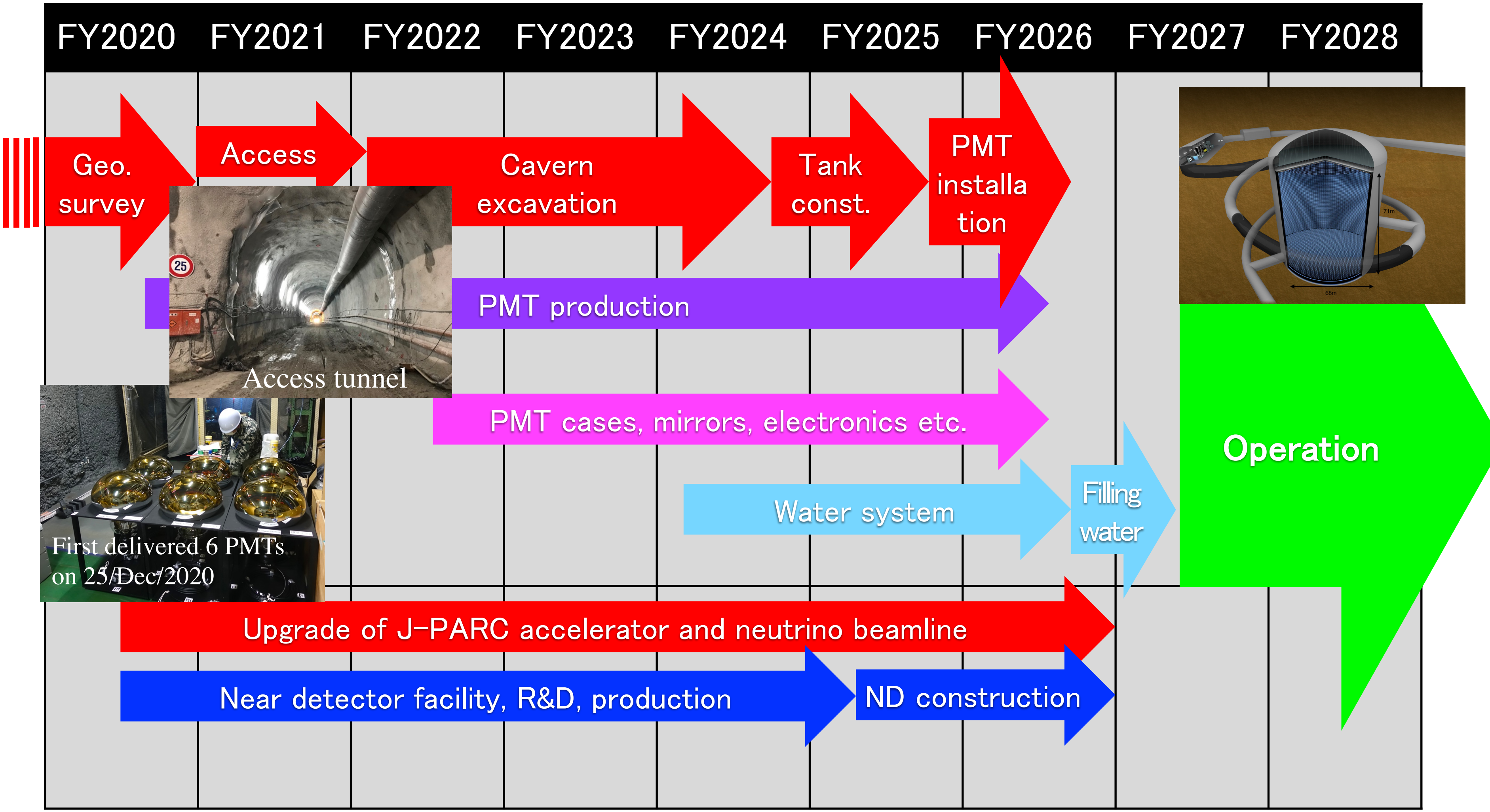
Hyper-K Reference Design





Charge and timing information from photosensors are collected to issue event triggers

Construction Schedule



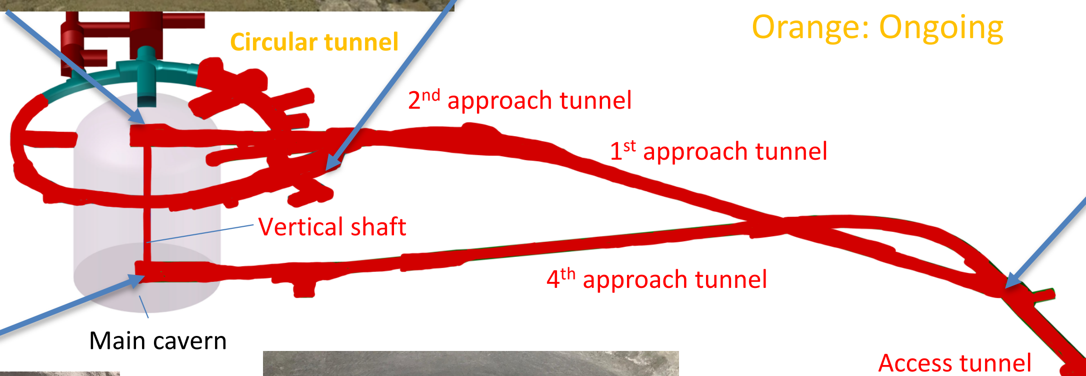
Site Construction

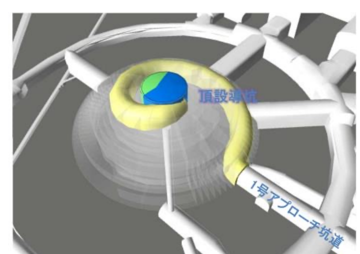
Jun 2022

May 2021

— Completed

Orange: Ongoing





Cavern excavation by 2024
Detector construction in 2025

PMT Inspection during Production

Mass production has started in 2020 and will end in 2026.

Evaluation of performance and quality check during mass production

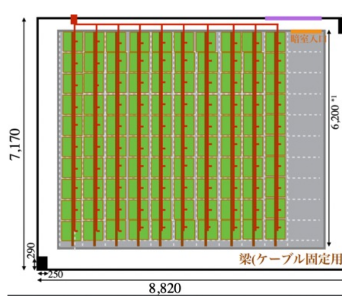
Delivery → Signal check → Visual inspection (Sampling)

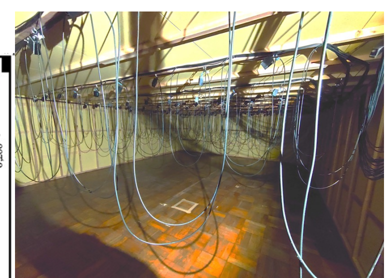
Detailed evaluation and characterization

Long-term measurement

Mass measurement setup of 100 PMTs

(from Dec 2022)





With SK electronics

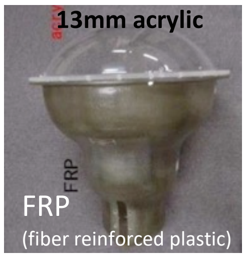
Measurement room in SK mine with 7-16 PMTs

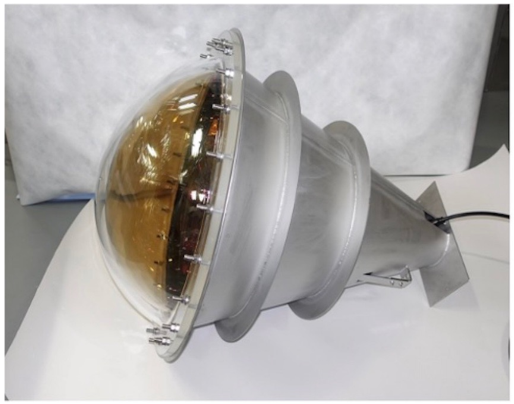
And pre-calibration for reference PMTs is planned in addition.

Prototypes of Components in the water

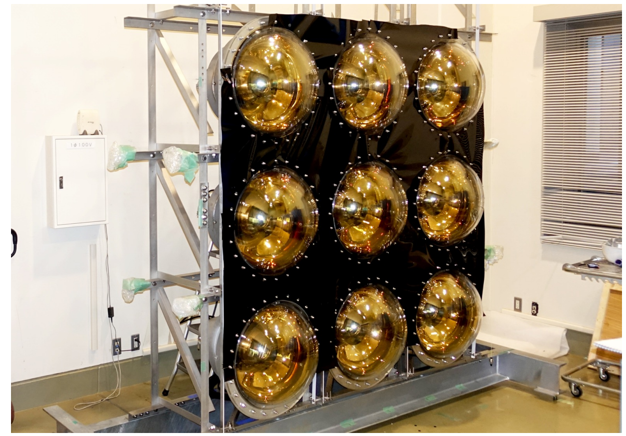
PMT Cover

Super-K FRP cover
for 40 m water depth

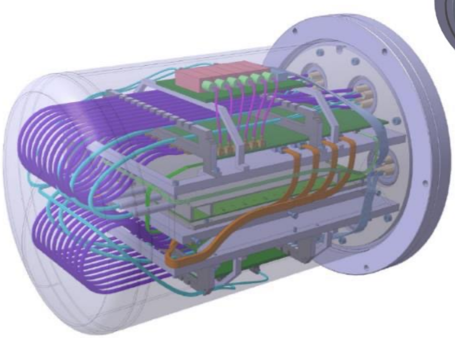


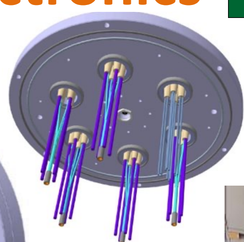


PMT frame structure



Underwater electronics

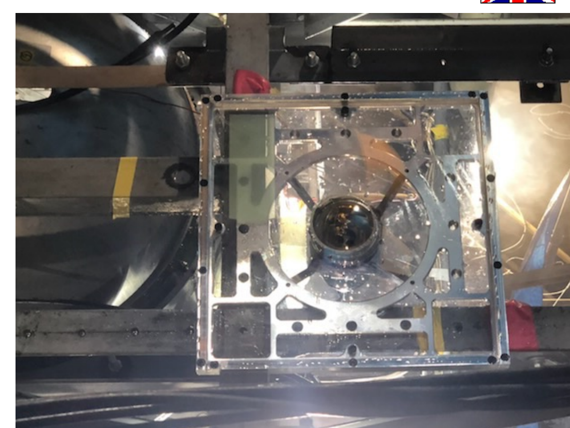




Feedthroughs
for ID and OD

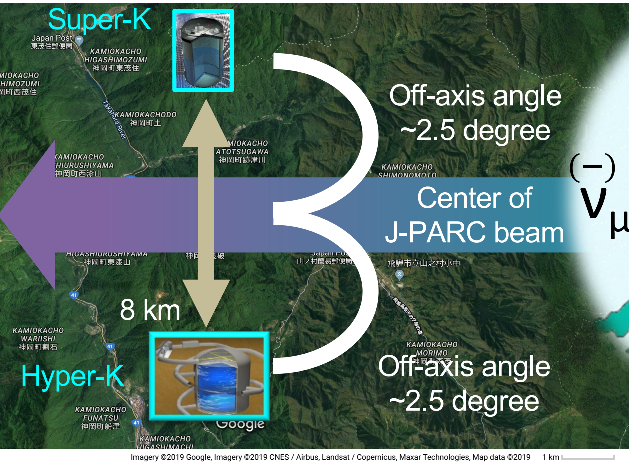
Prototyping of vessel,
PMT cable w/ feedthrough,
optical/power cable and connector

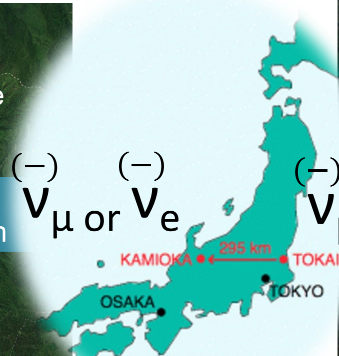
OD sensors



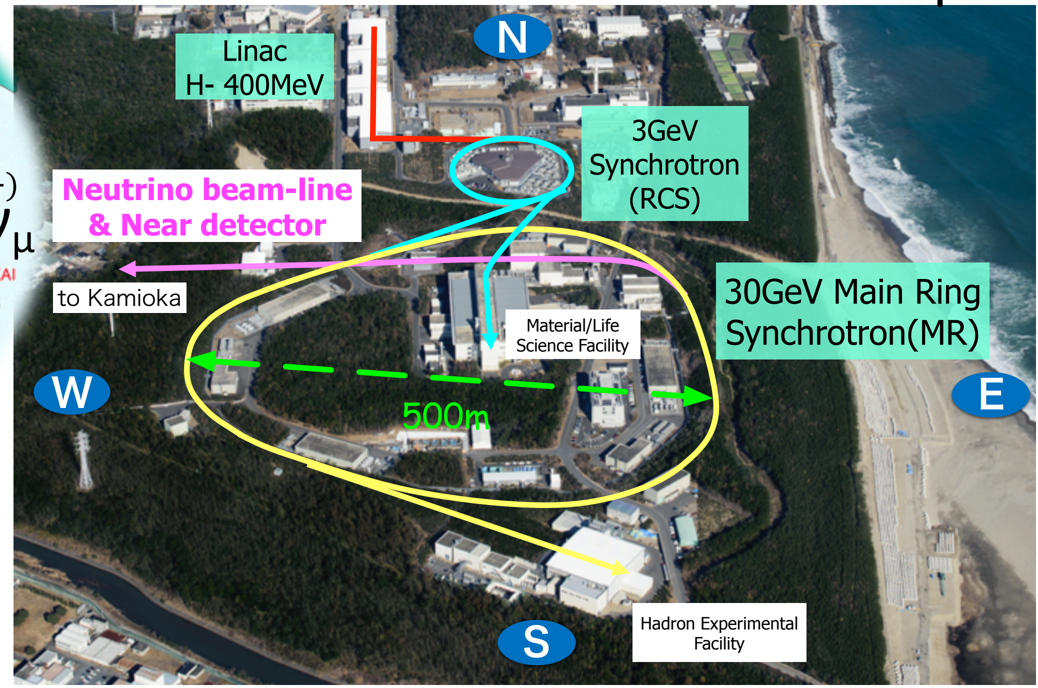
Long baseline ν from J-PARC to Hyper-K

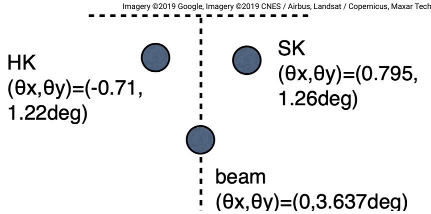
Kamioka

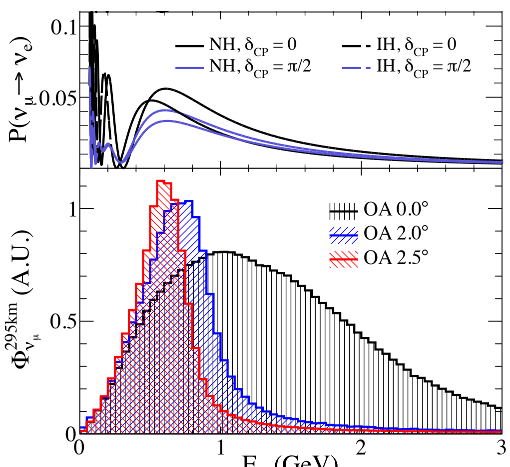


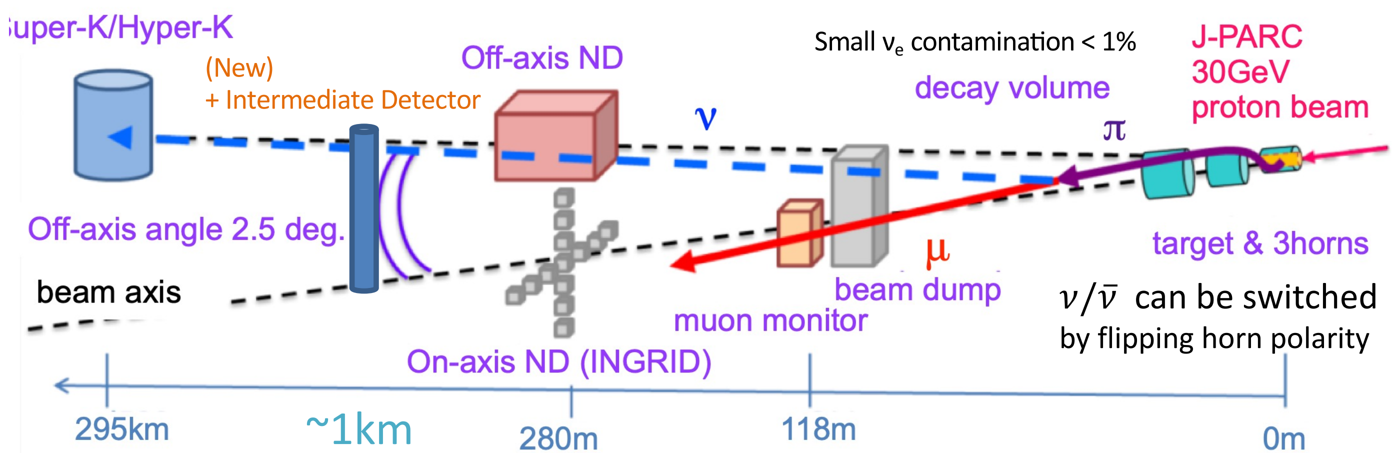


Japan Proton Accelerator Research Complex





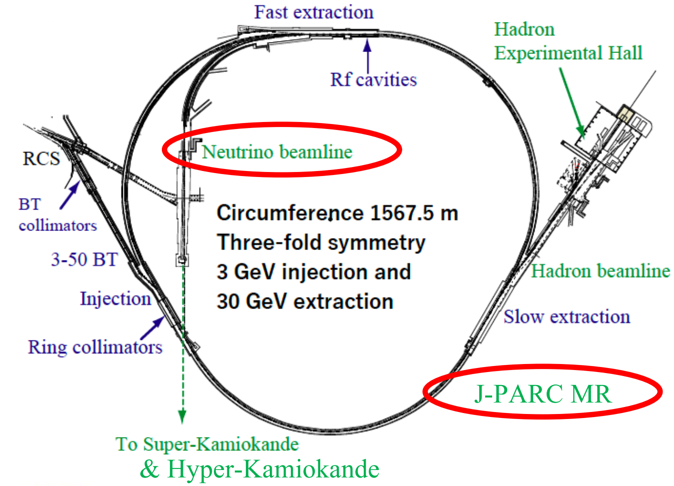




J-PARC Upgrade

Beam Power upgrade from ~0.5 to 1.3 MW

J-PARC MR & neutrino beam-line upgrade towards 1.3MW are parts of HK project.

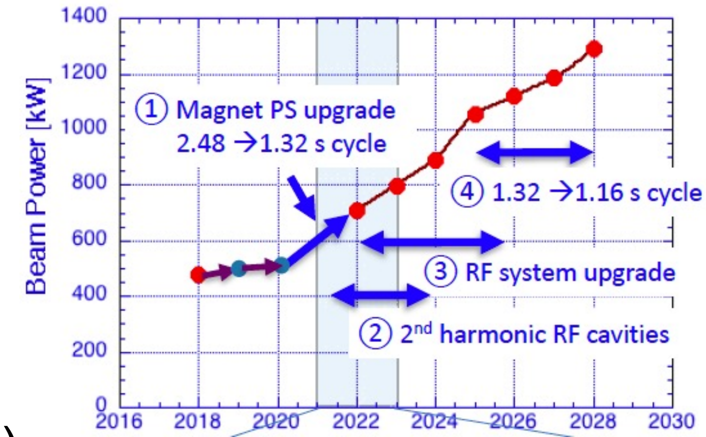


J-PARC-MR:

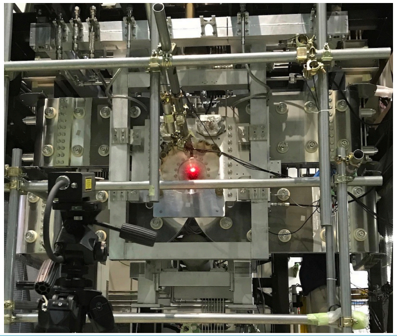
- MR magnet power supply upgrade
  ← Commissioning has been started in 2022.
- MR RF upgrade
- MR Fast Extraction Kicker upgrade, …

Neutrino beam-line:

- Upgrade of target, horn (250kA→320kA), beam monitors, …
- Facility upgrade (cooling, radiation protection, …)



Upgraded horns for neutrino beamline



New main magnet PS for high repetition rate

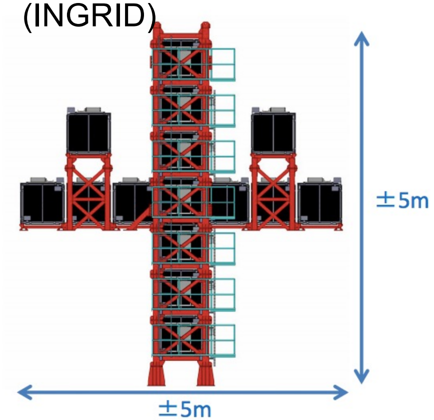
MR-RF cavities

Near/Intermediate Detectors

Critical components to precisely understand J-PARC beam and neutrino interactions for lepton CPV search.

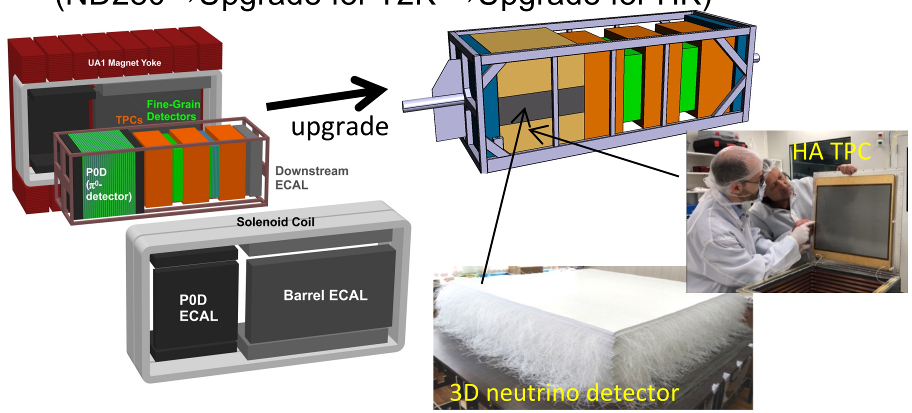
On-axis Detector

(INGRID)



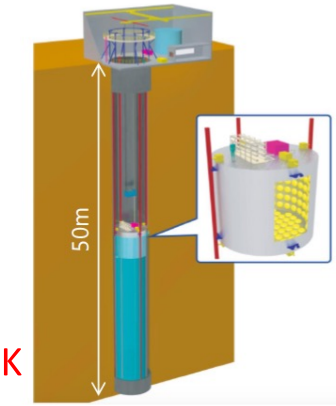
Off-axis Magnetized Tracker

(ND280→Upgrade for T2K →Upgrade for HK)



Off-axis spanning intermediate water Cherenkov detector

(IWCD)



New for HK

•On-axis detector: Measure beam direction and event rate

•Off-axis magnetized tracker: Measure primary (anti)neutrino interaction rates, spectrum and properties. Charge separation to measure wrong-sign background
→ Upgrade by T2K experiment and Intensive discussion for further upgrade in HK-era is on-going.

•Intermediate WC detector: H_2O target with off-axis angle spanning orientation.
→ Detector site investigation and conceptual facility design is on-going.

+ Beam test of prototype detectors, Hadron production measurements for precision determination of J-PARC neutrino flux, etc.

Summary

- Super-K observation has started in 1996.
  - Supernova ν burst by Kamiokande, discovery of neutrino oscillation by Super-Kamiokande, and next evolution is desired.

- High sensitivity in various particle and astronomical physics
  - ×8.4 of Super-K, ×20 of accelerator neutrinos
    - With high-performance ID PMT, etc.
  - Aiming at proton decay search, discovery of ν CP violation, etc.

- Hyper-K plans the operation in 2027.
  - Construction started in 2020 with Japanese budget approval.
    - Cavern excavation, PMT production, detector under preparation
  - Detector installation coming in 2026.
    - Still open for more contributions and new collaborators